ECT*

EUROPEAN CENTRE FOR THEORETICAL STUDIES
IN NUCLEAR PHYSICS AND RELATED AREAS
TRENTO, ITALY
Institutional Member of the ESF Expert Committee NuPECC

# Perspectives for muon colliders and neutrino factories

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LFC15: Physics prospects for Linear and other
Future Colliders after the discovery of the Higgs
Trento, September 7-11, 2015

# Outline

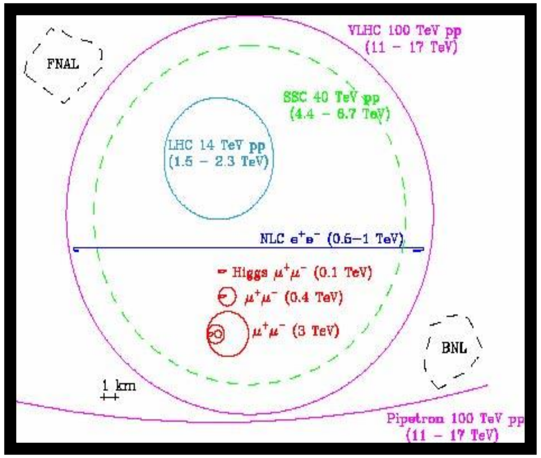
- introduction: high intensity and high brightness muon beams
- The Neutrino factory (NF) concept
- The Muon collider (MC) concept
- R&D towards NF and MC
    - Proton drivers
    - Targetry
    - Beam handling
    - Ionization cooling
- The MICE ionization cooling experiment at RAL
- Conclusions

# Why muon beams

- **Muon beams have potential to :**
  - Serve neutrino physics with intense beams ($\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$) that have equal fractions of electron and muon neutrinos at high intensity with a precisely known energy spectrum - Studies of neutrino oscillations: the Neutrino Factory (NF) concept
  - Muon collisions offer a large coupling to the "Higgs mechanism" (Higgs factory)

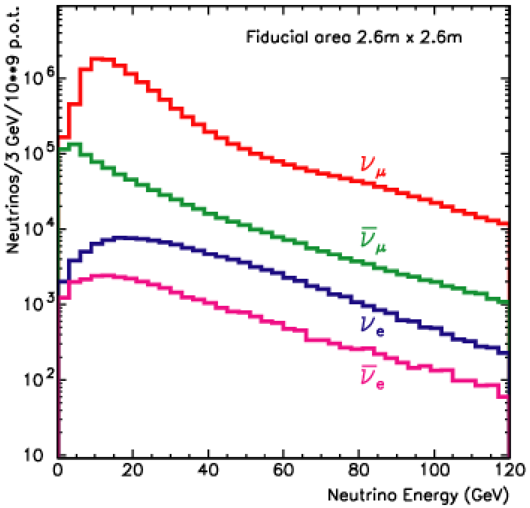
$$\sim \left( \frac{m_\mu^2}{m_e^2} \right) \cong 4 \times 10^4$$

  - As with an $e^+e^-$ collider, a $\mu^+\mu^-$ collider would offer a precision probe of fundamental interactions
    - With extremely small energy spread;
    - Most effective way to achieve $E_{cm}$ > 1 TeV
    - Small footprint to fit inside existing HEP labs



# ν beams: conventional and NF beams

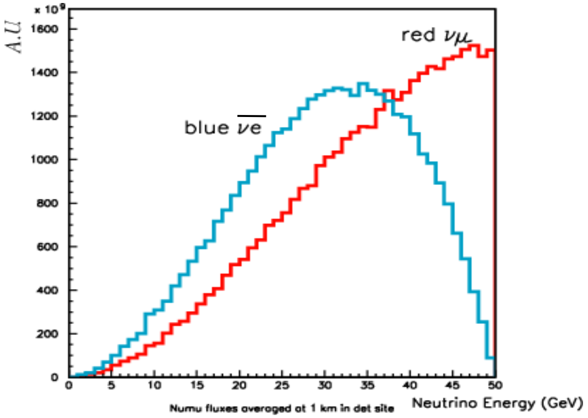
**WANF (conventional ν beam at SPS)**



- Problem in conventional ν beams: a lot of minority components (beam understanding)
- Following muon collider studies, accelerated muons are ALSO an intense source of “high energy” ν

$$\mu^- \to e^- \nu_\mu \bar{\nu}_e \qquad \mu^+ \to e^+ \bar{\nu}_\mu \nu_e$$

**NUFACT beam**



- Crucial features:
- ☐ high intensity (x 100 conventional beams)
- ☐ known beam composition (50% $\nu_\mu$ 50% $\nu_e$)
- ☐ Possibility to have an intense $\nu_e$ beam
- Essential detector capabilities:

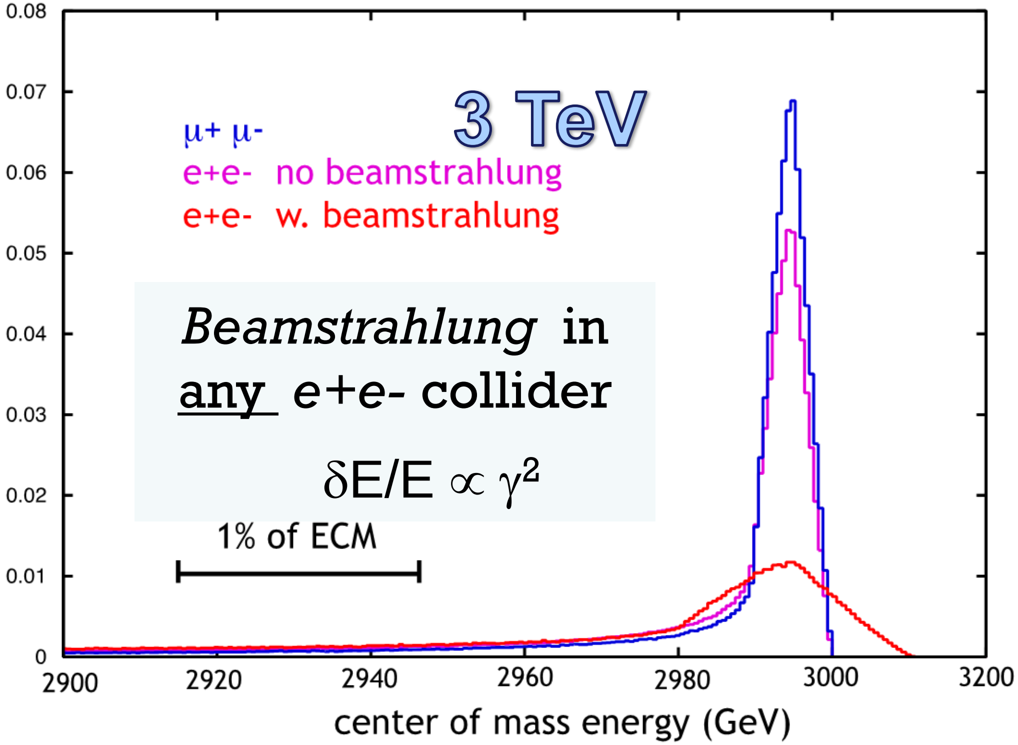
detect μ and determine their sign

# Applications outside HEP

- Of course the potential applications for high intensity muon sources go beyond high energy physics
  - Muon radiography
  - Atomic and nuclear physics applications, for example…
    - Catalysis of atomic and molecular reactions
    - Nuclear reactions
    - Muon capture studies of radiological materials
  - ……

# Key points

- μ – an elementary charged lepton:
  - 200 times heavier than the electron
  - 2.2 μs lifetime at rest
- The large muon mass strongly suppresses synchrotron radiation
  - ➪ Muons can be accelerated and stored using rings at much higher energy than electrons
  - ➪ Colliding beams can be of higher quality with reduced beamstrahlung



# Key points (II)

- Impacts of the short muon lifetime
  - Acceleration and storage time of a muon beam is limited
  - Collider ⇨ a new class of decay backgrounds must be dealt with
- For a collider, beam energy measurement by g-2 method ⇨ precision Higgs mass/width determination

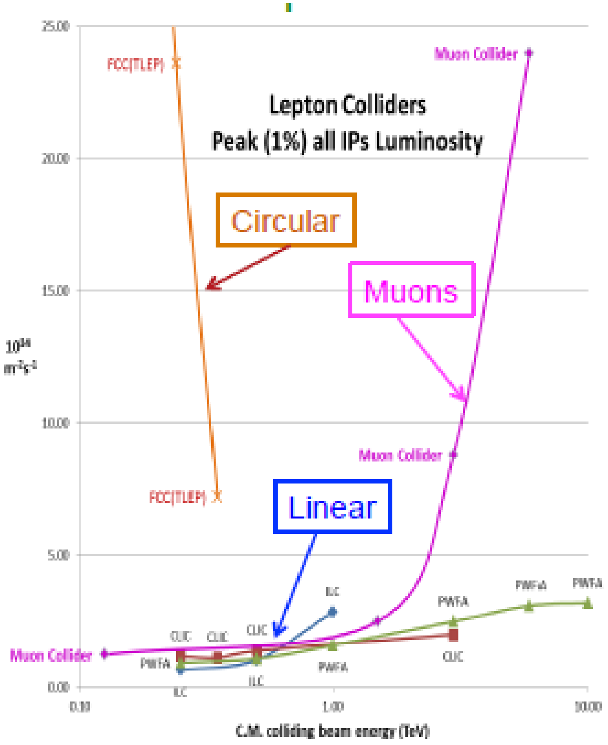
- Muon beams produced as tertiary beams:

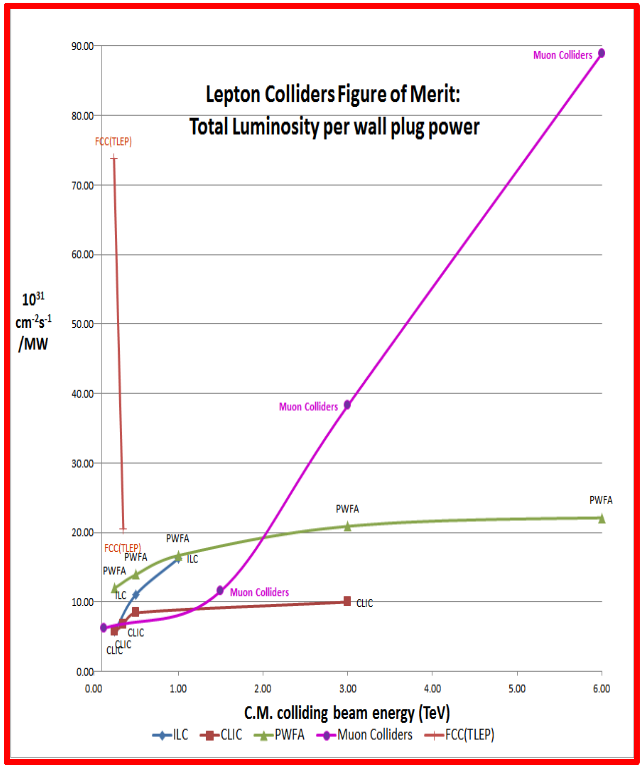
$p \rightarrow p \rightarrow m$

  - Offers key accelerator challenges…
  - It is more than 50 years that S. Van der Meer invented the magnetic horn to improve the performances of neutrino beam production at accelerators
  - We have not yet moved beyond this paradigm and NF may be a big step further

# Lepton collider comparison

Negligible radiative effects and multiple interaction regions, makes muons the lepton of choice for multi-TeV collider

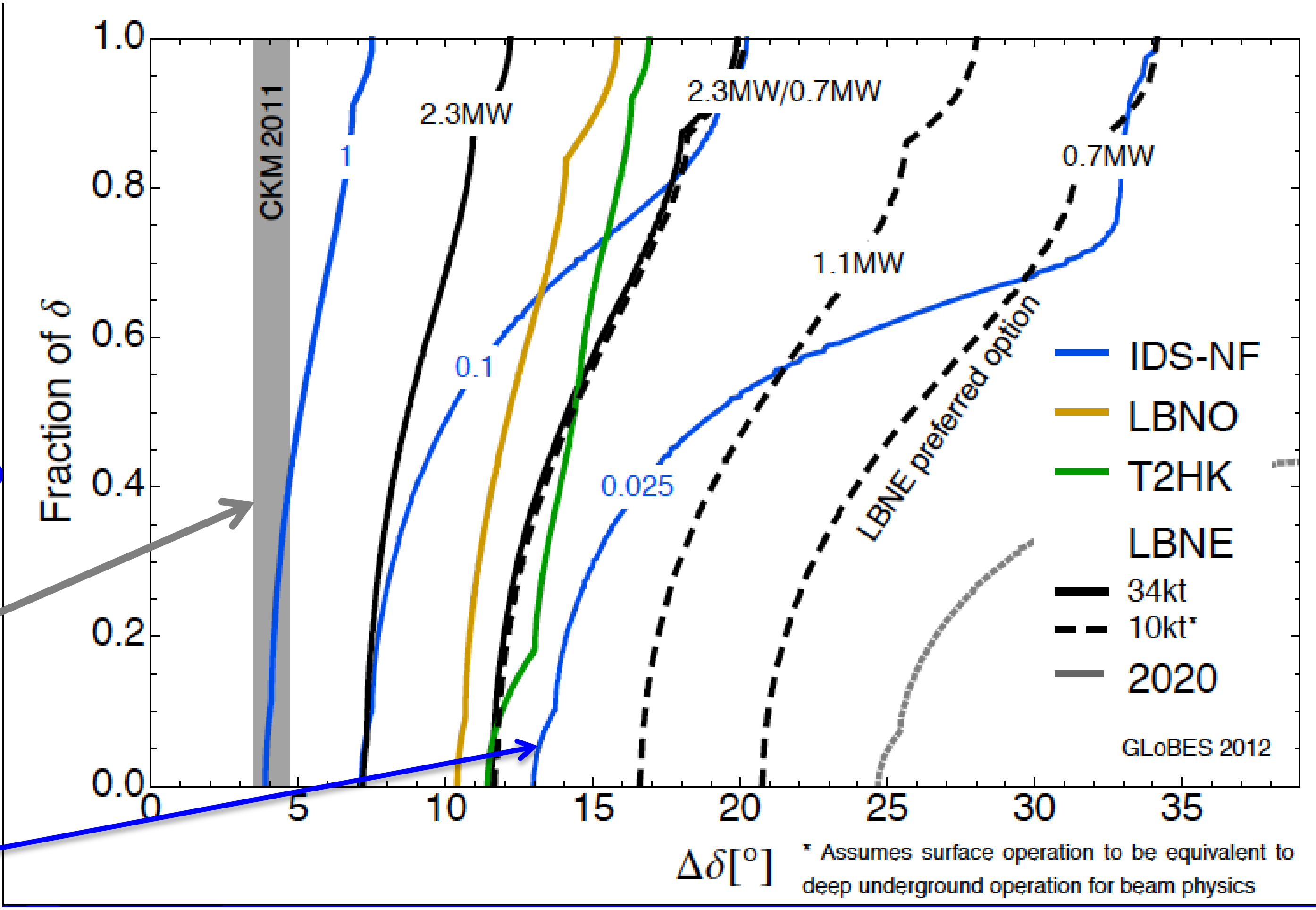




# HEP Motivations: Neutrinos

- CP violation physics reach of various facilities

Can we probe the CP violation in the neutrino sector at the same level as in the CKM Matrix?



* Assumes surface operation to be equivalent to deep underground operation for beam physics

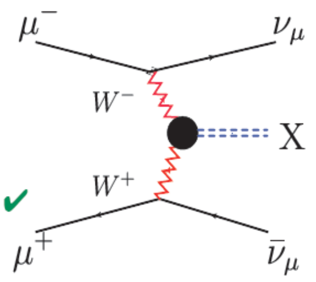
Measurement sensitivity in the quark sector

0.025 IDS-NF:
700kW target,
no cooling,
$2\times10^{8}$ s running time
10-15 kTon detector

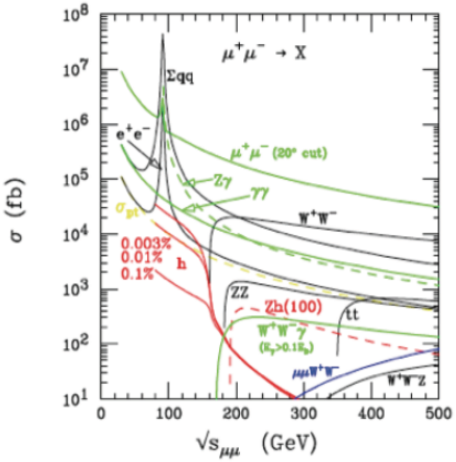
# HEP Motivations: Colliders

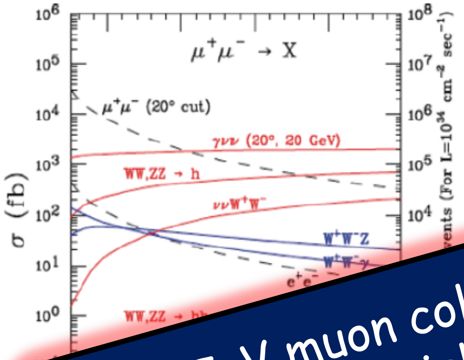
- For √s < 500 GeV
  - SM thresholds: $Z^0h$ ,$W^+W^-$, top pairs
  - Higgs factory (√s≈ 126 GeV) ✔
- For √s > 500 GeV
  - Sensitive to possible Beyond SM physics.
  - High luminosity required. ✔
    - Cross sections for central (| θ | > 10°) pair production ~ R × 86.8 fb/s(in $TeV^2$) (R ≈ 1)
    - At √s = 3 TeV for 100 $fb^{-1}$ ~ 1000 events/(unit of R)
- For √s > 1 TeV
  - Fusion processes important at multi-TeV MC

$$\sigma(s) = C\ln(\frac{s}{M_X^2}) + \ldots$$



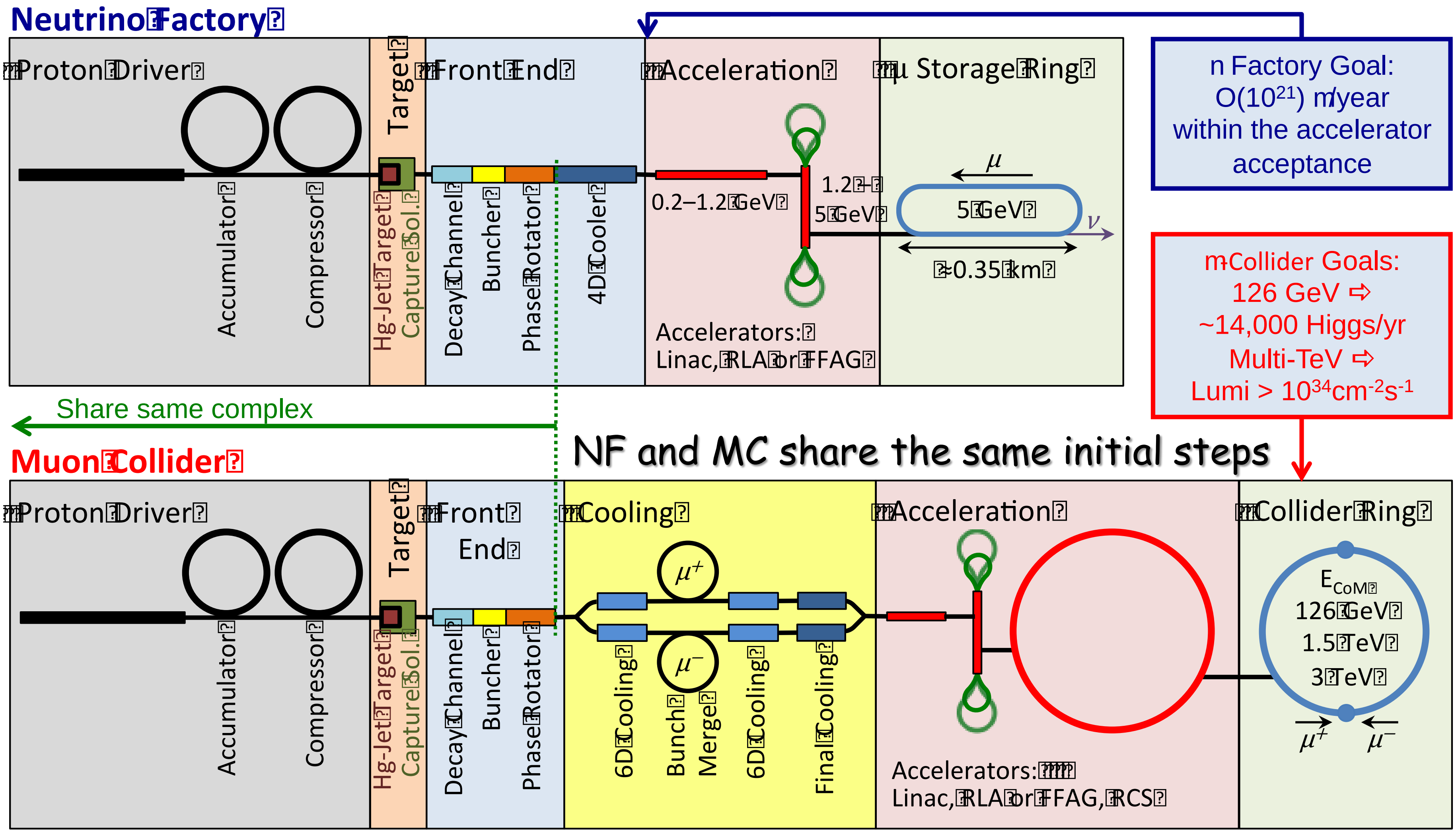
  - An Electroweak Boson Collider ✔





A ~10 TeV muon collider provides discovery potential for BSM processes in the EW sector that can exceed that of a 100 TeV pp machine

# The US Muon Accelerator Program (MAP)



n Factory Goal:
O($10^{21}$) m/year
within the accelerator
acceptance

m-Collider Goals:
126 GeV ⇨
~14,000 Higgs/yr
Multi-TeV ⇨
Lumi > $10^{34}$cm$^{-2}$s$^{-1}$

NF and MC share the same initial steps

# A COMPLETE DEMONSTRATOR OF A COOLED-MUON HIGGS FACTORY

**Monday, 18 May 2015 at 3:30 pm**
**Fermilab, Ramsey Auditorium**

In analogy with the discovery of the W and Z with hadrons and the subsequent study of the Z resonance in the pure s-state with LEP, the recent discovery of the Higgs particle of 125 GeV has revised the interest in the so-called second generation Higgs factory. However the direct production of the $H^o$ scalar resonance in the s-state has a remarkably small, narrow width, since $\Delta E/E < 4$ MeV / 125 GeV = $3.2 \times 10^{-5}$. We describe here a $\mu^+\mu^-$ collider at a modest energy of 62.5 GeV and the adequate cooled muon intensity of about $6 \times 10^{12}$ muons of each sign, a repetition rate of 15-50 p/s and $L \approx 10^{32}$ cm$^{-2}$ s$^{-1}$, corresponding to about 10'000 $H^o$ for each detector x year. Its partial widths can be studied with remarkable accuracies. With the help of the decay frequency of the polarized muon decay electrons, the $H^o$ mass itself can also be measured to about ±100 keV, i.e. $\Delta m/m \approx 10^{-6}$.

The next modest step, prior to but adequate for the subsequent $H^o$ physics programme, could be the practical realization of an appropriate *muon cooling demonstrator*. Starting from a conventional pion beam, the required longitudinal and transverse emittances are achieved with a cascade of two unconventional but very small muon rings of few meters radius. Low momentum muons of about 250 MeV/c, initially with $\Delta p/p \approx 0.1$, are cooled in a first ring, extracted and ionization cooled to about 70 MeV/c, and cooled ultimately in a second small ring up to a longitudinal momentum spread of 0.7 MeV/c r.m.s. The operation of the demonstrators may be initially explored and fully demonstrated with the help of a modest muon beam already available in a number of different accelerators.

The additional but relatively conventional components necessary to realize the facility with the appropriate muon current and luminosity should then be constructed only after this *initial cooling experiment* has been successfully demonstrated. The ultimate $\mu^+\mu^-$ collider for a Higgs Factory may be situated within the existing CERN site or elsewhere.

**Nobel Laureate**

# Prof. Carlo Rubbia

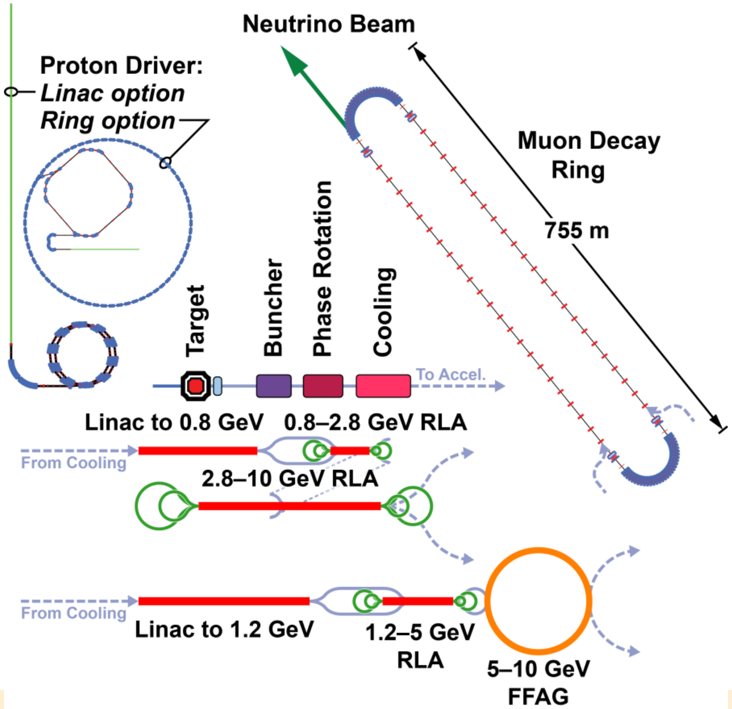
Muon Accelerator Program

U.S. DEPARTMENT OF ENERGY | Office of Science

Fermilab

http://map.fnal.gov/events/CarloRubbia.shtml

# Neutrino Factory a closer look
# *(International Scoping Study baseline)*



**S.Choubey et al., Design Study, IDS-NF-20 (arXiv:1112.2853) and updates**

**NF may be considered technology ready: MERIT, MuCool, MICE, EMMA**

neutrino factory:
accelerate muons and store to produce neutrinos

$$\boxed{\mu^+ \longrightarrow e^+ \nu_e \overline{\nu}_\mu}$$

- Flux known to 1% or better
- High energy electron neutrinos

**Golden Channel:**
long baseline oscillation manifests itself by wrong sign muons:

$$\boxed{\nu_e \rightarrow \nu_\mu \, ; \, \nu_\mu + N \longrightarrow \mu^- + X}$$

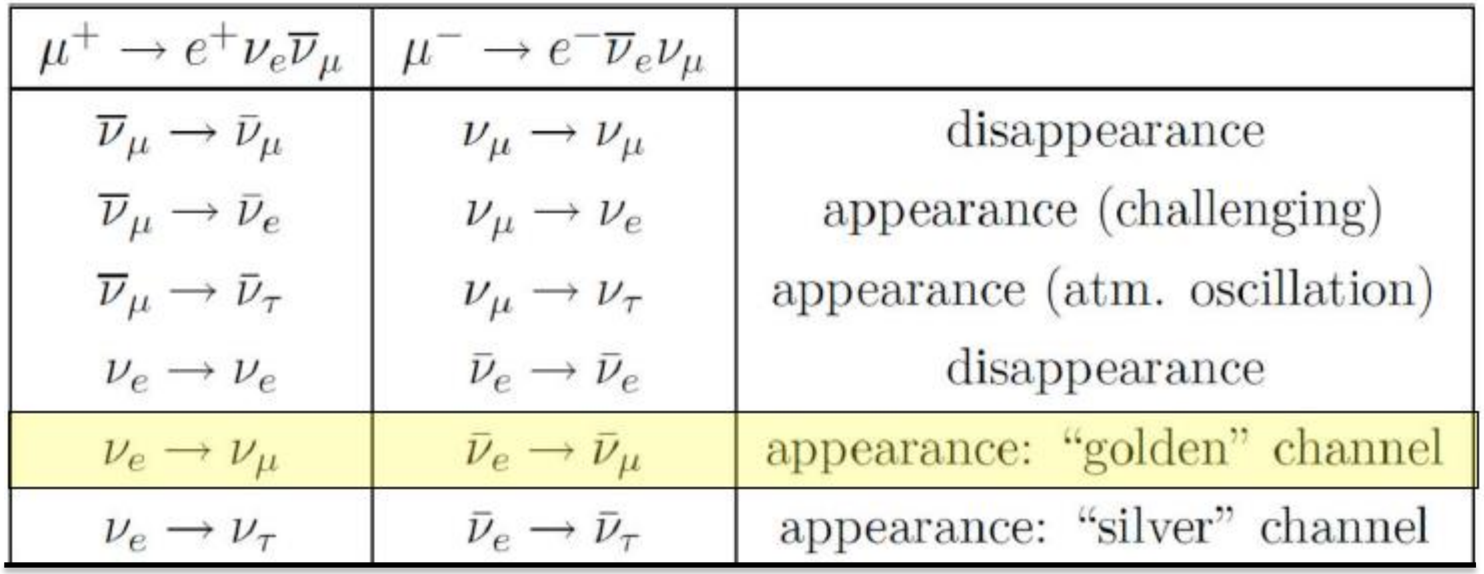
Large (100 kton) magnetized iron detector
Unique ability to test $\nu_e \rightarrow \nu_\tau$

# *The NF landscape*

- ☐ Study 1 (US-Fermilab) [2000]
- ☐ Study 2 (US-BNL) [2001]
- ☐ Nufact-Japan study [2001]
- ☐ CERN NF study [2002]
- ☐ Study 2a (APS Neutrino Study) [2004]
- ☐ ISS (first international study; ISS group) [2006]
- ☐ International Design Study for a Neutrino Factory (IDS-NF) [2013]

**During this period the physics landscape changed dramatically**

# Oscillation channels accessible at NF

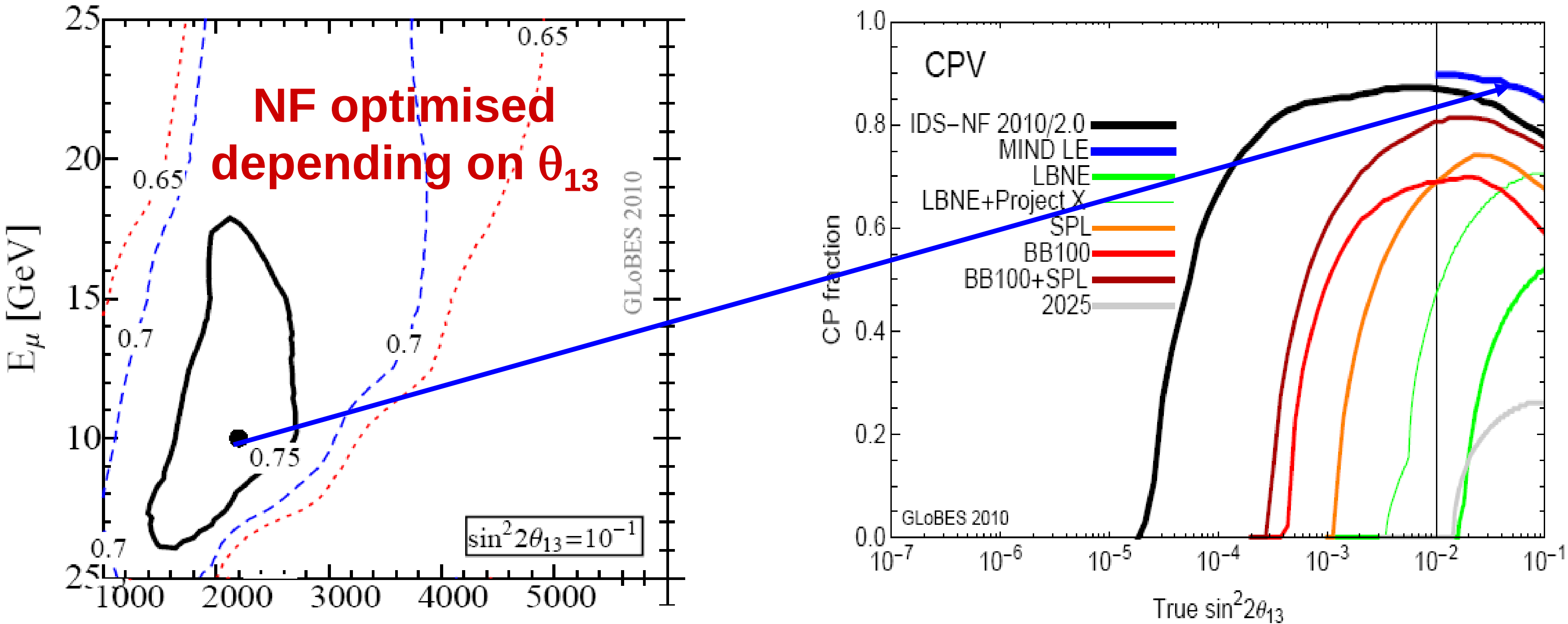


| $\mu^+ \to e^+ \nu_e \overline{\nu}_\mu$ | $\mu^- \to e^- \overline{\nu}_e \nu_\mu$ |  |
|---|---|---|
| $\overline{\nu}_\mu \to \bar{\nu}_\mu$ | $\nu_\mu \to \nu_\mu$ | disappearance |
| $\overline{\nu}_\mu \to \bar{\nu}_e$ | $\nu_\mu \to \nu_e$ | appearance (challenging) |
| $\overline{\nu}_\mu \to \bar{\nu}_\tau$ | $\nu_\mu \to \nu_\tau$ | appearance (atm. oscillation) |
| $\nu_e \to \nu_e$ | $\bar{\nu}_e \to \bar{\nu}_e$ | disappearance |
| $\nu_e \to \nu_\mu$ | $\bar{\nu}_e \to \bar{\nu}_\mu$ | appearance: “golden” channel |
| $\nu_e \to \nu_\tau$ | $\bar{\nu}_e \to \bar{\nu}_\tau$ | appearance: “silver” channel |

12 channels accessible if $E_\nu$ is above the $\tau$ threshold

# Neutrino Factory optimisation

- Neutrino Factory optimisation depends on value of $\theta_{13}$
- At $\sin^2 2\theta_{13}$~0.1 optimum is ~10 GeV NF with ~2000 km baseline
- Neutrino Factory offers best sensitivity and smallest $\Delta\delta_{CP}$ ~ $5^o$ out of all future facilities



**NF optimised depending on $\theta_{13}$**

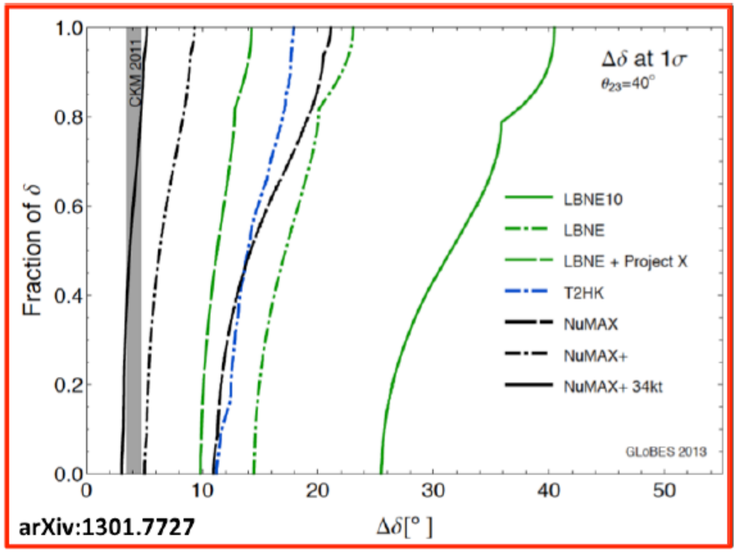
# Near detector physics at NF

- **Not a primary focus of any NF design study, but far reaching physics potential**

- **Some examples:**
    - Cross section measurements: DIS, QES, RES scattering
    - Exhaustive study of $\nu_e$ and $\nu_e$ interactions
    - $\sin^2\theta_W$ : $\delta \sin^2\theta_W \sim 0.0001$
    - Parton distribution functions, nuclear shadowing
    - Charm production $|V_{cd}|$ and $|V_{cs}|$, $D^0/D^0$ mixing
    - Polarised structure functions
    - $\Lambda$ polarization
    - Beyond SM searches: tests of $\nu_\mu - \nu_e$ universality, heavy $\nu$, ...

# *NF results within the SνM*

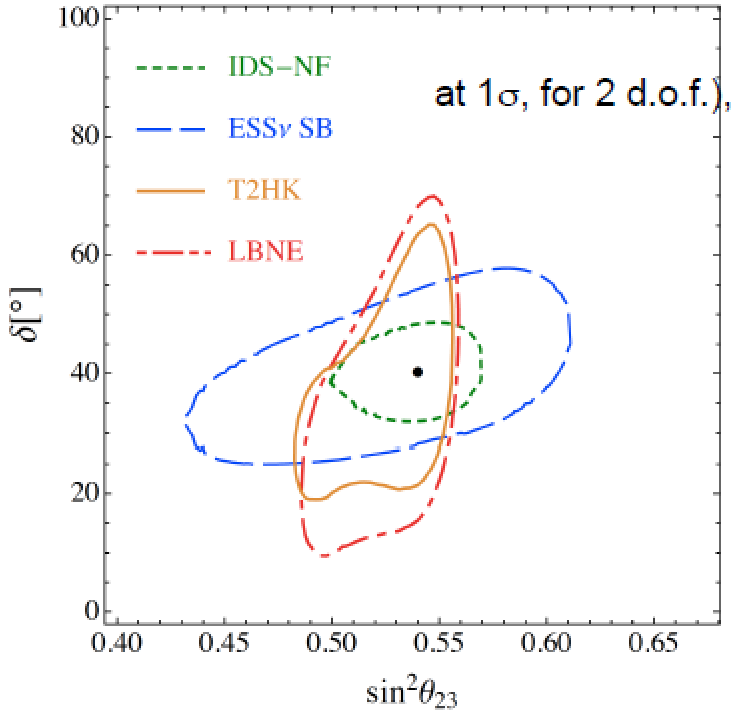
- ☐ Following DUNE/HyperK LBL experiments much of the SνM will be studied exaustively
- ☐ But NF can :
  - Improve the measurement of $\delta$
  - Measurement of $\theta_{23}$ ….



arXiv:1301.7727

Precision on $\delta$

# $\theta_{23}$

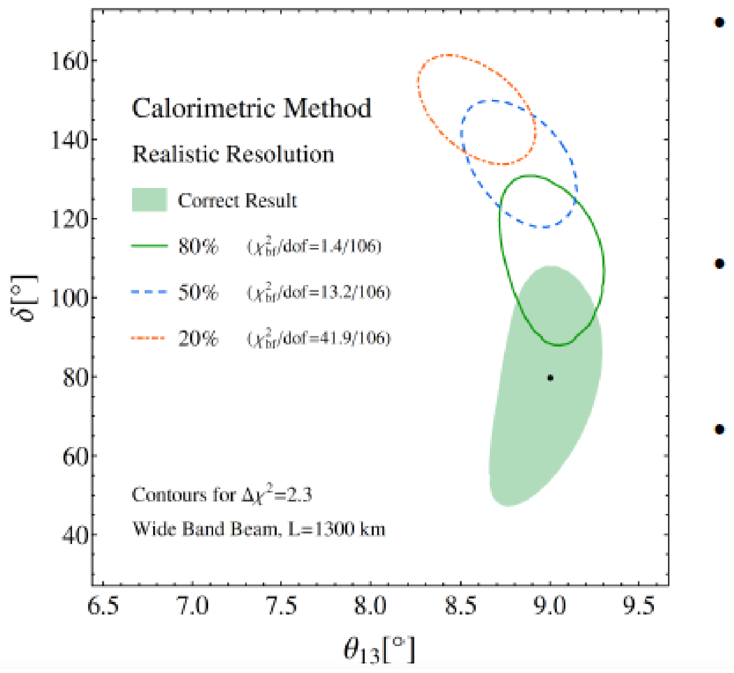


at 1σ, for 2 d.o.f.),

Coloma *et al.*, arXiv1406.2551v1

**Potential contribution of NF in the DUNE/HyperK era**

# Effects of systematics: an example



Ankowski *et al.*, arXiv:1507.08561v1

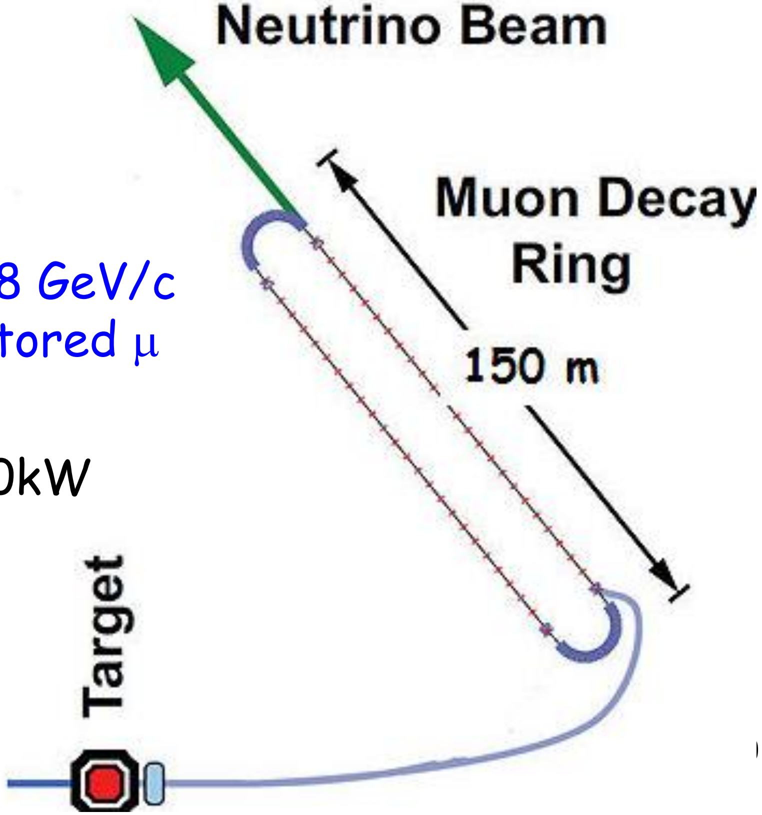
- Plot to right shows the affect on determining $\delta$ if the missing E in an event is underestimated by 20%, 50% and 80% in a “DUNE-like” detector
- Near detectors and test beam will help, but a more accurate understanding of $\nu$ interactions may be needed
- This is a detector effect and, of course, applies to all facilities.
  - However, the NF has the advantage of the Golden Channel
    - Muon neutrino final state
      - Flexibility/Robustness

# An entry level NF ? NuSTORM

*Neutrino Factory Light*: conventional target + horn, pion capture & then injection into a ring

Annual Reviews of Nuclear and Particle Science, Volume 65, Adey *et al.*

DOES NOT
Require the
Development of
ANY
New Technology



3.8 GeV/c
stored μ

10-100kW

## $\nu$STORM

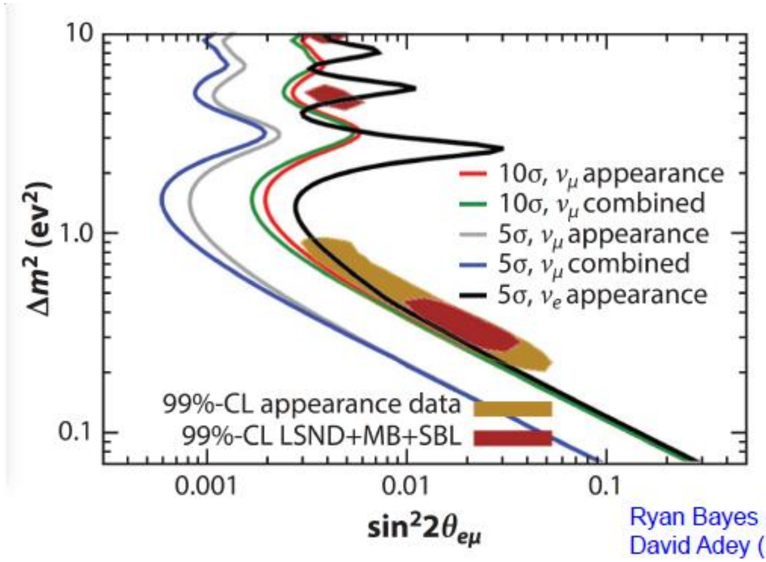
Low energy, low luminosity muon storage ring. Provides with $1.7 \times 10^{18}$ $\mu^+$ stored, the following oscillated event numbers

| | |
|---|---|
| $\nu_e \to \nu_\mu$ CC | 330 |
| $\bar{\nu}_\mu \to \bar{\nu}_\mu$ NC | 47000 |
| $\nu_e \to \nu_e$ NC | 74000 |
| $\bar{\nu}_\mu \to \bar{\nu}_\mu$ CC | 122000 |
| $\nu_e \to \nu_e$ CC | 217000 |

and each of these channels has a more than $10\,\sigma$ difference from no oscillations

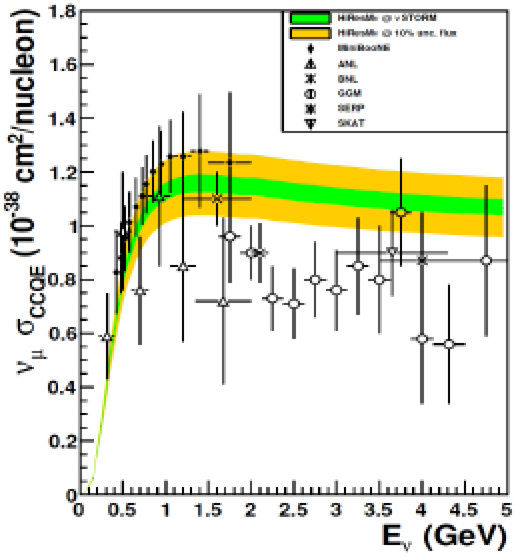
With more than 200 000 $\nu_e$ CC events a %-level $\nu_e$ cross section measurement should be possible

# NuSTORM physics reach



Ryan Bayes (Glasgow)
David Adey (Fermilab)

Sterile ν search

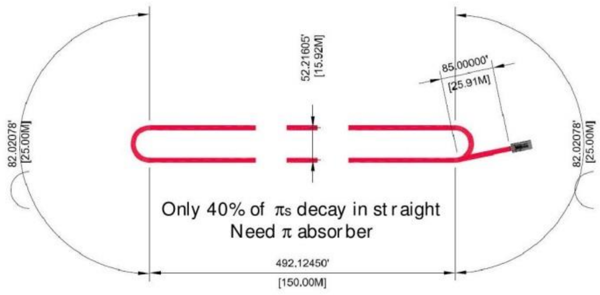


Data for $\nu_\mu$ and $\bar{\nu}_e$ interactions

# νStorm as an Accelerator R&D Platform

- A high-intensity pulsed muon source
- $100<p_\mu<300$ MeV/c muons
  - Using extracted beam from ring
  - $10^{10}$ muons per 1 μsec pulse

- Beam available simultaneously with physics operation
  - Sterile ν search
  - ☐ ν cross section measurements needed for ultimate precision in long baseline measurements



DECAY RING - PLAN

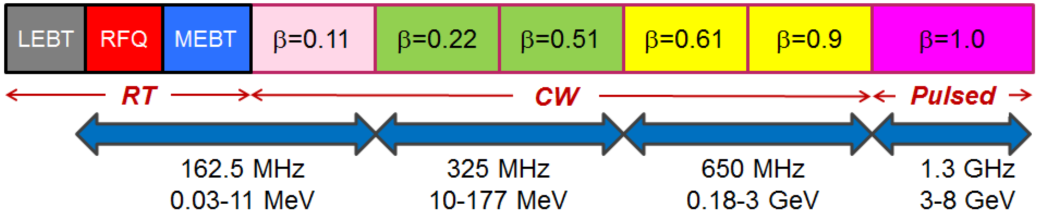
☐ νSTORM also provides the opportunity to design, build and test decay ring instrumentation (BCT, momentum spectrometer, polarimeter) to measure and characterize the circulating muon flux.

# Technical challenges for MC and NF

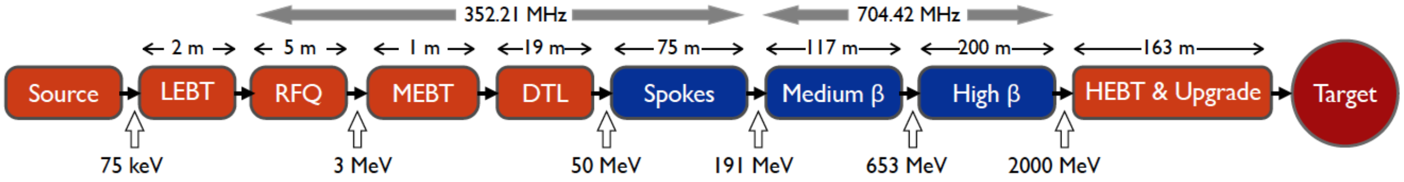
1. High-power (multi-MW) p beam (e'g. SNS, ESS, … proton driver)
2. Suitable targetry (MERIT @CERN, 2007 demonstrated that a > 4 MW Hg jet target is feasible)
3. Muon cooling (small 4D cooling (transverse) sufficient for NF , final 6D cooling essential for MC )
   - $\mu$ unstable -> must cool quickly [MICE]
   - Requires high-gradient RF cavities in B > 1 T fields [FNAL MTA]
4. Rapid acceleration
   - Linac-RLAs-(FFAGs)-RCS [EMMA@DL, 2011 proved principle of non-scaling FFAG technique]
5. High storage-ring bending field (to maximize # of cycles before decay and small $\beta$ _|_ for high $\mathcal{L}$
   [solution devised @ FNAL B~10 T, $\beta$ ~1 cm]

# Key technologies: proton drivers

| | Beam power (MW) | Linac Energy (GeV) | RF duty factor (%) | Peak current (mA) | SC cavity types |
|---|---|---|---|---|---|
| MOMENT | 15 | 1.5 (~2.5) | 100 | 10 | 5 |
| Neutrino Factory | 4 | 5 (SPL) | 4 | 20 | 2 |
| Project-X (PIP-II) | 3 (0.2) | 3 (0.8) | 100 (10) | 5 (2) | 6(5) |
| ESSnuSB | 5 | 2 | 4 | 62.5 | 3 |



Project-X (Upper)
ESSnuSB (Lower)



# Key technologies: targetry problems

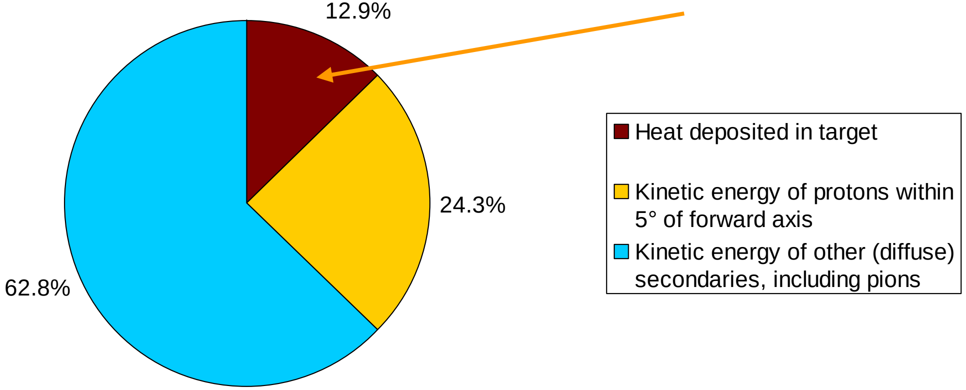
**Targetry** = the task of producing and capturing π's and μ's from proton interactions with a nuclear target: a real major challenge.

Need a production target that can survive multi MW proton beams (problem mainly studied in the framework of n spallation source targets)

- Optimization of target material, beam energy, shape …
- Severe materials issues for target AND beam dump.
  - Radiation Damage.
  - Melting.
  - Cracking (due to single-pulse "thermal shock").

Where does the proton beam power go?

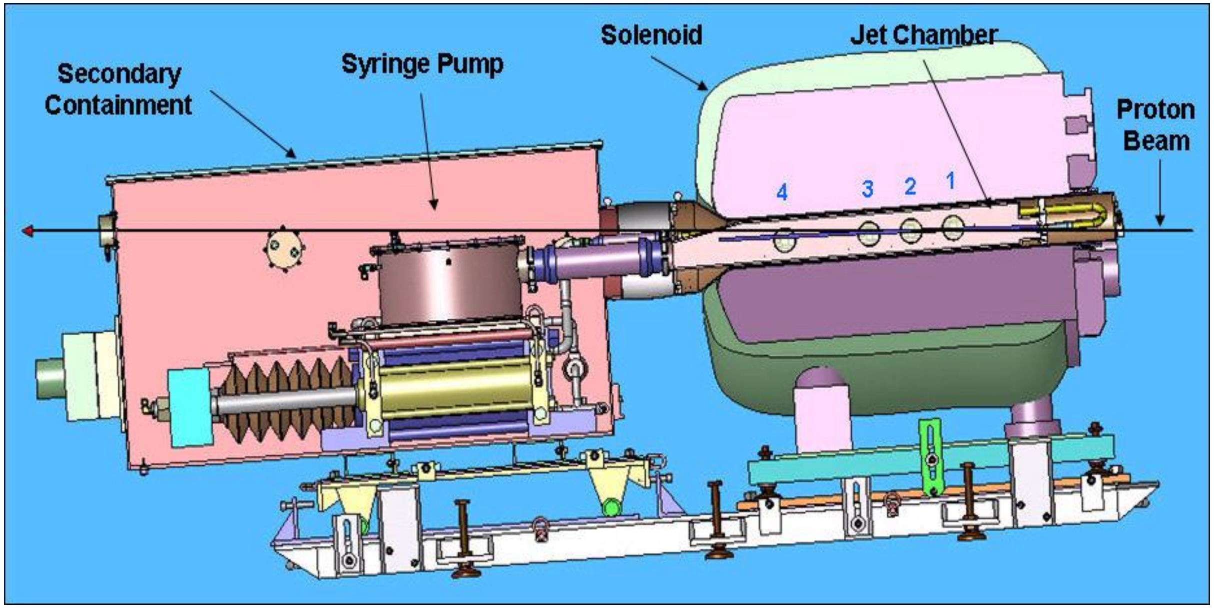
643kW heat dissipation

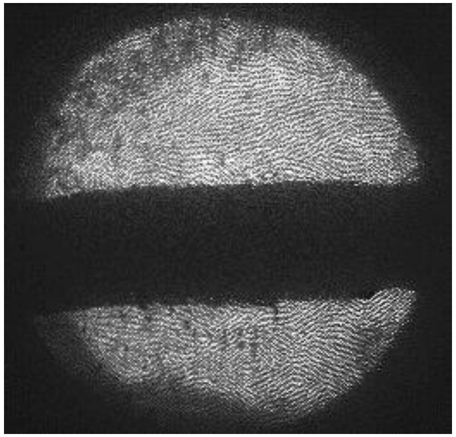


Figures from a 10GeV proton beam (ISS baseline) hitting a 20cm long, 2cm diameter tantalum rod target

# Key Technologies – Target (II)

- The MERIT Experiment at the CERN
  - Demonstrated a 20m/s liquid Hg jet injected into a 15 T solenoid and hit with a 115 KJ/pulse beam!
  - ⇨ Jets could operate with beam powers up to **8 MW** with a repetition rate of 70 Hz





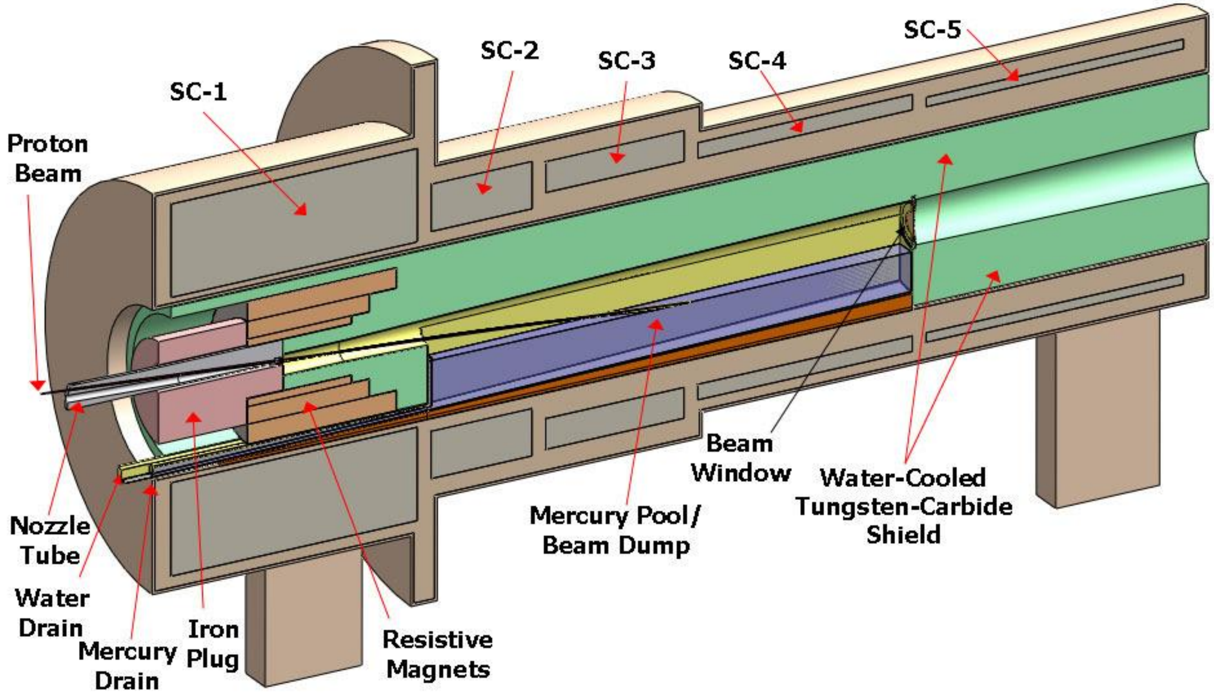
Hg jet in a 15 T solenoid with measured disruption length ~ 28 cm

# Key technologies: Capture Solenoid

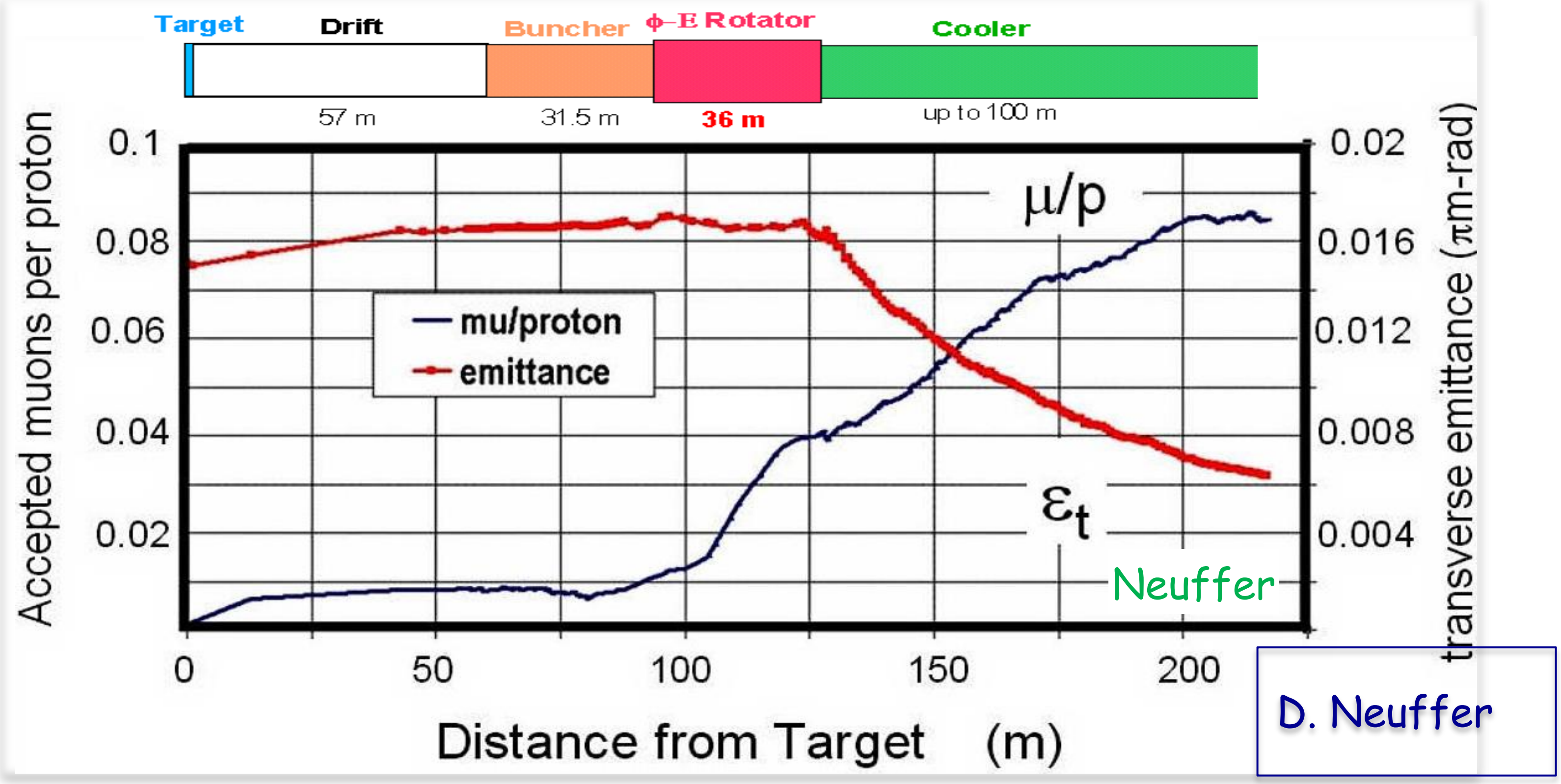
- A Neutrino Factory and/or Muon Collider Facility requires challenging magnet design in several areas:
  - Target Capture Solenoid (15-20T with large aperture) $E_{stored}$ ~ 3 GJ to collect both signs

O(10MW) resistive coil in high radiation environment

Possible application for High Temperature Superconducting magnet technology



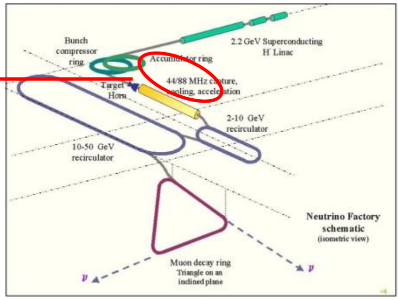
# Key technologies: tertiary production

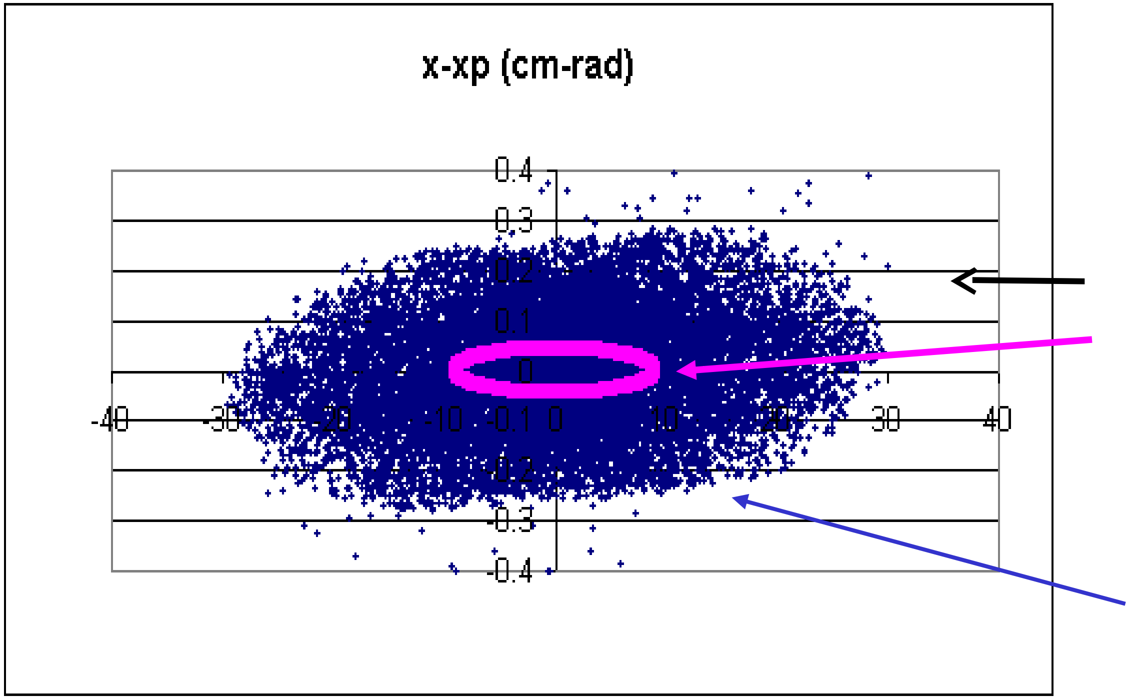


D. Neuffer

**A multi-MW proton source, *e.g.*, Project X, will enable O($10^{21}$) muons/year to be produced, bunched and cooled to fit within the acceptance of an accelerator.**

# The big problem:reduction of μ emittance





Accelerator acceptance

R ≈ 10 cm, x’ ≈ 0.05 rad
rescaled @ 200 MeV

**π and μ after focalization**

**The muon beam emittance must be reduced for injection into the acceleration system**

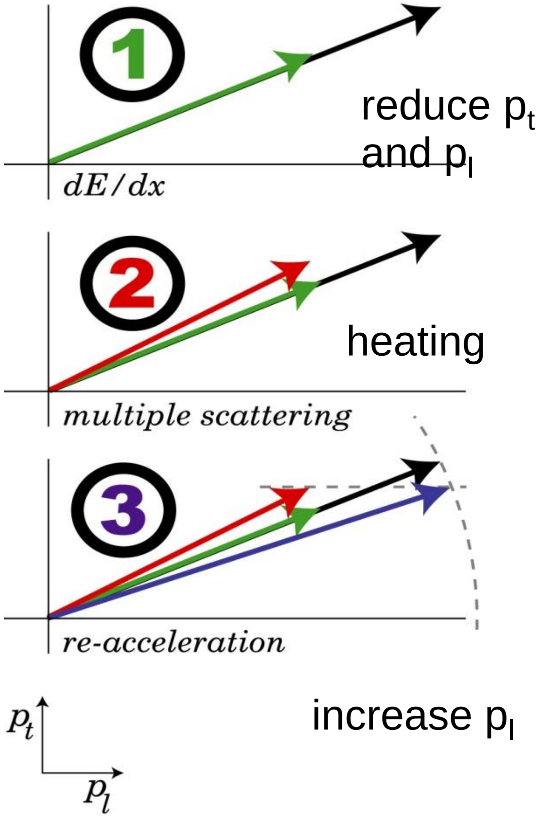
- Energy spread ► phase rotation
- Transverse emittance ► cooling

# Muon ionization cooling

Stochastic cooling is too slow.

A novel method for $\mu$+ <u>and</u> $\mu$- is needed: **ionization cooling**

**principle**

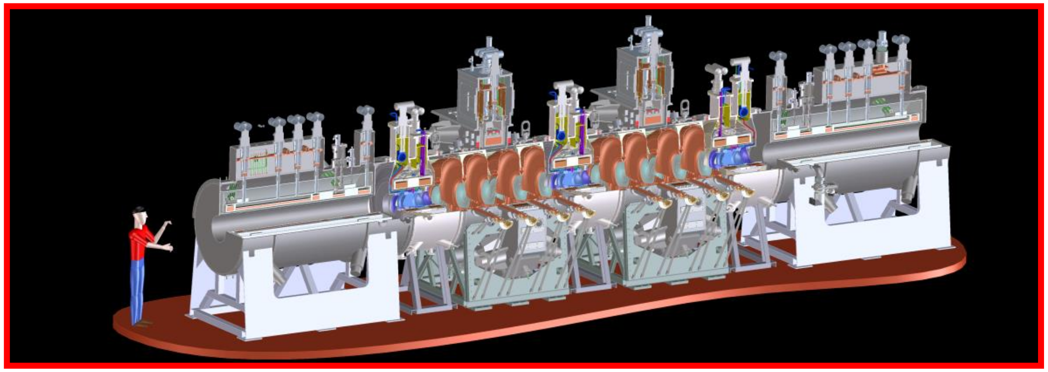


reduce $p_t$ and $p_l$

heating

increase $p_l$

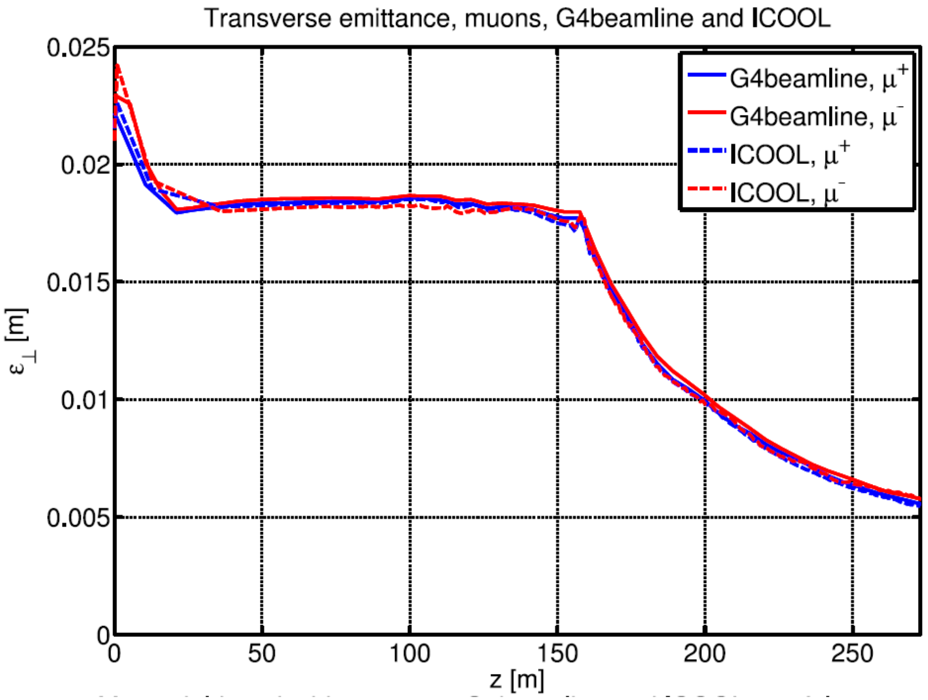
**reality including beam diagnostics(simplified)**

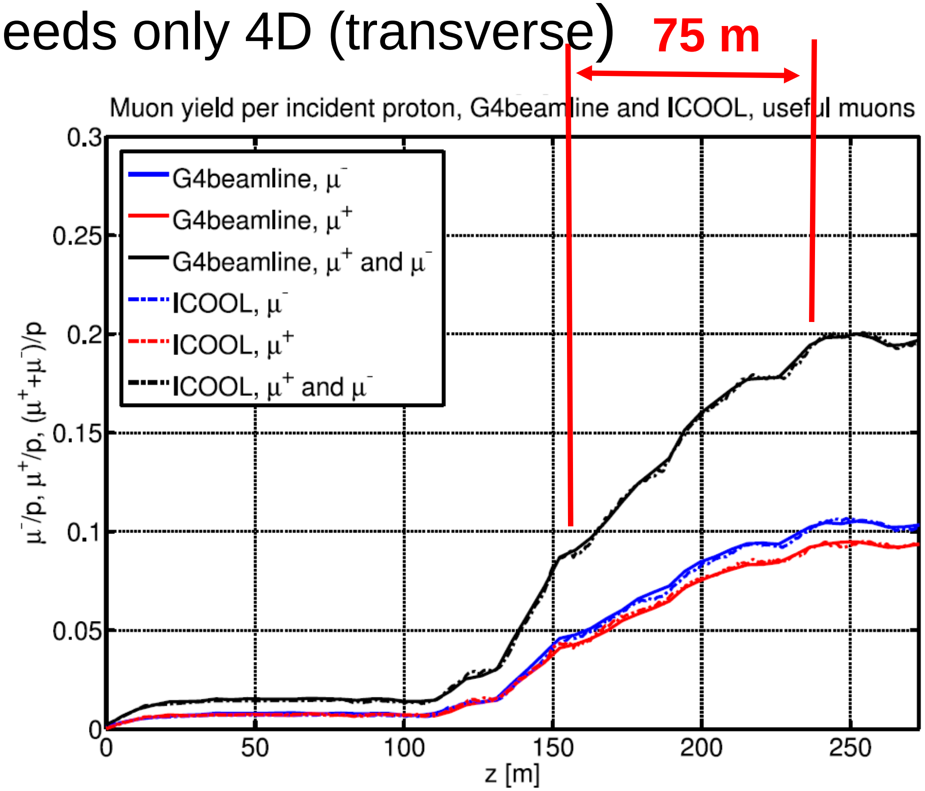


- Build a section of cooling channel long enough to provide measurable cooling (10% ) and short enough to be affordable and flexible
- Wish to measure this change to 1%
- Requires measurement of emittance of beams into and out of cooling channel to 0.1% !
- Cannot be done with conventional beam monitoring device
- Instead perform a single particle experiment:
  - High precision measurement of each track (x,y,z,px,py,pz,t,E)
  - Build up a virtual bunch offline
  - Analyse effect of cooling channel with bunches of different emittances
  - Study cooling channels parameters over a range of initial beam momenta and emittances

# Neutrino Factory: cooling reqs.

- Cooling important to deliver Neutrino Factory performance (increase by a factor 2-10), but needs only 4D (transverse)



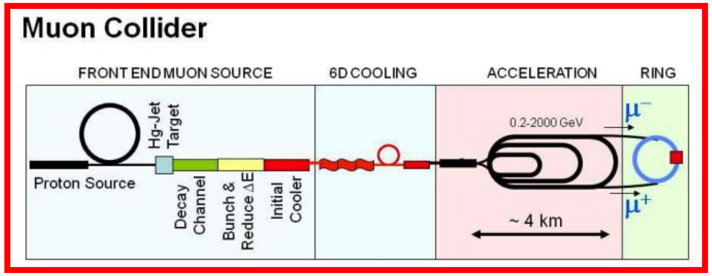


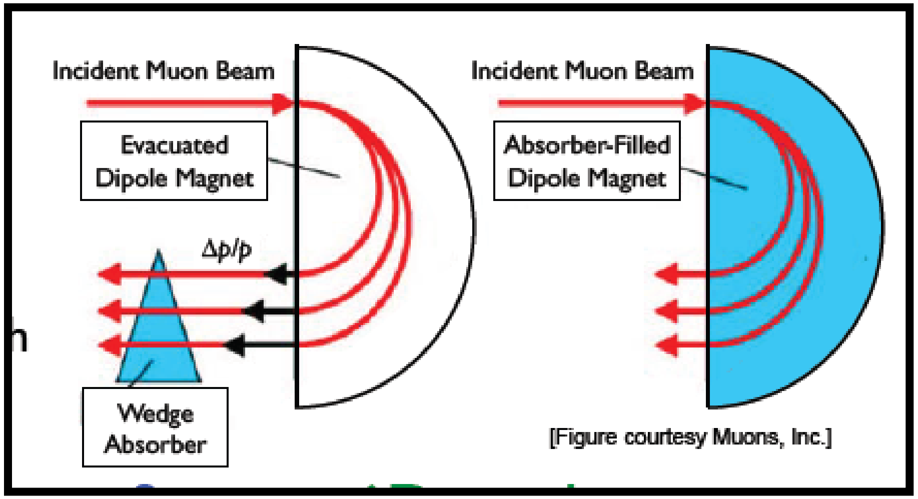
**Emittance: 18 mm rad→7.5 mm rad** **Muon yield: 0.08 μ/p.o.t.→0.19 μ/p.o.t.**

**IDS-NF design increase in performance: 2.4**

# $\mu$-collider : cooling reqs.

- Cooling essential for Muon Collider performances (a factor ~$10^6$ needed)
- 6D cooling via emittance exchange





[Figure courtesy Muons, Inc.]

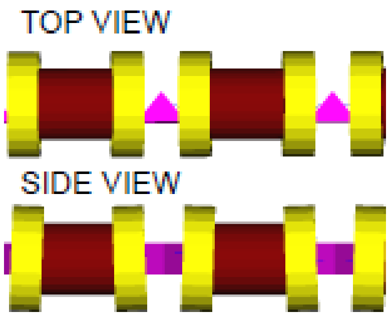
- Negligible synchrotron radiation (and beamstrahlung)
- Precise det of $E_{beam}$ (0.003%)
- Strong coupling to the Higgs

- Ionization cooling is not directly effective for longitudinal emittance
- Two approaches to longitudinal cooling via emittance exchange
  (cool $\varepsilon_t$ , exchange $\varepsilon_t$ & $\varepsilon_{||}$ )
- A wedge shaped dE/dx absorber is introduced, to increase (decrease) ionization losses for faster (slower) particles

# How to cool in 6D ?

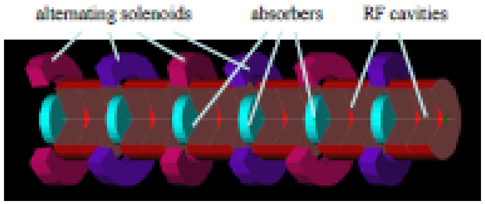
- Tricky beam dynamics: must handle dispersion, angular momentum, nonlinearity, chromaticity, & non-isochronous beam transport
- 3 types of solutions viable in simulation:

Rectilinear FOFO



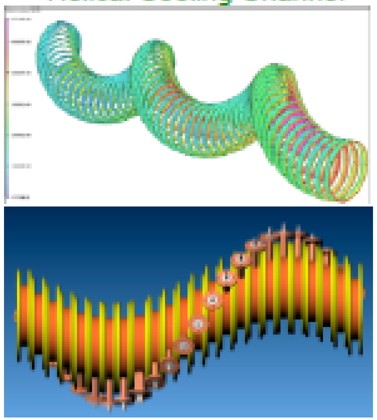
BNL & FNAL

FOFO Snake



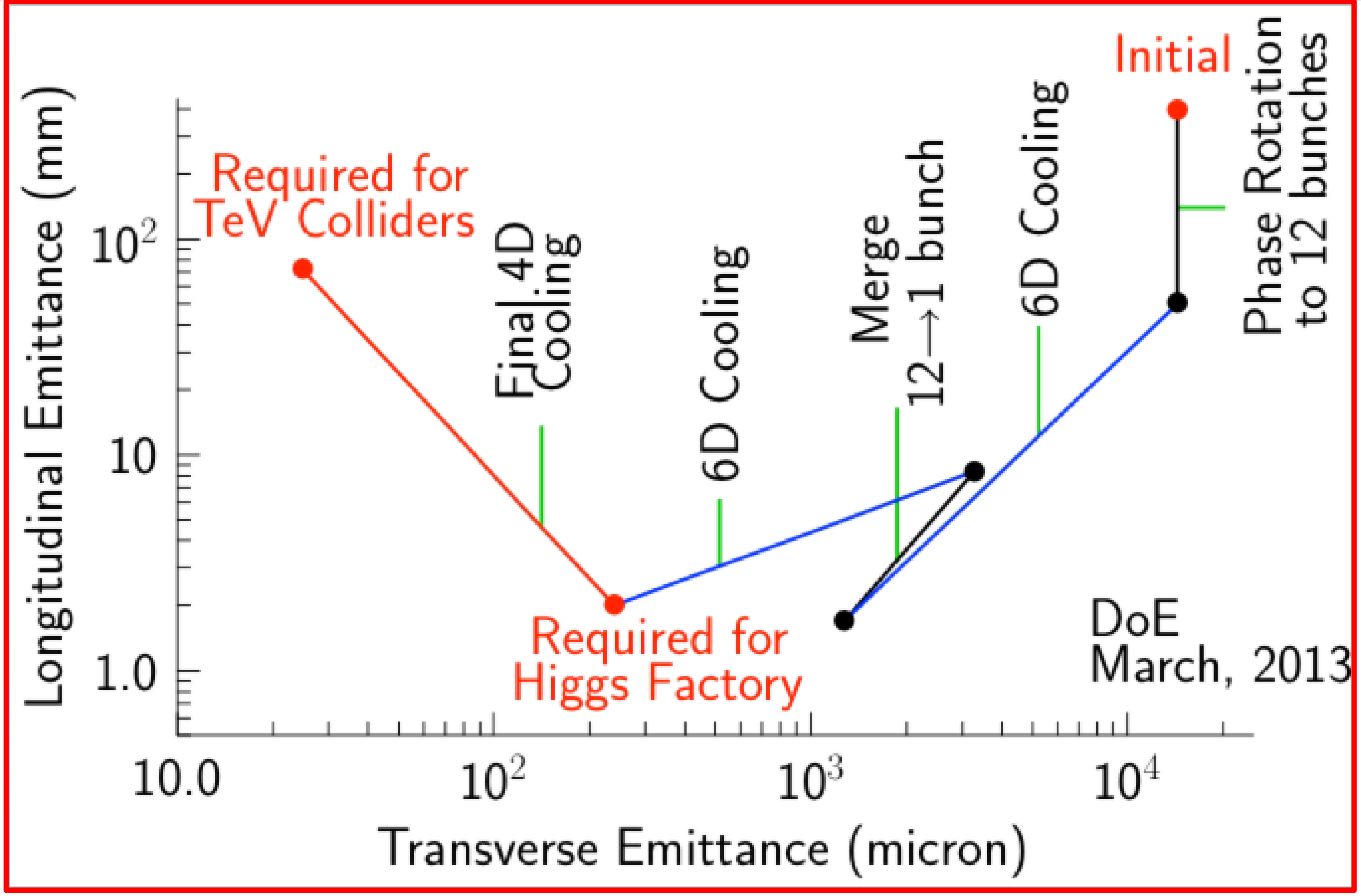
Y. Alexahin, FNAL

Helical Cooling Channel

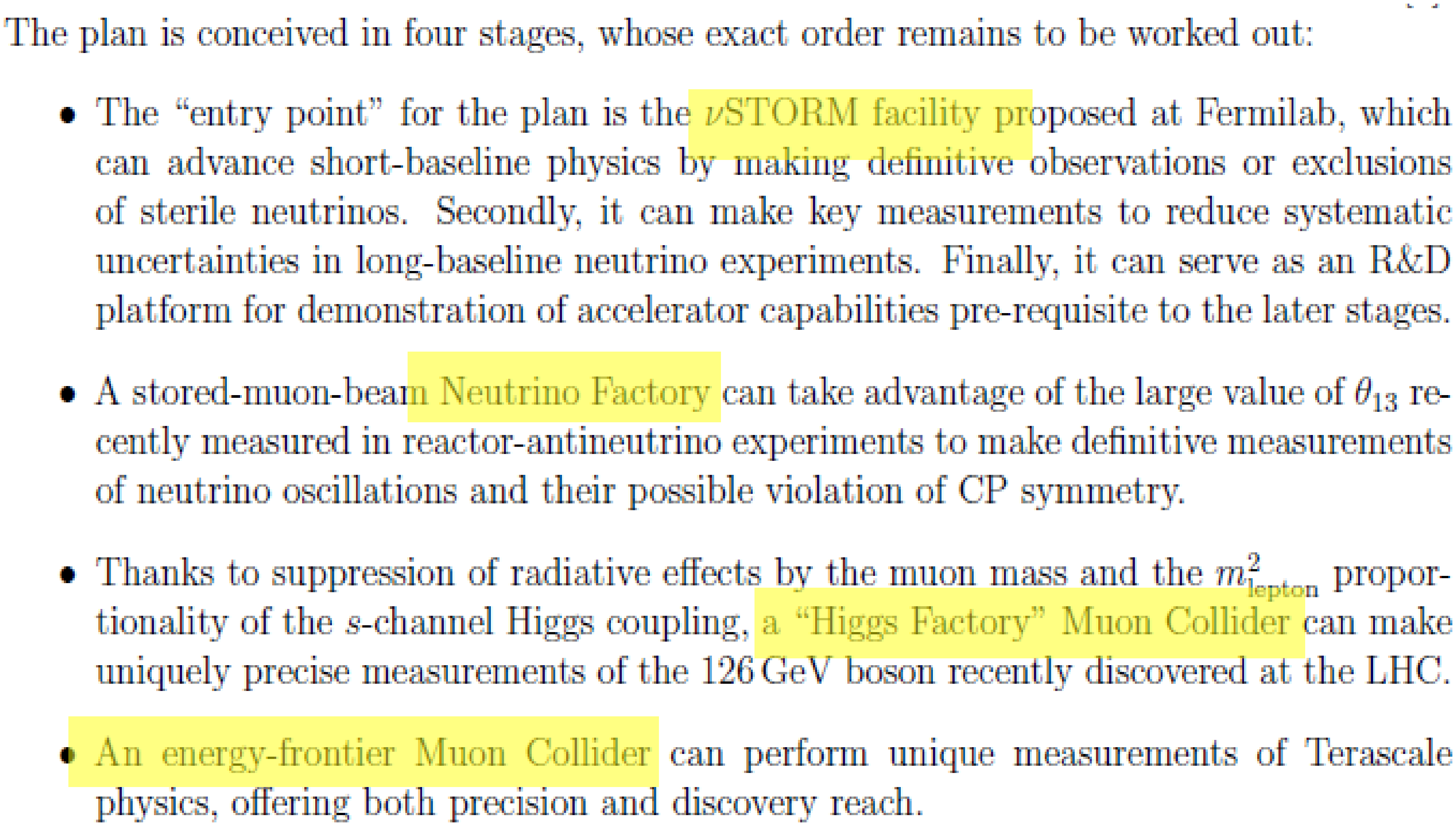


Muons, Inc. & FNAL

# Muon Collider: cooling system



# A Staged Muon-Based Neutrino and Collider Physics Program



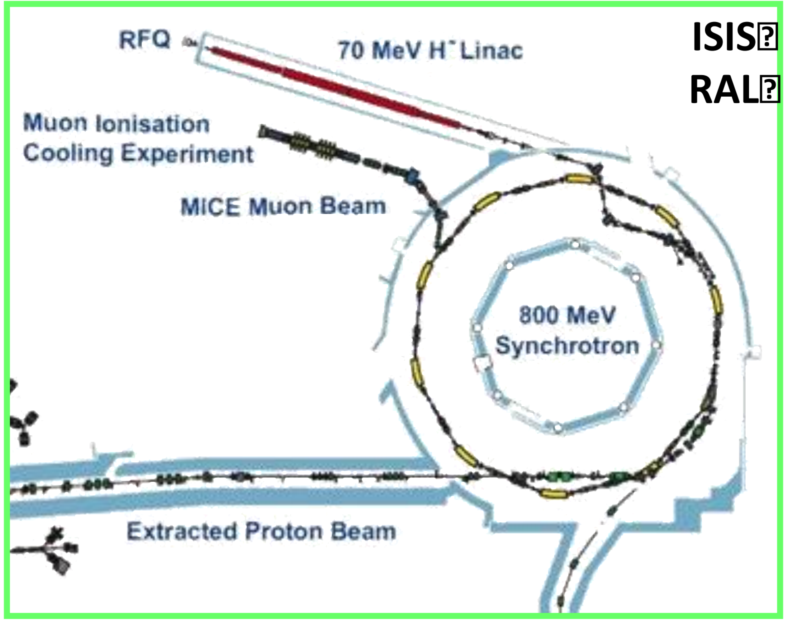
The plan is conceived in four stages, whose exact order remains to be worked out:

- The "entry point" for the plan is the $\nu$STORM facility proposed at Fermilab, which can advance short-baseline physics by making definitive observations or exclusions of sterile neutrinos. Secondly, it can make key measurements to reduce systematic uncertainties in long-baseline neutrino experiments. Finally, it can serve as an R&D platform for demonstration of accelerator capabilities pre-requisite to the later stages.
- A stored-muon-beam Neutrino Factory can take advantage of the large value of $\theta_{13}$ recently measured in reactor-antineutrino experiments to make definitive measurements of neutrino oscillations and their possible violation of CP symmetry.
- Thanks to suppression of radiative effects by the muon mass and the $m^2_{\text{lepton}}$ proportionality of the $s$-channel Higgs coupling, a "Higgs Factory" Muon Collider can make uniquely precise measurements of the 126 GeV boson recently discovered at the LHC.
- An energy-frontier Muon Collider can perform unique measurements of Terascale physics, offering both precision and discovery reach.

# MICE:

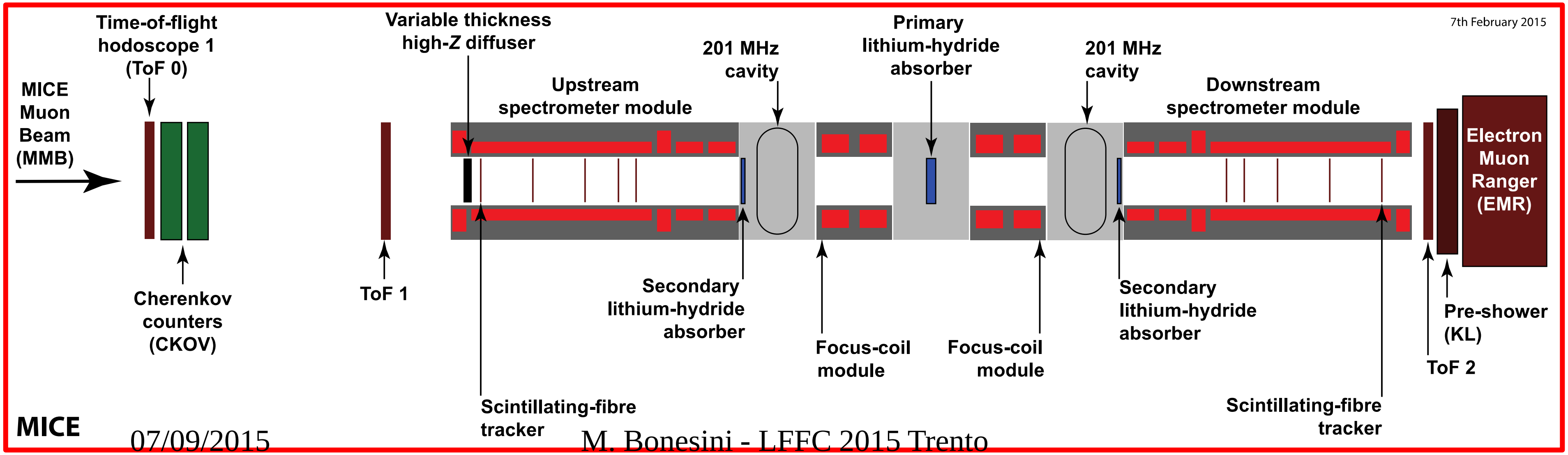
- Design, build, commission and operate a realistic section of cooling channel
- Measure its performance in a variety of modes of operation and beam conditions
  - Results will allow Neutrino Factory [and Muon Collider] complex to be optimised

- Normalised transverse emittance: 0.1%
  - Requires selection of 99.9% pure muon sample

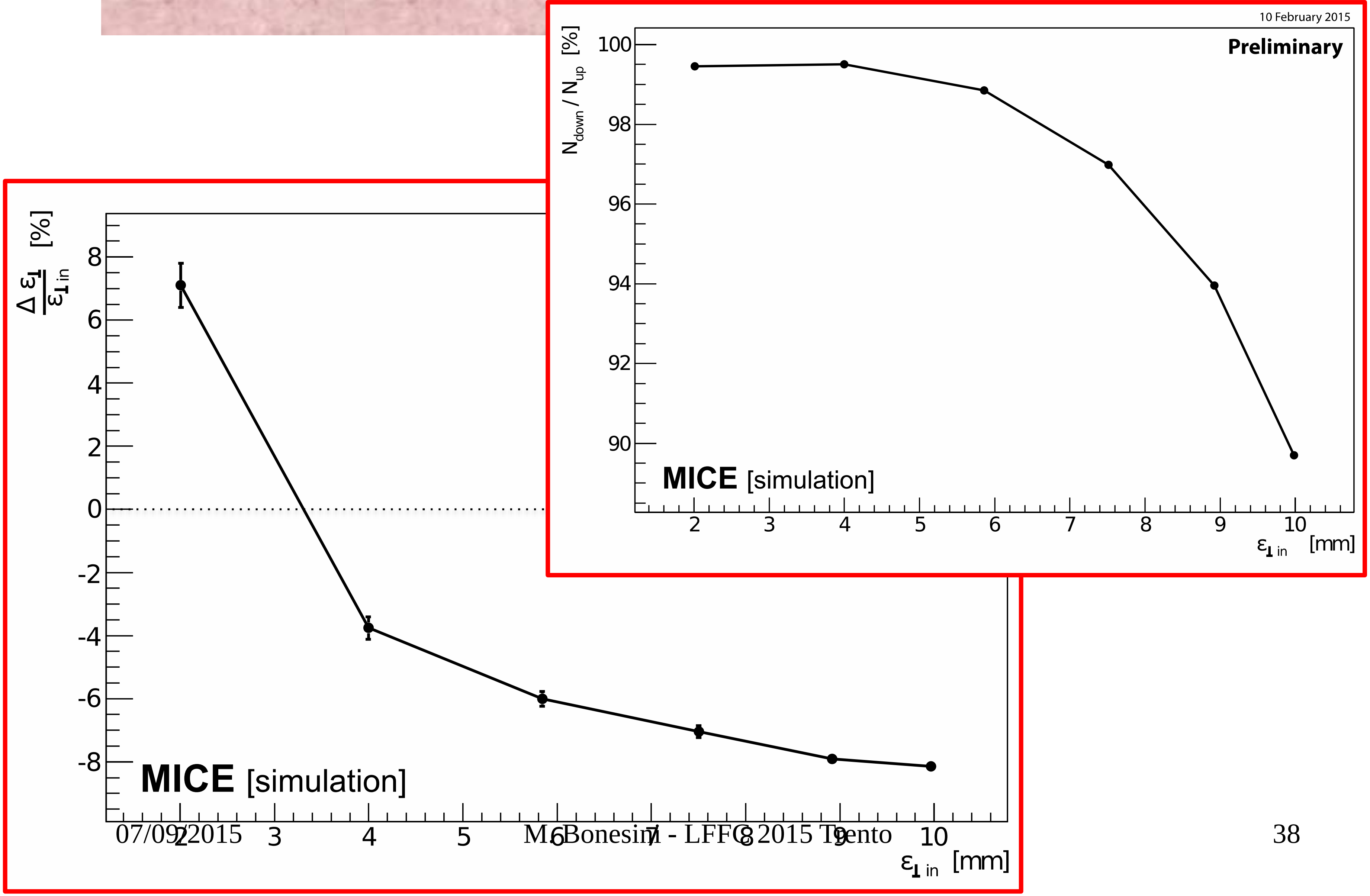


ISIS
RAL

## MICE

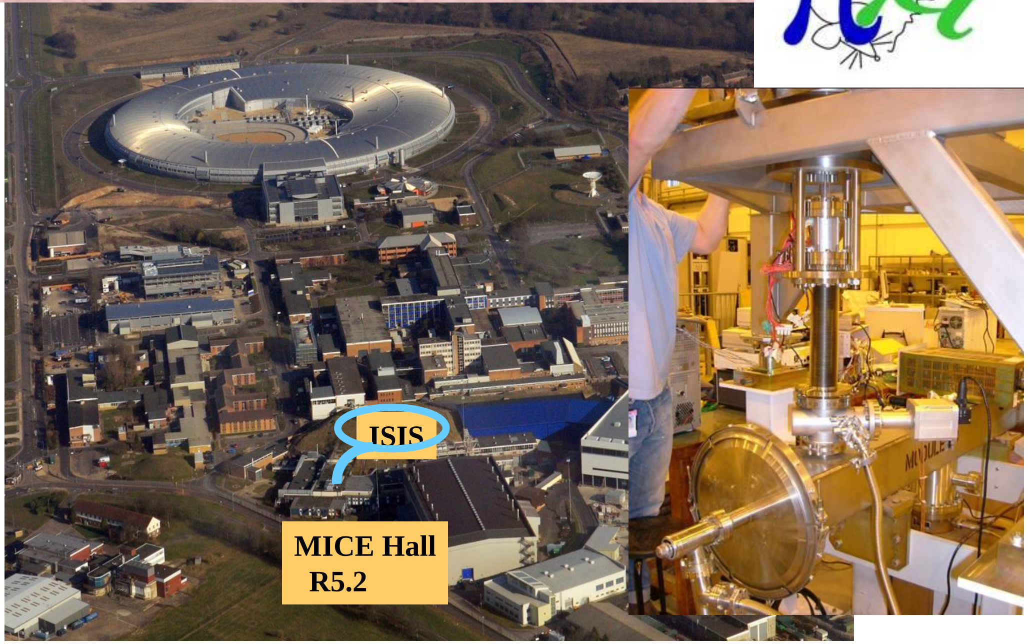


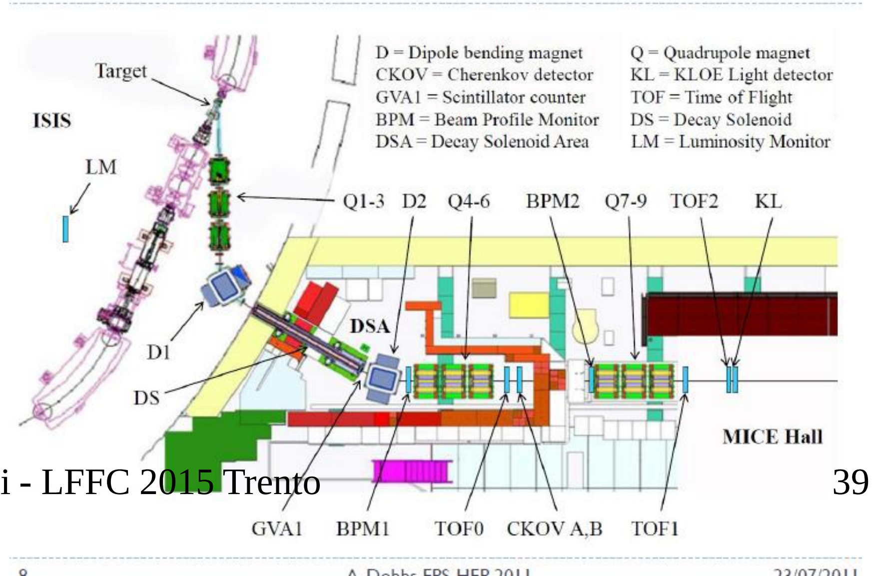
# Cooling demonstration; performance:



# MICE Beamline

- ISIS 800 MeV proton synchrotron at RAL
- Titanium target, dipping rapidly into ISIS beam
- $\pi$ captured by quad triplet and momentum selected by dipole (D1)
- Followed by 5T decay superconducting solenoid (5 m long): contain $\pi$ and decay $\mu$
- Second dipole momentum select muons (D2)
  - $p_{D1} \sim 2 \times p_{D2}$ $\mu$ beam
  - $p_{D1} \sim p_{D2}$ $e/\pi$ calib beam





# MICE beam instrumentation

- **Particle identification: TOF, CKOV, Calorimeter**
  **important to insure high μ purity for muon cooling measurement.**
  - Upstream:
    - Time of Flight TOF0 + TOF1 x/y hodoscopes
    - 2 Aerogel Cherenkov detectors (n=1.07 and 1.12)

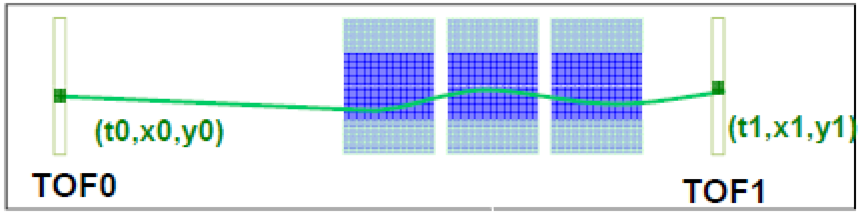
    ➔ π/μ separation up to 360 MeV/c

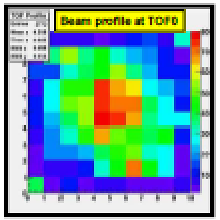
    ➔ Beam purity better than 99.9%
  - Downstream:

    **0.5% of μs decay in flight: need electron rejection at $10^{-3}$ to avoid bias on emittance reduction measurement**
    - TOF2 x/y hodoscope
    - EMC Calorimeter
      - Kloe-like (KL) Lead-scintillating fiber sandwich layer
      - Electron-Muon Ranger (EMR)
        - 1m$^3$ block extruded scintillator bars
        - Also measure muon momentum

- Particle tracking
  - Scintillating Fiber trackers
  - Measure position and reconstruct momentum

# Beam characterization



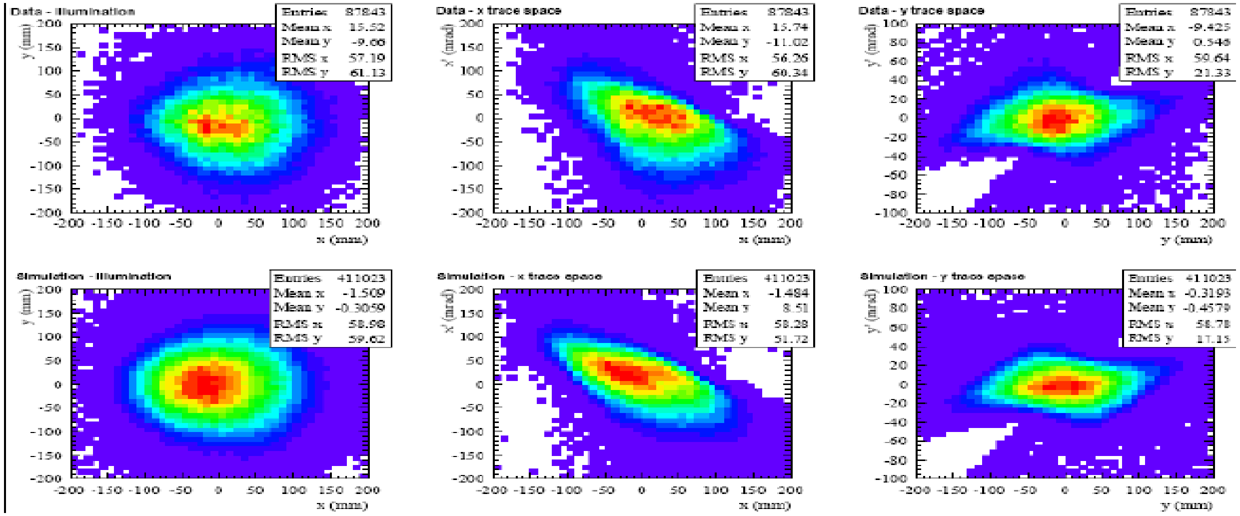


Momentum-dependent matrix relates: $(t_0,x_0,y_0,t_1,x_1,y_1)$ -> $(t_1,p,x_1,x'_1,y_1,y'_1)$ solved by iteration

**Reconstructed transverse phase space of the baseline MICE beam (6-200) at TOF1**

data

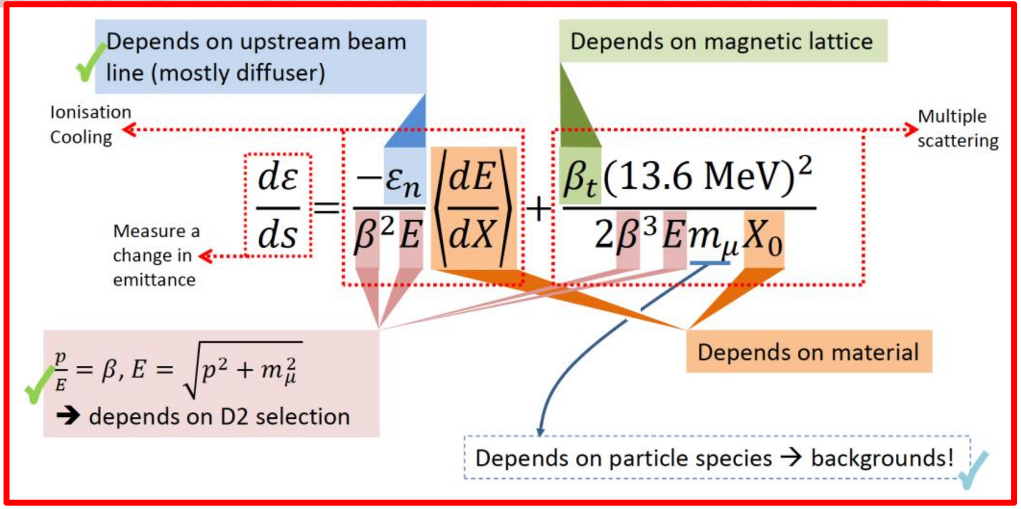
MC



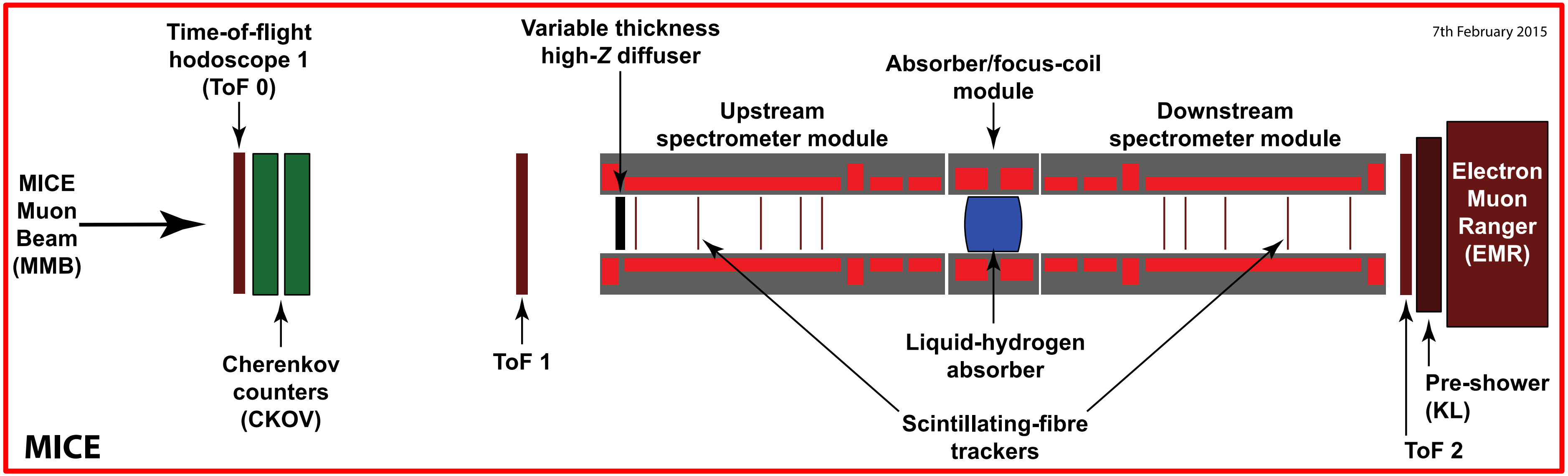
**y(mm) vs x(mm)** **x' (mrad) vs x (mm)** **y'(mrad) vs y (mm)**

# Study of factors that affect cooling:

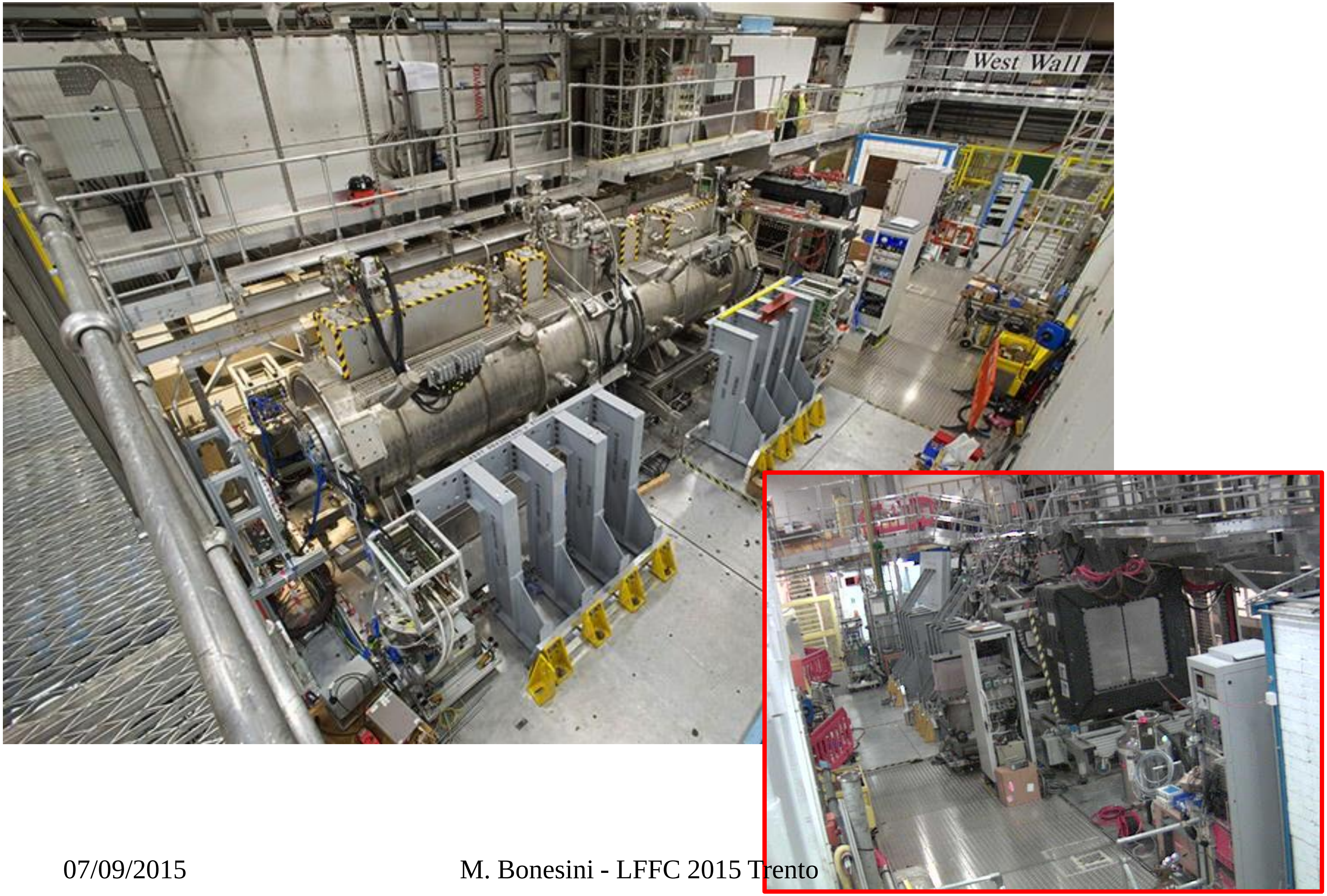
- Emittance:
  - MICE Muon Beam optics and diffuser settings
- Material:
  - Absorber change (LH2; LiH);
- *p*, *E* and β:
  - Vary beam momentum, optics


$$\frac{d\varepsilon}{ds} = \frac{-\varepsilon_n}{\beta^2 E}\left\langle\frac{dE}{dX}\right\rangle + \frac{\beta_t (13.6\ \mathrm{MeV})^2}{2\beta^3 E m_\mu X_0}$$

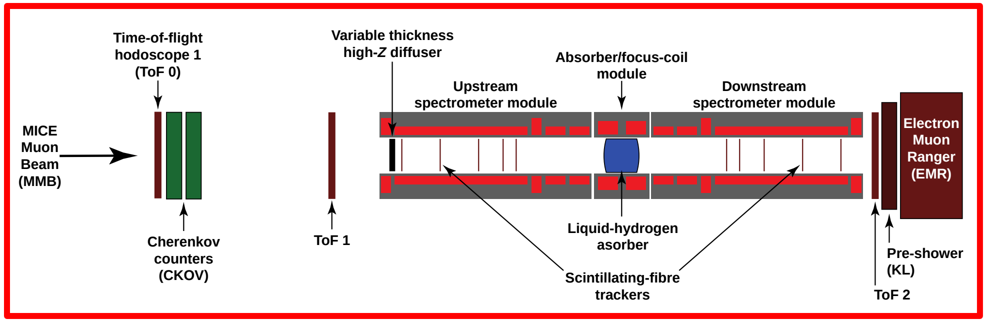
$\frac{p}{E} = \beta, E = \sqrt{p^2 + m_\mu^2}$

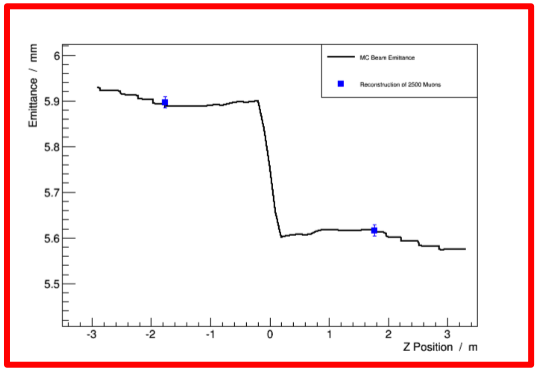


# MICE Step IV

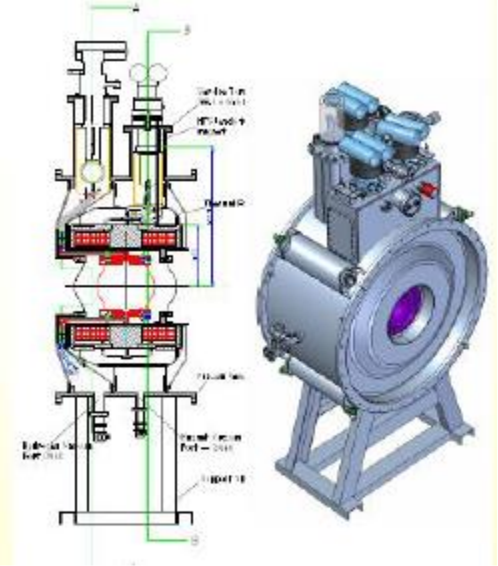


# STEP IV overview





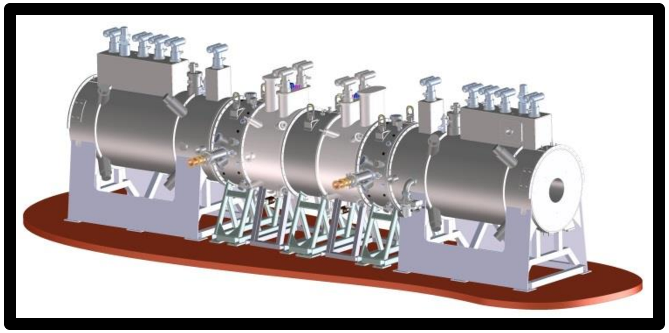
4T SC solenoids. Trackers inside.

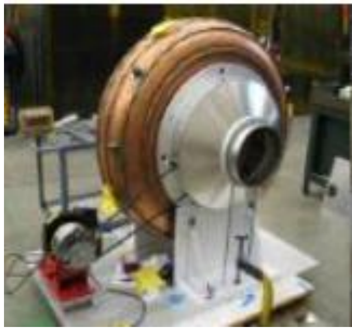


Absorber-Focus-Coil modules

# … and to completion

The addition of RF cavities (built) and absorber modules will permit an emittance reduction of ~10% to be measured to an absolute accuracy of 0.1%





201-MHZ RF cavities

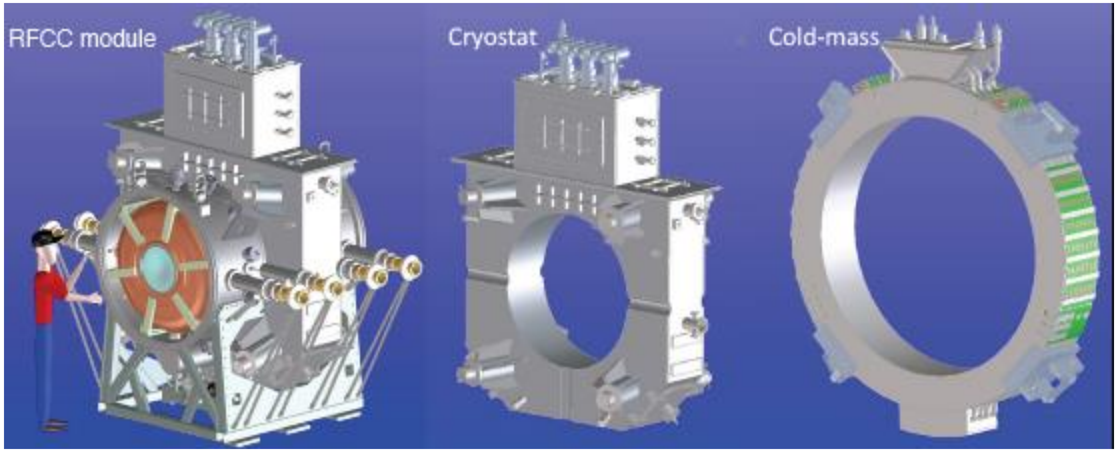
RF amplifier

RF power coupler

CC cold mass

# RF: cavities & power

- 2 RFCC modules (LBNL,U. Miss.) needed for STEP VI
- novel Be cavity windows double accel gradient for a given power (MuCool)
- RFCC modules designed, cavities built
- Coupling coils fab in China (HIT,SINAP) led by LBNL
- 4 recycled (LBNL,CERN) 2 MW triode power supplies for RF ( refurbished at DL )



# Conclusions

- ❑ Use of muon beams is a promising option both for neutrino physics studies and frontier physics
- ❑ The involved R&D is critical, but much has been done. In particular the MICE experiment is an essential R&D milestone towards a Neutrino Factory and a Muon Collider
- ❑ A very interesting option is the Higgs factory (low-energy muon collider) as proposed by C. Rubbia
- ❑ A lot of options are on the market: NF, Higgs factories, nu-STORM, …
- ❑ thanks to the organizers