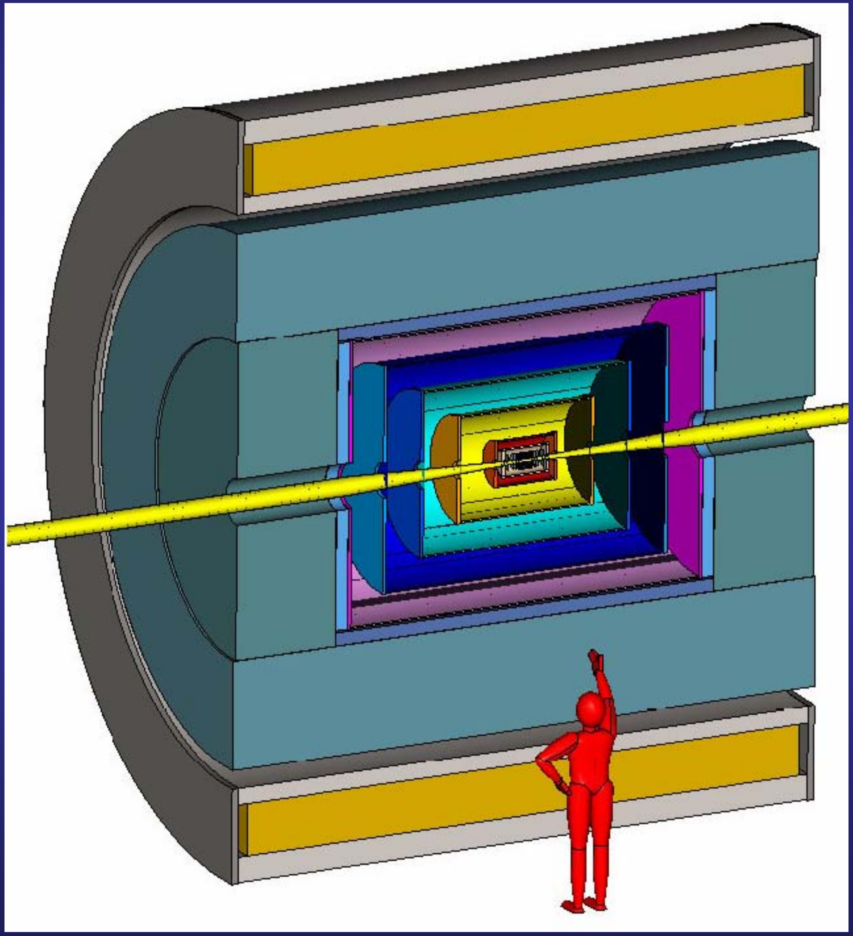
SiD Calorimeter Overview



José Repond
Argonne National Laboratory

Snowmass Workshop, August 14 – 27, 2005

Very active group

		See the **dial-in instructions** in the meeting announcement email. (Request to receive these emails.)	
July 27, 205	Graham Wilson	on improving jet EM resolution in the ECal	ppt pdf
	Ray	update on 20+10 configuration	ppt pdf
	all	Snowmass plans update; Discussion doc:	html pdf
July 20, 2005	Guilherme Lima	tools for non-projective geometries, status	pdf
	Ray Frey	ECal sampling update I --> see July 27 talk	
		plans for Snowmass, contd.	pdf
July 13, 2005	all	Plans for Snowmass	pdf
	Steve Magill	clustering, status report	interactive
	Lei Xia	projective/non-projective simulations	ppt
	Guilherme Lima	tools for non-projective geometries, status	pdf
June 22, 2005	Ray Frey	EGS Studies (contd)	ppt pdf
	Graham Wilson	EGS/Geant4 comparisons	pdf
	Lei Xia	HCal: geometry, n response, resolution	ppt
June 8, 2005	Ron Cassell	Neutral hadron response	ppt
	Lei Xia	Neutral hadron response	ppt
	Ray Frey	EGS Studies for the ECal	ppt pdf
May 25, 2005	Steve Magill/Norman Graf	Neutral hadron response	ppt
	Lei Xia	Neutron energy resolution	ppt
	Ray Frey	EGS studies for the ECal	pdf ppt
May 4, 2005	Jose, Ray	Welcome, working group goals, 10'	
	Tim Barklow	SiD Benchmarking, 20'	pdf ppt
	All	PFA status and plans, 5' each; A mini-workshop in early summer?	

(Almost) weekly meetings

Concentrating on development of PFAs with the goal of tuning the detector design

Talks can be downloaded from SiD web page

Rôle of the Calorimeter

We all believe in PFAs…

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

18%/√E

Calorimeter

Identifies energy associated with charged particles in a jet

Provides measurement of neutrals in jets

+ Identifies electrons through shower shape
Identifies and measures muons and tau's
Measures missing energy
Vetoes 2-γ events (forward)
Measures luminosity spectrum (endcaps) ….

Concept of the SiD Calorimeter

1) **Located inside the coil**

2) **Finest readout segmentation possible**

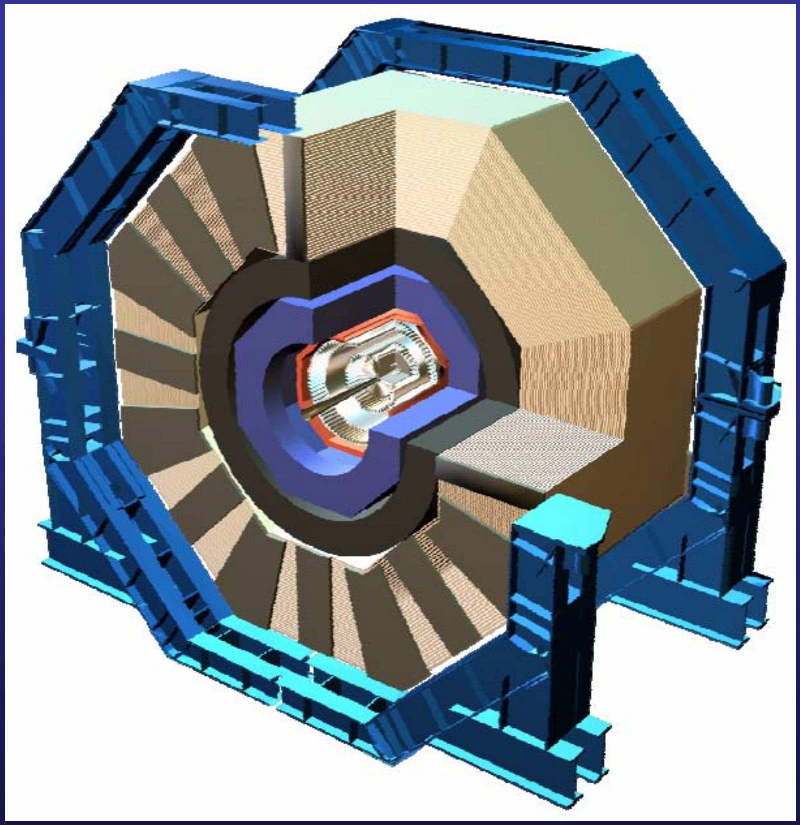
In ECAL of order 0.2 cm^2 } laterally
In HCAL of order 1.0 x 1.0 cm^2
Layer – by – layer longitudinally

3) **Thinnest possible active detectors**

Minimize $R_{Moliere,}$ and cost
In ECAL of order 1 – 2 mm
In HCAL of order 5 – 10 mm

4) **Absorber**

Tungsten in ECAL ($R_{Moliere}$ ~ 9 mm)
Steel (default) or Tungsten in HCAL



Technical Realization: ECAL

Ray's preferred structure

$20 \times 5/7\ X_0 + 10 \times 10/7\ X_0$ corresponding to $29\ X_0$

Silicon – Tungsten Sandwich

30 x

Tungsten	0.250 cm	corresponds to $5/7\ X_0$
G10	0.068 cm	
Silicon	0.032 cm	
Air	0.025 cm	
	0.375 cm	

→ $R_{Moliere} \sim 14$ mm

Overall thickness

$\sim 22\ X_0$ or $\sim 0.8\ \lambda_I$

Barrel

$R_I = 127$ cm → $R_O = 138.25$ cm
-179.5 cm $< z < +179.5$ cm

Endcaps

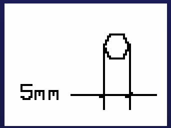
$z_I = 168$ cm → $z_O = 179.25$ cm
20 cm $< R < 125$ cm

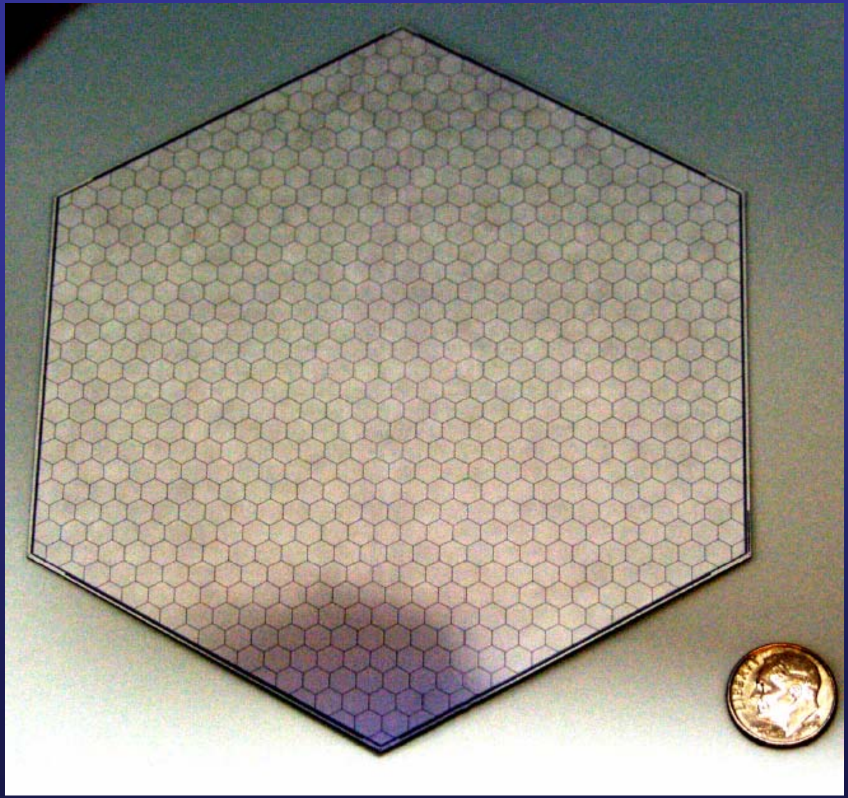
Readout segmentation

$\sim 0.16\ cm^2$

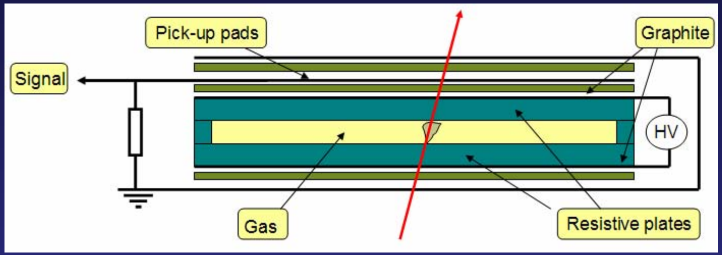
Single electron resolution

$\sim 16\%/\sqrt{E}$





Technical Realization: HCAL



RPC – Steel Sandwich

34 x

Steel	2.00 cm	corresponds to 1.1 X_0
G10	0.30 cm	
Pyrex Glass	0.11 cm	
RPC gas	0.12 cm	
Pyrex Glass	0.11 cm	
Air	0.16 cm	
	2.80 cm	

Overall thickness

~ 45 X_0 or ~ 4.1 λ_I

Barrel

R_I = 138.5 cm → R_O = 233.7 cm
-277 cm < z < +277 cm

Endcaps

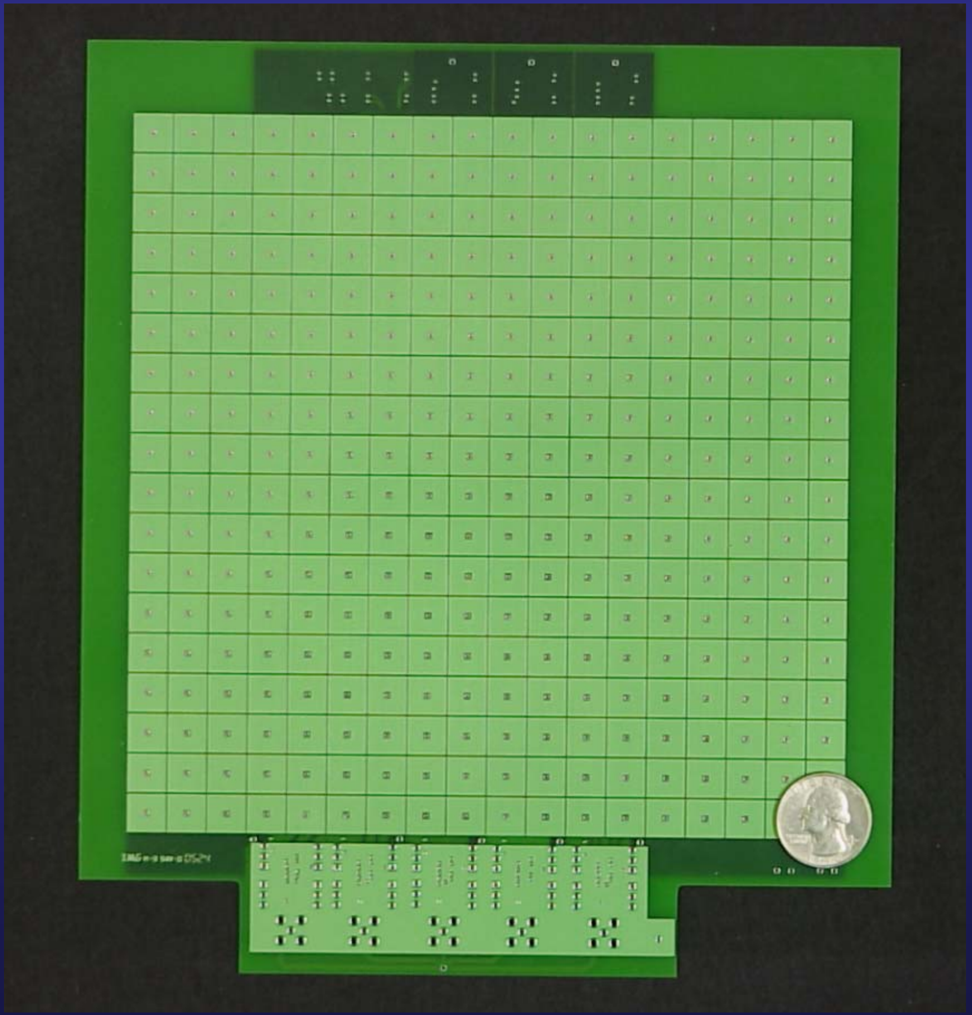
z_I = 179.5 cm → z_O = 274.7 cm
20 cm < R < 138.25 cm

Readout segmentation

1.0 x 1.0 cm^2 …is this the default in the simulation now?

Single π^+ resolution

55 – 65 %/√E



Choices for HCAL active media

	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
Sensitivity to neutrons (low energy)	Yes	Negligible	Negligible ?
Recharging time	Fast	Fast?	Slow (20 ms/cm^2)
Reliability	Proven	Sensitive	Proven (glass)
Calibration	Challenge	Depends on efficiency	Not a concern (high efficiency)
Assembly	Labor intensive	Relatively straight forward	Simple
Cost	Not cheap (SiPM?)	Expensive foils	Cheap

Entries in [shaded] are concerns/possible problems/limitations

Technical Realization: Very Forward Calorimeter

Still needs to be developed/implemented….

Fine Tuning of the Calorimeter Design

Many design parameters to adjust

Overall	Inner radius of calorimeter Outer radius of calorimeter Transition from barrel to endcaps Transition from endcaps to very forward calorimeters
ECAL	Absorber thickness (uniform, varying with depth) Number of layers Segmentation of readout
HCAL	Absorber choice $\rightarrow$ Tungsten (2 X_0) versus steel (1 X_0) Number of layers Active medium (RPC, GEM, Scintillator) Segmentation of readout Resolution of readout (number of bits)
Tail catcher	Needed? Same technology as HCAL

Need reasonably well performing PFA to evaluate different designs

Reasonably well performing PFA

Jet energy resolution of 40%/√E or better

Test with $e^+e^- \rightarrow W^+W^-$ at $\sqrt{s}$ = 500 GeV
Reconstruct W mass with $\Gamma \leq 4$ GeV

Allowed tricks (at the moment)

Use of MC truth for track parameters
Cut on event axis to be within 55 degrees of normal
Eliminate events with significant energy in neutrinos
Use of code by other developers

Reward for 1st person/group to achieve goal

Several bottles of champagne (John, José, Harry)

Particle Flow Algorithms

Clustering of calorimeter hits

Matching of clusters with charged tracks

Photon finder

Neutral hadron energy measurement

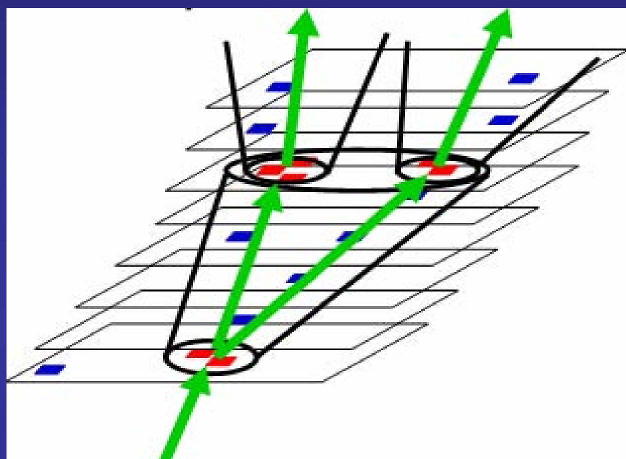
Special tasks

Most important subtask of PFAs…

Clustering of calorimeter hits

Tubes (Kuhlmann, Magill)

Adding hits in cones originating at high density points
Tuned cone size



Cone algorithm (Yu)

Using maximum density cells as centroids
Add hits (energy) in cones

Layer – by – layer (Ainsley)

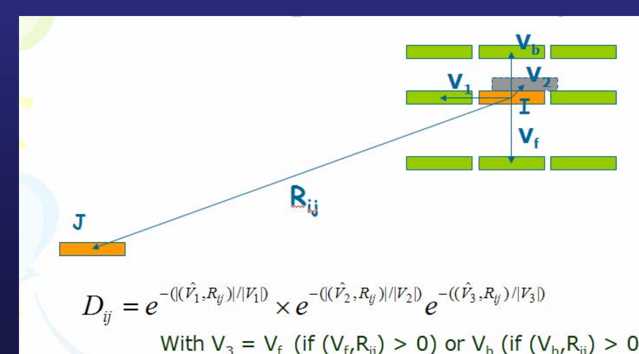
Minimizing distance between hits in adjacent layers
Tracking algorithm

Directed tree (NIU)

Calculate density differences for pairs of cells
Use maximum density difference to either start new cluster or merge cells

Density weighted (Xia)

Defined geometry independent density function
Seeds are cells with highest density
Cluster hits with densities above a given cut



….more

Clustering of calorimeter hits

Criteria for performance

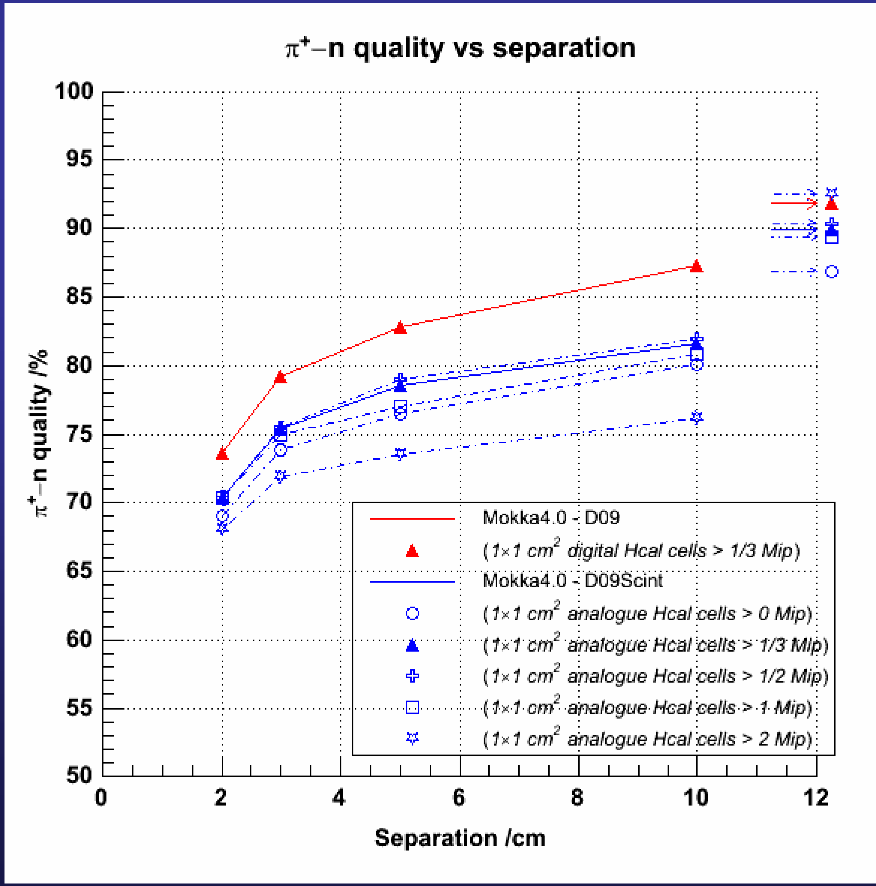
Efficiency (find all hits belonging to a given particle)
Purity (reject hits not associated with a given particle)

Example from Ainsley

5 GeV (π^+n) event at a distance of 5 cm

Distribution of event energy [%]	True cluster ID	
Reconstructed cluster ID	7.4	40.1
	46.3	6.1

Quality = Fraction of event energy that maps in a 1:1 ratio between true and reconstructed clusters



Photon finders

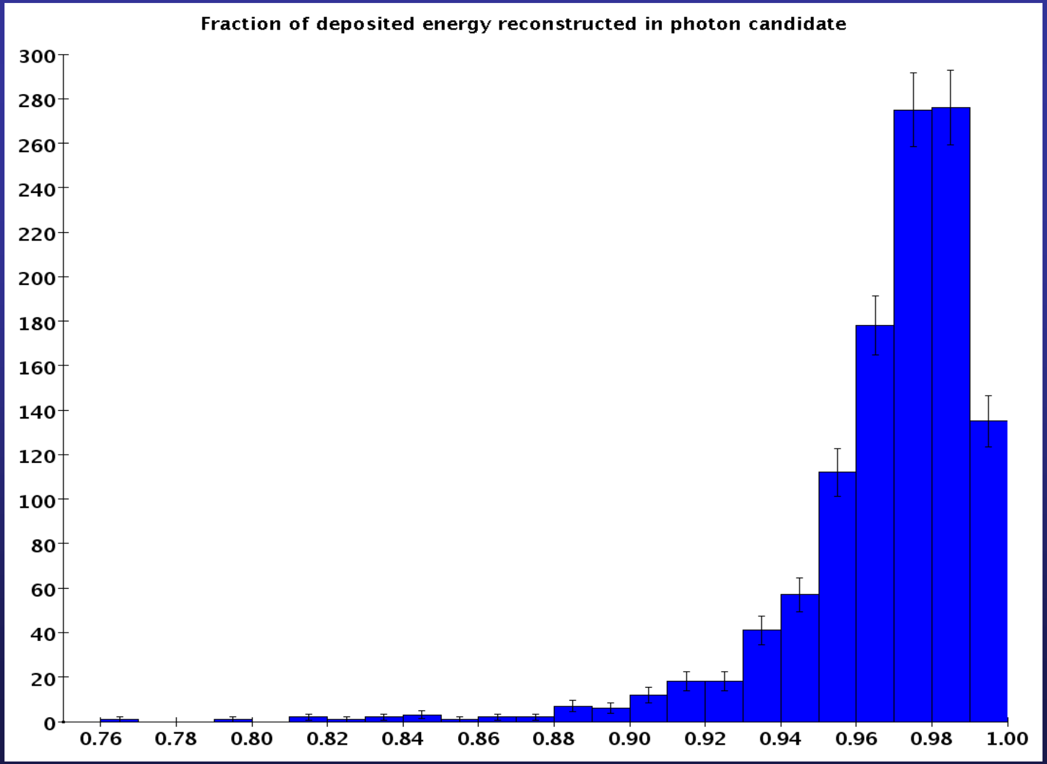
Using Minimum Spanning Tree clustering (Iowa)

Evaluation of
Number of hits in cluster
Distance to closest MIP track
Eigenvalue of energy tensors

Performance
99% γ efficiency with 5% π^+ contamination
Good energy reconstruction

Using HMatrix (Graf, Wilson)

Waiting for input from Norman

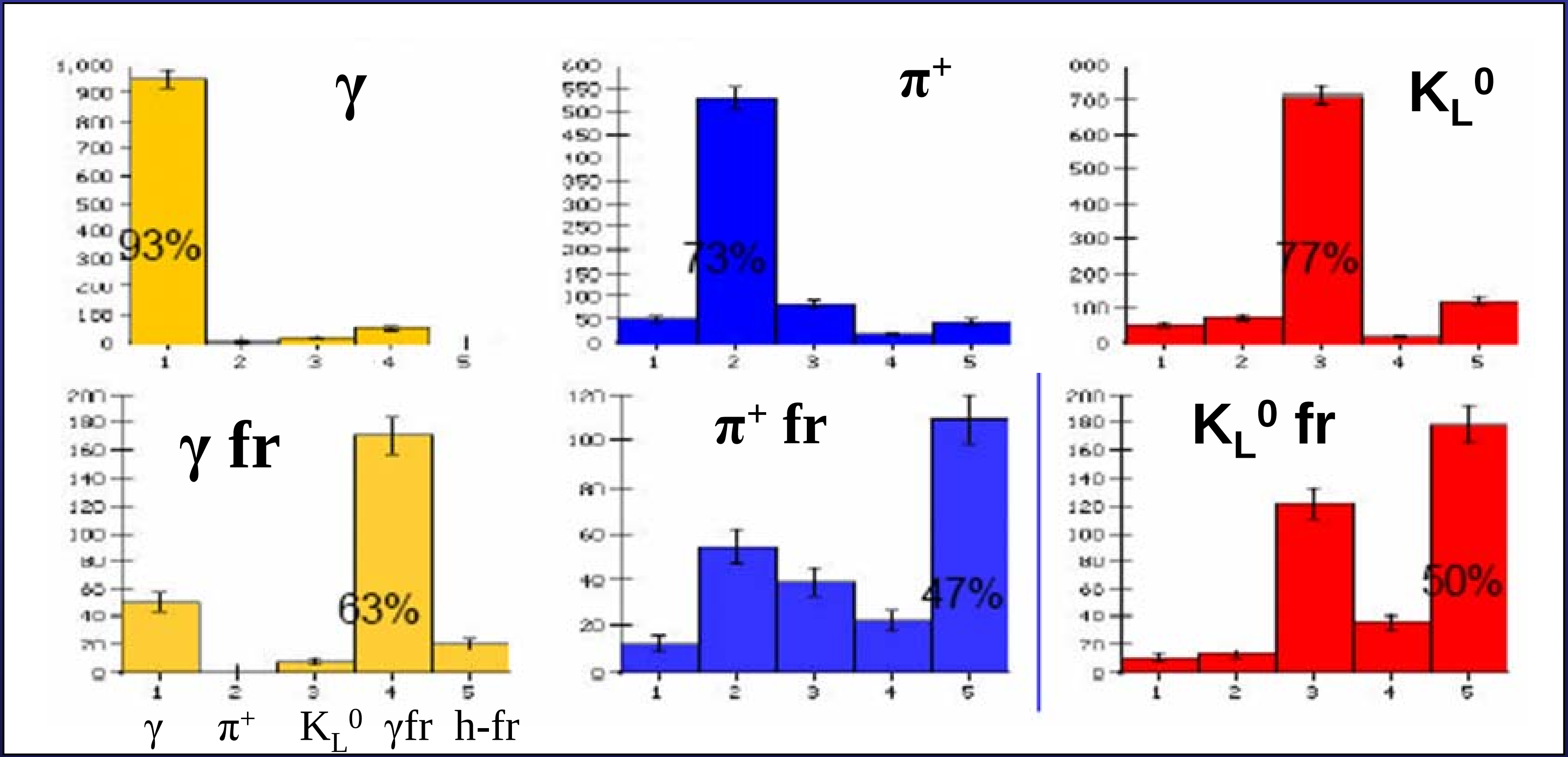


Example using Neural Nets (Bower, Cassell)

Calculates energy tensor of clusters
Neural net separates into

- EM clusters
- Neutral hadronic
- Charged hadronic
- EM fragment
- Hadronic fragment

Putting it all together



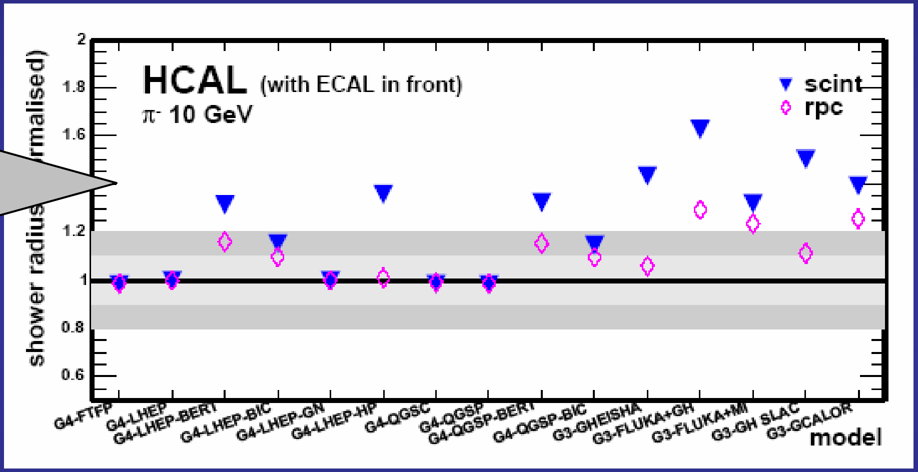
Problem I: Can we trust GEANT4?

Tuning of detector relies on

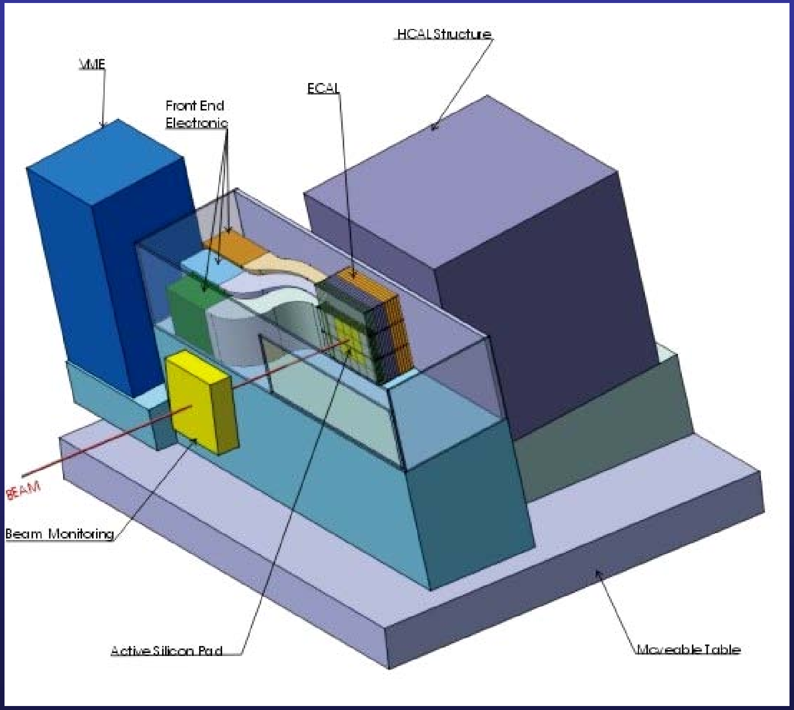
PFAs and a
Realistic simulation of hadronic showers

Comparison of various models

Differences up to 60%



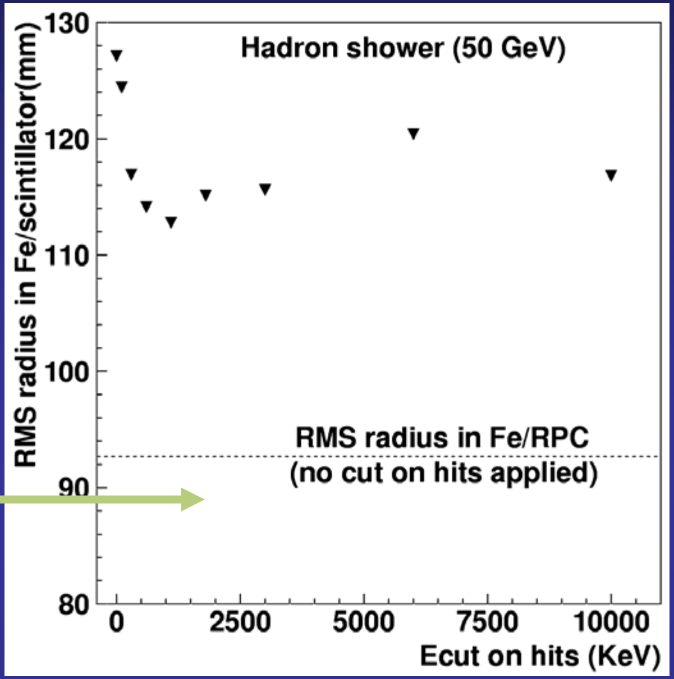
Plot by G Mavromanolakis



Measurements with fine granularity prototype calorimeters absolutely mandatory

Problem II: Sensitivity to slow neutrons?

	Scintillator	RPC Gas
Molecule	$C_6H_5CH{=}CH_2$	$C_2H_2F_4$
Density	1.032 g /cm^3	4.3 x 10^{-3} g/cm^3
Thickness	5 mm	1.2 mm
Sensitivity to slow neutrons	small	negligible
Hadronic shower radius	**larger**	smaller
Single particle resolution	better	**worse**



K_L^0

Momentum [GeV/c]	5	10	20
$\sigma = x\sqrt{E}$ Scintillator		(54.2)	(55.5)
$\sigma = x\sqrt{E}$ RPC	0.57	0.66	0.64

Neutron

Momentum [GeV/c]	5	10	20
$\sigma = x\sqrt{E}$ Scintillator		(54.2)	(55.5)
$\sigma = x\sqrt{E}$ RPC	0.78	0.80	0.74

Different shower models in G4?

Tradeoff

More studies needed…

Plans and Goals for Snowmass

Tue Aug 16	8:30 -12	SiD plenary; 15 min Calorimeter talk - Jose Repond, ANL
	1:30-2:30	SiD mini-plenary • SiD concept discussion - Marty Breidenbach, SLAC • LC simulation tools for SiD - Norman Graf, SLAC
	2:30-3:30	**SiD calorimeter parallel session** • Schedule and overview - Jose Repond, ANL • Current Particle Flow (PFA) status, goals for Snowmass - Steve Magill, ANL (unconfirmed)
Wed Aug 17	8:30 - 9:30	**SiD calorimeter parallel session** ECal pattern recognition/clustering algorithms - Series of 10 minute talks: • Chris Geraci, Colorado - comparing existing algorithms • Mathew Phillips, Colorado - pi0 clustering • Niels Meyer, Iowa: MST for the ECal • Graham Wilson, Kansas - H-matrix clustering and pi0's
	10:00 - 12	**SiD calorimeter parallel session** HCal/hadron clustering algorithms - Series of 10 minute talks • Steve Kuhlman, ANL - neutral clustering • Guilherme Lima, NIU - density weighted clustering • Mathew Charles, Iowa - MST in the HCal • Lei Xia, ANL - hadron clustering HCal response and technology choices/tradeoffs • Lei Xia, ANL - neutral hadron response with Geant4 - 15' • Steve Magill, ANL - Alternative HCal configurations (unconfirmed) - 15' • Dhiman Chakraborty, NIU - The case for a scintillator HCal for SiD - 15'
	1:30 - 3:30	Joint MDI session with all concepts
	4:00 - 5	**SiD calorimeter parallel session** Forward calorimeter issues and technologies • Wolfgang Lohmann, DESY - technology options - 20'
Thur Aug 18	8:30 - 12	Detector parallel sessions (see program web pages) • 30 min talks on calorimetry for each concept - SiD: Jose Repond, ANL • detector or test beam talks for people not attending week 2

Goals

Introduce more people to PFA studies

Make progress toward a default PFA

Preliminary studies of detector design parameters

(Confront HCAL technologies)