Preliminary study of the JUNO signal using Digital Signal Processing Techniques

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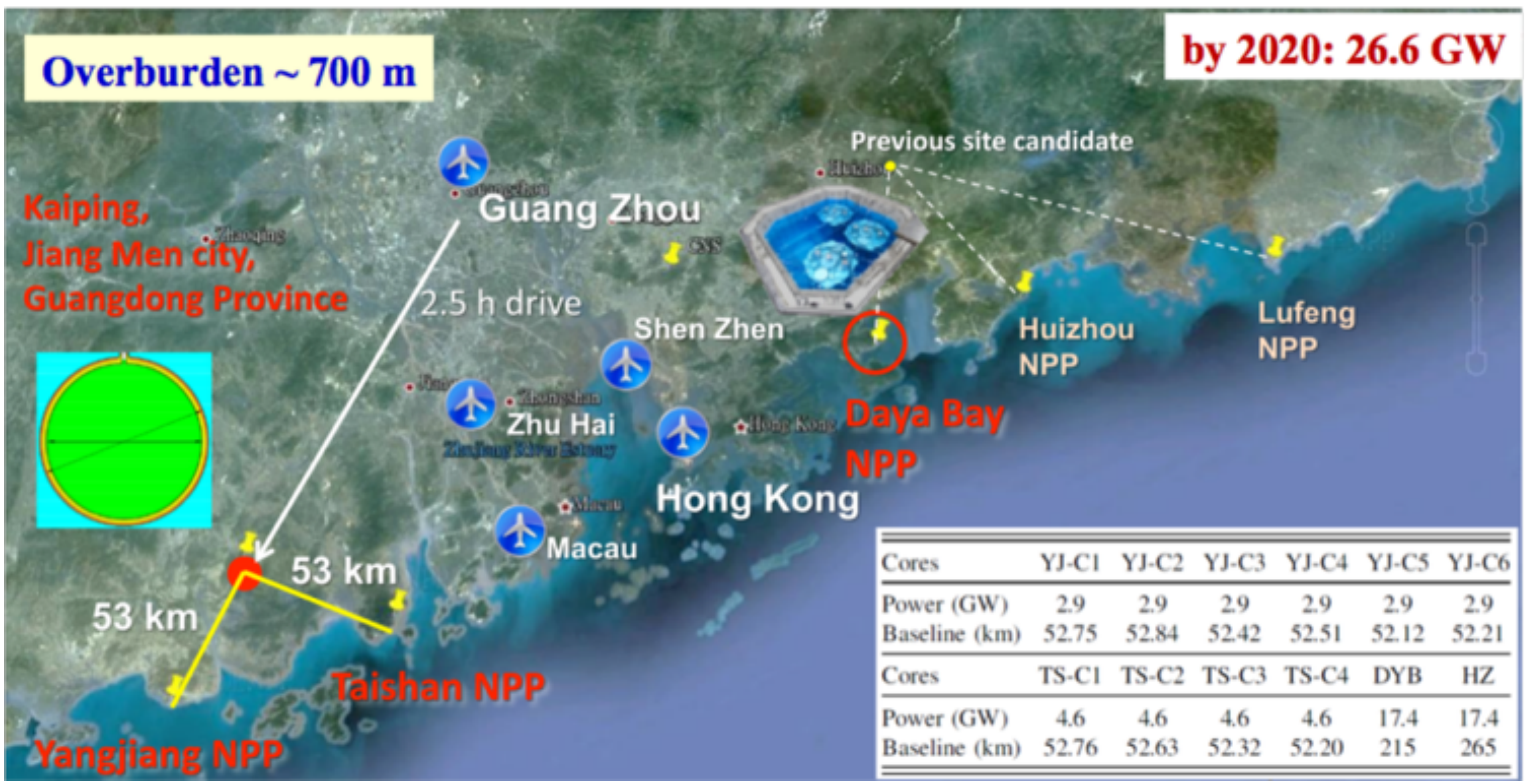
Introduction

- Jiangmen Underground Neutrino Observatory (JUNO) is a reactor anti-neutrino experiment under construction in Jiangmen City, Guangdong Province, China.
- Approved in Feb 2013 in China



Cores	YJ-C1	YJ-C2	YJ-C3	YJ-C4	YJ-C5	YJ-C6
Power (GW)	2.9	2.9	2.9	2.9	2.9	2.9
Baseline (km)	52.75	52.84	52.42	52.51	52.12	52.21
Cores	TS-C1	TS-C2	TS-C3	TS-C4	DYB	HZ
Power (GW)	4.6	4.6	4.6	4.6	17.4	17.4
Baseline (km)	52.76	52.63	52.32	52.20	215	265

Juno Detector Design

JUNO central detector is a 20 kton liquid scintillator (LS) detector with a total overburden of 1850 meter water equivalent.

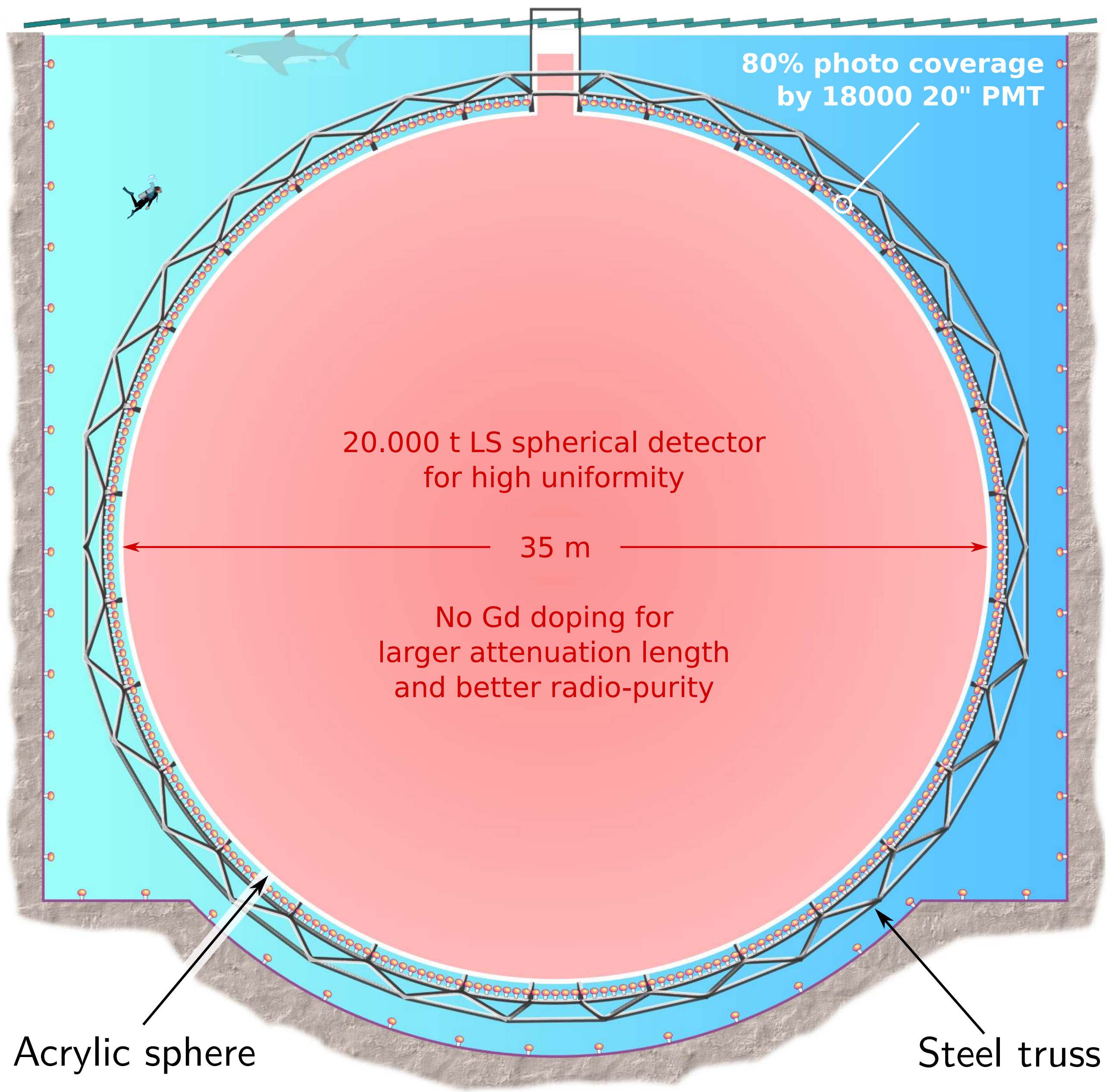
Key Features

- PMTs
  - Photo-multiplier tube (PMT) coverage ~75%
  - PMTs with high quantum efficiency ~35%

- High performance liquid scintillator
  - high photon yield with >14,000 photons /MeV
  - optical attenuation length order of 30 m

- The spherical central detector will be placed inside an instrumented water pool to identify cosmic muons and provide shielding from radioactive backgrounds.

- A muon tracker on top of the detector will further enhance the muon identification.



Juno Collaboration

Asia (28)

BNU
CAGS
CQ U
CIAE
DGUT
ECUST
Guangxi U
HIT
IHEP
Jilin U
Nanjing U
Nankai U
Natl. CT U
Natl. Taiwan U
Natl. United U
NCEPU
Pekin U
Shandong U
Shanghai JTU
Sichuan U
SYSU
Tsinghua
UCAS
USTC
Wuhan U
Wuyi U
Xiamen U
Xi'an JTU

Observers:

US institutions
HEPHY Vienna
PUC Brazil
PCUC Chile
MPP Munich
Jyvaskyla U.

Europe (23)

APC Paris
Charles U
CPPM Marseille
FZ Julich
INFN-Frascati
INFN-Ferrara
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IPHC Strasbourg
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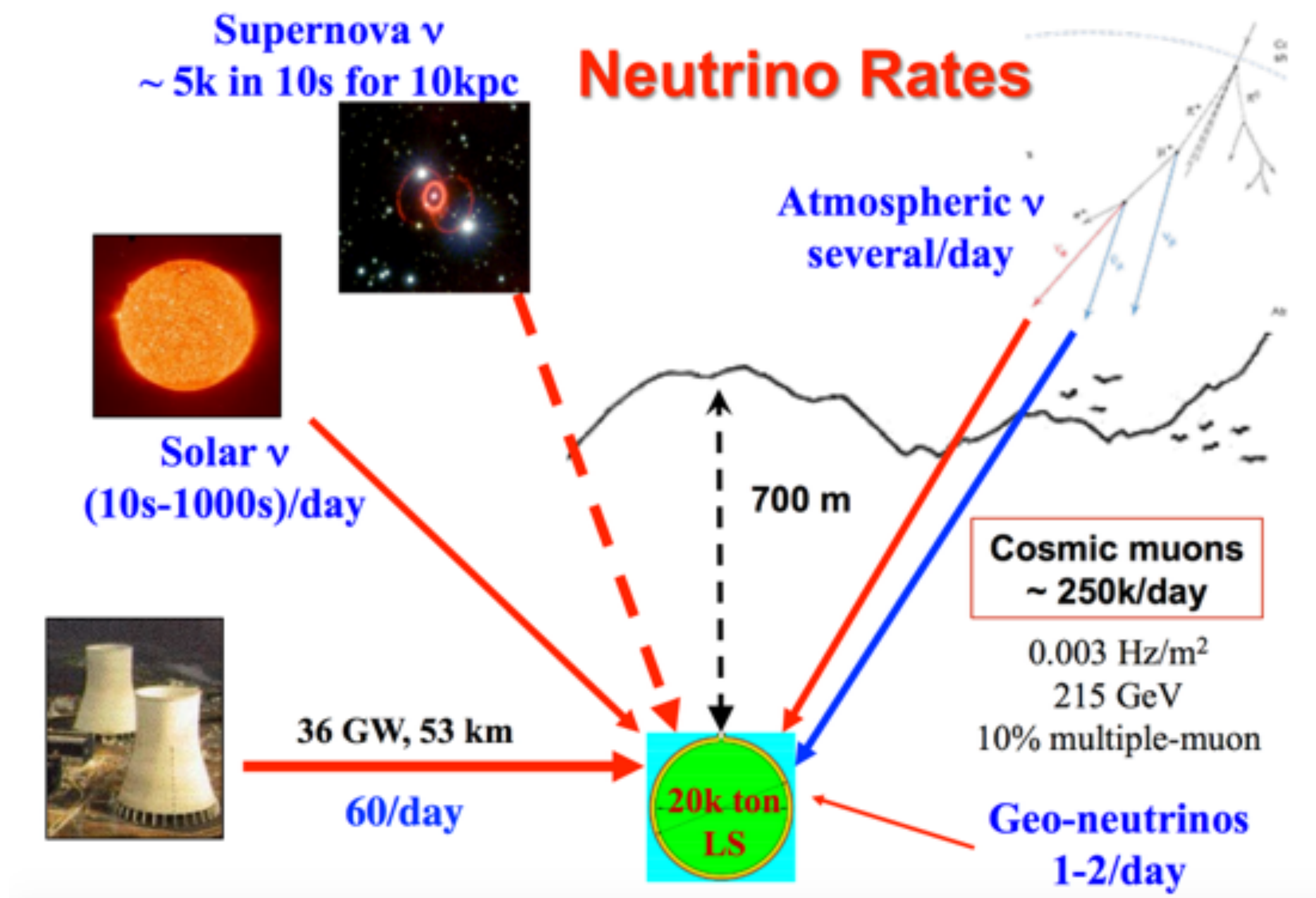
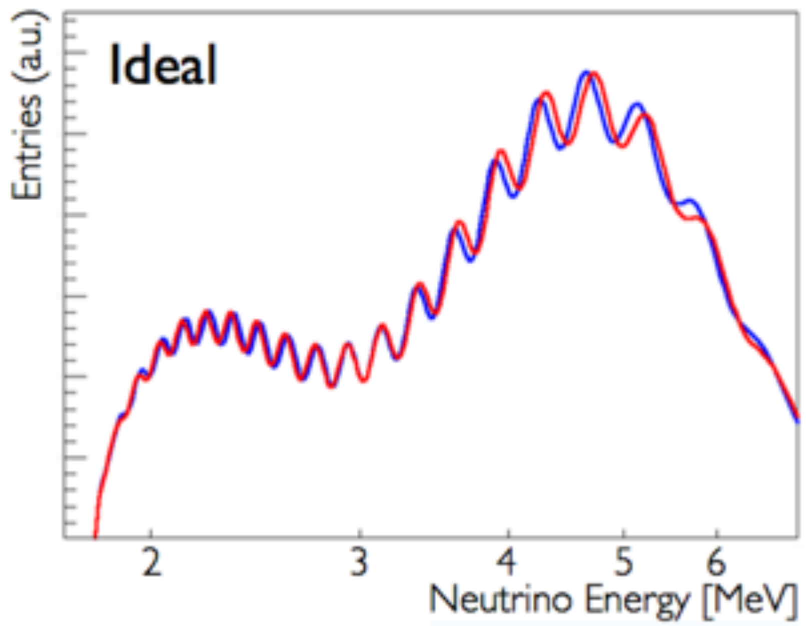
LLR Paris
RWTH Aachen
Subatech Nantes
TUM
U.Hamburg
ULB
U Mainz
U Oulu
U Tuebingen
YPI Armenia

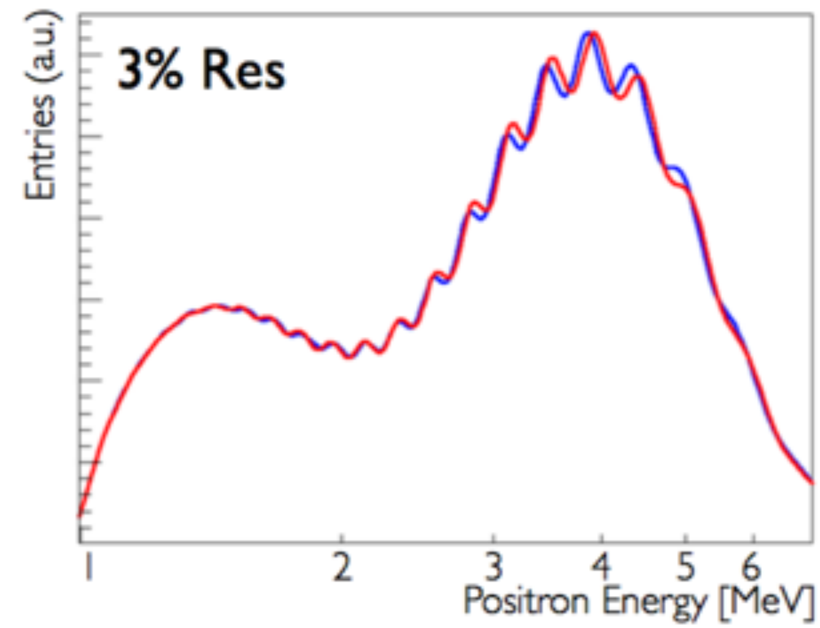
JUNO: A Multi-purpose Neutrino Observatory

- Neutrino Mass Hierarchy determination (primary goal).
- Precision measurement of mass-squared splittings and mixing angle.
- Underground science including supernova burst neutrinos, geo-neutrinos, solar neutrinos and proton-decay.



anti-Neutrino Energy Spectrum (at 50 km baseline)





from Marco Grassi talk in Ferrara "The JUNO Experiment Entering the Era of Precision Neutrino Physics"

Standard Resolution Function in Calorimetry

$$\frac{\sigma(E)}{E} = \sqrt{\left(\frac{a}{E} + \frac{b}{\sqrt{E}} + c\right)}$$

A 3% resolution at 1MeV is pivotal

Term b (stochastic) is mainly driven by the number of detected photons (aka photo-coverage, aka number of pmts)

Constant term (c) is sensitive to all the "experimental issues" (Spatial Uniformity, Energy Linearity, Quantum Efficiency Fluctuations...)

$c \leq 1\%$ is an ambitious but unavoidable

Experimental Challenges

- Keep Constant Resolution Term Below 1% (Energy Calibration)
  - Energy Non-linearity due to Liquid Scintillator Response and Readout of the Electronics
  - Non-uniformity
- Reduce Natural Radioactivity (Purification) Reduce Cosmogenic Backgrounds (MuonTracking) Maximize Light Collection (PMTS)

Scintillator Non Linearity

Quenching

- If the concentration of excited molecules in the LS is high they can interact and quench the total light output
- Particles with low initial energy have a large dE/dx so the total light output is quenched.
- More energetic particles have most of their energy lost with small dE/dx.
- Ionization quenching leads to a non-linear relation between the energy of the ionizing particle and the light produced by the scintillator

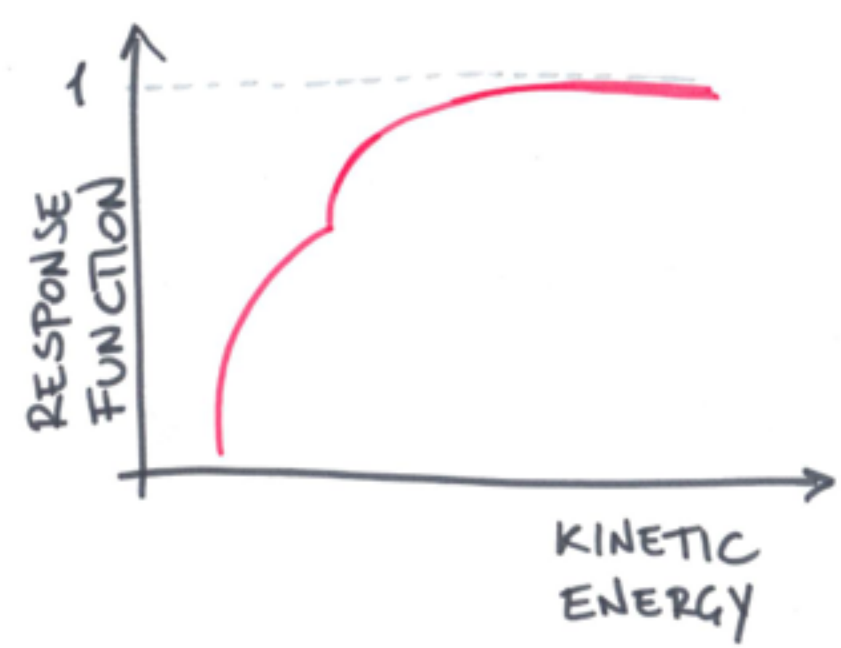
Cherenkov

- Charged particles in LS have speed greater than phase velocity of light
- Cherenkov light emission (mostly UV)
- LS is opaque to UV light Cherenkov light is re-absorbed by LS Sometimes it is re-emitted as scint. light Re-emission prob is poorly known

Overall Scintillator Non-Linearity

Ionization quenching reduces light at low particle energy Cherenkov light mildly enhances LS light yield at higher particle energy

Overall non-linear energy dependence of the light output needs to be carefully evaluated



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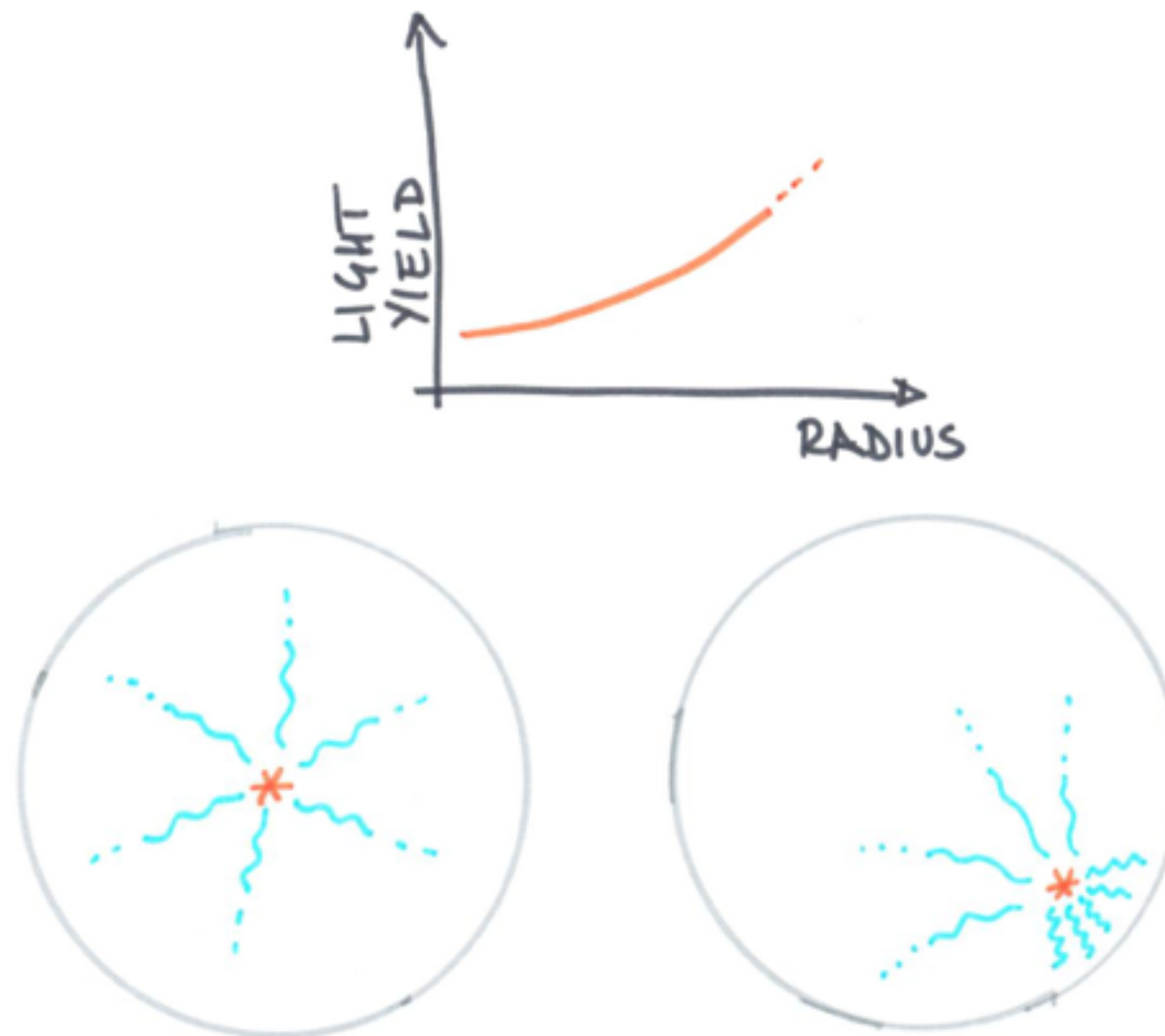
Electronics Non-Linearity

Light yield increases towards the edge of the detector:

a) Energy deposition in the center: all the photons are attenuated

b) Energy deposition at the edge: some pmts see many photons

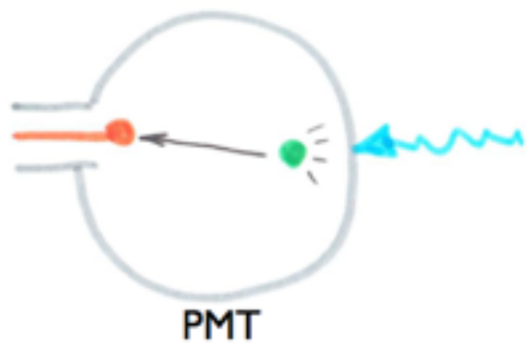


(a) (b)

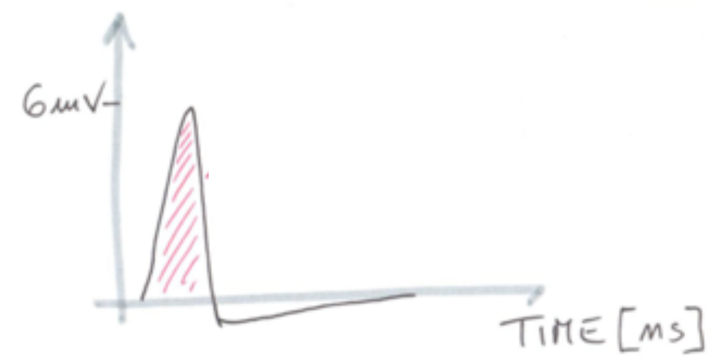
from Marco Grassi talk in Ferrara "The JUNO Experiment Entering the Era of Precision Neutrino Physics"

Electronics Non-Linearity

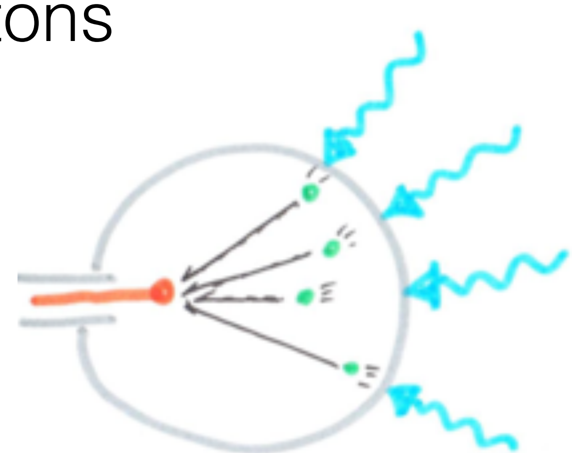
Single Photon

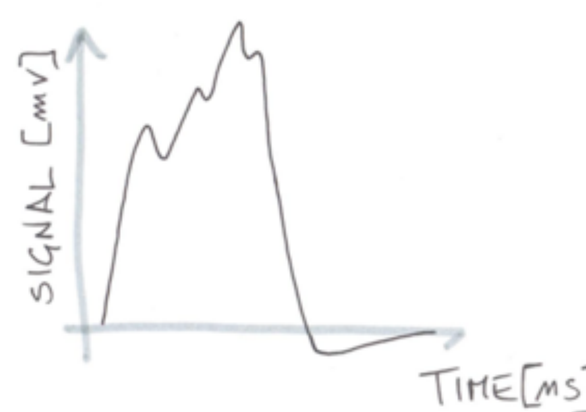


Output Signal from FADC



Multiple Photons





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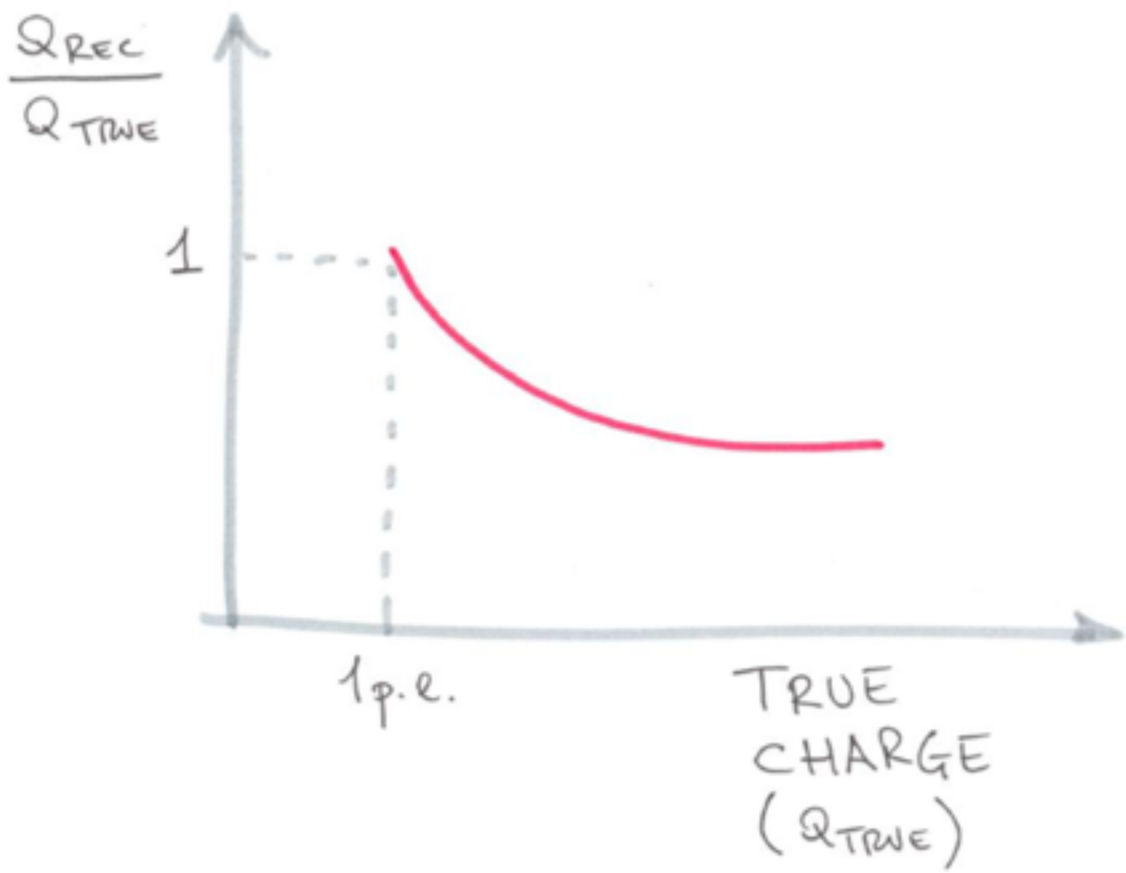
Electronics Non-Linearity



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Experience (i.e. previous experiments) tells us that charge extraction from complex waveforms tends to be biased

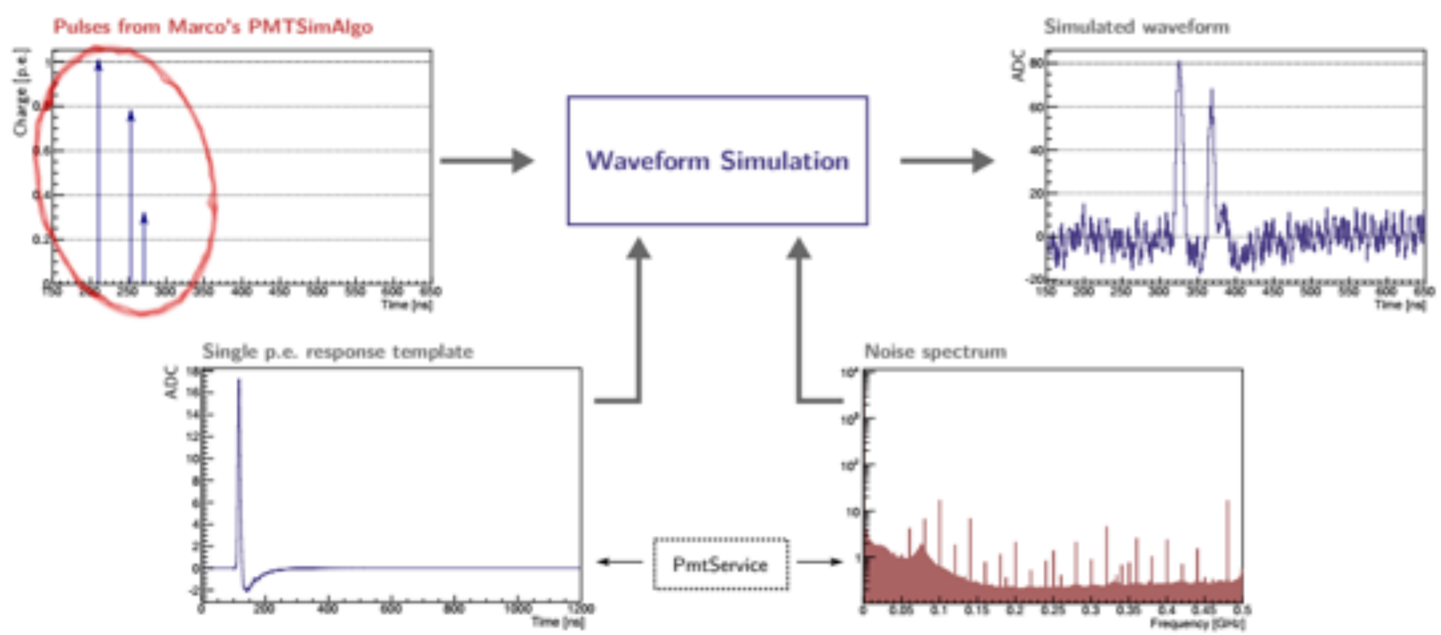
Such bias is both energy and position dependent
(it is a function of the number of p.e. collected at the PMT anode)

Ad hoc correction might be implemented on single-channel basis

Study this Non-Linearity with Digital Signal Processing (DSP) Techniques to reconstruct the # of Hits and the total charge

Simulated Signal 1/2

Waveform simulation



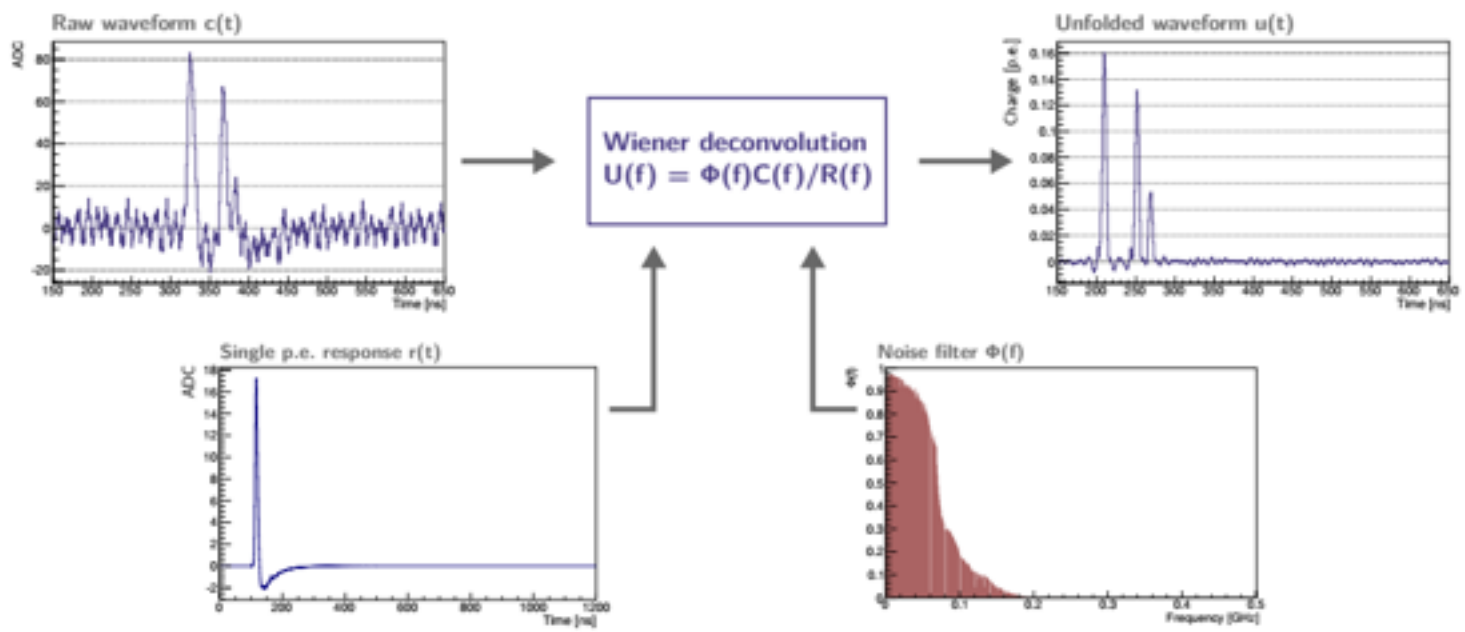
2 main inputs to configure simulation via PmtService

- Single p.e. response encapsulates correlated response from PMT+electronics
- Noise spectrum encapsulates uncorrelated response from PMT+electronics
- Both templates can be configured to allow for testing of different PMT prototypes and electronics setups

From Soeren Jetter and Marco Grassi

Simulated Signal 2/2

Scheme of waveform deconvolution

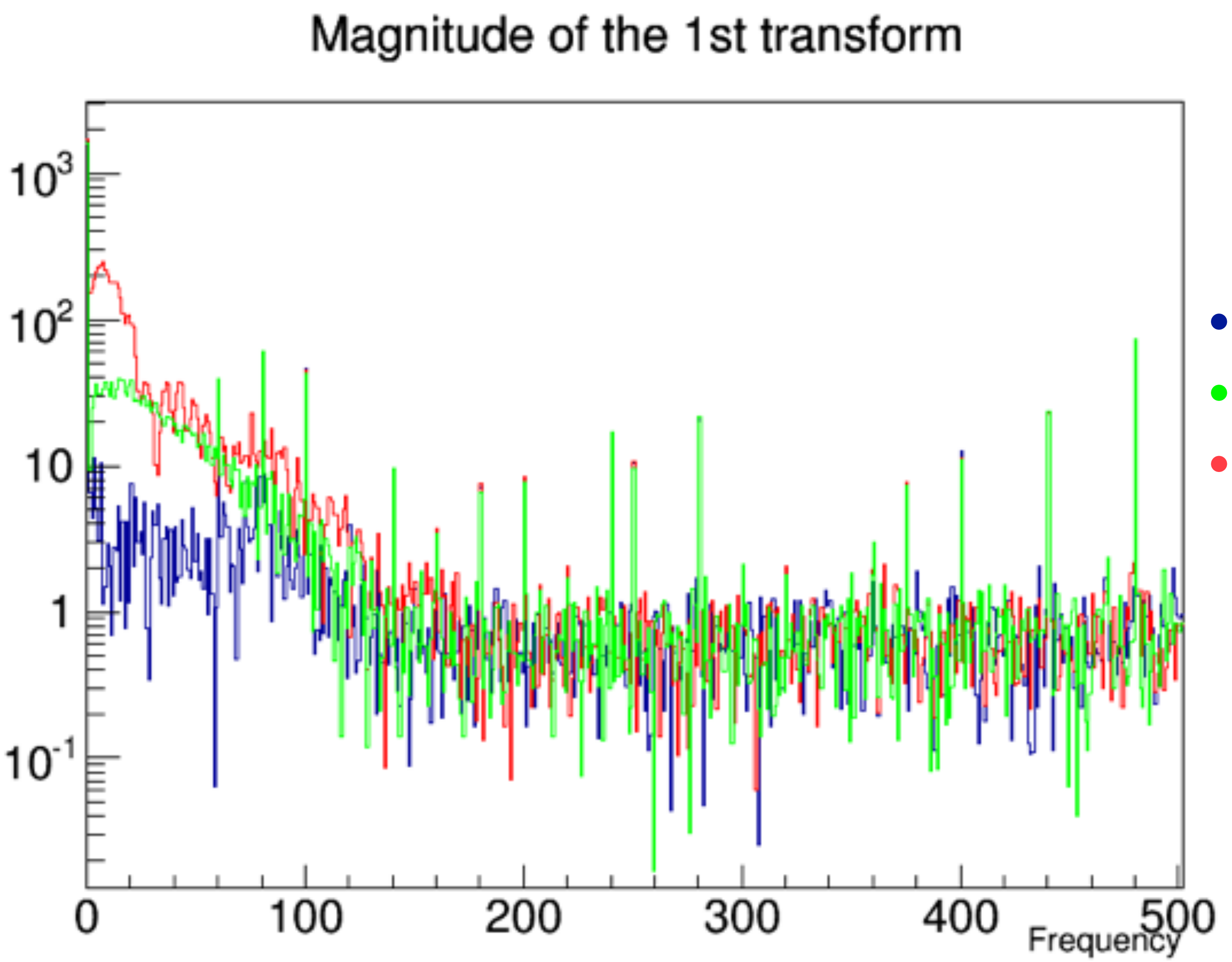


Model-independent unfolding scheme

- MC response and noise to be extracted from MC data to avoid closed loops
- Performance heavily depends on level of noise contamination
- Unfolded waveform can be used to either integrate charge or count photons

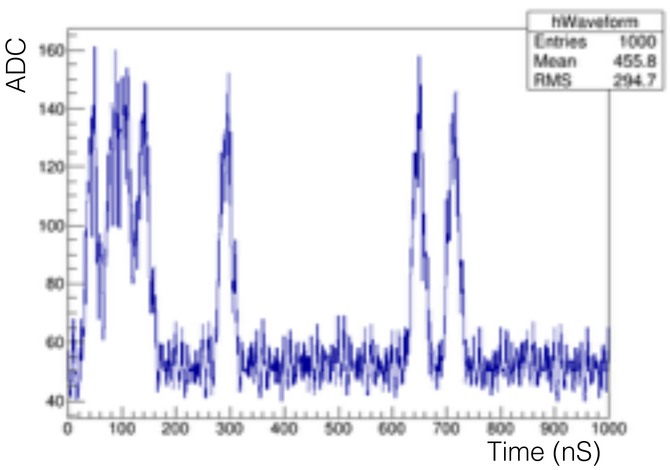
From Soeren Jetter and Marco Grassi

Fourier Transform of the Signal

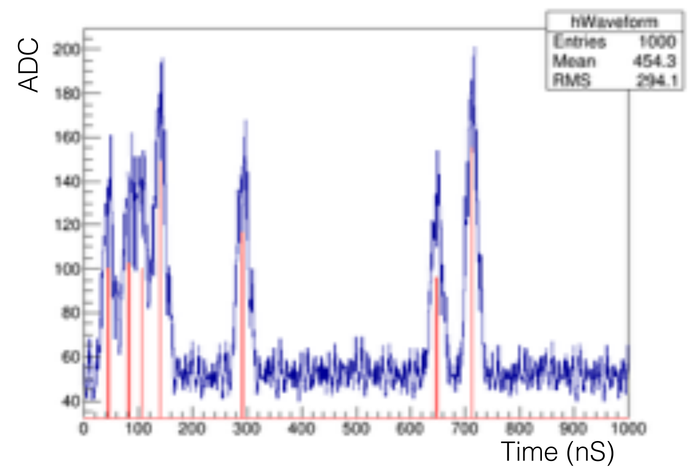


- Noise
- Single Photo Electron Signal
- Multiple Photo Electron Signal

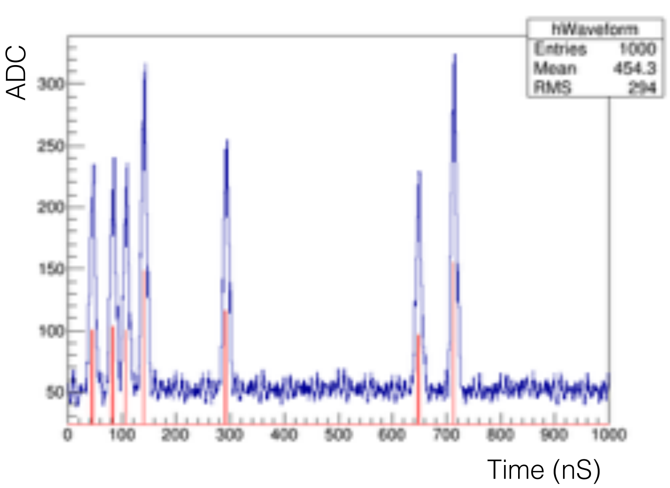
Gaussian Signal



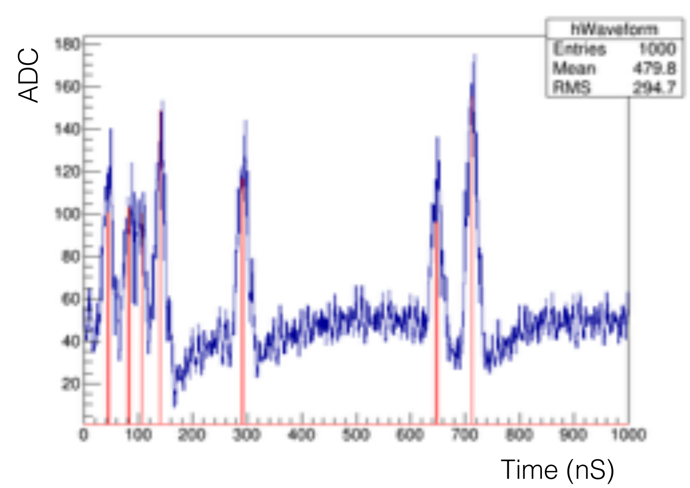
(1)



(2)



(3)



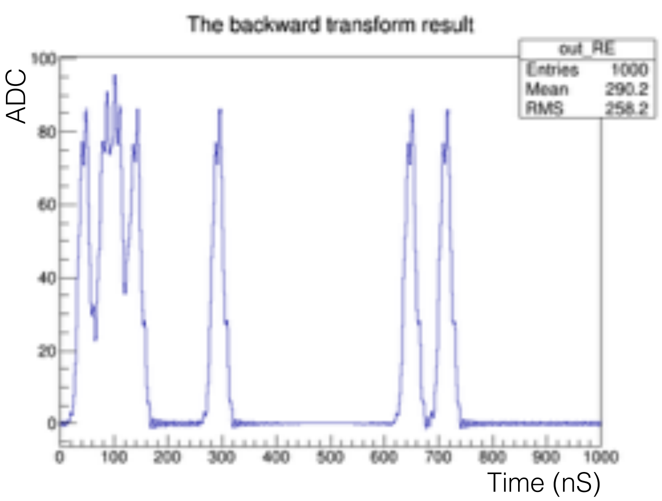
(4)

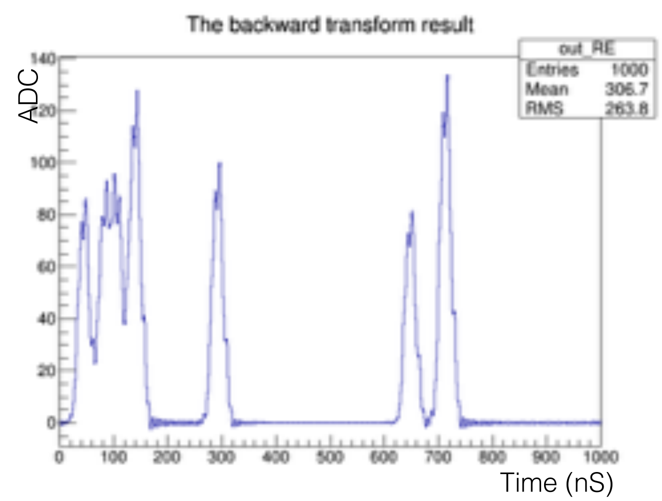
Use of Gaussian Signal to investigate the effectiveness of DSP techniques

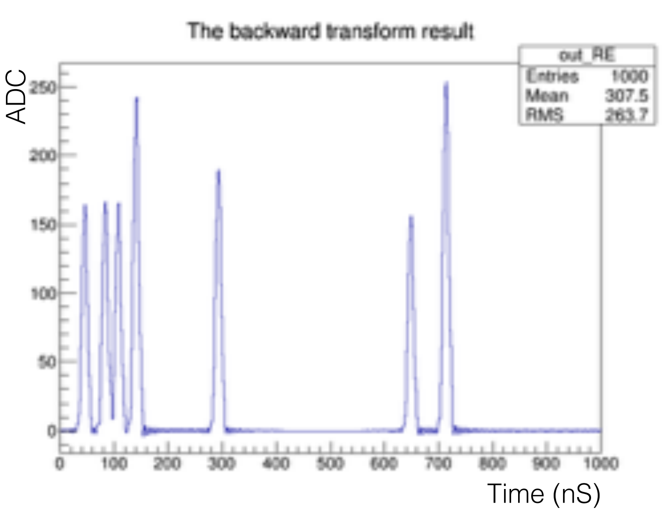
Data Sets Features

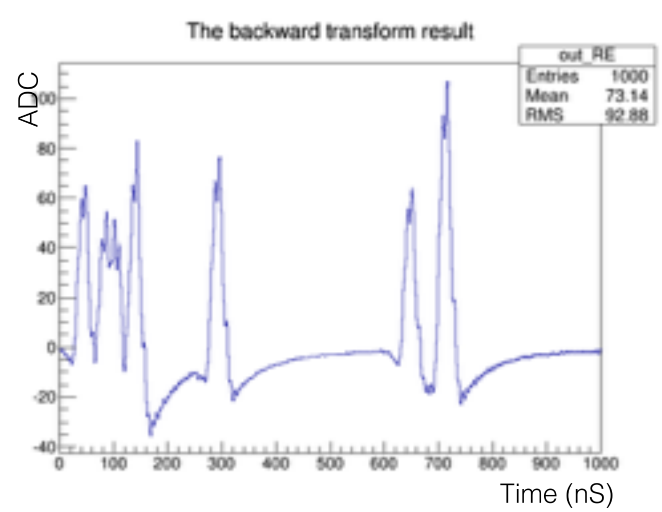
1. # of Hits
2. height of Hits
3. Width of hits
4. Overshoot

Preliminary Filtered Signal





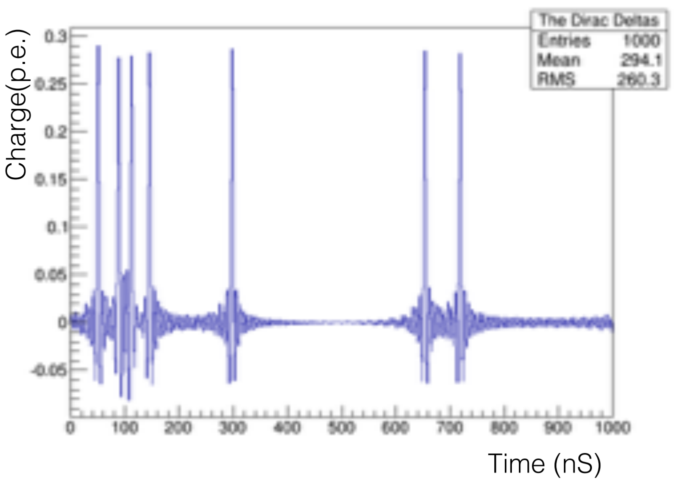


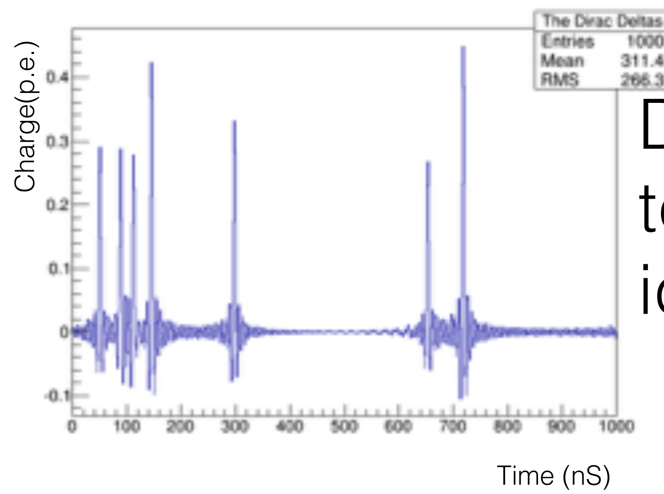


Filtering Signals in Frequency Domain

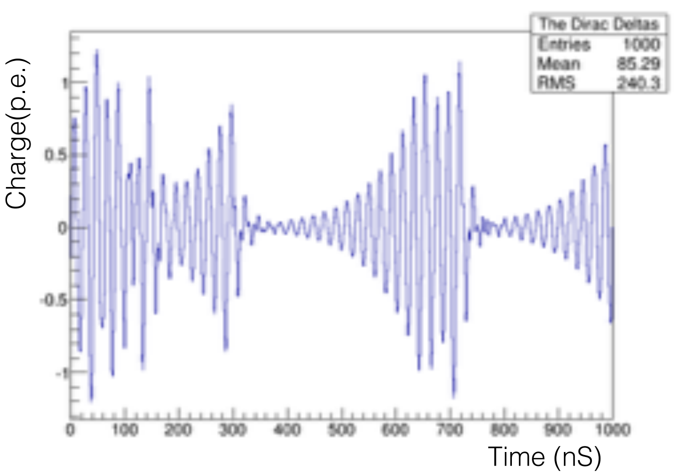
- Subtract the noise frequencies from the signal frequencies
- Cut all the frequencies grater than a threshold

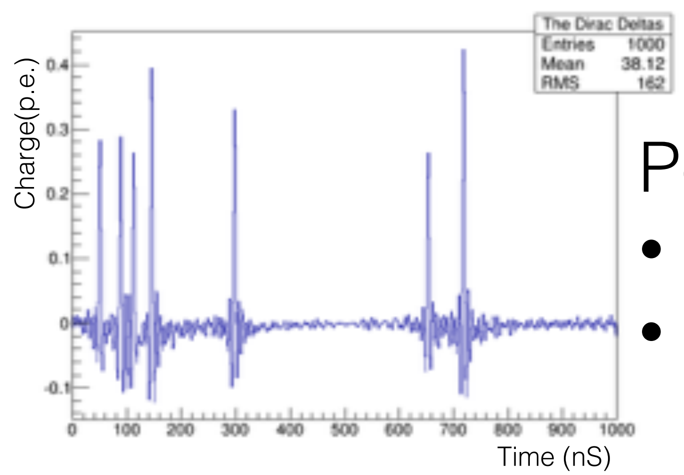
Wiener Deconvolution





Deconvolution in the Frequency Domain to obtain informations about Peaks, ideally Dirac Deltas.



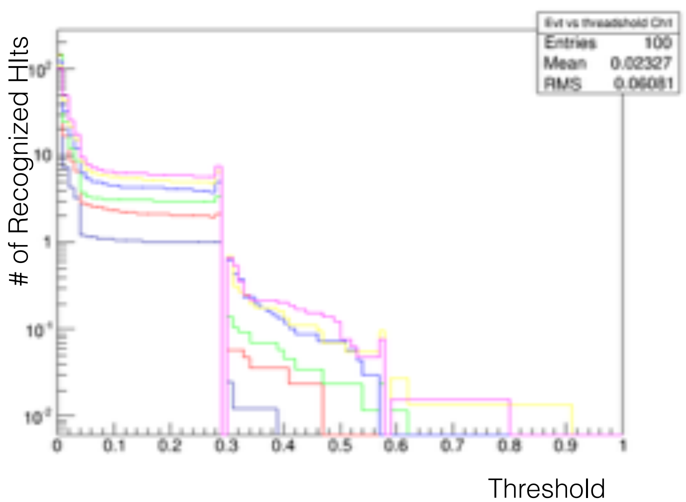


Peak Analysis

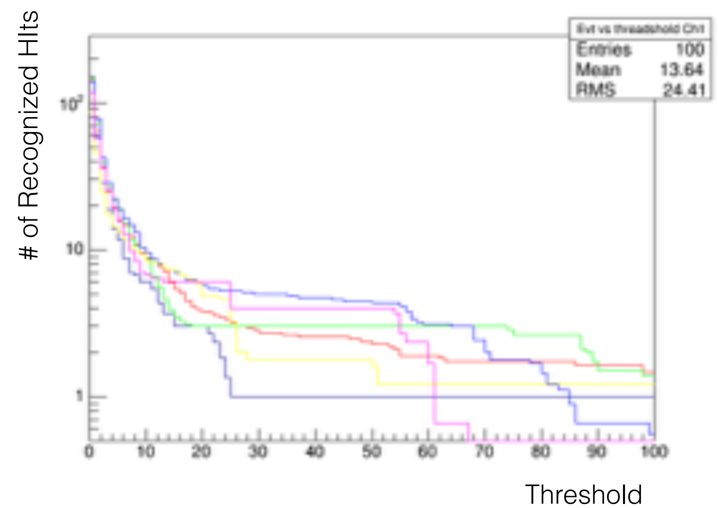
- Fixed Threshold
- Variable Threshold for eache event

Fixed Threshold vs Variable Threshold

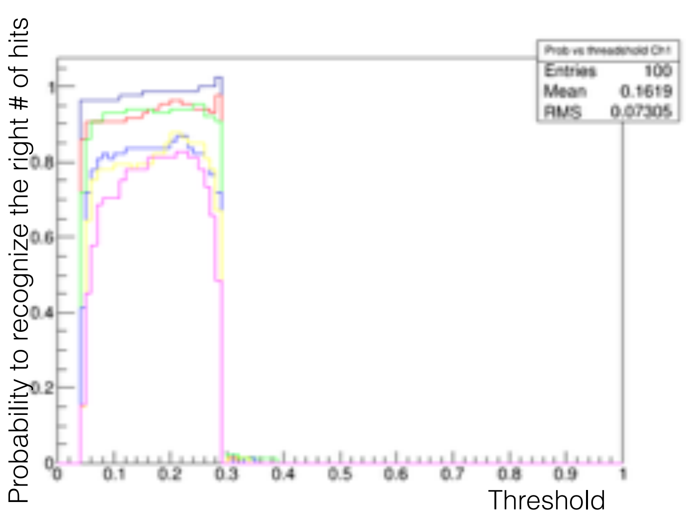
Fixed Threshold

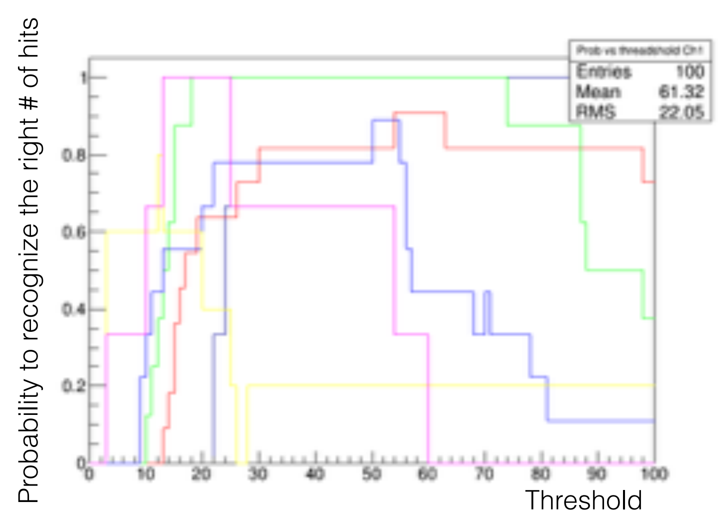


Variable Threshold



vs

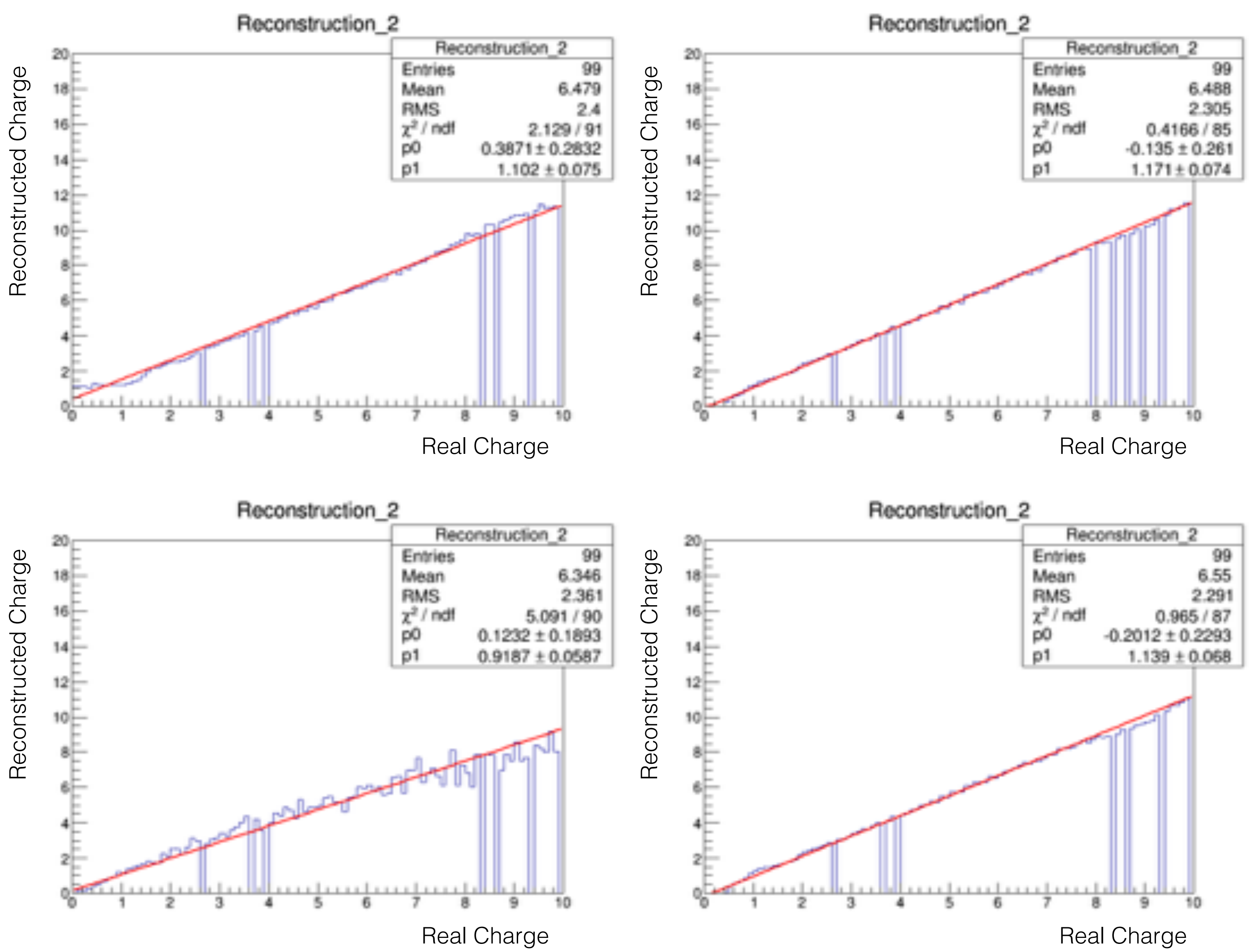




Number of hit recognized vs Threshold

Probability to Recognize the right # of hit vs Threshold

Preliminary Charge Reconstruction



Real Charge vs Reconstructed Charge

What Next?

- New Filters to increase the Signal to Noise Ratio
- Increase the effectiveness of the Deconvolution
- Explore new ways to Reconstruct the Peaks and the Charge
- How to integrate informations on # of peaks and Charge?
- Study Border Effect