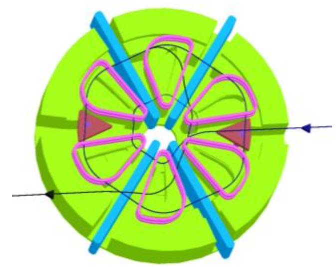
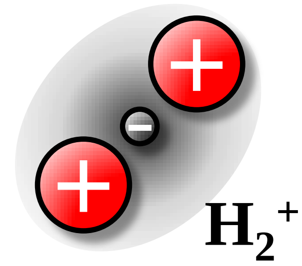
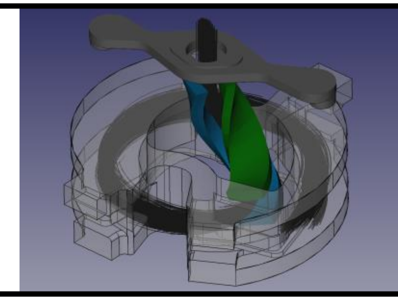
DAEδALUS
IsoDAR







Accelerator Design & Modeling for the Decay-at-Rest Neutrino Experiment DAEδALUS

Daniel Winklehner, MIT/PSI

Hyper-K Meeting, Vancouver, 07/20/2014

PAUL SCHERRER INSTITUT
PSI

Massachusetts Institute of Technology

DAEδALUS IsoDAR Collaboration

USA:

Amherst College
Columbia University
Duke University
Lawrence Livermore National Laboratory
Los Alamos National Laboratory
Massachusetts Institute of Technology*
Michigan State University*
New Mexico State University
University of California, Berkeley (Nucl. Eng.)
University of California, Irvine
University of California, Los Angeles
University of Maryland*
University of Tennessee

International:

University of Manchester*
University of Huddersfield*
Imperial College London*
LNS-INFN (Catania)*
Paul Scherrer Institut*
RIKEN*
Tohoku University*

Industry:

AIMA*
Best Cyclotron Systems, Inc.*
IBA*
Sumitomo Heavy Industries*

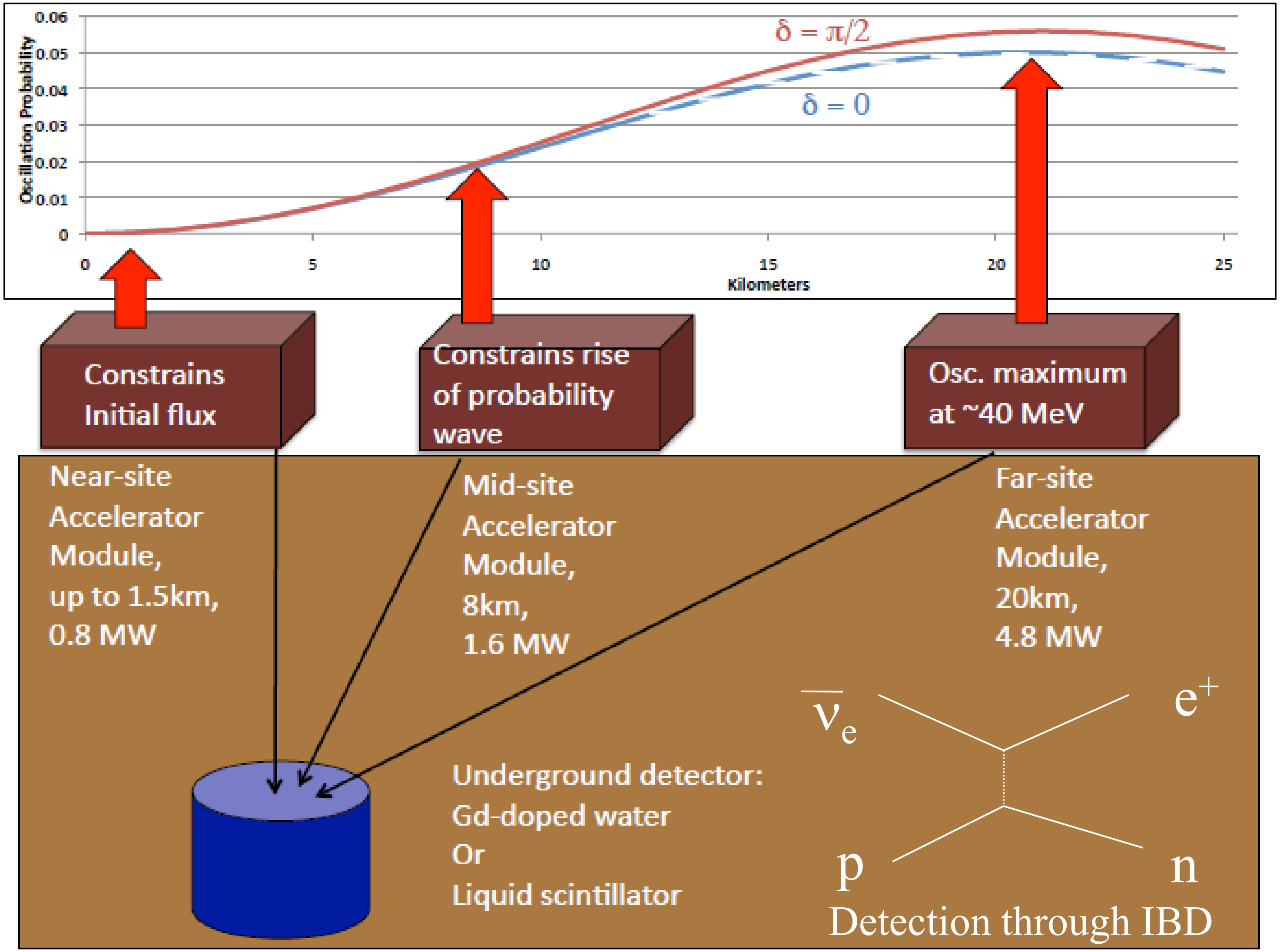
Very Active – Ramping Up – Low Level,but interested

* group includes experienced accelerator scientists

Decay At rest Experiment
for δ_{cp} studies
At a
Laboratory for Underground
Science

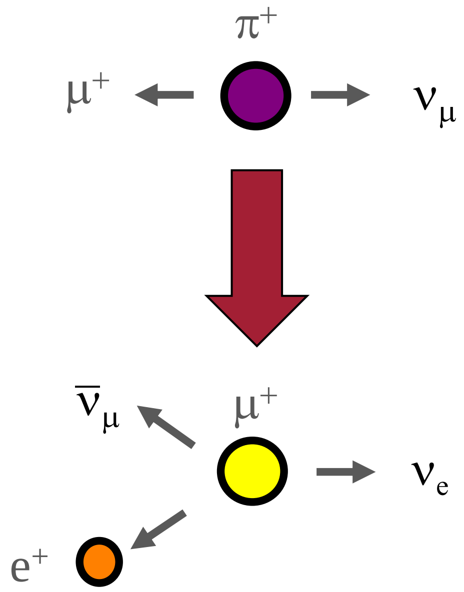
THE DAEδALUS CONCEPT

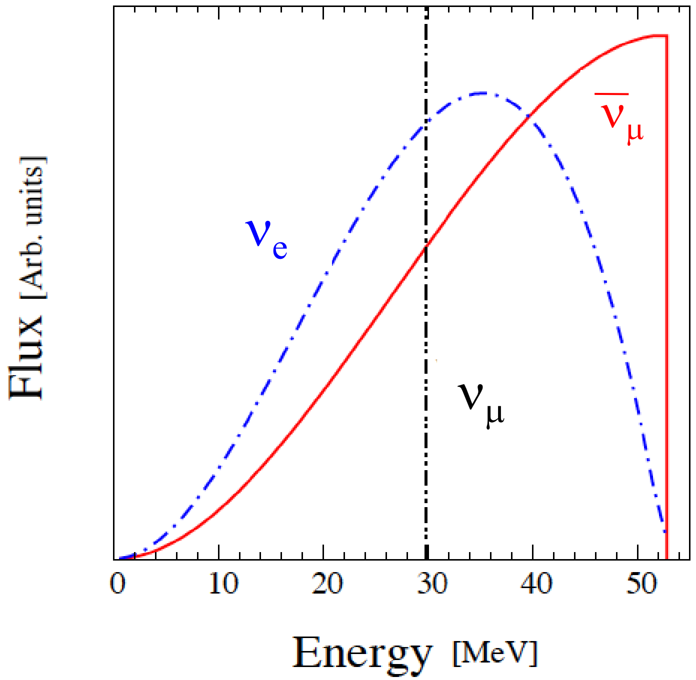
DAEδALUS – Three Accelerator Concept



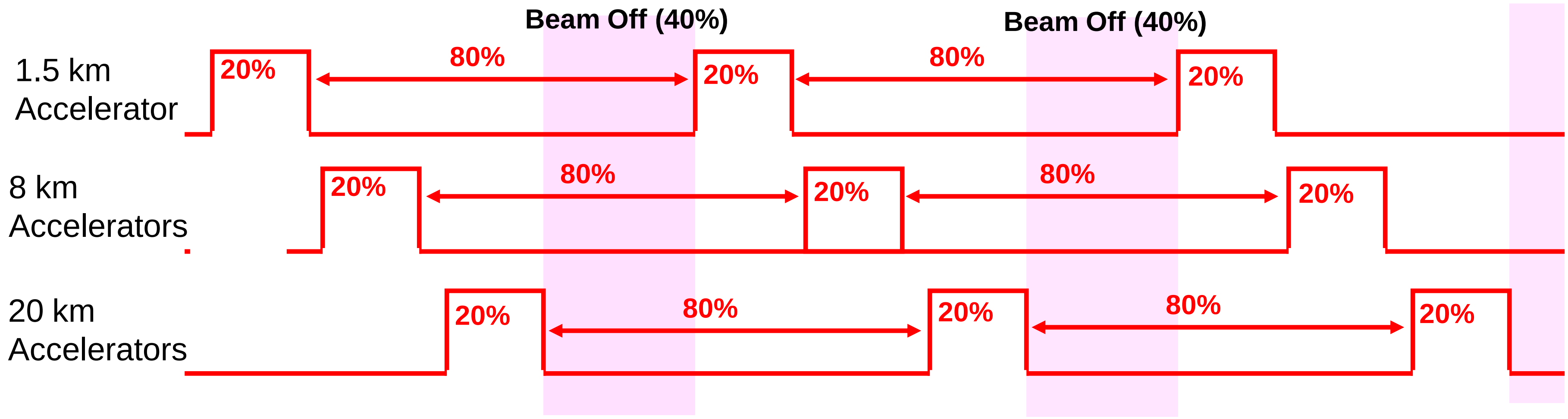
DAEδALUS Neutrino Production

- Use Pion/Muon decay-at-rest induced by 800 MeV protons for neutrino production, virtually free of $\bar{\nu}_e$
- Use inverse beta decay (IBD) to measure $\bar{\nu}_e$ appearance
- Need detector with large number of protons (free hydrogen): Liquid Scintillator or Gd doped water Cherenkov detector





Distinguish between sites by timing



- Daeδalus has good CP sensitivity as a stand-alone experiment.
  - Small cross section, flux, and efficiency uncertainties

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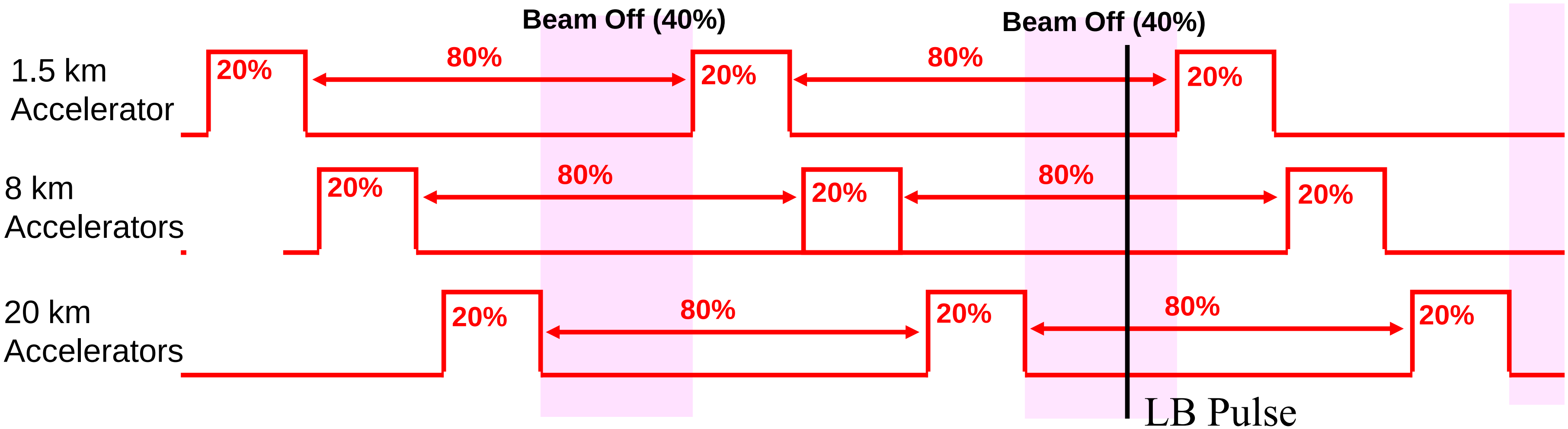
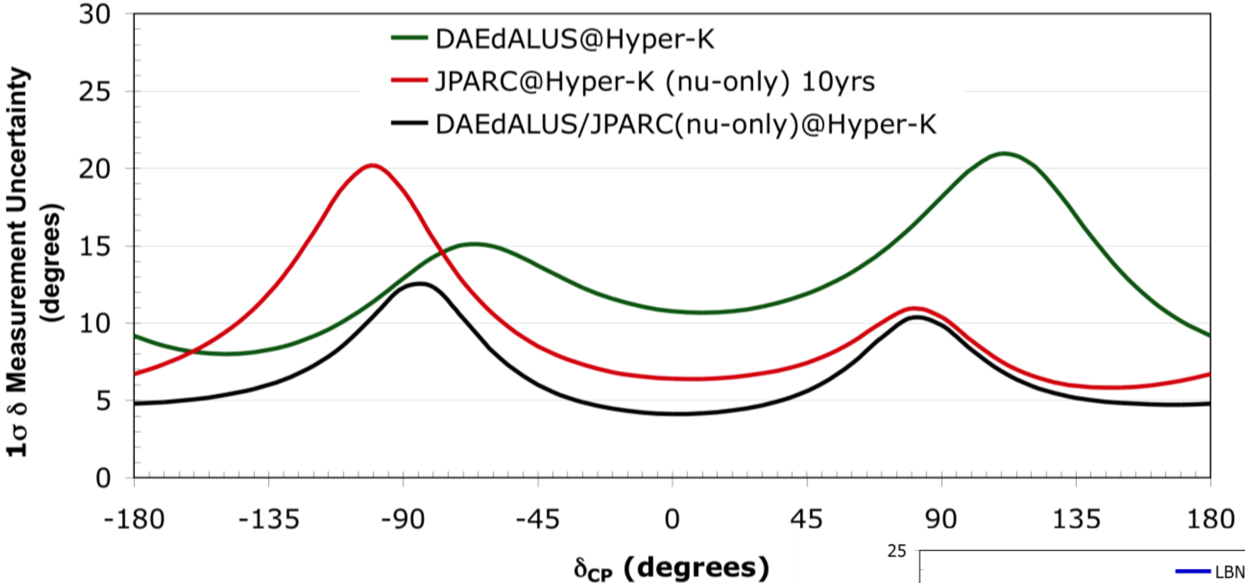
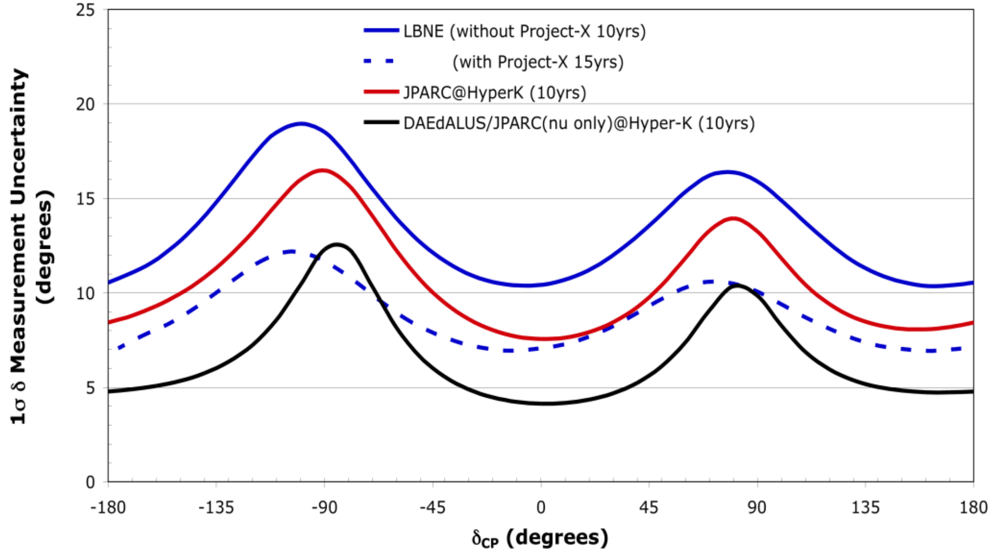


- Daeδalus has good CP sensitivity as a stand-alone experiment.
  - Small cross section, flux, and efficiency uncertainties
- 40% of „beam-off“ leave enough time to measure signal from long baseline experiment → DAEδALUS can be combined with long baseline ν-only data to give enhanced sensitivity, i.e. Hyper-K
  - Long baseline experiments have difficulty obtaining good statistics for $\nu_\mu \rightarrow \nu_e$ which DAEδALUS can provide
  - Daeδalus has no matter effects and can help remove ambiguities.

Predicted Uncertainties, 10 Years Runtime





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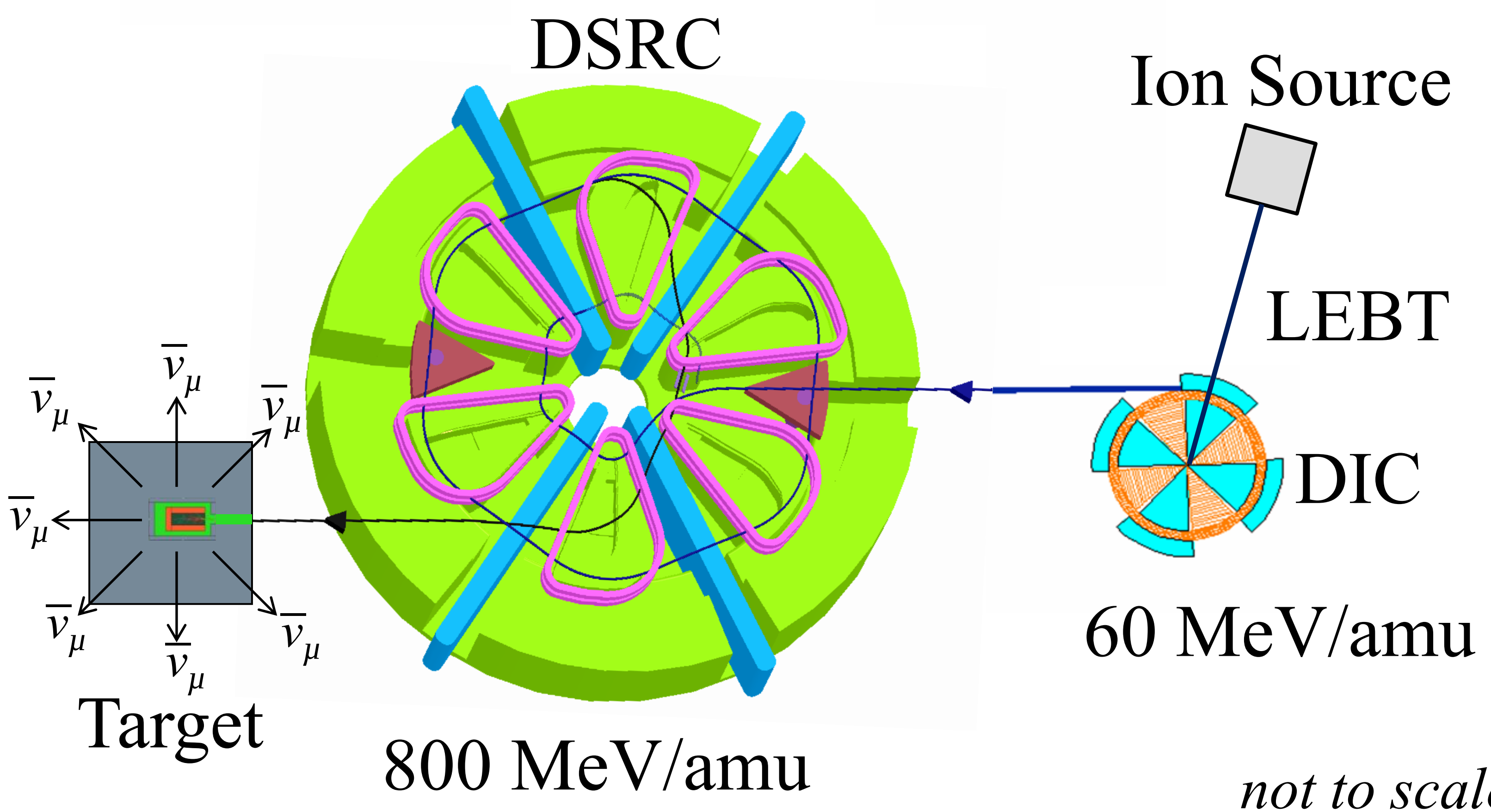
How to provide the 800 MeV protons?

DAEδALUS Module



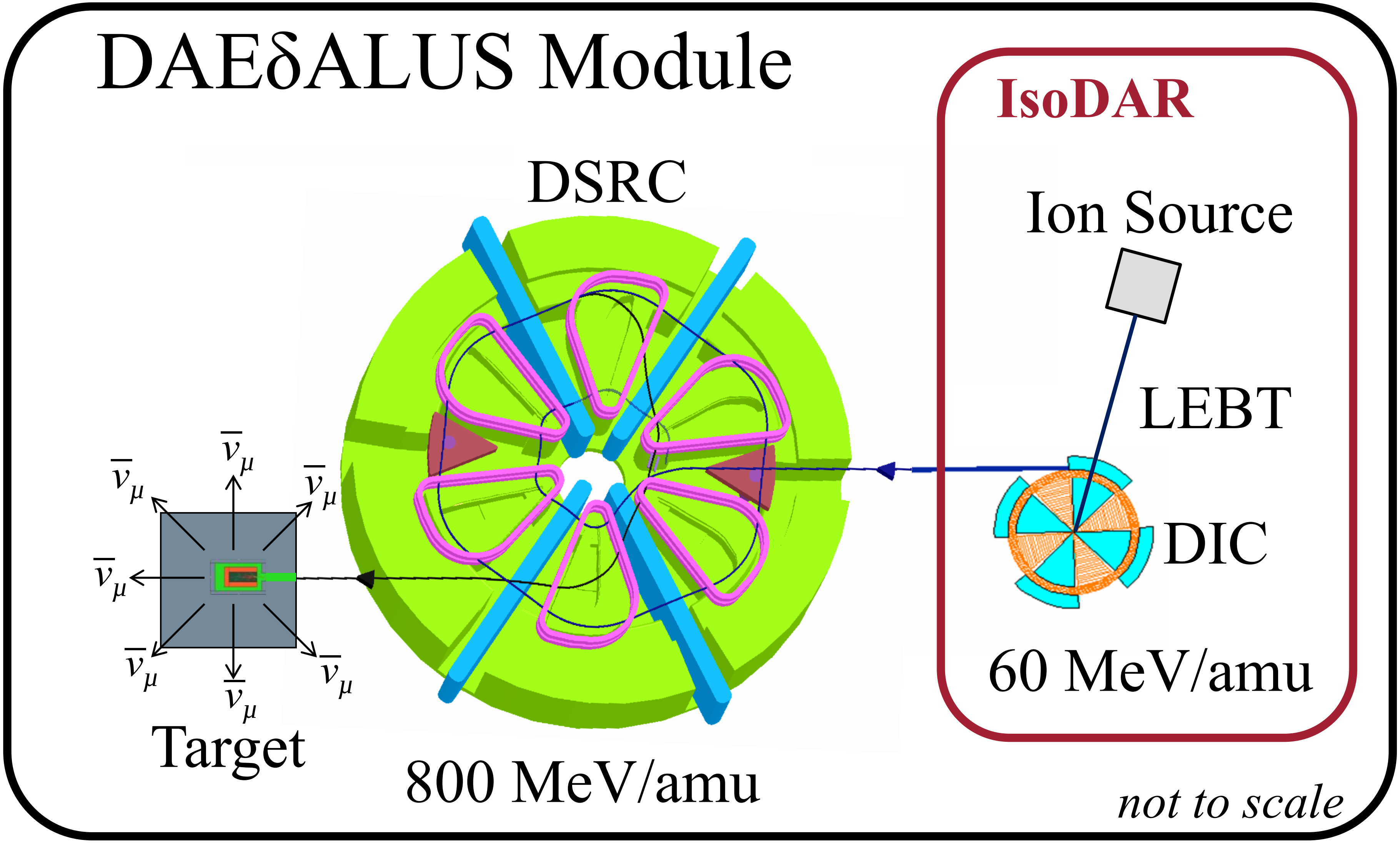
not to scale

The 4 Phases of DAEδALUS

Phase			Location/Detector	Science
I		Produce 50 mA H_2^+ source, inflect, capture 5 mA and accelerate	BCS Inc. Teststand, Experiment at INFN-LNS Catania	Accelerator Science
II	IsoDAR	Design & Build DIC, extract, produce antinu flux via ^{8}Li	WATCHMAN, KamLAND, JUNO	SBL $\bar{\nu}_e$ physics
III		Design & Build first DSRC, Run as a "near accel." at existing large detector	NOvA, LENA, Super K	SBL $\bar{\nu}_\mu$ physics
IV		Build the high power DSRC, Construct DAEδALUS	JUNO HyperK, LENA	~~CP~~

We are here

Can we use the injector cyclotron alone?



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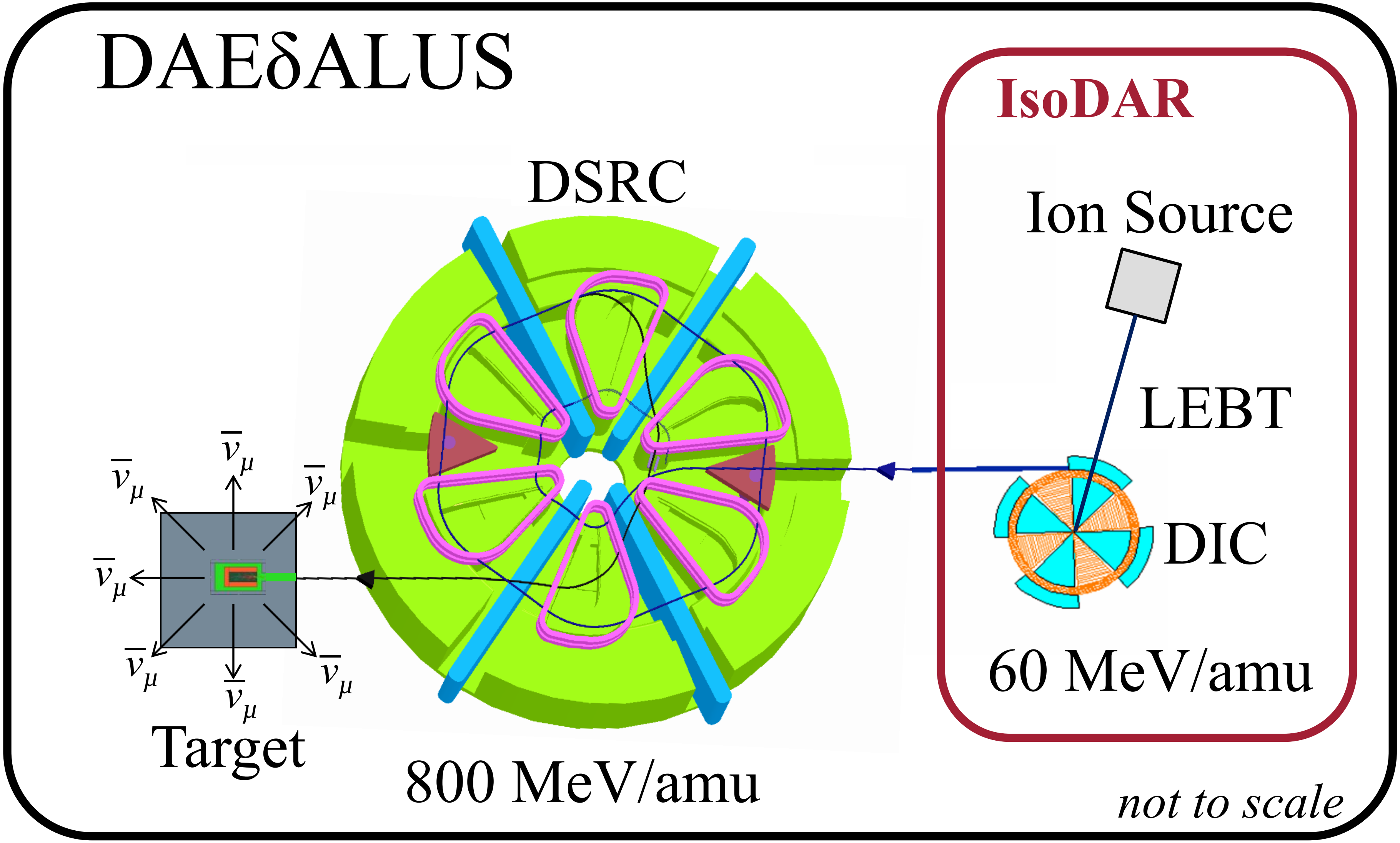
We are here

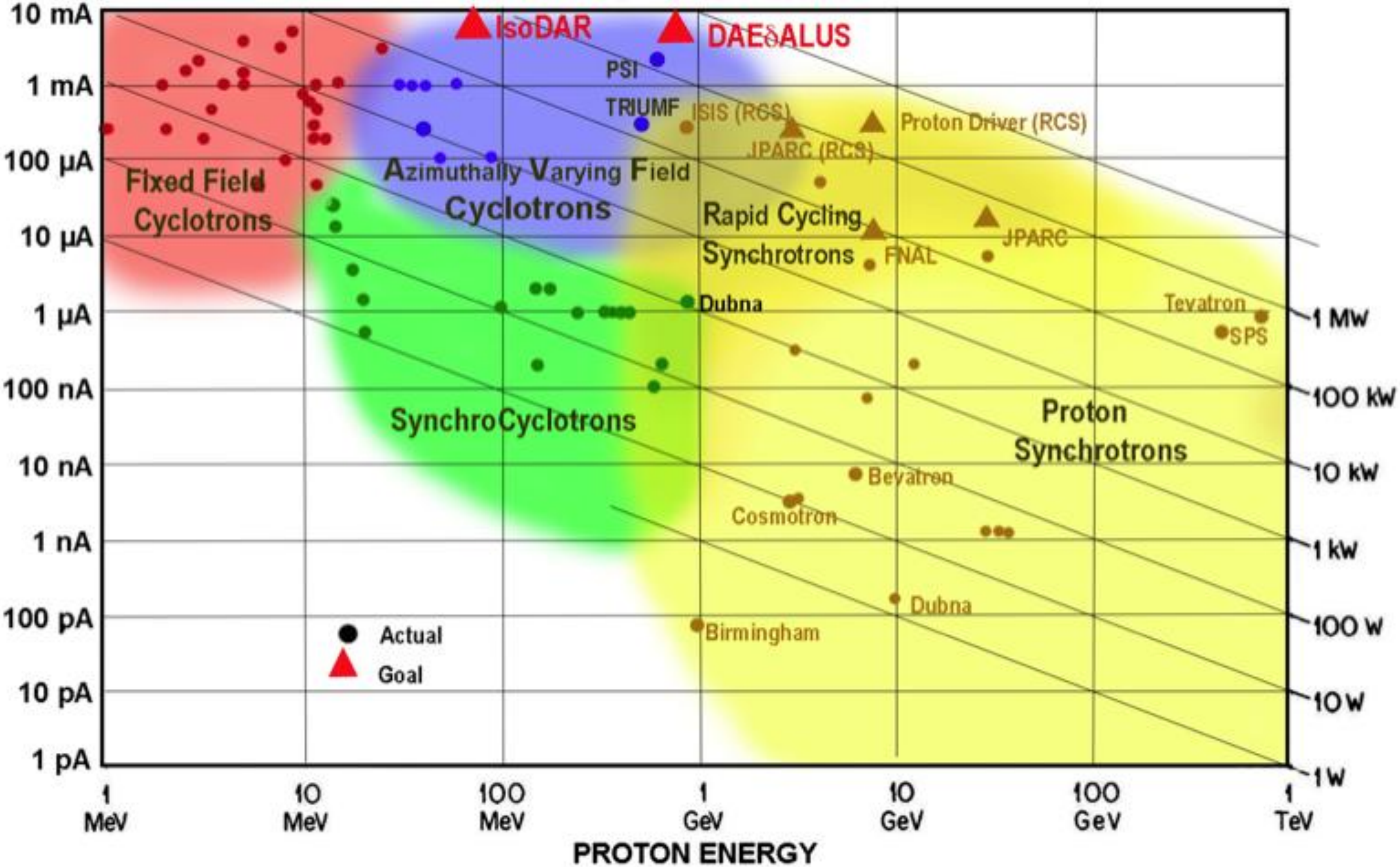
…A selection of

ACCELERATOR LAYOUT & CHALLENGES

Reminder: One DAEδALUS complex



Beam Power Comparison



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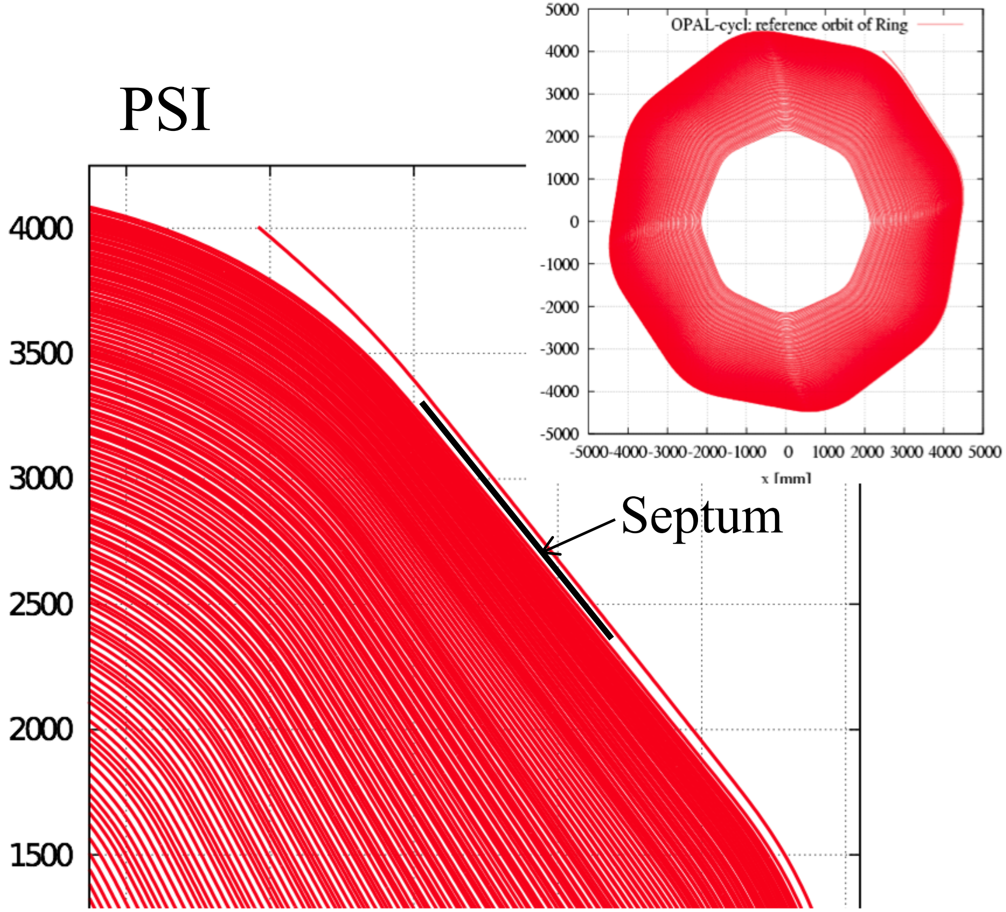
Challenge: Extraction

- "Classical" with Septum
- Requires extreme beam stability
- Need good turn separation
- Need to play with resonance to increase turn separation
- PSI (2.2 mA) has 99.98% efficiency, still loses 200 W of beam on septum
- Upper limit for hands-on maintenance (activation)
- No good for 10 mA beam



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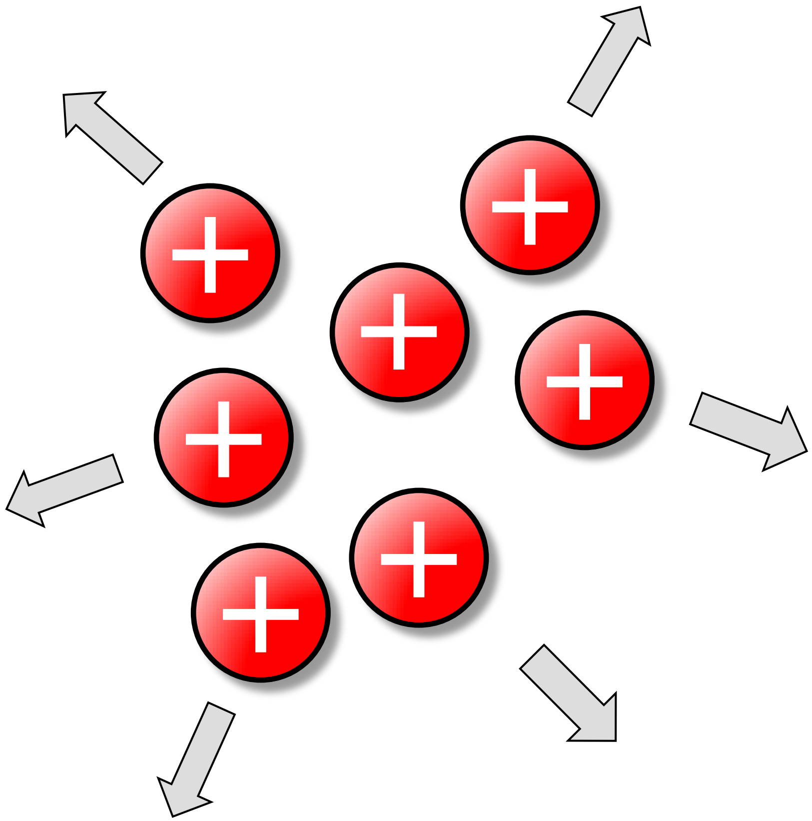
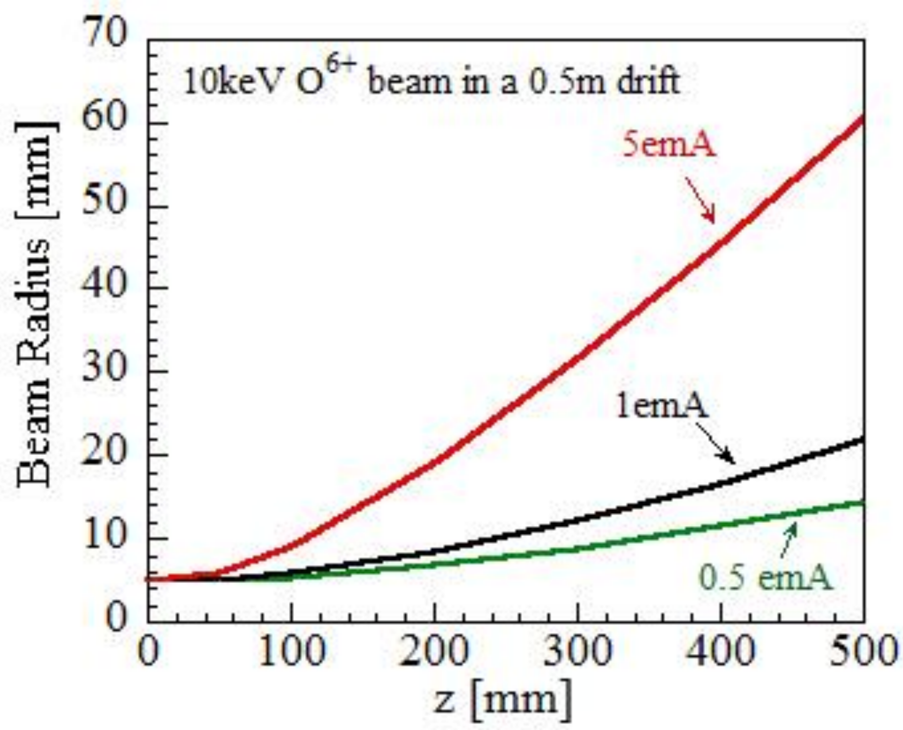
Challenge: Space Charge





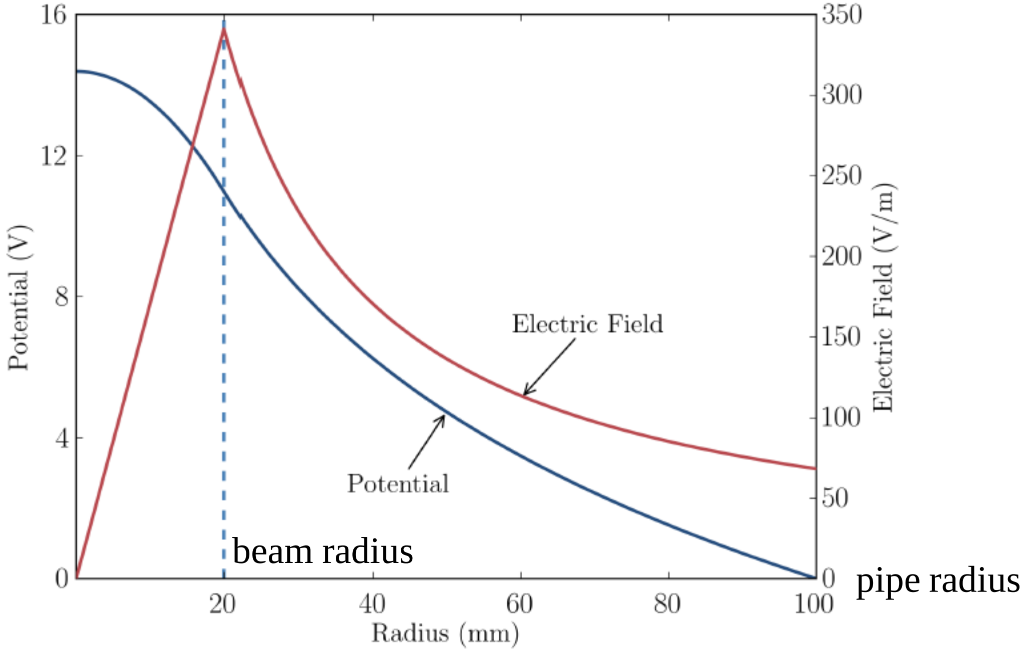
Space charge acts defocusing on the beam

Beam Potential from Space Charge

- Space charge potential of a uniform and round beam with beam radius r_b in a grounded beam pipe r_p:

$$\phi(r) = \begin{cases} \Delta\phi \left(1 + 2\ln\frac{r_p}{r_b} - \frac{r^2}{r_b^2}\right) & \text{for } r \le r_b \\ \Delta\phi \; 2\ln\frac{r_p}{r} & \text{for } r_b \le r \le r_p \end{cases}$$

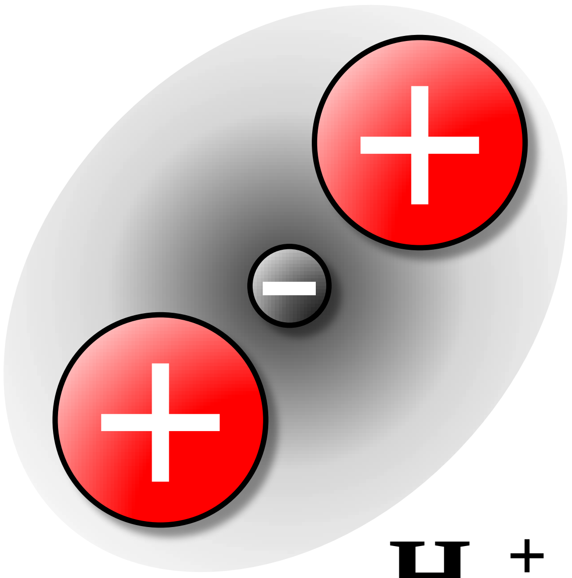
$$\Delta\phi = \frac{I}{4\pi\epsilon_0 v_b}$$



- Problem for high I and low v
- Transport line from source to 1st cyclotron (LEBT)
- Injection into 1st cyclotron (Spiral Inflector)

Solution: Accelerate H_2^+

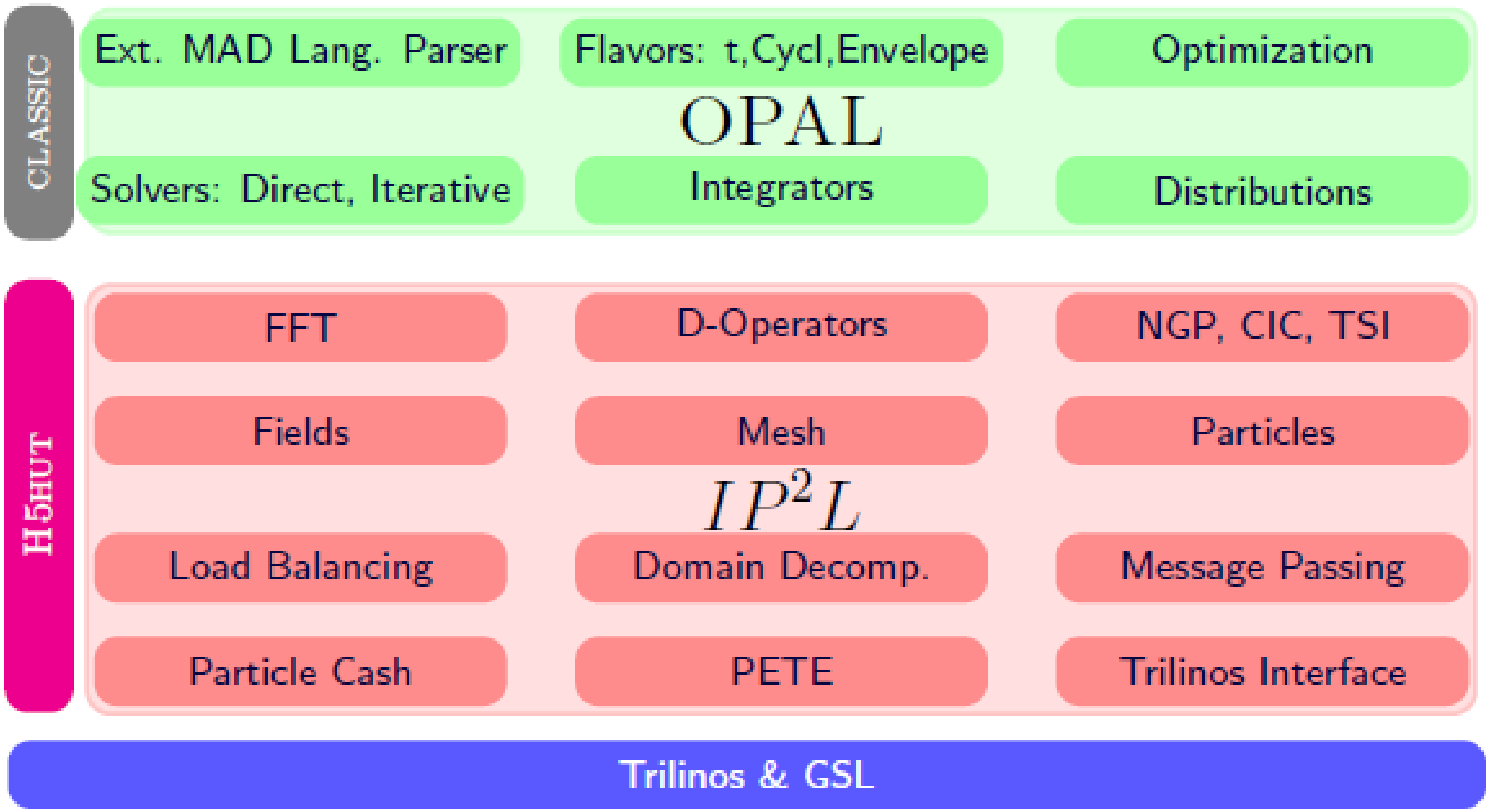
- 2 protons for each charge state
- Reduces Space Charge in LEBT and Spiral Inflector
- Can do stripping extraction in Superconducting Ring Cyclotron for DAEδALUS
- Challenges:
  - Ion Source? Microwave or Multicusp
  - Vibrational States



H_2^+

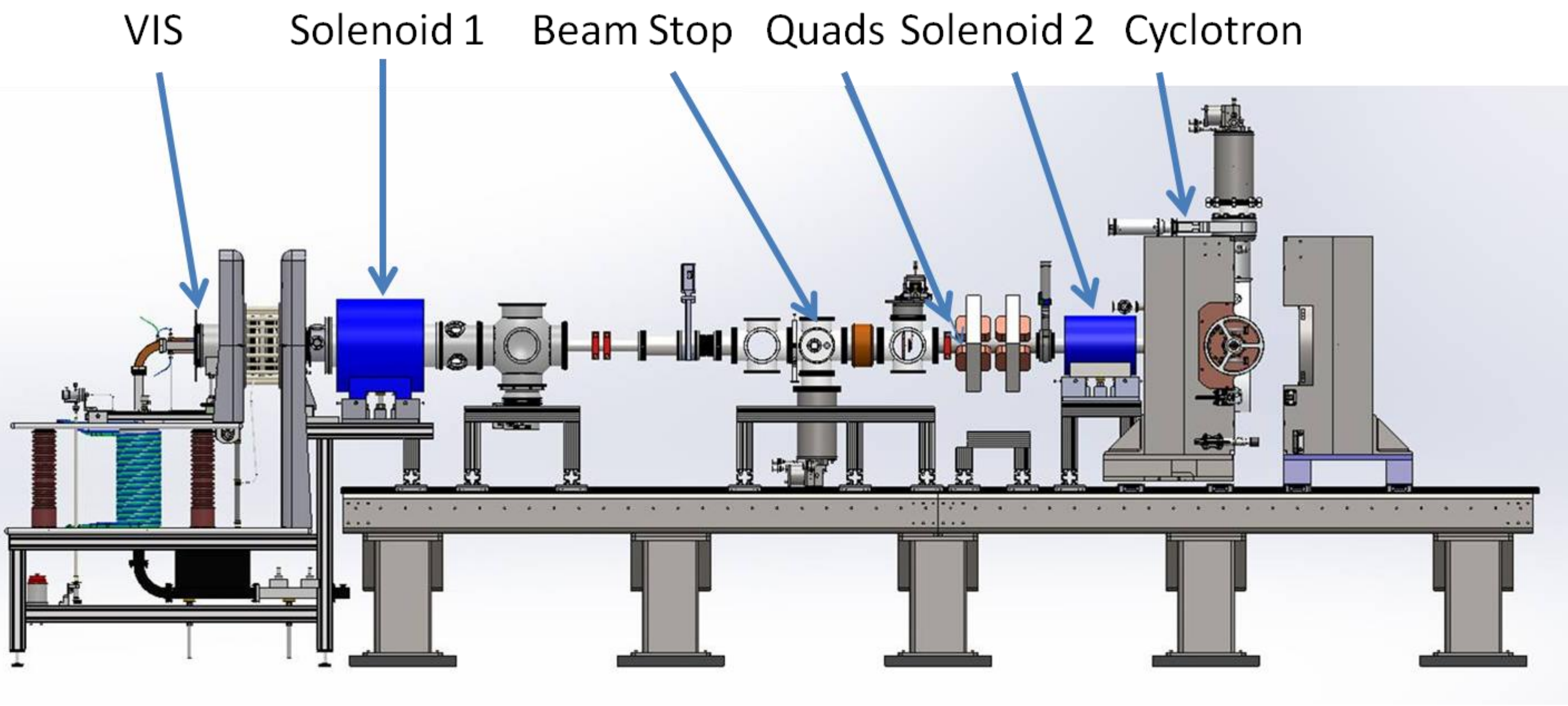
OPAL Architecture

http://amas.web.psi.ch

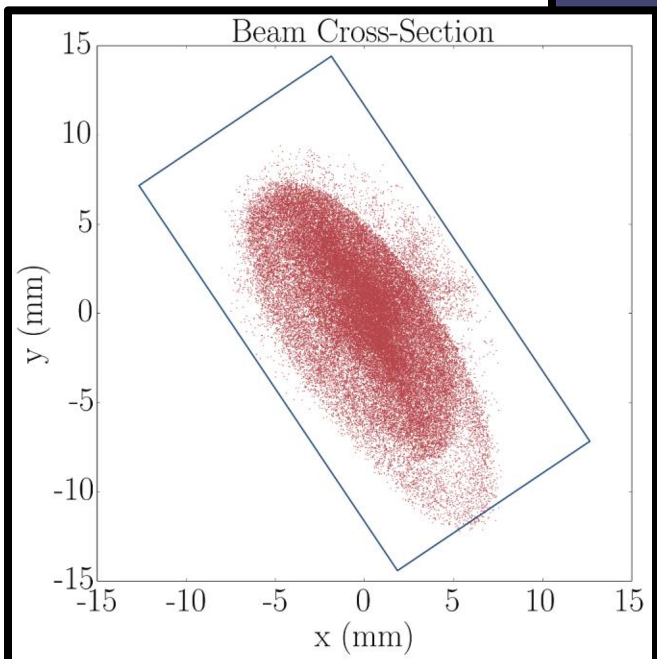


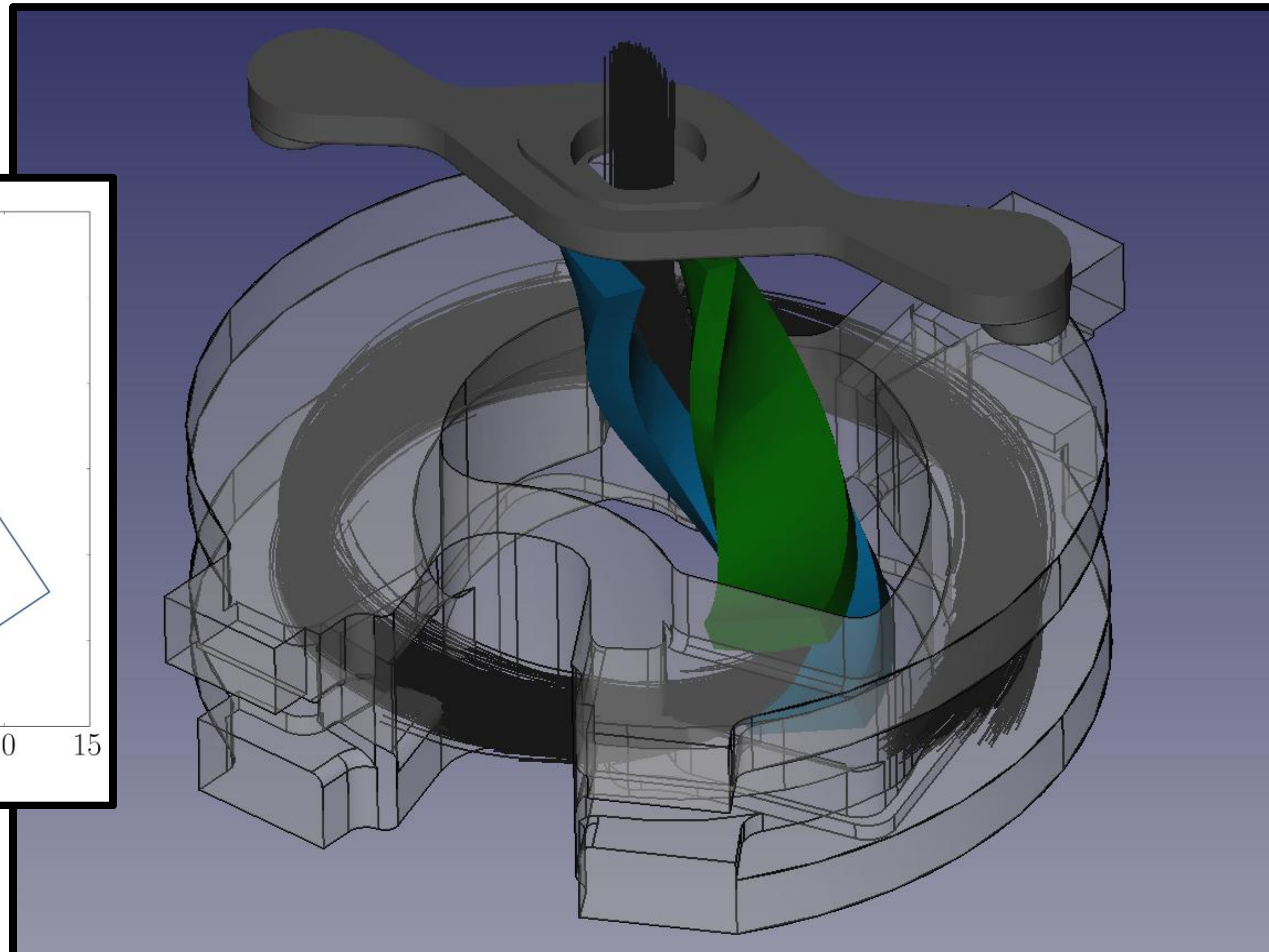
- OPAL – Object oriented Parallel Accelerator Library
- IPPL – Independent Parallel Particle Layer
- H5Hut – parallel particle and field I/O (HDF5)

Source + Transport + Cyclotron



DC Beam from realistic LEBT simulation

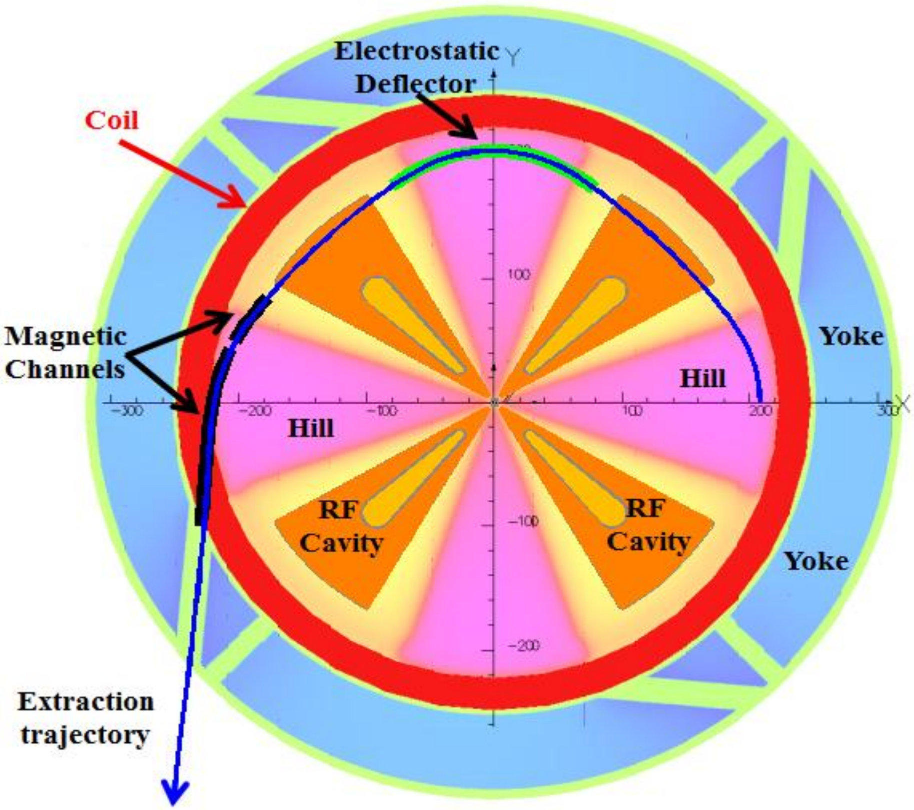




Simulation including full space charge pending…!

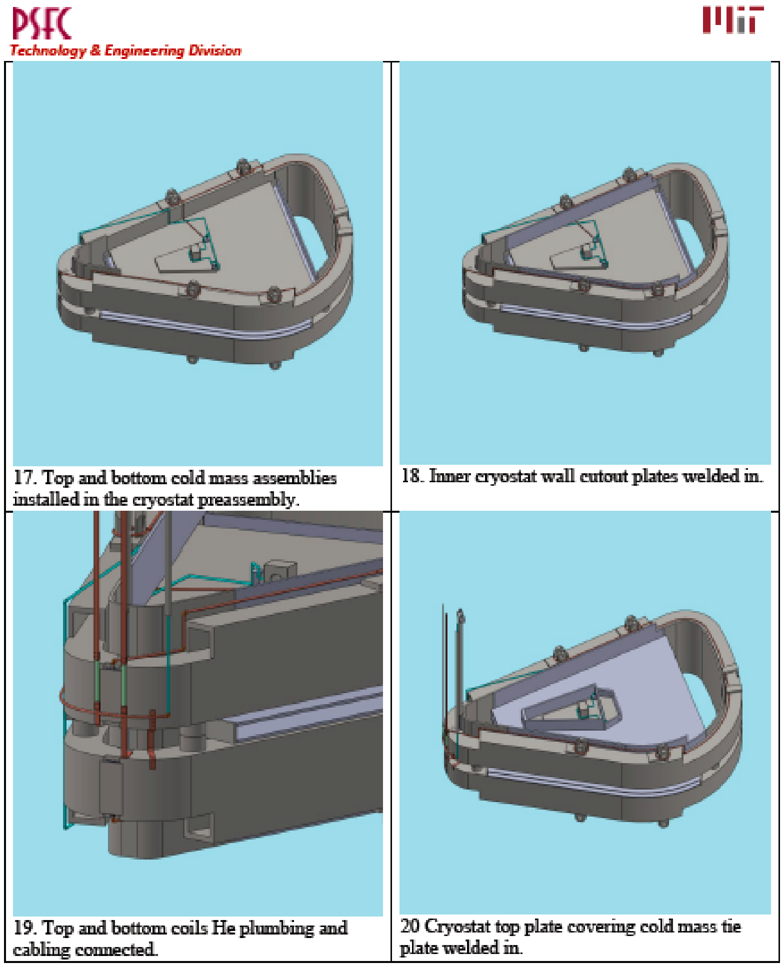
Status of Injector Cyclotron (DIC)

- Iron and Magnet design by LNFN Catania, good single particle tracking (OPERA)
- OPAL simulation including space charge and inter-bunch effects for gaussian bunch
- Missing: Spiral inflector and connecting results from SI to
- Tests of Injection ongoing at this moment here in Vancouver at Best Cyclotron Systems, Inc.



Status of Supercon. Ring Cyclotron (DSRC)

- Iron and Magnet design by LNFN Catania, good single particle tracking (OPERA)
- Coil and Cryo design by PSFC @ MIT:
  - Engineering design,
  - Assembly Plan,
  - Structural analysis,
  - Cryo system design
- Full OPAL simulation of previous 8-sector design. Actual 6-sector pending… … But: Very similar to RIKEN design!



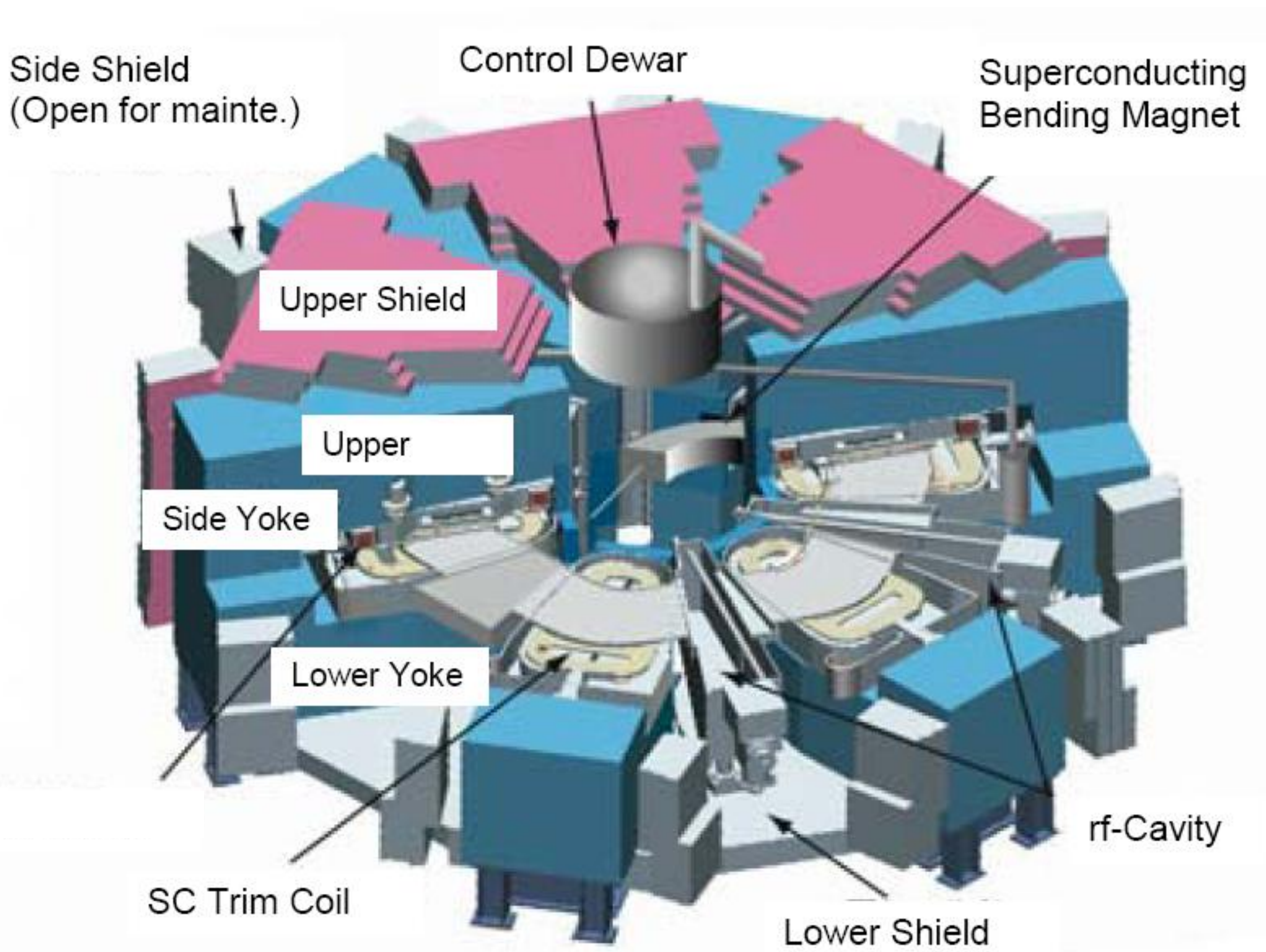
17. Top and bottom cold mass assemblies installed in the cryostat preassembly.

18. Inner cryostat wall cutout plates welded in.

19. Top and bottom coils He plumbing and cabling connected.

20 Cryostat top plate covering cold mass tie plate welded in.

RIKEN Superconducting Ring Cyclotron



Conclusion: DAEδALUS is…

- …A phased program to develop decay-at-rest neutrino beams,
- …Using Cyclotrons as the drivers.
- …An exciting new resource for neutrino physics, that also overlaps with interests in:
  - Nuclear Engineering (ADS)
  - Medical Isotope Production
- …Moving forward on most fronts!
- Next Steps:
  - Spiral Inflector tests in Vancouver (July/August) Happening Now!
  - Full Start-To-End simulations including Space Charge using OPAL
- As an aside: DIC Prototype (IsoDAR) possibly installed at KamLAND