ORKA Calorimeter: Expected Performance

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2012 Project X Physics Studies
June 14-23, 2013
Fermilab

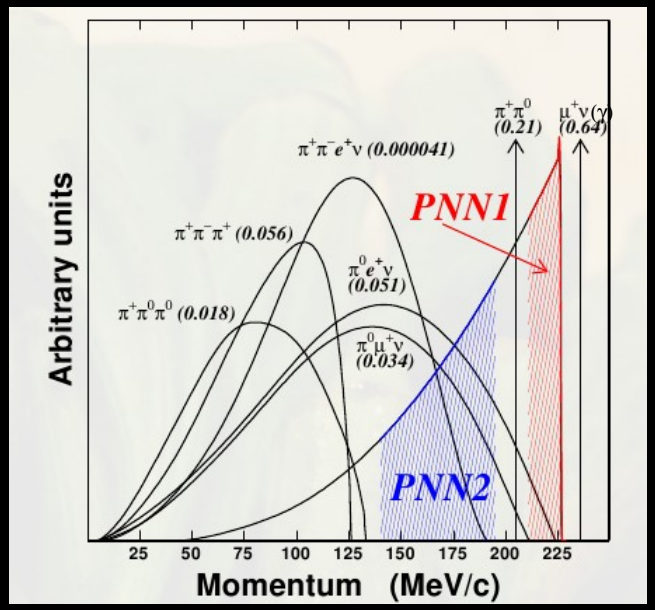
Introduction

- Preliminary simulations (Geant4) of different calorimeter layouts proposed at ORKA
- Main goal is to stimulate the discussion at this workshop
- Must be followed by dedicated simulations to fully understand and optimized the detector

ORKA experiment

- $K^+ \to \pi^+ \nu\nu$ very challenging measurement
  - $\mathcal{B}_{SM}(K^+ \to \pi^+ \nu\nu) = 0.00000000078$
  - $\mathcal{B}_{SM}(K^+ \to \mu^+ \nu(\gamma)) = 0.64$
  - $\mathcal{B}_{SM}(K^+ \to \pi^+ \pi^0) = 0.21$

  Experimentally weak signature with background exceeding signal by > 10^{10}



- Several events observed at BNL (E749/E949 experiments)

- The aim of the proposed ORKA experiment at Fermilab:
  x100 sensitivity (x10 from kaon flux, x10 from detector)

Detector must be efficient in rejecting the background while capable of retaining most of the signal

Photon Detection Inefficiency

- Photons from $K\pi 2$ decays have E_γ = 20-200 MeV

- However:
  - 3 body Dalitz decay of π^0 (1.17%) source of em particles below 20 MeV
  - γ can loose energy in the materials in front of the calorimeter
  - charged particles can emit bremsstrahlung γ
  - other processes of interest under study require sensitivity to γ below 20 MeV

→ **Not only $(K^+ \to \pi^+)\pi^0 \to \gamma\gamma$ rejection**

See previous talks

- Sources of calorimeter inefficiency:
  - Sampling fluctuations (significant at low E_γ)
  - EM inefficiency (i.e. punchthrough)
  - Photonuclear interactions (can be the dominat effect)

Single photon inefficiency measured in E949

Simulation Framework

Geant 4.9.5 patch 01 (March 2012)

Geometry:

Range stack: 28.5 cm polystyrene (X0=40cm)

Calorimeter: alternating planes of polystyrene and lead/lead glass/crystal (see next slide)

Dedicated physics list with low energy cuts:

Rayleigh Scattering (Livermore model, when applicable)

PhotoElectric Effect (Livermore model, when applicable)

Compton Scattering (Livermore model, when applicable)

Gamma Conversion

Photonuclear reaction (G4GammaNuclearReaction model in 0-3.5 GeV range)

G4EmExtraPhysics

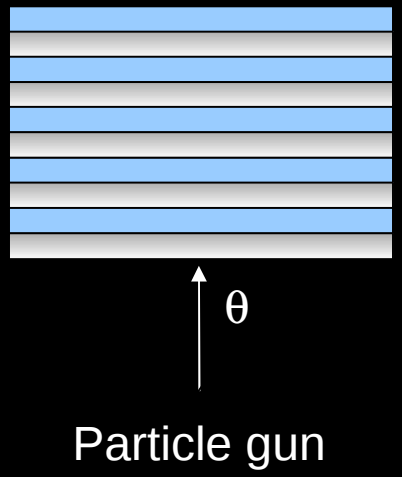
G4HadronElasticPhysicsHP

G4QStoppingPhysics

G4IonPhysics

G4NeutronTrackingCut

QGSP_BERT_HP



- 4 particle species (γ,e,n,π)
- 6 energies (1,5,10,20,30,50 MeV)
- 5 impinging angles (90, 60, 45, 30, 20 degree)
- With and without 28.5 cm Polystyrene

Very low energy cuts:

Lower production limit: 250 eV

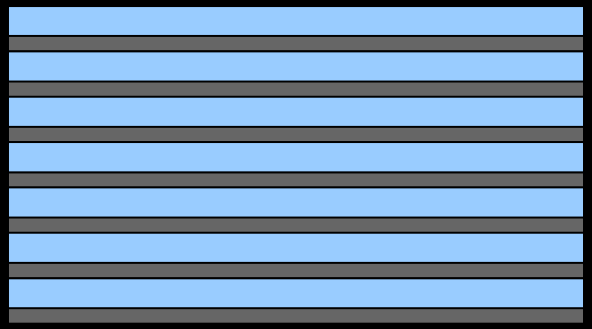
Min range: 2 μm for γ, electron, positron ; 20 μm for proton & neutrons

Stepping: 1 μm (but also shown different steppings)

Detector Layouts Considered

Shashlyk (baseline approach)

- 155 layers, Pb 0.8mm, Scint. 1.6mm



ADRIANO (proposed for ORKA)

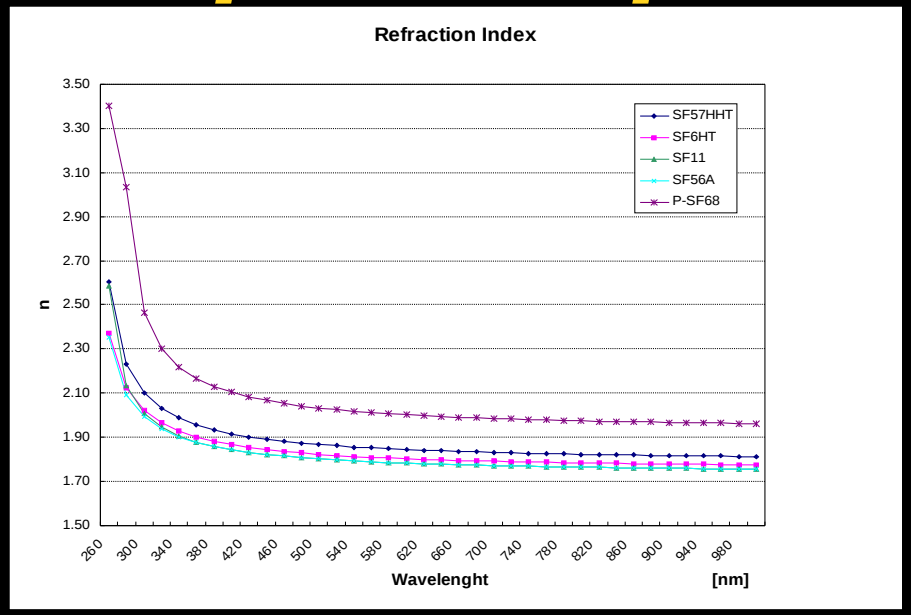
- 150 layers, SF57HHT (X0=1.5) 2-4mm, Scint. 2mm
- 160 layers, SF6HT (X0=1.69) 2mm, Scint. 2mm
- 150 layers, SF5 (X0=2.36) 3mm, Scint. 2mm
- 130 layers, PbF2 (X0=0.93) 2mm, Scint. 2mm

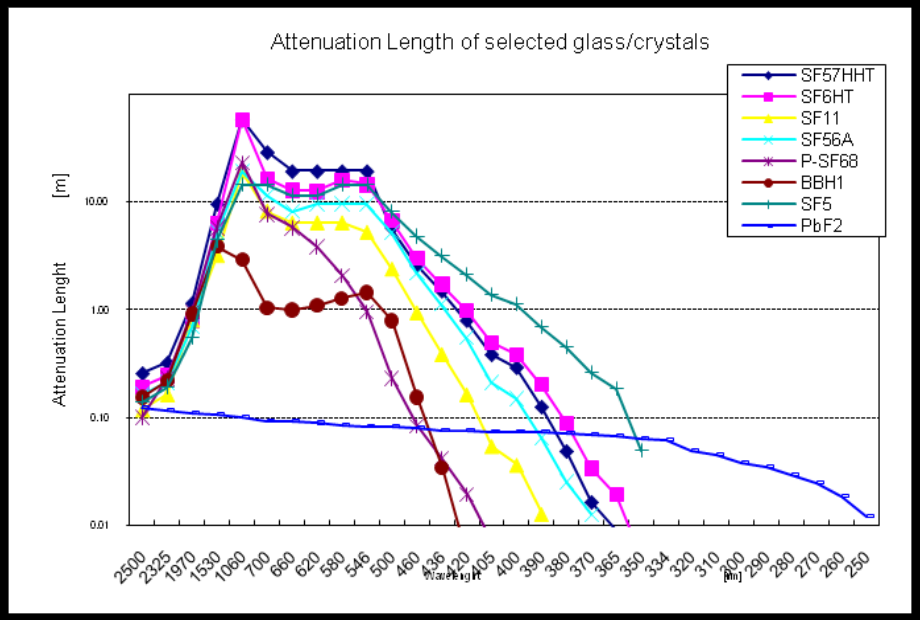
Light Yield Parameters

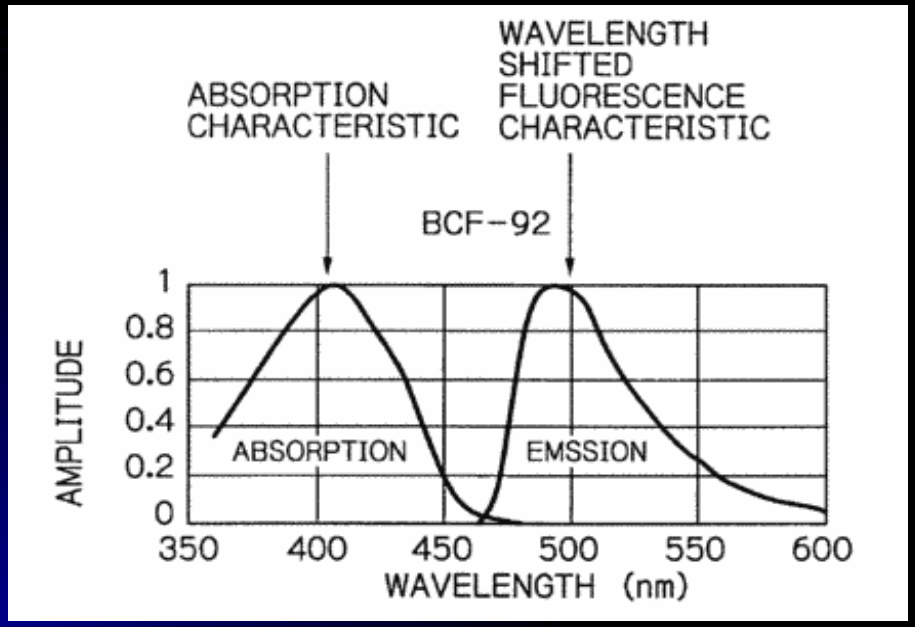
- Scintillating light (assume WLS readout from ADRIANO simulations)
  - photons/mev=167
  - QE=24% (assume SiPM at 530 nm)
  - Attenuation length in scintillator: 3.4 m
  - Birk's corrected light yield

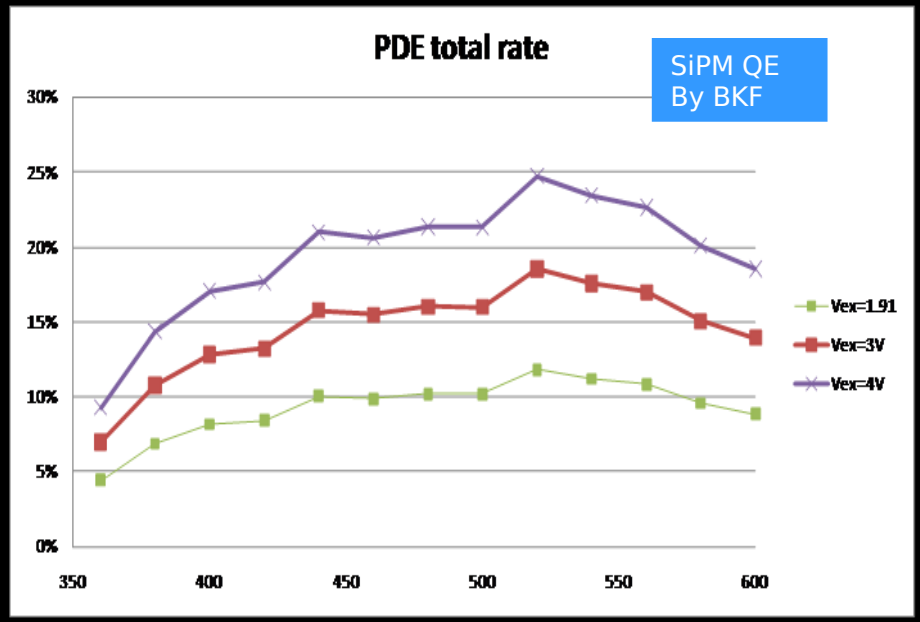
- Cerenkov light (assume WLS readout from ADRIANO simulations)
  - Cerenkov light production with wavelength dependent n_D
  - Wavelength dependent attenuation of Cerenkov photons traveling through the glass/crystal
  - Photon angle must be larger than $\theta_{critical}$ in order to enter the WLS fiber/plane (Snell's law).
  - Attenuation length in WLS: 3.4 m
  - Shift of the wavelength of Cerenkov photon according to absorption/emission of the WLS
  - Acceptance of the fiber for the re-emitted photon: 4.8%
  - Wavelength dependent QE (assume SiPM from BKF)

Optical Spectra in ADRIANO

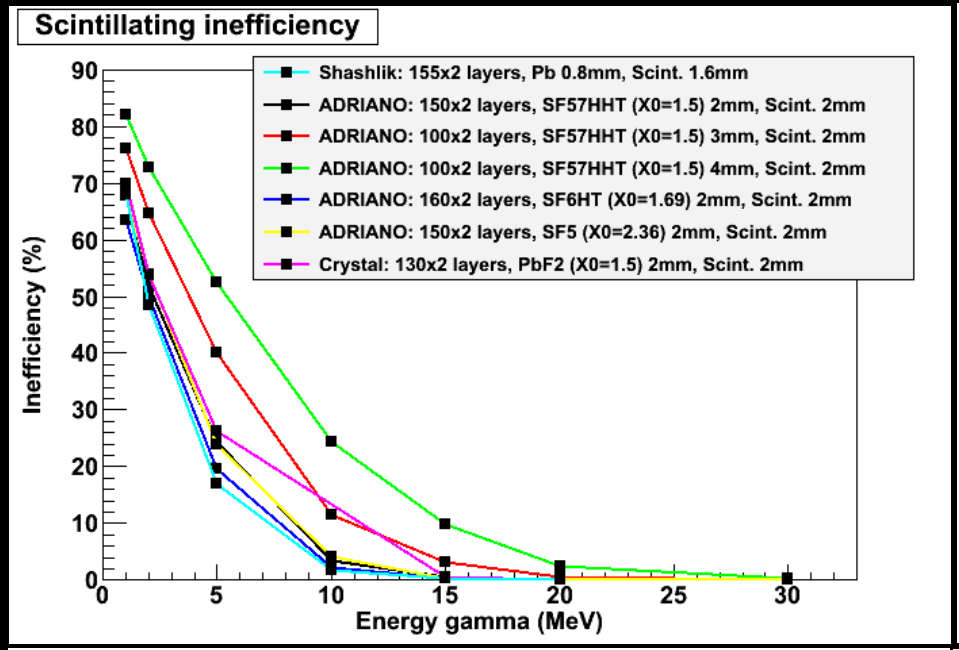


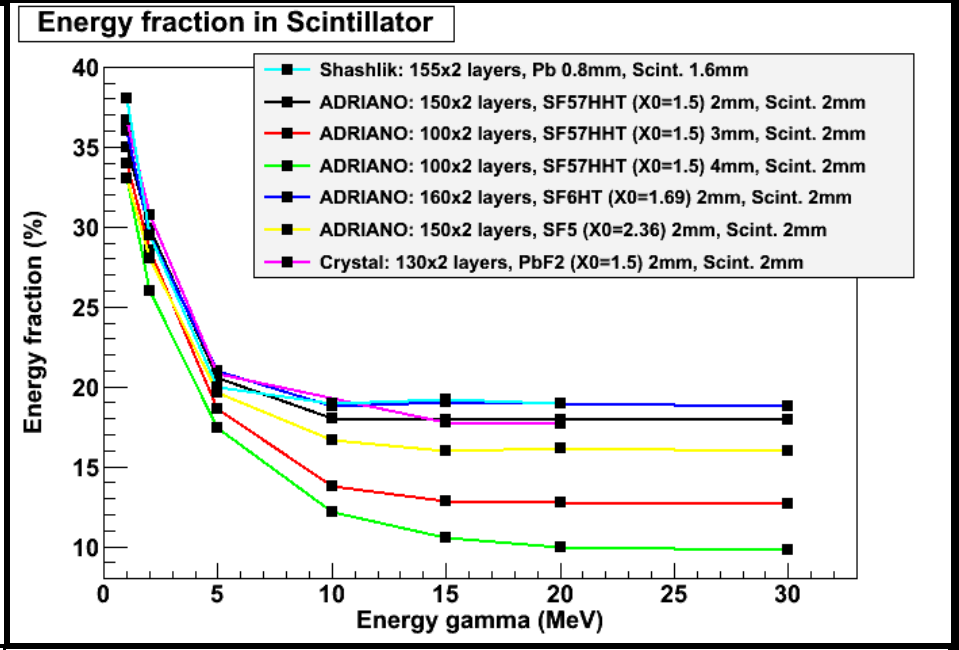


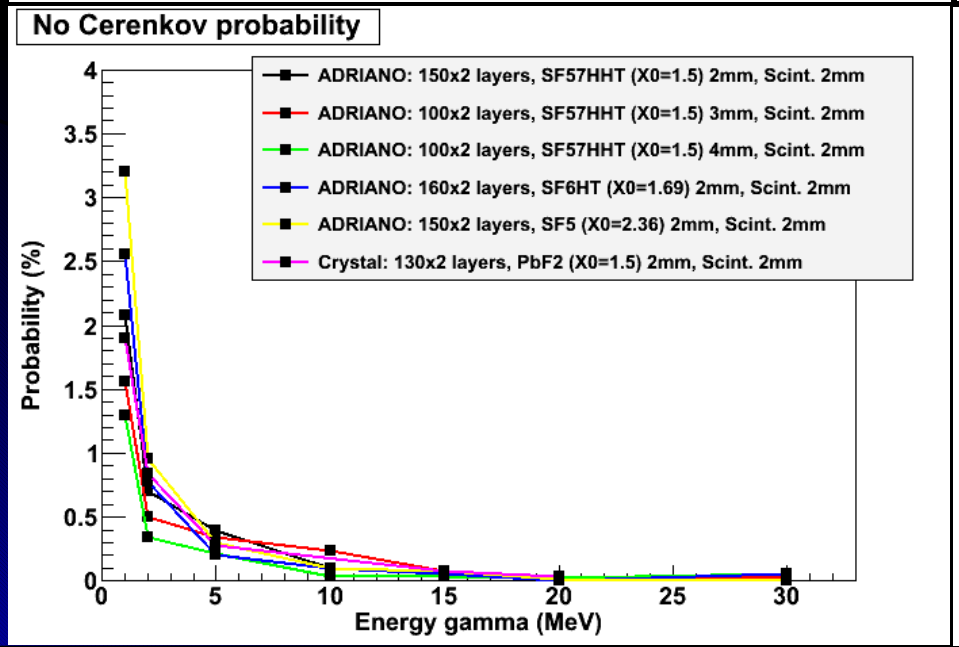


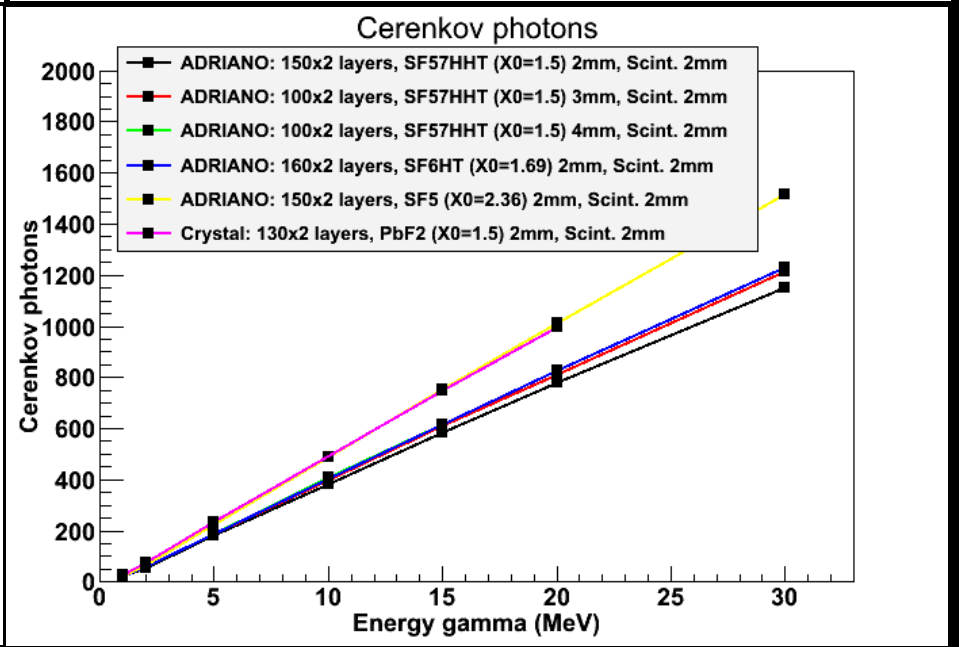


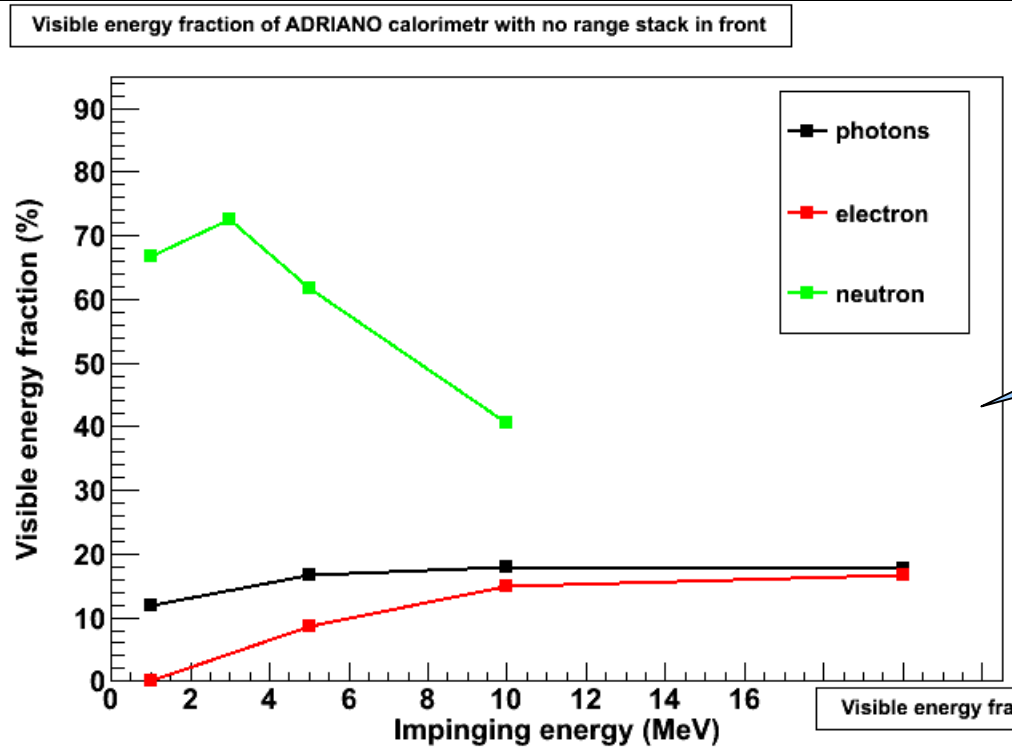
Compare results



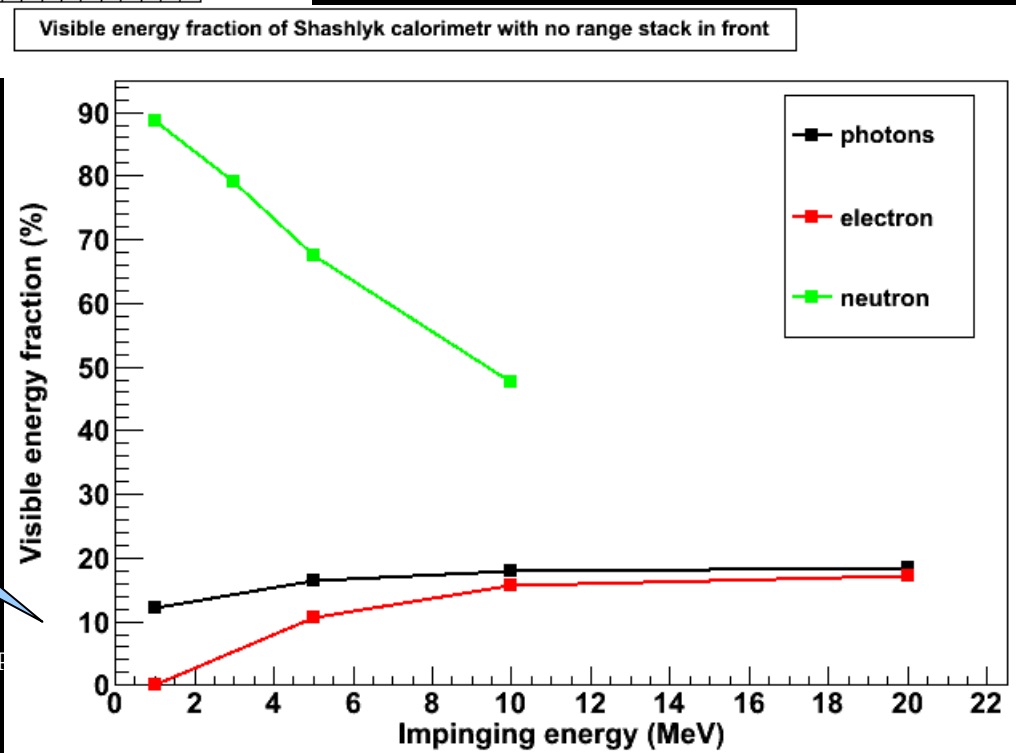




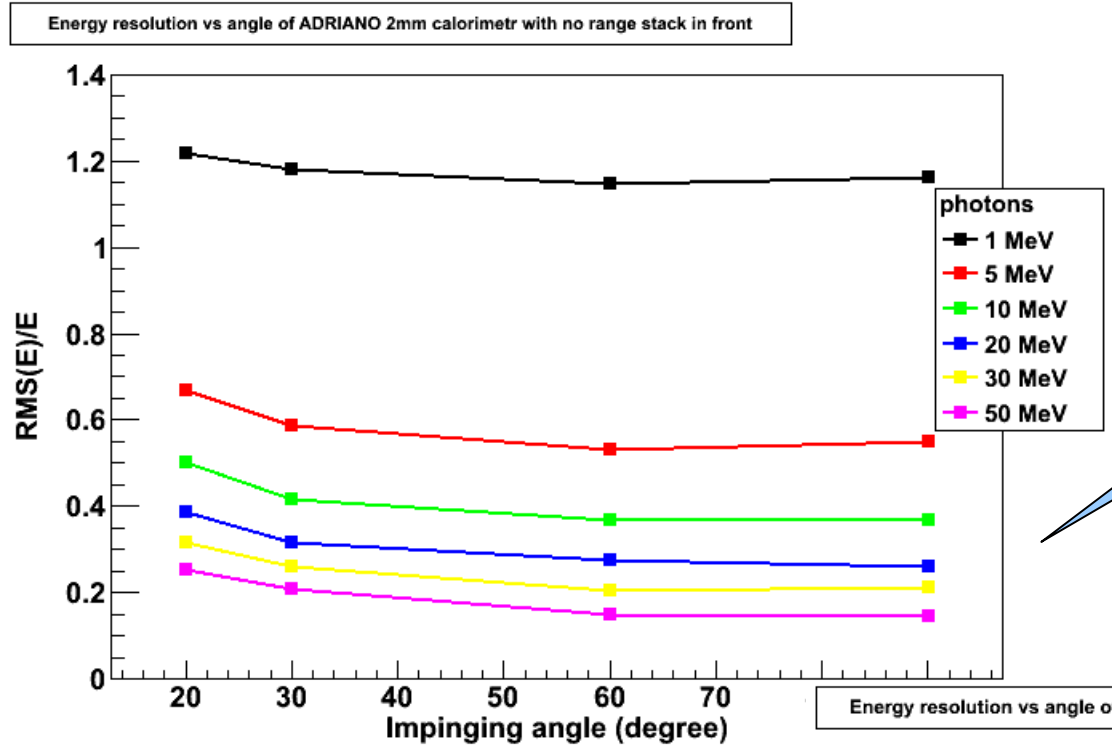




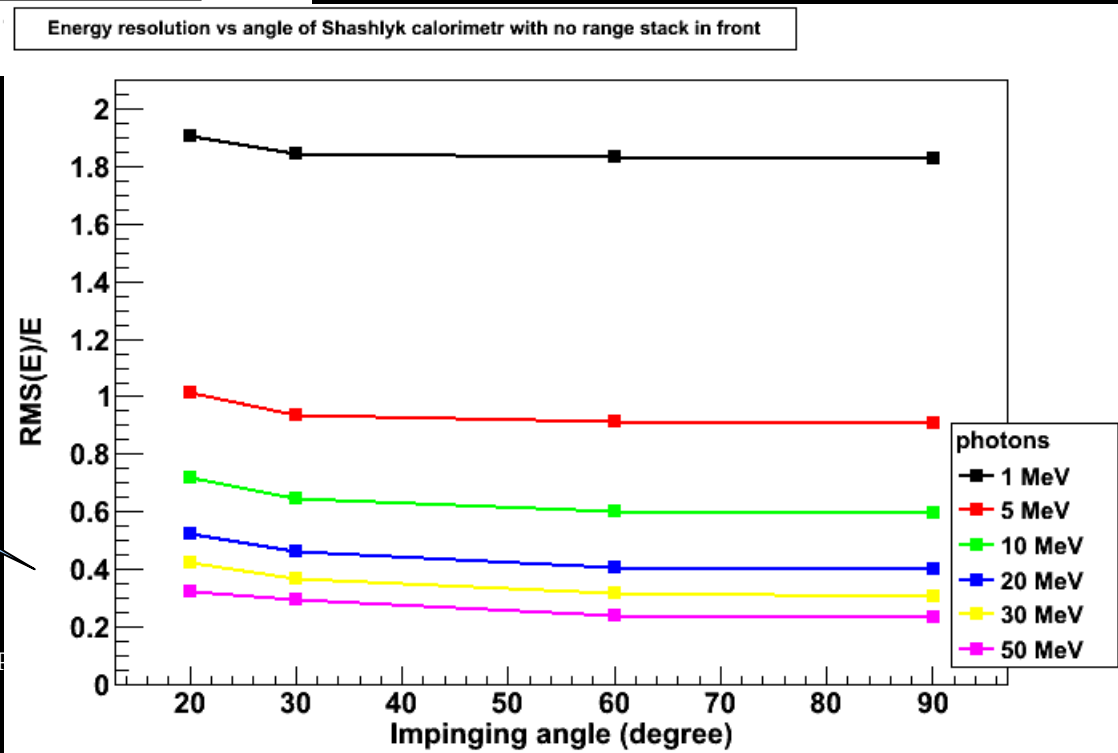
Fraction of the deposited energy in ADRIANO scintillator



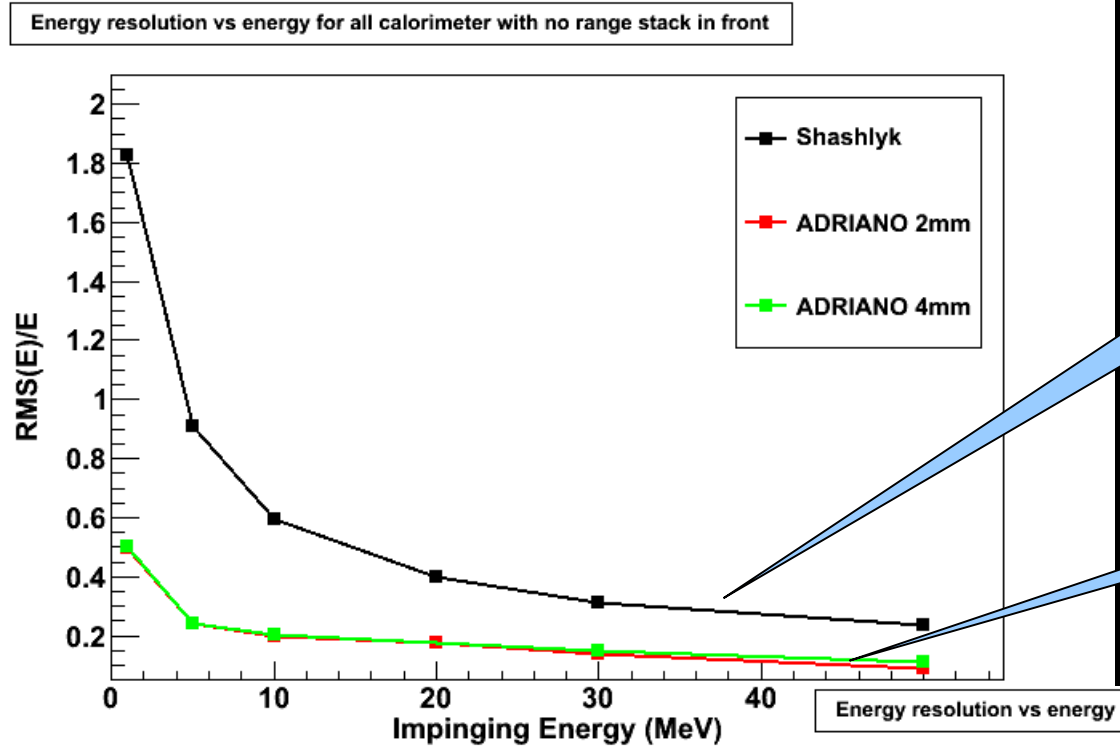
Fraction of the deposited energy in Shashylk scintillator



$$\frac{RMS(LYSCI+LYCER)}{MEAN(LYSCI+LYCER)}$$

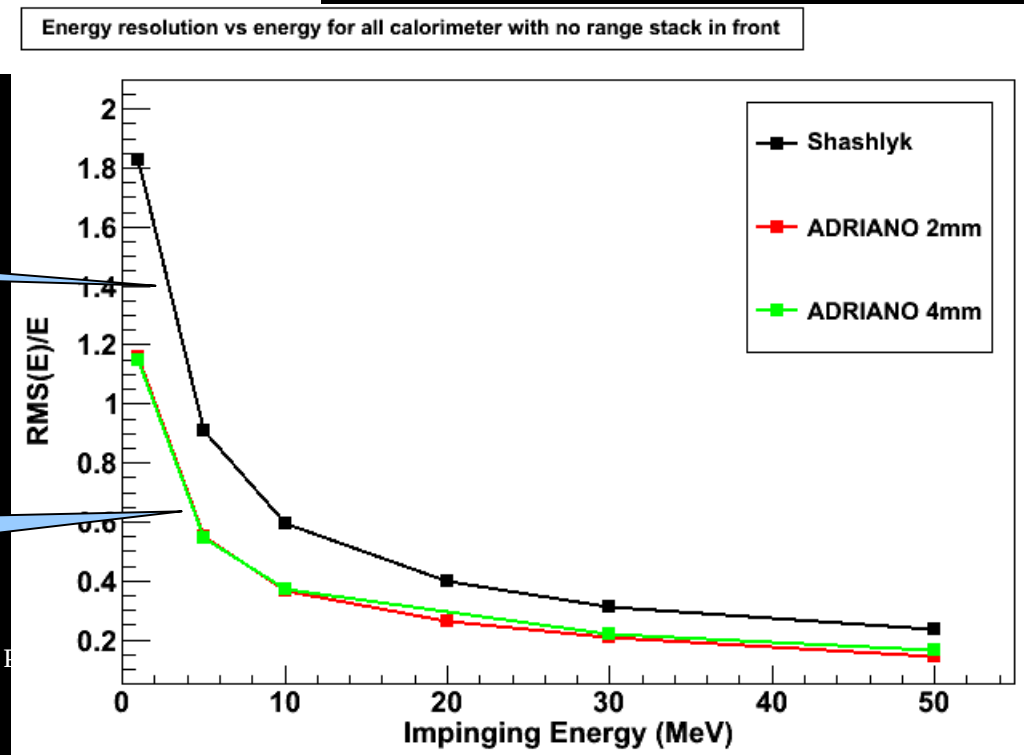


$$\frac{RMS(LYSCI)}{MEAN(LYSCI)}$$



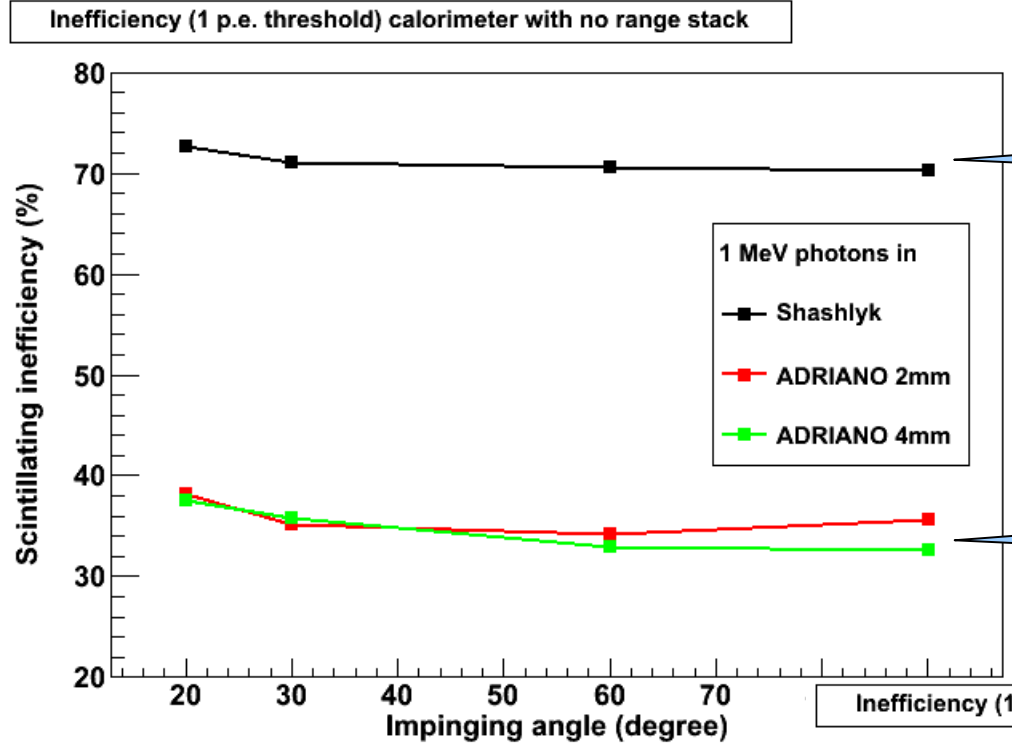
$$\frac{RMS(LYSCI)}{MEAN(LYSCI)}$$

$$\frac{RMS(LYCER)}{MEAN(LYCER)}$$



$$\frac{RMS(LYSCI)}{MEAN(LYSCI)}$$

$$\frac{RMS(LYSCI+LYCER)}{MEAN(LYSCI+LYCER)}$$

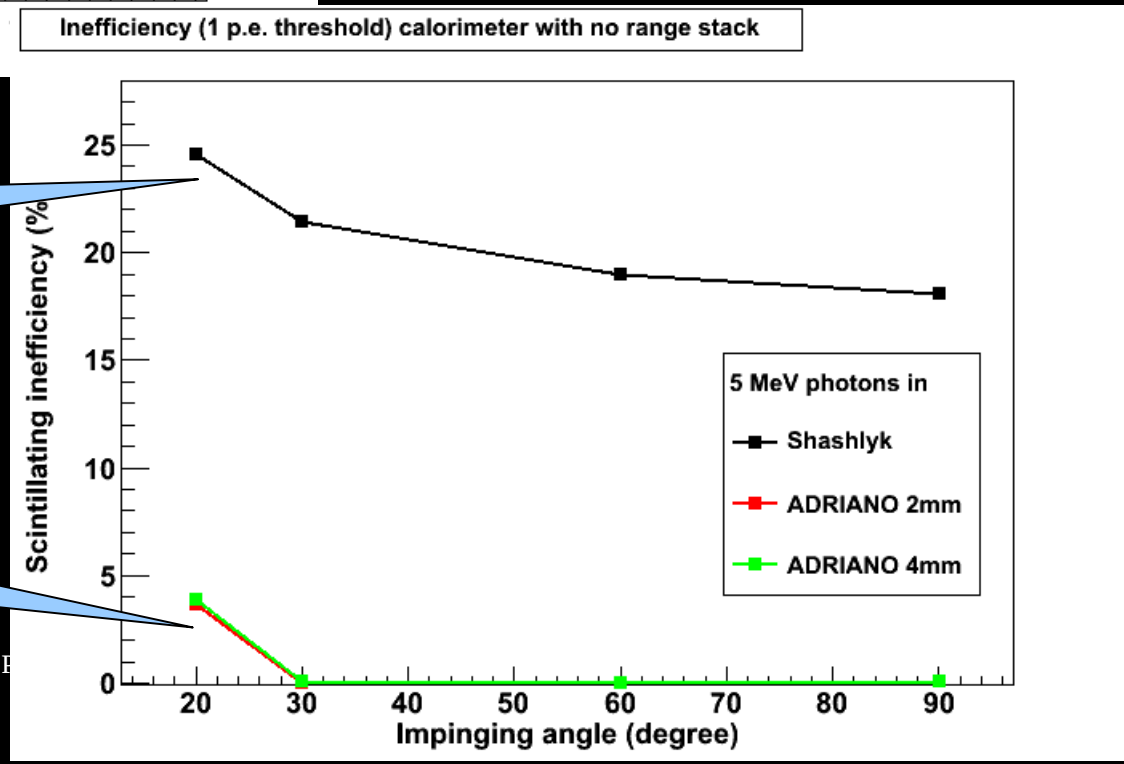


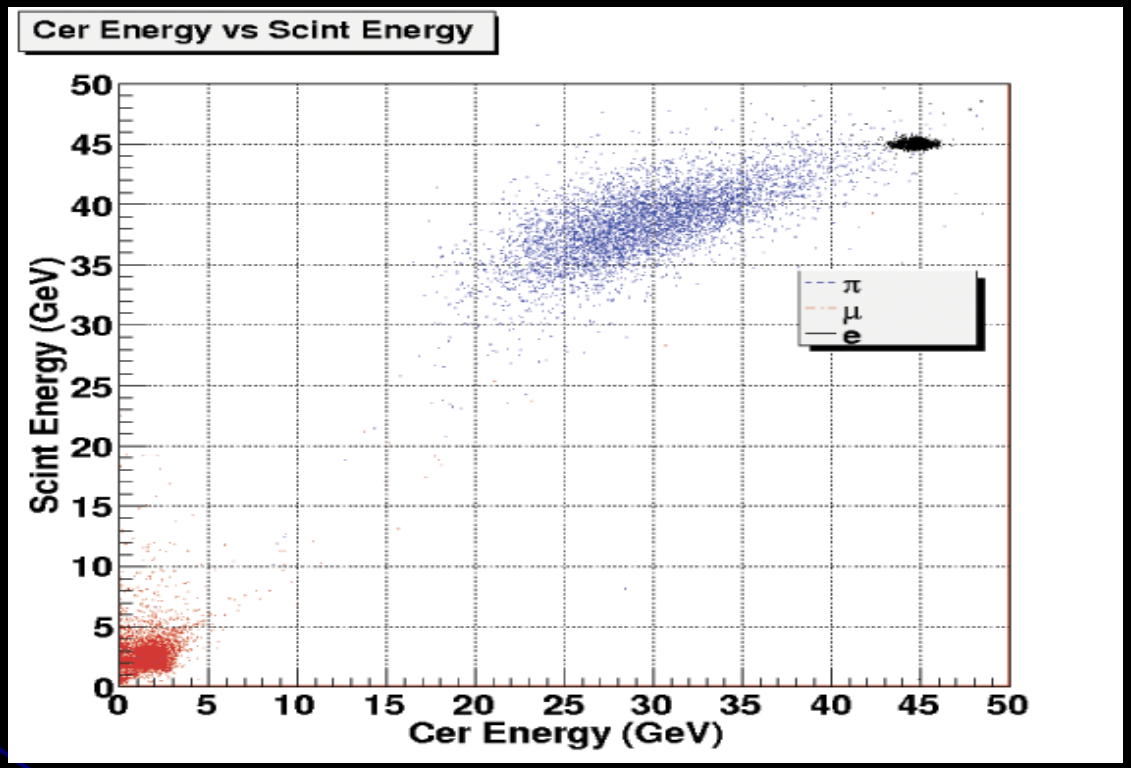
Fraction of events where (LYSCI)> 1p.e. at 1 MeV

Fraction of events where (LYSCI+LYCER)> 1p.e. at 1 MeV

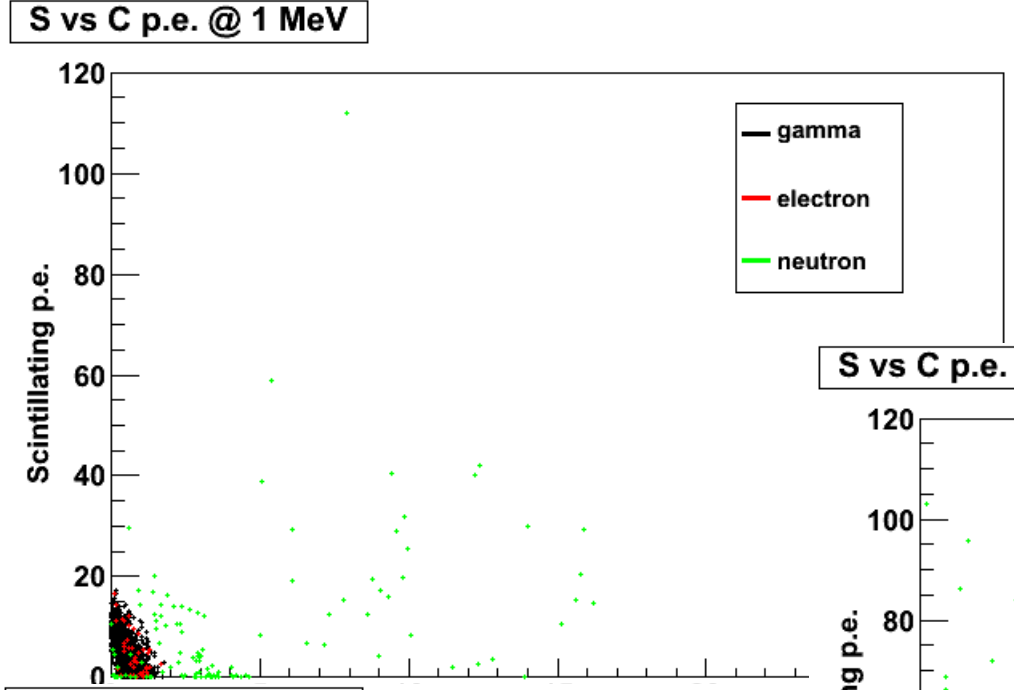
Fraction of events where (LYSCI)> 1p.e. at 5 MeV

Fraction of events where (LYSCI+LYCER)> 1p.e. at 5 MeV

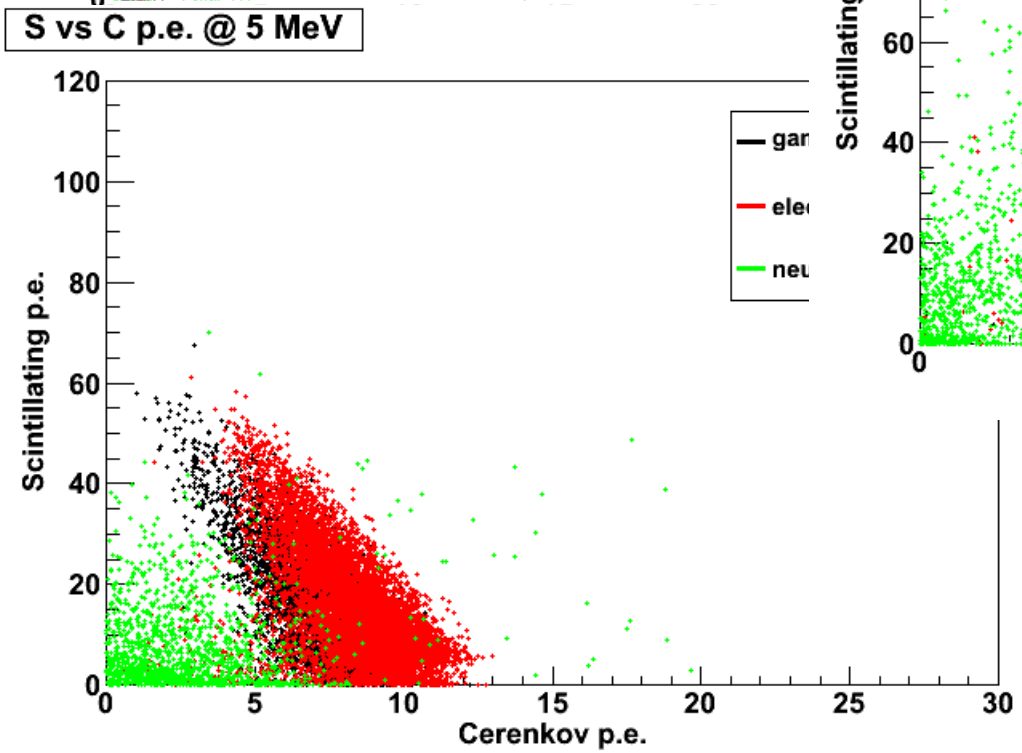


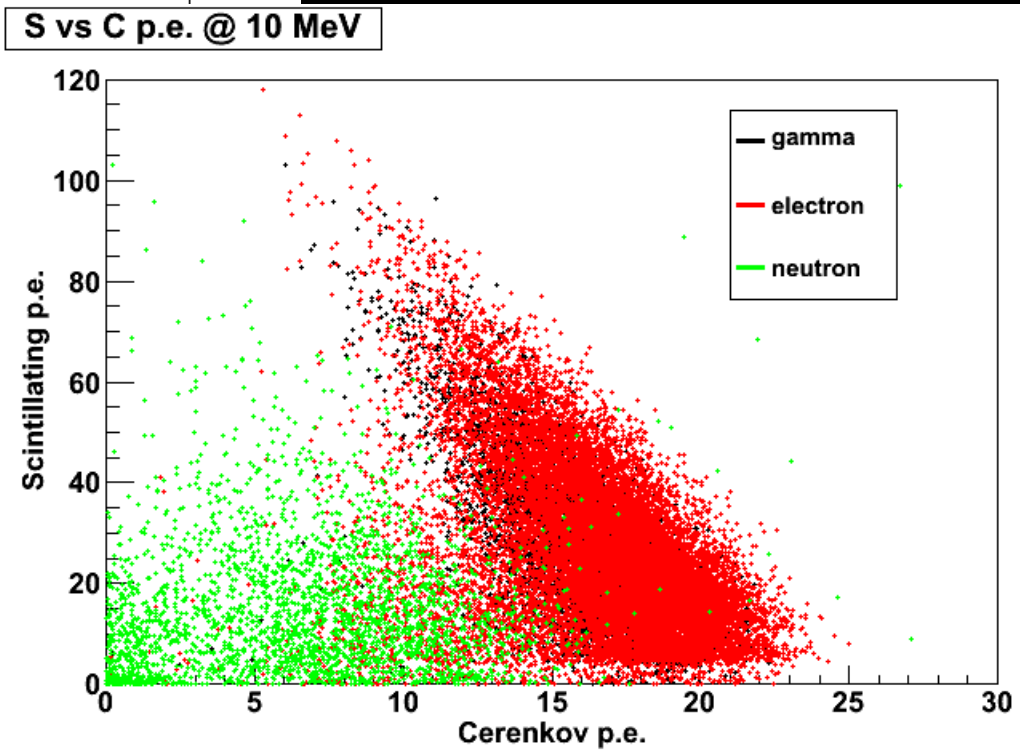


ADRIANO capability
to distinguish among
different particles
at high energy



ADRIANO capability
to distinguish among
different particles
at lower energy





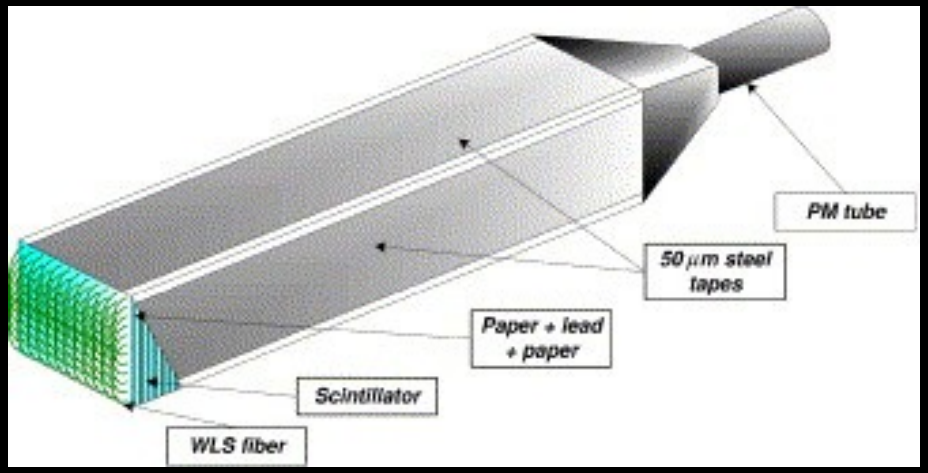
Conclusions

- I have presented very preliminary G4 simulations with 5 different layouts and materials
- Inefficiency of scintillating materials is worrisome
- Transparent materials like heavy glass or crystal may help in recovering some of these inefficiencies
- ADRIANO Cerenkov yield at high energy is 0.16 p.e./MeV
- Working on new ADRIANO layout optimized for ORKA
- **Needs lot of simulations!!!!!!**

Backup slides

Baseline Approach

- Shashlyk-style calorimeter with 155x0.8mm lead+1.6mm scintillating plates readout by 400 WLS
- Typical usage is for $E\gamma$>100MeV (see Atoian et al. NIM Volume 531, Issue 3, 1 October 2004)
- Danger is: range of compton e- is <0.5mm
- It could bring large inefficiencies



ADRIANO FOR ORKA

Sandwhich of scintillating plates and heavy glass/crystal WLS + SiPM readout

Two approches under considerations:
1) Sci and Cer lights separated (dual readout)
2) Sci and Cer lights merged (preferred)

ADRIANO R&D

Laboratory R&D and Montecarlo simulations are in advanced state

Four test beams at FTBF

Results from recent test beams prove that Cerenkov light readout from heavy glasses with WLS is feasible

Preliminary results presented at Calor2012:

http://indico.ads.ttu.edu/getFile.py/access?contribId=8&sessionId=7&resId=0&materialId=slides&confId=3

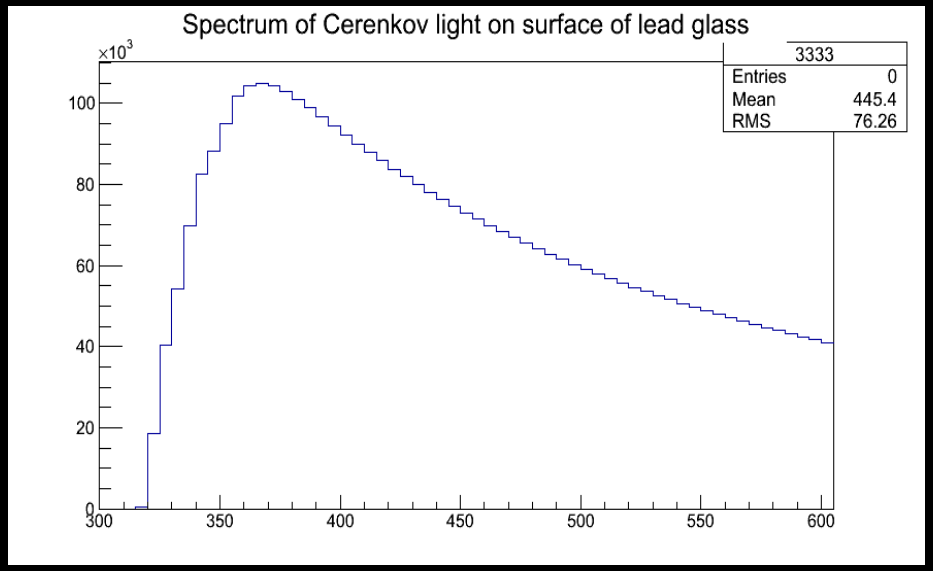
Just starting:

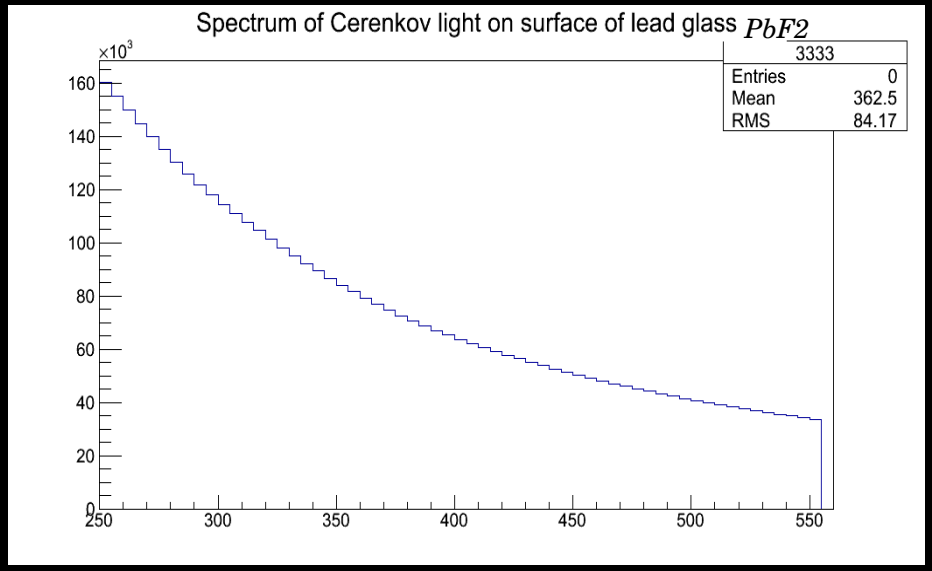
200 lbs SF57 recently shipped to Fermilab from Italy for ORKA R&D

Scintillating plates: need R&D to decide doping (will working in a hybrid way: scintillation + WLS)

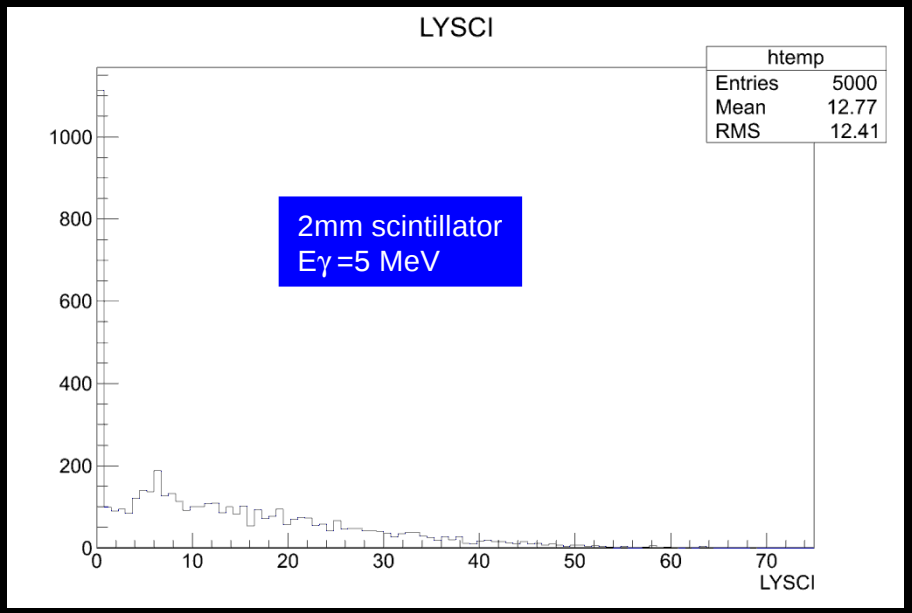
Welcome participation of A. Pla

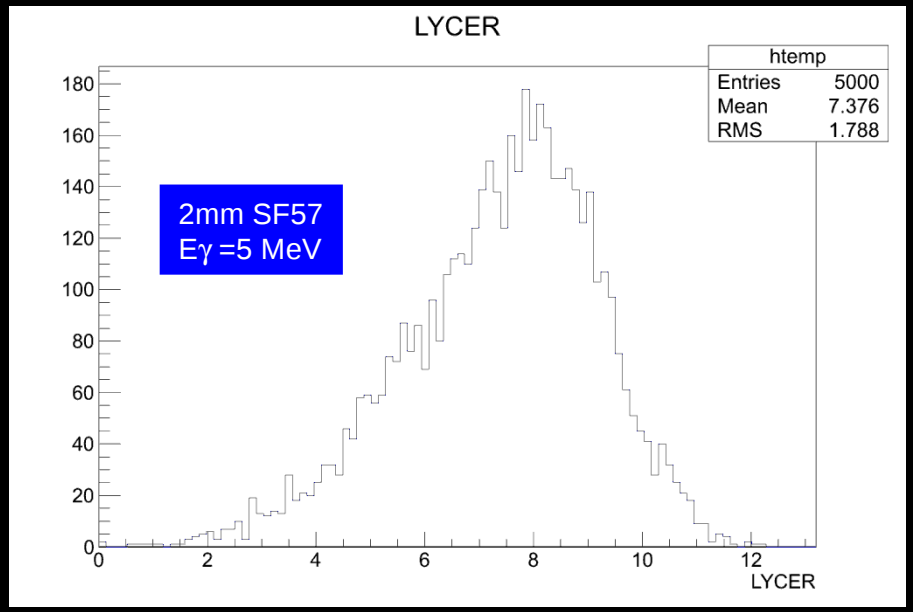
Glass VS PbF2

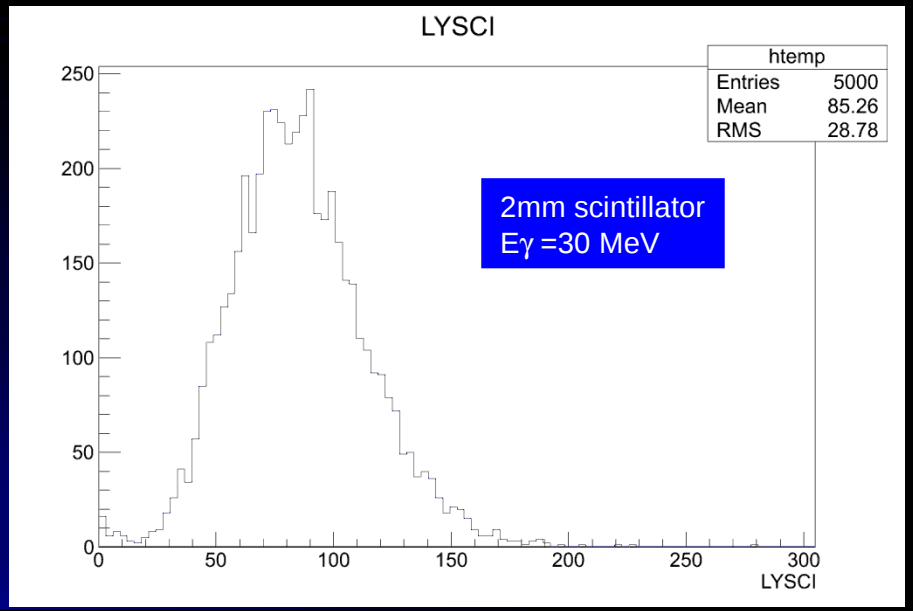


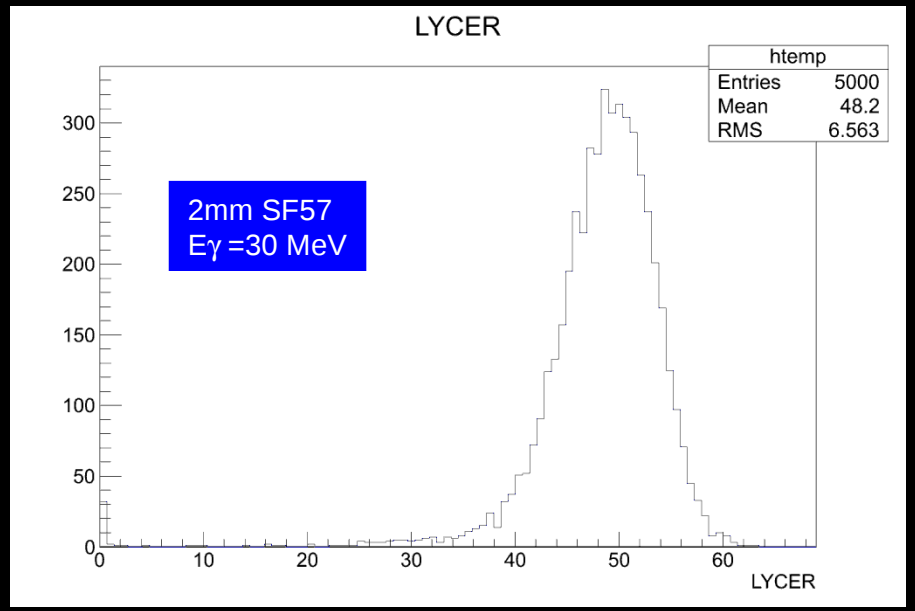


Simulated Light yield from Scintillator and Glass

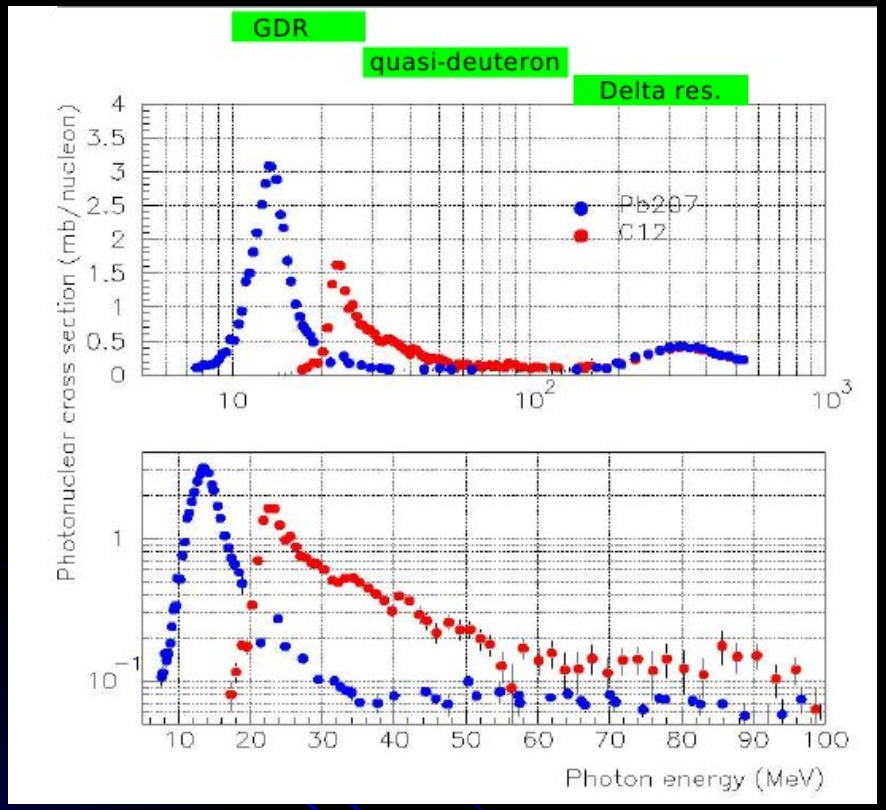


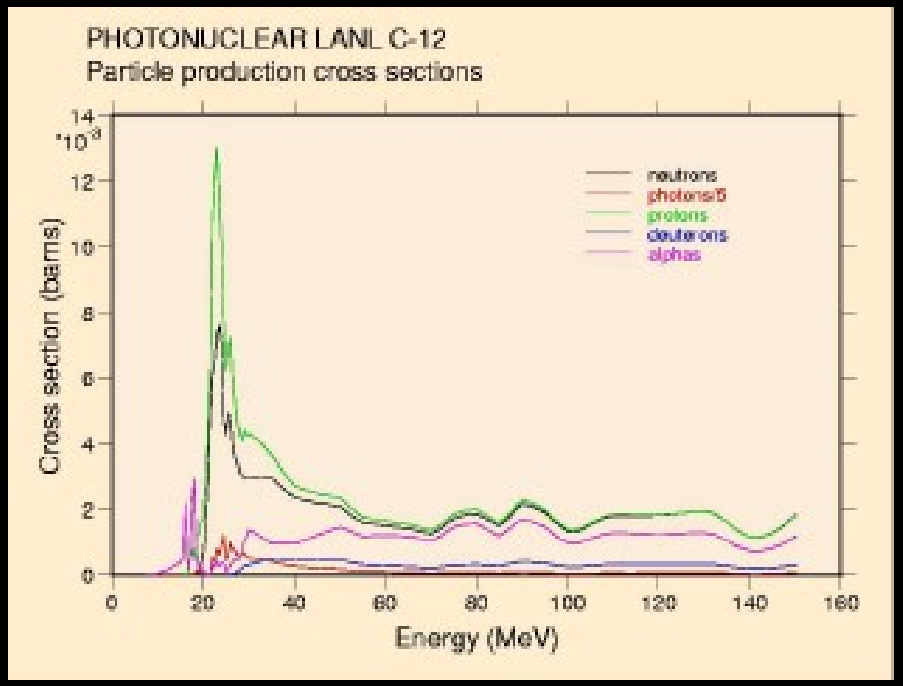






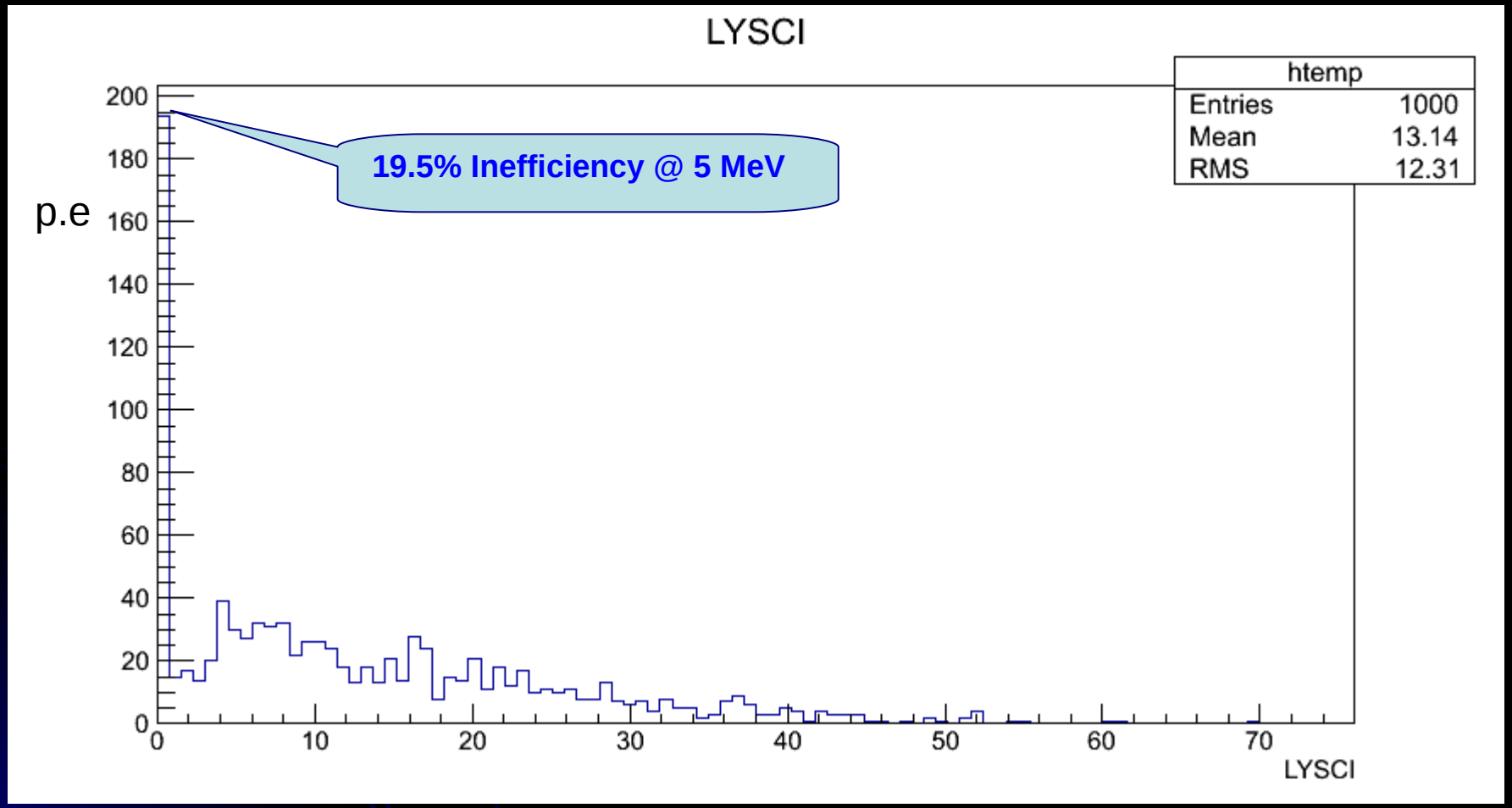
Photonuclear Interactions



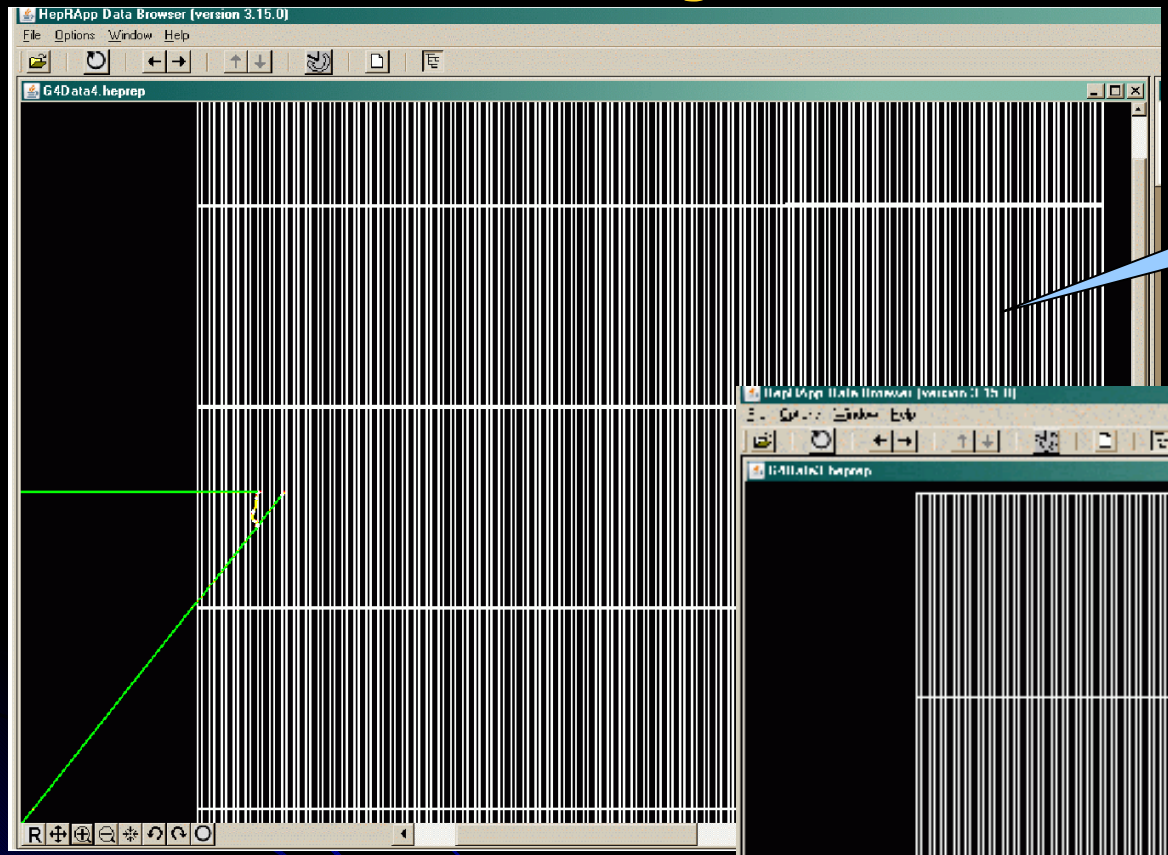


Rare K Workshop 26-27 May 2005

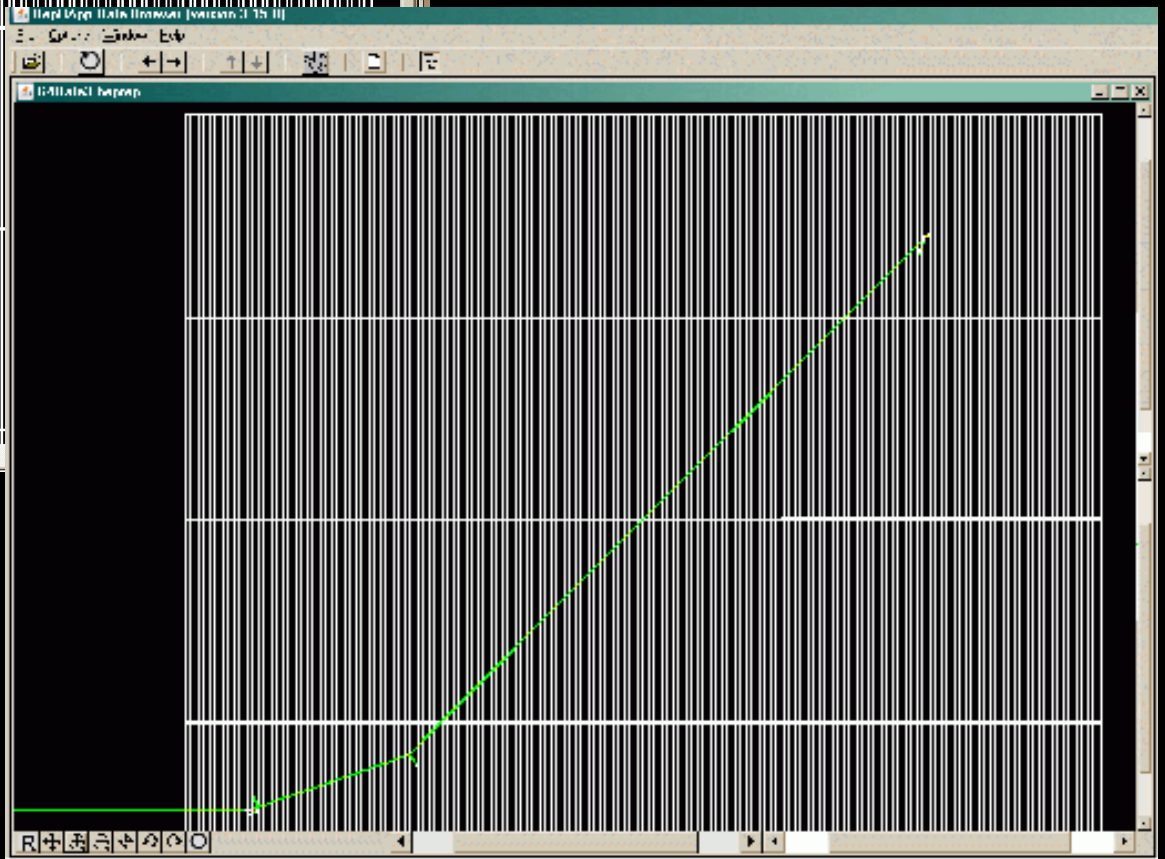
Shashlyk G4 simulation



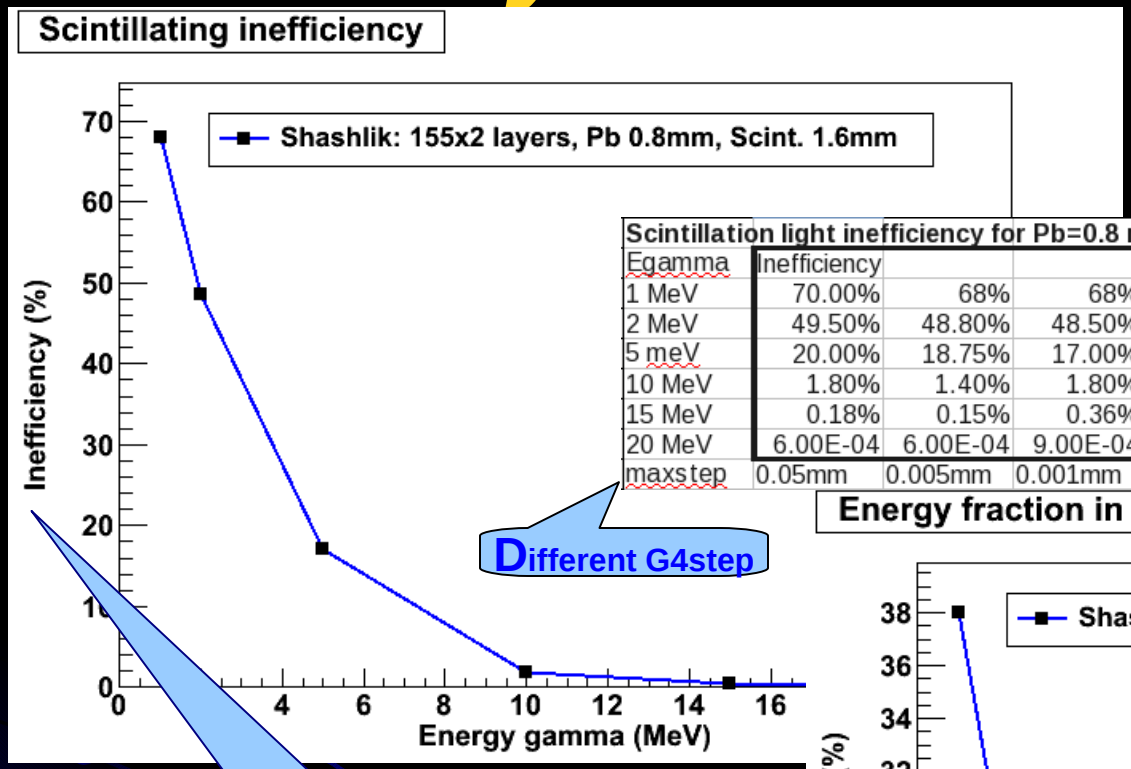
Shashlyk event display



Potentially dangerous situation.
Need to simulate the other subdetectors



Shashlyk Pb 0.8mm, Scint. 1.6mm

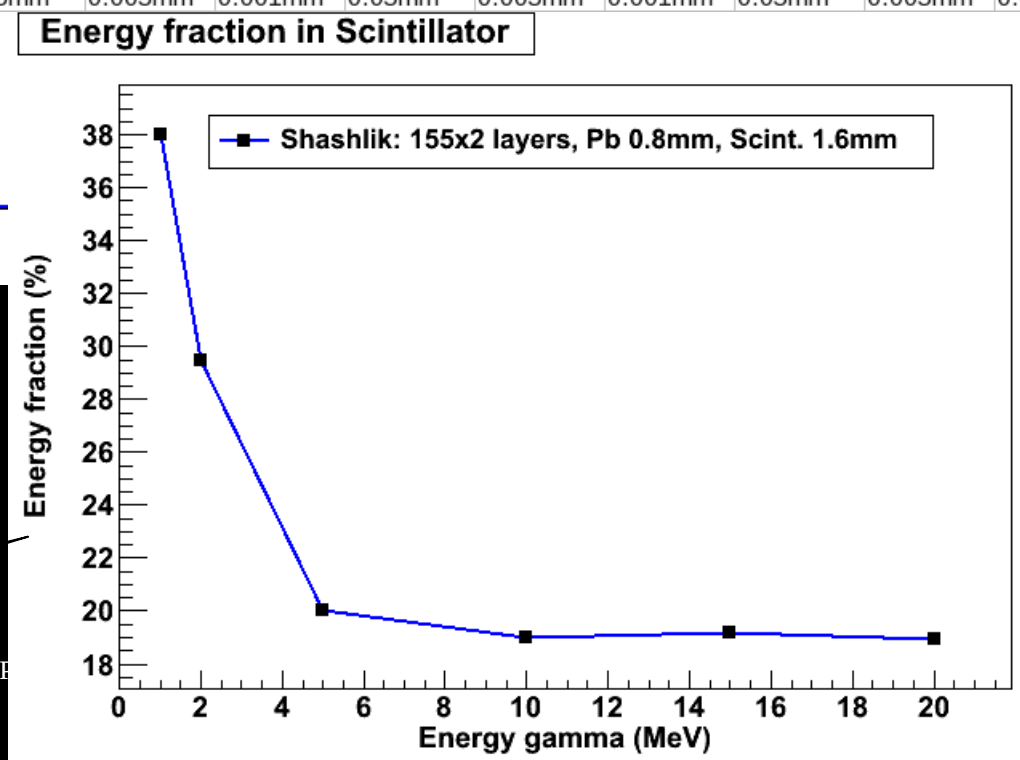


Scintillation light inefficiency for Pb=0.8 mm thick. Scintillator=1.6 mm thick. Total layers=155x2									
Egamma	Inefficiency			Edep in scintillator [MeV]			Efraction in scintillator		
1 MeV	70.00%	68%	68%	0.35	0.36	0.38	35.00%	36.00%	38.00%
2 MeV	49.50%	48.80%	48.50%	0.29	0.59	0.59	14.25%	29.50%	29.50%
5 meV	20.00%	18.75%	17.00%	0.93	1.01	1.00	18.60%	20.20%	20.00%
10 MeV	1.80%	1.40%	1.80%	1.7	1.85	1.90	17.00%	18.50%	19.00%
15 MeV	0.18%	0.15%	0.36%	2.67	2.76	2.88	17.80%	18.40%	19.20%
20 MeV	6.00E-04	6.00E-04	9.00E-04	3.6	3.73	3.79	18.00%	18.65%	18.95%
maxstep	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm

Different G4step

Inefficiency corresponds to 0 p.e.

E_{dep} / Eγ



ADRIANO

SF57HHT (X0=1.5) 2-4mm, Scint. 2mm

2mm SF57HHT + 2mmSCSF81 Total layers=150x2 X0[cm]=1.5 Total[X0]=20 Depth[cm]=60

Egamma	Inefficiency			Edep in scintillator [MeV]			Efraction in scintillator			Cerenkov photons			No-Cerenkov probability		
1 MeV		68%	68%		0.35	0.35		34.50%	35.00%		20.8	21.3		1.60%	2.08%
2 MeV		52.20%	51.82%		0.58	0.6		28.75%	29.85%		57.3	56.9		0.70%	0.70%
5 meV		21.10%	24.50%		0.97	1.03		19.48%	20.60%		181	180		0.30%	0.40%
10 MeV		2.30%	3.30%		1.75	1.8		17.50%	18.00%		386	384		0.16%	0.10%
15 MeV		0.26%	0.64%		2.64	2.69		17.60%	17.93%		589	584		0.06%	0.08%
20 MeV		0.08%	0.10%		3.5	3.58		17.50%	17.90%		787	779		0.00%	0.04%
30 MeV		0.02%	0		5.3	5.38		17.67%	17.93%		1181	1152		0.00%	0
maxstep	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm

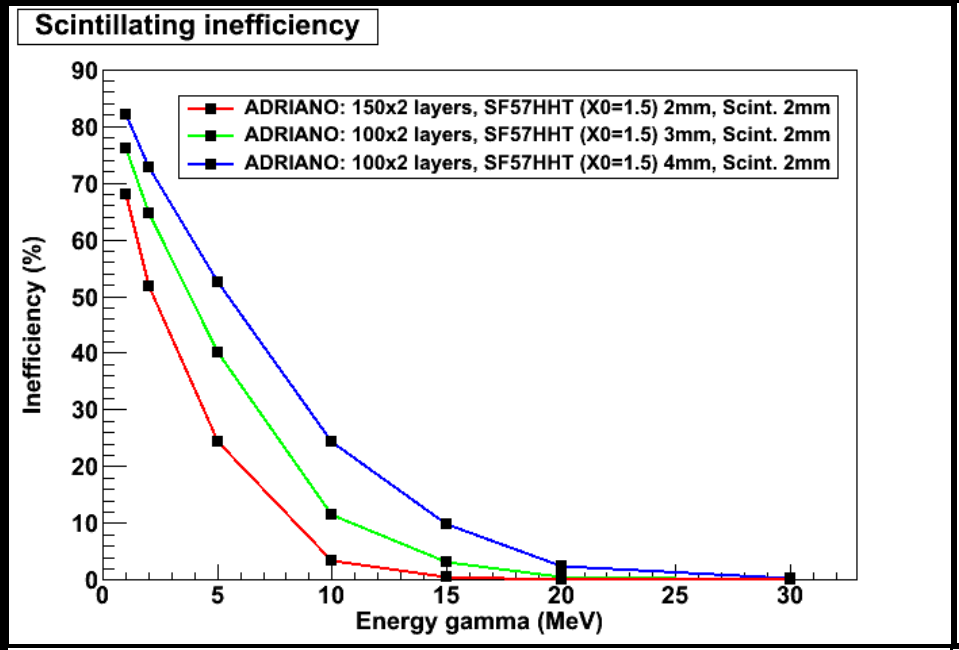
4mmSF57+2mmSCSF81 Total layers=100x2

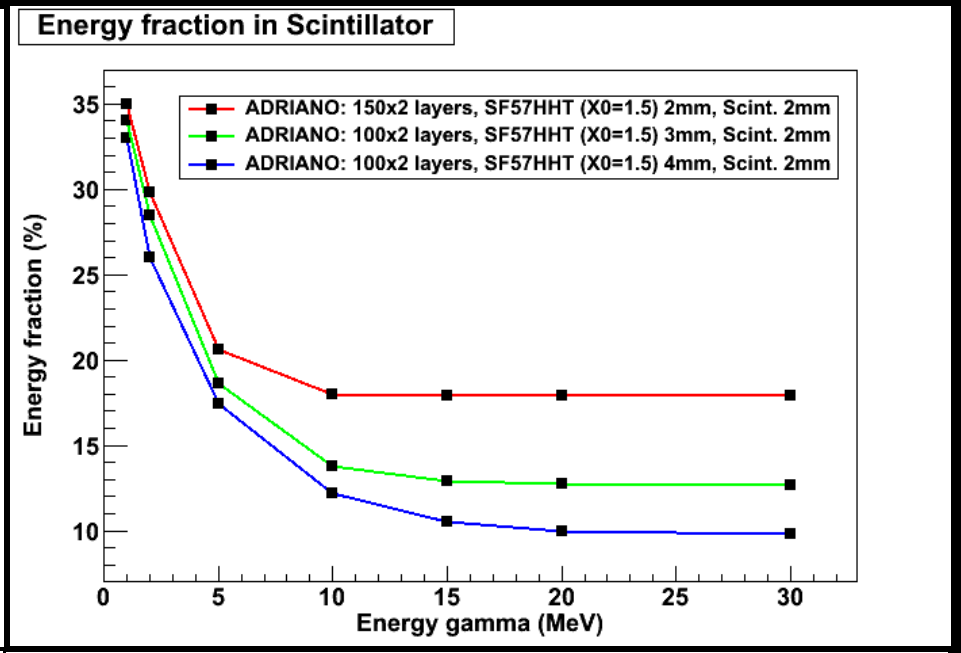
Egamma	Inefficiency			Edep in scintillator [MeV]			Efraction in scintillator			Cerenkov photons			No-Cerenkov probability		
1 MeV			82%			0.33			33.00%			21.6			1.30%
2 MeV			72.70%			0.52			26.00%			60			0.34%
5 meV			52.50%			0.87			17.40%			189			0.22%
10 MeV			24.30%			1.22			12.20%			408			0.04%
15 MeV			9.90%			1.58			10.53%			618			0.04%
20 MeV			2.36%			2			10.00%			827			0.02%
30 MeV			0.34%			2.93			9.77%			1233			0.06%
maxstep	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm			

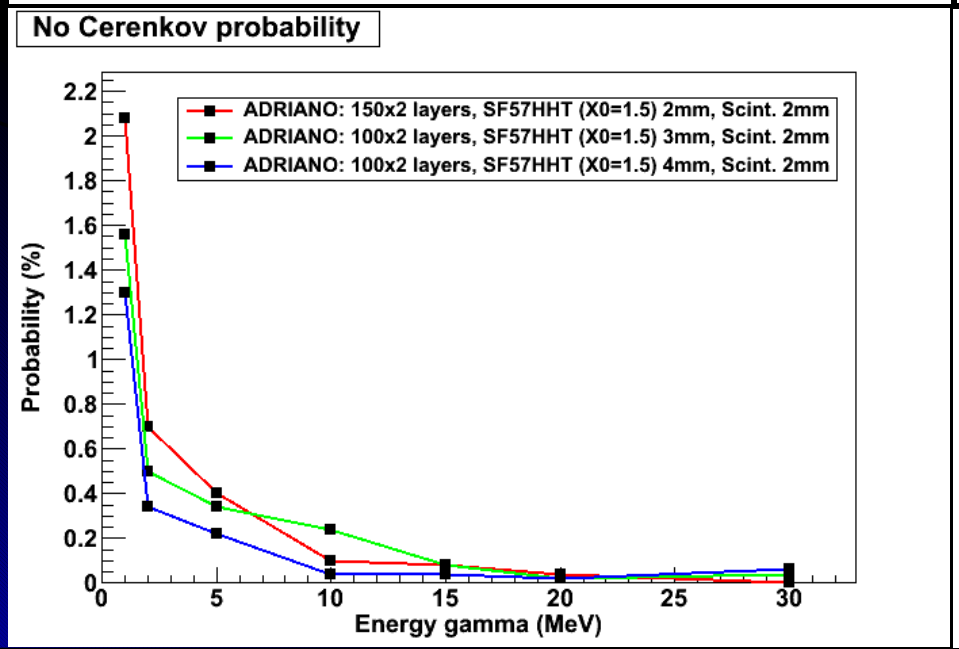
3mmSF57+2mmSCSF81 Total layers=100x2

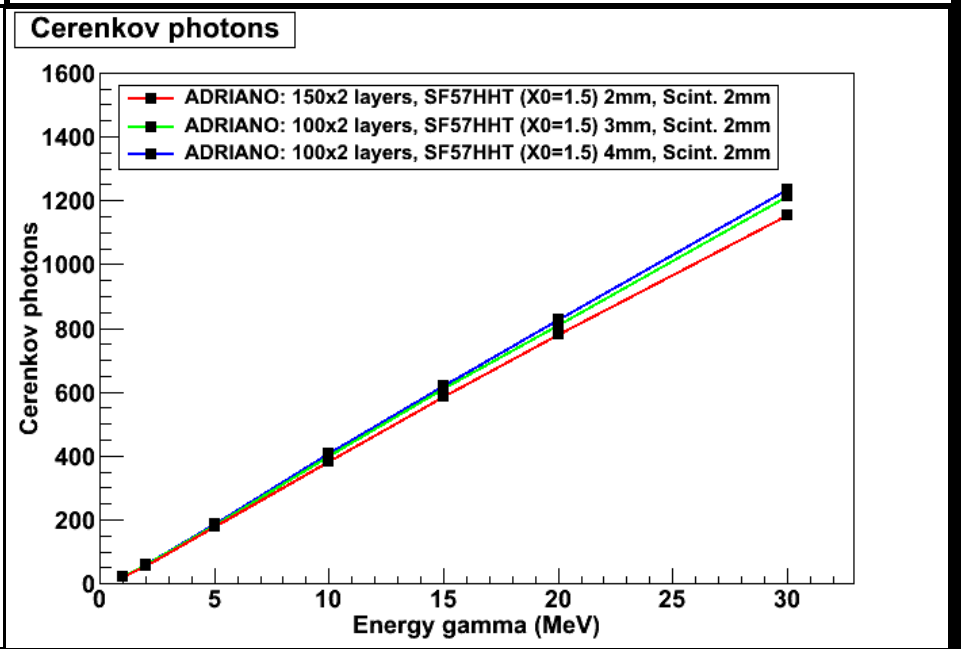
Egamma	Inefficiency			Edep in scintillator [MeV]			Efraction in scintillator			Cerenkov photons			No-Cerenkov probability		
1 MeV			76.06%			0.34			34.00%			21.5			1.56%
2 MeV			64.70%			0.57			28.50%			59			0.50%
5 meV			40.10%			0.93			18.60%			185			0.34%
10 MeV			11.50%			1.38			13.80%			398			0.24%
15 MeV			3.16%			1.93			12.87%			610			0.08%
20 MeV			0.64%			2.55			12.75%			811			0.02%
30 MeV			0.16%			3.81			12.70%			1214			0.04%
maxstep	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm			

ADRIANO SF57HHT (X0=1.5) 2-4mm, Scint. 2mm







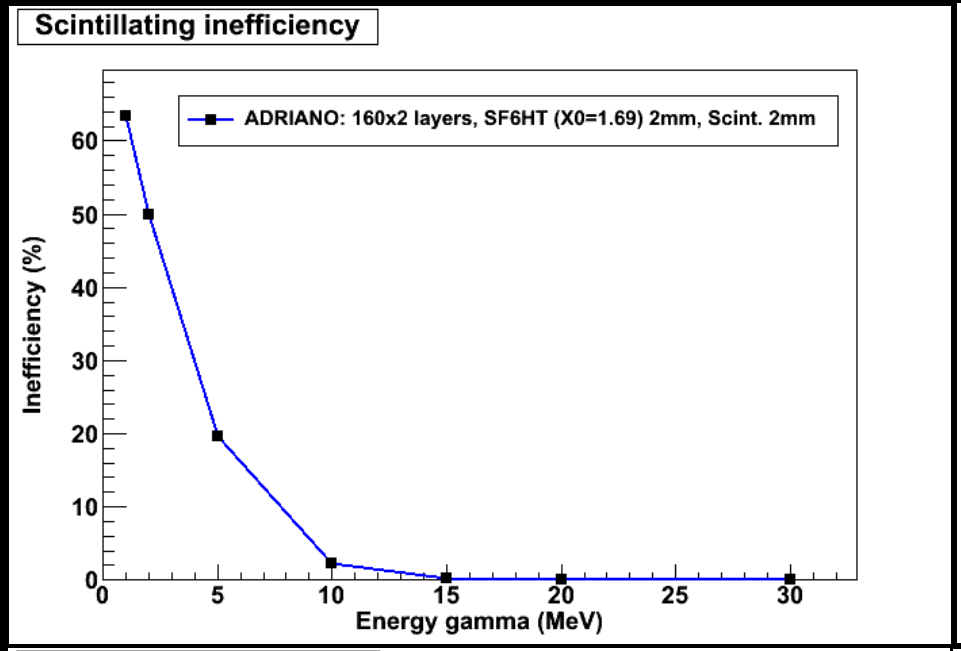


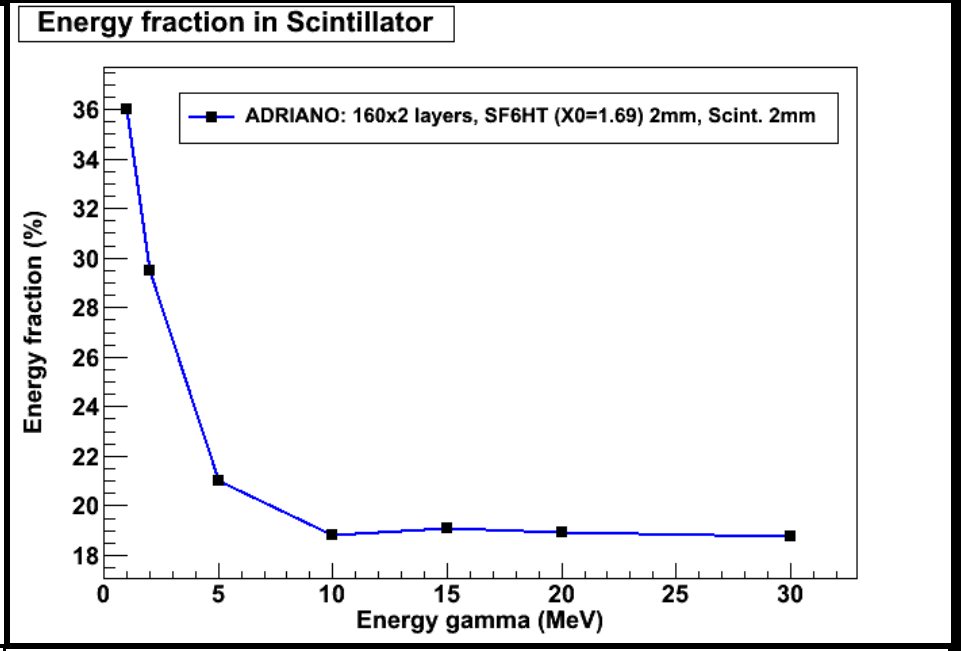
ADRIANO

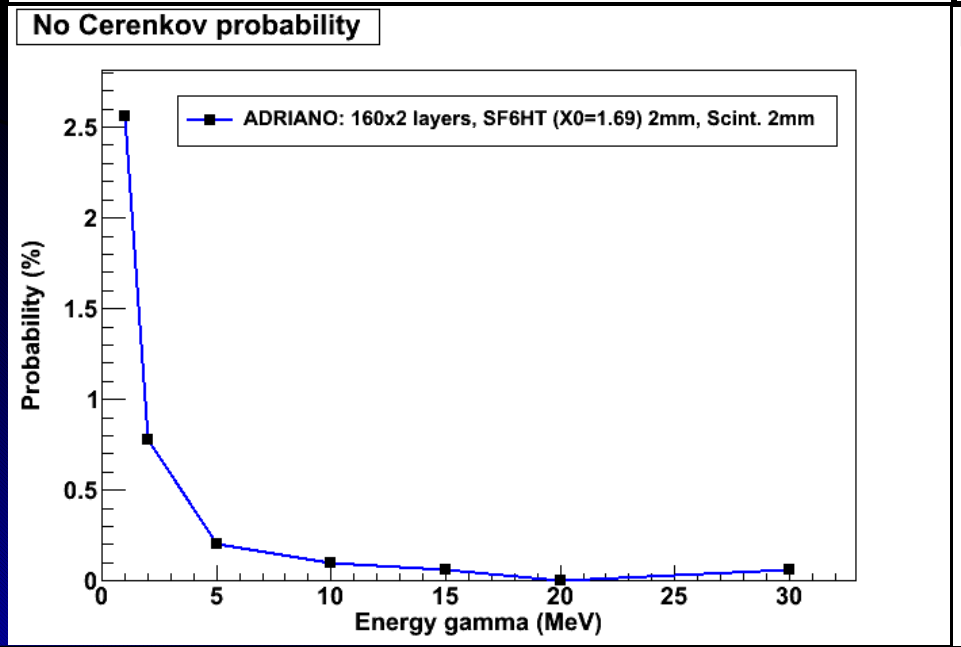
SF6HT (X0=1.69) 2mm, Scint. 2mm

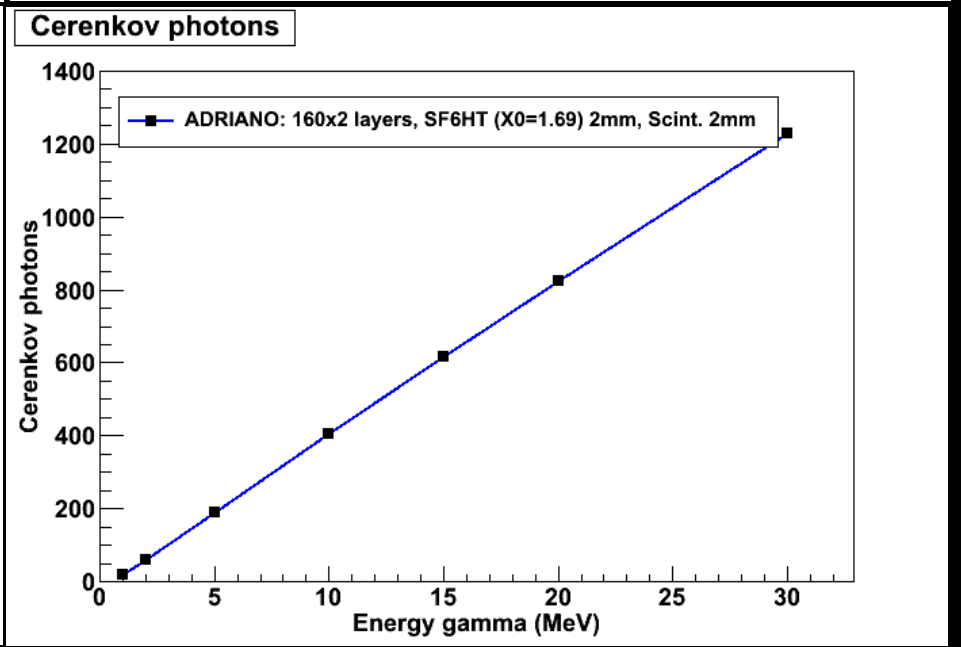
2mmSF6HT+2mmSCSF812mm Total layers=160x2 X0[cm]=1.69 Total[X0]=18.93 Depth[cm]=64												0		
Egamma	Inefficiency			Edep in scintillator [MeV]			Efraction in scintillator			Cerenkov photons			No-Cerenkov probability		
1 MeV			63.40%			0.36			36.00%			21.2			2.56%
2 MeV			49.96%			0.59			29.50%			60.1			0.78%
5 meV			19.60%			1.05			21.00%			189			0.20%
10 MeV			2.22%			1.88			18.80%			406			0.10%
15 MeV			0.24%			2.86			19.07%			617			0.06%
20 MeV			0.06%			3.79			18.95%			826			0.00%
30 MeV			0.14%			5.63			18.77%			1230			0.06%
maxstep	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm

ADRIANO SF6HT (X0=1.69) 2mm, Scint. 2mm







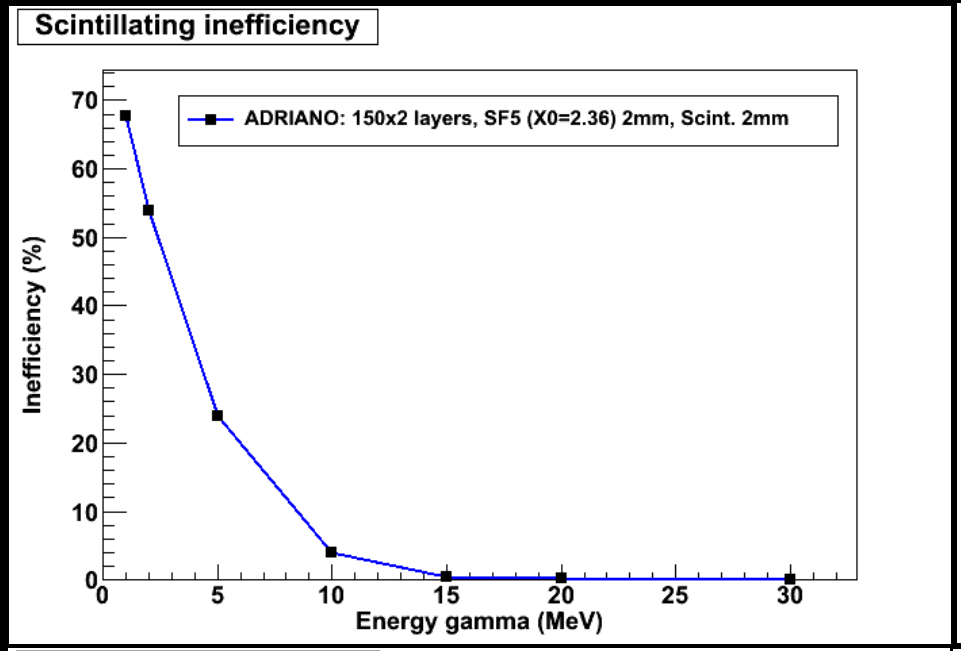


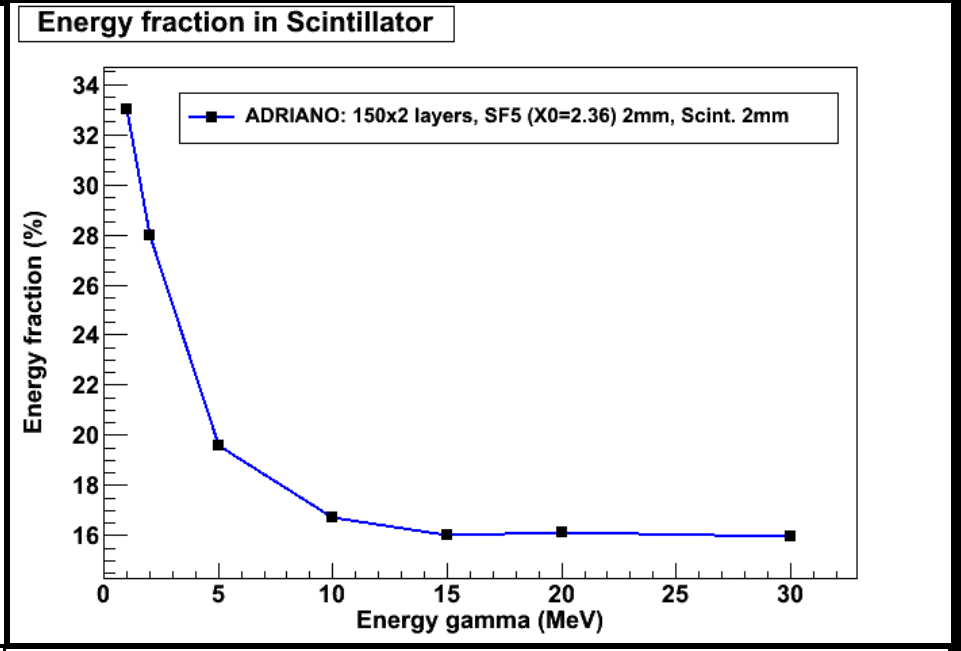
ADRIANO

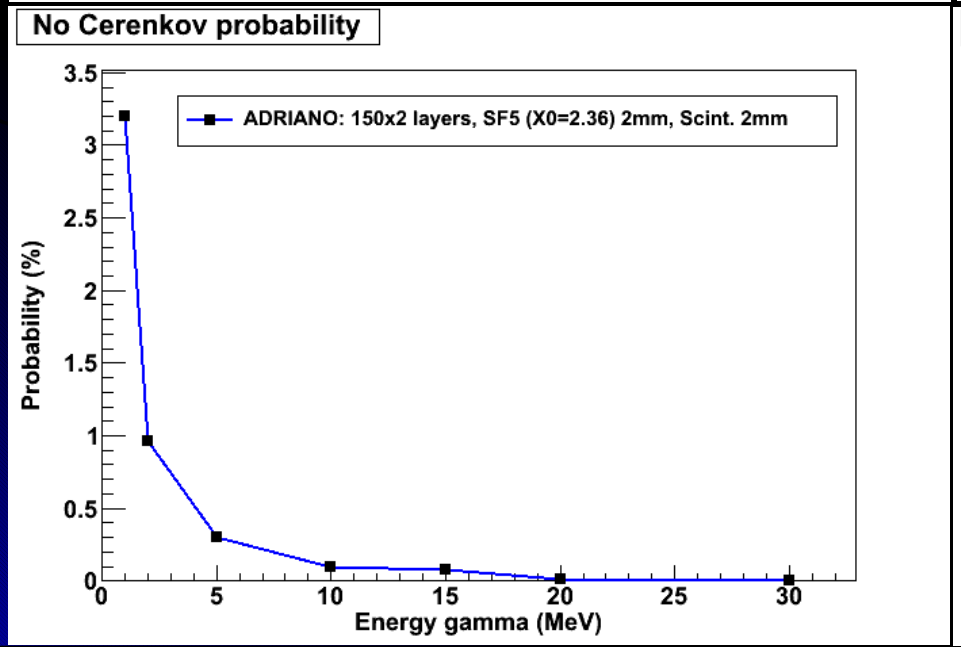
SF5 (X0=2.36) 3mm, Scint. 2mm

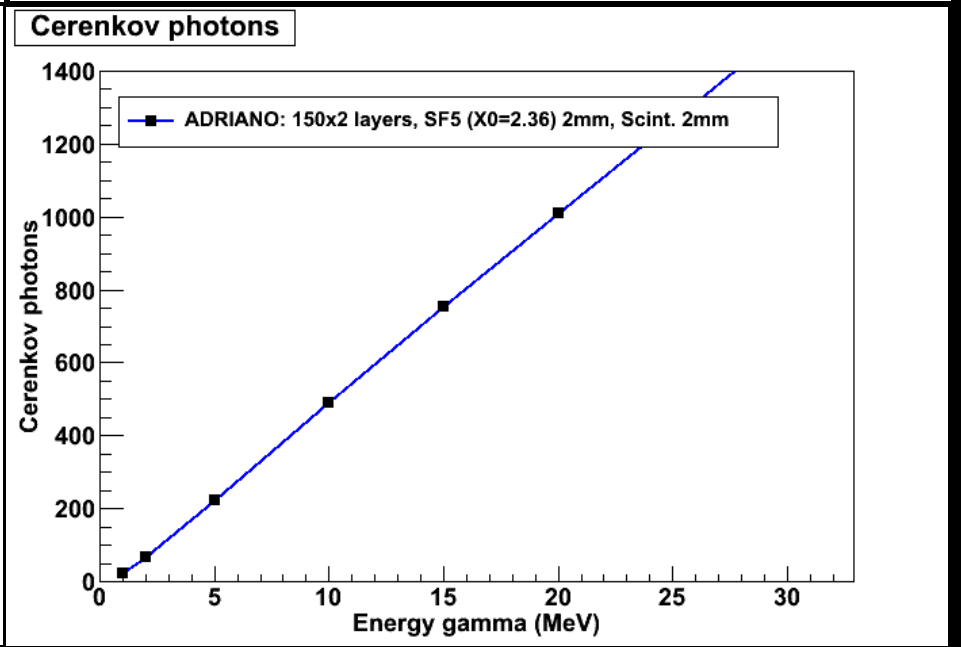
3mmSF5+2mmSCSF81 Total layers=150x2 X0[cm]=2.36 Total[X0]=19.07 Depth[cm]=75												0		
Egamma	Inefficiency			Edep in scintillator [MeV]			Efraction in scintillator			Cerenkov photons			No-Cerenkov probability		
1 MeV			67.70%			0.33			33.00%			22.6			3.20%
2 MeV			53.88%			0.56			28.00%			67.7			0.96%
5 meV			24.00%			0.98			19.60%			224			0.30%
10 MeV			4.06%			1.67			16.70%			491			0.10%
15 MeV			0.40%			2.4			16.00%			754			0.08%
20 MeV			0.16%			3.23			16.15%			1011			0.01%
30 MeV			0.00%			4.79			15.97%			1514			0%
maxstep	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm

ADRIANO SF5 (X0=2.36) 3mm, Scint. 2mm







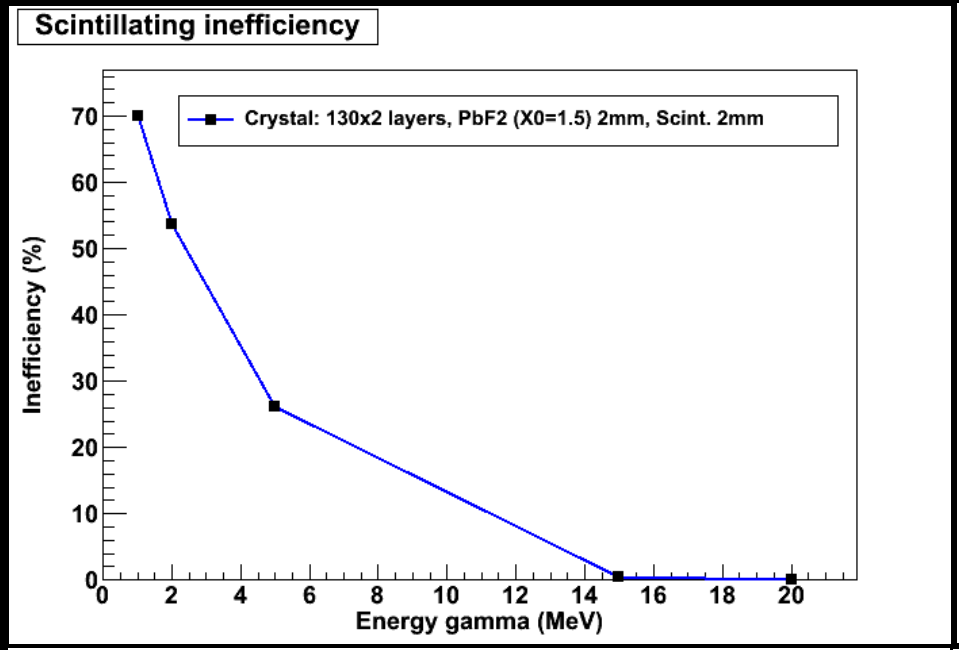


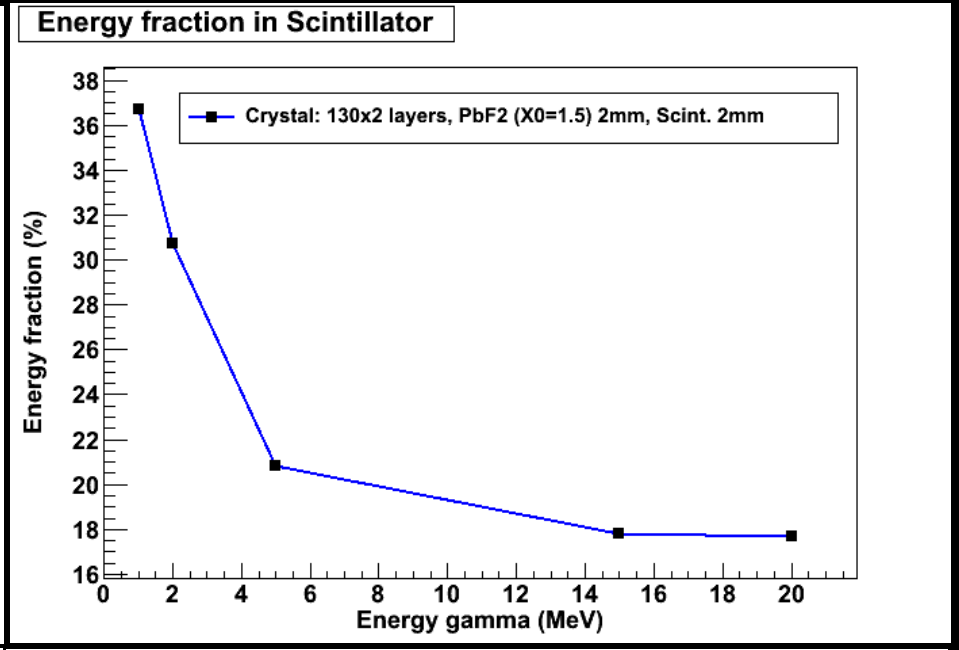
Crystal

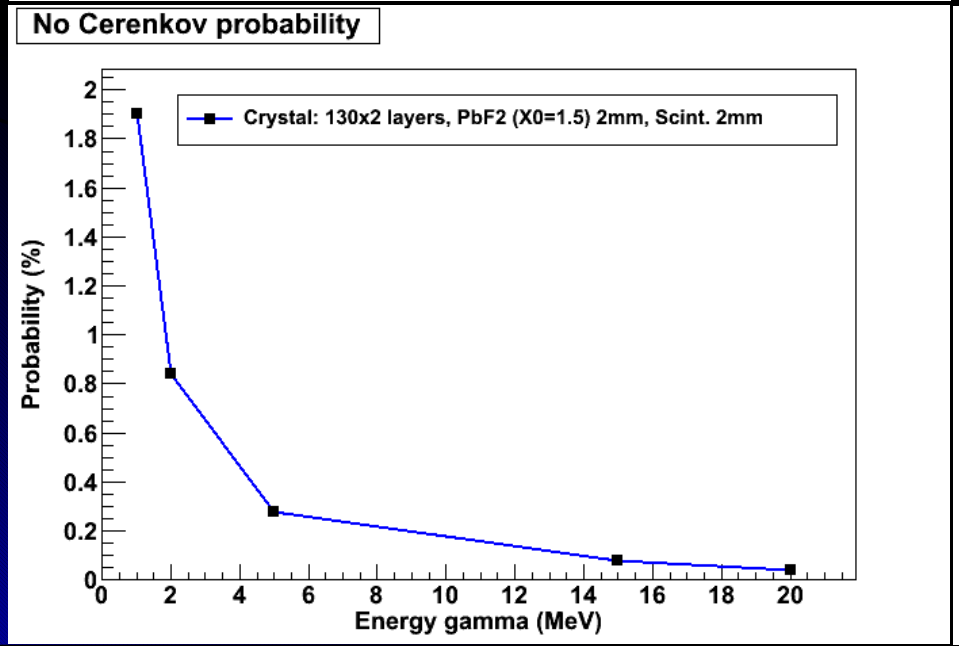
PbF2 (X0=0.93) 1.5mm, Scint. 2mm

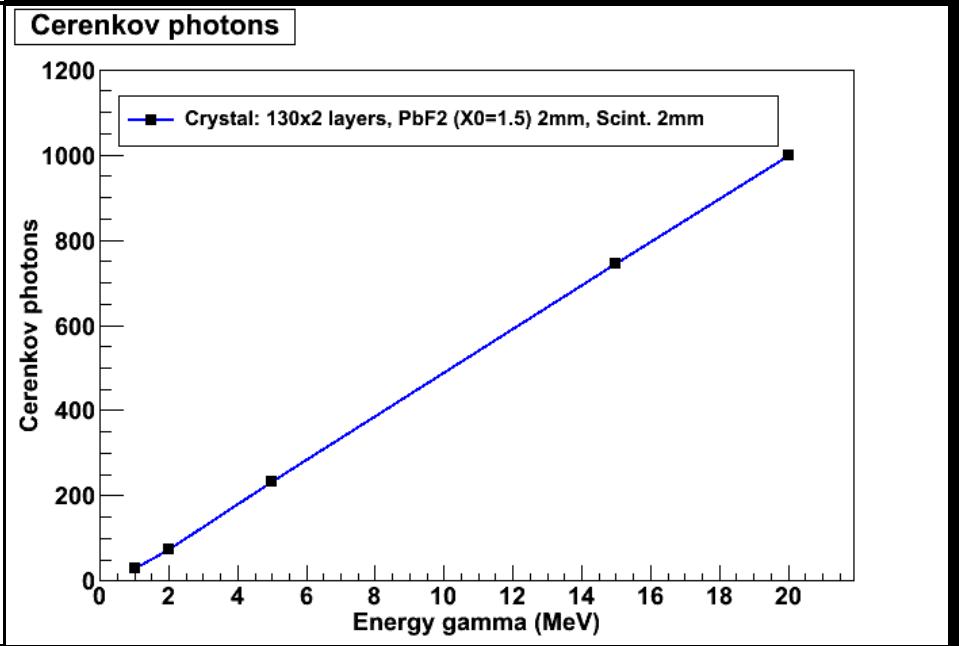
1.5mmPbF2+2mmSCSF81 Total layers=130x2 X0[cm]=0.93 Total[X0]=20.97 Depth[cm]=45.5															0
Egamma	Inefficiency			Edep in scintillator [MeV]			Efraction in scintillator			Cerenkov photons			No-Cerenkov probability		
1 MeV			70%			0.37			36.70%			29			1.90%
2 MeV			53.60%			0.62			30.75%			74			0.84%
5 meV			26.20%			1.04			20.80%			233			0.28%
10 MeV									0.00%						
15 MeV			0.46%			2.67			17.80%			746			0.08%
20 MeV			0.12%			3.54			17.70%			998			0.04%
30 MeV									0.00%						
maxstep	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm	0.05mm	0.005mm	0.001mm

Crystal PbF2 (X0=0.93) 1.5mm, Scint. 2mm

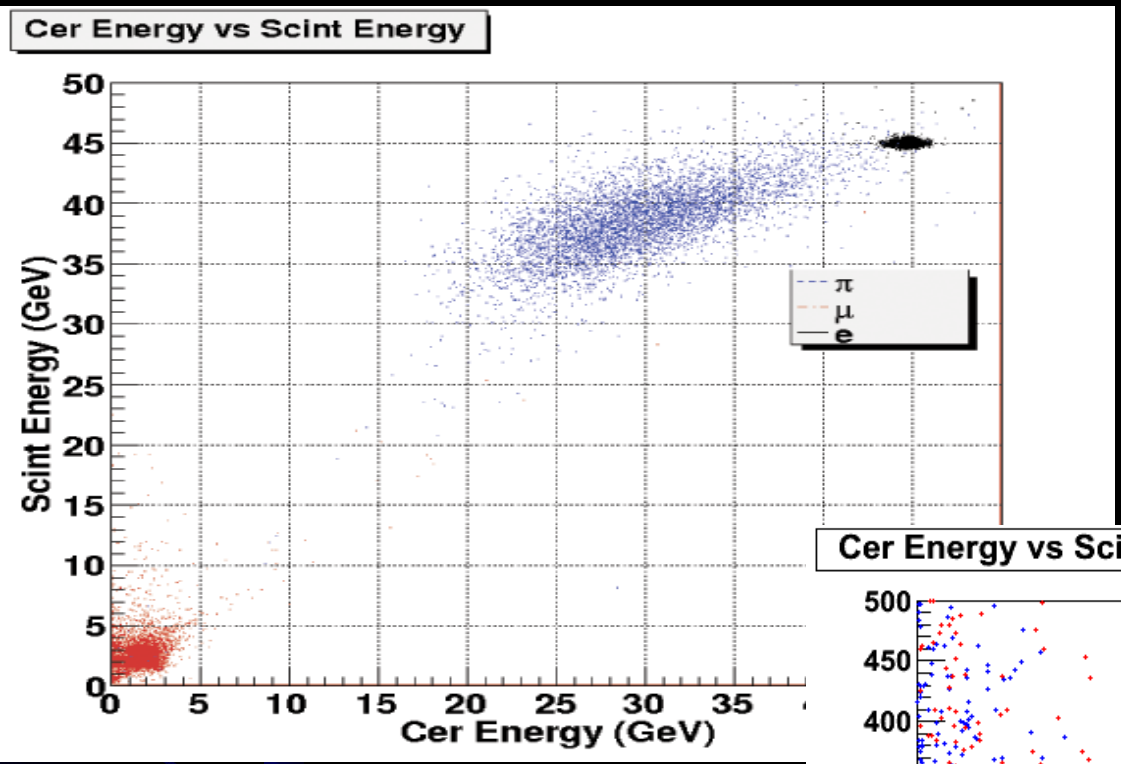


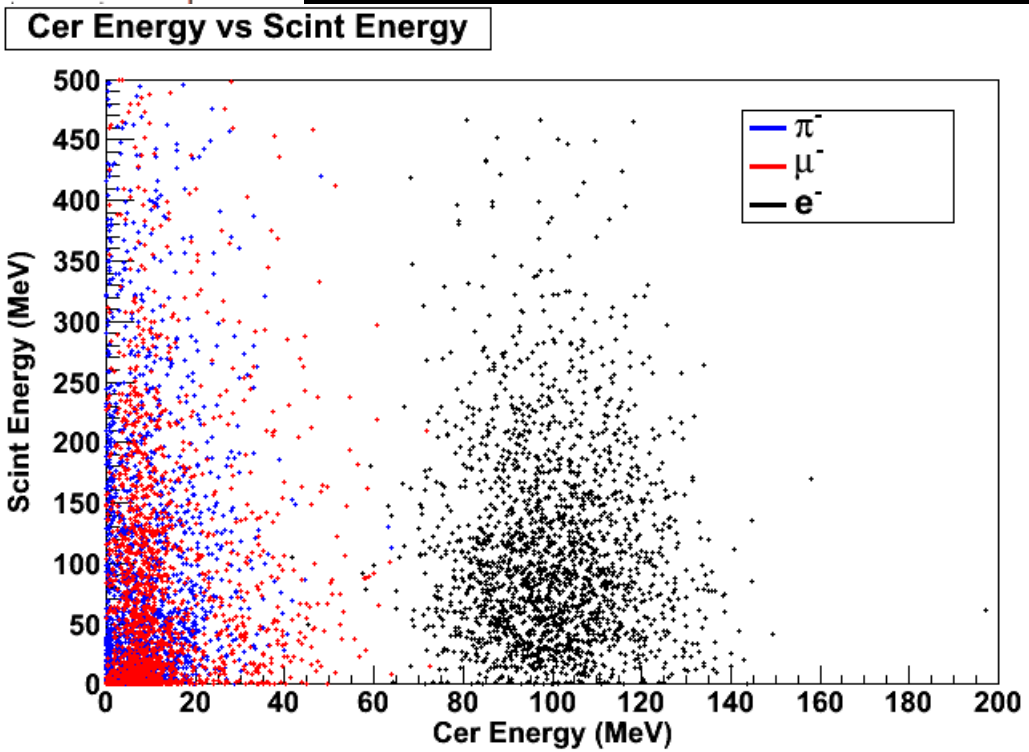






PID


Cer Energy vs Scint Energy
Scint Energy (GeV)
Cer Energy (GeV)
π
μ
e


Cer Energy vs Scint Energy
Scint Energy (MeV)
Cer Energy (MeV)
π⁻
μ⁻
e⁻