

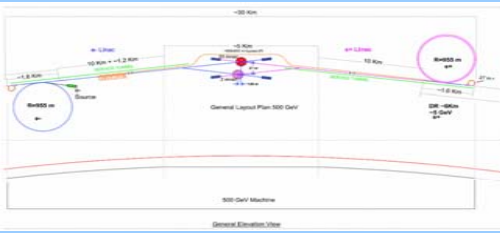
**April 28/2008-ALCPG**



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***The BeamCal Simulation Project***  
***Progress Report***

***Keith Drake, Tera Dunn, Jack Gill,***  
***Gleb Oleinik, Uriel Nauenberg***  
***University of Colorado at Boulder***

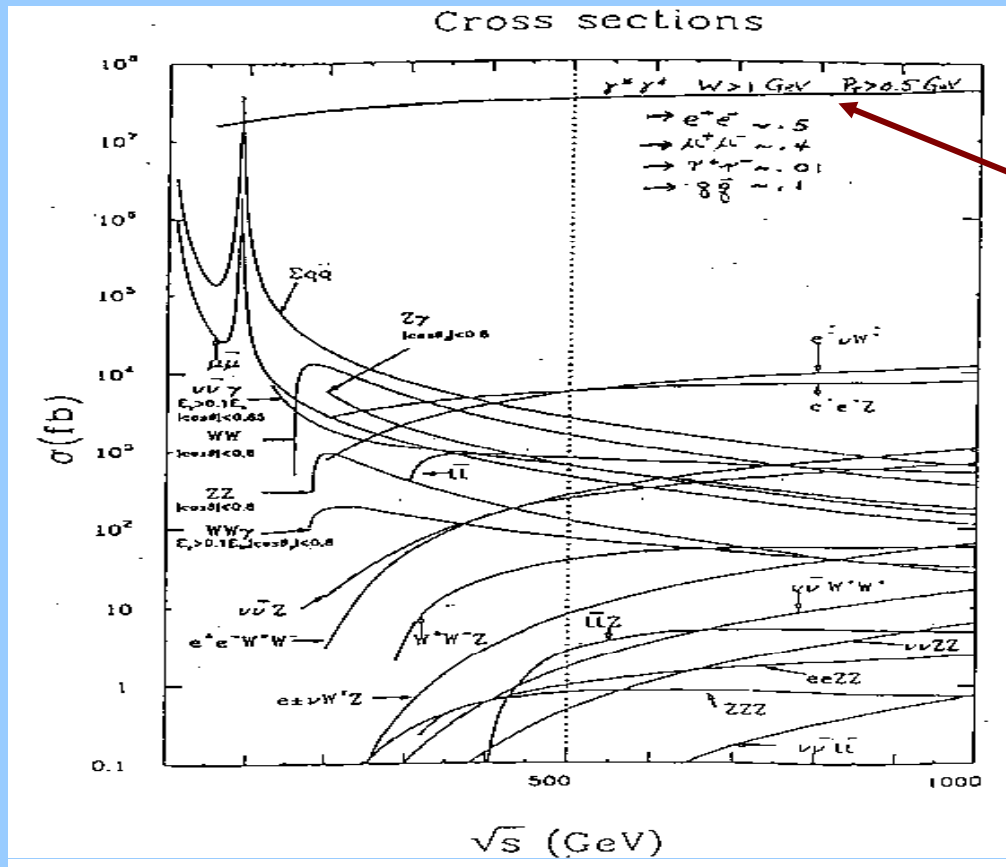


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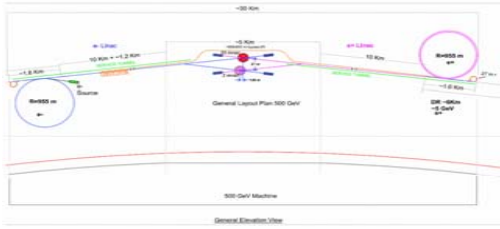
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## Beam Calorimeter Studies



*Two photon process cross section about  $10^5$  larger than SUSY cross section. Serious source of background for SUSY if not tagged.*

*Pointed out by our group around 1998*

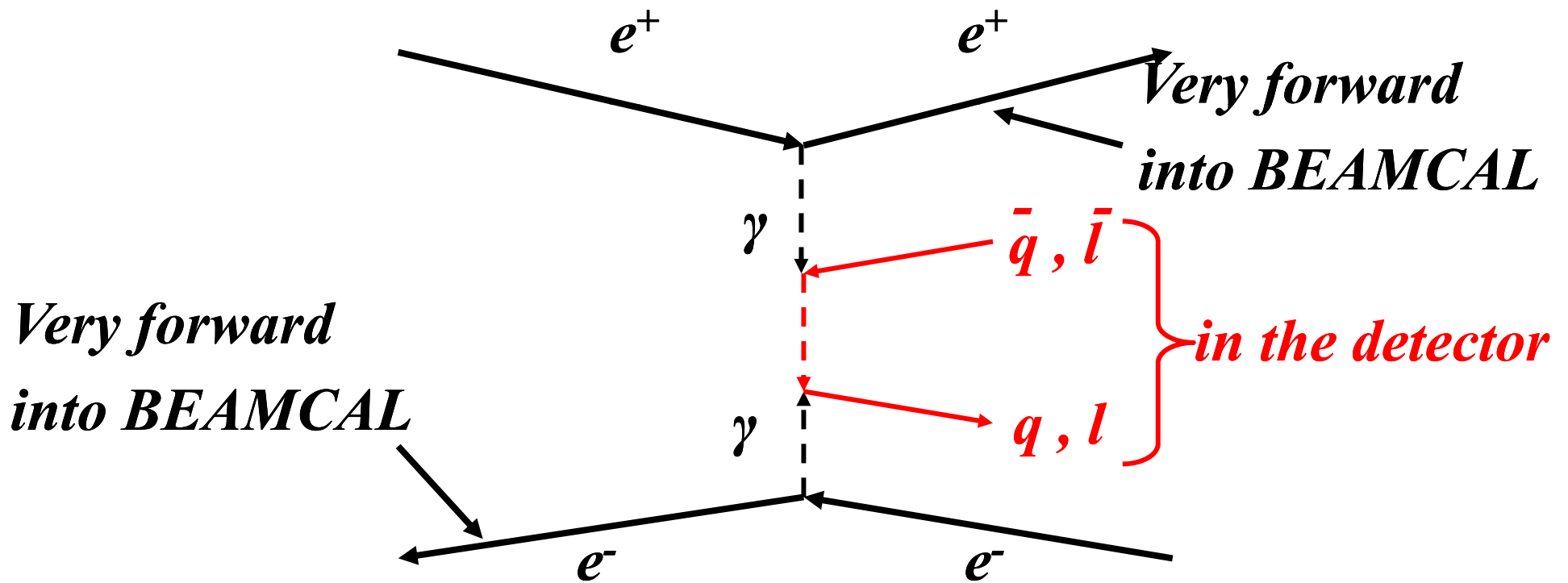


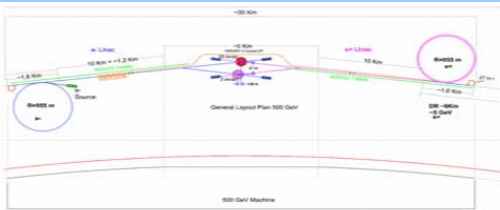
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## 2 Photon Process

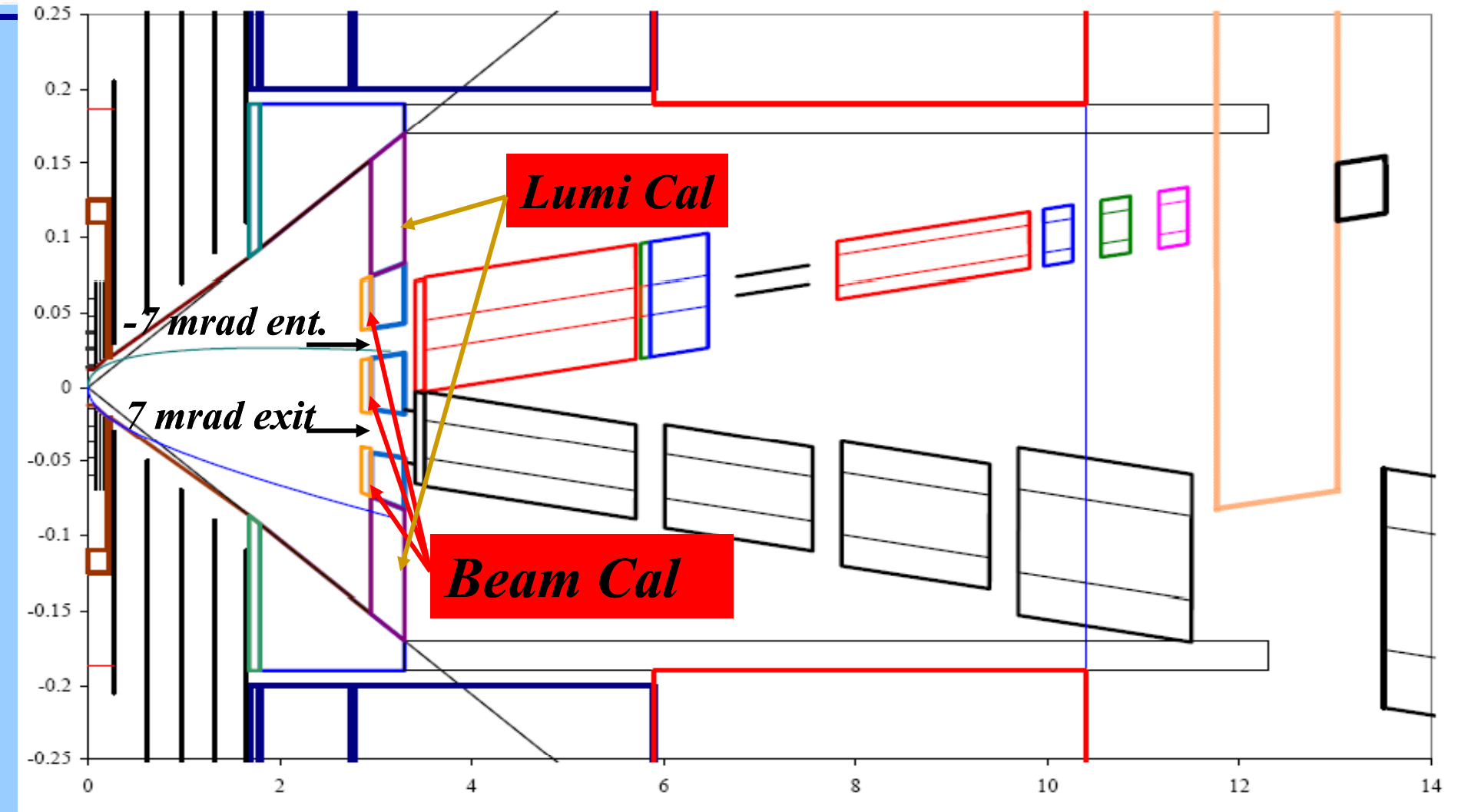


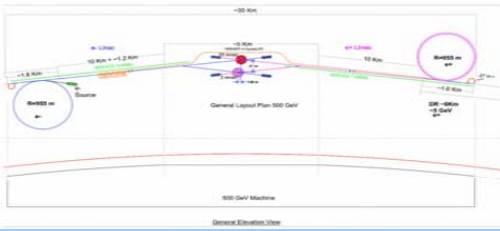


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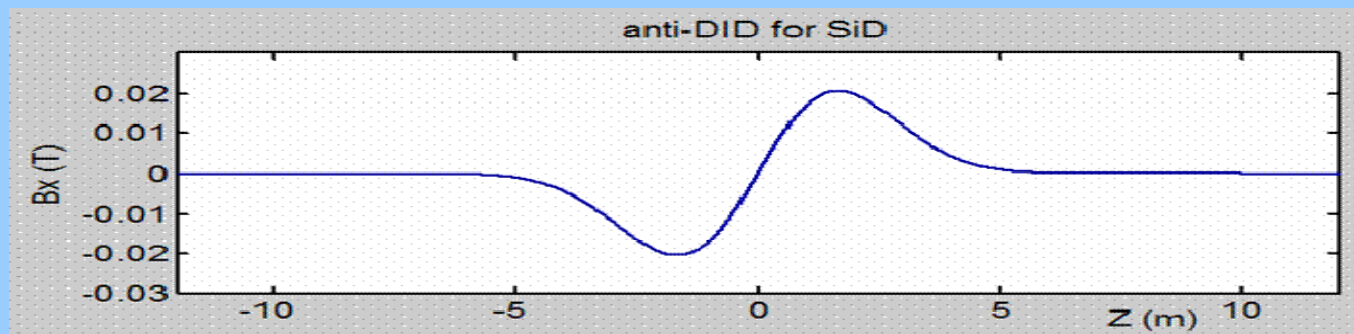


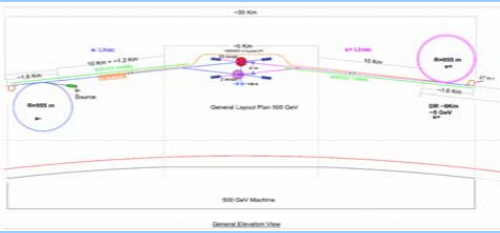
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*Solenoid field keeps the low energy charged particle in the forward direction. Beam hole is at 7 mrad. Need to add an x field component to move low energy charged particles in the 7 mrad direction. Anti-DiD dipole field proposed by Andrei Seryi.*



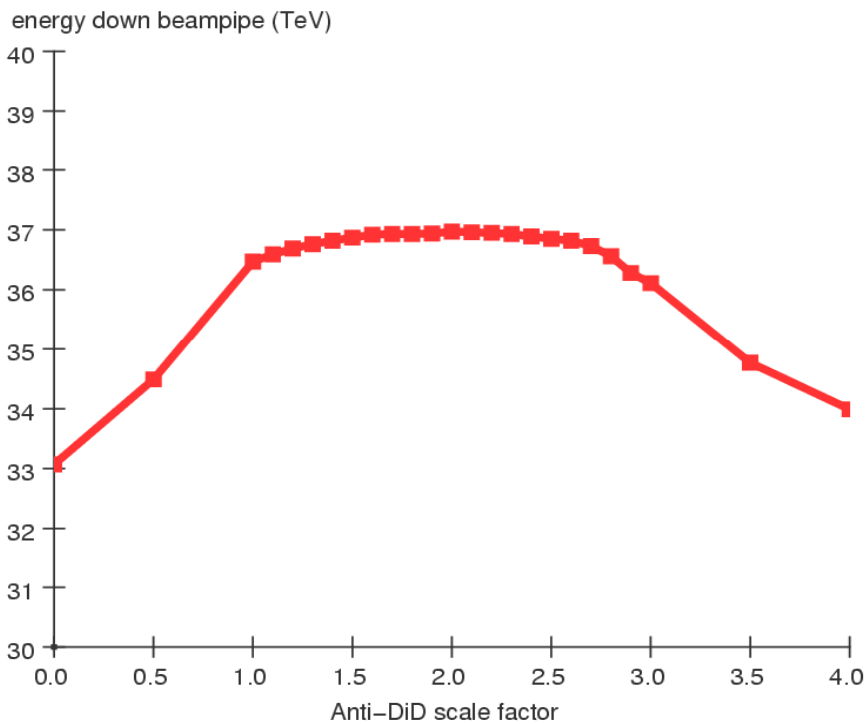


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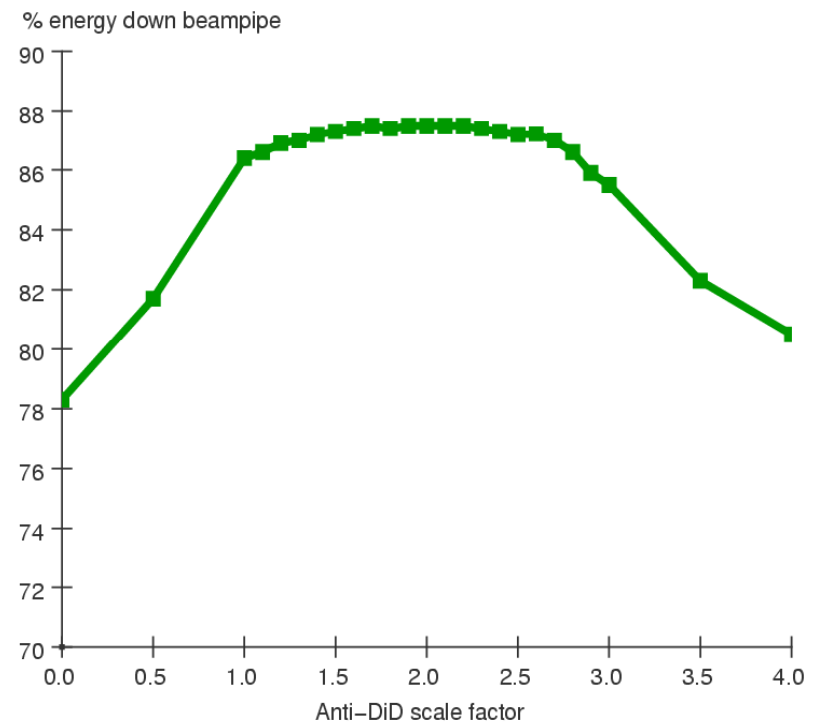


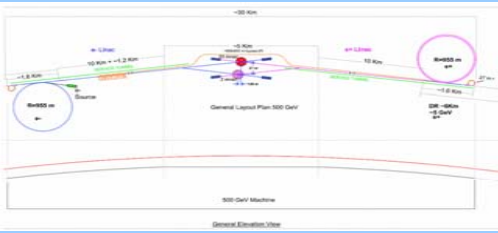
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**Anti-DiD optimization for detector @ z=295cm (TeV)**



**Anti-DiD optimization for detector @ z=295cm (%)**

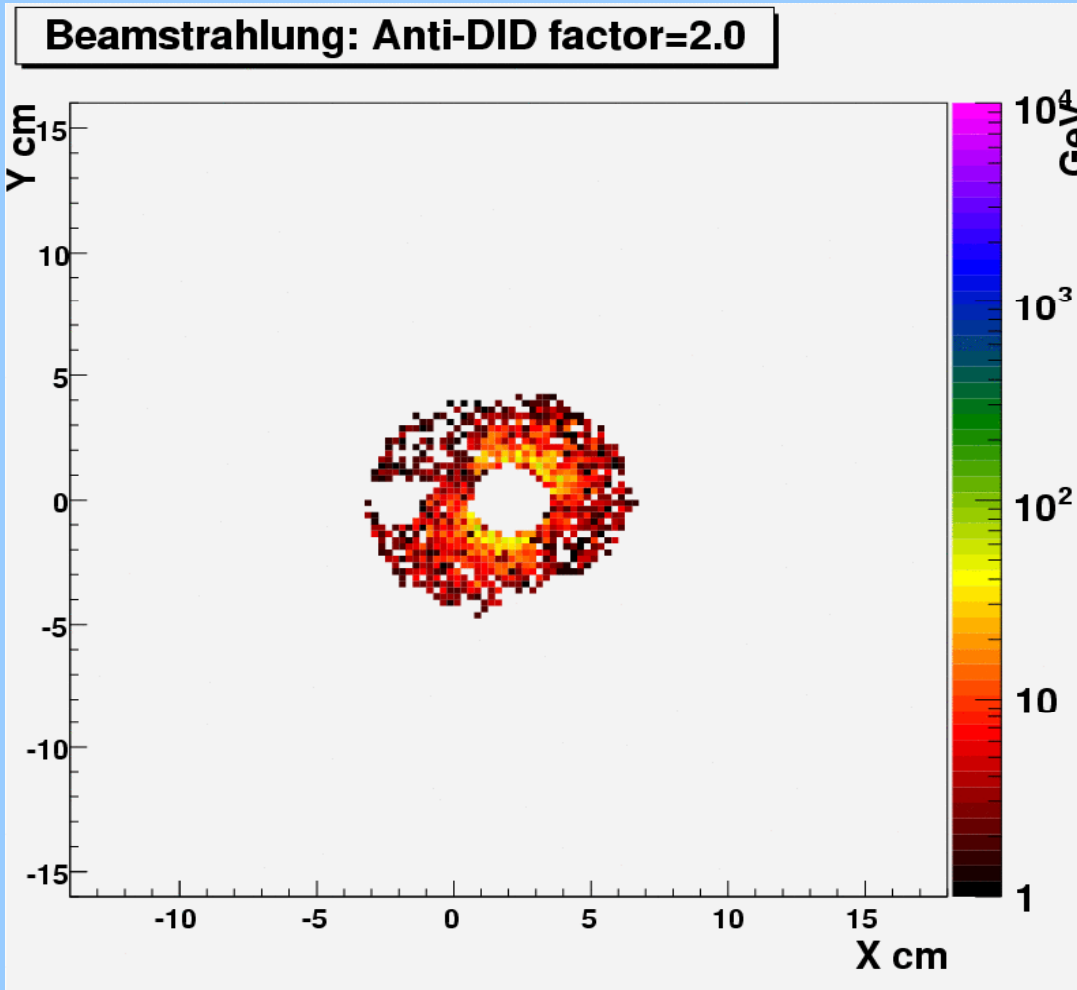




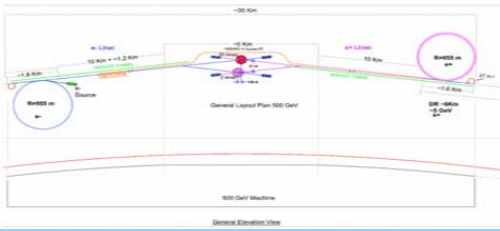
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*Beamstrahlung  $e^+e^-$  pairs.  
Energy deposited in  
 $0.25 \times 0.25 \text{ cm}^2$  cells.*



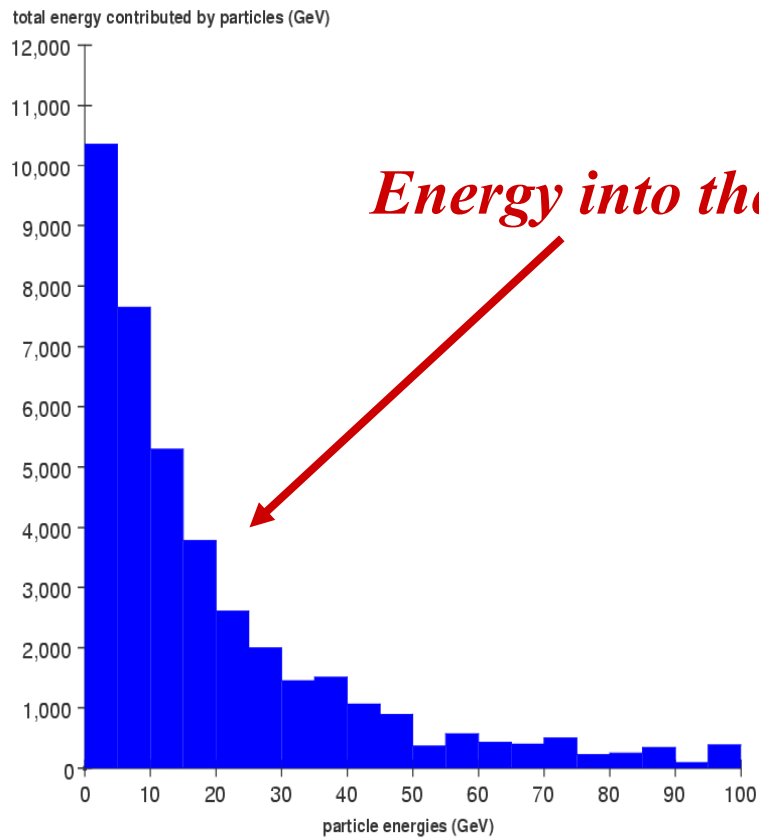
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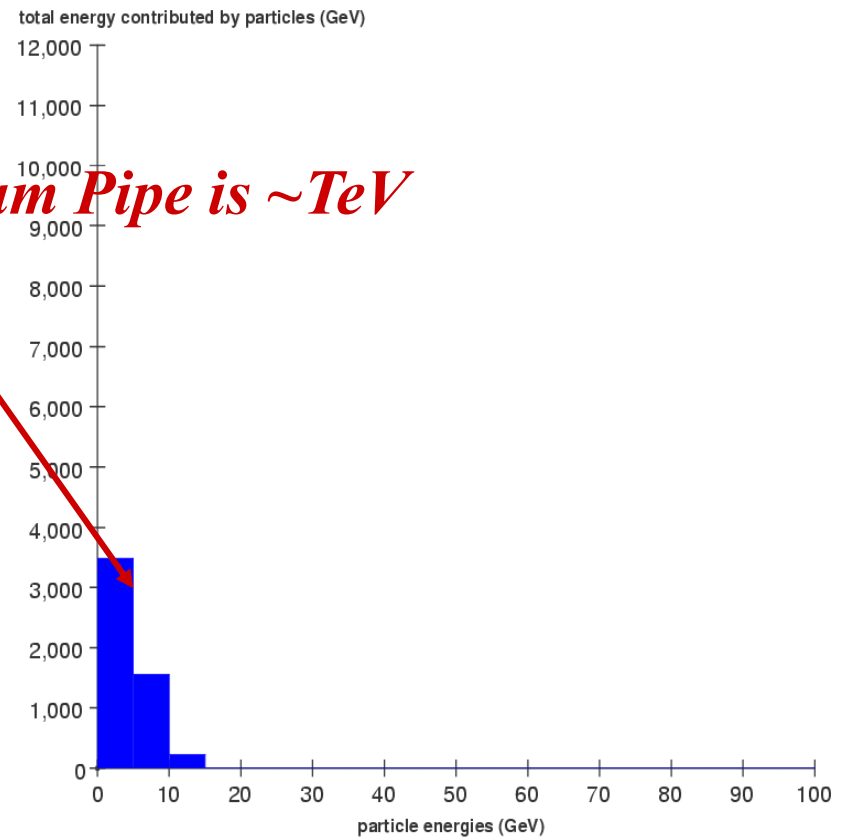
## *Integrated*

Total beamstrahlung energy distribution up to 100 GeV



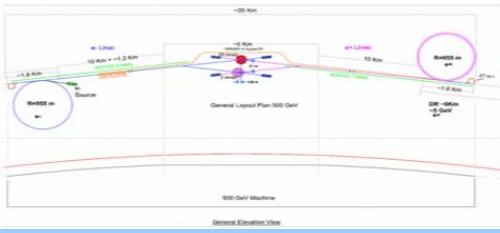
## *Outside Beam Pipe*

Non-beampipe beamstrahlung energy distribution up to 100 GeV



*Energy into the Beam Pipe is ~TeV*



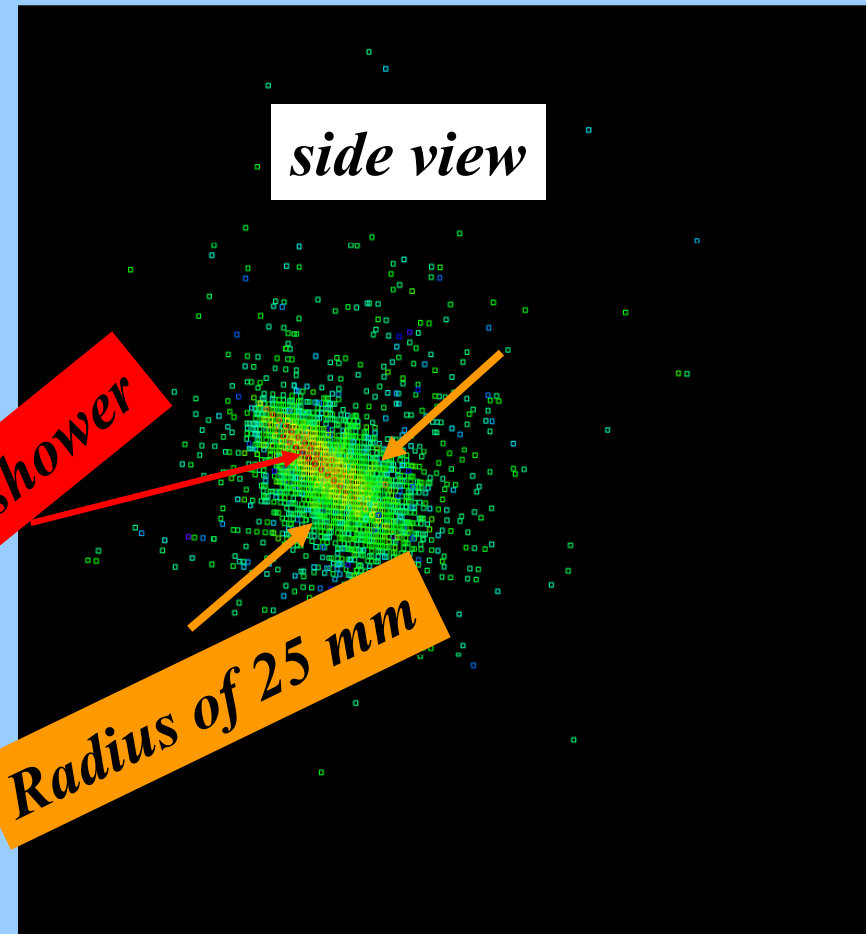
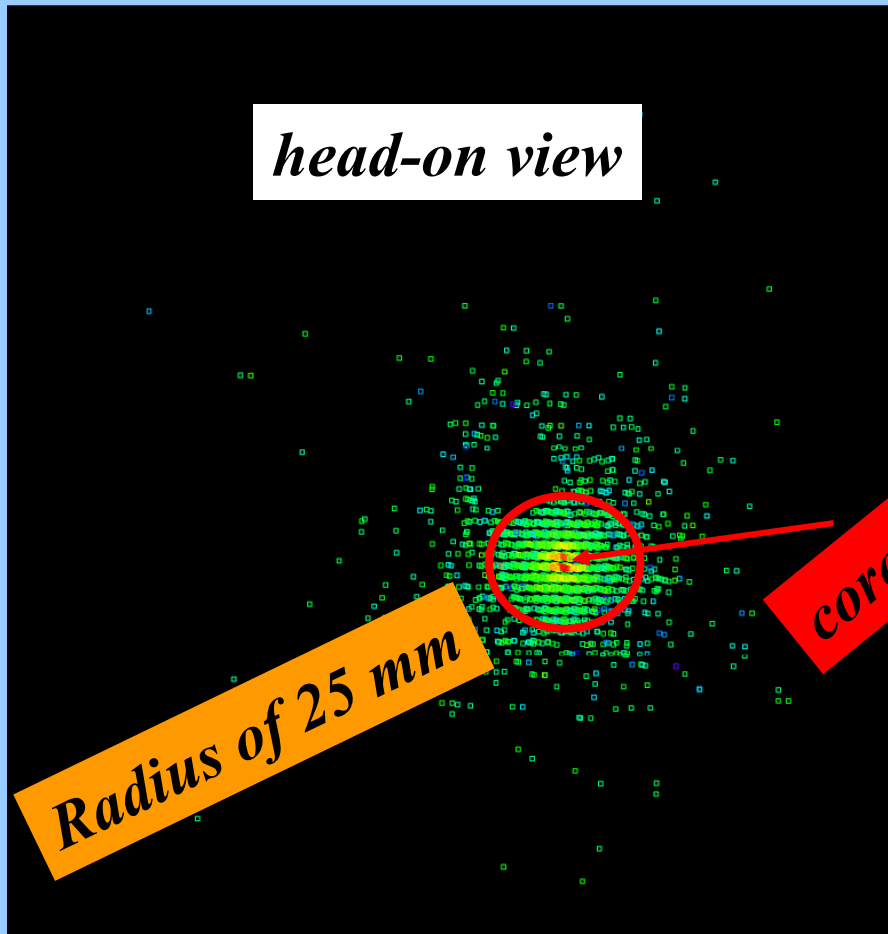


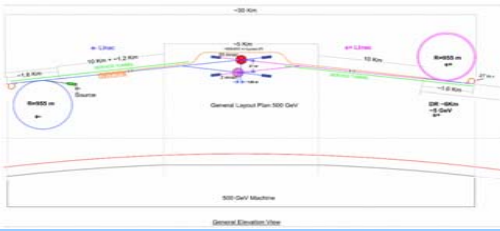
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## *Shower in Beamcal from $2\gamma$ process alone*





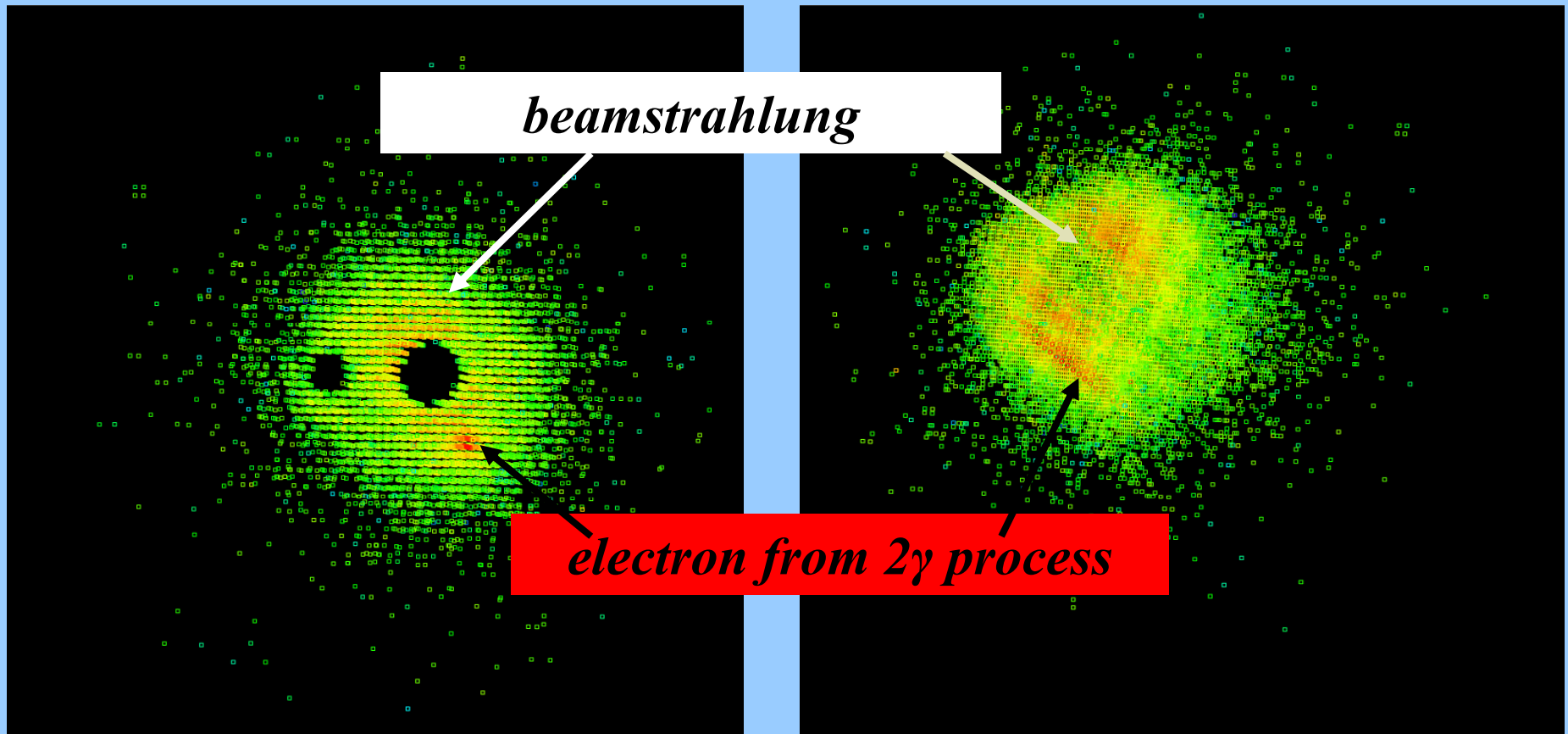
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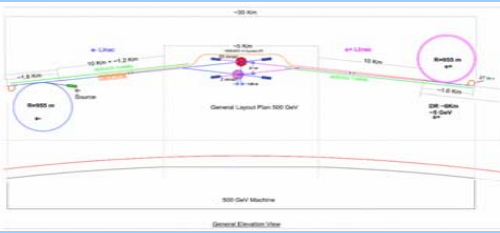


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*head on view*

*side view*





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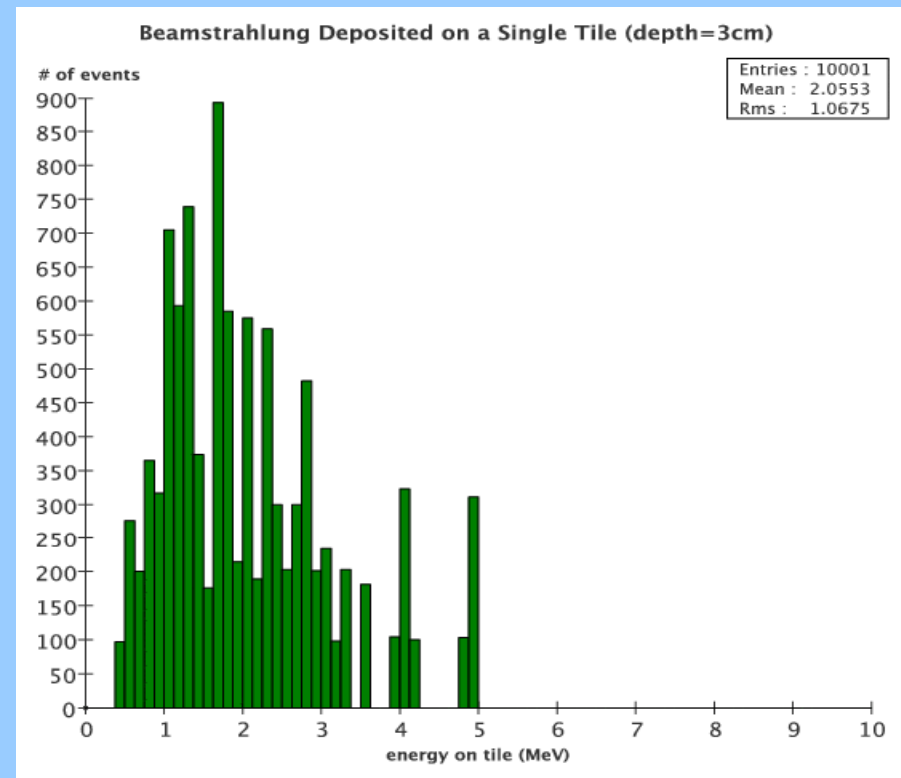
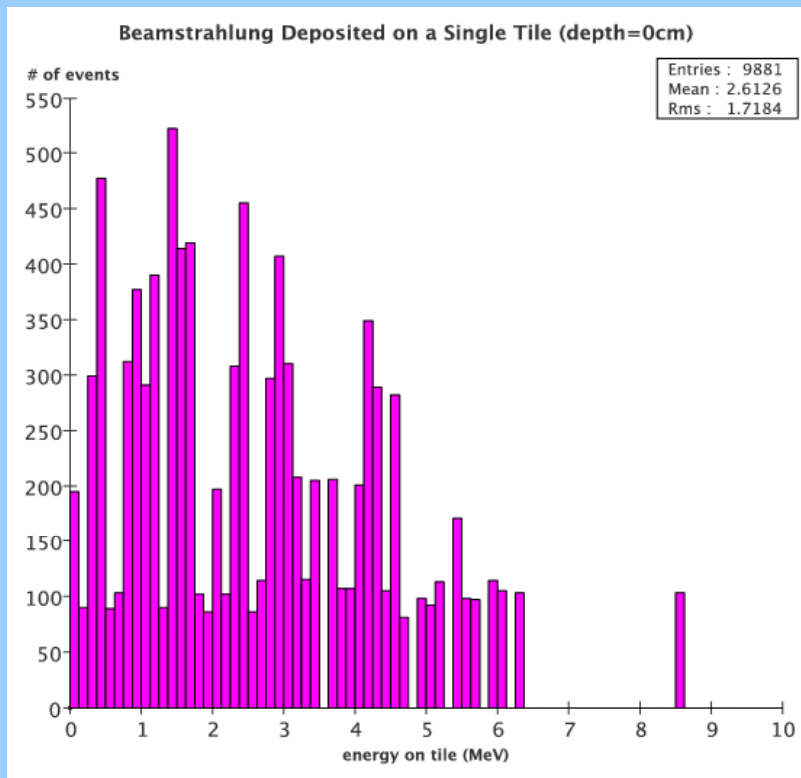


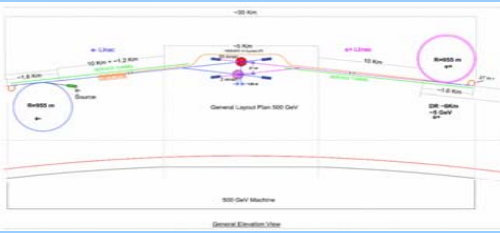
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## *Beamstrahlung Energy Deposition in a Tile*

Tile at start of BeamCal

Tile 3.0 cm in





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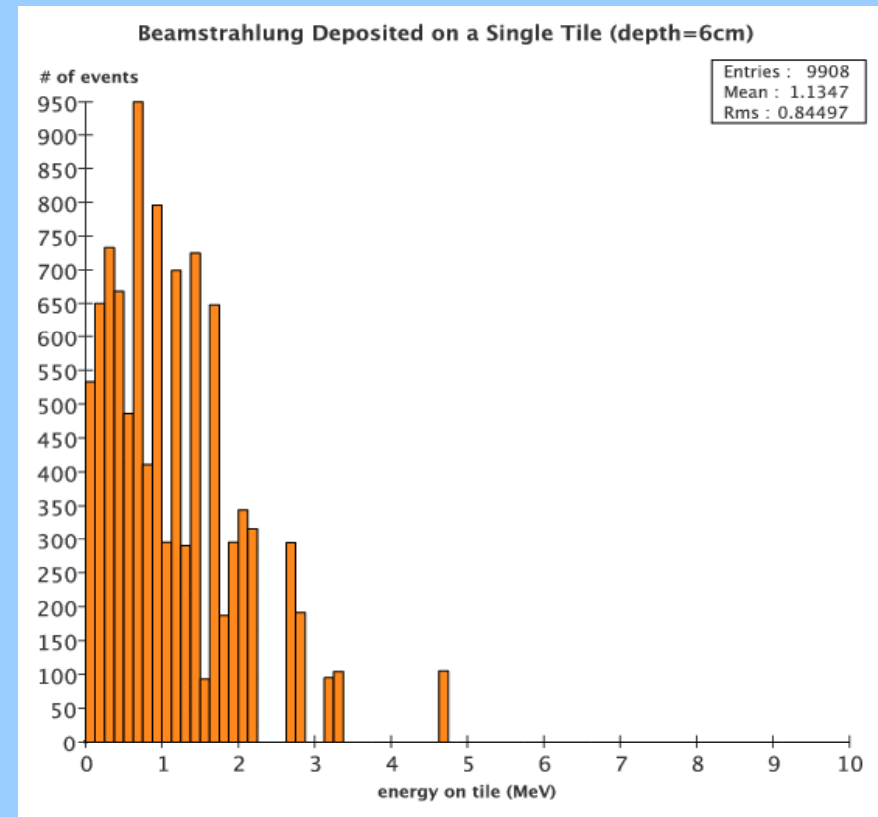
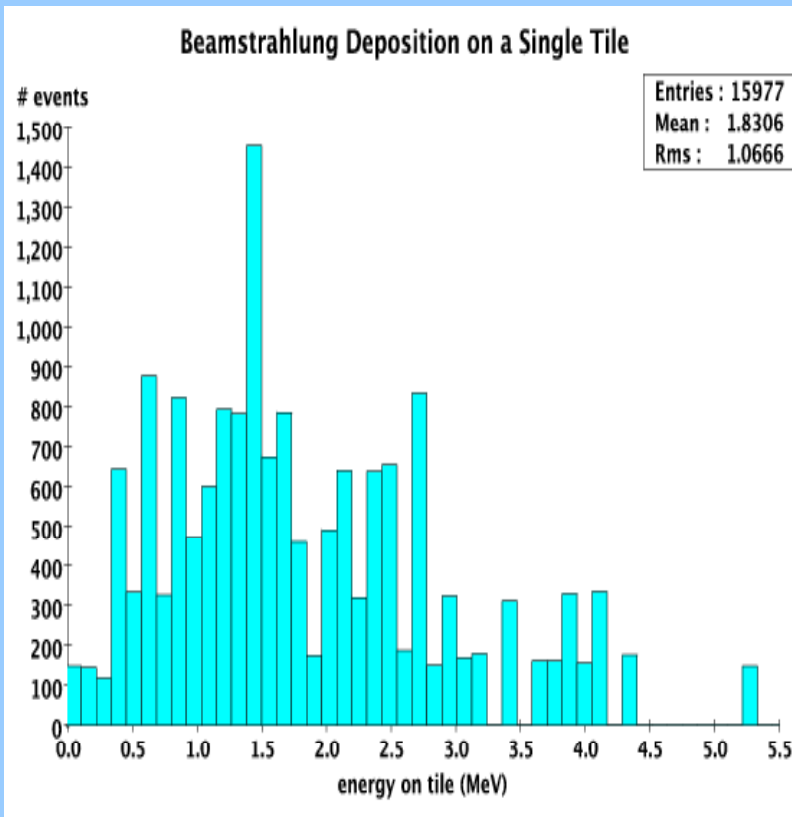


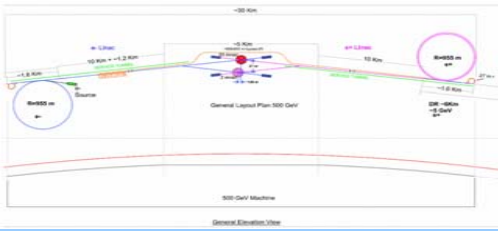
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## *Beamstrahlung Energy Deposition in a Tile*

Tile 4.7 cm in

Tile 6.0 cm in





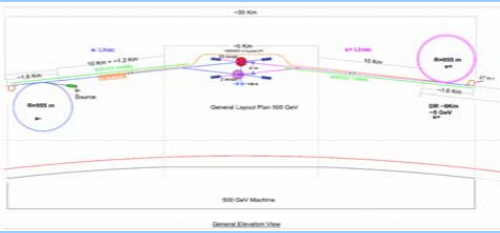
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## *Consequences of Beamstrahlung Energy Deposition*

- ❖ *Energy Deposition is not Gaussian until one reaches a depth  $> 3$  cms.*
- ❖ *Distribution is very wide and hence affects energy resolution if we subtract an average value.*
- ❖ *This problem is seen in the study how to measure the electron/positron energies. Resolution.*

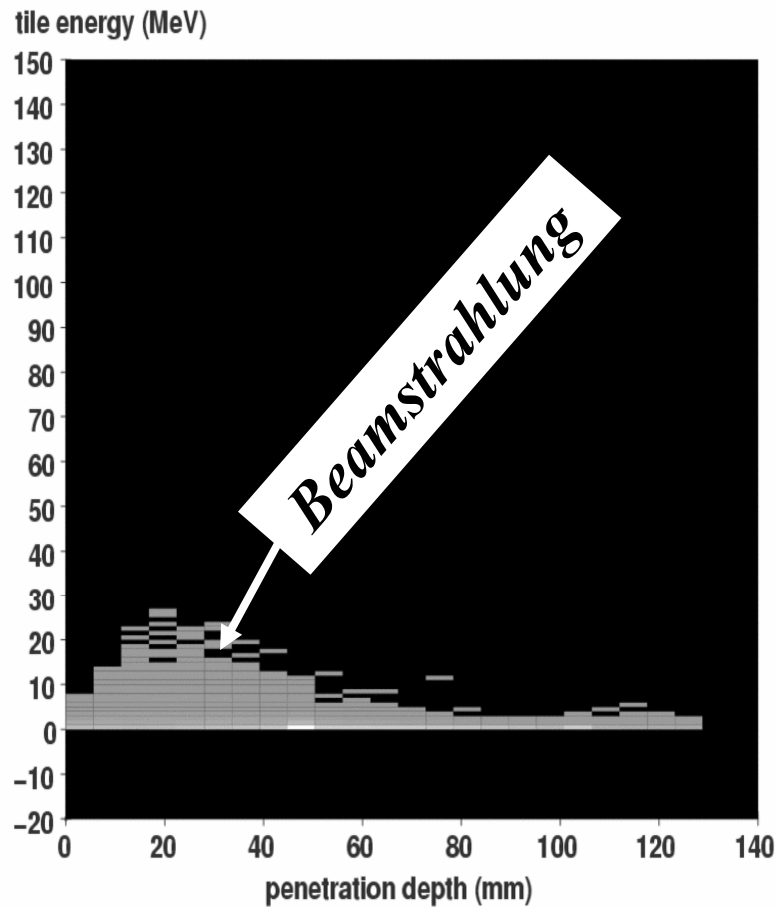


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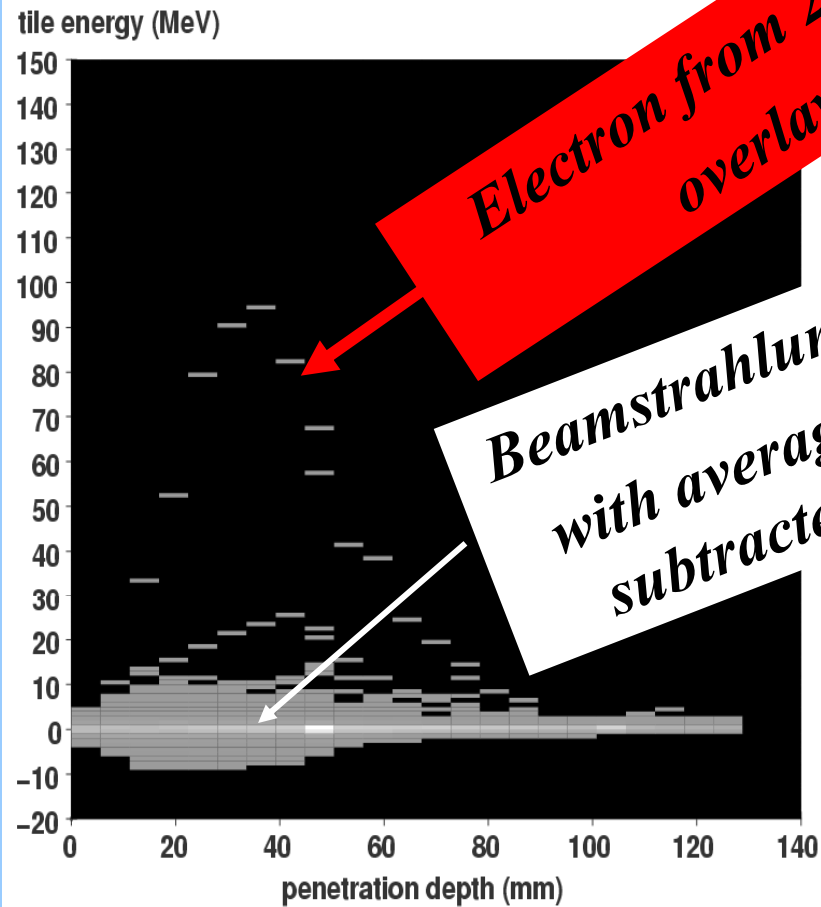


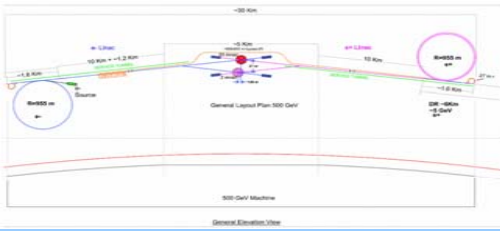
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Beamstrahlung Tile Energy



Subtracted Tile Energy





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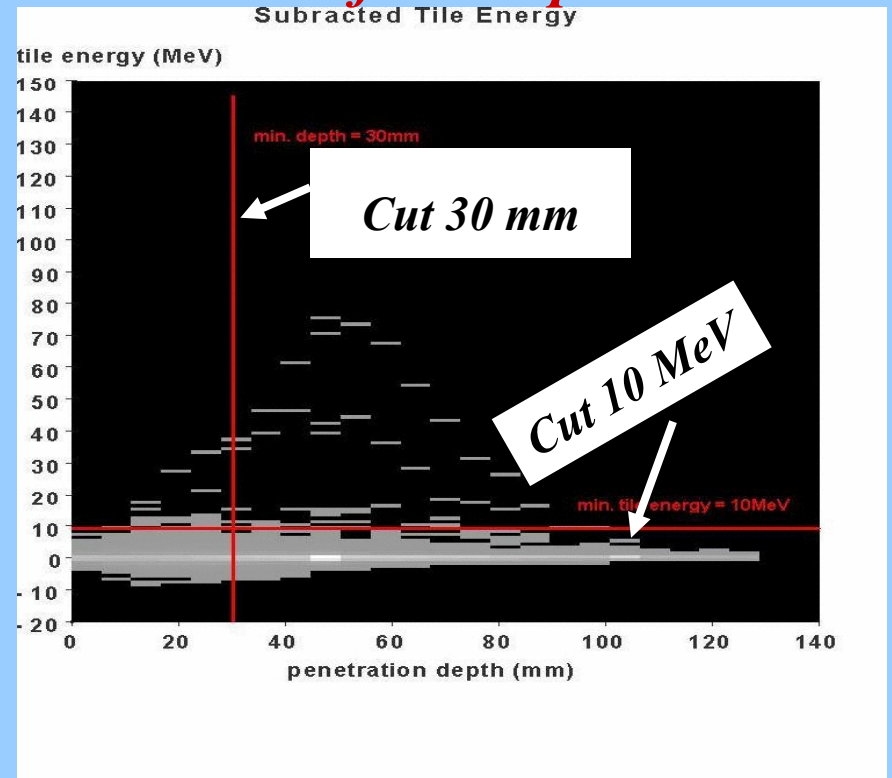
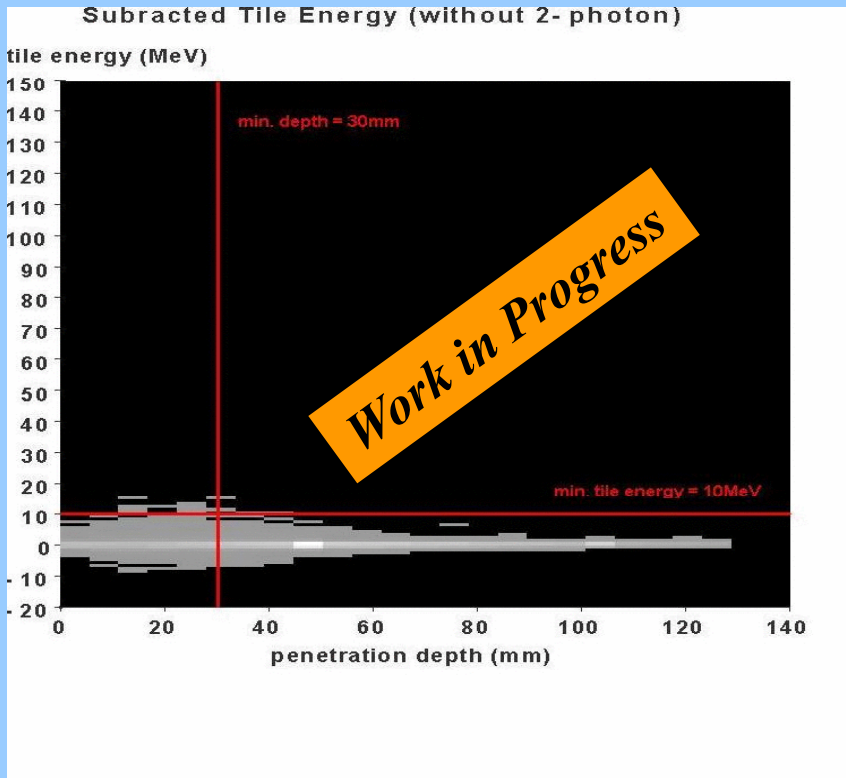


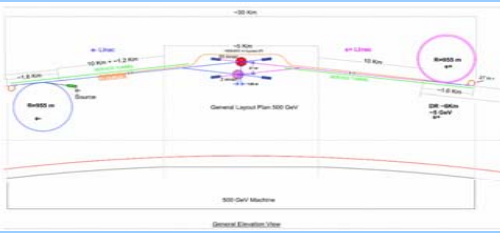
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## Clustering Cuts in Depth and Energy, Example 1

### Beamstrahlung Alone

### Electron from 2-photon





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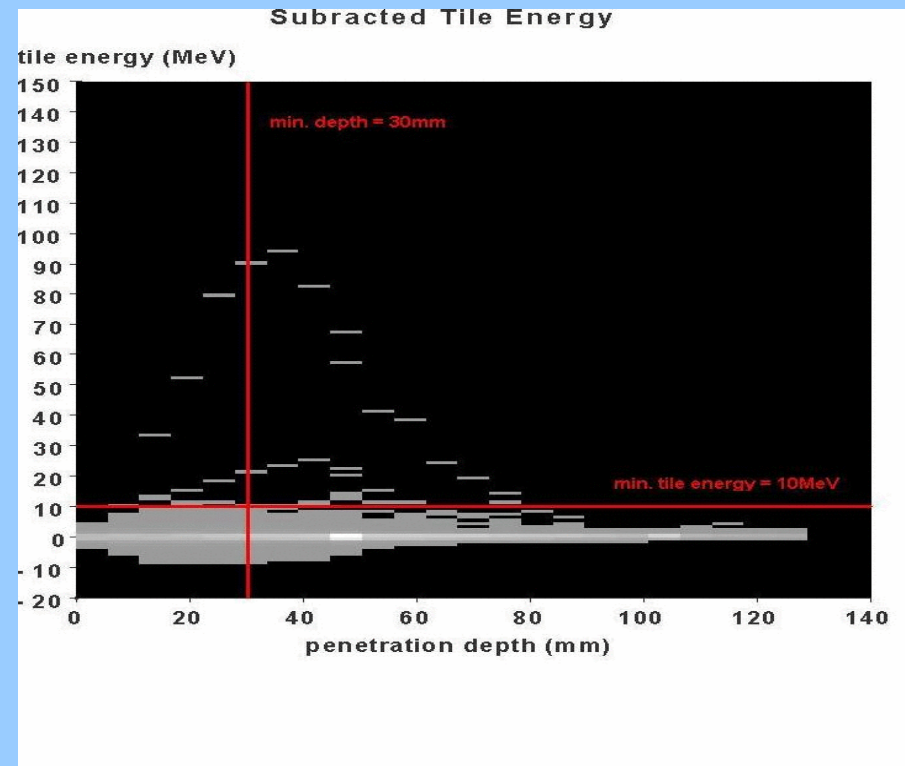
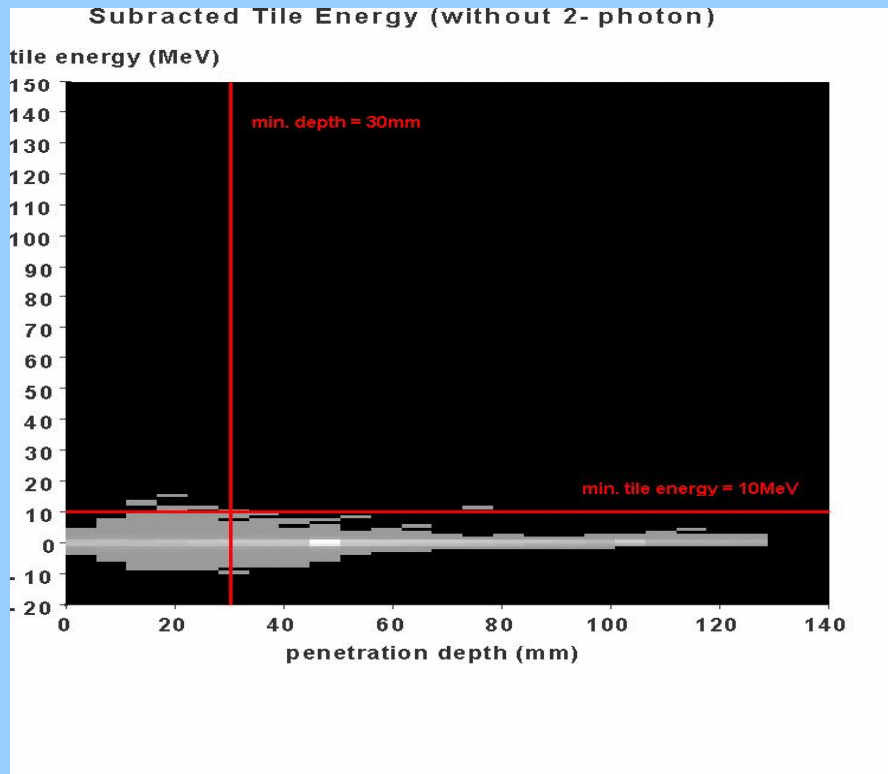


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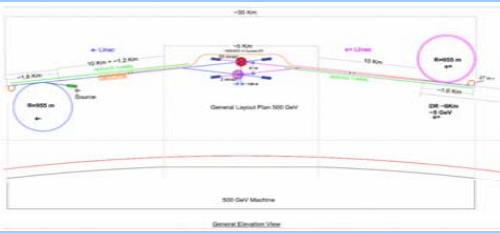
## Clustering Cuts in Depth and Energy, Example 2

*Beamstrahlung +  
Electron from 2-photon*

*Beamstrahlung Alone*







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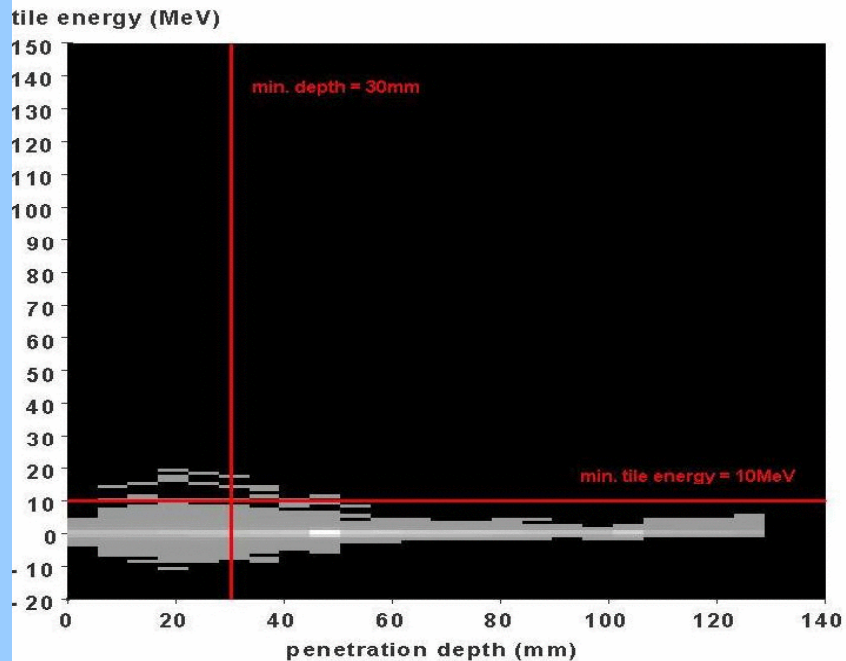
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## Clustering Cuts in Depth and Energy, Example 3

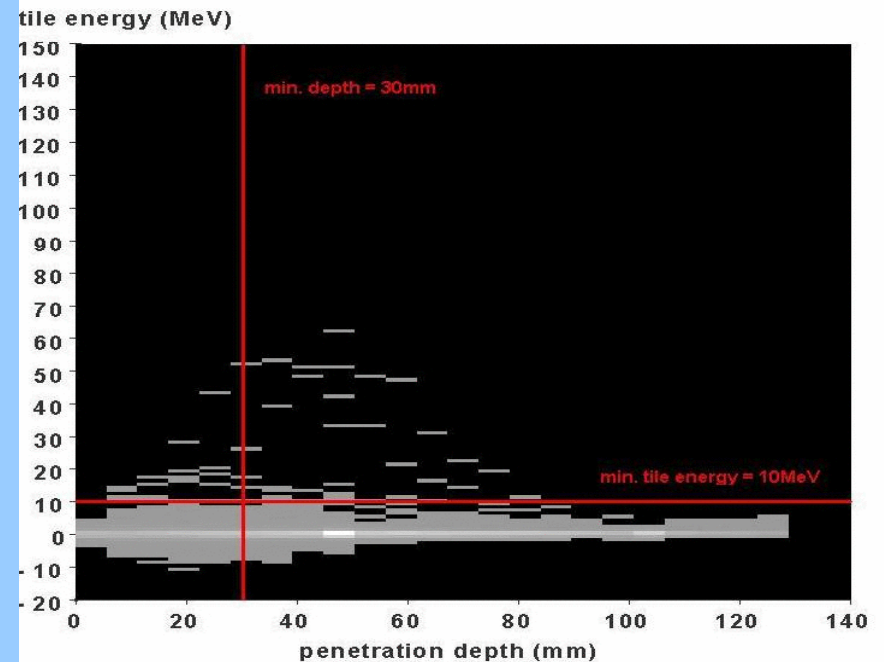
*Beamstrahlung +  
Beamstrahlung Alone*

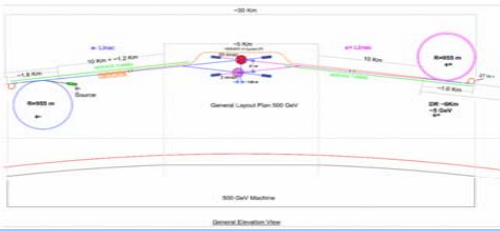
## *Electron from 2-photon*

Subtracted Tile Energy (without 2-photon)



Subtracted Tile Energy



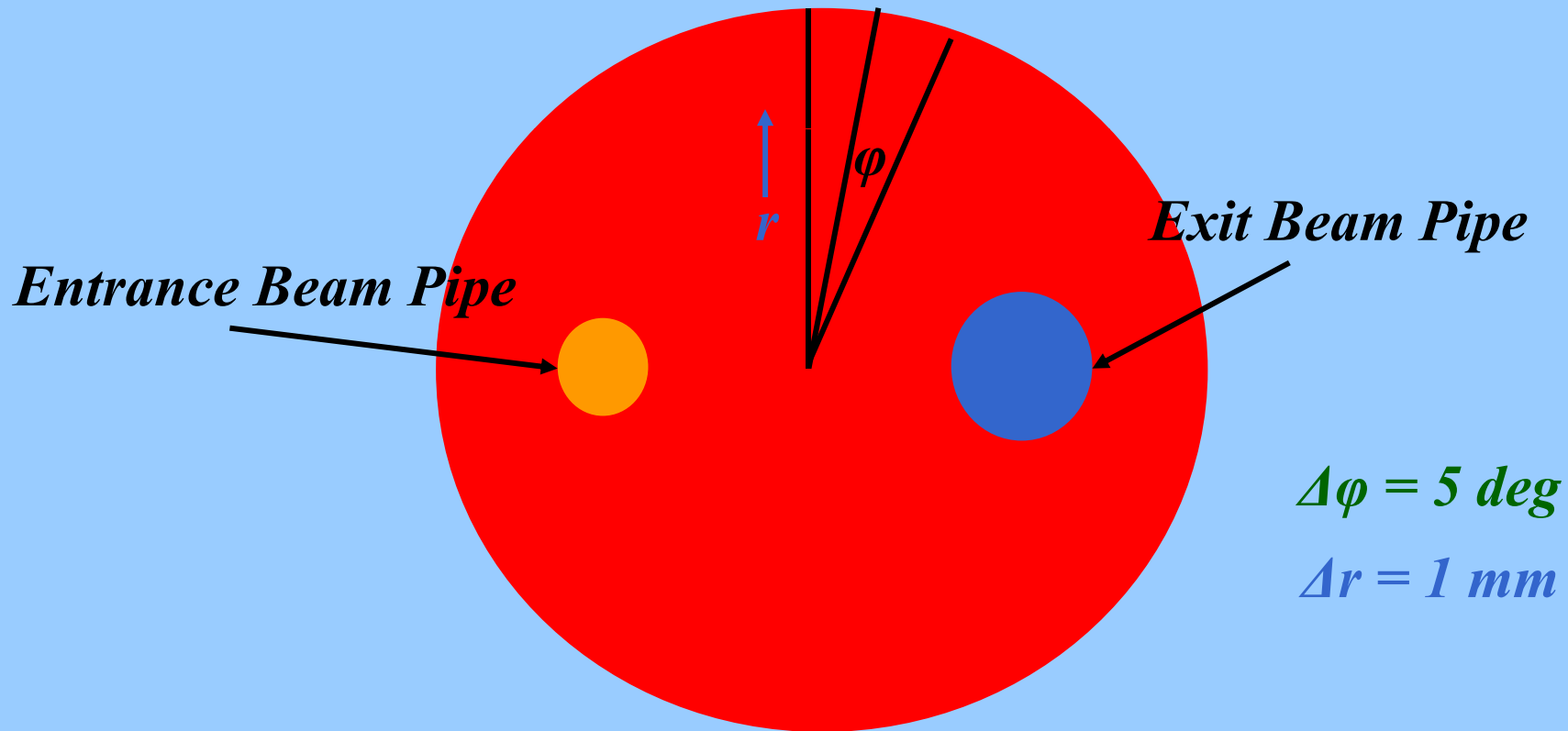


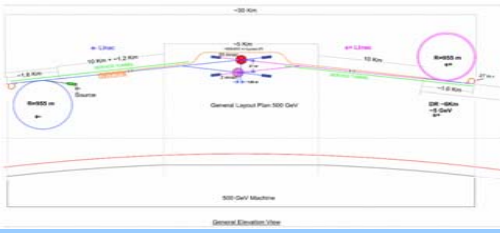
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*Energy observed as a function of distance from center of BeamCal*





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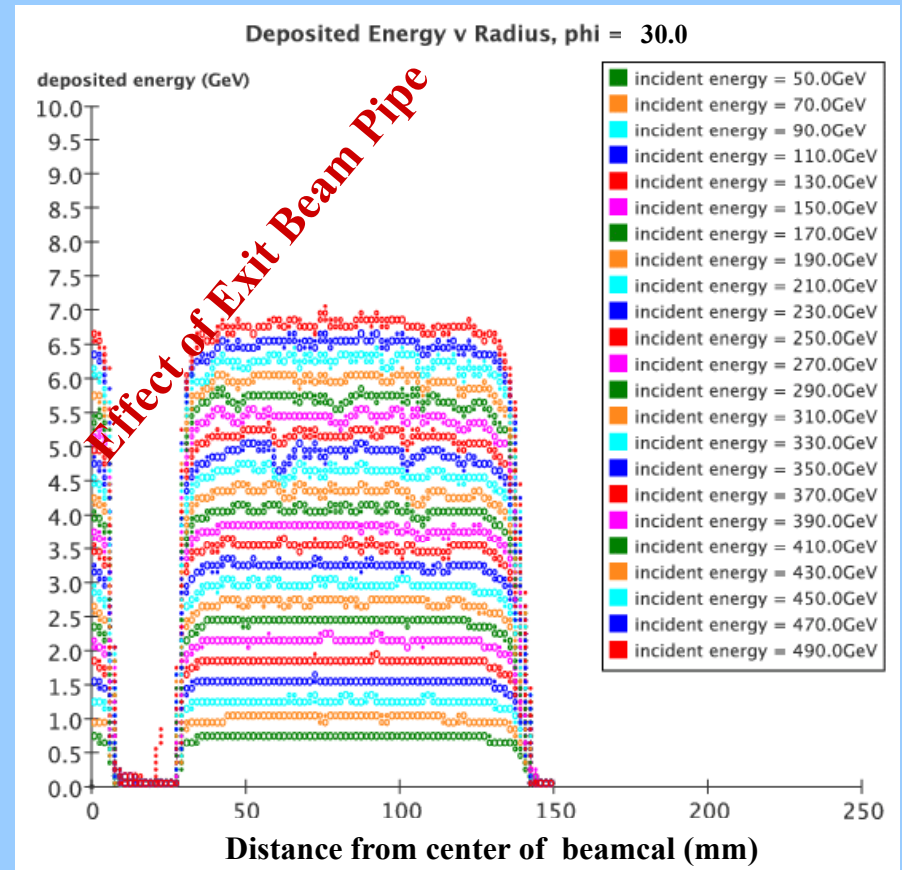
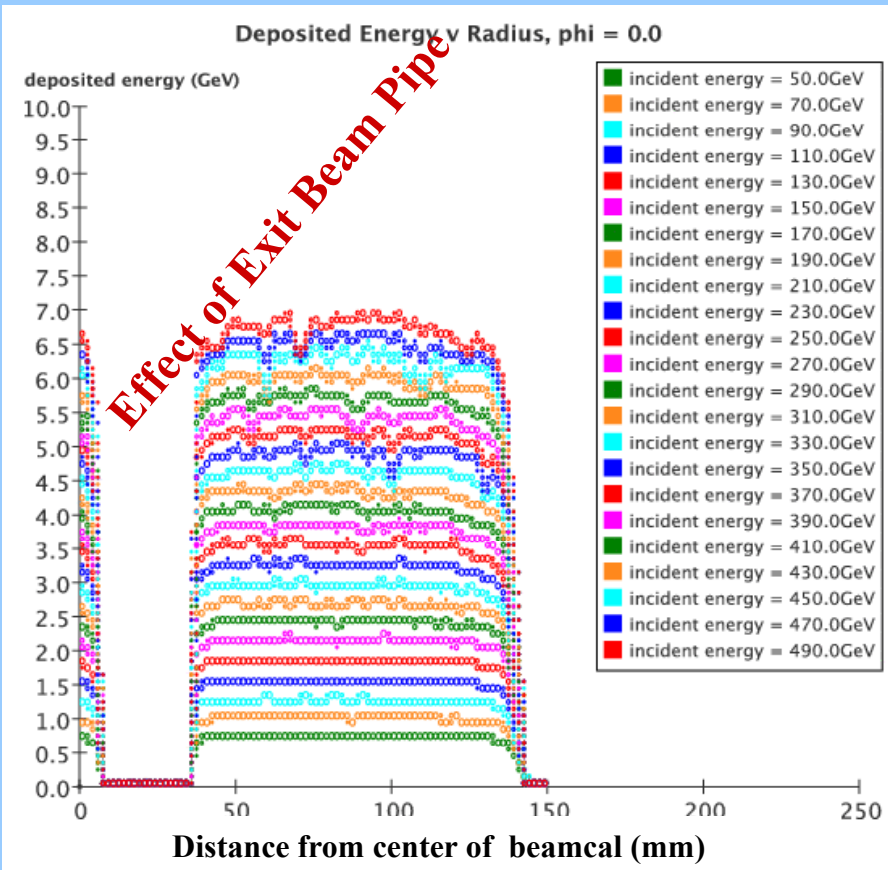


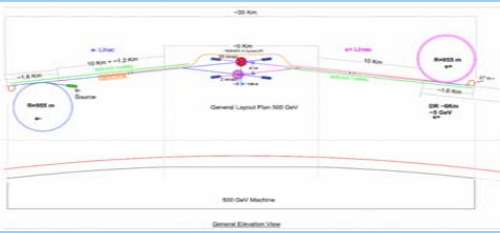
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## Energy Deposition versus $r$ and $\phi$

$\Phi=0.0$

$\Phi=30.0$





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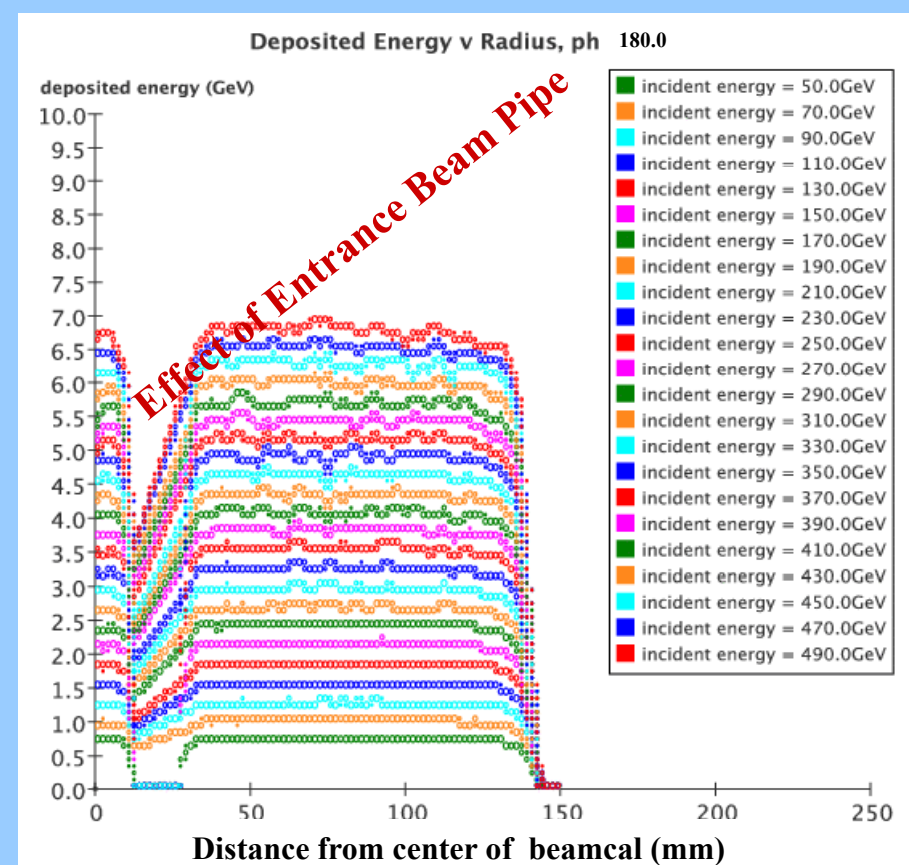
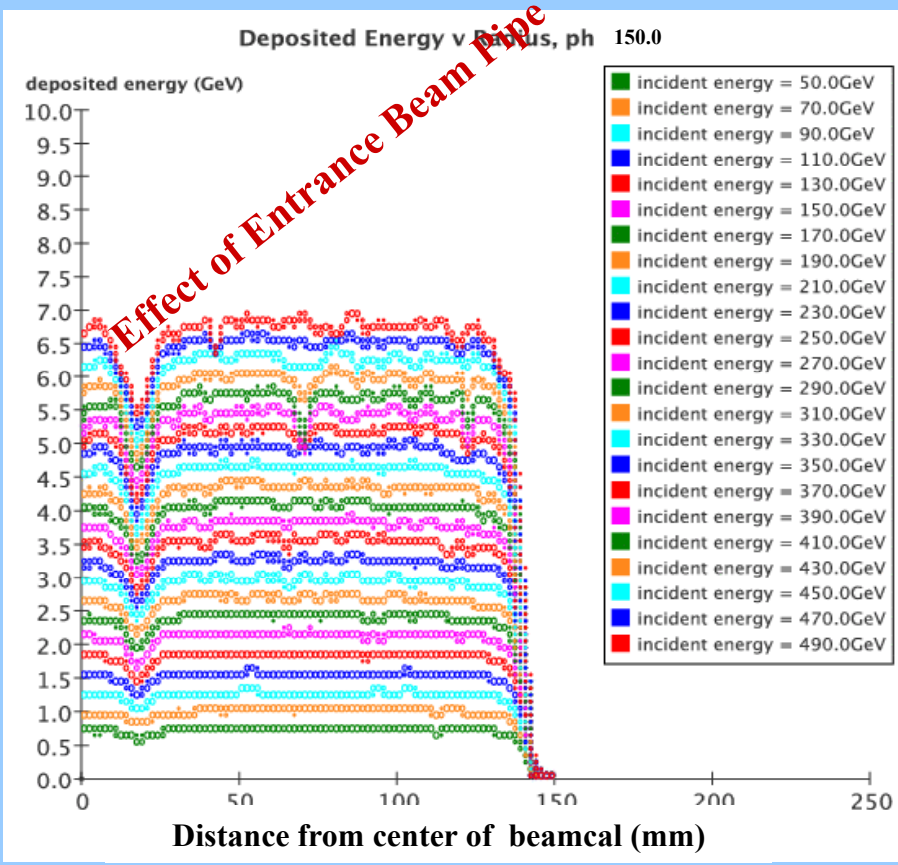


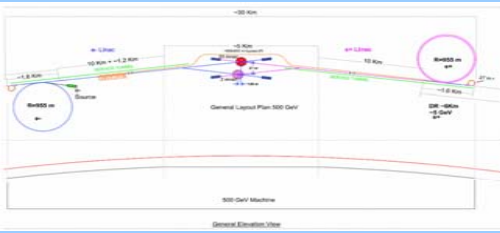
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## Energy Deposition versus $r$ and $\phi$

$\Phi=150.0$

$\Phi=180.0$

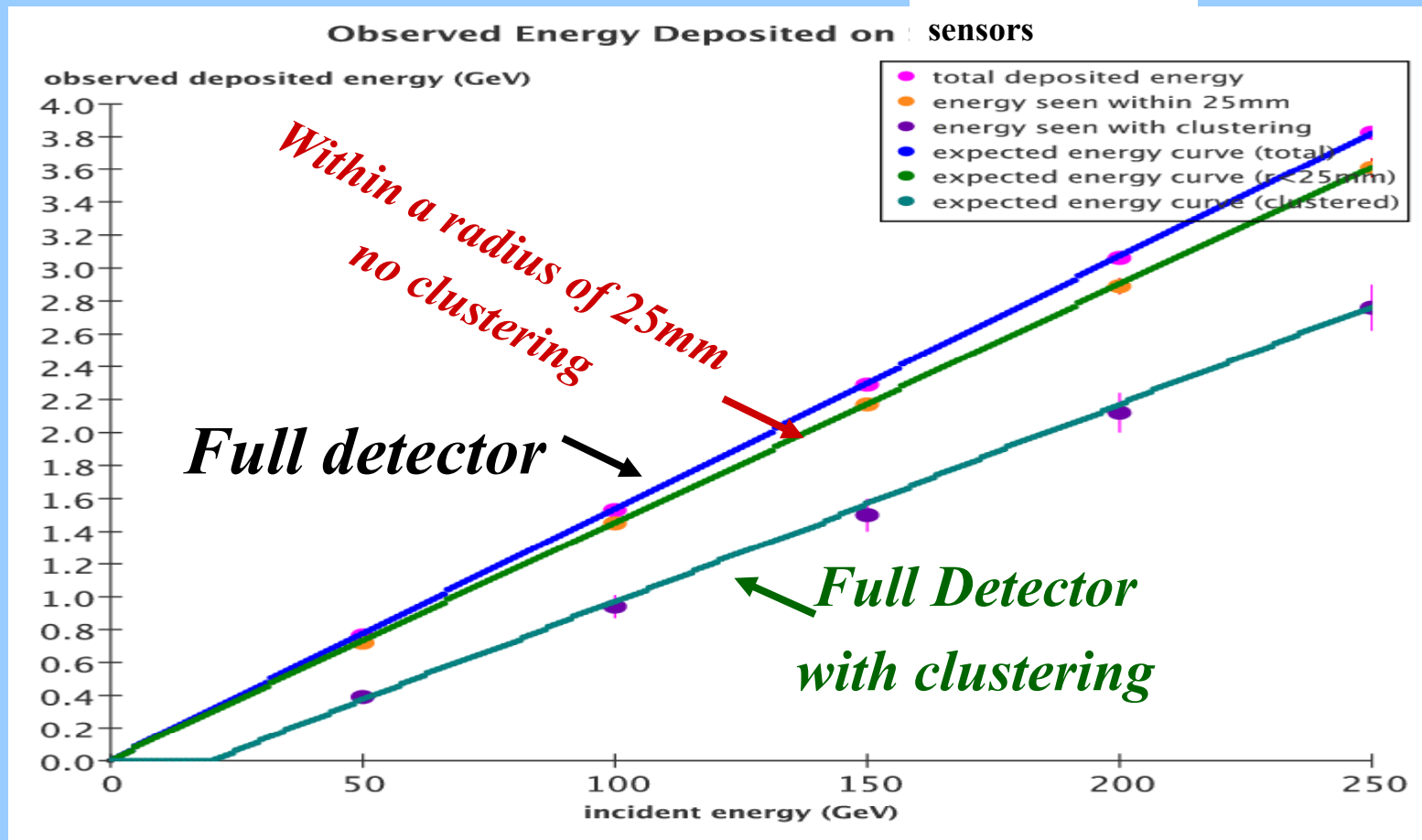




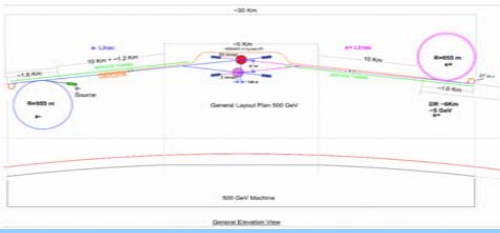
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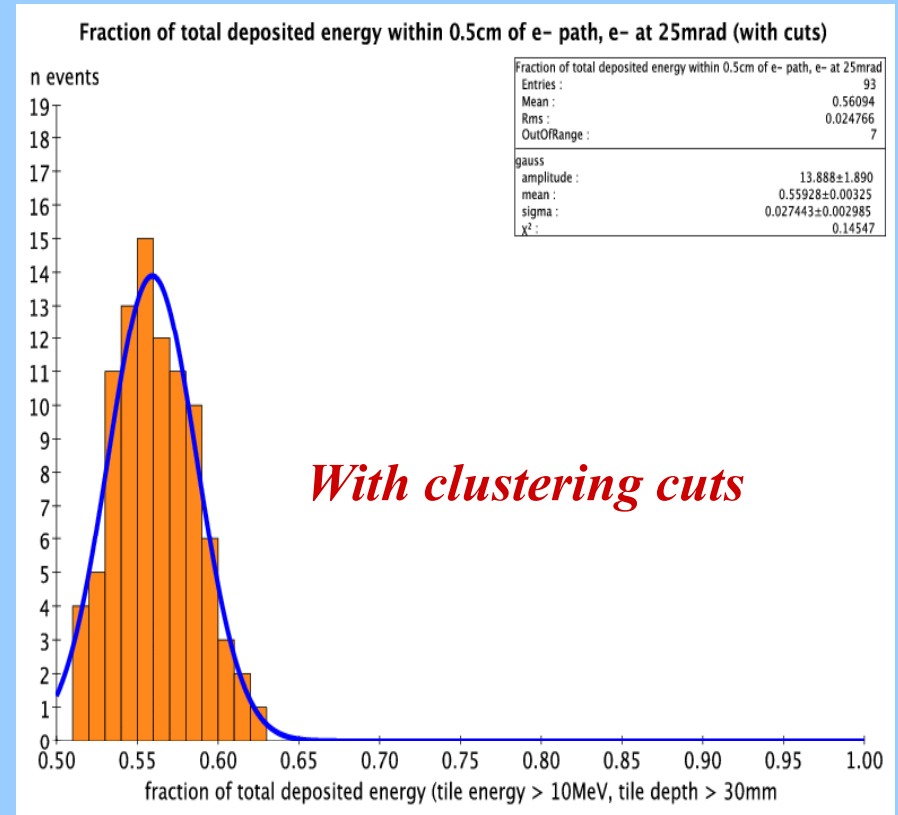
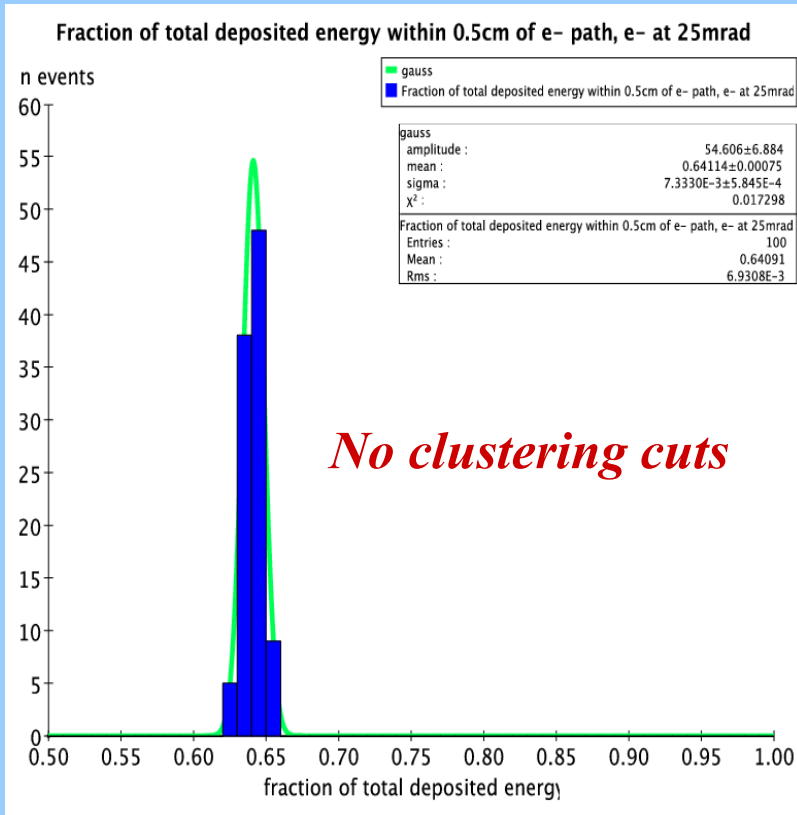


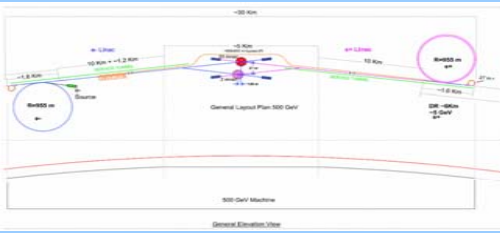
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## *Fraction of Energy Observed within a Radius of 0.5 cm of Electron Path*





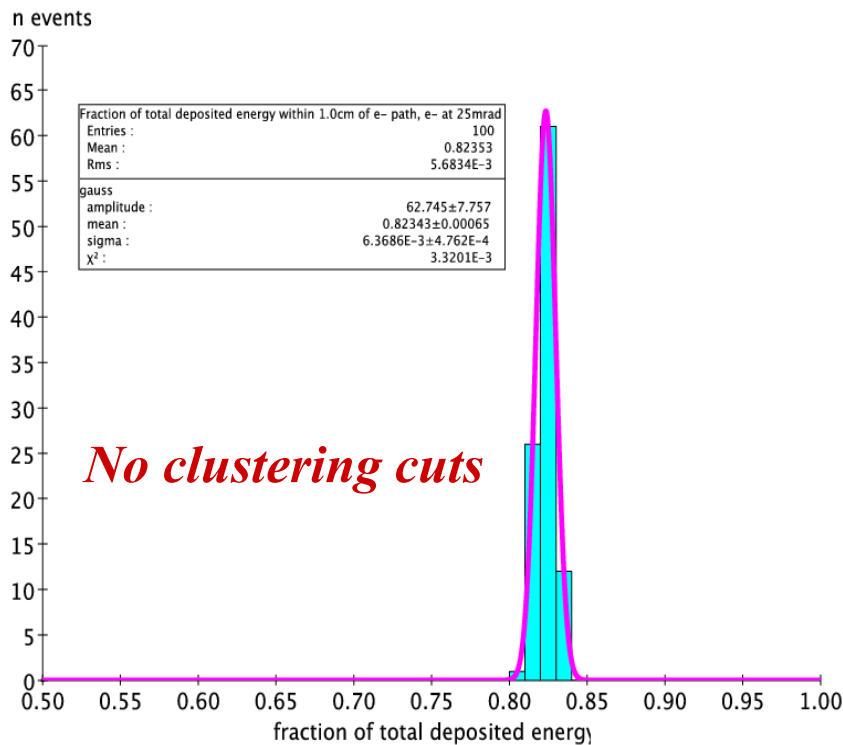
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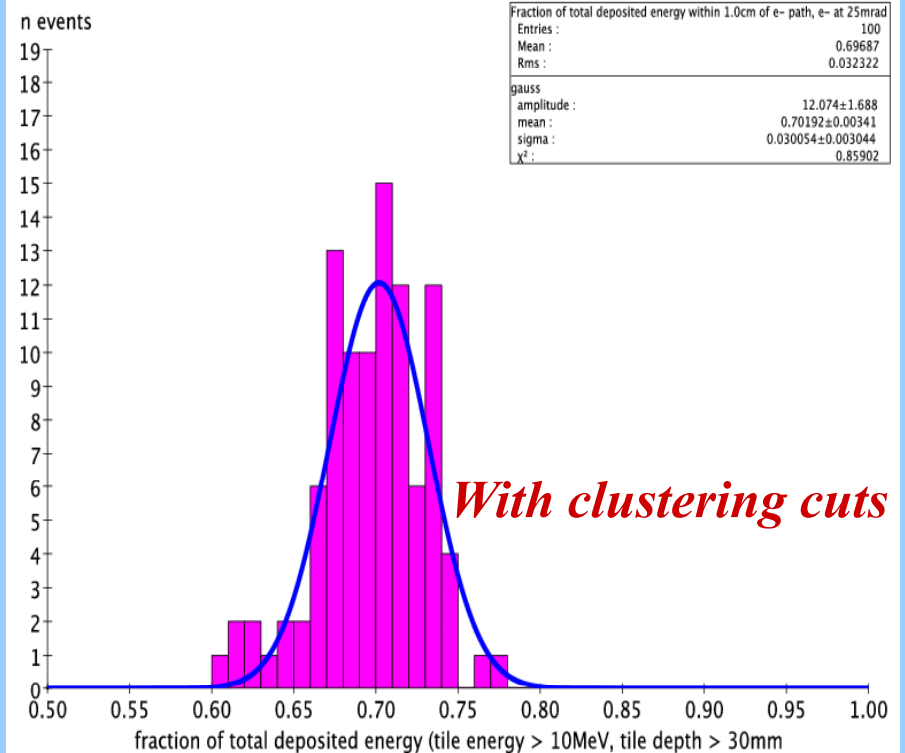
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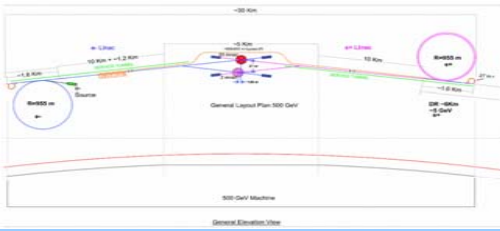
## *Fraction of Energy Observed within a Radius of 1.0 cm of Electron Path*

Fraction of total deposited energy within 1.0cm of e<sup>-</sup> path, e<sup>-</sup> at 25mrad



Fraction of total deposited energy within 1.0cm of e<sup>-</sup> path, e<sup>-</sup> at 25mrad (with cuts)





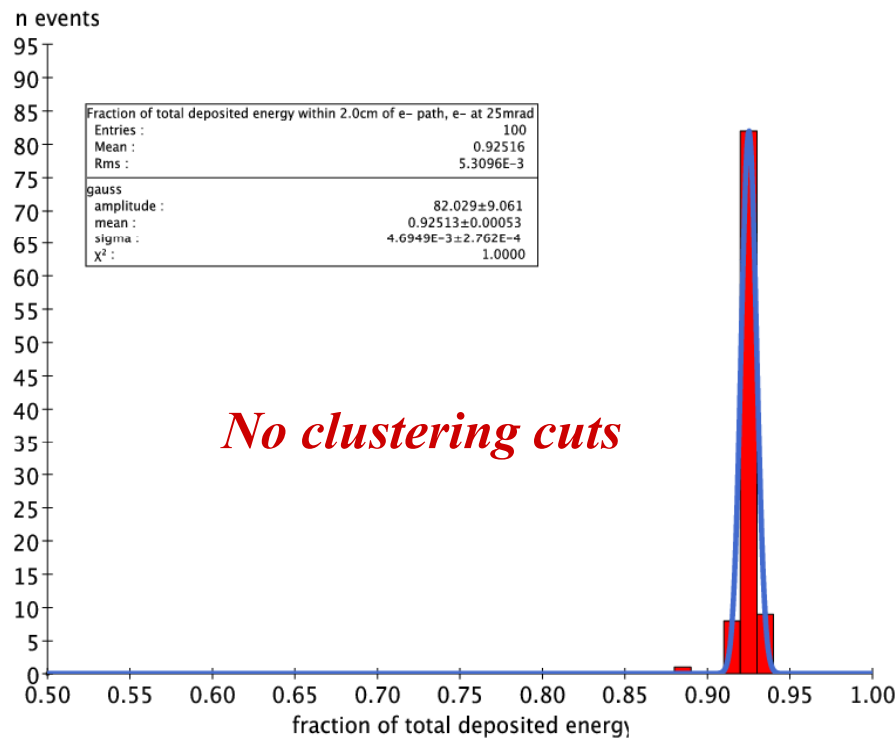
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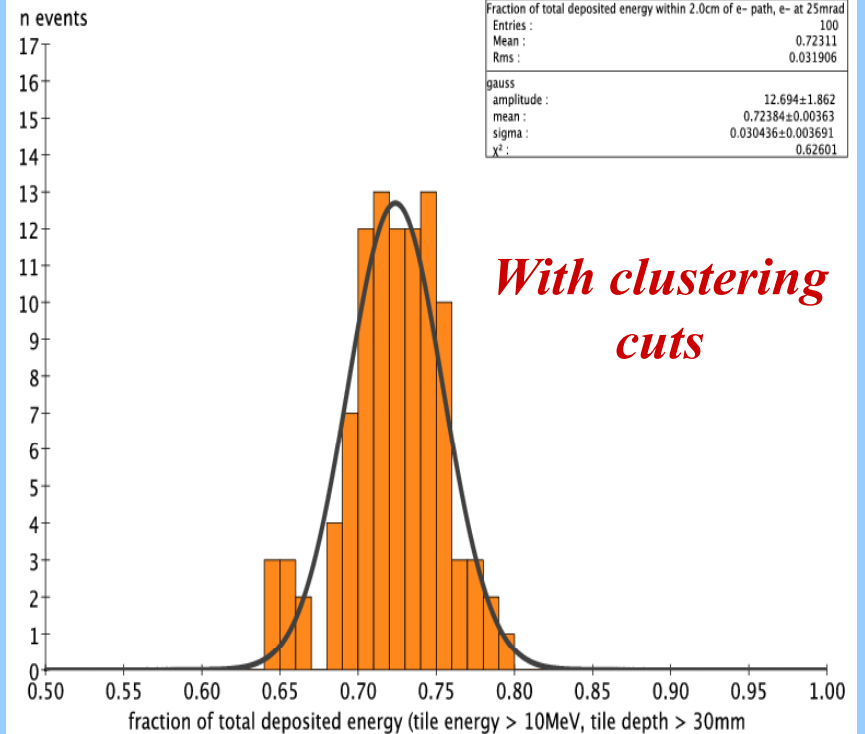
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## *Fraction of Energy Observed within a Radius of 2.0 cm of Electron Path*

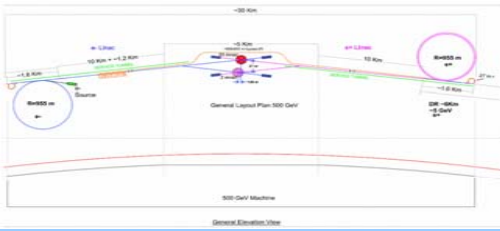
Fraction of total deposited energy within 2.0cm of e- path, e- at 25mrad



Fraction of total deposited energy within 2.0cm of e- path, e- at 25mrad (with cuts)







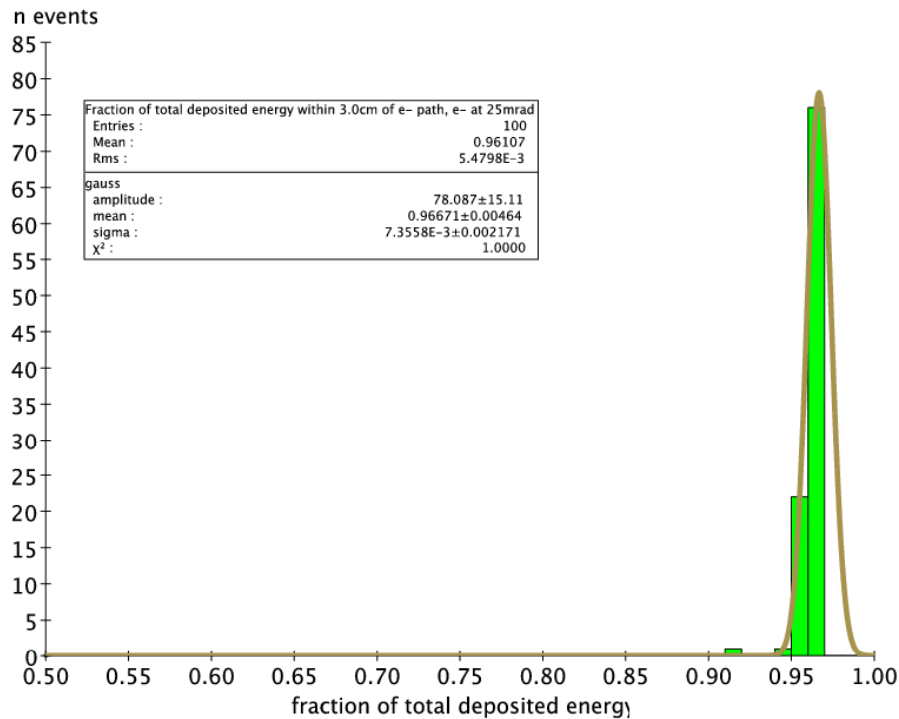
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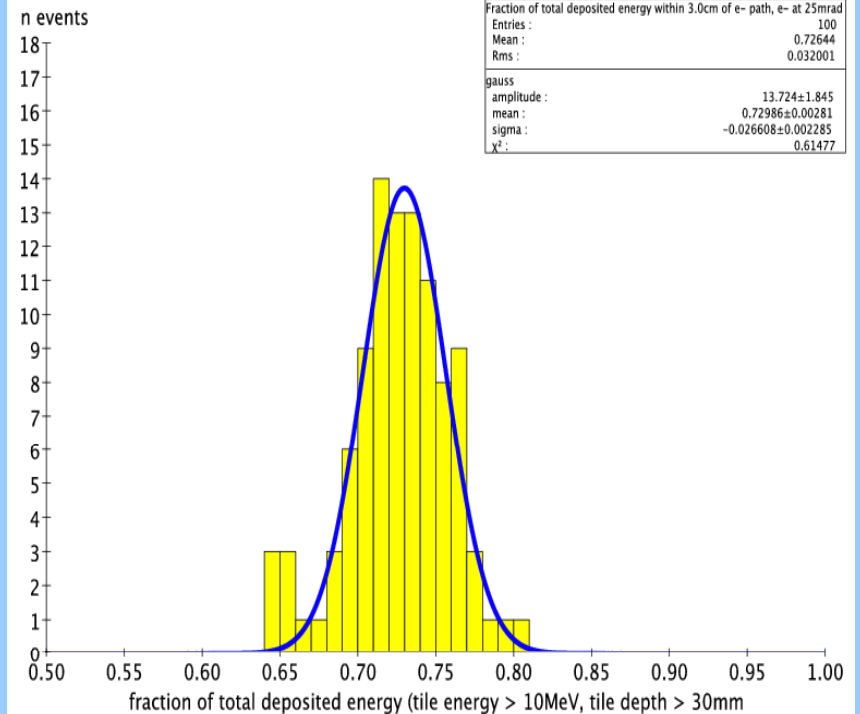
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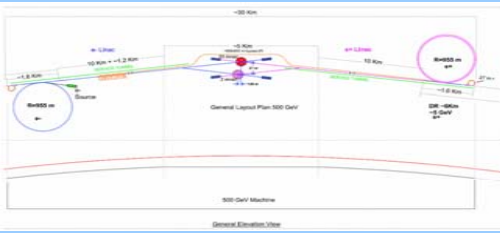
## *Fraction of Energy Observed within a Radius of 3.0 cm of Electron Path*

Fraction of total deposited energy within 3.0cm of e- path, e- at 25mrad



Fraction of total deposited energy within 3.0cm of e- path, e- at 25mrad (with cuts)





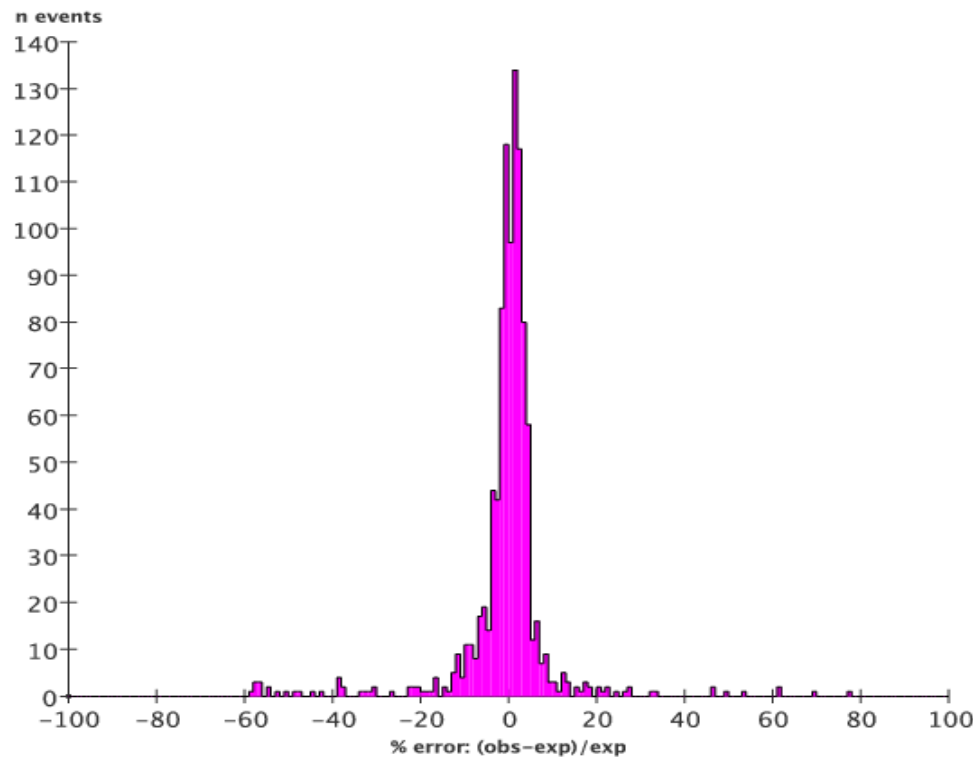
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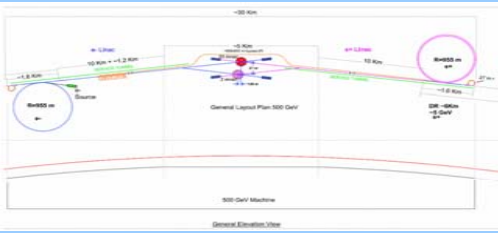
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## *Energy Resolution of High Energy Electrons* $\{E(\text{measured}) - E(\text{expected})\} / E(\text{expected})$

Error in Two-Photon Energy Determination – Run 1



**Best Possible Resolution**  
**No Beamstrahlung effects**  
**included**

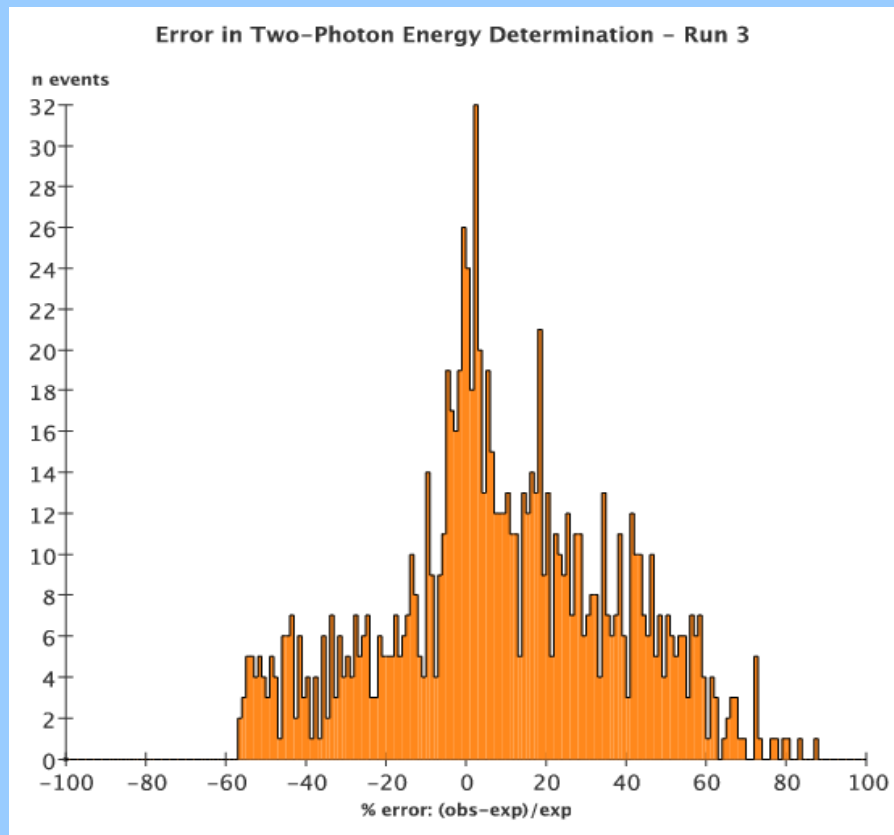


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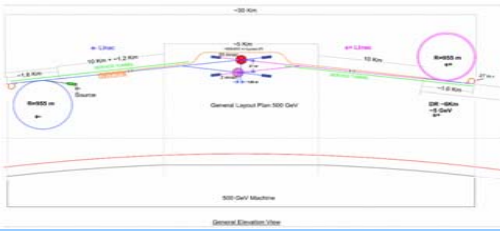
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## *Energy Resolution of High Energy Electrons* $\{E(\text{measured}) - E(\text{expected})\} / E(\text{expected})$



*Energy Resolution with  
 Beamstrahlung Included.  
 Average Subtracted. Only  
 energy deposited in a 25 mm  
 radius from maximum. Sum  
 energy over full Beamcal  
 thickness.*

*Effect of Beamstrahlung  
 fluctuation in resolution clearly  
 has an effect*

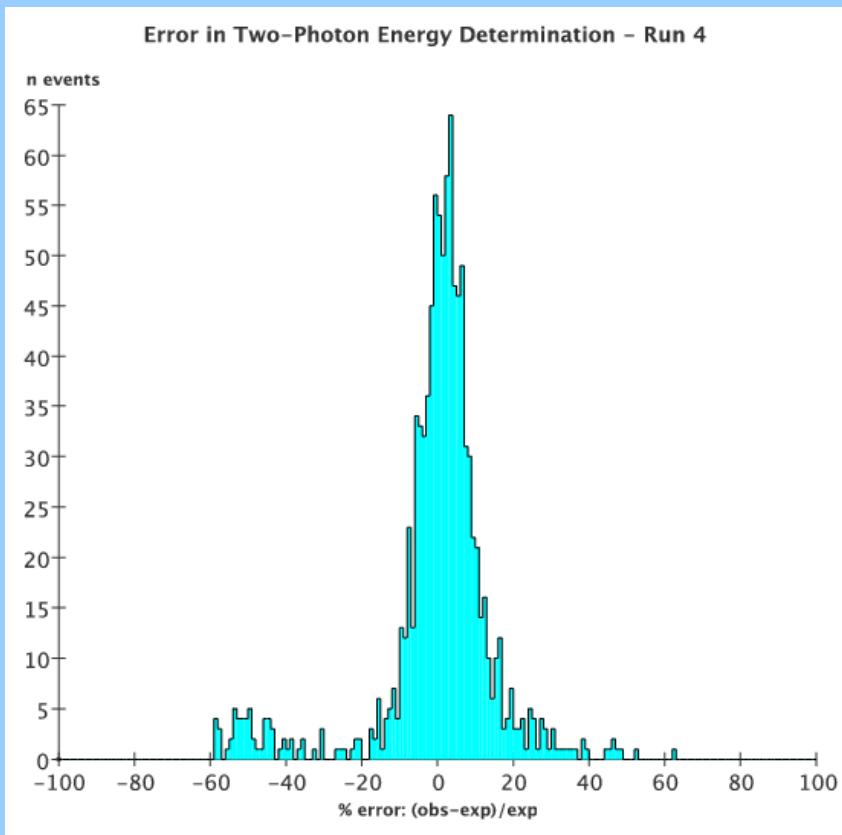


# April 28/2008-ALCPG

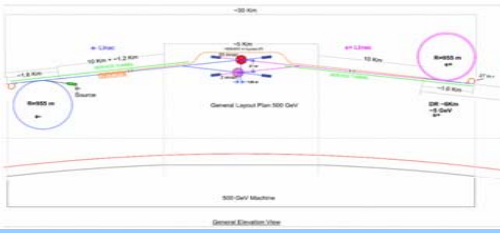


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## *Energy Resolution of High Energy Electrons* *$\{E(\text{measured}) - E(\text{expected})\} / E(\text{expected})$*



*Energy Resolution. Beamstrahlung  
Included and Average Subtracted.  
Measurements from 3.0 cm in and  
Including only cells with more than  
10 MeV energy deposited.*

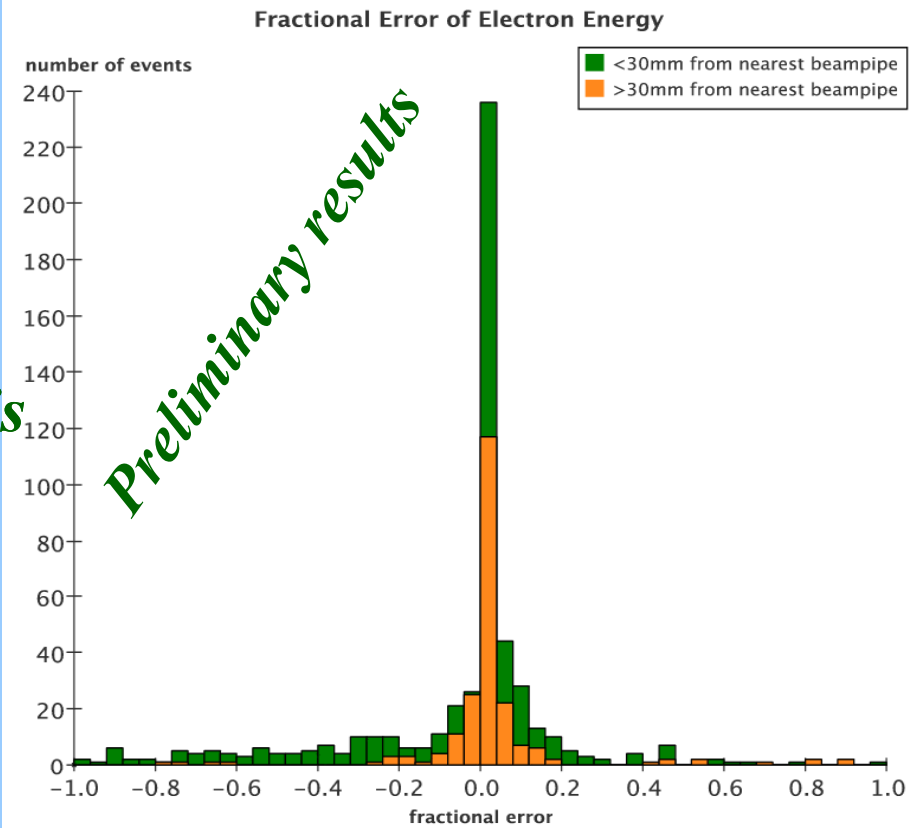
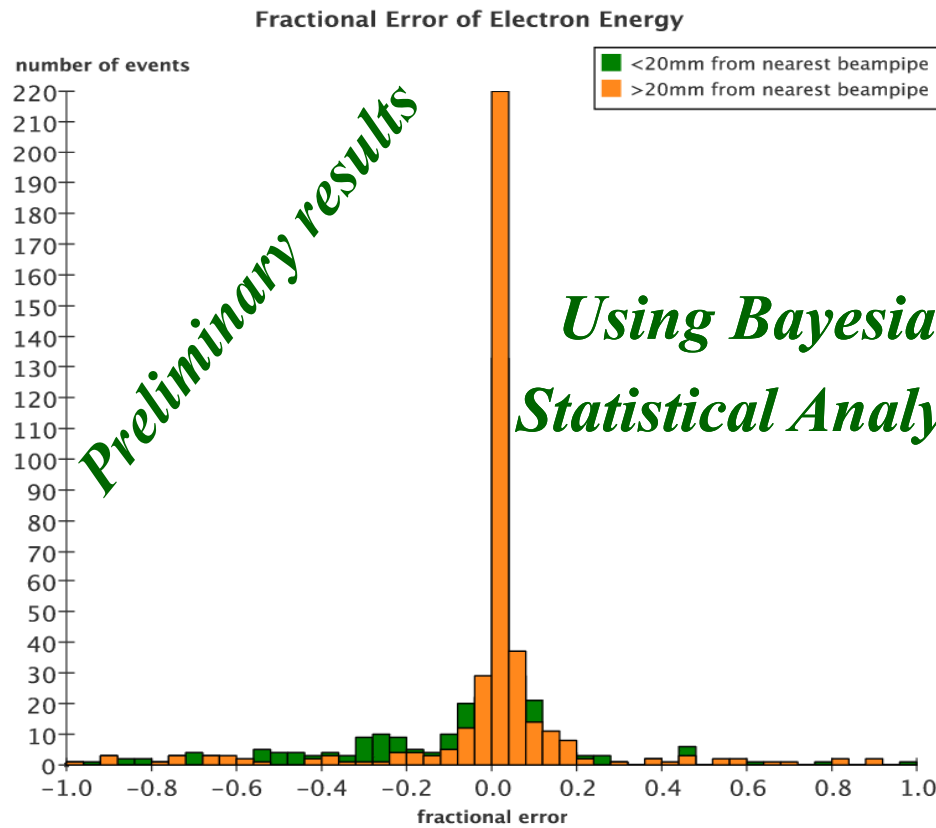


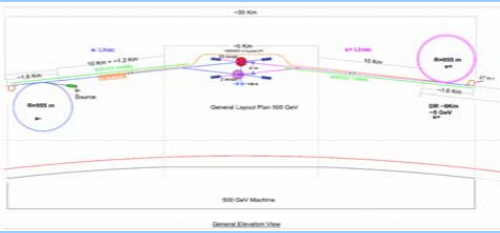
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## *Energy resolution of the reconstruction of the electrons from 2-photon events including the effects of beamstrahlung*

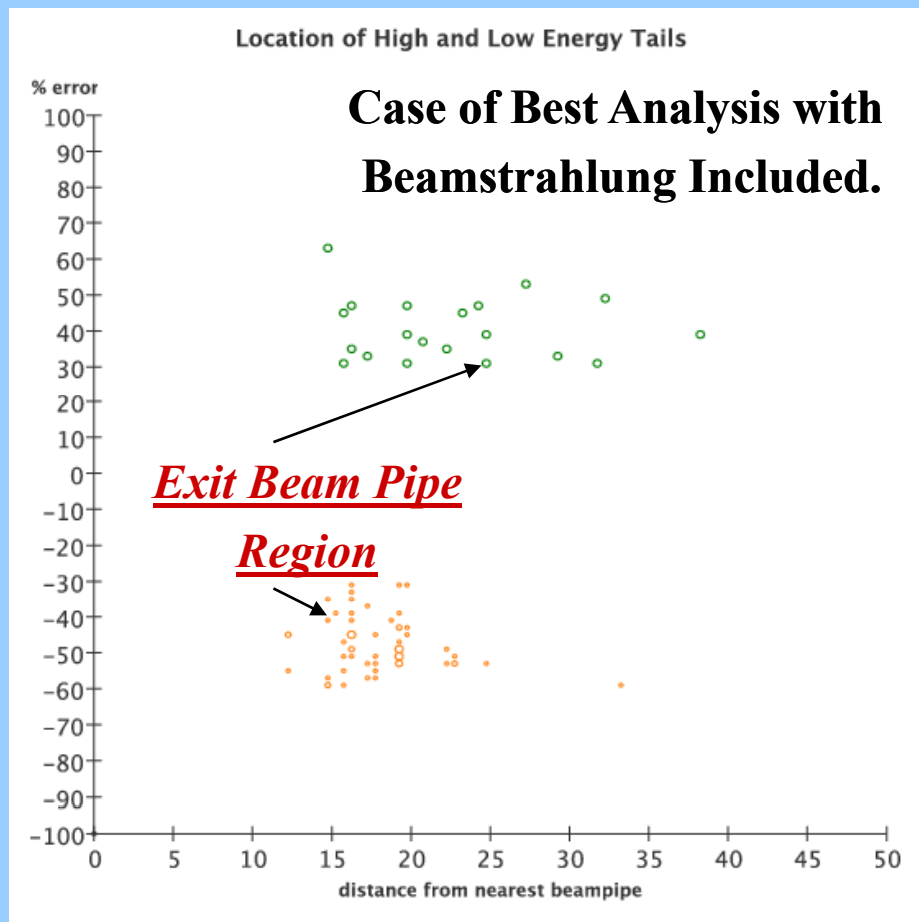
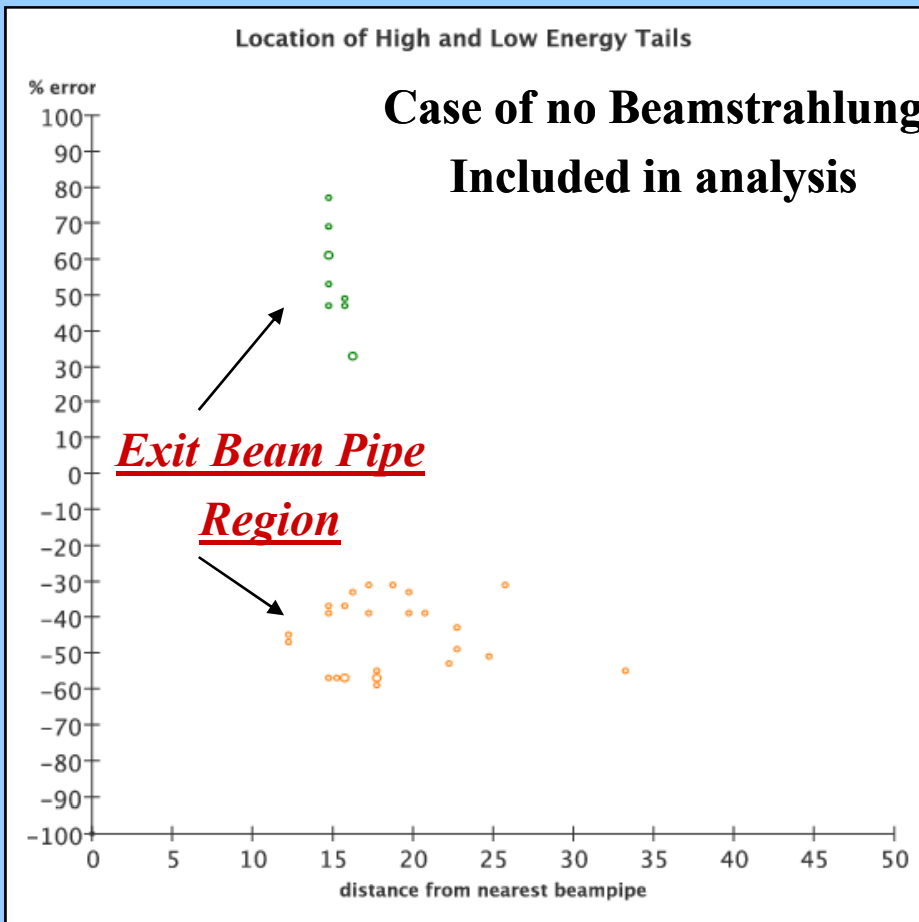


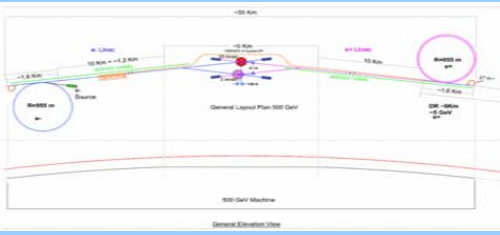


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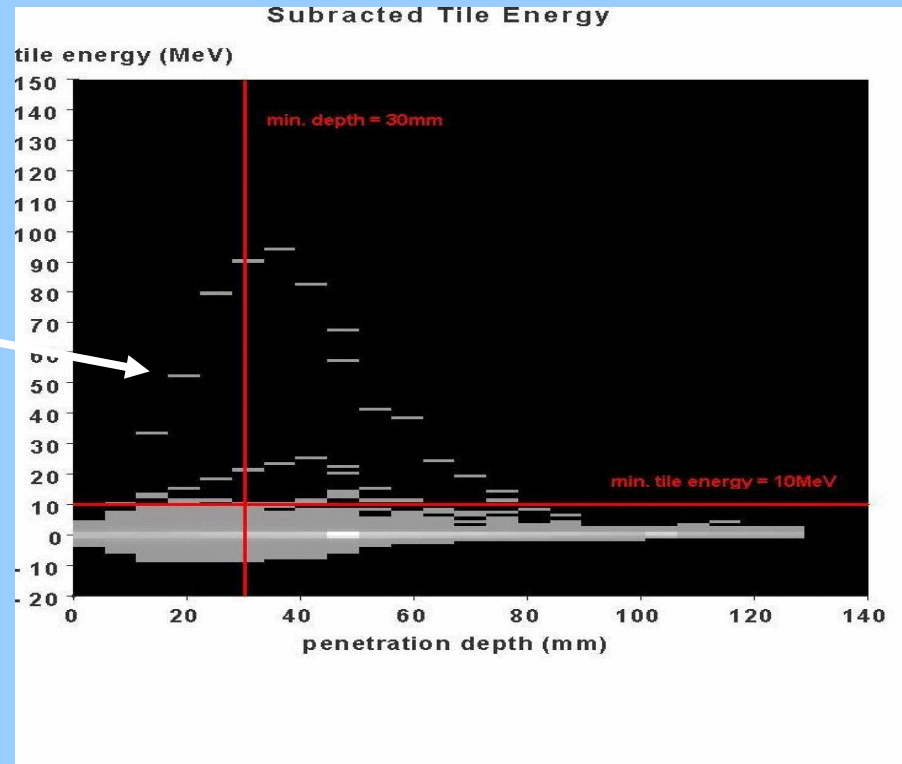
# April 28/2008-ALCPG

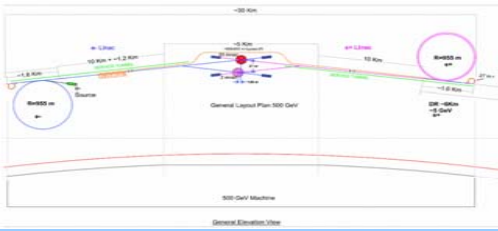


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## *Reason for Resolution Tail*

*Measured Energy loss  
due to cuts*





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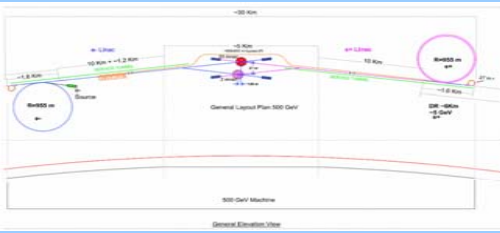


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## *Work to be Done*

- ❖ *Understand the low energy tails of the energy resolution distribution. Develop a better scan.*
- ❖ *What is the missing  $P_t$  distribution of 2 photon events given the resolution.*
- ❖ *Study the resolution of new geometries.*

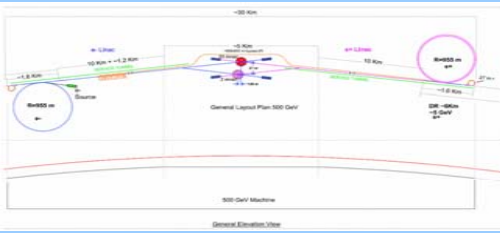




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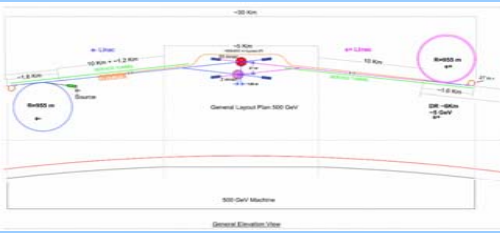
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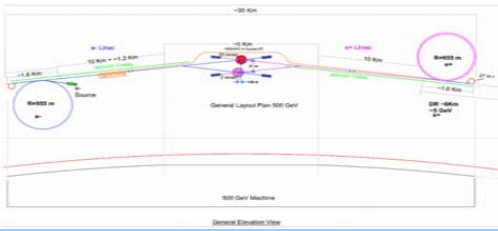
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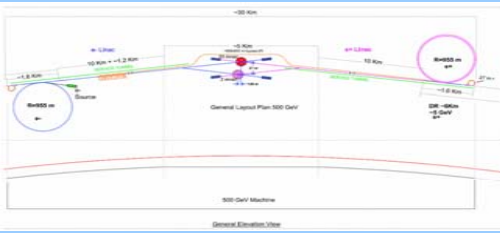
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## *Work to be Done*

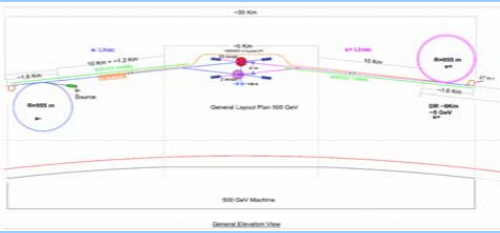
- *Optimize signal to Background.*
- *Check all our Calculations.*
- *Find other analysis techniques that reduce the beamstrahlung fluctuations and hence improve the signal resolution.*
- *Study the effect of this analysis on SUSY signal. Missing Pt limits.*



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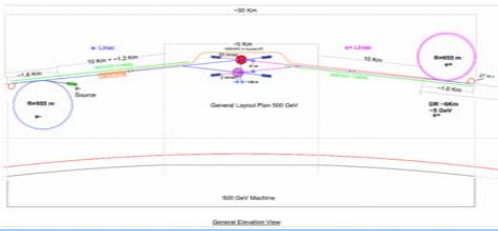
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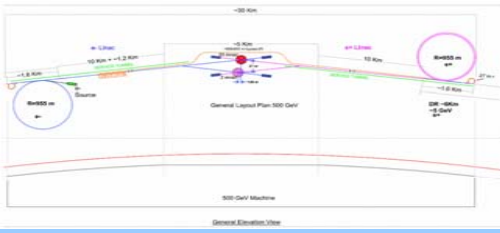
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## *Study of a Scintillator Calorimeter*

*We are simulating a scintillator based calorimeter where the tiles are offset in alternate layers. We are making now a great deal of progress.*

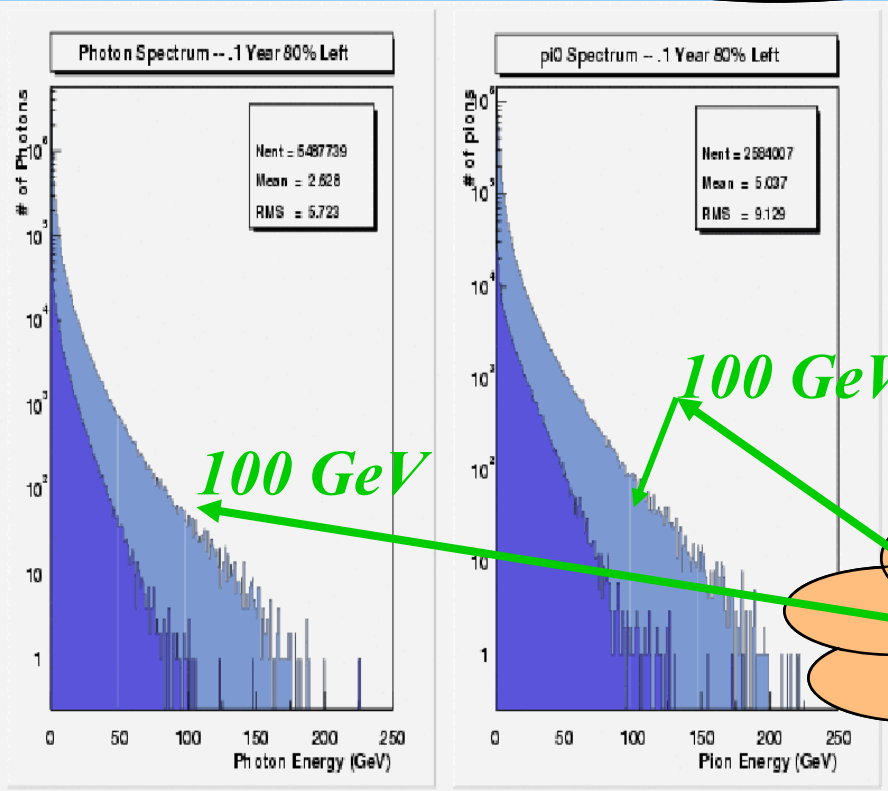
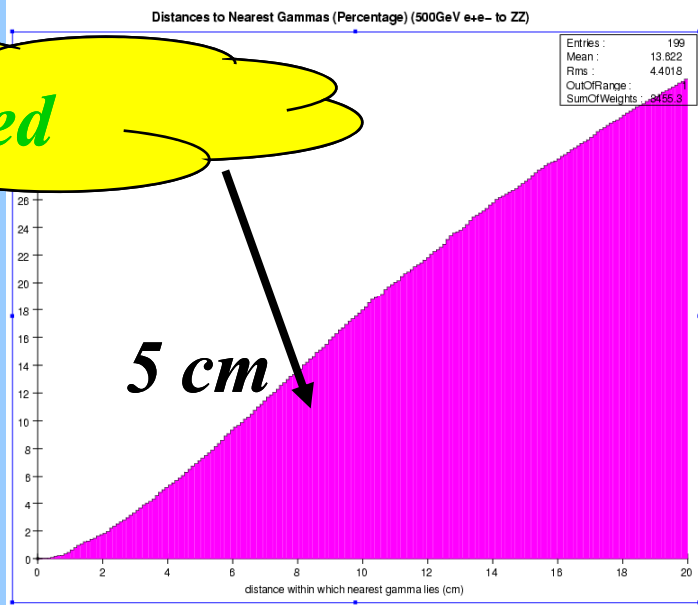


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*$\gamma$  s are well separated*



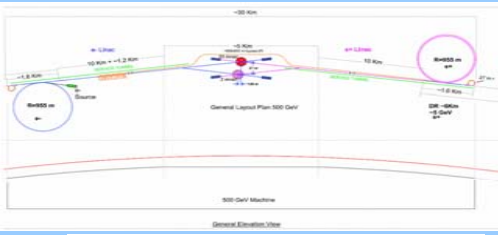
*$\pi^0$  mostly low p*



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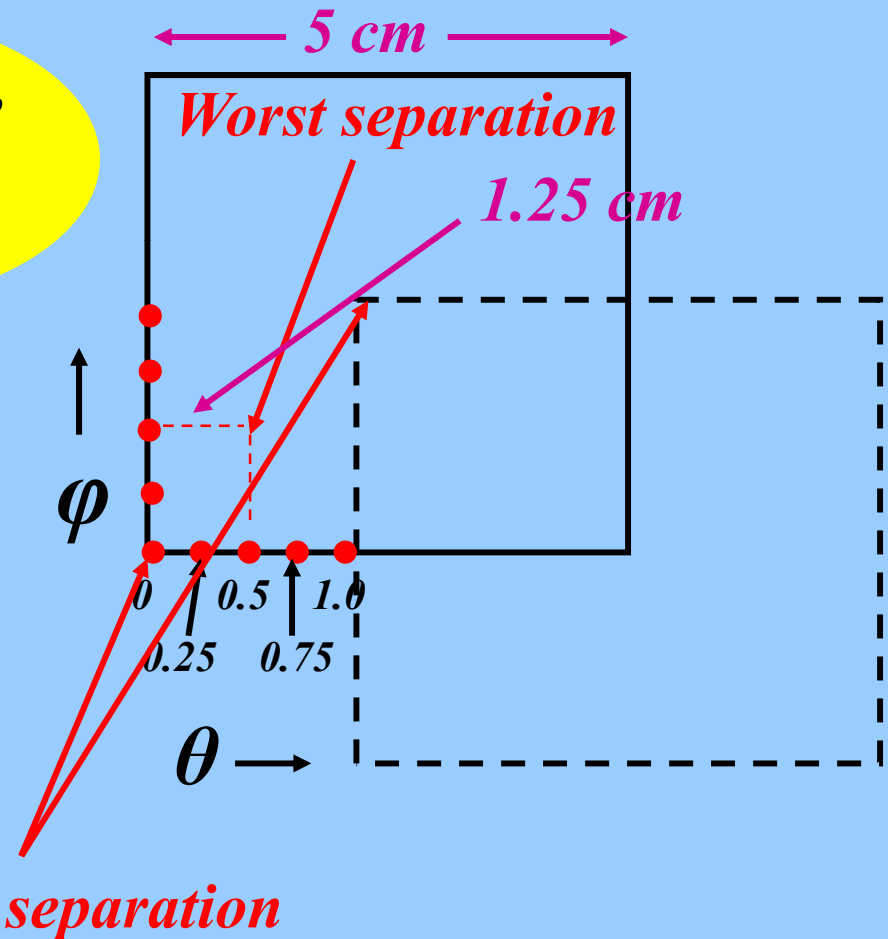
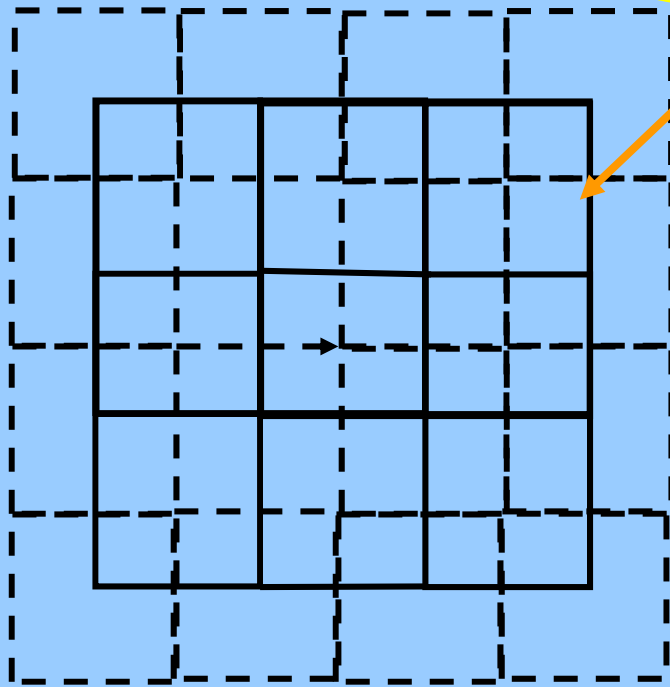
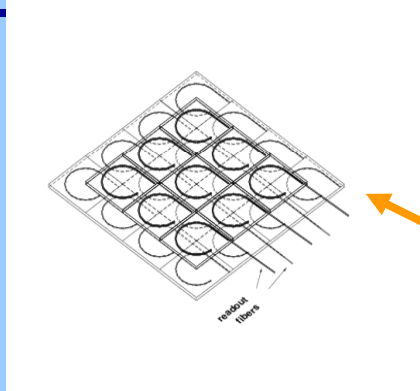


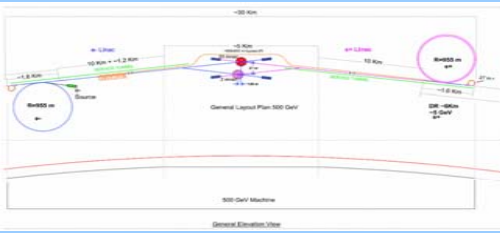
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## Geometrical Arrangement

**Scintillator Panels**



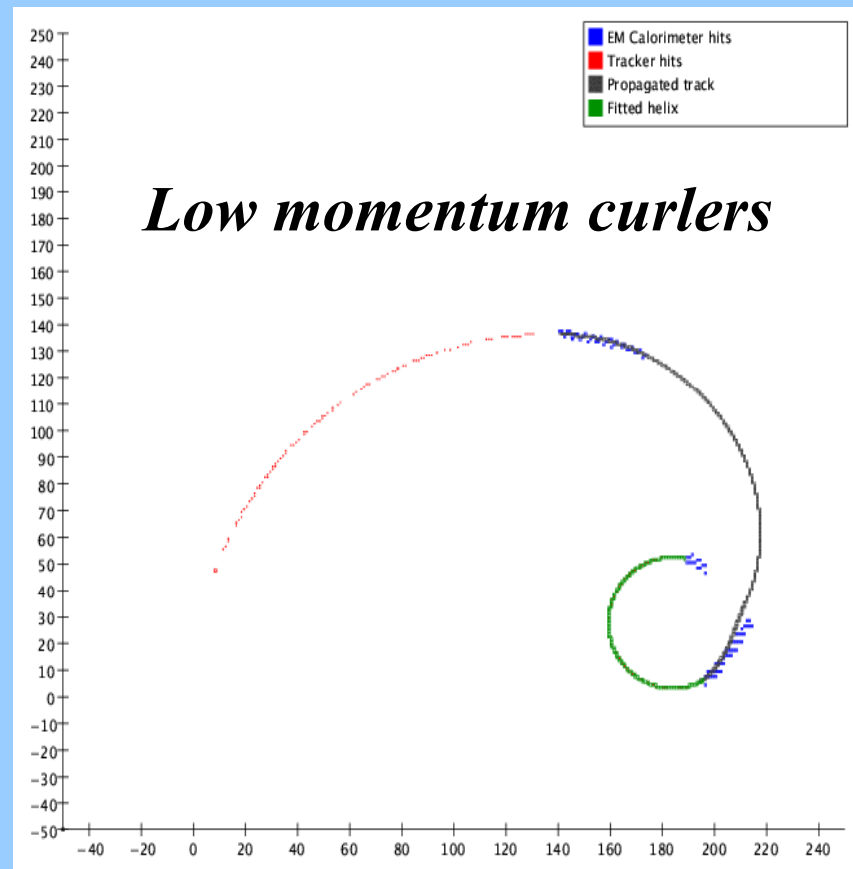
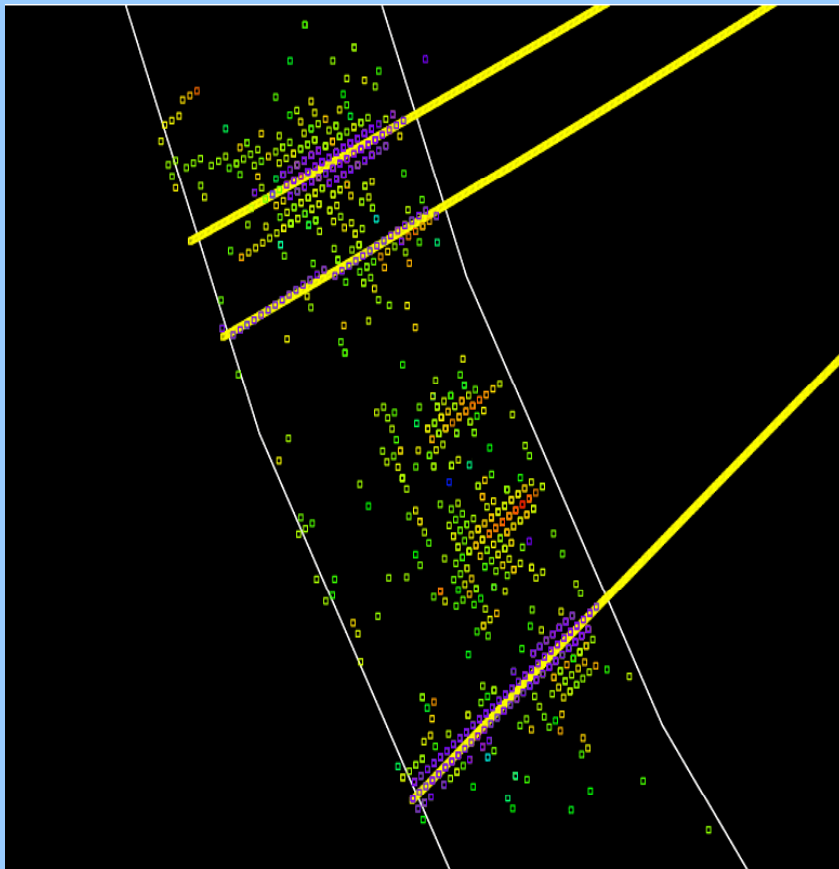


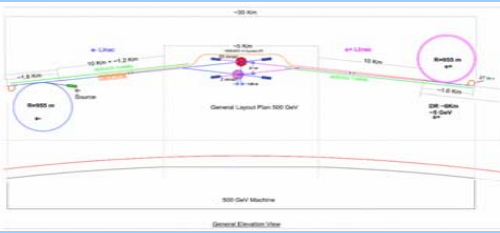
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## *Track Following into the Calorimeter*



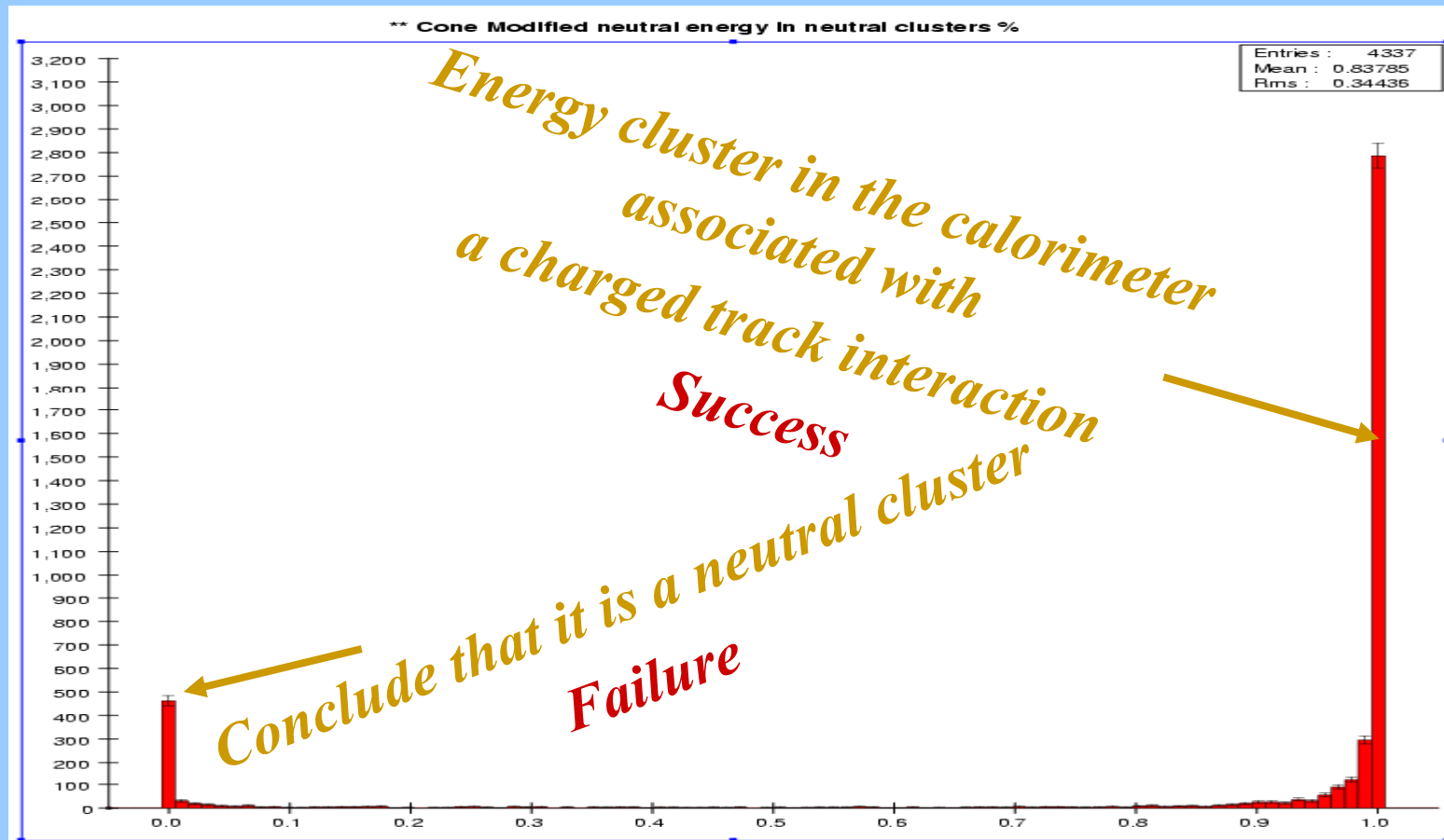


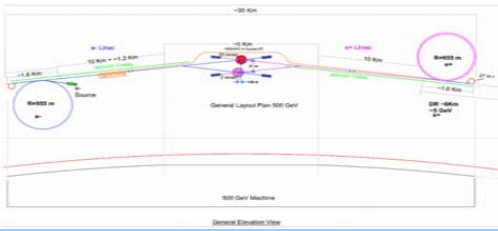
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## Cluster Correlation with Charged Tracks Success Probability





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## *The Chi-Square Structure*

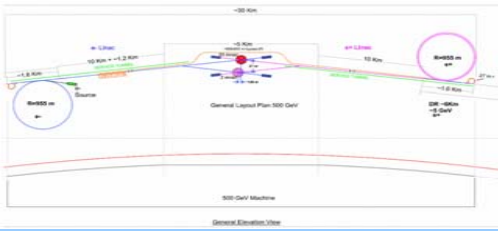
*$\mu_i$  = average photon energy deposited in  $i$ th tile*

*$\sigma_i$  = standard deviation in the energy deposition*

$$H_{ij} = \sigma_i \sigma_j$$

$$\chi^2 = \sum_{i,j=1}^9 (x_i - \mu_i) H_{ij}^{-1} (x_j - \mu_j)$$

*where  $x_i$  is the energy deposited by the shower being tested in the  $i$ th tile.*

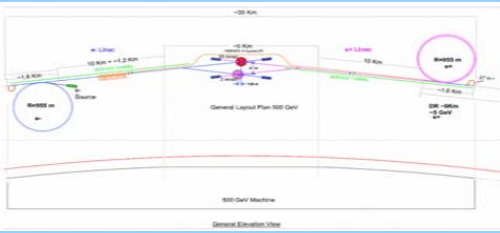


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*We are now in the middle of trying to separate photon clusters by means of the chi-square method. Hard problem. Crucial aspect of pattern recognition and calorimeter resolution.*

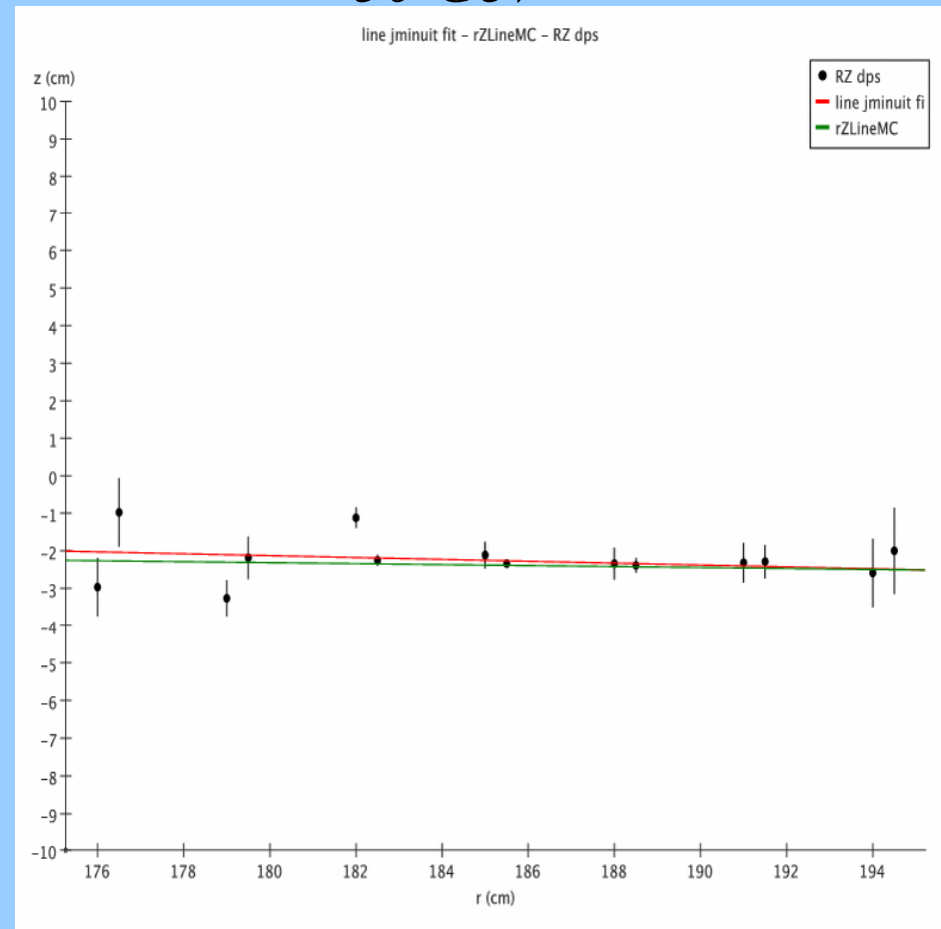
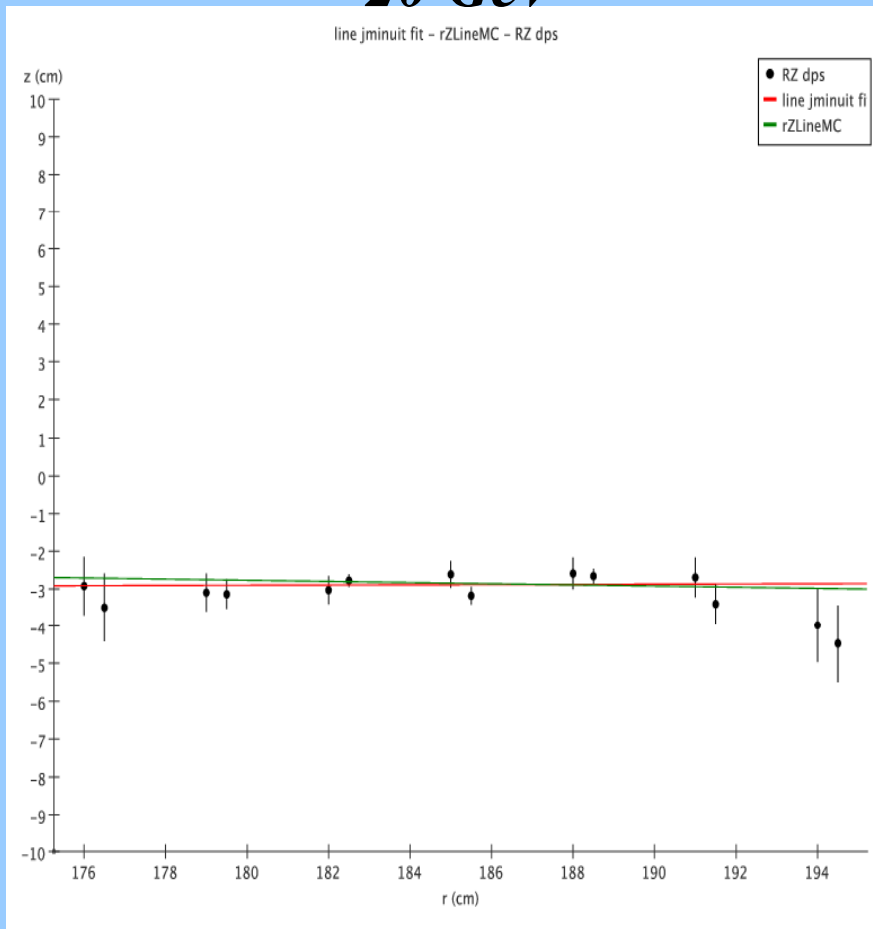


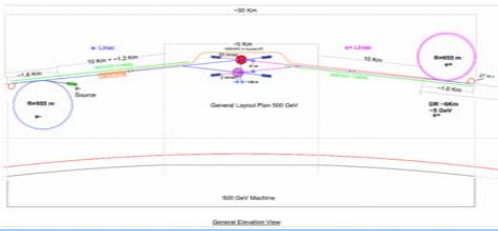
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## *Fitted $\gamma$ direction from shower energy distribution* **20 GeV** *Z vs R* **50 GeV**



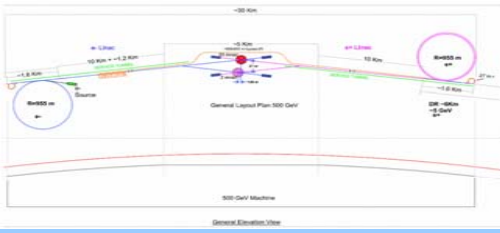


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## *Study of the Characteristics of Silicon Photomultipliers*



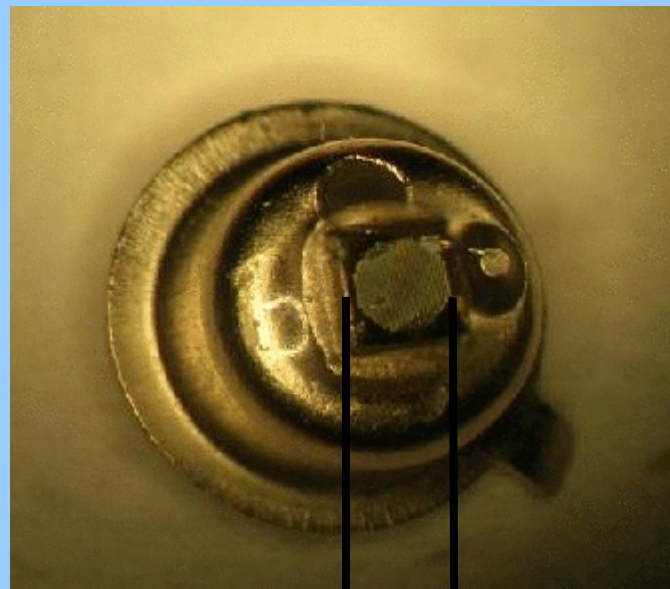
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## *New Silicon Photo-Detectors*

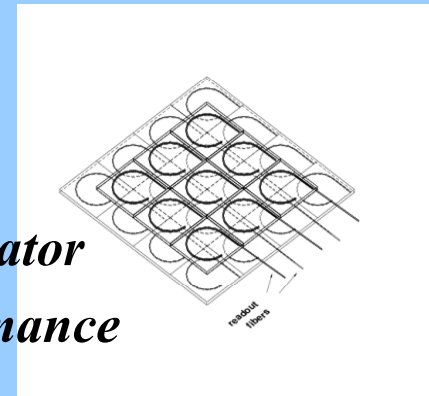
*Photonique, SA*  
*Pulsar, Russia*  
+  
*Moscow Eng.*  
*Physics Inst.*



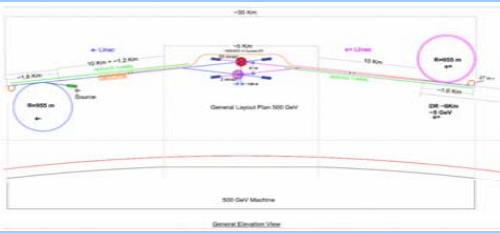
*Bias Voltage*  
*~40 volts*

*2mm*

*Scintillator*  
*performance*





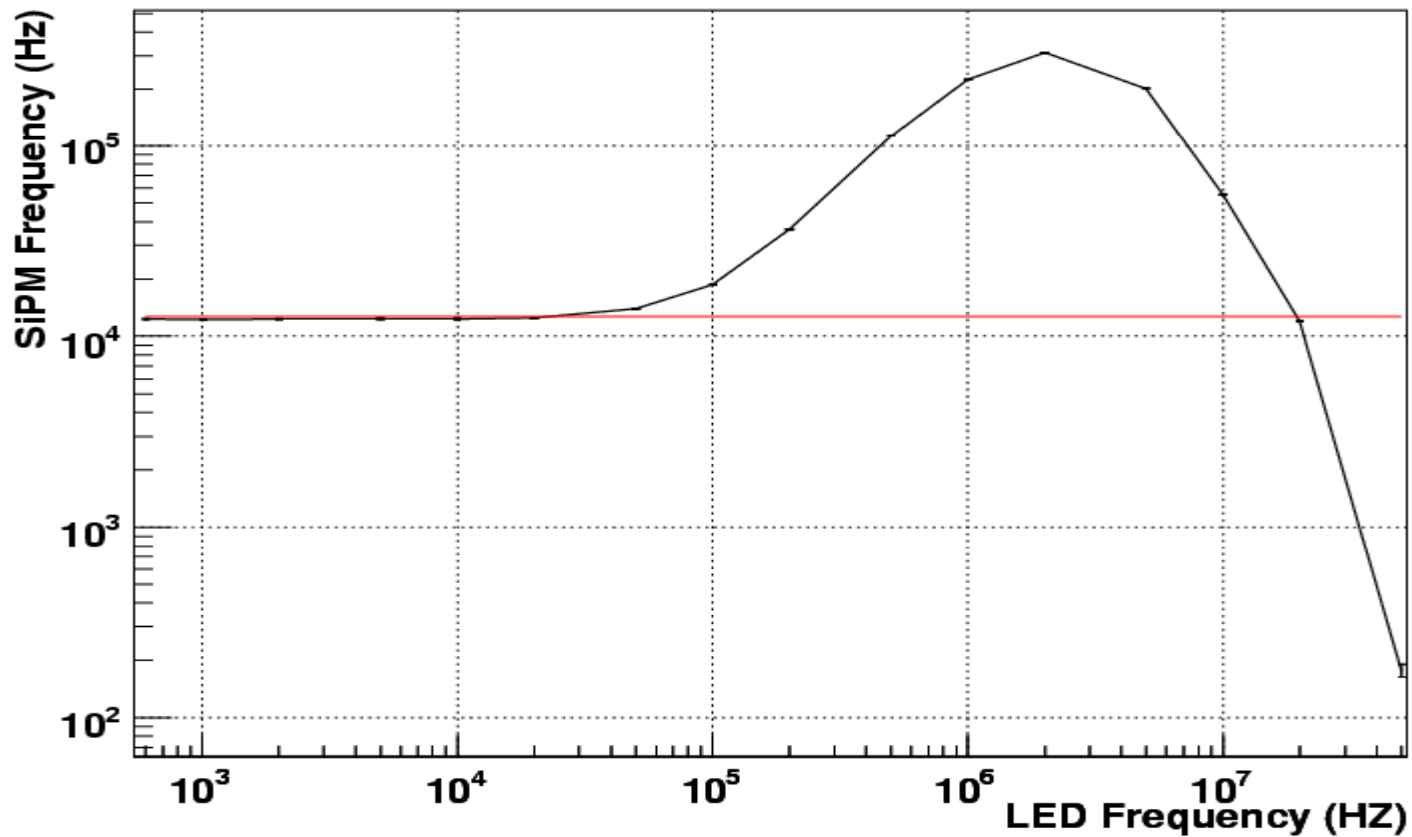


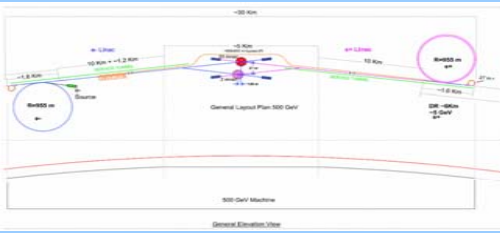
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**LED Frequency vs. SiPM Frequency (log-log)**





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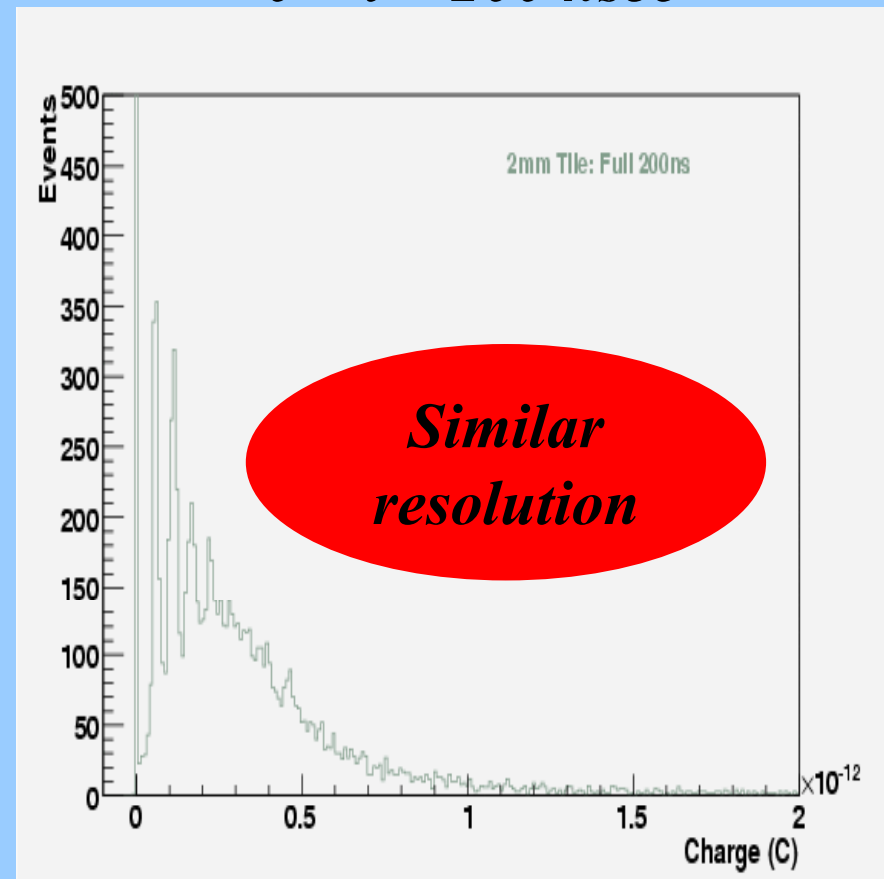
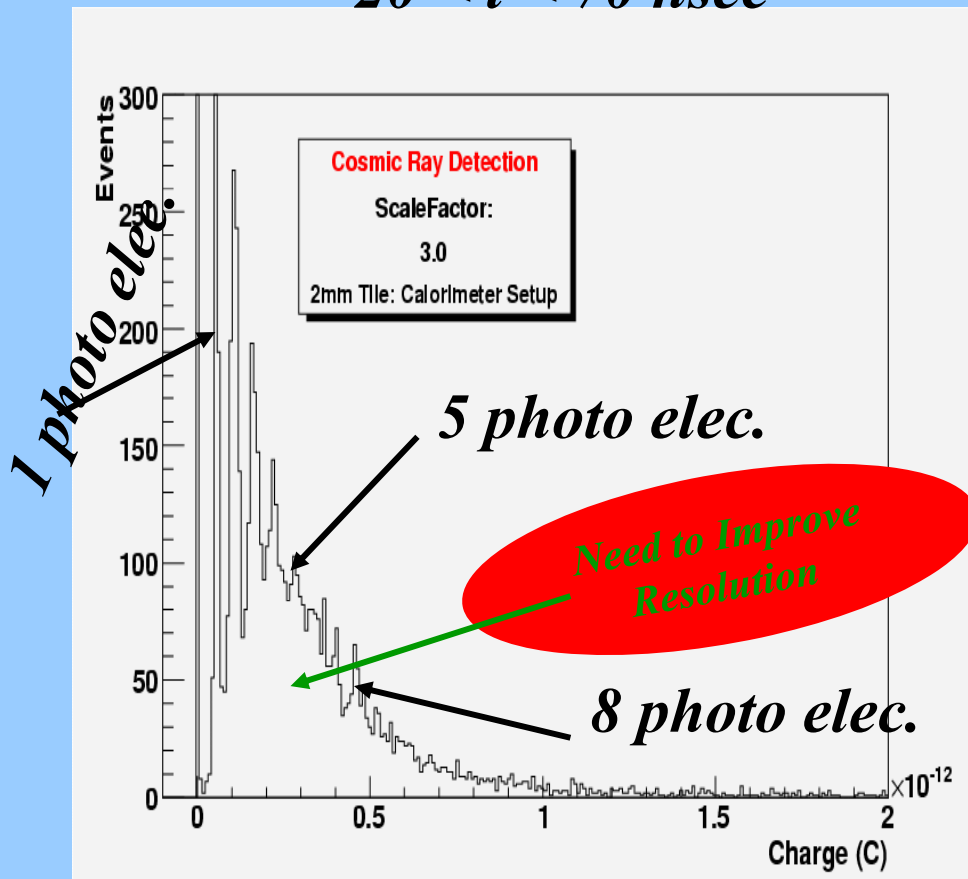


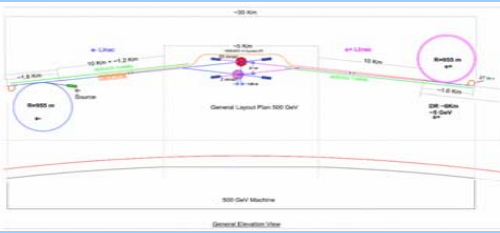
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*2mm scint., cosmic rays*

*20 < t < 70 nsec*

*0 < t < 200 nsec*



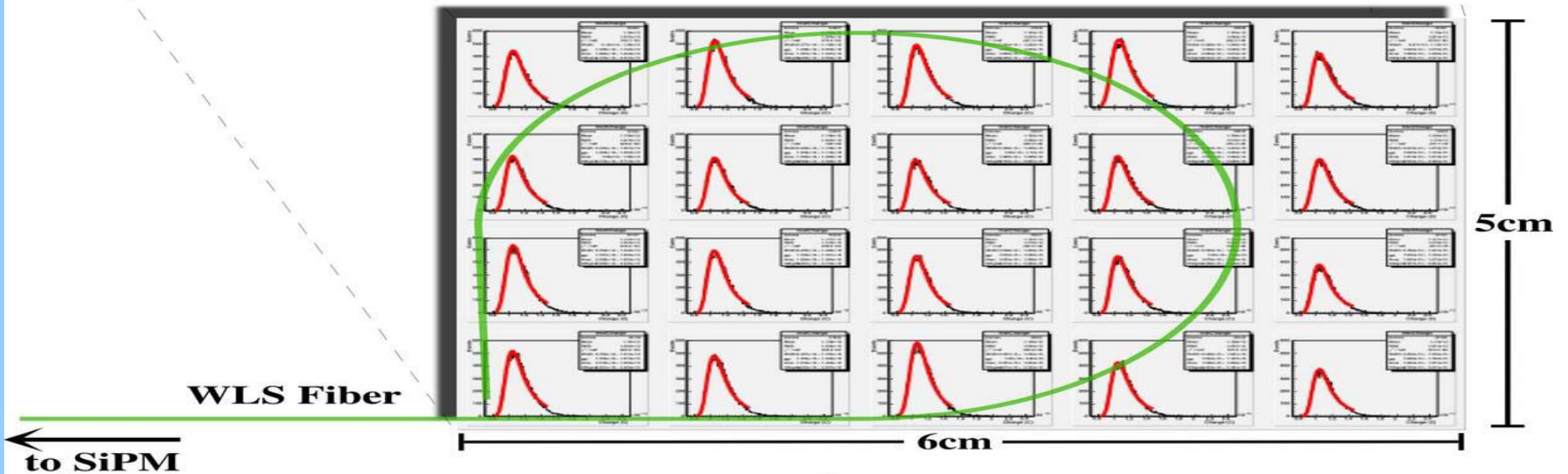


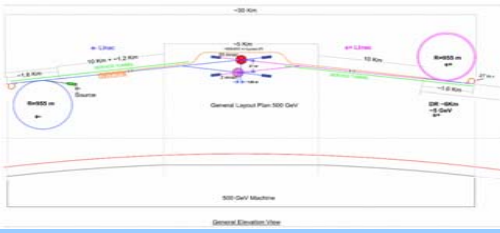
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Most Probable Values (Coulombs)				
$(1.0352 \pm 0.0011)e-12$	$(1.0385 \pm 0.0010)e-12$	$(1.0365 \pm 0.0010)e-12$	$(1.0381 \pm 0.0010)e-12$	$(1.0261 \pm 0.0011)e-12$
$(1.0332 \pm 0.0011)e-12$	$(1.0325 \pm 0.0011)e-12$	$(1.0297 \pm 0.0011)e-12$	$(1.0321 \pm 0.0011)e-12$	$(1.0263 \pm 0.0011)e-12$
$(1.0372 \pm 0.0010)e-12$	$(1.0323 \pm 0.0010)e-12$	$(1.0330 \pm 0.0011)e-12$	$(1.0304 \pm 0.0011)e-12$	$(1.0245 \pm 0.0012)e-12$
$(1.0345 \pm 0.0010)e-12$	$(1.0322 \pm 0.0010)e-12$	$(1.0395 \pm 0.0010)e-12$	$(1.0337 \pm 0.0011)e-12$	$(1.0282 \pm 0.0012)e-12$



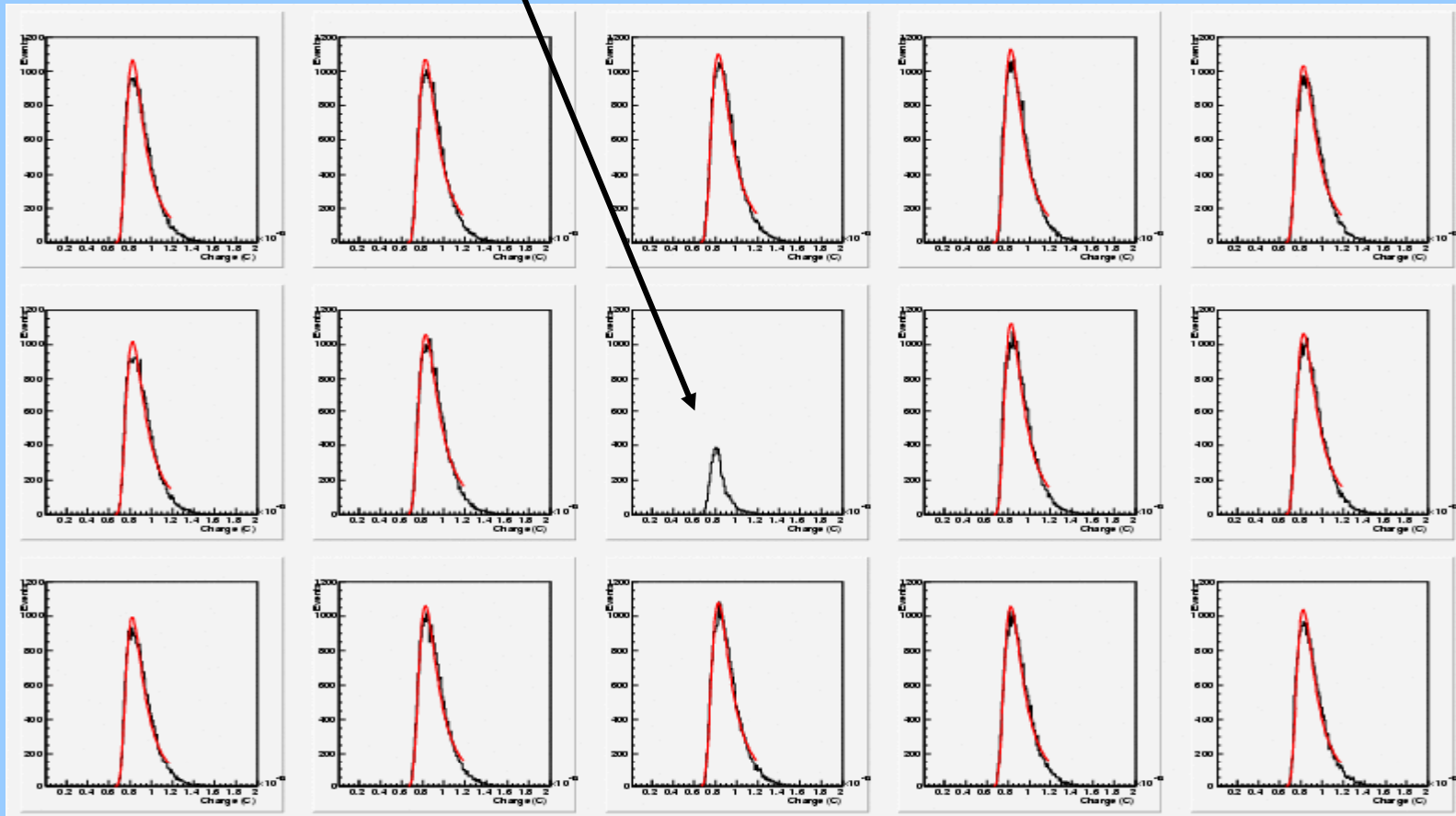


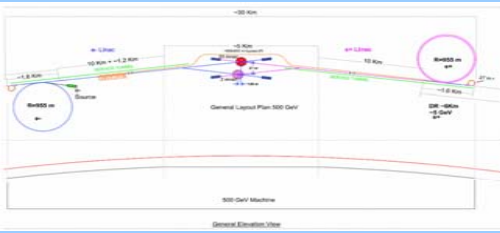
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*Sipm attached to the center of surface of the scintillator tile*



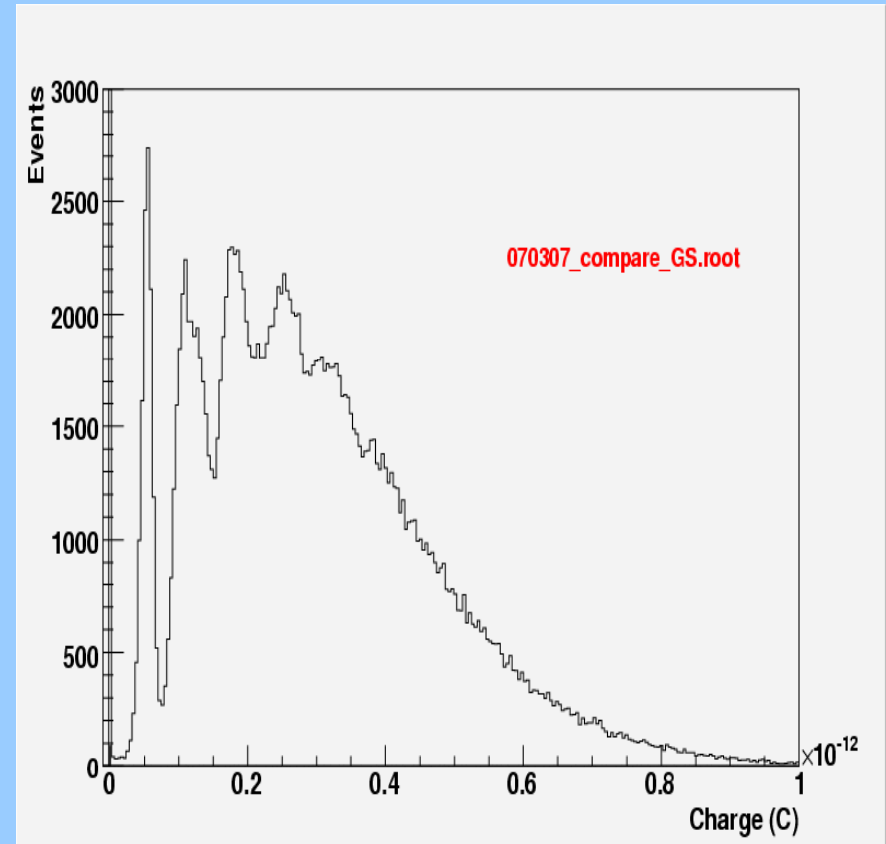
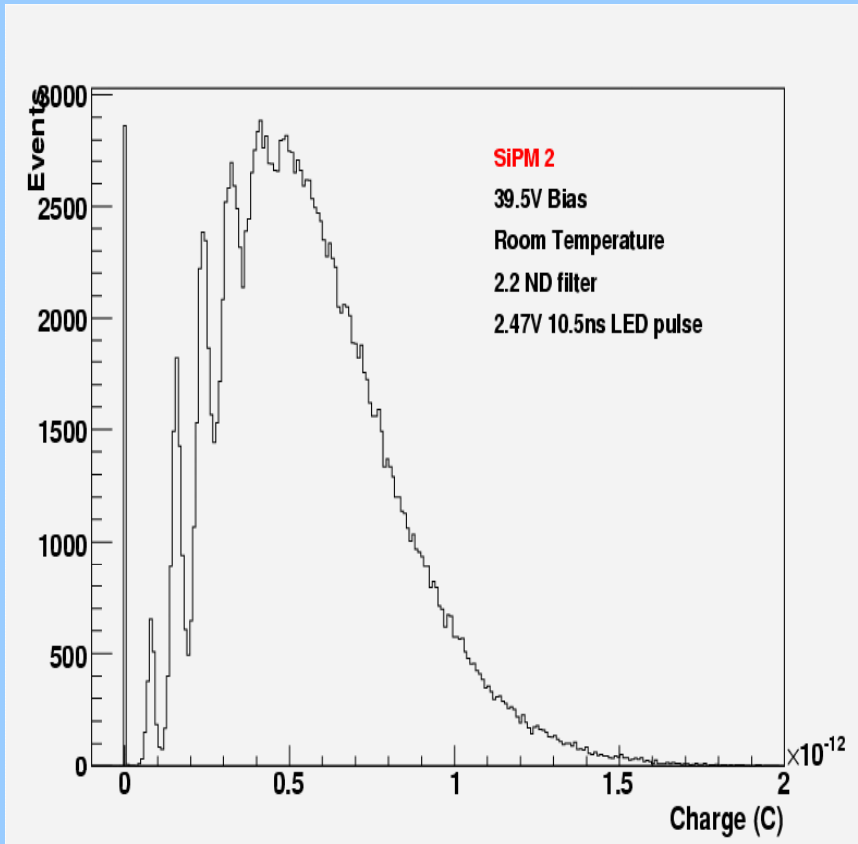


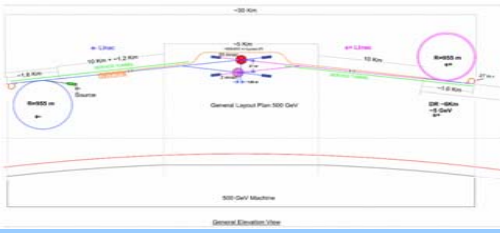
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## *New Nat. Inst. PHA*





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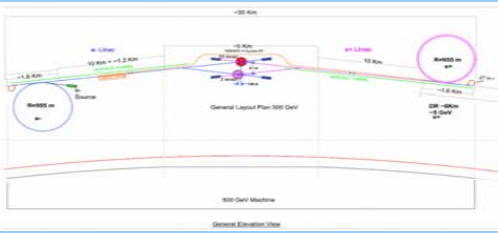


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## *Special Budgetary Issue*

*ILC R&D in DOE (Paul Grannis) awarded us a \$20 K late award that could not be sent to CU but could only be deposited at SLAC because of the timing.*

*I request that I use these funds for BaBar work and be allowed to use BaBar funds deposited in Colorado for ILC R&D work.*



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*Because ILC R&D funds become available in  
~ July the funds cover 2 years of BaBar work*

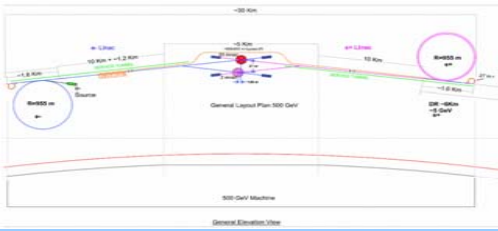
*1 year of differential housing costs for Nagel*

*\$5 K*

*1 year travel costs from Colorado to SLAC*

*\$5 K*

*The total award from ILC R&D is \$53 K*



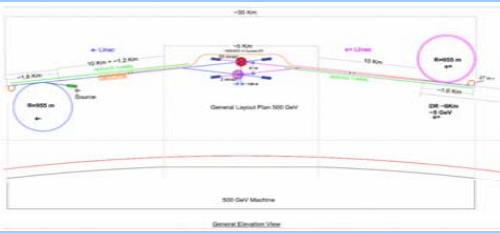
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*The University has contributed to my research a total of \$38 K towards support of a Research Associate since I have become Chair of the Boulder Faculty Assembly and my research time is now limited. I propose to use these and the ILC R&D funds towards the Research Associate if DOE accepts the ILC-BaBar fund exchange.*





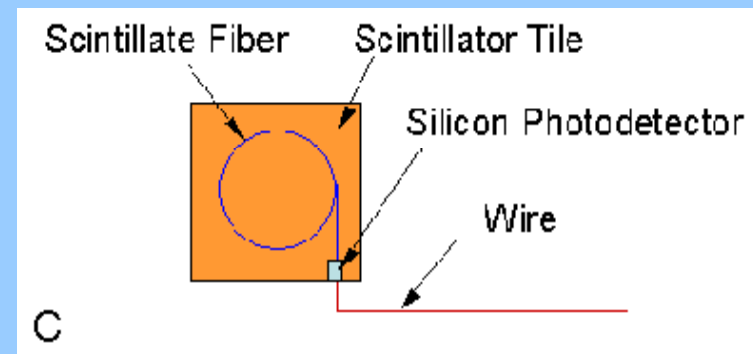
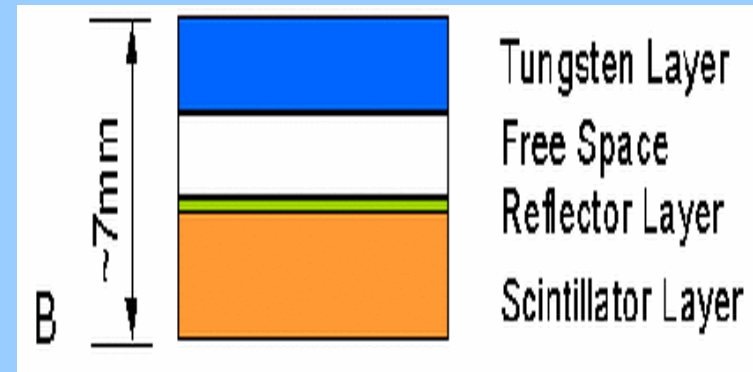
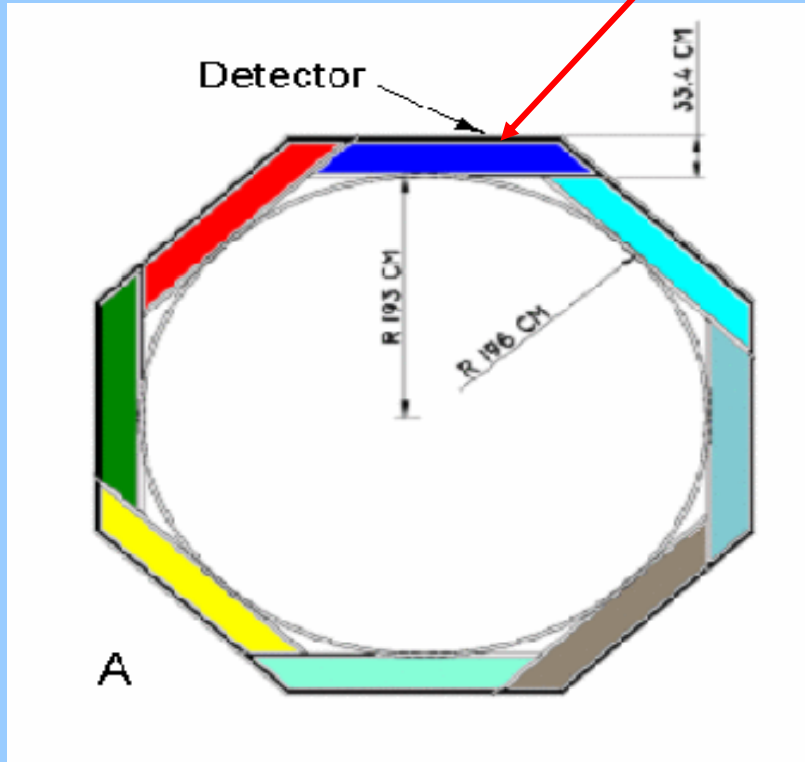
# April 28/2008-ALCPG

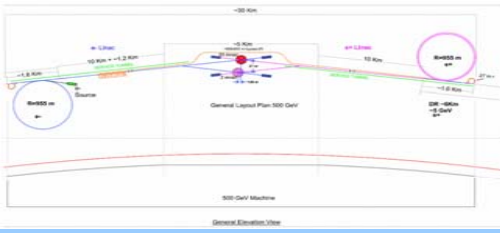


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## *The Calorimeter Modules*

*Each module = ~12 tons*



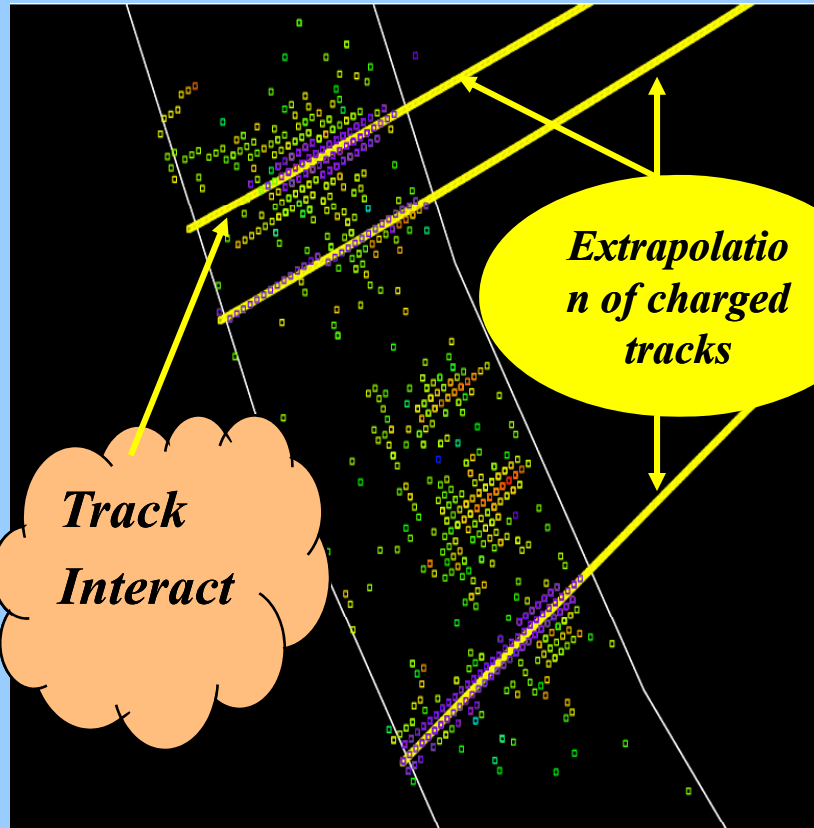


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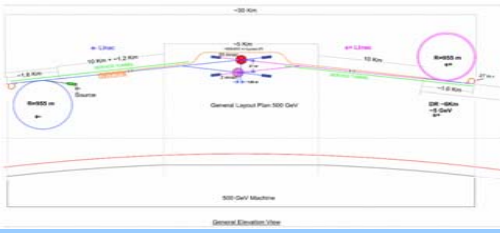


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## *Removal of Charged Track Hits*



*Jason Gray, Jiaxin Yu*

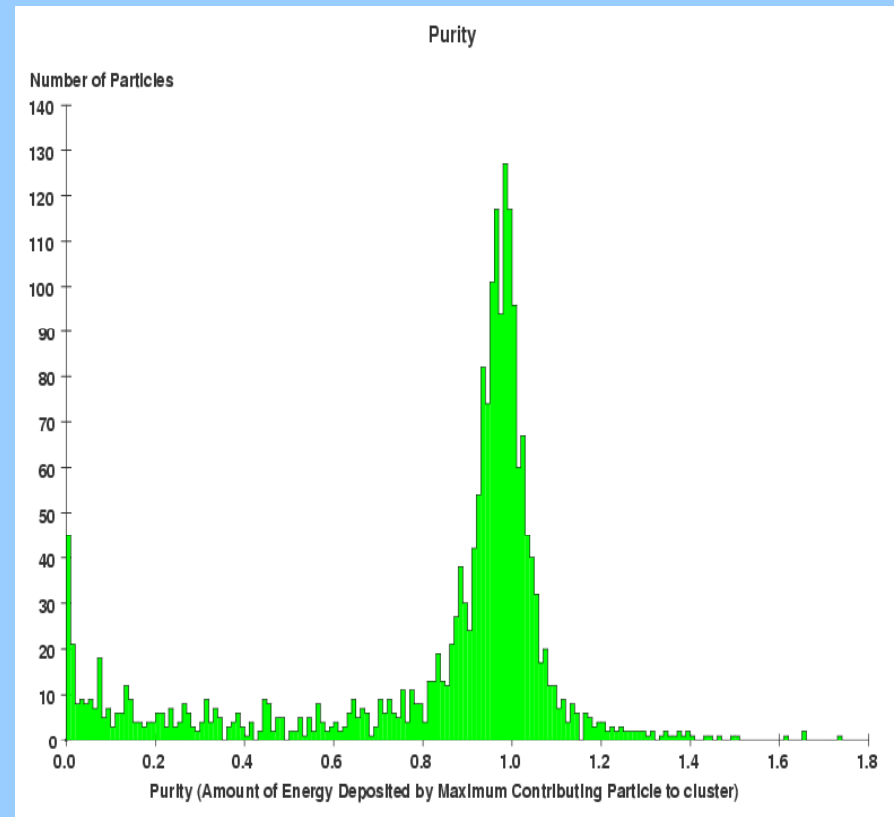
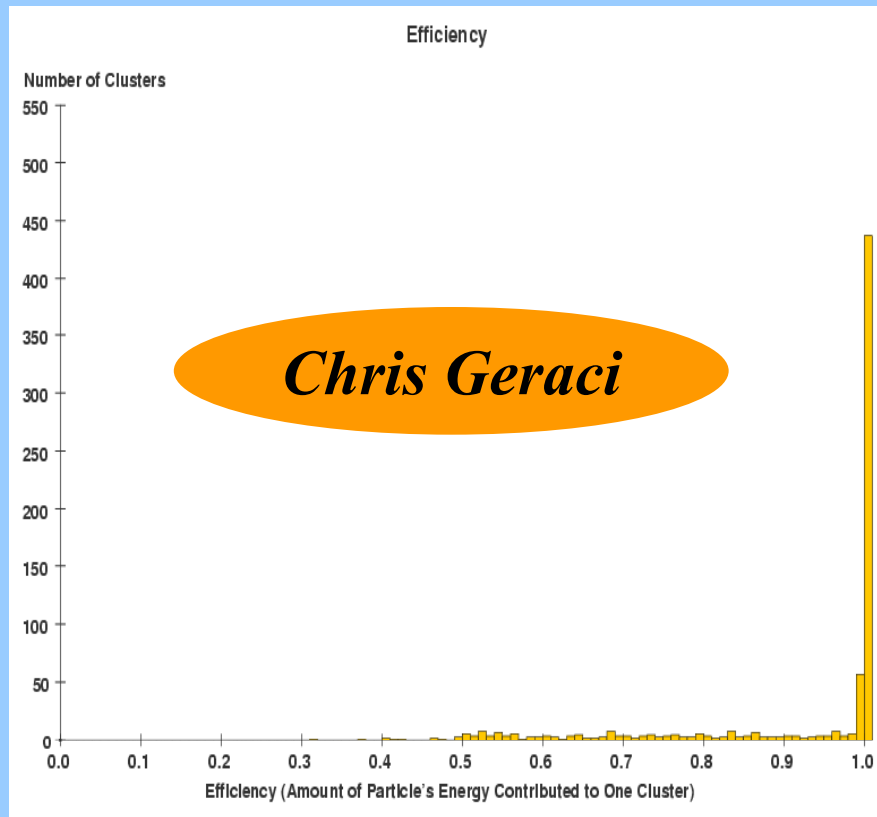


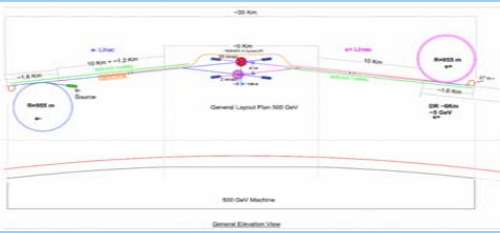
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## *Pattern Recognition of Showers*



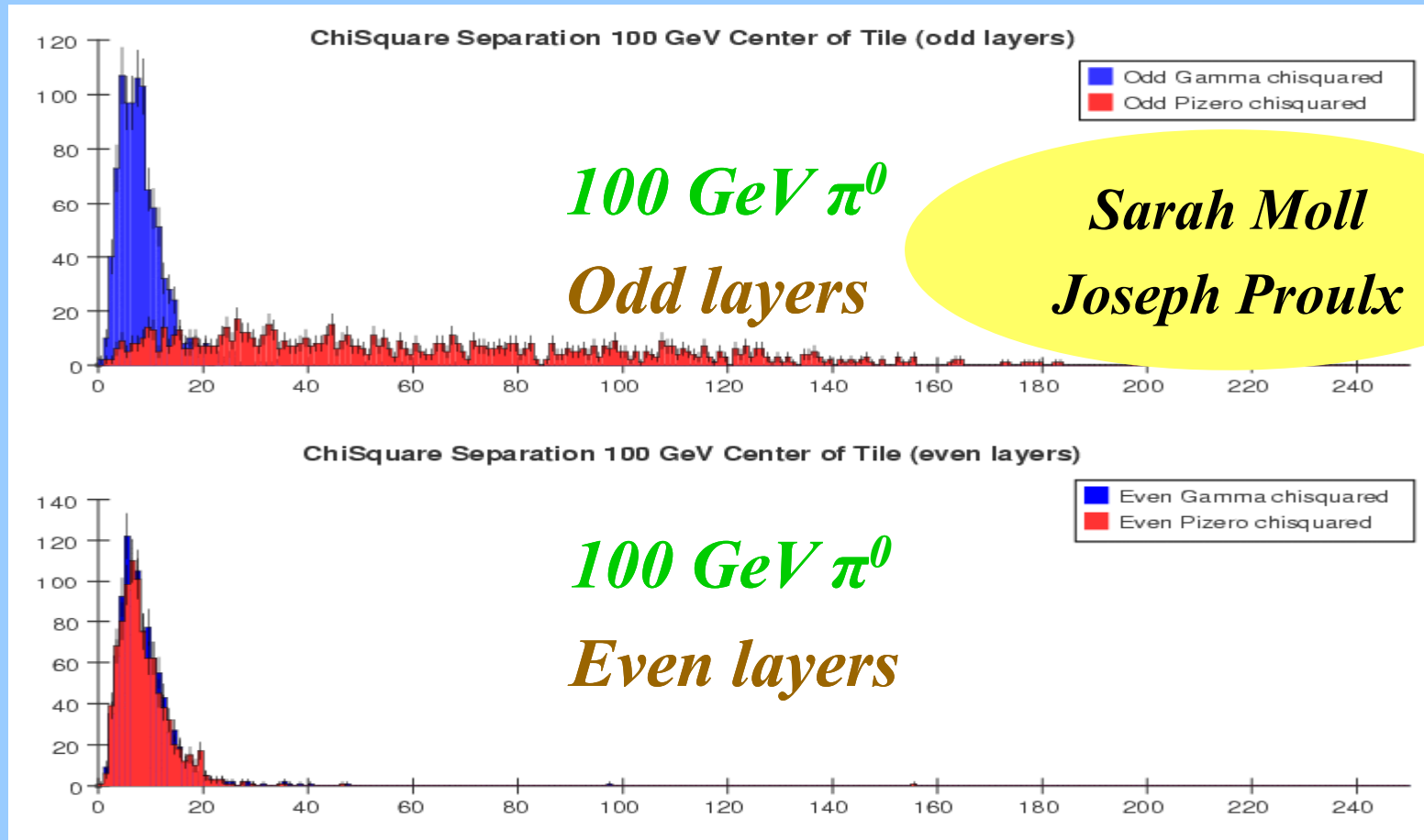


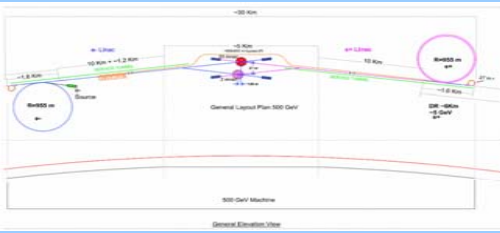
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## *Chi Square Separation, 1<sup>st</sup> order*



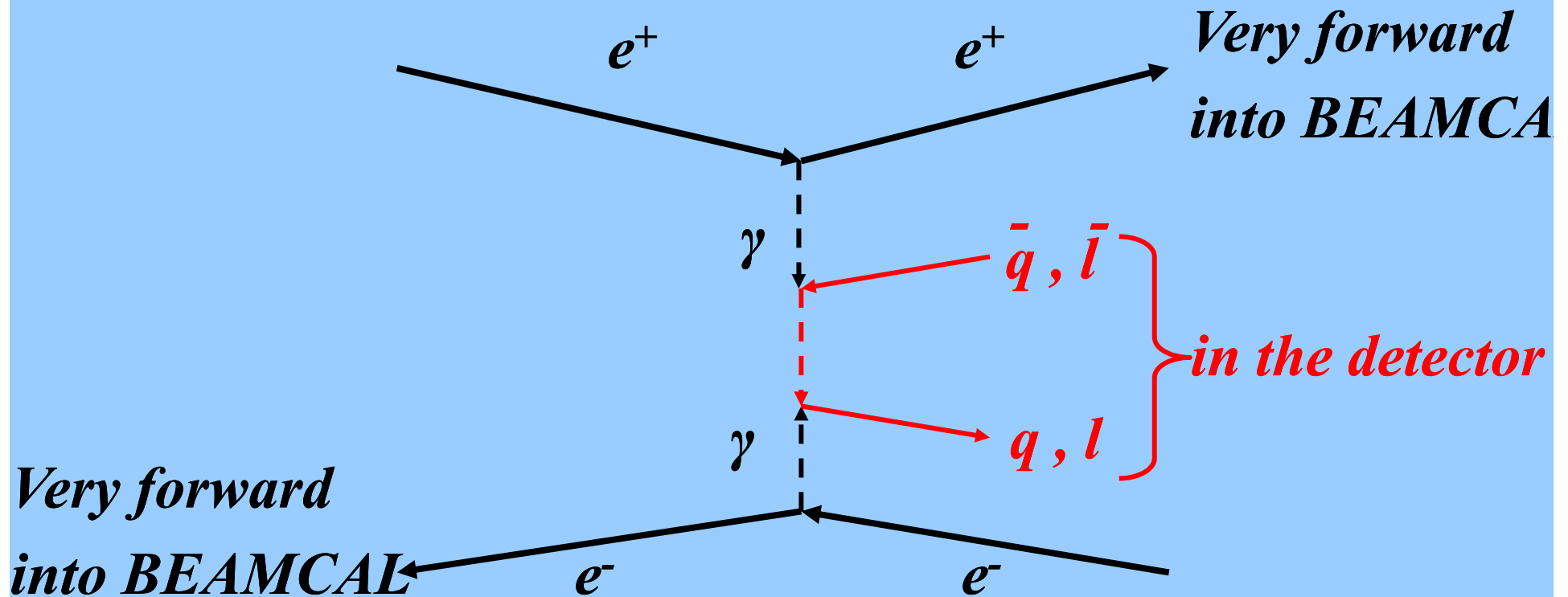


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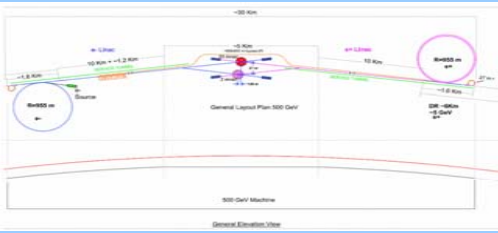


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## *2 Photon Process*



*Discussion in Beam Cal section at end*



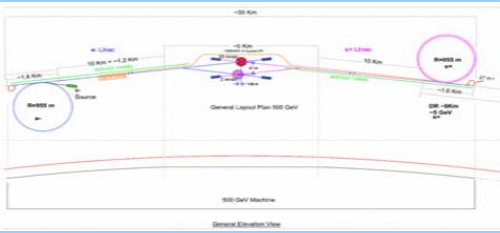
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*Study the efficiency to observe the electron and positron of the two photon process above the beamstrahlung background*

*Essential to remove this background in the study of Supersymmetry in the dynamic region of low  $P_t$ . Needed to measure the masses.*

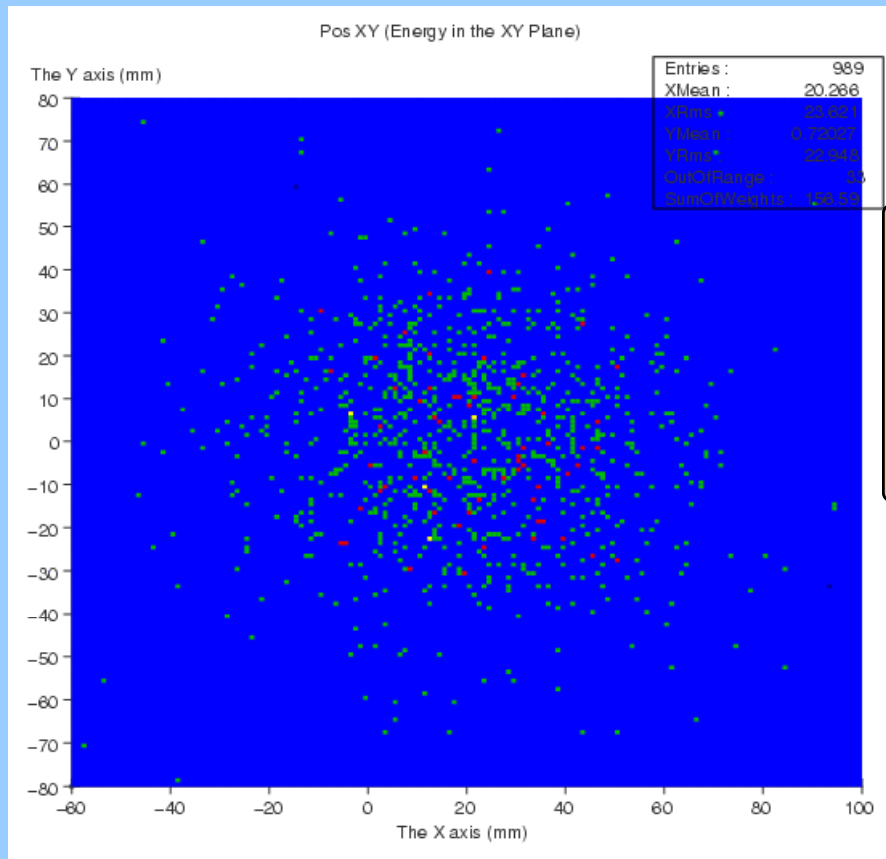


# April 28/2008-ALCPG

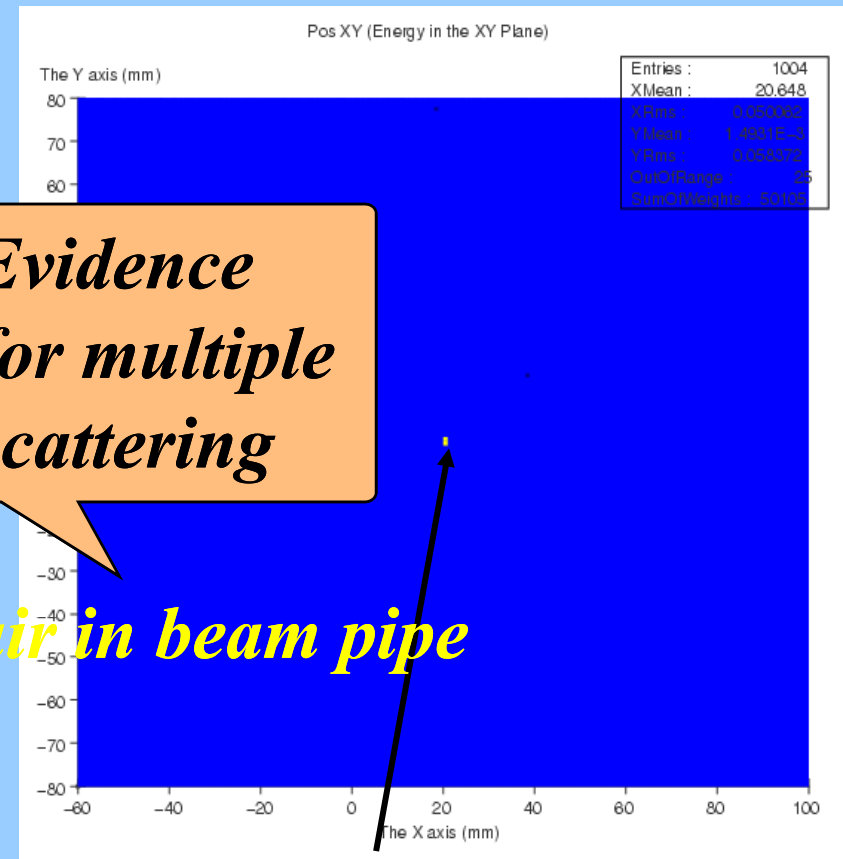


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## Testing GEANT 4.0



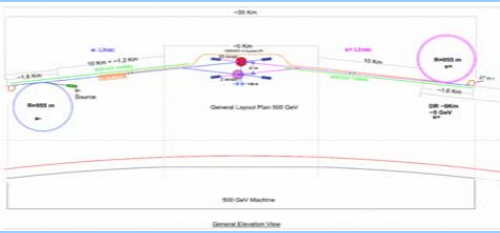
*No field, 50 MeV muons*



*Evidence for multiple scattering*

*air in beam pipe*

*No field, 50 GeV muons*



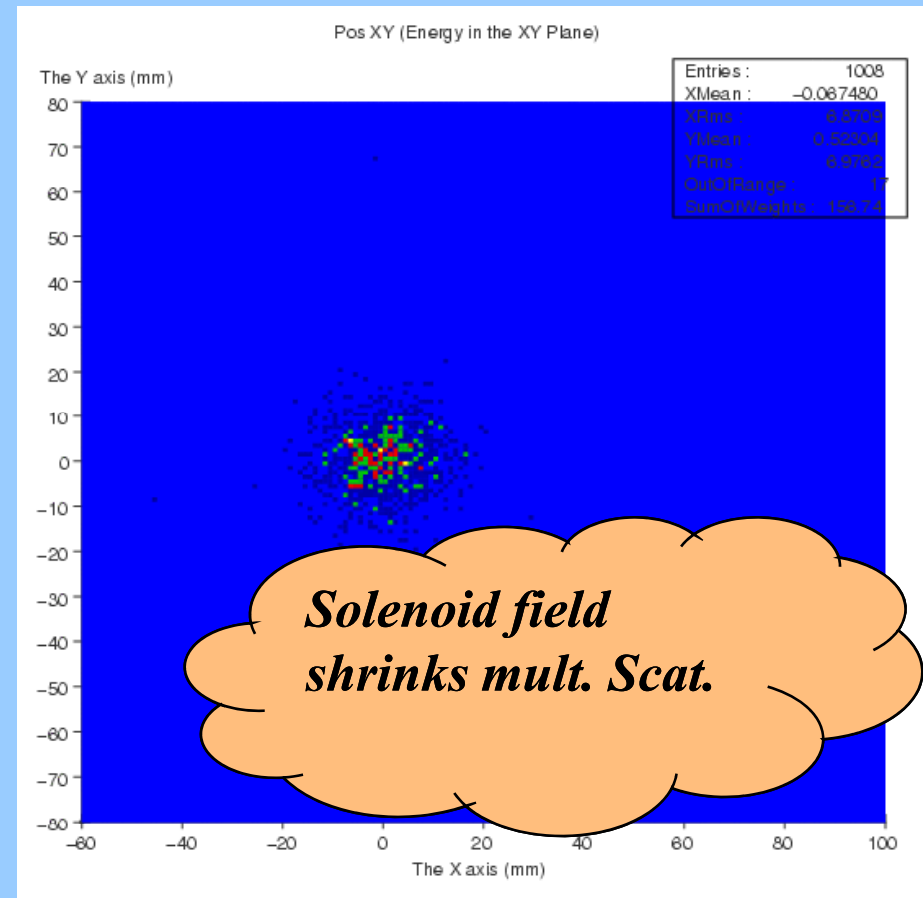
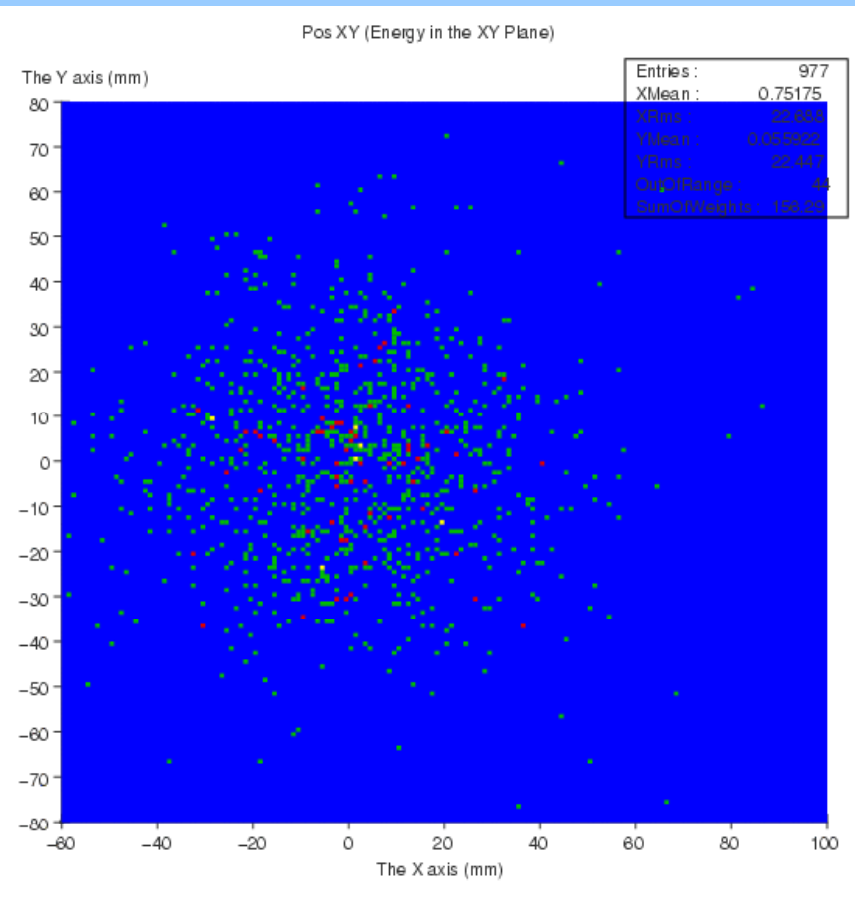
# April 28/2008-ALCPG



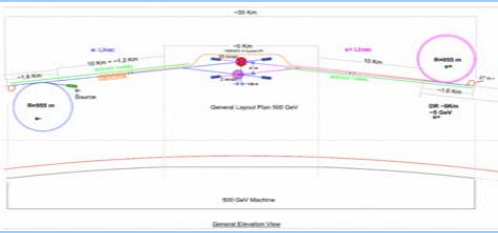
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*50 MeV, no field, forward*

*50 MeV, solenoid on, forward*





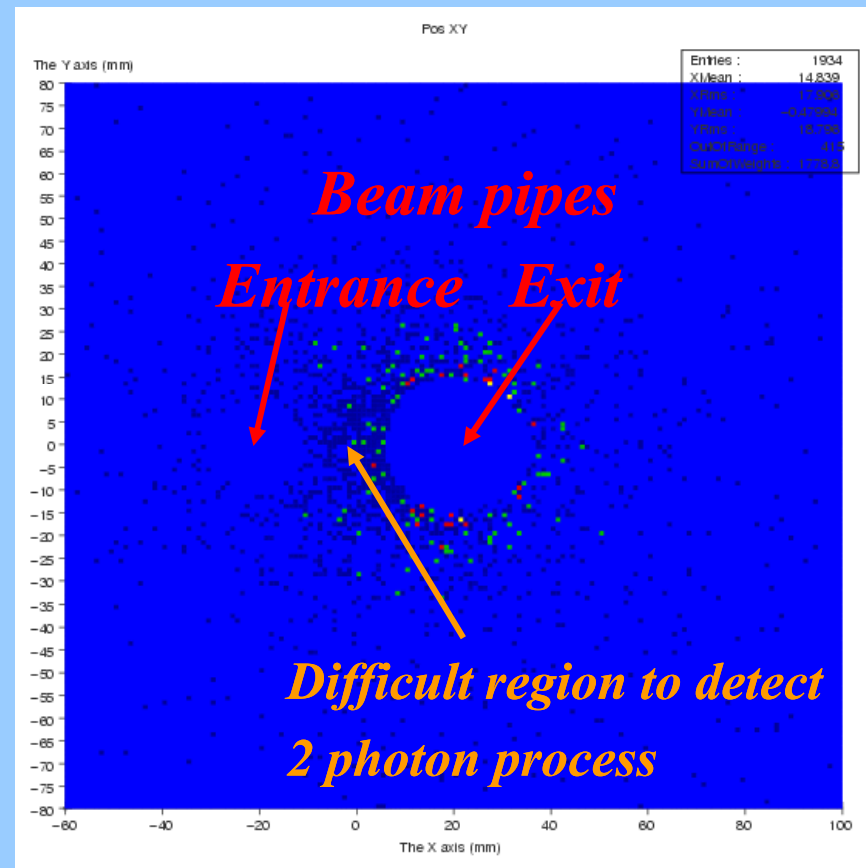
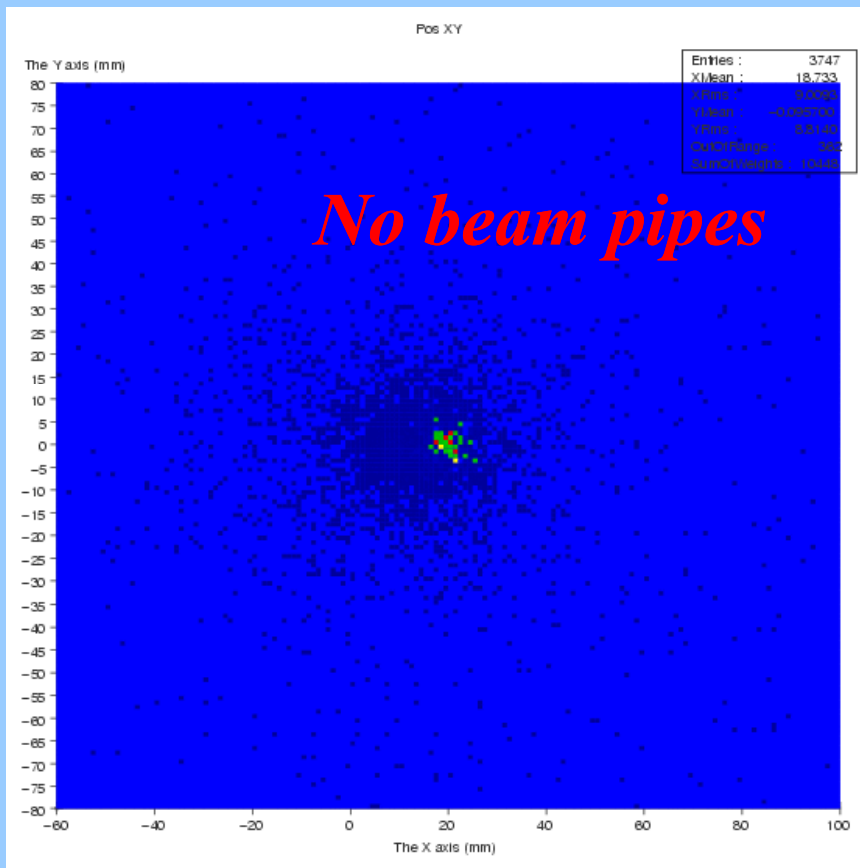


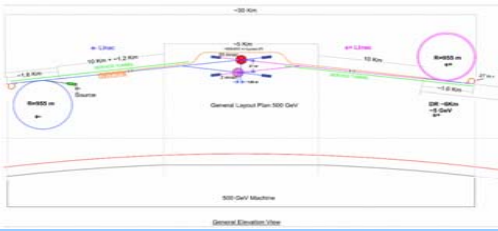
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## *Beamstrahlung Distribution with Solenoid + Anti-DiD*





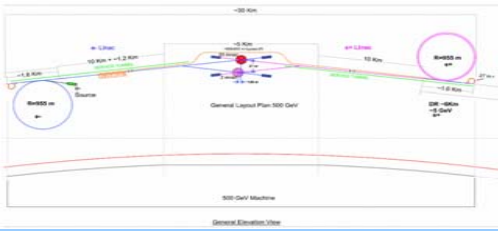
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*GEANT 4.0 seems to be working properly We have fixed various bugs in collaboration with SLAC team.*

*All Simulation is work in progress.*



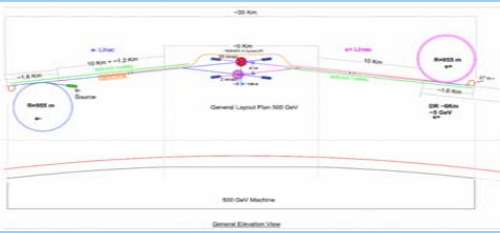
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## *Hardware Studies*

*Keith Drake, Elliot Smith*

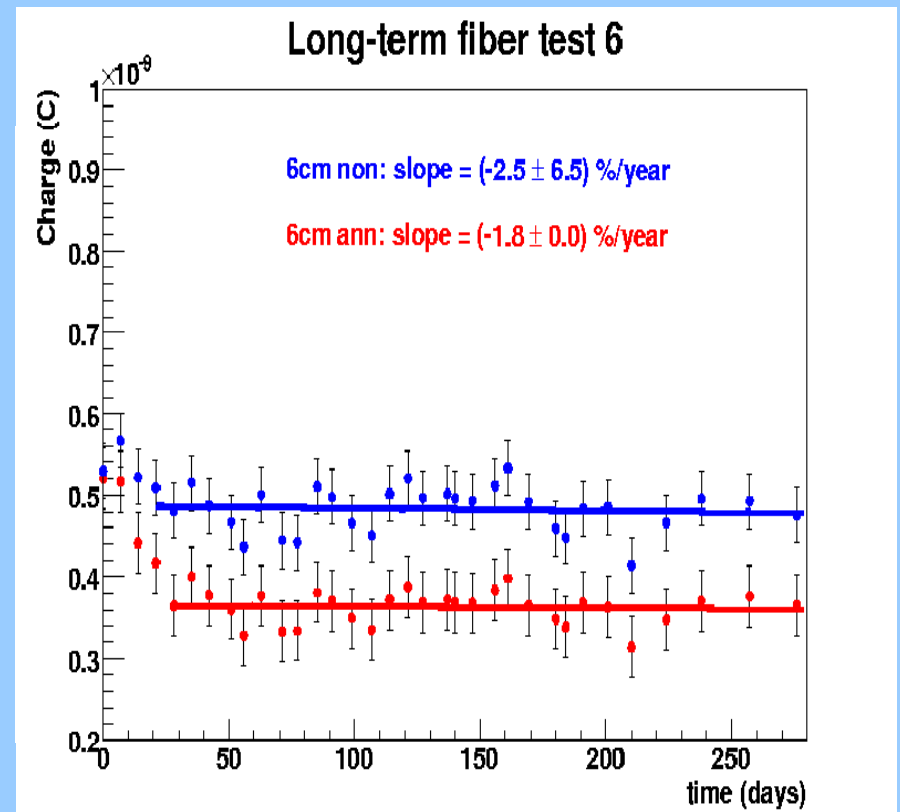
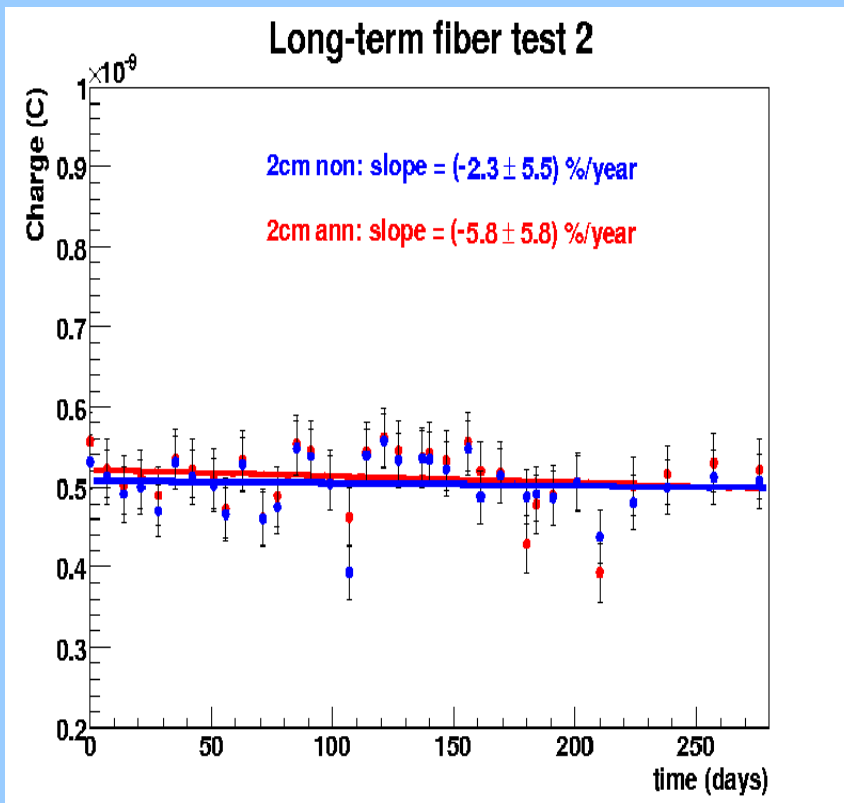


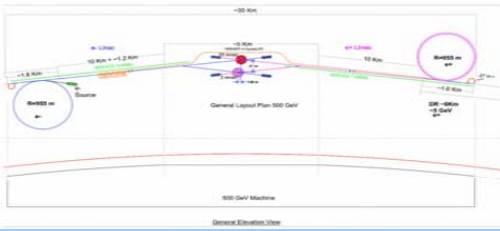
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## *Long Term Tests of Scint. Fiber Stability*



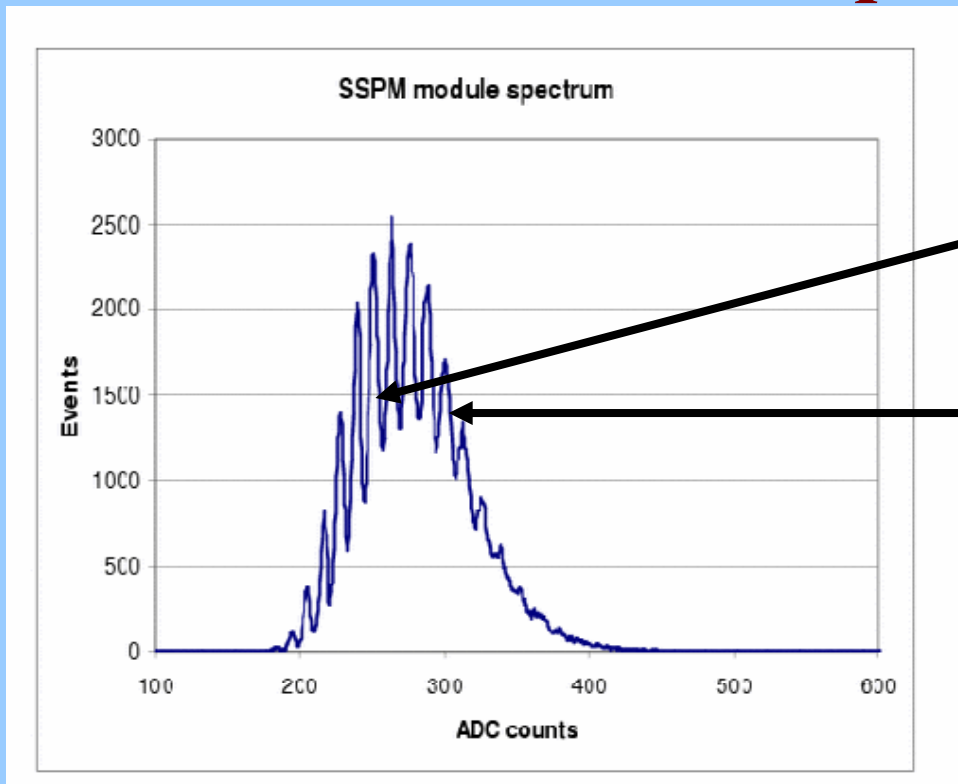


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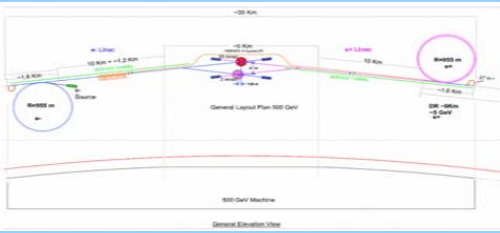
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## *Latest Pulse Distribution from Photonique/Russia*



*6 photoelectrons*

*10 photoelectrons*

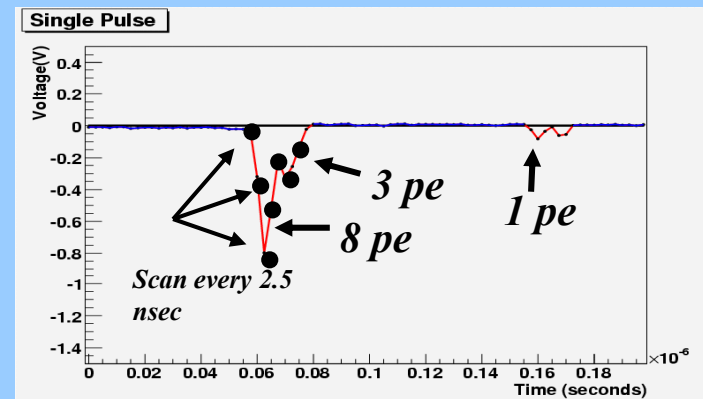
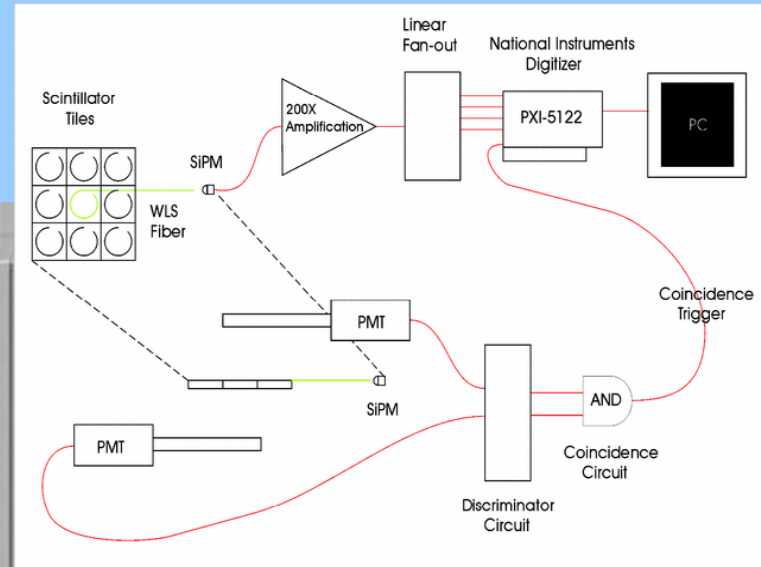
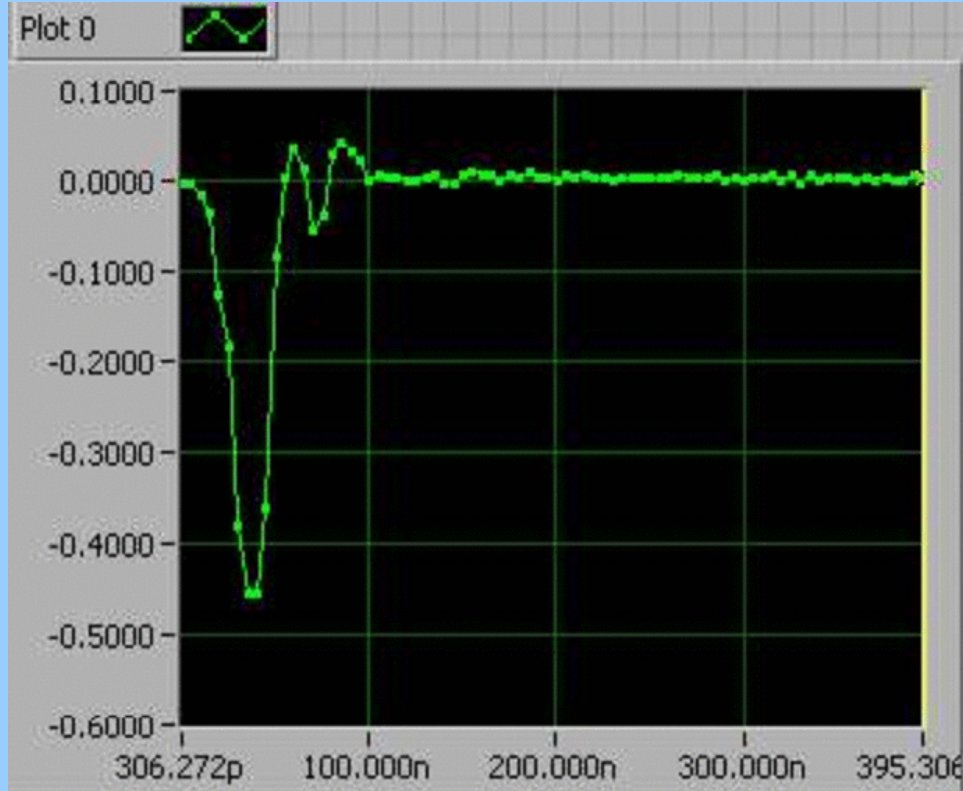


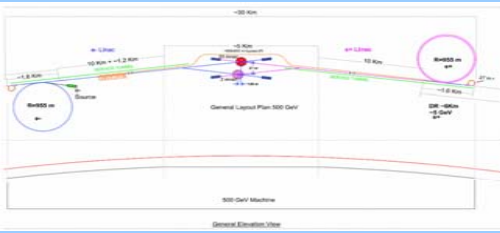
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## *Pulse National Inst.*





# April 28/2008-ALCPG



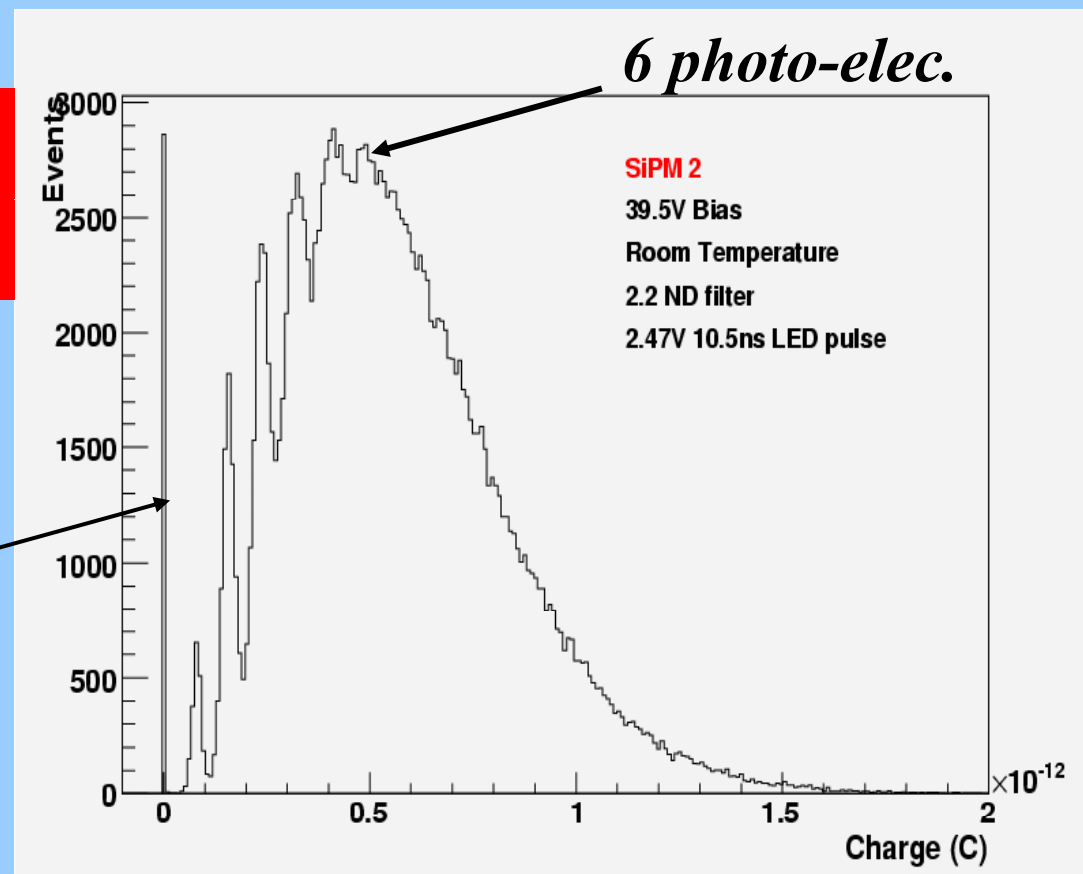
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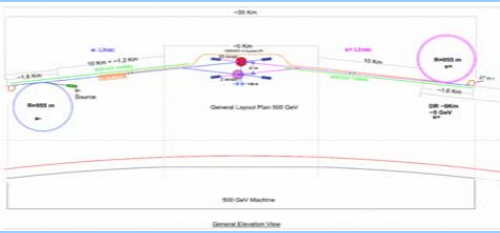
## Our Measurements

**Blue LED,  
10nsec, 2.5 volts drive**

**50 nsec gate**

**noiseless  
SiPD**

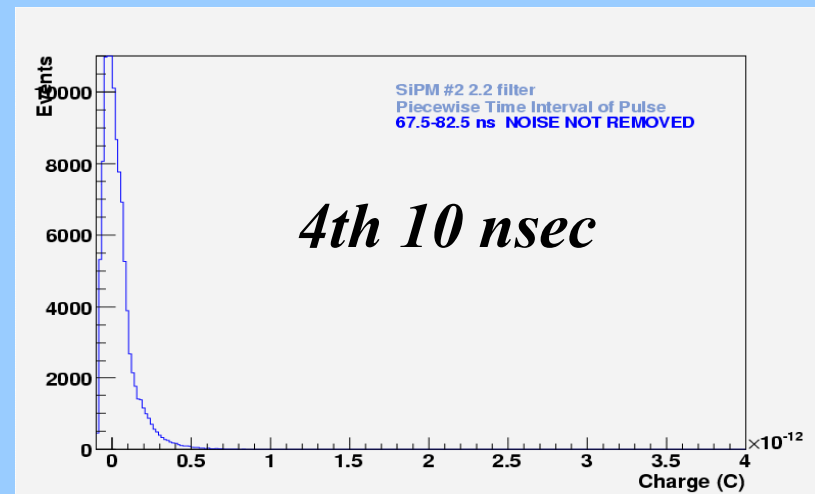
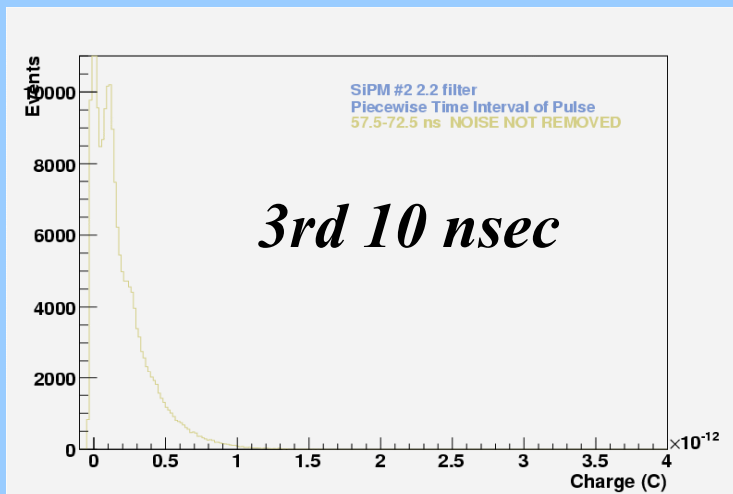
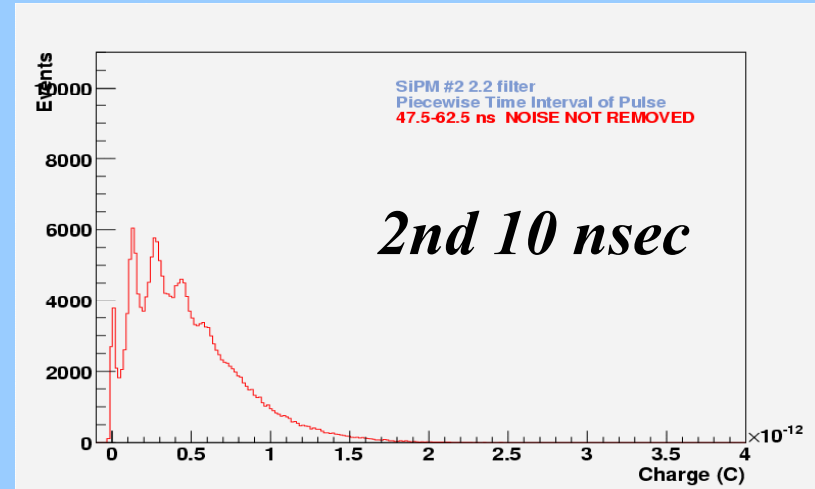
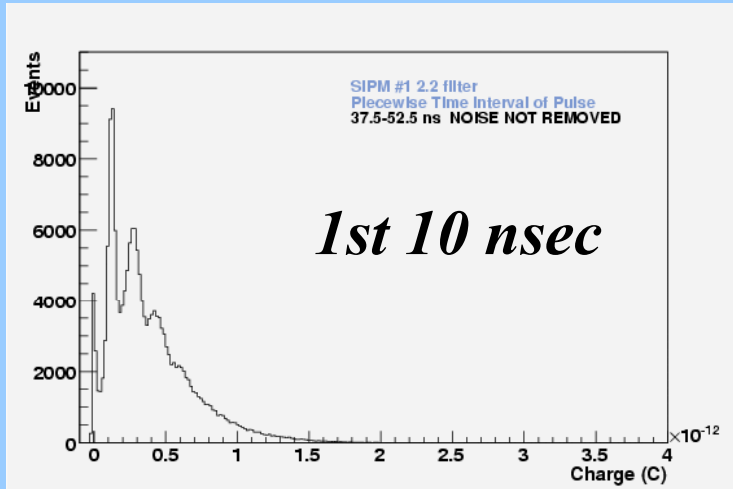




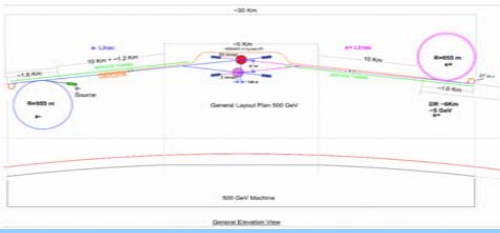
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# April 28/2008-ALCPG

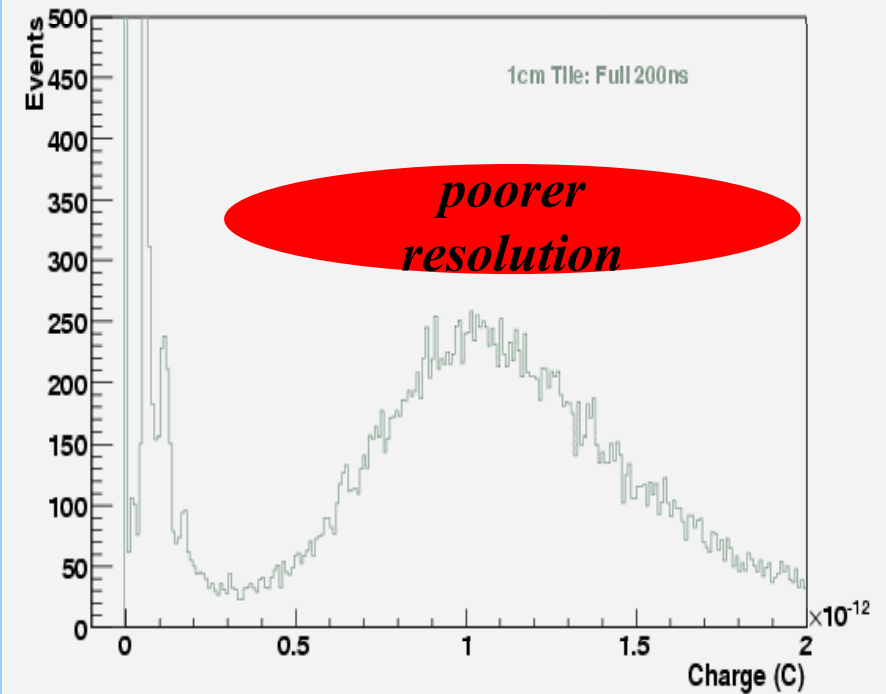
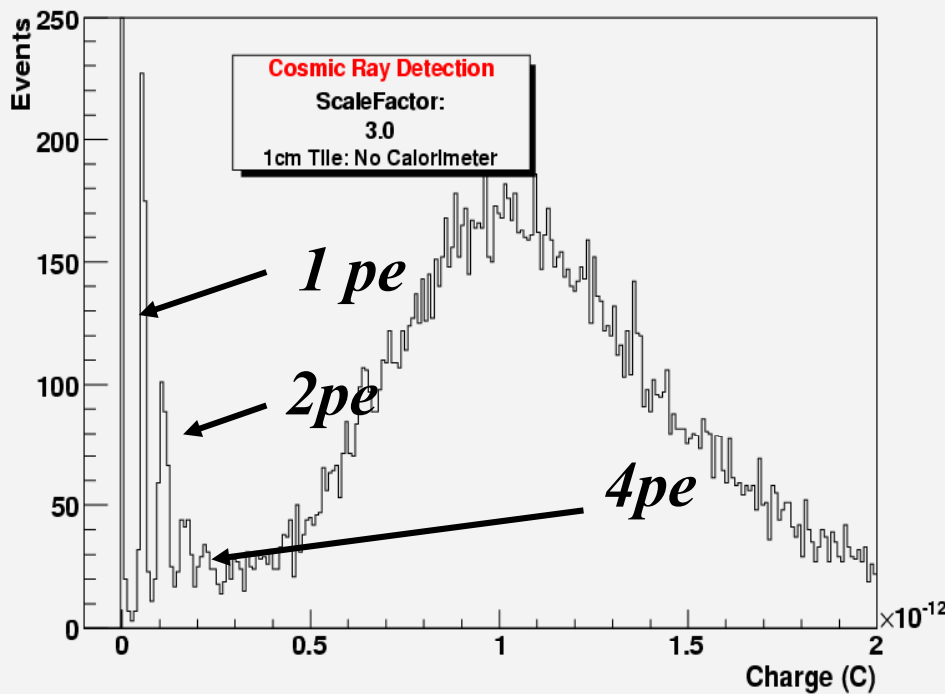


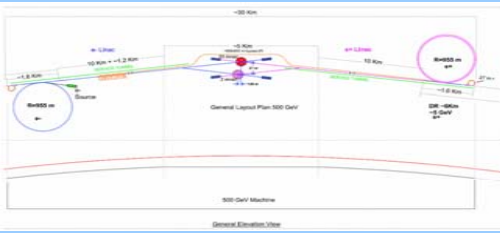
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## Cosmic Rays in a 1 cm Thick Scintillator

$20 < t < 70 \text{ nsec}$

$0 < t < 200 \text{ nsec}$



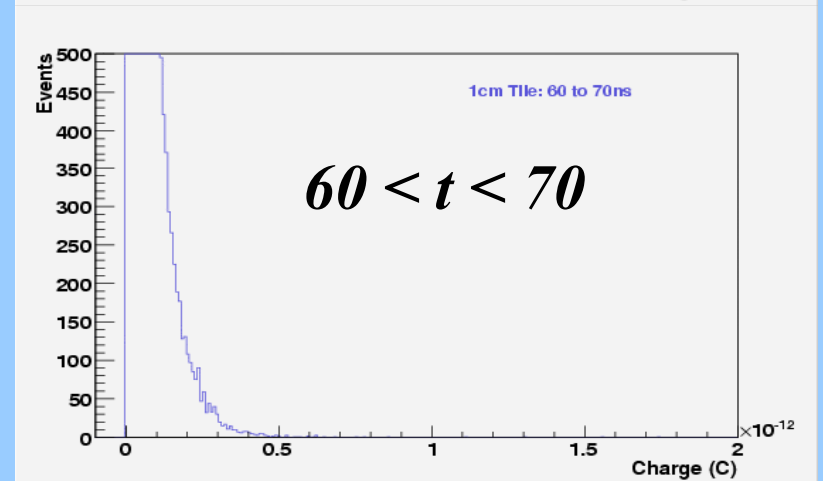
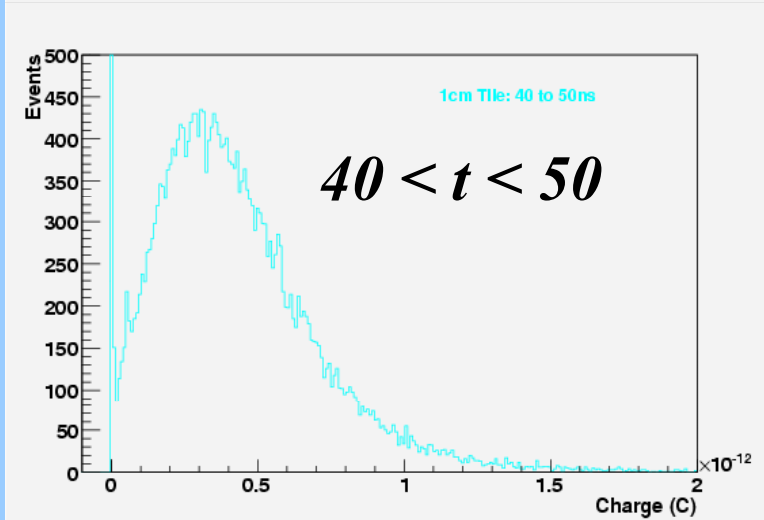
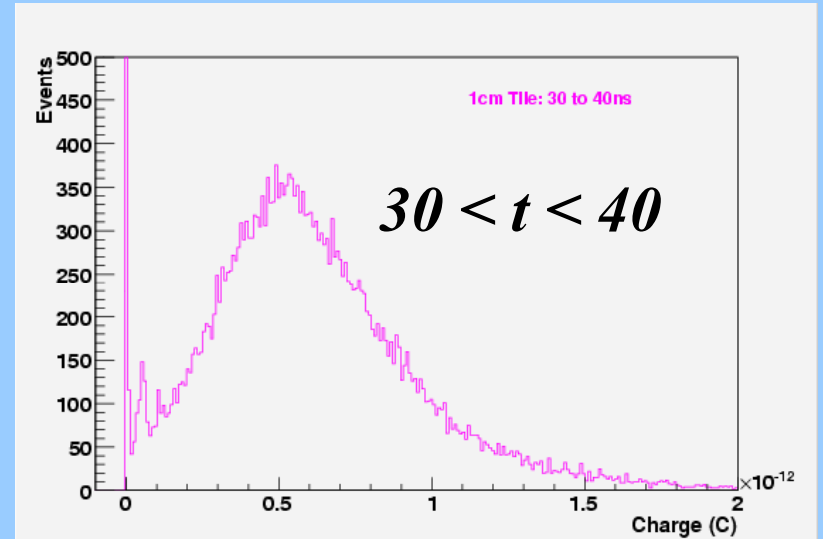
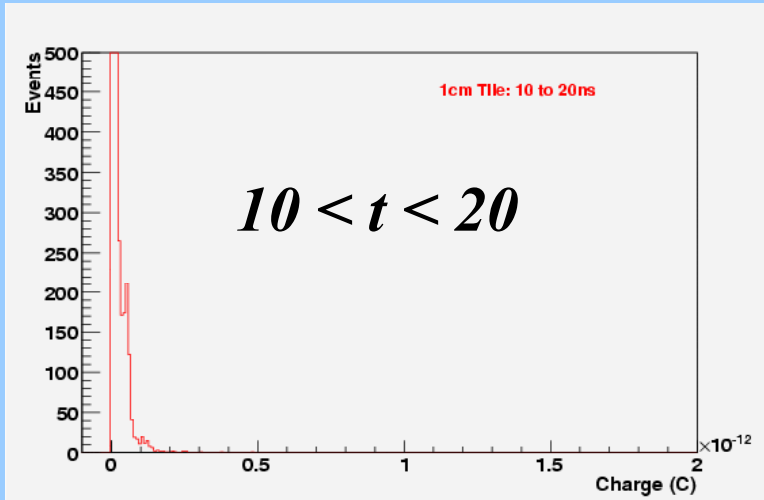


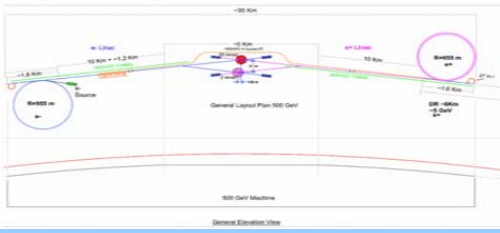
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## *1cm scint*





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## Pulse Height versus Temperature

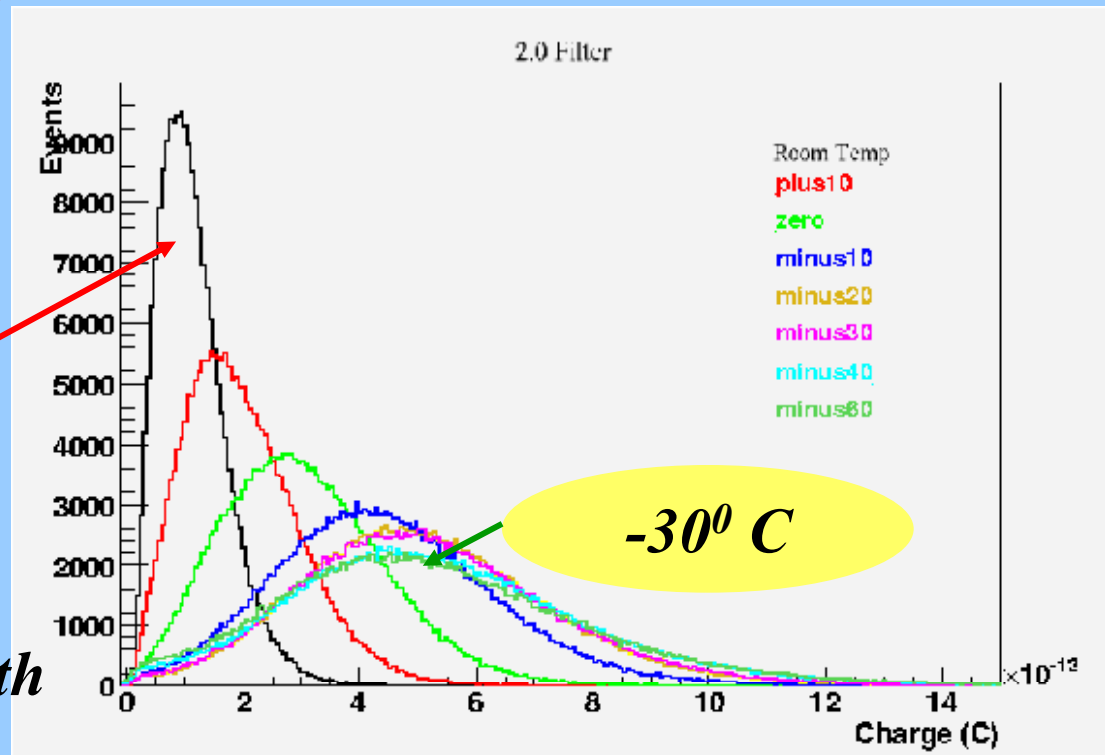
### Gain of SiPD Increases ~x4

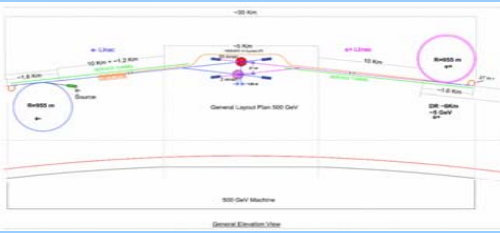
Noisy SiPD

Could not detect peaks

Room temp

Needs to be repeated with New SiPDs; noiseless



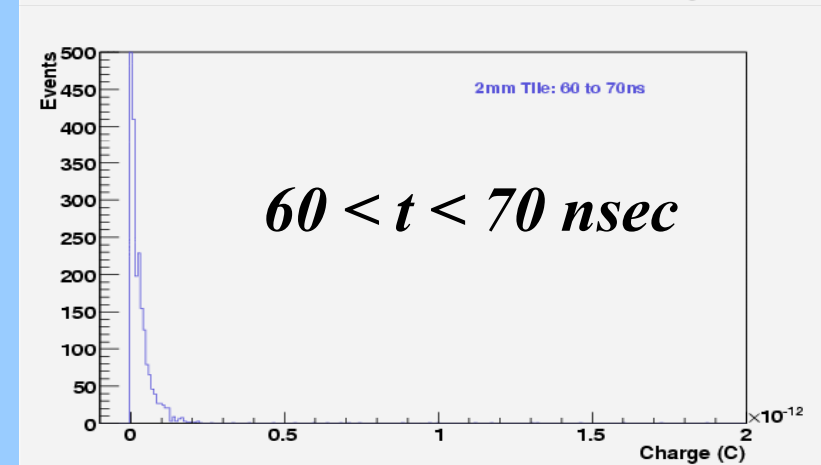
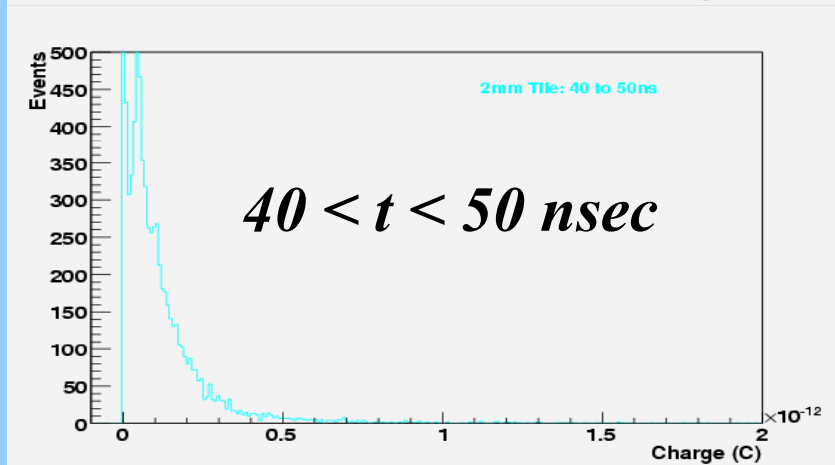
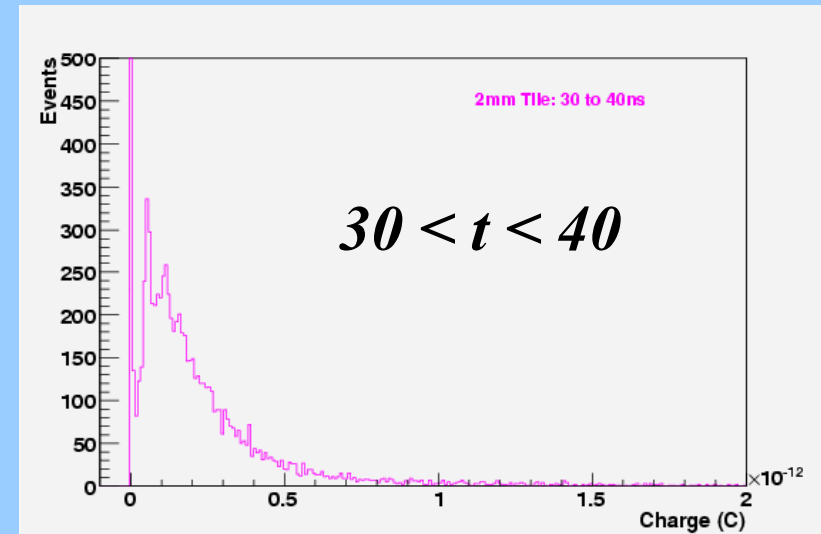
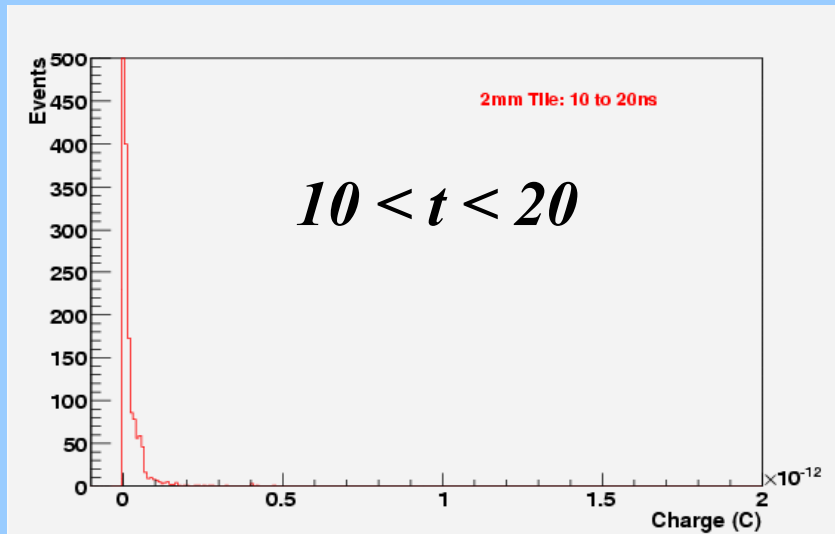


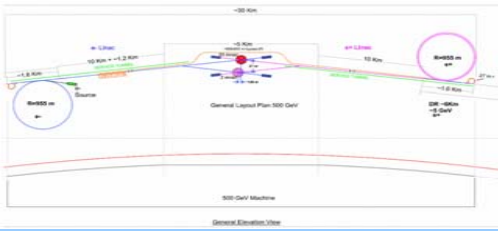
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## *2 mm scint*



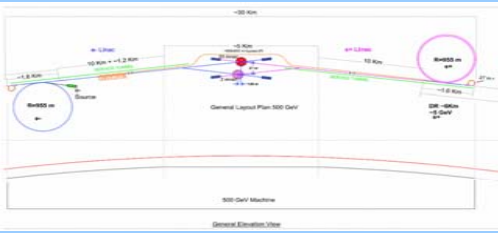


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*By time tagging we are observing the photons arriving in time sequence. Possibility to use this to improve resolution. Need beam tests to check this hypothesis.*



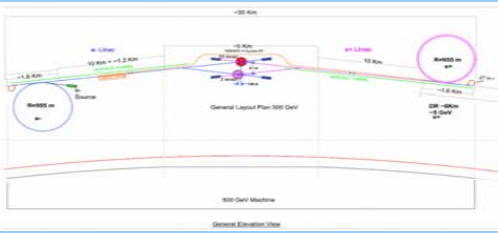
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*Work still in progress. Comparison with Russian plots indicate 100 Mhz x 4 (measuring pulse height every 2.5 nsec) not enough resolution.*

*National Instruments has just released a 2 Gigahertz unit. Using our trick of x4 will allow us to scan every 0.125 nsec. A demo is on its way here to check whether 8 bits resolution is good enough.*



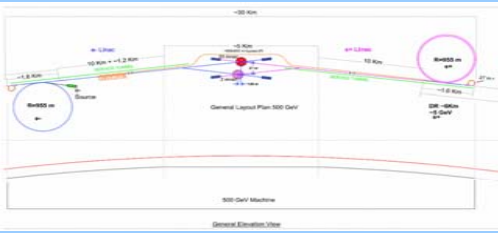
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## *Conclusions*

*A new revolution in photo-detection. A lot of improvements still possible. A lot of work to be done in this area. If one is bold and reckless one may say that “It may revolutionize calorimetry resolution.”*



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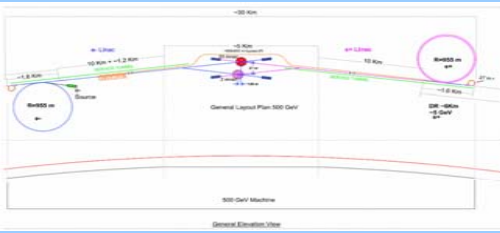


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## *Conclusions*

*Our simulation work with the undergraduates is moving ahead. A lot of work needs to be done still. Need manpower help. Most of the pieces are in place to study  $Z$  and  $W$  mass resolution.*

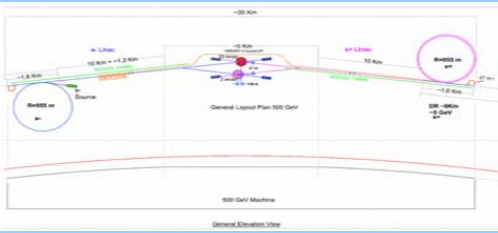




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*We helped with the organization of the Linear Collider Workshop and the various ALCPG meetings up to but not including Vancouver*

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## 2005 International Linear Collider Workshop at Snowmass

August 14-27, 2005

The American Linear Collider Physics Group (ALCPG) will host a two week workshop in Snowmass, Colorado, August 14-27, 2005.

The workshop is being organized for the particle physics community to facilitate broad participation in studying and planning the linear collider program. Particle physicists from all regions of the world are invited and encouraged to participate, and the overall steering committee and working group conveners will include leaders from all regions.

**THE PURPOSES OF THE WORKSHOP ARE:**

- 1.) To develop the linear collider detector design studies with detailed understanding of the technical details and physics performance of candidate detector concepts, as well as the required future R&D, machine plans, machine-detector interface and baseline instrumentation, cost estimates, and other aspects.
- 2.) To advance the linear collider physics studies, including synergy with the LHC; connections to cosmology and astrophysics, and relationships to the detector design studies.
- 3.) To facilitate and strengthen the broad participation of the community in linear collider physics, detectors, and accelerators.

This workshop will be an excellent opportunity for individuals new to the linear collider to learn about the program and to begin active participation.

The Global Design Initiative is moving ahead with a state-of-the-art for the accelerator conceptual design report (CDR) and technical design report (TDR), including detailed and reliable understanding of the costs of the linear collider. In parallel, the Worldwide Study is organizing the global experimental programs, with plans for detector design studies, detector cost studies, detector CDRs and TDRs and cooperation with accelerator designers on the machine-detector interface.

The 2005 ALCPG Snowmass Workshop should serve to advance the detector and physics studies and keep them in pace with the accelerator developments.

The ALCPG web page is <http://ilcwww.slac.stanford.edu/~alcp2005>

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[linearcollider.org](http://linearcollider.org)

Univ. of Colorado, Boulder, April 28/08