Muon colliders e … molto altro

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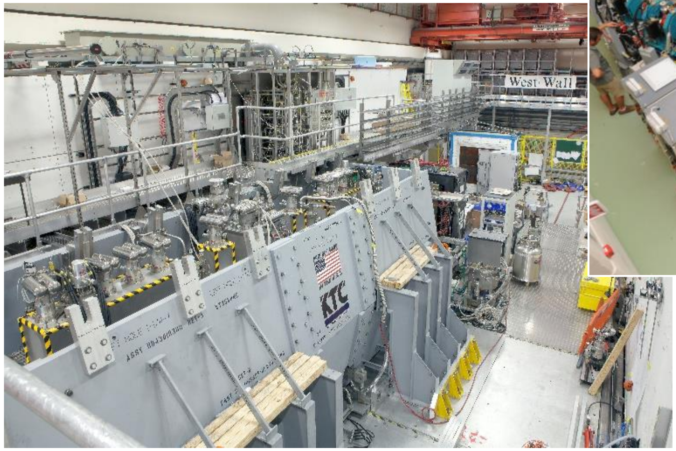
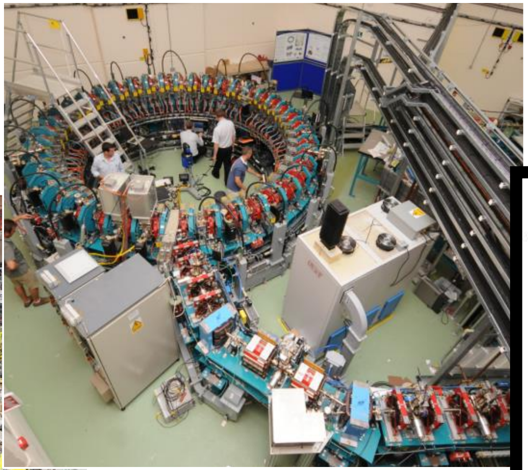
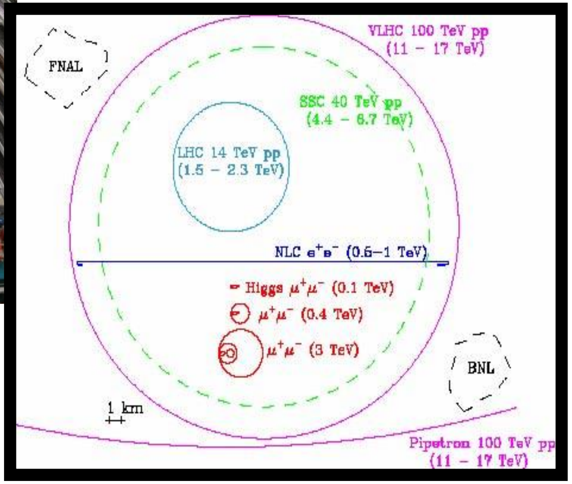




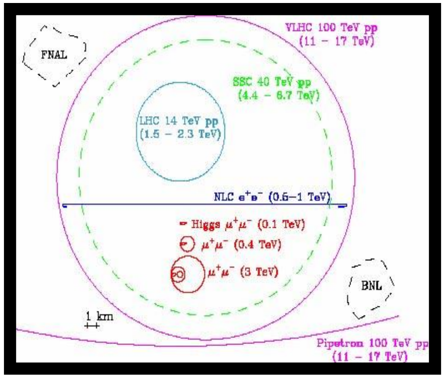


Why muon beams

- **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 - the Neutrino Factory (NF) concept
  - Muon collisions offer a large coupling to the "Higgs mechanism" (Higgs factory)
  - As with an e^+e^- collider, a $\mu^+\mu^-$ collider would offer a precision probe of fundamental interactions

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

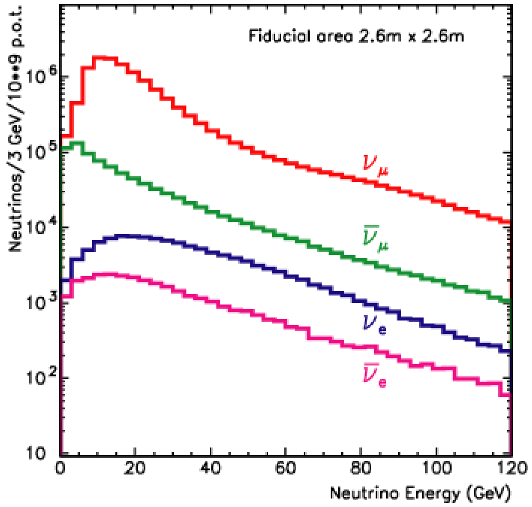
    - **With extremely small energy spread;**
    - **Most effective way to achieve E_{cm} > 1 TeV**
    - **Small footprint to fit inside existing HEP labs**



- **Potential applications outside HEP**
  - Muon radiography
  - Muon capture studies of archelogical materials (CHNET)
  - Study of fundamental physics (proton radius puzzle, QED … FAMU at RIKEN-RAL)

ν beams: conventional and NF beams

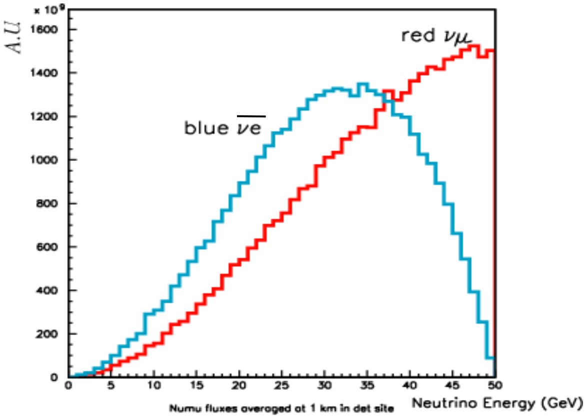
WANF (conventional ν beam at SPS)



- **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**

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

NUFACT beam

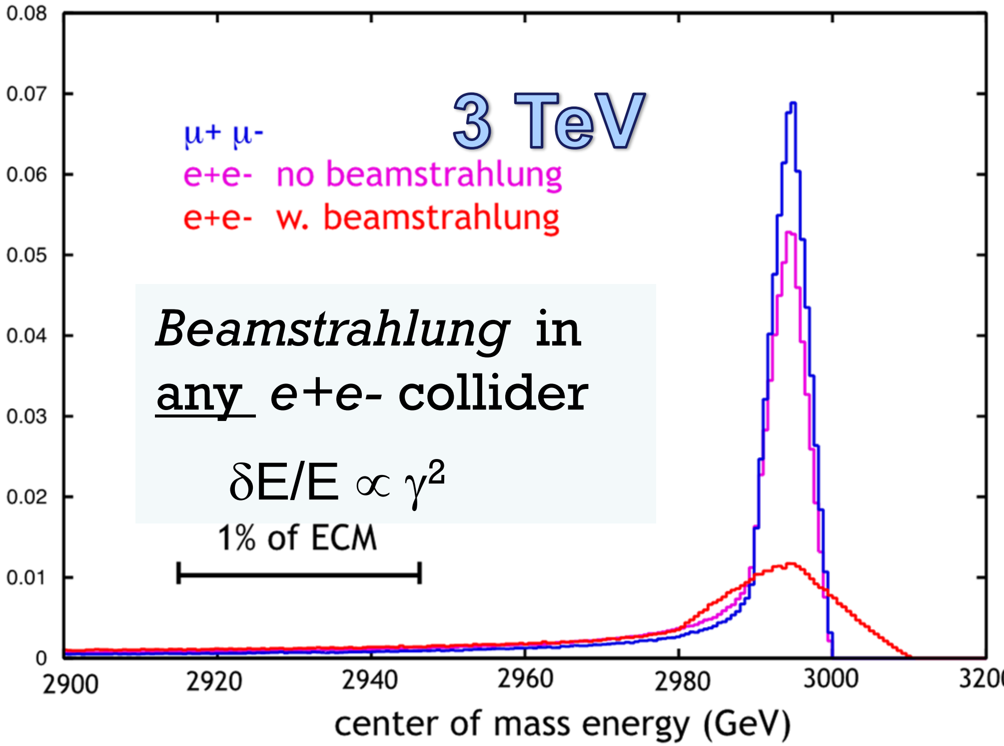


- **Crucial features:**
  - high intensity (x 100 conventional beams)
  - known beam composition (50% ν_μ 50% ν_e)
  - Possibility to have an intense ν_e beam
- **Essential detector capabilities:**

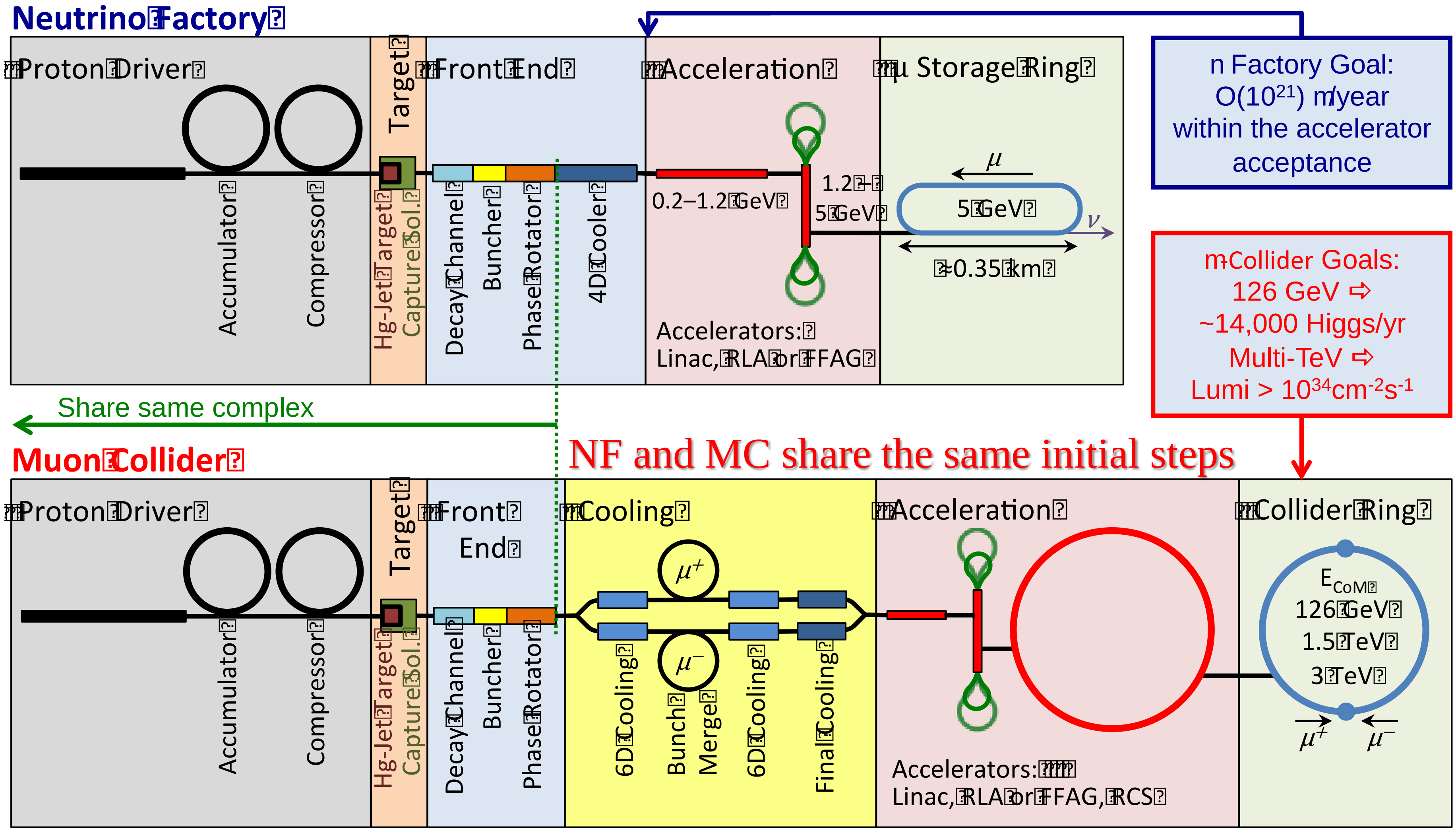
detect μ and determine their sign

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



The Muon Accelerator Program (MAP)



NF and MC share the same initial steps

An entry level NF ? NuSTORM (demonstrator for muon collider ?)

νSTORM

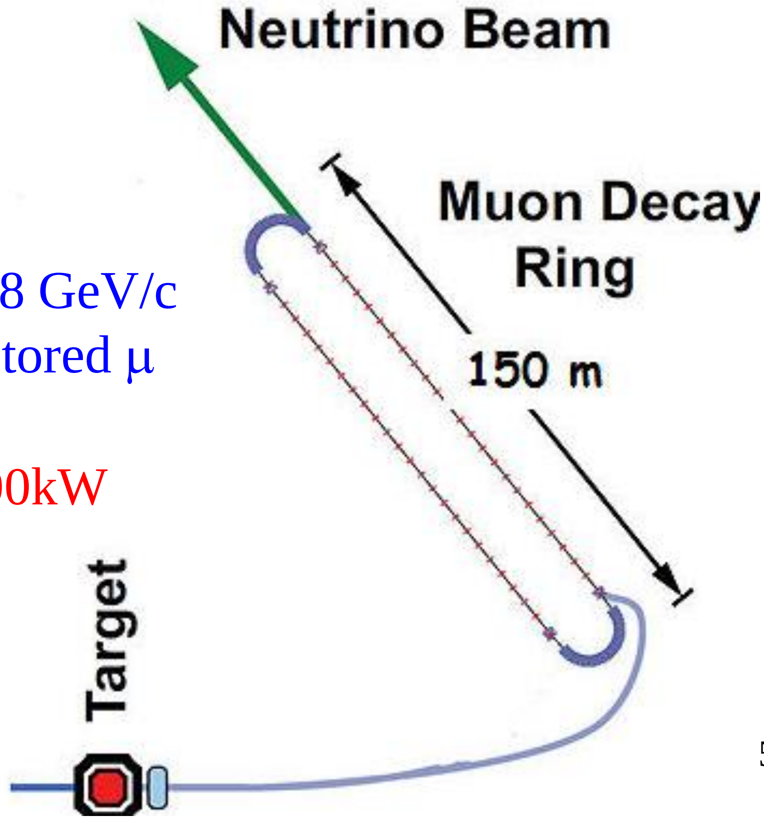
Neutrino Factory Light: conventional target + horn, pion capture & then injection into a ring

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



νSTORM

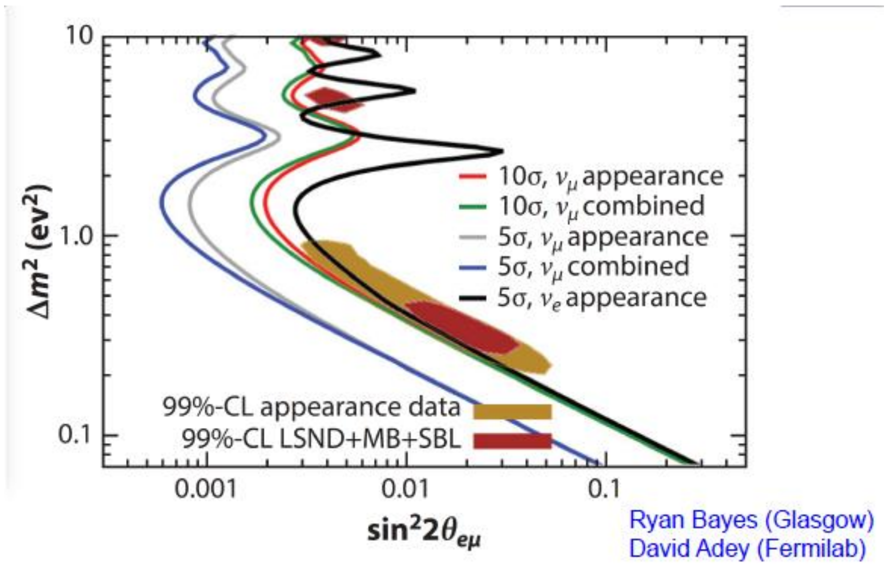
Low energy, low luminosity muon storage ring. Provides with $1.7 \times 10^{18}\ \mu^+$ stored, the following oscillated event numbers

$\nu_e \to \nu_\mu$ 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

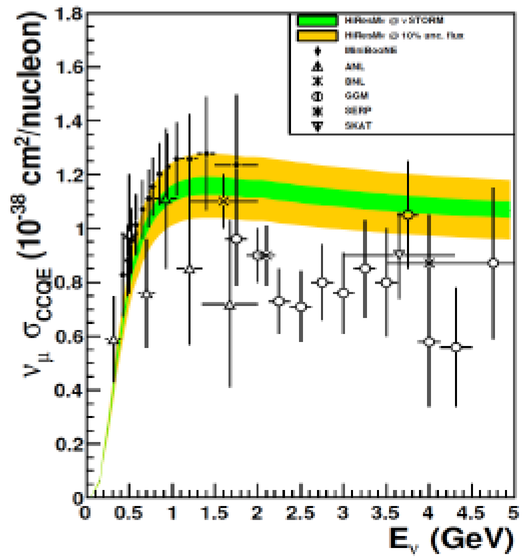
and each of these channels has a more than $10\,\sigma$ difference from no oscillations

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

NuSTORM physics reach

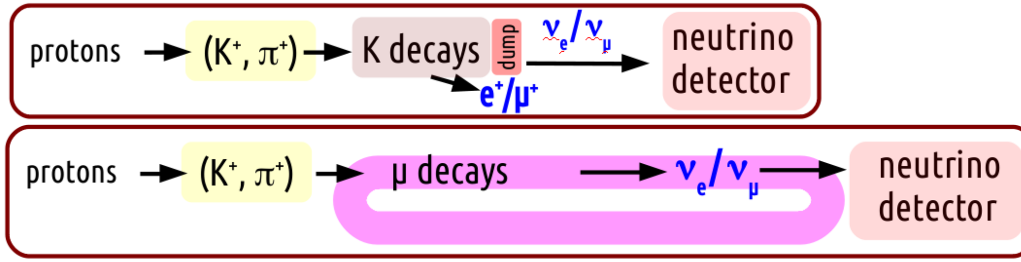


Sterile ν search



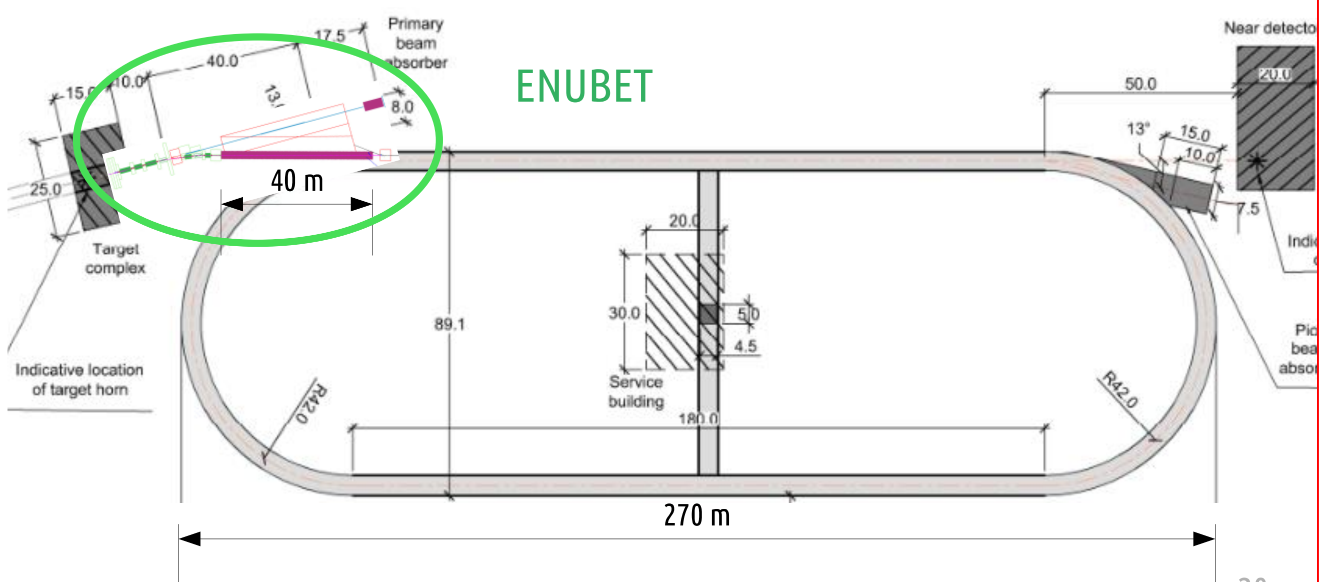
Data for ν_μ and ν_e interactions

nuSTORM & ENUBET



	Decay region	Hadron dump	Proton extraction	Target, sec. transfer line, p-dump	Neutrino detector
ENUBET	~40 m. Instrumented.	Yes. Dumps muons in addition preventing a (small) ν_e pollution to K_{e3} - ν_e	Slow, 400 GeV (flexible)	Yes, similar	~100 m (some flexibility)
nuSTORM	Replaced by straight section of the ring (180 m).	No. Muons are kept: the most interesting flux parents.	Fast, 100 GeV	Yes, similar	> 300 m from target (ring straight section)

- Different concepts, budget, geometry.
- Main synergy: target facility, 1st stage of meson focusing, proton dump.



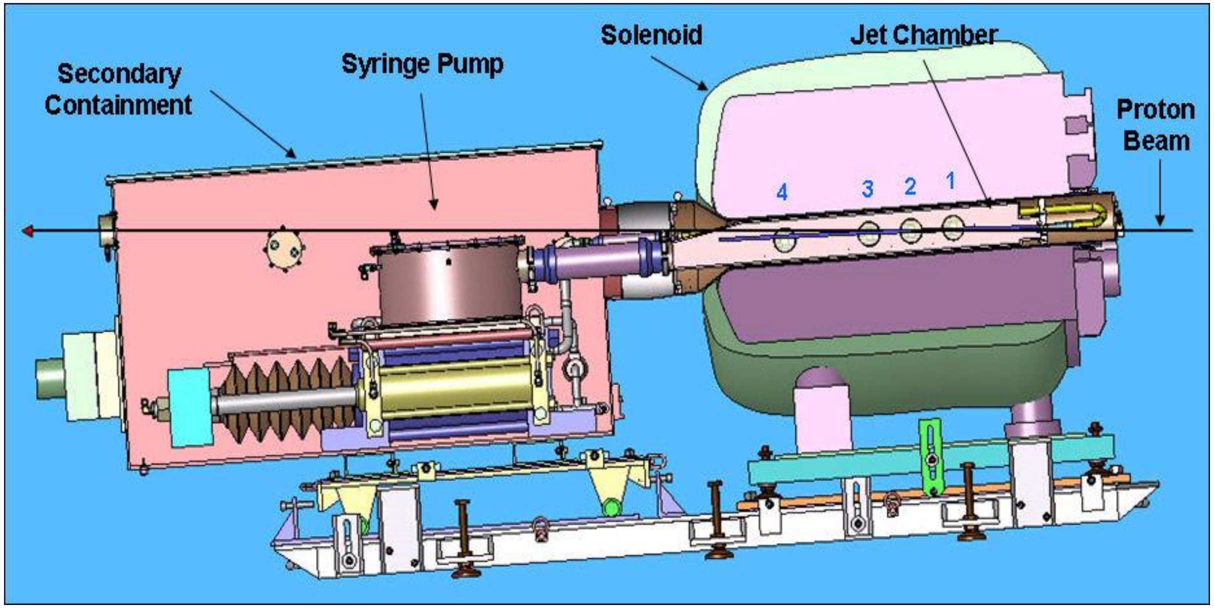
Technical challenges for MC and NF: a long list

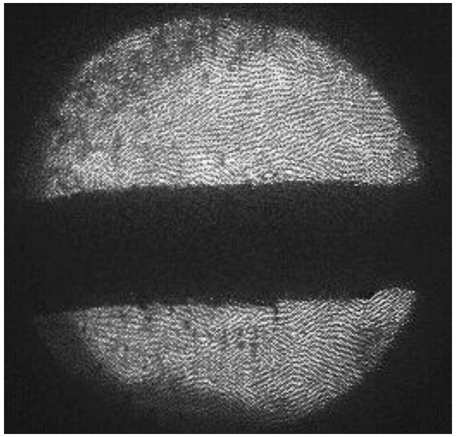
1. High-power (multi-MW) p beam (e’g. SNS, ESS, … proton driver)
2. Suitable targetry (MERIT @CERN, 2007 demonstrated that a > 4 MW Hg jet target is feasible)
3. Muon cooling (small 4D cooling (transverse) sufficient for NF , final 6D cooling essential for MC)
   - μ unstable -> must cool quickly [MICE]
   - 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 β _|_ for high $\mathcal{L}$

   [solution devised @ FNAL B~10 T, β ~1 cm]

Key Technologies – Target

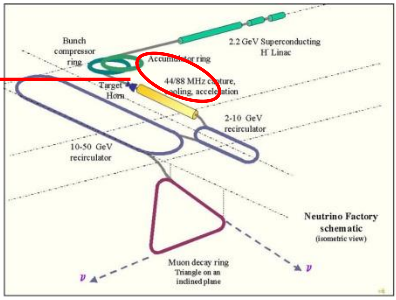
- The MERIT Experiment at the CERN
  - Demonstrated a 20m/s liquid Hg jet injected into a 15 T solenoid and hit with a 115 KJ/pulse beam!
  - ⇨ Jets could operate with beam powers up to **8 MW** with a repetition rate of 70 Hz

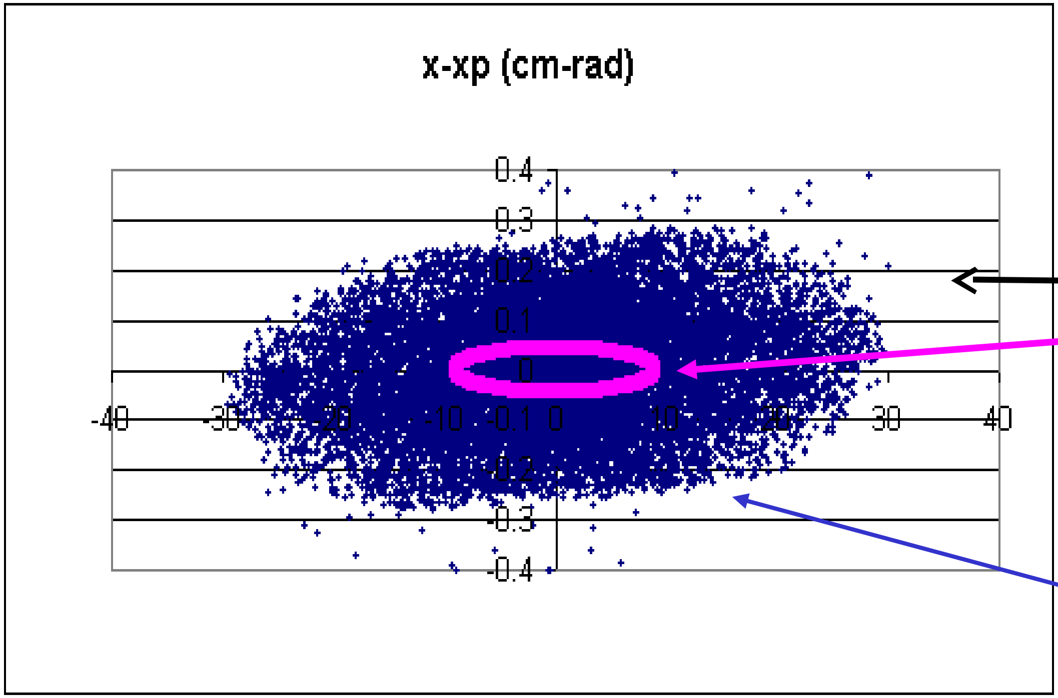




Hg jet in a 15 T solenoid with measured disruption length ~ 28 cm

Reduction of μ emittance: μ cooling





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

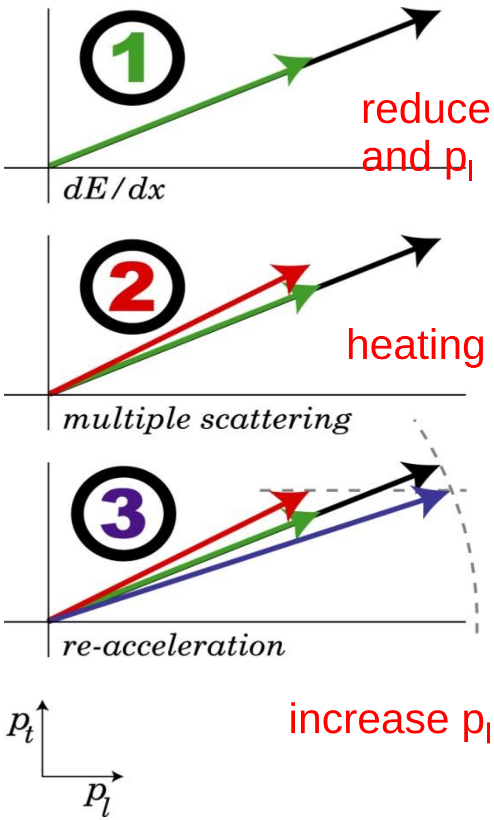
- Energy spread ► phase rotation
- Transverse emittance ► cooling

Muon ionization cooling

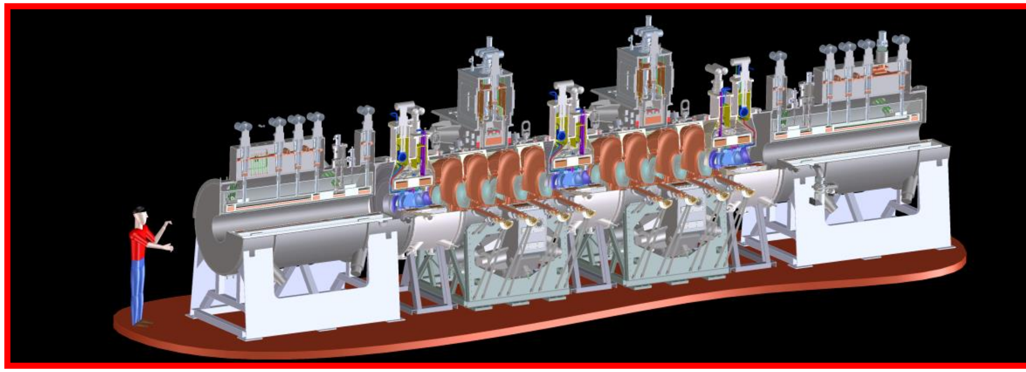
Stochastic cooling is too slow.

A novel method for μ+ and μ- is needed: **ionization cooling**

principle



reality including beam diagnostics(MICE)



- 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

Possible thesis arguments

- Inside the International Muon Collider collaboration (CERN based)
  - Study of new targets (with Roma 3, LNL, …)
  - Application of the cooling techniques (follow up of MICE, with STFC,…)
  - Contribution to the design of a demonstrator (see NuStorm)

For more details:

- https://muoncollider.web.cern.ch/welcome-page-muon-collider-website
- https://indico.cern.ch/event/1030726/
- http://mice.iit.edu/

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