Research Directions on the Pegasus Toroidal Experiment

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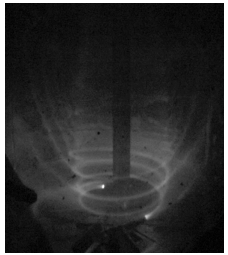
PEGASUS Toroidal Experiment

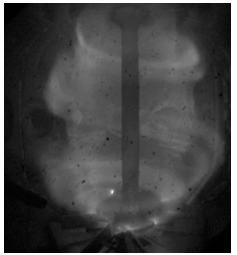
Non-Solenoidal Startup Remains a Critical Need for Spherical Tokamak, and May Benefit AT

- PEGASUS research program has focused on LHI
  - Local DC helicity injection + poloidal field induction
  - Demonstrated $I_p > 200$kA with $I_{inj} < 8$kA*
- Need for dedicated facility for NS startup studies
  - LHI/CHI/RFCD/PF induction and others
- Enhancements to PEGASUS will provide a dedicated development station for non-solenoidal startup

Pegasus HFS LHI



$I_p \sim N_{turns}\, I_{inj}$



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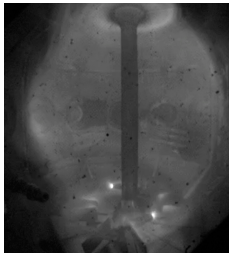

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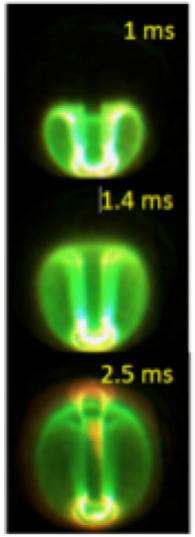

NSTX Transient CHI

RF Startup Experiments

RF Method	Device	I_p [kA]
ECH + PF induction	DIII-D	166
	JT60-U	100
ECH	QUEST	70
	DIII-D	33
	KSTAR	15
ECH + LHCD	T-7	20
EBW	MAST	73
	LATE	15
LH	PLT	100
	TST-2	25
	GLOBUS-M	21

*see G.M. Bodner contributed talk (up next)

URANIA Experiment: Converted PEGASUS Facility for US Non-Solenoidal Startup Development Station

- Mission: compare / contrast / combine reactor-relevant startup techniques
  - Goal: guidance for ~1 MA startup on NSTX-U, beyond
- PEGASUS to URANIA:
  - New centerstack and divertor assembly
  - Next generation LHI injectors
  - Transient, Sustained CHI (w/ Univ. Washington, PPPL)
  - EBW RF Heating & CD (w/ ORNL, PPPL)
  - Improved diagnostics including diagnostic neutral beam

URANIA Experiment

Collaborative Enterprise:

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UNIVERSITY of WASHINGTON

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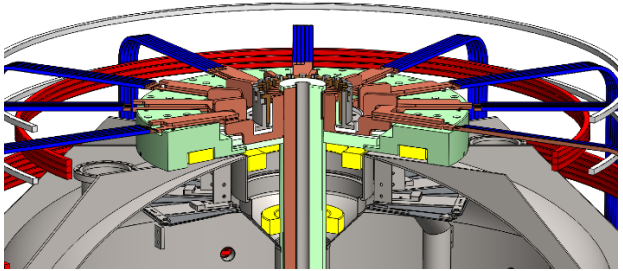
Heart of the Facility Enhancement is New TF Assembly

Parameter	PEGASUS	URANIA
I_{TF}	0.288 MA	1.15 MA
N_{TF}	12	24
ψ_{sol} (mWb)	40	0
R_{inner} [cm]	5.5	12
TF Conductor Area [cm^2]	13.2	151
$B_{T,max}$ [T] at R_0~0.4 m	0.15	0.60
B_T Flattop [ms]	25	100
ΔT_{bundle}	< 10°C	< 40°C
R_0 [cm]	45	48
A	1.15-1.3	1.33-1.4

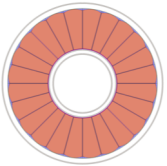
URANIA Concept Drawing



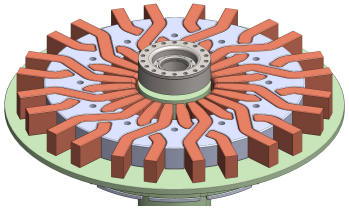
PEGASUS

High-Stress OH Solenoid
12-turn TF Bundle

URANIA



Solenoid-free
24-turn TF Bundle



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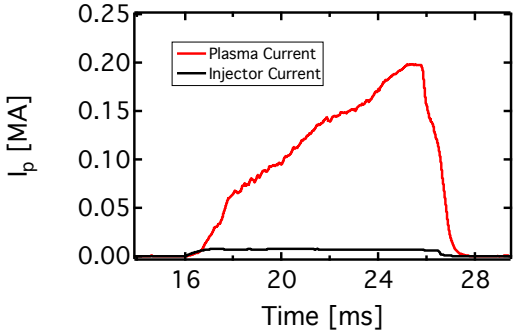
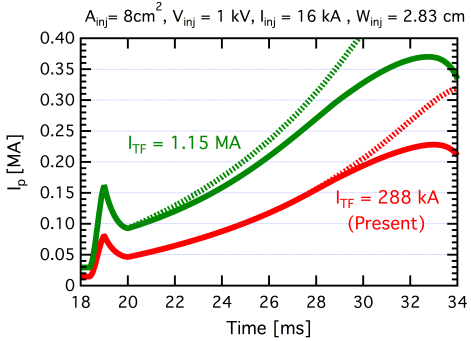
Local Helicity Injection on URANIA Will Test Critical Scalings for Extrapolation to Larger Scale

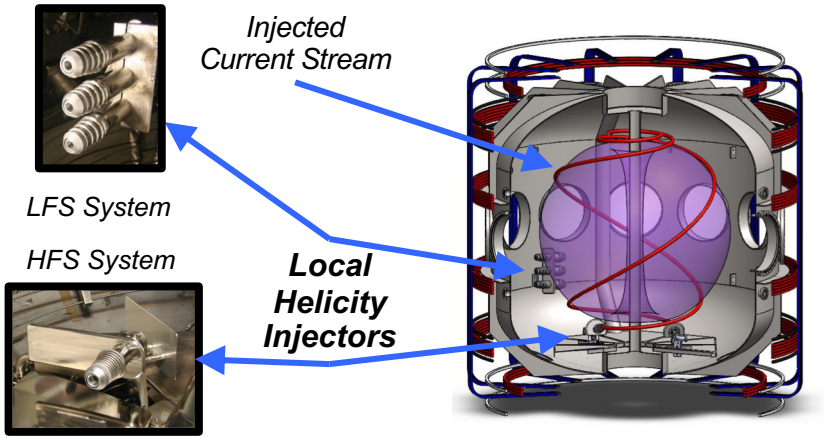
- LHI physics basis at increasing B_T
  - MHD, I_p scaling and CD mechanism
  - Electron heating and confinement
  - PMI
  - Compatibility with subsequent sustainment
- Injector technology
  - Large-area
  - Low V_{inj}
  - High B_T
  - Longer pulse

I_p > 0.2 MA Demonstrated on Pegasus



0-D Power-Balance Projections for URANIA

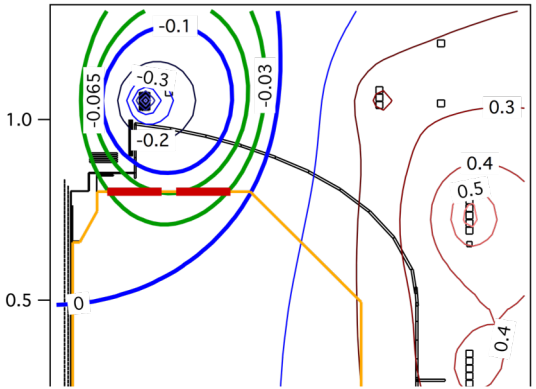




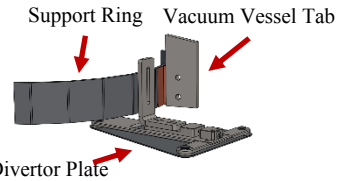
High-B_T of URANIA Facilitates Coaxial HI Studies

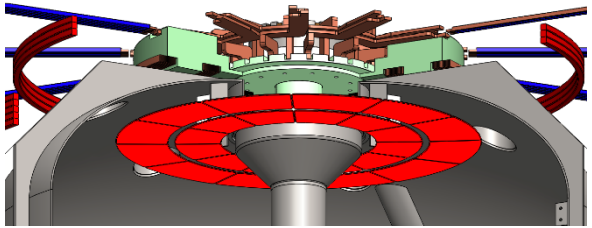
- CHI utilizes coaxial passive electrodes
  - RF heating compatibility
  - Target plasma characteristics
  - Flux conversion efficiency (T-CHI)
- Next-Gen CHI systems
  - Transient and sustained CHI capability
  - No vacuum vessel break
  - Flexible, segmented floating electrodes
    - Refractory metallic electrodes initially
  - Consider active (LHI-like) electrodes

Vacuum Field for 300kA Transient CHI on URANIA



Pre-Conceptual Segmented CHI Electrode Design on URANIA





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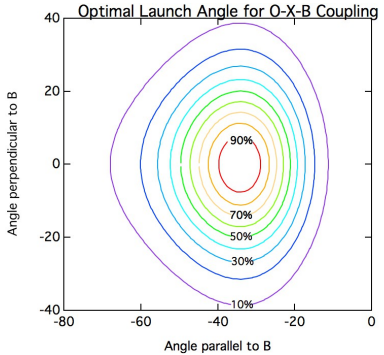
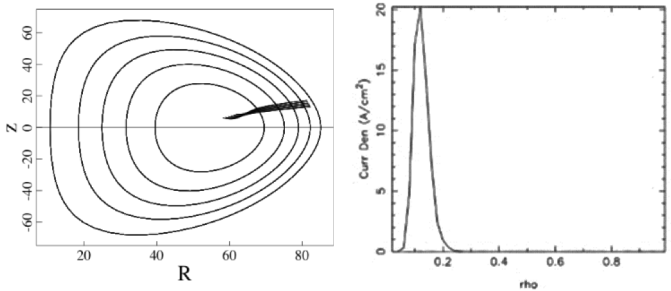
RF/EBW for Startup and Sustainment

- ~ 400 kW EBW, 8 GHz
- Synergy of heating with LHI/CHI
- Explore EBW CD as handoff tool
- Direct RF current drive for startup
- High T_e for non-inductive sustainment (e.g. NBCD)
- Pre-ionization for PF induction experiments

Favorable wide range of injection angles for O-X-B



GENRAY, CQL3D Modeling Indicates Core Absorption for EBW Heating, CD



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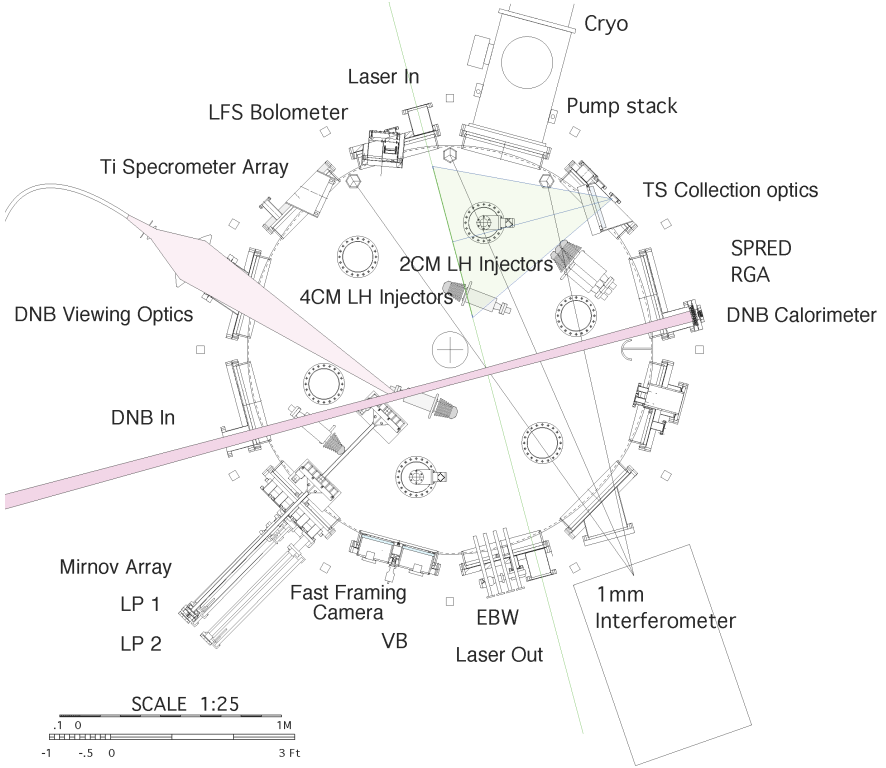
Improved Diagnostic Suite of URANIA Facilitates Physics Understanding for Extrapolation to Larger Scale

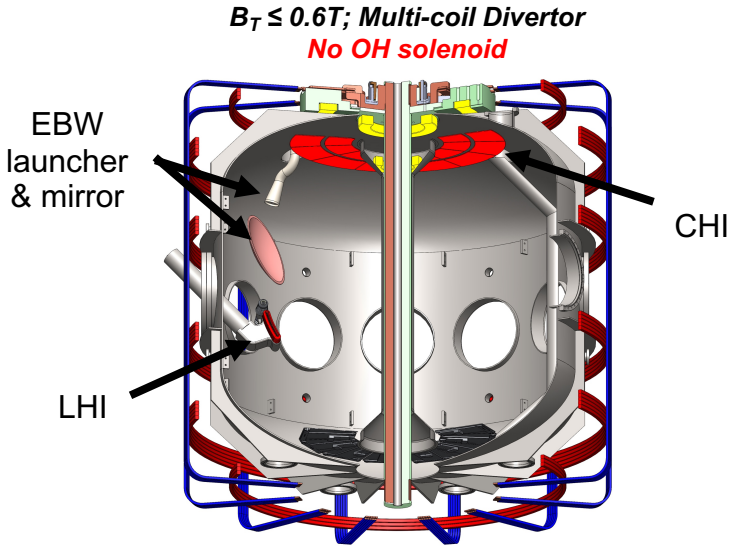
- DNB spectroscopy
  - $B(R,t), J(R,t), T_i(R,t), n_Z(R,t), v(R,t), n_e(R,t)$
- Impurity diagnostics
  - SPRED
  - Bolometry
- Insertable probe arrays
  - 3D magnetics (Hall, $\dot{B}$)
  - Langmuir, Mach, Rogowski

Diagnostic Layout for URANIA



Broadening Studies of Non-Solenoidal Startup on PEGASUS with Transition to URANIA

- **Evaluate leading concepts for non-solenoidal startup in single dedicated facility**
  - Local Helicity Injection
  - Coaxial Helicity Injection (Transient, Sustained)
  - EBW startup and assist
  - Poloidal Field Induction
  - Future: NBI heating and current drive
- **Develop common understanding & validation of all approaches**
- **Goal: develop validated concept, equipment for ~ 1 MA startup on NSTX-U and beyond**



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