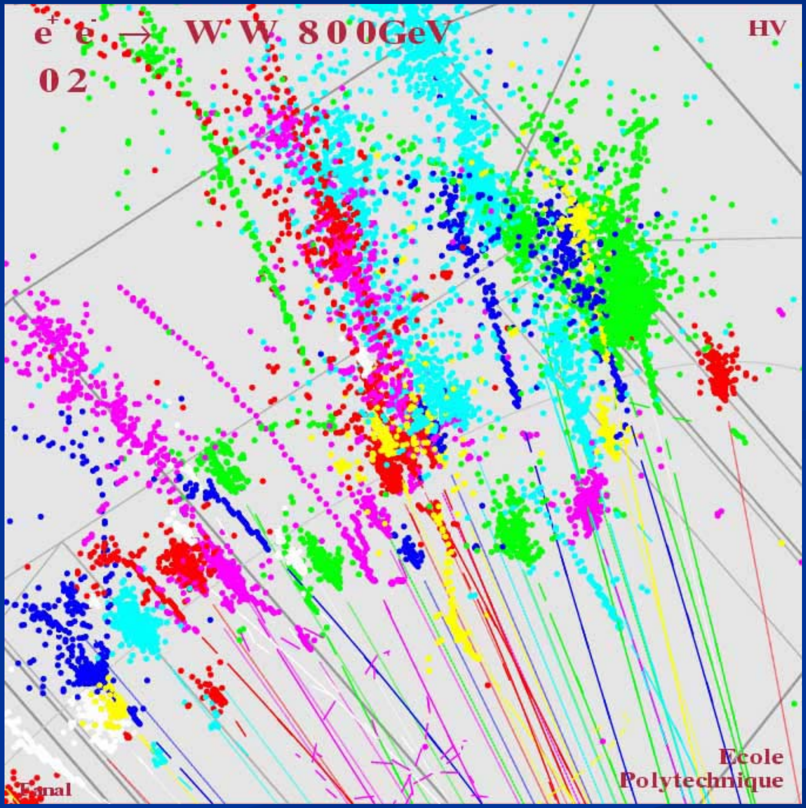
Linear Collider Detector R&D

Presented by Lei Xia

Relatively new group within ANL-HEP

	FTE [%]	(Other) activities
Gary Drake	50	Electronics engineer
Vic Guarino	5	Mechanical engineer
Steve Kuhlmann	15	CDF, CTEQ, Auger
Steve Magill	75	ZEUS
José Repond	75	ZEUS
Dave Underwood	33	ATLAS, STAR
Barry Wicklund	5	CDF
Lei Xia	100	Postdoc

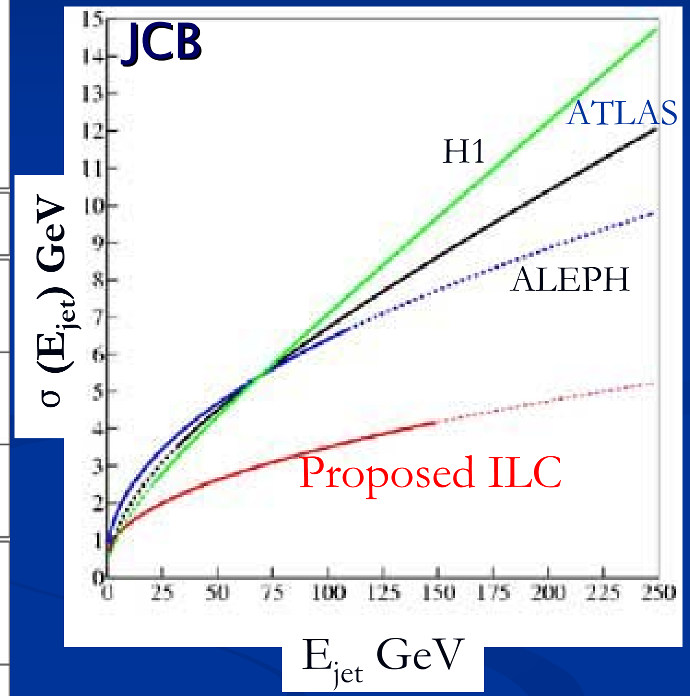


Total = 3.28 FTEs

Why do we need calorimeter R&D for ILC

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

– Physics Benchmarks for the ILC Detectors



Goal = 30%/ √ E_{jet}

Particle Flow Algorithm

Key: Calorimeter

PFA drives the design of the calorimeters

- Measure jets in the PFA way…

Particles in Jets	Fraction of jet energy	Measured with
Charged	65%	Tracker, negligible uncertainty
Photon	25%	ECal, 15%/ √ E
Neutral hadron	10%	ECal + HCal, ~50-60%/ √ E

  - Clear separation of the 3 parts is the key issue of PFA
    - Charged particle, photon and neutral hadron: all deposit their energy in the calorimeters
    - Maximum segmentation of the calorimeters is needed to make the separation possible
- Major R&D issues
  - Development of PFA
    - That works with a highly segmented calorimeter system
    - Meets the ILC goal for jet energy resolution
    - Can be used for detector optimization

Argonne leading role

  - Technical implementation
    - ECal: Si/W analog
    - HCal: fine segmentation (digital readout possible)
      - Active medium: affordable and can be finely segmented
      - Read out a huge number of channels is a big challenge

Argonne leading role

Difference choices of active medium

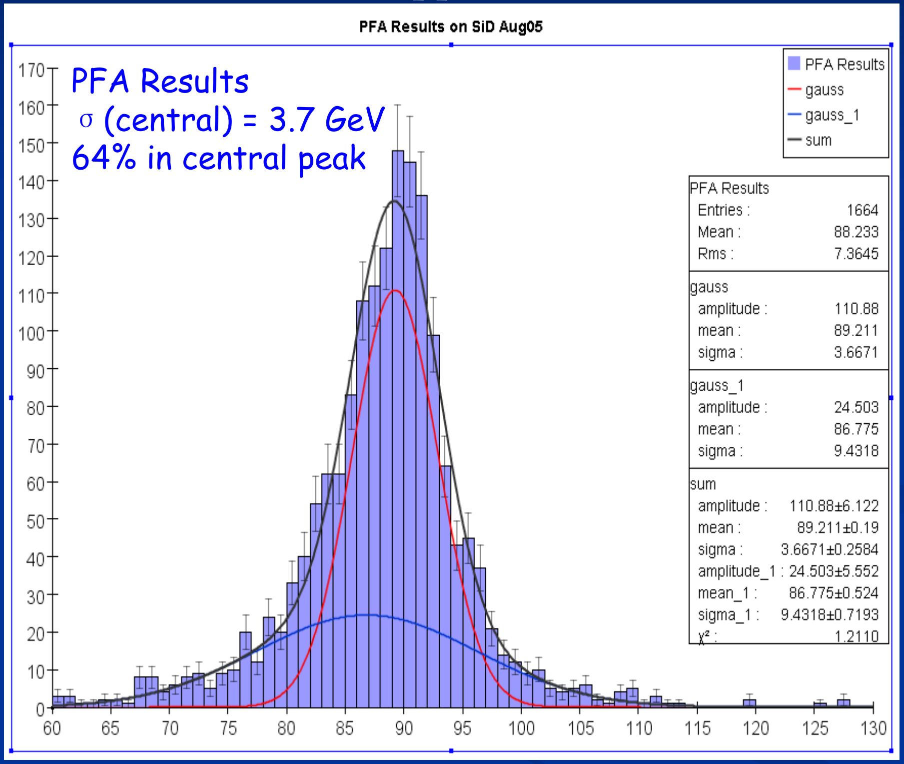
HCAL	Scintillator	GEMs	RPCs
Technology	Proven (SiPM?)	Relatively new	Relatively old
Electronic readout	Analog (multi-bit) or Semi-digital (few-bit)	Digital (single -bit)	Digital (single -bit)
Thickness (total)	~ 8mm	~8 mm	~ 8 mm
Segmentation	3 x 3 cm^2	1 x 1 cm^2	1 x 1 cm^2
Pad multiplicity for MIPs	Small cross talk	Measured at 1.27 (?)	Measured at 1.6 / 1.1
Sensitivity to neutrons (low energy)	Yes	Negligible	Negligible
Recharging time	Fast	Fast?	Slo[illegible] ms/[illegible]
Reliability	Proven	Sensitive	Pro[illegible]
Calibration	Challenge	Depends on efficiency	[illegible]cern (high [illegible]ncy)
Assembly	Labor intensive	Relatively straight forward	Simple
Cost	Not cheap (SiPM?)	Expensive foils	Cheap
Electronic readout cost	Expensive	Expensive	Expensive

DHCal with RPC

PFA development: recent results

- Argonne has two parallel efforts on PFA development, both deliver the best results in North America
- First effort: S. Magill, S. Kuhlmann
- Features:
  - Delivered the first full PFA in North America
  - Multiple clustering algorithms dedicated for constructing/finding MIP, photon, neutral hadron clusters
  - Include H-matrix for photon identification
  - Track – cluster matching includes E/p check
  - In cooperation with other institutes

$e^+e^- \rightarrow Z^0 \rightarrow q\bar{q}$ at 91 GeV



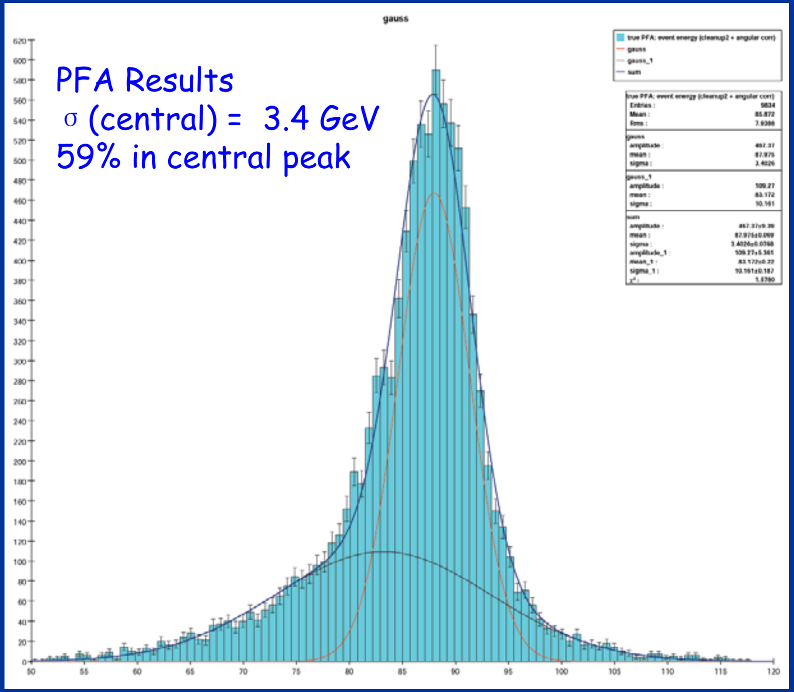
Barrel events with detectable energy > 85 GeV

PFA development: recent results

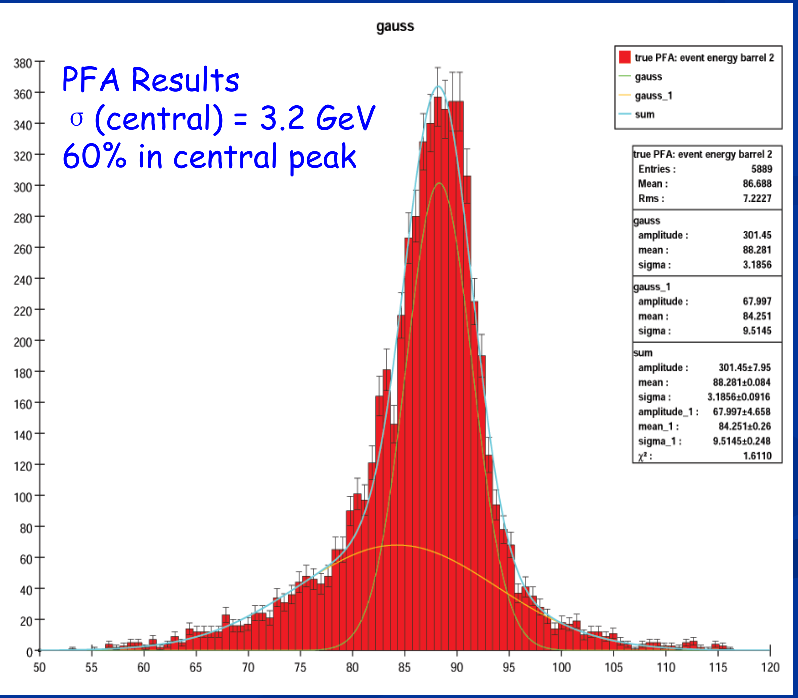
- Second effort: L. Xia
- Features:
  - Single, density driven clustering algorithm for all cluster finding
  - Track – cluster matching without E/p check
  - Charged fragment identification
  - Photon identification, jet algorithm still need to be implemented

More details:

see Steve Magill's parallel session talk on PFA



No event cut



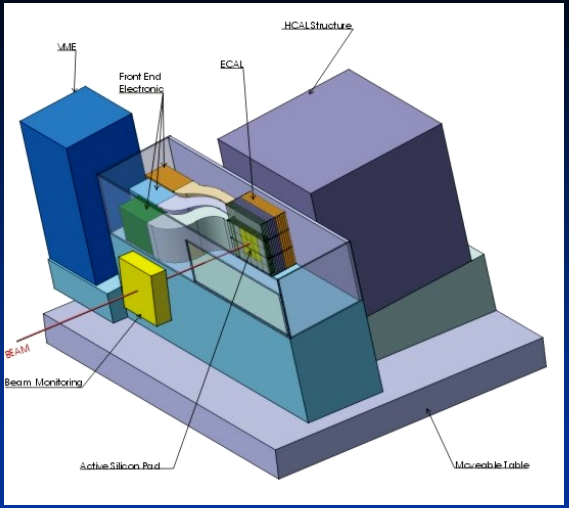
Barrel events only

$$e^+e^- \rightarrow Z^0 \rightarrow q\bar{q} \text{ at 91 GeV}$$

HCAL R&D Goal

Prototype section (PS)

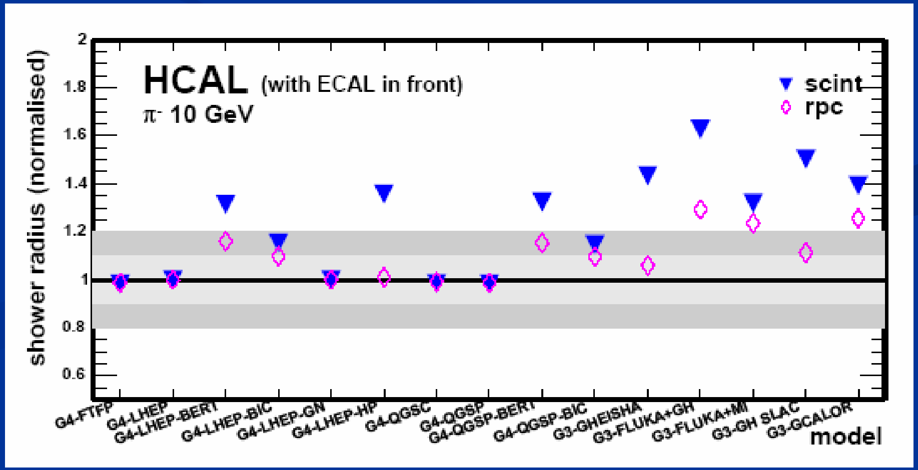
- 1 m^3 (to contain most of hadronic showers)
- 40 layers with 20 mm steel plates as absorber
- Lateral readout segmentation: 1 cm^2
- Longitudinal readout segmentation: layer-by-layer
- Instrumented with Resistive Plate Chambers (RPCs)



Motivation for construction of PS and beam tests

- Validate RPC approach (technique and physics)
- Validate concept of the electronic readout
- Measure hadronic showers with unprecedented resolution
- Validate MC simulation of hadronic showers
- Compare with results from Scintillator HCAL

Comparison of hadron shower simulation codes by G Mavromanolakis



Collaborators

Institute	CALICE	Contributions to date
Argonne	Yes	R&D on RPCs Conceptual design of electronic readout system Specification of front-end ASIC Measurements with prototype front-end board Evaluation of front-end ASIC prototype
Boston	Yes	
Chicago	Yes	Measurement of geometrical acceptance
Fermilab	No	Design of front-end ASIC
Iowa	Yes	Investigation of HV supplies
IHEP Protvino	Yes	R&D on RPCs
Regina	Yes	

197 Physicists 34 Institutes 9 Countries 3 Regions

Staged approach

I R&D on RPCs
Development of conceptual design of electronic readout

➡ **Tests with cosmic rays and in particle beams** **Done**

II Prototyping of RPCs for prototype section (PS)
Prototyping of all components of electronic readout for PS

➡ **Slice test in particle beam** **Planned for November 2006**

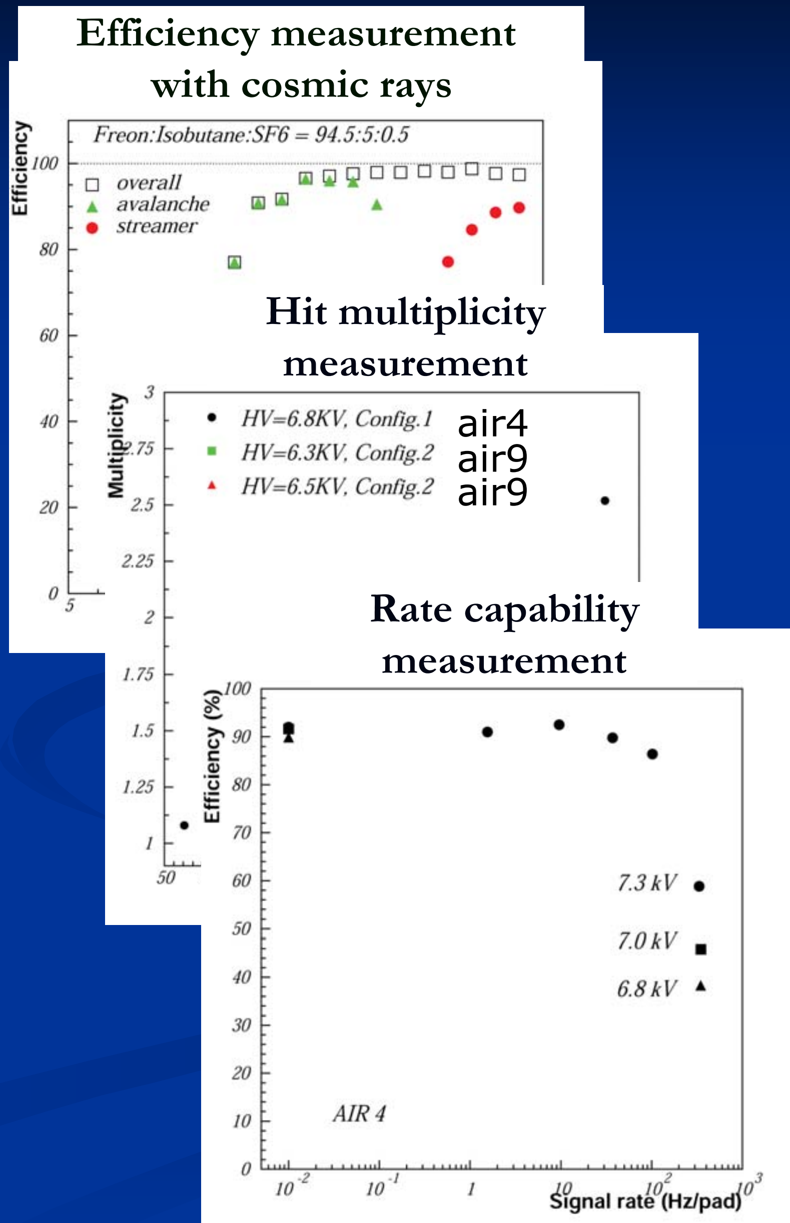
III Construction of PS

➡ **Detailed test program in Fermilab test beam** **Earliest in 2007**

IV Design of Hadron Calorimeter for ILC detector **Started**

Status of RPC R&D: expertise in hand

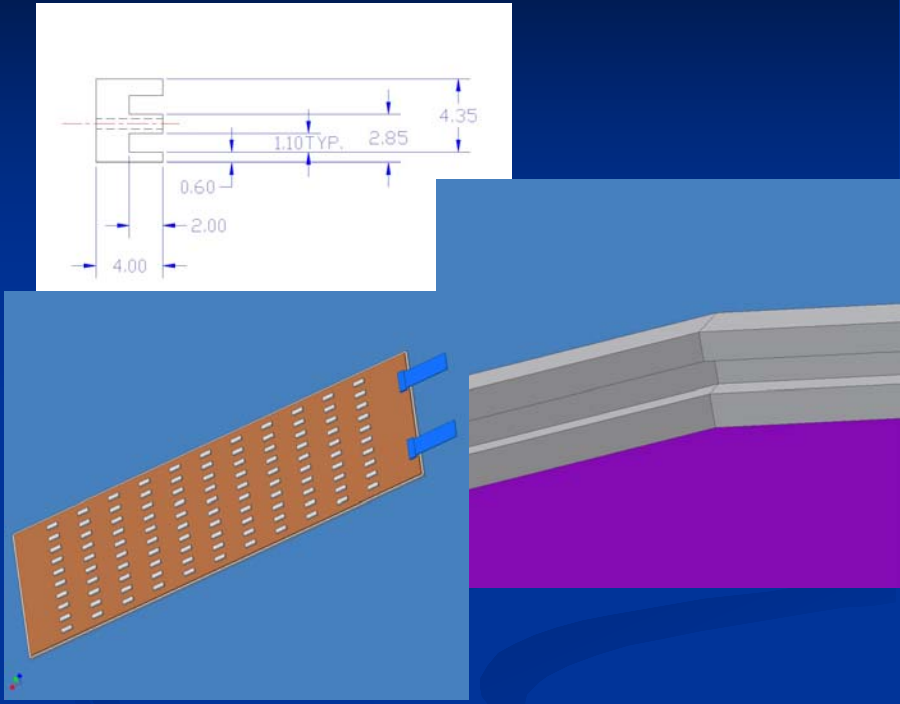
Measurement	RPC Russia	RPC US
Signal characterization	yes	yes
HV dependence	yes	yes
Single pad efficiencies	yes	yes
Geometrical efficiency	yes	yes
Tests with different gases	yes	yes
Mechanical properties	?	yes
Multipad efficiencies	yes	yes
Hit multiplicities	yes	yes
Noise rates	yes	yes
Rate capability	yes	yes
Tests in 5 T field	yes	no
Tests in particle beams	yes	yes
Long term tests	ongoing	ongoing
Design of larger chamber	yes	ongoing

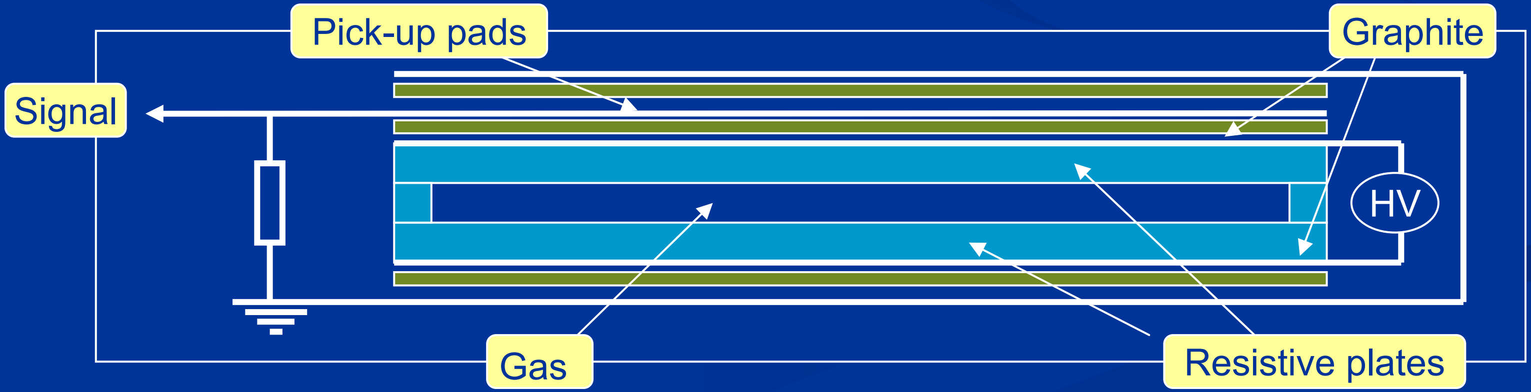


Virtually all R&D completed

Default RPC chamber designs for PS

Layer	Russia	US
Resistive layer anode	Anode readout pads	1 – 50 MΩ/□
Glass thickness in [mm]	0.55	1.1
Gas gap in [mm]	1.2	1.2
Glass thickness in [mm]	0.85	1.1
Resistive layer cathode	~1 MΩ/□	1 – 50 MΩ/□





Recent Tests in Fermilab's MT6 Test Beam

Iron blocks
(not used in most of our measurements)

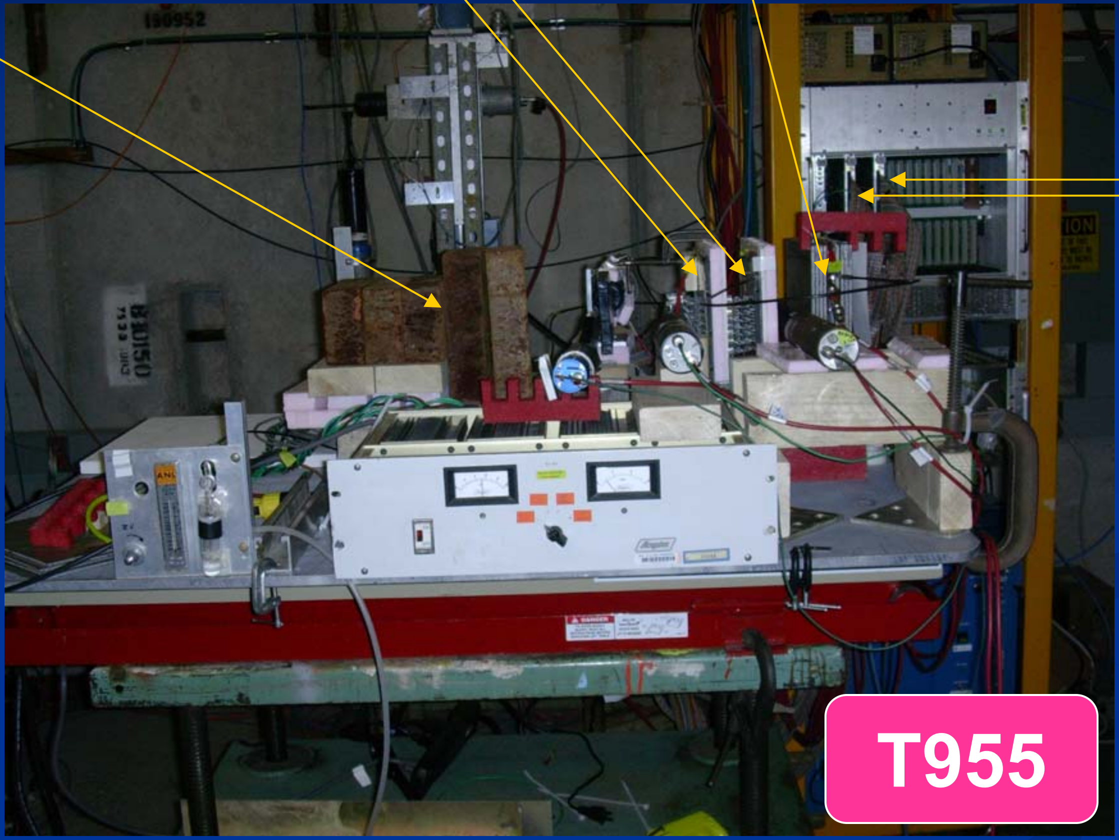
RPC 1 & 2
8x8 digital readout

RPC 3
4x8 shift-register readout

VME readout board 1 & 2

For RPC 1 & 2

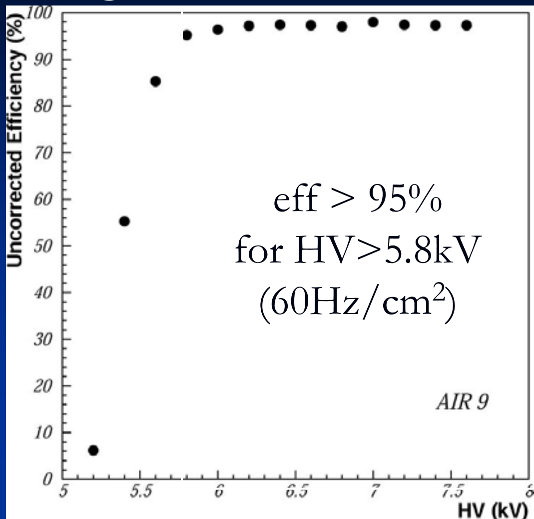
Beam direction

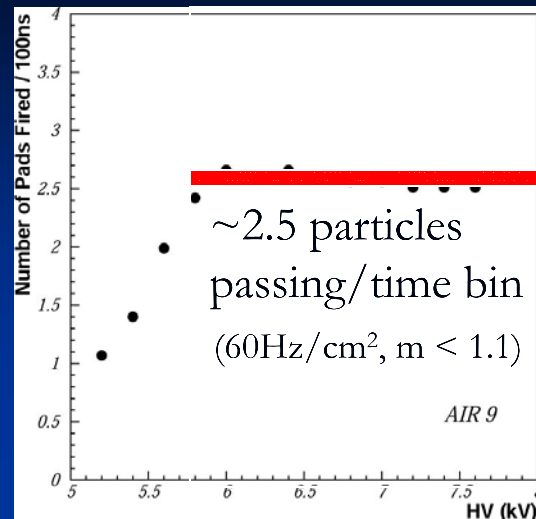


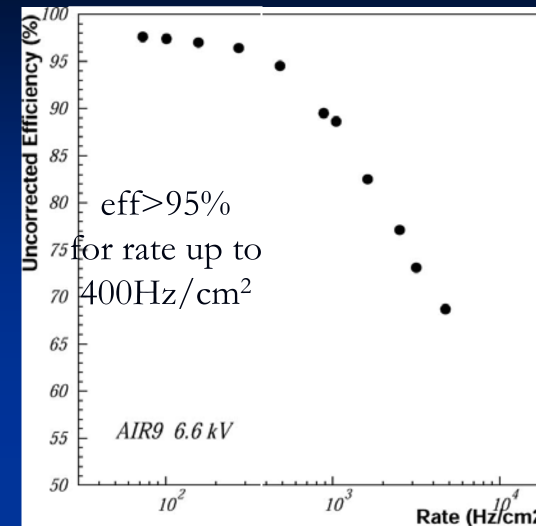
- Taken data with 120 GeV proton and 16 GeV pion, at beam intensity 70 – 5k Hz/cm^2
- Overall very positive experience

First look of the test beam data

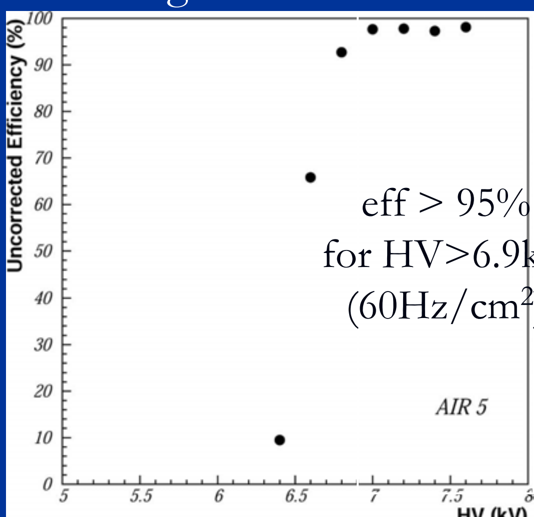
New design

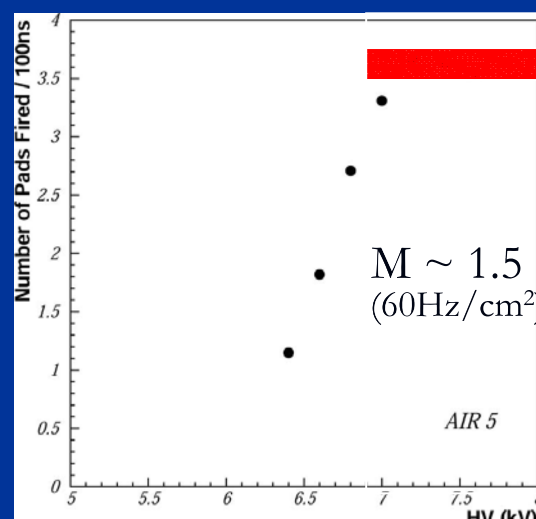


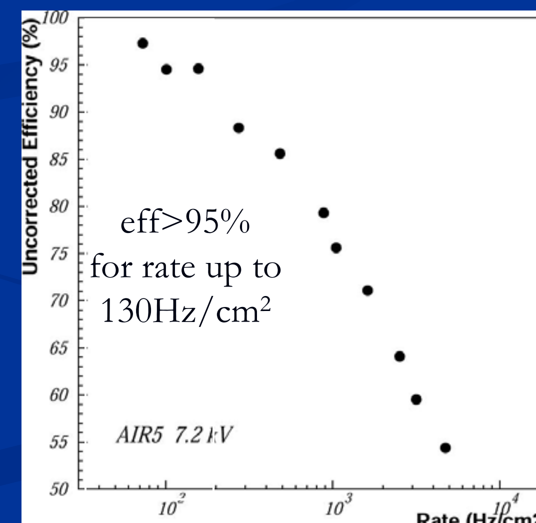




Baseline design







Efficiency: not corrected for multi-particle passing / time bin
(not a problem for nearly 100% efficient points)

Formal result will be available very soon …

Electronic Readout System for Prototype Section

400,000 readout channels

Conceptual Design of the Readout System is done
Specification of the system completed (Gary Drake, ANL)

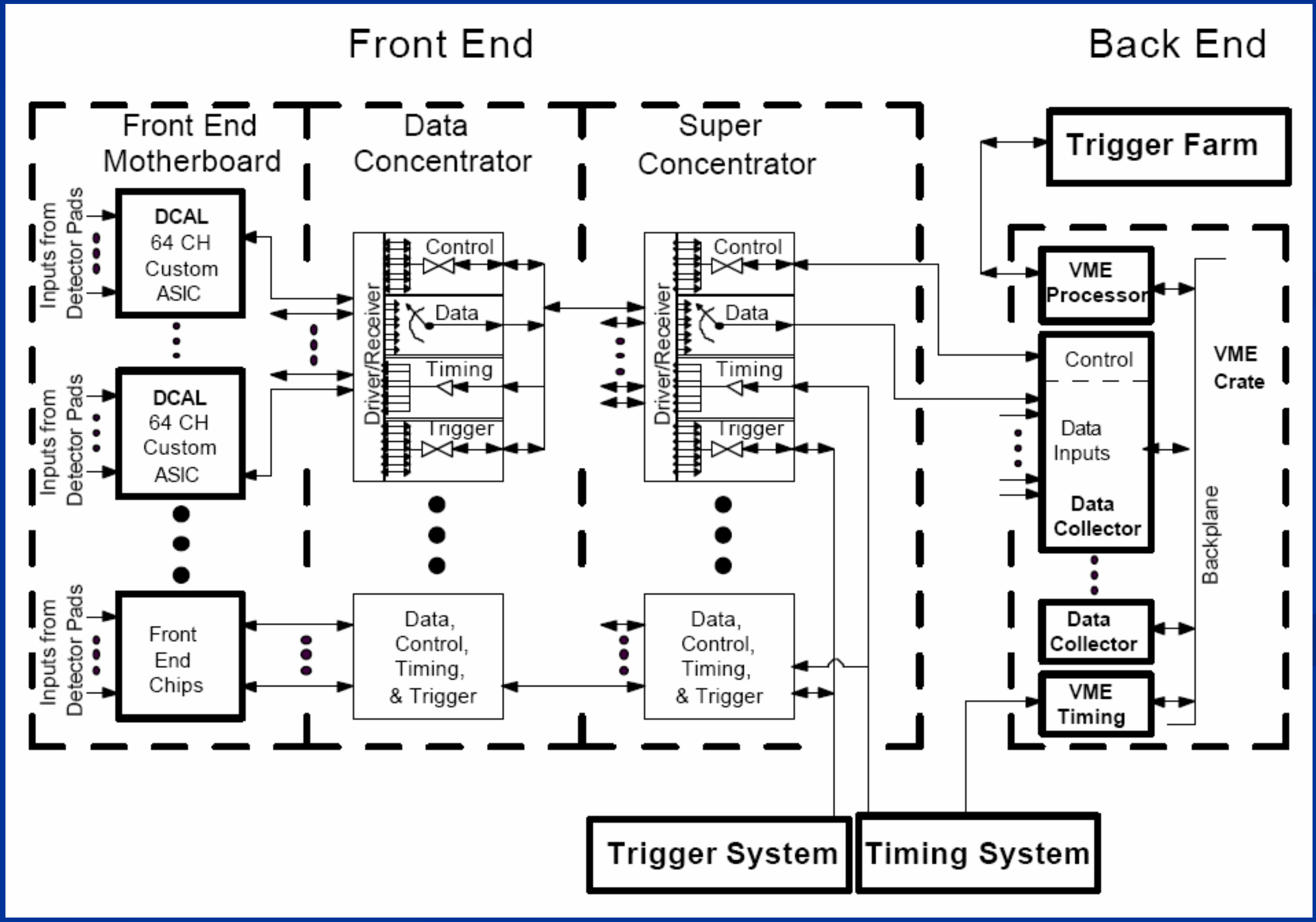
I Front-end ASIC and motherboard

II Data concentrator

III Super Concentrator

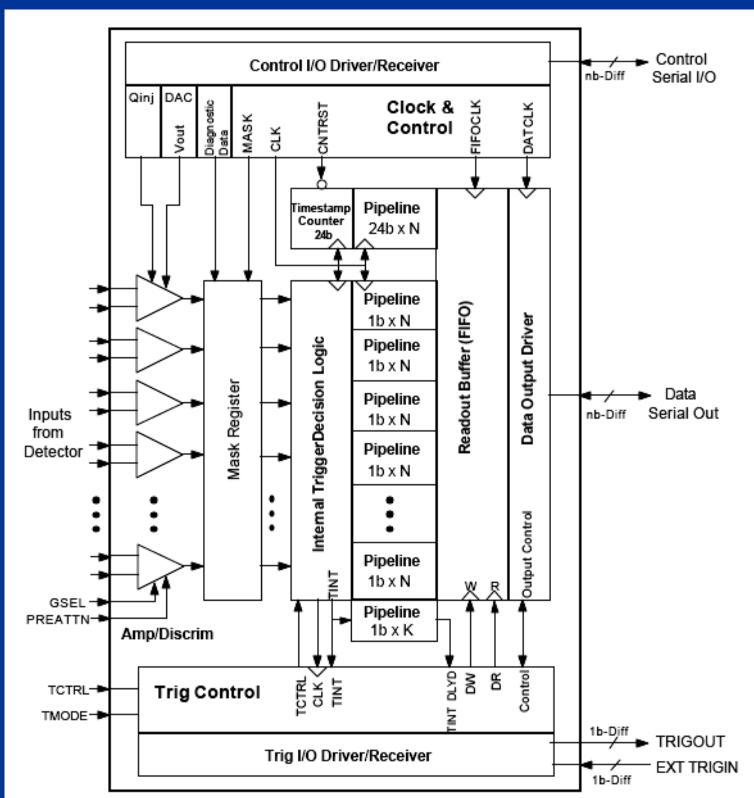
IV VME data collection

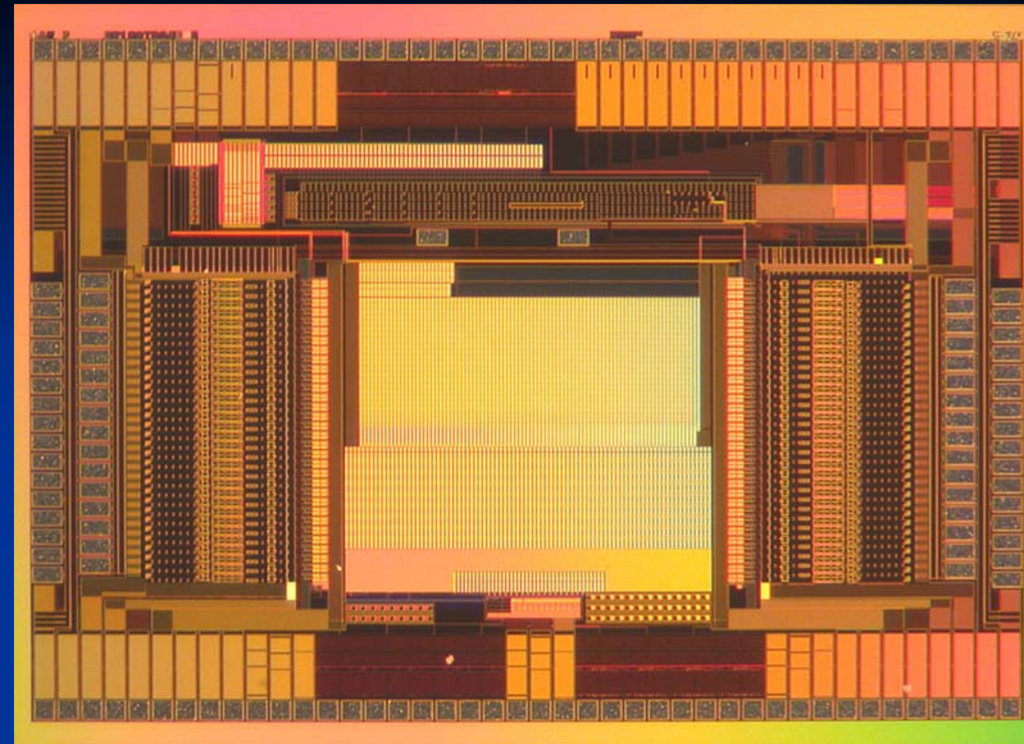
V Trigger and timing system



Front-end ASIC…

- 64 inputs with choice of input gains
  - RPCs (streamer and avalanche), GEMs…
- Triggerless or triggered operation
- 100 ns clock cycle
- Output: hit pattern and time stamp





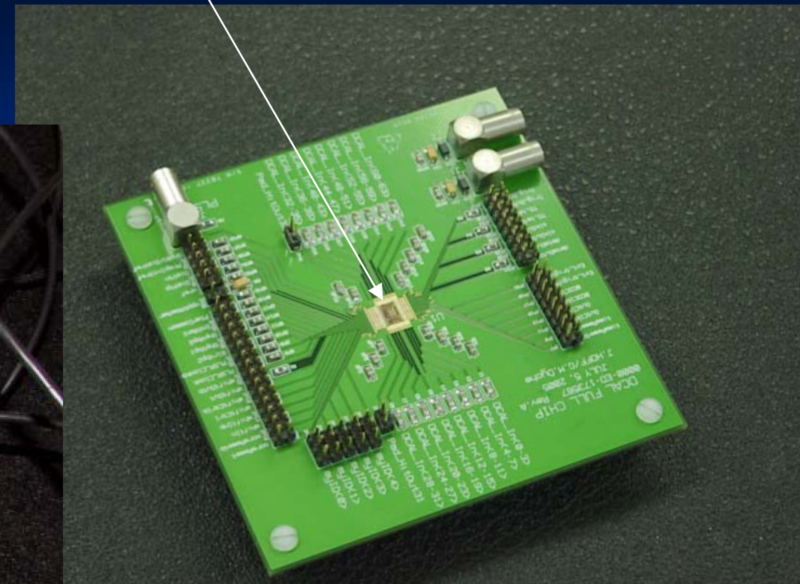
Abderrezak Mekkaoui
James Hoff
Ray Yarema

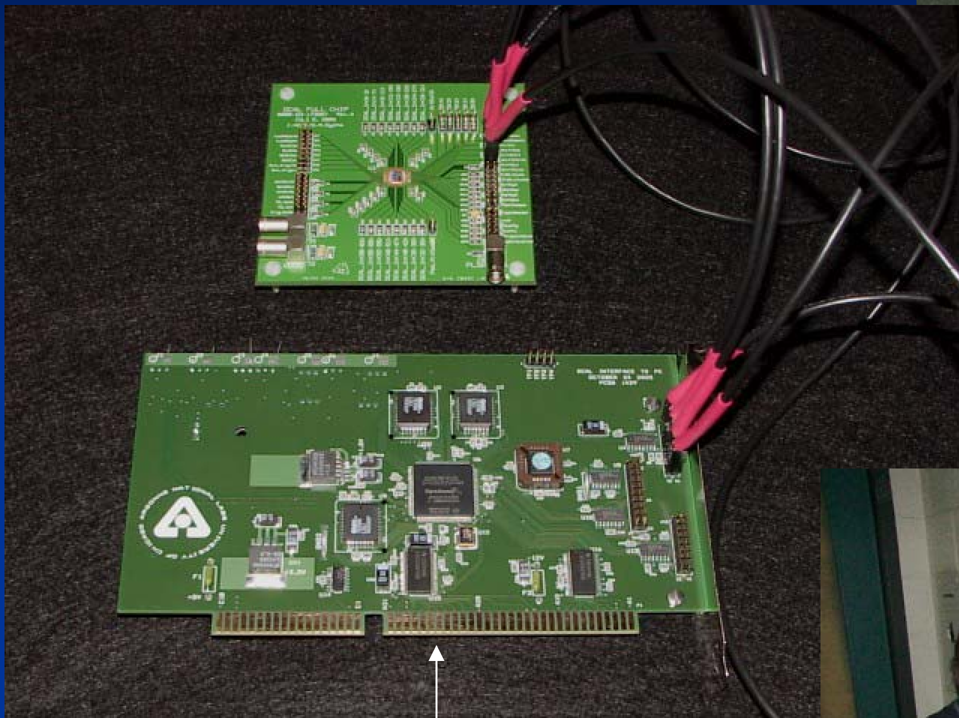
Design work at FNAL

- Design work started in June, 2004
- Prototype run submitted on March 18th 2005
- 40 unpackaged chips in hand
- Tests started…

Tests of ASIC at Argonne

Unpackaged chip housed on small test board





Built computer interface for test

Wrote software for automated tests

First Results

a) All digital functions seem operational

b) Detailed tests with injected charges
so far look good

2nd Iteration of ASIC Prototype

- Decrease of input sensitivity by x 10 – 20

  Currently upper threshold corresponds to 7.6 fC
  Smallest RPC signals ~ 100 fC
  Noise from digital lines ~ 11 fC (preliminary)

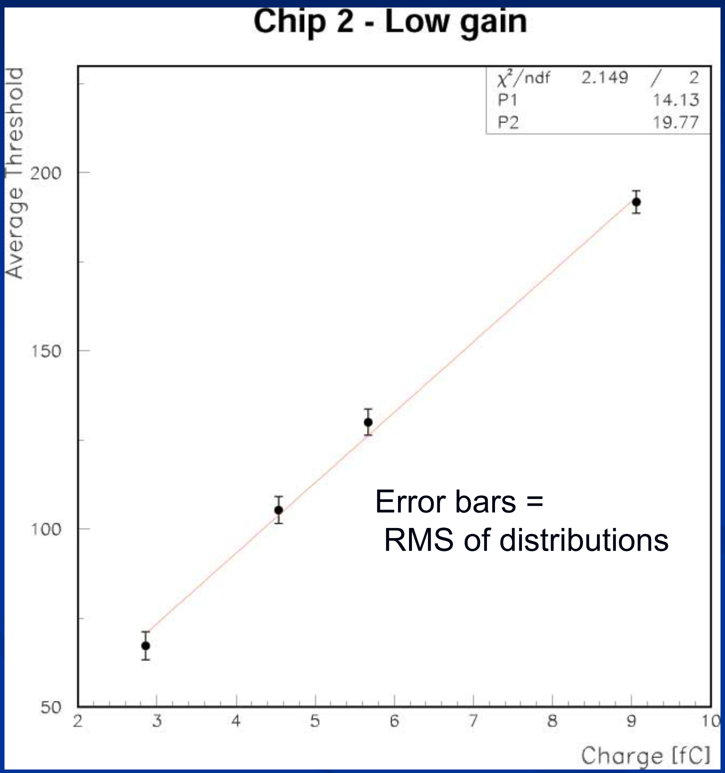
- Possibly decrease of serial line speed by x 10

  Currently 10 times faster than 10 MHz clock speed

- Other minor changes needed

- Submission on May 22nd

  Redesign will start in late March



Nice linear dependence!

Time scales

FY2006	Develop and test design of larger chambers
	ASICs: finalize design for production
	Design and prototype all subsystems
FY2007	Perform slice test of prototype section
	Produce chambers
	Produce ASICs
	Produce other subsystems
FY2007 or FY2008	Move to test beam
	Take data

This part
Is funded

Only possible with additional funding

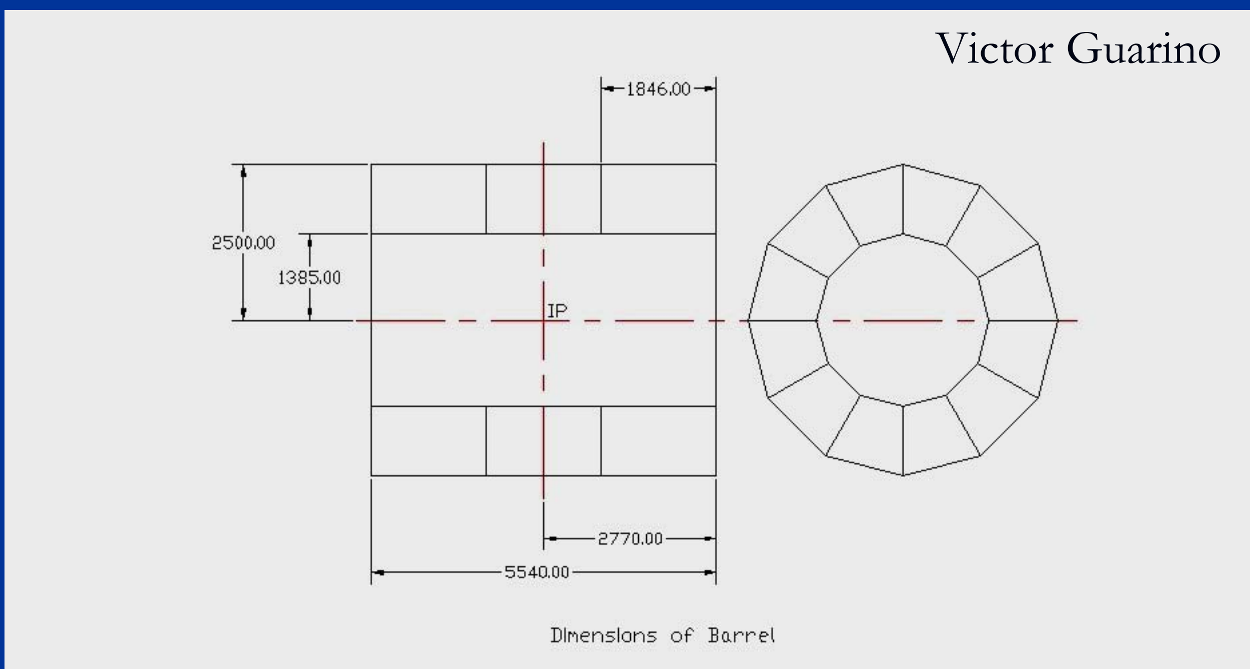
Mechanical Structure for ILC Detector

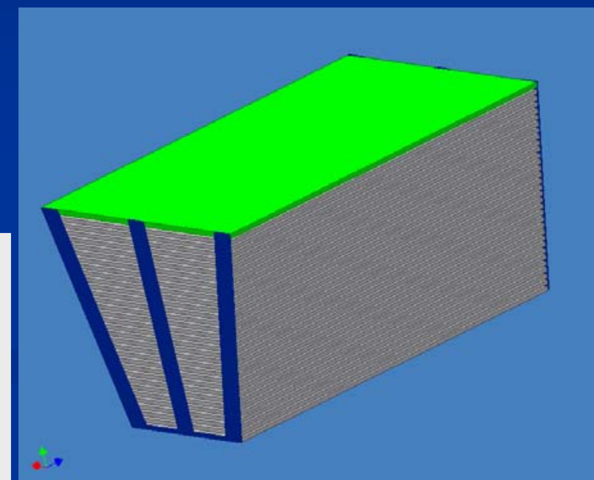
Initiated study in context of SiD concept

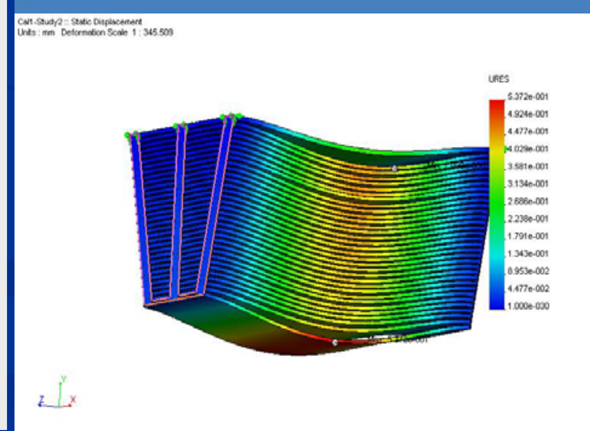
3 barrels in z

- to provide space for readout cables, gas supplies…
- to minimize deflections along z and for modules in 90^0 position

12 modules in ϕ







Conclusions

- Particle Flow Algorithms are being developed at Argonne
  - Deliver results approaching ILC goal
  - Will be used for ILC detector optimization

- Digital Hadron Calorimetry with extremely fine granularity is a

great, novel, revolutionary and untested idea

- RPCs as active medium for a DHCAL have been developed
- Conceptual design of the electronic readout system exists and system is being designed and prototyped

Funding permitting, we will make a great contribution to the

understanding of hadronic showers

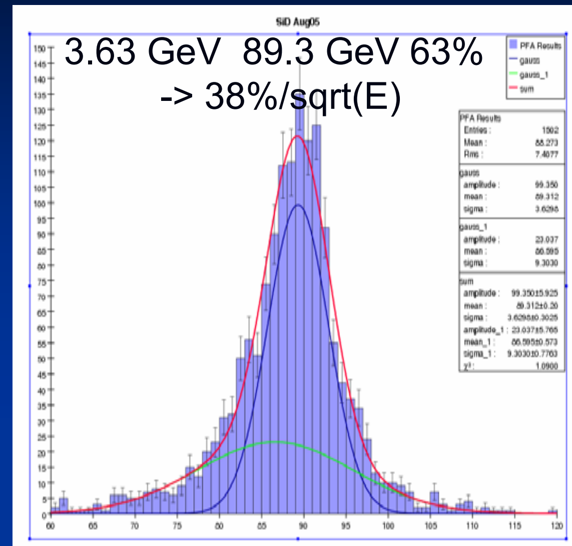
and build a basis for

designing the ILC detectors

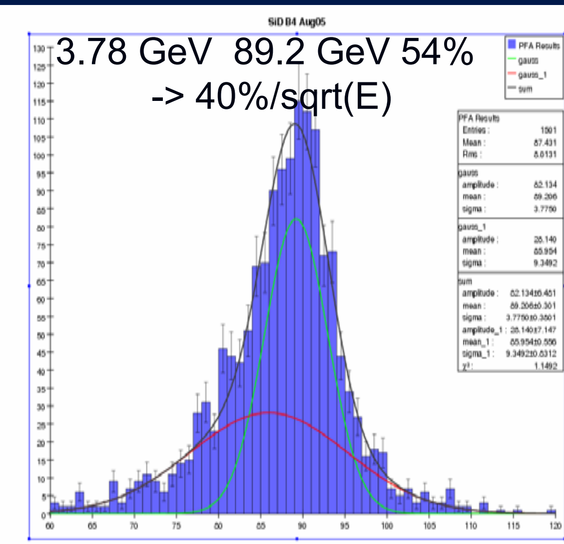
Backup slides

PFA development: recent results

- Detector comparison using PFA has just started



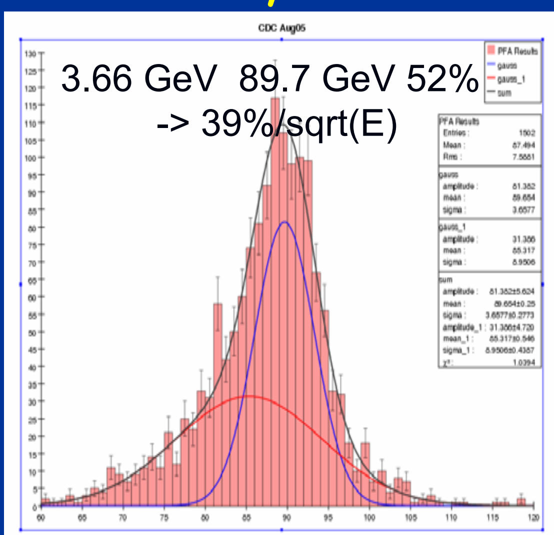
SiD SS/RPC - 5 T field



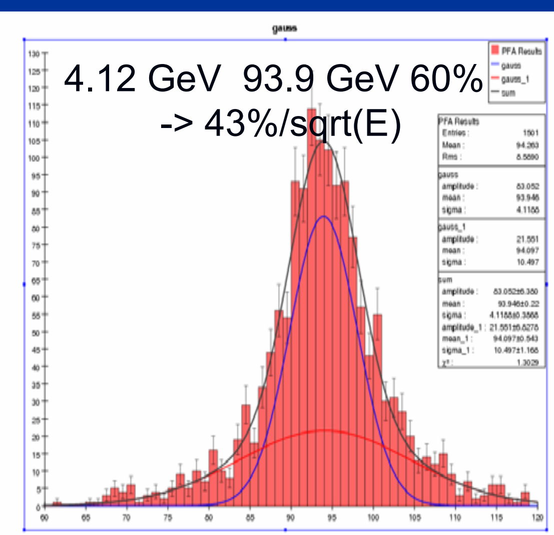
SiD SS/RPC - 4 T field

Vary B-field

Vary CAL inner radius



CDC W/Scin – CAL IR ~ 125 cm



CDC W/Scin – CAL IR ~ 150 cm

Front-end Board

Houses ASICs (24)
Provides readout pads for RPCs
Routes output signals (LVDS) to receivers

Data Concentrator

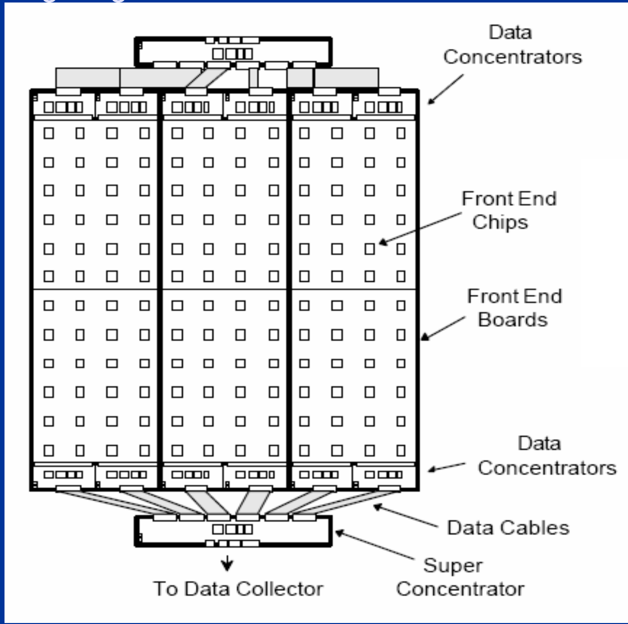
Read out 12 ASICs (serial lines)
Can buffer events
Distribution of trigger and timing

Super Concentrator

Introduced by urge to reduce cost of back-end
Reads out 6 data concentrators

Data Collector

VME based system (7 cards and 1 VME crate)
Each card reads out 12 super concentrator
investigating alternatives



1	Overall engineering and design	**ANL**
2	ASIC engineering and design	**FNAL**
3	ASIC testing Test board design Test board production Measurements	ANL **FNAL**
4	Front-end PC board engineering and design prototyping and testing	**ANL** **FNAL**
5	Data concentrator engineering and design prototyping and testing	ANL Chicago
6	Data super concentrator engineering and design prototyping and testing	ANL Chicago
7	Data collector engineering and design prototyping and testing	ANL Boston
8	DAQ system: VME processor and programming	**Washington**
9	Timing and trigger system engineering and design prototyping and testing	**UTA**
10	High voltage system	**Iowa**
11	Gas mixing and distribution system	**Iowa**
12	Chamber construction	ANL Regina Russia

Cost estimate for PS (M&S only)

Item	Cost	Contingency	Total
RPC chambers	20,000	7,000	27,000
FE-ASICs	208,000	11,600	219,600
FE-boards	110,000	55,000	165,000
Data concentrators	106,000	53,000	159,000
Super concentrators	25,000	12,500	37,500
Data collectors including crates…	51,500	19,250	70,750
HV and LV supplies, gas system, cables…	132,500	45,750	178,250
Total	653,000 +	204,100 =	857,100

Probably Not needed

Recent Proposals to Funding Agencies…

Agency	Institutes	Request	Award
LDRD (ANL directorate) used for manpower mostly	ANL	400,000	150,000
LCRD (DOE)	ANL, Boston, Chicago, Iowa	105,000	?
U of C Collaborative Grants	ANL, Chicago	50,000	?
US-Japan	ANL	50,000	0
MRI DHCAL prototypes	UTA	798,000	?