WG3 Summary

(Accelerator Physics Working Group)

Conveners

Chris Densham (STFC/RAL)

Ben Freemire (Northern Illinois University)

Tetsuro Sekiguchi (KEK/J-PARC)

Presentations

- 3 plenary talks
- 20 individual parallel session talks
- 4 joint parallel session talks

WG3 Parallel Sessions

1. Current beamlines and their upgrades
2. Target and beam window
3. Neutrino factories
4. Future machines
5. EuroNuNet
6. MICE
7. Muon beam facilities (joint w/ WG4)

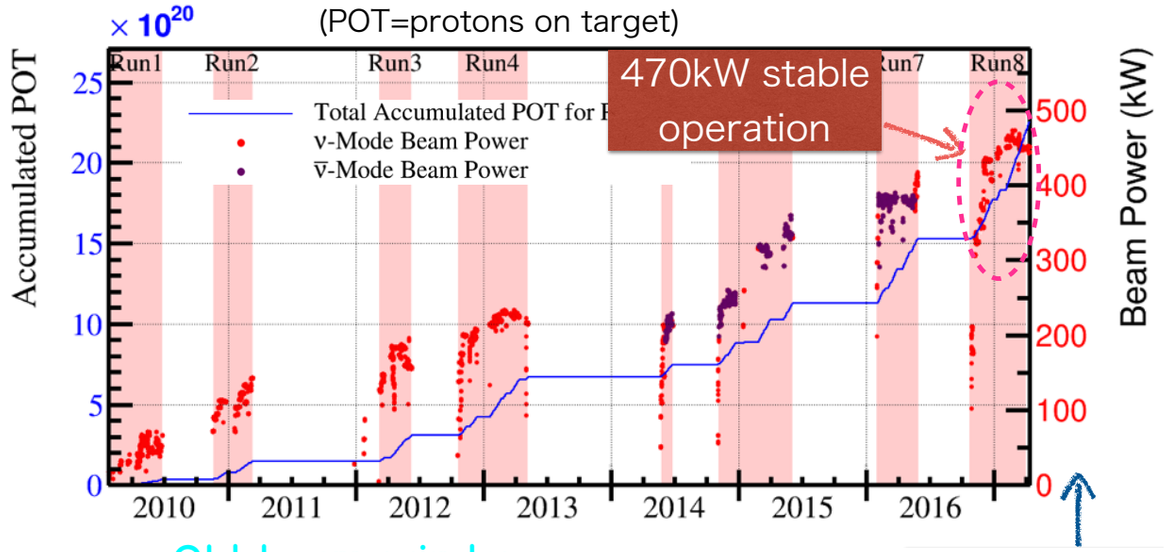
Highlight of Talks

1. Current Beamlines and Their Upgrades

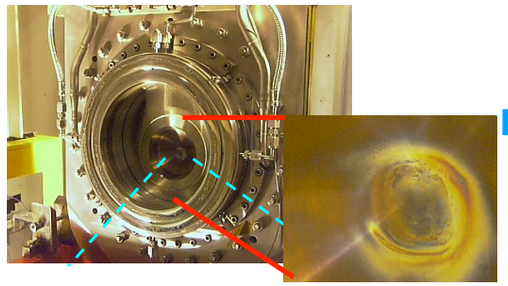
- Operational Experience of J-PARC Neutrino Beamline — Ken Sakashita
- Upgrade of J-PARC Accelerator and Neutrino Beamline toward 1.3MW — Tetsuro Sekiguchi
- Beam Delivery for the Fermilab Mu2e Experiment — Kevin Lynch
- Status of the LBNF Beamline — Tristan Davenne

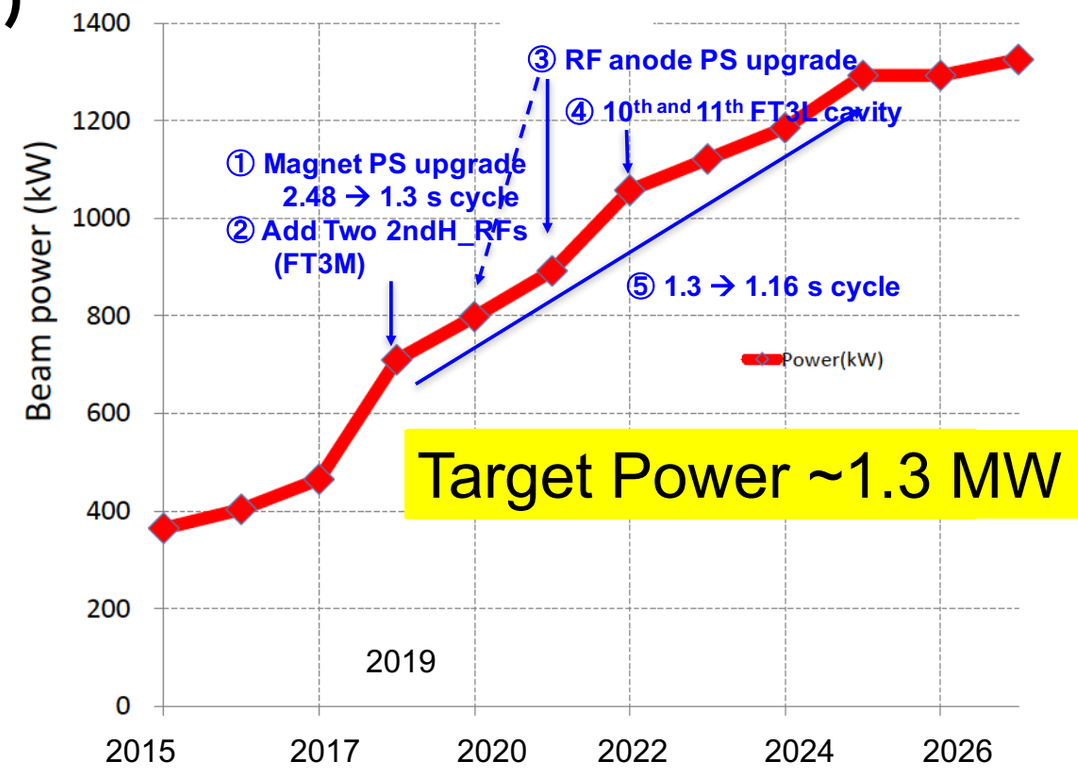
J-PARC Status and Upgrade

- **Operation status** K. Sakashita
  - 470kW stable operation
  - 510kW trial performed
  - ν beam stability <1% & <1mrad
  - Beam window replacement
- **Future upgrade toward 1.3MW (~2026)**
  - Accelerator upgrade T. Sekiguchi
    - Cycle : 2.48 s → 1.16 s (PS, RF upgrade)
    - Intensity : 2.4×10^{14} → 3.2×10^{14} ppp (RF)
  - ν beamline upgrade
    - Beam monitor
    - Control/DAQ
    - Target
    - Horn current increase
    - Water/He cooling
    - Treatment of radioactive materials



Old beam window

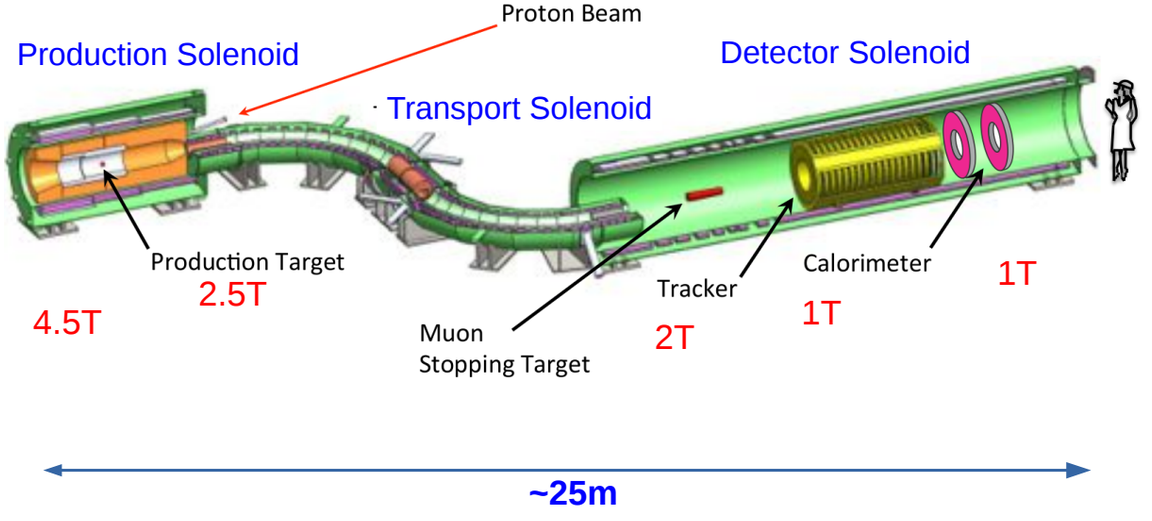


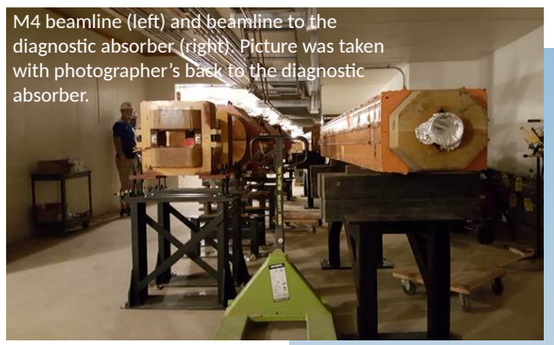


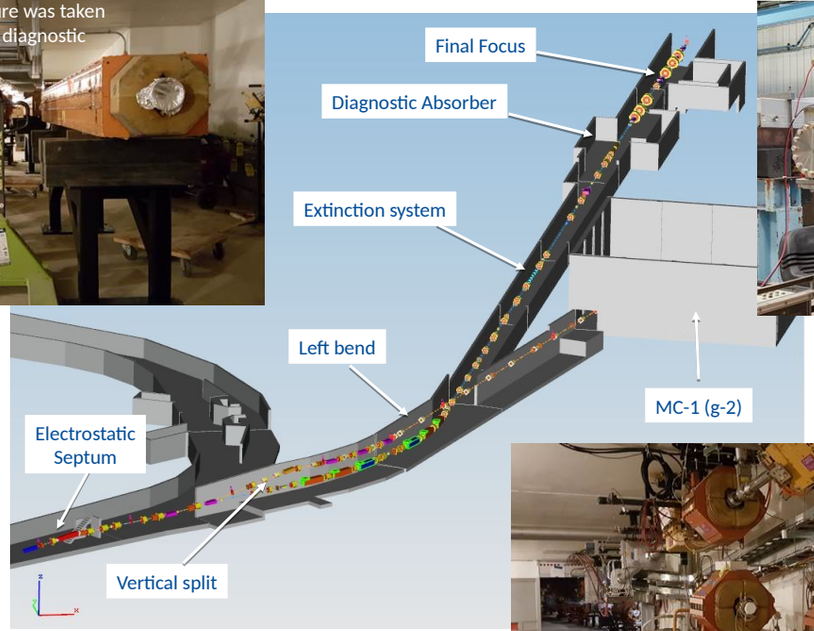
Mu2e

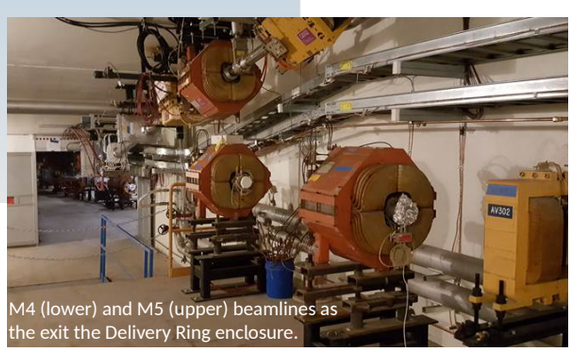
K. Lynch

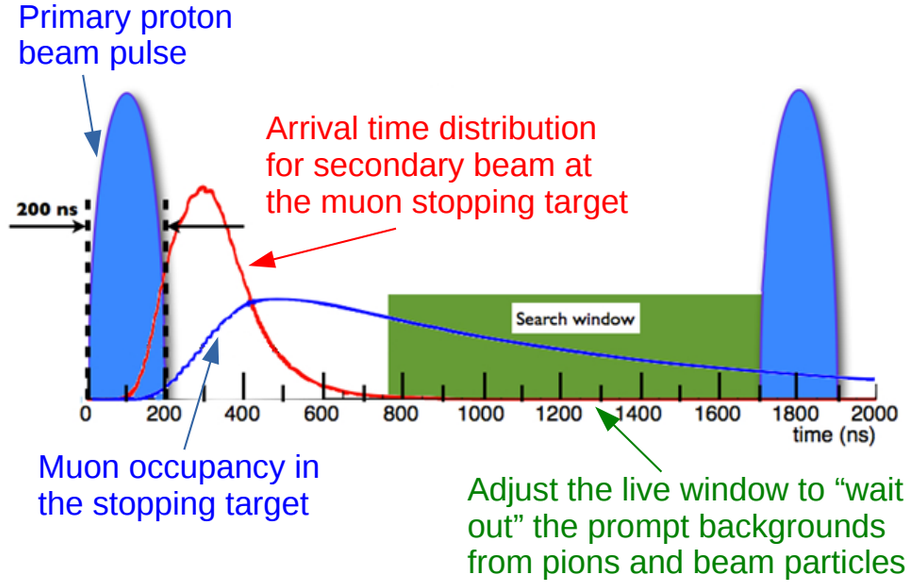
- **Pulsed muon beam**
  - Extinction is key
  - 10^{-12} to be achieved by AC Dipole
- **Beamline construction ongoing**
  - Proton transport line
  - Prototype AC Dipole
- **Schedule**
  - Beamline commissioning 2020~2022

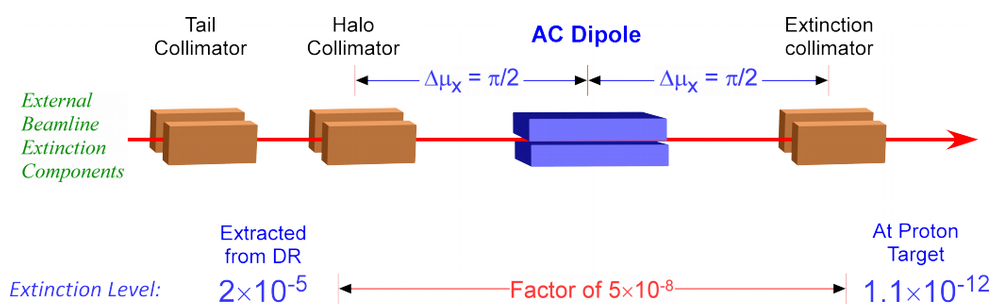








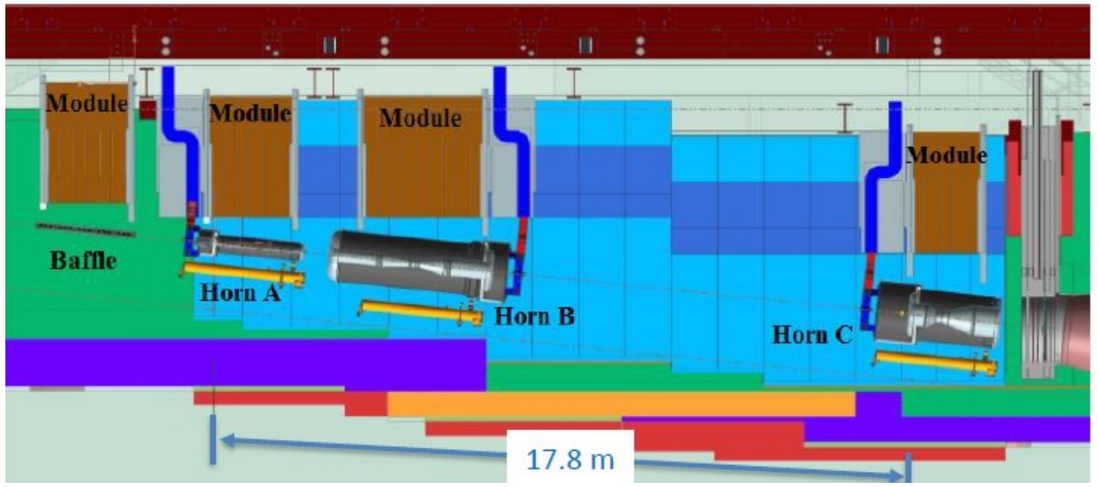




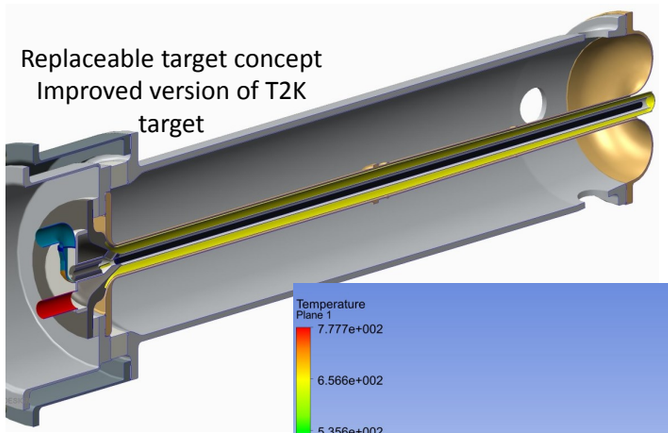
LBNF

T. Davenne

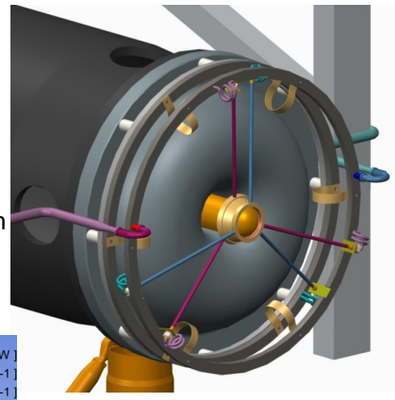
- **Design optimization**
  - 3horns + long-target ⇒ flux improvement
- **Mechanical Simulation**
  - New Horn design looks OK
  - Long target is also reasonably designed
- **Other design ongoing**
  - Target pile
  - Decay volume
  - Absorber
- **Schedule**
  - 1.2MW (2026) ⇒ 2.4MW (2032)

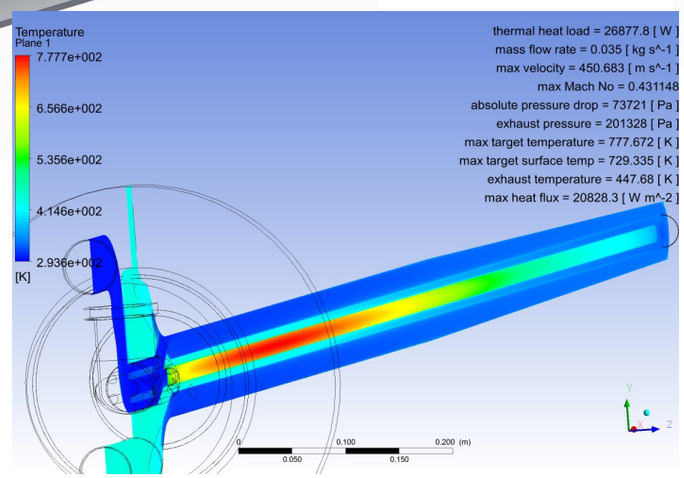


RAL 1.2MW outline target design completed

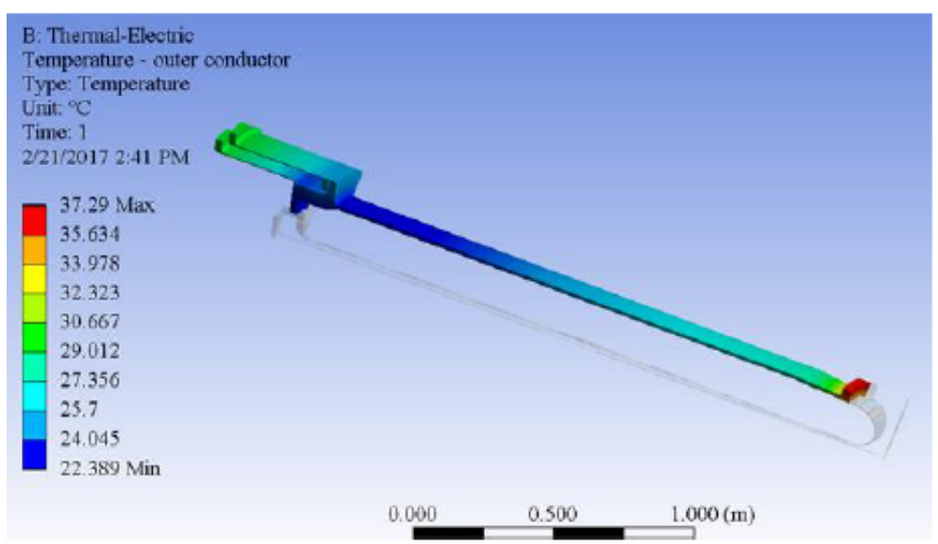


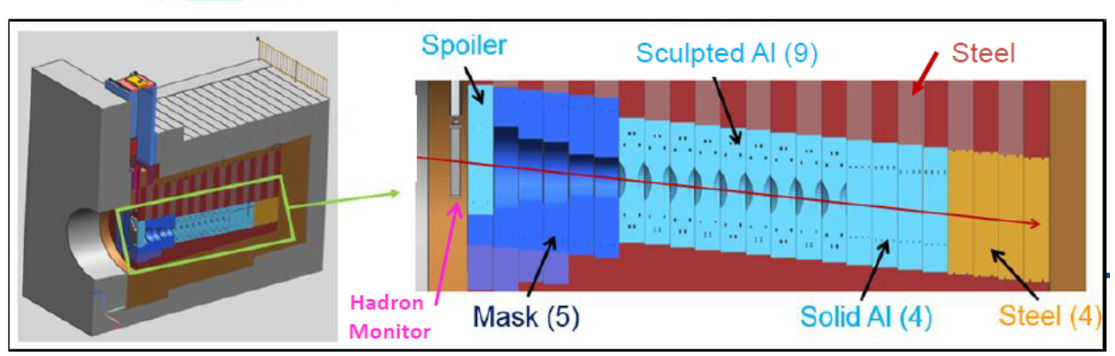
2m+ target must remotely dock into a cooled downstream support





CFD and FEA indicate that with 28kW heat load and 35g/s of helium operating temperature, pressure and stress OK





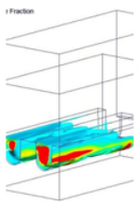
2. Target and Beam Window

- Target and beam window challenges and limits — Tristan Davenne
- RaDIATE Collaboration and Proton Irradiation Campaign at BLIP — Yongjoong Lee
- HiRadMat facility experimental programme — Yacine KADI

2. Target and Beam Window

- Design philosophy for high power targets
  - Many aspects should be considered
  - Challenges on heat transfer (i.e. cooling) and stress T. Davenne
- For future neutrino beamlines (1~2MW)
  - Graphite target scheme can be adopted
  - Although some improvements on cooling are needed
- Unknown factor is radiation damage
  - Necessity for radiation damage studies

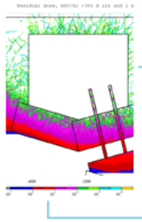
Y.J. Lee


Heat removal


Thermal shock

Physics performance


Radiation damage


Operational safety


Storage and disposal

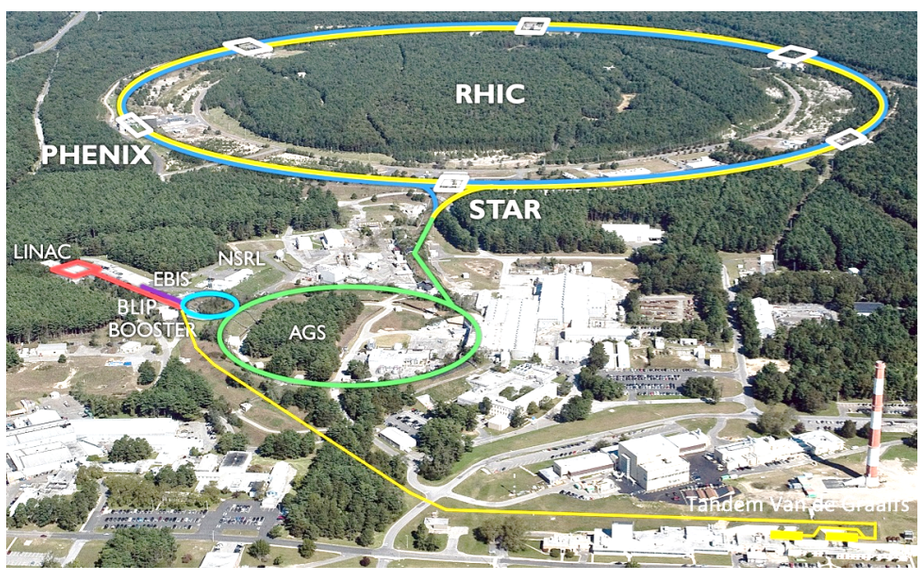
RaDIATE: Radiation Damage Studies

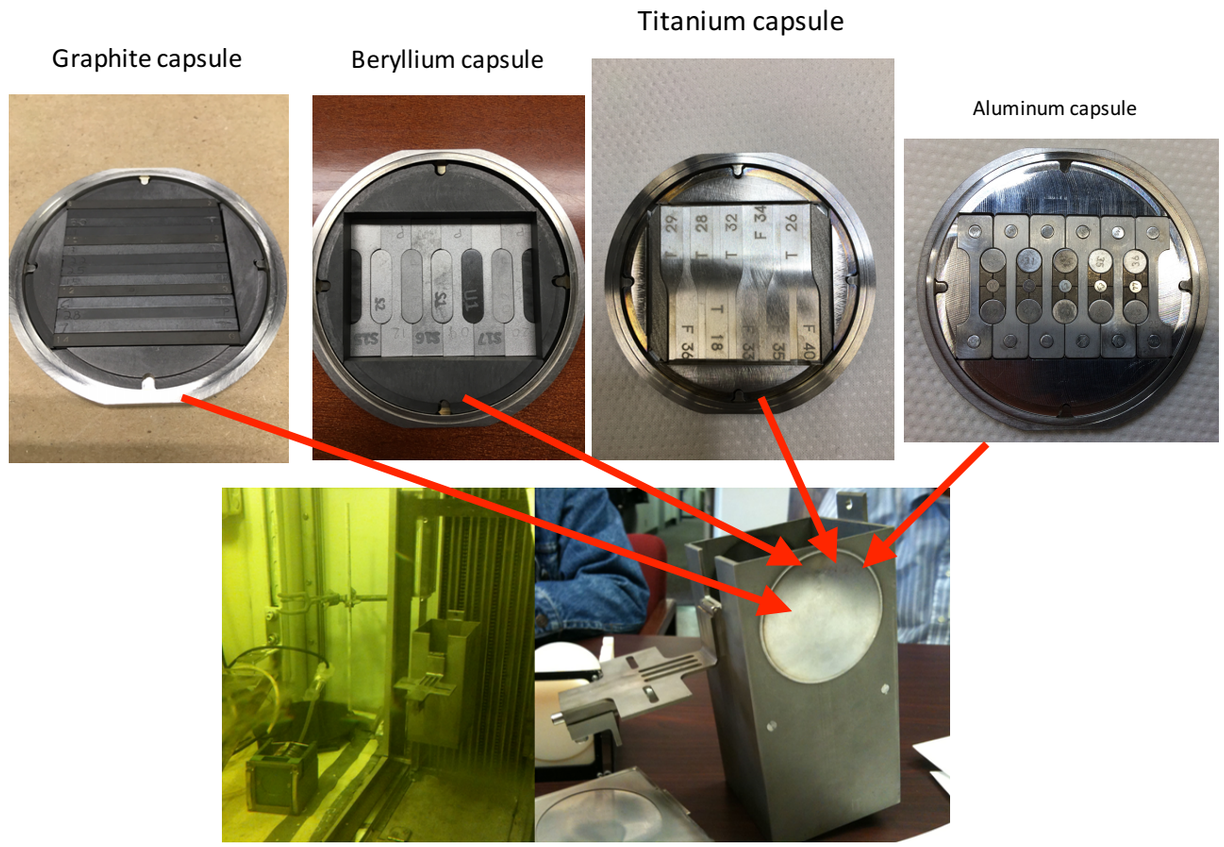
Y.J. Lee

- Material response depends on material properties
  - However, material properties also depend on radiation damage
- Post Irradiation Examination (PIE) is really important
- RaDIATE collaboration studies PIE w/ BLIP @ BNL
  - ~200MeV/c proton beam
  - Material properties after irradiation to be examined
- Many samples (Ti, Be, Graphite, Al, etc) are studied

RaDIATE Collaboration

Radiation Damage In Accelerator Target Environments

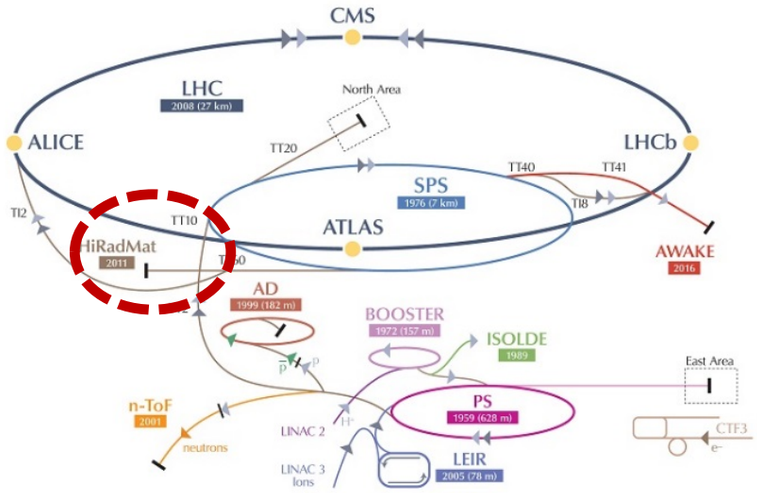


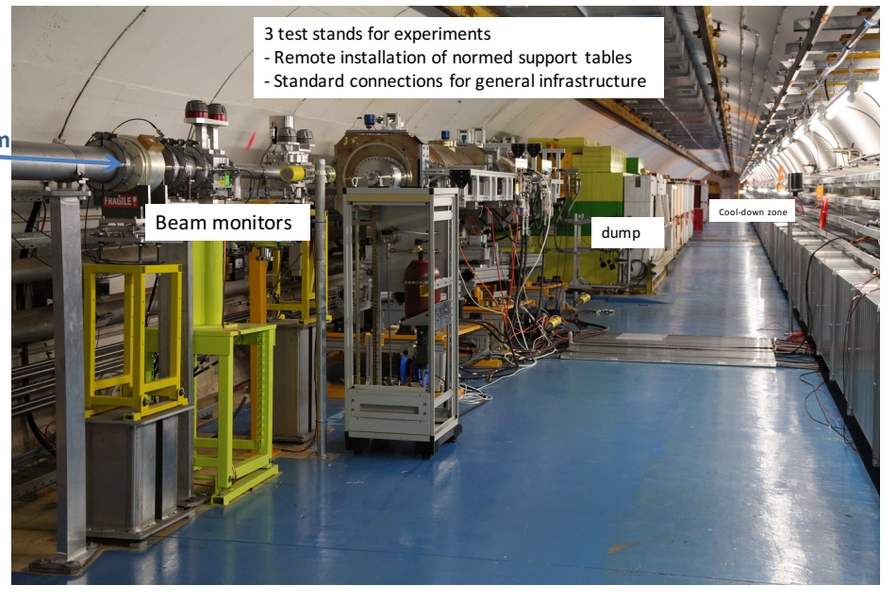


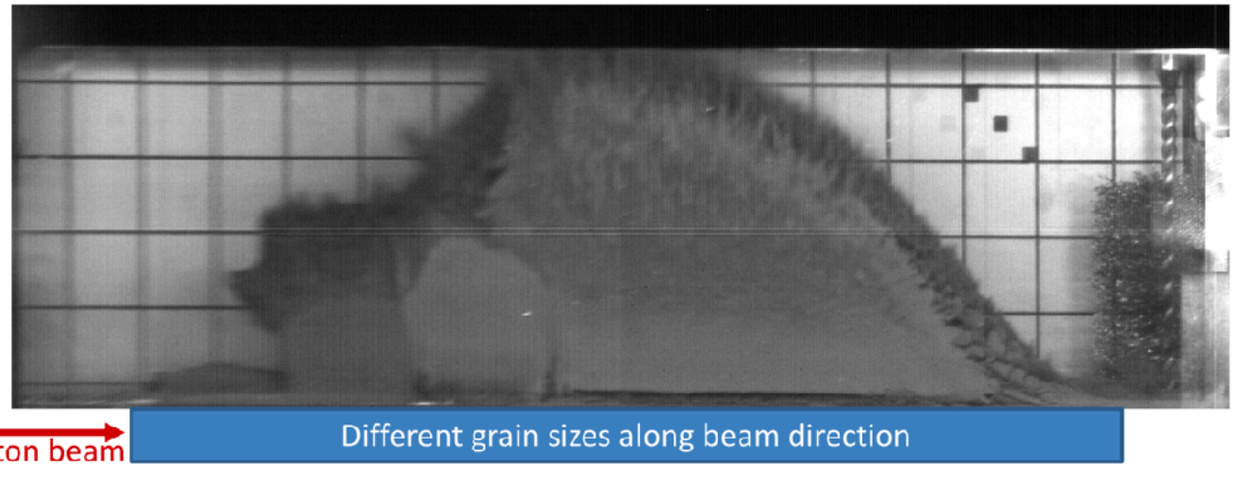
HiRadMat

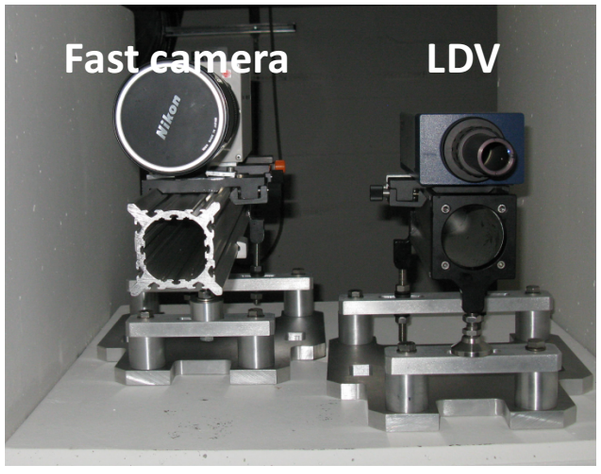
Y. Kadi

- A direct measurement of material response impacted by high intensity beam
  - Can reduce uncertainties of design
- Dedicated experimental area @ CERN
  - 440GeV proton beam : $3x10^{13}$ ppp (max)
  - Many measurement instruments
    - Laser Doppler vibrometer to measure surface velocity
    - High speed camera
- Many experiments performed/planned
  - W powder target









3. Neutrino Factories

- ENUBET: high precision neutrino flux measurements in conventional neutrino beams — Fabio Pupilli
- EMuS in CSNS — Guang Zhao
- Accelerator R&D Toward Proton Drivers for Future Particle Accelerators — Ben Freemire

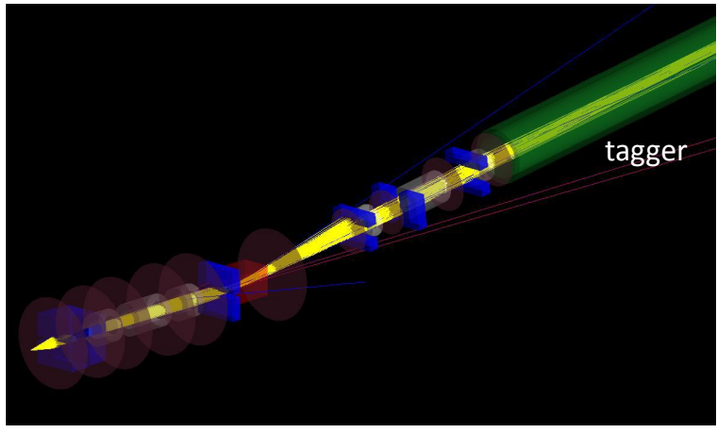
ENUBET

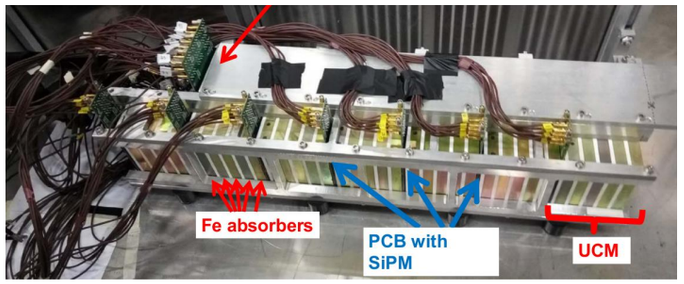
F. Popilli

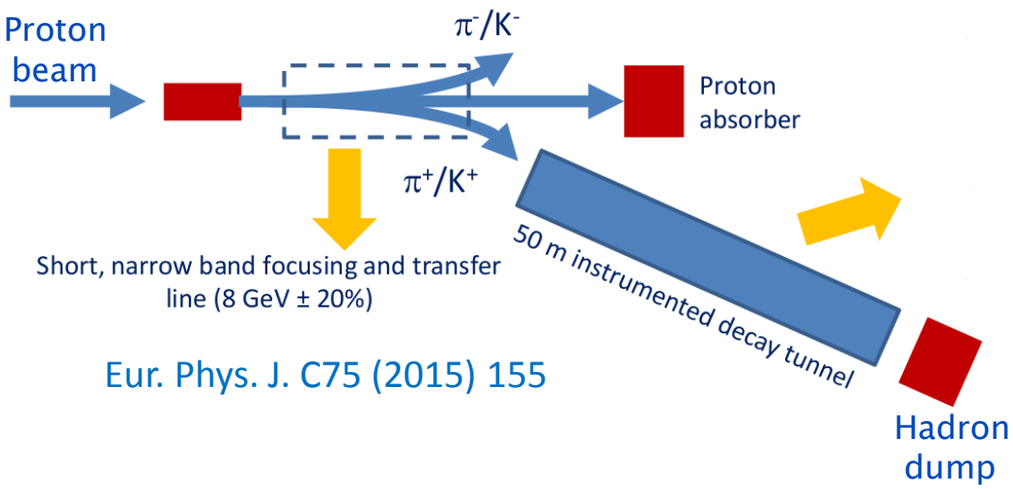
- A pure and precise (O(1%)) ν_e source from Kaon-monitored ν beams
  - Project approved by ERC : 5 year program 2016-2021
- Challenges
  - High rate ~500kHz/cm² and rad. damage
- Many progress on simulation and prototyping
  - Calorimeter performance tested w/ beam

Monitored

- **Fully instrumented** decay region
- $K^+ \rightarrow e^+ \nu_e \pi^0 \rightarrow$ large angle e^+
- **ν_e flux prediction = e^+ counting**







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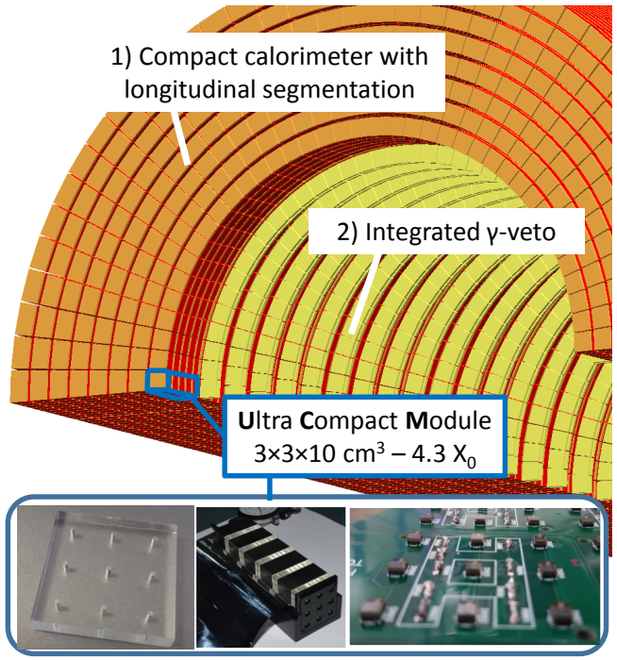
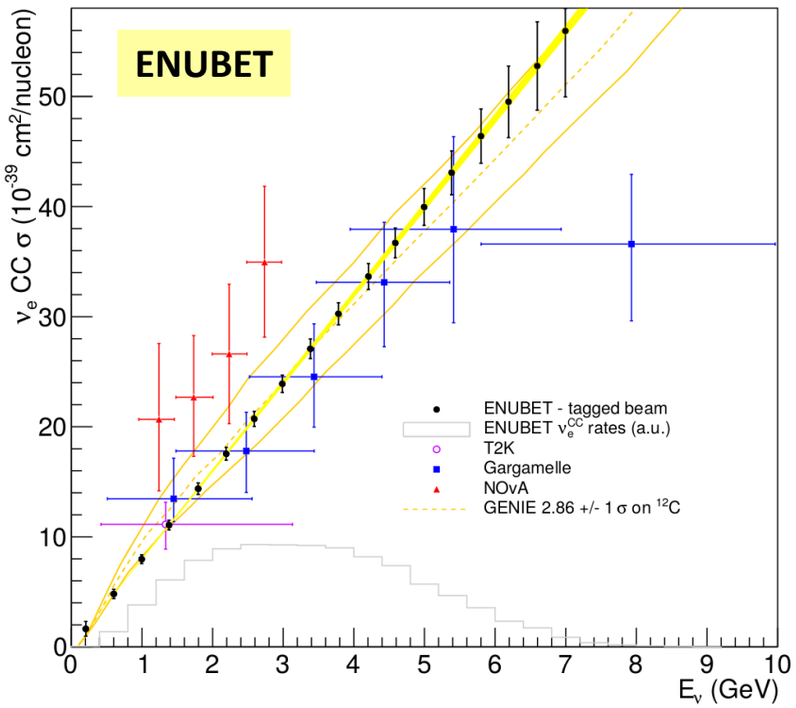


$\sigma(\nu_e)$



1% syst. + 1% stat. (10^4 ν_e^{CC}) **errors**

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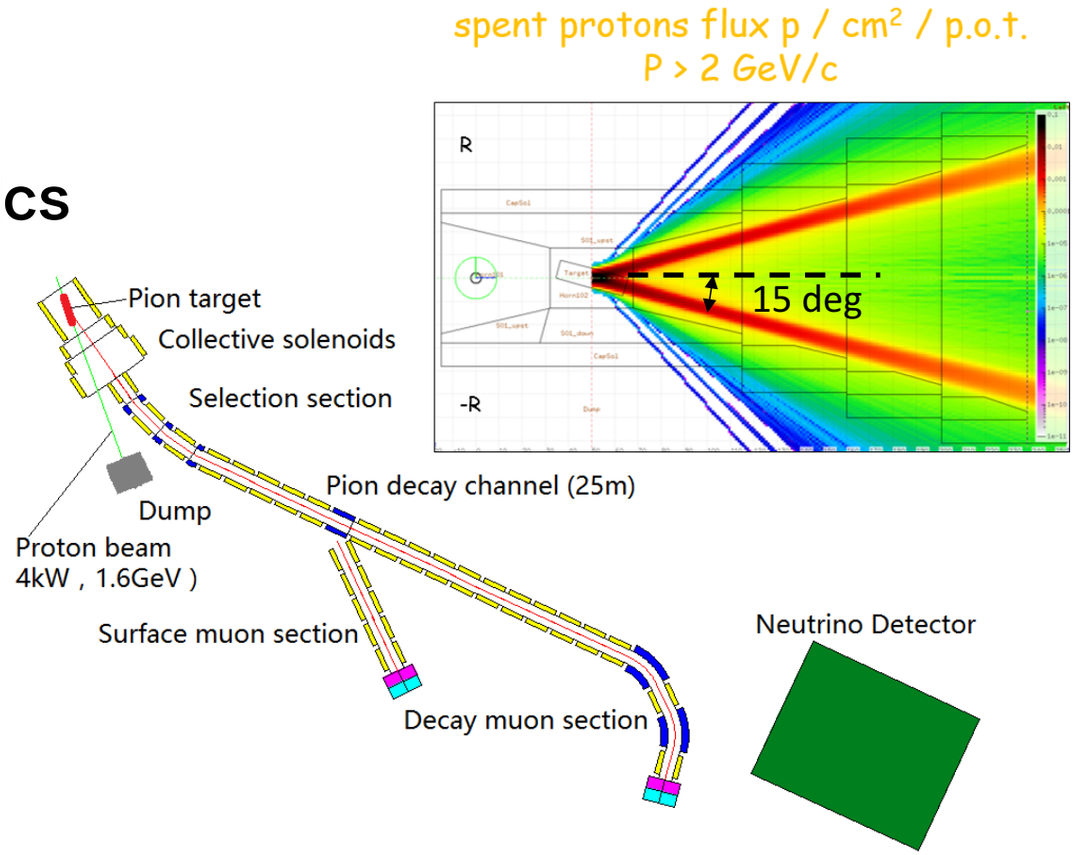
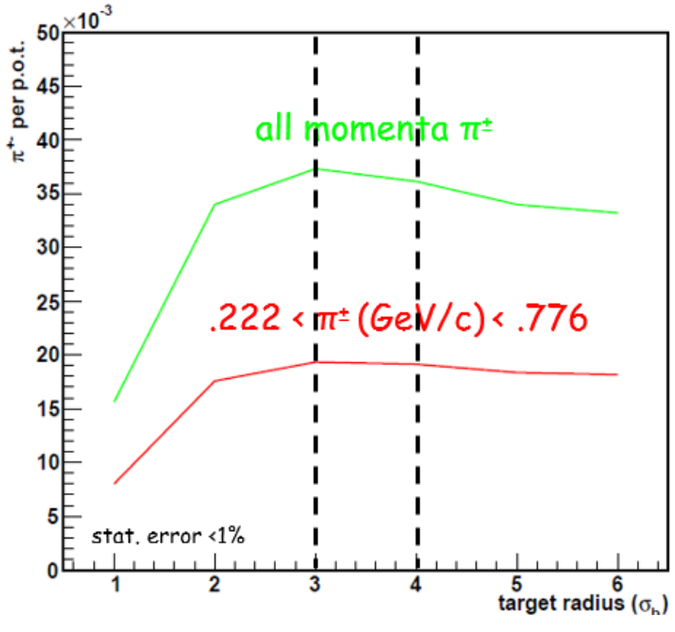
EMuS

G. Zhao

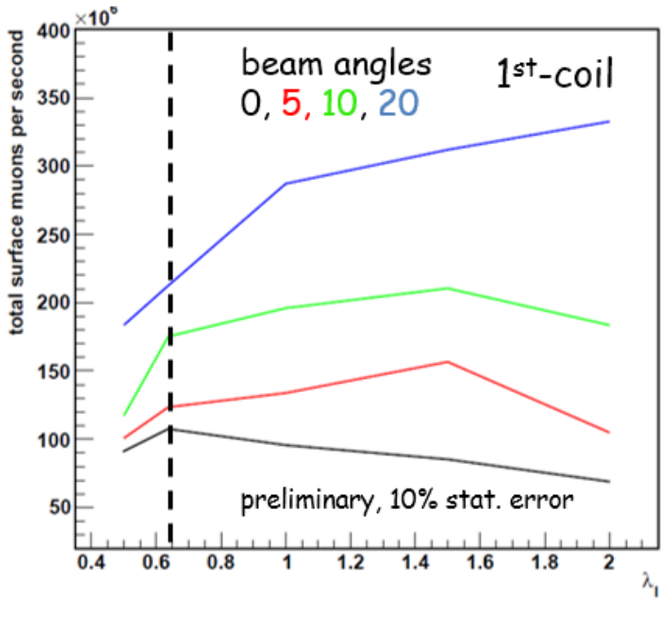
- Experimental Muon Source from CSNS
  - MOMENT R&D, muSR, ν XSEC, Muon physics
  - Design, R&D supported : 2016-2020
- R&D progress
  - Target optimization
    - material, radius, length, beam angle, shape
  - Surface muon optimization
  - Radiation study



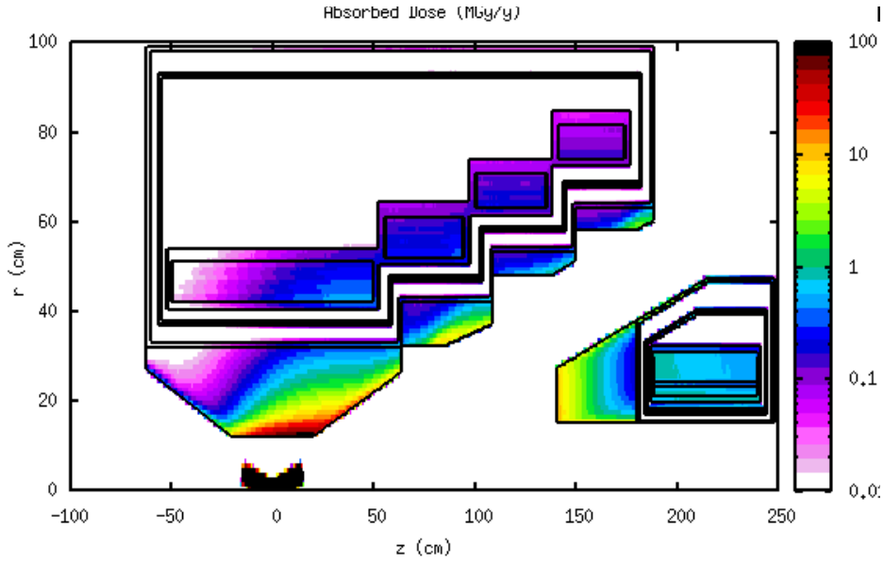
Pion yield vs radius



Muon yield vs length



Absorbed dose (MGy/y) in Al

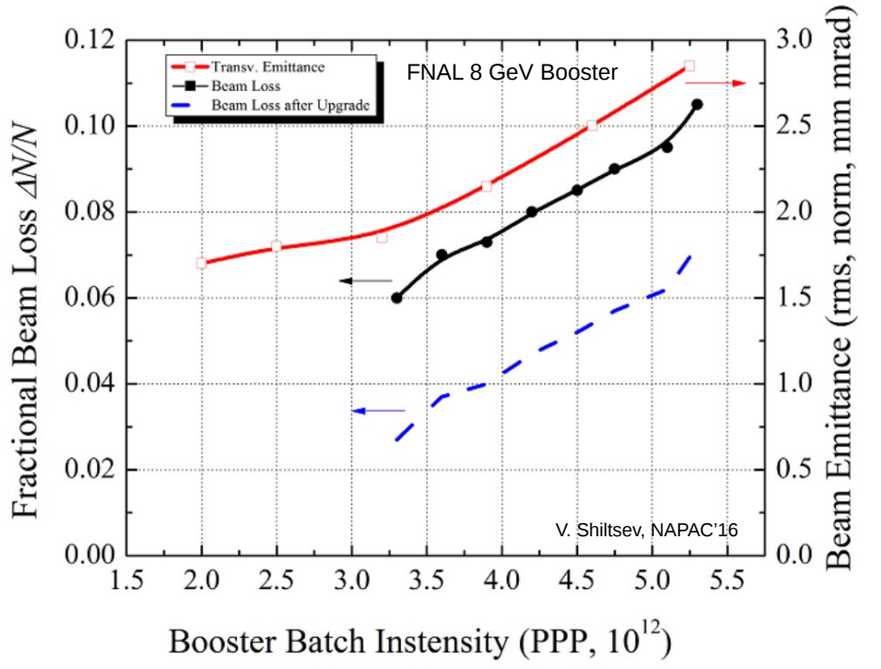


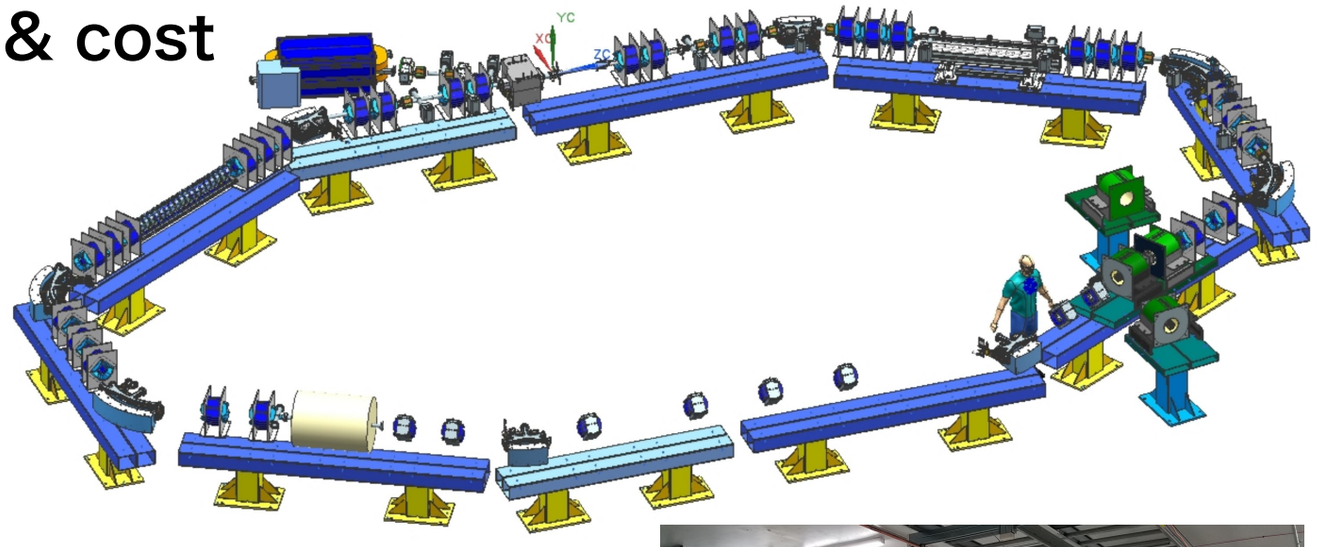
Max dose in CS: 1.0 MGy
Max dose in MS: 1.1 MGy

Accelerator R&D

B. Freemire

- Accelerator upgrade toward >2MW needed for LBNF/DUNE
- Challenges
  - Reduction of beam loss is key ⇒ space charge effect is limiting factor
- IOTA
  - Dedicated ring based accelerator test facility
  - To study performance increase & cost reduction
- Schedule
  - Installation till summer 2018
  - Electron exp. 2018~2019
  - Proton exp. 2019~2020





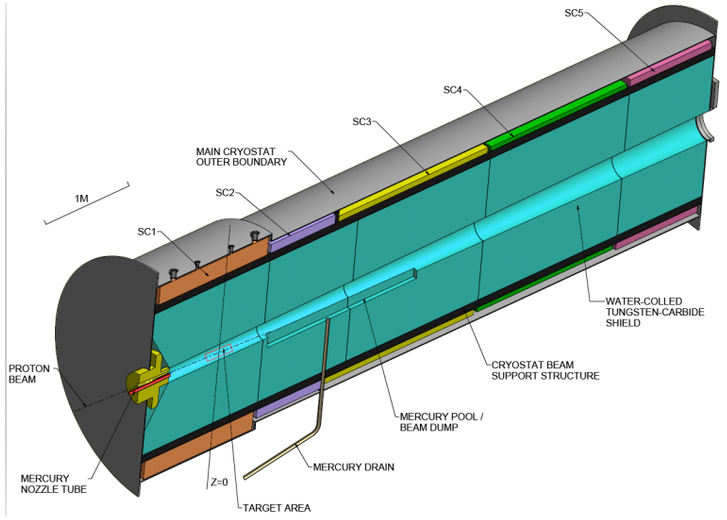
4. Future Machines

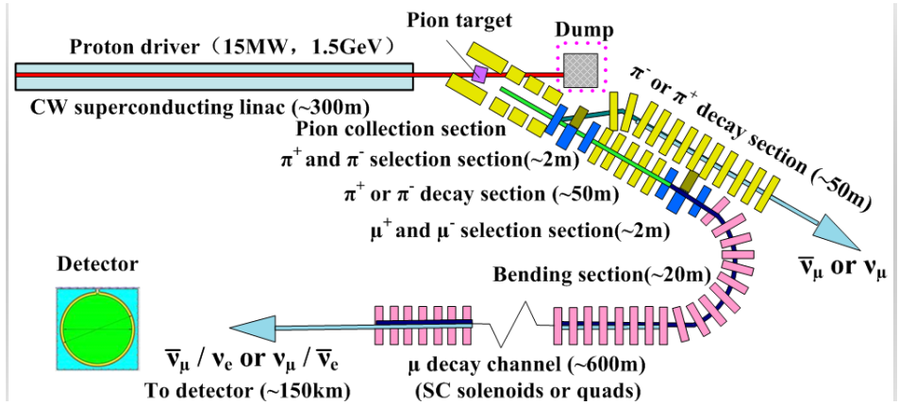
- Update on MOMENT's Target Station Studies — Nikolaos Vassilopoulos
- Towards nuSTORM facility - overview of accelerator design — Jaroslaw Pasternak

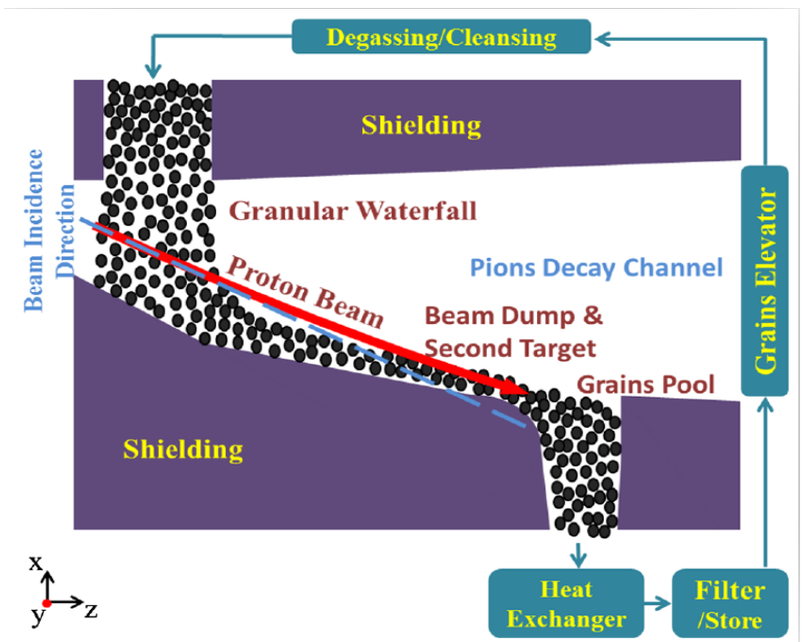
MOMENT

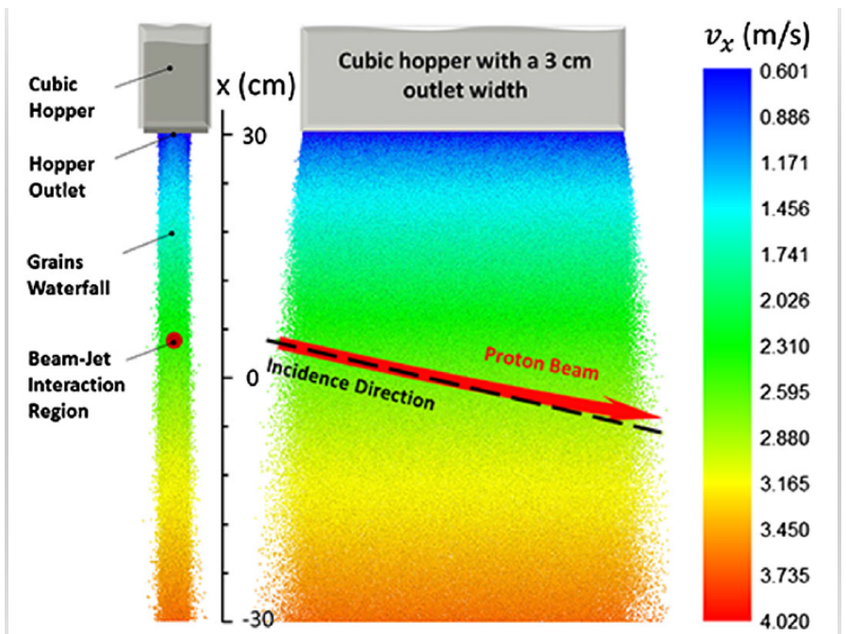
N. Vassilopoulos

- SC-based pion capture
  - Hg-jet target ⇒ optimization performed
  - W granular waterfall as other option
    - Simulation studies for optimization
    - Comparable muon yield can be adopted





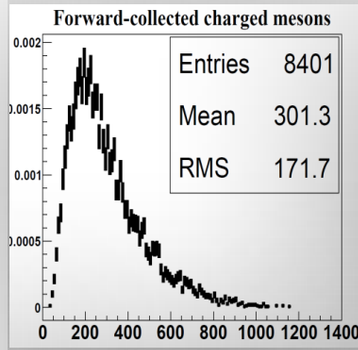


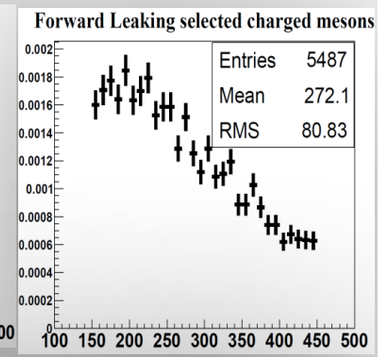


Collected Muons

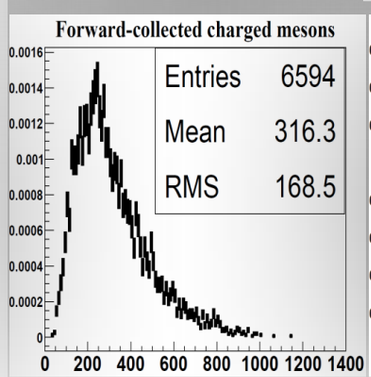
P (GeV/c) > 0 | 150 < P (GeV/c) < 450

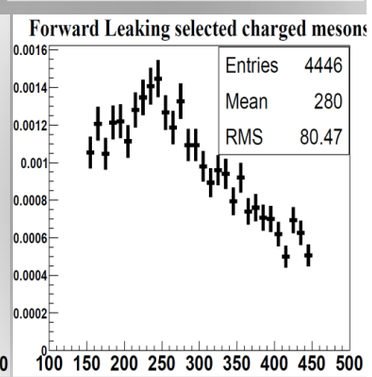
Hg Jet





Granular Waterfall





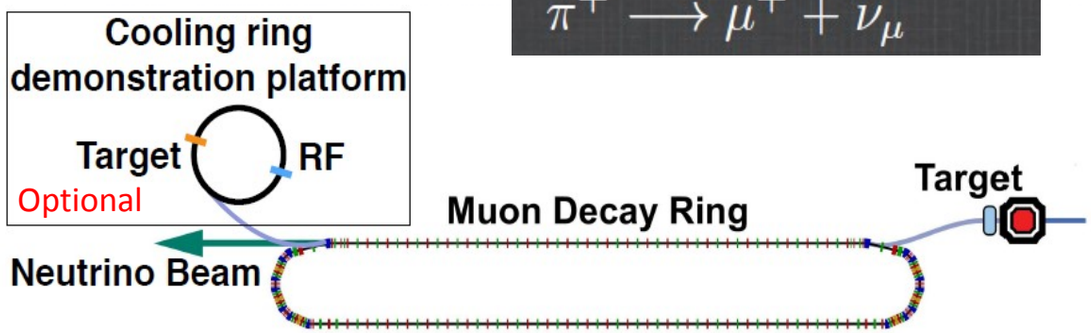
Muon yield: ~20% less
Averaged energy: higher

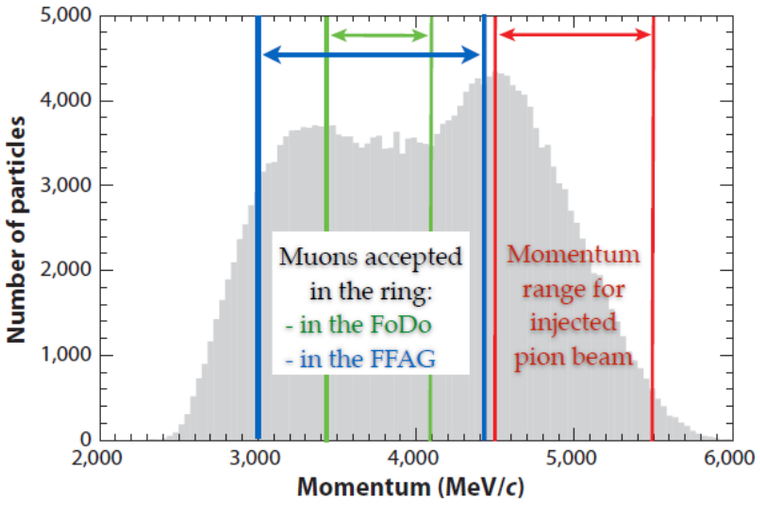
nuSTORM

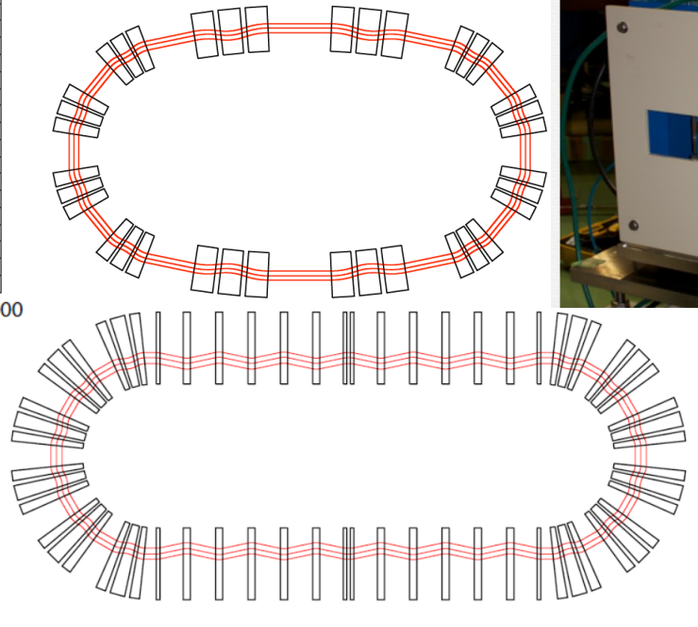
J. Pasternak

- Motivation
  - Muon beams for precision neutrino physics
  - Sterile neutrino search
  - Accelerator&detector technology test bed
- FFAG for muon decay ring
  - Larger momentum acceptance
  - Optics design studies ongoing
- Aiming for implementation at CERN

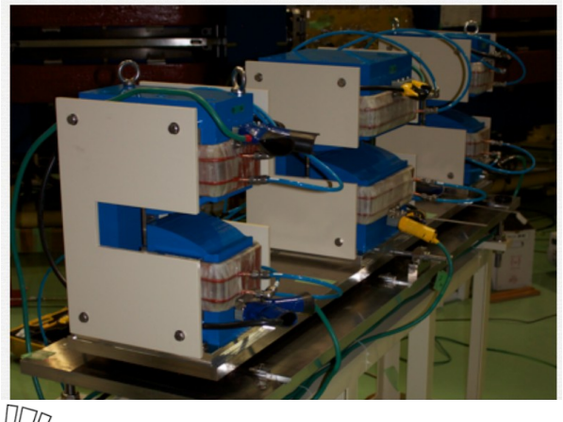
$$\mu^- \longrightarrow e^- + \bar{\nu}_e + \nu_\mu$$
$$\mu^+ \longrightarrow e^+ + \nu_e + \bar{\nu}_\mu$$
$$\pi^- \longrightarrow \mu^- + \bar{\nu}_\mu$$
$$\pi^+ \longrightarrow \mu^+ + \nu_\mu$$



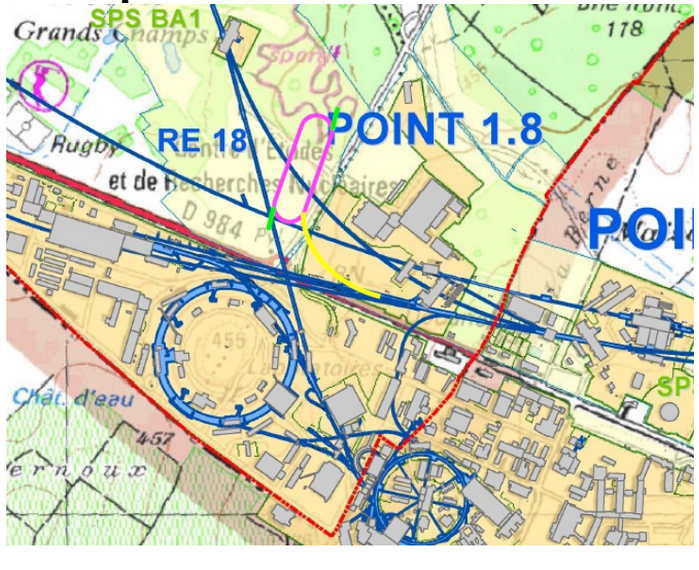




Straight scaling FFAG:
FFAG cell with no overall bend.

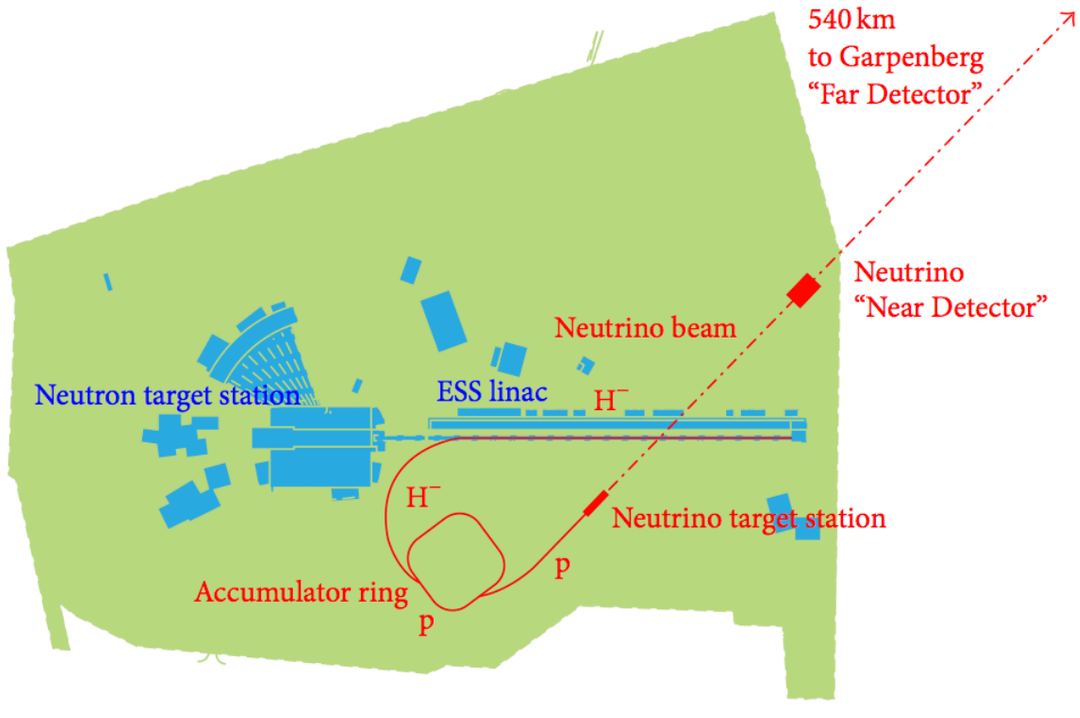


A possible site @ CERN



5. EuroNuNet

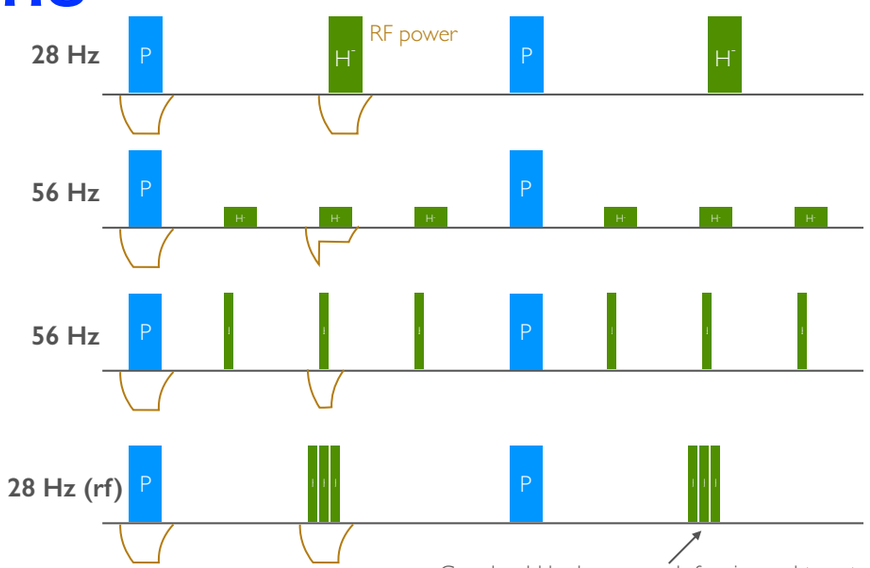
- Status of the ESS Project — Mats Lindroos
- The ESS Linac and Upgrades for the Neutrino Facility — Mohammad Eshraqi
- The ESSnuSB Accumulator — Elena Wildner
- The ESSnuSB Switchyard, Target Station, and Facility Performance — Eric Baussan



ESS Linac and Accumulator

- Linac upgrade needed for neutrino beams
  - 5MW beam (n) ⇒ 5MW (n) + 5MW (ν)
  - H- injection & stripping for ν beams
  - Increase RF frequency 14Hz ⇒ 28 or 56 Hz
- Accumulator **E. Wildner**
  - Pulse length 2.8ms ⇒ ~1 μs for horn ope.
  - Optics simulation performed
  - H- stripping
    - Foil stripping can be OK (temp. ~1700K)
    - Laser stripping under study

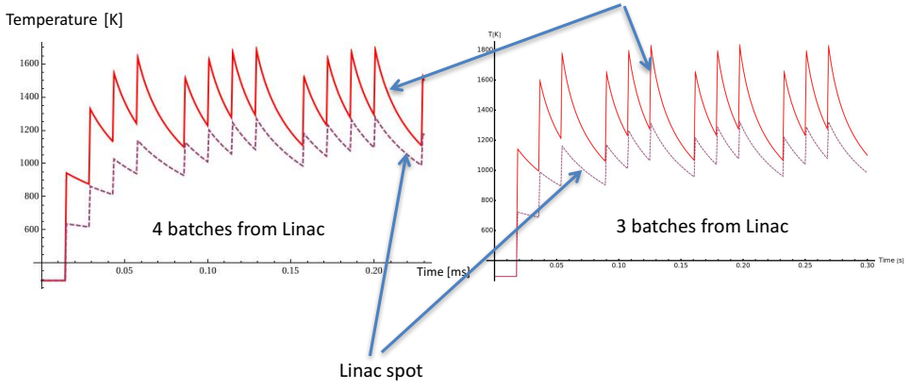
M. Eshraqi

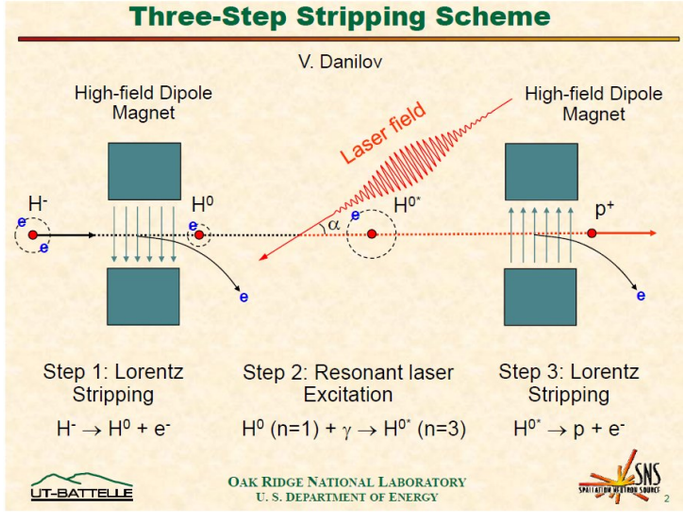


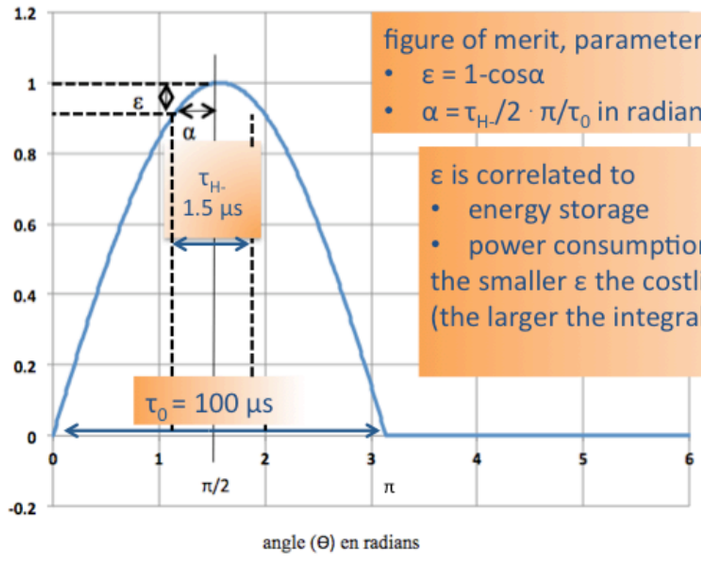
Temperature on foil

Horst Schönauer

Combined linac spot and circulating beam





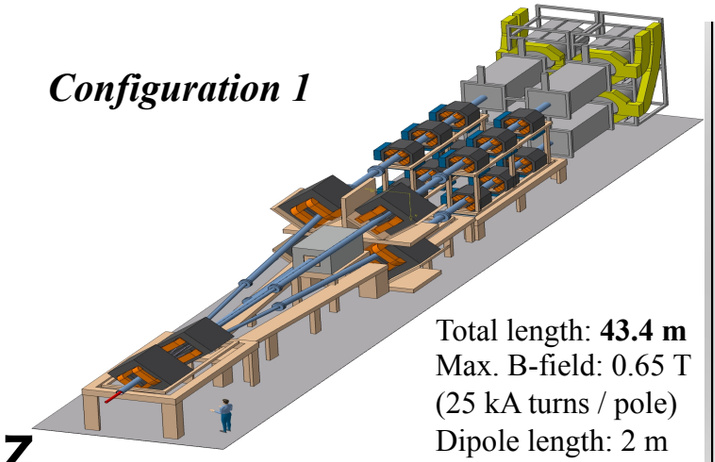


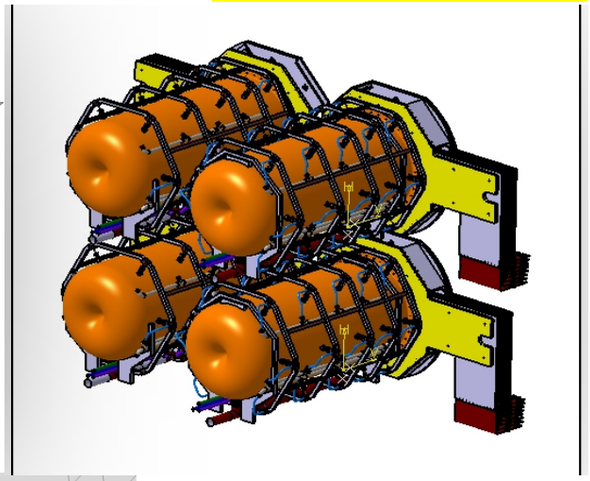
Switchyard, Target Station, Facility Performance

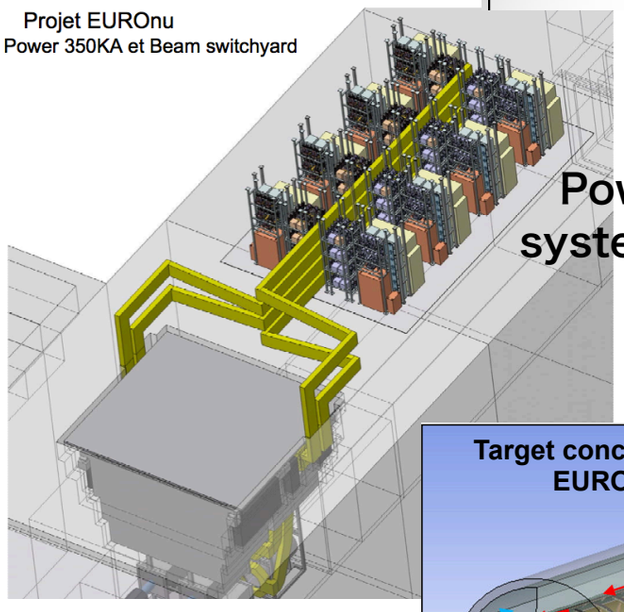
E. Baussan

Conceptual design done

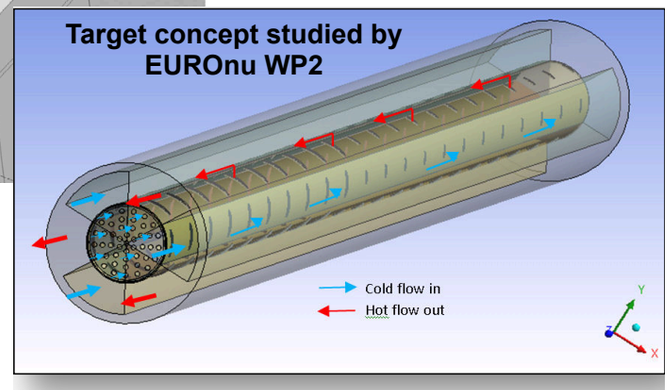
- Switchyard
  - Divide into 4 beams
- 4-in-1 magnetic horns
  - Each operated at 350kA/17.5Hz
  - Temp/stress analysis performed
- Packed Bed Target
  - Ti sphere (d=3mm)
  - Each target receives 1.25MW beam
  - Max temp < 673℃ (M.T. 1668℃)
- Target Station facility design
- To be updated in near future

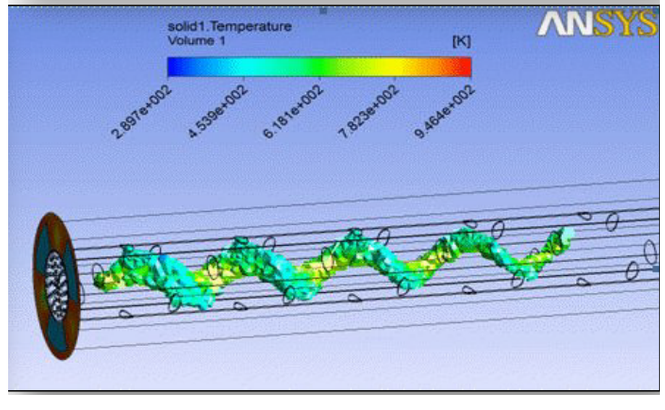


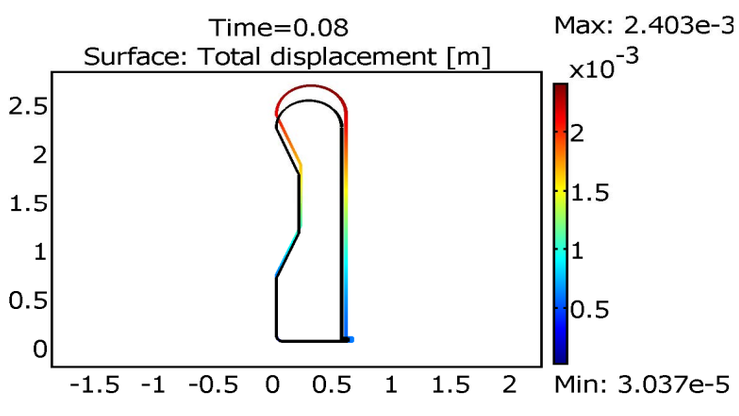




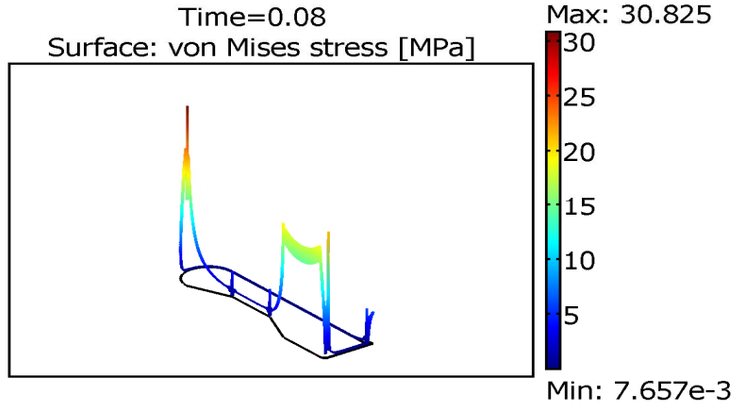
Power supply system for horns







a) $u_{max} = 2.4$ mm, $t = 80$ ms



b) Von Mises stress $s_{max} = 30.$ MPa, $t = 80$ ms

6. MICE

- The MICE Experiment : Status and Prospects — Jaroslaw Pasternak
- Recent Results from MICE on Multiple Coulomb Scattering and Energy Loss — John Nugent
- Recent Results from the Study of Emittance Evolution in MICE — Christopher Hunt
- Measurement of Phase Space Density Evolution in MICE — Francois Drielsma

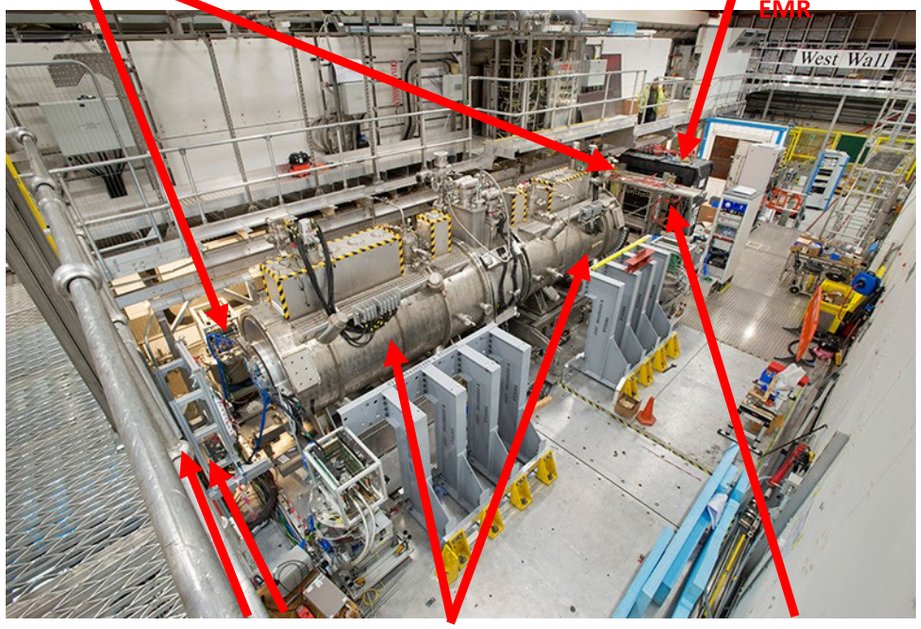
MICE Overview

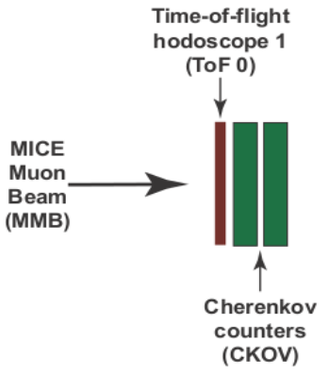
J. Pasternak

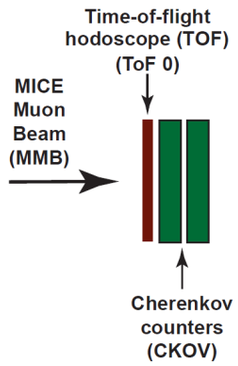
- Muon ionization cooling for ν factory/muon collider
  - to reduce muon beam emittance before acceleration
- Muon Ionization Cooling Experiment (MICE)
  - Emittance measurement
  - Multiple scattering measurement
    - LiH data taking ⇒ LH_2 started
  - RF cavities and some upgrades

What is Muon Ionization Cooling?

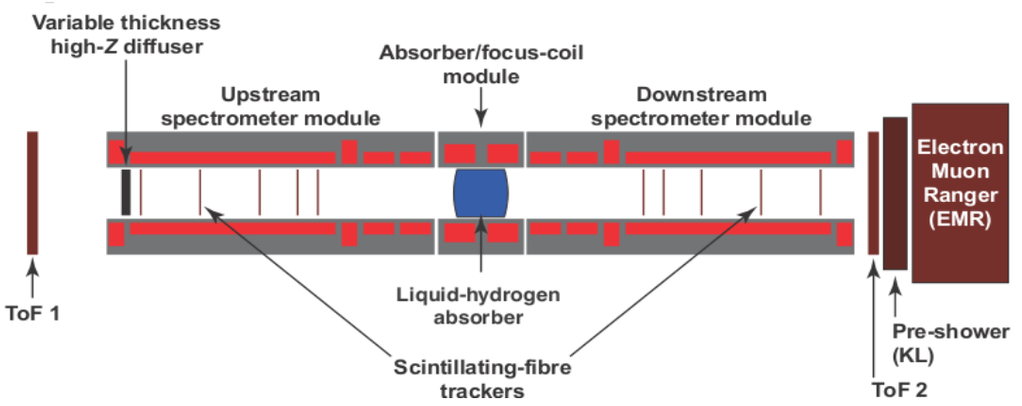
The Detectors

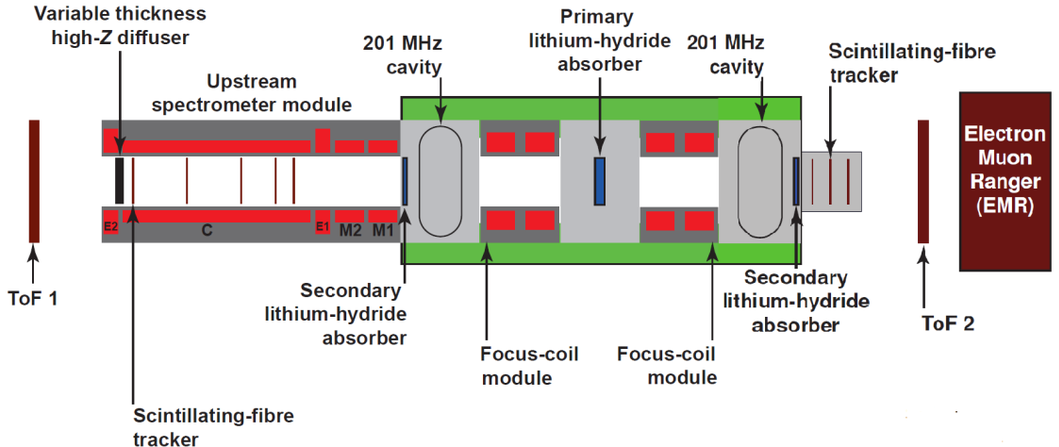






MICE



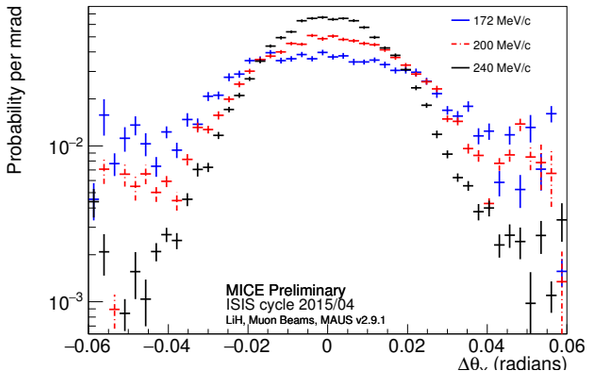


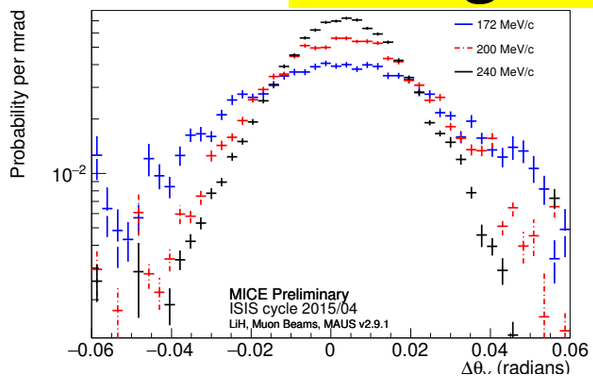
MICE Results

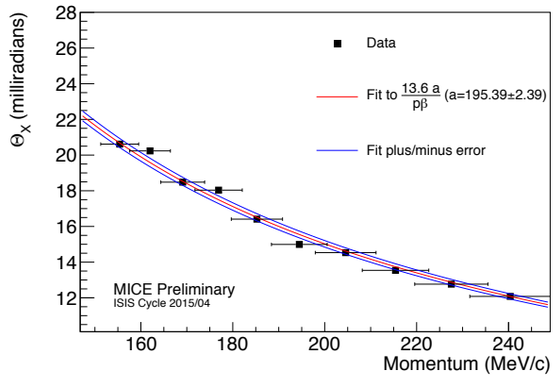
Multiple scattering measurement

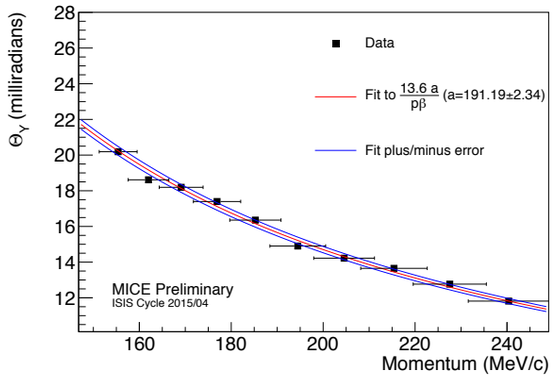
J. Nugent

Preliminary MICE result





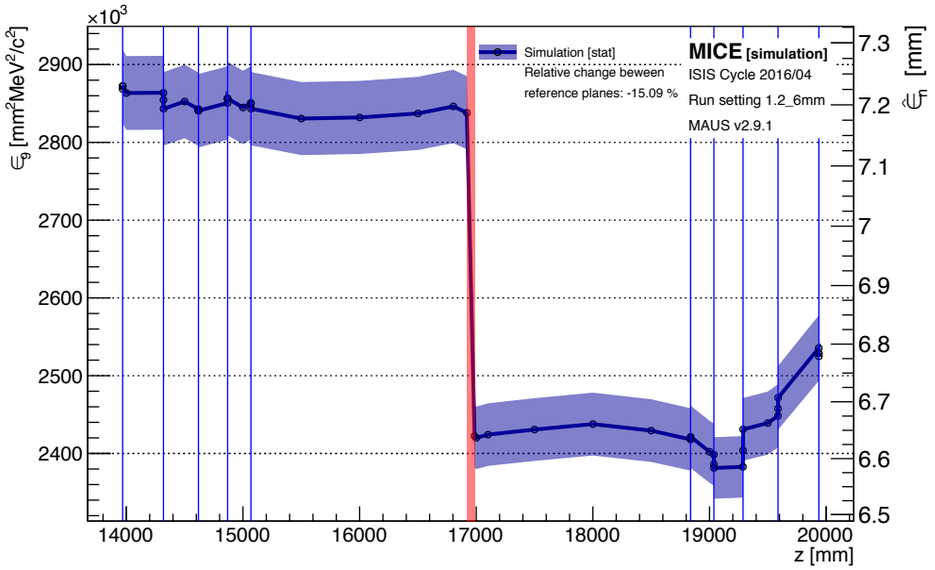




Phase space evolution measurement

F. Drielsma

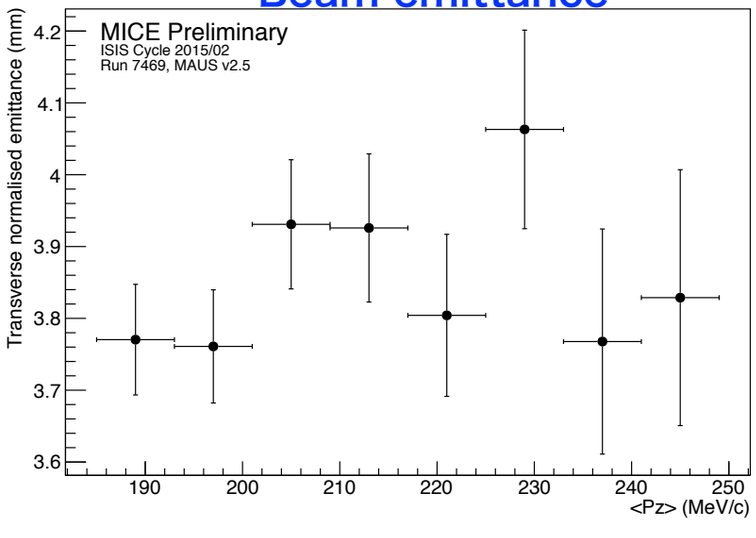
Phase space volume evolution



Emittance measurement

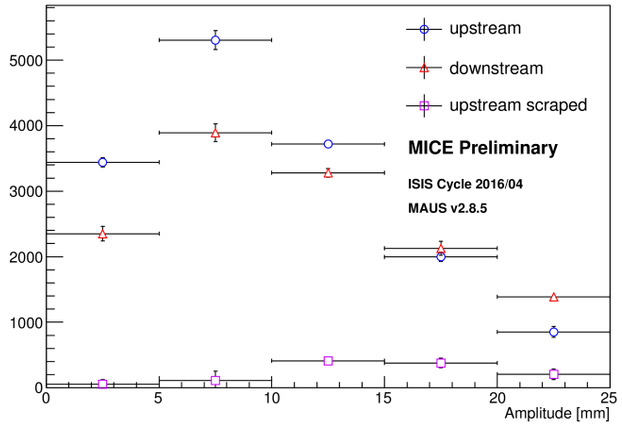
C. Hunt

Beam emittance



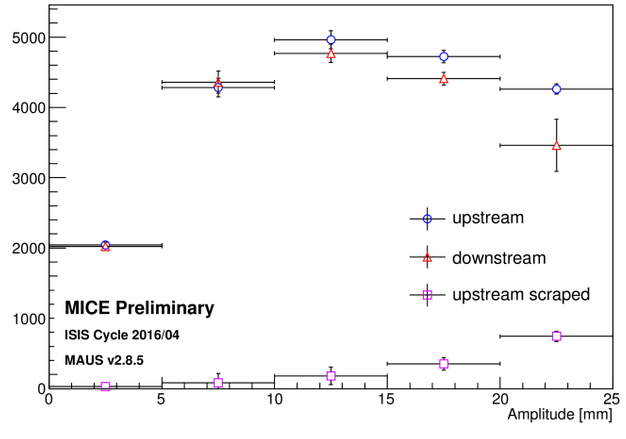
Emittance evolution via absorber

Nominal 3mm Beam



Consistent with emittance increase/heating.
Core density decrease.

Nominal 6mm Beam



Consistent with equilibrium emittance.
No change in core density.

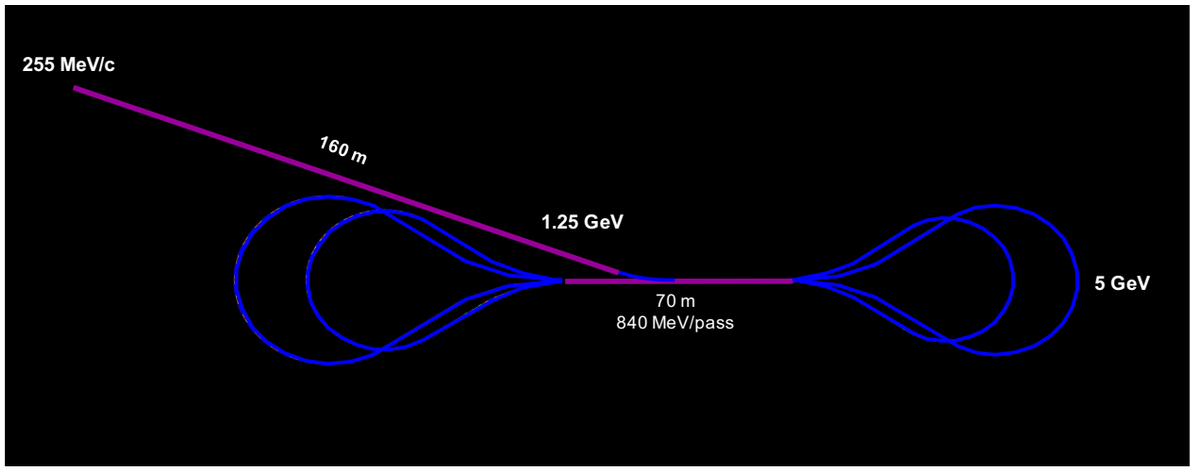
7. Muon Beam Facility (joint w/ WG4)

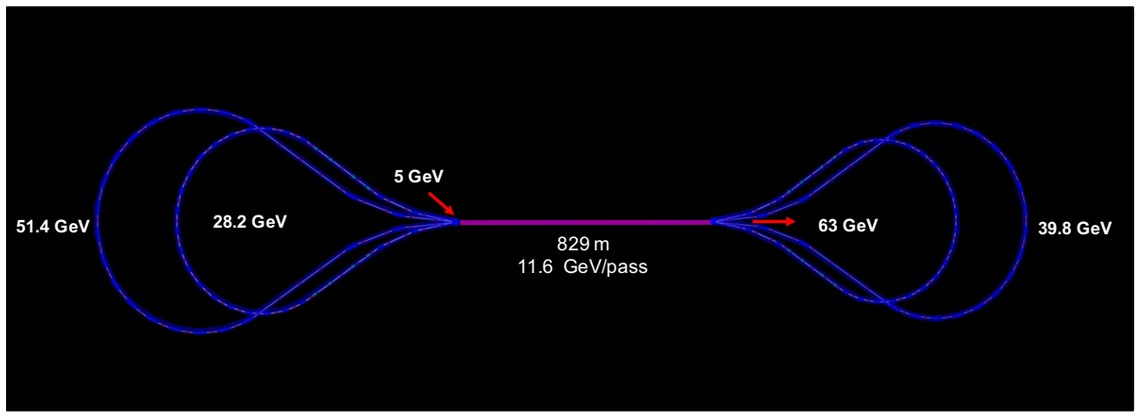
- The high-intensity muon beam line (HiMB) project at PSI — Andreas Knecht
- muCool : A novel high-brightness low-energy muon beam — Ivana Belosevic
- Muon Acceleration : Neutrino Factory and Beyond — Alex Bogacz
- Low Emittance Muon Beams from Positrons — Francesco Collamati

Muon Acceleration

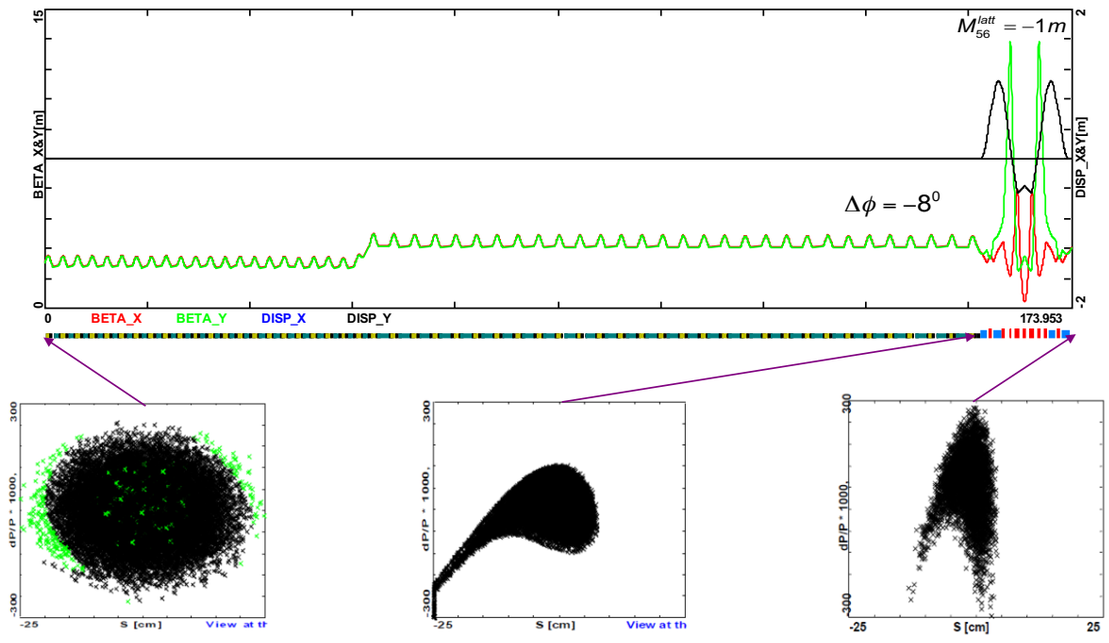
A. Bogacz

- 5GeV Neutrino Factory based on multi-pass Dogbone RLA
  - Linac (255MeV-1.25GeV) Longitudinal compression
  - Delay/Compression Chicane - Transition from 325 to 650 MHz SRF
  - RLA (1.25-5GeV) 4 droplet Arcs and multi-pass linac
- Optimized RLA scheme for Higgs Factory and beyond
  - RLA with multi-pass arcs (~63GeV)
  - TeV scale acceleration - Rapid Cycling Synchrotrons





Longitudinal compression



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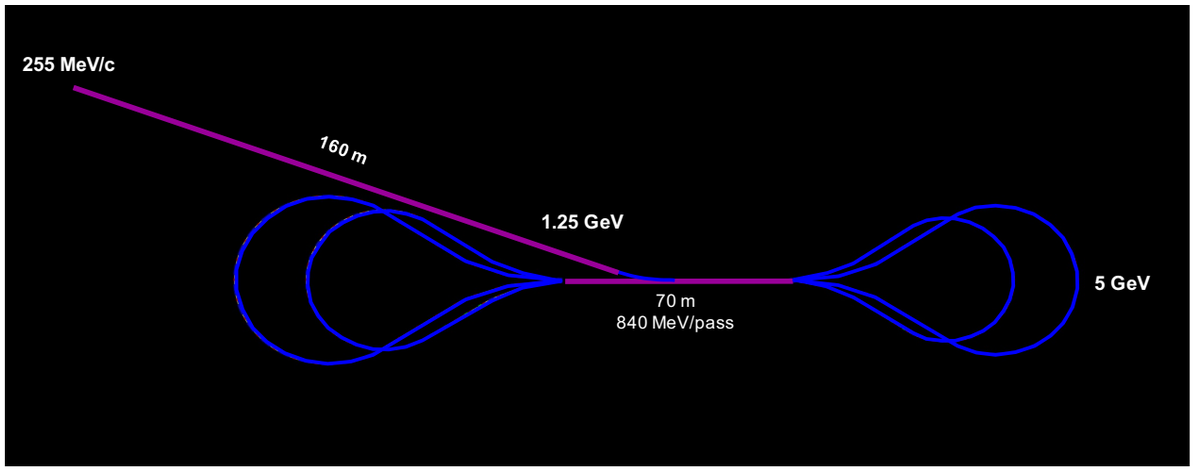
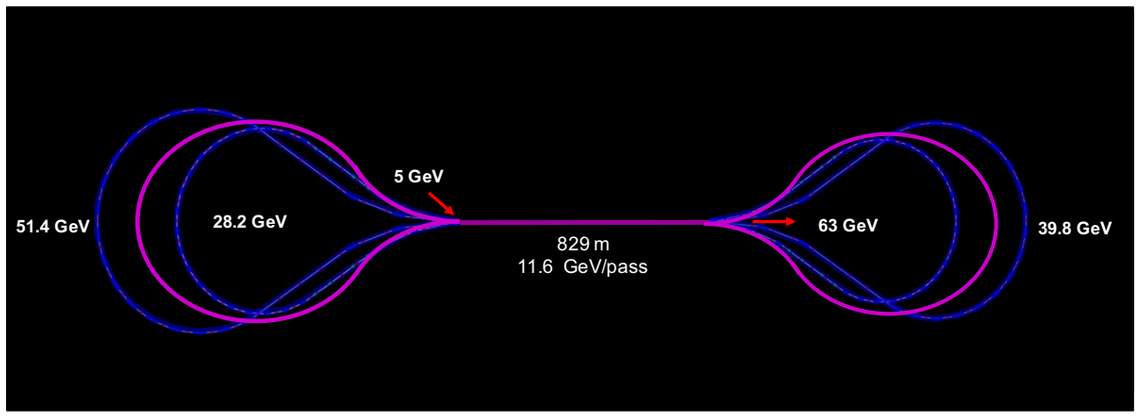
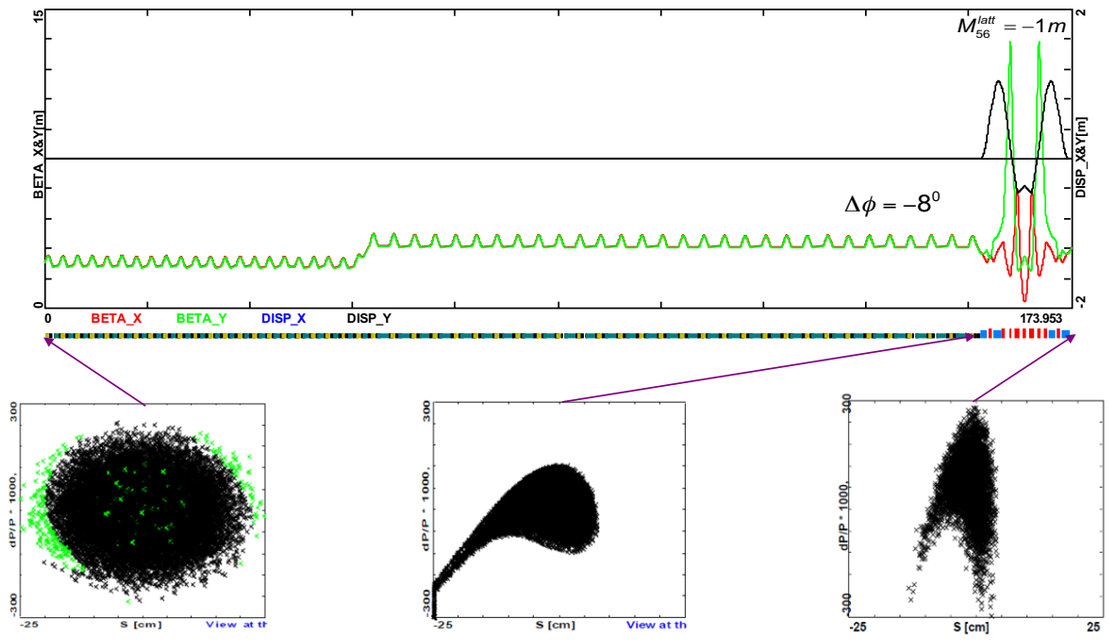




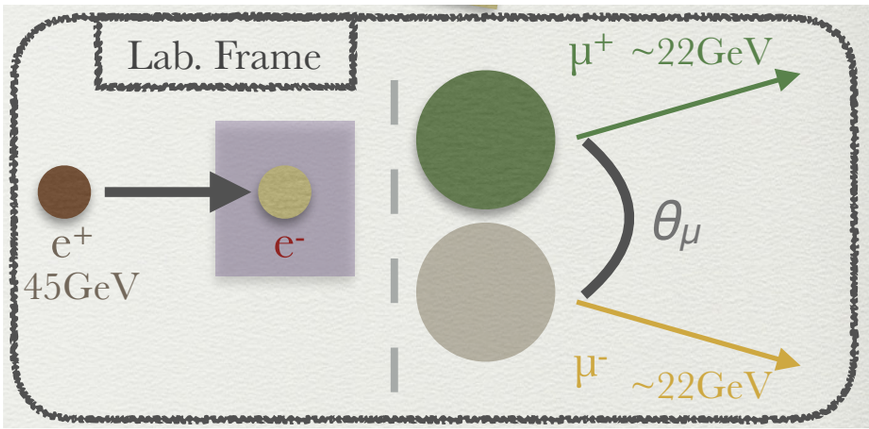
Longitudinal compression

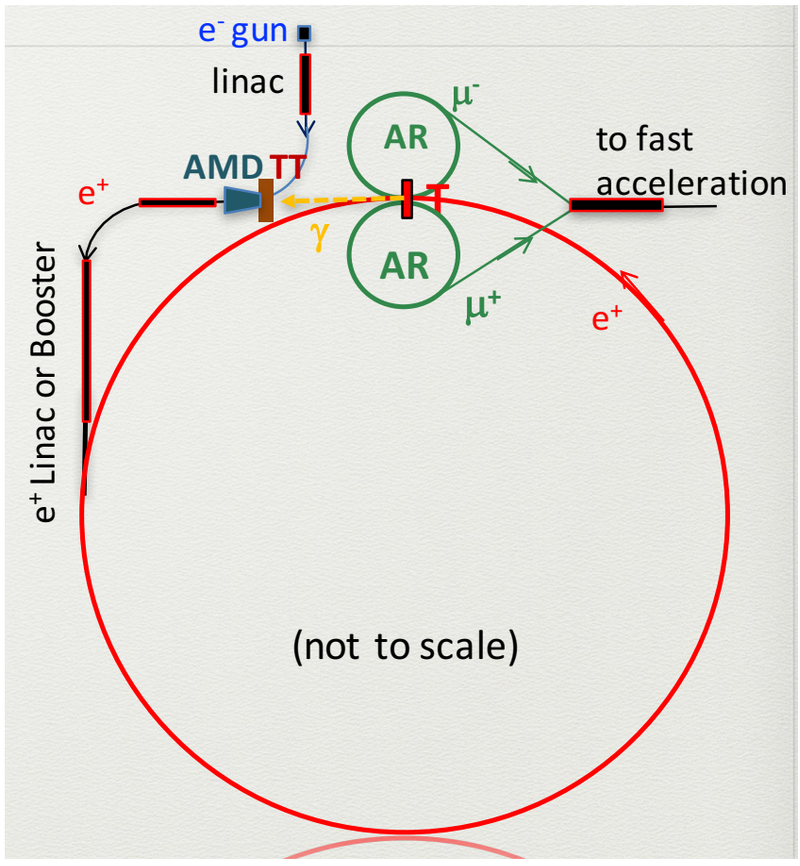


Low Emittance Muon Beams from Positrons

F. Collamati

- Muon beams from $e^+e^- \rightarrow \mu^+\mu^-$
  - Low emittance, small energy spread, low background, reduced loss
  - Rate is small
  - Target choice (material, length) studied
- Parameters
  - 45GeV e^+, 3x$10^{11}$$e^+$/bunch, 6.3km ring
  - $\mu^+\mu^-$ rate : 9x10^{10} Hz
  - Emittance : 40nm
- First design done
  - Preliminary studies are promising
  - Optimization needed





Questions

Questions from NuFact'16

- Target/Capture:
  - Will a fluidized or granulated target work?
    - Simulations are encouraging for granulated target (not as efficient as Hg jet, but more environmentally friendly).
    - Proposal for experimental studies to be submitted in 2018.
- Are systems envisioned for Muon Colliders still relevant?
  - Producing multi-MW beams and targets capable of handling them are still challenging (e.g. LBNF, J-PARC, MOMENT).

Questions from NuFact'16

- MICE:
  - Do we understand how measurements of multiple scattering and emittance reduction in MICE factor into the design of a muon cooling channel?
    - Confirmation of scattering models looks good, and first emittance data collected. Improved scattering models allow more accurate simulation results, and confirmation of emittance reduction, i.e. demonstrating ionization cooling is an important milestone!
  - Is a muon cooling experiment after MICE needed, and what scope would such an experiment entail?
    - Current MICE scope does not include re-acceleration (i.e. full ionization cooling demonstration), so an extension/addition that would include 6D cooling is desirable.

Questions from NuFact'16

- nuSTORM:
  - Is a nuSTORM-like ring with a wider momentum range possible, and what is the performance?
    - Momentum acceptance of FFAG concept larger than FODO concept; performance looks good.
- How would you do nuSTORM at CERN?
  - Study ongoing for siting at CERN as part of the Physics Beyond Collider program; report planned ~2018.

Questions from NuFact'16

- Other topics:
  - Should there be room to further improve slow extraction efficiency in high power synchrotrons, which is important for muon physics experiments and fixed target sterile neutrino searches (such as ShiP)?
    - No progress reported at this workshop; pass to next NuFact.
- Are cooling schemes other than ionization cooling (e.g. e^+e^- annihilation) well enough developed to be convincing?
  - Preliminary studies of direct muon production from e^+ on target (e^-) are encouraging. Optimization studies of parameters underway.

Questions for NuFact'18

- What is the status of accelerator upgrades for the major accelerator based neutrino experiments in the Americas, Asia, and Europe?
- Can targets in the range of 5+ MW be made of solid materials, or are granular/liquid targets required?
- Are requirements for target stations (handling, shielding, cooling, etc.) well understood and possible to fulfill?
- How are measurements of flux progressing and contributing to ongoing/future neutrino experiments?

Questions for NuFact'18

- How is the problem of space charge and beam loss in high intensity proton machines being addressed?
- Is nuSTORM needed as a complimentary program to the future planned accelerator based neutrino facilities, and is the design deemed affordable?
- What is the status of the accelerator upgrades needed to build a neutrino beamline at ESS?
- Has MICE reached a satisfactory conclusion, and how do the results fit into the accelerator based neutrino beam landscape?