Overview of the US Accelerator Based HEP Programs — PIP-II & Muon Accelerator Program (MAP) and LBNL's R&D Progress

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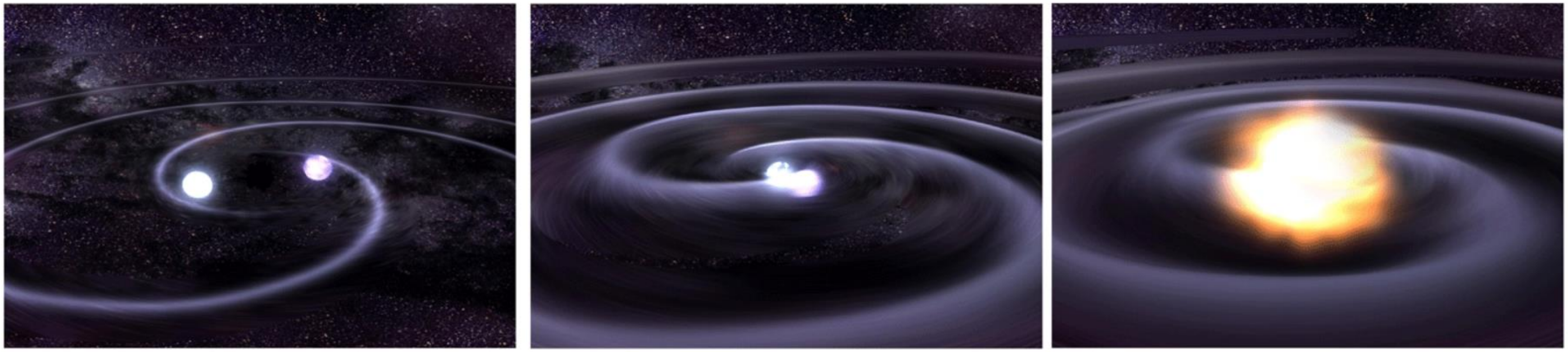
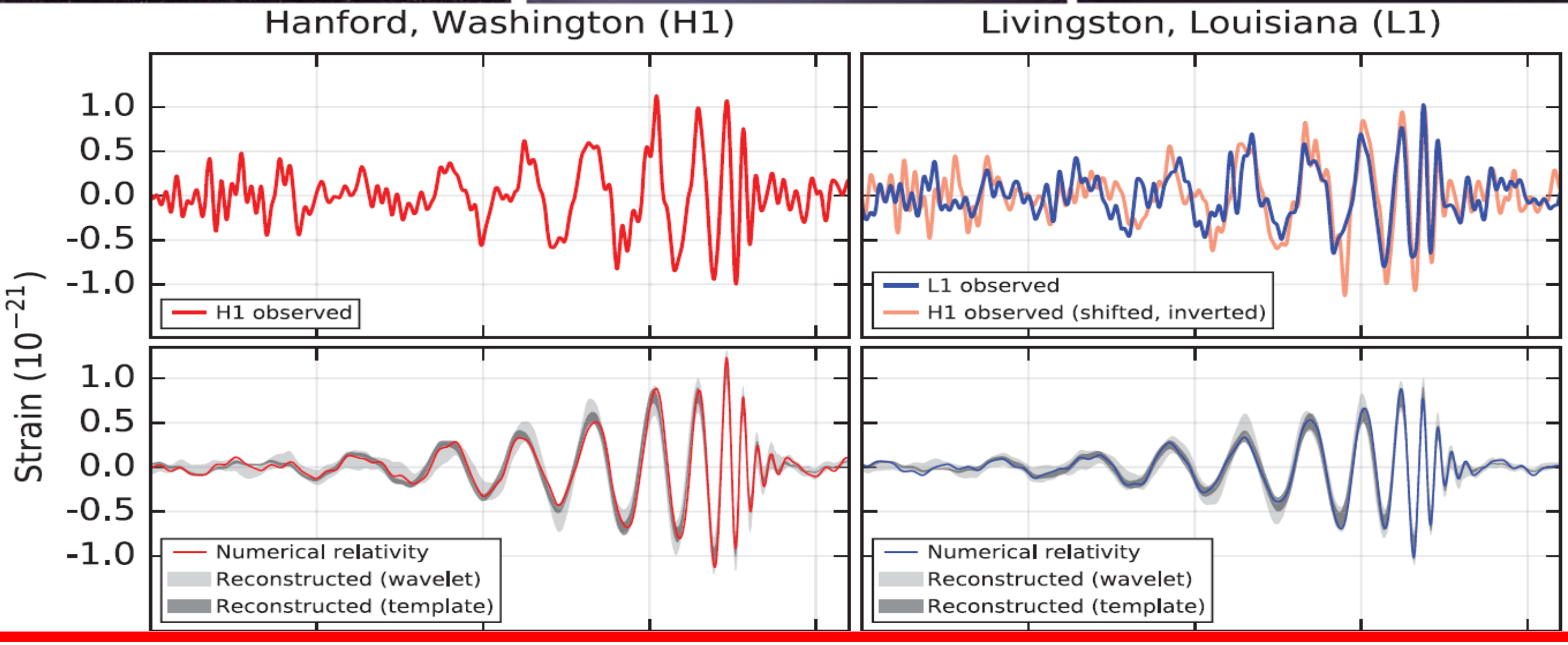
人类首次直接探测到引力波





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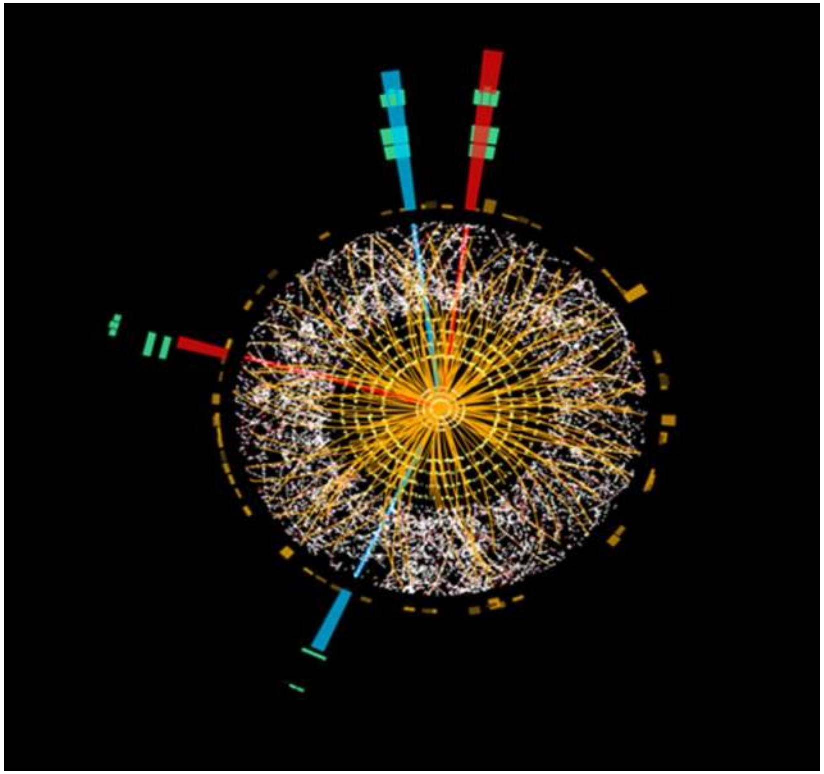
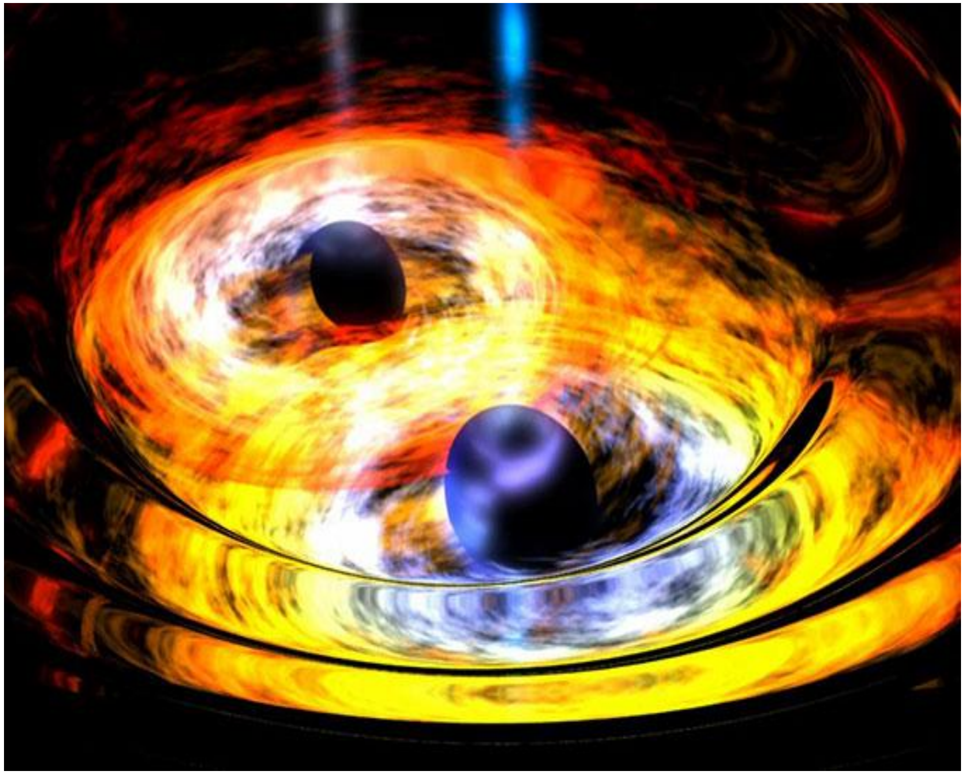
Two HUGE Scientific Breakthroughs in Physics!

Higgs Boson discovered at CERN in 2012

Gravitational wave was directly detected first time in 2015





Scientific Device/Tool & Instrumentation is the Key to new discovery!

Higgs boson

Large Hadron Collider

Gravitational wave measurement

LIGO & Virgo

Personal Comments

- Discoveries of Higgs Boson and GRW took decades of technology development and advancement and generations of efforts, including significant contributions from Accelerator Technology R&D;
- International collaboration;
  - We are and should be proud of what we have achieved!
- Support for technology development is a smart investment for future success in science and huge benefit return to our society. Wide applications of accelerators are perfect examples.

Technology Investment and Development is Crucial

Outline of my presentation (many slides freely taken from presentations from my colleagues and Online information):

- **Overview of the US accelerator-based HEP programs and P5**
  - LHC Upgrade
  - **PIP-II accelerator complex**
- **Overview of the US Muon Accelerator Program R&D Progress**
  - P5 recommendation on Muon Accelerator Program (MAP)
    - Termination of US MAP
    - International MICE at RAL, UK
- **LBNL Accelerator R&D**
  - Newly formed magnet development program (center)
  - Laser plasma accelerator
  - LCLS-II and APEX
  - ALS accelerator physics
- **Summary**

Current Accelerator Programs Under Science Office

HEP

- **LARP - LHC luminosity upgrade**
- **Proton Improvement Plan II (Fermilab)**
- **ILC**
- **Muon Accelerator Program (complete FY17)**
- **General Accelerator R&D (GARD)**
  - Advanced Accelerator R&D: LPA, High Gradient RF, …
  - Generic Accelerator R&D: NC and SC RF, …

BES (Light sources and SNS)

  - **SNS Upgrade (beam power and target)**
  - **APS Upgrade**
  - **ALS-U**

NS

  - **CEBAF 12 GeV Upgrade**
  - **FRIB**
  - **Electron and Ion Collider (BNL and JLab)**

What is P5?

P5 stands for:
Particle **P**hysics **P**roject **P**rioritization **P**anel

P5 is a subpanel of HEPAP, the **H**igh **E**nergy **P**hysics **A**dvisory **P**anel.

Through HEPAP, advises the DOE and NSF by making recommendations on projects, including priorities among projects.

The latest P5 report release in May 2014

HEP is a highly successful, discovery-driven science

P5 emphasized that the field is driven by science.

- It distilled the 11 groups of physics questions from Snowmass into five compelling lines of inquiry, that show great promise for discovery over the next 10 to 20 years.

Subjects driving the science:

- Use the Higgs boson as a new tool for discovery.
- Pursue the physics associated with neutrino mass.
- Identify the new physics of dark matter.
- Understand cosmic acceleration: dark energy and inflation.
- Explore the unknown: new particles, interactions, and physical principles.

P5 recommended a balanced program to address all 5 drivers.

- *Pursue a program to address the 5 science Drivers.*

P5 Recommended Projects

The P5 strategic plan includes a number of projects (and time ordering)

- These projects provide the opportunities to study the science drivers
- Large projects (in time order):
  - Muon g-2 & Mu2e
  - LHC Upgrades
  - LBNF/DUNE & Proton Improvement Plan (PIP)-II
- Small and Medium projects (in subject order):
  - Dark matter (3): DM G2, DM G3
  - Cosmic surveys (2,5): DESI, LSST, CMB-S4
  - Small Projects Portfolio
  - SBNE (2)
  - Accelerator R&D
- ILC (*handled specially*)

LHC, LBNF/DUNE, ILC are large projects & involve major international partnerships

- LHC was an int'l. partnership by nature + US & JAPAN participation
- P5 recommended the transformation to LBNF/DUNE (a major change in direction)
- ILC was conceived as global project (funding model still evolving)

PROTON IMPROVEMENT PLAN (PIP) AT FERMILAB

Proton Improvement Plan (PIP)-I

The goal of PIP is to allow continuous operation of the Fermilab **Linac/Booster** at 15 Hz, through

- The elimination of the *physical* limitations of the pulsed elements
  - Injection and extraction hardware
  - RF cooling
  - Solid state RF amplifiers
  - Bias supplies
  - Anode supplies

Complete!

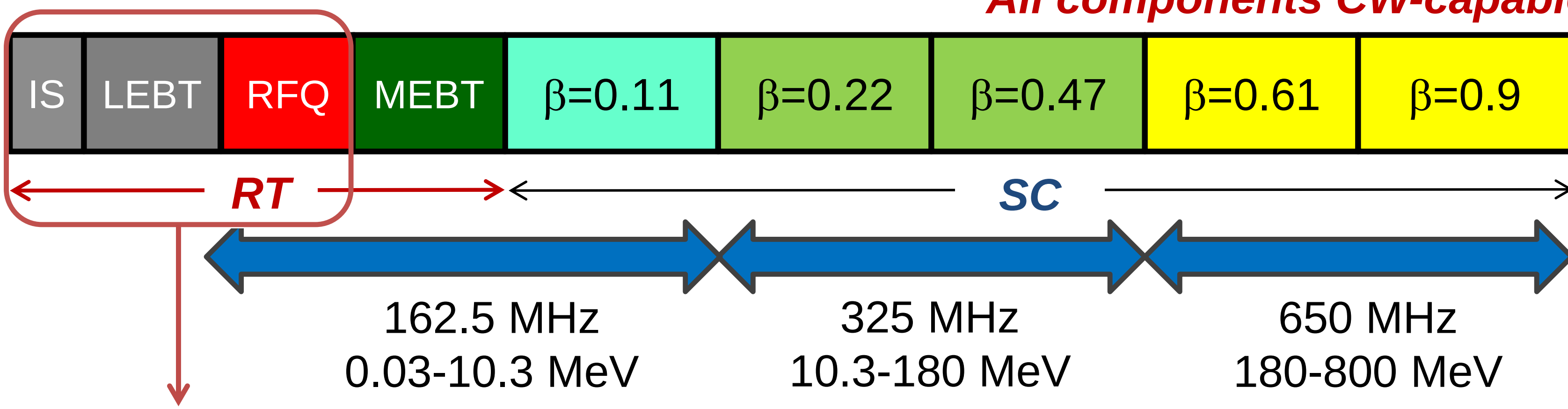
- Reduction of beam loss, such that higher throughput is allowed
  - New ion source
  - Improved beam control and collimation
  - Improved beam cogging
  - New, larger aperture, RF cavities (designed for later use)

(P5) Upgrade the Fermilab Proton Accelerator Complex to Produce Higher Intensity Beams

The PIP-II, an accelerator complex at Fermilab, its goal is to support long-term physics research goals by providing increased beam power to **LBNF**, while providing a platform for the future

– Design Criteria: deliver > **1 MW** of proton beam power from the Main Injector over the energy range 60 – 120 GeV, at the start of LBNF operations

All components CW-capable



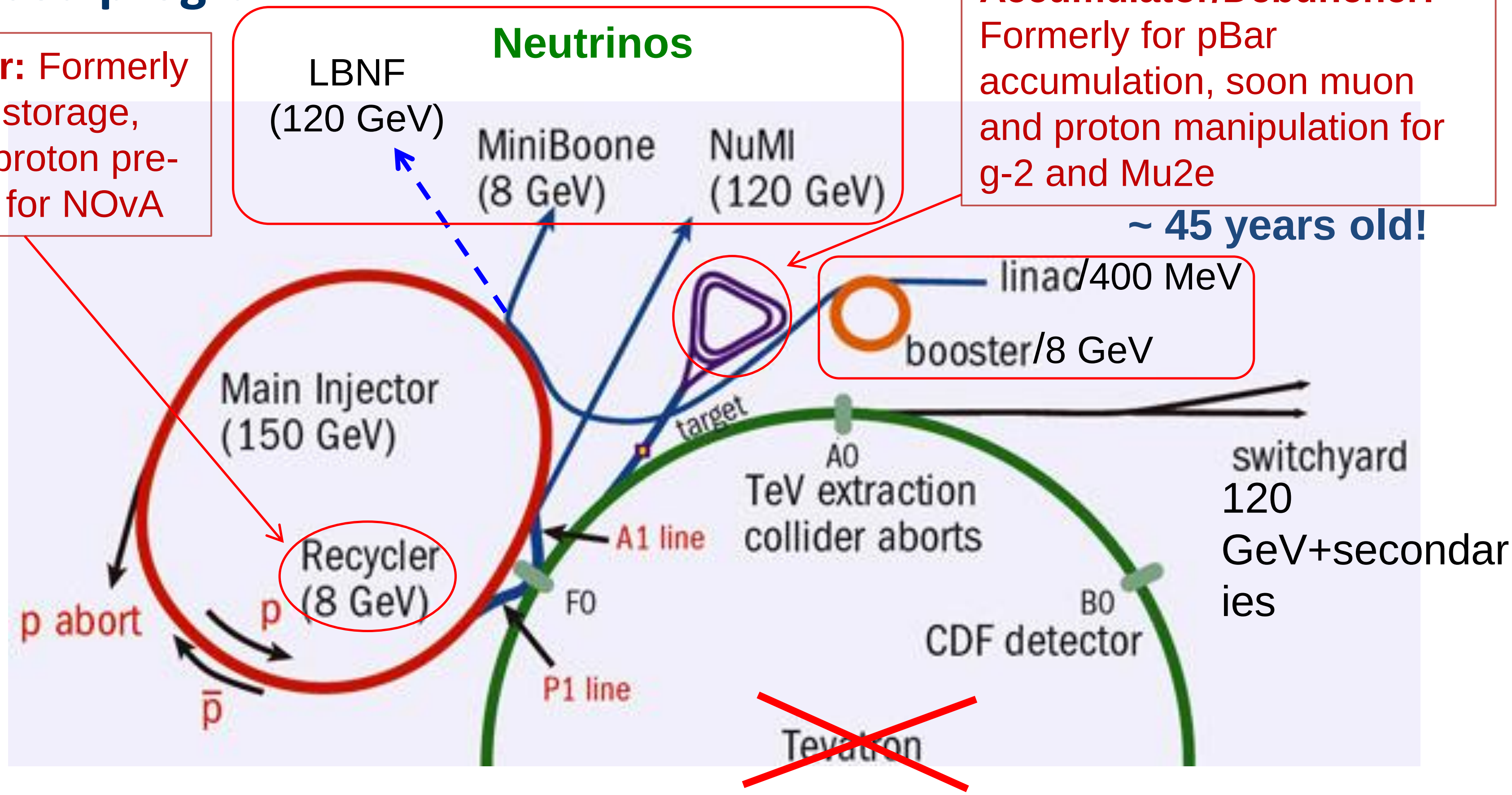
LBNL delivered H^- ion source and RFQ, involved in LEBT and MEBT study;
Responsible for RFQ design, fabrication and support of commissioning

Fermilab Accelerator Complex

Following the LHC turn-on, FNAL has transitioned to an intensity based program

Recycler: Formerly for pBar storage, now for proton pre-stacking for NOvA

Accumulator/Debuncher: Formerly for pBar accumulation, soon muon and proton manipulation for g-2 and Mu2e



The 8 GeV source is the chief limit to intensities

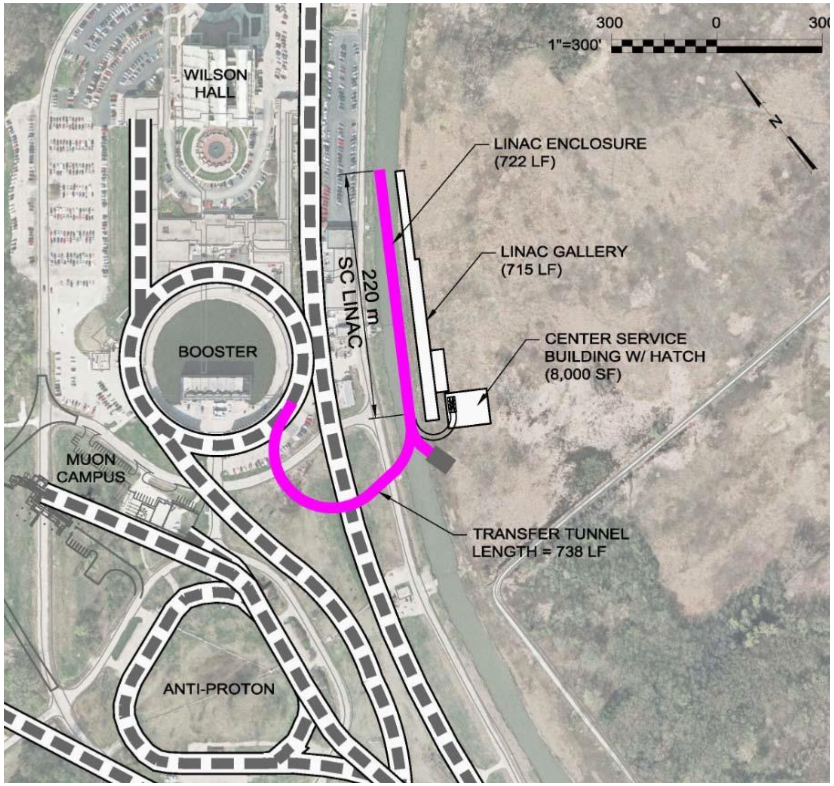
Proton Improvement Plan (PIP-II)

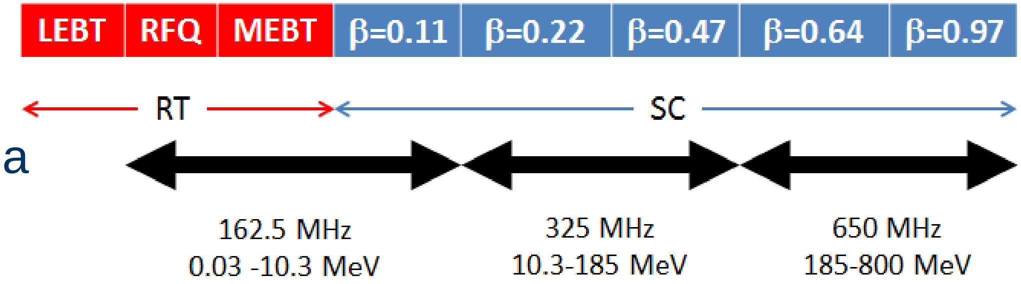
Key elements:

- Replace existing 400 MeV linac with an **800 MeV** linac capable of CW operation.
  - Higher energy + painting = more beam in Booster
- Increase Booster rate to 20 Hz
- “Modest” improvements to Recycler and MI

Goals:

- **1.2 MW @ 120 GeV**
- **100+ kW @ 800 MeV**
  - Cryoplant contribution from India



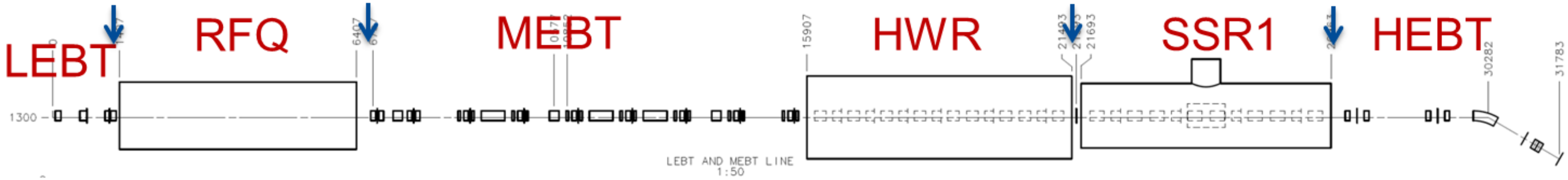


PIP-II R&D: PXIE (formerly Project X Injector Exp.)

The PIP-II Injector Experiment (PXIE)* is designed to test the technology needed for the PIP-II Linac

– Now — 2015 — 2016 — 2017 → 2018

30 keV | 2.1 MeV | 10 MeV | 25 MeV



← 40 m, ~25 MeV →

Among other things, PXIE will investigate

- Low Energy Beam Transport (LEBT) pre-chopping. Demonstrated.
- Validation of chopper performance
- Bunch extinction
- Operation of Half Wave Resonator (HWR) in close proximity to 10 kW absorber
- Emittance preservation
- CW RFQ

LBNL Designed and Fabricated RFQ Installed in PXIE Hall at FNAL: commissioning in progress

Beyond PIP-II

By the time PIP-II is realized, the Booster will be more than a half century old, and it's unrealistic to believe that it can be pushed further, in terms of performance:

- No beam pipe in magnets! ➔ troublesome impedances from magnet laminations.
- Presently the decelerating voltage (from impedance) at transition is above 100 kV/turn
  - Transition crossing with more than 50% intensity increase looks impossible without reducing impedance
  - No realistic way to do this.

Further increases in power will require replacing the Booster. Options are:

- A pulsed linac to go from the PIP-II linac to 8 GeV
  - Possibly increase the energy of the CW portion to 3 GeV?
- Some sort of Rapid Cycling Synchrotron (RCS)

Replacing the Booster is the core component of "PIP-III"

Novel Ways to Mitigate Space Charge

Non-linear integrable optics

- All synchrotrons ever built are based on linear optics (magnetic quadrupoles). Non-linearities are handled perturbatively, and eventually lead to instabilities.
- Is has been shown* that non-linear magnetic fields that satisfy a very particular set of conditions can result in stable orbits, but without a unique tune
  - Extremely insensitive to harmonic instabilities
  - Stable up to space charge tune shifts of order unity!

Electron lens

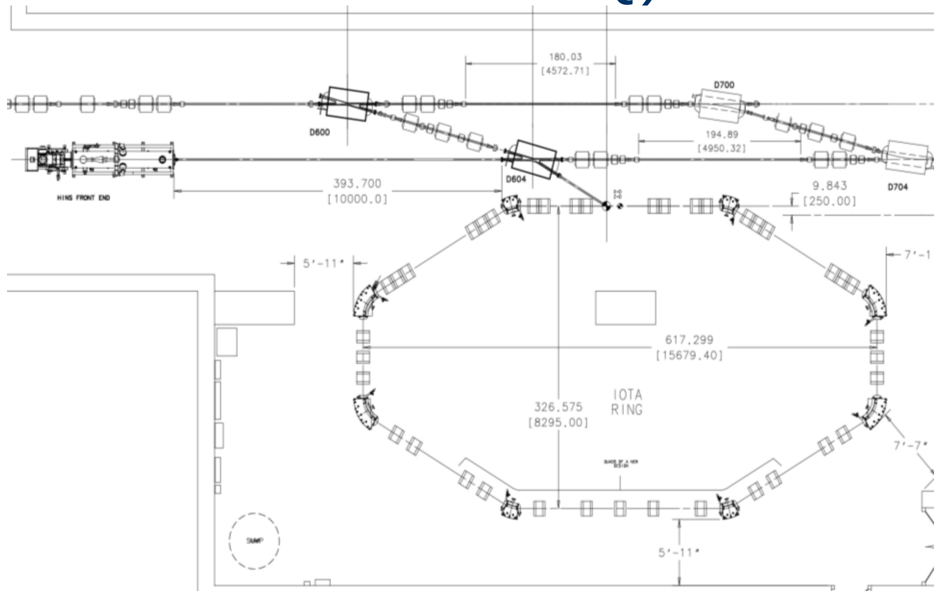
- A beam of electrons can be used to cancel the space charge effects of the protons
- Demonstrated in the Tevatron
- Used operationally at RHIC

FAST/IOTA Program*

The Fermilab Accelerator Science Test (FAST) facility, including the Integrable Optics Test Accelerator (IOTA) is being built to test non-linear integrable optics, electron lenses, and other novel accelerator physics.

– Electrons in FY17 (formerly ASTA program)

– Protons a bit later (reuse old HINS source and RFQ)



*Danilov, Nagaitsev, PRSTAB 2010

R&D Towards Future Neutrino Factory and Lepton Collider Capabilities

OVERVIEW OF THE US MUON ACCELERATOR PROGRAM (MAP)

Muon Accelerators for HEP

μ – an elementary charged lepton:

- 200 times heavier than the electron
- 2.2 μs lifetime at rest

Physics potential for the HEP community using muon beams

- Tests of Lepton Flavor Violation
- Anomalous magnetic moment ⇨ hints of new physics (g-2)

MAP Charge

- Can provide equal fractions of electron and muon neutrinos at high intensity for studies of neutrino oscillations – the Neutrino Factory concept

$$\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$$

$$\mu^- \to e^- \bar{\nu}_e \nu_\mu$$

- Offers a large coupling to the "Higgs mechanism"

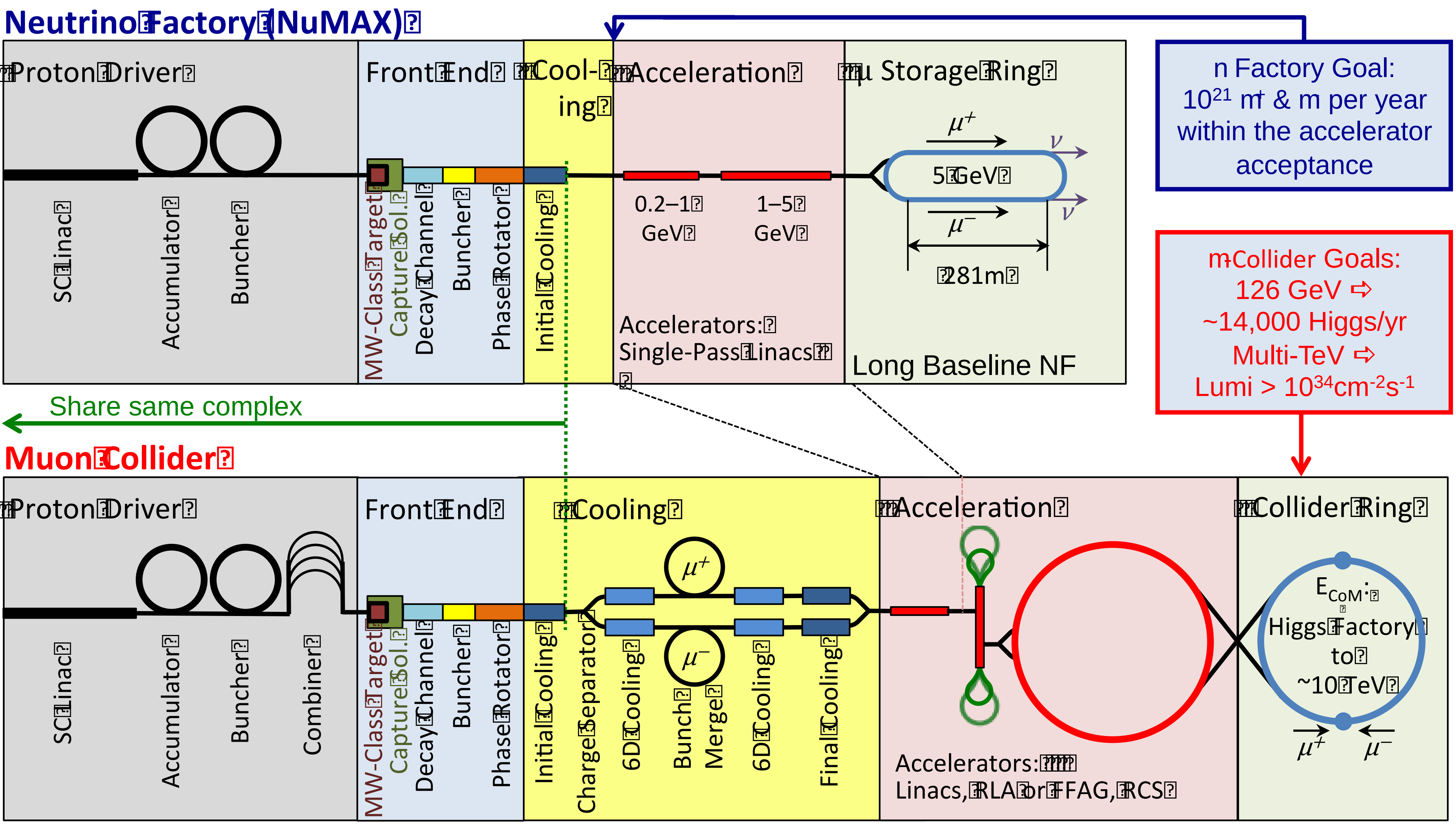
$$\left(\frac{m_\mu^2}{m_e^2}\right) \cong 4 \times 10^4$$

- As with an e^+e^- collider, a $\mu^+\mu^-$ collider would offer a precision leptonic probe of fundamental interactions

Summary of the Muon Accelerator Program

- Neutrino Factory Capabilities
  - Short baseline a nSTORM
  - Long Baseline a IDS-NF and **NuMAX**
- Going Beyond a Neutrino Factory Facility
  - Possibilities for a future Muon Collider Capability
  - Higgs Factory to >5 TeV
- MAP R&D Progress
  - Technology development
  - MICE

The US Muon Accelerator Program



NF Development Under MAP

Short Baseline NF

- nuSTORM
  - Definitive measurement of sterile neutrinos
  - Precision ν_e cross-section measurements (systematics issue for long baseline SuperBeam experiments)
  - Would serve as an HEP muon accelerator proving ground…

Long Baseline NF with a Magnetized Detector

- IDS-NF (International Design Study for a Neutrino Factory)
  - 10 GeV muon storage ring optimized for 1500-2500km baselines
  - "Generic" design (ie, not site-specific)
- NuMAX (Neutrinos from a Muon Accelerator CompleX)
  - Site-specific: FNAL ⇨ SURF (1300km baseline)
  - 4-6 GeV beam energy optimized for CP studies
  - Can provide an ongoing short baseline measurement option
    - Flexibility to allow for other operating energies
  - Detector options
    - Magnetized LAr is the goal
    - Magnetized iron provides equivalent CP sensitivities using ~3x the mass

MASS NF Parameters

Neutrino Factory Parameters					
Parameters	**Unit**	**nuSTORM**	**NuMAX Commissioning**	**NuMAX**	**NuMAX+**
ν_e or ν_μ to detectors/year	-	3×10^{17}	4.9×10^{19}	1.8×10^{20}	5.0×10^{20}
Stored μ+ or μ-/year	-	8×10^{17}	1.25×10^{20}	4.65×10^{20}	1.3×10^{21}
Far Detector:	Type	SuperBIND	MIND / Mag LAr	MIND / Mag LAr	MIND / Mag LAr
Distance from Ring	km	1.9	1300	1300	1300
Mass	kT	1.3	100 / 30	100 / 30	100 / 30
Magnetic Field	T	2	0.5-2	0.5-2	0.5-2
Near Detector:	Type	SuperBIND	Suite	Suite	Suite
Distance from Ring	m	50	100	100	100
Mass	kT	0.1	1	1	2.7
Magnetic Field	T	Yes	Yes	Yes	Yes
Accelerator: Ring Momentum (P_μ)	GeV/c	3.8	5	5	5
Circumference (C)	m	480	737	737	737
Ionization Cooling	-	No	No	**6D Initial**	**6D Initial**
Proton Beam Power	MW	0.2	1	1	2.75

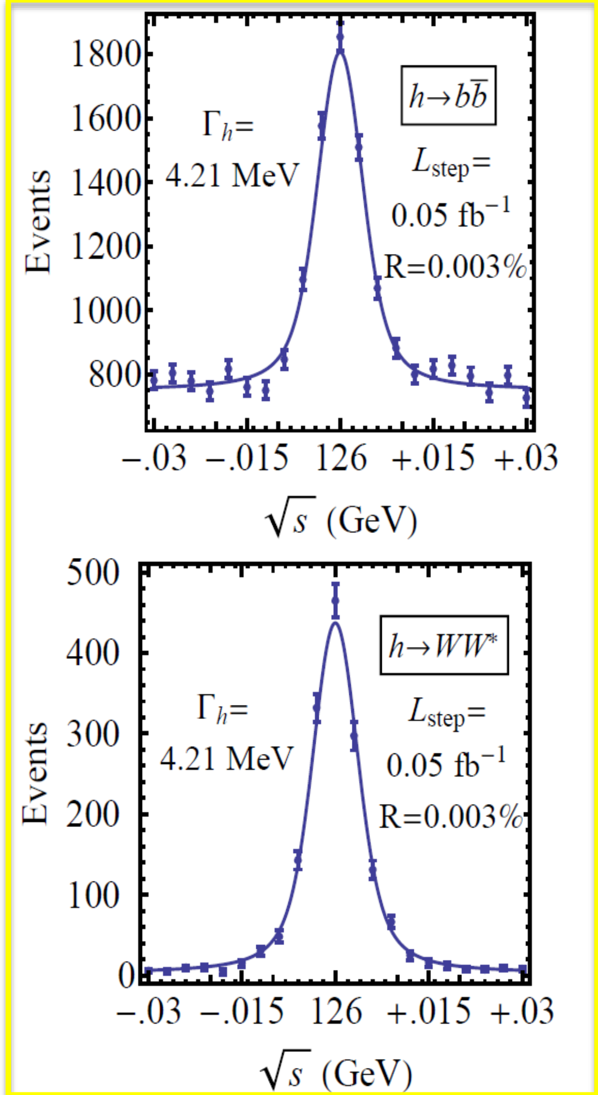
Going Beyond NF → Muon Collider

Superb Energy Resolution
- SM Thresholds and s-channel Higgs Factory operation

Multi-TeV Capability (≤ 10TeV):
- Compact & energy efficient machine
- Luminosity > 10^{34} cm^{-2} s^{-1}
- Option for 2 detectors in the ring

- For $\sqrt{s}$ > 1 TeV: Fusion processes dominate
  ⇨ an Electroweak Boson Collider
  ⇨ a discovery machine complementary to a very high energy pp collider
  - >5TeV: Higgs self-coupling resolution <10%

What is our most efficient accelerator option if new LHC data shows evidence for a multi-TeV particle spectrum?



Muon Collider Parameters

Muon Collider Parameters

		Higgs	Multi-TeV		
Parameter	***Units***	*Production Operation*			*Accounts for Site Radiation Mitigation*
CoM Energy	TeV	**0.126**	**1.5**	**3.0**	**6.0**
Avg. Luminosity	$10^{34}cm^{-2}s^{-1}$	0.008	1.25	4.4	12
Beam Energy Spread	%	0.004	0.1	0.1	0.1
Higgs Production/10^7sec		13,500	37,500	200,000	820,000
Circumference	km	0.3	2.5	4.5	6
No. of IPs		1	2	2	2
Repetition Rate	Hz	15	15	12	6
b*	cm	1.7	1 (0.5-2)	0.5 (0.3-3)	0.25
No. muons/bunch	10^{12}	4	2	2	2
Norm. Trans. Emittance, e_{TN}	p mm-rad	0.2	0.025	0.025	0.025
Norm. Long. Emittance, e_{LN}	p mm-rad	1.5	70	70	70
Bunch Length, s_s	cm	6.3	1	0.5	0.2
Proton Driver Power	MW	4	4	4	1.6
Wall Plug Power	MW	200	216	230	270

Success of advanced cooling concepts ⇨ several ⇙ 10^{32}

Exquisite Energy Resolution Allows Direct Measurement of Higgs Width

MAP R&D PROGRESS

Accelerator R&D Effort Under MAP

Design Studies

- Proton Driver
- Front End
- Cooling
- Acceleration and Storage
- Collider
- Machine-Detector Interface
- Work closely with physics and detector efforts

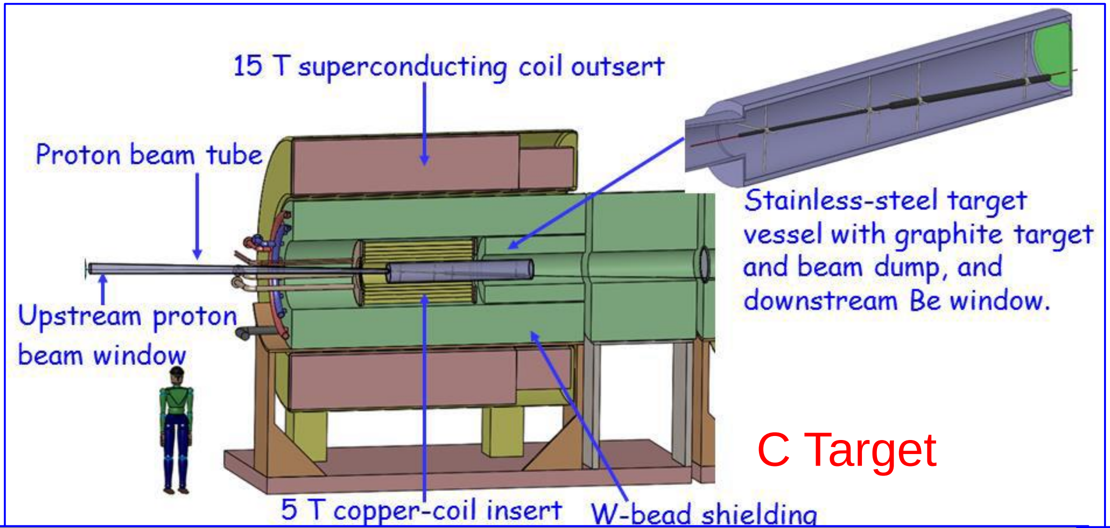
Technology R&D

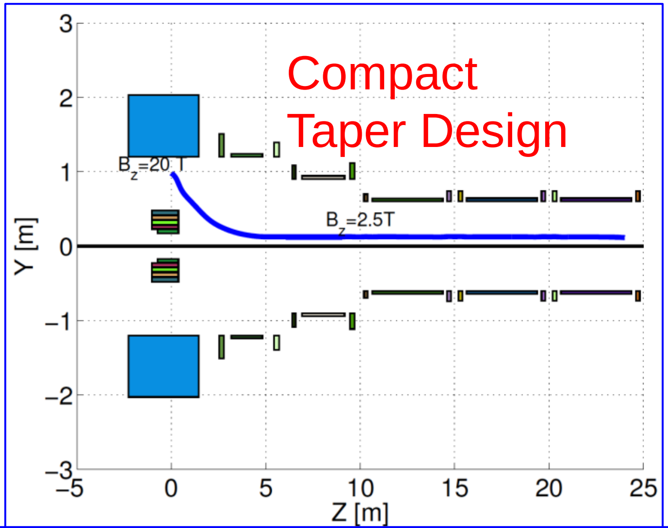
- RF in magnetic fields
- SCRF for acceleration chain (Nb on Cu technology)
- High field magnets
  - Utilizing HTS technologies
- Targets & Absorbers
- MuCool Test Area (MTA)

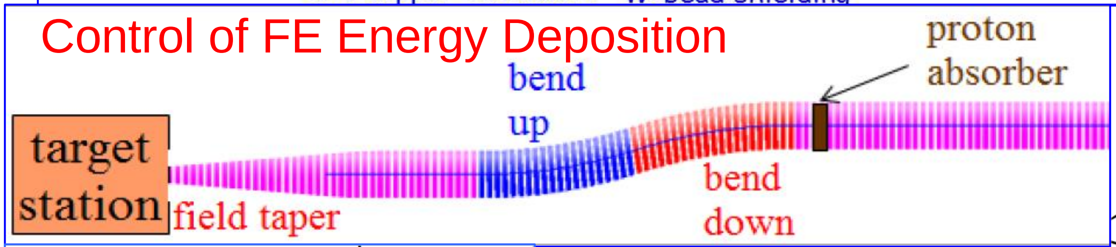
Major System Demonstration

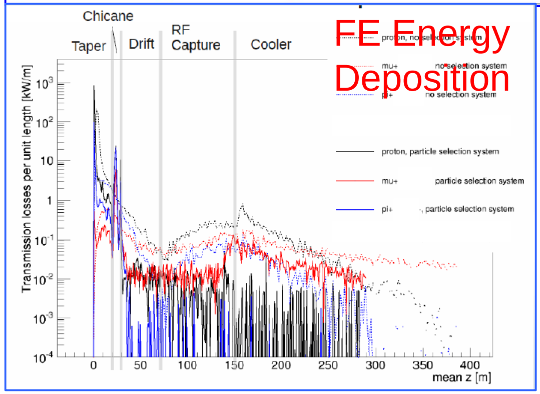
- The Muon Ionization Cooling Experiment – MICE
  - Major U.S. effort to provide key hardware: *Spectrometer Solenoids, Partial Return Yoke, RF Modules*
  - Experimental and Operations Support

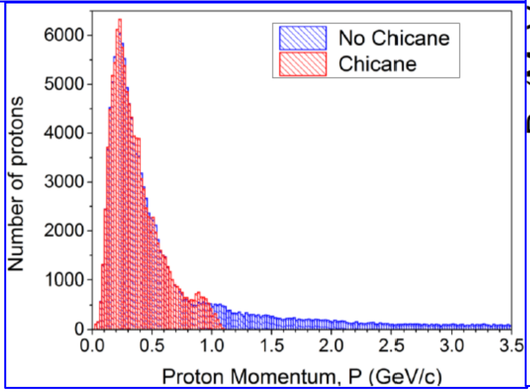
Target & Front End Progress

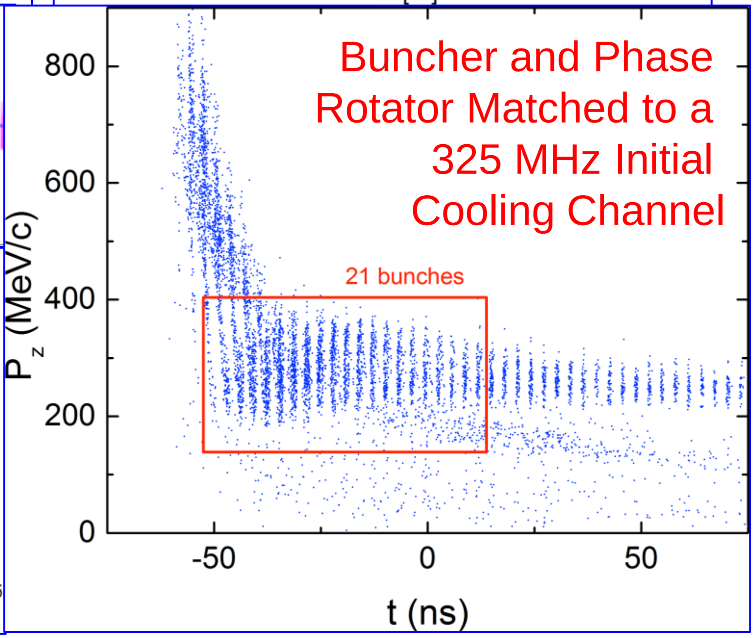








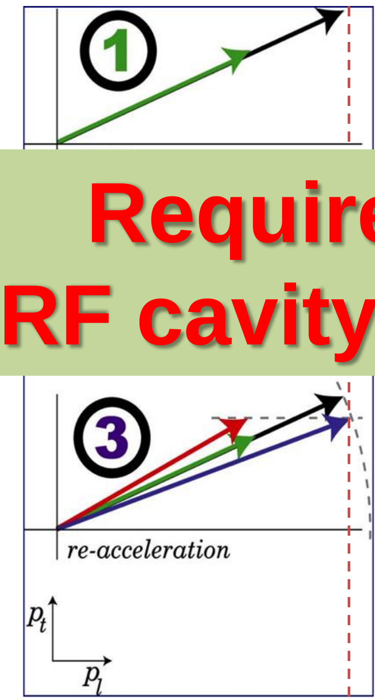




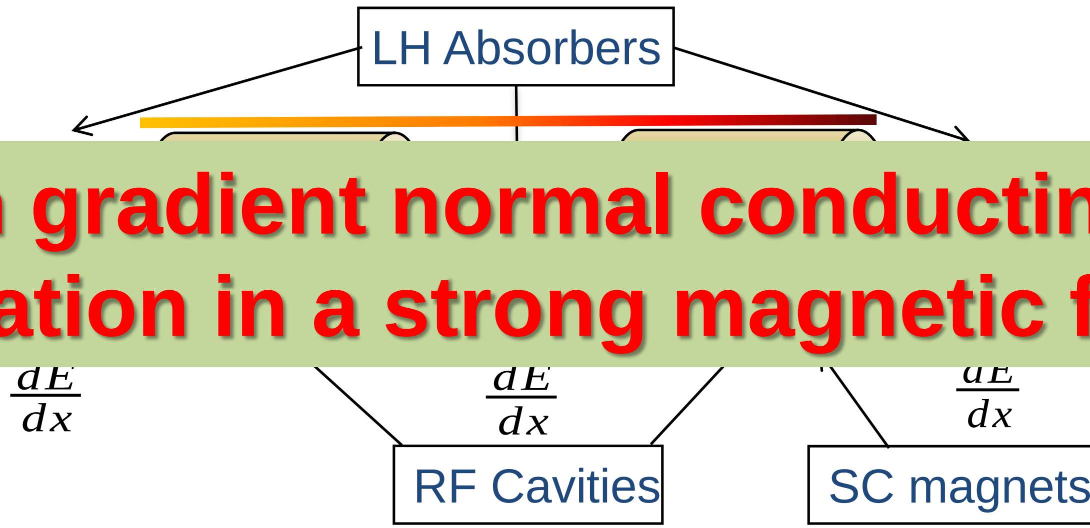
What is Muon Ionization Cooling?

- Muons have very short lifetime (2.2 μs @ rest) & must be manipulated quickly
- High gradient RF cavities compensate for lost longitudinal energy in liquid hydrogen (LH) absorbers
- Strong magnetic field to confine muon beams

Require high gradient normal conducting RF cavity operation in a strong magnetic field



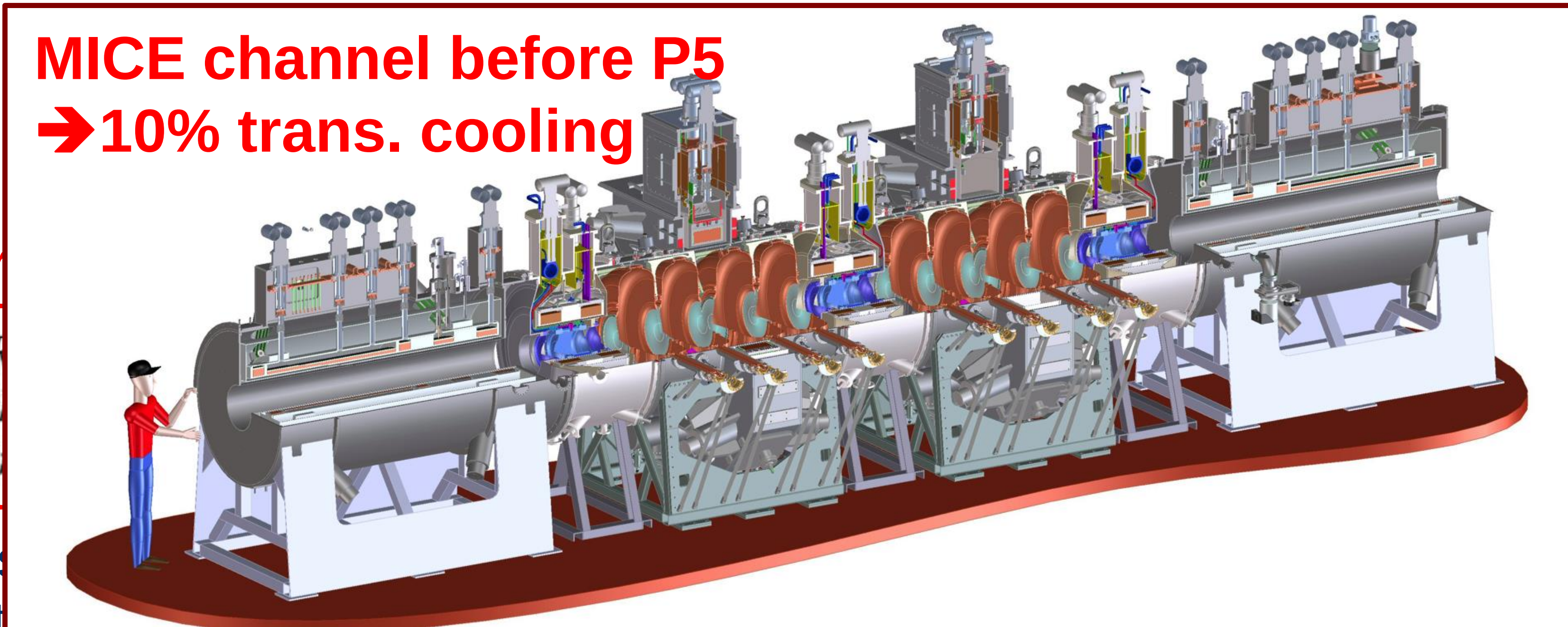
Transverse cooling



$$\frac{d\epsilon_N}{ds} \approx -\frac{1}{\beta^2}\left\langle \frac{dE_\mu}{ds} \right\rangle \frac{\epsilon_N}{E_\mu} + \frac{\beta_\perp (0.014GeV)^2}{2\beta^3 E_\mu m_\mu X_0}$$

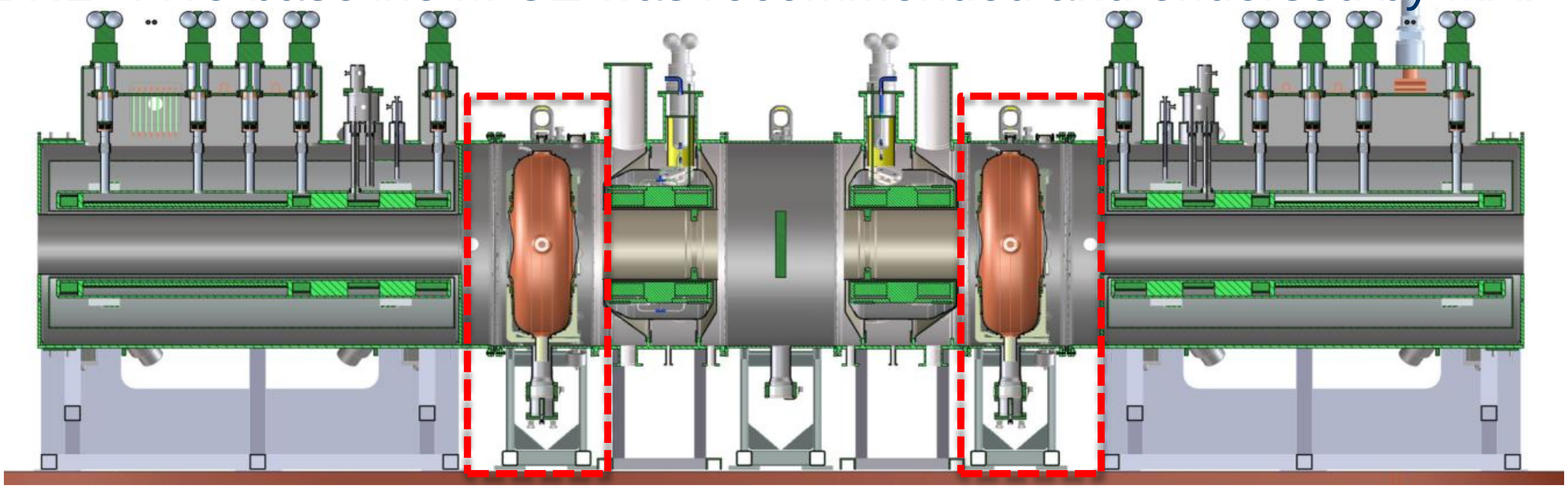
Cooling Heating

P5 r



In res

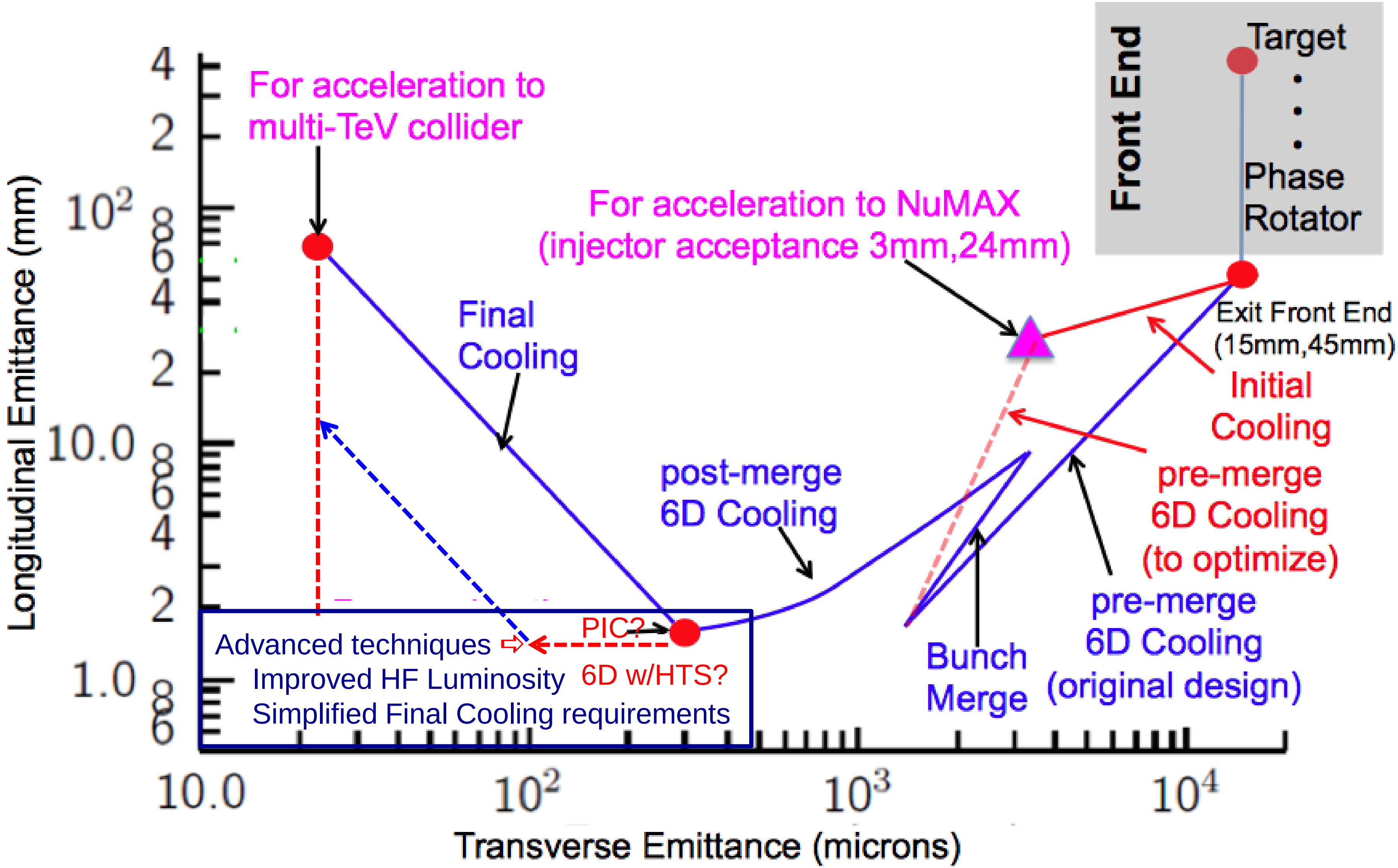
at



Delivered two SS magnets last year and support the magnets training now

No SC coupling coils, 2 RF cavities only ➔ 6 % transverse cooling

Muon Ionization Cooling (Design Study)



Muon Ionization Cooling (Design)

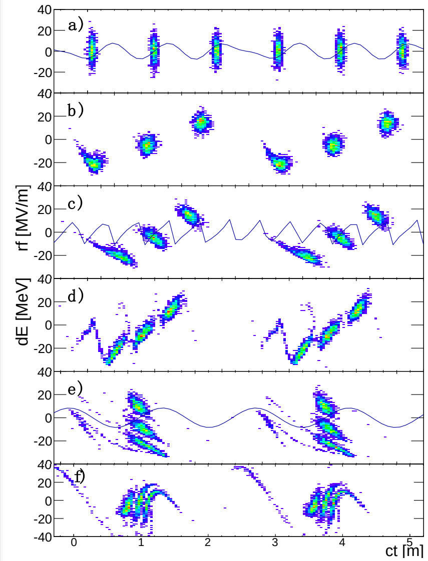
Bunch Merge

- MAP Baseline Designs offer
  - Factor >10^5 in emittance reduction
- Alternative & Advanced Concepts
  - Hybrid Rectilinear Channel (gas-filled structures)
  - Parametric Ionization Cooling
  - Alternative Final Cooling
    - ➪ Early stages of existing scheme
    - ➪ Round-to-flat Beam Transform
    - ➪ Transverse Bunch Slicing
    - ➪ Longitudinal Coalescing (at ~10s of GeV)

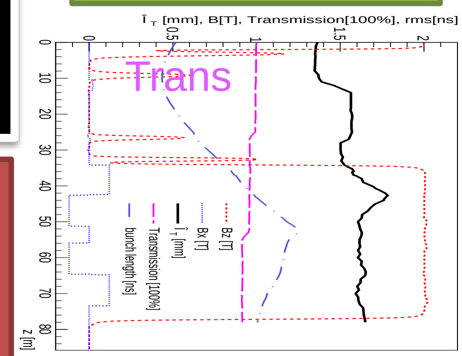
➪ *Considerable promise to exceed our original target parameters*

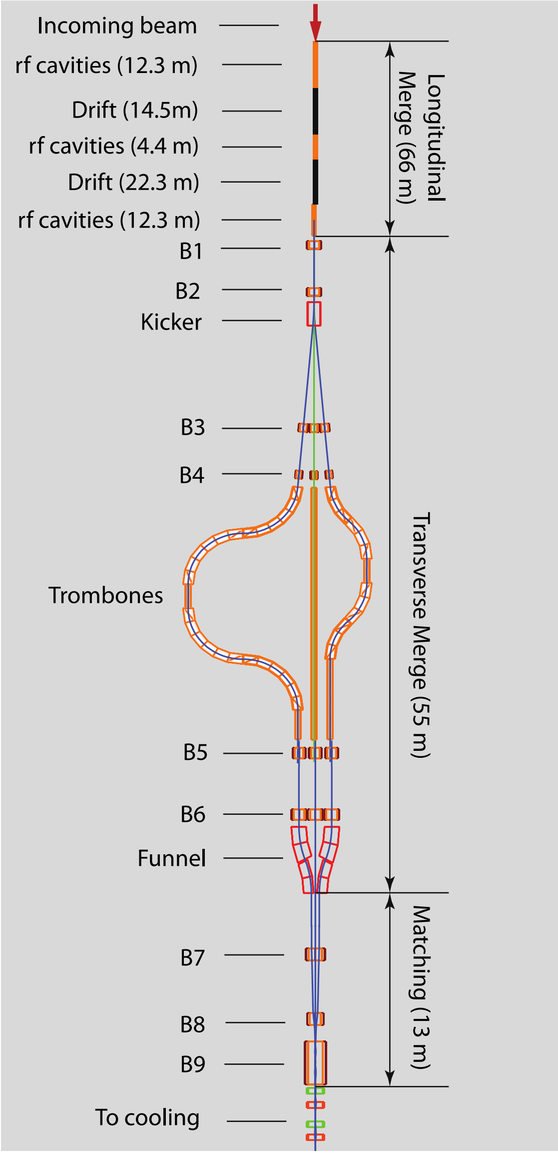
MASS identified extension of the 6D cooling concepts and modification of Final Cooling scheme to be one of most likely areas of performance improvement

Longitudinal Merge

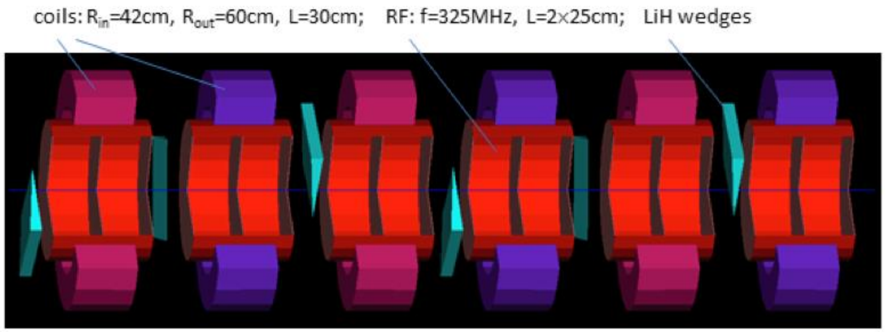


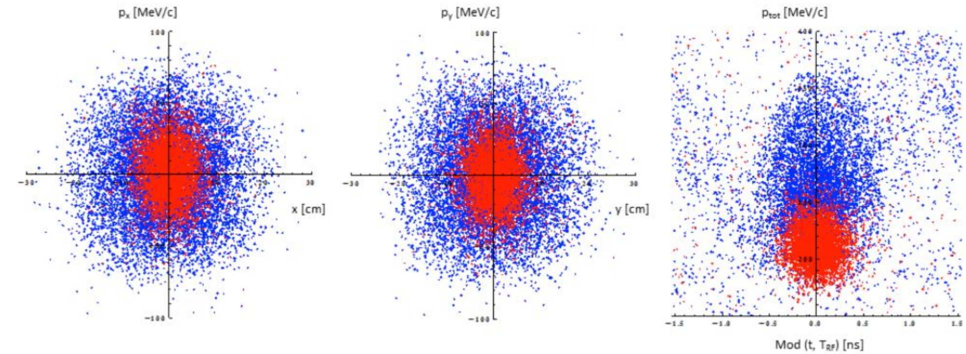
Transverse Merge



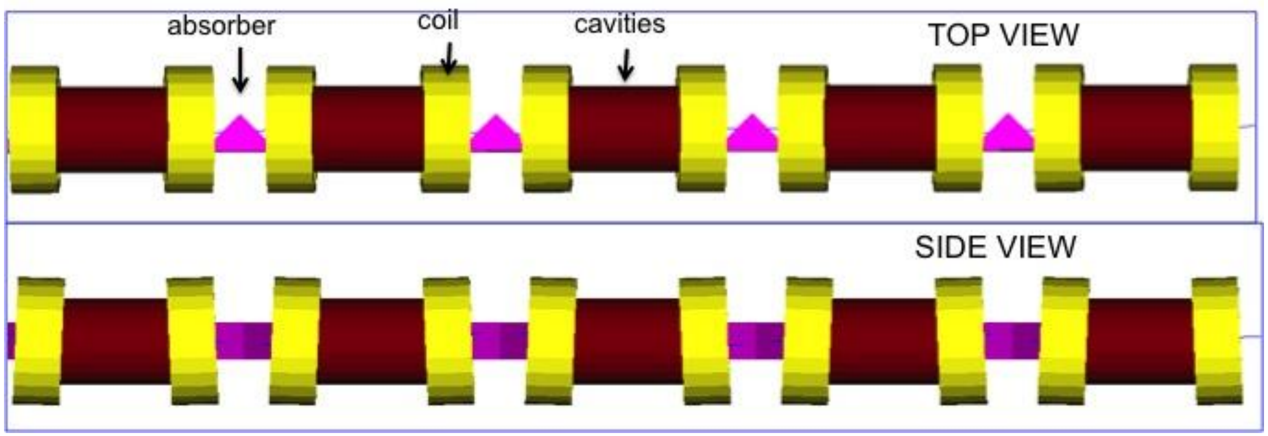


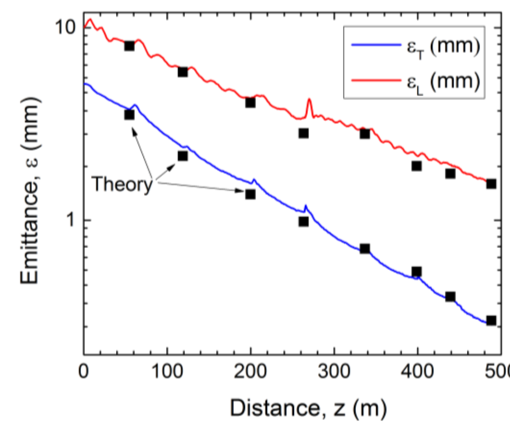
Muon Ionization Cooling (Design)





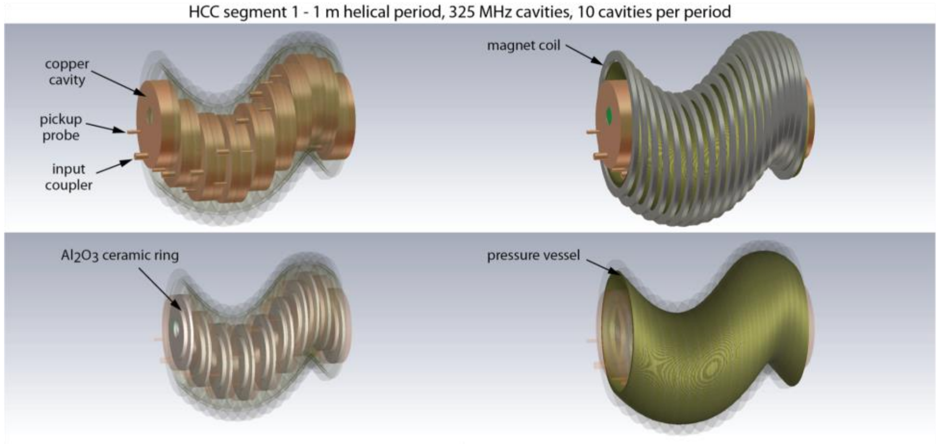
Initial 6D Cooling: ε_{6D} 60 cm^3 ⇨ ~50 mm^3; Trans = 67%

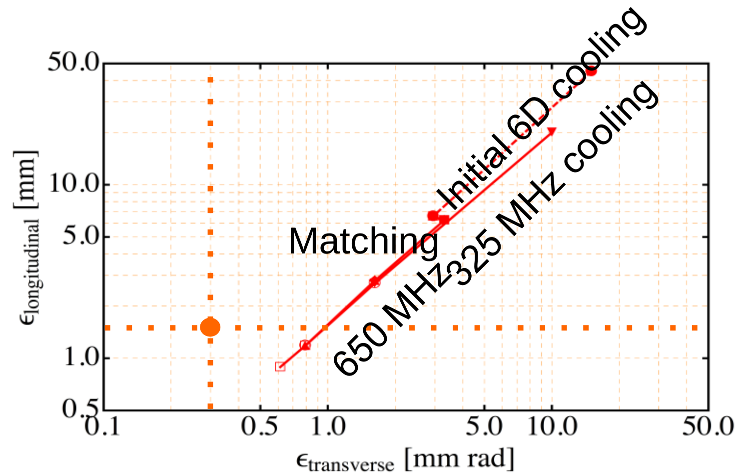




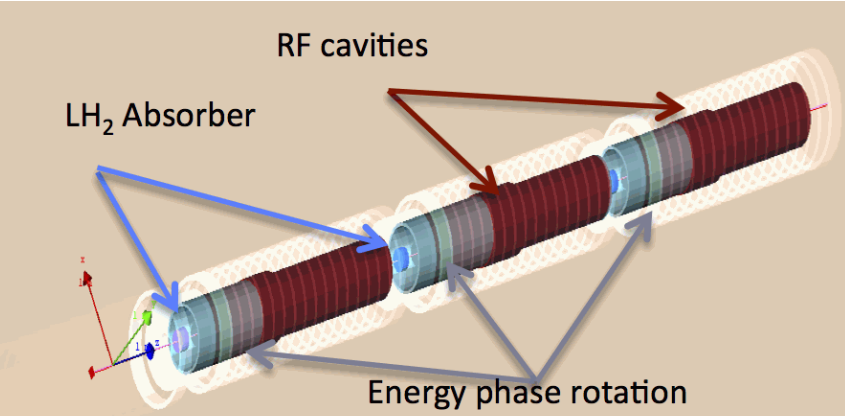
6D Rectilinear Vacuum Cooling Channel (supersedes Guggenheim):
Trans = 55%(40%) without(with) bunch recombination

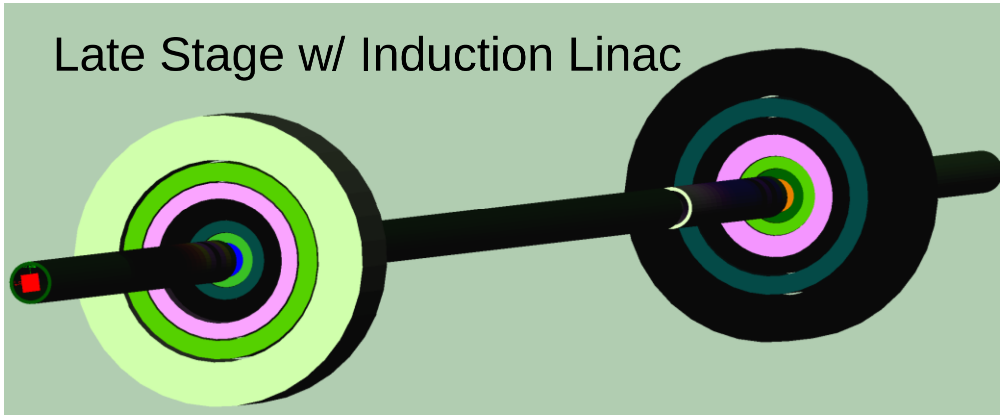
Muon Ionization Cooling (Design)





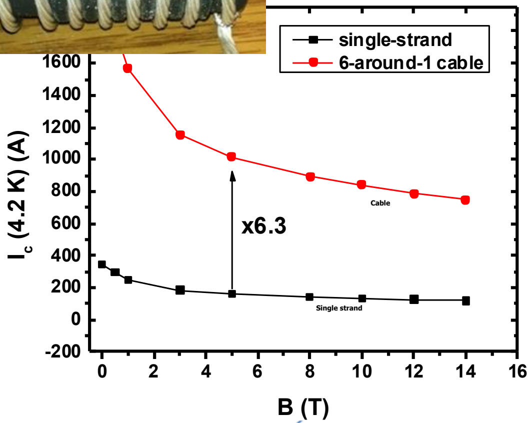
Helical Cooling Channel (Gas-filled RF Cavities): ε_T = 0.6mm, ε_L = 0.3mm





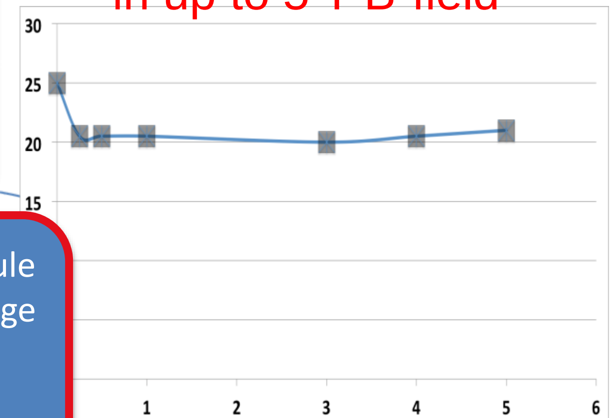
- Final Cooling with 25-30T solenoids (emittance exchange):
  ε_T = 55µm, ε_L = 75mm

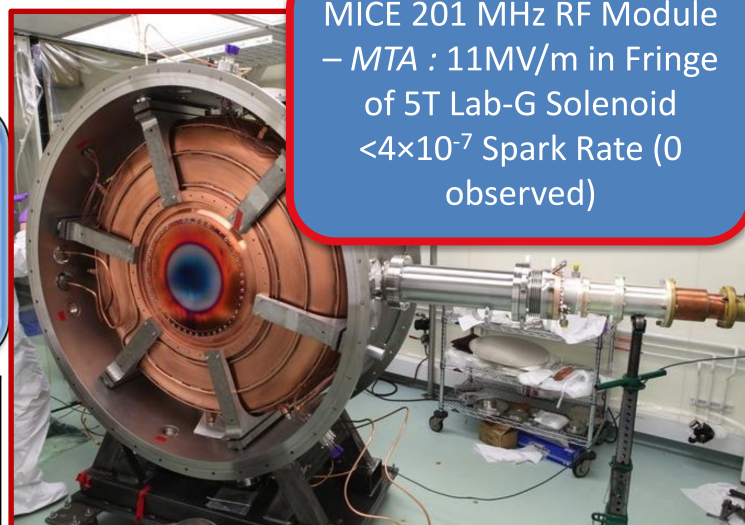
Cooling Technology R&D



Successful Operation of 805 MHz "All Seasons" Cavity in 5T Magnetic Field under Vacuum

> 20MV/m operation in up to 5 T B-field

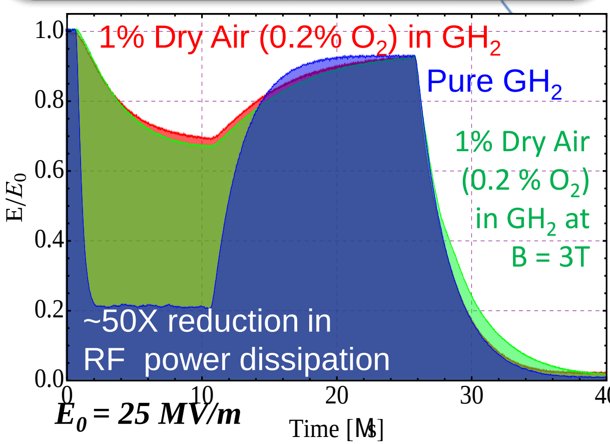




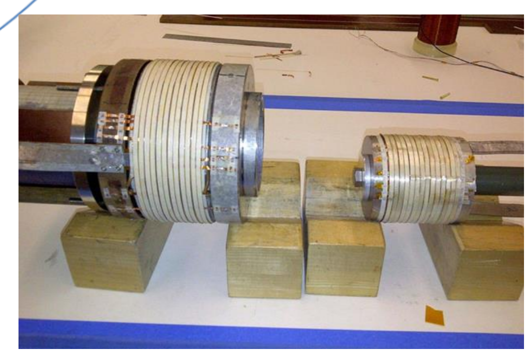
MICE 201 MHz RF Module – *MTA* : 11MV/m in Fringe of 5T Lab-G Solenoid $<4\times10^{-7}$ Spark Rate (0 observed)

Breakthrough in HTS Cable Performance with Cables Matching Strand Performance

World Record HTS-only Coil: 15T on-axis field (16T on coil)

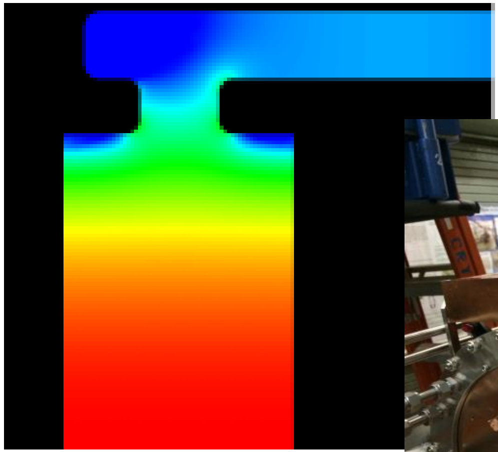


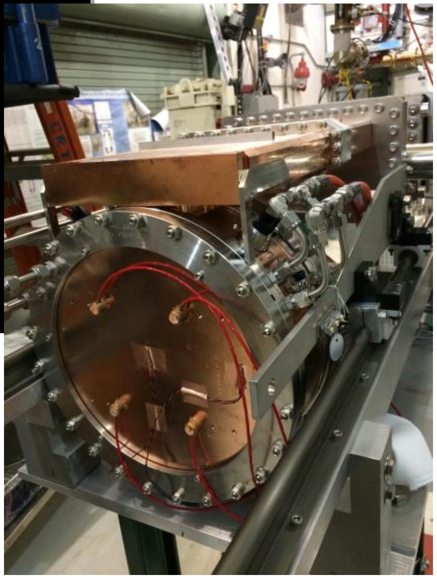
Demonstration of High Pressure RF Cavity in 3T Magnetic Field with Beam; Extrapolates to required μ-Collider Parameters



Cooling Technology R&D

- Magnets
  - MAP Initial Baseline Selection process has yielded 6D cooling baselines that do ***not*** require HTS magnets
  - HTS Solenoids may be required as part of a higher performance 6D Cooling Channel and for parts of the Final Cooling Channel
- RF Cavities
  - The *successful test in magnetic field* of the MICE RF Module Prototype demonstrates
    - The importance of surface preparation
    - The importance of detailed simulation in magnetic field as part of the design process
  - High Pressure Gas-Filled RF Cavities provide a *demonstrated route to the required gradients with high intensity muon beams*
  - Recent results with vacuum RF cavities in magnetic field have shown results consistent with our physical models
    - **805 MHz "Modular" Cavity:**
      A test vehicle to characterize breakdown effects in vacuum cavities
      - » SCRF-style surface preparation
      - » Design optimized for use in magnetic field
      - » Data-taking

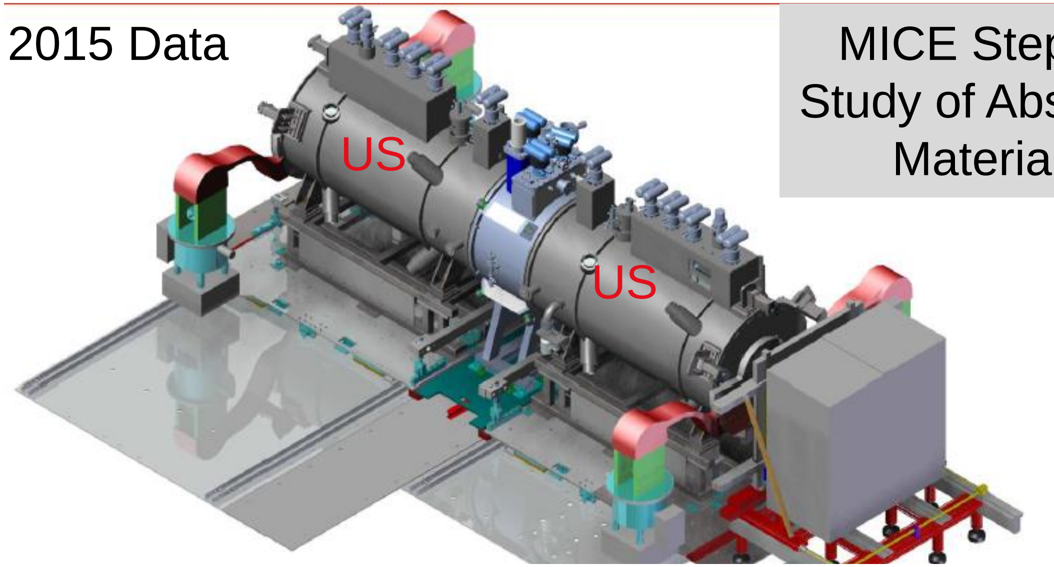




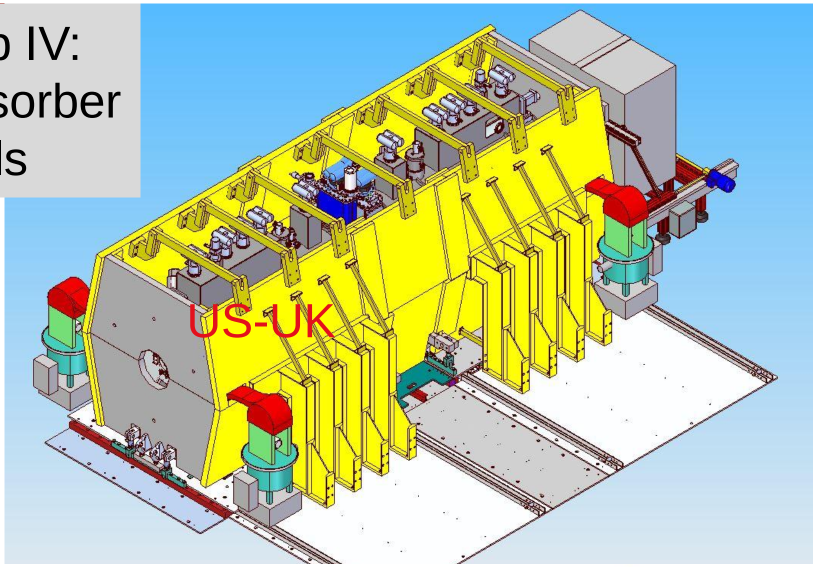
The MAP Feasibility Assessment aimed to provide a full 6D cell prototype for testing at high beam intensity in the MTA

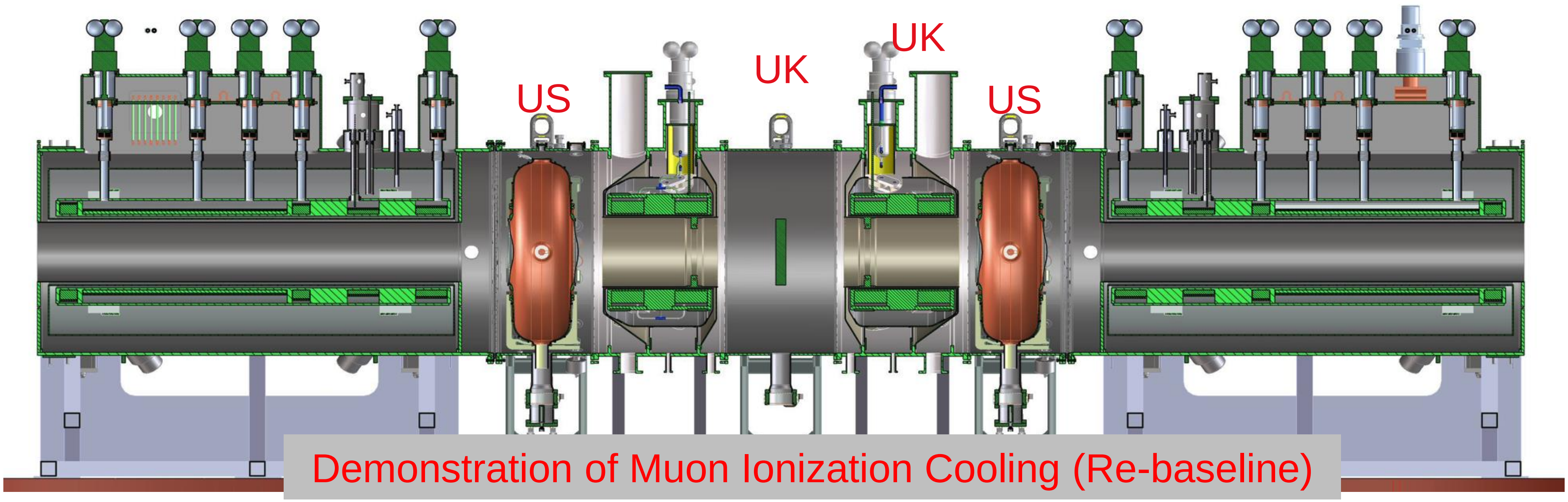
MICE Demonstration @ RAL

2015 Data



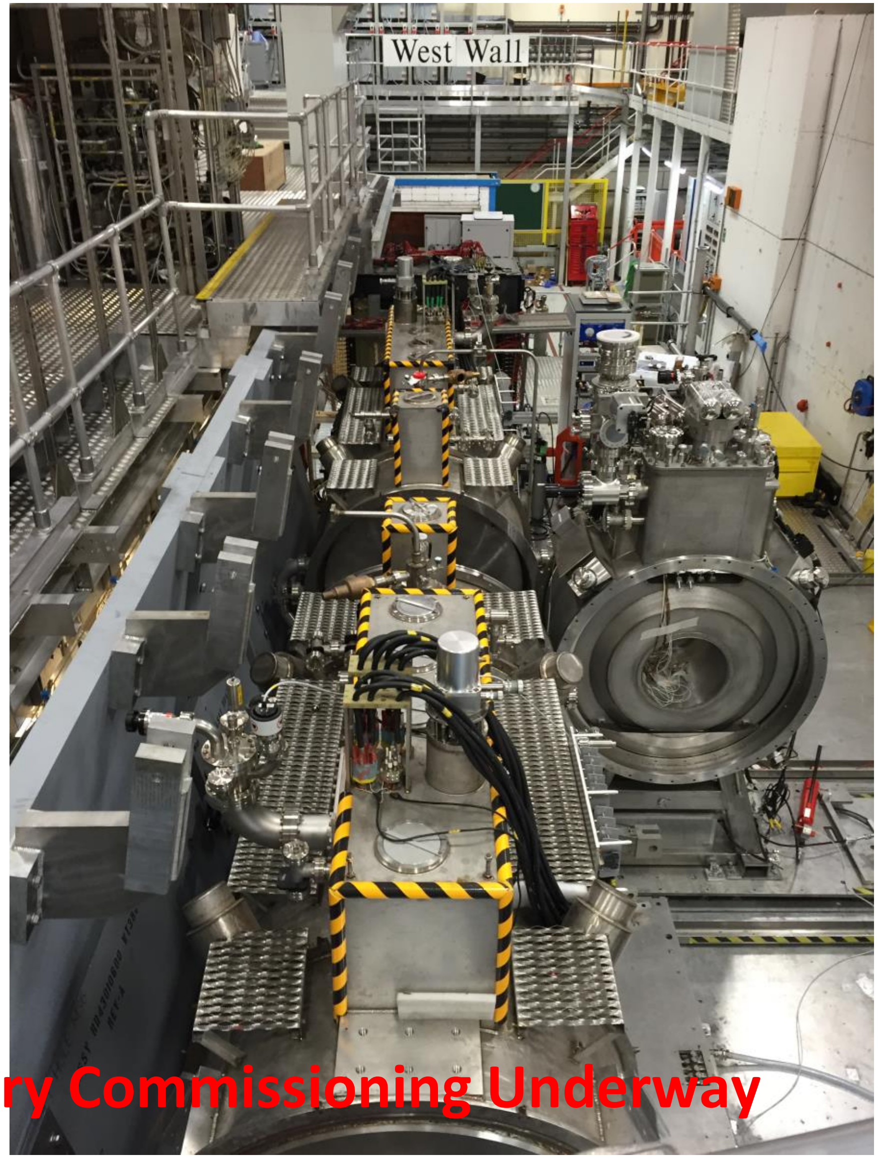
MICE Step IV:
Study of Absorber Materials





Demonstration of Muon Ionization Cooling (Re-baseline)

MICE Installation/Commissioning



Integration and Preliminary Commissioning Underway

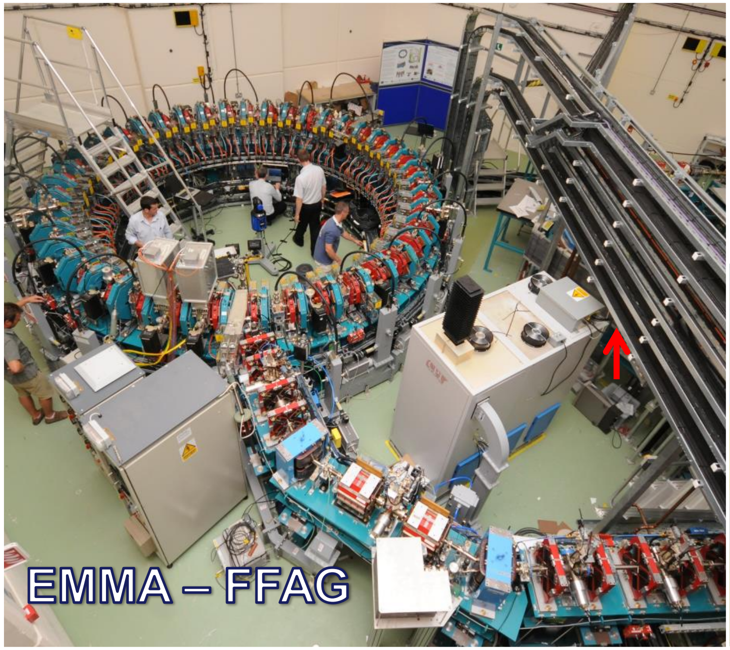
Technology Challenges - Acceleration

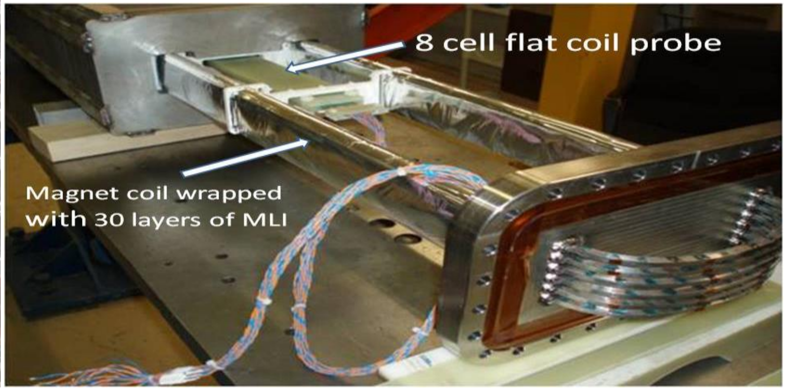
Muons require an ultrafast accelerator chain

⇨ ***Beyond the capability of "standard designs"***

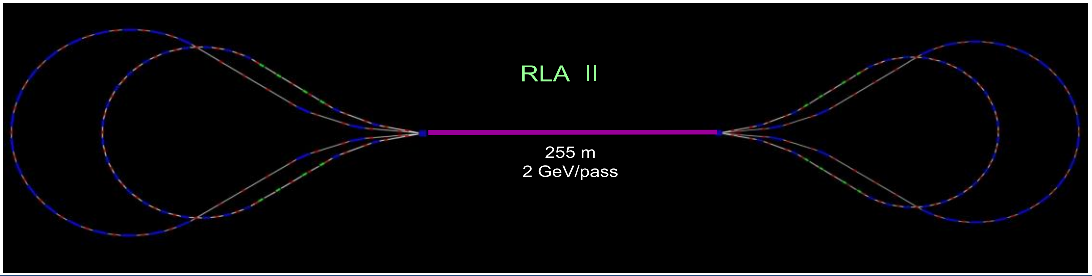
– Solutions include:

- Superconducting Linacs (NuMAX choice)
- Recirculating Linear Accelerators (RLAs)
- Fixed-Field Alternating-Gradient (FFAG) Rings
- Rapid Cycling Synchrotrons (RCS)





RCS requires 2 T p-p magnets at f ≥ 400 Hz (U Miss, BNL & FNAL)



JEMMRLA Proposal: JLAB Electron Model of Muon RLA with Multi-pass Arcs

MAP R&D Summary

- MASS process has developed a coherent and robust path towards muon accelerator capabilities
- Design & Simulation team has developed simulation codes and provided more detailed simulations leading to *realistic design concepts* for all sub-systems
  - With well-understood performance
  - Ready to move towards engineering designs and prototyping
- Technology R&D has yielded significant advances
  - Improved target system concepts
  - *A solution to the RF in magnetic field problem!*
  - HTS and pulsed magnet advances
  - The precursors to a 6D cooling channel engineering concept design
- The International Muon Ionization Cooling Experiment
  - Step IV hardware delivered and commissioning imminent
  - MICE RF Module
  - A clear path has been defined to complete the Ionization Cooling Demonstration
- A first formal machine proposal (νSTORM) has been prepared
- All represent major steps towards establishing feasibility!

It has been a privilege to work with such a talented team capable of making this much progress over such a short period

High energy muon accelerator capabilities are on much more solid footing than was the case just a few years ago!

Termination of US MAP

In light of the 2014 P5 recommendations that this directed facility effort no longer fits within the budget-constrained US research portfolio, we are now in a ramp-down phase

Nevertheless, muon accelerator capabilities offer unique potential for the future of high energy physics research

Starting in FY16, MAP funding is constrained to those activities which are core to completing the MICE Cooling Demonstration

- MICE Construction
- Remaining Critical R&D
- ½ year of MTA Funding
- MICE Experimental Support

Funding Profile

- FY16: \$6M a FY17: \$3M
- In FY18, MAP will **terminate, unfortunately.**

Dedicated JINST Volume

- It is important to HEP community to document the recent R&D advances as an achievable path to muon accelerator capabilities
- **Muon Accelerators for Particle Physics**

Abstract:

Muon accelerators offer unique potential for particle physics applications. The decay of muon beams within a storage ring can provide pure, well-characterized and intense neutrino beams for short- and long-baseline neutrino-oscillation studies – thus providing measurements of key parameters, such as the CP-violating phase, with unmatched precision and uniquely-sensitive probes for new physics. Muon beams are not subject to the synchrotron radiation and beamstrahlung limits imposed on electron-positron colliders because the muon mass is 200 times that of the electron. Thus muon beams can be accelerated to TeV-scale energies and stored in collider rings where the beams can interact for many revolutions. For center-of-mass energies >1 TeV, muon colliders provide the most power efficient route to providing a high luminosity lepton collider…

NEWS AND R&D HIGHLIGHTS FROM LBNL

New Name: Accelerator Technology & Applied Physics Division (ATAP) Organization Structure

Wim Leemans
Division Director

Soren Prestemon
Division Deputy, Technology

Asmita Patel
Division Deputy, Operations

Eric Esarey
Senior Scientific Advisor

ALS Accelerator Physics

David Robin, Head
Tom Scarvie, Deputy

Center for Beam Physics

John Byrd, Head
Derun Li, Deputy

Fusion Science Ion Beam Tech

Thomas Schenkel, Head
Peter Seidl, Deputy

Superconducting Magnets

Steve Gourlay, Head
Dan Dietreich, Deputy

LOASIS / BELLA

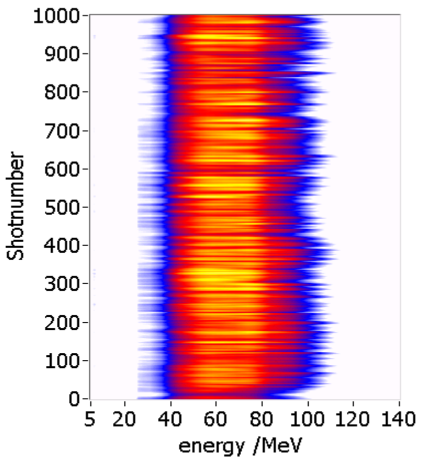
Wim Leemans, Head
Eric Esarey, Deputy

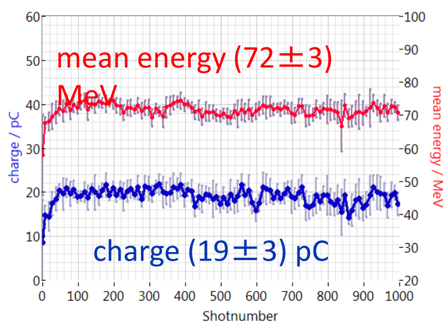
Special Projects

John Corlett, LCLS II
F. Sannibale, APEX

LBNL has succesfully achieved acceleration in a 2nd independently powered laser plasma accelerator

Stage I: gas jet

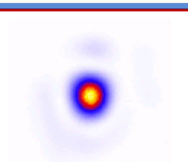


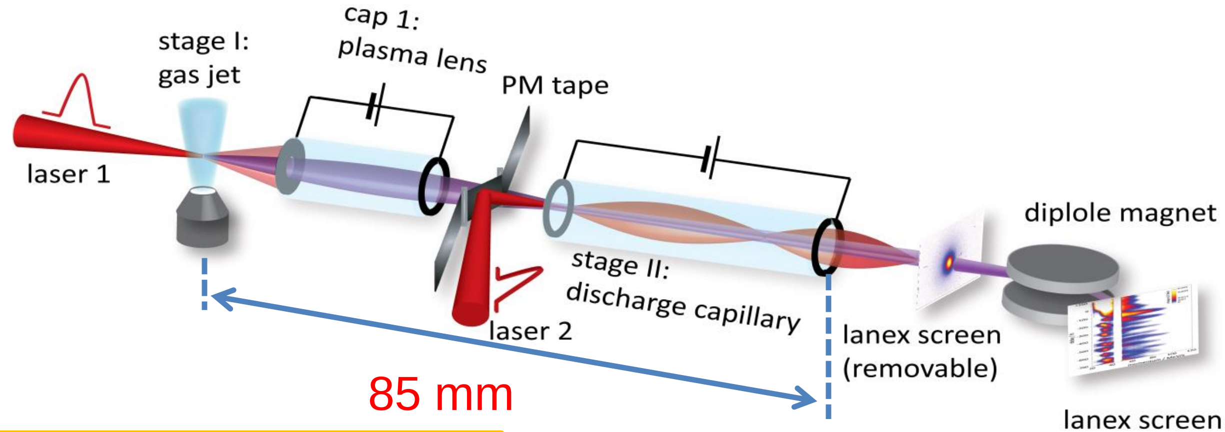


Steinke *et al.*, Nature 2016

PM

reflected mode





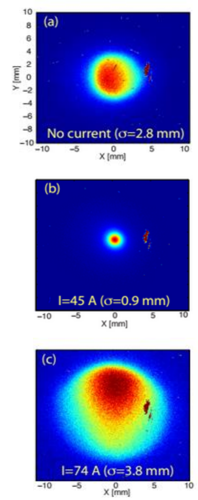
Active plasma lens

1.5 cm, up to 3,000 T/m

I = 0 A

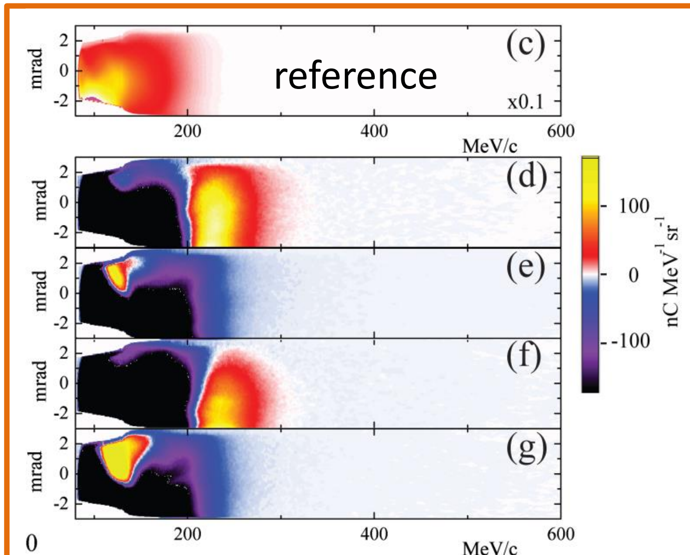
I = 45 A

I = 74 A

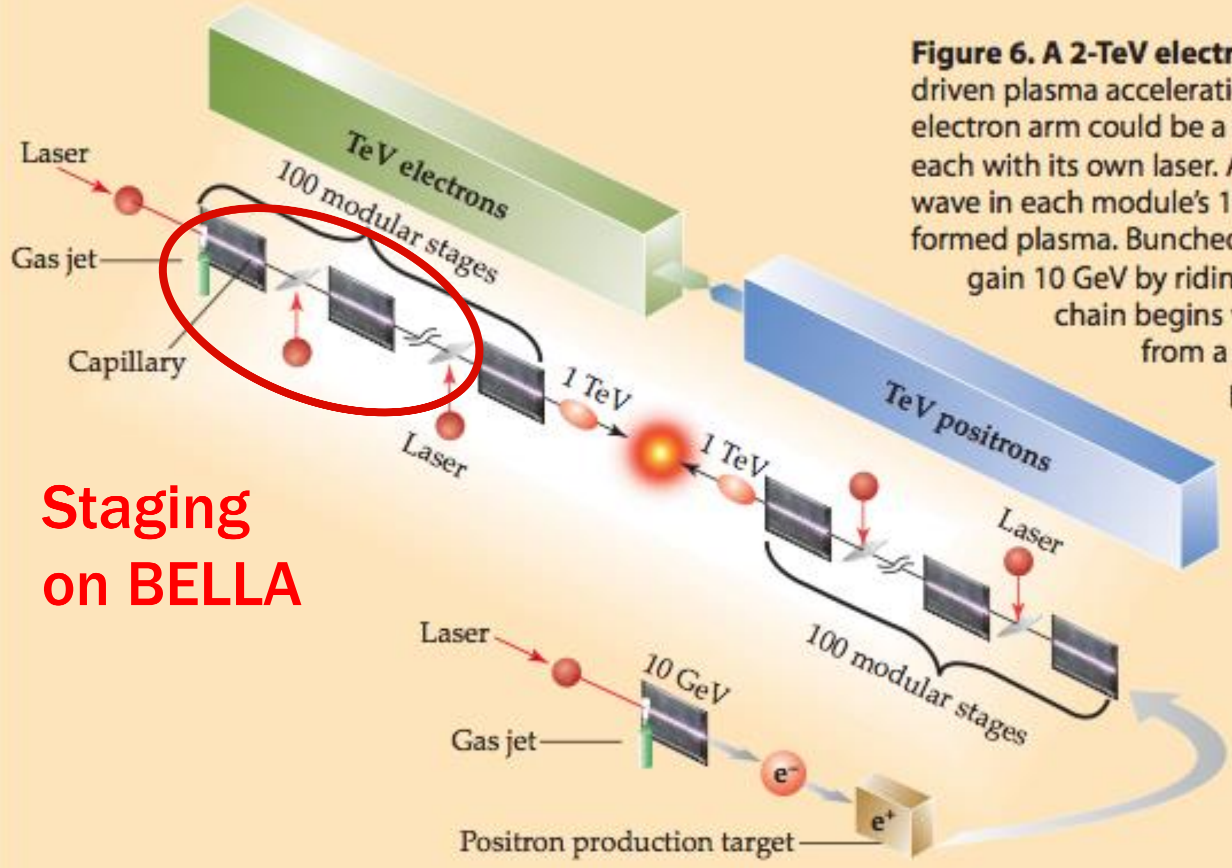


van Tilborg *et al.*, PRL 2015

Stage I + II



Steinke *et al.*, Nature 2016



Staging on BELLA

Figure 6. A 2-TeV electron–positron collider based on laser-driven plasma acceleration might be less than 1 km long. Its electron arm could be a string of 100 acceleration modules, each with its own laser. A 30-J laser pulse drives a plasma wave in each module's 1-m-long capillary channel of pre-formed plasma. Bunched electrons from the previous module gain 10 GeV by riding the wave through the channel. The chain begins with a bunch of electrons trapped from a gas jet just inside the first module's plasma channel. The collider's positron arm begins the same way, but the 10-GeV electrons emerging from its first module bombard a metal target to create positrons, which are then focused and injected into the arm's string of modules and accelerated just like the electrons.

feature article

Laser-driven plasma-wave electron accelerators

Wim Leemans and Eric Esarey

March 2009 Physics Today

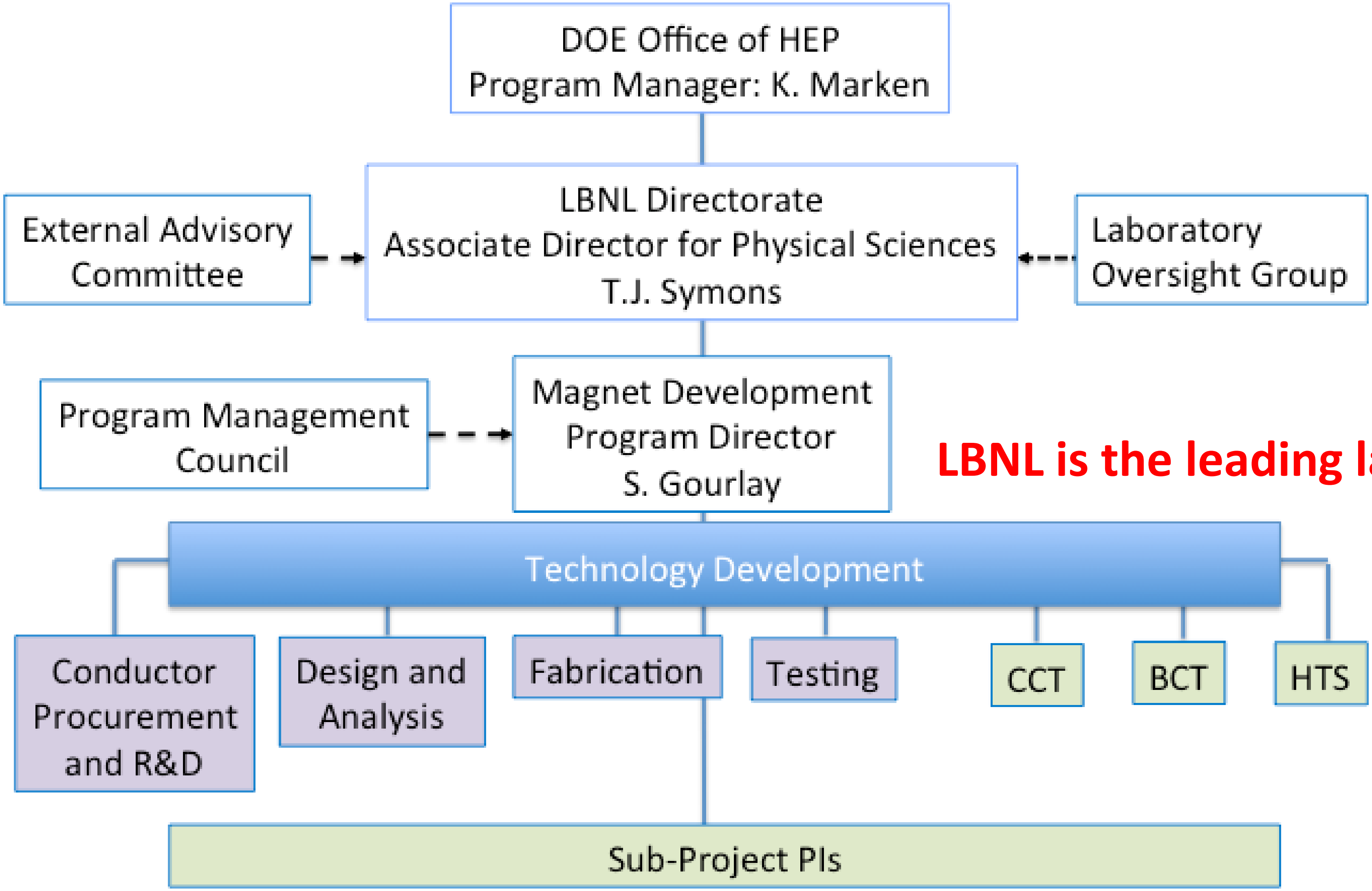
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 13, 101301 (2010)

Physics considerations for laser-plasma linear colliders

C. B. Schroeder, E. Esarey, C. G. R. Geddes, C. Benedetti, and W. P. Leemans
Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA

(Received 11 June 2010; published 4 October 2010)

Formation of National Magnet Development Program

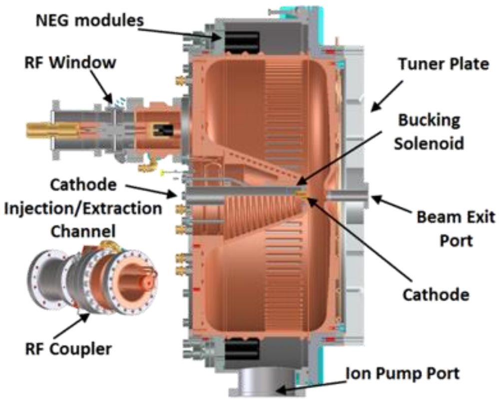


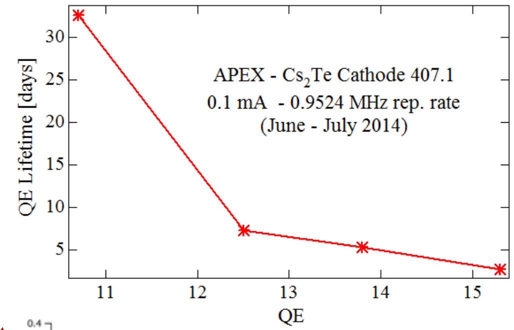
LBNL is the leading lab

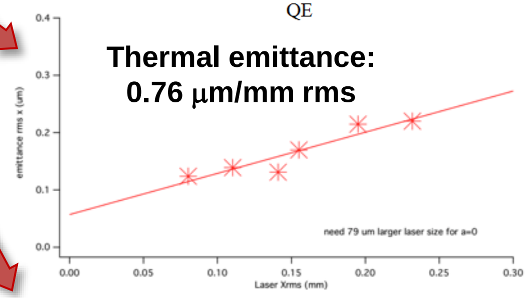
Input for Program Development – P5

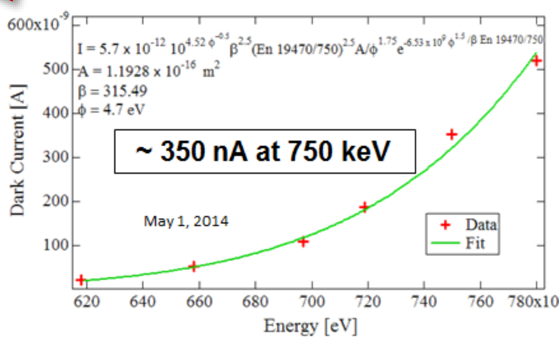
The P5 report states, "A very high-energy proton-proton collider is the most powerful future tool for direct discovery of new particles and inte ractions
under any scenario of physics results that can be acquired in the P5 Time window."
The report also says, "The U.S. is the world leader in R&D on high-field superconducting magnet technology, which will be a critical enabling technology for such a collider." In light of these observations, the P5 strategic plan endorses medium-term R&D on high-field magnets and materials in the context of its recommendation 24:
"Participate in global conceptual design studies and critical path R&D f or
future very high-energy proton-proton colliders. Continue to play a leadership role in superconducting magnet technology focused on the dual goals of increasing performance and decreasing costs."

APEX Highlights

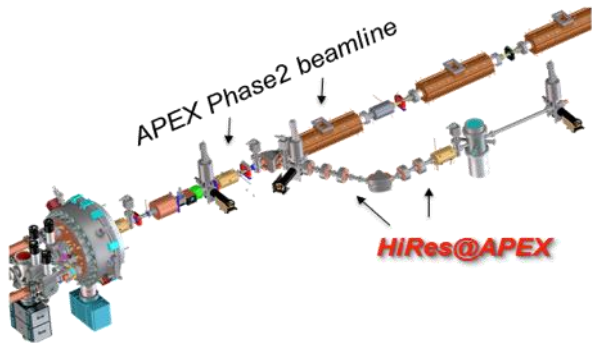






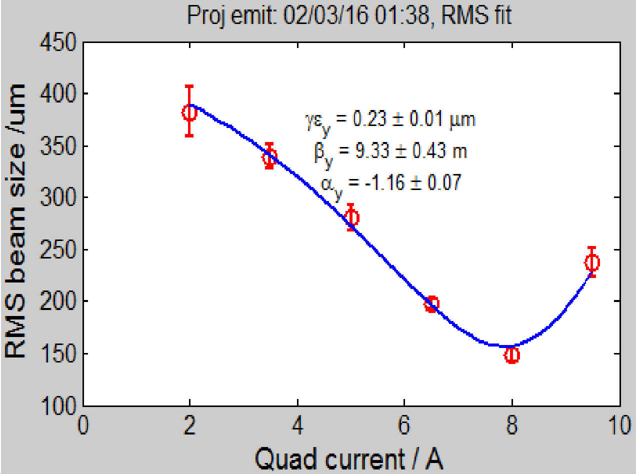


- LCLS-II baseline injector is based on the VHF gun
- APEX demonstrated most of the key performances for LCLS-II:
  - CW operation, cathode high field, current, beam energy
  - Cs_2Te cathode excellent lifetime & low intrinsic emittance
  - Sufficiently small dark current
  - Reliability and stability of operation

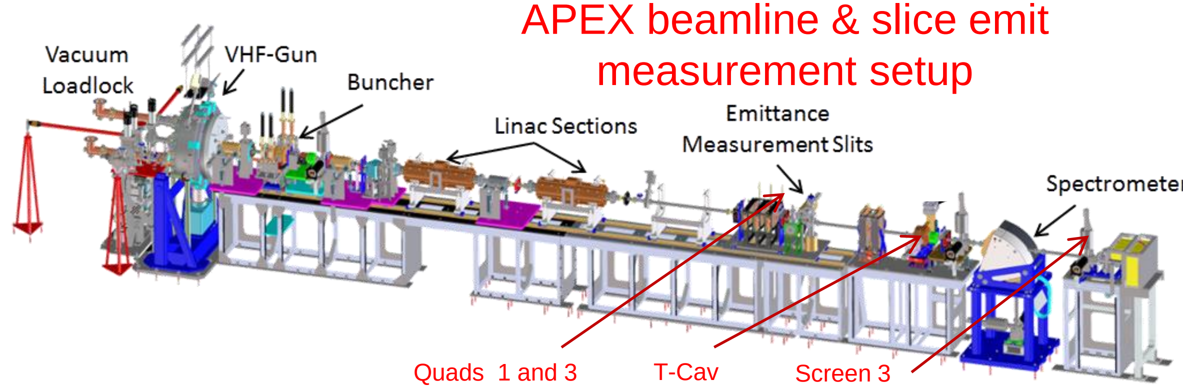


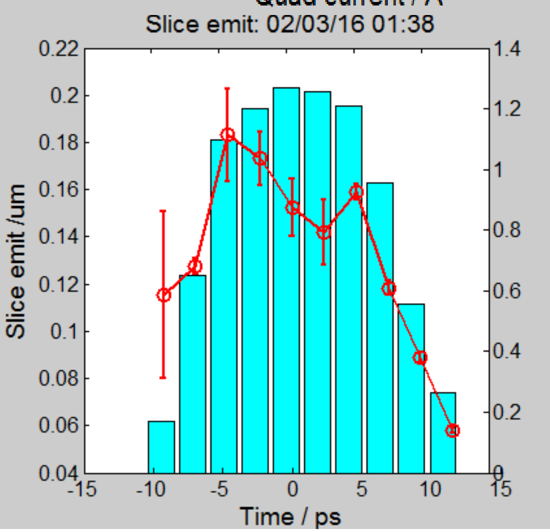
- Early Career Award to develop high-repetition rate ultrafast electron diffraction at APEX

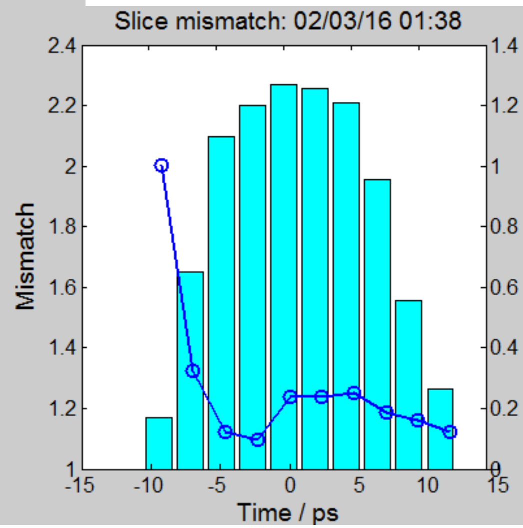
20 pC emittance and peak current: optimizations on going

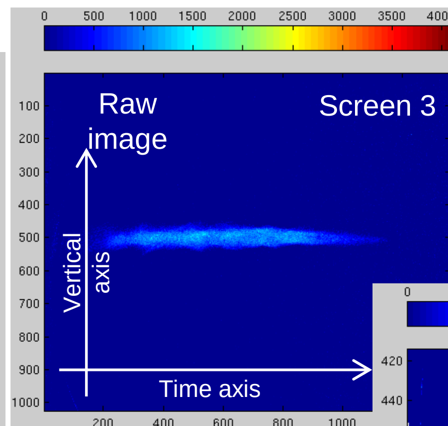


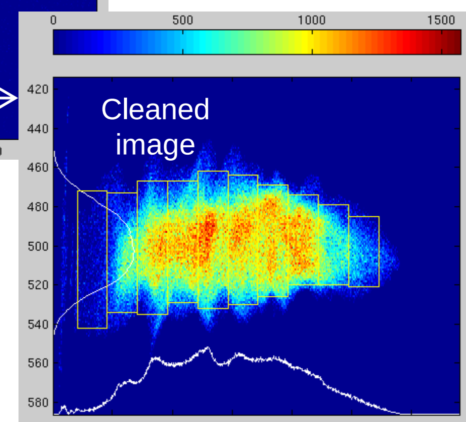
APEX beamline & slice emit measurement setup





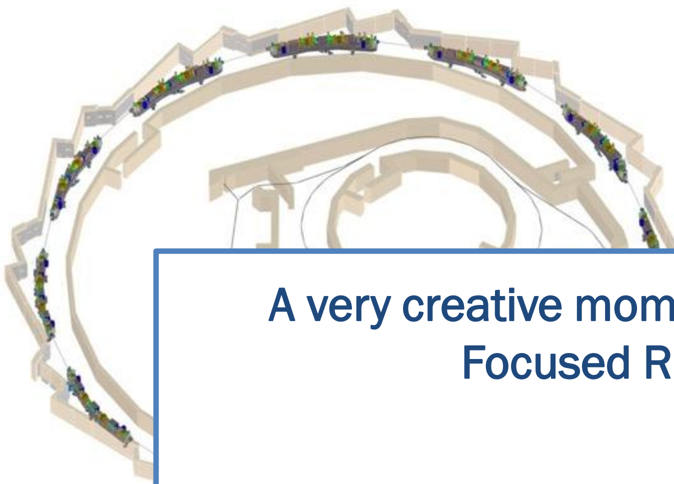


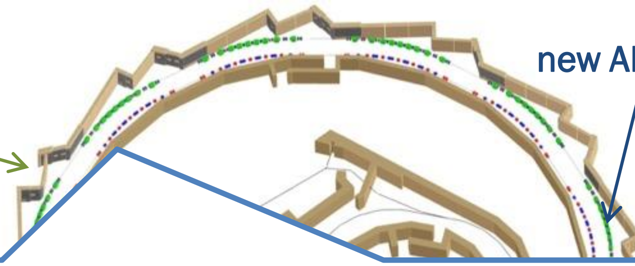




Measured ~0.16 µm slice emit. At 15.7 MeV (630 kV, 10 Hz, 18 ms ➔18% DF at gun and 10 Hz rep. rate of Laser and Linac) and ~1.2 A peak current. (LCLS-II needs 0.2 µm and ~ 3-4 A)

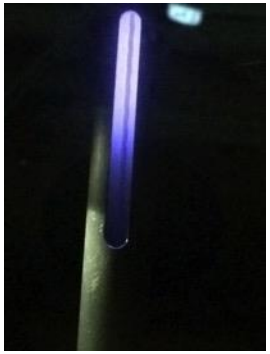
Diffraction-limited Advanced Light Source: A Major Breakthrough in Control of Electrons and Photons



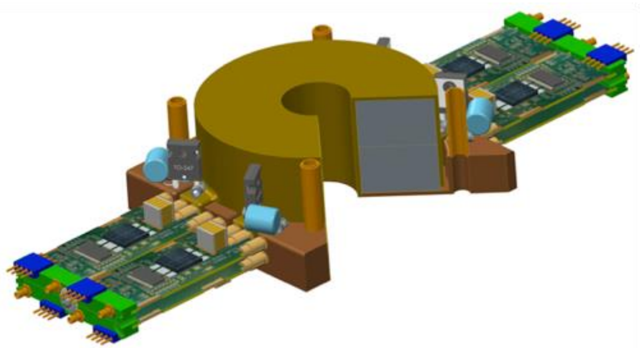


A very creative moment for accelerator physics and technology
Focused R&D for ALS-U will also help APS-U

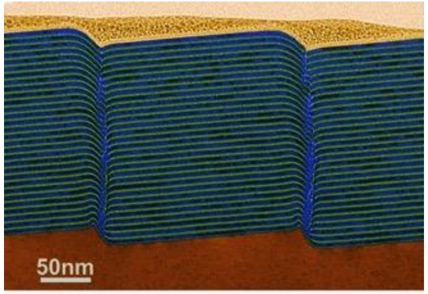
Vacuum for *very* small diameters

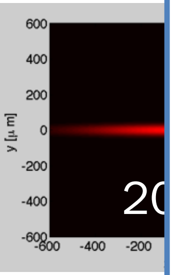


On-axis injection



Brightness preserving photon optics





Upgrad
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Summary

- **Overview of the US accelerator-based HEP programs & P5**
  - PIP-II
  - MAP/MICE
- **LBNL Accelerator R&D**
  - Newly formed national magnet development center
  - Laser plasma accelerator
  - LCLS-II and APEX
  - ALS accelerator physics
- **Concluding comments**
  - Accelerator Physics and Technology is a science and needs huge investment and time for development;
  - Technology development is an R&D program and should allow for failure;
  - Failure defines the edge of the envelope;
  - 人才引进、培养和提拔（体制）should consider 技术科研人员对科学研究项目和技术发展的贡献，NOT ONLY Paper publications! 以吸引更多的优秀人才加入到我们的队伍。