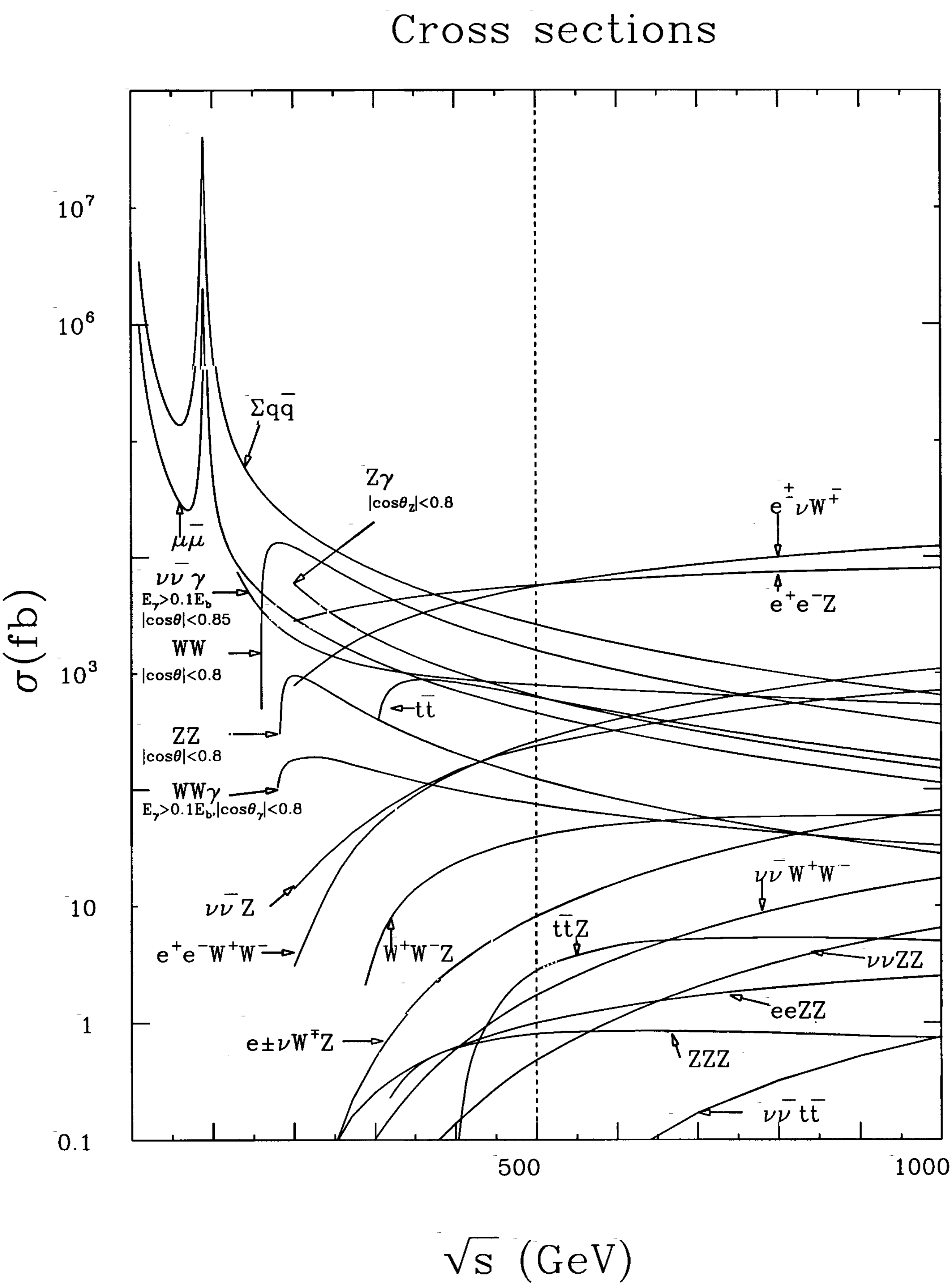
# LC Muon System R & D

- Sources of Muons
- Muon System Specifications
- Example Muon Systems
  - RPC Detector Studies
  - Scintillator Detector Studies
- R & D Issues
- How you can get involved

Gene Fisk April 5, 2002
R&D Opportunities for the LC

# Sources of Muons

- Conventional EW Physics
- New Physics
- Beamline Muons



Cross sections
σ(fb)
√s (GeV)
10^7
10^6
10^3
10
1
0.1
500
1000
Σqq̄
μμ̄
Zγ
|cosθ_Z|<0.8
νν̄ γ
E_γ>0.1E_b
|cosθ|<0.85
WW
|cosθ|<0.8
ZZ
|cosθ|<0.8
WWγ
E_γ>0.1E_b,|cosθ_γ|<0.8
tt̄
e^±νW^∓
e^+e^-Z
νν̄ Z
e^+e^-W^+W^-
W^+W^-Z
tt̄Z
νν̄ W^+W^-
ννZZ
eeZZ
e±νW^∓Z
ZZZ
νν̄ tt̄

# Conventional Physics –Muon Sources

| Final State | 500 GeV | | 1000 GeV | |
|---|---|---|---|---|
| | σ(fb) | σ*BR(fb) | σ(fb) | σ*BR(fb) |
| $e^{\pm}$? $W^{\mp}$ $e^{\pm}$? $\mu^{\mp}$? | 5,640 | 625 | 12,400 | 1,380 |
| $e^{+}e$ $Z$ $e^{+}e$ $\mu^{+}\mu$ | 5,900 | 200 | 8,100 | 275 |
| $q\bar{q}$ $b,c$ $\mu$ | 2,700 | 180 | 660 | 22 |
| $WW$ ? $q\,\bar{q}\,\mu$ ? | 1,660 | 350 | 360 | 76 |
| $t\,\bar{t}$ $W^{+}bW\ \bar{b}$ | 565 | 215 | 180 | 68 |
| $\mu\ \mu$ | 435 | 435 | 115 | 115 |
| Totals | 16,900 | 2,005 | 21,815 | 1,936 |

$$\int l\,dt = 10^{34}\,cm^{-2}s^{-1} * 10^{7}\,s = 100\,fb^{-1}$$

$$\Rightarrow \quad 200K\ \mu\text{'s per year}$$

# Higgs Production

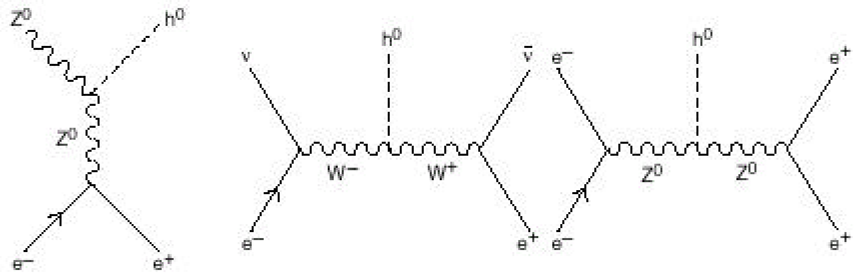
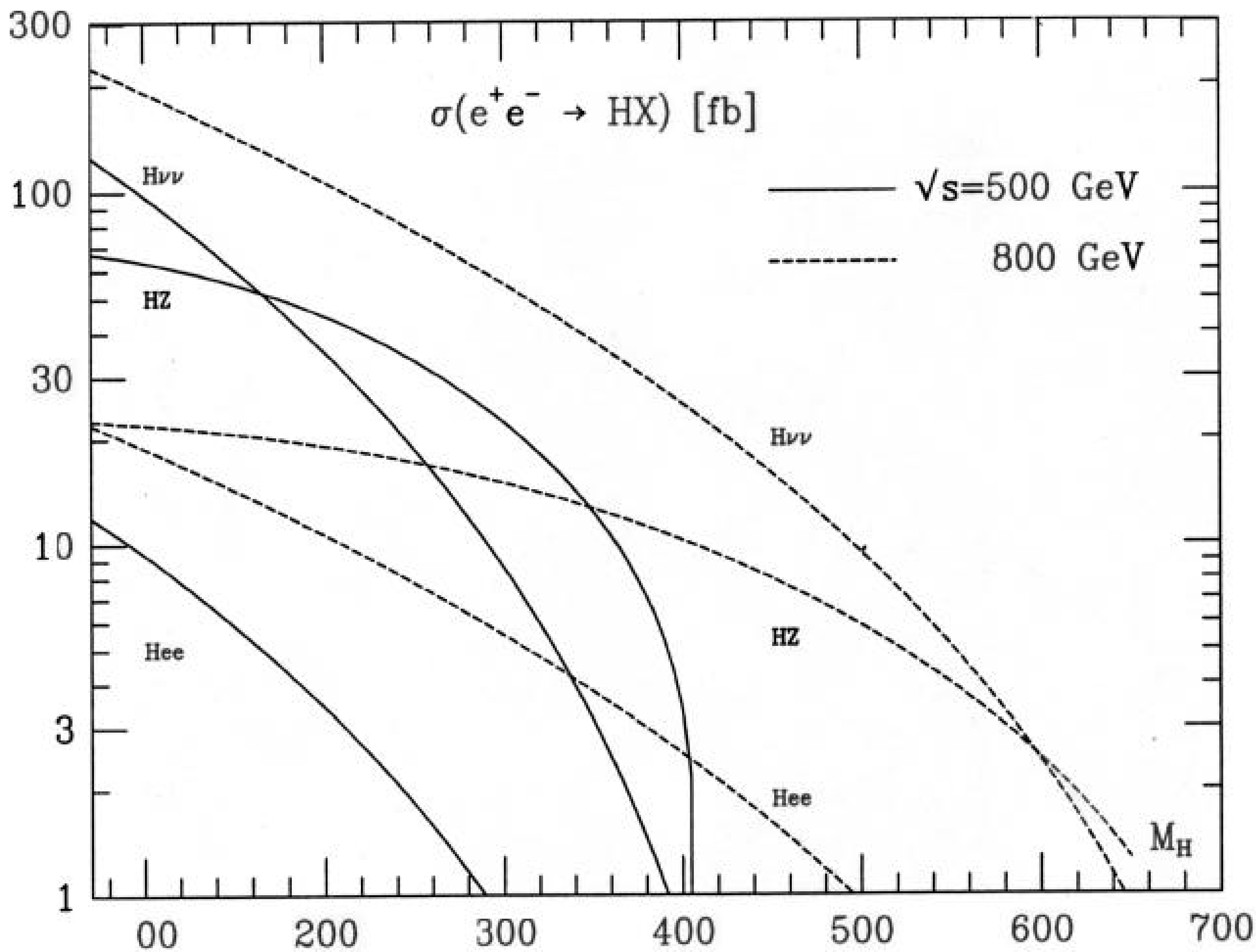



Figure 3: Processes for production of the Higgs boson at an $e^+e^-$ linear collider.

From J. Bagger et al, The Case for a Linear Collider ..



## Muon Sources – New Physics

| SM Higgs | 500 GeV | | | 800 GeV | | |
|---|---|---|---|---|---|---|
| **Final State** | $\sigma$(fb) | $\sigma$*$BR_Z$(fb) | $\sigma$*$BR_H$(fb) | $\sigma$(fb) | $\sigma$*$BR_Z$(fb) | $\sigma$*$BR_H$(fb) |
| *Z H* (140) ?*μ μ H* | 58 | 2 | 10 | 22 | 0.7 | 4.0 |
| *H* (140) ? ?¯ | 67 | | 12 | 150 | | 27 |
| $e^+e^-$ *H* (140) | 6.5 | | 1.2 | 15 | | 2.7 |
| *H* (140) *Totals* | 131.5 | 2 | 23.2 | 187 | 0.7 | 33.7 |
| *Z H* (350) *μ μ H* | 12 | 0.4 | 2.2 | 12 | 0.4 | 2.2 |
| *H* (350) ? ?¯ | 3.2 | | 0.6 | 38 | | 6.8 |
| $e^+e^-$ *H* (350) | 0.4 | | 0.1 | 3.9 | | 0.7 |
| *H* (350) *Totals* | 15.6 | 0.4 | 2.9 | 53.9 | 0.4 | 9.7 |

*BR of H to one or more muons
for H(140), ignoring Z =>bb +> $\mu$

$BR_H$ = BR(H=WW*2*BR(W=>$\mu$) +
BR(H=>bb*2*BR(b=> $\mu$)

= 0.48*2*(1/9) + 0.37*2*0.1
= 0.181

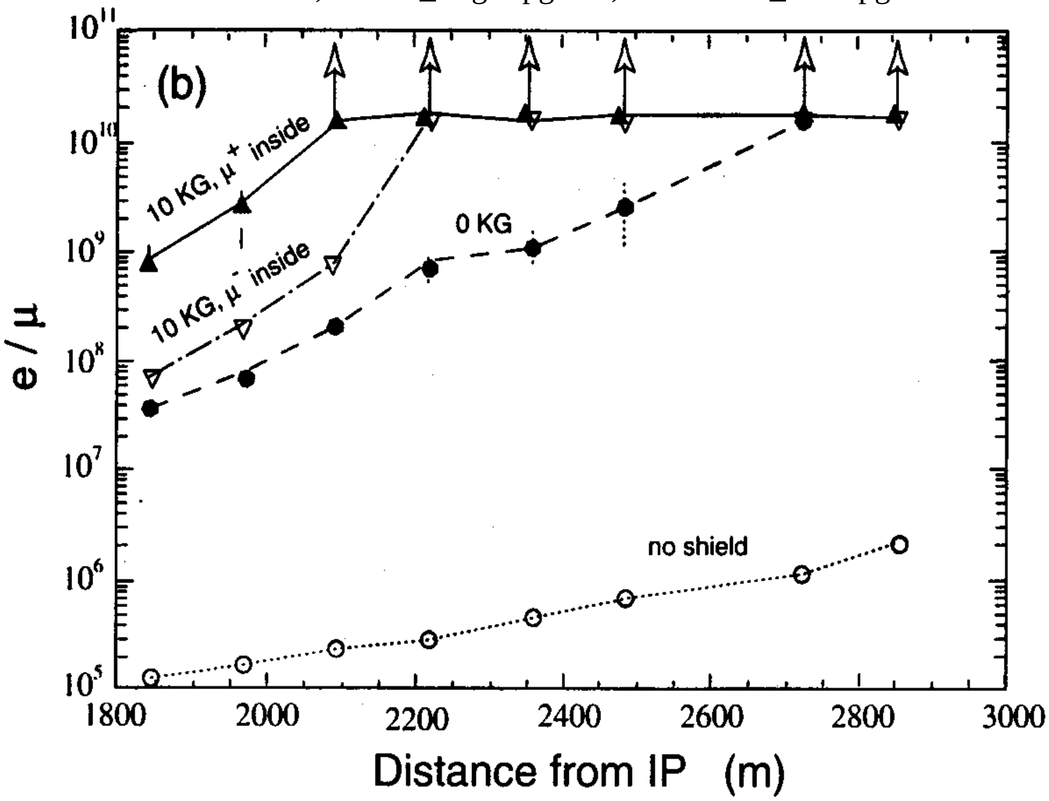
for H(350), ….

$BR_H$ = BR(H=WW*2*BR(W=>$\mu$) +
BR(H=>ZZ)*2*BR(Z=> $\mu$) +
BR(H=>tt)*2*BR(t=> $\mu$)
= 0.68*2*(1/9) +
0.31*2*0.03367 +
0.01*2*0.19
= 0.176

**Higgs with 1,2 or 3 muons is rare; hundreds/year**
**Muon detection must be very efficient.**

# Beam Line Muons

T. Tauchi, LCWS_Sitges pg 811, and LCWS_2000 pg 107




**Collimation using concentric magnetized axial toroids.**
**B = 10KG; B+ for 1 < r < 10 cm; B- for 10 <r < 30 cm.**

**~$10^{10}$ e's/RF bucket with 0.1 - 1% lost in phase-space tails.**

**Attenuation:**

**~1 X $10^5$ - No shield**
**~3 X $10^7$ - Collimation (x, y, $p_x$, $p_y$) w/o B**
**~$10^9$ - $10^{10}$ - Collimation w B**

**Also will attempt to eliminate phase-space tails at 8 GeV.**

**Expect < 1 to 10 beamline m's per pulse.**

# Muon Rate Summary

One year ($10^7$ s) at $10^{34}$ $cm^{-2}$ $s^{-1}$ is 100 $fb^{-1}$.

- **Conventional** sources of muons:

  2 pb * 100 $fb^{-1}$ * 50% eff. = 100K events.

- **New Physics**: Higgs => muons

  25 – 50 fb * 100 $fb^{-1}$ * 50% = 3 – 5 K events

- **Beamline Muons**: Assume 1μ for each $10^{12}$ electrons.

NLC: 190 pulses w/0.75 E10 e's/pulse in
266 ns => 1.46 μ's per train.

JLC: 72 pulses w/ 1.1 E10 e's/pulse in
202 ns => 0.8 μ's per train.

TESLA: 2820 pulses in 0.95ms => 29 pulses
in 10μs w/ 2E10e's/pulse, =>
0.58 μ's per 10 μs.

# R&D Topics: Physics & Backgrounds

We need to look at:

- Muons from interesting sources:

  $c\bar{c}, b\bar{b}, t\bar{t}, W^{+}W^{-}$

  Overlap with physics groups:

  Higgs (VanKooten),
  Top (Gerdes),
  W pairs (Barklow)
  SUSY e.g. Smuons (Nauenberg)

  Not competition, but to make sure the muon system can do what is required. (efficiencies, etc.)

- Muon backgrounds from linac, IR, and $u, d, s$ decays

- Compilation of what is known/needed. X

# Simulation Help

In addition to Norm Graf et al, at SLAC, there is local help for generating event samples: NICADD (No. Ill Center for Accelerator & Detector Development).

Muon Detector Simulation Personnel:

David Hedin
Arthur Maciel*
Rob McIntosh

Recently joined: Caroline Milstene

# Muon System Specifications

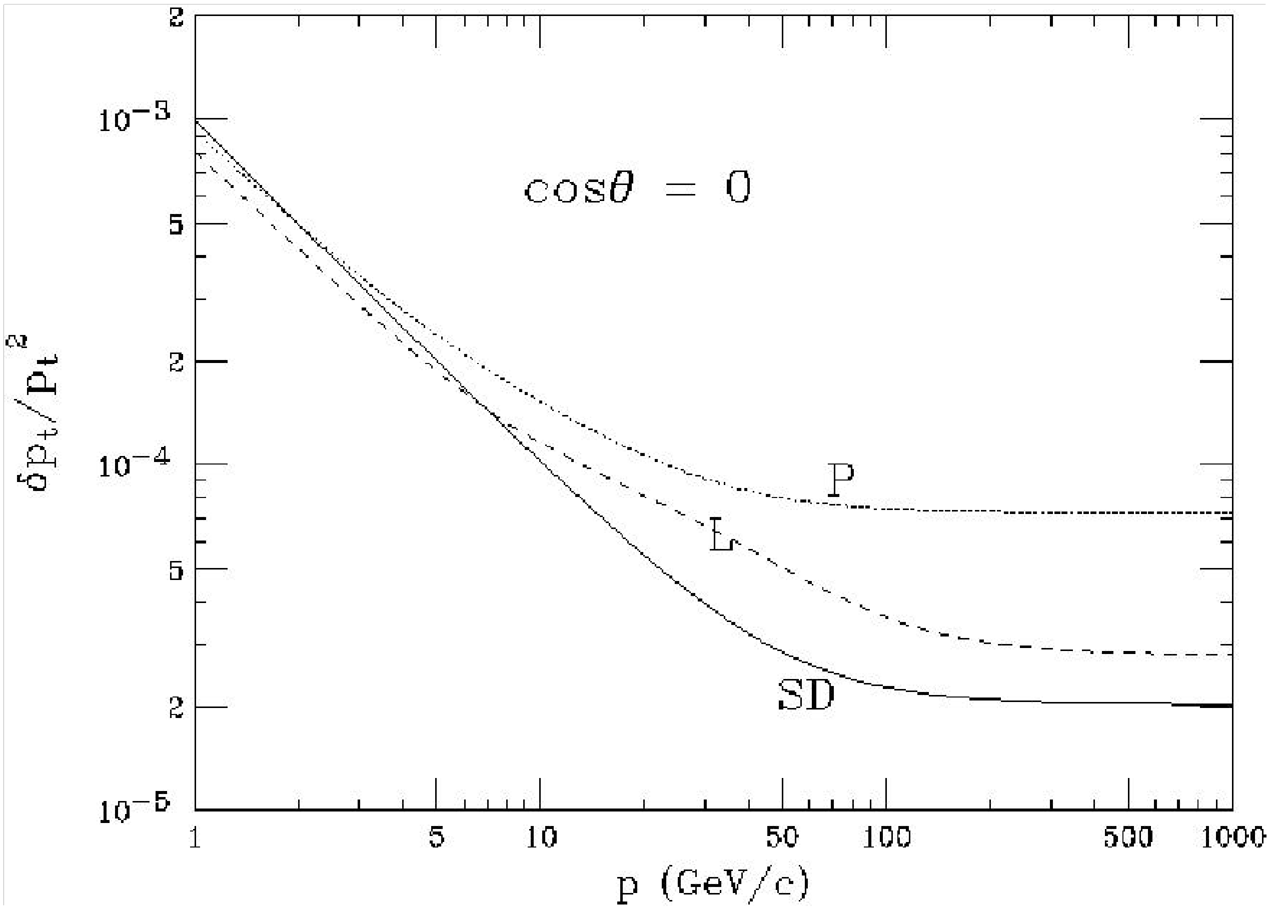
- Muon **Identification** by penetration through **12 – 14 l**.
- Muon **Charge** & precise **Momentum** from central tracking.
- Muon **Tracking** and **Link-up** with cent. tracking: **~15 hits**
- High **Tracking Efficiency**.
- **Tail-catcher Calorimeter**.
- **Must identify conventional and new physics muons and background muons from the beams and cosmic sources.**

**Candidate technologies:**

(1) Resistive Plate Chambers

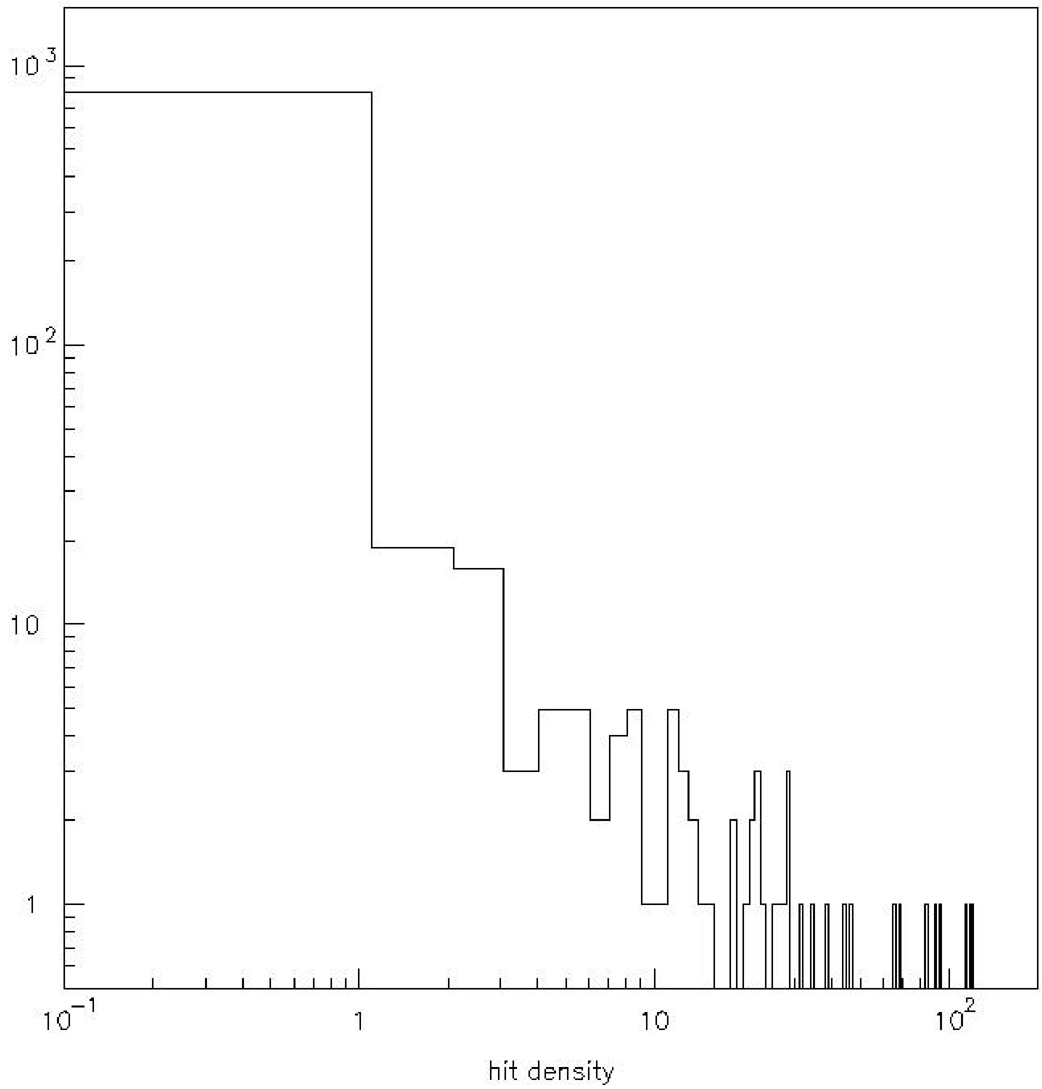
(2) Scintillator Based Detectors

# Central Tracking Momentum Resolution




From: “Detectors for the Next Linear Collider”
ed. J. Brau et al; Snowmass 2001

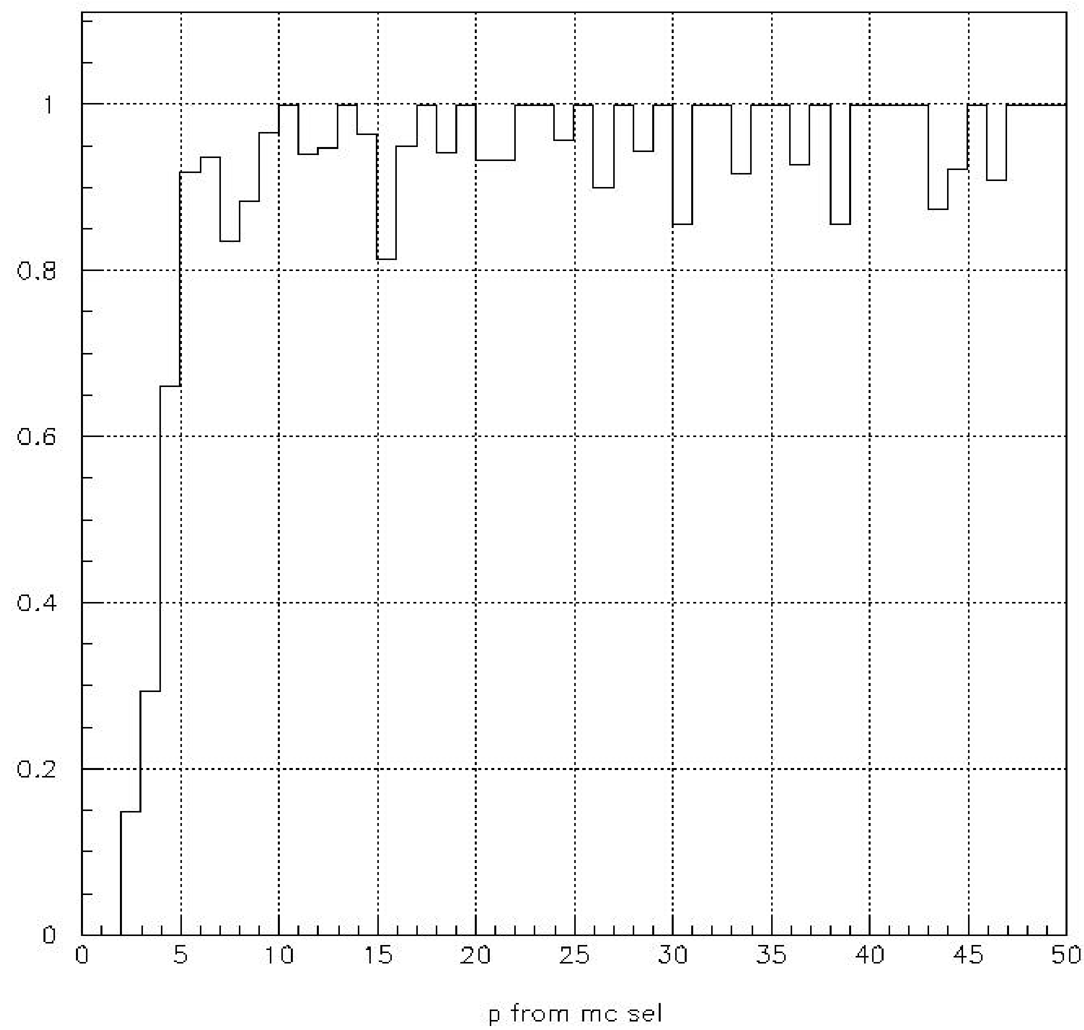
# Hit Density for b b Events




Max. hit density (/sq. cm)

From TESLA Design Report – M. Piccolo et al

# Efficiency vs. Muon Momentum

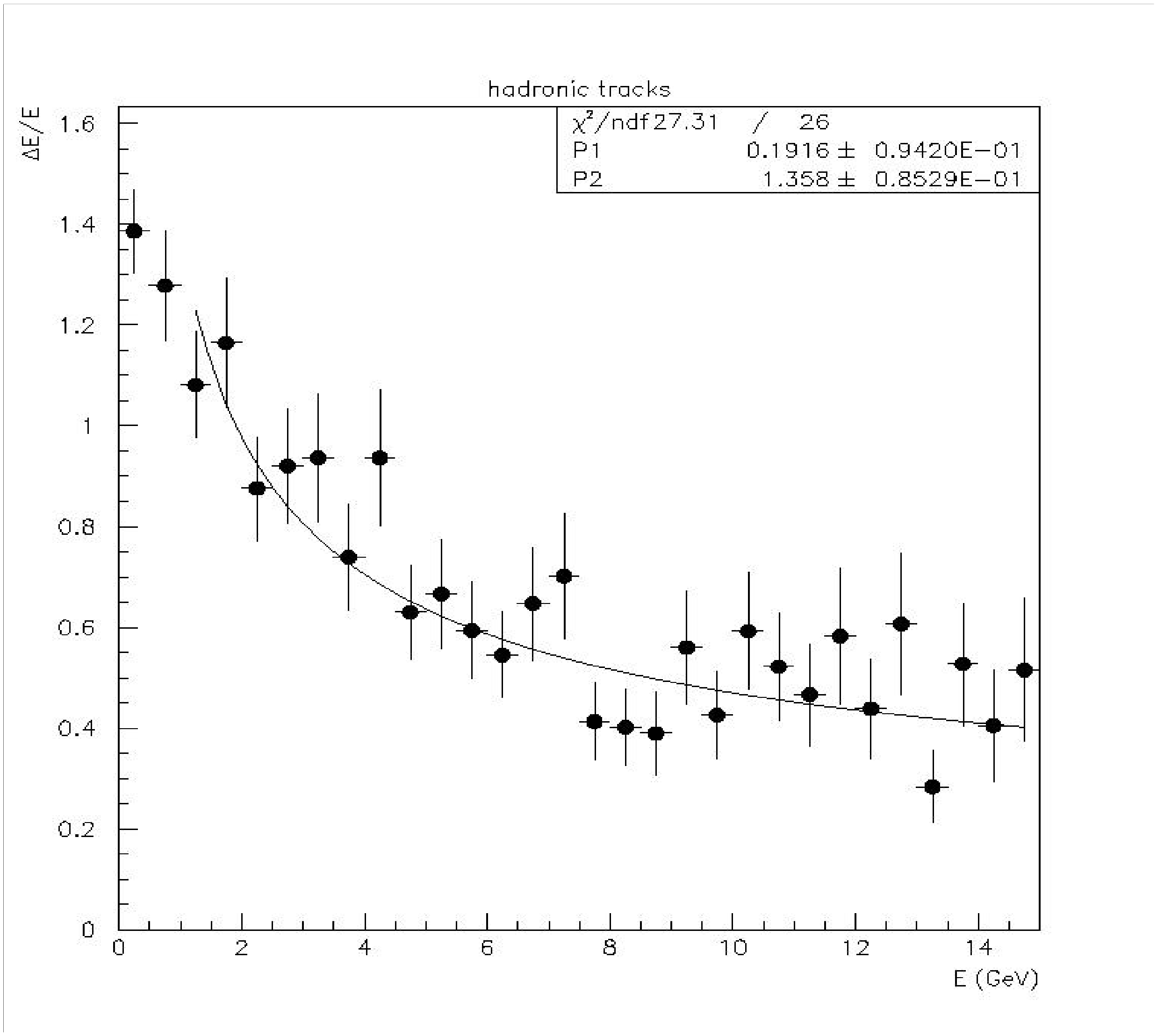



Monte Carlo Muon Momentum

From TESLA Design Report – M. Piccolo et al

# Leakage Hadronic Energy Resolution

From: TESLA Design Report – M. Piccolo et al




Calorimetric Energy for Hadrons Entering the Muon System

# Scintillator Based Muon System

- Why scintillator?
  - Backup calorimetry needed. Cal depth is:
    3.2 l , 5.4 l, 6.7 l for NLC(P), TESLA, NLC(L)
    Example from Dishaw et al
  - Demonstrated technology. Robust.
    **Used in many neutrino expts for m's & h's.**
    **MINOS, e.g.**
  - Detectors can be calibrated:
    **LED pulser plus initial beam tests.**
  - With scintillator strips, m 's can be tracked.
  - The precise measurement of of $p_m$ is done
    via central tracking.

- Proposed Layout
  - 16 – 5cm gaps between 10cm thick Fe plates.
  - Module sizes: 940(L)X(174 to 252)(W)X1.5 cm$^3$.
  - 4.1 cm X 1 cm extruded scint.: 8u & 8v planes.
  - Light output from both ends: 11(n) + 6(f) p.e.s.
  - Use multi-anode PM; 94K fibers X 2 channels?
  - Expect ~ 1/vE for calorimetry.

# Sampling Calorimeter

E379 P. Dishaw Thesis   SLAC-216

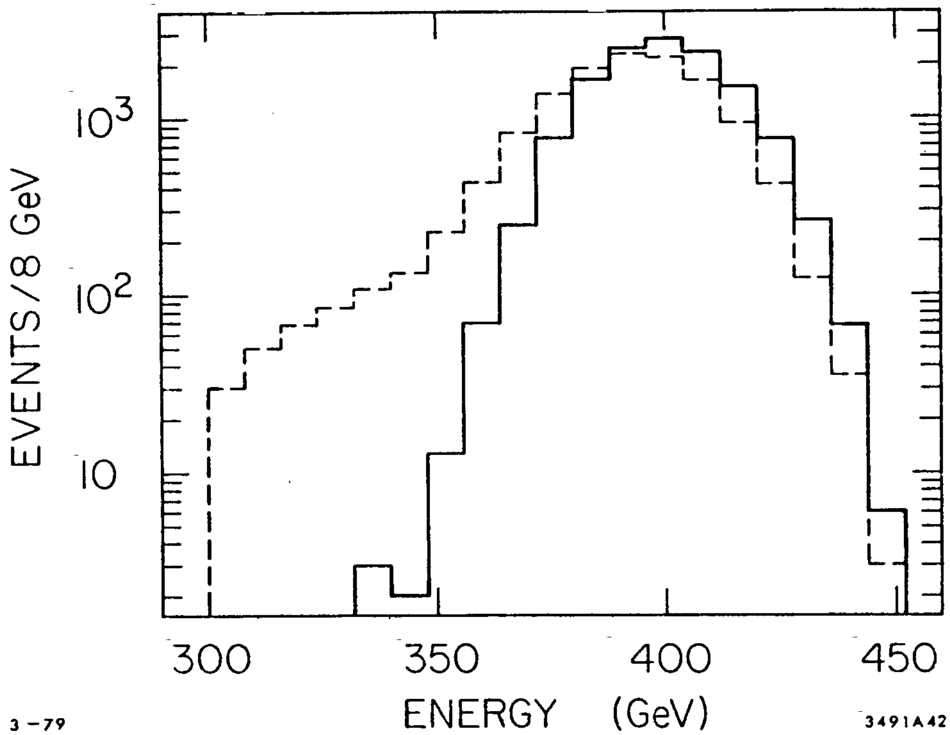



Fig. 39 Calorimeter measured energy for the full calorimeter (approximately 3 meters) (solid histogram) and the same distribution for a calorimeter consisting of only the first 30 plates (approximately 1.3 meters) (dashed histogram, arbitrarily cut off at 300 GeV). Noncontainment in the second case leads to nonGaussian behavior in the low side of the measured energy.

Fe & Plastic Scintillator 30” H X 30” W

Plates: 1 – 20 1.5” Fe

21 – 45 2” Fe

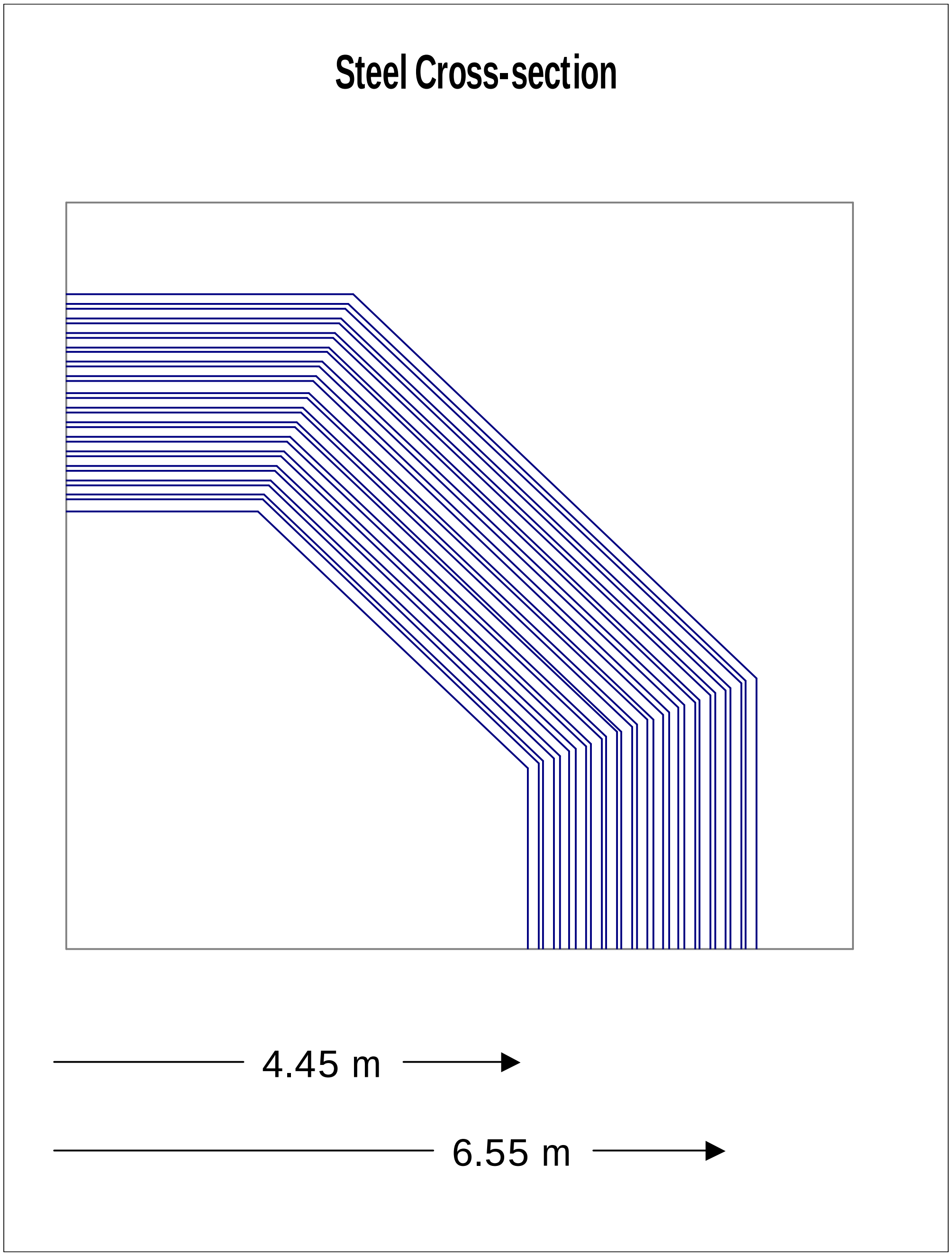
46 – 49 4” Fe

$\sum_{i=1}^{30} C_i$ , $\frac{\sigma_{30}}{E} = 6.38\%$   $\sum_{i=1}^{49} C_i$ , $\frac{\sigma_{49}}{E} = 3.63\%$

7.58 $\lambda$   11.52 $\lambda$

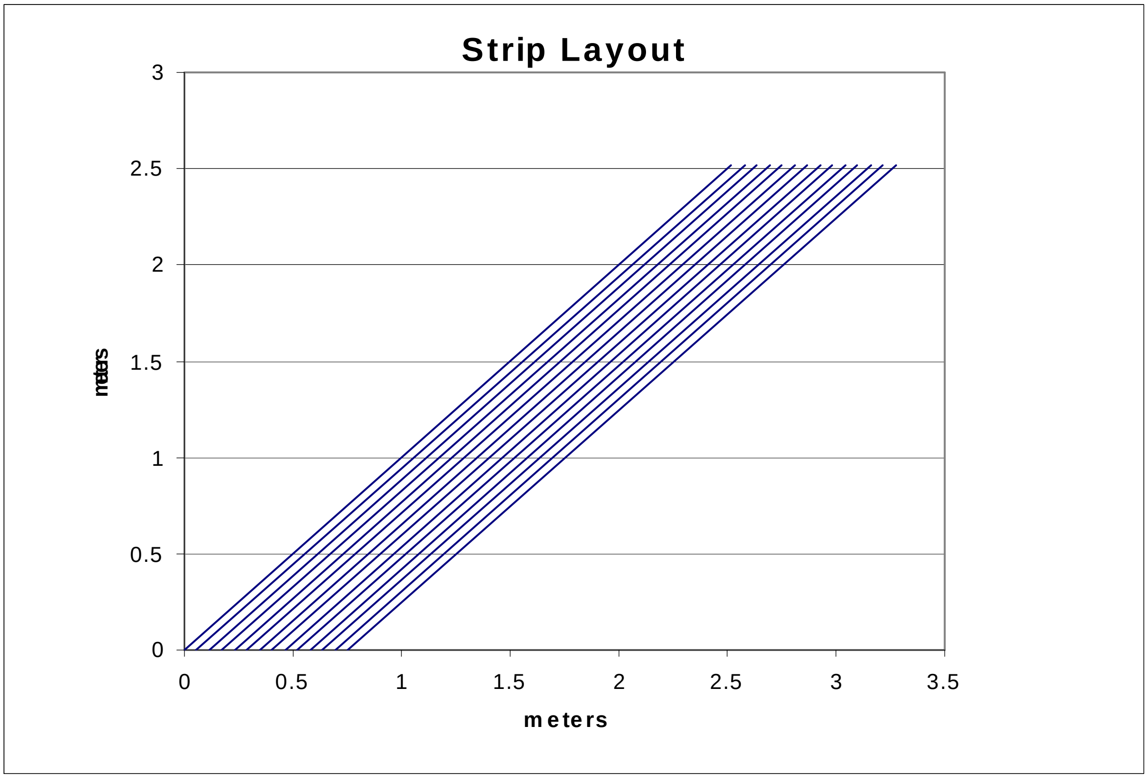
**<E> = 389 GeV**   **<E> = 400 GeV**

# Steel Cross-section

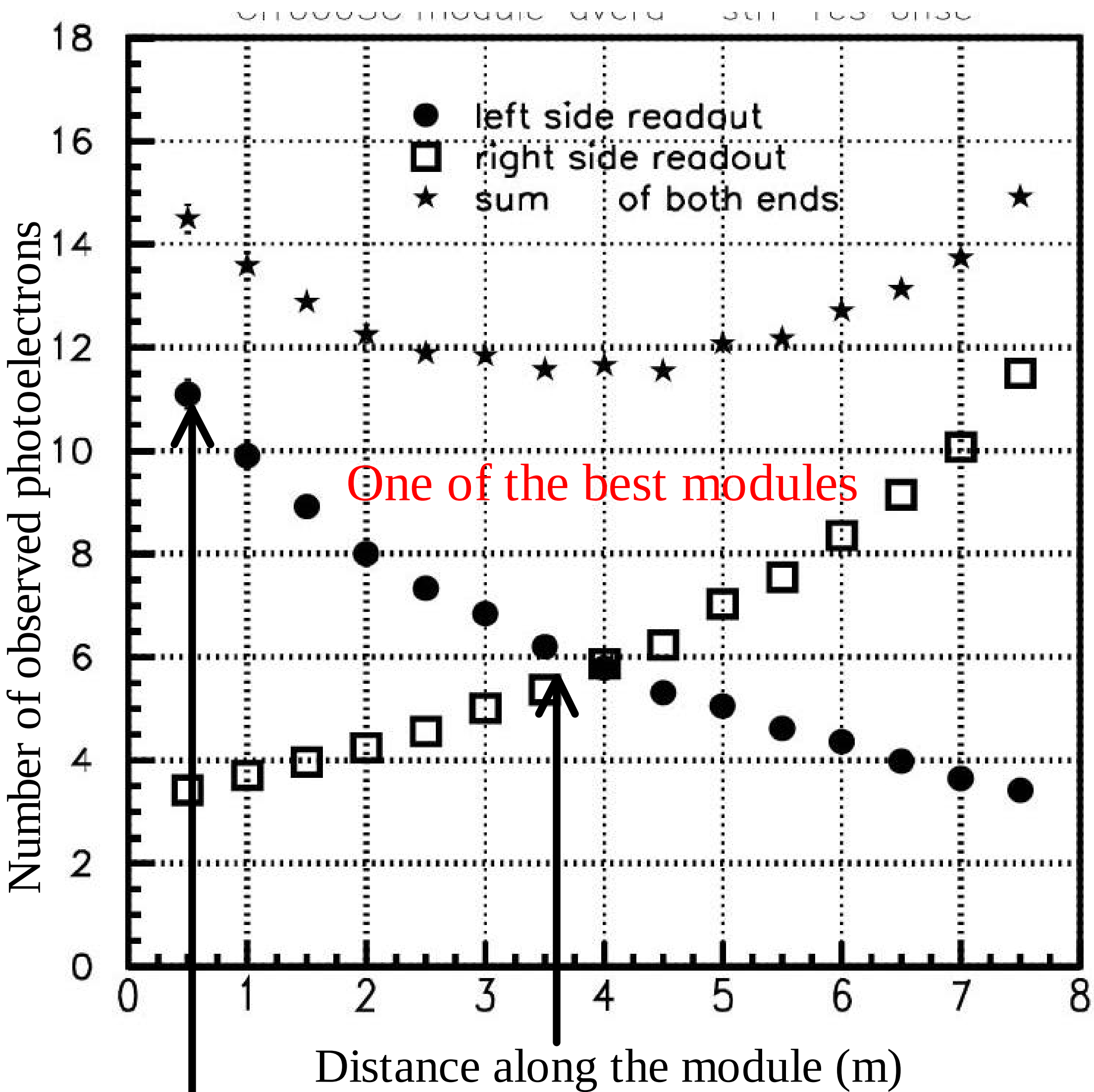



Fe thickness = 10 cm, Gap = 5 cm

# Scintillator Layout u and v strips



# MINOS Scintillator




**Q.E. 13.5%**

**Near**
**11±3 p.e.s**

**3.6 m**
**Far – proposed geometry**
**6±2 p.e.s**

**Light output using the full MINOS apparatus: Connectors, clear fibers, multi-anode PMTs, ….**

# R&D Issues

- Mechanical (w. K. Krempetz)

Fe structural engr; constr. techniques; muon plane supports; cable routing; impact on other systems; installation issues. (X)

- Muon Software (w. D. Hedin, A. Maciel)

Muon detector tracking and link-up with central tracking.

Shower leakage into muon detectors. (w. A.M. , C.M., Marcello Piccolo INFN)

Sampling calorimeter and Energy Flow algorithms: e.g. $\langle E_{jet1} + E_{jet2} \rangle$ comparison. X

Is 4.1 X 1 $cm^2$ the optimal scint. cross-section? (A. Para, X)

Muon detector Web page development. X

# R&D Issues (cont.)

- Muon Detector Planes

Scintillator design, specs, prototype extrusions using Fermilab machine.

(A. Bross, NICADD, X)

Prototype detector plane engr., R&D proposal, construction (J. Blazey, G. Fisk, + X)

Fiber specs, fiber routing, bending, fiber guides/molds. Two fiber OR. (A.B., NICAAD, X)

Quality checks – mechanical, meas. w. radioactive sources, test electronics. X

- Electronics/Cosmic Ray Test Stand

PM Specs, PM tests & selection, FE electronics (10 p.e.s), CR => LC detector?

Small DAQ sys., Test scenario (NIU, X)

# R&D Issues (cont.)

<u>Test Beam</u>

A proposal is needed for a 120 GeV/c test beam from the MI. X

Muon prototype detector tests with Fe + scint. planes (full width, shortened length) to understand system issues including backgrounds from jets, software, calibration, participation with other detectors. X

Such a facility would provide an opportunity to test different technologies and therby provide input for decisions on detector design issues.

Examples: Energy flow software/algorithm development with prototype detectors; calorimetry, muon, electronics tests

# Muon Detector Summary

- Many physics/detector issues to understand such as:

  1 TeV impact on detector design;

  Tail catcher use in E-flow algorithm.
- Further development of detector specifications.
- Preliminary designs for scintillator, test modules, electronics and CR test stand.
- Write a proposal, including the costs and schedule for a cosmic ray test.
- Develop an understanding of the issues and requirements for a test beam for muon and other detectors. Proposal.

❖ R&D Plans and your involvement!

# Other Information

From : **Mike Witherell** Nov. 9, 2001

Gene,

As we said, I would like you to be the detector R&D coordinator for the linear collider detector work here. What exactly that means and how we do it still needs some work. But in connection with that, I would also like you to be part of the steering group for the linear collider physics and detector activity that is starting anew here. The other members will be:
Andreas Kronfeld, Slawek Tkaczyk, Marcela Carena,
Rick van Kooten (Indiana), Young-Kee Kim (Berkeley),
David Gerdes (Michigan), and Mark Oreglia (Chicago). It is a good group. Andreas will serve as chair initially, but as things evolve it is up to all of you how to organize yourselves and how you interact with the national effort.

---

## Muon R&D Contacts:

**Adam Para: para@fnal.gov (originator of scintillator based muon system)**

**Dave Hedin (NIU): hedin@fnal.gov (muon tracking)**

**Arthur Maciel (NIU): maciel@fnal.gov (simulation, muon sys cal, tracking)**

# Channel Count, etc.

| | Barrel | Ends | Total |
|---|---|---|---|
| WLS fibers | 51,200 | 42,766 | 93,966 |
| Scintillator | | | |
| Area ($m^2$) | 7,174 | 4,353 | 9,527 |
| Vol. ($m^3$) | | | 95.3 |
| M ($\rho$=1.2g/$cm^3$) | | | 114.3Tm |

Cost Drivers:

Extruded scintillator: ~$13/kg => $1.5M
WLS fiber: $2 - $3/m => $2.5M
Multi-anode PM $1400 ea./16 ch
=> $88/pix + elect $50/pix
= $138/pix
4x MUX => 25,000 pix *$138/pix=> $3.5M
Possible, but too early to quote real costs!

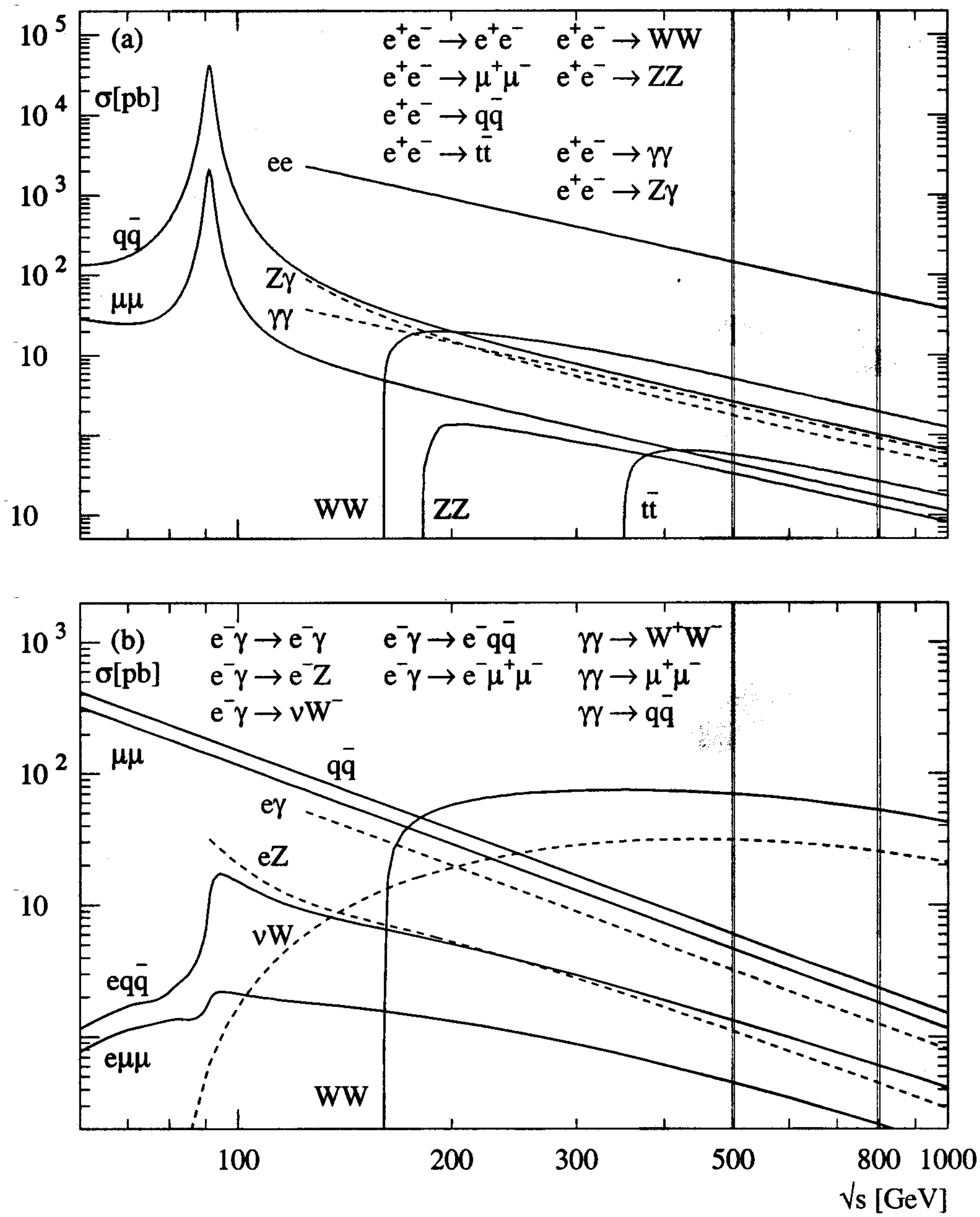
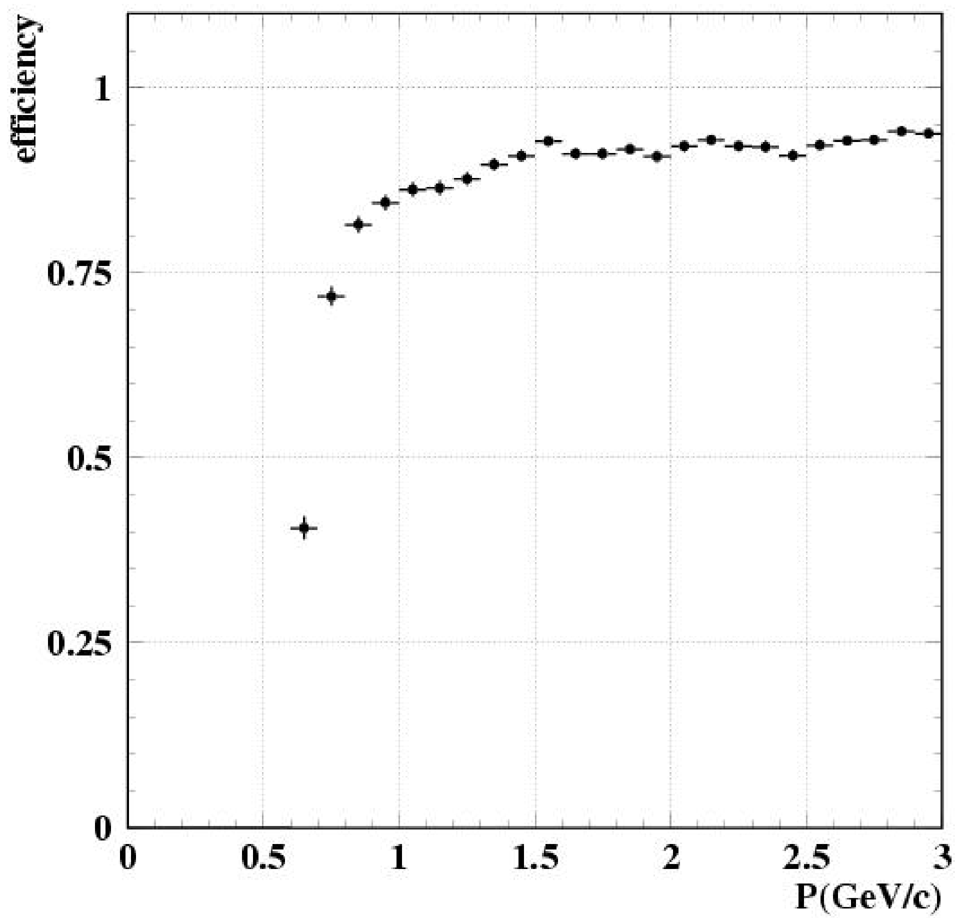



Figure 1: *(a) The basic processes of the Standard Model: $e^+e^-$ annihilation to pairs of fermions and gauge bosons. The cross sections are given for polar angles between* $10^0 < \theta < 170^0$ *in the final state. (b) Elastic/inelastic Compton scattering and $\gamma\gamma$ reactions. $\sqrt{s}$ is the invariant $e\gamma$ and $\gamma\gamma$ energy. The polar angle of the final state particles is restricted as in (a); in addition, the invariant $\mu^+\mu^-$ and $q\bar{q}$ masses in the inelastic Compton processes are restricted to $M_{inv} > 50$ GeV.*

# Efficiency for BELLE RPC's




From the BELLE Website:

http://beauty.bk.tsukuba.ac.jp/belle/nim/total/node88.html