NEW ACCELERATOR DEVELOPMENTS

A Discussion Not a Survey

How do be get beyond LHC energies?

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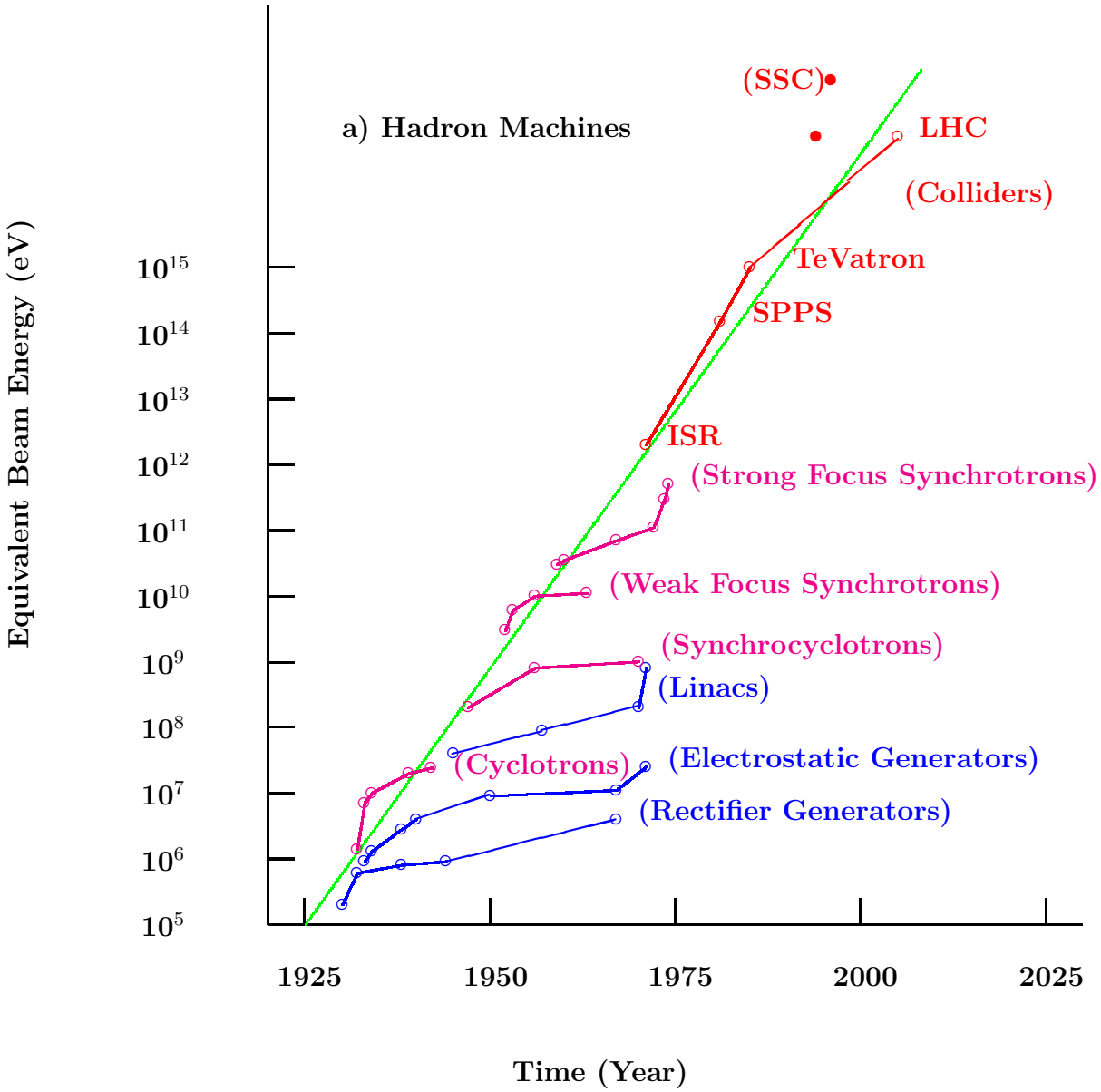
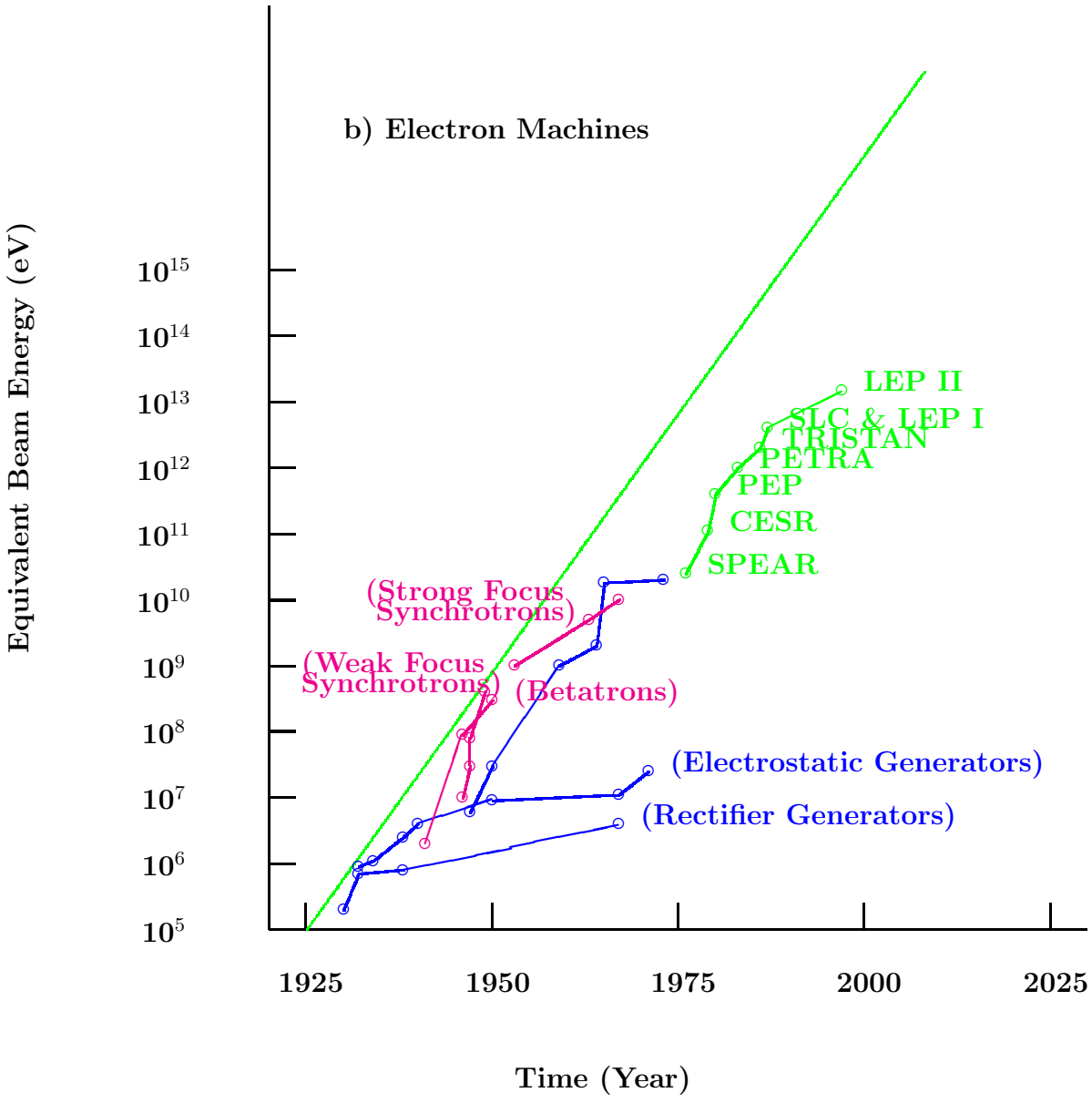
http://pubweb.bnl.gov/people/palmer/talk/columbus.ps

LIVINGSTON PLOTS



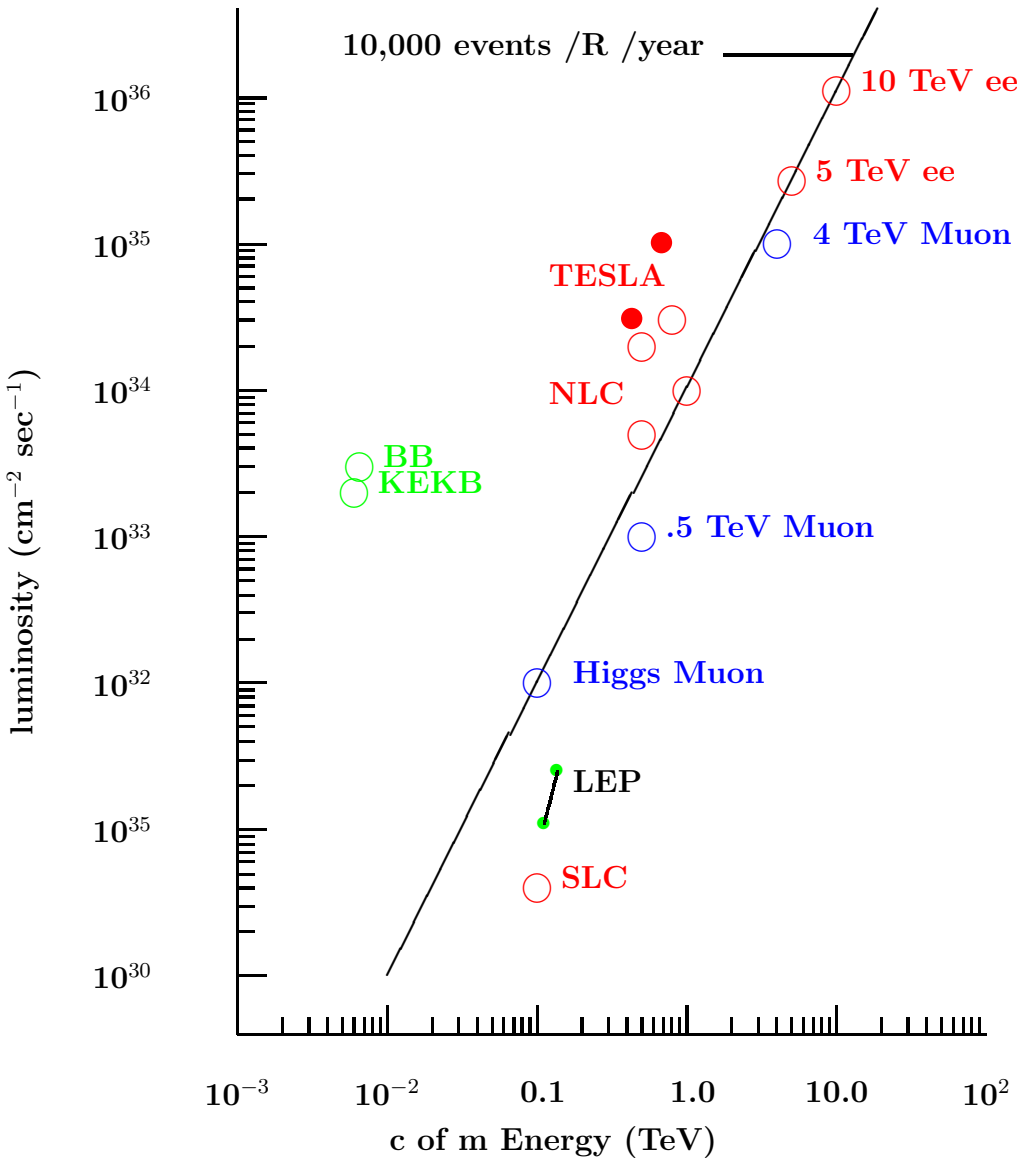

b) Electron Machines
Equivalent Beam Energy (eV)
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
1925
1950
1975
2000
2025
Time (Year)
LEP II
SLC & LEP I
TRISTAN
PETRA
PEP
CESR
SPEAR
(Strong Focus Synchrotrons)
(Weak Focus Synchrotrons)
(Betatrons)
(Electrostatic Generators)
(Rectifier Generators)

$e^+ e^-$ COLLIDERS

- **E advantage over protons (5-10)**
- **Known initial state**
- **Low backgrounds & radiation**
- **Complements protons**
- **Must be linear for E > .2 TeV**

- **1.3 GHz Superconducting**
  - **TESLA (DESI, Germany)**
- **11 GHz Copper**
  - **NLC (SLAC, USA)**
  - **JLC (KEK, Japan)**
- **30 GHz Copper**
  - **CLIC (CERN, Swizerland)**
- **90 MHz**
  - **Matrix (SLAC, USA)**
- **Laser, Wake, Plasma**
  - **Many**

LUMINOSITY


10,000 events /R /year
10 TeV ee
5 TeV ee
4 TeV Muon
TESLA
NLC
BB
KEKB
.5 TeV Muon
Higgs Muon
LEP
SLC
10^{36}
10^{35}
10^{34}
10^{33}
10^{32}
10^{35}
10^{30}
luminosity (cm^{-2} sec^{-1})
10^{-3}
10^{-2}
0.1
1.0
10.0
10^{2}
c of m Energy (TeV)

WHY IS LUMINOSITY HARD ?

$$L = \frac{N^2 \ f \ n_c}{4 \ \pi \ \sigma_x \ \sigma_y}$$

$$L \propto \frac{P_{ave}}{\gamma} \ n_c \ \frac{N}{\sigma_x \ \sigma_y}$$

For electons, accelertion must be linear: $n_c = 1$

At energies $\geq$ about 2 TeV:

Radiation problems in Final Focus and Intersection.

1. **Radiation in focus**
   set limit (Oide) on σ_y:

$$\sigma_y \quad \geq \quad const \quad \epsilon_n^{5/7}$$

independent of energy. This minimum requires:

$$\beta_{focus} \quad = const \quad \epsilon_n^{3/7}$$

$\rightarrow$ **Need small ϵ_n**

Use Adiabatic focussing to remove Oide Limit

But we do not have a practical way of doing this.

2. Radiation at intersection function of Field B from oncomming bunch:

$$B \quad \propto \quad \frac{N}{\sigma_z \ \sigma_x}$$

Radiation genrates energy spread and backgrounds.

$\rightarrow$ **Need small N/σ_x**

Use 4 beams colliding to Cancel Field from oncoming bunch

But instabilities and jitter limit the possible gain

Luminosity :

$$L \quad \propto \quad \frac{P_{ave}}{\gamma} \quad \left(\frac{N}{\sigma_x}\right) \quad \left(\frac{1}{\epsilon_n^{5/7}}\right)$$

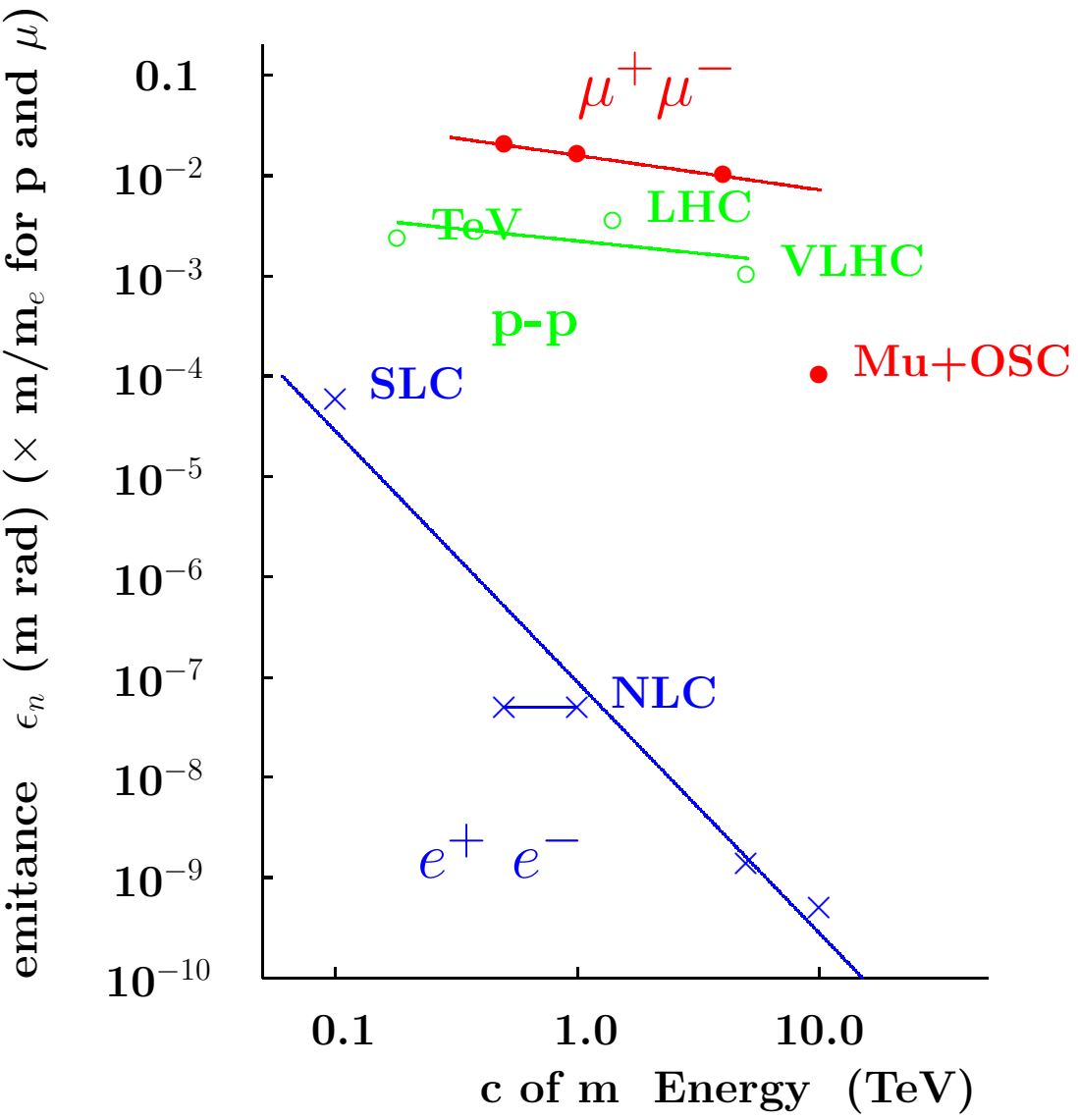
N/σ_x is limited by radiation considerations, and we need

$$L \quad \propto \gamma^2$$

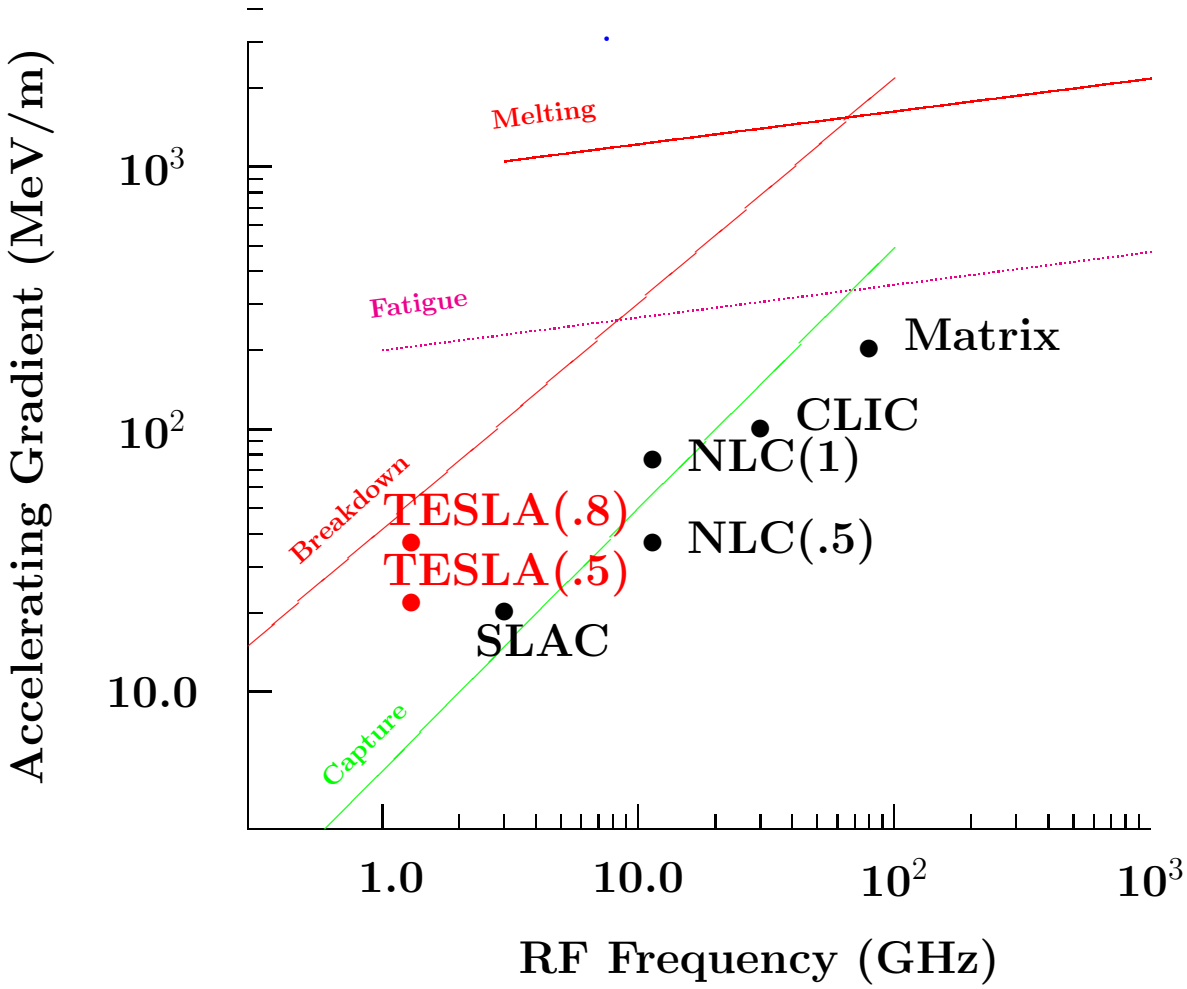
So we Need:

- **High Beam Power**
- **Low normalized emittance**

EXAMPLE:


emitance ϵ_n (m rad) ($\times$ m/m$_e$ for p and μ)
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
$\mu^+\mu^-$
LHC
TeV
VLHC
p-p
Mu+OSC
SLC
NLC
e^+ e^-
0.1
1.0
10.0
c of m Energy (TeV)

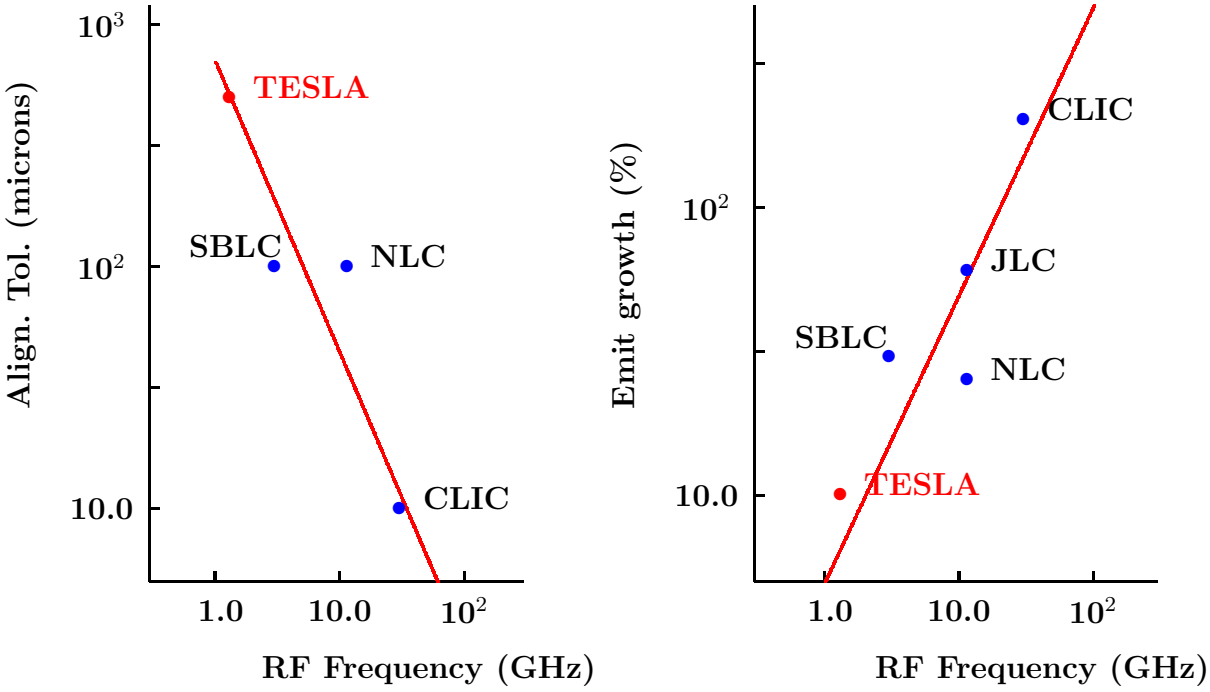
SIZE AND COST



Higher Frequencies favoured for size

But

Alignment and emittance growth:



High Freq not favored for Lum.

Note: with SC cavities (TESLA)

- Easier tollerances
- Low emittance growth
- good power to beam efficiency
  $\approx$ 13 % (cf $\approx$ 7 % for NLC)
- better Luminosity
  3 $\times$ at 0.8 TeV with L upgrade
  ($\times$ 10 without)
- Gradient not so much lower
  0.6 $\times$

	E TeV	Lum 10^{34}	grad MV/m
TESLA	.5	3	22
TESLA	.8	10	35
NLC	.5	.5 $\rightarrow$ 2	37
NLC	1 $\rightarrow$ .8	1 $\rightarrow$ 3	59

Note:

Both have gradients for .5 TeV in full structures.

Both have gradients for 0.8 TeV in short structures.

Neither have gradients for .8 TeV in full structures.

Laser and Plazma Acc's even higher gradients

Record Holders:

		I W/cm^2	λ μm	ΔE MeV	E_z GV/m
Laser Wake	LULI(France)	4×10^{17}	1.05	1.6	1.5
Plasma Beat Wave	UCLA (USA)	10^{14}	10	28	2.8
Self Modulated LW	RAL (UK)	10^{19}	1.05	44	100

c.f. conventional

	E_z GV/m
SLC	0.02
NLC	0.37
Matrix	0.2

However, Laser and Plazma Acceleration have even worse problems for luminosity

But they are being studied, as they must be. In particular, the SLC plasma "afterburner" study is very important: what luminosity will they get?

e.g. Burt's Problem

Transverse jitter due to Klystron power fluctuations

Require

$$\Delta_{p_t} \quad < \quad \sigma_{p_t} \quad = \quad \frac{m_e \quad \epsilon_n}{\sigma_{x,y}}$$

Compare with total acceleration:

$$\Delta_{p_z} \quad \approx \quad \frac{E_{c \ of \ m}}{2}$$

For: $\sigma_{x,y} = 1 \ \mu\mathbf{m}$, $\epsilon_n = 1 \ 10^{-9}$ **m,** **E=**$2 \ 10^{12}$ **eV,** $\mathbf{m}_e = .5 \ 10^6$ **eV:**

$$\frac{\Delta_{p_t}}{\Delta_{p_z}} \quad \approx \quad 5 \ 10^{-10}$$

In a circular symmetric copper structure, transverse kicks come only from "bookshelf" errors

(in non circular structures there are intrinsic transverse kicks)

If

- **Bookshelf angle** $< \ 10^{-5} \ (.1 \ \mu\text{m/cm})$
- **Klystron fluctuations**$< \ 10^{-3}$
- **Nunber of klystons = 4000**

Then

$$\frac{\Delta_{p_t}}{\Delta_{p_z}} \approx \frac{10^{-5} \ 10^{-3}}{\sqrt{4000}} \approx 2 \, 10^{-10}$$

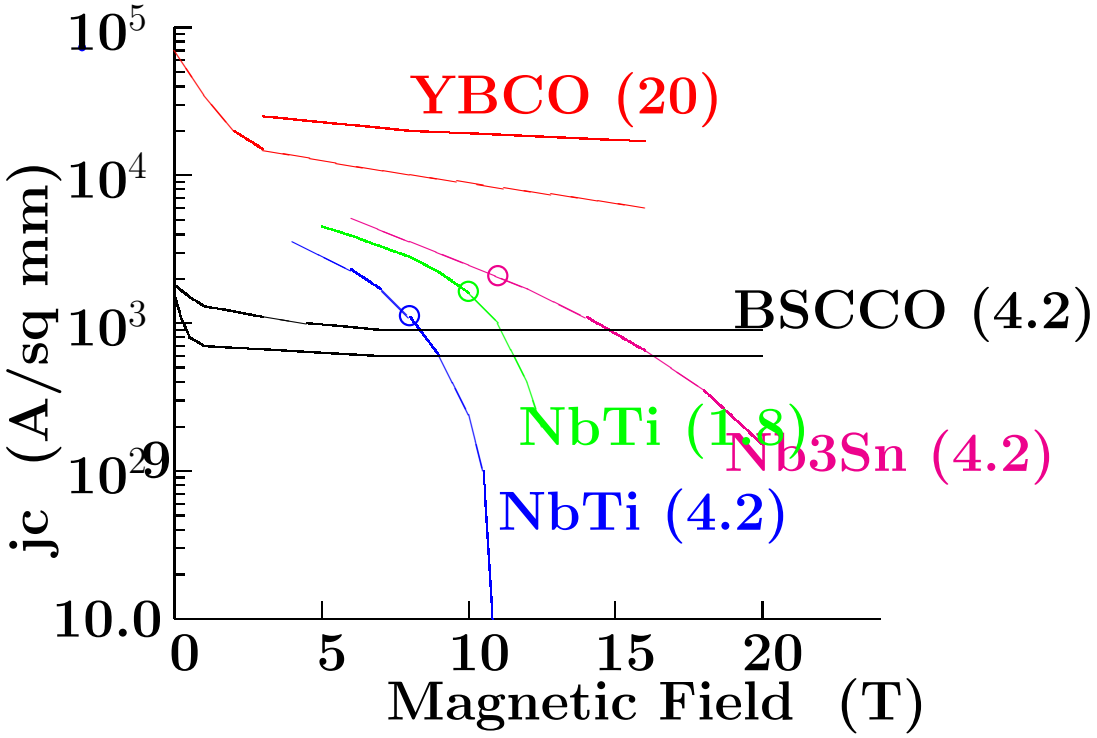
Which is just ok (c.f.req. $< \ 5 \, 10^{-10}$**)**

But for smaller, non circular, 2 beam, plasma or other exotic acceleration, it is less clear that the requirement can be met.

HADRON COLLIDERS

- **High Field (B > 10 T)**
  - **LBNL (USA)**
  - **BNL (USA)**
- **Low Field (B ≈ 2 T)**
  - **Fermi (USA)**
- **Moderate Field (2<B<10 T)**
  - **?????**

Will High Field, HiTc, reduce costs?



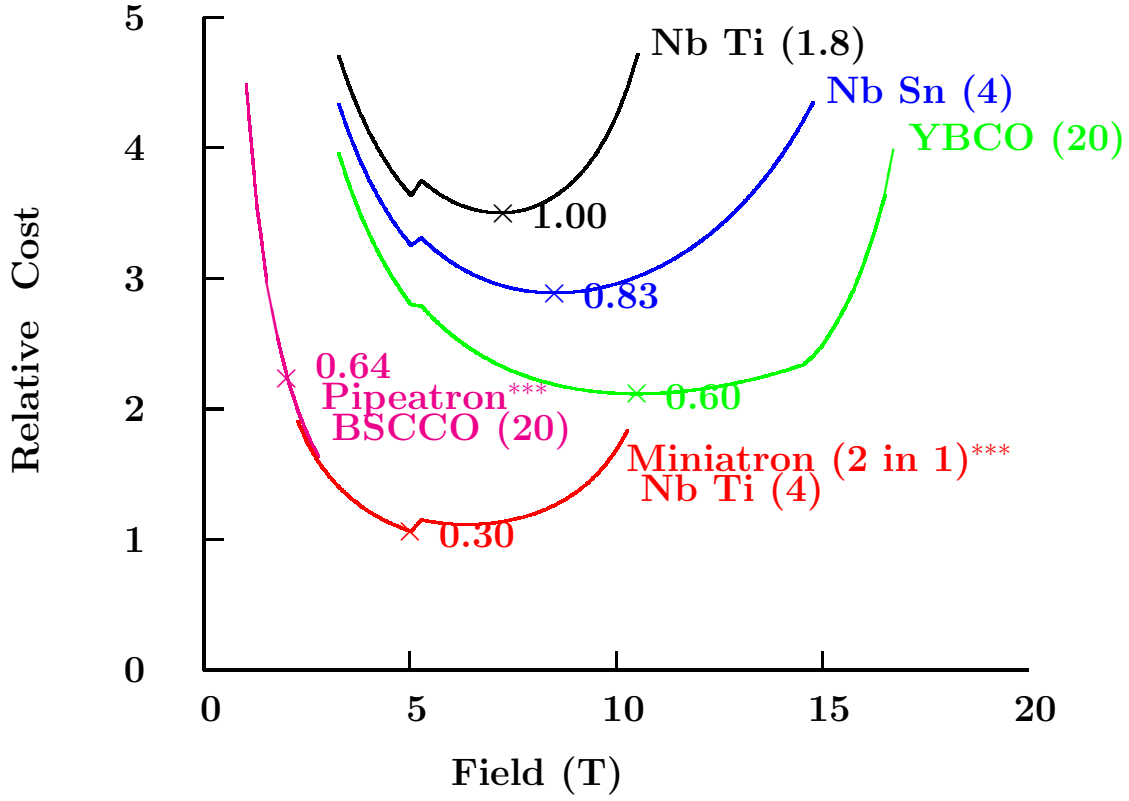
But YBCO not yet available

Parametric Study of Costs

- Assume required aperture $\propto$ circ$^{-1/3}$
- Design "2-in-1" and "pipeatron" magnets using approximate formulae
- Calc weights of materials etc.
- Scale unit costs from SSC

Relative Costs vs. Fields

WARNING: For Illustration Only



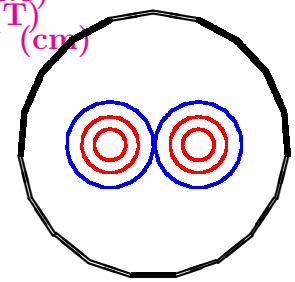
for "Pipeatron" and "Miniatron"

- **Linear costs can be reduced**
  - improved tunneling methods
  - very long combined fucntion magnets
- **Impedance contrains** ($\propto r^3/B$) $\approx 1/30$
  - More sophisticated Feedbacks
  - Smooth tube

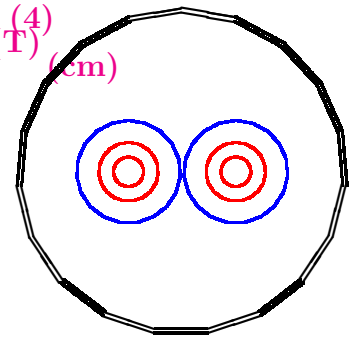
At Cost Minimums

With SSC costs and LHC Impedance constraints

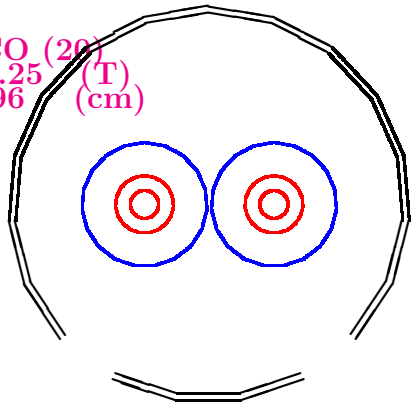
Nb Ti (1.8)
B 7.5 (T)
ap 5.55 (cm)

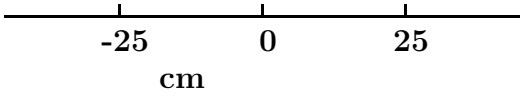


Nb Sn (4)
B 9 (T)
ap 5.27 (cm)



YBCO (20)
B 11.25 (T)
ap 4.96 (cm)





Linear $'s/3 & Impedance constraint/30

Pipeatron
B 2 (T)
ap 1.79 (cm)

Miniatron
B 5.25 (T)
ap 1.26 (cm)

Miniatron with same assumptions, has less SC and Fe, and uses a smaller tunnel than Pipeatron

200 km tunnel gives 65 TeV (5 × LHC)

Problems could be field tollerances

Needs Study

MUON COLLIDERS

- **BNL (USA)**
- **Cornell (USA)**
- **Fermi (USA)**
- **LBNL (USA)**

- **CERN (Switzerland)**
- **RAL (UK)**

- **KEK (Japan)**

- **BINP (Russia)**

- **+ many others**

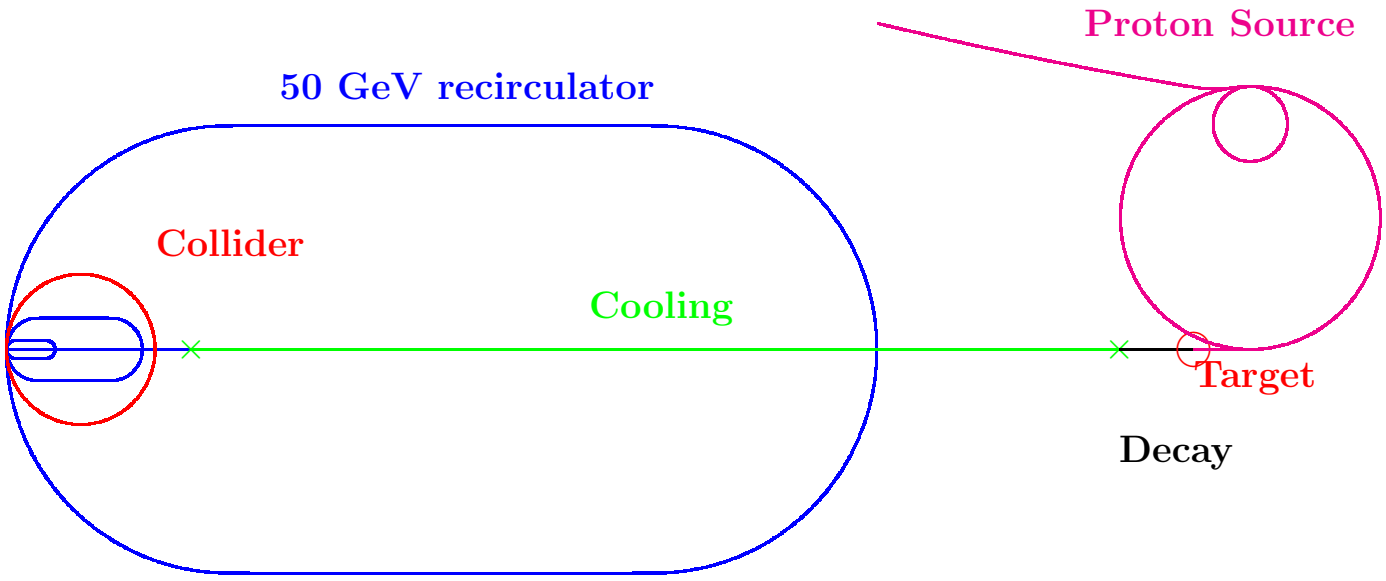
WHY

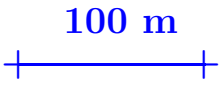
- **Energy advantage over p's (as for e's)**
- **Suppressed Synchrotron Radiation ($\propto \gamma^4 \propto m^{-4}$)**
  - **Circular**
    - **smaller**
    - **$\approx$ 1000 turns**
  - **no "beamstrahlung"**
    - **dE/E $\rightarrow$ 0.003 %**
    - **allows larger N**
  - **larger spot size & emittance**
    - **easier tollerances**
- **Direct Higgs Production**
  - $\mu^+ \mu^- \rightarrow h, A, H$ ($\sigma \propto m^2$)
- **ν_e & ν_μ Neutrino Beams**
  - **as bi-product, and/or**
  - **as phase 1**

But: μ's in diffuce phase space and μ's Decay

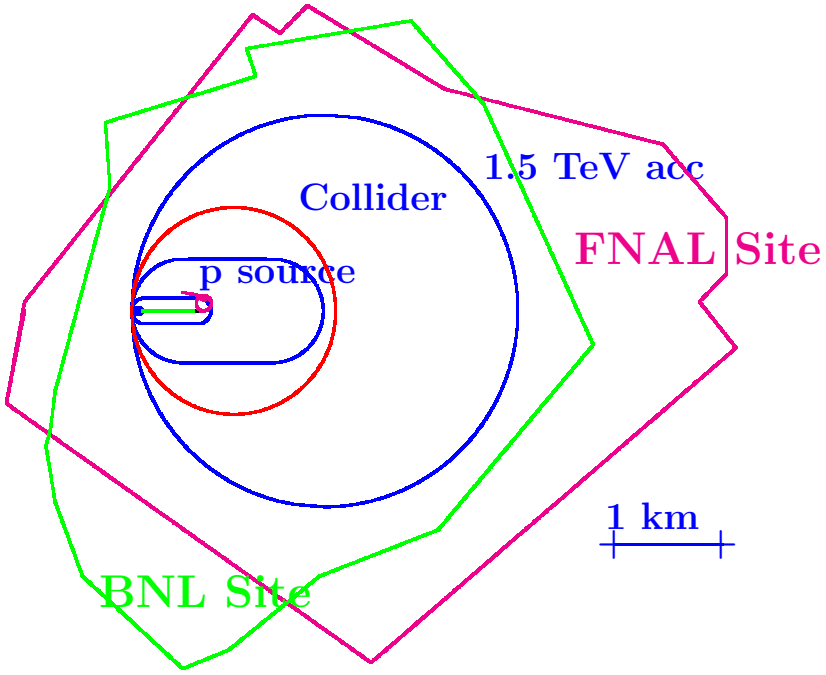
- **Efficient μ Production**
  - **20 T Solenoid to capture π's**
  - **RF Phase Rotation to reduce dE/E**
- **Rapid Cooling**
  - **ionization cooling certain**
  - **study optical and other exotics**
- **Rapid Acceleration Required**
  - **Recirculating Acceleration**
- **Beam Pipe Heating**
  - **3-6 cm Tungsten Shields**
- **Detector Background**
  - **Loss of Forward Cone**
- **Neutrino Radiation**
  - **Limits Energy to 3-10 TeV**

100 GeV HIGGS FACTORY



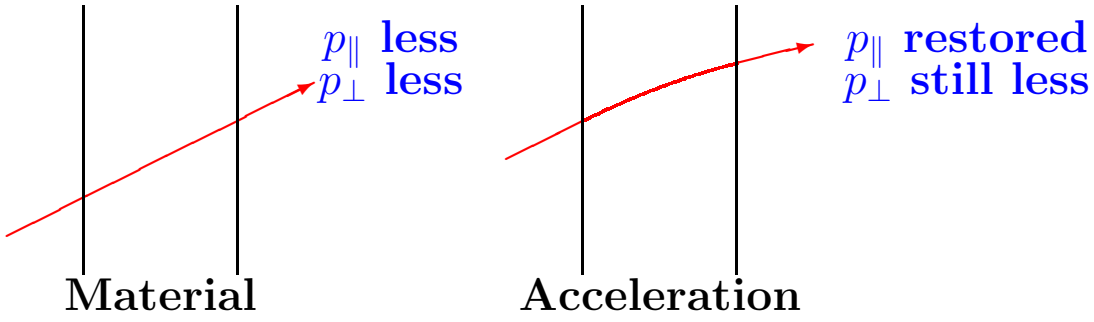


3 TeV COLLIDER

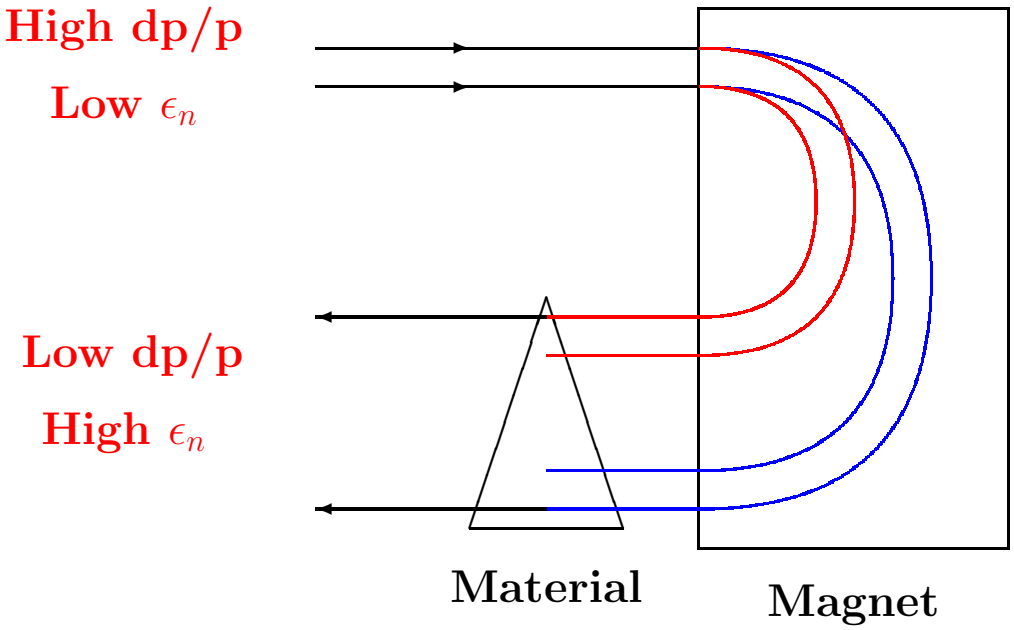


IONIZATION COOLING

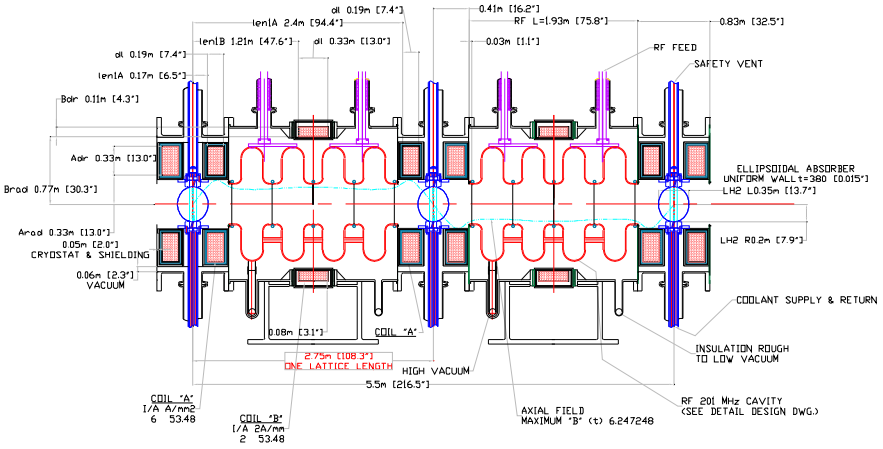
- **TRANSVERSE**



- **dE/E Red by EMIT EXCHANGE**



Cell of Transverse Cooling



SFOFOSTART201MHZrev1

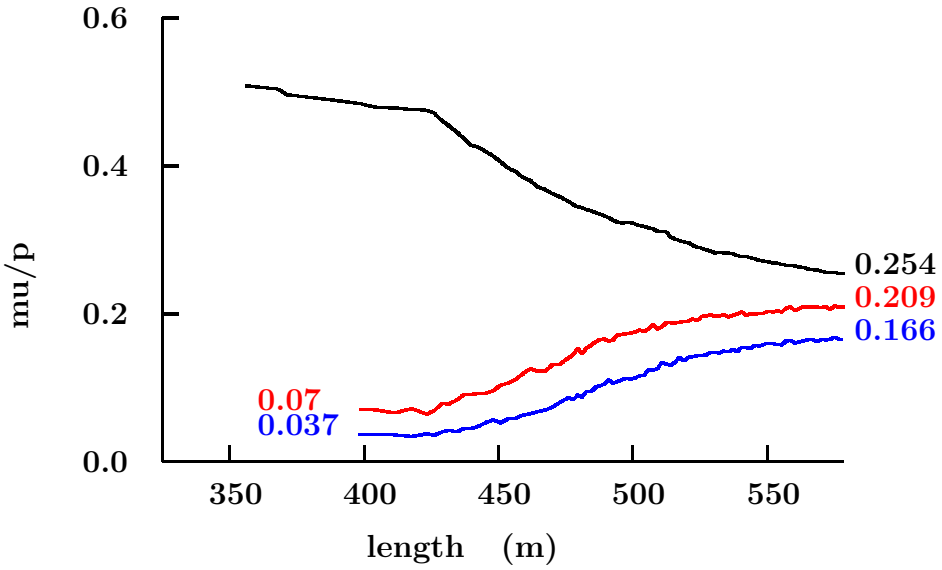
Super FOFO LATTICE
at start of cooling
(PRELIMINAR)

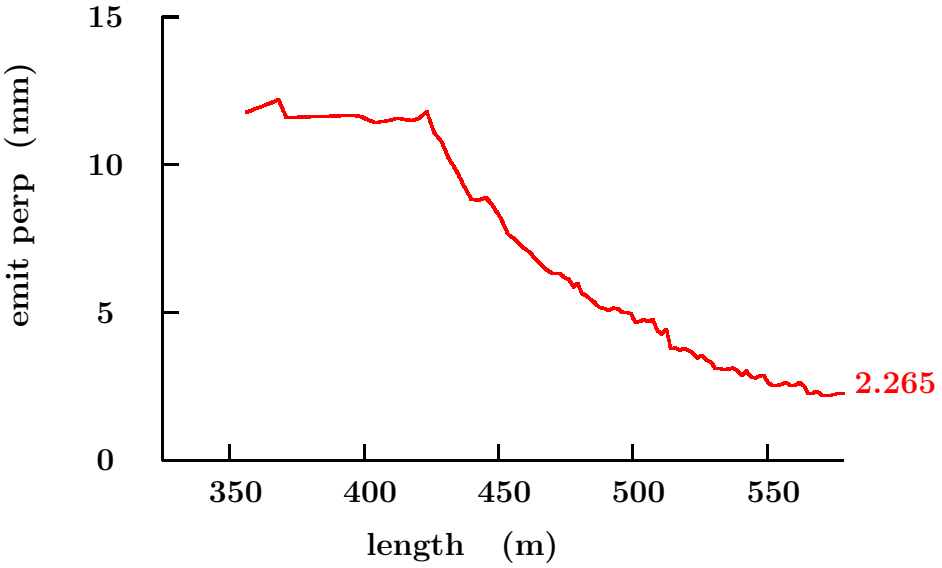
E.L.Black IIT
6/22/2000
6/28/2000 REV. 1

ICOOL Simulation of Study II Cooling

Preliminary

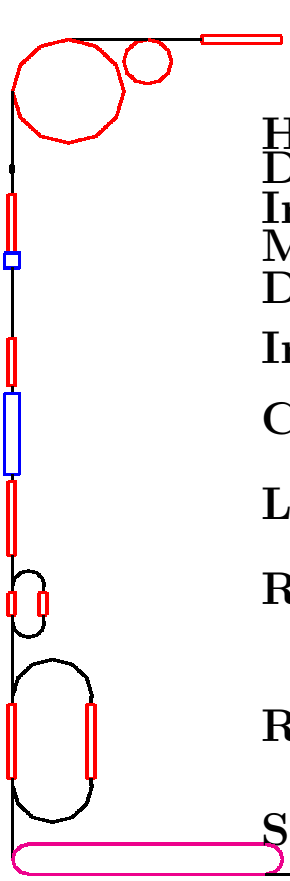
.3 Pzmax GeV/c
0.15 Pzmin in GeV/c
0.0095 first transverse acceptance cutoff (m rad)
0.015 second transverse acceptance cutoff (m rad)
0.150 longitudinal acceptance cutoff (m)





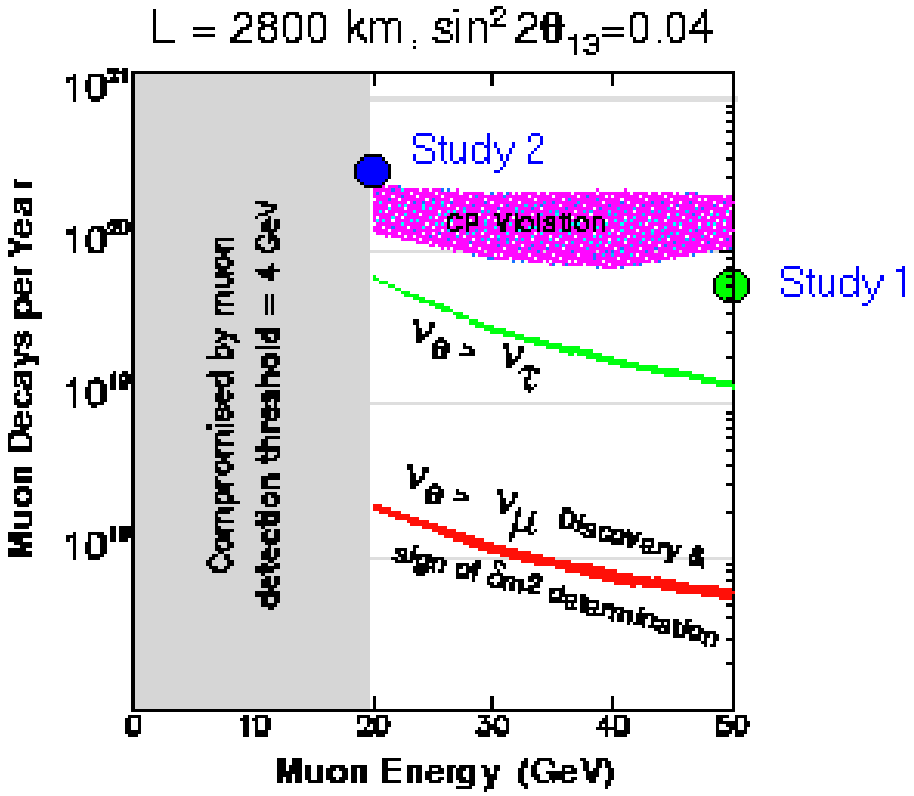
STATUS

- Good theoretical progress
- But
  - no emittance exchange lattice yet
  - Many technical challenges
- Continue theoretical studies of Muon Collider
- Feasibility Studies of "ν Factory"



c: aaprog scheme nupict.td

- **Study I**
  - **sponsored by Fermi**
  - **finished March 00**
  - **50 GeV**
  - **"Entry Level"** ($\approx 6\ 10^{19}\ \mu/2\ 10^{7}$**sec**)
- **Study II**
  - **sponsored by BNL**
  - **finished April 01**
  - **20 GeV**
  - **"Higher Flux"** ($\approx 3\ 10^{20}\ \mu/2\ 10^{7}$**sec**)



muon decays in straight section / $2\ 10^{7}$ **sec**

CONCLUSION

The speaker's views

- e^+ e^-
  - **High Grad + High Lum. is hard**
  - **for** ≤ 500 **GeV SC (TESLA) may be prefered**
  - **for** ≥ 1 **TeV more R&D required**
- p p
  - **Little cost gain with high fields**
  - **Possible large cost gain with small aperture. R&D Required**
- μ^+ μ^-
  - **Needs much R&D**
  - ν **storage ring "feasible" but still needs R&D**