The New PEGASUS-III Experiment

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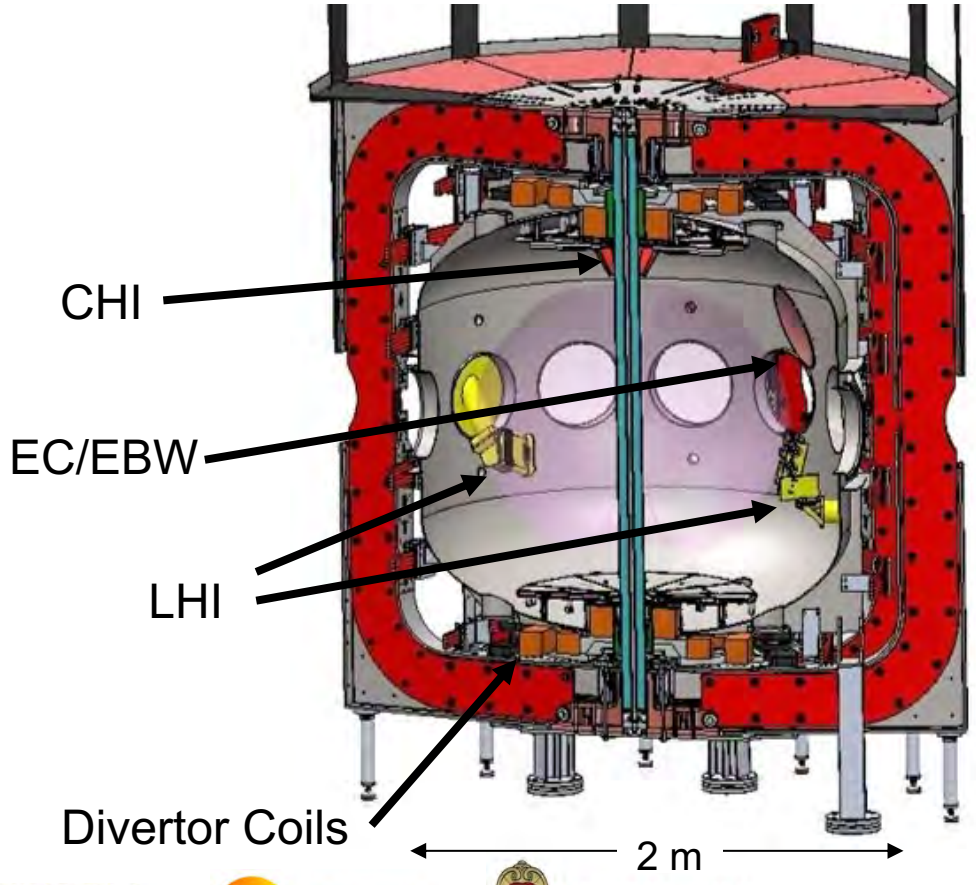
PEGASUS-III Experiment

PEGASUS-III Experiment Provides Bold Test of Non-Solenoidal ST Startup Using Reactor Relevant Technology

- Future ST designs call for solenoid-free operation
  - Nuclear ST: no OH due to shielding/cost
- Mission: Solving solenoid-free startup
  - Advanced Local Helicity Injection
  - Floating Coaxial Helicity Injection
  - RF assist, sustainment and startup
  - Compatibility with NBI heating and current drive
- Research program will provide a predictive understanding of these solenoid-free techniques
  - Extrapolatable techniques to MA-class STs (and ATs)

PEGASUS-III features:

- **No solenoid**
- 4x toroidal field
- Advanced control
- Expanded diagnostics



Projecting LHI to High-Performance Facilities Requires Tests at Increasing B_T

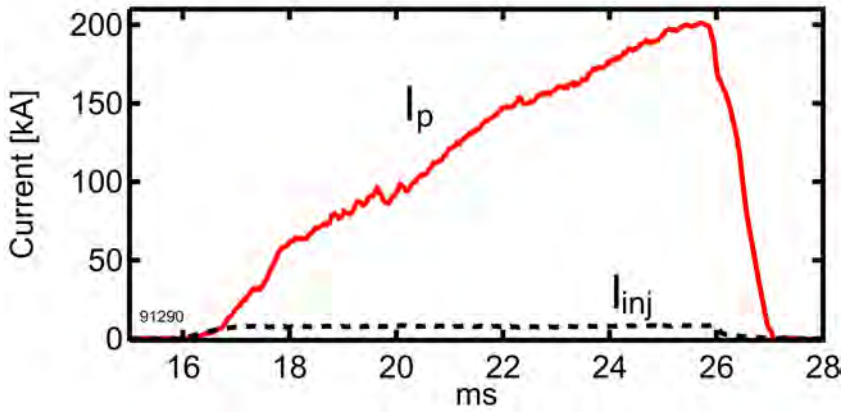
- Critical physics issues:
  - Realize the increased I_p expected with higher B_T
  - Characterize core confinement scaling
  - Test turbulence-driven dynamo current drive model
  - Coupling of LHI plasmas

$$I_{p,TL} \propto \sqrt{\frac{I_{inj} I_{TF}}{w_{inj}}}$$

- Utilize two injector configurations
  - Two arrays: 2x4 cm^2 circular injectors
  - Advanced non-circular injector

- Goal: routine experiments at ~ 0.3 MA

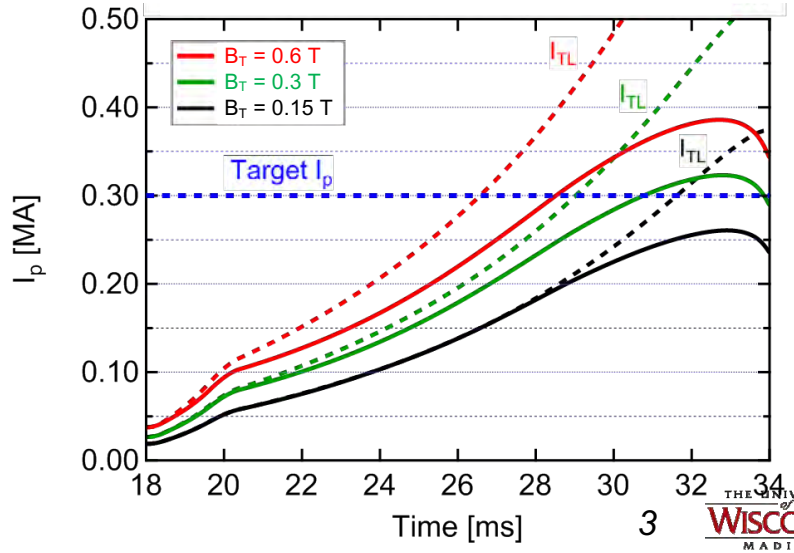
LHI Produces High-I_p = 0.2 MA Tokamak Plasma (I_{inj} ≤ 8 kA)



Monolithic LHI Injector



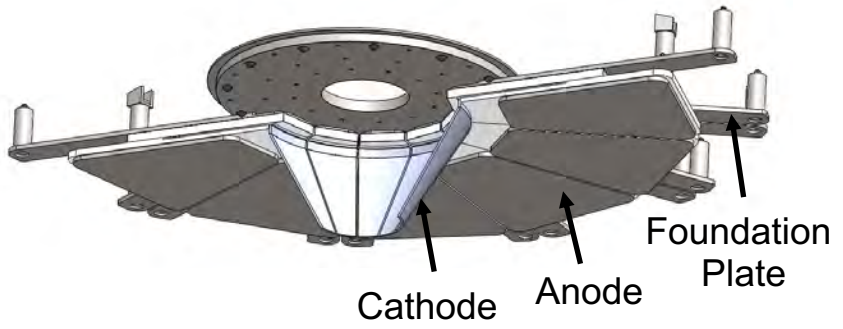
Power balance projections for Pegasus-III ops



Novel, Flexible CHI Enabled by Increased B_T of PEGASUS-III

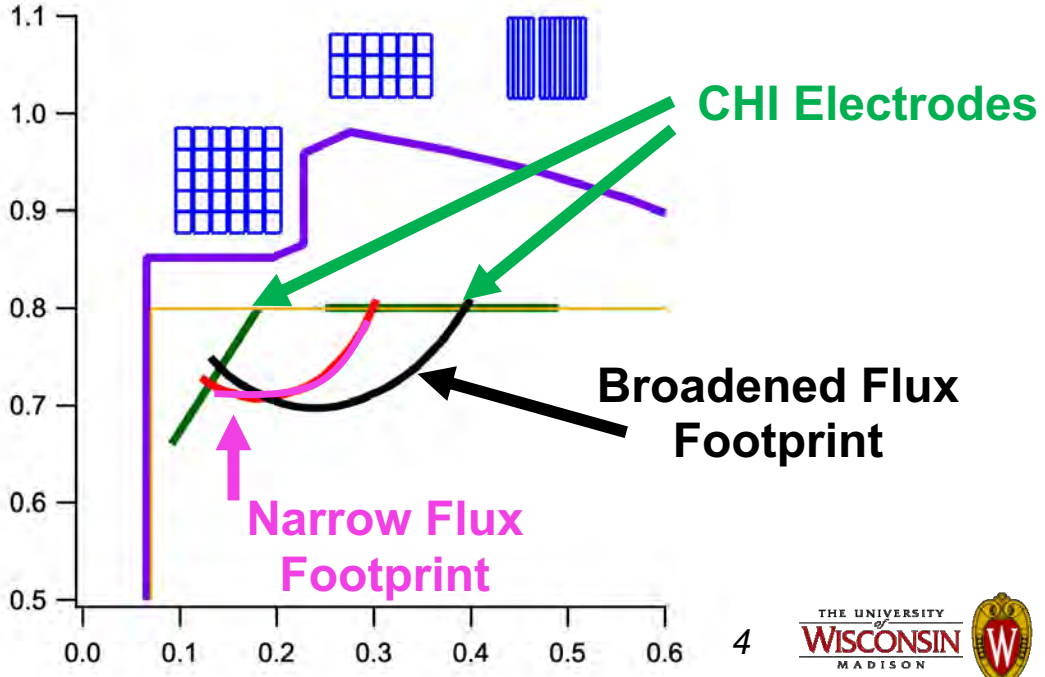
- Address critical physics and direct comparison to LHI
  - Flux conversion efficiency
  - Role of footprint in efficiency
  - Comparison and synergies with other methods
  - Role of non-axisymmetric current flows & structures

3D Sketch of Electrode Plate Concept



- Validate projection to ≥1 MA system
  - Test bubble burst and Taylor limit up to 0.3 MA
  - Vary flux distribution across electrodes
- Two floating electrodes
  - Transient and sustained CHI
- Longstanding goal to test auxiliary heating of HI plasmas

Floating electrodes, flexibility high field divertor coil system

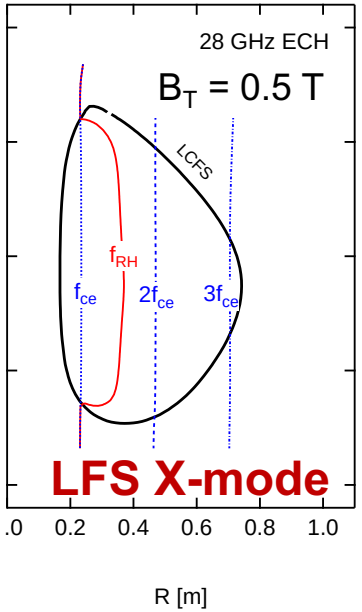


RF Heating and Current Drive Can Enhance Helicity Injection, Provide Standalone Startup

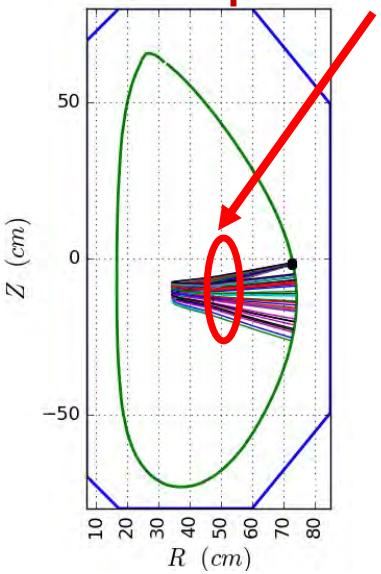
- RF heating synergistic with LHI/CHI through:
  - Increase T_e to reduce helicity dissipation
  - Freezing low-inductance helicity-driven current profile
  - Providing $J(R)$ tailoring for improved MHD stability

- Initial PEGASUS-III experiments with 0.2 MW, 28 GHz RF system
  - ECH/ECCD for lower n_e scenarios
  - Electron Bernstein wave (EBW) via O-X-B mode conversion for overdense ST plasmas for heating

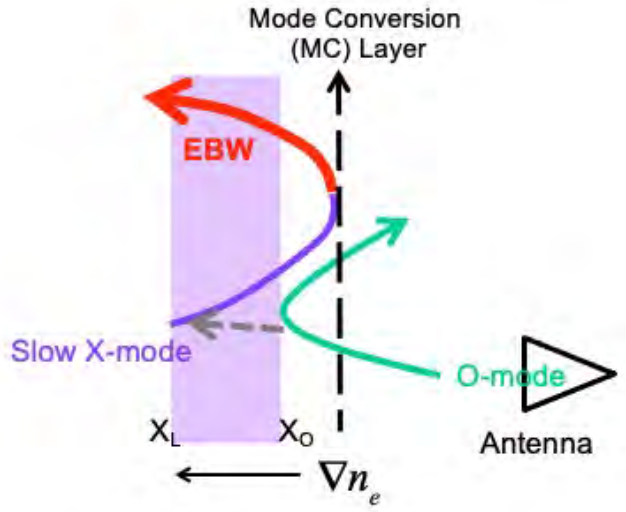
- Future: Increased RF power at 28 GHz needed for heating and CD
  - Handoff to RF sustainment
  - Tests of enhanced EBW CD efficiency at higher power/currents
  - Direct RF startup studies



ECH Absorption region



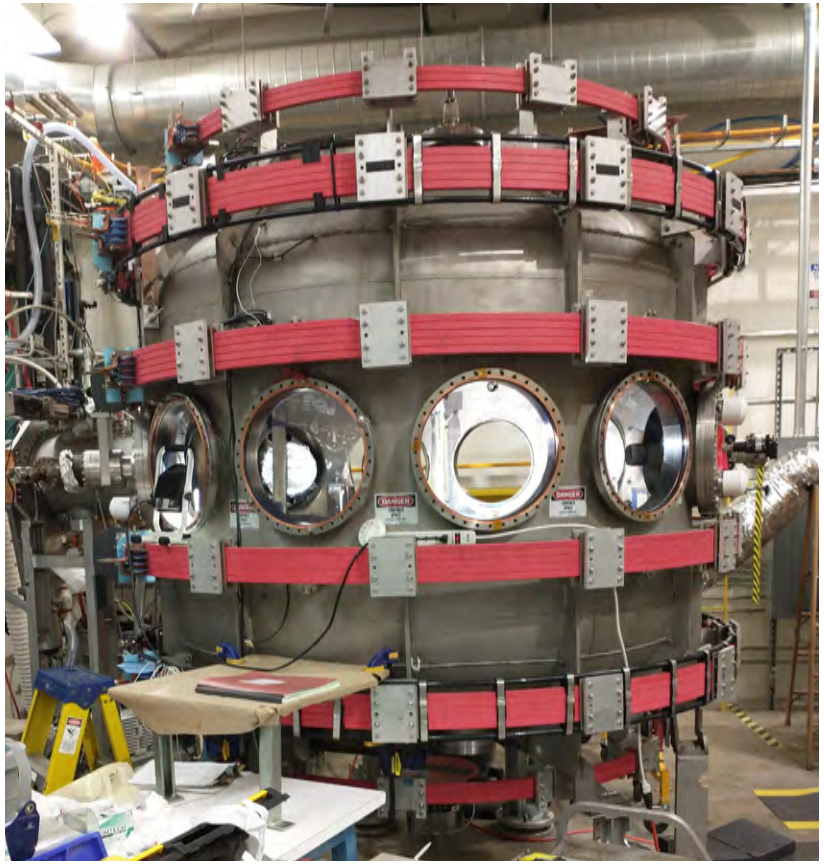
O-X-B coupling



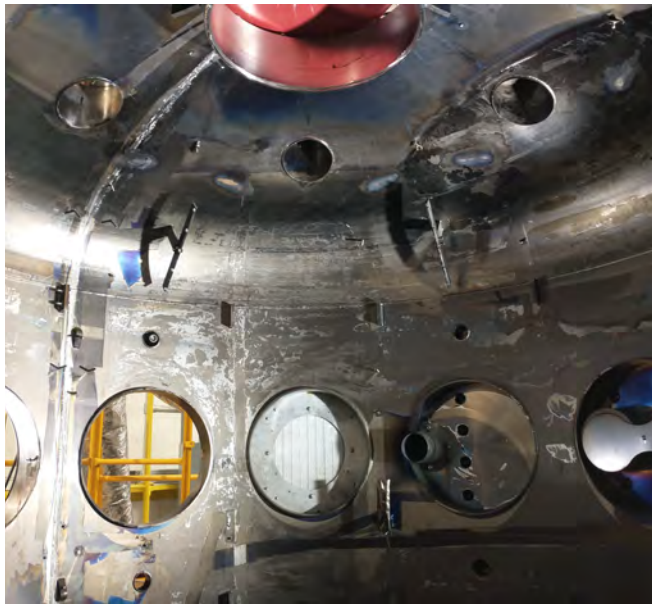
PEGASUS-III Experiment & Facility Fully Decommissioned

- Mechanical components of facility being upgraded:
  - **New solenoid free center stack**
  - New outer TF assembly
  - New programmable LHI PS
  - Structural enhancement to tank
  - New divertor assembly
  - Refurbished magnetic diagnostics
  - Gas system
- Only parts that remain
  - Primary vacuum vessel
  - Equilibrium field (red) coils
  - Vacuum system

All External diagnostics, TF returns, and bus work removed



Old centerstack cut out and majority of internal diagnostics removed

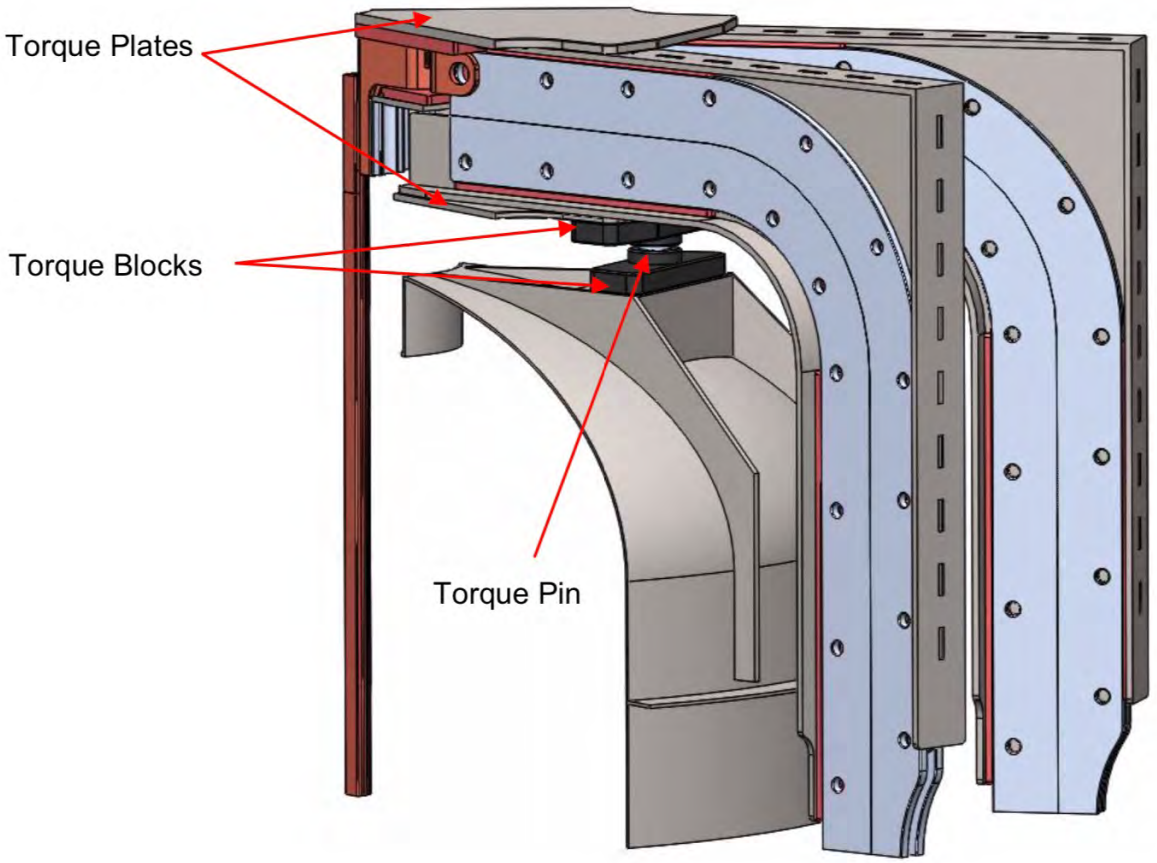


Reentrant cylinder prepped for new core



Central to PEGASUS-III mission is an Increased TF, Requiring a New Center Column, Support Assembly, and Return Conductors

- New, 24 turn toroidal field bundle and center column *without* central Ohmic solenoid is designed for up to 0.6 T



- All major components of TF in house, assembly in progress



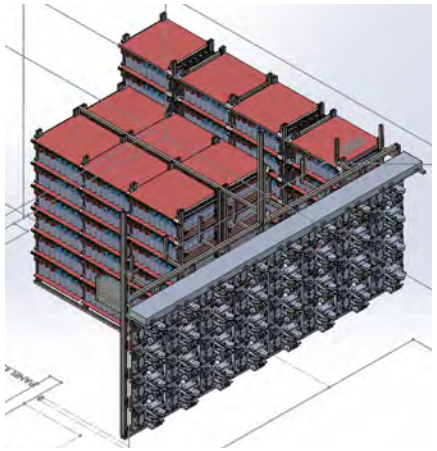




~ 175 MVA of Switching Power Amplifiers Built for Electromagnets, HI Systems

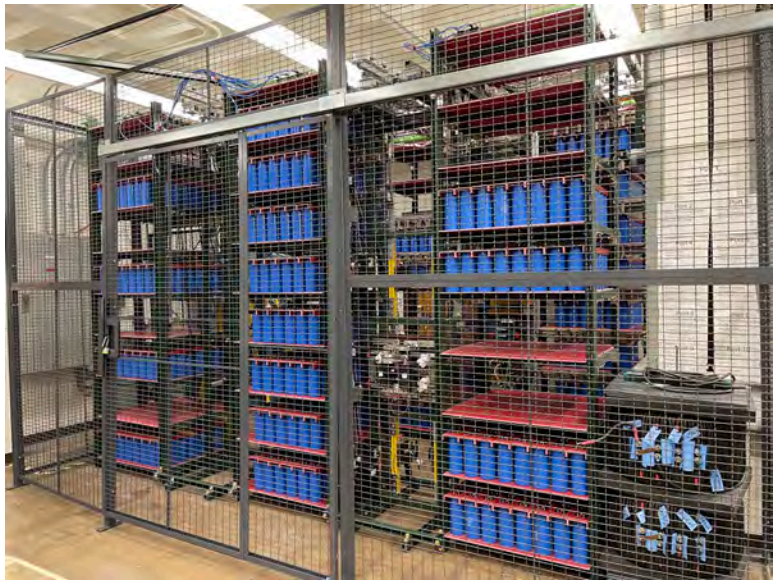
- 32 modular 4 kA, 0.9 kV supplies for coils
  - Expansion to 40 units planned
- Replaced and expanded stored energy
  - 7 MJ of new stored energy built for TF, PF, LHI
- 43 MVA voltage controlled LHI power supply
  - Multilevel buck converter
- Fully digital facility timing, control, and protection

New TF/PF Energy Storage and Switchyard Built





New LHI Arc and Bias Energy Storage and Switchyard Built



Elimination of Solenoid Greatly Simplifies ST Design and Requires Non-Inductive Startup Pathway

- **Solenoid-free central column**
- Stronger, high-B_T assembly
- Active divertor coils
- Programmable LHI PS
- CHI, RF, and next-gen LHI
- Expanded diagnostics

Parameter	PEGASUS	PEGASUS-III
I_{TF}	0.288 MA	1.15 MA
N_{TF}	12	24
ψ_{sol} (mWb)	40	0
R_{inner} [cm]	5.5	7.0
TF Conductor Area [cm^2]	13.2	72
$B_{T,max}$ [T] at R_0~0.4 m	0.15	0.58
B_T Flattop [ms]	25	50-100
A	1.15	1.18

S.J. Diem, APS-DPP 2021

Pegasus-III at assembly, commissioning stage



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