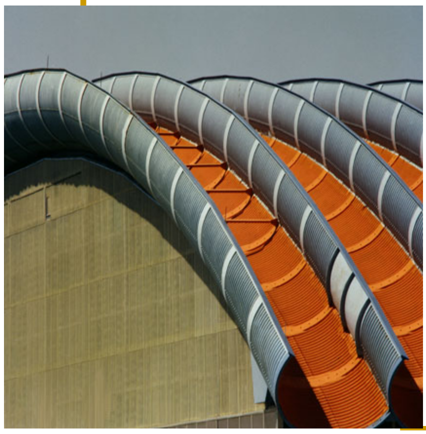
ILC Detector R&D and Test Beams

Test Beam Workshop Summary



D. Karlen / University of Victoria & TRIUMF

Fermilab Wine and Cheese Seminar
January 19, 2007

ILC Detector R&D and Test Beams

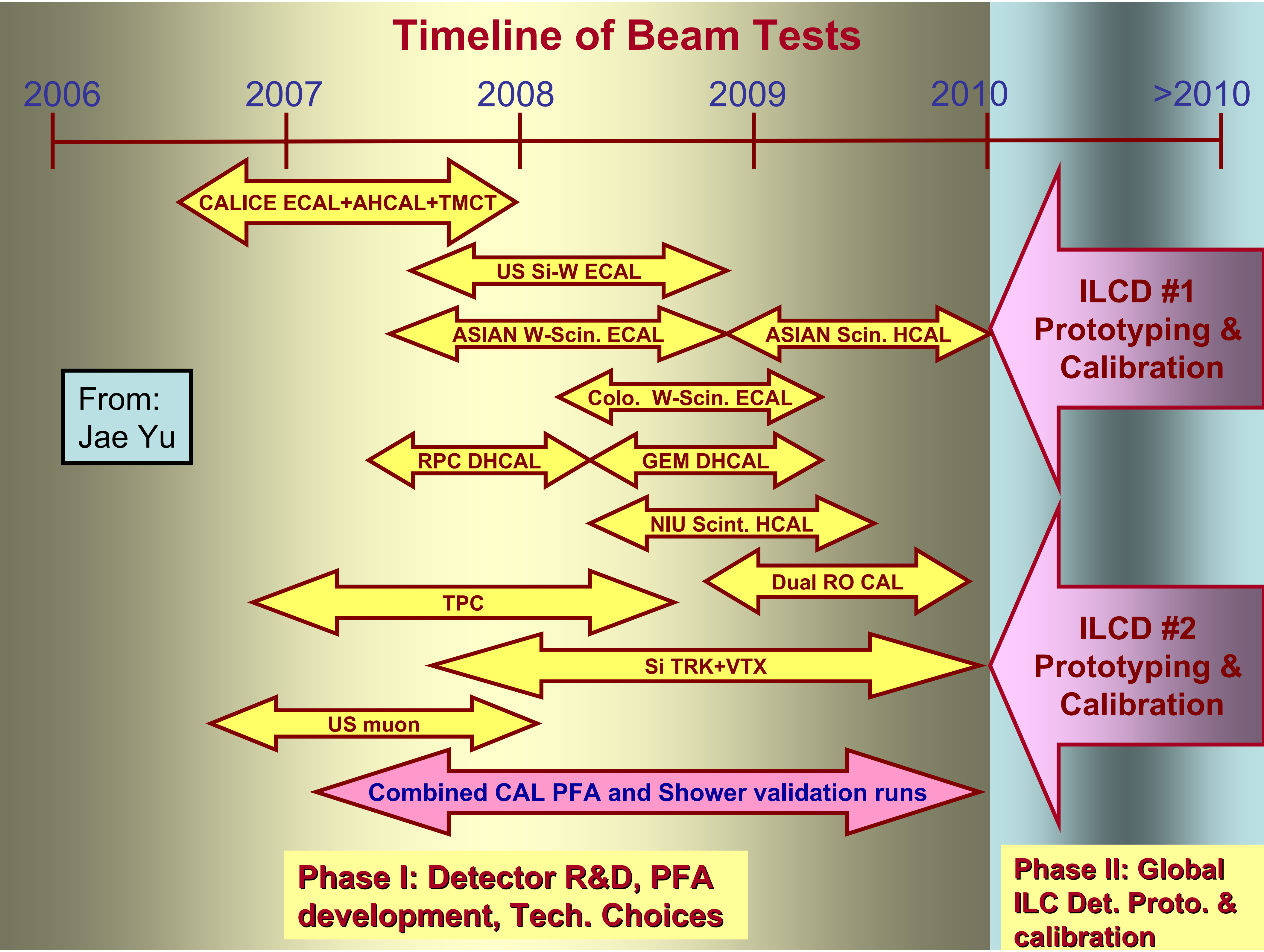
- This talk concludes the workshop on Test Beams for ILC Detector R&D, held during the past 3 days here in “One West”
  - a very impressive set of presentations and useful discussion
- Here, I give a sampling of the presentations to give you a taste of the work that is underway and planned
  - the work is shown in context of the many interesting challenges that remain for the ILC detectors.

The great ILC detector challenge: precision

- The strength of the ILC physics case lies in the precision of a broad range of measurements that can be achieved with electron-positron collisions
  - bringing important new information to allow a deeper understanding of Nature in the LHC era
- The high level of precision required of the detector sub-systems presents the greatest challenge in the design of the ILC detectors
  - the ILC detectors need to exceed the performance of their predecessors by large factors

ILC detector test beams

- ILC detector tests in particle beams are becoming increasingly important
  - as sub-detector concepts develop into more refined prototypes – we must demonstrate that the challenging performance goals can be met in as realistic an environment as possible
- There is some concern that with fewer high energy accelerators operating in the future, there may be insufficient test beam facilities
  - in some cases, very strong user support and arguments are needed to keep facility operational


Timeline of Beam Tests
2006
2007
2008
2009
2010
>2010
CALICE ECAL+AHCAL+TMCT
US Si-W ECAL
ASIAN W-Scin. ECAL
ASIAN Scin. HCAL
Colo. W-Scin. ECAL
RPC DHCAL
GEM DHCAL
NIU Scint. HCAL
Dual RO CAL
TPC
Si TRK+VTX
US muon
Combined CAL PFA and Shower validation runs
ILCD #1 Prototyping & Calibration
ILCD #2 Prototyping & Calibration
From: Jae Yu
Phase I: Detector R&D, PFA development, Tech. Choices
Phase II: Global ILC Det. Proto. & calibration

Test Beams available for detector R&D

- On Wednesday we heard from the test beam coordinators from several laboratories:
  - FNAL (Erik Ramberg)
  - SLAC (Carsten Hast)
  - KEK (Osamu Tajima)
  - LBNL (Devis Contarato)
  - IHEP-Beijing (Li Jia Cai)
  - IHEP-Protvino (Alexander Kozelov)
  - DESY (Ingrid Maria Gregor)
  - CERN (Christoph Rembser)
- A nice summary of the facilities was presented by Marcel Demarteau

Test Beams available for detector R&D

- All of the coordinators extended open invitations to perform detector tests at their facilities
  - services provided include:
    - cabling, DAQ, gas services, cranes, alignment, pixel test stands, telescopes, remote controlled moving stands
  - a real opportunity to further international cooperation

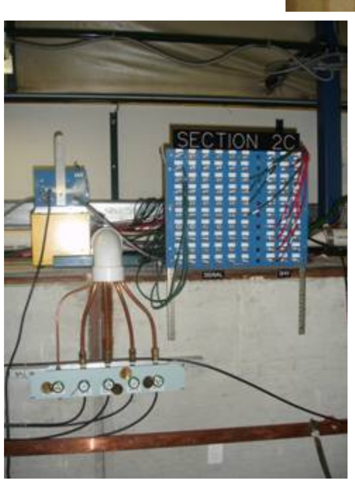
- Unfortunately, US govt. is not extending an equally warm welcome to all international scientists
  - difficult visa process prevented the China and Russia test beam coordinators from attending the meeting
  - situation is improving but not yet solved

FNAL test beams

- Impressed by the facilities here
  - workshop participants got a chance to see first hand
  - motivated by the ILC community, an extensive upgrade to the beamline was recently undertaken
    - commissioning has started
    - flexible spill structure

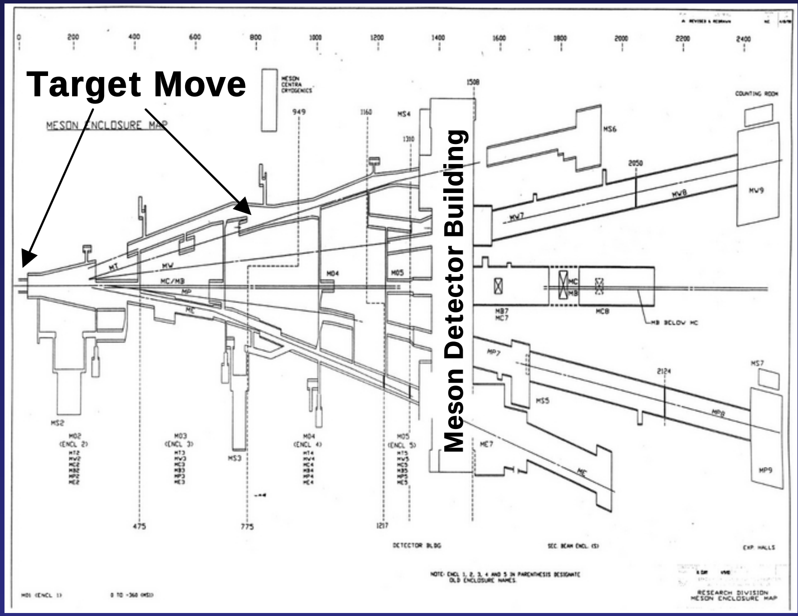
Energy (GeV)	Present Hadron Rate MT6SC2 per 1E12 Protons	Estimated Rate in New Design (dp/p 2%)
1	---	~1500
2	---	~50K
4	~700	~200K
8	~5K	~1.5M
16	~20K	~4M

FNAL meson test beam facility



Possible Enhancement of Fermilab Beam Test

- Further enhancements of the ILC R&D activities could be explored, with a concurrent scientific program, which could benefit the ILC community
- MCenter beam line, which houses the MIPP experiment, is currently not scheduled
- MCenter beamline
  - Beamline with excellent characteristics
    - Six beam species ($p^{\pm}$,$K^{\pm}$,$\pi^{\pm}$) from 1 -- 85 GeV/c
  - Excellent particle id capabilities



- Experimental setup
  - Could allow for better understanding of hadron-nucleus interactions, which could benefit our understanding of hadronic shower development, which is currently poorly understood
    - Nuclei of interest that can be measured with an upgraded MIPP
      - H_2, D_2, Li, Be, B, C, N_2, O_2, Mg, Al, Si, P, S, Ar, K, Ca, Fe, Ni, Cu, Zn, Nb, Ag, Sn, W, Pt, Au, Hg, Pb, Bi, U, Na, Ti,V, Cr, Mn, Mo, I, Cd, Cs, Ba
  - Moreover, experimental setup with the full spectrometer would allow for a tagged neutron beam from fully constrained reaction pp ➔ p,n,π^+

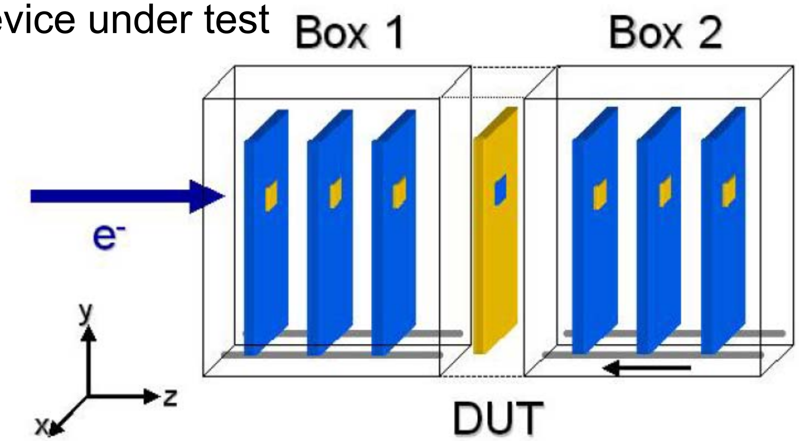
From Marcel Demarteau

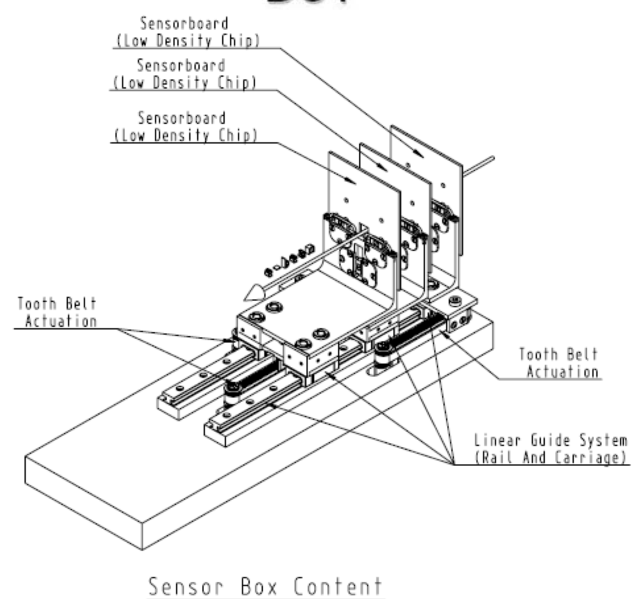
EUDET: test beam infrastructure for ILC

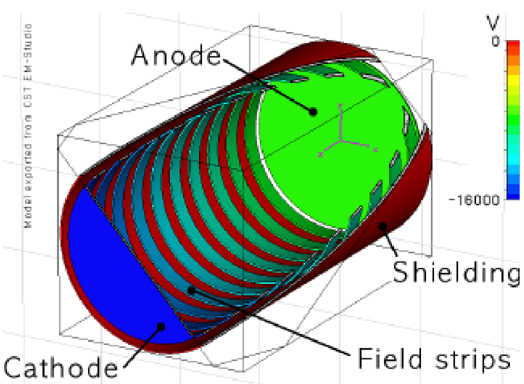
- 21.5 M€ European funding, 2006-2009
- Open invitation to all to exploit the infrastructure

Felix Sefkow

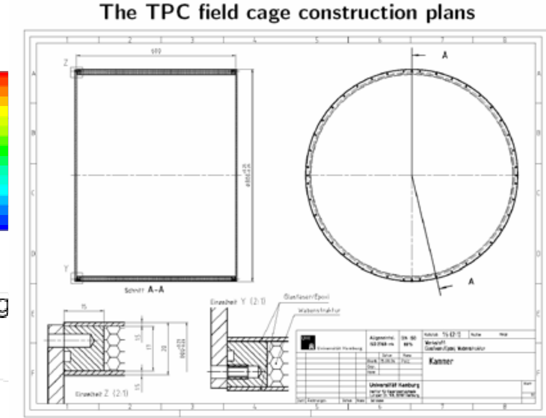
1 µm precision on device under test







The TPC field cage construction plans



ILC Beamline detectors

- Many ILC physics measurements rely on the precise knowledge of the initial state:
  - luminosity
  - polarization
  - centre of mass energy
    - WW threshold: 5 MeV (50 ppm)
    - tt threshold and Higgs mass: ~50 MeV (100-200 ppm)
- These require dedicated instruments – in the interface between machine and detector: “MDI”
- Tests of these and other beam diagnostic detectors can be done at SLAC’s ESA

Beam Parameters at SLAC ESA and ILC

Parameter	SLAC ESA	ILC-500
Repetition Rate	10 Hz	5 Hz
Energy	28.5 GeV	250 GeV
Bunch Charge	2.0×10^{10}	2.0×10^{10}
Bunch Length	300-500 μm	300 μm
Energy Spread	0.2%	0.1%
Bunches per train	1 (2*)	2820
Microbunch spacing	- (20-400ns*)	337 ns

*possible, using undamped beam

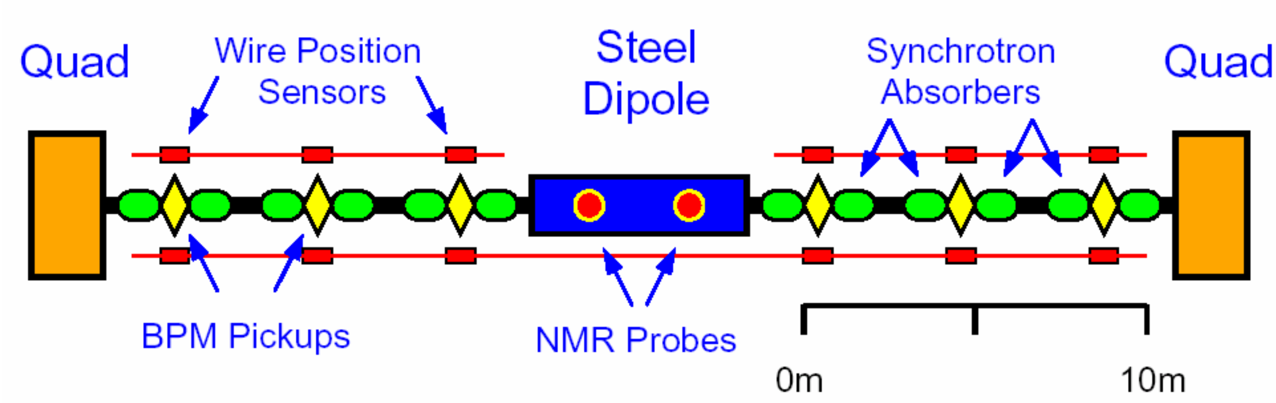
Spectrometry: A Reminder

- Required measurement precision is set by the expected statistical and systematic errors of “benchmark” measurements of m_{top}, m_{higgs}:
  - require $\delta E_{beam}/E_{beam}$ ~ 100-200 ppm
  - So far, only spectrometer techniques have come anywhere near this precision with very high energy electron beams
- Previous efforts:
  - LEP2
    - Achieved 120 ppm by combining three different methods, only one of which (BPM Spectrometer) is available at ILC
      - Spectrometer was able to do 170 ppm
  - SLC
    - WISRD systematic errors estimated at 220 ppm, σ_E/E~20 MeV
    - C of M was shifted by 46 ± 25 MeV (500 ppm) compared with Z lineshape scan

⇒ Many constraints more severe at ILC than at low energy ⇒ Need R&D!

Two Spectrometers Designed for ILC

- **"LEP-Type"**: BPM-based, bend angle measurement



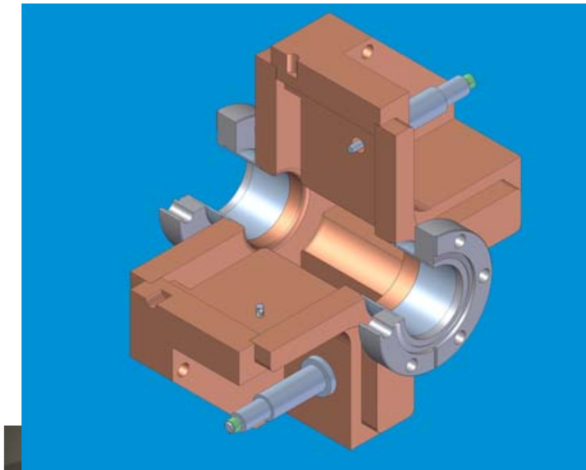
θ_{bend} = 3.8 mrad (LEP)
~ 0.2 mrad (ILC)

$$\theta = \frac{ec}{p} \int B \cdot d\ell$$

→ located in BDS, upstream of IR

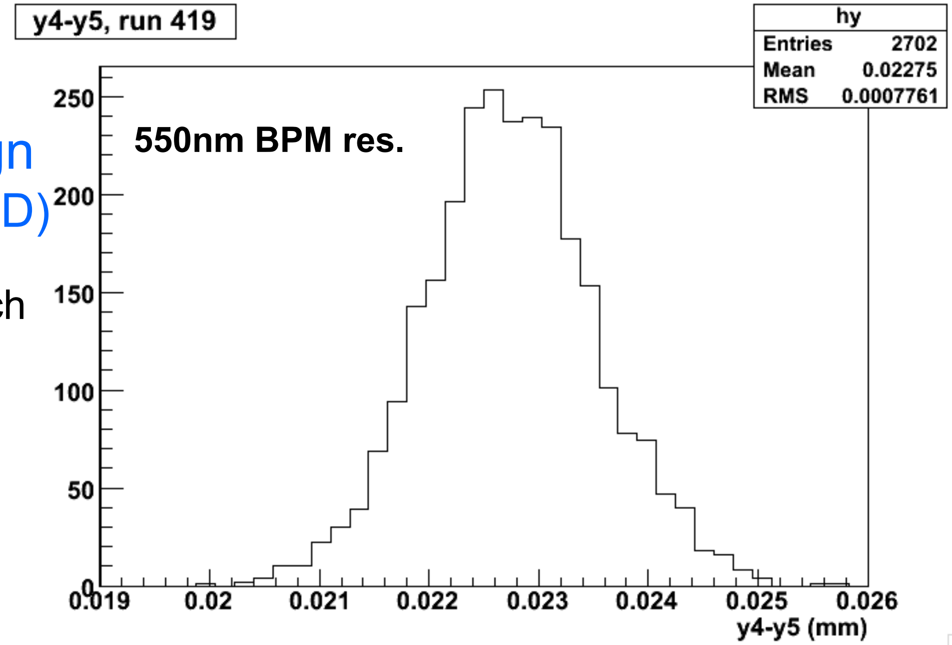
100 ppm → 0.5 μm over 30 m

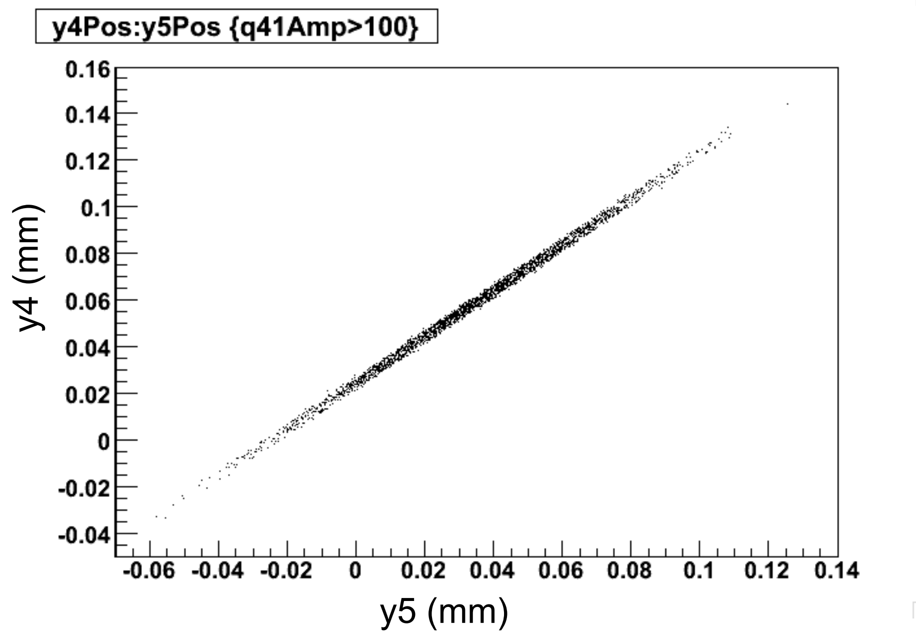
T-474 Run I, Preliminary Results



S-Band BPM Design
(36 mm ID, 126 mm OD)

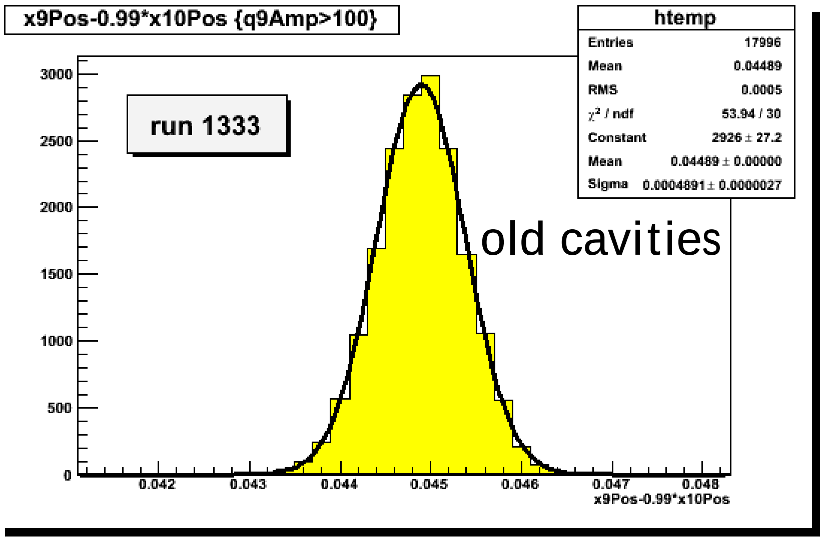
Q~500 for single bunch resolution

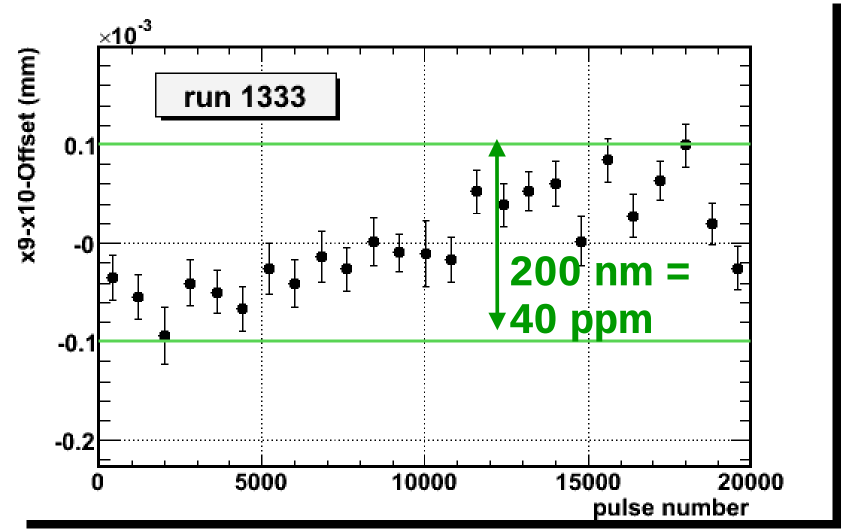




New Linac BPM Prototype
(C. Adolphsen, G. Bowden, Z. Li)
→ **used as BPM3-5 for T-474**

T-474: BPM Local Resolution, Stability

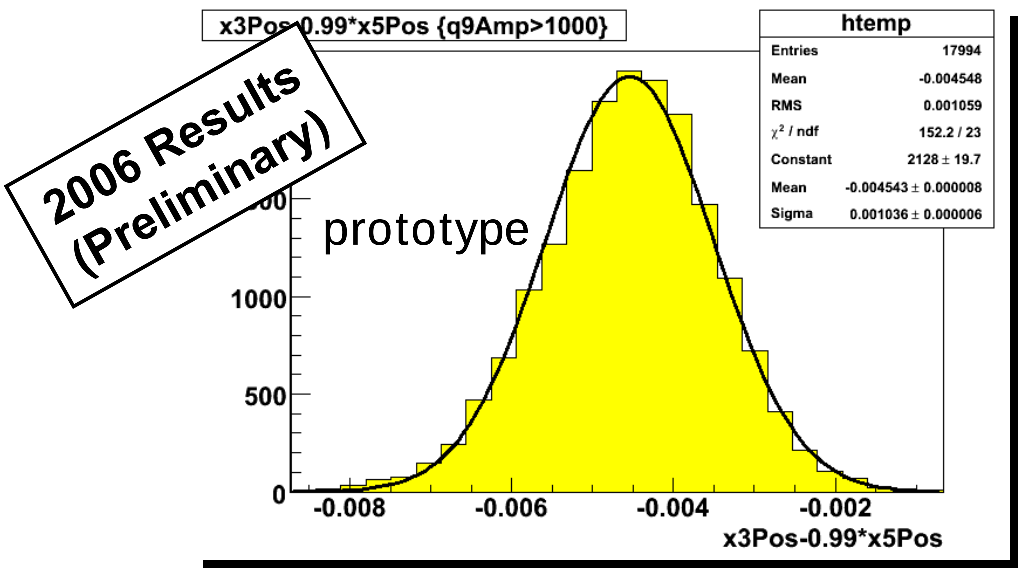


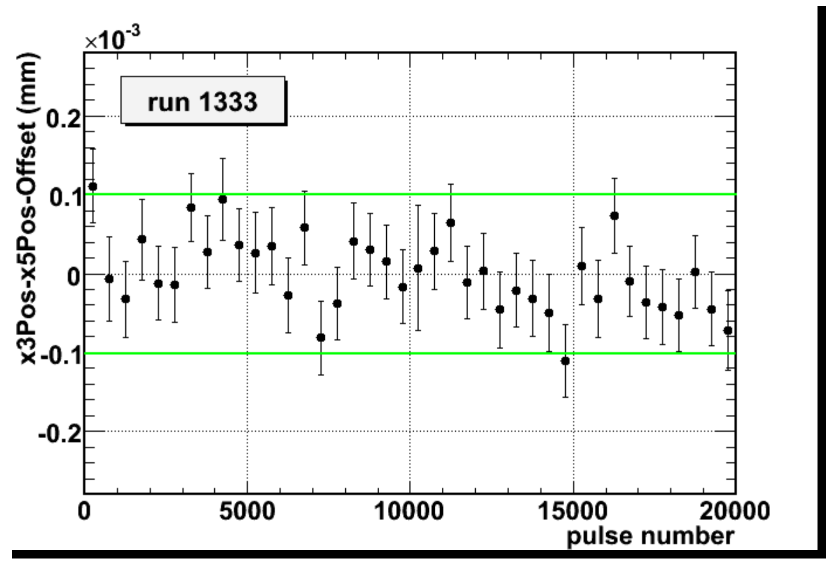


Resolution : BPM 9-11: ~350 nm in x

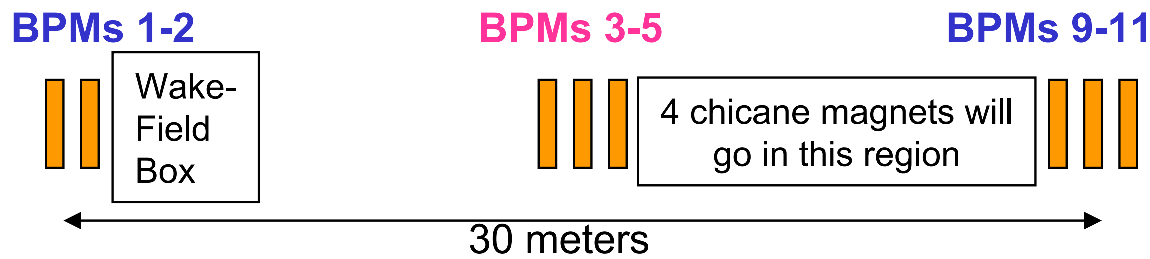
BPM 3-5: ~ 700 nm in x,

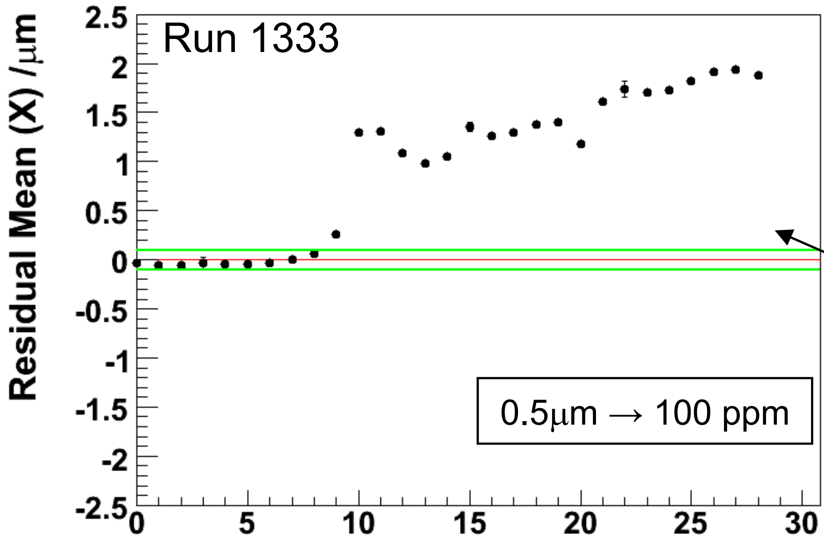
<40 ppm stability for 20k pulses ~ 30 min





T-474: Linking BPM Stations

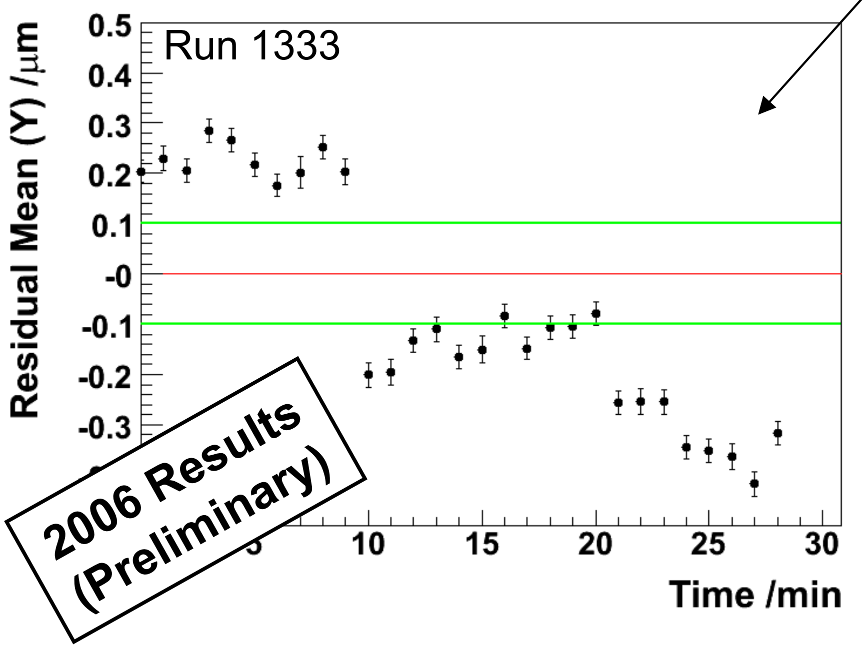




⇒ **use BPMs 1-2 and 9-11 to fit straight line**
- predict beam position at **BPMs 3-5**
- plot residual of **BPM 5** wrt predicted position

Why jumps and drifts in residuals when linking bpm stations?

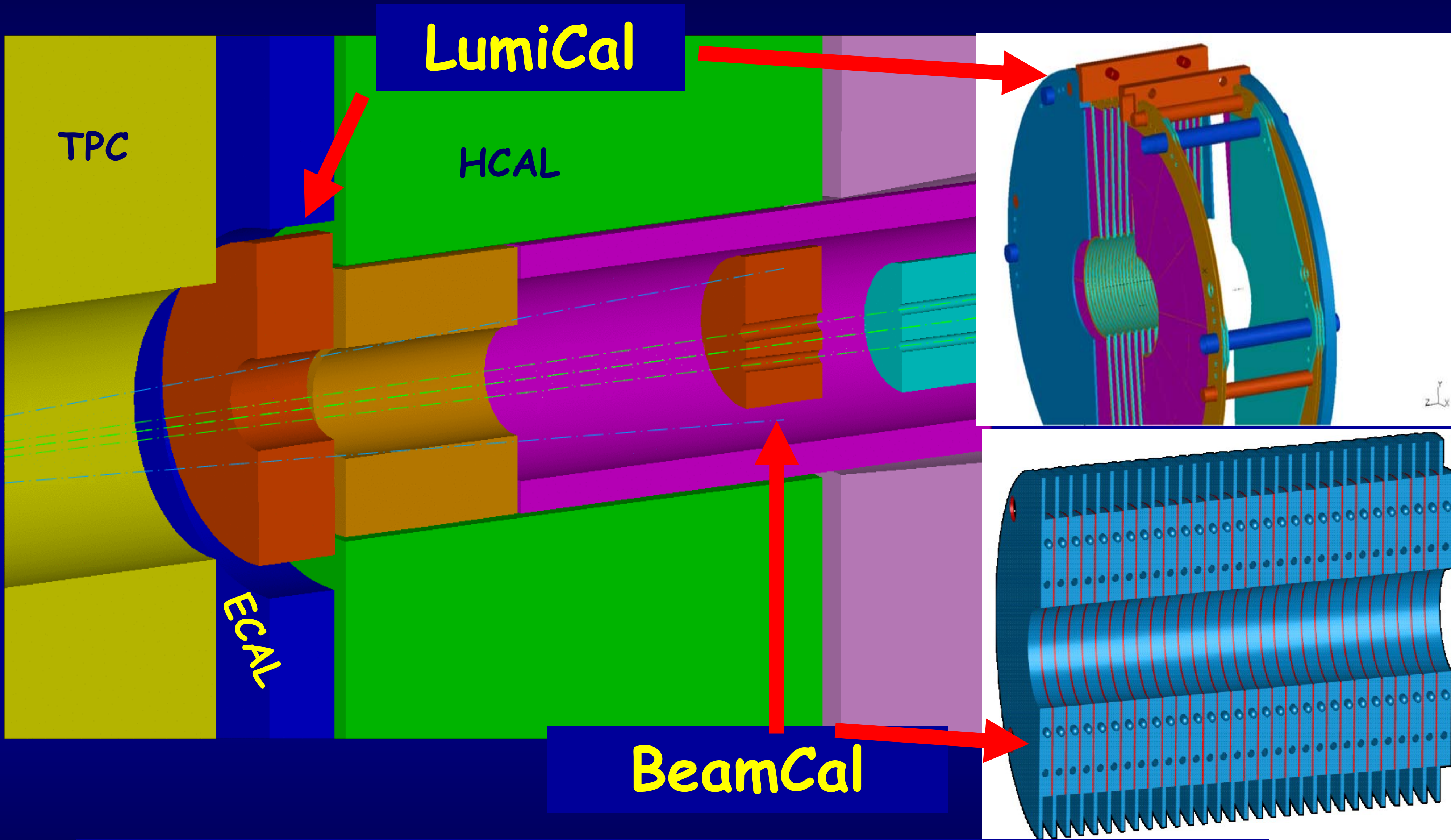
Investigate possibilities:
- analysis bug?
- changes in LO phase or BPM electronics?
- bias related to change in beam trajectory, beam energy or other beam parameters?
- relative alignment of bpm stations changed?



→ A primary goal of T-474 is to investigate sensitivity of energy measurement to changes in beam parameters and electronics stability, and whether goals for systematic errors <100ppm can be met.

Need more data!

Current design (Example LDC, 20 mrad):



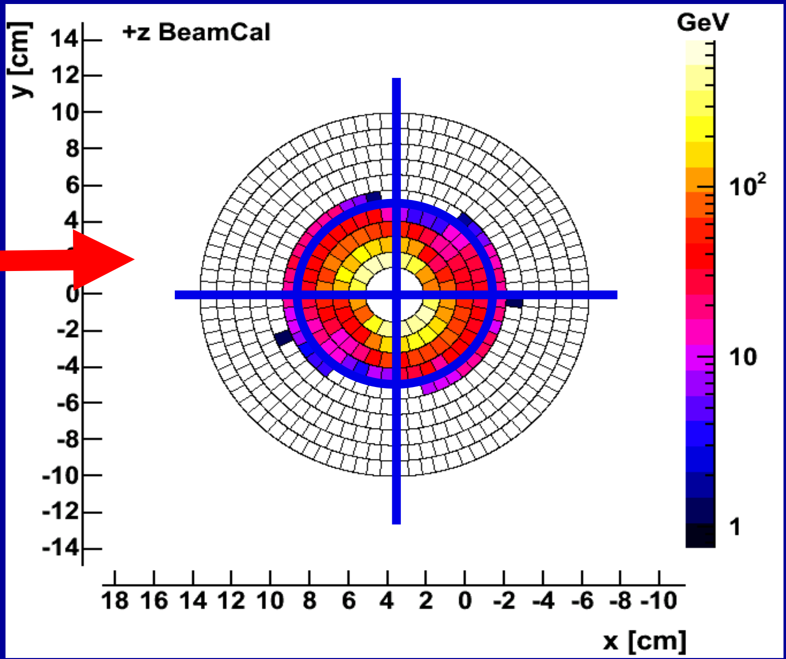
Technology: Tungsten/sensor sandwich

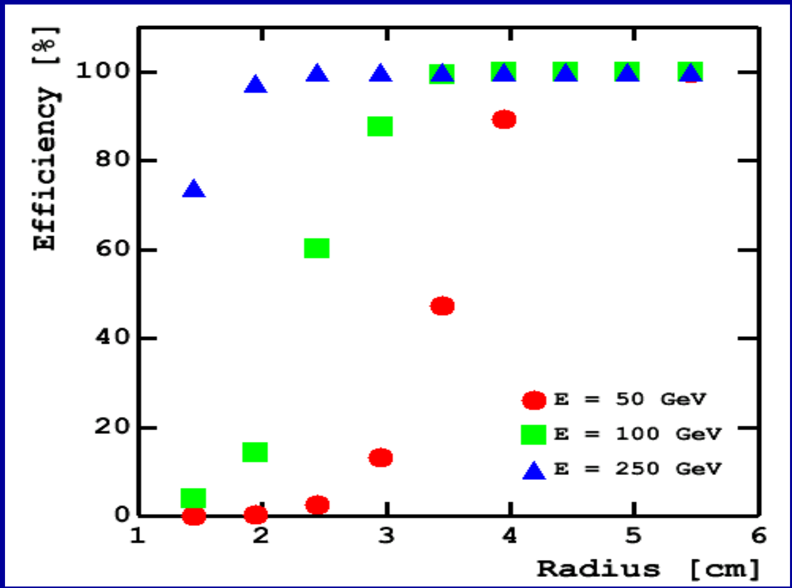
Wolfgang Lohmann

BeamCal

Challenge: BeamCal

- 15000 e^+e^- per BX, MeV range, total 10 – 20 TeV
- ~10 MGy dose per year
- single electron detection capability





→

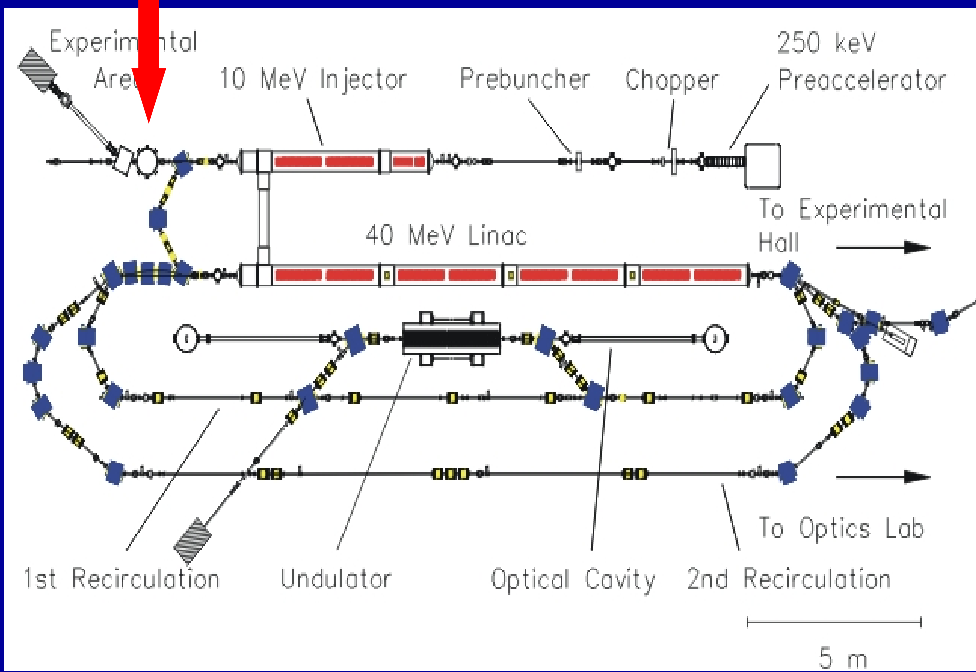
-Radiation hard sensors
-Linearity and dynamic range
- Readout speed (design stage)
-Compactness and granularity

Radiation hardness

Beams available:

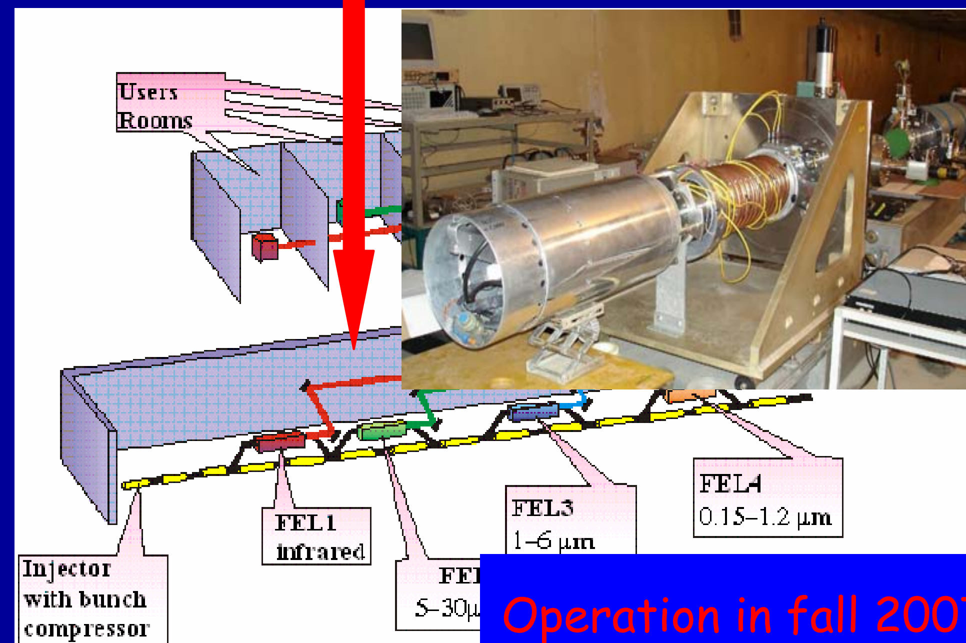
SDALINAC (TU Darmstadt)

10 MeV



JINR LINAC 800

20-40 MeV



Operation in fall 2007

beam currents from 1 to 100 nA (10 nA ≈ 50 kGy/h)

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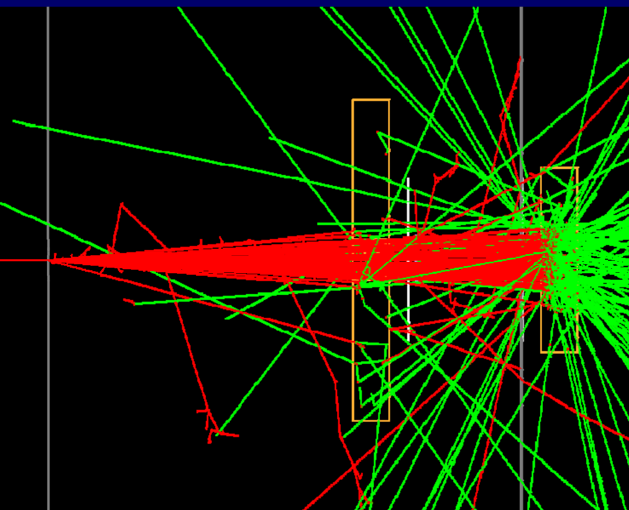
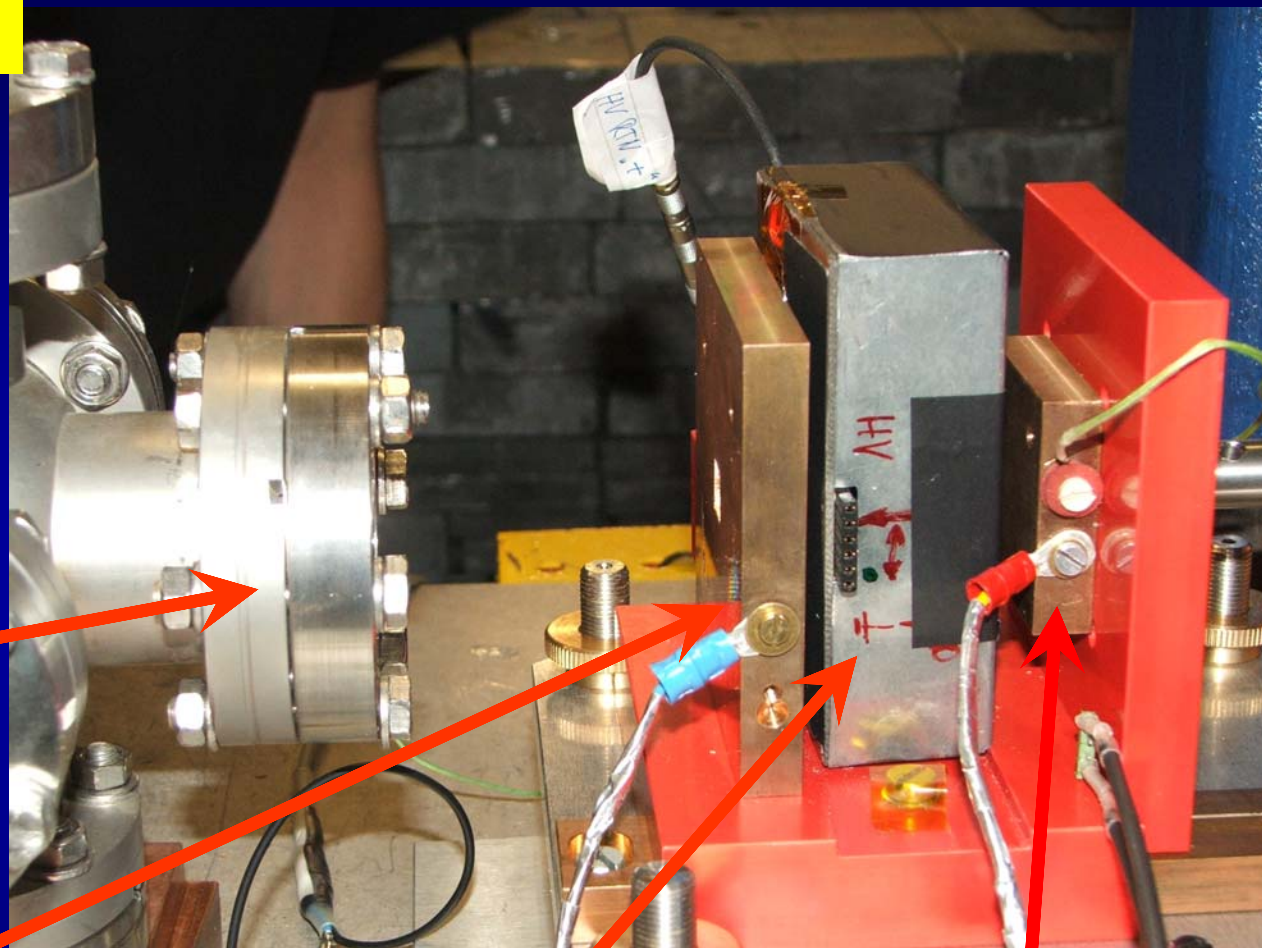
Radiation hardness

The testbeam setup





exit window
of beam line

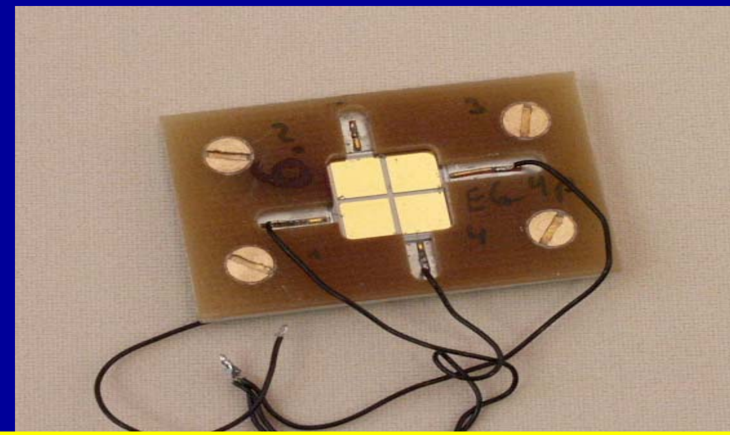
collimator (I_{Coll})

Faraday cup (I_{FC}, T_{FC})

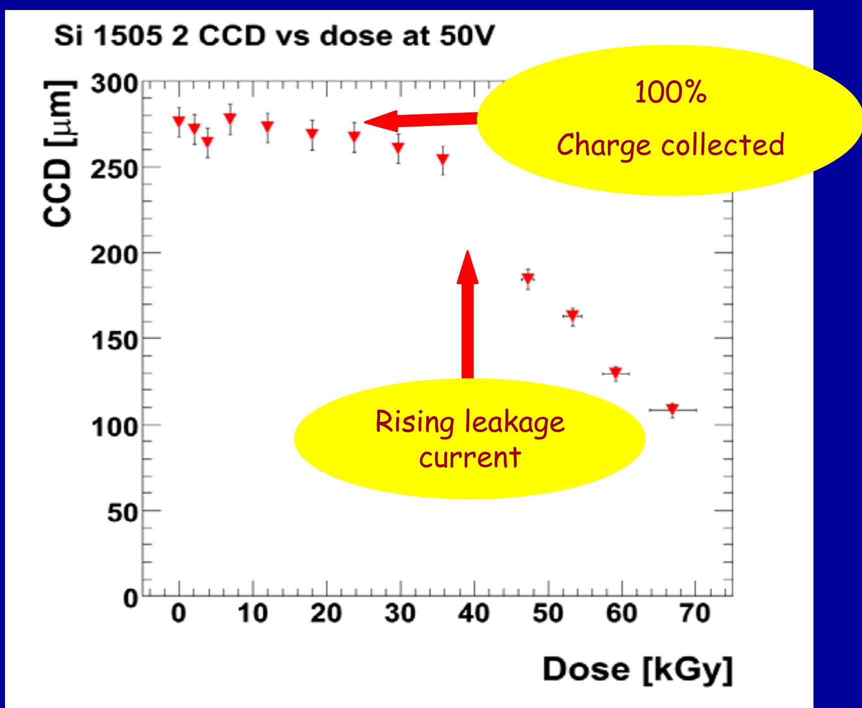
sensor box (I_{Dia}, T_{Dia}, HV)

Radiation hardness

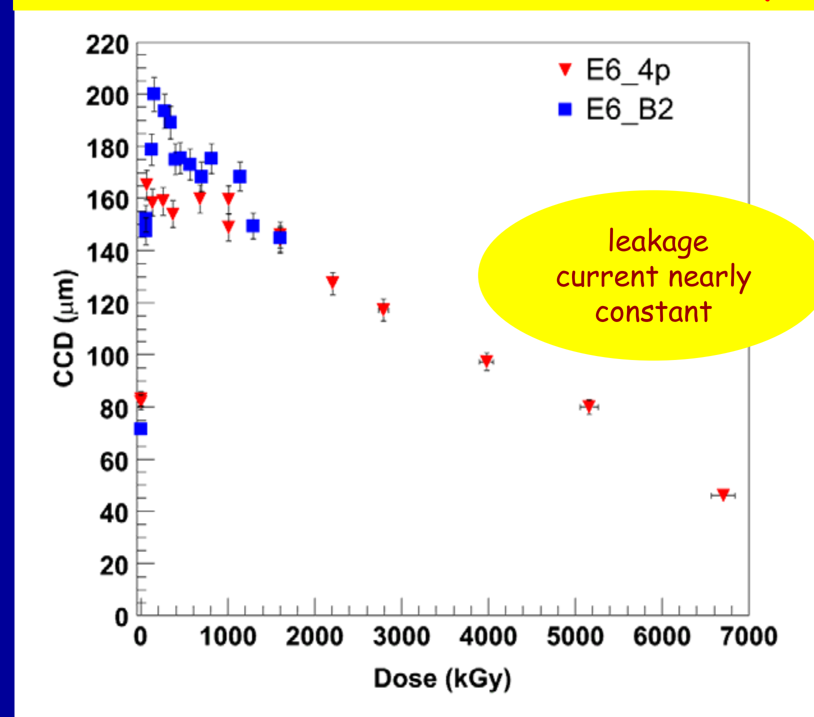
Results from 2006 (DALINAC)
Si and diamond sensors:



Si pad sensor



Diamond sensor after ~7 MGy



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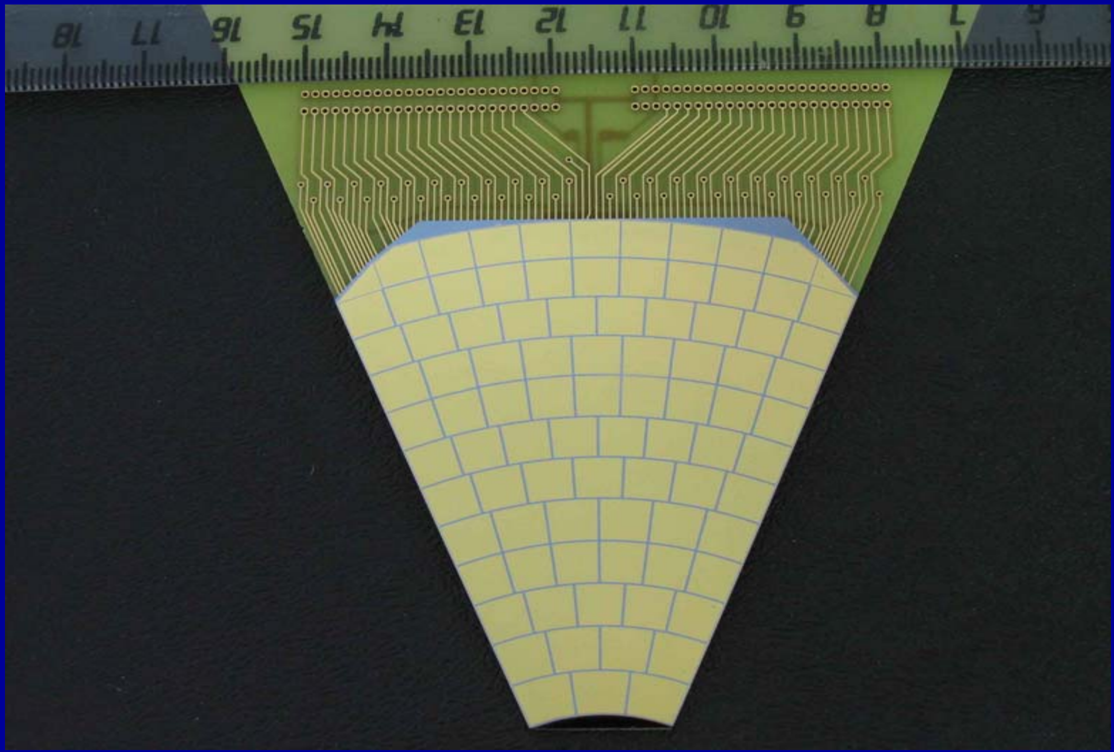
Radiation hardness

Plans for 2007/2008

- Repeat measurements with new diamond samples
- Measurements with lower dose rates
- Test alternative sensor materials
  - GaAs (produced by Russian Collaborators)
  - SiC (collaboration with BTU, Cottbus)
  - Rad. hard Si (BNL?)

GaAs Segment prepared for tests



ILC beamline instrumentation

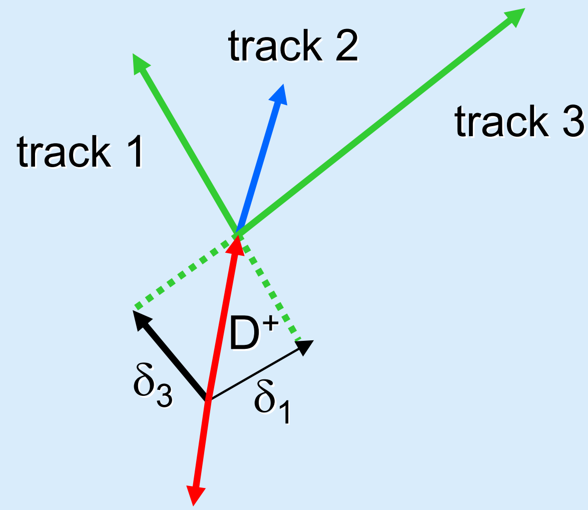
- Apologies for not including more…
  - Experiments at ATF2, KEK (Marc Ross)
  - Experiments at ESA, SLAC (Mike Woods)
  - Feedback on Nanosecond Timescale R&D (Christine Clark)
  - Collimator R&D (Andre Sopczak)

ILC Vertex detector

- The power of having many precise 3D points measured close to the IP was demonstrated by the SLD CCD vertex detector at SLC
- These precise points:
  - improve momentum resolution
  - indicate displaced vertices arising from heavy flavours – identifying the flavour and/or vertex charge:
    - study decays of Higgs and possibly other new particles
    - helps in combining jets to form W, Z, H, t in events with large numbers of jets
    - $b\bar{b}$ forward backward asymmetry
  - can help seed tracks (pattern recognition)

The Vertex Detector at the ILC

Measure impact parameter, charge for every charged tracks in jets, and vertex mass.

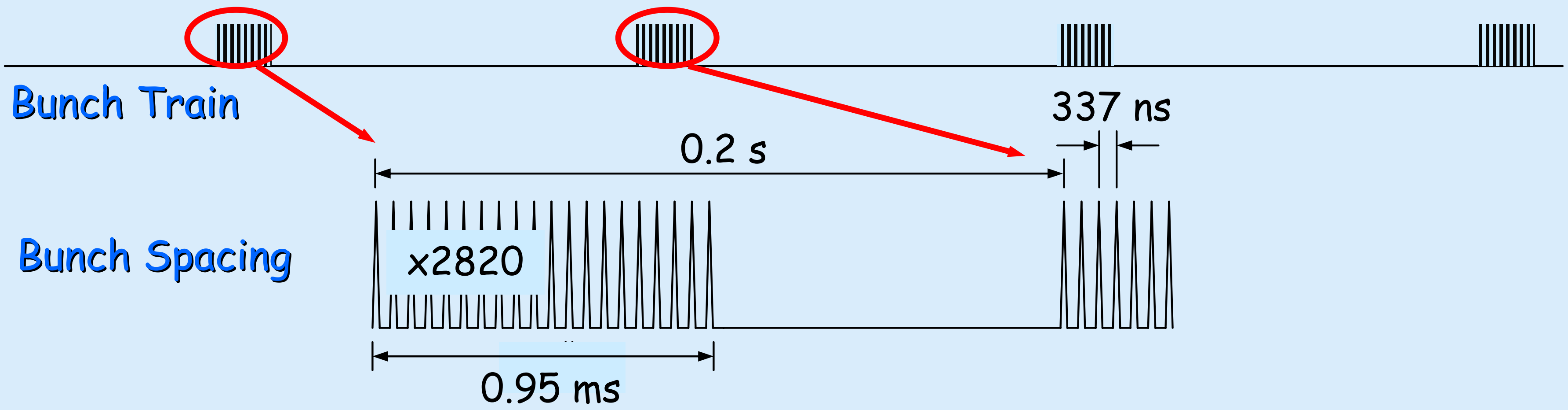


Need:

- Good angular coverage with many layers close to vertex:
  - |cosθ|< 0.96.
  - First measurement at r ~ 15 mm.
  - Five layers out to r ~ 60 mm.
- Efficient detector for very good impact parameter resolution
- Material ~ 0.1% X_0 per layer.
- Capable to cope with the ILC beamstrahlungs background
- Modest average power consumption < 100W
- Hit resolution better than 5 µm.

NOTE: 1/5 r_beampipe, 1/30 pixel area, 1/30 thickness c.f. LHC

The Vertex Detector at the ILC



- Approximately 10 different technologies under study for ILC vertex detector
  - All use silicon pixels
  - Sensitive window varies from single bunch (ie. <300ns), through 50us (20 time slices per train) to integration over the entire bunch train (1ms)

ILC Pixel Technologies

ILC long bunch trains
~10^9 pixels
relatively low occupancy

Read out during the bunch train:

- DEPFET
- MAPS
- CPCCD
- CAPS/FAPS
- SOI/3-D
- SCCD

All assume 20 frames/train

Read out in the *gaps*:

- FPCCD
- Chronopixel*
- ISIS

*During bunch train to the level of digitised data

Beam Test Activity Summary Table

Marco Battaglia

Beam	E (GeV)	Technology	Detector	Activity	Status
SPS X7, H2	120 GeV π	CMOS	MimosaX	Resolution,S/N, Efficiency	In Progress
SPS X7, X5	120 GeV π	CMOS	Mimosa5	Rad Hard, Backthinning	Completed
SPS H2	120 GeV π	DEPFET	CGE,HE	Telescope Setup, Res.	Completed
KEK PS	4 GeV e-	CMOS	CAP	Telescope Setup, Res.	Completed
DESY II	3-6 GeV e-	CMOS	Mimosa5	Resolution, Rad Hard.	Completed
DESY II	6 GeV e-	CMOS	MimosaX	Resolution,SN,	In Progress
DESY II	6 GeV e-	DEPFET	CGE,HE	S/N, Resolution	Completed
DESY II	6 GeV e-	DEPFET	CGE,HE	Inclined Tracks	Completed
LBNL ALS	1.5 GeV e-	CMOS	LDRD-1	**S/N,Inclined Trks,Rad Hard**	Completed
LBNL ALS	1.5 GeV e-	CMOS	Mimosa5	**Backthinning, Inclined Trks**	Completed
LBNL ALS	1.5 GeV e-	CMOS	Mimosa5	**Telescope Setup, Tracking**	Completed
LBNL ALS	1.9 GeV e-	CMOS	MimoStar	S/N, r/o Tests	In Progress
LBNL ALS	1.9 GeV e-	CMOS	LDRD-2	S/N, Tests, Resolution	In Progress
LBNL LOASIS	**0.1-1 GeV e-**	CMOS	LDRD-1	Pair Response	In Progress

Pixel Beam Telescope Summary Table

Telescope	Detector Type	Pixel Size (µm)	Nb. of Planes	Plane Spacing (mm)	S/N	**Extrapolation** resolution (µm)	Beam
CAP@KEK 2004	**CMOS CAP-1**	22.5	3+1	35		4 @46mm	4GeV e^-
TPPT@LBNL 2006	**Thin CMOS Mimosa 5**	17	3+1	17	14	6.5 @17mm 3.3 @ 5mm	1.5GeV e^- 1.9GeV e^-
DEPFET@CERN 2006	**DEPFET CCG**	32x22	3+1	25	90	1 @25mm	120GeV π

Marco Battaglia

EUDET JRA-1 Pixel Telescope

Dedicated Pixel Telescope to support ILC R&D effort part of EUDET program, funded in part by EU through "6th Framework Programme for Research and Technological Development"

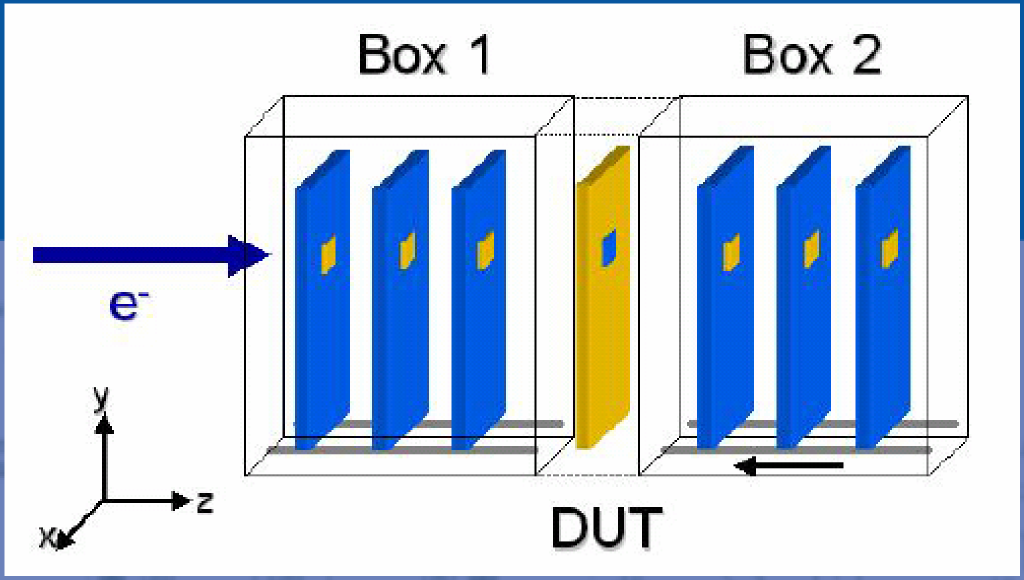
Workpackage foresee construction of Pixel Telescope based on CMOS Pixel sensors, integration of a large-bore, high-field (1.2T) magnet;

Telescope to be commissioned and operated on DESY-II beamline 24/1 but built so can be moved to other beam test facilities, such as CERN;

Telescope demonstrator based on thinned MimoSTAR chip, developed by IReS, in collaboration with LBNL for STAR HFT project: 7x7mm^2, 256x256 array, 30x30mm^2 pixels

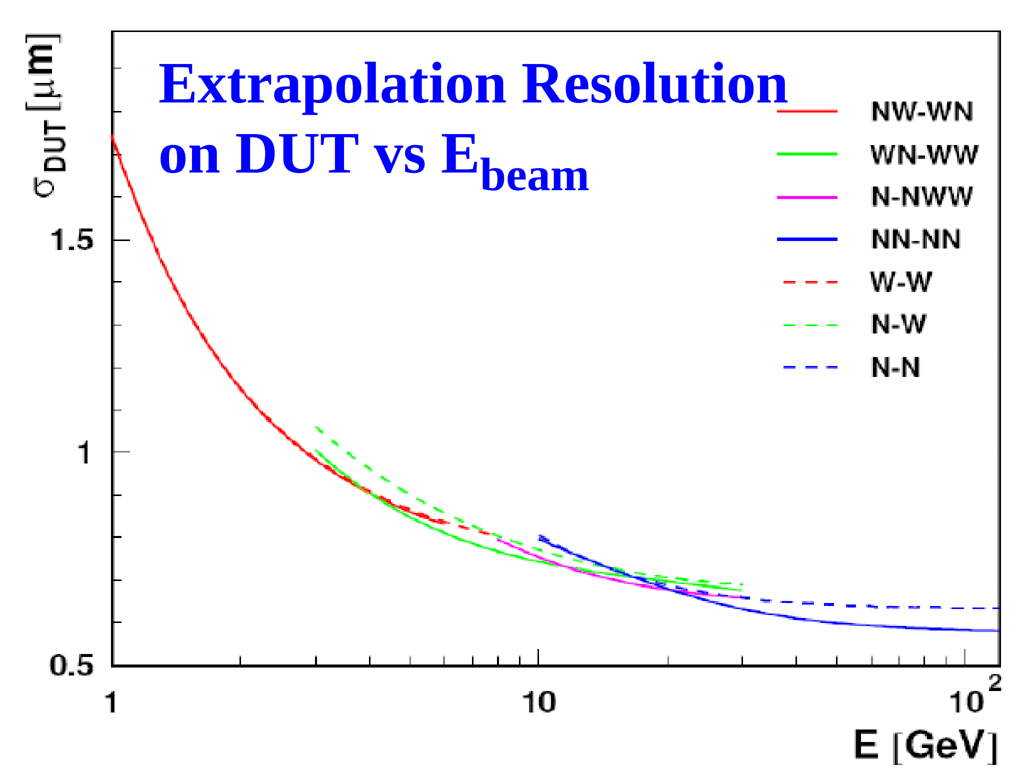
EUDET JRA-1 Pixel Telescope

Marco Battaglia



Collaborative Effort

CERN: Magnet
DESY: Magnet, Support, Beam Telescope,
CNRS: Beam Telescope
CEA: Beam Telescope
INFN: DAQ
Geneva: DAQ
MPI+Bonn: Infrastructures



	Demonstrator	Final
Area (mm^2)	7.68x7.68	20.48x10.24
Frame r/o	1.6ms	100μs
Chip	Analog, col //	Digital, in-pixel CDS

Marco Battaglia

LBNL-Fermilab Pixel Telescope Proposal

Joint LBNL-Fermilab Proposal submitted to DOE for construction of Pixel Telescope similar to EUDET JRA-1;

Stage-1 based on same CMOS MimoSTAR thin sensors as EUDET, optional Stage-2 adopting sensors derived by current US R&D effort;

Proposed Task Sharing

LBNL: Detector Testing, DAQ, Offline C++ Reco
Fermilab Detector Testing, Mechanics, Installation, Offline Java Reco
University Groups: Detector Testing, Online sw

Proposed timeline:

2007: Simulation, Design and Back-thinning and Testing
2008: Testing, Mechanics, Assembly, Test at ALS
Stage-1 deployed at Fermilab MBTF by end 2008.

Marco Battaglia

Beam tests are not only for single point resolution determination;

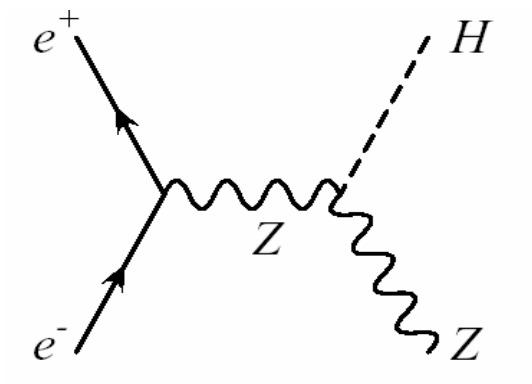
Significant activities aimed at validating all aspects of performance for candidate sensors for an ILC Vertex Tracker:

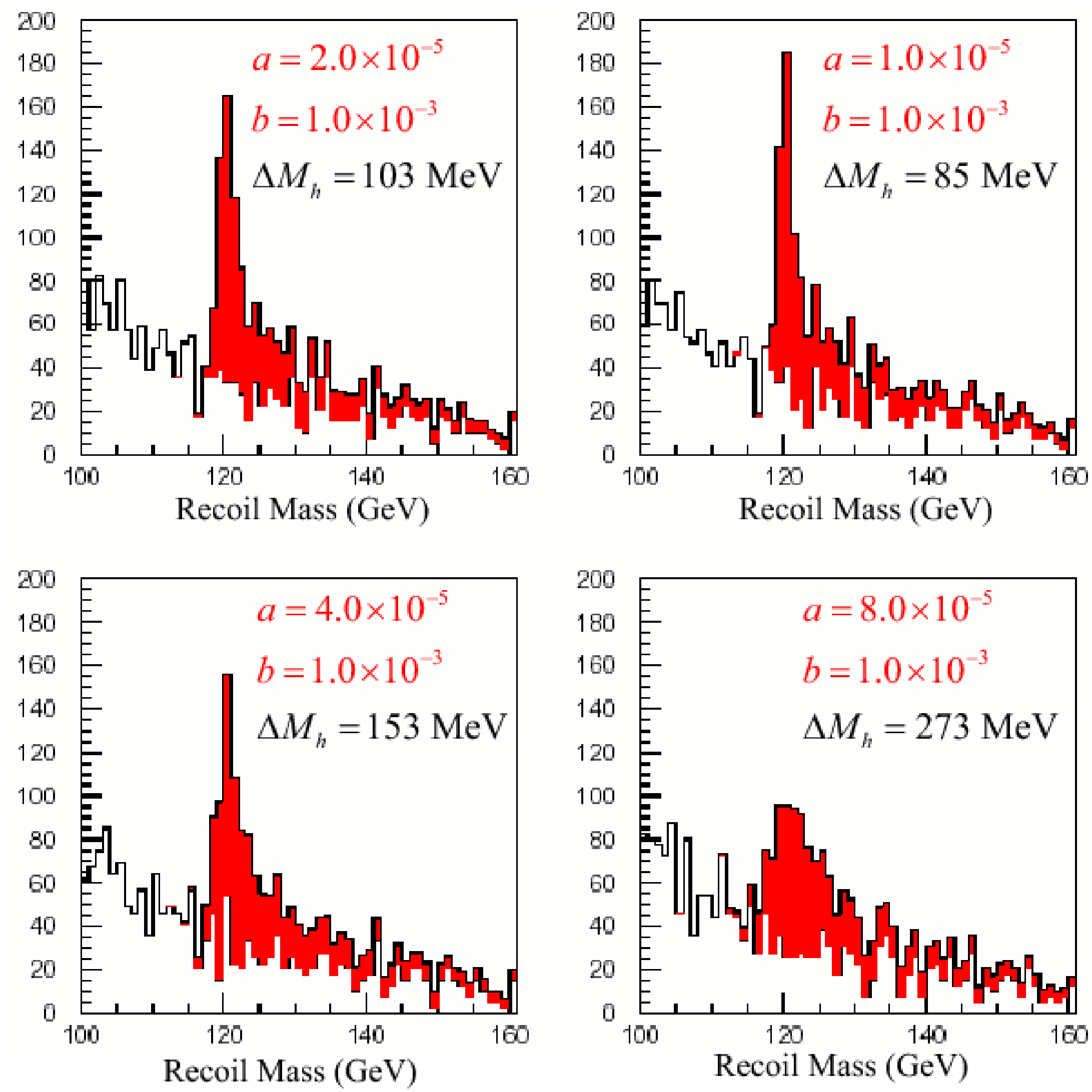
- detection efficiency;
- pixel response vs. angle of incidence of particles;
- G4+Digi simulation validation;
- S/N response before/after sensors irradiation or post-processing;
- tracking/vertexing in high density environments;
- response to low energy pairs;
- immunity from EMI;

Until past year, facilities used for ILC VTX R&D almost completely relied on infrastructures legacy of LHC, HERA, over past year several new initiative started, tailoring specifics needs of current ILC R&D.

ILC Tracking

- High precision in momentum determination is driven by mass resolution of recoil to leptonic Z^0





  - $M_H = 120$ GeV
    $E_{cm} = 350$ GeV
    $L = 500\ fb^{-1}$

$$\delta p_t / p_t^2 = a \oplus b/(p_t \sin\theta)$$

ILC Tracking

- Good momentum resolution is also important for measuring the luminosity weighted E_{cm} using

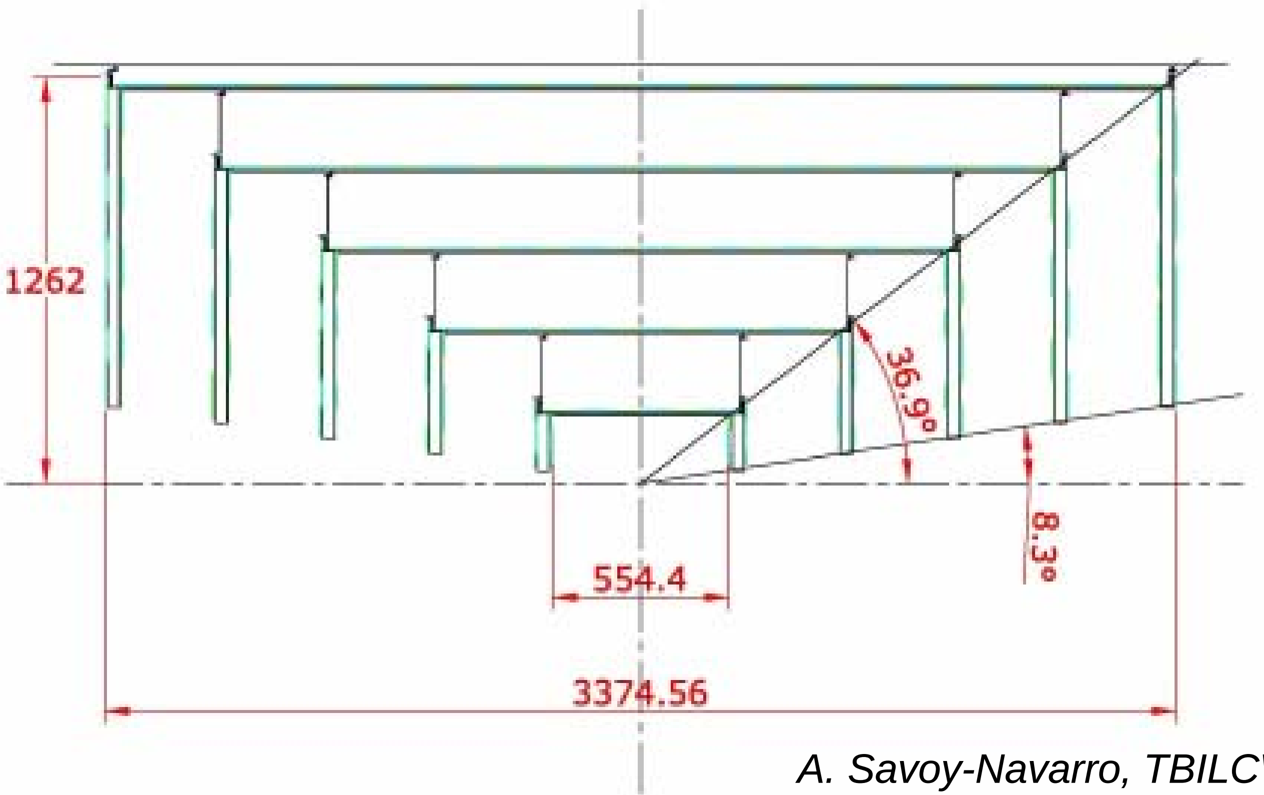
$$e^+e^- \to \mu^+\mu^-\gamma$$

- General goal for the full tracking system is
  - $\sigma(1/pt) \sim 5 \times 10^{-5}$ GeV^{-1} (or better)
  - **Note: 1/10 of LHC/LEP.**
    ~1/6 material in tracking volume cf. LHC
- Two approaches: Silicon and gaseous trackers

The SiD Tracker

Slide prepared by Rich Partridge for the SiD

- Integrated silicon strip tracker with uniform technology and a fully integrated forward tracking system
- Minimal material in the tracking volume to reduce multiple scattering and secondary particle production
- High precision in a compact tracking volume with B = 5T

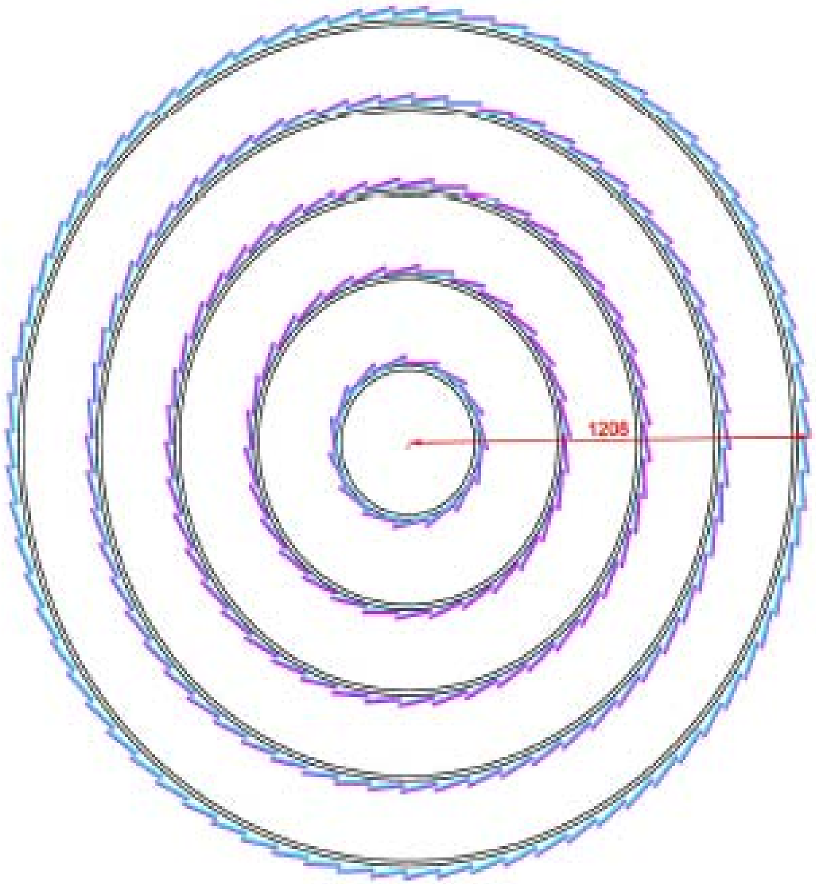


A. Savoy-Navarro, TBILCW'hp, FNAL, 011807

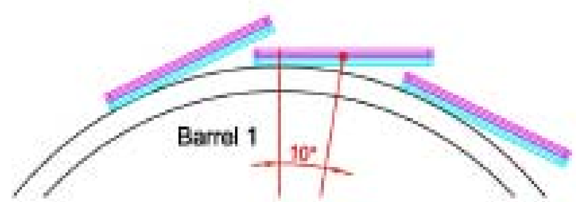
The SiD Tracker

Slide prepared by Rich Partridge for the SiD

- Baseline tracker design has 5 barrel layers, 4+4 disk layers
- Supports are carbon fiber / foam / carbon fiber sandwiches
- Modules are mounted on the supports in a pinwheel design



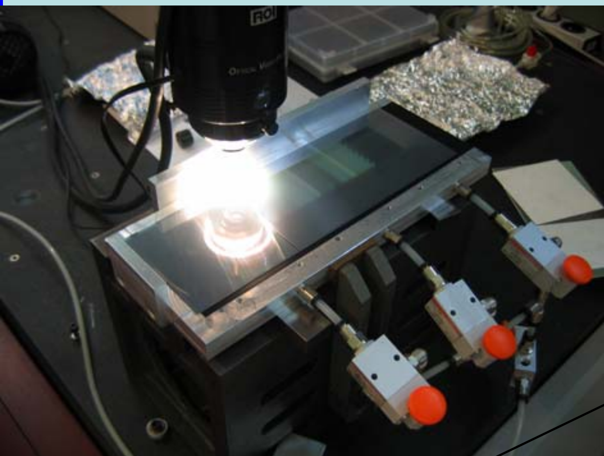
Sensors:
Cut dim's: 104.44 W x 84 L
Active dim's: 102.4 W x 81.96 L
Boxes:
Outer dim's: 107.44 W x 87 L x 4 H
Support cylinders:
OR: 213.5, 462.5, 700, 935, 1170
Number of phi: 15, 30, 45, 60, 75
Central tilt angle: 10 degrees
Sensor phi overlap (mm):
Barrel 1: 5.3
Barrel 2: 0.57
Barrel 3: 0.40
Barrel 4: 0.55
Barrel 5: 0.63
Cyan and magenta sensors and boxes are assumed to be at different Z's and to overlap in Z.
Within a given barrel, cyan sensors overlap in phi as do magneta sensors.



A. Savoy-Navarro, TBILCW'hp, FNAL, 011807

Detector prototypes

CERN(A.Honma), IEKP-Karlsruhe, LPNHE-Paris, IEHP-Vienna, Hamamatsu



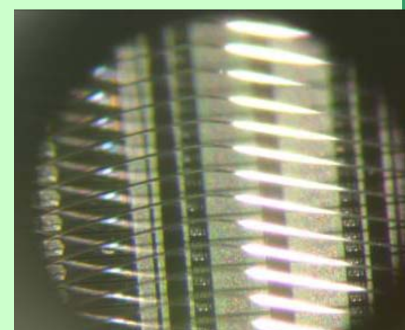
Assembly

3 CMS sensors 28 cm strip long
Read out:
VA1+180UMC r.o
and all VA1 r.o.

2 modules fabricated in Paris,
bonding CERN on automated CMS system
(Collab CERN-LPNHE)

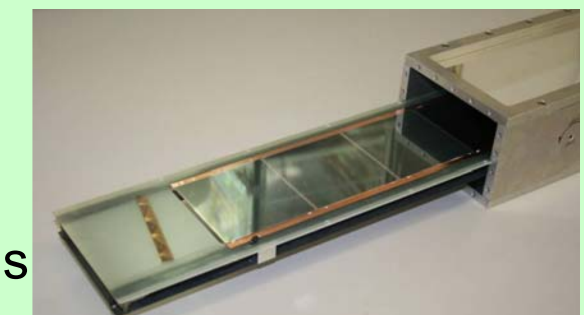
Assembly:
Module = 10 GLAST sensors
90 cm strip long

Bonding



The full construction done at IEKP

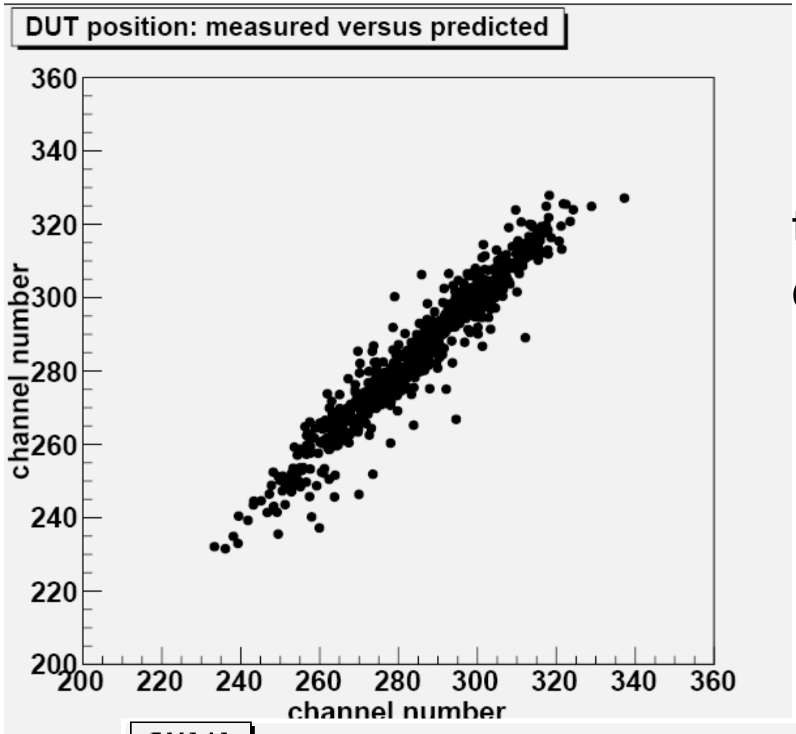
R.O.
Pitch adapter +
VA1 + 180UMC
provided by Paris



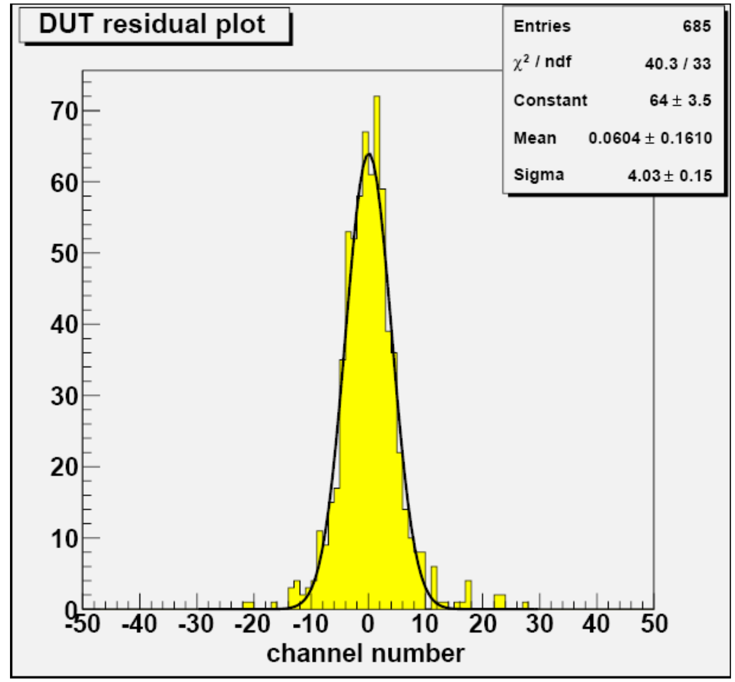
Beams

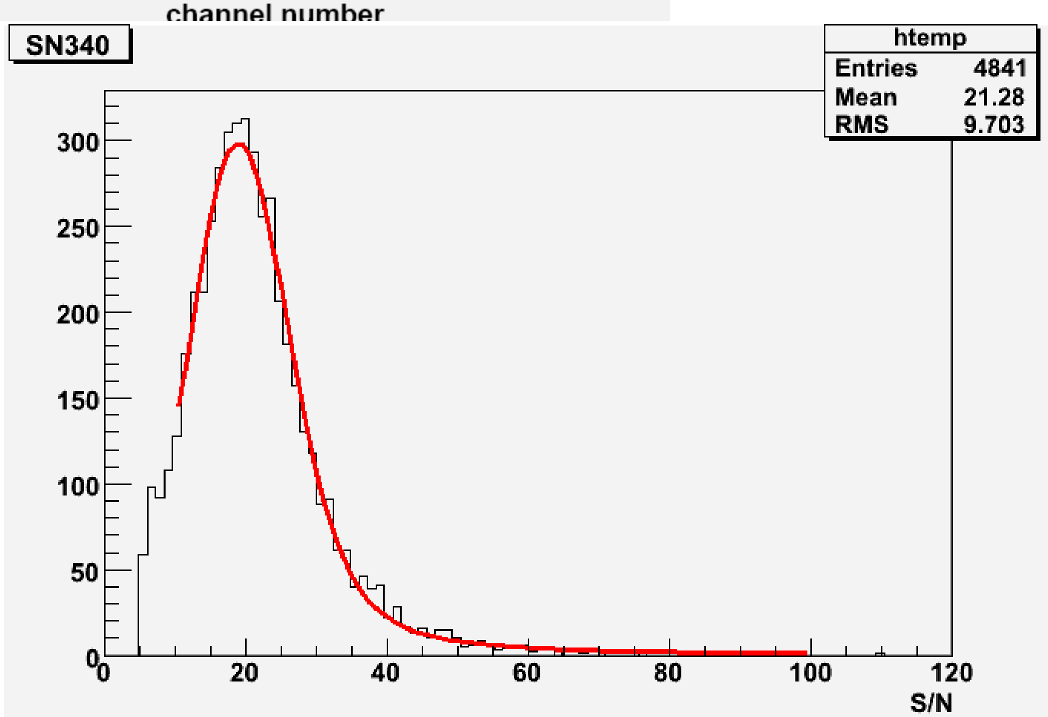

October 23 to November 3 2006
SiLC test beam at DESY
On line

DESY Beam test analysis



Correlation beam telescopes & Silicon detector, based on the CMS-4VA1 module

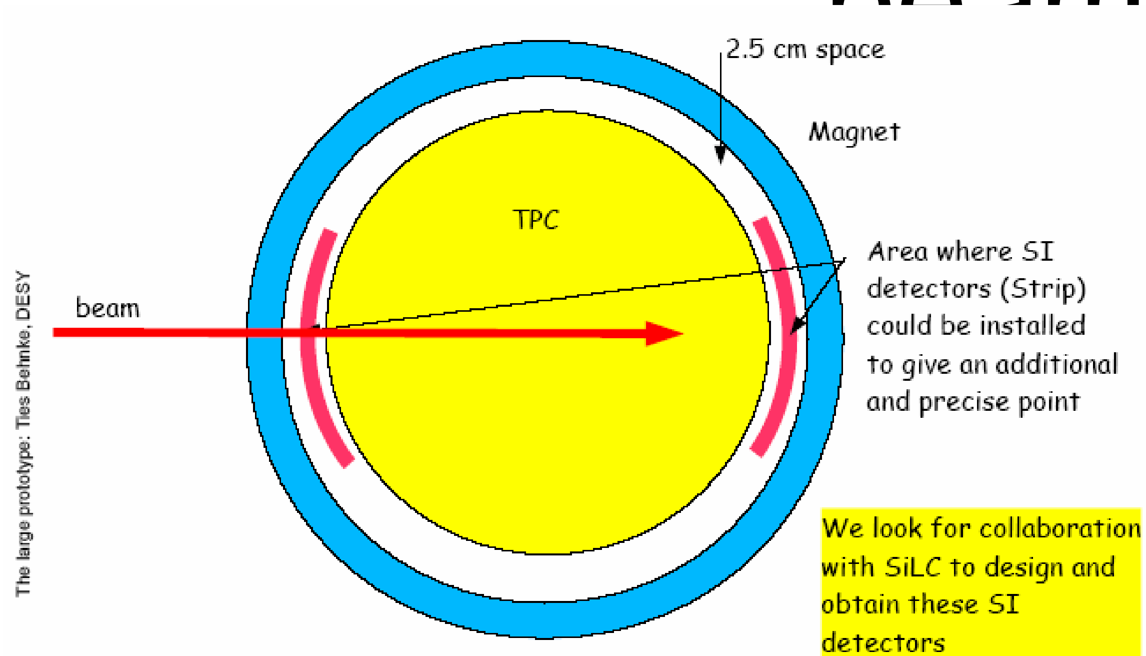




Bias voltage	S/N (MPV)
200	13.62 +/- 0.33
260	15.79 +/- 0.29
299	15.70 +/- 0.25
350	**16.52 +/- 0.73**

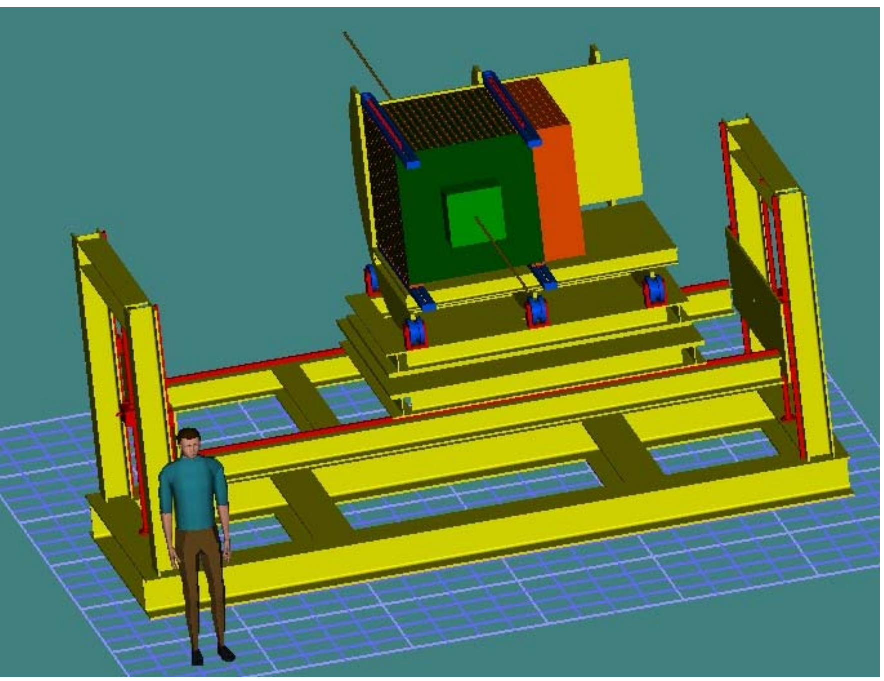
Signal from the CMS-4VA1 module

2008 & beyond: combined test beams

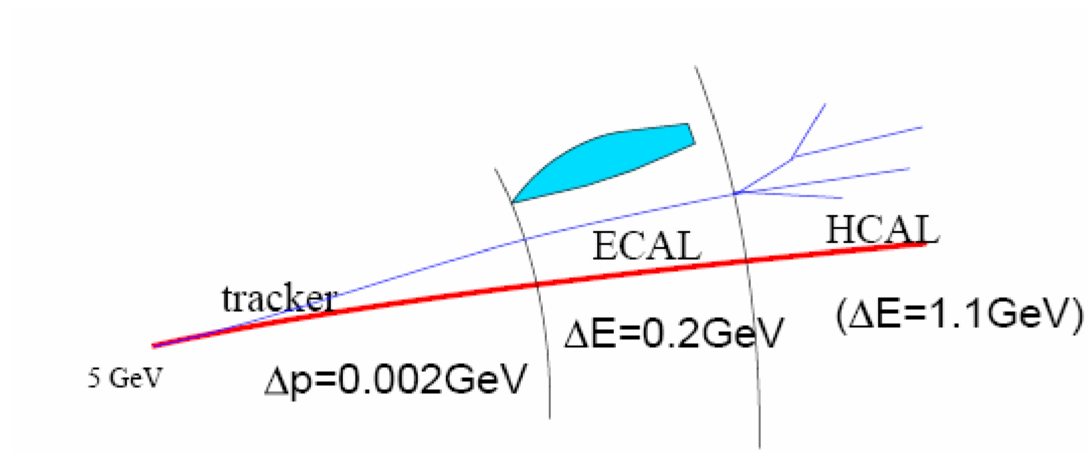


Testbeam with TPC Field Cage & strip layer surrounding it: SET(LDC)

Test beam with pixel detectors: tests on internal tracking region & Vertex + Silicon tracker



Testbeam with Si-W calorimeter & few Silicon strip layers in front: experience particle flow



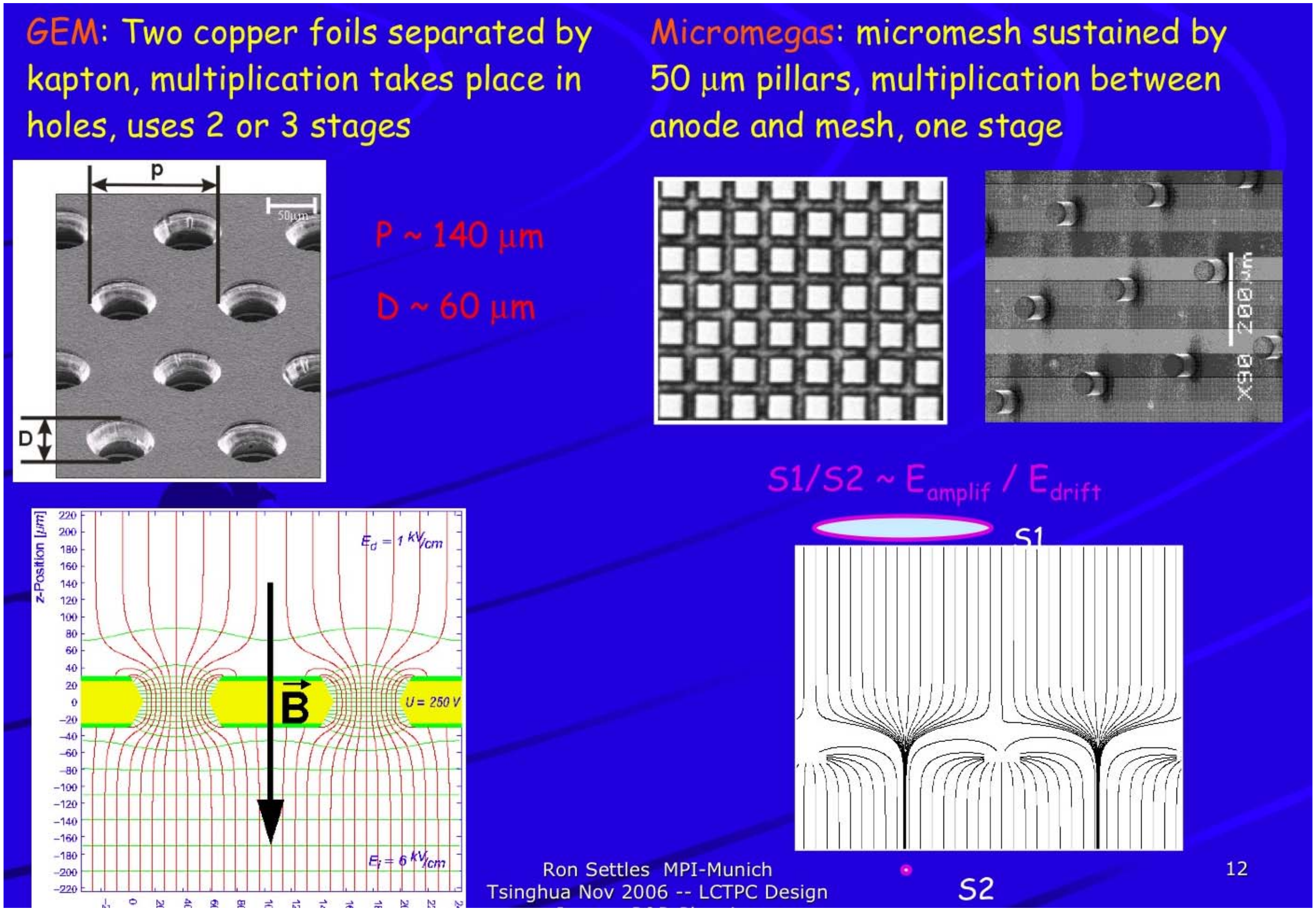
ILC gaseous tracking

- For gaseous detectors, the TPC design gives the best performance because the data is recorded in 3D
  - pattern recognition
  - background tolerance
- General design parameters:
  - r_outer = 1.5-2 m, length = 2-2.5 m
  - ~ 200 samples (each ~6 mm)
    - $\sigma(r,\phi)$ ~ 100 μm, $\sigma(z)$ ~ 500 μm
  - two track resolution: ~2 mm (r,ϕ) and ~5 mm (z)
  - $\sigma(dE/dx)$ ~ 5%

ILC challenge: σ_{Tr} ~ 100 μm (all tracks 2 m drift)

Classical anode wire/cathode pad TPC limited by ExB effects

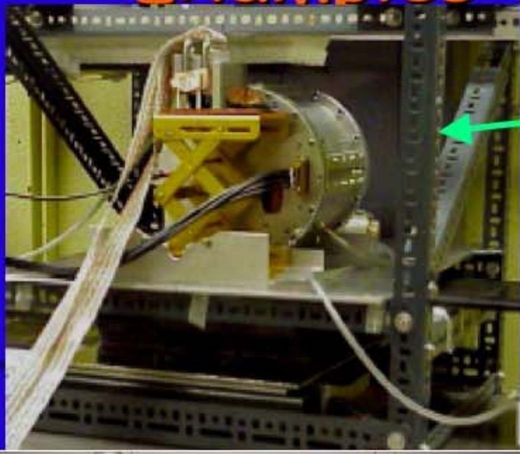
Micro Pattern Gas Detectors (MPGD) not limited by ExB effect



Worldwide R&D to develop MPGD readout for the ILC TPC

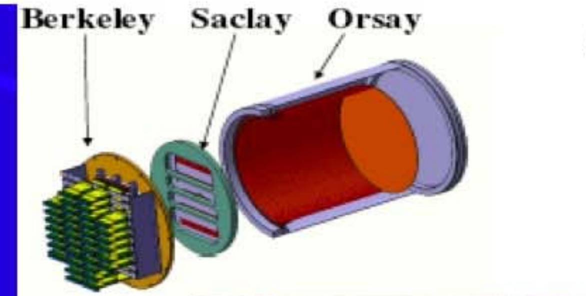
From: Madhu Dixit

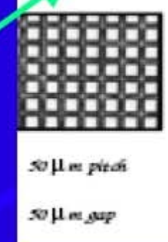
Examples of Prototype TPCs

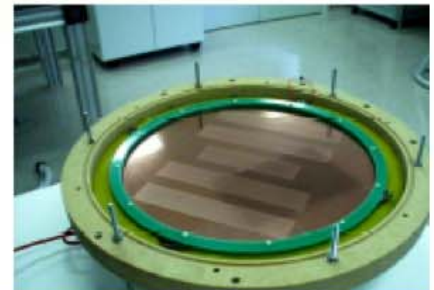


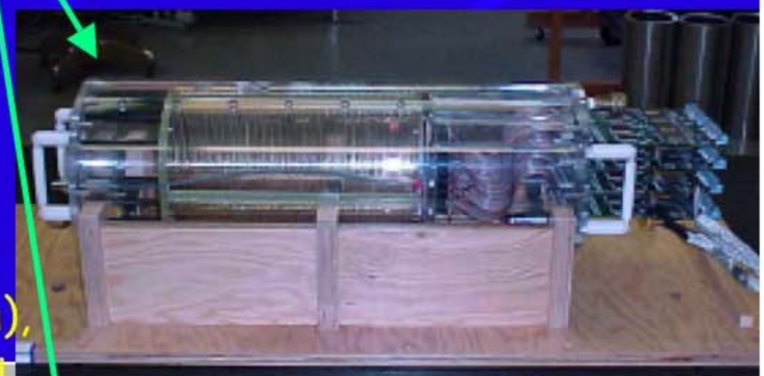
Carleton, Aachen,
Cornell/Purdue,Desy(n.s.)
for B=0or1T studies

Saclay, Victoria, Desy
(fit in 2-5T magnets)

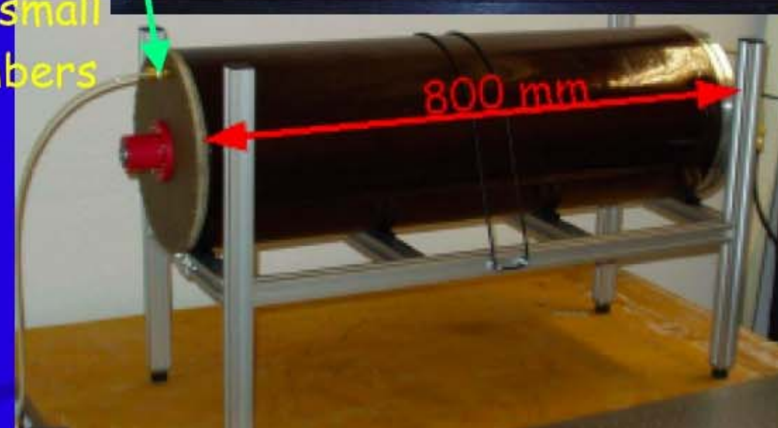






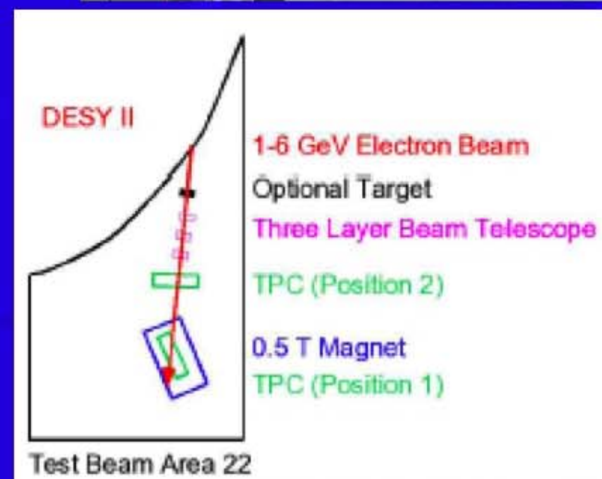


Karlsruhe, MPI/Asia,
Aachen built test TPCs
for magnets (not shown),
built small
chambers



Facilities

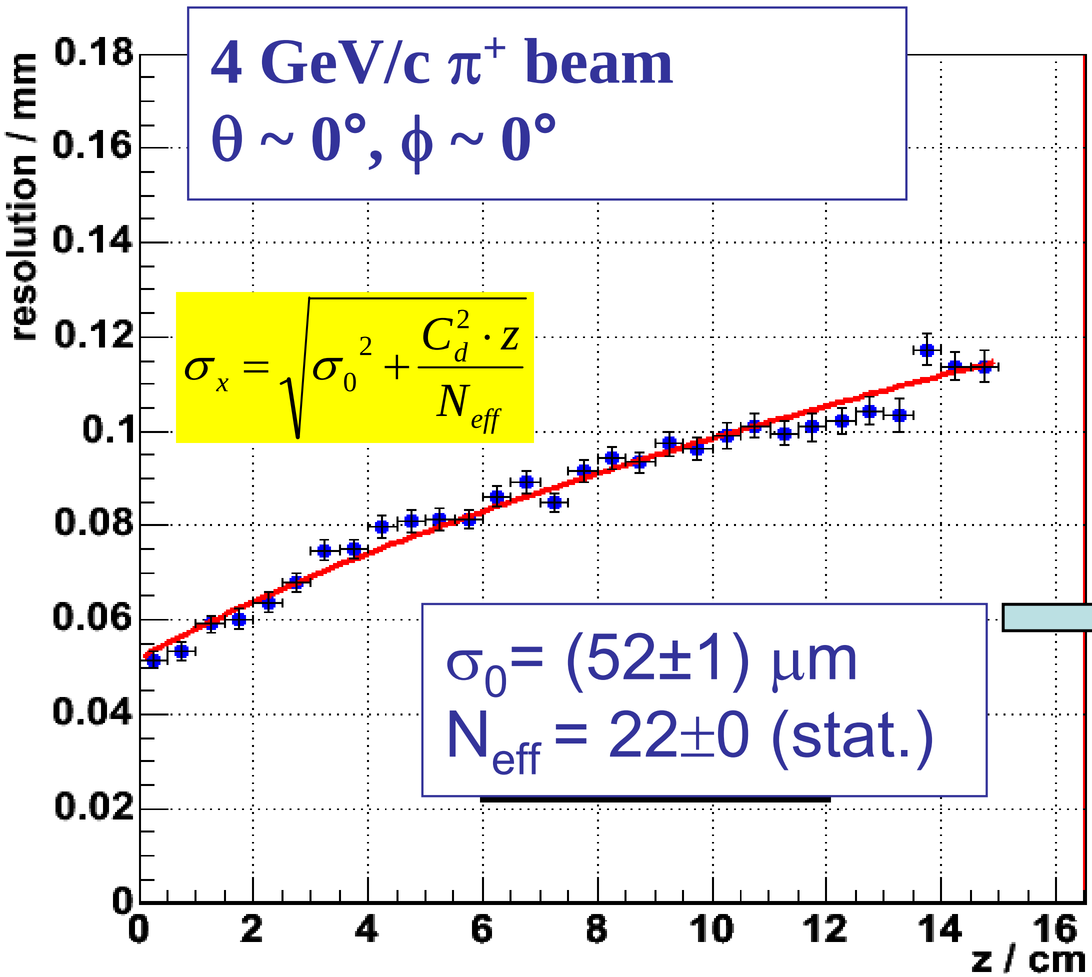
Cern test-beam (not shown)



EUDET

Transverse spatial resolution Ar+5%iC4H10 E=70V/cm D_{Tr} = 125 µm/√cm (Magboltz) @ B= 1T

Micromegas TPC 2 x 6 mm² pads - Charge dispersion readout



- **Strong suppression of transverse diffusion at 4 T.**

Examples:

D_{Tr}~ 25 µm/√cm (Ar/CH4 91/9) Aleph TPC gas

~ 20 µm/√cm (Ar/CF4 97/3)

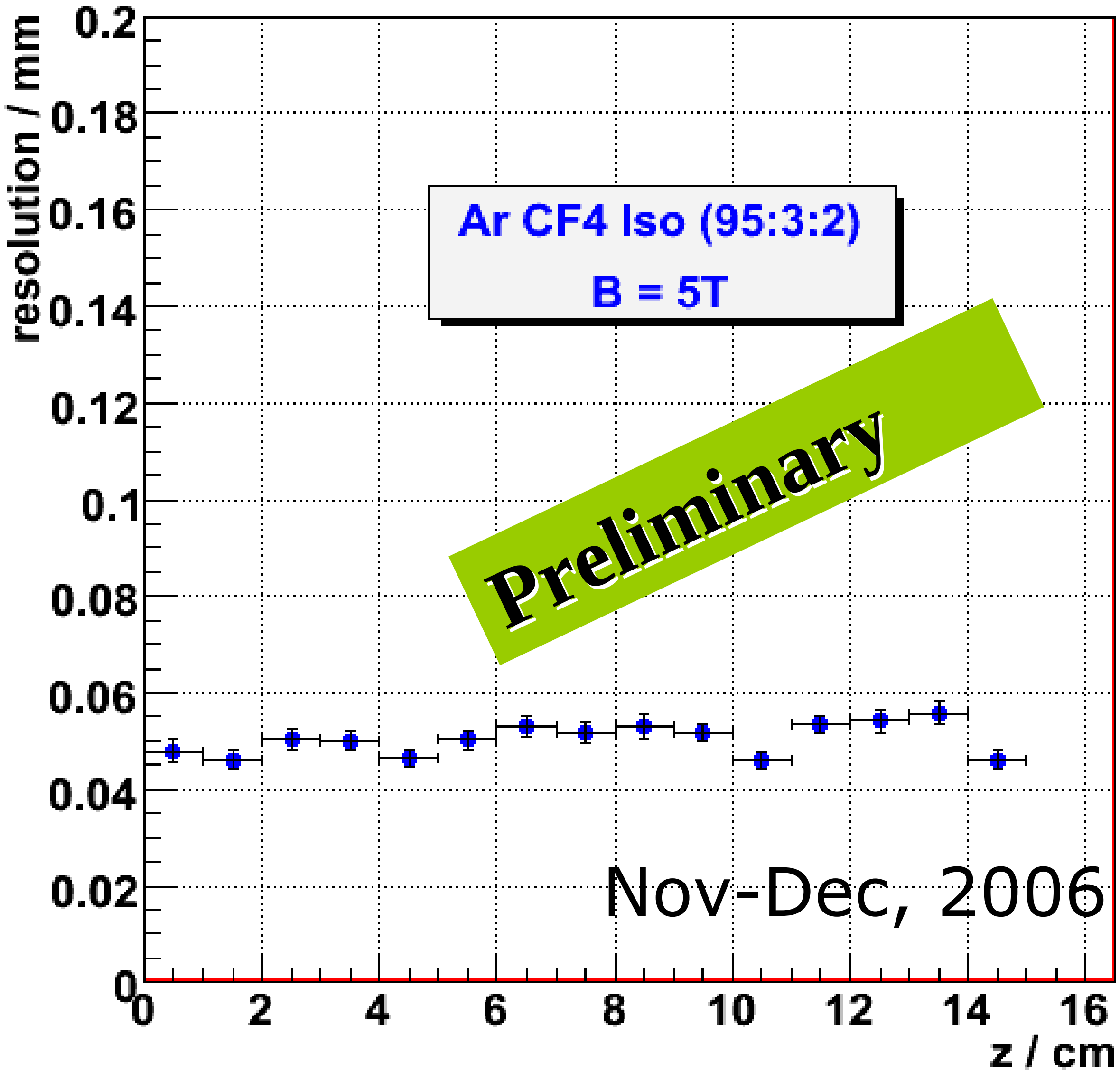
Extrapolate to B = 4T
Use D_{Tr} = 25 µm/√cm
Resolution (2x6 mm² pads)
σ_{Tr} ≈ 100 µm (2.5 m drift)

From: Madhu Dixit

Confirmation - 5 T cosmic tests at DESY

COSMo (Carleton, Orsay, Saclay, Montreal) Micromegas TPC

D_{Tr}= 19 μm/√cm, **2 x 6 mm² pads**



~ 50 μm av. resolution (diffusion negligible over 15 cm)
100 μm over 2 meters appears feasible
(~ 30 μm systematics Aleph TPC experience)

From: Madhu Dixit

Phase II - Measurements with Large Prototype

- LP will be used for:
  - Sector/panel shapes & pad geometry
  - Gas studies
  - Positive ion space charge effects & gating schemes
  - LCTPC electronics
  - Choice of technology GEMs or MicroMegas
- Finally, the LP will be used to confirm that the ILC-TPC design performance can be reached at high magnetic field.
  - Momentum resolution ~ $\Delta(1/p_T)$ ~ 1×10^{-4} (GeV^{-1})
  - 2 track resolution ~ 2mm (r, φ) & ~ 5 mm (z)
  - dE/dx ~ 5%

From: Madhu Dixit

ILC Calorimetry

- The design challenge is to achieve high precision jet energy reconstruction
  - to reconstruct W,Z,H in multijet events
  - precisely measure $\nu\nu$WW (strong scattering?)
  - BR(H $\rightarrow$ WW)
  - HHZ (Higgs self coupling)
  - HZ (Z hadronic)
- jet energy resolution goal: 30% / $\sqrt{(E)}$
  - allows good discrimination of W and Z, similar to their natural widths. Needed for jet energies 50-150 GeV
  - ~ 60% / $\sqrt{(E)}$ achieved at LEP

Particle flow paradigm

- try to reconstruct every particle of the event in order to improve the jet energy resolution

- visible energy of a typical jet
  - $\sim$ 60 % charged particles
  - $\sim$ 30 % photons
  - $\sim$ 10 % neutral hadrons

- particle flow step-by-step
  - use tracker to measure charged particle momentum
  - use ECAL to measure photon energy
  - use HCAL+ECAL to measure neutral hadron energy
  - use tracker+ECAL+HCAL to disentangle charged from neutrals

Jet energy resolution

particles in jet	fraction of energy in jet	detector	single particle resolution	jet energy resolution
charged particles	60 %	tracker	$\frac{\sigma_{p_t}}{p_t} \sim 0.01\% \cdot p_t$	negligible
photons	30 %	ECAL	$\frac{\sigma_E}{E} \sim 15\%/\sqrt{E}$	$\sim 5\%/\sqrt{E_{jet}}$
neutral hadrons	10 %	HCAL+ECAL	$\frac{\sigma_E}{E} \sim 45\%/\sqrt{E}$	$\sim 15\%/\sqrt{E_{jet}}$

- $\sigma_{jet} = \sigma_{charged} \oplus \sigma_{photon} \oplus \sigma_{neutral} \oplus \sigma_{confusion}$

  : confusion term comes from misassignment of energy to wrong particles due to double-counting, overlapping clusters, bad track-shower reconstruction etc

  : improve confusion term by having

  better pattern recognition → highly granular calorimetry

Challenge

- role for calorimeters

  : not so much as efficient energy measurement devices
  but mostly as
  imaging detectors to provide excellent 3D reconstruction of showers
  for very efficient pattern recognition and particle separation

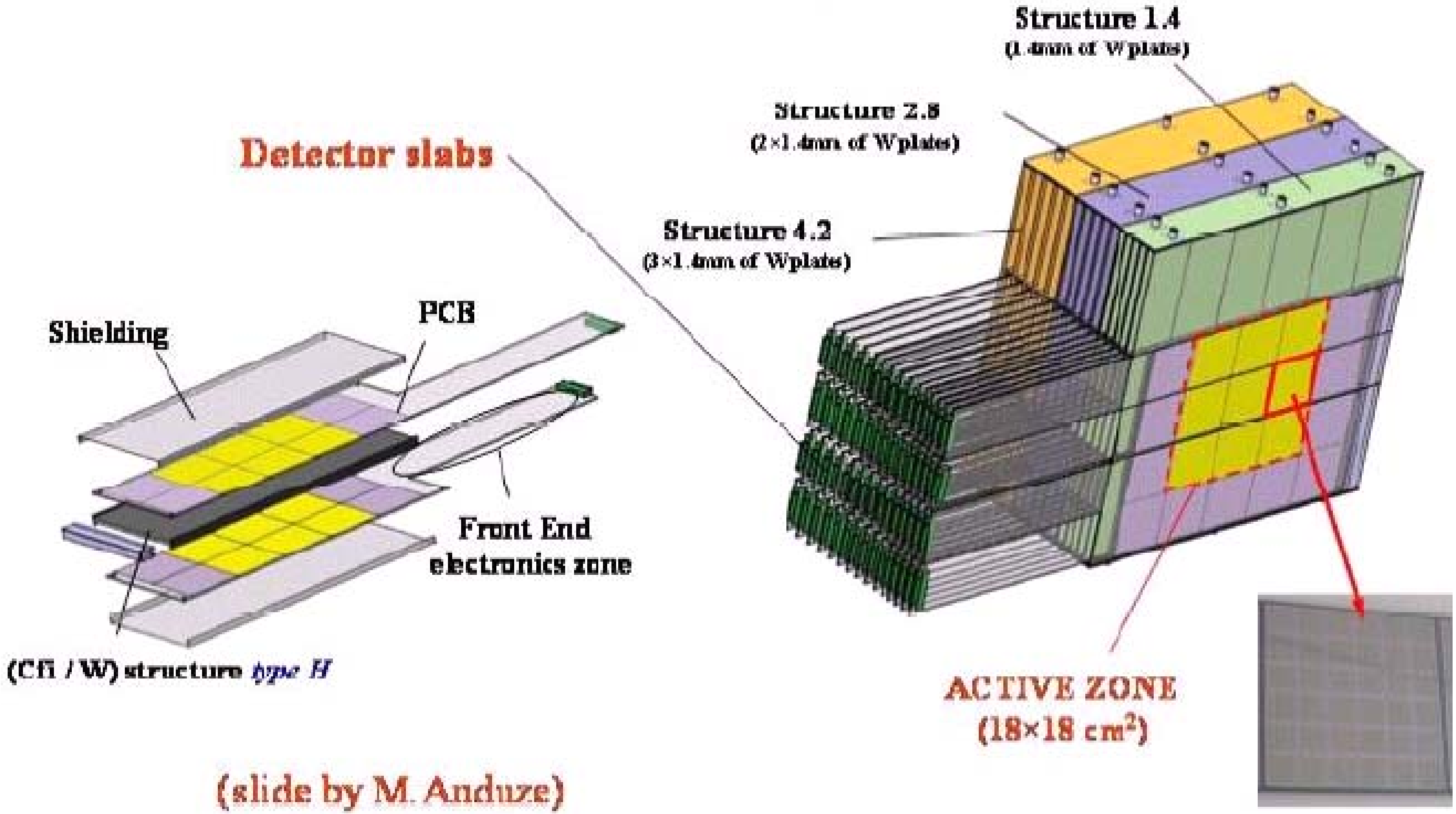
- strong interplay between hardware and software

CALICE Collaboration

- : formed to conduct the R&D effort needed to bring
  initial conceptual designs for the **calorimetry** to a final proposal
  suitable for an experiment at the future linear collider

- : 30+ institutes from 10+ countries from Europe, America, Asia
  organic growth, open invitation to join

CALICE ECAL prototype



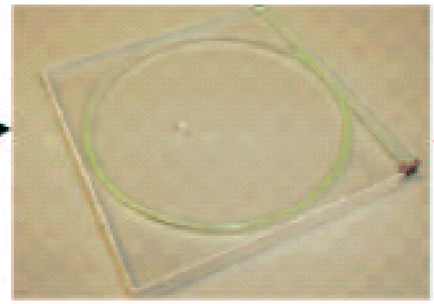
Si Wafer :
6×6 pads of detection
(10×10 mm²)

full Si/W prototype (24 X_0)

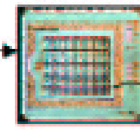
- 30 layers × 18 cm × 18 cm, interleaved with 0.5 mm Si pads
- W absorber, 10+10+10 layers, 1.4 mm:2.8 mm:4.2 mm thick per respective layer
- readout by **1 × 1 cm² cells, total: 9720 channels**

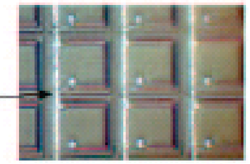
HCAL readout chain

Read out 216 tiles/module
~8000 channels

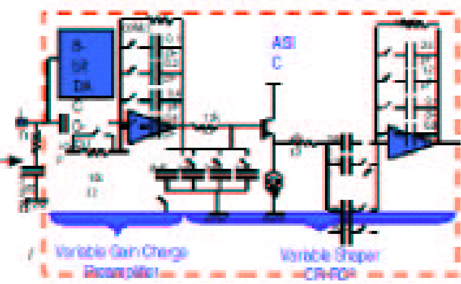


Single tile readout with
SiPM

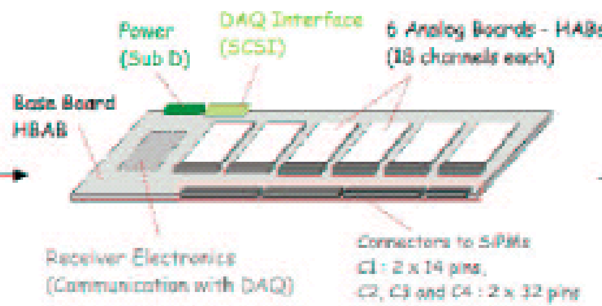




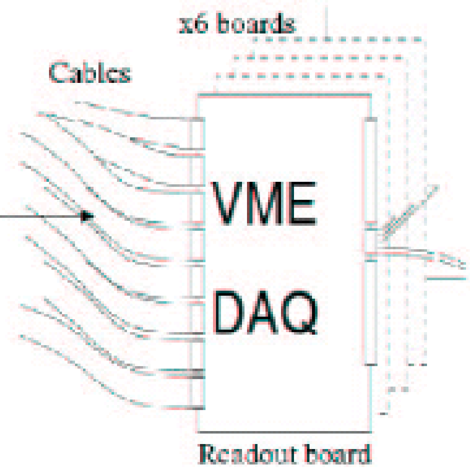
SiPM: pixel device
operated in Geiger mode



ASIC: amplification +
shaping + multiplexing



VFE: control 6 ASICs connect
to SiPM



(M.Groll)

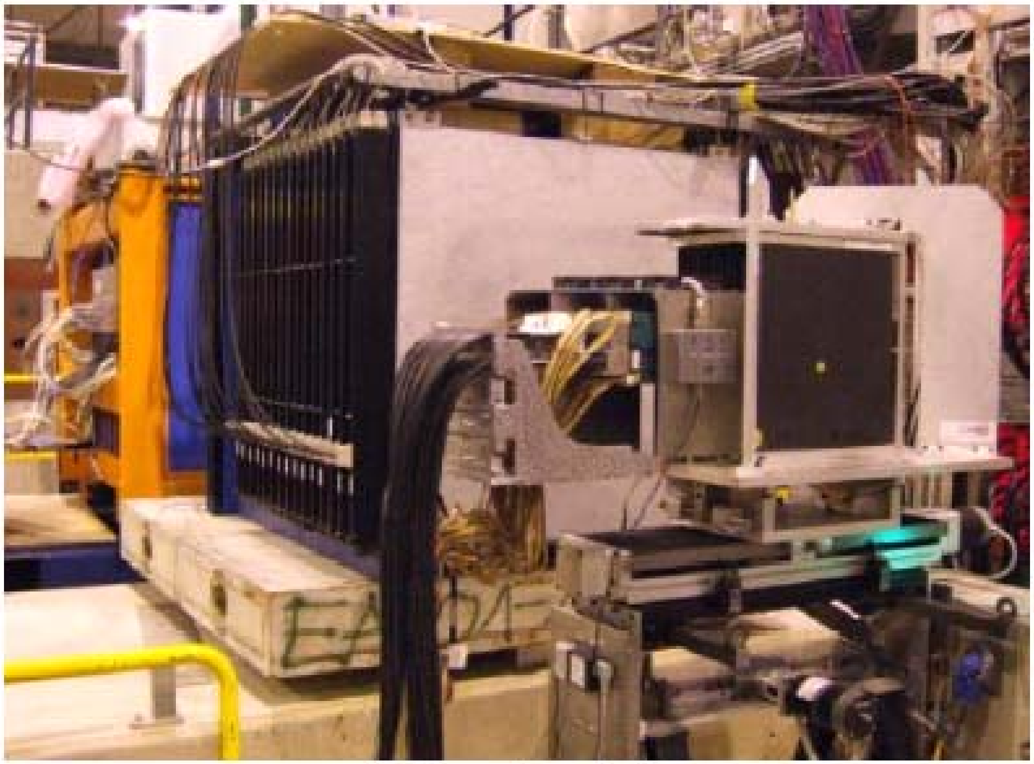
CALICE Tail-Catcher Muon-Tracker Prototype

Kurt Francis

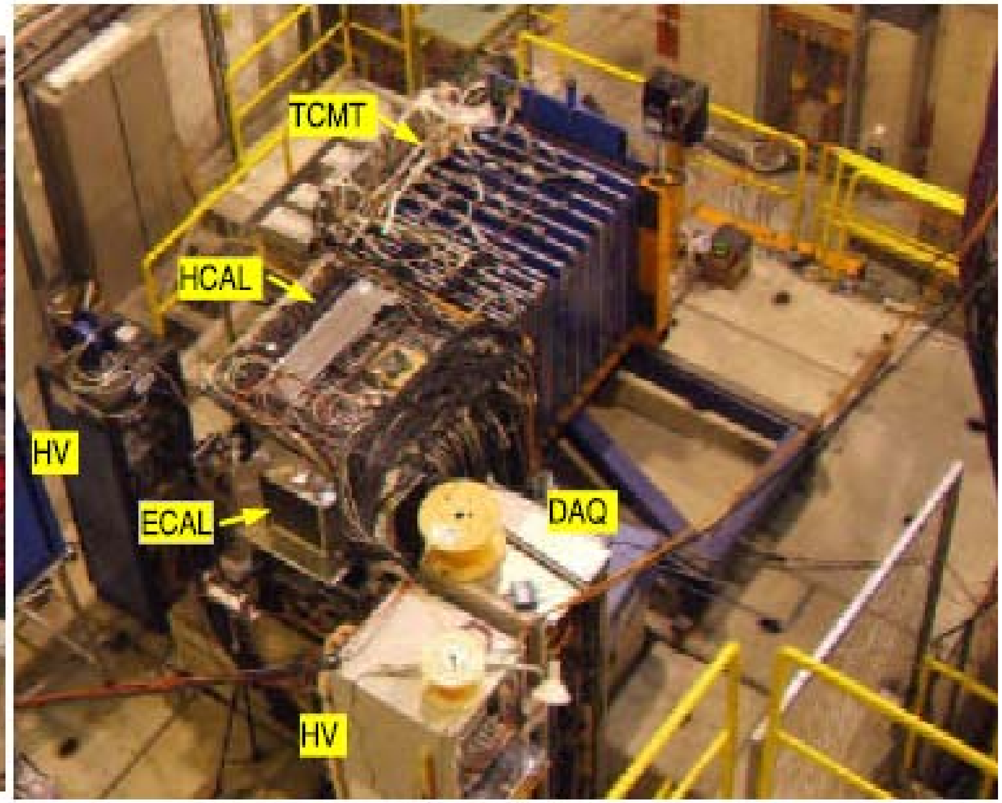
- Mechanical Structure / Absorber
  - "Fine" section (8 layers)
    - 2 cm thick steel
  - "Coarse" section (8 layers)
    - 10 cm thick steel
- 16 Cassettes:
  - Extruded Scintillator Strips
    - 5mm thick
    - 5cm wide strips
    - Tyvek / VM2000 wrapping
    - Alternating x-y orientation
  - Readout
    - WLS Fiber
    - SiPM photo detection
    - Common readout with CALICE HCAL
- Dimensions:
  - Length (along beam) - 142 cm
  - Height - 109 cm
- Weight ~10 tons

Mechanical Structure Engineered and Assembled by Fermilab PPD

CALICE Testbeam at CERN 2006



(perspective view)



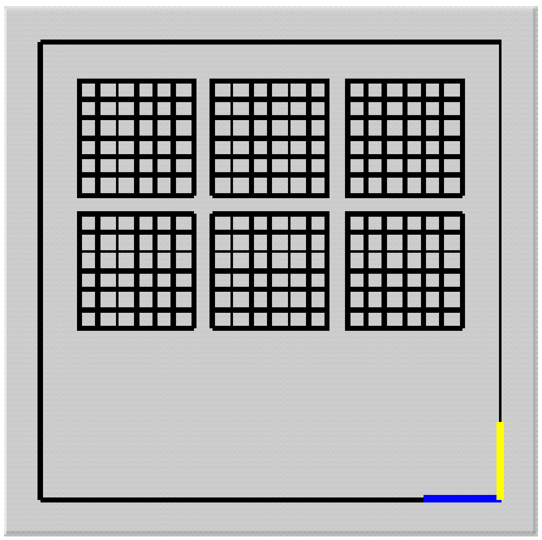
(top view)

Transverse granularity

ECAL 18×18 cm^2

Si cells of 1×1 cm^2

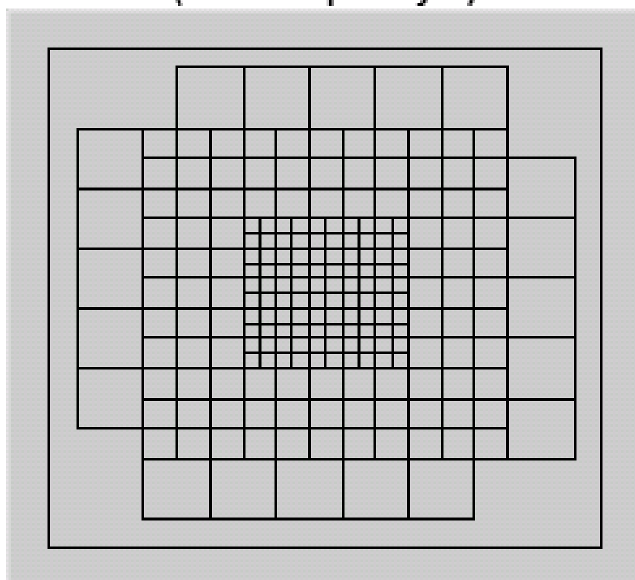
(216 cells per layer)



HCAL 100×100 cm^2

scint.tiles of 3×3, 6×6, 12×12 cm^2

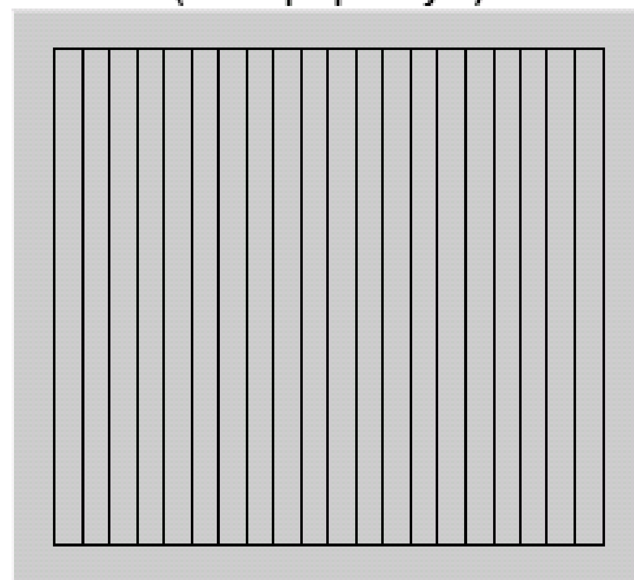
(216 tiles per layer)



TCMT 100×100 cm^2

scint.strips X or Y of 5×100 cm^2

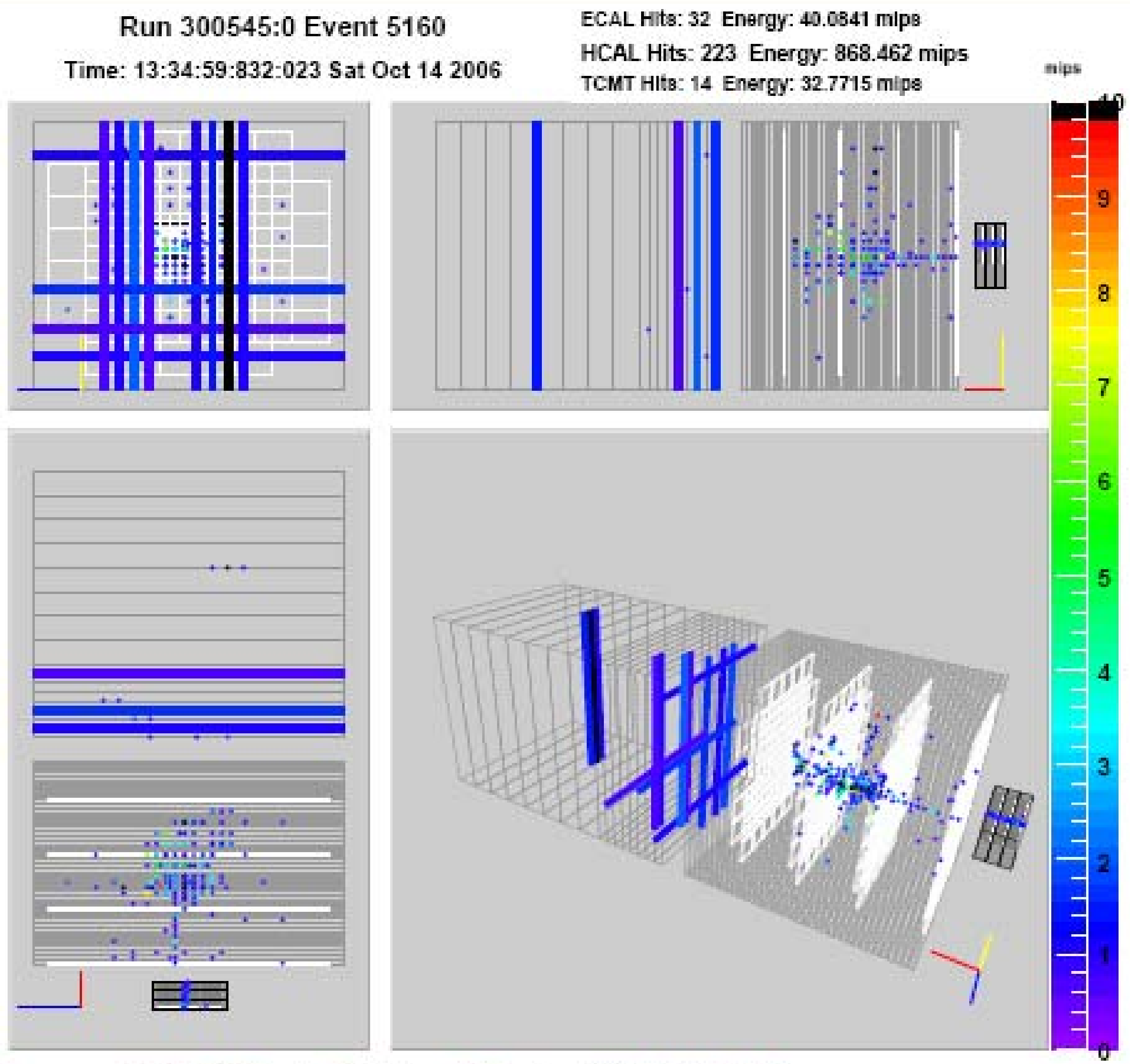
(20 strips per layer)



Tail Catcher - Muon Tracker

(see talk by K.Francis)

CALICE testbeam at CERN



π^- **30 GeV**

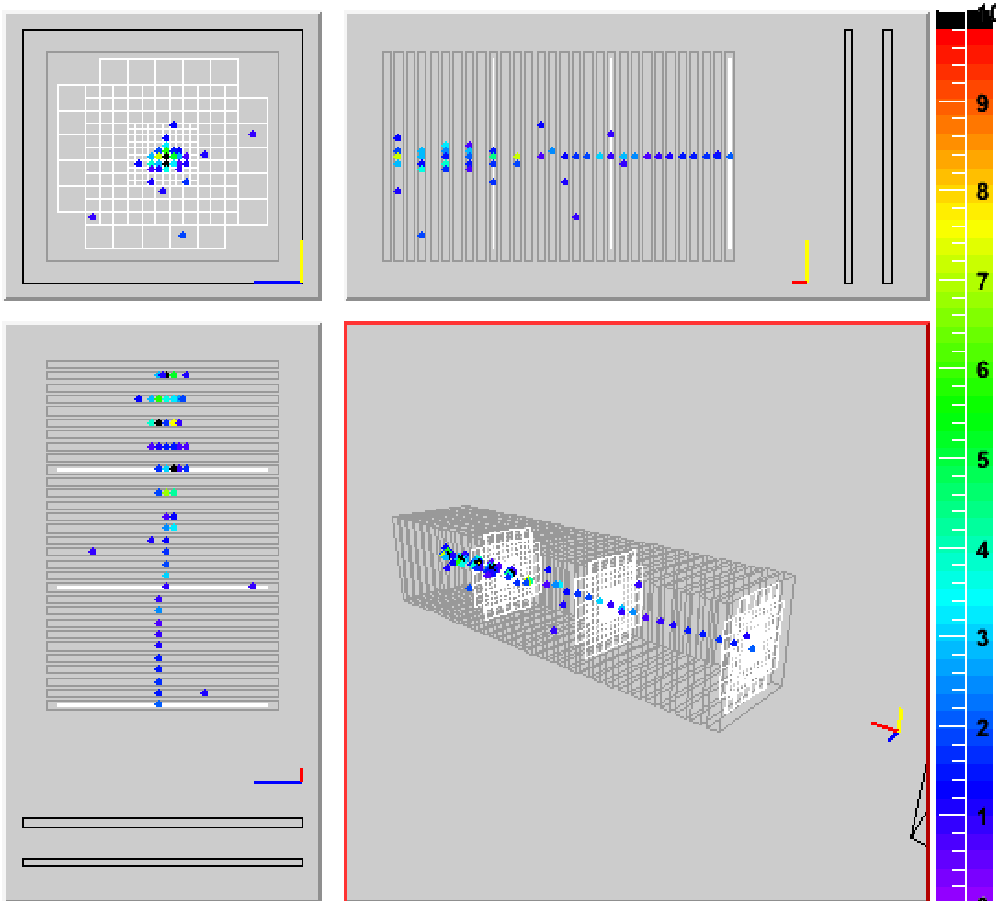
ECAL threshold = 0.5 mip
HCAL threshold = 0.5 mip
TCMT threshold = 0.7 mip

Example pion event display

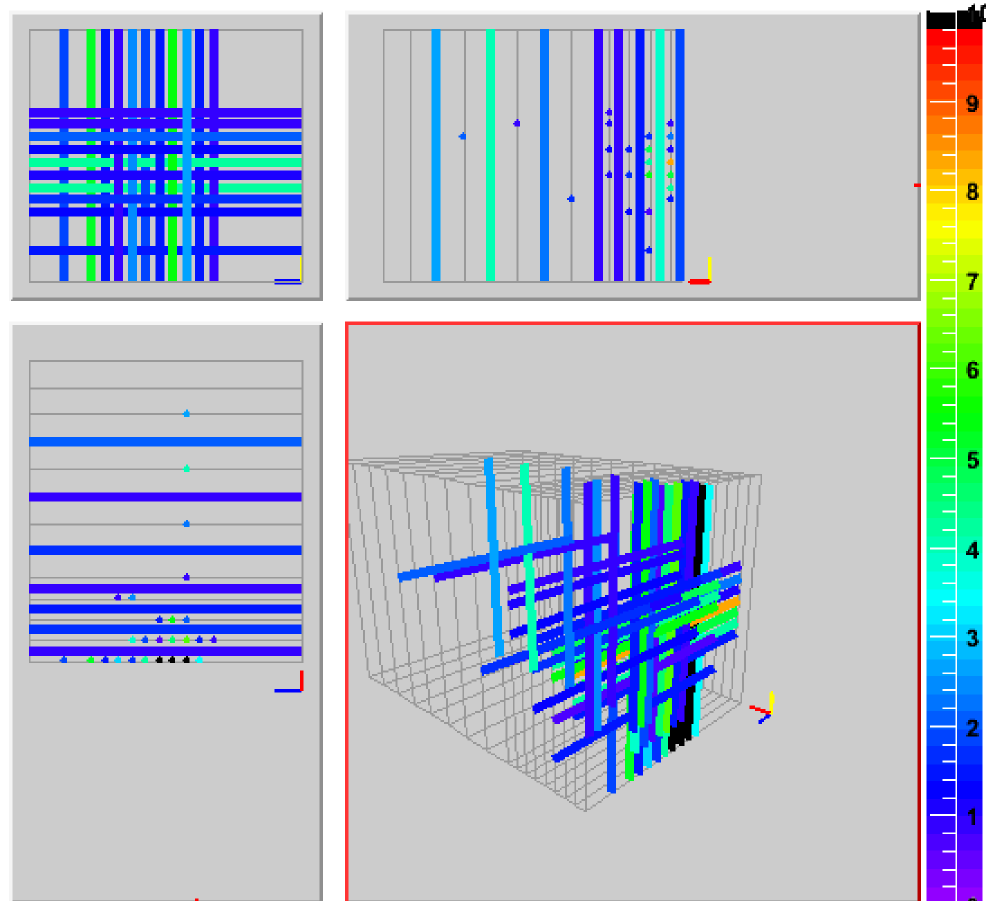
40GeV/c pion
with CALICE online analysis software

Kurt Francis

HCAL



TCMT



Late shower in HCAL

TCMT clearly needed to contain shower

CALICE Testbeam Plans for 2007-8

► . **Si ECAL + scint HCAL/TCMT**

: complete ECAL(transversally), complete HCAL(longitudinally), mount HCAL on movable/rotatable stage

: 2nd round of combined testbeam at CERN (summer 2007)

: **move to FNAL-MTBF in fall 2007**

todo list

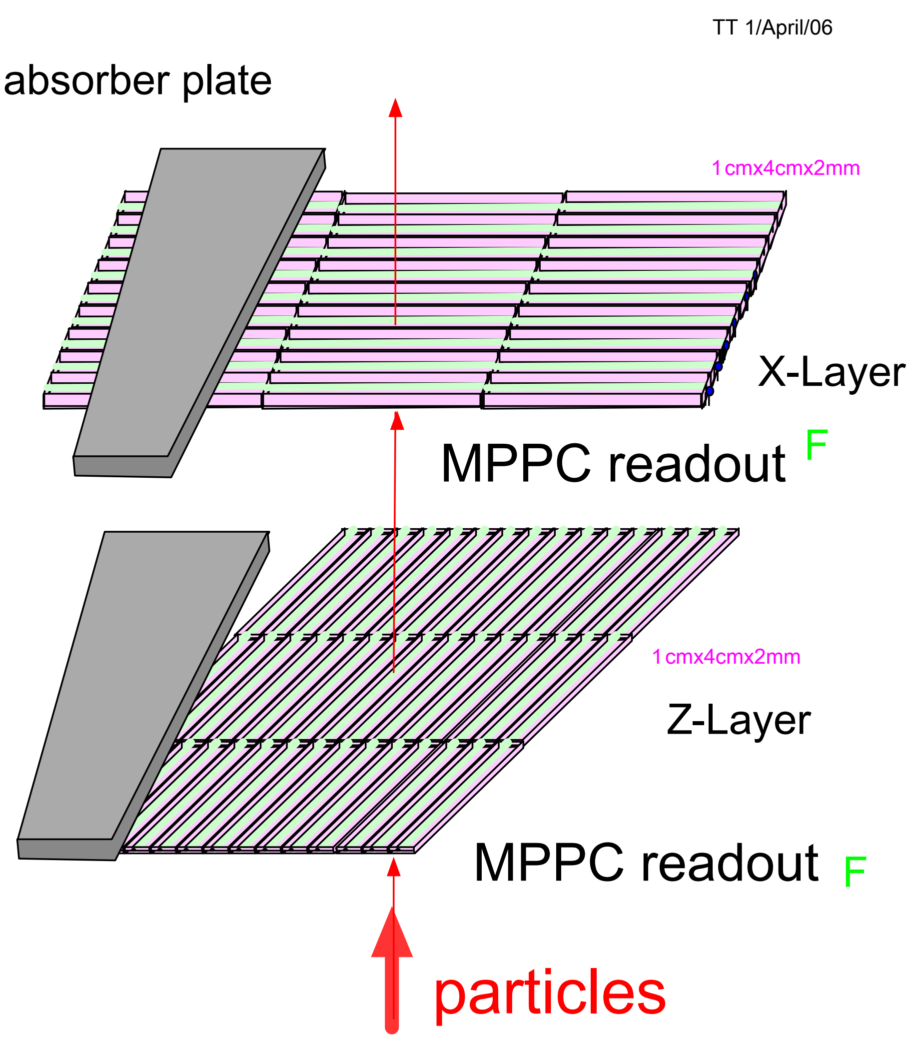
- data collection with complete instrumentation
- scans with incidence angle variation
- increase statistics at low energies (around 10 GeV)
- extension of the energy range towards smaller energies (down to $\sim$ 2 GeV)
- proton/antiproton data collection
- direct comparison with gaseous HCALs under identical beam conditions
- ... ...

CALICE Testbeam Plans for 2007-8

- **scint ECAL**
  - : testbeam at DESY with small prototype in early 2007
  - : testbeam at FNAL-MTBF with prototype completed, late 2007
- **digital HCAL with RPCs, GEMs**
  - : "slice" test at FNAL-MTBF, early 2007
  - : start production of $1m^3$ prototype, early 2008 (?)
  - : join combined testbeams at FNAL-MTBF, late 2008 (?)
- **digital HCAL with μMegas**
  - : build single chamber(s), first tests at CERN in 2007
  - : build/test $1m^2$ chamber(s) in 2008

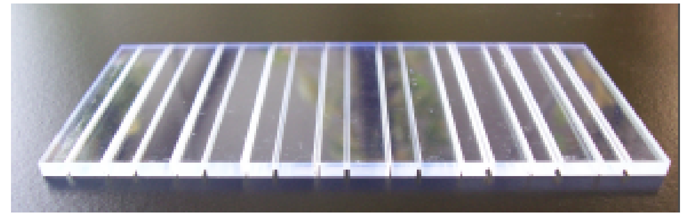
Concept of strip calorimeter

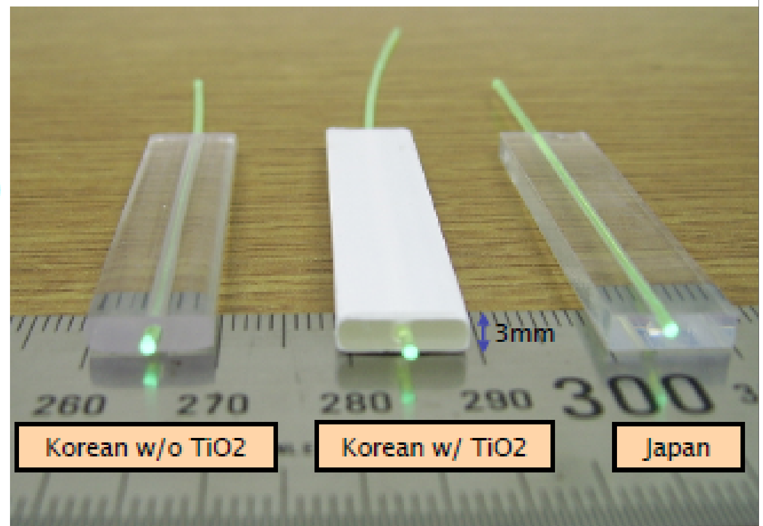
GLD-ECAL-Scintillator-layer model



- Sampling calorimeter with
  - scintillator and W for ECAL
  - scintillator and Pb (Fe) for HCAL
- Realize fine granularity (effective segmentation ~1cm x 1cm) for PFA with strip structure
- Huge number of readout channels for a ILC detector
  - ~10Mch for ECAL,
  - ~4Mch for HCAL
- This is achieved by MPPC (or SiPM) readout
- Clustering algorithm for the strip structure is under development.

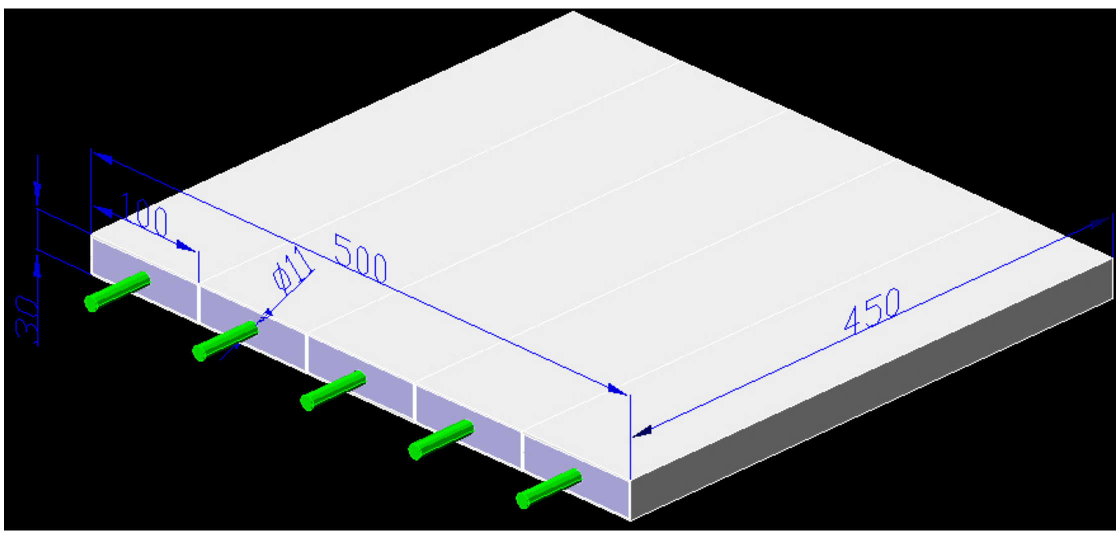
scintillator

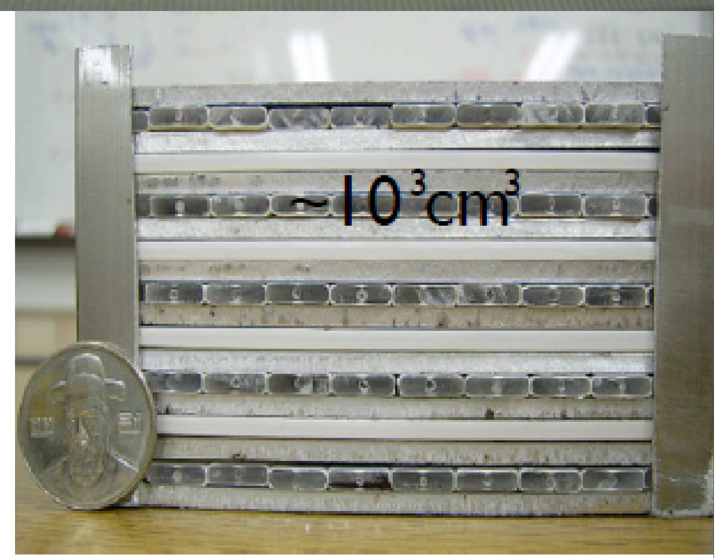




- KURARAY : Mega strip plate
- KNU (Kyungpook National U.) extruded and covered by TiO2

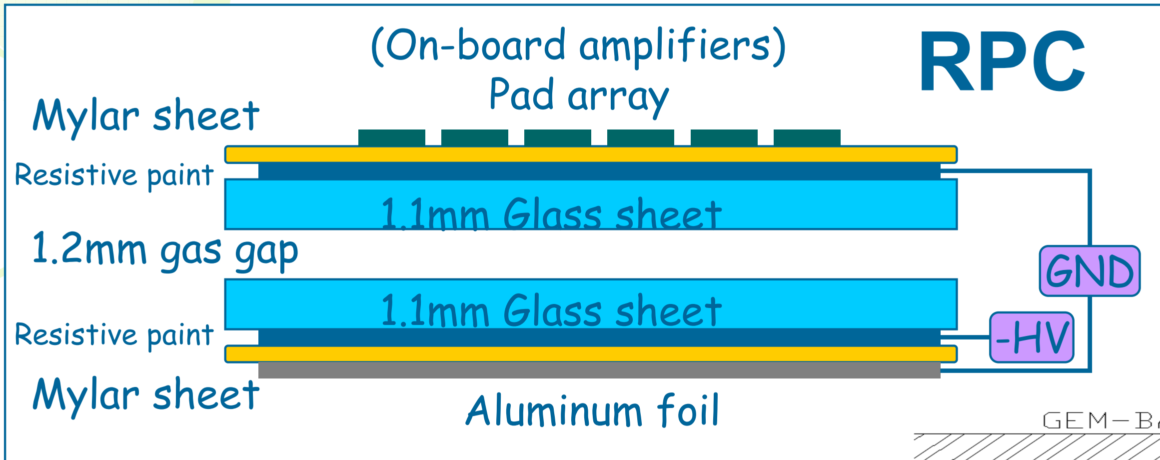
(Extruded Mega-strip under development)





DHCAL Active Medium Candidates

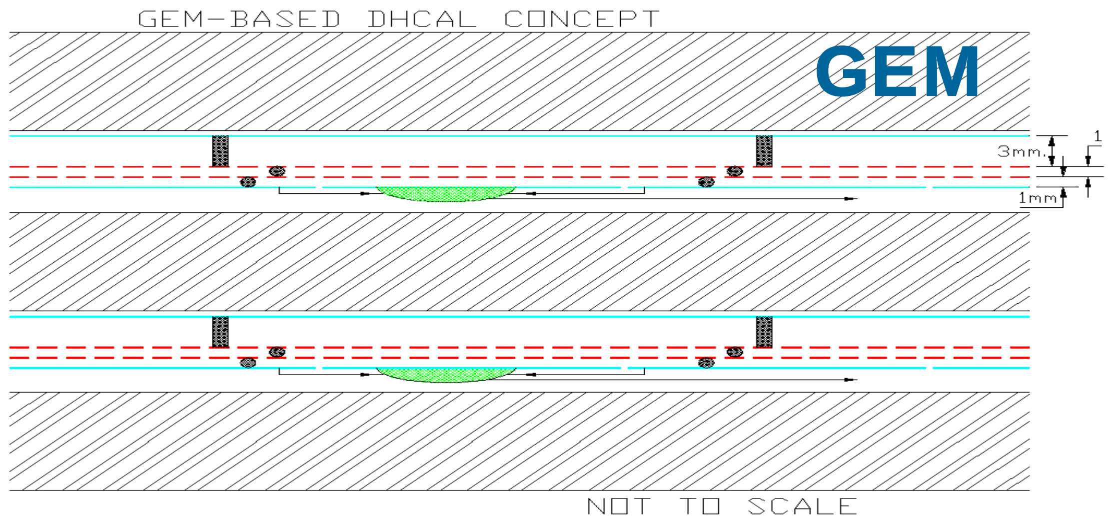
Lei Xia

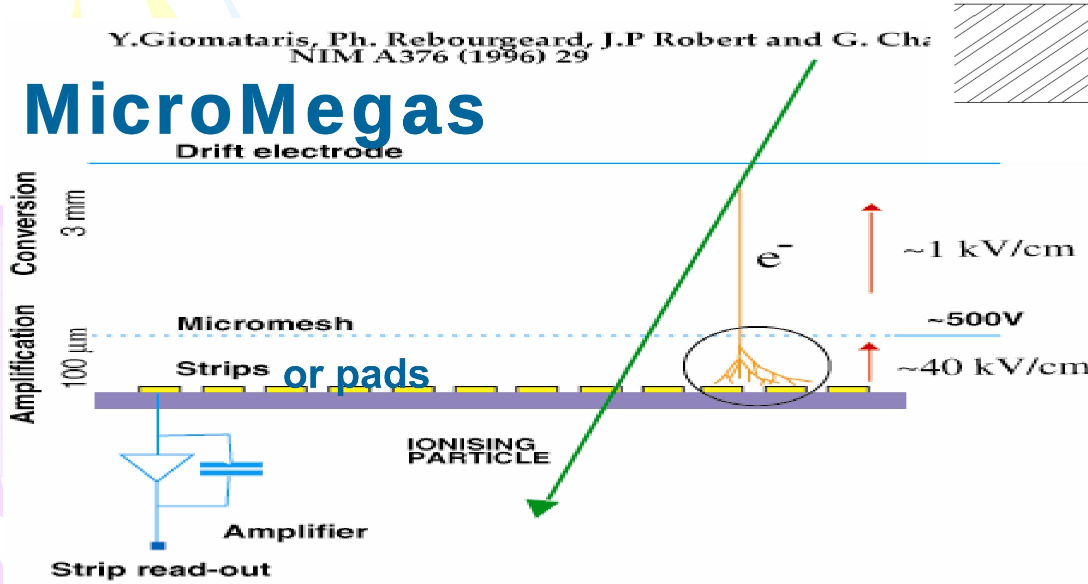


European Group:
IHEP (Protvino) + collaborators

US Group:
Argonne + collaborators

UTA + collaborators





LAPP (Annecy) + collaborators

CALICE Calorimeter for ILC

DHCAL Active medium R&D status

Lei Xia

Measurement	European RPC	US RPC	GEM	mMegas
Signal characterization	yes	yes	yes	yes
HV dependence	yes	yes	yes	yes
Single pad efficiencies	yes	yes	yes	
Geometrical efficiency	yes	yes		
Tests with different gases	yes	yes	yes	
Mechanical properties	?	yes		
Multipad efficiencies	yes	yes	ongoing	
Hit multiplicities	yes	yes	ongoing	
Noise rates	yes	yes	ongoing	
Rate capability	yes	yes		
Tests in 5 T field	yes	no	no	
Tests in particle beams	yes	yes	ongoing	planned
Long term tests	ongoing	ongoing	ongoing	
Design of larger chamber	yes	yes	ongoing	ongoing
Overall R&D	**Done**	**Done**	**Ongoing**	**Started**

Readout summary

Lei Xia

	Item	DCAL	KPix	HaRDROC
FE ASIC	**Current version**	v2	v3	v1
	Current ch# / final ch#	64/64	64/1024	64/64
	Test	Almost done	Ongoing	Started?
	Additional submission	No	Yes	?
	Overall status	Almost done	Ongoing	Ongoing
Readout system for PS	**Conceptual design**	Done	Yes	?
	FE board	Design finished	No	Started?
	Concentrator	Design started	Design started	No
	Data Collector	Design ongoing	No	No
	Trigger Timing module	Specified	No	No
	DAQ software	Started	Started	No
	Overall system	Well advanced	Started	No

- If funding permits, given current progress
  - The 1st PS stack would (naturally) be: RPC + DCAL based readout
  - The 2nd PS stack would be: GEM + ? Readout
- DCAL readout will be validated through the slice test (Apr.07, MTBF)

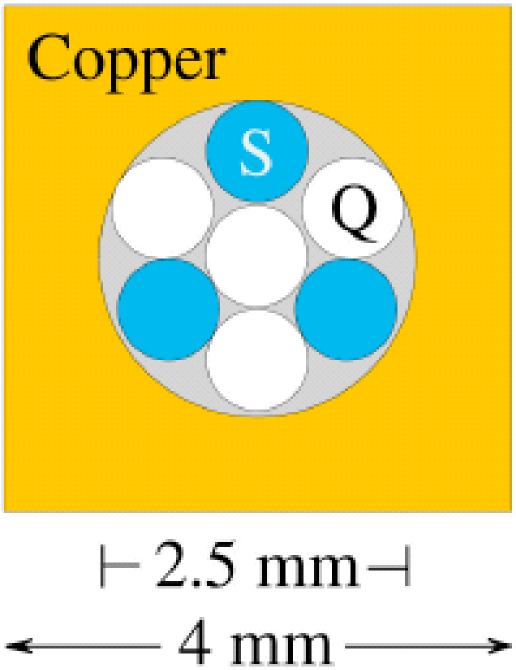
ECal with Integrated Electronics

Ray Frey, U of Oregon

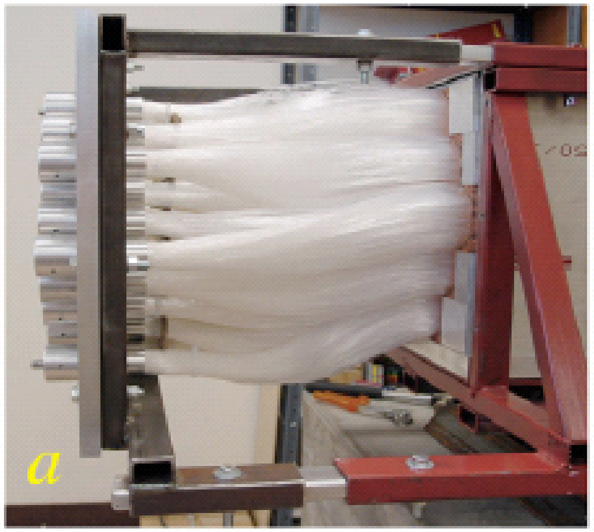
Ongoing R&D Efforts:

- CALICE silicon-tungsten ECal – 2 parallel efforts:
  - Technology Prototype → "Eudet Module" (integrated electronics)
  - Physics Prototype → currently in test beam (electronics external)
- MAPS ECal
  - Led by a sub-group of CALICE
  - More recent – needs some proof of principle work before test beams
- "U.S." silicon-tungsten ECal
  - Has developed only an integrated approach from the start

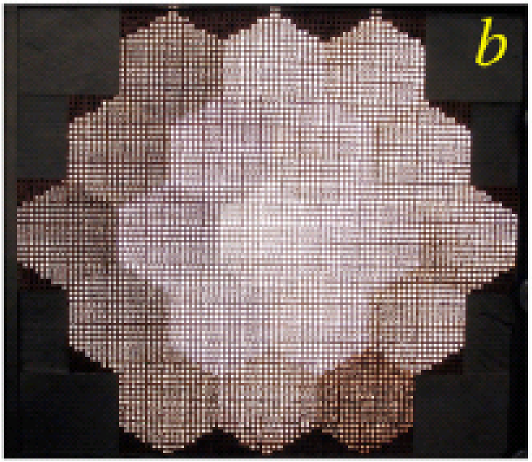
DREAM module: simple, robust, not intended to be "best" at anything, just test dual-readout principle

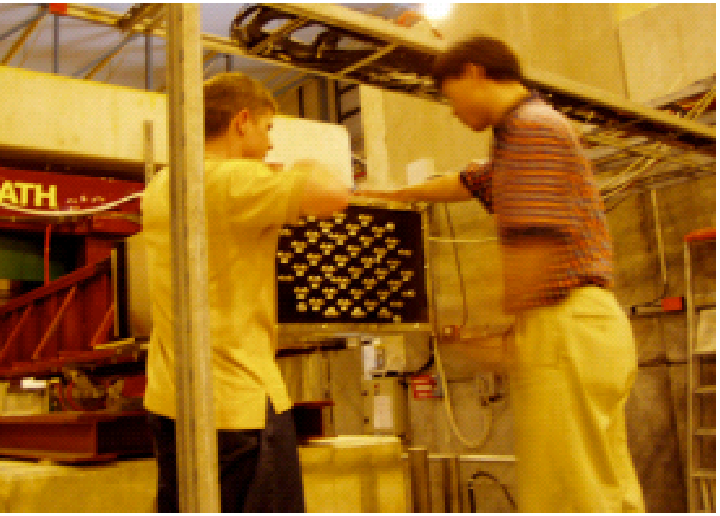


Back end of 2-meter deep module

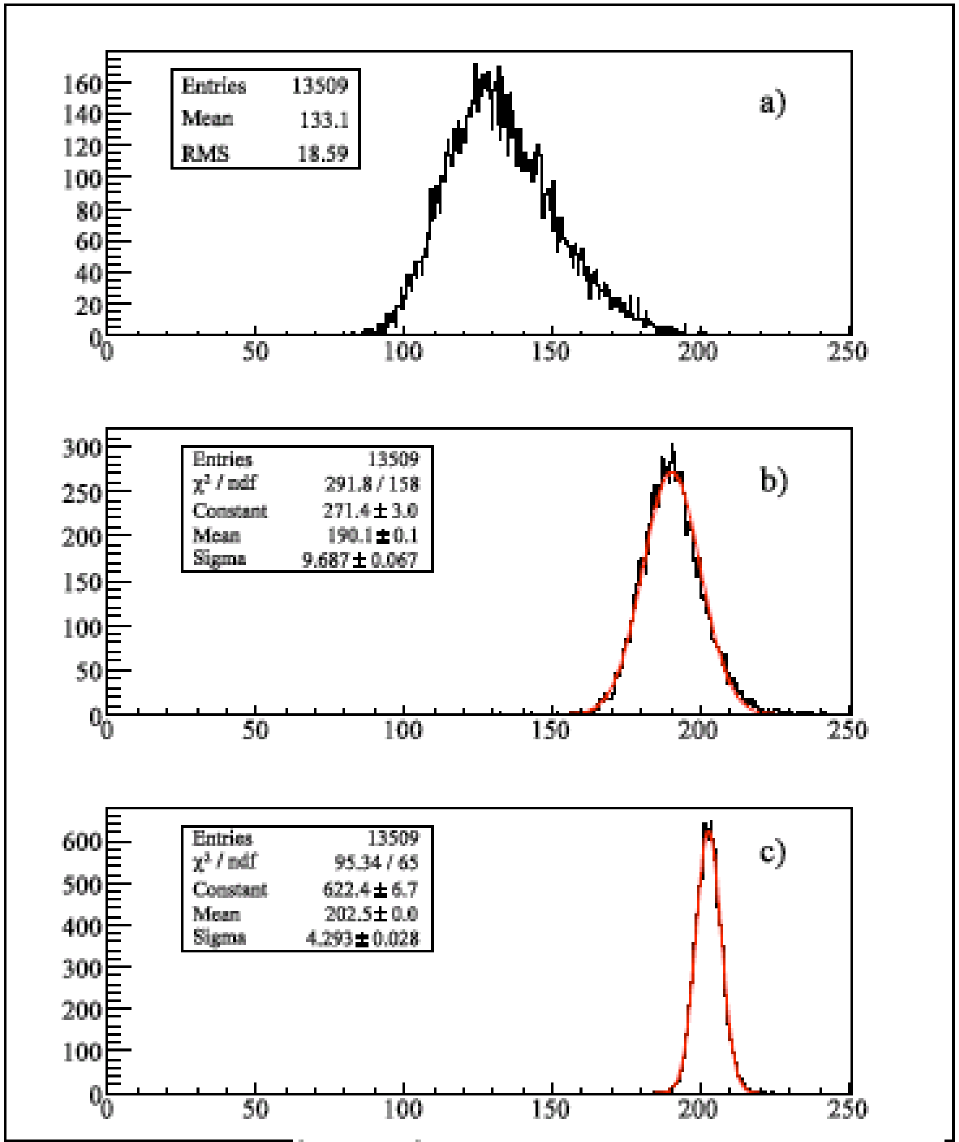


Physical channel structure





DREAM data 200 GeV π^-: Energy response



Scintillating fibers

Scint + Cerenkov

$f_{EM} \propto (C/E_{shower} - 1/\eta_C)$

(4% leakage fluctuations)

Scint + Cerenkov

$f_{EM} \propto (C/E_{beam} - 1/\eta_C)$

(suppresses leakage)

Data NIM A537 (2005) 537.

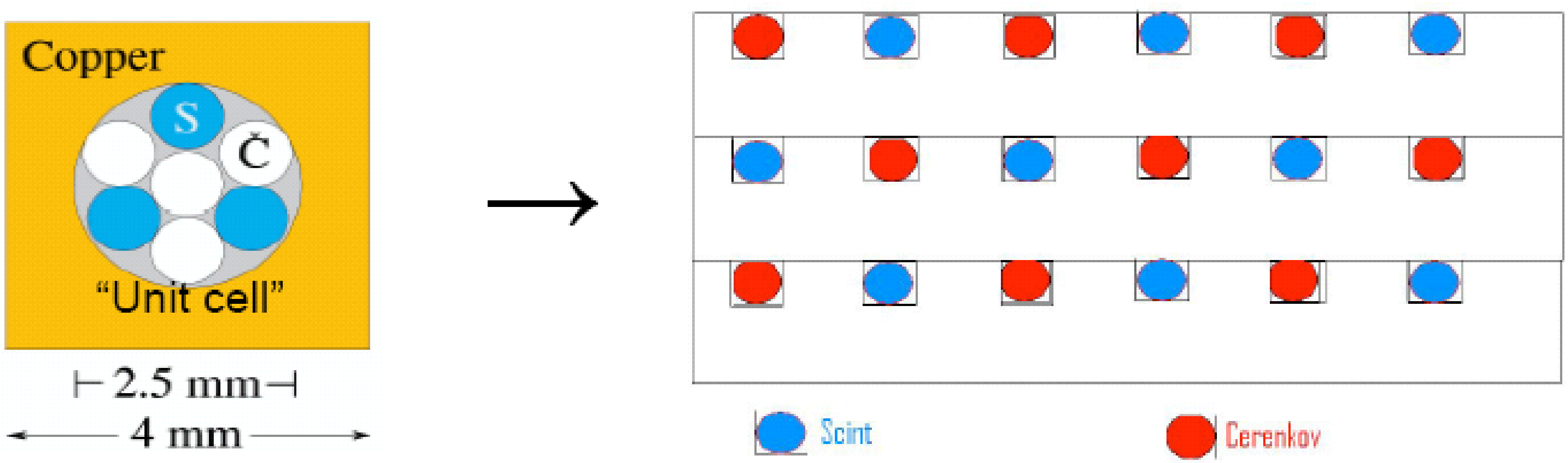
DREAM module

3 scintillating fibers
4 Cerenkov fibers

ILC-type module

2mm W, Pb, or brass plates;
fibers every ~2 mm

(Removes correlated fiber hits)

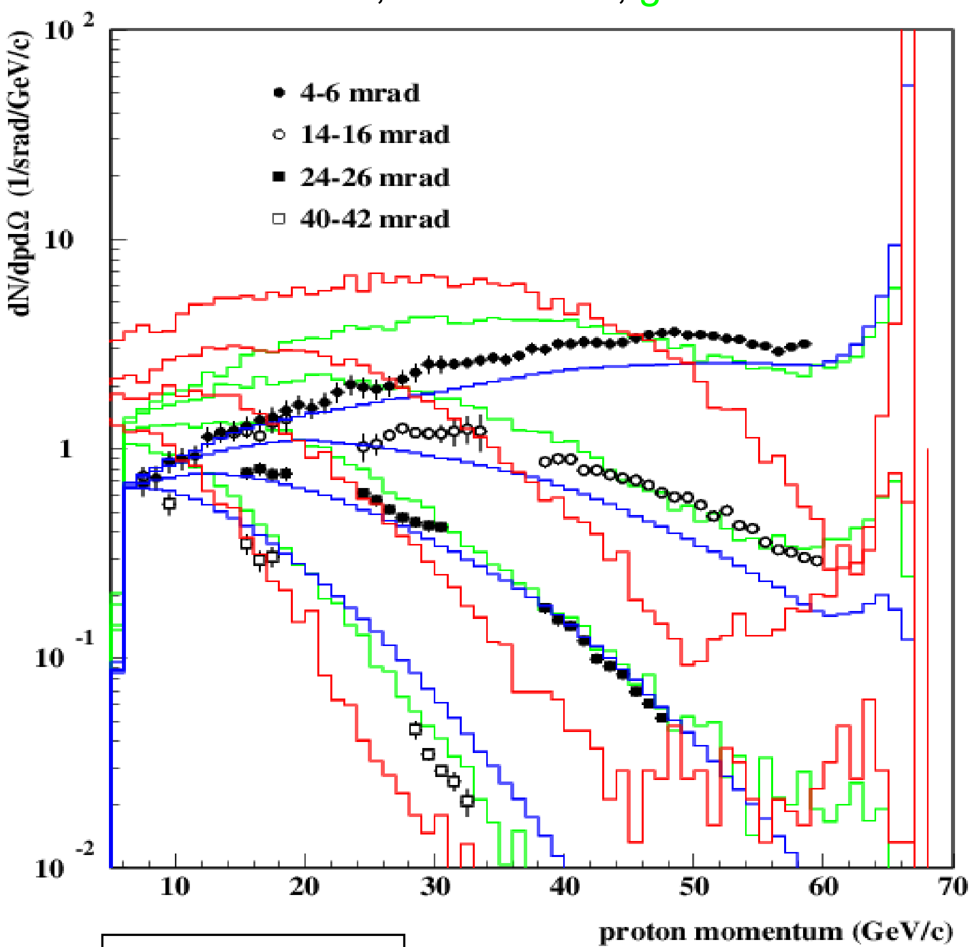


PFA status

- PFA algorithms continue to be developed:
  - jet energy reconstruction of full simulations getting close to target
  - no shower simulation code, however, is reality
    - need to continue program of tuning simulations to data
  - HCAL response to neutral hadrons not well understood (little data)
    - FNAL MIPP upgrade (incl. tagged neutrons) could help a lot

p + Al at 67 GeV/c -> p X

red: Geant4, blue: MARS, green: PHITS



Dennis Wright

Comparing with other methods for jet

From:
Jean-Claude Brient

WARNING

The stochastic term is not the only parameter

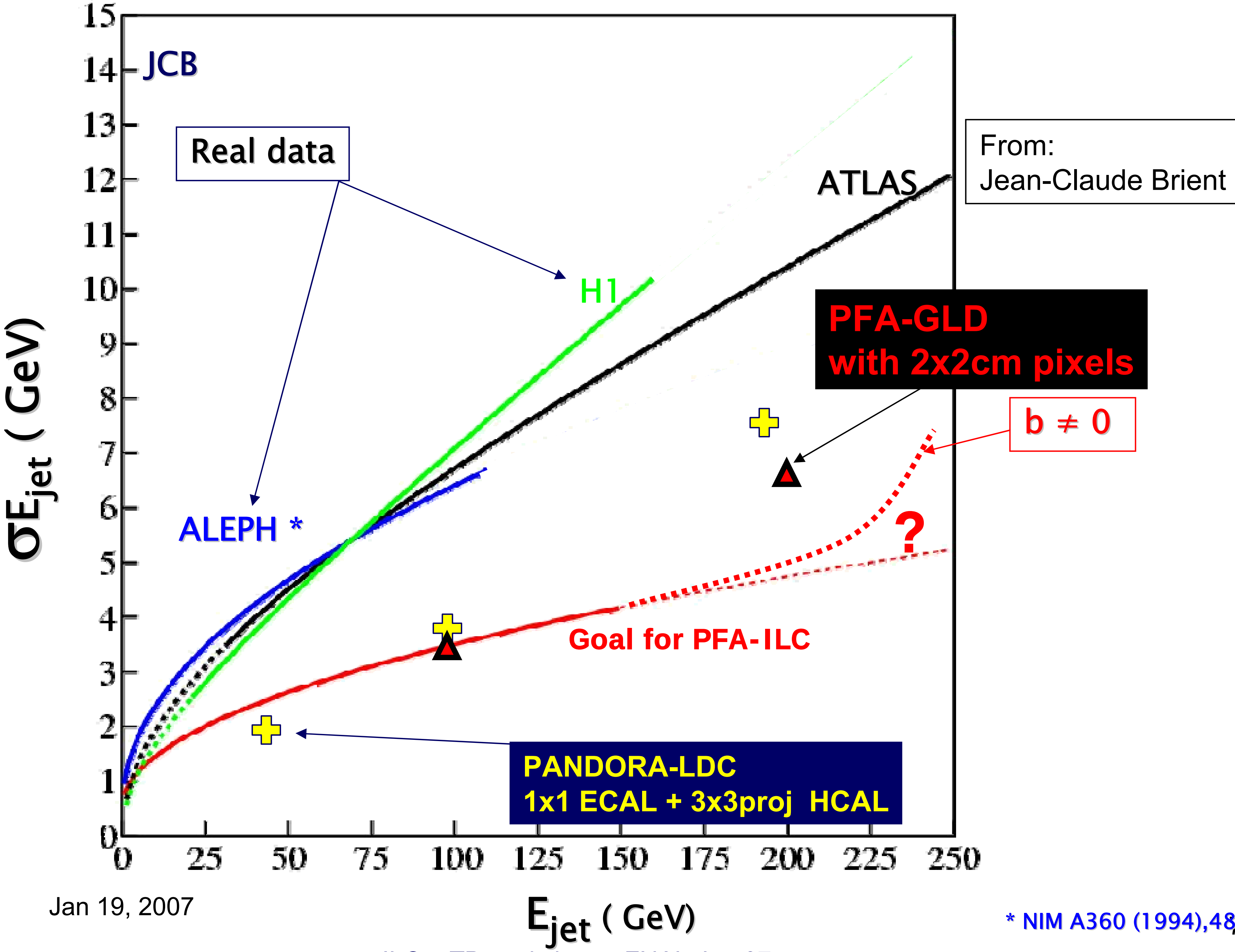
A more complete law

$\Delta E_J = a \times \sqrt{E_J} \oplus b \times E_J + c$

	a	b	c (GeV)
ALEPH method QPFLOW	0.59	0	0.6
ATLAS at best !!	0.6	0.03	0
H1	0.5	0.05	0
PFLOW–ILC	**0.3**	**0**	**0.5**

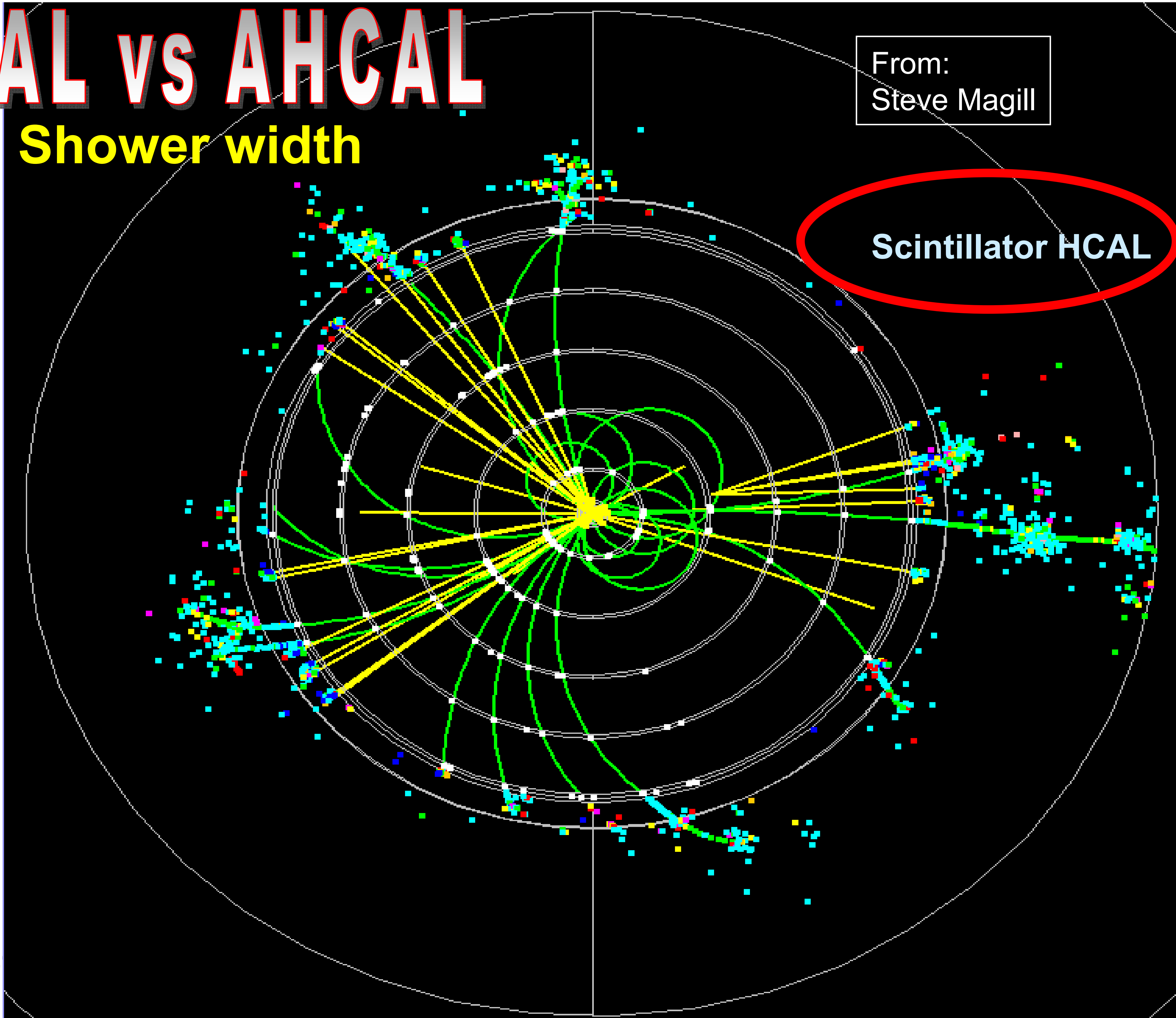
NIM A360 (1994),480

AND the Angular Dependence !!

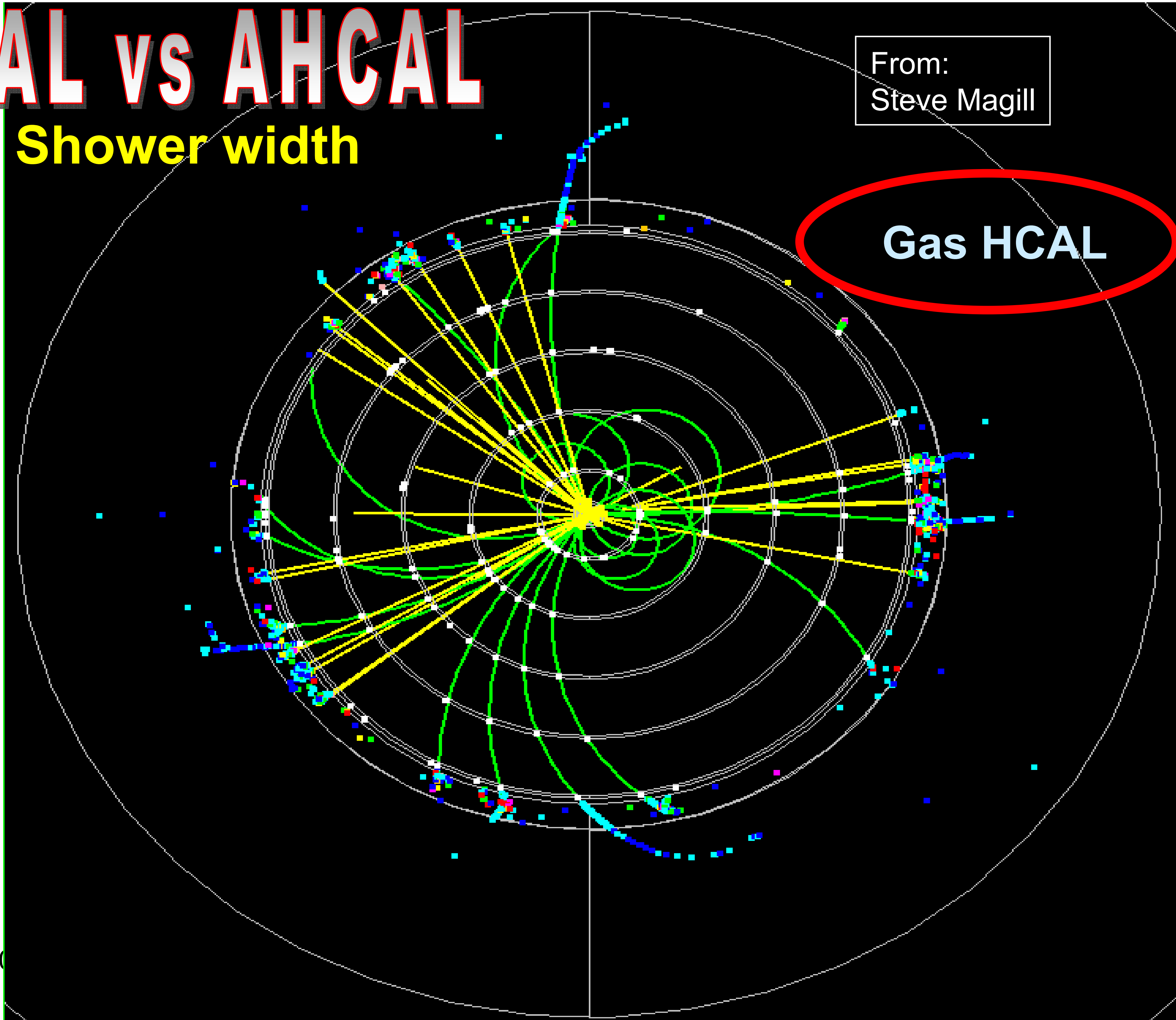


* NIM A360 (1994),480

DHCAL vs AHCAL

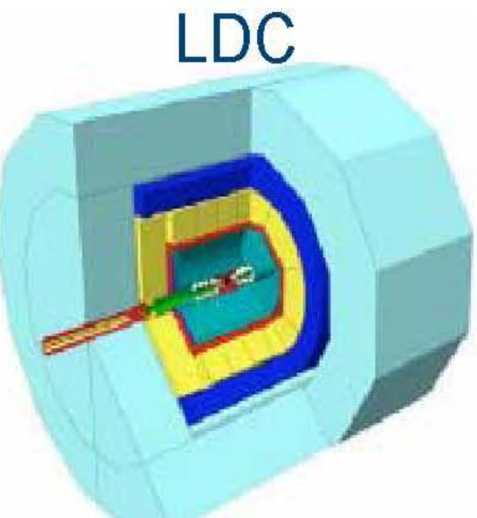


DHCAL vs AHCAL

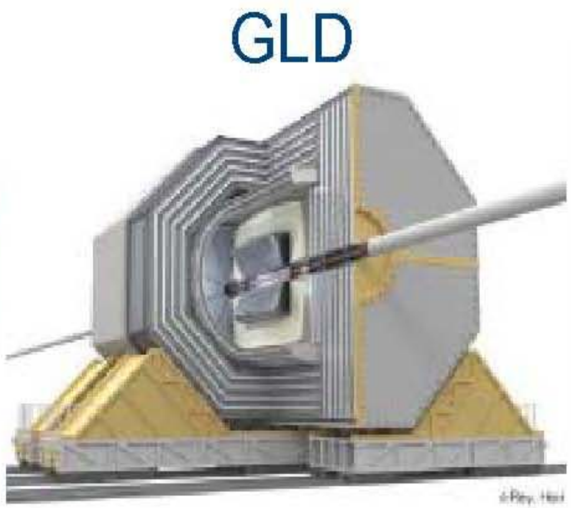


ILC detector future steps

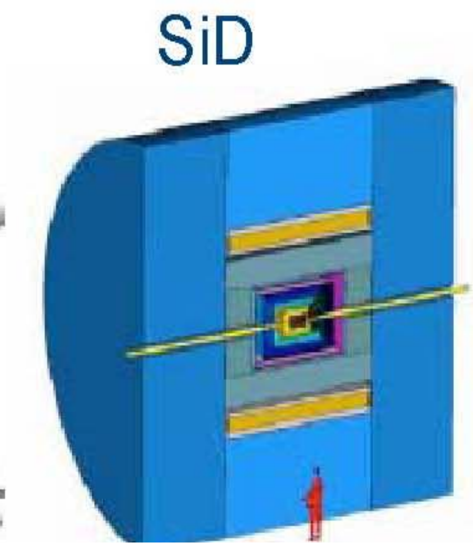
- 4 detector concept groups



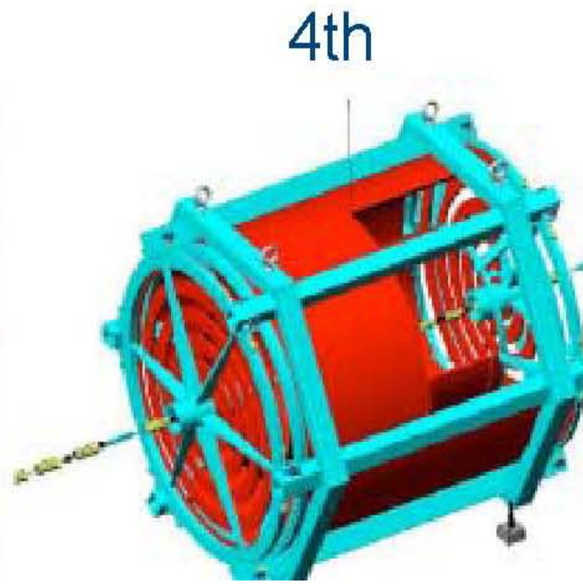
TPC (B=4T)



TPC (B=3T)



Silicon (B=5T)

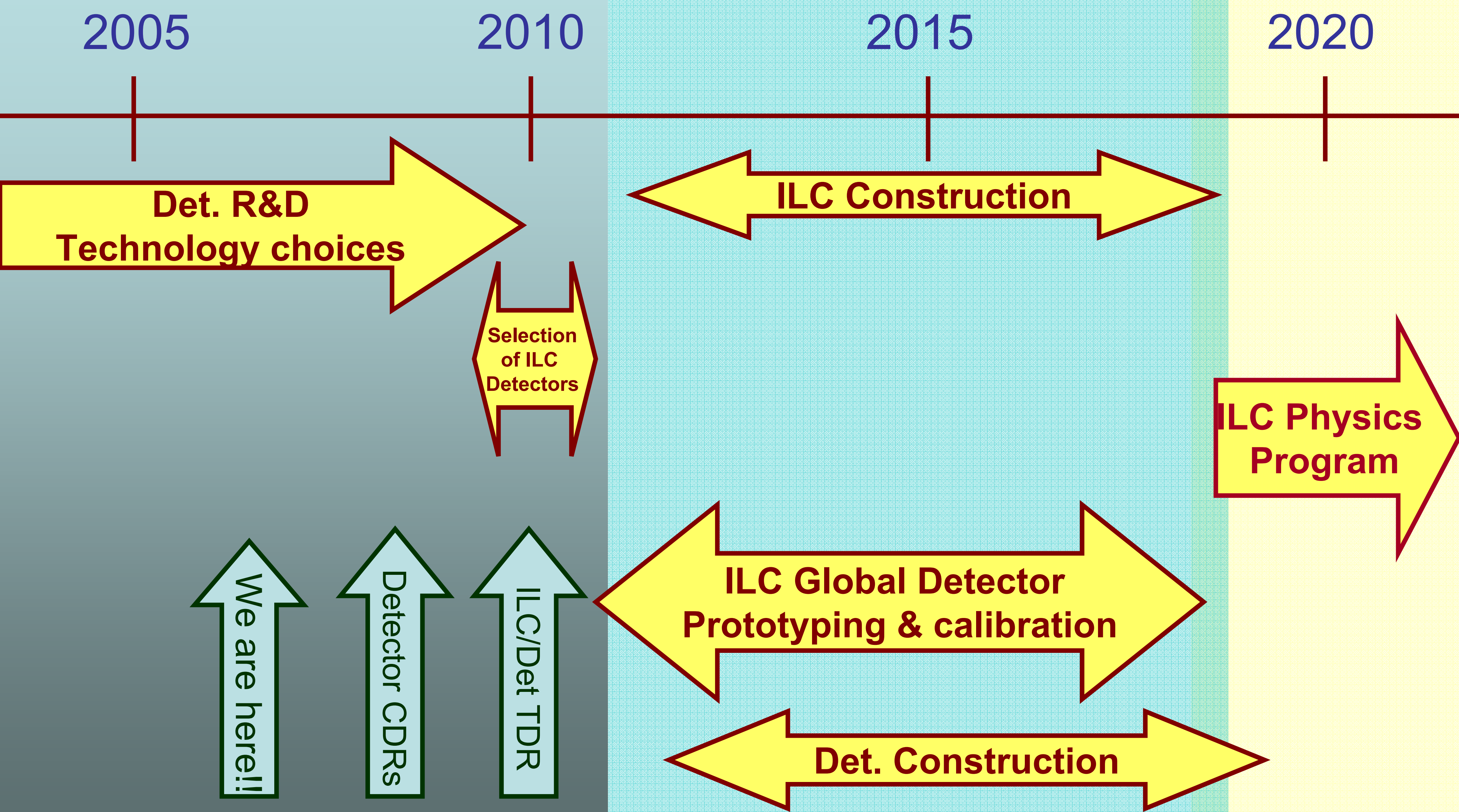


TPC (B=3.5 T)

- transition to 2 fully engineered detectors…

LC Detector Time Line

From:
Jae Yu



Detector R&D, ILC Detector Concept Development

ILC Detector prototype testing, Construction & Calibration

ILC Physics

Summary

- The precision ILC physics program presents many challenges to detector design
- Test beams are essential to develop the detectors to reach the unprecedented performance goals
- A lot of room for new ideas
  - existing R&D groups are open to new collaborators