Next Collider the ILC?
The physics and the detectors

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!!! ILC candidate site in Japan announced 23 August 2013 !!! Very Recent!!!

- **The ILC site evaluation committee of Japan announced the result of the assessment on the two candidate sites in Japan in a press conference held at the University of Tokyo on 23 August 2013. As a location, they recommended the Kitakami mountains in the Iwate and Miyagi prefectures.**

- **The scientific case for building the ILC is very strong and has the support of the world high-energy physics community. "It, together with the LHC at CERN in Geneva, will allow us to take the next steps in understanding our universe," said Evans.**

Two Candidate Sites in Japan

- Kyushu
  - Sefuri mountains
- Tohoku
  - Kitakami mountains

Strong and stable granite bedrocks

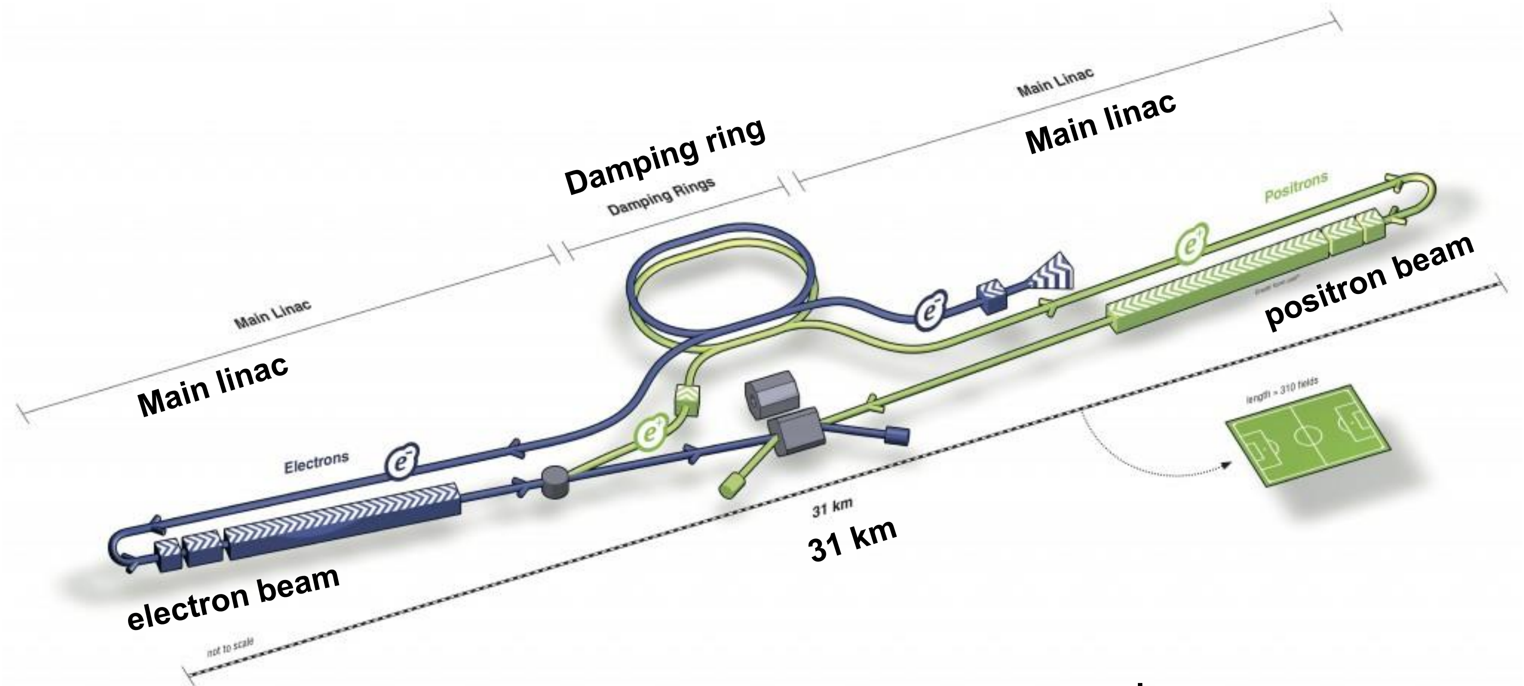
One of them will be chosen by this summer based on:

- Geology
- Economic ripple effects
- Political issues

Introduction

- With the discovery of the 126 GeV "higgs" at the LHC the stage is set to seriously think about the next high energy accelerator program
- Motivations for the **ILC (International Linear Collider),** an e^+e^- linear collider of c.m. energy 300/500 – 1000 GeV are very strong
- We briefly look at the physics at the ILC and the detectors that are being proposed
- Being a linear collider it will have a single interaction region. So two detectors are being proposed, one taking data at a time. Push-pull mechanism used for alternating the detectors.

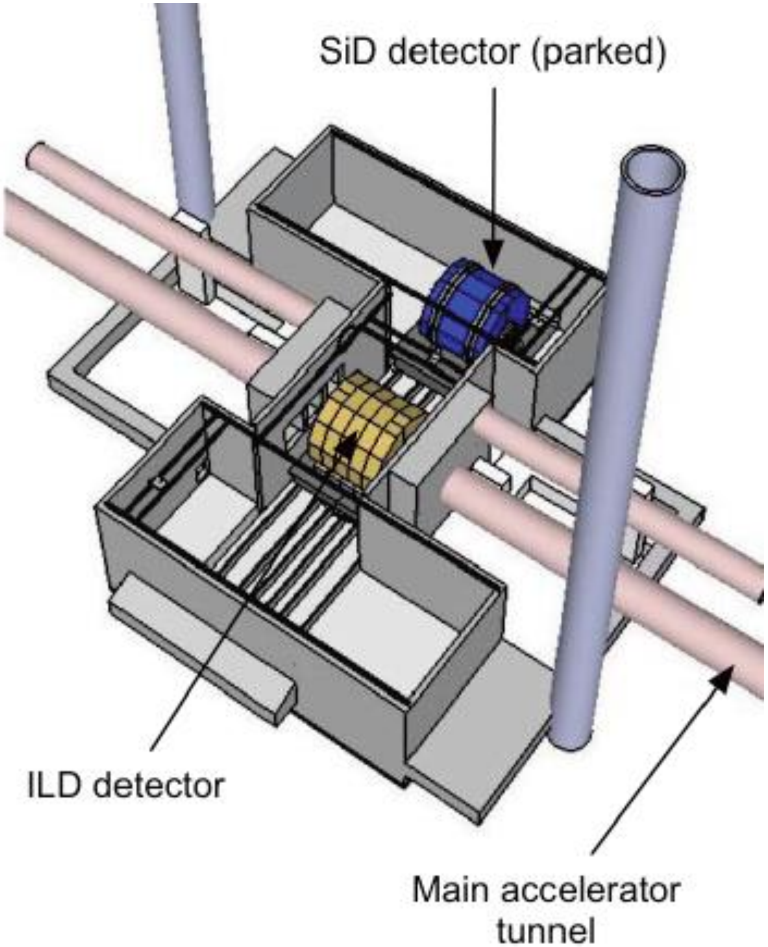
ILC (International Linear Collider)



not to scale

- 500 GeV CM with 31 km → upgrade later to ~ 1TeV CM with 50 km
- Beam size at IP : 6 nm x 500 nm x 300 μm
- Luminosity ~ 2 x 10^{34} /cm^{2}s
- Beam crossing angle = 14 mrad

ILC Experimental Hall



(Flat site version)

Two detectors : ILD and SiD

- Scientific complimentarity
- Competition
- No loss of luminosity while one detector is in repair
- More physicists can participate

One collision point

→ Push-pull

Physics at the ILC

- At the ILC physicists will be able to:

- Measure the mass, spin, and interaction (coupling) strengths of the **Higgs boson**
- Measure the mass and couplings of the **W boson** and the **top quark** to even higher precision

- If existing, measure the number, size, and shape of any TeV-scale extra dimensions
- Investigate the lightest supersymmetric particles, possible candidates for dark matter

- To achieve these goals, a new generation of **precision particle detectors** are necessary.

Plan of the talk

- Will discuss the precision measurements of the KNOWN particles: **Higgs, W, top**

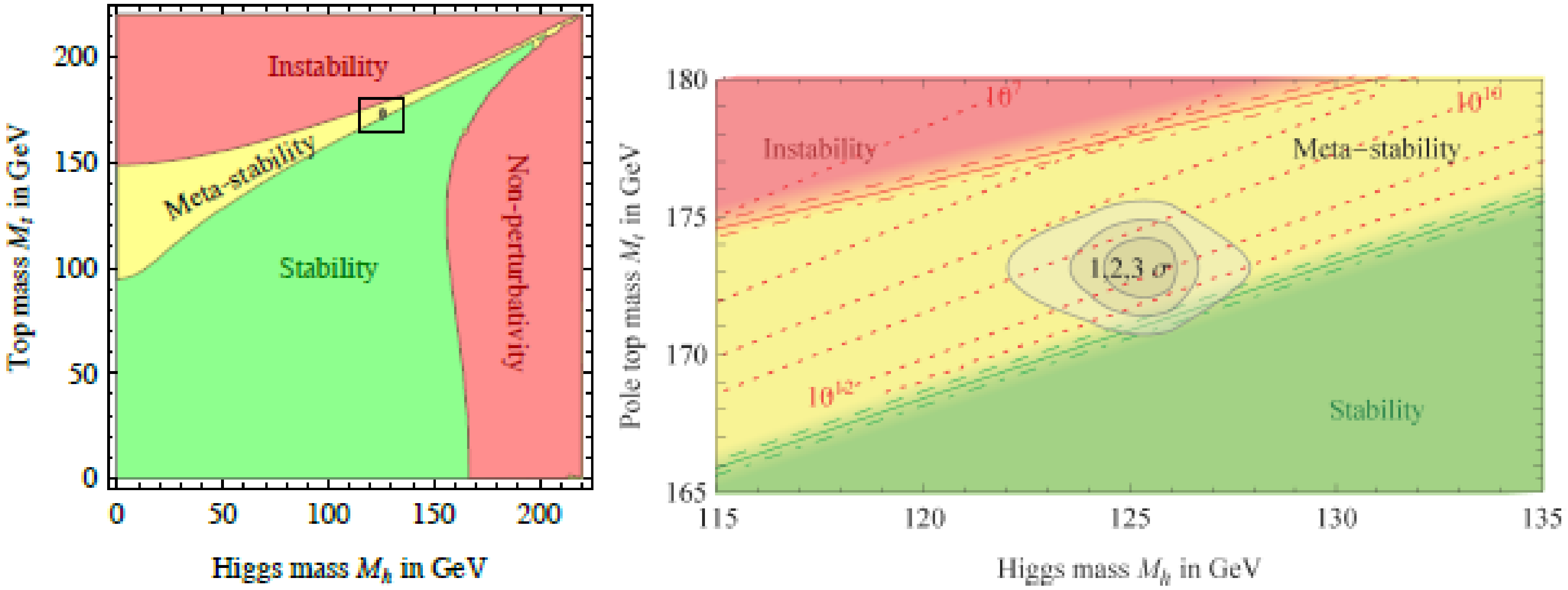
  Most crucially the Higgs, which is the cornerstone of the SM and determination of its properties to maximum precision is obviously very desirable to probe if anything is there BSM

- Will NOT discuss the so-far un-detected new physics, not because it doesn't exist, BUT

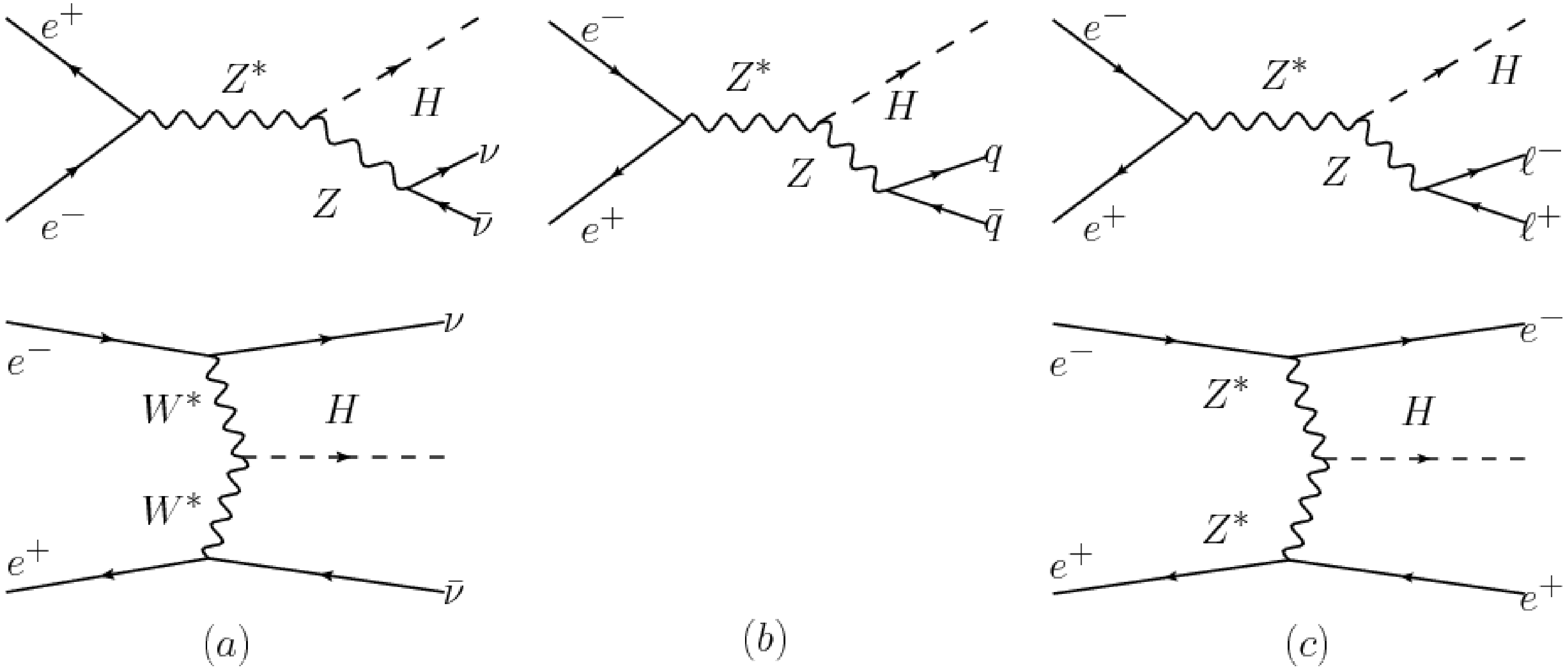
  there are TOO MANY speculative scenarios, and the most favorite one is NOT SEEN yet (SUSY). And there is limited time today!!!
- with the high resolutions (spatial and energy) of the ILC detectors, any new particle can be studied with precision.

- Will give a brief introduction to the **2 proposed ILC detectors, ILD and SiD**

Importance of precision measurements of higgs & top mass



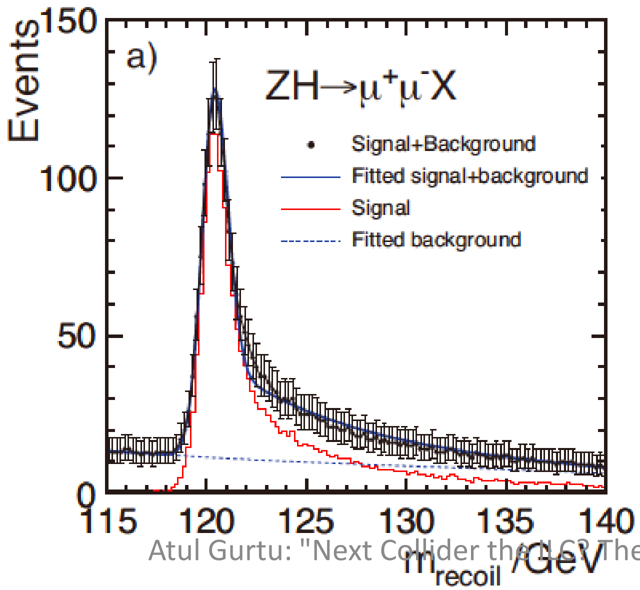
LC: Higgs production main diagrams



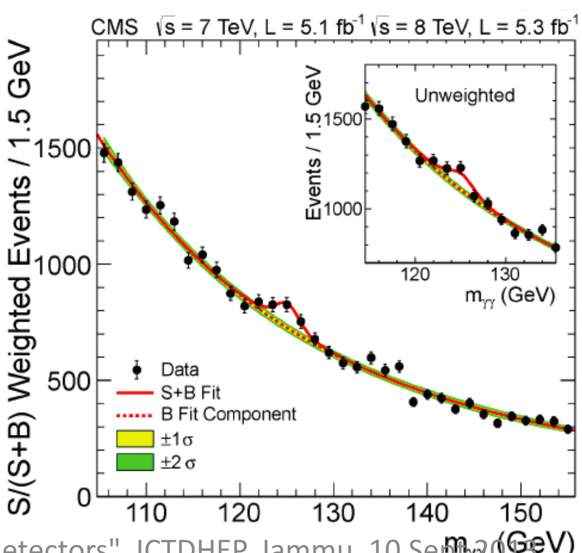
LC: simple initial state, unlike LHC

- Initial state of the electron-positron interaction :
  - Energy-momentum 4-vector is specified
  - Electron polarization is specified
    - Positron polarization is optional

Energy-momentum 4-vector
→ e.g. recoil mass analysis
Higgs to ALL (including invisible final state) is seen



LC



LHC

Estimate of error on higgs mass LHC vs ILC

- LHC: ATLAS and CMS estimate that with 300 fb^{-1} at 14 TeV, the accuracy of higgs mass will be ~ 100 MeV. This works out to

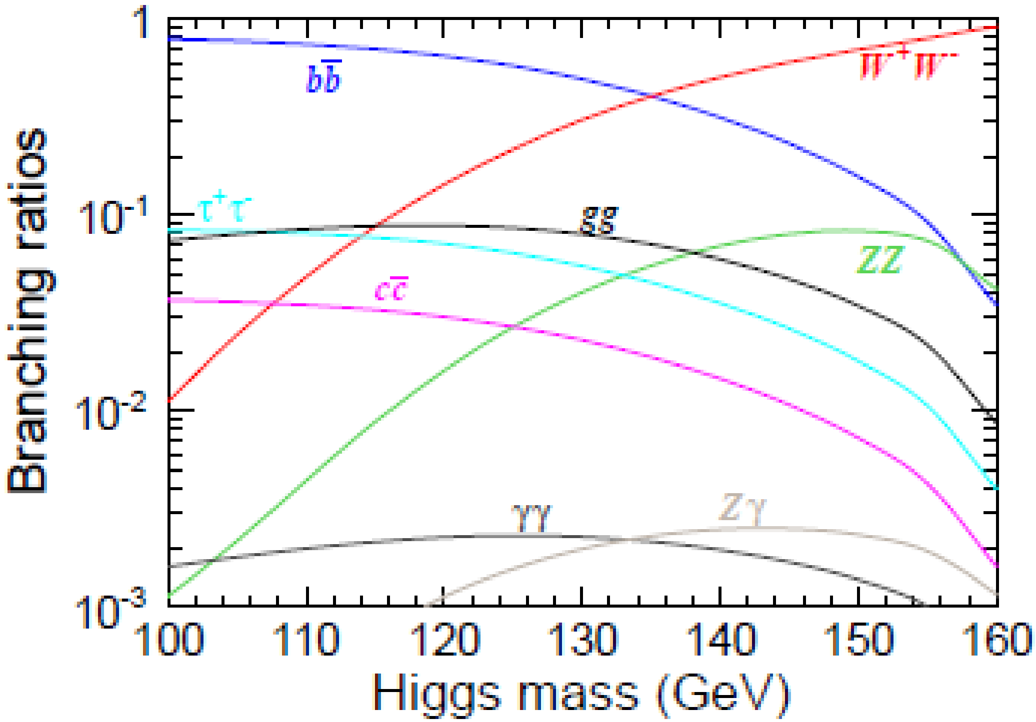
$$\Delta M/M \sim 0.08\%$$

- **ILC: without any model dependence and with ~ 250 fb^{-1} at 250 GeV**

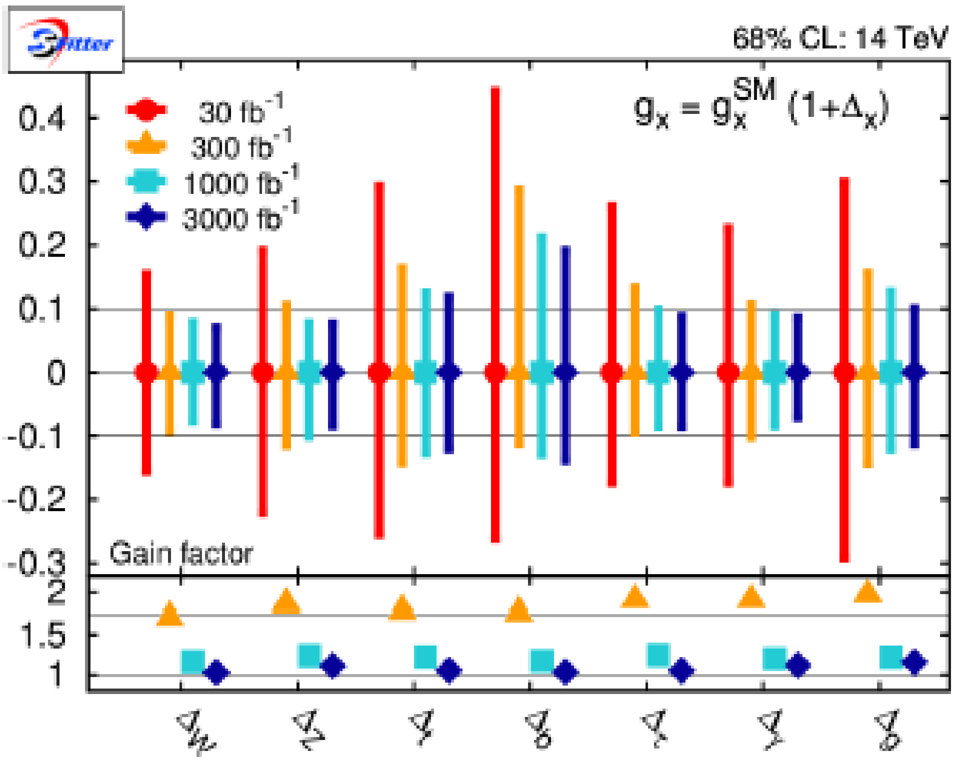
$$\mathbf{\Delta M/M \sim 0.03\%}$$

Which is almost a factor of 3 better precision

Branching fractions of higgs with its mass:
note that at 126 GeV one is in a “favorable” situation
because many decay modes are “comparable”.
For mass > 150 GeV, WW would dominate and others
would be much more difficult to measure with precision



Estimated accuracies of higgs couplings at the LHC



The branching ratios story LHC vs ILC

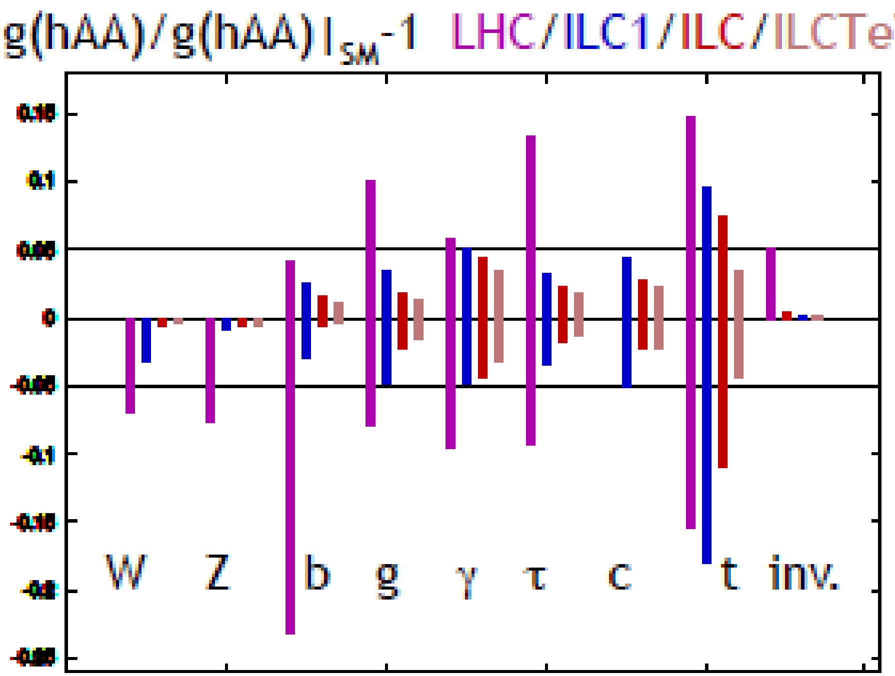
higgs → WW; ZZ; bb; gg; γγ; ττ; cc; tt (1TeV); inv.

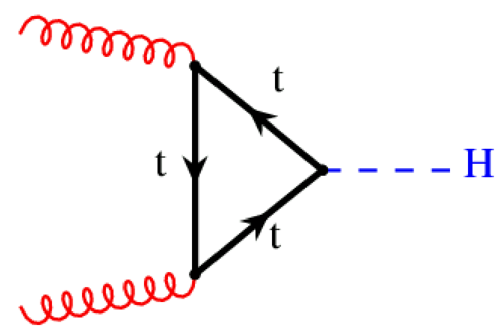
LHC: 300 fb^{-1} at 14 TeV

ILC1: 250 fb^{-1} at 250 GeV | e+/e- polzn = 80%/ 30%

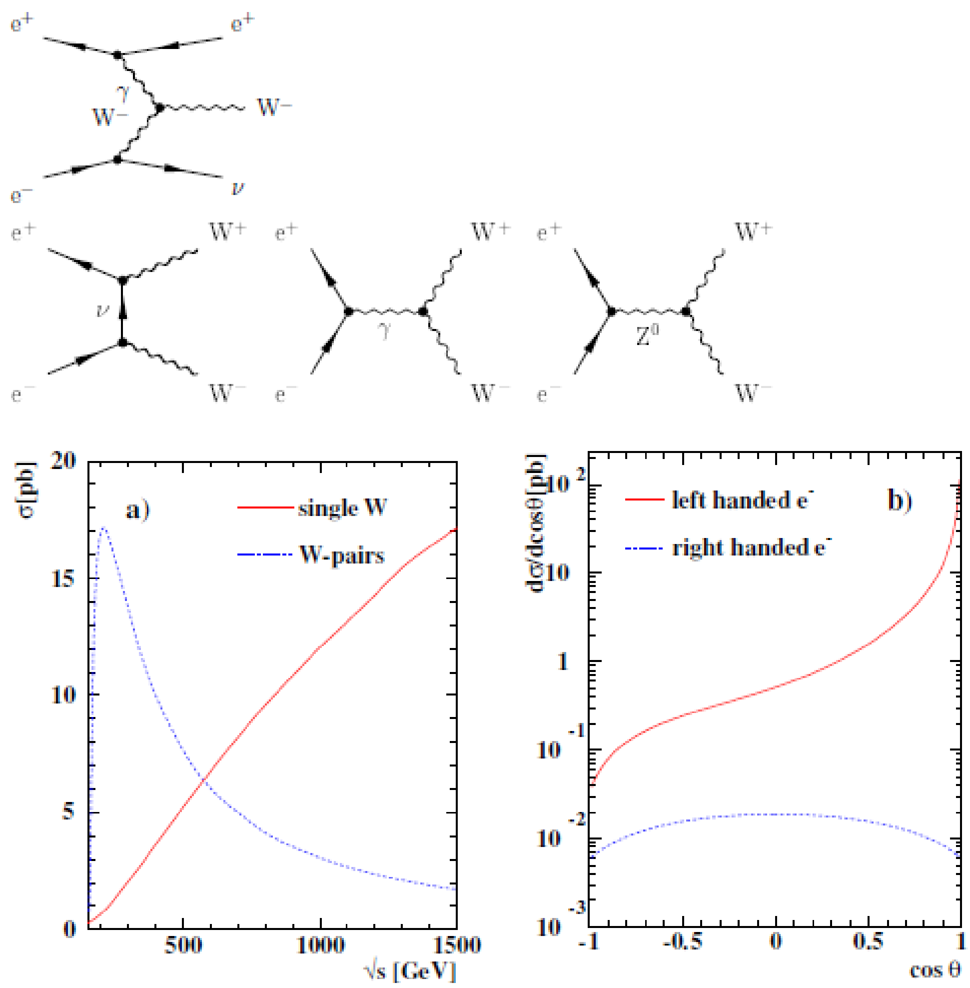
ILC: 500 fb^{-1} at 500 GeV |

ILCTeV: 1000 fb^{-1} at 1 TeV | e+/e- polzn = 80%/ 20%





Vector boson physics: W
Main interests: mass (?) and couplings

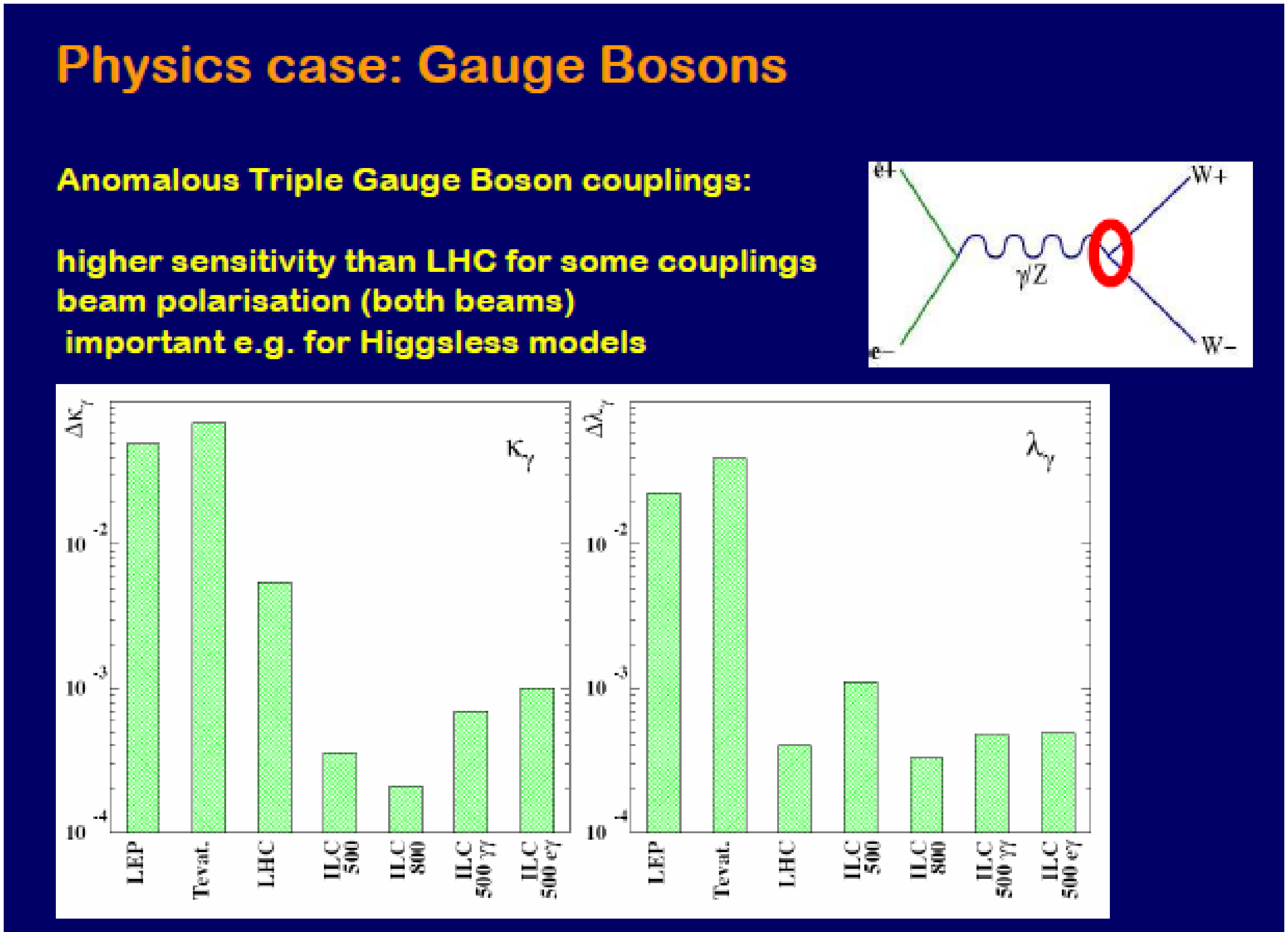


Triple and quartic couplings

- The W-pair and single W production diagrams provide information on the triple gauge couplings (as seen from the vertices).
- They are parametrized in the SM context and have been determined at LEP, Tevatron and (now) LHC studying W and Z/γ production.
- **Their values are precisely fixed in the SM, so any deviation from these indicate BSM physics**
- Determination of quartic couplings requires the production of an additional γ, e.g., WWγ events at LEP.
- The ILC will provide a much more accurate determination (or limits) of many couplings, which would enable very stringent test of the SM

κ_γ and λ_γ are given below; at the ILC some other TGC's will be determined to the following precision

g_1:0.16%, κ_Z :0.03%, λ_Z :0.07%



The top quark

- Being the heaviest of the SM particles, it has a special place in EW theory (coupling is proportional to mass).
- To investigate any BSM scenario, mass of the top must be known as accurately as possible
- Because of its large mass, it is the only quark that decays before it can hadronize, so one is seeing the decay of the bare quark

- It was discovered at the Tevatron and studied extensively.
- Lately the LHC collaborations have also published studies on it.

- Mass = 173.20 $\pm$ 0.87 GeV from Tevatron
  = 173.54 $\pm$ 1.01 GeV from CMS (EPS July 13)
  = 174.5 $\pm$ 0.6 $\pm$ 2.3 (old value, pre-EPS, July 13)

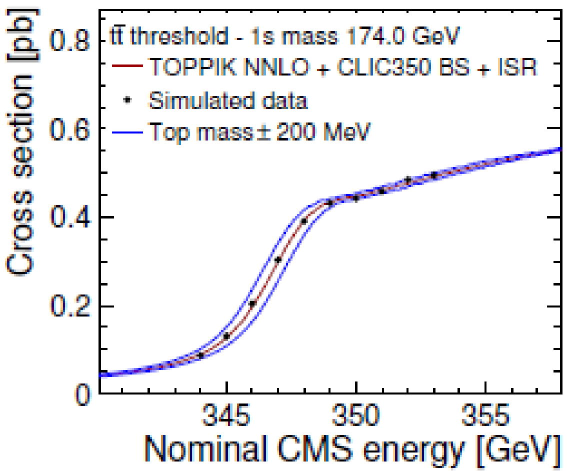
Hadron colliders: top-reconstruction method for top mass;
ILC: do a threshold scan, like done for W at LEP 2. With high statistics, one can get very accurate mass determination **(~34 MeV error)**

Strategy of the threshold scan template fit

- top quark production cross-sections are "measured" around the expected $t\bar{t}$ pair creation threshold
- in parallel, many of these dependencies are simulated with different parameter values (m_t, α_s, ...)

⇒ fit template

- the "measured" data points are fitted with the templates
- top mass and α_s are extracted from the fits
- in principle, also further parameters fan be fitted, but would need higher measurement precision



Other top topics of interest

- Within SM, $t \rightarrow Wb$ is almost exclusively the decay mode
- Moreover, both the *b* and the W are left-handed polarized and the W additionally is longitudinally polarized, with the polarization

$$f_0 = m_{top}^2 / (m_{top}^2 + 2\, m_W^2)$$

- SM: $f_0 = 0.703$; **CDF: 0.78 +0.19 -.20 ± 0.06**
- With very accurate m_{top} determination at the ILC, one can test for BSM

$t\bar{t}$ Couplings to Z and γ

- Top ($t\bar{t}$) couplings to the Z and γ are also very important

$$\Gamma_\mu^{ttX}(k^2, q, \overline{q}) = ie\left\{\gamma_\mu\left(\widetilde{F}_{1V}^X(k^2) + \gamma_5\widetilde{F}_{1A}^X(k^2)\right) + \frac{(q-\overline{q})_\mu}{2m_t}\left(\widetilde{F}_{2V}^X(k^2) + \gamma_5\widetilde{F}_{2A}^X(k^2)\right)\right\}$$

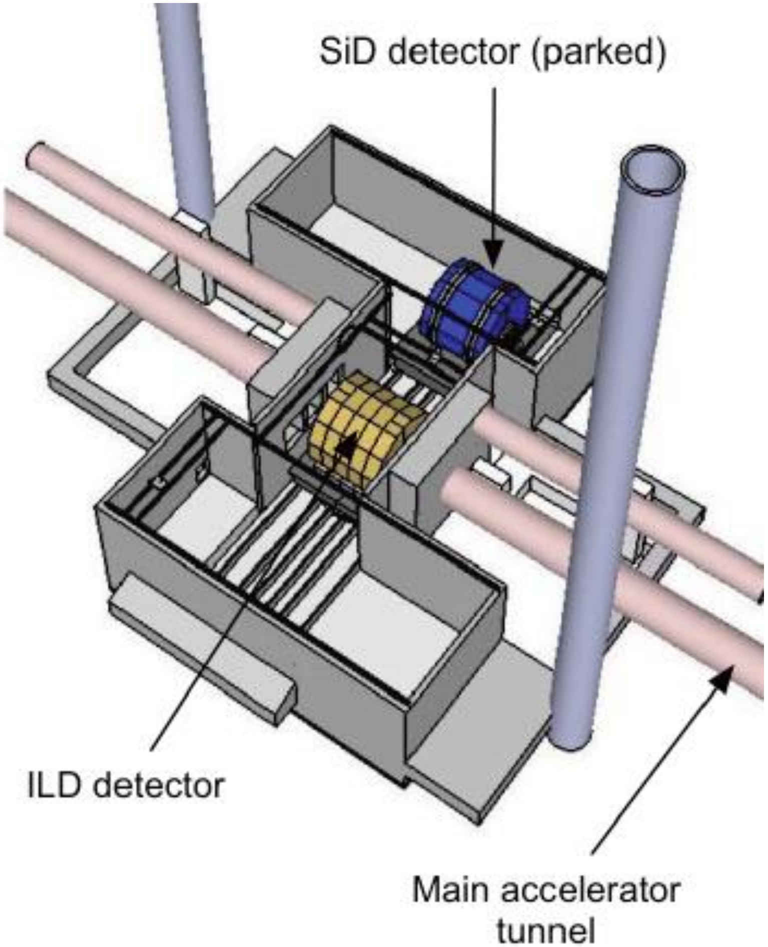
- At the LHC one can study the $t\bar{t}Z$ final state, but to reduce background, only Z → lepton decays are useful.
- → low statistics, larger errors.
- **With a few hundred fb^{-1} one expects 10 – 40% kind of errors.**

- **At the ILC with CM energy 500 GeV, the errors come down to <1%**

  (simple $t\bar{t}$ production diagram)

- **Again, with this much higher precision BSM scenarios can be probed more deeply.**

ILC Experimental Hall



(Flat site version)

Two detectors : ILD and SiD

- Scientific complimentarity
- Competition
- No loss of luminosity while one detector is in repair
- More physicists can participate

One collision point

→ Push-pull

Modern HEP detectors

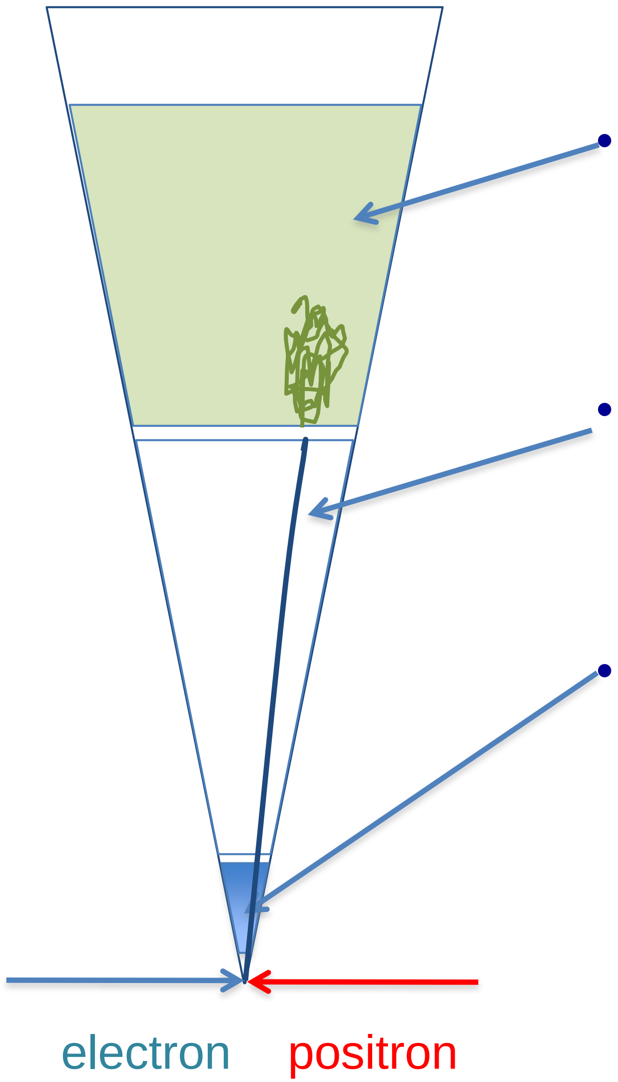
- Goal: to detect all the outgoing particles from the interaction
  → as close to 4π coverage as possible

- To be able to search and detect secondary vertices to identify heavy flavor decays (mainly b,c,τ)
  → vertex detector (silicon pixel) as close to beam as possible

- To be able to measure the momentum of charged particles by bending in magnetic field
  → inner tracker, outer muon detector system

- To measure energy of particles, and detect neutral hadrons
  → electromagnetic and hadron calorimeters

Typical SLICE of Detector



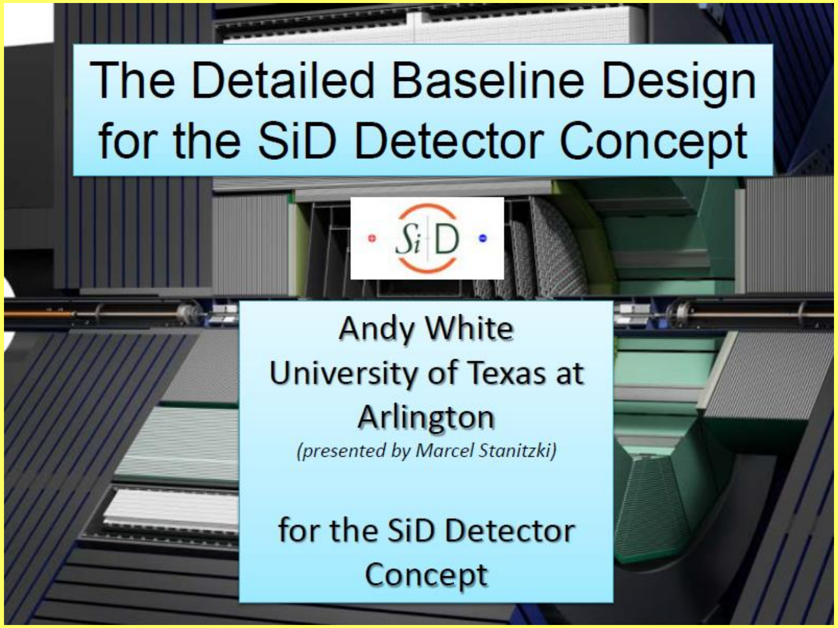
- Calorimeter
  - Measure showers created by particles
    - Energy of shower → energy of the particle
- Tracker
  - Detector tracks by charged particles
    - Curvature in magnetic field → momentum
      - typically better resolution than showers
- Vertex detector
  - Measure tracks of charged particles with high precision
    - Identify b and c quarks that decay after flying ~0.1 mm

Acknowledgements

Have borrowed heavily from

Hitoshi Yamamoto,Tohoku University

EDIT 2013, March 22, KEK



ILC vs LHC detectors

- One heard a lot of fuss made about very hi-tech LHC detectors, so why the big deal about ILC detectors?

→**General purpose "discovery" machine (LHC) vs precision measurement machine (ILC).**

1. LHC needed very fast & radiation hard detectors owing to high multiplicity and very high radiation levels in an intense proton-proton collider
2. One needs real precision detectors at ILC to give detailed information.
3. Precision translates into highly segmented detectors and very precise momentum and energy resolutions.

Required ILC Detector Performances

- Vertexing $(h \to b\bar{b}, c\bar{c}, \tau^+\tau^-)$
  - ~1/5 $r_{beampipe}$,1/50~1/1000 pixel size, ~1/10 resolution (wrt LHC)

$$\sigma_{IP} = 5 \oplus \frac{10}{p \sin^{3/2}\theta} (\mu m)$$

- Tracking $(e^+e^- \to Zh \to \ell^+\ell^- X; \quad \text{incl. } h \to \text{nothing})$
  - ~1/6 material, ~1/10 resolution (wrt LHC)

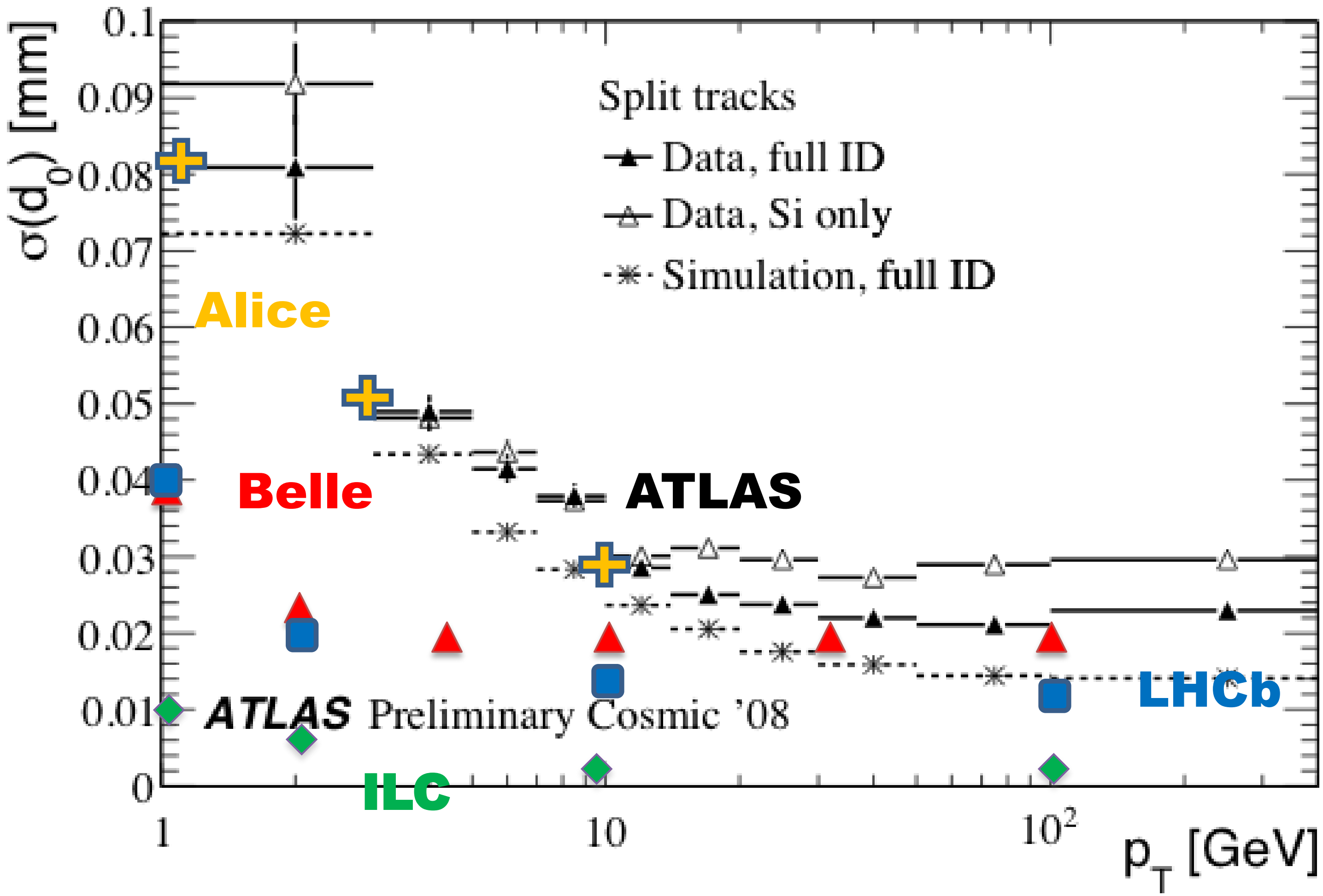
$$\sigma(1/p) = 2 \times 10^{-5} (\mathrm{GeV}^{-1})$$

- Jet energy (quark reconstruction)
  - 1000x granularity, ~1/2 resolution (wrt LHC)

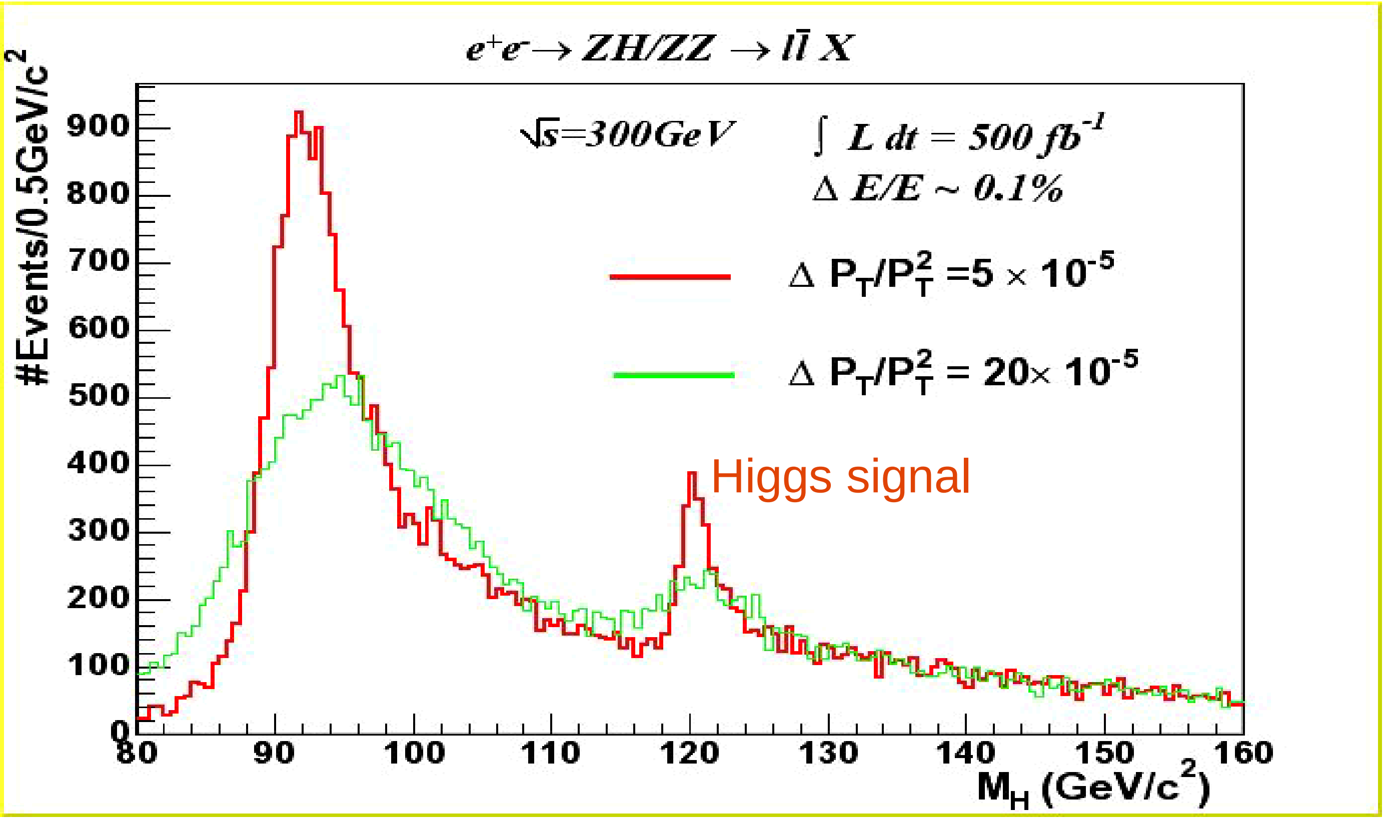
$$\sigma_E / E = 0.3 / \sqrt{E(\mathrm{GeV})}$$

Above performances achieved in realistic simulations

Impact parameter resolution



Recoil mass resolution

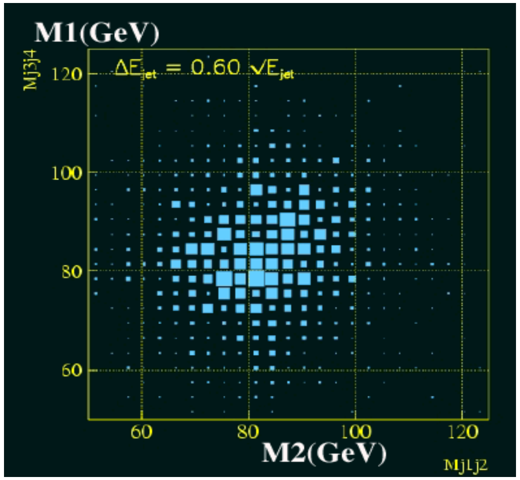


- Good momentum resolution of tracking is <u>required.</u>

Jet(quark) reconstruction

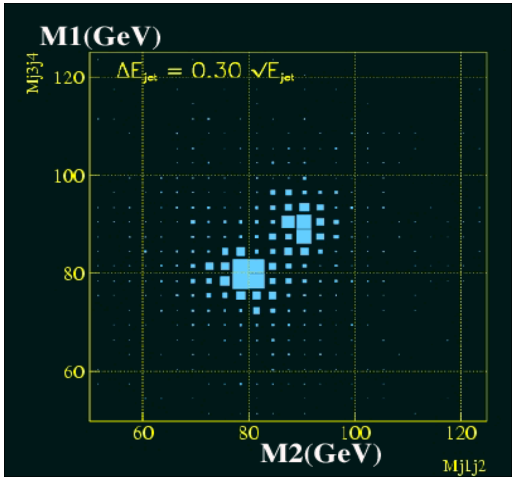
$$e^+e^- \to \nu\bar{\nu}WW, \nu\bar{\nu}ZZ \quad W/Z \to jj$$

Current



$$\sigma_E/E = 0.6/\sqrt{E(\mathrm{GeV})}$$

Goal



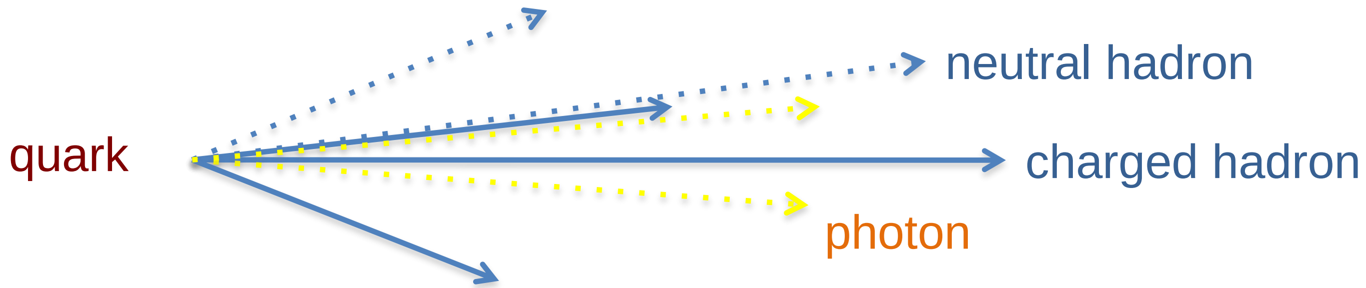
$$\sigma_E/E = 0.3/\sqrt{E(\mathrm{GeV})}$$

- $\sigma_E/E = 0.3/\sqrt{E}$ is required for Z/W→jj to be separated
- A promising technique : PFA (particle flow algorithm)

Quark energy measurement

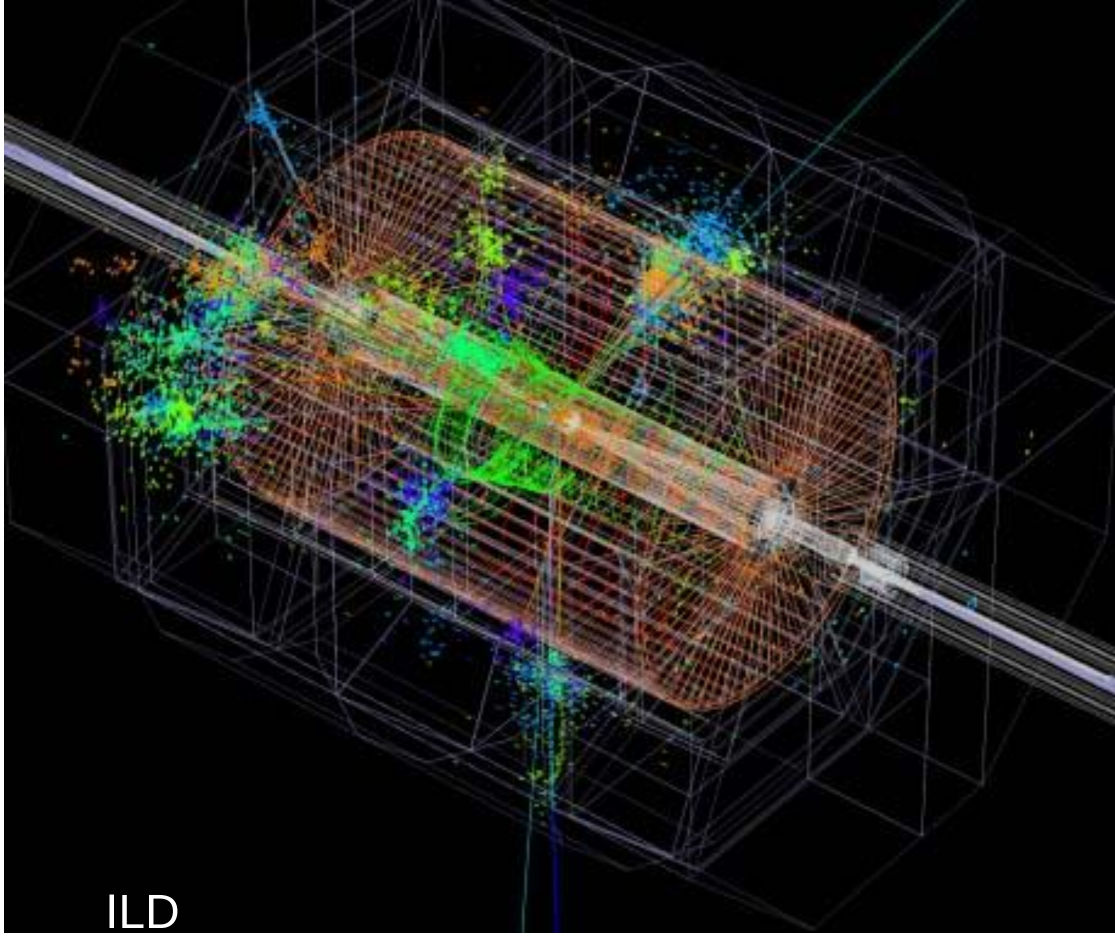
- A quark becomes a bundle of various particles (a ‘jet’) immediately after it is generated
  - Sum of energies of all the particles in the jet

    = energy of the quark
  - If a particle has both a track and a shower, then use track to measure the energy (momentum)
    - Avoid duplicate measurement of the shower energy



PFA

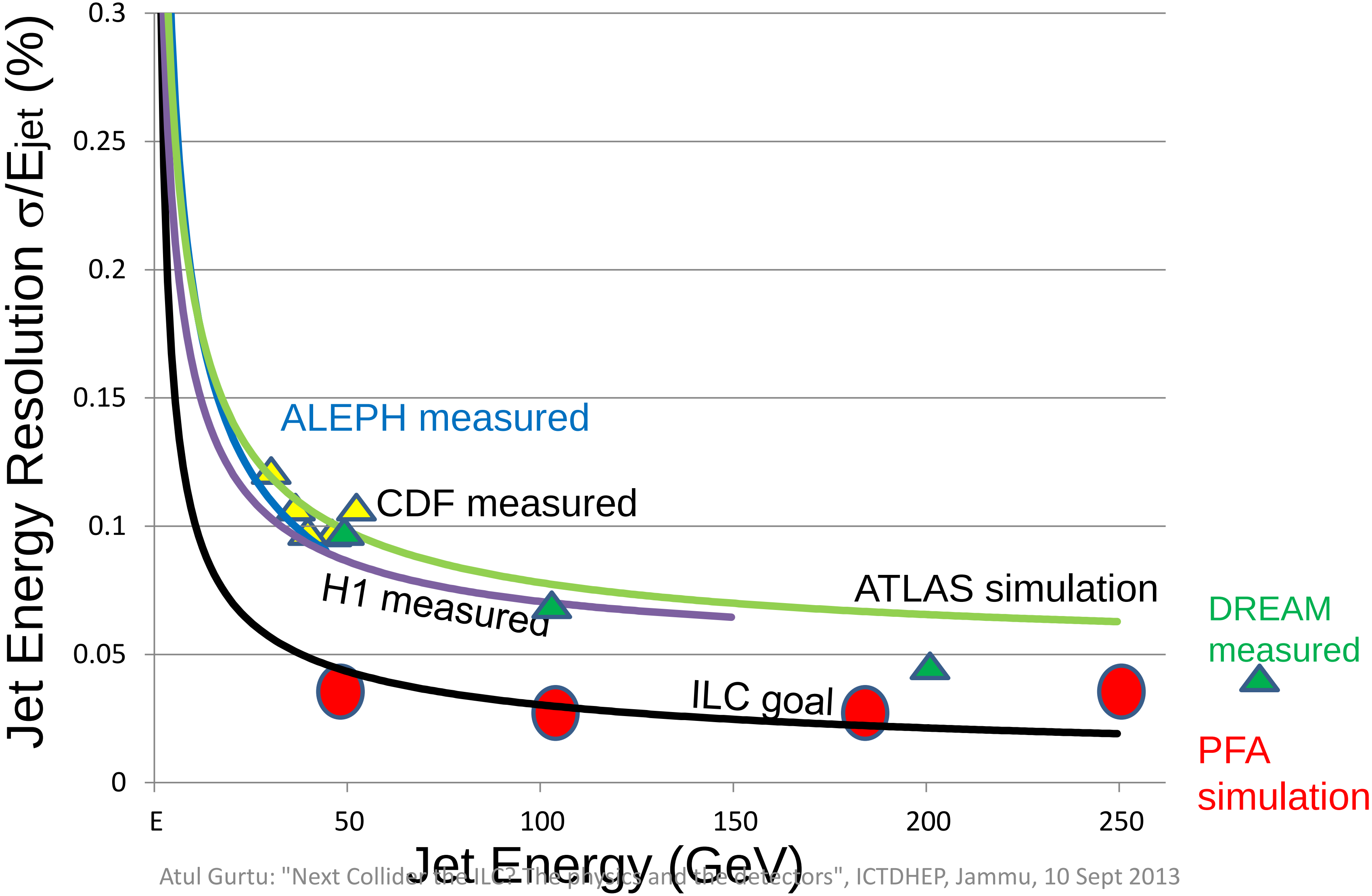
- Charged particles
  - Use trackers
- Neutral particles
  - Use calorimeters
- Remove double-couting of charged showers
  - Requires high granularity



#ch	ECAL	HCAL
ILC (ILD)	100M	10M
LHC	76K(CMS)	10K(ATLAS)

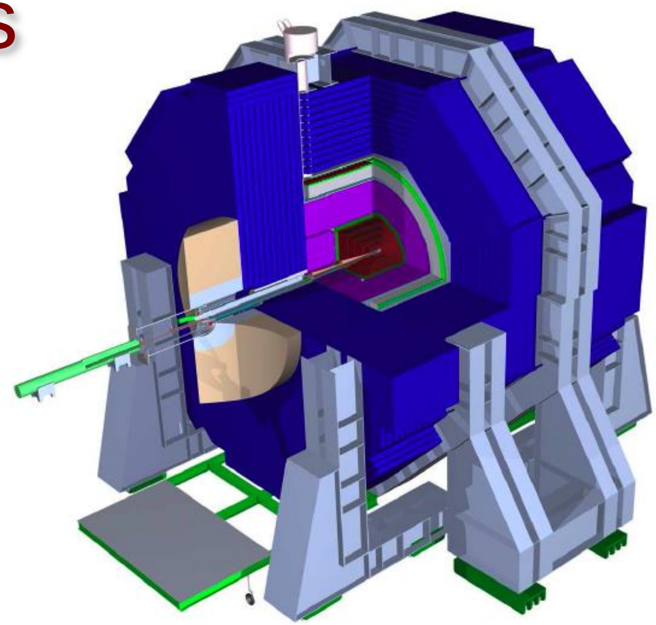
X10^3 for ILC
Need new technologies !

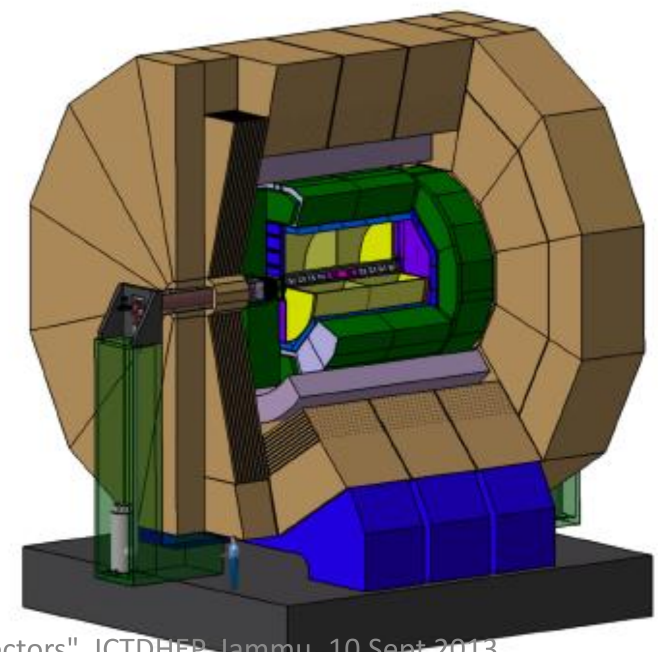
Jet energy resolution



Design Strategies

- SiD
  - High B field (5 Tesla)
  - Small ECAL ID
  - Small calorimeter volume
    - Finer ECAL granularity
  - Silicon main tracker
- ILD
  - Medium B field (3.5 Tesla)
  - Large ECAL ID
    - Particle separation for PFA
  - Redundancy in tracking
  - TPC for main tracker



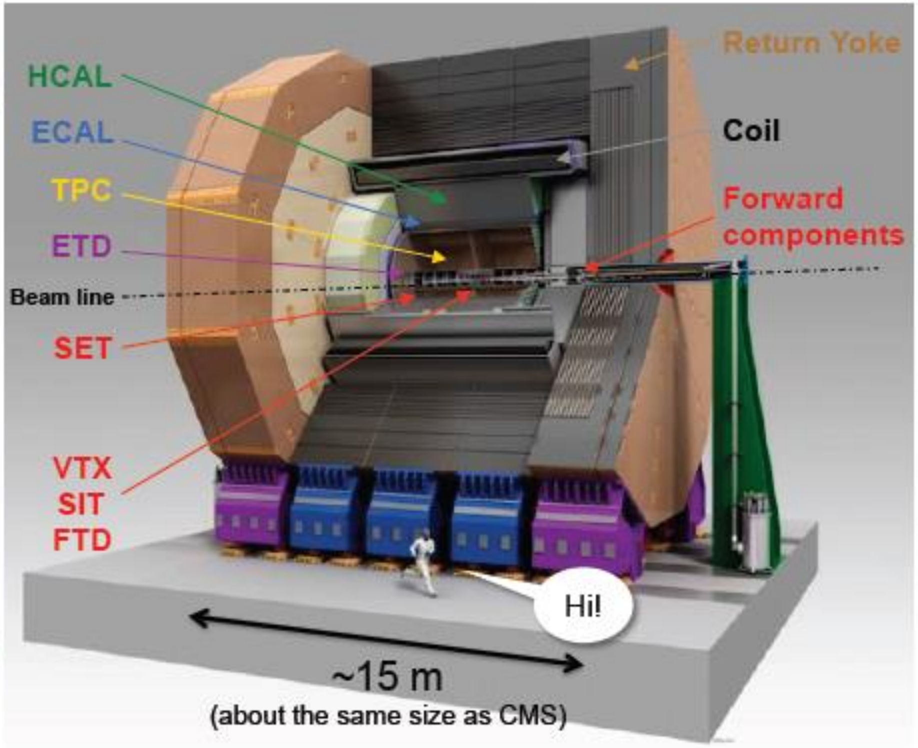


International Large Detector

ILD: optimized for particle flow

- Precision tracking & vertexing
- Highly granular calorimeters [ECAL ~0.5cm, HCAL 1~3cm]
- Large: ECAL inner radius 1.85m
- B-field: 3.5 T
- ECAL + HCAL inside solenoid

- ≈4π coverage
- Triggerless operation
- Low background (except in very forward region)

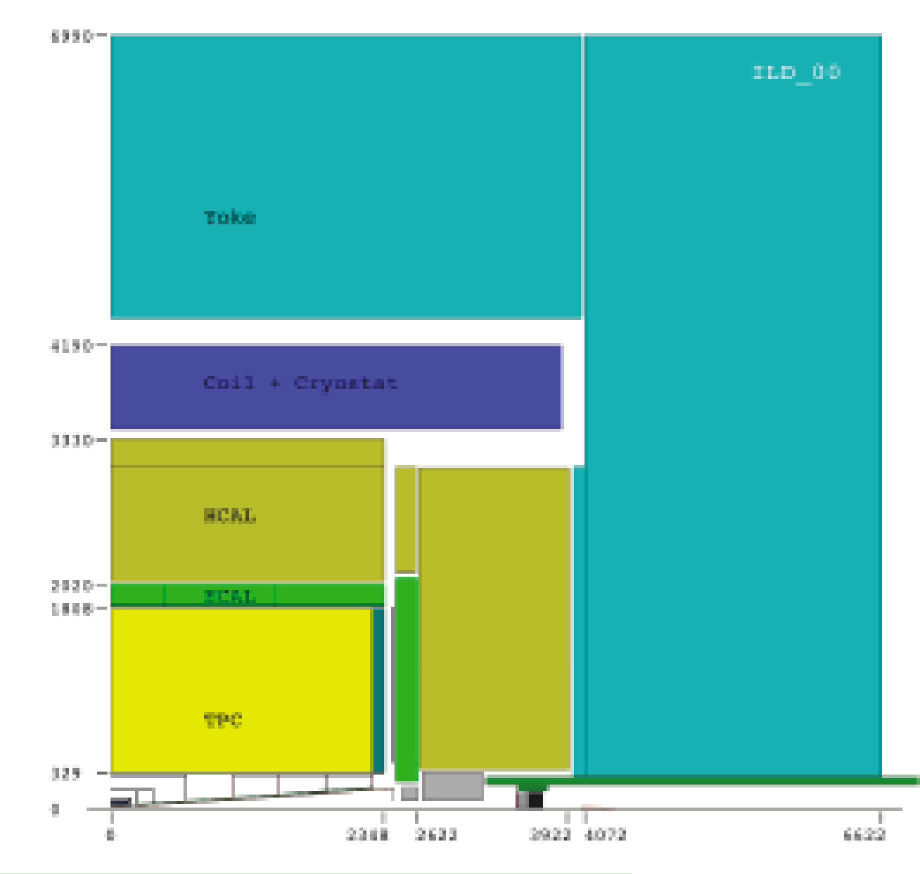


Current phase: Preparation towards a Detailed Baseline Design
DBD report due end of 2012

ILD

- **B: 3.5 T**
- **Vertex pixel detectors**
  - 6 (3 pairs) or 5 layers (no disks)
  - Technology open
- **Si-strip trackers**
  - 2 barrel + 7 forward disks

    (2 of the disks are pixel)
  - Outer and endcap of TPC
- **TPC**
  - GEM or MicroMEGAS for amp.
  - Pad (or si-pixel) readout
- **ECAL**
  - Si-W or Scint-W (or hybrid)
- **HCAL**
  - Scint-tile or (semi)Digital-HCAL (DHCAL or SDHCAL)

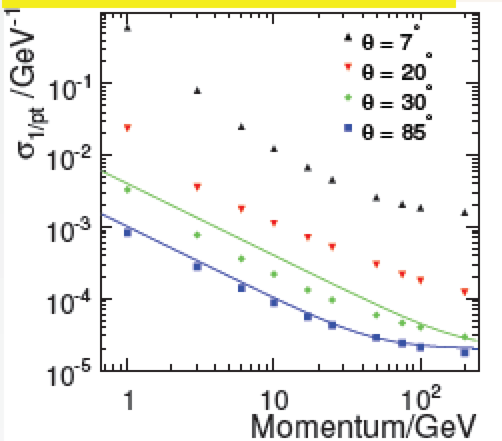


All above inside solenoid

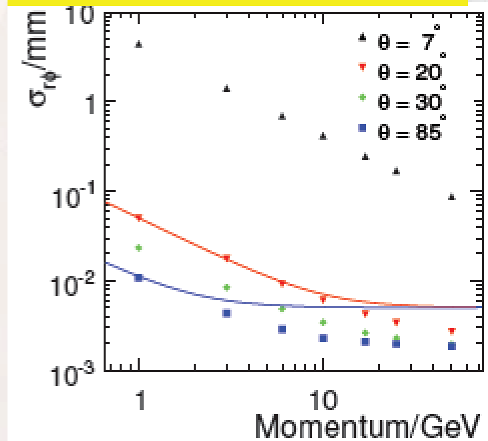
Overall Performance

* LOI performance.
To be updated for DBD.

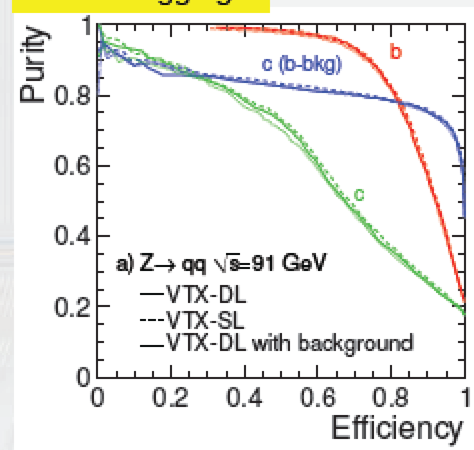
Track Momentum Resolution *



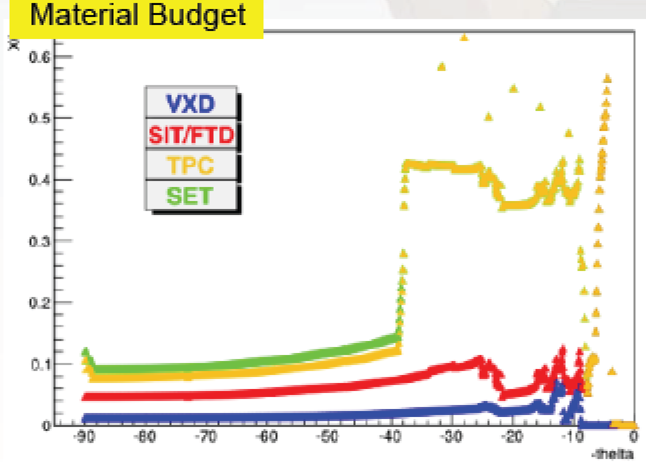
Impact Parameter Resolution *



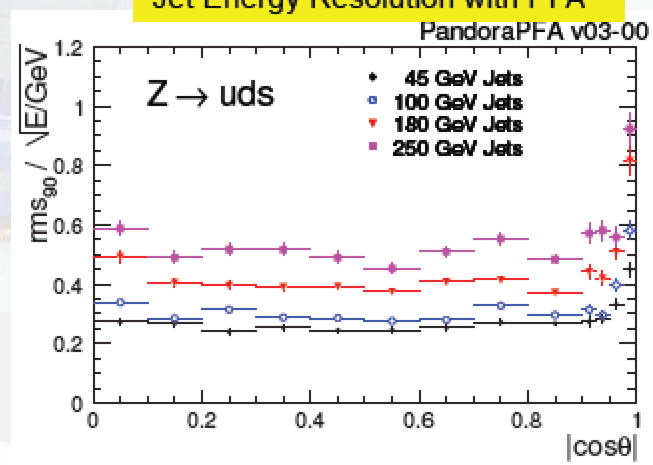
Flavor Tagging *



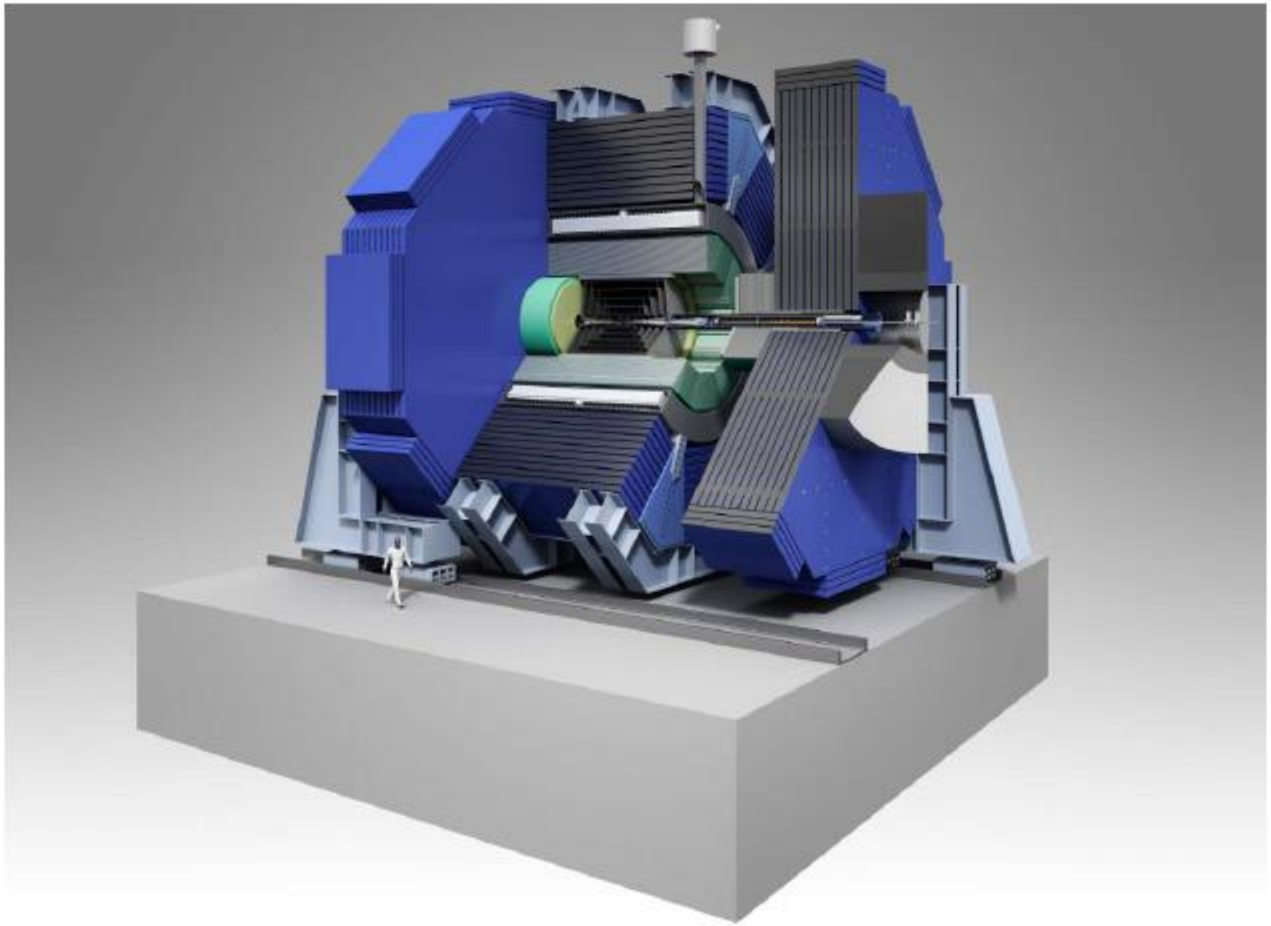
Material Budget



Jet Energy Resolution with PFA *



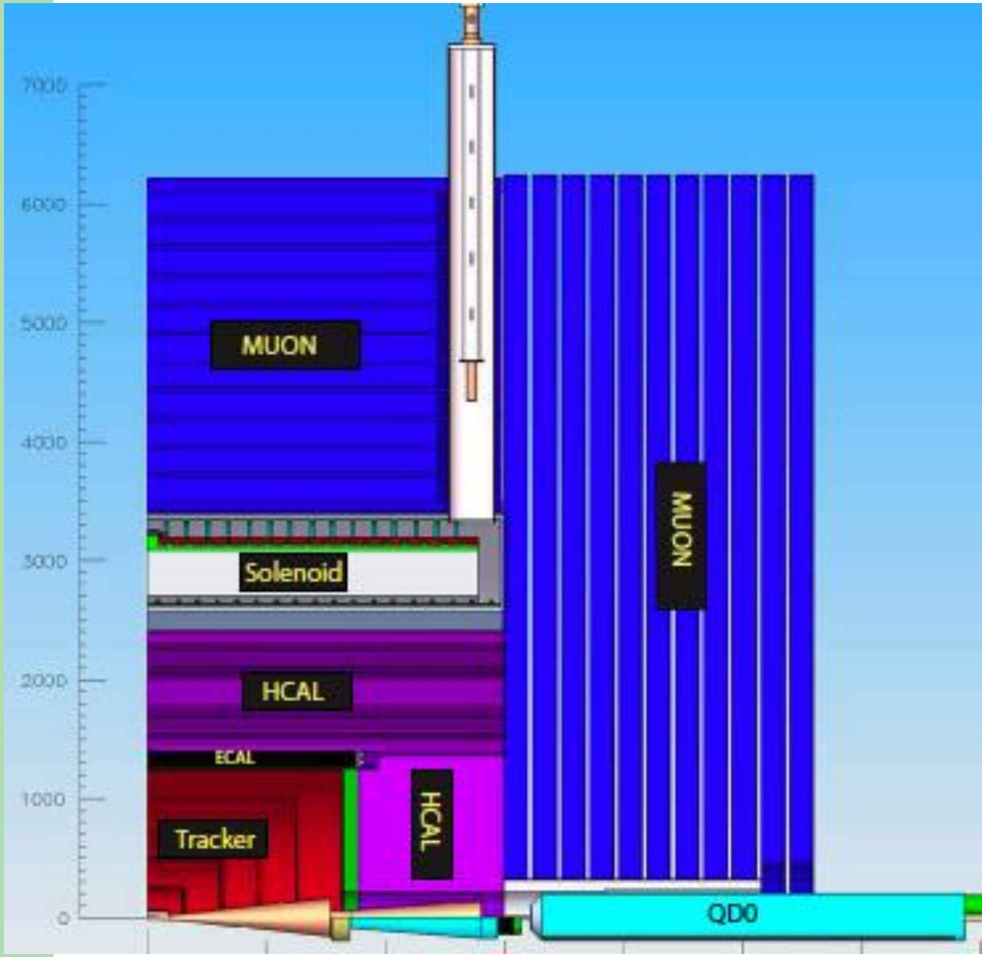
The SiD DBD Detector



SiD

- **B: 5T**
- **Vertex pixel detectors**
  - 5 barrel lyrs +
    (4 disks+3 fwd)/side
  - Technology open (incl. 3D)
- **Si-strip-trackers**
  - 5 barrel lyrs + 4 forward disks/side
- **EMCAL**
  - Si-W 30 lyrs, pixel ~$(4mm)^2$
- **HCAL**
  - Digital HCAL with RPC or GEM with $(1cm)^2$ cell
  - 40 lyrs

All above inside solenoid



The SiD DBD Detector - parameters

SiD BARREL	Technology	Inner radius	Outer radius	z max
Vertex detector	Silicon pixels	1.4	6.0	± 6.25
Tracker	Silicon strips	21.7	122.1	± 152.2
ECAL	Silicon pixels-W	126.5	140.9	± 176.5
HCAL	RPC-steel	141.7	249.3	± 301.8
Solenoid	5 Tesla	259.1	339.2	± 298.3
Flux return	Scintillator/steel	340.2	604.2	± 303.3

SiD ENDCAP	Technology	Inner z	Outer z	Outer radius
Vertex detector	Silicon pixels	7.3	83.4	16.6
Tracker	Silicon strips	77.0	164.3	125.5
ECAL	Silicon pixel-W	165.7	180.0	125.0
HCAL	RPC-steel	180.5	302.8	140.2
Flux return	Scintillator/steel	303.3	567.3	604.2
LumiCal	Silicon-W	155.7	170.0	20.0
BeamCal	Semiconductor-W	277.5	300.7	13.5

SiD Costs

- Costing is based on SiD Parametric Model
- Basic items have agreed cost (SiD, ILD and CLIC):

	agreed unit cost (US-$)	agreed error margin (US-$)
Tungsten for HCAL	105/kg	45/kg
Tungsten for ECAL	180/kg	75/ kg
Steel for Yoke	1000/t	300/t
Stainless Steel for HCAL	4500/t	1000/t
Silicon Detector	$6 / cm^2$	$2 / cm^2$

- Costs in 2008 U.S. $

M&S 315 $M
Contingency 127 $M
Labor 748 $M

- Model allows exploration of sensitivity to cost increase and detector parameter changes

Summary

- **Discovery of the higgs has focused the HE Physicists' minds towards the ILC for precision measurements to verify/probe the SM for possible deviations**
- In this scheme, the main known goals are **detailed studies of the higgs, the W-boson and the top quark**
- These ILC physics goals are precision oriented, needing detectors that push the envelope of current state-of-the-art
- Thus the proposed ILC detectors are characterized by **unprecedented high resolutions implying highly segmented, dense-readout detectors**
- **Low material budgets** needed to minimize unwanted interactions with dead material. Very light-weight materials are used to achieve this goals
- **ILD and SiD** are the two ILC detectors with Detailed Baseline Designs

Possible ILC Timeline

- July 2013
  - Non-political evaluation of 2 Japanese candidate sites complete, followed by down-selecting to one **(DONE!!)**
- End 2013
  - Japanese government announces its intent to bid
- 2013~2015
  - Inter-governmental negotiations
  - Completion of R&Ds, preparation for the ILC lab.
- ~2015
  - Inputs from LHC@14TeV, decision to proceed
- 2015~16
  - Construction begins (incl. bidding)
- 2026~27
  - Commissioning

THANK YOU!

Preamble: LC Beginnings in India…

- Phenomenological work had been done for quite some time… Rohini & others…

- Date: Fri, 11 Dec 1998 15:44:14 +0530 (IST)
- From: Atul Gurtu <gurtu@tifr.res.in>
- To: Prof. Rohini M. Godbole <rohini@cts.iisc.ernet.in>, dproy@theory.tifr.res.in
- Cc: PAC for DAE98 Symposium <adatta@juphys.ernet.in>, gavai@tifr.res.in, kaul@imsc.ernet.in, Prof. J.M. Kohli <jmkohli%phys@puniv.chd.nic.in>, Dr. Manjit Kaur <manjit%phys@puniv.chd.nic.in>, mukhi@tifr.res.in, Naba K Mondal <nkm@tifr.res.in>, pijush@milkyway.gsfc.nasa.gov, Saurabh D. Rindani <saurabh@prl.ernet.in>, Prof S.N. Ganguli <ganguli@tifr.res.in>
- Subject: LC

Dear Rohini,

The Programme Advisory committee and the Convenor of the 1998 DAE symposium at Chandigarh have kindly agreed to my request for a session on possible Indian participation in the Linear Collider programme…

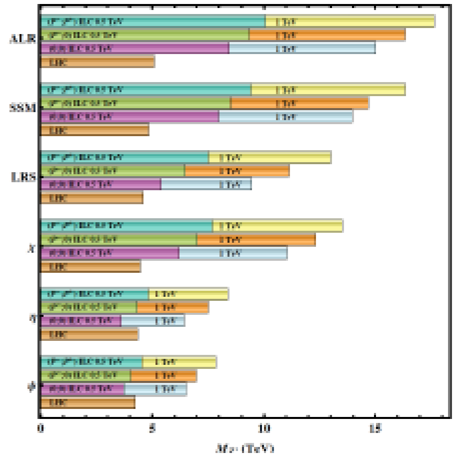
It is clear that both physics as well as detector issues have to be addressed during the next 2 years and so it would be desirable to have a core group of say 7-8 persons to sort of coordinate the activity.

…. Atul

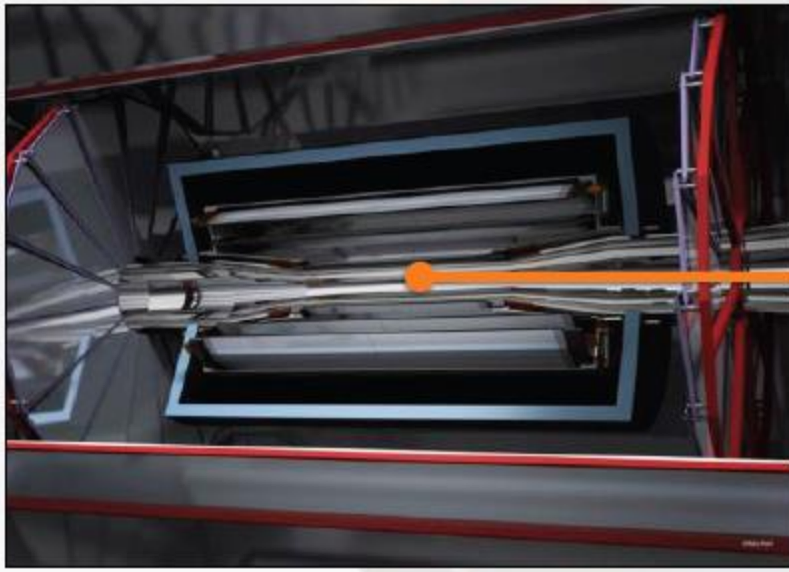
- **India-ILC Forum….**
- **And the ILC program has taken a much longer time to mature than imagined in 1998!!**
- **Here we are today getting into something serious *vis a vis* ILC**

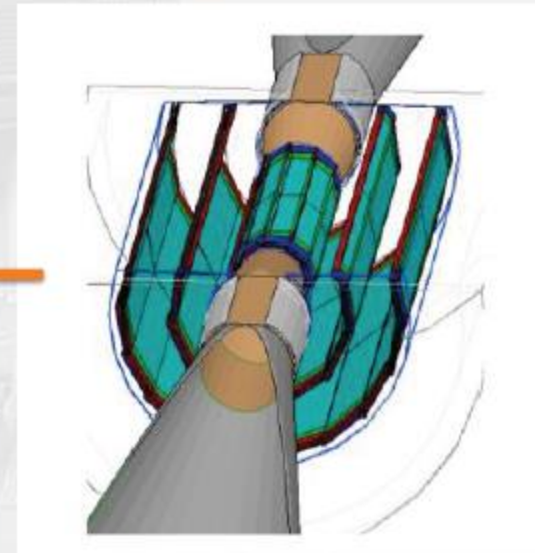
coupling	error $\times 10^{-4}$	
	$\sqrt{s} = 500$ GeV	$\sqrt{s} = 800$ GeV
C,P-conserving, $SU(2) \times U(1)$ relations:		
Δg_1^Z	2.8	1.8
$\Delta \kappa_\gamma$	3.1	1.9
λ_γ	4.3	2.6
C,P-conserving, no relations:		
Δg_1^Z	15.5	12.6
$\Delta \kappa_\gamma$	3.3	1.9
λ_γ	5.9	3.3
$\Delta \kappa_Z$	3.2	1.9
λ_Z	6.7	3.0
not C or P conserving:		
g_5^Z	16.5	14.4
g_4^Z	45.9	18.3
$\tilde{\kappa}_Z$	39.0	14.3
$\tilde{\lambda}_Z$	7.5	3.0

Z'



Vertex Detector

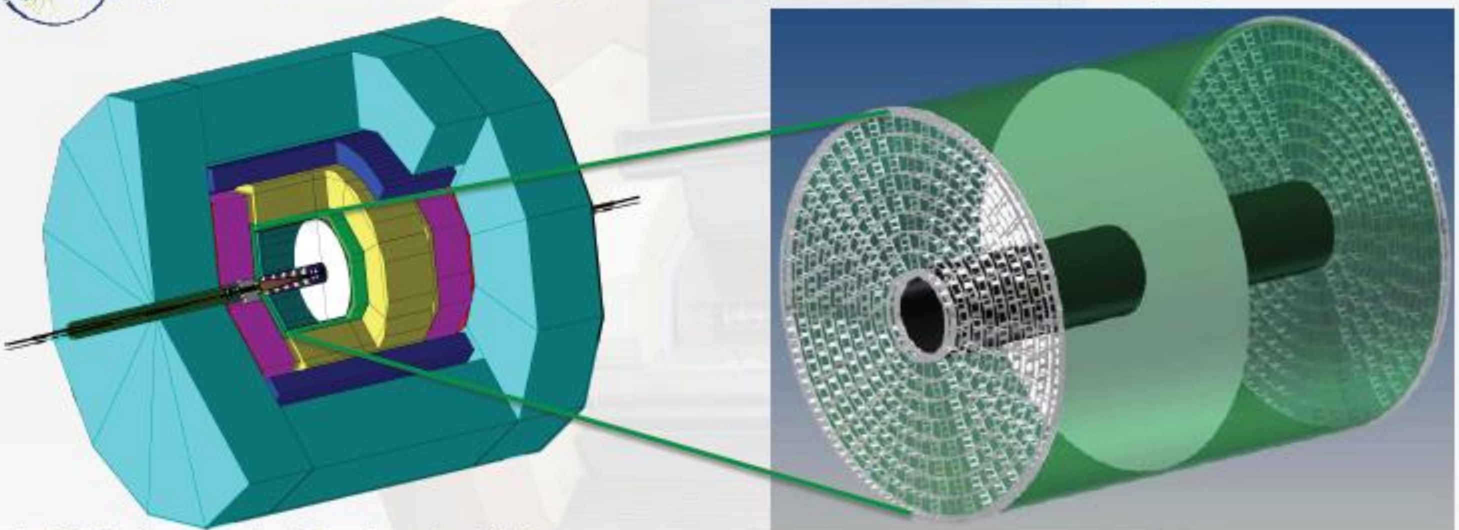




- Key to jet flavor tagging via vertex reconstruction
- 3 double layers, r_{min}=16 mm, 3 μm point resolution
- Impact parameter resolution: $\sigma_b < 5 \oplus 10/p\beta \sin^{3/2}\theta$
- Main challenges: beam backgrounds, power consumption, **material budget** (0.2-0.3% X_0 per layer)
- 3 options: **CMOS**, **FPCCD**, DEPFET

Talk by S. Rummel

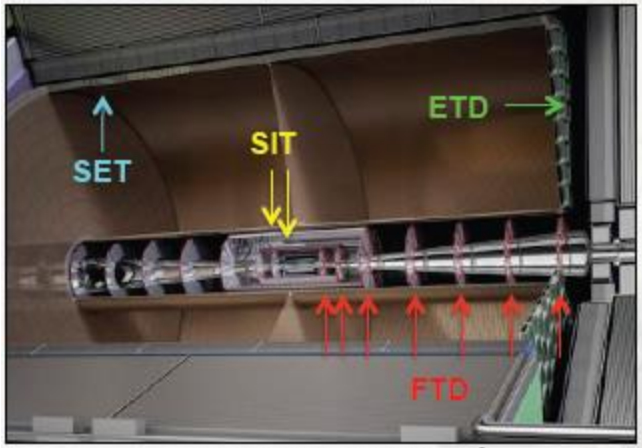
Time Projection Chamber (1)

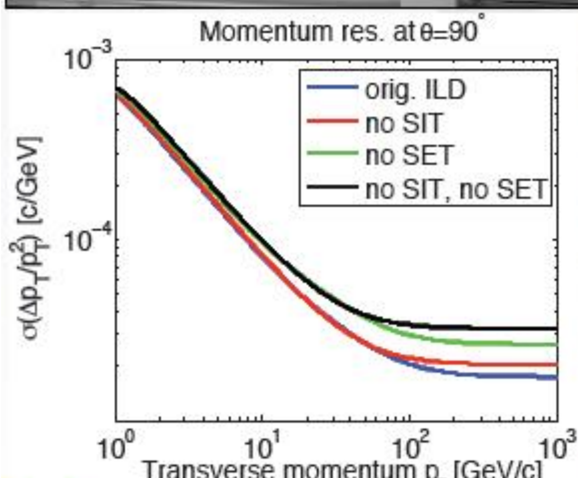


- TPC is the central tracker for ILD
  - Large number of 3D points → continuous tracking
- Low material budget inside the calorimeters important for PFA
  - Barrel: ~5% X_0
  - Endplates: ~25% X_0
- Two options:
  - **GEM:** 1.2x5.4 mm^2 pads, 28 pad rows x 176-192 pads/row
  - **Micromegas:** 3x7 mm^2 pads, 24 pad rows x 72 pads/row
- Alternative: **pixel** read out with pixel size ~55x55 μm^2

Requirements
Momentum resolution:
$\delta(1/p_T) < 9\times10^{-5}$ GeV
Spatial resolution:
$\sigma(r\phi) < 100$ μm
$\sigma(z) < 500$ μm
97% tracking eff. for p_T>1 GeV
dE/dx resolution ~5%

Silicon Tracking





Extra silicon trackers provide:

- Better angular coverage (FTD: ~0.15 rad)
- Improve momentum/position resolution
- Time stamping (20-40 ns for beam bunch)
- Calibration & alignment

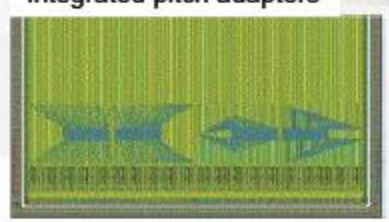
LHC-LC synergy in R&D:

- $10x10cm^2$ strip sensor for SIT, SET, ETD
- Edgeless sensors, integrated pitch adapters
- New on-detector electronics, support architecture
- Embedded sensors

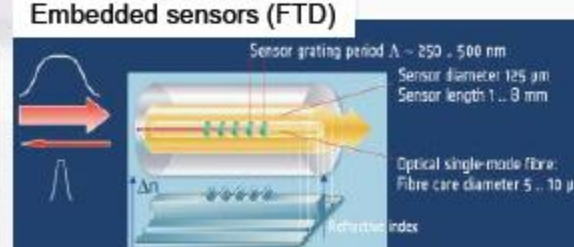
Challenges:

- **Material budget**, low power consumption, high spatial resolution

Integrated pitch adapters



Embedded sensors (FTD)



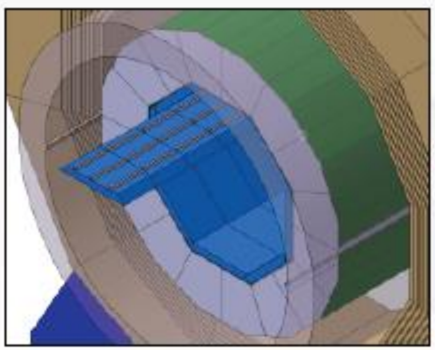
Calorimeters

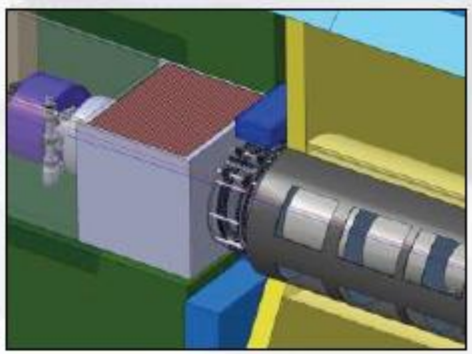
See also: talk by T. Yoshioka (ECAL+HCAL)

ECAL
- Tungsten as absorber material
- Silicon and/or scintillator as active material

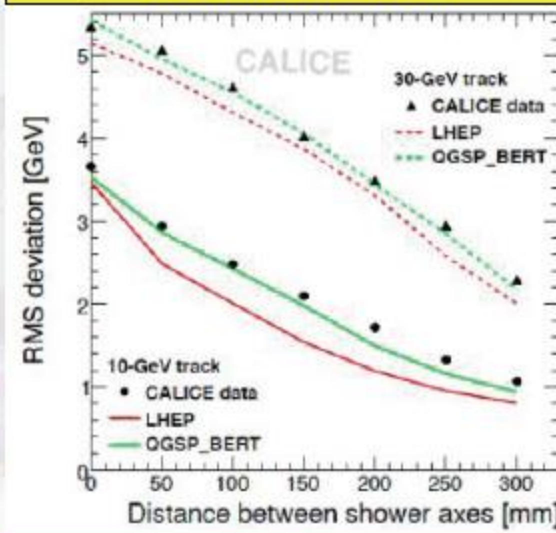
HCAL
- Steel as absorber material
- Analog: scintillator tiles read-out by SiPM
- Semi-digital / (Digital) RPCs

Forward Calorimeters
- Luminosity Calorimeter (LumiCal)
- Beam Calorimeter (BeamCal)
- Forward hadron calorimeter (LHCAL)





Particle Flow with test beam
AHCAL + SiECAL
10 GeV neutral + 10/30 GeV track
[JINST 6, P07005 (2011)]



Good agreement between data and simulation

ECAL

Sampling calorimeter with tungsten as absorber.

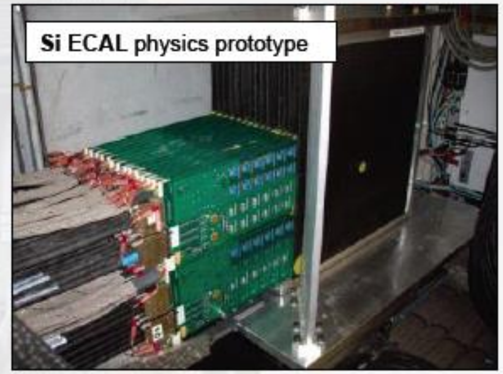
→ Compact design, 24 X_0 within 20 cm

→ Longitudinal segmentation: ~30 layers

Options for active layers:

- **Silicon PIN diodes** (0.5 x 0.5 cm^2)
- **Scintillator strips** (0.5 x 4.5 cm^2), MPPC readout
- Silicon/scintillator **hybrid**

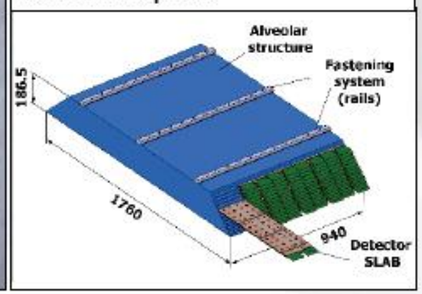
Basic performance established; transition from physics prototype to technological prototype ongoing



Si ECAL physics prototype

Sci ECAL physics prototype

Sci ECAL technological prototype under development



Si ECAL technological prototype

* Multi-Protocol Communications Controller

HCAL

Absorber material: **steel**. Active material options:

- **Analog HCAL:** 3x3 cm^2 scintillator with SiPM
- **Semi-Digital/(Digital) HCAL:** 1x1 cm^2 glass RPC

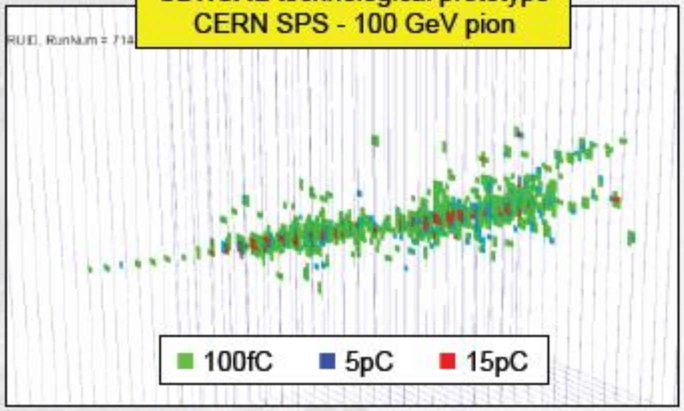
Both have constructed 1 m^3 sized prototypes and exposed them to test beams.

AHCAL: physics prototype with external electronics built. Completed data taking and analysis, validated the simulation and tested first technological demonstrator units.

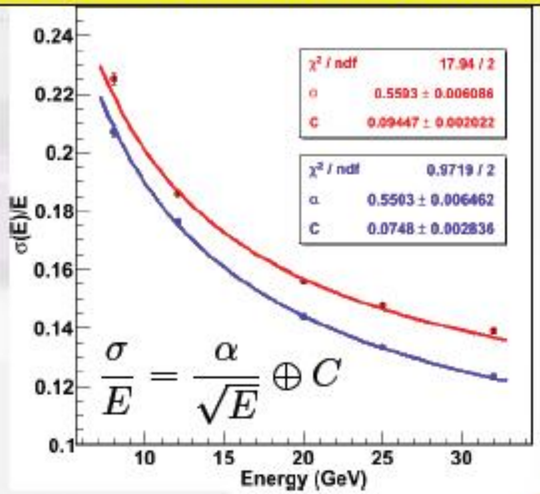
SDHCAL: technological prototype with embedded electronics and power-pulsing built. Data taking is ongoing, first look into data is encouraging.

DHCAL: test beams with physics prototype → proof of principle demonstrated.

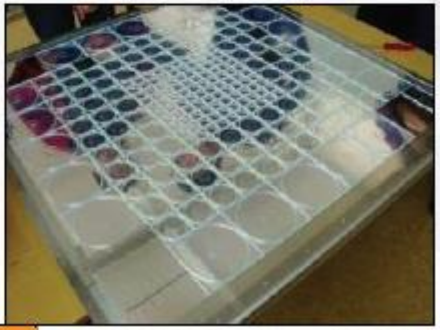
SDHCAL technological prototype
CERN SPS - 100 GeV pion



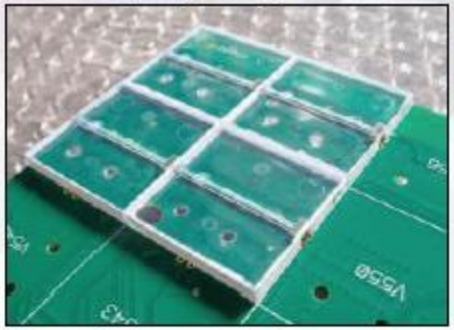
DHCAL test beam: pion energy resolution



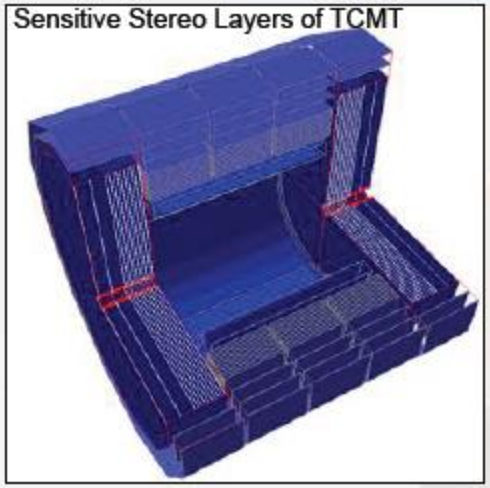
AHCAL physics prototype



AHCAL tiles and SiPMs for technological prototype



Tail Catcher / Muon Tracker (TCMT)



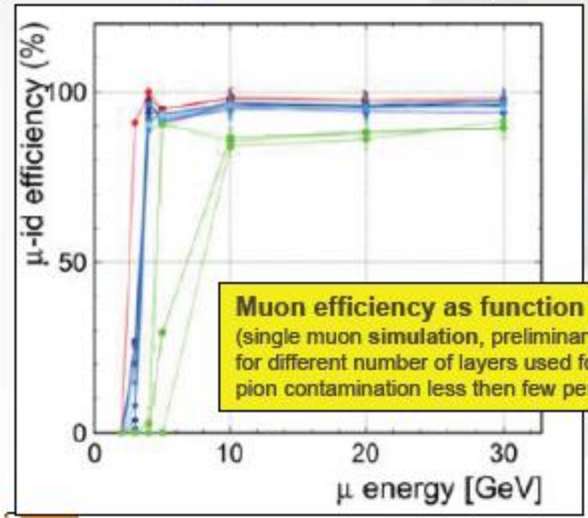
Main tasks:

- Identification and tracking of muons
- Measure the tail of showers escaping the HCAL

Sensitive Detectors:

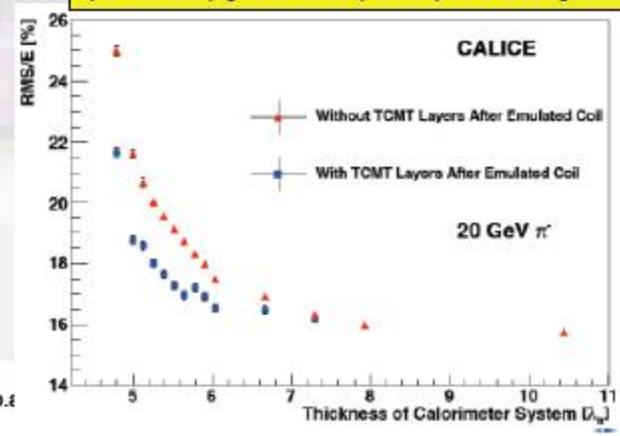
Main option: Scintillation Stereo Strips (10 mm thick, 30 mm wide, max 200 mm long) with WLS and SiPM readout:

- **Barrel:** 14 layers (1st in front of Yoke, 10 with Iron filter 100 mm thick, last 3 with Iron filter 560 mm thick)
- **Endcap:** 12 layers (first 10 with Iron filter 100 mm thick, last 2 with Iron filter 560 mm thick)
- **Cryostat:** 2 additional layers



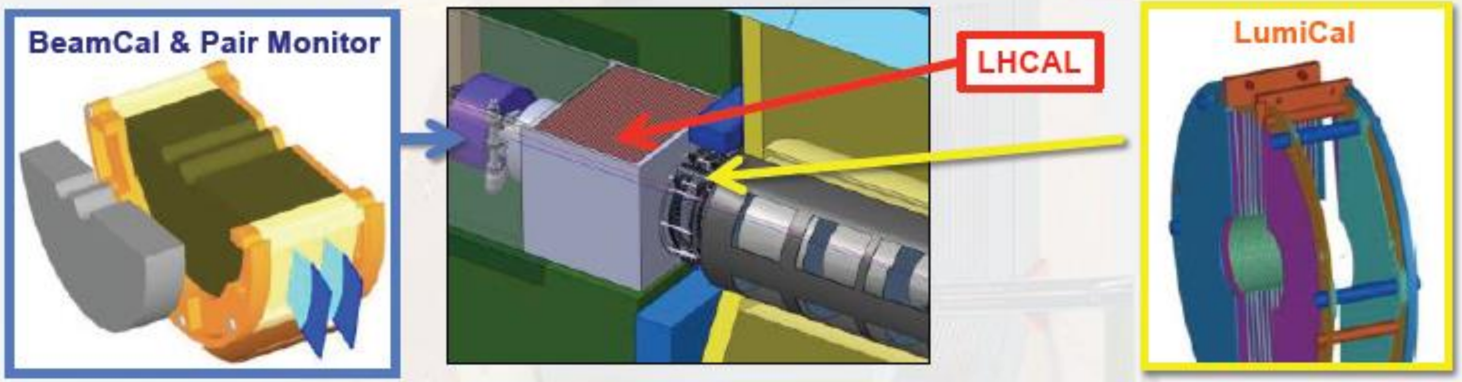
Muon efficiency as function of energy
(single muon simulation, preliminary)
for different number of layers used for identifications
pion contamination less then few percent

Resolution improvement with TCMT
(CALICE) [JINST 7 (2012) P04015]



Forward Calorimeters

Poster by O. Novgorodova
"FCAL Test Beam Results"



Forward Calorimeters

- Luminosity measurement
- Hermeticity: electrons + pions down to ~5 mrad (**LumiCal + LHCAL**)
- Assisting beam tuning (fast feedback of BeamCal data to machine)

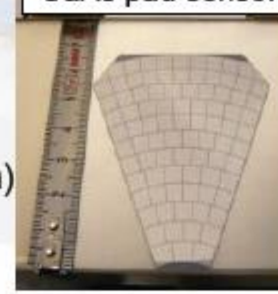
Challenges:

- Radiation hardness (BeamCal), high precision (LumiCal) and fast readout (both)

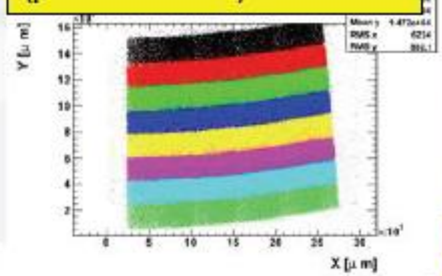
Baseline:

- Sampling calorimeter with tungsten absorber disc (3.5 mm thick)
- LumiCal: Si readout
- BeamCal: GaAs

GaAs pad sensor

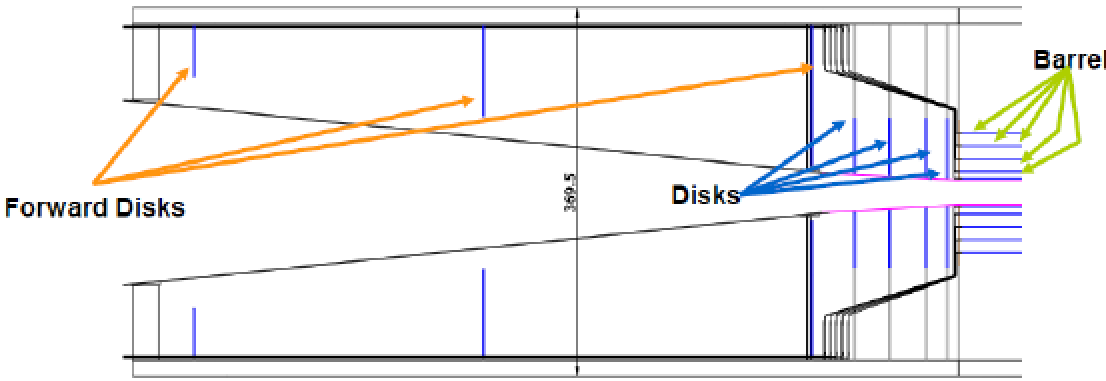


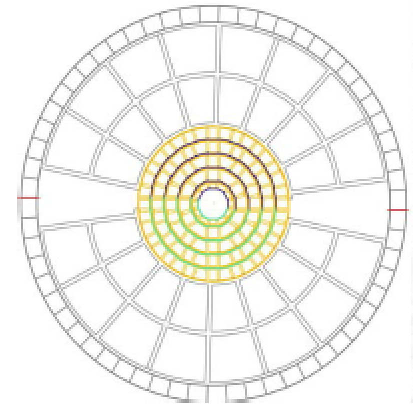
Occupancy of beam particles on a fully assembled sensor plane (pads color-coded)



The SiD DBD Detector

Vertex Detector



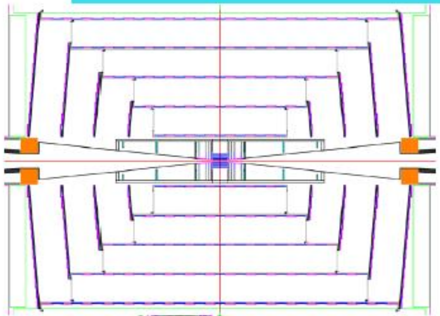


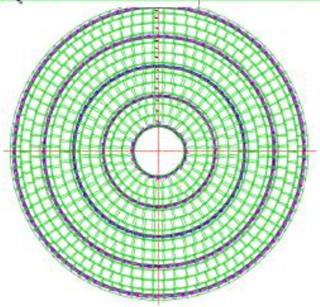
Split-cylinder support structures

- Requirements
  - < 5 µm hit resolution
  - ~ 0.1 % X_0 per layer
  - < 130 µW/mm^2
  - Single bunch timing resolution

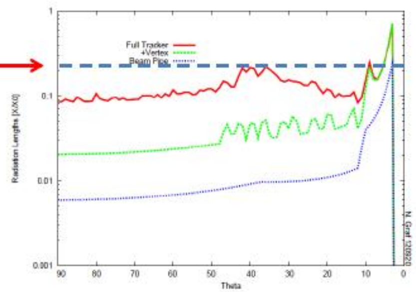
- ILC bunch timing and low radiation environment allows very light, low power vertex system
- Pulsed power/DC-DC conversion
- Forced dry air cooling

Silicon Tracking





Below 20% X_0 for whole VTX/TRK system



Silicon Tracking

ILC Physics requires:

- excellent momentum resolution over wide P_T range
- high point precision, mechanical stability for high P_T
- low material budget for low P_T
- high efficiency for all momenta/angles

-> Performance goals

Parameter	Design Goal
coverage	hermetic above $\theta \sim 10^\circ$
momentum resolution $\delta(1/p_T)$	$\sim 2-5\times10^{-5}/GeV/c$
material budget	$\sim 0.10-0.15X_0$ in central region
	$\sim 0.20-0.25X_0$ in endcap region
hit efficiency	$>99\%$
background tolerance	Full efficiency at $10\times$ expected occupancy

Calorimetry

SiD Calorimetry is designed for the PFA approach:

- ECAL and HCAL must be "imaging": high granularity
- Small Moliere radius for ECAL – separate e^-/charged h
- Minimize gap between tracker and ECAL
- Sufficient overall depth

- SiD ECAL
  - Tungsten absorber
  - 20+10 layers
  - $20 \times 0.64 + 10 \times 1.30\ X_0$
- Baseline Readout using
  - 5x5 mm^2 silicon pads

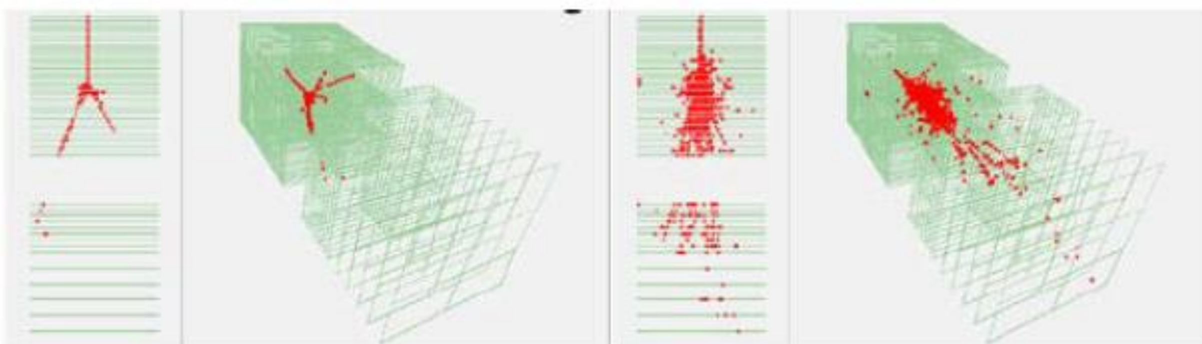
- SiD HCAL
  - Steel Absorber
  - 40 layers
  - 4.5 λ_i
- Baseline readout
  - 1x1 cm^2 RPCs

Hadronic Calorimetry

Baseline: RPC DHCAL

Test beam with 1 m^3 stack

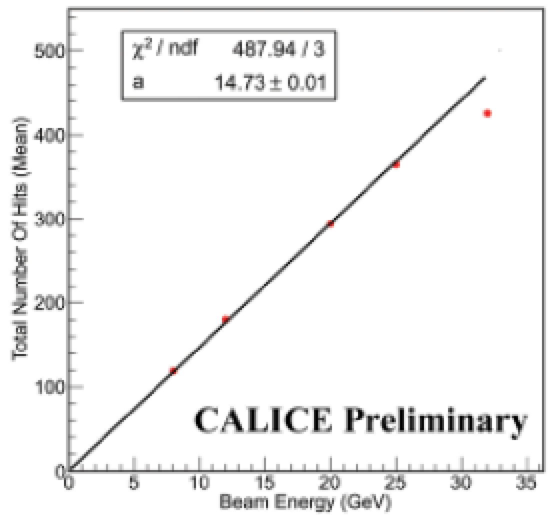
Largest Calorimeter by channel count

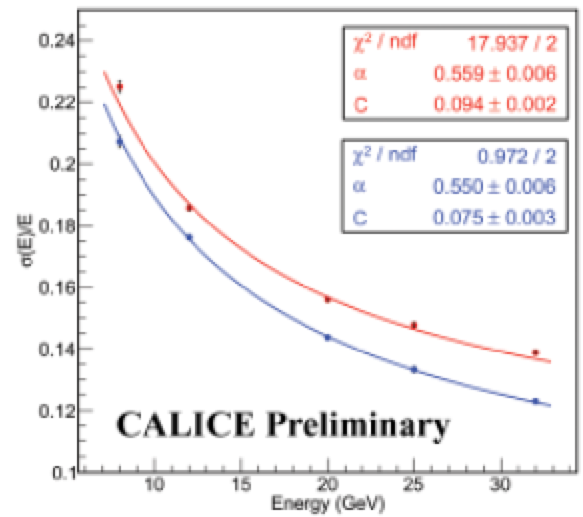


8 GeV pion shower 120 GeV proton shower.

Hadronic Calorimetry

Baseline: RPC DHCAL

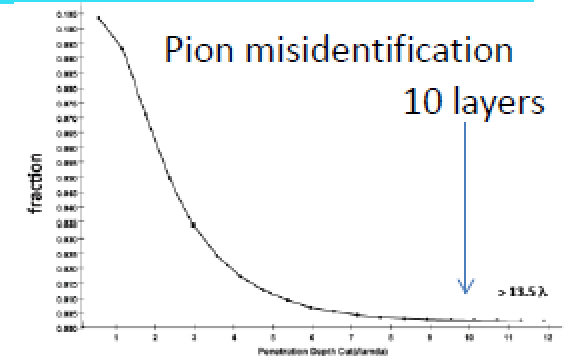


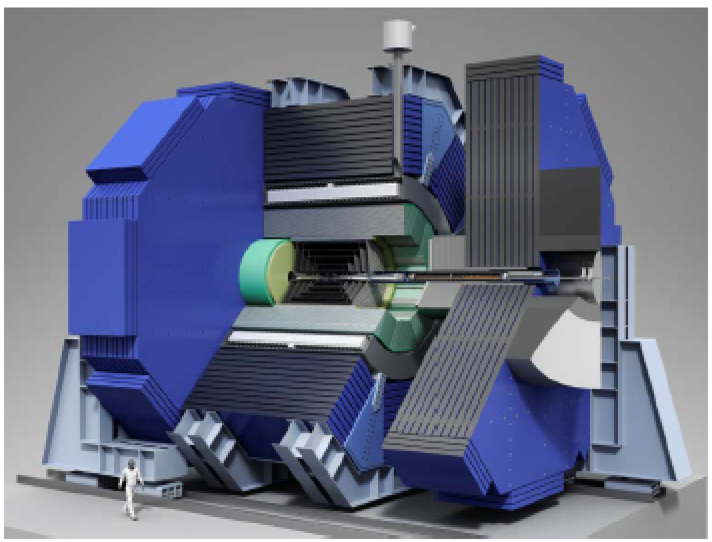


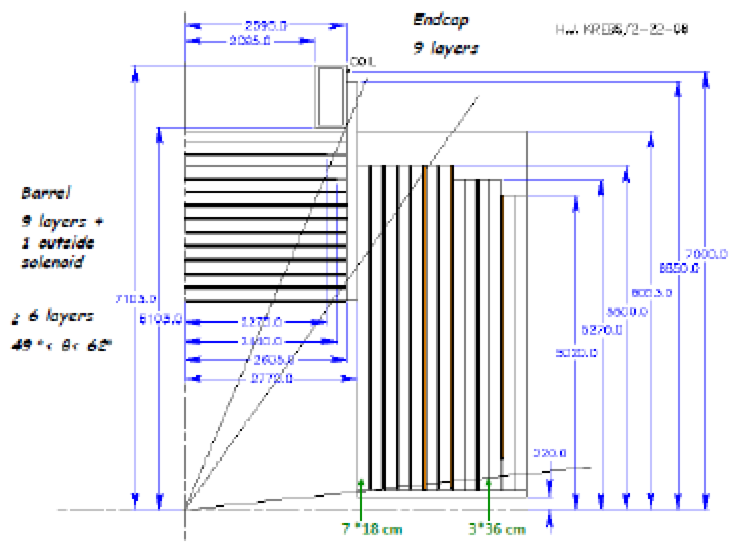
- The RPC technology is a great candidate for the readout of a highly segmented calorimeter.
- The dark rate in the DHCAL is very low
- The response is linear up to about 30 GeV/c.

Muon System

- Muon identification/hadron rejection
- Flux return
- Tail catcher for calorimeter system
- Low rates/large area





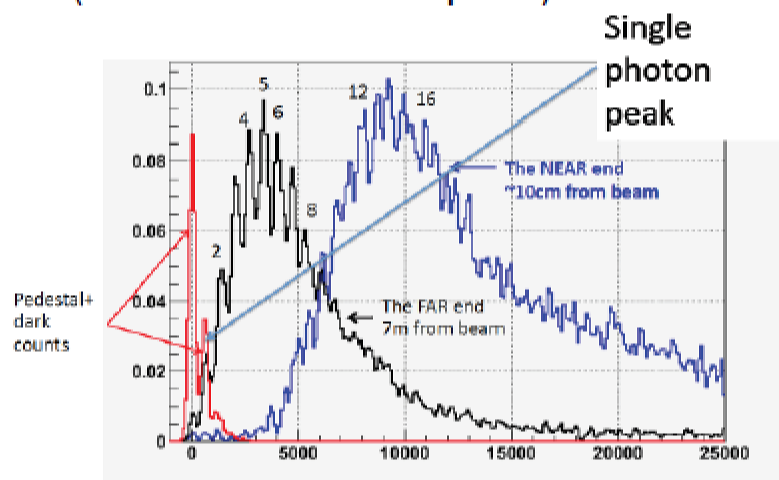


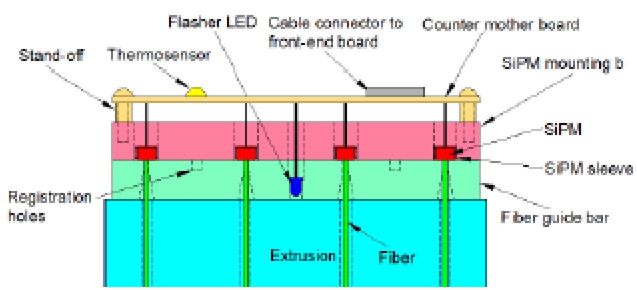
Muon System

Major change of baseline vs. LOI:

Scintillating strips/wavelength shifting fibers

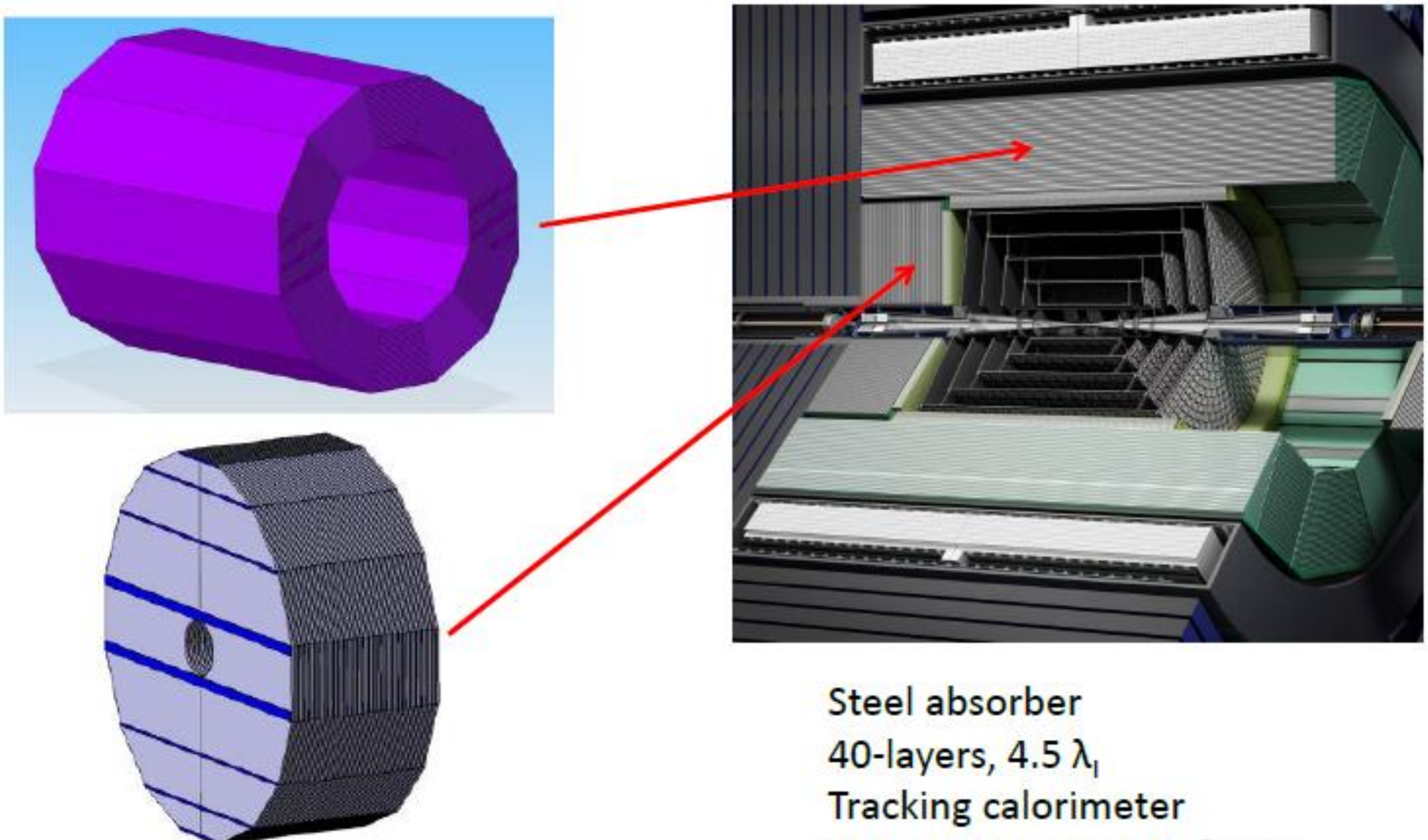
(RPC remains as an option)





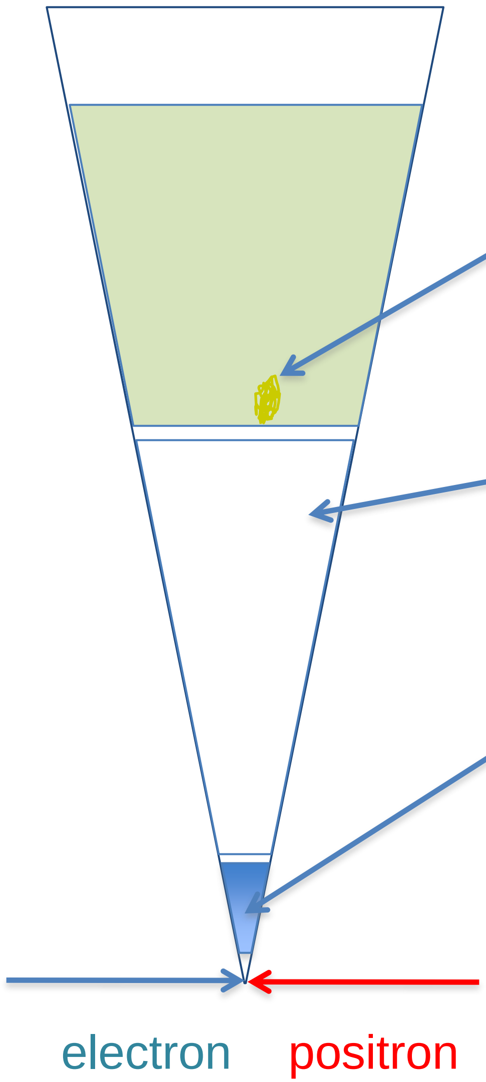
Development of system to position SiPM at the end of a fiber

Hadronic Calorimetry



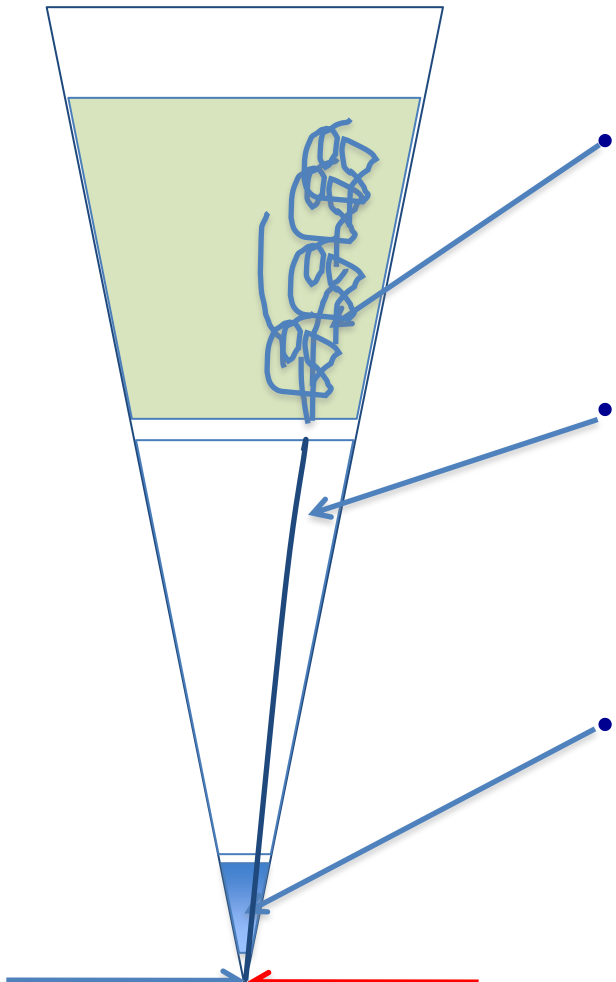
Steel absorber
40-layers, 4.5 λ_I
Tracking calorimeter
RPC Baseline. 1x1 cm^2 cells

Photon



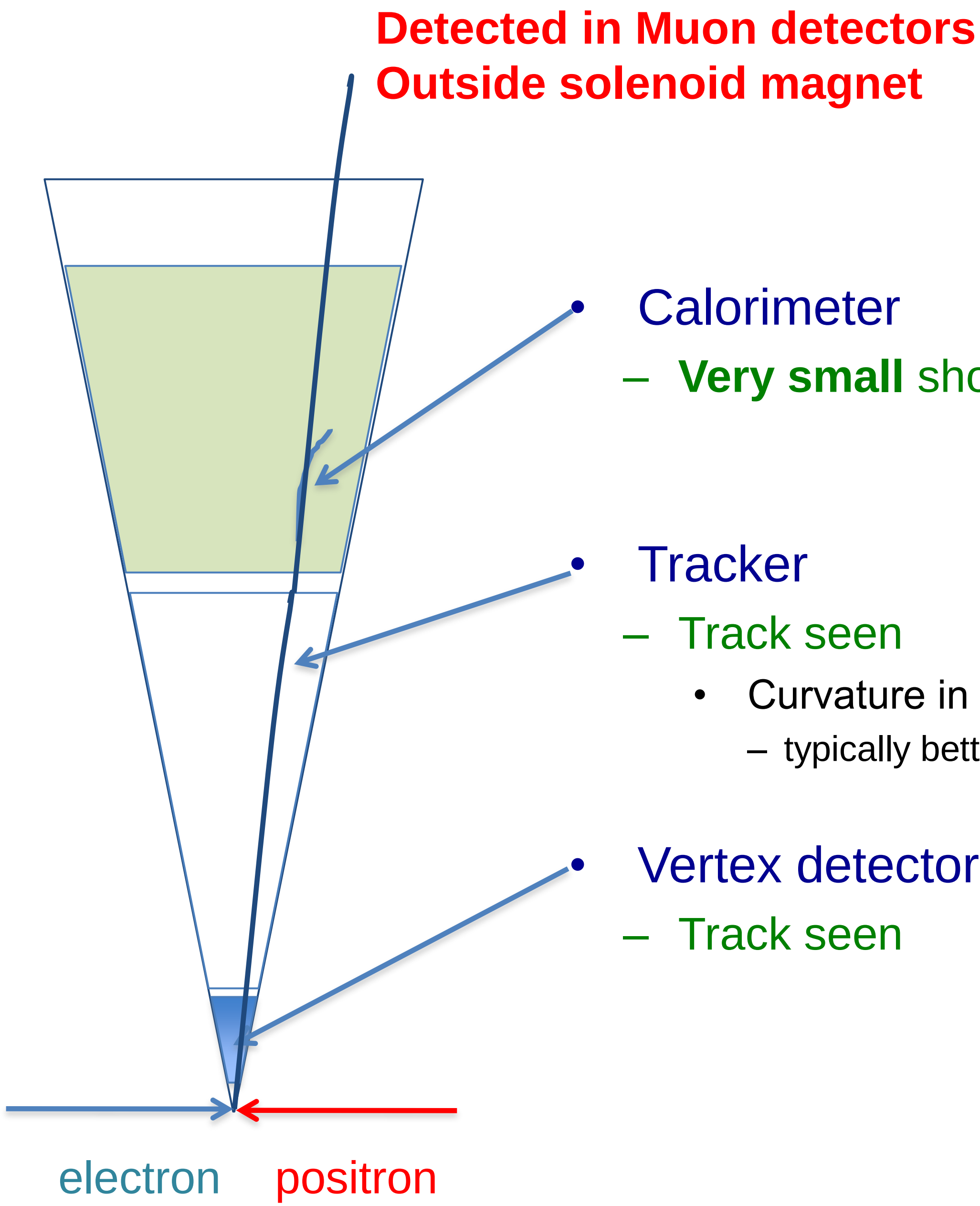
- Calorimeter
  - small shower
- Tracker
  - No track
- Vertex detector
  - No track

Electron

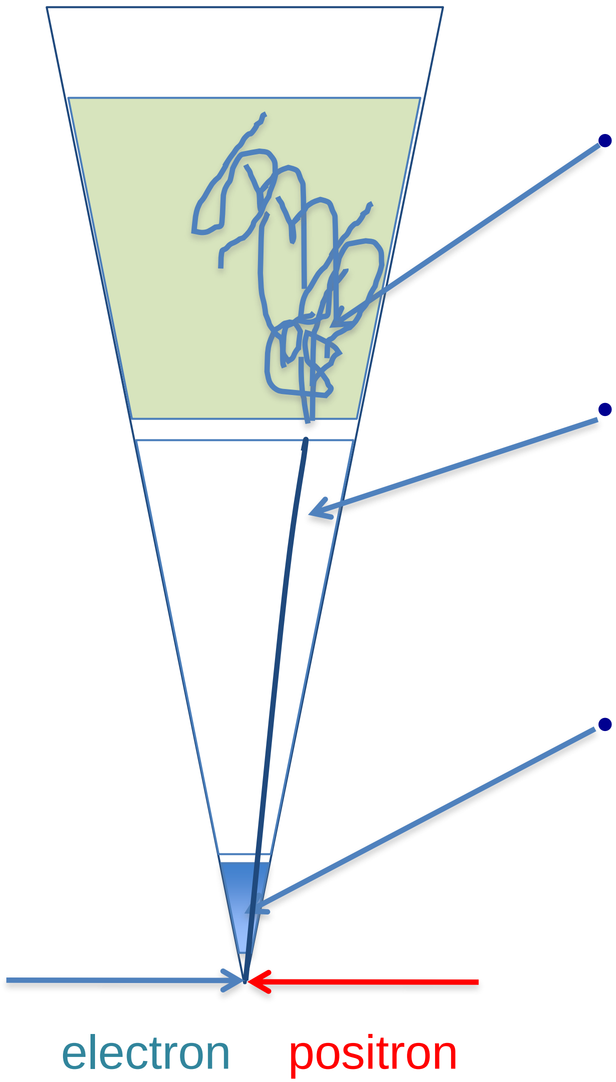


- Calorimeter
  - **Small dense** shower
- Tracker
  - Track seen
    - Curvature in magnetic field → momentum
      - typically better resolution than showers
- Vertex detector
  - Track seen

Muon



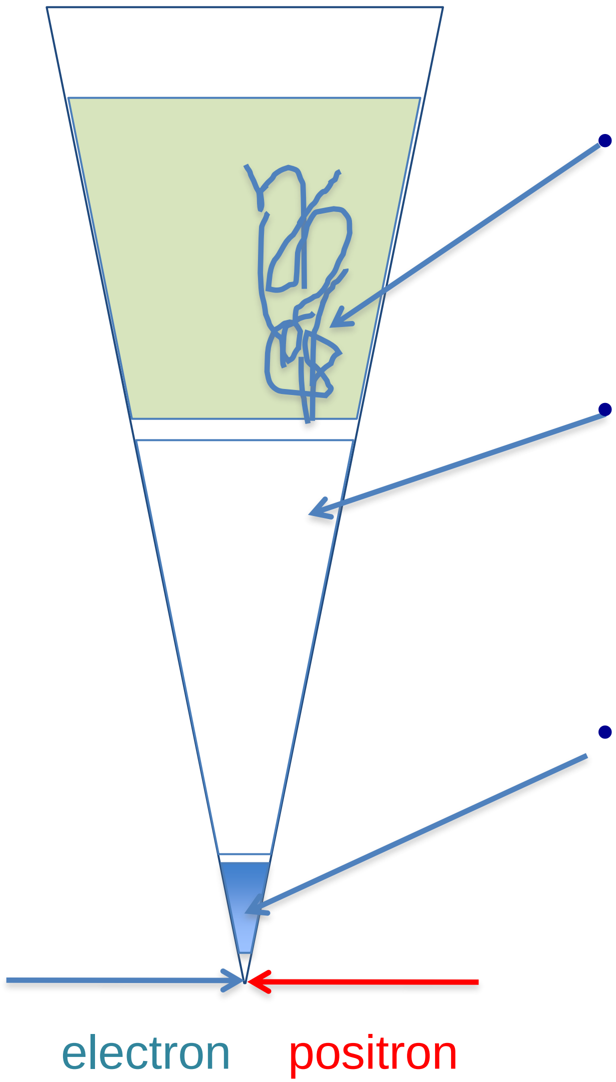
- Calorimeter
  - **Very small** shower
- Tracker
  - Track seen
    - Curvature in magnetic field → momentum
      - typically better resolution than showers
- Vertex detector
  - Track seen



Charged hadrons (e.g. proton/pion…)

- Calorimeter
  - **Large, spread out** shower
- Tracker
  - Track seen
    - Curvature in magnetic field → momentum
      - typically better resolution than showers
- Vertex detector
  - Track seen

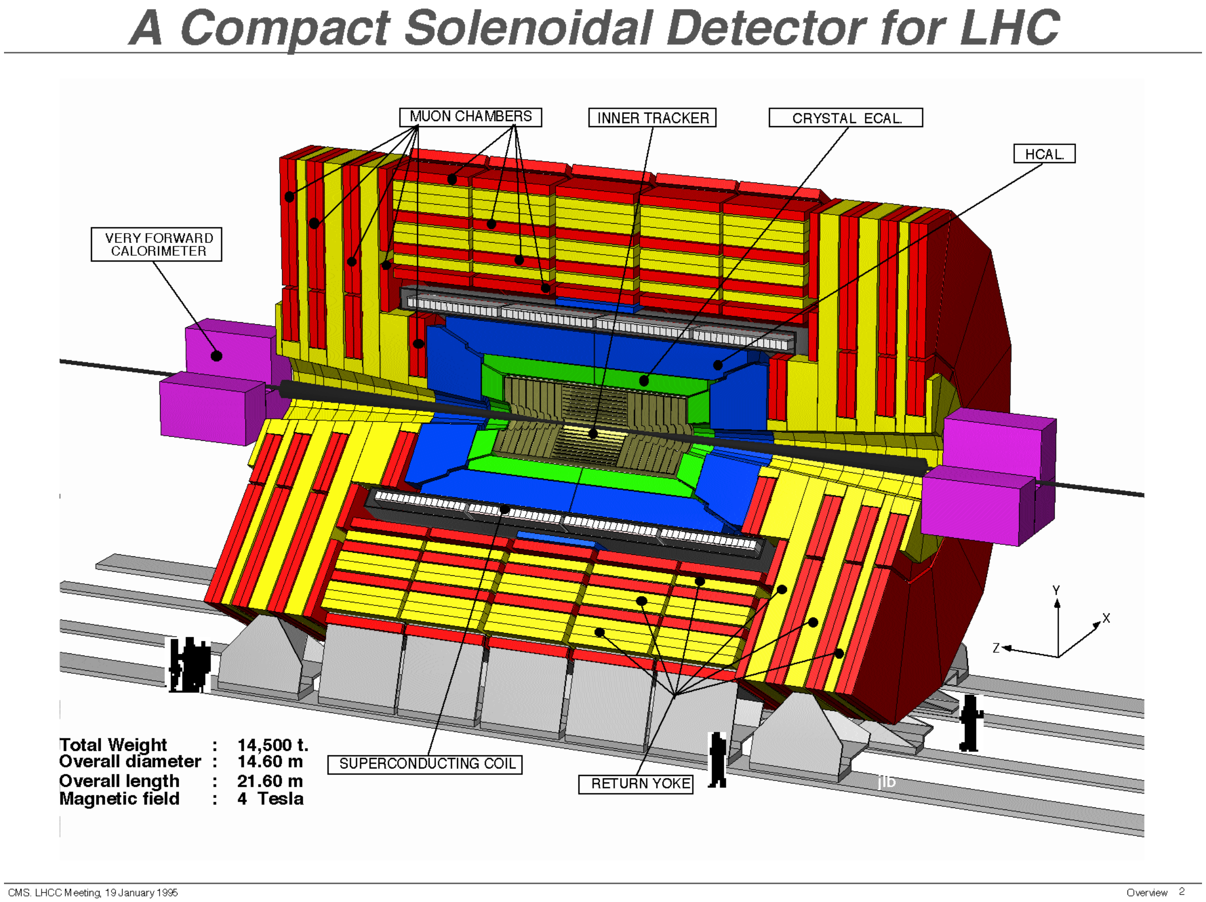
Neutral hadrons (e.g. neutron)

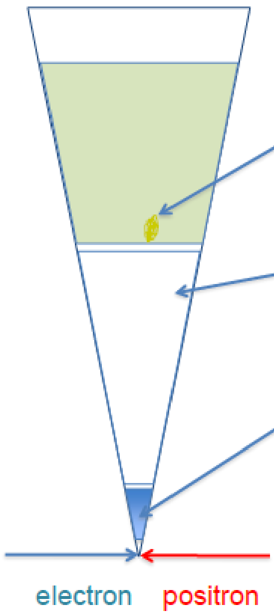


- Calorimeter
  - Large shower
- Tracker
  - No track
- Vertex detector
  - No track

Structure of modern HEP detectors

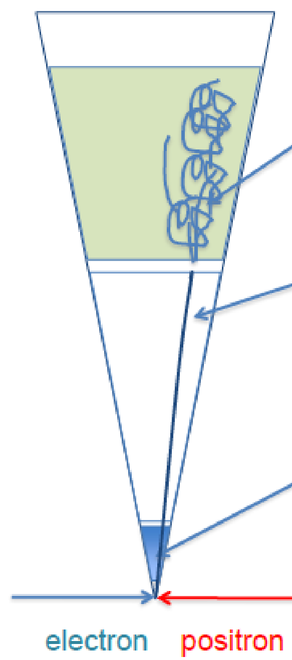
- Barrel region: concentric cylinderical layers of detectors
- End regions: similar layers in Z direction





Photon

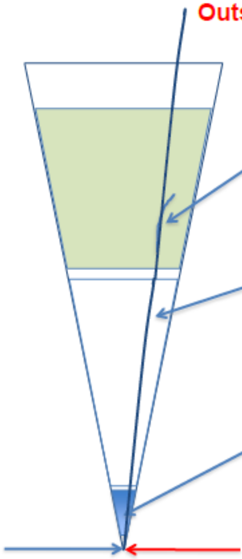
- Calorimeter
  - small shower
- Tracker
  - No track
- Vertex detector
  - No track



Electron

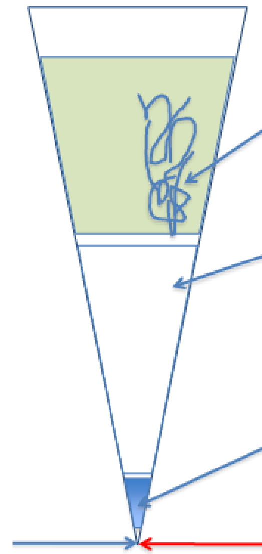
- Calorimeter
  - **Small dense** shower
- Tracker
  - Track seen
    - Curvature in magnetic field → momentum
      - typically better resolution than showers
- Vertex detector
  - Track seen

Muon



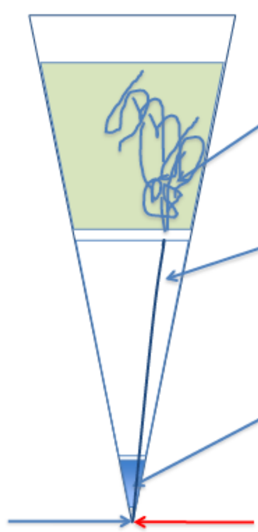
- Calorimeter
  - **Very small** shower
- Tracker
  - Track seen
    - Curvature in magnetic field → momentum
      - typically better resolution than showers
- Vertex detector
  - Track seen

Neutral hadrons (e.g. neutron)



- Calorimeter
  - Large shower
- Tracker
  - No track
- Vertex detector
  - No track

Charged hadrons (e.g. proton/pion…)



- Calorimeter
  - **Large, spread out** shower
- Tracker
  - Track seen
    - Curvature in magnetic field → momentum
      - typically better resolution than showers
- Vertex detector
  - Track seen