Muon Collider--
Backgrounds and Detectors and Physics potential

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Summary of talk

- Brief history and motivation
- Physics Potential of Muon Collider
  - » s-Channel Higgs, techni-particles
  - » top quark and W threshold scans
  - » SUSY
  - » High energy reach
- Backgrounds
  - » Neutrino Induced Radiation
  - » Halo Backgrounds
  - » Pair production at IP
  - » Muon Decay Background at IP
    - Design of Interaction area shielding
    - Neutrons
    - Photons
    - Bethe-Heitler Muons
- Detector Options
- Detector Simulation plans

Brief History of the Muon Collider

- An old idea.. Muon colliders mentioned by Tinlot(1960), Budker(1969), Skrinsky(1971), Neuffer(1979)
- A key concept for a high luminosity muon collider is ionization cooling: Skrinsky and Parkhomchuk(1981).
- The realization that a high luminosity muon collider might be feasible (Neuffer&Palmer) resulted in a series of workshops. After the Sausalito workshop in 1995, Fermilab and BNL joined in an effort to study the concept and publish a report. The muon collider collaboration grew -->26 institutions and ~ 100 Physicists.
- -->$\mu^+\mu^-$ collider: A feasibility study, Snowmass (1996): Fermilab-conf-96/092-->feasibility of a 2x2 TeV Collider.

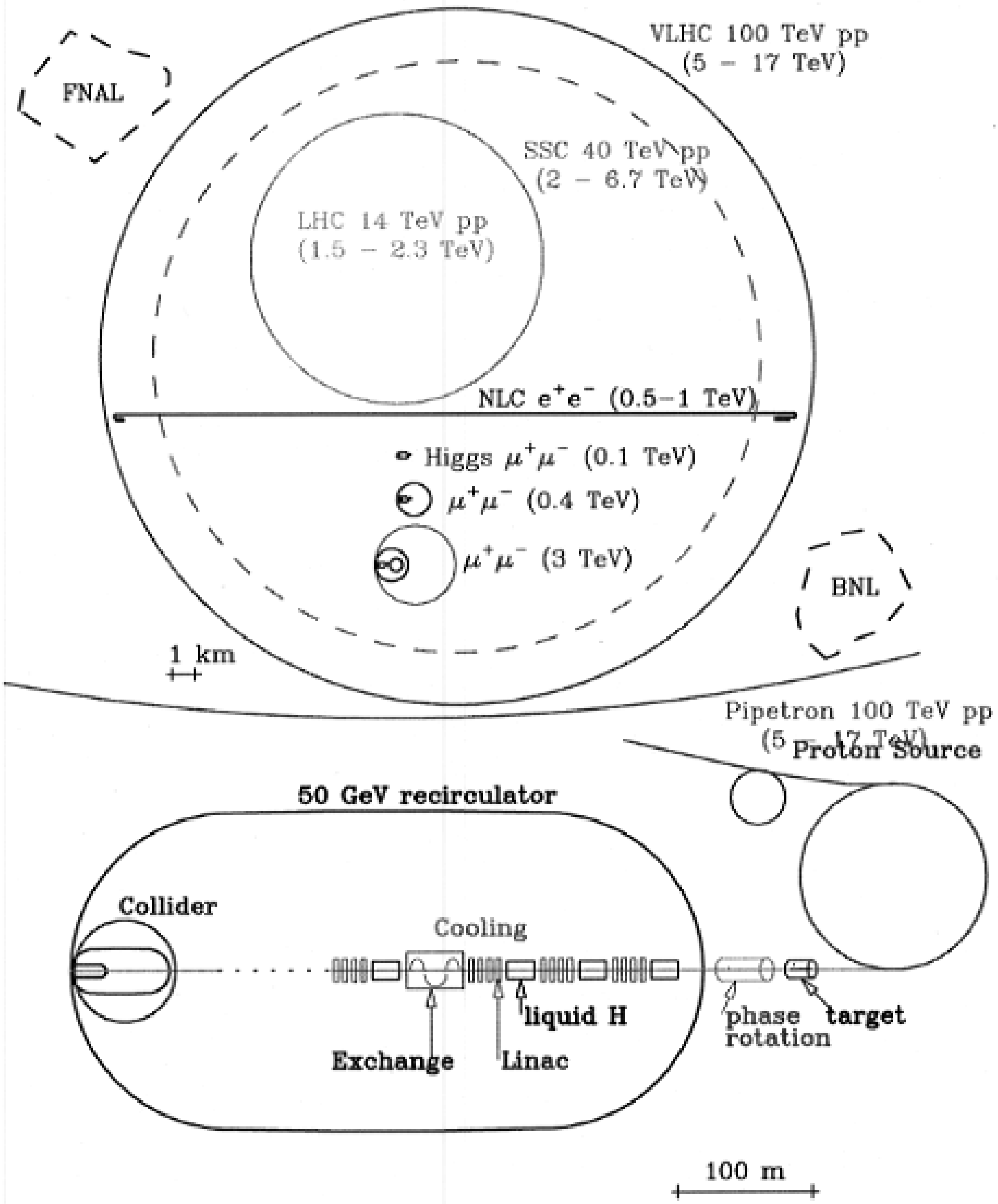
Brief History of the Muon Collider

- Although many questions were left open in the Snowmass report, no show stoppers were identified… and the muon collider collaboration has continued to develop the concepts.
- Workshop on Physics at the first Muon Collider and the front end of the muon collider- Nov 97- AIP proceedings S.Geer, R.Raja eds.
- Status of Muon Collider Research and future plans BNL-625-623,Fermilab -Pub 98/179, LBNL-41935, submitted to PRSTAB

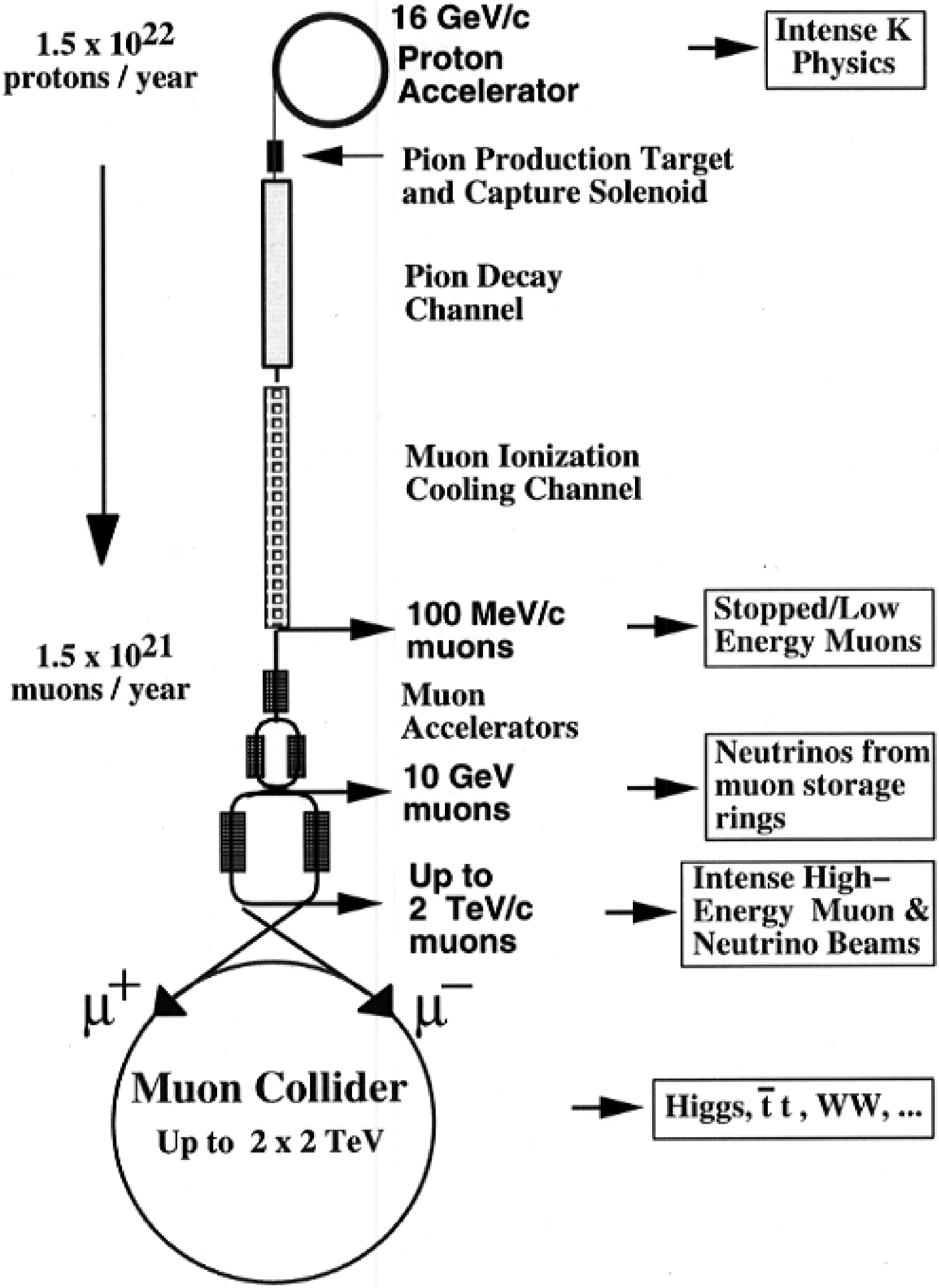
Motivation

- The muon is more massive than the electron by factor 200--> radius of acceleration not limited by synchrotron radiation. Compact machines
- $\mu^+\mu^-$ couples directly to Higgs can produce Higgs in the s channel as well as other Higgs like entities such as techni-η's,ρ's and π^0's.
- Muon can be polarized. Polarizations of 20% are easy. The above s-channel resonances can be scanned by a muon collider (A standard model Higgs at 110 GeV/c^2 mass has a width of a few MeV), since the bunch to bunch energy can be calibrated using g-2 spin precession.
- Higher energies such as 4 TeV (or higher) in the CMS are feasible, if the concept works at all.
- As one upgrades the proton driver in intensity, existing physics (e.g Tevatron experiments) benefits. Rare K decays.
- Cool muons can be used for neutrino sources, stopped muon physics. The neutrino option might be sufficient to justify this approach by itself.

Schematic of Muon Collider



Muon Collider Schematic



CANDIDATE MUON COLLIDER (E_{cm} = 500 GeV)

July 1998
FERMILAB

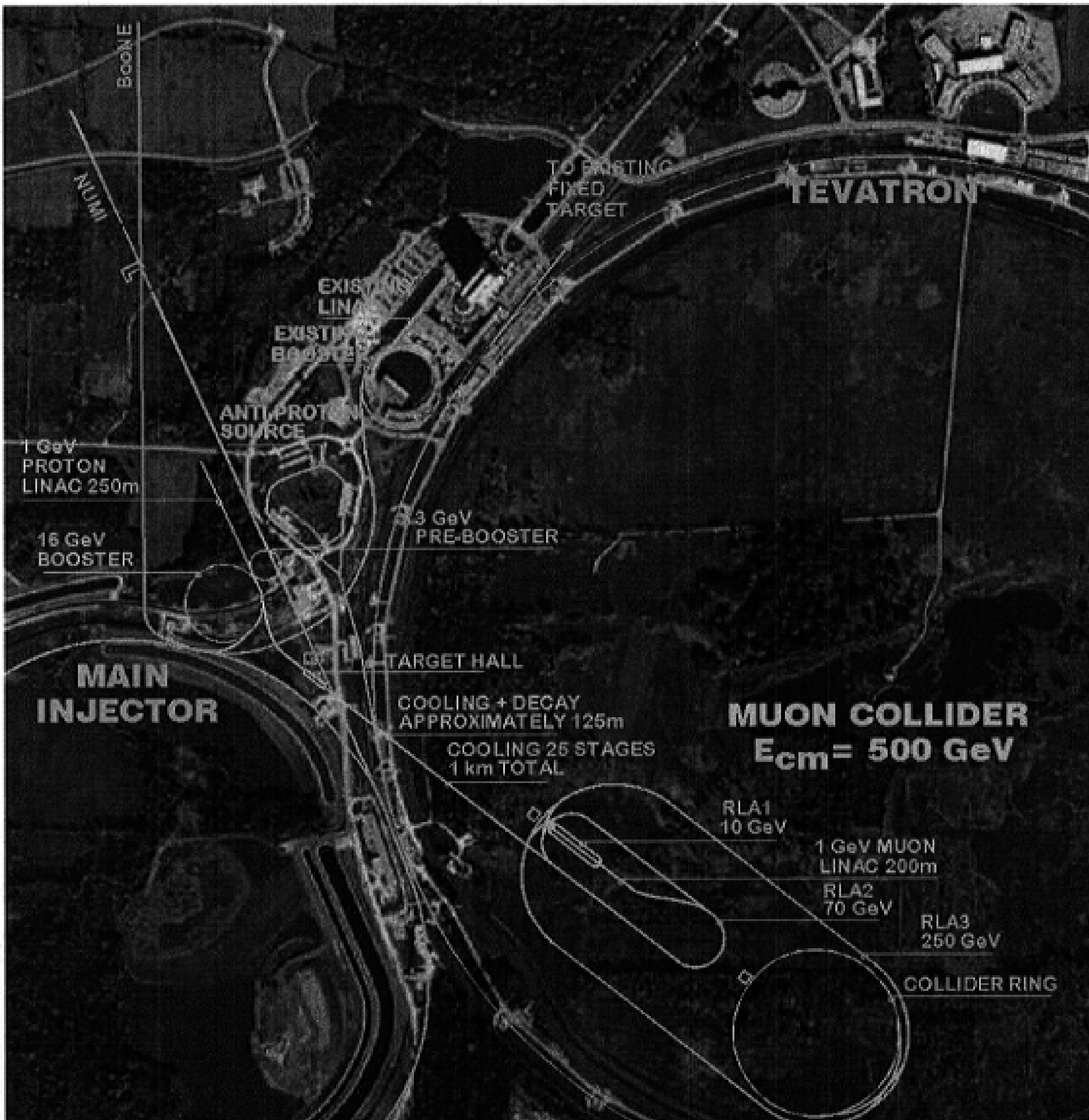
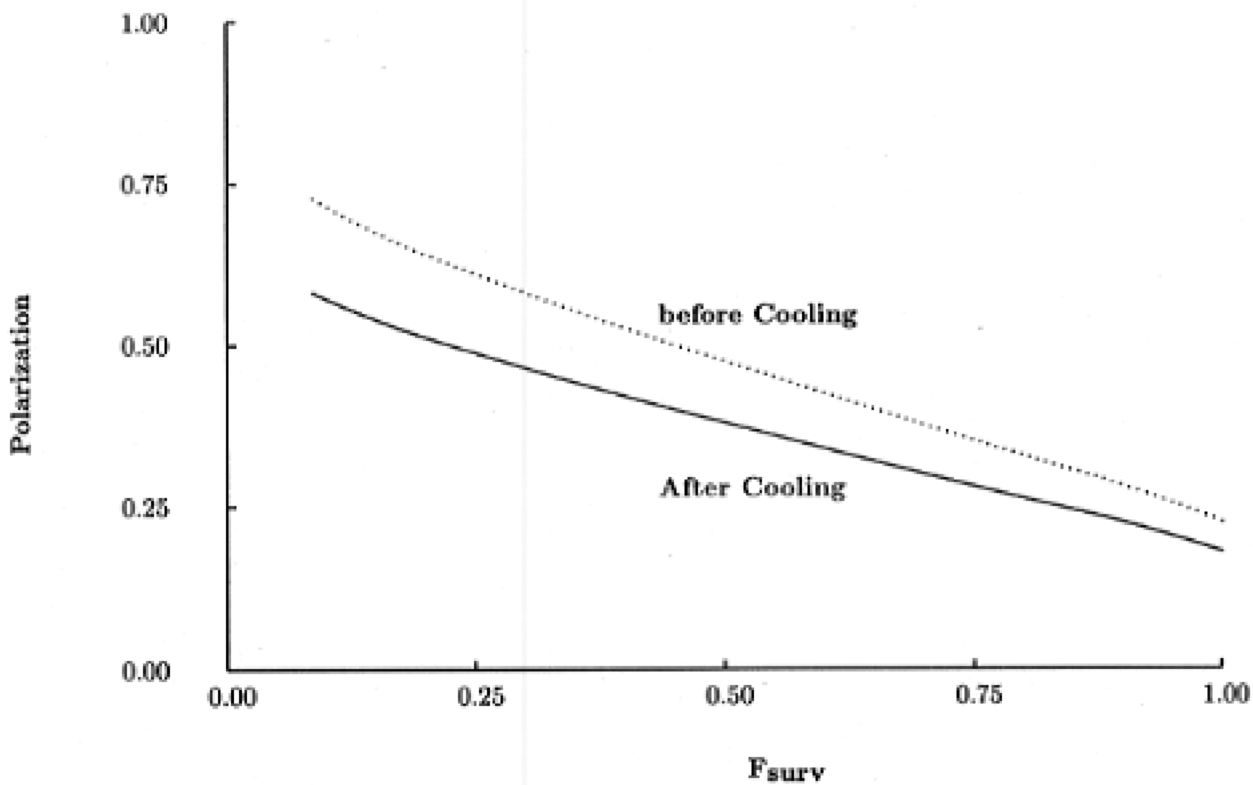


PHOTO DATE: OCTOBER 1997

Muon Collider Physics

- Polarization of muons will play a crucial role in many physics areas.
- Both charges polarizable.



Calibrating the energy of the collider to 1E-6

Bargmann-Michel-Telegdi Equation

$$\frac{d\vec{S}}{dt} = \vec{\Omega} \times \vec{S}$$

$$\vec{\Omega} = -\frac{e}{m\gamma}((1+a\gamma)\vec{B}_{\perp} + (1+a)\vec{B}_{\parallel} - (a\gamma + \frac{\gamma}{1+\gamma})\vec{\beta} \times \frac{\vec{E}}{c})$$

$$\vec{\Omega} = \vec{\Omega}_{cyc}(1+a\gamma)$$

$$a = (g-2)/2$$

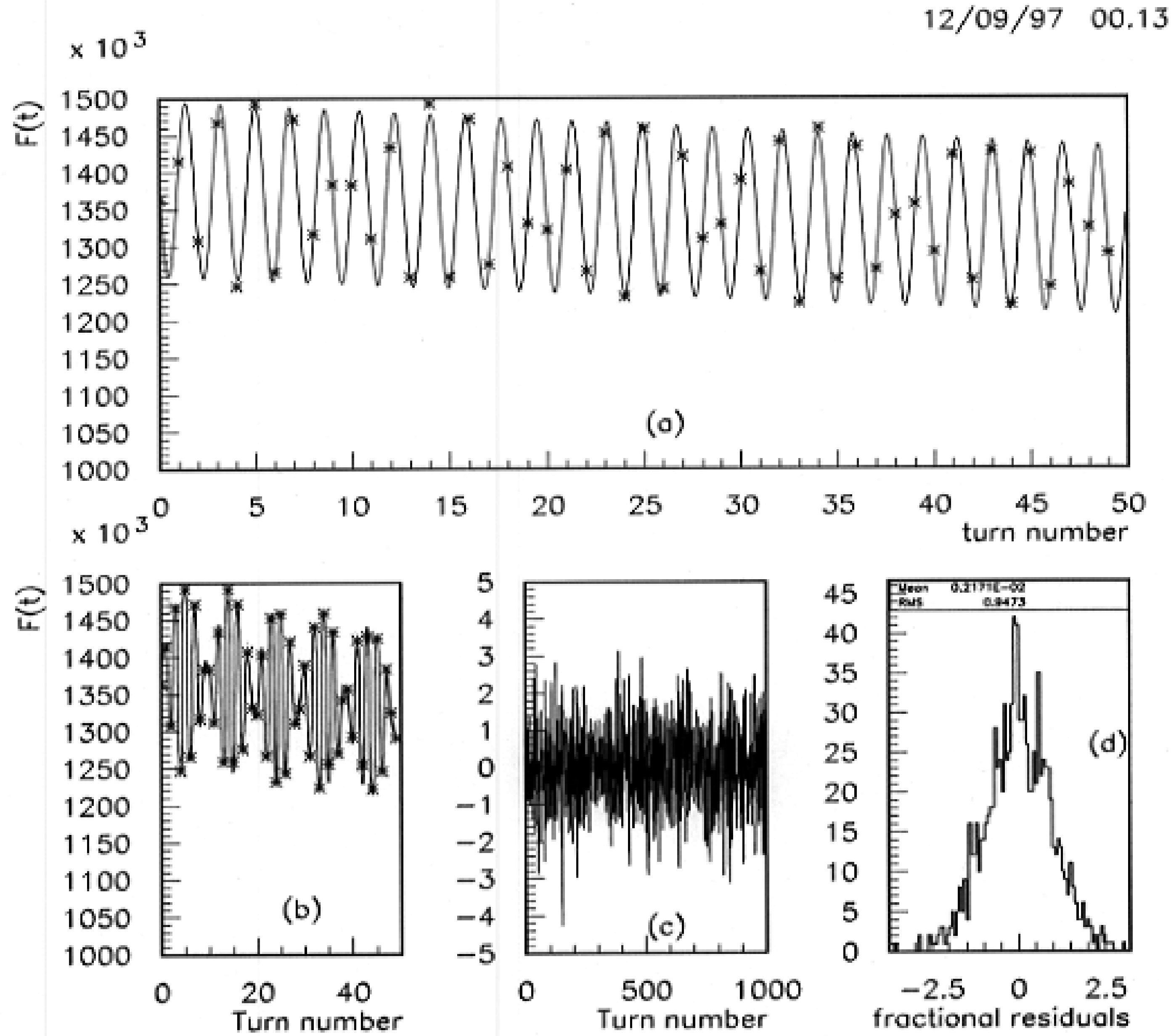
$B_{\perp}, B_{\parallel}$ are the components of magnetic field perpendicular and parallel particle direction

This equation controls the evolution of the spin vector $\vec{S}$. Polarization is the average of the spin vectors over the muon ensemble. Per revolution spin rotates by $a\gamma 2\pi$ radians more than momentum

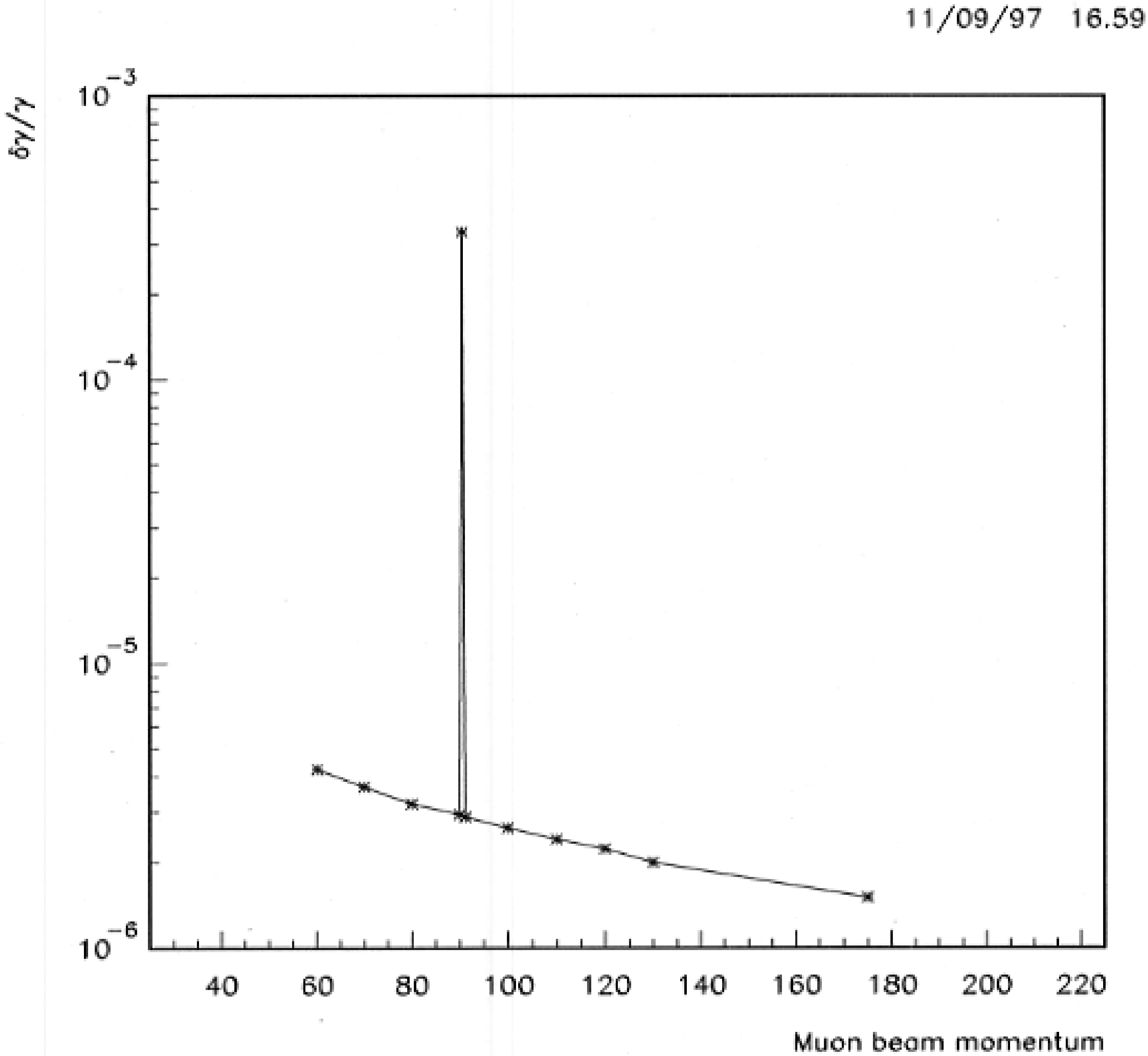
Method described in

R.Raja and A. Tollestrup, Phys. Rev. D58(1998)013005

Fit to 50 GeV μ⁻, P=0.26
δp/p=0.03E-2



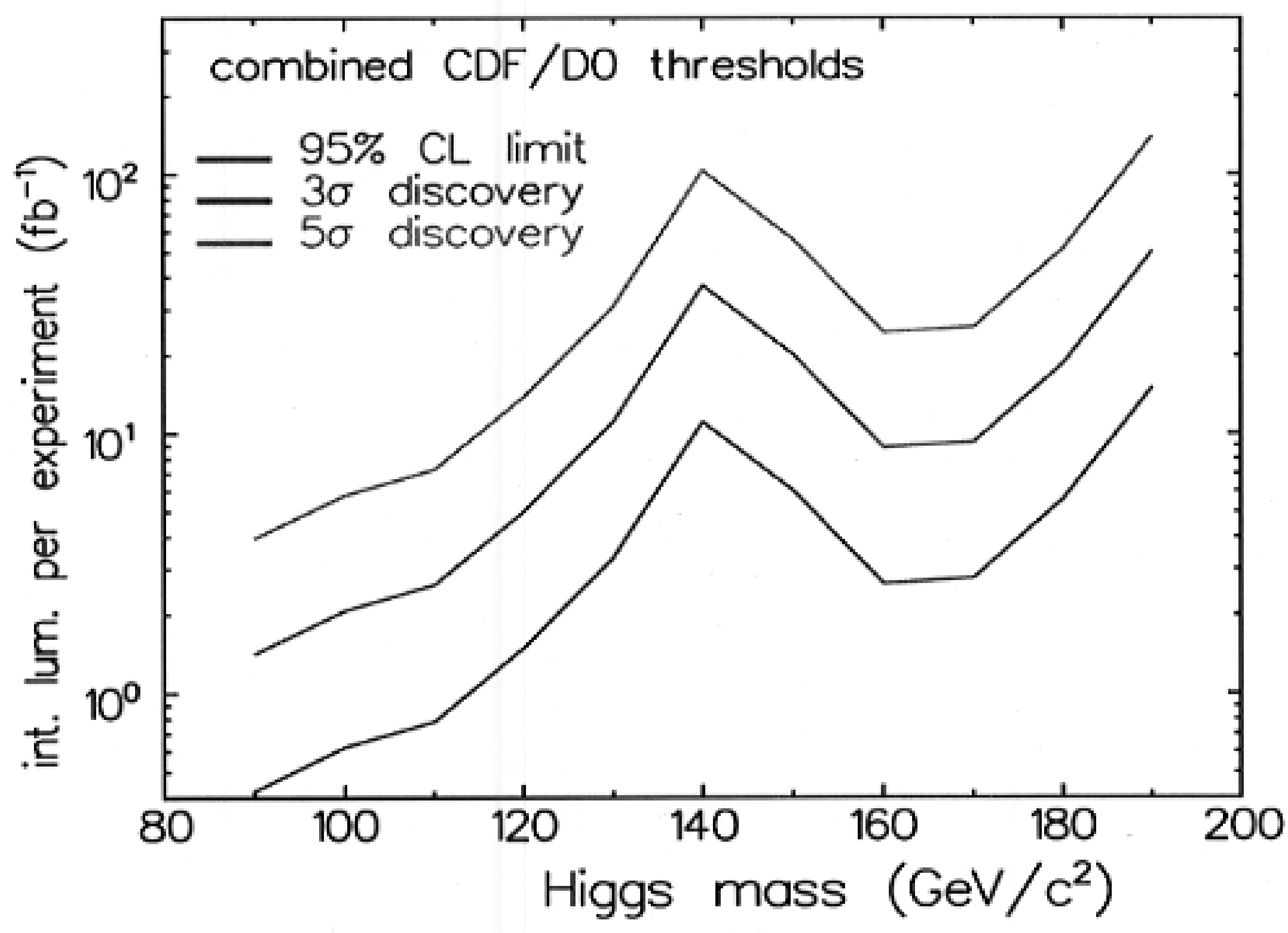
$\delta\gamma/\gamma$ vs muon beam momentum



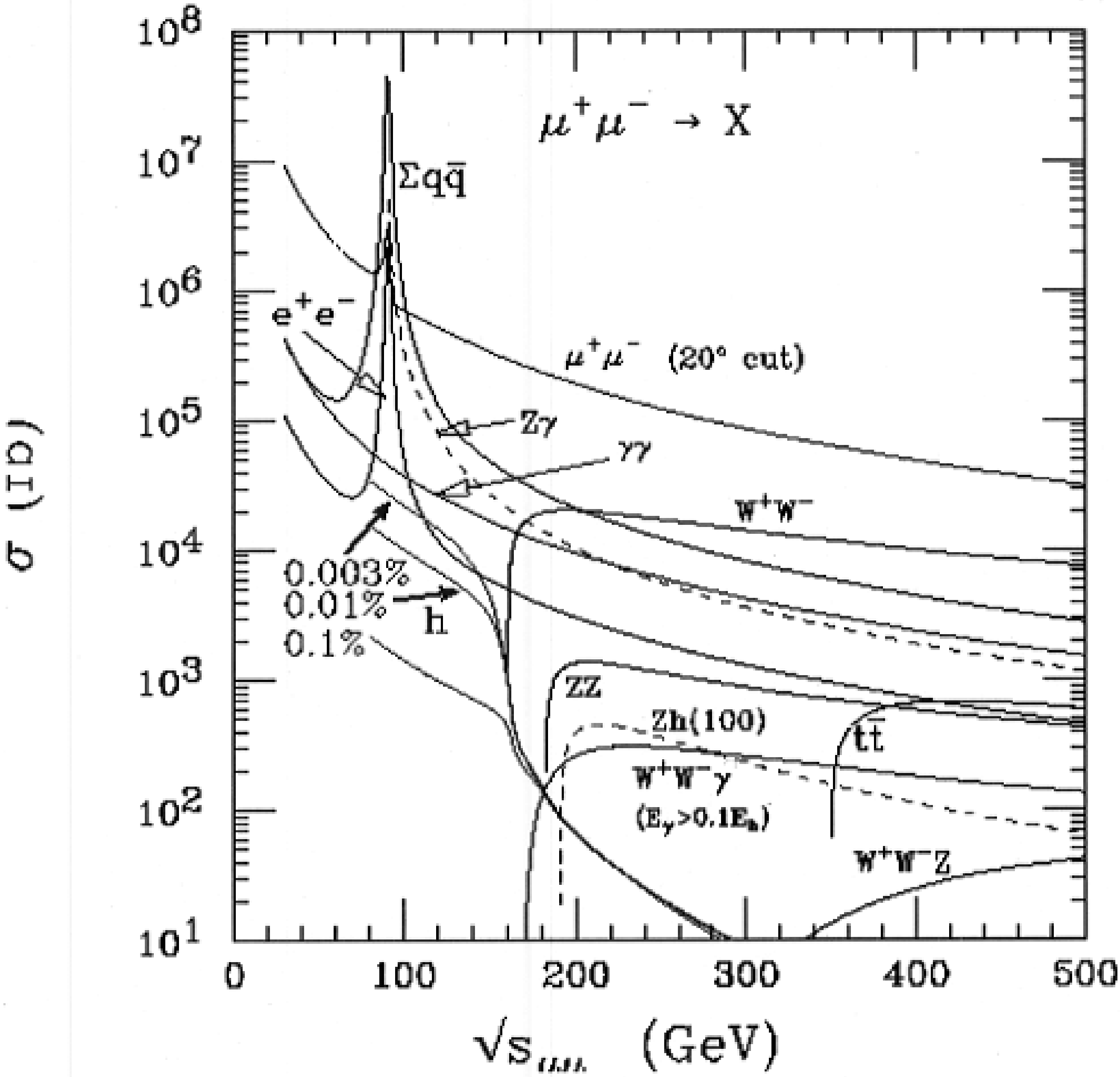
Tevatron Run III Standard model Higgs limits

<u>Combined channel thresholds</u>

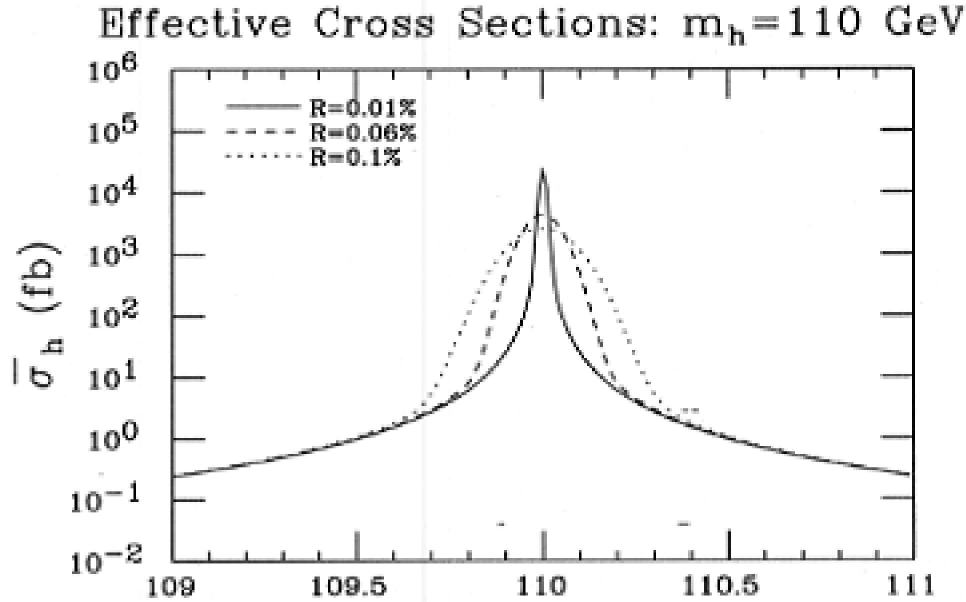
→ Gaussian approximation in combination
→ 30% better $m_{b\bar{b}}$ resolution than Run 1
→ Run 2 acceptance ×1.3 NN improvement
→ 10% systematic error on background
→ all except $\ell^{\pm}\ell^{\pm}jj$



Standard model cross sections at the first muon collider

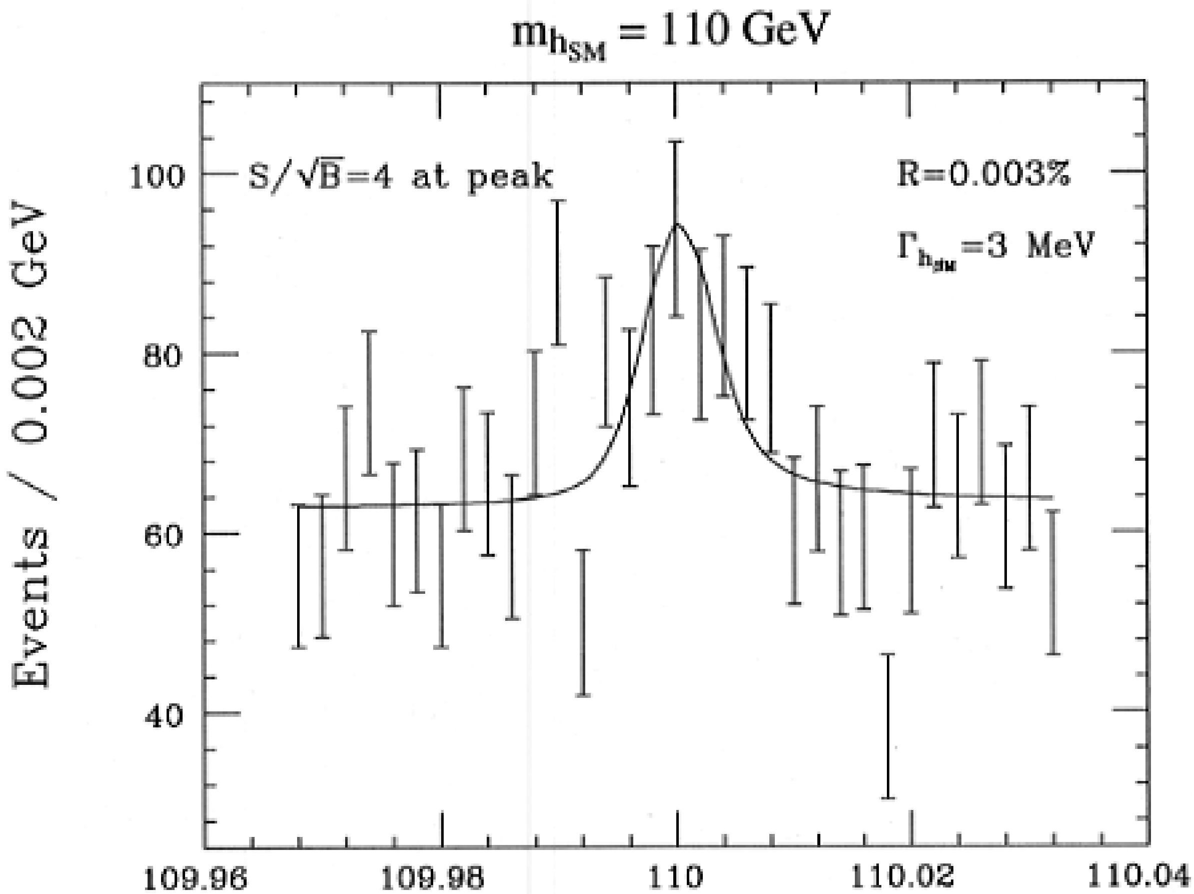


Scanning a light Higgs at the First Muon Collider



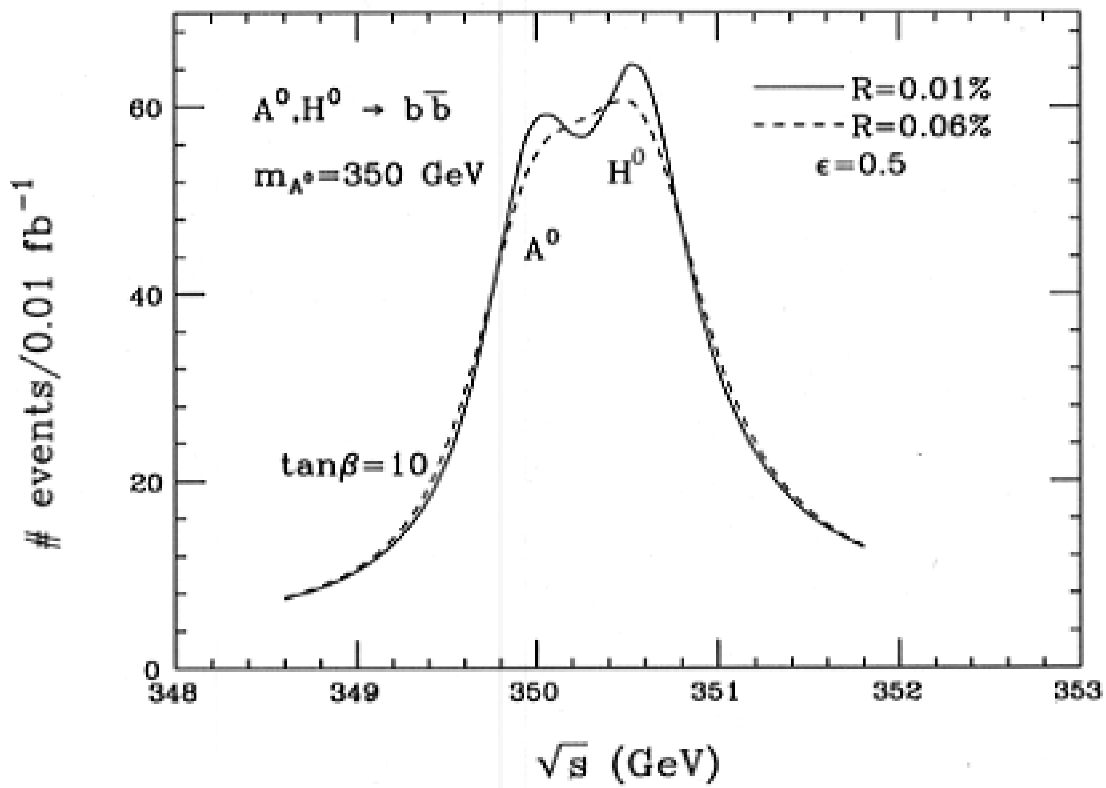
- Γ_h = 2-3 MeV if tan β = 1.8
- Γ_h = 2-800 MeV if tan β = 20
- 0.4fb-1 , will give the following measurement errors
  Γ_h = 16%, σ.BF(bb)=1%, σ.BF(WW*)=5%
- r=BF(WW*)/BF(bb) is sensitive to m_{A0} for m_{A0}<500GeV.
- r_{MSSM}/r_{SM} = 0.3,0.5,0.8 for m_{A0}= 200,250,400 GeV

Scanning the Higgs peak using the muon collider



- 1 year of running at $L=1.5\times10^{31} cm^{-2} s^{-1}$
- ($0.15 fb^{-1}$)/year to measure the Higgs mass to 1MeV

Resolving a degenerate H^0 and A^0 in MSSM using the muon collider



- H^0 and A^0 are broader. Γ~30MeV $m_{A0}<2m_t$, and Γ~3GeV for $m_{A0}>2m_t$. Can use broad-band collider.
- In the MSSM, $m_{A0}\sim m_{H0}\sim m_{H+}\sim m_{H-}$ for large m_{A0}.
- In this case only the muon collider s-channel scan can distinguish between the two nearly degenerate states.

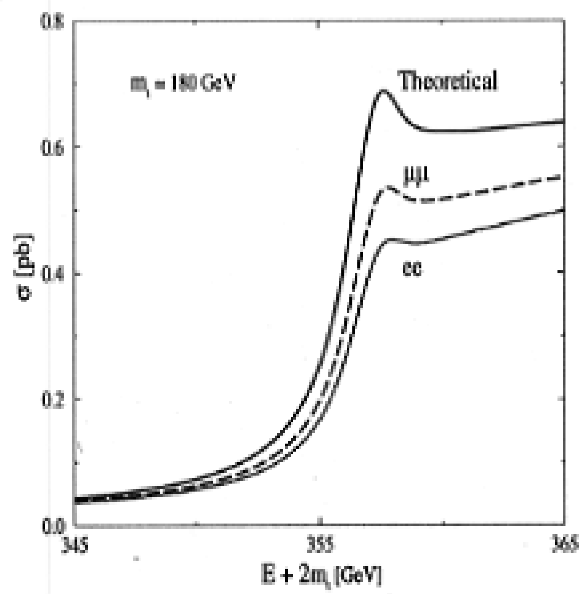
Threshold scans

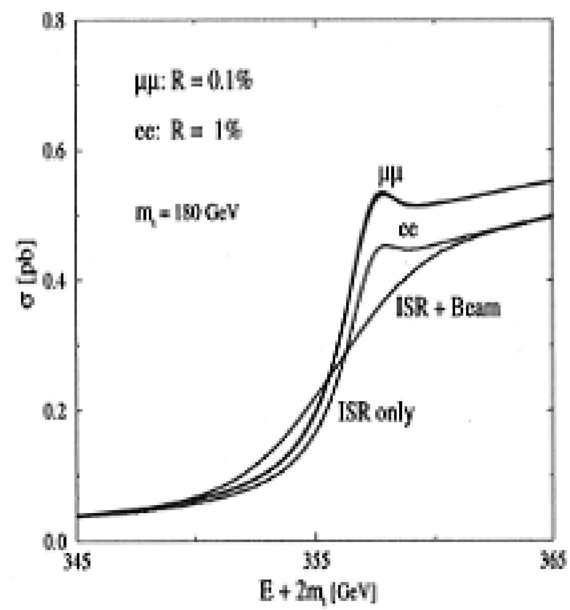
- With 10 fb^{-1} of luminosity devoted to a threshold scan cross-section, the following precisions on particle masses may be achievable.

$$\mu^+\mu^- \rightarrow W^+W^- \;--\Delta m_W = 20\,MeV$$

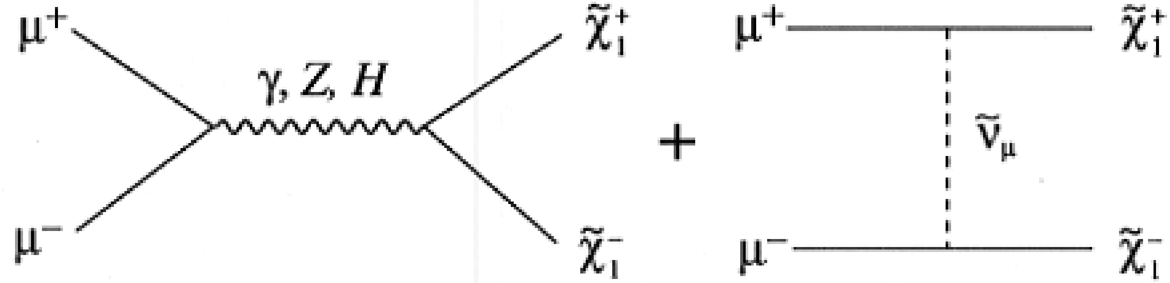
$$\mu^+\mu^- \rightarrow t^+t^- \;--\Delta m_t = 200\,MeV$$

$$\mu^+\mu^- \rightarrow Zh \;\;--\Delta m_h = 140\,MeV$$

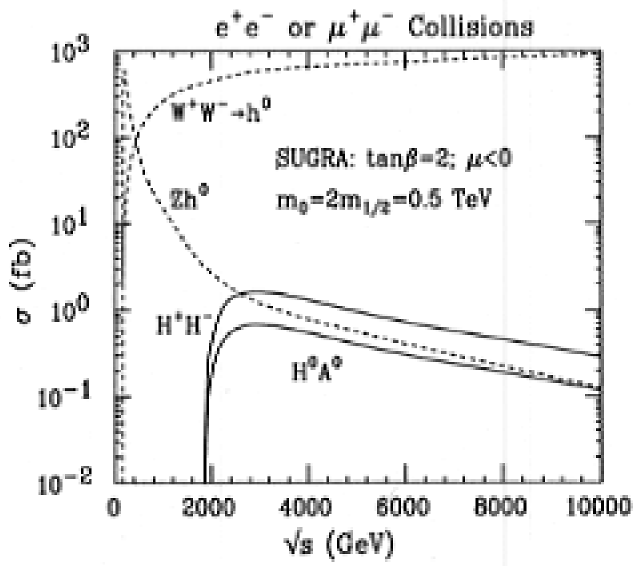


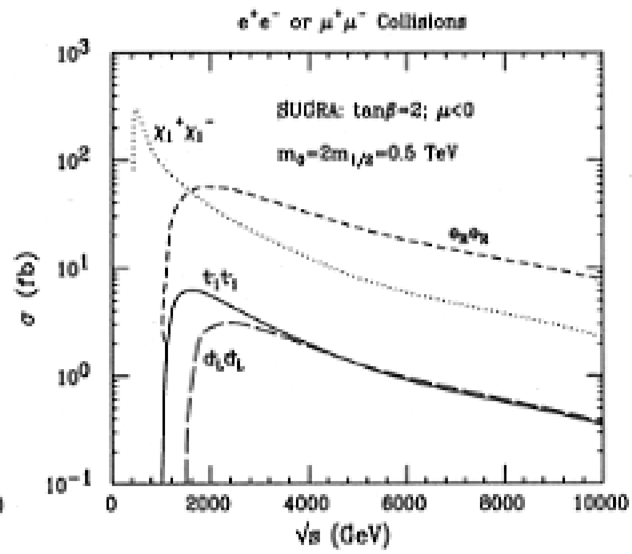


Susy production

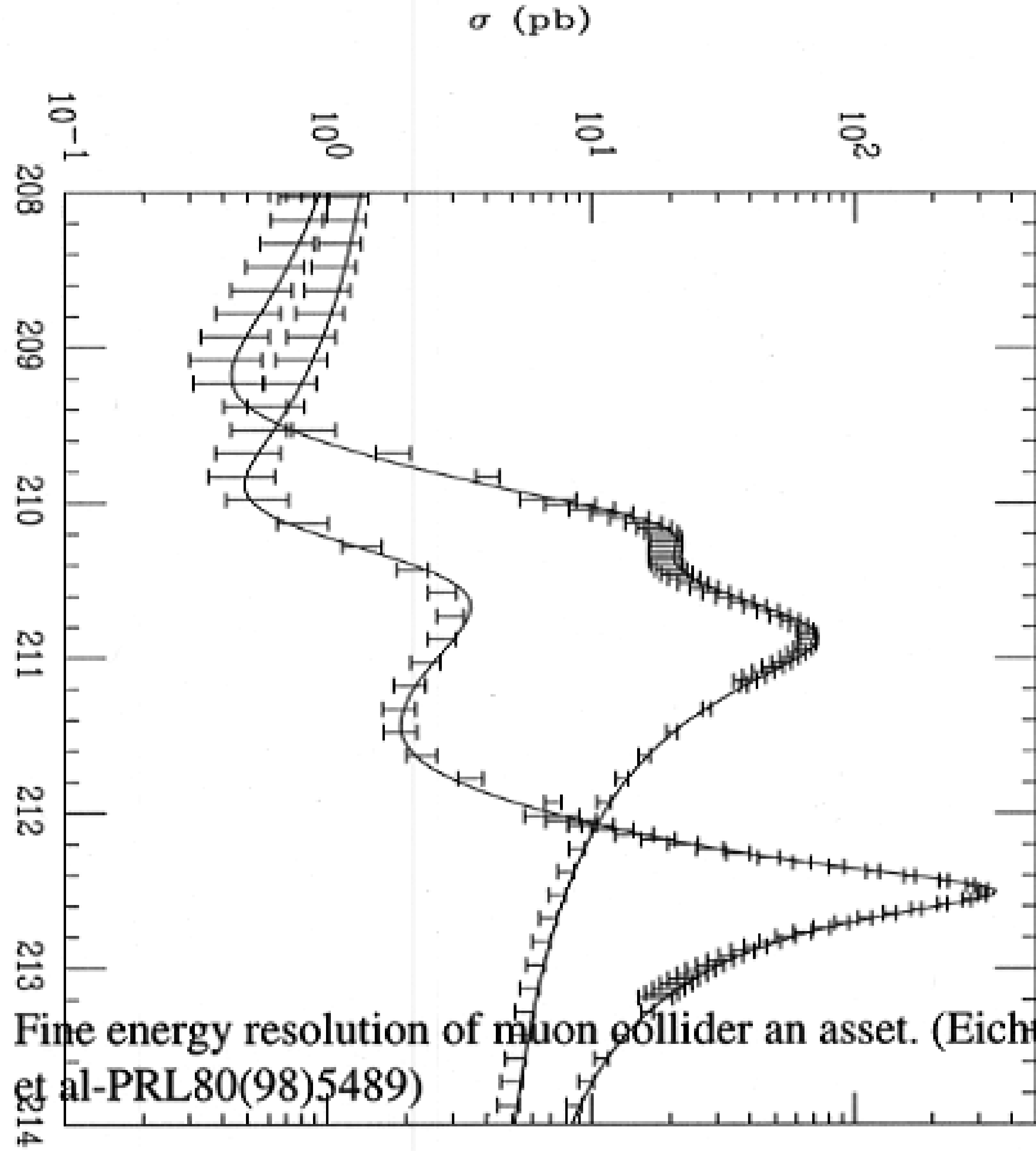


- $50 fb^{-1}$ and momentum resolution =0.1% and two scan points can lead to mass determination of chargino to 35(45) MeV for a chargino mass of 100 GeV and a sneutrino mass of 500 (300) GeV; mass errors of 150(300)MeV for chargino mass of 200 GeV and a sneutrino mass of 500(300)GeV.
- Heavy Susy Scalar pair production is P-Wave suppressed. For masses of 1TeV, collider energy of 3-4 TeV CMS is needed. Muon Collider would do the job.



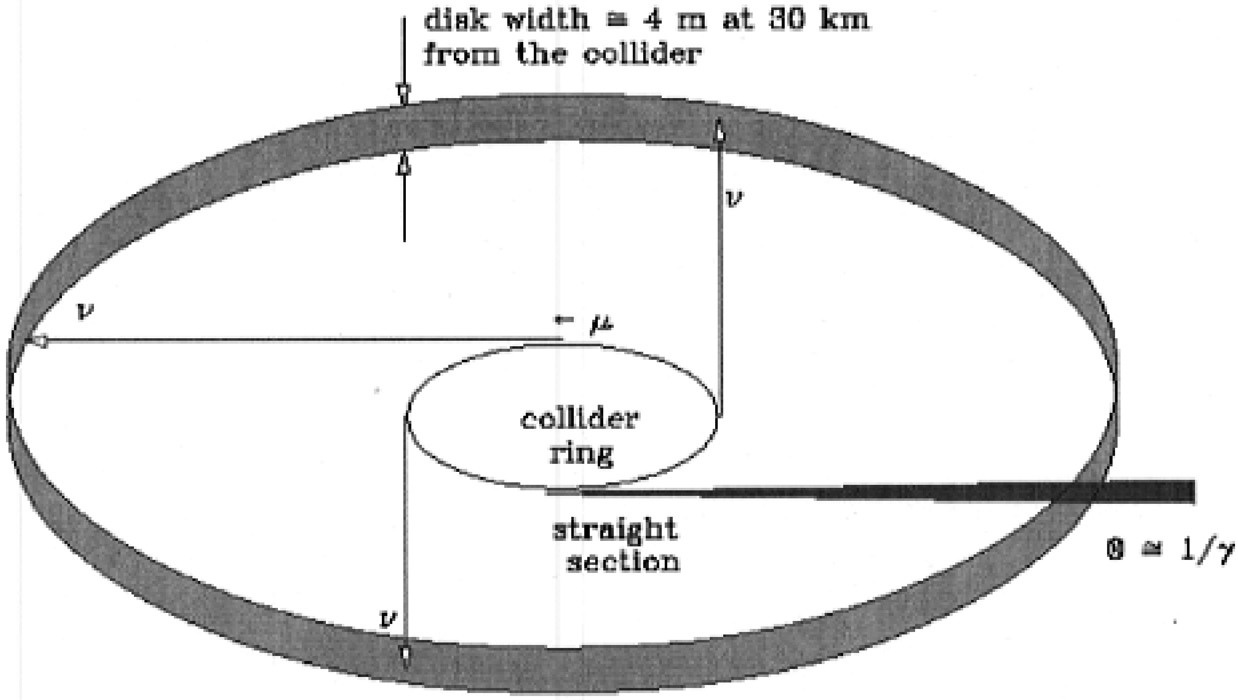


Technicolor s channel production-ρ_T ω_T interference



- Fine energy resolution of muon collider an asset. (Eichten et al-PRL80(98)5489)

Neutrino Induced Radiation



$$DB = 4.4\mathrm{x}10^{-24}\, I_{\mu} E^{3} t\langle B\rangle/(Bd)$$

Where DB(Sv) is the radiation dose acquired over time t sec in the plane of a bending field B(Tesla) in a circular collider of energy E(TeV) and average field $\langle B\rangle$(Tesla) and muon current of I_{μ} (muons/sec/sign) buried at depth d (meters)

Neutrino radiation

- In the case of a high beta straight section of length l (meters),

$$D_s = 6.7\text{x}10^{-24}\ I_\mu\ E^3\ t\ l\ \langle B \rangle/d$$

- For a low beta IP region, these formulae do not apply, since they assume that the divergence angles of the beam $<<1/\gamma$.
- For 3 TeV Com energy, $I_\mu = 6\text{x}10^{20}\ \mu/\text{yr}$, $\langle B \rangle = 6\text{T}$, B=10T and d=500m and taking the federal off site limit $D_{fed}=1\text{mS}_V/\text{year}$ (100 mrem/year) the annual dose D_B in the plane of the bending dipole is

$$D_B = 1.07 \text{ x } 10^{-5}\ S_V = 1\% D_{fed}.$$

For a straight section of length 0.6m,

$$D_s = 9.7\text{x}10^{-5}\ S_V = 10\% D_{fed}.$$

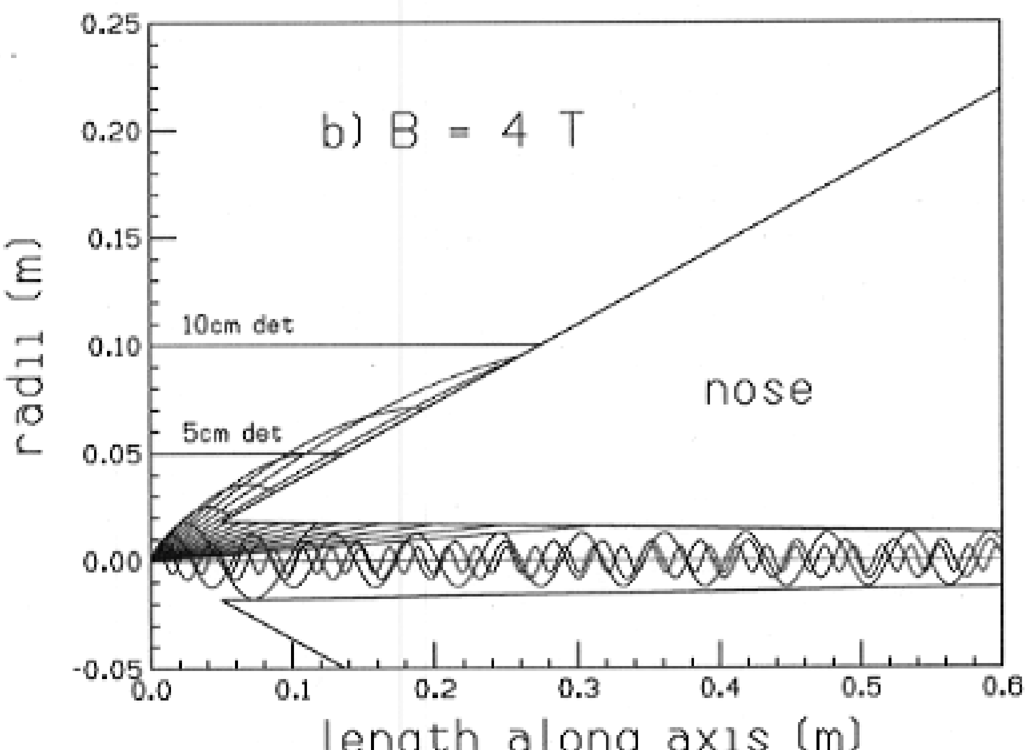
Beam manipulation tricks can be played. We feel that 3 TeV collider can be buried at ~300 meters.

Halo Background

- More work needs to be done in calculating injection losses and to develop a credible model for beam halo and beam losses.
- Beam gas scattering has been studied and shown to be a negligible source of beam halo generation.
- Beam-beam effects need further study.
- A scraper system has been studied and shown to suppress halos by a factor of 10^3.

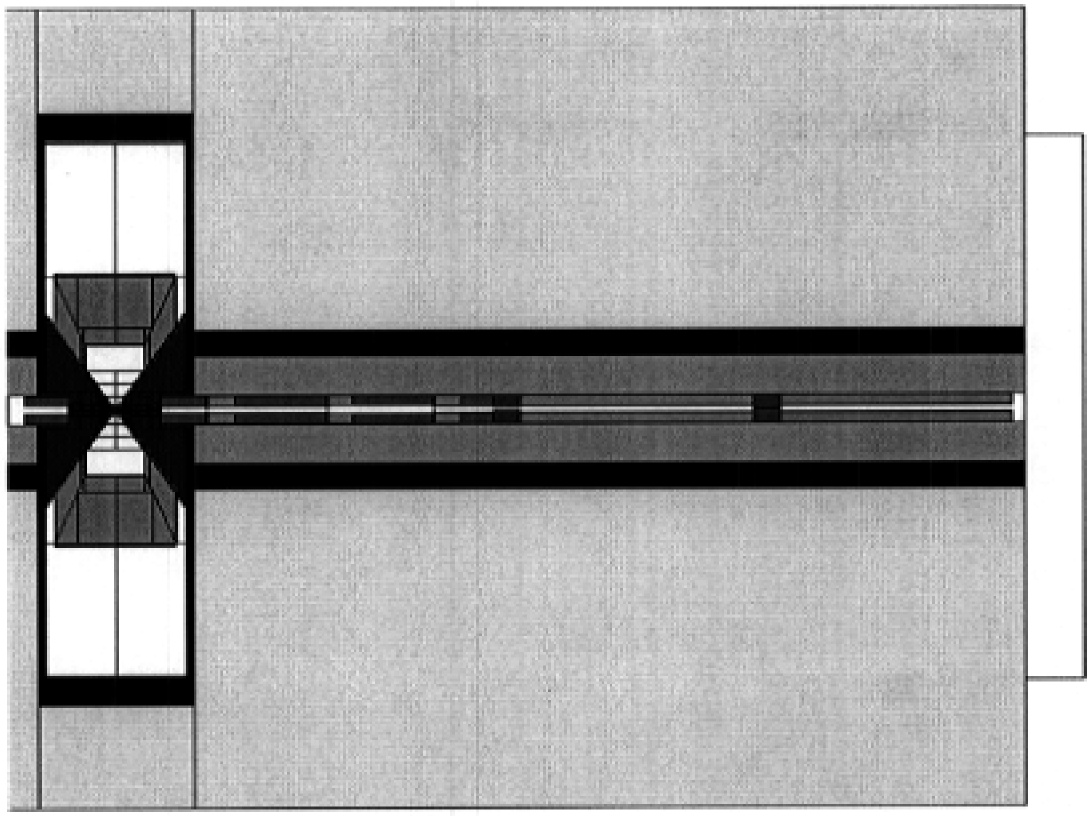
e^+e^- pair production at IP

- Coherent beam-beam electron pair production (beamstrahlung) has been shown to be negligible.
- Incoherent production $\mu\mu \rightarrow \mu\mu ee$) in the 4 TeV collider case is significant-10mb of cross section!



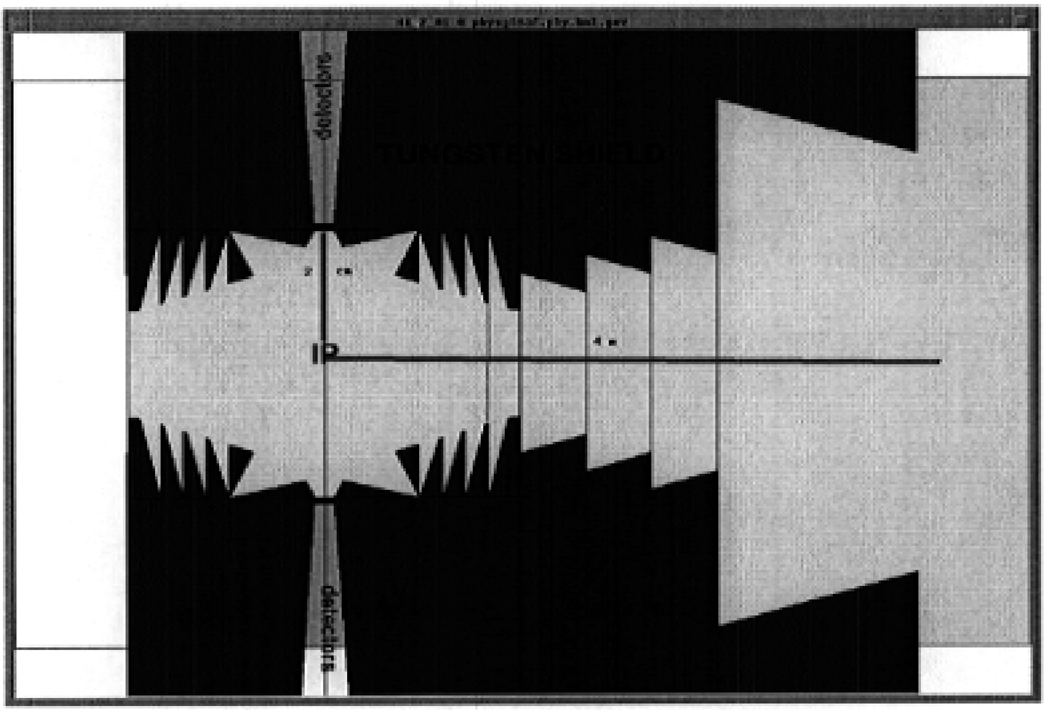
- Electrons with momenta from 3.8 MeV to 3000 MeV for the 4 Tesla solenoid detector.

Muon decay background-Design of shielding



- Region up to 130 m from the IP for 4 TeV collider. Triangular blue regions represent tungsten shielding. Red areas represent quadrupoles in beamline. Geant calculations done. Detector (white +green) is 10 m in diameter and 20 meters long.

Muon decay background-Design of shielding

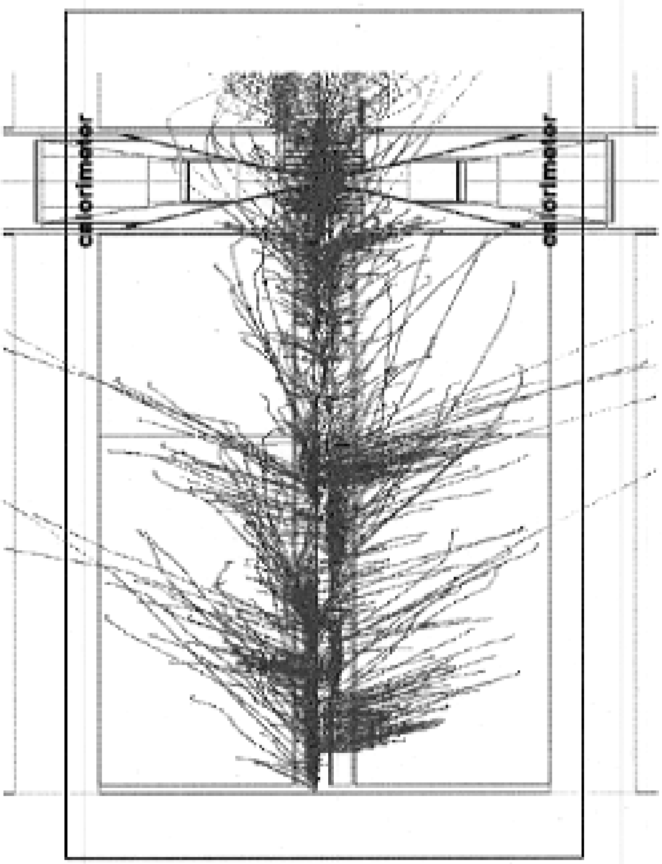


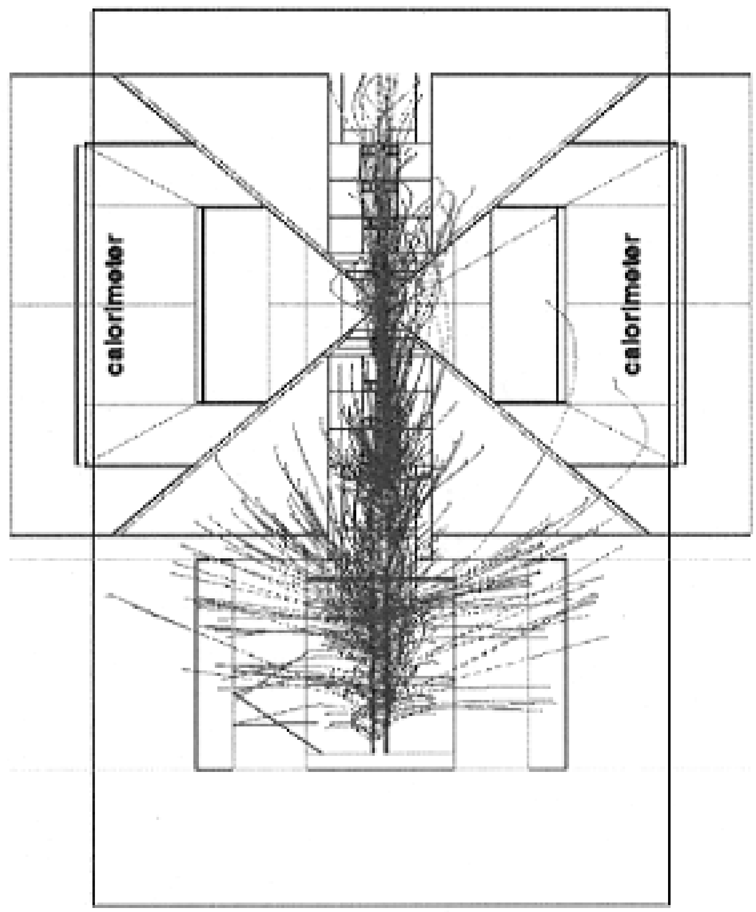
- IP design for 100GeV CoM collider. It is designed so that the detector is not connected by a straight line with any surface hit by decay electrons in forward or backward directions. Y axis goes to 6 cm and X axis 4 meters from IP.

Muon Decay backgrounds

- For a 4 TeV CoM collider, 4 x 10^{12} muon per bunch and 4 x 10^5 muon decays per meter.
- The off-energy, off-axis electrons undergo brehmsstrahlung when they traverse magnetic fields. When they exit the beam pipe, they produce electromagnetic showers and to a lesser extent hadrons and muons (Bethe-Heitler muons).
- The showers produce
  - » Low energy photons of ~1 MeV. These enter the detector and produce knock-on electrons.
  - » Photons interact with nucleii (Giant dipole resonance) and produce neutrons. These enter the detector and produce knock-on protons.
  - » Muon pairs are produced instead of electron pairs (~$1/10^4$) by photons in EM showers. These are called Bethe_Heitler muons and cause problems when they are energetic and enter the detector

Bethe-Heitler Muons





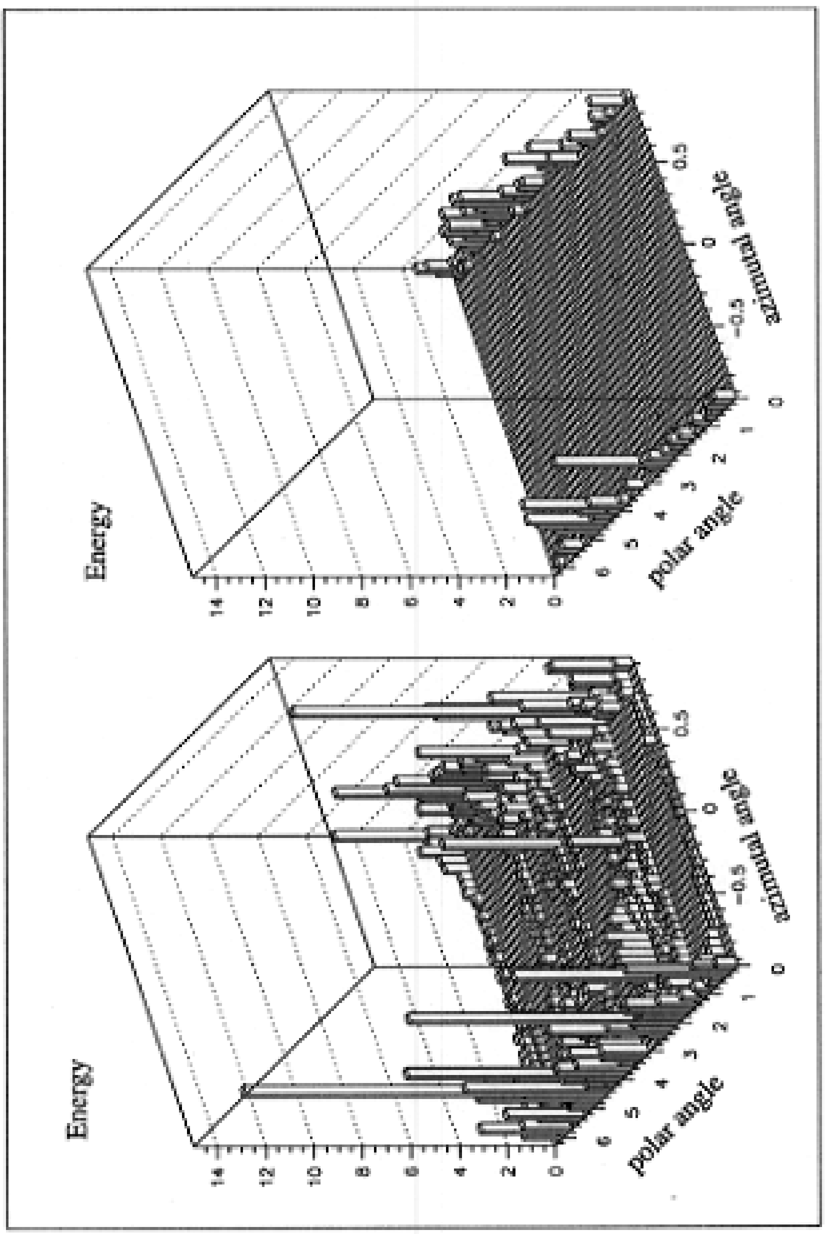
- 4TeV CoM case

100GeV CoM case

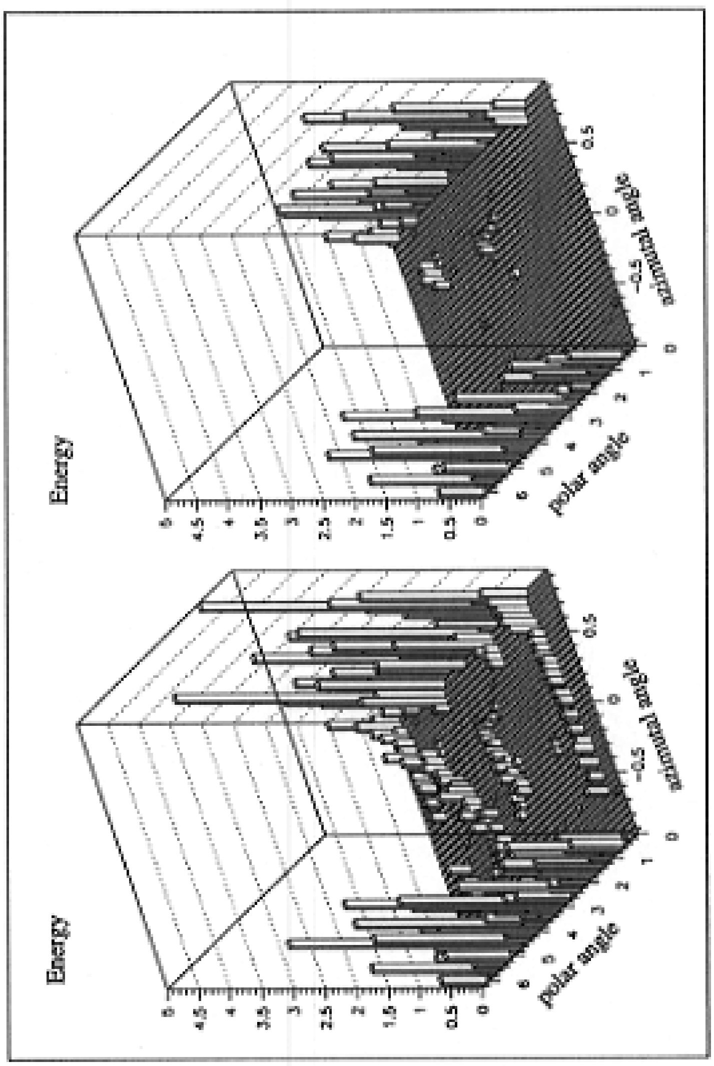
Bethe-Heitler Muons

oM Collider Energy (TeV)	*4*	*0.5*	*0.1*
ssumed source length	'30	33	20
μ ($p\mu$>1 GeV/c) per electron	$5.4x10^{-4}$	$8.3x10^{-5}$	$9.6x10^{-5}$
eam μ's per bunch	$2x10^{12}$	$2x10^{12}$	$4x10^{12}$
ethe_Heitler μ's per crossing	28000	17500	6100
$<p\mu>$ initial GeV	22	9.5	4.4
μ's in calorimeter	220	160	25
eposited energy GeV/muon	2.9	1.3	0.4
otal deposited energy GeV	640	210	10
edestal Subtracted E dep. GeV	50	25	1
luctuation in E dep. GeV	55	15	1
ransverse energy GeV(p.s)	15	15	.5
luctuation E trans	40	8	0.5

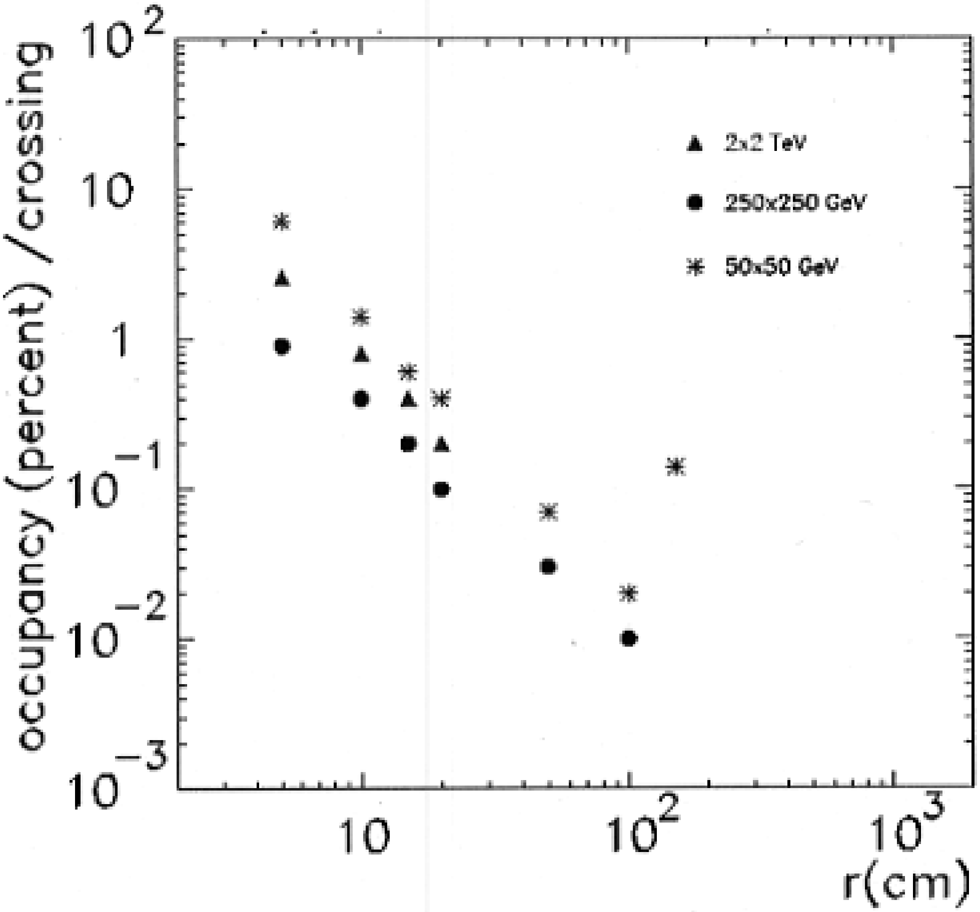
Bethe-Heitler Muons



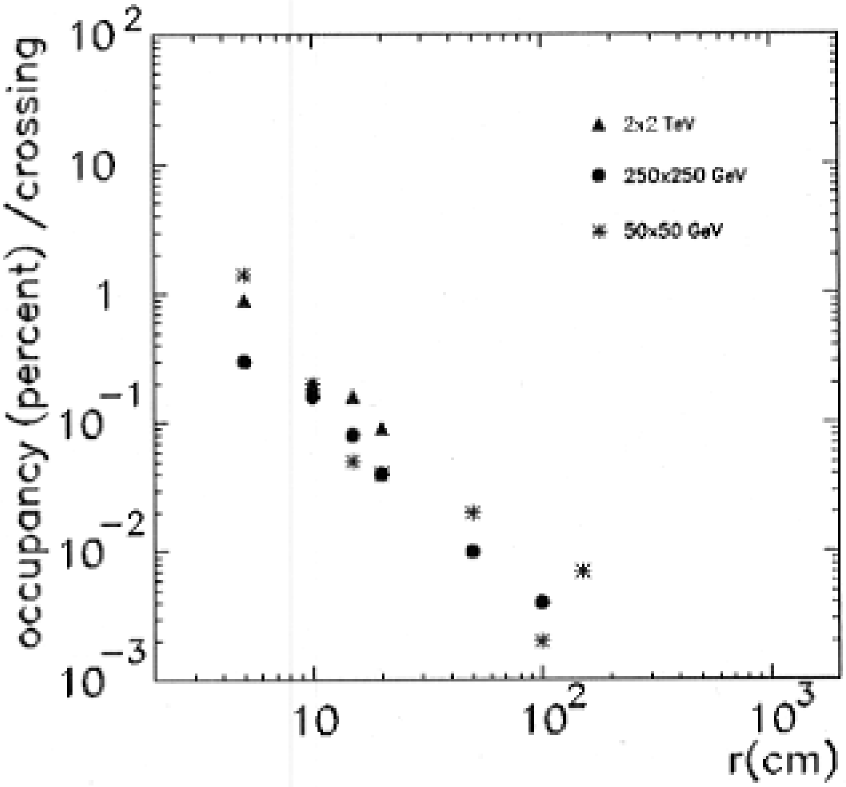
Bethe-Heitler Muons



Background Summary Neutral particles



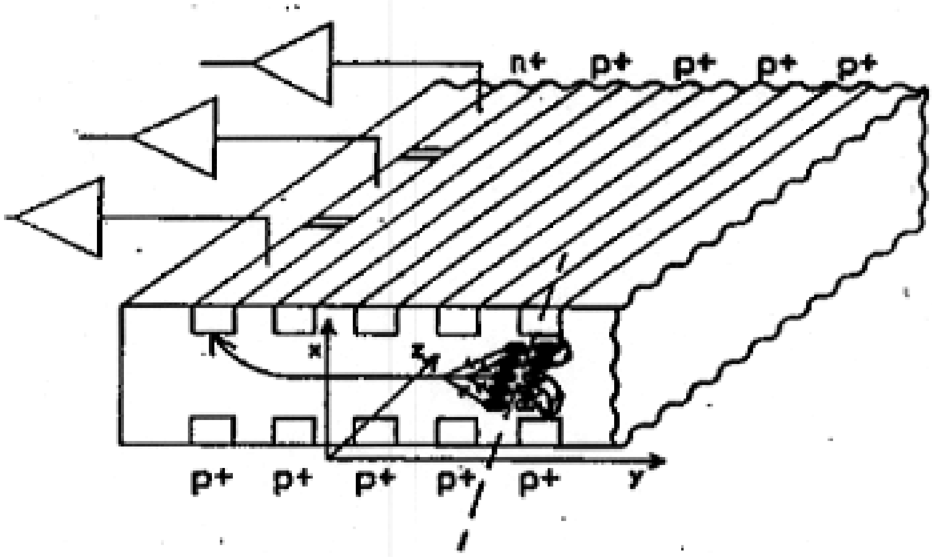
Background Summary
Charged particles

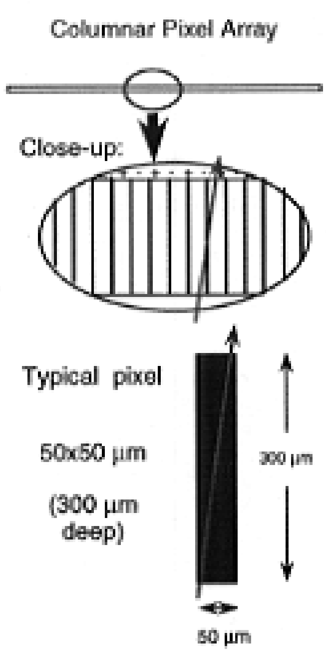


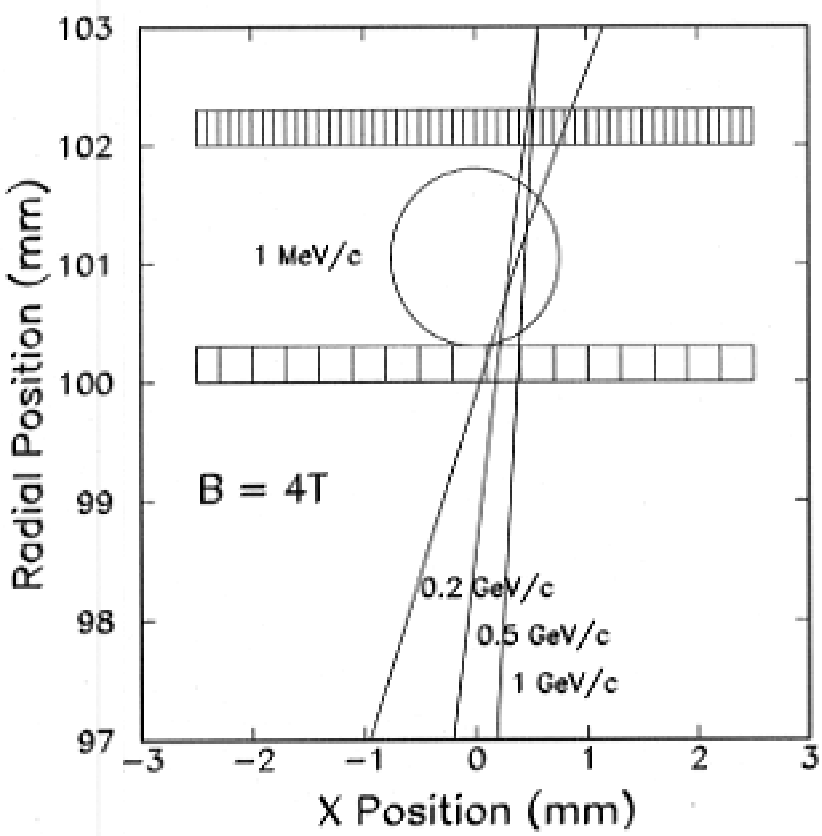
Background summary

Radius	*cm*	*5*	*10*	*20*	*100*
Photon hits	cm^{-2}	26	6.6	1.6	0.06
Neutron hits	cm^{-2}	0.06	0.08	0.2	0.04
Charged hits	cm^{-2}	8	1.2	0.2	0.01
Total hits	cm^{-2}	34	8	2	0.12
Pixel size	μm x μm	60 x 150	60 x 150	300x300	300 x 300
Total occupancy	%	0.6	0.14	0.4	0.02
Occupancy from Charged particles	%	0.14	0.02	0.04	0.002

Detector Scenarios-Silicon





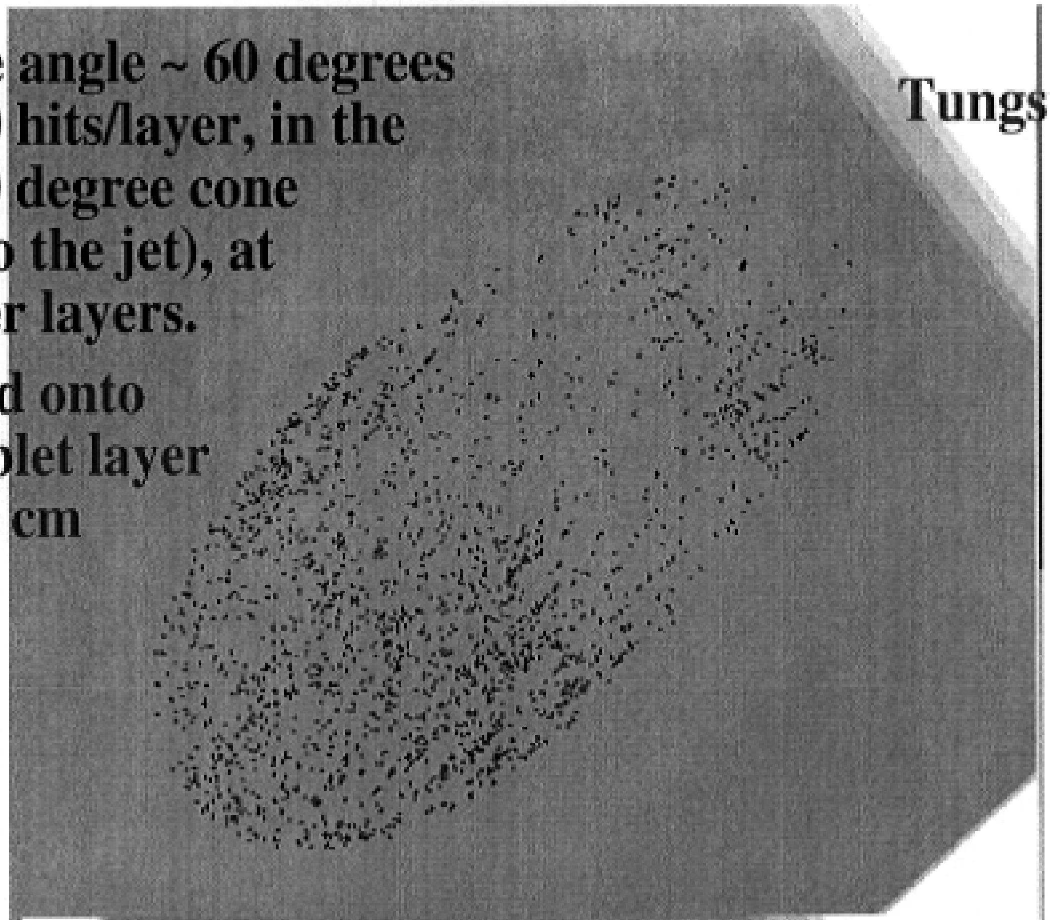


Effect of requiring Pixel Microtelescope micro–coincidence

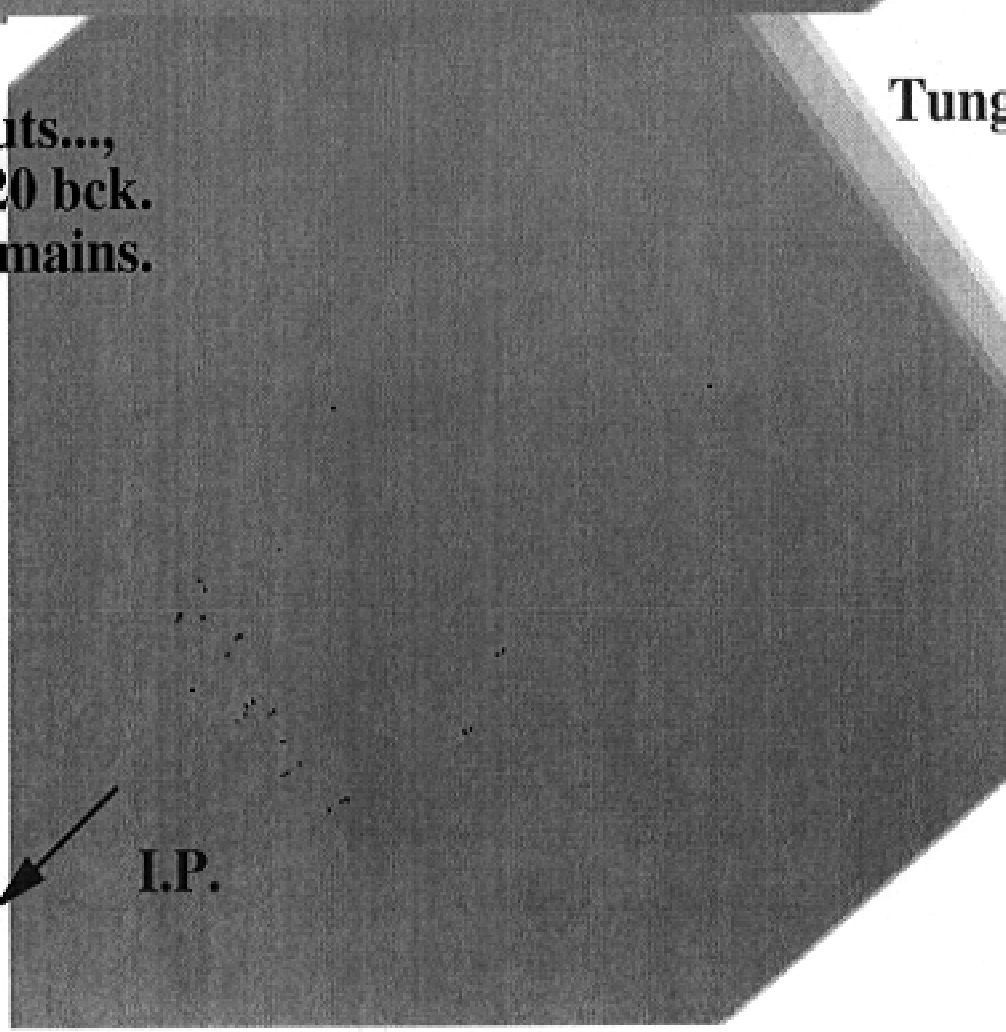
Paul Lebrun

At large angle ~ 60 degrees ~ 2,000 hits/layer, in the same 10 degree cone (perp. to the jet), at the outer layers.

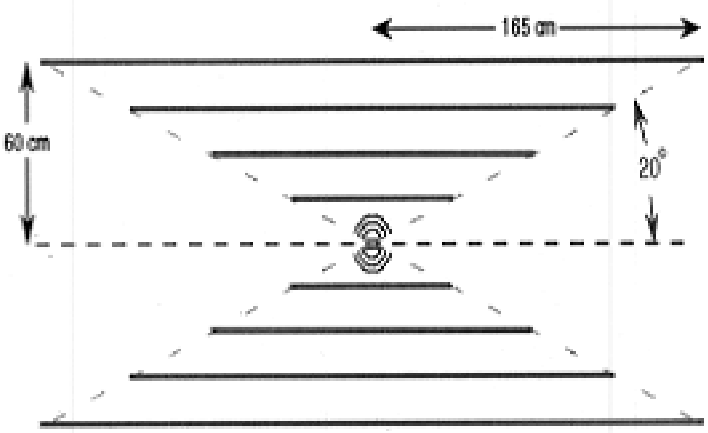
Projected onto one doublet layer at r = 25 cm

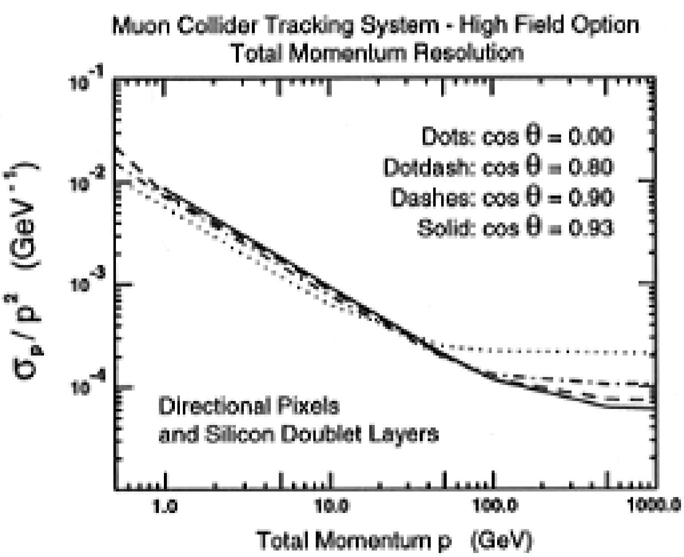


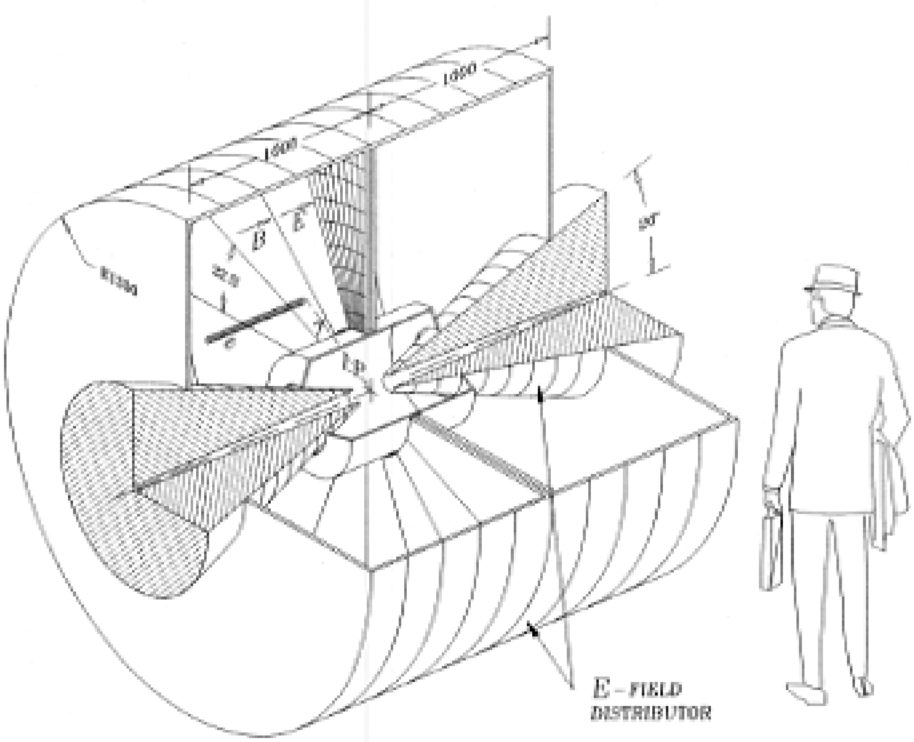
After cuts..., only ~20 bck. hits remains.



Detector Scenarios

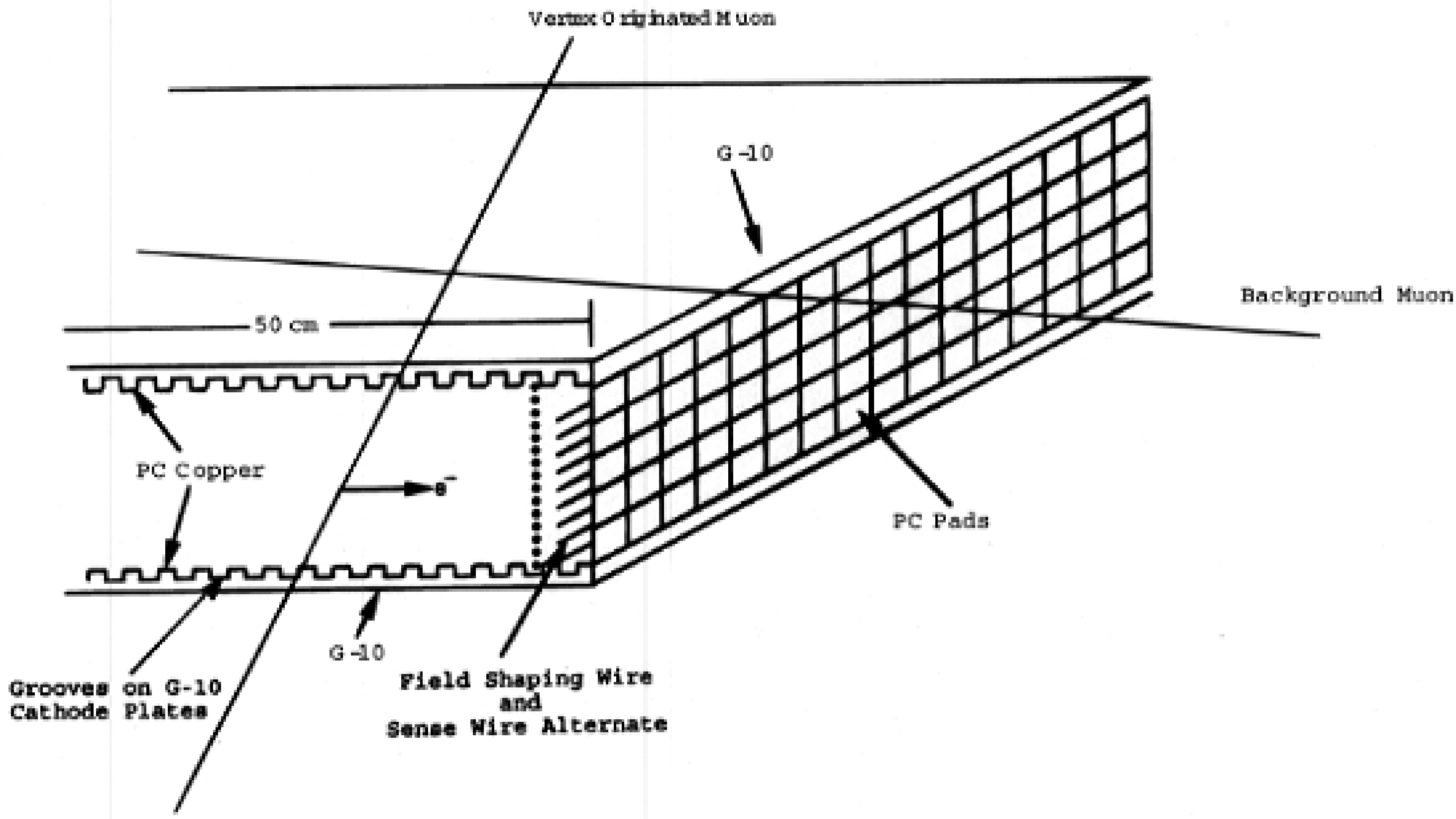




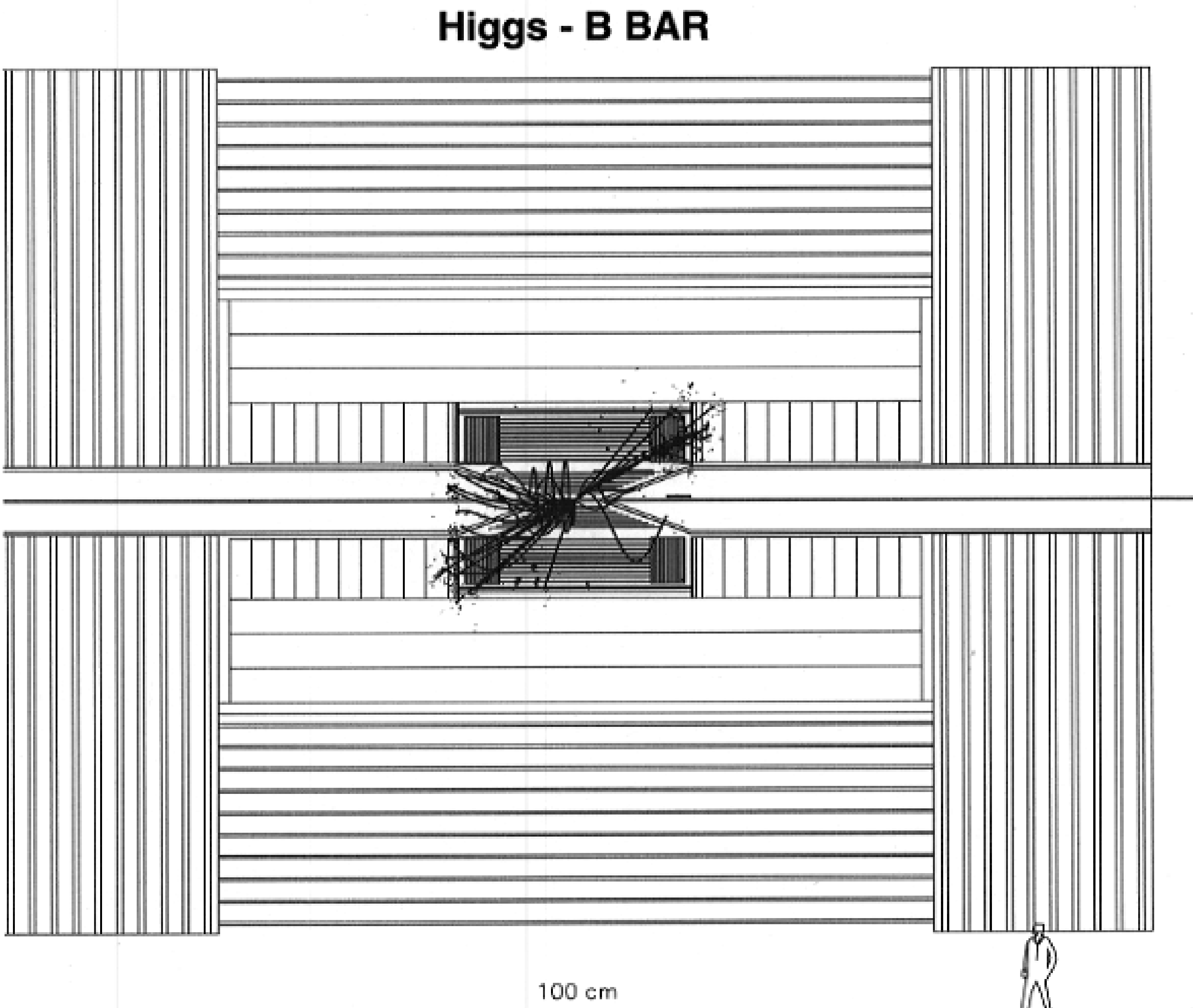


TIME PROJECTION CHAMBER

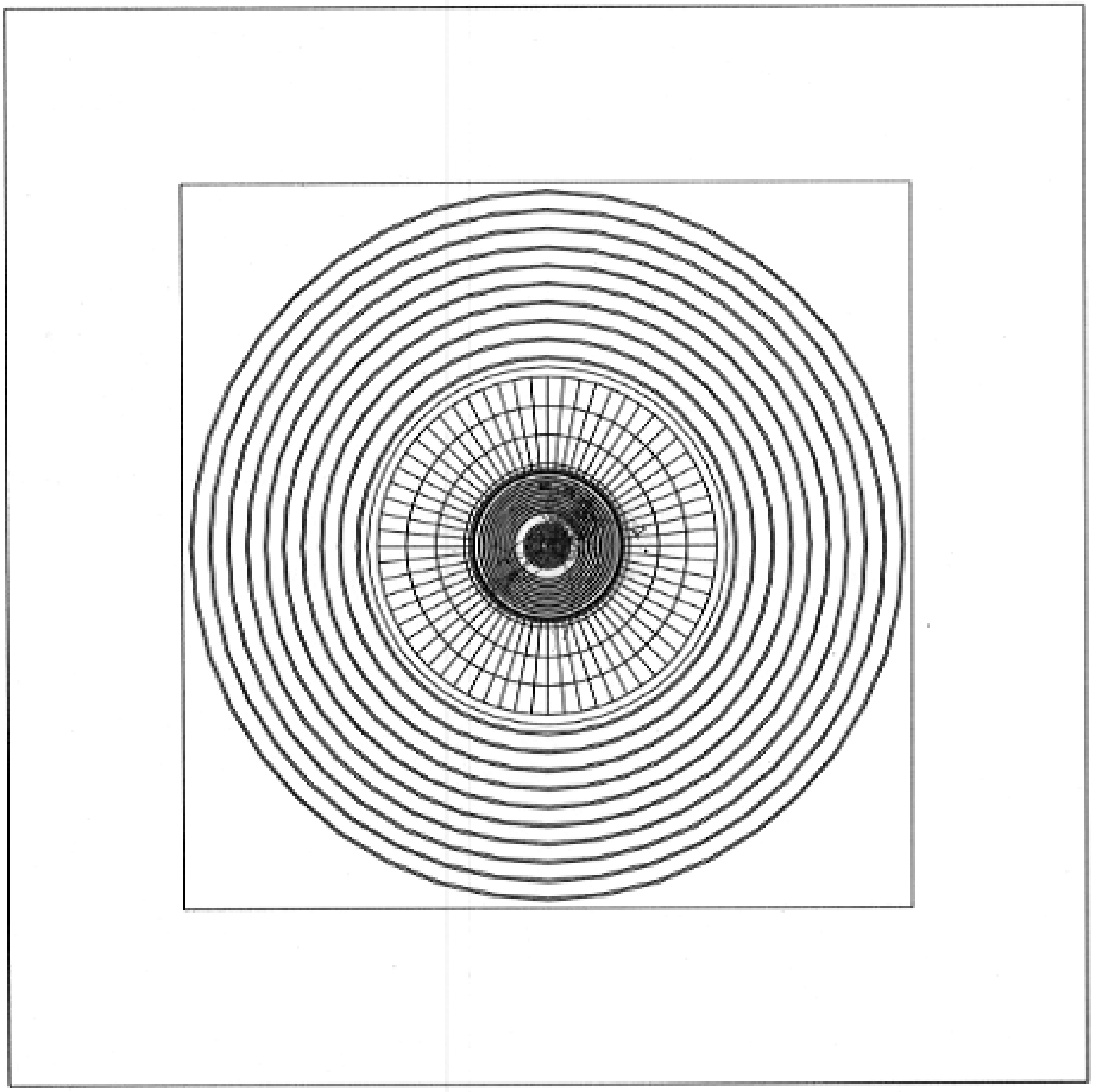
Detector Scenarios
Muon Systems



Detector Simulation



Detector Simulation



Jul 21,1999 Rajendran Raja, Mutac Review, FNAL 3

Simulation Questions to be answered

- Can one optimize the lattice near the interaction region to reduce the backgrounds further? (2 man-years)
- Can one do b-tagging using silicon pixels given the large number of hits caused by the photon background? (1 m.y.)
- What is the efficiency vs. purity of b-tagging? (1 m.y.)
- Can c-tagging be contemplated? (0.5 m.y.)

Simulation Questions to be answered

- How can one design a fast vertex algorithm so that silicon hits are readout only for projective coincidences in a pixel micro-telescope? (1 m.y.)
- Will a TPC work at all energies as an outer tracker? (1 m.y.)
- What segmentation does the calorimeter need to possess to pattern recognize Bethe-Heitler muons? (0.5 m.y.)
- What e/π ratio, linearity and resolution are necessary for the calorimeter? (0.5 m.y.)

Conclusions

- The muon collider is a concept worth investigating further
- Not all problems are solved, i's dotted and t's crossed. It is possible to take a critical look at any one component and immediately see further problems.
- It is by this process of critical examination that problems have been solved and the examiners become proponents.
- Promise of physics on the way to the collider.
- Collider promises unique access to s-channel Higgs and higher energies.