

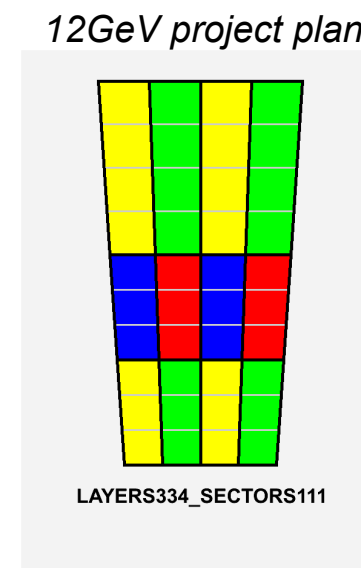
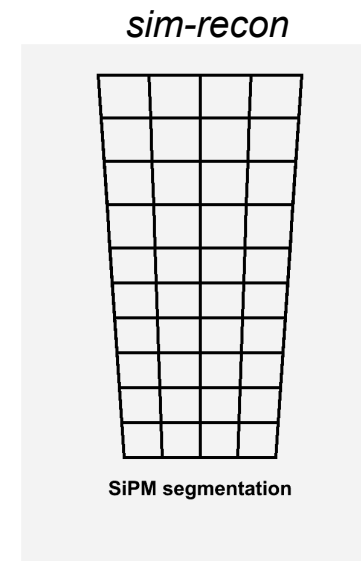
BCAL Segmentation

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Oct. 7, 2011

Introduction

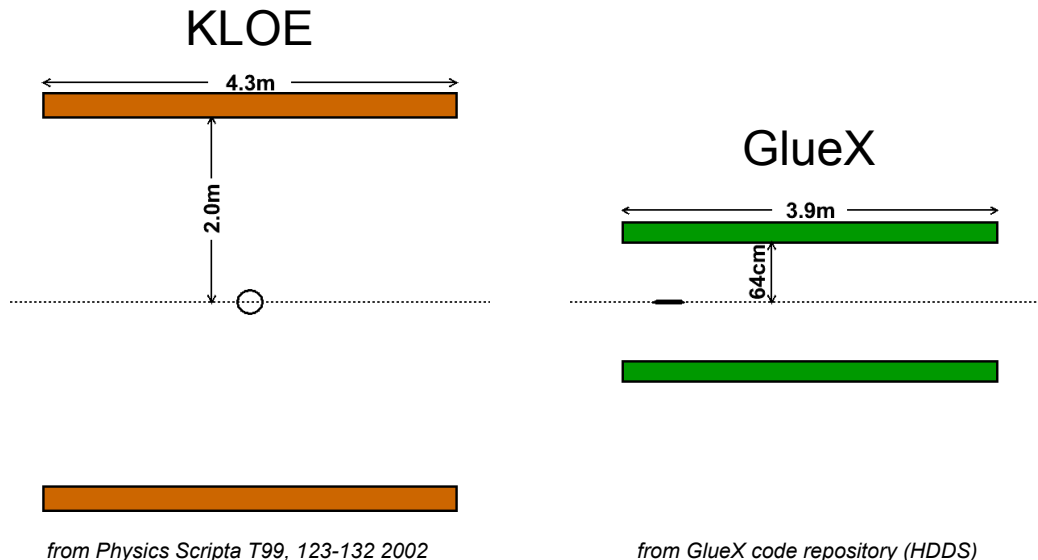
- BCAL light collection is done via a grid of light guides and SiPMs on both ends
- Project plan calls for amplifier boards to sum multiple SiPM signals together, reducing the number of digitization channels
 - Only inner two summed layers would have both TDC and fADC readout
 - Outer summed layer would have fADC digitization only
- Simulation studies of full BCAL in the GlueX detector have been done assuming every SiPM channel would be read out
- Concerns over the impact on the photon reconstruction capabilities of the summed segmentation scheme relative to the fine-grained segmentation motivated the current work
- Adding one more readout layer would increase the cost by ~\$370k (see Elton's slides from Sept. 19, 2011 BCAL Segmentation meeting)



Reconstruction Code

- Reconstruction algorithm in *sim-recon* taken from KLOE code
 - Numerous refinements to adapt it to GlueX and optimize for CPU performance.
 - No optimization for physics
- Difficult to compare different segmentation schemes using full-featured reconstruction.

Geometries of KLOE and GlueX calorimeters. Drawn to scale



Are differences due to segmentation, or optimizations in the reconstruction?

- Alternate simulation/ reconstruction code developed with simplified reconstruction and more detailed simulation

Special Simulation

In a nutshell:

- **hdgeant** used to generate list of steps for every shower particle in an event (~10k-30k steps/shower)
 - geometry defines each cell in the BCAL (40 per module)
 - homogeneous material

• Energy loss for each step propagated to SiPM to form energy-weighted time distribution

• Signal convoluted with example electronic pulse shape to form electronic pulse shape

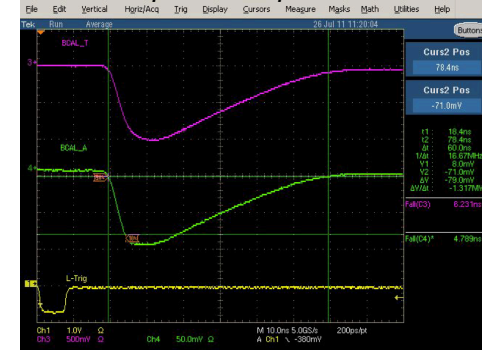
• Other effects added (*n.b. not using mcsmeas*)

- sampling fluctuations
- photo-statistics
- dark hits
- ...

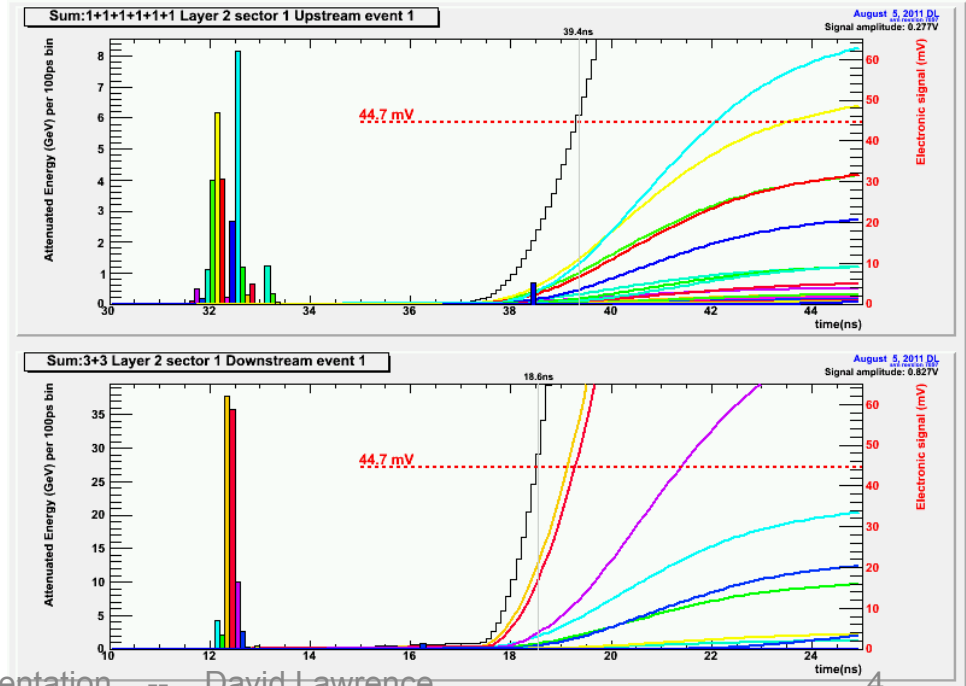
• Time extracted from first bin above threshold

• Timewalk calibration applied and resolutions extracted

Example electronic pulse shape from GlueX-doc-1754

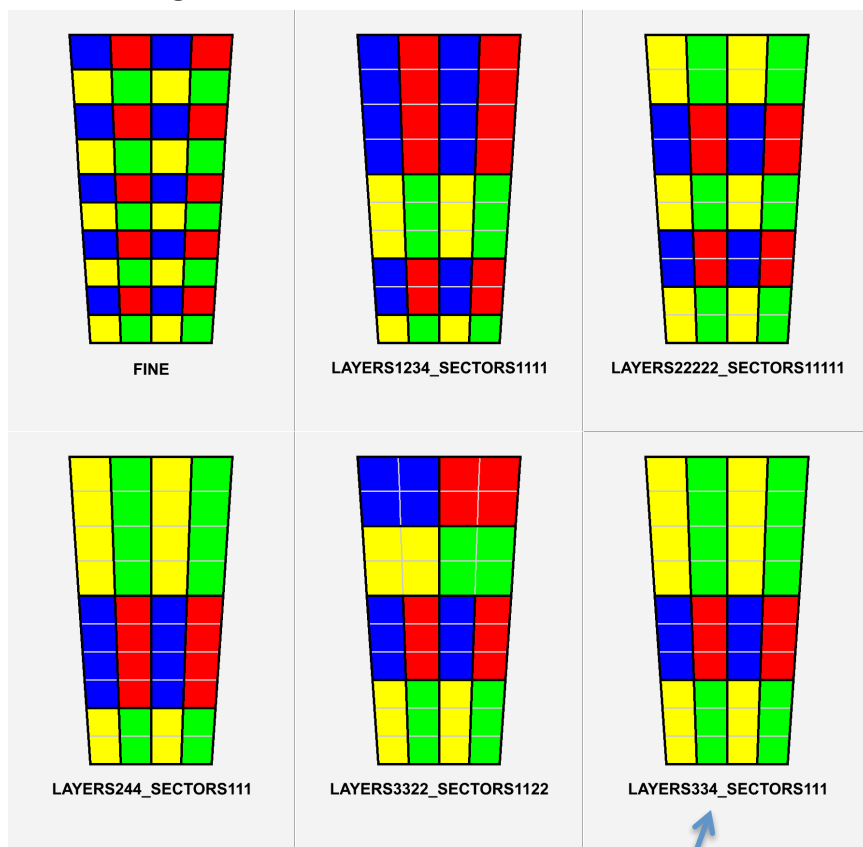


Attenuated energy signal plotted against left-hand axis. That distribution convoluted with electronic pulse shape plotted vs. right-hand axis. Black is total electronic pulse. Colors are the contributions from the corresponding bins in the signal distribution on the left.



Geometry and Kinematics

Six segmentation schemes were studied



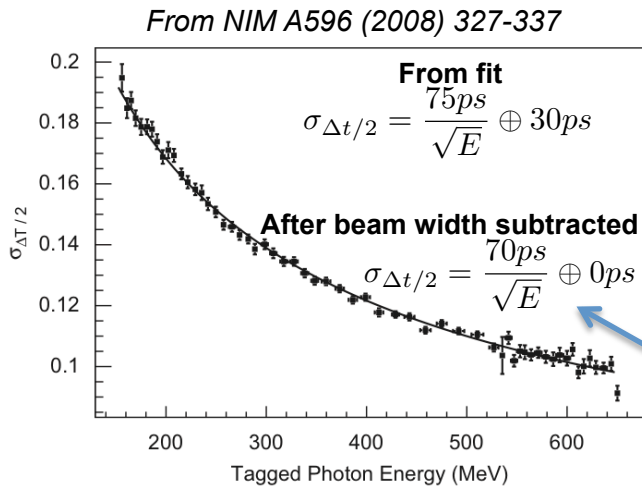
Project default

- 3 datasets: $\theta=12^\circ$, 20° , and 90°
- Each data set contained 10k events
- $0 \leq E_\gamma \leq 2.0\text{GeV}$

Reconstruction done by looking at all cells where both ends were above threshold (45mV)

Since only one generated photon per event, all cells used (no cluster finding or splitting)

Comparison to 2006 Beam Test

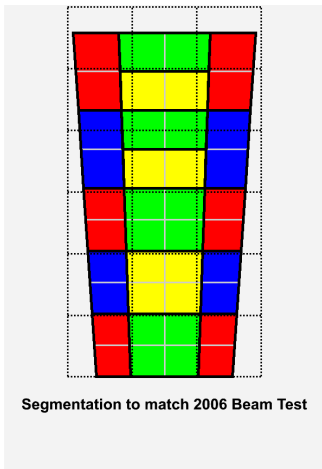


Geometry made to match that of 2006 beam test:

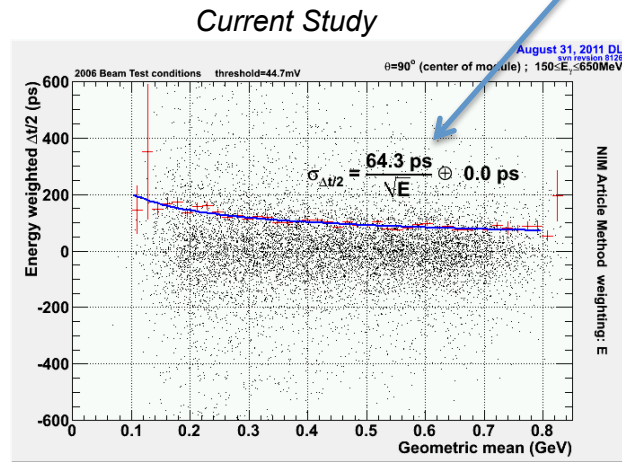
- 90° incident angle
- Center of module (z and ϕ)
- $150MeV \leq E_\gamma \leq 650MeV$

Fig. 15. The time difference resolution, in nanoseconds, for segments 7, 8, 9 and 10 as a function of energy. The fit gives $\sigma_{\Delta t/2} = 75 \text{ ps}/\sqrt{E(\text{GeV})} \oplus 30 \text{ ps}$. The fit of Fig. 14 corresponds to the 40th datum from the right (19th from the left) in this figure.

Time difference resolutions roughly match



A new segmentation scheme was used to try and match that of the 2006 geometry



n.b. The prototype module used for the beam test was made using fibers with roughly half the light output compared to that of the fibers in the final design.

Time difference resolutions

$\Delta t/2$ resolution

Resolution functions
evaluated at specific
energies

Improvement relative to
334 segmentation scheme

<i>12 degrees</i>						
Segmentation	p0	p1	E=500MeV	E=1GeV	% better 500MeV	% better 1GeV
FINE	58.4	54.1	98.73	79.61	23.8%	27.7%
1234	63.6	49.3	102.57	80.47	20.8%	26.9%
22222	54.5	89.6	118.19	104.87	8.8%	4.8%
244	66	80.6	123.32	104.17	4.8%	5.4%
3322	67.3	88.9	130.24	111.50	-0.5%	-1.2%
334	68.2	86.5	129.56	110.15	0.0%	0.0%
<i>20 degrees</i>						
Segmentation	p0	p1	E=500MeV	E=1GeV	% better 500MeV	% better 1GeV
FINE	41.5	35.3	68.49	54.48	36.1%	40.7%
1234	42.1	38.3	70.79	56.91	34.0%	38.1%
22222	56.3	42.9	90.44	70.78	15.6%	23.0%
244	52.6	51	90.19	73.26	15.9%	20.3%
3322	61.9	66.7	110.06	91.00	-2.6%	1.0%
334	55.2	73.5	107.22	91.92	0.0%	0.0%
<i>90 degrees</i>						
Segmentation	p0	p1	E=500MeV	E=1GeV	% better 500MeV	% better 1GeV
FINE	26.2	10.8	38.59	28.34	3.4%	11.5%
1234	25.7	19.2	41.10	32.08	-2.9%	-0.2%
22222	26	18.5	41.16	31.91	-3.0%	0.3%
244	24.6	23.9	42.21	34.30	-5.6%	-7.1%
3322	24.1	20.6	39.82	31.70	0.3%	1.0%
334	23.9	21.3	39.95	32.01	0.0%	0.0%

- The time difference is obtained by doing an energy weighted average of all summed cells in the event

- Time difference resolution contributes to θ resolution

- Both ends must have signal above threshold for cell to have “fired”

- For 12° (downstream end of module) and 20° (middle of module) 20%-40% improvement is seen for 1234 scheme

- For 90°, no improvement is seen

Time average resolutions

Resolution functions
evaluated at specific
energies

Improvement relative to
334 segmentation scheme

t_{avg} resolution

<i>12 degrees</i>						
Segmentation	p0	p1	E=500MeV	E=1GeV	% better 500MeV	% better 1GeV
FINE	47	24.3	70.77	52.91	16.0%	21.9%
1234	48.8	20.4	71.97	52.89	14.6%	21.9%
22222	48.9	41.1	80.45	63.88	4.5%	5.7%
244	53.8	37.6	84.87	65.64	-0.7%	3.1%
3322	53.4	41.1	85.98	67.39	-2.0%	0.5%
334	50.1	45.6	84.26	67.74	0.0%	0.0%
<i>20 degrees</i>						
Segmentation	p0	p1	E=500MeV	E=1GeV	% better 500MeV	% better 1GeV
FINE	33	26.6	53.72	42.39	27.7%	33.8%
1234	37.9	24.4	58.89	45.08	20.7%	29.6%
22222	41.4	29.6	65.61	50.89	11.7%	20.5%
244	36.2	53.8	74.27	64.85	0.0%	-1.3%
3322	42.1	48.5	76.79	64.22	-3.4%	-0.4%
334	37.7	51.7	74.27	63.99	0.0%	0.0%
<i>90 degrees</i>						
Segmentation	p0	p1	E=500MeV	E=1GeV	% better 500MeV	% better 1GeV
FINE	32.5	0	45.96	32.50	1.3%	10.0%
1234	29	20.4	45.81	35.46	1.7%	1.9%
22222	27.8	19.6	43.93	34.01	5.7%	5.9%
244	31.4	27.9	52.44	42.00	-12.6%	-16.3%
3322	29.2	21.4	46.51	36.20	0.1%	-0.2%
334	29.4	21	46.58	36.13	0.0%	0.0%

- The time average is obtained by doing an energy weighted average of all summed cells in the event

- Time average resolution used for time-of-flight
 - PID
 - background cuts

- Both ends must have signal above threshold for cell to have “fired”

- For 12° (downstream end of module) and 20° (middle of module) 15%-30% improvement is seen for 1234 scheme

- For 90°, no improvement is seen

Summary

- Timing resolutions for reconstructed showers in the BCAL may be improved by about 20%-30% on average by choosing the “1234” segmentation scheme that has 1 additional readout layer compared to the “334” scheme (current default)
- Adding one layer will require an additional \$370k
- Decision on this according to Project schedule is already past due
- Energy resolution dependence is currently under investigation.
- Details can be found in GlueX-doc-1801

Backup Slides

Simulating Timing Spread

- Produced ROOT tree with *DMCTrajectoryPoint* objects:

```
hd_ana \  
  -PPLUGINS=janaroot \  
  -PAUTOACTIVATE=DMCTrajectoryPoint \  
  -PJANAROOT_MAX_OBJECTS=50000 \  
hdgeant.hddm
```

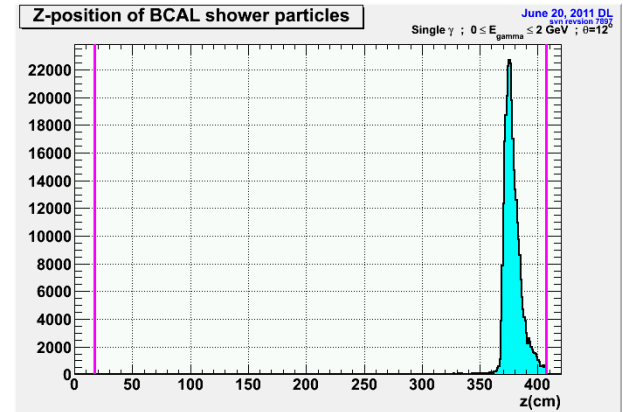
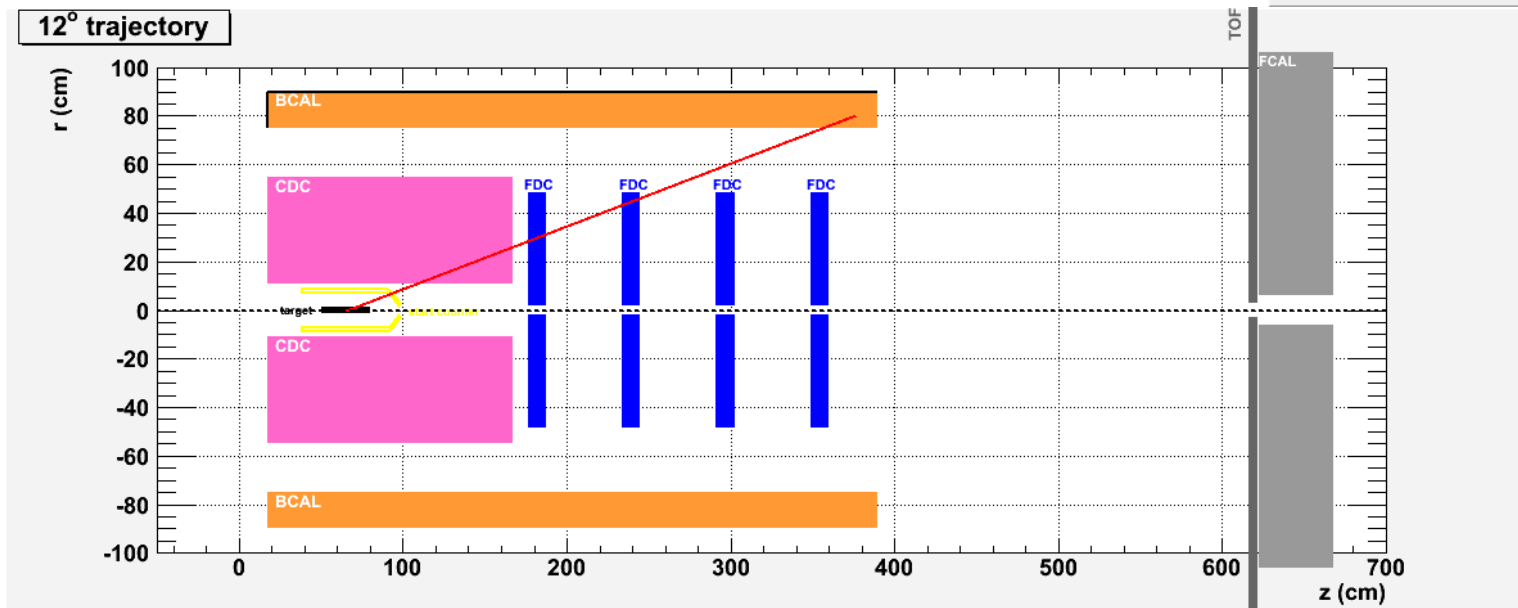


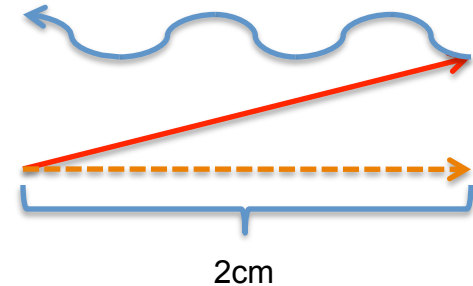
Diagram showing 12° trajectory



Convolute Pulse shape with energy weighted timing distribution

Effective speed of light in BCAL is 16.75 cm/ns or $\sim 0.5c$

A particle traveling 2cm in z at β_z will have a time spread of:
 $2\text{cm}/\beta_z + 2\text{cm}/(0.5c)$ at the upstream SiPM and
 $2\text{cm}/\beta_z - 2\text{cm}/(0.5c)$ at the downstream one



Upstream is worst-case. Assume $\beta_z=c$, then spread is:

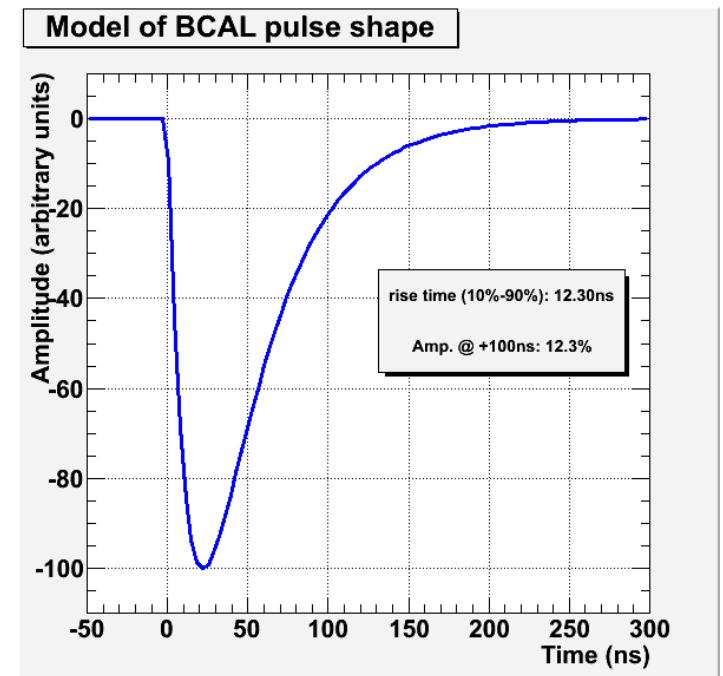
$$2\text{cm}(1/c + 1/(0.5c)) = 3\text{cm}/c = 6\text{cm}/(30\text{cm/ns}) = 200\text{ps/step}$$

Slower shower particles will lead to larger dispersions in time.

To investigate the effect of signal timing spread, an electronic pulse shape was convoluted with the signal distribution of single events. (*next slide*)

Pulse shape is:

$$f(x) = e^{-x/\alpha} (1 - e^{-x/\beta})$$



Summary of contributors to resolution for fine segmentation

The table below summarizes the fit results for the energy resolution as various effects are added. **Conclusions:**

- Leakage is only significant contributor to constant term
- No significant contributors to noise term

All three terms (a,b,c) allowed to float in fit

	a 1/sqrt(E)	b constant	c 1/E
Leakage only	0.6%	3.3%	0.0%
+ Dark hits	2.4%	3.7%*	0.0%
+ Elec. Noise	2.4%	3.7%*	0.0%
+ Threshold	2.7%	2.9%	0.0%
+ Photostatistics	4.2%	2.9%	0.0%
+ Sampling Fluct.	5.8%	2.9%	0.6%

* $E_{raw} > 150 \text{ MeV}$ used instead of $N_{recon} == 1$

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$

Stochastic term:

- a
- intrinsic shower fluctuations
 - photoelectron statistics
 - dead material in front of calorimeter
 - sampling fluctuations

Constant term:

- b
- detector non-uniformity
 - calibration uncertainty
 - non-compensation (hadronic showers)
 - radiation damage

Noise term:

- c
- electronic noise

← $\sigma_{sf} = \frac{4.2\%}{\sqrt{E}} \oplus 1.3\%$, Gauss fit

Summary of contributors to resolution for fine segmentation (refit)

Only a allowed to float in fit

	a (total)	a (contrib)
Leakage only	0.6%	0.6%
+ Dark hits	2.7%*	2.6%
+ Elec. Noise	2.8%*	0.7%
+ Threshold	2.4%	-1.4%
+ Photostatistics	4.0%	3.2%
+ Sampling Fluct.	5.9%	

Dark hits + threshold contribute 2.2%

$$\sigma_{sf} = \frac{4.2\%}{\sqrt{E}} \oplus 1.3\% \text{ , Gauss fit}$$

* $E_{raw} > 150\text{MeV}$ used instead of $N_{recon} == 1$

$$\begin{aligned} \frac{\sigma_E}{E} &= \frac{2.2\% \oplus 3.2\%}{\sqrt{E}} \oplus 3.3\% \\ &= \frac{3.9\%}{\sqrt{E}} \oplus 3.3\% \end{aligned}$$

No sampling fluctuations

Summary for 90° Tracks

Stochastic Term summary

	NIM article	sim-recon
Sampling Fluctuations	4.5%	4.2% (calibDB)
Photo- statistics	3.1% (2.7% KLOE)	3.2%
Dark Hits	0.0%	2.2%
Total	5.4%	5.7%

Recommendations:

- *Sim-recon currently has 1.3% in calibDB for constant term. This is primarily due to leakage so should be set to 0 so that it is not included twice*
- *Leave Sampling fluctuations at 4.2% until energy dependent function is derived*

(?Andrei or Irina using Fluka?)

Relating MeV to Signal Amplitude

From CalibDB

75 photons/side/MeV in fiber
0.21 PDE
0.095 Sampling fraction

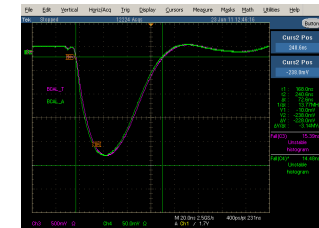
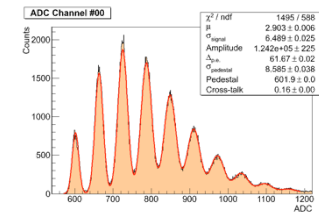
0.668 MeV/PE

61.67 QCD counts/PE
CAEN V792 QCD: 100fC LSB

9.23 pC/MeV

SiPM pulse shape:
1.20 nC for 2.293V peak

17.6 mV/MeV



Discriminator Thresholds

Convert effective thresholds in MeV from June 2nd presentation to electronic thresholds in mV that can be applied to signal distributions.

Effective thresholds

	inner	outer
fine (near)	2.3 MeV	2.3 MeV
fine (far)	8.4 MeV	8.4 MeV
course (near)	2.4 MeV	2.6 MeV
course (far)	8.8 MeV	9.5 MeV



	inner	outer
fine	40.5 mV	40.5 mV
course	42.2 mV	45.8 mV

from June 2nd presentation

Uncertainty dependence on Energy

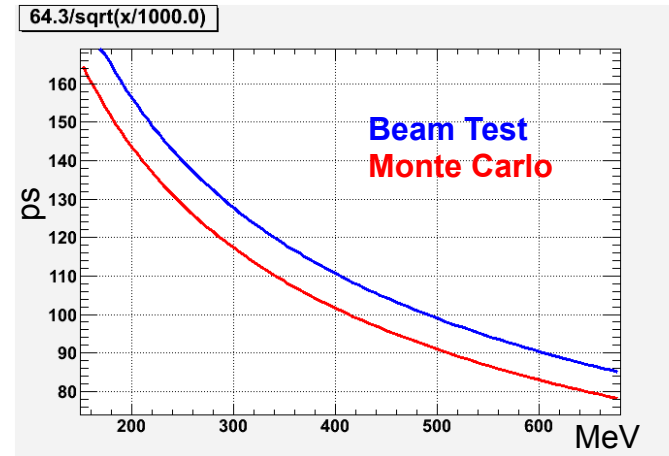
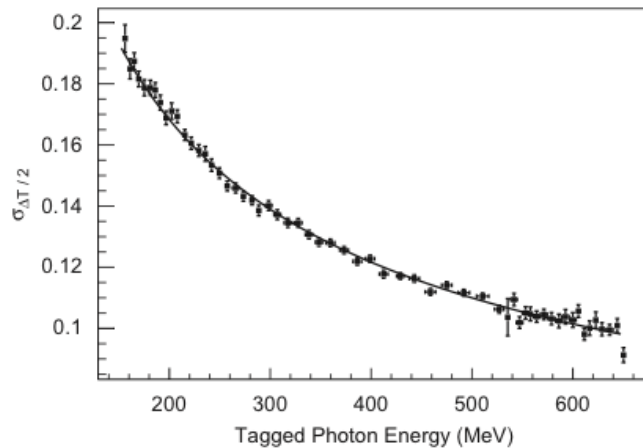
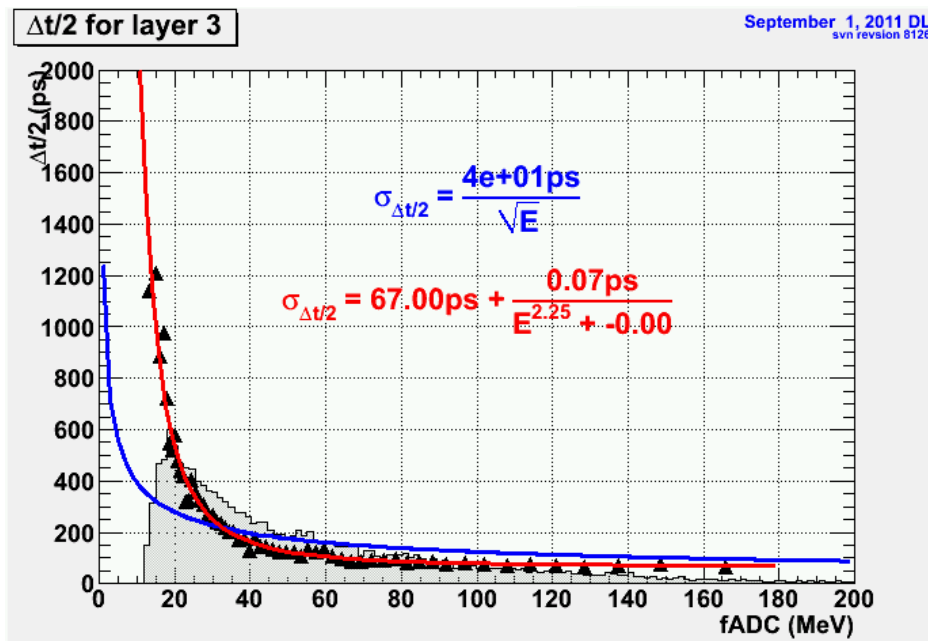


Fig. 15. The time difference resolution, in nanoseconds, for segments 7, 8, 9 and 10 as a function of energy. The fit gives $\sigma_{\Delta T/2} = 75 \text{ ps}/\sqrt{E(\text{GeV})} \oplus 30 \text{ ps}$. The fit of Fig. 14 corresponds to the 40th datum from the right (19th from the left) in this figure.



Simulation seems to match well with beam test result. However, better resolutions were achieved by using non-E weighting for cell times

$$\frac{\Delta T}{2} = \frac{1}{2} \frac{\sum_i E_i (T_{N,i} - T_{S,i})}{\sum_i E_i}$$

NIM article used energy weighted mean