Muon Collider

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Outline

1. Introduction

    Why use Muons...

2. Towards a μ accelerator facility

    Physics program/R & D Plans/Status

3. Summary/Outlook

Introduction: Considering a new accelerator...

- Start with current knowledge

  (Precision EW results, t mass, SM global analysis, ...)

- Extrapolate to future, "approved" machine running (Run II, LEP2, LHC)

- Which are the physics opportunities for a new machine?

  (Higgs, Physics "beyond the SM", ...)

- Can it provide a diverse physics program?

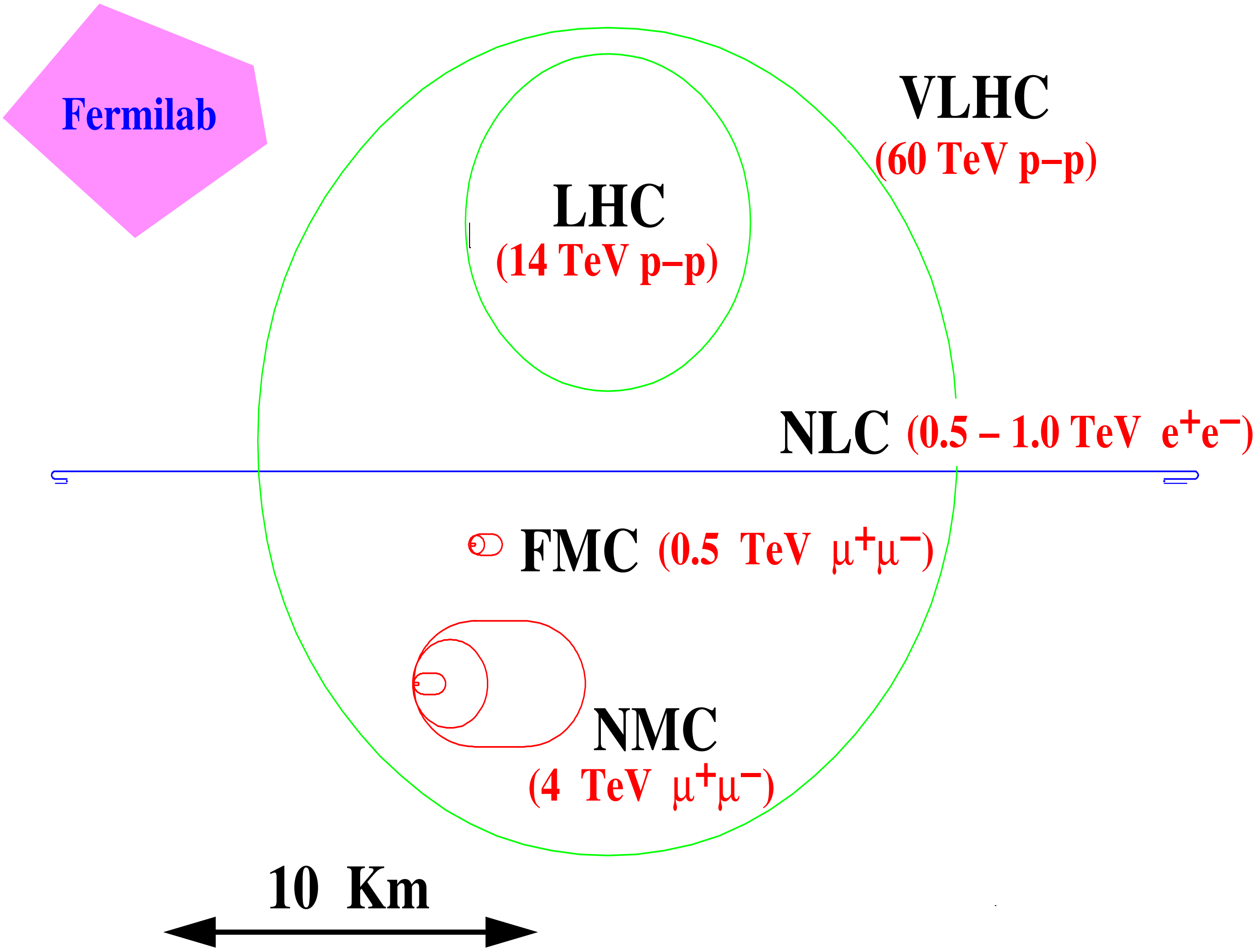
- Is it technically possible (cost?)

Why consider a Muon Collider Facility?

- To explore new Physics need both hadron and lepton colliders
- Need high energy $\longrightarrow$ **μ's** good candidate ($m_\mu \sim 207 \times m_e$):
  - $\Rightarrow$ Less synchrotron radiation ($\sim m^{-4}$) $\longrightarrow$ small ring size
  - $\Rightarrow$ Less brems and initial state radiation $\longrightarrow$ better energy determination
  - $\Rightarrow$ s-channel Higgs production ($\sigma \sim m^2$)
  - $\Rightarrow$ Rich Front end Physics (low energy p, μ, and ν beams)
- But of course there are technical challenges:
  - ▷ Short lifetime $\longrightarrow$ need rapid acceleration
  - ▷ Large PH initial μ beam $\longrightarrow$ need rapid beam cooling
  - ▷ Backgrounds:

    μ halo, $\mu^- \rightarrow e^-\nu_\mu\bar{\nu}_e$, beamstrahlung, incoherent e pair production, μ pair production in EM showers (Bethe-Heitler)

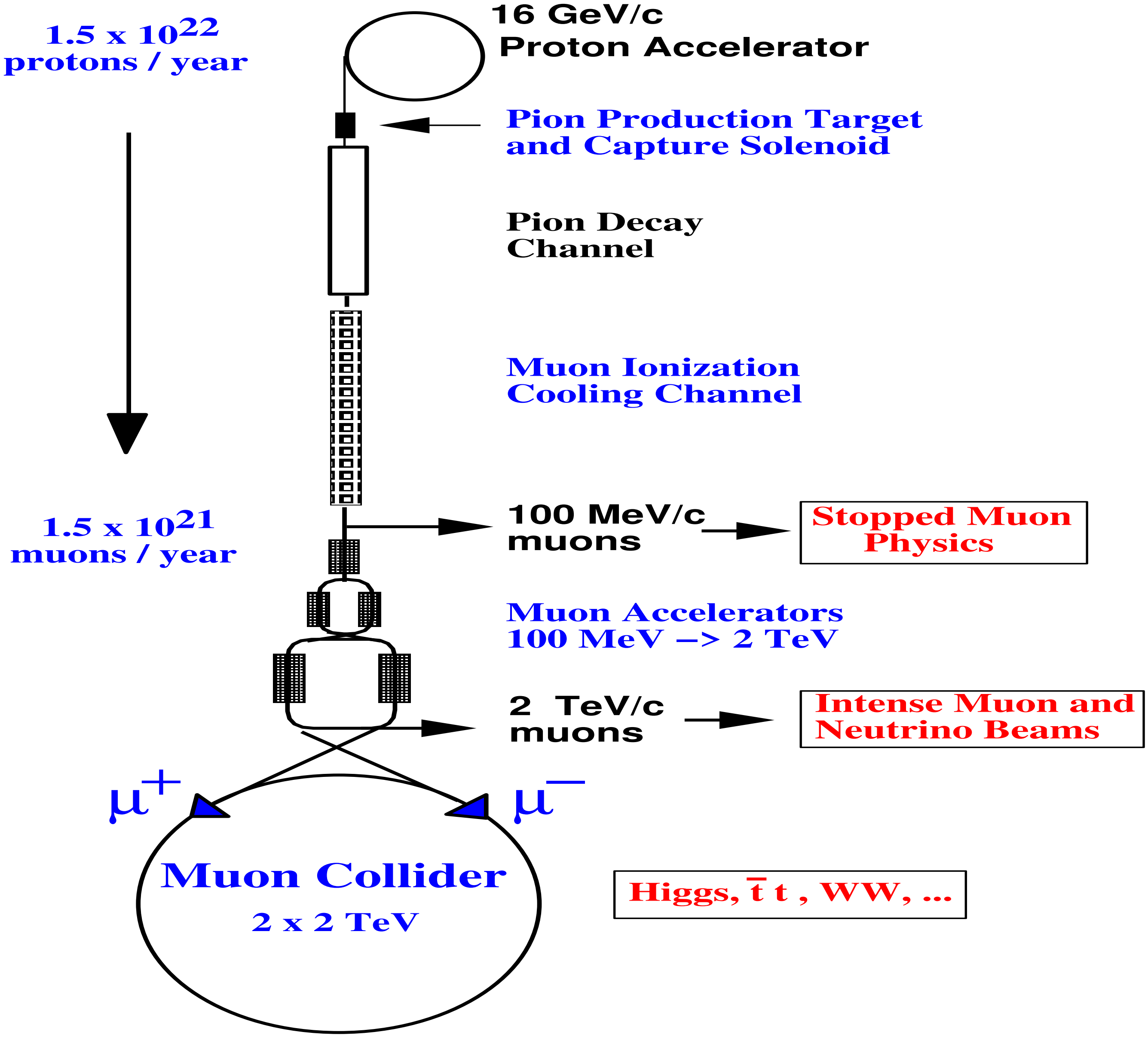
Muon Collider: appealing idea for a new lepton machine



Challenge: capture & cool μ by $\sim 10^5$ in 6D PS.

Result: collider, proton driver, **intense μ & ν beams**

Muon Collider accelerator facility



Front end FNAL: **Cold** μ **source** $\sim 7.5 \times 10^{20} \mu/$**year** **(proton driver** $1.5 \times 10^{15} p/$**sec, 16**GeV**, 15 Hz, 1ns rms bunch)**

Physics with a Muon Collider Facility

1. Front end Physics
   - ν oscillation and DIS (**flux** $\sim$ 1000$\times$ present flux)
   - Stopped μ physics (**flux** $\sim 10^{14}\mu$ **/sec**, compare to present sources $\sim 10^8$).
   - μp collider (200GeV on 1Tev, $\sim 300\times$ HERA $\mathcal{L}$)

2. First Muon Collider, $\sqrt{s} \sim$ 100-500 GeV (use EW fits as a guide, first measurement before FMC)
   - Higgs s-channel production, precise mass and width determination
   - SUSY
   - precision EW measurements

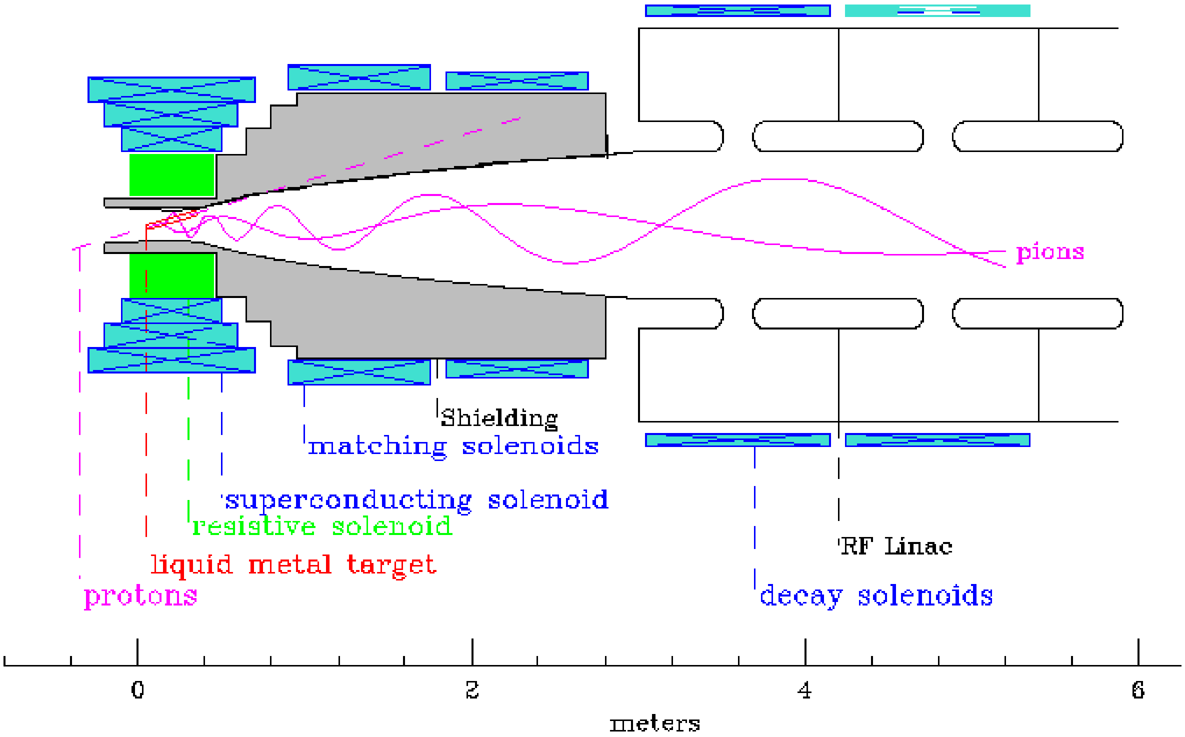
3. Next Muon Collider ($\sqrt{s} \sim$ 3-4 TeV). Explore SUSY spectrum/new physics.

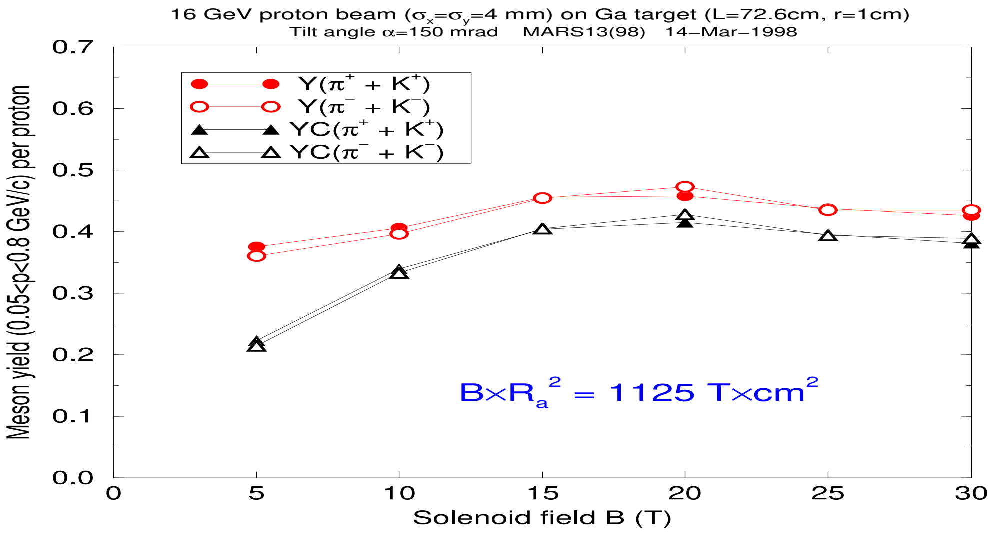
Design Strategy

- Physics requirements $\longrightarrow$ determine desirable parameters
- Obtain baseline design for each component (constraints from existing facilities)
- Detailed simulation of each component
- Iterate solution
- In parallel, hardware **R & D**
- Integrate components; simulate full system
- In parallel, need simulations to understand effects of machine environment to physics potential

Not an easy job, lots of new concepts...

π production and capture channel

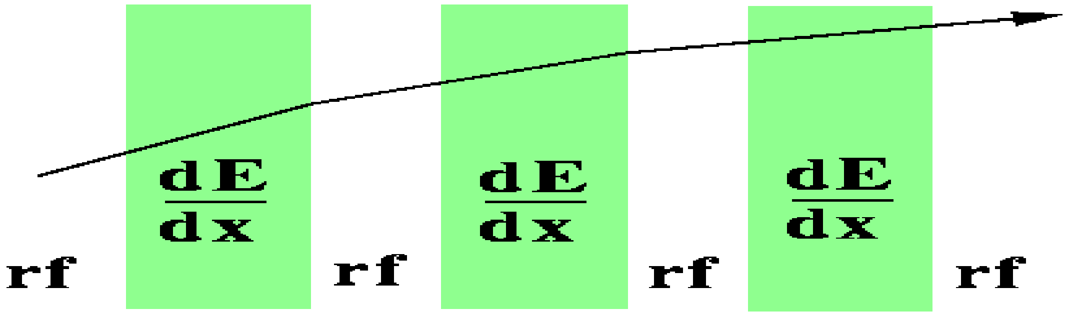




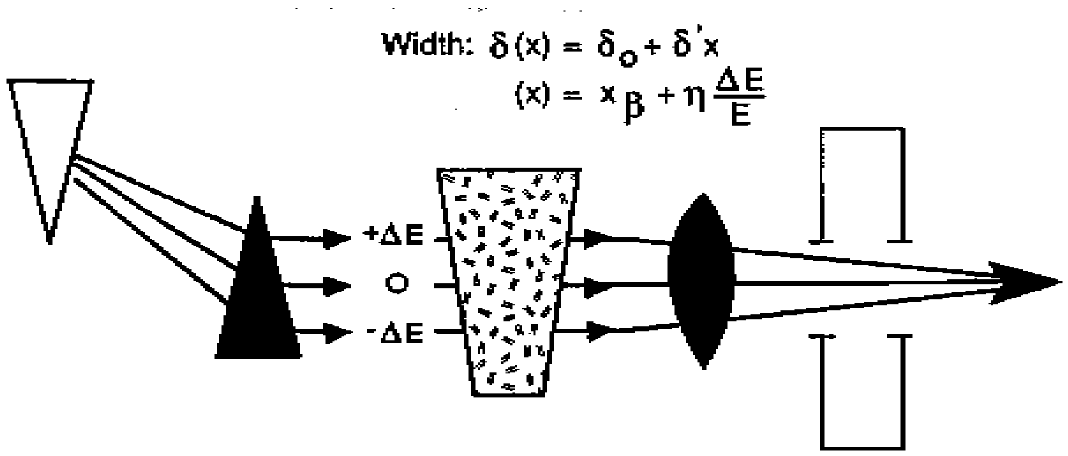
Need high yield and reduction of Δ P

Ionization Cooling Concept

$$\frac{d\epsilon_n}{ds} = -\frac{1}{\beta^2}\frac{dE_\mu}{ds}\frac{\epsilon_n}{E_\mu} + \frac{1}{\beta^3}\frac{\beta_\perp(0.014)^2}{2\ E_\mu m_\mu\ L_R} \qquad (1)$$

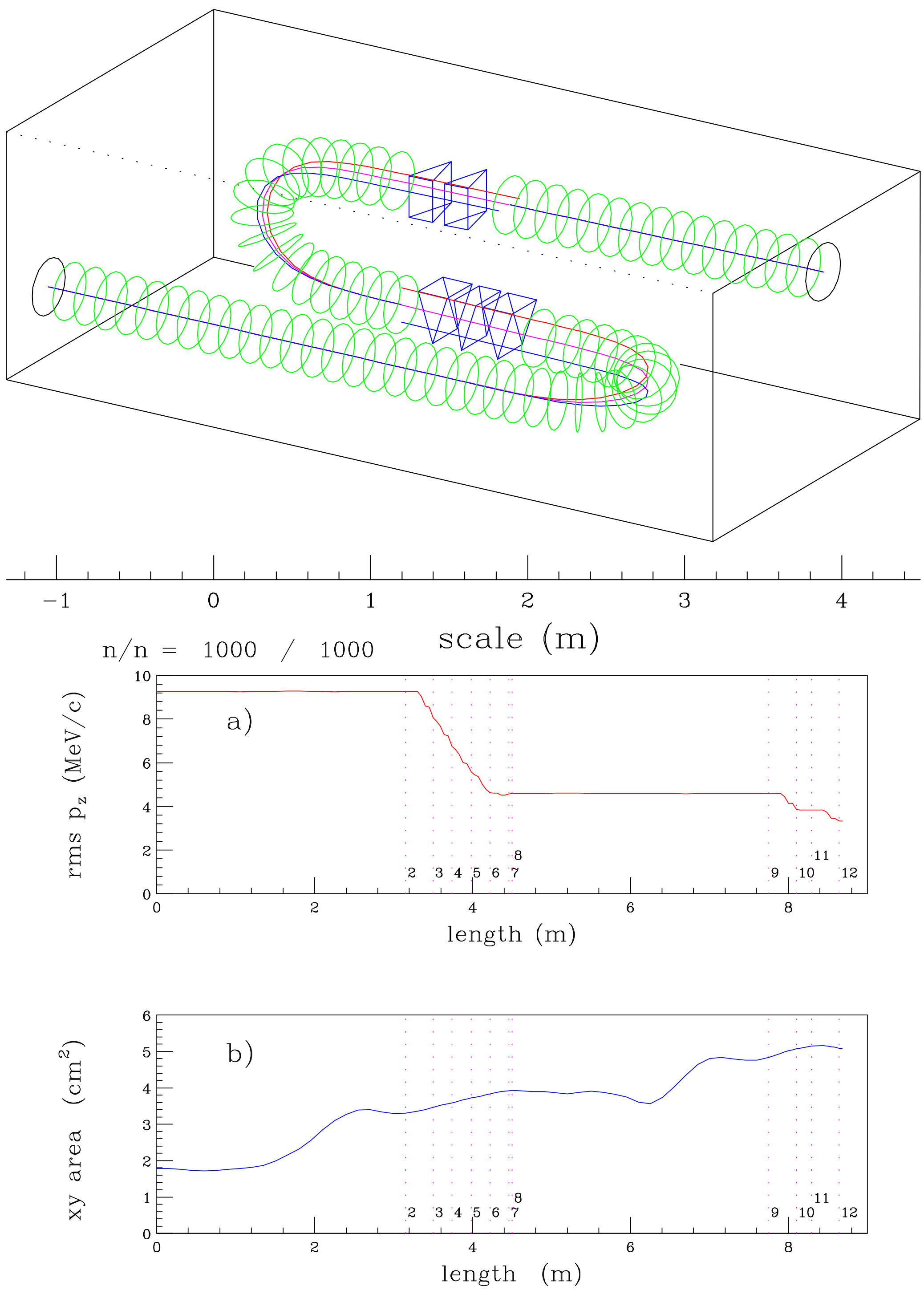


Ionization cooling concept

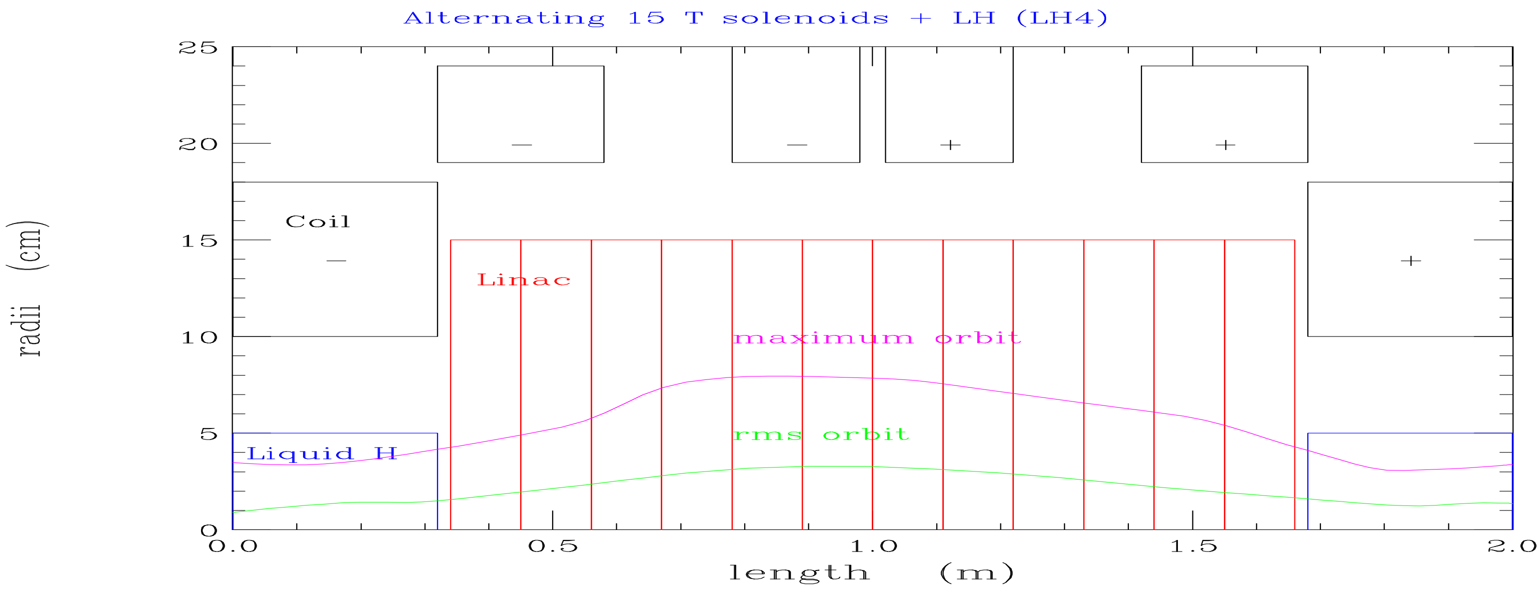


Schematic of longitudinal-transverse emittance exchange

Emittance exchange example

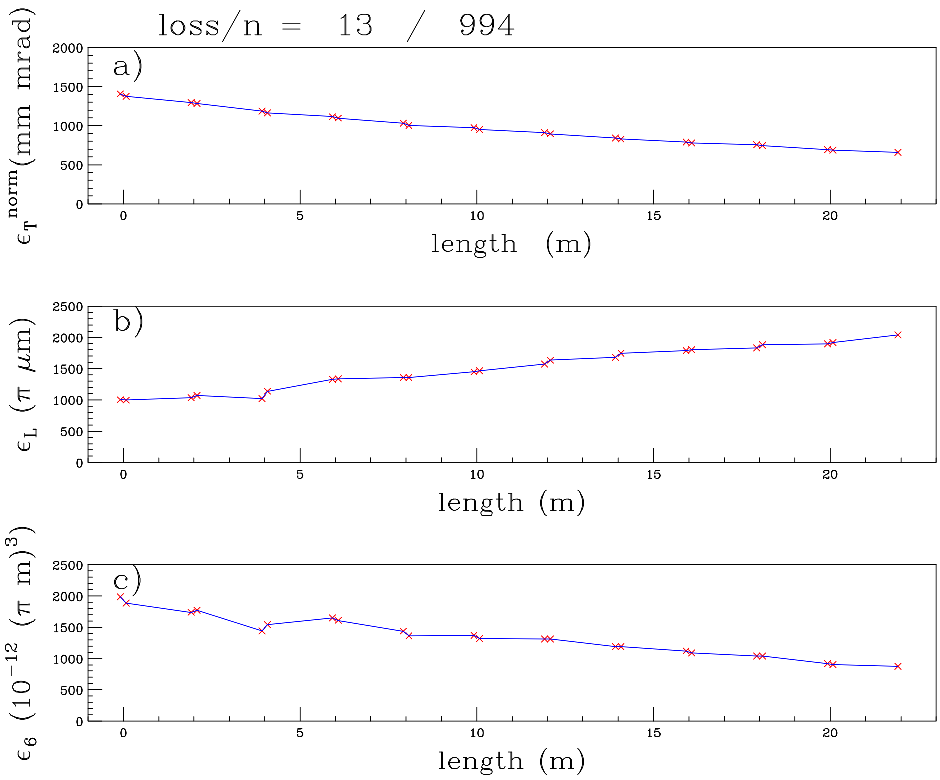


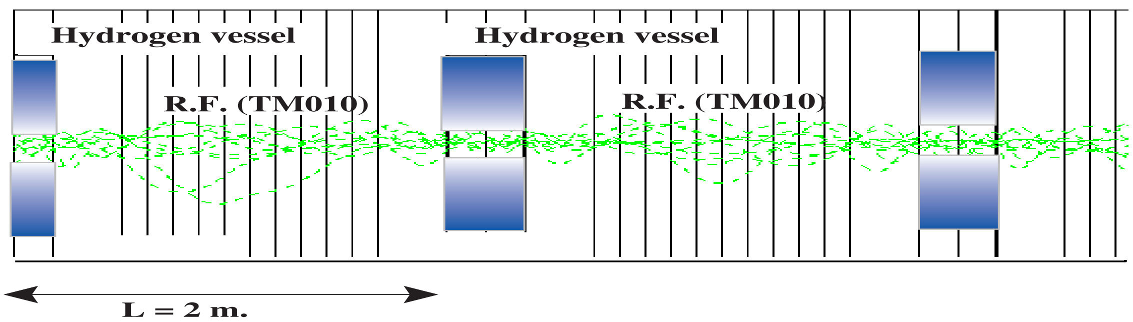
Transverse cooling example



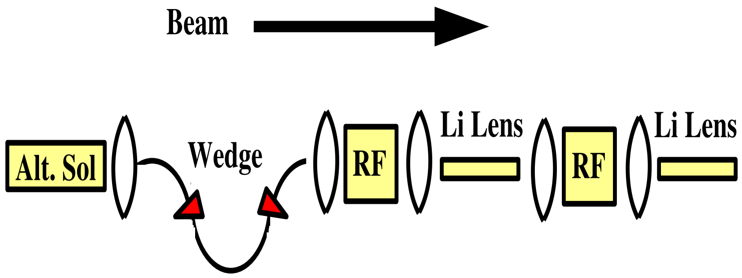
- Use strong solenoid focusing fields
- Interleave short linacs
- Liquid H_2 absorbers
- Reverse field in successive absorbers to control L_c
- Field increases as ϵ reduces

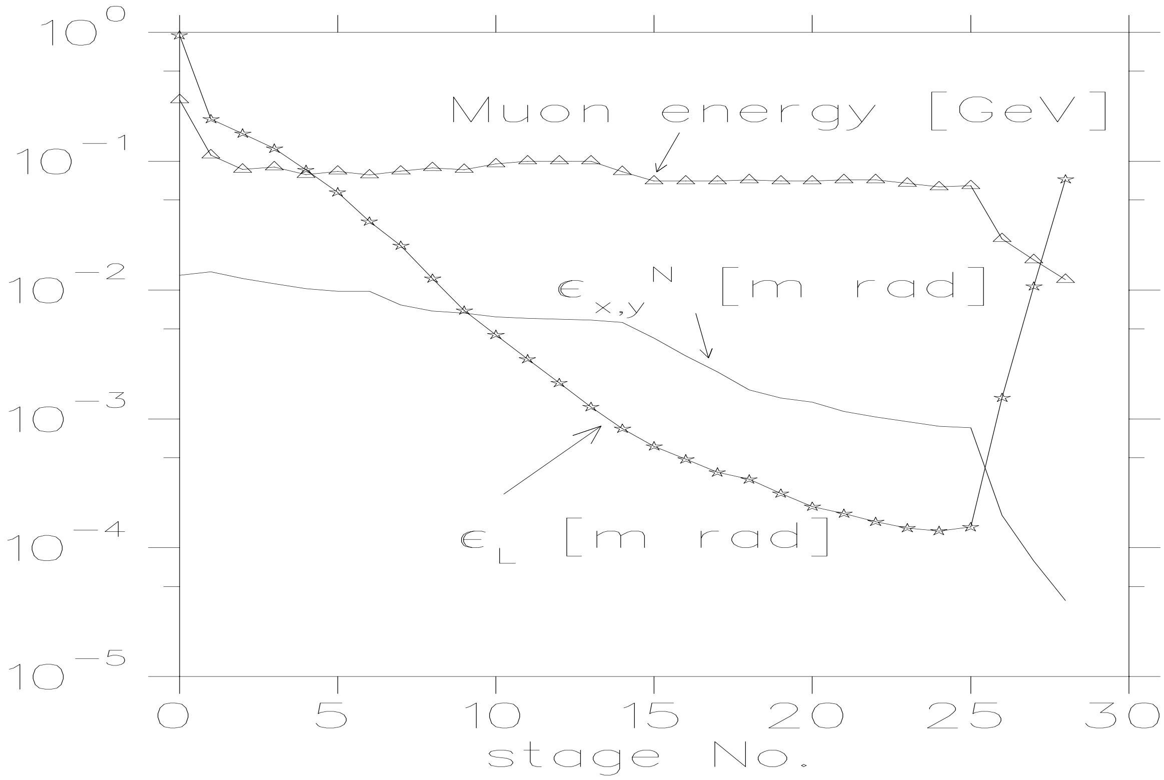
Simulation Results



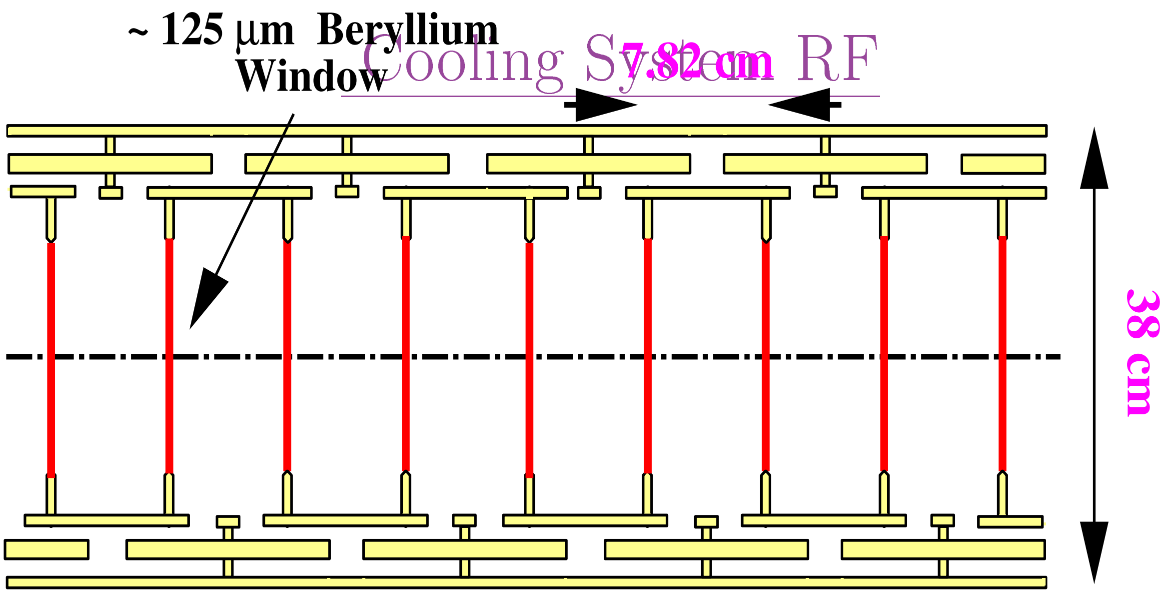


Overall Cooling scenario





Cooling System RF



- Minimize length (losses), cost

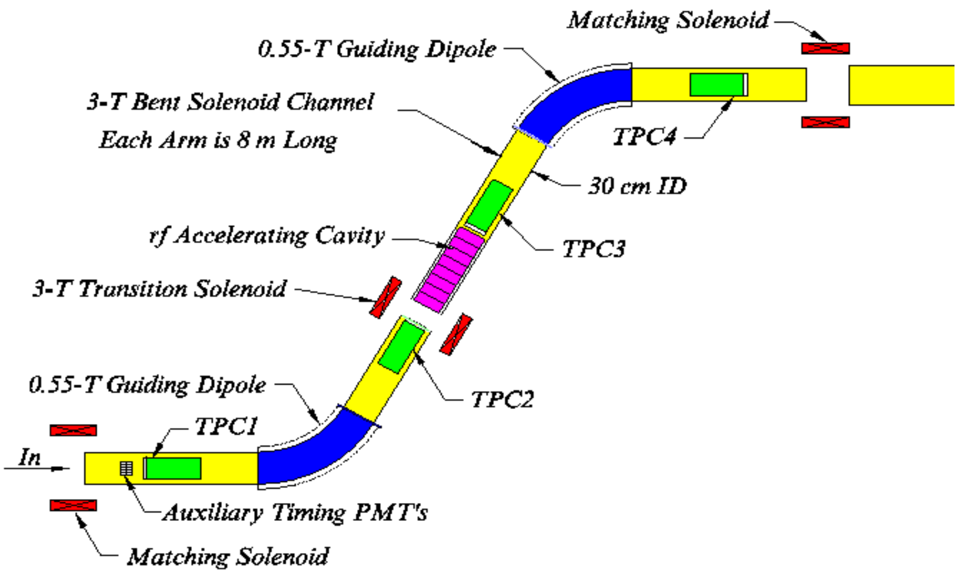
$\Rightarrow$ Maximize acceleration gradient:

explore μ penetration $\longrightarrow$ introduce Be windows

Ionization Cooling Experiment

- **Prototype** each section of the cooling channel
- Experimentally test prototypes in a μ beam $\longrightarrow$ demonstrate cooling

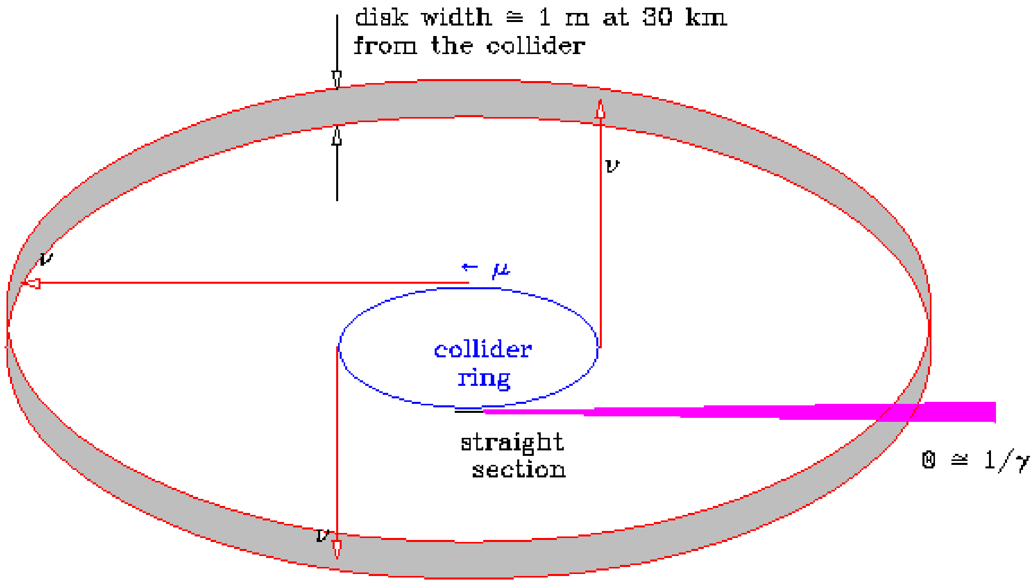
$\Rightarrow$ Propose to develop ionization cooling **test facility**



$\Rightarrow$ Measure phase-space volume in and out of the channel to a few % (σ_t needed 8 ps!)

Neutrino Radiation

- Secondary radiation from ν's (from μ decay)
- Dose $\sim$ to μ current, E^3, L straight, 1/depth
- For 100 GeV machine doses negligible
- For 500 GeV machine with 25m straight sections need 100m depth
- For machines above 3 TeV, depth $> 500m$ needed



3 TeV case

Collider Detector Backgrounds

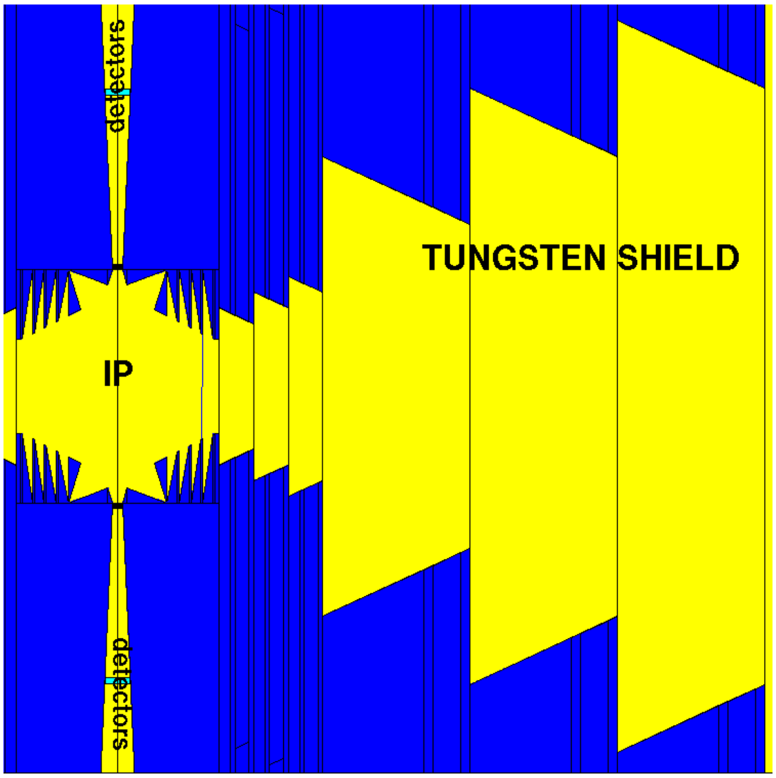
- Start with a generic design (VTX, tracker, CAL)
  - ▷ Study radiation damage for VTX
  - ▷ Determine particle fluences, occupancy for VTX and tracker

- Lattice parameters have to be integrated in simulations
  - ▷ design shields
  - ▷ implement lattice modifications

- Proceed with specific detector design for each energy
  - ▷ Optimize VTX/tracker for b, t reconstruction
  - ▷ Optimize CAL for W and Z identification

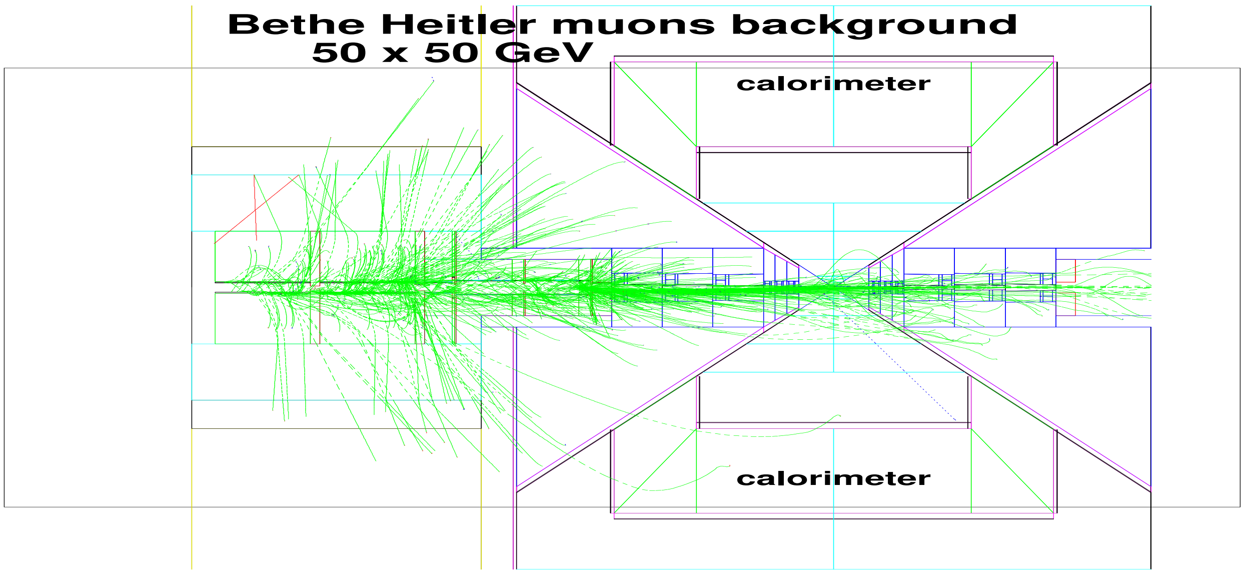
Muon Decay Backgrounds

- Detailed simulation (GEANT, MARS) resulted in:
  - ▷ Design of beam shield
  - ▷ Define necessary active beam elements
- Radiation damage and occupancies for vertex detector OK for Higgs factory



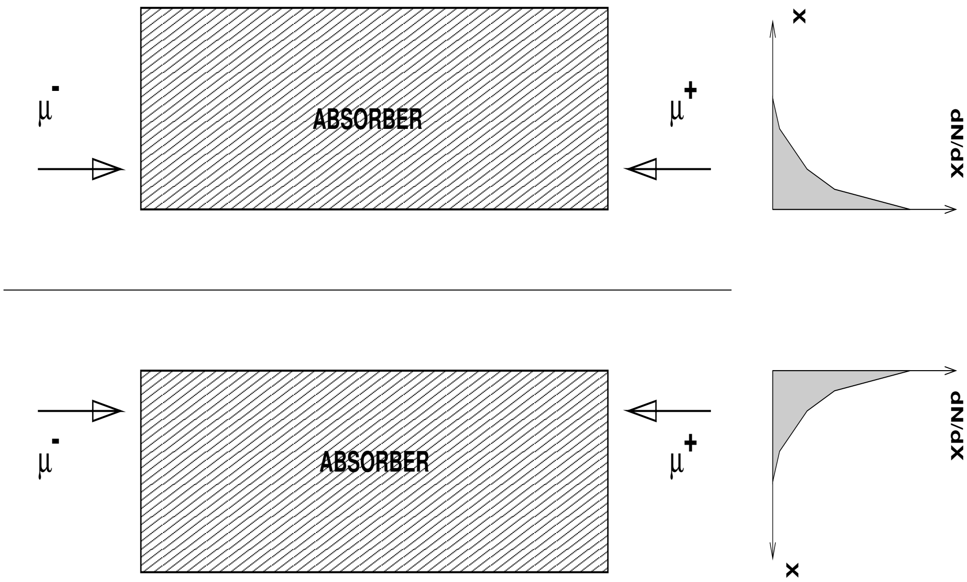
Bethe-Heitler μ background

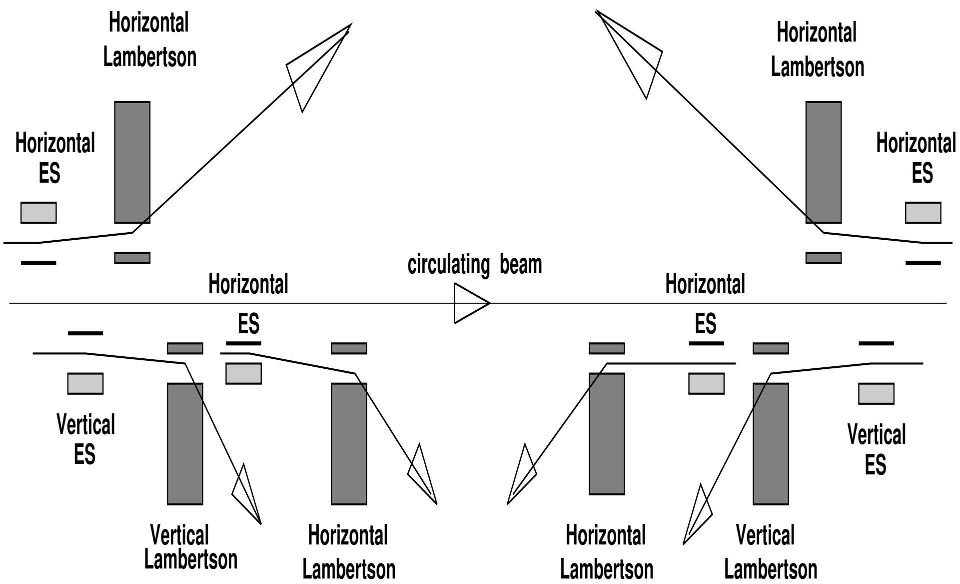
- Could generate significant fluctuations in calorimetric measurements
- Not a problem for Higgs factory, higher energies under study



μ halo background

- Study lattice upstream of IP
- Include scrapers and deflectors





Higgs Physics with the FMC

$\Rightarrow$ $\mu^+\mu^-$ collider at the s-channel Higgs pole

- For $m_h \sim 2m_W \Rightarrow$ small width, large BF$(h \to \mu^+\mu^-)$. SM fits: $m_h < 215 GeV$ at 95 % CL.
- Assume discovery at TEV or LHC $(\Delta m_h \sim 100 MeV)$. Scan $\sqrt{s} \Longrightarrow$ need to dial E_{beam} with $\Delta E_{beam} \sim 10^{-6}$.

  $\Rightarrow$ $L = 0.1 fb^{-1}$, E_{beam} resolution 0.003% $\to$ 1 year scan...
- Need to measure:
  - ▷ Total width (1-10MeV for SM Higgs with $m_h < 140 GeV$)
  - ▷ Partial widths for $t\bar{t}$, $b\bar{b}$, $c\bar{c}$, WW^*, $ZZ*$

$\Rightarrow$ Is the Higgs SM or SUSY?

... of course need to understand tagging efficiencies

Muon Collider Neutrino Sources

1) **Neutrinos from a muon storage ring** **(μ decay)**

   - ▷ **For $\sim \times 10^{20}$ μ/year could get $\mathcal{O}\left(10^{20}\right)$ ν/year in the straight section.**
   - ▷ **Point straight section to desired direction.**

arc length = straight length

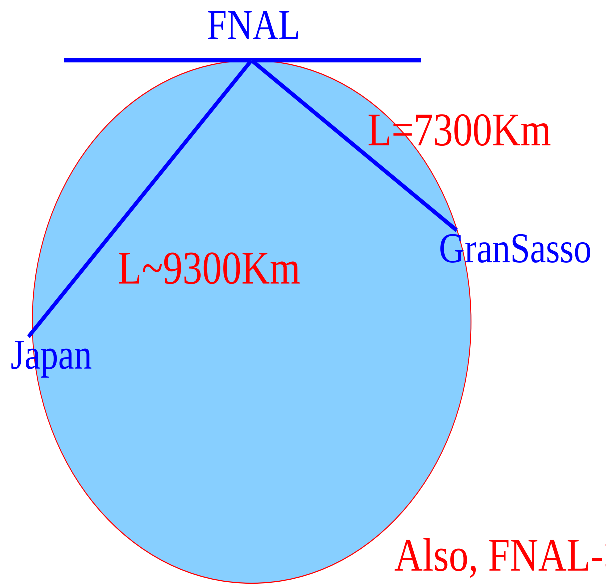
25% of decays could be pointed

arc length ~ 50m for 10 GeV, 200m for 100GeV (lattice calc. by C. Johnstone)

For arc = straight, 25% of ν could be pointed to desired location

- Precisely known **flavor content**
  $\mu^+ \longrightarrow e^+\nu_e\overline{\nu}_\mu$, 50% ν_e ($\overline{\nu_\mu}$)
- **Absolute flux** (constrained kinematics, machine parameters)

Long Baseline Options

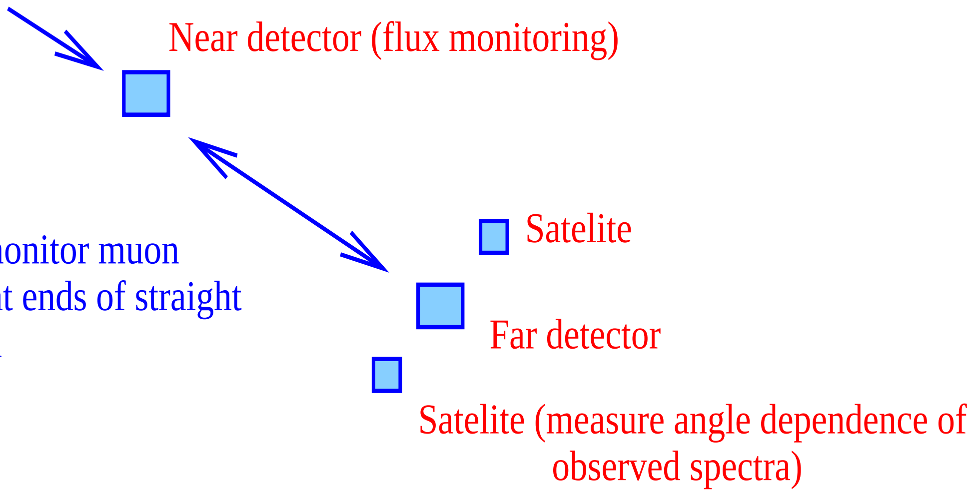


E (GeV)	L/E(Km/GeV) GranS.	Japan
10	730	930
20	370	470
30	240	310
50	150	190

Also, FNAL-> Soudan (L/E 73-18 Km/GeV)

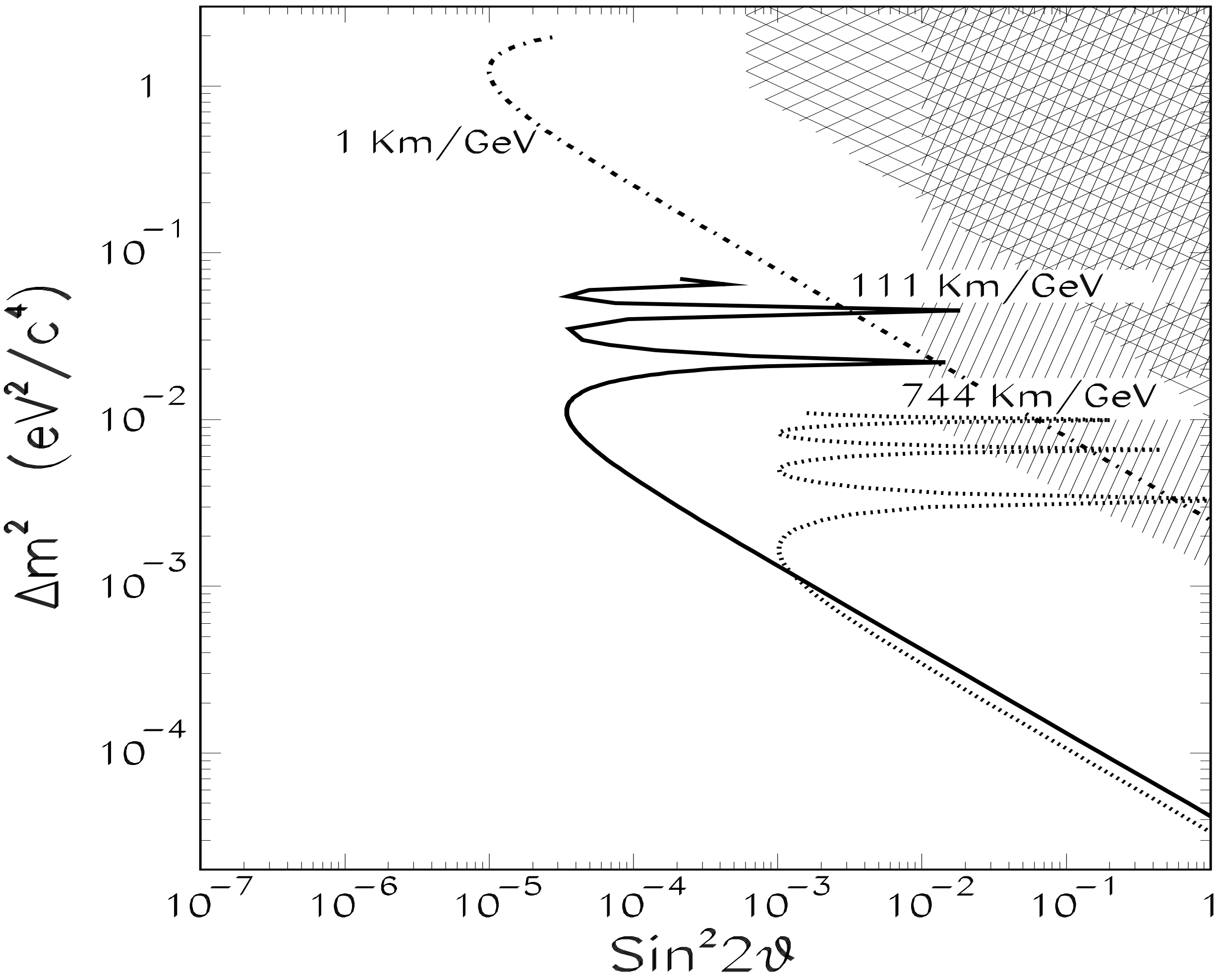
or KEK ->SuperK (L/E 25-6.3 Km/GeV)

Experimental Layout:



also, monitor muon beam at ends of straight section

Oscillation Sensitivity Example



- **Look for "wrong sign" μ's** from CC interactions
- $\nu_e \to \nu_\mu$, 1 year running
- 10kT long baseline, 20T near detectors

  assumed no background/systematics

Summary/Outlook

- An interesting and diverse physics program could be pursued with a μ accelerator facility
- This program could start before the collider:
  - ▷ Stopped muon physics
  - ▷ ν oscillation searches (very intense ν beams from a storage ring)
  - ▷ low energy hadron physics
- The collider has the unique capability of studying h s-channel production. If the h is light then the FMC would be the ideal machine to study it.
- Both machine design and physics capabilities are studied
  - ▷ Obtain a complete design/simulation of cooling
  - ▷ Complete R & D
  - ▷ Test ionization cooling (MUCOOL experiment)
- The task is challenging (lots of new concepts), the objective is to complete feasibility study and experimental tests early 2000
- Work necessary to select the best possible next generation lepton machine