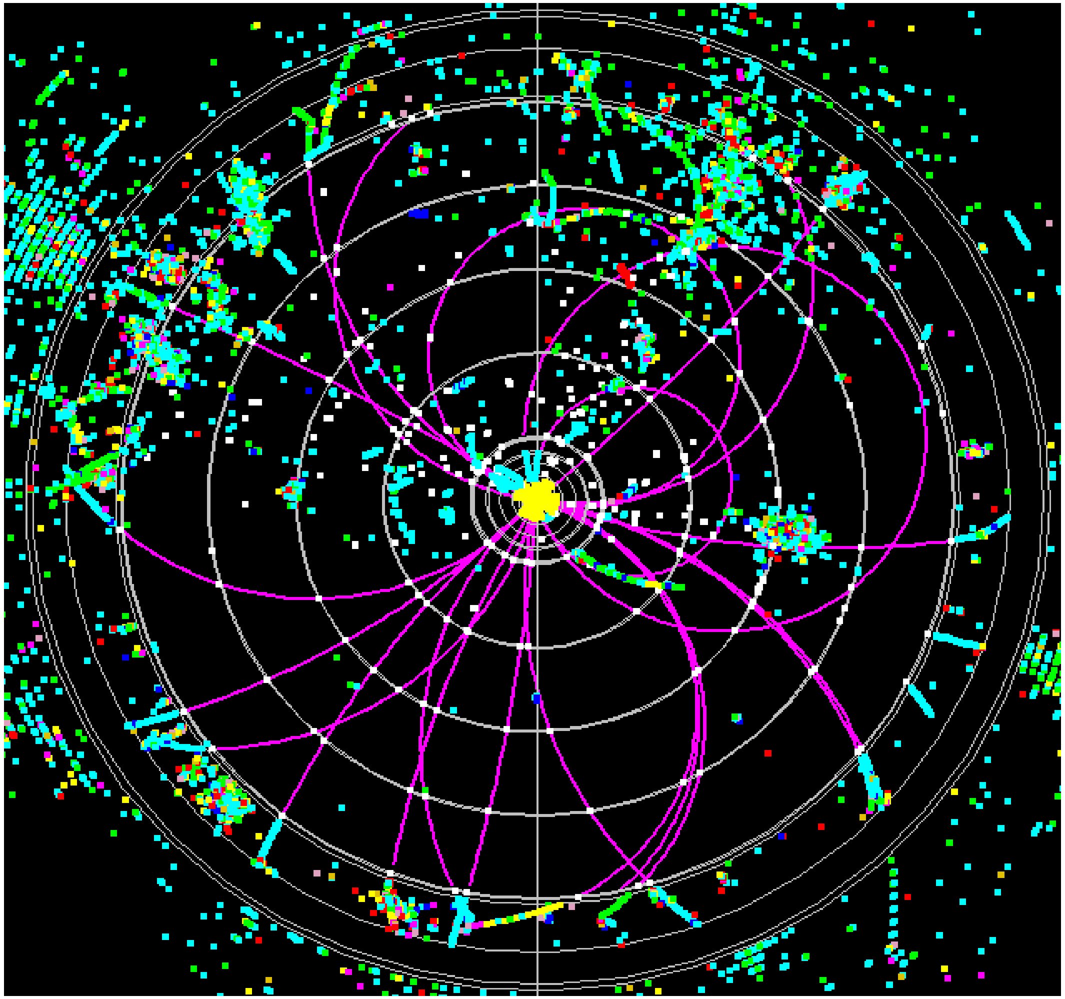
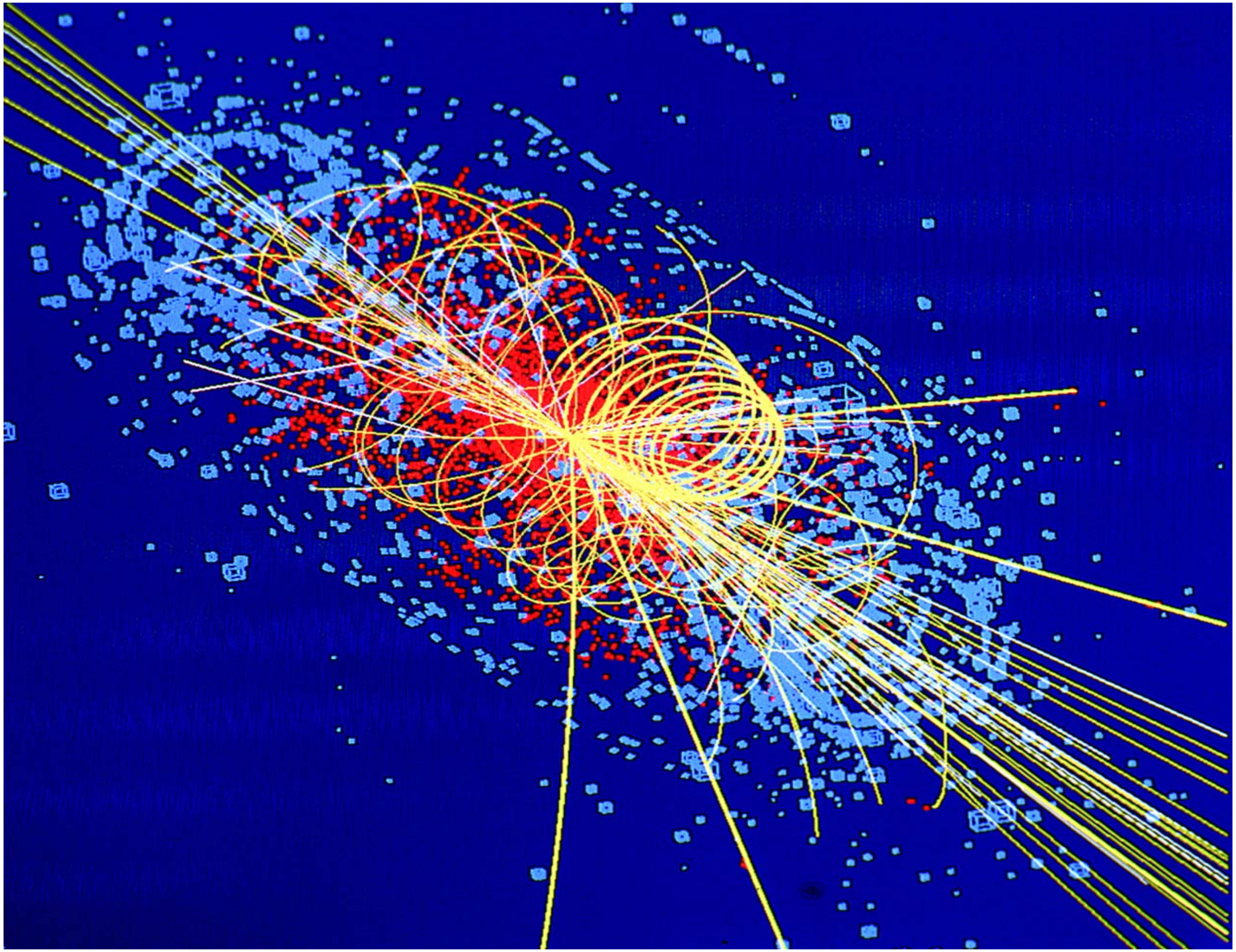
Detector Challenges at the ILC



Aspen Winter Conference
February 15, 2005

John Jaros

CMS Event



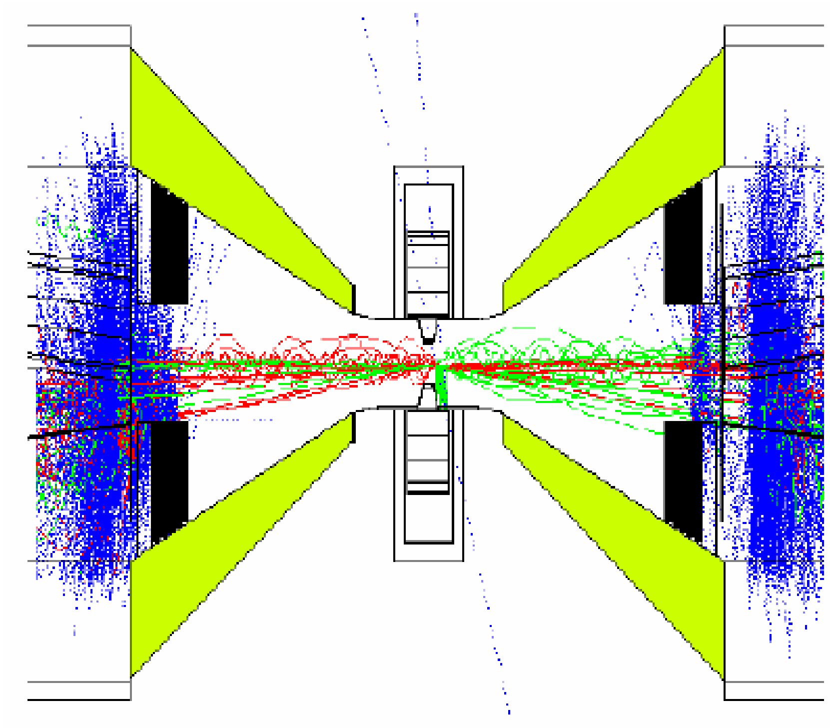
Anti-Challenge: Not the LHC

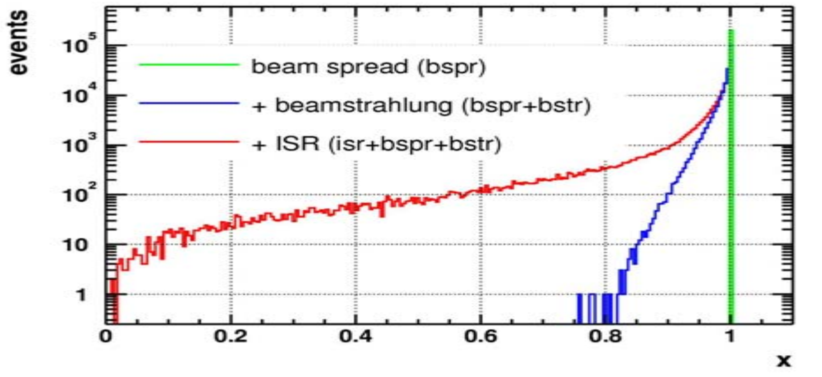
	LHC	ILC
• **Event Rates**		
Inclusive	1 GHz (min bias)	1 kHz ($\gamma\gamma$ -> hadrons)
• **Bunch Crossings**		
	25ns (40 Mhz)	300ns (15kHz)
	DC	0.5% Duty Factor
• **Triggering**		
Level 1 & 2	40MHz -> 1kHz	No Hardware Trigger
Level 3	~100 Hz Software	~100 Hz Software
• **Radiation Field**		
	1-100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

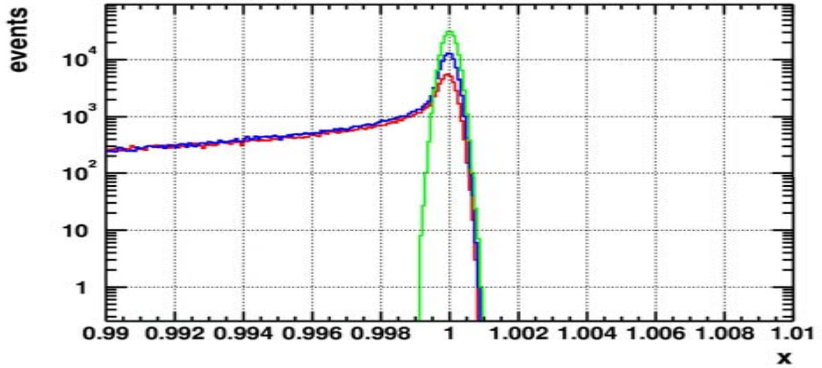
ILC Environmental Challenges

(every silver lining has its cloud)

- Intense, high $\mathcal{L}$ e^+e^- collisions produce beamstrahlung, pair backgrounds, and a luminosity spectrum that must be precisely measured.





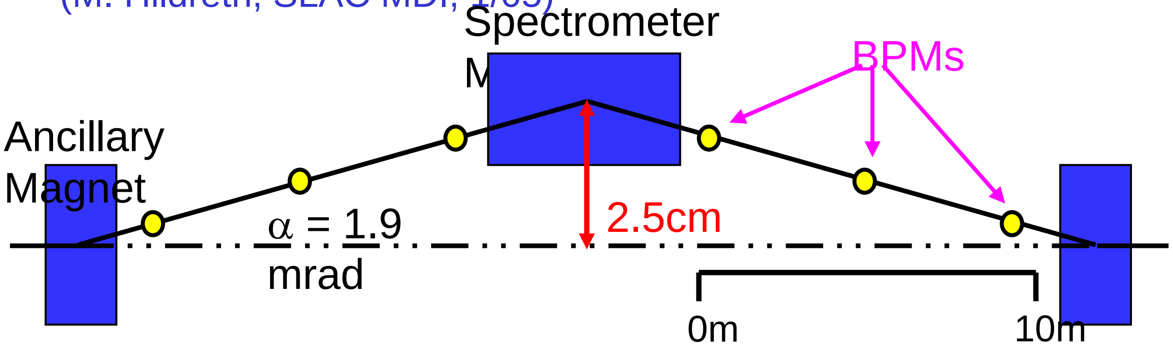


Challenge #1: Measure E_{beam} to 200 ppm

Higgs and Top mass precision set ΔE/E requirement

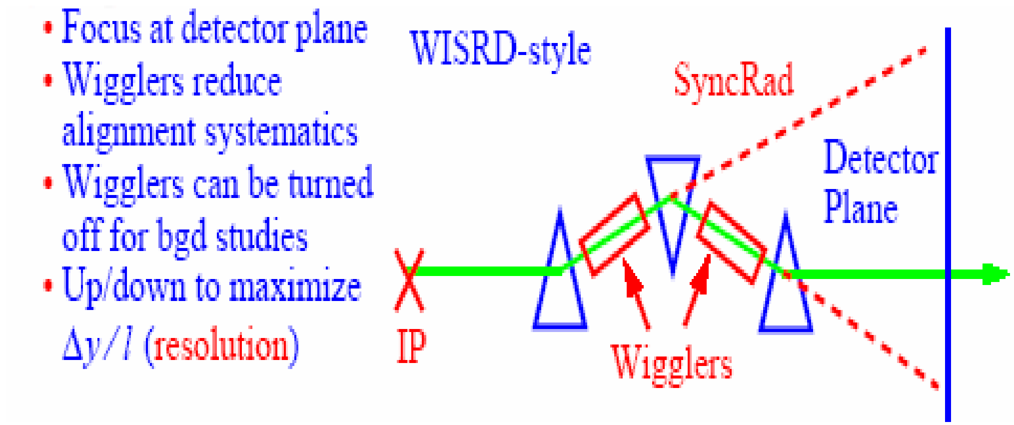
Beam Deflection with Precision Bend and BPMs

(M. Hildreth, SLAC MDI, 1/05)



Synchrotron Stripes with Precision Bend

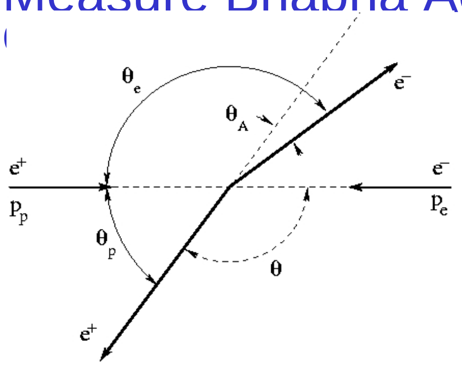
(E. Torrence, SLAC MDI, 1/05)

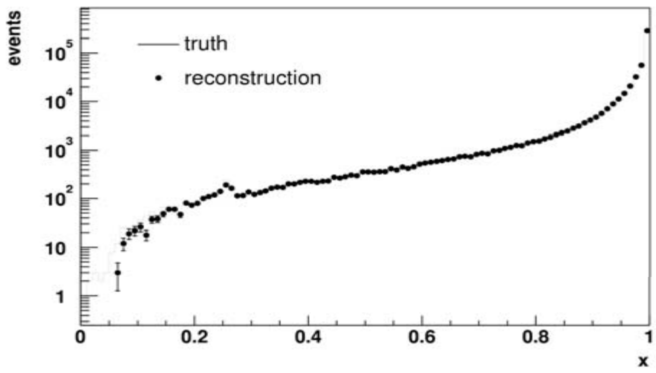


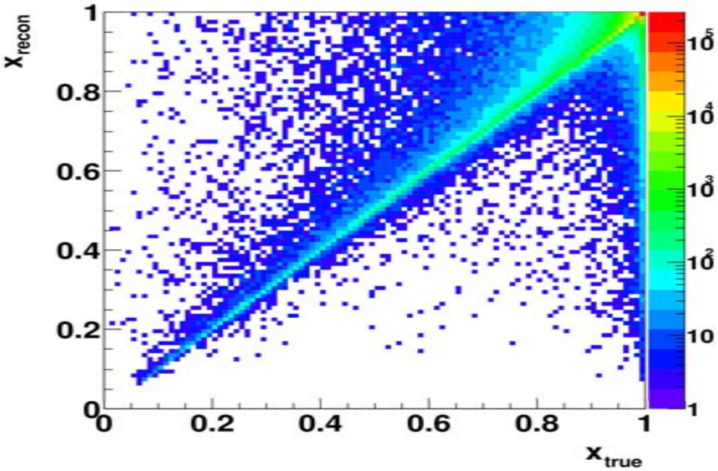
Challenge #2: Measure d$\mathcal{L}$/dE to 0.1%

Top threshold scan and Slepton masses need precise luminosity spectrum.

Measure Bhabha Acolinearity ($\Delta\Theta/\Theta \sim 10^{-5}$ *very* demanding)





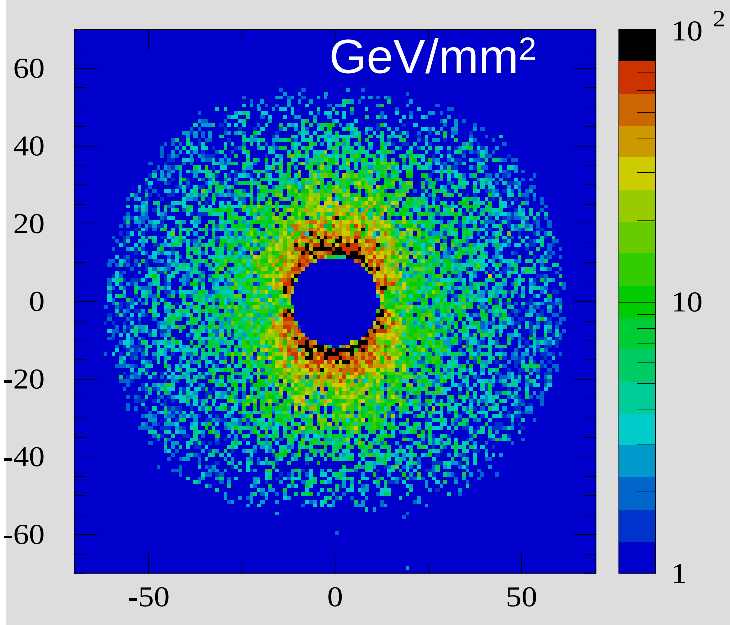


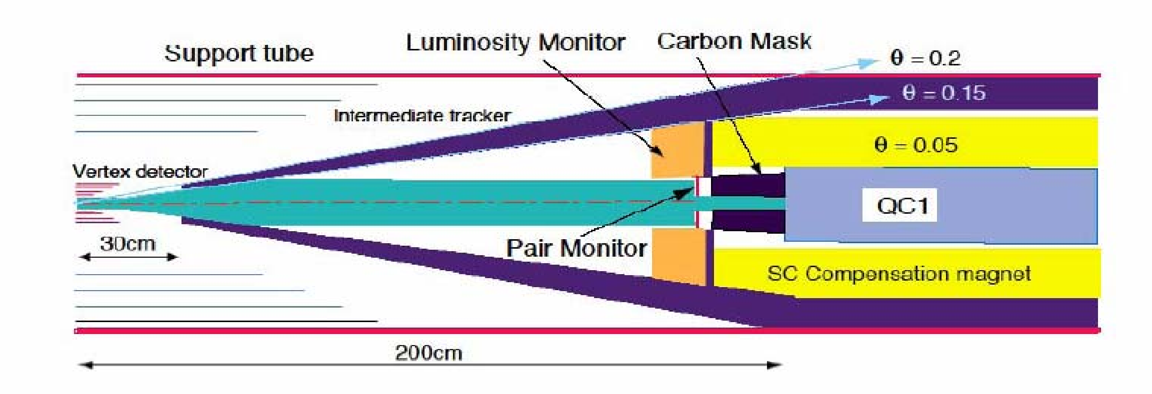
Bunch to bunch fluctuations complicate analysis.

Absolute calibration with physics events (ZZ, $\mu\mu\gamma$,ee)?

Challenge #3: Monitor Collision Bunch by Bunch

- Pattern of energy deposition measures $\mathcal{L}$ and beam properties pulse by pulse.
- High Radiation Environment
  15k $e^+ e^-$ / BX
  10-20 TeV/ BX
  10 MGy/year
- Fast response (~100ns) needed
- Premium on single electron detection efficiency for SUSY veto

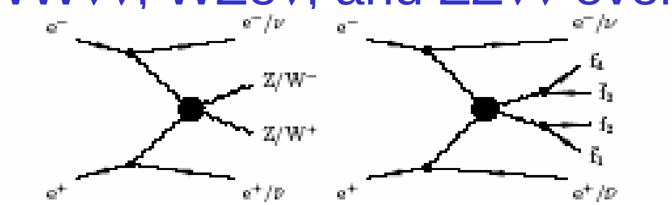




Physics Demands, Environment Allows Precision Calorimetry

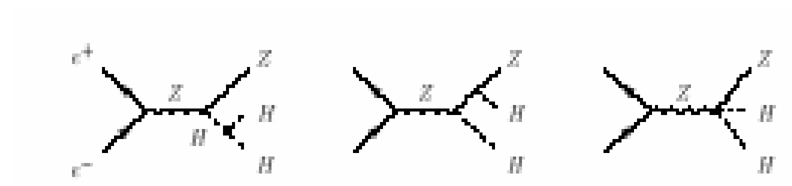
Bread and Butter Precision EW or Signal of Stong EWSB?

Unconstrained kinematics needs high resolution cal to discrimminate WWνν, WZeν, and ZZνν events.

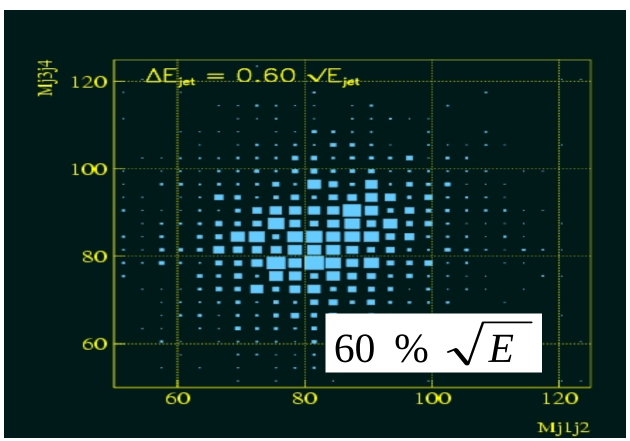


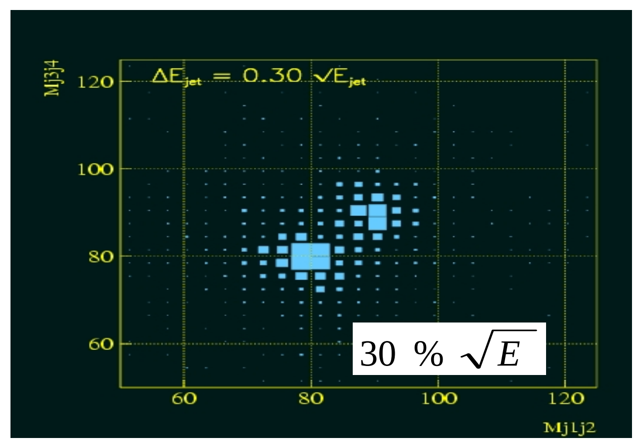
Measure Higgs Self Coupling λ_{hhh}

Tiny (0.2 fb @ 500 GeV) signal on large multijet backgrounds is only visible with high resolution



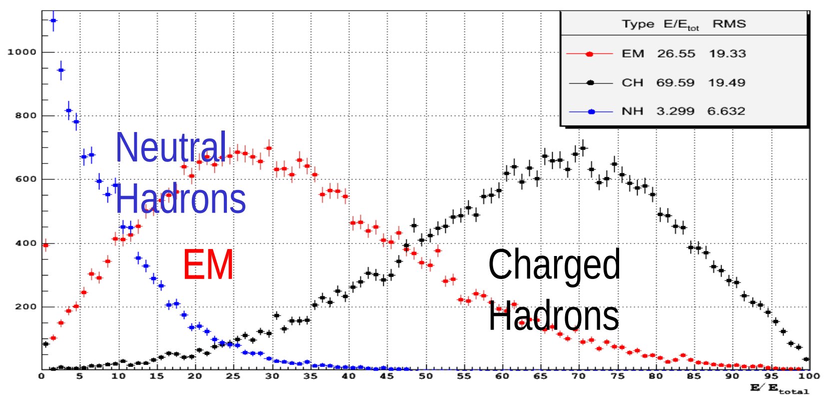
$$e^+e^- \rightarrow WW\ \nu\bar{\nu}\ ,\ e^+e^- \rightarrow ZZ\ \nu\bar{\nu}$$

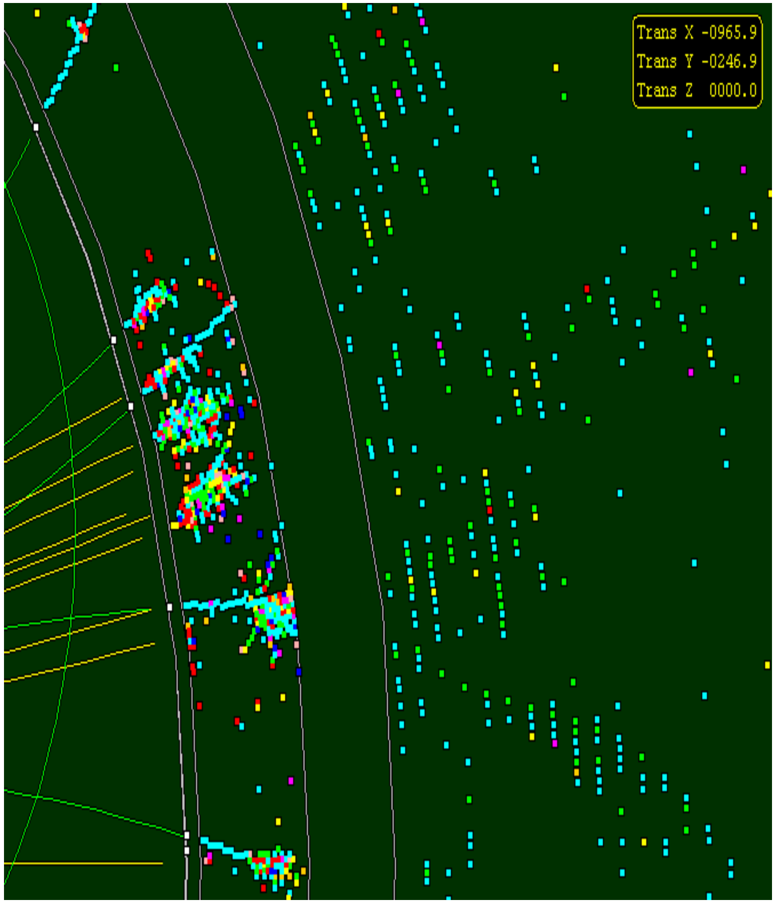




Challenge #4: Demonstrate Performance of Particle Flow Calorimetry

- **P-Flow measures the energy of the particles, not all that deposited in calorimeter modules:**
- Measure charged energy in tracker
- Excluding charged energy depositions in ecal, measure photon shower energy
- Excluding charged and em neutrals, catch remaining hadronic

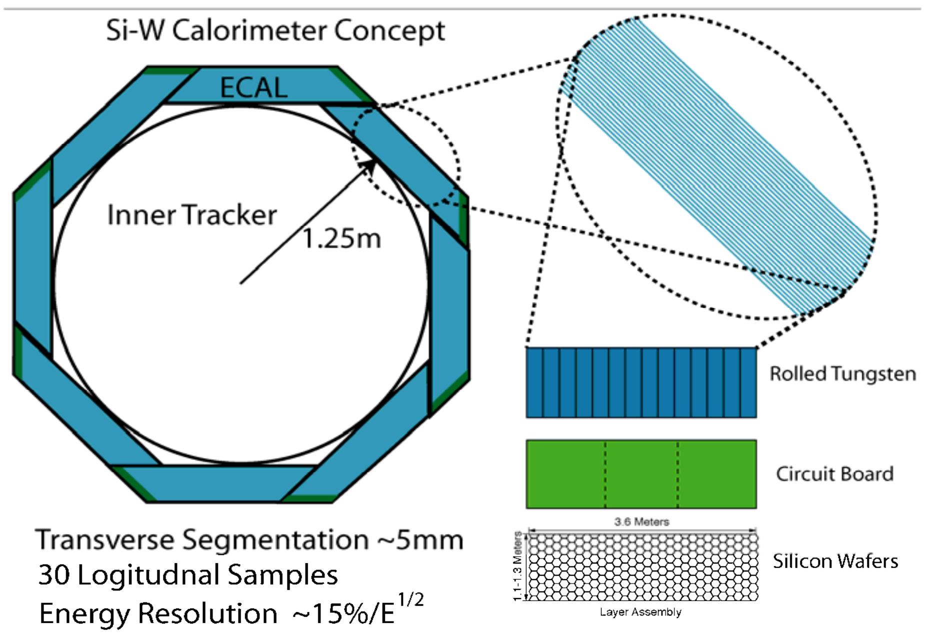


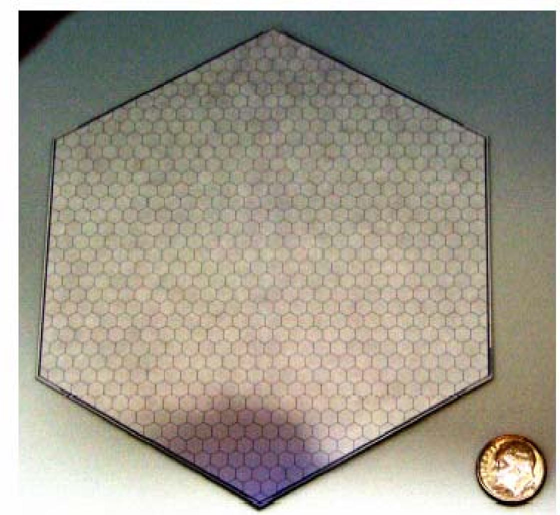


Challenge #5: How to Pixellate an EM Calorimeter?

P-Flow requires high transverse and longitudinal segmentation.

SiW can provide 5 x 5 mm^2 segmentation and minimal effective Moliere radius to limit transverse shower size. Cost and power consumption are the issues.





SiW Readout R&D

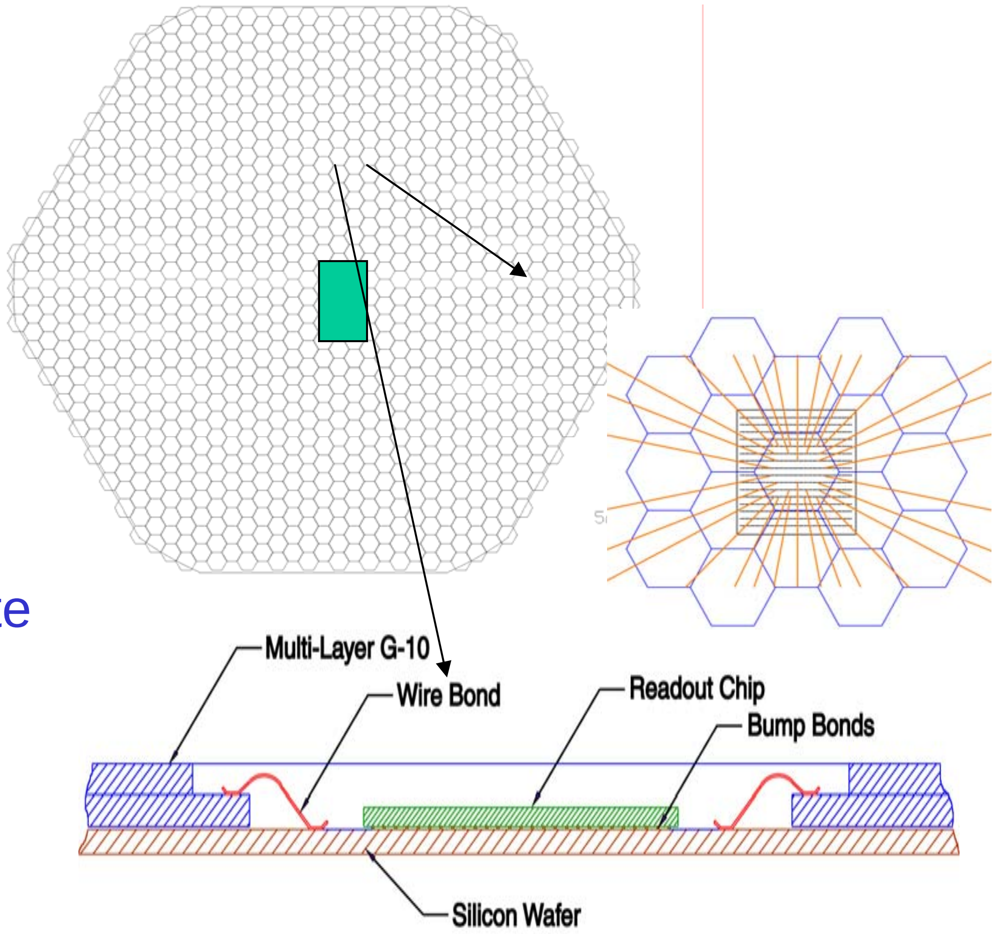
Readout ~1k pixels/detector with bump-bonded ASIC (X10 current ASICs)

Power cycling – only passive cooling required

Dynamic range OK
(0.1 - 2500 mip)

Pulse Height and Bunch Label buffered 4 deep to accommodate cold ILC pulse train

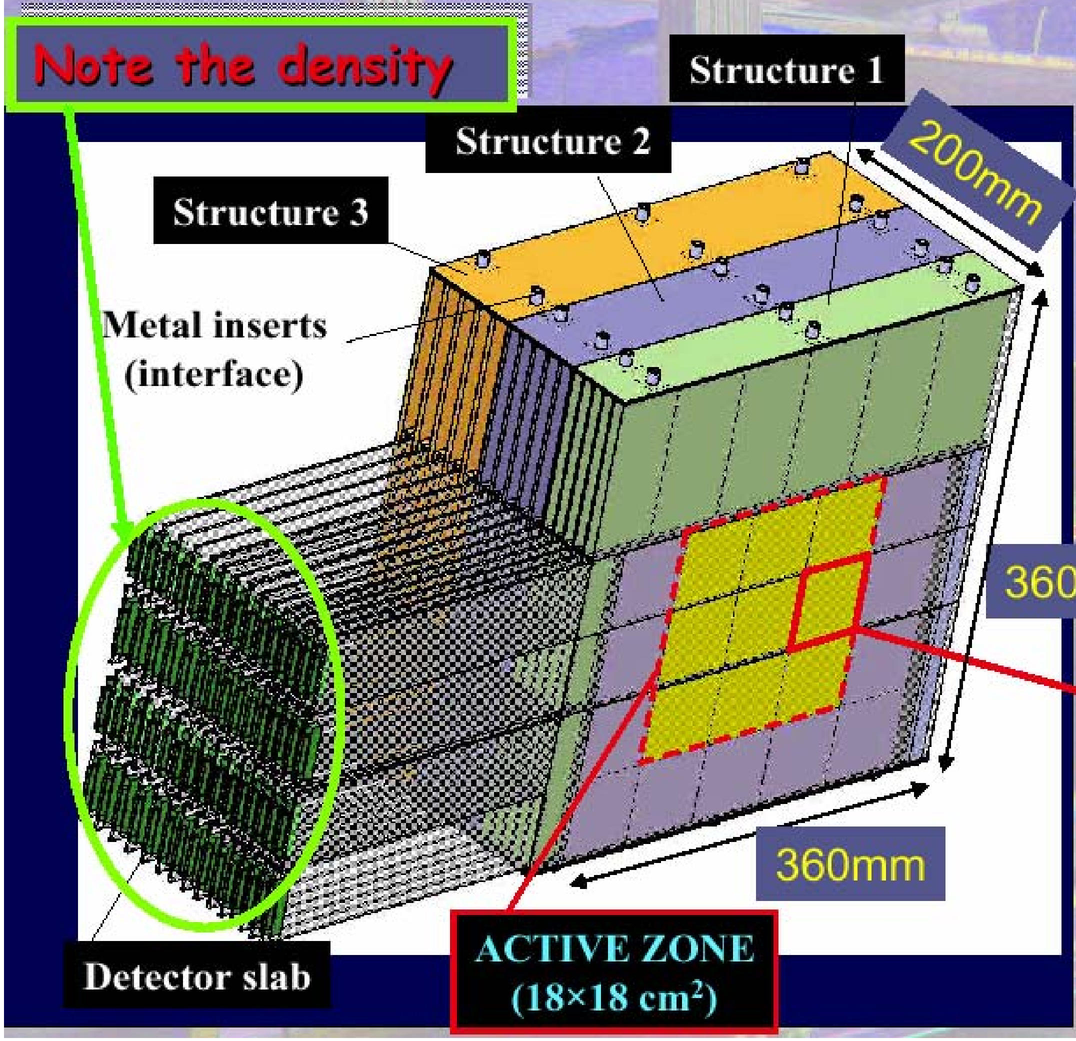
Engineering underway
(U Oregon, BNL, SLAC)



The ECAL prototype

CALICE ECAL

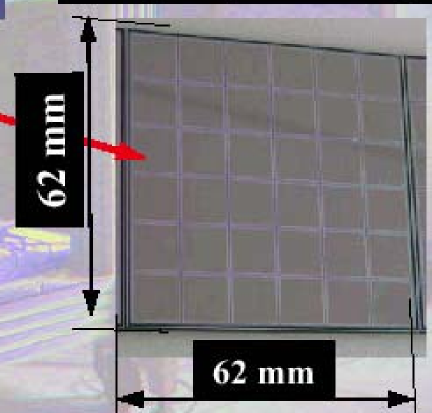
- LAL,LLR,LPC,PICM
- Imperial College, UCL, Cambridge, Birmingham, Manchester, RAL
- ITEP,IHEP,MSU
- Prague (IOP-ASCR)
- SNU,KNU



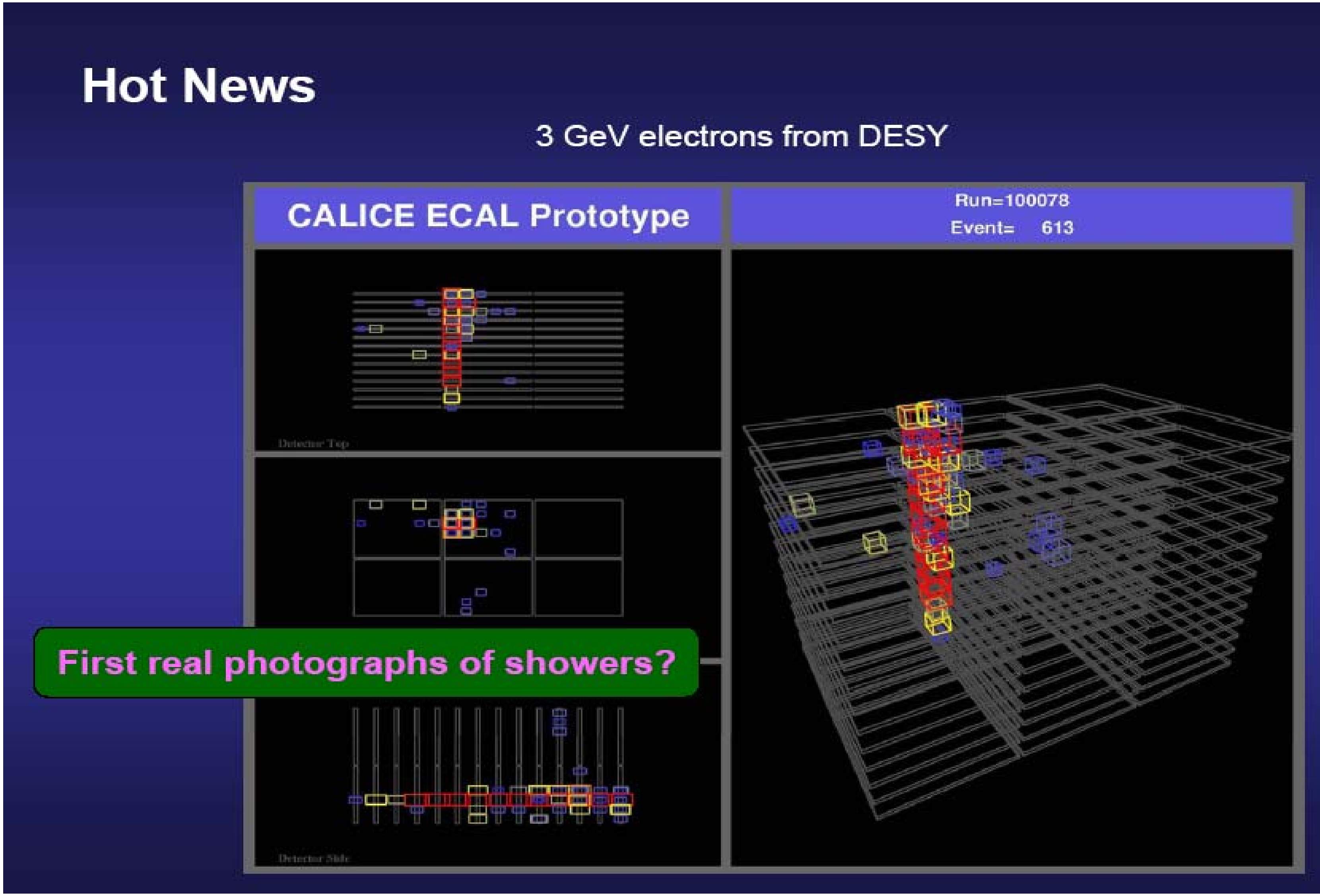
- 3 structures W-CFi (1,2,3 x1.4mm)
- 15 « detector slabs »
- Dimension 200x360x360 mm

→ 9720 channels in prototype

Silicon wafers with 6×6 pads **(10×10 mm²)**



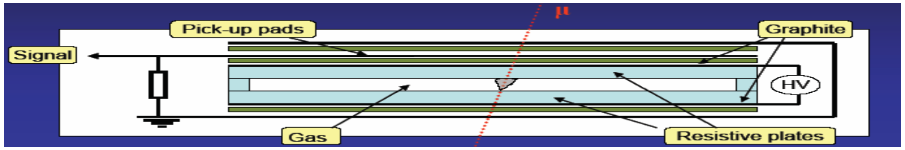
First Calice Test Beam Results



Challenge #6: P-Flow Hcal

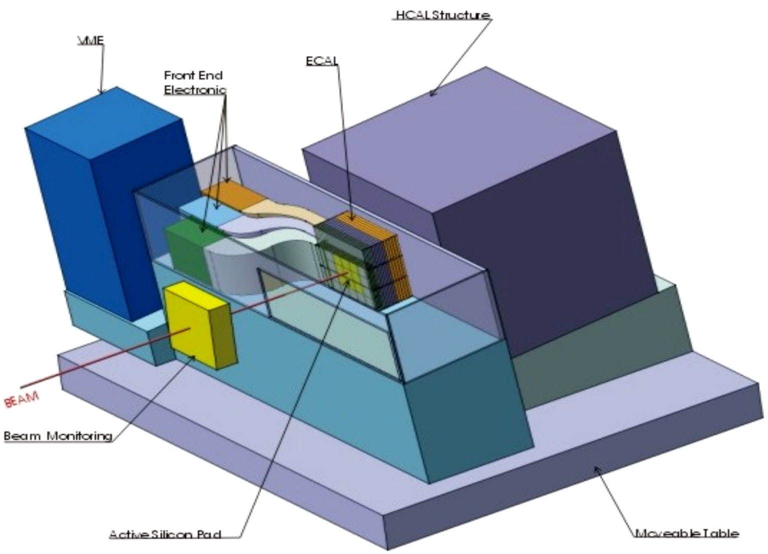
P-Flow demands ~1 x 1 cm^2 segmentation in Hcal. Several technologies are being explored, including Resistive Plate Chambers, Scintillating Tiles, and GEMs.

RPCs are cheap and compact. Reliability, readout, resolution need R&D.



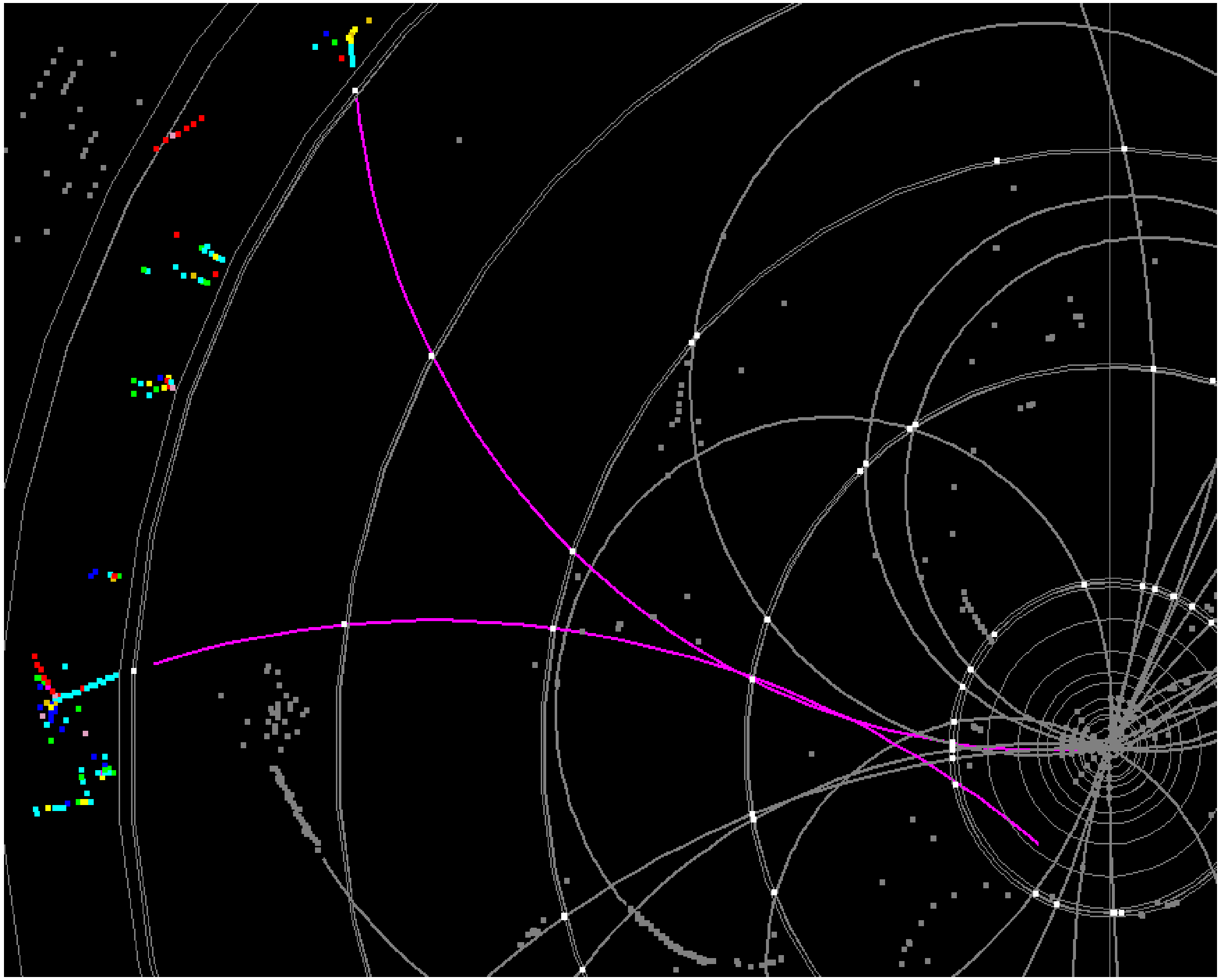
Beam Tests of Digital Calorimetry are needed. International collaboration is underway.

Overall engineering and design	**ANL**
ASIC engineering and design	**FNAL**
ASIC testing Test board design Test board production Measurements	ANL **FNAL**
Front-end PC board engineering and design prototyping and testing	**ANL** FNAL
Data concentrator engineering and design prototyping and testing	**Chicago**
Data collector engineering and design prototyping and testing	ANL Boston
DAQ system: VME processor and programming	**Washington**
Timing and trigger system engineering and design prototyping and testing	**UTA**
High voltage system	**Iowa**
Gas mixing and distribution system	**Iowa**



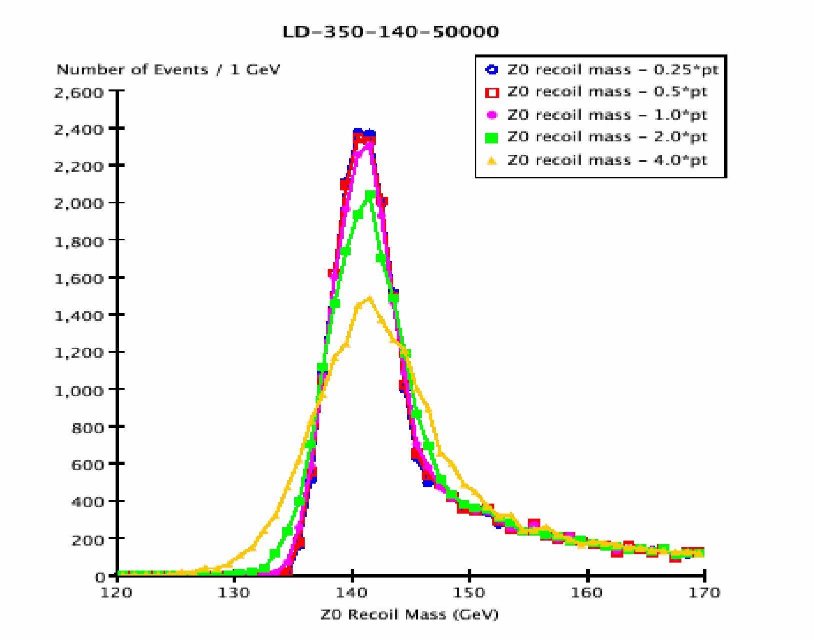
Bonus of a Tracking Calorimeter

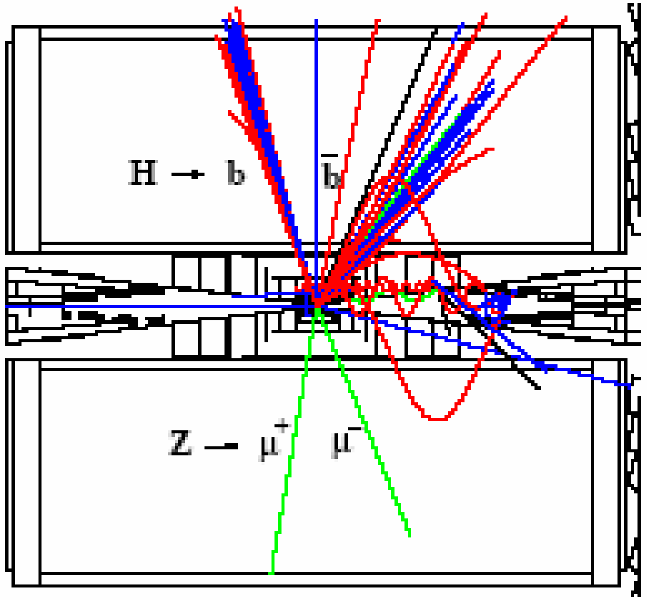
Track from outside in: K^0_s and Λ *or* long-lived SUSY!



Higgs Studies Push Tracker Resolution

- Higgs recoil mass resolution improves until $\Delta p/p^2 \sim 5 \times 10^{-5}$. Accuracy of higgs mass determination, sensitivity to invisible higgs decays, and purity of recoil-tagged higgs sample, improve accordingly. (Yang and Riles. Nominal $\Delta p/p^2 \sim 3 \times 10^{-5}$; 1% beam E spread)



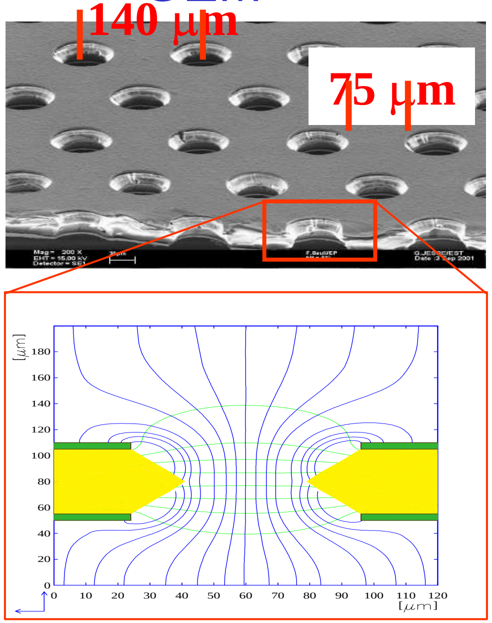


- Tracker resolution improvement is 10X LEP/SLC and 3X CMS. New territory.

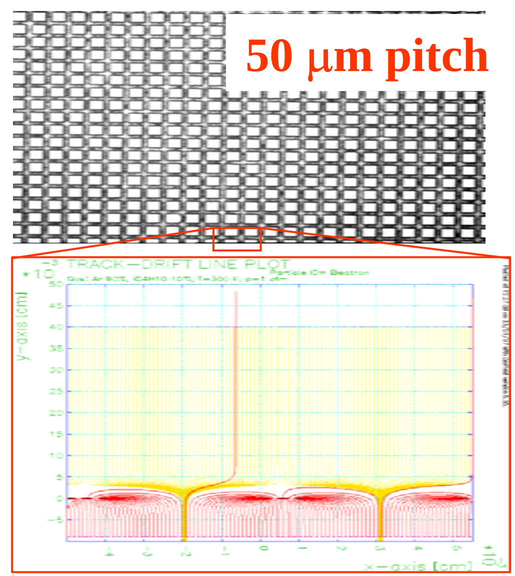
Challenge #7: Reach Tracker Momentum Resolution $\Delta p/p^2 \sim 5 \times 10^{-5}$

- Pushing TPC's to Higher Resolution requires high B, new readout techniques, improved point resolution, thinning field cages and endplates, and great attention to systematics. R&D underway.
- Micromega and GEM readouts reduce endplate distortions and positive ion feedback and boost resolution.

GEM

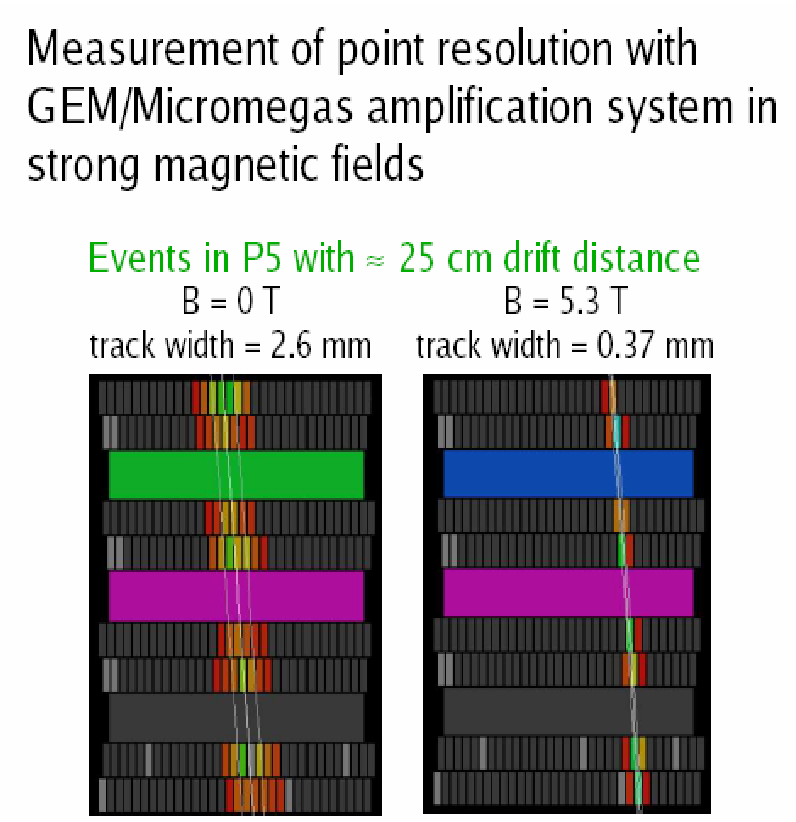


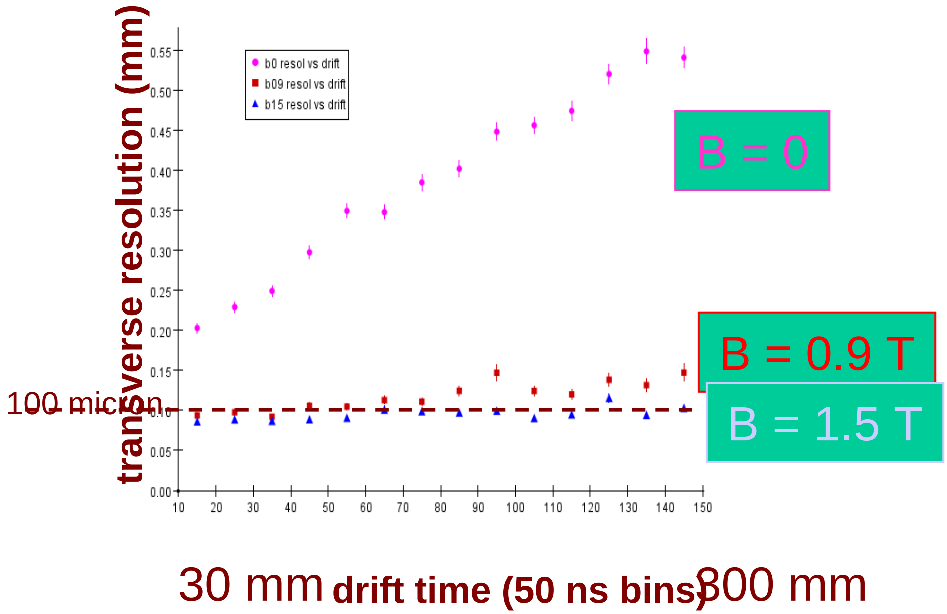
MICROMEGA



TPC R&D Required, Underway

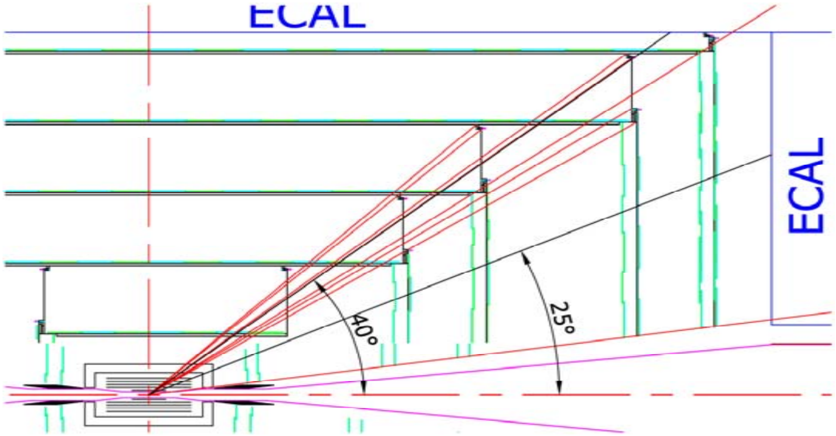
High B field, new readouts, improve resolution for TPCS

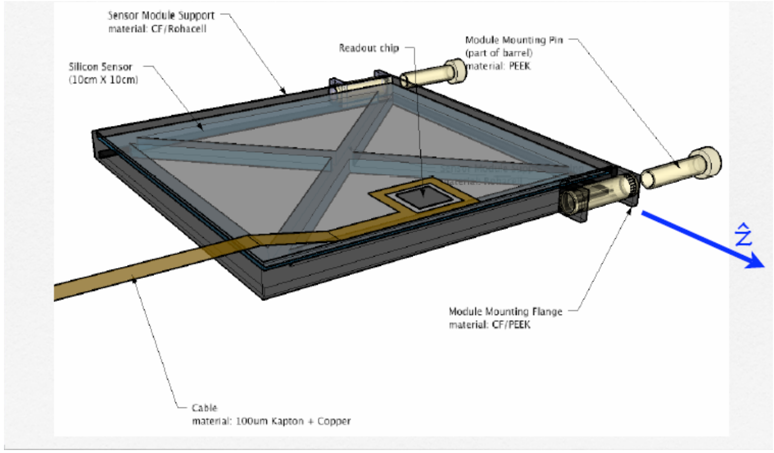




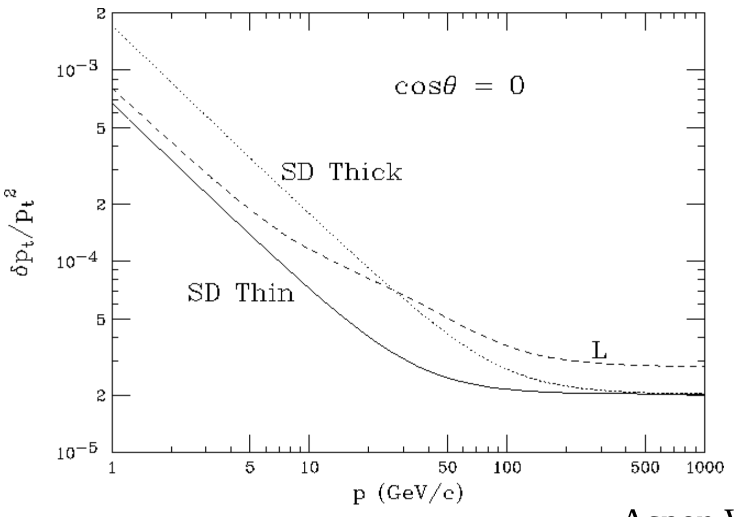
All Silicon Tracking Option: Resolution is OK, is Pattern Recognition?

Designing thin, stable supports and services:

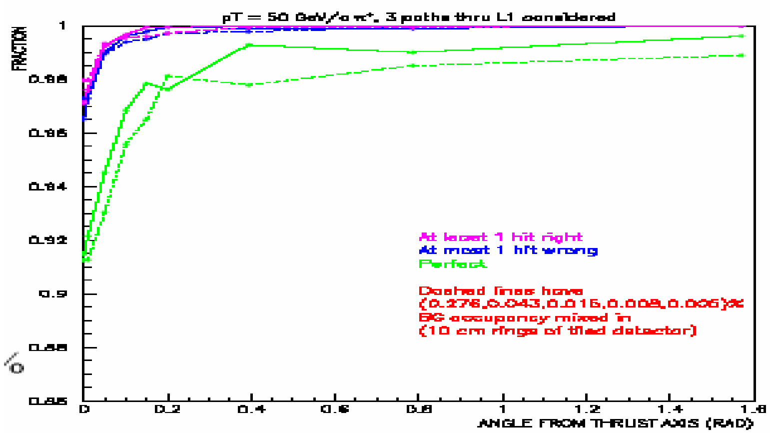




Excellent momentum resolution

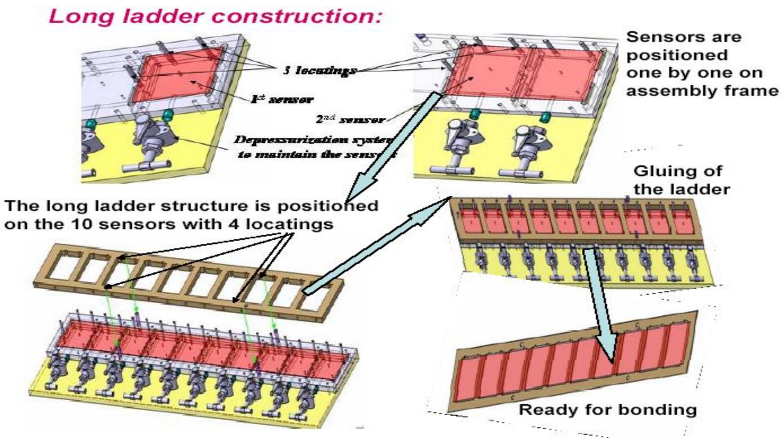


Studying Pattern Recognition Capability (S. Wagner, Paris LCWS04)



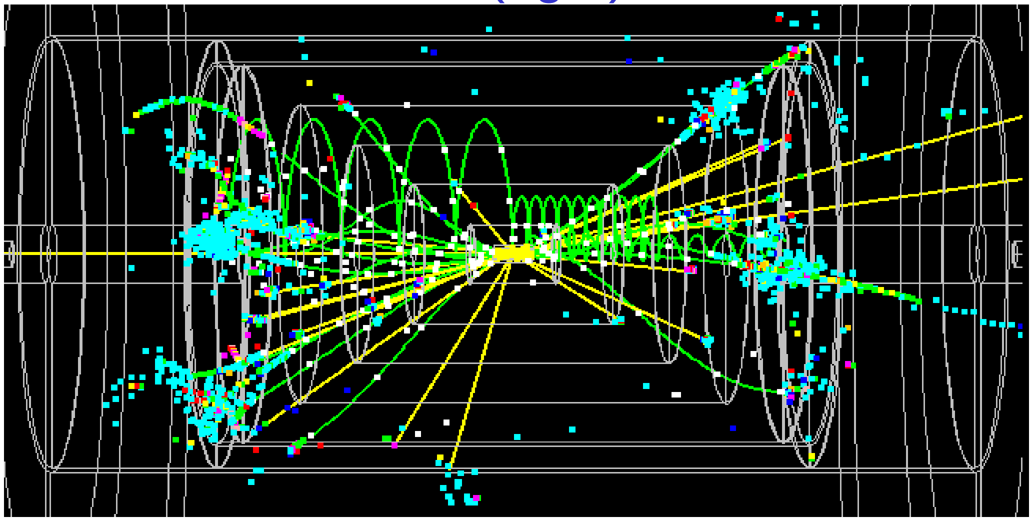
Challenge #8: Si μstrip Readout

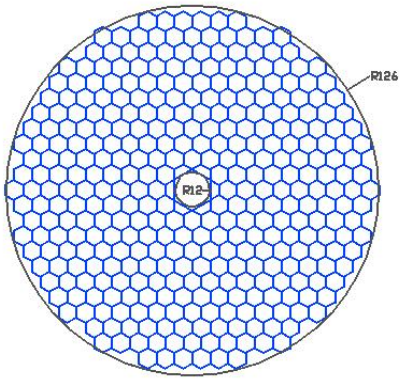
- Readout needs power cycling, on-board ASIC, buffered readout. Development needed.
- S/N considerations and packaging favor common 10cm detectors.
- ~1m long detectors, daisy-chained, minimize material for readout and power.
- Long shaping times can recover S/N for high capacitance strips. Power cycling exploits low duty cycle and eliminates need for cooling. UCSC and LPHNE Paris are doing R&D.



Challenge #9: Forward Tracking

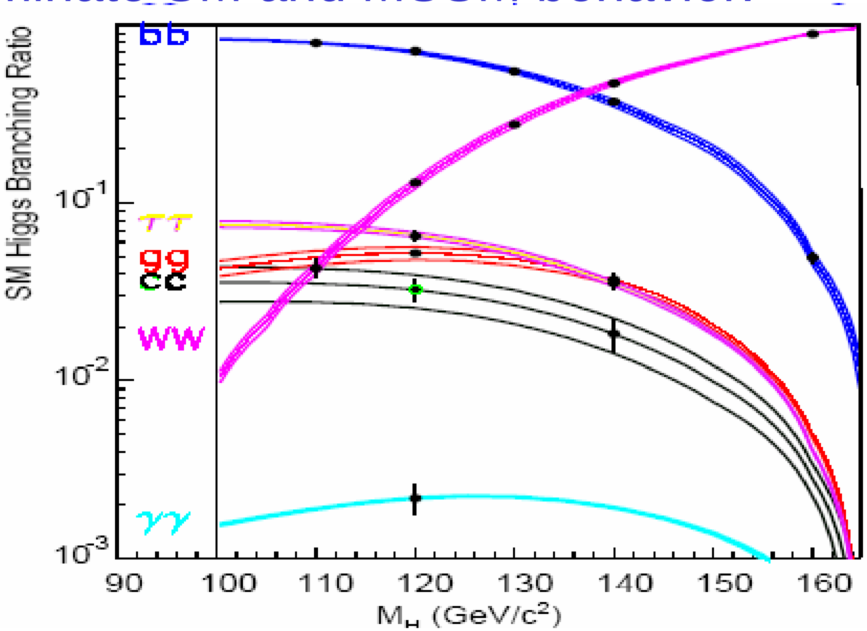
- P-Flow calorimetry needs good tracking to |cosθ|~0.98
- Forward tracking must be thin enough not to degrade forward calorimetry or spoil electron ID and robust enough to track loopers and K shorts.
- Differential luminosity requires extremely precise angular measurements: $\Delta\theta/\theta \sim 10^{-5}$
- Never been done (right)!





Higgs Physics Pushes Vertex Detector Resolution

- Precision measurements of Higgs branching fractions test how the Higgs generates the fermion and gauge boson masses, and can discriminate SM and MSSM behavior.



- Tagging b jets with high efficiency, discriminating b and c jets, and anti-tagging u,d,s,g jets, requires small beam pipe radii, thin detector layers, and μm level measurement accuracy.

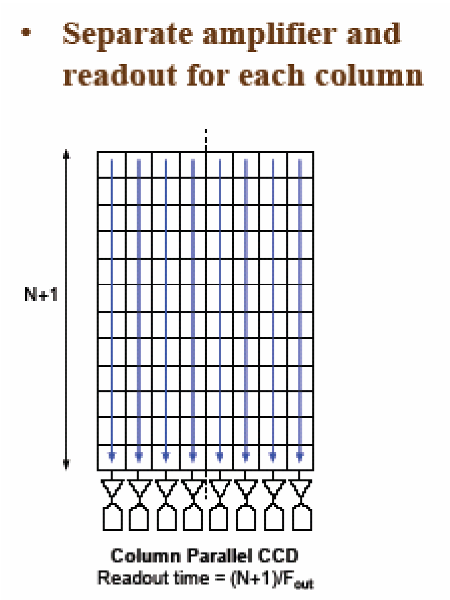
Challenge #10: Readout a Precision Vertex Detector

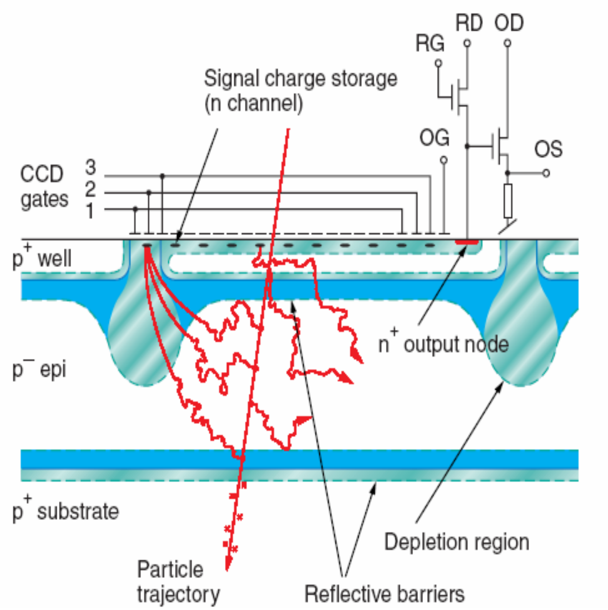
- CCDs provide superb resolution, but their slow readout speed can't handle the 1/mm^2 /BX backgrounds from pairs.
- **Real problem.** Several promising solutions are being pursued.

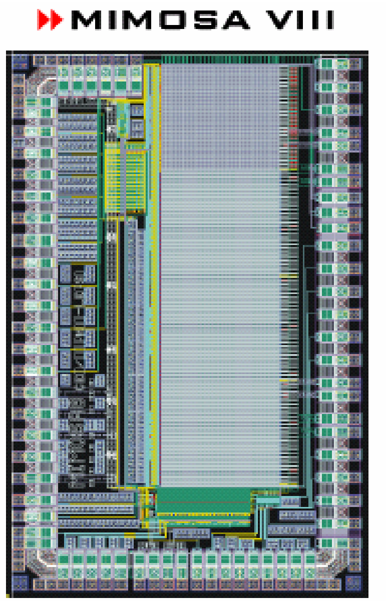
CPCCD

Image Sensor with In-situ Signal storage

CMOS





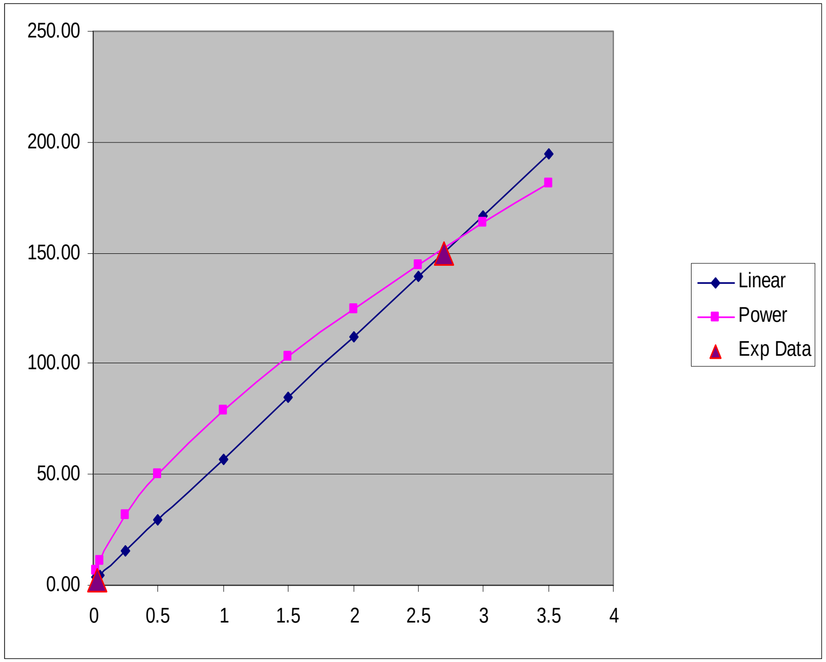


Challenge #11: High Field/ High Stored Energy Magnets

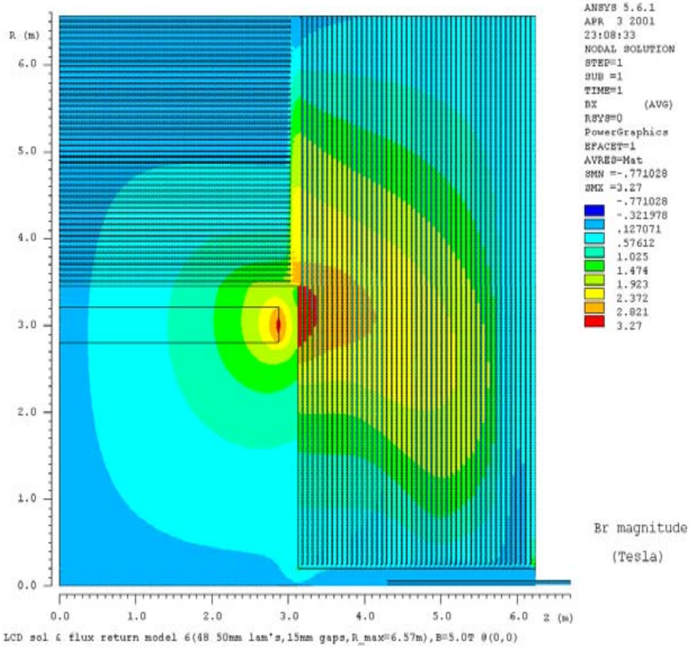
- Current detector concepts use 3-5T solenoids with GJ stored energies. The CMS coil is the lone prototype for such magnets. Serious engineering design is required. Cost optimization and dipole compensation for crossing angles are needed.

Stored E [GJ]

Cost [M$]



B_r



More Challenges

- Boosted R&D funding is needed now if we are to keep pace with ILC machine developments.
- Detector Design Studies need to internationalize, refine detector concepts, benchmark costs and physics performance, push detector R&D.

  SiD *GLD* *LDC*
- *Join us in this enterprise at Snowmass Aug. 14-25.*