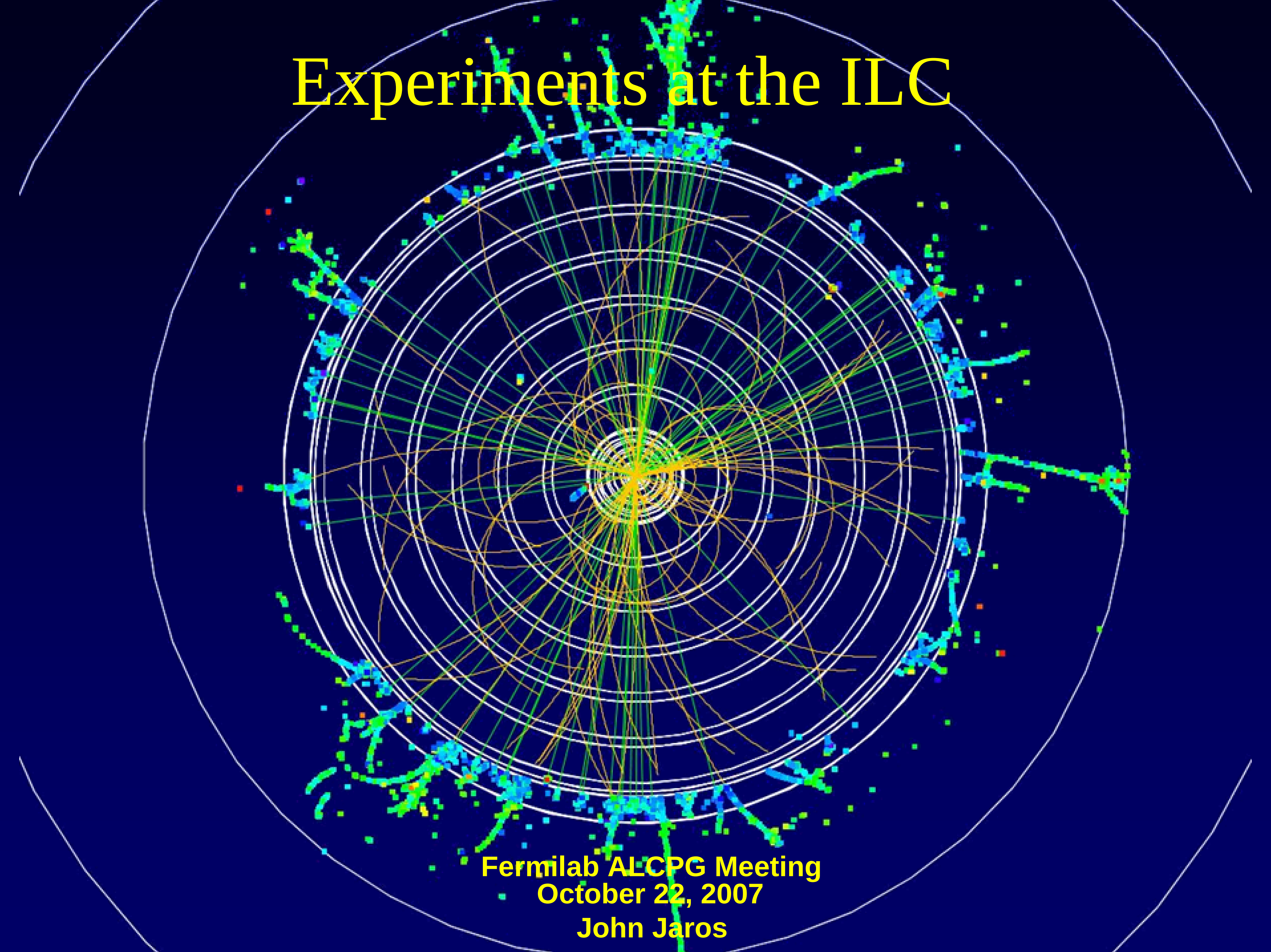
Experiments at the ILC



Fermilab ALCPG Meeting
October 22, 2007
John Jaros

ILC Physics Challenges Detector Design

Not just a LEP/SLC or LHC Detector

Physics Process	Measured Quantity	Critical System	Critical Detector Characterstic	Required Performance
ZHH $HZ \to q\bar{q}b\bar{b}$ $ZH \to ZWW^*$ $\nu\bar{\nu}W^+W^-$	Triple Higgs Coupling Higgs Mass $B(H \to WW^*)$ $\sigma(e^+e^- \to \nu\bar{\nu}W^+W^-)$	Tracker and Calorimeter	Jet Energy Resolution, $\Delta E/E$	Jet Energy Resolution $\Delta E/E$ = 3-4%
$ZH \to \ell^+\ell^- X$ $\mu^+\mu^-(\gamma)$ $ZH + H\nu\nu \to \mu^+\mu^- X$	Higgs Recoil Mass Luminosity Weighted E_{cm} $B(H \to \mu^+\mu^-)$	Tracker	Charged Particle Momentum Res., $\Delta p_t/p_t^2$	Momentum Resolution $\Delta p/p^2 = 10^{-5}$ [GeV^{-1}]
$HZ, H \to b\bar{b}, c\bar{c}, gg$ $b\bar{b}$	Higgs Branching Fractions b quark charge asymmetry	Vertex Detector	Impact Parameter, δ_b	Impact Parameter Resolutio $\Delta\delta_b = 5 \oplus 10/p \sin^{3/2}\theta$ [μm]
SUSY, eg. $\tilde{\mu}$ decay	$\tilde{\mu}$ mass	Tracker, Calorimeter	Momentum Res., hermeticity	Solid Angle Coverage $\Delta\Omega = 4\pi - \varepsilon$

Present studies have quantified the benefits of excellent performance

Challenges for Calorimetry

What Jet Energy Resolution do we Need?

Clean identification of W's, Z's, …→ dijet mass resolution ≤ few GeV.

$$M_{12}^{2} \approx 2E_1E_2\left(1-\cos\theta_{12}\right)$$

$$\frac{dM_{12}}{M_{12}} \approx \frac{1}{2}\left[\frac{dE_1}{E_1} \oplus \frac{dE_2}{E_2} \oplus \ldots\right]$$

Requiring $\sigma \sim \Gamma_Z$, sets dM/M = 2.5/92 = 2.7 %.

$\Rightarrow dE_{jet}/E_{jet} = \sqrt{2}\,(2.7\%) = 3.8\ \%$, independent of E_{jet}.

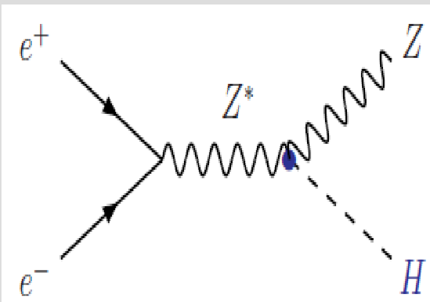
This is roughly comparable to the goal often cited,
$dE_{jet}/E_{jet} = 30\%/\sqrt{E(\text{GeV})}$, for $E_{jet} \leq 100$ GeV.

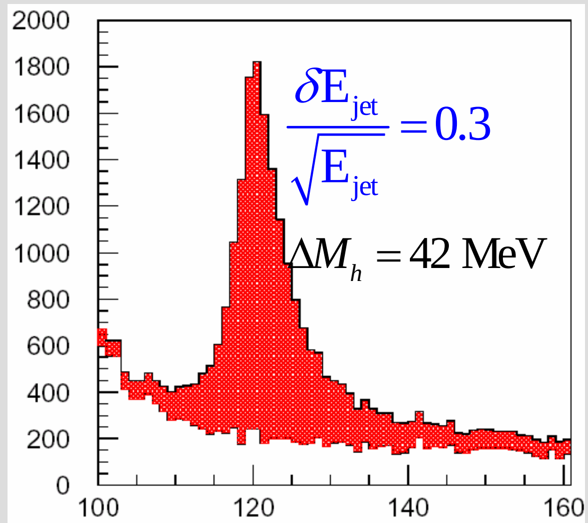
It is ~2 x better than existing calorimeters!

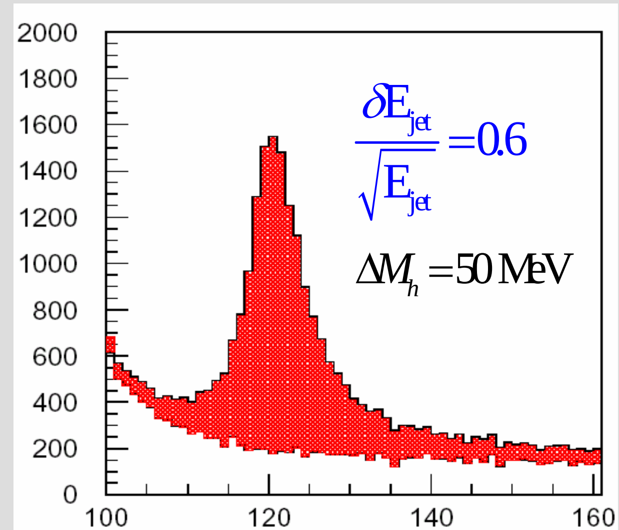
Challenges for Calorimetry

Good Jet Energy Resolution is worth 40% more integrated luminosity

- Improved Accuracy: Higgs mass from $e^+e^- \rightarrow ZH \rightarrow qqbb$

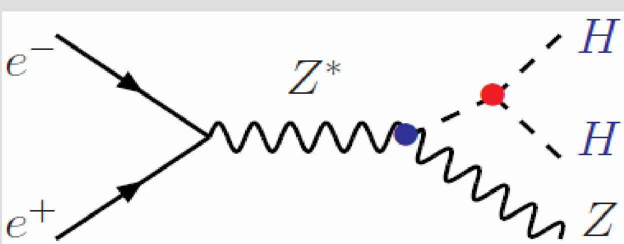




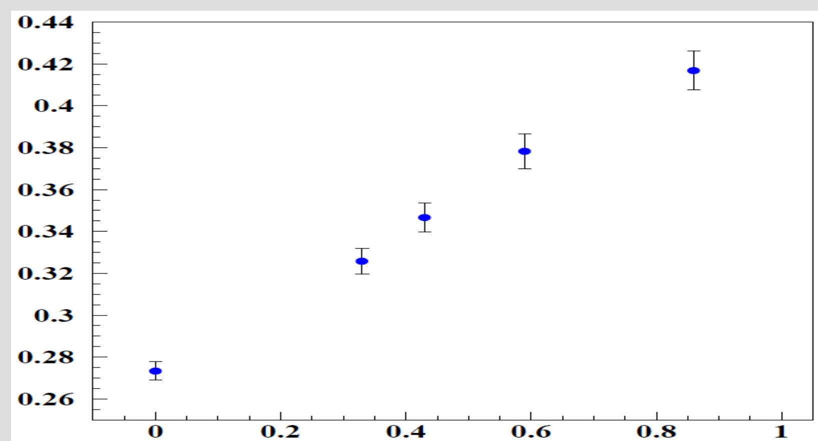


T. Barklow

- Significance for Higgs Self Coupling



$$\frac{\Delta g_{hhh}}{g_{hhh}}$$



$\Delta E/\sqrt{E} \rightarrow$

Challenges for Tracking

Higgs Recoil Mass Measurement Improves as Tracker Momentum Resolution Improves

$$e^+e^- \rightarrow ZH \qquad \sqrt{s} = 350\ GeV$$

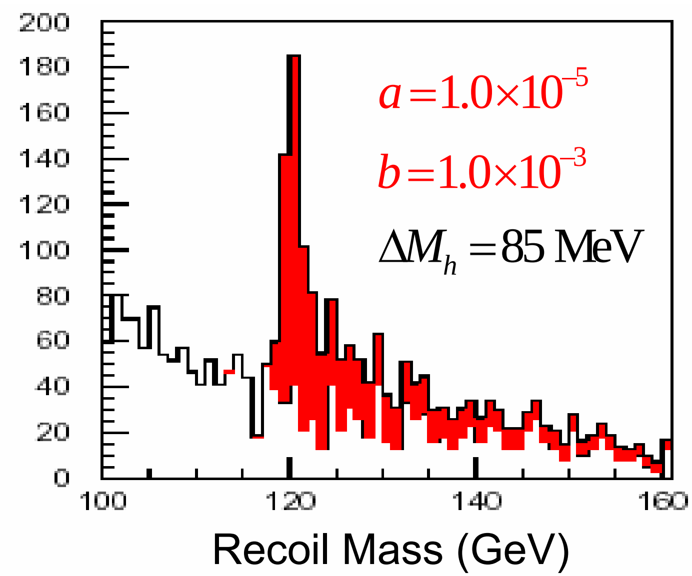
$$\rightarrow \mu^+\mu^- X \qquad L = 500\ fb^{-1}$$

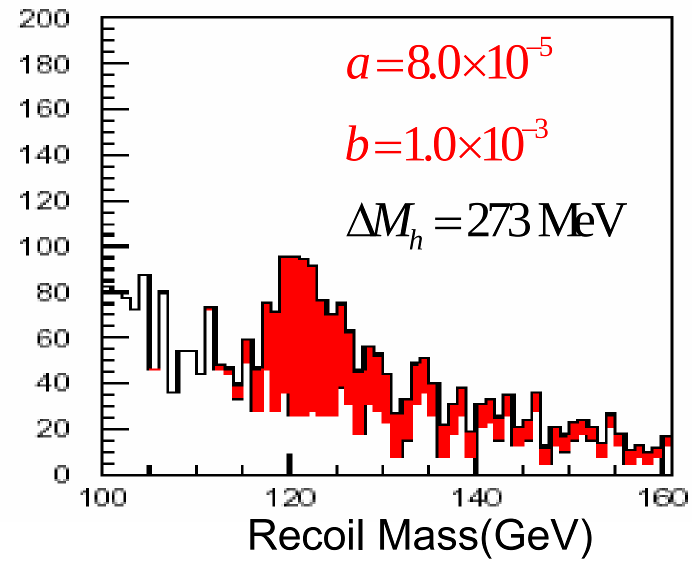
Characterize the Momentum Resolution with the parameter a:

$$\frac{\delta p_t}{p_t^2} = a \oplus \frac{b}{p_t \sin\theta}$$

An eightfold improvement in resolution is worth a factor of 10 in luminosity! Present designs would achieve part of that improvement.

T.Barklow





Challenges for Tracking

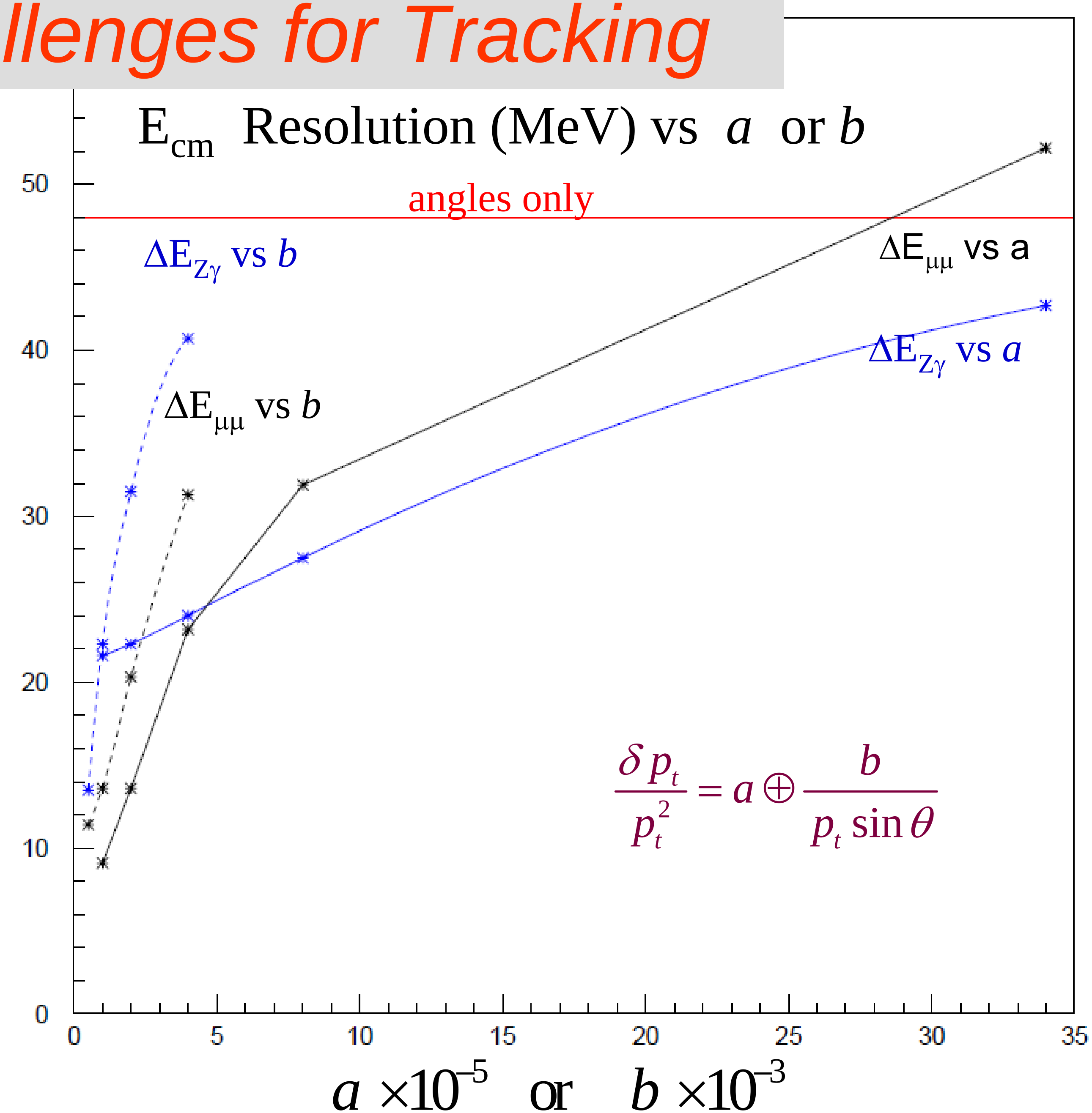
$$e^+e^- \to \mu^+\mu^- \quad (\gamma)$$

$$\sqrt{s} = 350\ GeV$$

$$L = 100\ fb^{-1}$$

ΔE_{cm} (MeV)

The accuracy of the luminosity weighted E_{cm} improves with excellent momentum resolution.

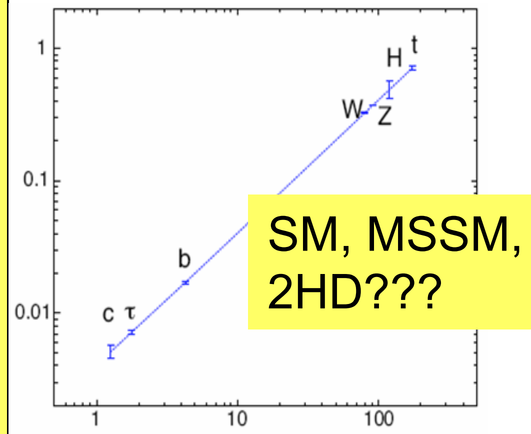


T. Barklow

Challenges for Vertexing

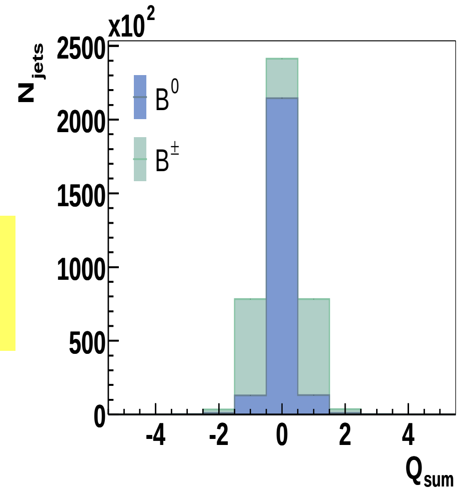
- Precision Measurement of Higgs Branching Fractions are needed to pin down the theory of EWSB.
- Quark charge measurements are sensitive to anomalous couplings, could see evidence for Extra D.
- Maximizing b and c tagging efficiency and purity requires superb impact parameter resolution, minimal radius and thickness for VXD.
- Optimizing Quark Charge resolution requires good resolution for soft tracks, minimal material for VXD.
- More work is needed to quantify benefits.

Higgs Coupling to Mass

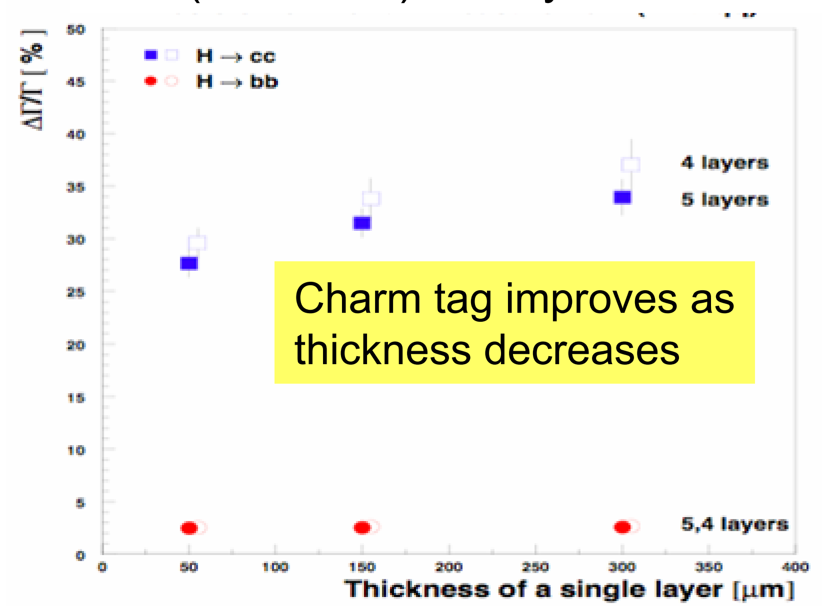


Mass (GeV)

B Quark Charge

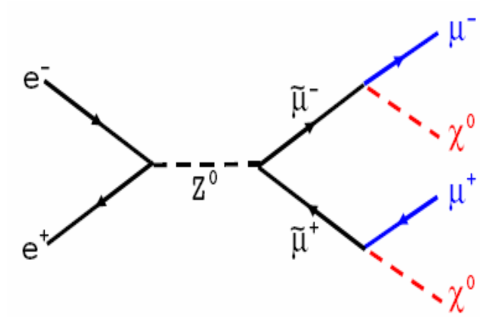


ΔBR(H→bb,cc) vs Layer Thickness

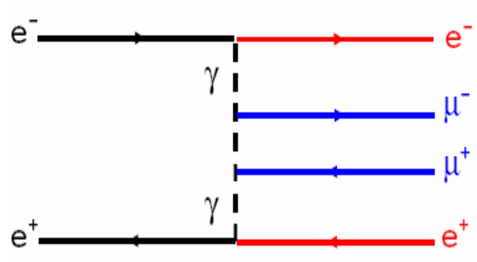


Challenges for Beamcal

- SUSY Challenge: Detect single highly energetic $e^{\pm}$ above a background of 10^4 low energetic e^+e^- pairs.



Physics signal:
e.g. SUSY smuon production

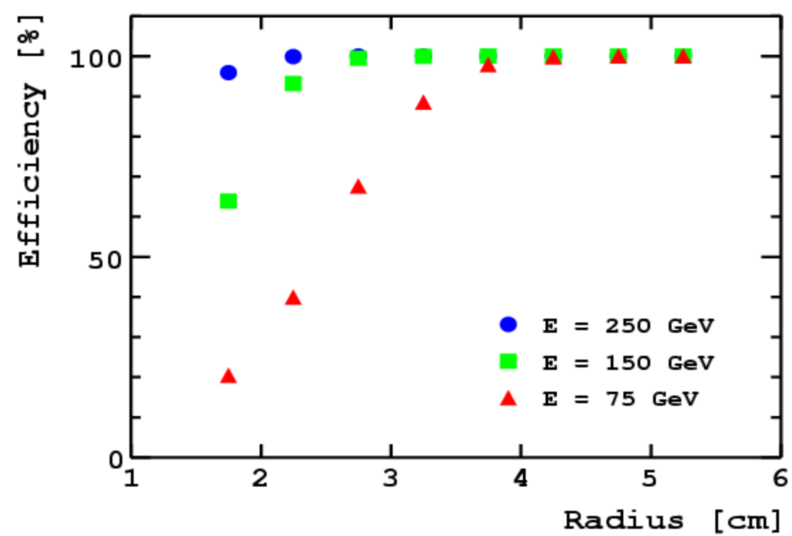


Background signal:
2-photon event, may fake the upper signal if the electron is not detected.

From Ch. Grah

Electron detection above pairs background in the beamcal

$e^{\pm}$ Detection Efficiency vs Radius



ILC Environmental Challenges

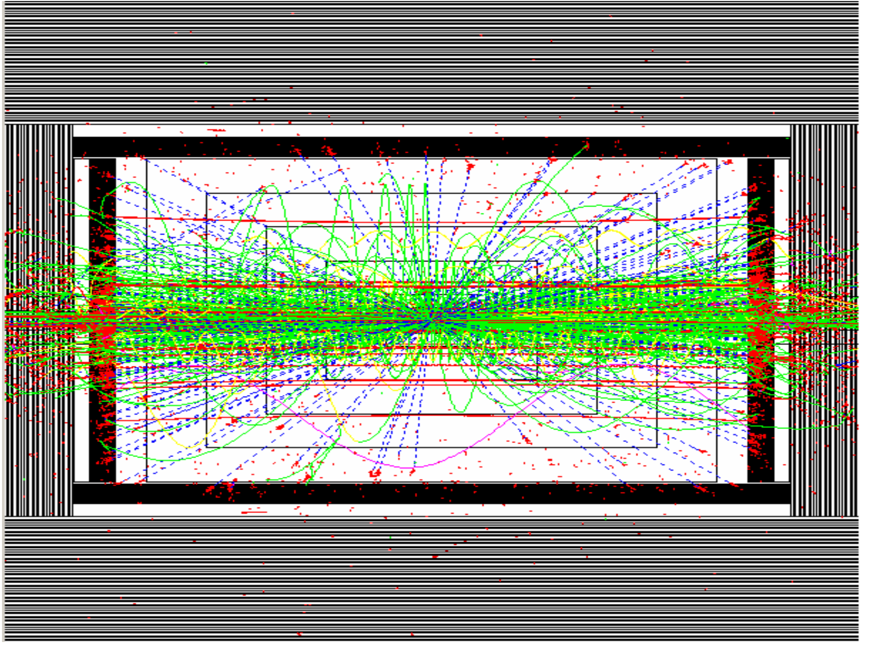
ILC is benign compared to LHC, …

	LHC	ILC
• **Event Rates**		
Inclusive	**1 GHz (min bias)**	**1 kHz ($\gamma\gamma$ ->hadrons)**
• **Bunch Crossings**	**25ns (40 Mhz)** **DC**	**300ns (15kHz)** **0.5% Duty Factor**
• **Triggering**		
Level 1 & 2	**40MHz -> 1kHz**	**No Hardware Trigger**
Level 3	**~100 Hz Software**	**~100 Hz Software**
• **Radiation Field**	**1-100 MRad/Yr**	**$\leq$ 10 kRad/Yr**
• **Occupancy**		
Per bunch	**23 min bias** **100 tracks**	**0.3 $\gamma\gamma$->hadrons** **2 tracks**

…but ILC poses its own challenges:

Event Pile Up During Bunch Train

Livetime 40 μs ~ 130 BX

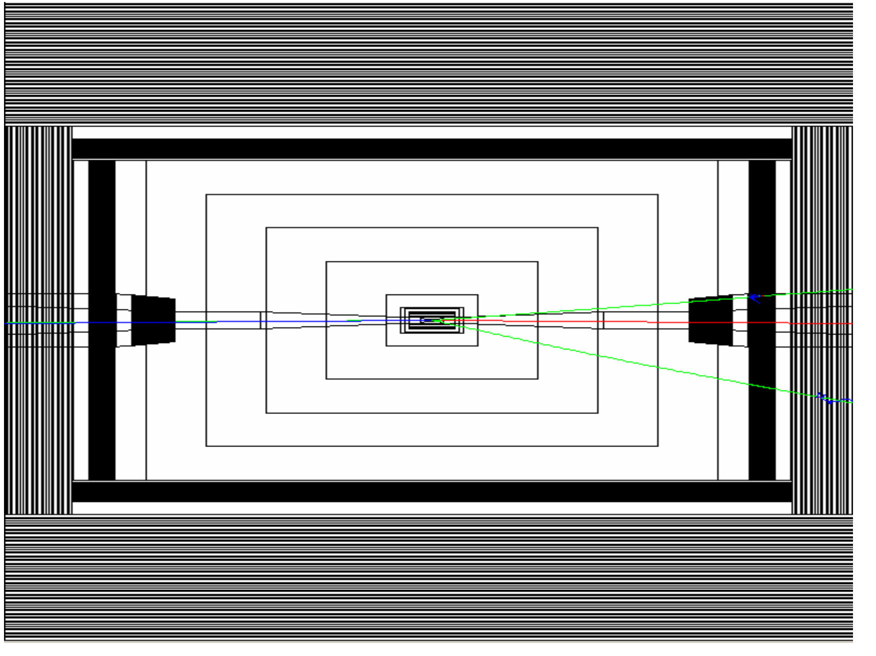


18k e pairs/130 BX

50 μ pairs/130 BX

86 hadronic events/130 BX

Livetime 100ns ~ 1 BX



140 e pairs/ BX

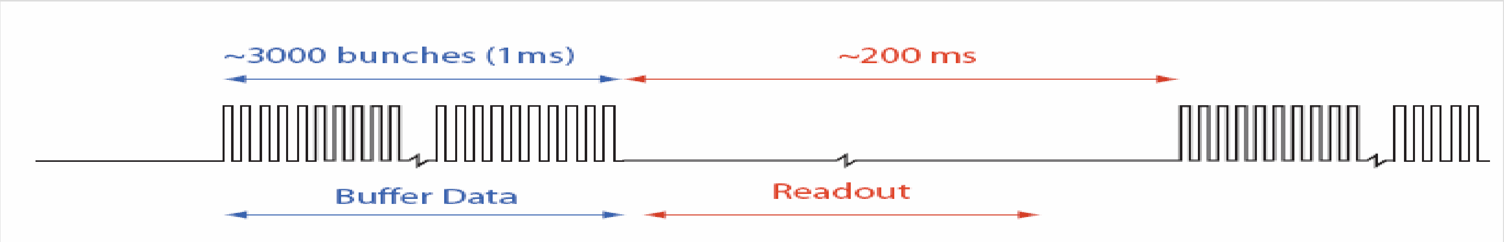
0.4 μ pairs/BX

0.7 hadronic events/BX

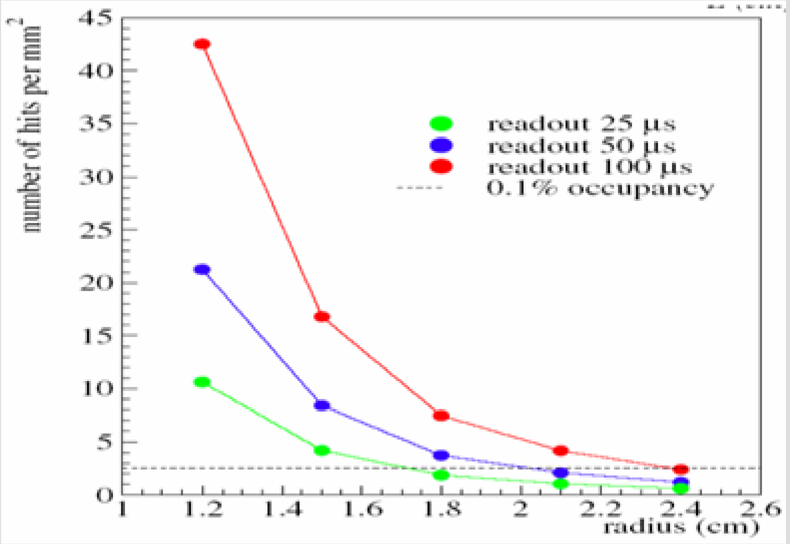
Add Muons from Collimators, MeV Photons from Pairs, Neutrons, Synchrotron Radiation and Possible Shower Products from Uncertain Beam Tails!

Vertex Readout Challenge

- Bunch train structure can swamp the inner layers of the VXD with beamstrahlung-induced pair backgrounds.



- To reduce occupancies to ≤ 5 mm^{-2}, the detector livetime must be reduced. Faster effective readout speeds are required.



- Getting enough power in for faster readout, taking enough heat out, are real challenges for “massless” detectors!

ILC Detector R&D

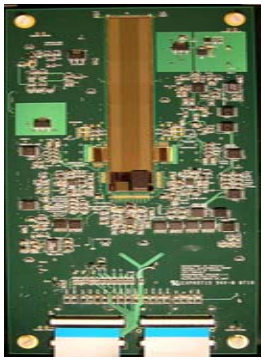
- ILC physics and the ILC environment require detector R&D beyond that developed for LEP/SLC, the Tevatron, and LHC.

- An impressive world effort is underway on R&D for ILC detectors, including that organized by R&D Collaborations (TPC, SILC, CALICE, FCAL), the detector concepts, and individual institutions.

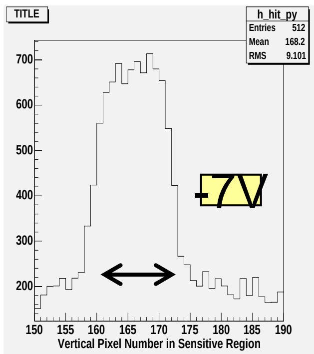
R&D Progress: Vertexing

- **Development of ILC compatible VXD Sensors**

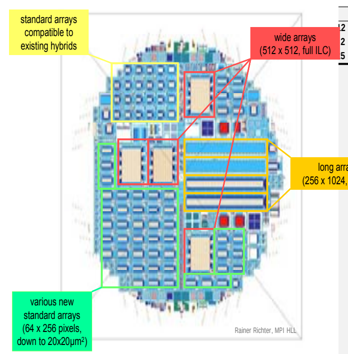
CPCCD



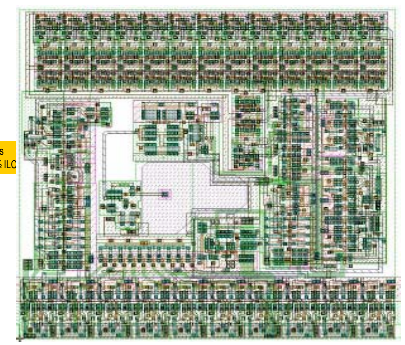
FPCCD



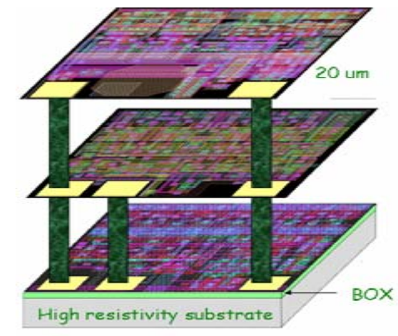
DEPFET



CMOS/Chronopix



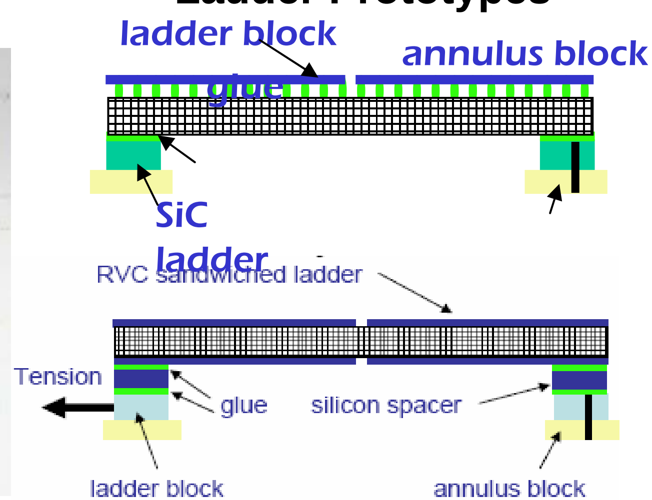
3D-SOI



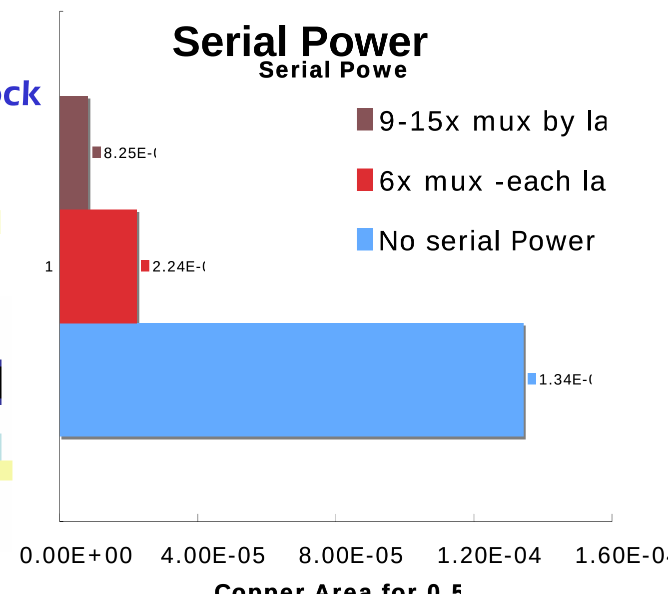
- **Progress on Integration Issues (mechanics, power, heat,…)**

Structures

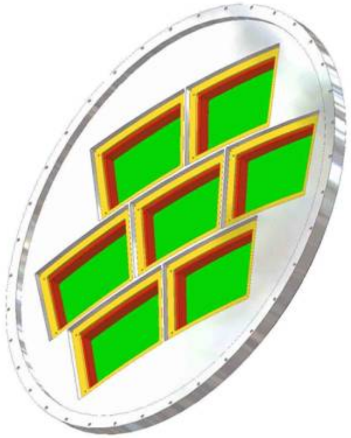
Ladder Prototypes



Serial Power



R&D Progress Tracking

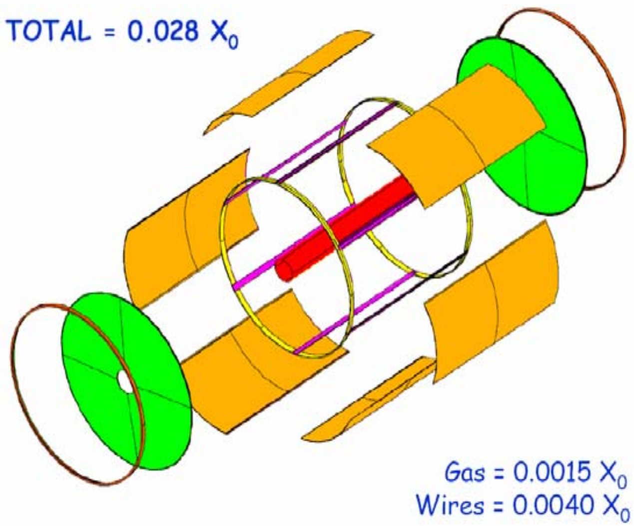


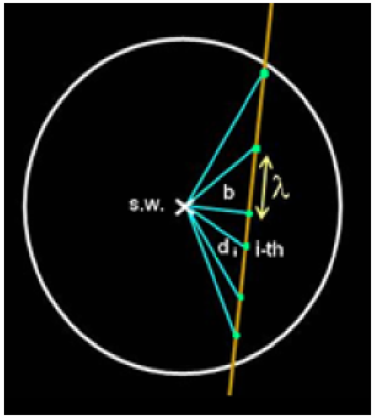
LCTPC constructing Large Scale Prototype

80 cm diameter/80 cm drift length
Test GEMS and Micromega Readout
7 Modules ~20x20cm each

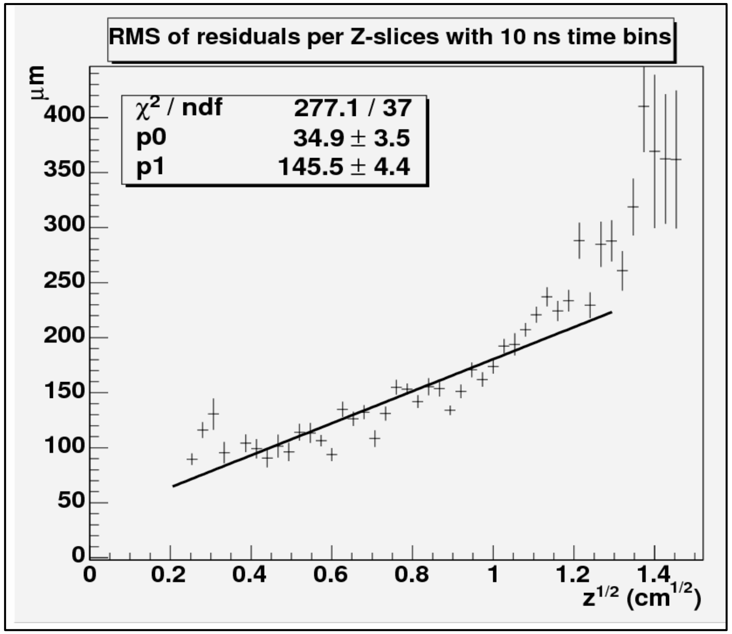
High Resolution Detectors for TPC

Cluster Counting Drift Chamber (4th)





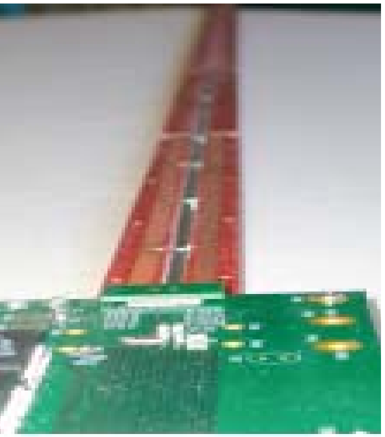
Micromega Results



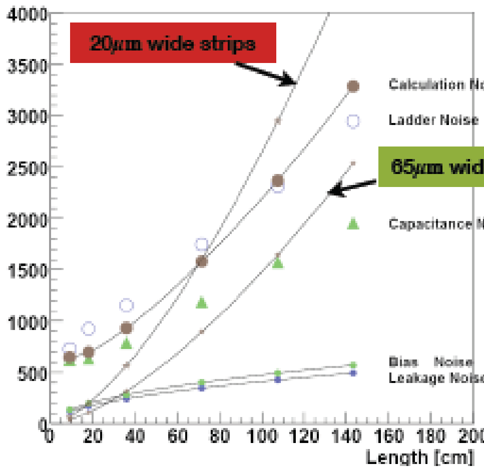
R&D Progress: Si Tracking

- **The Long and Short of Si Microstrip Readout**

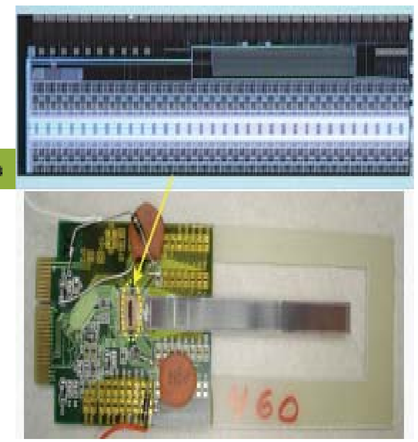
SiLC/ UCSC Ladder + Readout



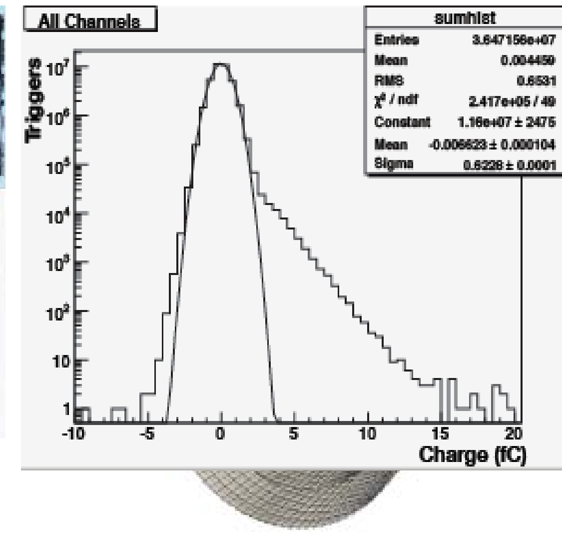
LSTFE Performance



KPiX Prototype

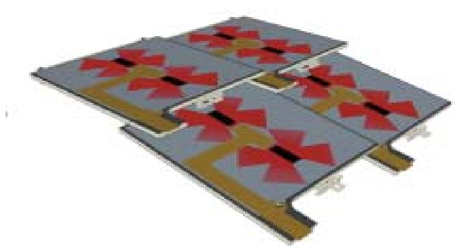


KPiX Beam Test

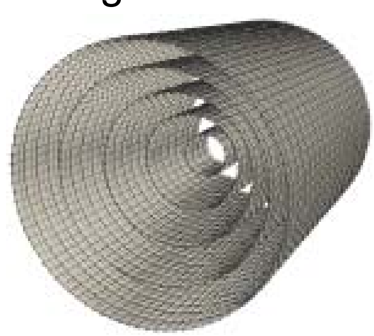


- **Low Mass Modules and Support Structures**

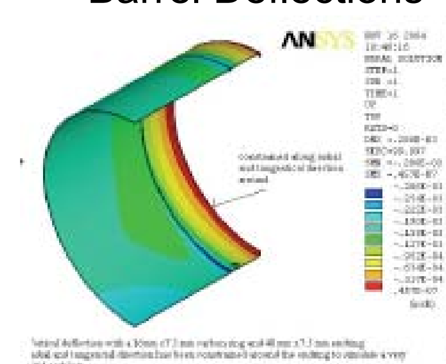
Module Design



Tiling on C Fiber Barrels



Barrel Deflections

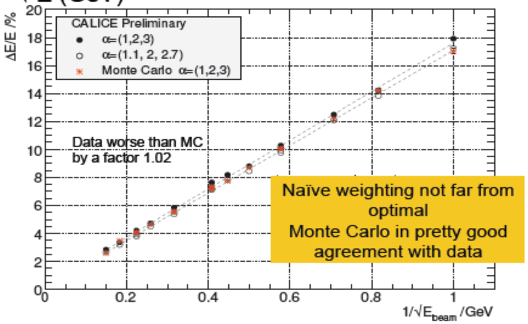


R&D Progress: Ecal

- Silicon Tungsten Pixels

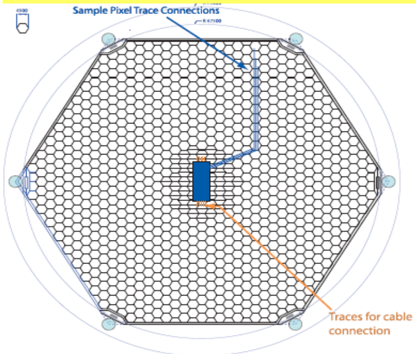
Calice Beam Test Results

$$\frac{\Delta E}{E}(\%) = \frac{17.7 \pm 0.07}{\sqrt{E\ (GeV)}} \oplus (1.1 \pm 0.08) \qquad (\alpha_1, \alpha_2, \alpha_3) = (1, 2, 3)$$

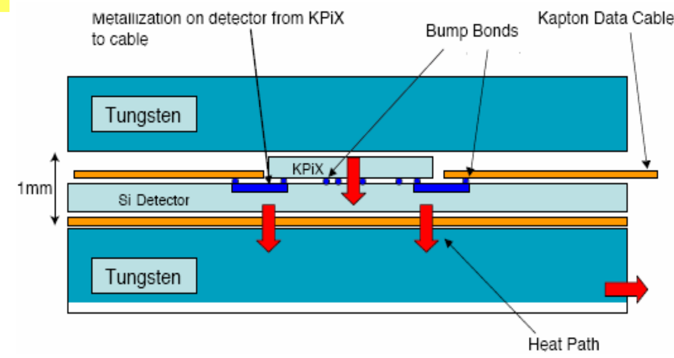


$$\frac{\Delta E}{E}(\%) = \frac{17.1 \pm 0.07}{\sqrt{E\ (GeV)}} \oplus (0.5 \pm 0.15) \qquad (\alpha_1, \alpha_2, \alpha_3) = (1.1, 2, 2.7)$$

12 mm^2 SiD Sensor with KPiX Readout

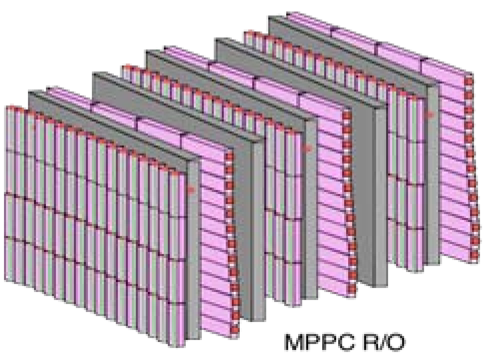


Minimize Sensor Gap

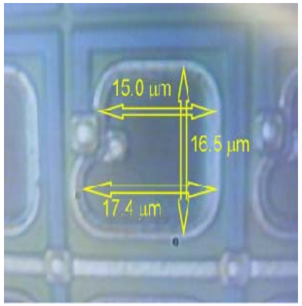


- Scintillator Tungsten Strips

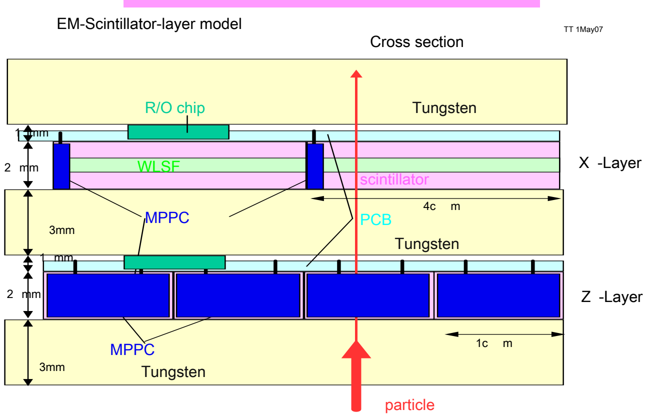
Crossed 1 x 4 cm Scint Strips



MPPC Readout

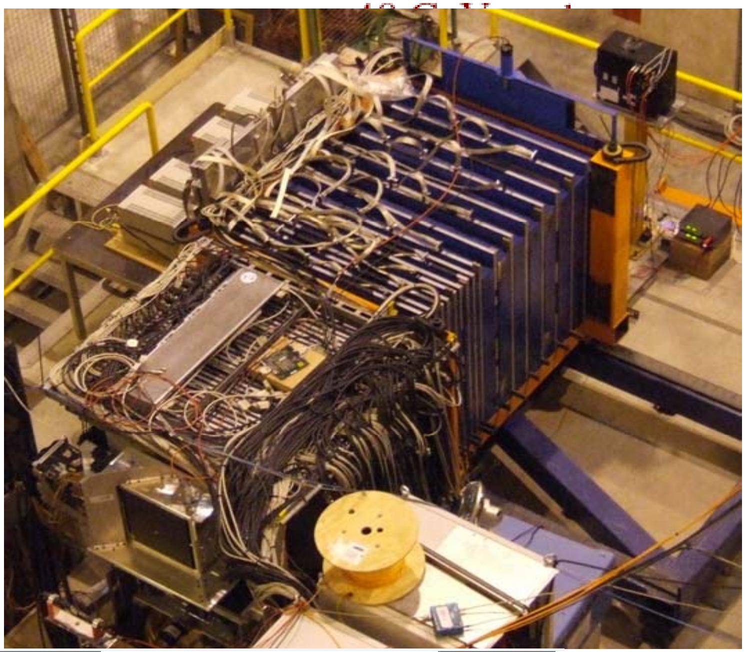


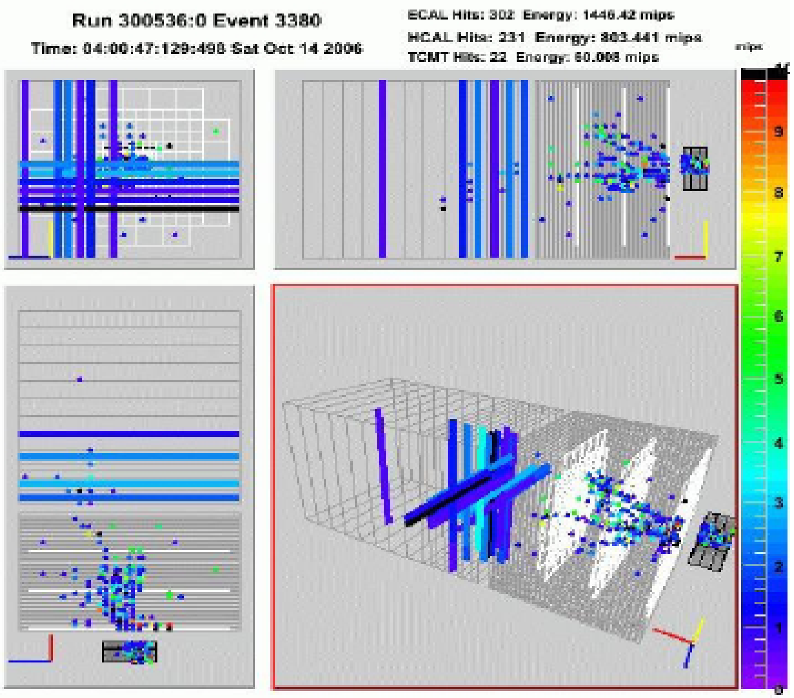
Readout Gaps

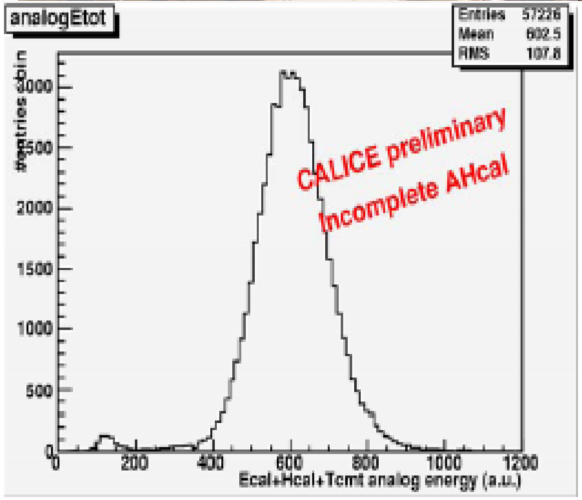


R&D Progress: Hcal

- AHCAL + TCMT Test by Calice Collaboration at CERN SPS





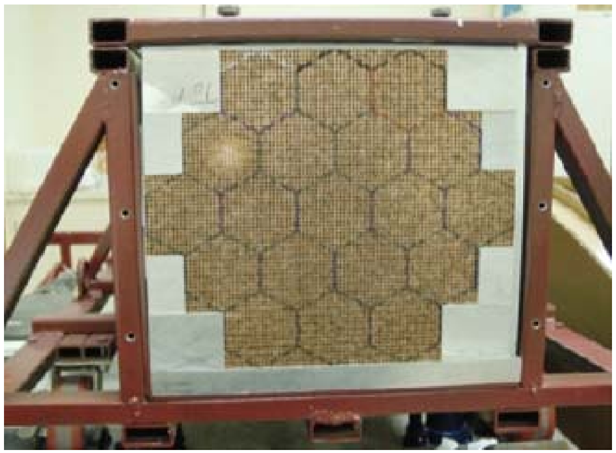


Early Results for 20 GeV π's AHCAL + TCMT Linearity and Resolution are "within expectations"

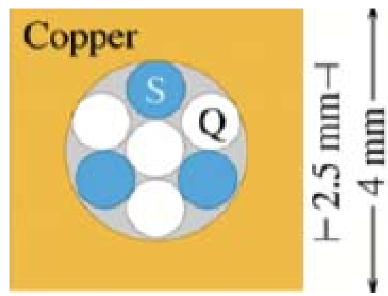
R&D Progress: Hcal

- **Dual Readout Calorimetry Provides Software Compensation**

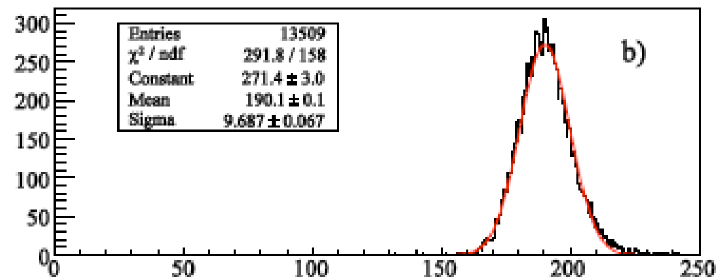
DREAM Test Module (4th)



"Unit Cell" segmented transversely, not depth

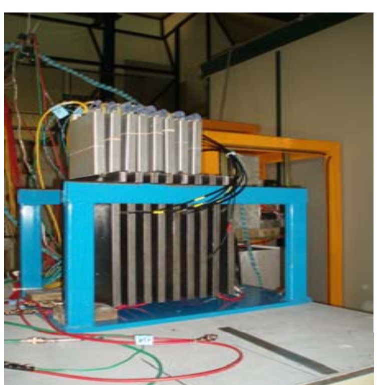


Encouraging Results from Test Beam (Scint+Cerenkov) 200 GeV π's

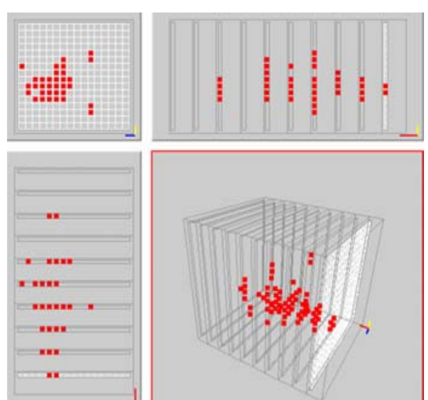


- **RPCs and GEMs are being developed for DHCAL**

RPC Slice Test

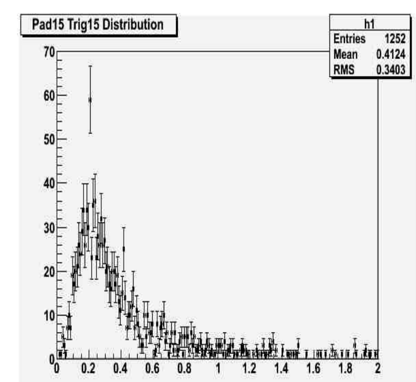


Sliced 8 GeV Electron



30x30 cm^2 GEM

GEM MIP Signal



R&D Progress: PFA

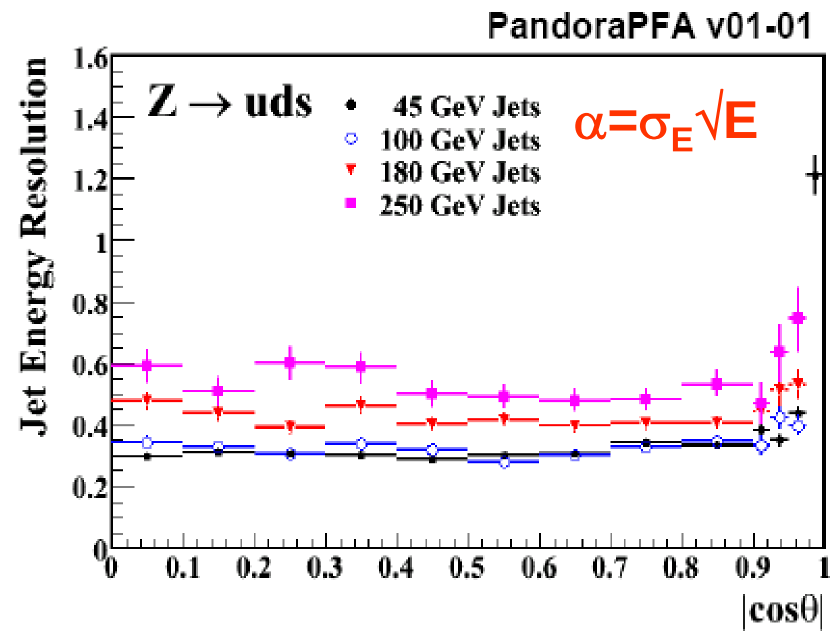
- **Can Particle Flow Algorithms meet ILC Performance Specs?**

PFA's measure jet energies by summing up charged track momenta, photon energies, and neutral hadron energy. This requires differentiating their respective depositions in the calorimeters. Highly segmented, imaging calorimetry is the key.

Mark Thompson's Pandora is a PFA Proof of Principle

rms90

E_{JET}	$\sigma_E/E = \alpha/\sqrt{(E/GeV)}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E
45 GeV	0.295	4.4 %
100 GeV	0.305	3.0 %
180 GeV	0.418	3.1 %
250 GeV	0.534	3.3 %



- **An excellent start! Still need**
  Confirmation
  Experimental Proof (not so easy!)

- PFAs illustrate the importance of optimizing Integrated Detector Performance: Magnet +Tracking + Ecal + Hcal)

ILC Detector R&D Status & Funding

- The World Wide Study has instituted R&D reviews of the various detector subsytems, including tracking (Beijing07), calorimetry (DESY07), and now vertex detection (Fermilab07).

- Among the regions, Europe has been the most successful in supporting detector R&D, with the US a rather distant second. Asia (mostly Japan) has recently increased support to roughly the level of the US.

- In the US, support for detector R&D has been administered by LCDRD for the DOE and NSF, under the auspices of the ALCPG.
  Support has grown from 500k$/year in FY03 to 2.2M$/year for FY07, but is still well shy of support in Europe.

- The DOE and NSF conducted a joint review of US ILC detector R&D at Argonne in June 2007. Plans for further increases in support were discussed.

Argonne Overview (Weerts)

US program | "Top Down" ILC US detector R&D program | Version - | AR 0.14

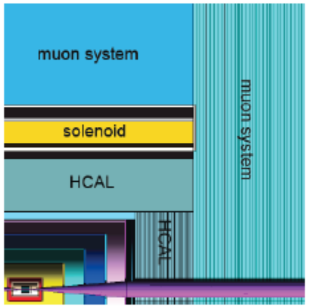
TOTAL		FY08 Cost(K$)	FY09 Cost(K$)	FY10 Cost(K$)	FY11 Cost(K$)	FY12 Cost(K$)	FY13 Cost(K$)	Total Cost
LEP	TOTAL	$ 1,684	$ 1,684	$ 1,684	$ 2,916	$ 2,916	$ -	$ 10,883
VXD	TOTAL	$ 2,440	$ 2,800	$ 3,440	$ 3,650	$ 3,650	$ -	$ 15,980
Si-tr_tot	TOTAL	$ 1,025	$ 1,215	$ 1,375	$ 1,330	$ 1,280	$ -	$ 6,225
TPC	TOTAL	$ 822	$ 1,519	$ 1,315	$ 1,566	$ 943	$ -	$ 6,165
ECALall	TOTAL	$ 1,175	$ 1,490	$ 1,825	$ 1,630	$ 1,485	$ -	$ 7,605
HCALall	TOTAL	$ 4,084	$ 3,631	$ 2,404	$ 2,110	$ 1,850	$ -	$ 14,079
Forward	TOTAL	$ 565	$ 793	$ 813	$ 813	$ 788	$ -	$ 3,772
Solenoid	TOTAL	*$ 452*	*$ 724*	*$ 1,004*	*$ 1,114*	*$ 702*	*$ -*	*$ 3,996*
MUON	TOTAL	*$ 661*	*$ 1,105*	*$ 1,141*	*$ 1,224*	*$ 1,281*	*$ -*	*$ 5,412*
								$ -
Algo & Reco	TOTAL	*$ 1,570*	*$ 1,630*	*$ 1,630*	*$ 1,630*	*$ 1,630*	*$ -*	*$ 8,090*
								$ -
								$ -
Back End Elec	TOTAL	*$ 205*	*$ 375*	*$ 660*	*$ 920*	*$ 1,020*	*$ -*	*$ 3,180*
INFRA_EE	TOTAL	*$ 182*	*$ 188*	*$ 193*	*$ 199*	*$ 205*	*$ -*	*$ 968*
Test_FNAL	TOTAL	$ 970	$ 1,270	$ 870	$ 1,255	$ 1,515	$ -	$ 5,880
Test-SLAC	TOTAL	$ 525	$ 525	$ 525	$ 625	$ 625	$ -	$ 2,825
US program		**$ 16,360**	**$ 18,948**	**$ 18,879**	**$ 20,982**	**$ 19,890**	**$ -**	**$ 95,060**
Mngmt reserve	10%	$ 1,000	$ 1,500	$ 2,000	$ 2,500	$ 2,000		$ 9,000
US program	TOTAL	**$ 17,360**	**$ 20,448**	**$ 20,879**	**$ 23,482**	**$ 21,890**	**$ -**	**$ 104,060**

Everything included as far as we know

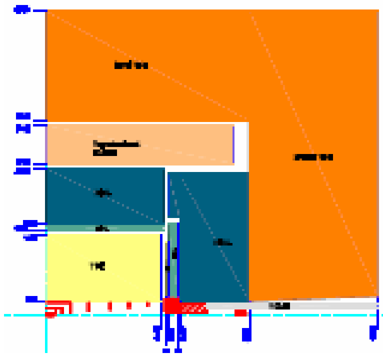
ILC Detector R&D Needs 100M$/5 years

Evolving Designs for ILC Experiments

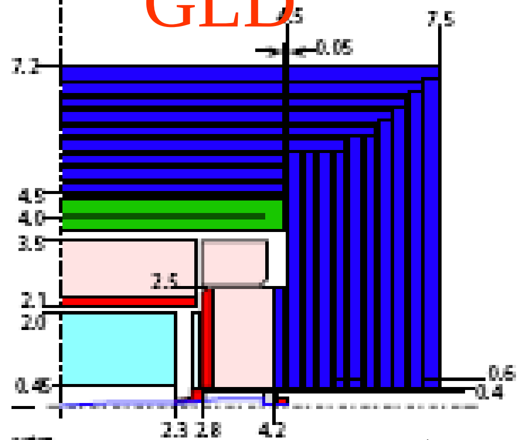
SiD



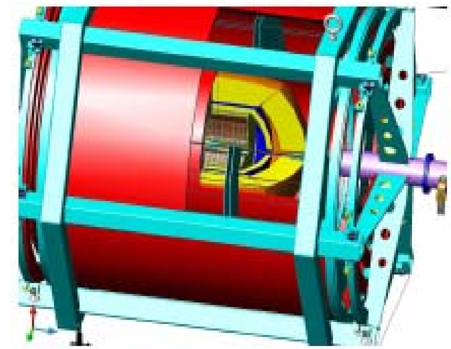
LDC

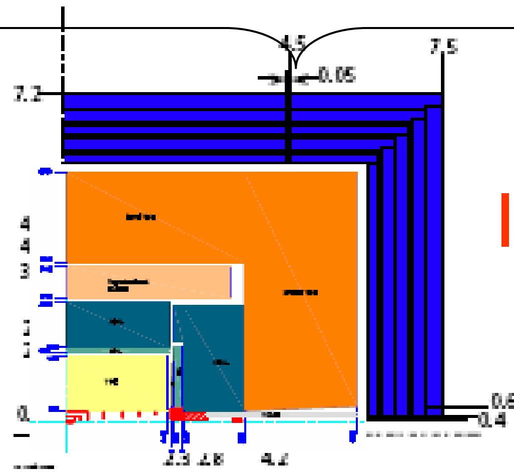


GLD



4th





ILD

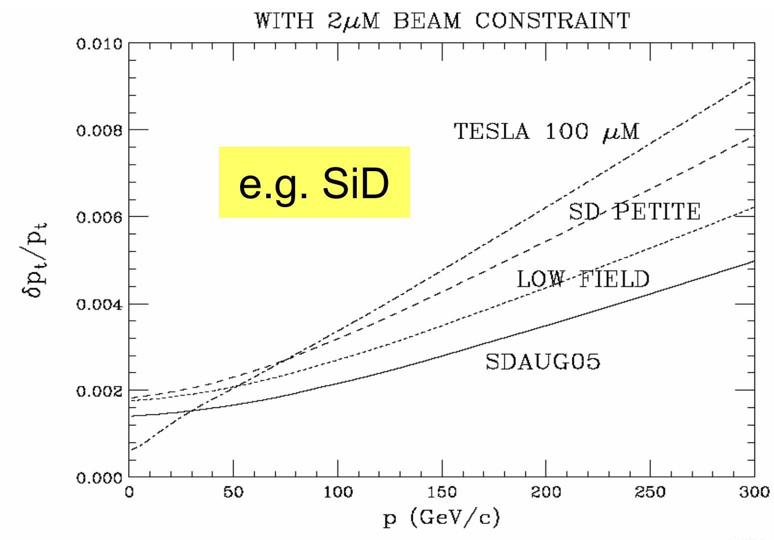
- Solenoid Designs B=5,4,3 Tesla
- Si vs TPC Tracking
- “Particle Flow” Calorimeters

- Dual Solenoid
- Compensating Cal
- TPC Tracking

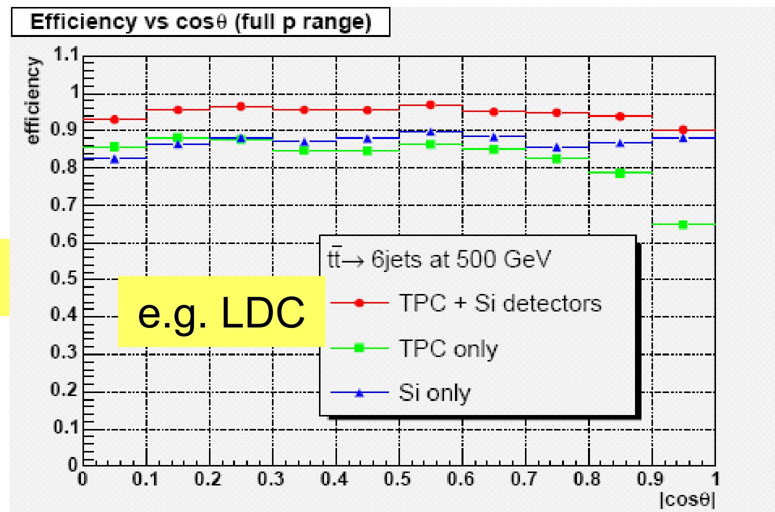
Experiments Meet ILC Performance Requirements

Momentum Resolution meets goal of $\Delta p/p^2 < 5 \times 10^{-5}$ (GeV^{-1})

Tracking Efficiency ~ 100%

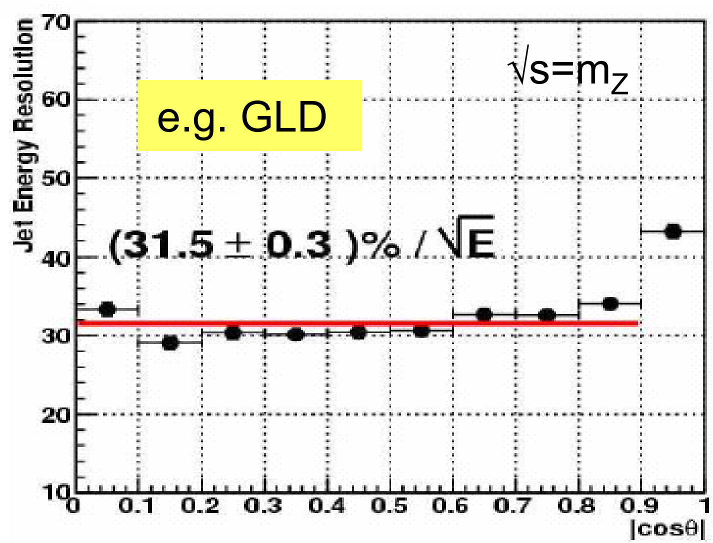


0.5%



Jet Energy Resolution α

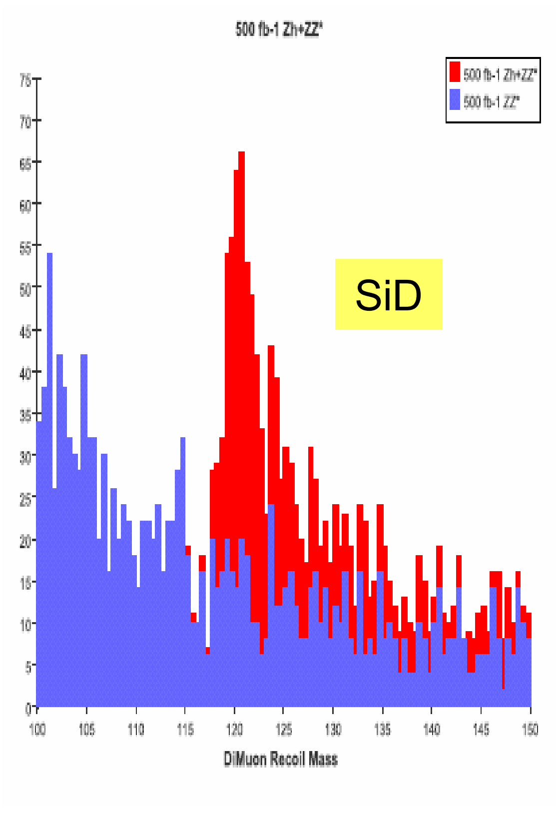
$\sigma_E/E = \alpha/\sqrt{E} \sim 30\ \%/\sqrt{E}$



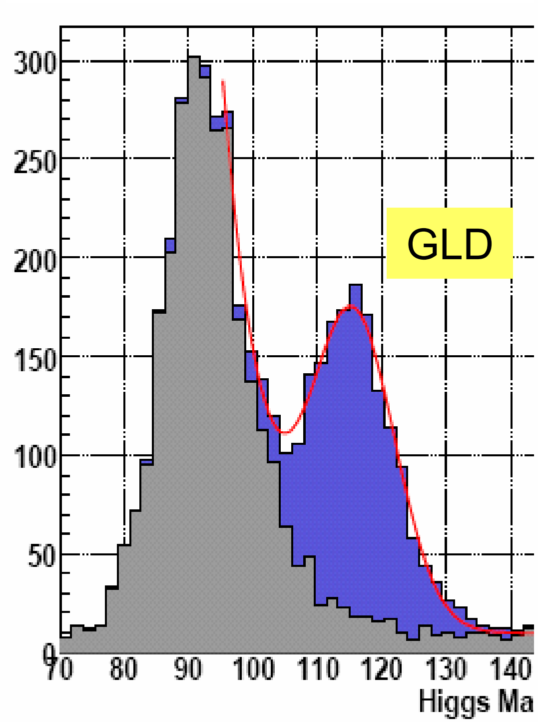
ILC Detectors can do the physics

Standard for ILC Physics Analyses is moving from Fast MC → Full MC, with full pattern recognition (tracking and PFA). More realism in the simulations means more believable, more robust results.

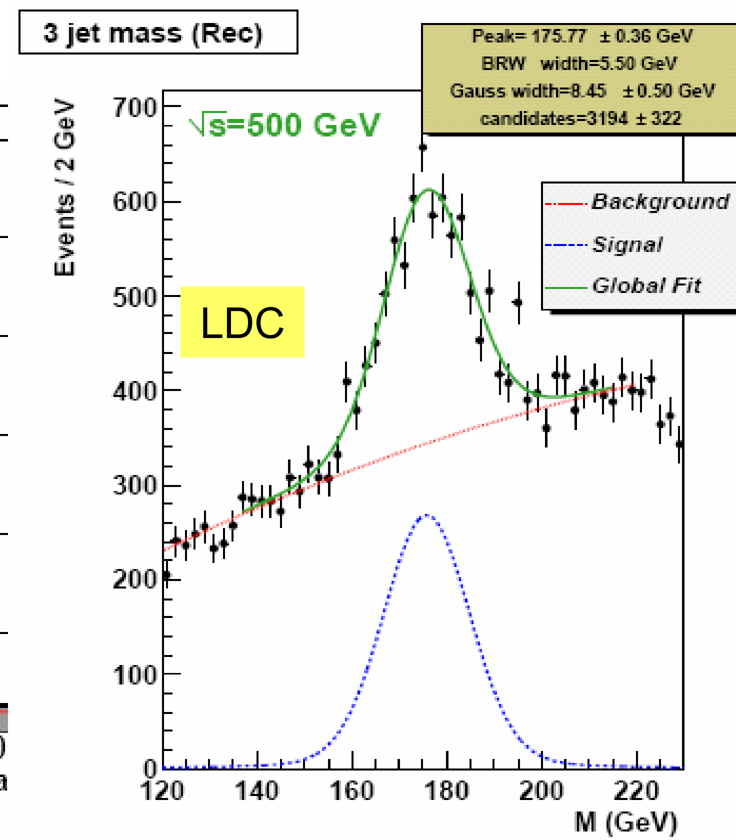
$e^+e^- \to ZH \to \mu\mu X$



e+e-→ZH→ννbb



e+e-→tt→WbWb



Integrating Machine and Detector

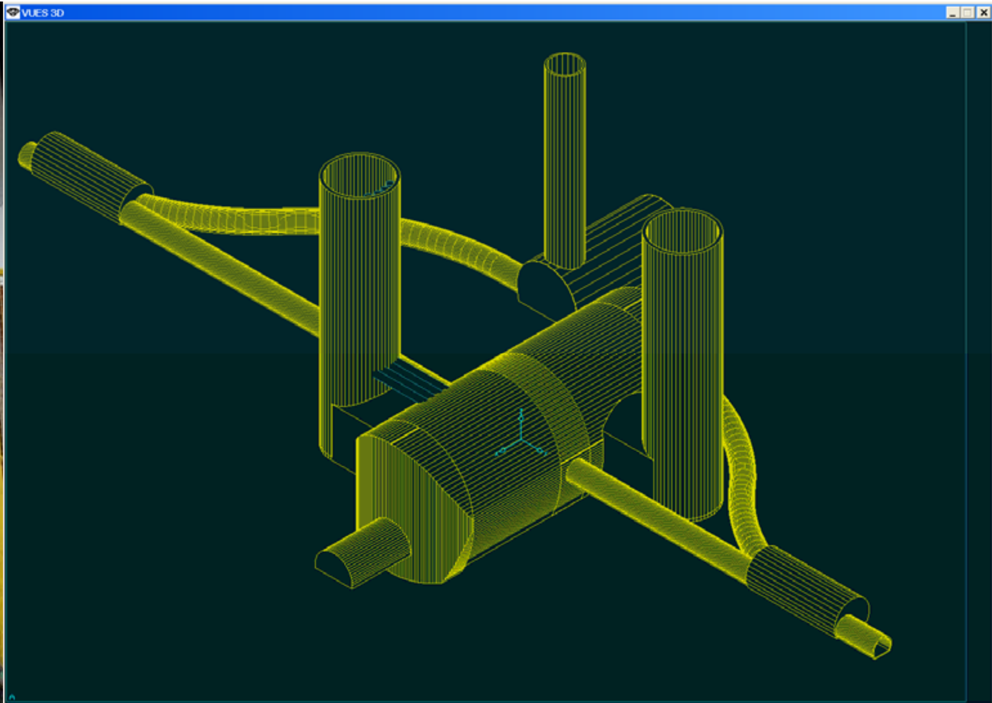
- ILC Baseline: 14 mrad crossing, 2 detectors push-pull, surface assembly
- Two Detectors provide

  Cross Checks, Confirmation, Scientific Redundancy
  Efficiency, Reliability, Insurance
  Broad Participation and Scientific Opportunity

- IRENG2007 advanced designs for the experimental hall, surface assembly, push-pull, cryo, and vacuum.

Push Pull Debate: Platform vs Hillman Rollers

Experimental Hall and Access Shafts

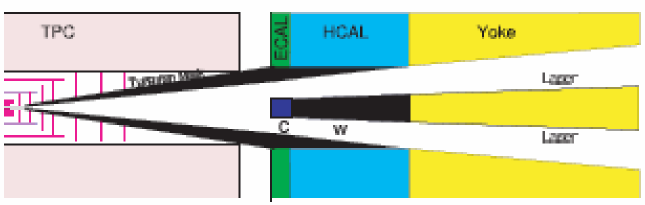


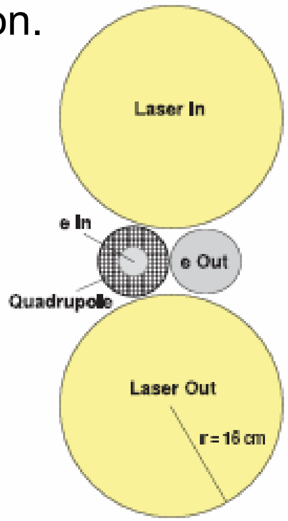
Keeping Options Alive

- **The Physics may lead us to Giga Z or Gamma Gamma.**
  ILC machine design should minimize future modifications needed.

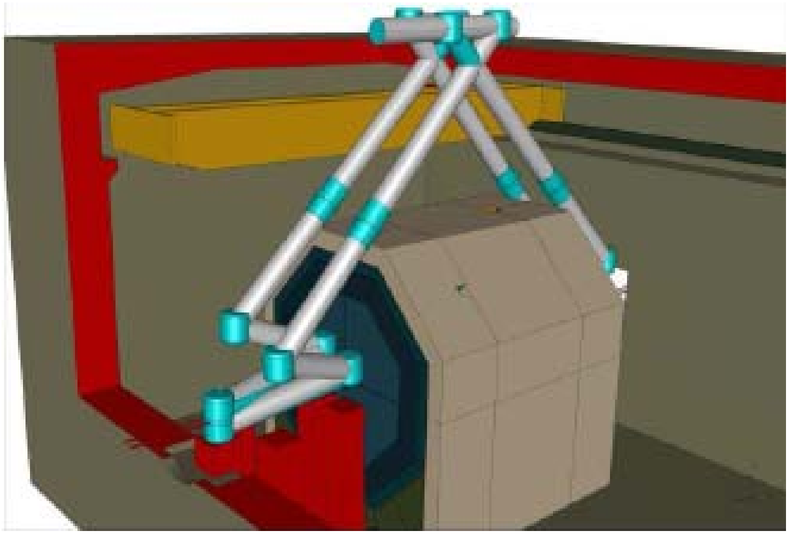
- **Gamma Gamma Physics**
  S channel production of Higgs and study of CP properties
  Single and Associated particle production extends mass reach
  for higher mass Higgs and SUSY

$\gamma\gamma$ needs 25 mr crossing angle
to accommodate beam disruption.
Mirrors focus lasers to collide
with beams ~ mm from IP



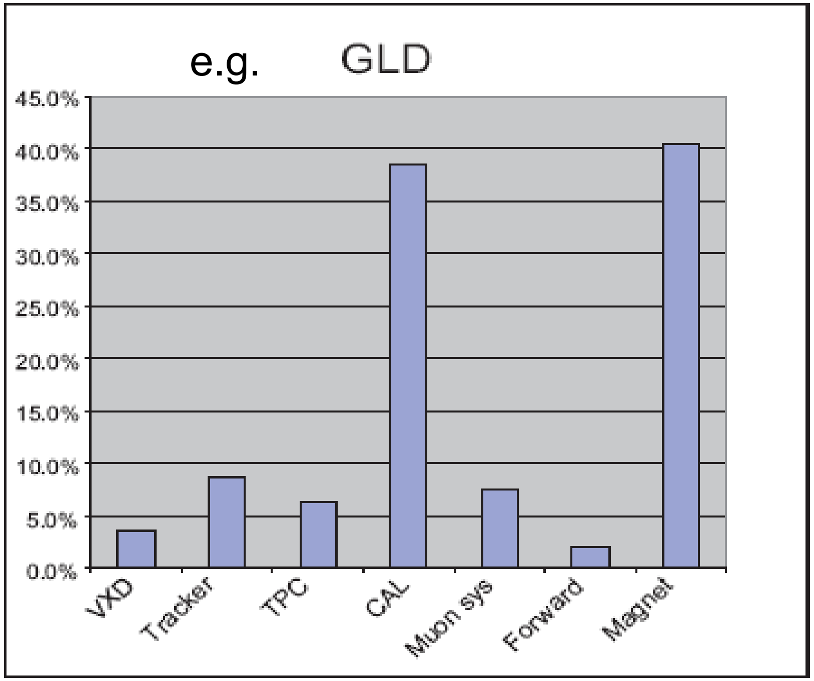


Laser Cavities Recirculate Light
to match the bunch spacing



Detector Costs

- WWS Cost Panel (Breidenbach, Videau, Maki) evaluated costs of GLD, LDC, and SiD
- Costs include M&S and Manpower and Contingency in 2007 $'s. (Assumed 1 Yen=.00854$; 1 Euro=1.20$)
- Mix of Manpower and M&S varies region by region by custom, but totals are comparable.
- Cost Drivers:
  Solenoids and Calorimeters
- Manpower:
  1250-1550 person-years



Detector Cost: 460-560 M$

WWS has guided ILC Experiment Development

- WWS Oversees Concept Launch
  SiD and LDC Concepts at ALCPG Vancouver 2004
  GLD Concept at ACFA Meeting Taipai 2004
  4th Concept at ECFA Vienna 2005
- WWS Calls for Detector Outline Documents 2005
- WWS Calls for Detector Concept Report 2006
  Companion to GDE's Reference Design Report
- ILCSC calls for Detector Roadmap 2007
- WWS Outlines Detector Roadmap at LCWS07 DESY
- RDR Goes Public at Lepton Photon 2007 Daegu
  Executive Summary, Physics, Accelerator, Detector
- ILCSC Calls for Detector Letters of Intent and appoints Sakue Yamada Research Director

Concepts Defined
Teams Assembled

Get Detectors Ready
in time for ILC EDR

Our case for the
Next Step

Toward an EDR!

ILCSC Calls for Letters of Intent

Dear Colleague,

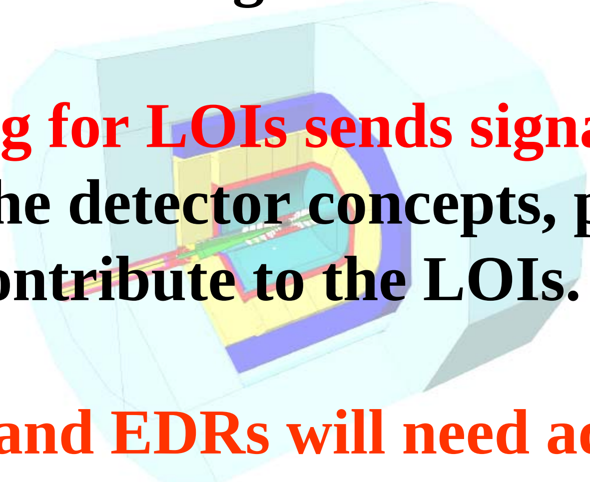
The International Linear Collider Steering Committee (ILCSC) announces a call for Letters of Intent (LOIs) to produce reference designs for the two ILC detectors. These designs will be detailed in two Engineering Design Reports (EDRs) to be completed on the timeline of the machine EDR being prepared by the Global Design Effort.

The guidelines for the LOIs are presented in the appended document and a public presentation of the WWS roadmap for detectors can be found in the LCWS07 web site. The LOIs should be sent to the ILCSC by October 1, 2008 and will be reviewed by an advisory body appointed with the approval of ILCSC. This body, together with a management team led by the Research Director Sakue Yamada who has been appointed by ILCSC, will start a process leading to the formation of two groups capable of preparing the two engineering designs and the EDR documents.

Sincerely Yours,
Shin-ichi Kurokawa

Chairman of the International Linear Collider Steering Committee

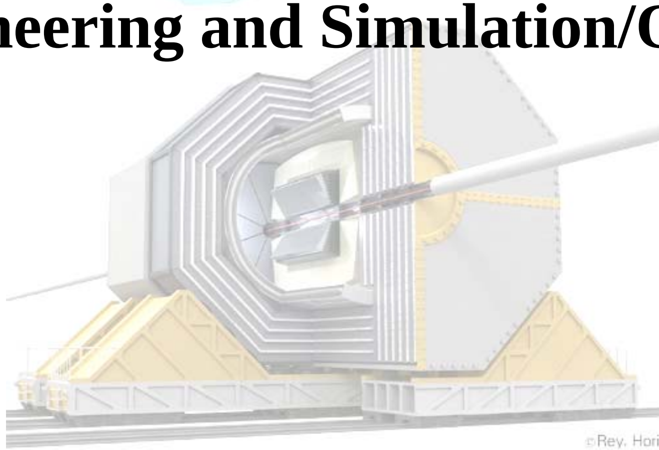
Implications

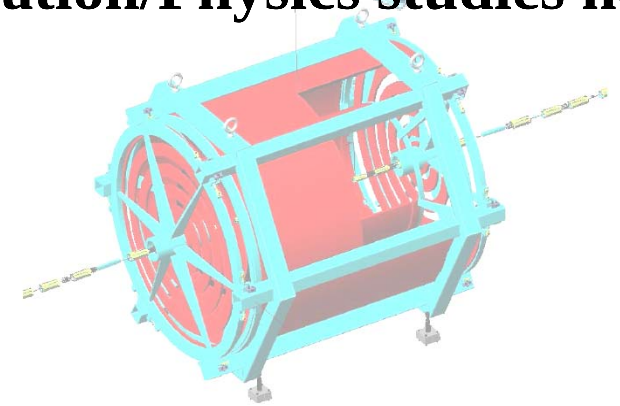


Calling for LOIs signals a Phase Change for the Detector Concepts.
Detector "Design Studies" are becoming "Detector Collaborations."

Calling for LOIs sends signals to the ILC Detector R&D Community
Join the detector concepts, participate in the optimization process, and contribute to the LOIs.

LOIs and EDRs will need additional support.
Engineering and Simulation/Optimization/Physics studies needed.





Conclusions

- ILC Physics and Environment challenge the current state of the art for detectors. R&D is required.
- New detector technologies for ILC detectors are within reach. There's been impressive progress, but continued development is needed.
- US Funding for ILC detector R&D needs a significant boost to be ready for LOIs and EDRs.
- Detector Concepts are being developed which can do the physics.
- IR planning is moving rapidly, in coordination with the machine.
- We are starting on the next step, developing detector LOIs, that will lead to detector EDRs on the timescale of the Machine EDR.

Definite Forward Progress!

Definitely Interesting Times!

Backup Slides

A Lot is Happening in the ILC Detector World

- Real Progress on the Machine. The **Reference Design Report (RDR)** and **Cost** were unveiled in February. This has put pressure on the detector community to put ILC Detectors on the same timeline as the Machine.

- The ILC Case: The **Detector Concept Report (DCR)** has been incorporated into the **RDR.** The **RDR** makes the case for the ILC physics, machine, and detectors, and justifies moving to the next step, engineering designs (**EDRs**) for machine and detector.

- Next Steps: ILCSC has appointed a Experimental Research Director and called for detector Letters of Intent, due October 2008, to be followed by detector EDRs.

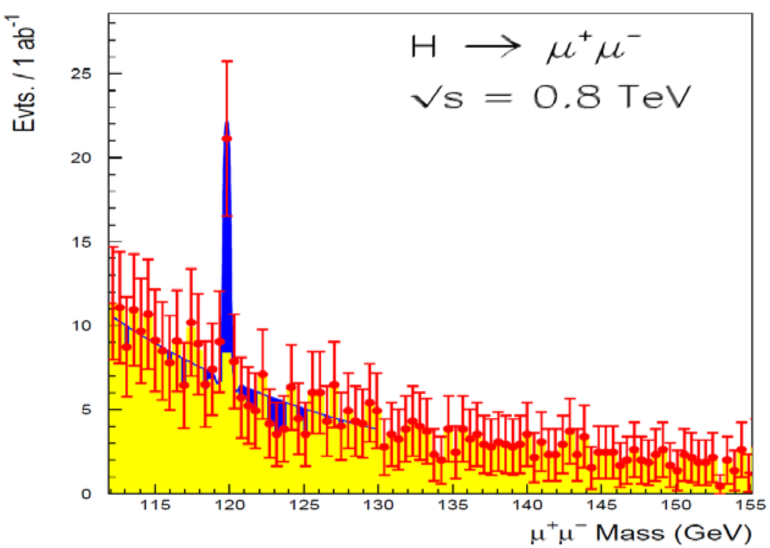
Challenges for Tracking

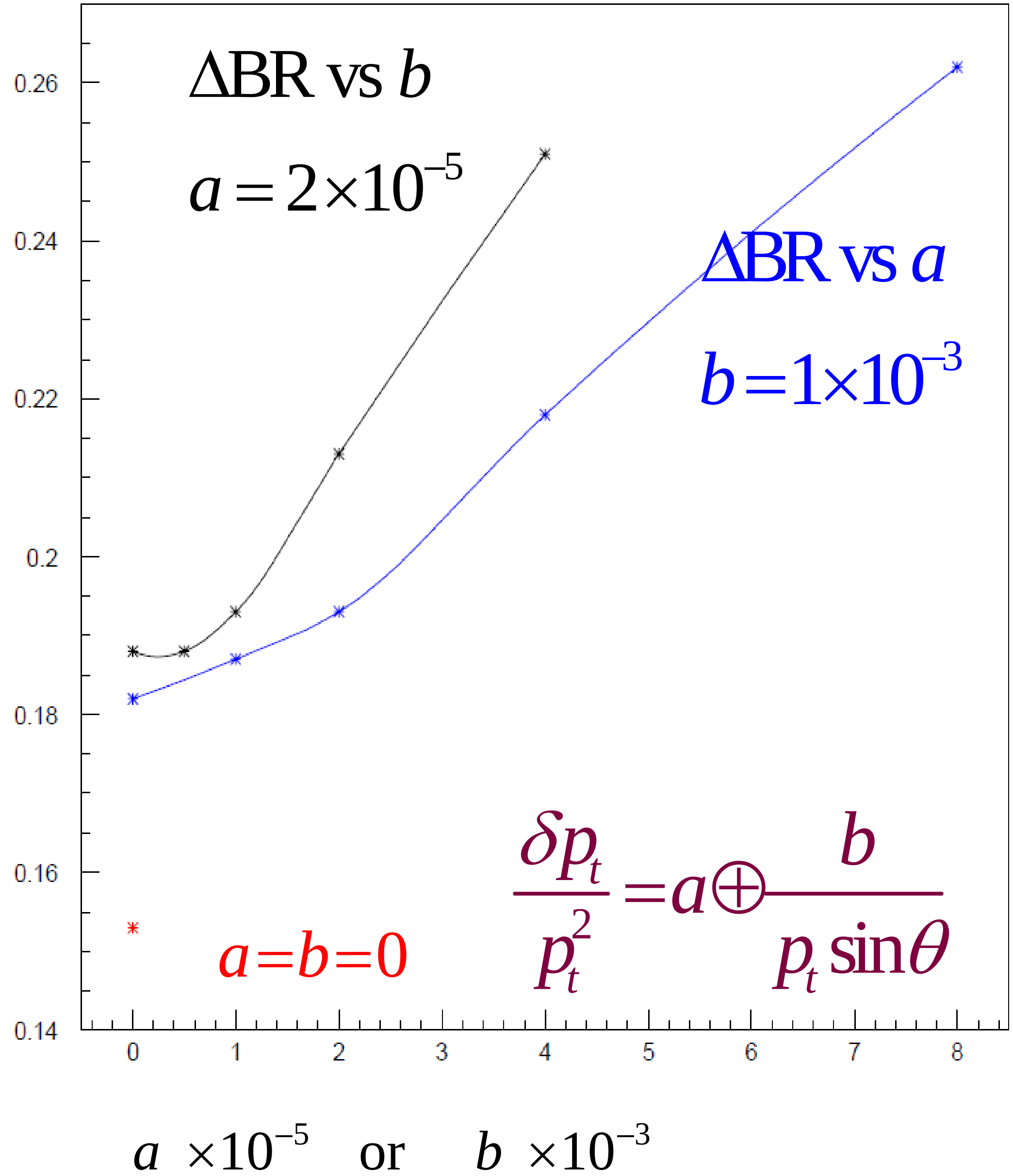
Measuring H→μμ

$$\sqrt{s} = 1\,TeV$$

$$L = 1000\ fb^{-1}$$

A fourfold improvement in resolution (a = 8 → 2) is worth a factor 1.9 in $\mathcal{L}$





More Challenges for Beamcal

- Beamcal sensors and readout must survive high radiation from pairs and beamstrahlung. 5 MGy/yr.

- Beamcal must be readout every bunch crossing for bunch by bunch machine diagnostics.