ADRIANO technology for ORKA: updated studies

Anna Mazzacane

ORKA meeting July 27 2012 Fermilab

Outline

- ***Photonuclear reactions issues in Geant4***
- ***Update on efficiency and resolution studies***
  - ***Increased statistics***
  - ***More layouts***
- ***Particle ID with dual-readout ADRIANO***
- ***Timing studies***
  - ***Dual readout vs single readout***
  - ***Fast fibers vs slow fibers***

What's New wrt PXPS12

- ***Introduced parameters for green scintillator***
- ***Added absorption length for Cerenkov WLS***
- ***Added timing to simulations***
- ***Extended energy range: 1 MeV – 50 MeV***
- ***More statistics***
- ***Single readout ADRIANO with radial layout***

However:

- ***Radial layout still has longitudinal sampling***

  (should not affect present studies)

Photonuclear reactions issues in Geant4

Photonuclear reactions in G4

The photonuclear cross sections parameterized in the G4PhotoNuclearCrossSection class cover all incident photon energies from the hadron production threshold upward. The parameterization is subdivided into five energy regions, each corresponding to the physical process that dominates it.

- The Giant Dipole Resonance (GDR) region, depending on the nucleus, extends from 10 Mev up to 30 MeV. It usually consists of one large peak, though for some nuclei several peaks appear.
- The ``quasi-deuteron'' region extends from around 30 MeV up to the pion threshold and is characterized by small cross sections and a broad, low peak.
- The Δ region is characterized by the dominant peak in the cross section which extends from the pion threshold to 450 MeV.
- The Roper resonance region extends from roughly 450 MeV to 1.2 GeV. The cross section in this region is not strictly identified with the real Roper resonance because other processes also occur in this region.
- The Reggeon-Pomeron region extends upward from 1.2 GeV.

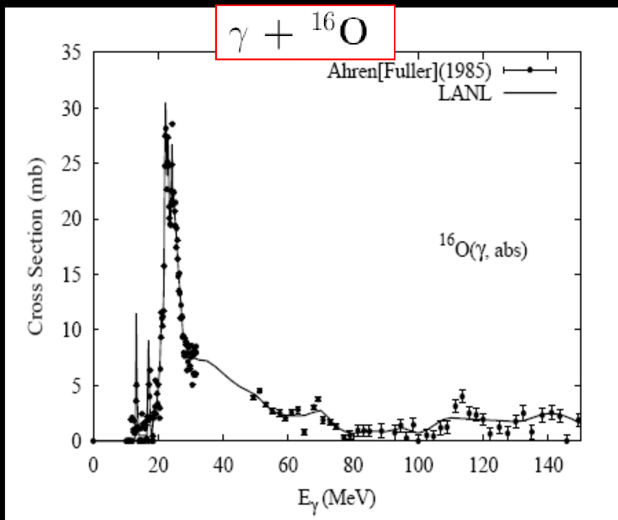
In the GEANT4 photonuclear data base there are about 50 nuclei for which the photonuclear absorption cross sections have been measured in the above energy ranges. For low energies this number could be enlarged, because for heavy nuclei the neutron photoproduction cross section is close to the total photo-absorption cross section. Currently, however, 14 nuclei are used in the parameterization: ^{1}H, ^{2}H, ^{4}He, ^{6}Li, ^{7}Li, ^{9}Be, ^{12}C, ^{16}O, ^{27}Al, ^{40}Ca, Cu, Sn, Pb, and U. The resulting cross section is a function of A and $e = log(E_\gamma)$, where E_γ is the energy of the incident photon. This function is the sum of the components which parameterize each energy region.

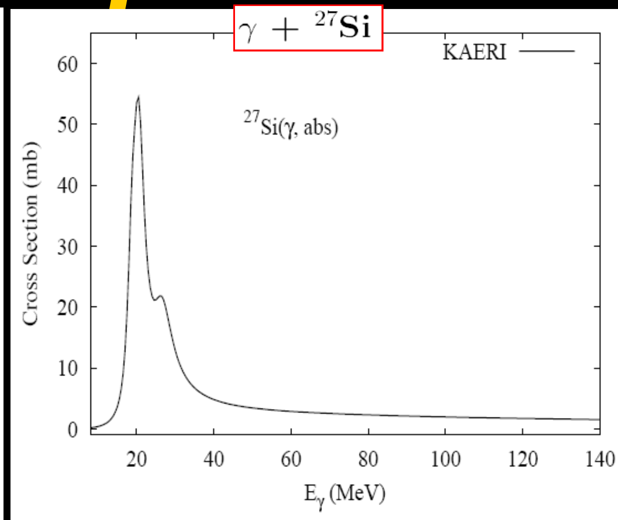
of interest for ORKA

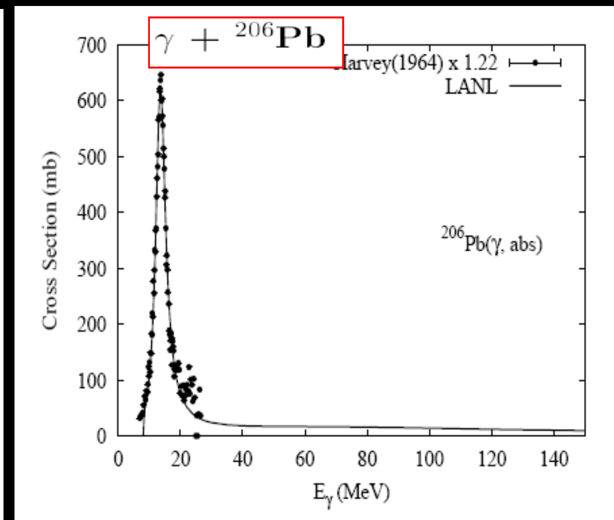
Approximation of photonuclear Cross Sections

http://geant4.cern.ch/G4UsersDocuments/UsersGuides/PhysicsReferenceManual/html/node75.html

What to expect in ADRIANO







- *SF57 composition (w/w)*
  - *69% Pb*
  - *19% O*
  - *11% Si*
  - *1% low Z atoms*

- *SF57 atomic proportions*
  - *Pb : O : Si = 1 : 3.5 : 1.2*

- $\sigma^{1}_{photonuclear}$ *[mbarn]*
  - *Pb : O : Si = 348 : 14.5 : 1.2*

Probability of Photonuclear interaction in ADRIANO (30 cm SF57)

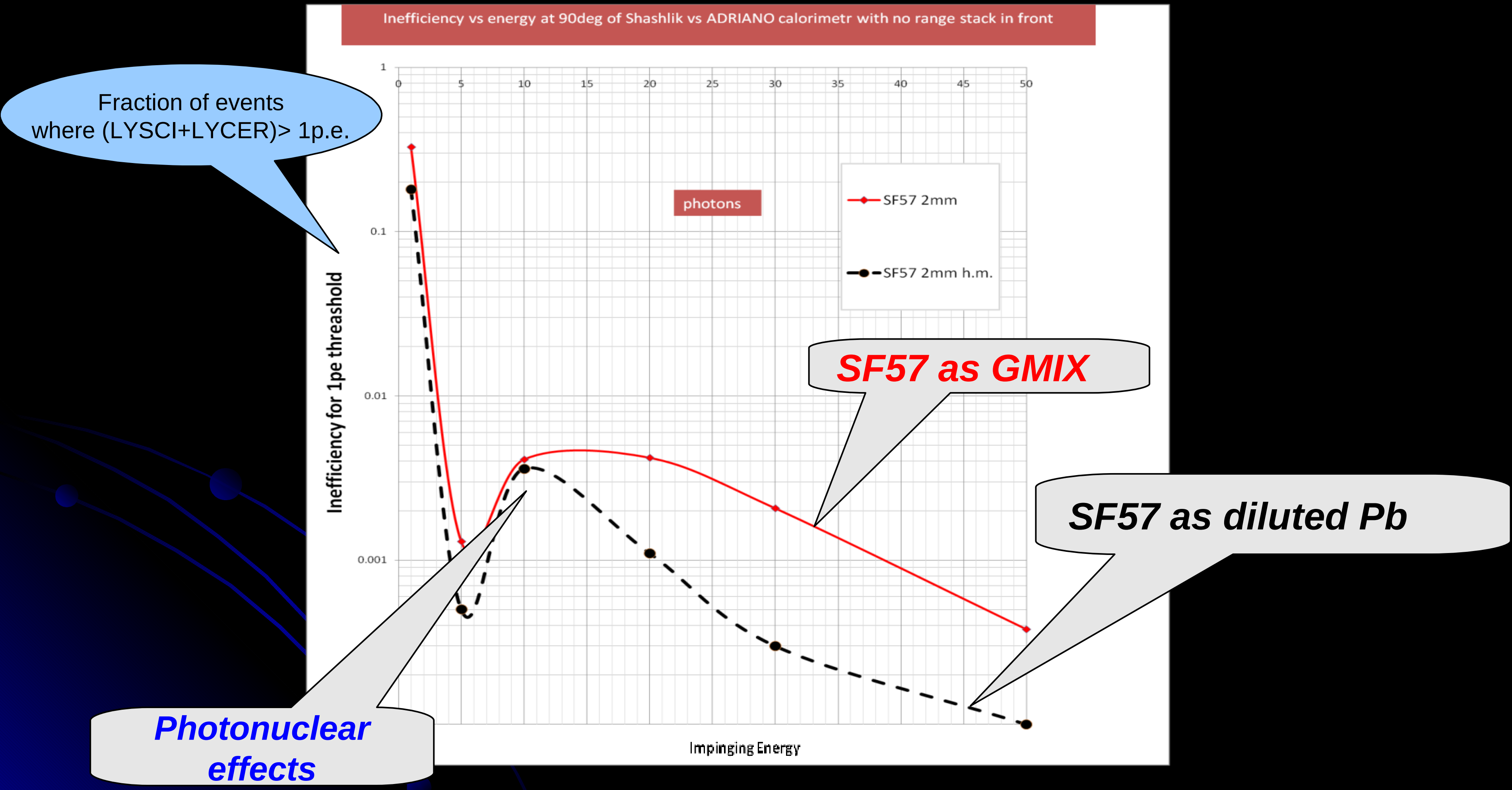
Pb: 1.2%

O: 0.15%

Si: 0.08%

Discovered a Possible Problem in GEANT4

Prob(Pb) ~ Prob (O) (from code debugging)



Check with MARS

Sergei S. accepted to make studies with MARS

MARS15 CODE INTRODUCTION

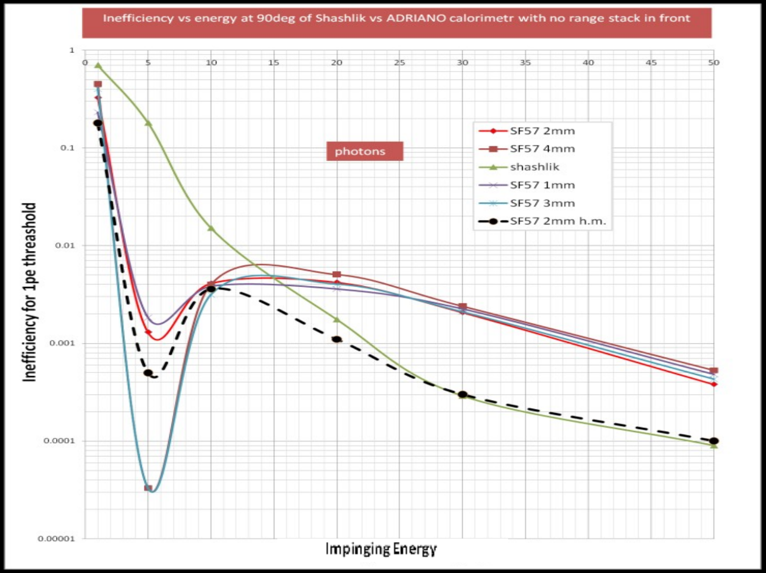
The MARS code system is a set of Monte Carlo programs for detailed simulation of hadronic and electromagnetic cascades in an arbitrary 3-D geometry of shielding, accelerator, detector and spacecraft components with energy ranging from a fraction of an electronvolt up to 100 TeV. It has been developed since 1974 at IHEP, SSCL and Fermilab. The current MARS15 version combines the well established theoretical models for strong, weak and electromagnetic interactions of hadrons, heavy ions and leptons with a system which can contain up to 105 objects, ranging in dimensions from microns to hundreds kilometers. A setup can be made of up to 100 composite materials, with arbitrary 3-D magnetic and electric fields. Powerful 2-D and 3-D user-friendly GUIis used for visualization of the geometry, materials, fields, particle trajectories and results of calculations. MARS15 has 5 geometry options and flexible histograming options, can use as an input MAD optics files through a powerful MAD-MARS Beam Line Builder, and provides an MPI-based multiprocessing option, with various biasing and other variance reduction techniques.

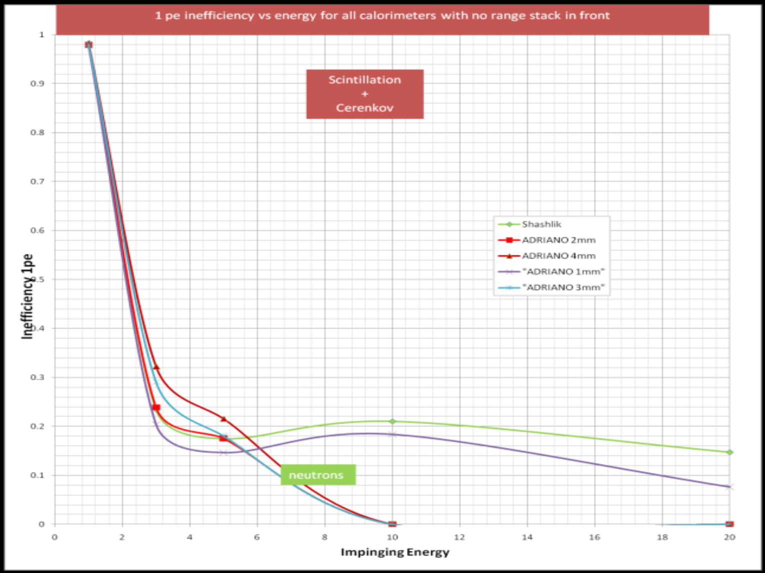
Targetry Wkshp, Oak Ridge, Oct. 10-14, 2005 MARS15 Code - N.V. Mokhov

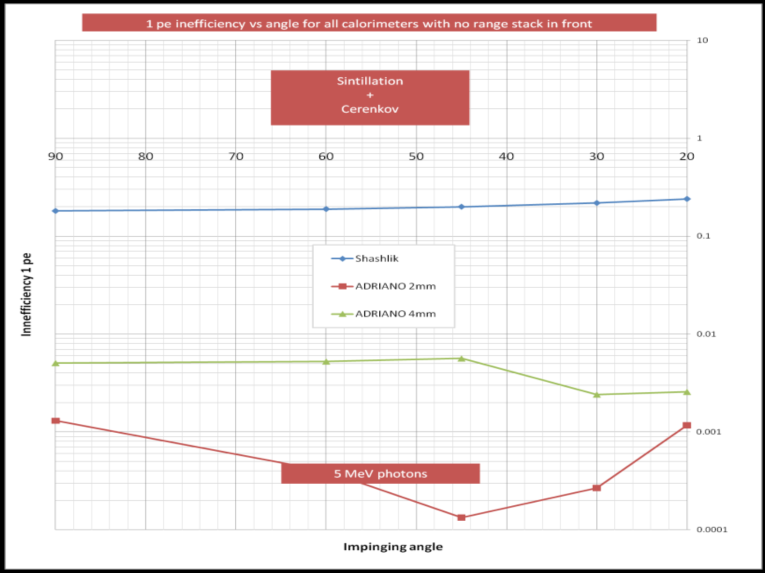
New release of MARS15 available since February 2011 at Fermilab (N. Mokhov, S. Striganov, see www-ap.fnal.gov/MARS)

Update on efficiency and resolution studies

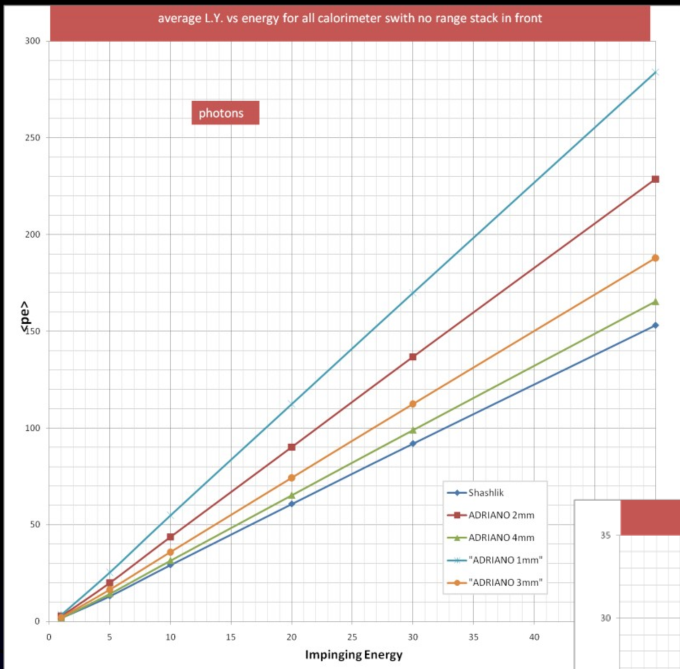
Summary of studies: 1pe Inefficiency
(S only for Shashlyk, S+C for ADRIANO)

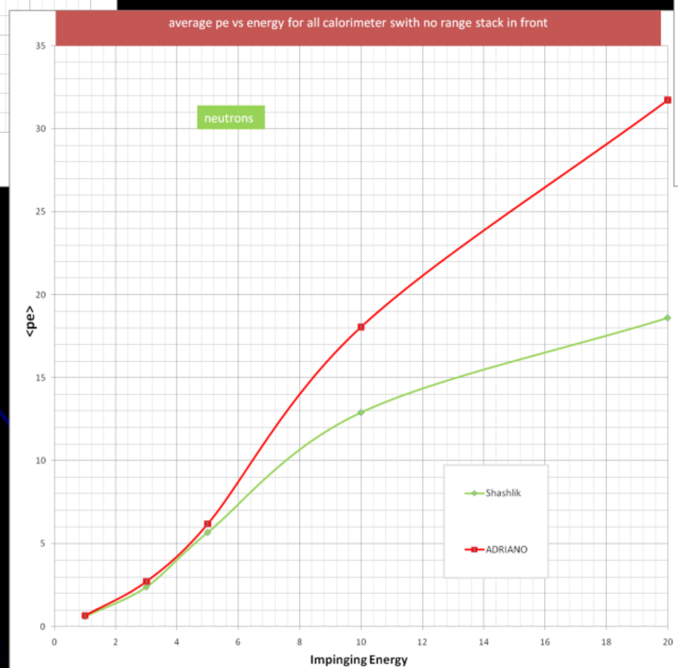


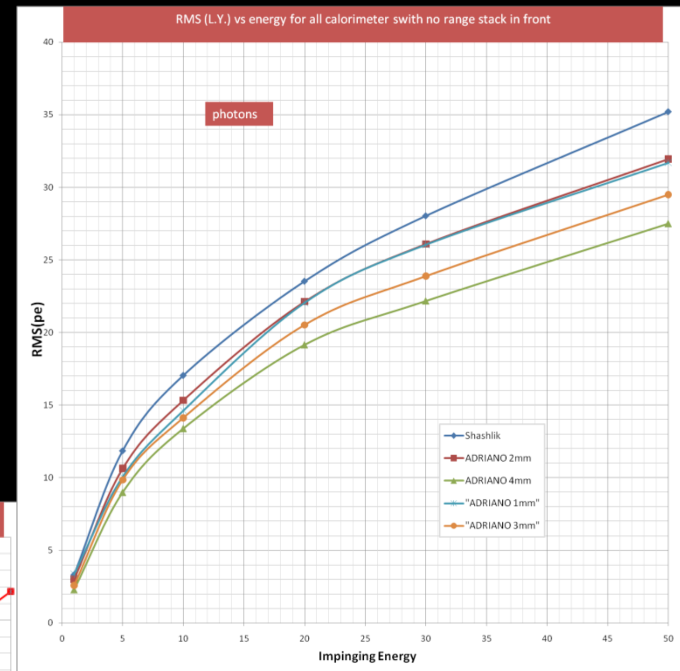




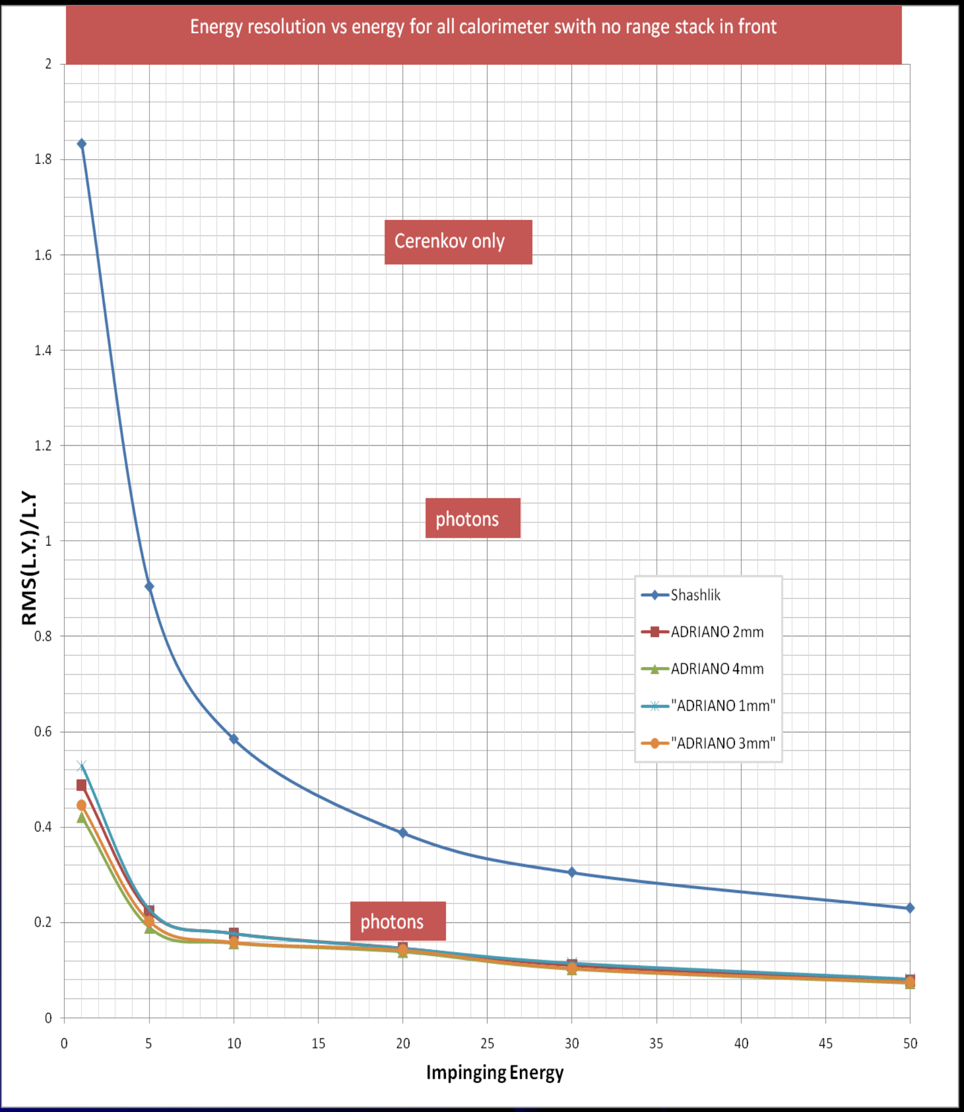
Summary of studies: Light Yield
(S only for Shashlyk, S+C for ADRIANO)

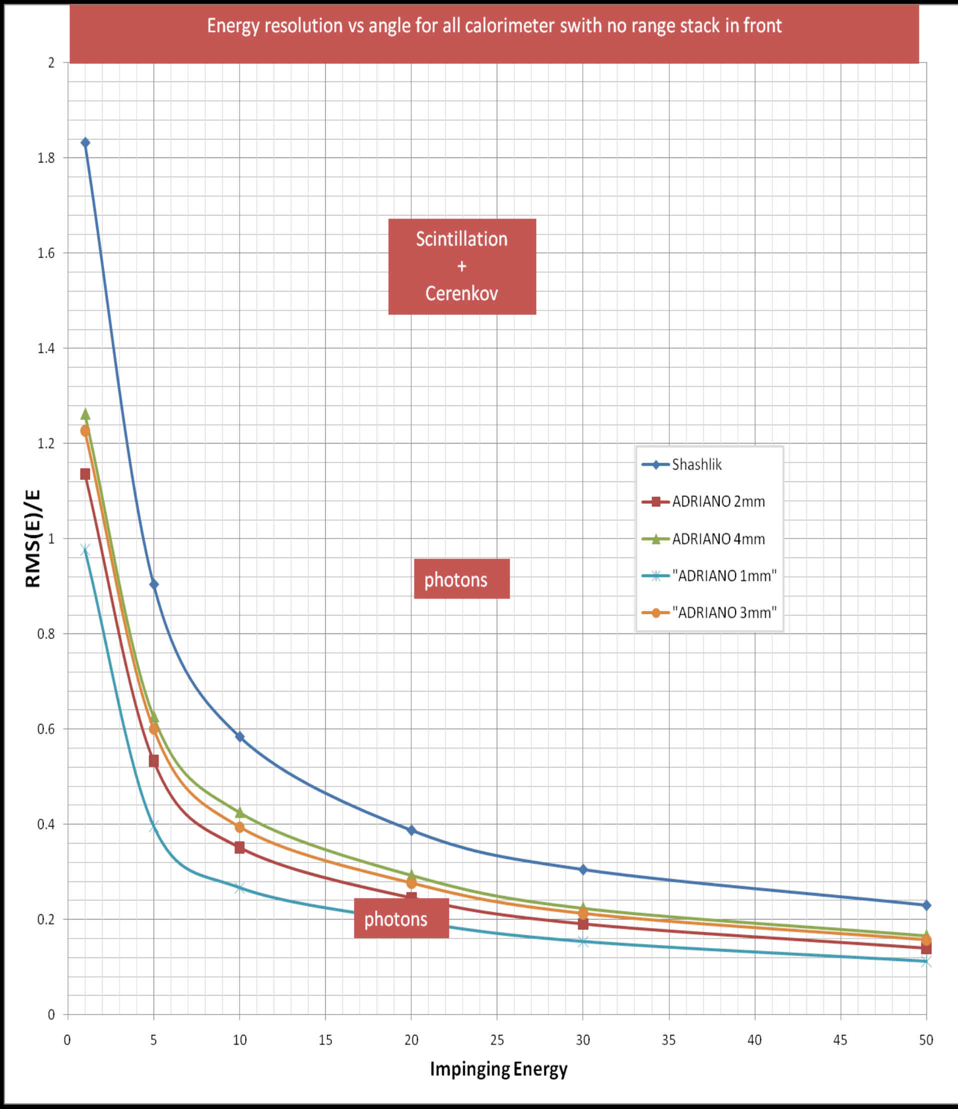






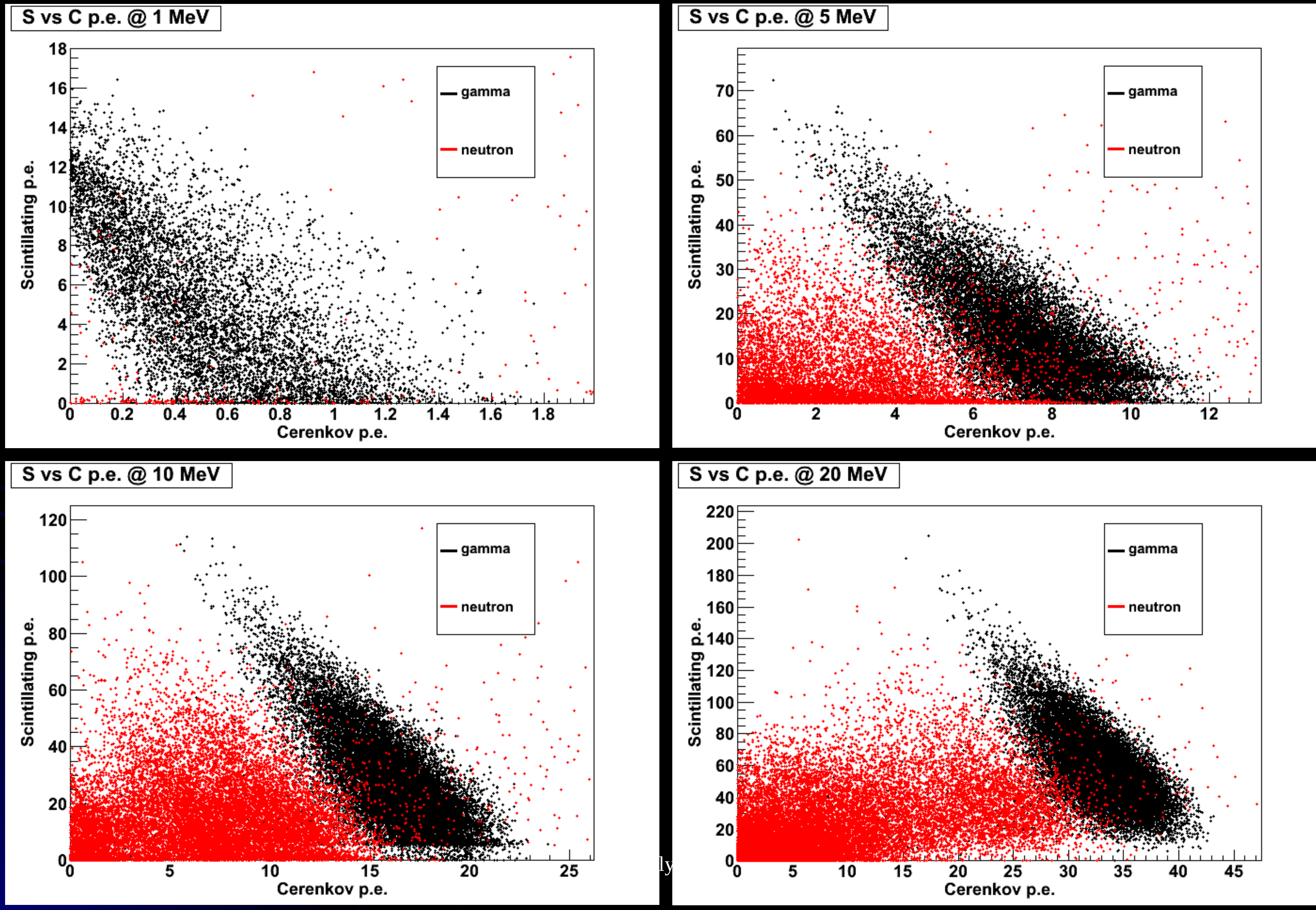
Summary of studies: Energy Resolution



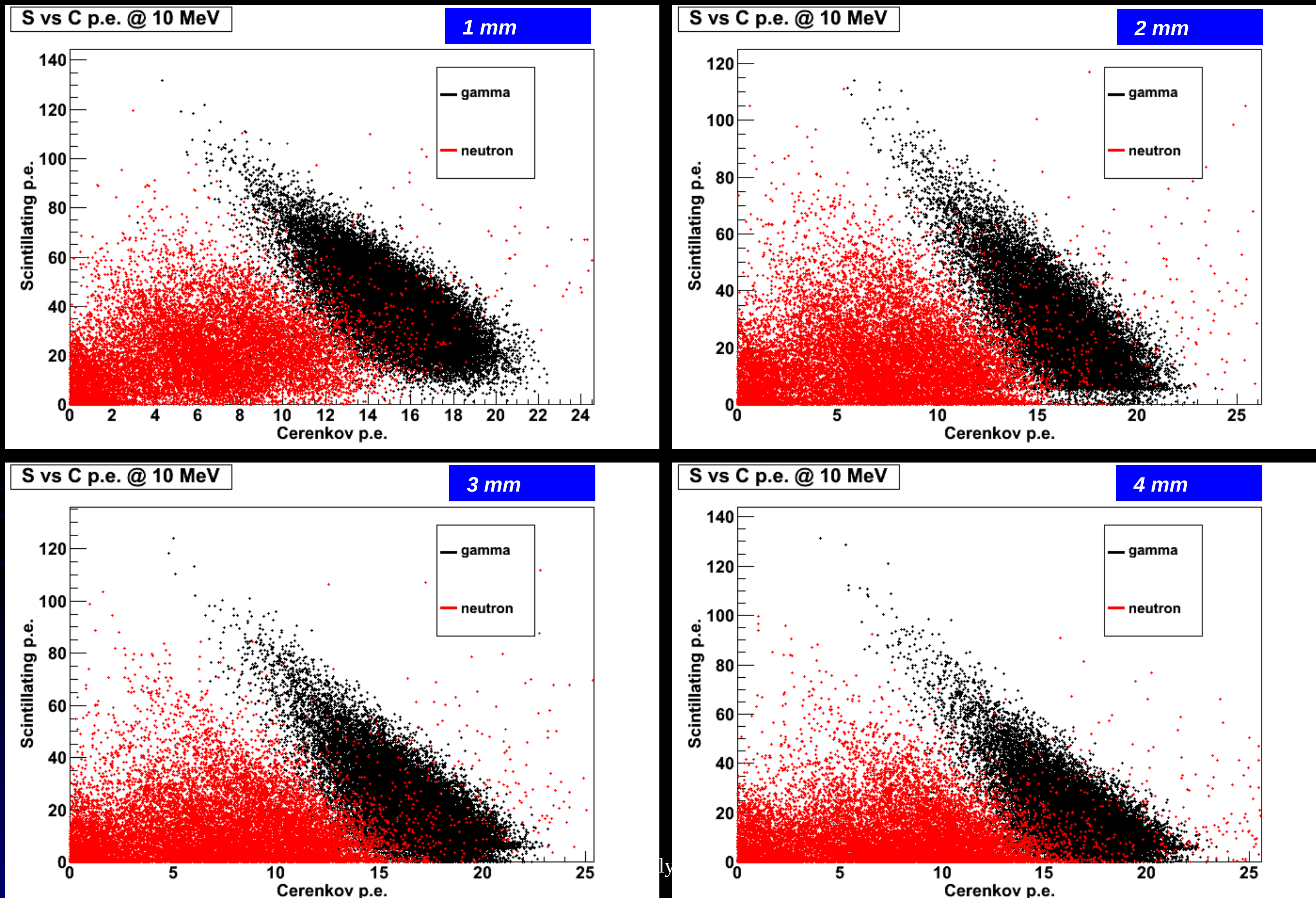


Particle ID with dual-readout ADRIANO

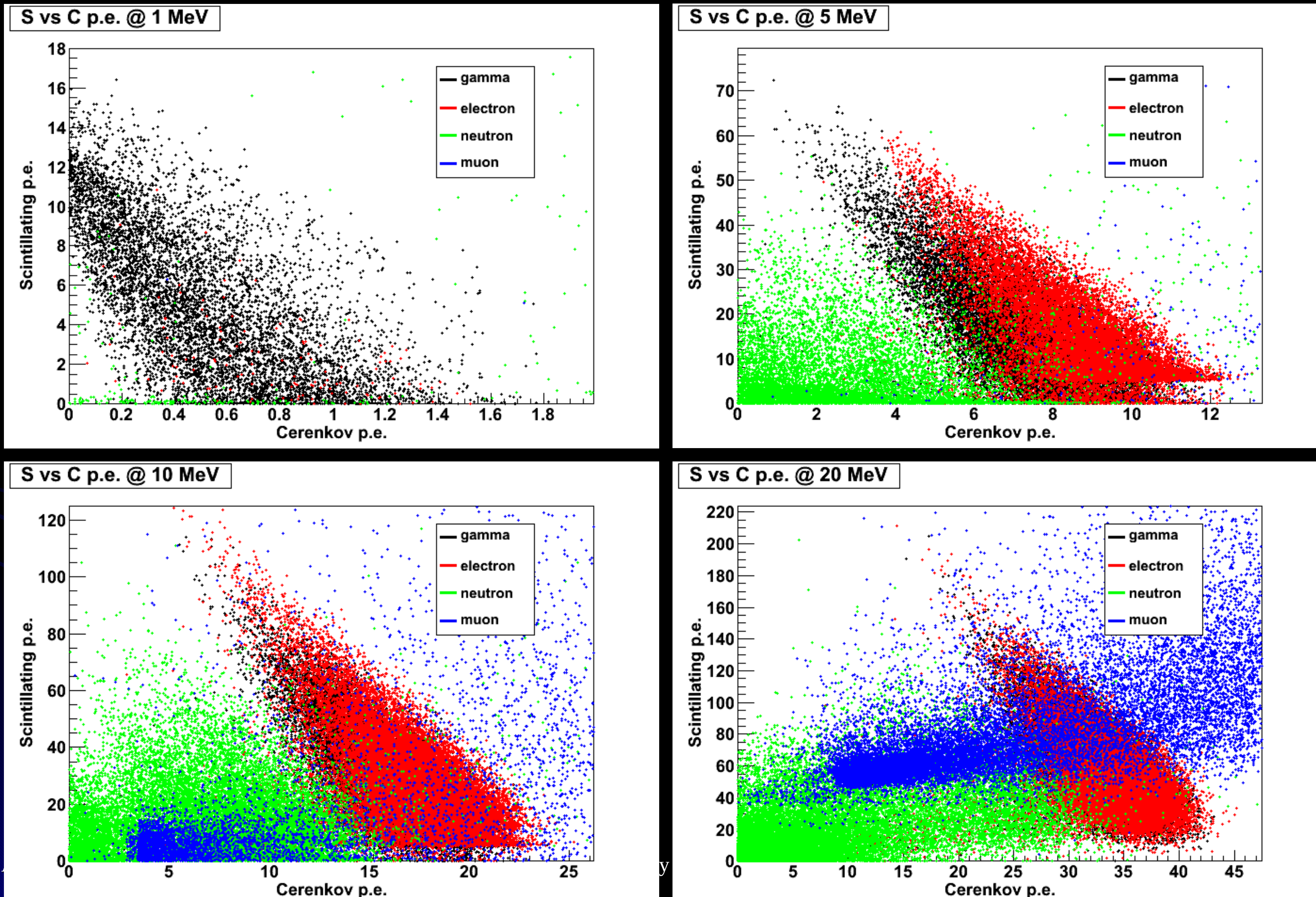
Gamma vs neutron: 2mm glass



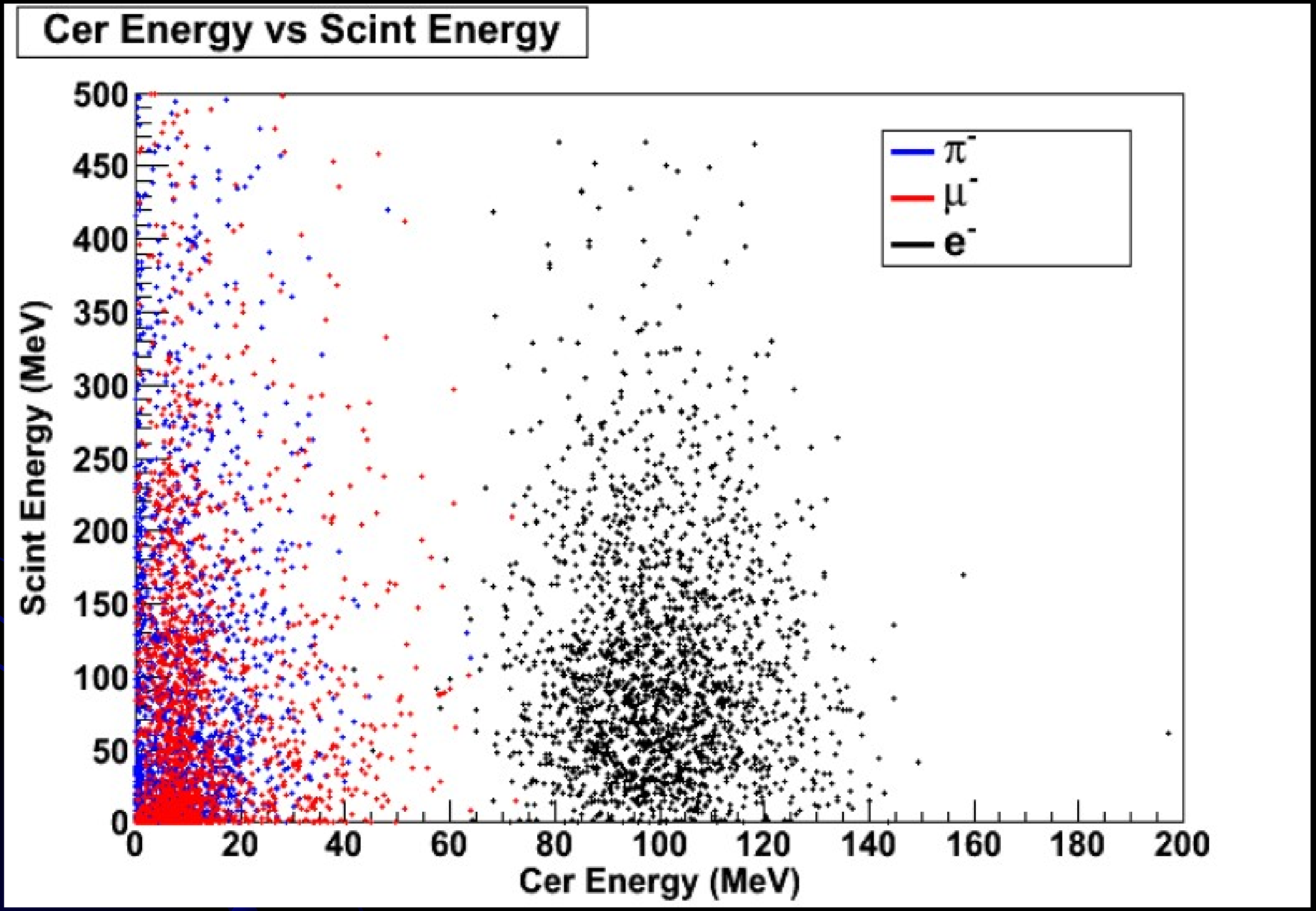
10 MeV: 1mm through 4 mm glass



All particles: 2mm glass

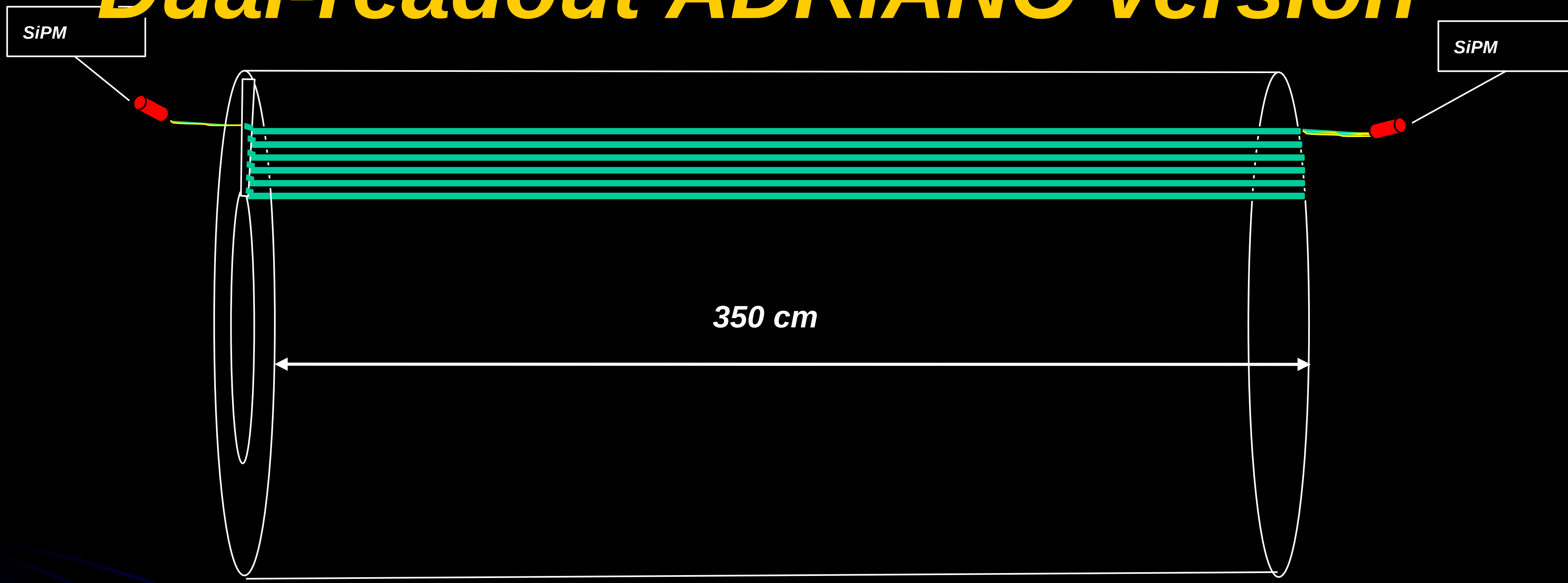


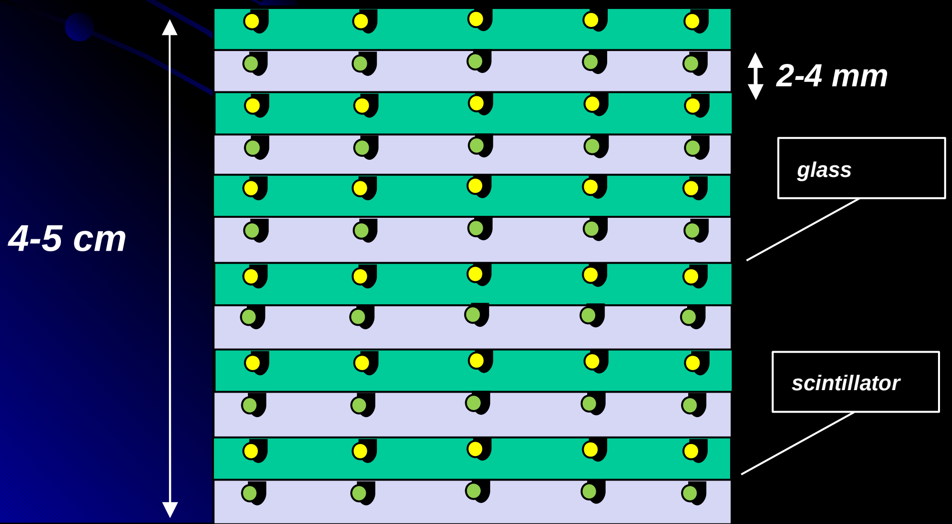
Particle Identification in Dual Readout Calorimeters at 100 MeV



Timing studies

Dual-readout ADRIANO version





- *Glass optically de-coupled from scintillator*
- *Blue fast scintillator*
- *Separated WLS's for glass and scintillator*
- *Two sides readout*

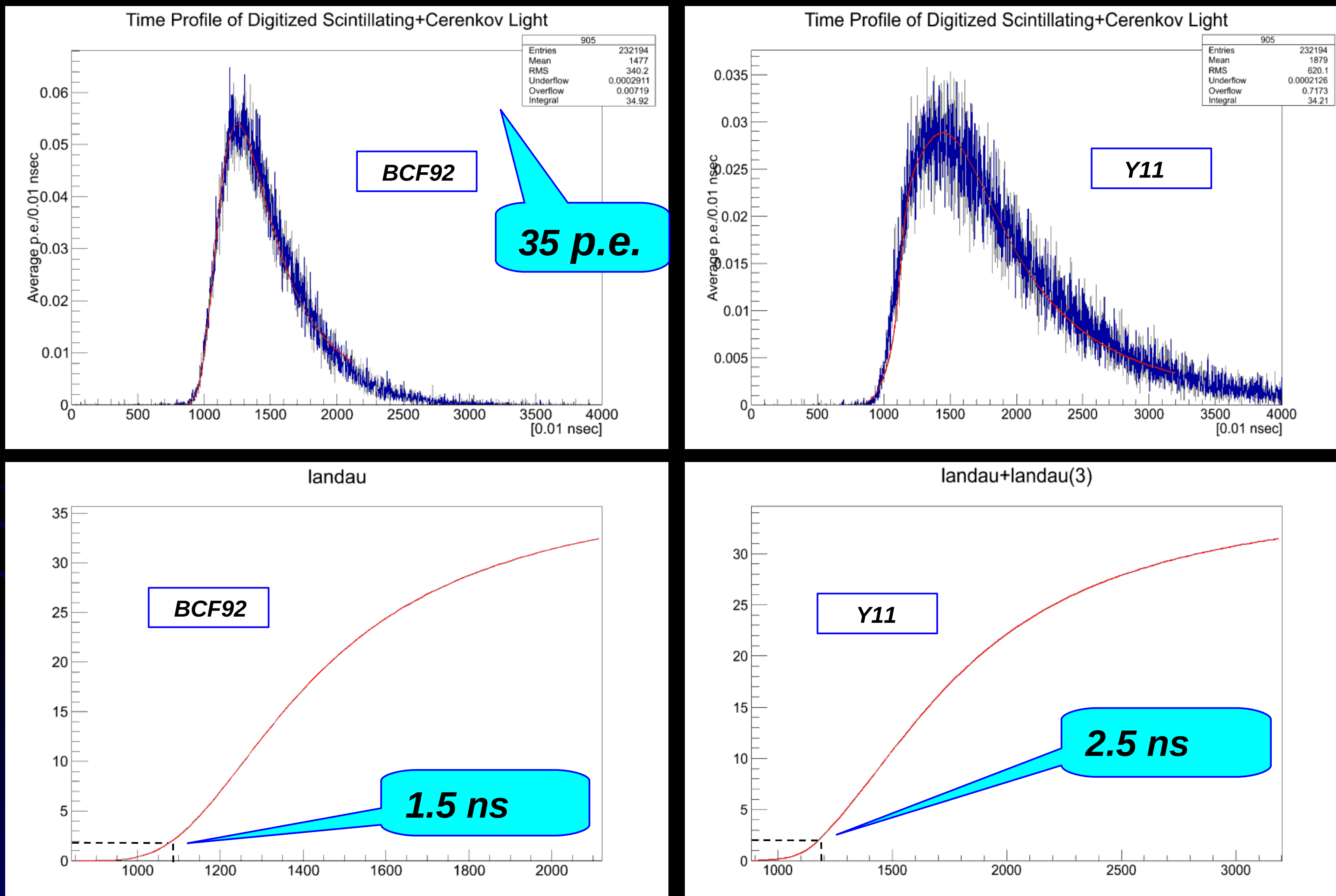
Timing Studies for Dual-Readout

- ***Assumptions***
  - ***Scintillating plates and glass light collection with WLS + SiPM***
  - ***3.5 meters WLS with 340 cm absorption length (optimistic, 250 cm realistic)***
  - ***2.4 nsec decay time for scintillator***
  - ***7.0 nsec or 2.4 nsec decay time for WLS (Y11 or BCF92)***

    same light yield (but BCF92 has lower yield)
  - ***0.5 nsec 10%-90% rise time***
  - $\sigma_z = 6\text{mm}/\sqrt{E}$ ***indetermination on z-coordinate (affects determination of*** t_o***)***
  - ***Readout at two ends of the fiber***
  - ***Photon impinges roughly in the middle of the calorimeter***

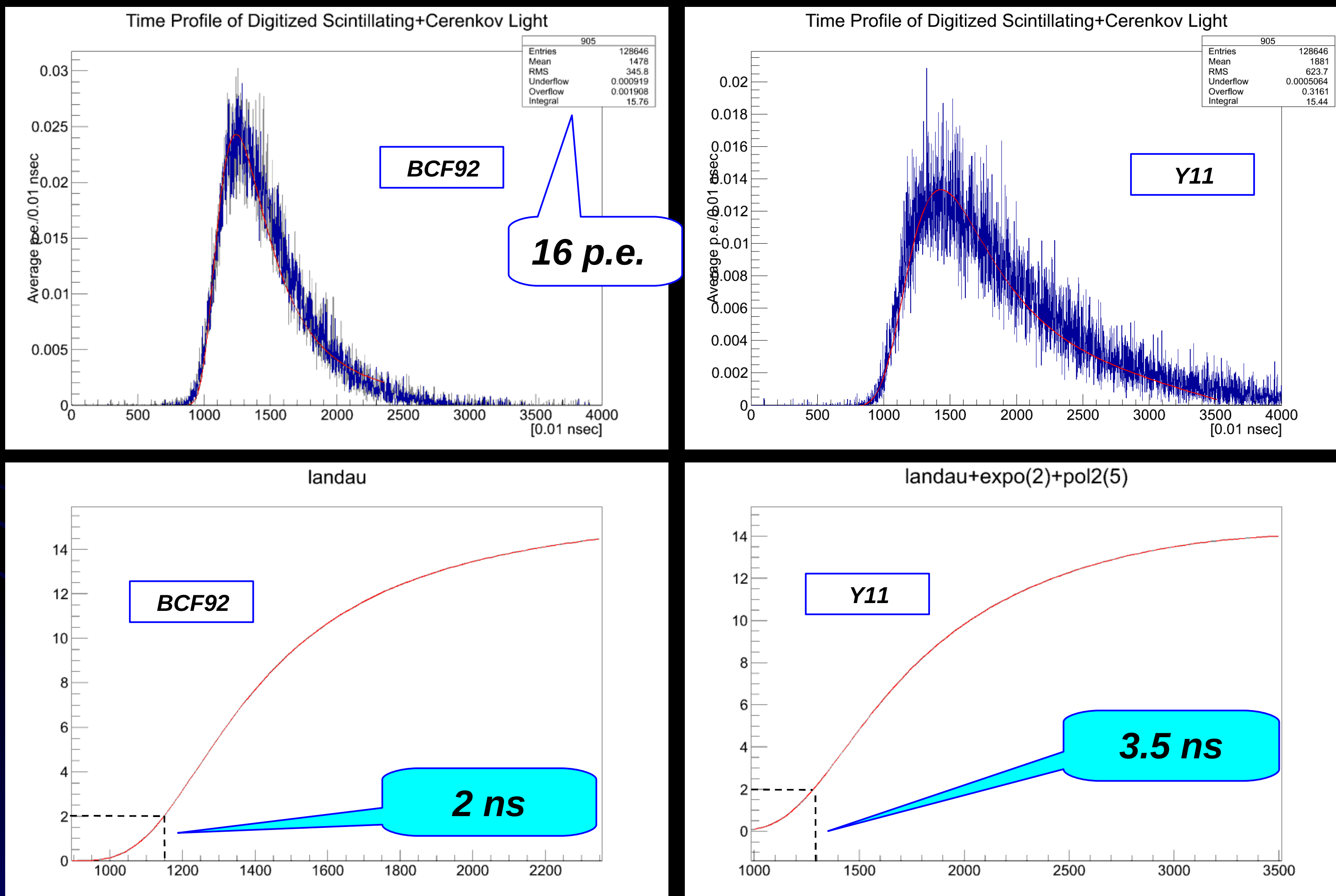
S+C timing for 10 MeV gamma

Expected light yield vs time at one end of WLS (average over 10^4 events)

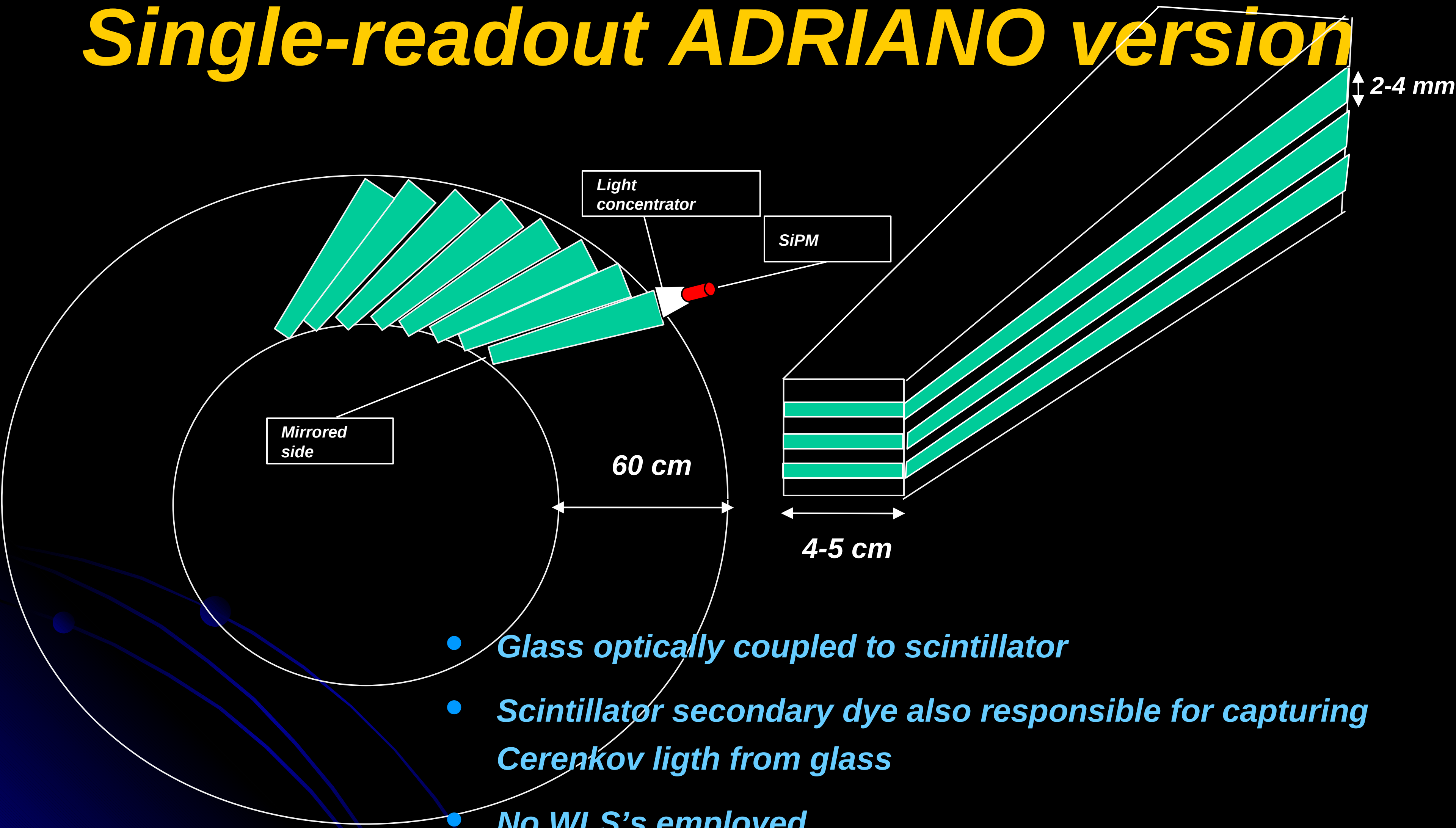


S+C timing for 5 MeV gamma

Expected light yield vs time at on end of WLS (average over 10^4 events)



Single-readout ADRIANO version



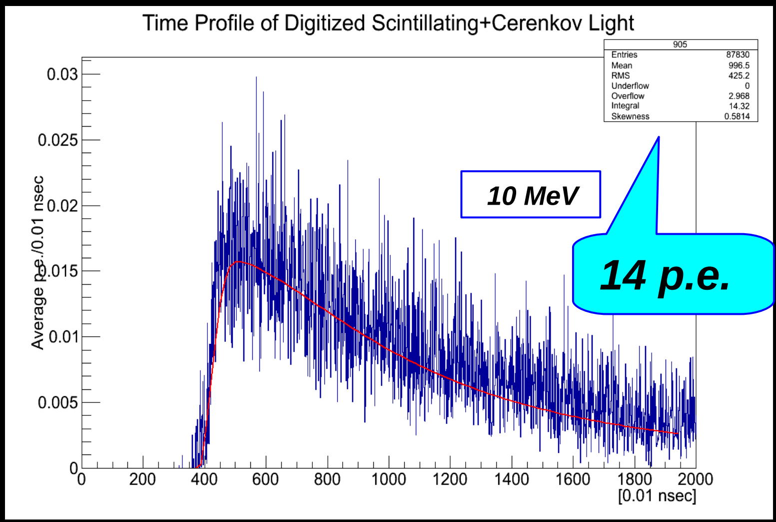
- Glass optically coupled to scintillator
- Scintillator secondary dye also responsible for capturing Cerenkov ligth from glass
- No WLS's employed
- Radial layout (to cope with short scintillator absorption length)
- Single side readout

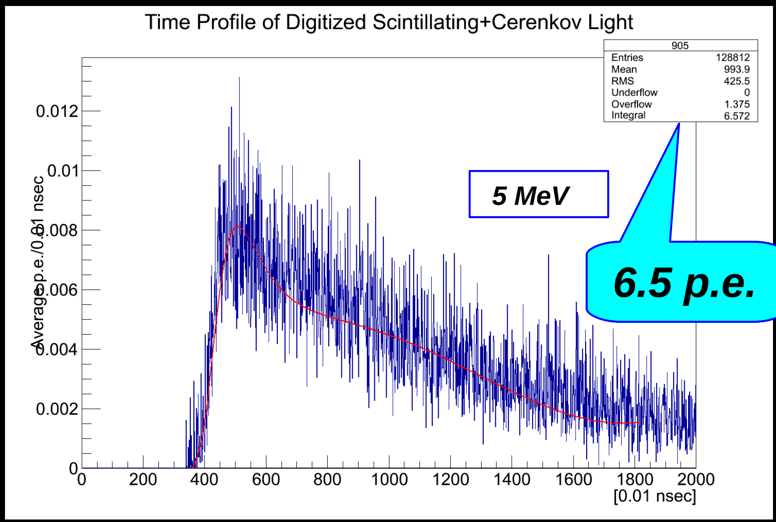
Timing Studies for Single-readout

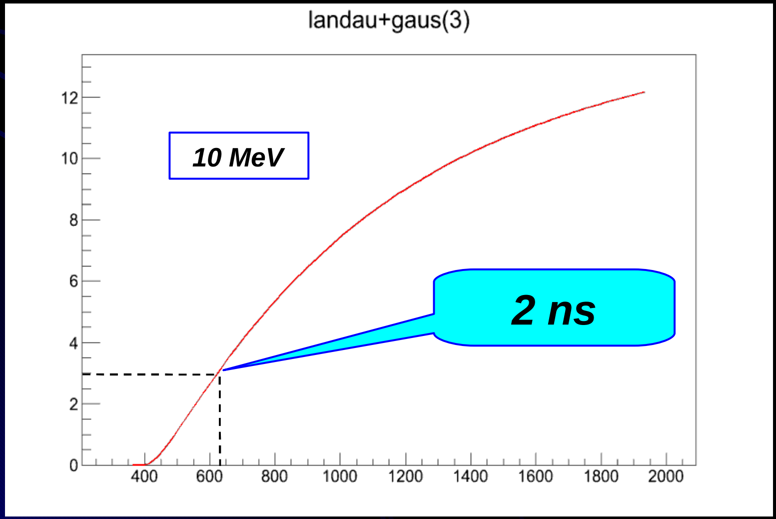
- *Assumptions*
  - *Green scintillating plates without WLS connected to SiPM with light concentrators*
  - *Collect S+C light (no dual-readout)*
  - *40 cm absorption length (private discussion with manufacturer)*
  - *9 nsec decay time*
  - *0.5 nsec 10%-90% rise time*
  - *Readout at one ends of the plate*
  - *Other plate is mirrored (eff=95%)*

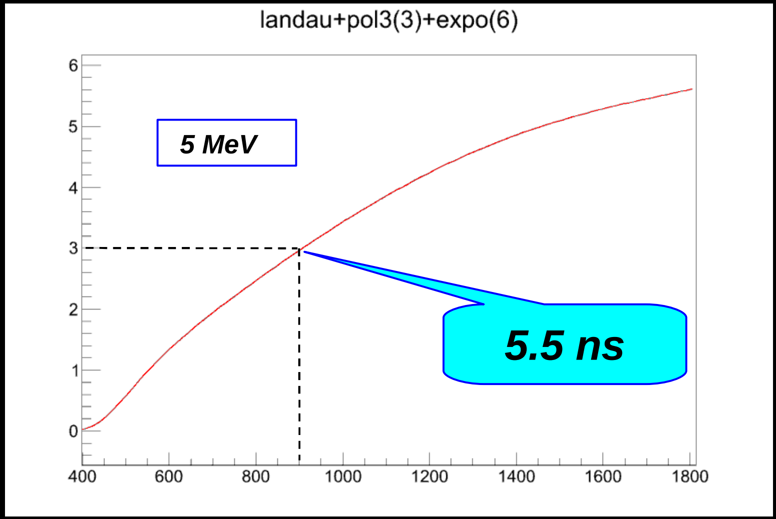
S+C timing for single readout

Expected light yield vs time at rear end of the cell (average over 10^4 events)









Conclusions

- *Two configurations are being considered:*
  - *Single-readout with radial segmentation*
  - *Dual-readout with longitudinal segmentation*
- *Single readout is simpler and cheaper*
- *Dual-readout has particle ID capabilities*
- *Dual-readout radial version not excluded (but lower priority)*
- *Radial layout simulations do not fully reflect the radial geometry (probably, no of not much concern): will be fixed shortly*
- *Simulations on Dual-readout assume 10 times more Cerenkov ligth than ADRIANO tested at FTBF*
  - *Factor 5 from larger number of WLS*
  - *Factor of 2 from closely spaced fibers*

Test of real prototypes mandatory

Backup slides

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

Giant Dipole Resonance in G4

Cross section for GDR is described as the sum of two peaks

$$GDR(e) = th(e, b_1, s_1) \cdot exp(c_1 - p_1 \cdot e) + th(e, b_2, s_2) \cdot exp(c_2 - p_2 \cdot e).$$

$$\begin{aligned} p_1 = 1, p_2 = 2 \ \text{for} \quad & A < 4 \\ p_1 = 2, p_2 = 4 \ \text{for} \quad & 4 \le A < 8 \\ p_1 = 3, p_2 = 6 \ \text{for} \quad & 8 \le A < 12 \\ p_1 = 4, p_2 = 8 \ \text{for} \quad & A \ge 12. \end{aligned}$$

The A-dependent parameters b_i, c_i and s_i were found for each of the 14 nuclei listed above and

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

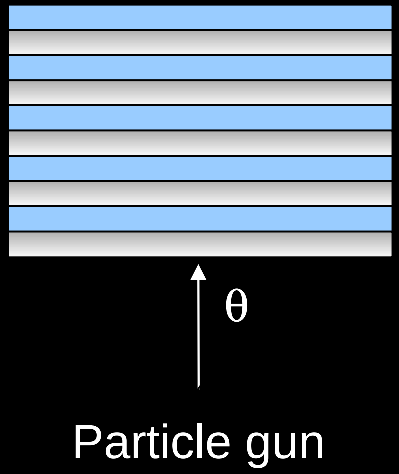
G4HadronElasticPhysicsHP

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

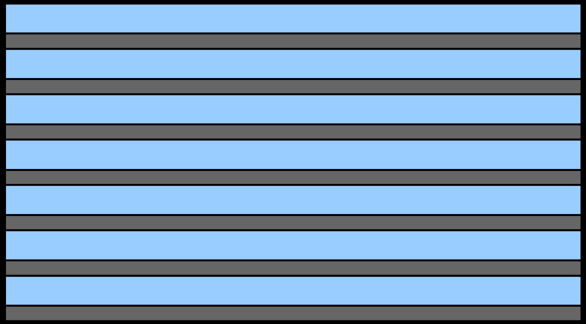
Min range: 2 μm for γ, electron, positron ; 20 μm for proton & neutrons

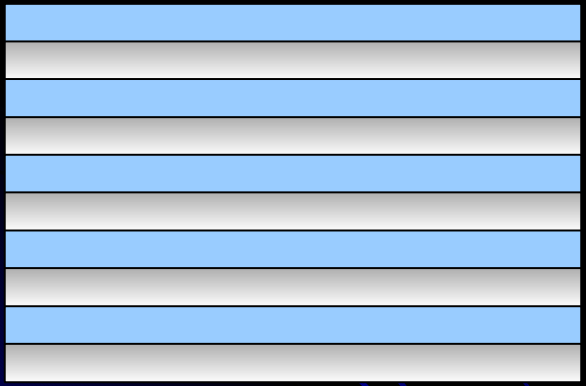
Stepping: 1 μm (but also shown different steppings)

Detector Layouts Considered

Shashlyk (baseline approach)

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





ADRIANO (proposed for ORKA)

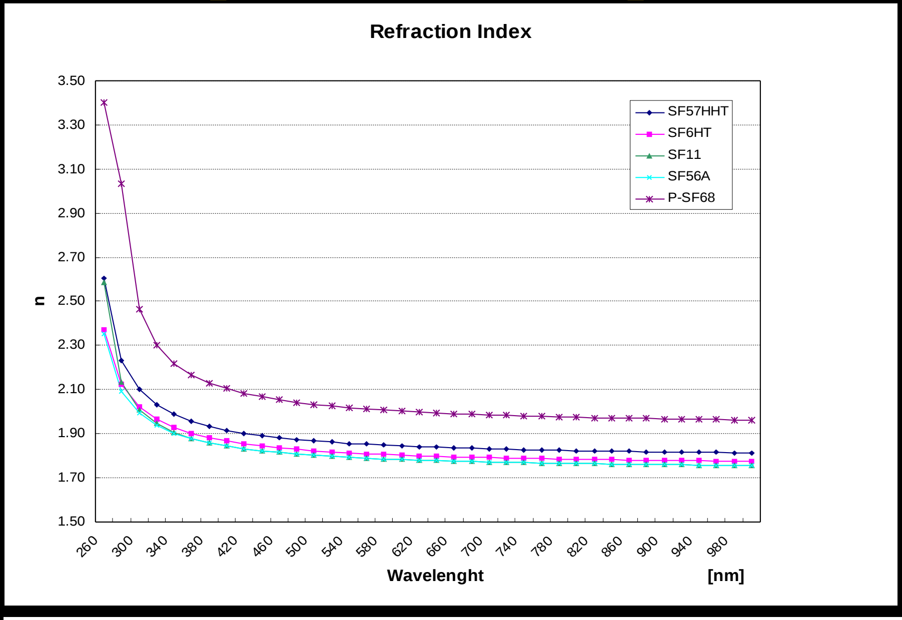
- 150 layers, SF57HHT (X0=1.5) 2-4mm, Scint. 2mm
- 160 layers, SF6HT (X0=1.69) 2mm, Scint. 2mm
- 150 layers, SF5 (X0=2.36) 3mm, Scint. 2mm
- 130 layers, PbF2 (X0=0.93) 2mm, Scint. 2mm

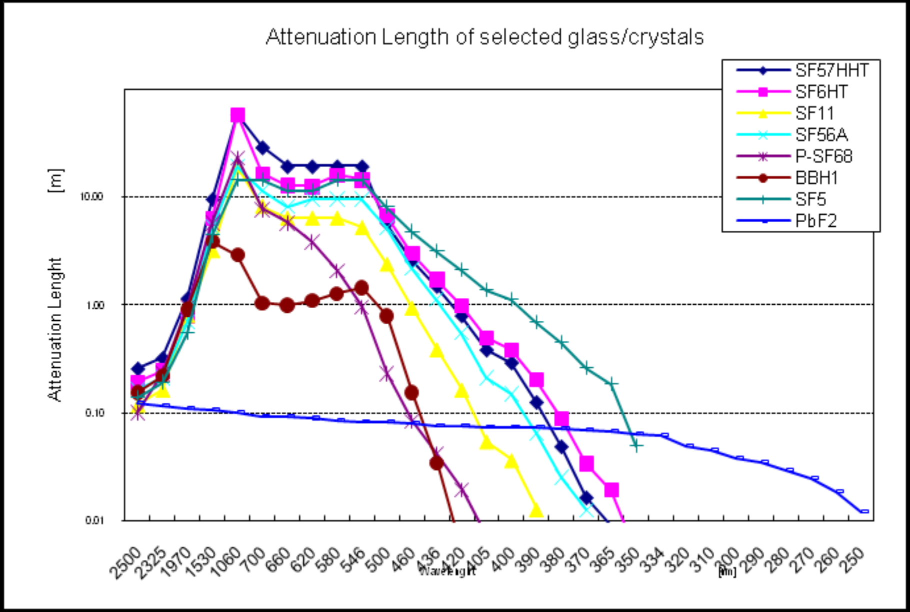
Light Yield Parameters

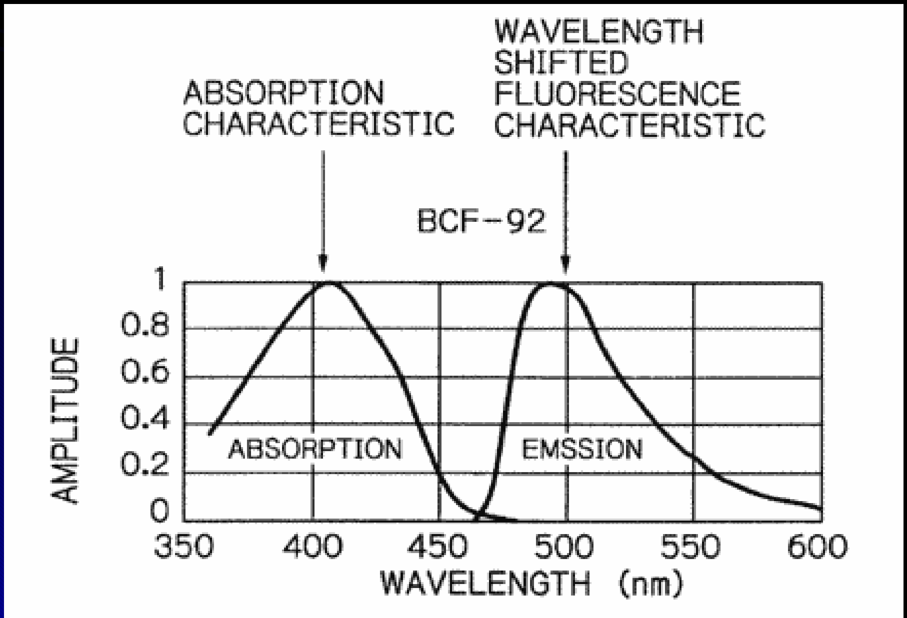
- Scintillating light (assume WLS readout from ADRIANO simulations)
  - photons/mev=167
  - QE=24% (assume SiPM at 530 nm)
  - Attenuation length in scintillator: 3.4 m
  - Birk's corrected light yield

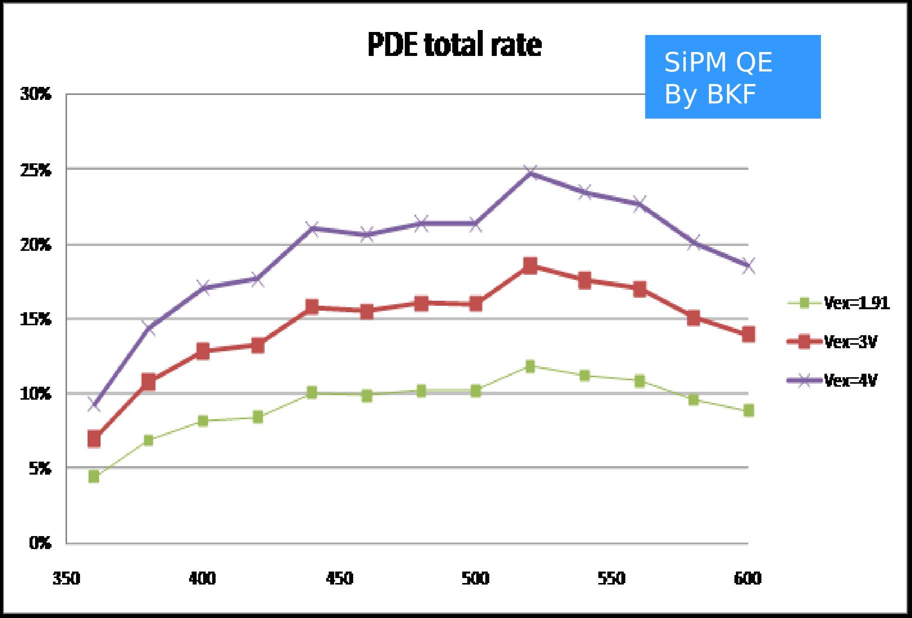
- Cerenkov light (assume WLS readout from ADRIANO simulations)
  - Cerenkov light production with wavelength dependent n_D
  - Wavelength dependent attenuation of Cerenkov photons traveling through the glass/crystal
  - Photon angle must be larger than $\theta_{critical}$ in order to enter the WLS fiber/plane (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)

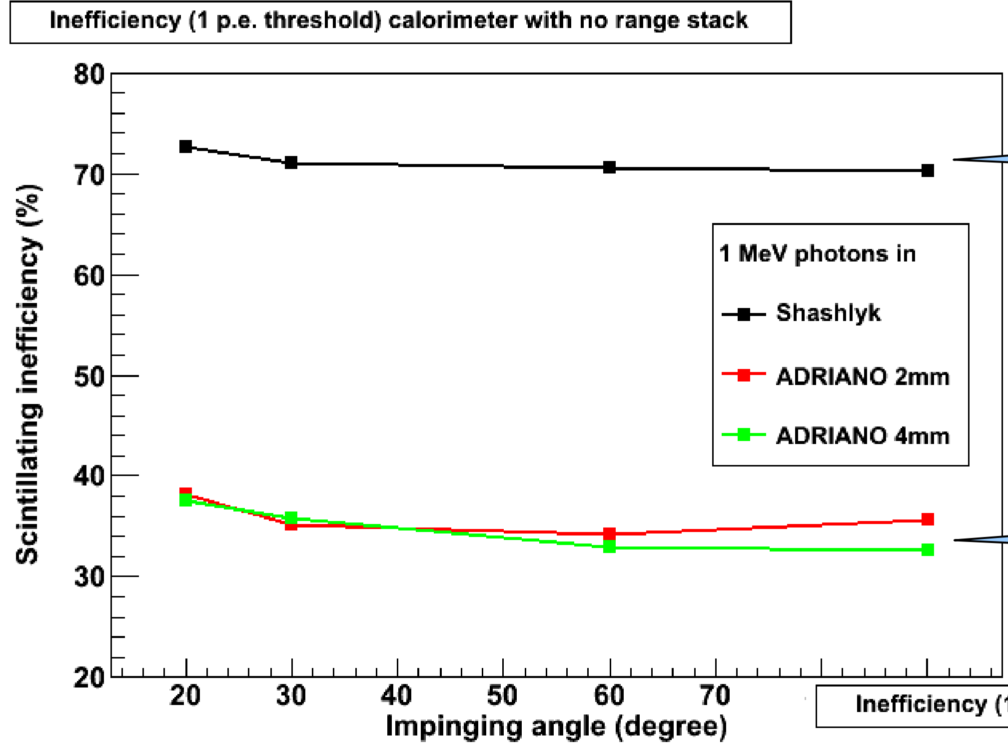
Optical Spectra in ADRIANO





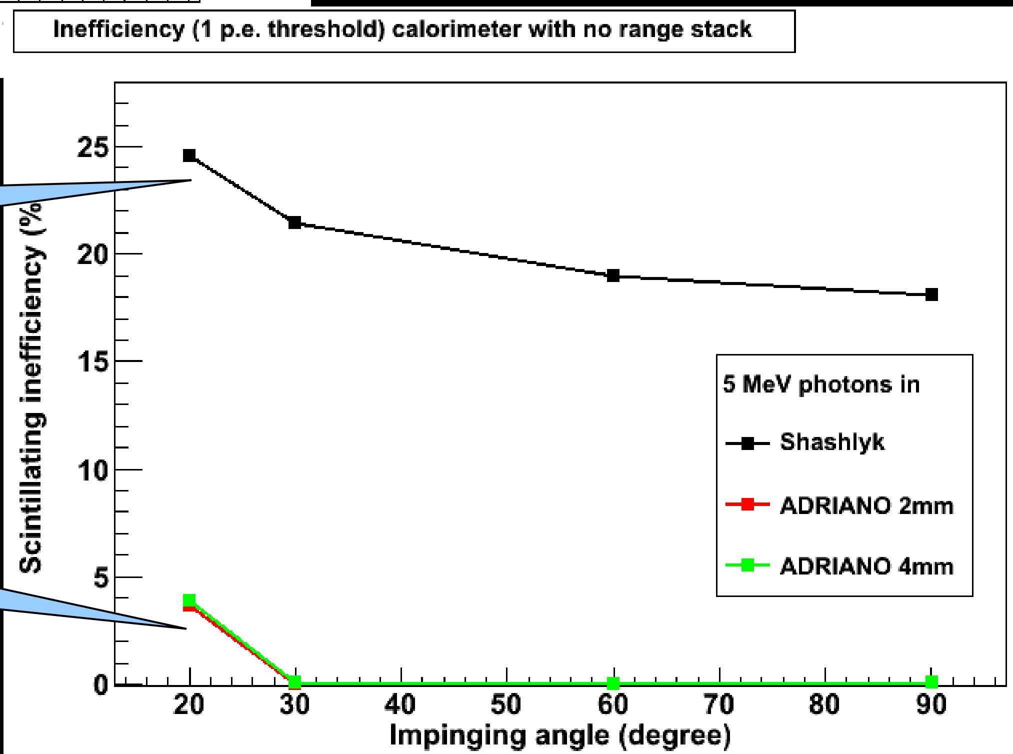






Fraction of events where (LYSCI)> 1p.e. at 1 MeV

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

A. Mazzacane (Fermilab)