Muon Collaboration

Neutrino Factories, Muon Cooling, and the MICE Experiment

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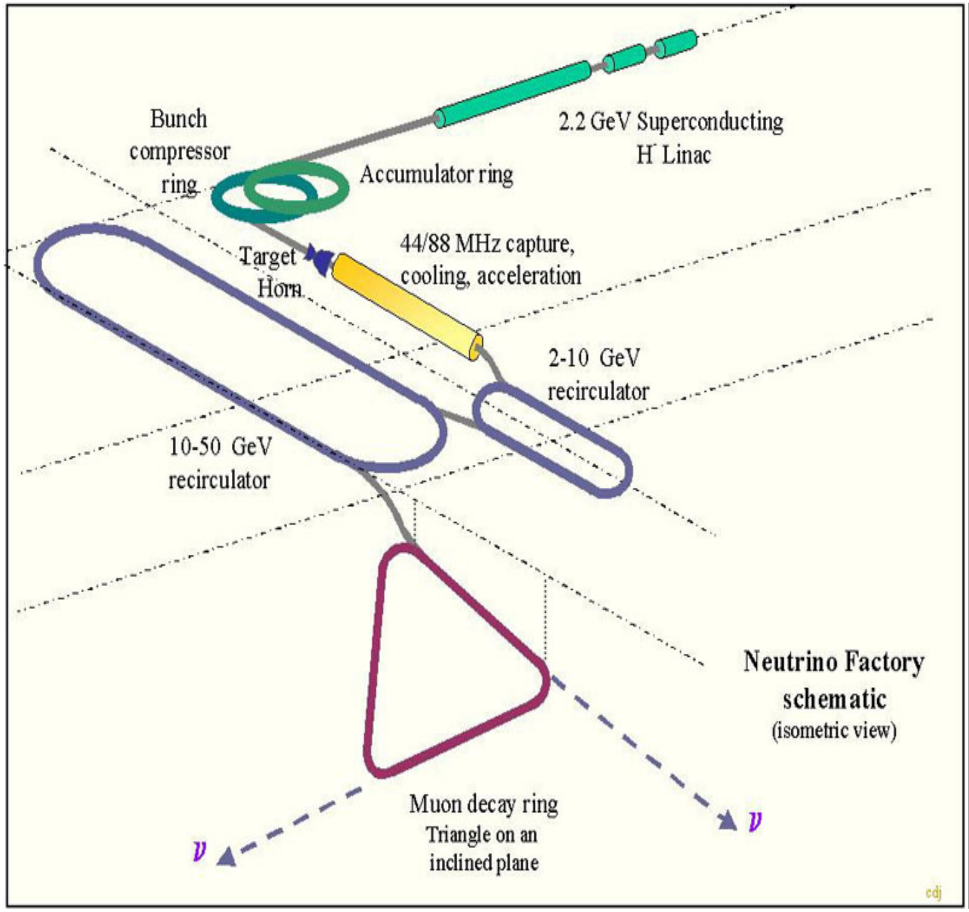
Outline:

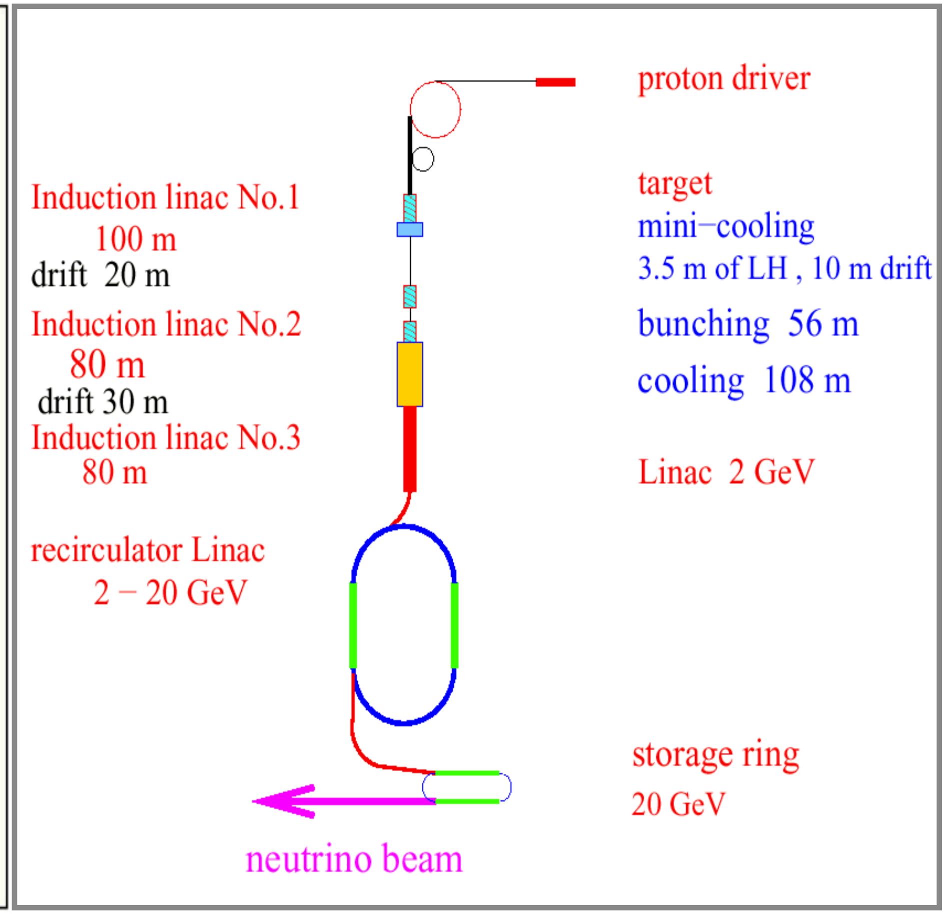
1. Brief overview of Neutrino Factories
2. Motivation: Neutrino Factory and Muon Collider physics
3. Need for muon cooling
4. Ionization cooling
5. Neutrino Factory cooling lattices and simulated performance
6. Muon Ionization-Cooling Experiment (MICE)
7. MICE schedule & status
8. International collaboration
9. Cost estimates
10. Summary

Neutrino Factory Overview

CERN scheme:



U.S. scheme:



- ~MW proton beam → high-power target, pions collected, decay in focusing channel
- Decay muons undergo longitudinal phase-space manipulation (“phase rotation”), cooling, acceleration, and storage in decay ring
- Produces intense beam of high-energy electron and muon neutrinos via $\mu^- \to e^- \nu_\mu \bar{\nu}_e$
- Also ∃ Japanese design – does not require cooling but could benefit from it

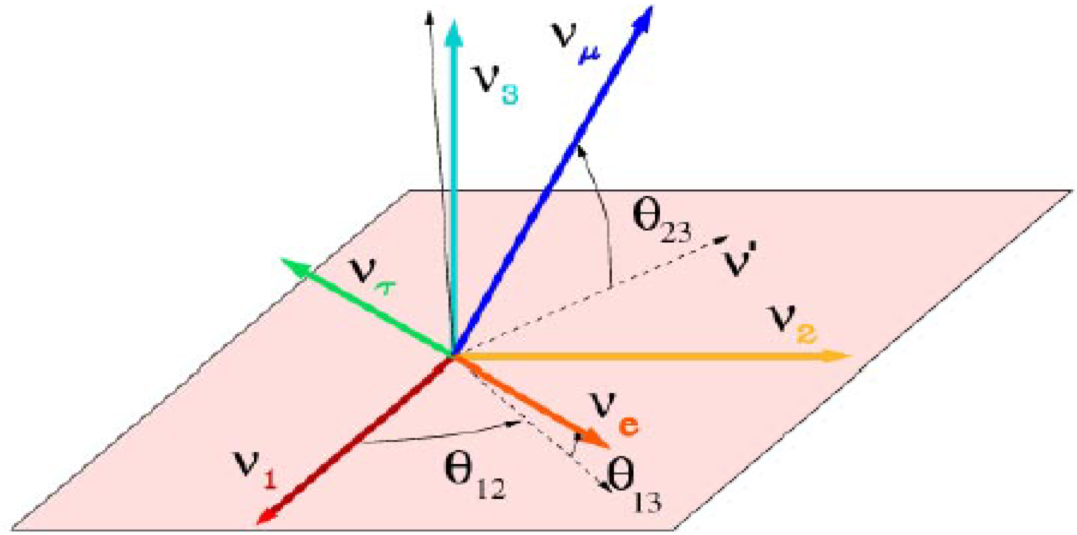
Motivation: Neutrino Factory Physics

- Most fundamental particle physics discovery of past decade:

  neutrinos have mass and mix

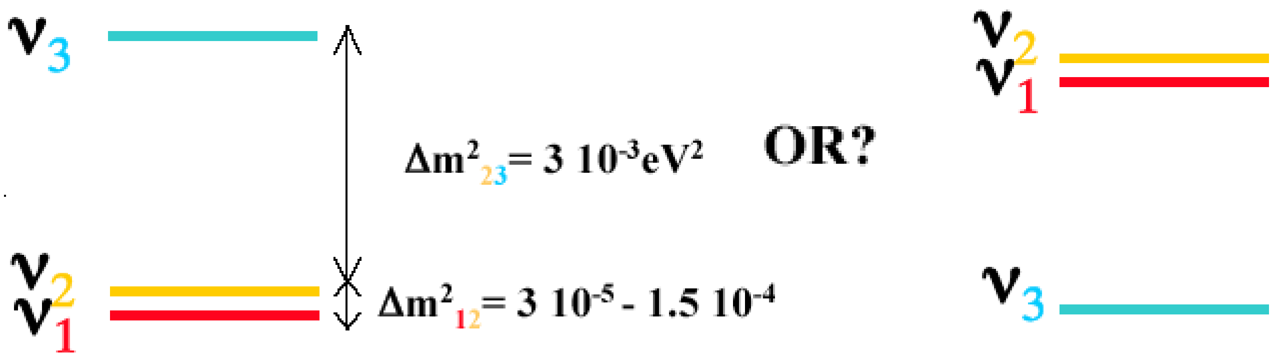
  ⇒ 3 Euler angles (and ≥1 phase)

  ⇒ neutrino mixing could violate CP → arguably the leading explanation for the cosmic baryon asymmetry



- Raises fundamental questions:

  1. what is neutrino mass hierarchy?



  2. why is pattern of neutrino mixing matrix so different from that of quarks?

CKM matrix:

$\theta_{12} \cong 12.8°$

$\theta_{23} \cong 2.2°$

$\theta_{13} \cong 0.4°$

nearly diagonal

PMNS matrix:

$\theta_{12} = 30°$ (solar)

$\theta_{23} = 45°$ (atmospheric)

$\theta_{13} < 13°$ (Chooz limit)

$$U_{MNS}: \begin{pmatrix} \sim \frac{\sqrt{2}}{2} & \sim -\frac{\sqrt{2}}{2} & \sin\theta_{13}\, e^{i\delta} \\ \sim \frac{1}{2} & \sim \frac{1}{2} & \sim -\frac{\sqrt{2}}{2} \\ \sim \frac{1}{2} & \sim \frac{1}{2} & \sim \frac{\sqrt{2}}{2} \end{pmatrix}$$

  3. what are the values of the small PMNS parameters: θ_{13}, δ?

Neutrino Factory Physics (cont'd)

- Such questions in the quark sector have fueled 4 decades of research
- Answers predicted in GUTs, testable via long-baseline ν-oscillation experiments:
  - to leading order (assuming natural hierarchy),

$$P(\nu_e \to \nu_\mu) = \sin^2\theta_{23} \sin^2 2\theta_{13} \sin^2(1.267\delta m^2_{32} L/E_\nu)$$

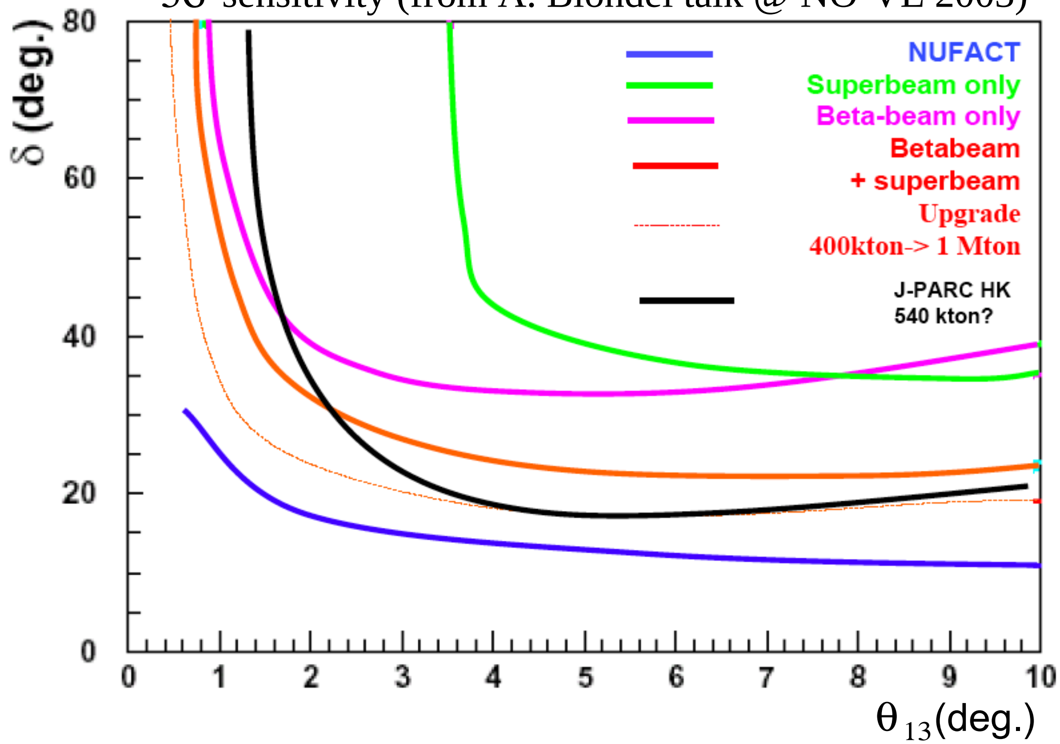
$$P(\nu_e \to \nu_\tau) = \cos^2\theta_{23} \sin^2 2\theta_{13} \sin^2(1.267\delta m^2_{32} L/E_\nu)$$

$$P(\nu_\mu \to \nu_\tau) = \cos^4\theta_{13} \sin^2 2\theta_{23} \sin^2(1.267\delta m^2_{32} L/E_\nu)$$

where L = baseline (km) and E_ν = neutrino energy (GeV)

- ν_e most sensitive to θ_{13}, prefer μ in final state ⇒ **HE ν_e beam uniquely powerful!**

3σ sensitivity (from A. Blondel talk @ NO-VE 2003)

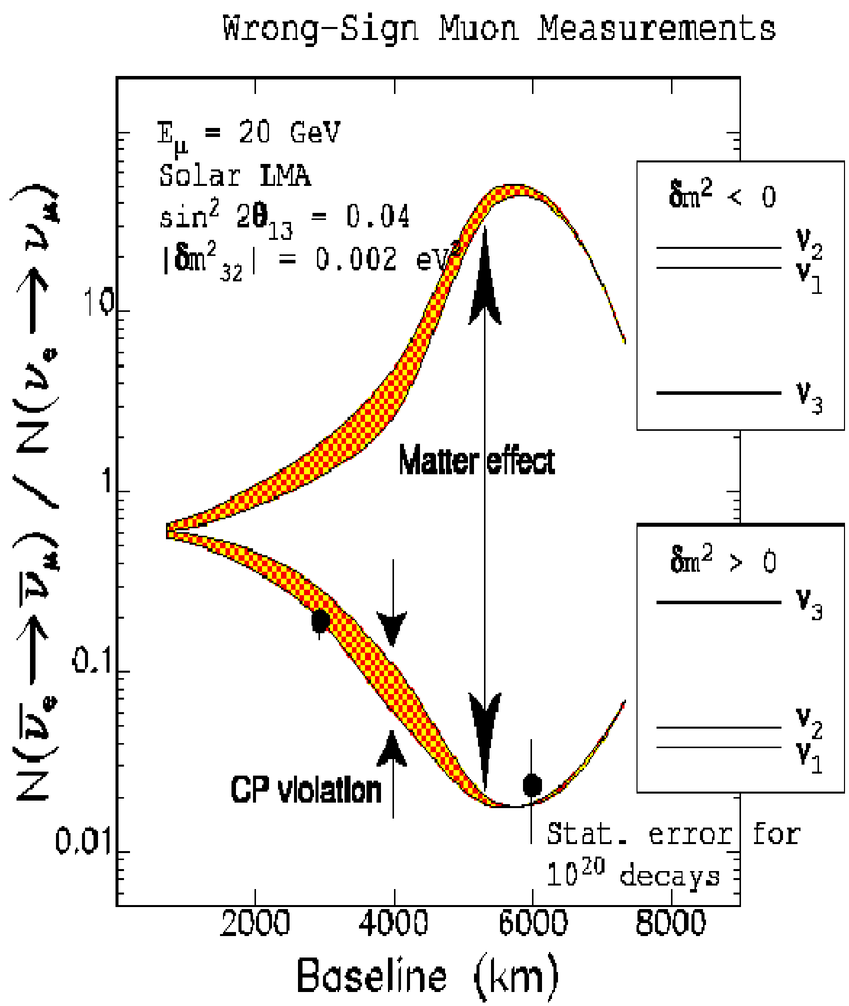


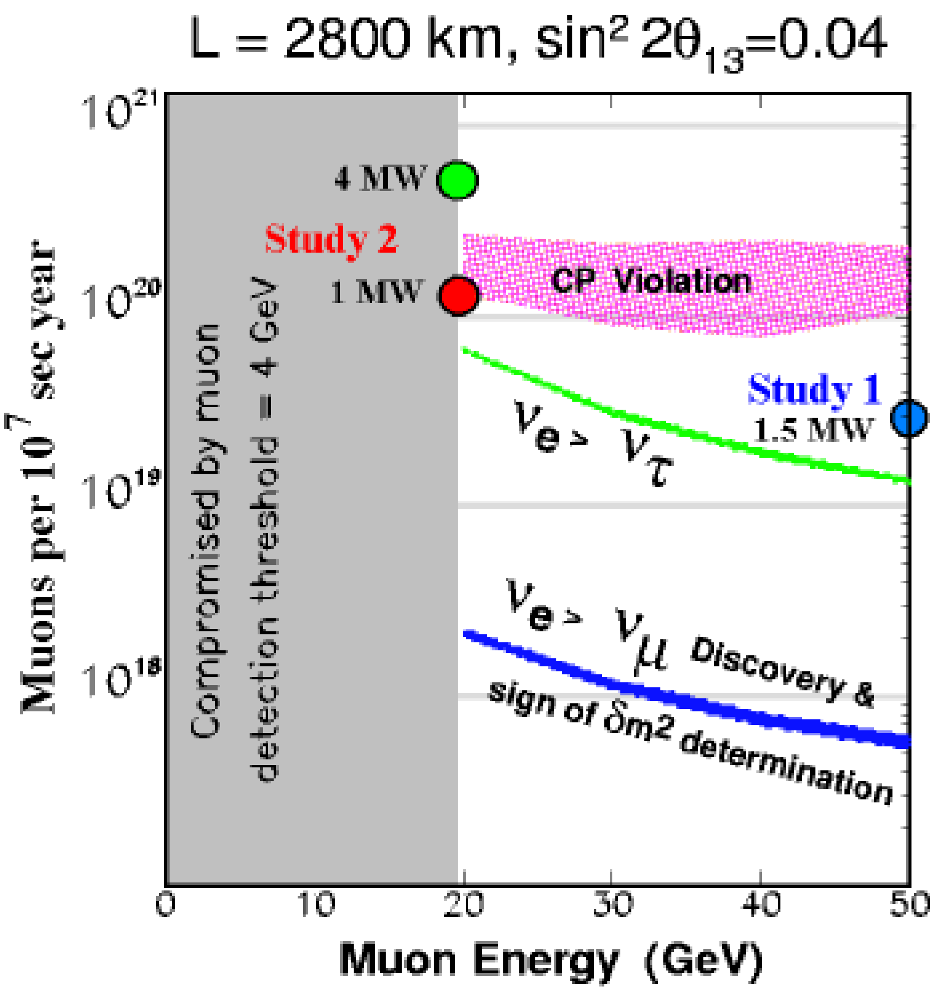
- LMA solution (assumed here) now definitively established by KamLAND
  - favors observability of CP violation at Neutrino Factory

(LSND result: life may be even more interesting!
  - yet to be confirmed/refuted by MiniBOONE)

Neutrino Factory Physics (cont'd)

- With suitably chosen baseline(s), comparing $\nu_e \to \nu_\mu$, $\bar{\nu}_e \to \bar{\nu}_\mu$ gives both sgn(Δm^2_{32}) (via matter effects) and CP phase δ:



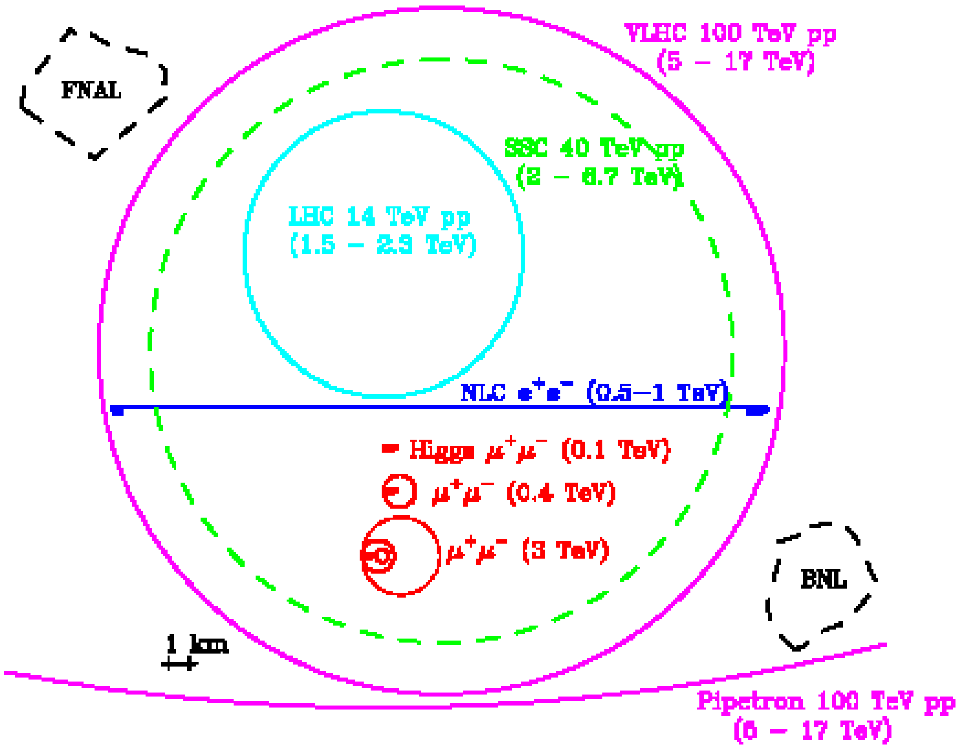


- To set scale, 10^{20} decays with 50-kT detector sees δ down to 8°

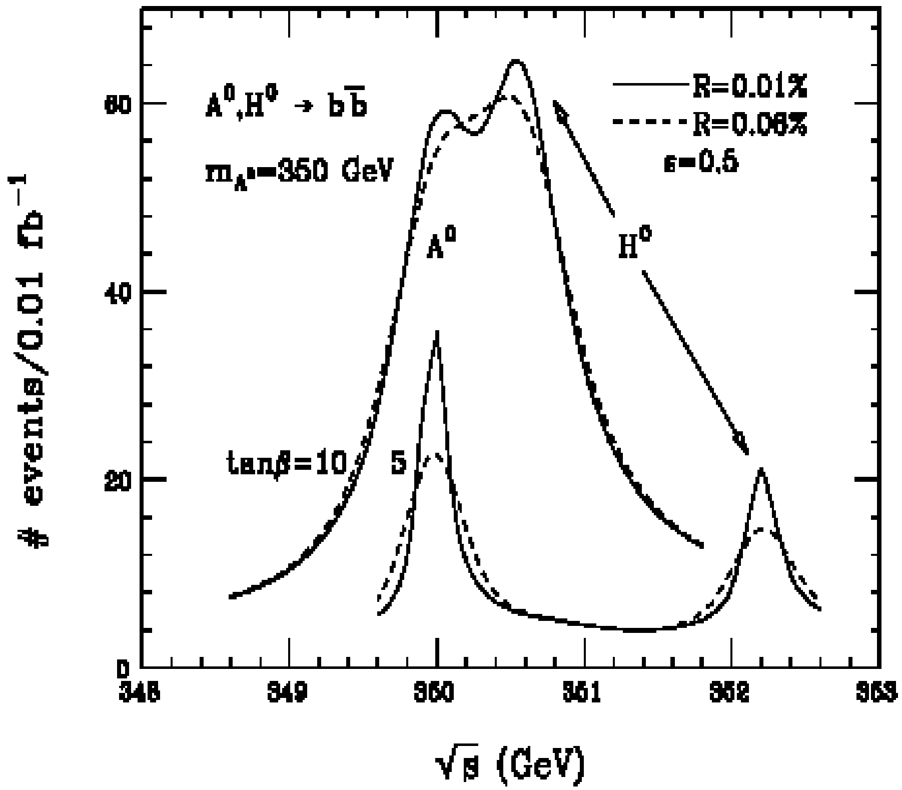
$\Rightarrow$ flux is crucial!

Motivation: Muon Collider

- A pathway to *high-energy* lepton colliders
  - unlike e^+e^-, $\sqrt{s}$ not limited by radiative effects
  - a muon collider can fit on existing laboratory sites even for $\sqrt{s}$ > 3 TeV



- s-channel coupling of Higgs to lepton pairs $\propto m^2_{\text{lepton}}$



- E.g., μμ-collider resolution can separate near-degenerate scalar and pseudo-scalar Higgs states of minimal SUSY

νF Feasibility Studies

- νF R&D in progress in Europe, US, Japan
- Feasibility studies performed 2000-01 in US under FNAL & BNL auspices
  - included enough conceptual engineering to estimate cost & identify "cost drivers" for further R&D
  - FS-II cost estimate:

System	Sum ($M)	Others[a] ($M)	Total ($M)
Proton Driver	167.6	16.8	184.4
Target Systems	91.6	9.2	100.8
Decay Channel	4.6	0.5	5.1
Induction Linacs	319.1	31.9	351.0
Bunching	68.6	6.9	75.5
Cooling Channel	317.0	31.7	348.7
Pre-accel. linac	188.9	18.9	207.8
RLA	355.5	35.5	391.0
Storage Ring	107.4	10.7	118.1
Site Utilities	126.9	12.7	139.6
Totals	1,747.2	174.8	1,922.0

(cf. SPS cost: ≈1 GSF in 1976)

- Conclude: with these technologies, νF feasible (but a bit expensive)
  - cost drivers: phase rotation, cooling, acceleration

  $\Rightarrow$ potential for substantial cost reduction w/ further R&D on these (cooler beam can reduce acceleration costs as well)

Why Muon Cooling?

- νF physics needs ~ 0.1 μ/p-on-target $\Rightarrow$ **very** intense μ beam from π decay

  $\Rightarrow$ must accept large (~10π mm·rad rms) beam emittance
- No acceleration system yet demonstrated with such large acceptance

  $\Rightarrow$ must cool the muon beam or develop new, large-aperture acceleration
  – in current studies, cooling $\rightarrow \times\, 3 – 10$ in accelerated muon flux
- But what cooling technique works in microseconds?
  – there is only one, and it works only for muons:

ionization cooling

BUT:

– It has never been observed experimentally

– Studies show it is a delicate design and engineering problem

– It is a crucial ingredient in the cost and performance optimization of a Neutrino Factory

$\Rightarrow$ Need experimental demonstration of muon ionization cooling!

Language of Beam Cooling: Emittance

Emittance: a measure of the size of a particle beam

- Includes volume beam occupies in momentum space as well as position space, i.e.,

  6D emittance $\varepsilon_6 \approx \varepsilon_x \varepsilon_y \varepsilon_z \propto \sigma_x \sigma_{p_x} \sigma_y \sigma_{p_y} \sigma_z \sigma_{p_z}$ is phase-space volume occupied by beam*

- Liouville's Theorem $\Rightarrow$

  Linear electromagnetic fields cannot change total emittance of charged-particle beam.

- Thus:

  Ignoring nonlinearities & interactions with matter, *normalized* emittance $\varepsilon_N \equiv \gamma\beta\varepsilon$ is a constant of the motion in accelerator or beamline.

  – while geometrical emittance ε decreases with acceleration, ε_N does not

NB: convenient to describe a beamline by focusing functions β:

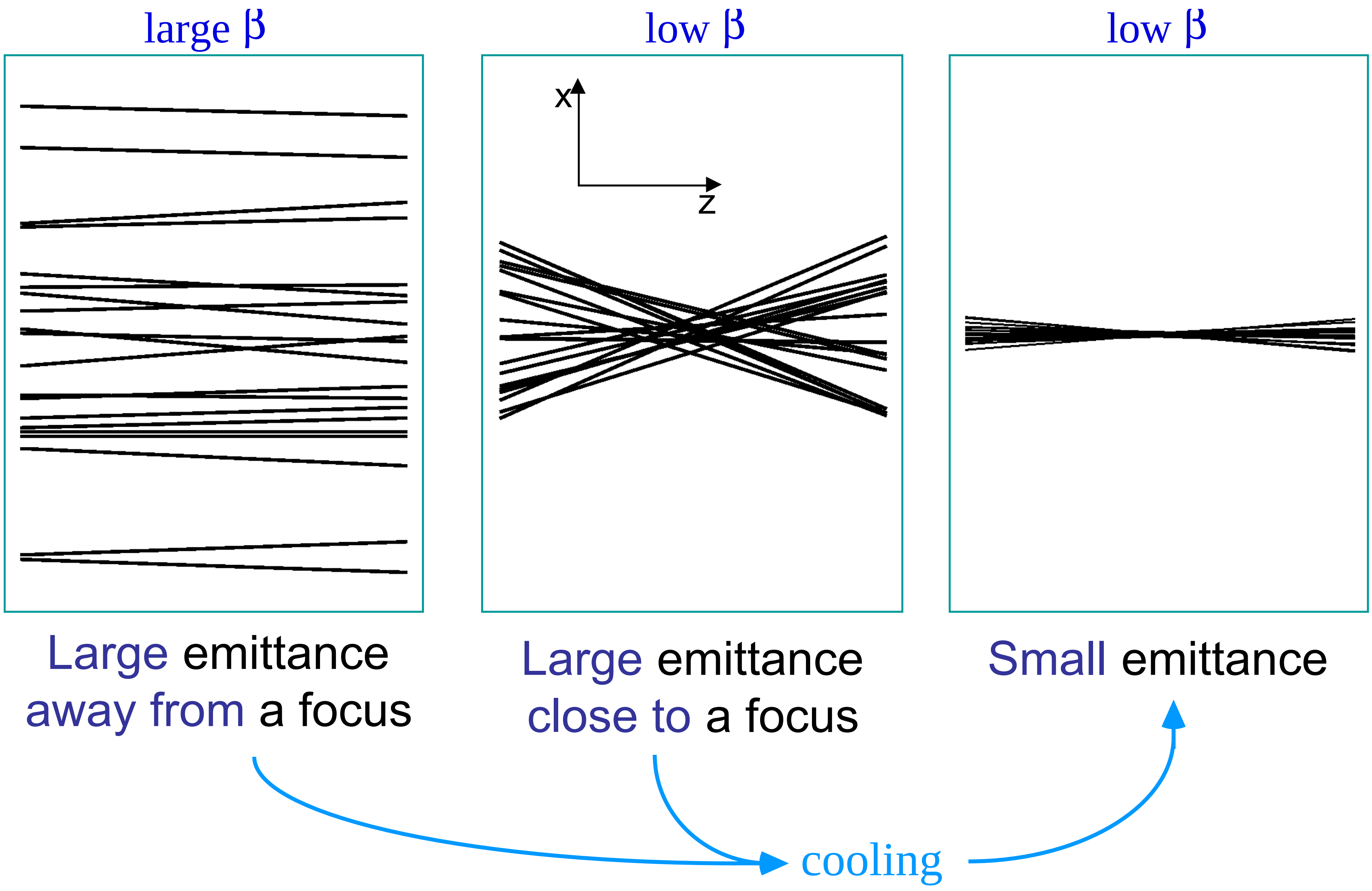
$$\pi\sigma_x^2 = \beta_x \varepsilon_x \, , \quad \pi\sigma_y^2 = \beta_y \varepsilon_y$$

---

* Expression for ε above ignores possible correlations; more generally, $\varepsilon_{6,N}$ = det (V) / $(mc)^6$ where V = covariance matrix of (x,p_x,y,p_y,z,p_z)

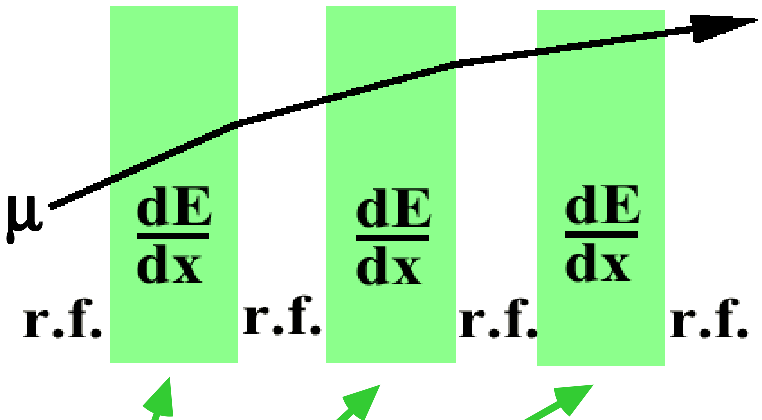
Emittance (cont'd)

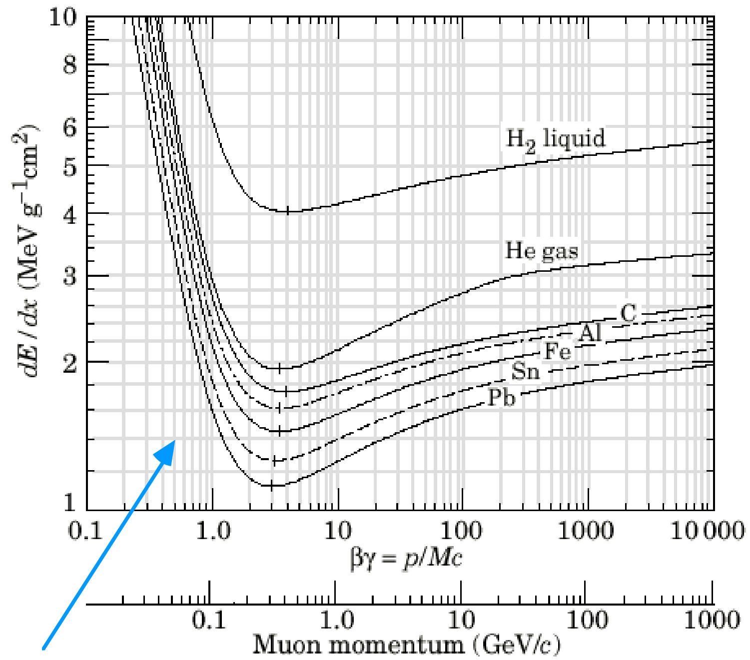
- Illustrative example:



What is Ionization Cooling?

- Simple idea: (Skrinsky et al., 1978 et seq., Neuffer, 1979 et seq.)





- Absorbers:

$$\begin{cases} E \to E - \left\langle \dfrac{dE}{dx} \right\rangle \Delta s \\ \theta \to \theta + \theta_{space}^{rms} \end{cases}$$

ionization energy loss

multiple Coulomb scattering

- RF cavities between absorbers replace ΔE
- Net effect: reduction in $p_\perp$ w.r.t. $p_\parallel$, i.e., transverse cooling:

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

$\Rightarrow$ want strong focusing, large X_0, and low E_μ

(NB: close analogy with SR damping in *e* rings)

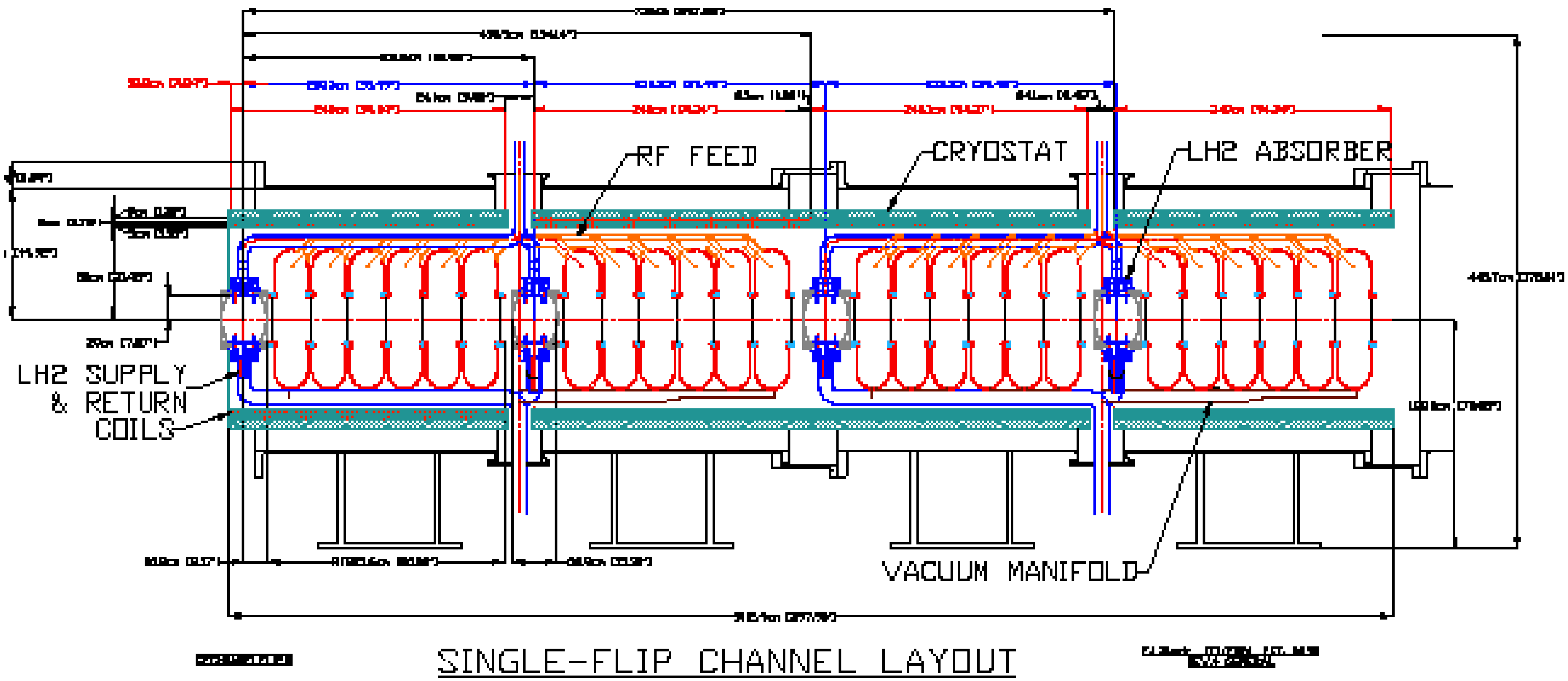
NB: The **physics** is not in doubt

$\Rightarrow$ in principle, ionization cooling **has** to work!

...but in practice it is subtle and complicated so a test is important

Simplest Conceptual Scheme

- Long SC solenoids containing LH_2 absorbers & high-field RF cavities:



Concept: V. Balbekov (FNAL)

Eng. design: E. Black (IIT), A. Moretti (FNAL), J.-M. Rey (Saclay)

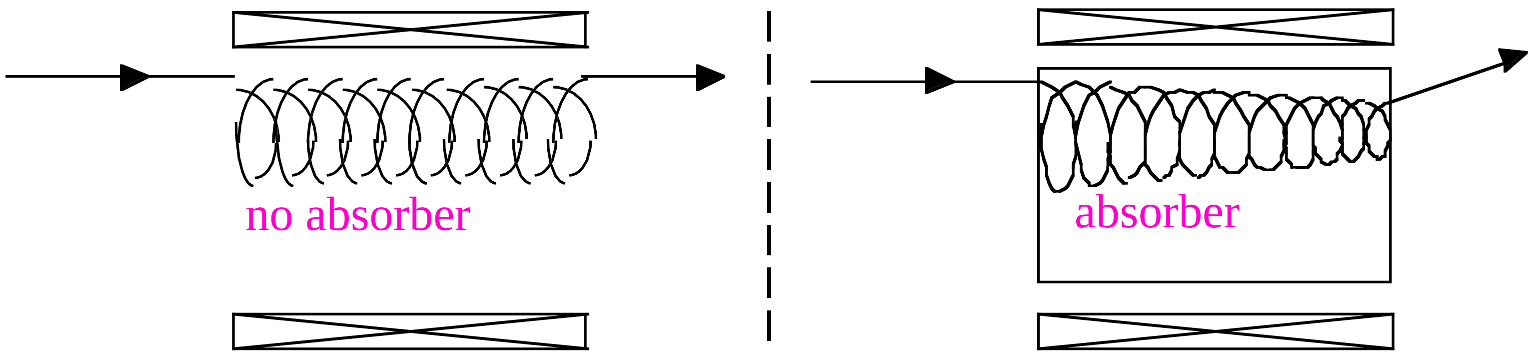
- But ∃ important optics subtlety:
  - need to alternate direction of focusing field to avoid build-up of net angular momentum

Angular Momentum

- Consider particle entering long solenoid off-axis but || to axis:
  - receives $p_\perp$ kick $\rightarrow$ helical motion within field
  - at end of solenoid, inverse $p_\perp$ kick restores straight trajectory
- But if particle loses momentum within solenoid, helix radius decreases

$\Rightarrow$ particle receives wrong $p_\perp$ kick at exit, emerges with net angular momentum

$\Rightarrow$ particle entering parallel to axis emerges at angle:

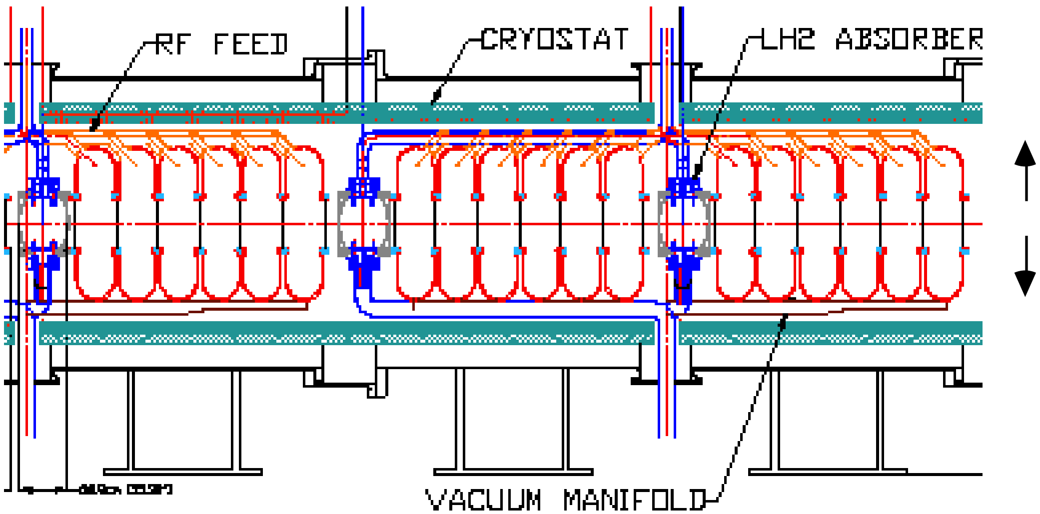


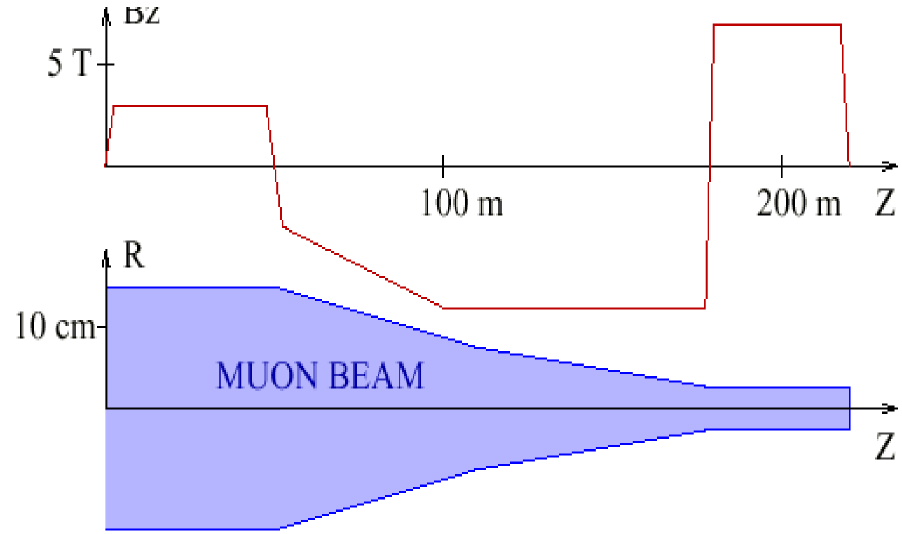
- Would disrupt beam if not handled correctly

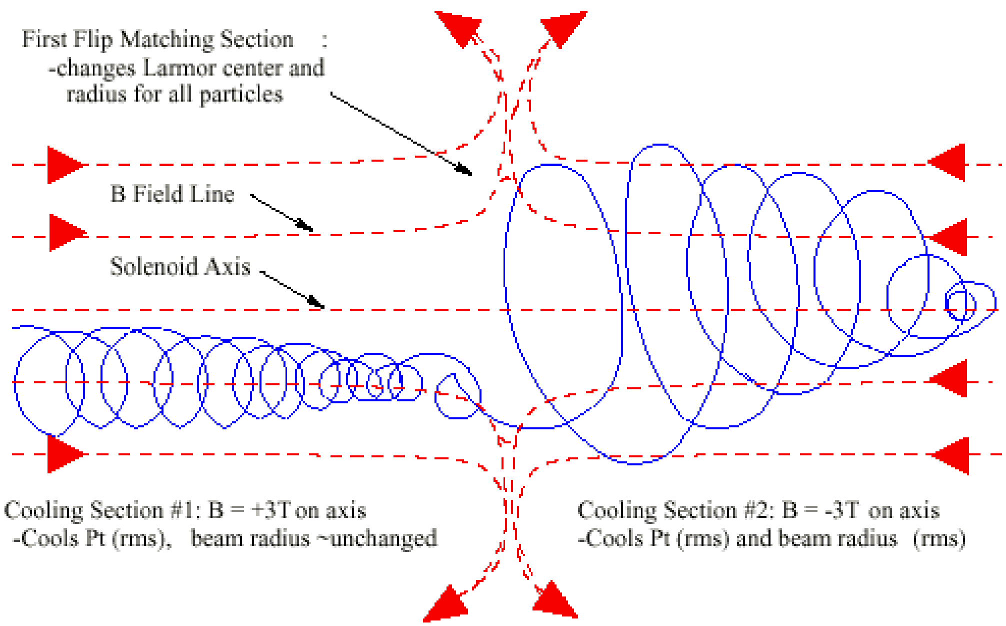
Double-Flip Cooling Channel

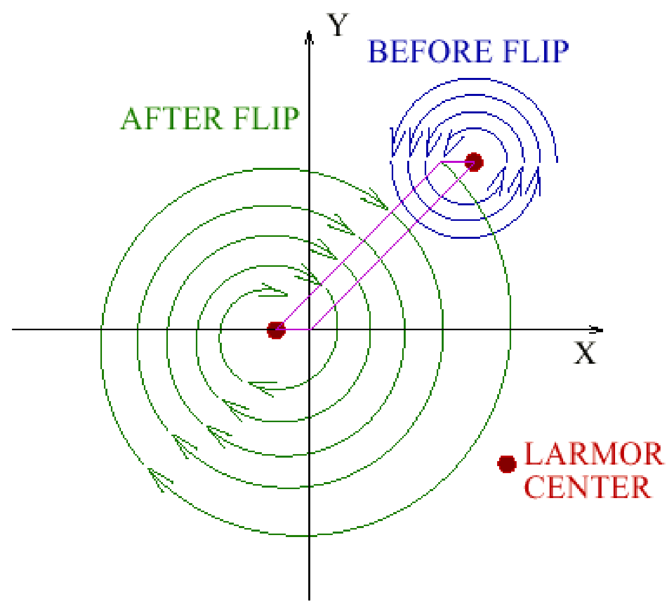
(V. Balbekov & D. Elvira, FNAL)

- NB: Low β → big S/C solenoids & high fields!



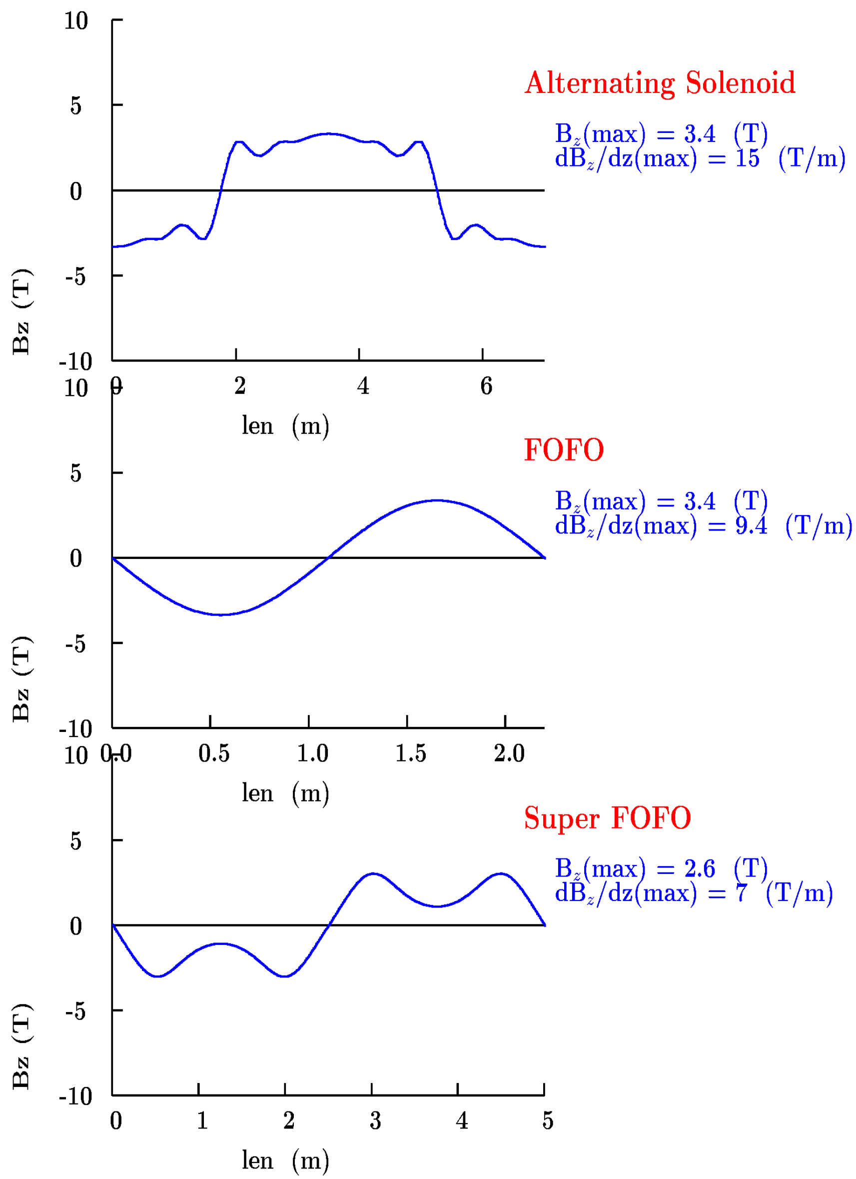


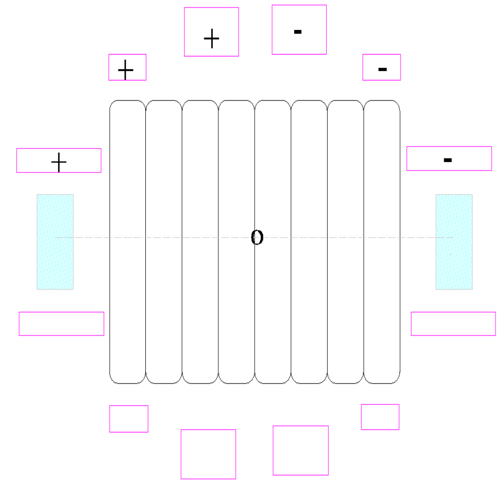




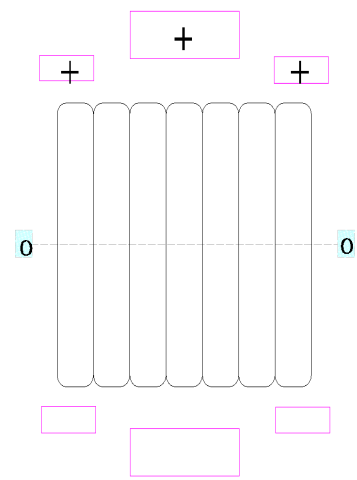
Periodic Cooling Lattices

- Various lattice designs have been studied:

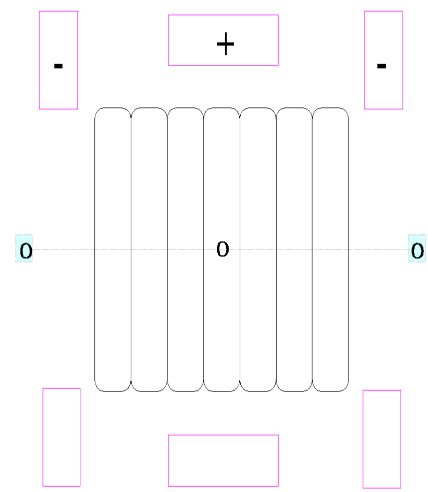




Alternating solenoid



FOFO



Super-FOFO

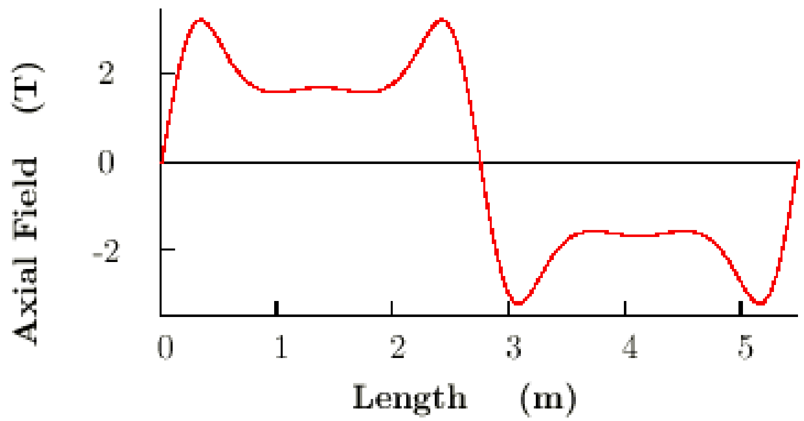
(+ RFOFO, DFOFO, Single-Flip, Double-Flip)

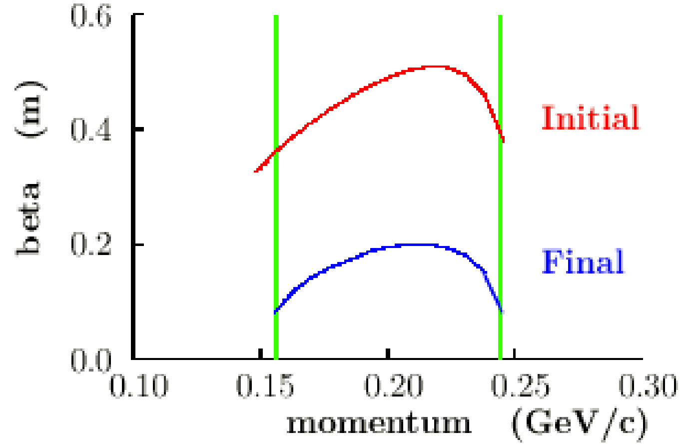
→ Alternating gradient allows low β with much less superconductor

Tapered-SFOFO Cooling Lattice

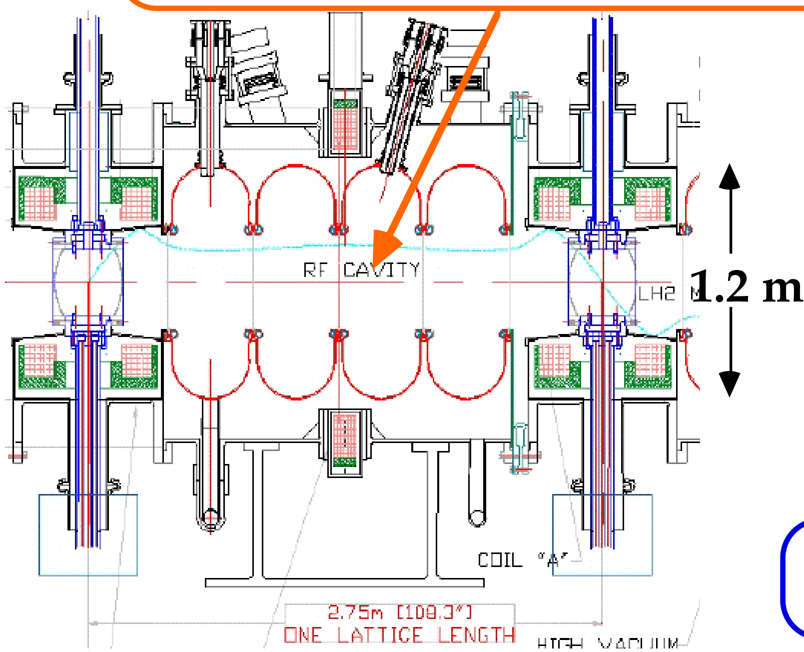
(R. Palmer, BNL)

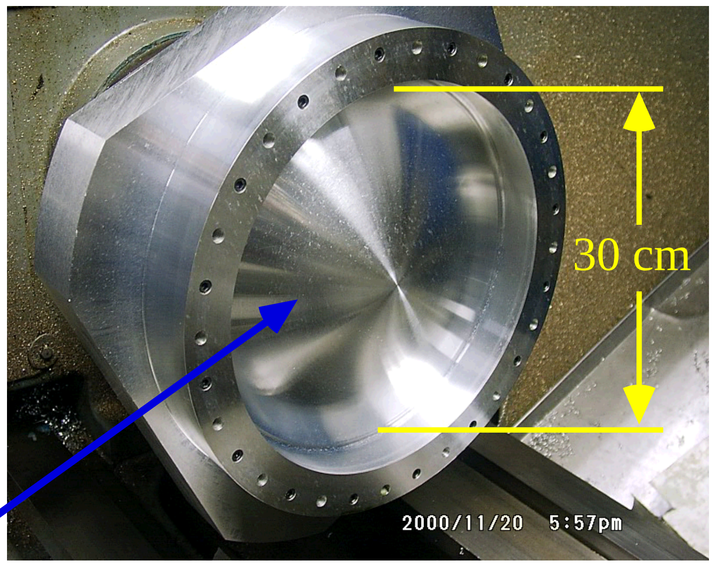
- FS-II baseline cooling channel





Cavities have thin (≈0.5-mm) Be windows to reduce surf. fields and req'd RF power





Absorbers have thin (<300-μm) tapered Al windows to minimize muon scattering

Challenging Technology

- Cooling channel is a “linac filled with hydrogen flasks” focused by superconducting solenoids

  $\rightarrow$ such a system has never been built or operated

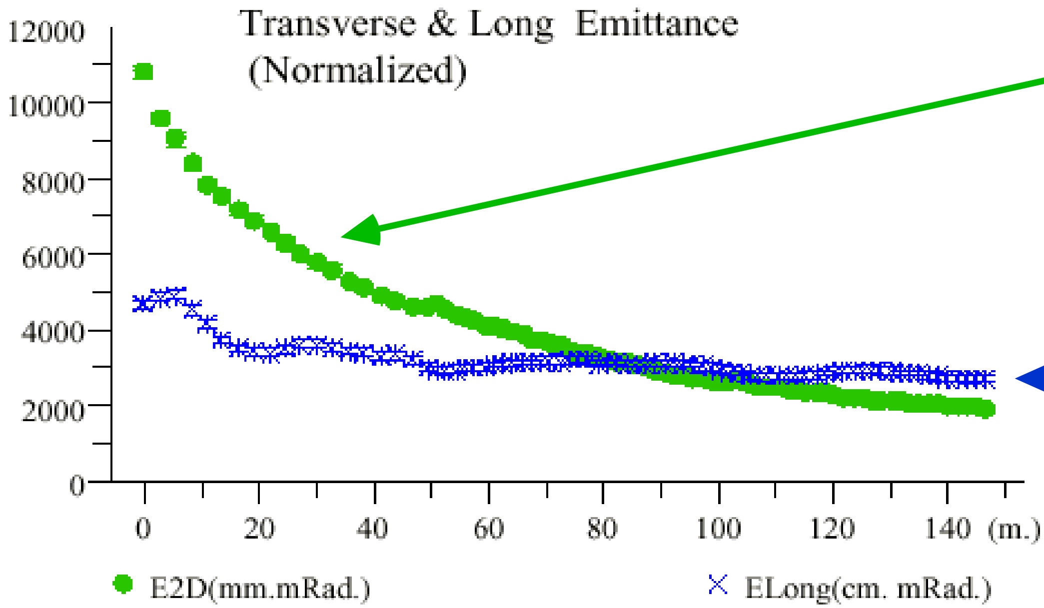
- No accelerator uses closed-cell RF cavities or operates cavities in strong solenoidal *B* field
  - prototype tests at Fermilab: surface field emissions enhanced & focused by *B* field
  - 16 MV/m @ 201 MHz not easy parameters, but good progress being made
- Tightly packed system with difficult access to interior
- Engineering constraints of safety & reliability could impact performance
  - LH_2 safety rules forbid operating near ignition sources
  - but cavities can spark & magnets can quench

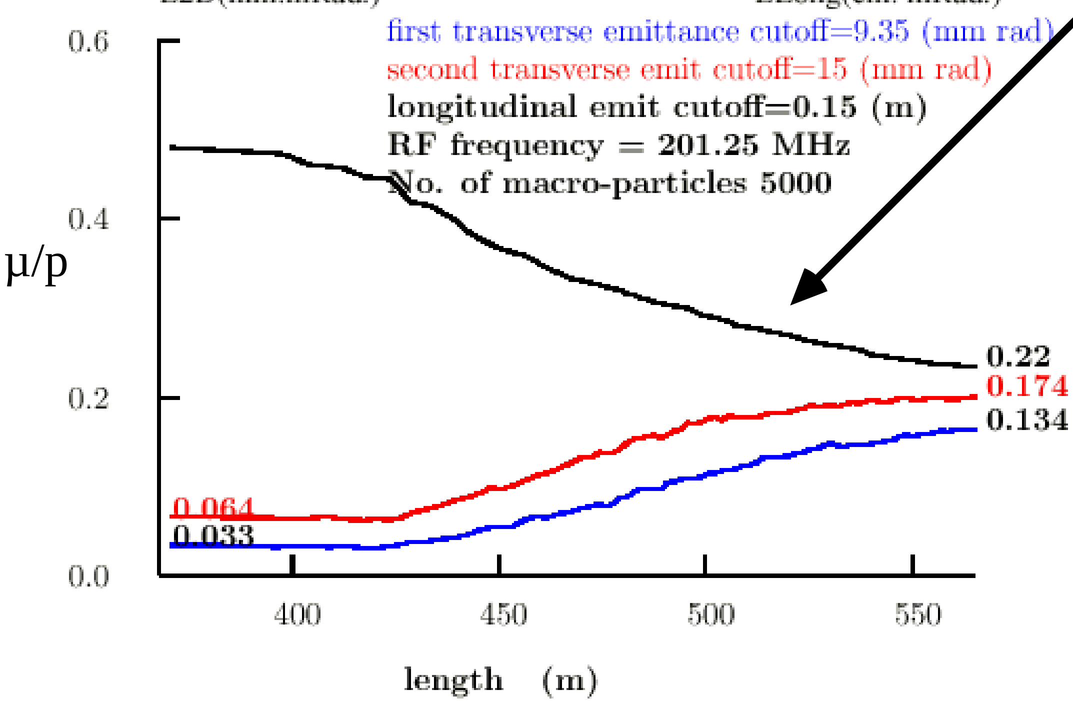
$\rightarrow$Such issues cannot be resolved reliably on paper!

$\Rightarrow$ Need actual exp’tal test w/ real safety reviews, engineering, etc...

Tapered-SFOFO Cooling Performance

- FS-II simulation results:





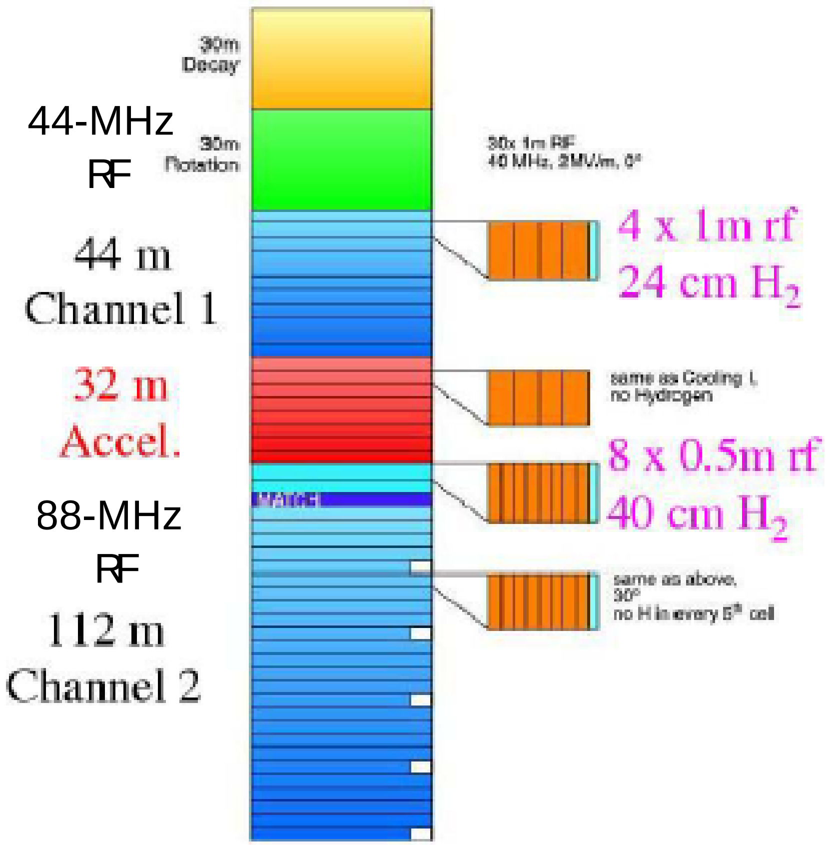
- Transverse emittance damps ≈exponentially
- Longitudinal emittance growth with scraping of tails gives ≈constant longitudinal beam size due to losses
- Two indep. codes used for these sims, Geant and ICOOL
- Codes agree on emittance decrease & beam transmission within ≈10%, as well as with analytic calculations

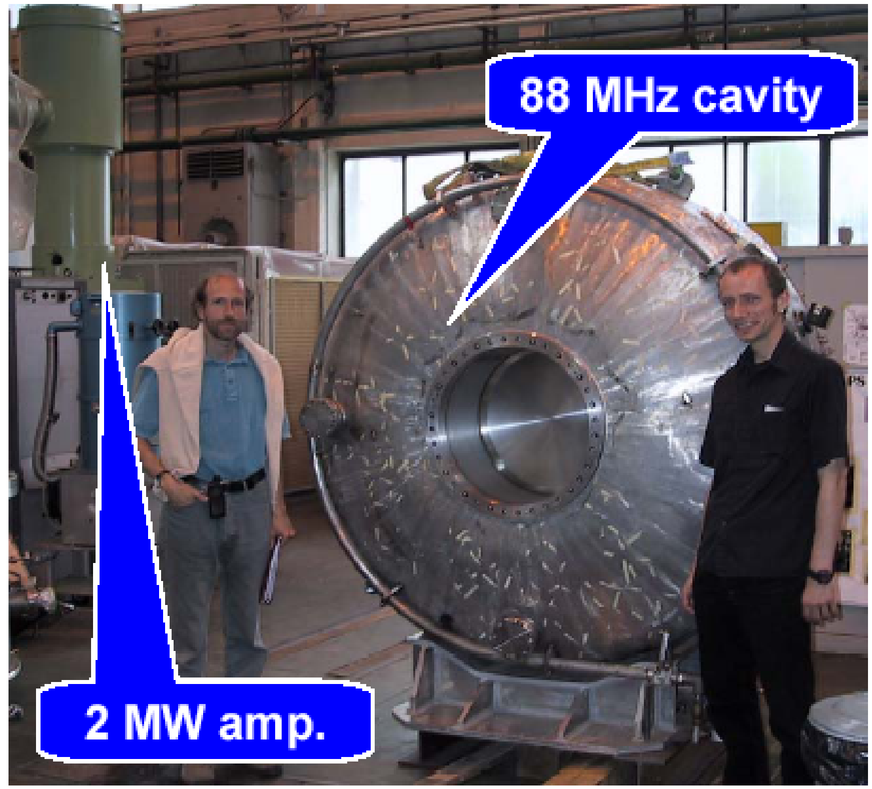
Assuming 15mm trans. acceptance
9.5mm

CERN Cooling Channel Design

(A. Lombardi, CERN, Neutrino Factory Note NF-34)

- Uses lower-frequency RF (44 & 88 MHz)
- Coils "tucked into" cavities to reduce solenoid cost





High-power test planned for later this year

- Perfomance simulated using PATH – comparable to that of US design

Longitudinal Cooling

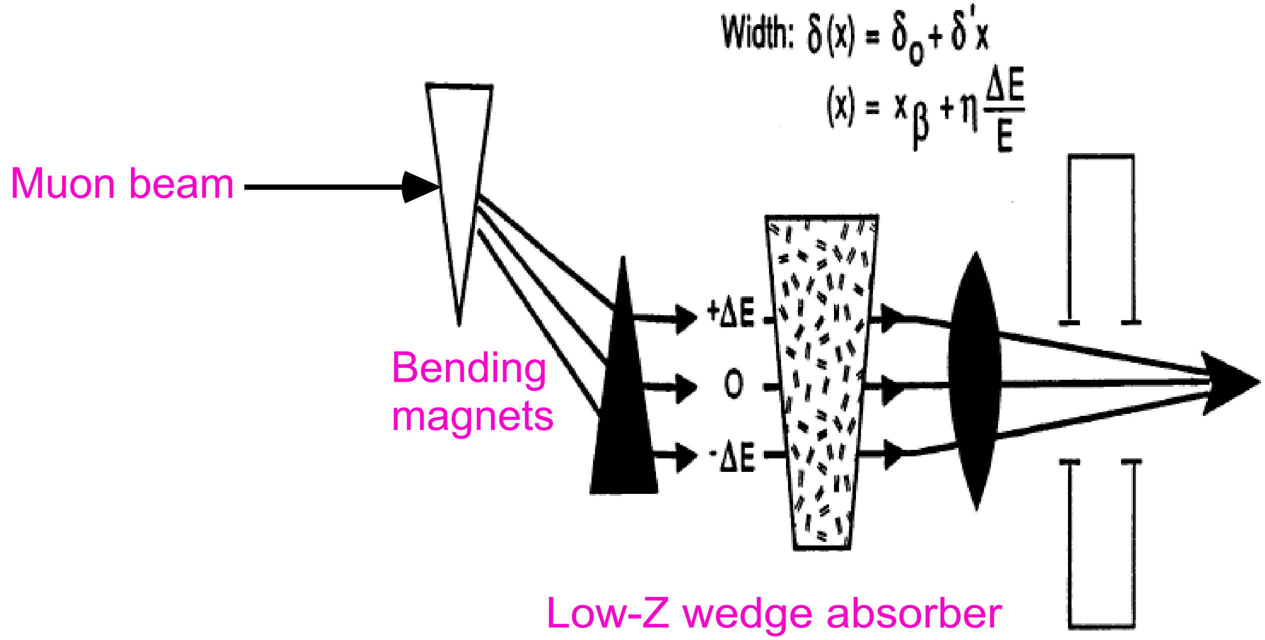
- Transverse ionization cooling self-limiting due to longitudinal-emittance growth

  ⇒ need longitudinal cooling for muon collider; could also help νF by

  - reducing losses
  - allowing cheaper, smaller-aperture acceleration

- Possible in principle by ionization above ionization minimum, but inefficient due to small slope *d(dE/dx)/dE* and increase of straggling with energy

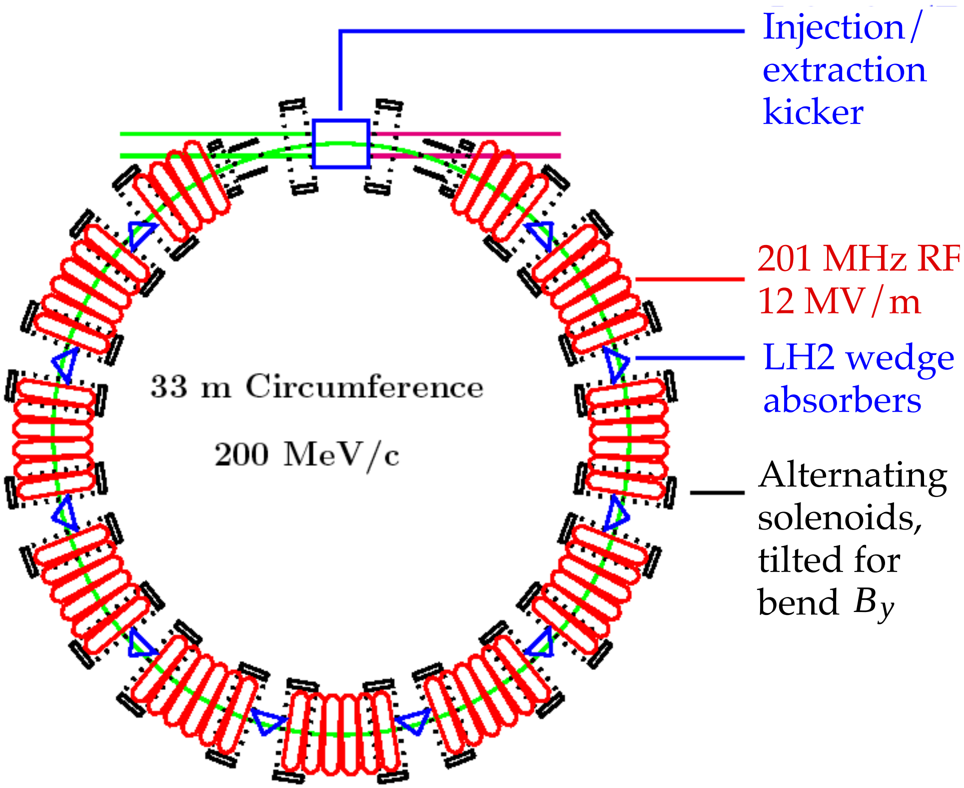
  → Emittance-*exchange* concept:



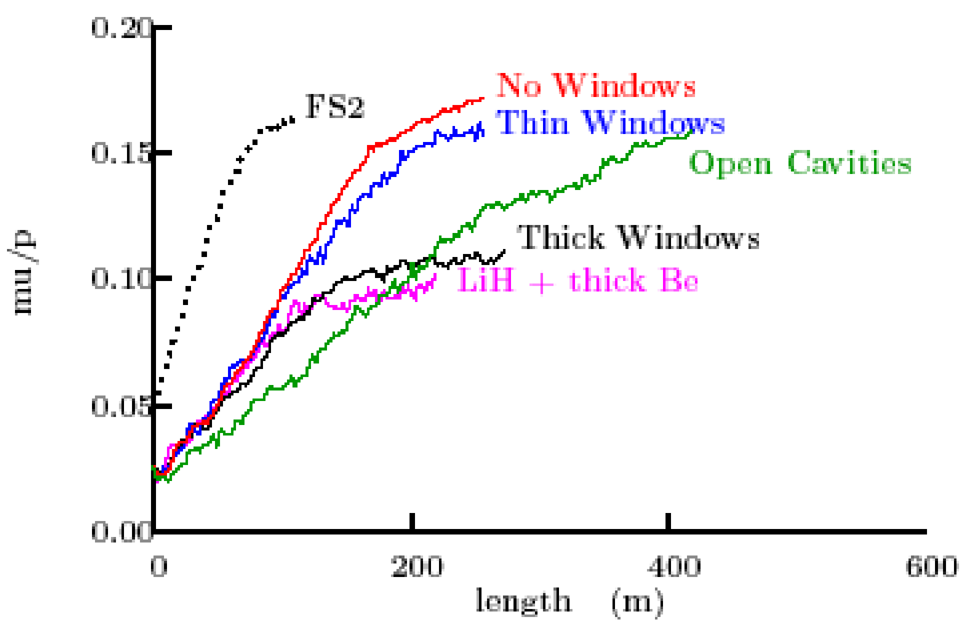
- Several promising designs under exploration, none yet engineered

Ring Coolers

- Combine transverse cooling with emittance exchange
- Allow re-use of (expensive) cooling hardware via multiple passes



Ring Cooler Performance:



(from Palmer MuTAC Review talk 1/14/03)

  - could lead to νF that is both cheaper and higher-performance
  - injection & extraction appear soluble but require very fast, large-aperture kicker
  - performance very sensitive to scattering: LH_2 absorbers with thin windows crucial

Why a Cooling Experiment?

The aims of the Muon Ionization Cooling Experiment are:

- to show that it is possible to design, engineer and build a section of cooling channel capable of giving the desired performance for a Neutrino Factory;
- to place it in a muon beam and measure its performance in a variety of modes of operation and beam conditions.

From the U.S. Muon Technical Advisory Committee (MUTAC) and European Muon Cooordination and Oversight Group (EMCOG) reviews:

MUTAC (14-15 jan 2003):
The committee remains convinced that this experiment, which is absolutely required to validate the concept of ionization cooling, and the R&D leading to it should be the highest priority of the muon collaboration.

EMCOG: (6 feb 2003)
EMCOG was impressed by the quality of the experiment, which has been well studied, is well organized and well structured. The issue of ionization cooling is critical and this justifies the important effort that the experiment represents.
EMCOG recommends very strongly a timely realization of MICE.

⇒ The "cooling demonstration" is the key systems test for the Neutrino Factory.

Why MICE Now?

- Much work over many years has established the components needed for muon cooling: SC solenoids, absorbers, RF cavities
- Performing a realistic ionization-cooling test will take several years
- Neutrino physics gets more exciting year by year
- The world of HEP will need to know by ≈2008 (startup of LHC & J-PARC→SuperK) what are the options for the next big project
- Knowledge gained by building and operating a realistic piece of a cooling channel will provide crucial input to further design and optimization studies

⇒ **The time to start is now!**

Design Choices & Issues

Q: What to test?

- All have common hardware elements: absorbers & cavities in strong solenoidal fields
- Choice constrained by availability of infrastructure (esp. low-frequency RF sources)

A: One 201-MHz SFOFO cell:

→ smaller and less expensive installation
- surplus RF power supply components available
- may propose future upgrades as more resources available (e.g., adding more cooling cells) or to test new ideas (e.g., emittance exchange)

Q: Multi-particle vs. single-particle emittance measurement:

Multi-particle: traditional beam-physics approach

- based on multiple beam-profile measurements
- compute emittance using known transfer matrices

detector resolution and knowledge of transfer matrices limits precision to 10%

Single-particle: traditional HEP techniques

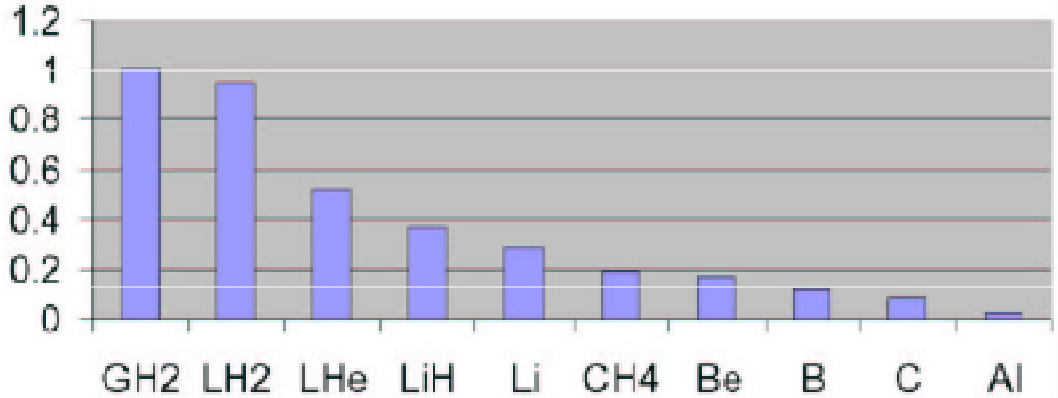
- measure trajectory of each muon (x,y,z,x´,y´,z´,t)
- collect statistics
- form "virtual bunch" off line and compute emittances

should be capable of 0.1% precision; “software collimation” cut outs e.g. decay electrons

← Our choice

Choice of Absorber Material

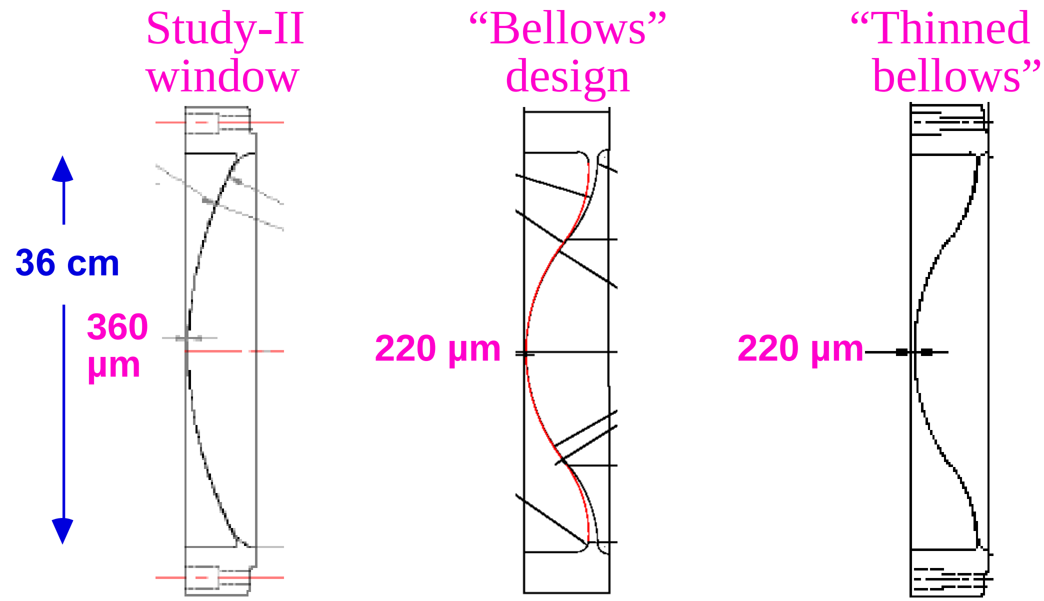
- Transverse cooling merit factor $F \propto (L_R\, dE/dx)^2$:



Hydrogen is best material by factor ≈ 2

(...all other things being equal, e.g., neglecting containment windows)

– IIT/Oxford U "thinned bellows" windows (in 2000-series Al alloy) degrade F_{LH_2} only to ≈ 0.8:



Mat'l	X0 (cm)	Len (cm)	%X0	Tot %X0	Merit
LH2	866	35	4.04		1
Al 6061-T6	8.86	0.072	0.81	4.85	0.693
Al 2090-T81	9.18	0.04	0.44	4.48	0.815

Important further issues

805-MHz cavity in SC solenoid in Lab G

- Detectors must operate in strong solenoidal fields & intense RF-cavity backgrounds & contribute negligible emittance degradation

  $\Rightarrow$ SciFi (or He TPC) in 4T solenoidal field $\rightarrow \delta\varepsilon \approx 10^{-3}$

- FNAL/MUCOOL tests of 805-MHz prototype cavities (up to $E_{surf} \approx 53$ MV/m) show high dark current ($\lesssim$100 mA inst.) and x-ray emission

  $\Rightarrow$ LH_2 absorbers must shield detectors from cavities

  R&D to reduce cavity bkg in progress at FNAL

  – exploring surface treatments and coatings

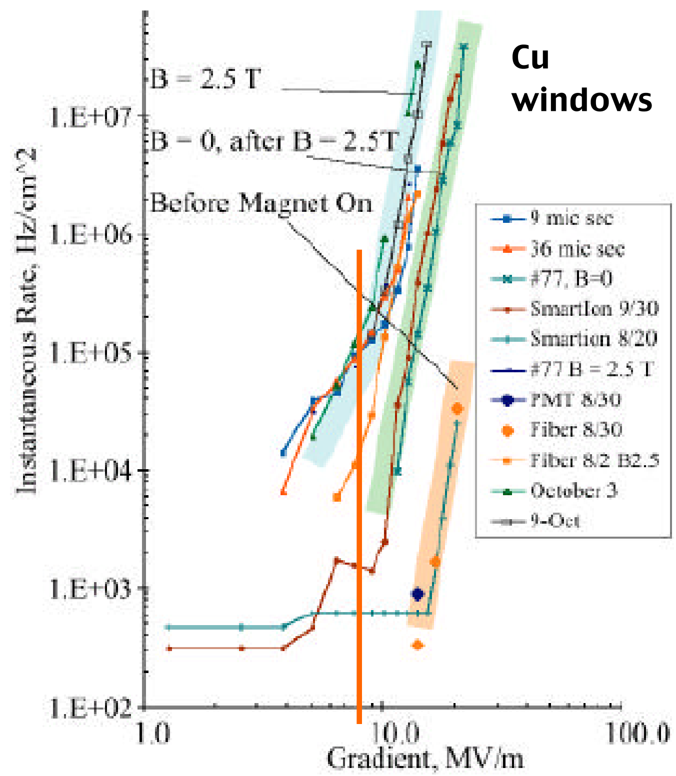
  – MICE 201-MHz cavities designed for $\lesssim$10 MV/m (rate ~ $E^{10} \Rightarrow$ ~10^{-7} in dark current $\Rightarrow$ should be OK)

- μ-cooling channel puts hydrogen flasks with thin windows in close proximity to possible ignition sources!

  $\Rightarrow$ working out safe design and operating approaches is a crucial and challenging part of the MUCOOL and MICE efforts and is in progress

  – MICE Absorber Focus-Coil Safety Working Group (LBNL/IIT/Oxford/NIU/RAL, M. Zisman, convener) has made good progress (passed internal review 9/12/03)

Dark current vs field



Single-Particle Emittance Measurement

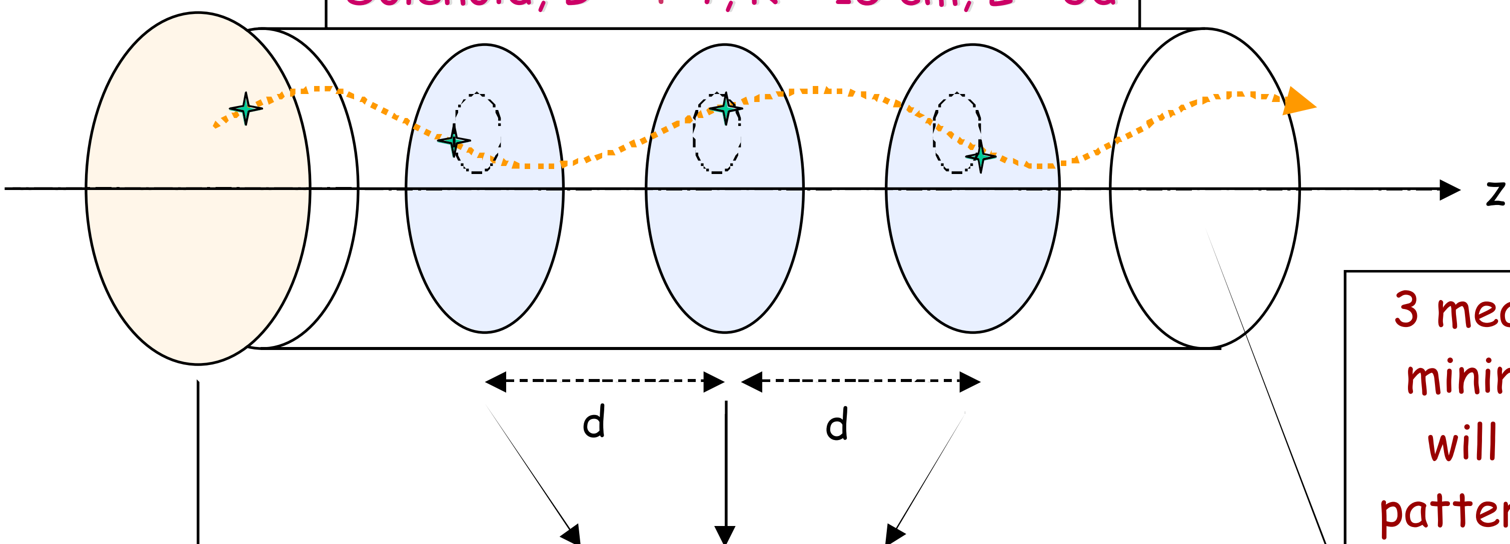
(P. Janot, CERN)

- **Principle:** Measure each muon precisely before and after cooling cell
  Off-line, form "virtual bunch" and compute emittances in and out

Need to determine, for each muon, x,y,t, and x',y',t' (=p_x/p_z, p_y/p_z, E/p_z) at entrance and exit of the cooling channel:

Solenoid, B = 4 T, R = 15 cm, L > 3d

(to keep B uniform on the plates)



T.O.F.
Measure t
With σ_t ~ 70 ps

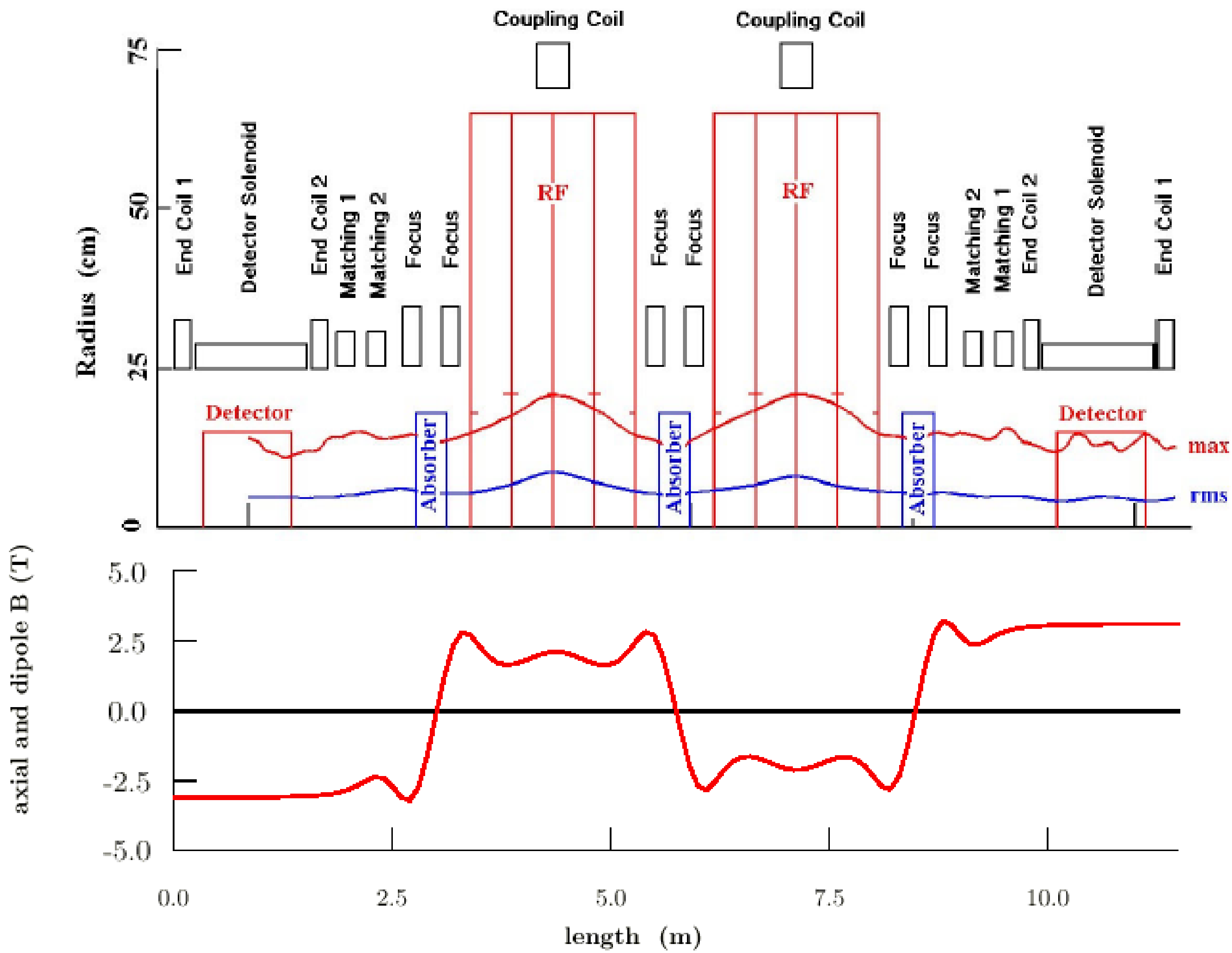
Three plates of, e.g.,
three layers of sc. fibres
(diameter 0.35 mm)
Measure x_1, y_1, x_2, y_2, x_3, y_3
with precision 0.35mm/√12

3 measurements is minimal set but 5 will be used for pattern-recognition redundancy

Extrapolate x,y,t,p_x,p_y,p_z, at entrance of the channel.
Make it symmetric at exit.

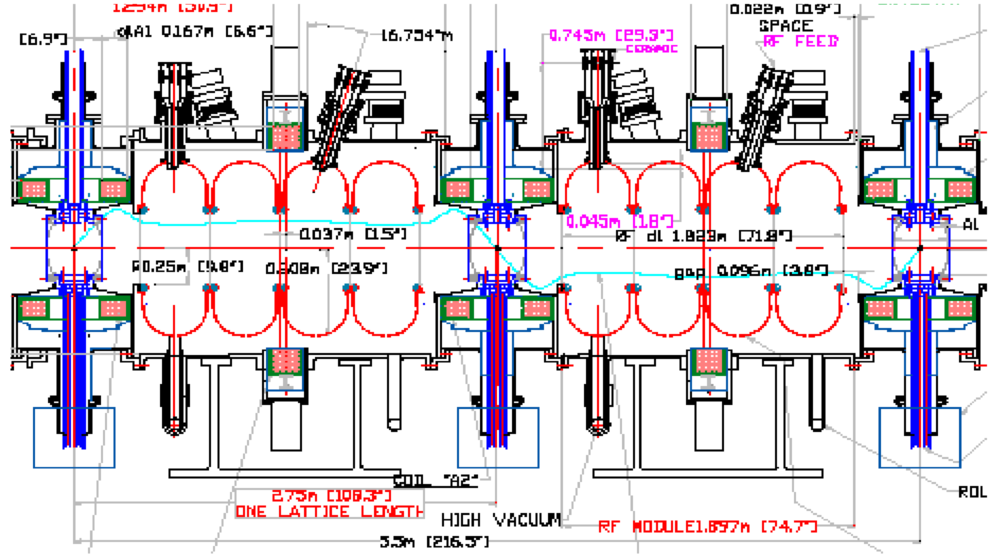
201-MHz Cooling Experiment

(R. Palmer & R. Fernow, BNL)

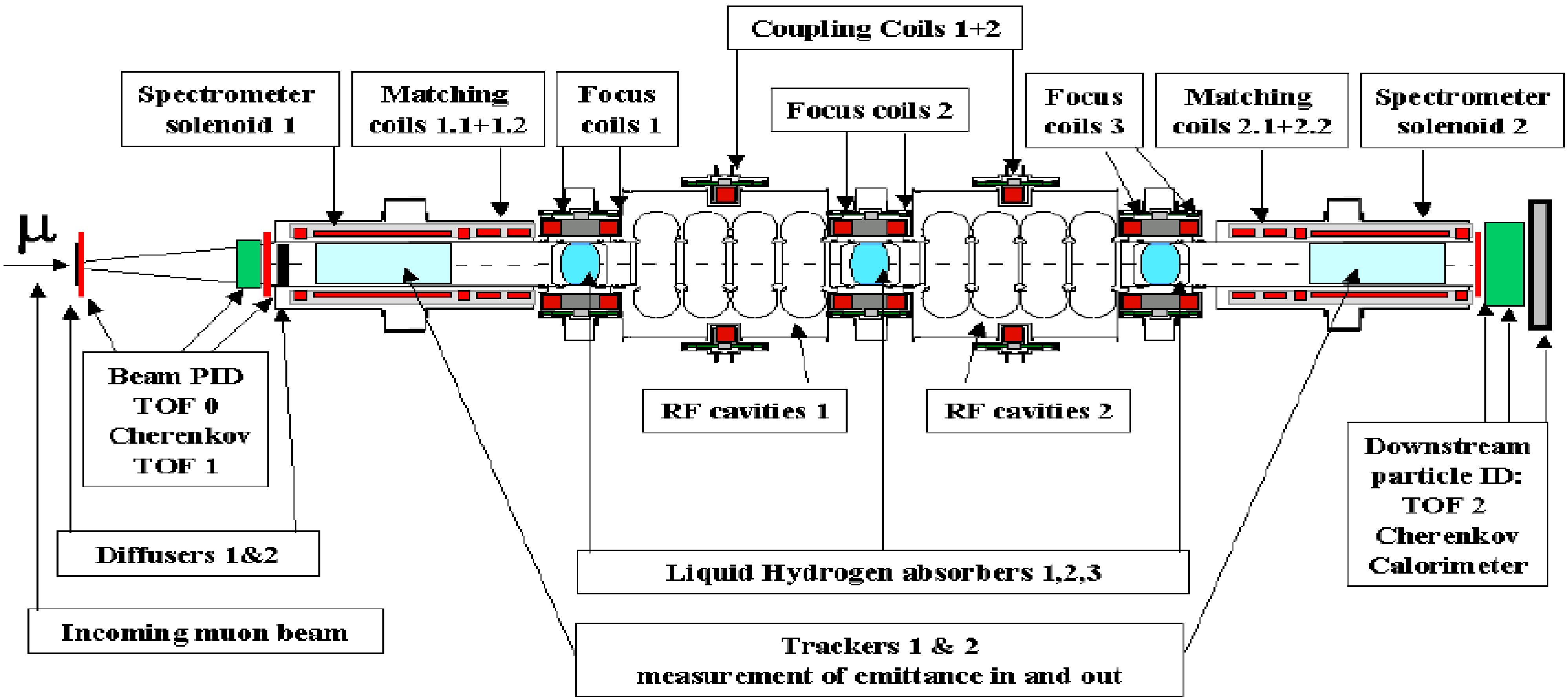


Experiment Layout

- Based on one 5.5m SFOFO lattice cell plus extra absorber (3 absorbers, 8 201-MHz cavities):

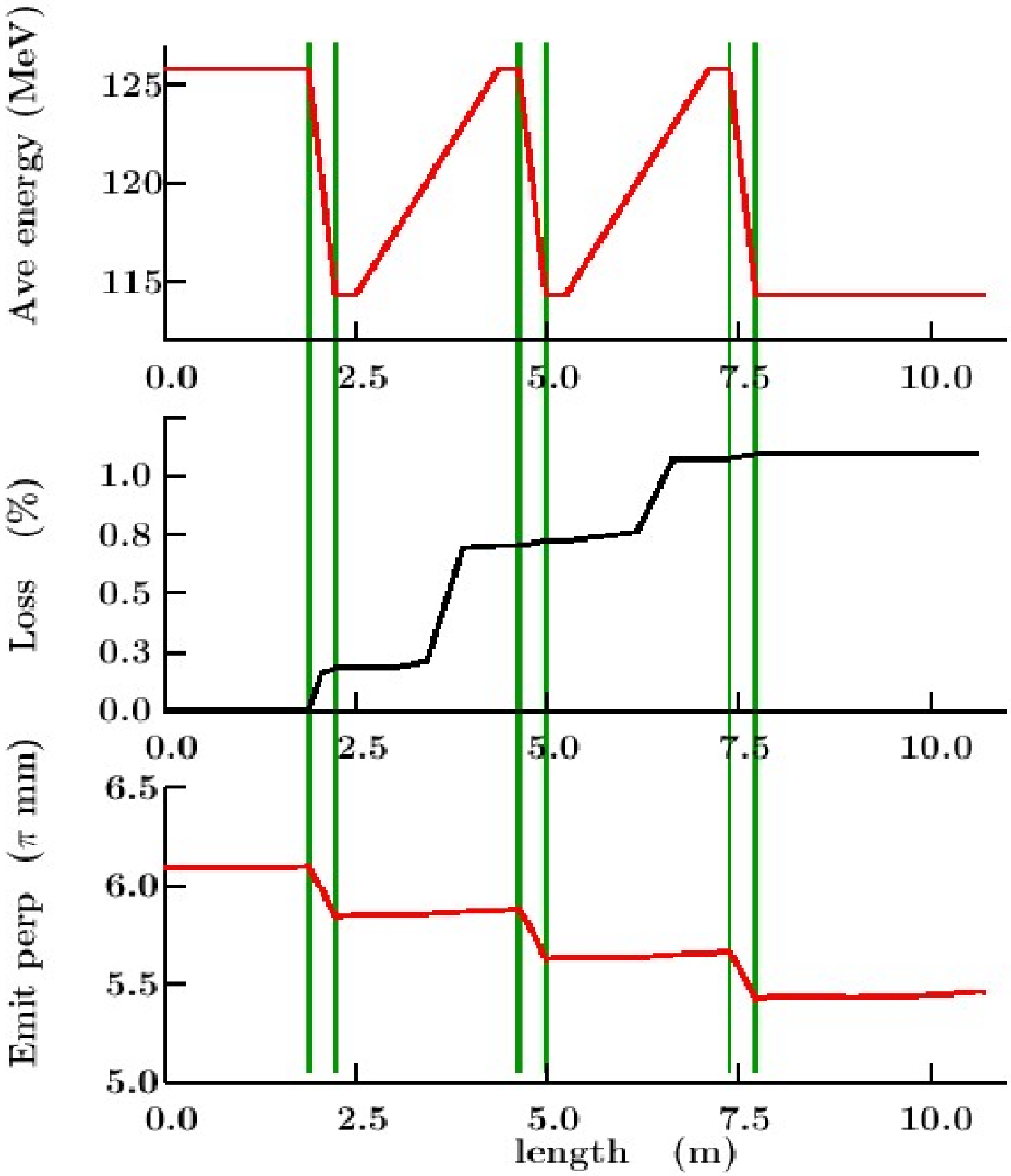


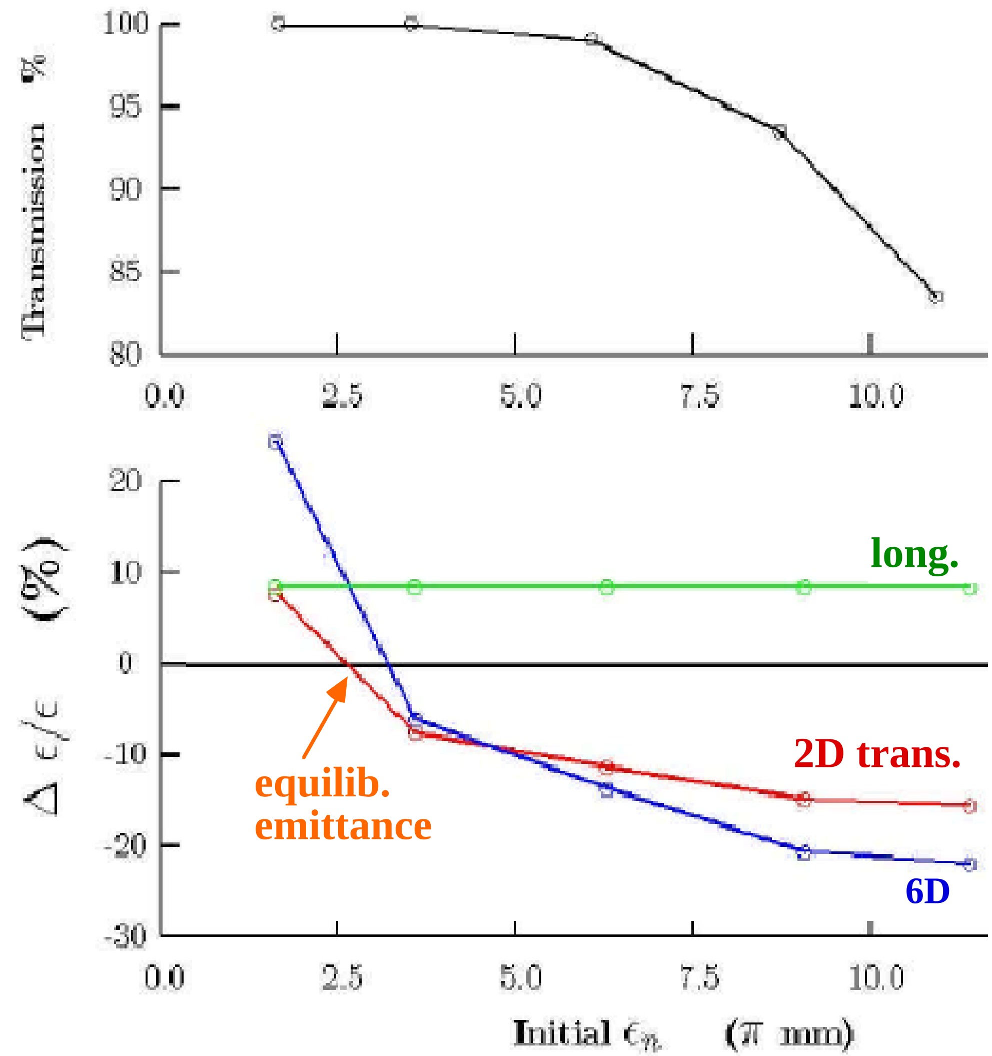
...with input & output spectrometers & beam preparation section added:



Performance

- Economy: build short piece of cooling channel ⇒ must measure small effect

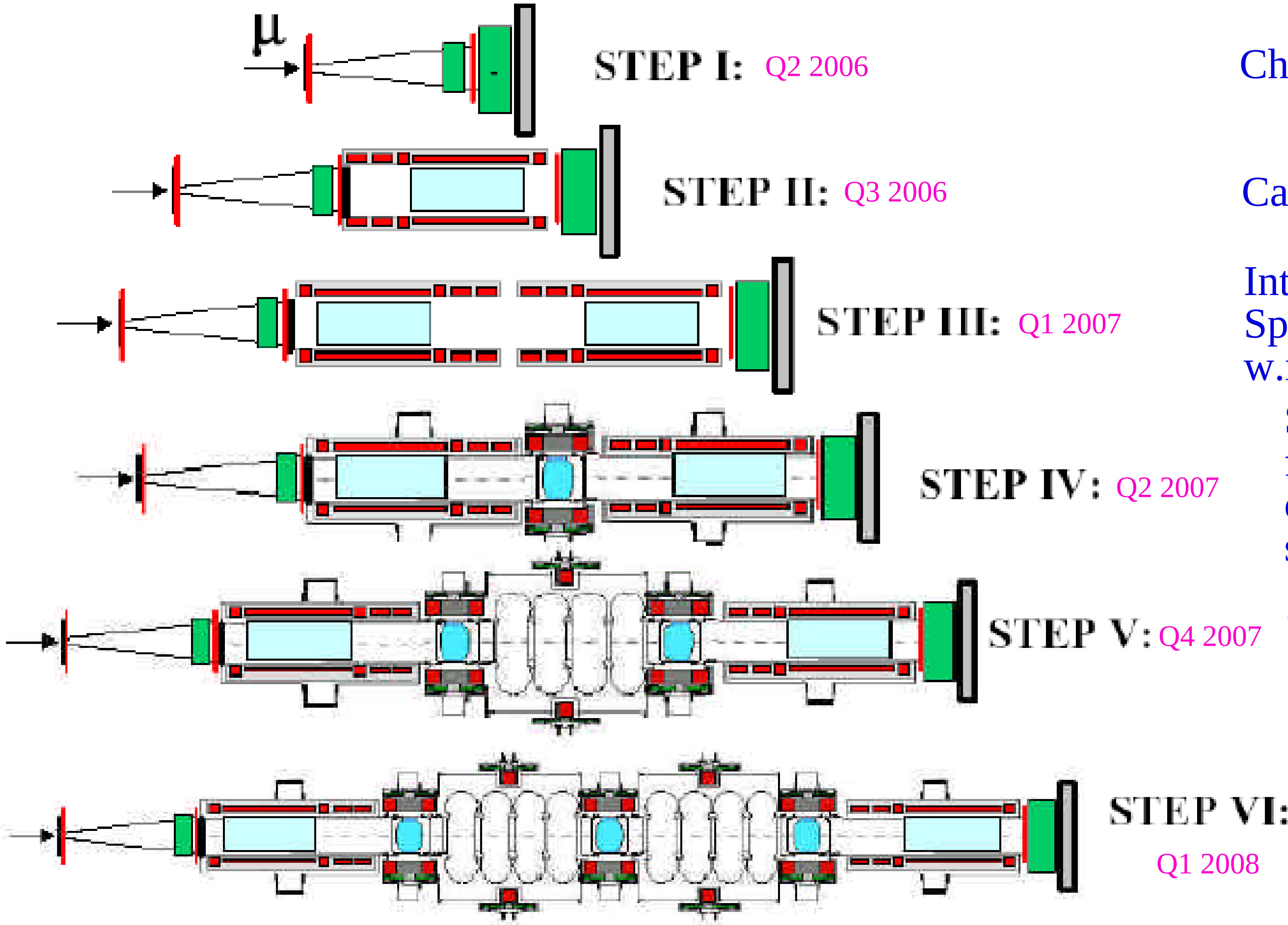




→ ≈10% transverse emittance reduction, measurable to 0.1% (abs.) given precise spectrometer, clean beam, and efficient, redundant particle ID

Systematics & Staging

- Measurement precision relies crucially on precise calibration & thorough study of systematics:



Characterize beam

Calibrate Spect. 1

Intercalibrate Spect. 2 w.r.t. Spect. 1

Study 1st abs./ focus-coil pair, check dE/dx and scattering

Cooling study w/ 1/2 lattice cell

Cooling study w/ full lattice cell & realistic field flip

MICE approved!

- October 6 letter to MICE Spokespersons from John Wood (Chief Executive, Council for the Central Laboratory of the Research Councils) and Ian Halliday (Chief Executive, Particle Physics and Astronomy Research Council) stated (in part):

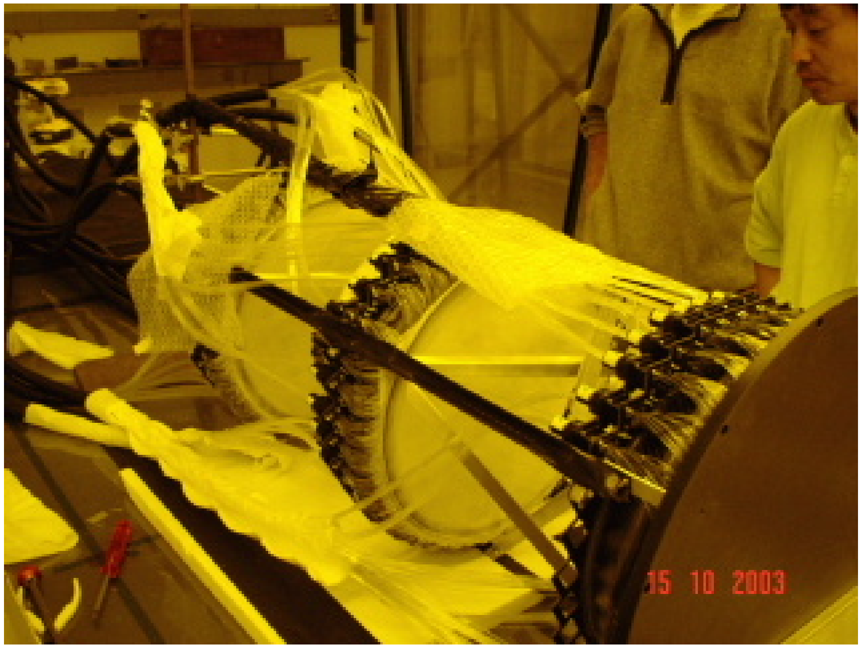
  The International Peer Review Panel chaired by Prof. Alan Astbury was established to review the MICE proposal, submitted on the 10th January 2003. The Panel "strongly recommends approval of the project", "endorses the scientific case for MICE" and considers that "proposed experimental technique is appropriate".

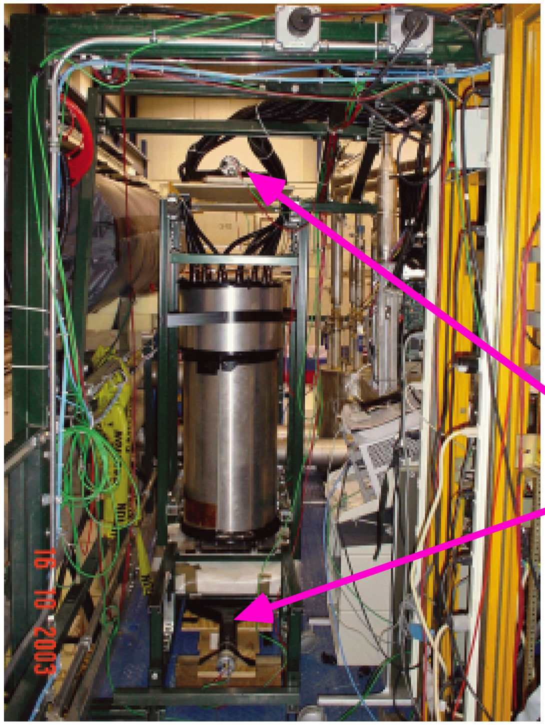
- October 24 letter from John Wood:

  ...CCLRC accepts the strong endorsement of the proposal by the Astbury panel and consequently considers the proposal to have full scientific approval.

Sampler of Recent Progress

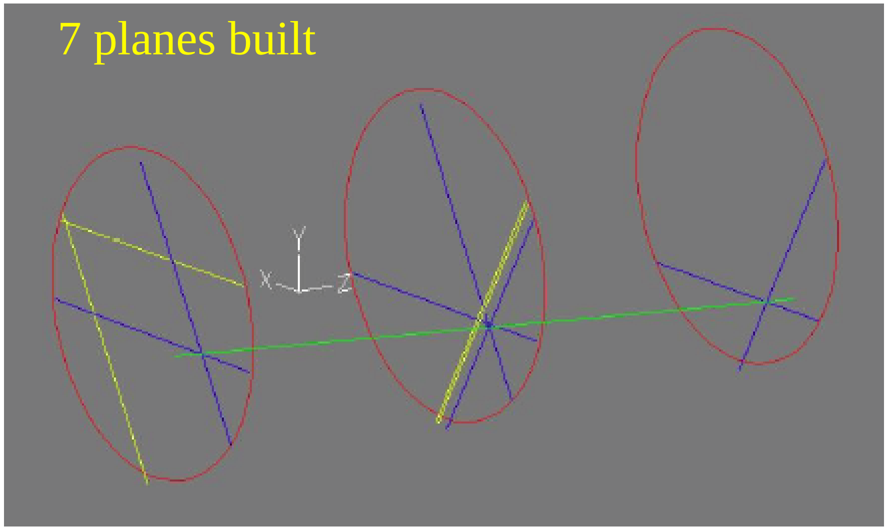
Assembly of 3-station SciFi prototype



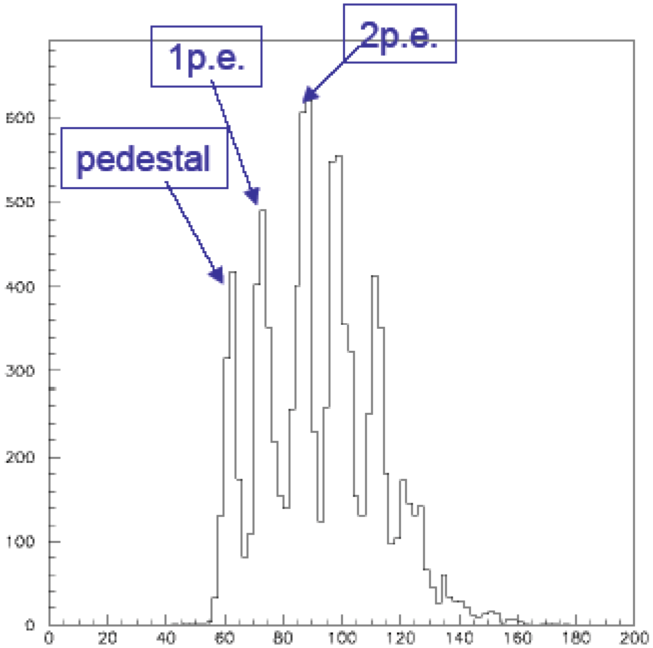


Mounted in D0 cosmic test stand

trigger scintillators



"Typical" event



VLPC performance (w/ LED & pulser)

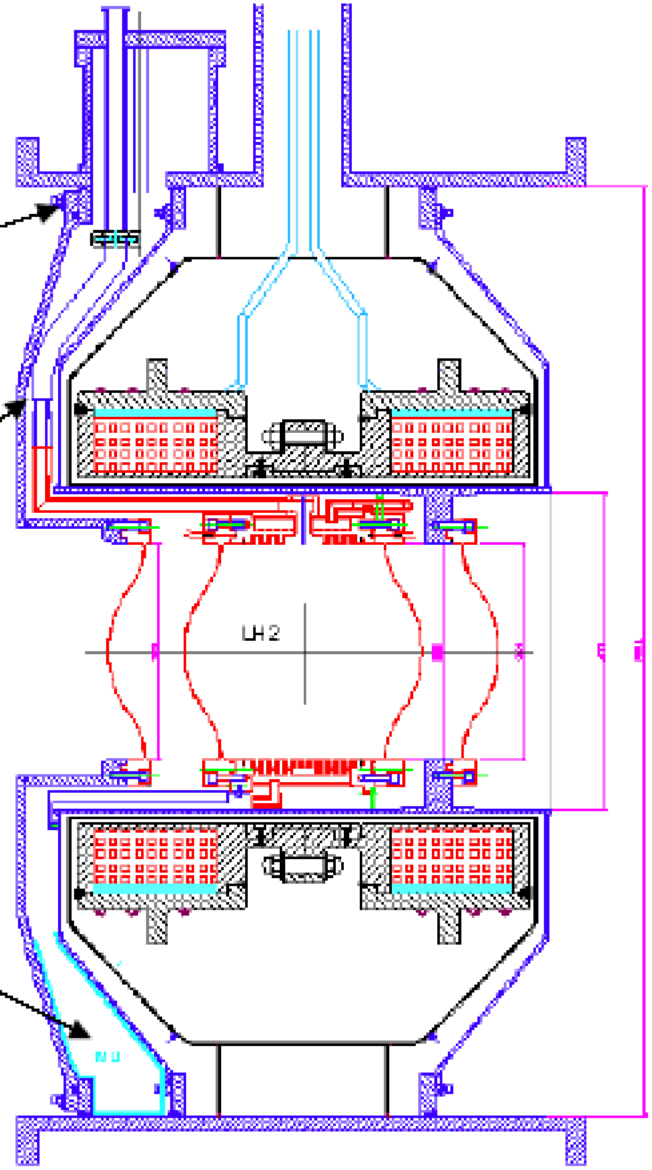
(for more photos see www-kuno.phys.sci.osaka-u.ac.jp/~yoshida/MICE/photos/prototype/index.html)

Absorber/Focus-Coil Module Engineering

a) Windows are mounted off RT interface

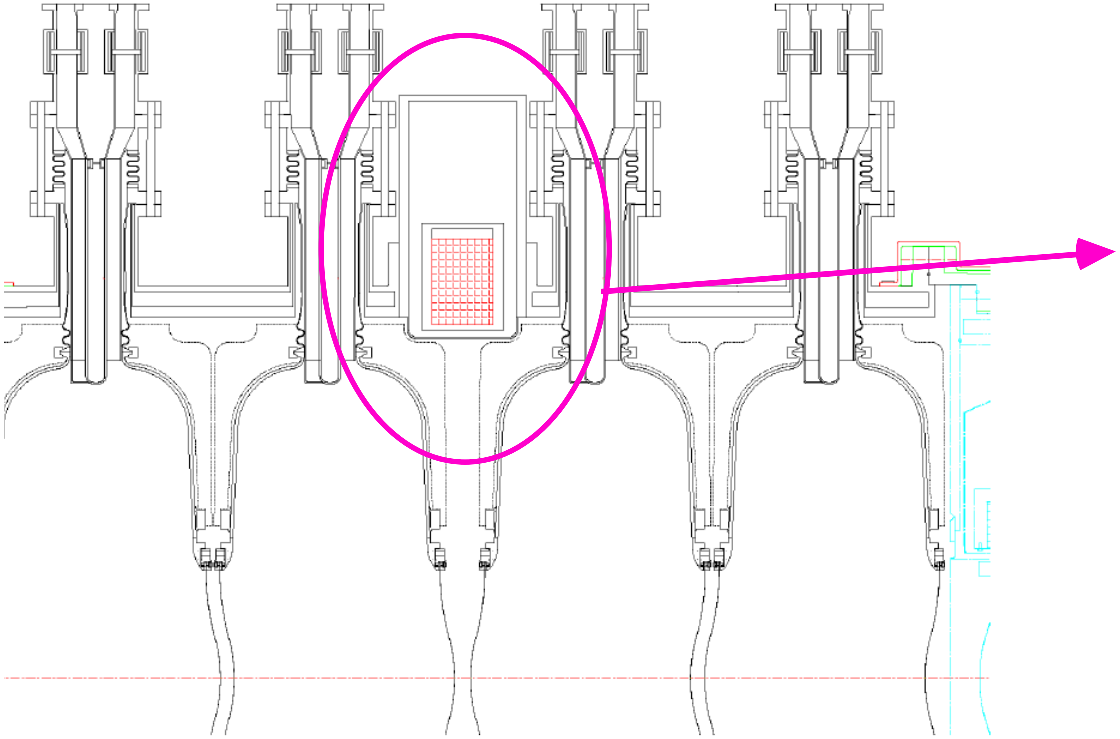
b) Space for change in pipe dimension close to magnet

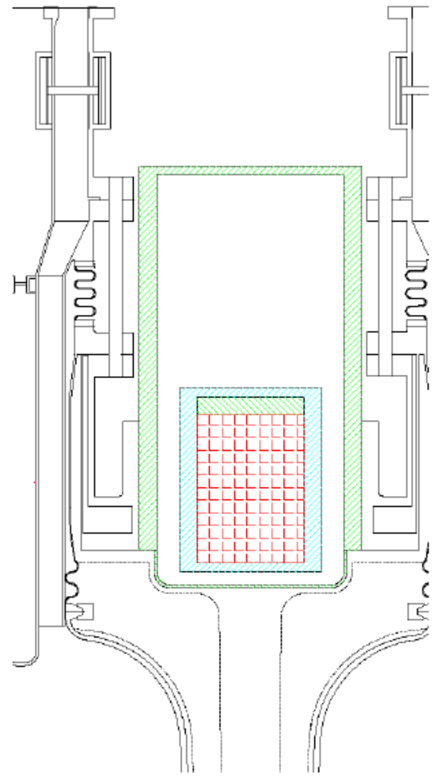
c) Large “bucket” at base to contain any rupture



RF Cavities

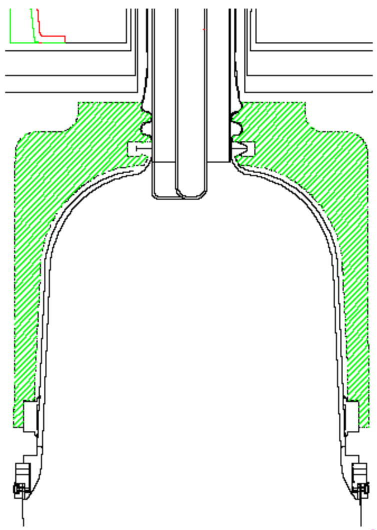
- Detailed design proceeding apace @ LBL (S. Virostek et al.):



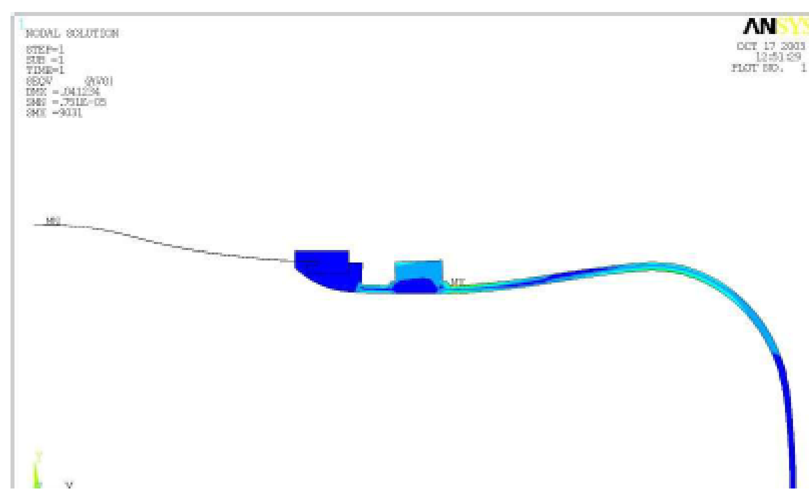


Revised coil design much narrower than previously

allows normal coupler geometry and increases interior clearance for tuners



Tuner design verified by FEA



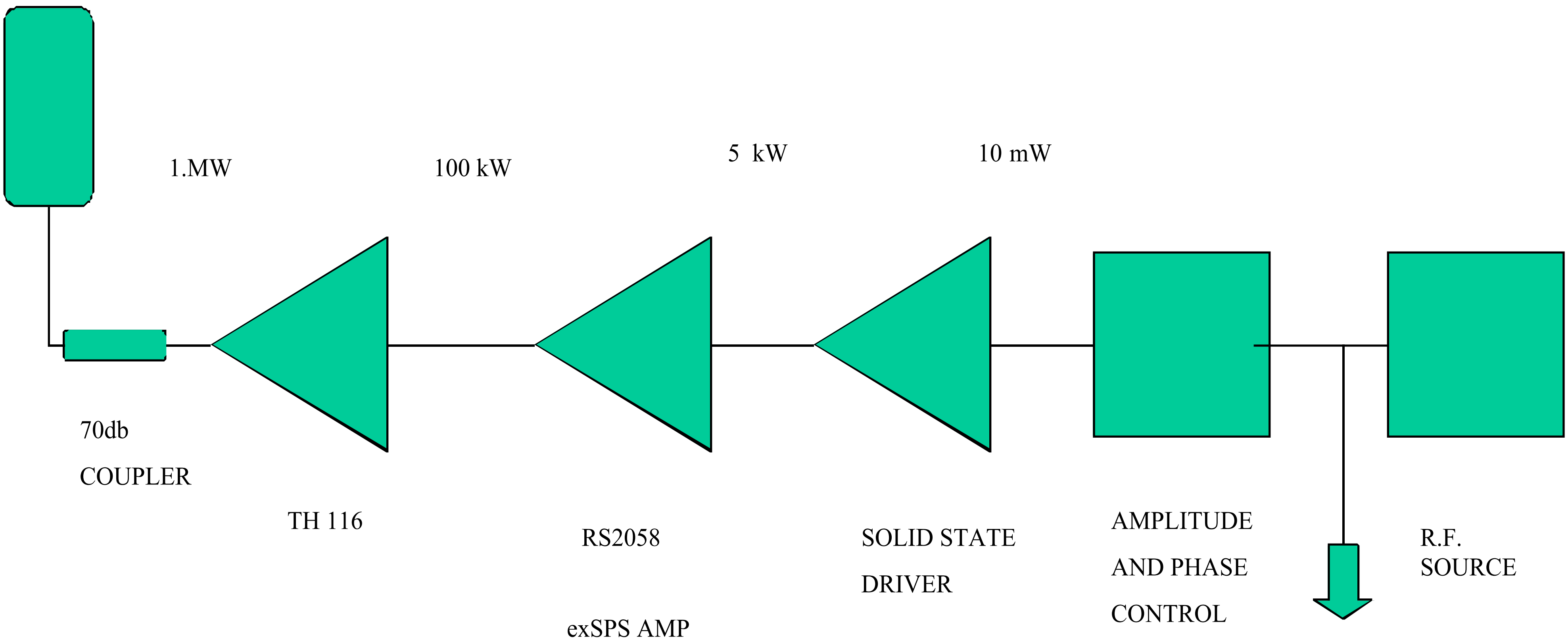
- Prototype now in fabrication

RF Power

- FS-II design calls for 16 MV/m cavity accelerating gradient at 201 MHz at 30° phase angle (compromise between rebunching & acceleration)
  - requires ≈32 MW peak RF power
- But RF power expensive (≈ €1 / W of peak power)

  → MICE spec: 8 MV/m, on-crest operation

  → lower X-ray rate at detectors
- RAL proposal: separate drive for each cavity:



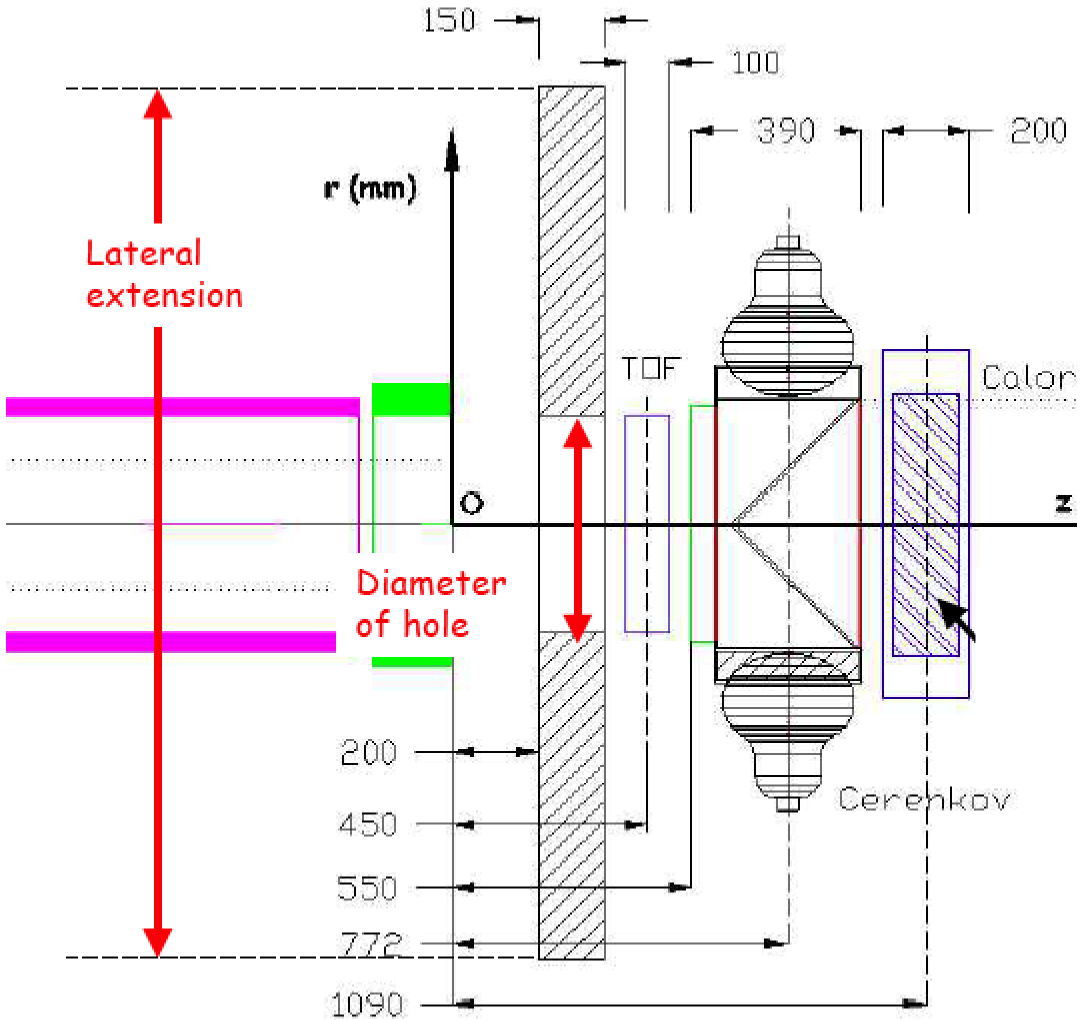
RF Power (cont’d)

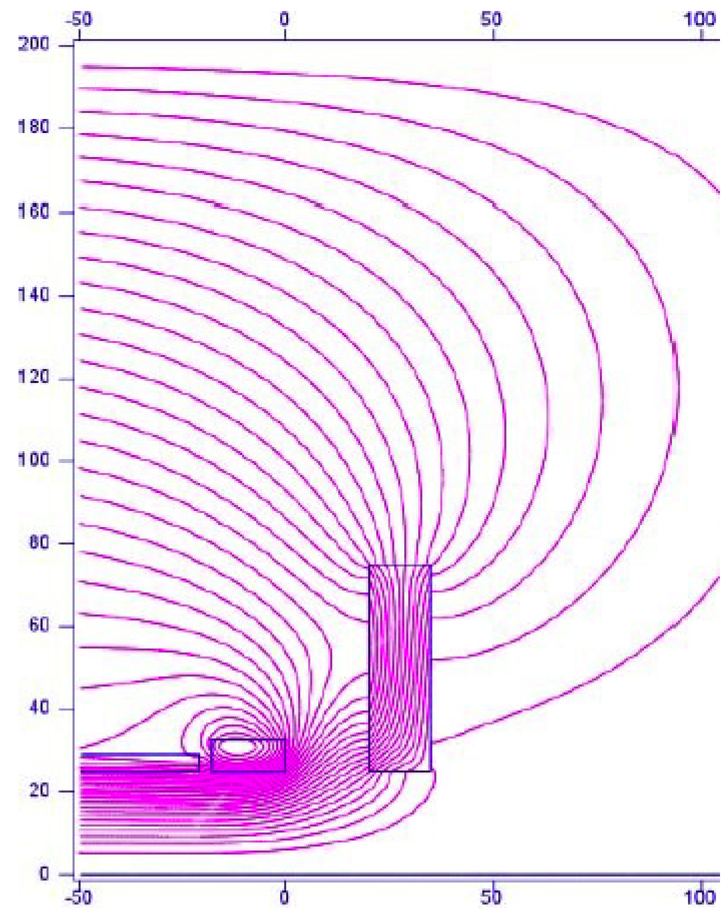
- RAL scheme requires 8 ≥1-MW tubes and circuits
  - ∃ surplus TH116s from ISIS (taken out of service when fall to ≈2 MW)
  - 2 high-power RF circuits and 3 driver amplifiers to be supplied by LBNL
    - will go 1st to Daresbury Lab for refurbishment & testing
  - negotiations ongoing at CERN to refurbish a 4-MW power source plus 1 add’l ckt
  - would need to buy 4 new tubes & ckts for 2nd set of cavities
- Alternative under consideration:
  - split output from each TH116 to 2 cavities

→ smaller cost increment to go from 4 to 8 cavities?

Particle ID

- Need to ensure that detected particle starts as a muon & remains a muon
  - proposed to use combination of TOF, Cherenkov counters, & EM calorimeter:





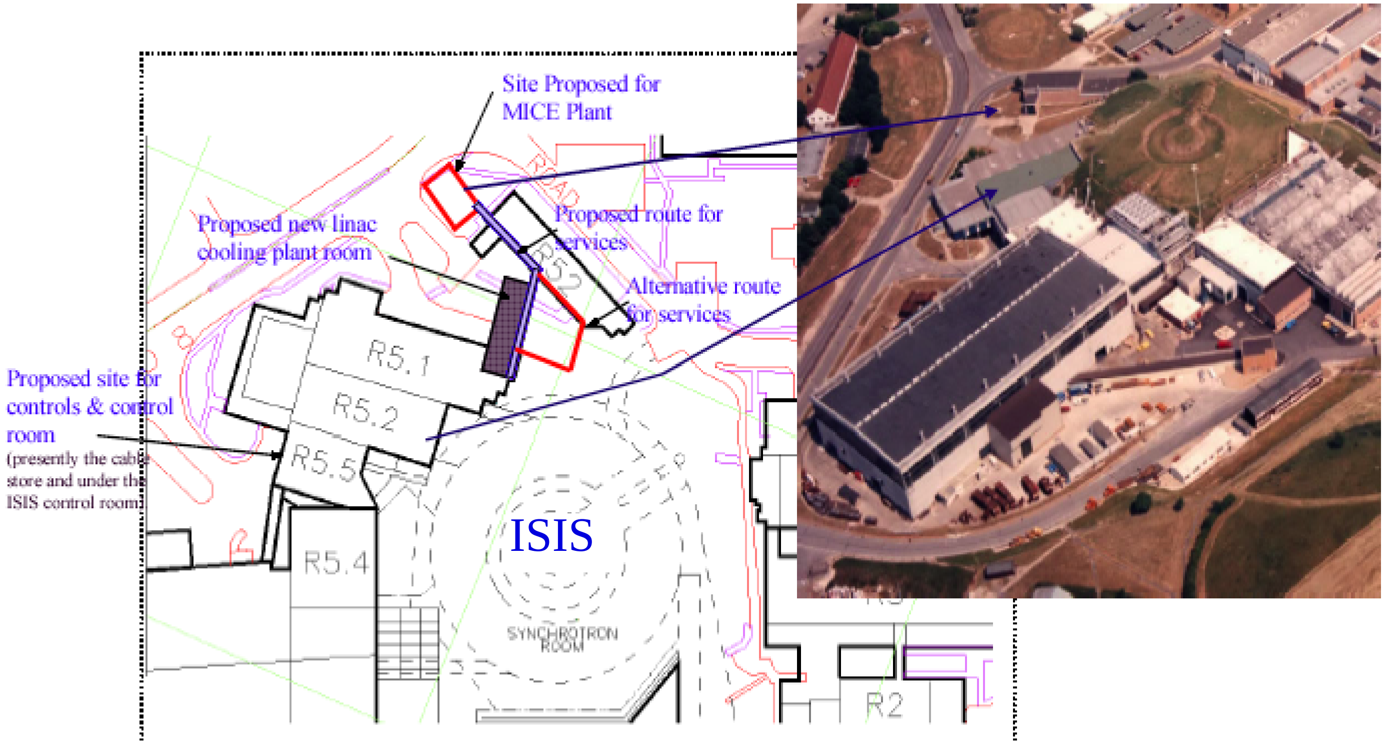
Hole diameter = 50 cm diameter

Shield radius = 75 cm

- Working through details of needed apertures, magnetic shielding, etc.
(G. Gregoire@Louvain / M. Bonesini@INFN Milano / L. Tortora, A. Tonazzo@Roma III / L. Cremaldi, D. Summers@UMiss)

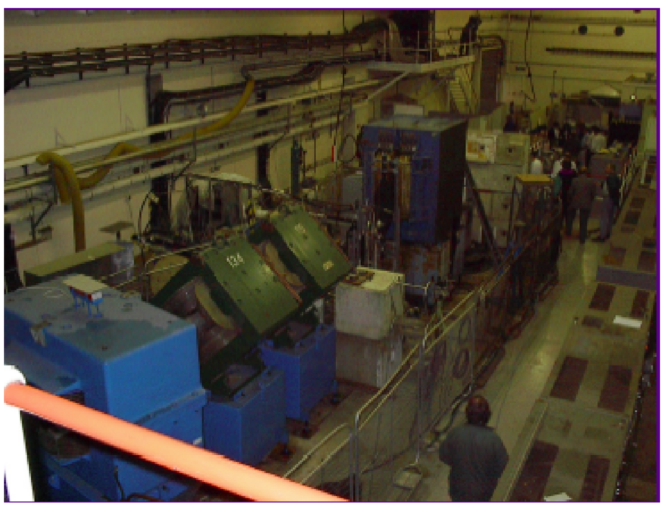
Preparations at RAL

- MICE Hall:



- Hall has been cleared in preparation for MICE beamline installation:

Before:



After:

- Next step (~ spring ’04): cut hole in shield wall between ISIS and hall

Participating Institutes (so far):

Louvain La Neuve	CEA Saclay
INFN Bari	INFN LNF Frascati
INFN Legnaro	INFN Milano
INFN Padova	INFN Napoli
INFN Roma I	INFN Roma II
INFN Roma III	INFN Trieste
NIKHEF	Budker Institute of Nuclear Physics
CERN	ETH Zurich
Paul Scherrer Institute	University of Geneva
KEK	Osaka University
Brunel University	University of Edinburgh
University of Glasgow	University of Liverpool
Imperial College London	University of Oxford
University of Sheffield	Rutherford Appleton Laboratory
Argonne National Laboratory	Brookhaven National Laboratory
Fairfield University	Fermi National Accelerator Laboratory
Illinois Institute of Technology	Lawrence Berkeley National Laboratory
Northern Illinois University	Thomas Jefferson Laboratory
University of California Los Angeles	University of California, Riverside
University of Chicago	University of Illinois at Urbana-Champaign
University of Iowa	University of Mississippi

Funding & Responsibilities:

- Allocation among collaborating regions (from MICE Proposal)

Table 11.1: Overall hardware costs for MICE in M€ (or, equivalently, M$) and effort levels in staff years. Funding assignments for the participating regions are indicated.

Item	Estimated cost (M€)	US	Japan	Europe	UK	Effort [staff·yr]
Cooling section[a]	13.9	6.3	0.3	3.7	3.6	67
Spectrometer section[b]	7.5	2.1	0.7	3.0	1.7	48.5
Ancillary items[c]	3.8	0.1	0	0.5	3.2	60.5
Total	25.2	8.5 (34%)	1.0 (4%)	7.2 (29%)	8.5 (34%)	176

- Overview of who does what (tentative & negotiable):

Beam & infrastructure: UK / Europe (PSI solenoid)

Cooling section: Japan / Europe / US / UK

RF power: Europe / UK

Tracking: Japan / Europe / US / UK

Spectrometer solenoids & magnet measurement: Europe

PID: Europe / US

DAQ: Europe / US

Collaboration Organization

- Executive Board:

Alain Blondel (Chair), Geneva	Alan Bross, Fermilab
Peter Dornan, Imperial	Paul V. Drumm, RAL
Rob Edgecock, RAL	Steve Geer, Fermilab
Helmut Haseroth, CERN	Yuri Ivanyushenkov, RAL
Daniel M. Kaplan, IIT	Yoshitaka Kuno, Osaka
Kenneth Long, Imperial	Vittorio Palladino, INFN Naples
Yagmur Torun (secretary), IIT	Michael S. Zisman, LBNL

- Technical Board:

Paul Drumm:	Technical Coordinator - Chair of TB
Mike Zisman:	Deputy Technical Coordinator, Cooling Channel Coordinator
Yury Ivanyushenkov:	Beam and Infrastructure Manager, Hall Manager for Installation, Document Librarian
Edgar Black:	Integration and Verification Manager
Alan Bross:	Detector Integration Coordinator
Yagmur Torun:	Software Coordinator
Elwyn Baynham:	Safety Overview
Alain Blondel:	MICE Spokesperson
Dan Kaplan:	MICE Deputy Spokesperson

- Collaboration Board (representatives from each institute)
- Website: http://mice.iit.edu/cooldemo/, Y. Torun (IIT), webmaster
- Meetings: bi-weekly videoconferences, 3 mtgs annually rotating among CERN/RAL/US
- Next Collaboration Meeting: 29 March – 1 April @ CERN

Summary

- Muon storage rings are a uniquely powerful option for large future facilities
- A Neutrino Factory may be the best way to study neutrino mixing and CPV
- νF technical feasibility has been demonstrated "on paper"
- Key prerequisite to νF approval: experimental demonstration of muon ionization cooling
- The Muon International Cooling Experiment is well defined and clearly focused on the key issues of cooling feasibility & performance
- MICE Proposal approved by RAL in October 2003
- International collaboration formed and leadership structure in place
- Scope and time-scale comparable to mid-sized HEP experiment
- Now seeking necessary resources (collaborators, equipment, funding) from among collaborating world regions
- Good opportunity to develop expertise on "cutting-edge" accelerator physics

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→Want to join?