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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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COMMITTEE FOR
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SECOND ICFA SCHOOL ON INSTRUMENTATION IN ELEMENTARY PARTICLE PHYSICS

12- 23 JUNE 1989

Conceptual Design of Collider Experiments

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- **Conceptual Design of Collider Experiments.**

(1) - Physics: what are we trying to do?

- make a specific measurement?
  - m_Z, Γ_Z ... $\left.\frac{d\sigma}{dp_T}\right|_{jets}$ .... $\frac{\varepsilon'}{\varepsilon'}$ ... $\frac{V_{ub}}{V_{cb}}$ ... B_s^0-$\bar{B}_s^0$ mixing
- discover something?
  - t .. H ... $Z^{0\prime}$ ... W_R .... $\tilde{\tilde{g}}$ ....
- everything! a general purpose detector..
  will certainly do "general purpose" physics,
- but does it make sense in the future?
- is it even possible at SSC / LHC.

(2) Machines : colliders and their characteristics.

- e^+-e^- LEP I LEP II.
  SLC
  Future TeV Linear Colliders.
- Hadron colliders SPS $\bar{p}p$ Tevatron $\bar{p}p$.
  SSC, LHC.
- e-p HERA.

(3) Detectors : how are we doing?

- UA2 UA1 CDF nofield - dipole - solenoid.
- LEP Detectors
- ZEUS.

(4) Experimental signatures can we achieve them

- charged leptons J/ψ, Υ, Z^0, ...
- jets - unused so far!
- W and Z into jets - barely..
- missing energy W, ... $\hat{\chi}$ ...
- single photons yes but...
- jet flavour identification ... no top yet
  $b\bar{b}$ v $c\bar{c}$?

- only really experienced "charged leptons" and "missing transverse energy" so far.
- LEP will be very educational for spectrometry using jets in calorimeters. $Z^0 \to$ jet + jet

(5) Conclusions. will not be any.

- are detectors conceptually designed?
- do they represent the "hunch" of a strong individual(s) 'in vogue' techniques.
- physics is no place for democracy.

• ——— •

Physics Outlook - very briefly.

concerned with colliders - certainly not the only frontier.

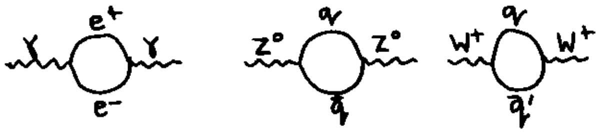
Standard Model • **works very impressively over a large energy range** Lamb Shift – Vector bosons 4.3×10^{-6}eV – 10^{11}eV

$SU(2)_L \times U(1) \times SU(3)_c$.

Something new must occur by ~ 1TeV.

• **Electroweak theory appears to work at all orders of QED.**

• we already know that we need radiative corrections.



• corrections depend on the mass of the missing pieces of SM.

m_t : strong dependence : already set upper limit < 180 GeV/c^2.

m_{Higgs} : weak dependence : very precise experiments with m_t known ?

unt for "top" is ongoing : CERN UA2(e's) UA1 (μ's) $m_t > 60$GeV/c^2
FNAL CDF(e's : μ's)

TRISTAN "classical method" $m_t > 30$GeV/c^2

nticipate a round of precision tests of SM.

m_Z : LEP I, SLC ± 50MeV/c^2 (accelerator physics)
m_W : CERN SPS ± 200MeV/c^2 (calorimetry/calibration)
FNAL CDF

Γ_Z . comment on N_ν :

nost satisfying : a direct experimental sighting of
"top" : for better for worse : conceptually designed.
"Higgs" : ? signatures ?

• Higgs driving force behind a lot of the existing and future collider experiments. LEP I, LEP II
SSC, LHC, ...

• essential missing ingredient of the S.M.

• initial doublet of scalar objects → physical neutral scalar H^0

• well known couplings but unknown mass.

roughly : $10\text{GeV}/c^2 < m_H < 1\text{TeV}/c^2$

Decays ⇒ experimental signatures

$2m_b < m_H < 2m_t$ $B(H\to b\bar b) \sim .89$ $B(H\to \tau^+\tau^-) \approx .04$.

$2m_t < m_H < 2m_W$ $B(H\to t\bar t) \sim .97$. **invisible at a hadron collider.**

if $m_t \gtrsim m_W$ then for "light(ish)" Higgs $H\to b\bar b$ is the channel.

• Heavy Higgs : $2m_Z < m_H$ **if $m_t \gtrsim m_W$ what happens to Higgs decay branching ratios?**

T.G. Rizzo

$$\Gamma(H\to W^+W^-(Z^0Z^0)) = \frac{\sqrt{2}\,G_F M_H^3}{16\pi}\underset{\overset{\uparrow}{Z^0Z^0}}{\left(\frac{1}{2}\right)} G(\varepsilon)$$

$$G(\varepsilon) = (1-4\varepsilon^2)^{1/2}(1-4\varepsilon^2+12\varepsilon^4) \qquad \varepsilon = M/M_H$$

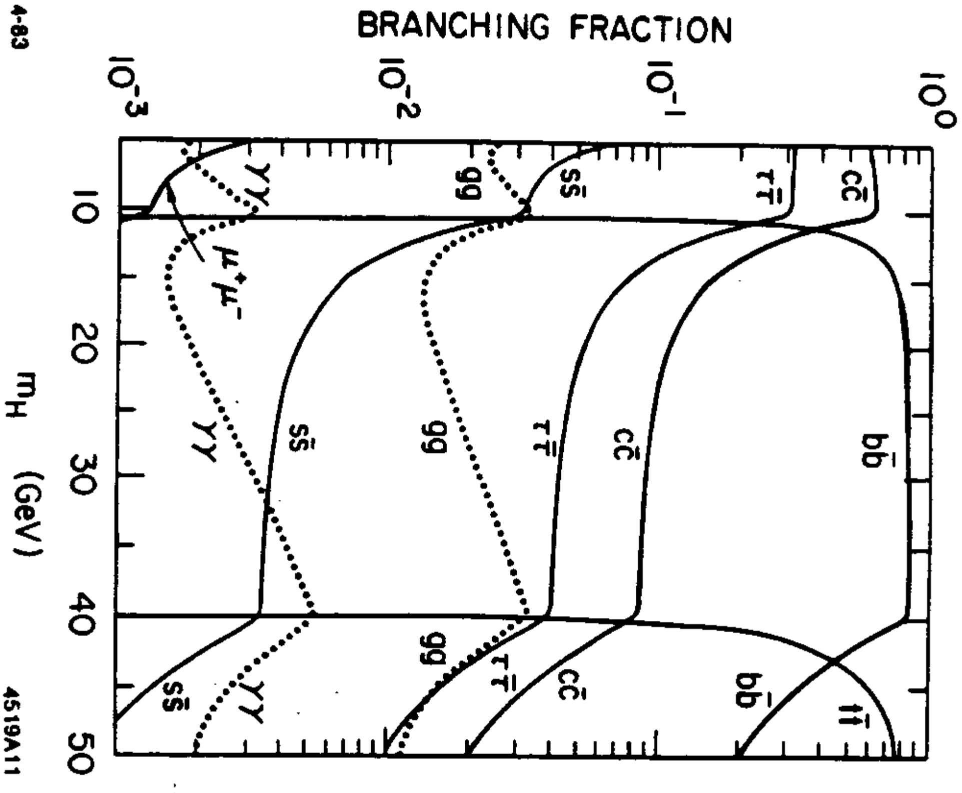
$$\Gamma(H\to f\bar f) = \underset{\overset{\uparrow}{\text{colour}}}{(3)}\,\frac{\sqrt{2}\,G_F M_H^3}{16\pi} H(\varepsilon) \qquad H(\varepsilon) = 2\varepsilon^2(1-4\varepsilon^2)^{3/2}$$

m_H(GeV)	W^+W^-	Z^0Z^0	$t\bar t$(200GeV).
300	53%	24%	23%
500	61%	29%	10%
800	64%	31%	5%

• heavy top does not "destroy" the "boson pair" decay

• $\Gamma(W^+W^-) \simeq 2\times\Gamma(Z^0Z^0)$

• $\Gamma(Z^0Z^0)$ always "healthy" fraction.

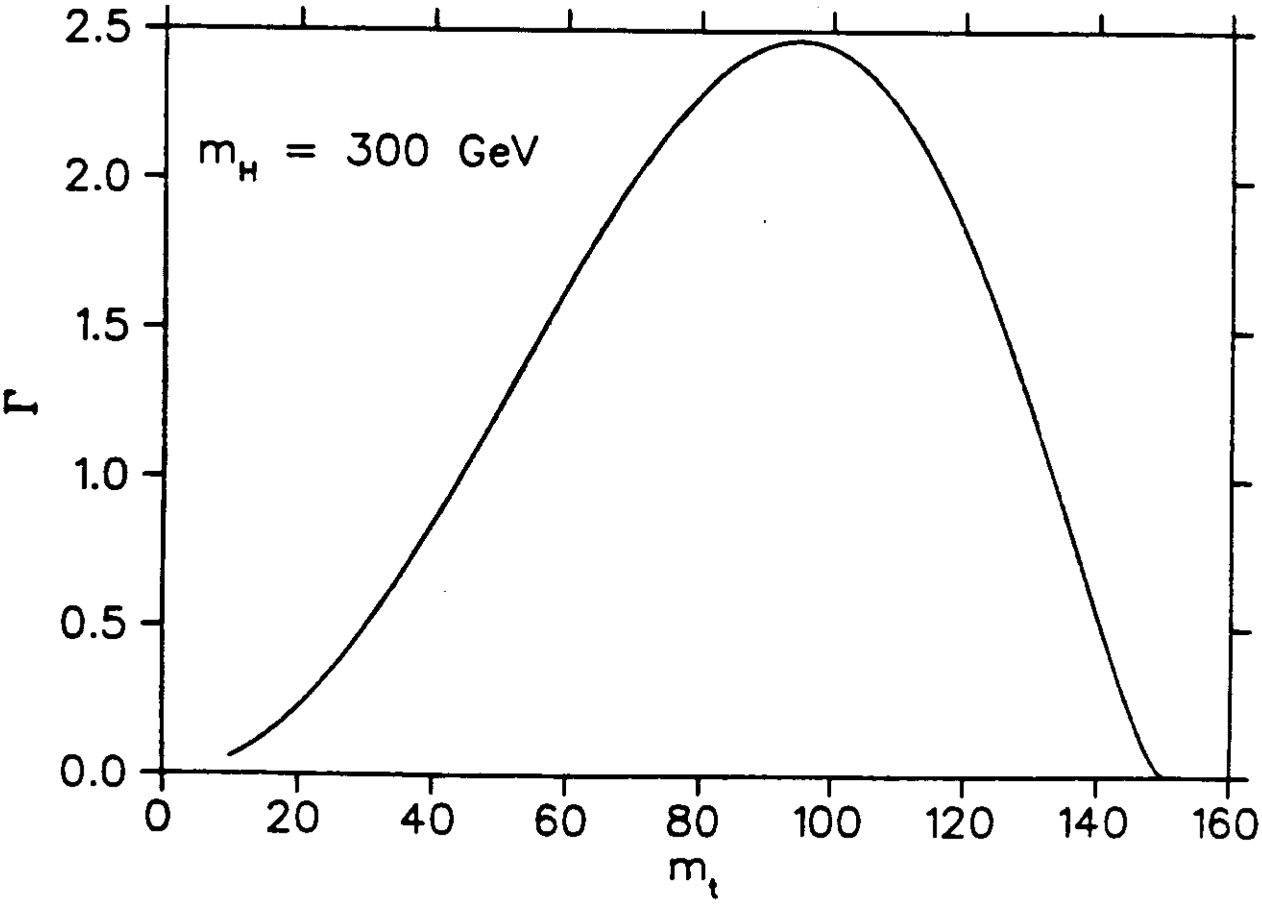


$\Gamma(H \to W^+W^-)$ 5.76 GeV 53%

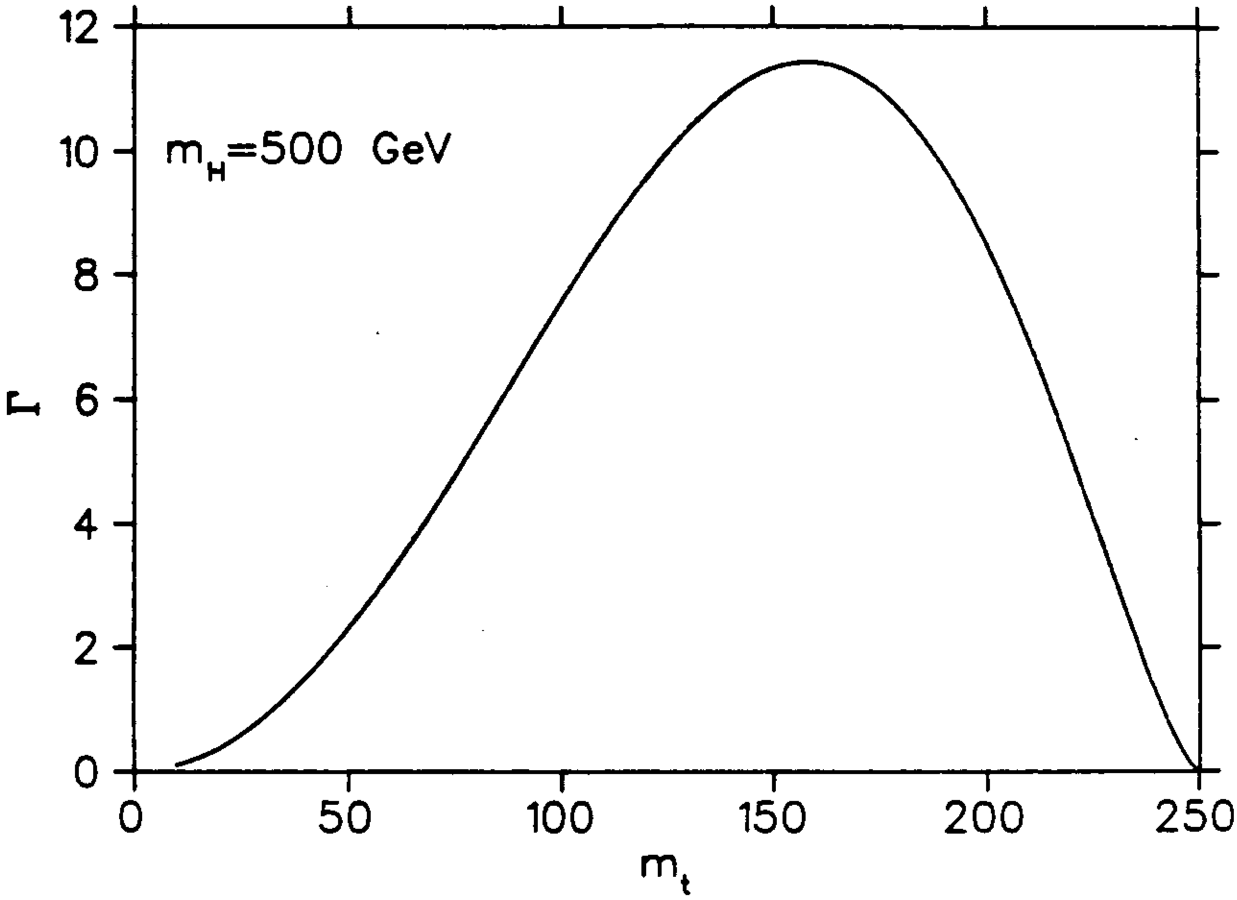
$\Gamma(H \to Z^\circ Z^\circ)$ 2.55 GeV 24%

$\Gamma(H \to t\bar{t})_{100\,GeV}$ 2.49 GeV 23%

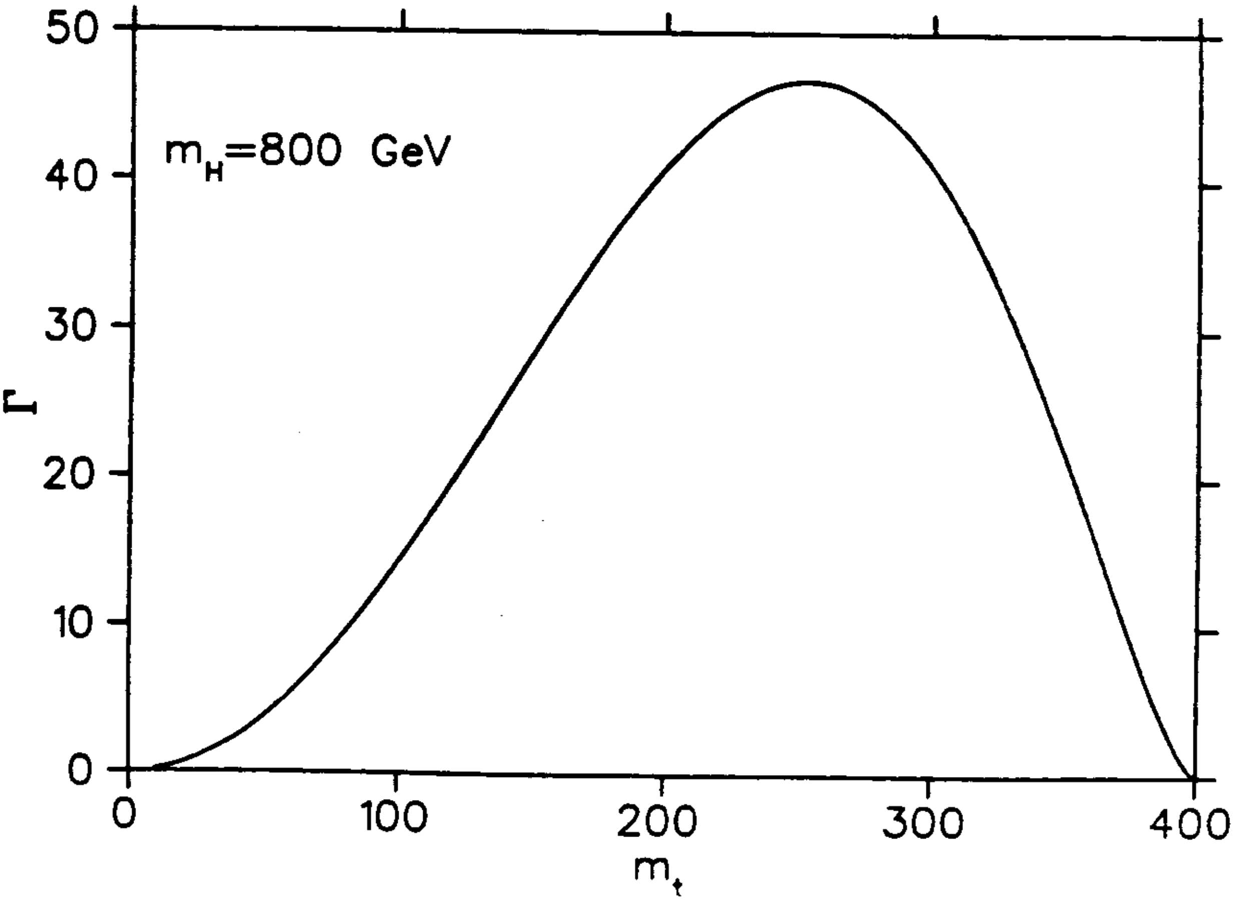
$\Gamma(H)_{total} = 10.8$ GeV



35.04 GeV	16.73 GeV	6.0 GeV	$\Gamma(H)_{total}$ = 57.8 GeV
61%	29%	10%	



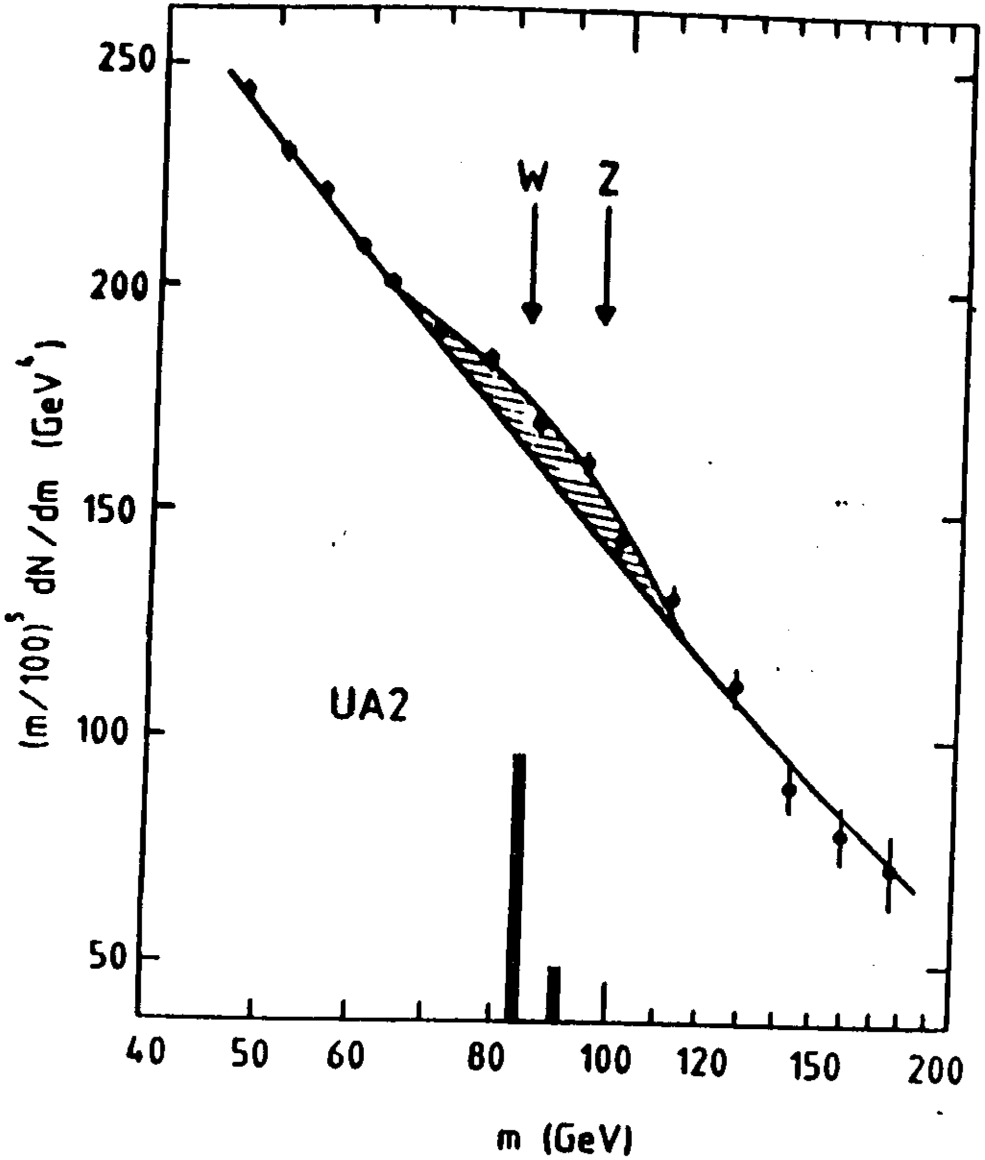
$\Gamma(H\to W^+W^-)$	$\Gamma(H\to Z^\circ Z^\circ)$	$\Gamma(H\to t\bar{t})_{100}$	
158 GeV	77.6 GeV	12 GeV	$\Gamma(H)_{total}$ = 248 GeV
64%	31%	5%	

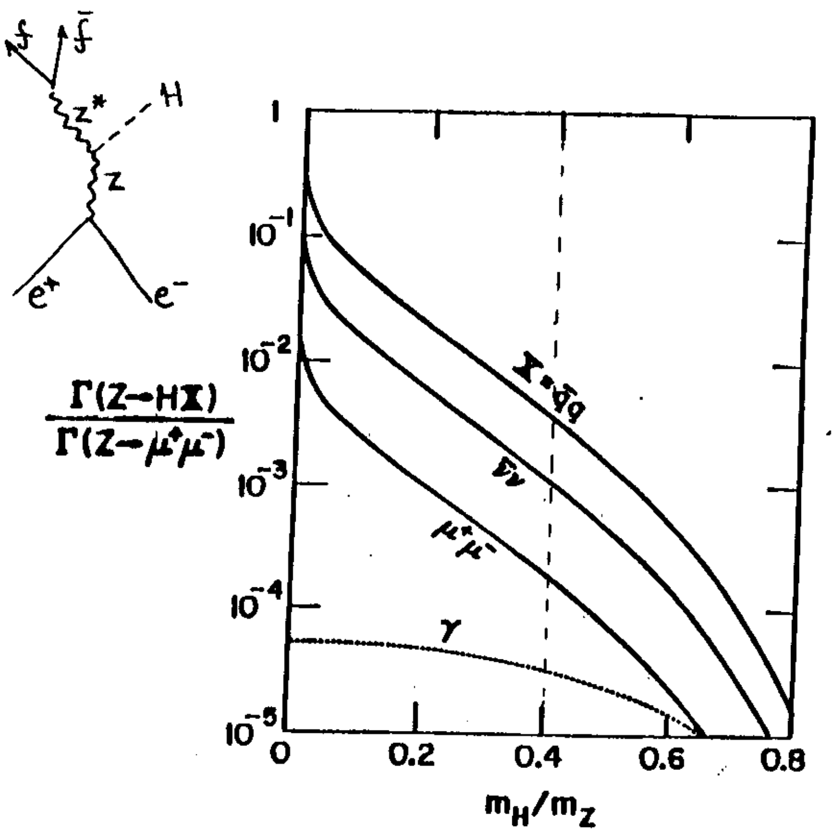


- Higgs experimental signatures ⇒ detector requirements
- $H \to b\bar{b}$: jet-jet mass spectroscopy : useless at hadron collider
  [true for LEP I and LEP II] : not possible with LEP calorimetry (?)
- $H \to W^+W^-$ dominant mode : possibility at future e^+e^- linear collider (with W tagged)
  : $W\to\ell\nu$ $W\to q\bar{q}$ not at hadron collider (?)
- $H \to Z^\circ Z^\circ$ (25% - 30%)
  : $Z \to q\bar{q}$ possibility linear collider.
  : $Z \to \mu^+\mu^-$ "clean" at hadron collider: Eff is low ≈ 2×10^{-4}
- Higgs becomes wide at high mass e.g. $m_H = 800$ GeV $\Gamma(H) = 250$ GeV.

** "forced" to reconstruct bosons to find high mass Higgs

- Detector requirements for LEP I and LEP II
- produced via bremsstrahlung from Z boson.
- see Higgs as missing mass peak of $\mu^+\mu^-$ or e^+e^-. $\sigma/E \sim \frac{10\%}{\sqrt{E}}$ $\frac{\Delta m}{m} \approx 1\,\mathrm{GeV}/c^2$
  $\sigma_P/P \sim 10^{-3} P$
- low mass Higgs: narrow: good return for good resolution e's, μ's
- if $X \to \nu\bar{\nu}$ then Higgs reconstructed from (jet:jet) significant gain but demands good calorimetry.
- Higgs decay $b\bar{b}$: $\tau_B \approx 10^{-12}$ s : secondary vertex LEP?
  impact parameter tagging → Linear collider yes.
- Particle ID in jet?





at $m_H/m_Z = 0.4$ $\Gamma(Z\to H\mu^+\mu^-) = 2\times10^{-4} \times \Gamma(Z\to\mu^+\mu^-)$

$\simeq 6\times10^{-6}$ i.e. 6/Million Z's:

- **Techniques for High Mass Higgs** e^+-e^- linear colliders

$\sqrt{s} = 0.5 - 2.0\,\text{TeV}$ $\mathcal{L} = 10^{33} - 10^{34}\,\text{cm}^{-2}\text{sec}^{-1}$

TLC : CLIC: ....

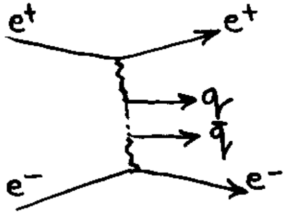
$$\sigma_{pt} = \frac{4}{3}\pi\frac{\alpha^2}{s} = \frac{87\,\text{nb}}{s(\text{GeV})^2} = \frac{87\,\text{fb}}{s(\text{TeV})^2} = 1R.$$

At 1 TeV : $10^{33} * 10^7$ gives $\sim 10^3$ events/unit R $(10\,\text{fb}^{-1})$

New problem of "Beamstrahlung". $P_z \neq 0$:

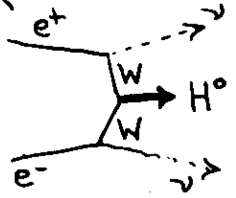
- Peripheral collisions

- $e^+e^-\to e^+e^-X$



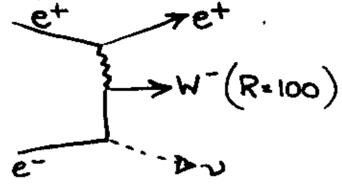
$P_T^X = 0$ $\{m_{q\bar{q}} > 300\,\text{GeV}$ $R=1\}$

- $e^+e^-\to\nu\bar{\nu}X$



$P_T^X \approx m_W$

$e^+e^-\to e\nu X$

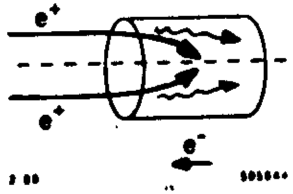


- Signature W^+W^-, Z^0Z^0 pair plus missing transverse enery.

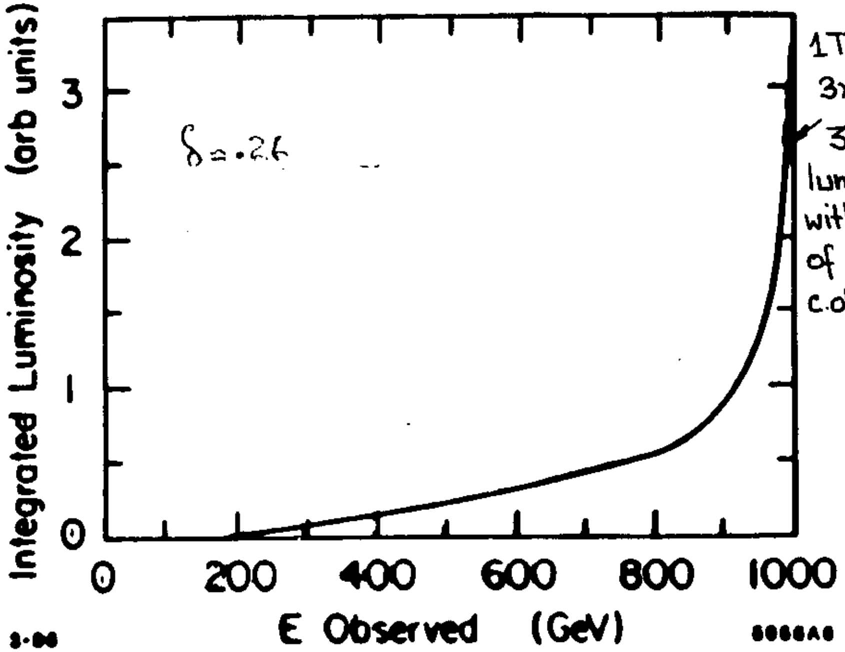
n.b. $e^+e^-\to e\nu W$ or $e^+e^-\to\nu\nu Z$ preclude region $M_H \sim M_W$ or M_Z

Alexander, Burke, Jung, Komamiya, Burchat.

Beamstrahlung.

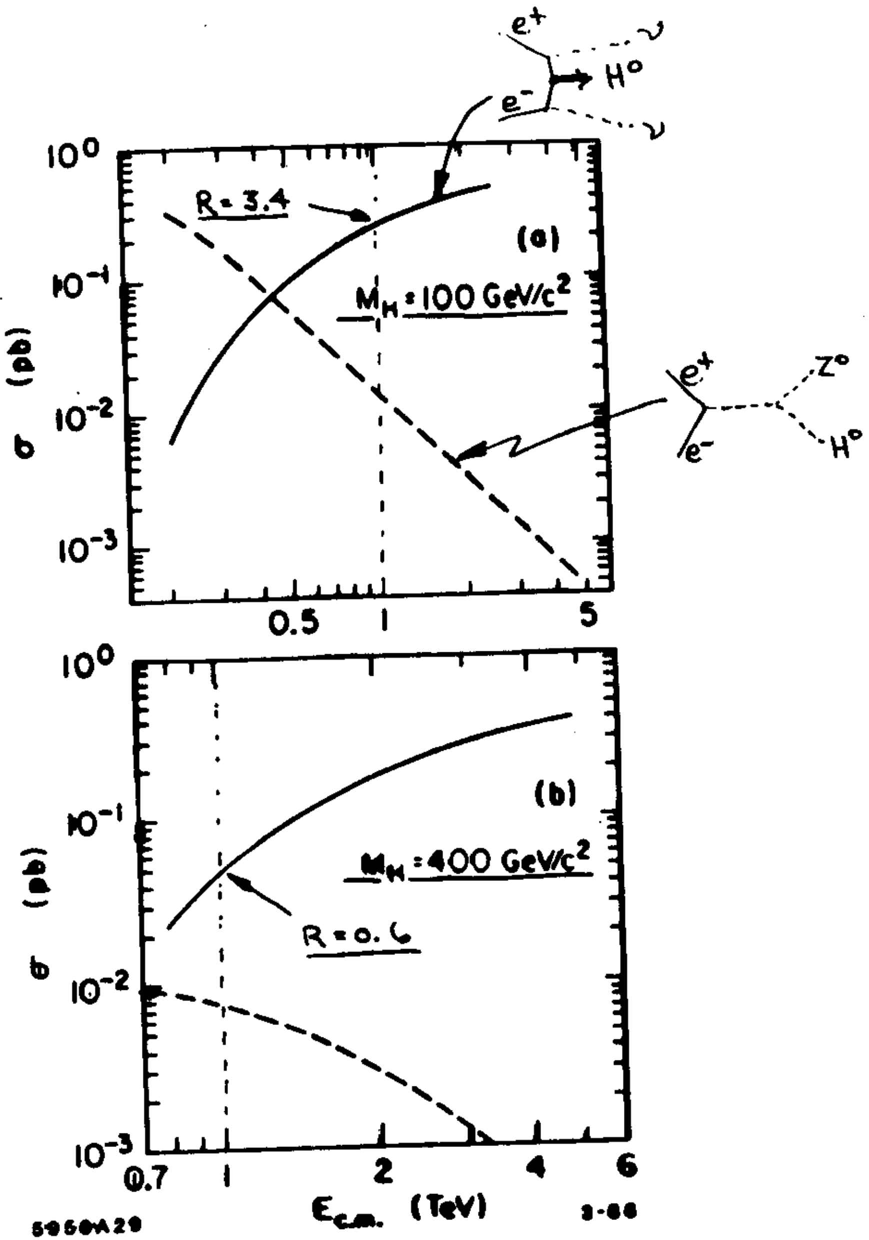


centre of mass energy not monochromatic.



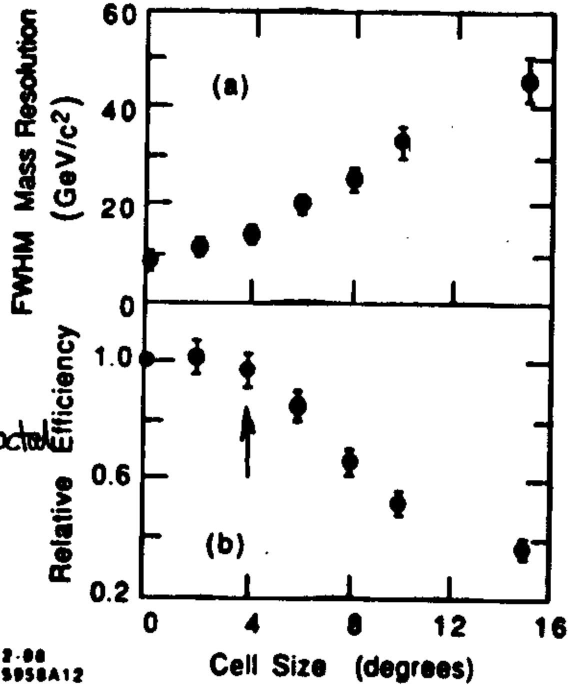
1 TeV
$3\times10^{33}\,cm^{-2}s^{-1}$
30% of luminosity within 2% of nominal c. of m. energy.

δ = mean fractional energy loss undergone by particles during beam-beam collision



Calorimetry.

- hadronic $\frac{50\%}{\sqrt{E}} + 2\%$
- electromagnetic $\frac{8\%}{\sqrt{E}} + 2\%$
- e/π $1 \pm 10\%$



W's reconstructable

- Segmentation is important

4°: calorimeter at 2 meter radius ⇒ 14cm □ towers.

The Higgs at Hadron Colliders:

- not at all clear that an intermediate Higgs is visible at a hadron collider. eg. $m_H = 140$ GeV $m_b > 70$ GeV.

  $B(H \to b\bar{b}) \approx 60\%$ $B(H \to WW^*) = 24\%$ one virtual W.

  no convincing simulation
- High Mass $m_H > 2m_Z$

  have $H \to W^+W^-$, $Z^\circ Z^\circ$ signatures BUT.....
- **SuperColliders** SSC: $\mathcal{L}\ 1 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ 20TeV * 20TeV

  LHC $\mathcal{L}\ 1\text{-}5 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ 8TeV * 8TeV.

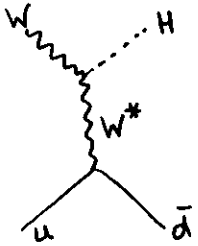
** **not clear that technology exists to reconstruct H via jet spectroscopy – recall the best so far is UA2 at SPS.**

- "so called" gold plated approach $H \to Z^\circ Z^\circ$, $\hookrightarrow \mu^+\mu^-$, $\hookrightarrow \mu^+\mu^-$

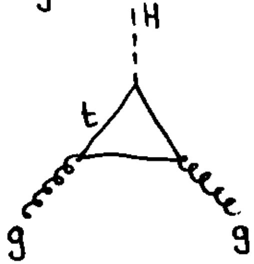
  pay the price of $Z \to \mu^+\mu^-$ ~3%

- muon spectroscopy is technically feasible now.
- dedicated experiment – far from "general purpose"

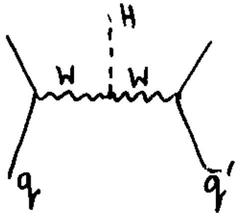
W-bremsstrahlung

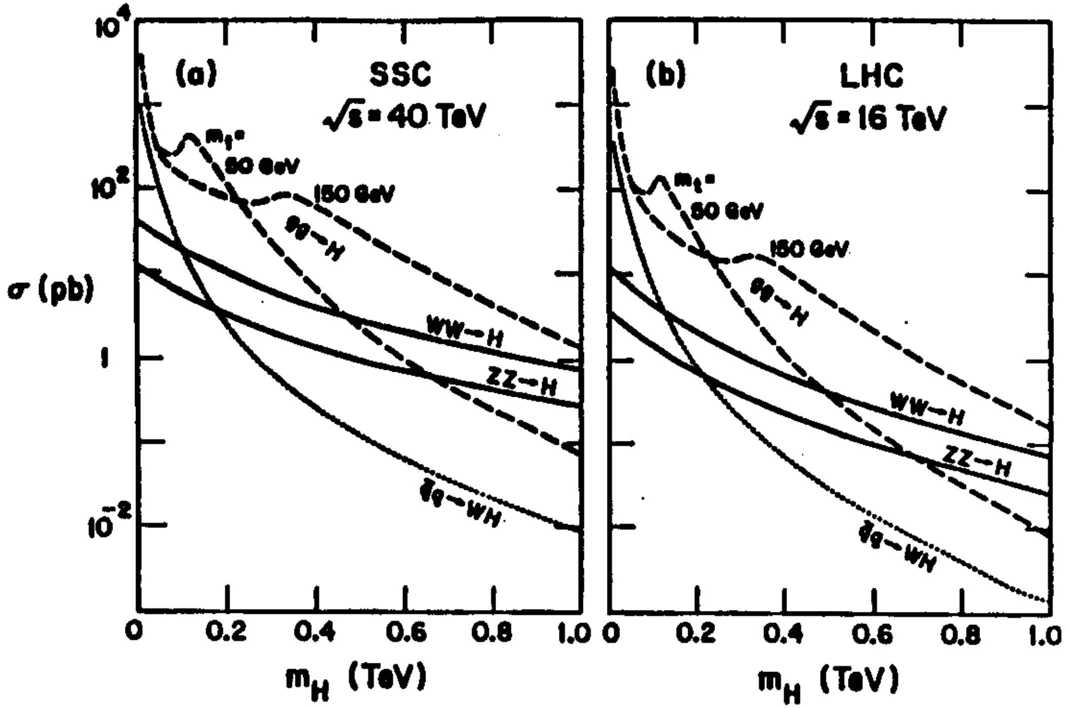


gluon-fusion



W W fusion.





if m_t=150GeV - gluon fusion is main contribution even at 1TeV=m_H.

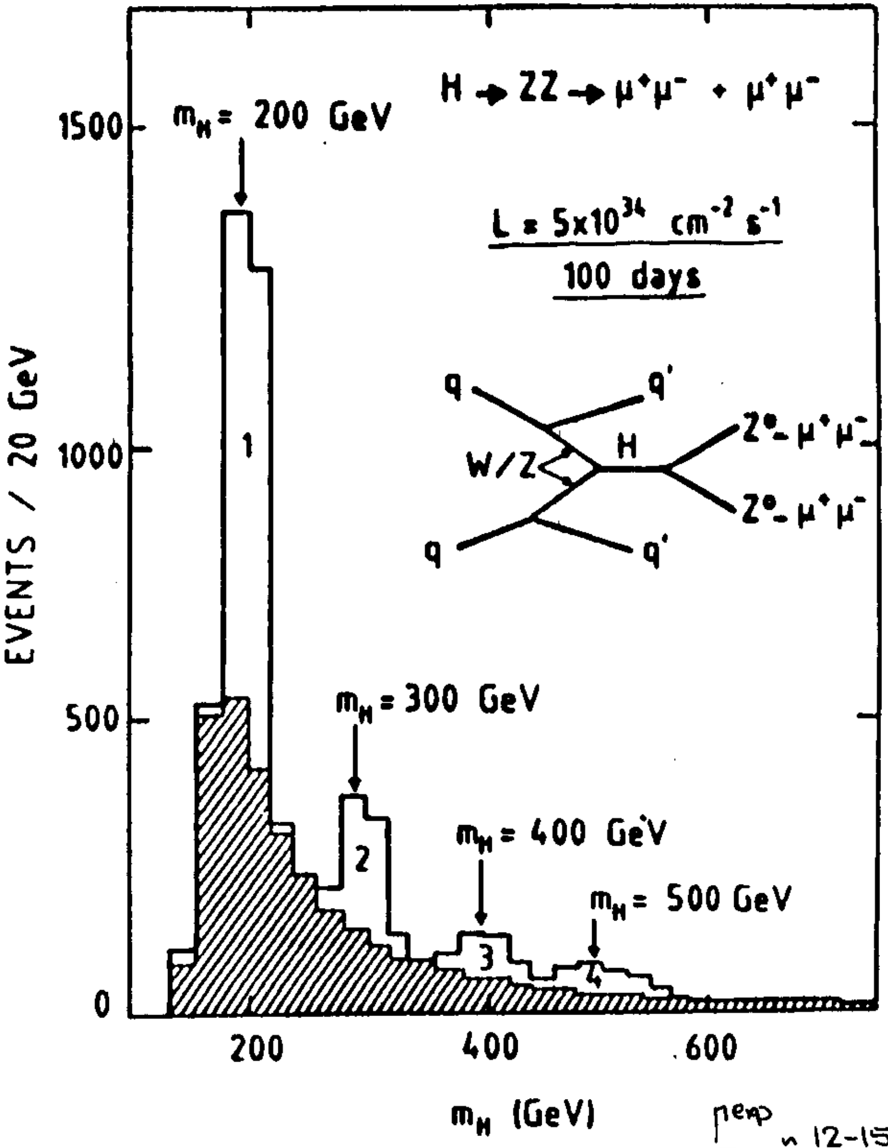
at LHC $\sigma_{H=1TeV} \sim 0.1$pb. $10^{34} cm^{-2}s^{-1} \times 10^{7}s \Rightarrow$ 10K events.

at SSC ~ 10times more.

events are produced - is spectroscopy feasible ?

C.Rubbia:

LHC. $\sqrt{s}$ = 16TeV.



$\frac{\Gamma^{exp}}{m_H} \sim 12$-15%

· 4μ invariant mass at LHC:
muon spectroscopy outside 4π absorber $\sigma_p/p \simeq 10\%$

[n.b. at $M_H \simeq 1$TeV $\Gamma(H) \simeq 0.5$TeV.]

- <u>Beyond the Standard Model.</u>

- $Z^{0\prime}$ $W^{\prime}$ .. **lepton signatures should suffice if machine has energy and luminosity to produce them.**

  just keep one's eyes open!

- Supersymmetry: usual assumptions

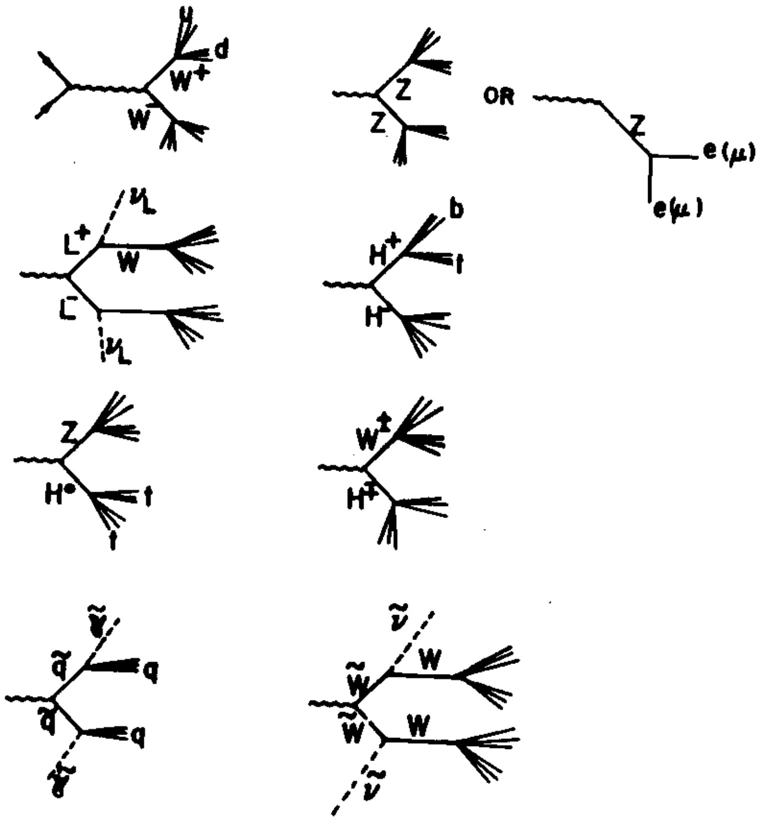
  $\tilde{q} \to q\tilde{\gamma}$ $\tilde{g} \to q\bar{q}\tilde{\gamma}$

  [SPS $m_{\tilde{q}} > 65\,GeV$
  $m_{\tilde{g}} > 55\,GeV$
  e^+e^- $m_{\tilde{e}} > 20\,GeV$]

  $pp \to \tilde{q}\tilde{q}X$
  ↳ $\bar{q} + \tilde{\gamma}$
  ↳ $q + \tilde{\gamma}$

  $pp \to \tilde{g}\tilde{g}X$
  ↳ $q\bar{q}\tilde{\gamma}$
  ↳ $q\bar{q}\tilde{\gamma}$

  signature - jets plus missing transverse energy



- topologies of new phenomena:
  - jets, leptons, missing energy
  - jet-jet effective mass needed to identify Z, W, H^0.

- The Machines: **their impact on detector design.**

- e^+e^- "circular"

- recall the practical unit for physics is R $\sigma_{pt} \sim \frac{87\,nb}{s(GeV)^2}$

- machine energy selects the centre of mass: i.e. already a constituent collision: parent mass is selected for the detector e.g. Z° at LEPI

- event is momentum balanced i.e. $\sum_i \vec{p}_i = 0$ - not yet exploited.

- synchrotron radiation background.

- e^+e^- linear colliders **SLC is the pioneer - aim is TeV L.C.**

- "beamstrahlung" - destroys longitudinal balance: W fusion also destroys transverse balance - can use as signature.

- high energy μ-ons: background: have to be handled/removed.

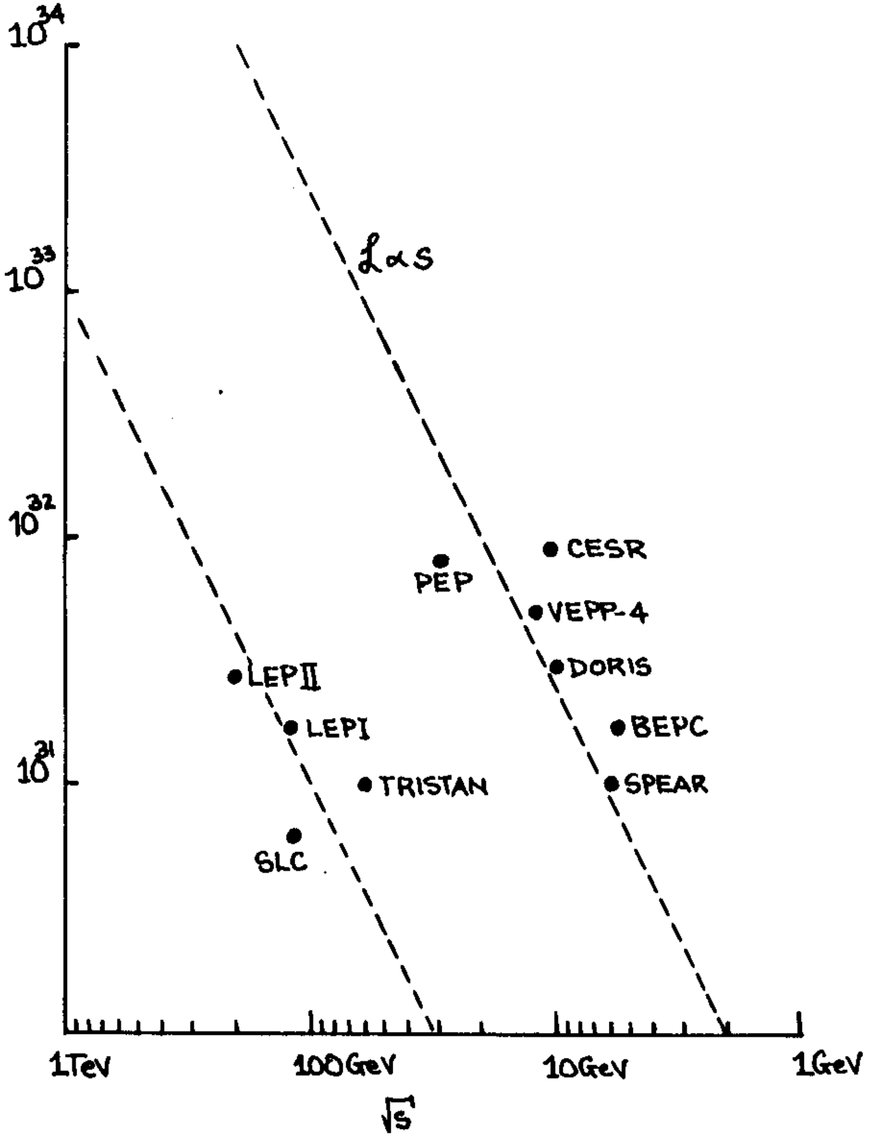
- repetition rates allow considerable multiplexing.

- luminosities should really be ~ $10^{34}\,cm^{-2}s^{-1}$

Machine	DORIS	CESR	BEPC	TRISTAN	LEPI	LEPII
E^{max}_{beam} (GeV)	5.6	6	2.8	30	60	100
Physics	Υ(4S) Beauty	Υ(4S) Beauty	τ-Charm	continuum	Z°	W^+W^-
$\mathcal{L}$ $10^{30}\,cm^{-2}s^{-1}$	30 at 5GeV	90 at 5.3GeV*	17	10	17*	27
Circumference (Km)	**0.288**	**0.768**	**0.2404**	**3.02**	**26.66**	
$\tau_{\mathcal{L}}$ (hr)	**0.3-1.5**	**3-4**	**5**	**4-5**	**5**	
ΔE 10^{-3}	**1.2 at 5GeV**	**0.6 at 5.3GeV**	**0.74**	**1.6**	**1.0**	
Beam radius 10^{-6}m	H ~ 570 V ~ 30	H ~ 500 V ~ 11	H 890 V 69	H ~ 520 V ~ 32	H ~ 300 V ~ 12	
time between crossings	0.96μs	0.36μs	0.8μs.	5μs	22.2μs.	
Event rate per s.	0.03 Υ(4S)	0.09 Υ(4S)	0.14 ($D\bar{D}$)	1×10^{-3} (R=4)	.43 (Z°)	2.7×10^{-4} (W^+W^- ~ 10pb)
$\langle\bar{n}\rangle$	~ 3×10^{-8}	~ 3×10^{-8}	~ 1×10^{-7}	5×10^{-9}	~ 1×10^{-5}	

* Beauty Factory proposal. $\mathcal{L}$ ~ $500\times10^{30}\,cm^{-2}s^{-1}$

* Z Factory proposal $\mathcal{L}$ ~ 1000×10^{30}



Machine	SLC	CLIC
E_{beam}^{max} (GeV)	50	1000
Physics	Z^0	H^0
$\mathcal{L}$ $10^{30} cm^{-2} s^{-1}$	6	1100
"Length" Km	1.45+1.45	
ΔE 10^{-3}	2	<67 0.33
Beam radius 10^{-6}m	1.7	$\sigma_x = 60$nm $\sigma_y = 12$nm.
time between crossings	8.3ms	0.6ms.
Event rate per s.	0.15(Z^0)	~10^{-4}(R=1unit)
$\langle \bar{n} \rangle$	~10^{-3}	

- <u>Hadron colliders</u> **currently $\bar{p}p$ -- in the future pp.**
- not in the centre of mass of the constituent collision
- energy balance in transverse plane is the important signature .. "missing transverse energy"
- detector design/characteristics selects the "centre of mass energy" .. or parent mass ... translates into P_T.
- high rates - triggering is crucial.
- more than one event per crossing - overlap problem
- response time for detector elements - short enough to avoid integrating over several crossings
- at high energies transverse "vertex definition" is good.

- <u>electron-proton collider</u>
- HERA - "fixed target" in "forward direction"

Machine	SPS $\bar{p}p$.	TeVatron $\bar{p}p$.	SSC pp	LHC pp.
E^{beam}_{max} (TeV)	·315	0.9–1.0	20	8
$\mathcal{L}$ 10^{30} $cm^{-2}s^{-1}$	~3	~3	1000	1400
Circumference Km.	6.911	6.28	83.631	26.66
$\tau_{\mathcal{L}}$ (hr)	24	6-20hr	~24hr	~18
Bunch length (cm)	20	50	6.8	7.5
β^* (m)	1H 0.5V	0.72	0.5	1
Beam radius 10^{-6}m	120H 86V	43	4.8	12
time between crossings	3.8μs	3.5μs	16ns	25ns.
Event rate per s.	1.3×10^5	1.6×10^5	10^8	10^8
$\sigma_{trigger}$. mb	43	52mb	100mb	75mb
$\langle\bar{n}\rangle$	0.5	0.55	1.8	2.6

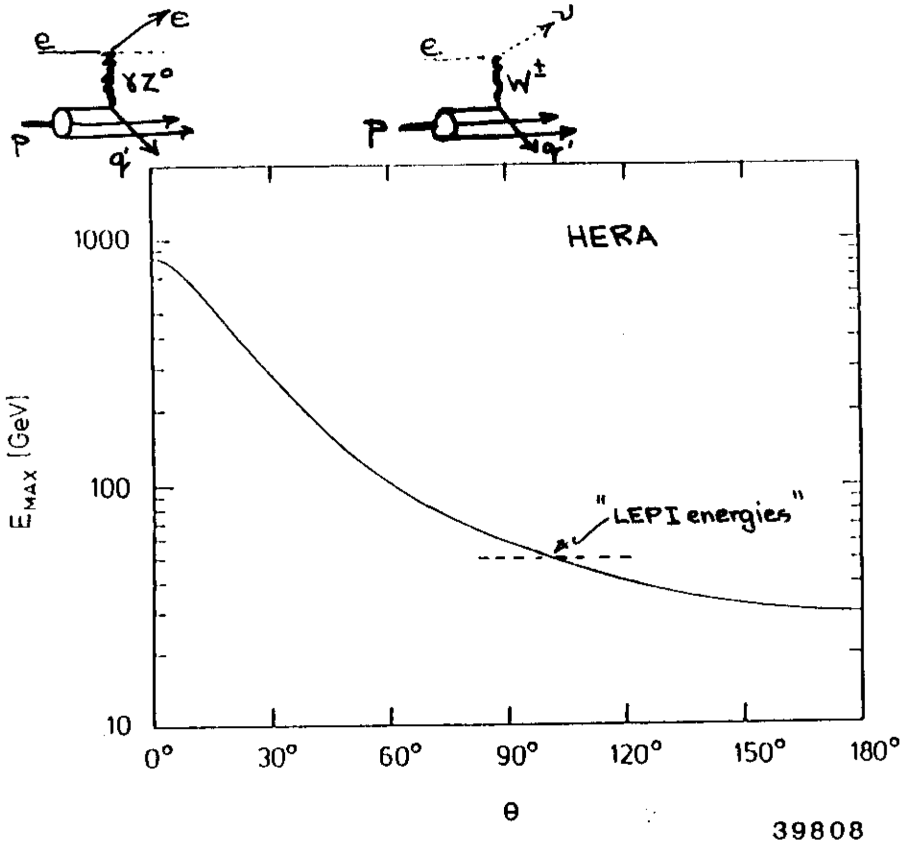
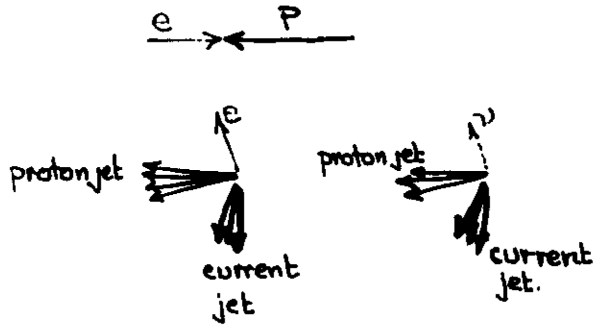


Fig. 48 Maximum jet energy as a function of polar angle.



Machine.	HERA ep
E^{beam}_{max} TeV	e 0.026 p 0.82
$\mathcal{L}$ 10^{30} $cm^{-2}s^{-1}$	15
Circumference Km	6.336
$I_{\mathcal{L}}$	>3
Bunchlength cm.	e .83 p 15
Beam radius 10^{-6}m	e 263 H 69 V p 293 H 95 V
time between crossings	96ns.

- Conclusions.

- we are entering the era of jet-jet spectroscopy (Learn from LEP!)
- W's and Z's have become tools
- if a linear collider (TeV) could be built we could use it NOW.
- a hadron collider could be built now (LHC/SSC) - we could use it in a dedicated μ - search but otherwise ....
- HERA is an interesting 'test bed' for triggering - pipelines etc..

- Take a look at "today's" detectors - a sample - are they matched to their tasks?
  - Hadron Colliders: [illegible] UA2 : (UA1) : CDF - top search.
  - LEP Detectors ALEPH, OPAL, DELPHI, L3 : Z° physics
  - HERA Detectors ZEUS ep collisions

- Given a 1TeV e^+e^- Linear collider - believe we have all of the technology to extract the physics - rather "charitable" machine.
  we can build the detector but not the accelerator.

- A high energy : high luminosity hadron collider? what is the detector environment like? can we sustain the traditional interesting signatures as luminosity and energy are extrapolated.
  we can almost certainly build the accelerator, not at all clear that we can build the detector except perhaps for some dedicated purpose e.g. $H \to Z^\circ Z^\circ \to \mu^+\mu^-\mu^+\mu^-$.

- "top"

What do we know about the mass of top?

- Radiative corrections $\Rightarrow m_t < 200 \mathrm{GeV}/c^2$
- TRISTAN : e^+e^- $m_t > 28 \mathrm{GeV}/c^2$
- UA1 $\bar{p}p$ $m_t \gtrsim 50 \mathrm{GeV}/c^2$.

- preliminary UA2 : UA1 : CDF $m_t > 60 \mathrm{GeV}/c^2$.

"top" Window [illegible]

Number of events where one $t \to \bar{b} \ell \nu$

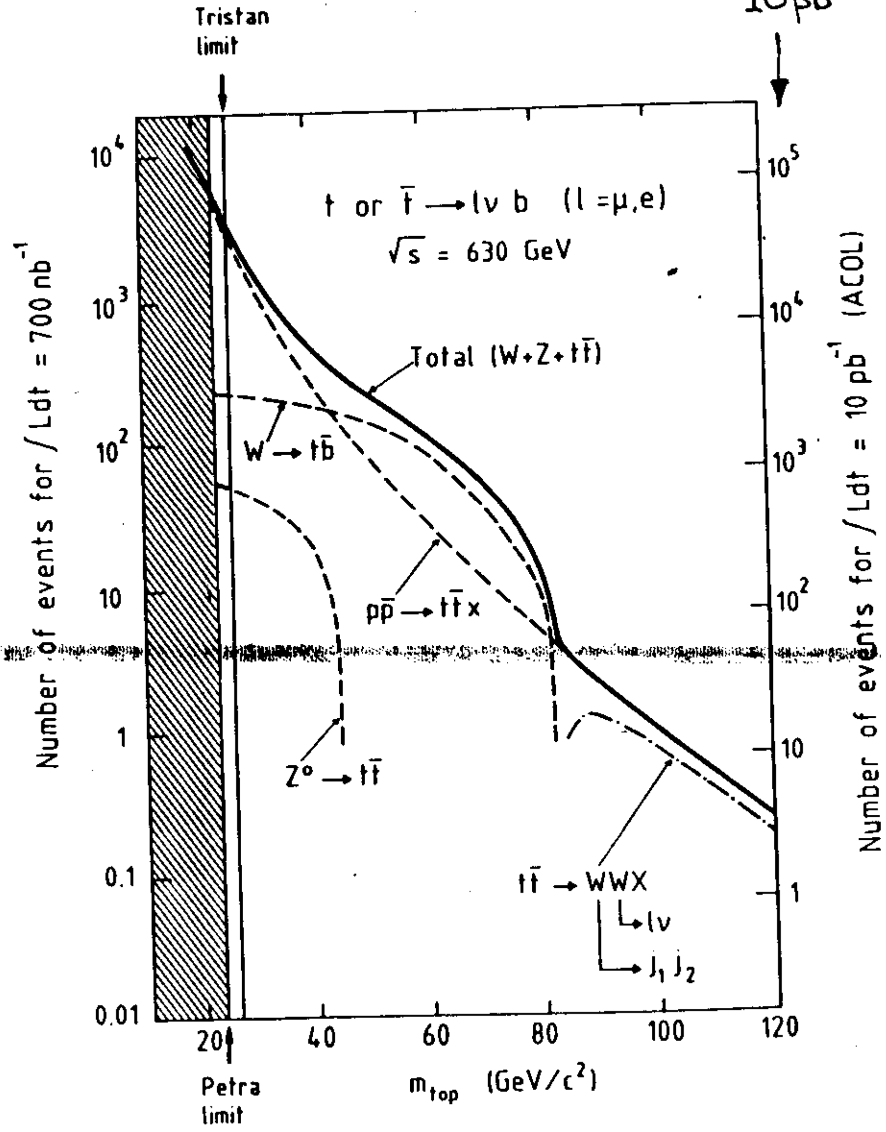


FIG 1

$$\bar{p}p \to t\bar{t}X \to \bar{b}\ell\nu b jj$$

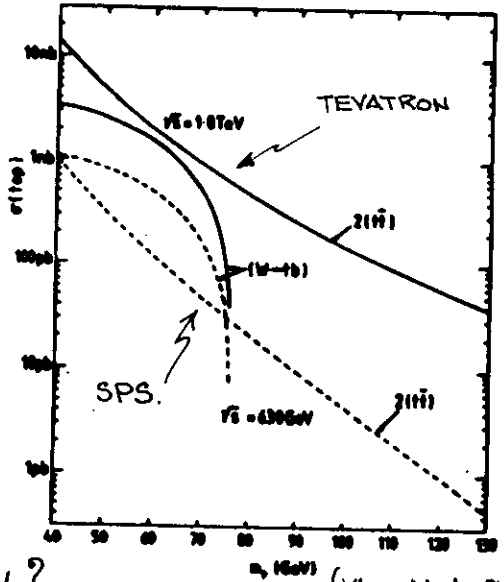
if $m_t > m_W + b$.

$$\bar{p}p \to t\bar{t}X \to \bar{b}W\,bW$$
$$\hookrightarrow \ell\nu \quad \hookrightarrow jj$$

- production via $W \to tb$ not so important at TEVATRON
- $m_t \sim 70$GeV $\sigma_{Tev} \sim 20\sigma_{SPS}$

  $m_t \sim 120$GeV $\sigma_{Tev} \sim 60\sigma_{SPS}$.

SPS is "out of steam" at ~70GeV ?

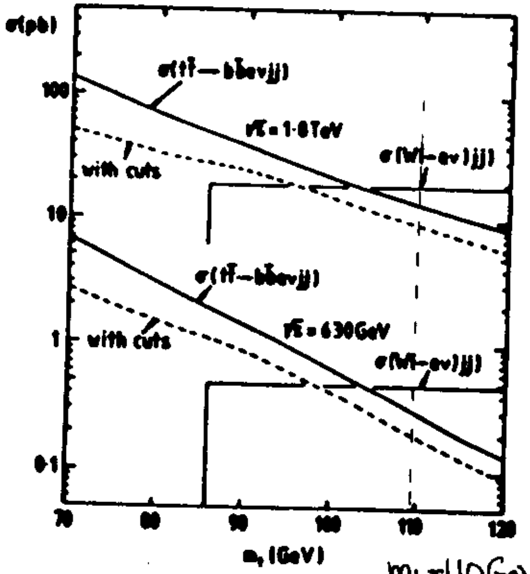


(Kleiss Martin Stirl

"cuts": 'central' ℓ, j

" $P_T(\ell, j, \nu) > 10$GeV

"angular separation" ℓj



m_t≈110GeV

Background:

$$\bar{p}p \to Wjj \quad m_{jj} \sim m_W.$$
$$\hookrightarrow \ell\nu$$

$m_t = 110$GeV : $\int \mathcal{L}dt = 5$pb^{-1}

TEVATRON

$(jj\ell\nu)$	(Wjj)
45events	95
$(bjj\ell\nu)$	
45events	~10

} "cuts on"

ℓ = e+μ

- What are the experimental signatures of "top" ?

(i) $t(\rightarrow b\bar{\ell}\nu)\bar{t}$: lepton + 2jets ("b" "$\bar{t}$")

(ii) $t(\rightarrow b\bar{\ell}\nu)\bar{t}(\rightarrow \bar{b}W^-)$ lepton + 3jets (b or $\bar{b}$ + 2jets from real or virtual W).

(iii) $t(\rightarrow b\bar{\ell}\nu)\bar{t}(\rightarrow \bar{b}\ell\bar{\nu})$ dilepton events $\ell\bar{\ell}$ $\ell\bar{\ell}'$

- Signature (i) should suffice for $m_t < 70\,GeV/c^2$ - because of lower energy at CERN SPS $\bar{p}p$ this is close to the limit of UA2 search.

usual. P_T (ℓ or jet) > 10 GeV : $|\eta(\ell \text{ or jet})| < 2.5$.
j and ℓ separated:

- $m_t > 70\,GeV$: W + 2 QCD jets is serious background.

$$\bar{p}p \rightarrow W(\rightarrow \ell\nu)jj$$

Two signatures : • isolated lepton + 3jets
$m_t \gtrsim m_W$ • isolated $e\mu$ events.

at Tevatron : large "minijets" cross section at Tevatron ⇒ favour $e\mu$:

- Signature (iii) - chosen by CDF at Tevatron.

At $\sqrt{s} = 1.8\,TeV$: $m_t = 110\,GeV$ $\int \mathcal{L}dt = 1\,pb^{-1}$: $e\mu \rightarrow 1$ event
$\ell + 3j \rightarrow 12$ events.

UA2 - lepton = "e" plus 2jets.
CDF - dileptons = $e\mu$
UA1 - μ + jets.
other information in the events eg. missing energy.

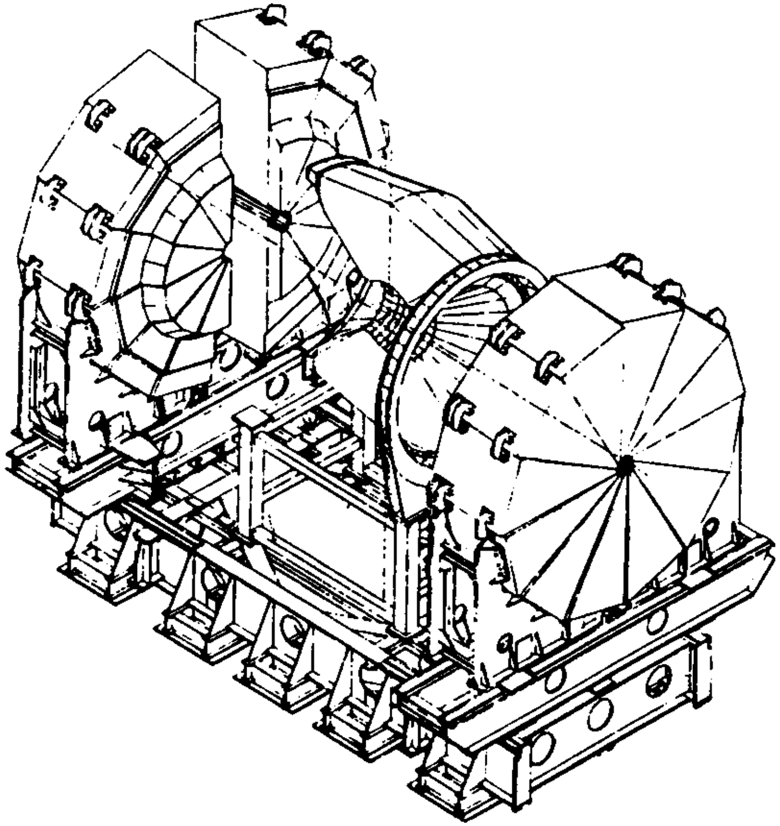
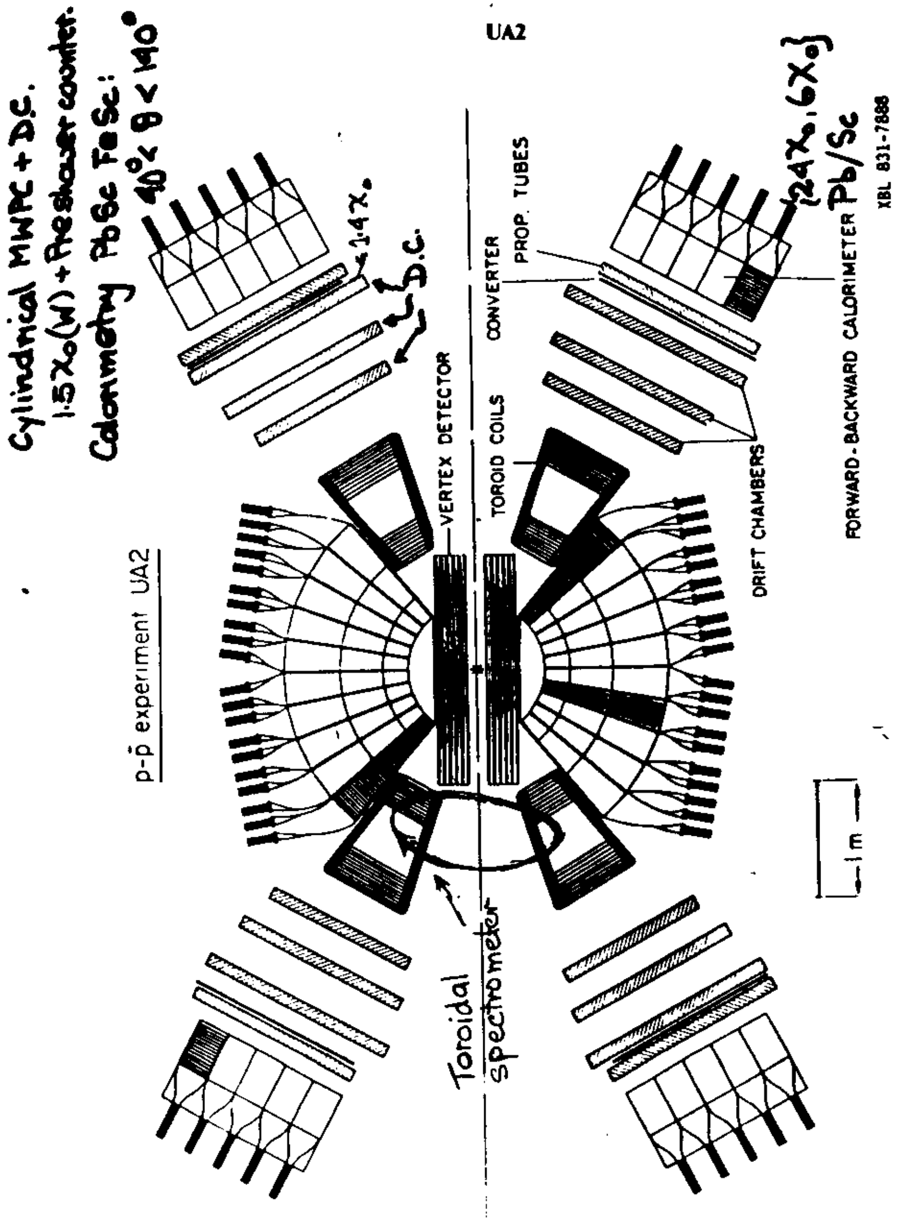
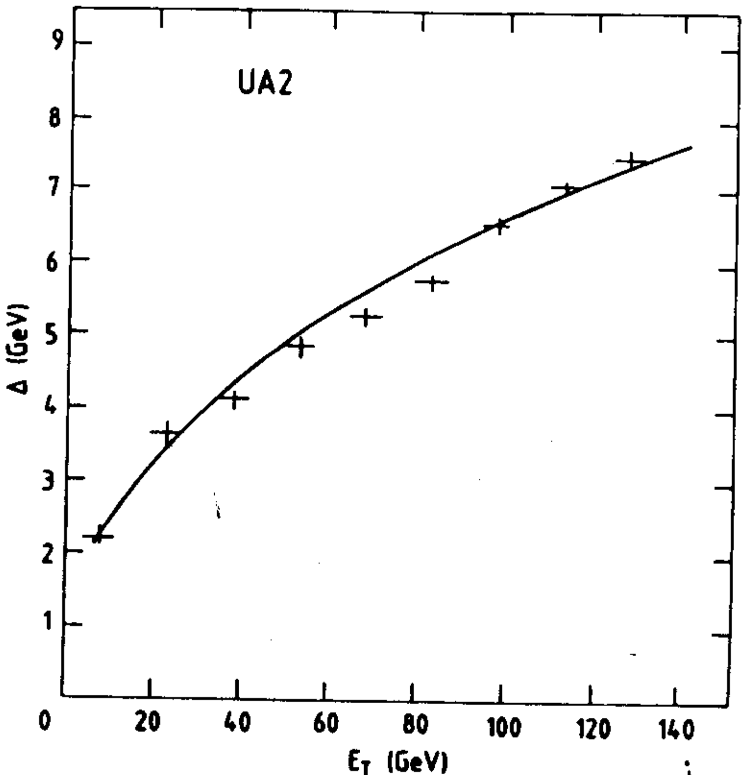


Fig. 1



Cylindrical MWPC + D.C.
1.5X₀(W) + Preshower counter.
Calorimetry PbSc FeSc: $40° < \theta < 140°$

p-p̄ experiment UA2

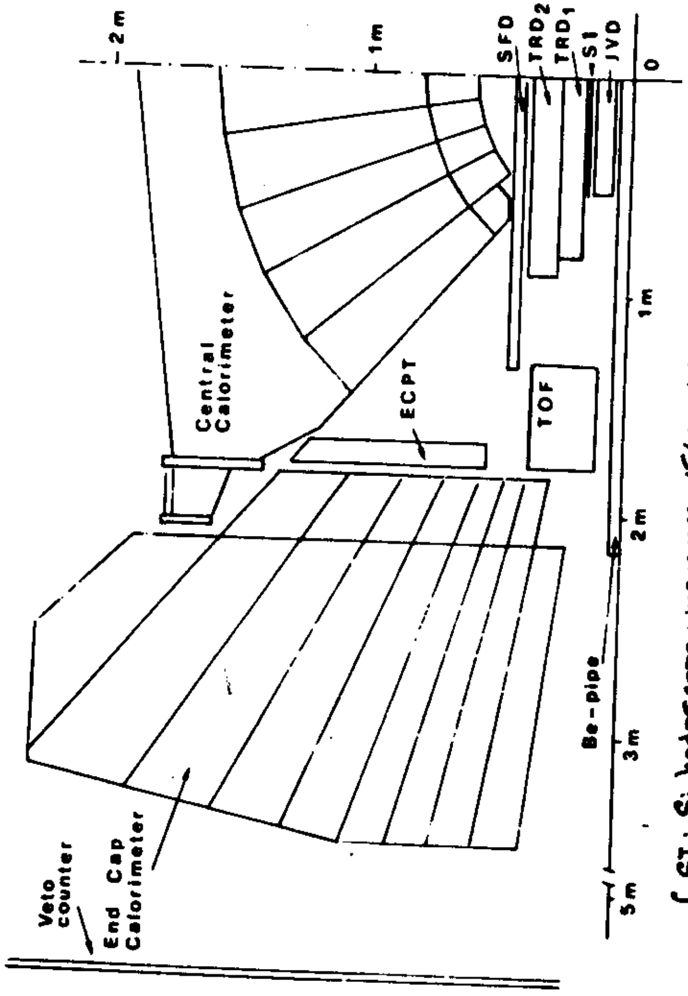


$E_T = \Sigma_j E_T^j$

Fig. 4

$\Delta = \alpha E_T^{\beta}$ $\alpha = 0.88$ $\beta = 0.433$: full line.

+ .. fit to Δ at each bin.



SI : Si hodoscope : measures dE/dx (early) :

TRD: separates "e" from hadron :

Scintillating Fibre Detector : 18 layers - tracking ∅ 1mm.
1.5 X_0 6 layers - pre sampler.

improved 'e' ID -

Fig. 2

• UA2

- "Traditionally" - UA2 was not "hermetic" full calorimetry $|\eta| < 1$
- Forward and backward spectrometers replaced by "endcaps"

EM compartment : Pb (3mm) Sc (4mm) : WLS : 17.1 – 24.4 X_0

$15\%/\sqrt{E}$

Hadronic compartment Fe (25mm) Sc (4mm) WLS total thickness ~ [illegible].

$60\%/\sqrt{E}$

Missing energy : transverse components p_x^m p_y^m - Gaussian distribution.

$\sigma_x = \sigma_y = \sigma$: select non interacting particles

$$p_T^m = [(p_x^m)^2 + (p_y^m)^2]^{1/2} \gg \sigma .$$

$$(p_T^m)^2 \quad \Rightarrow \quad dN/d(p_T^m)^2 = \left(1/\Delta^2\right) e^{-(p_T^m)^2/\Delta^2} \qquad \Delta = \sqrt{2}\sigma .$$

(exponential up to ~5Δ)

Δ is function of E_T :

(i) greatly improved missing energy capability :

(ii) improved electron identification - photon conversions
- overlaps : low energy hadron.
: high energy γ.

well matched to "e" + 2jets : SPS will "run out of steam" at $m_t \simeq m_W$.

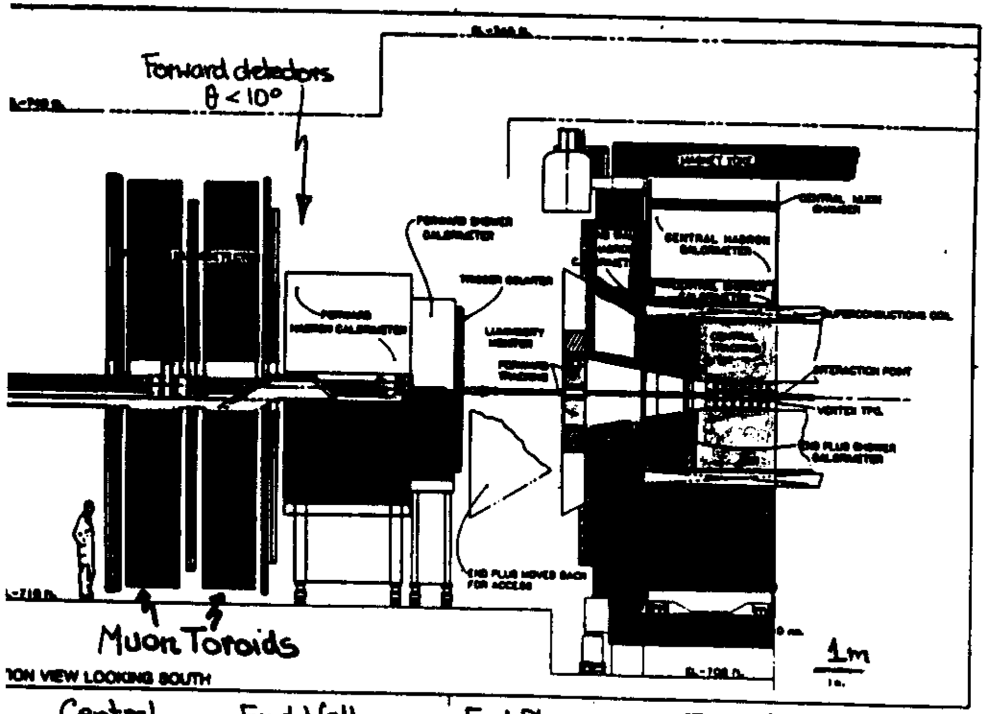
CDF: Superconducting solenoid 3m diam × 5m long 1.5T:

Calorimetry $2^\circ < \theta < 178^\circ$ full ϕ: (pointing towers)

Tracking: $\delta p_T / p_T = 2\times10^{-3} p_T$ $(40 < \theta < 140)$

$\delta p_T / p_T \approx 4\times10^{-3} p$ $(21^\circ < \theta < 40^\circ)$

7: An elevation view of half of the CDF Detector



	Central		End Wall	End Plug		Forward:	
	0-1		0.7-1.3	1.1-2.4		2.2-4.2	
mp.	1*	1	1	3	1	2	1
1.	0.5cm	1.0cm	1.0cm	Prop. Tubes.			
	Pb	Fe	Fe	Pb	Fe	Pb	Fe
	0.32	2.5	5.1	0.27	5.1	0.48	5.1
	$\sim\frac{14\%}{\sqrt{E}}$	$\sim\frac{77\%}{\sqrt{E}}$	$\frac{100\%}{\sqrt{E}}$	$\sim\frac{28\%}{\sqrt{E}}$	$\sim\frac{140\%}{\sqrt{E}}$	$\sim\frac{28\%}{\sqrt{E}}$	$\frac{140\%}{\sqrt{E}}$

Prop. tube chamber at shower max $6X_0$

- <u></u>CDF : $e\bar{\mu}$ (don't neglect entirely leptons + jets)
  - 1.5T field : sign information on leptons.
  - electron ID : (i) $p \Sigma E$
    (ii) leakage to hadron cell. (profile in End Plug)
    (iii) Central : Prop tube at shower max:
  - μ-detection : Central chambers 4 layers 250μm. 1.2mm σ_z.
    $\sigma_{p_T}/p_T^2 < 2\times10^{-3} (\text{GeV}/c)^{-1}$

$-.63 < \eta < .63$

Forward toroids $\delta p / p \approx 13\%$ $p > 8\,\text{GeV}/c$:

$-3.6 < \eta < -1.96$

$1.96 < \eta < 3.6$ Rapidity gap .63 to 1.96:
(1) tracking + minimum ionizing in calorimeter.
finds second μ in $Z^0 \to \mu\mu$.

- top searches.

- UA2: dedicated e: very good well understood e and missing E_T.
  machine limited to $m_{top} \leqslant 75$ GeV. no B field
  no complementary μ's.
- UA1 - μ only (technically KO'd ones)
  μ-good: calorimetry is poor "5cmFe" large granularity:
- CDF "minijet" troubles at 2TeV:
  "e" identification: one sampling: proportional tubes at peak of shower.
  μ: probably OK for second from Z° - not clear how good as "leading μ"
- before acceptance "top" will probably have to be seen in all channels at consistent rates. $e\mu$: e+jets : μ+jets.

- LEP Detectors.

ALEPH : OPAL : DELPHI : L3 :

$\langle \mathcal{L} \rangle = 50\%$ of peak ($17\times10^{30}\,cm^{-2}s^{-1}$) : 10^7 sec "Seen" Z° decays $\approx 2\times10^6$

- features of Z° decays - good lepton detection
  - neutrino "detection"
  - jet reconstruction.
- multiplicities not high : 20 charged 10 neutral (π°)

- Historical aside. • LEP Detectors L. of Intent Feb 1982
  • approved June '82 : physics climate - SPS $p\bar{p}$ far from proved. LEP may have to discover Z° hadron collisions - where are the jets?
- LEP detectors conceived in Hamburg and Palo Alto: sons or daughters of PETRA and PEP detectors:
  - good leptons $e\,\mu$
  - good tracking
  - a "shower counter" + "something" behind

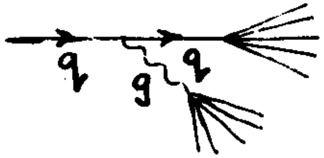
  little attention to "combined" calorimetry: probably OK at LEP I may begin to pay a price at LEP II: W pairs.

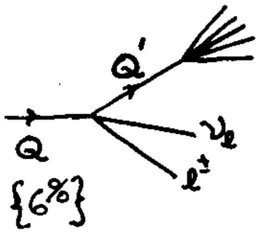
Features of Z° decays.

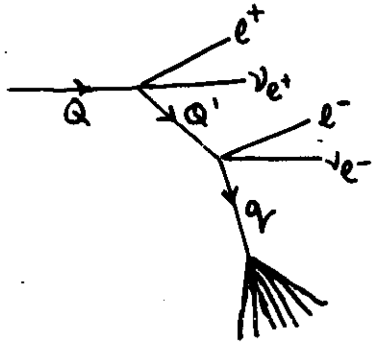
$Z^\circ \to \nu_i\bar{\nu}_i$ ~20%

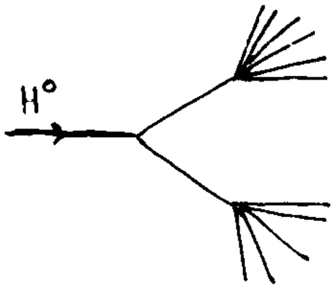
$\to e^+e^-, \mu^+\mu^-, \tau^+\tau^-$ ~7%

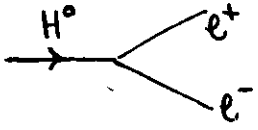
$\to q_i\bar{q}_i\{u,d,c,s,b,t\}$ ~73% $\{q\bar{q}g$ ~26%, $q\bar{q}gg$ ~3%$\}$











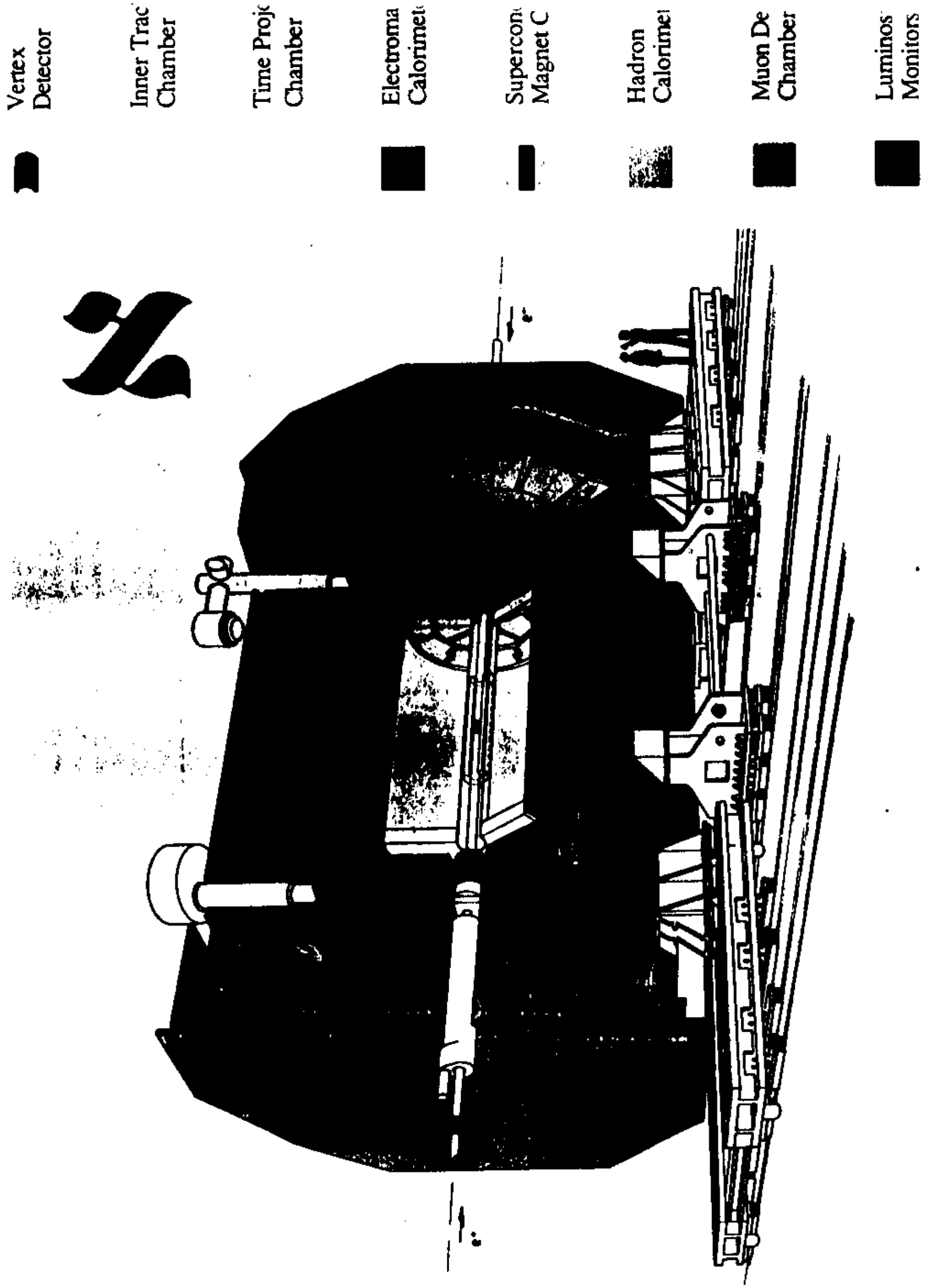


Fig. 1 - The ALEPH Detector

ALEPH

Large Superconducting Coil 2.65m radius 6.36m long 1.5T
[1.6 X_0 0.4λ]

electromagnetic calorimeter inside coil.

Tracking:

μVertex: multielectrode Si detector r.85mm-105mm.
staged.

Inner chamber: small cell drift chamber r: 142mm-260mm.
14° track: fully contained. $\ell = \pm 1050$mm.
used for triggering $\delta r\phi = 100\mu m$.

TPC 2.2m x 2 = drift ~35μs r = 330mm-1770mm.
320 "ionization" points : wires samplings large angles.
20K pads : each end (6mm)

$\sigma_{r\phi} \simeq 230\mu m$ $\sigma_z \simeq 1.1mm$ $\frac{\Delta p}{p} \simeq 1.2\times10^{-3}p\left(\text{GeV}/c\right)$ $\sigma\left(\frac{dE}{dx}\right) = \pm4.7\%$
$\left\{ e/\pi < 10\text{GeV}\ [3\sigma] \right\}$

- EM Calorimeter : Pb-gas (xenon 80% CO_2 20%)

Al extrusion 25μm wire - induce pad signal 3cm x 3cm pad:
pointing towers: (~12mrad)
4X_0 (2mmPb) : 9 X_0 (2mmPb) 9 X_0 (4mmPb)

48K towers barrel : 24K end caps x 3 = 216K channels (multiplexed)
$\sigma/E \simeq 16\%/\sqrt{E}$ 1.5T along wire → $22\%/\sqrt{E}$: Xenon increased mult. scatt.

- Hadron. limited streamer (plastic) Iarocci tubes 5cm Fe. (1.2m Fe)

strips parallel to wires pads 30cm x 30cm [outside plate 10mm]
$\Delta\theta = 5°$ $\Delta\phi$ 7.5° ~ $75\%/\sqrt{E}$: ($82\%/\sqrt{E}$ Hadron only)

- μ-detection : hadron strips + 2 double layers of streamer tubes 50cm apart
$\sigma \leq 2$mm.

ALEPH : Beam test of combined calorimeter

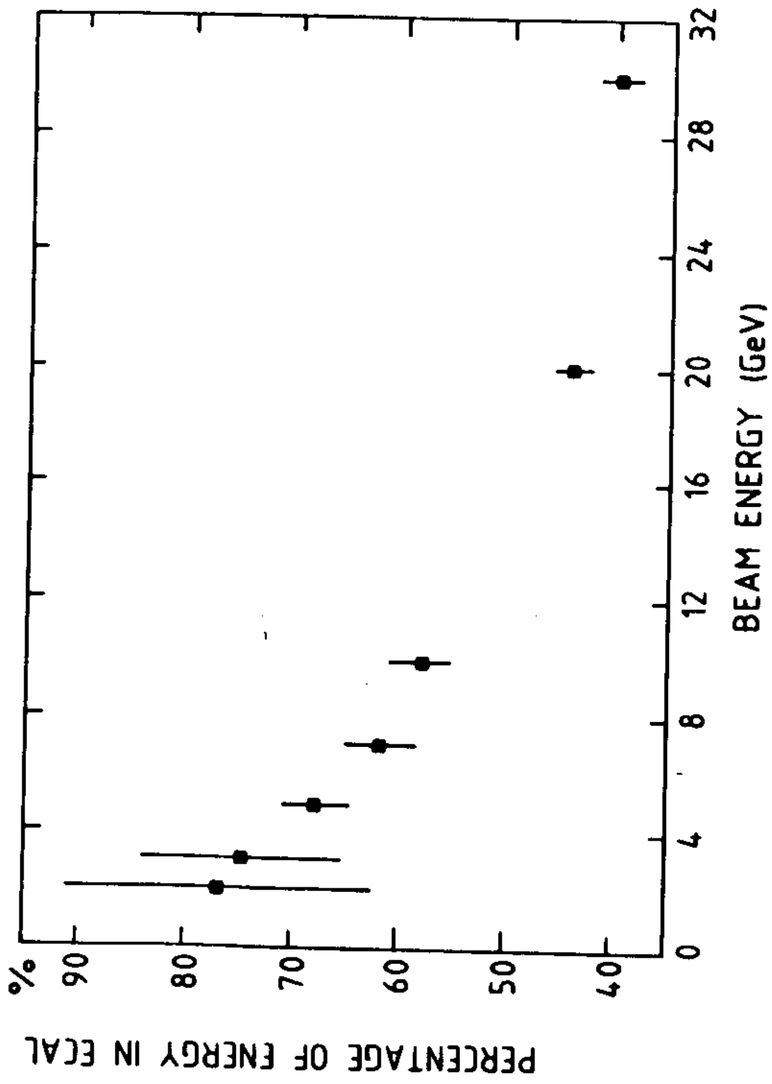


FIG.8

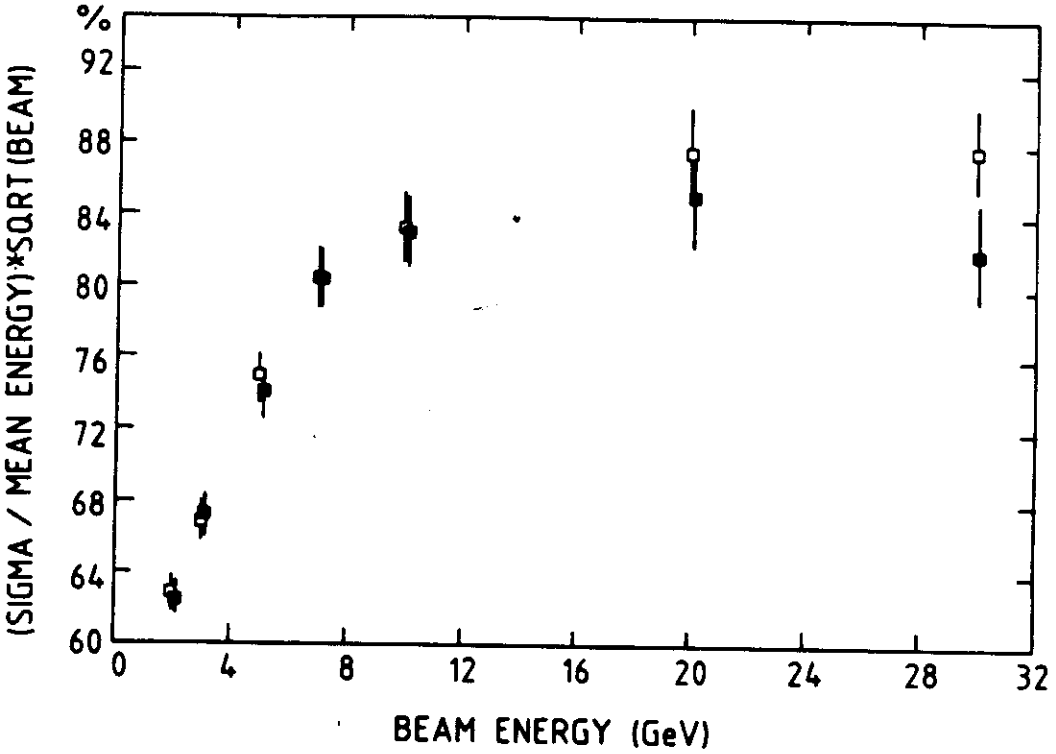
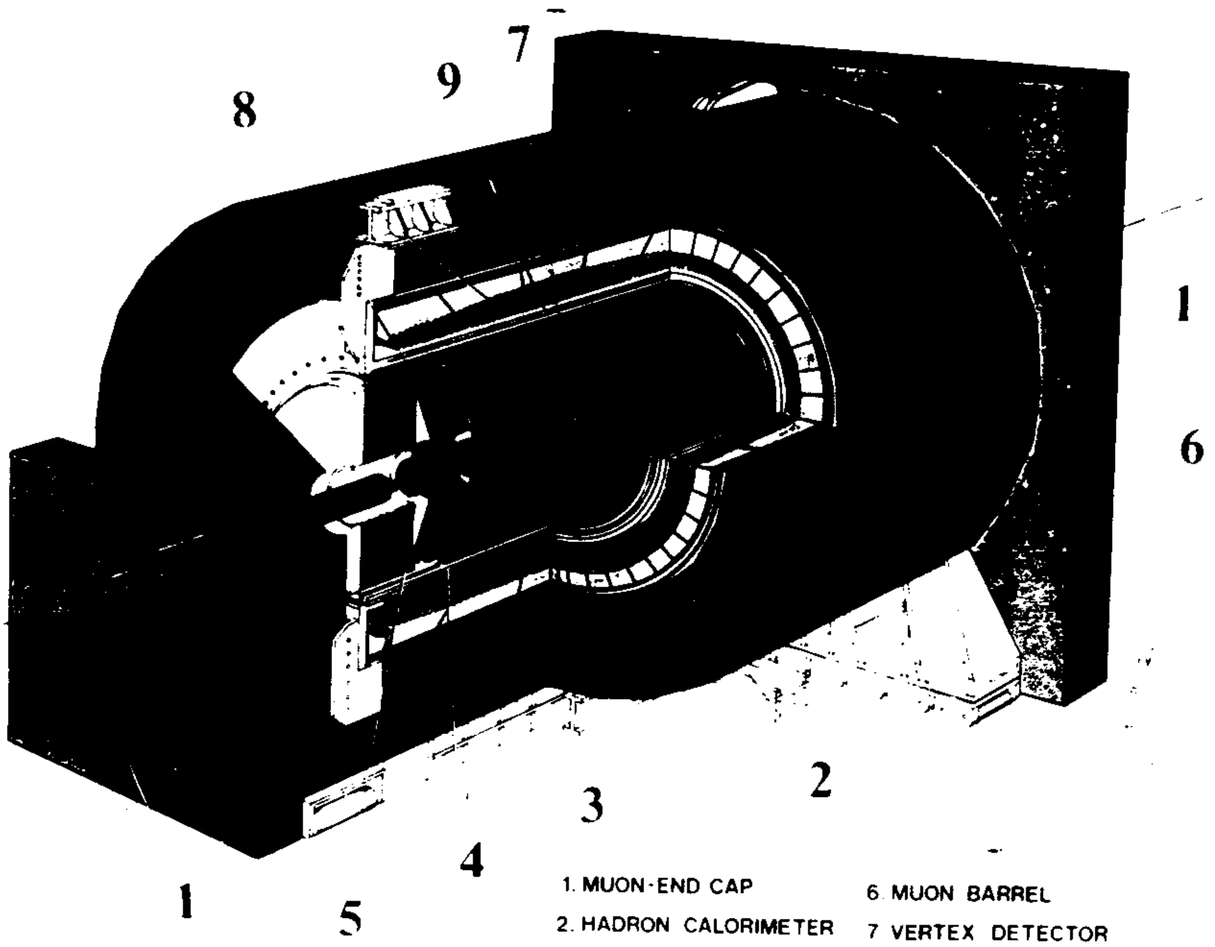


FIG. 9

e/π = 1·3 in region 20-30GeV ≈ 1·7 at 2GeV.



1. MUON-END CAP
2. HADRON CALORIMETER
3. JET CHAMBER
4. MAGNET COIL
5. FORWARD DETECTOR
6. MUON BARREL
7. VERTEX DETECTOR
8. LEAD GLASS
9. PRESAMPLER AND TIME-OF-FLIGHT DETECTOR

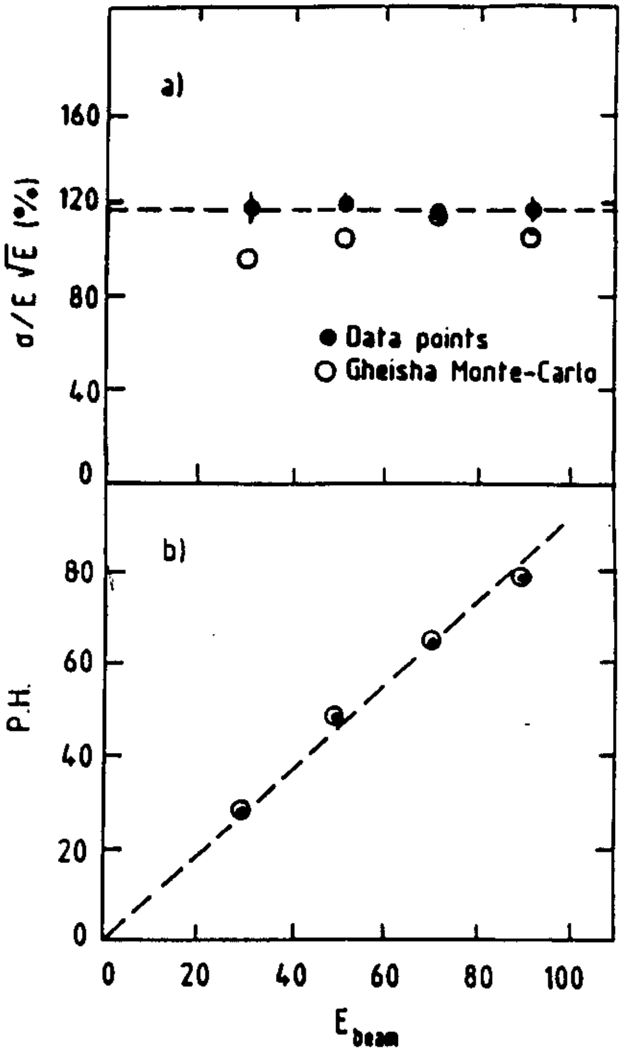
- **OPAL** Warm coil 2.25m diameter 6.5m long 0.4T : {Al 1.5 X_0}
  3 tracking systems inside coil : calorimetry outside.
- Tracking
  - Vertex chamber Jet type cells r 85mm – 200mm 1m long.
    $\sigma_{r\phi} \approx 50\mu m$: triggering :
  - Jet chamber : JADE experience 3840 wires 100MHz FADC
    $\Delta r = 1.6m$ 3.8m long
    4 bar operation Argon 90% methane 8% isobutane 2%
    $\sigma_{r\phi} \approx 150\mu m$ $\sigma_z \approx 1\%$ of. ℓ. $\sigma\left(\frac{dE}{dx}\right) = 3\%$ (~100 samplings)
    2 particle separation ~ 2.5mm.
    below 10 GeV $\Delta p/p$ ~ 1–2% mult. scat. limited [4 bar argon]
    $\Delta p/p \simeq 2\times10^{-3} p (GeV/c)$
  - z-chambers drift chambers $\sigma_z = 300\mu m$ $\sigma_{r\phi} \simeq 5mm$.
- EM Calorimetry Pb glass: barrel 9600 blocks : pointing :
  22 X_0 rear face 10×10cm² 3" P.M.

  endcap 1200 each VPT 3" work in B field
  {90×90 mm²} 22 X_0
  presampler outside coil 1.5 X_0 limited streamer tubes σ ~ 200μm.
  (drift)
  compare position with energy centroid in Pb glass.

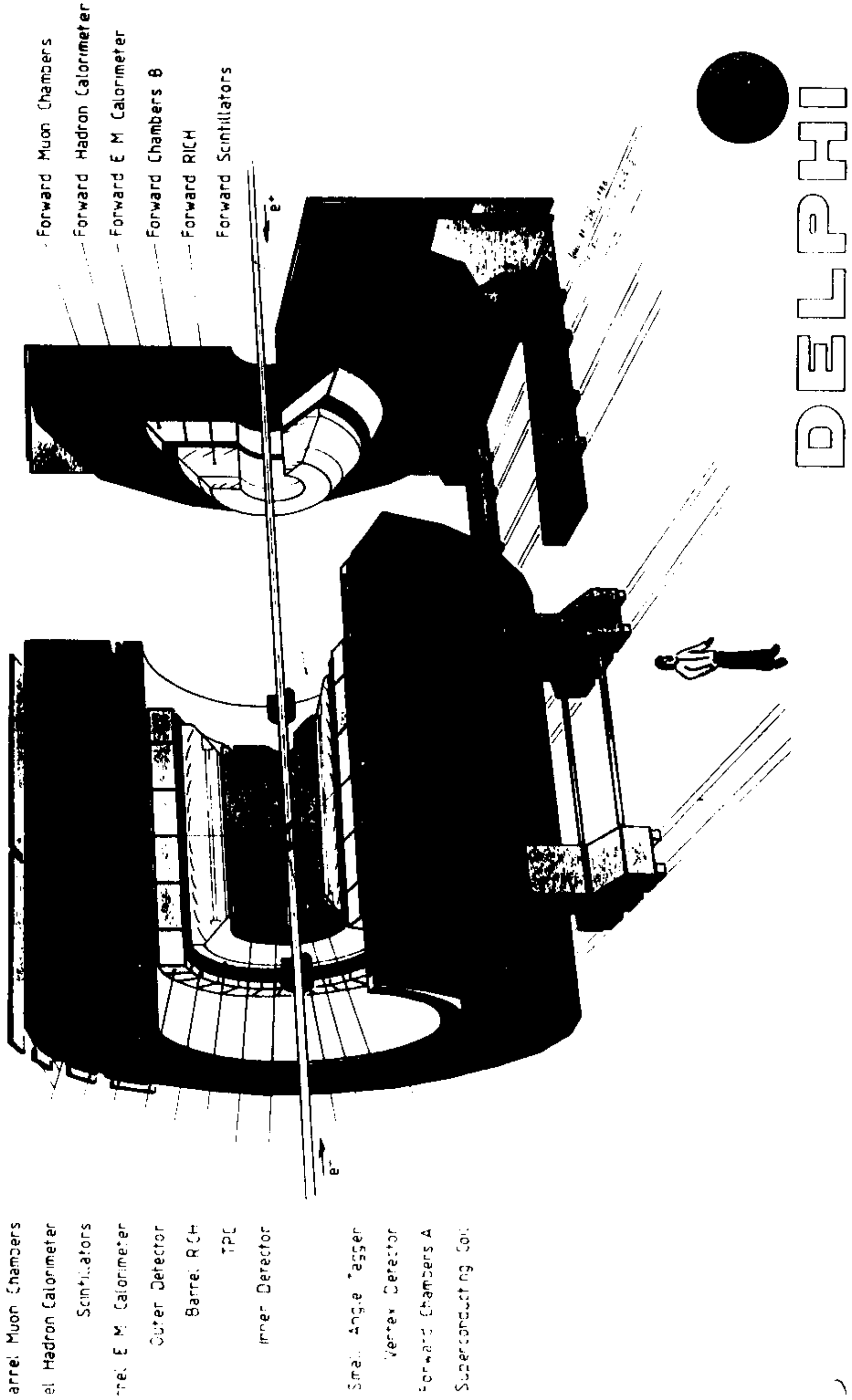
es

E	no material	14cm Al	corrected
1 GeV	~4%	~10%	8%
5 GeV	~2%	~3.5%	2.5%

- Hadron Calorimetry limited streamer plastic (Iarocci) tubes.
  Pb glass + coil = 1.5λ : Barrel 8×10cm Fe + 20cm Fe (9 samplings)
  $\sigma/E \simeq 1.2/\sqrt{E}$: Outer end cap 7×10cm Fe
  Inner end cap 10×8cm Fe. 50×50 cm pads
- μ detector Barrel . 4 layers of drift chambers $\sigma_{R\phi} \simeq 1mm$ $\sigma_z \sim 4mm$.
  Endcaps. 2 double layer streamer tubes $\sigma_{xy} \approx 1.5mm$!



Resolution and response of the OPAL hadron test calorimeter, as a function of beam energy.



• DELPHI

Superconducting coil 2·75m radius 6·8m long 1·2T:
Tracking: Barrel RICH: EM calorimeter inside.

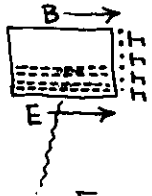
- Tracking

  - μVertex: solid state: Si: 2 cylinders: $\sigma_{r\phi}$: 5μm: (80mm-115mm)
    ·32°
  - Inner Detector "complete" tracks $\theta > 30°$ (118mm-223mm)
    Jet chamber 16 cells in ϕ 24 wires $\sigma_{r\phi} \sim 100\mu m$
    5 drift cells: z-coord determination. (223-280mm)
  - TPC: 1 atmos. r 290mm-1220mm: drift length 1·36m × 2 (23μs)
    $\sigma_{r\phi} \simeq 250\mu m$ $\sigma(z) \sim 0{\cdot}8mm$ $\sigma\left(\frac{dE}{dx}\right) \sim 5{\cdot}5\%$ (188 samples)
    $\{e/\pi\ (3\sigma) < 8 GeV/c\}$.

    6 sectors each end pads $6 \times 7 mm^2$
    TPC alone: $p \gg 1 GeV$ $\Delta p/p \simeq 0{\cdot}6\%\, p$
  - Outer Detector ~2m radius 6 layers Al drift tubes.
    $\sigma_{r\phi} \simeq 300\mu m$ $\sigma_z \sim 1\%$ of 460 cm.
  - Forward chambers $\sigma_x \sim \sigma_y \sim 150\mu m$. $\frac{\Delta p}{p} = \left[(0.06p)^2 + 1{\cdot}5\right]^{1/2}$ $p > 2 GeV/c$

    50 GeV ~4% down to ~30°.

- E.M. Calorimeter High Density Projection Chamber HPC: (Barrel)
  9mm slots 62cm drift (12μs) 6 depth samplings: pads
  time + 2D readout 20 layers 2mm Pb } 20X_0
  20 layers 3·6mm Pb }
  20 sections in ϕ
  Aim $13\%/\sqrt{E}$ at 1GeV.



Forward EM: Pb Glass with VPT.

- Hadron Calorimeter 5cm Fe: limited streamer plastic (Iarocci) tubes.
  Towers $\Delta\theta = 2{\cdot}8°$ $\Delta\phi$ 3·6°: 4 depth samplings.

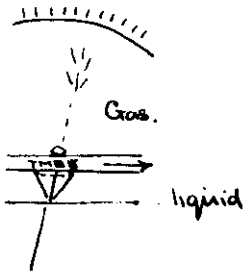
- μ-detector : planes of drift chamber : extruded Al.
  2 double planes + one inside yoke.

- Particle ID: RICH: measure Čerenkov rings:

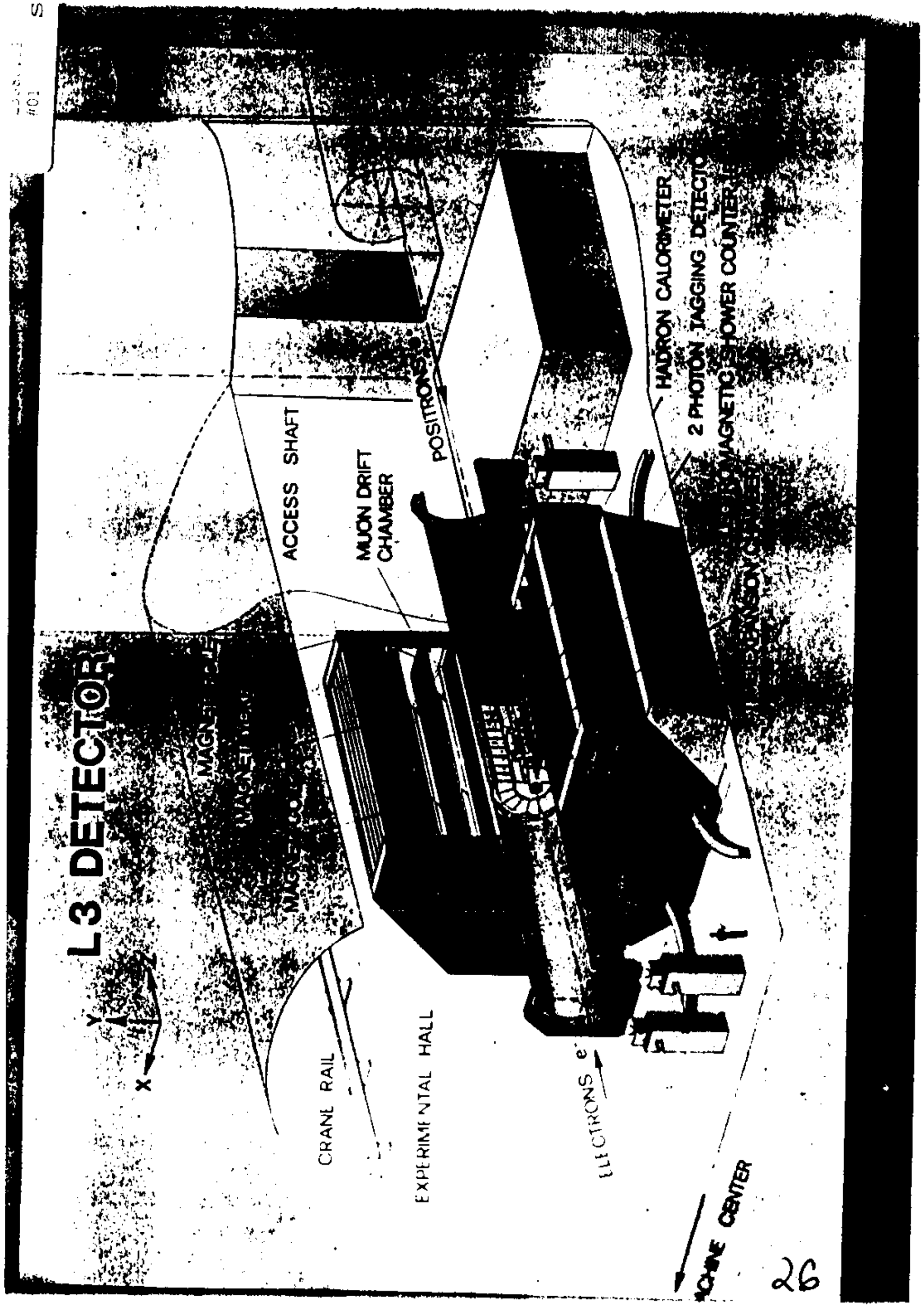
  liquid/gas radiators : liquid Freon ~ 1cm:
  proximity focussed.

  : gas: mirror focus
  same drift tube.

  : time: wire: cathode strip.



$\pi : K : p$ identified over momentum range 0.3–25 GeV/c.



3: Magnet built in ring: r = 5·7m 12m long 0.5T

racking Vertex Chamber (T.E.C.) 0.5m radius × 1m long.

slow: $5\mu m/ns$ } need $30\mu m$ (→ $50\mu m$)

proportional z chambers outside.

M Calorimeter BGO. crystals.

- spectrometer: basically what drives the design.

adron Calorimeter: behind BGO: inside tube 87cm < R < 213cm

Uranium: 60 plates 5mm: proportional mode readout

protect chambers by 1mm Cu. $Ag \cdot 8\ CO_2 \cdot 2$

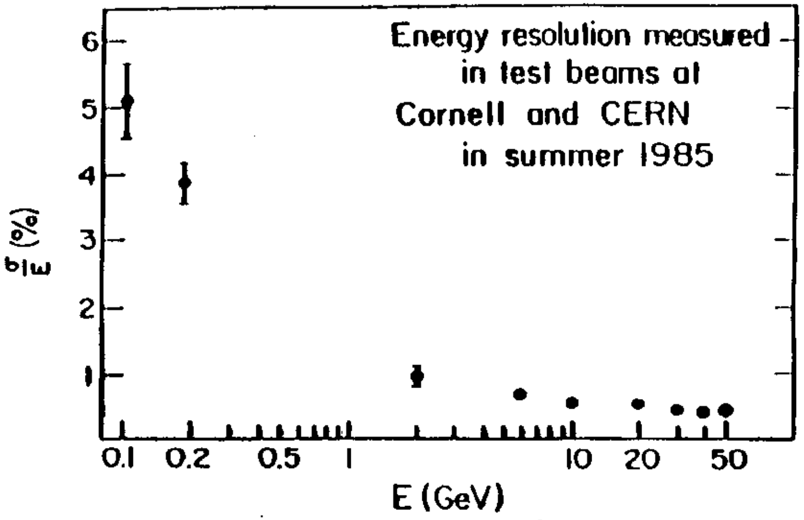
$U + BGO = 7\lambda$:

Gain from U v Cu is in density not calorimetry 18·95 v 8·96 gm cm^{-3}

$$\frac{\sigma}{E} \simeq \frac{55\%}{\sqrt{E}} + 5\%$$ — Hadron alone – not combined with BGO.

L3. BGO. $45° \leq \theta \leq 135°$:

Pointing geom: $2\times2\,cm^2$ – 24cm – $3\times3\,cm^2$ Photo diode.
~$22X_0$



$$\frac{\sigma}{E} \approx \sqrt{\left\{\left(\frac{0.5\%}{\sqrt{E}}+0.3\%\right)^2+\sigma_{re}^2+\sigma_{noise}^2+\sigma_{nc}^2\right\}^{\frac{1}{2}}}$$

↑ 1% leakage at 50GeV

↑ fluctuations charge particles in Photodiode.

Noise $0.5\sqrt{n}$ MeV $n = 5\times5$ $\sigma_{xy} \sim 3mm$ $E > 1GeV$.

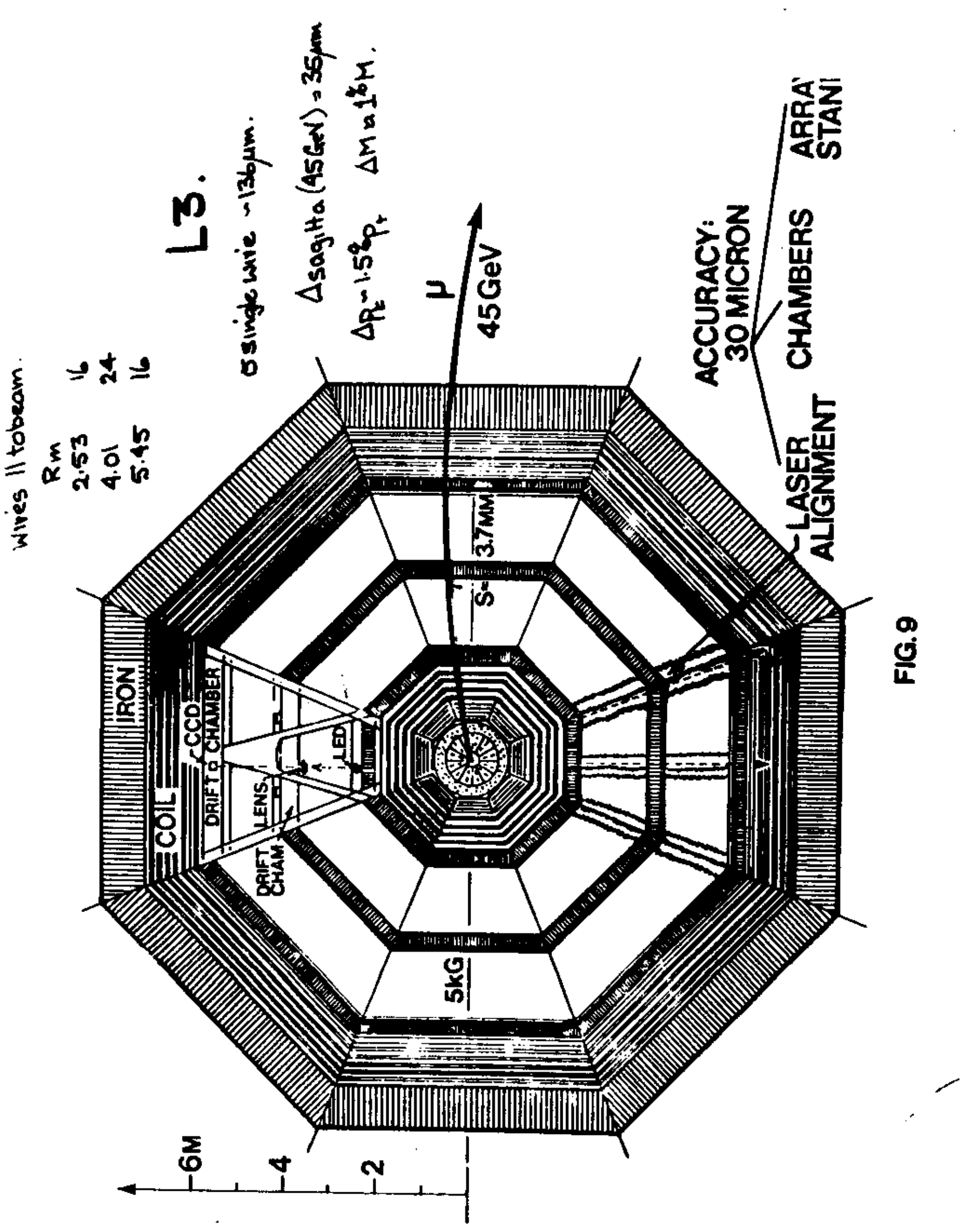


FIG.9

L3.

Wires || to beam.

Rm	
2.53	16
4.01	24
5.45	16

σ single wire ~136μm.

Δsagitta (45GeV) = 35μm

$\Delta p_t \sim 1.5\% p_t$ $\Delta M \approx 1\% M$.

- <u>LEP Detector comments</u>.

- Neglected altogether "combined" calorimetry

A:	O:	D:	L3
2.65m	2.25m	2.75m	6m

  Could have moved 3-4λ inside the coil + "gas" tail catcher.
  DELPHI has to give real estate to RICH.

- "Orgy" of tracking 2TPC's : JADE jet chamber.
  average event 20 charged tracks + 20 neutral hits.
  L3 seriously compromised tracking : BGO \$'s : need 30μm.
  a little more attention to jet response of calorimetry may have paid off – especially at W^+W^-

- $\sigma\left(\frac{dE}{dx}\right)$ is good : but not effective hadron ID : π/K/p at few GeV
  {eg UA1 and ARGUS ppπ}

- RICH - new interesting challenge - affords flavour tagging D.B.B_s^0-$\bar{B}_s^0$
  needs supplementing by secondary vertices
  (SLD at SLC)

- L3 banked on e/γ - especially low energy.
  μ - precision spectrometer.
  a lot of flexibility later for calorimetry.

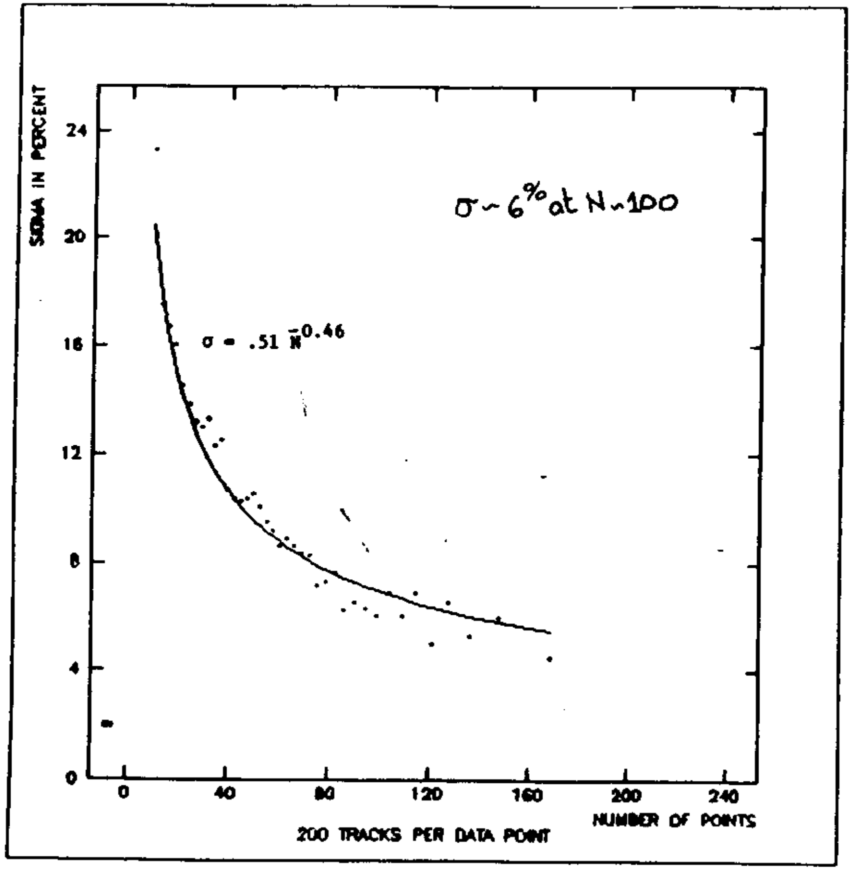
- ALEPH - mini towers - refine calorimeter response ?
  1.5T spreads jets separates charged/neutral. ?
  momentum of charged in B : EM-neutral ?

- Superconducting experience
  ALEPH - good.
  DELPHI - bad.
  OPAL - Warm (LEPC) but civil engineering delays.

- In "vogue" component . Iarocci tubes.

All well engineered and all will do good physics !

UA1 Central Detector.



ERROR ON $\frac{dE}{dx}$ vs NUMBER OF MEASURED POINTS

FIGURE 6

- **ZEUS** - HERA.

recall variation in jet energy with polar angle.

- Central Track Detector + Transition Radiation Detector + planar trackers - all within thin Solenoid - superconducting. 1.8T $r = 0.86m$ 2.8m ℓ. $0.8X_0$

- Calorimeter: depleted Uranium (3.8mm) + Scintillator (3mm).
  wavelength shifter + light guide to PM's.

EM towers $5 \times 20cm^2$ Hadron towers $20 \times 20cm^2$

Forward	Barrel	Rear
7λ	5λ	4λ

EM $\sigma/E = \frac{15\%}{\sqrt{E}} + 2\%$ Hadron $\frac{\sigma}{E} = \frac{35\%}{\sqrt{E}} + 2\%$. ← premium on uniformity.

Backing Calorimeter: Fe + limited streamer tubes $\sigma/E \approx 1.0/\sqrt{E}$.

- DU plates clad St.St $< 10^2$ rad/year.
- Scintillator: acrylic based (AFS : UA1 : UA2 : CDF) performance deteriorates in normal atmosphere $> 10^5$ rads.
  : aromatic NE110 : SCSN38 (ZEUS) x10 better:

e/π : measured: close to 1.0.

ZEUS is the only detector in sight with compensated calorimetry.
· a very delicately balanced detector - how will it wear?
· ~2 years less to build than LEP.

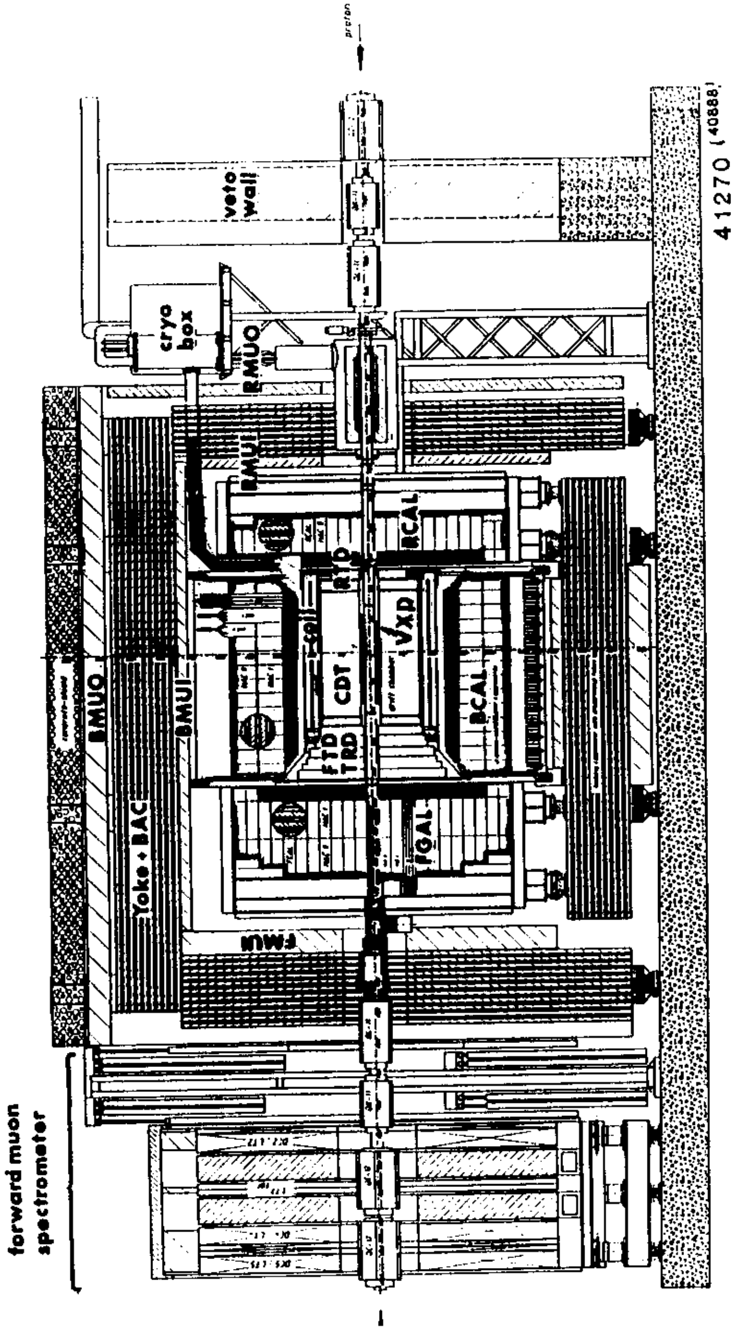
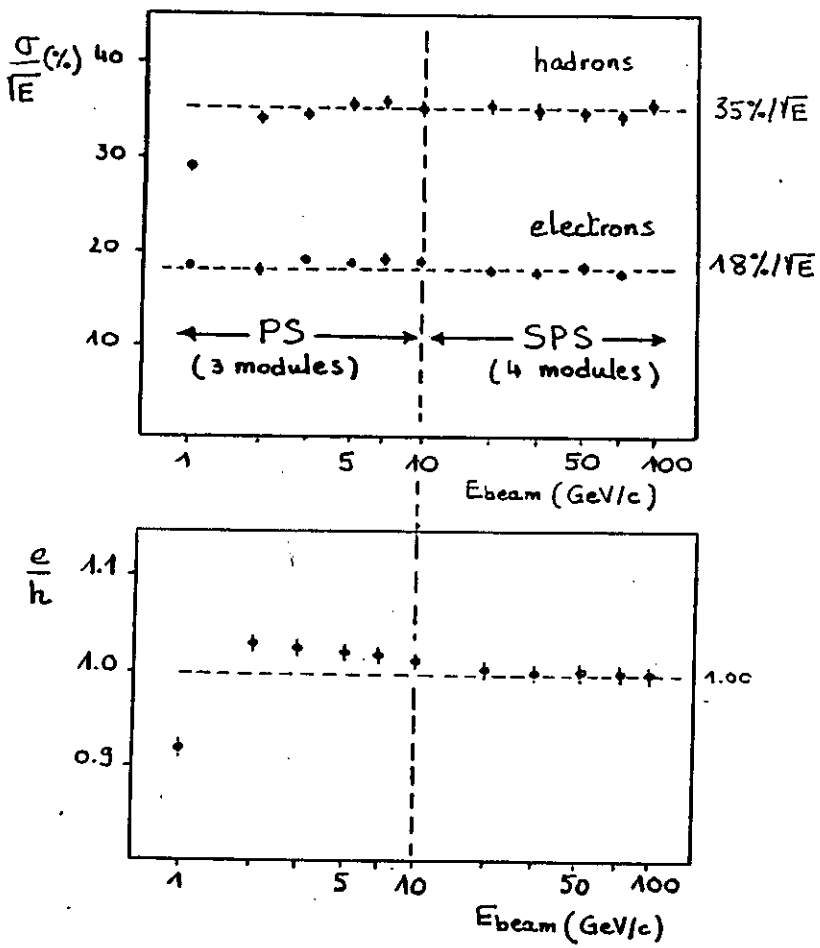


Fig. 2.2 Section of the ZEUS detector along the beam.

Energy Resolution and e/h (PS + SPS data)



Remarks for SPS data:

1) E(HAC2) < 10 % Ebeam
2) 1% beam momentum spread subtracted
3) Calorimeter noise (270 MeV) subtracted
4) energy leakage estimated at 30 GeV:
3% (4 modules) 4% (3 modules)

- Future hadron Colliders - SSC and LHC. [SSC-SR-1021]

- major experimental problems still exist: largely due to extremely high rates $10^8 s^{-1}$ at high multiplicity: interbunch time of 15ns and >1 real event ~~per~~ crossing.

Recall: that at a hadron collider the detector selects the mass i.e. $\sqrt{\hat{s}}$ · constituent centre of mass.

Link between rapidity range (angle range) and mass or distance scale. $\left[\eta = -\ln \tan \theta/2\right]$

also provides very rough idea of energy range over which particles may have to be detected and identified.

Secondary charged particle rate from minimum-bias is high.

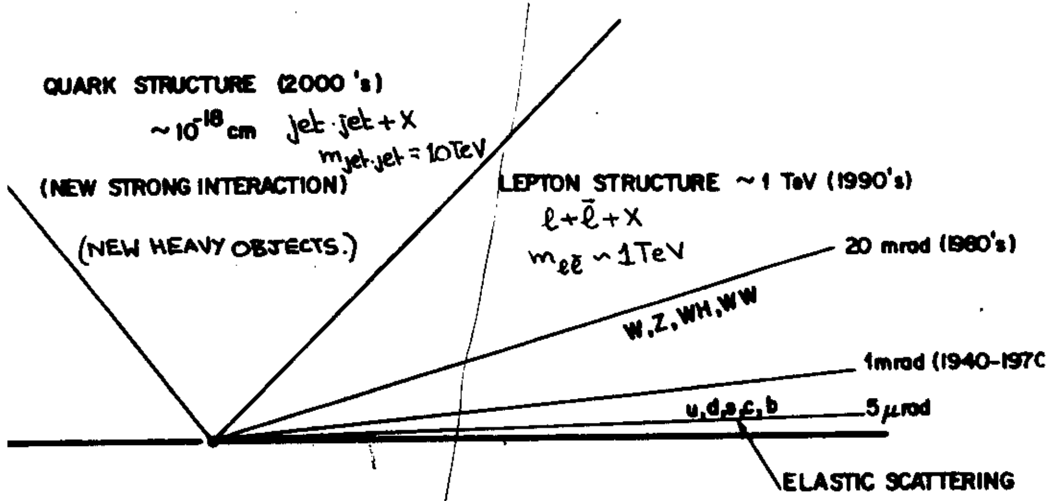
$$\frac{dn^{ch}}{d\eta} = 6 \qquad \eta = -\ln(\tan \theta/2)$$

detector at r polar angle θ $r_\perp = r \sin\theta$ -

can show $\frac{dn^{ch}}{ds} = \frac{.95}{r_\perp^2}$ per interaction $[10^8 \text{interactions/s}]$

Translates into serious radiation problem from minimum-bias alone.

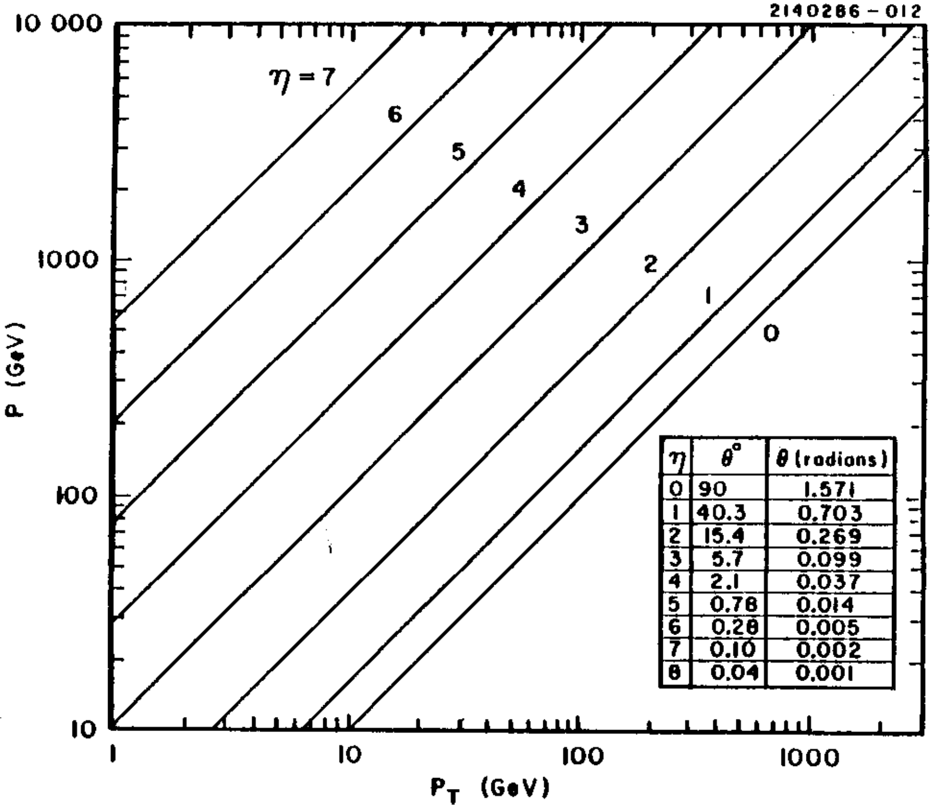
ANGLE OF ARCHEOLOGY



Hadron collider 20TeV * 20TeV.

- physics more or less divides into angular regions -

$\eta = -\ln(\tan \theta/2)$

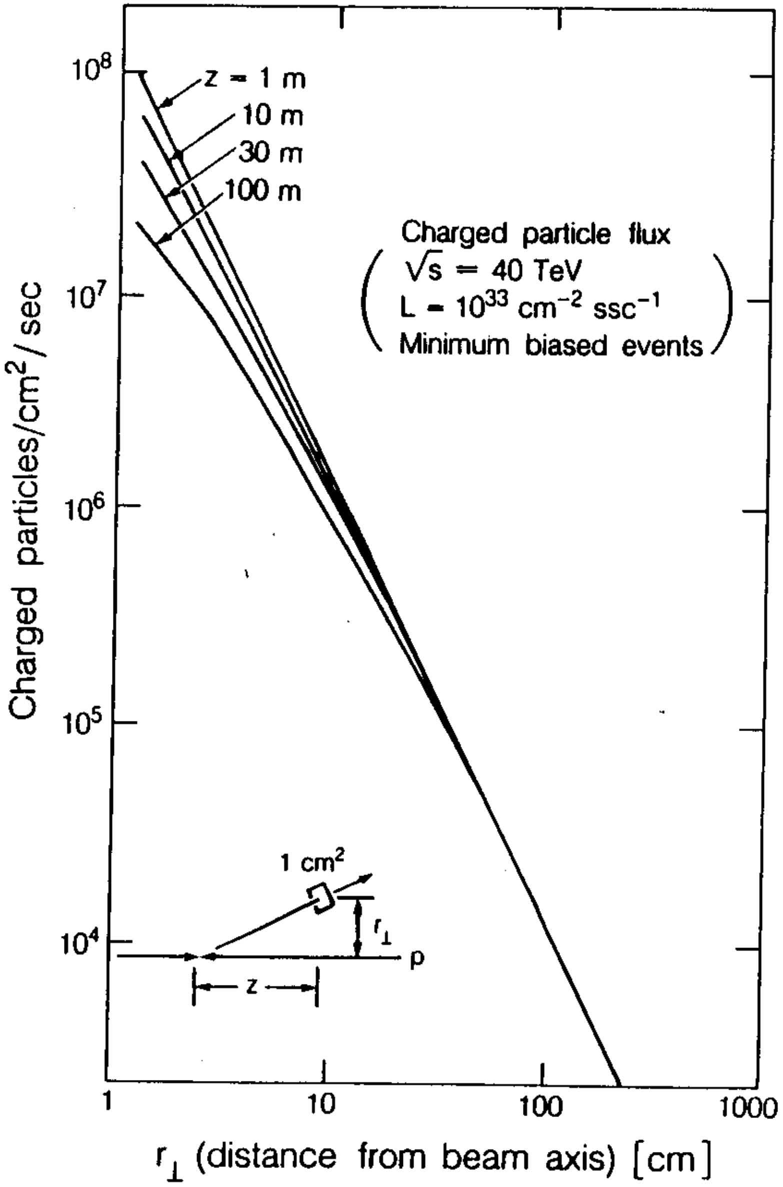


η	$\theta°$	θ (radians)
0	90	1.571
1	40.3	0.703
2	15.4	0.269
3	5.7	0.099
4	2.1	0.037
5	0.76	0.014
6	0.28	0.005
7	0.10	0.002
8	0.04	0.001

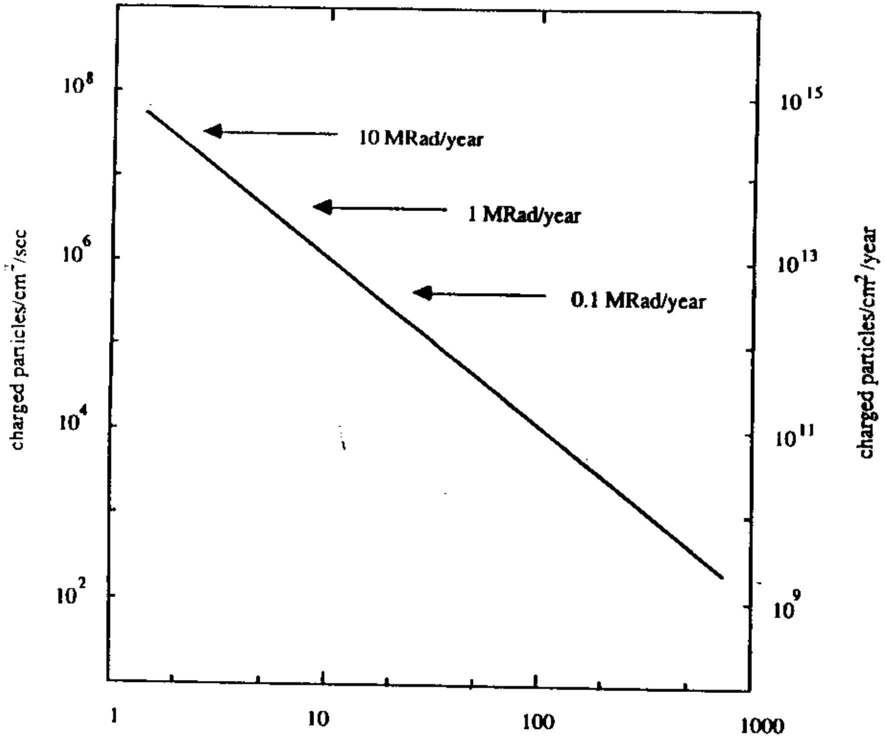
Momentum vs. p_T for different rapidities

"High mass" ~ 1TeV - central - $\eta \sim 0$ $P_T \approx \frac{1}{3} \to 1\,\text{TeV}/c \Rightarrow p : \frac{1}{3} \to 1\,\text{TeV}/c$

"Low mass" $\eta \gtrsim 4$ $P_T = 1\text{-}5\,\text{GeV}/c$ translates into
"b physics". doing physics with particles
30 GeV → few TeV:



Charged particle flux vs. distance from beam axis.



Charged particle rate at $L = 10^{33} cm^{-2} s^{-1}$.

1 year taken as 150 days ~ 10^7 secs.

detector components should not degrade appreciably at 10^6 Rad :

- Experimental signatures

- look at how they have traditionally been derived.

		Calorimeters	Central Tracking	μ detection	Particle I.D (hadrons)
charged leptons	μ	(✓)	(✓)	✓	
	e	✓	✓		
jets		✓	✓		
W, Z into jets.		✓	✓		
Missing E_T		✓			
jet flavours		✓	✓	✓	✓

- take μ-detection as "special case":
- examine requirements of calorimeters – workhorse of SSC/LHC
  (ii) tracking
- brief comment on particle ID.

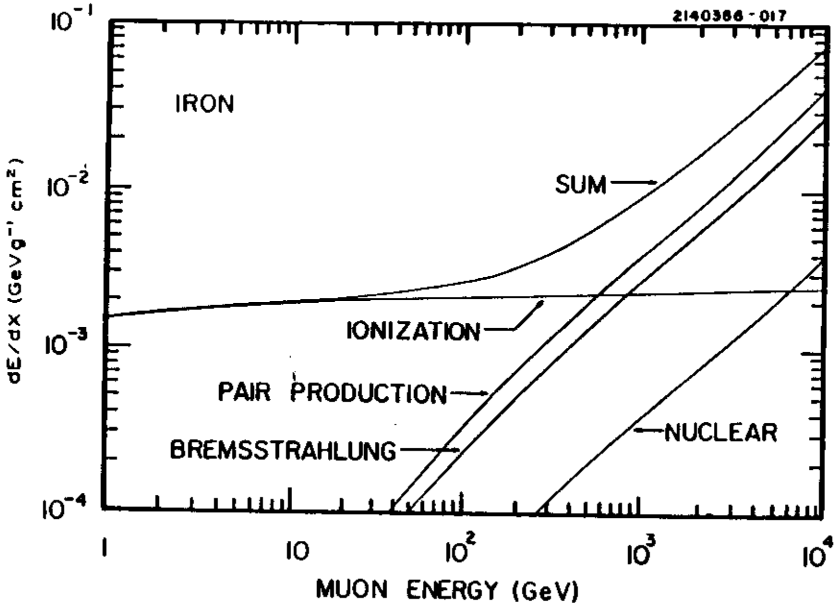
- Muon detection.

(1) particle tracking in B field – then penetration through Fe – usually not magnetised : {most common ALEPH, OPAL DELPHI, SLD.}

(2) absorption of hadrons : followed by muon spectrometer (L3

(3) measurements in magnetized iron : >10% at all momenta (CDF

muons undergo ionization – weakly energy dependent.
(pair production : bremsstrahlung : nuclear interactio
→ depend strongly on muon energy.



The various components of muon energy loss in iron.

Precision muon spectroscopy in TeV range (à la L3) demands electromagnetic energy lost in "material" is measured as well.

Precise measurements in or close to jets will become "impossible"

- electron detection:

  - calorimetry : longitudinal shower development in EM calorimeter:

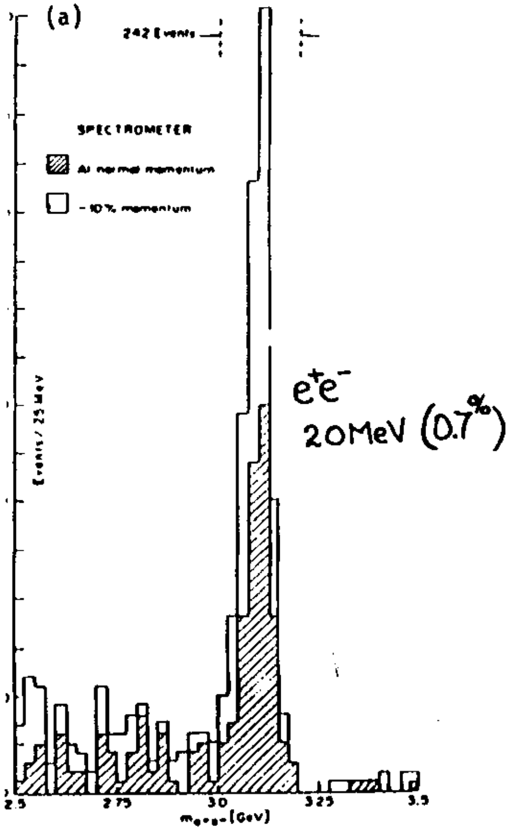
- To minimise hadron overlap and confusion the EM calorimeter should have a large value of λ_0/X_0 Fe = 9.5   Pb = 30.5   U = 33.2

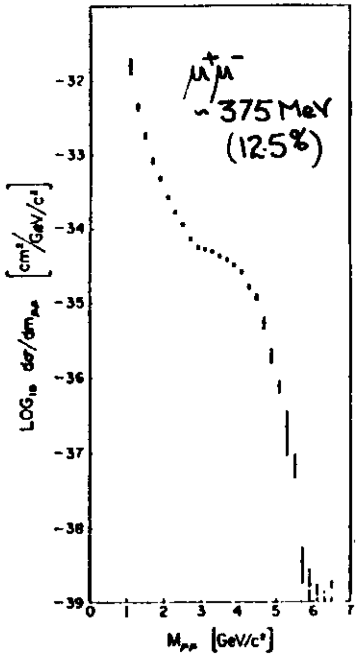
  - p I E using tracking : in addition to above produces typically 10^3 rejection against π's.

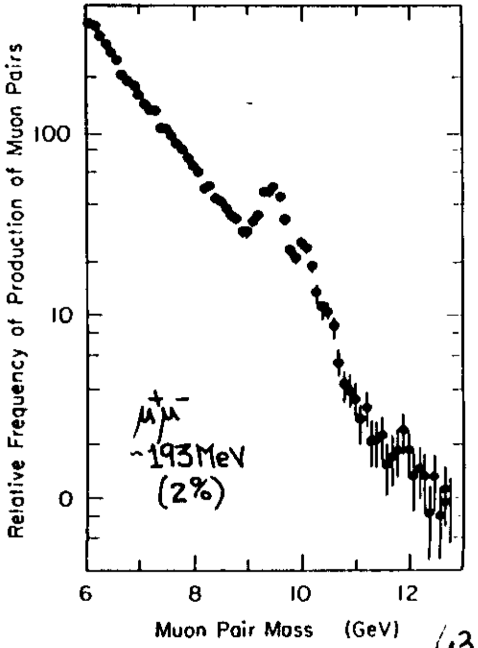
- > 100 GeV - have lost measurement of p - all done with calorimeters: "lateral segmentation" - to study transverse profiles - complexity and costs!

- note. TRD "goes off" at $p \simeq 100$ GeV - cannot use.

μ's look a much easier charged lepton "signature" than the e's, at least until μ's start to "radiate" ≃ 1 TeV:







Precision spectroscopy pays!

<u>Calorimetry</u> requirements that calorimetry will have to continue to meet if it is to be the workhorse of the detector

<u>Speed</u>: $\mathcal{L} = 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$ 10^8 interactions s^{-1} bunch spacing 15ns.
must have fast response:
must be able to 'tag' crossing and only integrate over a "few"
how many is a 'few': Liquid Argon 200 ns/mm:
CH4 speeds up:

<u>Resolution</u> jets as well as single particles.
"at few hundred GeV mass" – need few % jet-jet mass resolotion
this implies $< 50\%/\sqrt{E}$ and e/π rather close to 1.0: [±0.1]

<u>Granularity</u> traditionally set by attempts to see electrons in or close to jets.
jet-jet mass resolution few % implies $\Delta\eta \simeq 0.03$ $\Delta\phi \simeq 0.03$.

<u>Absolute Calibration</u>: yes: to ~1% and stable.

<u>Uniformity of Response</u>. "tower to tower" ≲ 1% otherwise will dominate resolution at high energy.

<u>Density</u>: high density $> 8\,\text{g/cm}^2$ desirable – makes compact calorimeter U – good candidate.

<u>Containment</u>. something like $24 X_0$ and $12\lambda_0$ for high energies
have 6λ - high quality + 6λ crude (gas calorimetry)

<u>Radiation hard</u>. should not degrade appreciably at 10^6 rads.
ideally much "harder" than this

<u>Linearity</u>. desirable for no saturation up to ~5TeV.

- Hermeticity should cover ± 5.5 units of η if detector is to qualify for 4π. care with mechanics.
- e/π Separation. 10^3: longtudinal and transverse shower development
  may be the only electron identifier.
- Homogeneity. : high quality hadronic and EM should be as homogeneous as possible : calibration.
- read out electronics. have to keep in mind: radiation etc.
- Costs must be cheap!

Tracking:

- Direct consequences of Luminosity and Energy:

  10^8 Hz. high multiplicity. large η coverage. high particle density in jets: high momentum measurements. >1 interaction.

- "Wish List"
  - primary vertex + secondary vertices
  - correlation with calorimeters: p v E for electrons.
  - topological definition of jets: multiplicity within jets.
    QCD ≠ W jets?
  - sign determination at all energies $\frac{\Delta p}{p} \simeq 40\%$ at highest E ?
  - will reveal event pile-up ?
  - aid to muon detection.

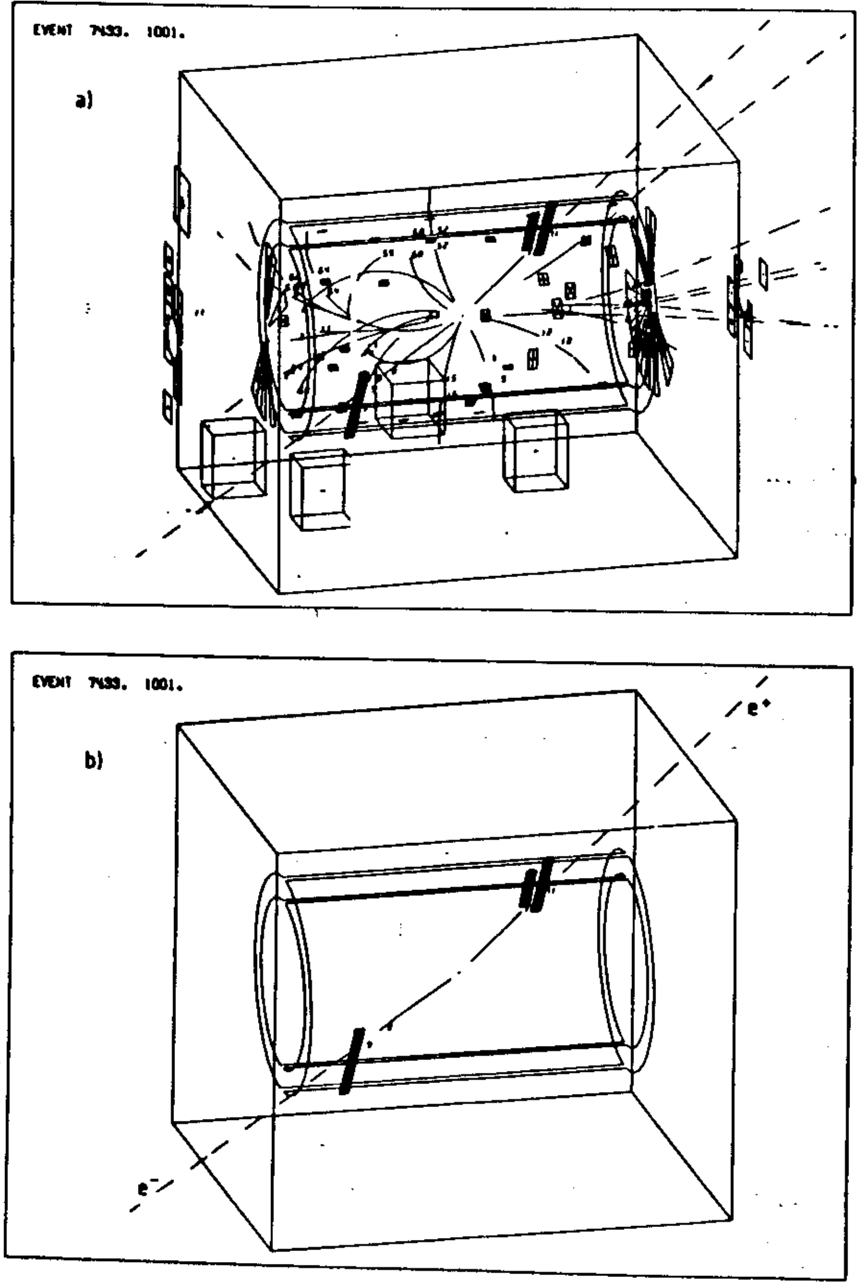
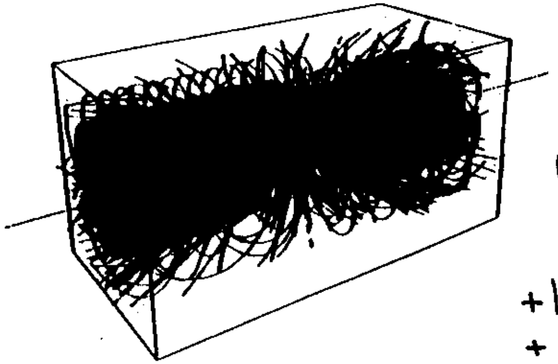
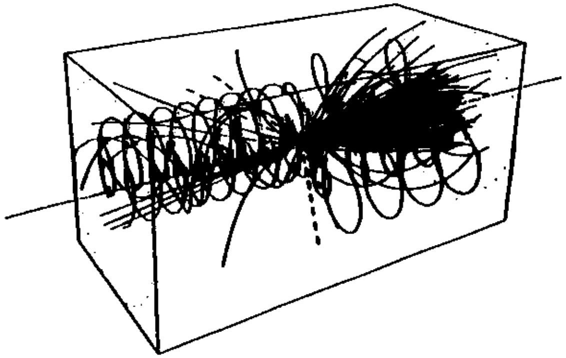


Fig. 2

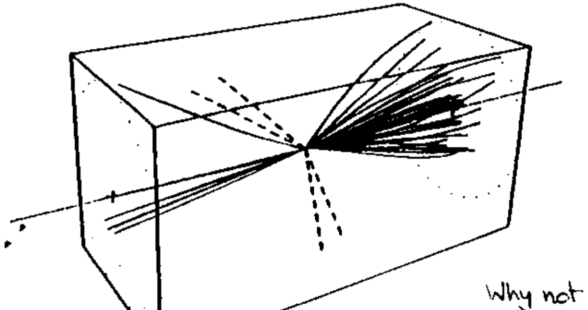


$H \rightarrow ZZ$ $m_H = 800$ GeV
$\hookrightarrow e^+e^-$
$\hookrightarrow e^+e^-$

+ low p_T event $p_T^{jet} < 50$GeV
+ 5 minimum bias



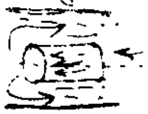
$H \rightarrow ZZ$ only
$\hookrightarrow e^+e^-$
$\hookrightarrow e^+e^-$



$H \rightarrow ZZ$
$\hookrightarrow e^+e^-$
$\hookrightarrow e^+e^-$

with $p_T^{track} > 1$ GeV.

Why not a solenoidal filter.



← $B \sim 6T$ traps $p_T \lesssim 1$ GeV/c $r = .3m$

- Preparations for Detectors at SSC/LHC: Can we learn from ISR?

	ISR	SSC/LHC
Accelerator physicists "confident"	✓	✓
Experimental physicists apprehensive	✓	✓
Experimental program - modest start	✓	?
Lead (indirectly) to poorer physics return J/ψ, charm, Υ...	✓	?
"LEP" tradition of full complement of completed detectors at "day one"	×	?
{HERA - community is saturated}		✓

- Your detector or your component of a detector must work

<< 1% missing channels
present > 95% of "on" time.
} if not the "off-line" analysis group will drop you out of the experiment!