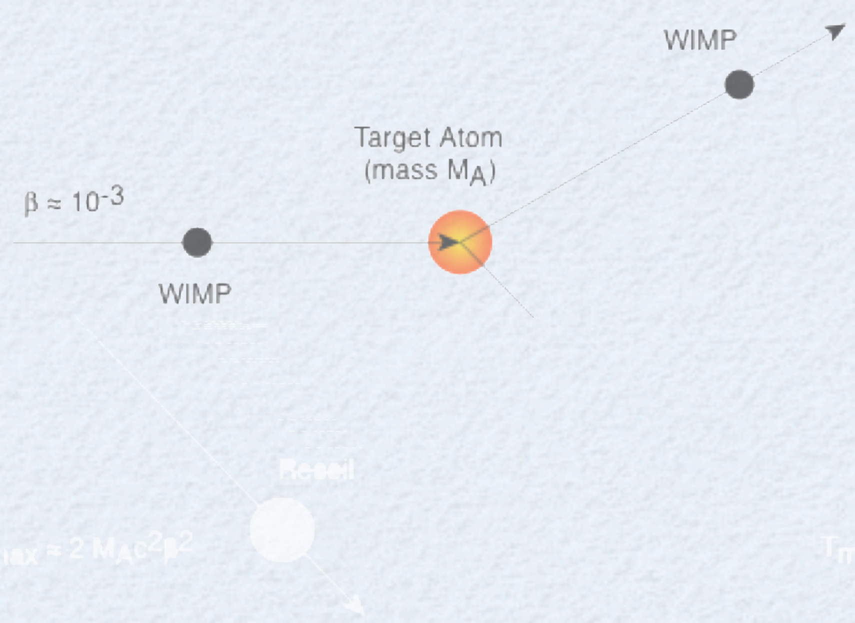
14th Geant4
Users and Collaboration Workshop
(Users Session)



Complete Monte Carlo simulation of the optical response of the WArP detector for Dark Matter search

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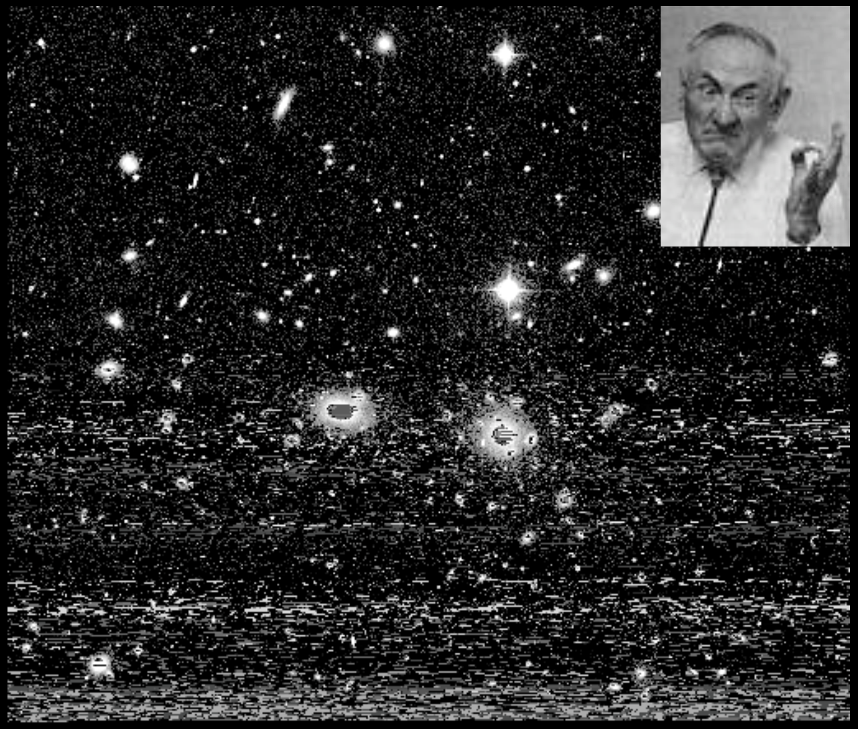
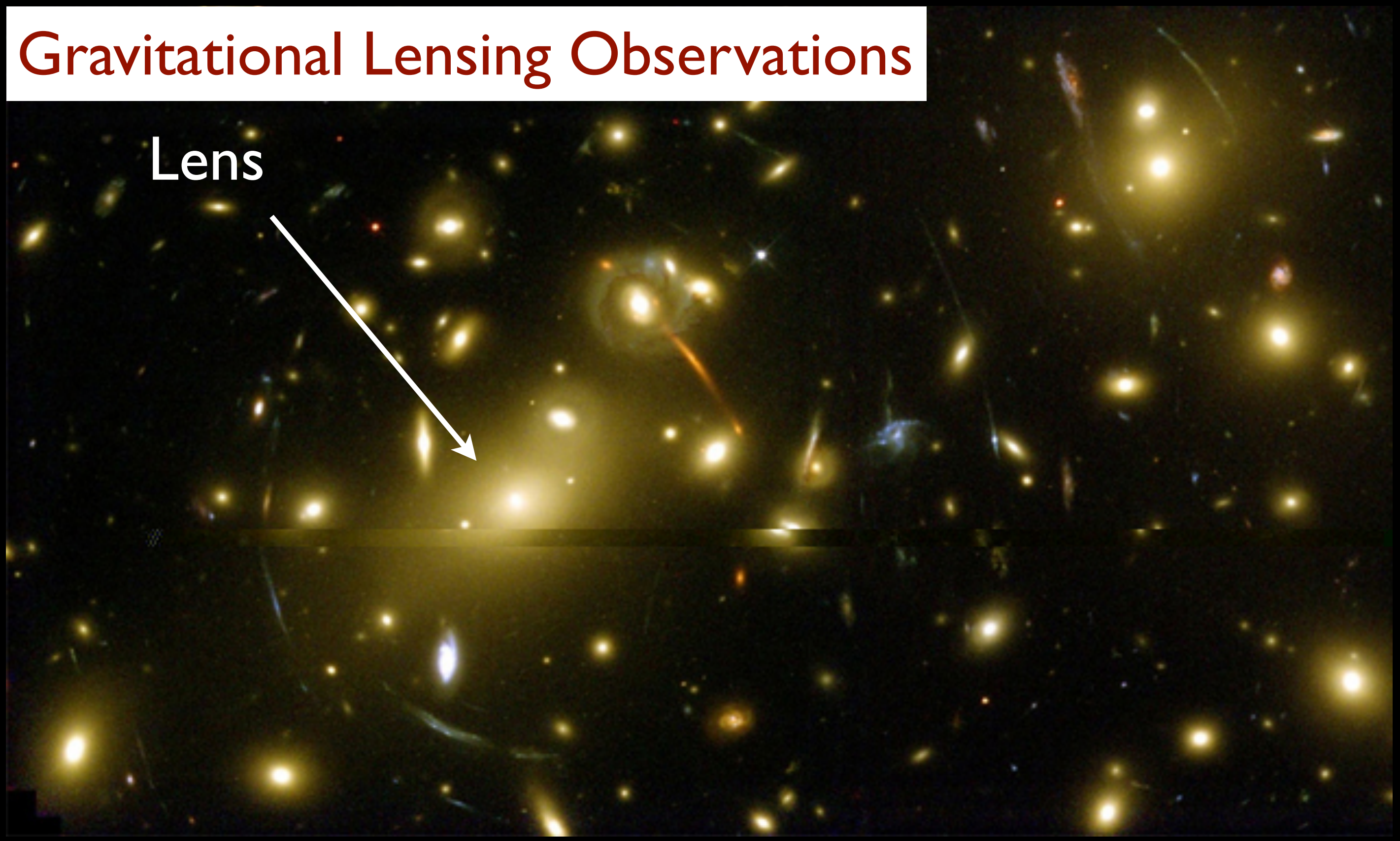
Laboratori Nazionali del Sud - INFN
Catania (Italy), October 15 - 17, 2009

Dark Matter Indirect Evidences

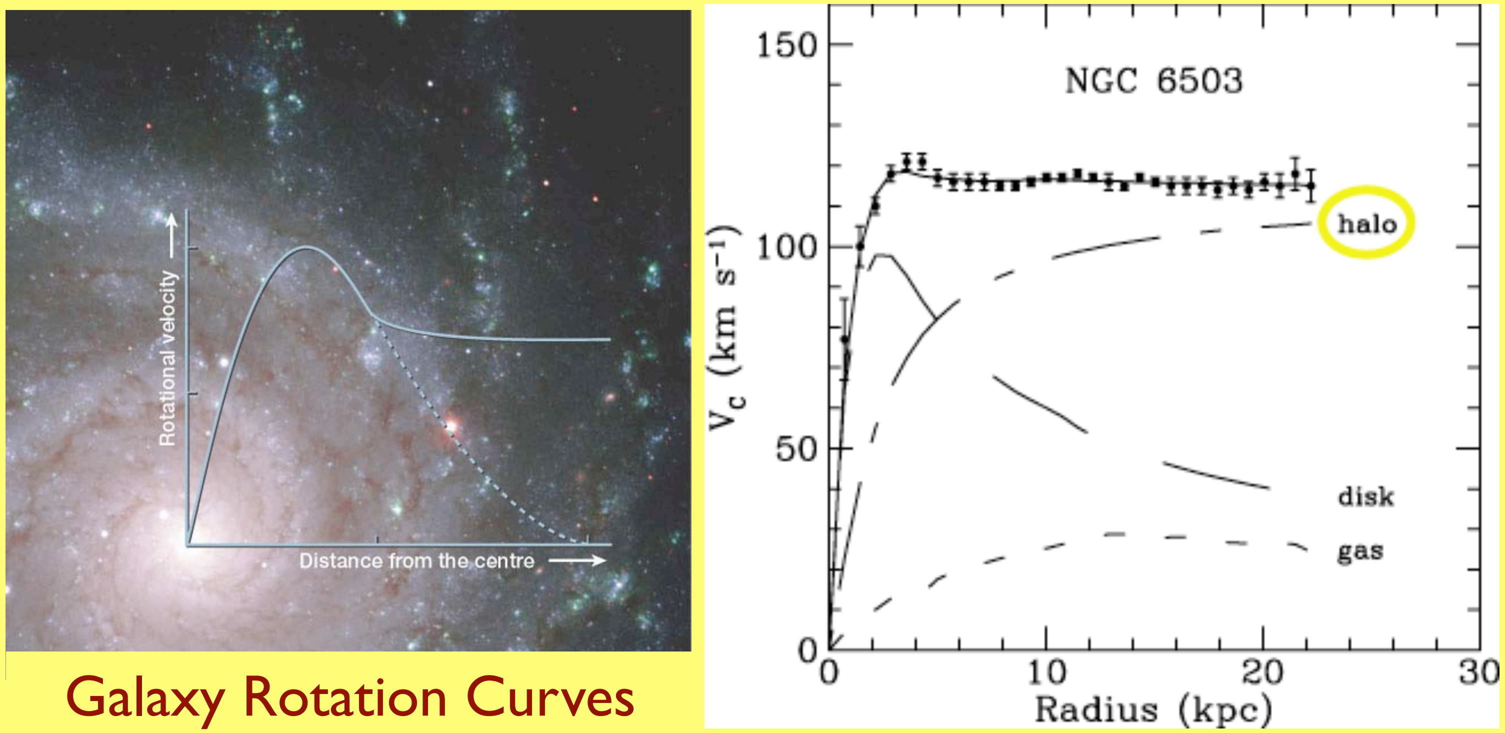


Dynamic of galaxies in Clusters



Gravitational Lensing Observations

Merger Cluster



Galaxy Rotation Curves

WIMP Direct Detection

Weakly
Interacting
Massive
Particle

1. They are expected to weakly interact with nuclei of ordinary matter.

expected rate below 0.1 event per kg of target per day

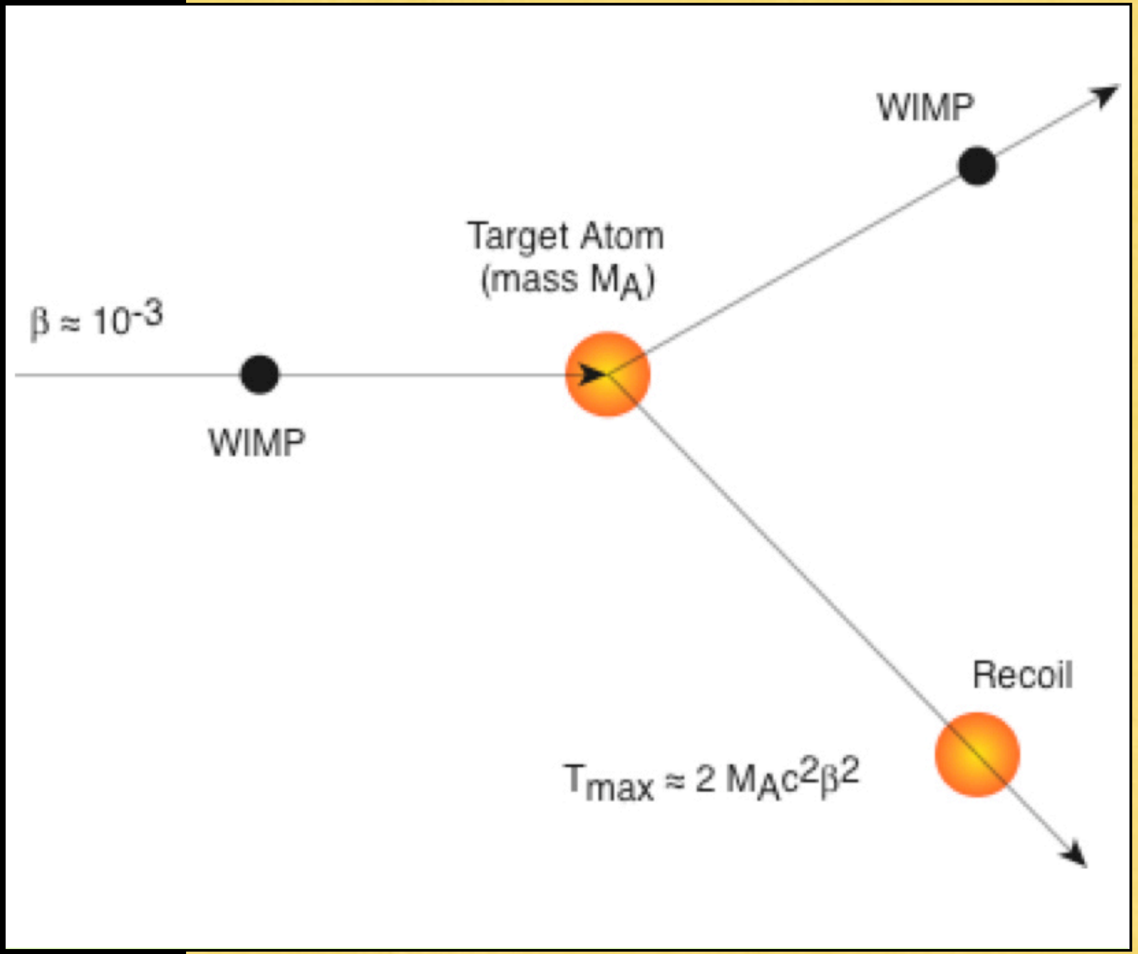
2. Ionizing particle is the recoiling nucleus

recoil energy very low (10-100 keV)

3. Energy range of interest is dominated by natural radioactivity

Need of very low radioactivity material and particle discrimination techniques to reject background events

Irreducible Background: Argon recoils induced by Neutron elastic scatterings



Dark Matter & Liquid Argon

Why noble liquids?

- High scintillation Yield
- Simultaneous measurement of scintillation and ionization (particle discrimination)
- Potentiality to be extended to multi-ton volumes

Scintillator	NaI(Tl)	Liquid Argon	Liquid Xenon
Photon Yield [ph/MeV]	4.3×10^4	4.0×10^4	4.2×10^4
Fast Decay Time [ns]	-	6	2.2
Slow Decay Time [ns]	250	1200-1500	27

Why liquid Argon?

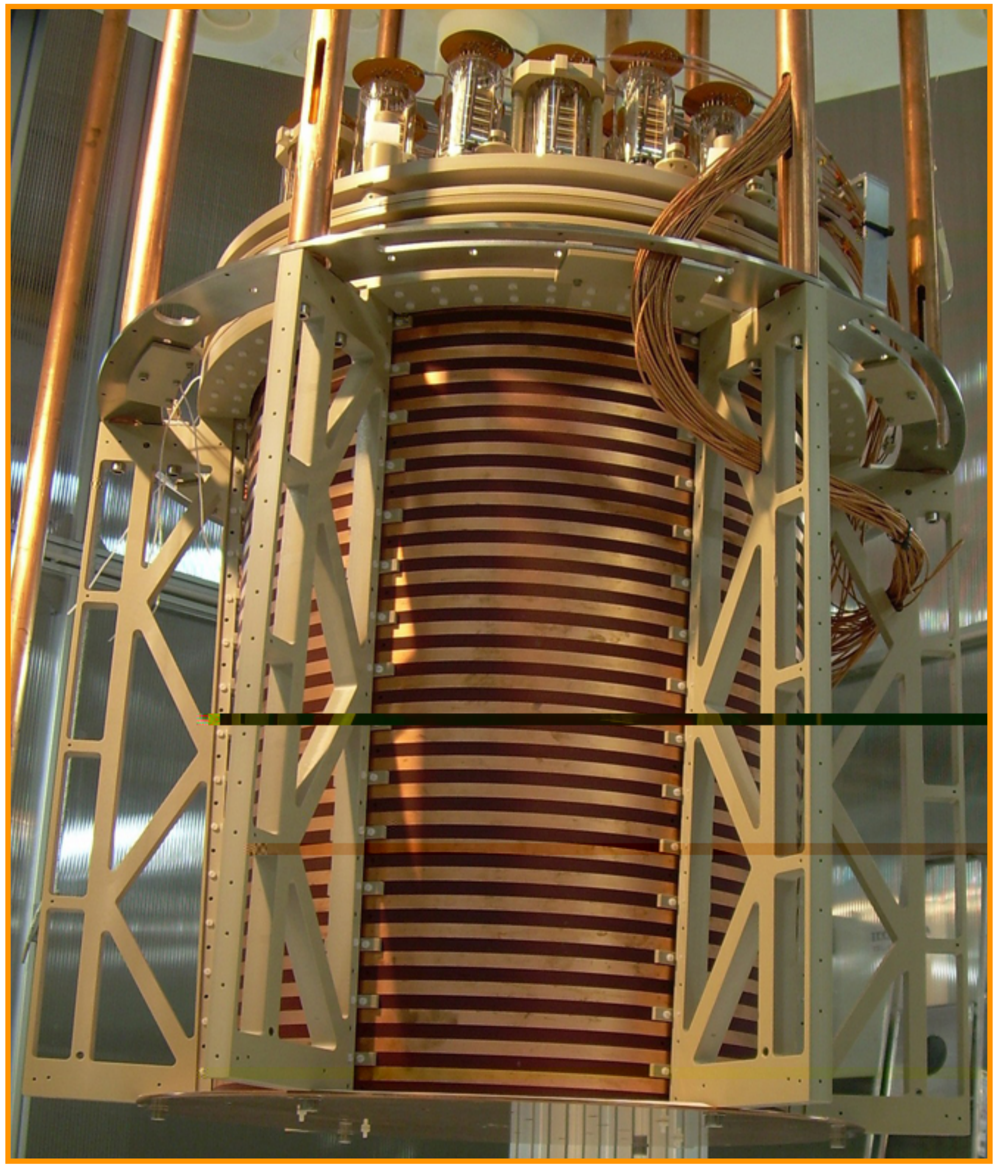
- Scintillation decay times very different ($\tau f \approx 6$ ns , $\tau s \approx 1200\text{-}1500$ ns) → Two independent discrimination tech. very efficient background reduction!
- Argon Technology fully operational
- Easily available (1% of atmosphere) → low cost

WArP detecors

2.3 liters

Working since 2005 @ LNGS
R&D + WIMP run

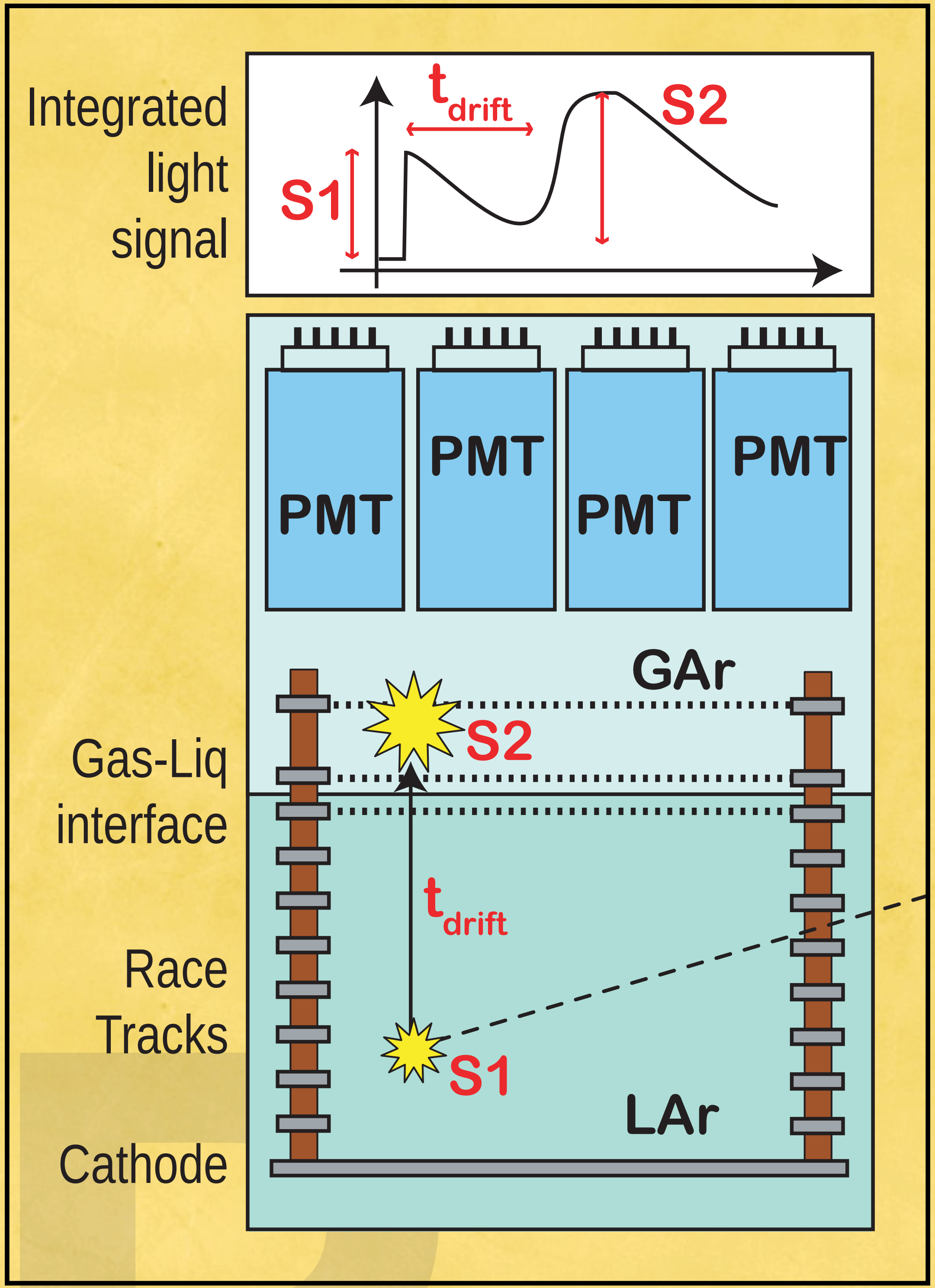
100 liters



Test Run in single phase @ LNGS
(sept09)

WArP Detection Technique

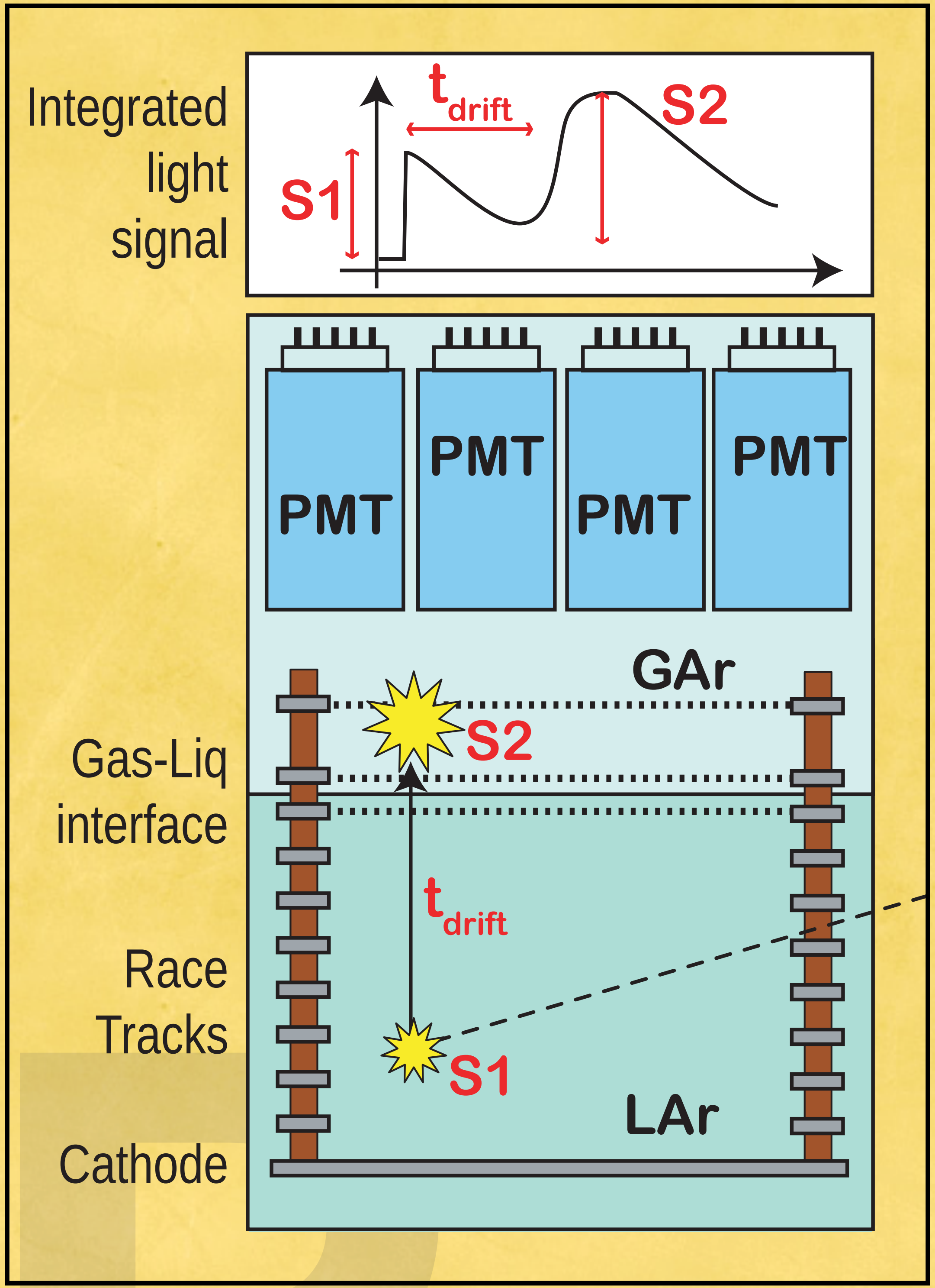
- Each interaction in liquid argon induce both atomic excitation and ionization
- By means of electric fields free ionization electrons are drifted, extracted and accelerated in the gas phase to produce electroluminescence
- prompt (S1) & electroluminescence (S2) signals are detected through the same set of PMTs.



WArP Detection Technique

For a given energy deposition, the nature of the primary recoiling particle affects both:

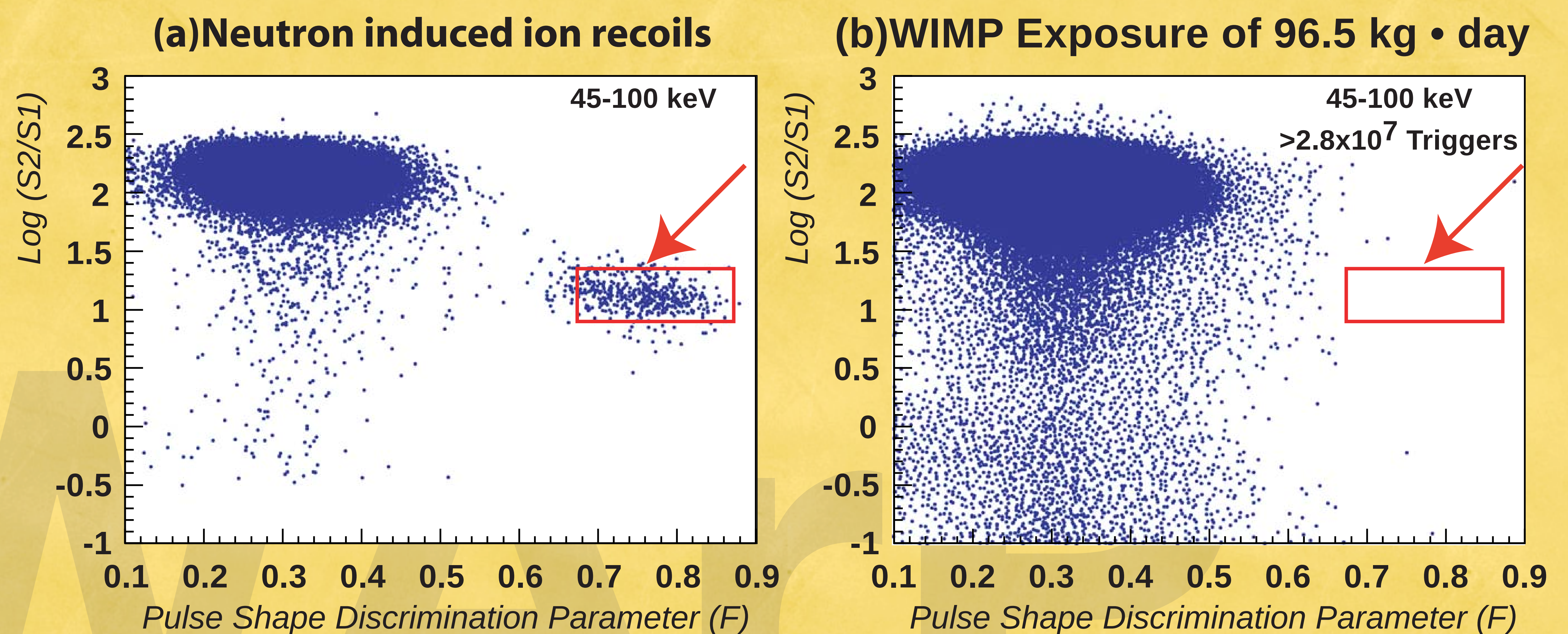
- The ratio between fast/low light intensity and hence the shape of the S1 signal
- The amount of ionization surviving recombination and hence the ratio between S1 and S2 signals



Double discrimination technique: unique feature of Argon due to the wide difference between the two decay times.

Detection Technique: results

- ✓ Double discrimination power estimated using a 2.3 liters detector inducing argon recoils by means of neutron source (*Astropart. Phys. 28 (2008), 495*).
- ✓ Fig. (a): Argon recoils populate the red box region
- ✓ Fig. (b): After removing neutron source we acquired ≈ 30 million of background events and no event fall in the argon recoil region



Need Of Optical Simulation

performance of WArP collection system

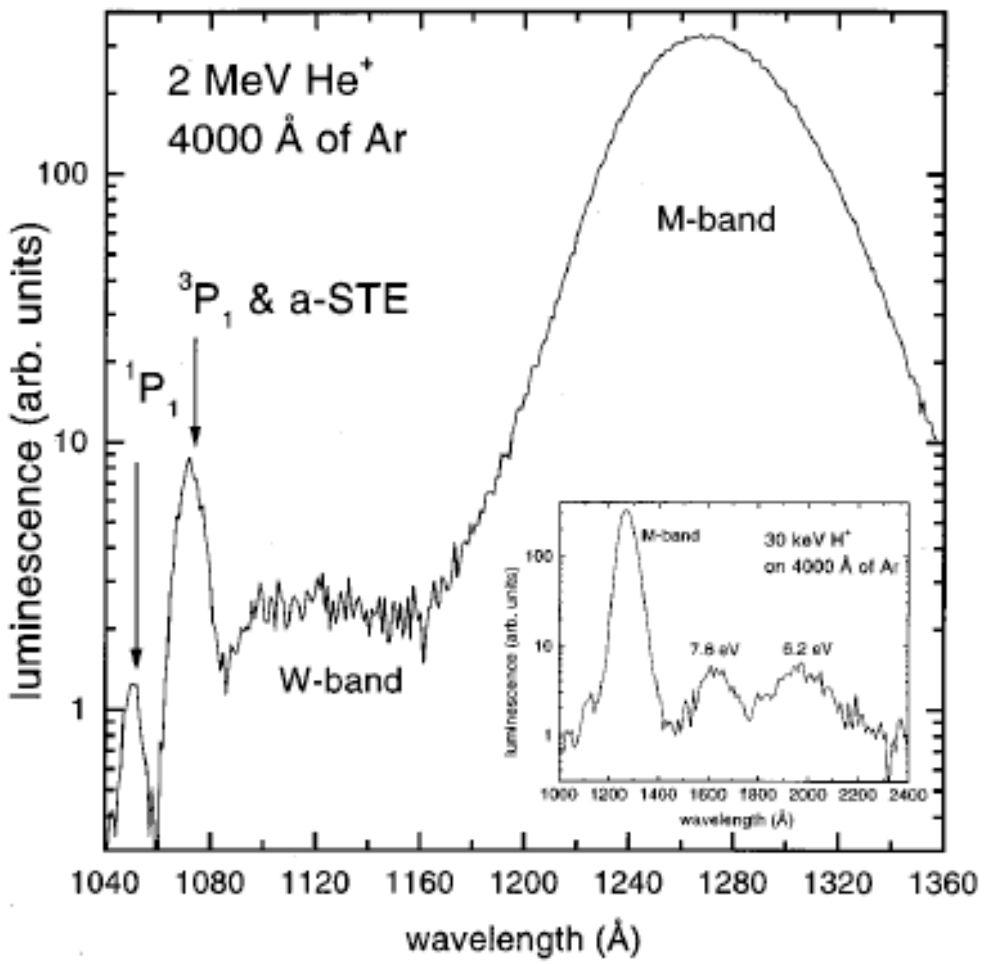
- Detection Efficiencies as a function of event Energy and Positions
- detected photons distribution on PMTs

produce Simulated Events like Raw Data

- Debugging of the WArP event reconstruction software by means of event-shape simulation (Preliminary.)
- performance of the pulse shape Discrimination (to be done)

WArP Detector Optical Response Simulated using GEANT4

LAr Scintillation Spectrum



Ar scintillation light is emitted with a narrow spectrum peaked @ 128 nm

UV optical properties to be implemented:

➡ refractive index of LAr and Gar

➡ TPB fluorescence efficiency

LAr Spectrum Parametrization

```
G4double Optic_Dete::ArScintillationSpectrum(const G4double kk)
{
  G4double waveL;
  waveL =exp(-0.5*((kk-128.0)/(2.929))*((kk-128.0)/(2.929)));
  return waveL;
}
```

Refractive Index Implementation

```
// Calculates the dielectric constant of LAr from the Bideau-Sellmeier formula.
// See : A. Bideau-Mehu et al., "Measurement of refractive indices of Ne, Ar,
// Kr and Xe ...", J. Quant. Spectrosc. Radiat. Transfer, Vol. 25 (1981), 395

G4double Optic_Dete::LArEpsilon(const G4double lambda)
{
  G4double epsilon;
  if (lambda < (lowLambda * nanometer)) return 1.0e4; // lambda MUST be > 110.0 nm
  epsilon = lambda / micrometer; // switch to micrometers
  epsilon = 1.0 / (epsilon * epsilon); // 1 / (lambda)^2
  epsilon = 1.2055e-2 * ( 0.2075 / (91.012 - epsilon) +
                          0.0415 / (87.892 - epsilon) +
                          4.3330 / (214.02 - epsilon) );
  epsilon *= (8./12.); // Bideau-Sellmeier -> Clausius-Mossotti
  epsilon *= (LArRho / GArRho); // density correction (Ar gas -> LAr liquid)
  if (epsilon < 0.0 || epsilon > 0.999999) return 4.0e6;
  epsilon = (1.0 + 2.0 * epsilon) / (1.0 - epsilon); // solve Clausius-Mossotti
  return epsilon;
}
```

Previous Work
from ICARUS simulation

```
// Calculates the refractive index of LAr

G4double Optic_Dete::LArRefIndex(const G4double lambda)
{
  return ( sqrt(LArEpsilon(lambda)) ); // square root of dielectric constant
}
```

J. Quant. Spectrosc. Radiat. Transfer,
Vol. 25 (1981), 395

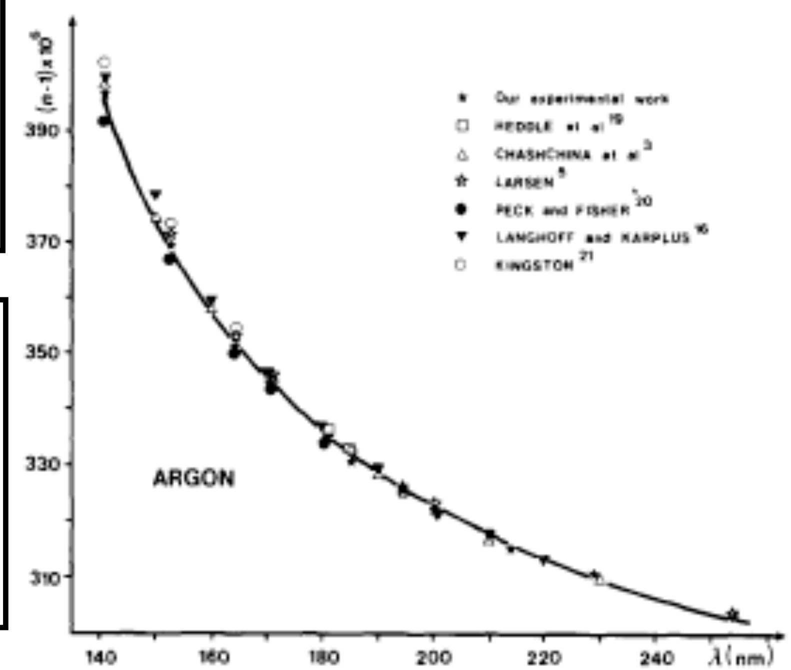
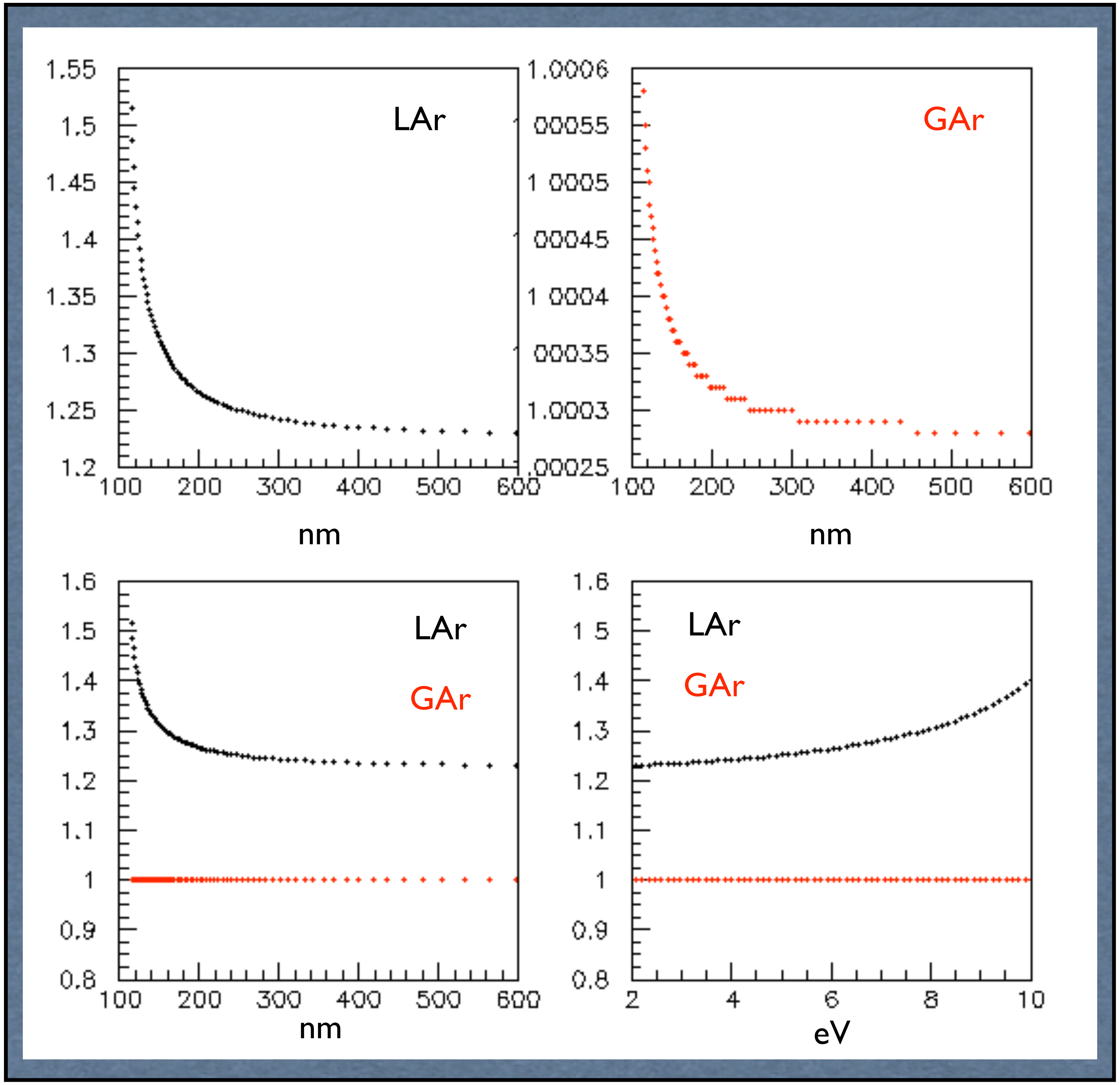


Fig. 2. Argon refractivity; the full line represents the Sellmeier formula.

```
G4MaterialPropertiesTable* LArMPT = new G4MaterialPropertiesTable();

LArMPT->AddProperty("RINDEX",LAr_PPCK, LAr_RIND, NUMENTRIES);
```

Refractive Index Implementation

- GAr Refractive Index is practically constant in the range (100-600 nm)
- LAr RINDEX variation of the order of 25%



LAr Scintillation implementation

```
LArMPT->AddProperty("FASTCOMPONENT",LAr_SCPP,LAr_SCIN,num);

LArMPT->AddProperty("SLOWCOMPONENT",LAr_SCPP,LAr_SCIN,num);

LArMPT->AddProperty("FASTCOMPONENT",Scnt_spe,Scnt_pp,scinum);
LArMPT->AddProperty("SLOWCOMPONENT",Scnt_spe,Scnt_pp,scinum);
LArMPT->AddConstProperty("FASTTIMECONSTANT", 7.*ns);
LArMPT->AddConstProperty("SLOWTIMECONSTANT",1400.*ns);
```

1

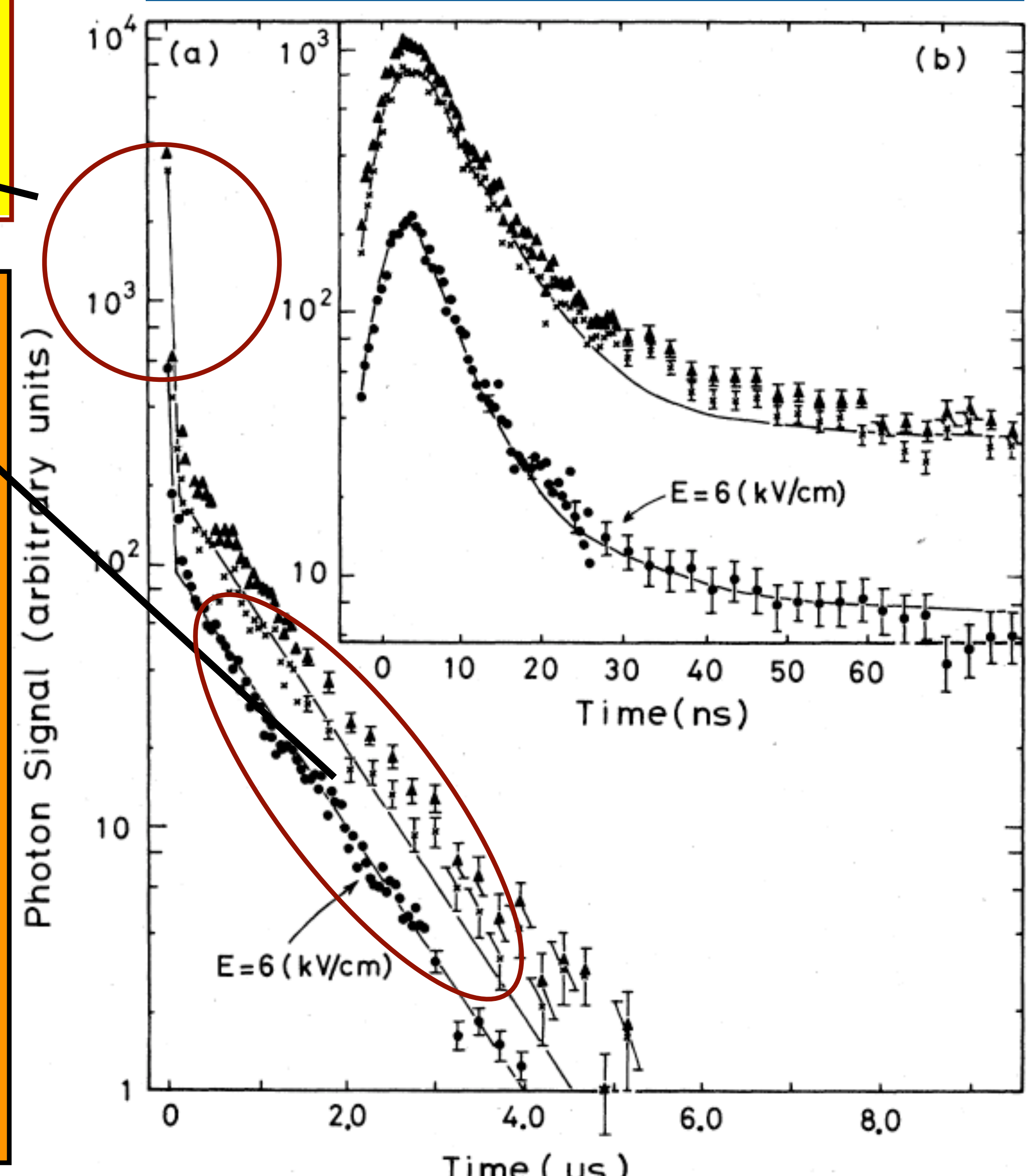
Fast and Slow wavelength spectra can be separately consider

The presence of fast and slow components is associated with Ar^{2*} molecular transition to fundamental dissociative state from a singlet and a triplet excited molecular states.

Practically the same scint. spectrum

2

LAr decay time behavior



LAr Scintillation implementation

```
LArMPT->AddProperty("FASTCOMPONENT",LAr_SCPP,LAr_SCIN,num);

LArMPT->AddProperty("SLOWCOMPONENT",LAr_SCPP,LAr_SCIN,num);

LArMPT->AddProperty("FASTCOMPONENT",Scnt_spe,Scnt_pp,scinum);
LArMPT->AddProperty("SLOWCOMPONENT",Scnt_spe,Scnt_pp,scinum);
LArMPT->AddConstProperty("FASTTIMECONSTANT", 7.*ns);
LArMPT->AddConstProperty("SLOWTIMECONSTANT",1400.*ns);
LArMPT->AddConstProperty("YIELDRATIO",0.75);
```

Fast/Total ratio for nuclear recoils

for other particles can bee sets in Physics.cc (SetScintillationExcitationRatio)

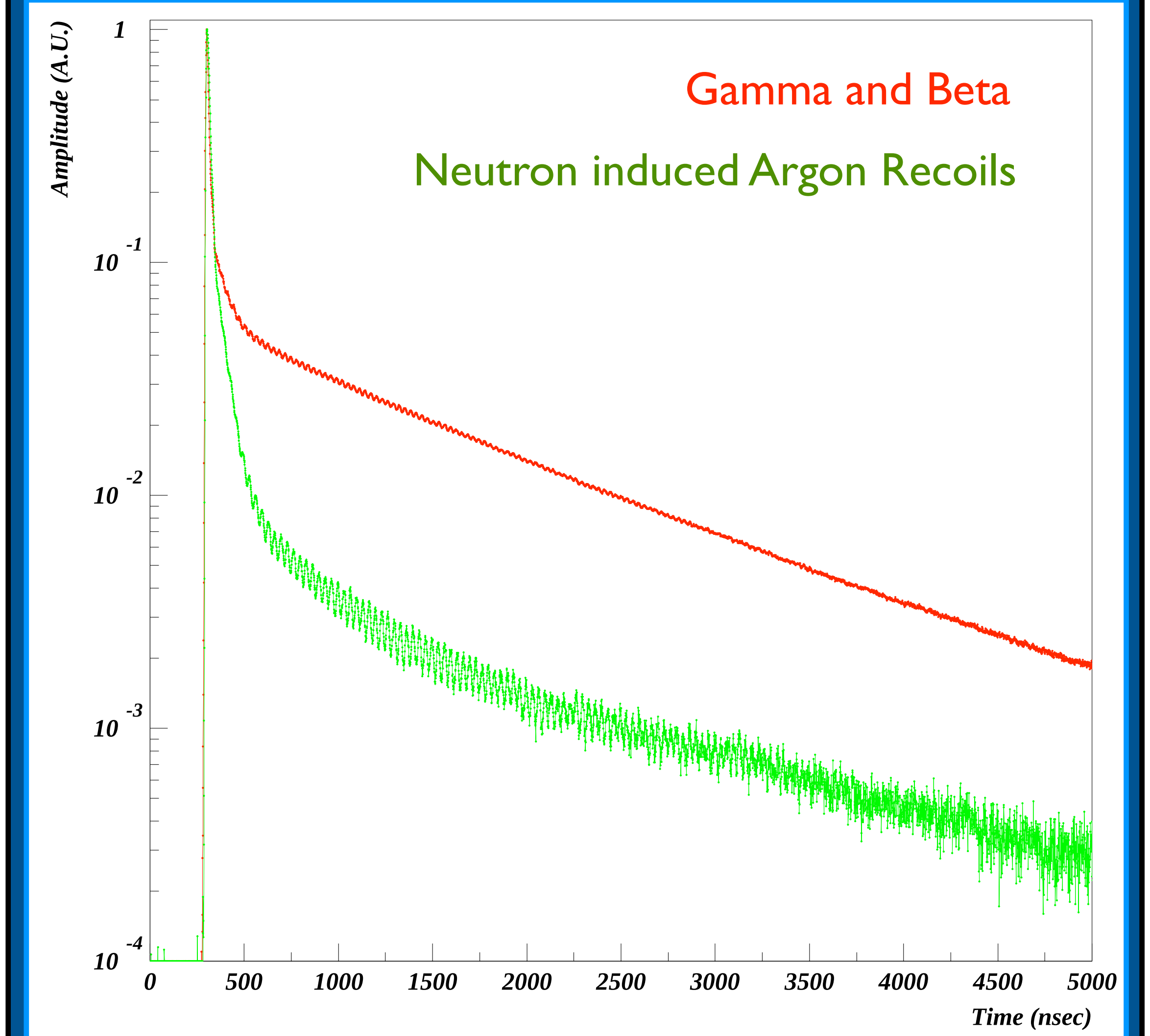
experimental results

1. decay constants are not functions of ionization density

2. for high ionization density the fast components intensity increases at expense of the slow one

$F_{rec.} = 0,75 \qquad F_{e-} = 0.23$

Effect of ionization density on time dependence of luminescence

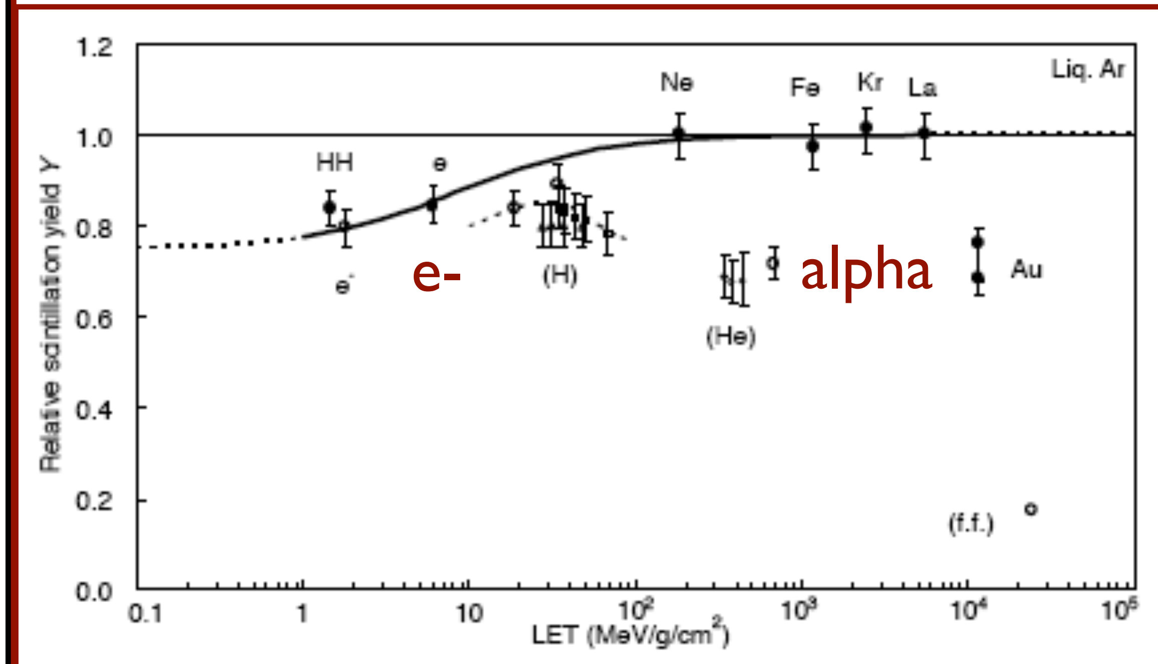


WArP DATA

LAr Scintillation implementation

```
LArMPT->AddProperty("FASTCOMPONENT",LAr_SCPP,LAr_SCIN,num);
LArMPT->AddProperty("SLOWCOMPONENT",LAr_SCPP,LAr_SCIN,num);

LArMPT->AddProperty("FASTCOMPONENT",Scnt_spe,Scnt_pp,scinum);
LArMPT->AddProperty("SLOWCOMPONENT",Scnt_spe,Scnt_pp,scinum);
LArMPT->AddConstProperty("FASTTIMECONSTANT", 7.*ns);
LArMPT->AddConstProperty("SLOWTIMECONSTANT",1400.*ns);
LArMPT->AddConstProperty("YIELDRATIO",0.75);
G4double scint_yield=1.0/(19.5*eV);
LArMPT->AddConstProperty("SCINTILLATIONYIELD",scint_yield);
```

ionization density effect on Scintillation Yield



Doke et al, J. Appl. Phys. 41 (2002)1538

- Scintillation Yield (mean energy to produce a UV photon) dependent on the nature of the impinging particles

➡ for flat top response particles the mean energy to produce a photon is 19.5 eV

➡ for other particles can bee sets in Physics.cc (ScintillationYieldFactor)

- Scintillation Yield dependent also on:

➡ Field configuration

➡ Quencher impurities

@ zero E field

$Y_{e-}=0.8\,Y \quad Y_{alpha}=0.7\,Y \quad Y_{recoils}= 0.2\text{-}0.4$

LAr Scintillation implementation

Scintillation for electron in Physics.cc

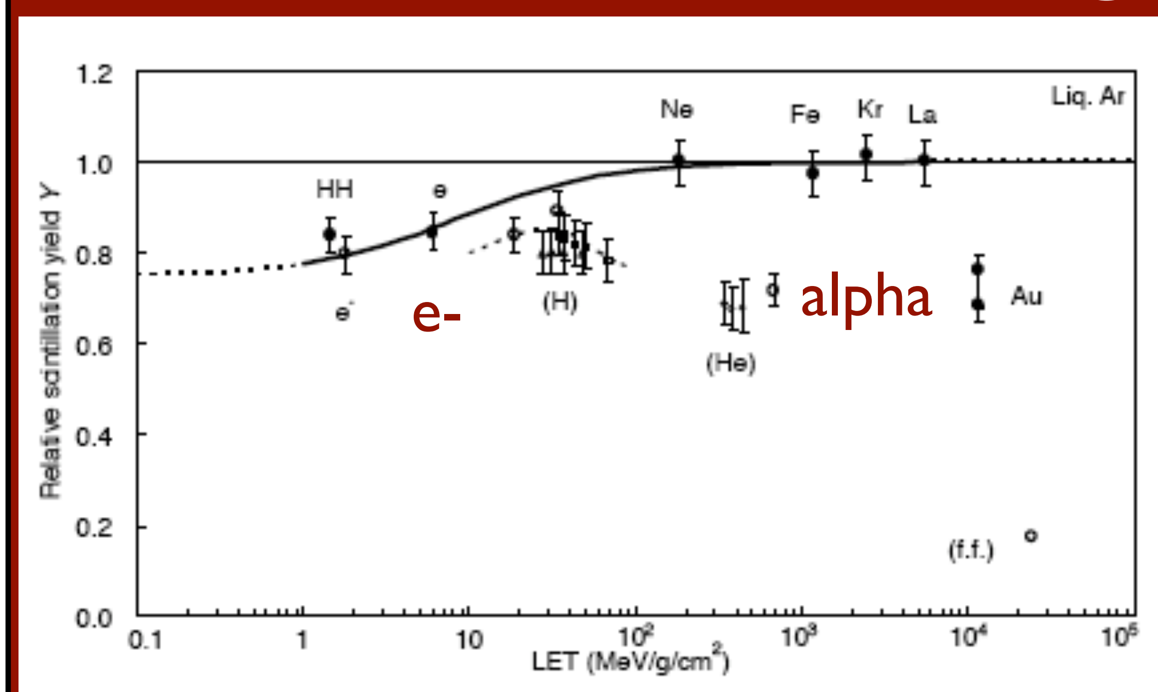
```
theScintProcess4Electron = new G4Scintillation("Scintillation");
theScintProcess4Electron->SetScintillationYieldFactor(0.8);
theScintProcess4Electron->SetTrackSecondariesFirst(true);
theScintilProcessElectron->SetScintillationExcitationRatio(0.23);
theScintProcess4Electron->SetVerboseLevel(OpVerbLevel);
```

- ➡ Defining a new Scintillation Process
- ➡ Yield Rescaling
- ➡ Fast/Total ratio for electron

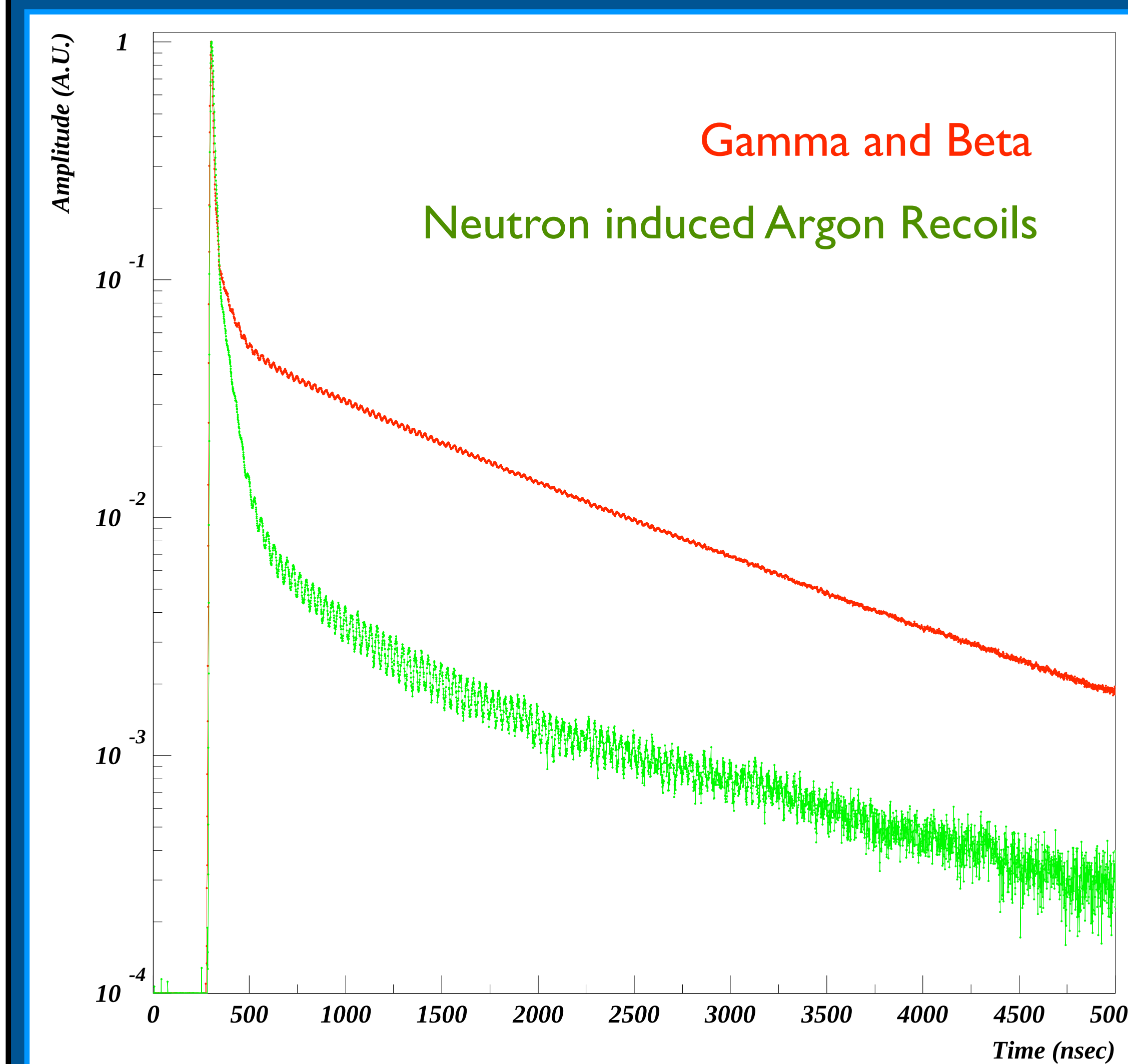
ionization density effect on Scintillation Yield

$Y_{e^-} = 0.8\,Y$ $\quad Y_{alpha} = 0.7\,Y$ $\quad Y_{recoils} = 0.2\text{-}0.4$

@ zero E field



Doke et al, J. Appl. Phys. 41 (2002)1538



LAr Scintillation implementation

```
LArMPT->AddProperty("FASTCOMPONENT",LAr_SCPP,LAr_SCIN,num);
LArMPT->AddProperty("SLOWCOMPONENT",LAr_SCPP,LAr_SCIN,num);

LArMPT->AddProperty("FASTCOMPONENT",Scnt_spe,Scnt_pp,scinum);
LArMPT->AddProperty("SLOWCOMPONENT",Scnt_spe,Scnt_pp,scinum);
LArMPT->AddConstProperty("FASTTIMECONSTANT", 7.*ns);
LArMPT->AddConstProperty("SLOWTIMECONSTANT",1400.*ns);
LArMPT->AddConstProperty("YIELDRATIO",0.75);
LArMPT->AddConstProperty("SCINTILLATIONYIELD",scint_yield);
G4double fano = 0.11;// Doke et al, NIM 134 (1976)353
LArMPT->AddConstProperty("RESOLUTIONSCALE",fano);
```

"[...]
The actual number of emitted photons during a step fluctuates around the mean number of photons with a width given by

*ResolutionScale*sqrt(MeanNumberOfPhotons)*
[...]"

statistical yield fluctuation can be broadened or narrower (impurities, fano factor)

LAr Fano factor = 0.11

(Doke et al, NIM 134 (1976)353)

RESOLUTIONSCALE according to the presence of the fano reduction

light collection system

Two kind of layers
in visible range

✓ TPB evaporated on VM2000*:
an high reflective layer in order to improve light collection efficiency

✓ TPB-Polystyrene mixture:
an high transparence layer for coating the PMT windows in order to shift direct XUV light and transmit optical photons

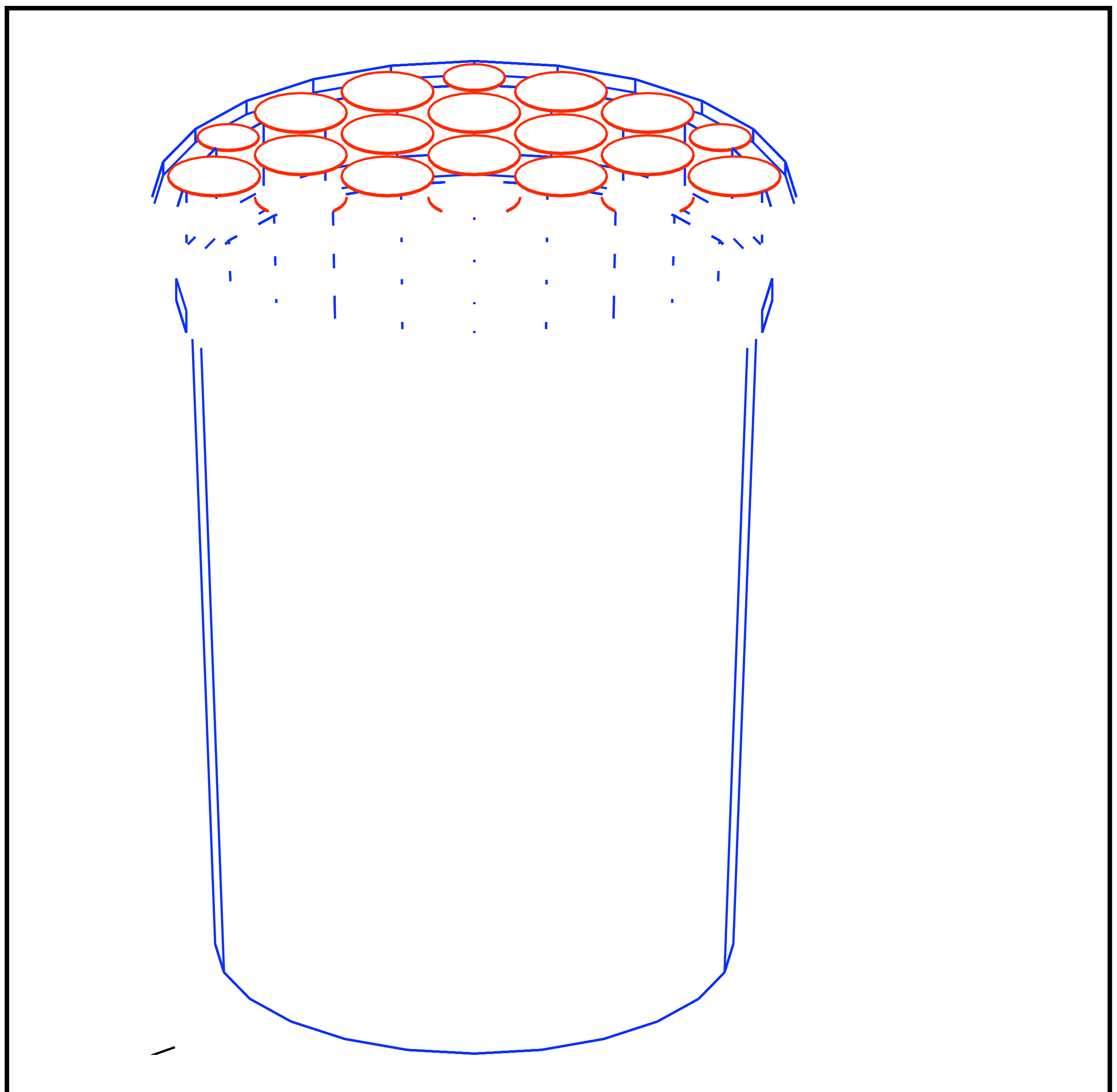
*dielectric mirror

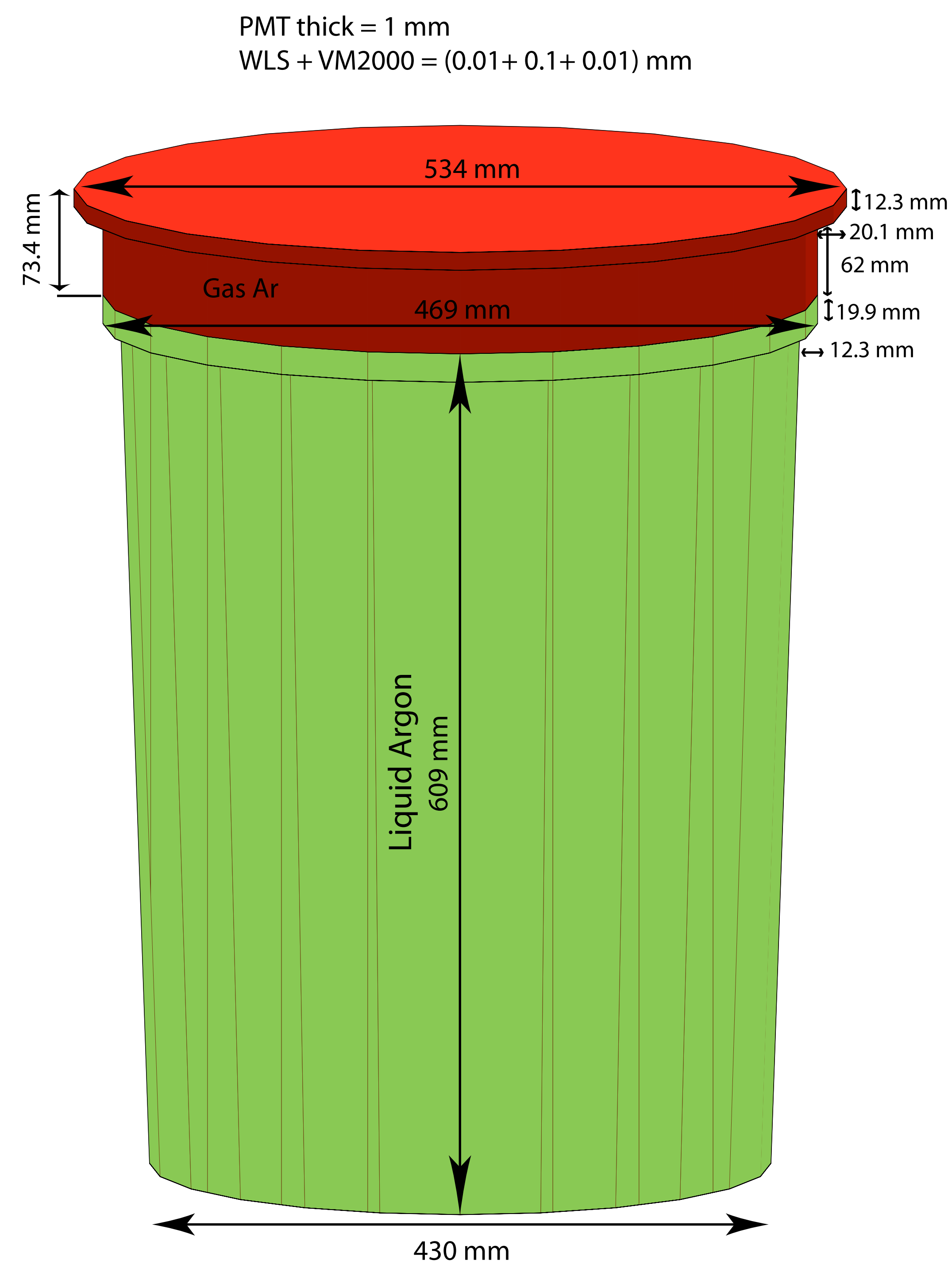
In order to characterize the optical properties of the light collection system a <u>series of measurements have been performed in collaboration with ENEA</u>

Detector Geometry Simulation

Detailed Simulation of the inner detector:

- Liquid & Gas Argon Volumes
- TPB evaporated Mirror foils
- TPB-Polystyrene coated PMTs Glass

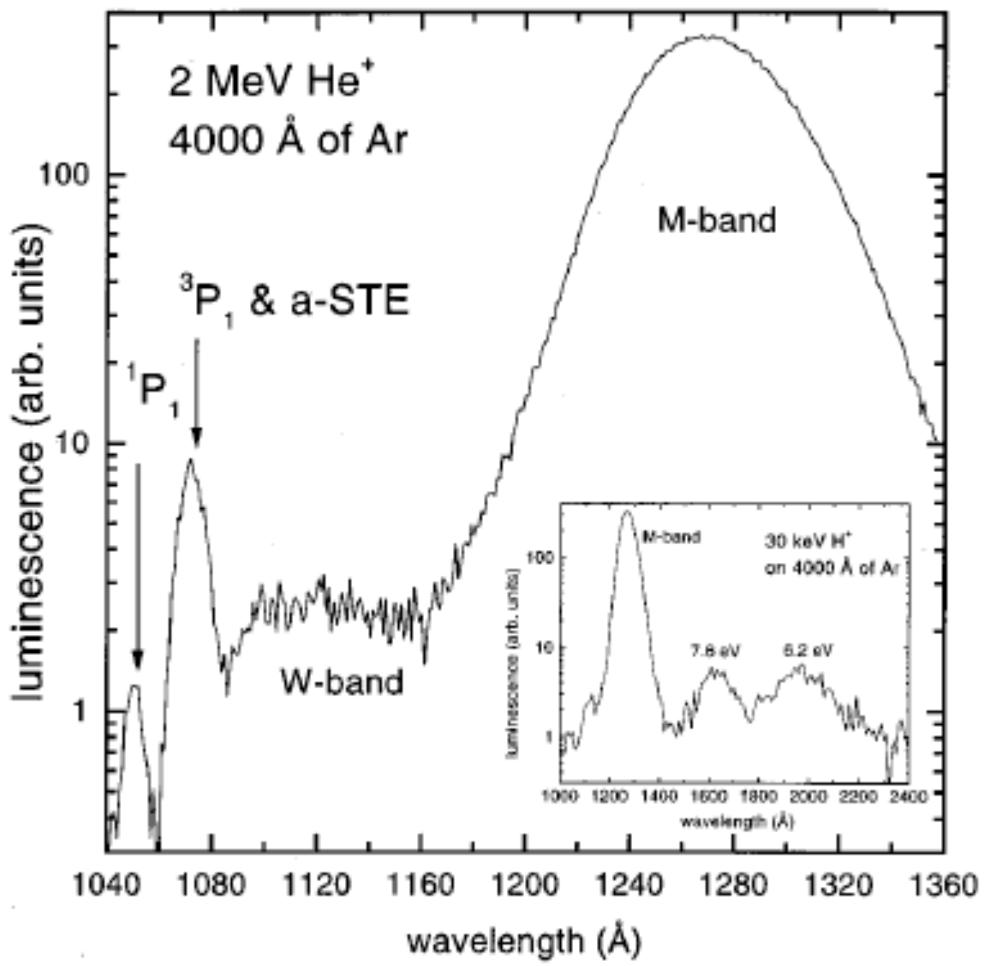




WArP WaveLength Shifting

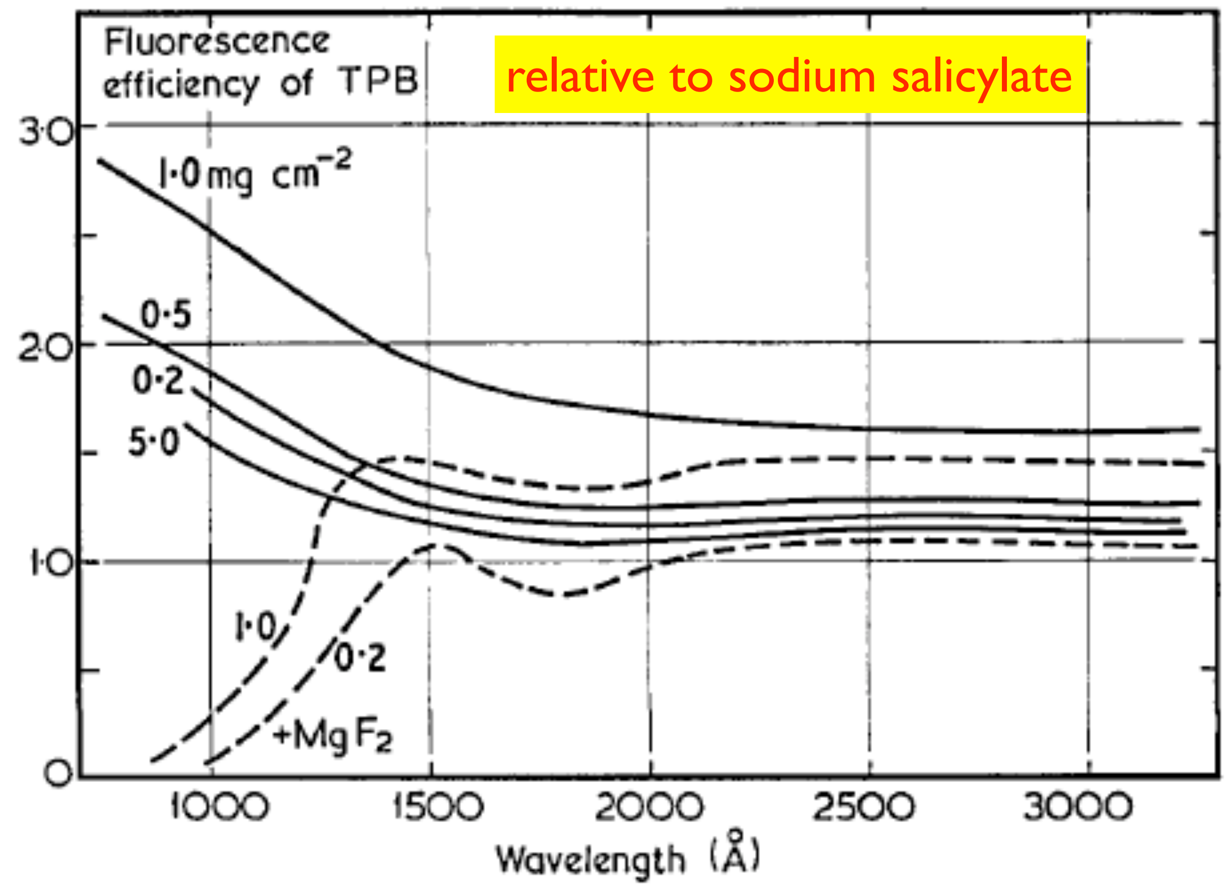
Discrimination power is very sensitive to the number of collected photons

Argon scintillation light is emitted with a narrow spectrum peaked @ 128 nm



PMTs efficiency is very low in the XUV wavelength region (glass transmittance)

Wavelength shift is needed. Solution we choose is Tetra-Phenyl-Butadiene (TPB)



TPB: high XUV conversion efficiency @ λ = 128 nm probably higher than 1 (depending on TPB thickness)

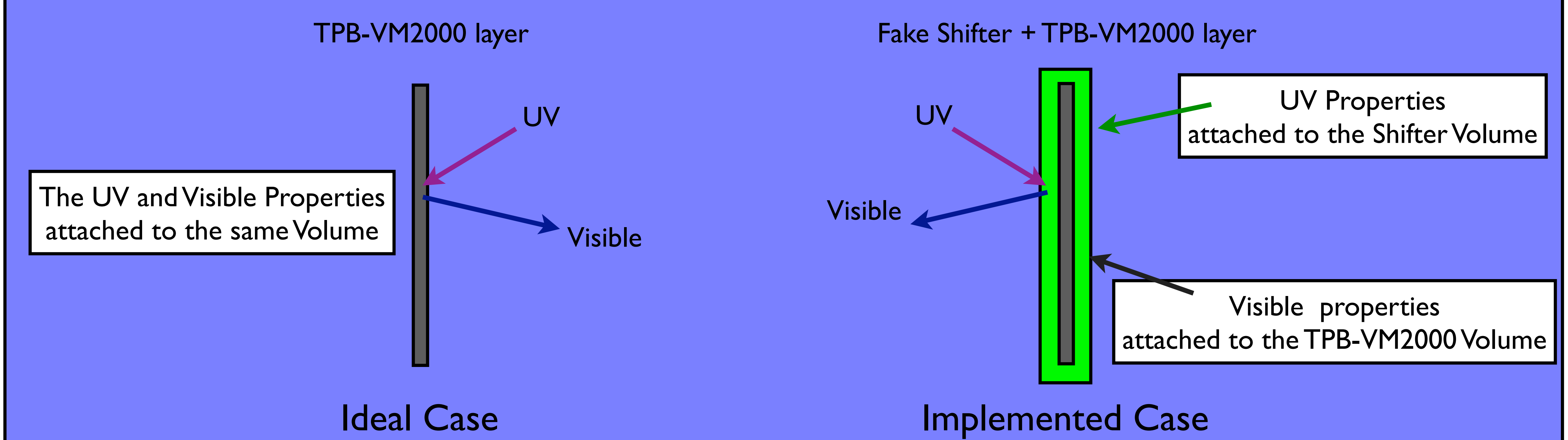
Detector Geometry Simulation

A unique layer with wavelength shifting and Optical Boundary Process properties (T, R,..) but:

- Wavelength Shifting is attached to a Material;
- Optical Boundary Processes implemented using the concept of *Surface*.

Implementation Strategy

WLS properties attached to a thin volume surrounding the layers with Optical Boundary Properties

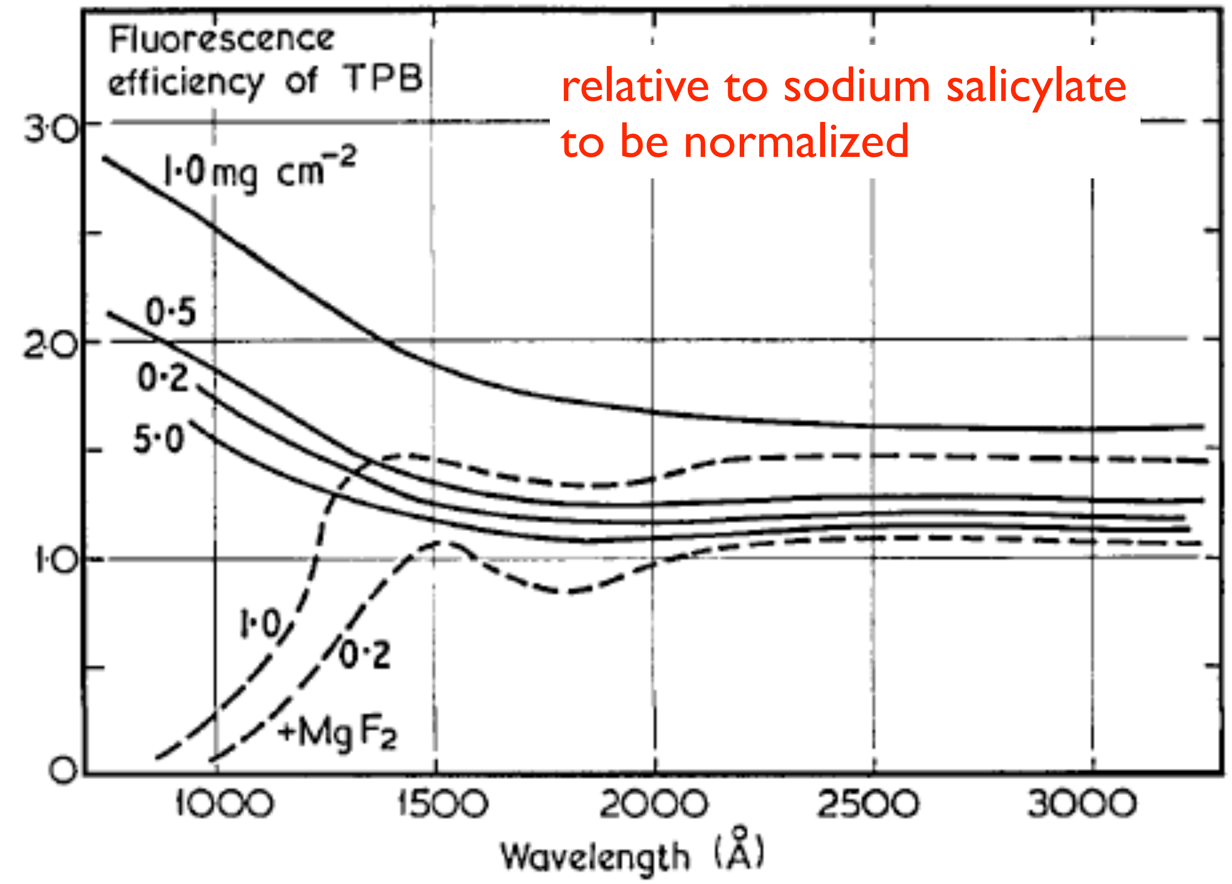


In similar cases can be useful an implementation of WLS attached to a Surface!

Wavelength Shifter Implementation

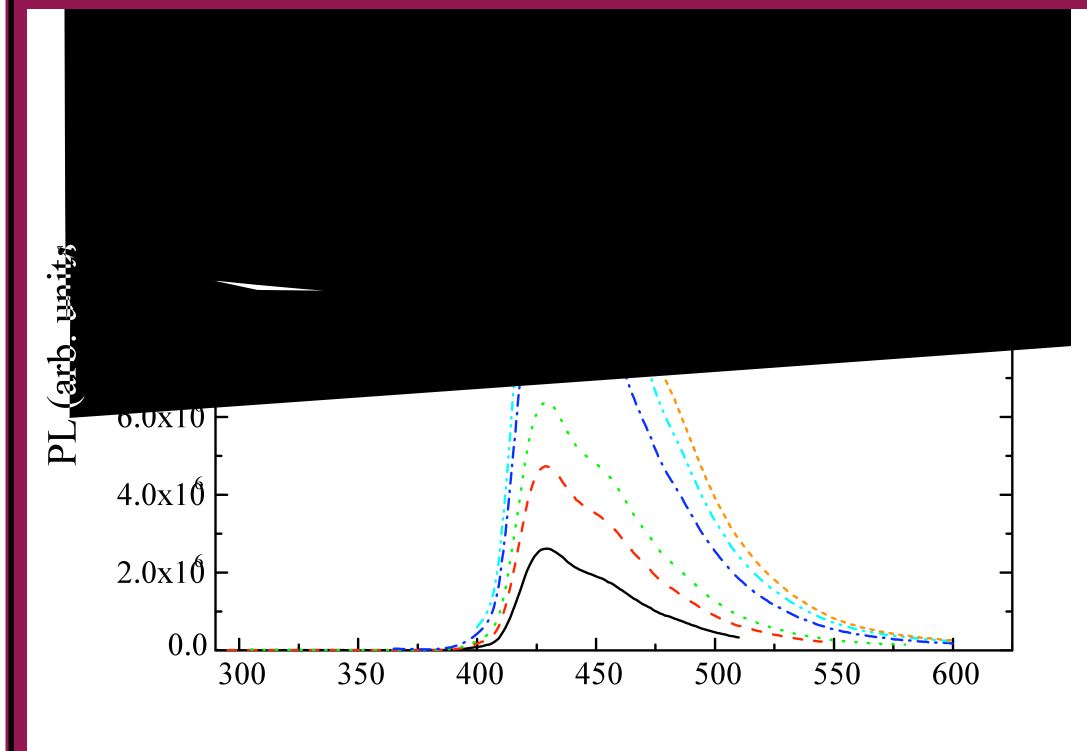
- Photon Absorption (as function of λ)
- Photon Emission Spectrum (as function of λ)
- Time delay from Absorption to Reemission

```
//-------Liquid argon Shifter

density = 1.4*g/cm3;

G4Material* WLSLAr = new G4Material
    (name="WLSLiquidArgon",density,ncomponents=1);

WLSLAr->AddElement(Argon,1.0);

//-----------------------------------------
```

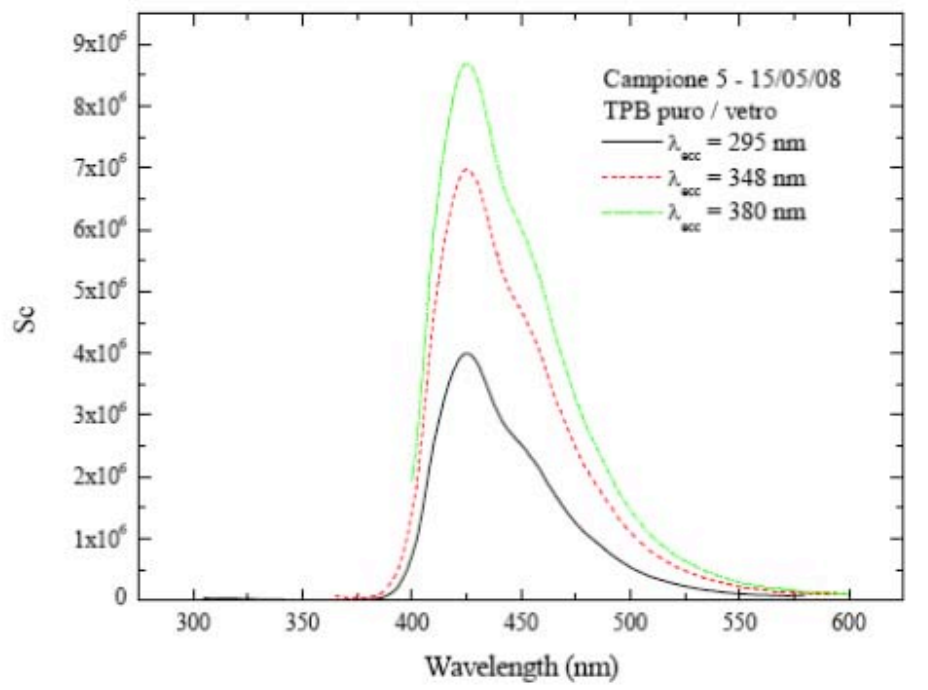


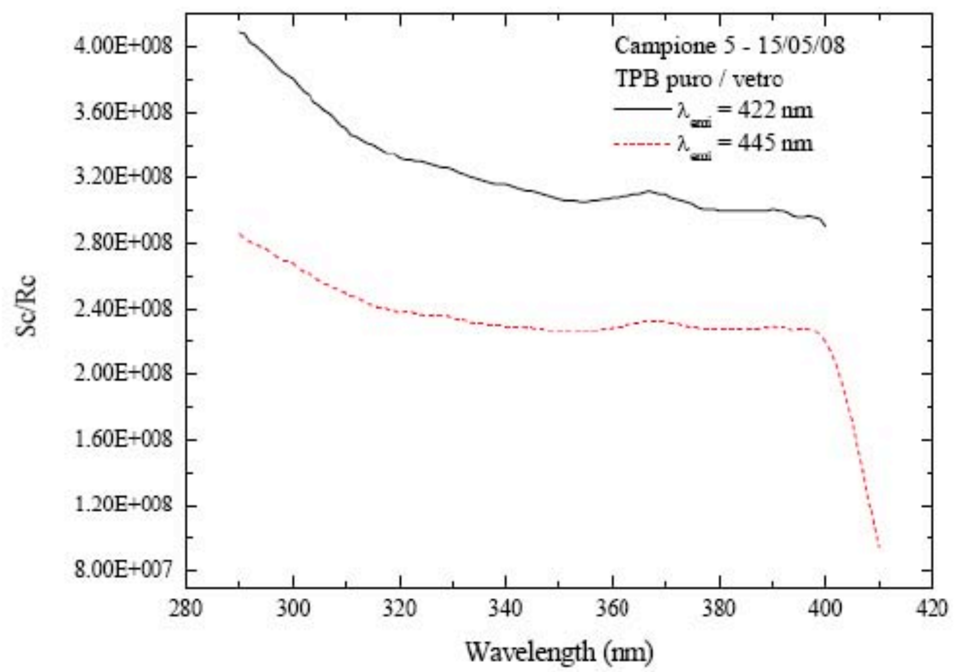

```
const G4int qua=4;
G4double ene_abso_WLS[qua]={10.0*eV, 9.0*eV,8.99*eV,2.*eV};
G4double abso_WLS[qua]={0.001*nm,0.001*nm,100000*m,100000*m};//100% shift efficency @ 128 nm

G4MaterialPropertiesTable* WLSMPT = new G4MaterialPropertiesTable();
WLSMPT -> AddProperty("WLSABSLENGTH",ene_abso_WLS,abso_WLS,qua);
WLSMPT -> AddProperty("WLSCOMPONENT",WLSenergy,WLS_Emission,NUMWLS);
WLSMPT -> AddConstProperty("WLSTIMECONSTANT",0.01*ns);
```

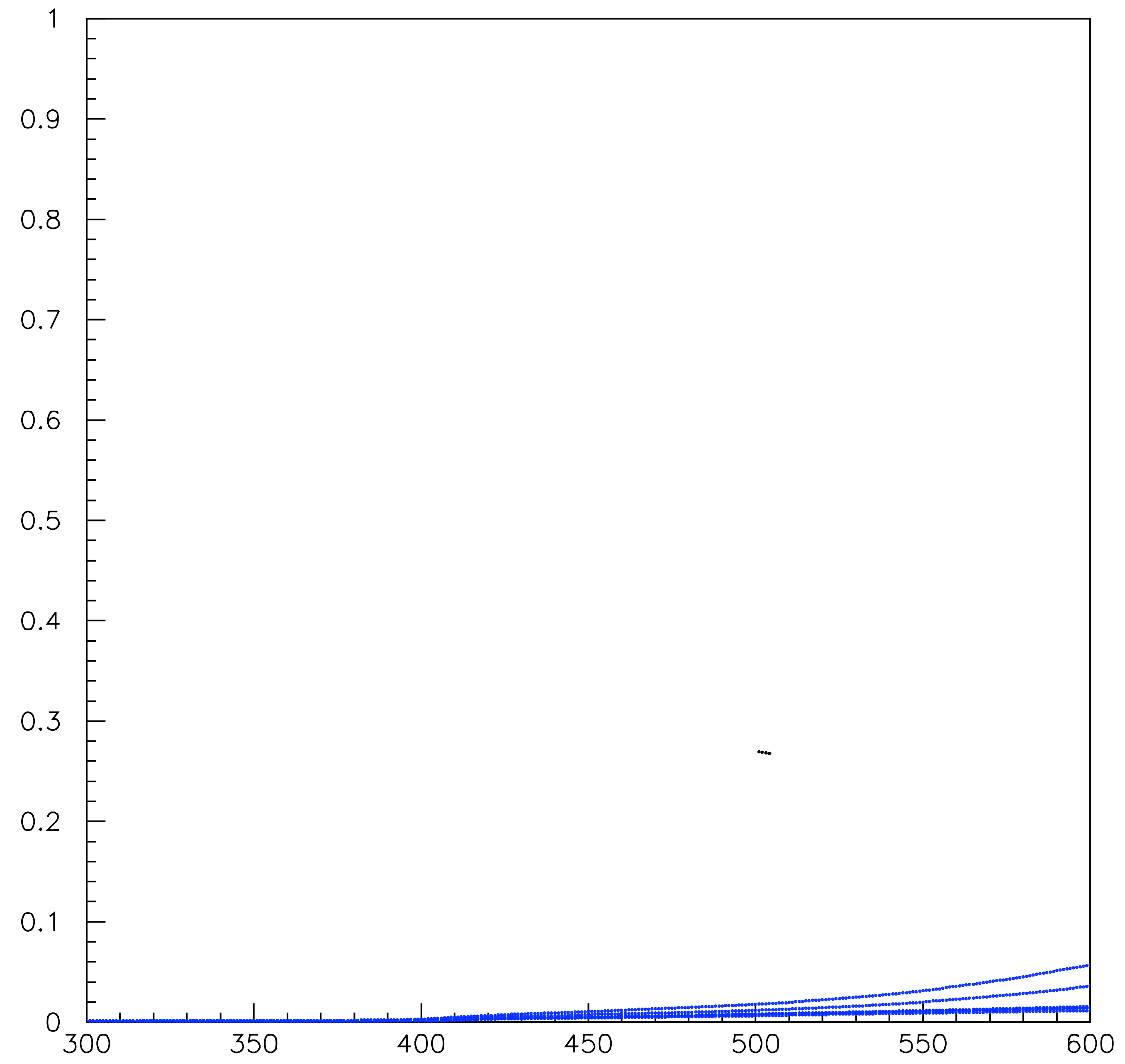
Wavelength Shifter Implementation



Evaporated TPB on glass





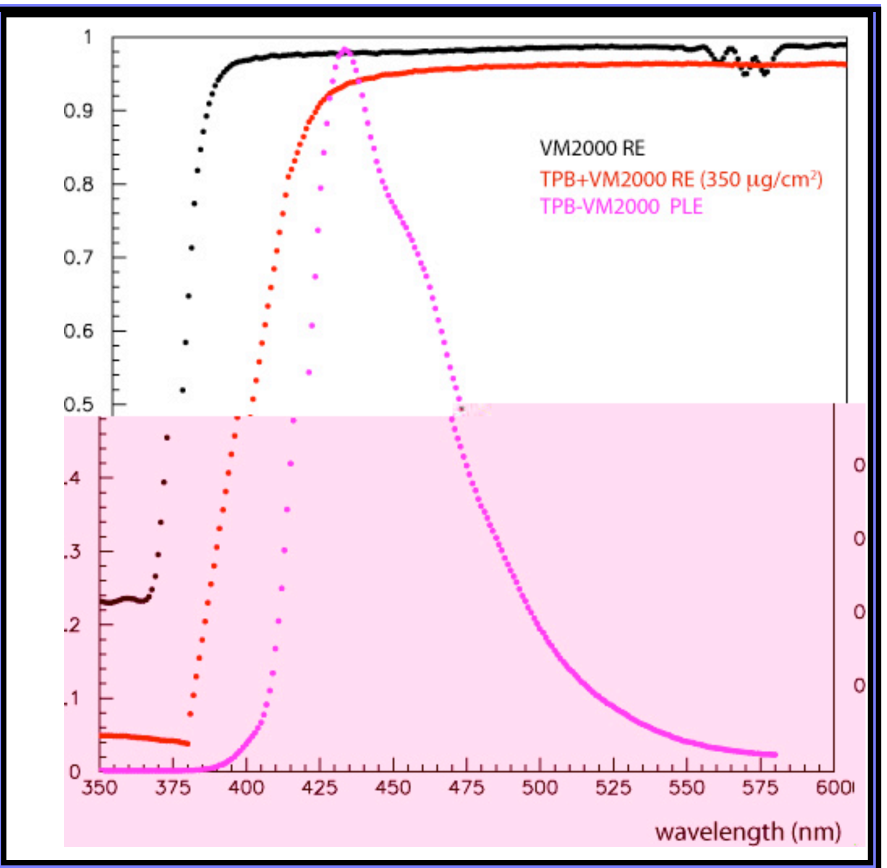


Boundary Processes Implementation

Evaporated TPB on VM2000

1. A very diffusive substrate (TPB) on a Mirror
2. Layer RINDEX not known
3. Also TPB thickness not known
4. VM2000 has almost null T: fully characterized by R

- ➡ SkinSurface
- ➡ dielectric-dielectric
- ➡ groundfrontpainted (only Lambertian Reflection)

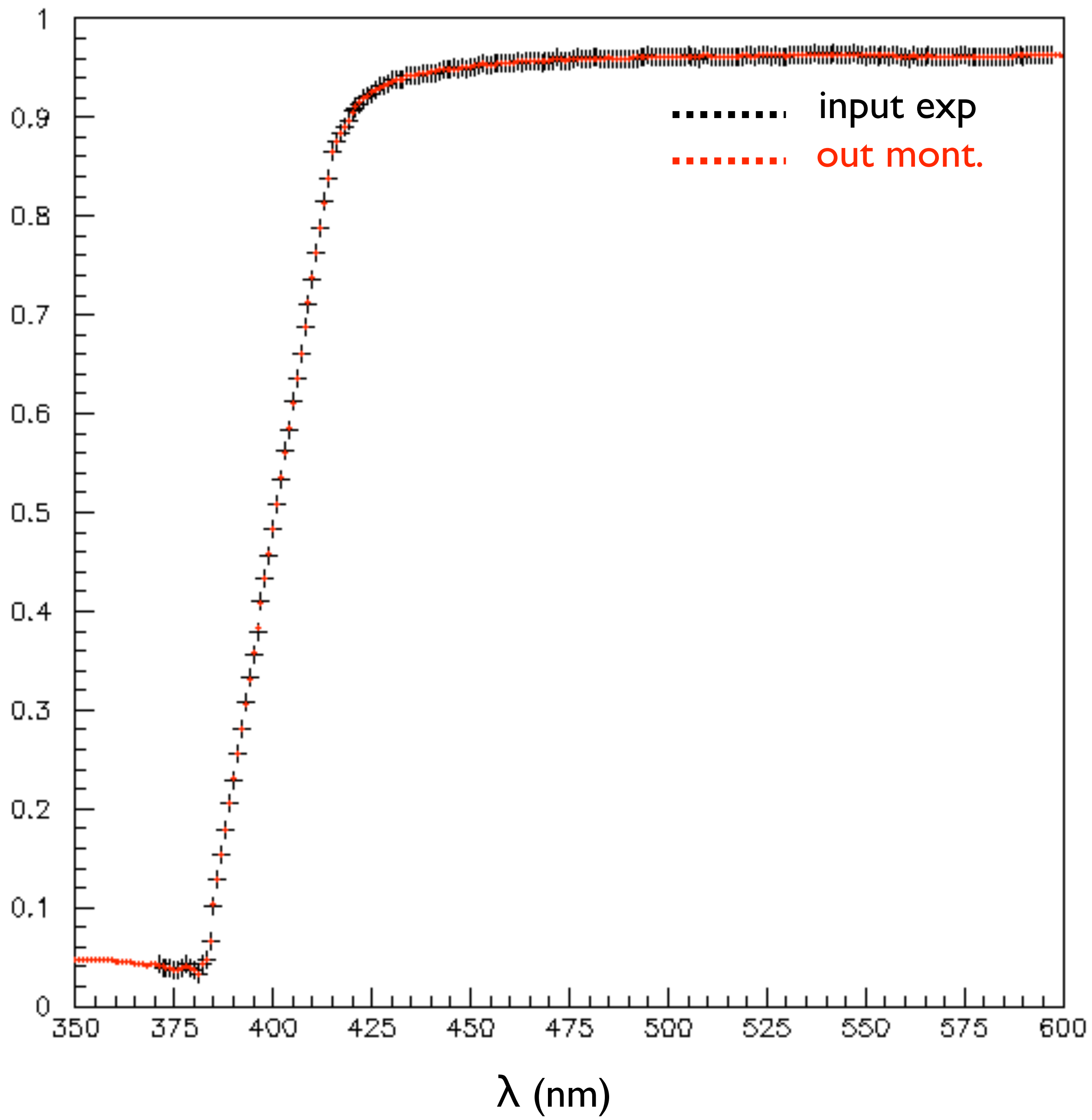



```
G4OpticalSurface* OpSurface = new G4OpticalSurface("OpS1");
G4LogicalSkinSurface* Surface = new G4LogicalSkinSurface("OpS1",VM2000_log,OpSurface);
OpSurface -> SetType(dielectric_dielectric);
OpSurface -> SetFinish(groundfrontpainted);
G4MaterialPropertiesTable *OpSurfaceProperty = new G4MaterialPropertiesTable();

OpSurfaceProperty -> AddProperty("REFLECTIVITY",pp,reflectivity,NUM);
```

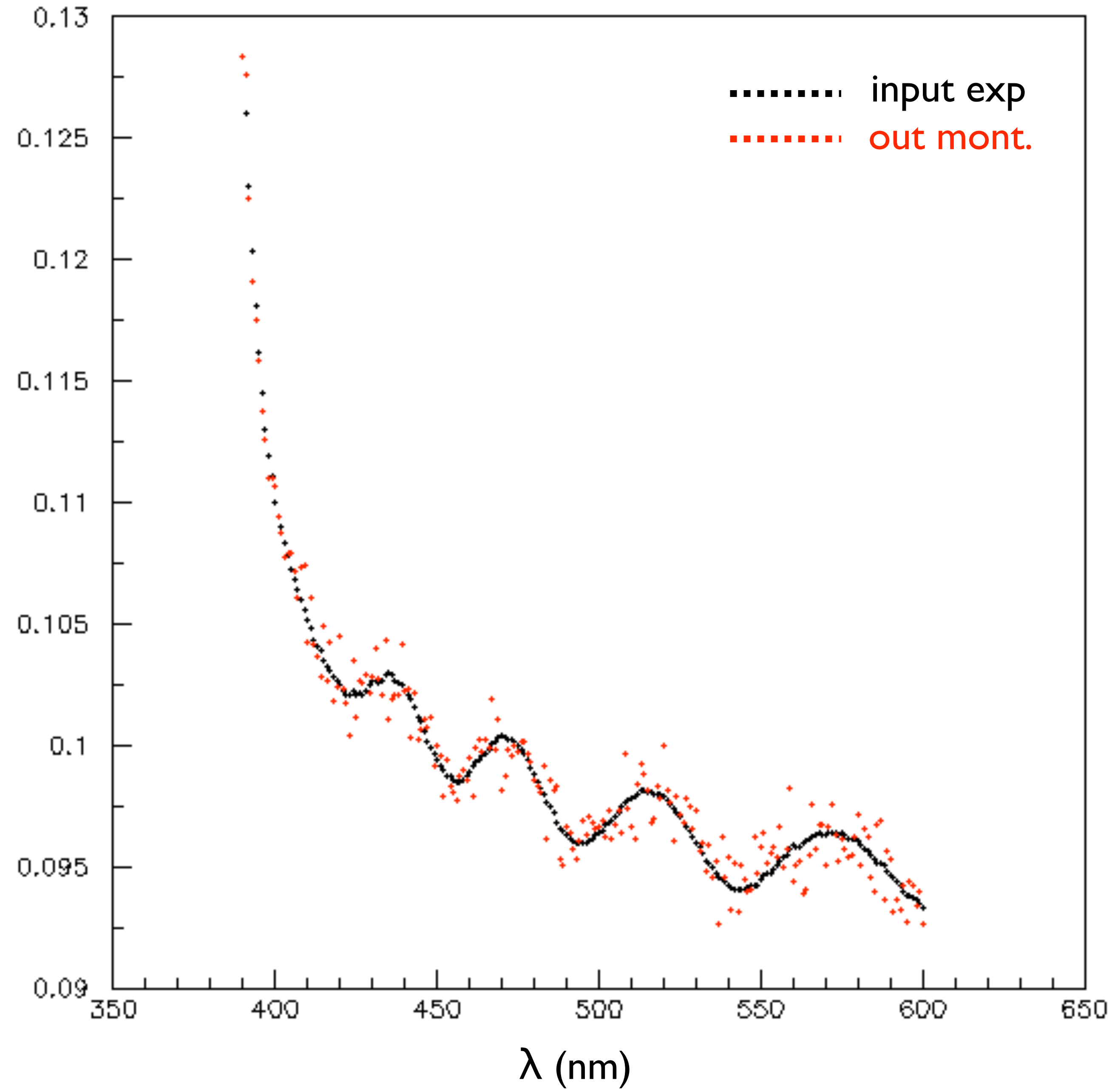
OpProperties Debugging

100000 Primary optical photon incidents with random angle on the surfaces

TPB-VM2000 Reflectance



TPB-Polystyrene Reflectance

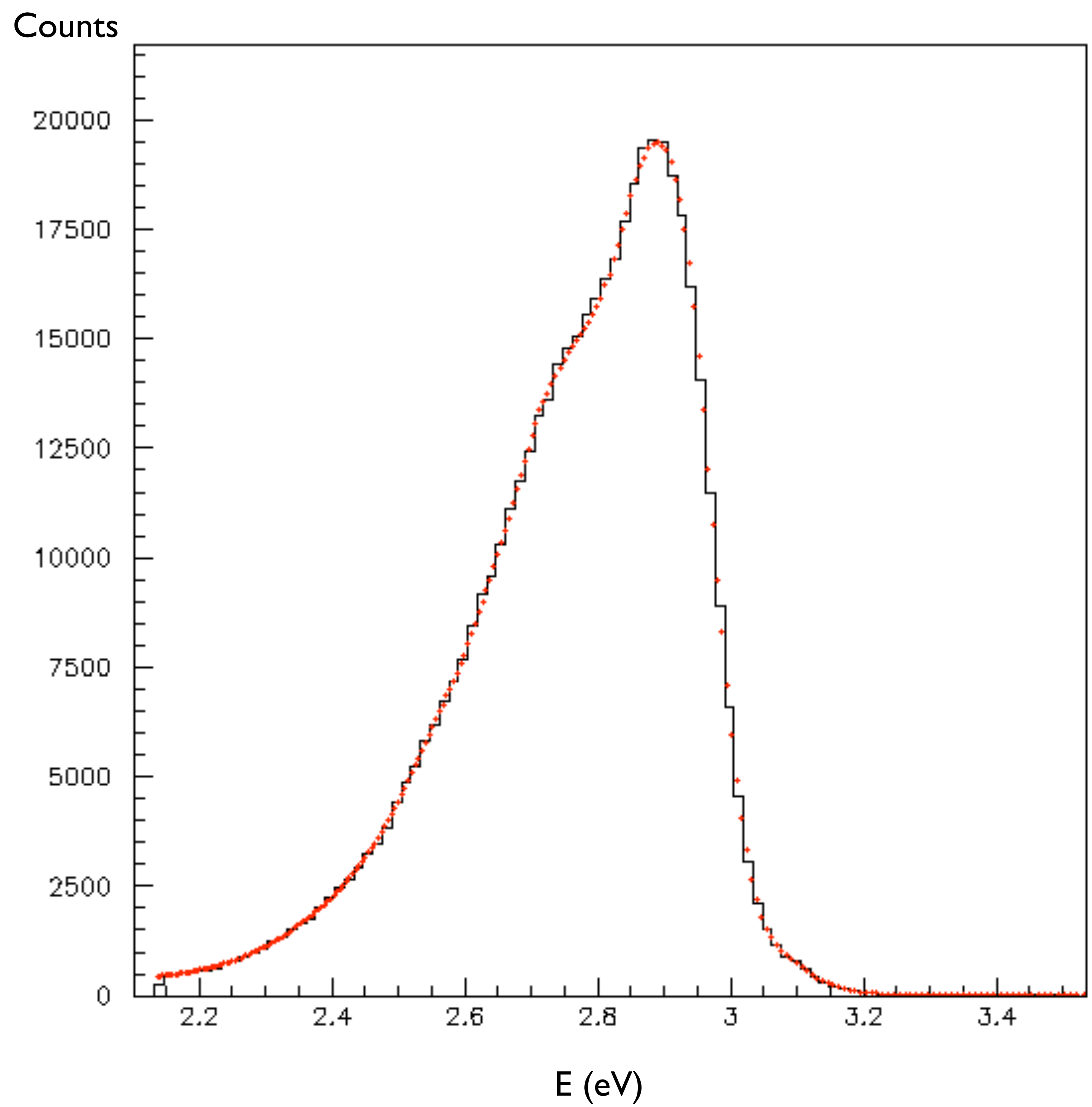


OpProperties Debugging

Fluorescence Spectrum

vs

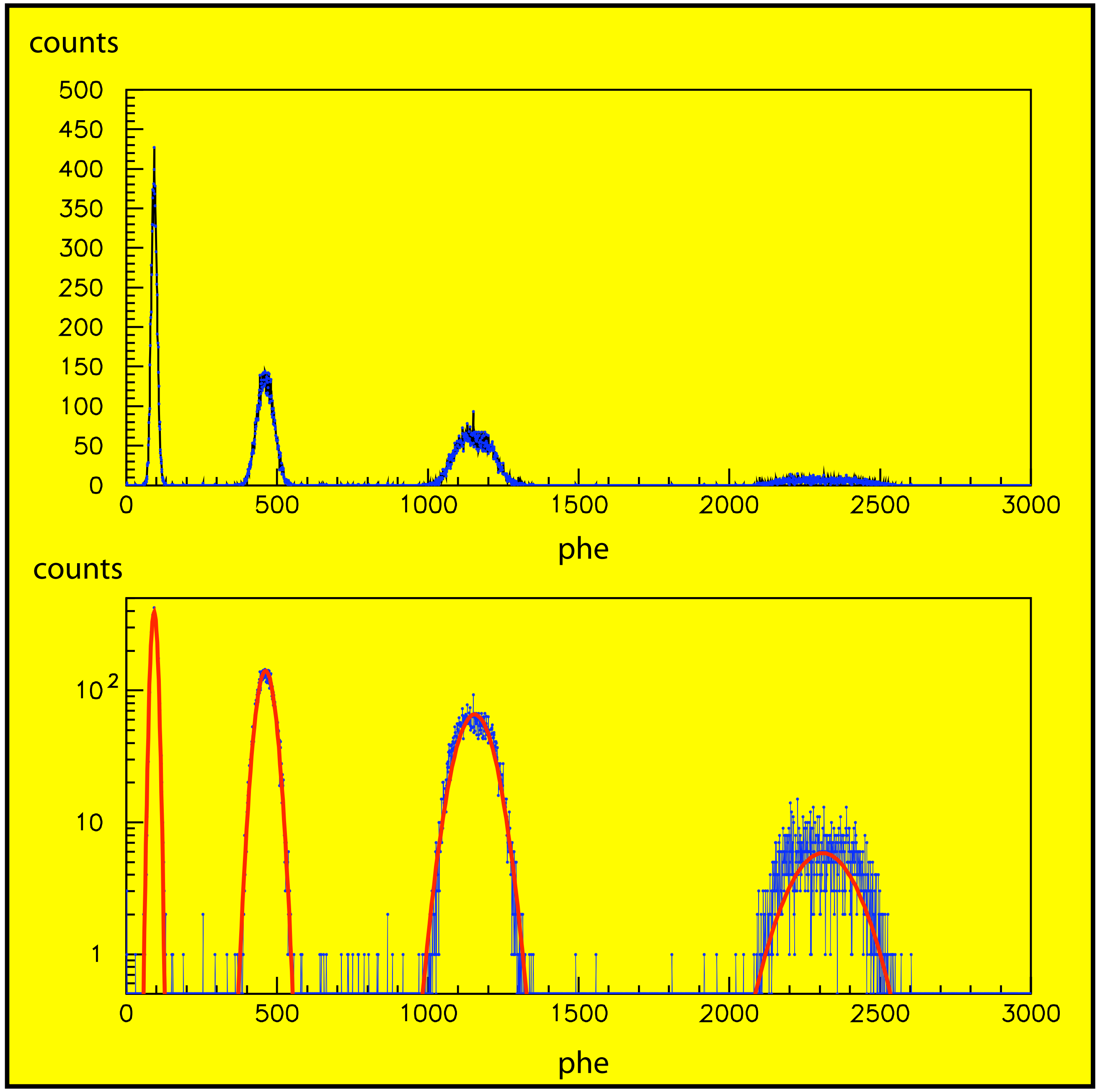
Energy Spectrum of the optical photons detected by the PMTs



Resolution Study

1. Monoenergetic e^- events (20,100,250,500) keV
2. Uniformly distributed in the LAr Volume
3. Fitted with the sum of 4 gaussian with:
   - ➡ $\sigma^2 = a + b\,(phe) + (c\ \ phe)^2$
   - ➡ free μ_i (also with constraints on μ_i ratios)

Montecarlo Light Yield = 4.6 phe/keV



Fit results

μ_1 = 92.8 (0.1)

μ_2 = 461.9 (0.3)

μ_3 = 1154.1 (0.6)

μ_4 = 2306 (4)

According to the primary E ratios

a = 1 (5)

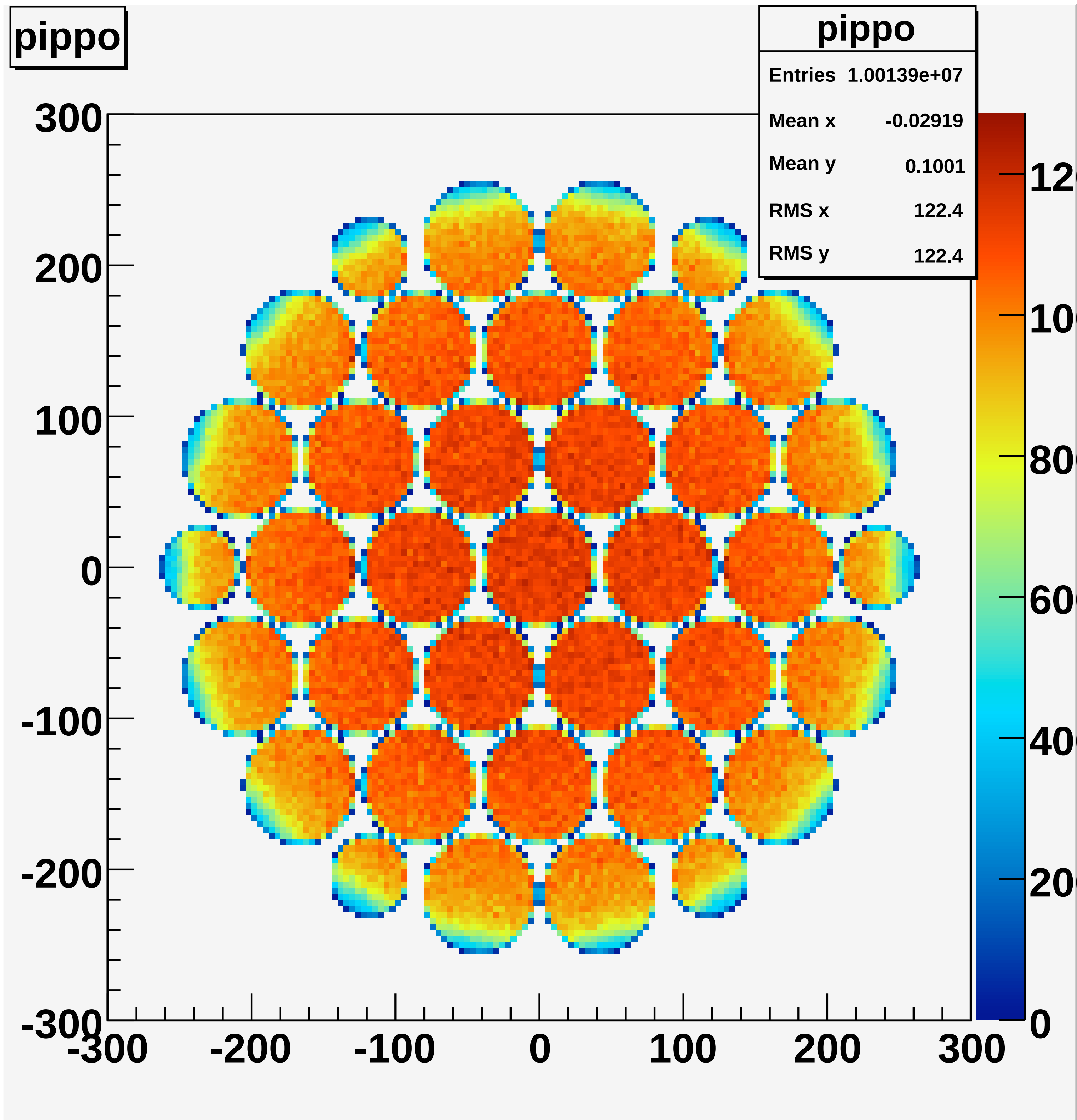
b = 0.84 (0.05)

c = 0.039 (0.001)

b according with expected binomial fluctuations

1-det_eff ≅ 0.89

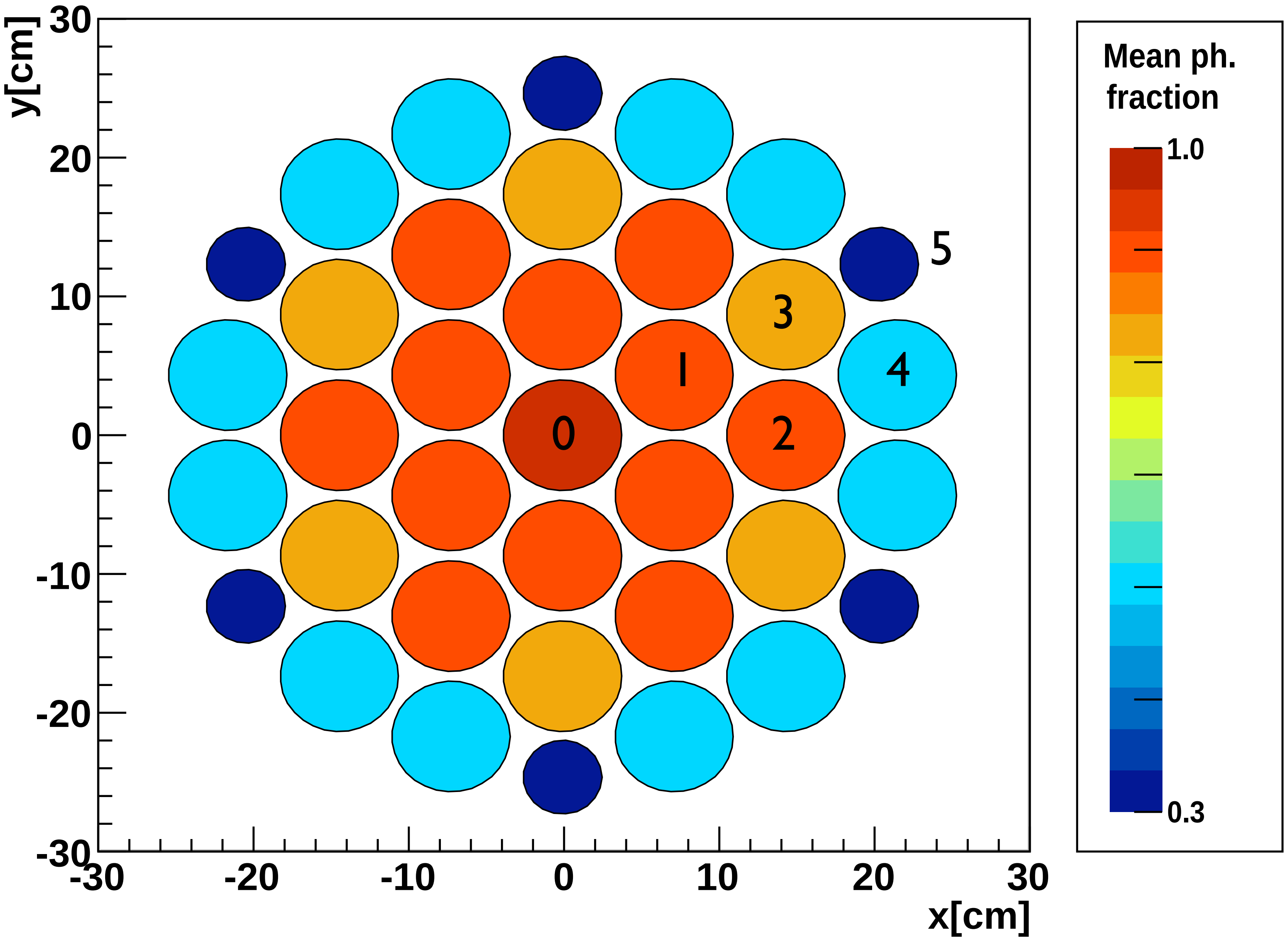
X-Y distribution on PMTs



- Primary Generated uniformly in the LAr volume
- There is a visible different collection efficiency, decreasing with R

distribution of hits on PMTs

- The number of photons detected by each phototube has been considered
- effective sensible surfaces for 3inch and 2inch (r=24 mm r=34 mm)
- The considered quantity is the relative efficiency, normalized to the most efficient PMT



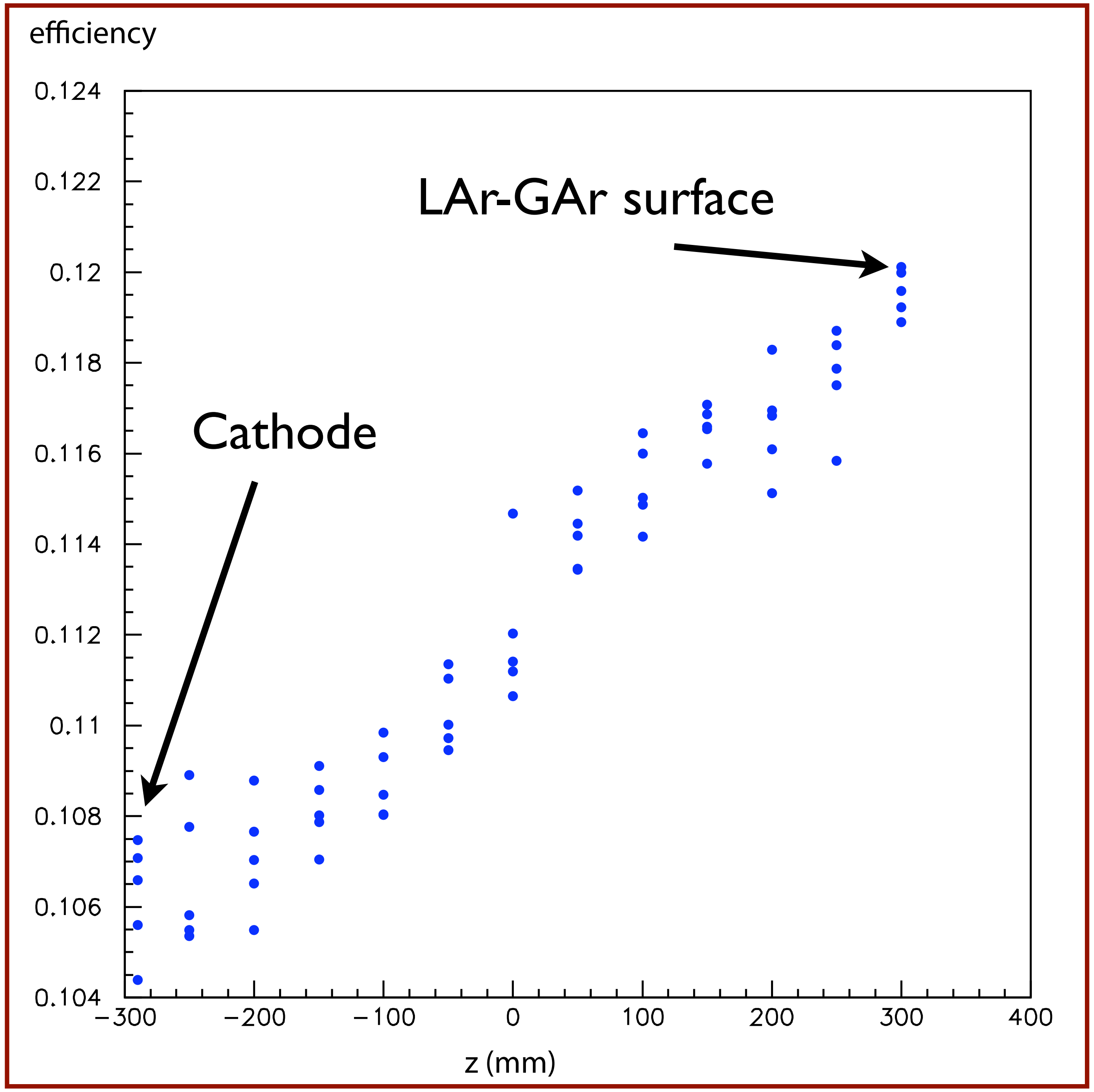
- the Most efficient is the PMT in the center
- Clear dependence on R
- 2inch PMTs have of course also smaller photocatode surface

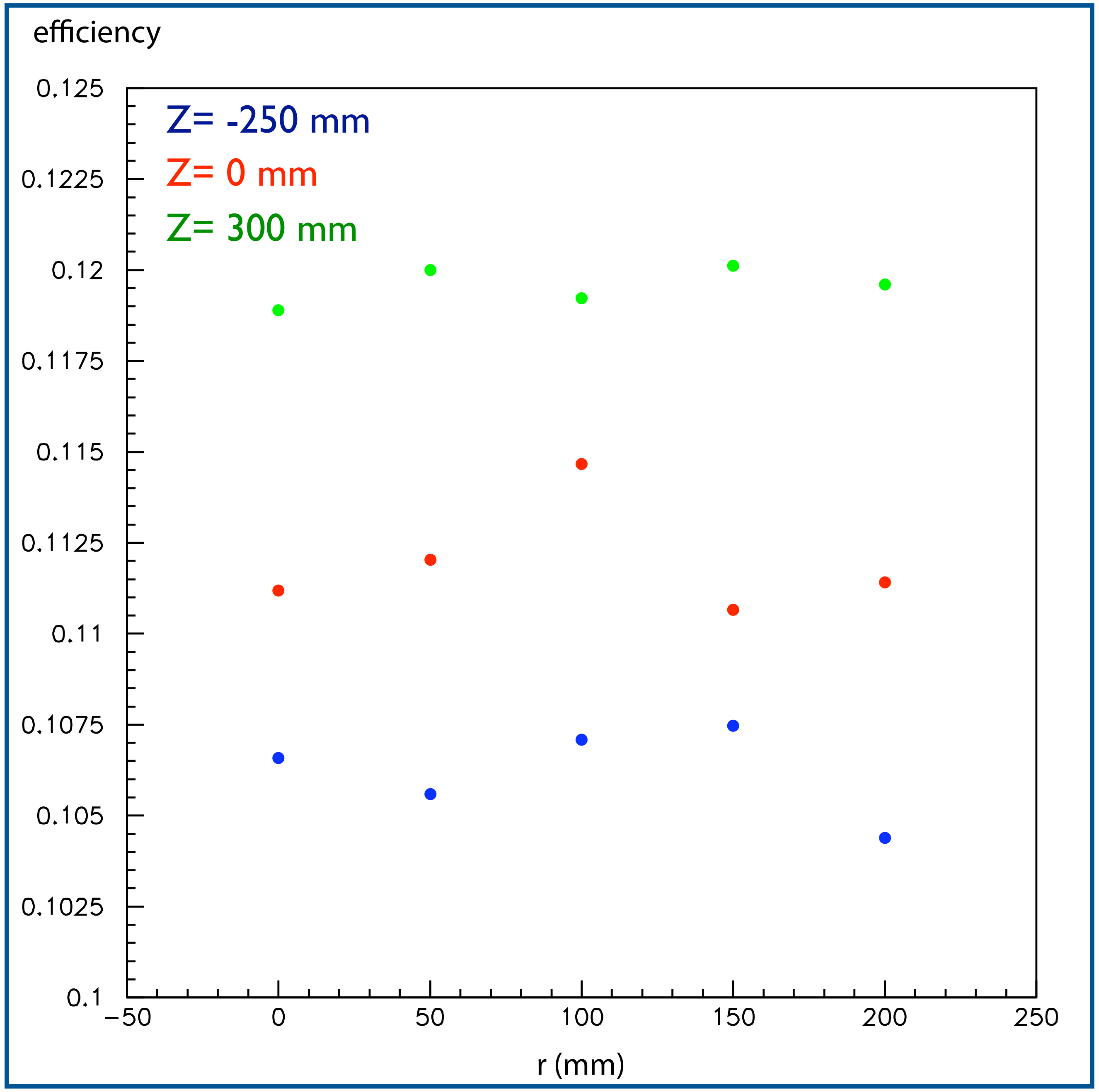
Efficiency ring values:

1. 0.99
2. 0.96
3. 0.94
4. 0.82
5. 0.33

Efficiency Vs Z,R

- bunches of 100.000 UV primary photons generated in a grid of 5 cm in Z & R
- Detection Efficiency defined as the ration between $N_{detected}/N_{Primary}$





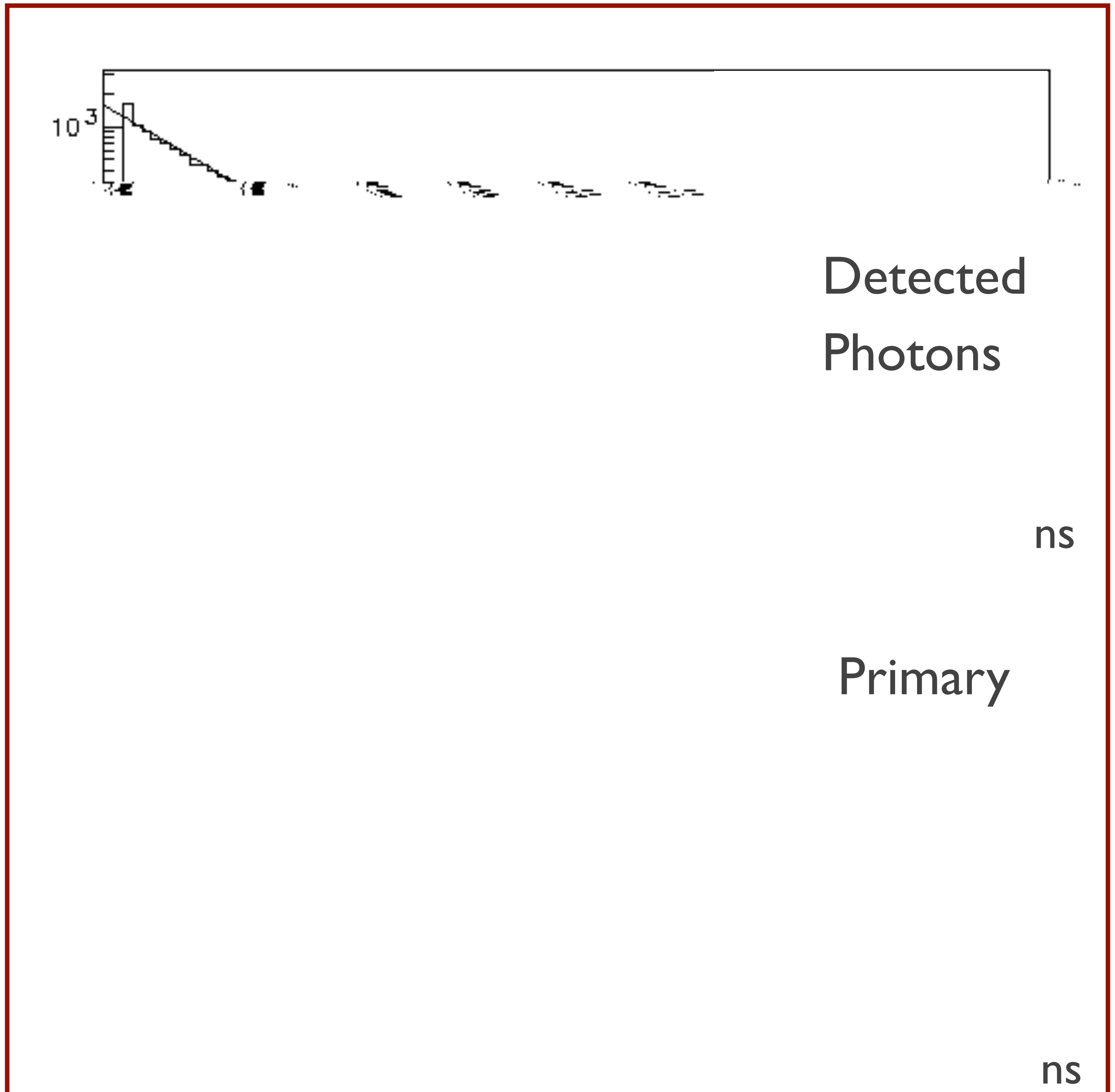
1. Efficiency of the oder of 10%

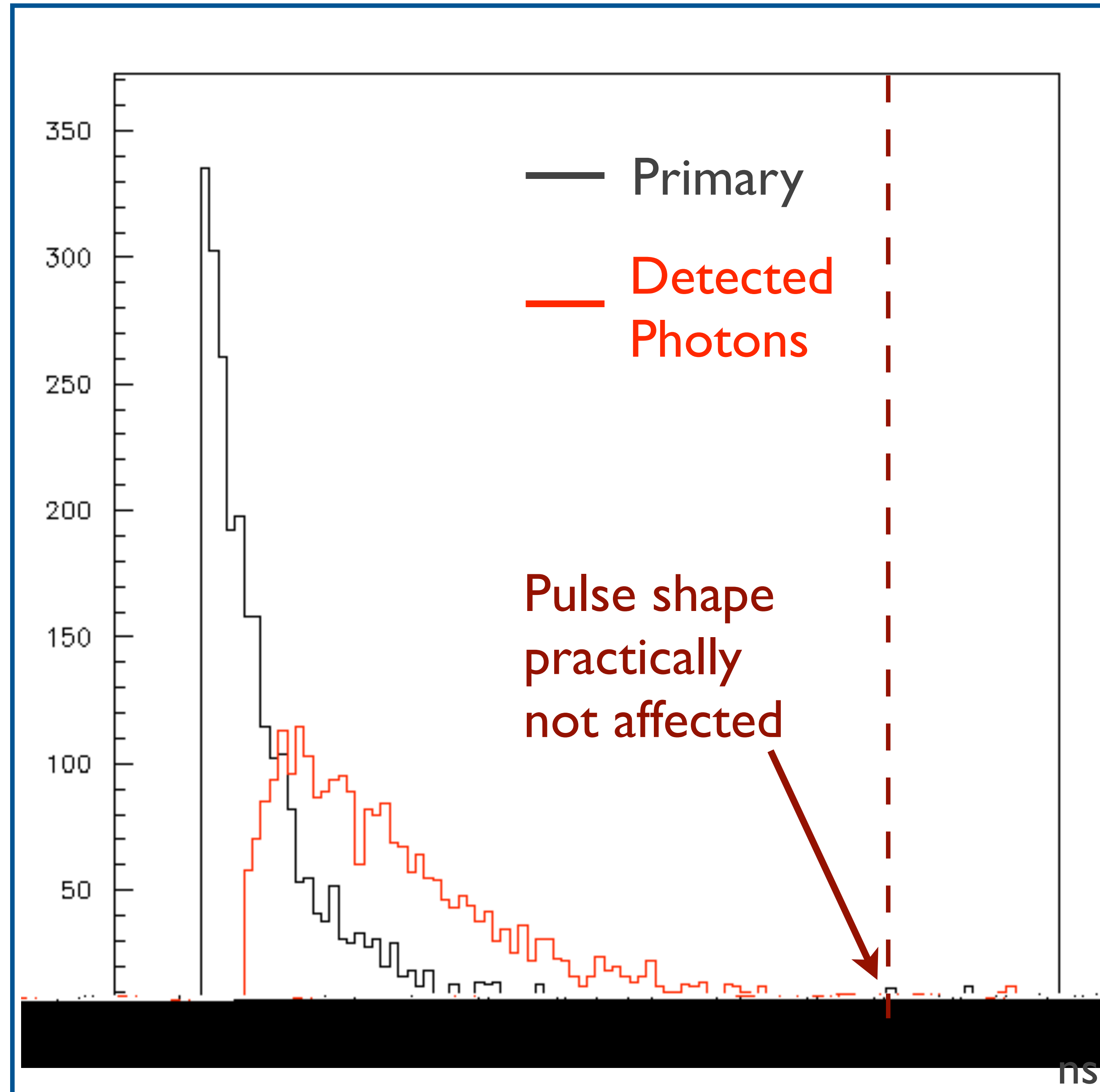
2. Increasing with Z (max variation 10 %)

3. no R dependence

Time Distribution

- 100.000 UV primary photons uniformly in the LAr Volume
- primary time fixed at zero (left) and according LAr scintillation decay times (right)



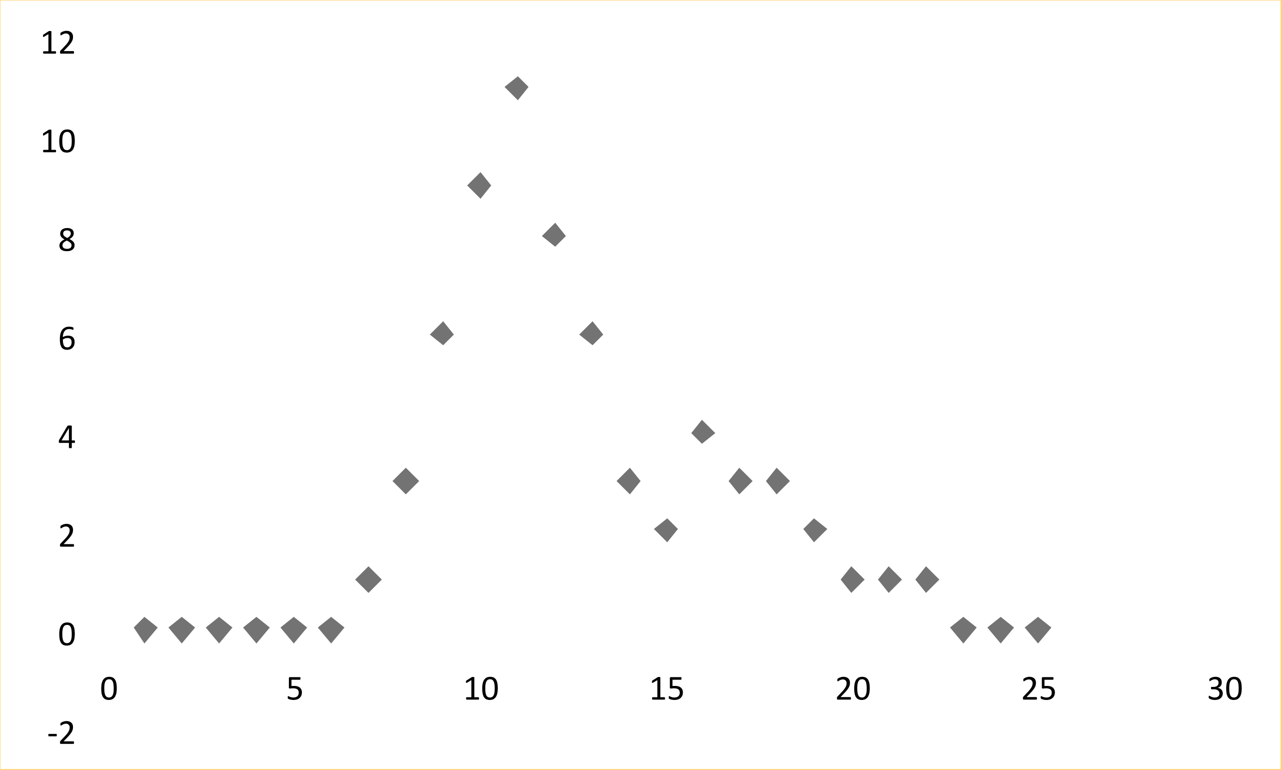


Detector time response is approximately exponential with "decay time" of 10.5 ns

Signal Simulation

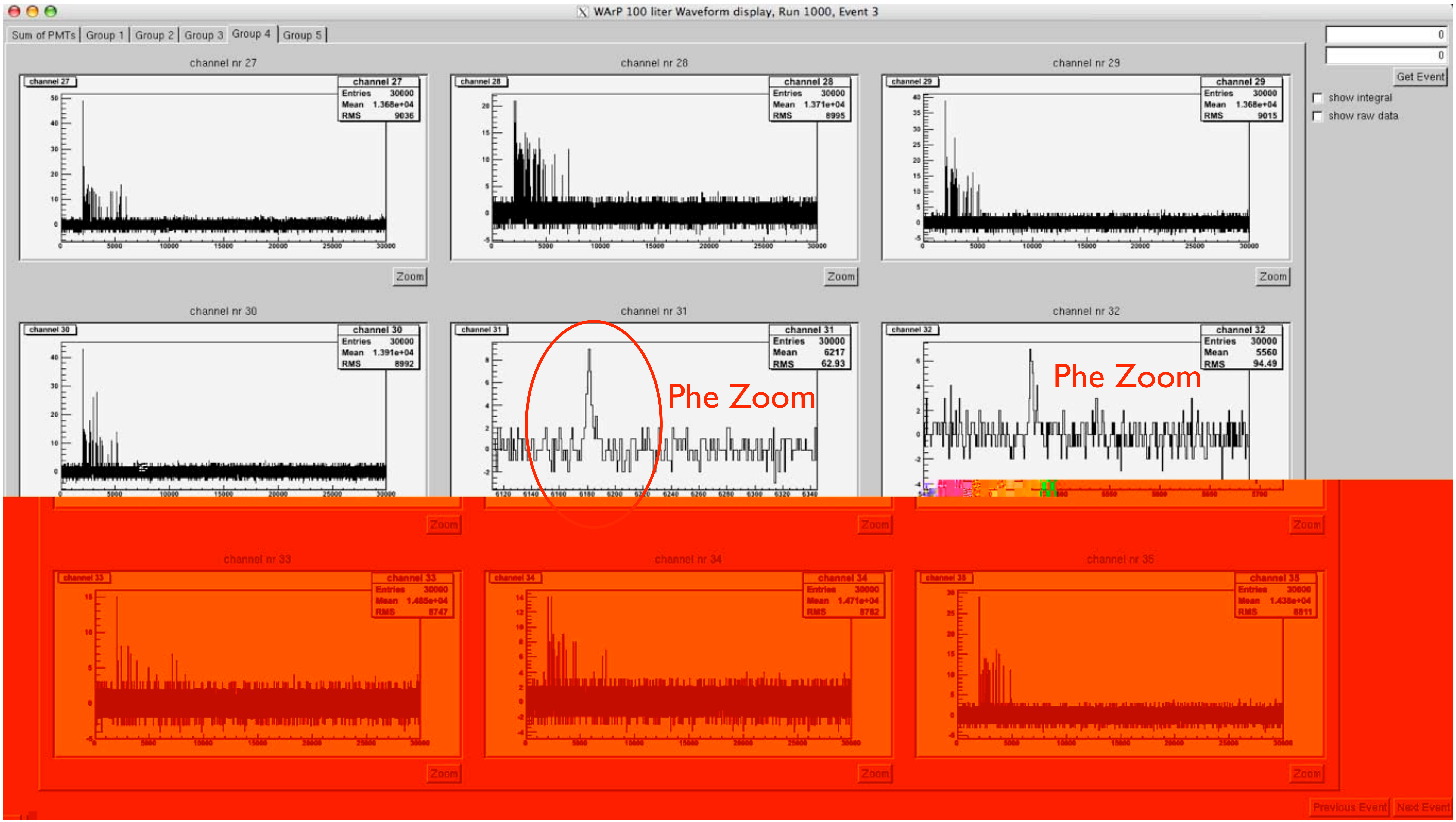
A dedicated C++ code has been made to simulate the electronics response:

- SER
  - ➡ SER shape obtained looking at real single photonelectrons shape in the acquired data
  - ➡ Convolution of the single hits
  - ➡ SER amplitude values and it's spread for each phototube according to experimental values

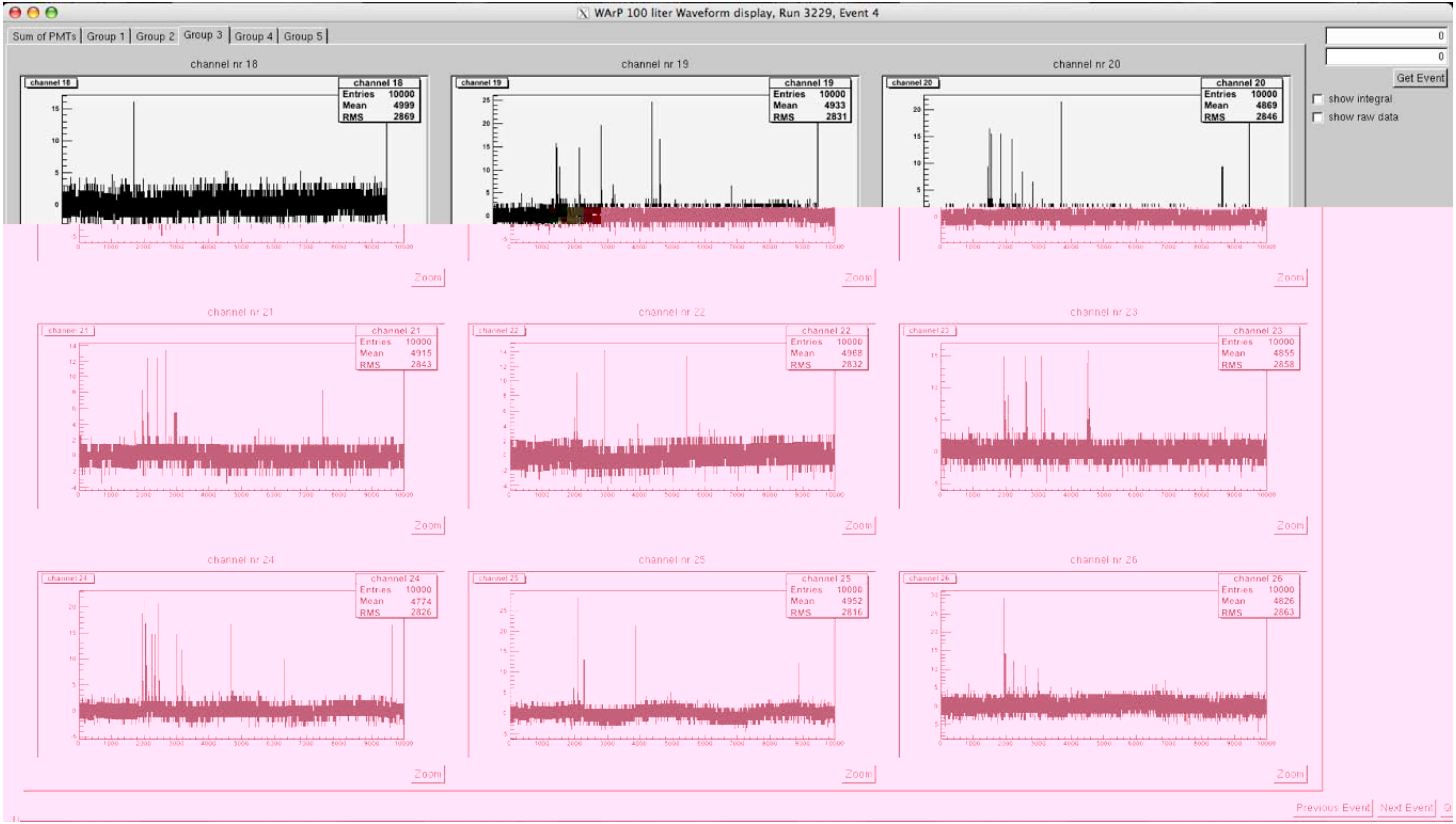


- noise
  - ➡ noise simulated using simple gaussian fluctuations around the baseline
  - ➡ Noise from exp. data: to be implemented

Signal Simulation

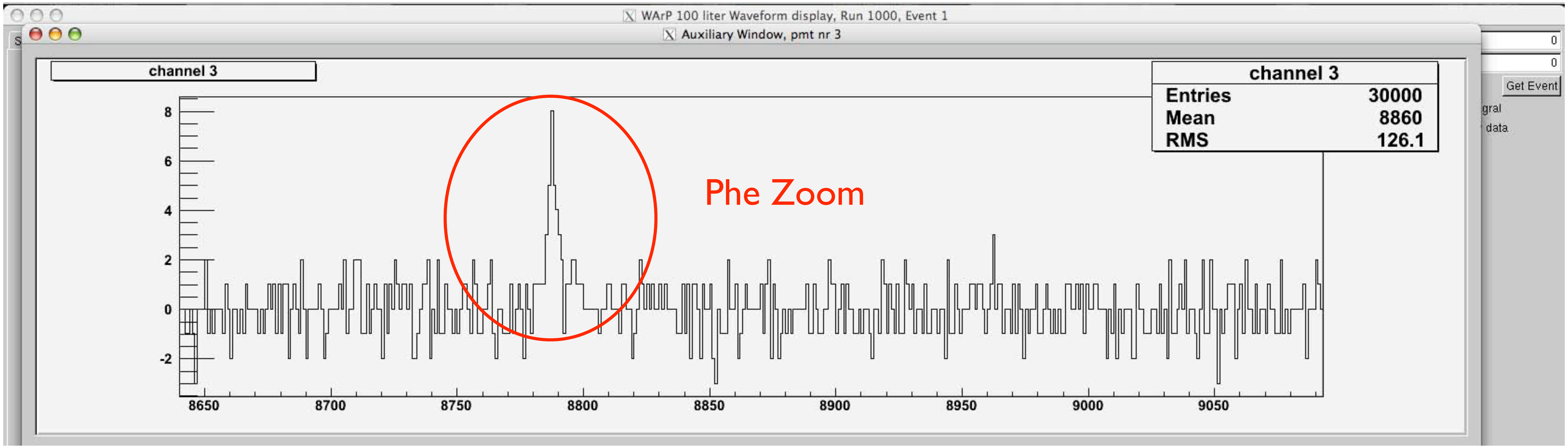


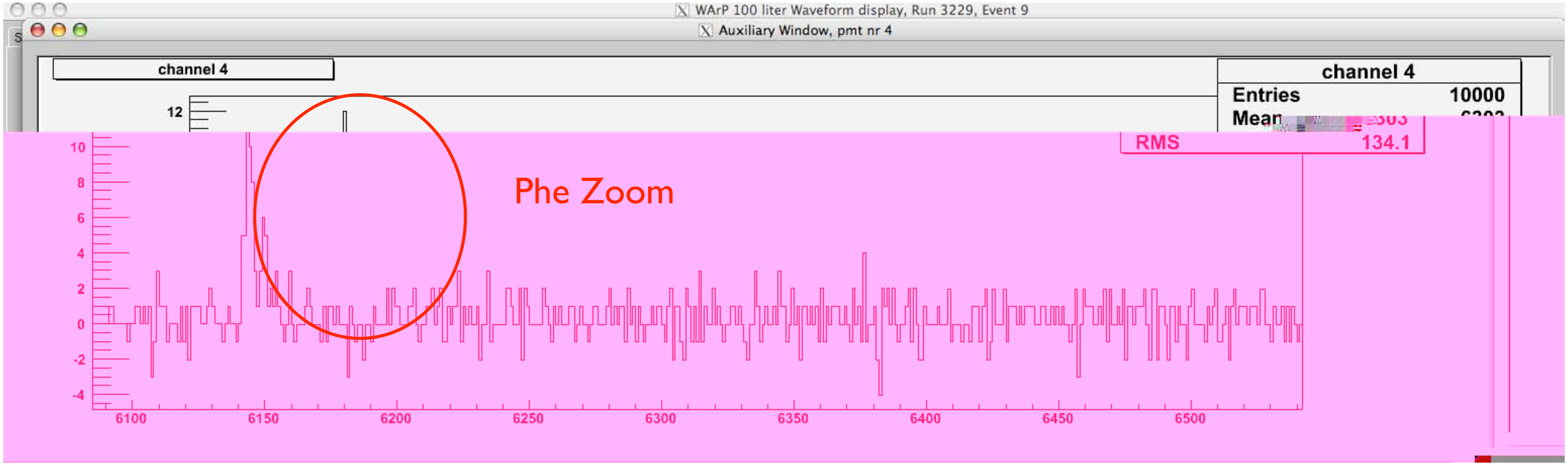
Real Events



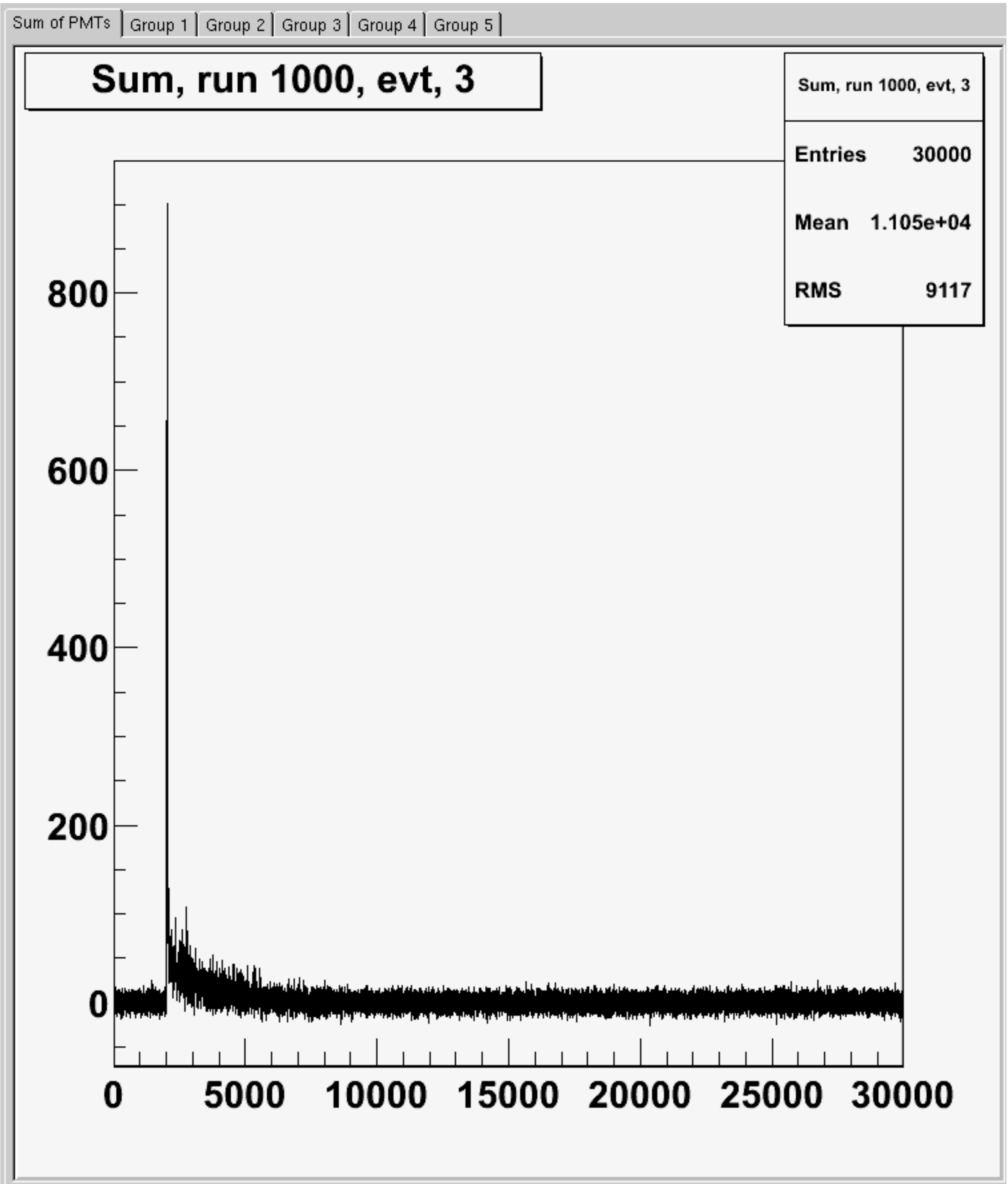
WArP 100 liter Waveform display, Run 3229, Event 4
Sum of PMTs
Group 1
Group 2
Group 3
Group 4
Group 5
channel nr 18
channel nr 19
channel nr 20
channel nr 21
channel nr 22
channel nr 23
channel nr 24
channel nr 25
channel nr 26
Get Event
show integral
show raw data
Zoom
Previous Event
Next Event

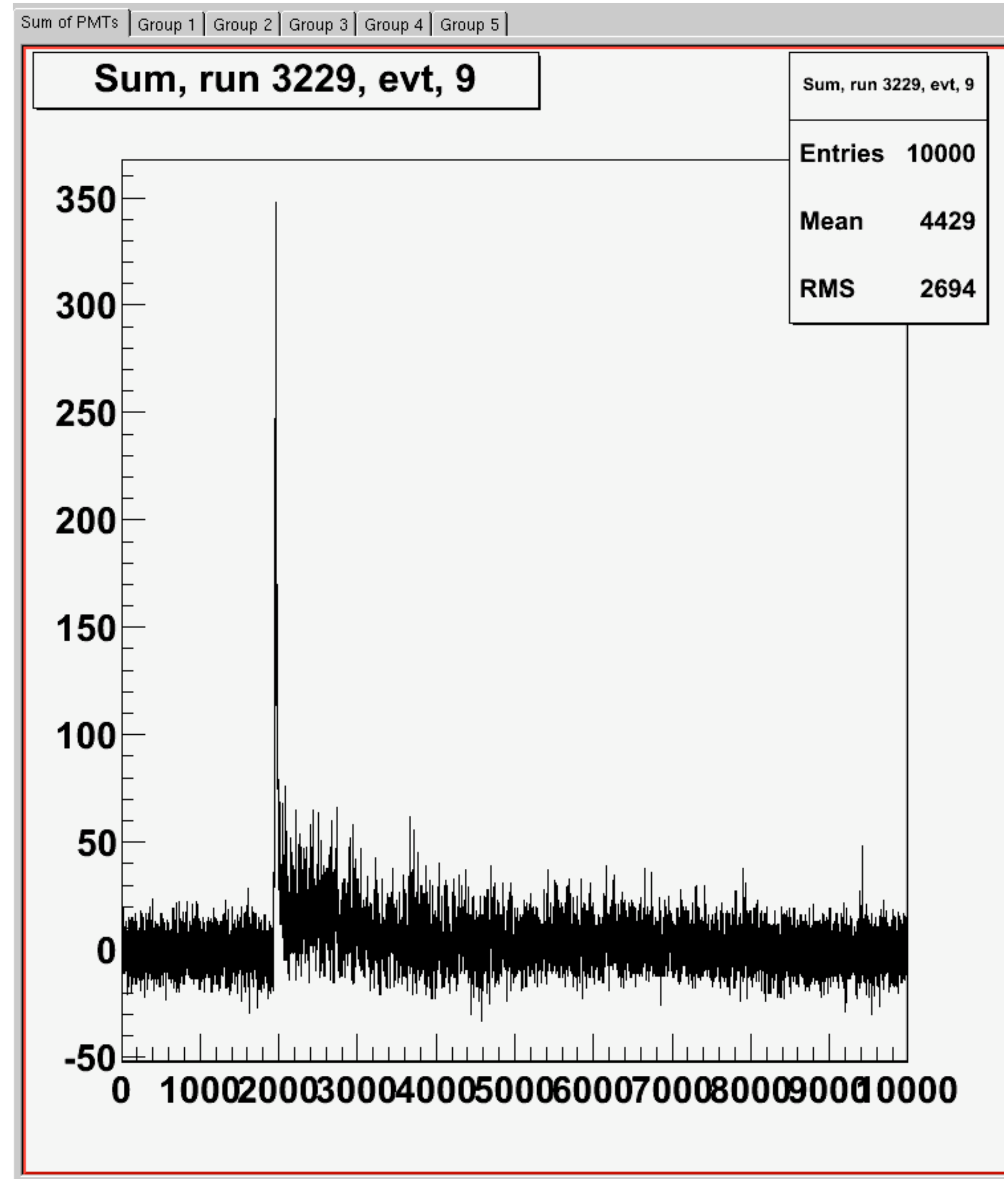
Signal Simulation





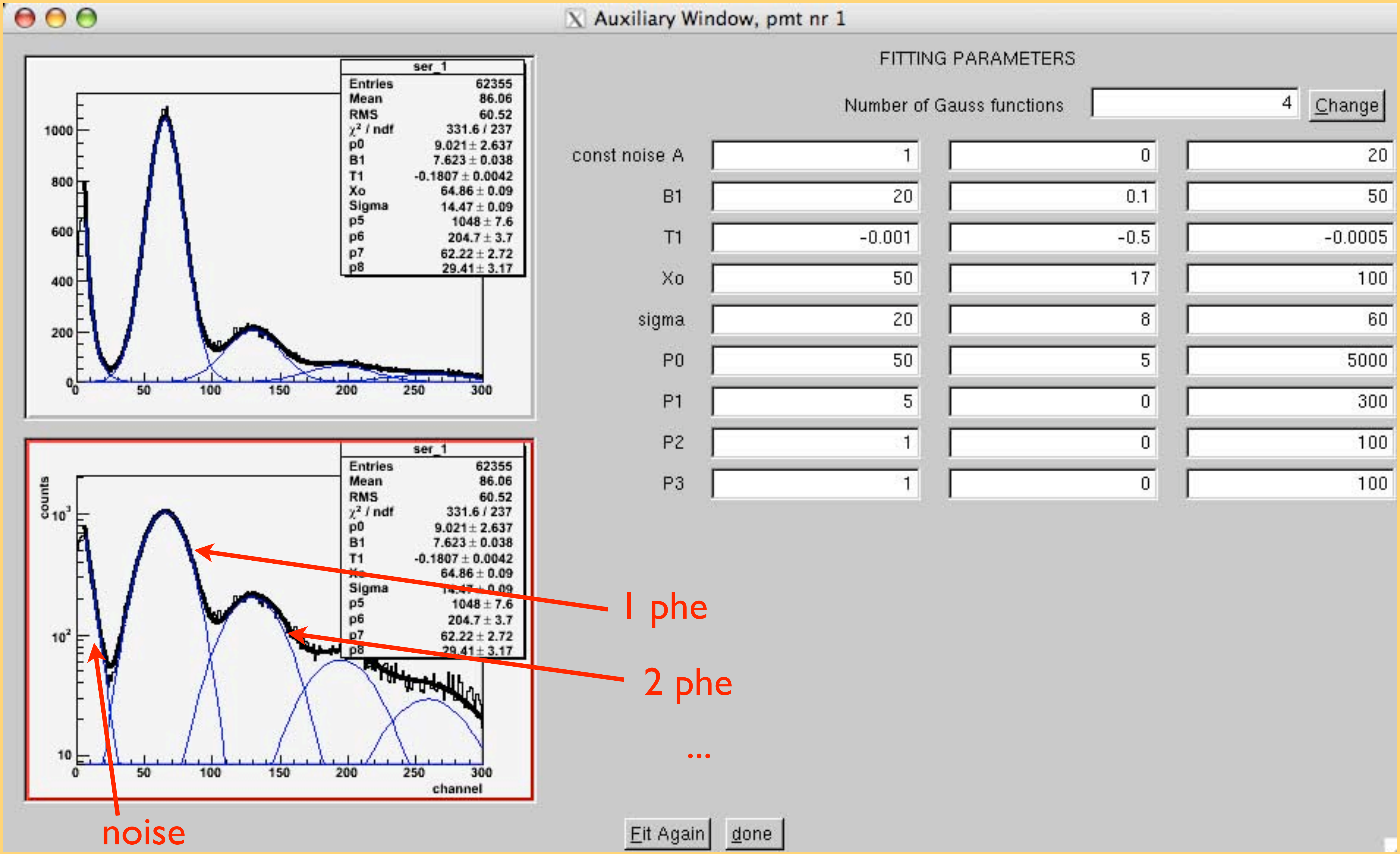
Simulation Vs Exp. Data



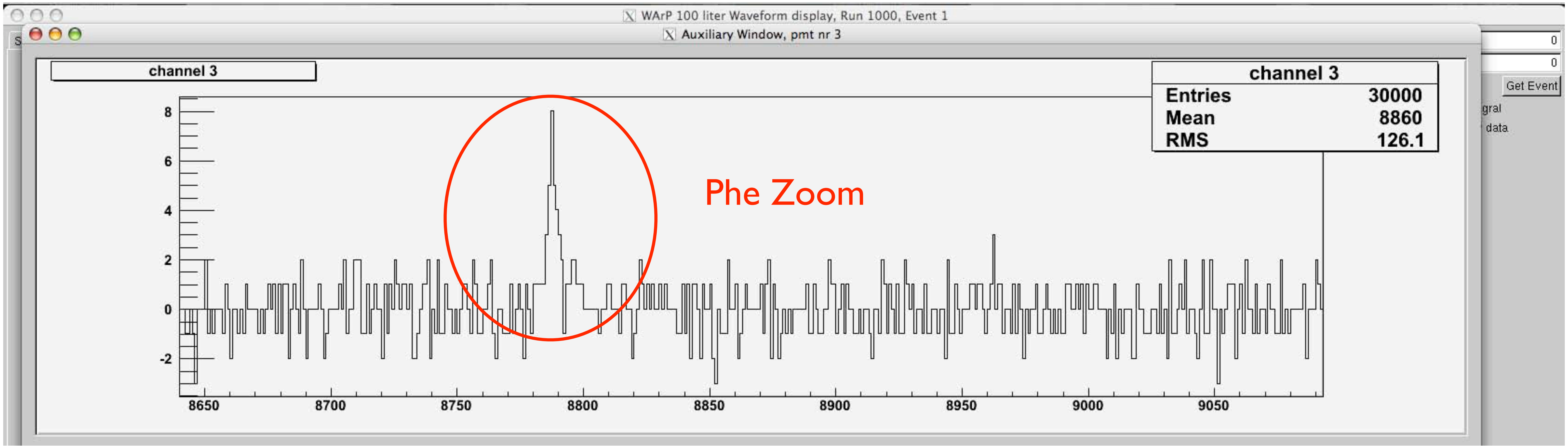


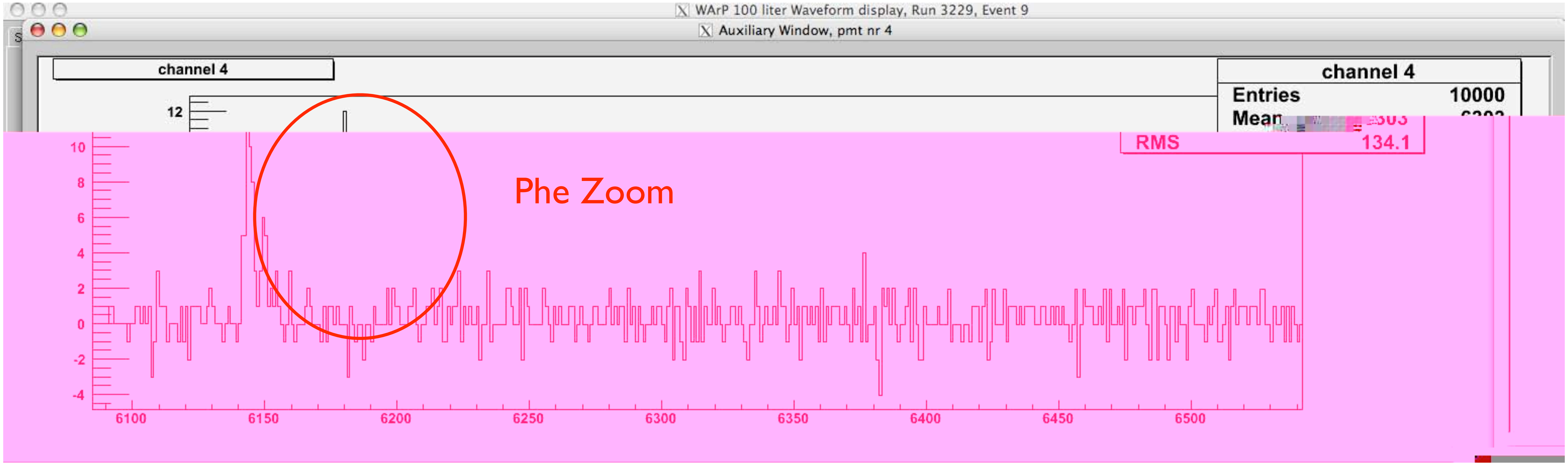
SER fit debugging

SER fitting algorithm search for isolated peaks on the tail of the acquired signal



Simulated Vs Real

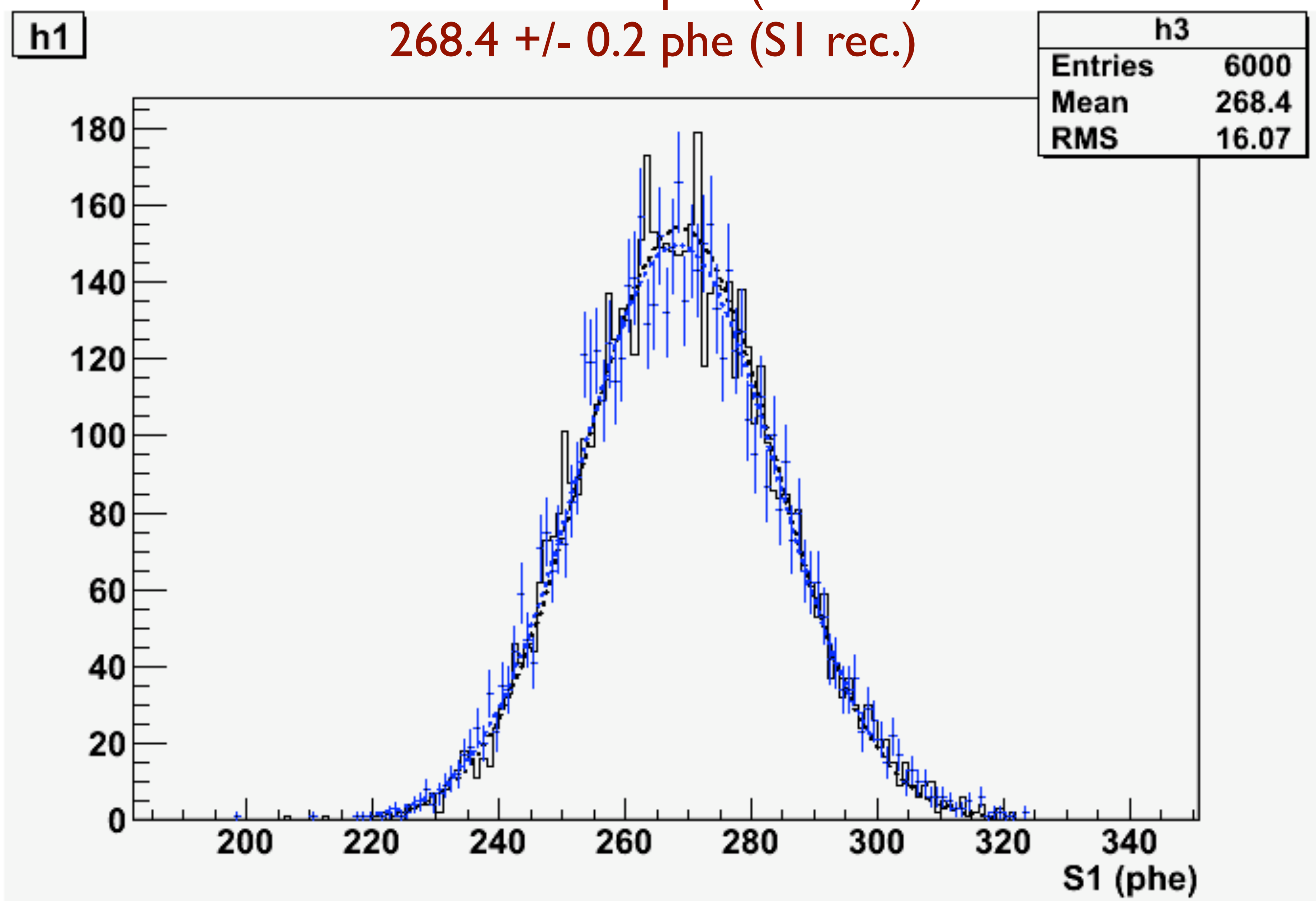




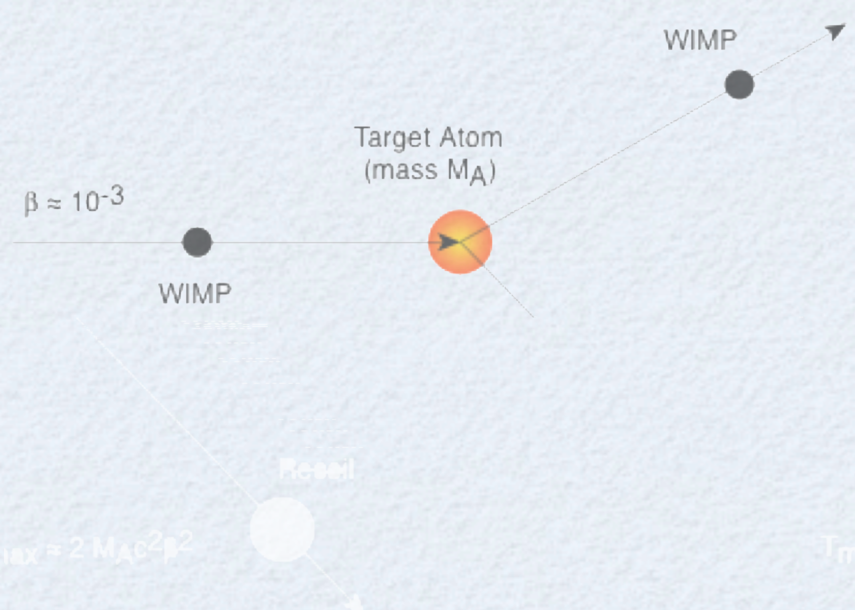
Software Efficiency

Reconstruction Software efficiency has been estimated:
- monoenergetic primary (e^- E=50 keV)
- number of detected photons VS reconstructed S1

268.6 +/- 0.2 phe (S1 true)
268.4 +/- 0.2 phe (S1 rec.)



Conclusions

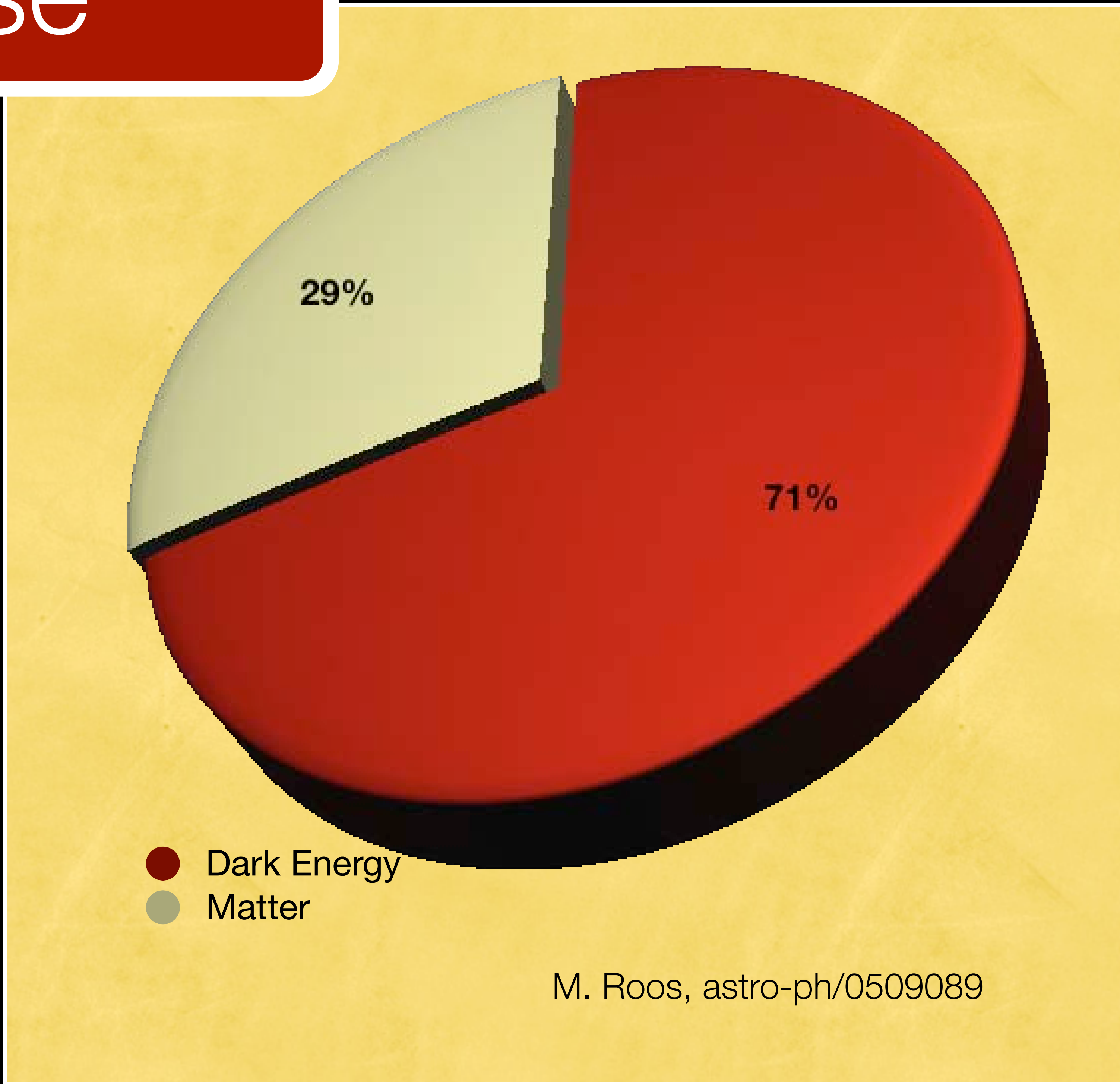


- A GEANT4 simulation of the optical response of the WArP inner Detector has been implemented
- visible & NUV Optical Properties Measurements done at ENEA labs
- UV measurements to be done in Nov09-Dic09
- Study of detector efficiencies done
- Electronics response simulated with a dedicated C++ code to obtain events like raw data
- Analysis Code debugging (preliminary)
- Preliminary results show that the reconstruction algorithm works well but
  - ➡ to be implemented Experimental noise
  - ➡ a more detailed analysis will be done

Backup

Universe

- CMB
- Supernovae Ia
- Gravitational lensing

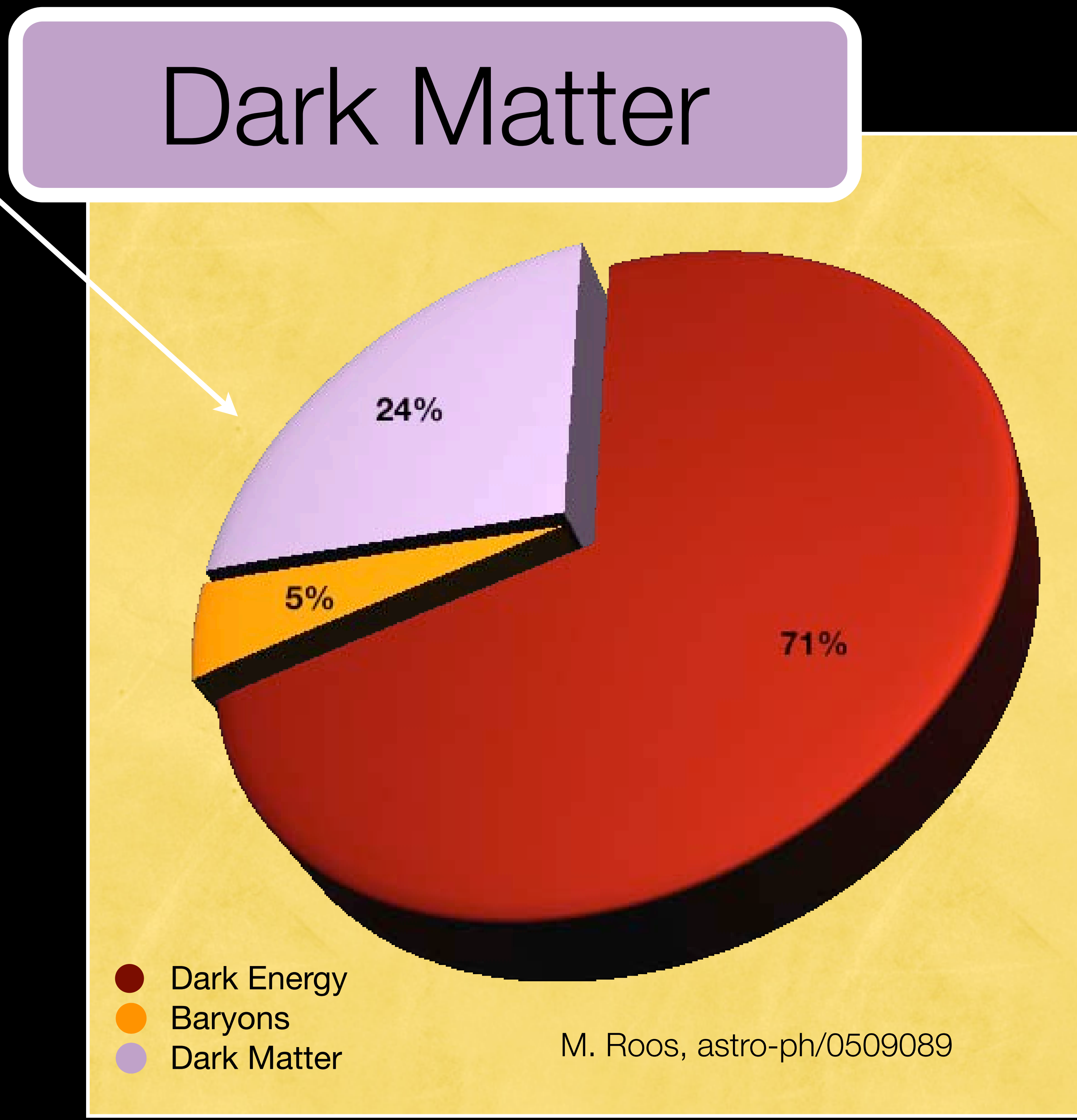


What is Dark Matter made of?

- Non-Baryonic
- Neutral
- Relic
- Cold

SUSY extension of standard model provides a Good candidate

WIMP



Substrate Characterizations

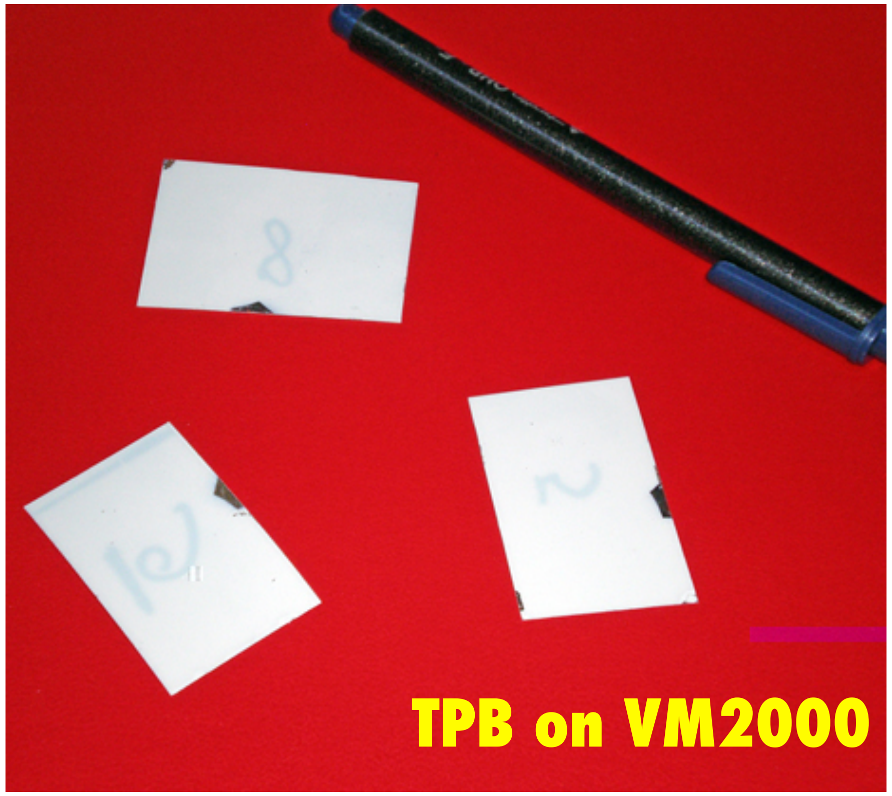
In order to optimize the light collection system dedicated measurements have been done

Measured samples can be divided as follows:

- TPB evaporated over glass
- TPB evaporated over VM2000
- TPB-Polystyrene mixture over glass
- VM2000

Measurements done*:

- Photoluminescence (PL)
- Photoluminescence Excitation (PLE)
- Direct Transmittance
- Hemispheric Transmittance & Reflectance



** in collaboration with ENEA:*

R.M. Montereali and **M.A. Vincenti**
Dip. Tecnologie Fisiche e Nuovi Materiali, FIM-FISACC, ENEA C.R. Frascati

E. Nichelatti
Dip. Tecnologie Fisiche e Nuovi Materiali, FIM-FISOTT, ENEA C.R. Casaccia

Boundary Processes Implementation

Evaporated TPB on VM2000

- ➡ A much diffusive substrate (TPB) on a Mirror (slide...)
- ➡ Layer RINDEX not known
- ➡ VM200 has almost null T: fully characterized by R

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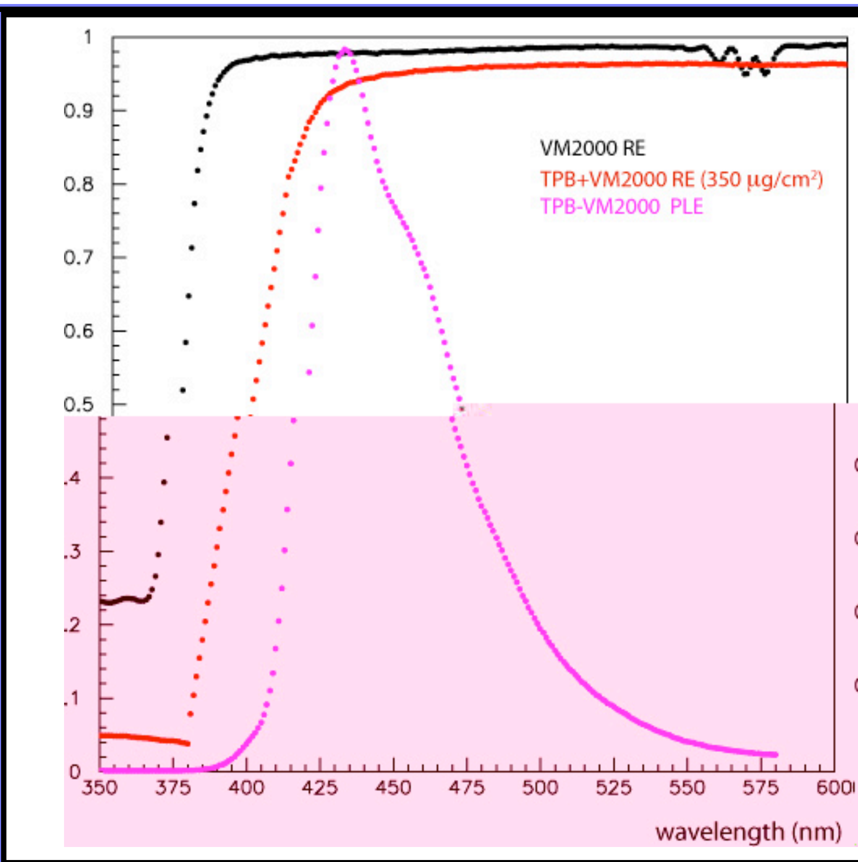
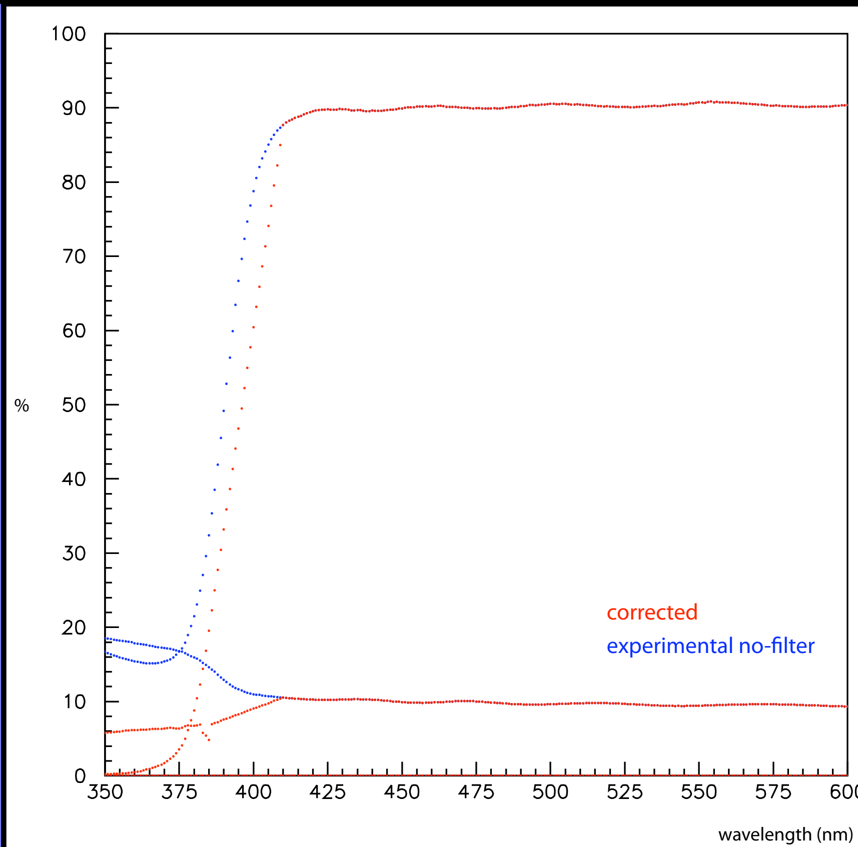


TPB Polystyrene Mixture

- ➡ Glass coated with TPB-Polystyrene mixture
- ➡ Practically zero Absorption

- ➡ Used only the Reflectance
- ➡ The absorbed light is collected according to the PMT Q.E. (EFFICIENCY=Q.E.)

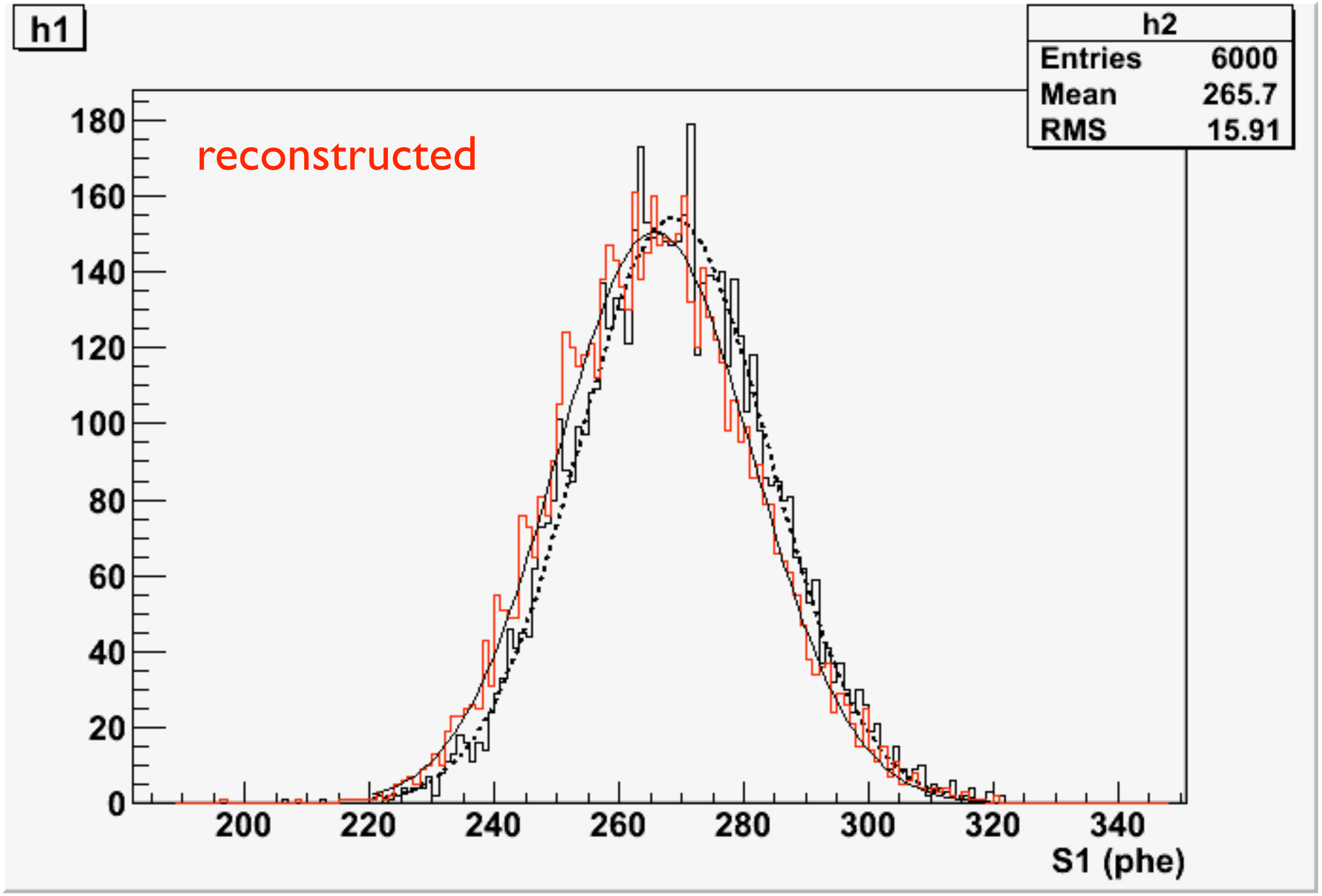
```
OpPMTProperty -> AddProperty("REFLECTIVITY",pp,refPMT,NUM);
OpPMTProperty -> AddProperty("EFFICIENCY",pp,effiPMT,NUM);
```



Rconstraction Software Efficiency

Rec. Software efficiency has been estimated:

- monoenergetic primary (e^- E=50 keV)
- number of detected photons VS reconstructed S1



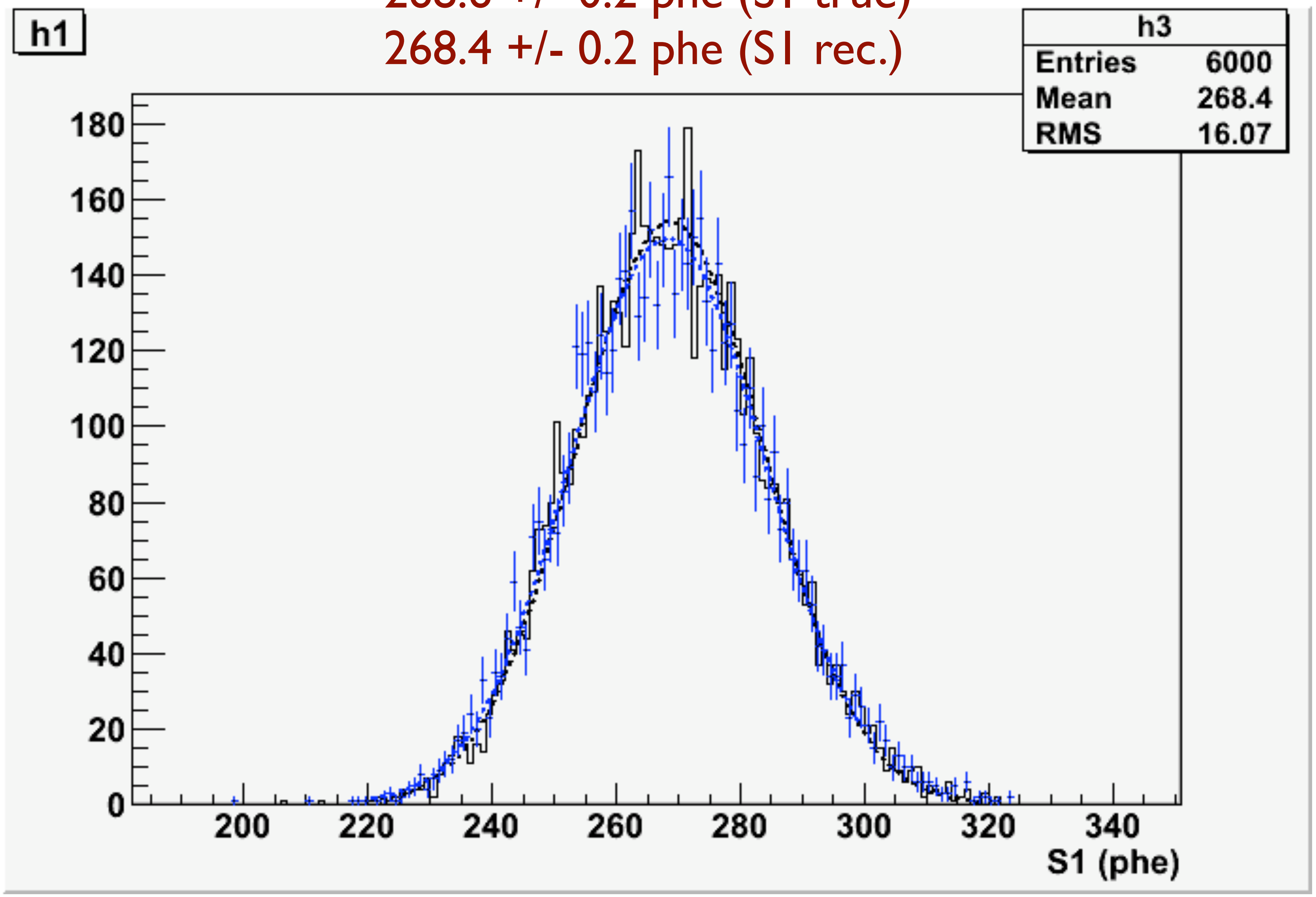
systematic underestimation of the order of 1%

Software Efficiency

It is due to the fact that the S1 integral is estimated in a time window of 7 µs

- the mean fraction of light lost is almost 1%
- applying the expected correction factor (1-0.75*exp(-7/1.6)) the two spectra are well superimposed

268.6 +/- 0.2 phe (S1 true)
268.4 +/- 0.2 phe (S1 rec.)



Liquid Argon scintillation light emission

An interaction in argon produces Atomic

- ✓ excitation
- ✓ ionization

→ emission of 128 nm luminescence through 2 processes

self trapped exciton luminescence

1)

$$Ar^* :$$

$$Ar^* + Ar \rightarrow Ar_2^*$$

$$Ar_2^* \rightarrow 2Ar + h\nu$$

recombination luminescence

2)

$$Ar^+ :$$

$$Ar^+ + Ar \rightarrow Ar_2^+$$

$$Ar_2^+ + e^- \rightarrow Ar^{**} + Ar$$

$$Ar^{**} \rightarrow Ar^* + heat$$

$$Ar^* + Ar \rightarrow Ar_2^*$$

$$Ar_2^* \rightarrow 2Ar + h\nu$$

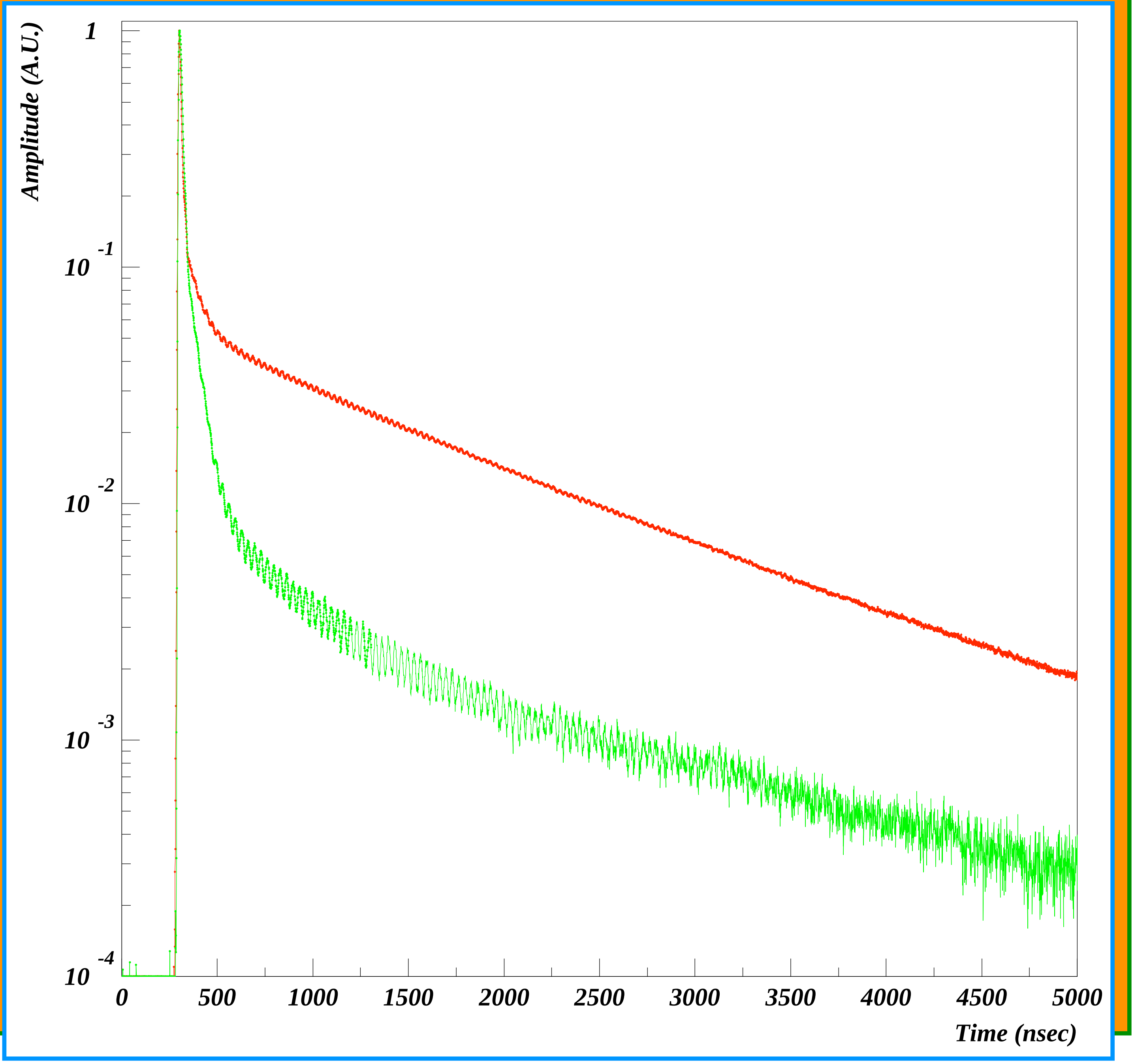
both processes

- ✓ ending up with the same radiative reaction
- ✓ inducing the emission of a 128 nm UV photon

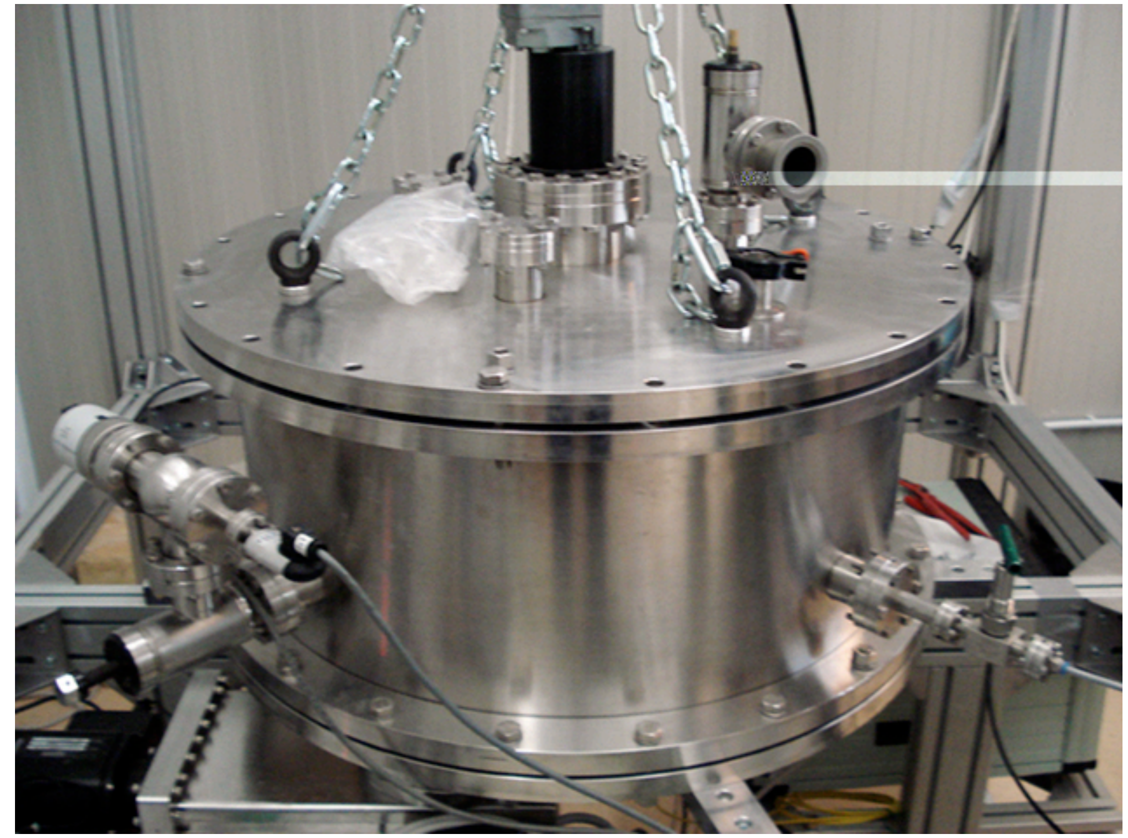
Effect of ionization density on time dependence of luminescence

1. decay constants are not functions of ionization density

2. for high ionization density the fast components intensity increases at expense of the slow one



Evaporation Procedure



- Internal Diameter 63 cm
- Volume 186 lt
- Evacuation time ≈ 30 min.
- heater filament: tantalum foil
- graphite furnace temperature monitored by a thermocouple

Evaporation procedure is done @ LNGS by members of the WArP collaboration

Experimental Setup

HeT and HeR measures

- Spectrophotometer UV-Vis-NIR Perkin-Elmer mod. Lambda 19 equipped with a integrating sphere (150 mm diameter).
- Wavelength experimental window: 200-600 nm (reduced to 250-600 nm).
- Filter: bandpass filter (250-390 nm), thickness 2.1 mm.

PL and PLE measures

- Spectrophotometer UV-Vis-NIR Jobin Yvon Fluorolog-3 FL-1

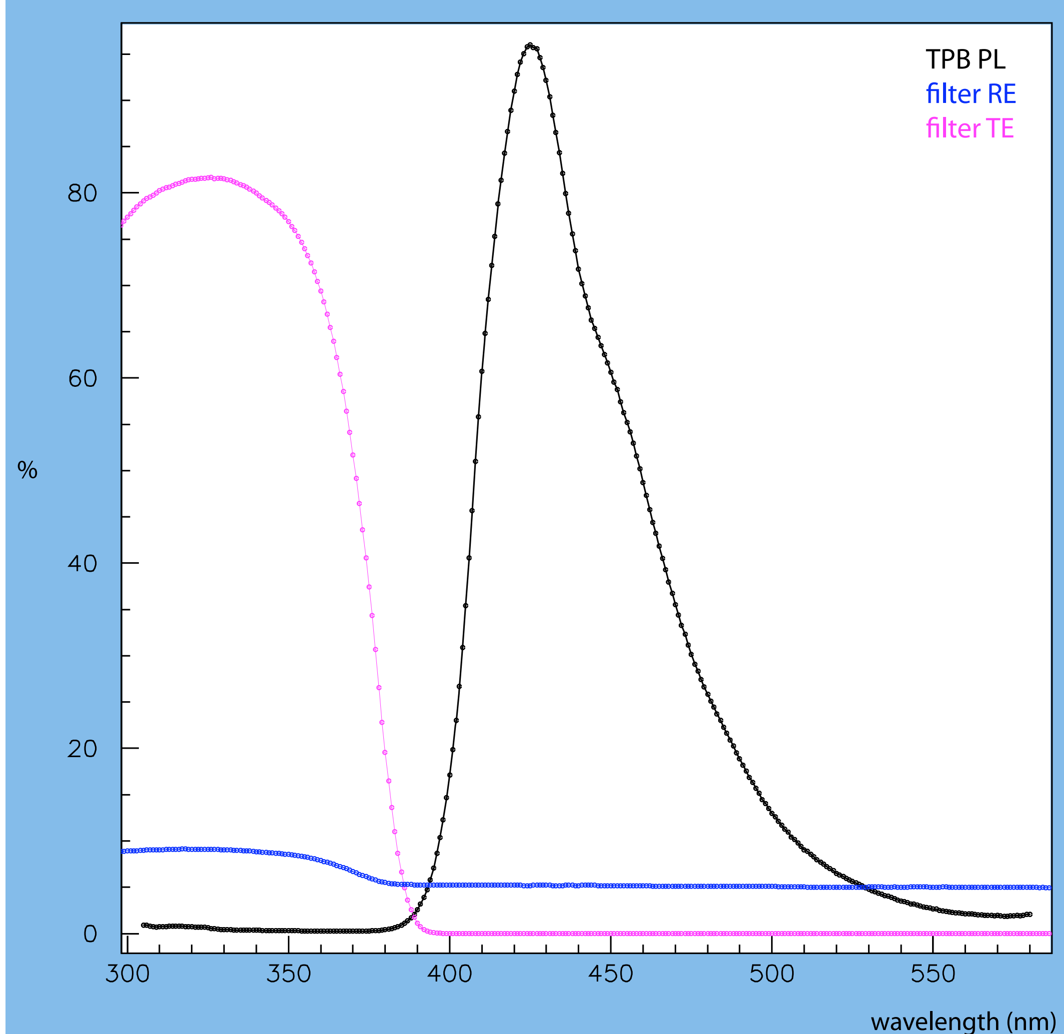
DT measures

- Spectrophotometer UV-Vis-NIR Perkin-Elmer mod. Lambda 19
- Wavelength experimental window: 200-1400 nm

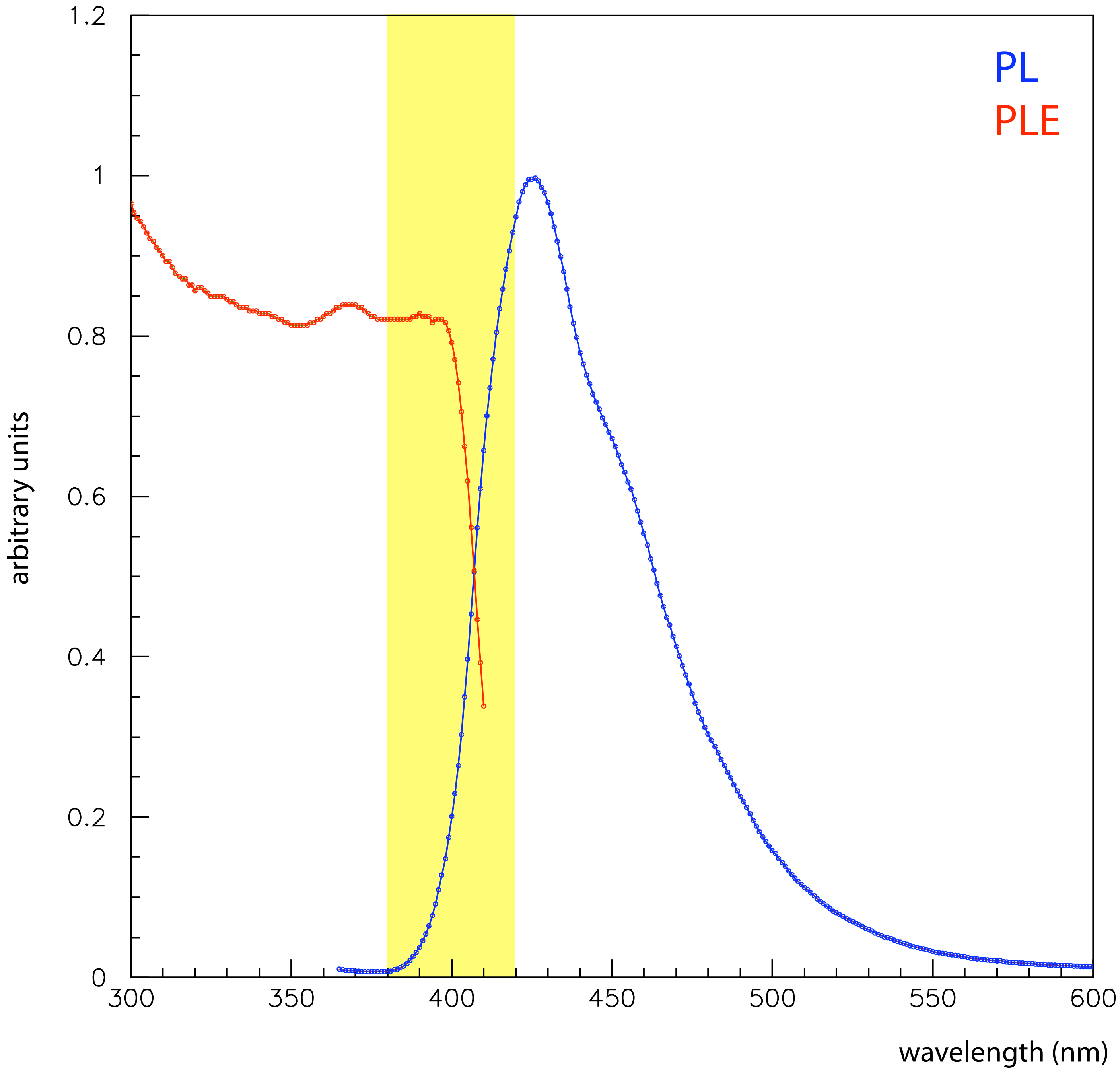
TPB PL and PLE

- TPB PLE is very large up to 420 nm
- 390-420 nm: TPB PL and PLE overlaps
- VM2000 exhibit a similar behavior

Need: filter to remove spurious PL



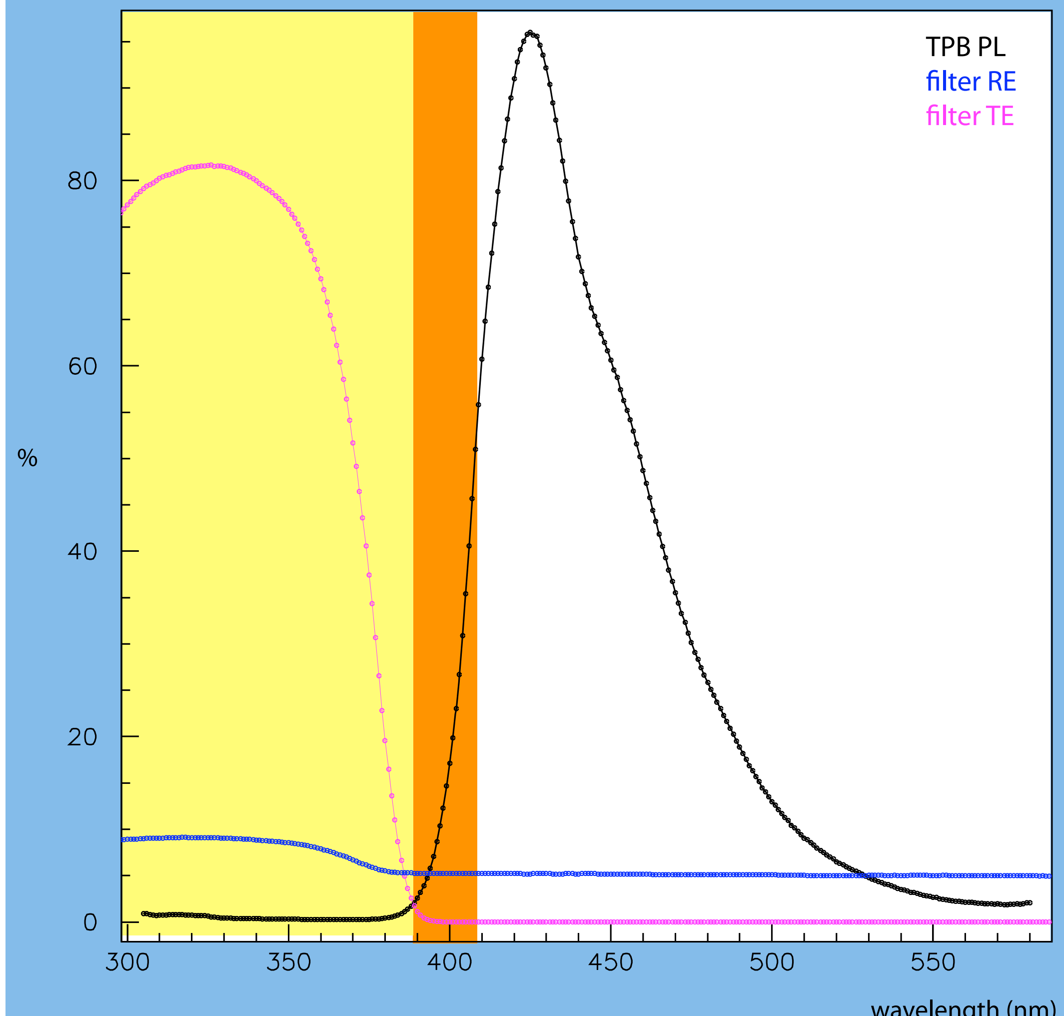
TPB PL and PLE



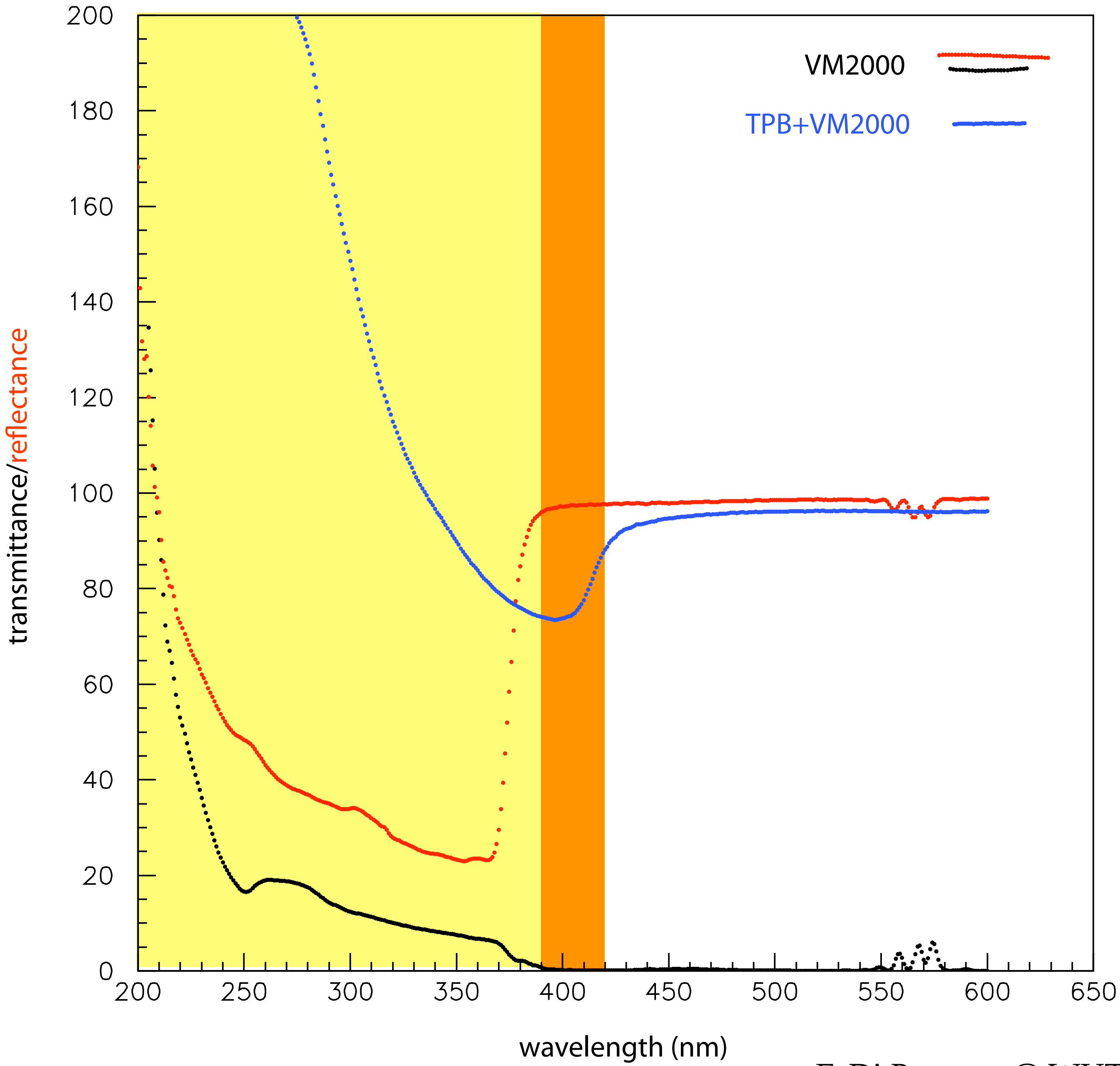
F. Di Pompeo @ WUTA08

Evaporated TPB on VM2000

- PL affects strongly hemispheric properties measurements
- pass band filter (250-390 nm)
- Linear interpolation (390-420 nm)



Hemispheric T and R



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Evaporated TPB on VM2000

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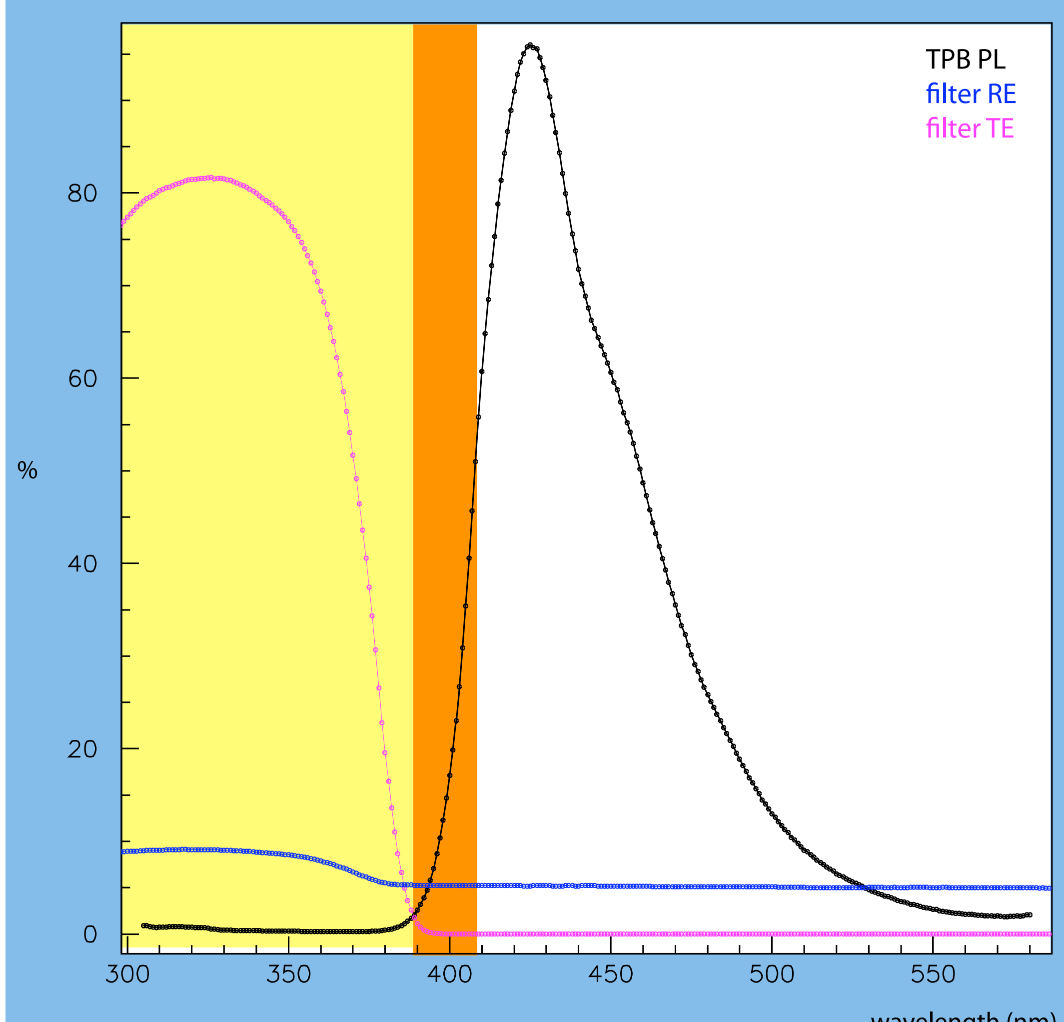
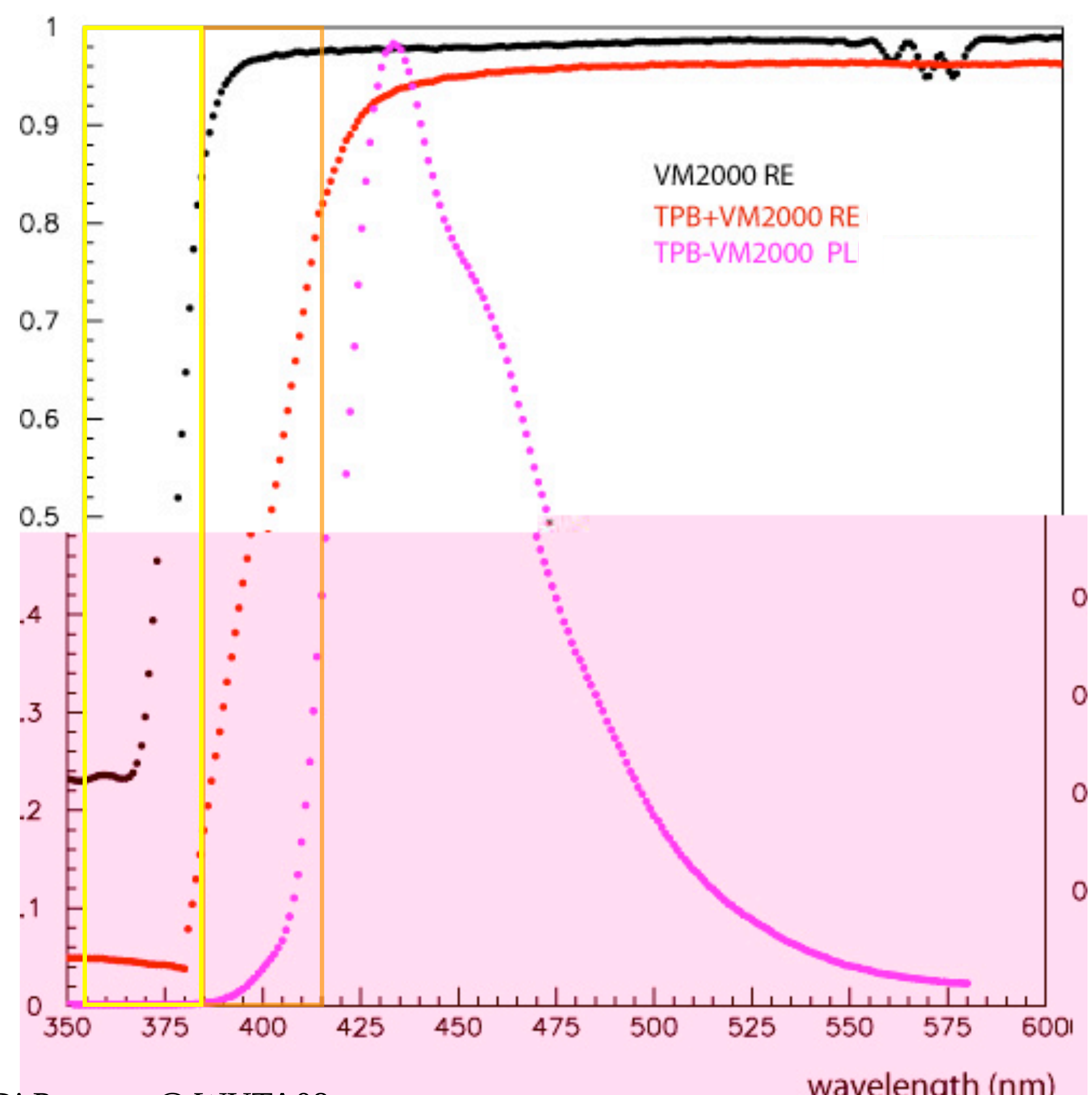


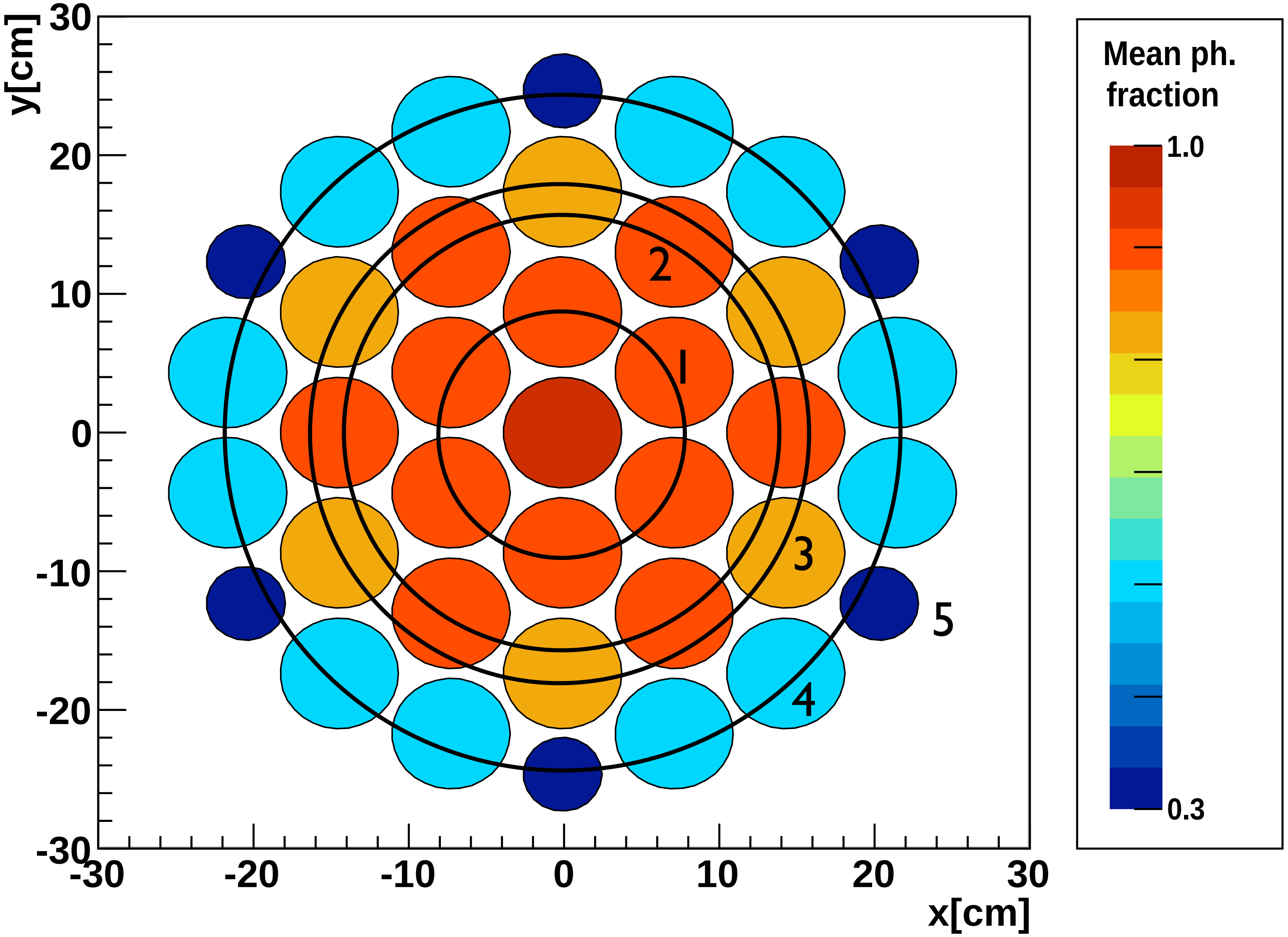
TPB-VM2000 sample



F. Di Pompeo @ WUTA08

hits distribution on PMTs

- The number of photon detected by each phototube has been considered
- effective sensible surfaces for 3inch and 2inch (r=? r=?)
- The considered quantity is the relative efficiency, normalized to the most efficient PMT



- Most efficient is the PMT in the center
- Clear dependence on R
- 2inch PMTs have also smaller photocatode surface

Efficiency ring values:

1.
2.
3.
4.
5.