Precision MUON Collider

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Goals. Establish Physics case

⊛ • Higgs boson(s) properties
($\Delta\Gamma \simeq 0.5$ MeV, $\Delta m_H \sim 0.1$ MeV)
what do we learn?

[study underway (Janot)

- can one do the measurement (Murray)
- MC simulations (Perret-Gallix)

⊛ Non standard scenario. (Dominici)
e.g. Strong electroweak sector. P_0
(difficult elsewhere)

⊛ Polarization (Blondel) easy at Z
difficult at Higgs.

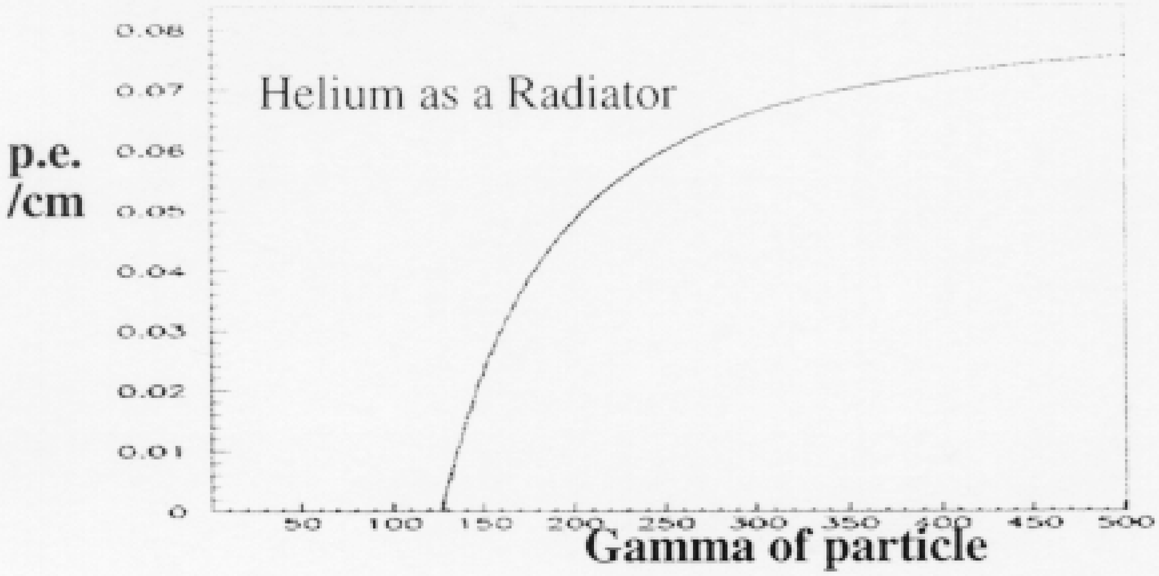
Establish Areas that badly need work

⊛ Backgrounds (I. STUMER)
- low Energy → electrons + photons
- high energy → stray muons + Bethe-Heitler process...

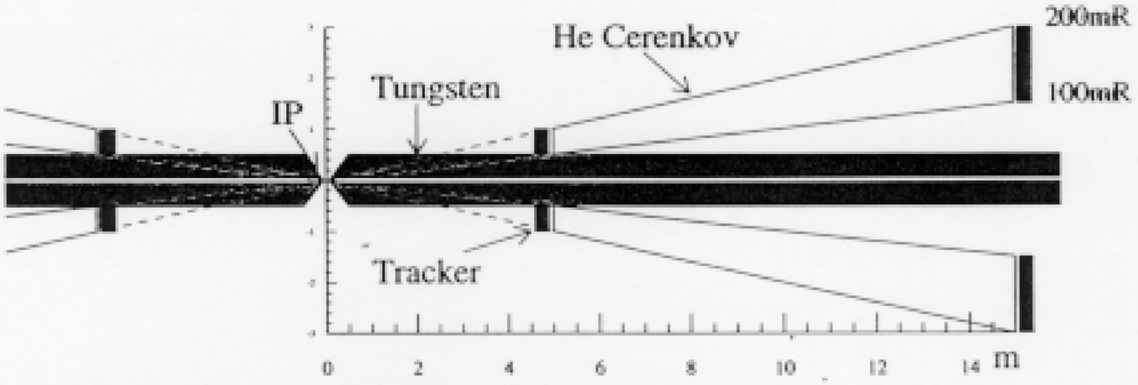
⊛ Luminosity. COOLING (D. TAQQU)
Frictional Cooling.

Bill Murray

Cerenkov muon I.D.



Helium has a Cerenkov threshold at 13GeV for muons but only 7 photo-electrons per metre.
With typical 20% efficiency, 10m of radiator gives 14 p.e.'s



So a 10m long Cerenkov, as above.

ϑ_c is only 9mR, so the cone is 9cm across at end plate. Therefore use 7500 3cm radius phototubes in each Cerenkov. Only muons traversing the volume will leave detectable p.e.'s.
But: multiple scattering in 5m of Tungsten is 13mR. If systematic errors on the inner edge are comparable, 25% error on cross-section!

Direct Calculation

The luminosity is CALCULABLE:

$$L = \frac{n_b f N_{\mu^-} N_{\mu^+}}{4\pi\sigma_x\sigma_y}$$

We need:

- the currents in the muon bunches - Straightforward
- the size of the interaction point. - harder

The proposed interaction point is ~200um in x and y

At LEP, with a 150um interaction region in x, using only hadronic Z^0 decays, we achieve:

$$\delta\sigma_x = \sigma_x/(\sqrt{N})$$

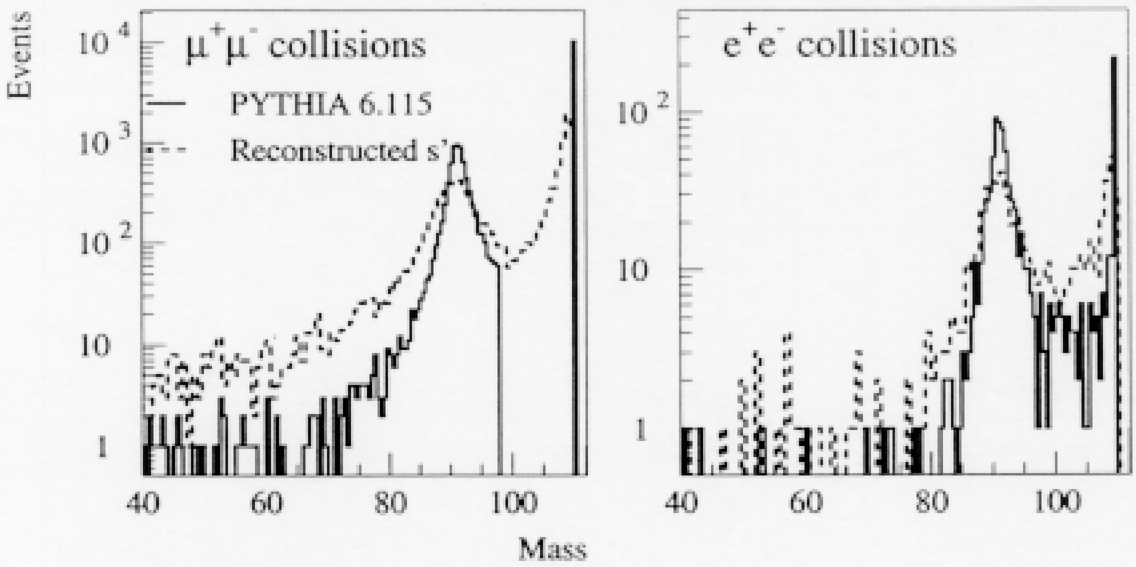
This implies a fractional statistical error of $\sqrt{2/N}$

- At a muon collider, each fill produces ~0 events, so we cannot measure the width, unless a BOM measures the position or the stability is very good.
- Using two-photon events can improve the measurement.

This is assumed to be possible

Radiative Return

Observed s' at 110GeV:



Centre-of-Mass Energy

PYTHIA 6.115 has no structure function for muons, so no ISR.
Use hard processes:

Table 1:

Beams	Process	Cross section, pb
muons	$\gamma\ /Z^0$	370pb
muons	$\gamma+\gamma\ /Z^0$	270pb
electrons	$\gamma\ /Z^0$	1211pb

The reconstructed s' in the above comes from a crude detector simulation (smearing + efficiency) applied to generated events. The s' is calculated from the reconstructed jet angles, or the energy of an isolated photon, if one is found.

We can certainly use radiative events.

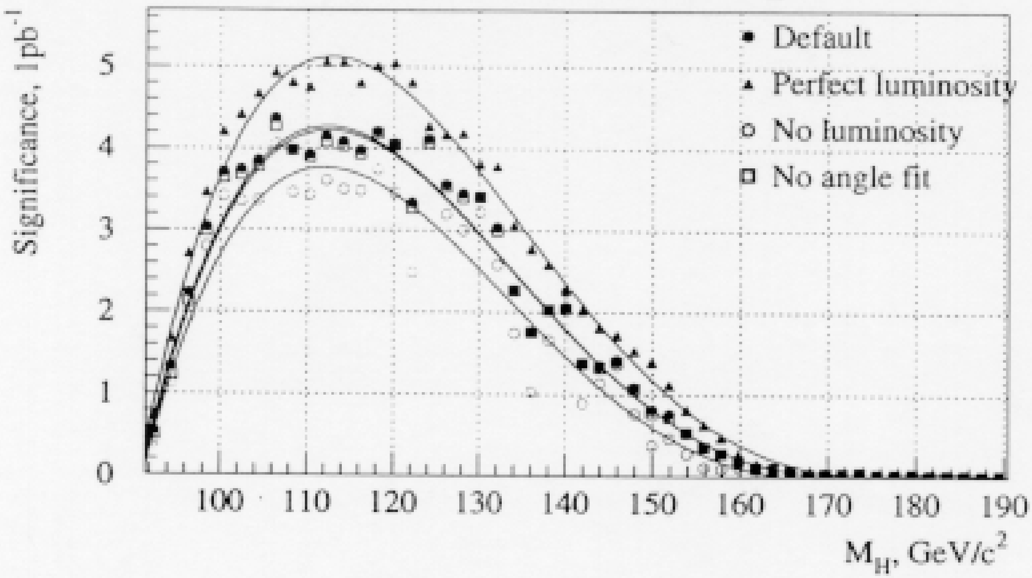
Summary of Luminosity:

1. Forward 'mama' will be difficult at best
2. Barrel 'mama' relatively straightforward
3. Relative measurements might use two-photon processes
4. Direct calculation gives $\sqrt{2/N}$ error - should be possible
5. Radiative return to Z^0 will always be available. Response depends upon energy.

I assume 4. and 5. can be used in what follows.
The effect of perfect luminosity is also shown.

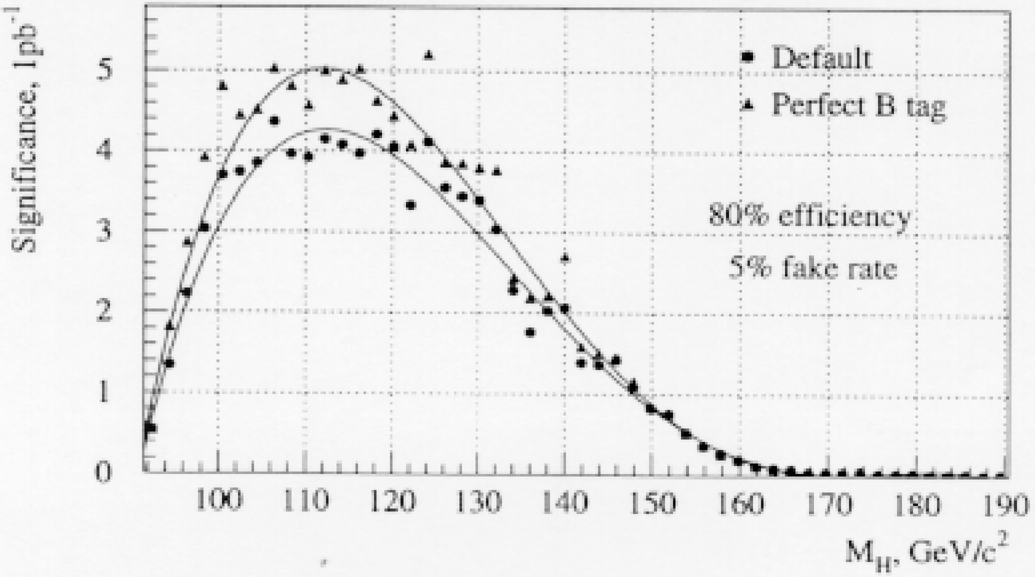
Sensitivity vs Higgs mass

Discovery with 1pb^{-1}



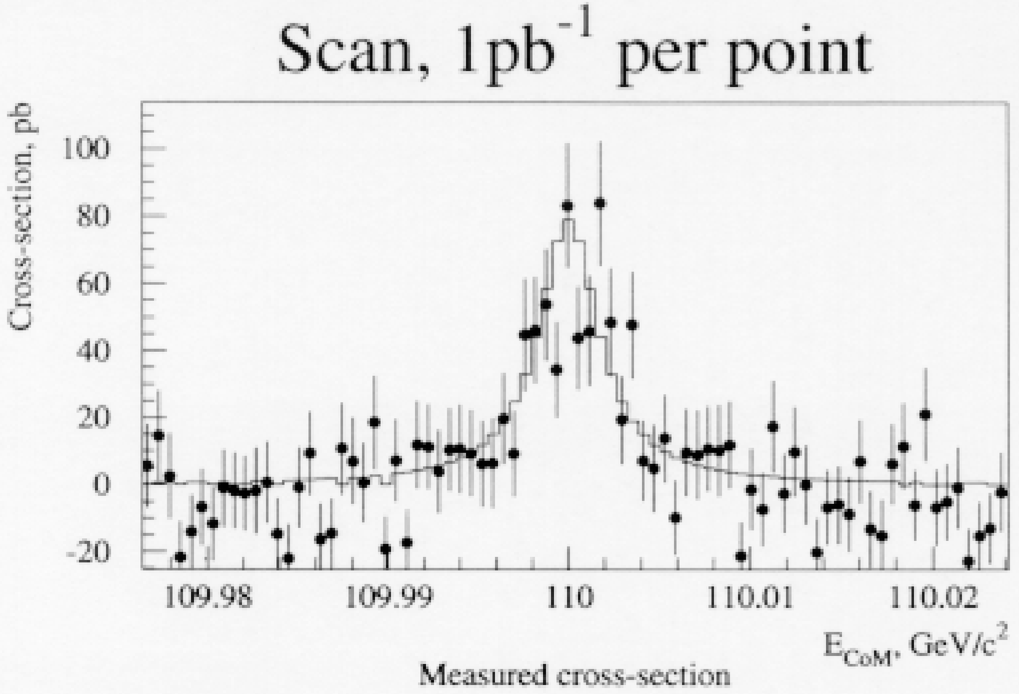
110GeV is BEST POSSIBLE place for this measurement.
Use of vector-boson decays at high mass would help.

Effect of b tag

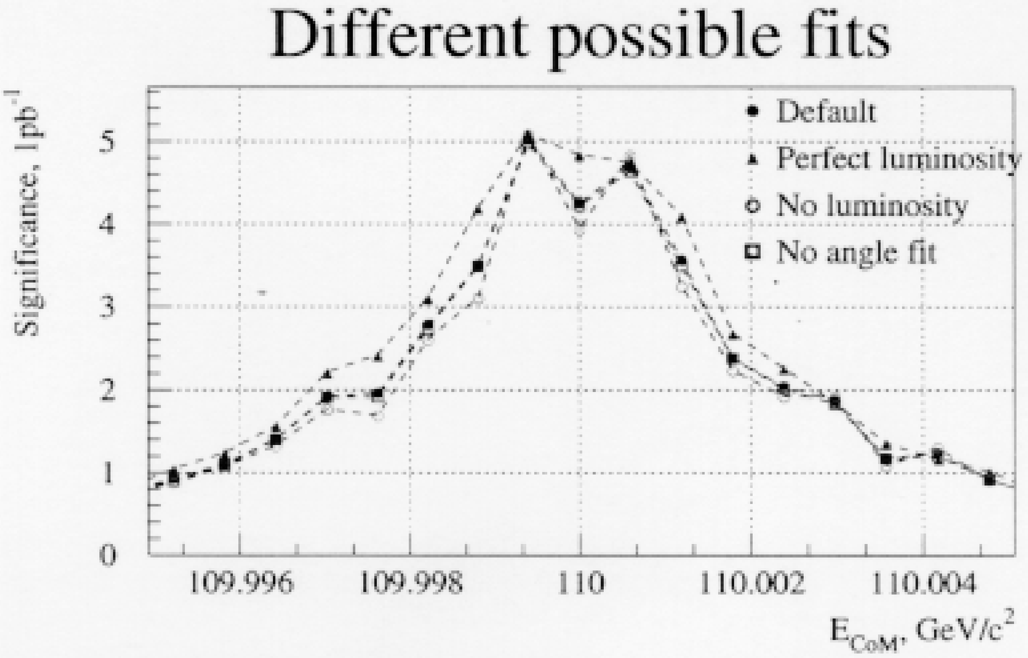


Flavour tagging is as important as luminosity measurement

Scan of Higgs resonance



No beam error uncertainty is allowed for here.



Scanning in 5MeV steps will give one 5 sigma or 2 two-sigma observations - 20 points for 100MeV.

COLLIDER PARAMETERS

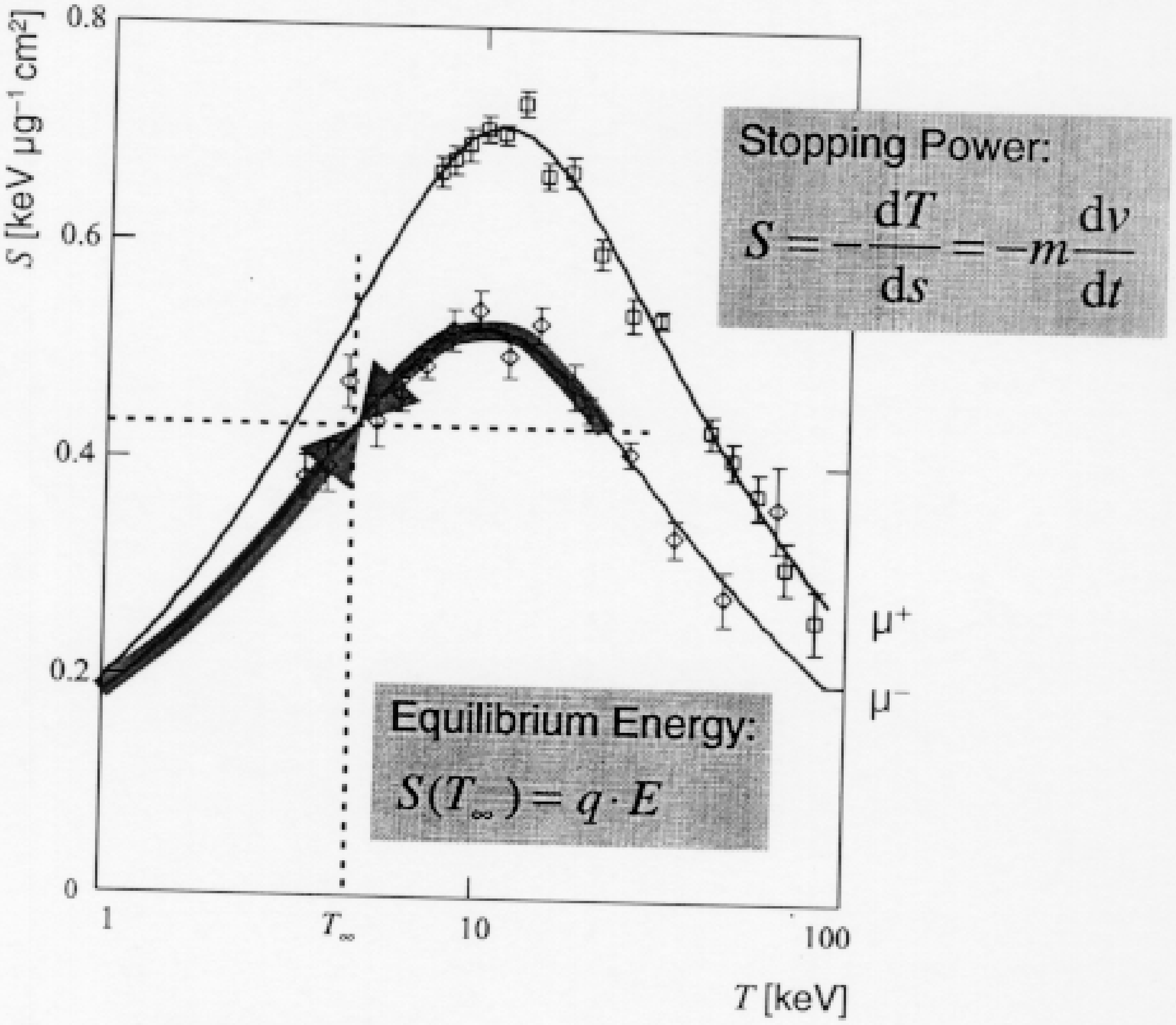
c of m Energy	GeV	3000	400	100		
p Energy	GeV	16	16	16		
p's/bunch	10^{13}	2.5	2.5	5		
bunches/fill		4	4	2		
rep rate	Hz	15	15	15		
p power	MW	4	4	4		
μ/bunch	10^{12}	2	2	4		
μ power	MW	28	4	1		
wall power	MW	204	120	81		
collider circ	m	6000	1000	300		
min depth (ν)	m	300	.7	.01		
rms dp/p	%	.16	.14	.12	.01	.003
rms ϵ_n	π mm mrad	50	50	85	195	280
β^*	cm	0.3	2.3	4	9	13
σ_z	cm	0.3	2.3	4	9	13
σ_r spot	μm	3.2	24	82	187	270
tune shift		0.043	0.043	0.05	0.02	.015
luminosity	$cm^{-2} sec^{-1}$	$5\ 10^{34}$	10^{33}	$1.2\ 10^{32}$	$2\ 10^{31}$	10^{31}
c of m dE/E	10^{-5}	80	80	80	7	2
Higgs/year	$10^3\ year^{-1}$			1.6	4	4

TAQQV

Frictional Cooling:

Basic Principle: I

Stopping power of graphite for μ^+ and μ^-
(P.Wojciechowski et al.)



Stopping Power:

$$S = -\frac{dT}{ds} = -m\frac{dv}{dt}$$

Equilibrium Energy:

$$S(T_\infty) = q \cdot E$$

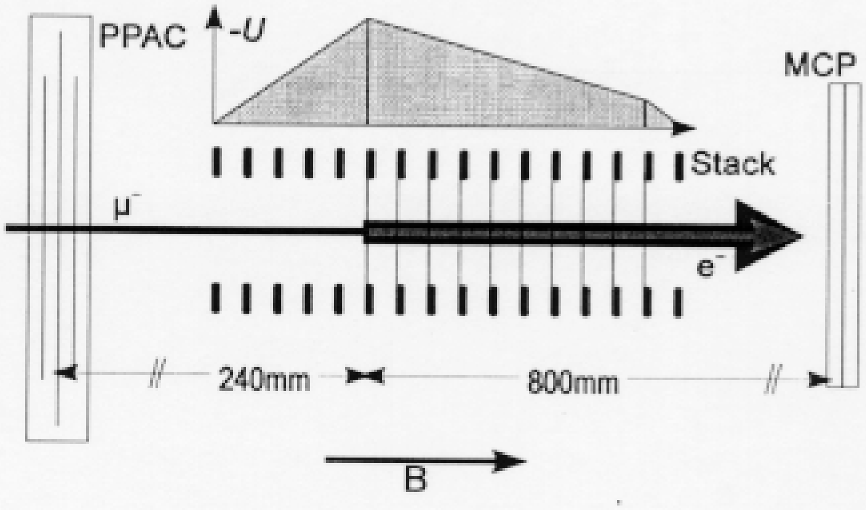
S : stopping power
E : electrostatic field
T : kinetic energy of the muon
T_∞ : kinetic energy at equilibrium
s : path length
t : time
m,q,v : muon mass, charge and velocity

Frictional Cooling:

Setup of the Experiment: II

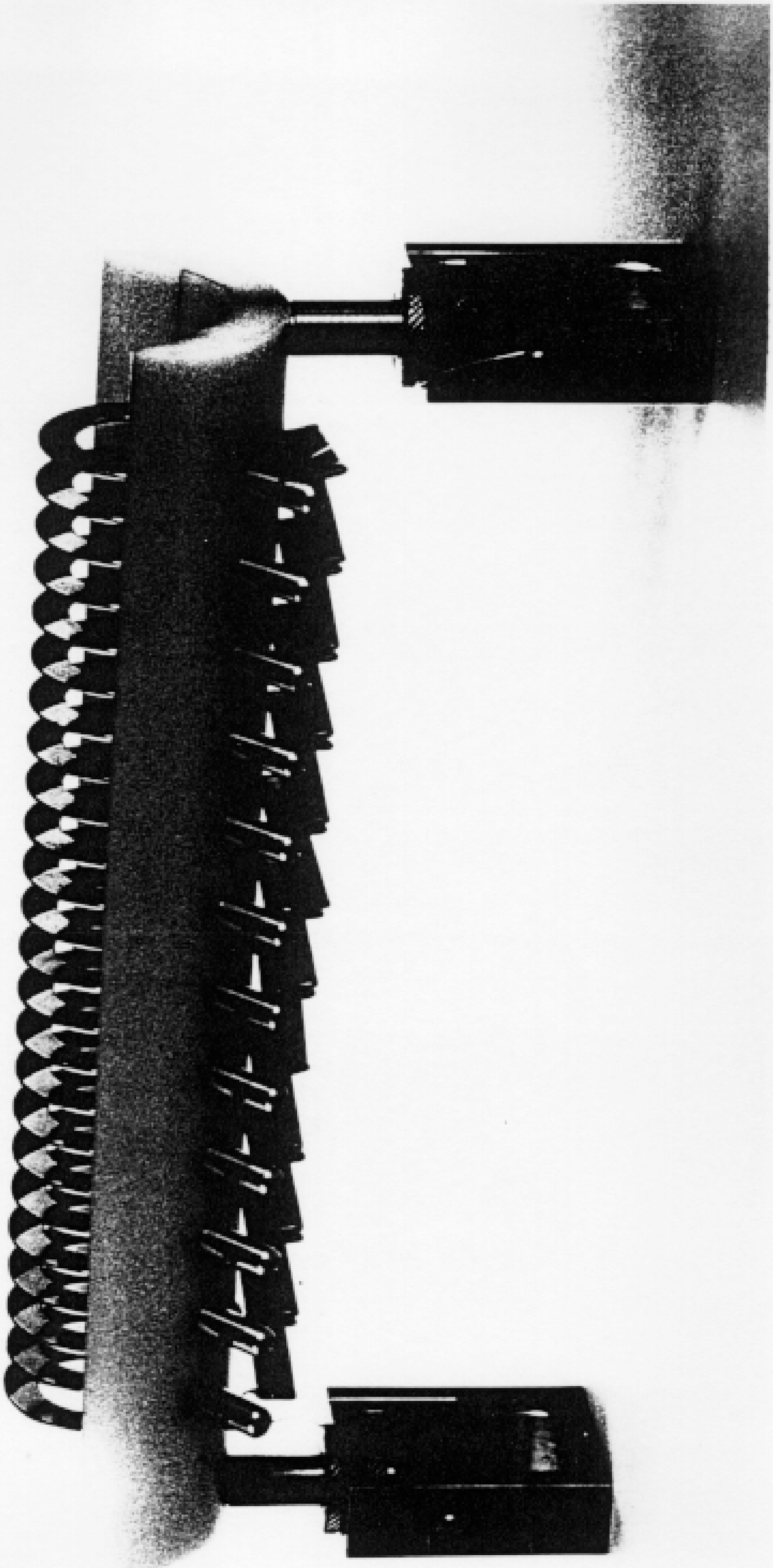
Overview:

× cooling device:	stack of carbon foils
foil thickness:	4.3 μg/cm^2
spacing:	8 mm
voltage:	~1 to 2 kV
× energy measurement:	via time of flight
× entrance detector (μ^-):	position sensitive PPAC
× end detector (μ^-,e^-):	MCP
× confinement:	strong axial magnetic field



Times measured:

- × t_{PPAC}: μ- hits the PPAC
- × t_{MCP1}: e- ejected from one of the first foils hits the MCP
- × t_{MCP2}: μ- hits the MCP



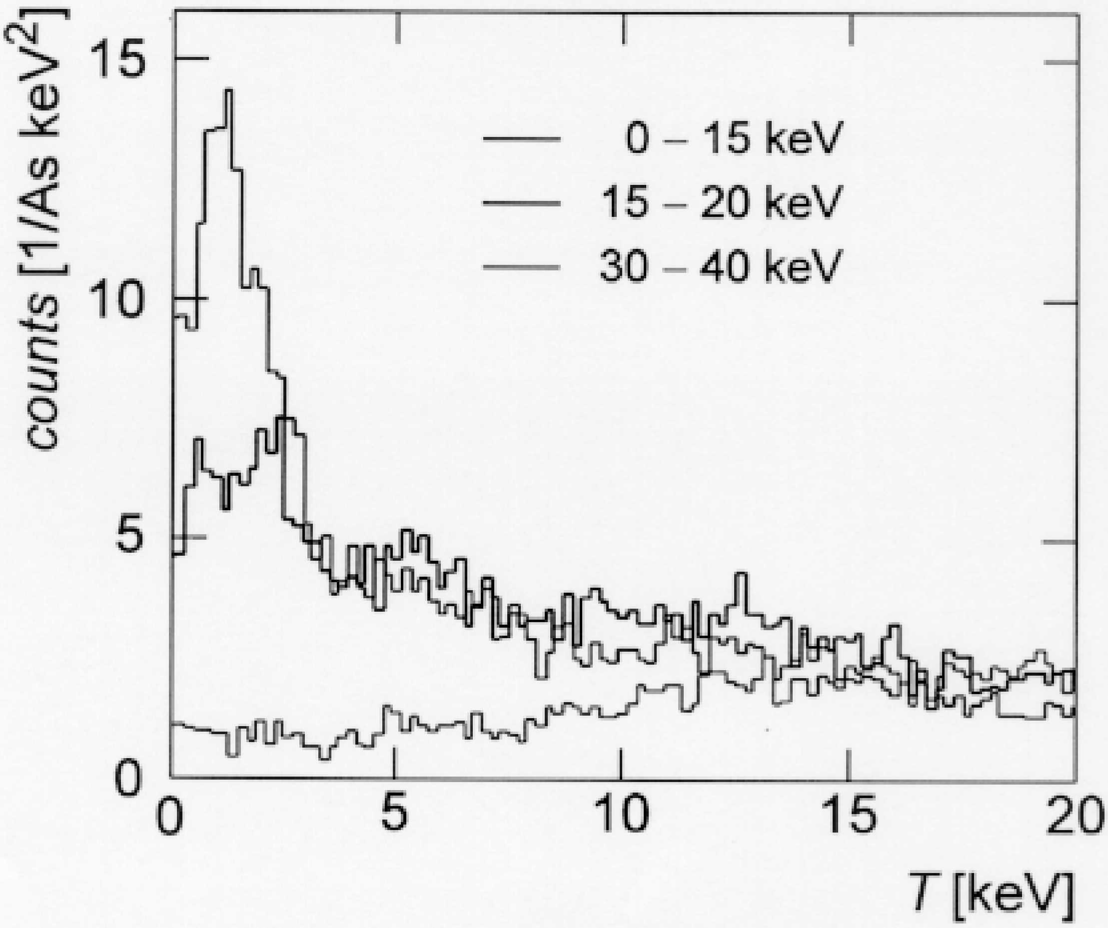
Frictional Cooling:

Recent Results: I

Effect of the frictional cooling on the energy distribution of the "cooled" muons:

Example: 10 carbon foils, 5.3 μg/cm² each
ΔU = 1.7 kV
U_{last} = 3 kV

Energy distribution of the cooled muons for different cuts on their incident energy



T : kinetic energy of the muon
ΔU : voltage between two foils
U_{last} : voltage of the last foil

M.Mühlbauer: 08.06.98

- TAQQU CLAIMS THAT FRICTIONAL COOLING CAN GIVE UP TO 10^3 SMALLER EMMITTANCE

  - (ONLY WORKS FOR μ^- !)
    (μ^+ form μ^+e^- atoms)

- PSI HAS EVERYTHING NEEDED TO PERFORM COOLING STUDY. @PSI

  - welcome people + money

BACKROUNDS | I. STUMER.

WORK HAS BEEN DONE TO $\boxed{\text{CALCULATE}}$
WITH **TRACKING + GEANT**
MOST IMPORTANT BACKGROUNDS

and $\boxed{\text{DESIGN SHIELDING}}$

⊛ OCCUPANCY is (CHARGED) 1.4 %
For $300 \times 300\ \mu m^2$ pixels
AT 5cm.

Q: what does this do to the b-tagging?

WELCOME A GROUP OF TRACKING EXPERTS
(ATLAS / CMS)

⊛ A POTENTIAL SERIOUS PROBLEM :

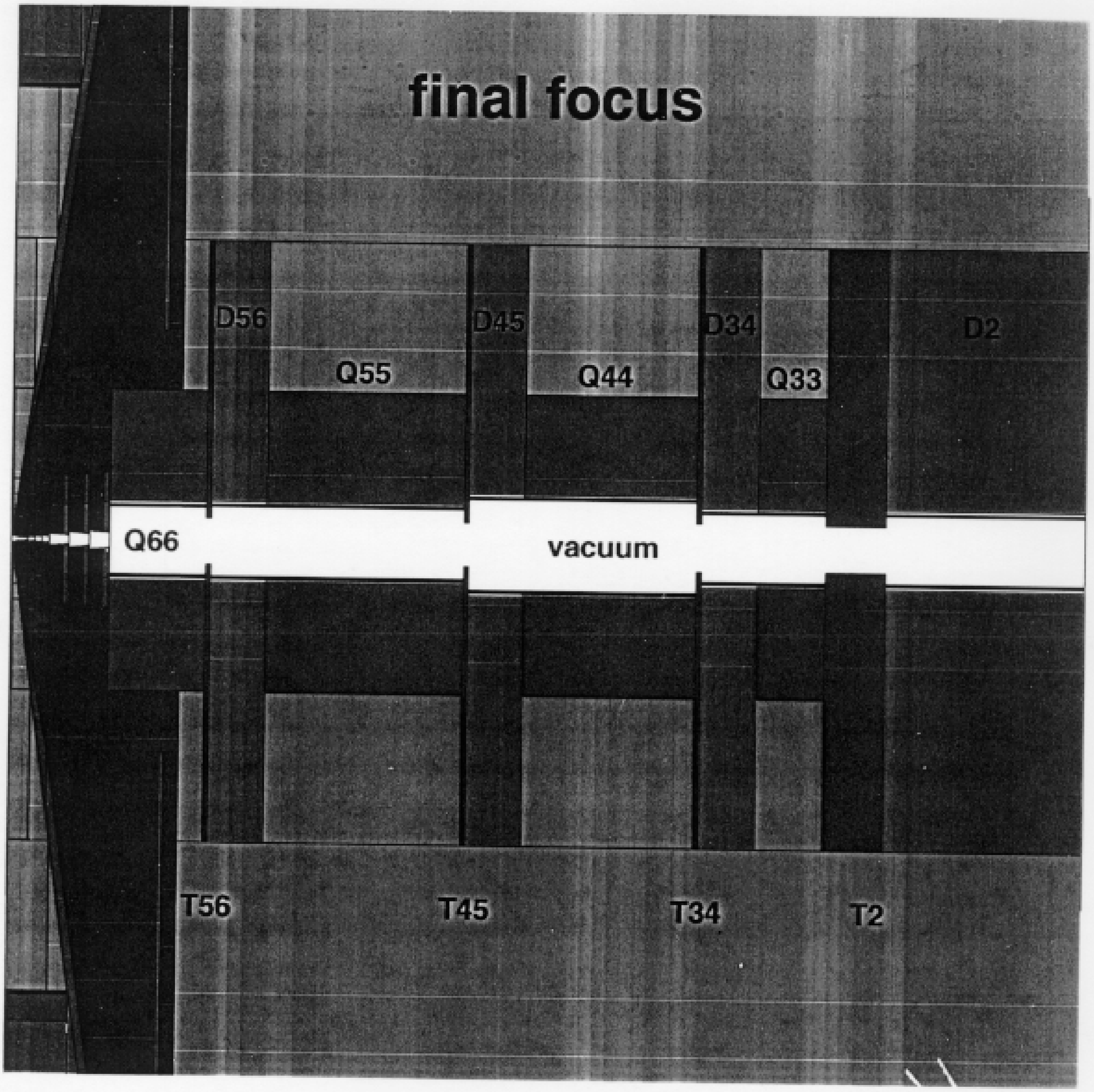
FOR $\frac{\Delta P}{P} \simeq 0.003\%$ $\left(\approx \frac{\Delta \Gamma_H}{\Gamma_H}\right)$

$\Rightarrow \sigma_Z^{\mu.\text{bunch}} = 12\text{cm}$!

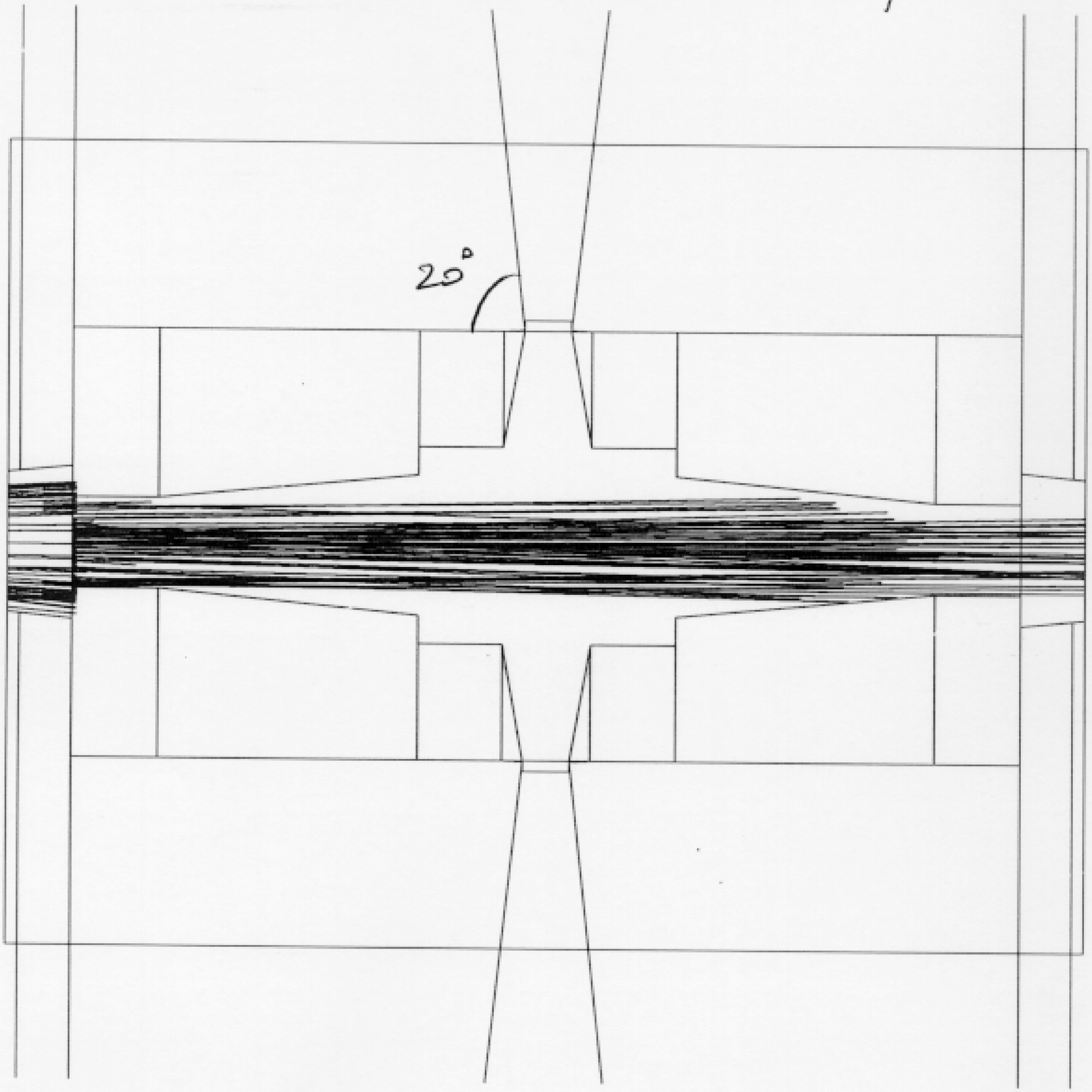
while shielding is designed for

$\sigma_Z \lll 5\text{ cm}.$

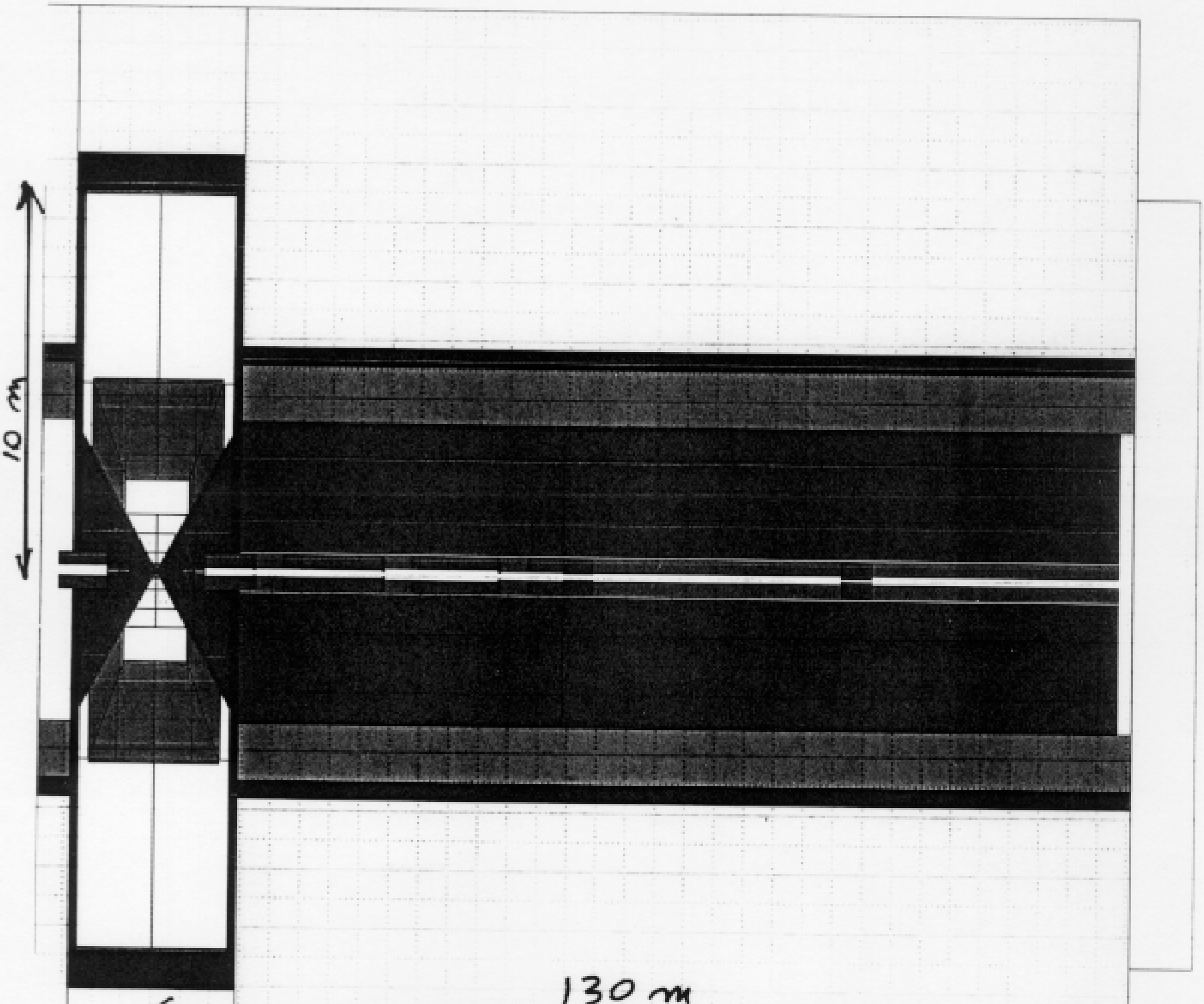
final focus



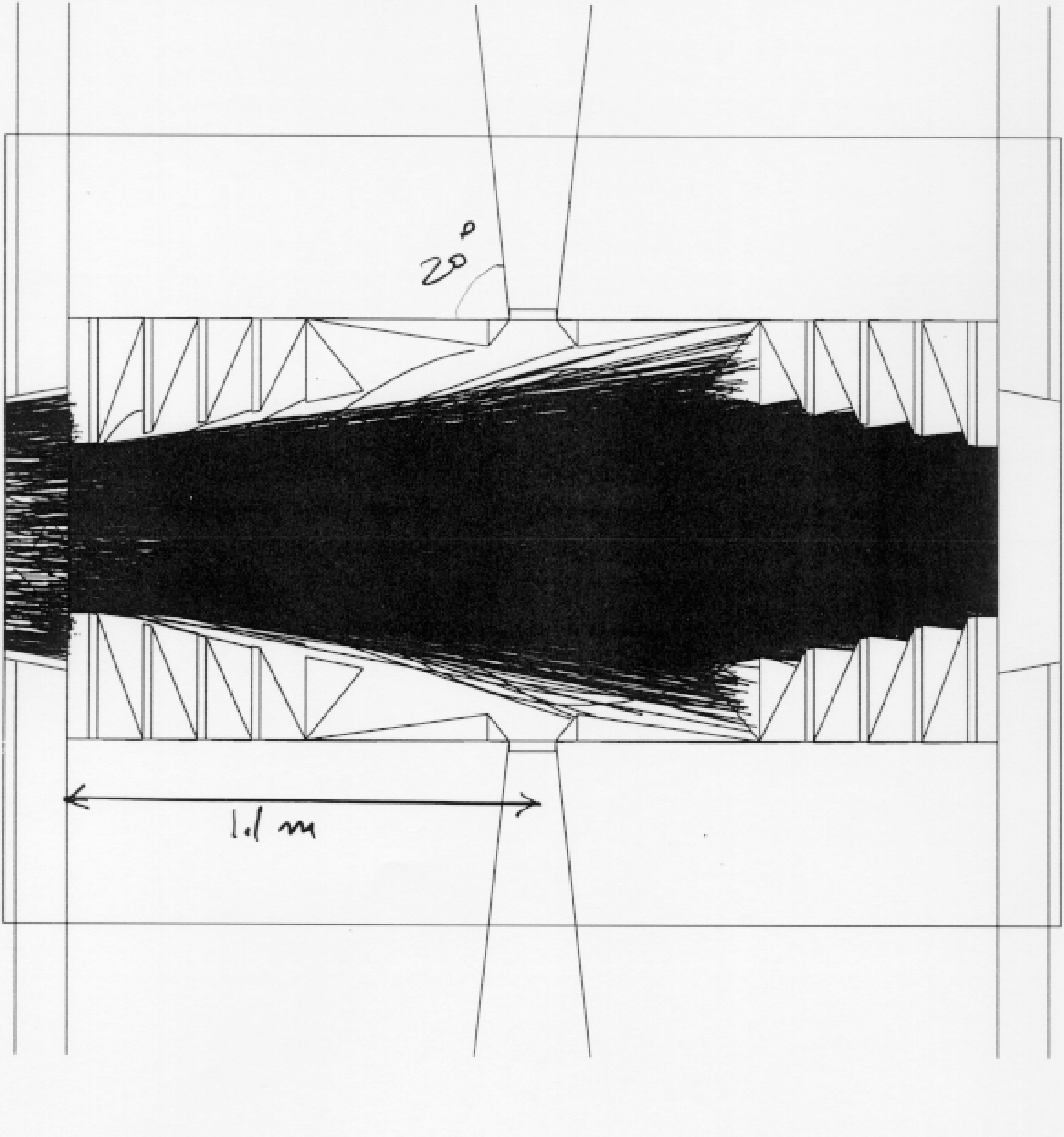
2x2 TeV

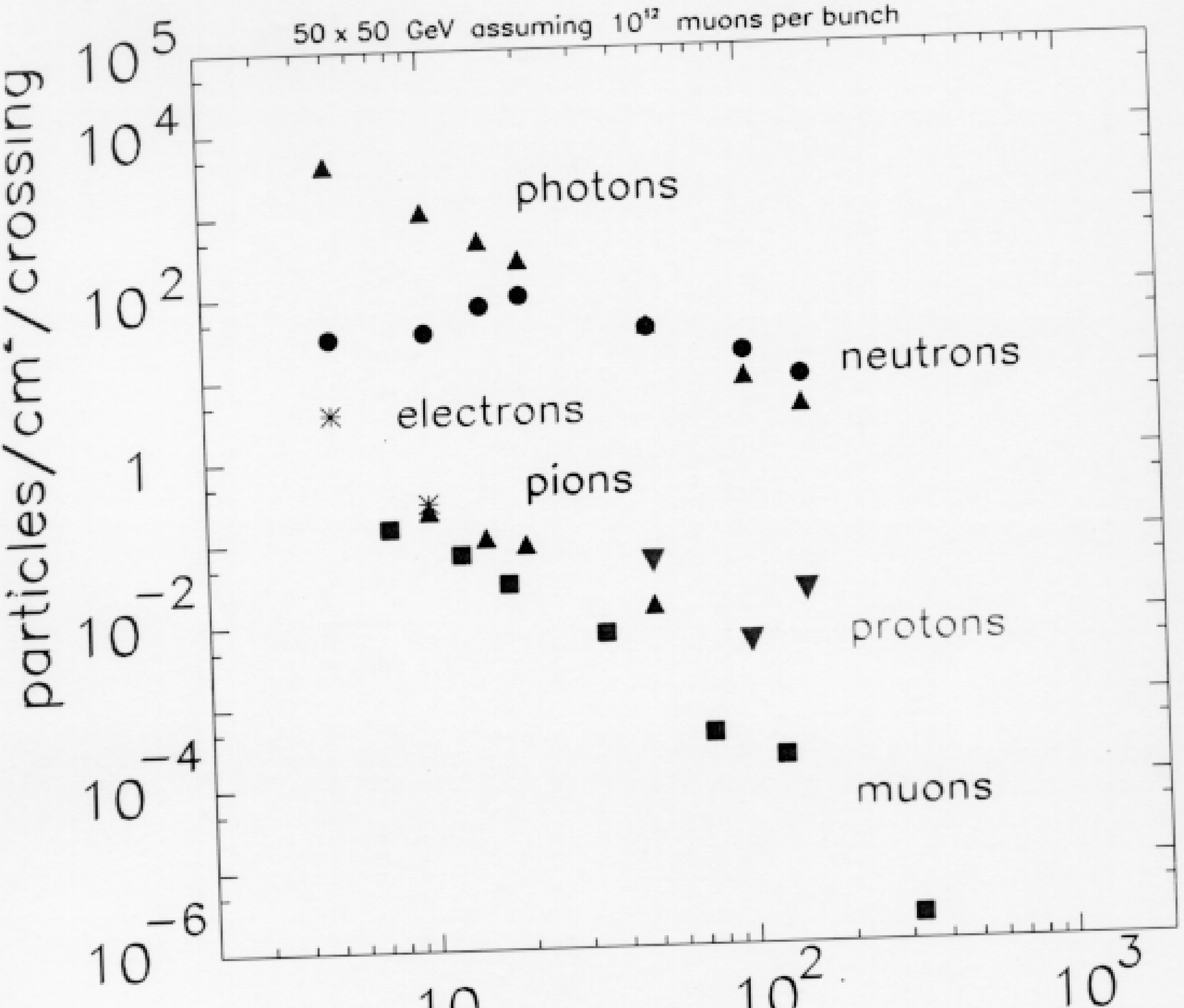


2 x 2 TeV



50 × 50 GeV

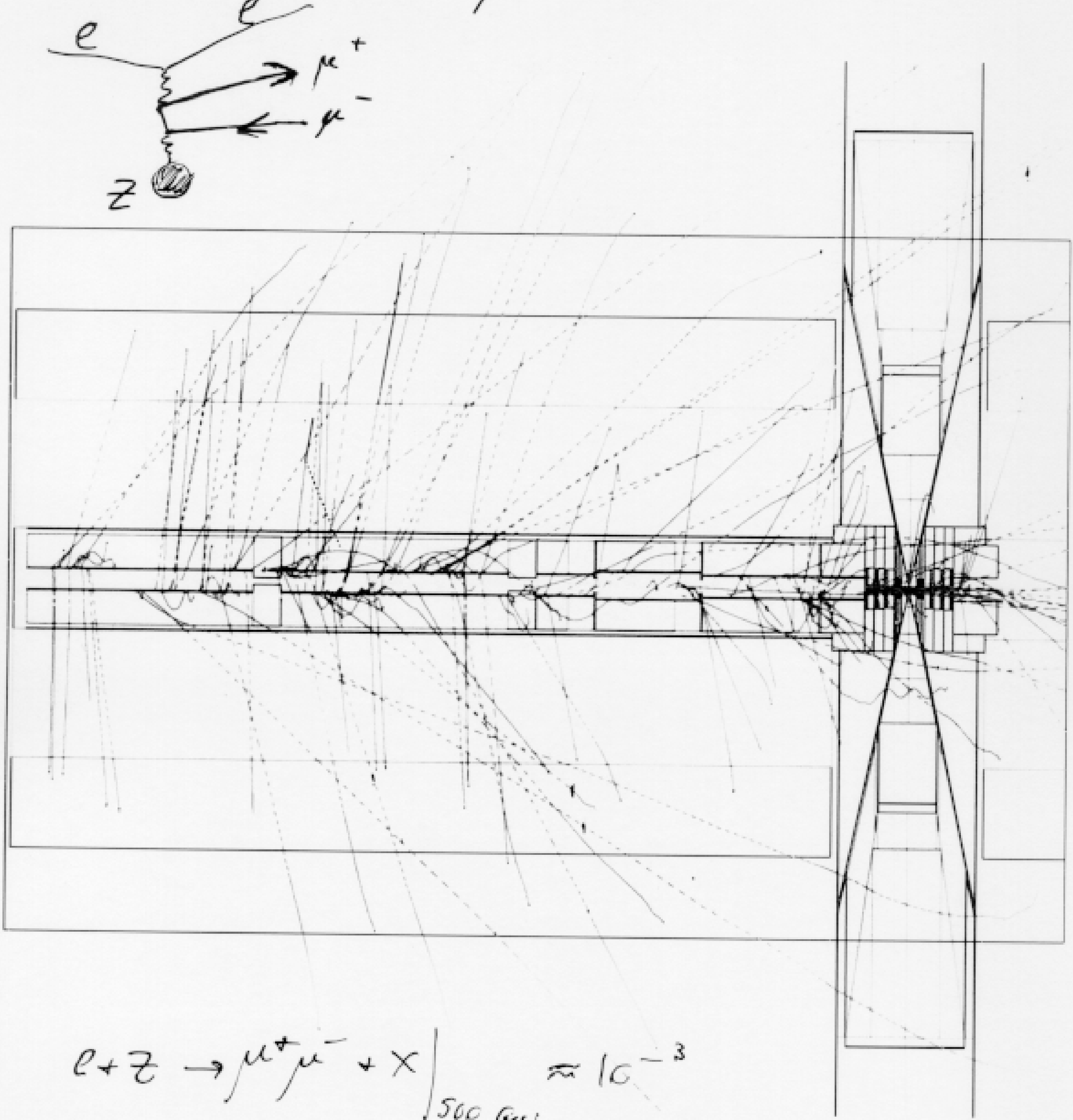




50 x 50 GeV assuming 10^12 muons per bunch
particles/cm²/crossing
10^5
10^4
10^2
1
10^-2
10^-4
10^-6
10
10^2
10^3
r(cm)
photons
neutrons
electrons
pions
protons
muons

2 × 2 TeV

BETHE HEITLER μ's REGULAR CONFIG.



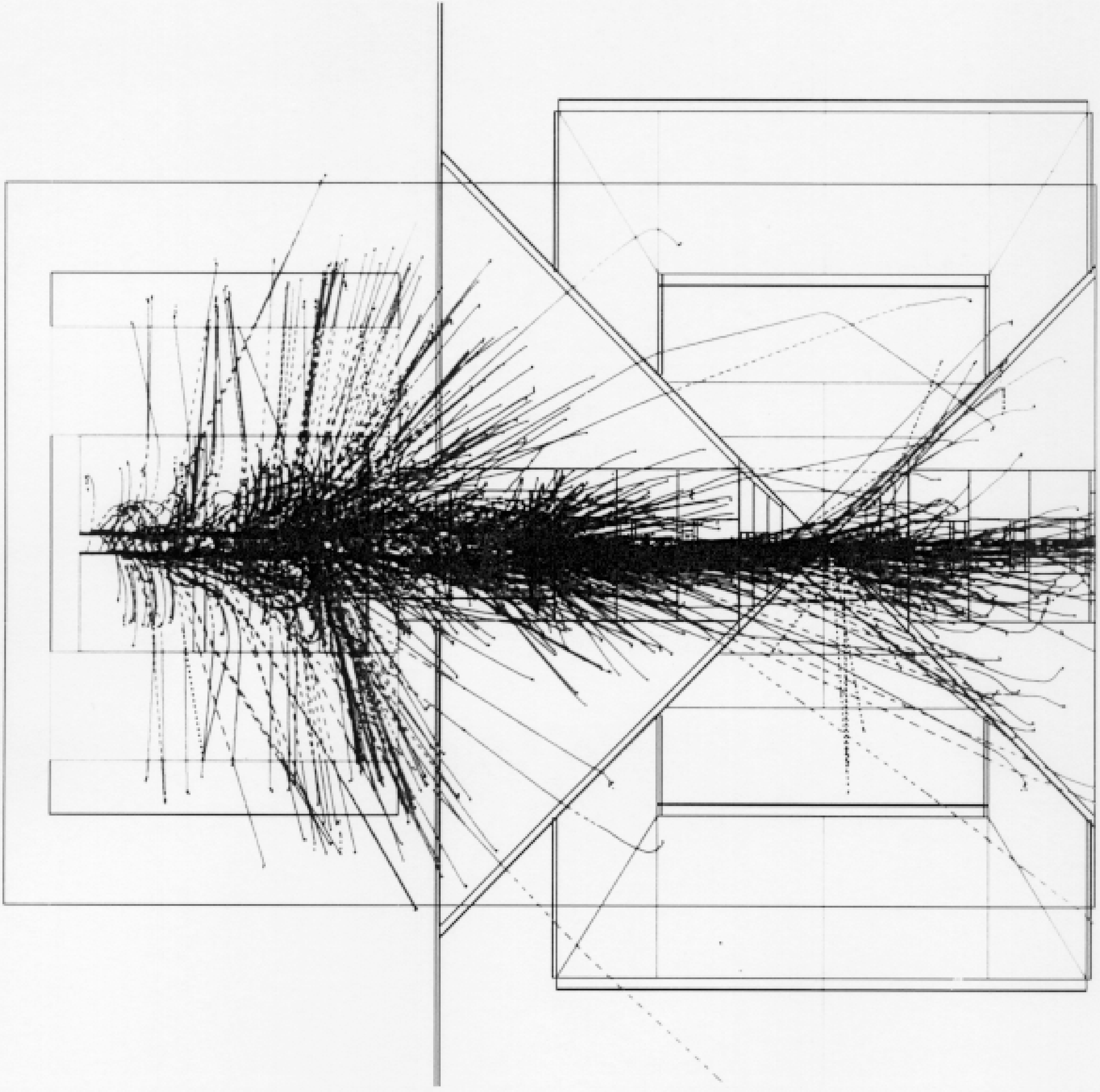
$$e + Z \to \mu^+\mu^- + X \Big|_{500\text{ GeV}} \approx 10^{-3}$$

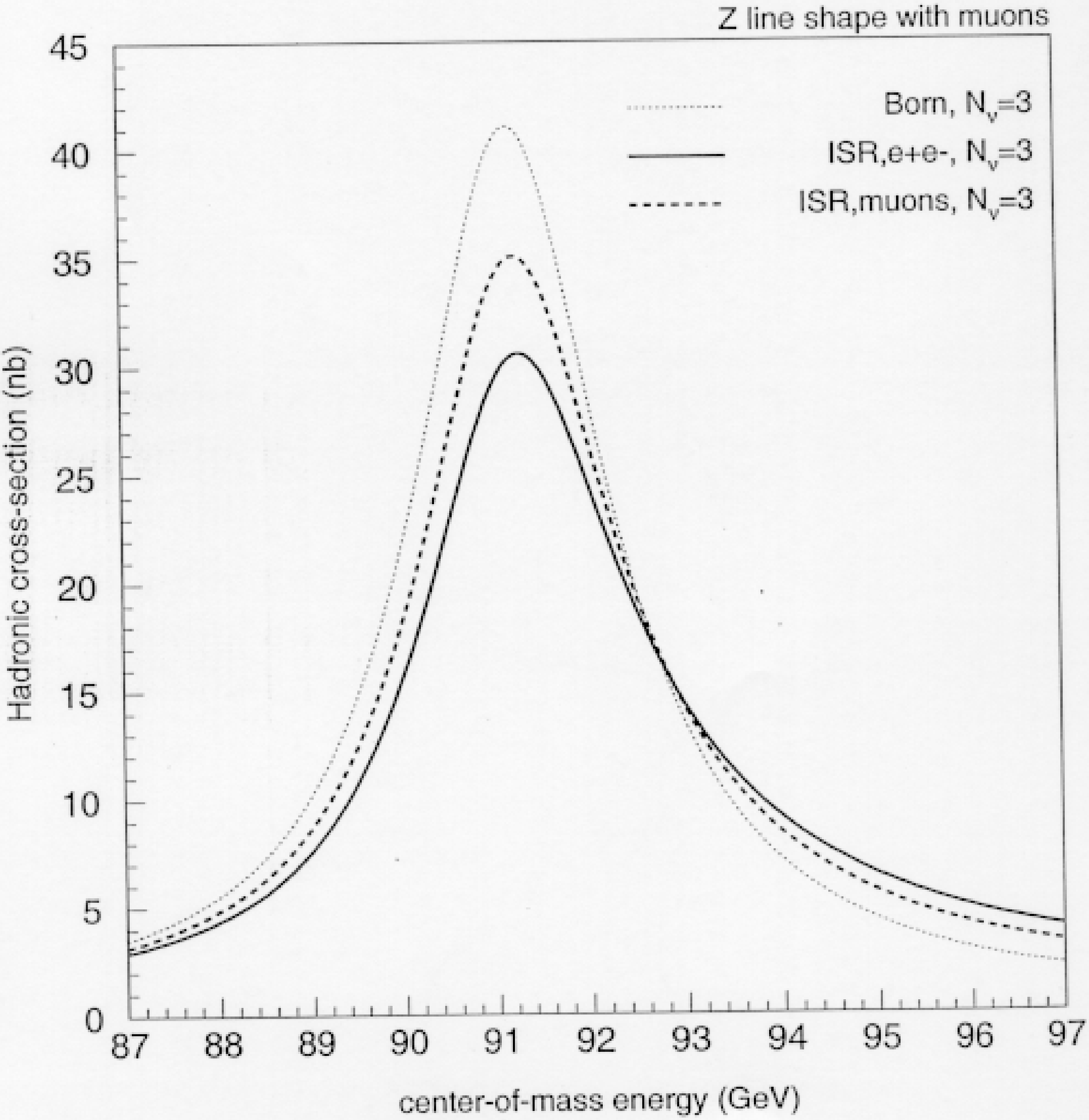
$$\Big|_{100\text{ GeV}} \approx 10^{-4}$$

$$\Big|_{20\text{ GeV}} \approx 10^{-5}$$

BETHE - HEITLER μ's

50 × 50 GeV




Z line shape with muons
Born, N_ν=3
ISR,e+e-, N_ν=3
ISR,muons, N_ν=3
Hadronic cross-section (nb)
45
40
35
30
25
20
15
10
5
0
87
88
89
90
91
92
93
94
95
96
97
center-of-mass energy (GeV)

BEAM POLARIZATION

μ^+ from π^+ is on average −28% Polarized.
μ^- π^- +28%

momentum selection → higher $\mathbb{P}$
(but lower $\mathcal{L}$)

Spin tune is SMALL

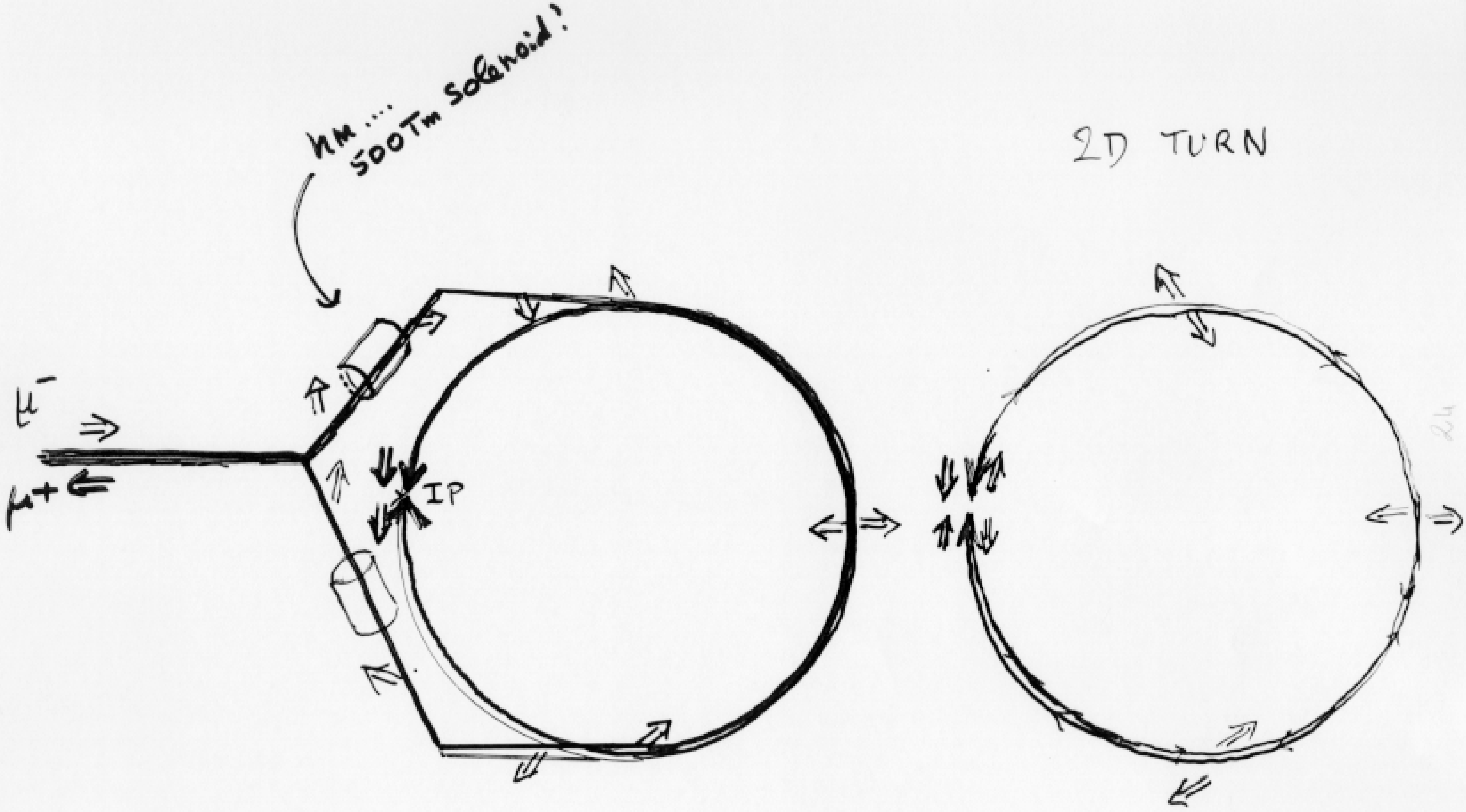
$$\nu = \frac{g-2}{2} \cdot \frac{E_{beam}}{m_\mu} = \frac{E_{beam}\,(\text{GeV})}{90.6223(6)}$$

at Z peak $\nu \approx 0.503$

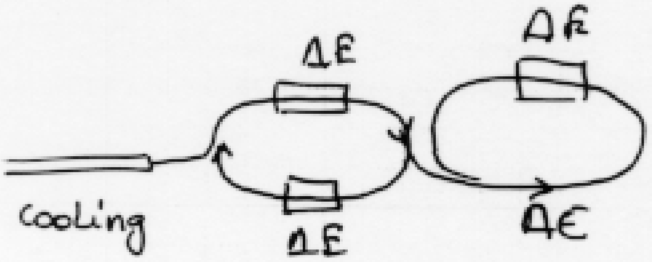
Cf electrons $\nu = 103.5$

and smaller at lower energies

⇒ polarisation of muons very hard to destroy!


hm.....
500Tm solenoid!
μ^-
μ^+
IP
2D TURN

HOWEVER, SPIN PRECESSION TAKES PLACE IN ALL ACCELERATORS PRIOR TO THE COLLIDER.



$$\Delta\Theta_{Spin} = \sum_{i=1}^{N} \pi \cdot \frac{g-2}{2} \cdot \epsilon_N \cdot \text{Sign.}$$

ex: ALL SIGNS THE SAME, $\Delta\epsilon = 1\,\text{GeV}$ $\epsilon_N = N\Delta$

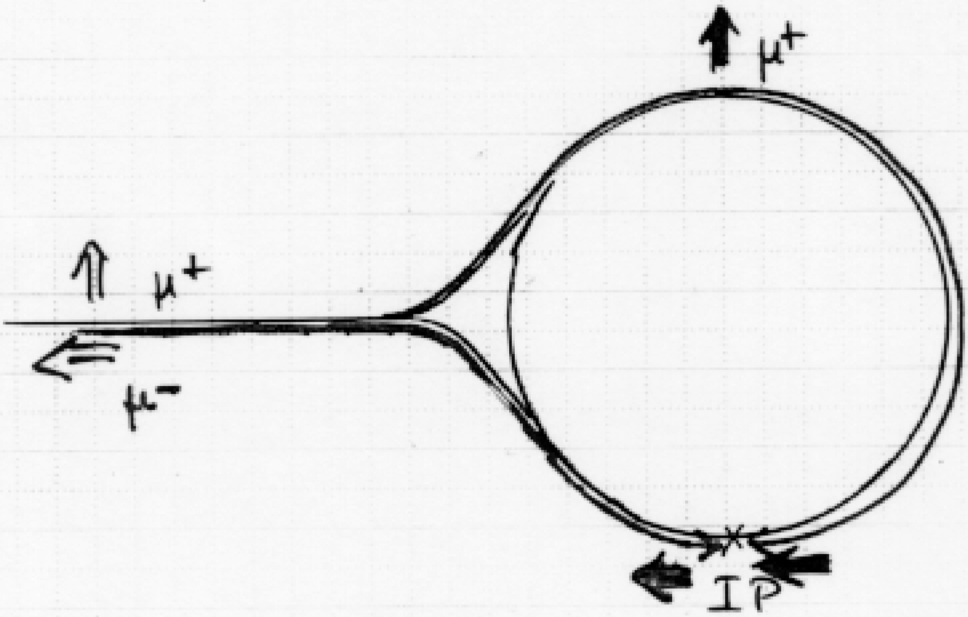
$$\Delta\Theta_{spin} = \sum_{i=1}^{45} \frac{\Delta E}{m_\mu} \cdot \frac{g-2}{2} \cdot N = \frac{\Delta\epsilon}{m_\mu} \frac{g-2}{2} N \frac{N+1}{2}$$

$$\simeq 10.5$$

$\Rightarrow$ ALL THESE RINGS ALLOW SPIN MANIPULATIO

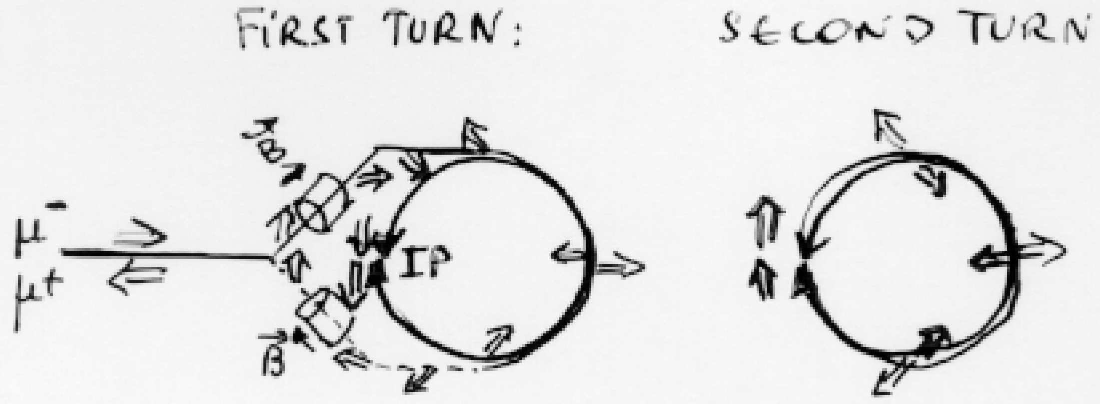
EX: ADD 1 extraturn at $\epsilon = \frac{90.6223}{4} = 22.655$ GeV.
<u>for μ^+</u>

$$\Rightarrow \Delta\Theta^{\mu^+}_{Spin} - \Delta\Theta^{\mu^-}_{Spin} = \pi/2$$



etc...

at Z peak $\nu = 0.5$



SUCCESSION OF SPIN CONFIGURATIONS

$\Rightarrow \Rightarrow$ ①

$\Leftarrow \Leftarrow$ ②

. . . .

. . .

on odd + even turns.

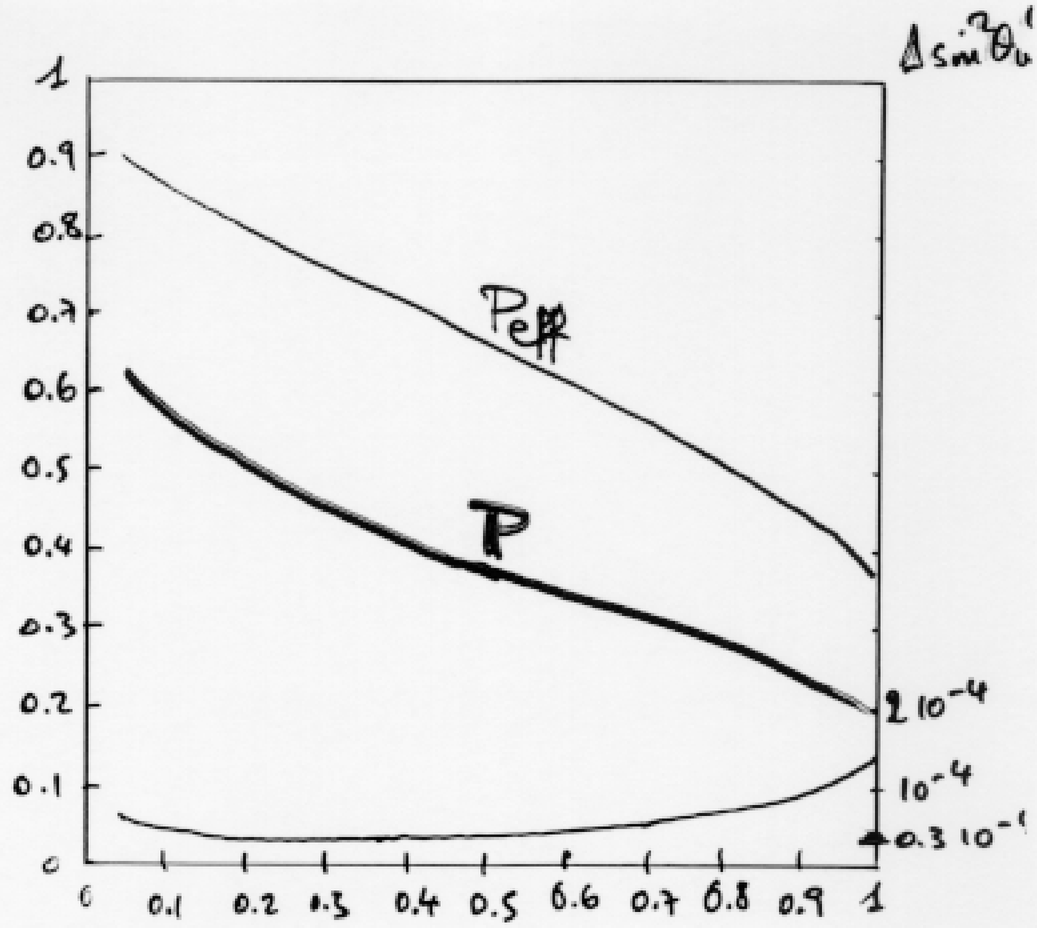
$$\sigma_1 = \sigma_\mu \left[\underbrace{1 - P_{\mu^+} P_{\mu^-}}_{\sigma \text{ increases}} + A_{LR} \underbrace{\left(P_{\mu^+} - P_{\mu^-} \right)}_{\text{asymmetry}} \right]$$

$$\frac{\sigma_{odd} - \sigma_{even}}{\sigma_{odd} + \sigma_{even}} = A_{LR} \cdot P_{eff} = A_{LR} \cdot \frac{P_{\mu^+} - P_{\mu^-}}{1 - P_{\mu^+} P_{\mu^-}}$$

$|P| = 20\% \Rightarrow P_{eff} = 38\%$

$50\% \Rightarrow P_{eff} = 80\%$

- calibration of P from increase of $\sigma_{odd} + \sigma_{even}$



$\Delta \sin^2\theta_W^{\text{eff}} \leq 0.3\ 10^{-4}$ (0.00003) ;

$10^8 Z$!