Montauk Sept. 27th 99

$\mu^+\mu^-$ Collider

Detector Challenges.
(10 - 100 TeV/c studies)

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Alternative Title.

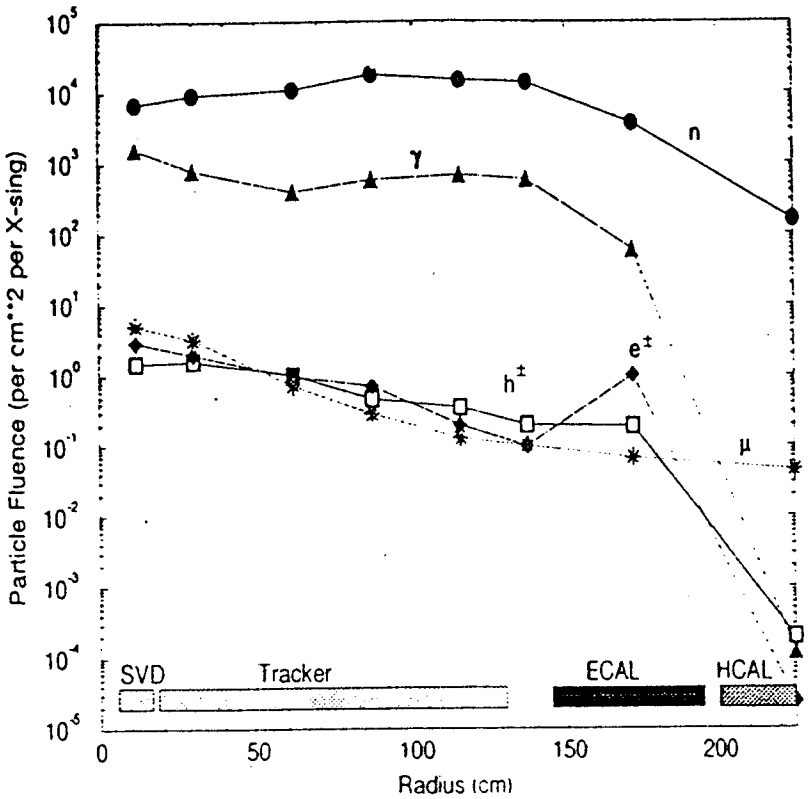
Radiation Hard, Background Blind $\mu^+\mu^-$ Collider Detector.

Outline:

1) Background at 2.2 TeV collider
2) Generic Detector
3) Introduction of Deep Detector Cell as a building block for a background blind vertex detector & tracker
4) Two dimensional interpolations within a cell.
5) Size of the tracker & channels
6) Drawbacks
7) Magnetic measurements for 10 - 100 TeV options
8) Calorimetry

PR 2

Machine Backgrounds vs Radius



MARS

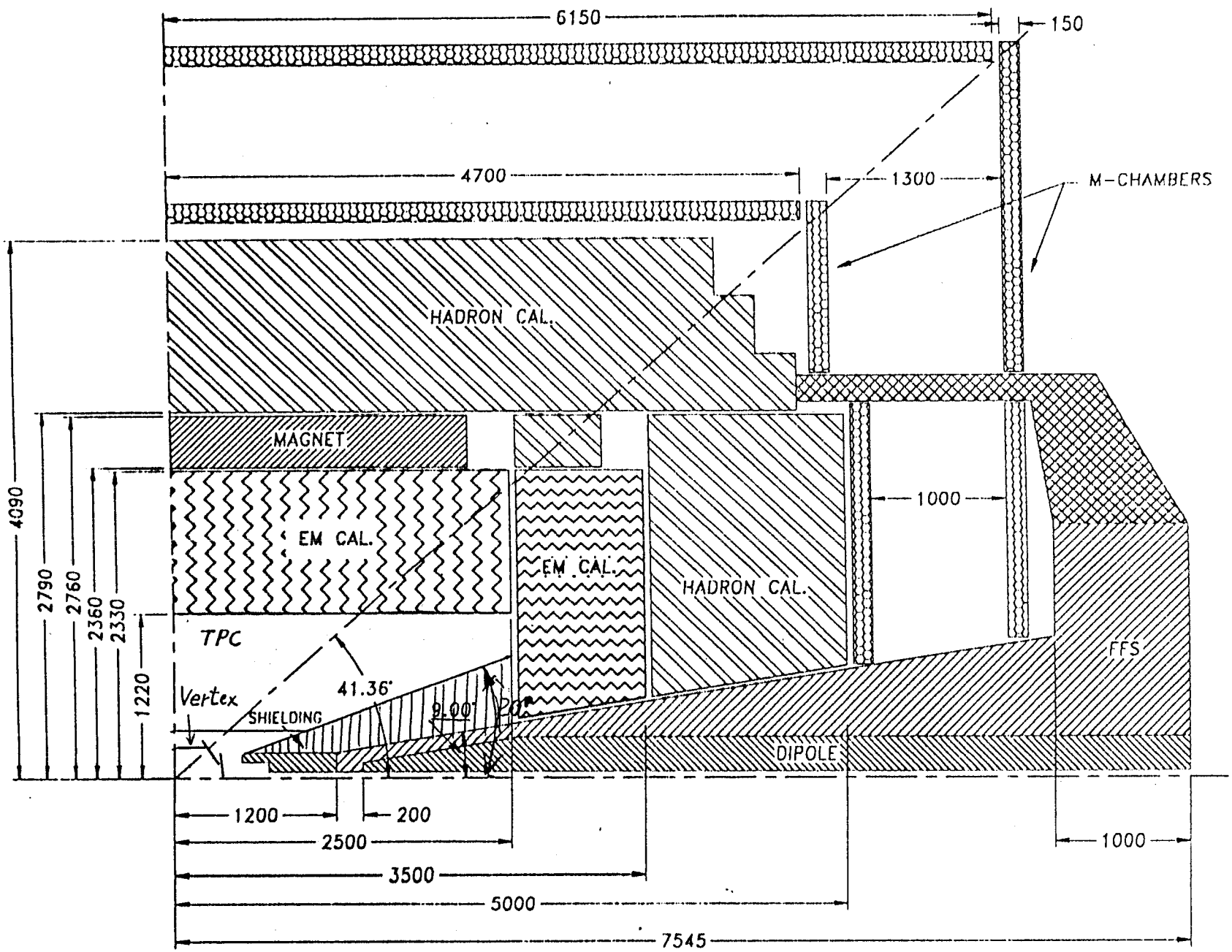
Table 9.1: Longitudinal Particle Fluences from Muon Decays and Interactions from the GEANT Calculation. Fluence = particles/cm^2/crossing for two bunches of $10^{12}\mu$'s each.

Detector	Radius(cm)	γ's	neutrons	$e^{\pm}$	$\pi^{\pm}$	protons	$\mu^{\pm}$
Vertex	5-10	7900	1100	69	14.4	0.8	1.5
	10-15	3100	1200		3.7	0.05	0.5
	15-20	1600	1000		4.6	4.0	2.3
Tracker	20-50	450	870		0.8	3.9	0.3
	50-100	120	520		0.1	2.2	0.06
	100-150	130	330		0.003	0.4	0.01
Calorimeter	160-310						0.002
Muon	310-10000						0.0002

GEANT

Table 9.2: Radial Particle Fluences from Muon Decays and Interactions from the GEANT Calculation. Fluence = particles/cm^2/crossing for two bunches of $10^{12}\mu$'s each.

Detector	Radius(cm)	γ's	neutrons	$e^{\pm}$	$\pi^{\pm}$	protons	$\mu^{\pm}$
Vertex	5	16900	1600	84.0	9.5	1.7	35
	10	4800	1400	9.4	4.5	1.4	0.43
	15	2200	1400	2.1	2.1	1.1	0.33
	20	1250	1400		1.3	1.9	0.20
Tracker	50	440	1500		0.22	4.2	0.032
	100	160	360		0.04	0.8	0.008


6150
150
4700
1300
M-CHAMBERS
HADRON CAL.
MAGNET
EM CAL.
EM CAL.
HADRON CAL.
1000
FFS
TPC
Vertex
SHIELDING
41.36°
9.00°
DIPOLE
4090
2790
2760
2360
2330
1220
1200
200
2500
3500
5000
7545
1000

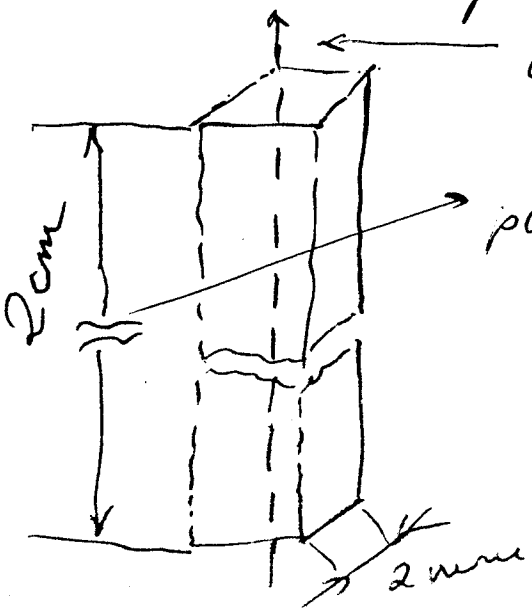
Radiation Hard, Background Blind Detector.

Full advantage of.

1) Small size of interaction point

2) Time structure of signal and background.

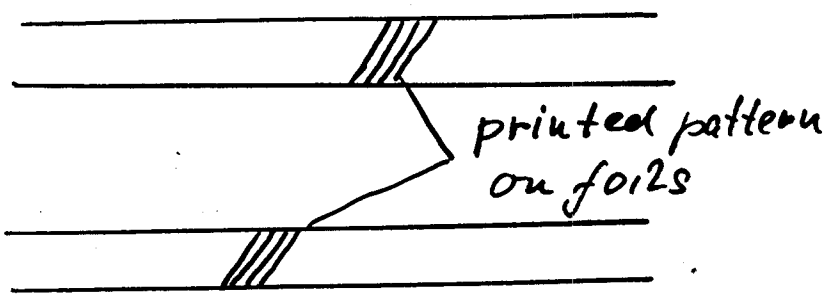
Vertexing & tracking based on Deep Detection Cell.

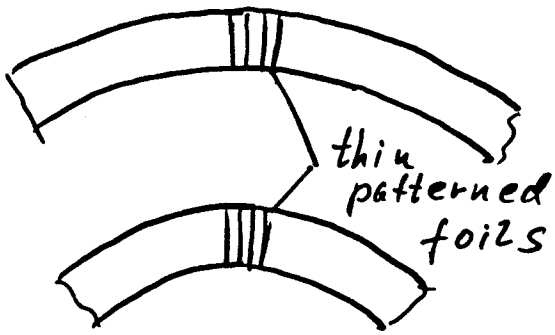


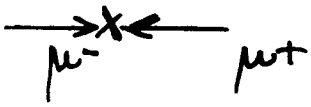
Directional selectivity

$$\simeq \frac{(2\,mm)^2}{2\pi(20\,mm)^2} = 2\times10^{-3}$$

1 %

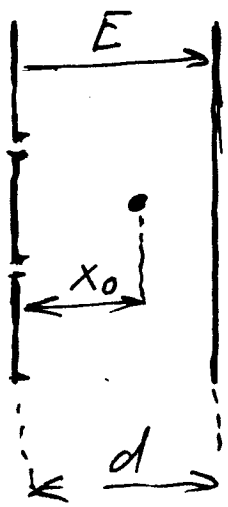


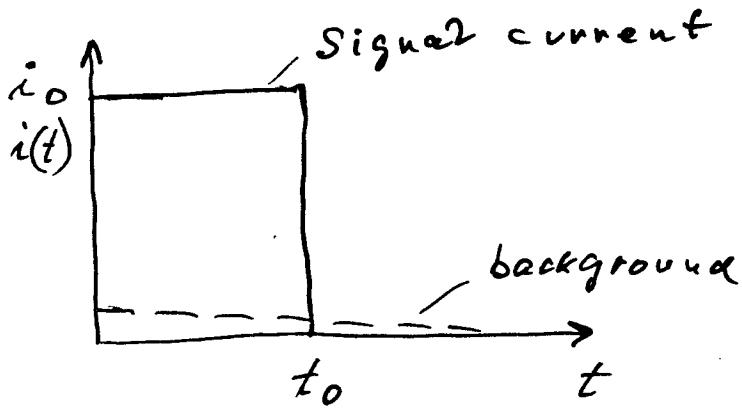




+ intersection point

Top view.

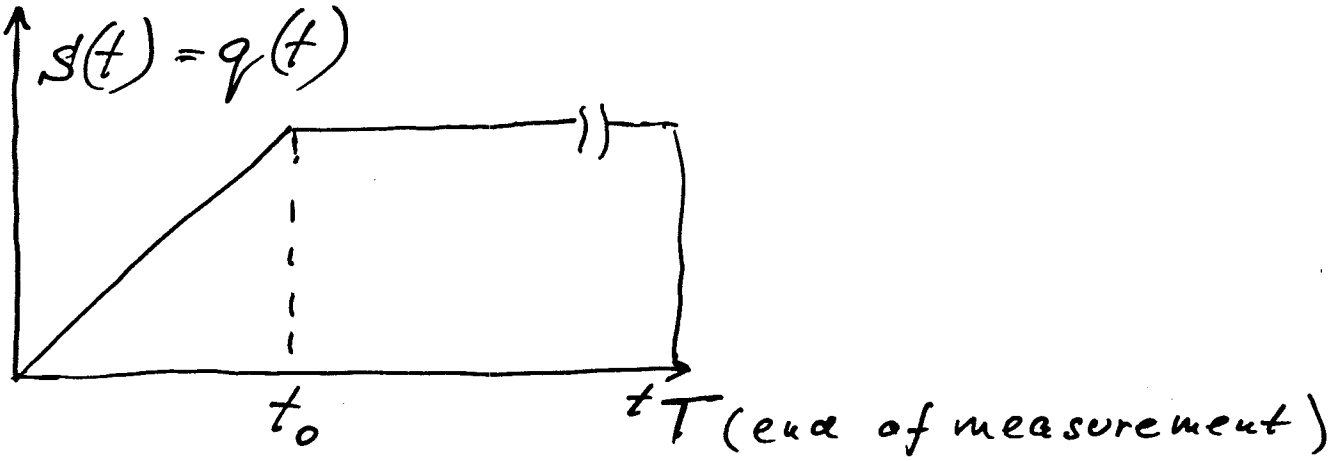




$$i_0 = \frac{Q}{d} \cdot V$$

Q - total charge created along the trajectory of particle ($\approx$ 160 000 el in 2 cm of L Ar)

V - electron drift velocity



$$s(t) = i_0 t \qquad 0 < t < t_0$$

$$s(t) = i_0 t_0 \qquad t_0 \leq t < T$$

Optimum processing of measured (recorded) integrated waveform. $w(t)$

$$t_0^2 = \frac{3 \int_0^{t_0} w(t) \cdot t \, dt}{\frac{1}{T - t_0} \int_{t_0}^{T} w(t) \, dt}$$

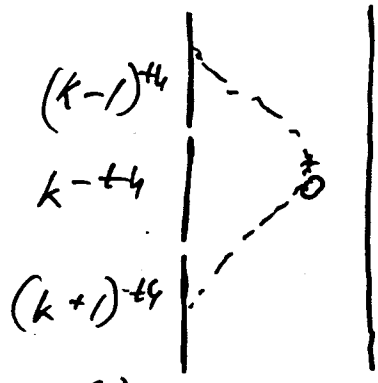
$$x_0 = v \cdot t_0$$

More studies are needed.

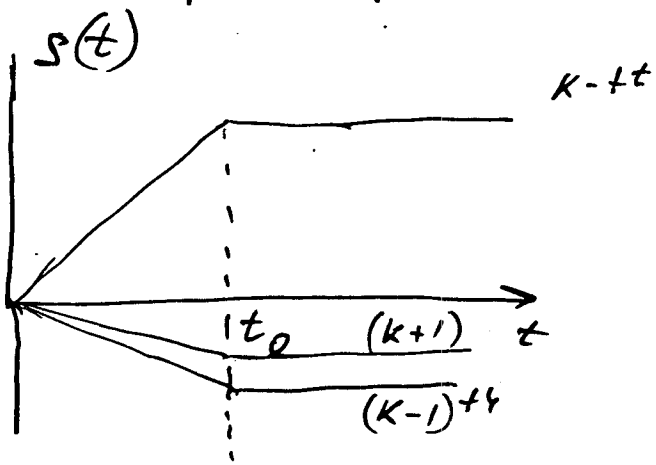
$$\sigma_{x_0} \approx (1-3)\% \text{ of } d \text{ or}$$

$$\sigma_{x_0} \approx (20-60) \text{ μm}$$

Other coordinate



After signal electrons were collected positive ion induce oposite polarity signals

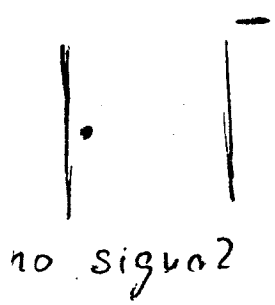


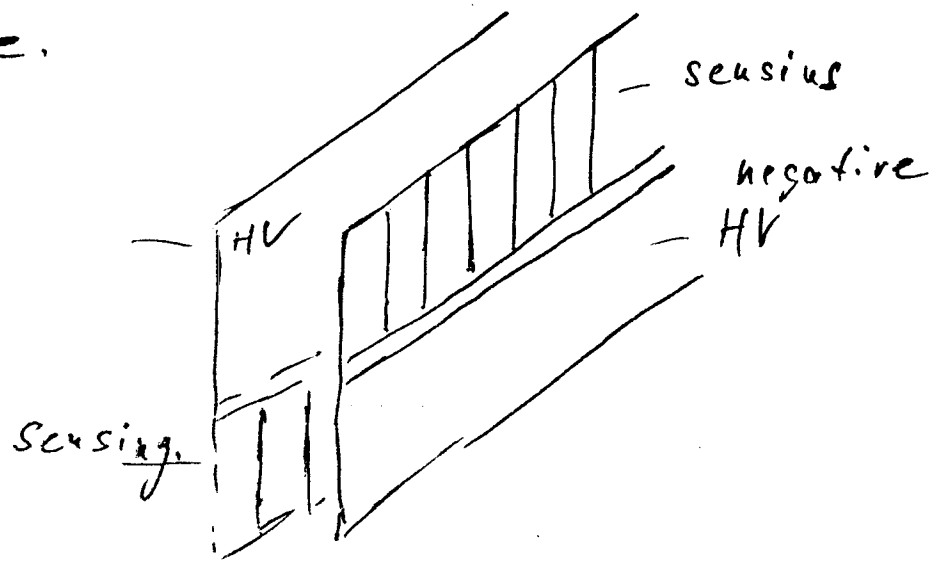
Induced charge allows interpolation along the "y" coordinate

Precision again (20-60) μm.

Possible problem.

Tracks too close to the sensing plane.





Effective thresholds.

Gas proportional counters: $\approx 100\,eV$

Silicon Detectors $\approx 10\,keV$

Liquid argon in DDC $\approx 1\,MeV$

(1 MIP deposits about 4 MeV in 2 cm of LAr)

Number of channels:

a) Vertex detector
3 layers at 5, 10 & 15 cm

Covers ϑ from 20° to 160°

Area for a 5 cm layer $= 860\ cm^2$

$n_{5cm} \doteq 22k$
$n_{10cm} \doteq 88k$
$n_{15cm} \doteq 200k$

$\Sigma \doteq 3 \times 10^5$
(6×10^5)

However # of effective pixels $10^3 - 10^4$ times # channels

b) Tracker

Depends on the size of tracker which depends on the $E_{\mu^+\mu^-}$ ($\sqrt{s}$) and the magnetic field.

High field option looks better than the low field option.

Deep Detection Cell may be larger.

$$n_{Tr} \approx (10-50) \times n_{vertex}.$$

Drawbacks.

Amount of material to be traversed by measured particles

a) Multiple scattering and showering in deep detector cells.

b) Photon conversions

a) is only negative
b) Electrons produced by conversions of background photons will unlikely

be detected in cells.

For μ-s of interest vertex detector and tracker might be considered to be a first class pre-shower detector.

a) Radiation length of 1 cell ≈ 2.5 cm LAr

$x = 0.18$

Multiple scattering for 100 GeV/c particle

$$\Theta \approx \frac{14\,\text{MeV}}{100\,\text{GeV}} \cdot \sqrt{.18} = 60\,\mu\text{rad}$$

$r \approx 1\,m$; $\quad r \times \Theta = 60\,\mu m$

Below $p \approx 100$ GeV/c - resolution limited by multiple scattering.

Let us assume $r_{\text{TRACKER}} \approx 1.2\,m$

$$B = 4T$$

Magnetic kick $\Delta P = 0.3 \times B \cdot L$ (GeV/c)

$$\doteq 1.2 \text{ GeV/c}$$

Initial direction with the knowledge

of the interaction point

$$\delta\vartheta_{vert} \approx \frac{15\,\mu m}{10\,cm} = 0.15\ mrad$$

If we keep tracker at the same quality

$$\delta\vartheta \approx 0.2\ mrad$$

$$\frac{\delta P}{P^2} = \frac{\delta\vartheta}{0.3BL} = \frac{2\times10^{-4}}{1.2\ GeV/c}$$

$$\frac{\delta P}{P} \text{ for } P = 100\ GeV/c \approx 2\%$$

$$P = 1\ TeV \approx 20\%$$

3σ sign determination

$$P_{MAX} = \frac{0.3BL}{3\cdot\delta\vartheta} = \frac{1.2\ GeV}{0.6\times10^{-3}} = 2\ TeV$$

Not good enough for 100 TeV option.

Larger B, R – better measurements of points.

Electromagnetic Calorimeter.

at $r \approx 120$ cm ~25 rad. length deep.

Neutron flux $\Rightarrow$ no H as a detection medium.

Accordion LA a possibility - TOWERS!!!

other technologies open - no speed required.

Entrance surface $\approx 16\ m^2$

Number of towers $= 4 \times 10^4$

1 tower covers $2\ cm \times 2\ cm = 4\ cm^2$

Photon flux into $4\ cm^2 \approx 400$ ph/crossing

Fluctuations in the energy carried by background photons.

for a crossing $E_T = \sum_{i=1}^{n} E_\gamma^{(i)}$

Compound process - both n & E_γ fluctuate

$$\overline{E_T} = \overline{n} \cdot \overline{E_\gamma}$$

$$var(E_T) = \overline{n} \cdot var(E_\gamma) + var(n)\,\overline{E_\gamma}^{\,2}$$

$\overline{E_\mu} = 1\ MeV$ from Geant

$\overline{E_\mu} = 2.5\ MeV$ MARS

$$var(E_\mu) \doteq \overline{E_\mu}^2$$

n – has Poisson statistics $var(n) = \bar{n}$

$$var(E_T) = \bar{n} \cdot \left(\overline{E_\mu}^2 + var(E_\mu) \right) \left(= \bar{n} \cdot \overline{E_\mu^2} \right)$$

$$= 2\bar{n}\, \overline{E_\mu}^2$$

or $\overline{E_T} = \bar{n} \cdot \overline{E_\mu} = 400\ MeV$

$$\sigma_{E_T} = \sqrt{800} \cdot \overline{E_\mu} \approx 30\ MeV$$

Additional noise due to photon flux in a shower occupying 4 towers

$$\underline{\sigma_{ph} = 60\ MeV}$$

Longitudinal segmentation ≈ 5

Tower area exposed to B-H μ-s

$= 2\ cm \times 25\ cm = 50\ cm^2$

1 segment $\approx 10\ cm^2$

PR28

B-H μ density $= 0.01\ cm^{-2}$

10% of segments has a μ-passing through

Number of channels 2×10^5

Multiplexing possible.

$E_{TOT}^{(ECM)}$ / crossing ≈ 16 TeV

PR29

HADRON CALORIMETER.

From $r = 1.5$ m to $r = 4$ m 2.5 m deep $\approx 10\lambda$

CENTRAL CALORIMETER from 30 to 150 mg.
35 to 145

TOTAL ENERGY/crossing $\approx$ 300 TeV

Mostly <u>soft hadrons</u>

<u>5×5 cm^2</u> entrance area of one tower.

$n_{neutron} = 100$/crossing $\Rightarrow \bar{n} = 2\,500$/tower/crossing

$\overline{E_h} = 10$ MeV

the same statistical analysis as for elm cal.

$$\overline{E_T} = \bar{n} \cdot \overline{E_h} = 2\,500 \times 10 \text{ MeV} = \underline{25 \text{ GeV}}$$

$$\sigma_{E_T} = \sqrt{2\bar{n}} \cdot \overline{E_h} = \sqrt{5000} \cdot 10 \text{ MeV} = \underline{\underline{0.7 \text{ GeV}}}$$

IF hadrons are in 400 towers this limits the energy resolution to $\sqrt{400} \times 0.7$ GeV $= \underline{\underline{14 \text{ GeV}}}$

(WW scattering had a cut $p_\perp > 50$ GeV
or 3σ) O.K

Number of towers $\approx 12\,000$

Additional problem.

B-H μ-ons flying "parallel" to beams

0.002/cm²/crossing

Central calorimeter has 50 m² gen to these μs.

1000 μ go through had. cal / chamb.

They deposit ≃ 4 TeV

However — a few produce catastrophic bremsstrahlung ~ up to the full energy ≈ 60 GeV

To reject we need longitudinal segmentation.

5-10 $n_{\text{read-out}}$ = 60 000 – 120 000.

Multiplexing.

Conclusions.

a) Radiation hard, background blind detector option merits more detailed studies.

b) Hadron calorimeter seems to be the hardest part to make "blind" to $\mu_+\mu_-$ generated background.