BNL, RHIC, PHENIX

Compact W-Si Calorimeters for the PHENIX Upgrade

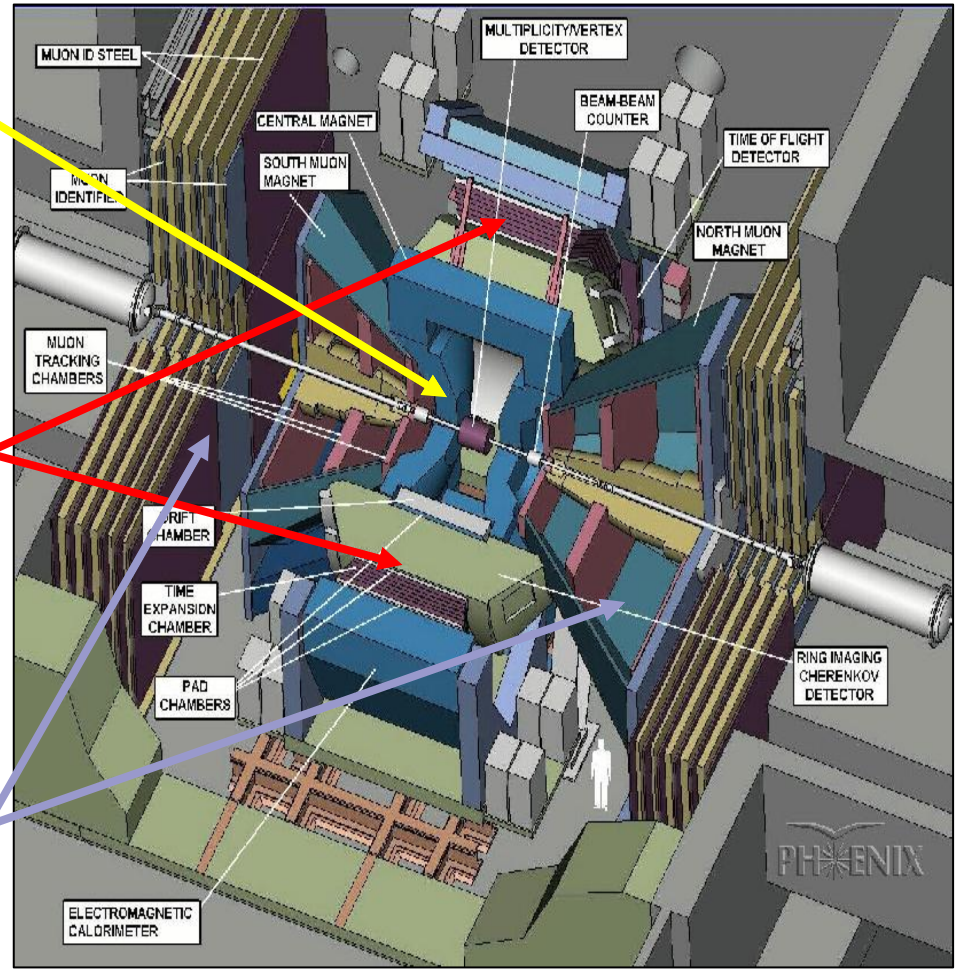
Presented by W. Cooper for
the Phenix Collaboration

PHENIX today

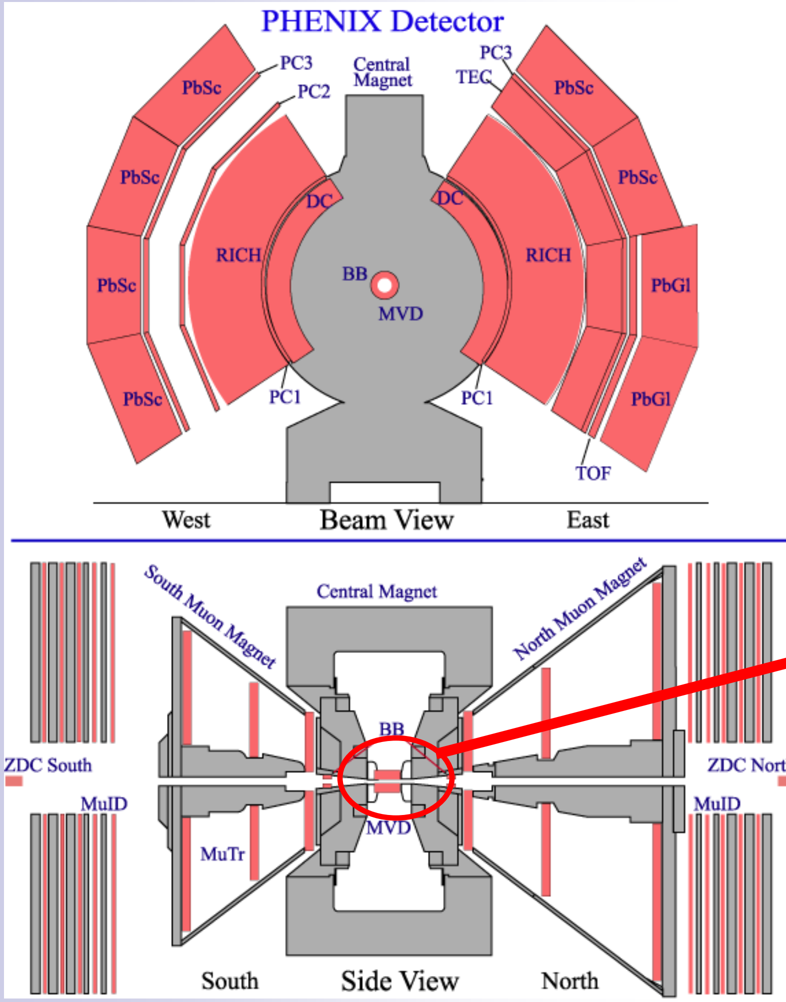
Event characterization detectors in middle

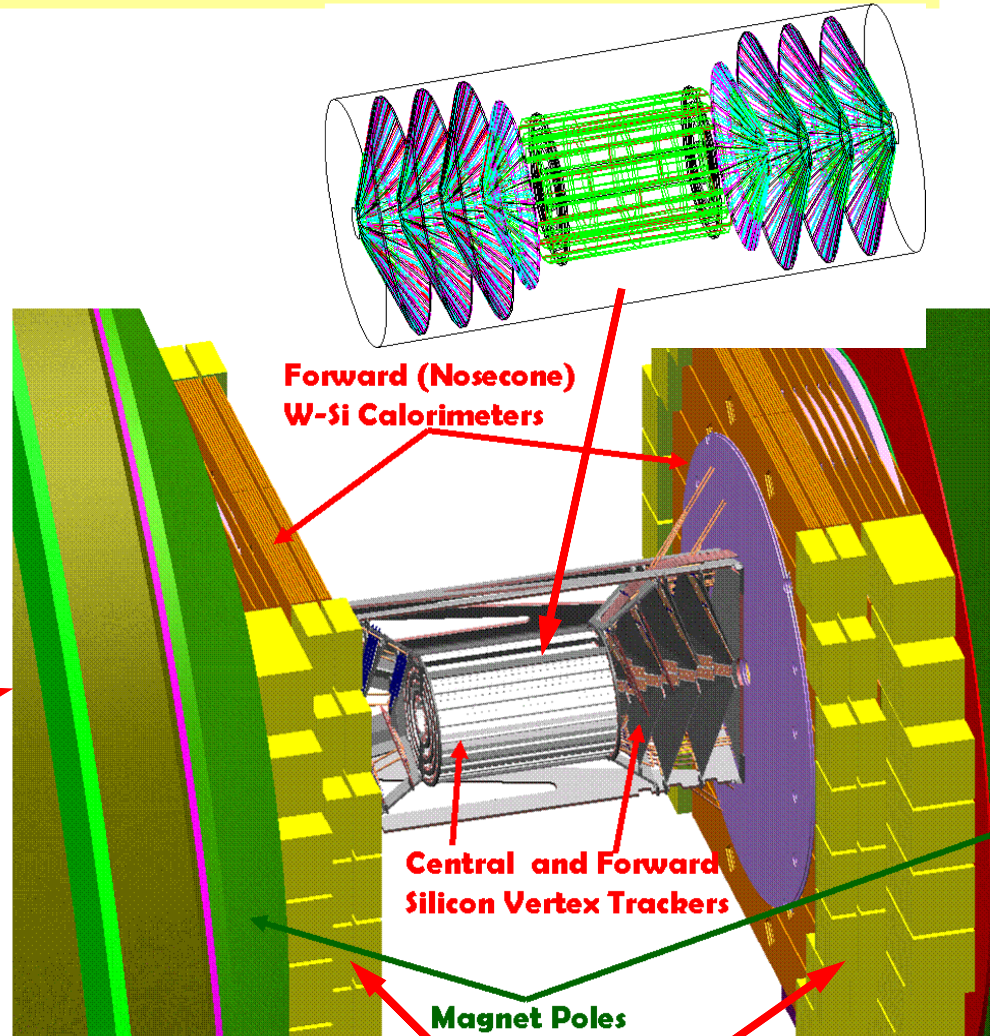
Two central arms for measuring hadrons, photons and electrons

Two forward arms for measuring muons



PHENIX Upgrade





Nose-Cone Calorimeters

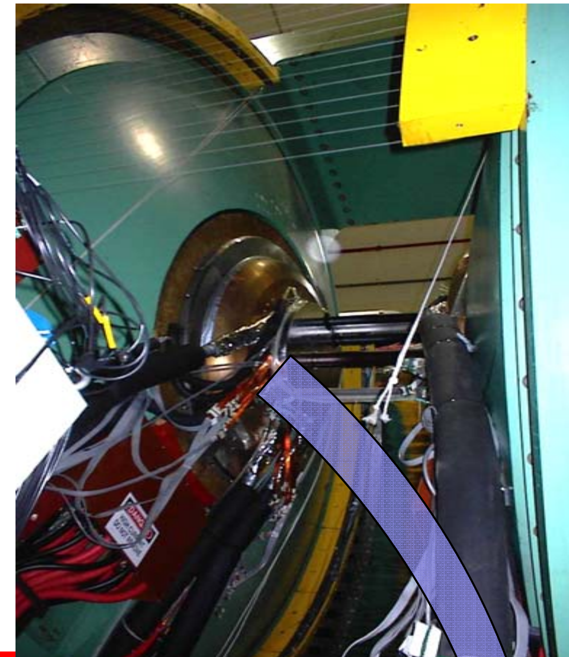
Constraints

-*space*

40 cm from collision vertex

20 cm total depth

-*no tracking upstream* (momentum and charge unknown)



Detector goals:

Reasonable energy resolution for em probes;

Best possible separation between em and hadronic signals

Ability to reconstruct p0's to ~30 GeV/c

Jet identification and cone energy measurements

Observables

π^0's: pT<15 GeV/c (p<30 GeV/c);

direct photons: pT>2 GeV/c

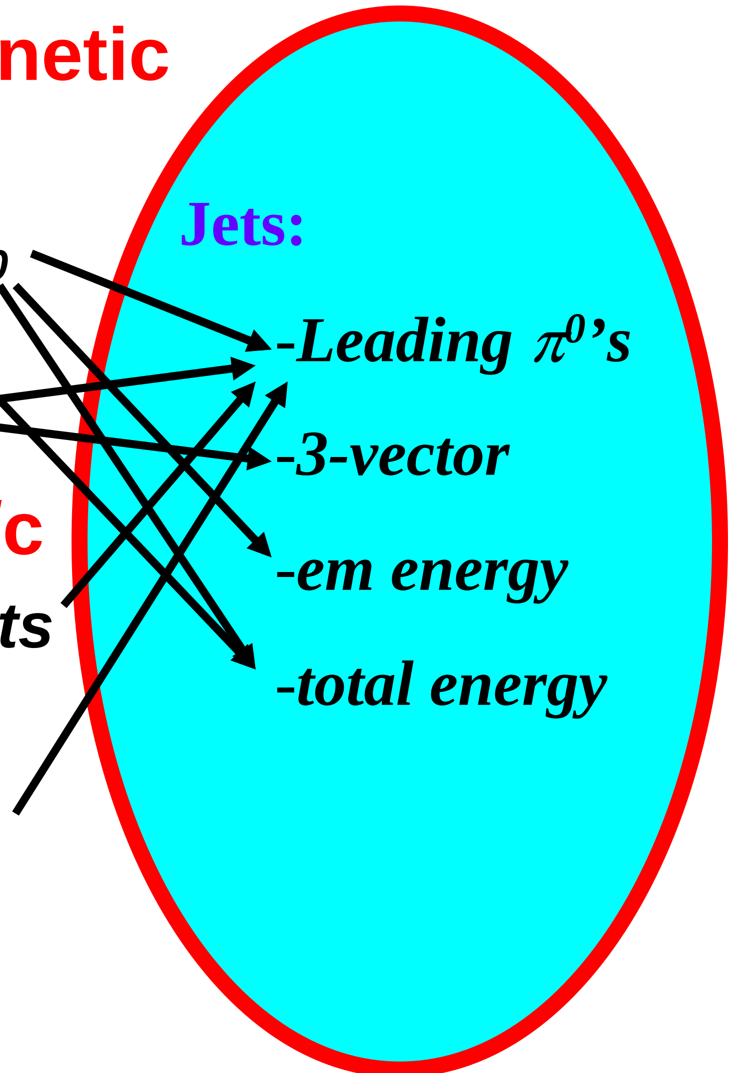
jets: recognition, 3-vector, total energy, leading particles (π^0);

leptons: 4-vectors for e/γ, 3-vector for muons;

lepton isolation

Considerations & compromises

- **Clean sample of electromagnetic showers**
  - ***Shallow em-section: ~10-15 X_0***
  - ***Leakage segment: ~ 1 L_{abs}***
  - ***Lateral segmentation: $<L_{molier}$***
- **π^0 reconstruction to 30 GeV/c**
  - ***Converter and Strips to see hits***
  - ***Lateral segmentation: $<L_{molier}$***
  - ***Second strip layer to measure decay asymmetry***



NCC –tracking calorimeter

Parameter		Value	Comment
Distance from collision vertex		40 cm	
Radial coverage		50 cm	
Geometrical depth		~19 cm	
Absorber		W	42 Lrad or 1.6 Labs
Readout		Si pads (15x15 mm2) and pixeleted strips (.0.5x0.5 mm pixels grouped into 60 mm long strips)	
Calorimeter		EMC(12 sampling cells: 3mm W + 2.5 mm readout) longitudinally structured into two identical nonprojective sections. Leakage(6 sampling cells: 15 mm W + 2.5 mm readout)	
Preshower detector (PS)		2 Lrad W converter followed by a stripixel layer (0.5 mm strips) with 2-d readout	
Shower max detector (SMD)		In between two EM sections at ~ 7 Lrad depth. Stripixel layer (0.5 mm strips) with 2-d readout	
Multiple scattering in NCC combined with Fe magnet pole		133 MeV	To compare with 106 MeV in the existing configuration with Cu NoseCone
Expected EM energy resolution %		~18/sqrt(E)	
Expected jet energy resolution %		~100/sqrt(E)	
Two showers resolved at	in calorimeter	3 cm	
	in preshower	2 mm	In simulation effective for shower separation down to 4 mm
	in shower max.	4 mm	

NCC –tracking calorimeter

Plate thicknesses:

- Preshower: 7 mm tungsten
- EM1: 3 mm tungsten (6 plates)
- 0.5 mm copper to close brick and provide electrical shielding in front of shower max gap
- EM2: 3 mm tungsten (6 plates)
- HAD: 15 mm tungsten (6 plates)
- 0.5 mm copper to close “brick” and provide electrical shielding

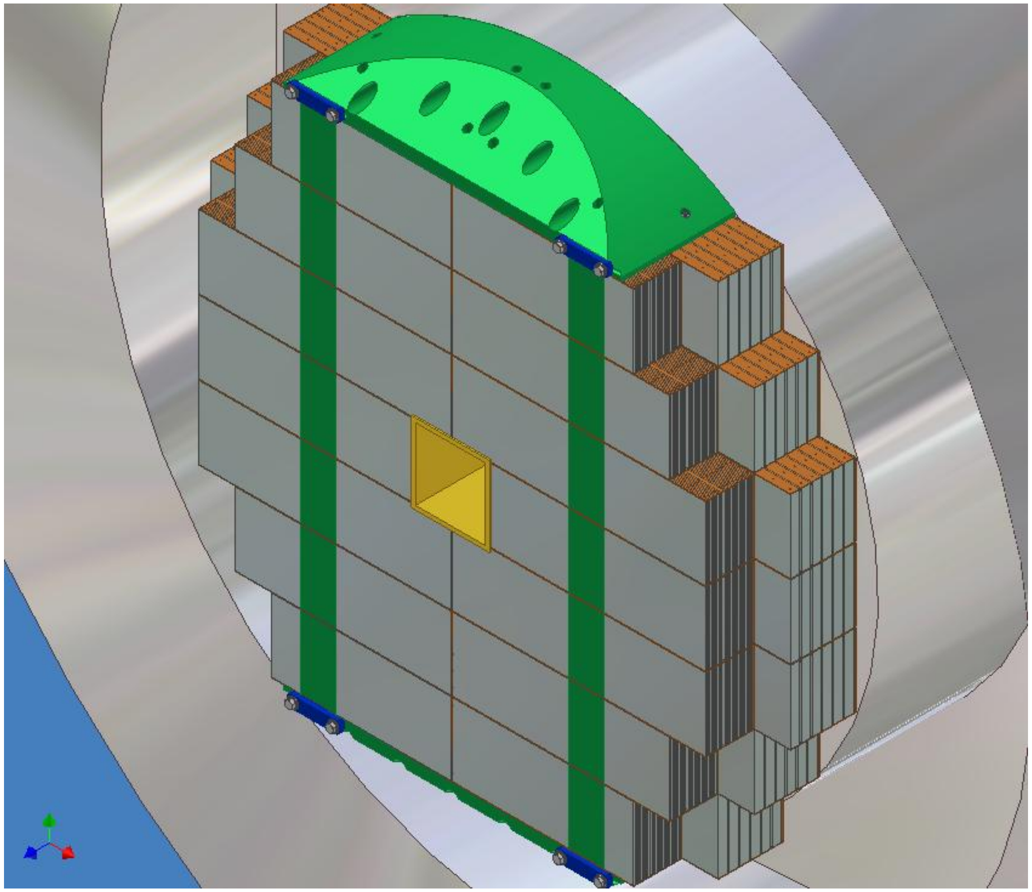
Readout gaps:

- Preshower and shower max:
  - 5 mm for StriPixels with an effective pad size of 0.5 x 0.5 mm^2
- All other gaps:
  - 2.5 mm for sensors with 15 mm x 15 mm pads

Sensor thickness: 525 μm

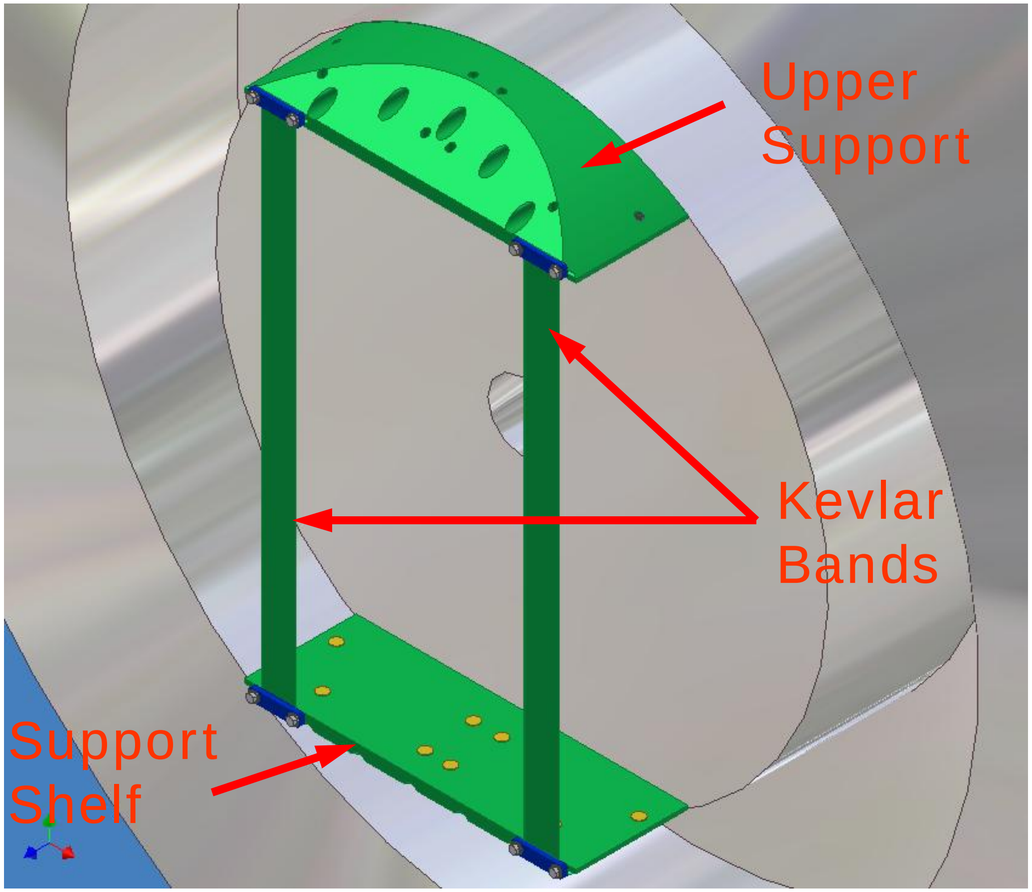
Features which May Interest ILC

- Cantilevered support from below & above
- Modular construction
- Granularity
- Fine-sampling gaps
- Cooling



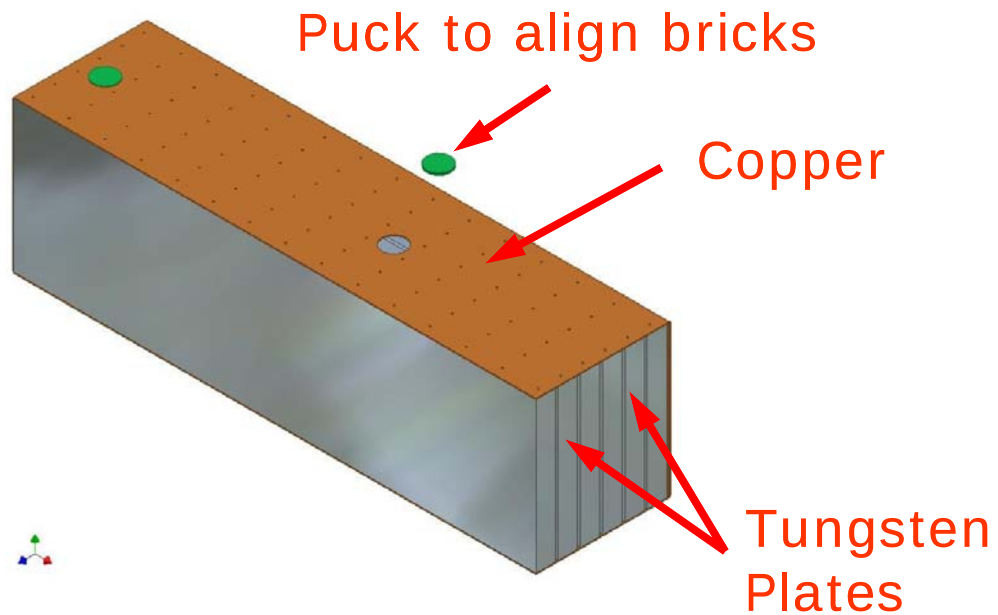
Support Features

- A lower shelf bolted to the magnet pole piece supports modules
- A similar piece above modules shares the load
- Kevlar bands connect
- the two pieces.
  - This use of bands may be quite interesting for the ILC.
- Modules are stacked after shelves are in place.



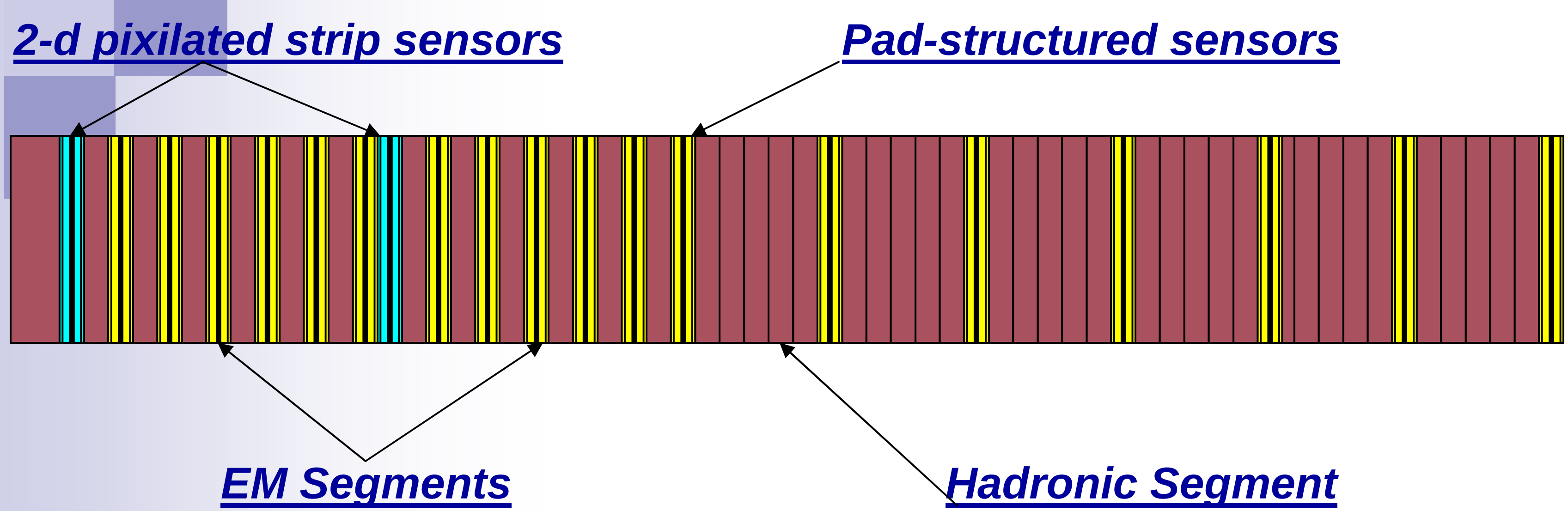
Module Features

- Modules (or bricks) consist of tungsten plates, sensors and their connections, and a copper exoskeleton.
- Except for fine granularity gaps, readout is off the end.
- The original intent was to keep modules “light” to allow hand stacking – probably not relevant to the ILC.
- Screws (M1.5) plus threaded holes in the tungsten plates hold a brick together.
- Copper sheets provide plate grounding.
  - Tungsten is gold-plated near screws.

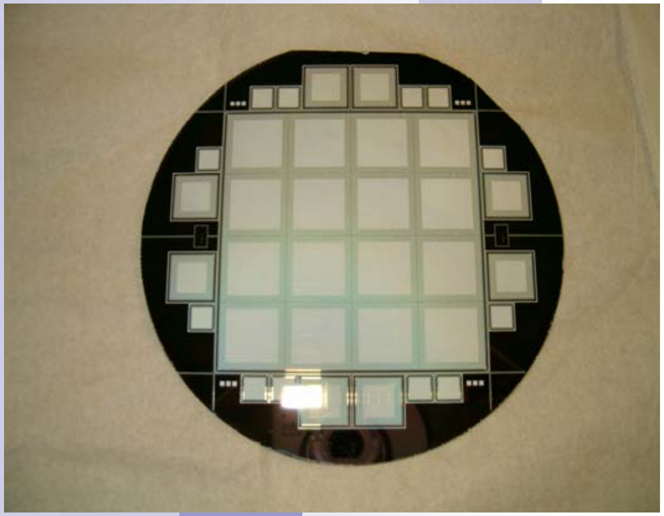


Module Features

- The majority of gaps have 15 mm x 15 mm pads with readout at the end of a module.
- For pre-shower sampling and sampling at shower max, crossed "StriPixels" provide a granularity of 0.5 mm x 0.5 mm.



Sensor R&D 2004-2005: BNL-MSU-UCR-RIKEN



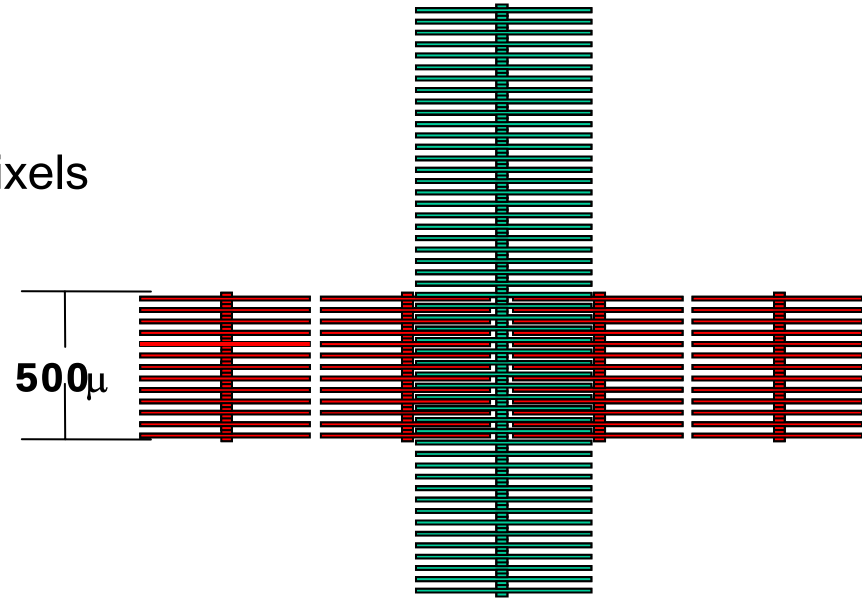
Silicon thickness = 525 µm

DC coupled, pad structured - ***completed***

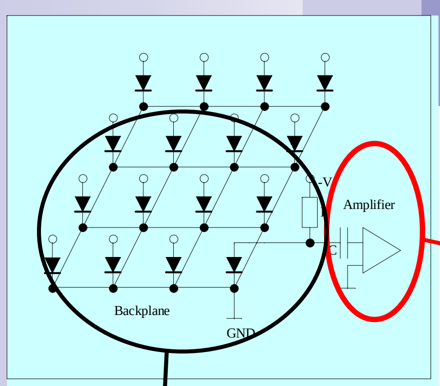
AC coupled, pad structued - ***completed***

DC coupled, r-biased, pad structured – ***at ELMA and ON Semi***

StriPixels



Pad cell design

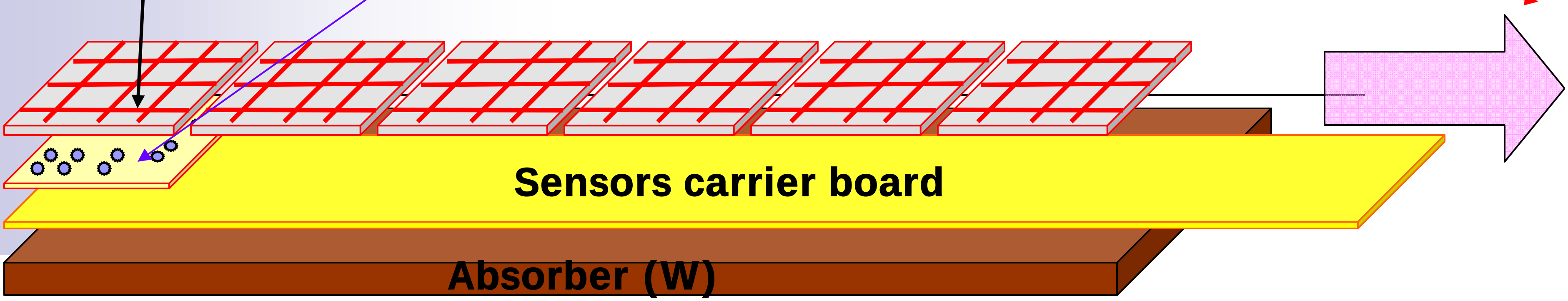


Detector ladder attached to the W plate

Decoupling capacitors are part of hybrid amplifiers

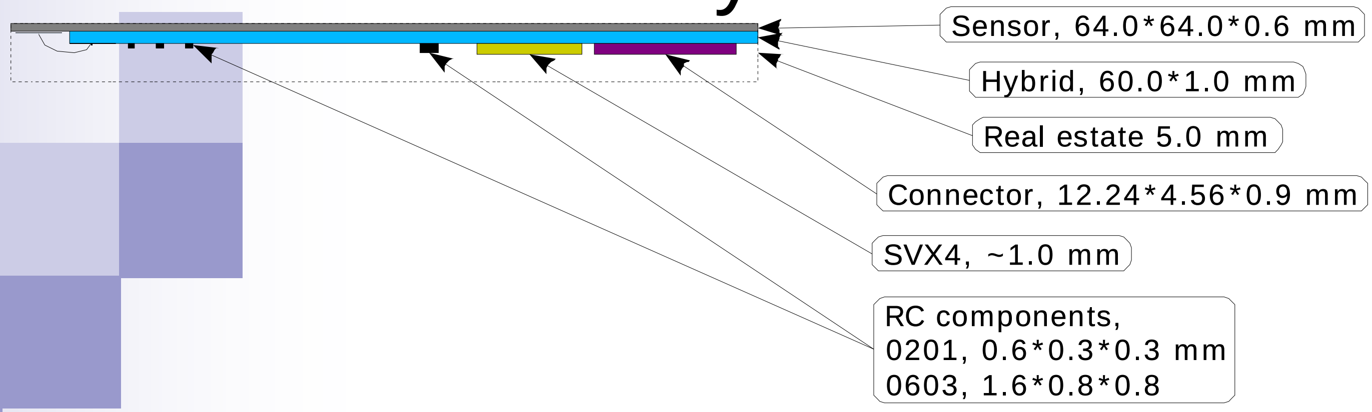
Bias resistors on silicon to simplify detector testing (may give up at a later time to save money)

Interconnect board to allow replacement of the sensor (last resort ...). Have bonding pads to wire-bond sensors and soldering pads to solder to the carrier board.



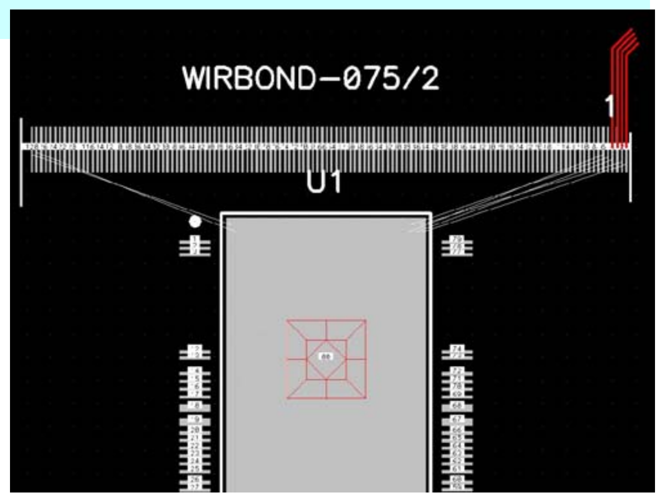
StriPixel cell design

Sensor+Hybrid



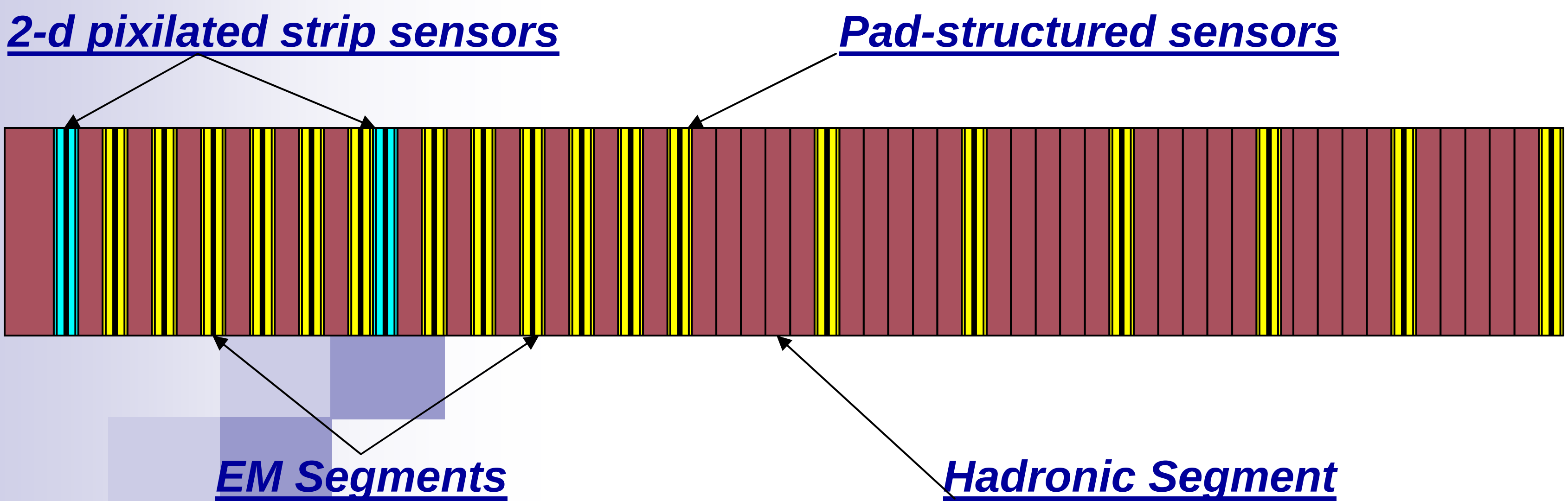
Status:

- Currently we are finishing layout of the PCB board using 0.075mm line width technology.
- The several prototypes will be manufactured at BNL
- The wire bonding will be done at BNL

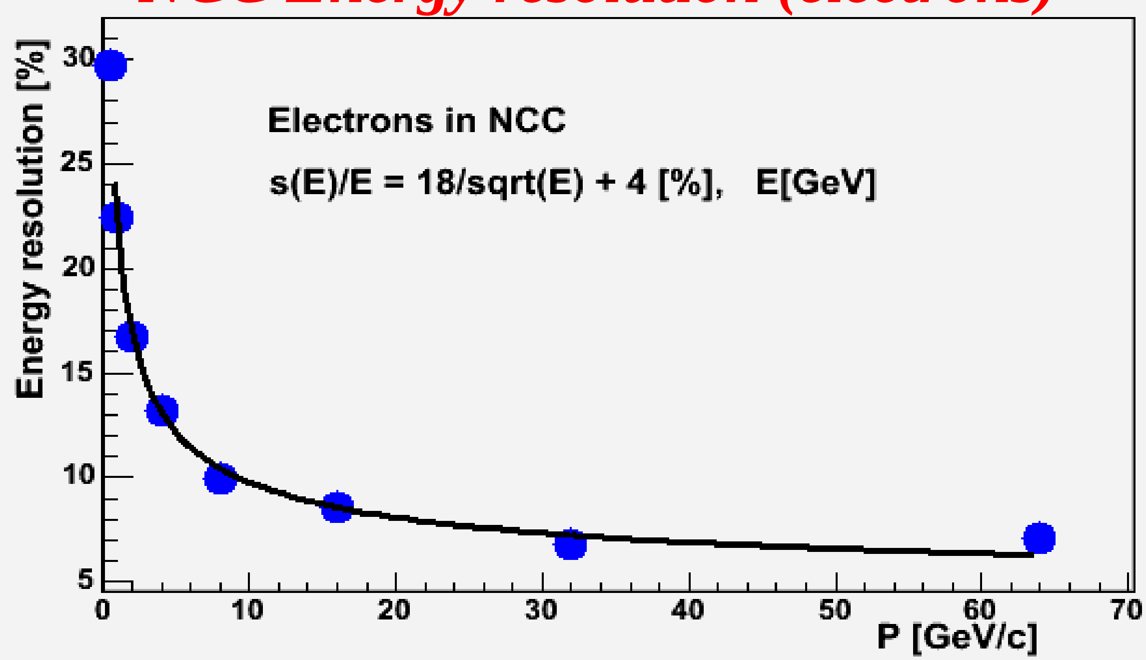


Cooling

- Operating temperature is expected to be room temperature or slightly above.
- Air cooling is assumed, although liquid cooling is not excluded.
- Forced-convection, rather than free-convection, is almost certainly required for gaps with StriPixels.
  - SVX-4 chips are located within those gaps.
  - Slots would be provided in the copper sheets above and below those gaps.
- Free convection may be satisfactory to cool electronics located at the outer ends of other gaps.



NCC Energy resolution (electrons)



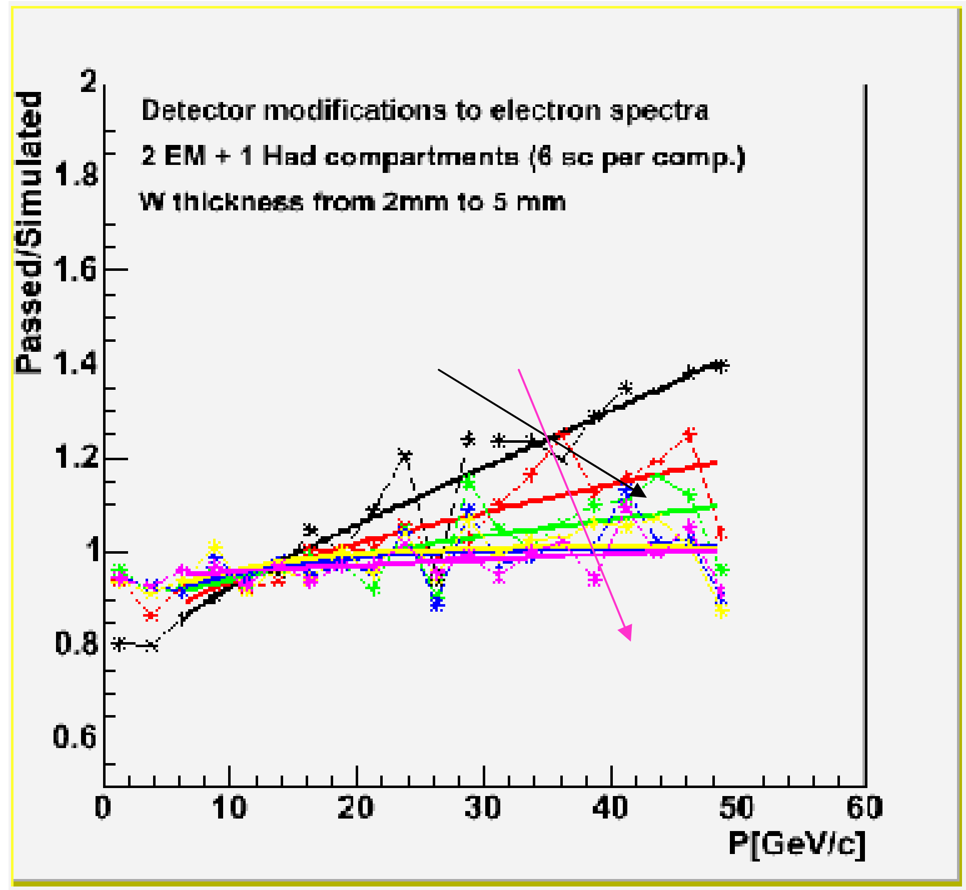
Energy resolution and p_T slope calculations

-Total depth fixed to 19 cm

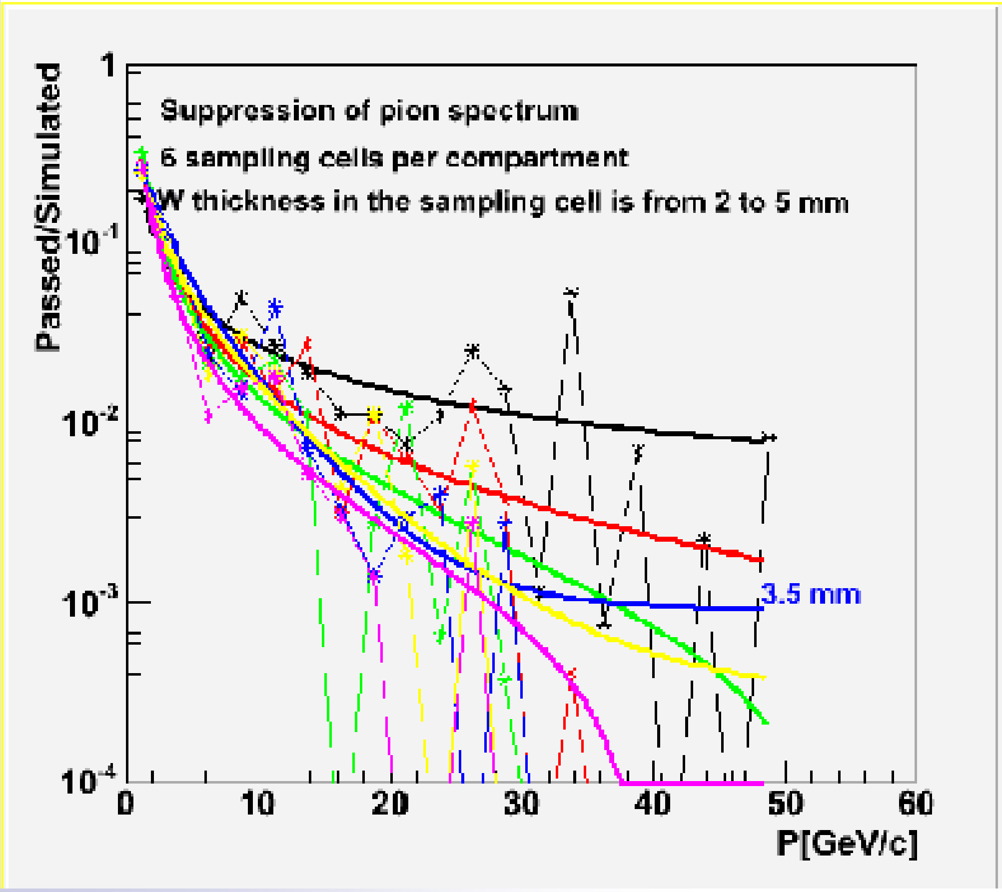
-Three segments (EM1/EM2/Hadronic)

-Plate thickness in EM segments varied from 2 mm up in steps of 0.5 mm

-Plate thickness in Had segment is “whatever fits” the total depth limit



Energy resolution and hadron rejection



-Correlations between plate thicknesses in em and hadronic segments push towards thicker plates in em segments;

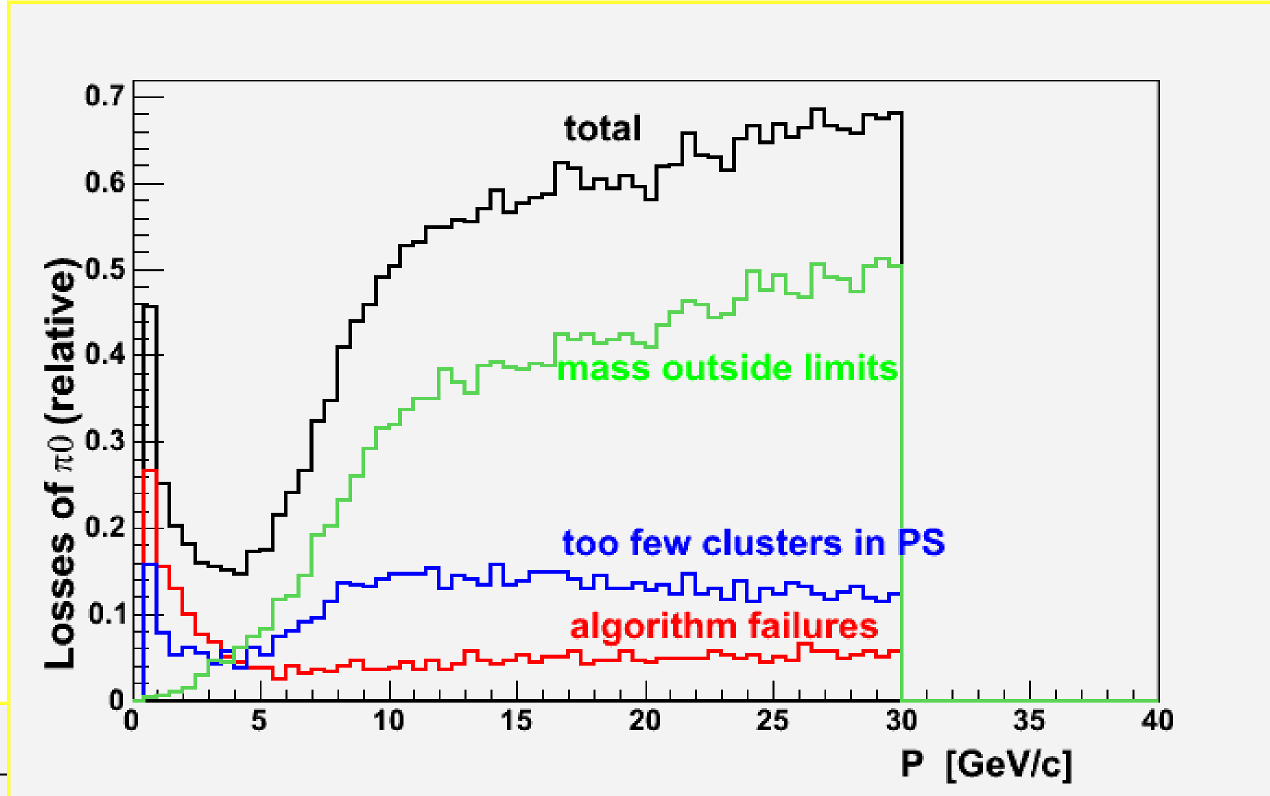
-Optimal em resolution and discrimination power is reached for W plates in em segments 3 mm or thicker;

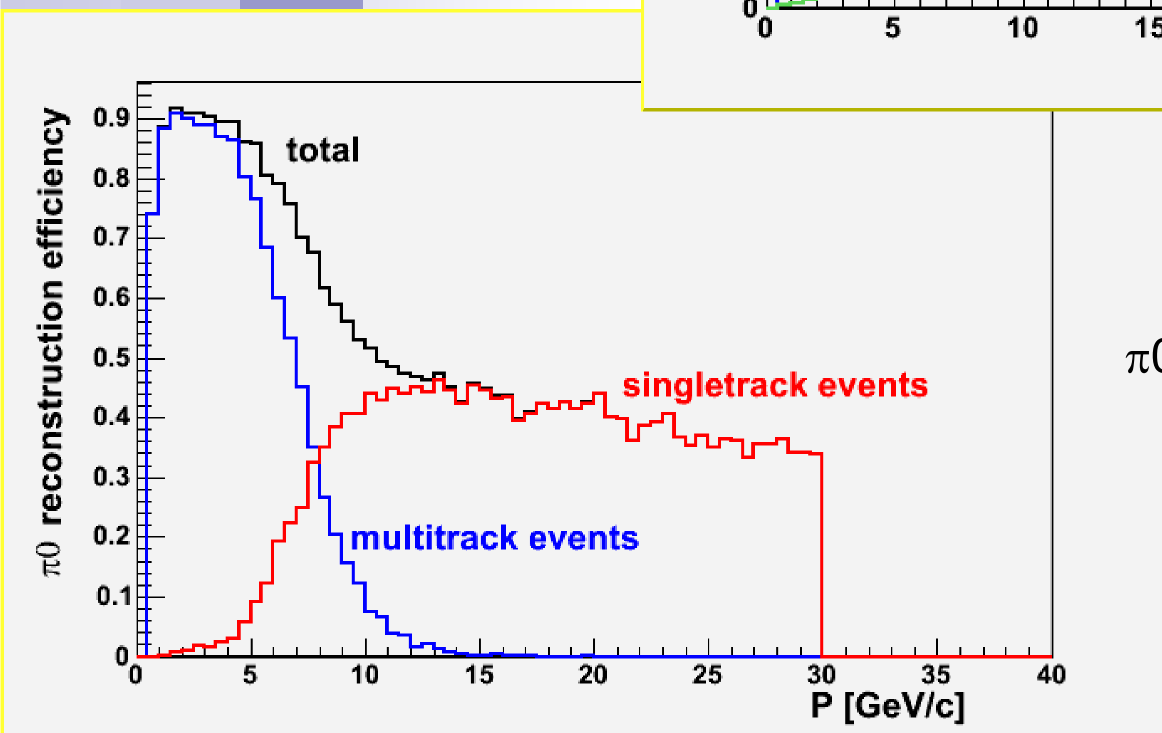
-For a fixed total calorimeter depth there could be advantages to using Pb instead of W in hadronic segment.

P0 – recognition/reconstruction

- Select clusters of amplitudes in all segments;
- Combine energy ordered clusters from different segments into “tracks”
- Define “regions of interest” in PS and SM for every cluster (cluster energy dependent);
- Discount clusters with only one hit in PS, for multiple hits in PS – compute separation between two hottest hits;
- Select two clusters in SM (constrained by hit separation in PS) and fit energy ratio;
- Use total track energy, hit separation from PS and energy ratio from SM to compute effective mass;
- Retain those within p0 window as “p0” candidates, build effective mass combinatorics among everything else.

π0 losses today

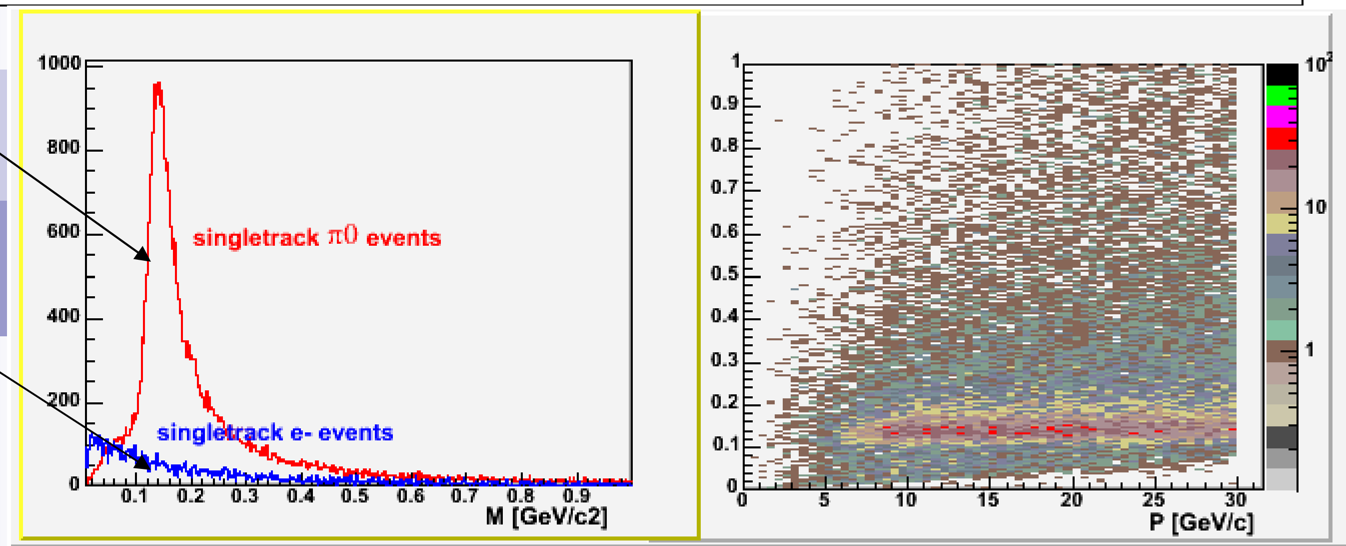


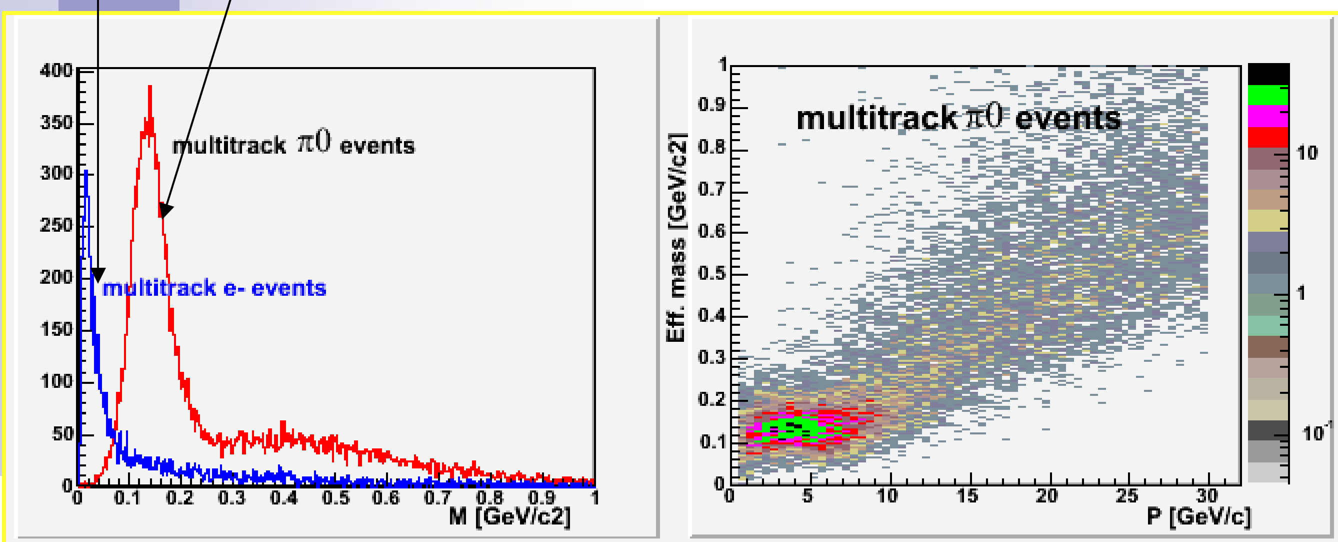


π0 efficiency today

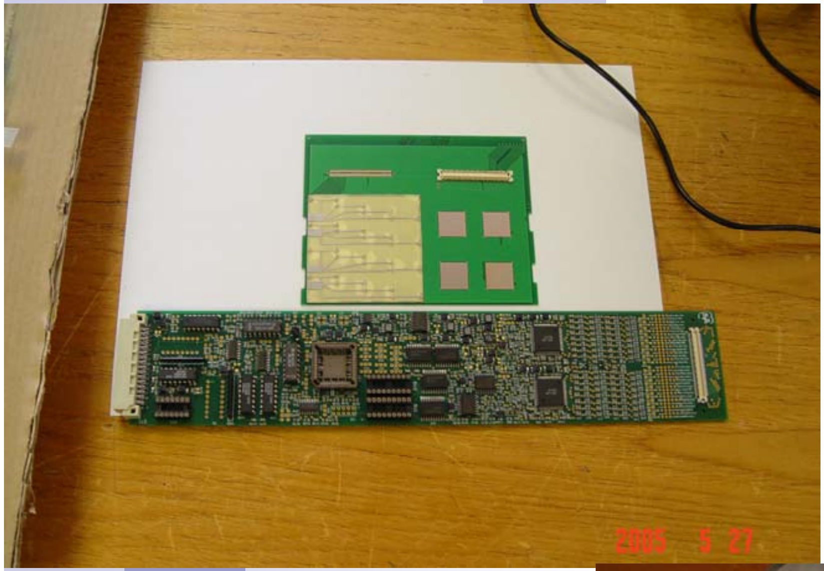
Claims to substantiate

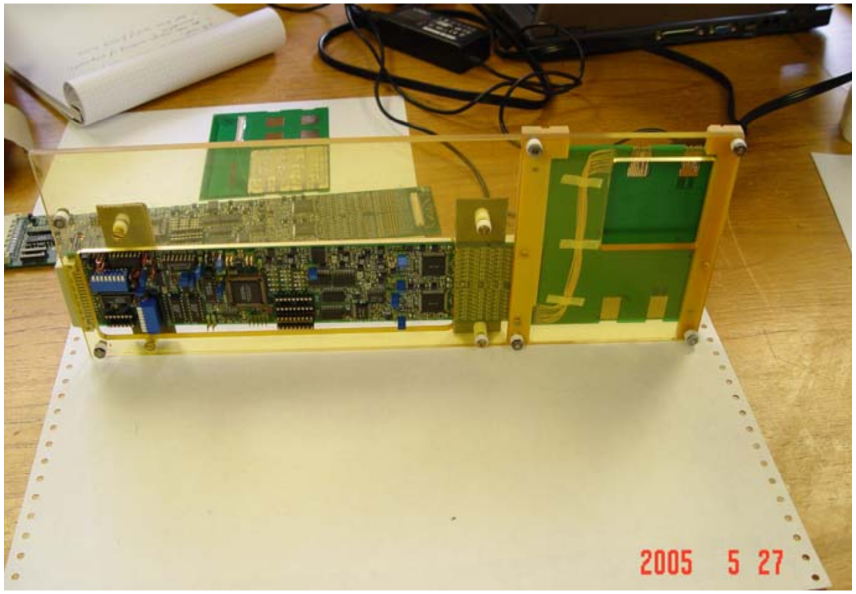
Single-particle ($\pi0$ and e) simulation in NCC

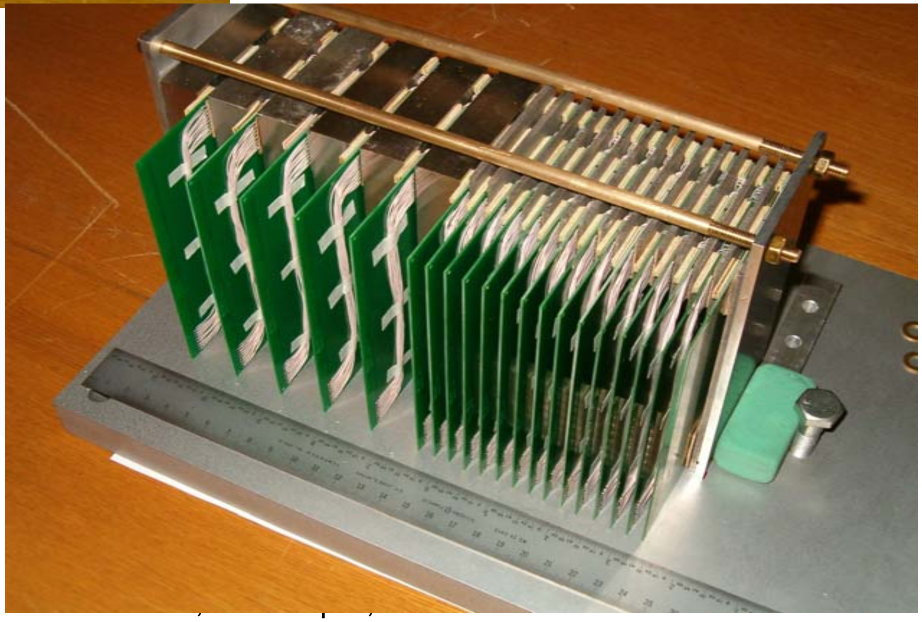




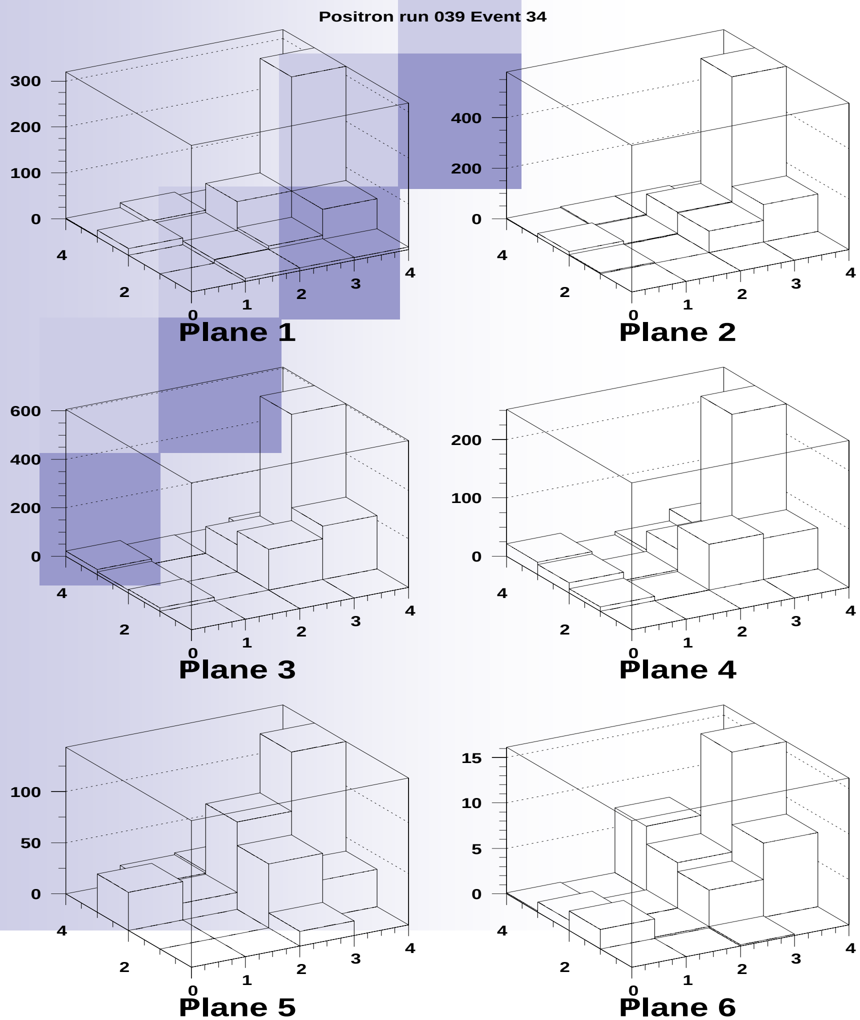
Proof of principle prototype

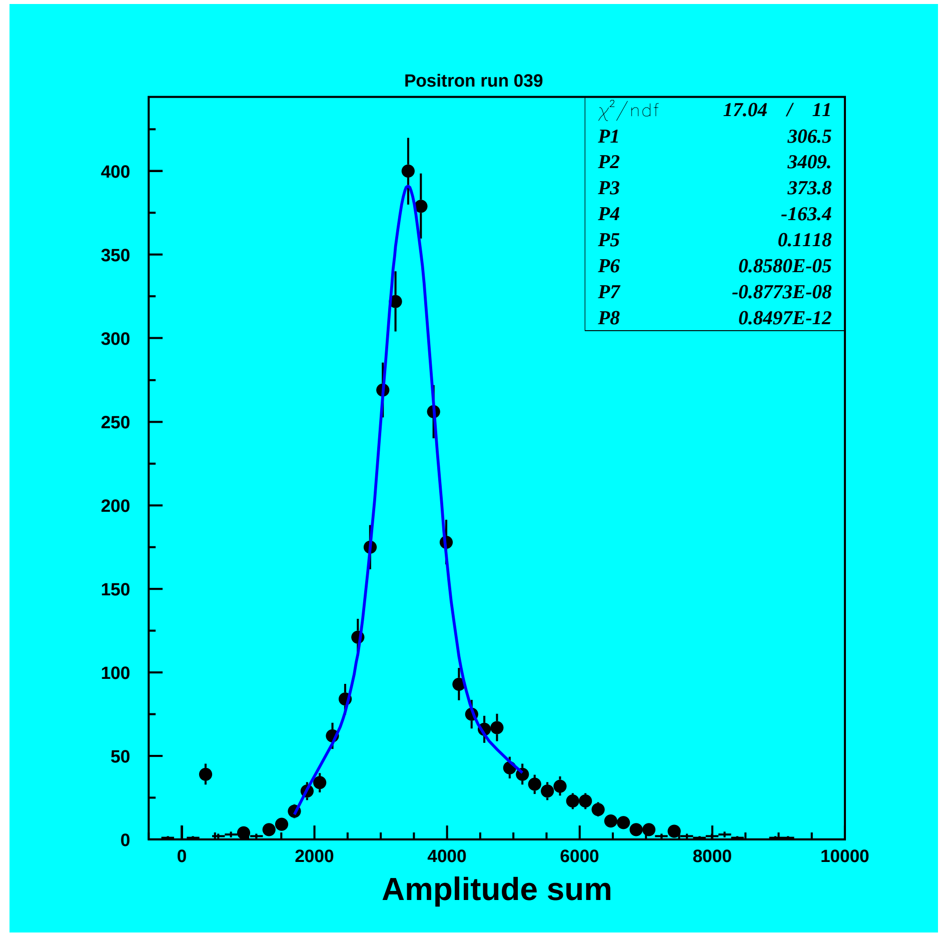




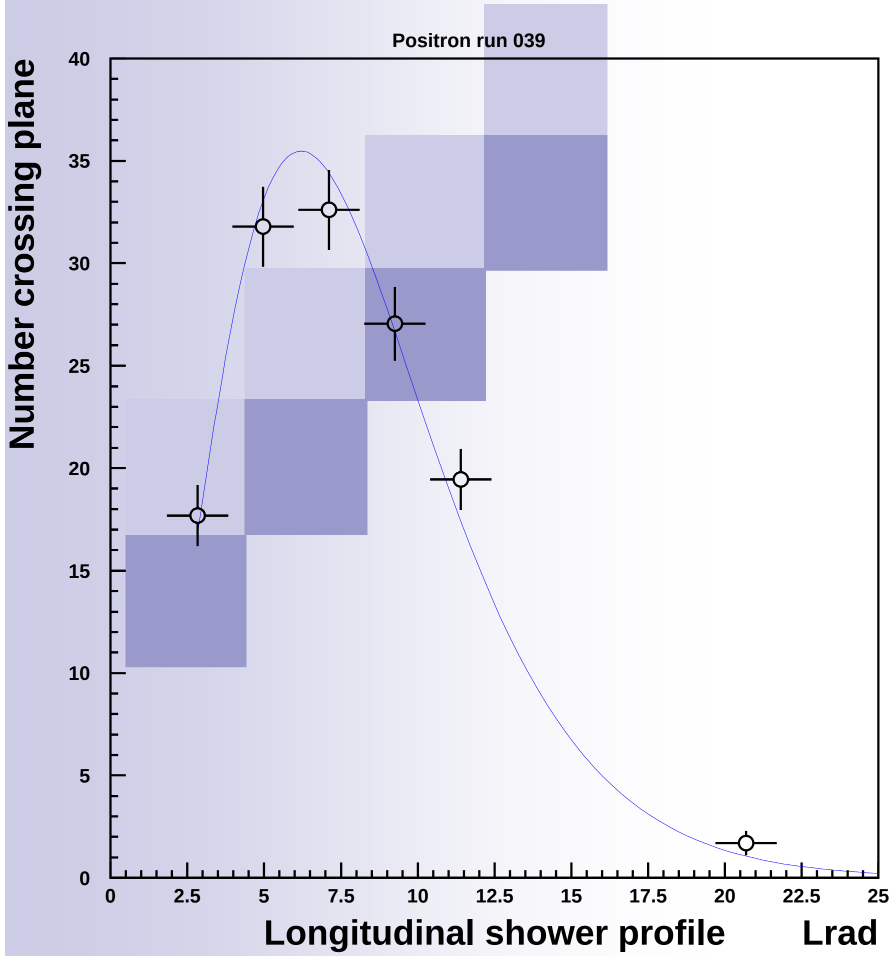


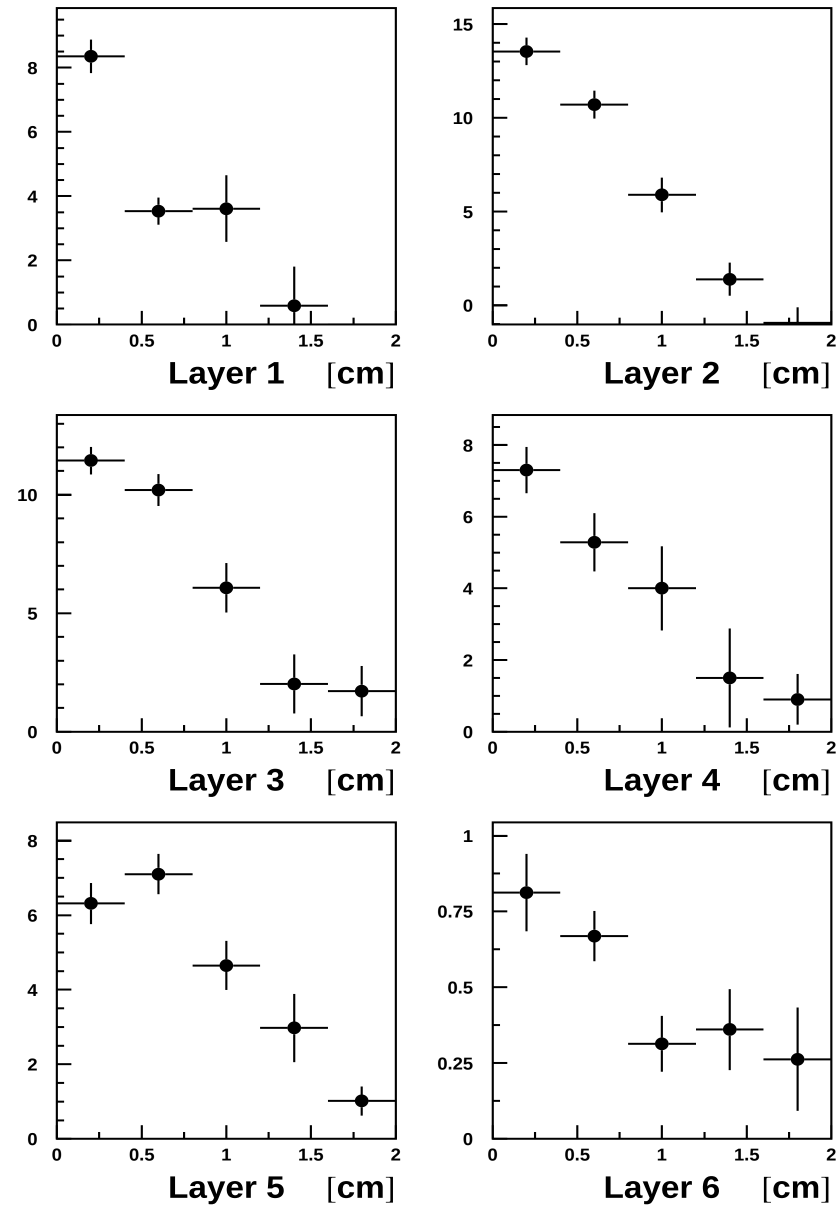
Energy resolution



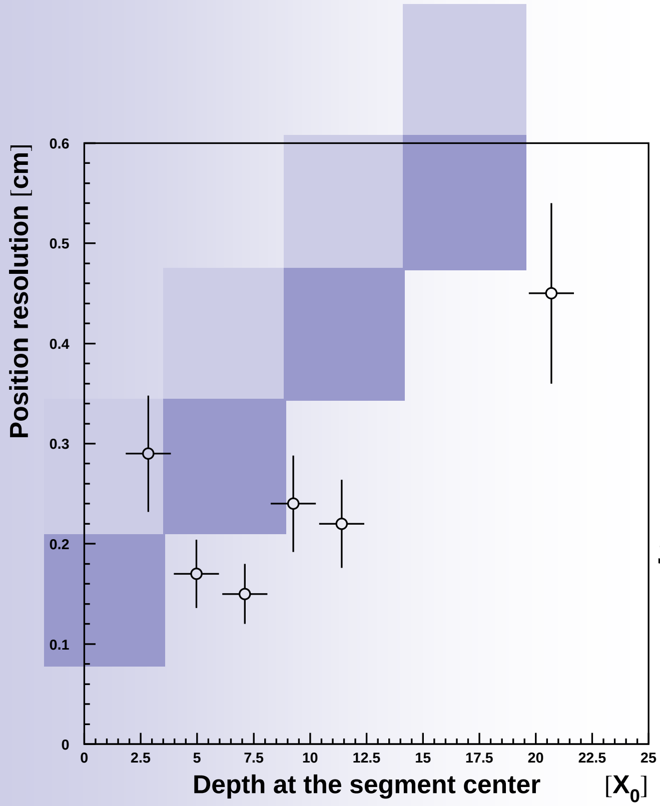


Shower shape

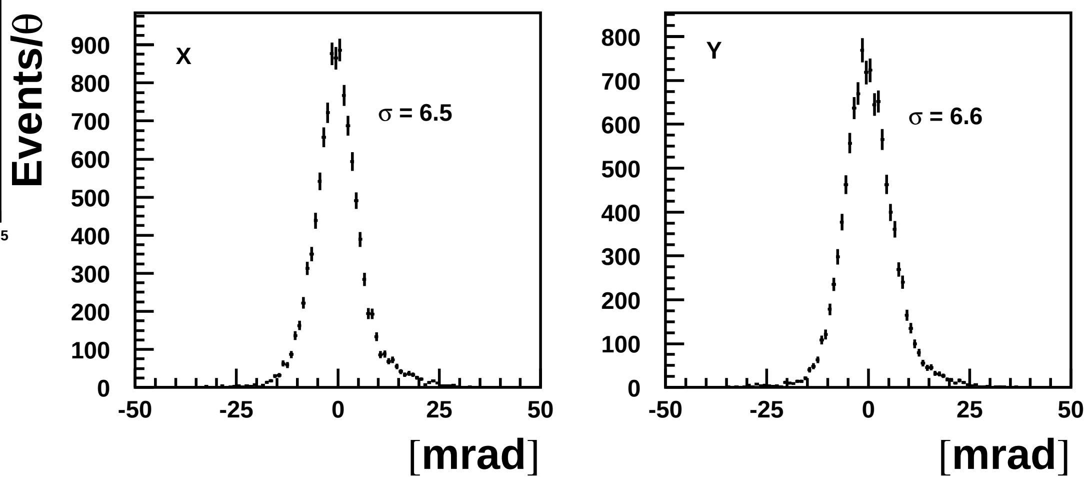




Pointing



Position resolution [cm]
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
Depth at the segment center
[X0]



Events/θ
X
σ = 6.5
900
800
700
600
500
400
300
200
100
0
-50
-25
0
25
50
[mrad]
Y
σ = 6.6
800
700
600
500
400
300
200
100
0
-50
-25
0
25
50
[mrad]

Summary

- ***There is a lot of momentum ……***
- ***Next two years are***
  - ***To substantiate the performance claims;***
  - ***To accumulate data to build analysis chain;***
  - ***To finish design and test production chain;***
- ***Three years for construction project are tough but feasible. We can get to the physics of saturation in 2010.***