31st INTERNATIONAL CONFERENCE ON
HIGH ENERGY PHYSICS AMSTERDAM

Muon Collaboration

ICHEP Conference Amsterdam

31st International Conference on High Energy Physics
24 – 31 July 2002

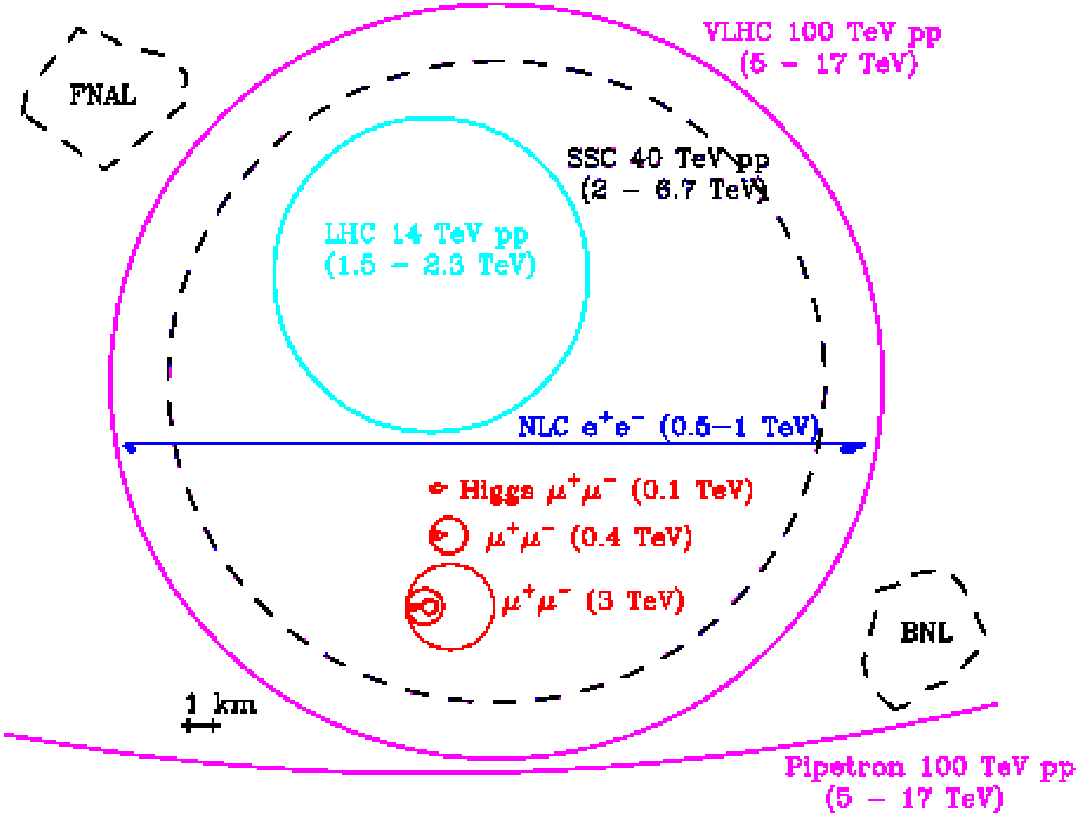
STATUS OF R&D ON NEUTRINO FACTORIES AND MUON COLLIDERS

Gail G. Hanson
University of California, Riverside
For The Neutrino Factory and Muon Collider Collaboration

WHY MUON COLLIDERS?

- Muons are fundamental particles, so same advantage as e^+e^- colliders:
  - ➜ Energy of interaction is full energy of particle, not of constituent quarks or gluons (factor ~10)
- Synchrotron radiation by muons is less than for electrons by factor of $(m_e/m_\mu)^4 \approx 6 \times 10^{-10}$
  - ➜ Energy lost by synchrotron radiation must be put back by rf power (cost of power for operation)
  - ➜ Muon beam can have narrow energy spread $(\geq 10^{-5})$
  - ➜ High energy collider can be much smaller!

COMPARISON OF HIGH ENERGY COLLIDERS



WHY MUON STORAGE RINGS?

- Muons decay:

$$\mu^- \rightarrow e^- \nu_\mu \overline{\nu}_e \quad \text{or} \quad \mu^+ \rightarrow e^+ \overline{\nu}_\mu \nu_e$$

- A muon storage ring can produce 10^{19} to 10^{21} muon decays per year

  ➜ The stored muons can have energy 20–50 GeV

  ➜ The stored muons can be polarized

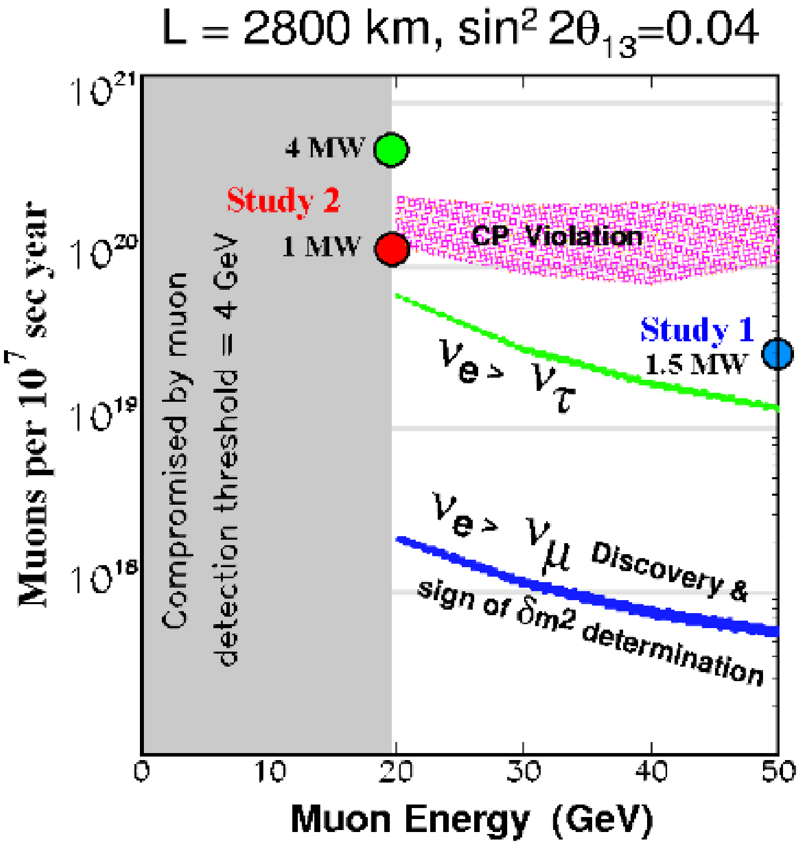
  ➜ There is no comparable source of electron neutrinos and antineutrinos

  ➜ Intense beams of neutrinos can be produced to study neutrino oscillations and possible CP violation

  ➜ A Neutrino Factory

NEUTRINO OSCILLATIONS

- A neutrino factory can measure
  - ➜ θ_{13} from $\bar{\nu}_e \to \bar{\nu}_\mu$
  - ➜ The sign of Δm^2_{32} using matter effects
  - ➜ *CP* violation in the leptonic sector if $\sin^2(2\theta_{13})$, $\sin^2(2\theta_{21})$ and Δm^2_{21} are sufficiently large



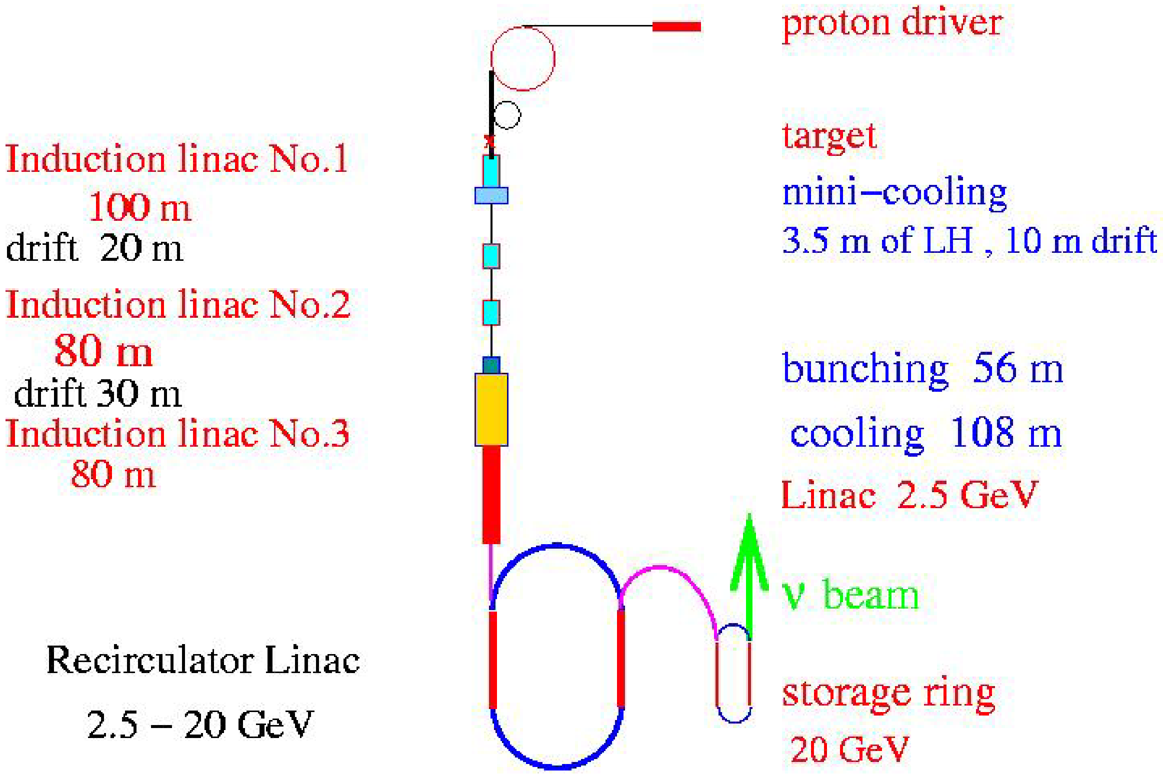
NEUTRINO FACTORY FEASIBILITY STUDIES

Two detailed feasibility Studies carried out:

- Feasibility Study I at Fermilab

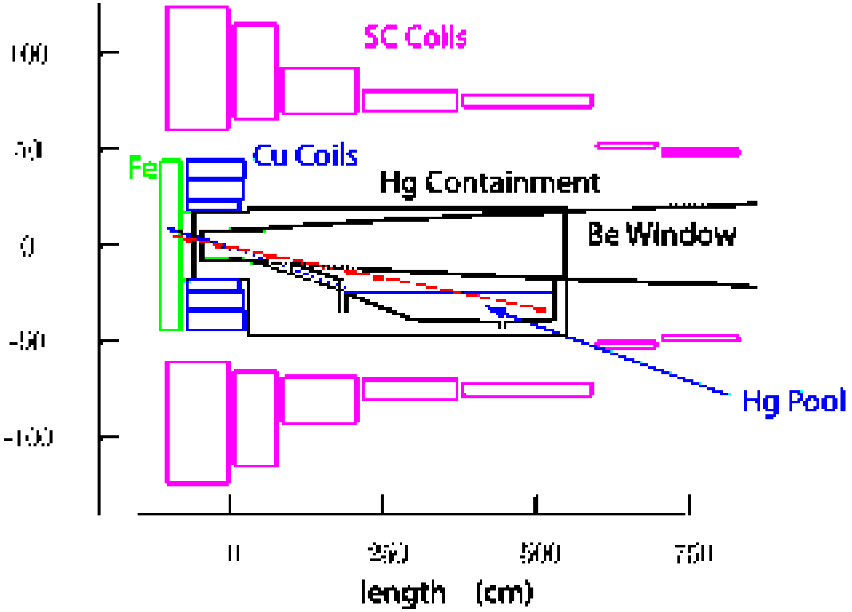
- Feasibility Study II at Brookhaven National Lab

Schematic of a Neutrino Factory – Study II Version

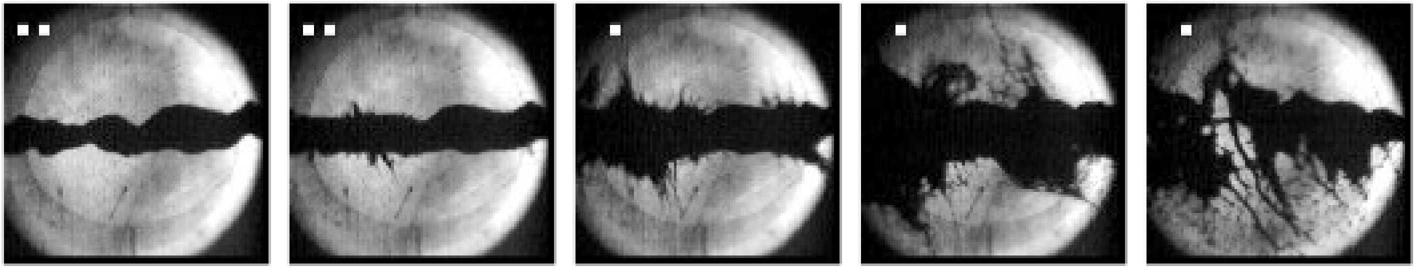


NEUTRINO FACTORY FEASIBILITY STUDY II: Target and Capture

Target, capture solenoids and mercury containment



BNL Experiment E951:

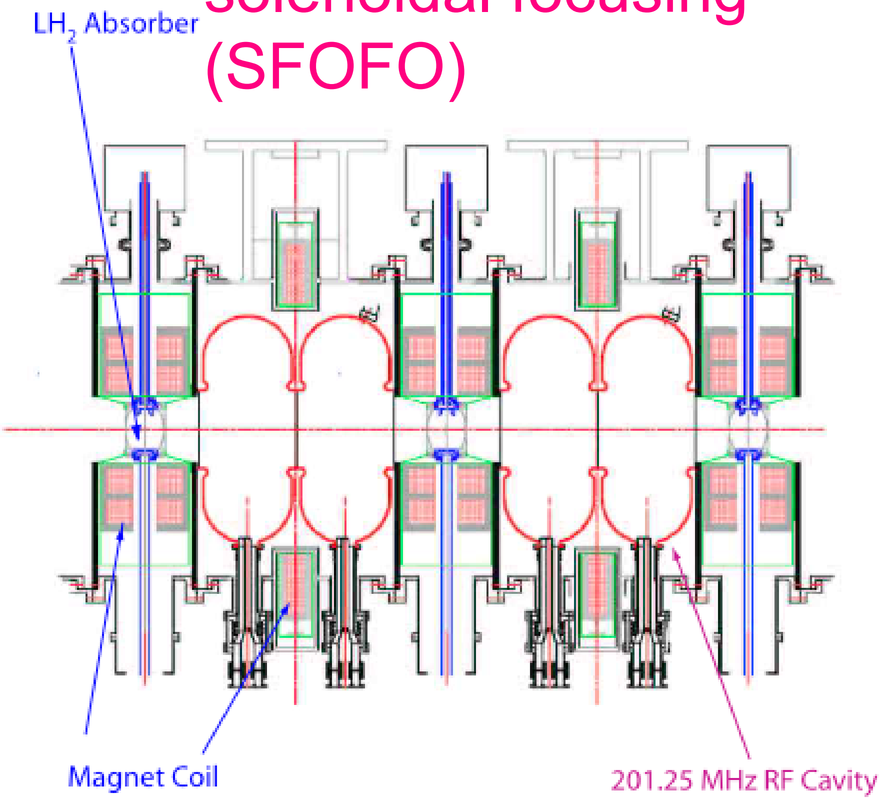


1-cm-diameter Hg jet in 2×10^{12} protons at t = 0, 0.75, 2, 7, 18 ms

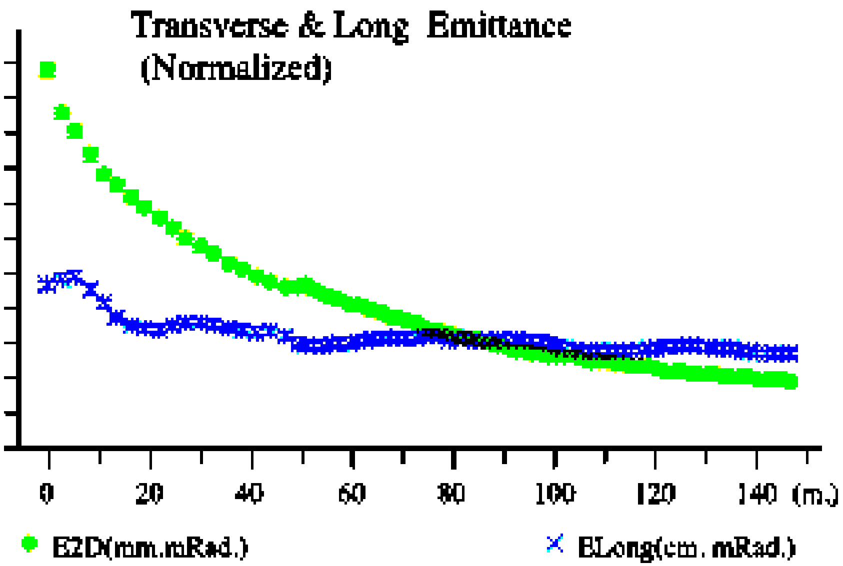
NEUTRINO FACTORY FEASIBILITY STUDY II:

Cooling

Cooling channel:
solenoidal focusing
(SFOFO)



Simulation results:



31st INTERNATIONAL CONFERENCE ON
HIGH ENERGY PHYSICS AMSTERDAM

WHY MUON COLLIDERS?

fact Muon Collaboration

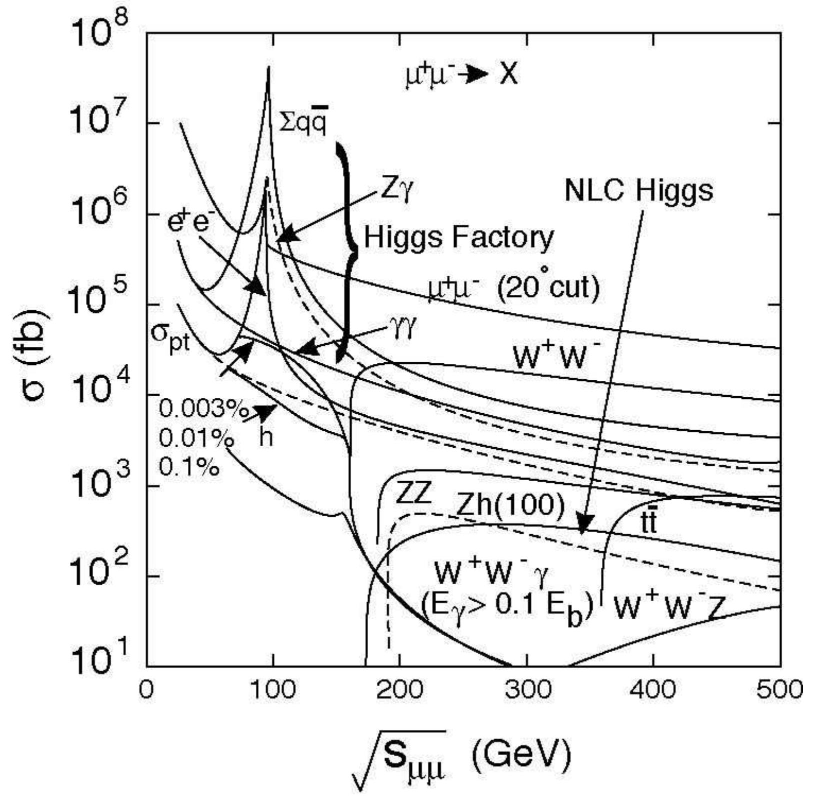
S-CHANNEL HIGGS PRODUCTION

The Higgs boson couples to mass, so cross section at *s*-channel Higgs pole is very large (Fig.)

➜ Small beam energy spread can allow measurement of m_H to few hundred keV

➜ Direct measurement of Higgs width Γ_H to ~ 1 MeV

➜ A Higgs Factory



(From T. Han, talk at FNAL, May 22, 1998)

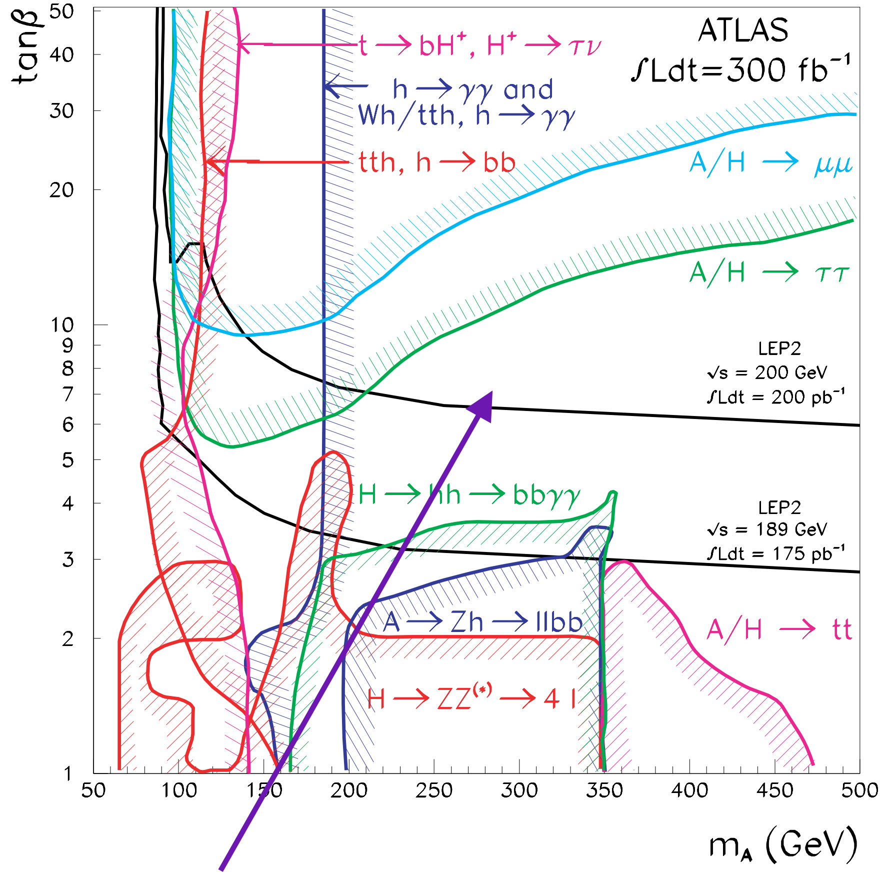
NEED FOR SUSY HIGGS FACTORY?

Muon Collaboration

31st INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS AMSTERDAM

For larger values of tan β, the heavy Higgs bosons H^0, A^0 may have couplings to gauge bosons suppressed.

We might need a muon collider to discover them.



Muon collider?

HIGGS FACTORY PARAMETERS

Baseline parameters for Higgs factory muon collider. Higgs/year assumes a cross section of 5×10^4 fb, Higgs width of 2.7 MeV, 1 year = 10^7 s. From “Status of Muon Collider Research and Development and Future Plans,” Muon Collider Collaboration, C. M. Ankenbrandt *et al.*, *Phys. Rev. ST Accel. Beams* **2**, 081001 (1999).

COM energy (TeV)		0.1	
p energy (GeV)		16	
p's/bunch		5×10^{13}	
Bunches/fill		2	
Rep. rate (Hz)		15	
p power (MW)		4	
μ/ bunch		4×10^{12}	
μ power (MW)		1	
Wall power (MW)		81	
Collider circum. (m)		350	
Ave bending field (T)		3	
rms $\delta p/p$ (%)	0.12	0.01	0.003
6D $\varepsilon_{6,N}$ $(\pi m)^3$	1.7×10^{-10}	1.7×10^{-10}	1.7×10^{-10}
rms ε_n (π mm mrad)	85	195	290
β^* (cm)	4.1	9.4	14.1
σ_z (cm)	4.1	9.4	14.1
σ_r spot (μm)	86	196	294
σ_θ IP (mrad)	2.1	2.1	2.1
Tune shift	0.051	0.022	0.015
n_{turns} (effective)	450	450	450
Luminosity (cm^{-2} s^{-1})	1.2×10^{32}	2.2×10^{31}	10^{31}
Higgs/yr	1.9×10^3	4×10^3	3.9×10^3

HIGH ENERGY MUON COLLIDER PARAMETERS

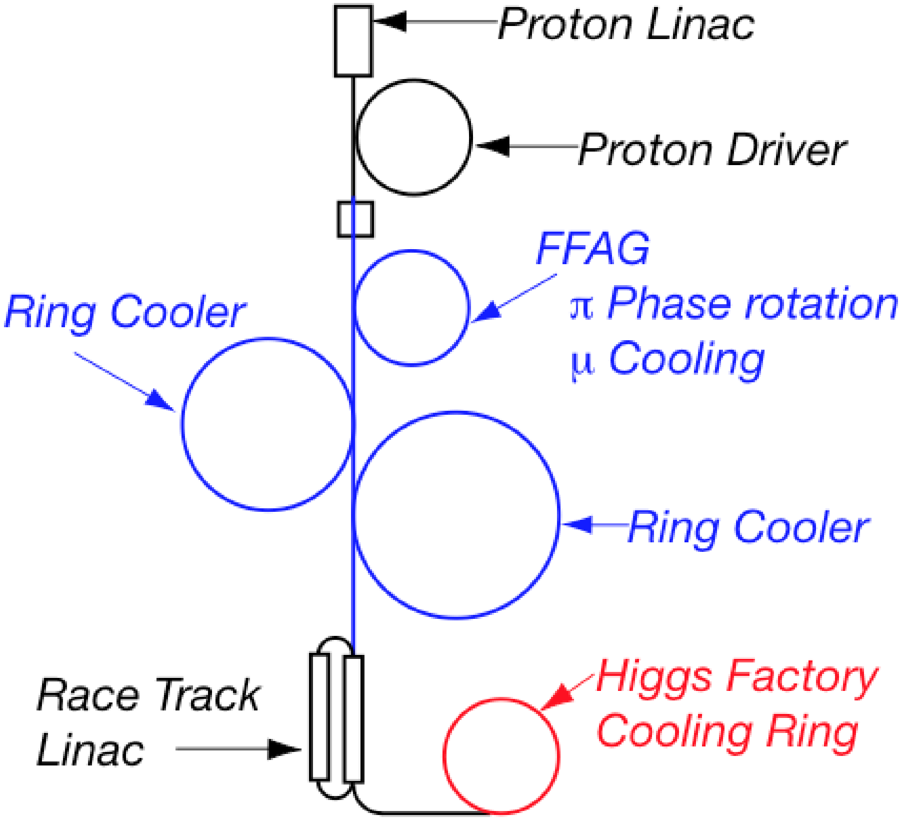
Baseline parameters for high energy muon colliders. From “Status of Muon Collider Research and Development and Future Plans,” Muon Collider Collaboration, C. M. Ankenbrandt *et al.*, *Phys. Rev. ST Accel. Beams* **2**, 081001 (1999).

COM energy (TeV)	0.4	3.0
p energy (GeV)	16	16
p’s/bunch	2.5×10^{13}	2.5×10^{13}
Bunches/fill	4	4
Rep. rate (Hz)	15	15
p power (MW)	4	4
μ/ bunch	2×10^{12}	2×10^{12}
μ power (MW)	4	28
Wall power (MW)	120	204
Collider circum. (m)	1000	6000
Ave bending field (T)	4.7	5.2
rms $\delta p/p$ (%)	0.14	0.16
6D $\varepsilon_{6,N}$ $(\pi \mathrm{m})^3$	1.7×10^{-10}	1.7×10^{-10}
rms ε_n (π mm mrad)	50	50
β^* (cm)	2.6	0.3
σ_z (cm)	2.6	0.3
σ_r spot (μm)	2.6	3.2
σ_θ IP (mrad)	1.0	1.1
Tune shift	0.044	0.044
n_{turns} (effective)	700	785
Luminosity ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$)	10^{33}	7×10^{34}

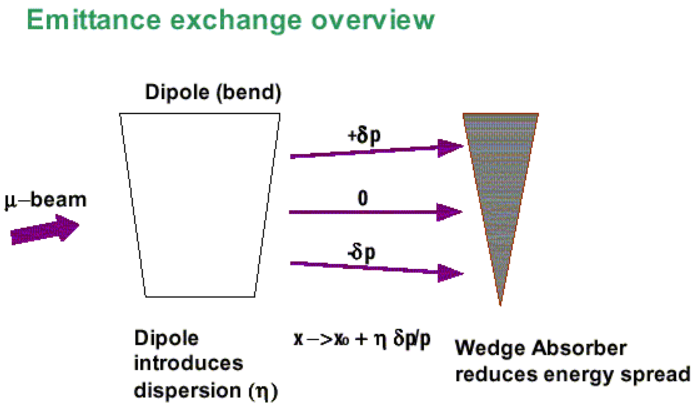
POSSIBLE HIGGS FACTORY SCHEMATIC

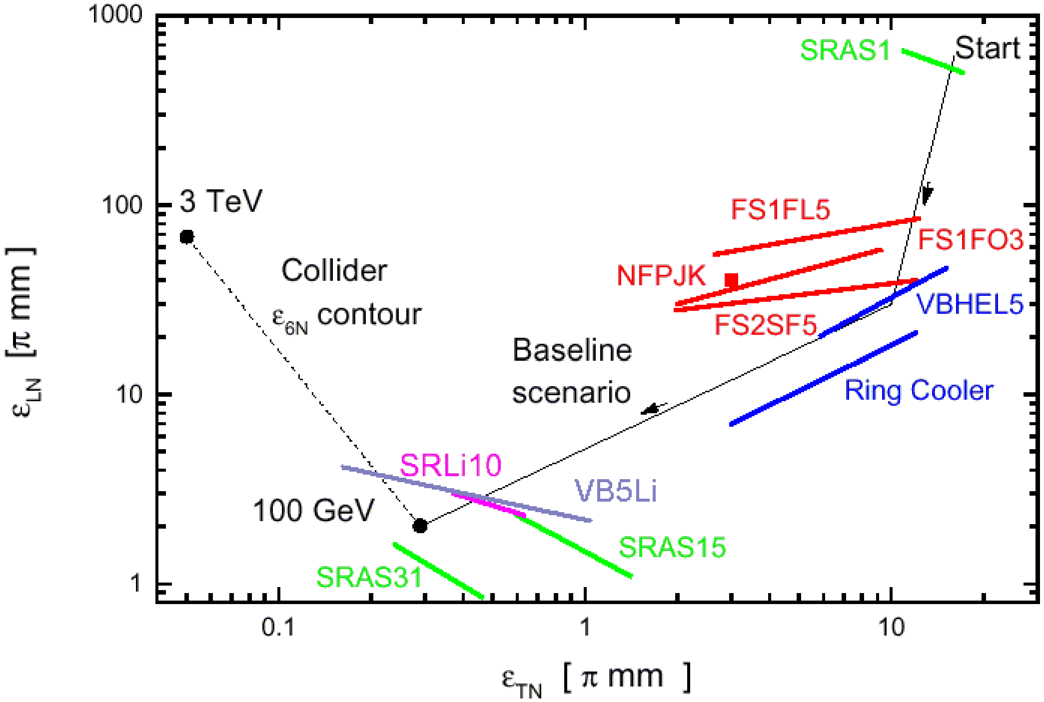
Ring Cooler Higgs Factory:

- One of the most crucial R&D issues for a muon collider is “cooling” the muons – making the beam smaller in 6D phase space



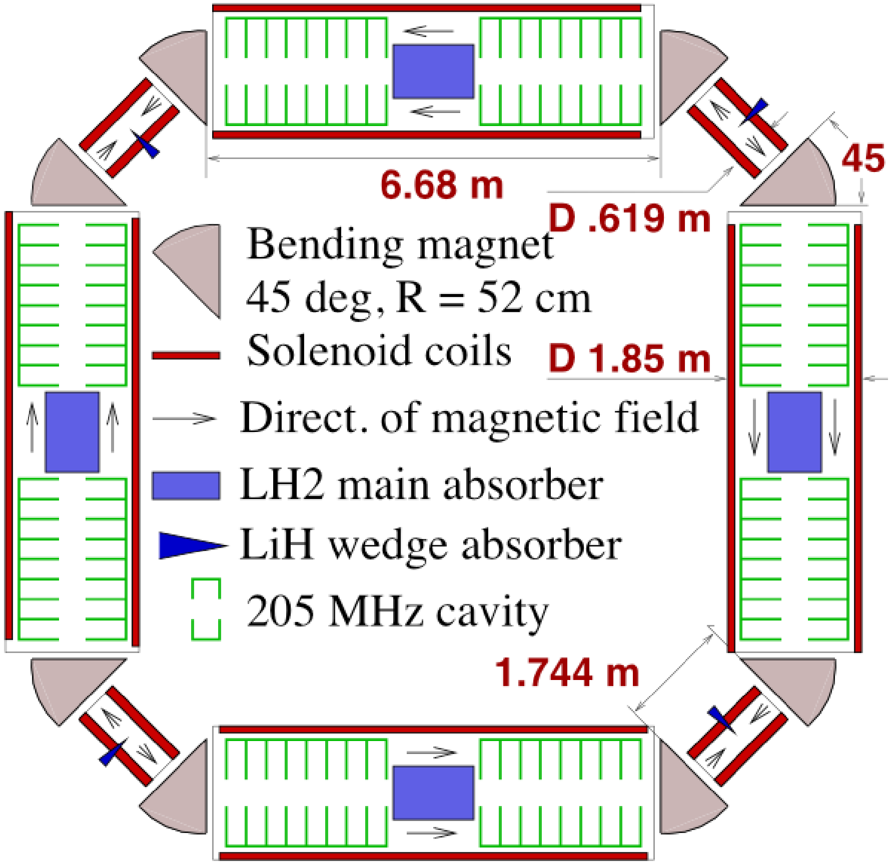
COOLING





× 100 cooling needed in each transverse and in longitudinal direction (~10^6 in 6D emittance) compared with μ's from π decay.

BALBEKOV RING COOLER



Bending magnet 45 deg, R = 52 cm

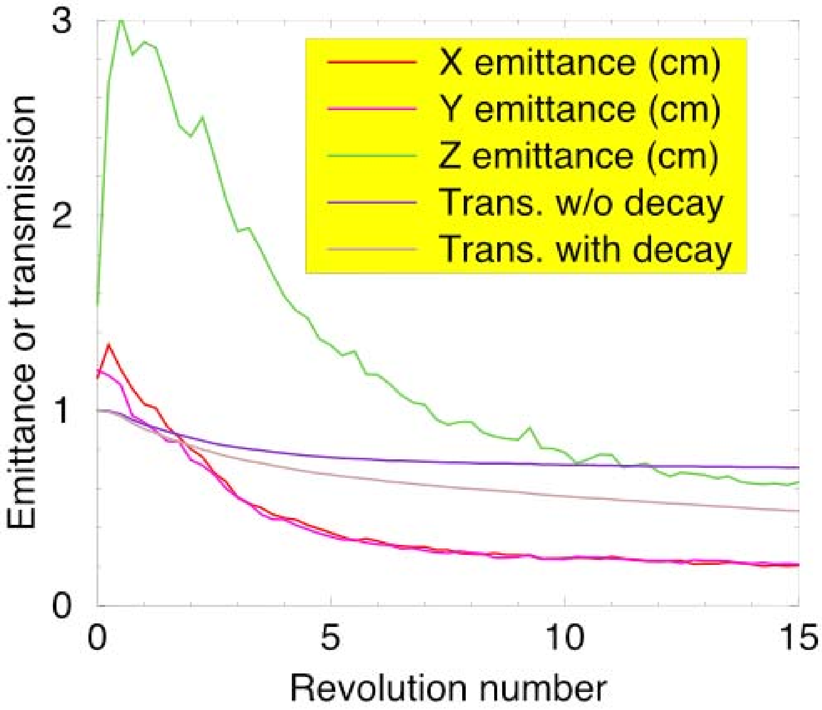
Solenoid coils

Direct. of magnetic field

LH2 main absorber

LiH wedge absorber

205 MHz cavity

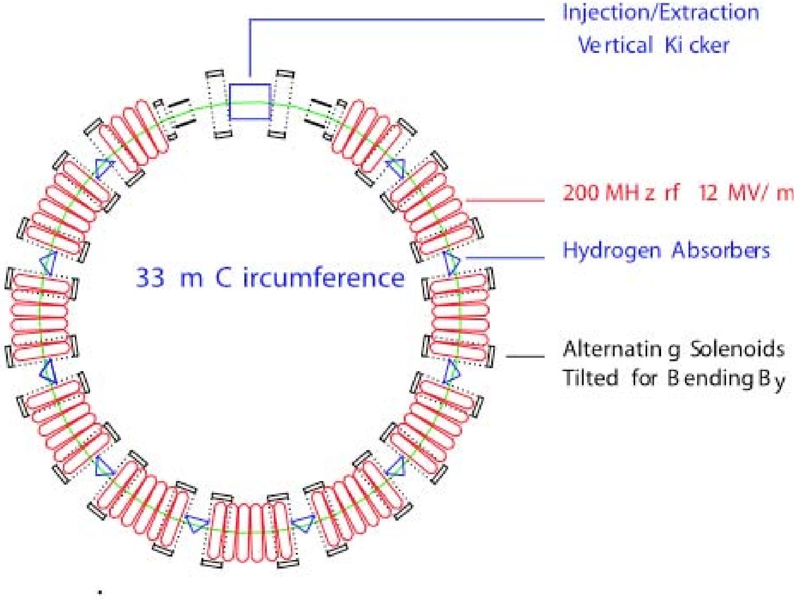


31st INTERNATIONAL CONFERENCE ON
HIGH ENERGY PHYSICS AMSTERDAM

RFOFO RING COOLER

(R. PALMER)

Muon Collaboration



Injection/Extraction
Vertical Kicker

200 MHz rf 12 MV/m

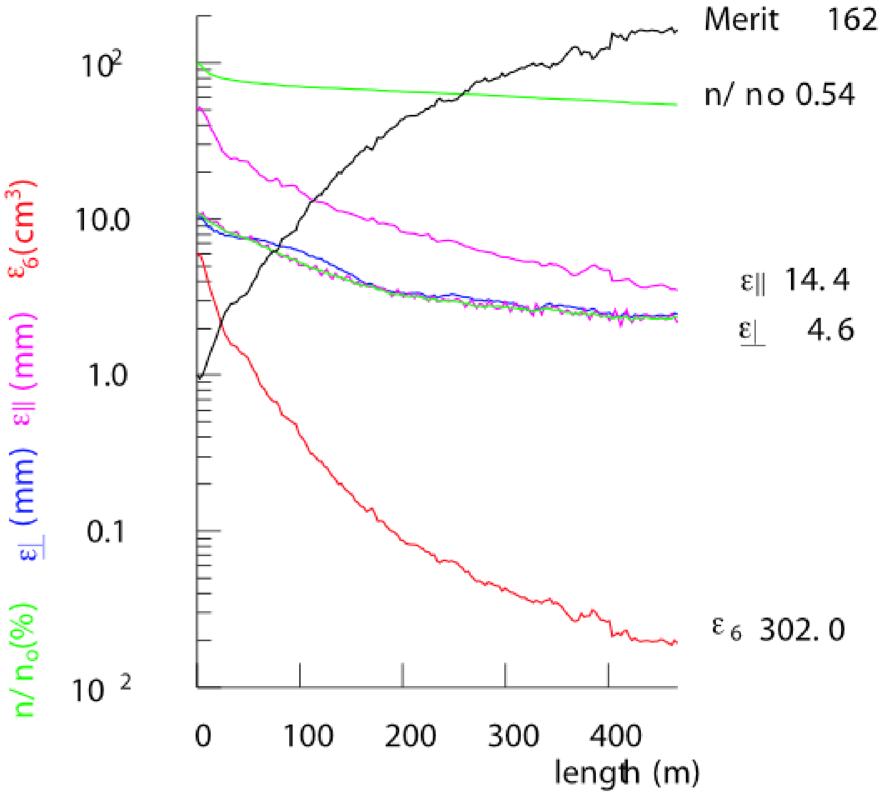
Hydrogen Absorbers

33 m Circumference

Alternating Solenoids
Tilted for Bending By

Performance

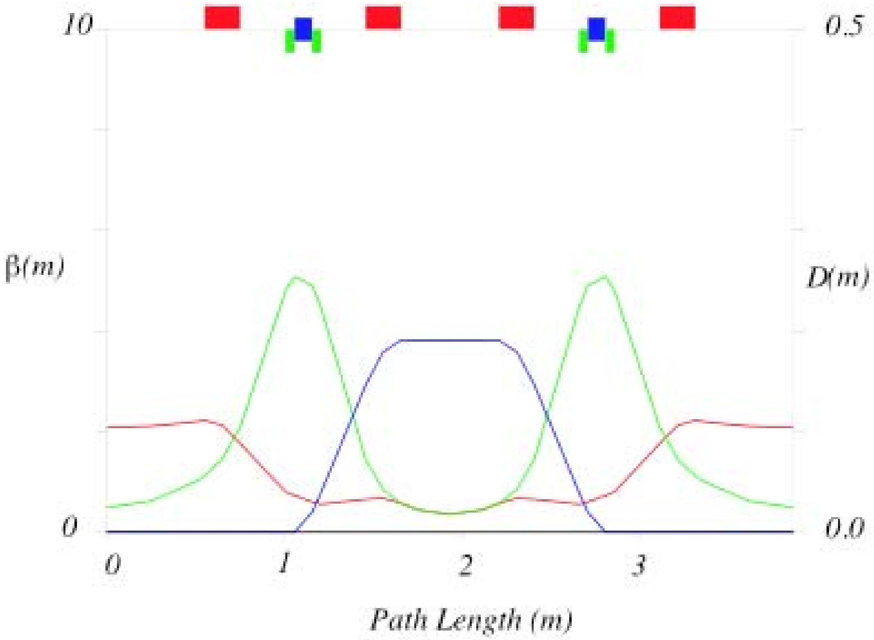
Simulation done with Maxwellian Fields



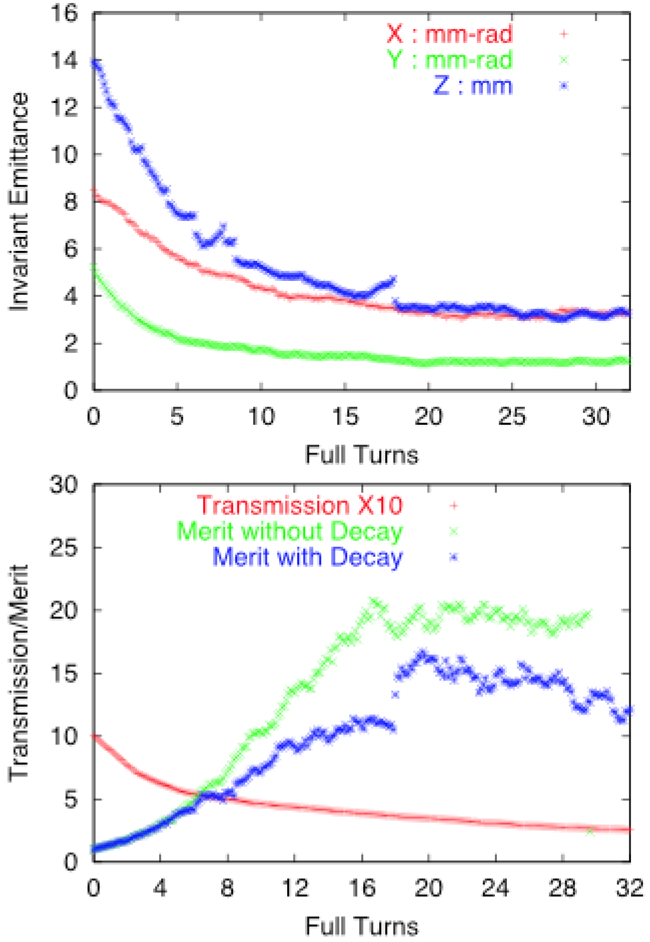
QUADRUPOLE RING COOLER

(A. Garren, H. Kirk)

One of 8 Cells



Performance



31st INTERNATIONAL CONFERENCE ON
HIGH ENERGY PHYSICS AMSTERDAM

SUMMARY OF PROGRESS TOWARDS MUON COLLIDER COOLING

fact Muon Collaboration

- Neutrino Factory feasibility study simulations show cooling to $\varepsilon_{TN} = 2\ \pi\text{mm}$ and $\varepsilon_{LN} = 30\ \pi\text{mm}$ (bunched!)
- Ring Cooler cools ~ × 5 transverse, × 2 longitudinal
- Lithium lens (or other?) needed to cool ~ × 10 to sub-mm in ε_{TN}

There has been a tremendous amount of progress in R&D on cooling, which can be used to develop a better Neutrino Factory design!