Hari Seldon, Please Call Your Office:

Linear Colliders, Big Science, and U.S. Universities

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Saywhut?

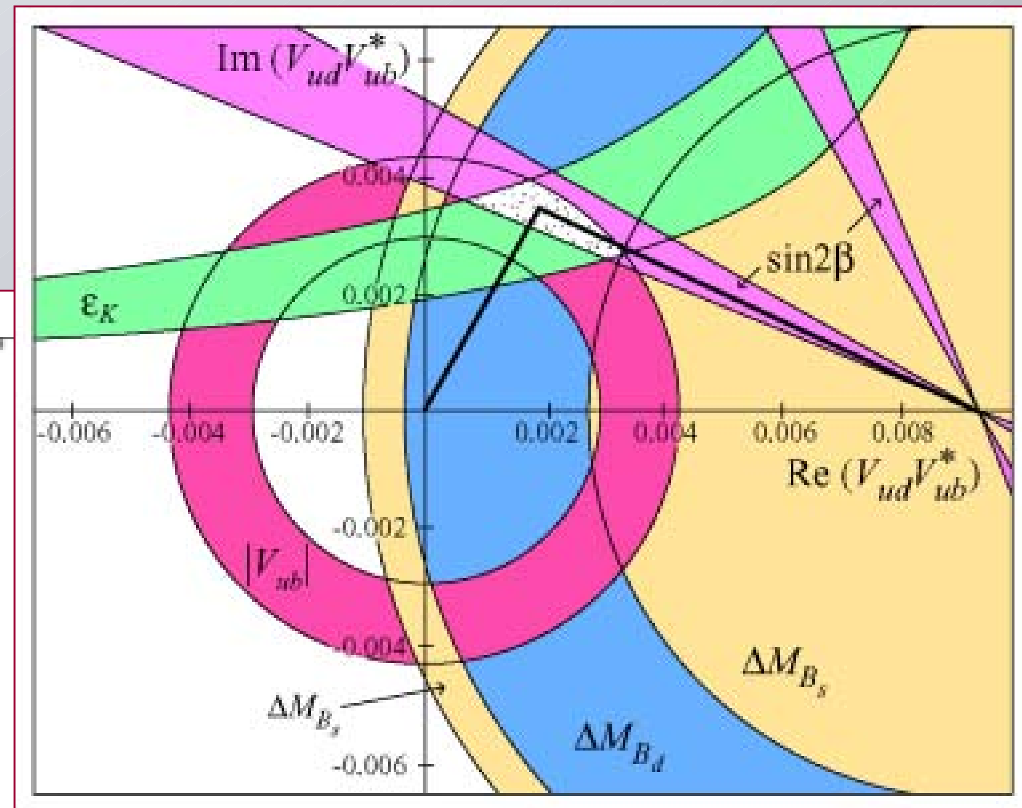
Hari Seldon: founder of “psychohistory” (see Isaac Asimov’s *Foundation* trilogy).

Psychohistory: “that branch of mathematics which deals with the reactions of human conglomerates to fixed social and economic stimuli.”

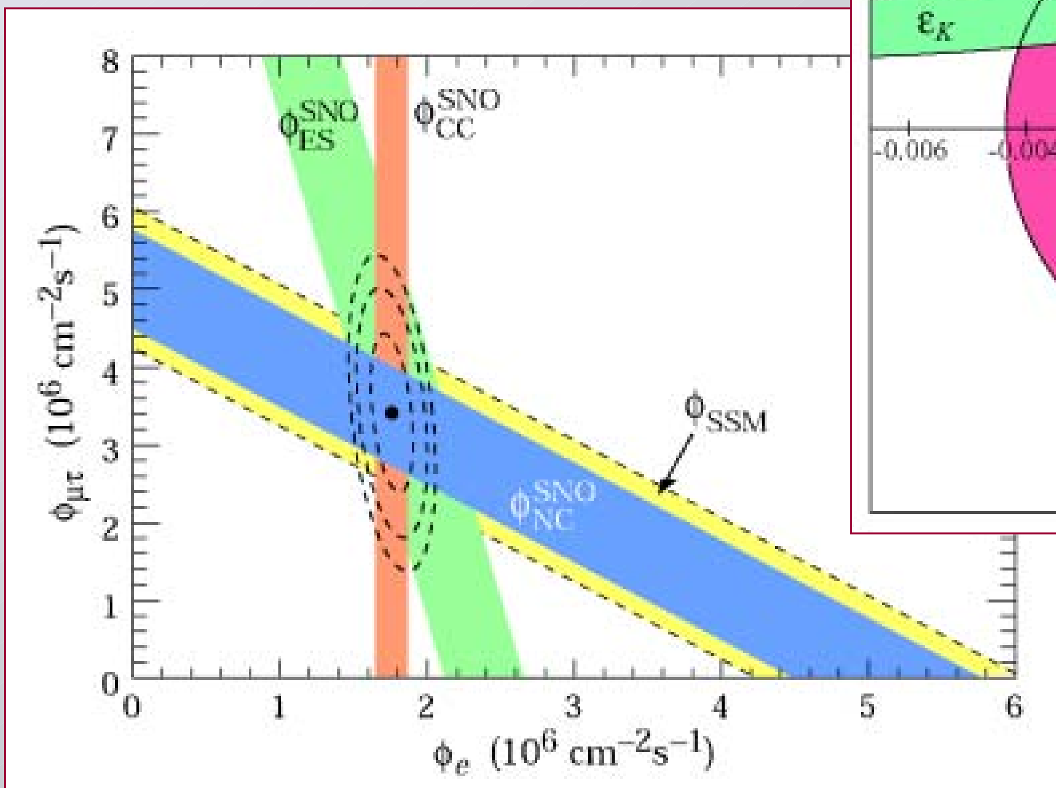
Big Science makes for complicated group dynamics.

This is a strange talk

Not very much of this today…

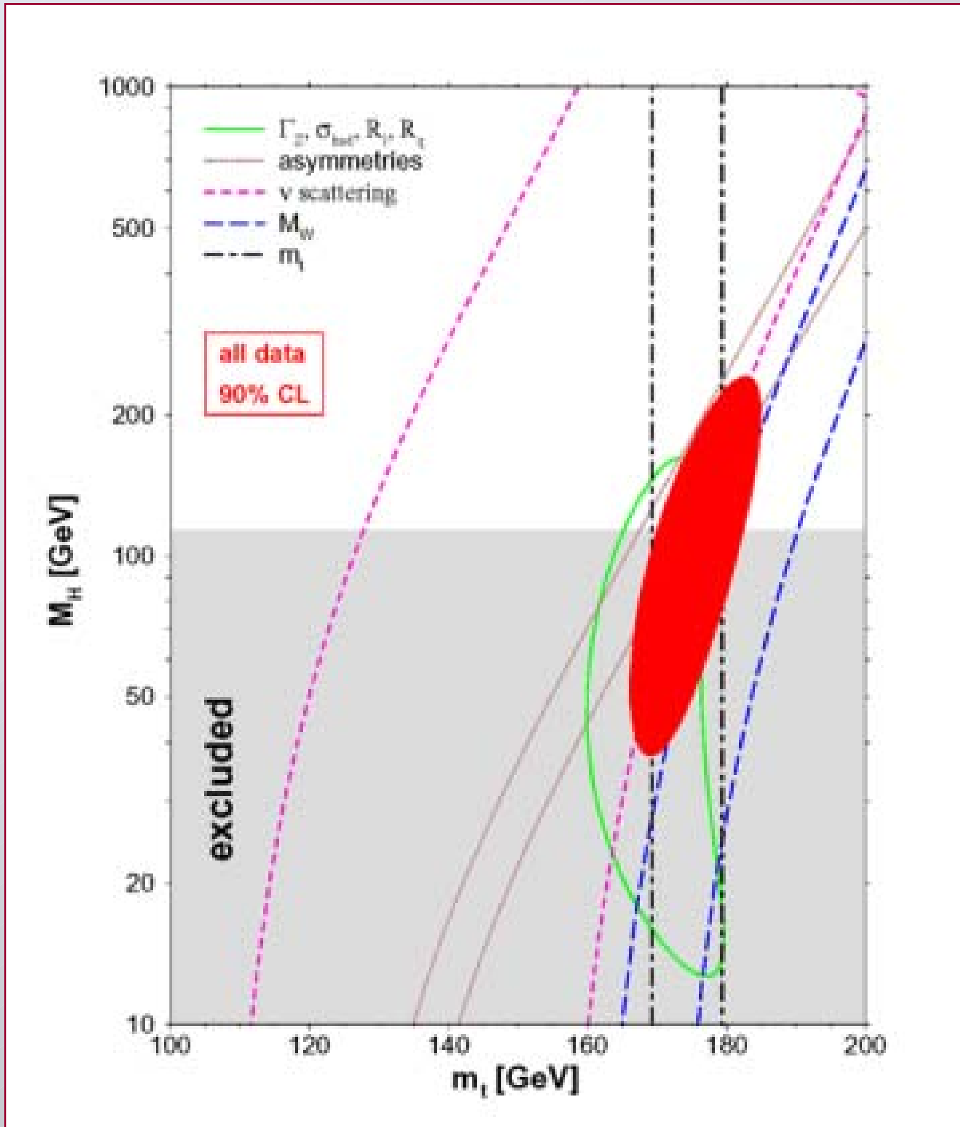


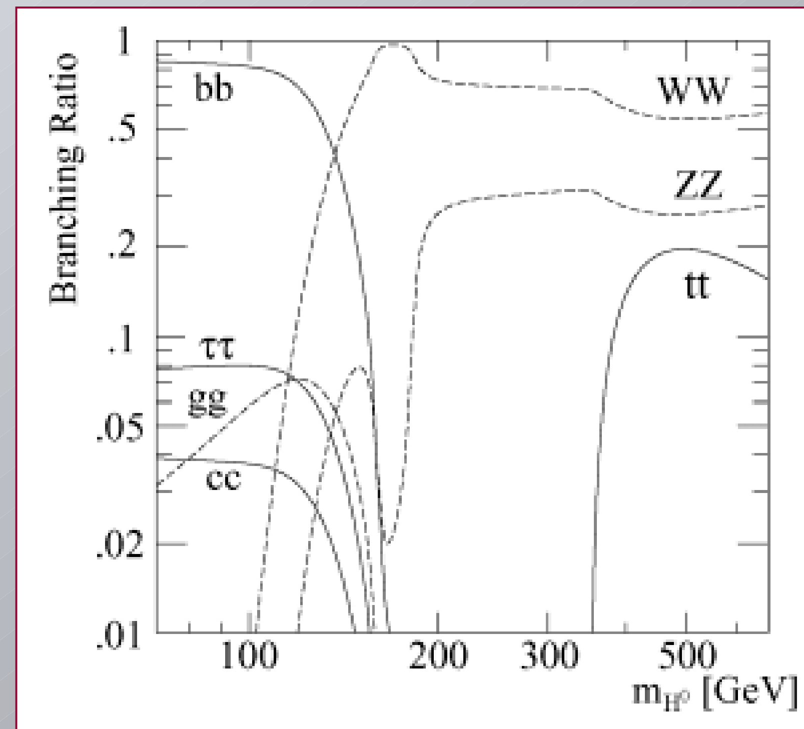
http://pdg.lbl.gov/2002/kmmixrpp.pdf



http://pdg.lbl.gov/2002/solarnu_s005313.pdf

…not even much of this:





http://pdg.lbl.gov/2002/higgs_s055.pdf

True Facts

1. We (scientists) are clueless about all but $(4.4 \pm 0.4)\%$ of the stuff in the universe. This is an opportunity!

2. As a species, our large collaborative efforts are often inefficient, unable to respond rapidly to new information.

3. Our professional politicians are not very good at politics. (Witness the 2000 presidential election!) It is naïve to think that physicists can be more skilled at it than the pros.

This talk:

- The physics landscape and the Linear Collider (that's #1)
- Comments on how #2 and #3 interfere with pursuit of #1

Outline

Technical stuff:

1. Physics of the fundamental interactions
2. Linear Collider technical matters (accelerator only)

Sociology, of sorts:

1. The Wild, Wild West *c*. 1987
2. Big experiments are different
3. Pathological decision making
4. Combining the Wild, Wild West and Big Science: university participation in Linear Collider R&D

University participation example: two UIUC projects

Fermilab picks up the pace

Physics

The physics of the fundamental interactions

Perhaps one might say that the physics of the fundamental interactions is concerned with three principal themes:

1. The nature of space and time;
2. The characteristics of the forces governing the interactions of matter and energy;
3. The origins of the fundamental properties (electric charge, mass, etc.) of the elementary particles, and the reasons for the existence of matter and energy.

We've figured out a lot about #1, #2, but much less about #3

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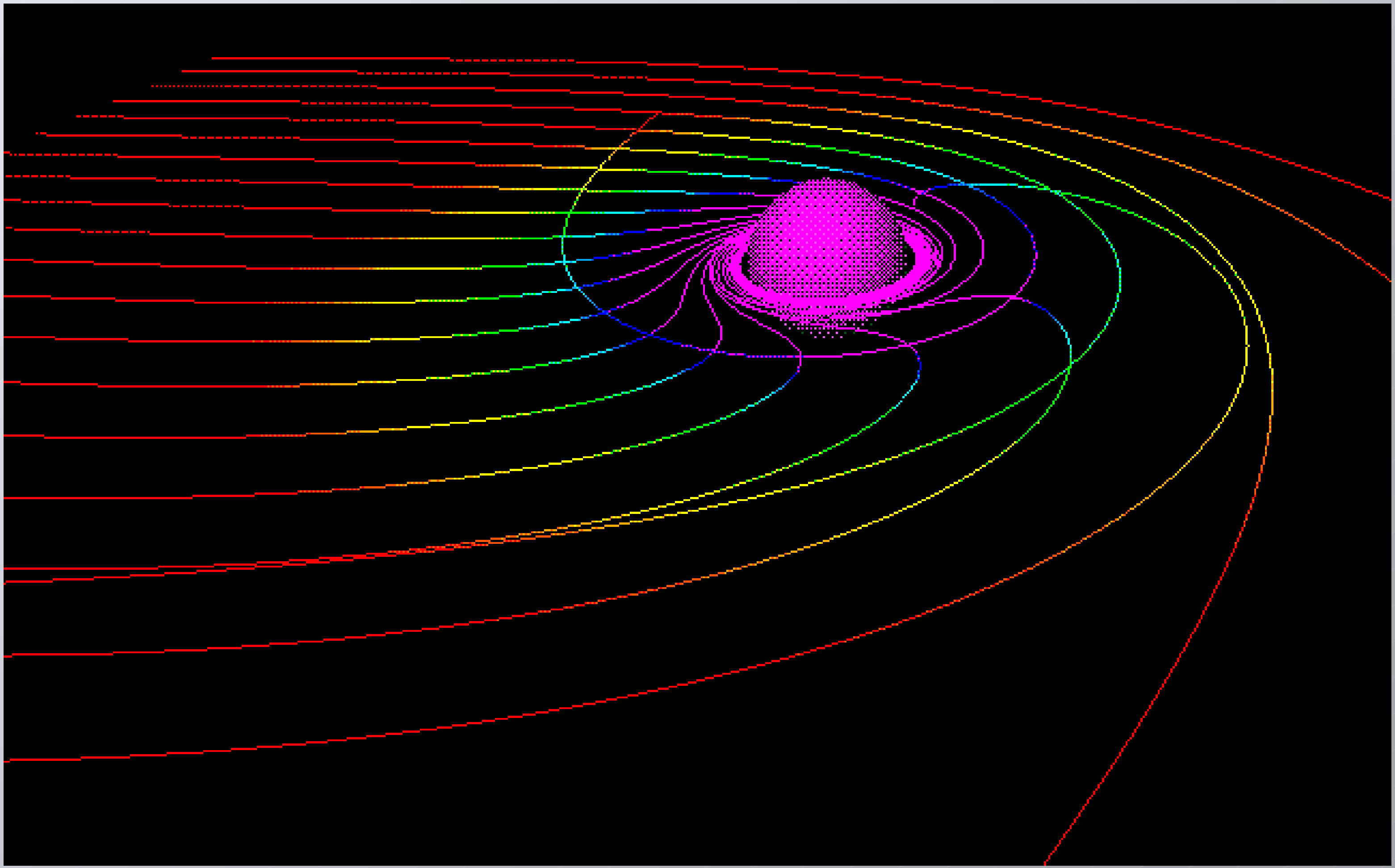
…understanding space and time…

1. The nature of space and time…

- The world is relativistic: moving clocks tick more slowly; moving objects become smaller; light rays bend in gravitational fields. (1916)
- The names of our theories: Classical Electrodynamics, Special/General Relativity
- The real work is in understanding the details.
- We're starting to consider what's underneath (string theory?).

…understanding space and time…



Photon trajectories near a rotating black hole: Michael Cramer Andersen (1996); http://www.astro.ku.dk/~cramer/RelViz/

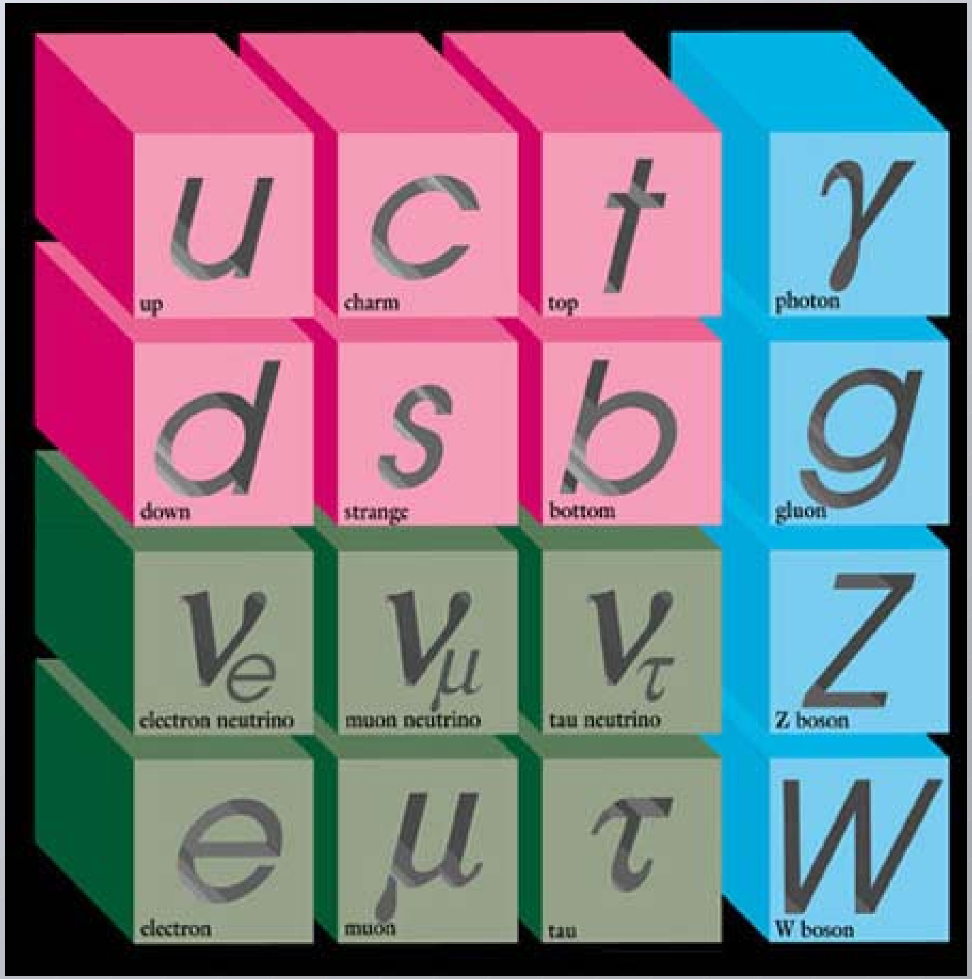
Physics Illinois

…understanding the forces…

2. The characteristics of the forces governing the interactions of matter and energy…

- Nature works according to the principles of quantum mechanics: it's not at all like a giant billiard table.
- The forces are mathematical generalizations of those associated with electric fields, with a particular gauge symmetry structure.
- The name of the theory: The Standard Model
- As before, the real work is in understanding the details.

…understanding the forces…



…understanding the origins of things…

3. The <u>origins</u> of the fundamental properties (electric charge, mass, etc.) of the elementary particles, and the reasons for the <u>existence</u> of matter and energy…

- We have good (but untested) ideas about the origin of mass. We're clueless about the origins of most other properties.

- Determination of Higgs' properties is necessary to provide guidance for development of theory. There's a strong prejudice that SUSY will also be found at these energy scales. (Maybe even dark matter!) We'll see…

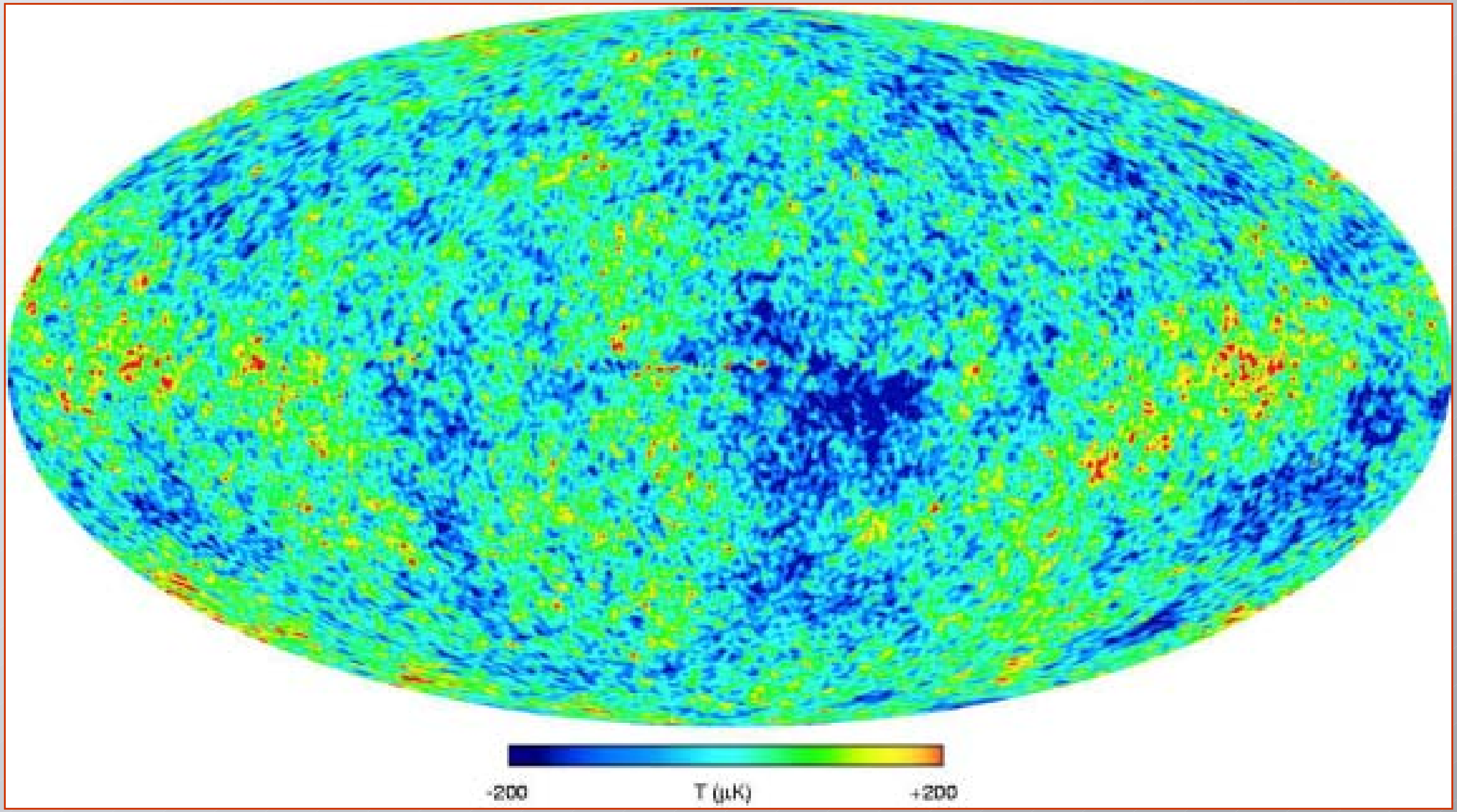
This is where much of HEP research is now focused.

Where we are going…

These are exciting times. It is clear that some of our ideas about fundamental physics have been wrong.

- Neutrinos have mass. (Many) relic neutrinos from Big Bang are non-relativistic.
- Contents of the universe:
  - $(4.4 \pm 0.4)\%$ baryons
  - $(23 \pm 4)\%$ "cold dark matter"
  - $(73 \pm 4)\%$ "dark energy"
- Higgs mass is probably less than 193 GeV
- Quantum field theory is probably wrong (cosmological constant is completely wacko)

How we know it's only 4.4% ordinary matter



From "First Year *Wilkinson Microwave Anisotropy* (*WMAP*) Observations: Preliminary Maps and Basic Results," C.L. Bennett et al., *The Astrophysical Journal*, submitted (2003).

Investigate the source of electroweak symmetry breaking with LHC and LC

…unless the Higgs has already been found!

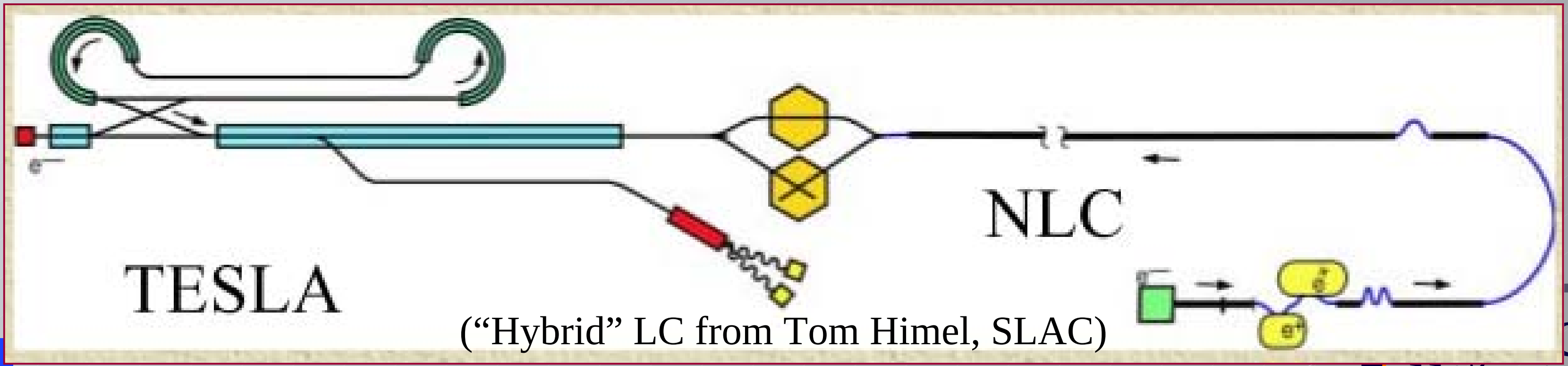
Linear Collider

Linear e^+e^- Collider

Linear Collider physics reach complements LHC:

- control of polarization of e^- beam (and maybe e^+ beam too)
- narrow-band beam
- lower multiplicity final states, easier detached vertex detection
- lower noise rates from underlying “minimum bias” events

I think: even if we move forward rapidly we will not begin the “production phase” of LC construction before LHC sees Higgs.



(“Hybrid” LC from Tom Himel, SLAC)

Linear e^+e^- Collider

HEPAP likes it:

We recommend that the highest priority of the U.S. program be a high-energy, high-luminosity, electron-positron linear collider, wherever it is built in the world. This facility is the next major step in the field and should be designed, built and operated as a fully international effort.

We also recommend that the United States take a leadership position in forming the international collaboration needed to develop a final design, build and operate this machine. The U.S. participation should be undertaken as a partnership between DOE and NSF, with the full involvement of the entire particle physics community... (January, 2002)

http://doe-hep.hep.net/lrp_panel/

TESLA and NLC parameters, briefly

Linear Collider designs, summarized in 2 slides…

parameter	**TESLA**	**NLC**
energy (GeV)	500 - 800	500 - 1000
particles/bunch	2×10^{10}	0.75×10^{10}
beam power (MW)	11.3	6.9
RF frequency (GHz)	1.3	11.4
pulses/second	5	120
bunches/pulse	2820	192
bunches/second	14,100	23,040
peak luminosity (10^{33} cm^{-2} s^{-1})	34	20
accelerating gradient (500 GeV)	23.4 MV/m	50 MV/m
accelerating gradient (800/1000 GeV)	35 MV/m	65 MV/m (?)

(Table content from Tom Himel, SLAC)

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TESLA and NLC parameters, briefly

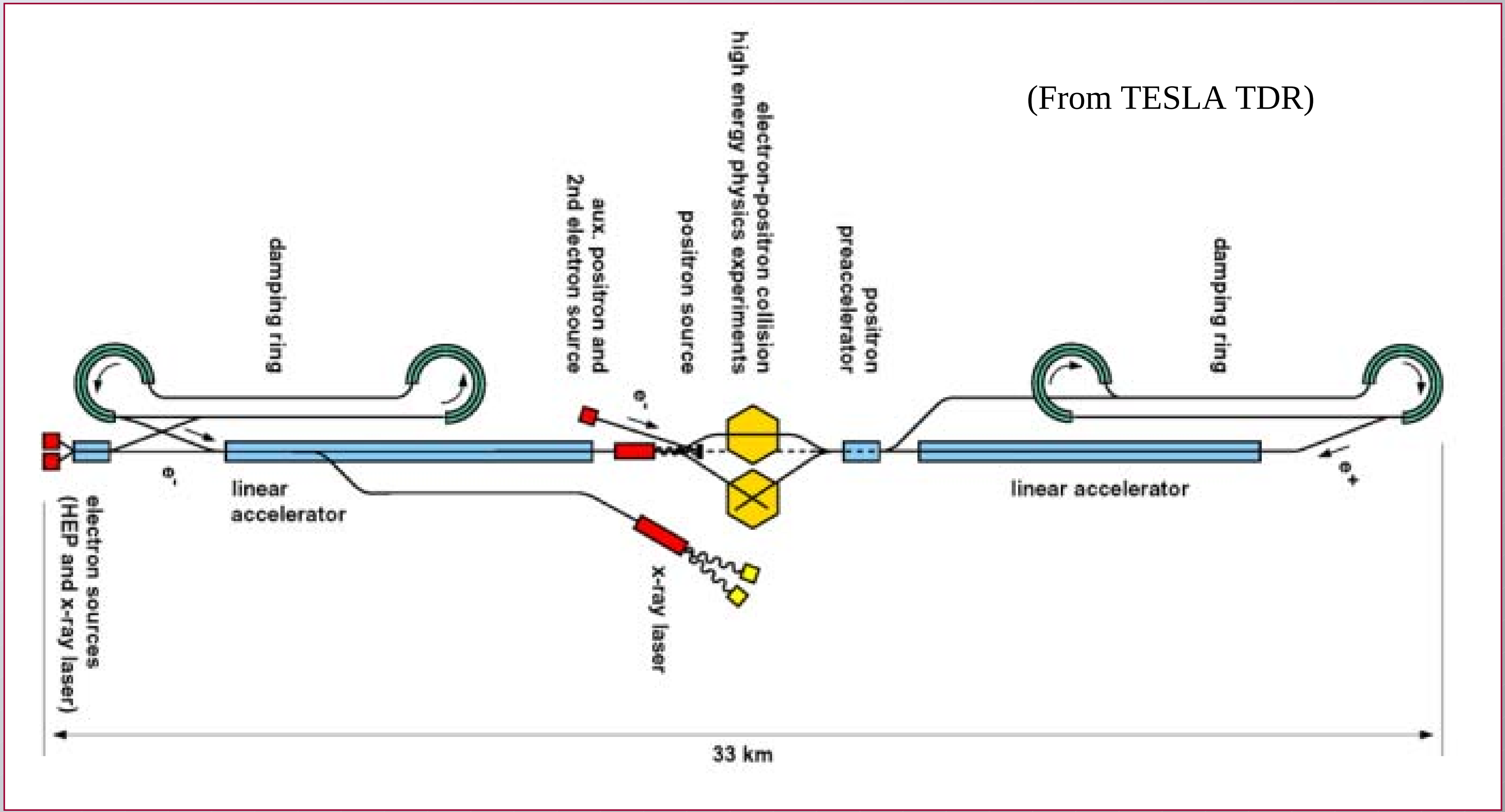
parameter	TESLA	NLC
peak luminosity (10^{33} cm^{-2} s^{-1})	34	20
inter-bunch spacing (nsec)	337	1.4
linac total length (km)	33	32
linac mechanical tolerances	~300 μm	~1 μm
damping ring circumference (km)	17	0.3
RF structure temperature (°K)	2	315
σ_x / σ_y at IP (nanometers)	553 / 5	243 / 3

Different RF frequencies: tighter mechanical tolerances for NLC.

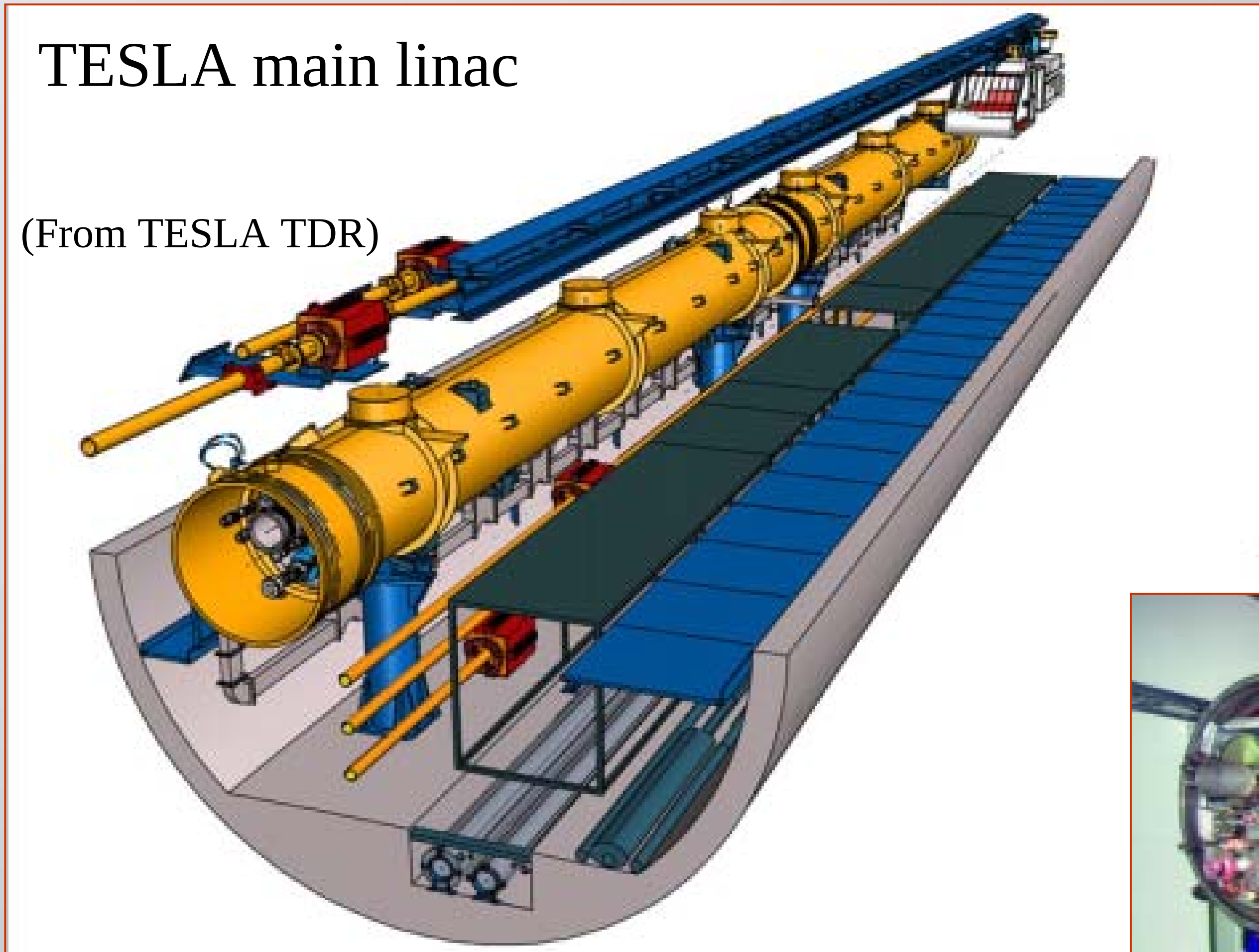
Different bunch spacing: NLC and TESLA damping rings are very different.

(Table content from Tom Himel, SLAC)

TESLA layout



TESLA main linac



Cryogenic “unit length” is ~2.5 km

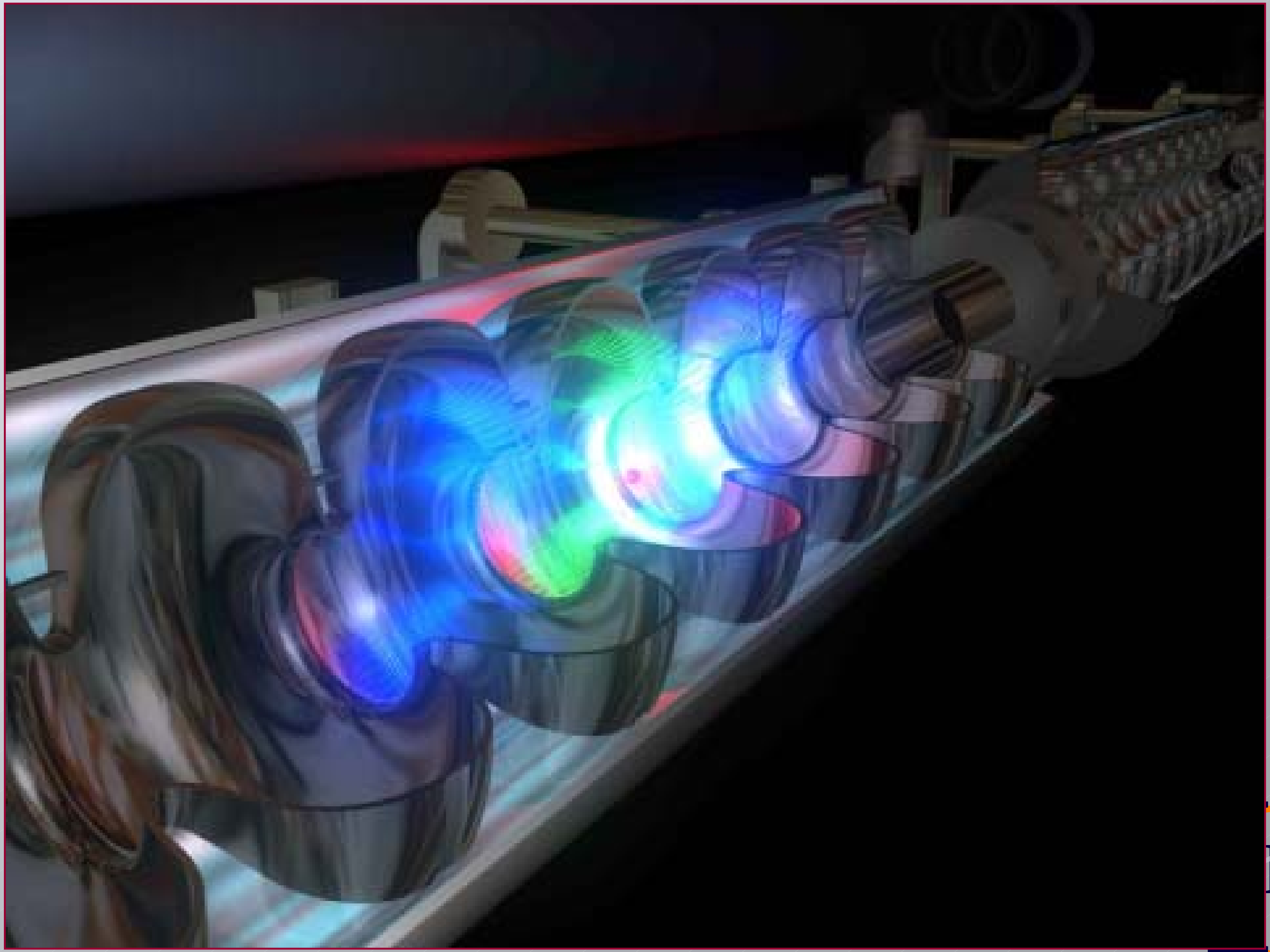
TTF

TESLA rf cavities

Accelerating structures:

- 500 GeV requires 23.4 MV/m gradient (theoretical limit is 50 MV/m)
- Niobium, 1.3 GHz cavities

(From TESLA TDR)



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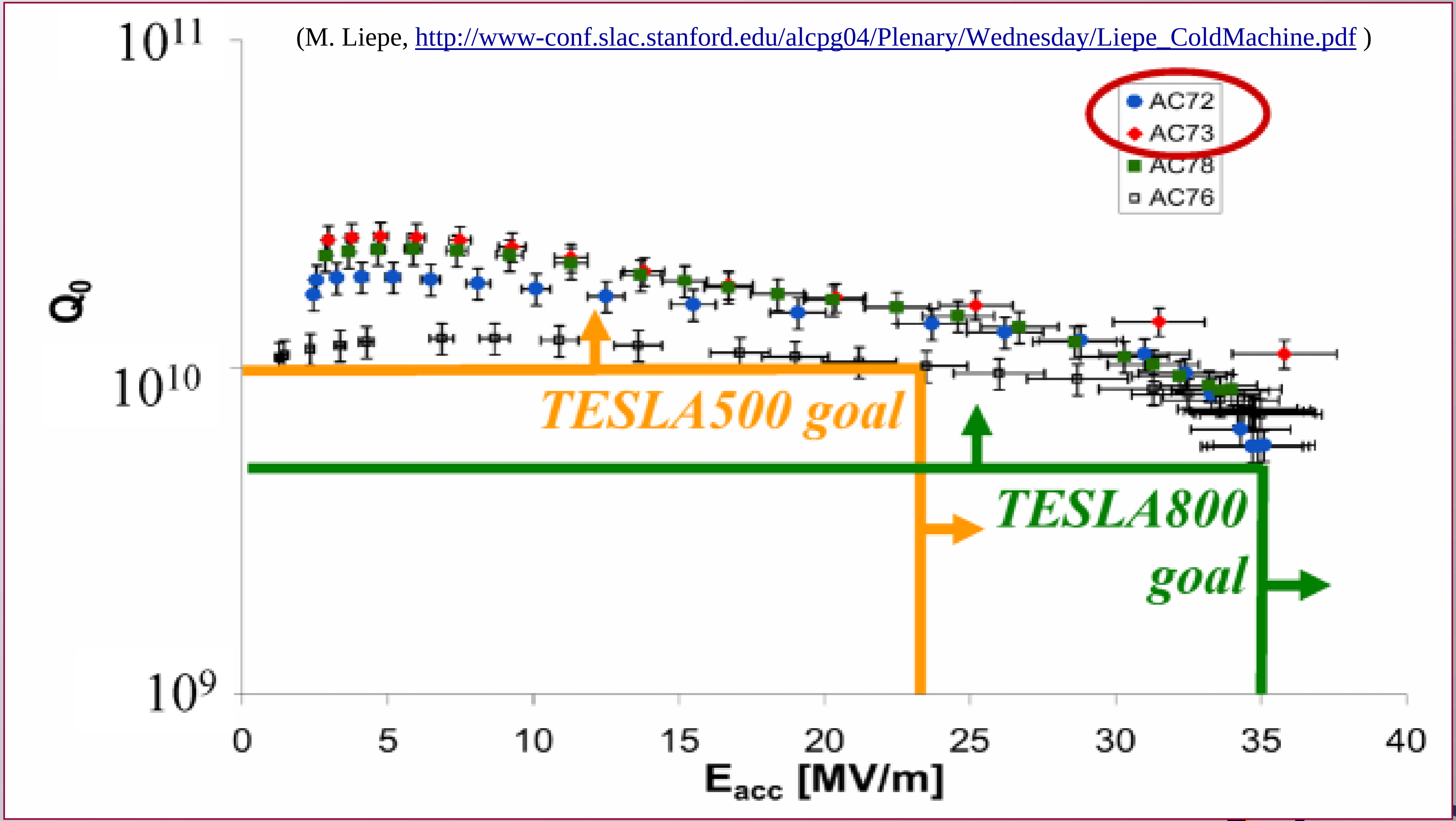
TESLA gradients

Good (recent) progress on reaching the desired gradients!



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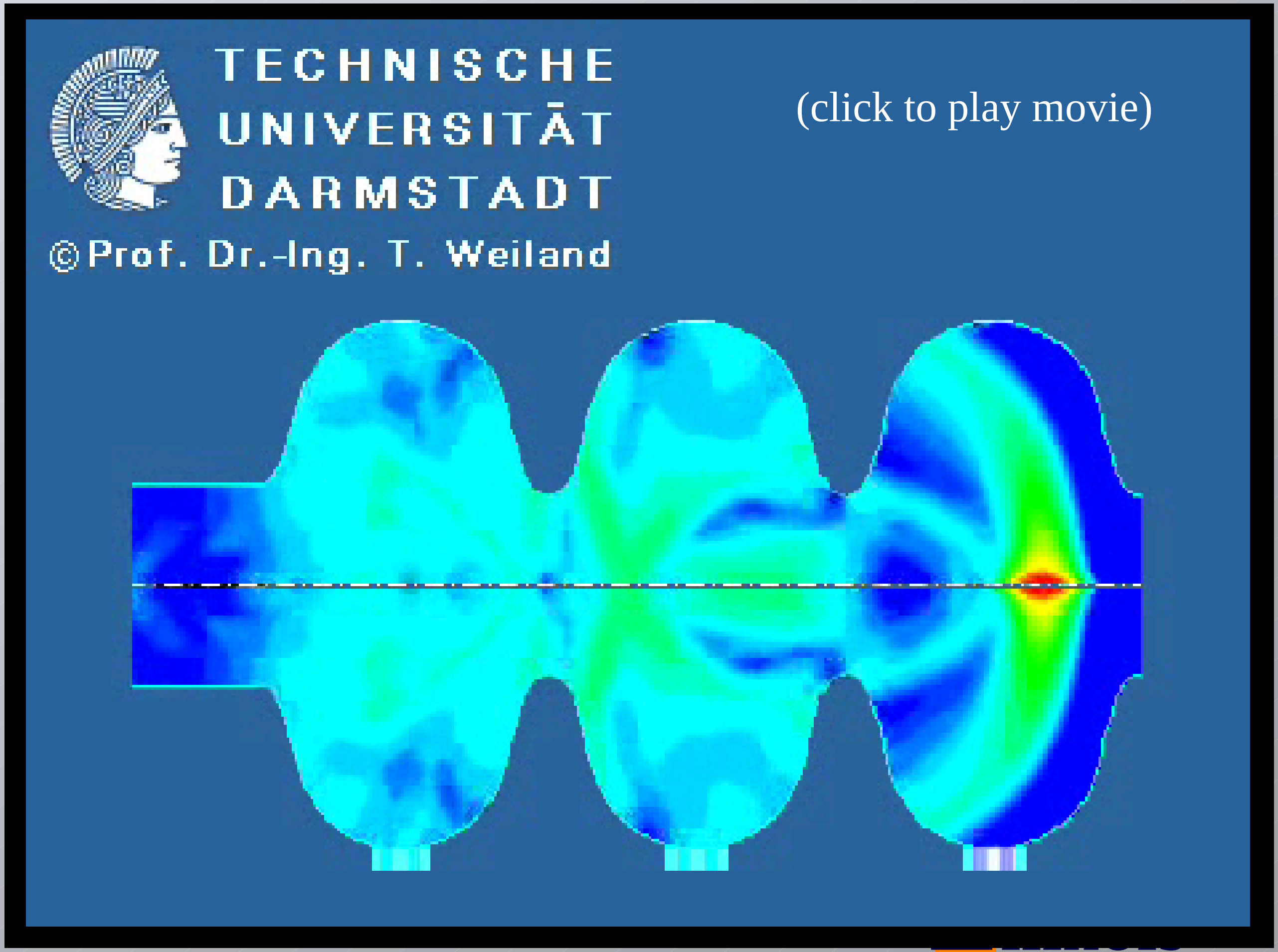
TESLA wake fields

High-Q (superconducting) structures: induced fields persist.

Bunch length ~20 picoseconds so lots of modes can be excited.

Long bunch spacing (337 nanoseconds) is necessary.



TESLA TDR damping ring

Long bunch spacing complicates the damping ring design:

- entire bunch train (2820 bunches) needs to be prepared before extraction to the linac

- 2820 bunches × 337 nsec × c = 285.1 kilometers circumference unless DR bunch spacing is reduced!!

TESLA TDR: 20 nsec bunch spacing ⇒ 17 km circumference

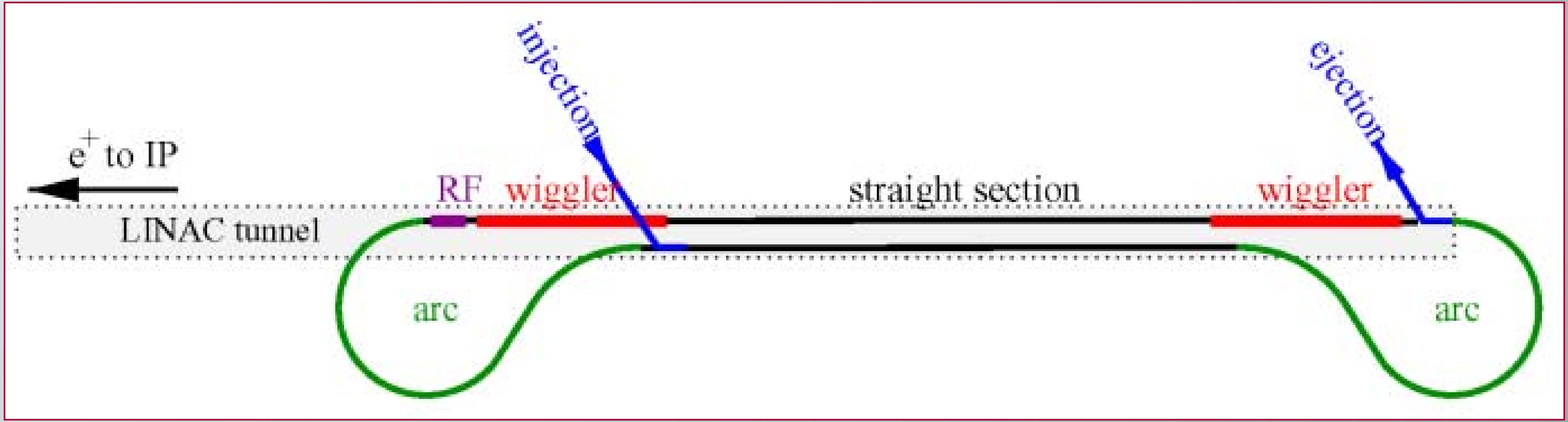
Kick every n^{th} bunch, leaving intervening bunches undisturbed. Minimum spacing entirely determined by injection/extraction kicker speed.

Damping time: 28 ms (50 ms) for e^- (e^+)

TESLA TDR damping ring

It’s expensive (TDR: 214 M€, but this is an underestimate).

Length is an issue: some sources of instability are made worse.



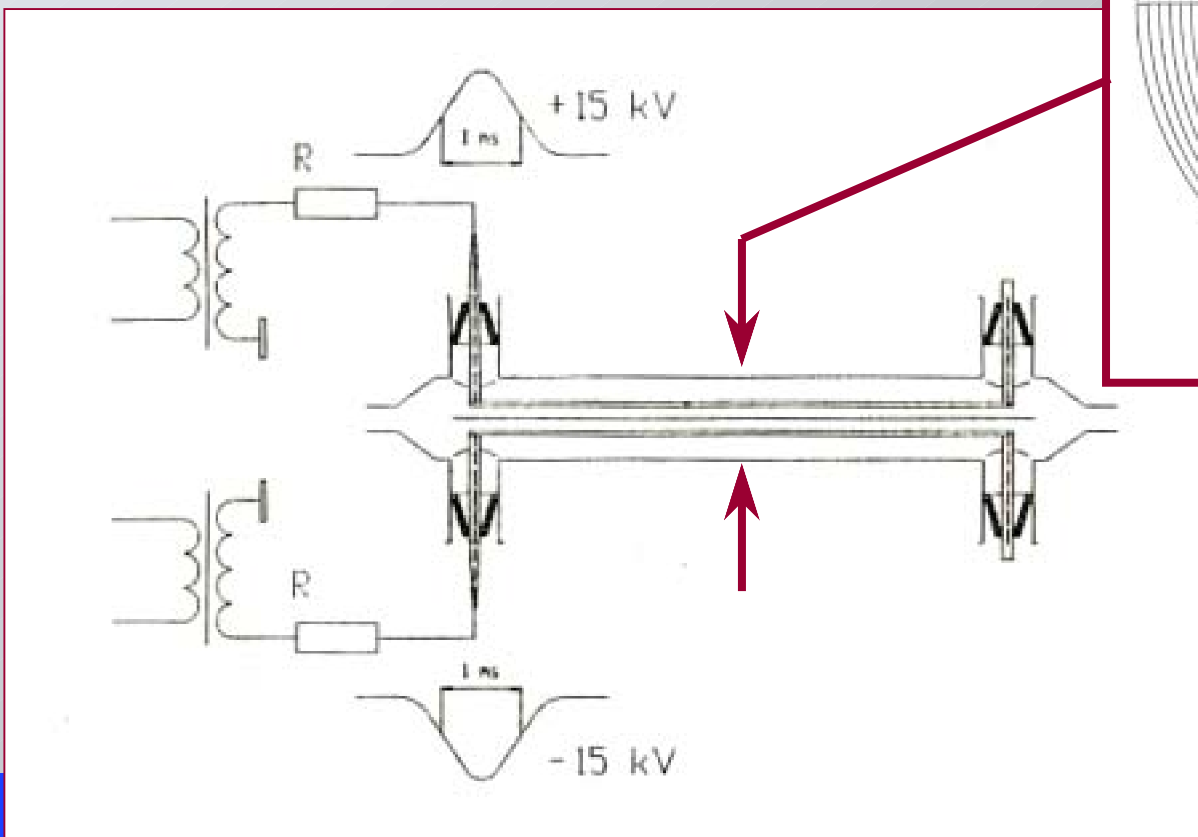
Some of the concerns:

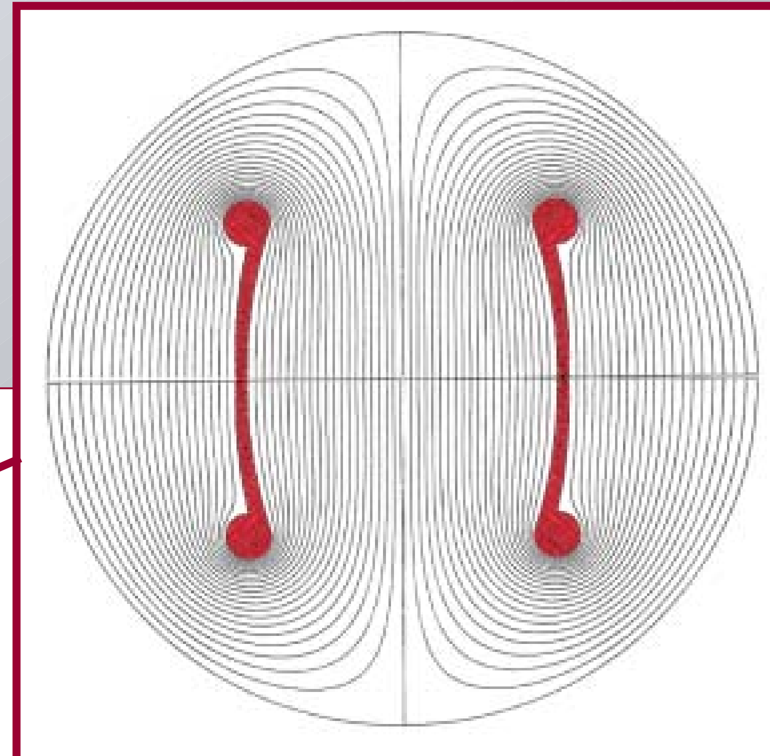
- electron cloud (builds up in the vacuum pipe, destabilizes beam)
- positive ions (residual gas in vacuum pipe is ionized by beam)
- “coupled bunch instabilities”

TESLA TDR damping ring kicker

Requirements:

- (100 ± 0.07) Gauss-m field integral
- residual (off) field integral ≤ 0.07 Gauss-m





Stripline kicker. (Not good enough yet.)

Need ~30 of them.

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Thinking in new ways

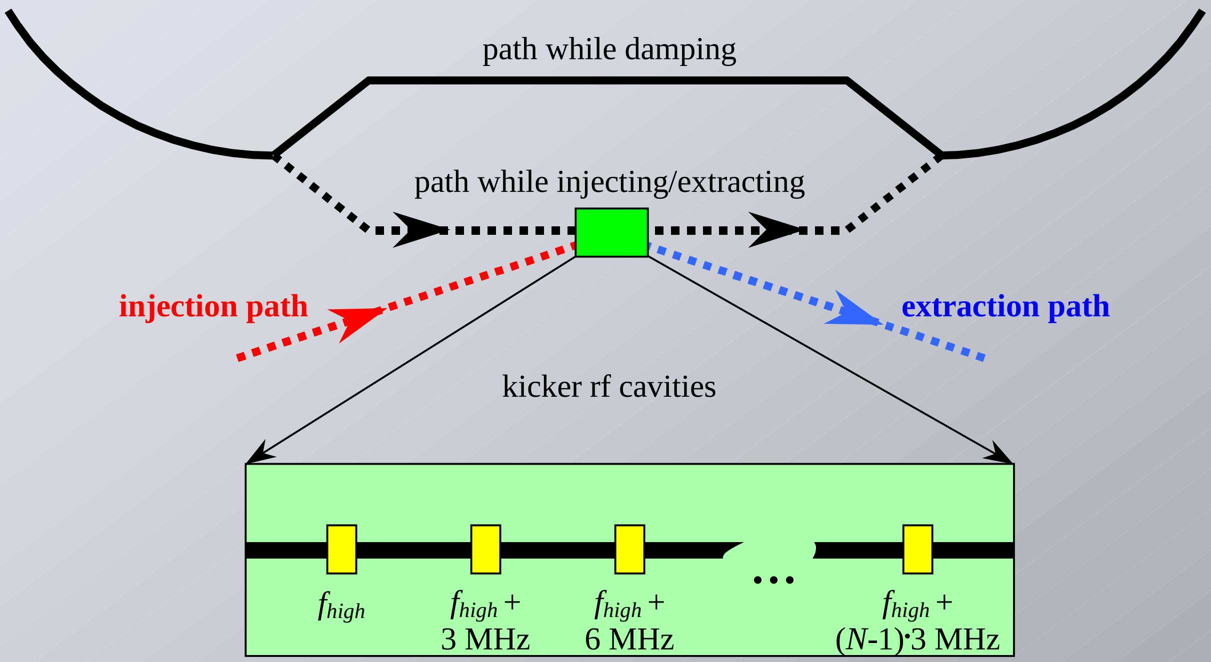
Different injection/extraction schemes would allow for a smaller damping ring.

Three schemes currently under investigation at Fermilab:

- Fourier series kicker (GG)
- Multiple bunch trains with ~100 nsec inter-train gaps (Joe Rogers)
- Longitudinal RF kick followed by dispersive elements (Dave Rubin)

Working meeting 3/15 – 3/18 at FNAL to model a ~4km damping ring which incorporates these kickers into straight sections. (We already have a simple lattice for the ring.)

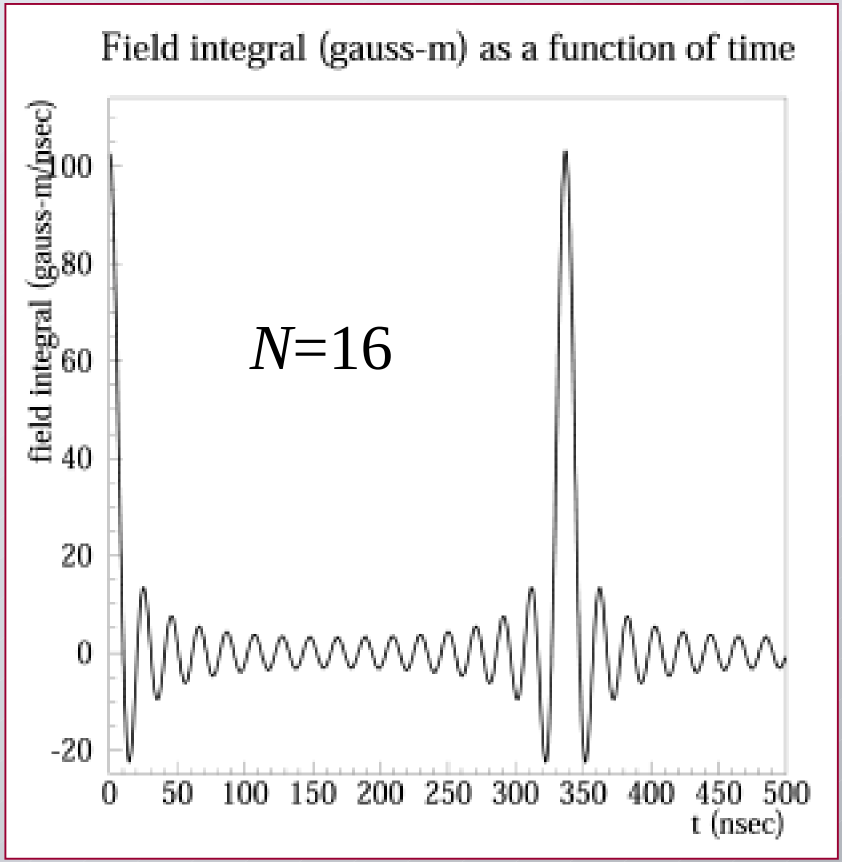
Fourier series kicker



Kicker would be a series of *N* "rf cavities" oscillating at harmonics of the linac bunch frequency 1/(337 nsec) = 2.97 MHz:

$$p_T = \sum_{j=0}^{j=N_{cavities}-1} A_j \cos\left[\left(\omega_{high} + j\omega_{low}\right)t\right]; \quad \omega_{low} = \frac{2\pi}{337 \text{ ns}}$$

A naïve version of the Fourier series kicker



$$\frac{1}{2}+\sum_{k=1}^{N}\cos\left(k\omega_0 t\right)=$$

$$\frac{1}{2}+\sum_{k=1}^{N}\frac{e^{ik\omega_0 t}+e^{-ik\omega_0 t}}{2}=$$

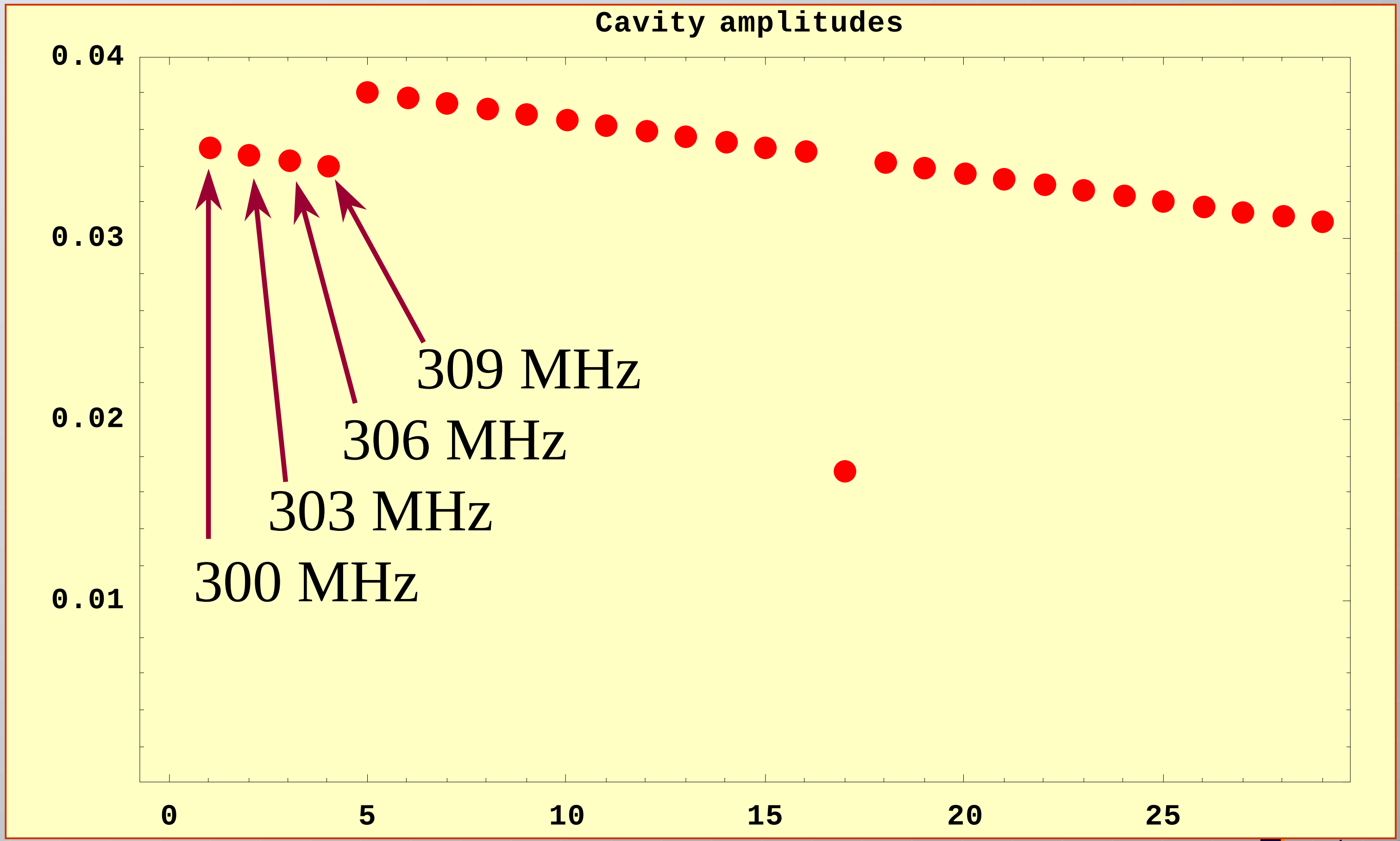
$$\frac{1}{2}\left[\sum_{k=0}^{N}\left(e^{i\omega_0 t}\right)^k+\sum_{k=0}^{N}\left(e^{-i\omega_0 t}\right)^k\right]=$$

$$\frac{1}{2}\frac{\sin\left[\left(N+\frac{1}{2}\right)\omega_0 t\right]}{\sin\left(\omega_0 t/2\right)}$$

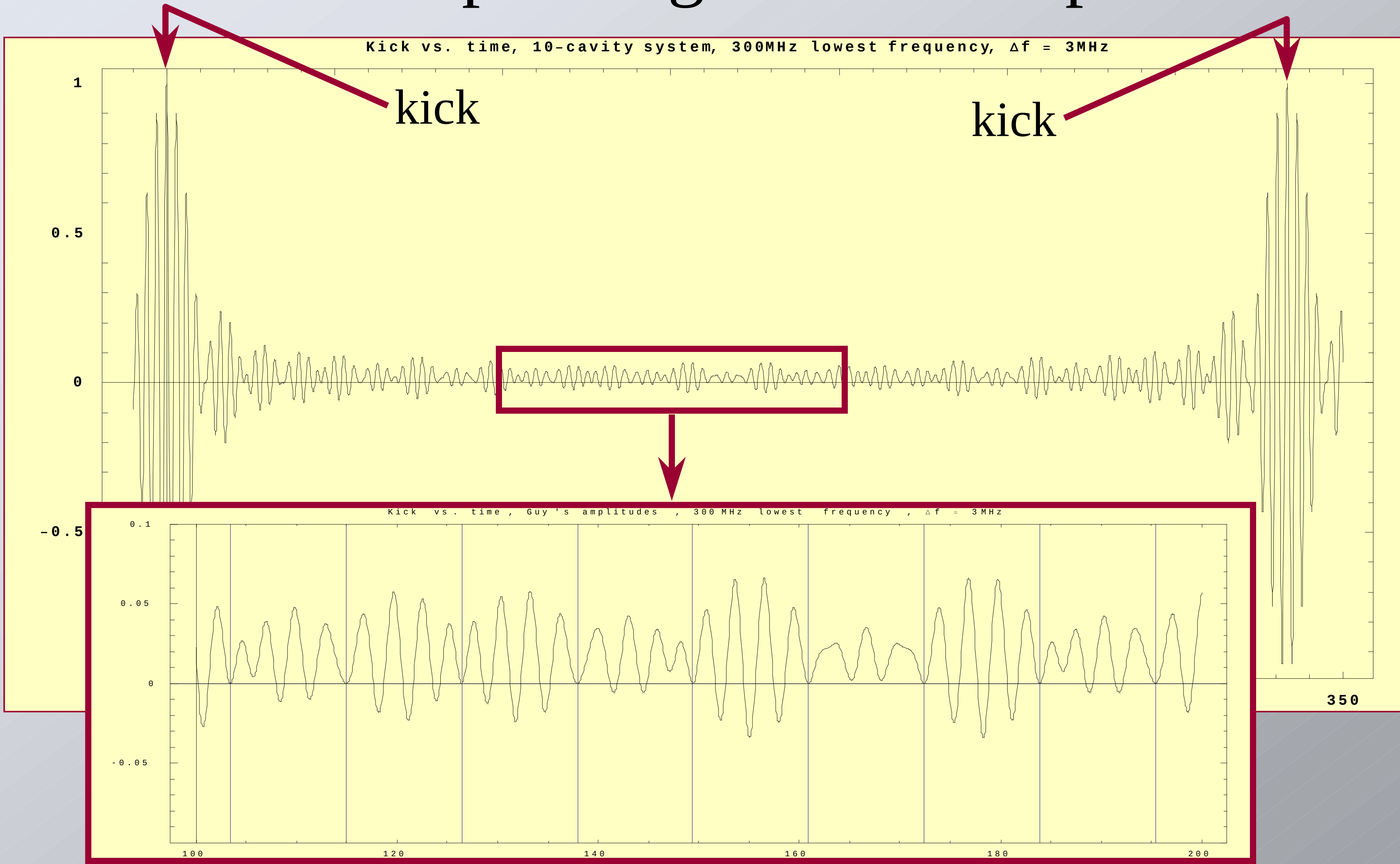
Note the presence of evenly-spaced "features" (zeroes or spikes) whenever $\left(N+\frac{1}{2}\right)\omega_0 t = m\pi$. The problems…

More sophisticated parameter choice

Higher base frequency, different amplitudes…



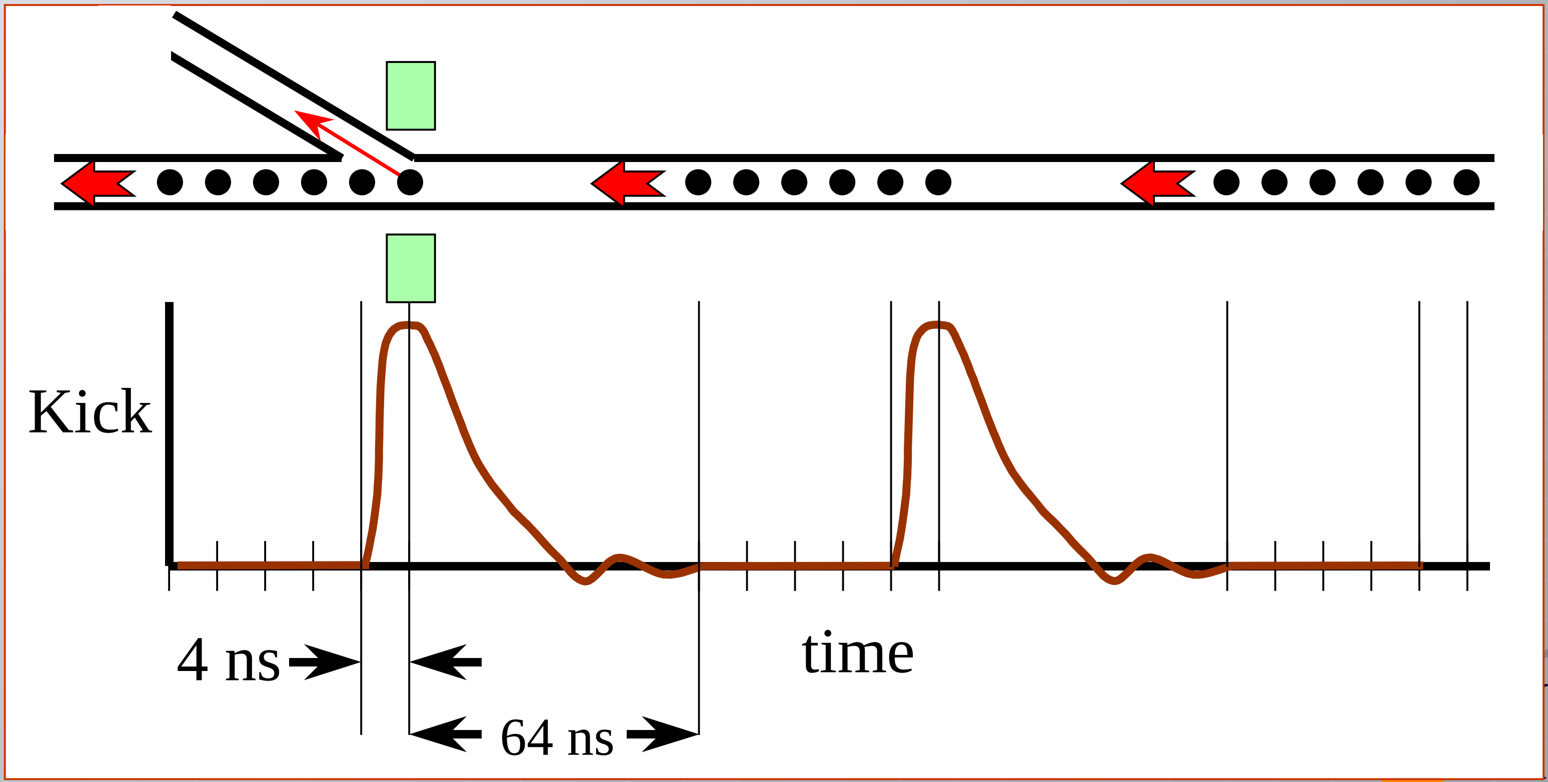
Kick corresponding to those amplitudes



p_T and dp_T/dt are zero for unkicked bunches;
head-tail differences are negligible this way.

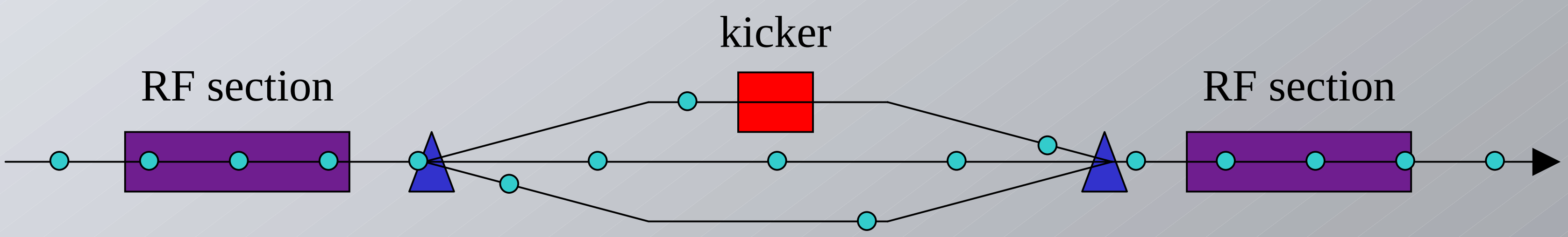
Multiple bunch trains with intertrain gaps

- It's easier to turn a kicker on than it is to turn it off.
- Bunches circulate in trains; each train is separated from the next train by a gap;
- Extract the last bunch in a train so that kicker must turn on rapidly but has the gap time to turn off.



RF separation at injection/extraction points (R. Helms, D. Rubin)

- A secondary RF system with a different frequency is used to separate the beam dispersively, bunch by bunch, into different channels.
- One such channel contains the injection/extraction kicker.



- Bunch spacing can be made smaller than the kicker rise/fall time (by a factor of 4), allowing for a smaller ring.

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My impressions

The (very large) TESLA damping ring design is widely viewed as the most unsettling technical issue for the cold machine.

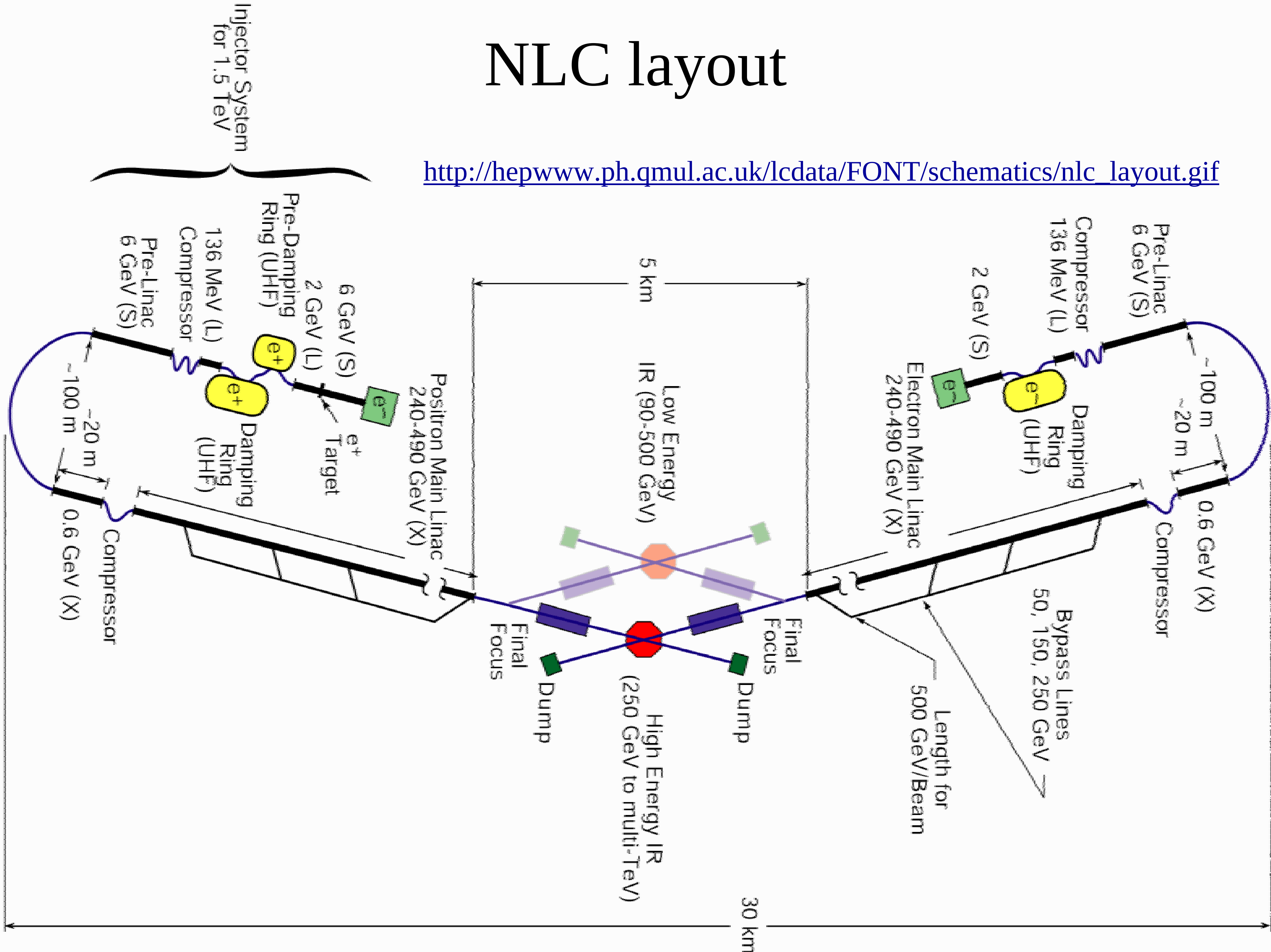
It is encouraging that there's a significant effort now underway to take another look at the design, and to compare it with a few new approaches.

A comment about linac mechanical tolerances:

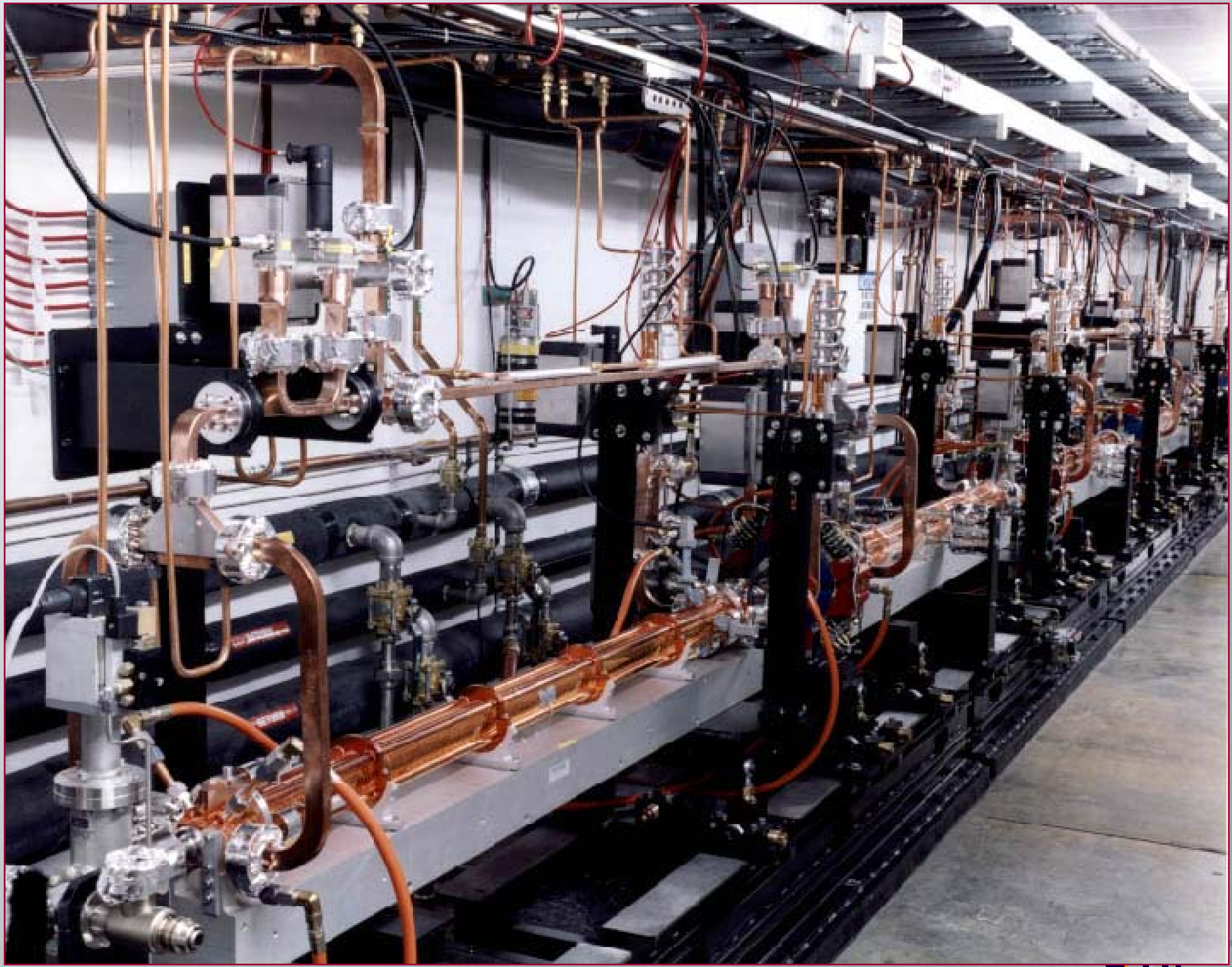
TESLA's 300μm tolerances are much looser than NLC's 1μm tolerances. However, the TESLA linac lives inside a cryostat. In addition, success at detecting misalignment (and correcting it to preserve luminosity) may differ between the designs. Bunch charge is different in the two machines so wakefield effects are different… Perhaps it's not so simple to compare.

NLC layout

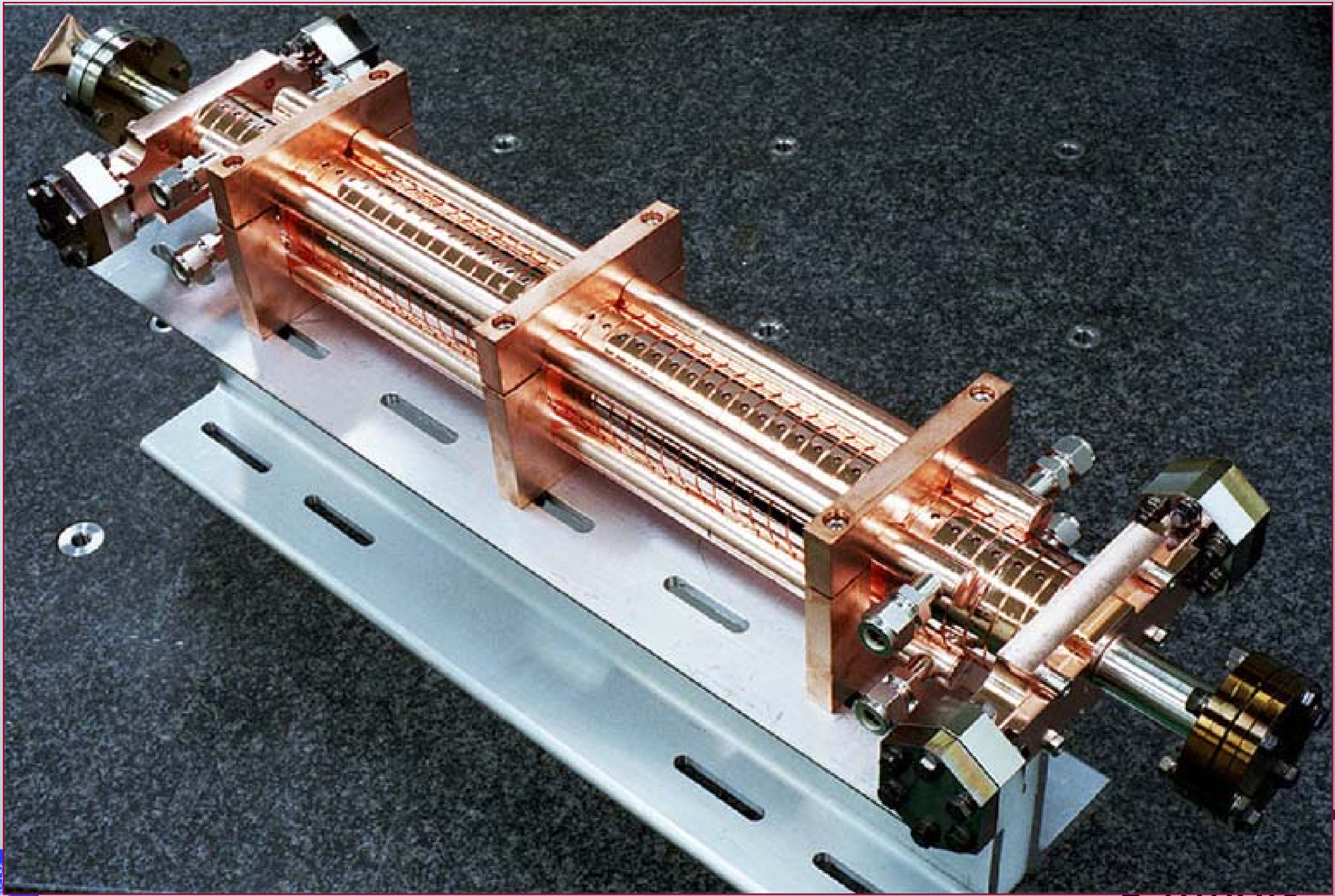
http://hepwww.ph.qmul.ac.uk/lcdata/FONT/schematics/nlc_layout.gif



NLC main linac (photo: NLCTA)

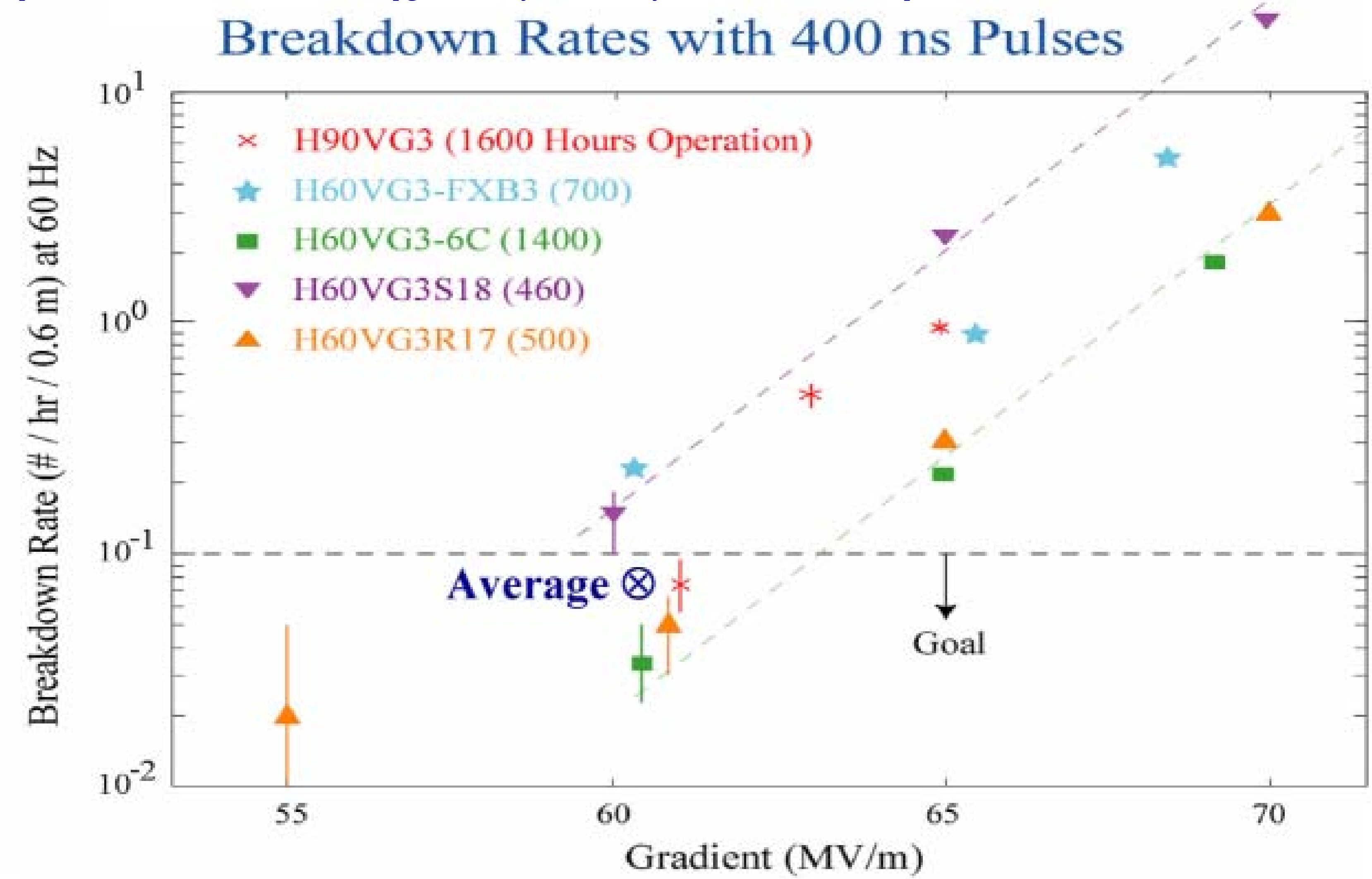


NLC accelerating structure



NLC gradients

http://www-conf.slac.stanford.edu/alcpg04/Plenary/Wednesday/Ross_WarmMachine.pdf



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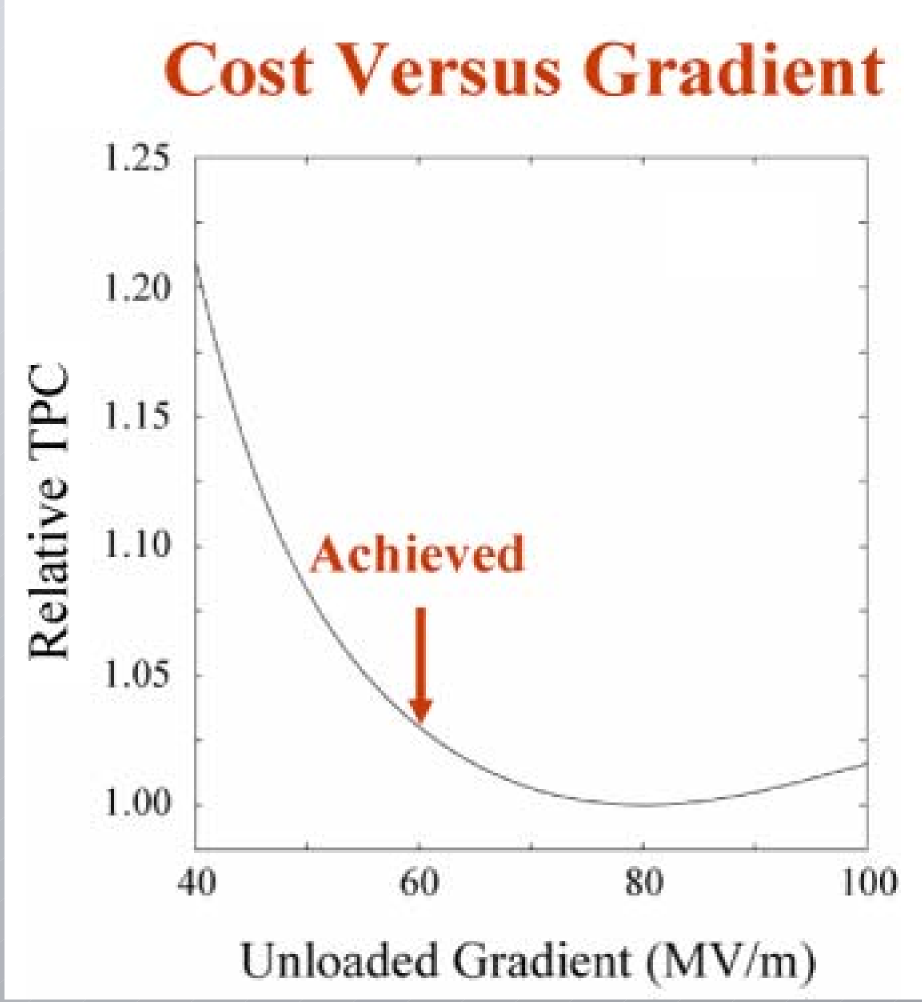
NLC gradients

Machine could be built with 60 MV cavities: it would increase the total project cost by ~10%.

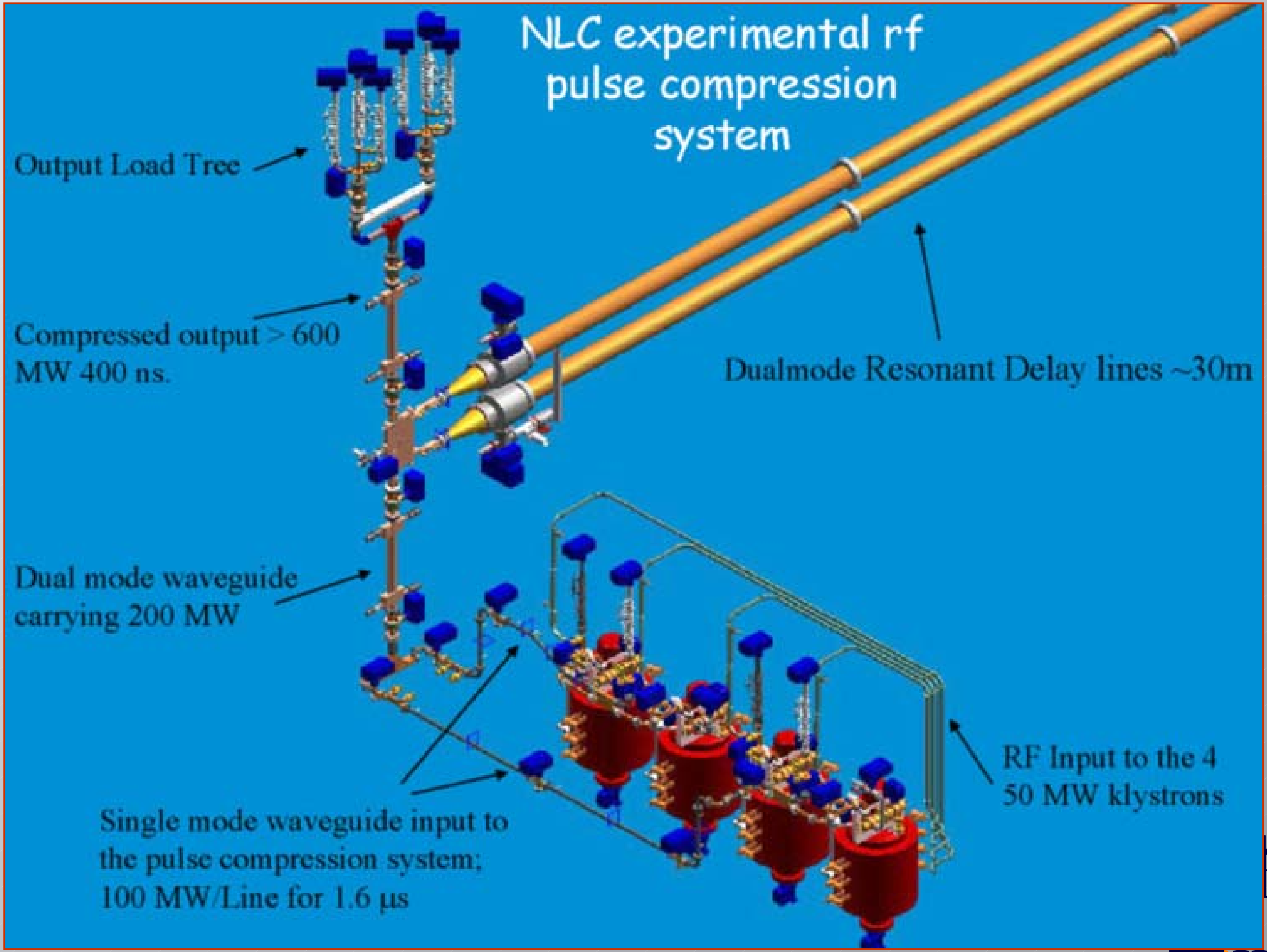
Interesting (to me): heat-anneal cavities to enlarge grain size: breakdowns occur more often at grain boundaries, so large grains are better.



http://www-conf.slac.stanford.edu/alcpg04/Plenary/Wednesday/Ross_WarmMachine.pdf

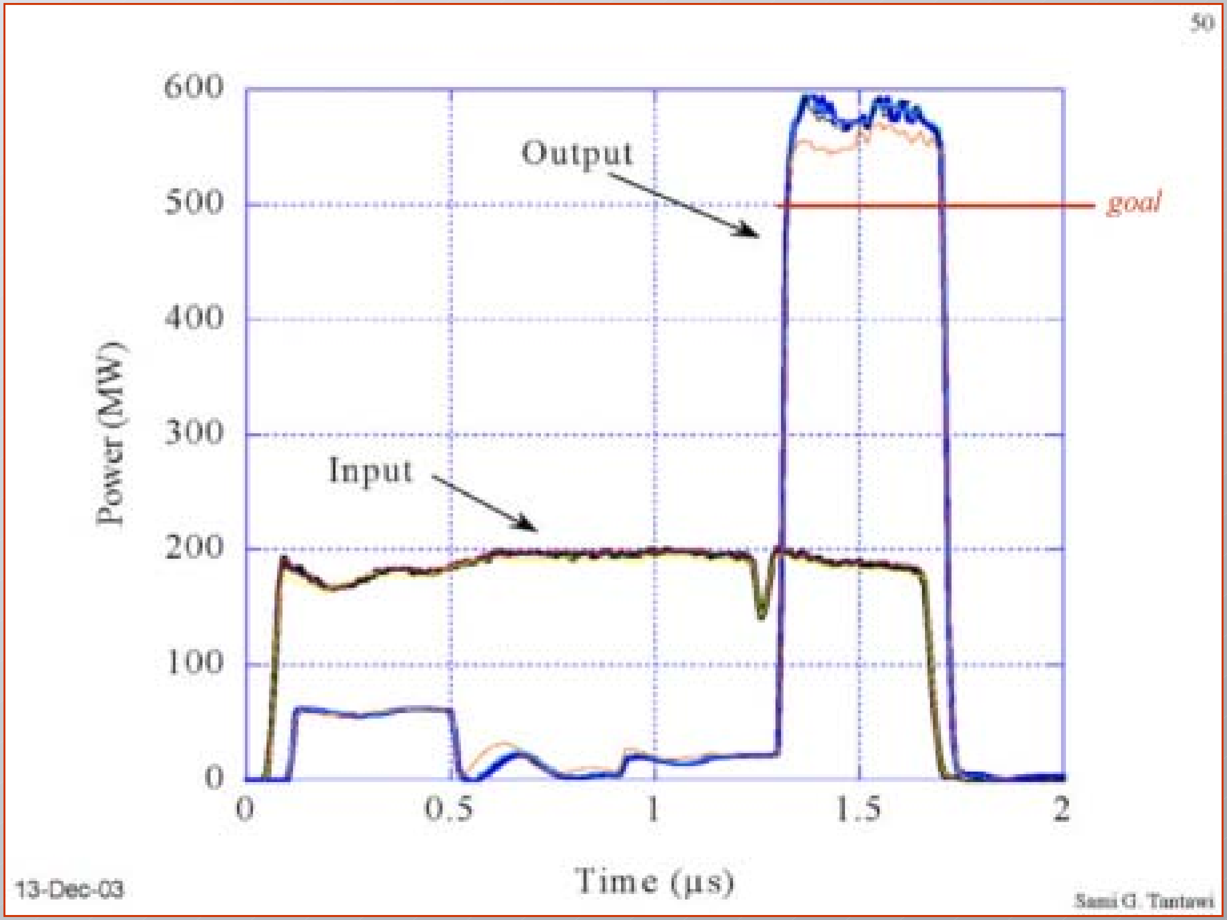
NLC RF power generation

RF pulse compression system is beginning to behave: SLED pulse compression from 1.6 μs to 400 ns can be made to work.



NLC RF power generation

SLED pulse compression from 1.6 μs to 400 ns…



http://www-conf.slac.stanford.edu/alcpg04/Plenary/Wednesday/Ross_WarmMachine.pdf

My impressions

NLC RF power distribution is still a challenge.

SLED system might be a touchy thing to operate…

I am concerned about required NLC mechanical tolerances.

Technical progress for both TESLA and NLC is very promising, but it would be unwise to go “into production” until a 1% ETF is built to demonstrate that an LC will really work:

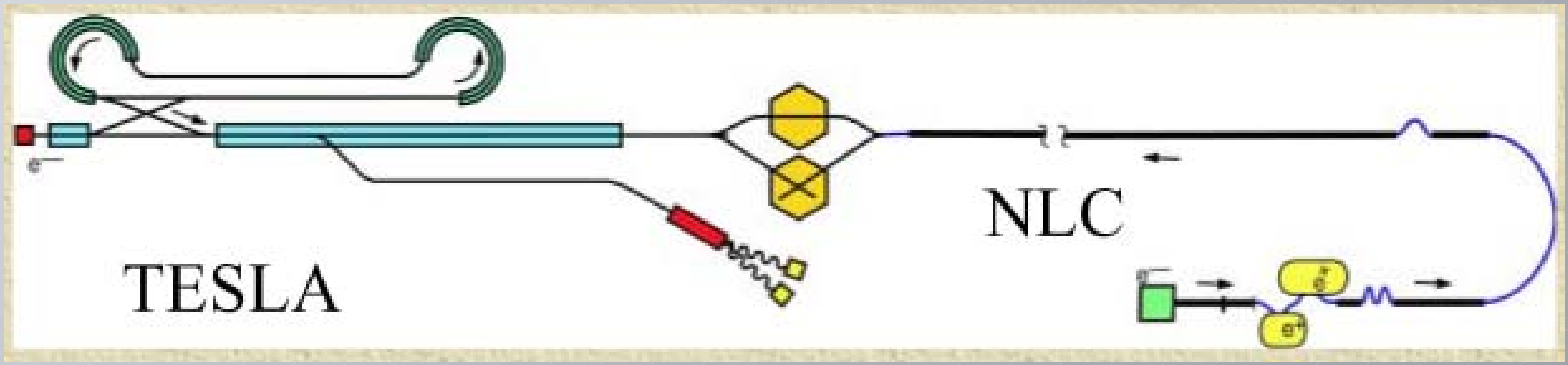
- e^+/e^- sources work as expected
- damping ring delivers desired emittance
- linac can accelerate beam while preserving emittance

Linear Collider's place in U.S. program

Linear Collider R&D is beginning to attract more interest from university-based HEP groups in the U.S.

Level of LC participation (by university groups) has increased ~50% since early 2002.

About half of the new projects taken on by "detector groups" at universities involve accelerator physics.



("Hybrid" LC from Tom Himel, SLAC)

Physics Illinois

The wild, wild west
c. 1987

A snapshot of the Wild, Wild, West…

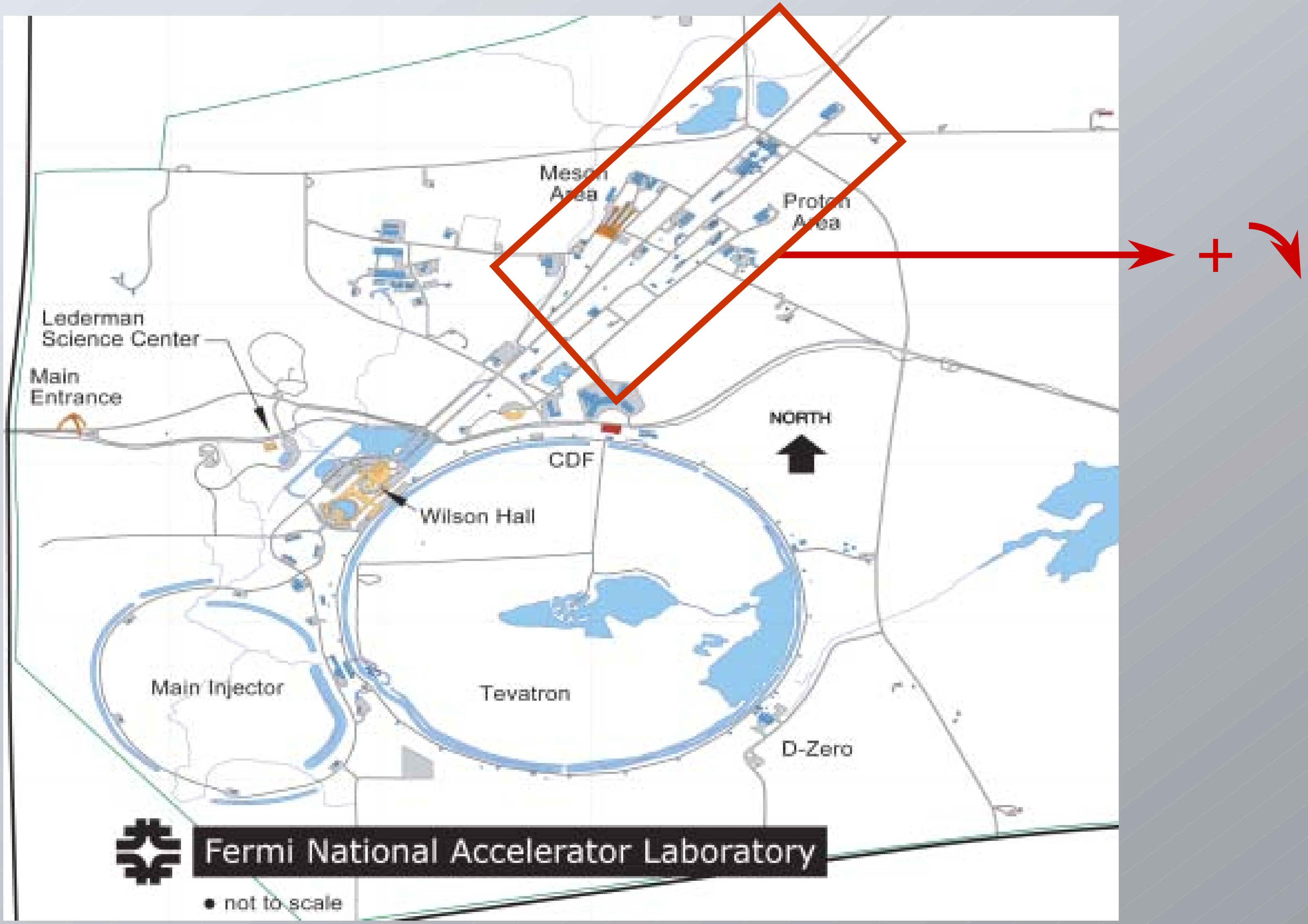
As experiments have grown larger, the style of collaboration has changed.

There was a sense of lively engagement and "ownership" that was characteristic of smaller collaborations at Fermilab during the 1980s.

It would be healthy to try to instill this in our much larger projects, such as Linear Collider R&D, today.

My impressions of the 1987-88 fixed target run at Fermilab…

Fixed target experiments at Fermilab, 1987-88



Fixed target beamlines…

The experiments which took data, 1987-88

1987-88 run:
- ~16 experiments
- ~675 physicists
- ~40,000 6250 BPI magnetic tapes
- ~2.5 countries per experiment
- ~8.5 institutions per experiment

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Physics goals of fixed target program, 1987-88.

Charm physics

- lifetimes, branching ratios
- production mechanisms: hadronic + electromagnetic
- *A* dependence

Nucleon and nuclear structure

- deep inelastic scattering structure functions
- "EMC effect"
- hyperon magnetic moments

QCD, etc.

- direct γ production
- the hadronic vertex in lepton-nucleon scattering

Standard model/electroweak tests

- CP violation
- wrong-sign dimuon events
- WIMP search
- ν_τ search

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Oy, the pressure!

Experiments were smaller:

- ~42 physicists per experiment
- ~5 physicists per institution (usually a university group)

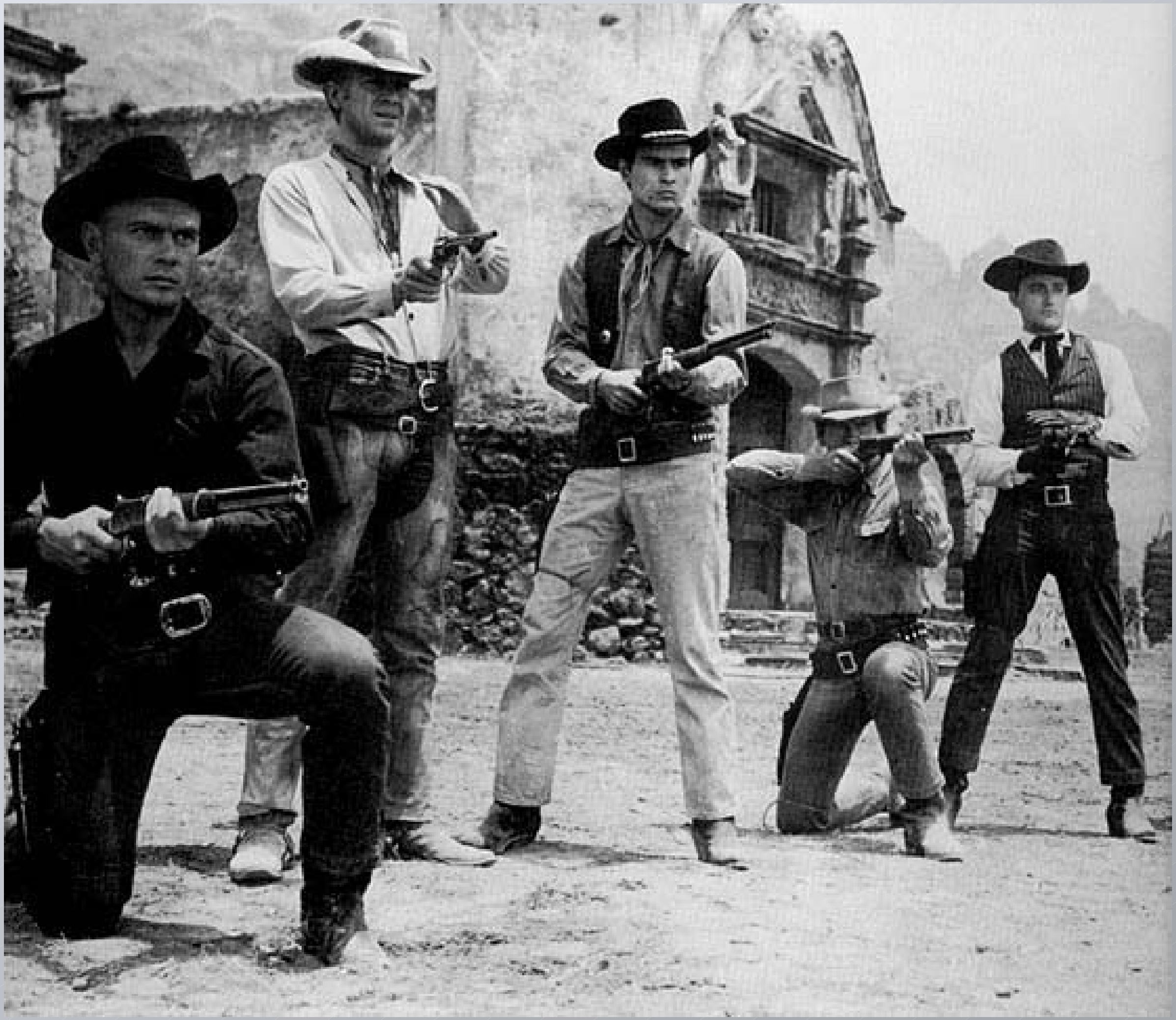
Typically, each university group would build a major subsystem for the experiment (*e.g.* the drift chambers)

- if it didn't work, the experiment would fail
- many experiments only ran once
- runs were short: ~6 months.

High stakes, high pressure, very exciting, very stressful.

…The Wild, Wild, West…

E731 discusses quality of DAQ support with Fermilab's Computing Division, 1987



Scene from *The Magnificent Seven* (1960)

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The atmosphere in which we worked

Most experiments were proposed by university groups.

Fermilab provided technical support (DAQ, installation, beams, offline computing resources, etc.)

University groups were autonomous; experiments were controlled by the off-site groups.

Fermilab program planning office kept track of experiment status as best as it could:

- in the cafeteria at lunch every day
- through unannounced visits to the experiments
- at weekly “all-experimenters” meetings

Grass-roots networking

Fermilab Visual Media Services #92-1168

Many (most?) on-site experimenters came to Wilson Hall for lunch.

- hear/spread rumors
- beg for resources
- brag and complain
- see friends from other universities

The place crackled with energy

The food was terrible

It was chaotic and exhilarating.

Smaller groups, different time scales

It seemed to be possible to accomplish a lot, very quickly

- much less oversight/bureaucracy/documentation than now
- instrumentation was simpler
- work was less compartmentalized: more sense of individual engagement in addition to responsibility for entire experiment.

University faculty would fly in every week; graduate students and postdocs would live at Fermilab.

My experiences: muon scattering and K^0 experiments.

The cultural origins of the Wild, Wild, West

Cultural origins:

- some universities had built their own cyclotrons, then accelerators (*e.g.* CEA at Harvard, PPA at Princeton)
- U.S. university research culture has always encouraged faculty independence and creativity

Princeton faculty pondering the τ-θ paradox, 1955

Scene from *The Seven Samurai* (1959)

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Advantages and disadvantages

Advantages of this sort of arrangement:

- collaboration is responsive to new information: it is possible to change direction of work rapidly
- greater breadth of experiences for all participants is possible
- sense of responsibility for all aspects of the experiment makes it more likely for problems to be found and corrected.
- sense of independence, engagement and "ownership" is very satisfying

Disadvantages:

- large projects (*e.g.* CDF) might be too complicated to execute
- oversight of experiments is difficult (a few experiments didn't work at all due to incompetence of the participants)

Big experiments are different

Big Science 2003…

Experiments have become much larger. CDF's collaboration list (shown on this page) includes 53 institutions.

D. Acosta {14}, T. Affolder {25}, H. Akimoto {50}, M. G. Albrow {13}, D. Ambrose {37}, D. Amidei {28}, K. Anikeev {27}, J. Antos {1}, G. Apollinari {13}, T. Arisawa {50}, A. Artikov {11}, T. Asakawa {48}, W. Ashmanskas {10}, F. Azfar {35}, P. Azzi-Bacchetta {36}, N. Bacchetta {36}, H. Bachacou {25}, W. Badgett {13}, S. Bailey {18}, P. de Barbaro {41}, A. Barbaro-Galtieri {25}, V. E. Barnes {40}, B. A. Barnett {21}, S. Baroiant {5}, M. Barone {15}, G. Bauer {27}, F. Bedeschi {38}, S. Behari {21}, S. Belforte {47}, W. H. Bell {17}, G. Bellettini {38}, J. Bellinger {51}, D. Benjamin {12}, J. Bensinger {4}, A. Beretvas {13}, J. Berryhill {10}, A. Bhatti {42}, M. Binkley {13}, D. Bisello {36}, M. Bishai {13}, R. E. Blair {2}, C. Blocker {4}, K. Bloom {28}, B. Blumenfeld {21}, S. R. Blusk {41}, A. Bocci {42}, A. Bodek {41}, G. Bolla {40}, A. Bolshov {27}, Y. Bonushkin {6}, D. Bortoletto {40}, J. Boudreau {39}, A. Brandl {31}, C. Bromberg {29}, M. Brozovic {12}, E. Brubaker {25}, N. 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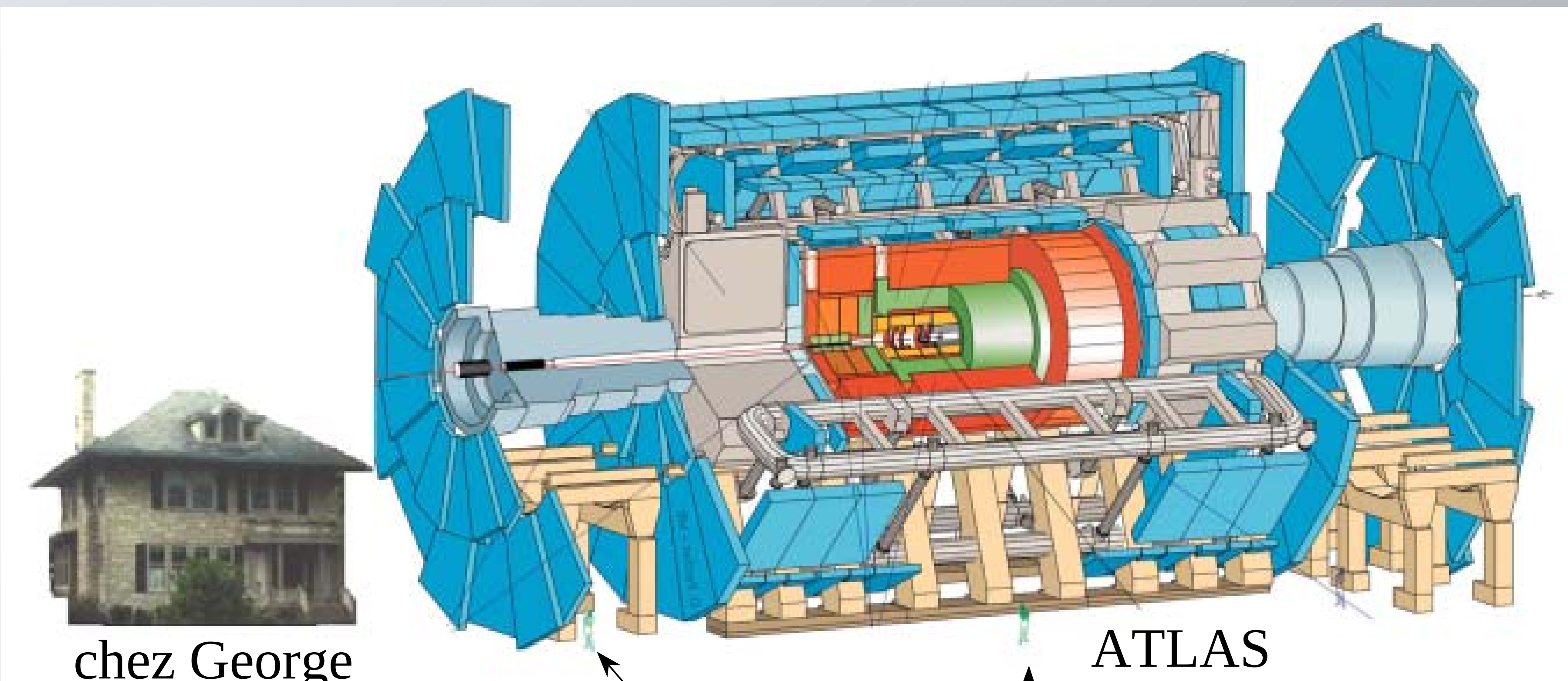
Very large devices

This is what we're talking about…

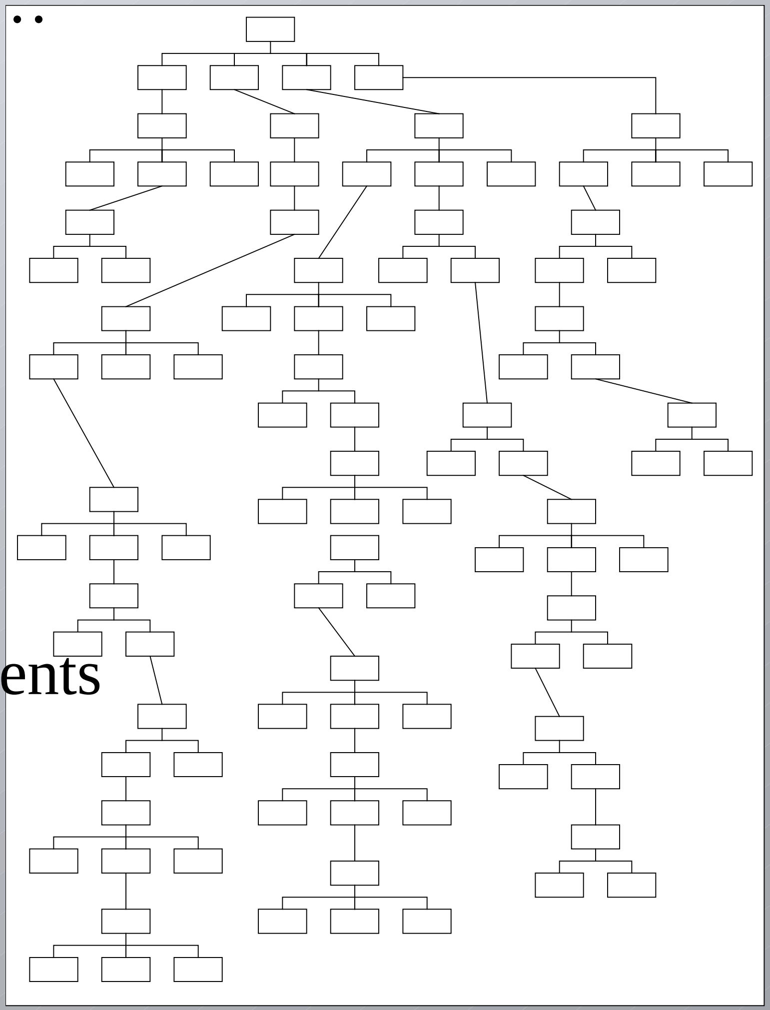


teeny-weeny people

Lots of documentation and structure

This is also what we're talking about…

- Expressions of Interest
- Letters of Intent
- Conceptual Design Reports
- Technical Design Reports
- Memoranda of Understanding
- Work Breakdown Structures
- Environmental Impact Assessments
- Technical Reviews
- Safety Reviews
- Progress Reports
- Director's Reviews



etc. etc.

Very ambitious physics objectives

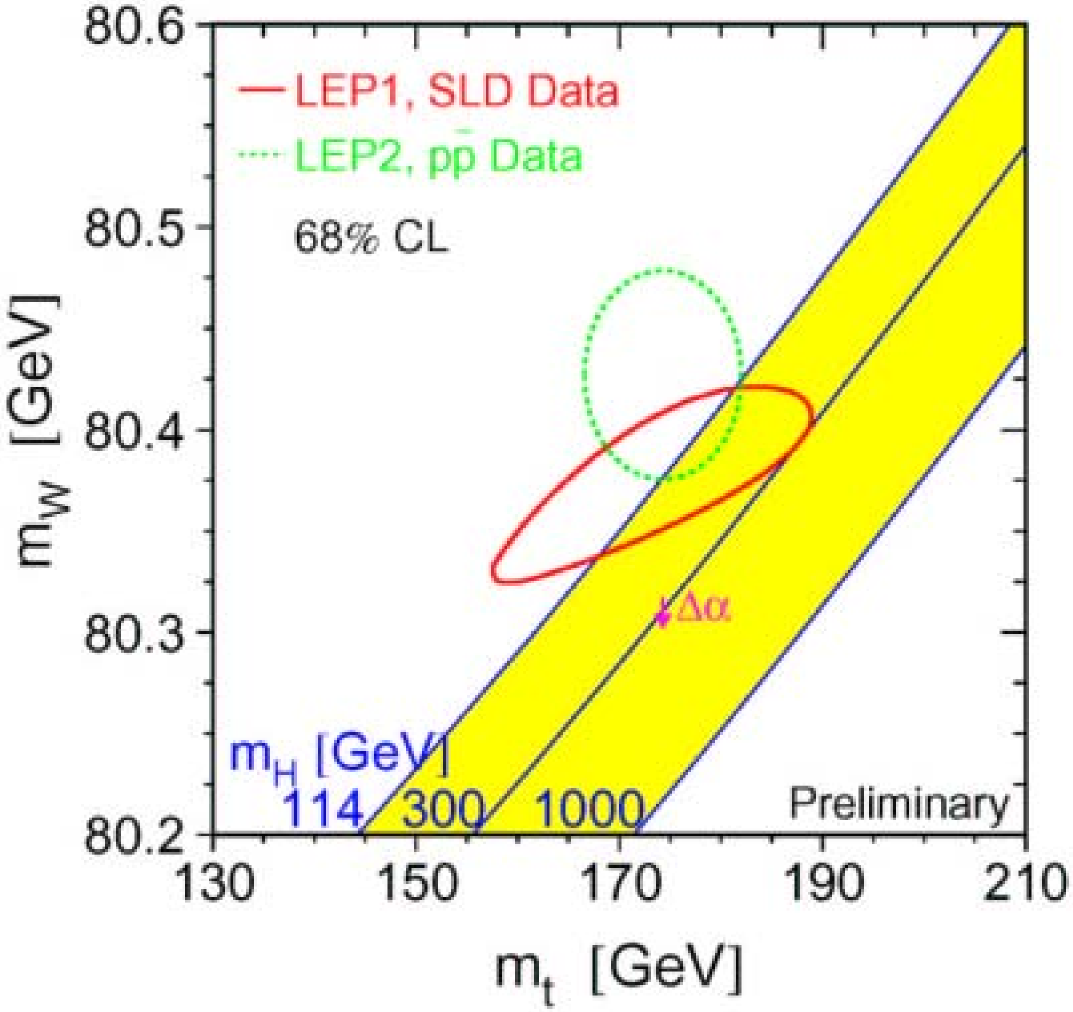
This is also what we're talking about…

- Observation of *CP* violation in *B* decays
- Discovery of the *t* quark
- Potential to identify the source of electroweak symmetry breaking (the Higgs?)
- Search for supersymmetry

The physics goals are very ambitious.

My contact with this: CLEO III and a little bit of ATLAS.

The holy grail: place m_H measurement onto this plot



(LEP EW WG http://lepewwg.web.cern.ch/LEPEWWG/plots/winter2003/)

Comments about the human side of things

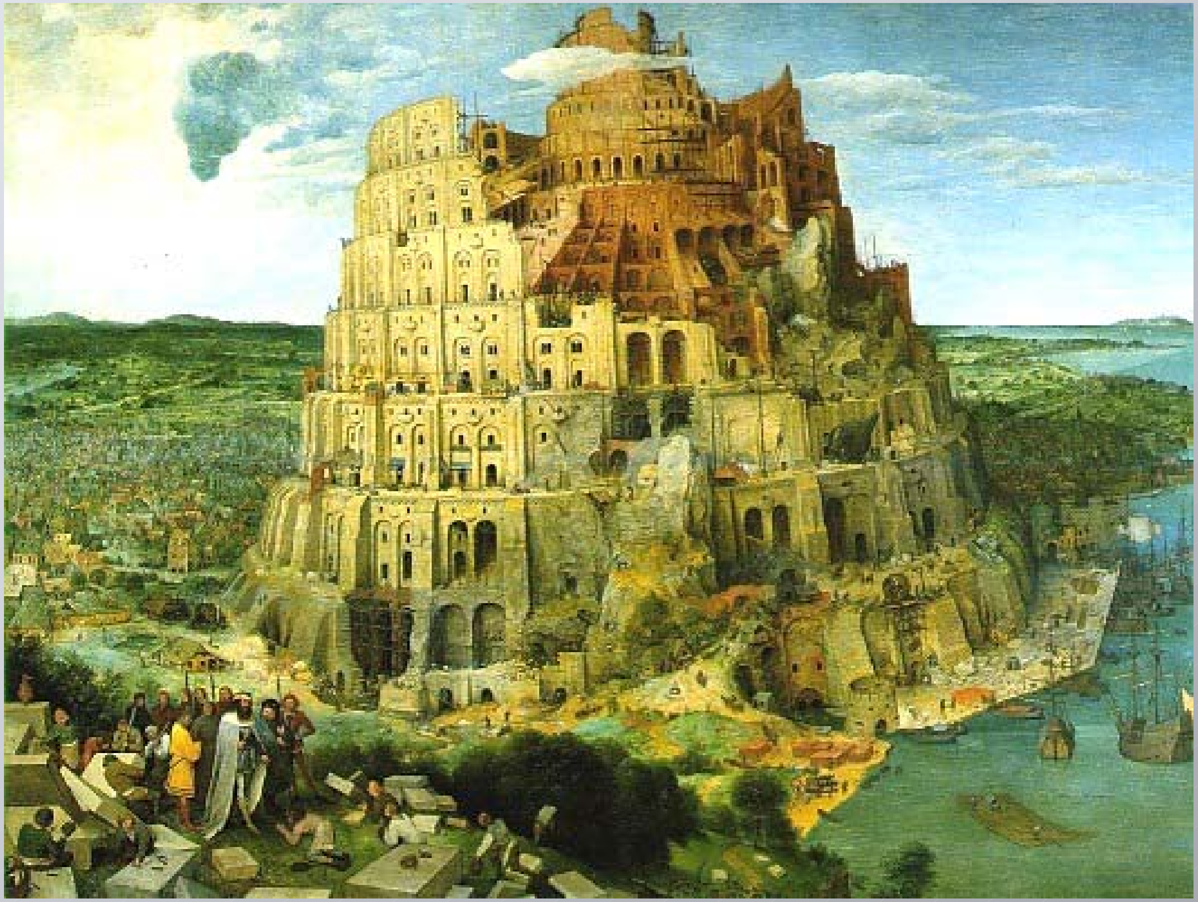
My experience is that communication is more difficult:

- more people
- more is happening so there's more to know
- it's harder to change direction based on unexpected information…

…and many participants exhibit a diminished sense of responsibility.

- "expert shifters" read newspapers (!!!), expecting that the "responsible person" will notice hardware problems offline
- problems observed online are thought to be "someone else's responsibility"

Communication difficulties



The Tower of Babel

Pieter Bruegel (1525-69)

"It's not my job"

More observations:

- It's less fun; people don't work as hard; progress is slower.
- data quality is reduced due to tardy correction of problems

The more general problem: lack of engagement, lack of responsibility…

- Unnecessary (and expensive) replacement of complex hardware systems because nobody chose to understand the details of the existing system (which was working fine!)
- Large amounts of data rendered useless by mistakes which go unnoticed because nobody bothers to look for problems

(Like some examples? [not from CLEO or ATLAS])

Physics Illinois

“Somebody else will catch it offline”

Physics
Illinois

Pathological decision making

Pathological decision-making…

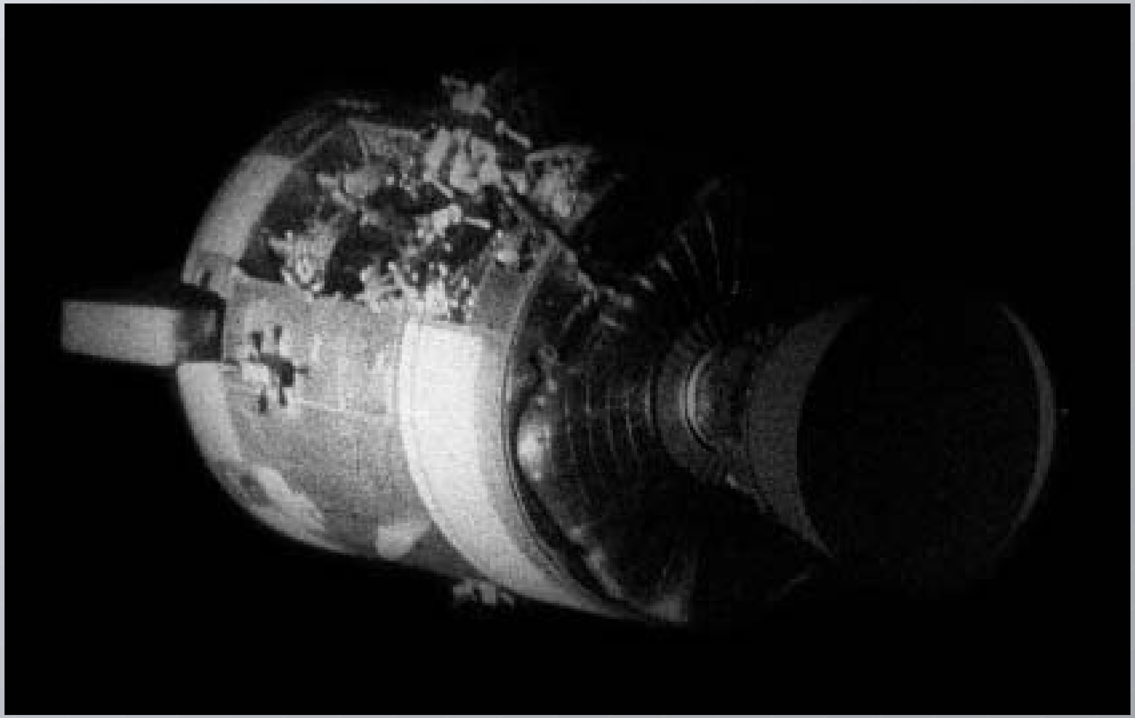
An organization's decision-making process can evolve in a pathological fashion. Here is an example from outside HEP:

Apollo 13

Challenger

This one they got right

En route to the moon, an oxygen tank exploded in the Apollo 13 service module on April 13, 1970. The entire oxygen supply normally intended for trans-lunar flight was lost. The service module's main engine (to be used to return to Earth) was damaged.

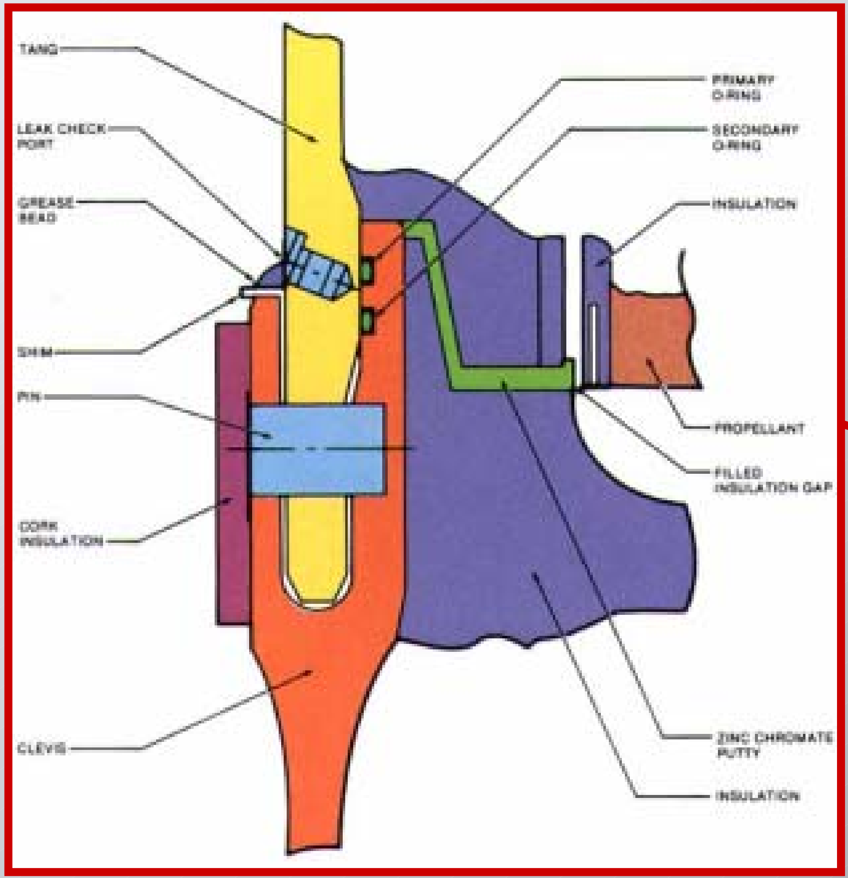


Rapid uptake of relevant information

NASA staff spent four days improvising solutions to propulsion and life support problems, allowing crew to return safely to Earth.

This was an extreme case, but NASA was able to use new information rapidly to decide on a proper (new) course of action.

1986 *Challenger* explosion



On January 28, 1986, the space shuttle *Challenger* exploded when an O-ring in the right solid rocket booster burned through, rupturing the shuttle's main fuel tank.

NASA knew cold O-rings were a problem

What NASA knew that day:

- At launch time, ambient temperature was 2°C (36°F)
- Morton-Thiokol engineers had unanimously recommended against a launch at that temperature. NASA asked them to reconsider. M-T management overruled the engineers.
- Next-coldest launch temperature had been 11.7°C (53°F)
- 4 of 21 previous launches at temperatures ≥ 16°C (61°F) had shown "O-ring thermal distress" (!!! burns, for example !!!)
- 3 of 3 previous launches at temperatures < 16°C (61°F) had shown "O-ring thermal distress"

Shuttle was launched in spite of SRB designers' fears/objections/launch veto

So… NASA was aware of the engineers' concerns, and knew that cold O-rings were (partially) burned during launch.

NASA was unable/unwilling to include this information in its decision regarding the shuttle launch.

There were seven people aboard the *Challenger*.

Does NASA do better now?

2003 *Columbia* accident

Not always.

On January 16, 2003, debris struck the space shuttle *Columbia's* left wing shortly after liftoff.

NASA engineers asked Ron Dittemore (shuttle program manager) to obtain satellite images of the shuttle to look for signs of damage.

NASA administrators vetoed engineers' requests for satellite imagery of shuttle wing…

Dittemore refused.

According to NASA, "he felt that satellite images would not necessarily help determine damage."

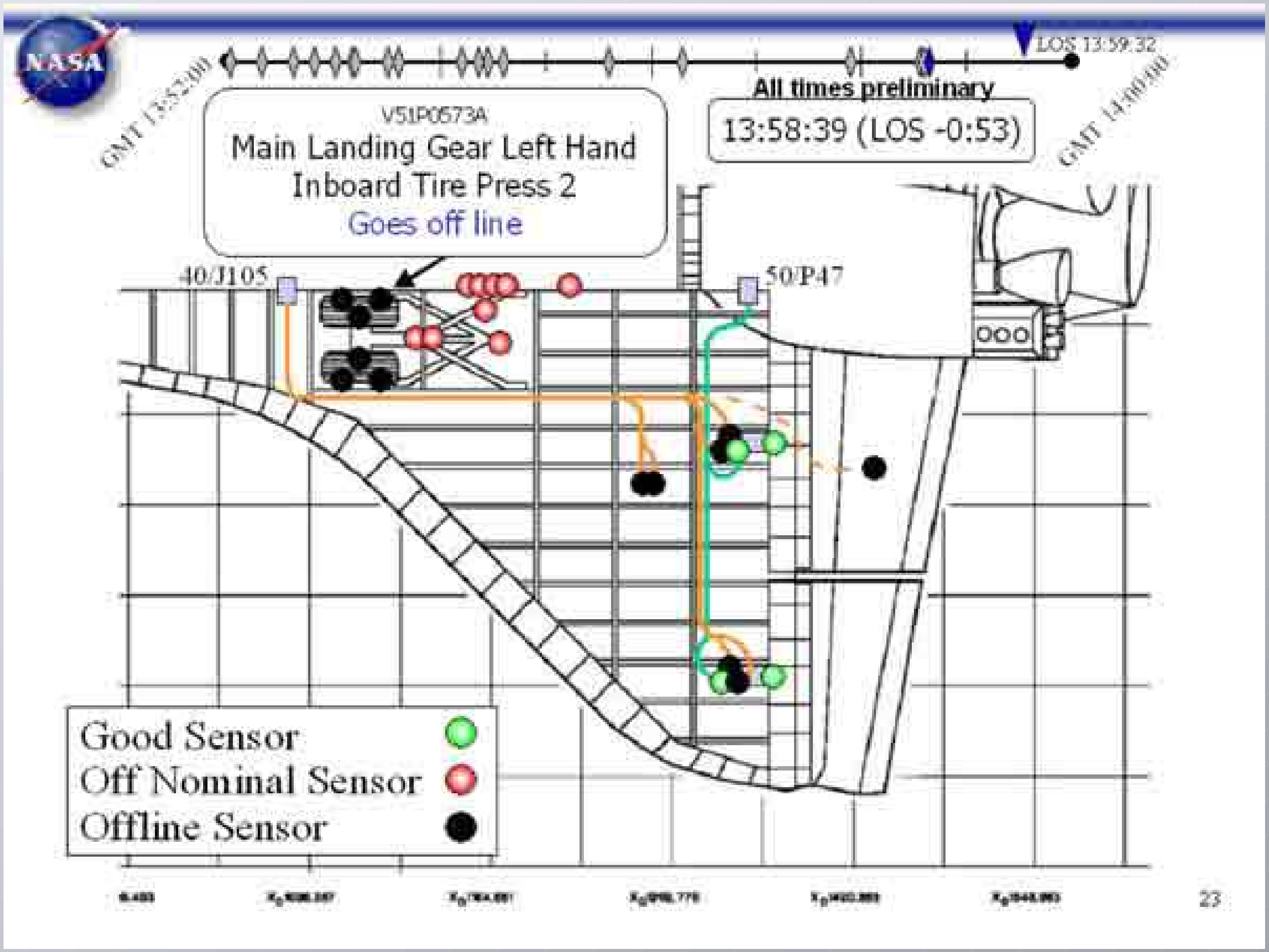
Also: "such images might not have been sharp enough." (NY *Times*, March 13, 2003.)

…and cancelled a request which had slipped through

NASA: "someone did make an early request for imagery to the Defense Department. But that request, which 'was not coordinated with the rest of the flight operations world,' was withdrawn by Roger D. Simpson, another NASA official." (*ibid.*)

January 23 email from Simpson "thanked officials at the United States Strategic Command [operates U.S. spy satellites] for considering a request to observe the *Columbia* for damage but criticized the request as not having gone through proper channels. Simpson apologized for any 'inconvenience the cancellation of the request may have caused' and said that it had served only to 'spin the community up about potential problems.' He added that the shuttle was 'in excellent shape.'" (*ibid.*)

Sensor telemetry from left wing



Pathological decision-making

Again, NASA was unwilling to acquire/include new information in its decision-making.

Images "would not necessarily help determine damage"… "might not have been sharp enough"… it sounds like a NASA turf battle had interfered with common sense.

On February 1, 2003 *Columbia* disintegrated during reentry.

There were seven people aboard the *Columbia*.

Damage to the left wing (during liftoff) was at fault.

How does this come about?

Is this sort of decision-making pathology inevitable?

Would more sense of ownership and engagement by participants have allowed the (expert) engineers to prevail over the (technically less knowledgeable) managers?

Is NASA's problem similar in origin to some of the unwise decisions we have seen in high energy physics?

Combining the Wild, Wild West and Big Science

Bringing the Wild, Wild West to Big Science, and *vice versa:* a U.S. university-based LC R&D program…

Is some sort of decision-making pathology inevitable in any large organization?

How might it be avoided in a large HEP effort (such as a Linear Collider accelerator and detector)?

Centralization *vs.* independence

The requirements, the problems:

- Centralized system is necessary to manage resources, interact with governments, and provide coherent oversight
- Engaged participants who feel they can influence the direction and goals of the entire project are necessary for best success.

It is not a simple matter to cause these to coexist.

Try combining the two…

Why not combine "Wild Wild West" and "Big Science" approaches in the project?

"Big Science" (a steering group) focuses on global issues: project oversight, internationalization, and interaction with funding agencies.

"Wild Wild West" (proponents of individual R&D efforts) organizes itself however it chooses, maintaining much of its independence from the steering group. Cooperation with the steering group is ~<u>voluntary</u>.

If the steering group does not act in a timely fashion, proponents can take matters into their own hands.

(It sounds like a disaster waiting to happen.)

The worries we bring to the table

Nightmare of the steering group

image from *Gangs of New York*

Nightmare of the participants

image from http://www.i-magin-ation.com/Newsletters/Hold_Up_Your_Hand_03282002/Hold-Up-Your-Hand.htm

It actually seems to be working

Surprise!

This is how a significant component of the U.S. university-based LC R&D has been organized as of late.

So far it is working better than we had thought it would.

Here's the recent history…

U.S. LC work before 2002

Status of Linear Collider efforts in the U.S. before 2002

- major effort on NLC (warm) design at SLAC.
- many (most?) university participants were already affiliated with SLAC through SLD collaboration
- most university participants were involved with physics and detector simulations. (almost) no "detector" physicists were doing accelerator physics R&D.
- less U.S. involvement with cold (TESLA) design: work at Argonne National Lab, Cornell, Fermilab, UCLA, Jefferson Lab
- Department of Energy (one of two U.S. funding agencies) was wary of U.S. duplication of TESLA work already underway in Europe, and did not encourage TESLA-related projects.

U.S. LC work before 2002

U.S. Linear Collider Steering Committee (USLCSC) had been created to oversee the entire U.S. LC effort and to interact with international efforts.

American Linear Collider Physics Group (ALCPG) had been created to provide structure to the U.S. detector R&D effort:

- executive committee composed of university people
- various working groups covering physics and detector topics
- no corresponding group for accelerator work at universities

Most university HEP physicists were not involved, and tended to think about the long-term problems of funding, technology and site selection, and possible role of LC when LHC was already running.

LC becomes highest priority U.S. (future) effort

HEPAP (High Energy Physics Advisory Panel to U.S. Department of Energy) endorsed Linear Collider in January, 2002:

> We recommend that the highest priority of the U.S. program be a high-energy, high-luminosity, electron-positron linear collider, wherever it is built in the world. This facility is the next major step in the field and should be designed, built and operated as a fully international effort.
>
> We also recommend that the United States take a leadership position in forming the international collaboration needed to develop a final design, build and operate this machine. The U.S. participation should be undertaken as a partnership between DOE and NSF, with the full involvement of the entire particle physics community…

http://doe-hep.hep.net/lrp_panel/

Trying to jump-start an LC effort: early 2002

Chicago Linear Collider Workshop, January 7-9, 2002…

- It was clear that FNAL management was focused on Run II problems, and had not yet been planning seriously for major LC participation. There were some projects underway though…
- University faculty already participating were focused on their own efforts, rather than on building a significant U.S. LC effort. It was unclear how other DOE groups (or NSF groups with NLC interests) could join in.
- Cornell was beginning to plan for a university-based effort (which it would manage), to be funded by the U.S. National Science Foundation. Nothing like this was in the works for DOE groups.
- SLAC was enthusiastic about helping university groups to begin working on accelerator physics topics.

Chicago Linear Collider Workshop

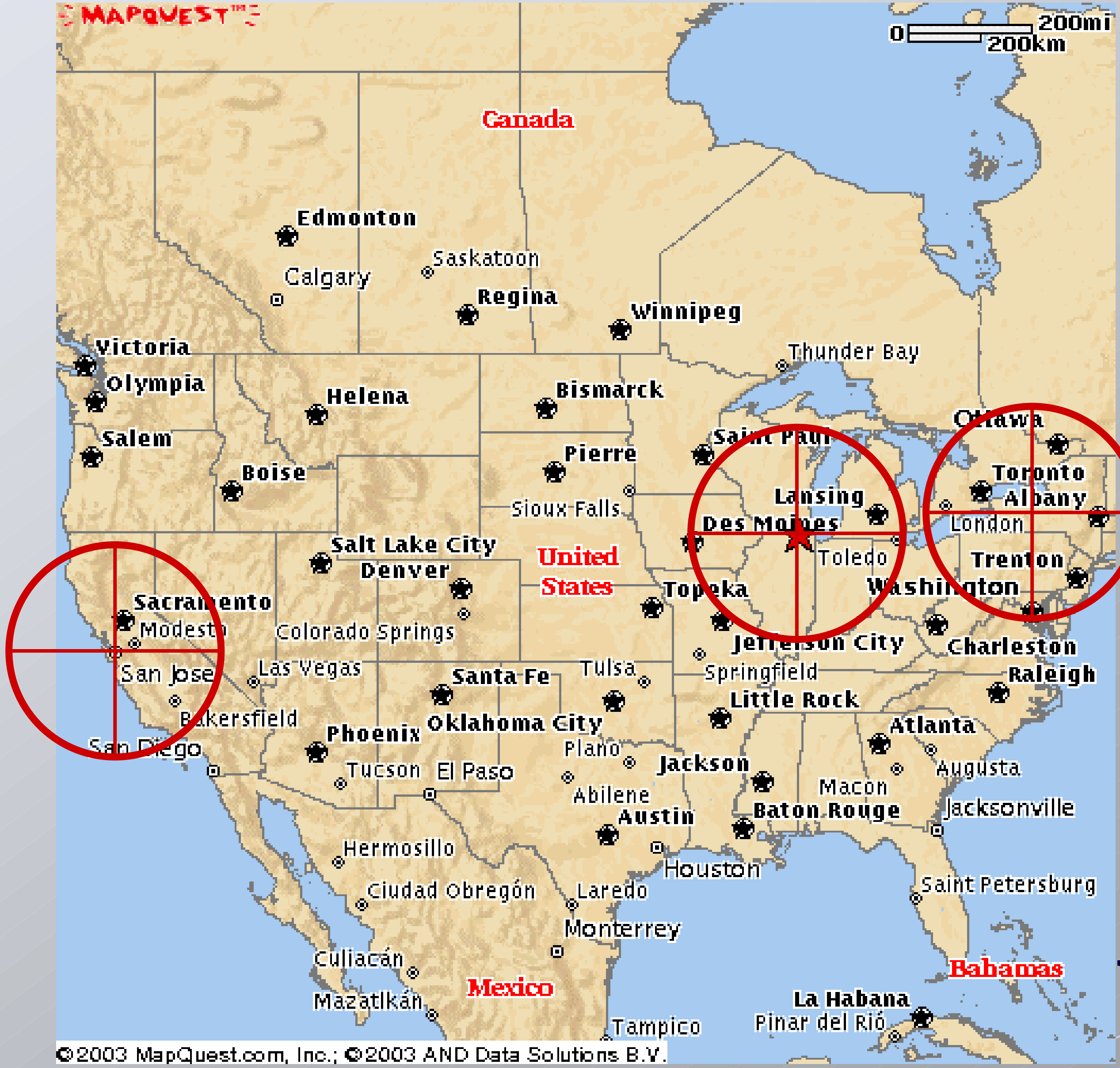
Self-organizing university efforts, early 2002

"Here come the professors!"

- USLCSC, ALCPG did not seem to have an effective plan for increasing university HEP involvement at that time.
- Some of us invented one and began to discuss it with our colleagues in February, 2002. Lots of phone calls.
- An accelerator physics working group spontaneously organized itself as an analog of the ALCPG detector WG's
- Several of us organized an unusual workshop, held at Fermilab on April 5, 2002. It was entirely driven by grass-roots interest to discuss a DOE-funded university program. (More on this later.)
- Cornell held a related workshop, to discuss organization of an NSF-funded consortium on April 19, 2002.
- SLAC held a follow-up workshop May 31, 2002.

Physics Illinois

Fermilab, Cornell, SLAC workshops



Physics Illinois

We hold a first workshop to present possible research topics to interested physicists

That Workshop at Fermilab April 5, 2002

Research and Development Opportunities for the Linear Collider

Fermi National Accelerator Laboratory

April 5, 2002

Organizing committee:
Dan Amidei, University of Michigan (co-chair)
George Gollin, University of Illinois (co-chair)
Gerald C. Blazey, Northern Illinois University
Marcela Carena, Fermilab
David Finley, Fermilab
Gene Fisk, Fermilab
David Gerdes, University of Michigan
Bob Kephart, Fermilab
Young-Kee Kim, University of California, Berkeley
Andreas Kronfeld, Fermilab
Nigel Lockyer, University of Pennsylvania
Slawomir Tkaczyk, Fermilab
Rick VanKooten, Indiana University

Physics Illinois

Why we wanted to hold the workshop

It was clear at the Chicago meeting that university-based physicists didn't know

- which R&D projects needed work
- how to get started

Existing US R&D had concentrated on accelerator design and simulation of detectors, with detector hardware R&D taking place abroad.

We wanted to stimulate participants' interest in the short/medium term tasks associated with R&D necessary for the Linear Collider.

We wanted people see what they could begin working on the day after the workshop

Most of us love working in the lab.

- Workshop speakers were asked to describe in detail some of the projects which awaited us. This way, we could start thinking about building stuff, rather than about LC politics.

Many people seemed to be waiting to be told what to do.

- Empower people to think for themselves and assess their own strengths and interests

"Ground rules" for speakers and participants

1. Stay clear of political issues. Discussions should be:

   •site-neutral when appropriate

   •inclusive of studies needed for both TESLA and NLC/JLC.

2. Think across traditional system boundaries:

   •required performance will couple many accelerator and detector systems' properties

   •cool projects abound in domains you might not have thought to consider (*e.g.* the accelerator!)

   •interesting possibilities for collaboration with colleagues in other domains (condensed matter, EE,...) exist.

What we did at the workshop

The program:

- •4 accelerator talks
- •4 detector talks

We did not bother with yet again another Higgs/SUSY talk.

Speakers were advised to "...to set before participants brief (but concrete) descriptions of a large number of research and development projects that participants might choose to undertake."

Tom Himel presented an amazing list of 80 (!!) R&D projects, of interest to the NLC design, the TESLA design, and of interest to both. It was the most interesting, and productive, part of the workshop.

Workshop URL: http://www.hep.uiuc.edu/LC/html_files/workshop_04_05_02_main.html

Tom Himel's list of accelerator projects

Note: current URL is http://www-conf.slac.stanford.edu/lcprojectlist/asp/projectlistbyanything.asp

An example of a suggested R&D project

Sample DB entry

ID: 16 **Priority:** Medium **project_size:** Large **skill_type:** physicist

short project description: superconducting quadrupole vibration test

Detailed project description: There are two options for the final doublet magnets: permanent and superconducting. The main concern about the superconducting method is that coils will vibrate too much since a strong support to the cryostat would cause a big heat leak, and boiling helium may jiggle the coils. Either by calculation, or finding an appropriate magnet, convince people that the quadrupole fields center will move by less than a nm relative to the outside of the cryostat.

Needed by who: NLC and TESLA **present status:** good idea needed
Needed by date: 6/1/2005

ContactPerson1: Joe Frisch **WorkPhone1:** 6509264005
EmailAddress1: frisch@slac.stanford.edu

Note that the contact person is someone who knows more about the project. He's not the person who will arrange who works on what.

http://www-project.slac.stanford.edu/lc/Project_List/intro.htm T. Himel 4/5/02

Sample accelerator projects

Here are a handful of items from Tom’s list:

- low level RF Digital Feedback Hardware
- Exception Handling for RF System
- TESLA Wave Guide Tuner Control
- Structure Breakdown diagnostics
- active vibration stabilization of Final Doublet
- Linac accelerator structure cooling without vibration
- Acoustic sensors for structure and DLDS breakdown
- beam profile monitor via Optical Transition Radiation
- Very fast injection/extraction kickers for TESLA damping ring
- RF BPM electronics, including tilt
- 5-10 kW magnet power supply
- flow switch replacement
- robot to replace electronic modules in tunnel
- Programmable Delay Unit
- linac movers: 50 nm step, rad hard
- Low Level RF 500 MHz digitizer

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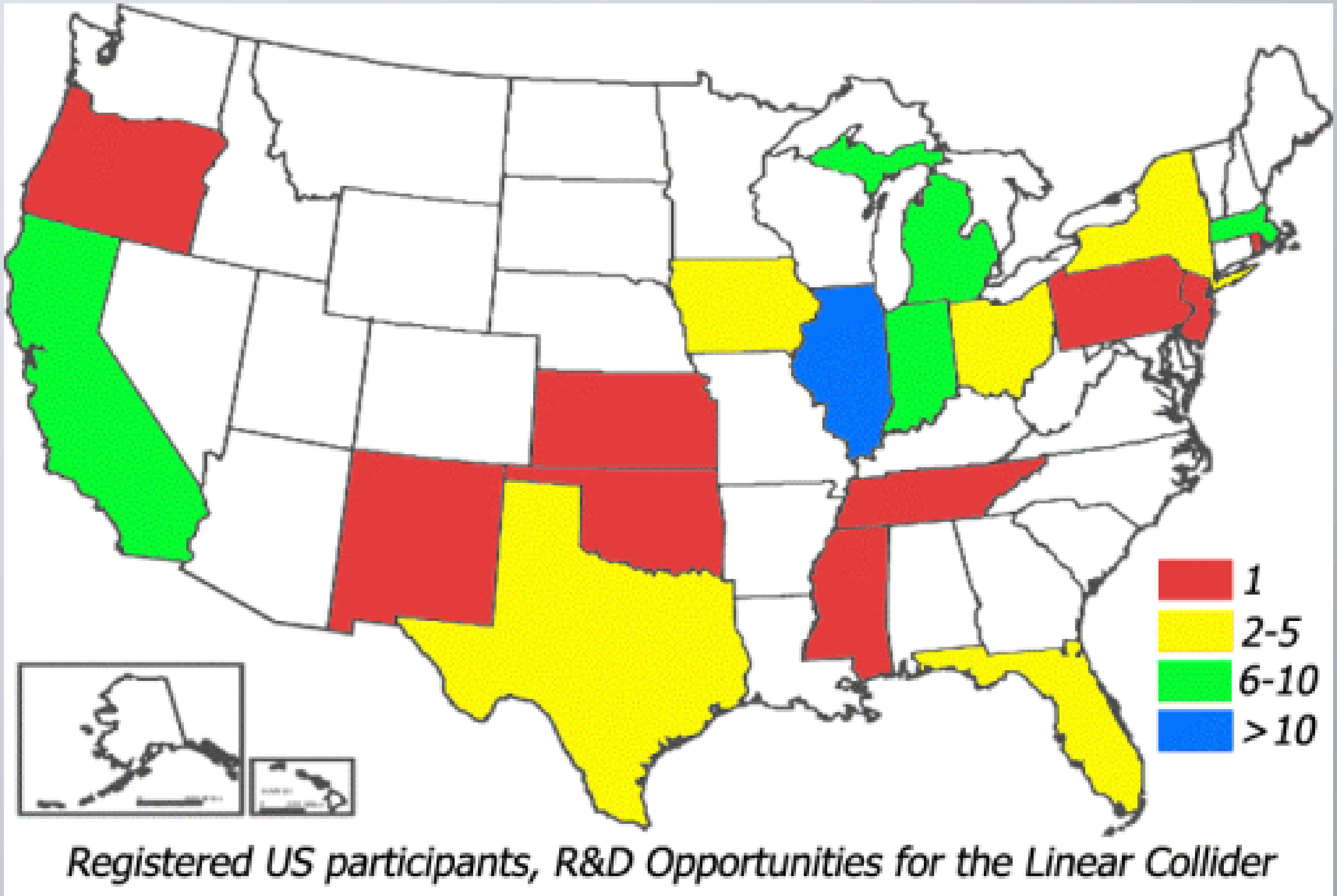
Who came

- 113 people registered in advance, 10 more at the workshop
- 94 people picked up ID badges at the workshop
- About 150 people were present at the summary/discussion
- Registrants' home institutions spanned 19 states + Italy + Russia
- 41 registrants turned in an interest survey/questionnaire; 46 who didn't had already described their interests when registering.
- Interests expressed:
  - both accelerator and detector 26
  - accelerator only 22
  - detector only 39

Where they came from



Registrants' home institutions spanned 19 states + Italy + Russia

Events since spring, 2002

More history, then on to the details:

- EOI letter submitted to Fermilab June 12, 2002, proposing that we form some sort of coherent LC R&D program, with a focus at Fermilab, and support from DOE. Letter had 91 co-signers from 24 institutions.
- Santa Cruz Linear Collider Retreat, June 27-29, 2002. Discussions among university proponents seeking DOE funding ("LCRD"), those seeking NSF funding ("UCLC"), ALCPG, USLCSC, and both funding agencies lead to an understanding of proposal schedules, review process, possible levels of support, and oversight, coordination, and cooperation with ALCPG working groups.

Wild, Wild West + Big Science at Santa Cruz

Santa Cruz Linear Collider Retreat, June 27-29, 2002.

Marty Breidenbach's suggestion… photograph the same people after LC is built

Physics Illinois

Bringing Big Science to the Wild, Wild West

The Problem: how to organize a university program when there are three different "diagonalizations" possible?

$$\text{University Program} = a_1 |\text{Department of Energy}\rangle + a_2 |\text{National Science Foundation}\rangle$$

$$\text{University Program} = b_1 |\text{Fermilab}\rangle + b_2 |\text{SLAC}\rangle + b_3 |\text{Cornell}\rangle$$

$$\text{University Program} = c_1 |\text{accelerator}\rangle + c_2 |\text{machine/detector interface}\rangle + c_3 |\text{vertex detector}\rangle + c_4 |\text{tracking}\rangle + c_5 |\text{calorimetry}\rangle + c_6 |\text{muon/particle ID}\rangle + \ldots$$

this one's the best

The solution…

Constructing a coherent R&D program

LCRD (DOE) proponents write short project descriptions — UCLC (NSF) proponents write short project descriptions — 7/02

ALCPG working group leaders offer suggestions for revision, collaboration with other groups, etc. — 8/02

LCRD proponents write "subproposals" — UCLC proponents write "project descriptions" — 9/02

proposal coordinators create one unified document combining LCRD and UCLC projects — 9/02

separate accelerator and detector committees review proposed work for both agencies — 9/02

LCRD proponents revise subproposals — UCLC proponents revise project descriptions — 10/02

proposal coordinators create new document combining revised LCRD and UCLC projects, then transmit to DOE and NSF. — 10/02

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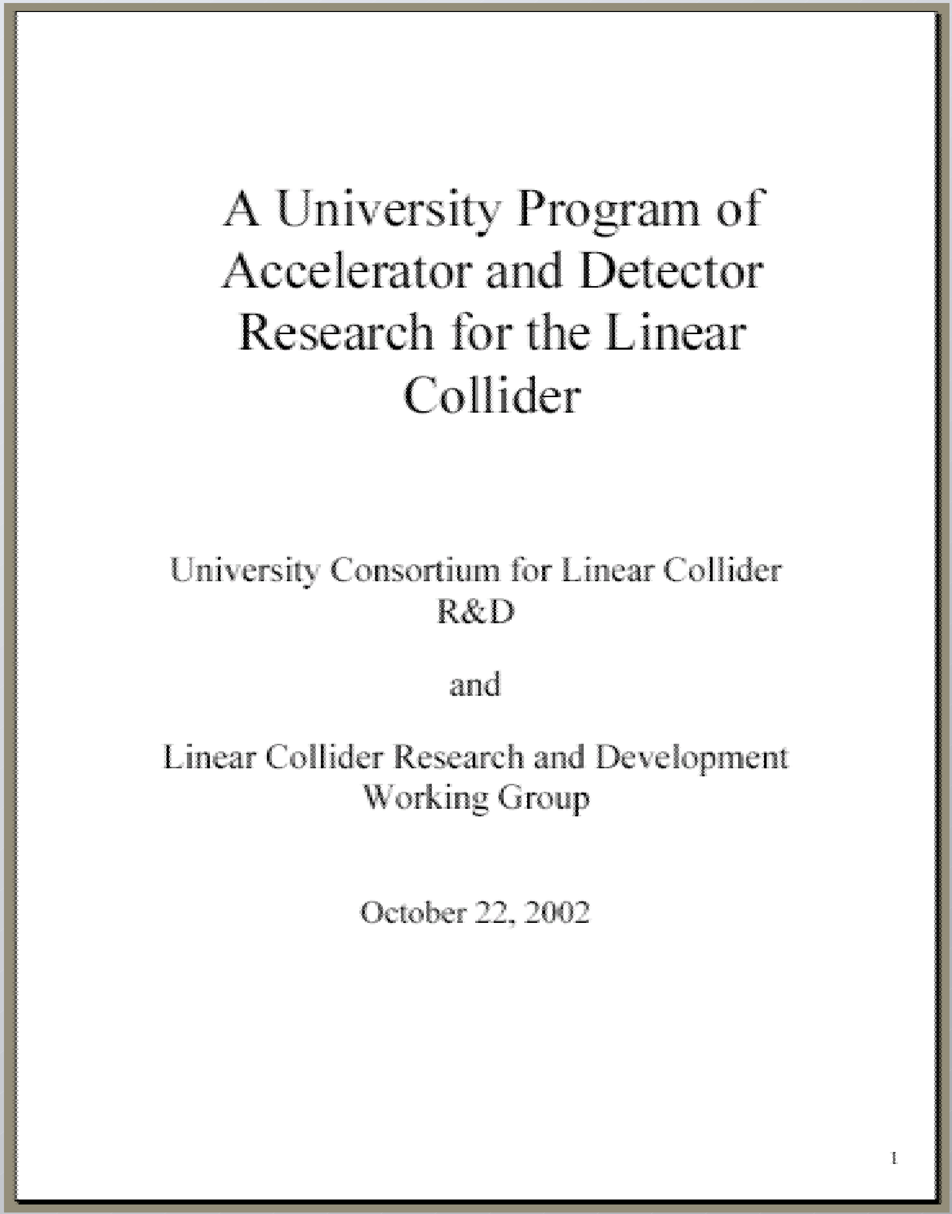
UCLC + LCRD "Big Document"

- At UC Santa Cruz (July, 2002):
  - DOE, NSF declared $400k, $500k as accelerator funding goals.
  - USLCSG organized schedule for proposal submission and review

- *A University Program of Accelerator and Detector Research for the Linear Collider* ("Big Document") sent to DOE, NSF October 24, 2002.
  - 33 accelerator, 38 detector proposals, 47 universities, 6 labs, 297 authors, 545 pages.

background image: copies of Big Doc on its way to Washington

The Wild, Wild West writes a proposal



A University Program of Accelerator and Detector Research for the Linear Collider

University Consortium for Linear Collider R&D

and

Linear Collider Research and Development Working Group

October 22, 2002

1

The result:

- 71 new projects
- 47 U.S. universities
- 6 labs
- 22 states
- 11 foreign institutions
- 297 authors
- 2 funding agencies
- two review panels
- two drafts
- 546 pages
- 8 months from t_0

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Scope of proposed work, first year

Projects are organized by research topic, not by funding agency or by supporting laboratory.

LCRD + UCLC	$FY2003	proposals
Accelerator Physics	$1,003,783	33
Luminosity, Energy, Polarization	$171,541	9
Vertex Detector	$119,100	3
Tracking	$395,662	11
Calorimetry	$514,540	12
Muon System and Particle Identification	$148,899	3
Total	$2,353,525	71

LCRD	$1,309,766	44
UCLC	$1,043,759	27

About the proposed work

The number of university physicists participating in Linear Collider R&D has increased ~50% through the creation of LCRD and UCLC.

This national Linear Collider R&D effort is coherent, well-balanced between accelerator and detector physics, and spans the administrative and geographical boundaries of different funding agencies and different supporting labs.

- Projects on both TESLA and NLC are included.

We did this in <u>8 months</u>.

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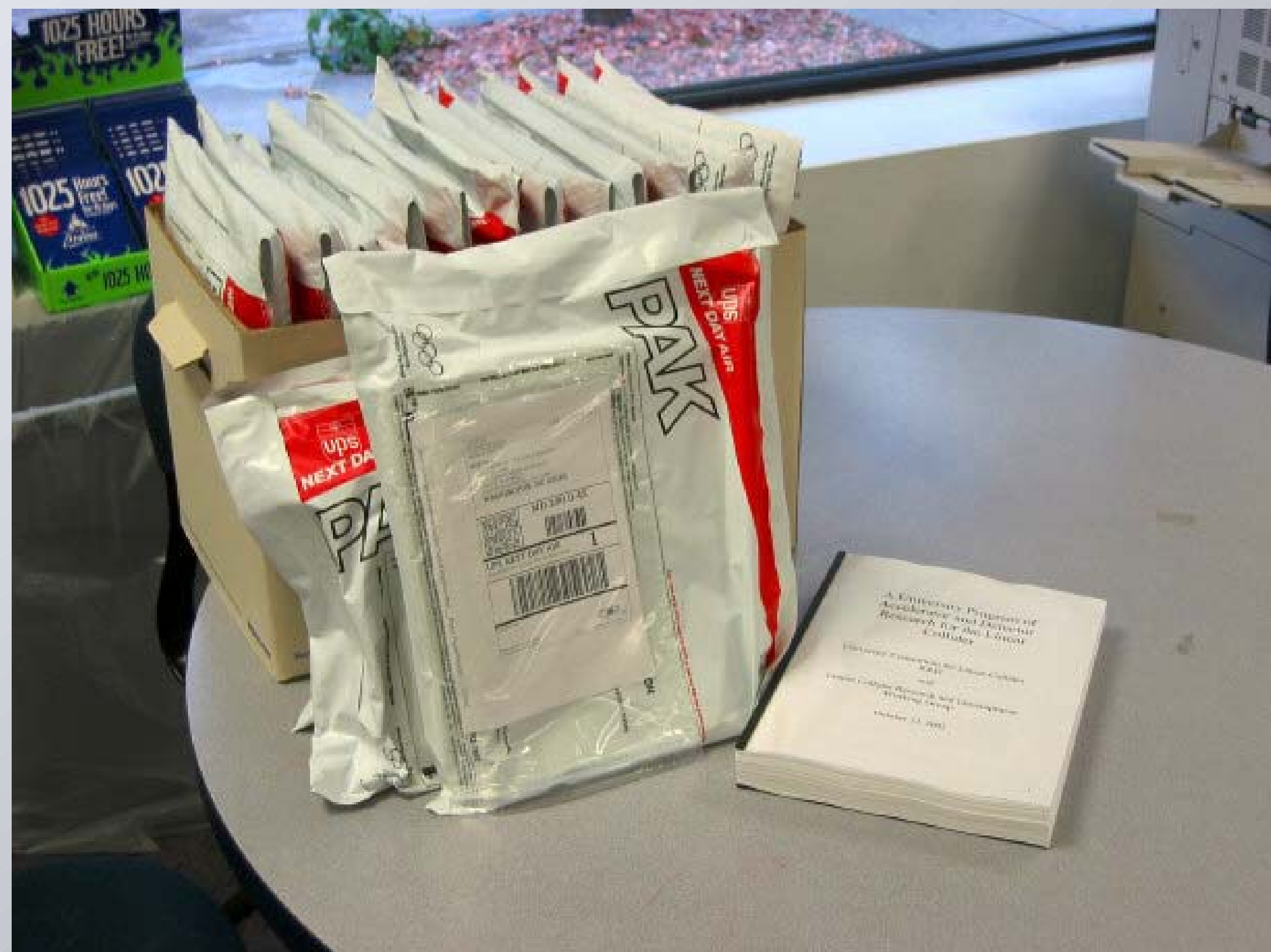
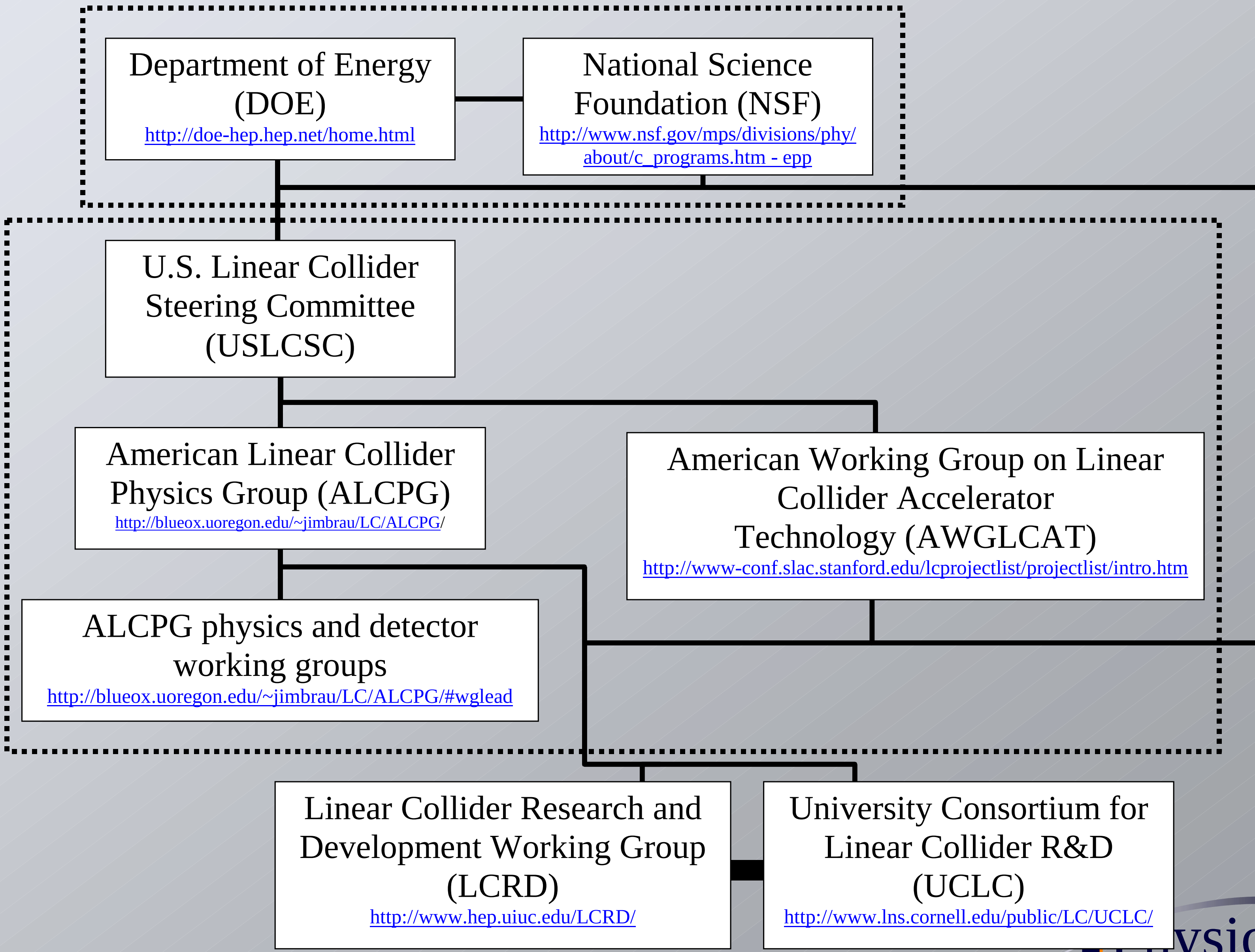
Pony Express



Shipping copies to Washington

US LC R&D "org chart" of sorts



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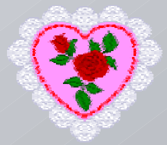
The startup has been bumpy

- Congressional budget was months late: Feb. 14, 2003 
- "The cap" on DOE LC accelerator R&D
- DOE funding began arriving July, 2003.
  - DOE managed to find ~all the funds they had hoped for: $400k/$500k accelerator/detector. (yippee!)
  - Long delay was a problem (some groups didn't get summer students). Discouraging (and ultimately inaccurate) projections came from some grant officers before funds were actually found.
- NSF hit a pothole. UCLC only received a $150k "planning grant."

Starting up; renewal proposals

Most groups started their projects, in spite of budget glitches.

Renewal/resubmission: autumn, 2003.

A University Program of Accelerator and Detector Research for the Linear Collider, volume II sent to DOE, NSF November 24, 2003.

- 29 accelerator, 39 detector proposals, 48 universities, 5 labs, 303 authors, 622 pages.
- FY04 accelerator support requests: $772k LCRD, $380k UCLC
- FY04 detector support requests: $1.23M LCRD, $828k UCLC

background image: Big Doc author list

Proposal reviews this year

December, 2003 reviews of UCLC, LCRD projects:

- Norbert Holtkamp (ORNL) chaired the accelerator review
- Howard Gordon (BNL) chaired the detector review.

Detector review procedures were adjusted so that reports from the Gordon Committee could be used by DOE to make funding decisions.

DOE chose not to do this with the Holtkamp Committee. There will be another round of reviews required before funding can be provided.

DOE has told us that it now has $400k for accelerator and $500k for detector work. (Yippee!!) No word from NSF yet.

A survey of accelerator R&D: UCLC, LCRD, and ALCPG04

ALCPG04 topics

- beam dynamics & simulation
- damping rings
- systems & instrumentation
- rf & accelerating structures
- beam delivery & IR
- sources

Holtkamp Committee topics

- Beam simulations and other calculations (6)
- Kickers, magnet technologies, mechanical support systems (4)
- Instrumentation and electronics (9)
- Ground Motion (1)
- Control Systems (1)
- RF Technology (5)
- Non-e^+e^- collisions (1)
- Electron and positron source technology (2)

background image: acoustic wave in copper simulation

Support for UCLC + LCRD is crucial

- HEPAP says LC is important. DOE/NSF need to find ways to support LC work.
- Engagement of (university) community is essential.
- Support from DOE/NSF is necessary to show it's really worth our time to put aside some of our other activities to do LC work

University participation example: one of the UIUC projects

Investigation of Acoustic Localization of rf Cavity Breakdown

LCRD project 2.15 (item 61 on "The List.")

Can we learn more about NLC rf cavity breakdown through acoustic signatures of breakdown events?

At UIUC ("UC" = Urbana-Champaign):

George Gollin (professor, physics)

Mike Haney (engineer, runs HEP electronics group)

Bill O'Brien (professor, EE)

Joe Calvey (UIUC undergraduate physics major)

Michael Davidsaver (UIUC undergraduate physics major)

Justin Phillips (UIUC undergraduate physics major)

Marc Ross is our contact person at SLAC.

An interdisciplinary university collaboration…

Haney’s PhD is in ultrasound imaging techniques

O’Brien’s group pursues a broad range of acoustic sensing/imaging projects in biological, mechanical,… systems

Ross is our contact at SLAC and participates in related work taking place there.

National labs can undertake large projects which demand significant industrial infrastructure but universities are ideally suited to initiate investigations which require a broad, interdisciplinary knowledge base.

Students have been exceptionally productive

A piece of NLC to play with

Ross sent us a short piece of NLC and some engineering drawings specifying the geometry.

We need to understand its acoustic properties.

Start by pinging copper dowels with ultrasound transducers in order to learn the basics.

Copper dowels from Fermilab NLC Structure Factory

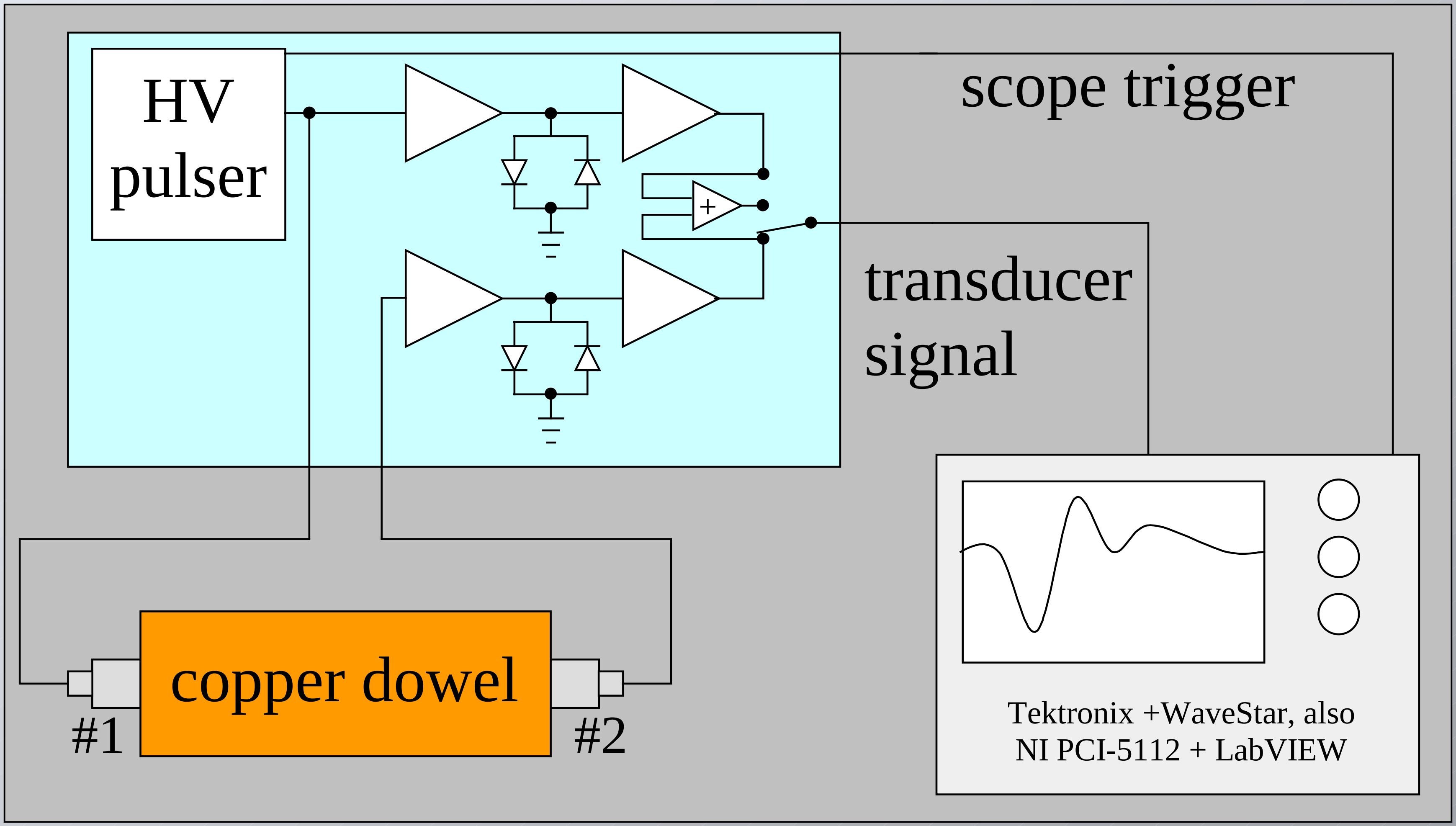
Harry Carter sent us a pair of copper dowels from their structure manufacturing stock: one was heat-treated, one is untreated.

NLC structures are heat-brazed together; heating creates crystal grains (domains) which modify the acoustic properties of copper.

Ross also sent us a (small) single crystal copper dowel.

We cut each dowel into three different lengths.

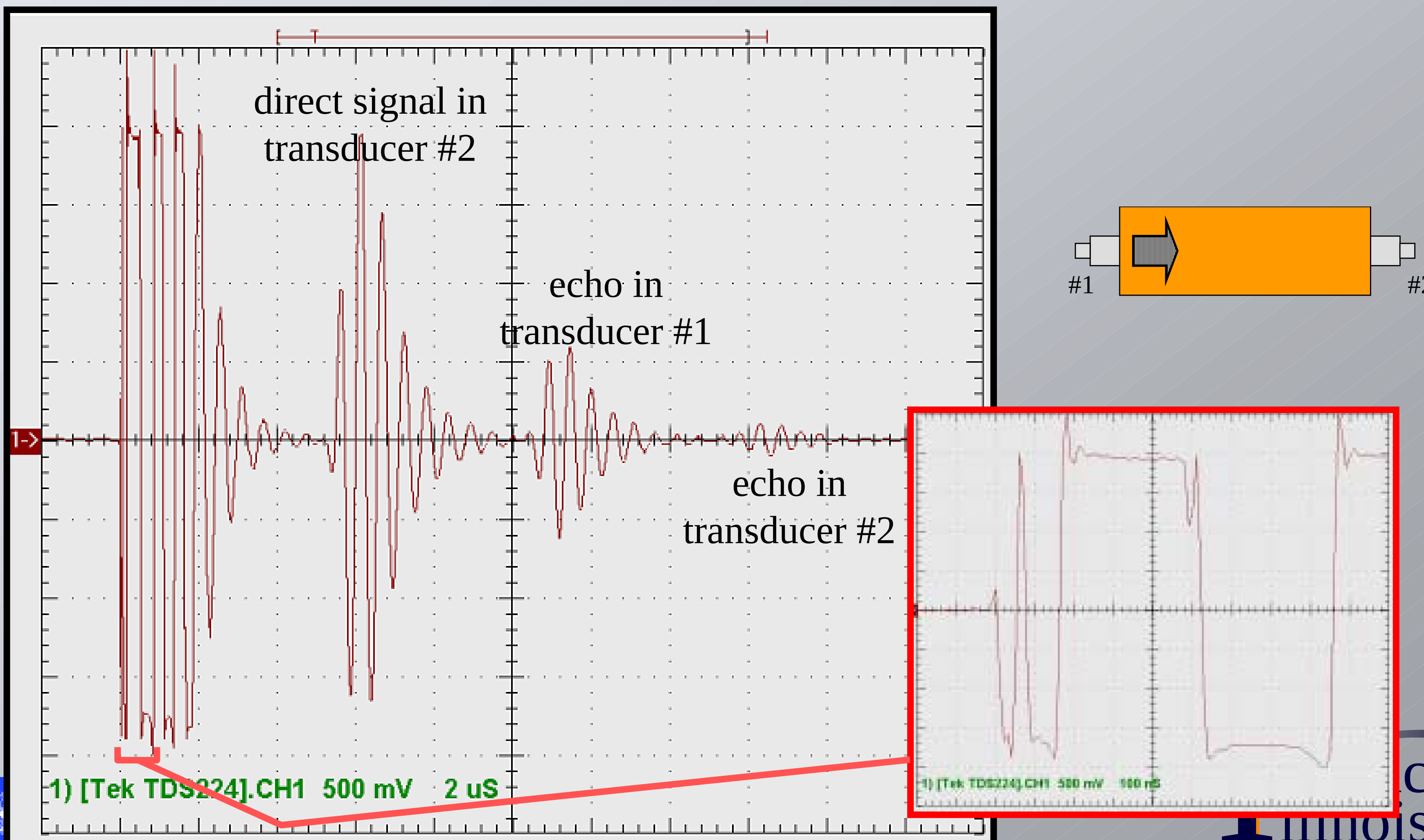
Transducer setup



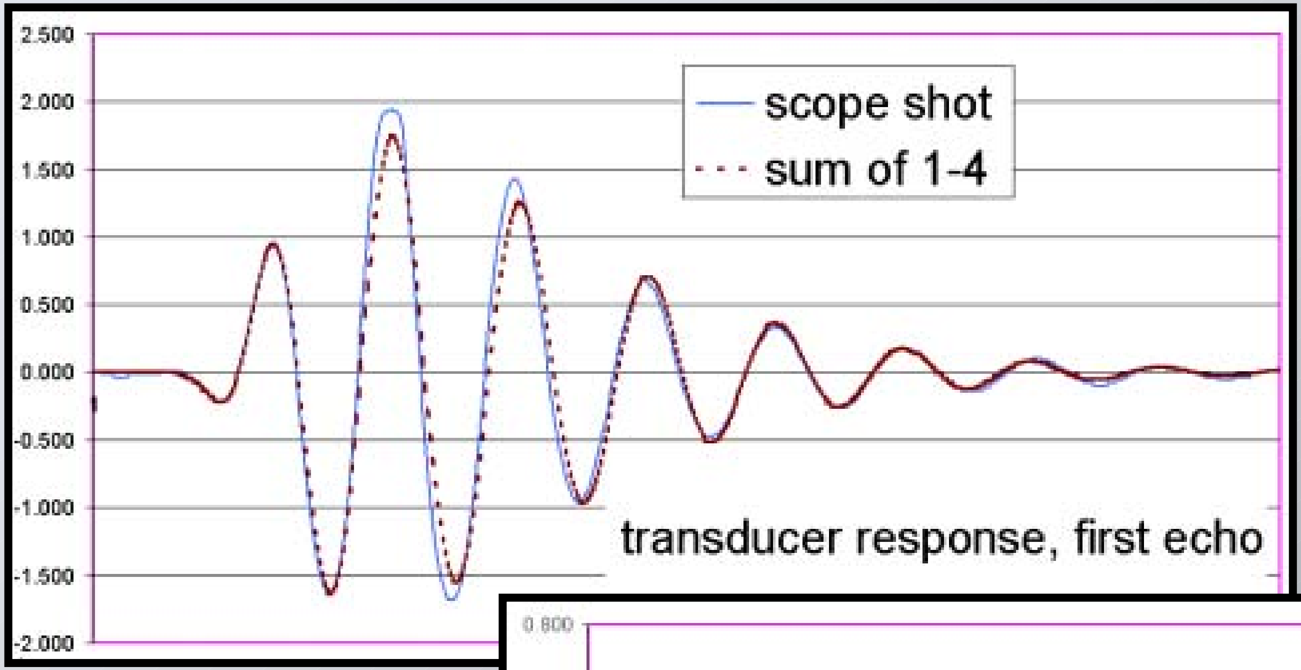
We can listen for echoes returning to the transducer which fires pings into the copper, or listen to the signal received by a second transducer.

Pinging the shortest heat-treated dowel

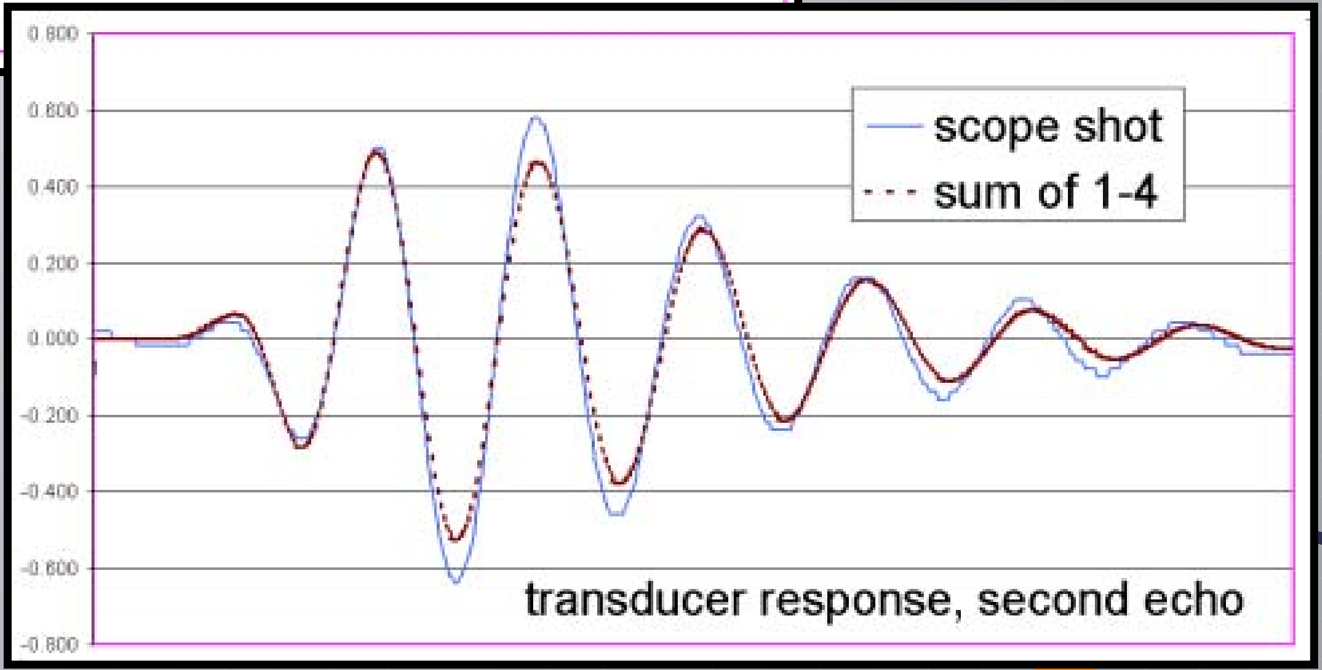
Two transducers: fire a ping, then listen for signals in both transducers.
The initial excitation is complicated (note the the protection diodes)



Transducer phenomenology



“sum of 1-4” is our four-δ model after hand-tuning its parameters using the first echo.



Speed of sound and grain structure…

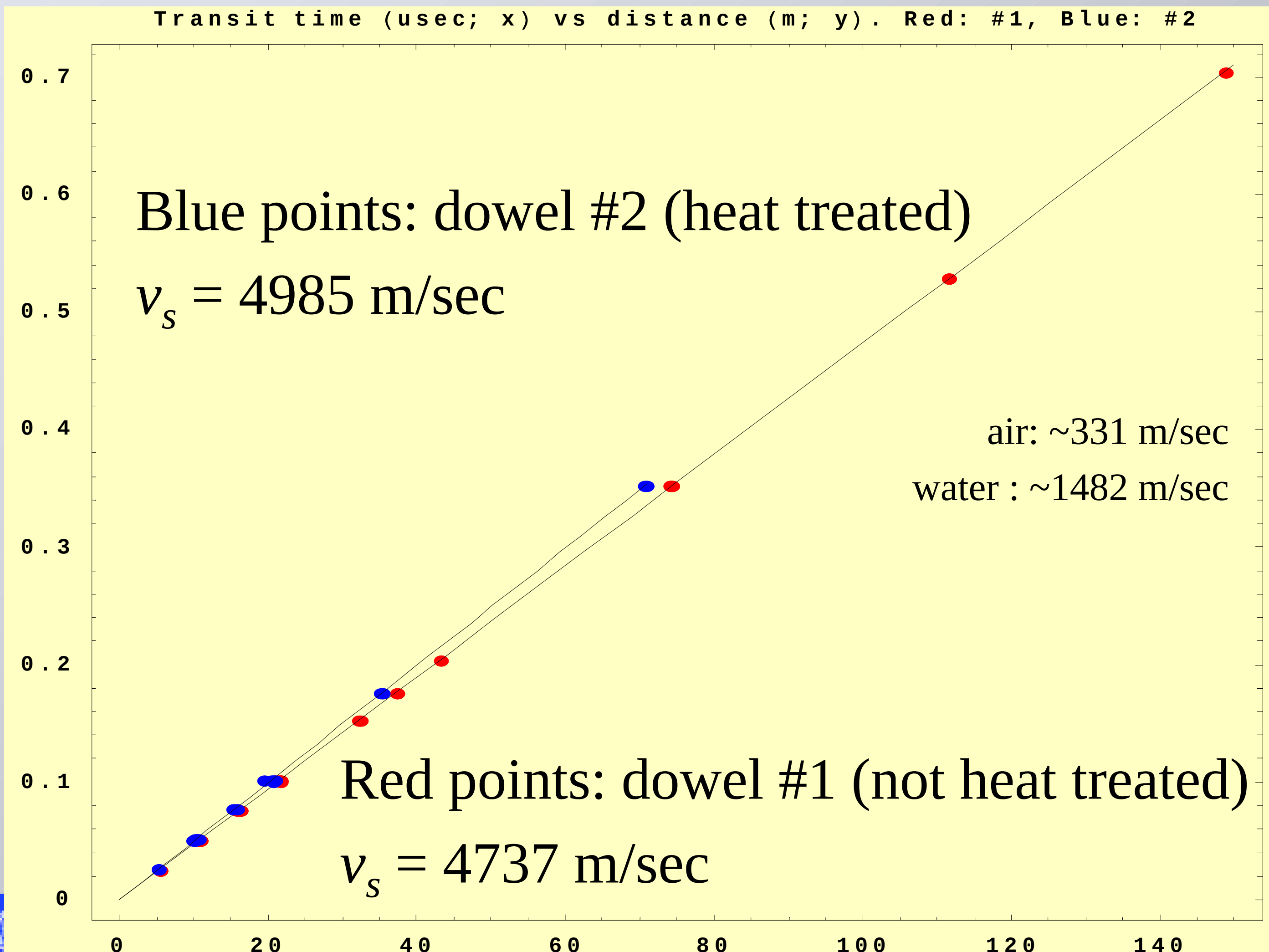
Closeup of one of the (heat-treated) dowel #2 sections.

Note that grain patterns visible at the copper's surface.

Grain structure is not visible on the surface of dowel #1.

Speed of sound at 1.8 MHz in copper

The speed of sound is different in the two kinds of copper dowels. It's 5.2% faster in the grainy (heat treated) copper. (You can hear it!)



…so λ ~ 2.8 mm

Single crystal:

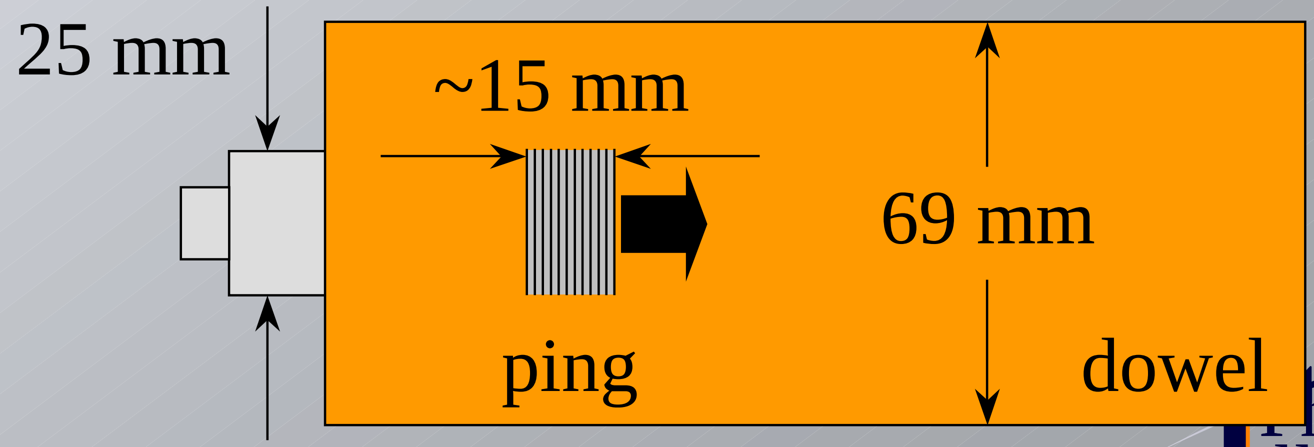
v_s = 4973 m/sec

(4.973 mm/μsec)

Scattering/attenuation at 1.8 MHz in copper

A “ping” launched into a copper dowel will bounce back and forth, losing energy through

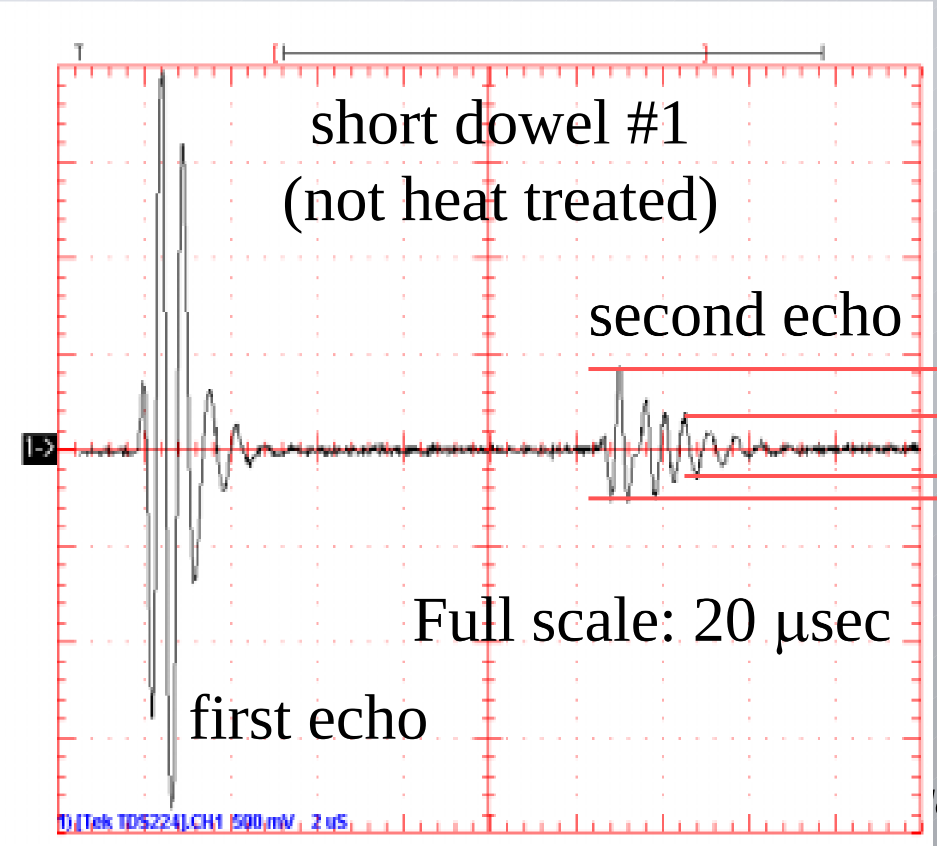
- absorption in the transducer (large acoustic impedance mismatch between the transducer and the copper: not much energy crosses the copper/transducer boundary)
- scattering of acoustic energy out of the ping
- absorption of acoustic energy by the copper.

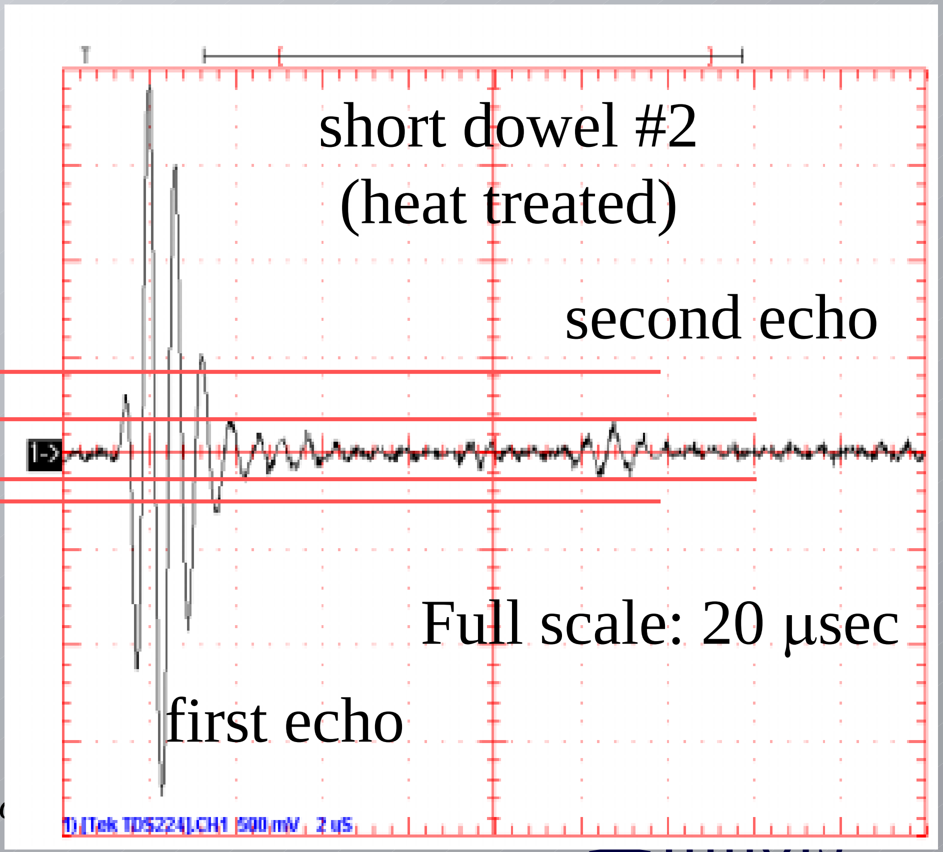


Scope shots

Single transducer: ping, then listen for echoes. Adjust ping energies so that first echoes are approximately equal in amplitude.

Note the difference in sizes of the second echoes as well as the different amounts of baseline activity between the echoes.

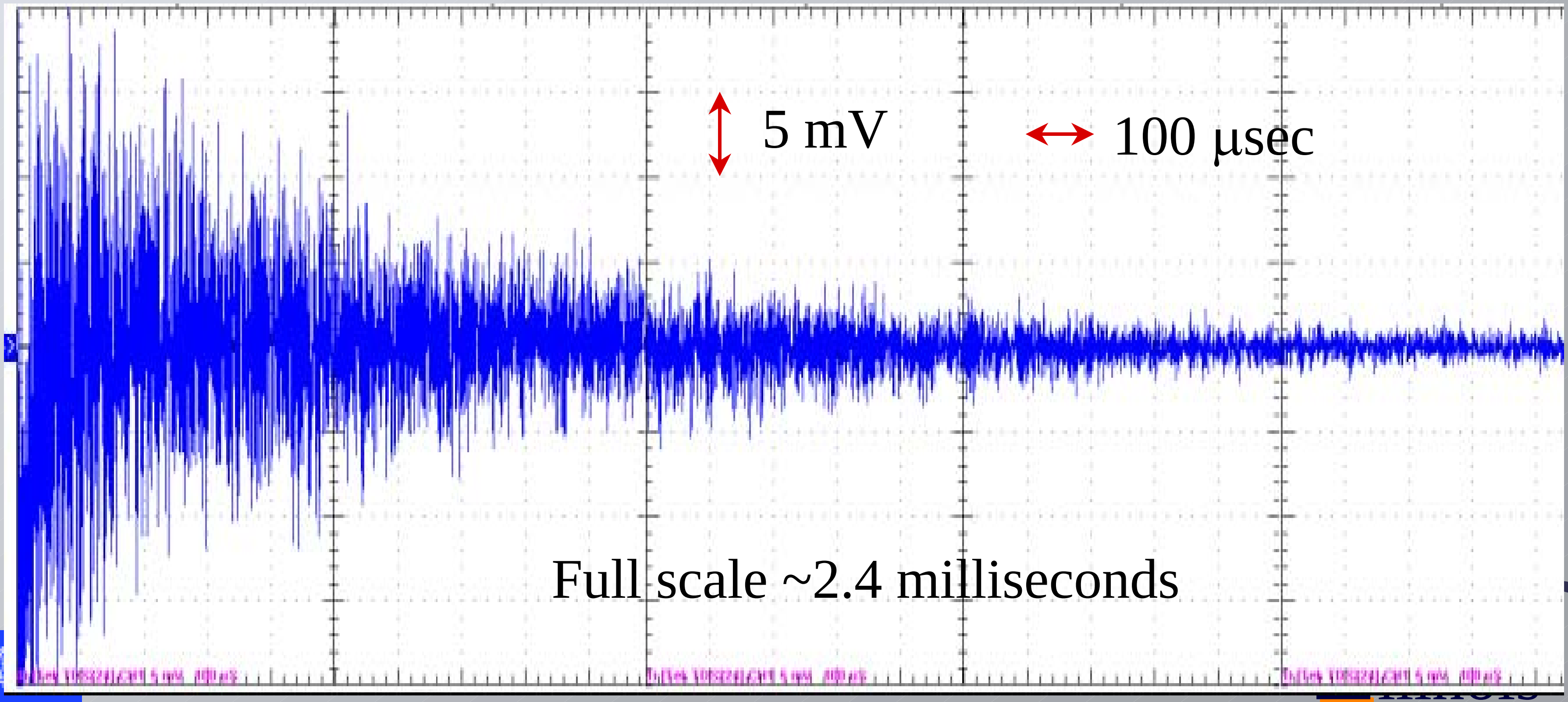




RMS baseline activity in scope shots

Single transducer: ping, then listen to baseline "noise" as pulse travels into copper, pumping energy into acoustic baseline "glow."

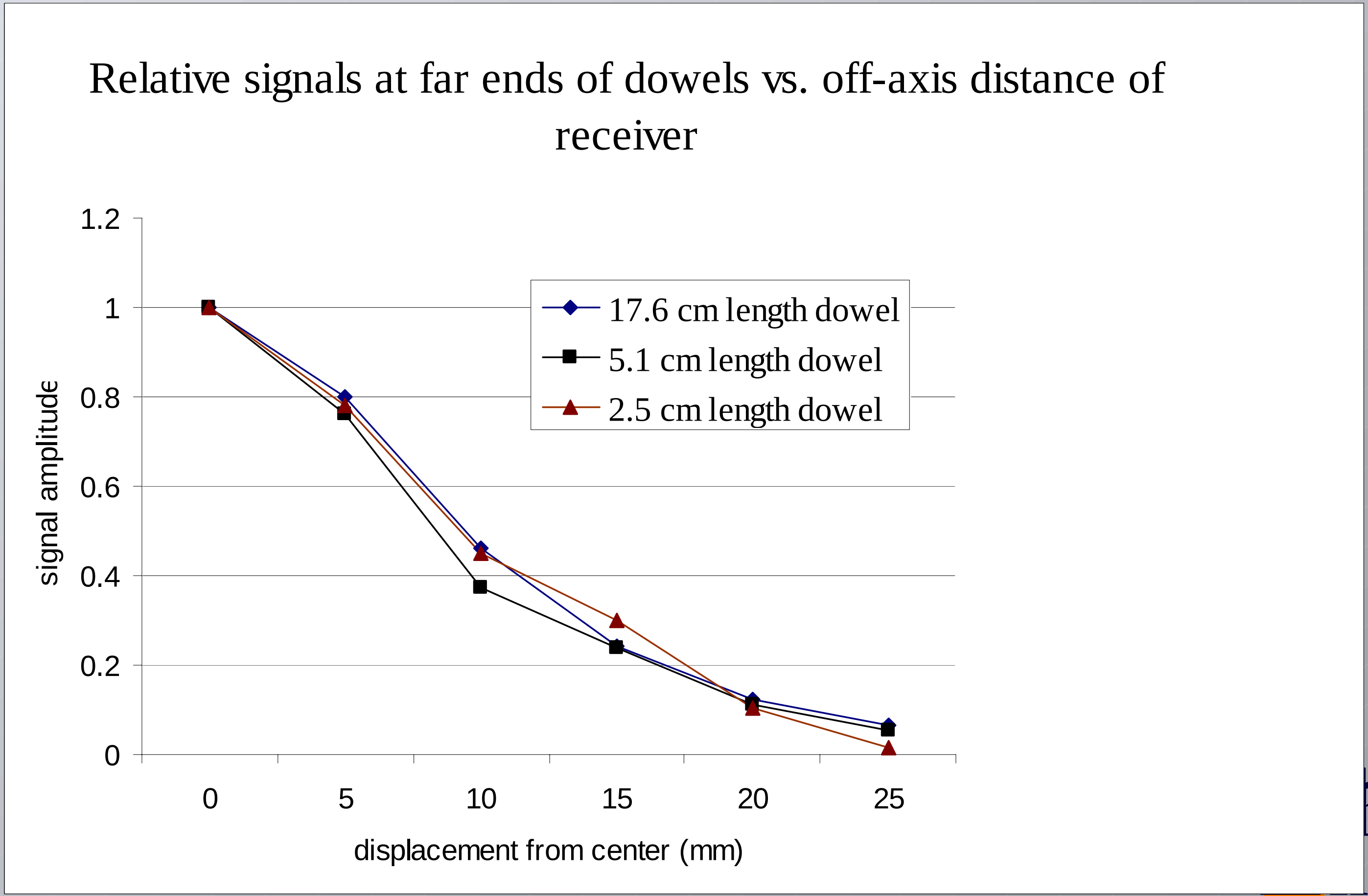
Here's the baseline glow, 5 mV and 100 μsec per division. Scope shot from heat-treated (grainy) long dowel.



Beam spread

Two transducers: ping using #1 (centered), then listen using #2.

Move #2 off center and measure signal size in different length dowels: we see very little beam spread in non-heat-treated dowels.



Measurements and modeling

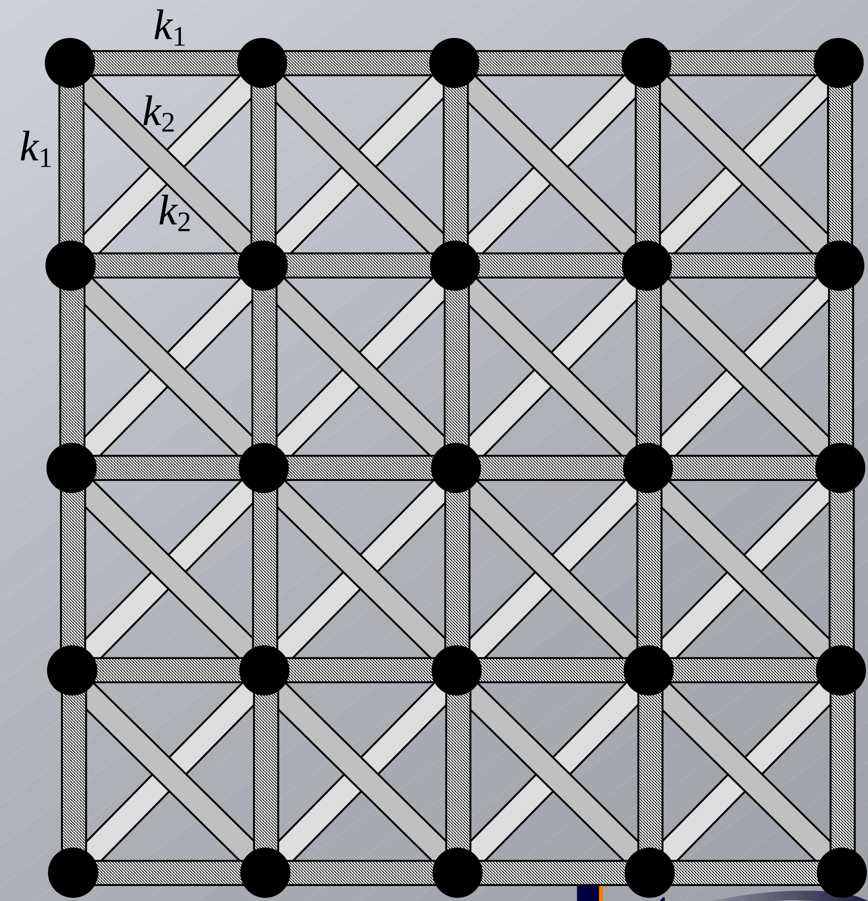
The plan: work up a simple phenomenological model (based on sensible physics) which includes scattering off grain (and other) boundaries and includes attenuation.

If we can model the copper cylinders adequately, perhaps we will be able to describe the NLC structure's acoustic properties.

Technical language: we would like to be able to understand how to describe the (acoustic) Green's function for our Copper structures.

Condensed matter, as done by folks in HEP

Initial models: regular (rectangular, 2*D* or 3*D*) grids of mass points connected by springs.



Speeds of propagation for pressure and shear waves are determined by k_1, k_2, and k_1/k_2.

We can vary spring constants arbitrarily.

Grain boundaries are modeled as sets of mass points with different spring constants.

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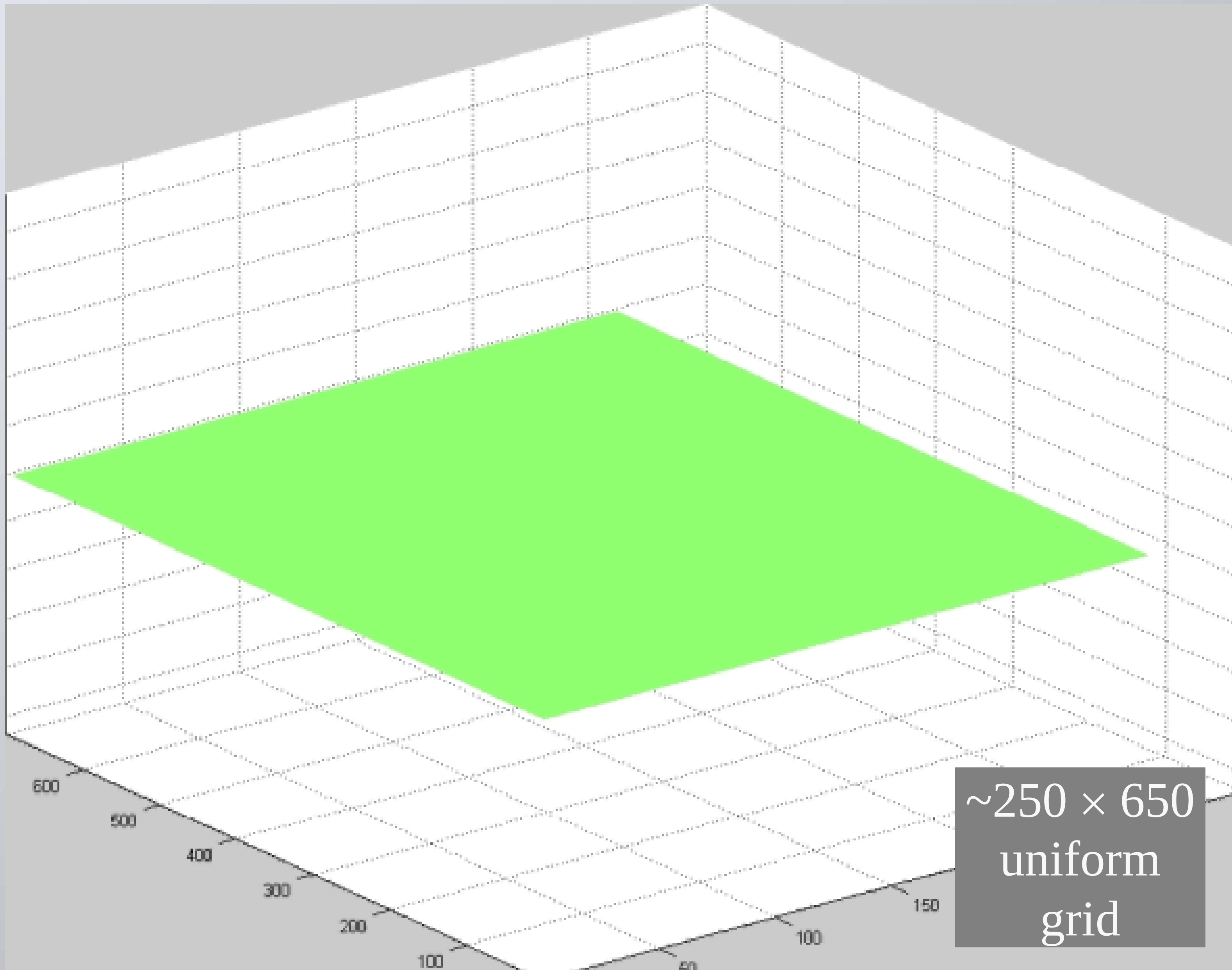
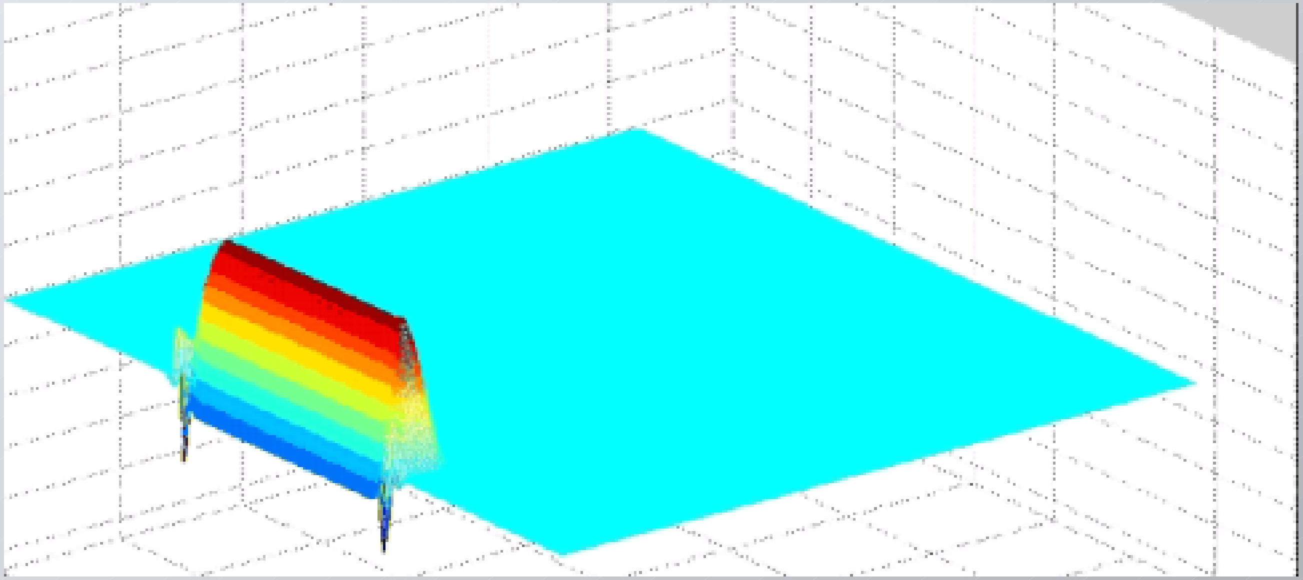
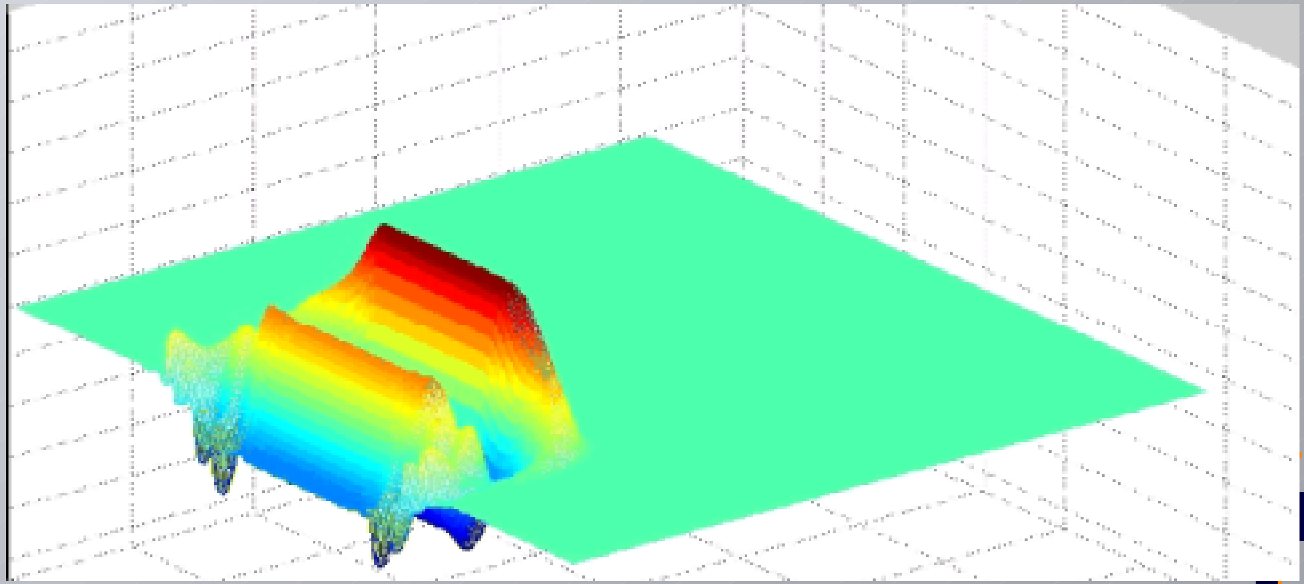
Propagation of a pressure wave in a homogeneous grid



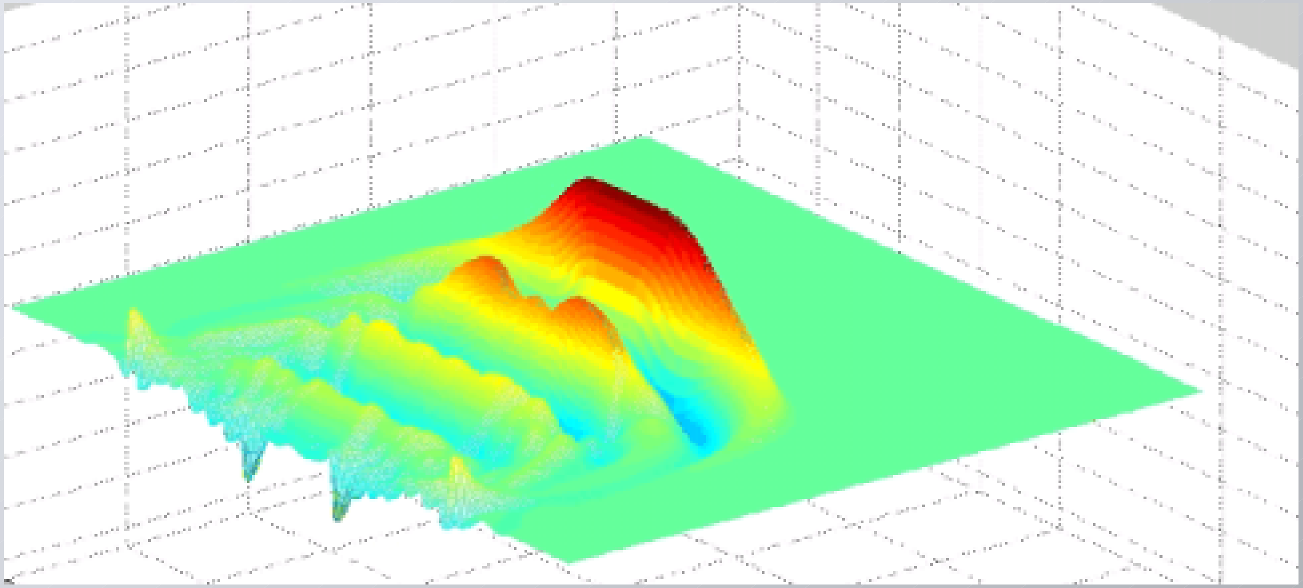
~250 × 650 uniform grid

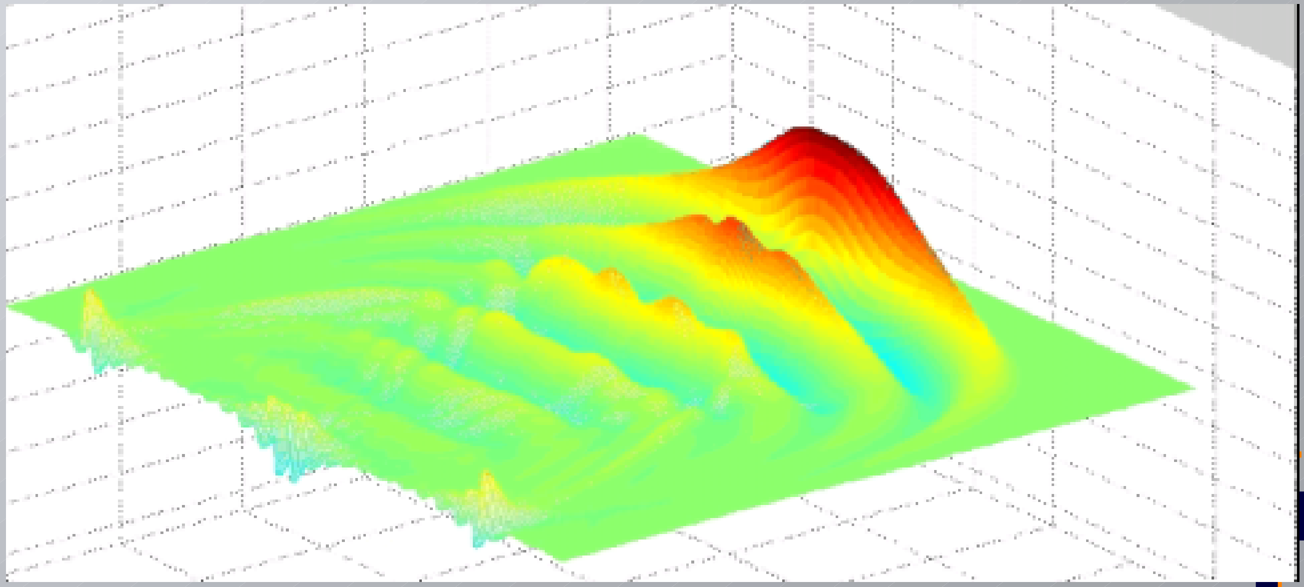
Pressure wave propagation: stills from the movie…



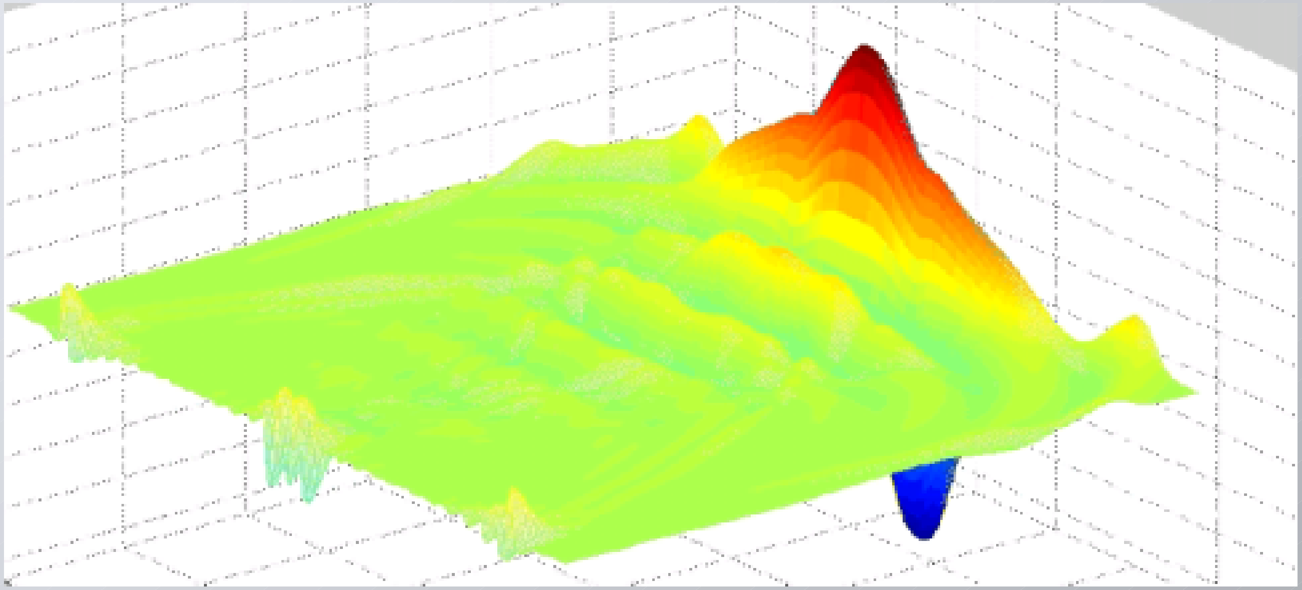


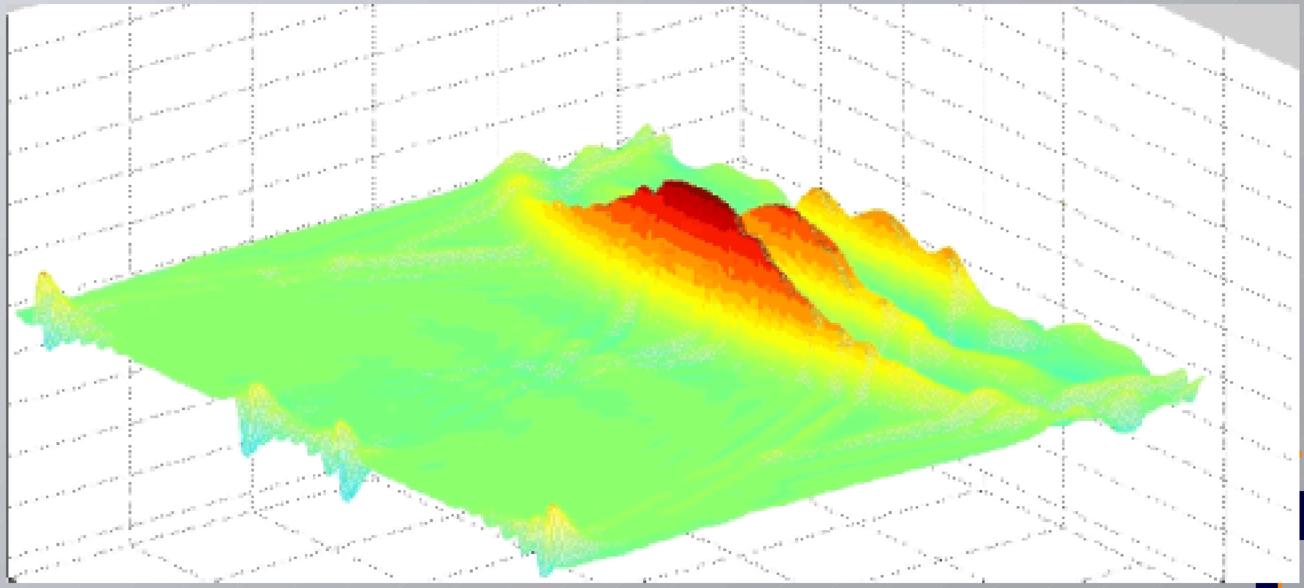
More stills from the movie…





More stills from the movie…





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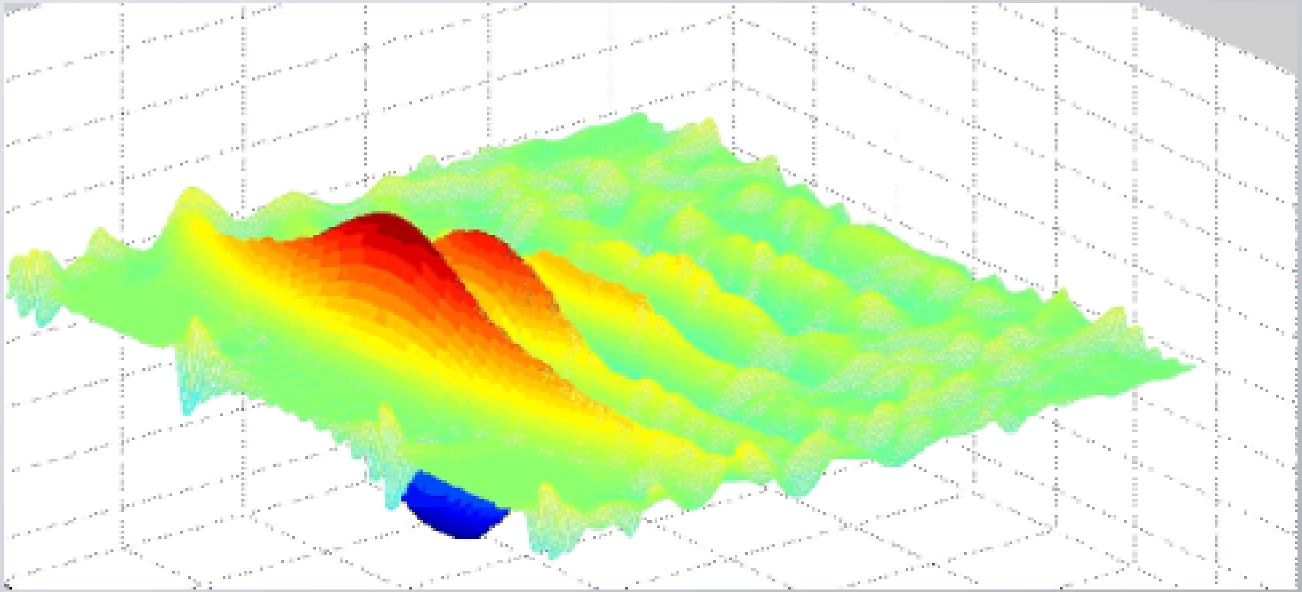
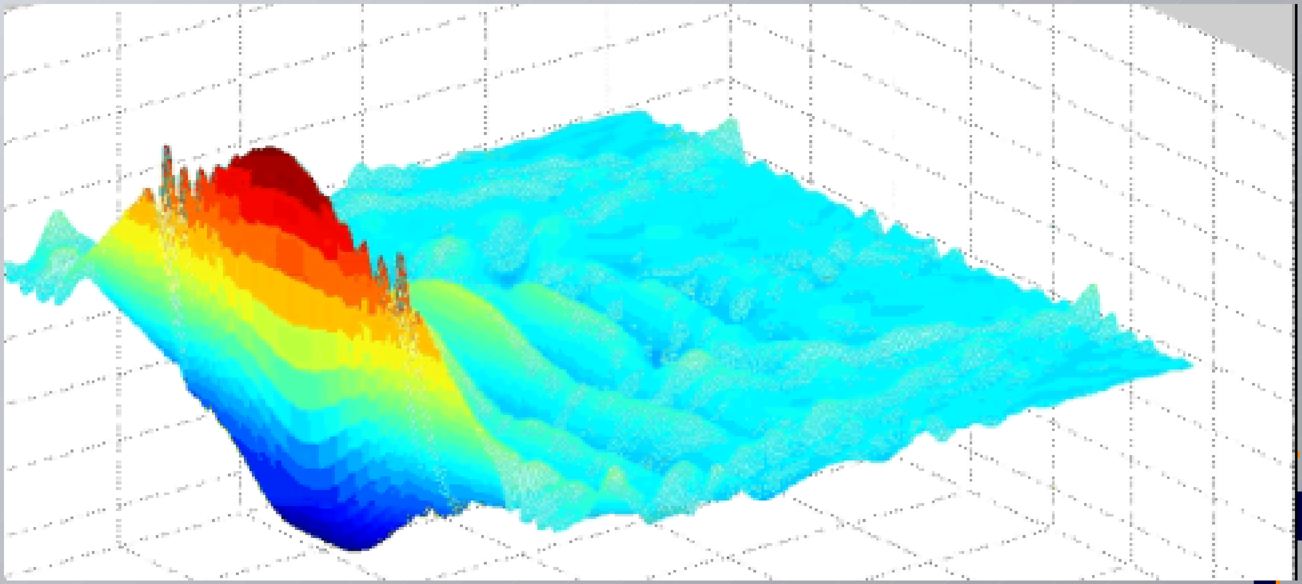
More stills from the movie…





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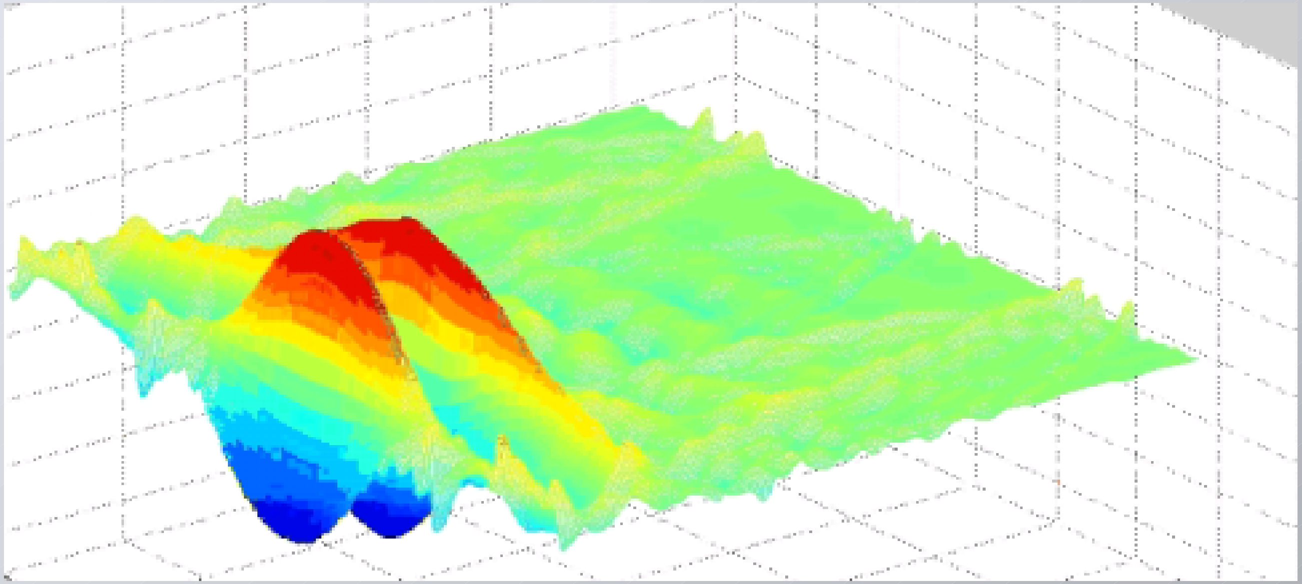
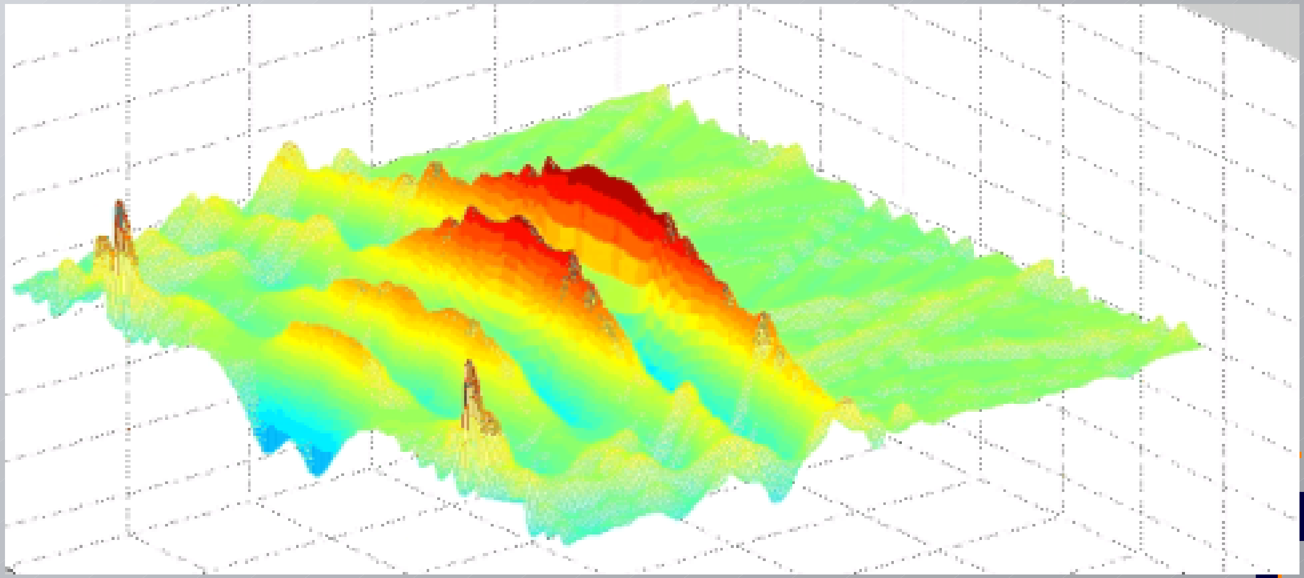
More stills from the movie…





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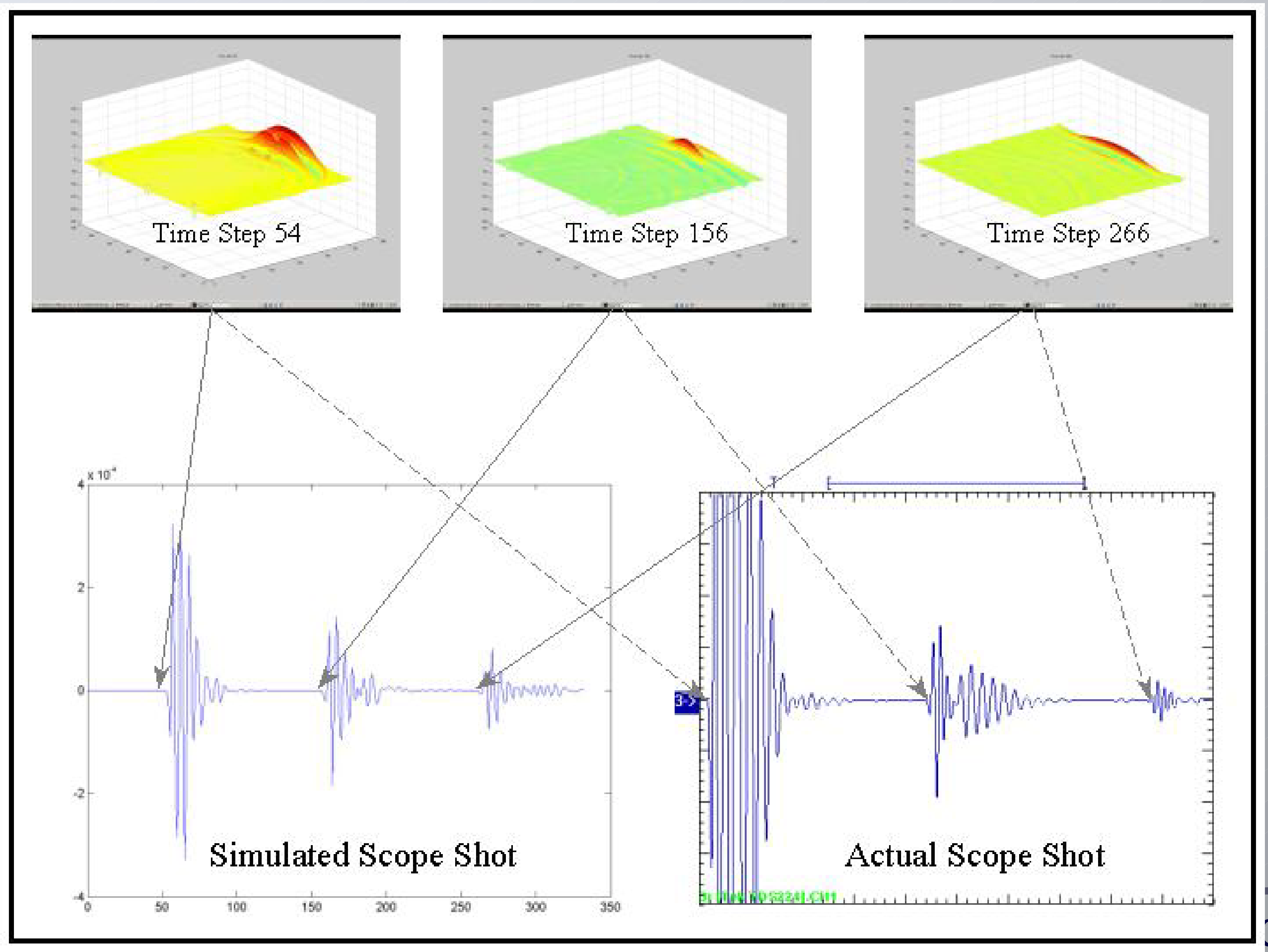
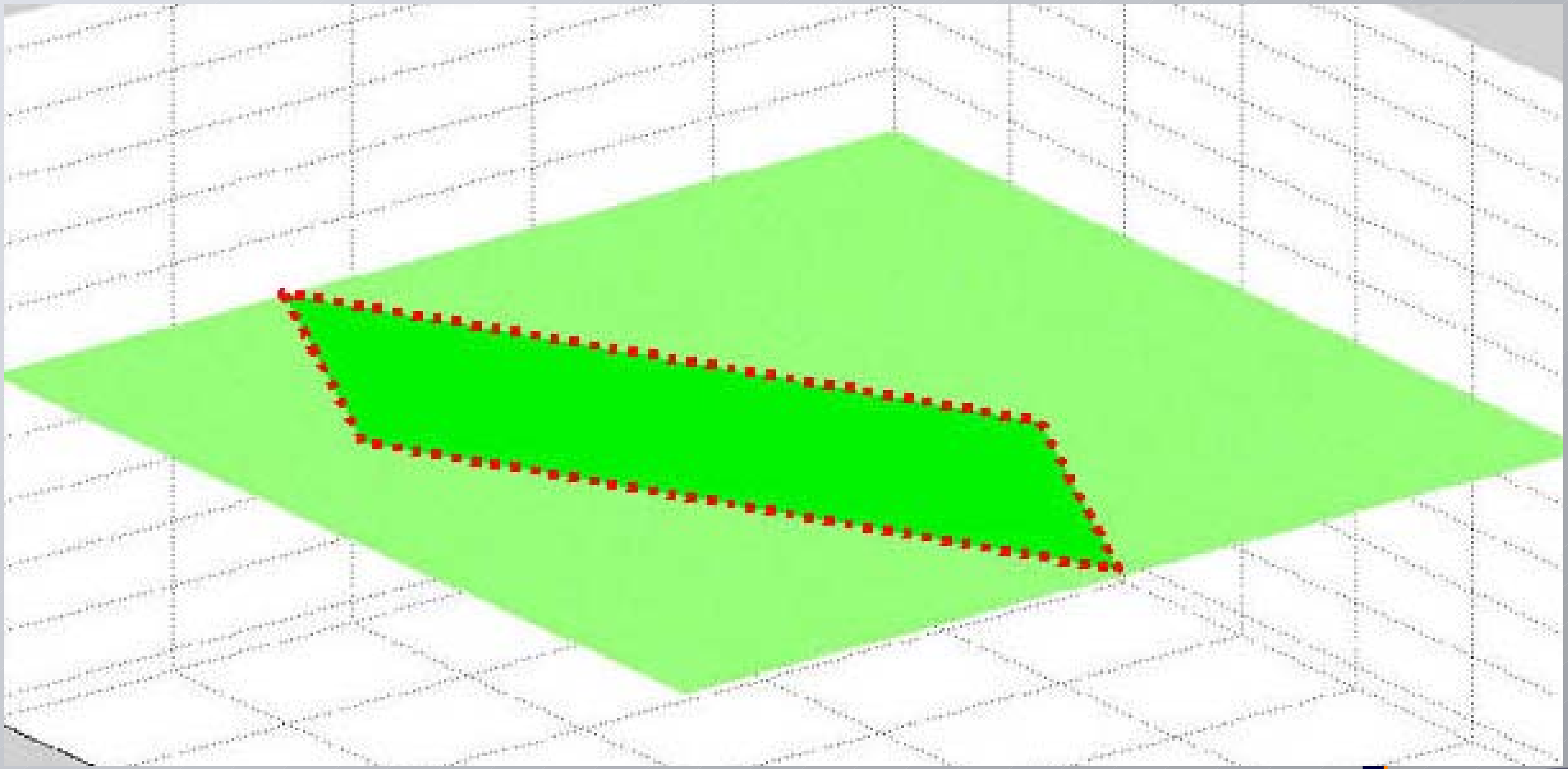
Simulated transducer response

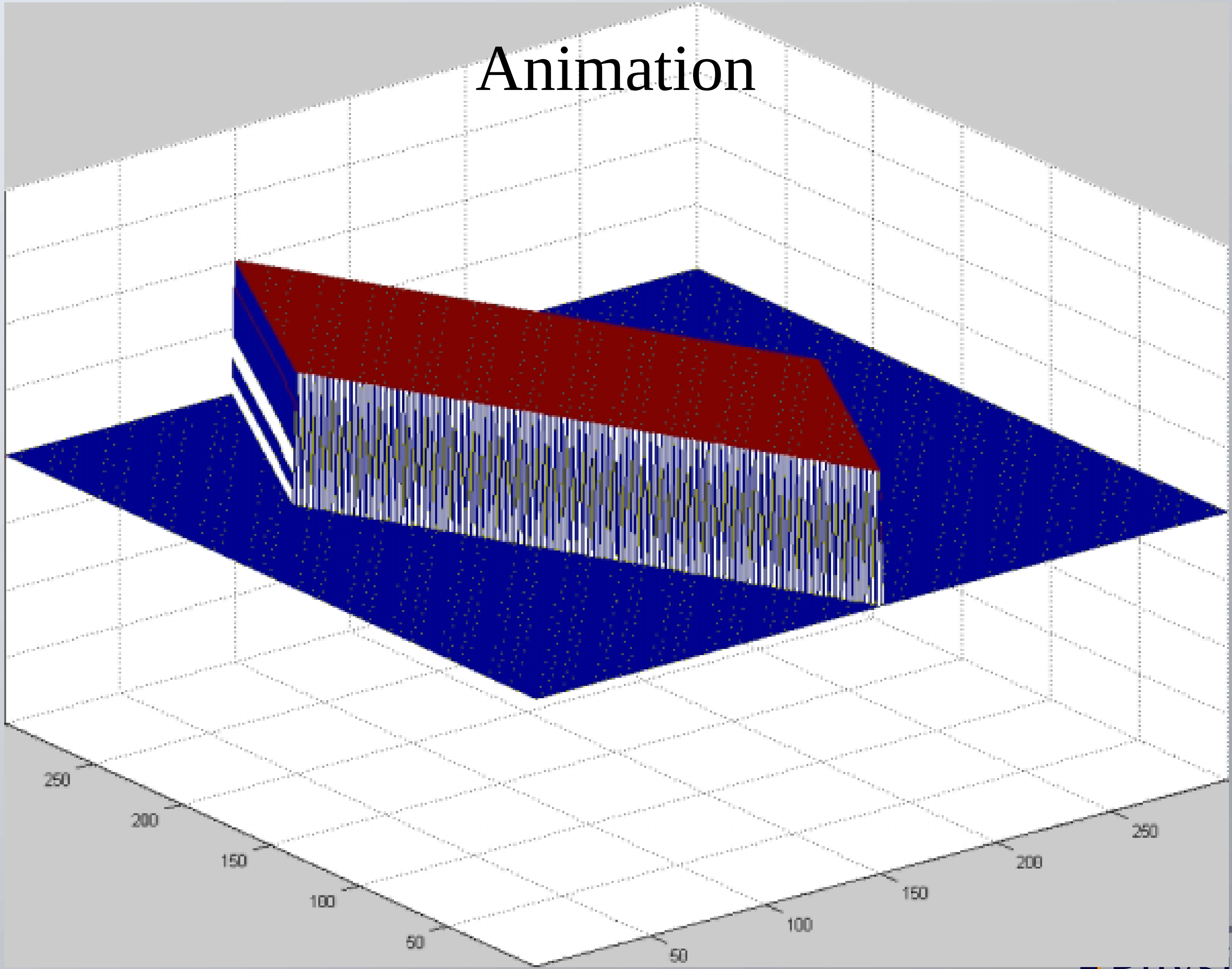


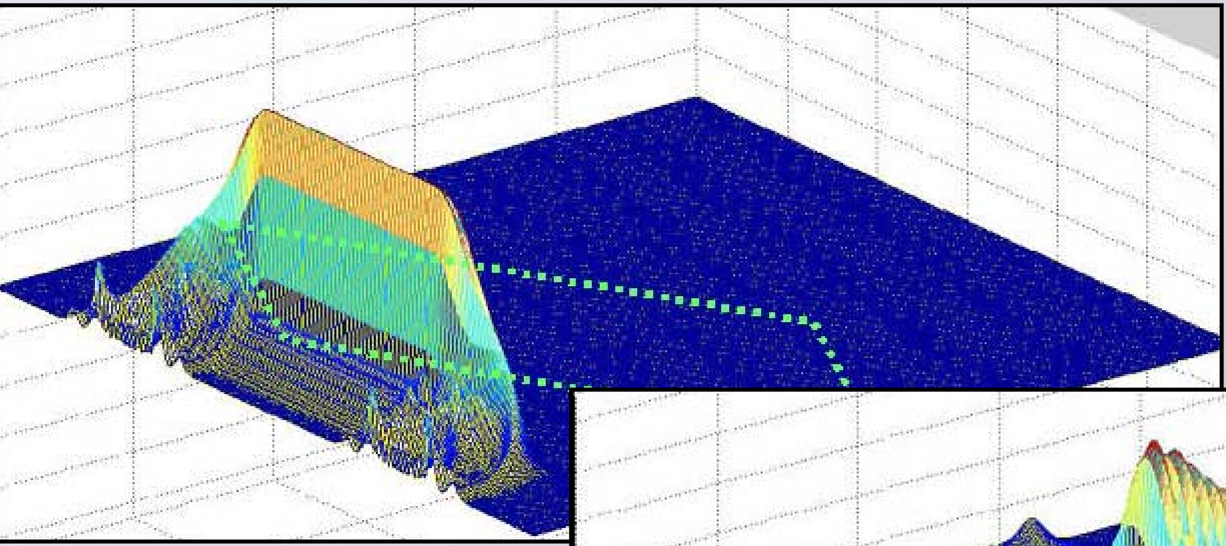
Propagation of a pressure wave through one “grain”

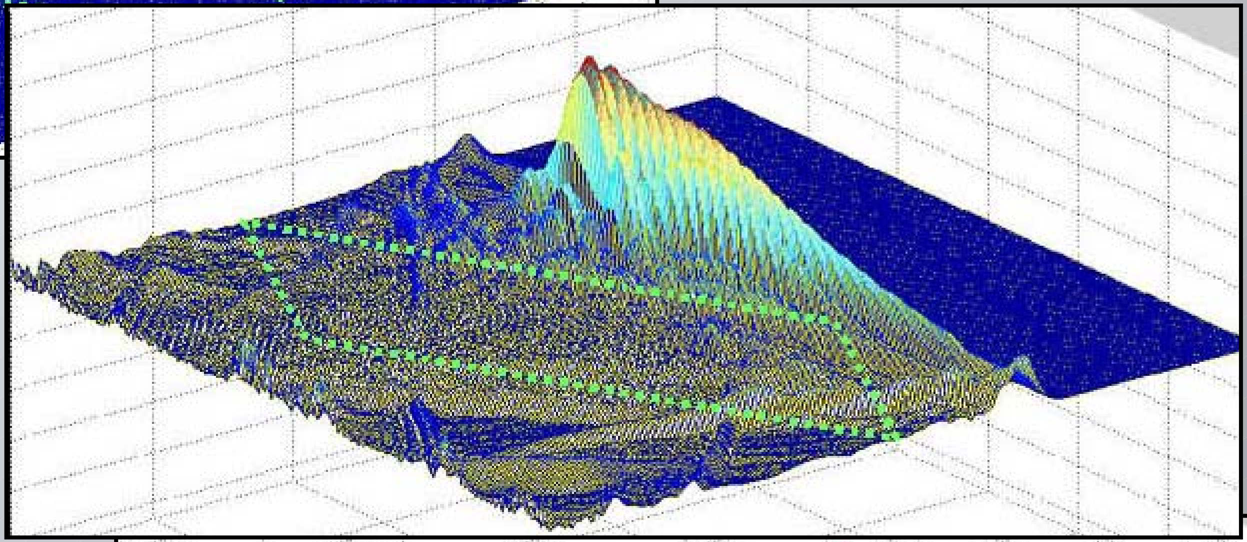
Change the spring constants inside a parallelogram-shaped region to see effects on pulse propagation.



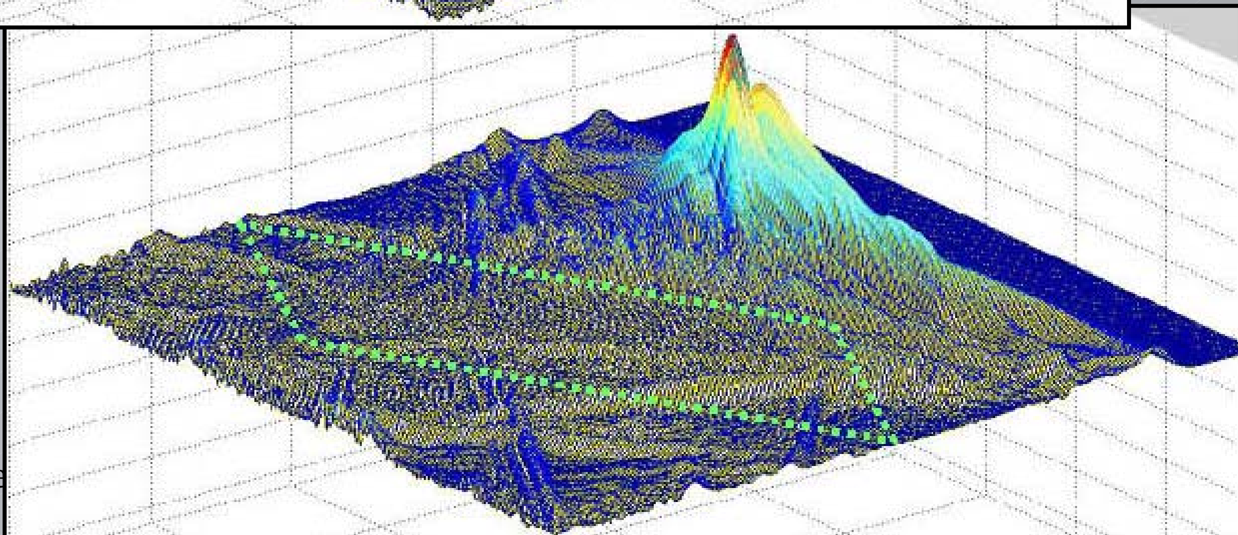
Animation



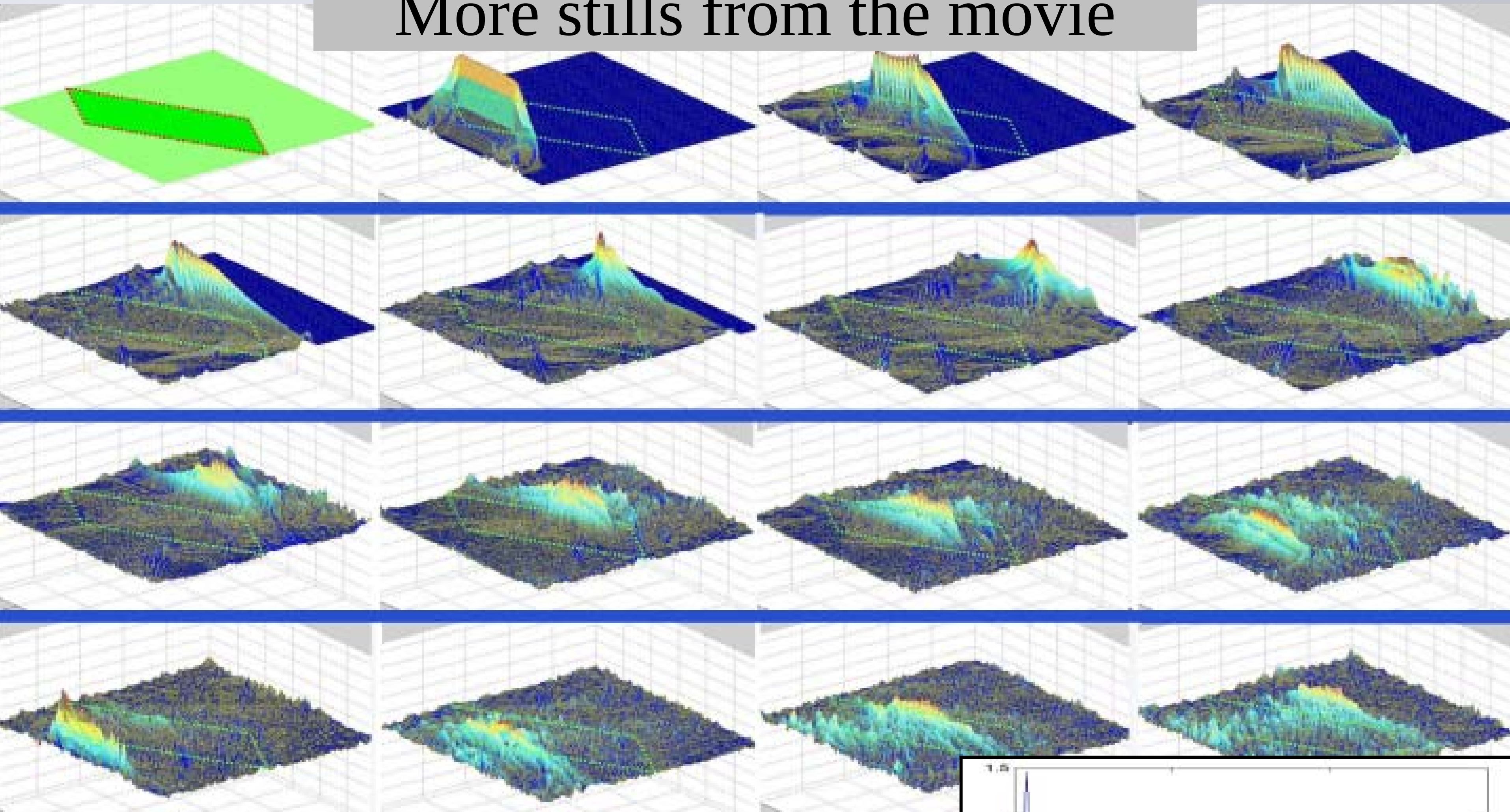


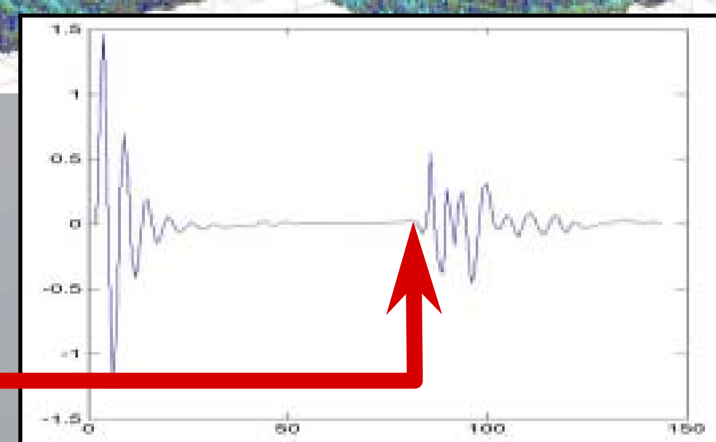


Some stills from the animation



More stills from the movie





What we are working on now

- We have a really good (I think) method for placing grains in our simulated copper. We haven't yet worked on selecting parameters to tune the simulation so that it reproduces data.
- Refinement of description of transducer-copper coupling. (Transducer absorbs some of the energy which arrives at its point-of-coupling.)
- Modeling of more complicated (2-*D*, 3-*D*) shapes (not yet).
- Porting code to NCSA supercomputers
- In the future: Inverting the simulation to uncover what we can learn about the underlying acoustic "event" from sensor data.

We are having a lot of fun

This particular project is well suited for undergraduate participation.

The students are very good! Joe and Michael are only in their second year, while Justin is a junior.

All three students will continue the work this summer.

The other project…

Comments on doing this at a university

- Participation by talented undergraduate students makes LCRD 2.15, 2.22 work as well as they do. The projects are well-suited to undergraduate involvement.
- We get most of our work done during the summer: we're all free of academic constraints (teaching/taking courses). The schedule for evaluating our progress must take this into account.
- Last summer support for students came from (NSF-sponsored) REU program and our DOE base grant. We borrowed PC's from the UIUC Physics Department instructional resources pool. This summer we'd like to support them with grant money aimed at LCRD projects.

Fermilab picks up the pace

Fermilab engages

In recent times Fermilab has been concentrating its resources on Run II matters.

The lab's budget is very tight.

The Linear Collider effort at Fermilab has been smaller than is desirable.

This is changing now. (well, maybe not the budget…)

Shekhar Mishra is leading a new LC effort which will be ambitious in scope. Initial commitment of resources: 6 to 12 full time (mostly accelerator) physicists.

Fermilab engages

Director's statement to HEPAP in 2001:

> We propose to the U.S. and to the international HEP community that we work together to build a linear collider at or near the Fermilab site.

Shekhar's 1/04 presentation at SLAC ALCPG04 meeting:

> Fermilab would like to take the lead in organizing an international effort to design warm/cold ETF once goals are set. We assume that the emerging design would go to the International Design Group as a proposal. Fermilab would be eager to host such a facility at Fermilab.

Fermilab engages

"ETF" stands for "Engineering Test Facility." Some of the possibilities presented include:

> ETF could be 1% demonstration machine for the technology chosen by ITRP.
>
> It could have an Injector, Linac (5 GeV), Damping Ring, post damping ring Linac (~0.5 GeV)

This is a significant change in Fermilab's level of engagement with the Linear Collider.

A first step: March 15 – 18 working meeting to study several schemes for a smaller TESLA damping ring. (We already have a simple lattice to use in our first attempts.)

ETF speculation… (from Shekhar)

- A0 photo injector that can be used for at least TESLA type beam.
- There are several discussions on front end of the warm Linac for other applications.
- A 5 GeV Linac can be designed to inject beam into either the Main Injector/Tevatron tunnel.
- In the Main Injector Tunnel one can imagine using either the Main Injector or the Recycler as a damping ring.
- One can build a damping ring using Recycler permanent magnet technology in either the Main Injector or the Tevatron tunnel.
- Beams after the damping ring can be extracted in existing long transfer lines, measured and/or accelerated.

Possible ETF site?

Summary/conclusions

The physics to be addressed by the Linear Collider is compelling.

Good progress has been made on a number of technical challenges facing both the TESLA and NLC designs, but further R&D is necessary before either can be built.

The way in which we work collaboratively on large projects deserves careful consideration.

The participation of North American university groups in Linear Collider R&D has increased by 50% in the last two years. This may help increase the sense of engagement (and responsibility) felt by LC participants.

Fermilab’s LC involvement has begin to increase dramatically.