General Intro: Neutral Particle Detection Facility

Tanja Horn

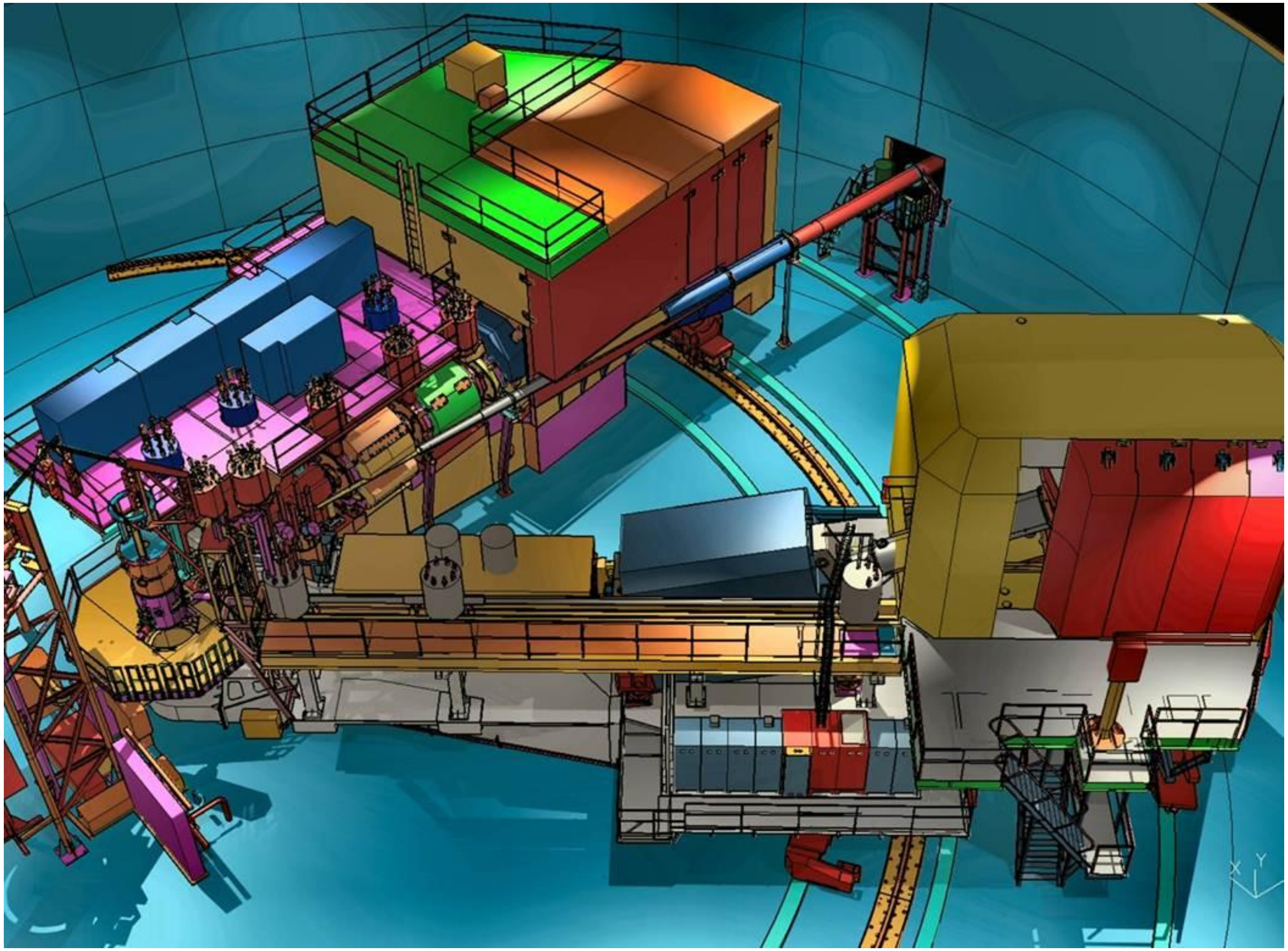
THE CATHOLIC UNIVERSITY of AMERICA

Workshop on DVCS and other Opportunties in Hall C at 12 GeV

Orsay, France, 10-13 November 2012

Hall C at 12 GeV

Two magnetic spectrometers: existing High Momentum Spectrometer (HMS) and new Super-High Momentum Spectrometer (SHMS)

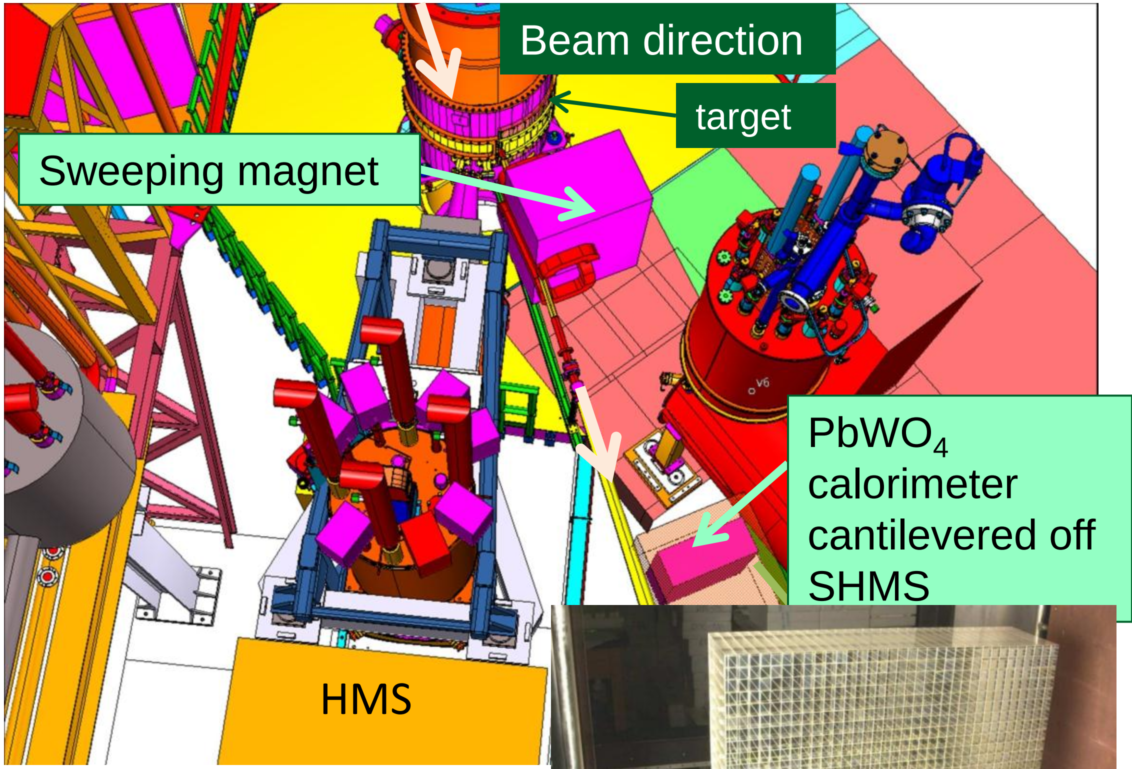


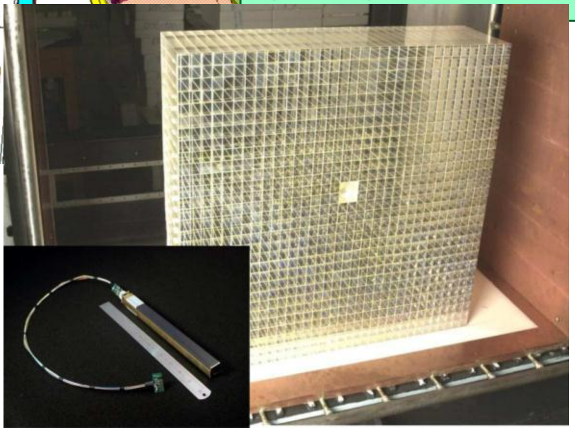
Neutral particle detection facility in Hall C

A new $PbWO_4$ calorimeter facility provides neutral particle detection in Hall C

Components of detector

- $PbWO_4$ blocks
- Small-diameter PMTs with new active HV base
- Temperature controlled frame
- Sweeping magnet
- Essentially dead-time-less digitizing electronics
- Pre-shower option

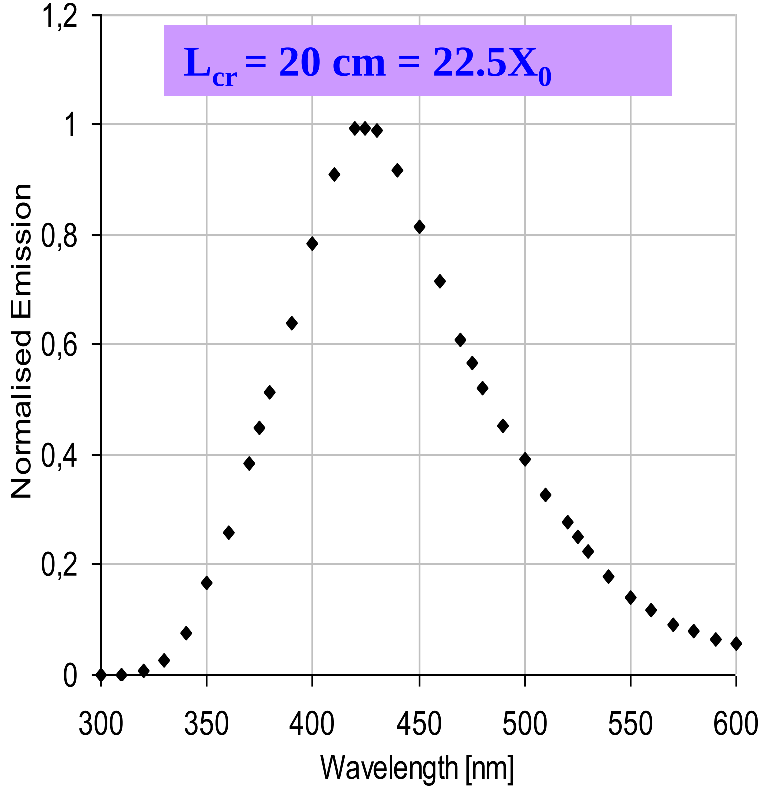




$PbWO_4$ crystals - general characteristics

Advantages ☺

- Dense and Radiation hard
- Short radiation length
- Fast



Disadvantages ☹

- Temperature dependence
- Low light yield

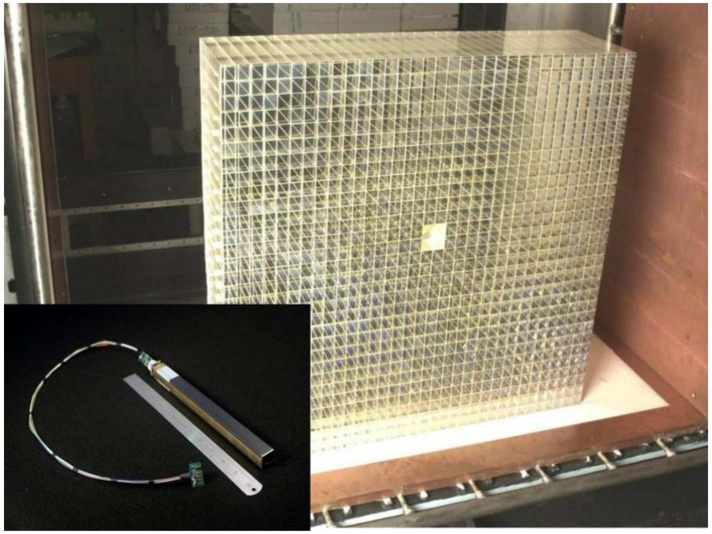
Properties of $PbWO_4$	
Density	8.28 g/cm^3
Radiation length	0.89 cm
Interaction length	19.5 cm
Moliére radius	2.2 cm
Emission peak	420 nm
Light yield	120 photons /MeV
Radiation hardness	10^7 rad

Experiments using $PbWO_4$: CMS, Phenix, Panda, PrimEX

$PbWO_4$ crystals in detector

Existing from PrimEX experiment

- Assembled with *Hamamatsu R4125* [d=19mm, 8.7E+5 gain at 1.5 kV anode voltage, rise time 2.5 ns]

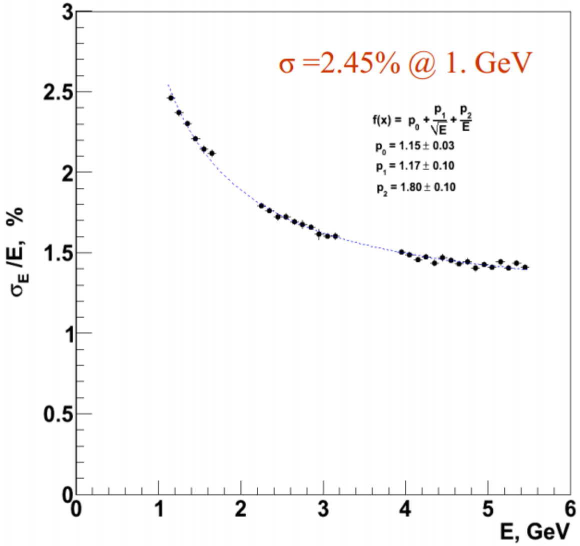


Detector features

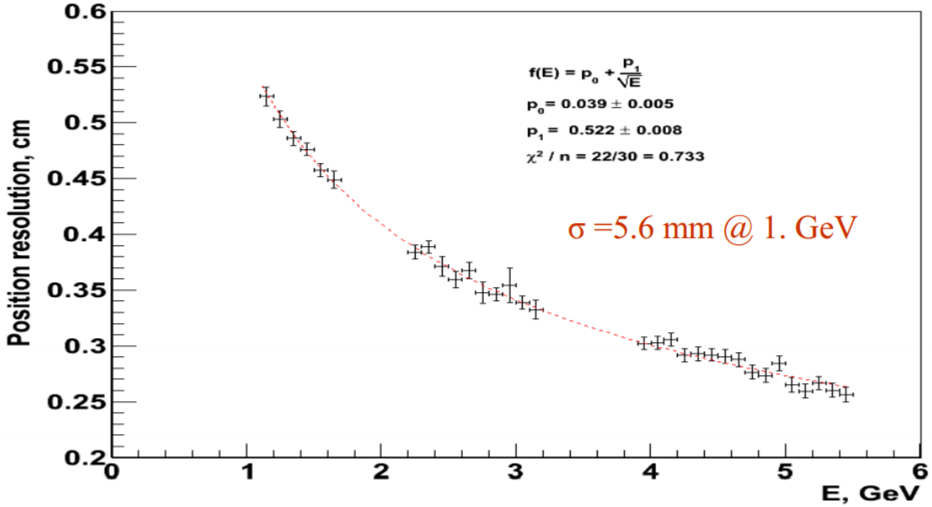
36 x 31 matrix of $PbWO_4$ blocks
Individual crystal dimensions: 2.05 x 2.05 x 18 cm^3

Covers 74x64 cm2 or 25msr at distance 4m from target

Energy resolution

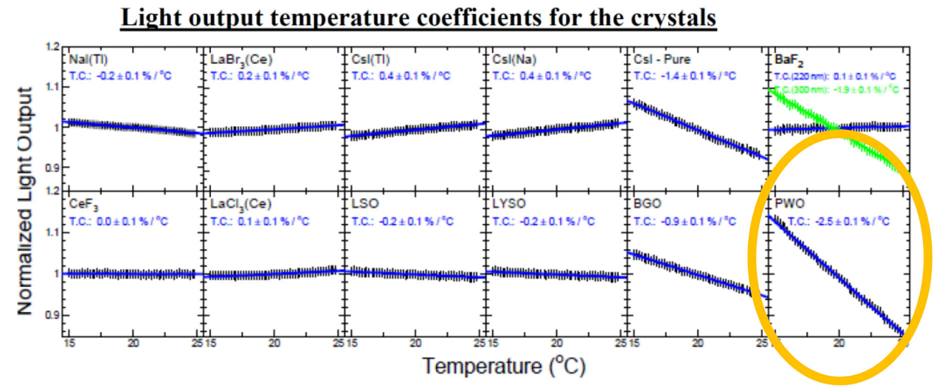


Spatial resolution



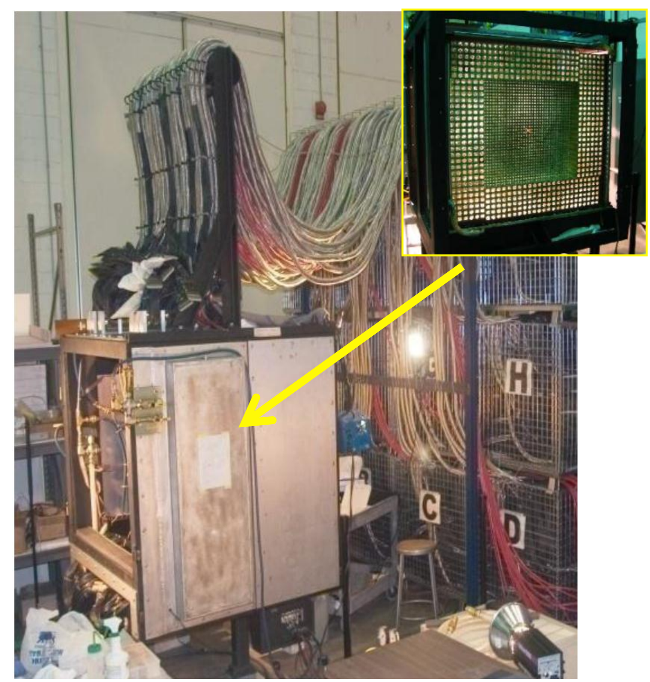
Temperature controlled frame

- $PbWO_4$ crystal light yield depends strongly on temperature
  - ➢ approximately 2% per °C



- For experiments, temperature must be stable to about 0.1°C to achieve energy resolution of 0.5%

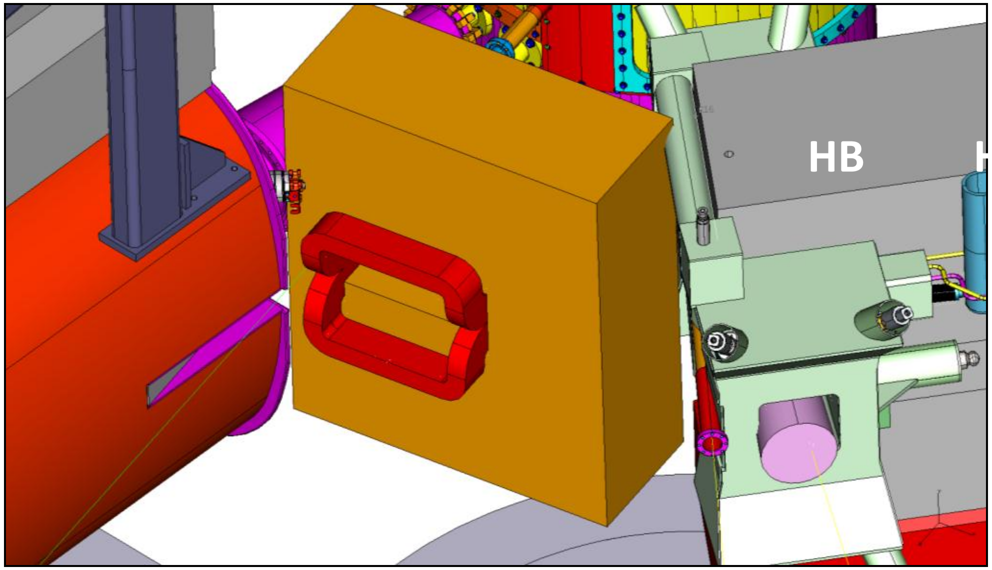
- Temperature controlled frame components
  - ➢ Temperature sensors
  - ➢ Copper plates for cooling
  - ➢ Water cooling system



Example: PrimEx temperature controlled frame

Sweeping magnet

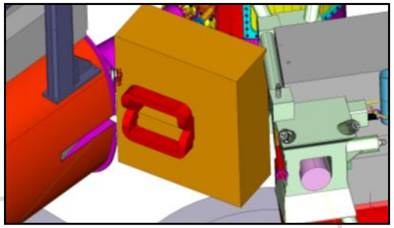
- Resistive magnet based on Hall C horizontal bend (HB) design for SHMS
  - Normal-conducting copper coil magnet
  - Aperture: 35x36cm^2
  - Magnetic field strength: 0.3 T-m
- Designed to work with existing JLab power supplies *[P. Brindza, 2012]*



Sweeping magnet schematic shown with HB

Hall C Sweeper Power and Cooling

P. Brindza



Option A			Option B		Option C		Option D	
Int B.dl	0.3114	T.M	0.3114	T.M	0.3114	T.M	0.311	T.M
curdent	750	A/cm^2	750	A/cm^2	750	A/cm^2	750	A/cm^2
coil A	2.9	cm	2.9	cm	2.9	cm	2.9	cm
Coil B	27.4		27.4		27.4		27.4	
Coil Area	79.46		79.46		79.46		79.46	
NI	119190		119190		119190		1E+05	
Na	2		4		4		4	
Nb	40		54		64		80	
Ins	0.01	in	0.01	in	0.01	in	0.01	in
Conda	1.3208	cm	1.0033	cm	0.84455	cm	0.686	cm
Condb	1.3208	cm	1.0033	cm	0.84455	cm	0.686	cm
Actual A	2.6416	cm	4.0132	cm	3.3782	cm	2.743	cm
Actual B	26.416	cm	27.0891	cm	27.0256	cm	27.43	cm
Cond A	0.5	in	0.375	in	0.3125	in	0.25	in
Cond B	0.5	in	0.375	in	0.3125	in	0.25	in
Cond hole	0.25	in	0.1875	in	0.15625	in	0.125	in
Cond Area	1.2962	cm^2	0.72912	cm^2	0.50633	cm^2	0.324	cm^2

Digitizing electronics

Flash ADCs sample the signal every 4 ns and store the information in internal memory

– When trigger received, the samples in programmable window around the threshold are read out for each crystal that fired

JLab fADC-250 module

fADC system provides:

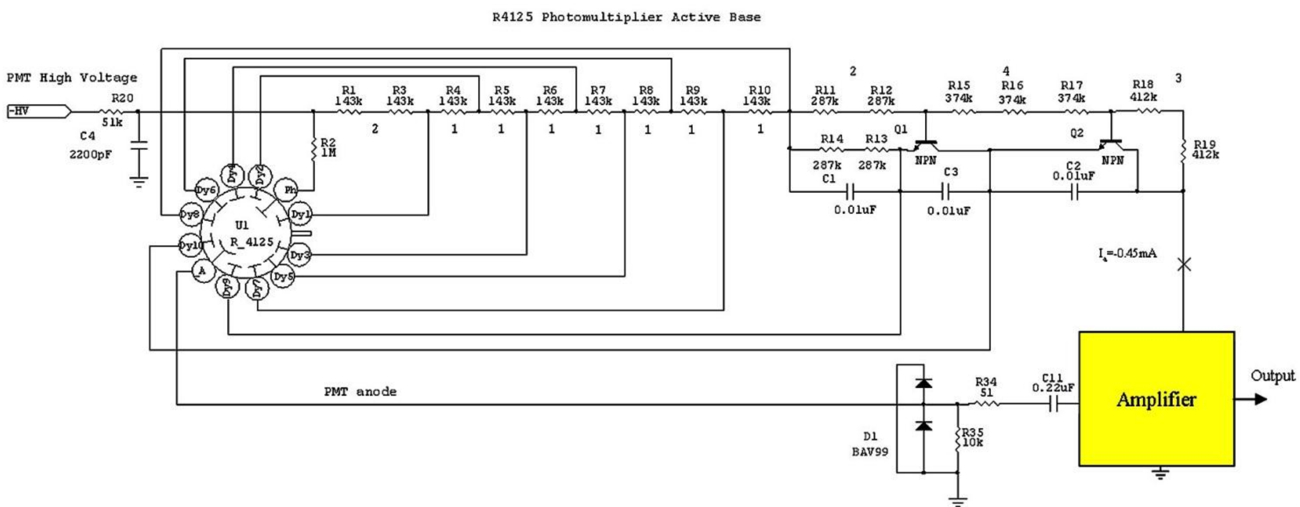
- **Low dead time** since readout of FPGA does not interfere with digitization

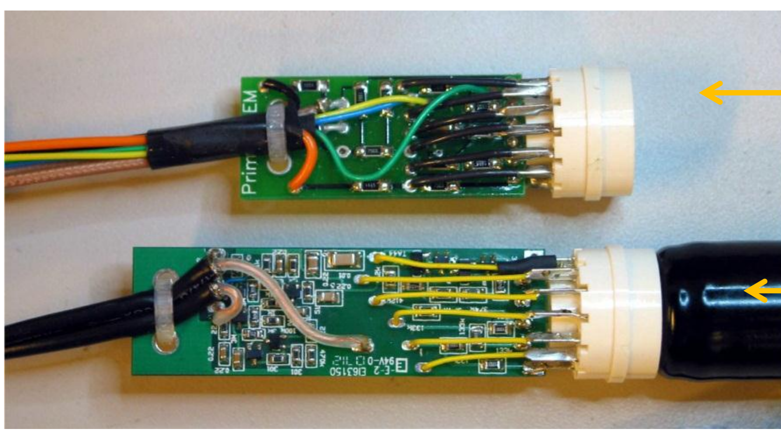
- **Precision signal processing off-line**
  - Sampled signals can be fitted and integrated off-line eliminating issues with pile-up, baseline shifts etc.

- **Support both high-rate operations in singles** mode as well as advanced, **trigger-level cluster finding in coincidence mode**
  - DAQ system supports windows up to 200-300 ns at 1 kHz and 100% occupancy (~200 MB/s)
  - Coincidence trigger takes advantage of fADCs ability to perform pulse integration and pass it along for cluster finding, e.g, to select DVCS events

High voltage base design

- New active base design has lower total impedance and has two added high-voltage transistors to the last two dynodes (9&10)
  - Reduce current and do not change the division ratio

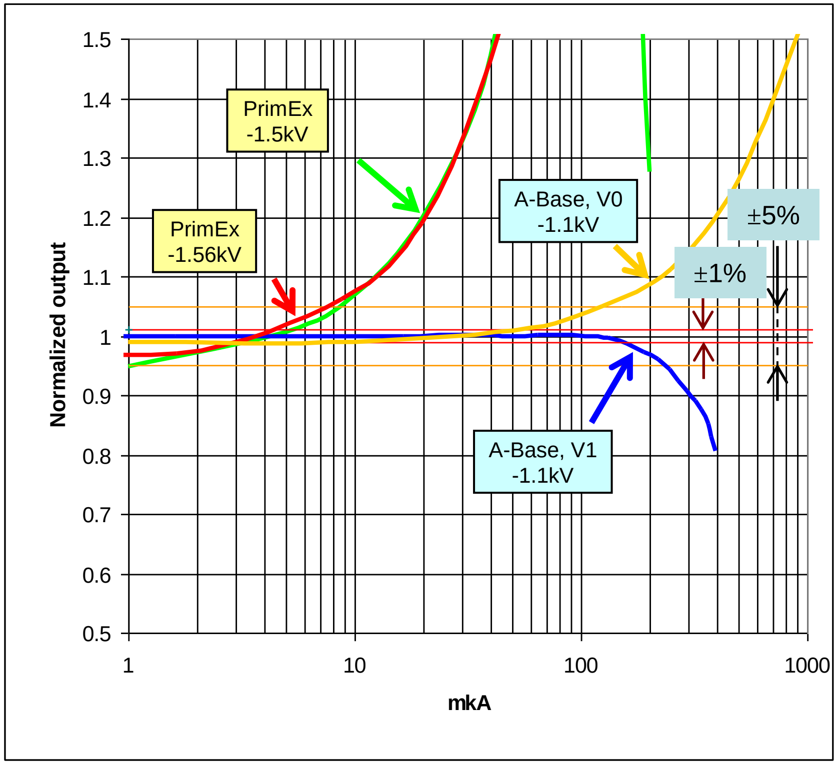


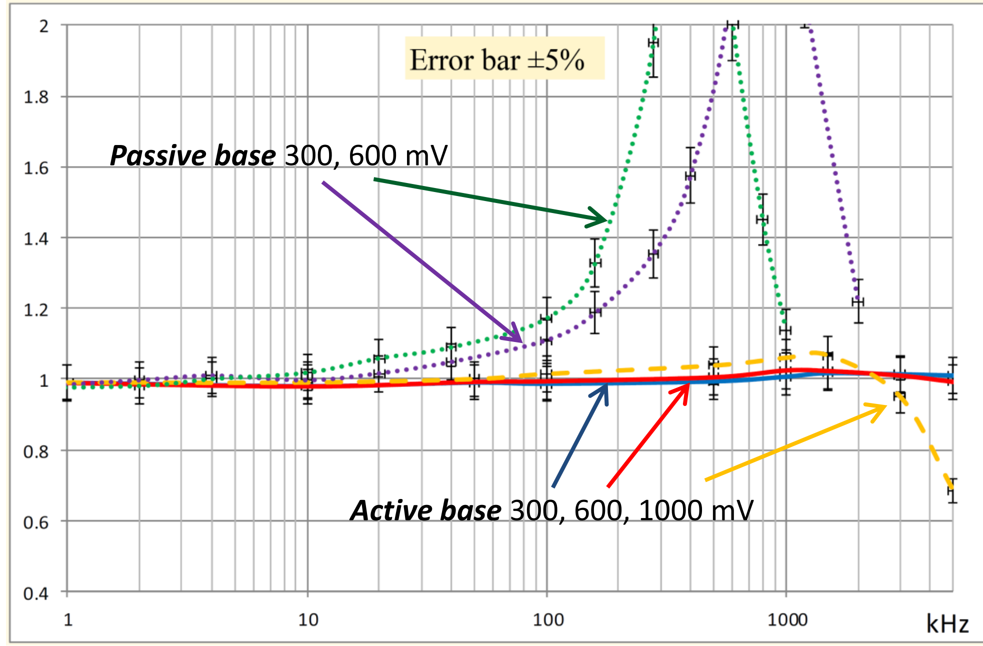


PrimEX ***passive*** base design

New ***active*** base design *[Popov et al., 2012]*

Active bases for PMTs





Active base equivalent output integral current is about 400 mkA and outperforms PrimEX passive base by factor of ~25

Active base has factor 10 lower anode current with linear operation rate over factor 50 higher

The new active base design out performs the PrimEX PMT/base

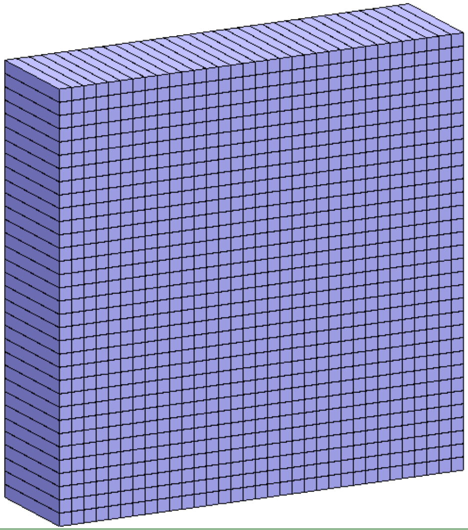
- Increases the maximum linear count rate: from 30kHz to 1.2MHz
- Improves the gain stability from ±5% to ±1%

[V. Popov, H. Mkrtchyan, "New Photomultiplier Active Base for Hall C Jlab Lead Tungstate Calorimeter" (2012)]

GEANT4 Detector Simulations

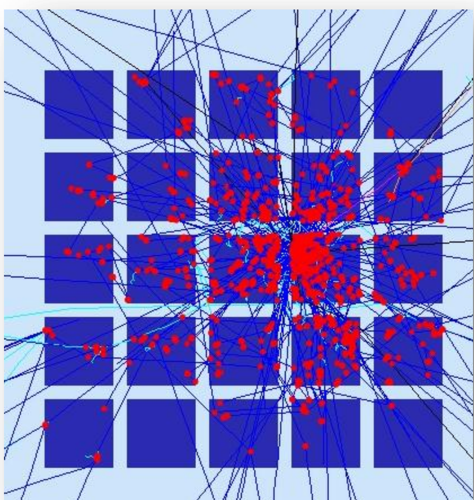
- **Simulation based on Hall B/GEMC package**

  Nominal assumptions:
  10cm LH2 at 1uA



Calorimeter matrix in GEANT4 simulation

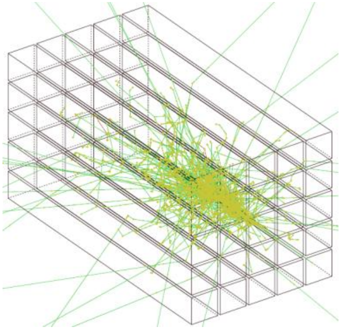
- **Single photon hitting the small detector in GEMC/GEANT4**

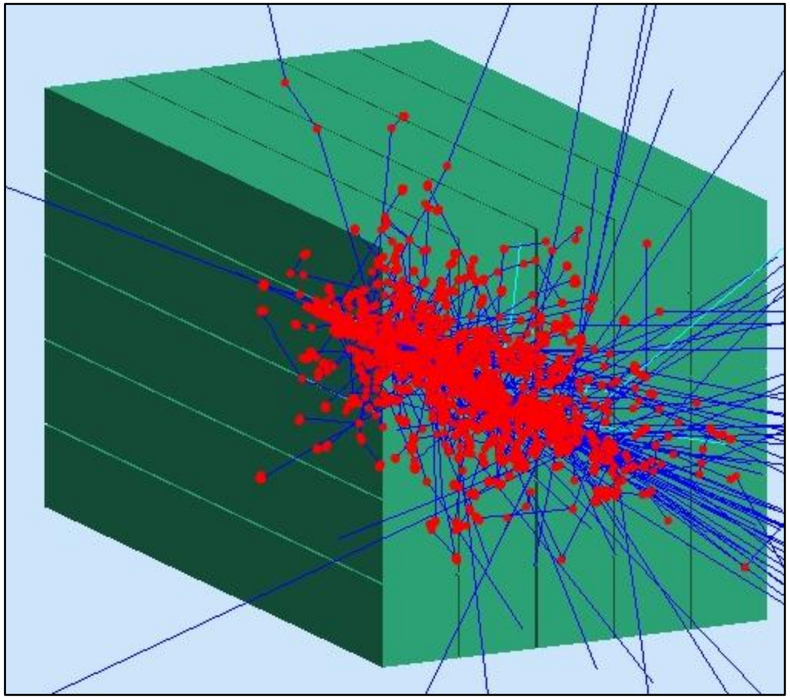


Shower spreads in the neighbor crystals, making possible a sub-crystal resolution

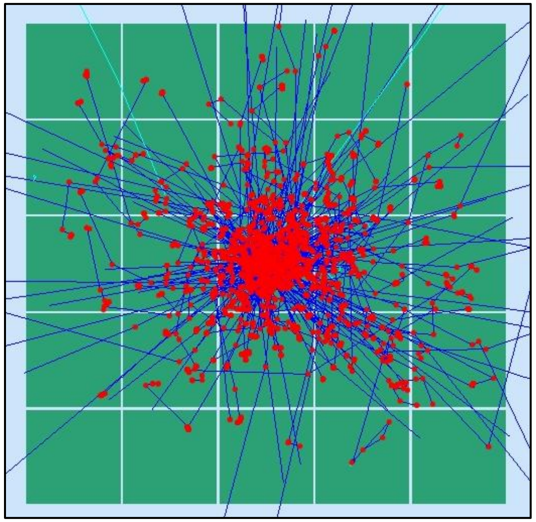
Shower profile

3 GeV photon hitting the center of the crystal

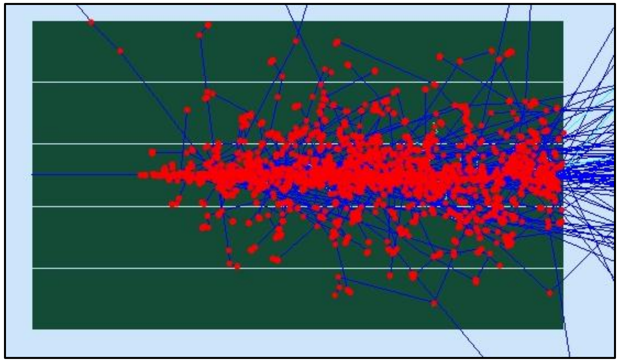




3D view



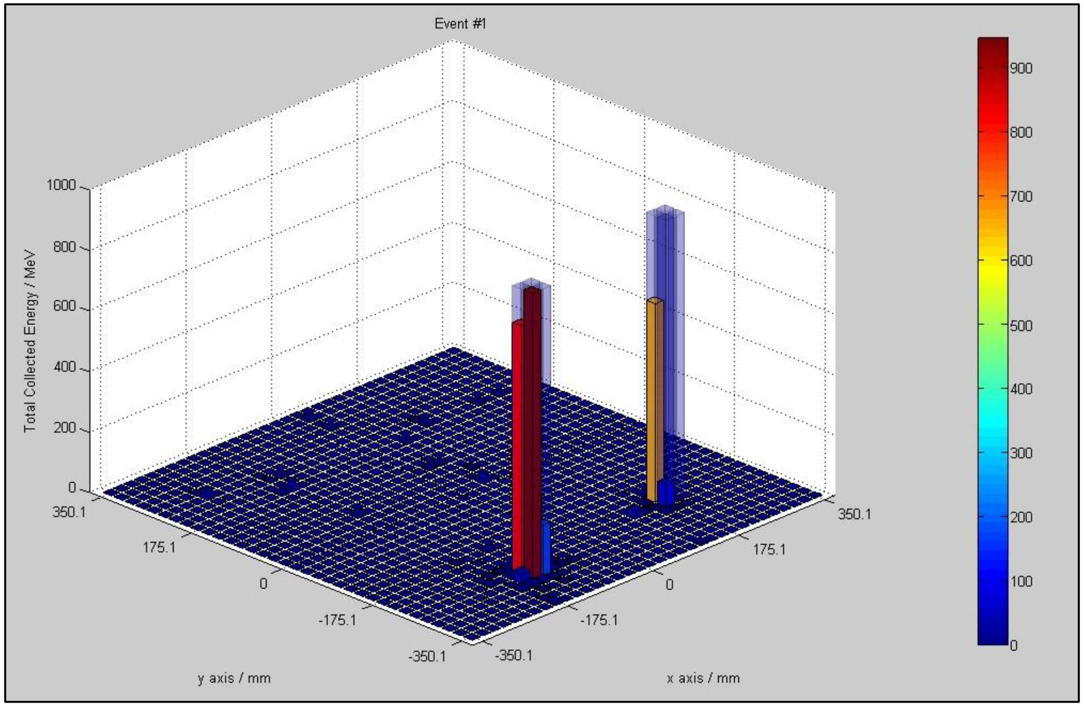
Front view



Side view

Cluster finding algorithm

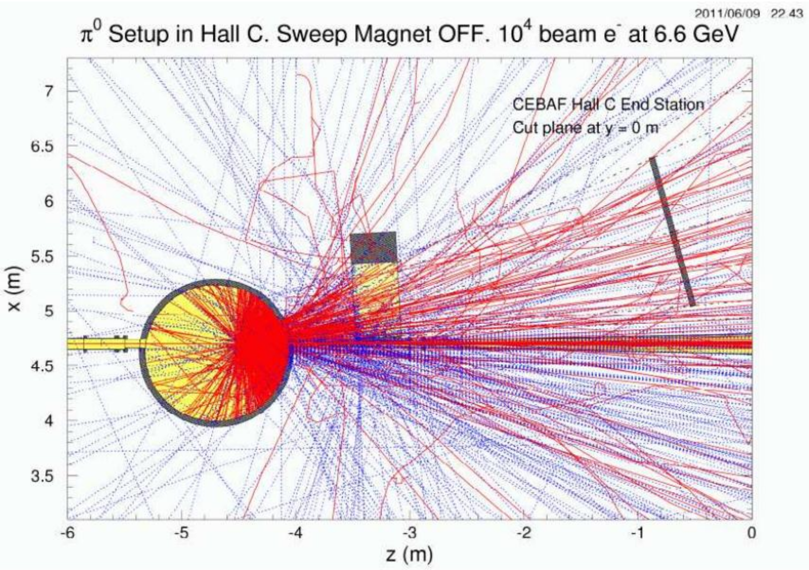
Simple case: NO background

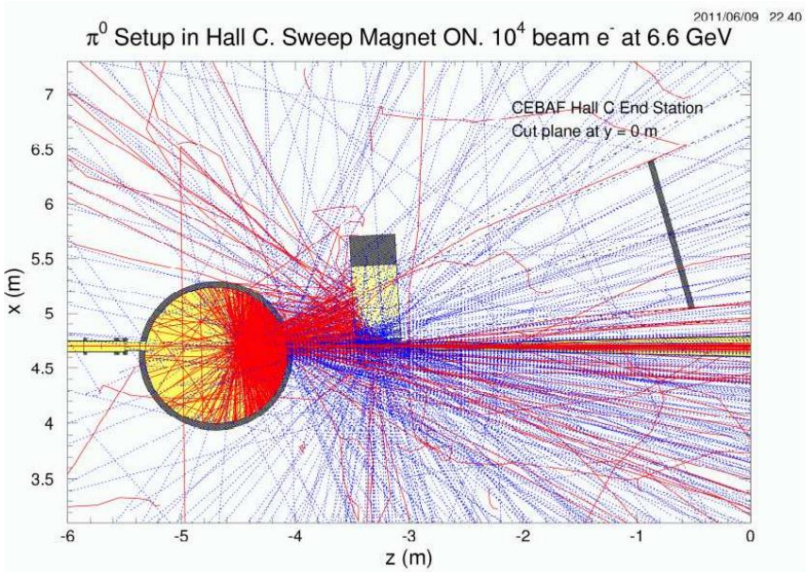


- Find two crystals with greatest energy and with a minimum distance between them
- Make a square cluster using the energetic crystal to maximize the energy in the cluster
- Fit a 3D Gaussian using the crystals in the clusters

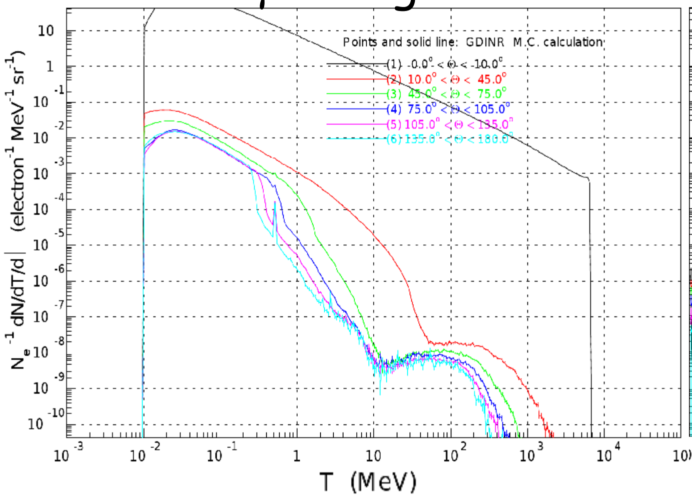
Simulations of the calorimeter

- **Magnetic field before the detector to reduce charged particles background**

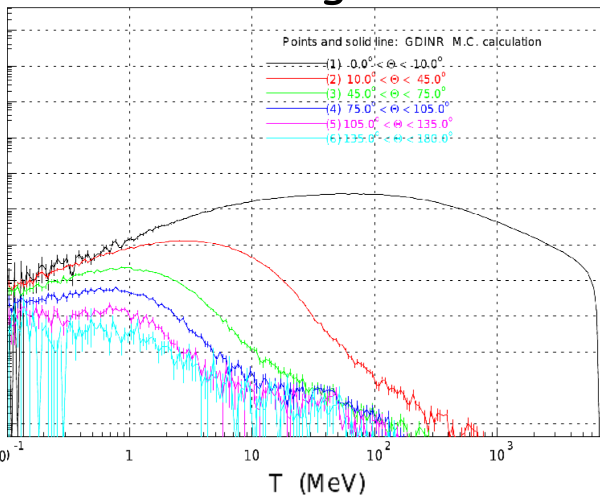




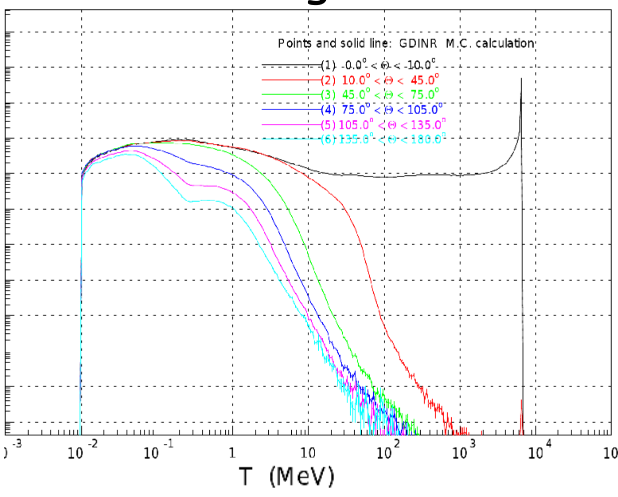
γ background



e^+ background

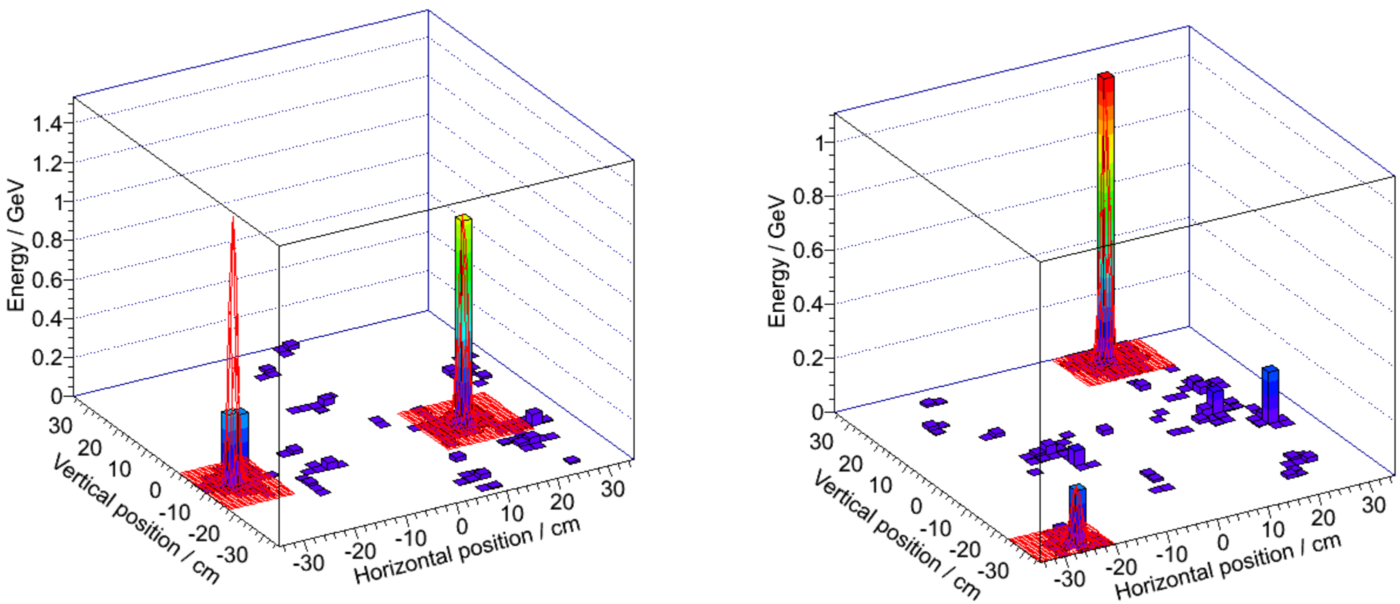


e^- background



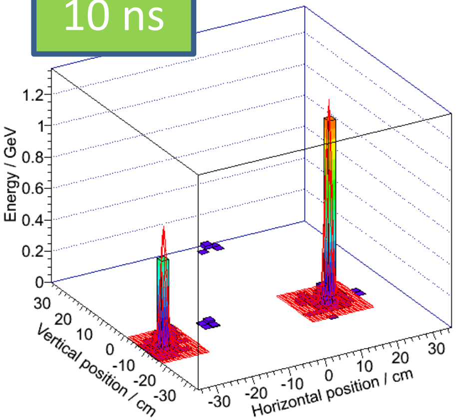
Simulations including background

- **Events with two photons from π^0 decay and background**

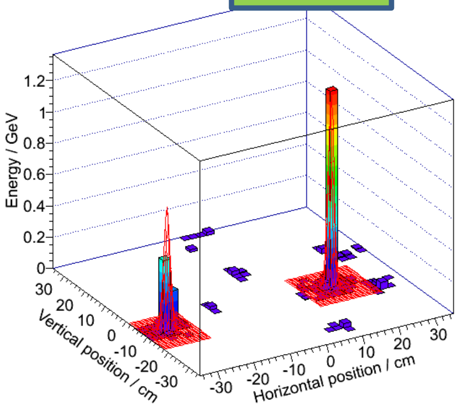


Simulations with changing integration time window

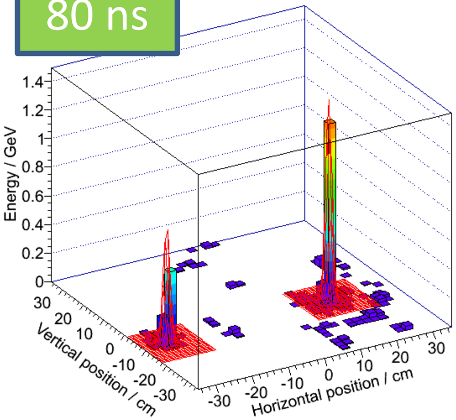
10 ns



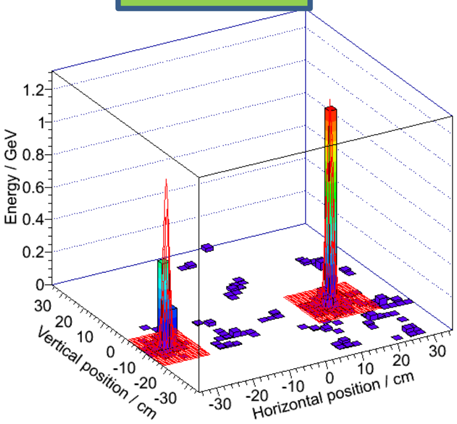
40 ns



80 ns

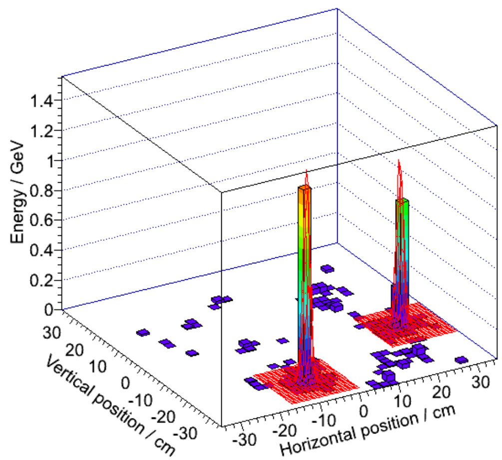


200 ns

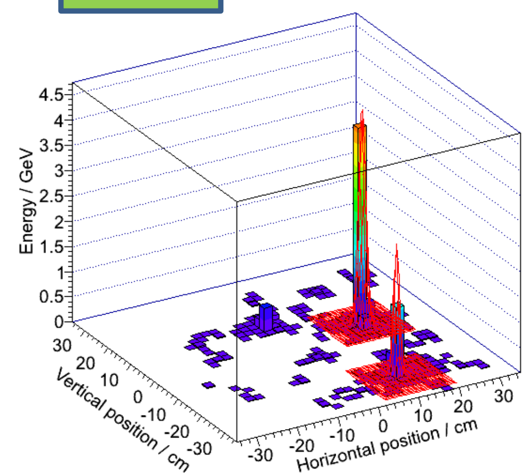


Simulations with higher currents

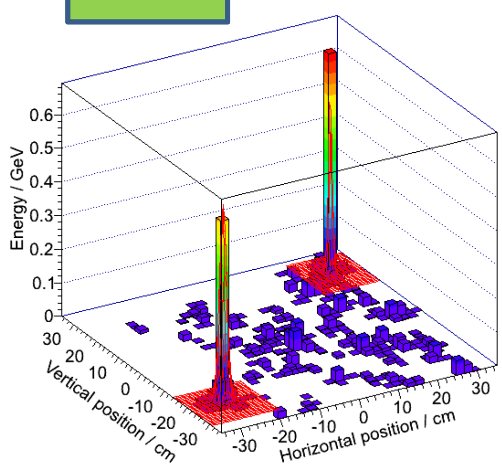
1 uA



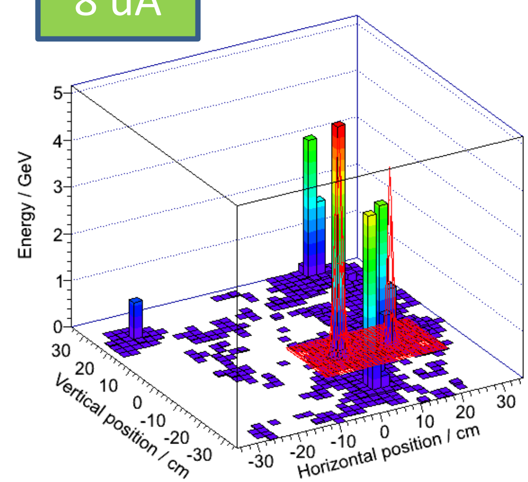
2 uA



5 uA



8 uA



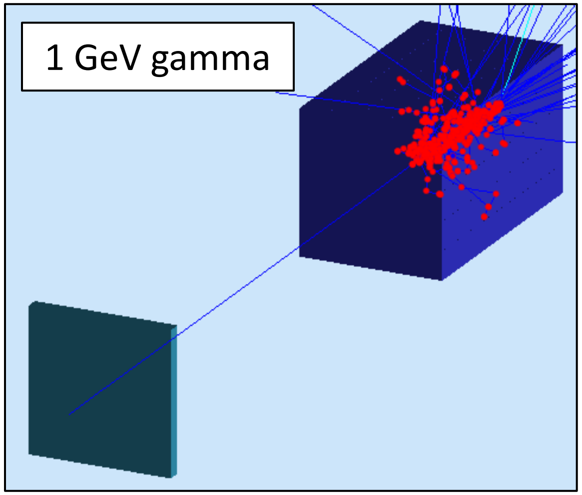
Simulations including a pre-shower

Possibility of working with pre-showers:

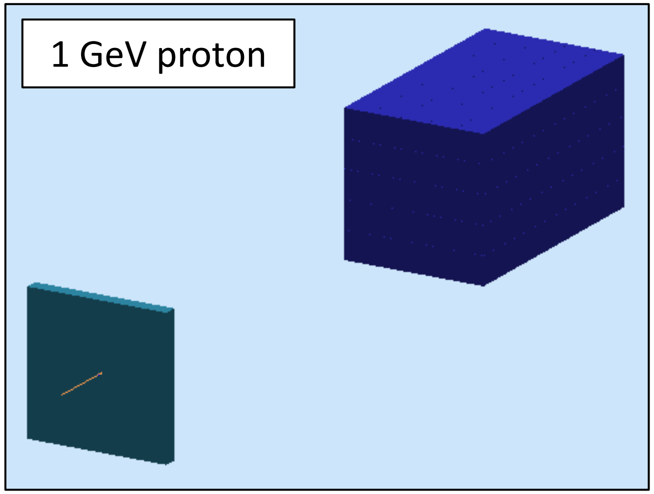
- Particle identification (e, p, gamma)
- A problem for two photons too close in a π^0 decay

<u>First simple pre-shower:</u>

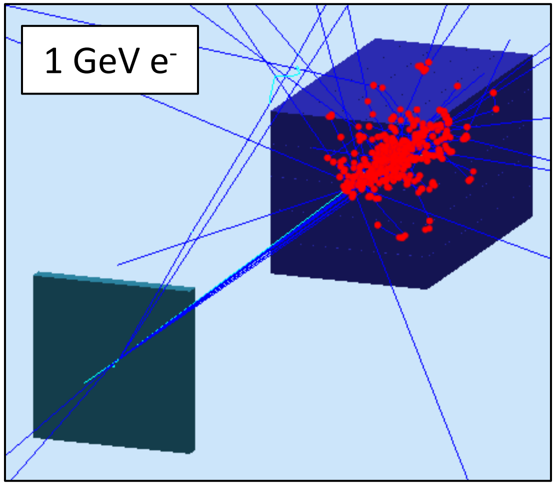
10mm thick $PbWO_4$ crystal



"No" interaction



Absorbed



Pre-shower created

Outlook

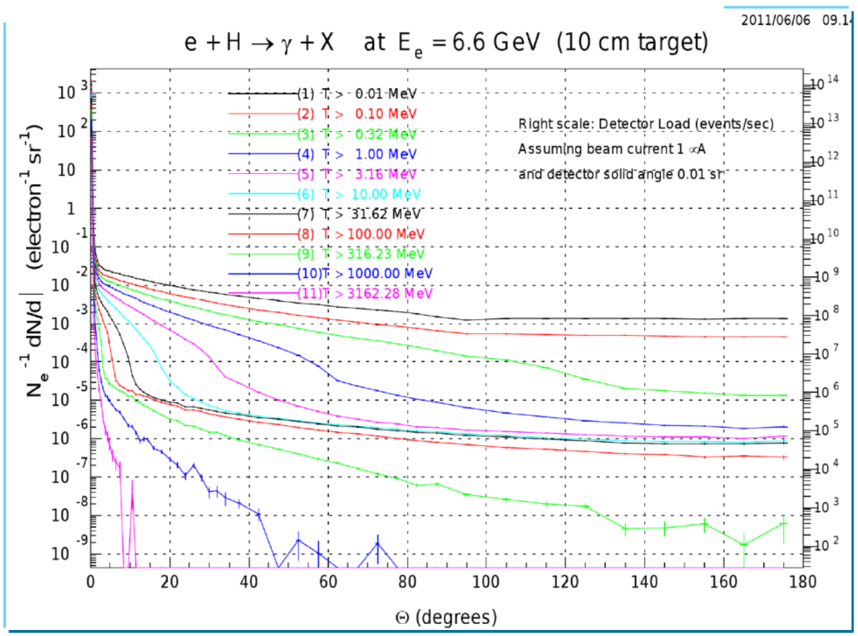
- Possible detector projects (universities in collaboration with labs)
  - Sweeper magnet construction and testing
  - Temperature controlled frame construction
  - Pre-shower construction
  - Photodetectors: PMT with active bases, APD, etc.
    - HV active base construction and testing
  - Electronics: fADC procurement and testing, FPGA programming
  - Lead tungstate (?)
  - Design simulations

- Available funding options
  - NSF MRI: funds collaboration of universities, cost sharing requirement
    - Next opportunity: January after PAC approval of program
  - DOE Early Career: funds individual beginning investigators at universities and labs, collaborations may be possible
  - Laboratory collaborations

Background Simulations

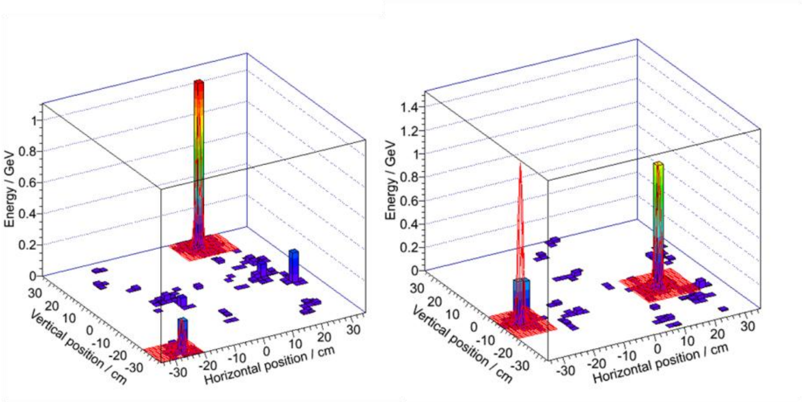
Background calculations performed by RadCon group (P. Degtiarenko)

- –Provide realistic fluxes of particles
- –Checked against 15+ years of radiation background measurements
- –Used for scheduling purposes to remain under DOE limits outside the Hall domes
- –Used to quantitatively estimate backgrounds and required shielding configurations for, e.g., G0 and Qweak



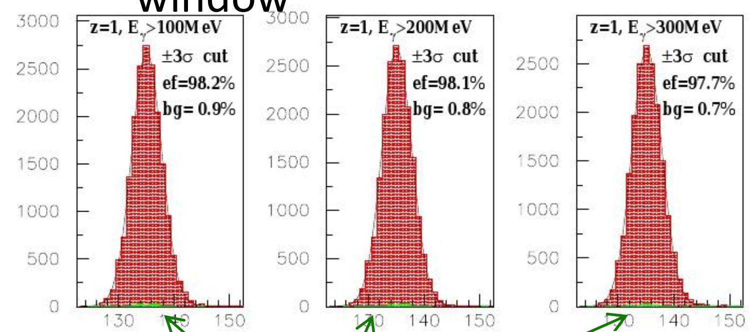
GEANT4 Detector Simulations

- Includes photons from π° decay
  - –Simulate π° signal normalized to rate.
  - –For each event decay π° into 2 γ



- Simulated background consists of realistic fluxes of neutral and charged particles, the latter suppressed by sweeper magnet

100 ns $\gamma\gamma$ coincidence time window



m_{π° m_{π° m_{π°

Combinatorial background

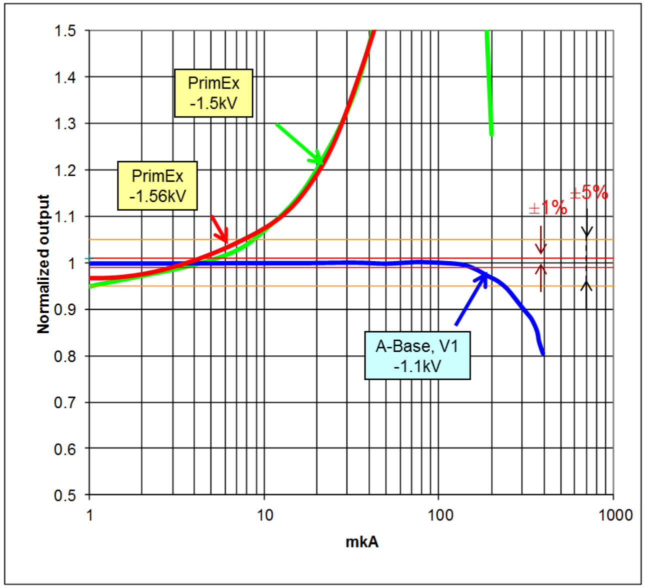
- Photon pair is selected from other processes in the calorimeter using a cluster finding algorithm

- π° invariant mass reconstructed for each hit in the calorimeter

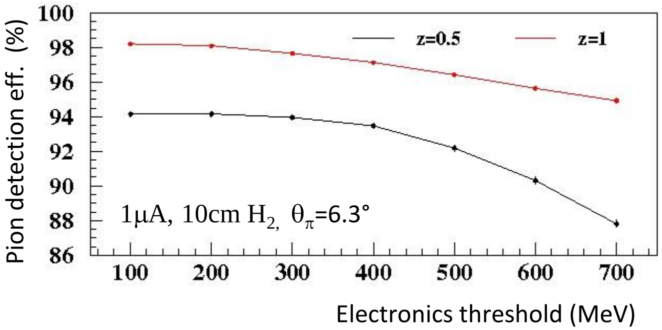
Combinatorial background is small (<1%)

Detector Linearity and Efficiency

- Realistic background simulations show that main contribution is low-energy photons
- With improved PMT base design gain stable to 0.2% for all kinematics and background conditions
  - –factor ~25 improvement compared to PRIMEX!
- Low-energy background can give (small) baseline shift
  - –Event-by-event subtraction using signal sampling fADCs

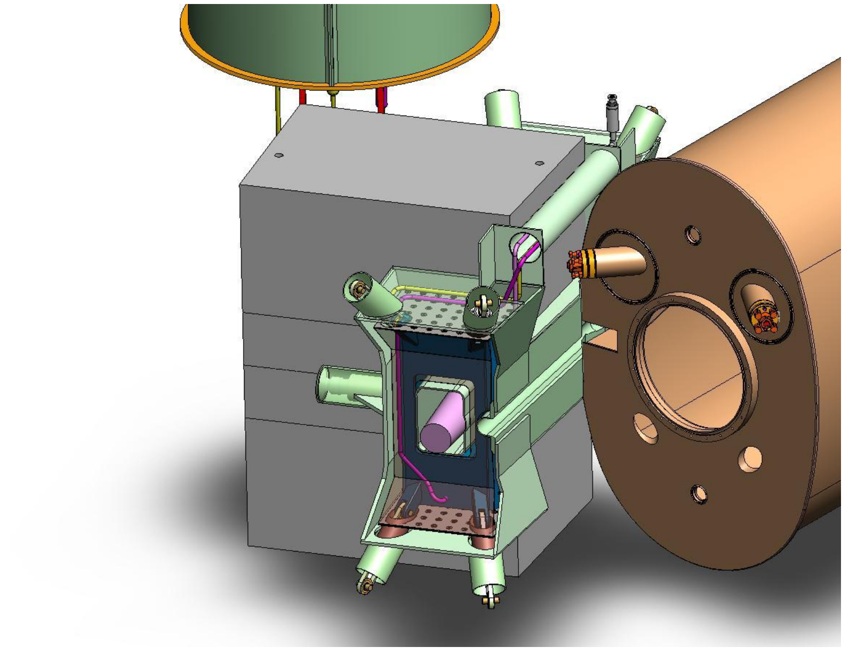


- Verified that combinatorial background is small (<1%), assumed to be known to 0.2-0.5%
- Geometric acceptance known to better than 0.1%
  - –Depends on survey and actual beam position



$\pi°$ detection efficiency is stable to better than 0.5%

Hall C Horizontal Bend(HB) SC Magnet



- **Superferric “C” magnet**
- 2.6 Tesla
- 21cmx25cm warm bore
- 0.75 M EFL
- 1.93 TM
- 19 % design margin
- 220 KJ stored Energy
- SC is SSC outer cable