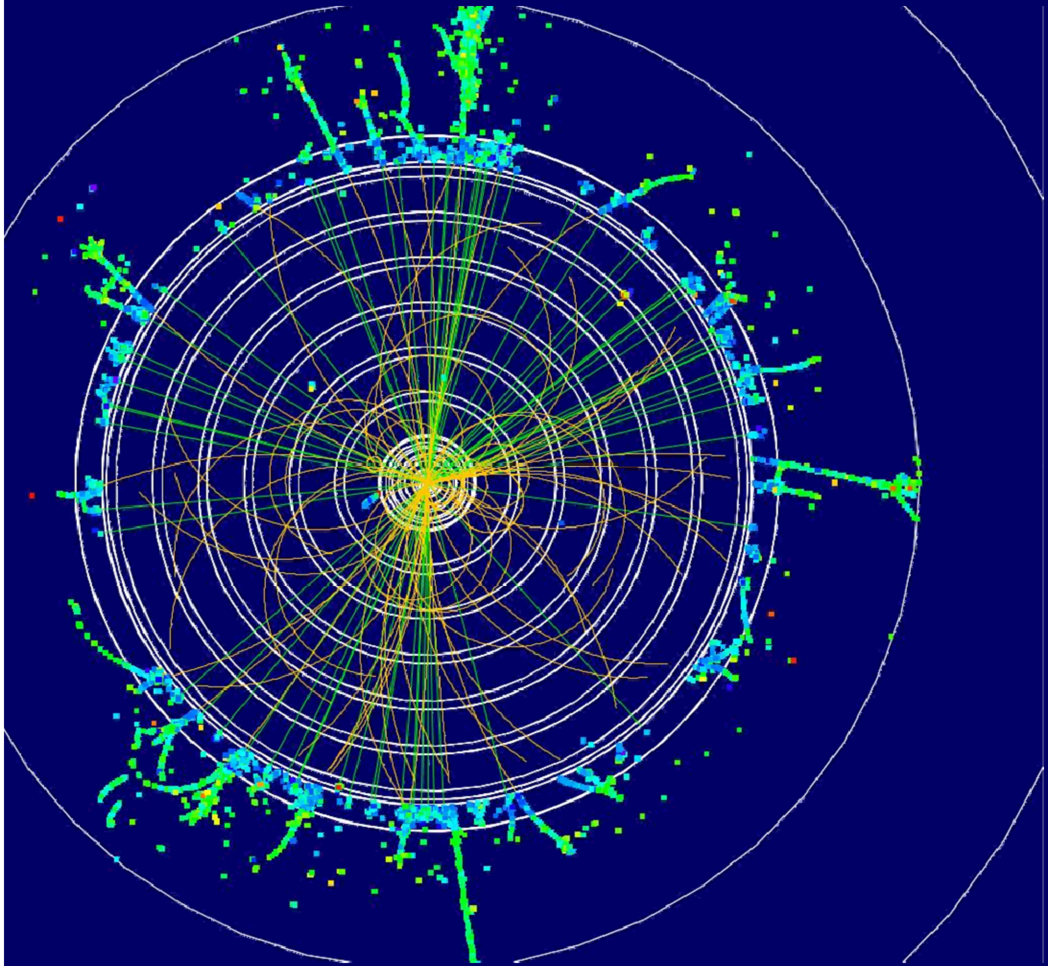
The SiD detector concept :
An Introduction



Harry Weerts

Argonne National Laboratory

Outline

The SiD detector concept

Introduction to ILC

recent goal changes

Detector Requirements

SiD assumptions

Detector description & performance

Later in day:

Areas for collaboration

Future plans

LHC potential and need for ILC

one page

The Large Hadron Collider (LHC), will open window to "remainder" of and physics "beyond" the Standard Model.

LHC

Starting in 2008.....

This is the energy/mass regime from ~0.5Tev to a few TeV

Completing the Standard Model and the symmetries underlying it plus their required breaking leads us to expect a plethora of new physics.

new particles and fields in this energy range

LHC will discover them or give clear indications that they exist.

We will need a tool to measure precisely and unambiguously their properties and couplings i.e. identify physics.

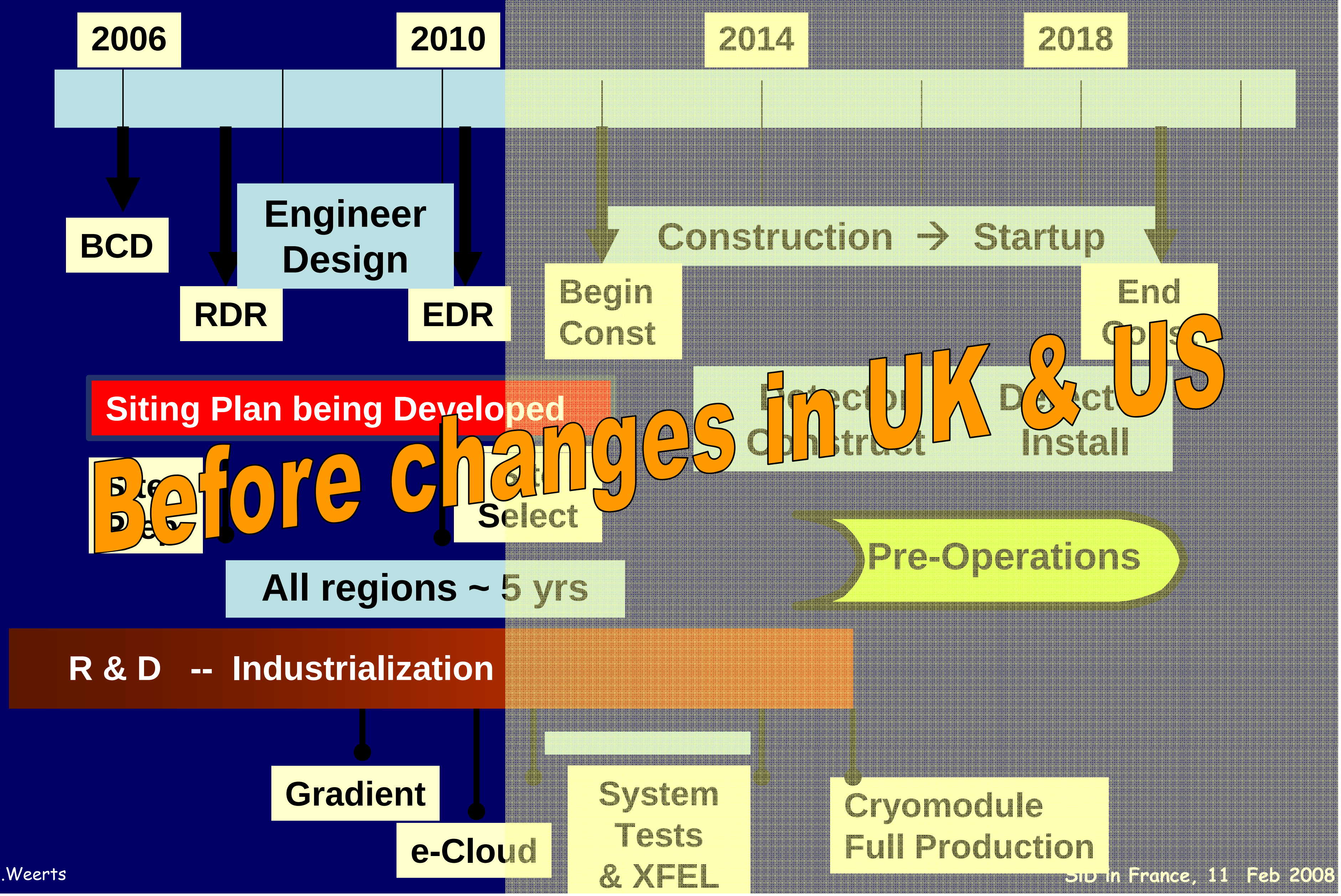
This is an e^+e^- machine with a centre of mass energy starting at 0.5 TeV up to several TeV

ILC

Starting next decade

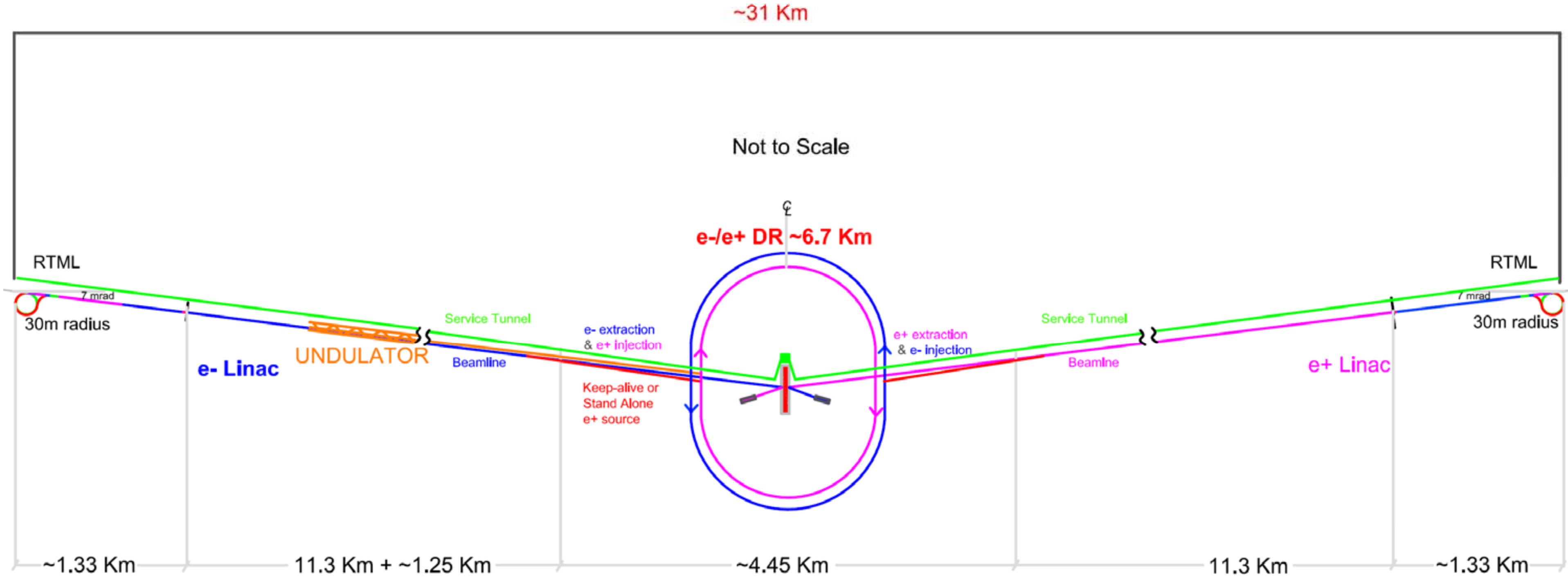
Status of ILC and recent changes in direction

Technically Driven Timeline



Reference Design: RDR ILC Schematic

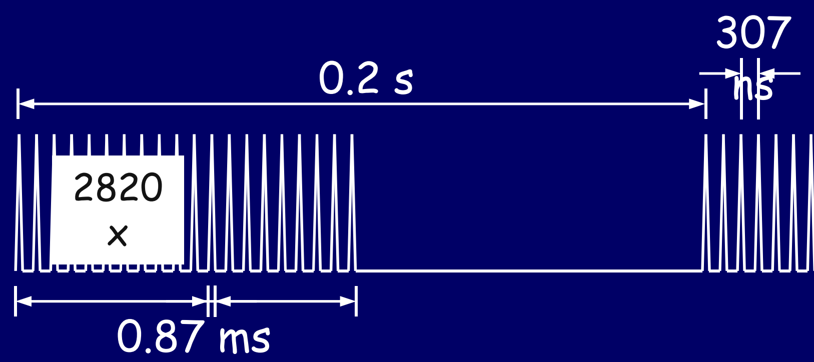
- 11km SC linacs operating at 31.5 MV/m for 500 GeV
- Centralized injector
  - *Circular damping rings for electrons and positrons*
  - *Undulator-based positron source*
- Single IR with 14 mrad crossing angle
- Dual tunnel configuration for safety and availability



Schematic Layout of the 500 GeV Machine

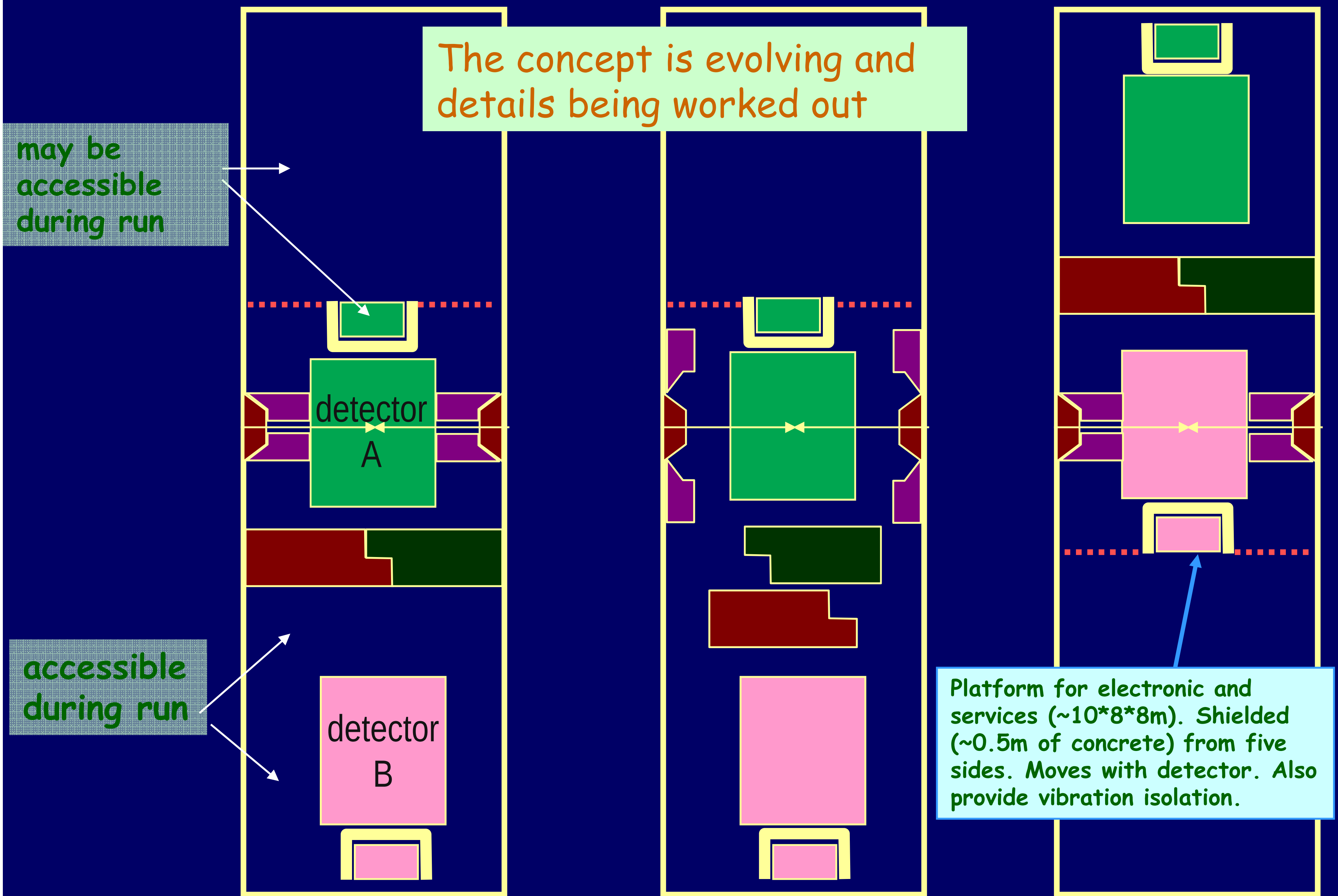
Parameters for the ILC

- E_{cm} adjustable from 200 – 500 GeV
- Luminosity → $\int L dt$ = 500 fb^{-1} in 4 years
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%
- The machine must be upgradeable to 1 TeV



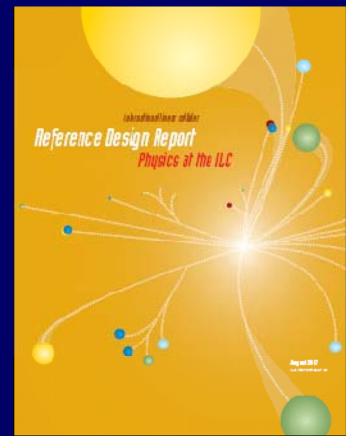
Center-of-mass energy	500	GeV
Peak Luminosity	~2×10^{34}	$1/cm^2 s$
Beam Current	9.0	mA
Repetition rate	5	Hz
Average accelerating gradient	31.5	MV/m
Beam pulse length	0.87	ms
Total Site Length	31	km
Total AC Power Consumption	~230	MW

Detector configuration: two at one IP



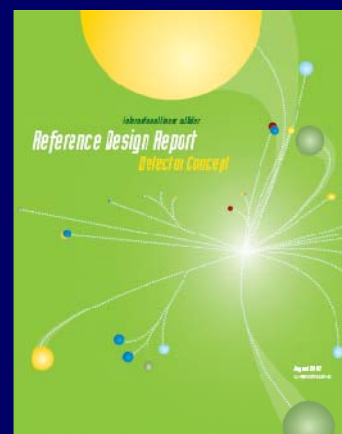
Reference Design Report complete

Executive Summary



Physics at the ILC

Accelerator



Detectors

Next phase: ~~Engineering Design report~~

Modifications to GDE plan… 1

Being proposed, not approved & negotiations ongoing

From B.Barish talk at SiD & P5

Technical Design Phase = TDP; not EDR anymore

TDP I -- 2010

- Technical risk reduction:
  - Gradient
    - *Results based on re-processed cavities*
    - *Reduced number 540 → 390 (reduced US program)*
  - Electron Cloud (CesrTA)
- Cost risks (reductions) – Main Cost Drivers
  - Conventional Facilities (water, etc)
  - Main Linac Technology
- Technical progress ? (global design & US??)
  - Cryomodule baseline design defined

TDP II - 2012

- RF unit test – 3 CM + beam (STF)
- Complete technical design and R&D needed for project proposal (some exceptions)
- Documented design
- Complete and reliable cost roll up
- Project plan developed by consensus
- Cryomodule Global Manufacturing plan
- Siting Plan or Process

Modifications to GDE plan… 2

From B.Barish talk at SiD & P5

TDP II 2012

what will not be done?

- Detailed Engineering Design (final engineering, drawings, industry, etc) will follow before construction.
- Global cryomodule industrial plant construction
- Other Unresolved Issues
  - Positron Source ???
  - Damping Ring Design work?

Evolution of ILC physics/detectors
(Coupled to the plan for the machine & revised)

Plans for near future: Next 3-4 years; keep pace with accelerator

WWS (discussions '06 & '07) prepared way for this plan.

Identify the ILC Research Director (RD).
Research Director identified/accepted: S. Yamada (Tokyo Univ.)

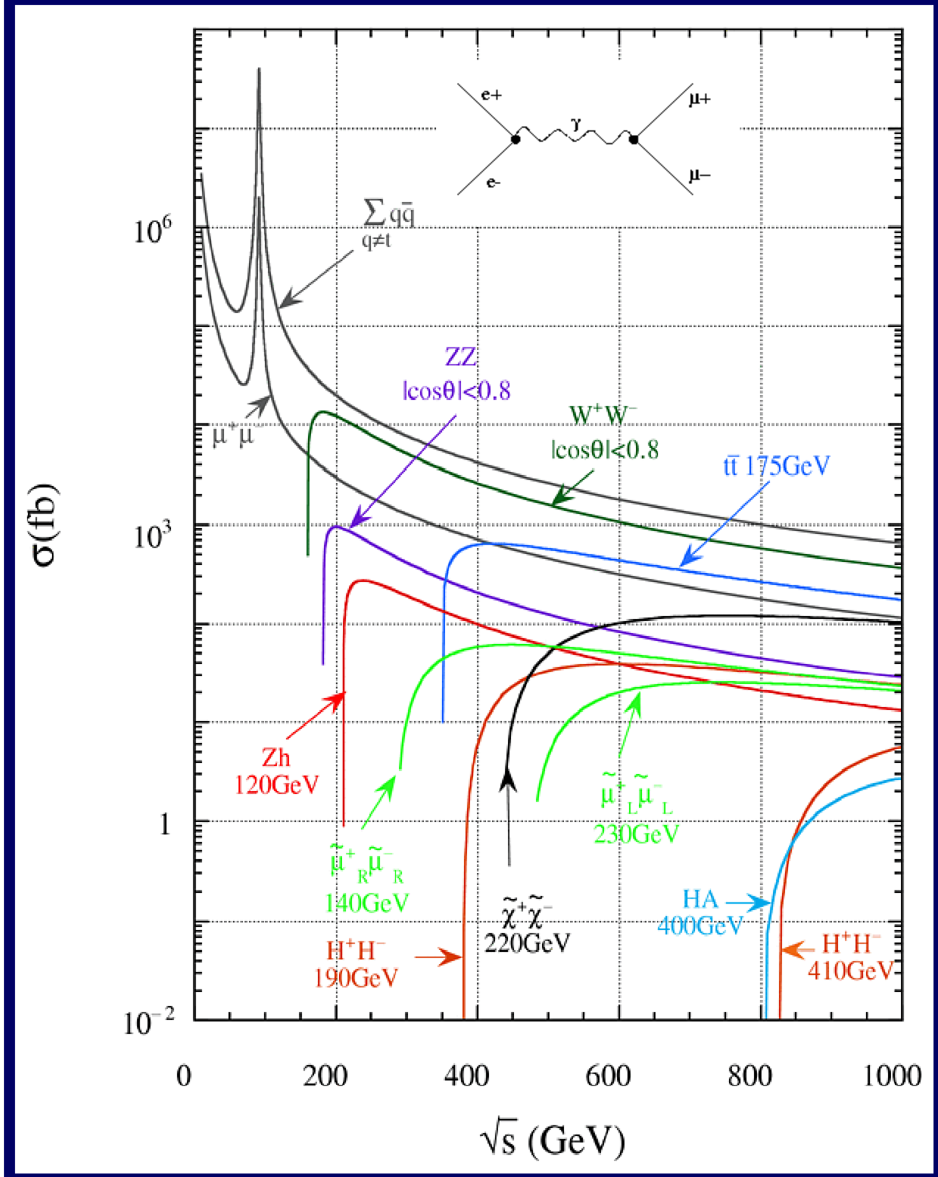
Fall 2007: call for Letters of Intent(LOI) for detectors

RD expected to:

- April 2009: Letters of Intent completed
- "Validate " submitted LOI's and therefore detector concepts. Some uncertainty here....
- Any other steps depend on RD........
- Continue & conclude the vigorous, worldwide detector R&D partly independent of any concepts.

Challenge: Produce LOI's in ~ >one year

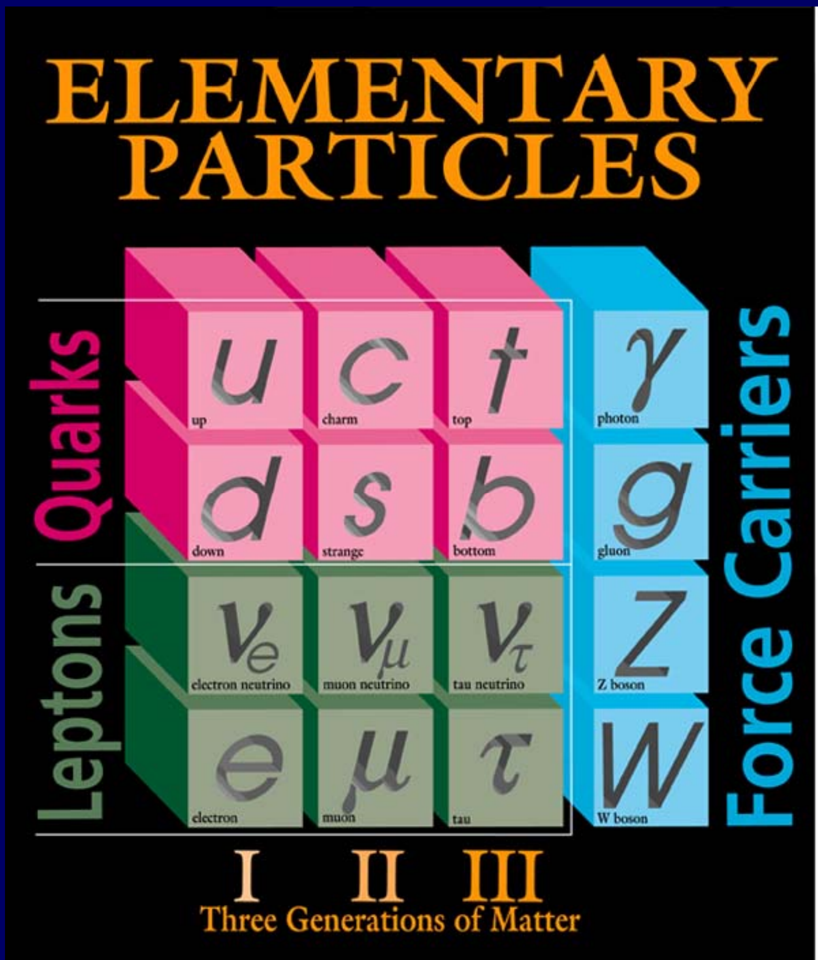
ILC: Physics Event Rates



- s-channel processes through spin-1 exchange: $\sigma \sim 1/s$
- Cross sections relatively democratic:
  - $\sigma(e^+e^- \rightarrow ZH) \sim 0.5 * \sigma(e^+e^- \rightarrow ZZ)$
- Cross sections are small; for $L = 2 \times 10^{34}\ cm^{-2}s^{-1}$
  - $e^+e^- \rightarrow$ qq, WW, tt, Hx ~ 0.1 event /train
  - $e^+e^- \rightarrow e^+e^-\gamma\gamma \rightarrow e^+e^- X$ ~ 200 /train
- Beyond the Z, no resonances
- W and Z bosons in all decay modes become main objects to reconstruct
- Need to reconstruct final states
- Central & Forward region important
- Highly polarized e^- beam: ~ 80%

What should ILC detector be able to do ?

Identify ALL of the constituents that we know & can be produced in ILC collisions & precisely measure their properties.
(reconstruct the complete final state)



u,d,s jets; no ID
c, b jets with ID
t final states; jets + W's
ν's: missing energy; no ID
e, μ: yes
τ through decays
γ ID & measure
gluon jets, no ID
W,Z leptonic & hadronic

Use this to measure/identify the NEW physics

Some Detector Design Criteria

Requirement for ILC

- Impact parameter resolution

$$\sigma_{r\phi} \approx \sigma_{rz} \approx 5 \oplus 10/(p\sin^{3/2}\vartheta)$$

- Momentum resolution

$$\sigma\left(\frac{1}{p_T}\right) = 5\times10^{-5}\ (GeV^{-1})$$

- Jet energy resolution goal

$$~~\frac{\sigma_E}{E} = \frac{30\%}{\sqrt{E}}~~ \qquad \frac{\sigma_E}{E} = 3-4\%$$

- Detector implications:
  - Calorimeter granularity
  - Pixel size
  - Material budget, central
  - Material budget, forward

Compared to best performance to date

- Need factor 3 better than SLD

$$\sigma_{r\phi} = 7.7 \oplus 33/(p\sin^{3/2}\vartheta)$$

- Need factor 10 (3) better than LEP (CMS)
- Need factor 2 better than ZEUS

$$\frac{\sigma_E}{E} = \frac{60\%}{\sqrt{E}}$$

- Detector implications:
  - Need factor ~200 better than LHC
  - Need factor ~20 smaller than LHC
  - Need factor ~10 less than LHC
  - Need factor ~ >100 less than LHC

Observation: LHC: staggering increase in scale, but modest extrapolation of performance
ILC: modest increase in scale, but significant push in performance

Design Driver for any ILC detector

To be able to achieve the jet resolution can NOT simply use calorimeters as sampling devices.

~~$\frac{\sigma_E}{E} \cong 0.30 \frac{1}{\sqrt{E(GeV)}}$~~

$$\frac{\sigma_E}{E} = 3-4\%$$

Have to use "energy/particle flow (PFA)". Technique has been used to improve jet resolution of existing calorimeters.

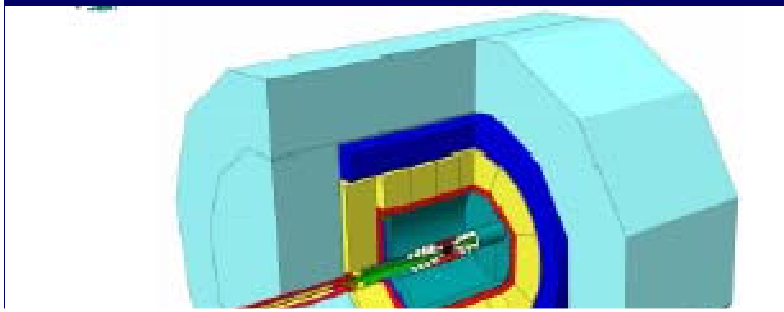
Algorithm:

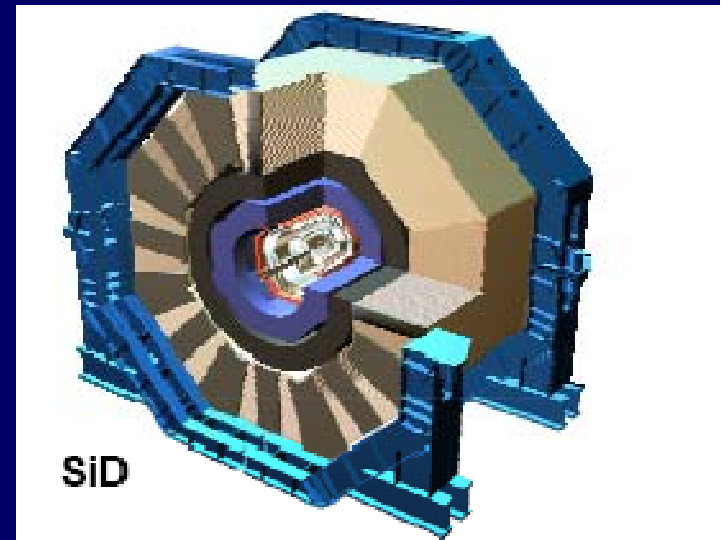
- use EM calorimeter (EMCAL) to measure photons and electrons;
- track charged hadrons from tracker through EMCAL,
- identify energy deposition in hadron calorimeter (HCAL) with charged hadrons & replace deposition with measured momentum (very good)
- When completed only E of neutral hadrons (K's, Lambda's) is left in HCAL. Use HCAL as sampling cal for that.

Require:

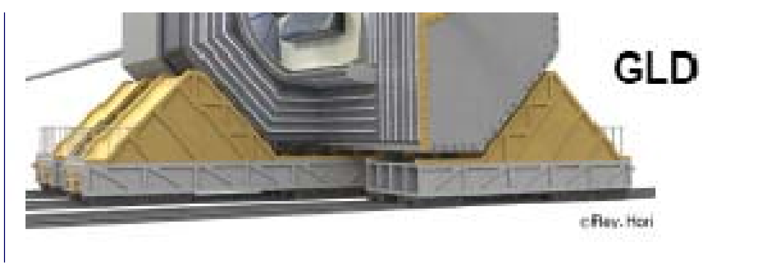
Imaging cal (use as tracker = like bubble chamber),
➔ very fine transverse & longitudinal segmentation
Large dynamic range: MIP…. to …..shower
Excellent EM resolution

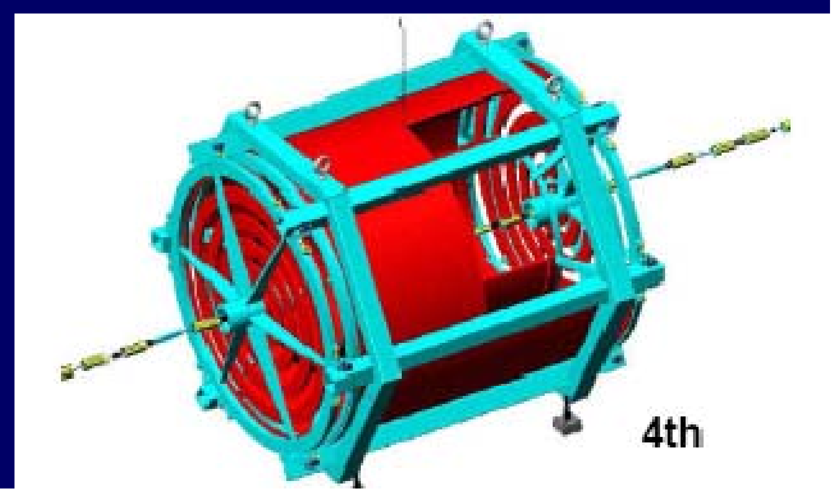
Emerged picture after some maneuvering





LDC & GLD merged➔ ILD
Expect a concept based on strengths of both & TPC based



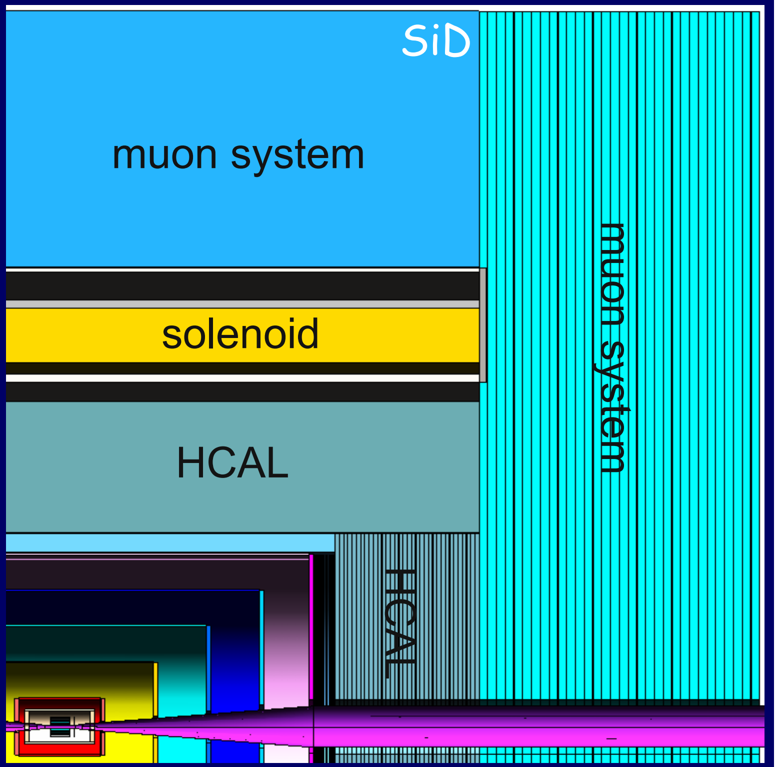


How does the SiD Concept address the requirements ?

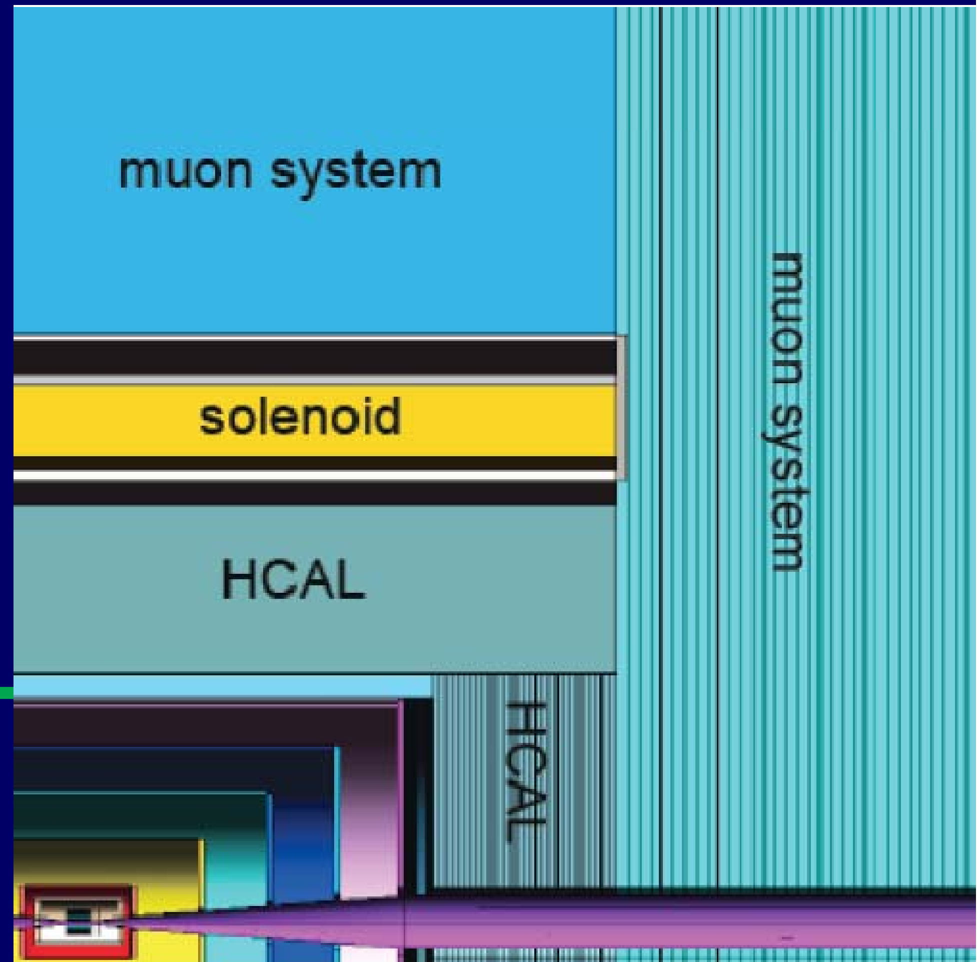
Here only outline.
Detailed talks on most aspects.

SiD Design Concept (starting point)

- "Jet Energy measurement =PFA" is the starting point in the SiD design
- Premises at the basis of concept:
  - Particle flow calorimetry will deliver the best possible performance
  - Si/W is the best approach for the ECAL and digital calorimetry for HCAL
  - Limit calorimeter radius to constrain the costs
  - Boost B-field to maintain BR^2
  - Use Si tracking system for best momentum resolution and lowest mass
  - Use pixel Vertex detector for best pattern recognition
  - Keep track of costs
- Detector is viewed as single fully integrated system, not just a collection of different subdetectors



SiD Starting Point
Details & Dimensions



Flux return / muon
R_{in} = 333 cm
R_{out} = 645 cm

Solenoid: 5 T; R_{in} = 250 cm

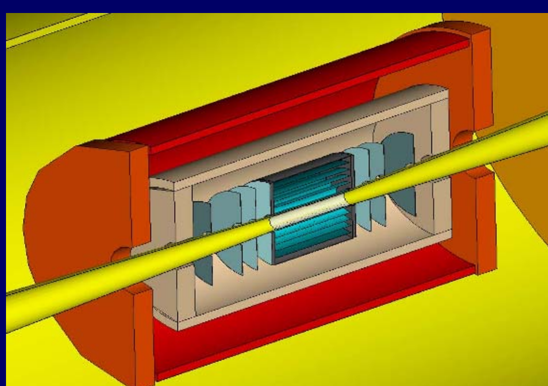
PFA

HCAL Fe: 34 layers; R_{in} = 138 cm

EMCAL Si / W: 30 layers R_{in} = 125 cm

Si

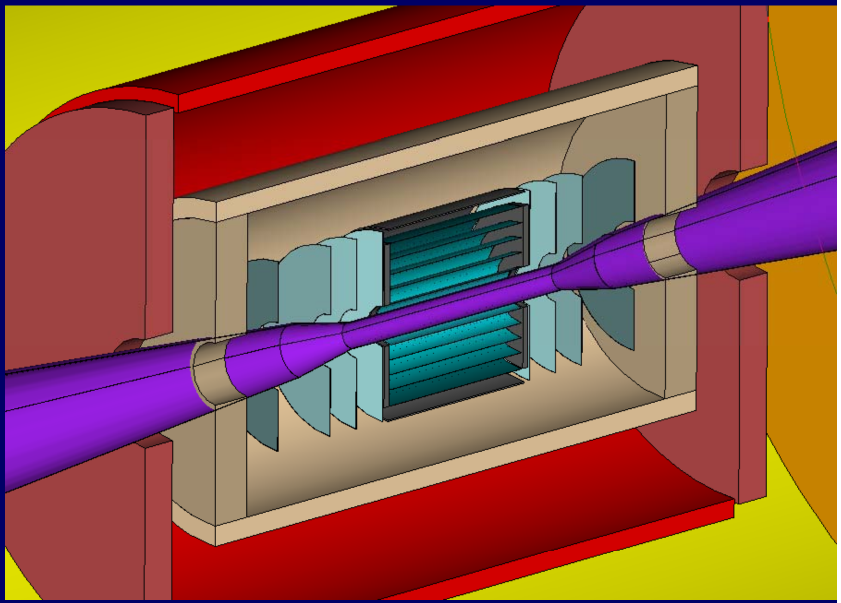
Si tracking: 5 layers; R_{in} = 18 cm



Vertex detector:
5 barrels, 4 disks; R_{in} = 1.4 cm

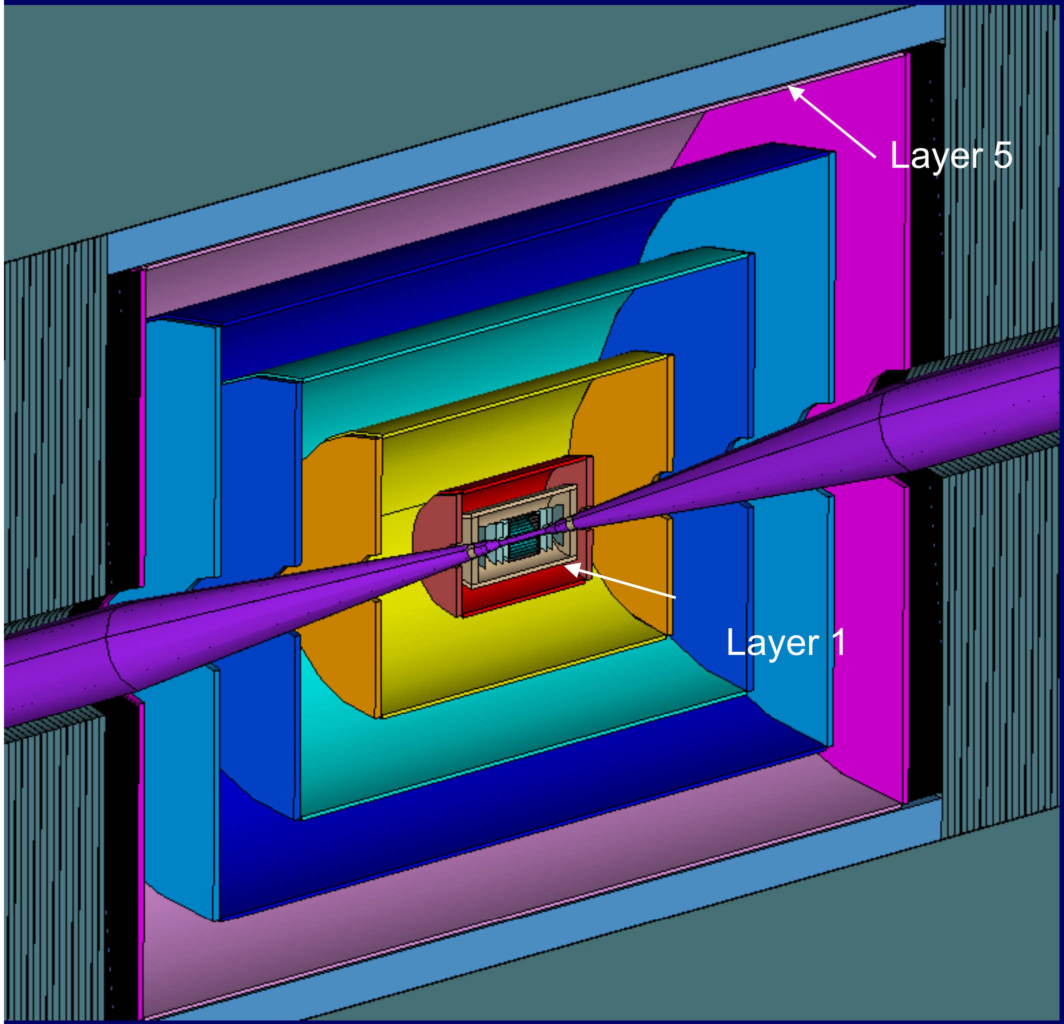
Vertexing and Tracking

- Tracking system is conceived as an integrated, optimized detector
  - Vertex detection
    - *Inner central and forward pixel detector*
  - Momentum measurement
    - *Outer central and forward tracking*
  - Integration with calorimeter
  - Integration with very far forward system
- Detector requirements (vertex)
  - Spacepoint resolution: < 4 μm
  - Impact parameter resolution
    $\sigma_{r\phi} \approx \sigma_{rz} \approx 5 \oplus 10/(p\sin^{3/2}\vartheta)\ \mu m$
  - Smallest possible inner radius
  - Momentum resolution 5 10^{-5} (GeV^{-1})
  - Transparency: ~0.1% X_0 per layer
  - Stand-alone tracking capability



Silicon Outer Tracker

- 5-Layer silicon strip outer tracker, covering R_{in} = 20 cm to R_{out} = 125 cm, to accurately measure the momentum of charged particles

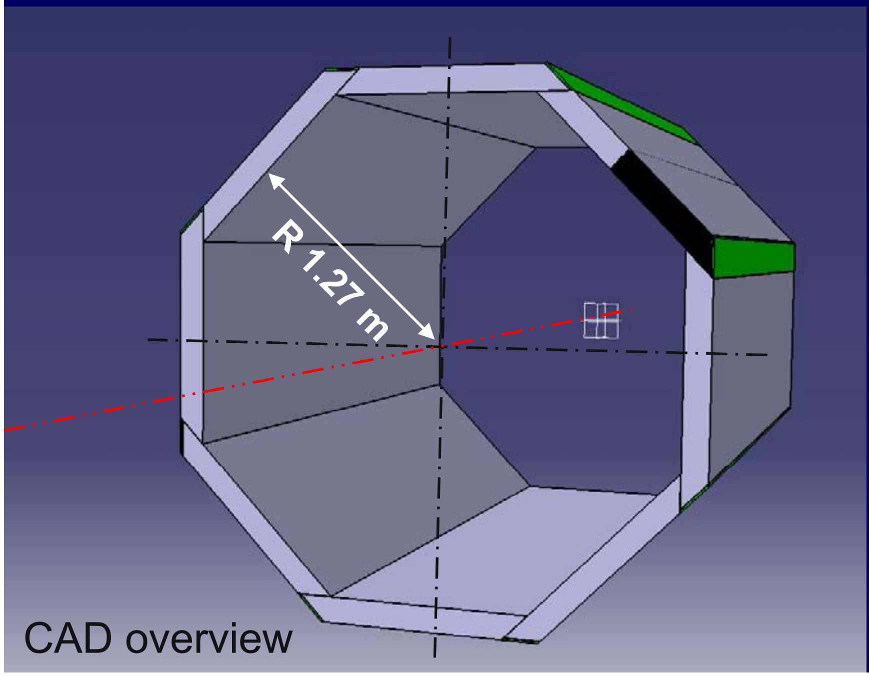


- Support
  - Double-walled CF cylinders
  - Allows full uniform, azimuthal and longitudinal coverage
- Barrels
  - Five barrels, measure Phi only
  - Eighty-fold phi segmentation
  - 10 cm z segmentation
  - Barrel lengths increase with radius
- Disks
  - Five double-disks per end
  - Measure R and Phi
  - varying R segmentation
  - Disk radii increase with Z

EM Calorimeter

Absorber	X_0 [mm]	R_M [mm]
Iron	17.6	18.4
Copper	14.4	16.5
Tungsten	3.5	9.5
Lead	5.8	16.5

- Particle-Flow requires high transverse and longitudinal segmentation and dense medium
- Choice: Si-W can provide very small transverse segmentation and minimal effective Molière radius
  - Maintain Molière radius by minimizing the gap between the W plates
  - Requires aggressive integration of electronics with mechanical design

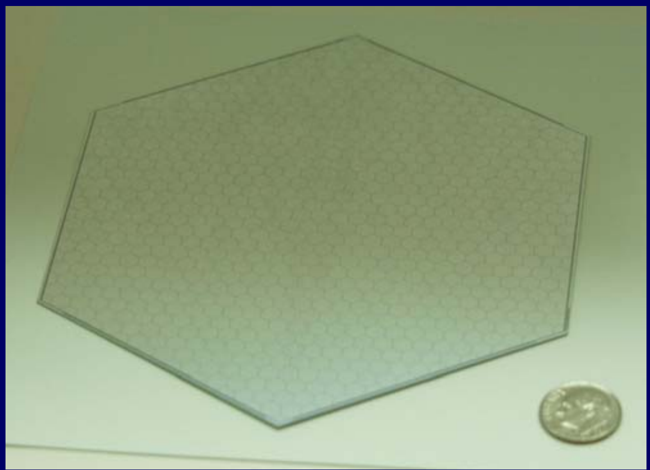


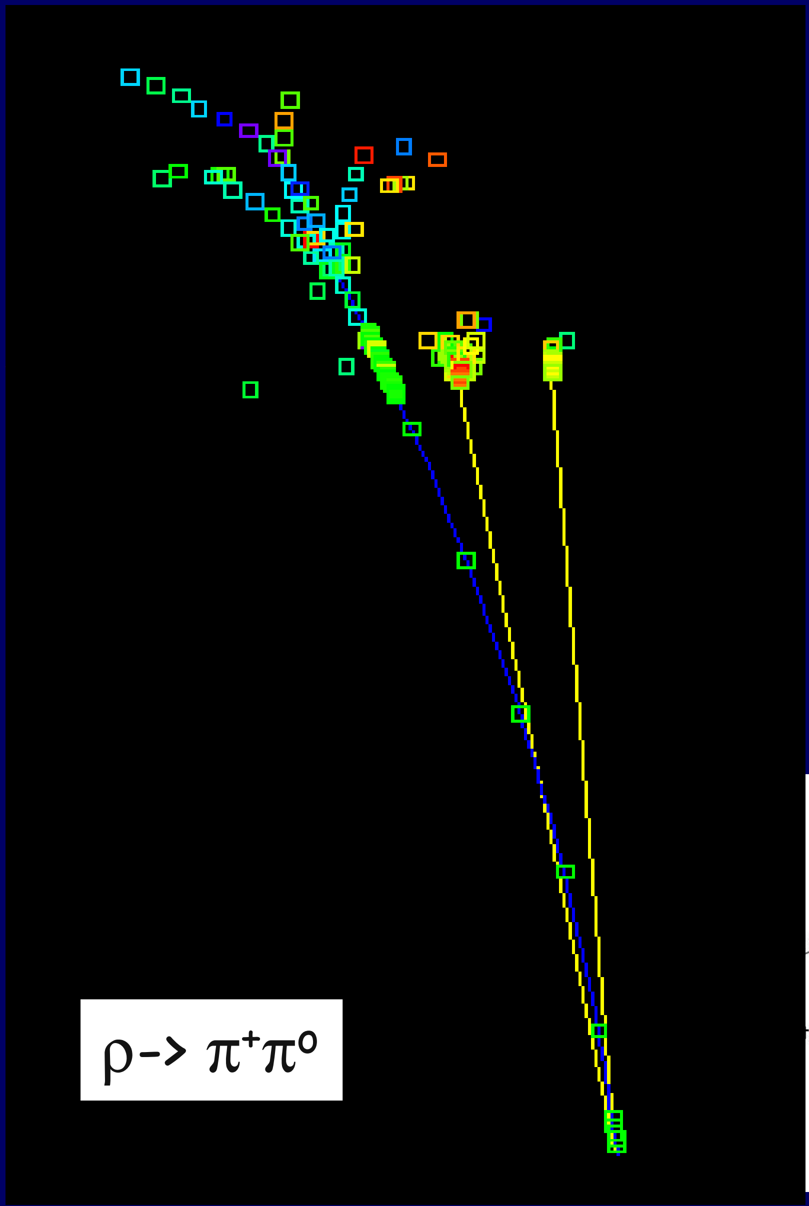
CAD overview

- 30 layers
- ~ 1mm Si detector gaps
  - *Preserve $R_M(W)_{eff}$= 12 mm*
- Pixel size ~ 4 x 4 mm^2
- Energy resolution 15%/√E + 1%

EM Calorimeter

- Statistics
  - 20/10 layers, 2.5/5 mm W
  - ~ 1mm Si detector gaps
  - Tile with hexagonal 6" wafers
  - 4x4 mm² pads
  - ~ 1300 m² of Si
- Readout with KPIX chip
  - 1024 channels, bump-bonded
  - 4-deep buffer (low occupancy)
  - Bunch crossing time stamp for each hit
  - 64 ch. prototype in hand





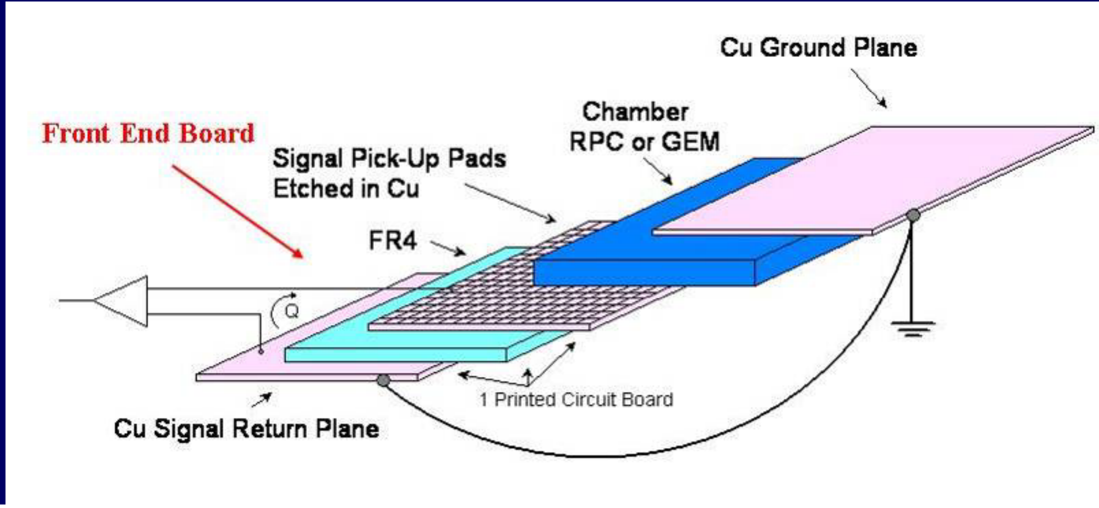
Data Cable

on

Hadron Calorimetry

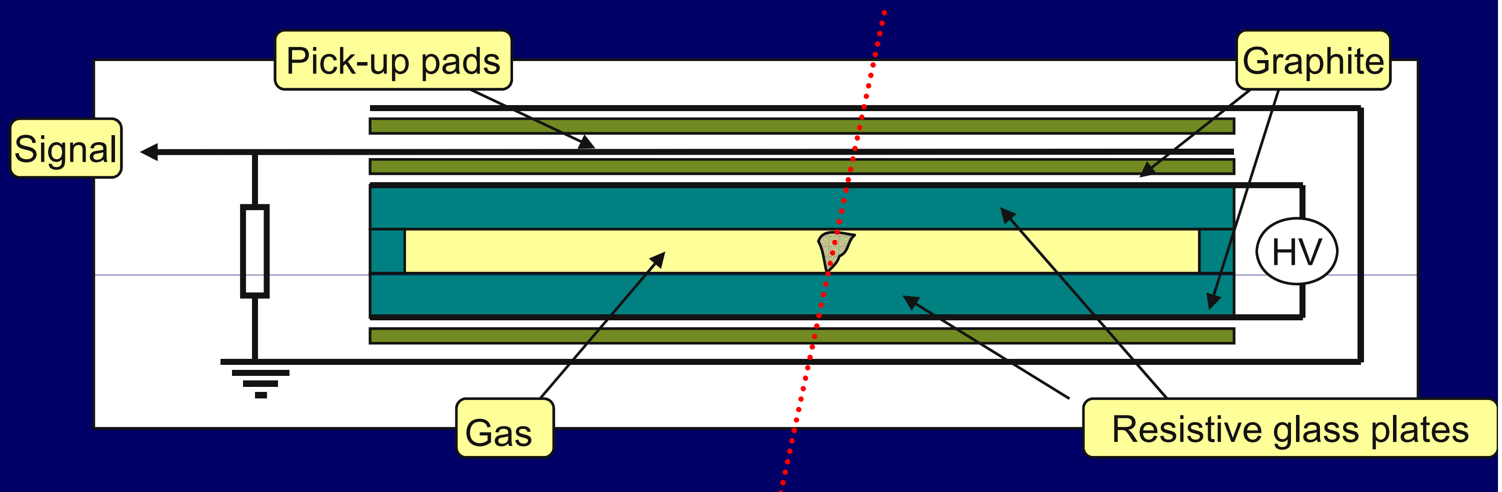
- Role of hadron calorimeter in context of PFA is to measure neutrals and allow "tracking" i.e. matching of clusters to charged particles.
  - HCAL must operate with tracking and EM calorimeter as integrated system
- Various Approaches
  - Readout
    - *Analog readout -- O(10) bit resolution*
    - *Digital readout -- 1-bit resolution (binary)*
  - Technolgoy
    - *Active*
      - Resistive Plate Chambers, Gas Electron multipliers, MicroMegas
      - Scintillator
    - *Passive*
      - Tungsten
      - Steel
  - PFA Algorithms
    - *Spatial separation*
    - *Hit density weighted*
    - *Gradient weighted*

Example of a configuration



Hadron Calorimeter

- Current baseline configuration for SiD:
  - Digital calorimeter, inside the coil
    - *R_i = 139 cm, R_o =237 cm*
  - Thickness of 4λ (thin)
    - *38 layers of 2.0cm steel*
    - *One cm gap for active medium*
  - Readout (one of choices)
    - *RPC's as active medium (ANL)*
    - *1 x 1 cm2 pads*



All other options for HCAL are being pursued & explored.

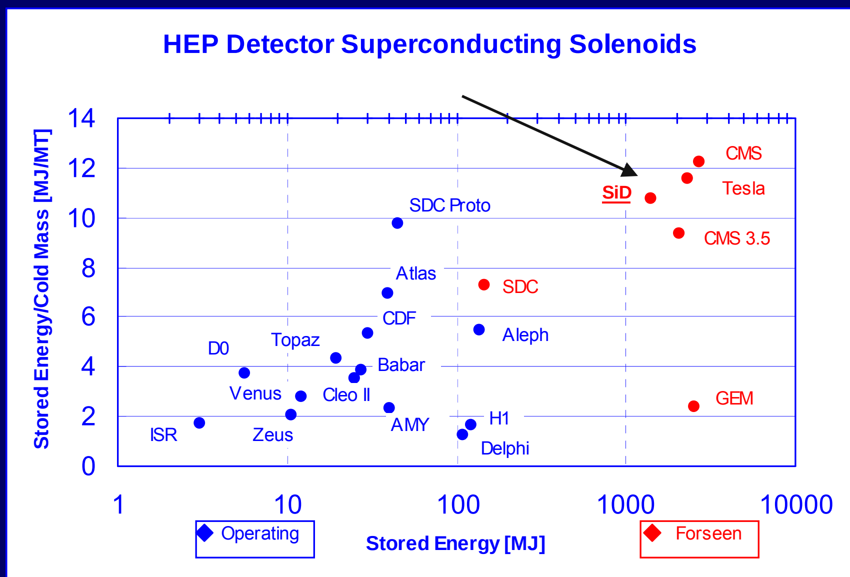
•Gas based: RPC, GEM and micromegas (single bit /multibit)

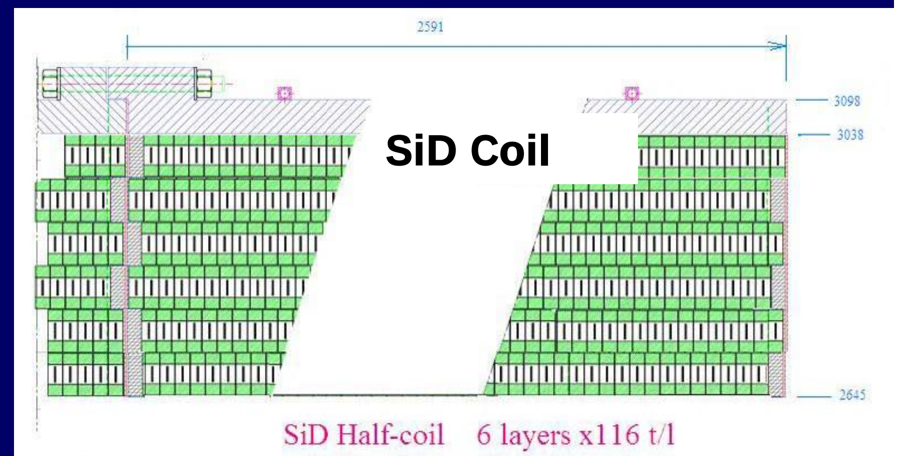
•Scintillator based (R&D in CALICE)

HCAL: area of controversy, debate, choices to be made, depth ?, simulation, related to PFA

Solenoid

- Design calls for a solenoid with B(0,0) = 5T (not done previously)
  - Clear Bore Ø ~ 5 m; L = 5.4 m: Stored Energy ~ 1.2 GJ
    - *For comparison, CMS: 4 T, Ø = 6m, L = 13m: 2.7 GJ*



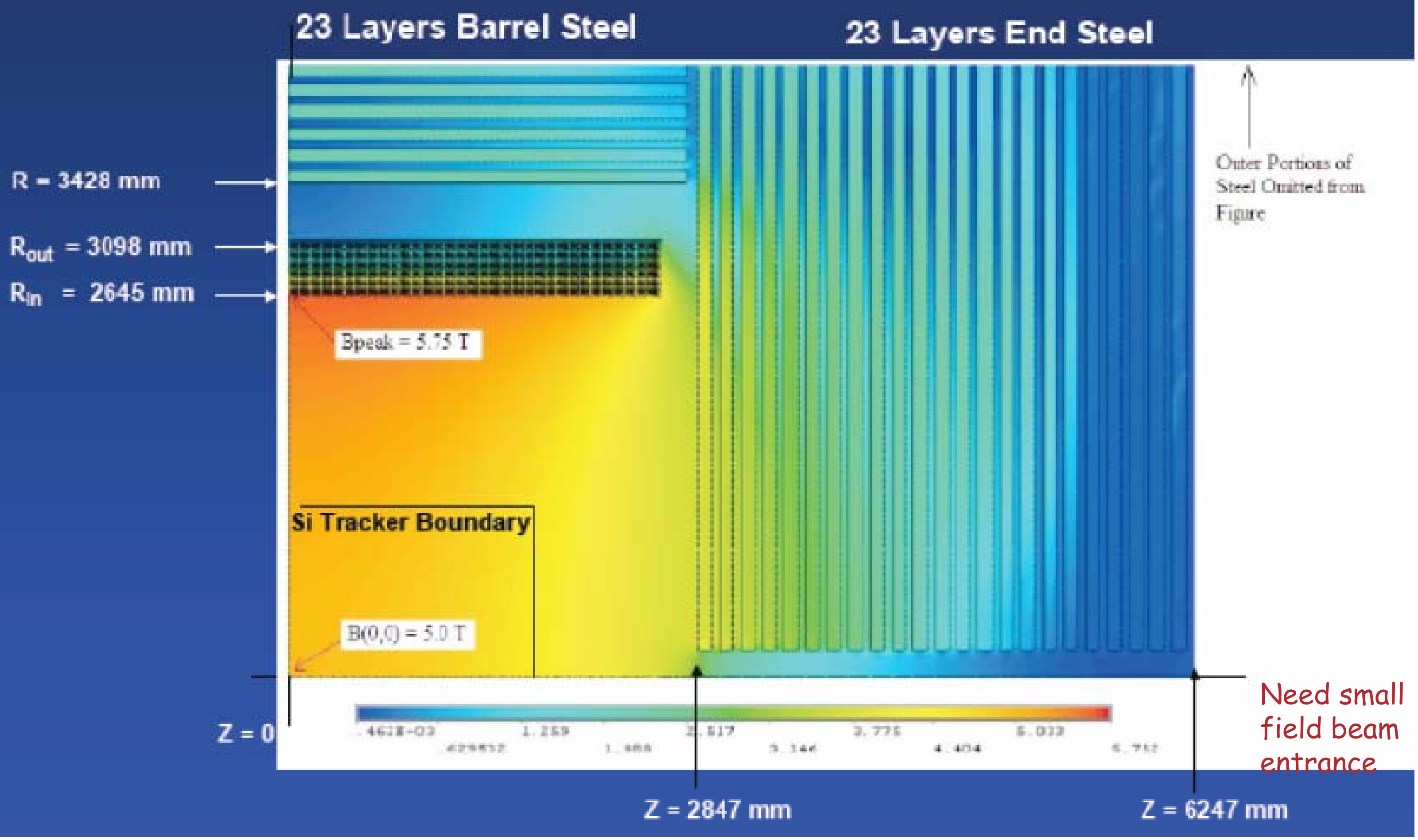


- Full feasibility study of design based on CMS conductor
  - Start with CMS conductor design, but increase winding layers from 4 to 6
    - *I(CMS)= 19500 A, I(SiD) = 18000 A; Peak Field (CMS) 4.6 T, (SiD) 5.8*
    - *Net performance increase needed from conductor is modest*

Studies on Dipole in Detector (DID) have been done/are being done as well

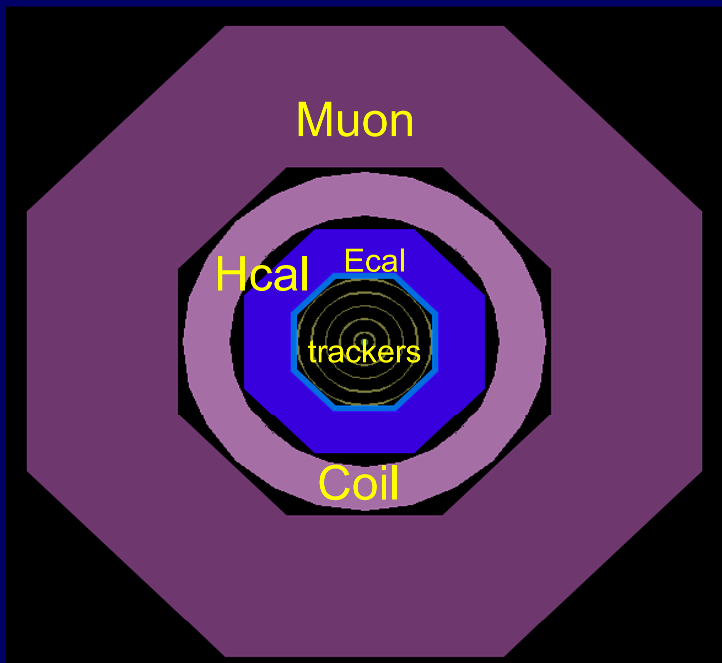
Field simulation

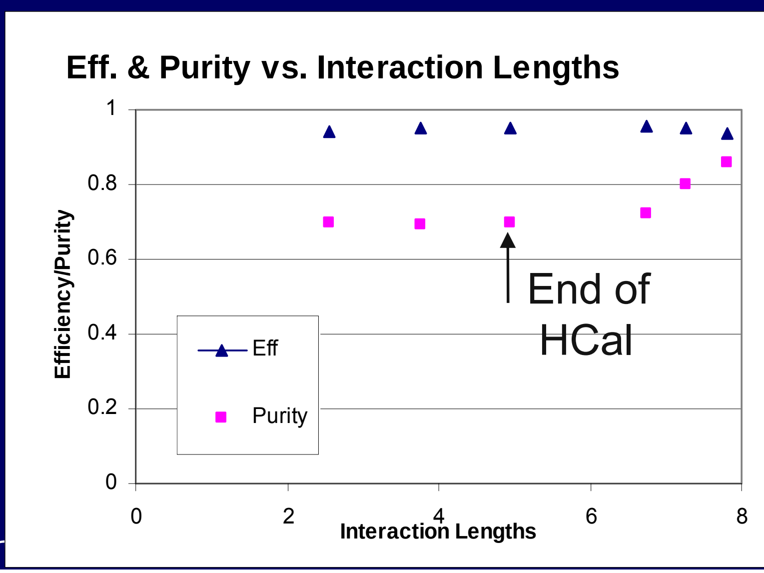
- ANSYS modeling of solenoid (2d, 3d)



Need expertise on conductor development and solenoid design.

Muon System



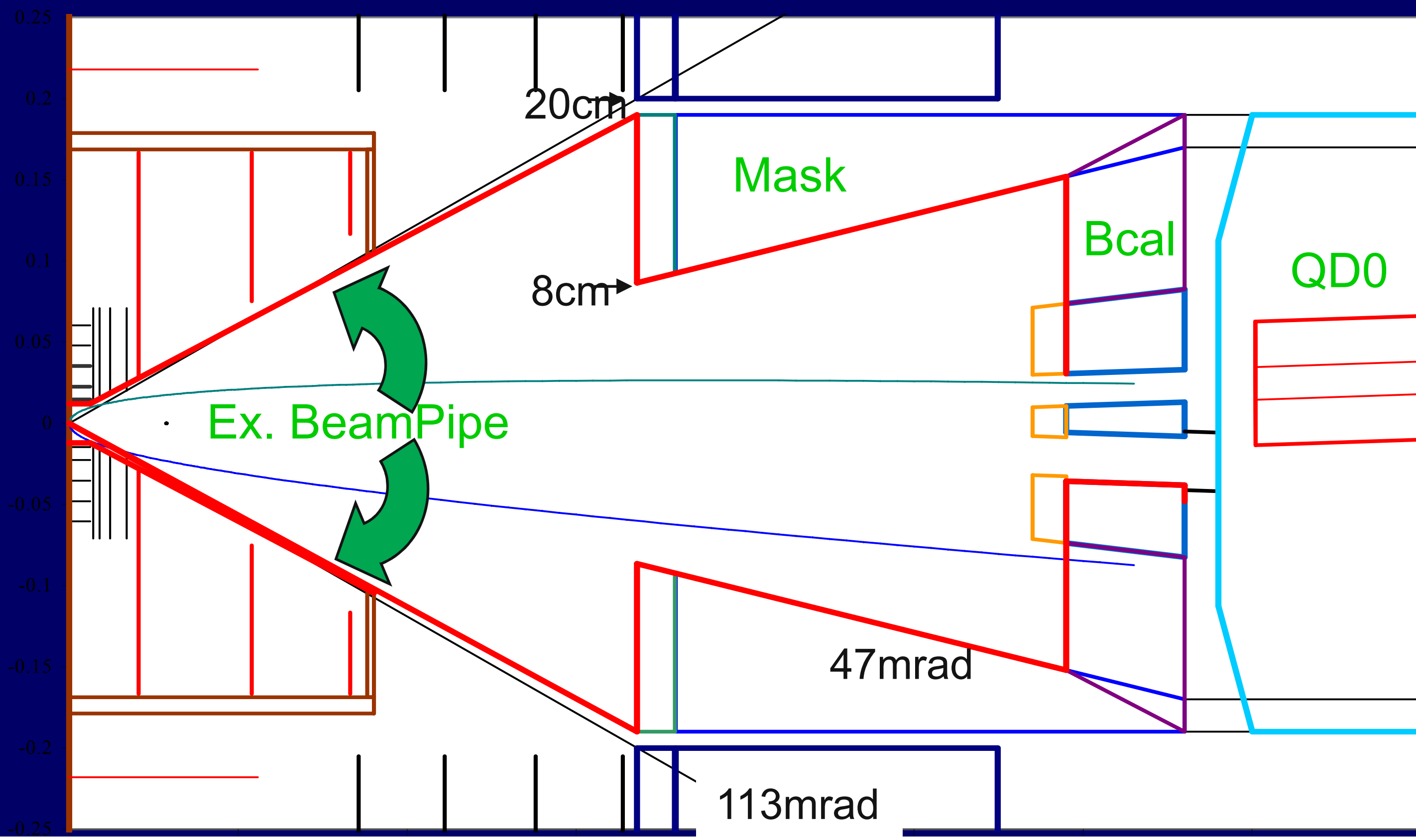


- Muon System Baseline Configuration
  - Octagon: 48 layers, 5 cm thick steel absorber plates
  - Six planes of x, y or u, v upstream of Fe flux return for xyz and direction of charged particles that enter muon system.
- Muon ID studies
  - 12 RPC- instrumented gaps
  - ~1cm spatial resolution
- Issues
  - Technology: RPC, Scin/SiPMs, GEMS, Wire chambers
  - Is the muon system needed as a tail catcher?
  - How many layers are needed (0-23)? Use HCAL ?
  - Position resolution needed?

(includes forward calorimetry)

Machine-Detector Interface at the ILC

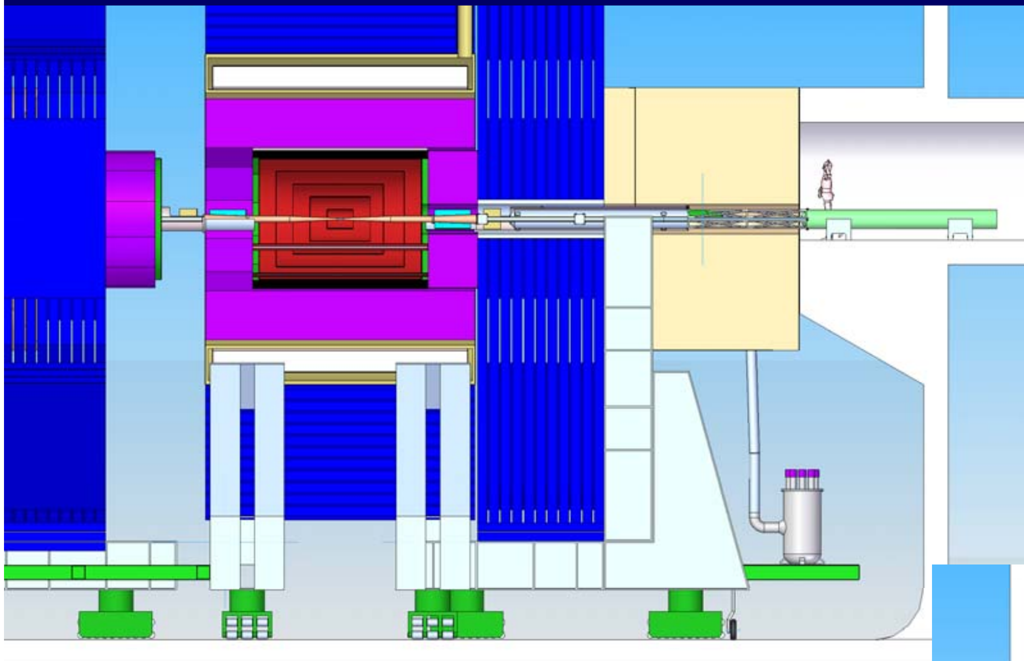
- (L,E,P) measurements: Luminosity, Energy, Polarization
- Forward Region Detector layout (lumcal, beamcal, gamcal)
- Collimation and Backgrounds
- IR Design and Detector Assembly
- EMI (electro-magnetic interference) in IR



Engineering Group/Effort

Have established a mechanical conceptual design group (word "engineer" not allowed anymore in US.)

Looking at mechanical issues
Examples



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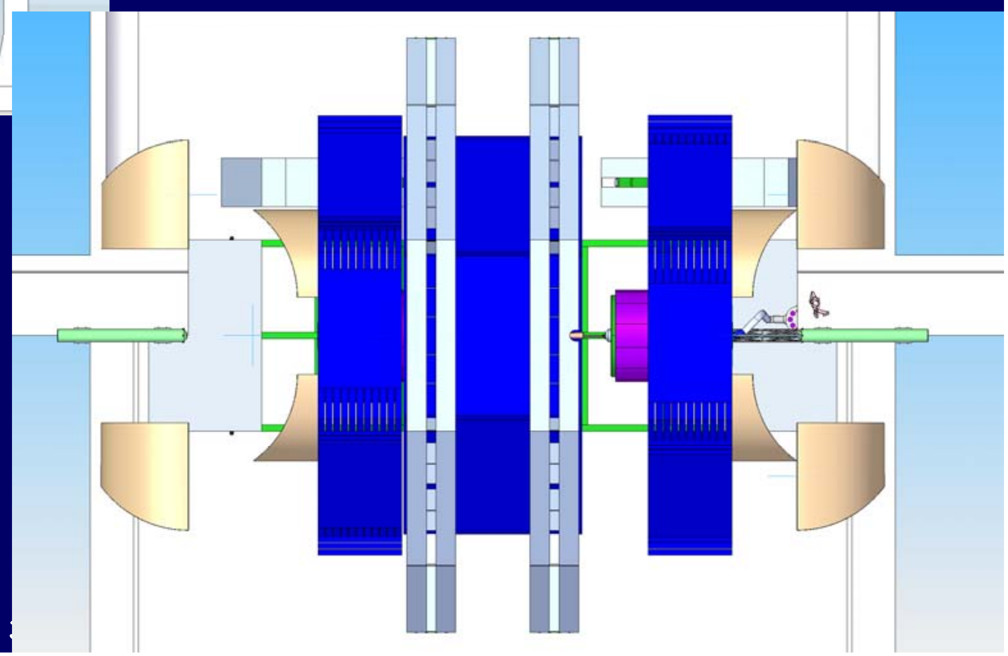
One side open completely →



Summary: Technical Strengths
(Leave to more expert talks)

- **Generally:** compact, highly integrated, hermetic detector
  Bunch by bunch timing resolution
- **Tracking:**
  - VTD: small radius (5T helps)
  - Tracker: excellent dp/p; minimized material all cos(θ)
  - Demonstrated pattern recognition
  - Solenoid: 5T (difficult but not unprecedented)
- **Calorimetry: imaging, hermetic**
  - ECAL: excellent segmentation=4x4 mm^2, $R_{Moliere}$=13mm
  - HCAL: excellent segmentation: ~1x1 to 3x3 cm^2
  - Working on PFA performance
- **Excellent μ ID:** Instrumented flux return & imaging HCAL
- **Simulation:** Excellent simulation and reconstruction software
  - Results shown only possible with that

Summary: Technical weak points…

Judge for yourself after today's presentations.

Detector concept summary

- A silicon-centric design offering
  - excellent vertexing and tracking precision
  - new potential in calorimetry
  - excellent muon identification
- Complementary to other concepts
- Many opportunities for new effort and expertise.
- Tools and organization in place to support efficient development and to get started.
- Great opportunity to explore ILC detector/physics.
- Open to new ideas, collaborators, increased internationalization

THE END

Backup slides

Summary

- It is a great time to get involved in SiD
- Many interesting projects that can use contributions
- Challenging to work on new detector
- More information can be found in the SiD talks at conferences & workshops
- Getting started is easy:

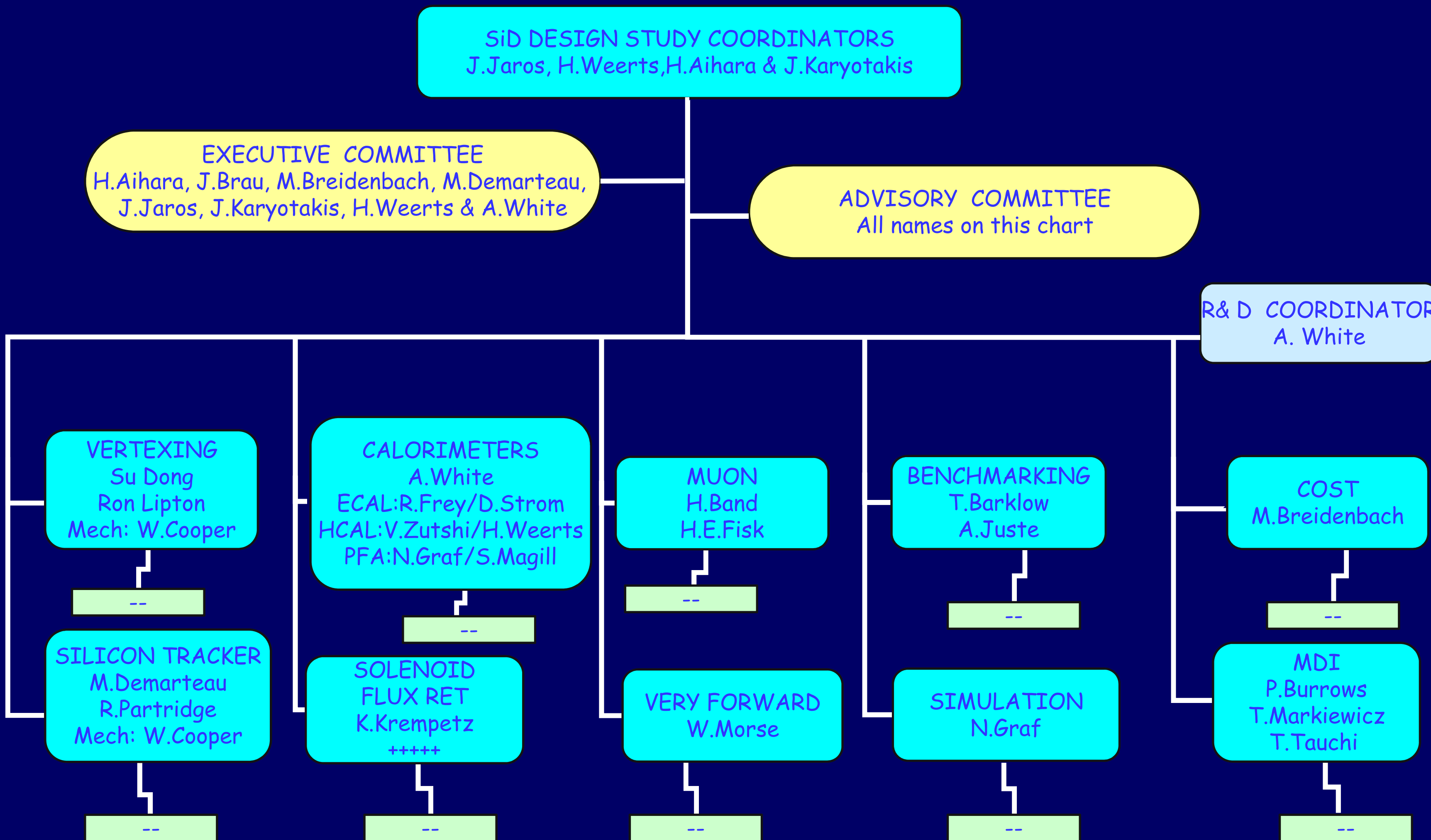
1. Identify an area in SiD where you would like to contribute
2. Talk with SiD leadership about your interests and SiD needs
3. Start attending meetings and begin contributing to SiD

See the SiD web page for links to further information:

http://silicondetector.org

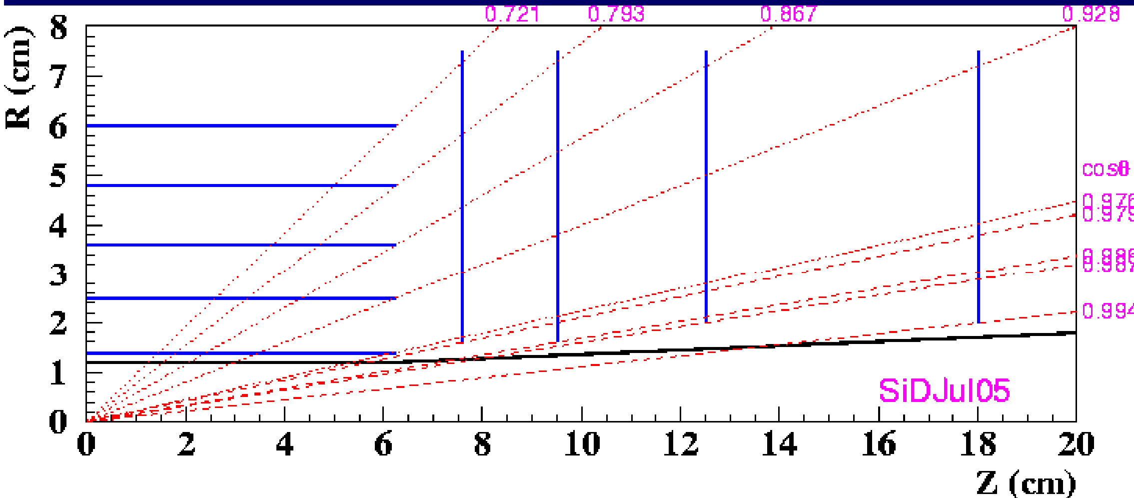
How to get involved in SiD/contacts

SiD organization and subgroups



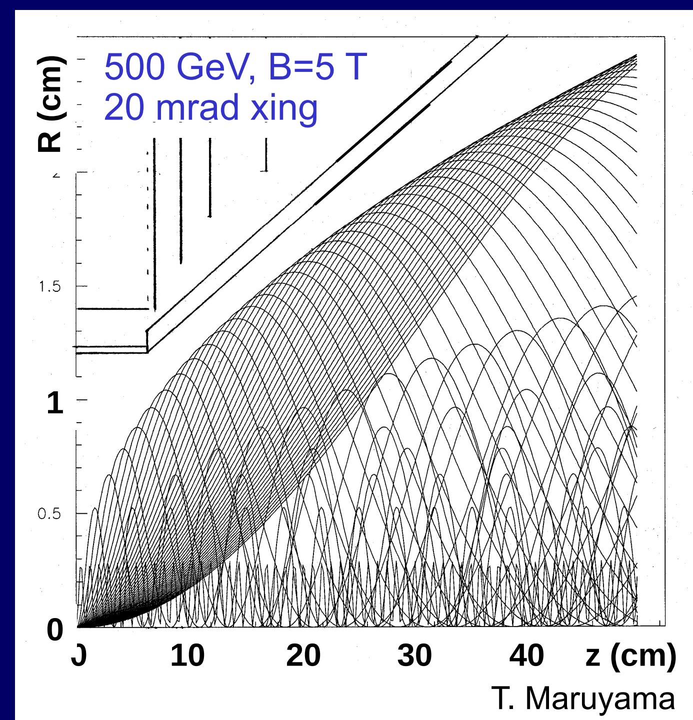
Version 0.3 July 2007

Vertex Detector



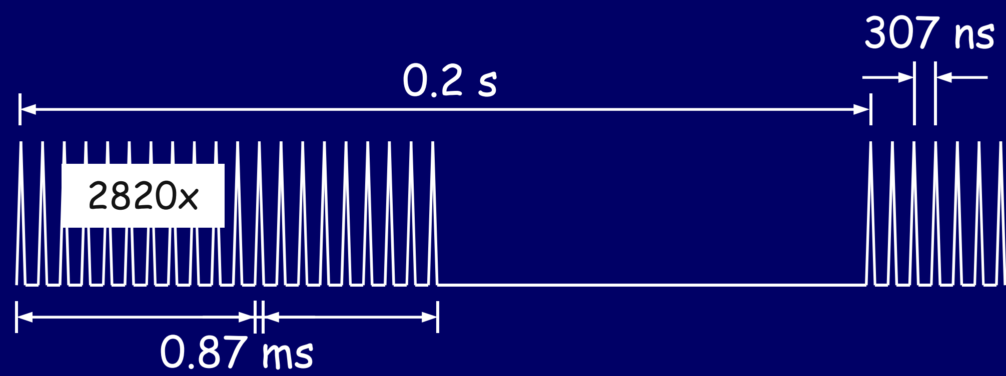
- Five Barrels
  - R_{in} = 14 mm to R_{out} = 60 mm
  - 24-fold phi segmentation
  - two sensors covering 6.25 cm each
  - All barrel layers same length
- Four Disks per end
  - Inner radius increases with z

- Small radius possible with large B-field
- Goal is 0.1% X_0/layer (100 μm of Si):
  - Address electrical aspects:
    - *Very thin, low mass sensors, including forward region*
      - Integrate front-end electronics into the sensor
    - *Reduce power dissipation so less mass is needed to extract the heat*
  - Mechanical aspects:
    - *Integrated design*
    - *Low mass materials*



Vertex Detector Sensors: The Challenge

- Beam structure



- What readout speed is needed ?
  - Inner layer 1.6 MPixel sensors; Background hits significantly in excess of 1/mm^2 will give pattern recognition problems
    - *Once per bunch = 300ns per frame* : too fast
    - *Once per train ~100 hits/mm^2* : too slow
    - *5 hits/mm^2 => 50μs per frame: may be tolerable*

For SiD: cumulative number of bunches to reach hit density of 1/mm^2

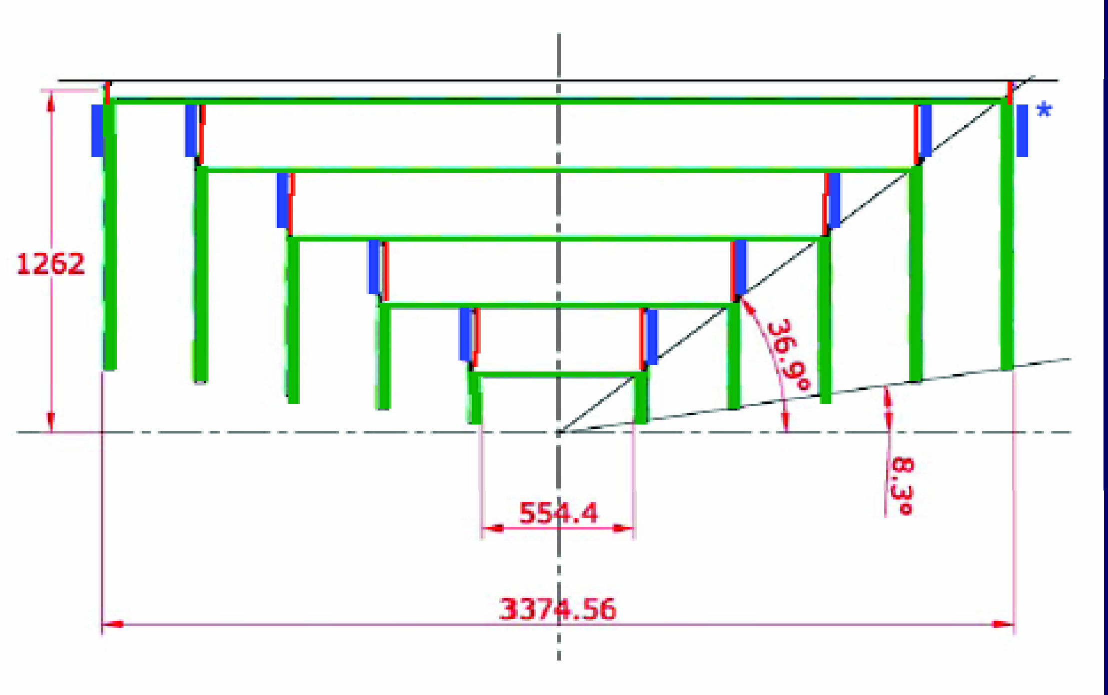
- *Layer 1: ~35*
- *Layer 2: ~250*

- Fast CCDs
  - Development well underway
  - Need to be fast (50 MHz)
  - Read out in the gaps

- Many different developments
  - MAPS
  - FAPS
  - HAPS
  - SOI
  - 3D

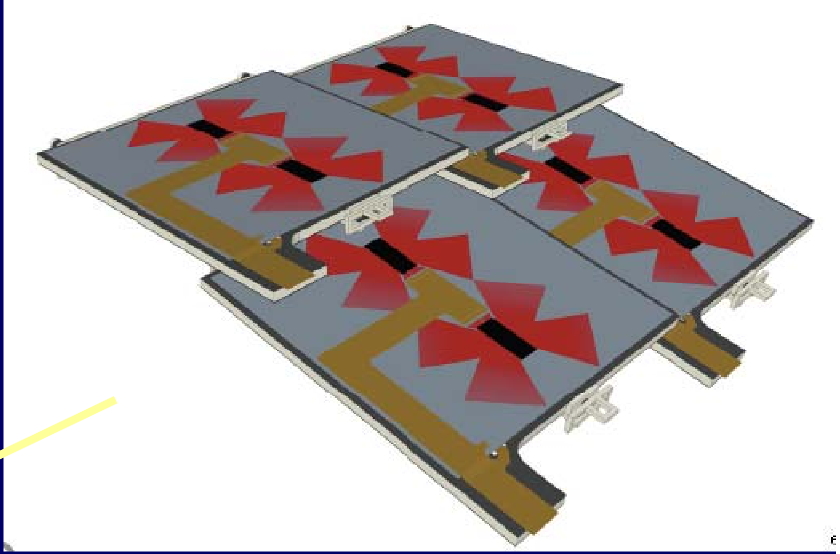
Tracker Design

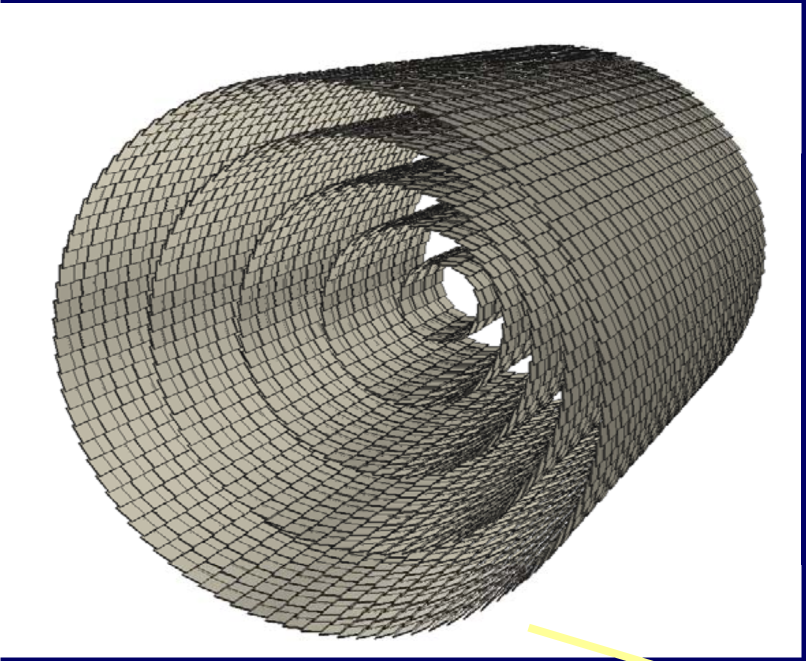
- Baseline configuration
  - Cylinders are tiled with 10x10cm^2 modules with minimal support
  - Material budget 0.8% X_0/layer
  - z-segmentation of 10 cm
  - Active volume, R_i=0.218 m, R_o=1.233 m
  - Maximum active length = 3.3 m
  - Single sided in barrel; R, ϕ in disks
  - Overlap in phi and z
  - Nested support
  - Power/Readout mounted on support rings
  - Disks tiled with wedge detectors
  - Forward tracker configuration to be optimized

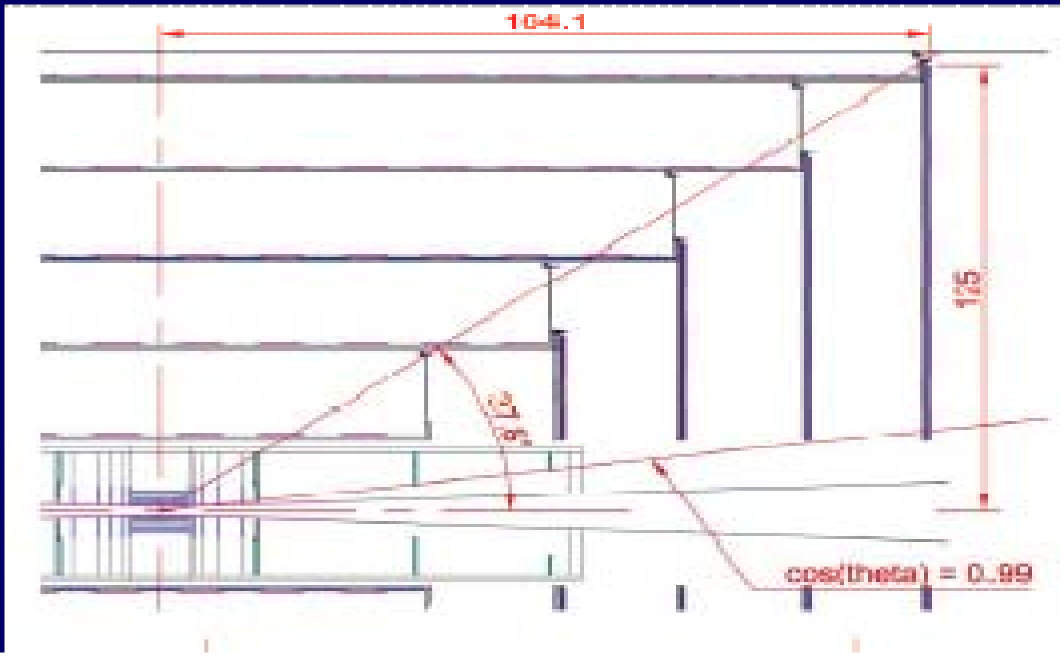


Si Sensor Module/Mechanics

- Sensor Module Tiles Tracker Cylinders, Endcaps
- Kapton cables route signals and power to endcap modules
- Next steps: FEA and Prototyping



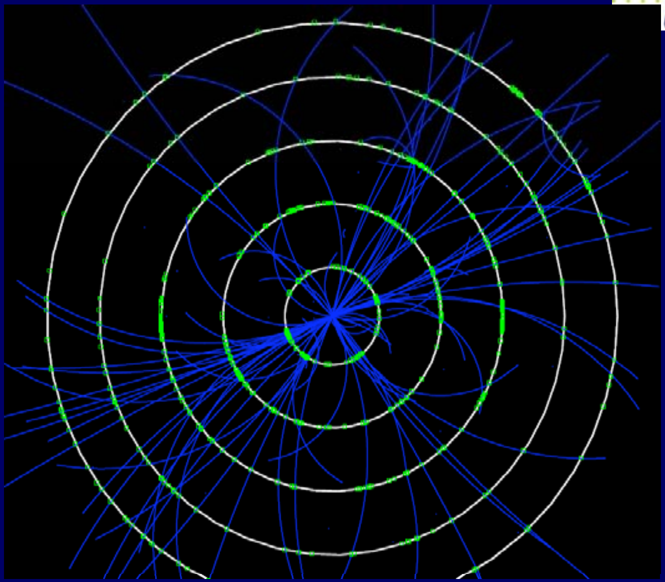


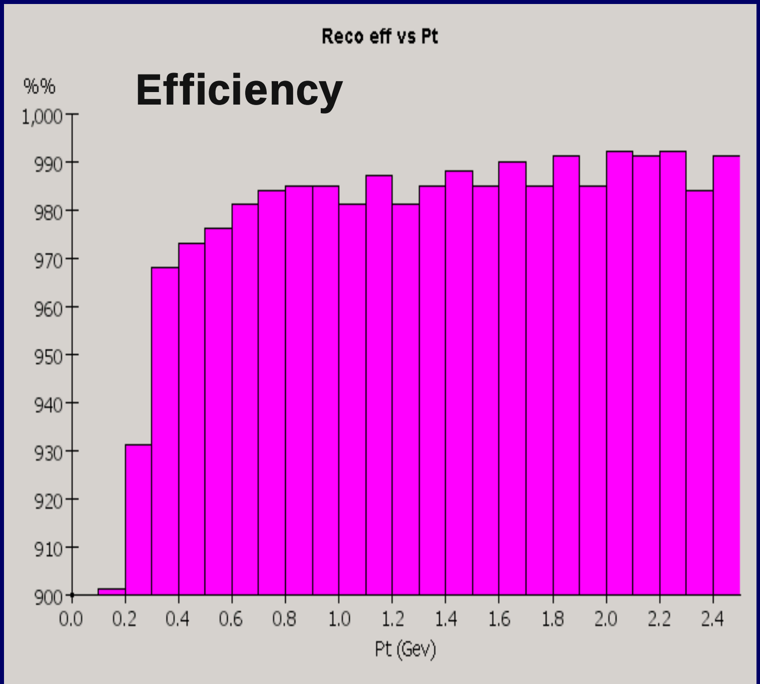


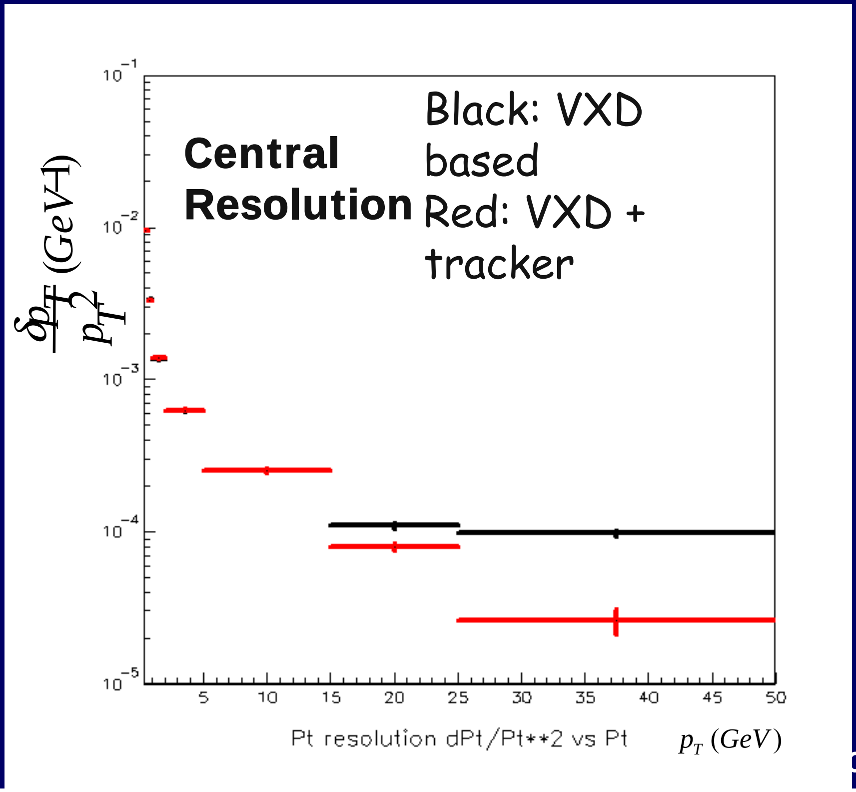
H.Weerts

Tracking Performance

- Full simulation
- Vertex detector seeded pattern recognition (3 hit combinations)
- Event Sample
  - ttbar-events
  - √s = 500 GeV
  - background included

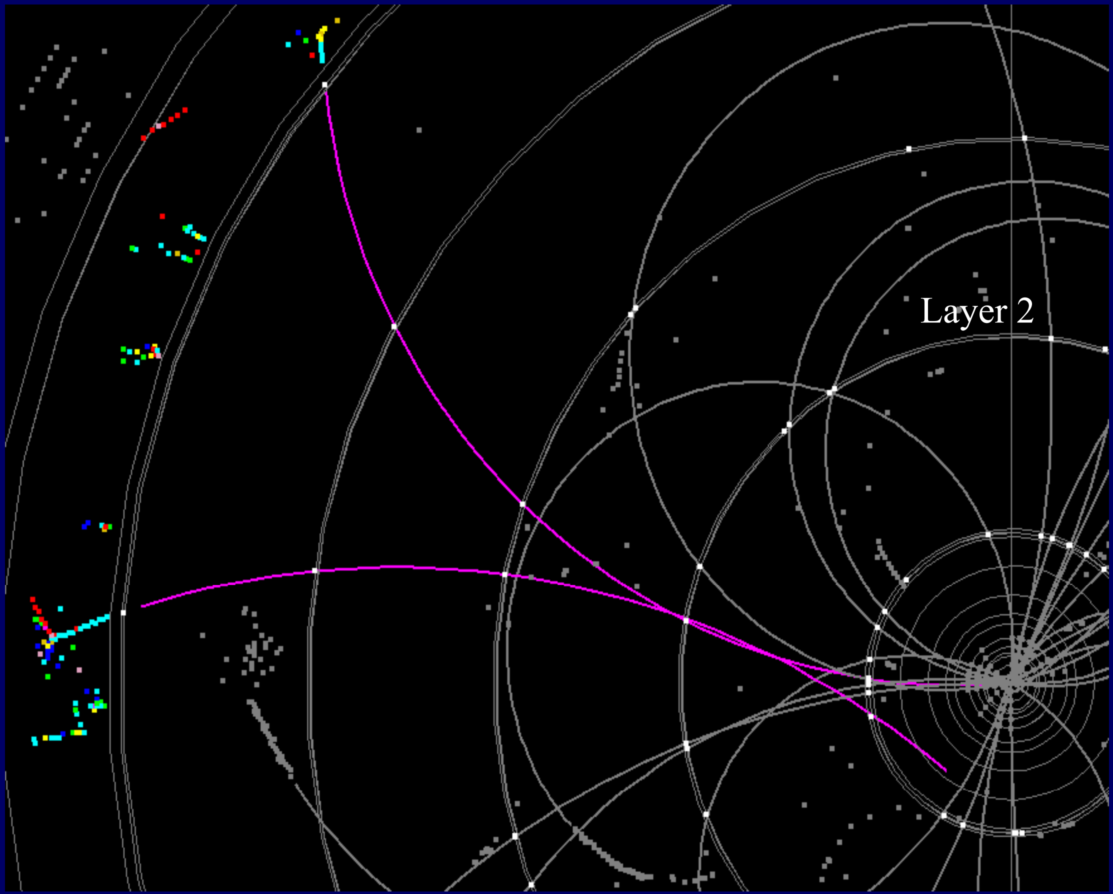




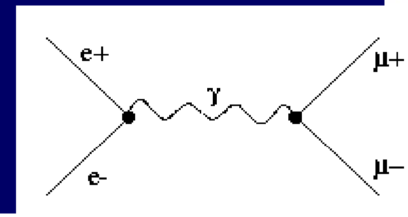


Calorimeter Tracking

- With a fine grained calorimeter, can do tracking with the calorimeter
  - Track from outside in: K^0_s and Λ or long-lived SUSY particles, reconstruct V's
  - Capture events that tracker pattern recognition doesn't find



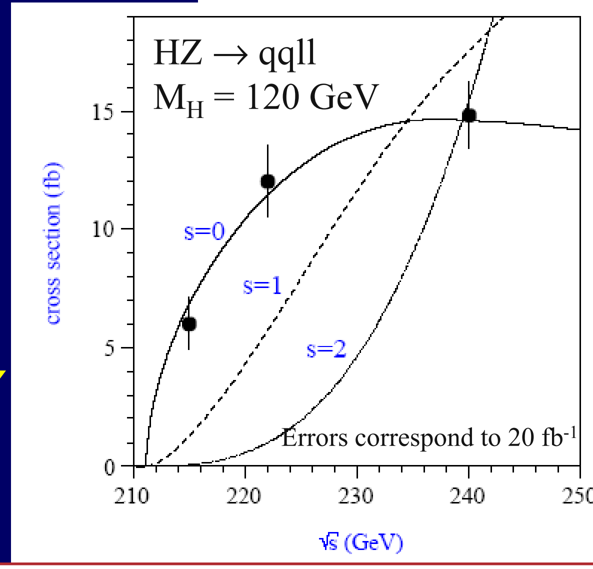
ILC Physics Characteristics



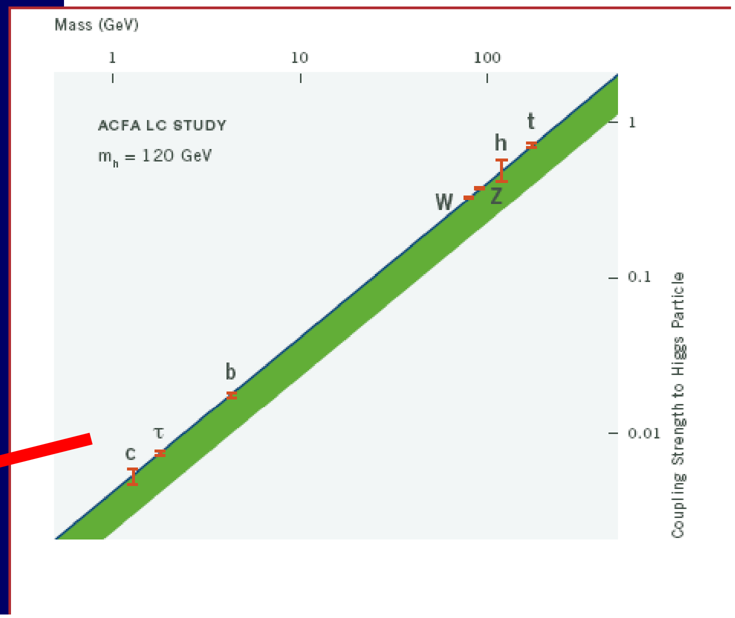
- Cross sections above Z-resonance are very small
- s-channel processes through spin-1 exchange
- Highly polarized e^- beam: ~ 80%

$$\frac{d\sigma_{f\bar{f}}}{d\cos\theta} = \frac{3}{8}\sigma_{f\bar{f}}^{tot}\left[(1-\mathcal{P}_e\mathcal{A}_e)(1+\cos^2\vartheta)+2(\mathcal{A}_e-\mathcal{P}_e)\mathcal{A}_f\cos\vartheta\right]$$

$$\mathcal{A}_f = \frac{2g_{Vf}\,g_{Af}}{g^2_{Vf}+g^2_{Af}} \qquad \mathcal{A}_b = 0.94 \quad \mathcal{A}_c = 0.67 \quad \mathcal{A}_l = 0.15$$



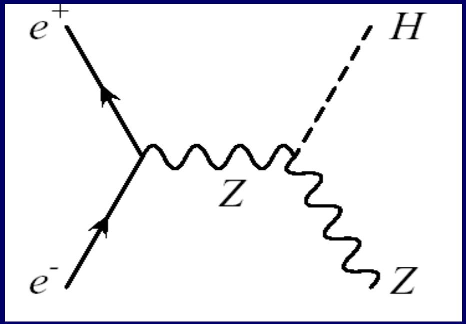
- Hermetic detectors with uniform strengths
  - Importance of forward regions
  - b/c tagging and quark identification
  - Measurements of spin, charge, mass, …
- Analyzing power of
  - Scan in center of mass energy
  - Various unique Asymmetries
    - *Forward-backward asymmetry*
    - *Left-Right Asymmetry*
    - *Largest effects for b-quarks*



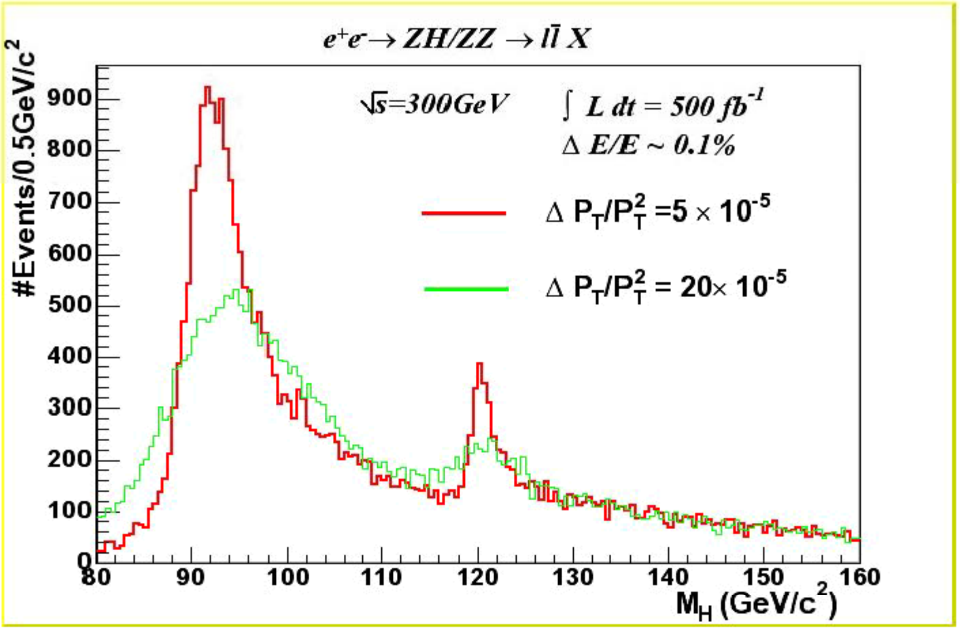
Identify all final state objects

Momentum resolution

- Benchmark measurement is the measurement of the Higgs recoil mass in the channel $e^+e^- \rightarrow ZH$
  - Higgs recoil mass resolution improves until $\Delta p/p^2 \sim 5 \times 10^{-5}$
  - Sensitivity to invisible Higgs decays, and purity of recoil-tagged Higgs sample, improve accordingly.



- *Example:*
  - $\sqrt{s}$ = 300 GeV
  - 500 fb^{-1}
  - beam energy spread of 0.1%
- *Goal:*
  - $\delta M_{11} < 0.1 \times \Gamma_Z$



Illustrates need for superb momentum resolution in tracker

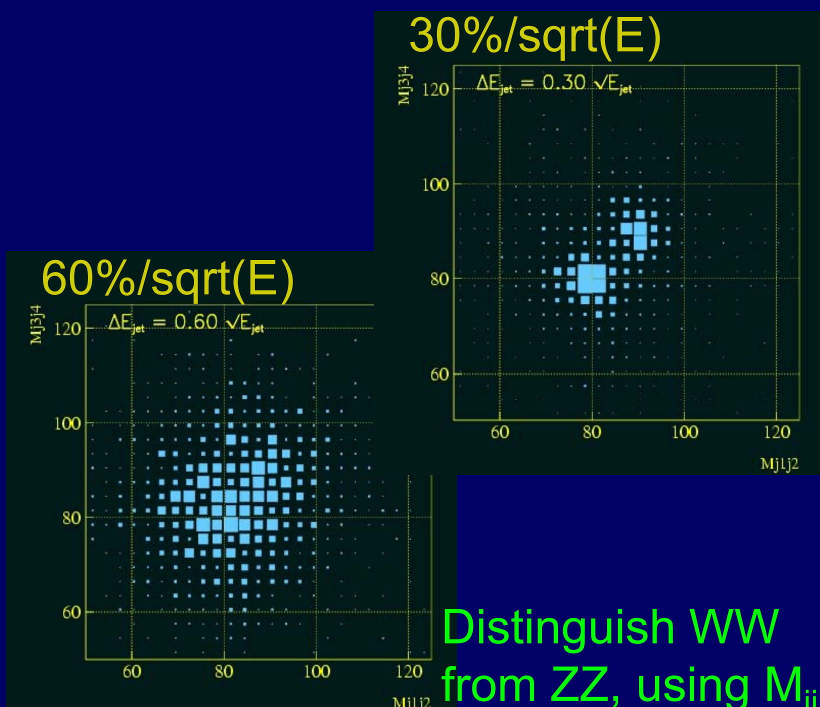
ILC requires precise measurement for jet energy/di-jet mass

Process	Vertex	Tracking	Calorimetry			Fwd		Very Fwd	Integration					Pol.
	σ_{IP}	$\delta p/p^2$	ϵ	δE	$\delta\theta,\ \delta\phi$	Trk	Cal	θ^e_{min}	δE_{jet}	M_{jj}	ℓ-Id	V^0-Id	$Q_{jet/vtx}$	
$ee \to Zh \to \ell\ell X$		x									x			
$ee \to Zh \to jjbb$	x	x	x			x				x	x			
$ee \to Zh, h \to bb/cc/\tau\tau$	x		x							x	x			
$ee \to Zh, h \to WW$	x		x		x				x	x	x			
$ee \to Zh,\ h \to \mu\mu$	x	x									x			
$ee \to Zh,\ h \to \gamma\gamma$				x	x		x							
$ee \to Zh, h \to invisible$			x			x	x							
$ee \to \nu\nu h$	x	x	x	x			x			x	x			
$ee \to tth$	x	x	x	x	x		x	x	x		x			
$ee \to Zhh,\ \nu\nu hh$	x	x	x	x	x	x	x		x	x	x	x	x	x
$ee \to WW$										x			x	
$ee \to \nu\nu WW/ZZ$						x	x		x	x	x			
$ee \to \tilde{e}_R\tilde{e}_R$ (Point 1)		x						x			x			x
$ee \to \tilde{\tau}_1\tilde{\tau}_1$	x	x						x						
$ee \to \tilde{t}_1\tilde{t}_1$	x	x							x	x		x		
$ee \to \tilde{\tau}_1\tilde{\tau}_1$ (Point 3)	x	x			x	x	x	x	x					
$ee \to \tilde{\chi}^0_2\tilde{\chi}^0_3$ (Point 5)									x	x				
$ee \to HA \to bbbb$	x	x								x	x			
$ee \to \tilde{\tau}_1\tilde{\tau}_1$			x											
$\chi^0_1 \to \gamma + \not{E}$					x									
$\tilde{\chi}^\pm_1 \to \tilde{\chi}^0_1 + \pi^\pm_{soft}$			x					x						
$ee \to tt \to 6\ jets$	x		x						x	x	x			
$ee \to ff\ [e, \mu, \tau; b, c]$	x		x				x		x		x		x	x
$ee \to \gamma G$ (ADD)				x	x			x						x
$ee \to KK \to f\bar{f}$		x									x			
$ee \to ee_{fwd}$						x	x	x						
$ee \to Z\gamma$		x		x	x	x	x							

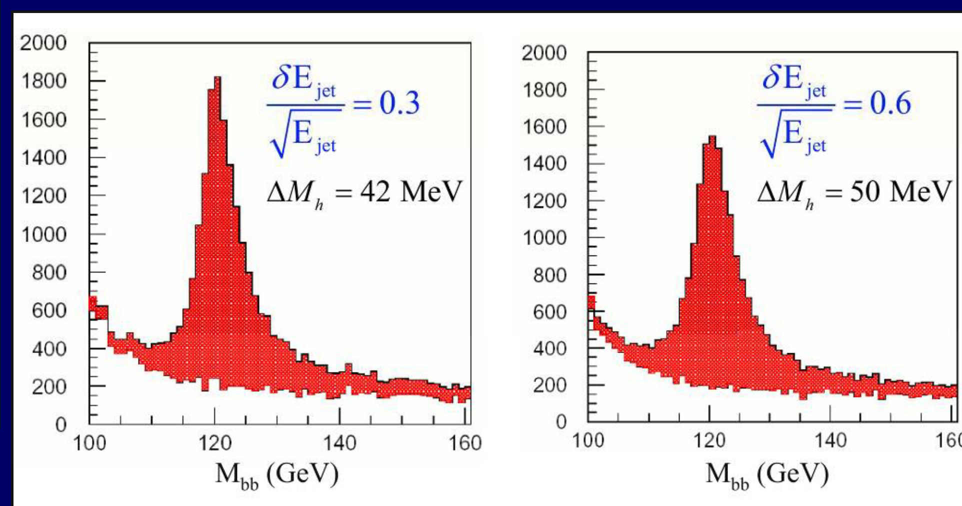
- At LEP, ALEPH got a jet energy resolution of ~60%/sqrt(E)
  - Achieved with Particle Flow Algorithm (Energy Flow, at the time) on a detector not optimized for PFA
- This is not good enough for ILC physics program, we need to do a lot better!

ILC goal for jet energy resolution

- ILC goal: distinguish W, Z by their di-jet invariant mass
  - Well known expression: jet energy resolution ~ 30%/sqrt(E)
  - More realistic goal (from physics requirement): flat 3-4% resolution
  - The two are about equivalent for M_{jj} ~100 GeV produced at rest
- Most promising approach: Particle Flow Algorithm (PFA) + detector optimized for PFA (← a whole new approach!)

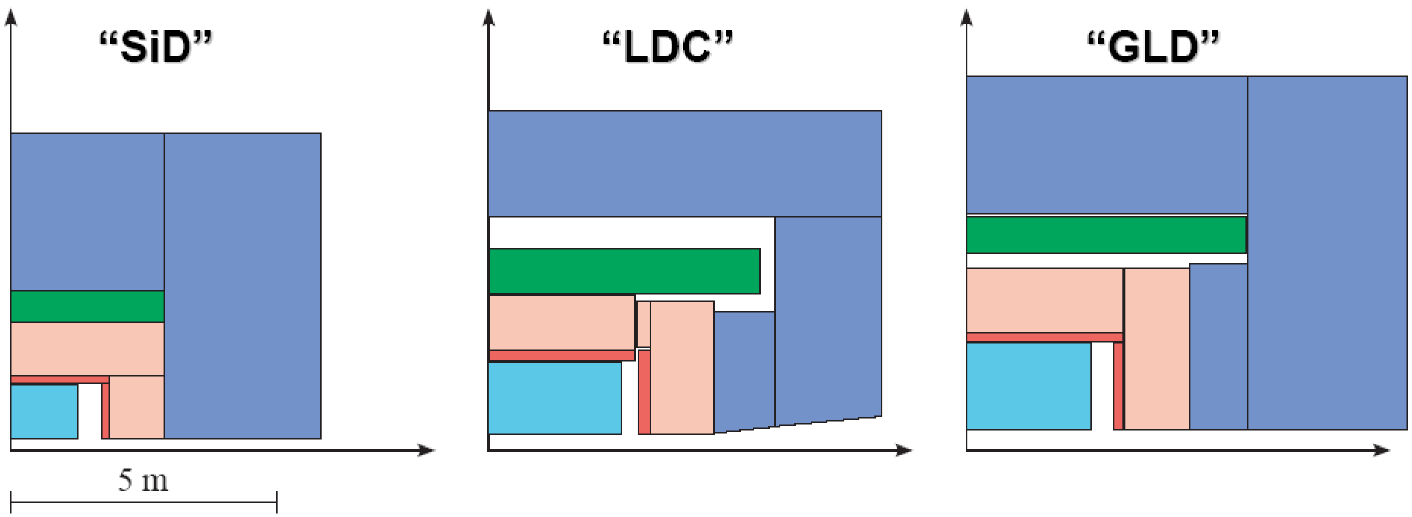


Distinguish WW from ZZ, using M_{jj}



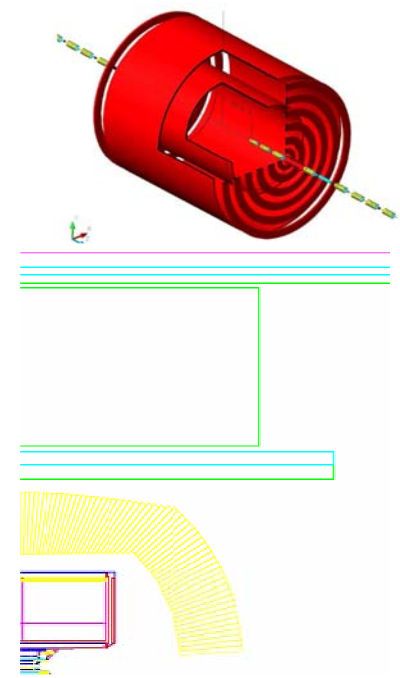
$e^+e^- \rightarrow ZH \rightarrow qqbb$ @ 350GeV, 500fb-1
M_{jj} of two b-jets for different jet energy resolution.
→ **40% luminosity gain**

Detector Concepts



- Main Tracker
- EM Calorimeter
- Had Calorimeter
- Cryostat / Solenoid
- Iron Yoke / Muon System

"4th "



- SiD: Silicon Detector — SiD: **B R**^{2}
  - Small, 'all' silicon
- LDC: Large Detector Concept — LDC: **B R**^{2}
  - TPC based
- GLD: Global Large Detector — GLD: **B R**^{2}

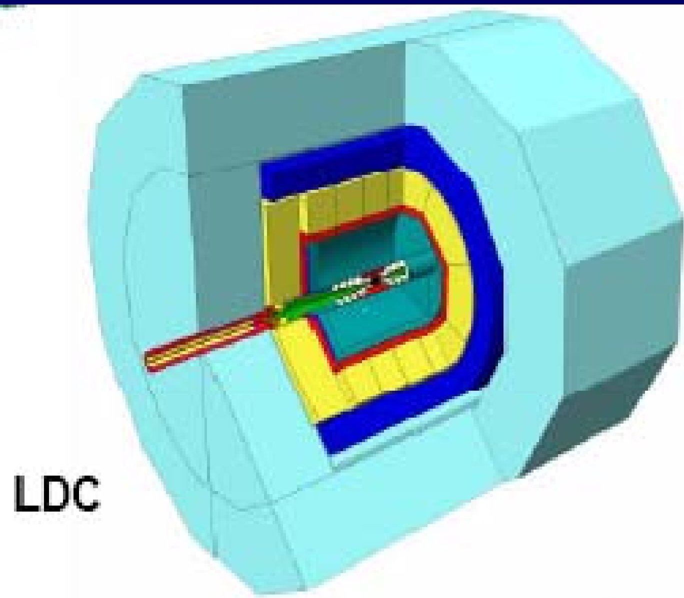
Different: no PFA; solenoid arrangement

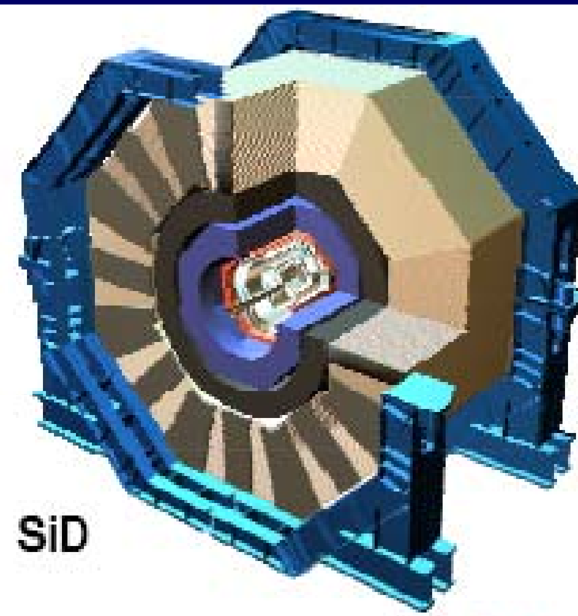
These detector concepts studied worldwide, with regional concentrations

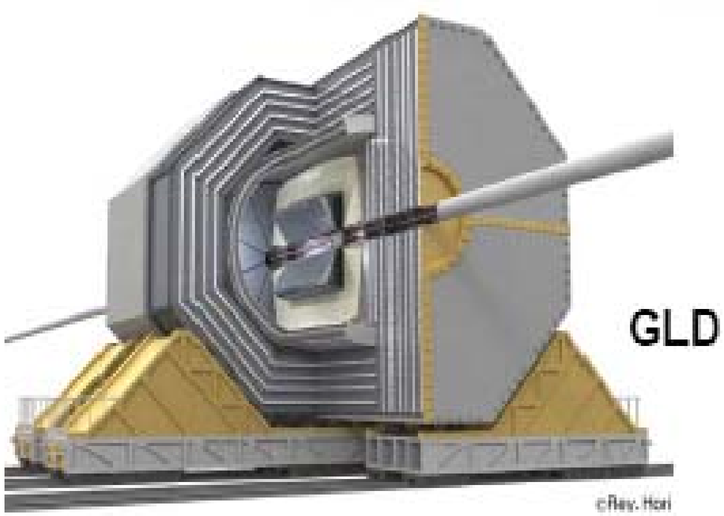
Recently submitted "Detector Outline Documents" (~150 pages each)

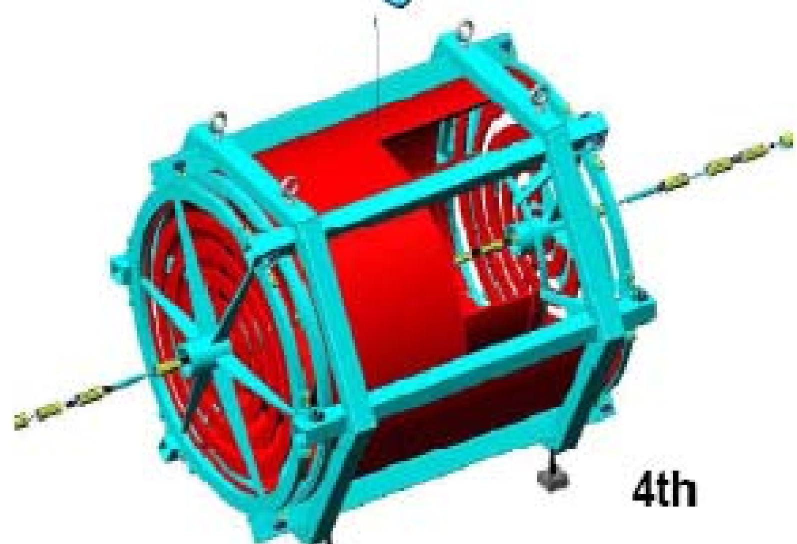
Physics goals and approach all similar. Approach of "4" different

Current detector concepts being pursued



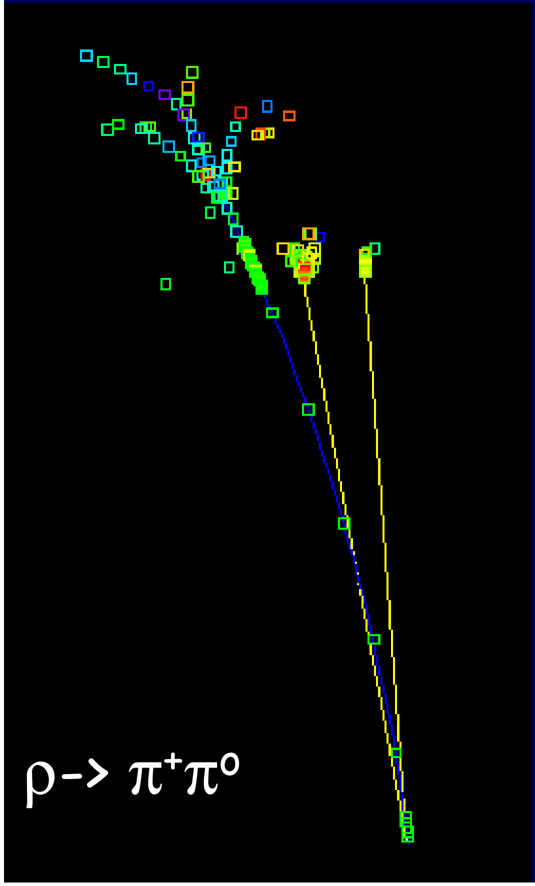




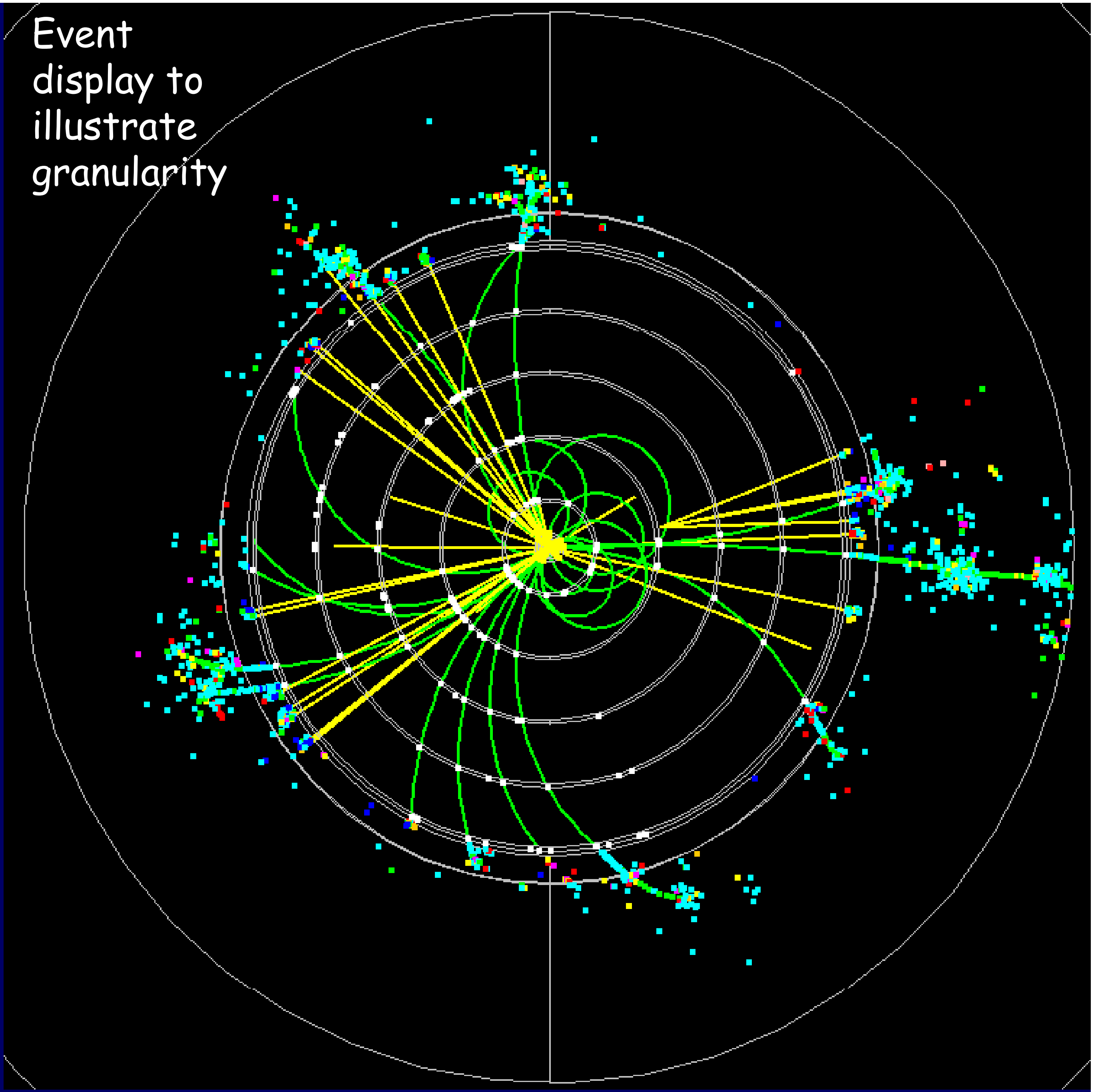


Very fine detail

More detail

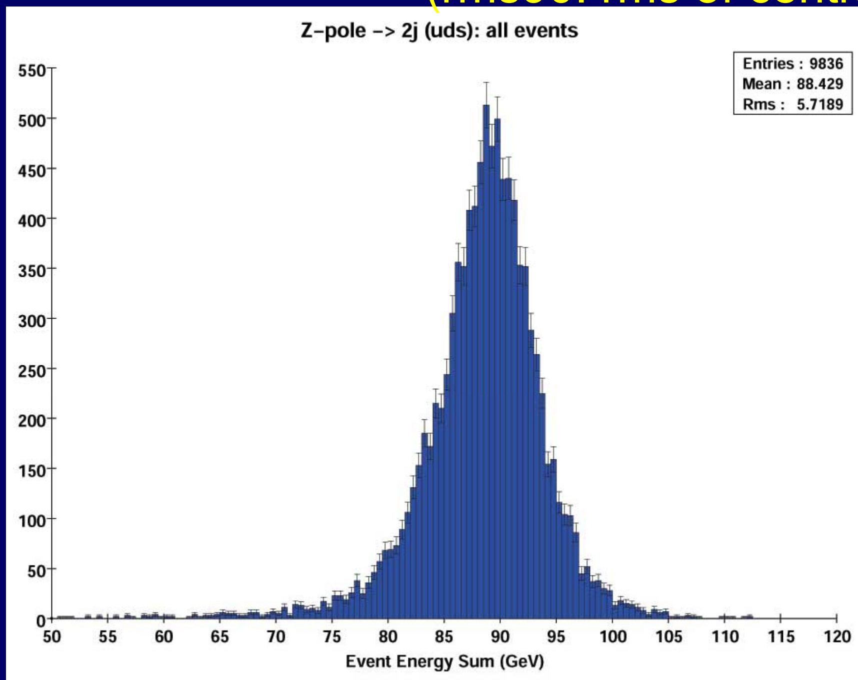


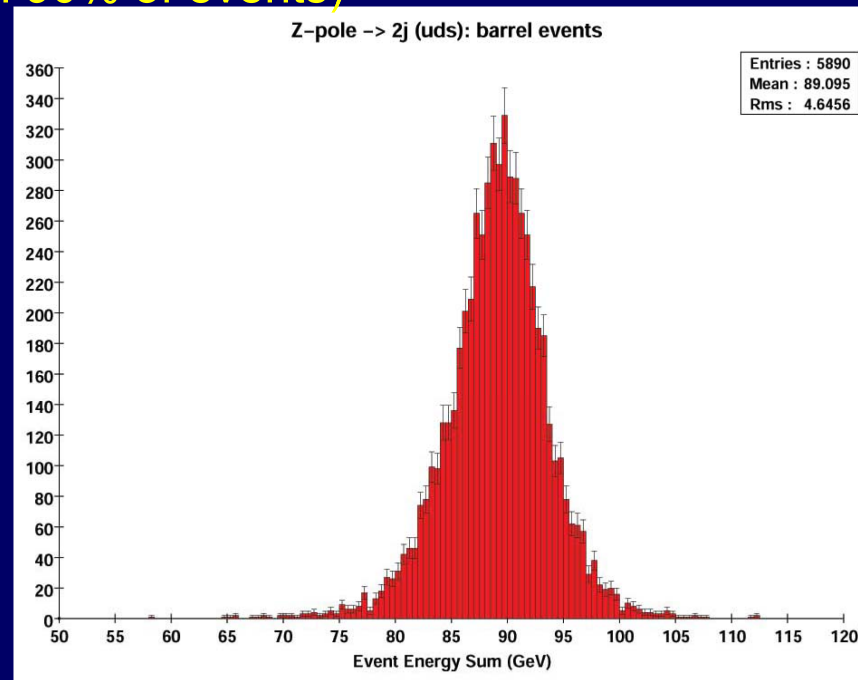
Event display to illustrate granularity



SiD PFA performance: $e^+e^- \rightarrow$ qqbar(uds) @ 91GeV

(rms90: rms of central 90% of events)





All events, no cut

Mean 88.43 GeV
RMS 5.718 GeV
RMS90 3.600 GeV
[42.6 %/sqrt(E) or σ_{Ejet} /Ejet=6.4 %]

Barrel events (cos(theta[Q]) < 1/sqrt(2))

Mean 89.10 GeV
RMS 4.646 GeV
RMS90 3.283 GeV
[34.7 %/sqrt(E) or σ_{Ejet} /E_{jet}=5.2 %]

Still not quite 30%/sqrt(E) or 3-4% yet, but close now

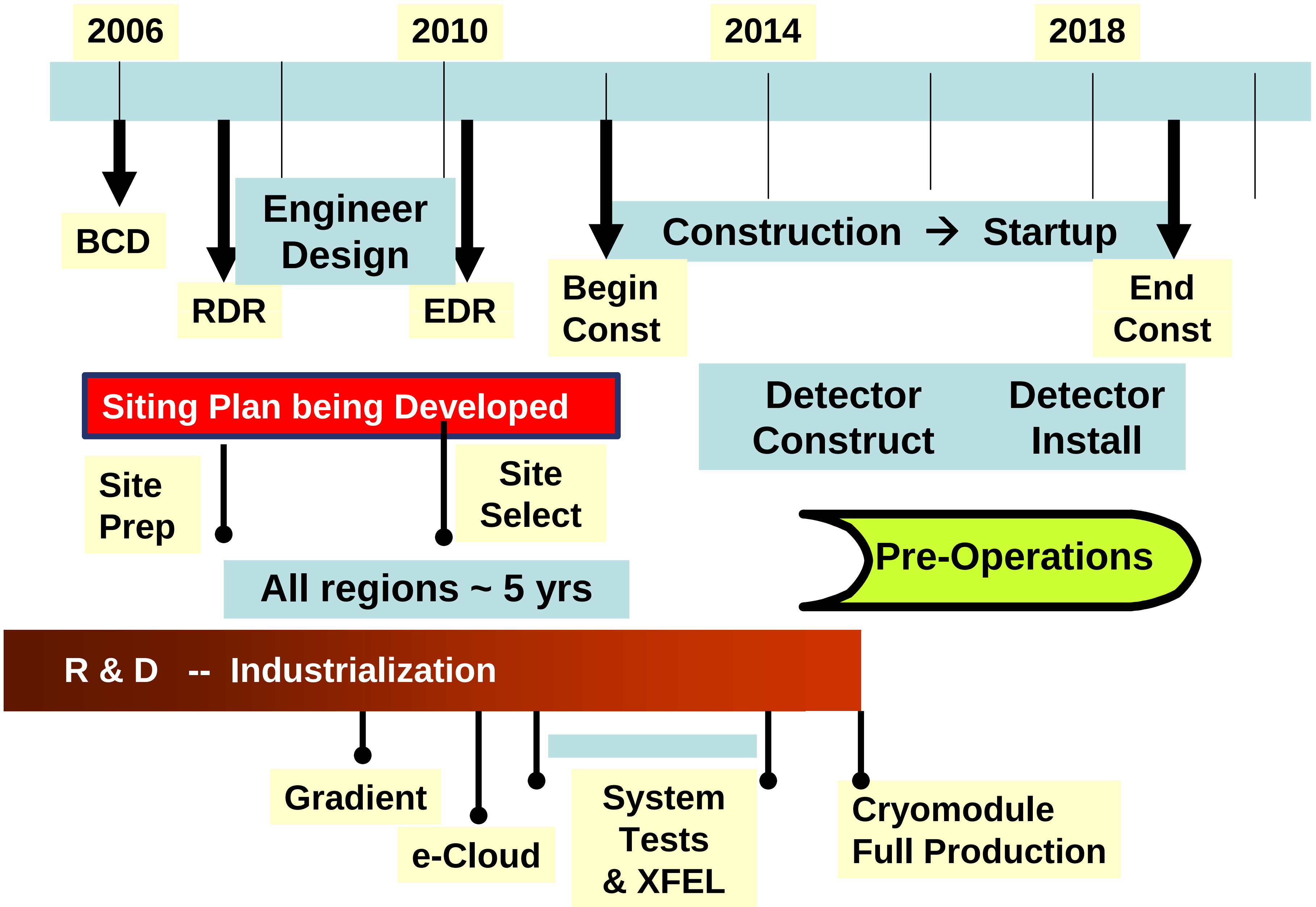
PFA performance: comparison

rms_{90}(GeV)	Detector model	Tracker outer R	Cal thickness	Shower model	Dijet 91GeV	Dijet 200GeV	Dijet 360GeV	Dijet 500GeV	ZZ 500GeV[b]
ANL(I)+SLAC	SiD	1.3m	~5 λ	LCPhys	3.2/9.9[a]				
ANL(II)					3.3	9.1		27.6	
Iowa									5.2[c]
NIU					3.9/11.[a]				
PandoraPFA*	LDC	1.7m	~7 λ	LHEP	2.8	4.3	7.9	11.9	___
GLD PFA*	GLD	2.1m	5.7 λ	LCPhys	2.8	6.4	12.9	19.0	___
30%/sqrt(E)	___	___	___	___	2.86	4.24	5.69	6.71	(?)
3%					1.93	4.24	7.64	10.61	(?)
4%					2.57	5.67	10.18	14.14	(?)

* From talks given by Mark Thomson and Tamaki Yoshioka at LCWS'07
a) 2 Gaussian fit, (central Gaussian width/2nd Gaussian width)
b) Z_1→nunubar, Z_2→qqbar (uds)
c) Di-jet mass residual [= true mass of Z2 - reconstructed mass of Z2]

- A fair comparison between all PFA efforts is NOT possible at the moment
- PandoraPFA (M. Thomson) achieved ILC goal in some parameter space
- SiD efforts: 30%/sqrt(E) or 3-4% goal has not been achieved yet, but we made a lot of progress during the last few years and we are much closer now

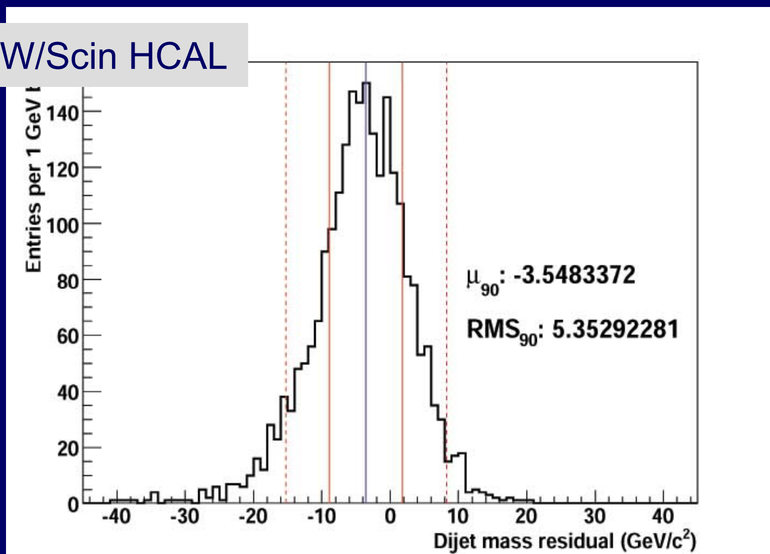
ILC Technically Driven Timeline



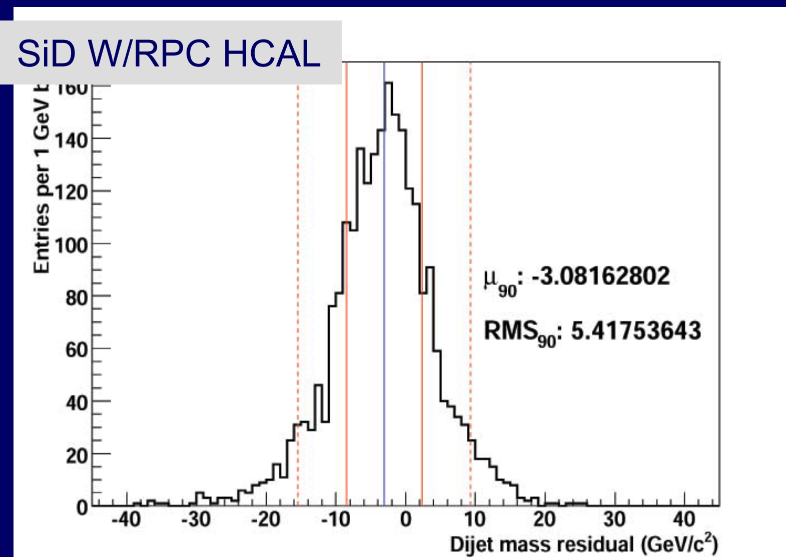
PFA performance: $e^+e^- \rightarrow ZZ$ @ 500GeV

- $Z_1 \rightarrow$ nunubar, $Z_2 \rightarrow$ qqbar (uds)
- Di-jet mass residual = (true mass of Z_2 - reconstructed mass of Z_2)
  - μ_{90}: mean of central 90% events
  - rms_{90}: rms of central 90% events

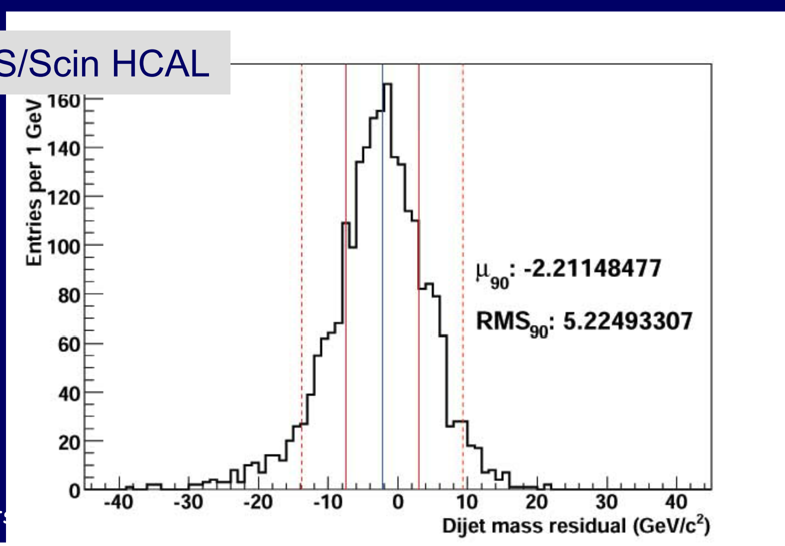
SiD W/Scin HCAL



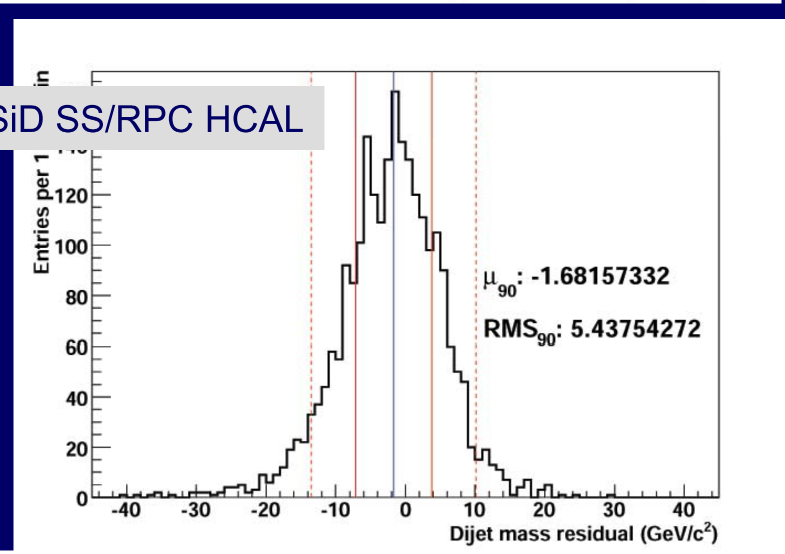
SiD W/RPC HCAL



SiD SS/Scin HCAL



SiD SS/RPC HCAL



Difference in “energy frontier” experiments (ee)

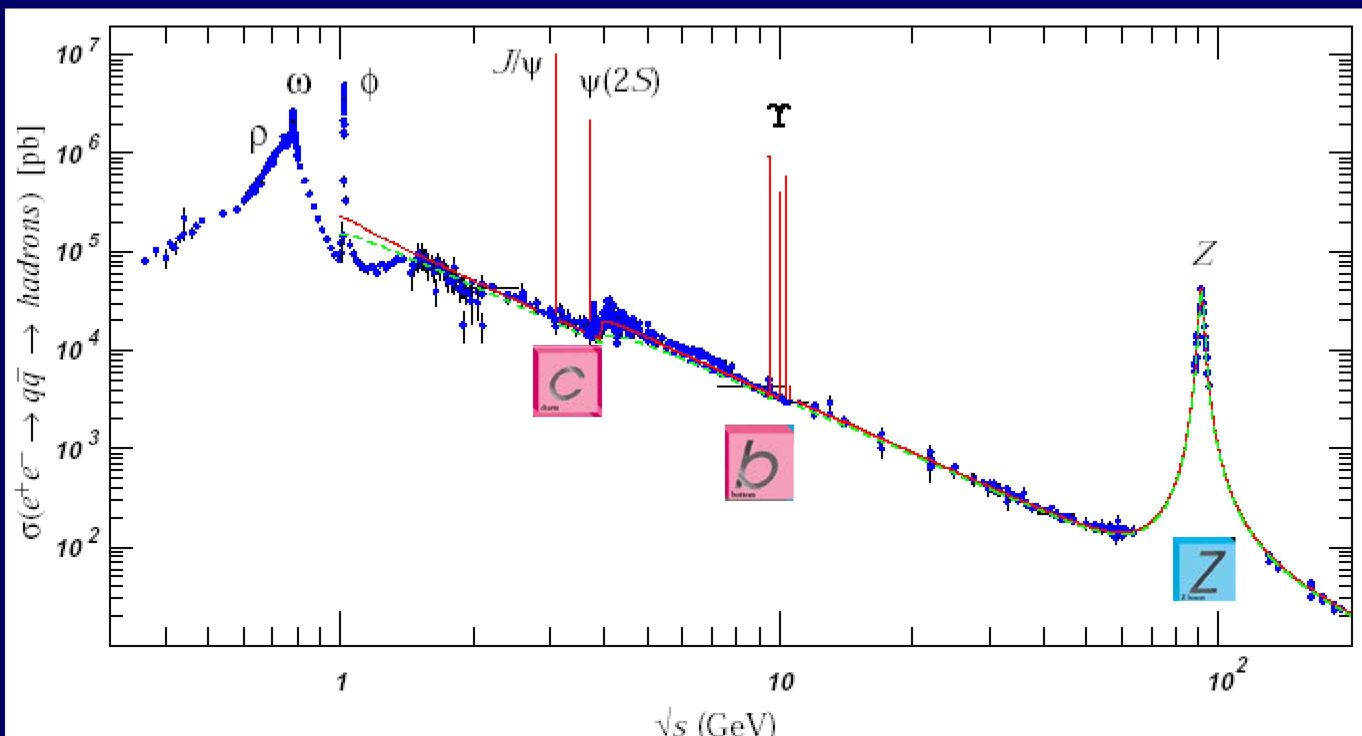
Two main kind of machines:

1)electron –positron (e^+e^- annihilation) colliders
2)proton-(anti)proton collider (Tevatron, future LHC)

e^+e^- annihilation:

Total energy of e^+ and e^- available as E_{cms} or $\sqrt{s}$
Scan over resonances

Maximum achieved for E_{cms} =192 GeV



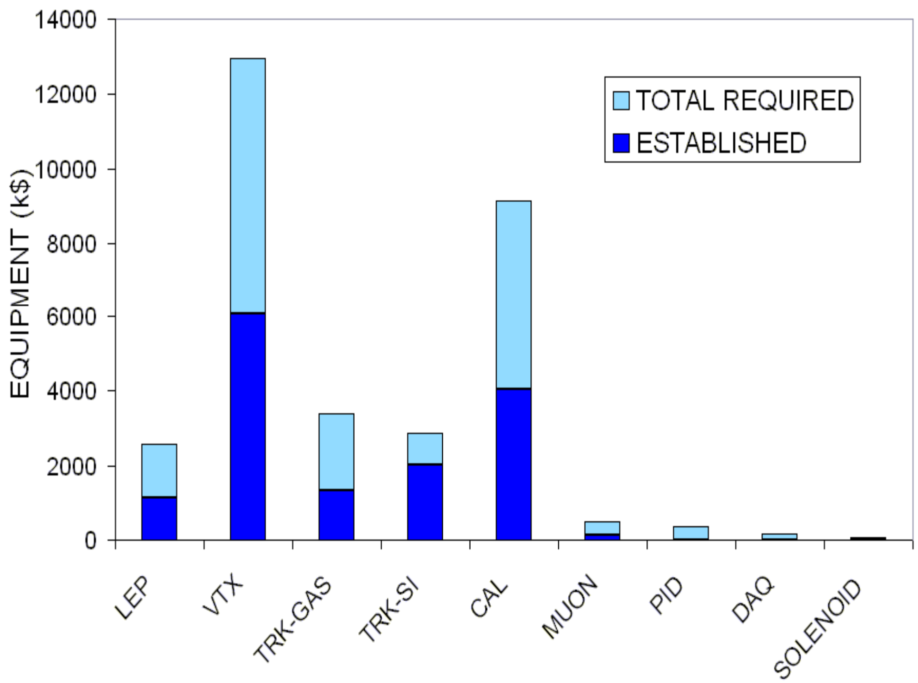
Energy range covered by e^+e^- colliders

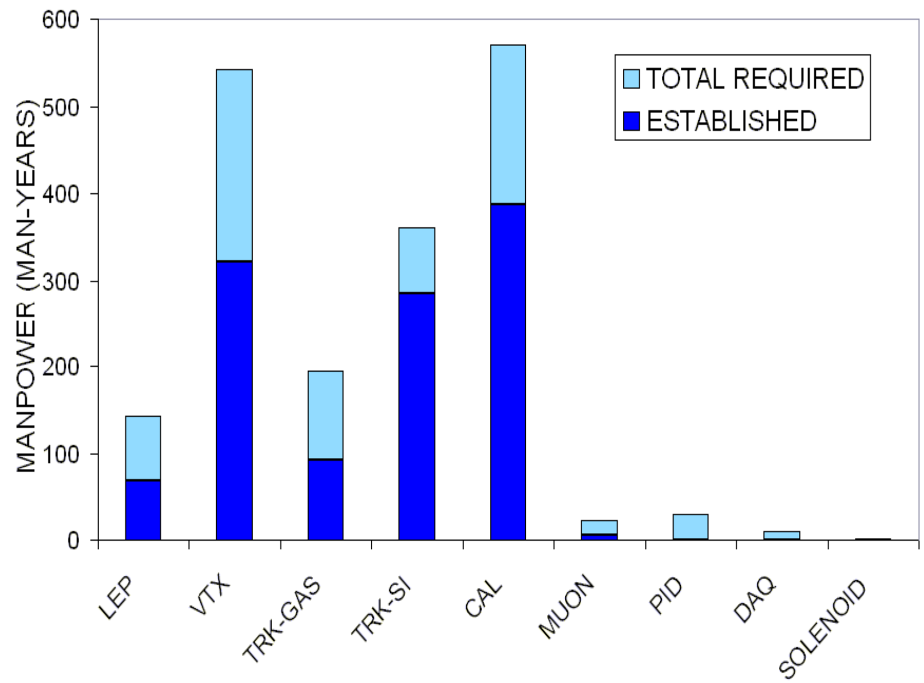
Very clean environment; precision physics

World Wide Study R&D Panel

- The World Wide Study Organizing Committee has established the Detector R&D Panel to promote and coordinate detector R&D for the ILC. Worldwide activities at:
  - https://wiki.lepp.cornell.edu/wws/bin/view/Projects/WebHome

ILC detector R&D needs: funded & needed





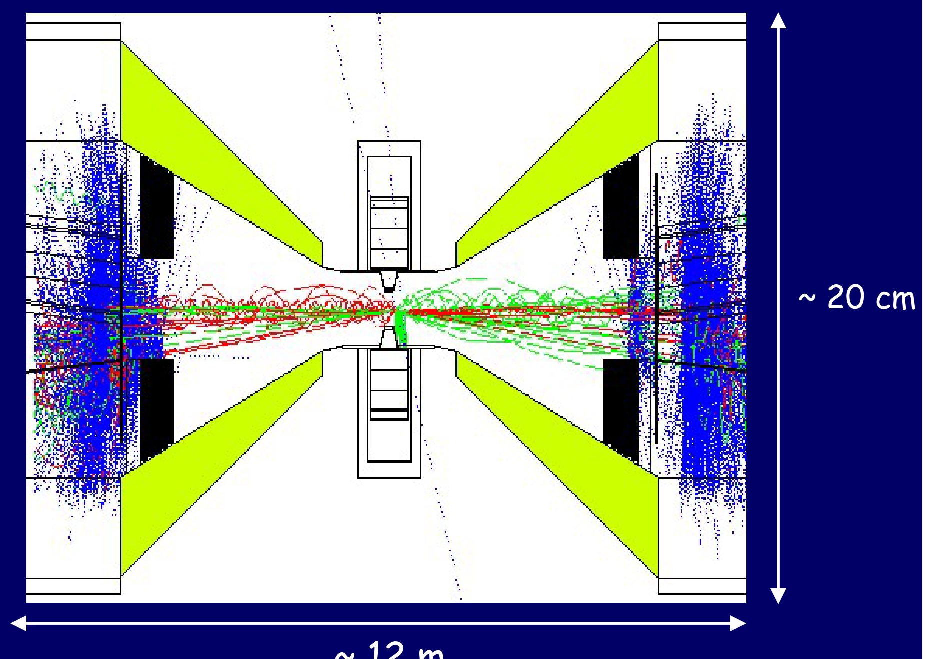
Urgent R&D support levels over the next 3-5 years, by subdetector type. 'Established' levels are what people think they will get under current conditions, and 'total required' are what they need to establish proof-of-principle for their project.

Backgrounds

- "At the ILC the initial state is well defined, compared to LHC, but…."
- Backgrounds from the IP
  - Disrupted beams
    - *Extraction line losses*
  - Beamstrahlung photons
  - e^+e^- - pairs

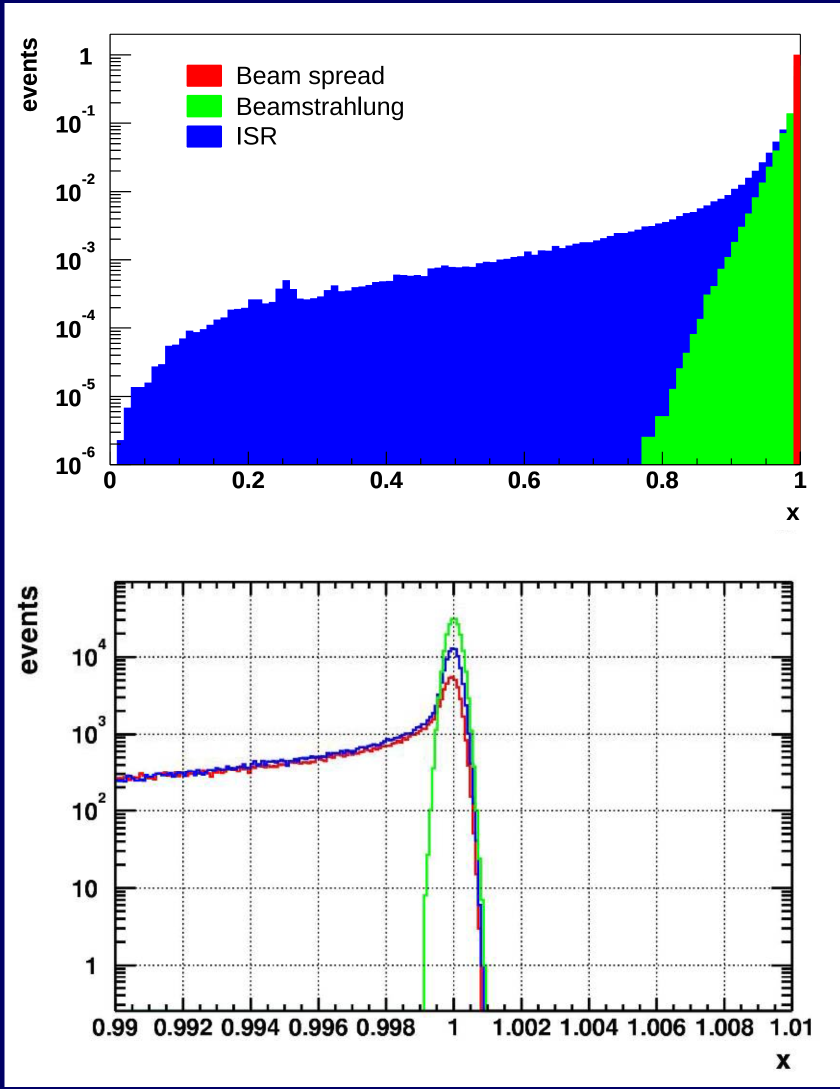
√s (GeV)	Beam	# e^+e^- per BX	Total Energy (TeV)
500	Nominal	98 K	197
1000	Nominal	174 K	1042

- Backgrounds from the machine
  - Muon production at collimators
  - Synchrotron radiation
  - Neutrons from dumps, extraction lines



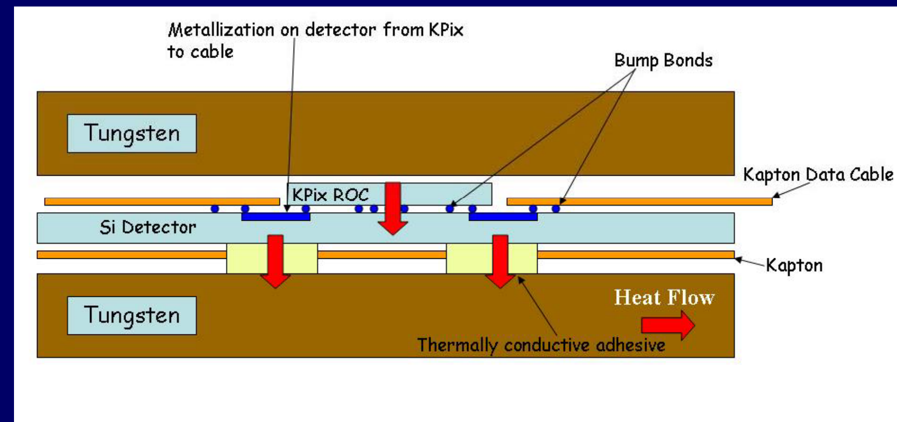
- Variation of the centre of mass energy, due to very high current, collimated beams: three main sources
  - Accelerator energy spread
    - *Typically ~0.1%*
  - Beamstrahlung
    - *0.7% at 350 GeV*
    - *1.7% at 800 GeV*
  - Initial state radiation (ISR)
    - *Calculable to high precision in QED*
    - *Complicates measurement of Beamstrahlung and accelerator energy spread*
    - *Impossible to completely factorize ISR from FSR in Bhabha scattering*
- But, there are many more challenges

Need: Reconstruct complete final state



EM Calorimeter Layout

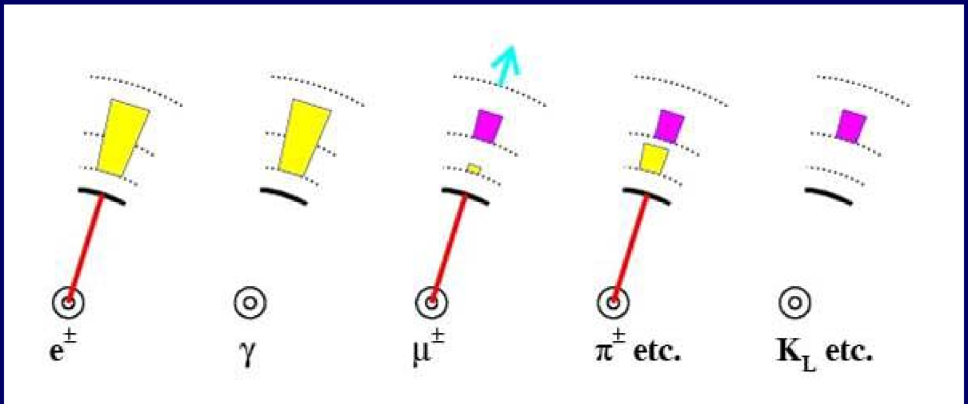
- Tile W with hexagonal 6" wafers
  - ~ 1300 m^2 of Si
  - 5x5 mm^2 pads
  - Readout by single chip
  - 1024 channels, bump-bonded
- Signals
  - Single MIP with S/N > 7
  - Dynamic range of 2500 MIPs
  - < 2000 e^- noise
- Power
  - < 40 mW/wafer through power pulsing !
  - Passive edge cooling



- Readout with kPix chip
  - 4-deep buffer (low occupancy)
  - Bunch crossing time stamp for each hit
- Testing
  - Prototype chip in hand with 2x32 channels
  - Prototype sensors in hand
  - Test beam foreseen in 2006

Calorimetry

- Goal is jet energy resolution of 30%/√E
- Current paradigm is that this can be achieved with Particle Energy Flow
- A particle flow algorithm is a recipe to improve the jet energy resolution by minimizing the contribution from the hadronic energy resolution by reducing the function of a hadron calorimeter to the measurement of neutrons and K^0's only
  - Measure charged particles in the tracking system
  - Measure photons in the ECAL
  - Measure neutral hadrons in the HCAL (+ ECAL) by subtracting calorimeter energy associated with charged hadrons



Particles in jets	Fraction of energy	Measured with	Resolution $[\sigma^2]$
Charged	~ 65 %	Tracker	Negligible
Photons	~ 25 %	ECAL with 15%/√E	$0.07^2\ E_{jet}$
Neutral Hadrons	~ 10 %	ECAL + HCAL with 50%/√E	$0.16^2\ E_{jet}$

} ~20%/√E

Why ILC detector R&D ?

ILC

bunch spacing	337 nsec
#bunch/train	2820
length of train	950 μsec
#train/sec	5 Hz
train spacing	199 msec
crossing angle	0-20 mrad (25 for γγ)

From a naïve perspective looks like simple problem

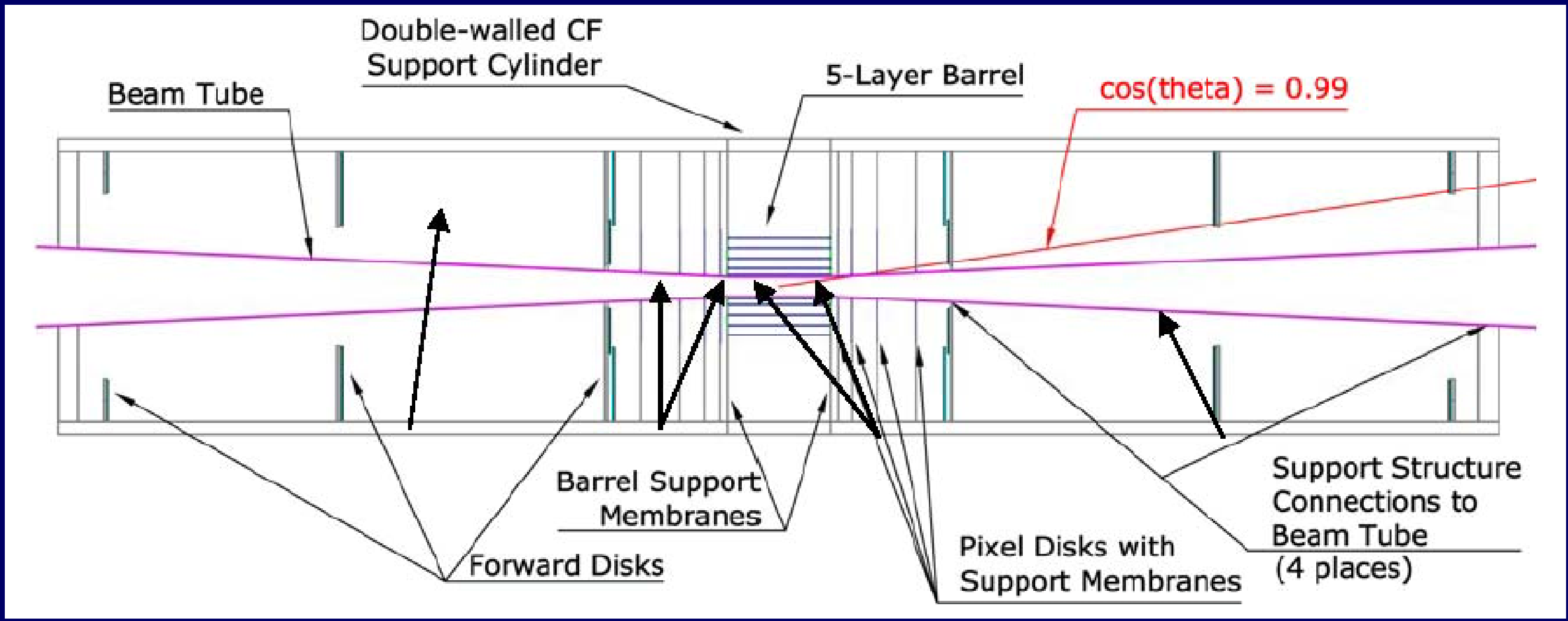
Extrapolating from LHC

	LHC	ILC
Bunch Crossing	25 ns (40 MHz); DC	337 ns 0.5% duty cycle
Triggering: L1, L2, and L3	40 MHz → 1 kHz → 100 Hz	No hardware trigger ~ 100 Hz Software
Radiation	1-100 MRad/yr	≤ 10 kRad/yr
Physics Occupancy Per bunch	23 min. bias; 100 tracks	0.3 γγ → hadrons; 2 tracks

But there are other factors which require better performance…..

Vertex detector

A lot of effort going into mechanical/electrical design considerations for vertex detector and tracking system



Example of current thinking