The GLD Concept

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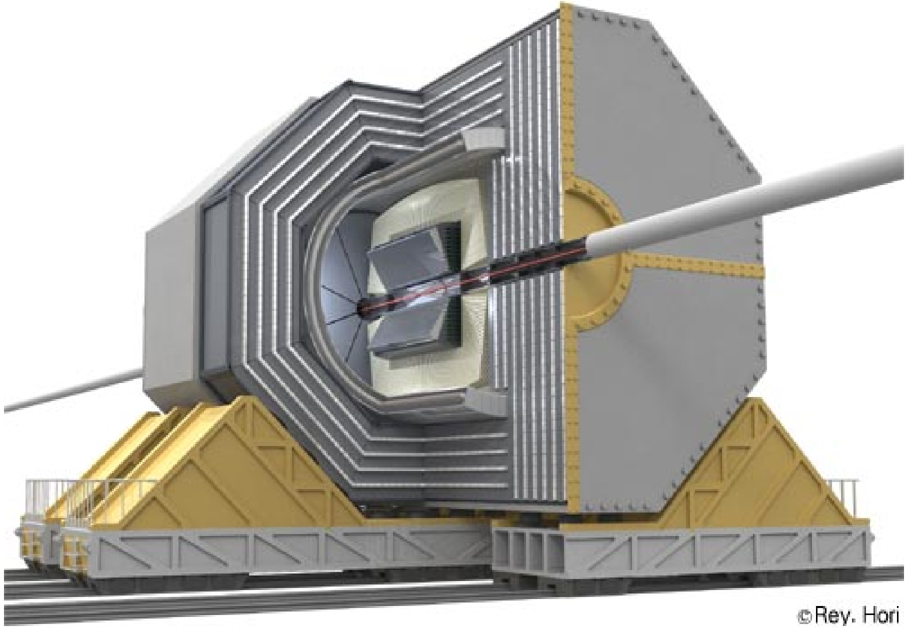


This Talk:

❶ Machine
❷ ILC Physics/Detector Requirements : why a large detector
❸ The GLD Concept
❹ Some comments on cost and optimisation
❺ Conclusions

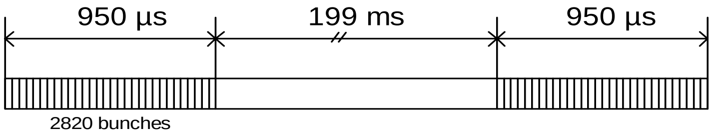
➊The ILC

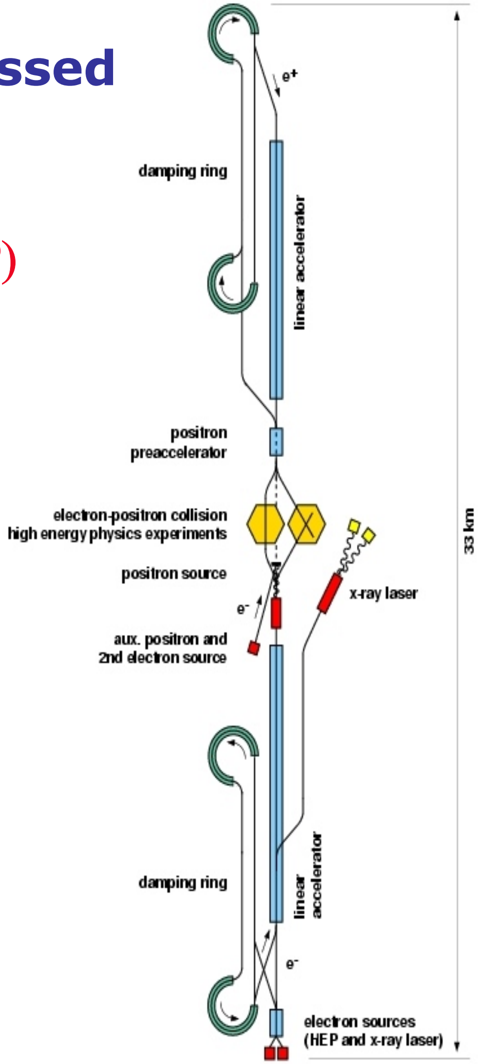
★ILC baseline parameters currently being discussed

- ♦ main features "known"

- Center-of-Mass Energy : ~ 90 – 1000 GeV
- Baseline Luminosity : 2x10^{34} cm^{-2}s^{-1} (>1000xLEP)
- Time Structure : 5 (10?) Bunch-trains/s
  - ♦ Time between collisions: ~ 300 (150) ns

e.g. TESLA TDR





- "Physics" Event Rate (fairly modest):

  $e^+e^-\to qq$ ~100/hr $e^+e^-\to W^+W^-$ ~1000/hr

  $e^+e^-\to tt$ ~50/hr $e^+e^-\to HX$ ~10/hr

- `Backgrounds` (depends on ILC parameters)

  $e^+e^-\to qq$ ~0.1 /Bunch Train

  $e^+e^-\to\gamma\gamma\to X$ ~200 /Bunch Train

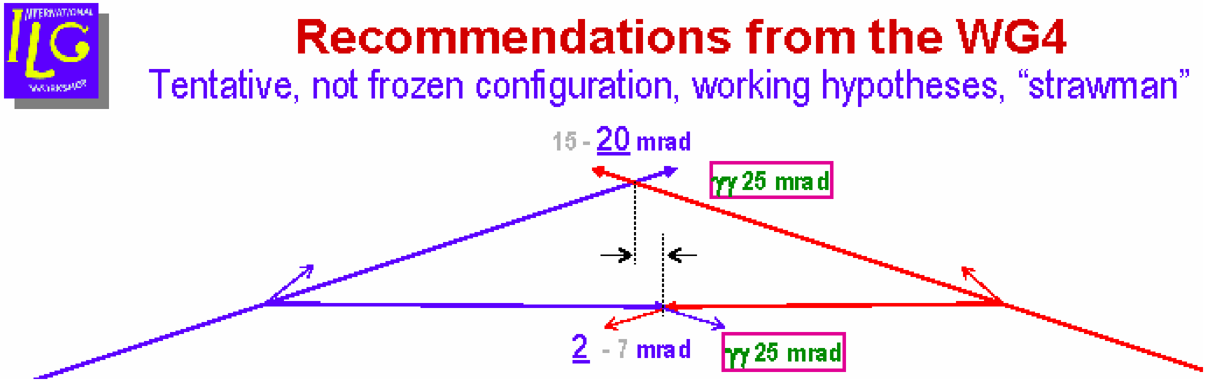
  ~500 hits/BX in Vertex det.

  ~5 tracks/BX in TPC

★ Event rates modest – small compared to LHC

Impact on Detector Design

- Radiation Hardness does not dictate detector design
- Modest timing requirements
- Must be able to cope with modest gamma-gamma bgd
- Impact of non-zero crossing angle ?



Recommendations from the WG4

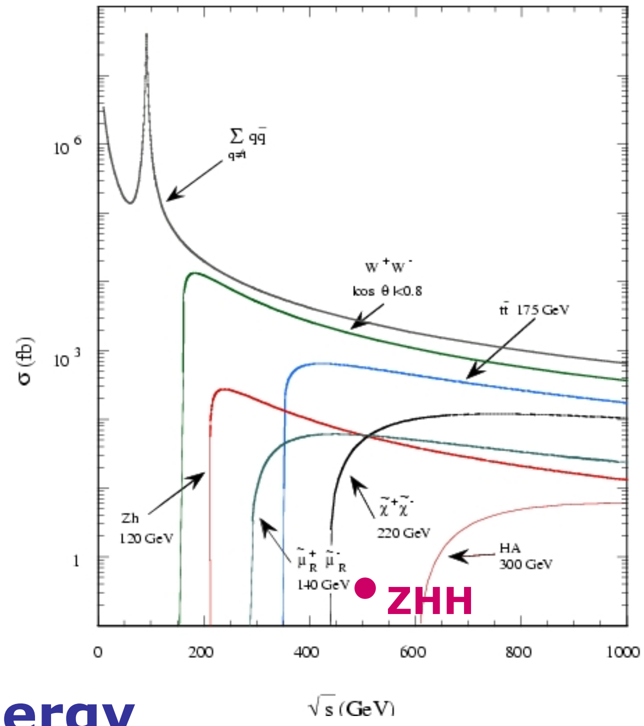
Tentative, not frozen configuration, working hypotheses, “strawman”

- Final focus **L*** has big effect on backgrounds/ forward region
  - major **MDI** issue

PHYSICS not the machine drives ILC Detector design

BUT MDI + crossing-angle also important

❷ ILC Physics / Detector Requirements



Precision Studies/Measurements

★ **Higgs** sector

★ **SUSY** particle spectrum

★ **SM particles** (e.g. W-boson, top)

★ and much more...

Difficult Environment:

★ **High Multiplicity final states**

often **6/8 jets**

★ **Small cross-sections**

e.g. **$\sigma(e^+e^- \rightarrow ZHH) = 0.3$ fb**

★ **Many final states have"missing" energy**

neutrinos + neutrilinos(?)/gravitinos(?) + ????

✷ **Detector optimized for precision measurements in difficult environment**

✷ **Only 1 or 2 detectors – make sure we choose the right option(s) + cost is not unimportant**

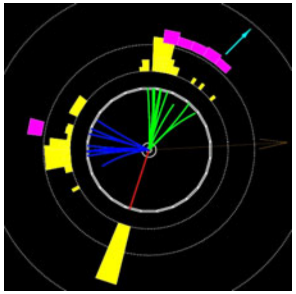
Compare with LEP

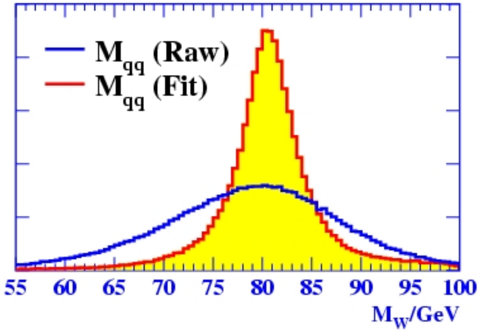
★ $e^+e^-\rightarrow Z$ and $e^+e^-\rightarrow W^+W^-$ dominate

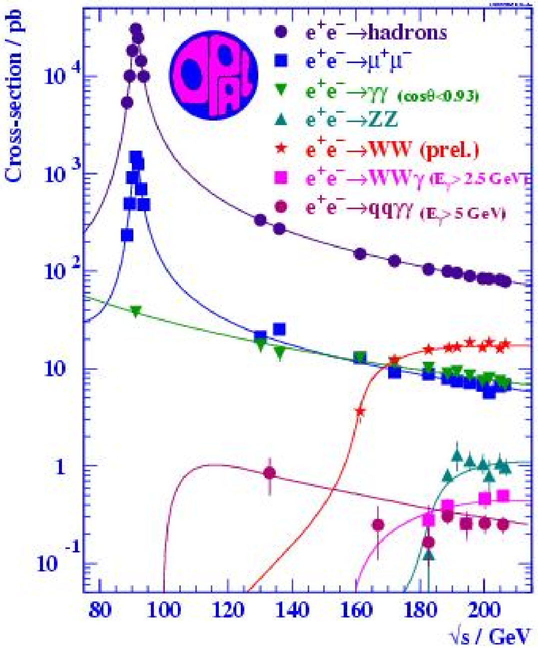
backgrounds not too problematic

★ Kinematic fits used for mass reco.

good jet energy resolution not vital







★ LEP Physics was "relatively" EASY

At ILC:

★ Backgrounds dominate 'interesting' physics

★ Kinematic fitting less useful (missing particles+Beamstrahlung)

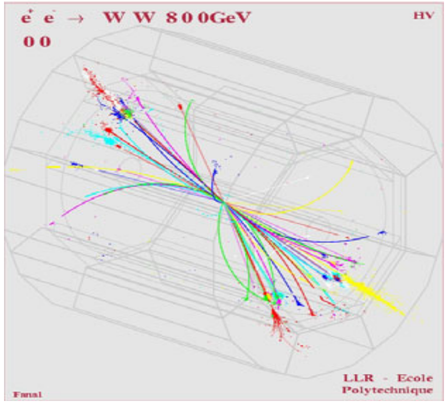
★ Much more exposed to flaws of detector !

✸ Physics performance depends critically on the detector performance

✸ Stringent requirements on an ILC detector – need to get it right

ILC Detector Requirements

- **Momentum:** $\sigma_{1/p} \sim 5\times10^{-5}$/GeV (1/10 x LEP)
  (e.g. Z mass reconstruction from charged leptons)
- **Impact parameter:** $\sigma_{d0} < 5\mu m \oplus 10\mu m/p(GeV)$ (1/3 x SLD)
  (c/b-tagging in background rejection/signal selection)
- **Jet energy :** $\delta E/E = 0.3/E(GeV)$ (1/2 x LEP)
  (W/Z invariant mass reconstruction from jets)
- **Hermetic down to :** $\theta = 5$ mrad
  (for missing energy signatures e.g. SUSY)
- **Sufficient timing resolution to separating events from different bunch-crossings**



Must also be able to cope with high track densities due to high boost and/or final states with 6+ jets, therefore require:

- High granularity
- Good pattern recognition
- Good two track resolution

- **General consensus that Calorimetry drives ILC detector design**

Calorimetry at the ILC

★ Much **ILC** physics depends on reconstructing invariant masses from jets in hadronic final states

★ Kinematic fits won't necessarily help – **Unobserved particles (e.g. ν)**, + (less important ?) Beamstrahlung, ISR

★ Aim for jet energy resolution ~ Γ_Z for "typical" jets
- the point of diminishing return

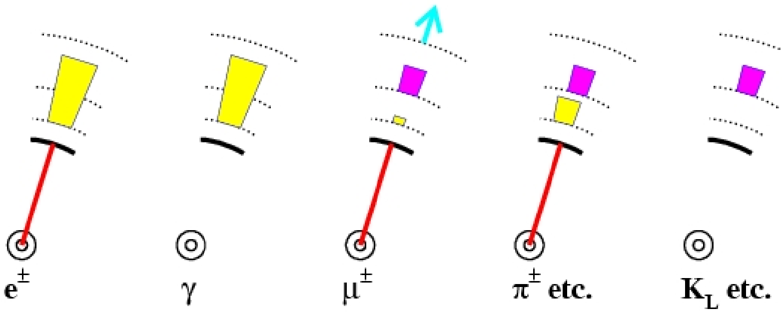
★ Jet energy resolution is the key to calorimetry

The visible energy in a jet (excluding ν) is:

60 % charged particles : 30 % γ : 10 % K_L,n

The Particle Flow Analysis (PFA):

- Reconstruct momenta of individual particles avoiding double counting



Charged particles in **tracking chambers**
Photons in the **ECAL**
Neutral hadrons in the **HCAL** (and possibly **ECAL**)

★ Need to separate energy deposits from different particles

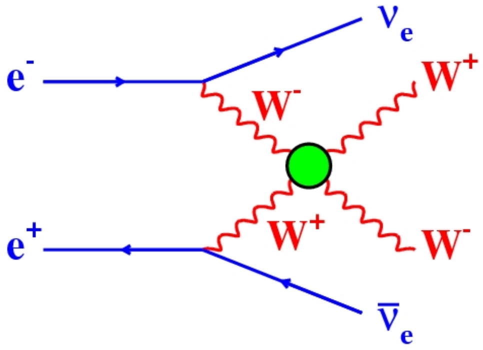
THIS ISN'T EASY !

Jet energy resolution:

Best at LEP (ALEPH):
$\sigma_E/E = 0.6(1+|\cos\theta_{Jet}|)/\sqrt{E(\mathrm{GeV})}$

ILC GOAL:
$\sigma_E/E = 0.3/\sqrt{E(\mathrm{GeV})}$

★ **Jet energy resolution directly impacts physics sensitivity**

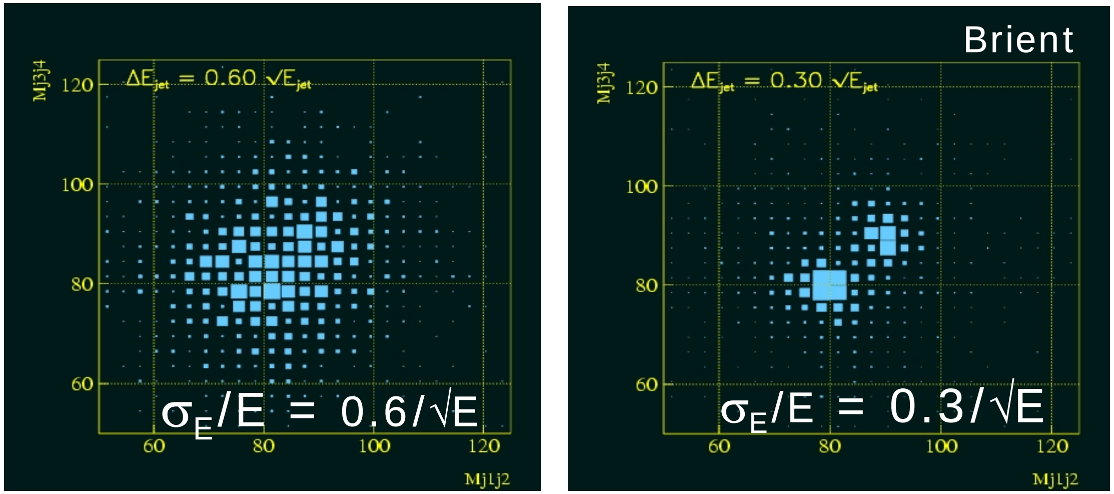


Reconstruction of two di-jet masses allows discrimination of WW and ZZ final states

Often-quoted Example:

If the Higgs mechanism is not responsible for EWSB then QGC processes important

$e^+e^- \to \nu\nu WW \to \nu\nu qqqq$, $e^+e^- \to \nu\nu ZZ \to \nu\nu qqqq$



Brient

★ **EQUALLY applicable to any final states where want to separate $W \to qq$ and $Z \to qq$!**

★ **Best resolution "achieved" for TESLA TDR : $0.30\sqrt{E_{jet}}$**

Component	Detector	Frac. of jet energy	Particle Resolution	Jet Energy Resolution
Charged Particles($X^{\pm}$)	Tracker	0.6	$10^{-4}\ E_X$	neg.
Photons(γ)	ECAL	0.3	$0.11\sqrt{E_\gamma}$	$0.06\sqrt{E_{jet}}$
Neutral Hadrons(h^0)	HCAL	0.1	$0.4\sqrt{E_h}$	$0.13\sqrt{E_{jet}}$

morgunov

★ **Energy resolution gives $0.14\sqrt{E_{jet}}$ (dominated by HCAL)**

★ **In addition, have contributions to jet energy resolution due to "confusion" = assigning energy deposits to wrong reconstructed particles (double-counting etc.)**

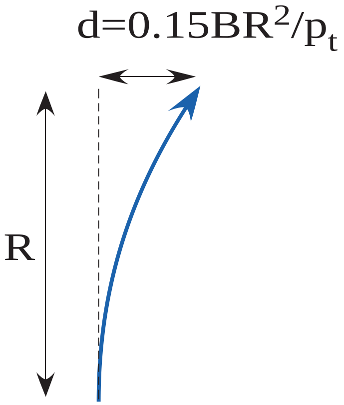
$$\sigma_{jet}^2 = \sigma_{x^\pm}^2 + \sigma_\gamma^2 + \sigma_{h^0}^2 + \sigma_{confusion}^2 + \sigma_{threshold}^2$$

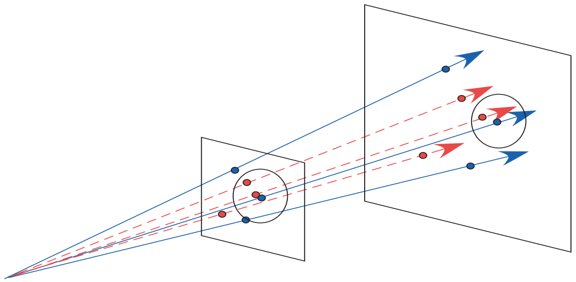
★ **Single particle resolutions not the dominant contribution to jet energy resolution !**

granularity more important than energy resolution

Calorimetry : Figure of Merit

- For good jet energy resolution need to separate energy deposits from different particles
  - **Large detector** – spatially separate particles
  - **High B-field** – separate charged/neutrals
  - **High granularity ECAL/HCAL** – resolve particles





Often quoted "figure-of-merit": $\frac{BR^2}{\sigma}$

Separation of charge/neutrals

Calorimeter granularity/R_{Moliere}

- Physics argues for : large + high granularity + ⇧ B
- Cost considerations: small + lower granularity + ⇩ B

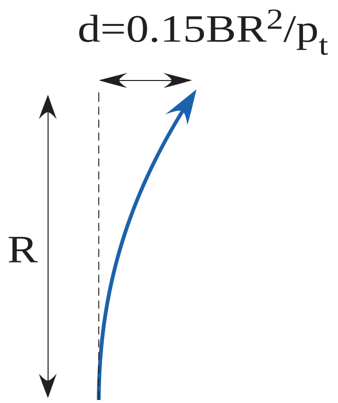
GLD Concept : investigate the large detector/slightly lower granularity phase-space

Aside : Why PFA argues "Big is Beautiful"

Comment : on useful (?) Figure of Merit:

- Often quoted F.O.M. for jet energy resolution:
  BR^2/σ ($R=R_{ECAL}$; σ = 1D resolution)
  i.e. transverse displacement of tracks/"granularity"
- Does this work ?
  - compare OPAL/ALEPH (W→qq no kinematic fit)

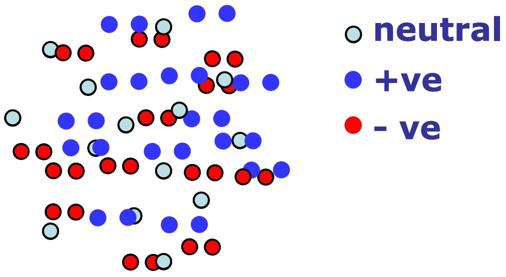
	BR^2	BR^2/σ	$\sigma_E/\sqrt{E}$	R^2/σ
OPAL	2.6 Tm^2	26 Tm	0.9	60 m
ALEPH	5.1 Tm^2	170 Tm	0.6	110 m



- **No !** Things aren't that simple….

My guess for FoM: R^2/σ

Dense Jet: B-field



- B-field just spreads out energy deposits from charged particles in jet
  – not separating collinear particles
- Size more important - spreads out energy deposits from all particles
- R more important than B

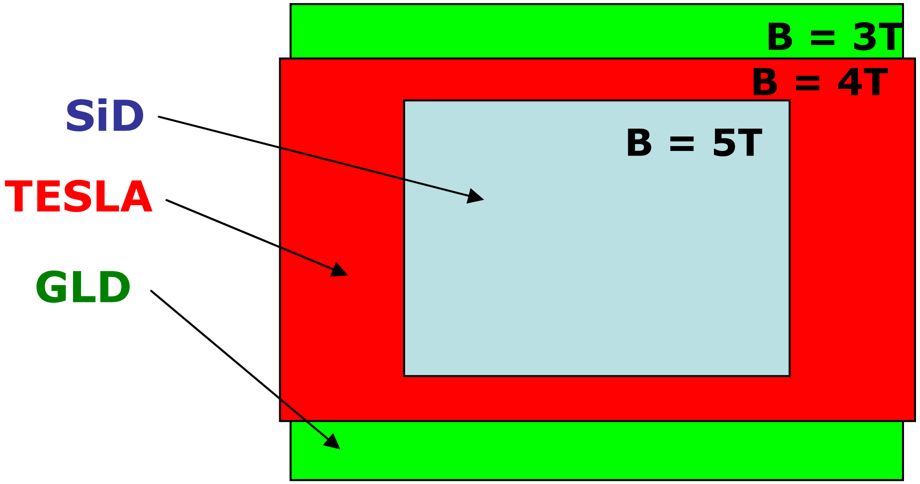
❸The GLD Concept

What is the GLD concept ?

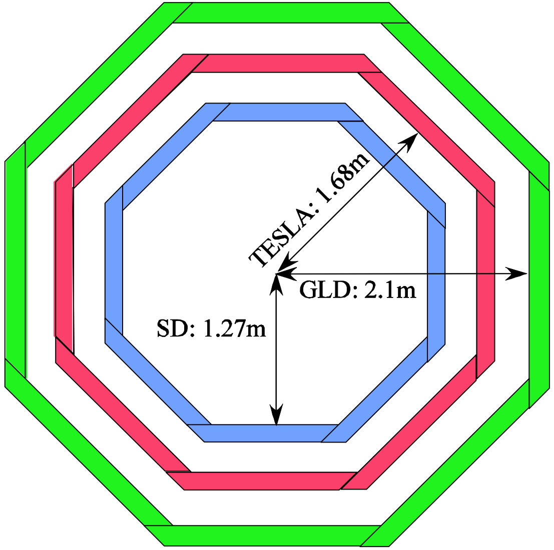
- **SIZE : quite large (larger than SiD/LDC)**

Compare:

- ★**Small Detector : SiD**
- ★**Large Detector: e.g. LDC (Tesla TDR)**
- ★**Truly Large Detector: GLD**



Tracker



ECAL

General Features of GLD Concept

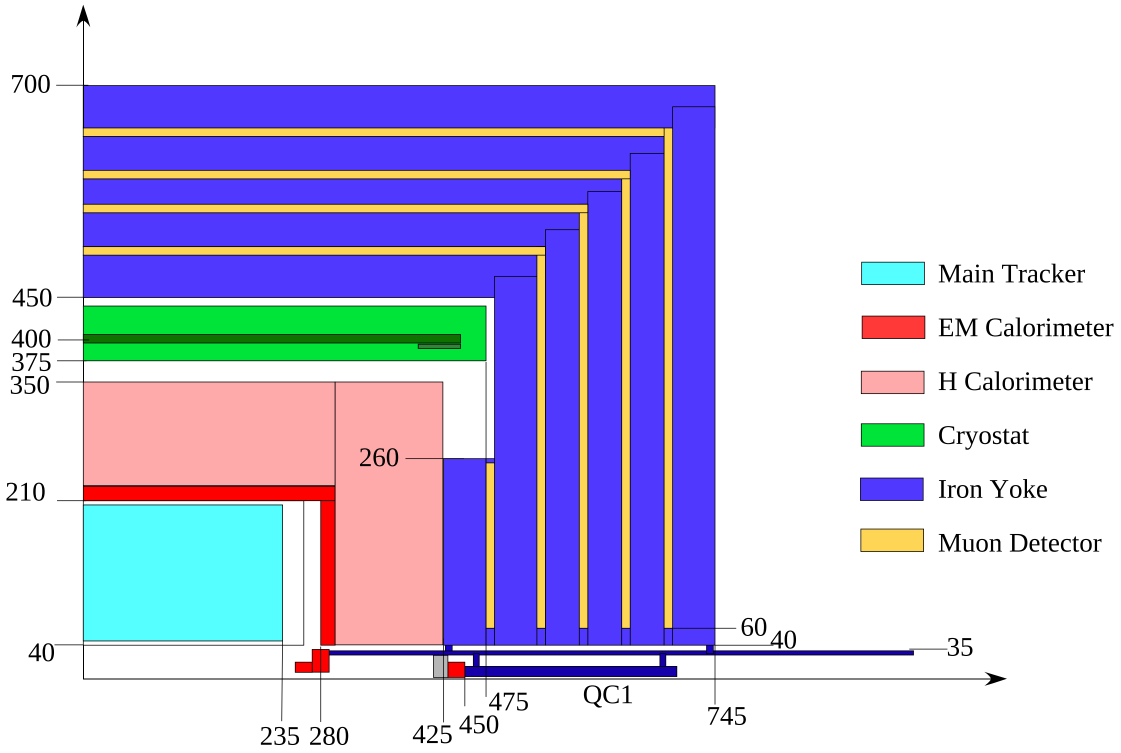
★ “Large” gaseous central time projection chamber (TPC)

★ “Medium/High” granularity ECAL : W-Scintillator

★ “Medium/High” granularity HCAL : Pb-Scint (inside solenoid)

★ Precision microvertex detector (first layer close to IP)

★ “Moderate” B-field : 3 Tesla



Vertex Detector

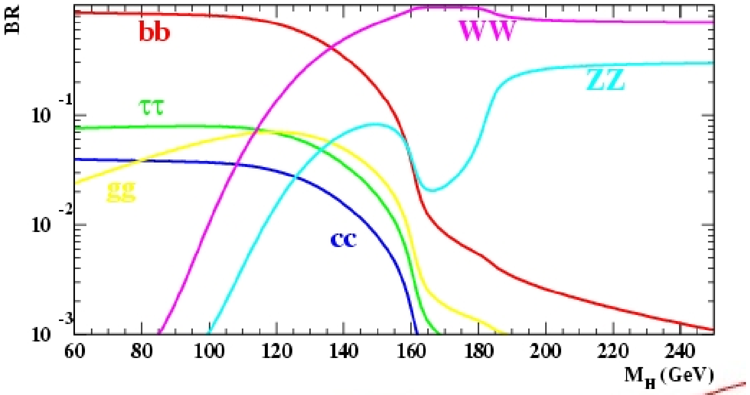
★ Requirements driven by heavy flavour tagging

- ★ **Important for many physics analyses**

  e.g. couplings of a low mass Higgs

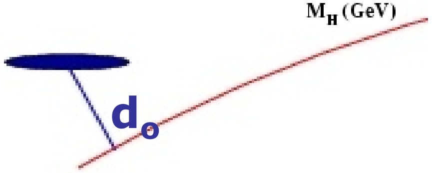
  Want to test $g_{Hff} \sim m_f$

  O(%) measurements of the branching ratios H→bb,cc,gg



- ★ **Also important for event ID and background rejection**

Flavour tagging requires a precise measurement of the impact parameter d_o

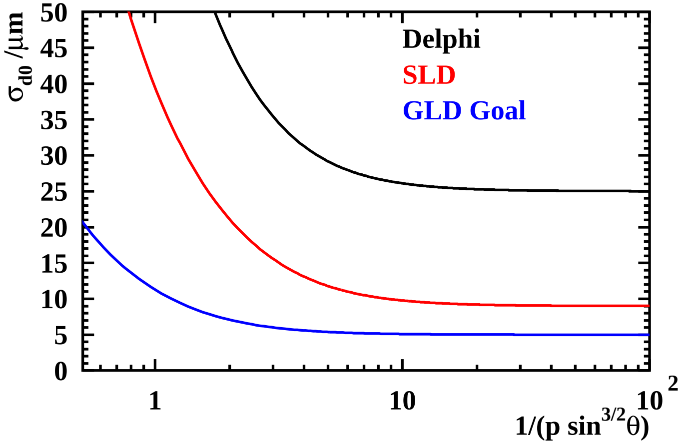


Aim for significant improvement compared to previous detectors

$$\sigma_{d0} \sim a \oplus b/[p(\mathrm{GeV})\beta\sin^{3/2}\theta]$$

Goal: a=5μm, b=10μm

a: point resolution, b : multiple scattering



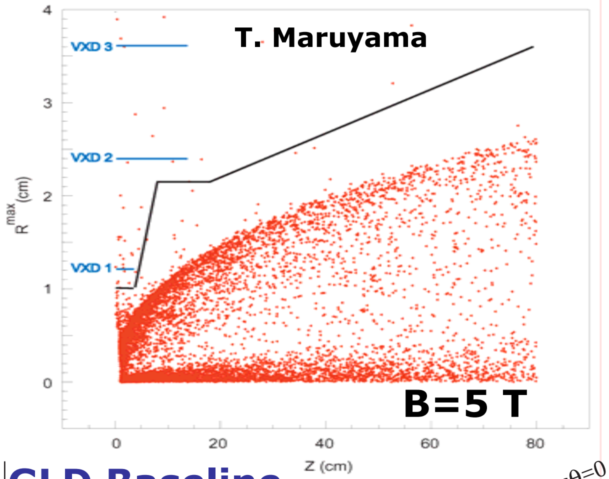
Main design considerations:

- ★**Inner radius:** as close to beampipe as possible, ~20 mm for impact parameter resolution
- ★**Layer Thickness:** as thin as possible suppression of γ conversions, minimize multiple scattering,...

Constraints:

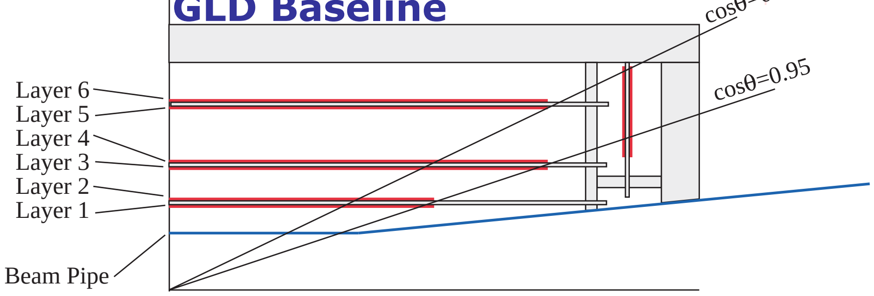
- ★ Inner radius limited by e^+e^- pair bgd. depends on the machine + B field
- ★ Layer thickness depends on Si technology

★ **Ultimate design driven by machine + technology !**



GLD Baseline design:

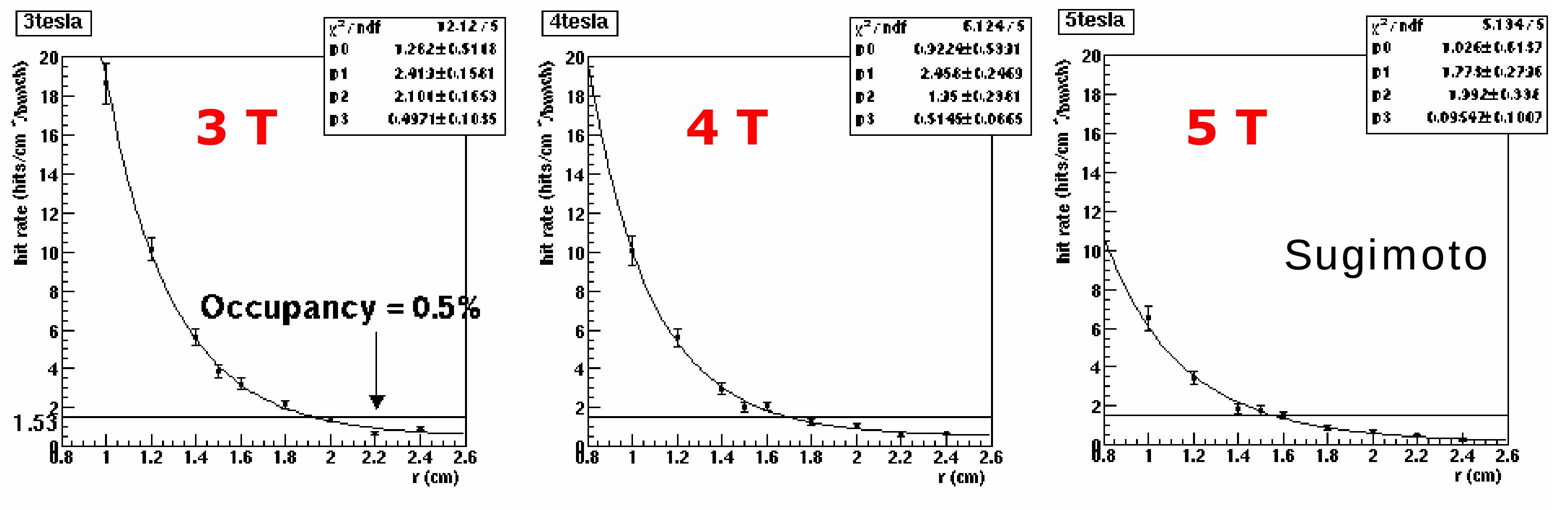
- ★Fine pixel CCDs (FPCCDs)
- ★Point resolution : 5 μm
- ★Inner radius : 20 mm
- ★Outer radius : 50 mm
- ★Polar angle coverage : |cosθ|<0.9


GLD Baseline

★ **BUT ultimate design depends on worldwide detector R&D**

Backgrounds in GLD VTX

- ★ Higher **B** helps as pairs constrained to smaller radii
  - ♦ How much of a disadvantage is B = 3T ?

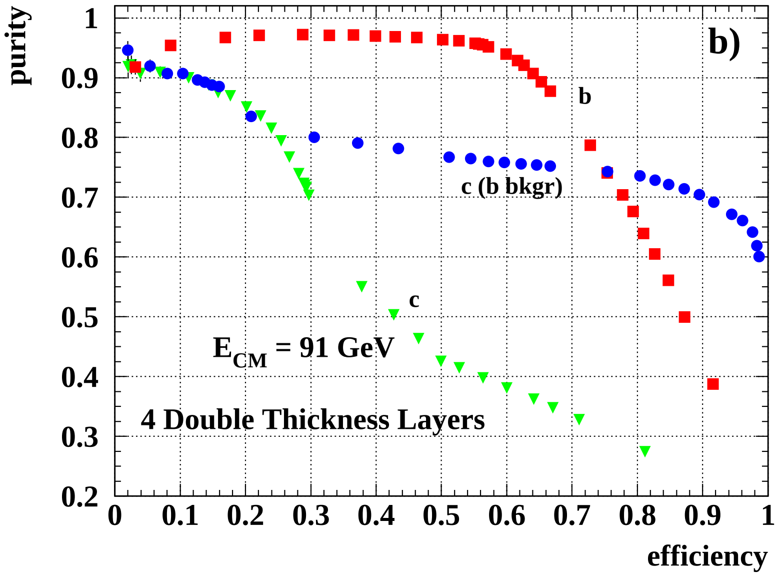


- ♦ GLD VTX Forced to a slightly larger inner radius : **2mm** ?
  - ♦ Will depend on ILC parameters/MDI !
- ♦ This is a disadvantage of lower B-field in GLD concept
  - ♦ How much does the larger inner radius matter ?

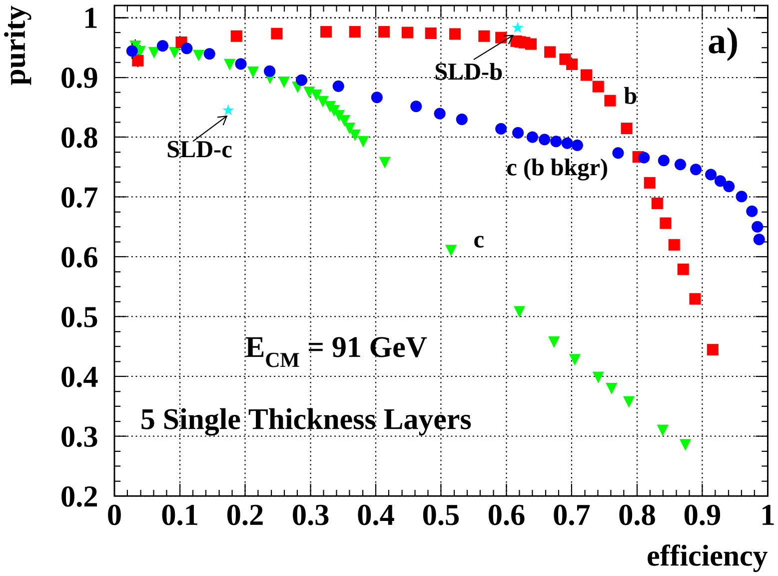
★ Main impact – charm tagging, e.g. Tesla study

R_{inner} = 26mm

T.Kuhl



R_{inner} = 15mm



★Here charm-tagging efficiency for 70 % purity decreases from 45 % ⇒ 30 % as R_{inner} increased from 15 mm ⇒ 26 mm

NOTE: not completely fair comparison as different wafer thickness

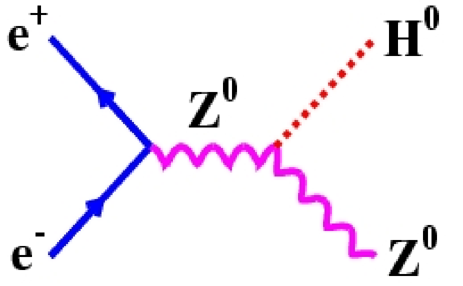
★ 3 Tesla field not helpful from point of view of charm-tagging

★ **BUT** probably not a big concern

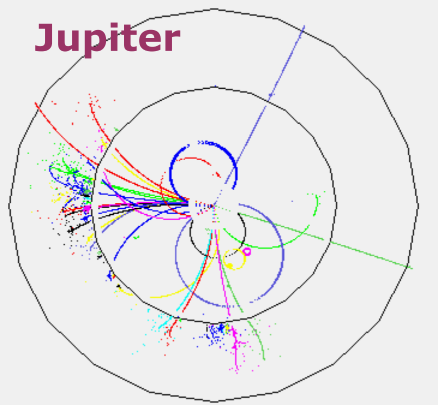
Central Tracking

- **Required momentum resolution driven by reconstruction of Z mass in $Z\rightarrow\mu^+\mu^-$ decays**

Classic Key process



$e^+e^-\rightarrow Z^*\rightarrow ZH\rightarrow\mu^+\mu^-X$



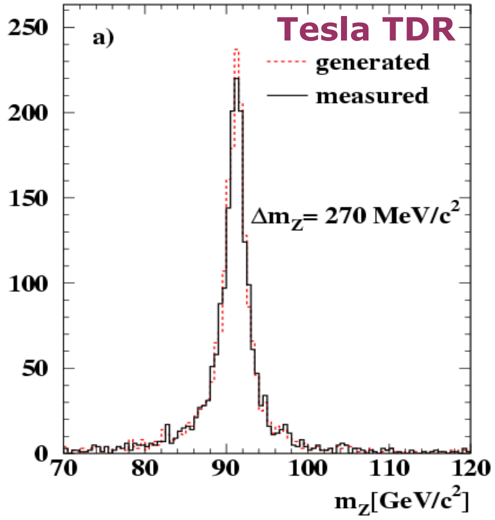
$\mu^+\mu^-$ angular distribution

⇨ Spin, CP,…

Recoil mass to $\mu^+\mu^-$

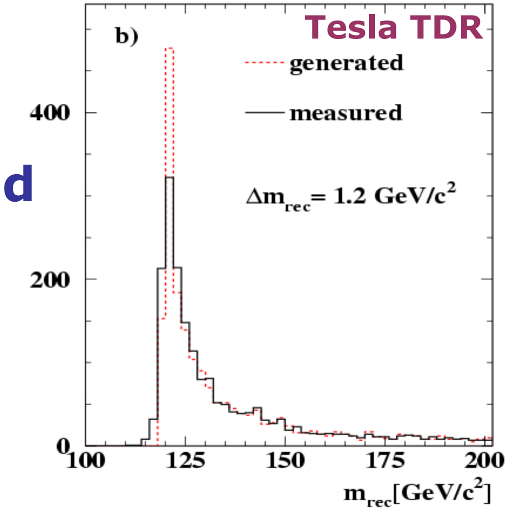
⇨M_H σ_{ZH}, g_{ZHH}

goal: $\Delta M_{\mu\mu} < 0.1 \times \Gamma_Z$ ⇨ $\sigma_{1/p} < 10^{-4}\ \mathrm{GeV}^{-1}$



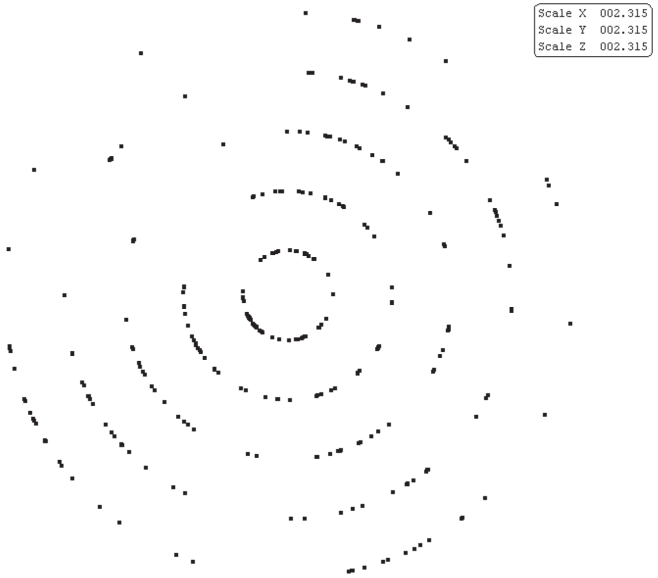
⇦rejection of background

good resolution for ⇨ recoil mass



TPC or Si Tracker ?

- ★ **Two favoured central tracker technologies:**
  TPC and Si Detector



- ★ **Large number of samples vs. smaller number of high precision points**
- ★ **PATTERN RECOGNITION in SiD looks non-trivial**
- ★ **GLD concept adopts a TPC**
  - used successfully in ALEPH/DELPHI

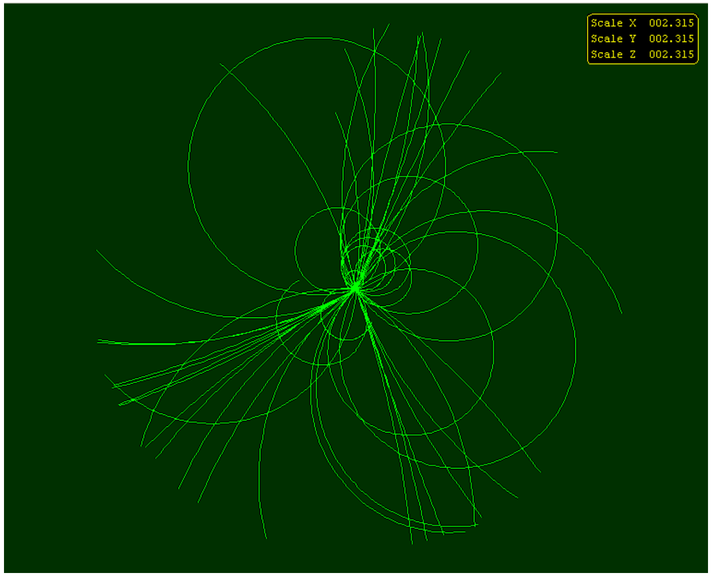
Motivation for a TPC

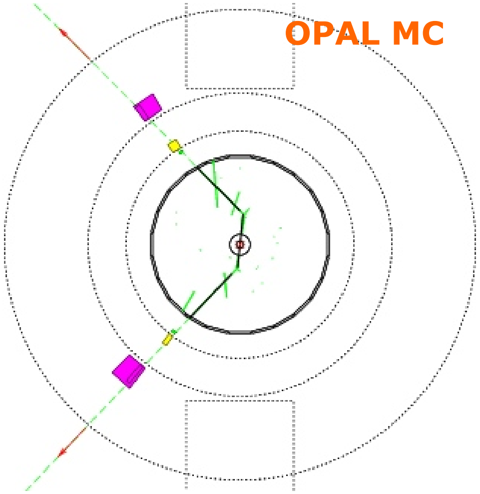
Advantages of a TPC:

- ★ Large number of 3D space points
  - good pattern recognition in dense track environment
- ★ Good 2 hit resolution
- ★ Minimal material
  - little multiple scattering
  - little impact on ECAL
  - conversions from background γ
- ★ dE/dx gives particle identification
- ★ Identification of non-pointing tracks
  - aid energy flow reconstruction of V^0
  - signals for new physics

e.g. Reconstruction of kinks

GMSB SUSY: $\tilde{\mu} \to \mu + \tilde{G}$

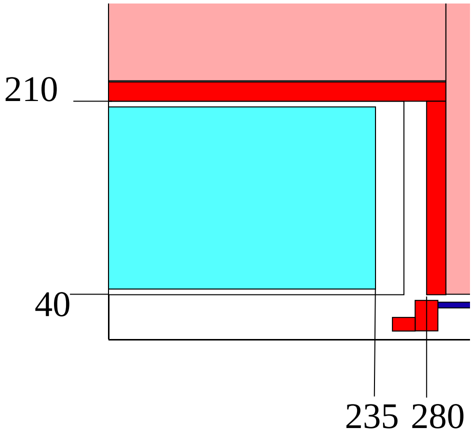




+ Large **WORLDWIDE** R&D effort suggests that a TPC for an ILC detector is viable

+ Size helps : $\sigma_{1/p} \sim \frac{1}{BR^2}$

e.g. GLD TPC Conceptual Design



- ★ **Inner radius:** **40 cm**
- ★ **Outer radius:** **200 cm**
- ★ **Half-length : 235 cm**
- ★ **Readout : 200 radial rings**

- **Drift velocity ~5cm μs^{-1}** (depends on gas)
- **Total Drift time ~ 50μs**
  - **i.e. integrate over ~100 BX**

★**Background ⇨ ~10^5 hits in TPC (depends on gas/machine)**

★**~10^9 3D readout voxels (1.2 MPads+20MHz sampling)**

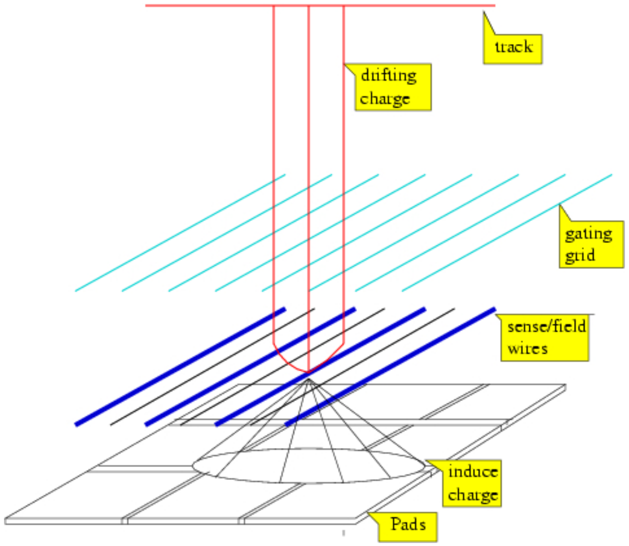
⇨**0.1% occupancy**

★**No problem for pattern recognition/track reconstruction even when taking into account background !**

✦ **One Major Question (?) : Readout technology**

Gas Amplification: MWPC vs MPGD

MWPC : Multi-wire proportional chambers
MPGD : Micro-pattern gas detectors



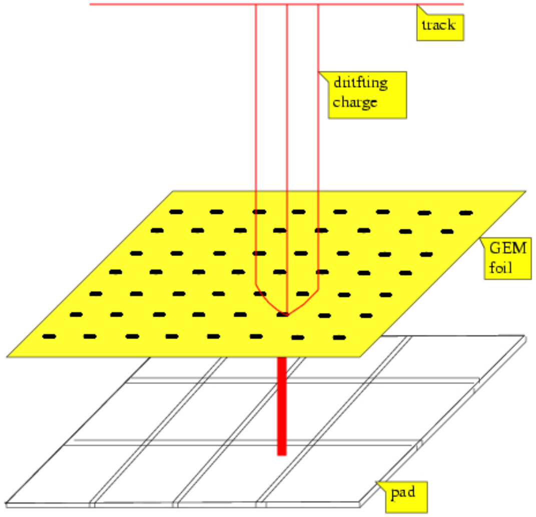
Previous TPCs used multiwire chambers not ideal for ILC.

resolution limited by:

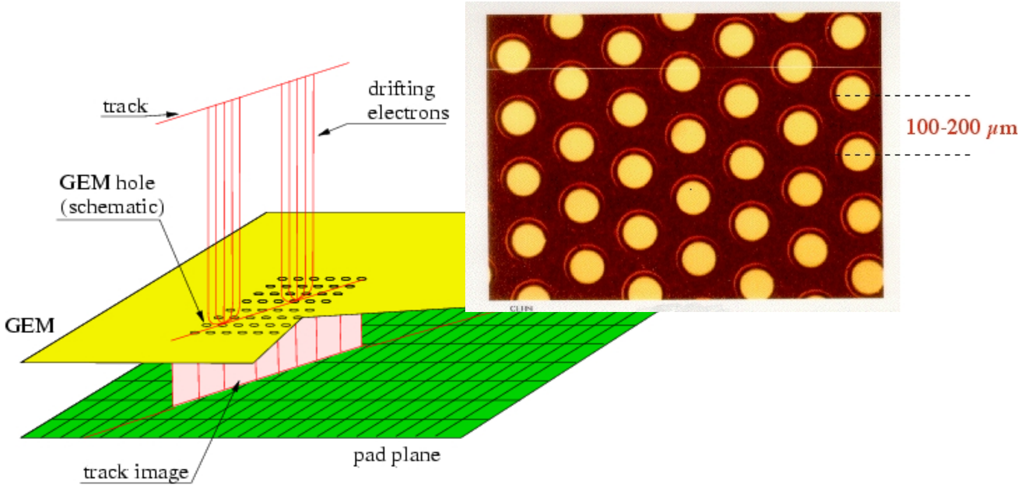
- **ExB effects**
  angle between sense wires and tracks
- **Strong ion feedback – requires gating**
- **Thick endplanes – wire tension**

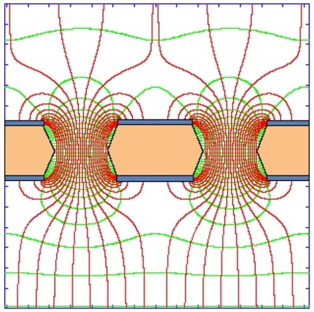
Gas Electron Multipliers or MicroMEGAS

- **2 dimensional readout**
- **Small hole separation ⇨**
  reduced ExB effects ⇨
  improved point resolution
- **Natural supression of ion feedback**
- **No wire tension ⇨ thin endplates**



e.g. GEMs





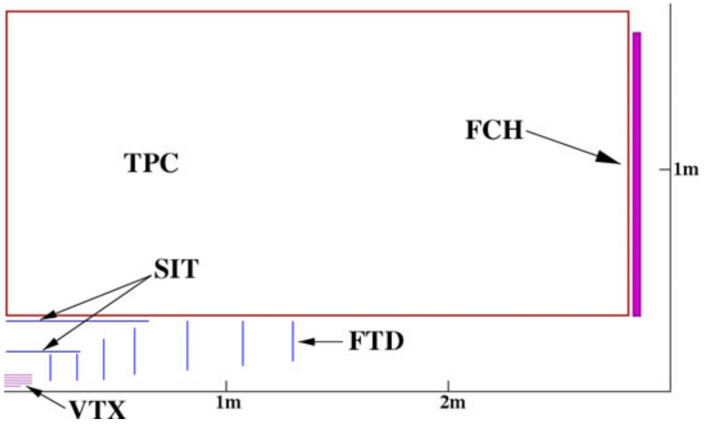
- High electric field strength in GEM holes ~ 40-80 kV/cm
- Amplification occurs between GEM foils (50 μm)
- Ion feedback is suppressed : achieved 0.1-1 %
- Limited amplification (<100) - use stack of 2/3 GEMs

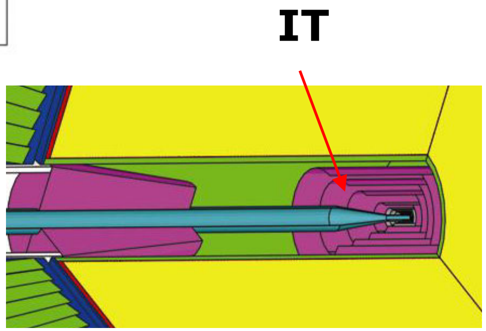
- Ultimate viability of **MPGDs** subject of active worldwide R&D (of which KEK test beam studies play importart role)
- **MWPCs** considered fallback option

Tracking = VTX + SIT + TPC +......

★To achieve good momentum resolution need to augment VTX/TPC particularly in the ENDCAP/far forward region

e.g. TESLA TDR



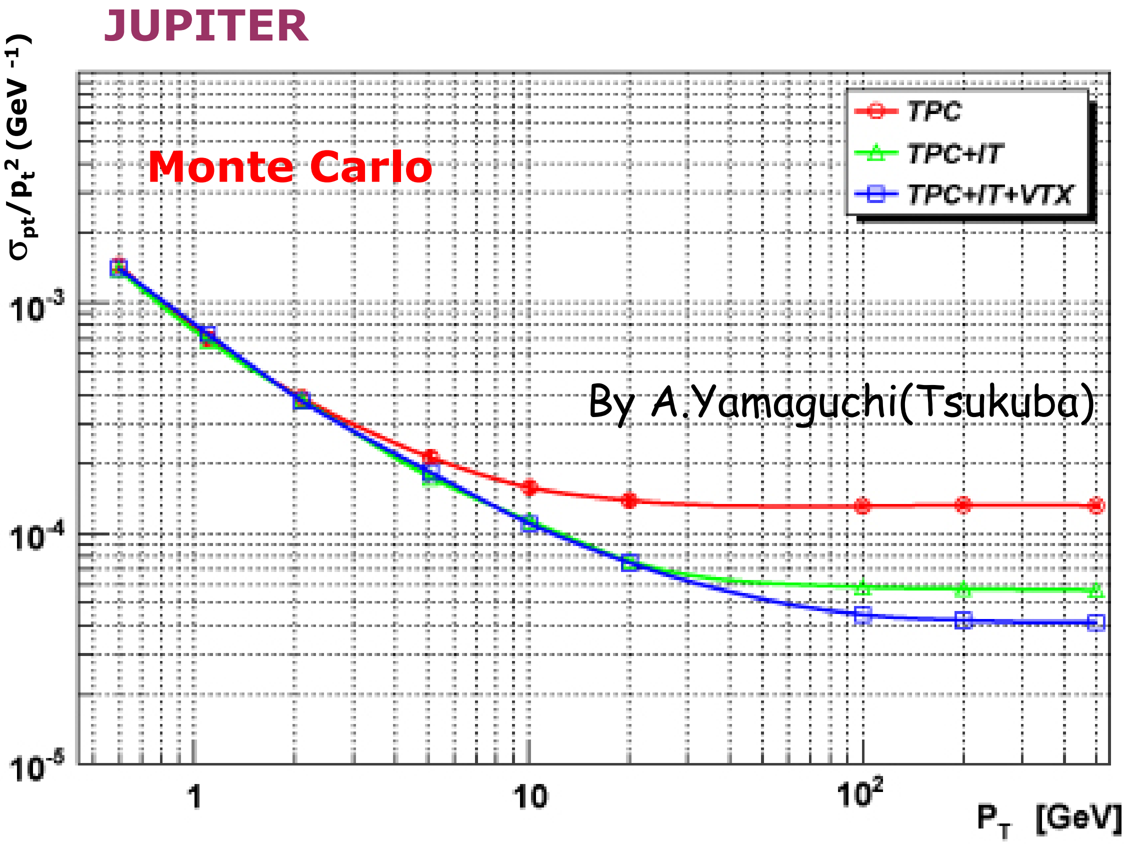


GLD Concept:

- ★ **Intermediate tracker (IT) :** 4 layers of Si
  - ★ 9cm – 30cm
  - ★ 20 μm Si strips
- ★ **Forward Si disks :** coverage down to 150 mrad

★Forward tracking is IMPORTANT
- needs carefully evaluation in GLD studies !
- including tracking behind TPC endplane…

GLD Tracking Performance



- **GLD conceptual design (barrel) achieves goal of :**

$$\sigma_{pT}/p_T < 5\times10^{-5}\, p_T$$

Calorimeter Requirements

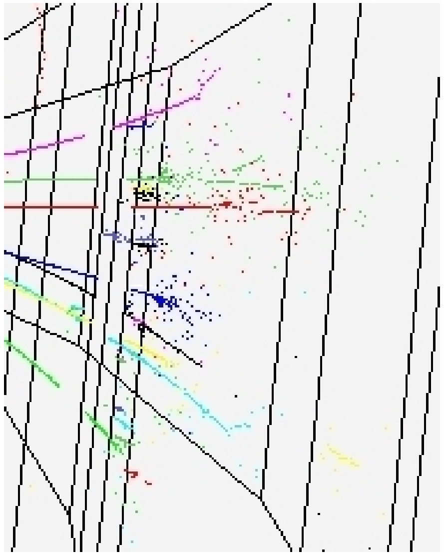
- Excellent energy resolution for jets – i.e. high granularity
- Good energy/angular resolution for photons – how good ?
- Hermeticity
- Reconstruction of non-pointing photons

Particle flow drives calorimeter design:

★ Separation of energy deposits from individual particles
  - small X_0 and $R_{Moliere}$: compact showers
  - high lateral granularity : $O(R_{Moliere})$

★ Discrimination between EM and hadronic showers
  - small X_0/λ_I
  - longitudanal segmentation

★ Containment of EM showers in ECAL



★ **W-Scintillator:** sampling calorimeter is a good choice

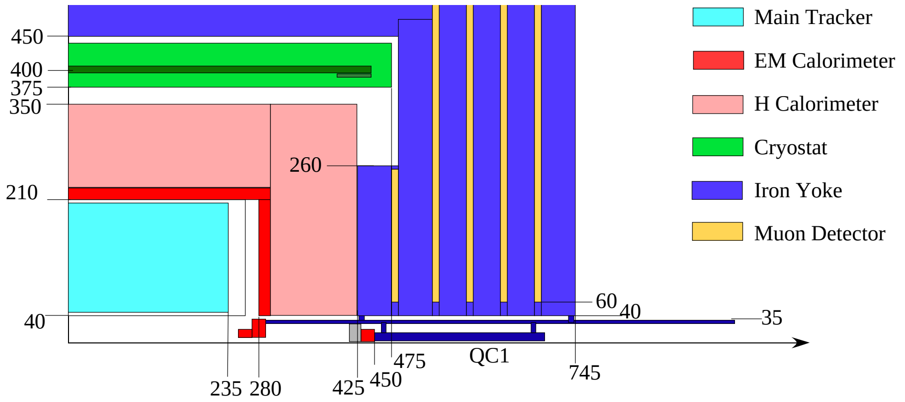
- Tungsten is great : $X_0 / \lambda_I = 1/25$, $R_{Moliere} \sim 9\text{mm}$

  EM showers are short/Had showers long

  + narrow EM showers
- Scintillator is relatively cheap !

Calorimeter Concept

- ★ **ECAL and HCAL inside coil**
  could we get away with some of HCAL beyond coil ? (probably not)

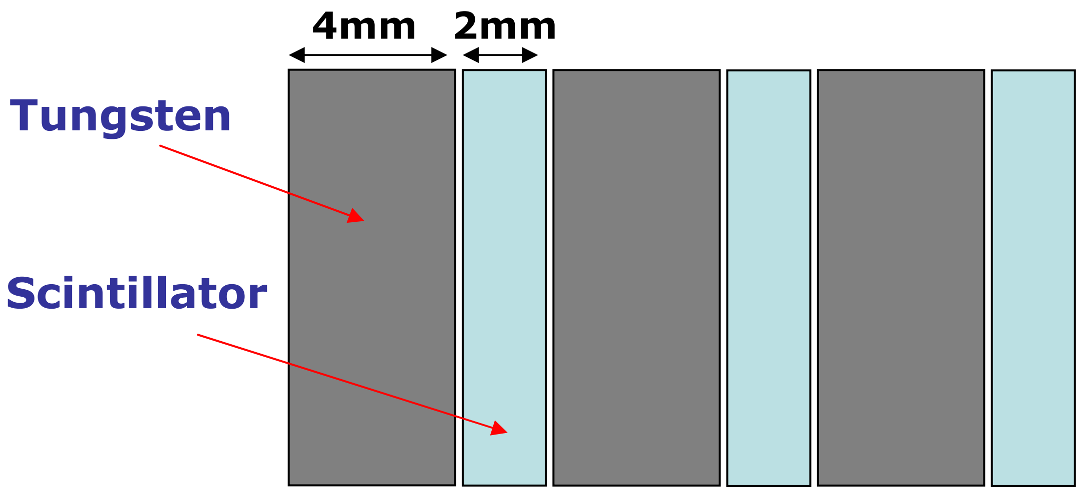


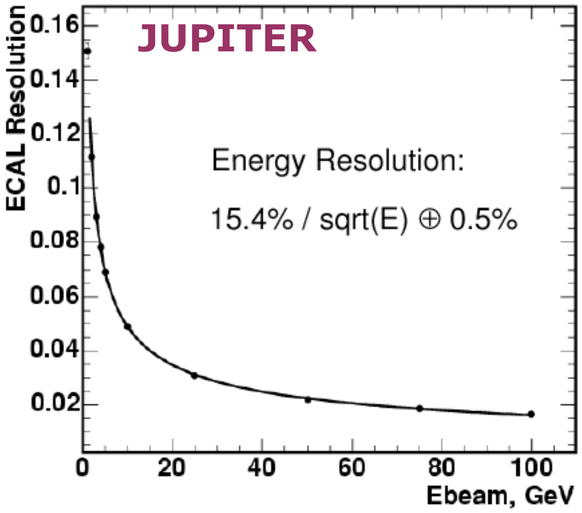
ECAL:

Longitudinal segmentation: 39 layers (~25 X_0; ~1 λ_I)

Achieves Good Energy Resolution:

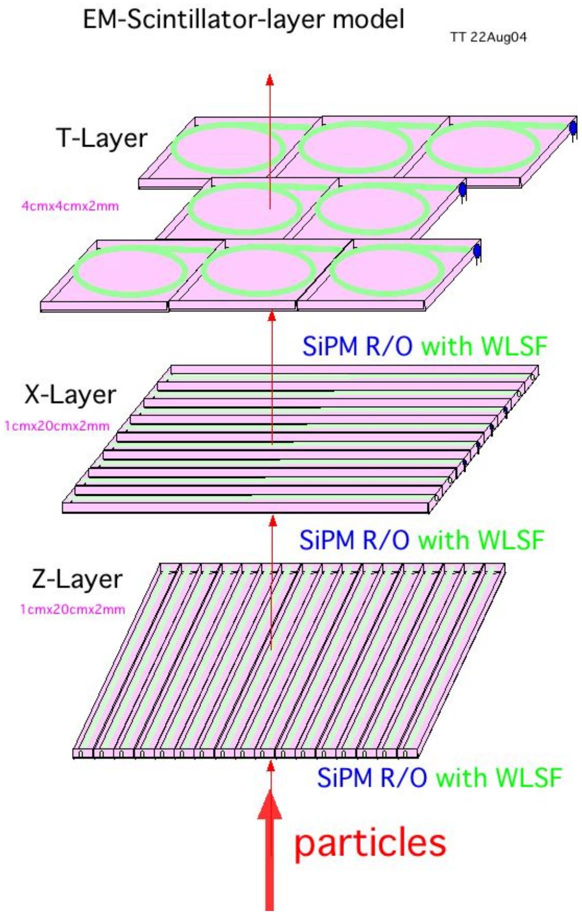
$$\sigma_E/E = 0.15/\sqrt{E(\mathrm{GeV})} \oplus 0.01$$





ECAL Structure

- $R_{Moliere}$ ~ 9mm for solid tungsten
  + scintillator layers increase effective $R_{Moliere}$ ~ 15 mm
- Aim for segmentation ~ $R_{Moliere}$
  ideally (?) ~ 1cm x 1cm - but cost !



Initial GLD ECAL concept:

- ★Achieve effective ~1cm x 1cm segmentation using strip/tile arrangement
- ★Strips : 1cm x 20cm x 2mm
- ★Tiles : 4cm x 4cm x 2mm

★Ultimate design needs to be optimised for particle flow performance

+ question of pattern recognition in dense environment

Scintillator Readout

Traditional Approach:

- Readout with Wavelength shifting fibres + Photomultiplier Tubes (PMT)
- Not suitable for ILC Calorimeter
  - PMTs in high B-field
  - Need long fibre lengths to get signals out - attentuation, +....

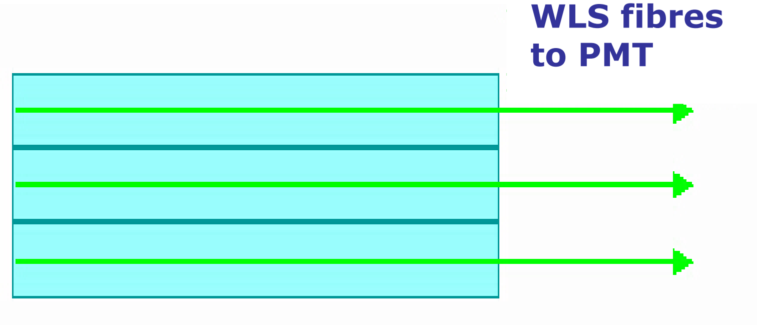
GLD ECAL/HCAL Readout:

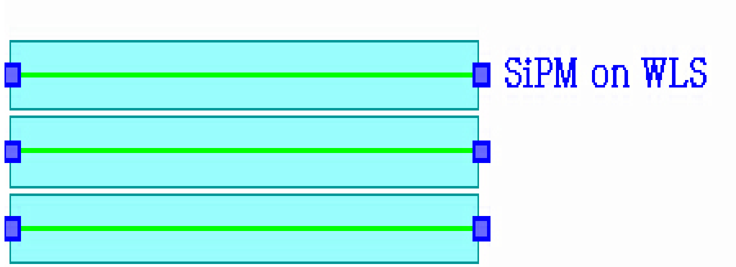
- Read out with WLS fibres + Silicon Multipixel Photon Counter directly on fibre at strip end

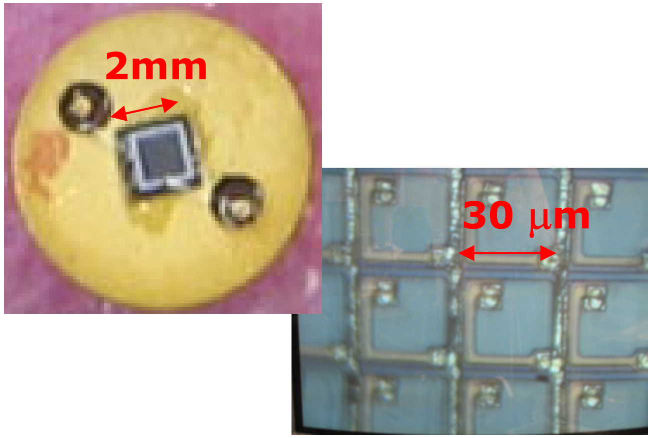
SiPM:

- Number of cells up to ~ 1000
- Effective area ~1mm x 1mm (very compact)
- High gain (~10^6); Detect + amplification
- Cheap (a few $/device in future ?)
- High Quantum efficiency ~ 70+%

SiPM cost will have significant impact on overall cost-perforance optimisation



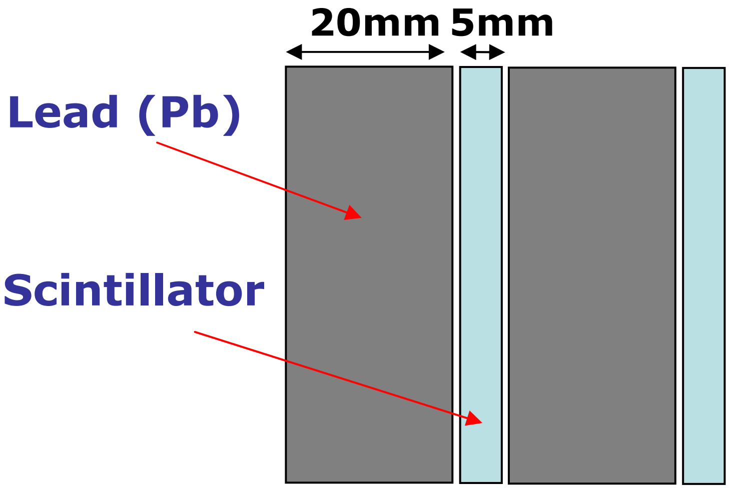




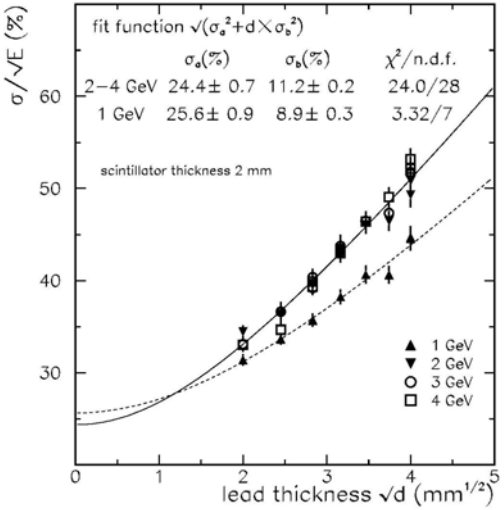
Hadron Calorimeter

Current Baseline Design:

- ★ Pb-Scintillator sampling calorimeter
- ★ Approximate hardware compensation
- ★ 51 layers (~6 λ_I)
- ★ Structure and readout same as ECAL
- ★ Needs to be optimised for PFA

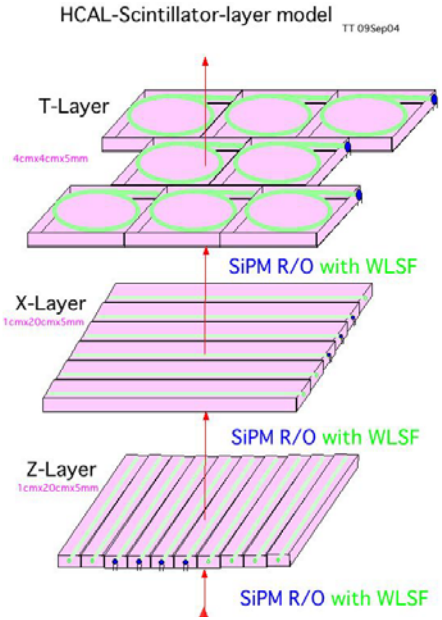


Performance:



Test beam data

$\sigma_E/E \sim 0.55/\sqrt{E(\mathrm{GeV})}$

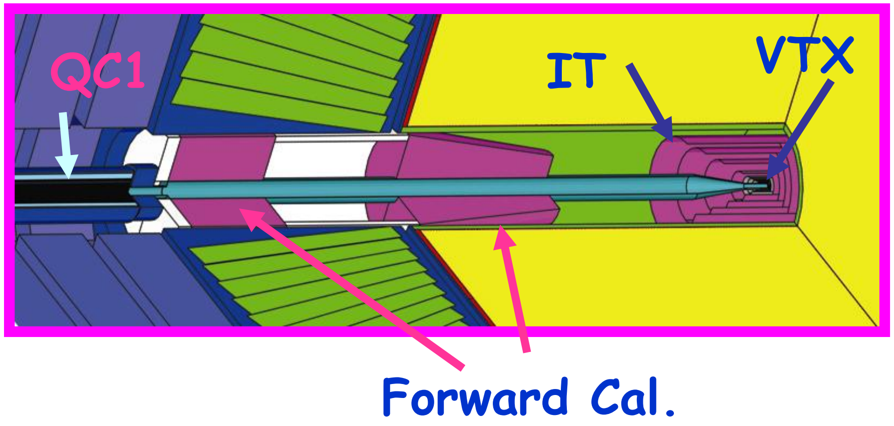


- ★ For low (<10 GeV ?) particles can probably obtain better performance by summing energy deposits “semi-digitally”

Aside….

- ★ Often argued that **Moliere** radius sets scale for **ECAL segmentation**
- ★ **Only** true **once** the shower has developed
- ★ In first "few" radiation lengths have energy deposits from a small number of electrons
- ★ May argue for fine/very fine segmentation in first N radiation lengths
- ★ Would be able to locate photon conversion point precisely
- ★ How much does this help PFA ?

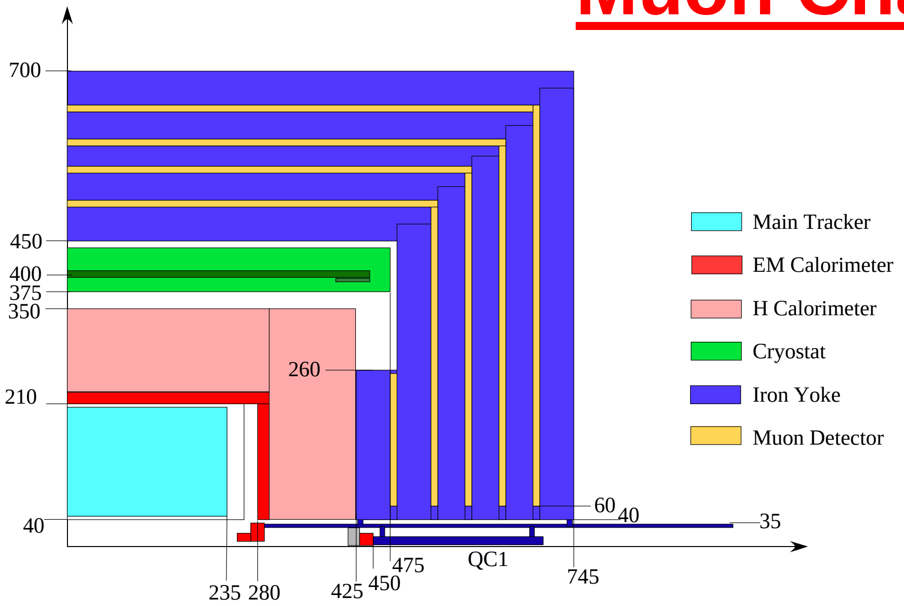
Forward Calorimeters



- ✦SiW for luminosity cal
- ✦Radiation hardness for "far forward" beam cal **issue for Worldwide R&D**

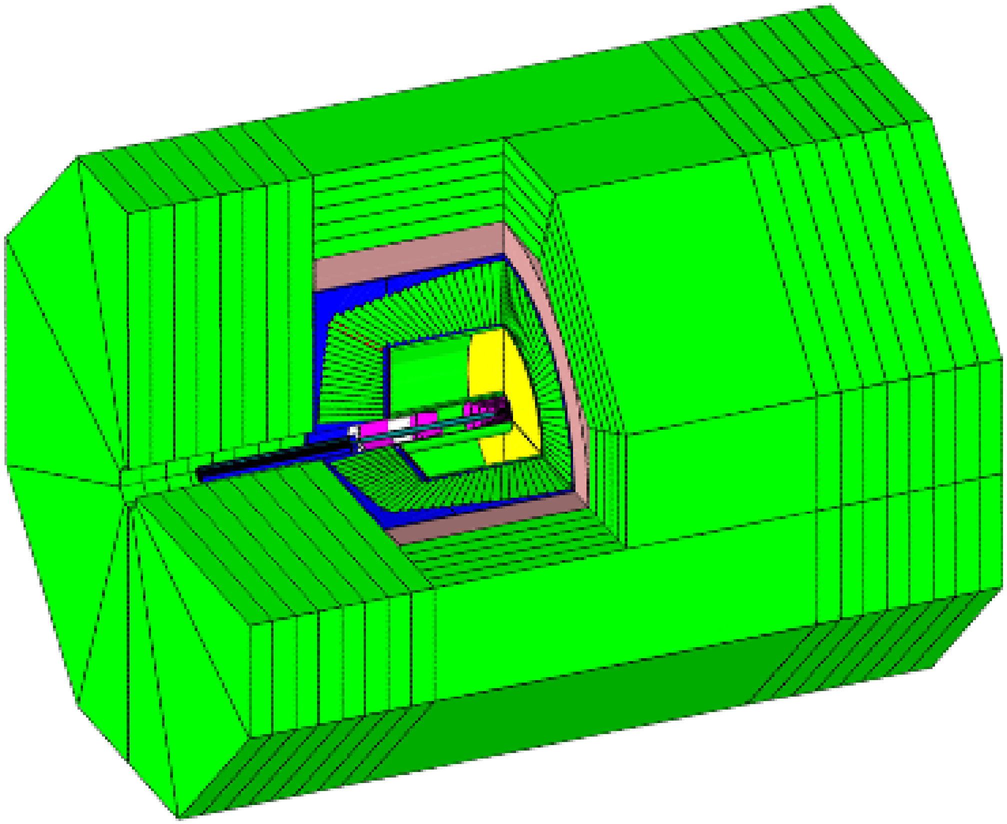
Final design MDI issue

Muon Chambers



- ★Integrated into return yoke
- ★Possible technology: Scintillator strips

Have covered the basic detector concept…



… now need to iterate towards a more optimal design

Simulation, simulation, simulation, simulation, simulation, …

❹ GLD Cost-performance Optimisation

Different requirements for different sub-detectors:

- ★ **VTX** : design driven by heavy flavour tagging, machine backgrounds, technology
- ★ **Tracker** : design driven by σ_p, PATREC, track separation, + R&D

(TRACKER does influence on size and therefore cost)

- ★ **ECAL/HCAL** : single particle σ_E not the main factor ➡ jet energy resolution ! Impact on particle flow drives calorimeter design

★ For VTX and TRACKER can learn a lot independent of rest of detector design. NOT TRUE for ECAL/HCAL need to consider entire detector

★★ For GLD concept "optimisation" of SIZE and CALORIMETRY (i.e. PARTICLE FLOW) appear to be the main issues

★ Many issues !

e.g.…….

e.g. HCAL vs Solenoid

- A 3 Tesla CMS like Solenoid presents “few” technical problems
  - Folklore - cost scales roughly as total stored energy **U**
  - pdg quotes $50\ \mathrm{M\$}\ (U/\mathrm{GJ})^{0.66}$

    (take with generous pinch of salt, based on pre-1992 data, but ~OKish for CMS)
  - the solenoid will contribute significantly to overall cost
    - $U \propto B^2 R^2 L$ $(R = R_{coil}, L = L_{coil})$
  - would like to keep the solenoid volume as low as possible

- Would using Tunsgten (W) rather than Lead (Pb) as the HCAL absorber reduce overall cost ?
  - The HCAL would cost more – W is relatively expensive
  - BUT – interaction length for W is **9.6 cm** c.f **17.1 cm** for Pb
    - HCAL would be more compact
  - **Therefore solenoid cost would be reduced**

Which effect wins in terms of cost ?

- **Desirable to consider cost issues whilst “finalising” baseline GLD concept**

❺ Conclusions I

- ★ **PFA** argues for as large a detector as possible
- ★ **GLD** is a viable large detector design
- ★ However, current GLD concept: not really optimised
- ★ Size, COIL and ECAL/HCAL (segmentation/readout) most important cost issues ?
- ★ VTX, TPC : design dependent on vital detector R&D
- ★ + COIL is important – need to get the real experts involved when trying to optimise overall cost/performance

Final words (personal opinion):

- ★ The **GLD** concept looks very promising
- ★ Need to fix baseline **GLD** design bearing in mind cost issues
- ★ For PFA optimisation within baseline GLD design should use full simulation – this optimisation is not easy
- ★ Vital to include backgrounds (close coupling to MDI)
- ★★ There is a lot of extremely interesting work to be done over the next few years…… **interesting = fun !**

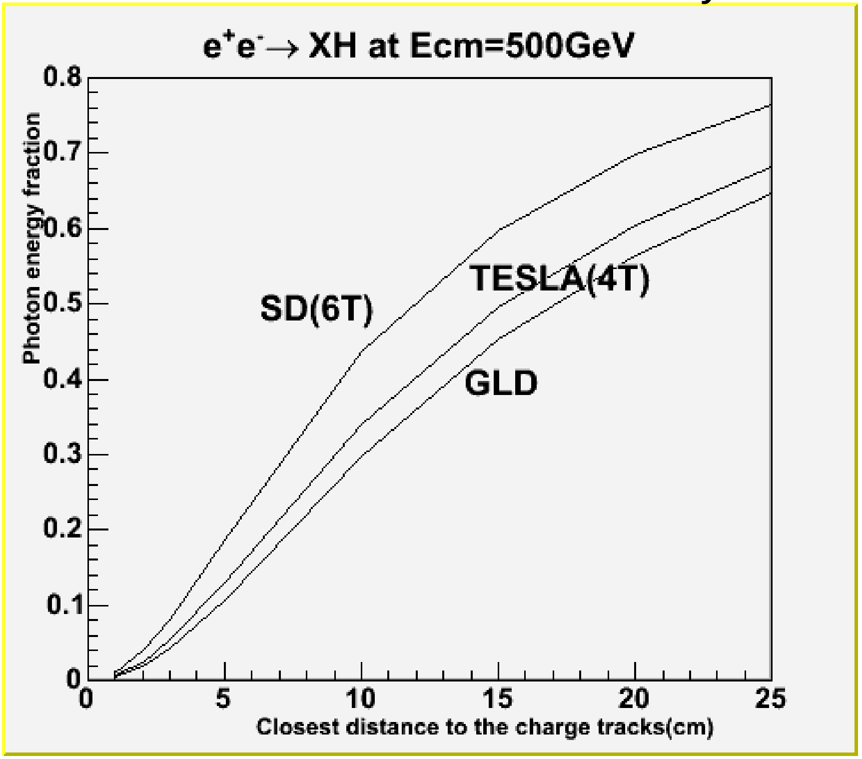
Conclusion II

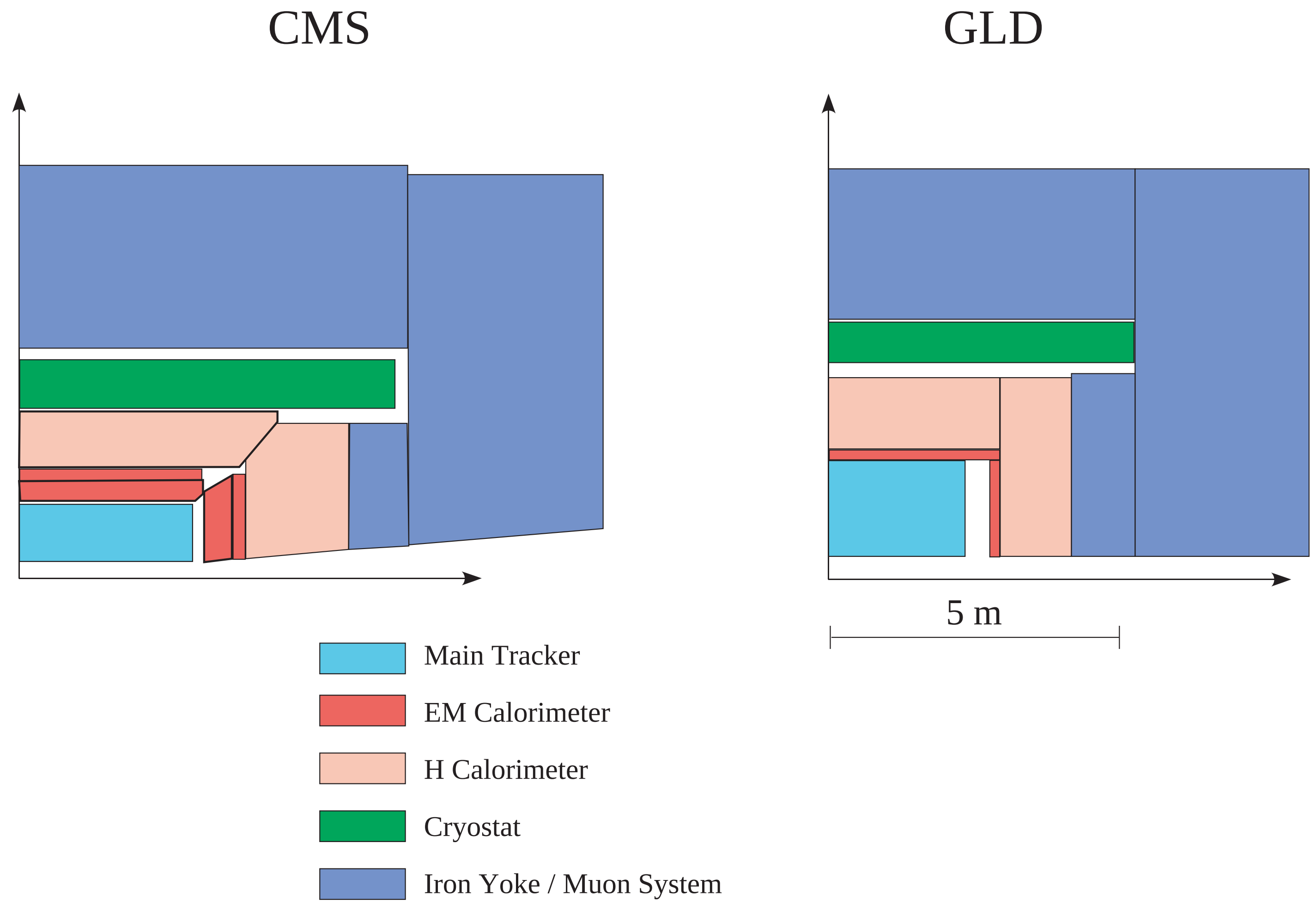
At the ILC : Big is Beautiful

End

Backup Slides

Miyamoto




CMS
GLD
5 m
Main Tracker
EM Calorimeter
H Calorimeter
Cryostat
Iron Yoke / Muon System