A Digital Hadron Calorimeter with Resistive Plate Chambers

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LCD Study Group Meeting
(by phone)
February 3, 2005

Outline

I	Hadron calorimeter for the ILC detector
II	What are RPCs?
III	Adapting RPCs to calorimetry with fine granularity
IV	The big plan: 1 m^3 prototype section
V	Electronic readout system
VI	Collaboration building and proposals
VII	Test beams
VIII	Time scale
IX	Conclusions

I Hadron Calorimeter for the ILC Detector

Particle Flow Algorithms…

Particles in jets	Fraction of energy	Detector	Resolution [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with 15%/$\sqrt{E}$	$0.07^2\ E_{jet}$
Neutral Hadrons	10 %	ECAL + HCAL with 50%/$\sqrt{E}$	$0.16^2\ E_{jet}$
Confusion	Required for 30%/$\sqrt{E_{jet}}$		**≤ $0.24^2\ E_{jet}$**

Requirements on hadron calorimeter and active medium

Good single particle energy resolution (not much worse than 50%/$\sqrt{E}$)
Extremely fine granularity (to separate different components of jets)
Inside the B-field (coil (corresponding to ~ 1 λ_I) spoils energy measurement)
Fit into gap of no more than 10 mm
Low noise
Reliable technology (has to last at least 10 years)
Recharge time after hit not more than about 0.1 seconds
Affordable (whatever that means these days)

Expected rates…

Assume $\mathcal{L}_{LC}$ = 0.5x10^{34} cm^{-2}s^{-1} = 0.5x10^{-2} pb^{-1}s^{-1}

$\sigma_{1\gamma}$(500 GeV) = 4 pb → **N/s = 0.02** **Easy**

$$\sigma_{e^+e^-\to e^+e^-l^+l^-} = \frac{28\alpha^4}{27\pi m_l^2}\left(\ln\frac{s}{m_e^2}\right)^2 \ln\frac{s}{m_l^2}$$

From V M Budnev et al.
Phys. Lett. 15(1974) 181-282

$\sigma_{2\gamma\to ee}$(800 GeV) = 34 mb → **N/s = 170x10^6** **Not an HCAL problem**

$\sigma_{2\gamma\to\mu\mu}$(800 GeV) = 473 nb → **N/s = 2400** **OK**

$$\sigma_{e^+e^-\to e^+e^-h} = \frac{\alpha^4}{18\pi^2 m_\pi^2}\ln\frac{s m_\rho^2}{m_e^2 m_\pi^2}\ln\frac{s m_\rho^6}{m_e^6 m_\pi^2}\left(\ln\frac{s}{m_\pi^2}\right)^2$$

$\sigma_{2\gamma\to h}$(800 GeV) = 189 nb → **N/s = 945** **???**

PYTHIA simulations

MSTP(14)=10

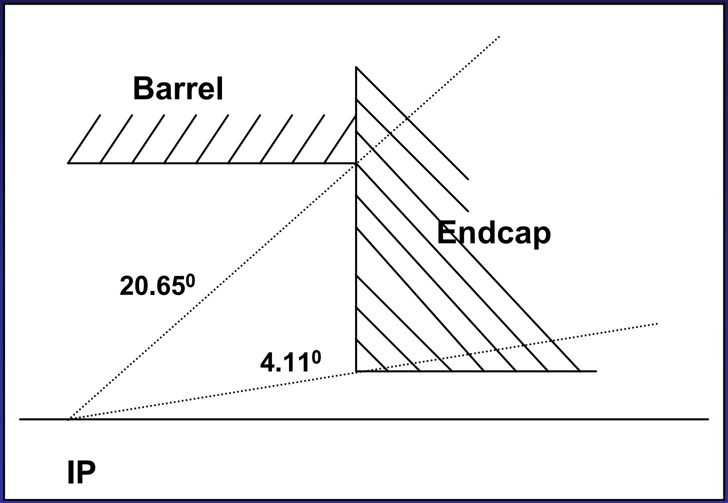
Mix of VMD, direct and anomalous component

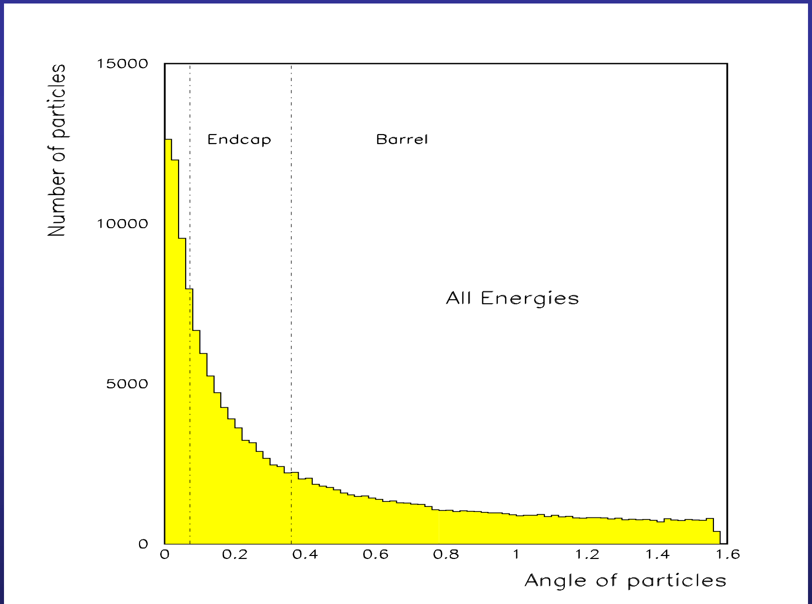
$\sigma_{2\gamma\to h}$ (800 GeV) = 43.41 nb

???

Used TESLA geometry

4T magnetic field





Particle rates

Beam pipe	**24.1 %**	**<E> = 15.7 GeV**
Endcaps	**75.8 %**	**<E> = 1.53 GeV**

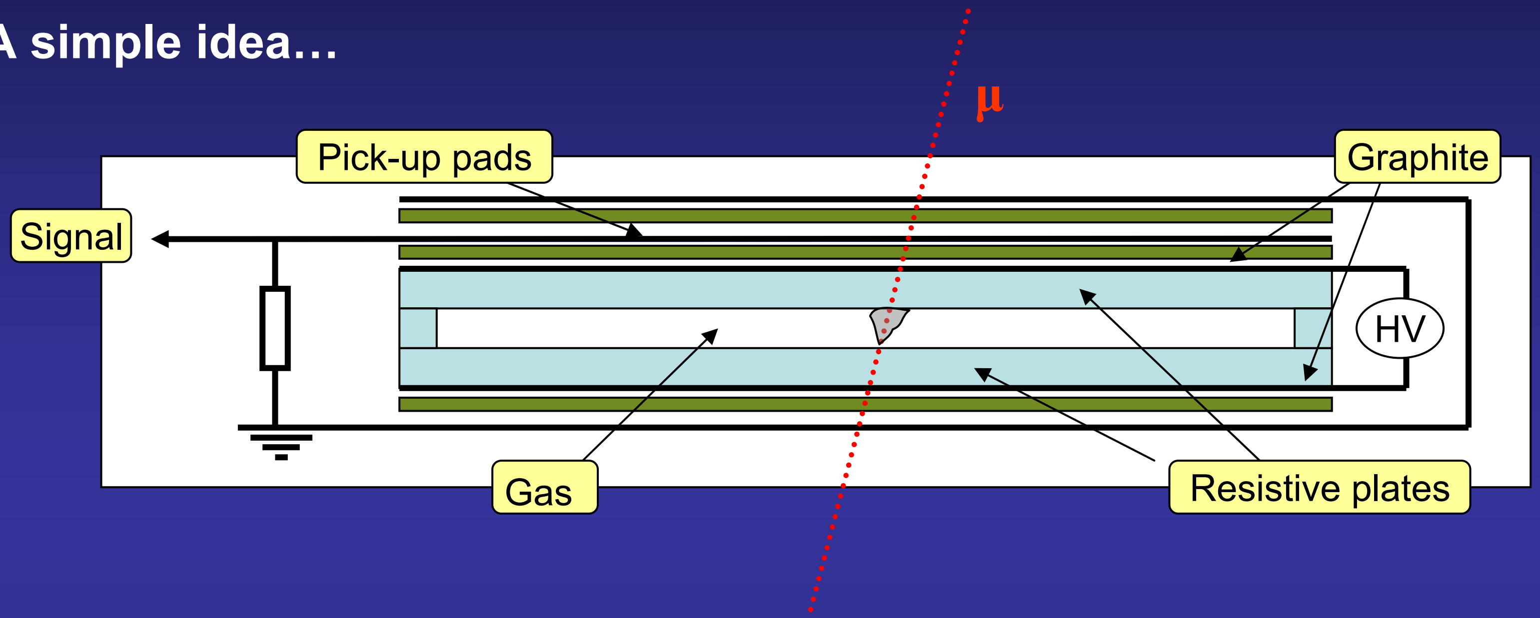
Rate/endcap = 613 Hz
283 Hz (E> 1GeV)

Barrel	**0.06 %**	**<E> = 5.0 GeV**

Need τ_{dead} < 0.1 seconds

II Resistive Plate Chambers

A simple idea…



A few facts about RPCs…

Resistive plates

- Bakelite
  - Needs to be coated (linseed oil)
  - Lower bulk resistivity → higher rate capability
  - Sensitive to T, humidity
  - Ageing problems
- Glass
  - No coating needed
  - Higher bulk resistivity → lower rate capability
  - Not sensitive to humidity
  - Small sensitivity to T
  - No ageing ever observed
  - Cheap

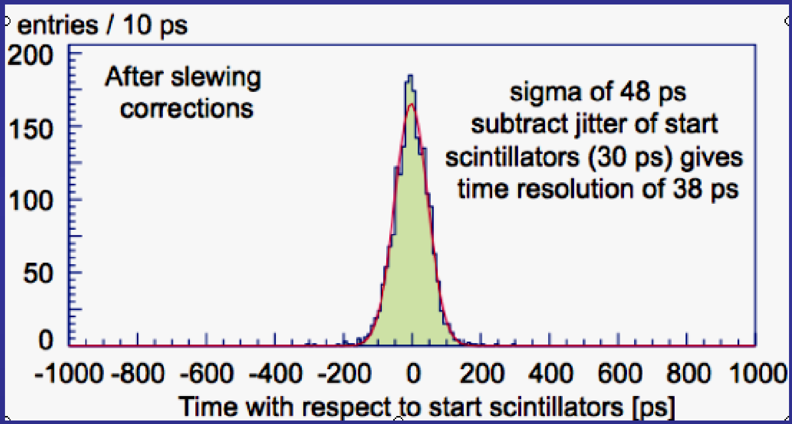
Unless you need the rate capability stay away from Bakelite

Operational mode

Avalanche
- At lower high voltage
- Big signals of $O(0.1 – 10\ pC)$
- Might need pre-amplification of signals
- Higher rate capability of $O(100\ Hz/cm^2)$

Streamer
- At higher high voltage
- Huge signal of $O(1 – 50\ pC)$
- Lower rate capability of $O(\text{few}\ Hz/cm^2)$
- More prone to ageing effects

No reason to work in streamer mode



No reason for multi-gap RPCs for the LC hadron calorimeter

Number of gas gaps

One
- Larger signal charge
- Ease of construction
- Lower cross talk into neighboring pick-up pads

Multiple
- Smaller signal charge for same overall gap size
- More intricate assembly procedure
- higher cross talk into neighboring pick-up pads
- Used for timing RPCs with resolution of $O(50\ ps)$

Resistivity of graphite

- Low
  - Shorter dead time
  - Wider area of induction onto pick-up pads (cross-talk)
- High
  - Longer recharging time of *O*(10 ms) in avalanche mode
  - Smaller hit-multiplicity

Rate capability with high resistivity graphite OK for LC

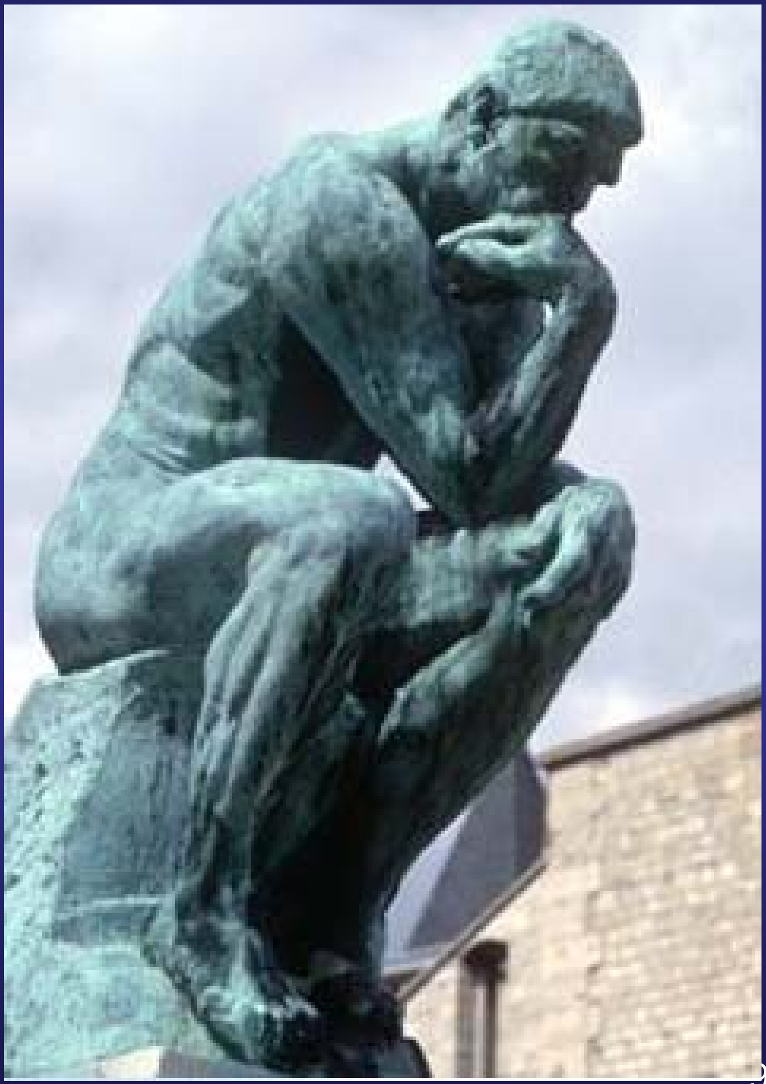
RPCs in HEP experiments and Astrophysics

- ALICE x2
- ATLAS
- BaBar
- Belle
- CMS
- HARP
- ~~LHCb~~
- L3
- OPERA
- STAR
- ARGO-YBJ

III Adapting RPCs to Hadron Calorimetry

Things to worry about…

Best design
Signal characterization
Signal charge measurements
Single particle efficiency
Noise rate
Mechanical stability
Optimal gas mixture
Hit multiplicity
Rate capability
Operation in B-field
Long term stability
Sensitivity to outlyers



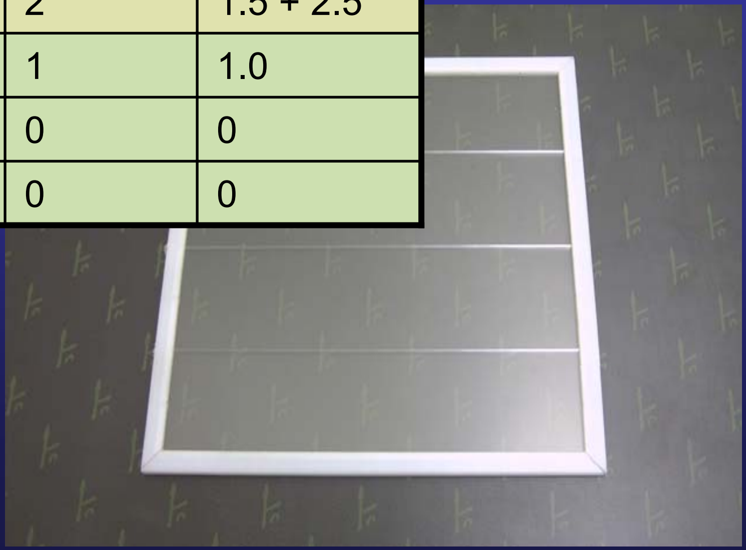
Best design…

Chambers built and tested at Argonne

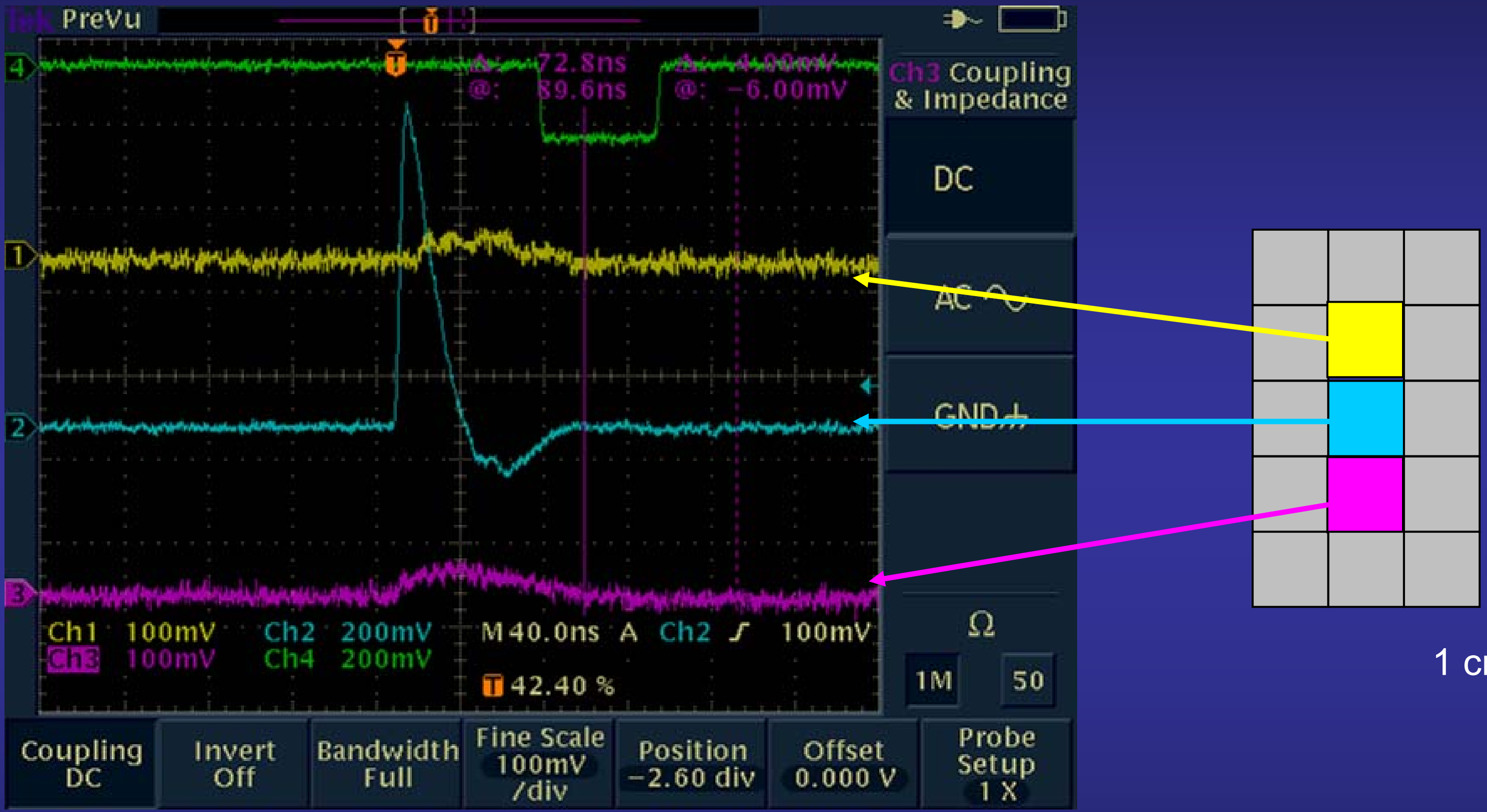
Name	Area [cm²]	# of gas gaps	# of glass plates	Glass thickness [mm]	Thickness of chamber [mm]	# of Graphite layers	Surface resistivity [MΩ/□]
Air0	20 x 20	2	3	0.85	3.75	2	0.3
Air1	20 x 20	2	3	1.1	4.50	2	0.2
Air2	20 x 20	2	3	1.1	4.50	2	1.2
Air3	20 x 20	1	2	1.1	3.40	2	1.0
Air4	20 x 20	1	2	1.1	3.40	2	1.0 + 50
Air5	20 x 20	1	2	0.85	2.90	2	1.5 + 2.4
Air6	30 x 91	1	2	1.1	3.40	2	1.5 + 2.5
Air7	20 x 20	1	2	1.1	3.40	1	1.0
Air8	20 x 20	1	2	1.1	3.40	0	0
Air9	20 x 20	1	1	1.1	2.30	0	0

Default design

Add ~3.00 mm for front-end readout board and ASIC



Signal Characterization…



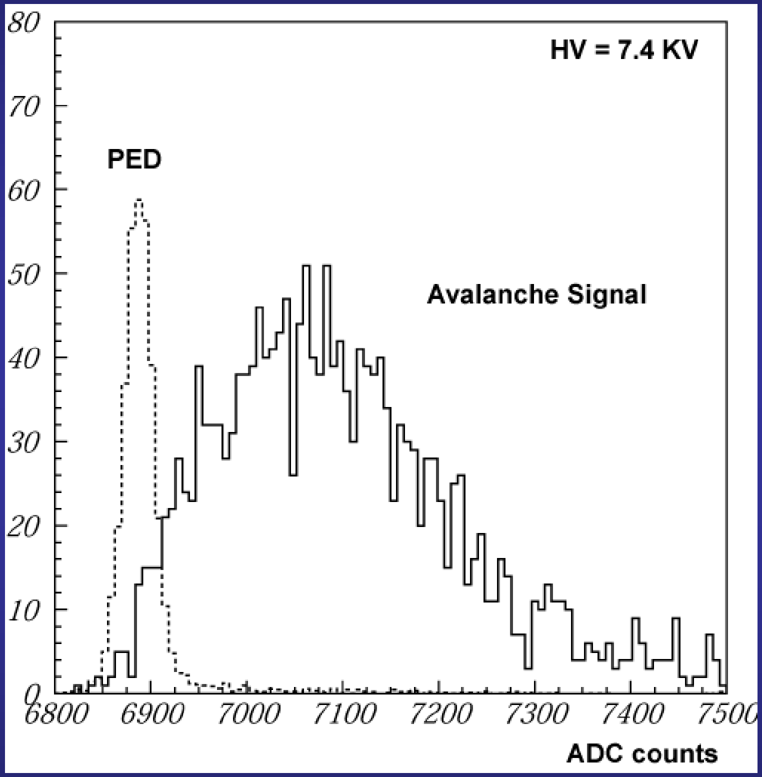
1 cm^2 pads

Studies with digital scope

Charge and timing characteristics
Signals on neighboring pads

Signal Charge Measurements…

Measured with RABBIT system

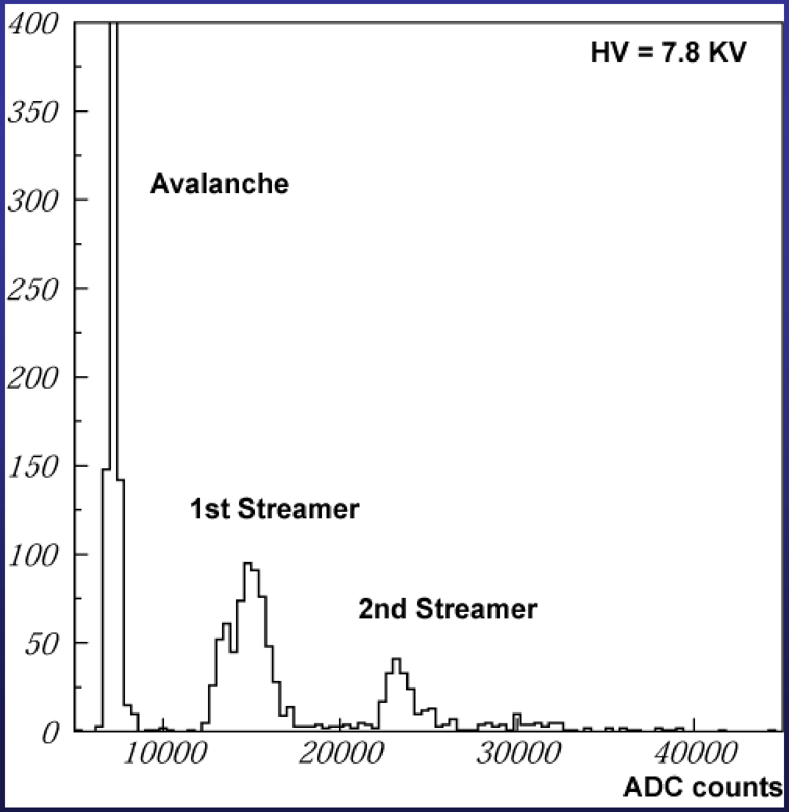


Avalanche signals

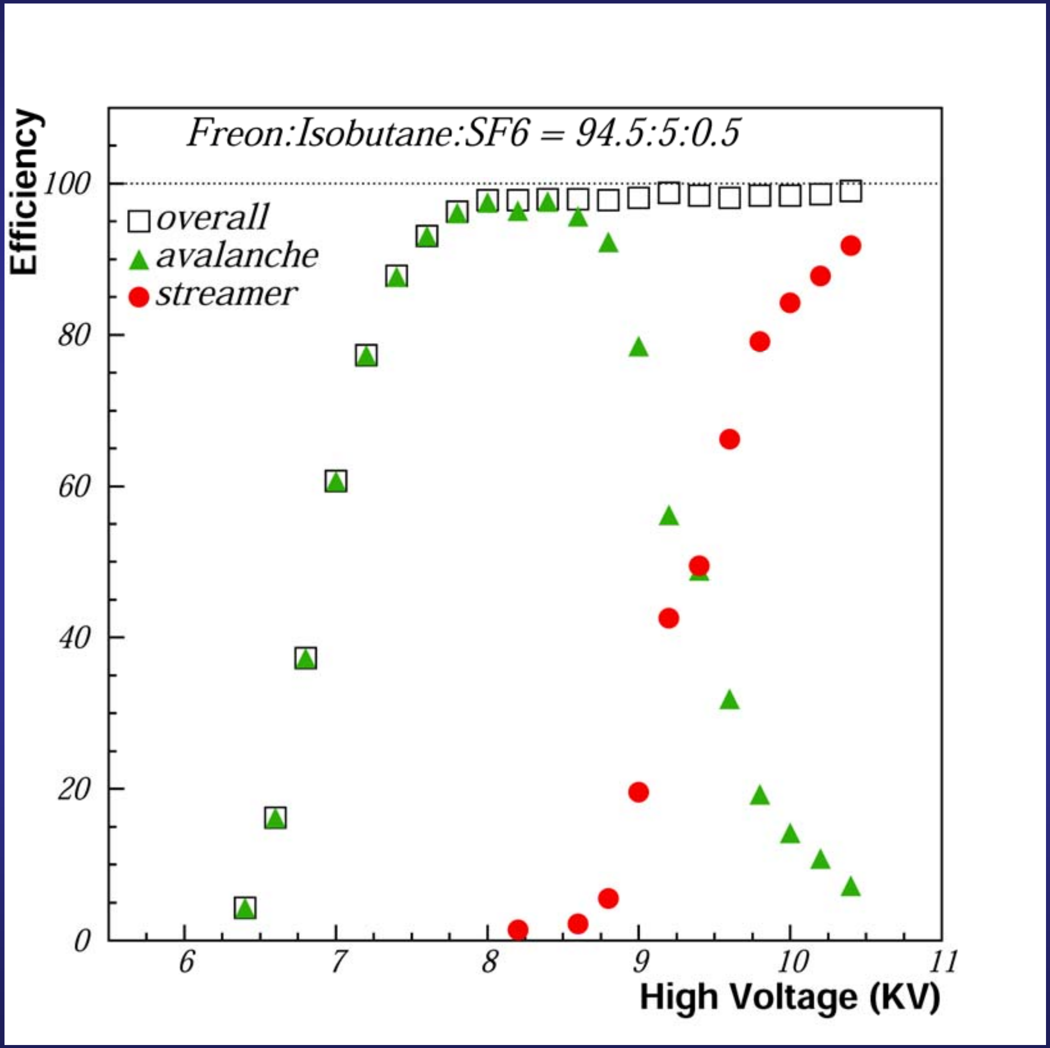
In broad range of charges
Analog information ~useless

Streamer signals

Well defined charge
Multiple streamers
Avalanches always present



Single Particle Efficiency…



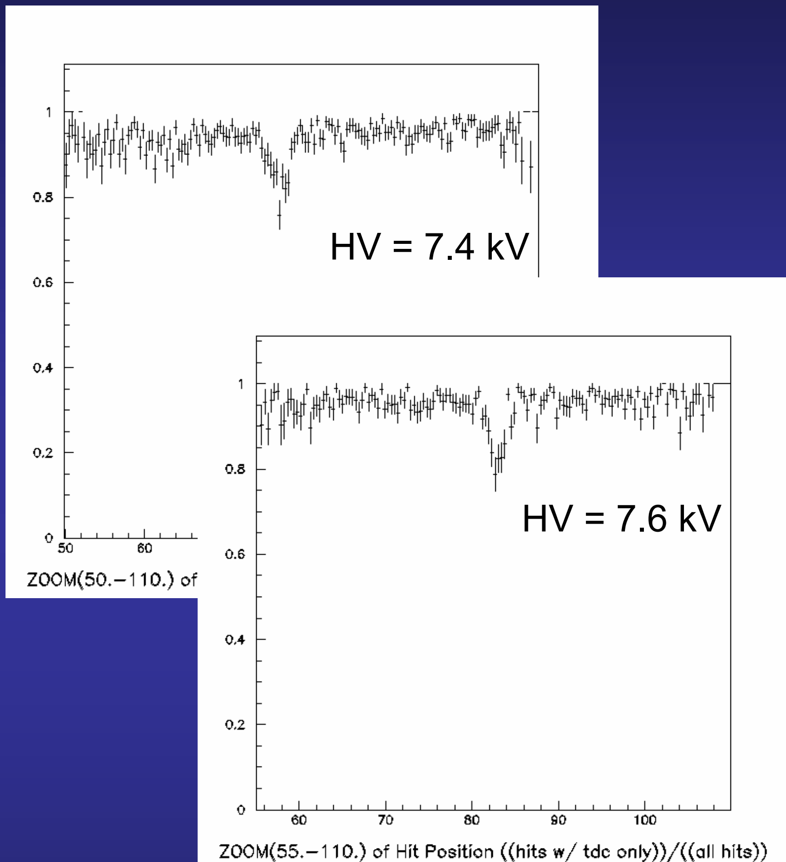
Plateau of ~ 1kV, where

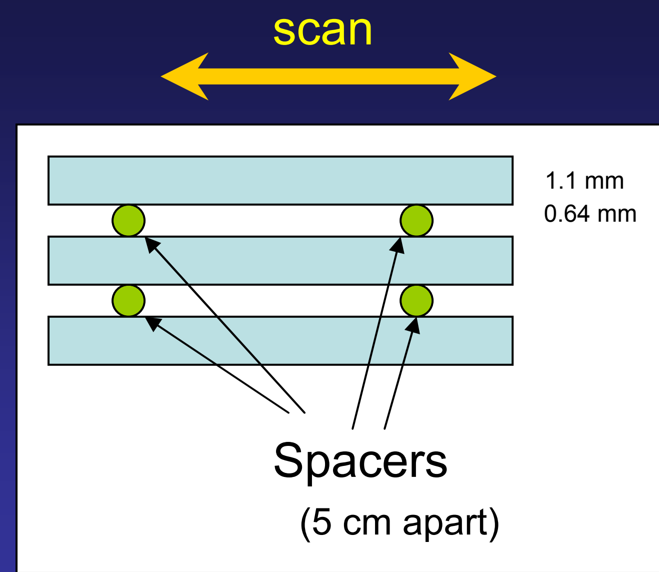
Efficiency > 95%
Fraction of streamers < few %

Overall efficiency

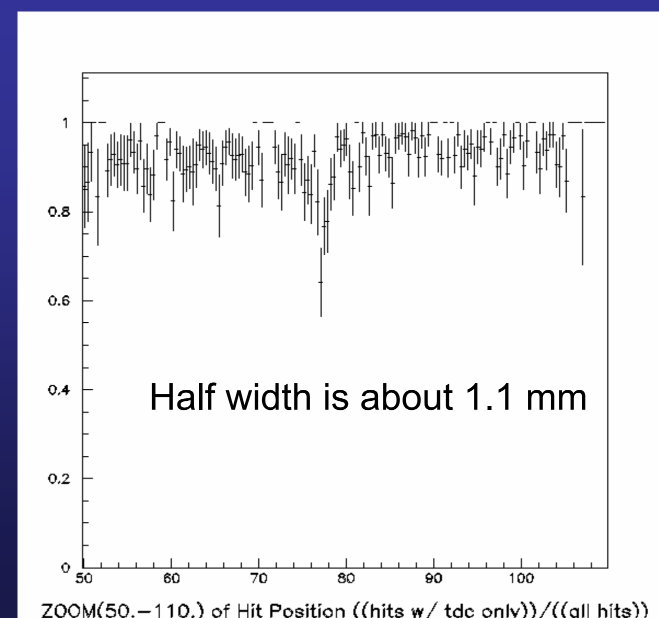
Close to 100%
Loss of efficiency at fishing line

Geometrical Efficiency…





Select vertical tracks only

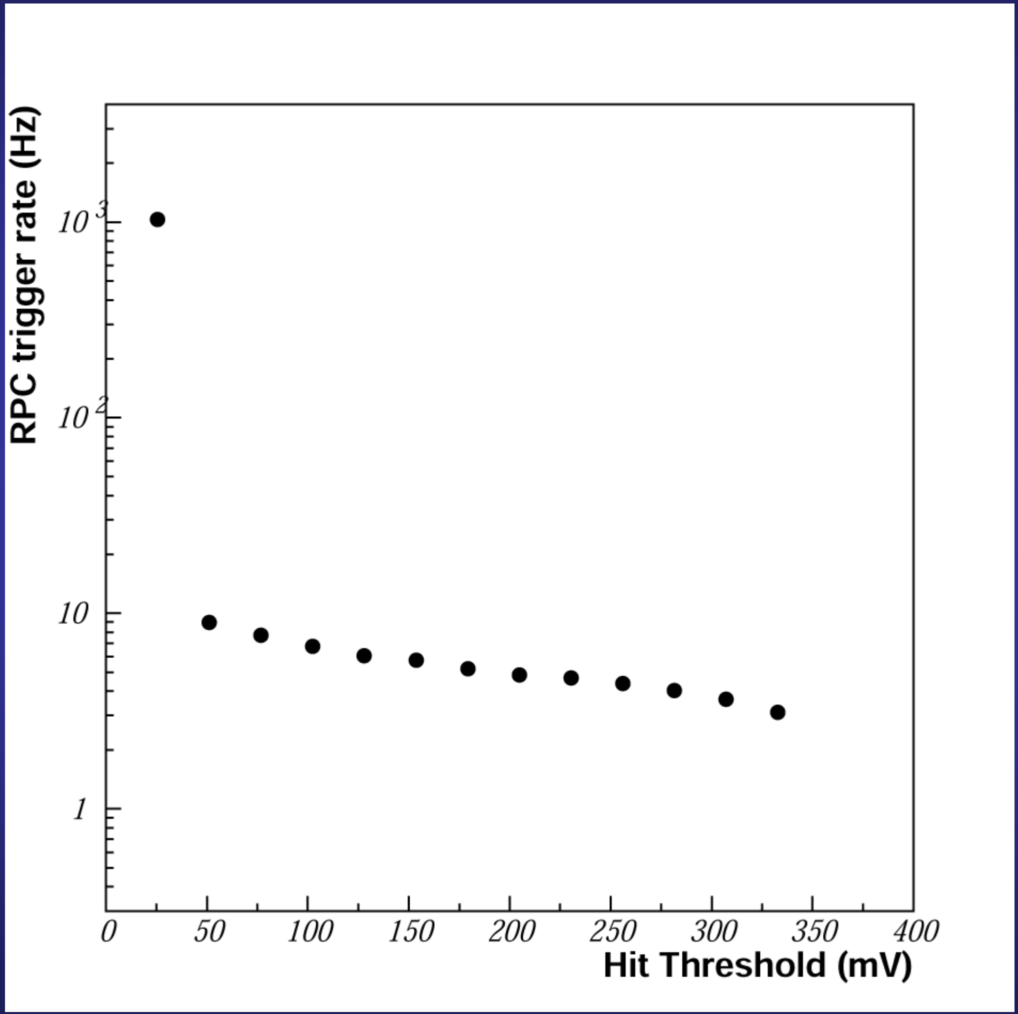


Half width about 1.8 mm

$\not\epsilon$ ~ 15% x 2 mm = 30% mm = 100% x 0.30 mm

Spacer Ø is 0.64 mm

Noise Rate…



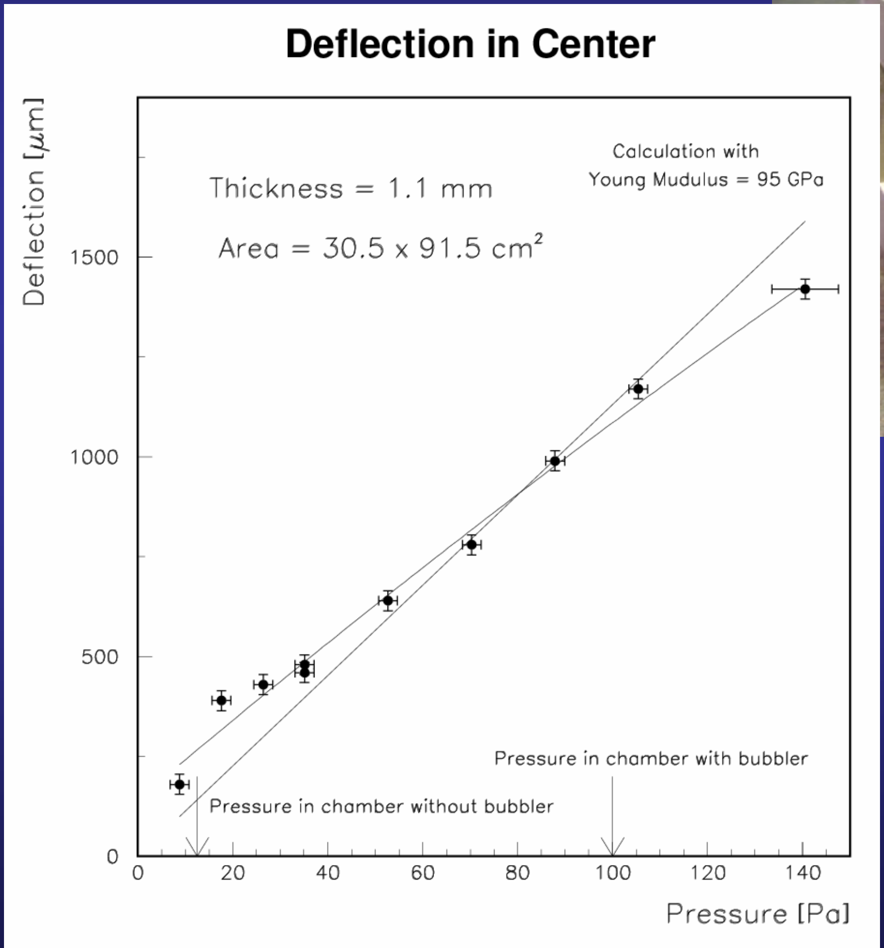
Measured with discriminators

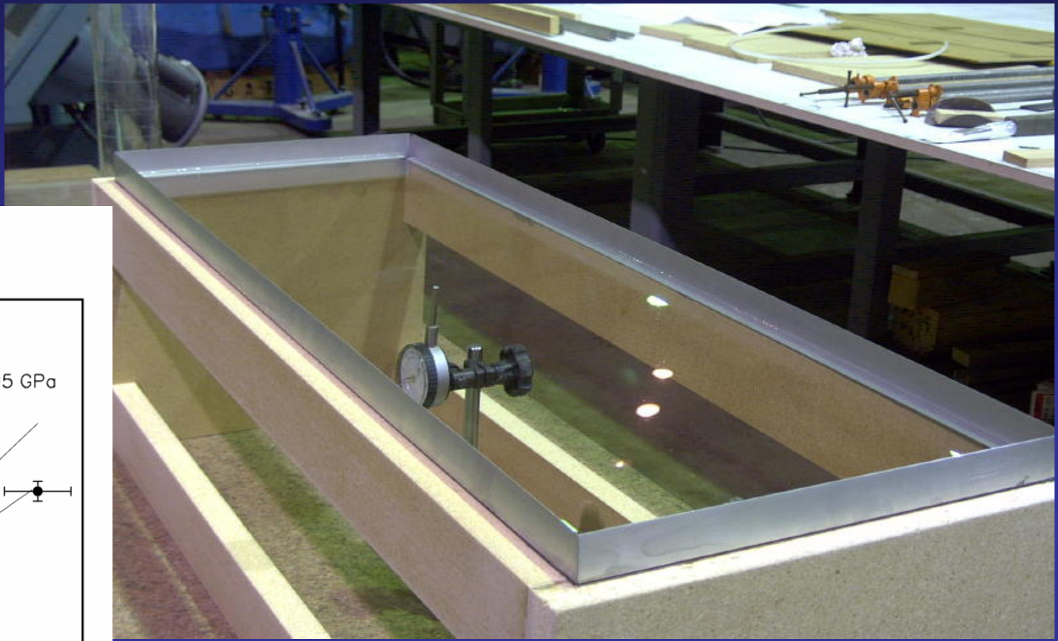
- 64 1 cm^2 pads

Noise rate

- ~0.1 Hz per pad

Mechanical Stability…





Pressure emulated with H_2O

Significant deflections

In agreement with calculations

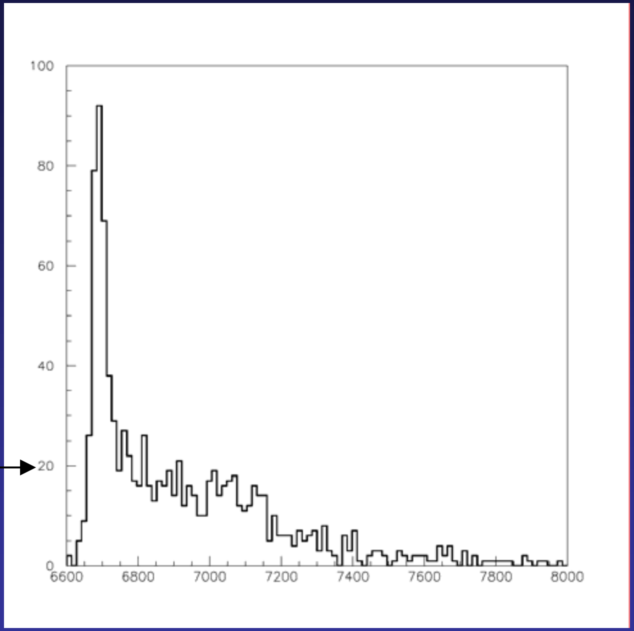
Gas pressure < Electric force from HV

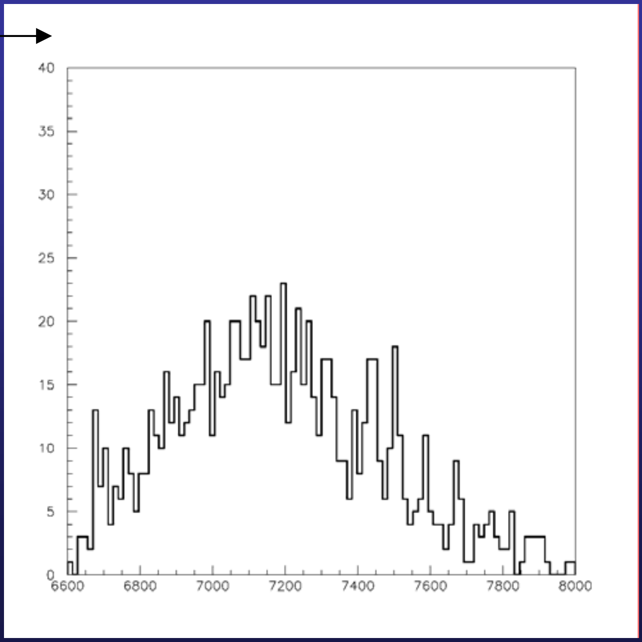
Optimal Gas Mixture…

Gas	Percentages	Saturated avalanches	Signal sizes
Ar : IB : SF_6	90 → 52 : 8 : 2 → 40	No	
C_3F_8	100	No	
Freon : IB : Ar	62 : 8 : 30	Yes	Small
Freon : IB : SF_6	94.5 : 5 : 0.5	Yes	Large

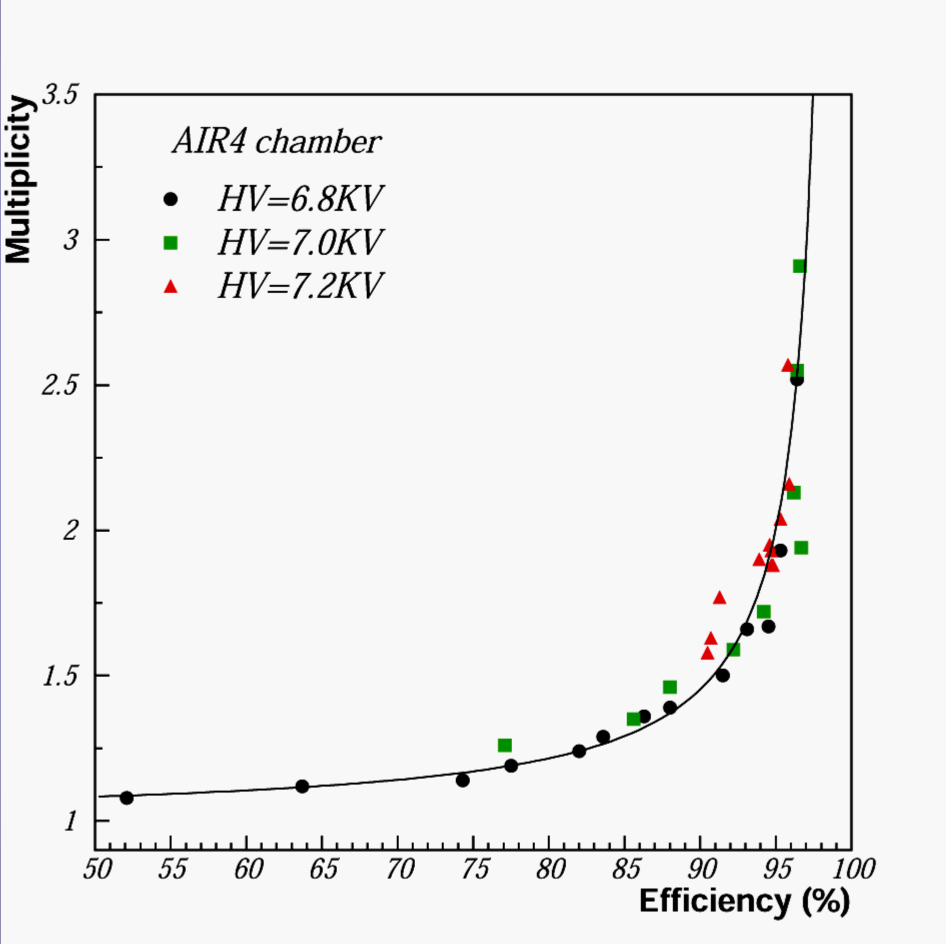
Default gas mixture

Mixtures with > 8 % IB are flammable





Hit Multiplicity…



Measurements

Using VME – based digital RO system
64 channels

Hit multiplicity

1.6 – 1.7 for efficiency = 95 %
1.4 – 1.5 for efficiency = 90 %

No strong dependence on HV

Rate Capability…

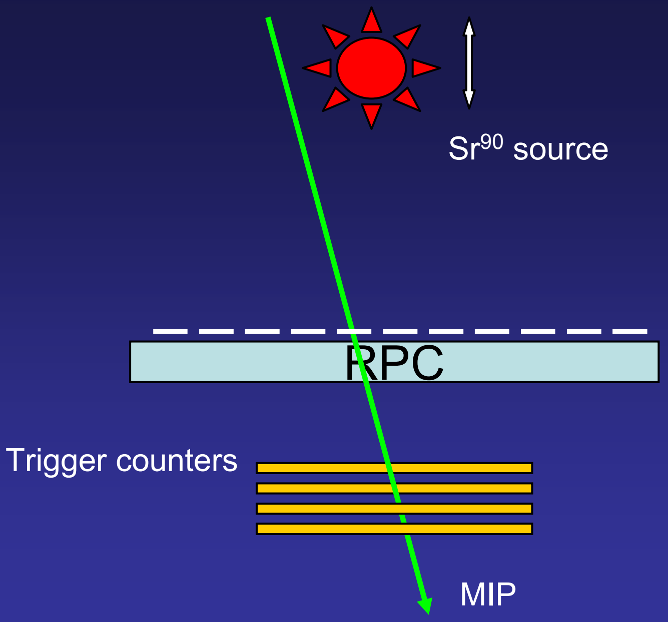
Cosmic Rays and Sources

Efficiency for MIPS

Measurement triggered by scintillation counters

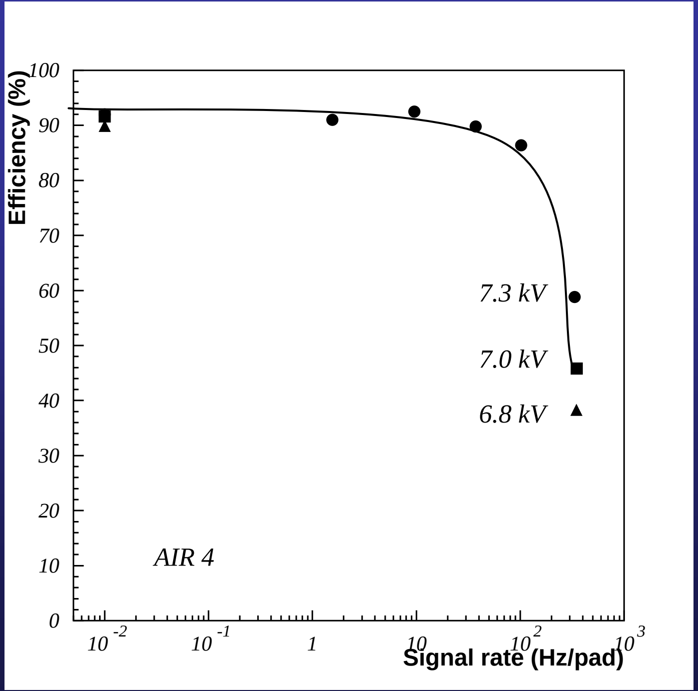
Variable rates

Measurement
Self-triggered



Problems with this method

- Rates from source not uniform over area
- Efficiency drop affects rate measurement
- Source provides e^-, not MIPs
- Cosmic ray trigger contaminated



Rate capability at least 50 Hz/cm²

Operation in B-Field…

Tests done by ITEP group (Ammasov et al.)

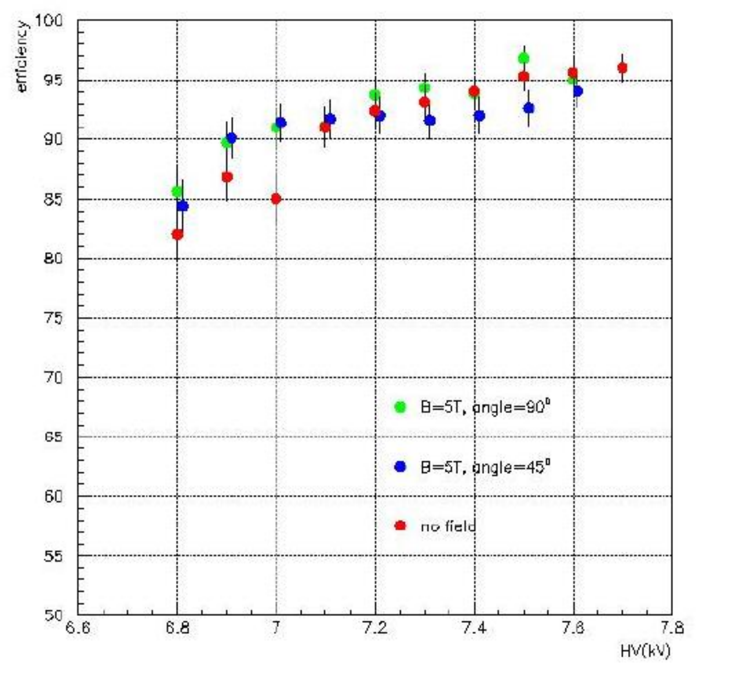
Using DESY 5T magnet

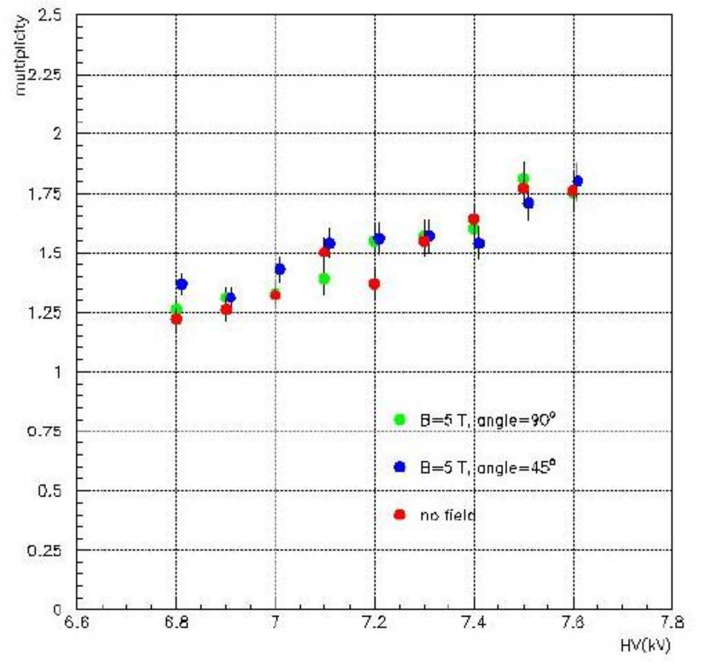
Test with 3 chambers (2 trigger, 1 efficiency)

Measurements with cosmic rays

- Magnet off
- Magnet on, angle between B and E fields = 90^0
- Magnet on, angle between B and E fields = $45^{\ 0}$

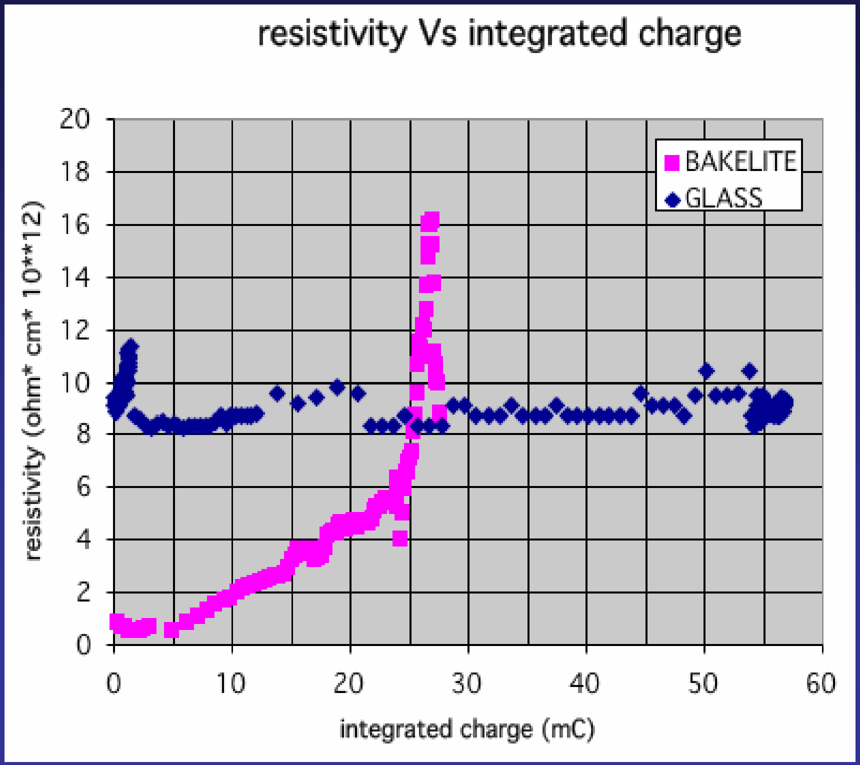
No effect from B-Field observed



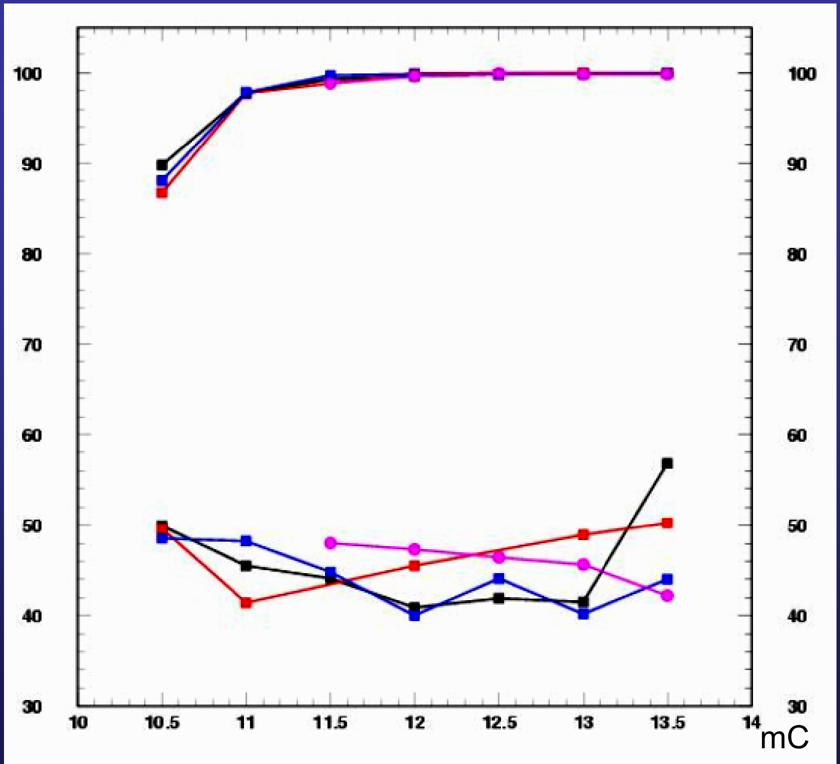


Long Term Stability…

Investigated by OPERA, ALICE…



Efficiency and timing resolution stable with integrated charge

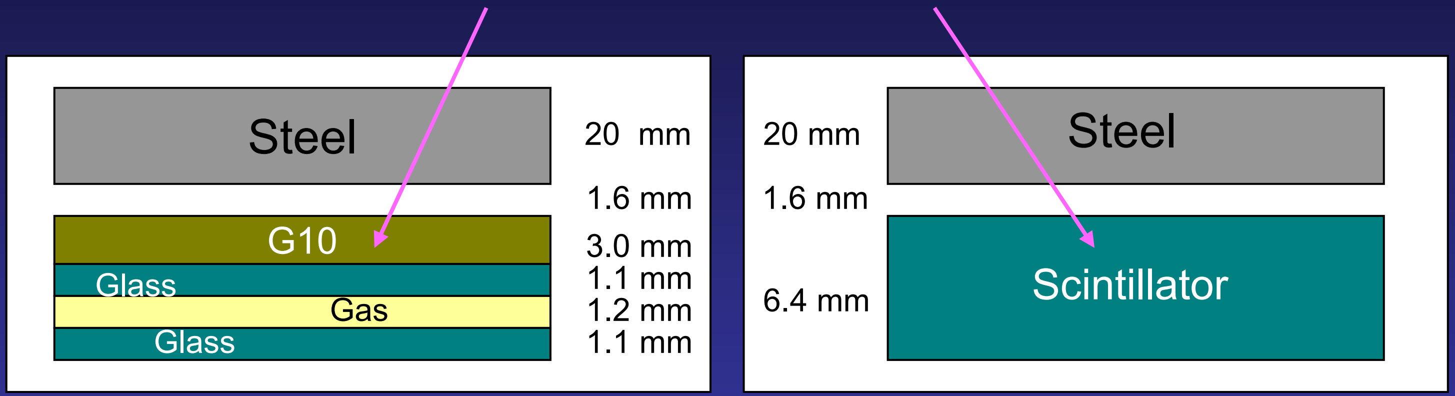


Glass resistivity stable with integrated charge

Own experience: no changes observed in over two years of operation

No ageing of glass RPCs ever observed

Comparison of RPCs with Scintillator

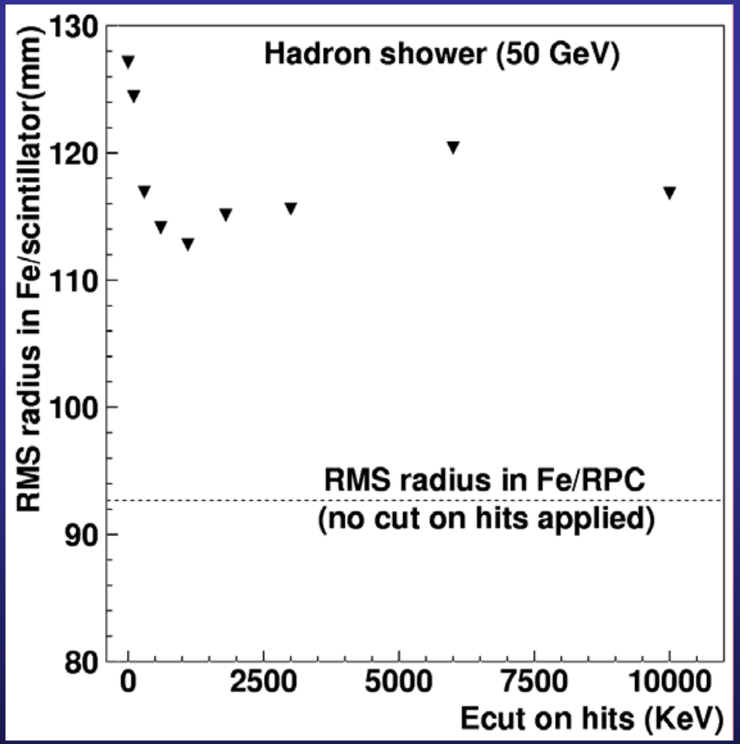


ANL studies based on GEANT4

Studies of lateral shower sizes with 1 cm^2 readout pad sizes

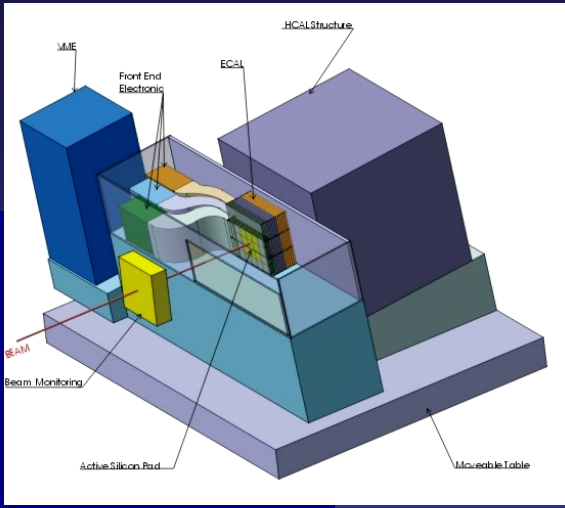
EM showers narrower in RPCs

Hardonic showers narrower in RPCs



Clear advantage for separating components of hadronic jets (PFA)

IV The Big Plan



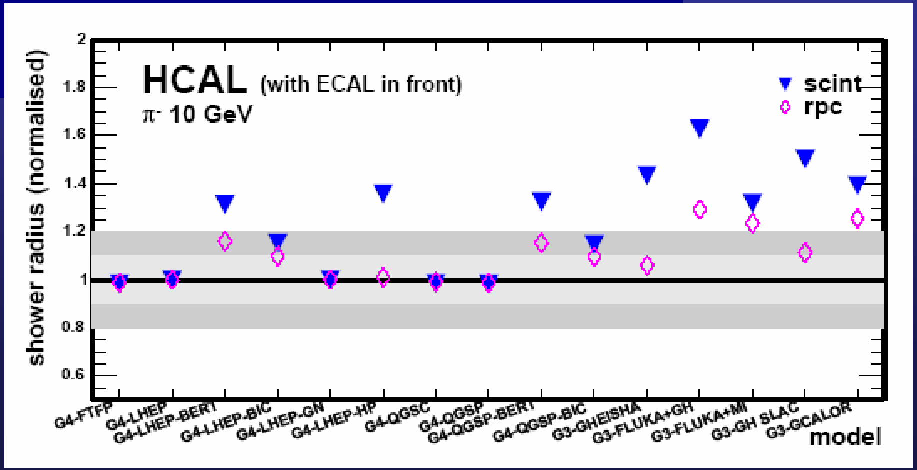
Prototype section

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
Gas Electron Multipliers (GEMs) and Resistive Plate Chambers (RPCs) evaluated

Motivation for construction and beam tests

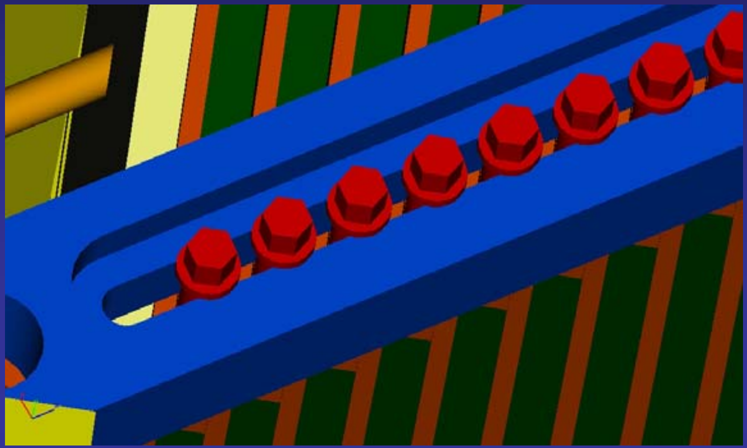
Validate RPC approach (technique and physics)
Validate concept of the electronic readout
Measure hadronic showers with unprecedented resolution
Validate MC simulation of hadronic showers
Compare with results from Analog HCAL

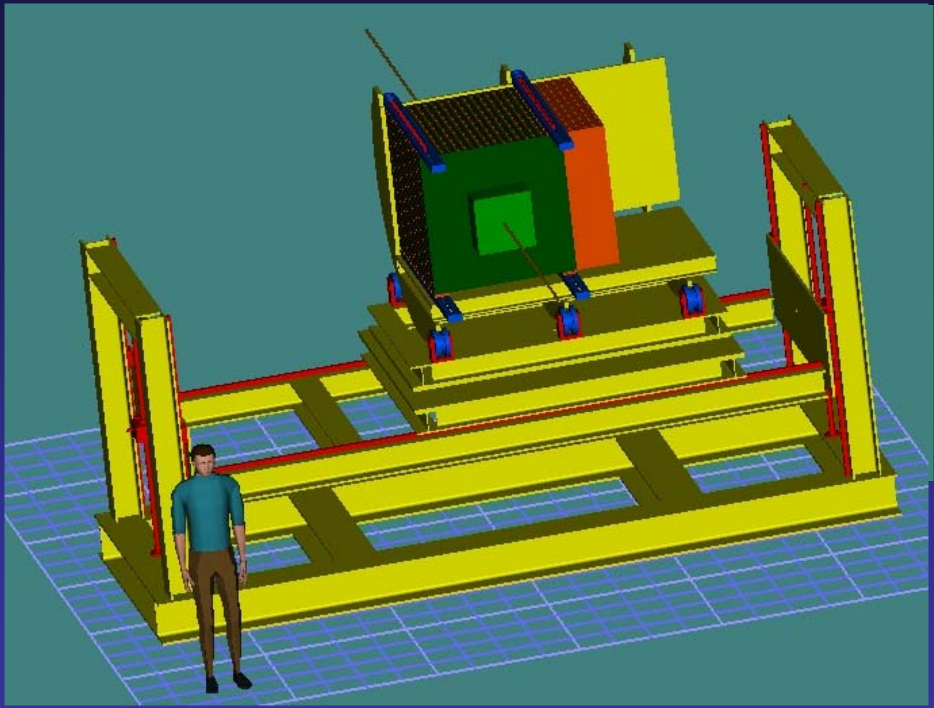
Comparison of hadron shower simulation codes by G Mavromanolakis



Mechanical structure…

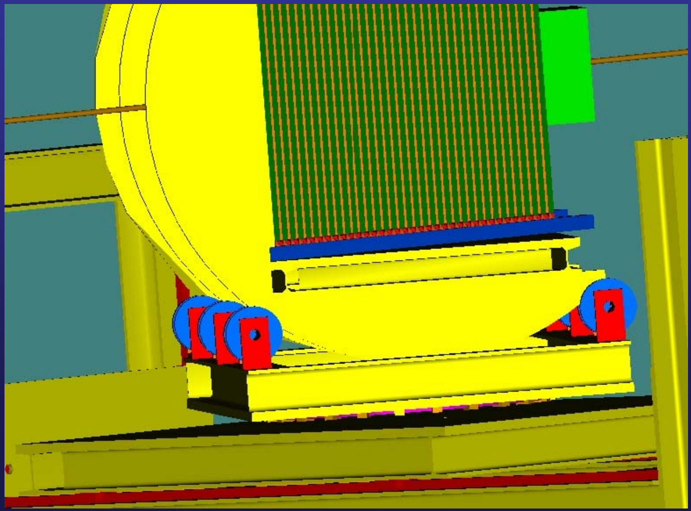
Conceptual design by K Gadow (DESY)





One mechanical structure for AHCAL and DHCALs
Absorber plates 16 mm of (regular) steel
4 mm steel plates as support of active medium
Option to increase gap for active medium to up to 10 mm
Possibility to change height, lateral position, angles

As part of the CALICE project



V The Electronic Readout System

40 layers à 1 m^2
1 cm^2 readout pads

400,000 readout channels

Real challenge
- Cheap (~ 1$/channel)
- Low cross-talk, noise…

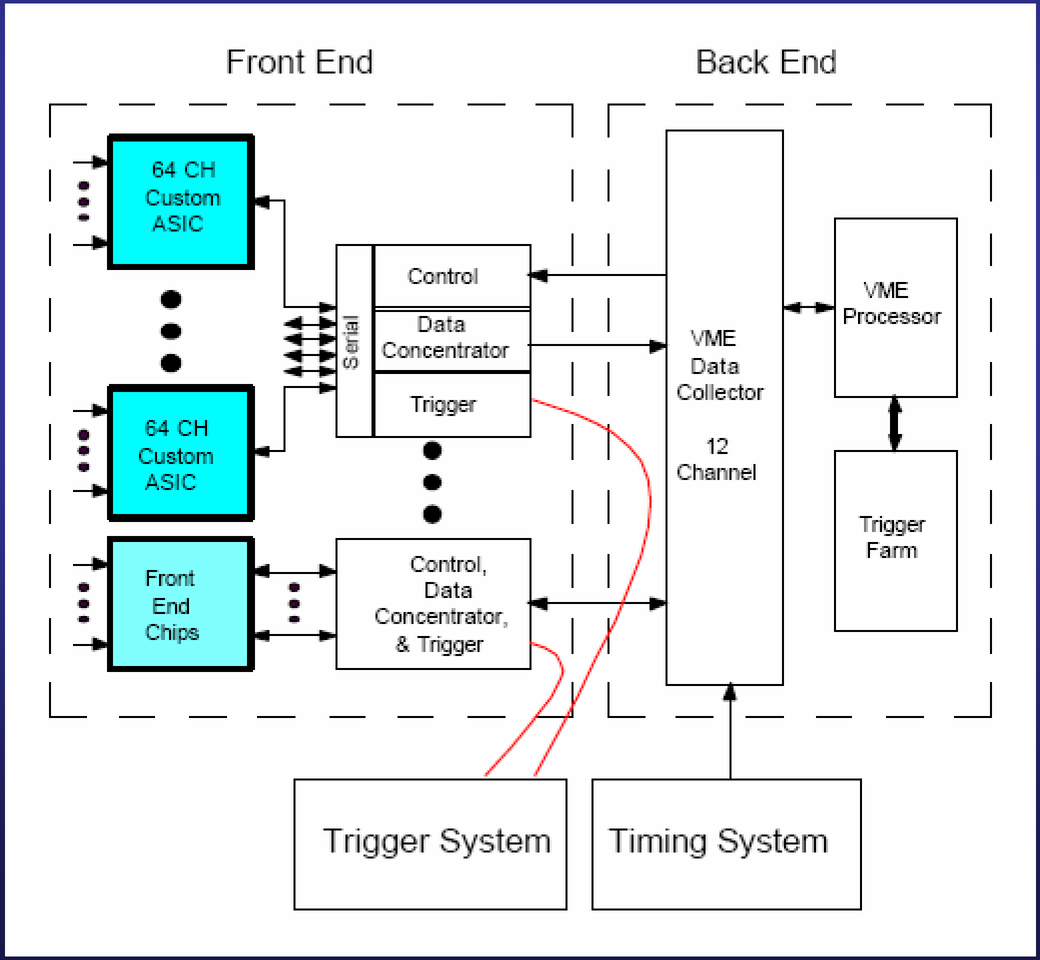
Conceptual design of system

I Front-end ASIC

II Data concentrator

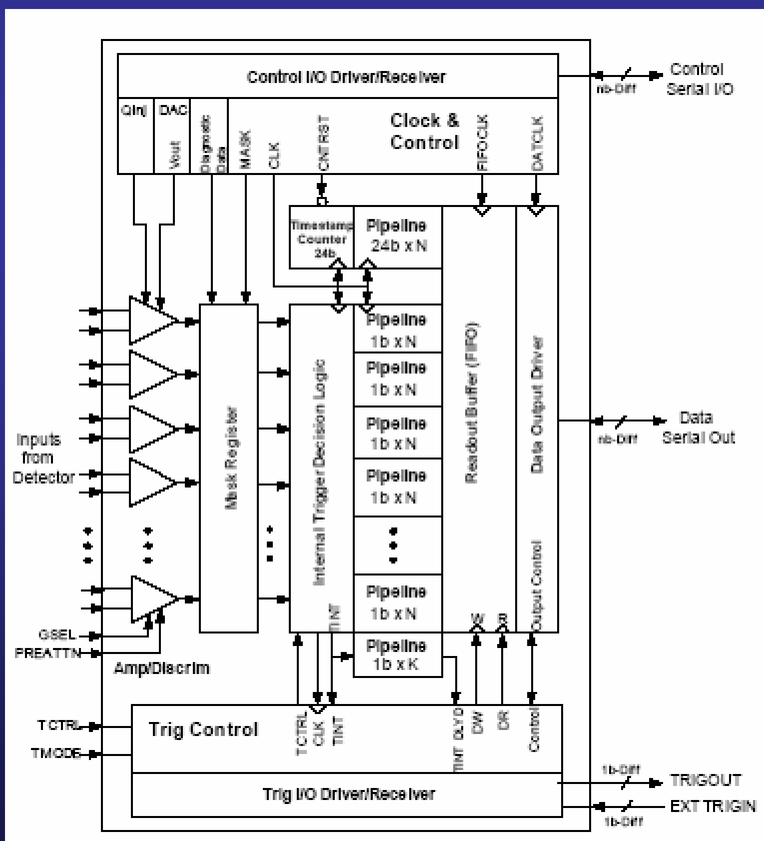
III VME data collection

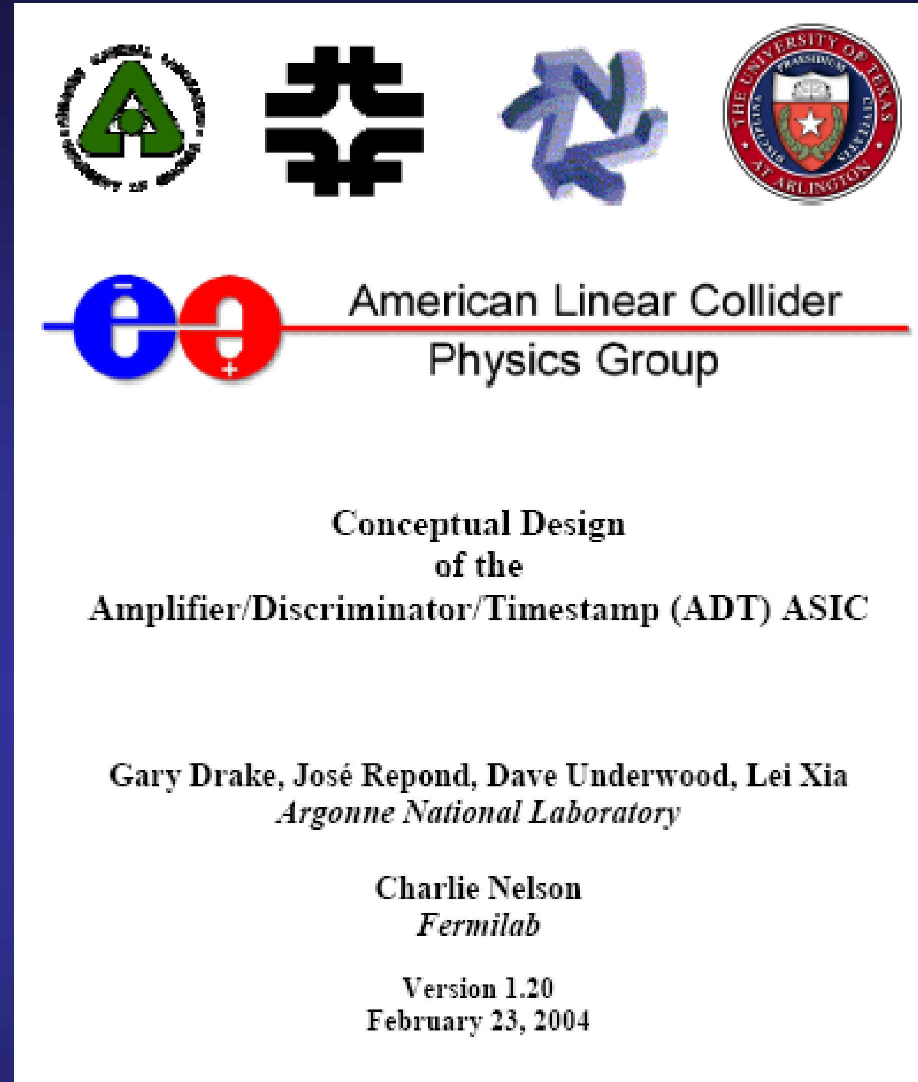
IV Trigger and timing system



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





American Linear Collider Physics Group

Conceptual Design
of the
Amplifier/Discriminator/Timestamp (ADT) ASIC

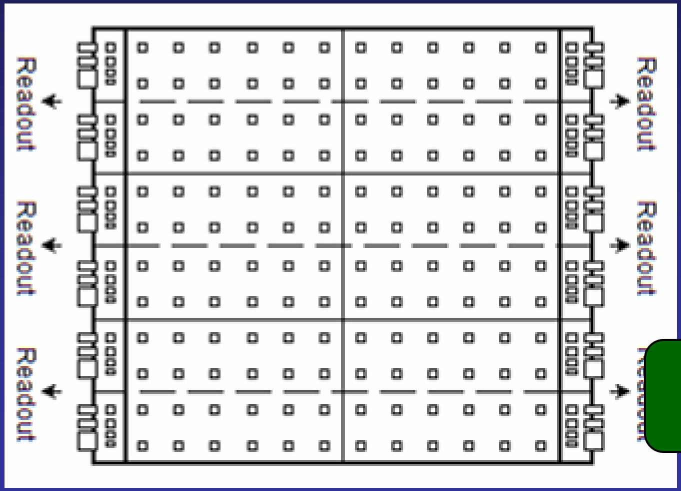
Gary Drake, José Repond, Dave Underwood, Lei Xia
Argonne National Laboratory

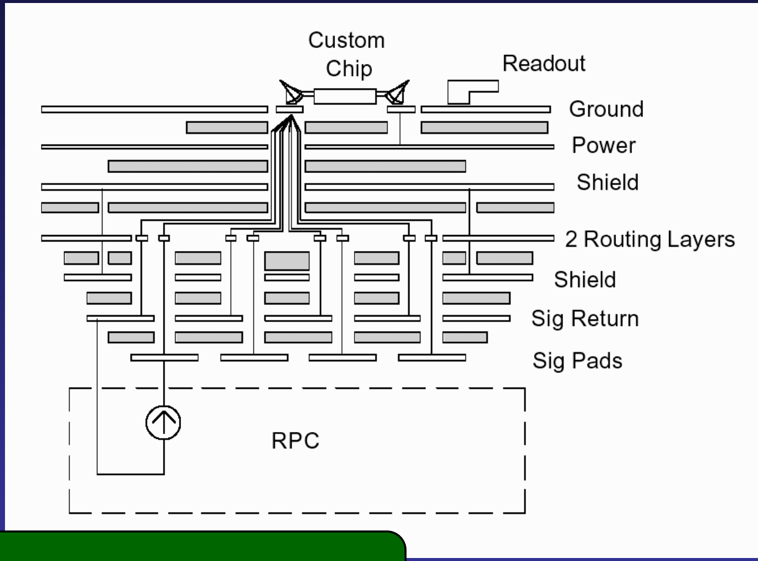
Charlie Nelson
Fermilab

Version 1.20
February 23, 2004

ASIC performance specified in 41 page document

Front-end boards…

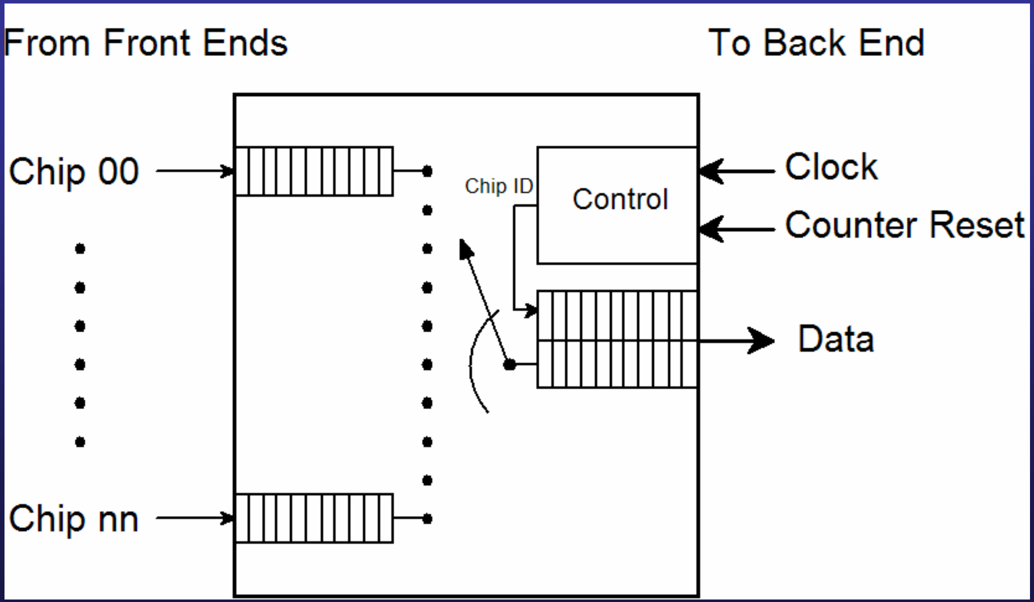




Design challenge

8 layer boards
Each housing 24 ASICs
Overall thickness < 3 mm
Contains both analog and digital signals

Data concentrators…

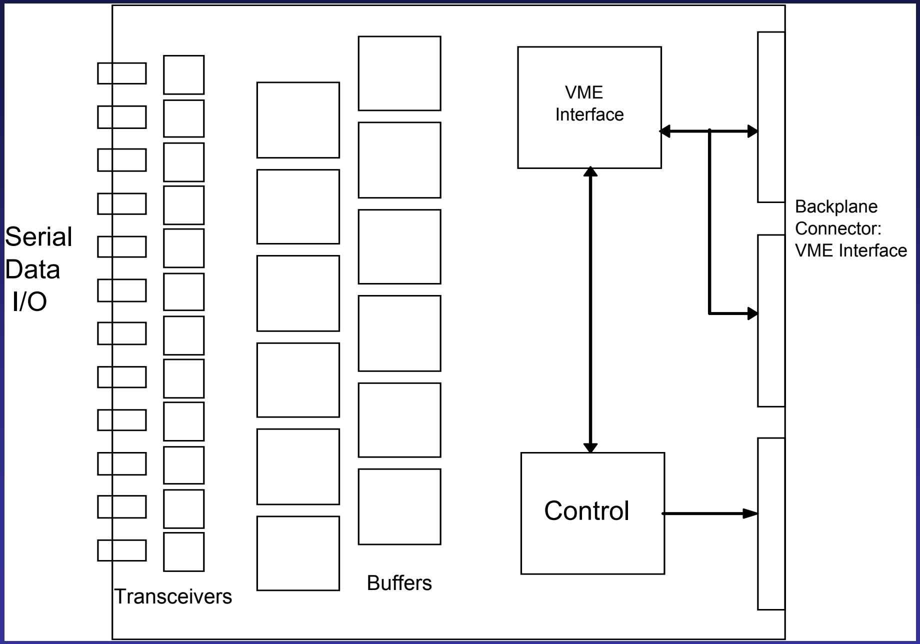


Readout 12 ASICs
Located on sides of section
Essentially FPGAs

Data collector…

Initiated design effort
Pursuing two possibilities

a) PCI links with switch
b) VME-based system



Component	#/chamber	#/plane	Total
Planes	-	1	40
Chambers	1	3	120
DCAL ASIC	48	144	5760
Front-end boards	2	6	240
Data concentrators	4	12	480
Data collectors	-	1	40
VEM crates	-	-	2

VI Collaboration Building and Proposals

List of subtasks for the electronic readout system of the DHCAL

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	**Chicago**
6	Data collector engineering and design prototyping and testing	ANL Boston
7	DAQ system: VME processor and programming	**Washington**
8	Timing and trigger system engineering and design prototyping and testing	**UTA**
9	High voltage system	**Iowa**
10	Gas mixing and distribution system	**Iowa**

Cost estimate (M&S only)…

Item	Cost
Resistive Plate Chambers	$20,000
Front-End ASIC	$225,000
Front-end Readout Boards	$50,000
Data Concentrator Boards	$85,000
Data Collector System	$60,000
Power Supplies, Optical Fibers, HV…	$60,000
Grand total	$500,000 + 50% contingency

Recent & Future Proposals to Funding Agencies…

Agency	Institutes	Request	Award
LDRD (ANL directorate) **used for manpower mostly**	ANL	300,000	181,500
LCRD	ANL, Boston, Chicago, Iowa	105,000	
US-Japan	ANL (LBNL. Oregon, SLAC…)	50,000	
MRI **3 calorimeter prototypes**	ANL, Oregon, UTA	964,000	

VII Testbeam Plans

Fermilab

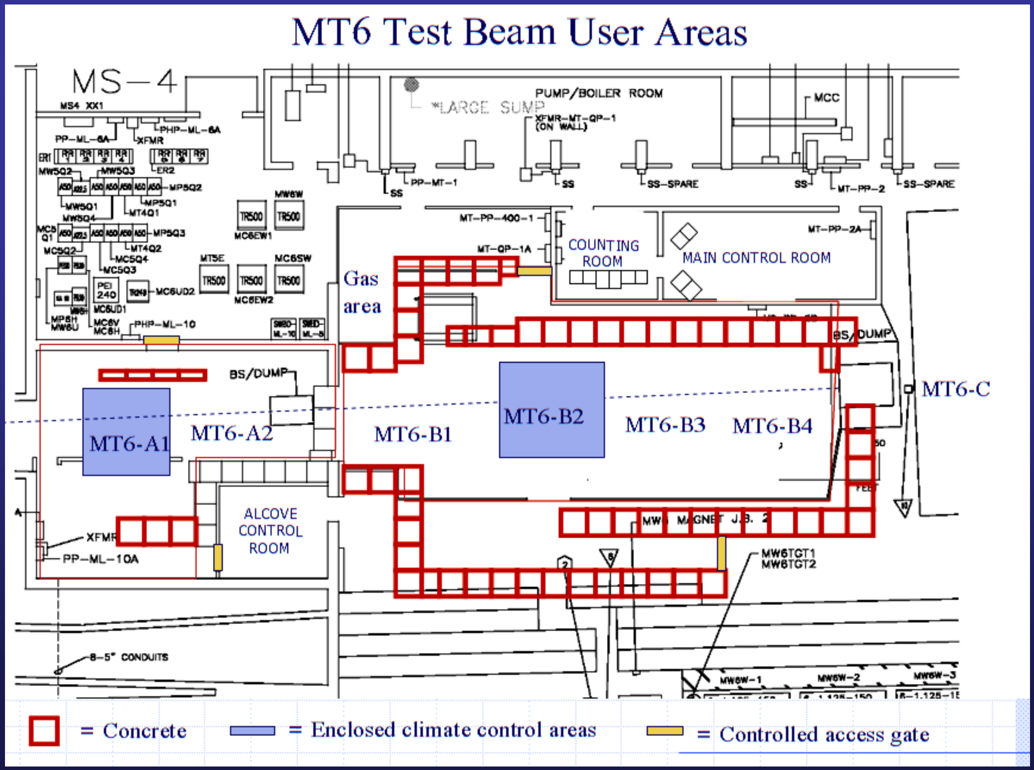
Test beam parameters matched to our needs

- Momentum between 5 and 100 GeV
- Protons, pions, muons, electrons
- Resonant extraction implemented
- Intensity can be reduced
- Up to 6 m in lateral space available

Produced lengthy document with all LC calorimeter developers and Fermilab

Request for

- Low energy electrons (~ 1GeV)
- Low energy pions (~1 GeV)
- Improved duty cycle



Possible test beam scenario…

Year	Calorimeter	Beam time request
2005	ECAL (CALICE)	3 weeks (electrons)
2006	Analog HCAL	4 weeks (hadrons, muons)
	ECAL + Analog HCAL + Tail catcher	5 weeks (hadrons)
2007	Digital HCAL (RPCs)	5 weeks (hadrons, muons)
	ECAL + Analog HCAL + Tail catcher	5 weeks (hadrons)
	ECAL + Digital HCAL + Tail catcher	10 weeks (hadrons)
	ECAL (US)	3 weeks (electrons)
	Digital HCAL (GEMs)	5 weeks (hadrons, muons)
2008	ECAL + Digital HCALs + Tail catcher	10 weeks (hadrons, muons)

VIII Time scale

2005	Develop design of larger chamber
	Prototype ASICs
	Design and prototype other subsystems
2006	Produce chambers
	Produce ASICs
	Produce other subsystems
2007	Move to test beam
	Take data
2008	Take data
	Design LC hadron calorimeter

Tune Hadron Simulation

IX Conclusions

- 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

Funding permitting, we will make a great contribution to

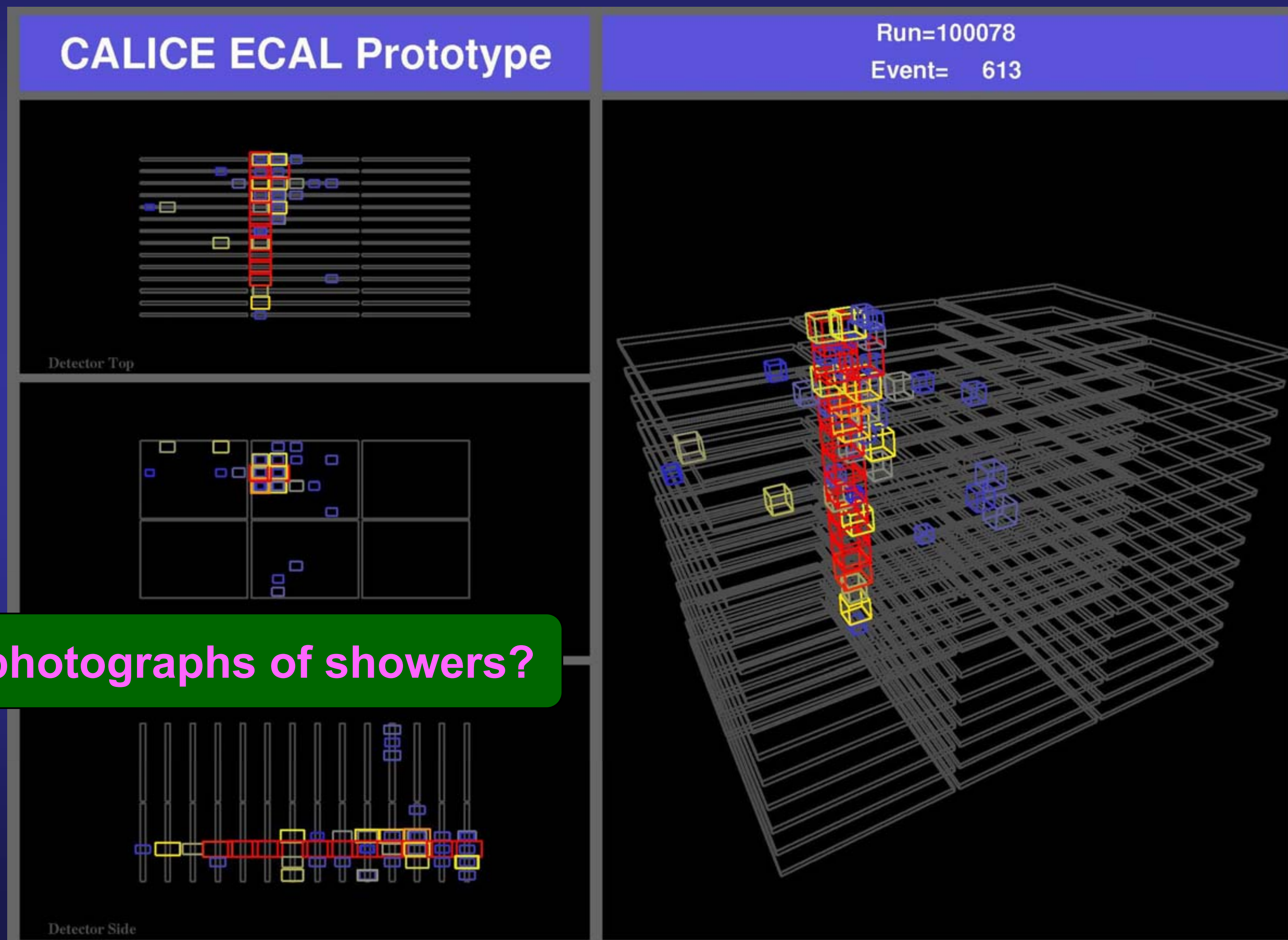
understanding of hadronic showers

and build a basis for

designing the ILC detectors

Hot News

3 GeV electrons from DESY



First real photographs of showers?