Quadrupole Ring Coolers for Neutrino Factories and a Higgs Factory

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Center for Advanced Accelerators - UCLA

1. The need for Emittance Exchange or Longitudinal Cooling
2. The concept of the UCLA Quad Ring Cooler
3. Progress to date in the simulation
4. Use of an Insert Li Lens on the next step

- Summary -

NUFACT 2002 Workshop
London, UK -June 2002

MUON BEAM COOLING

$\tau_\mu = 2.2 \mu s$ at Rest –

Need to Cool

(a) At or near Rest

friction Cooling

→ hard to accelerate

from this

(b) At modest energy

so that decay loss

is not large

Transverse Cooling

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

L_R ~ Rad. Length

Gain as $\beta_\perp^* \to$ small

Longitudinal Cooling or Emittance Exchange

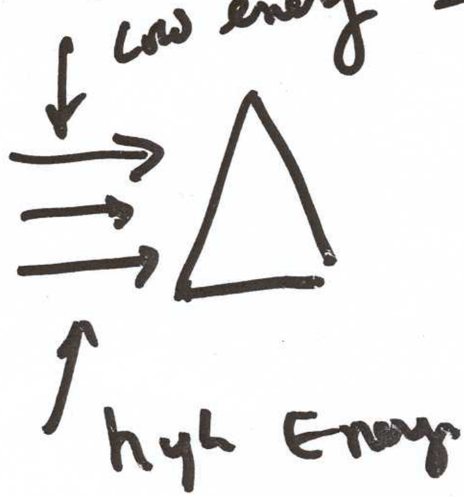
Only recently have we had success

- Ring Coolers - less than 2 years old

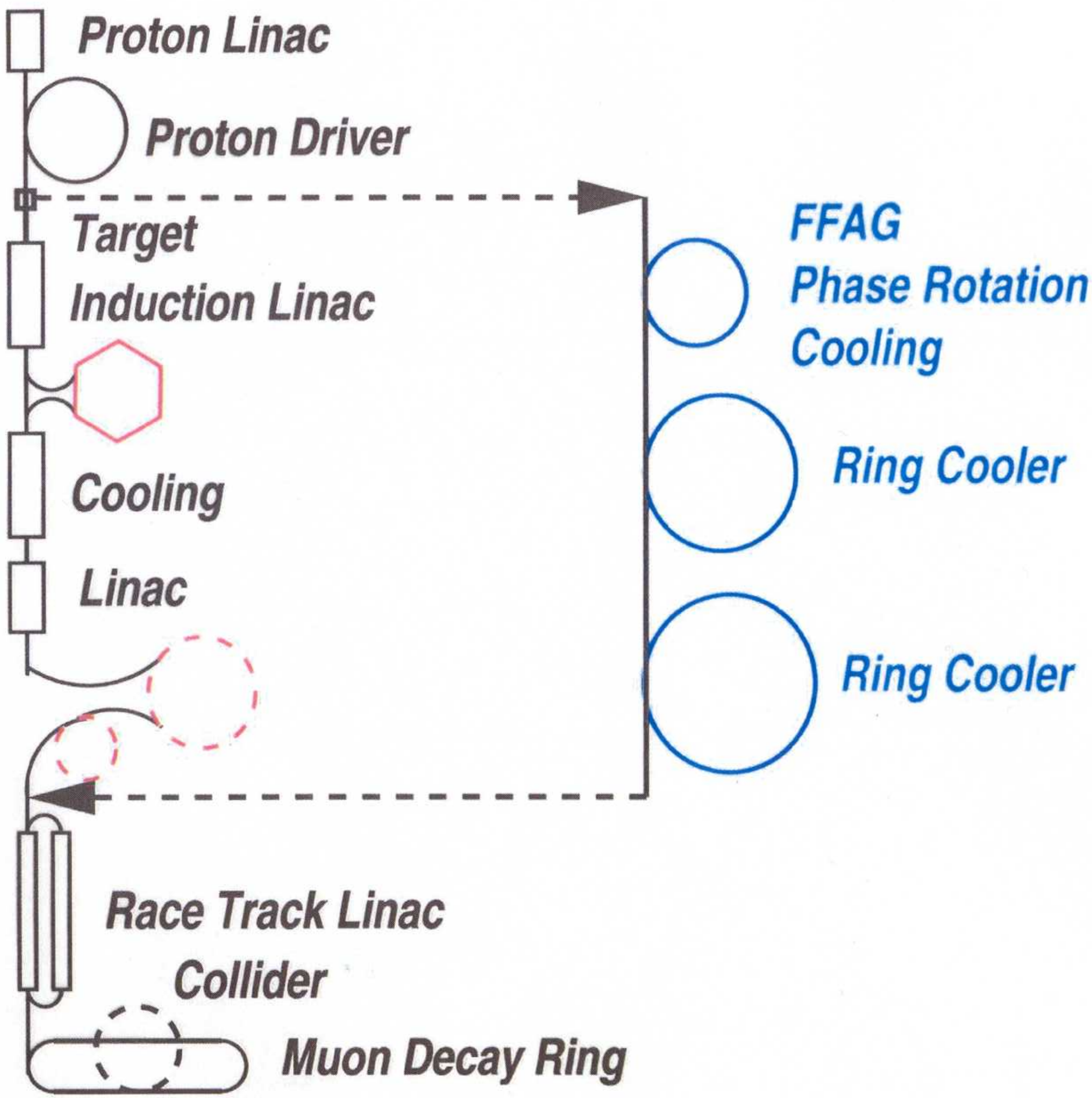
$$\frac{d(\Delta E_\mu)^2}{ds} = -2\,\frac{d\left[\frac{dE_\mu}{ds}\right]}{dE_\mu}\left\{(\Delta E_\mu)\right\}^2 + \frac{d(\Delta E_\mu)^2_{\text{straggling}}}{ds}$$

to cool need

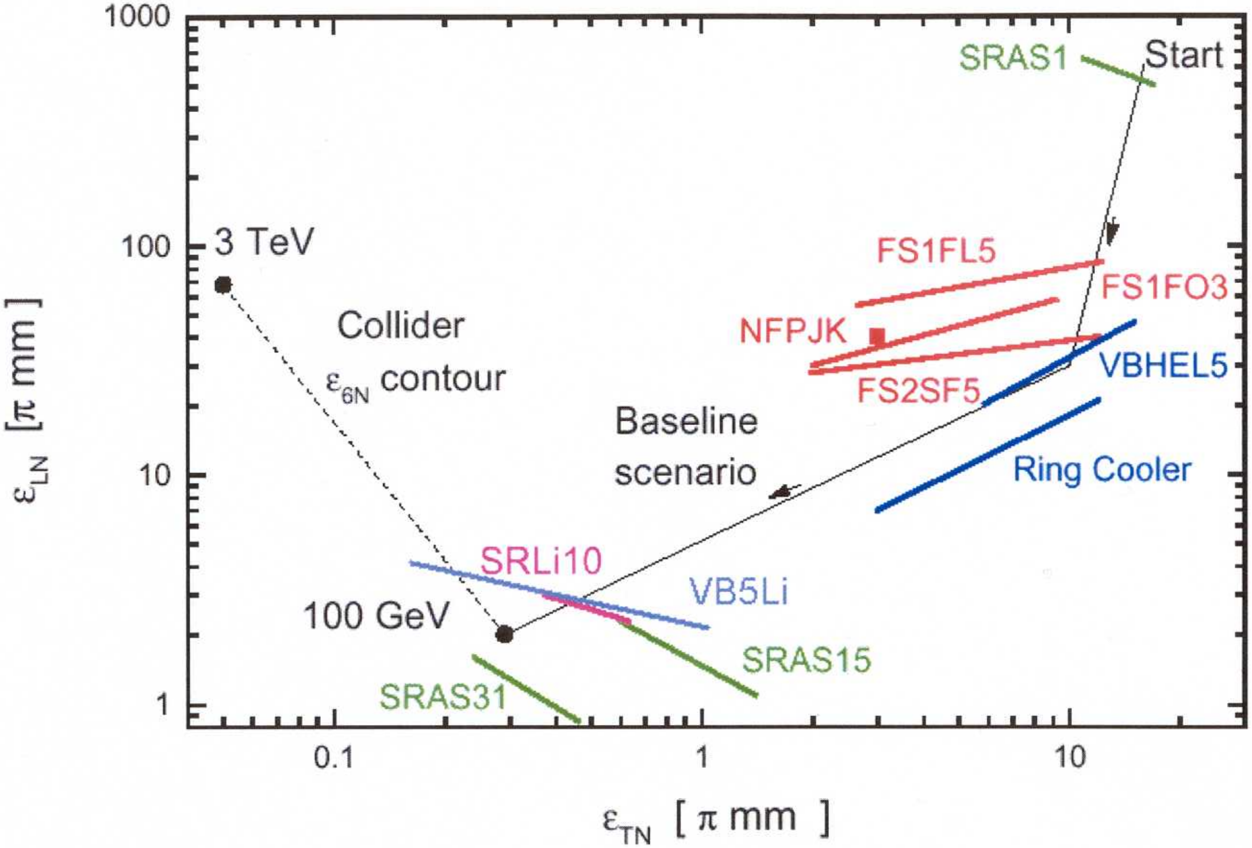
dispersion - Wedge



+ Must include straggling effects


Proton Linac
Proton Driver
Target
Induction Linac
Cooling
Linac
FFAG
Phase Rotation
Cooling
Ring Cooler
Ring Cooler
Race Track Linac
Collider
Muon Decay Ring

Cooling Status (Map)



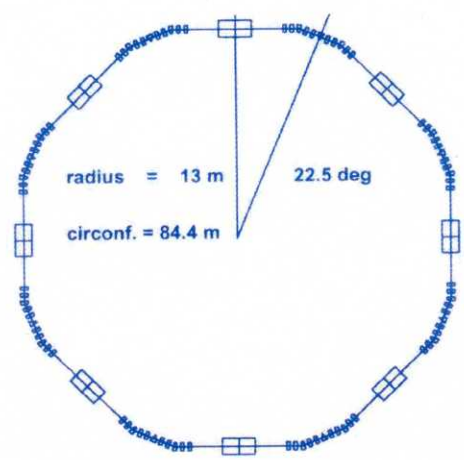
- **Cooling sections that have beem simulated in some detail**
  - ICOOL, Geant, VLB simulations
- From R. Fernow

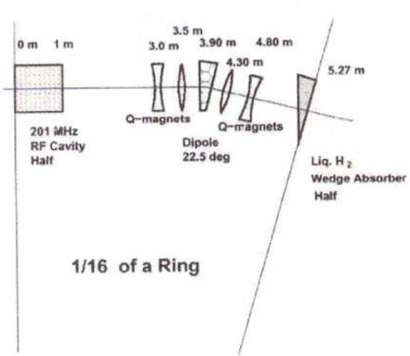
Muon Collaboration

Quadrupole rings

- Fukui,Cline,Garren,He,Kirk,Mills
- Easier to inject in and out of.

Overall Layout of the Muon Ring Cooler



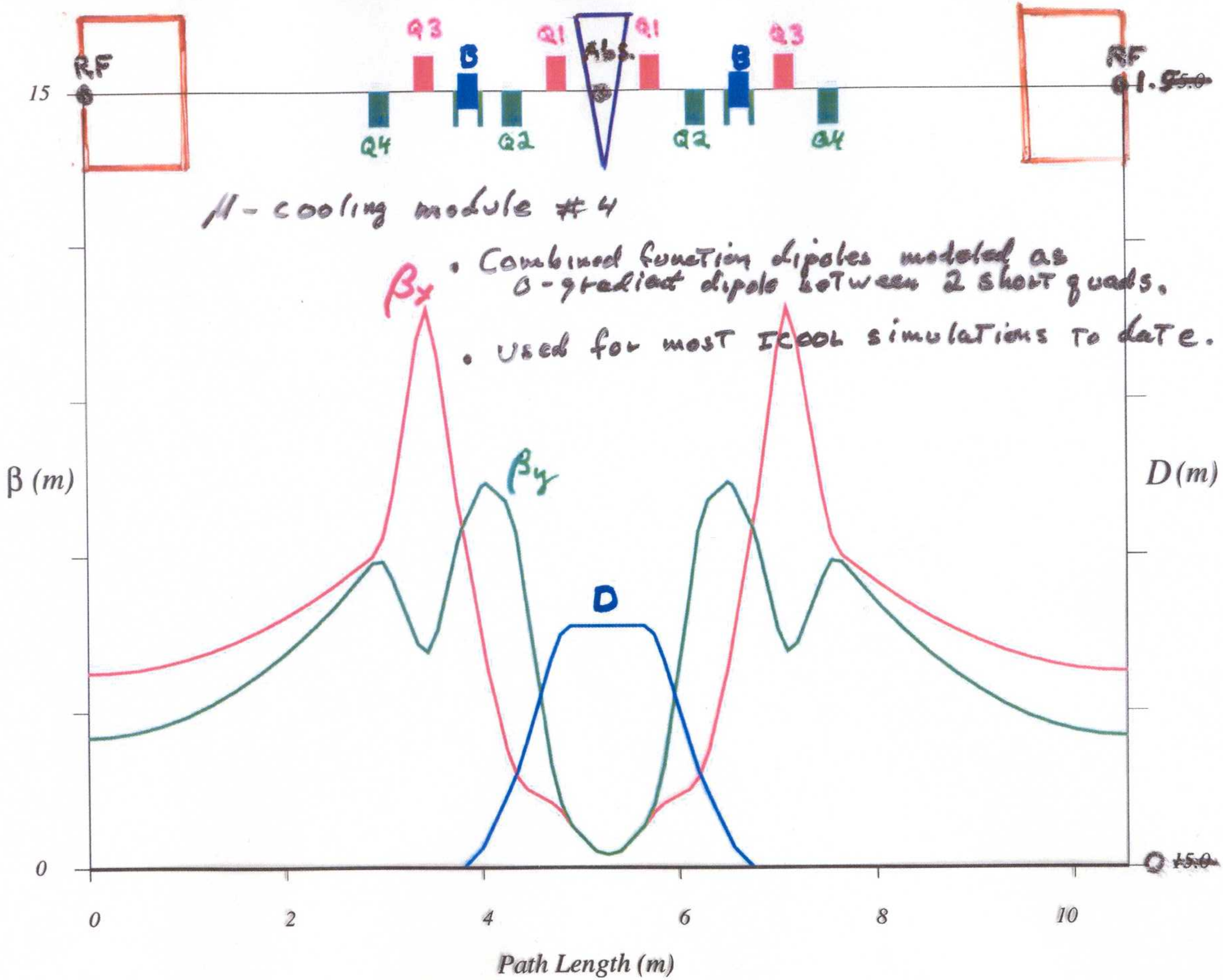


Half Section of Bending Cell

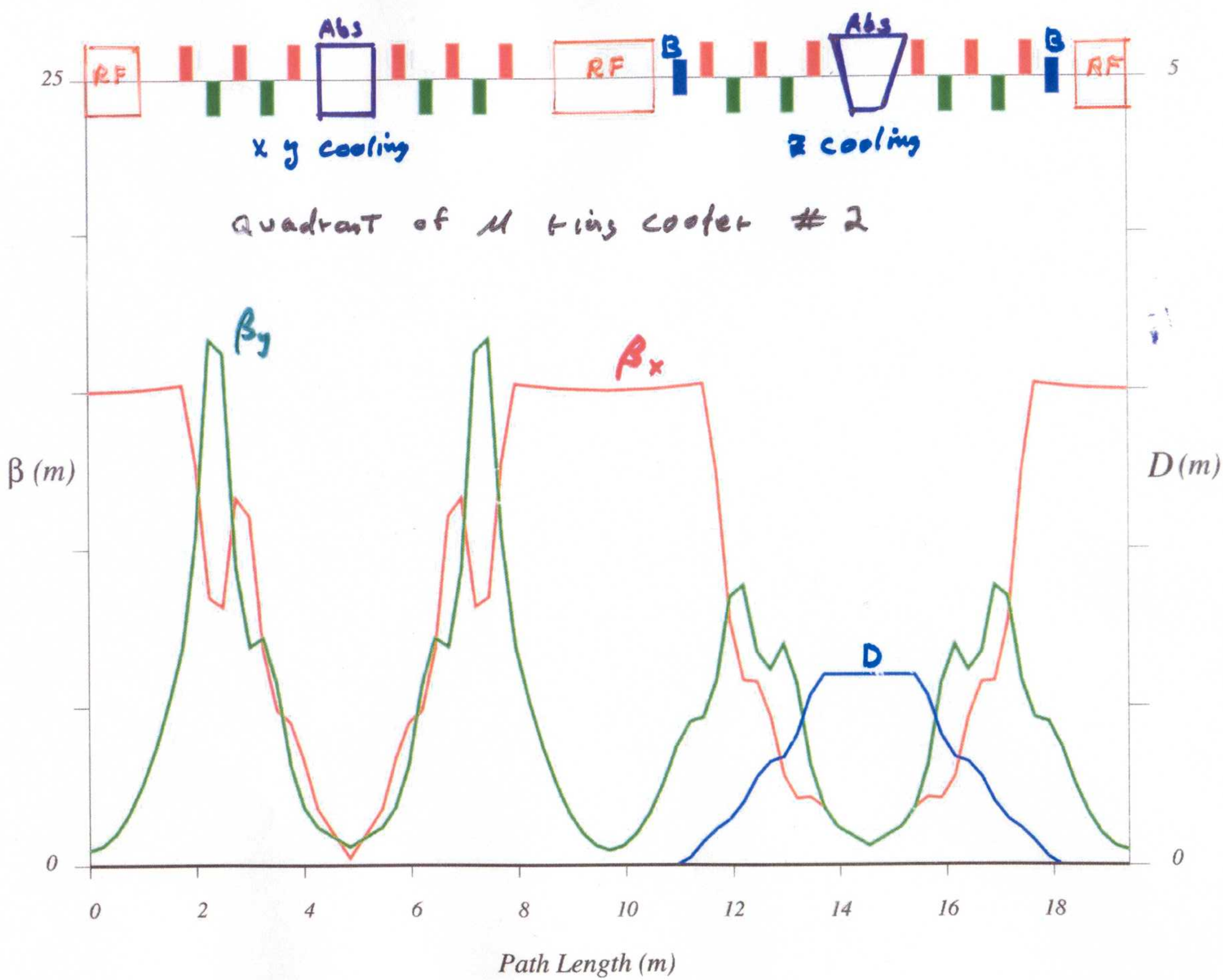
Quadrupole Ring Cooler – Beam Dynamics Issues

Alex Bogacz

- Original 8–cell ring lattice (Al Garren's design)
- Alternative 4-cell ring lattice
  - double bending compact ring
  - shorter cell architecture
  - longer lower field dipoles (3 Tesla)
- Comparison of both designs (8-cell vs. 4-cell)
- Longitudinal Nonlinearity Compensation with Sextupoles



RF
Q3
B
Q1
Abs.
Q1
B
Q3
RF
Q4
Q2
Q2
Q4
15
0
μ - cooling module #4
• Combined function dipoles modeled as 0-gradient dipole between 2 short quads.
• Used for most ICOOL simulations to date.
β_x
β_y
D
β (m)
D (m)
0
2
4
6
8
10
Path Length (m)


Abs
RF
RF
B
Abs
B
RF
25
5
x y cooling
z cooling
Quadrant of μ ring cooler #2
βy
βx
β (m)
D (m)
D
0
0
2
4
6
8
10
12
14
16
18
Path Length (m)

Tracking Simulation of the UCLA Ring Cooler

Yasuo Fukui
UCLA, e-mail: fukui@slac.stanford.edu

- UCLA Ring Cooler (Conventional magnet elements and wedge absorbers) has demonstrated emittance exchange and the 6D cooling with tracking simulation. A step towards the complete cooling simulation for a Higgs factory or a muon collider.
- 16 Cell Ring (22.5 deg bend.) performs better in the muon transmission and the slower emittance growth. Why is it the case? Is the performance difference caused by the size difference of dispersion in the absorber?
- As test models, I tried a new scheme in a Ring Cooler
  45 degree bent cell with short(long) wedge, and
  a straight lattice with long(short) absorber.
  - identify the effect of dE/dx straggling in the dispersive region.
- Emittance Growth (start at the cold muon beam) to equilibrium emittances

Parameters of a Muon Cooling Ring

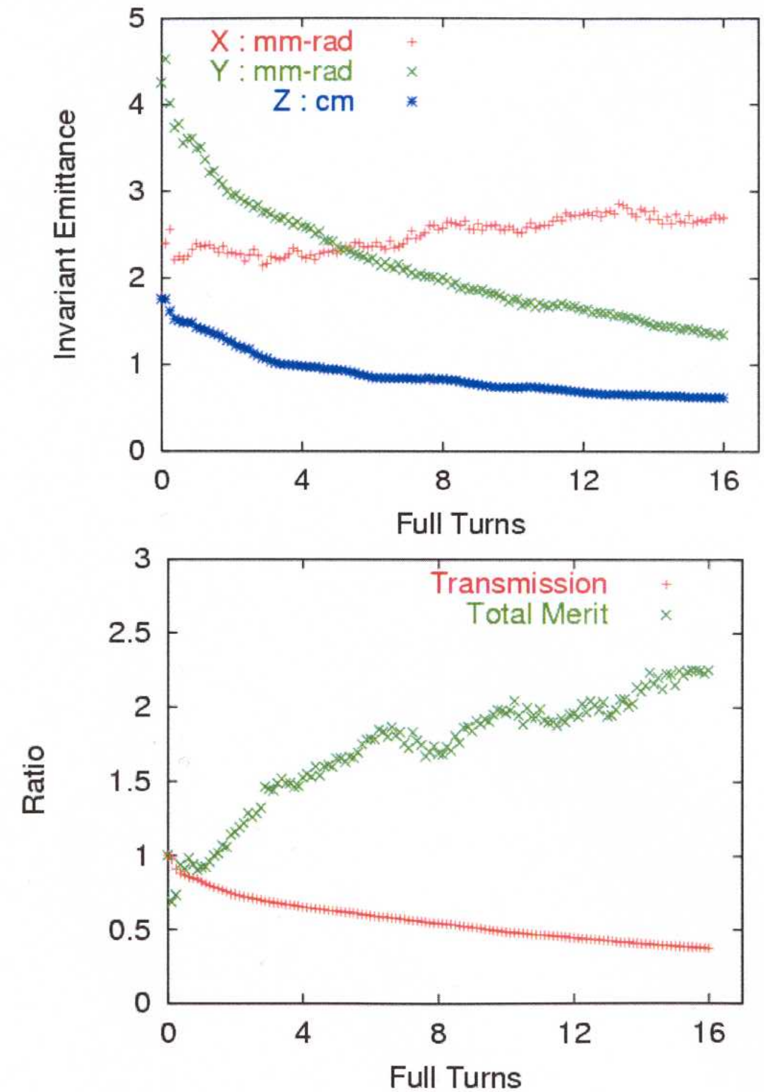
Momentum	Pc	1	GeV
	beta*gamma	9.47	
	beta	0.9945	
	gamma	9.522	
Initial emittance	epsn	2000	mm-mr
Momentum width	sigmap/p	2.50%	
Muon lifetime	taumu	20.9	µs
Circumference	C	124.44	m
Revolution time	T	0.4174	µs
Number cooling cells		8	
Number straight cells		4	
Cell length	Lc	10.37	m
Number dipoles		16	
Bend angle		22.5	deg
Absorber length		0.25	m
Energy loss-absorber		-7.5	MeV
Energy gain -rf		7.5	MeV
Energy loss/gain-ring		60	MeV
Typical damping time		16.7	revs
		6.96	µs
Beta value in absorber		0.25	m
Dispersion in absorber		0.47	m
Wedge angle of absorber		~12	deg
Maximum betax, betay in cool cell		10.6/7.0	m
Cell phase advance	mu/2pi	0.75	
Dipole field	Bo	6.55	T
Maximum gradient	Gmax	24	T/m

Snowmass Lattice Performance

Beam momentum 500 MeV/c
25 cm LH_2 wedges
Wedge angle 10^0
Rf frequency 201.25 MHz
E_{max} = 10 MV/m

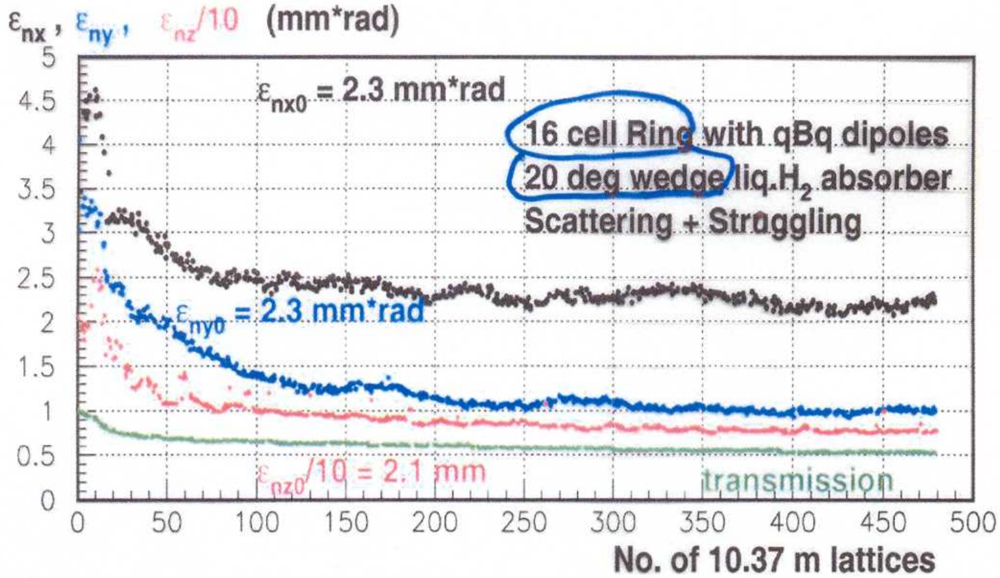
- initial ε_y > initial ε_x
- ε_y and ε_z decreases
- ε_x increases
- Transmission 40%

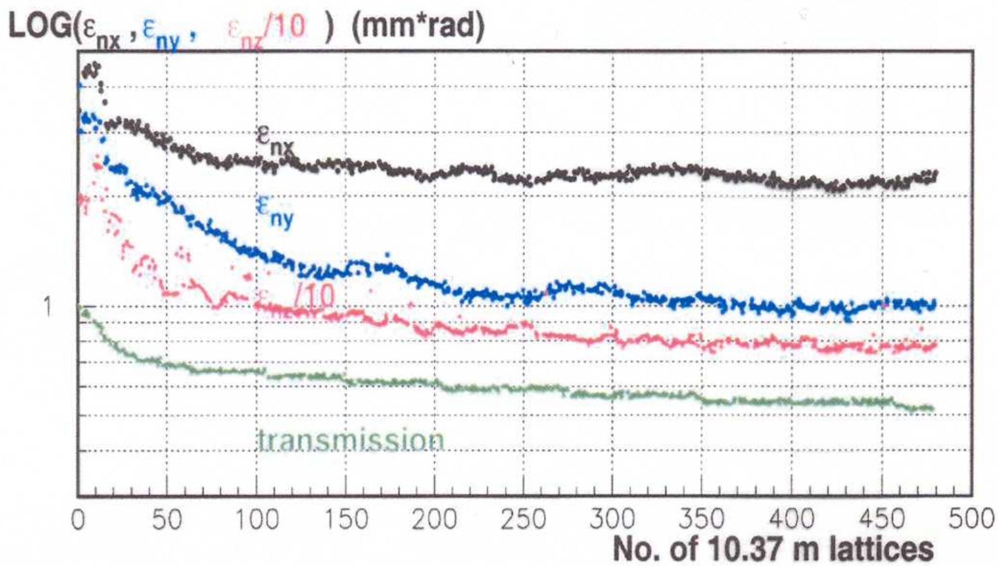
Total Merit = Transmission *x* $(\varepsilon_x \varepsilon_y \varepsilon_z)_{initial} / (\varepsilon_x \varepsilon_y \varepsilon_z)_{final}$



BROOKHAVEN
NATIONAL LABORATORY

Harold G. Kirk





Wedge <L> = 25 cm Liq H_2 Wedge Opening Angle

		20°	30°	40°	
ε_{N0x} 3 mm	$\varepsilon_{N.eq}$ X	2.3	2.8	4.2	mm.rad
ε_{N0y} 3 mm	$\varepsilon_{N.eq}$. Y	1.00	1.00	0.90	mm. rad
ε_{N0z} 20mm	$\varepsilon_{N eq}$ Z	7.8	6.0	4.8	mm. rad
	$\varepsilon_{Neq}X * \varepsilon_{Neq}Z$	18	17	20	$(mm \cdot rad)^2$
6 D Cooling Factor		10.1	10.7	9.9	

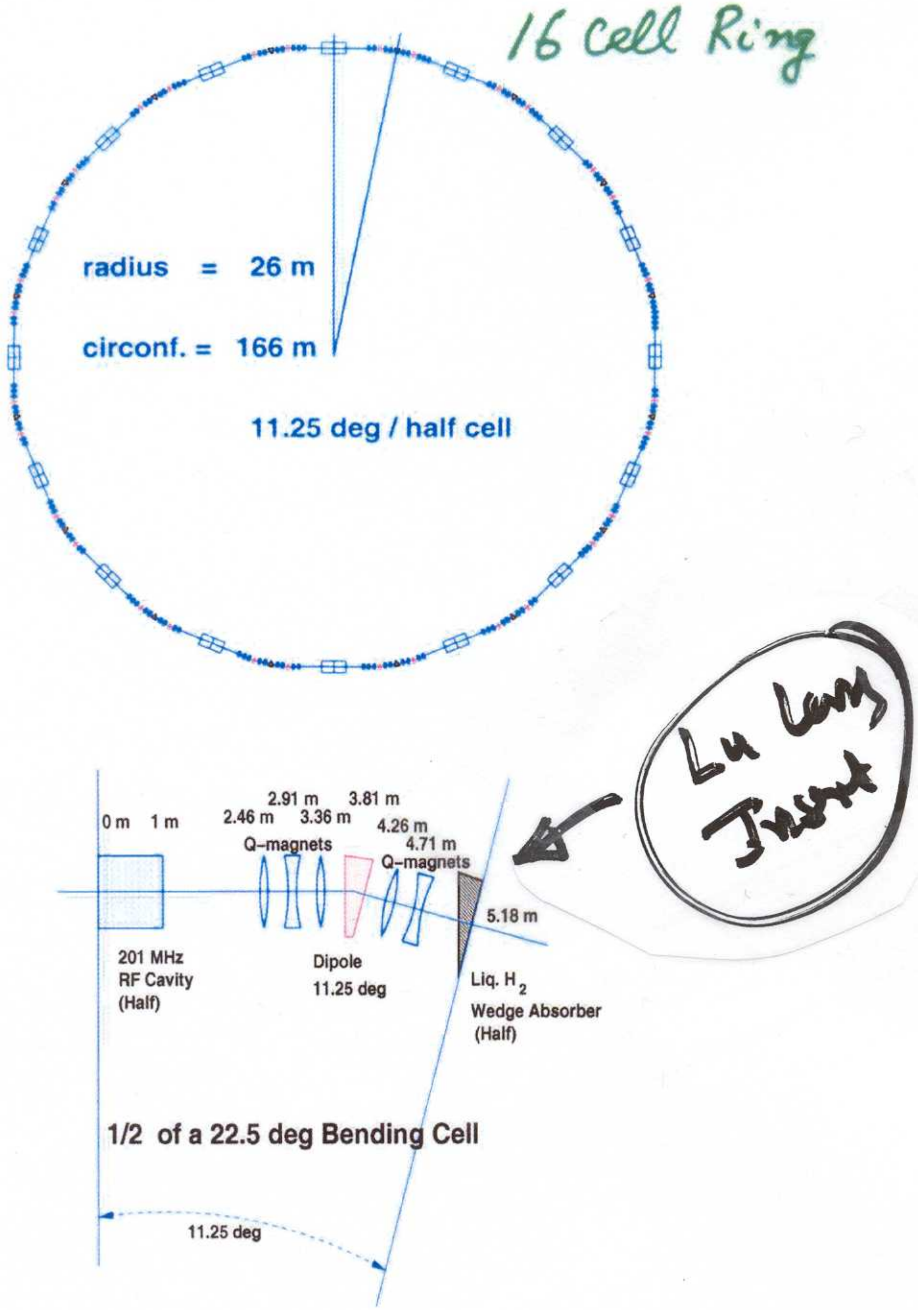


Figure 1: Top view of the 16 cell UCLA Emittance Exchange Ring, and a schematic drawing of a ring components in the 11.25 degree Half Cell section

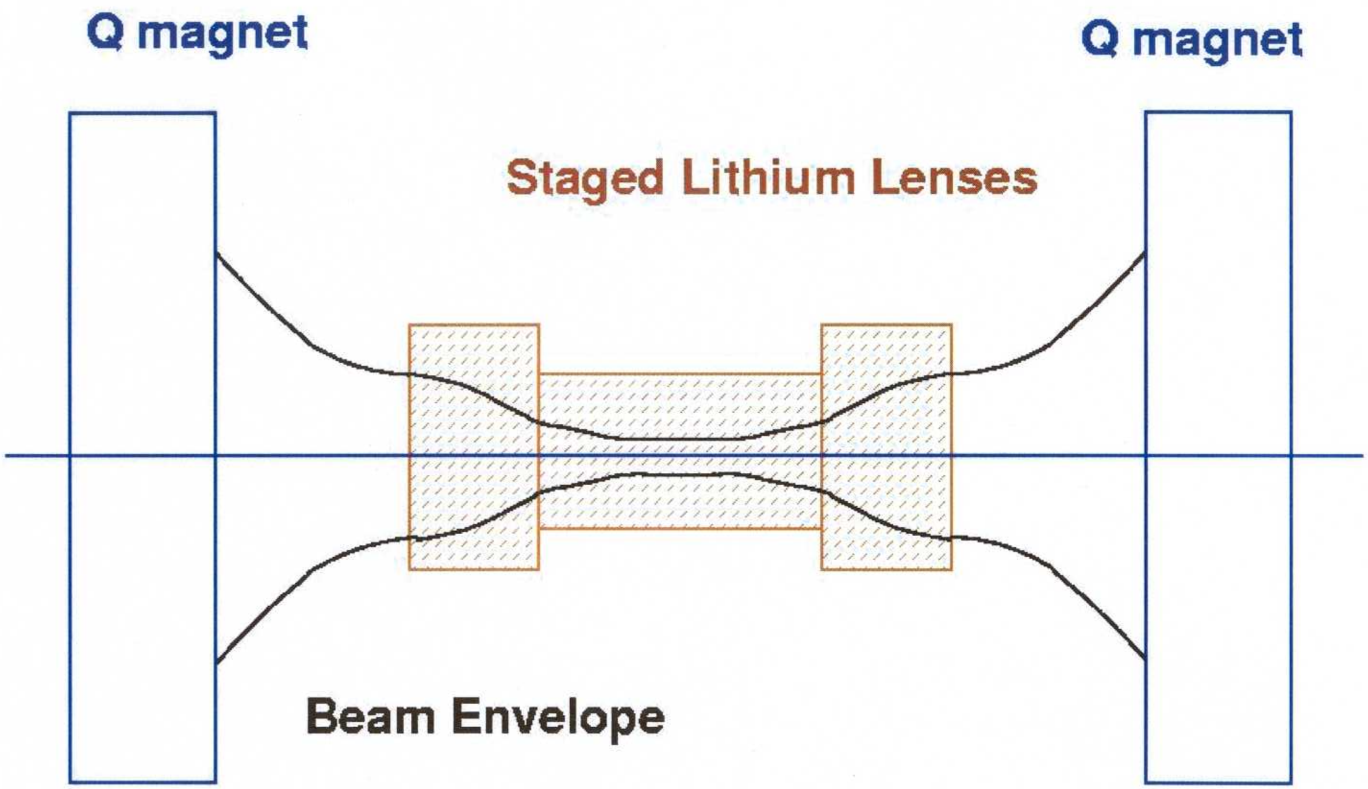


Figure 22. Schematic diagram of the Lithium Lens System at the low β section.

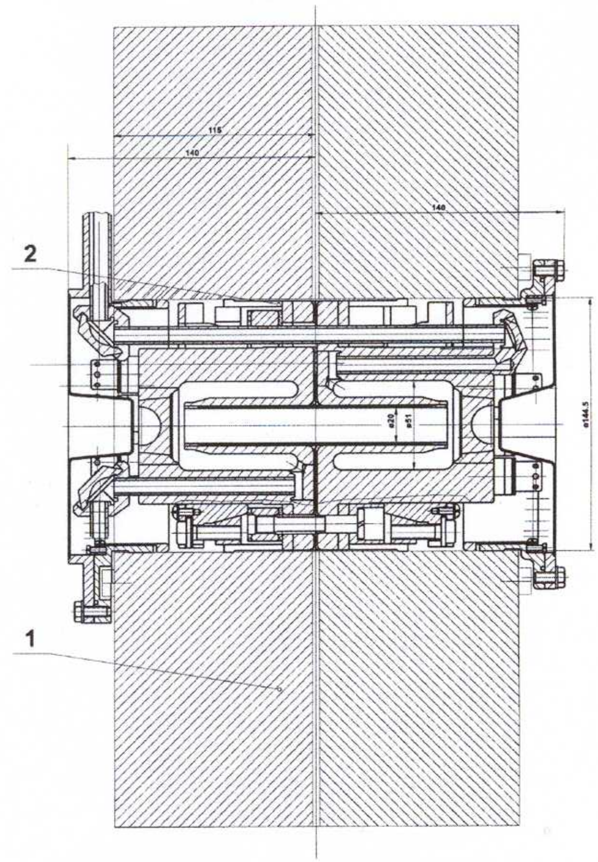
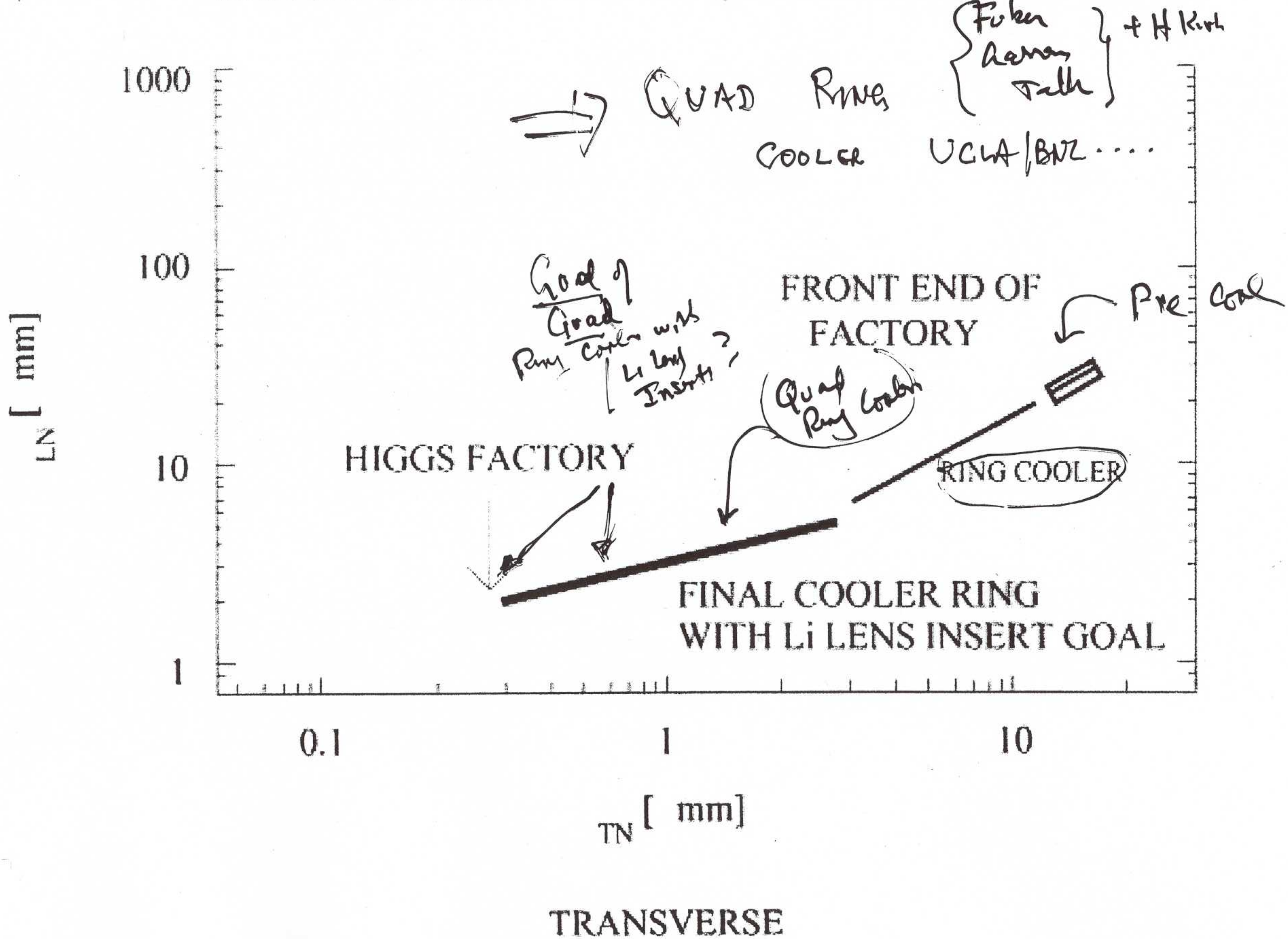


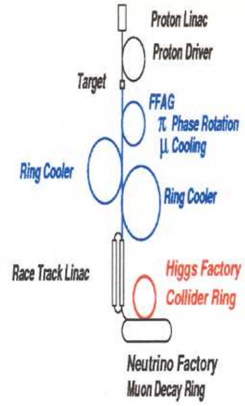
Fig.3b. New lens with Fermilab transformer.

1 – transformer; 2 – collet contact clamps.

Figure 23. Side view of the 15 cm Lithium Lens.

EMITTANCE REDUCTION REQUIRED FOR HIGGS FACTORY





MINI WORKSHOP AT

UCLA

THE USE OF A RING COOLER FOR A NEUTRINO FACTORY AND A HIGGS FACTORY / MUON COLLIDER

Organizers:

David Cline, Gail Hanson, Yasuo Fukui, Harold Kirk and David Neuffer

March 7, 8, 2002

UCLA FACULTY CENTER

PINE ROOM

http://www.physics.ucla.edu/hep/mc/ringcooler2002.htm

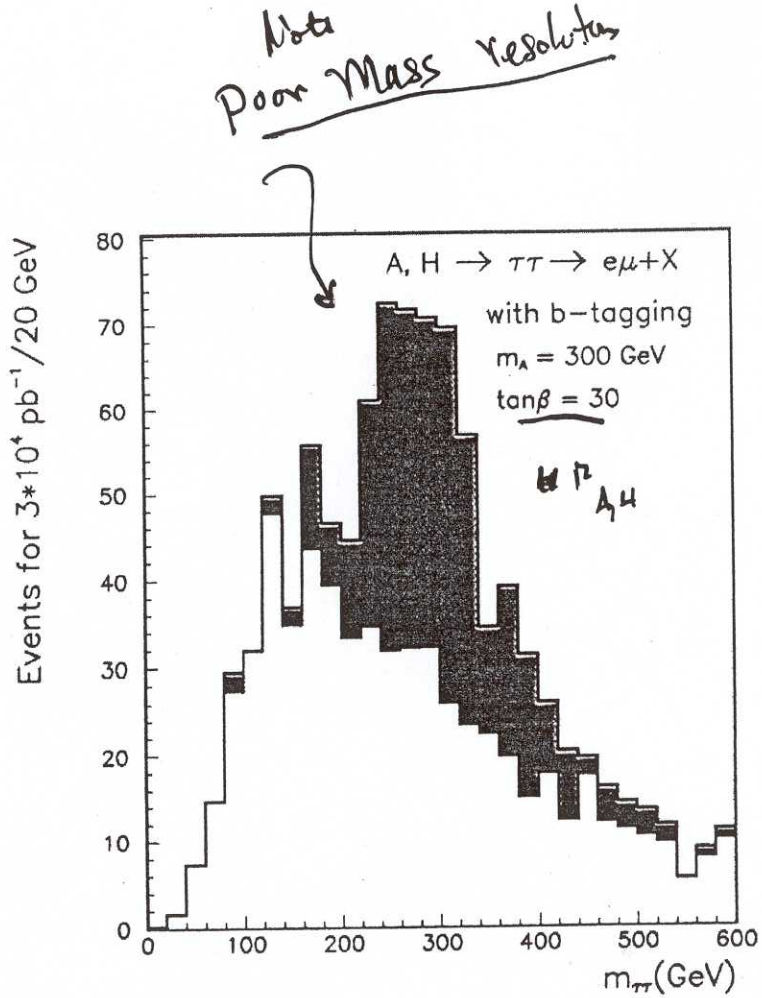
A MUON COLLIDER AS A HIGGS FACTORY

Muon Collaboration

- A beam energy spread as small as ~ 10^{-5} may be possible, allowing a measurement of m_{H} to a few hundred keV and a direct measurement of the width to about 1 MeV

- The *CP* properties of the Higgs bosons can be measured through asymmetries with transversely polarized μ^{+} and μ^{-} beams.

- A Higgs factory muon collider is also a step towards a high energy (3–4 TeV) muon collider.



LHC

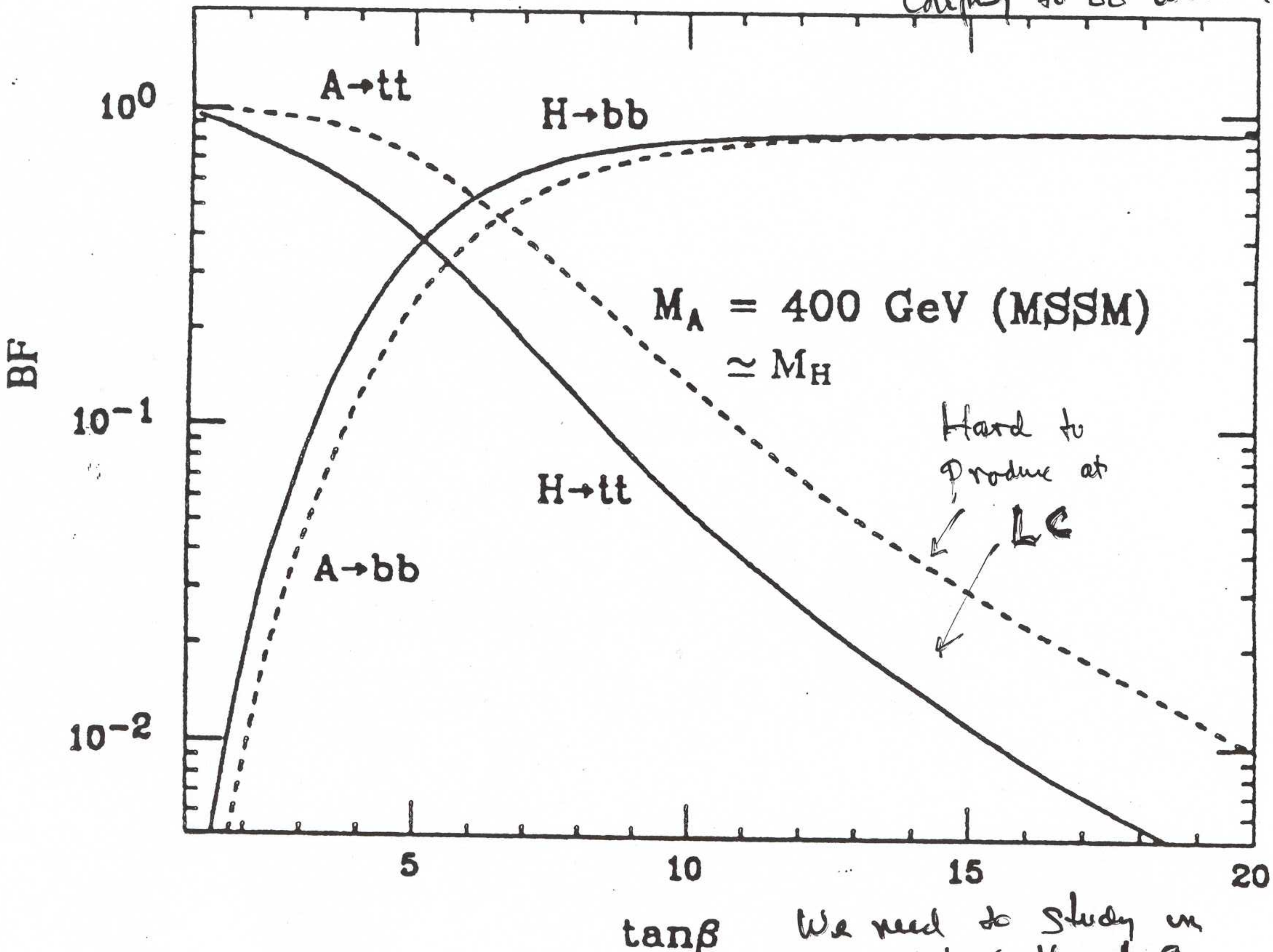
Searches for A, H

A, H → $\tau\bar{\tau}$

tan β = 30

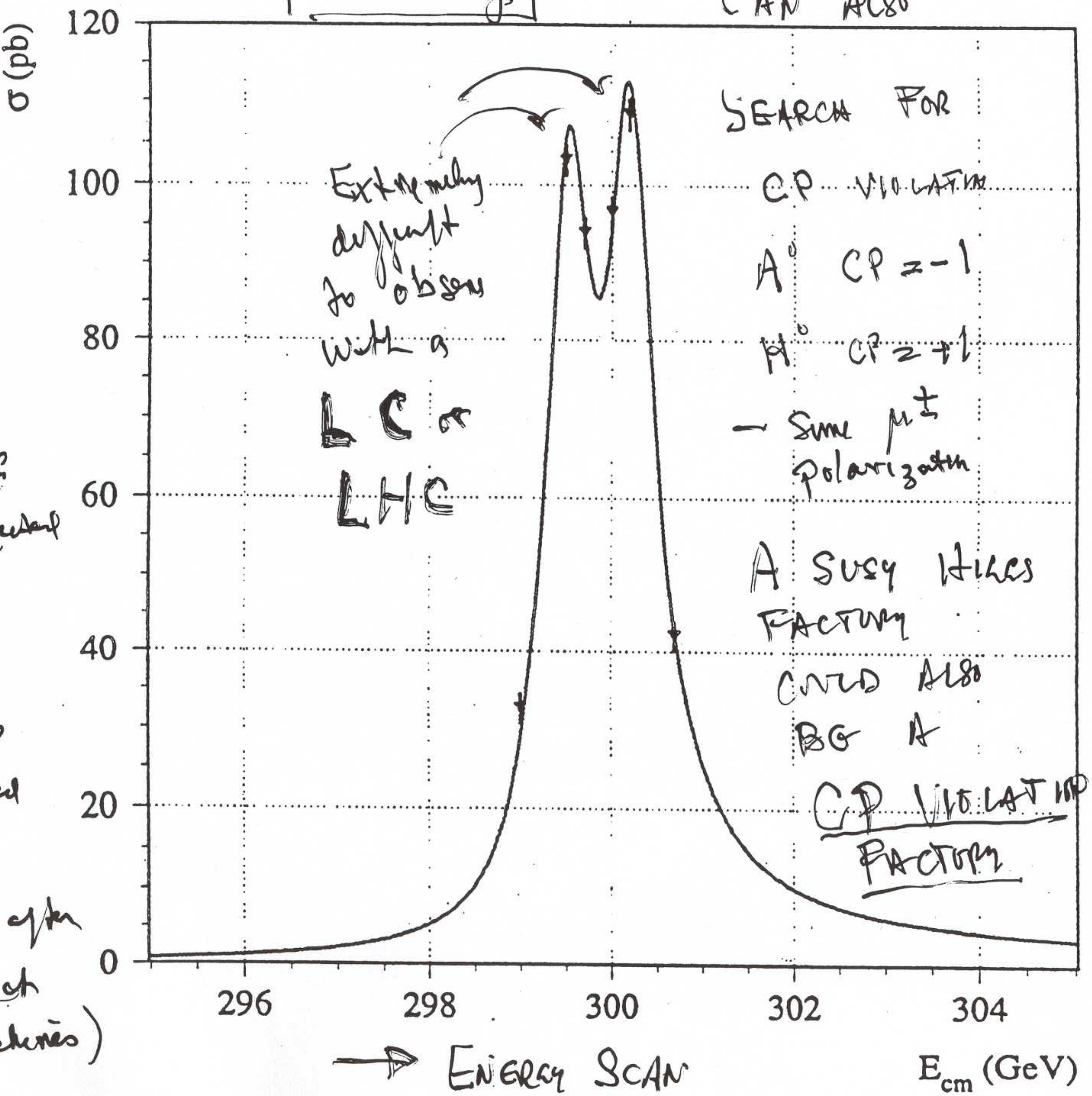
Figure 18: The reconstructed mass of $A/H \rightarrow \tau\tau \rightarrow e\mu + X$ over the background with 30 fb^{-1}in CMS[25].

At High $\tan\beta$
Coupling to $t\bar{t}$ weak → Hard for NLC to Study



We need to study in more detail the LC Ability to Study H, A

Summary



Extremely difficult to observe with a LC or LHC

CAN ALSO SEARCH FOR CP VIOLATION

A^0 CP = −1

H^0 CP = +1

— Same $\mu^\pm$ polarization

A SUSY HIGGS FACTORY COULD ALSO BE A CP VIOLATION FACTORY

Even if LC is constructed this key Physics will Remain to be studied (i.e. like B Factories after B studied at Hadron Machines)

Note Widths ~ few GeV Not 5 MeV as for light Higgs

Very difficult to do at LC

LHC-B BABR etc

→ ENERGY SCAN

SUSY - HIGGS FACTORY

MUON COLLIDER

— WORK TOWARDS A SIMPLE DESIGN —

CERN yellow Book

CoM energy (TeV)	0.4 ←
P energy (GeV)	16
P/bunch	2.5×10^{13}
Bunches/fill	4
Rep. Rate (Hz)	15
$1/\tau_\mu$ (Hz)	240
P power (MW)	4
μ/bunch	2×10^{12}
μ power (MW)	4
Wall power (MW)	120
Collider circum. (m)	1000
$<B>$ (T)	4.7
$\delta p/p$ (%)	0.14 ←
6-D $\varepsilon_{6,N}$ $(\pi m)^3$	1.7×10^{-10}
Rms ε_n (π mm-mrad)	50
β^* (cm)	2.6
σ_z (cm)	2.6
σ_r spot (μm)	26
σ_θ IP (mrad)	1.0
Tune shift	0.044
$n_{turns}^{effective}$	700
Luminosity ($cm^{-2}s^{-1}$)	10^{33}
Higgs/year	

MUCH EASIER SET OF PARAMETERS THAN h^0 Higgs Factory

Propose to 'give up' Low Mass h^0 Factory & Study SHF.

LOW-COST MUON COLLIDER

fact ν π μ Muon Collaboration

- Ring Cooler
  - Palmer Ring Cooler
  - Balbekov Ring Cooler
  - Garren Ring Cooler
  - UCLA Ring Cooler
  - FFAG - T. Yokoi
- Buncher - D. Neuffer
- Lithium Lens - D. Neuffer
- Magnet Design
  - F. Mills, M. Green
- Injection/Extraction - D. Summers
- Simulations
  - H. Kirk, Y. Fukui, S. Kahn, D. Errede, K. Makino, R. Godang

Important to find a possible lower cost solution after SNOWMASS 02 & HEPAP Sub Panel REPORT

Muon Collaboration

Cost Savings in Muon Acceleration

J. Scott Berg
Brookhaven National Laboratory
7 March 2002

CONCLUSIONS

A muon storage ring configured for ionization cooling is an attractive option due to the possibility of 6-D cooling and economy from multiple passes through absorbers and RF acceleration cavities.

The transverse cooling mechanism is the ionization slowing of particles in absorbers coupled with RF acceleration.
The longitudinal cooling mechanism involves use of wedge-shaped absorbers in dispersed regions of the lattice.

Muon cooling is counteracted by heating due to multiple coulomb scattering and energy straggling in the absorbers. The straggling unfortunately causes emittance growth in absorbers in dispersed regions.

The effect of scattering is minimized by placing the absorbers at low-beta points of the lattice. But these low beta points tend to reduce the dynamic aperture of the lattice, which leads to particle losses.

These often-contradictory requirements make for a considerable design challenge.