The physics with a large LS spherical detector

– LS large volume: ➔ for statistics

– High Light(PE) ➔ for energy resolution 1200 pe/MeV

Both crucial for the physics capabilities

Steel Truss

Holding PMTS

~20000 x 20”

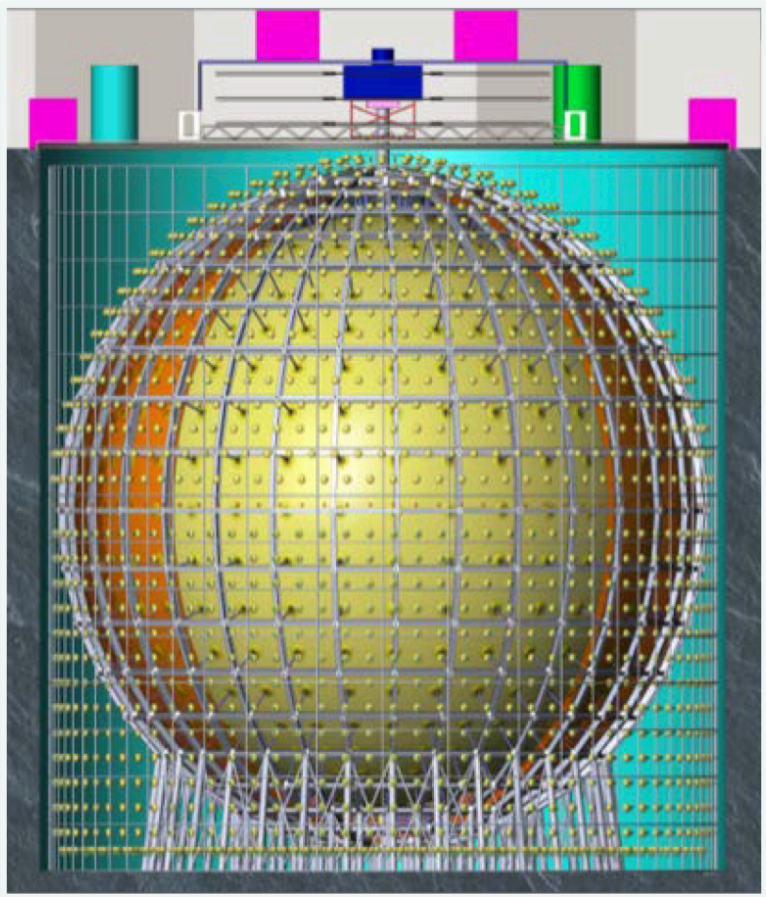
18000 Inner

2000 veto

~25000 x 3”

Acrylic Sphere

filled with 20 kt LS

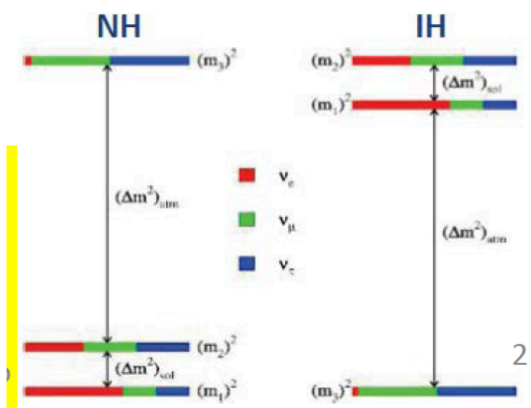


20 kton LS detector

~3 % energy resolution-the greatest challenge

Rich physics possibilities

- ⇨ **Mass hierarchy**
- ⇨ **Precision measurement of 3 mixing parameters**
- ⇨ **Supernovae neutrinos**
- ⇨ **Geoneutrinos**
- ⇨ **Diffuse Supernovae ν’s**
- ⇨ **Atmos&sol neutrinos**
- ⇨ **Nucleon Decay**
- ⇨ **Exotic searches**



Juno @ RM3

People: Paolo Aloe, Enrico Bernieri, Antonio Budano, Andrea Fabbri, SM, Paolo Montini, Cristina Martellini, Yury Malyshkin, Giuseppe Salamanna, Giulio Settanta,

(12 persons / ~7.0 FTE)

Paolo Aloe (2mu) Domenico Riondino (8mu), Diego Tagnani (1mu)

Activities:

- **Trigger: L2 layer of the Juno trigger** — Andrea Fabbri, sm, Domenico Riondino
- **Electronics for the TAO detector** — Andrea Fabbri, sm, Domenico Riondino, Diego Tagnani
- **Computing at CNAF** — sm, Cristina Martellini Giulio Settanta
- **Monte Carlo events production/validation** — Giuseppe Salamanna
- **Simulation of the TAO detector** — Paolo Montini
- **Analisys** — sm, Yury Malyshkin, Cristina Martellini, Paolo Montini, Giulio Settanta

Software & Computing

CNAF:
- IHEP mirroring
- MC production
- Still alive computing @ rm3

Juno experiment at CNAF

S. M. Mari, C. Martellini, G. Settanta
INFN and Università degli Studi Roma 3
E-mail: stefanomaria.mari@uniroma3.it; martellini@roma3.infn.it; giulio.settanta@uniroma3.it

Abstract.
The Jiangmen Underground Neutrino Observatory (JUNO) is a 20 kton multi-purpose underground neutrino detector which was proposed in order to determine, as its primary goal, the neutrino mass hierarchy. The large fiducial volume, together with the excellent energy resolution forseen, would allow to perform also a series of important measurements in the field of neutrinos and astro-particle physics.
To address the mass hierarchy issue, the JUNO detector will be surrounded by a cluster of nuclear power plants at a distance of around 50 km. The resulting reactor antineutrino flux gives the possibility to determine the neutrino mass hierarchy with a significance level of 3-4σ, with six years of running JUNO. The measurement of the antineutrino spectrum with excellent energy resolution will lead also to a precise determination of the solar neutrino oscillation parameters, $sin^2\theta_{12}$ and Δm^2_{21}, with an accuracy below 1%.
The JUNO characteristics make it a suitable detector not only for neutrinos coming from the power plants, but also for neutrinos generated inside the Sun, or during supernovae explosions, or even in the Eart's crust and atmosphere. Other topics of interest potentially accessible to JUNO include the search for sterile neutrinos, proton decay and dark matter annihilation.
Data taking is expected to start in 2020.

JUNO Computing Model:

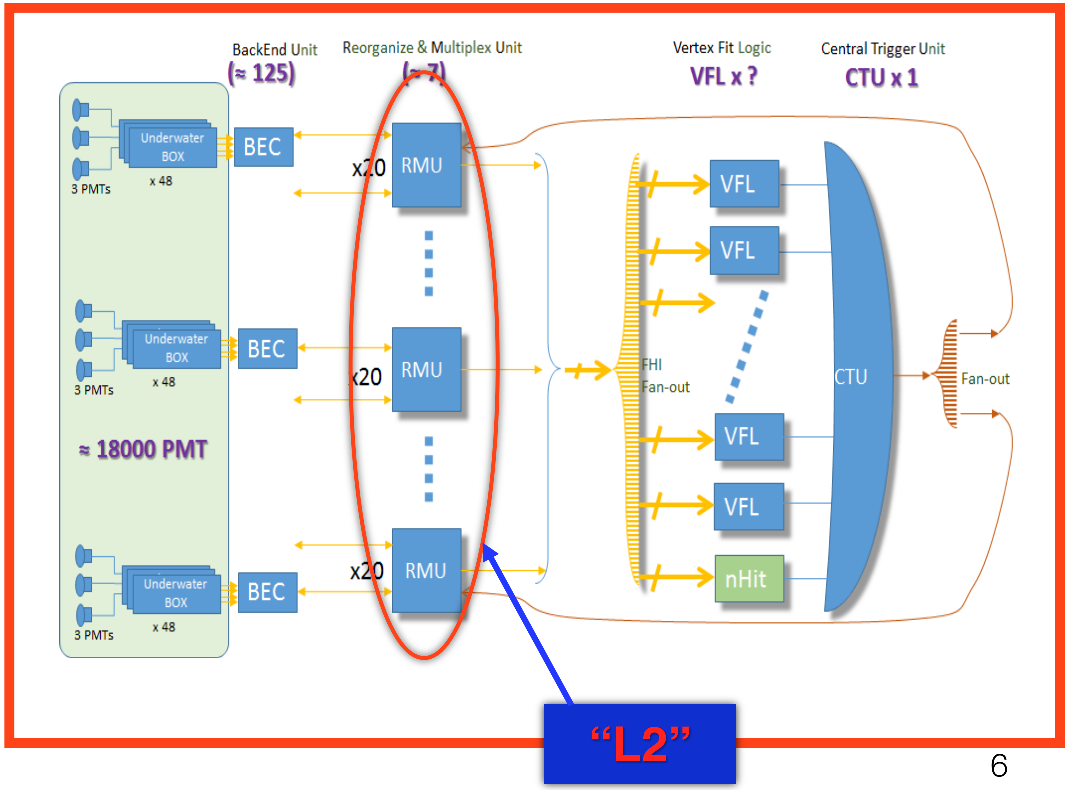
participating in the (confused) "debate"
data throughput still unknown
data transfer in a better shape

our suggestions: filtering & online farming

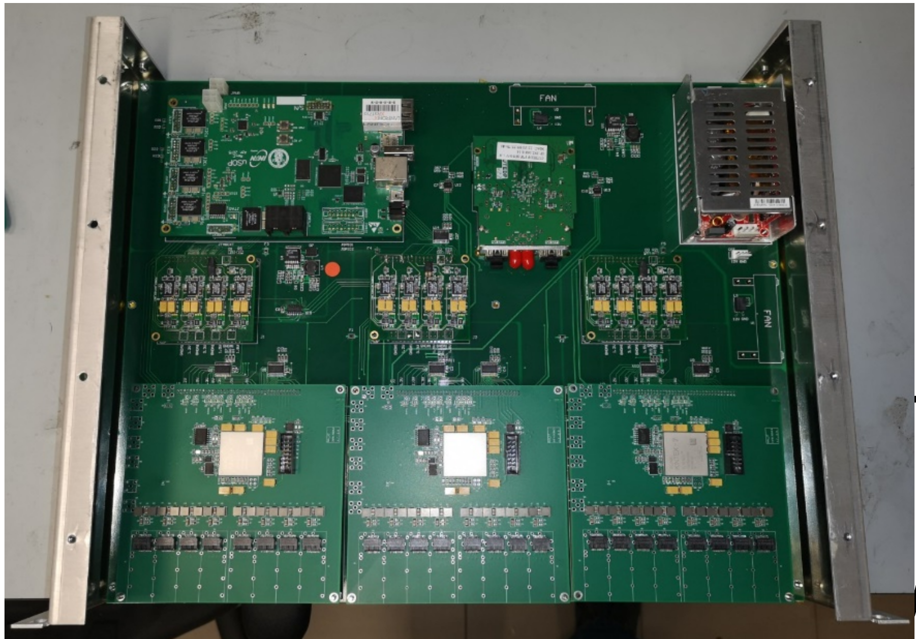
The L2 layer of the Juno trigger

Andrea Fabbri, SM, Domenico Riondino

- work done (almost): first bunch has been produced, boards are in our lab
- all boards needed for JUNO before the end of 2019
- details in the talk by Andrea



RMU Pre-production Status



Electronic Board (for 3 complete modules):

- Mother Board: **Delivered.**
- Power Board: **Delivered.**
- USOP (Slow Control): **Delivered.**
- K7 Board: **Delivered.**
- White Rabbit Board: **Delivered.**

- First box delivered, all checks passed.

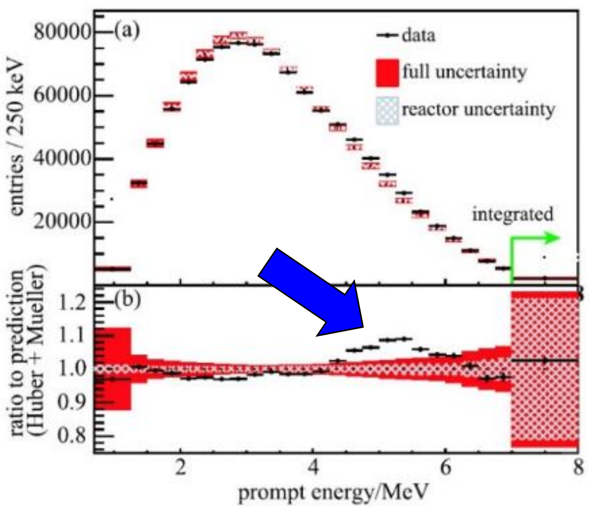
Three modules ready, we plan to bring one of them with us at next General Meeting .

We would like to start the mass production (10 modules) after summer.

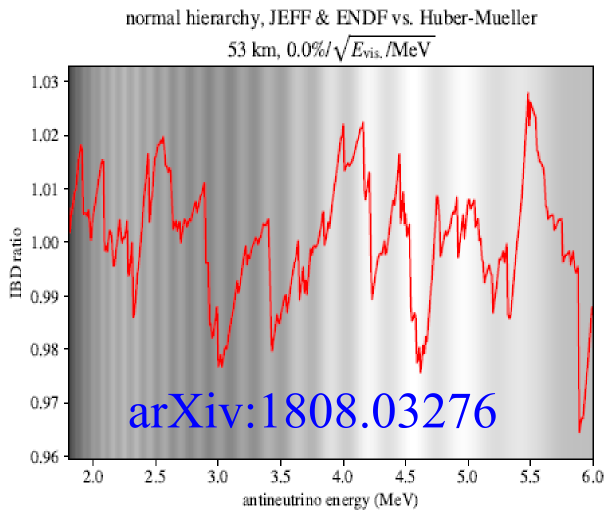
K7: fast TRG
SN
topology

JUNO-TAO

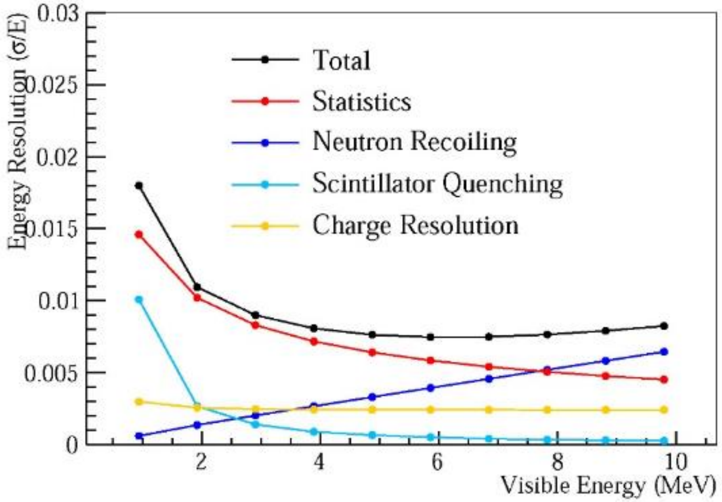
- **Taishan Antineutrino Observatory (TAO), a ton-level, high energy resolution LS detector at 30m from the core, a satellite exp. of JUNO.**
- **Measure reactor neutrino spectrum w/ sub-percent E resolution.**
  - ⇨ **Provide model-independent reference spectrum for JUNO**
  - ⇨ **Provide a benchmark for investigation of the nuclear database**
- **Full coverage of SiPM with 50% PDE (-50 °C) + LS → 4500 p.e./MeV**
  - ⇨ **$1.5\%/\sqrt{E}$ photon statistical resolution**
  - ⇨ **< 1% energy resolution for e^+ at >3 MeV**



5 MeV Bump



An example of possible fine structures



Energy resolution

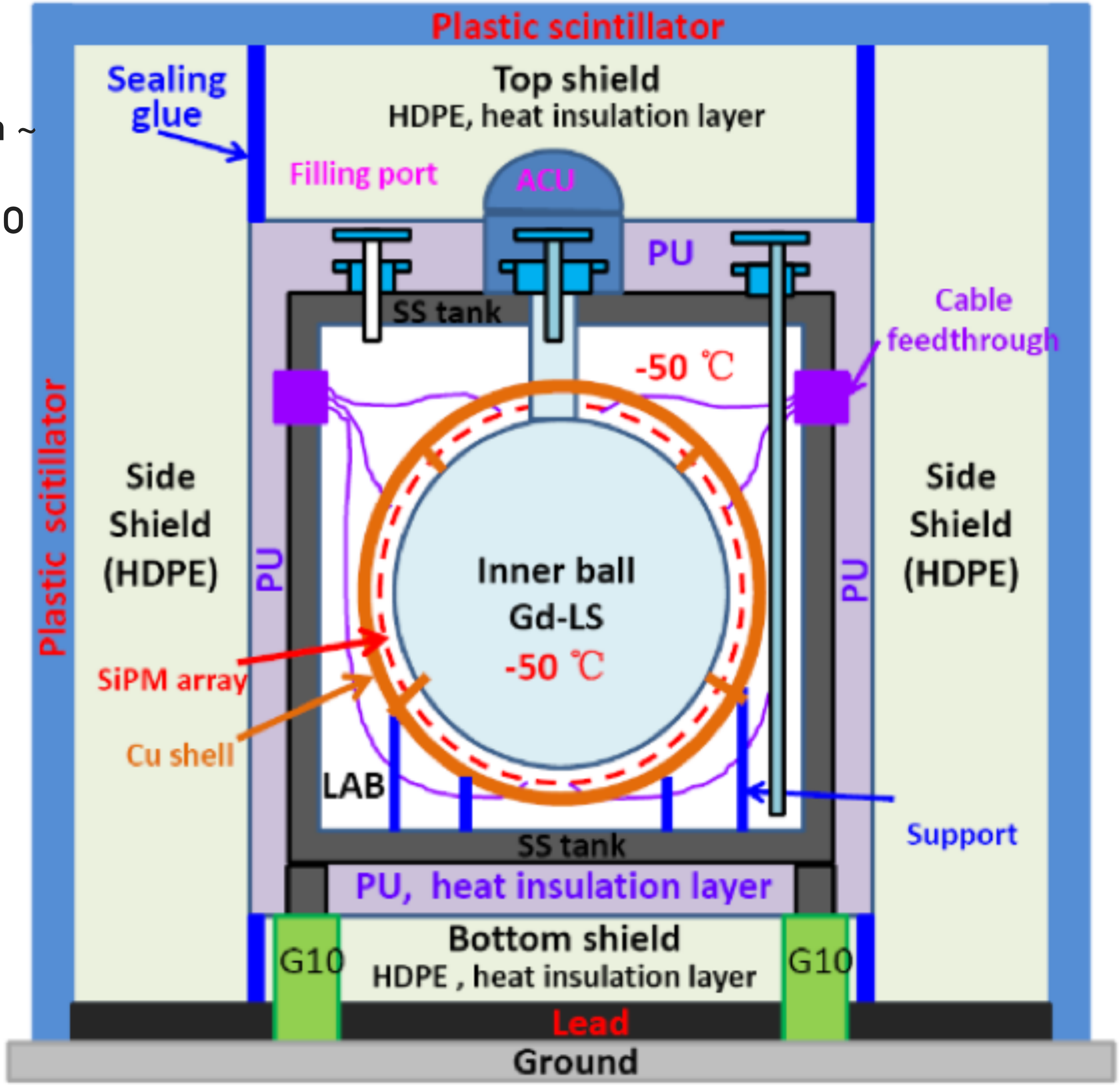
TAO

- Taishan Antineutrino Observatory: ton-level, high resolution LS detector close (~30 m) to the nuclear reactor core

- Measure reactor antineutrino spectrum with energy resolution ~ 1%
  - Reference spectrum for JUNO
  - Benchmark for the nuclear database

- Ton-scale GdLS detector
- Full coverage readout (~4000 SiPMs with ~50% PDE)
- Light Yield ~ 4000 PE/MeV
- Operated at low temperature

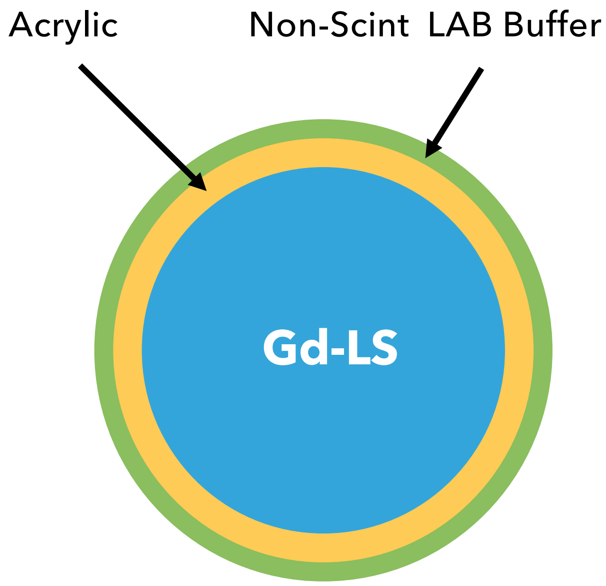
- Taishan Nuclear Power Plant
- 4.6 GW_{th} nuclear reactor
- More than 2000 IBD/day
- Will run in 2021

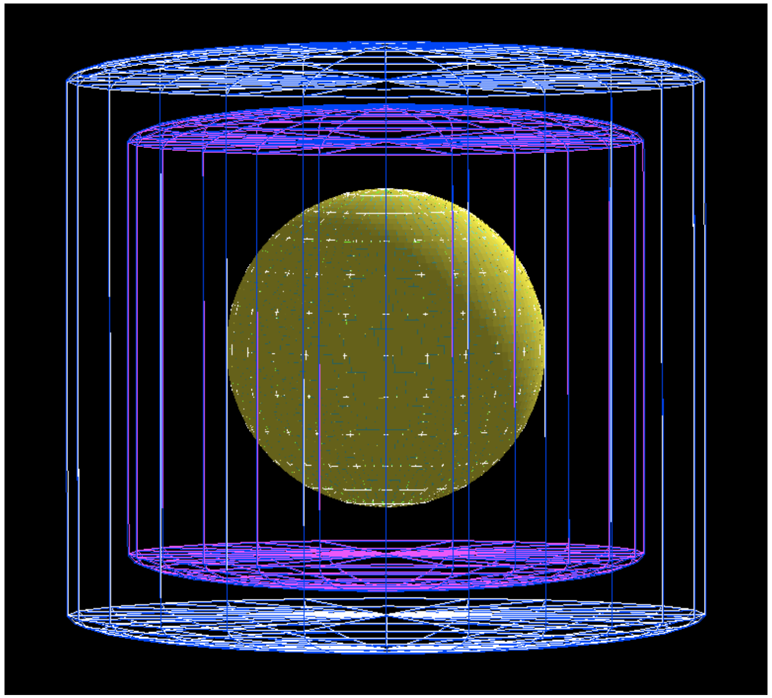


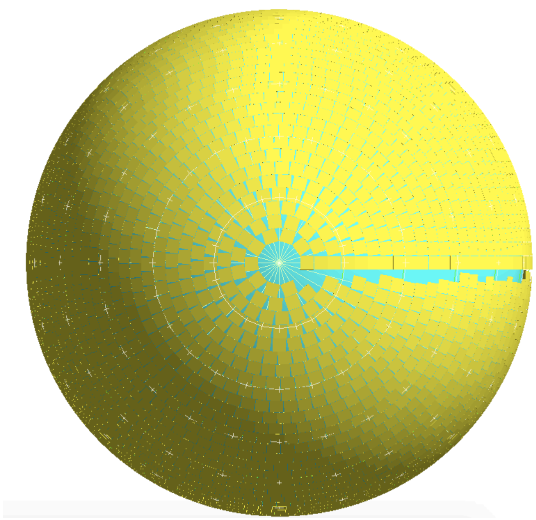
TAO SIM. SOFTWARE

(paolo montini)

- Geant4 10.4 p02
- Gd-LS sphere 90 cm diameter
- 2 cm thick acrylic shell
- 1 cm thick LAB Buffer (non scintillating)
- Total surface ~ 10.9 m^2
- 4056 5x5 cm^2 SiPM tiles
- ~ 94% coverage

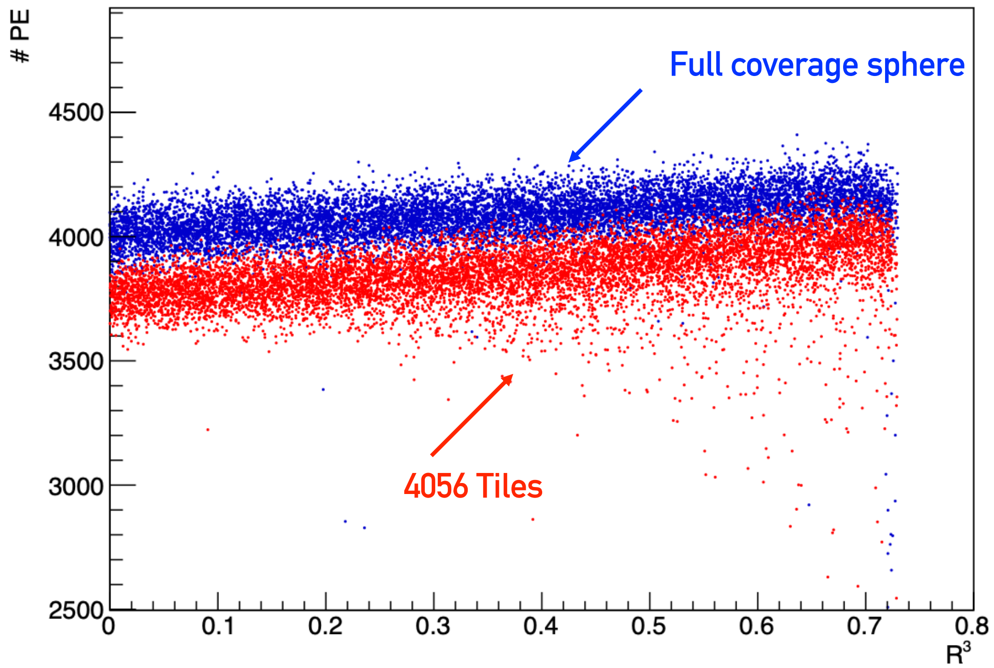


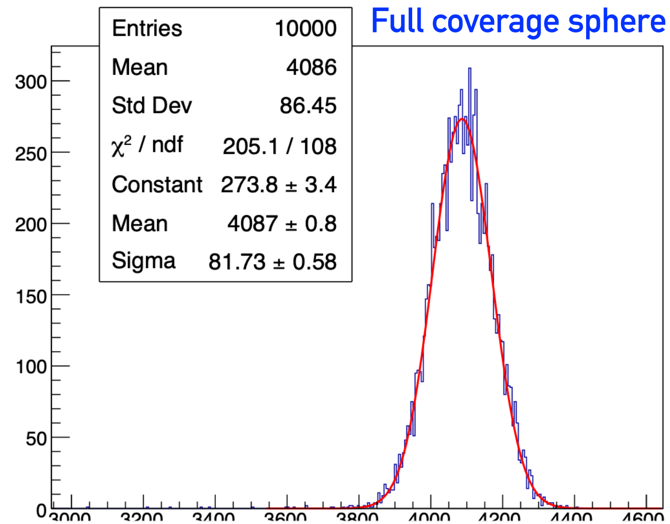


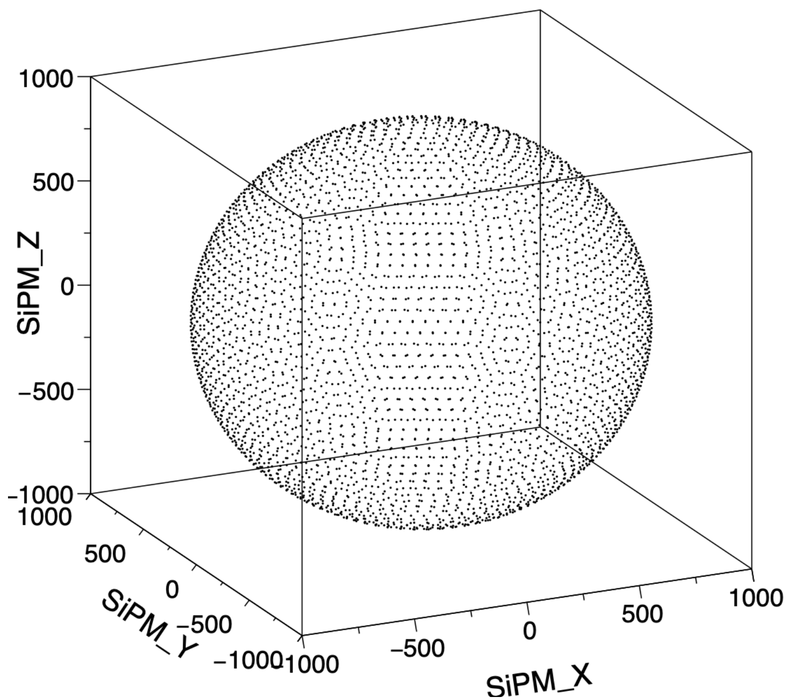


BASIC DISTRIBUTIONS

- 1 MeV electron randomly distributed in the LS volume
- PDE ~ 45% @ 420
- ~94% Coverage

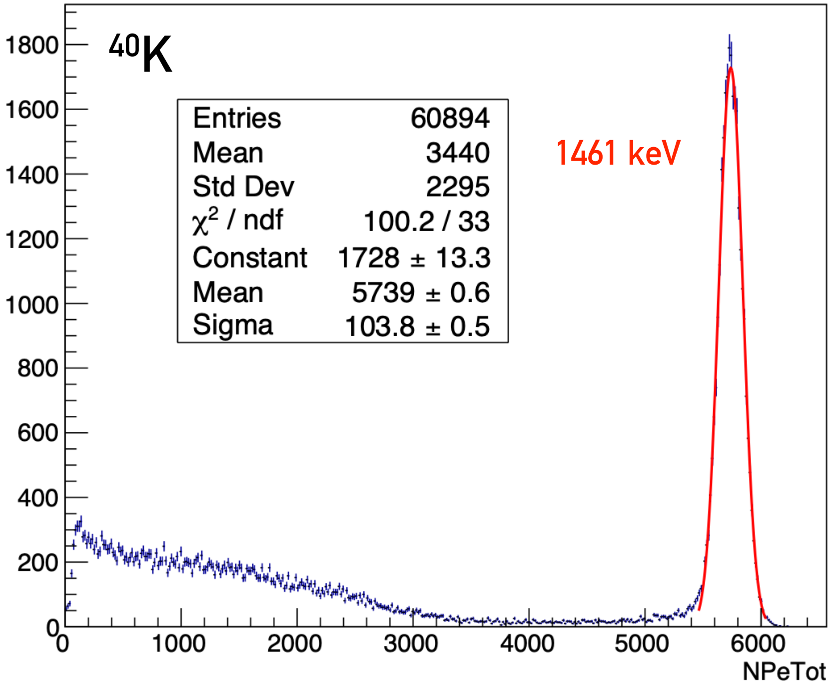


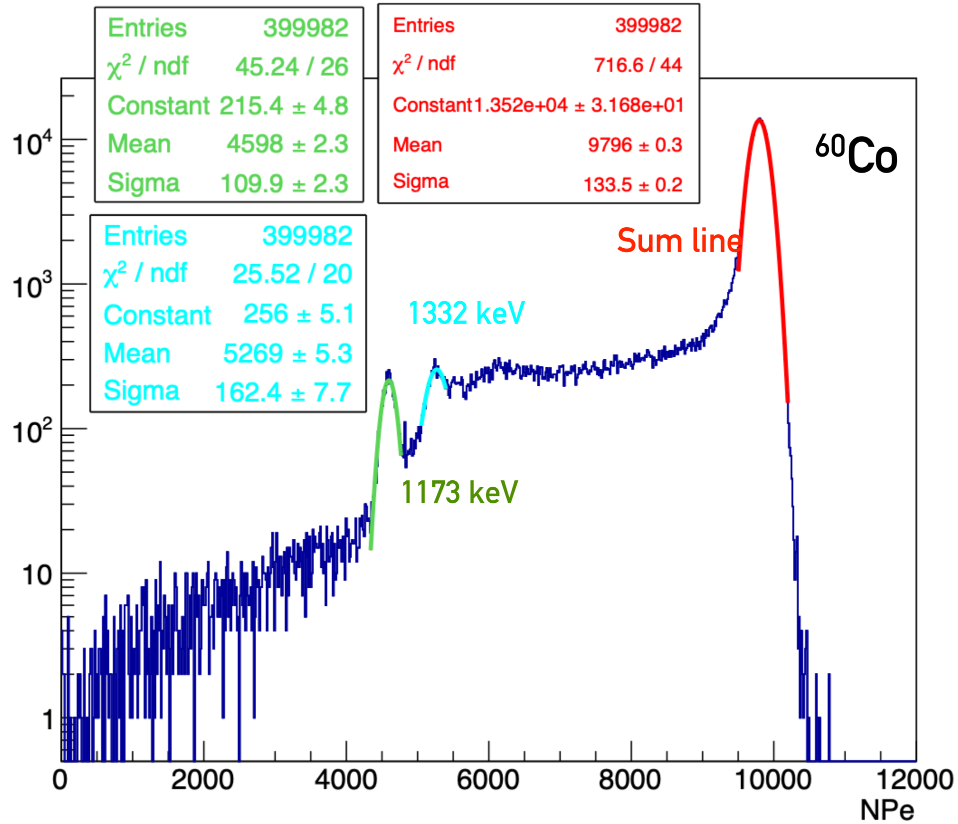




DETECTOR RESPONSE & RESOLUTION

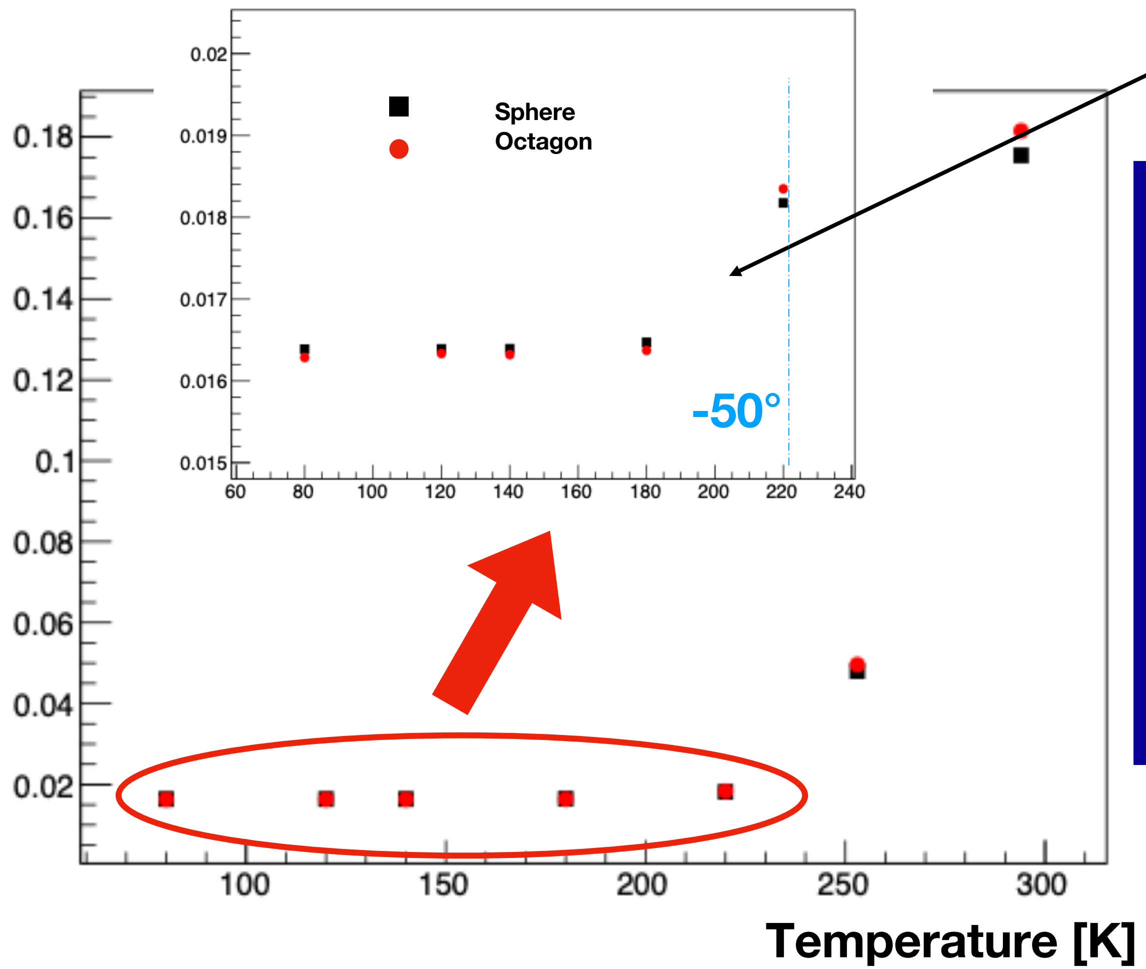
- "Calib. Source" in the detector center
- LY > 3900 PE/MeV
- Resolution ~ 1.6%/MeV

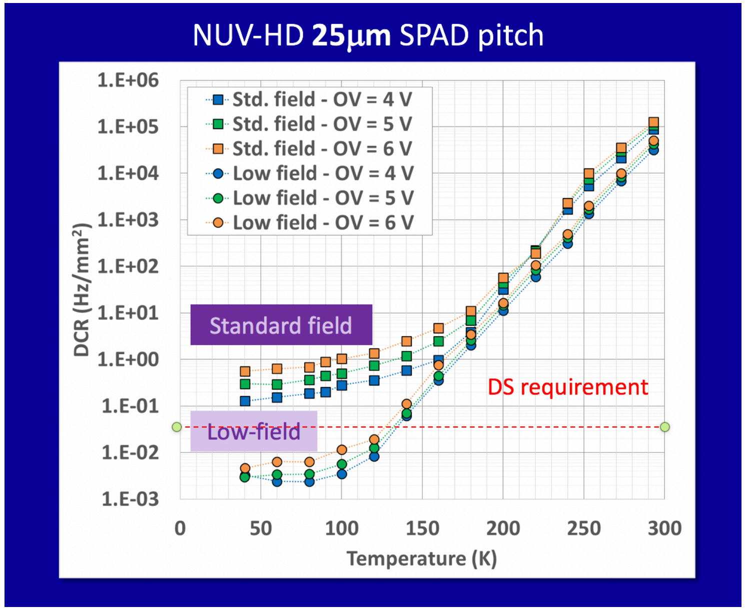




Energy resolution

Energy resolution reach a plateau for temperature lower than -50° for dark noise obtained from this FBK plot (OV = 5V):



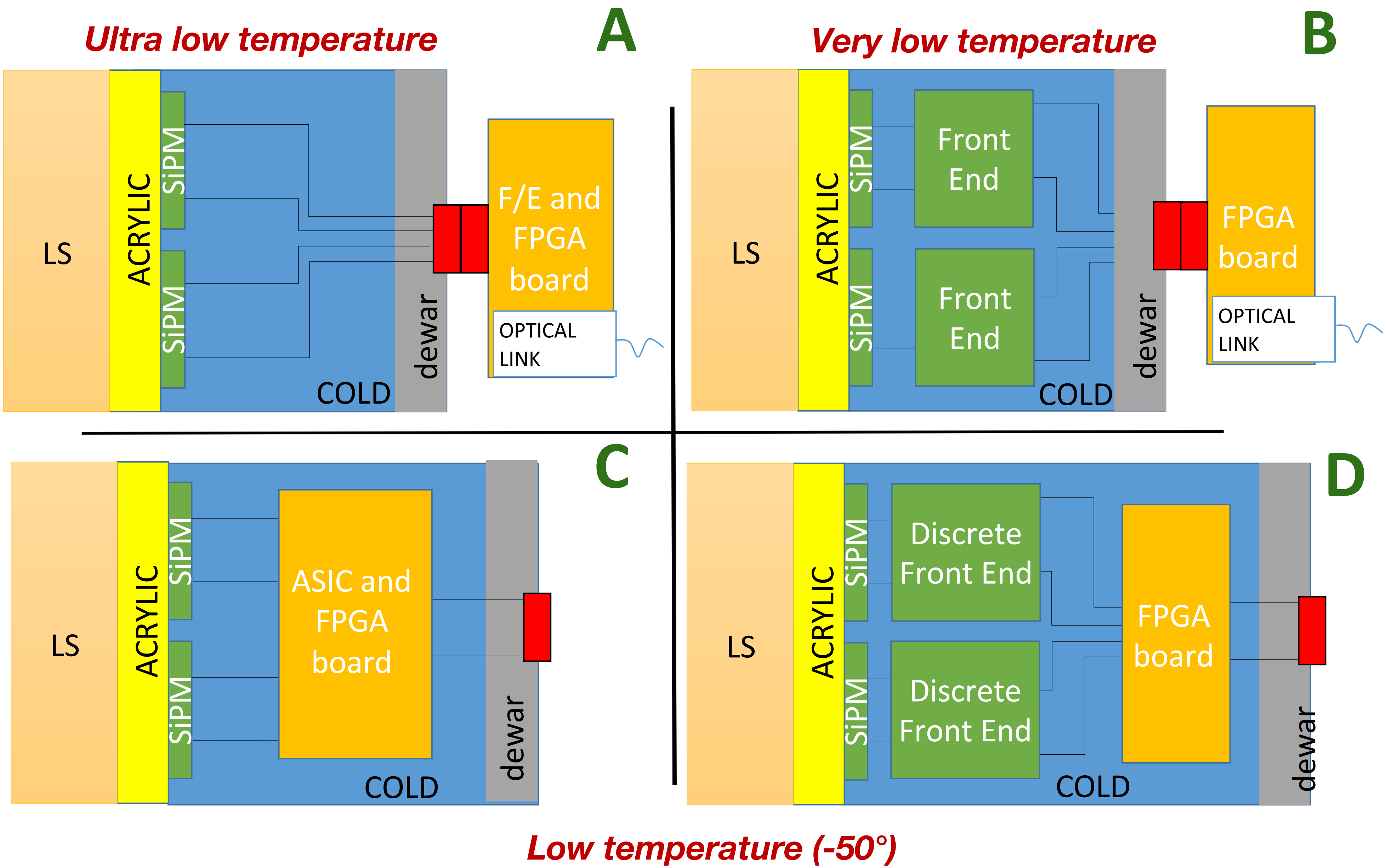


For NUV-HD 40 um SPAD could be different (better?)

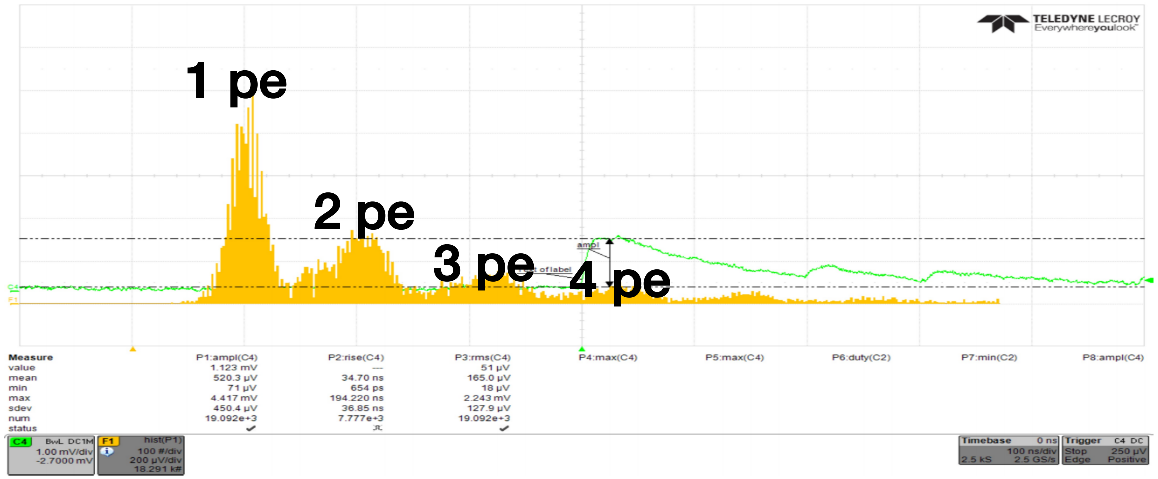
Energy resolution has been evaluated for 1 MeV electron in the detector center with dark rate from SiPM tiles at different temperatures assuming a 500 ns time window.

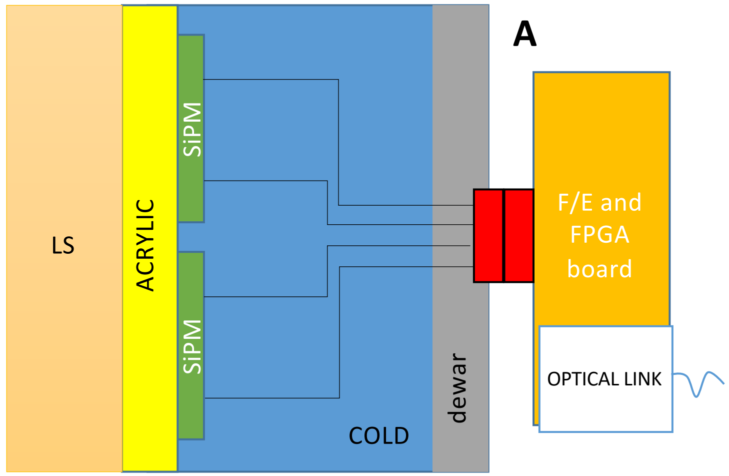
Electronic read-out hypothesis

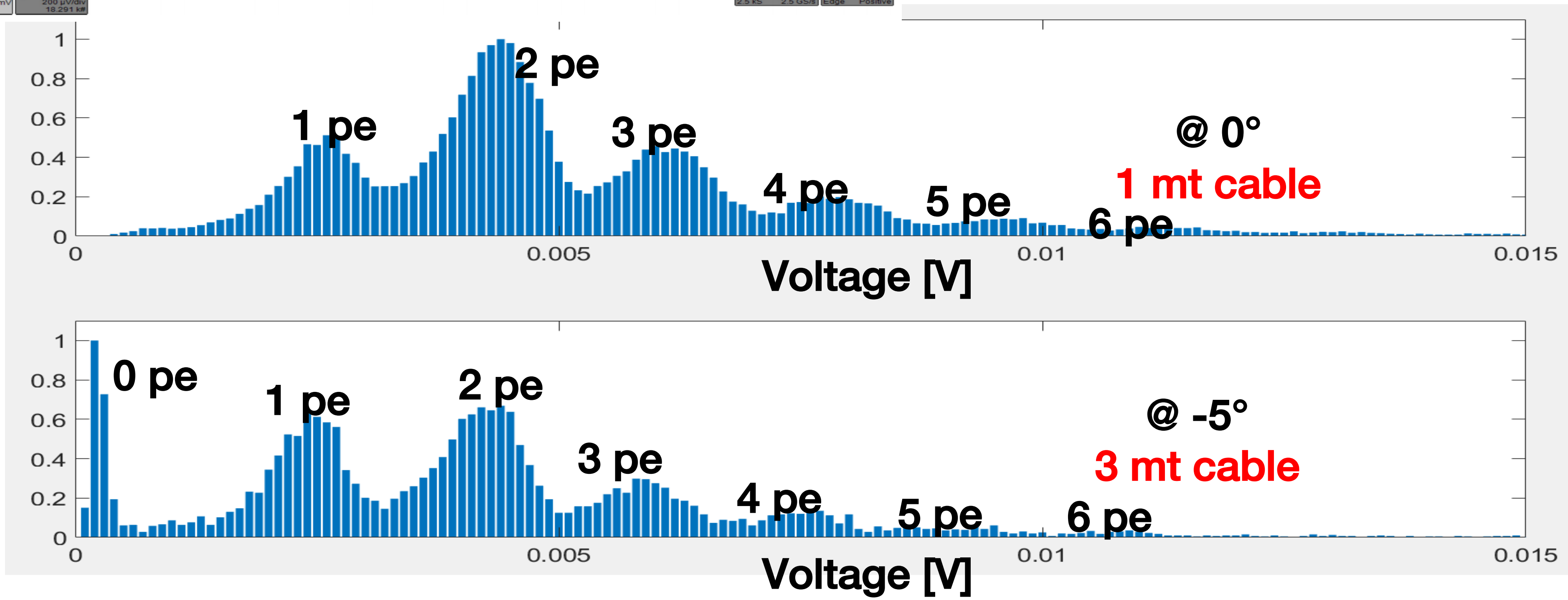
(Andrea Fabbri, sm, Domenico Riondino)



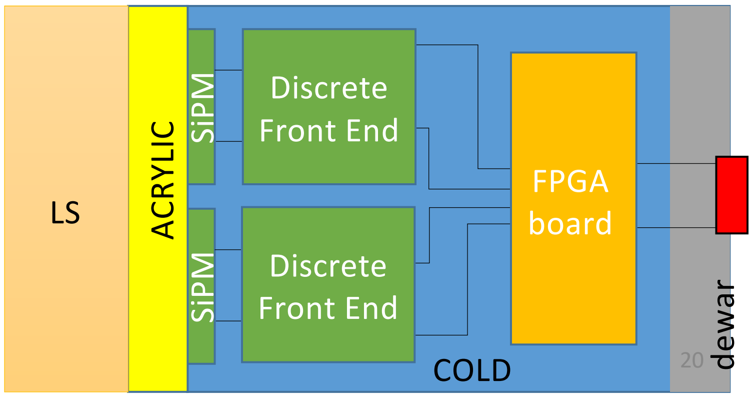
Single photon spectra



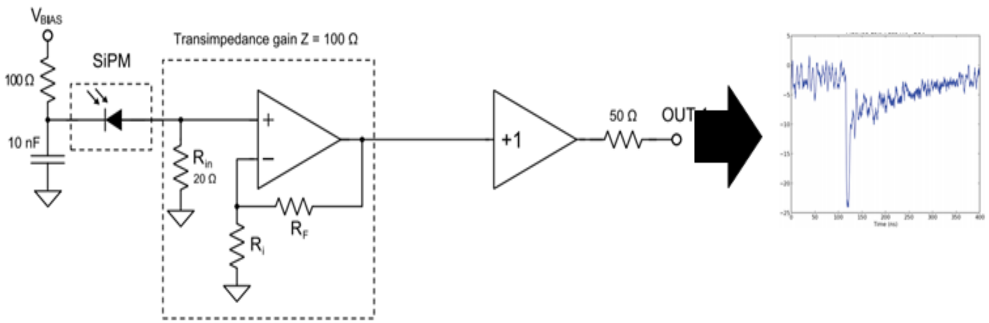


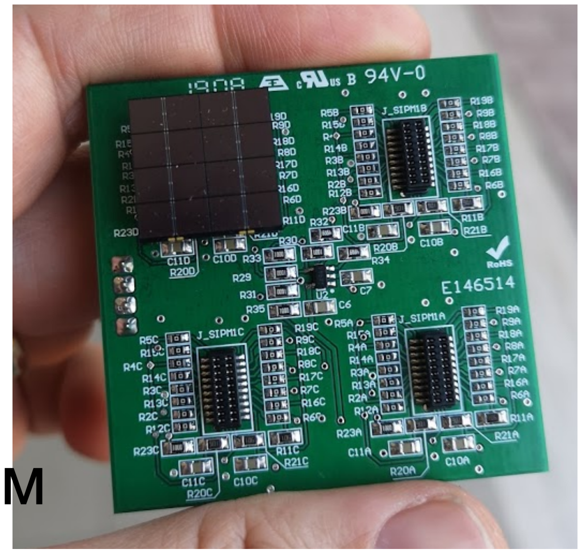


Electronic Architecture with Discrete Front End



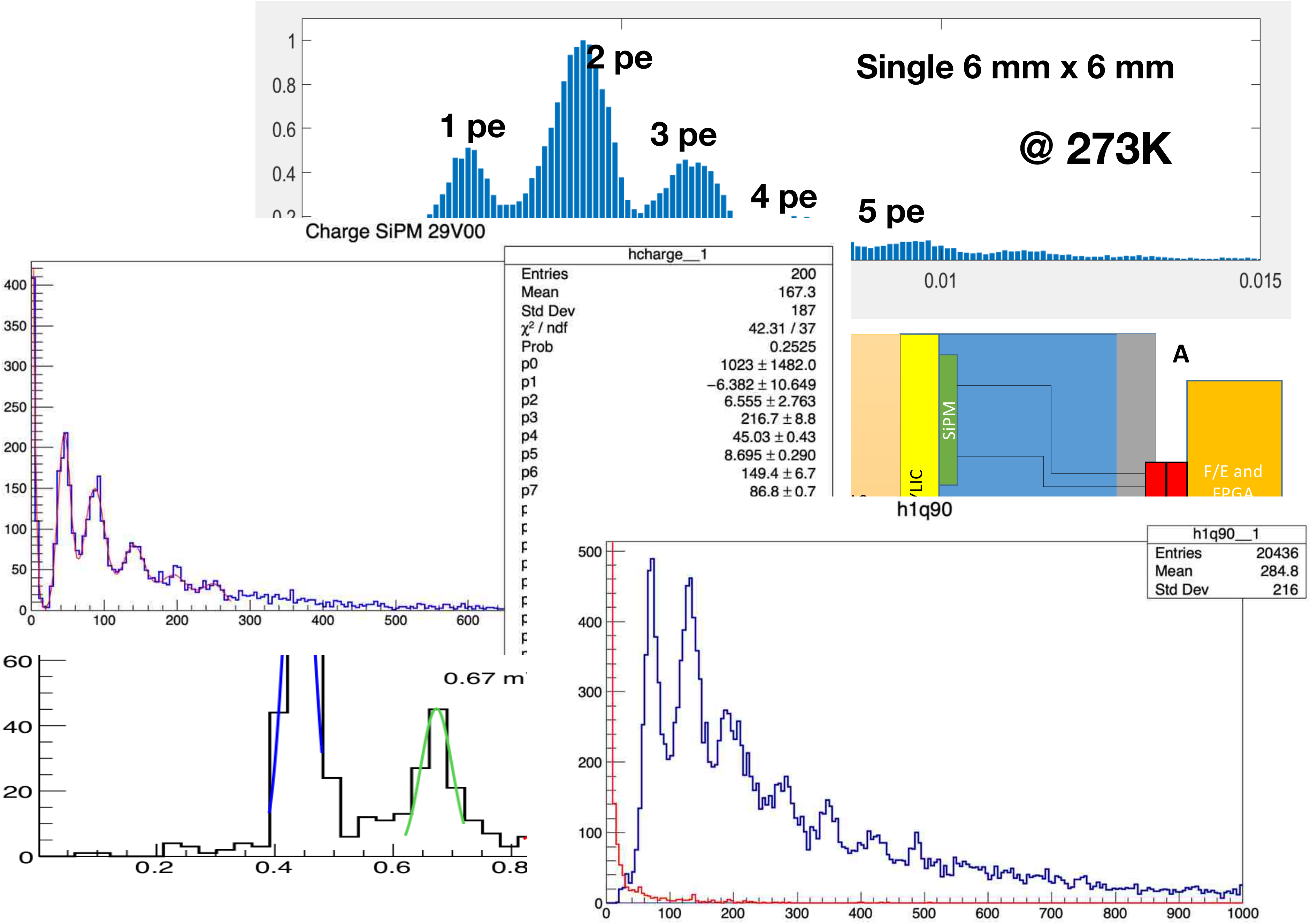
- 64 SiPM elements, $V_{bias} < 60$ V (series of two SiPM).





- One output channel for (up to) 25 cm^2 SiPM

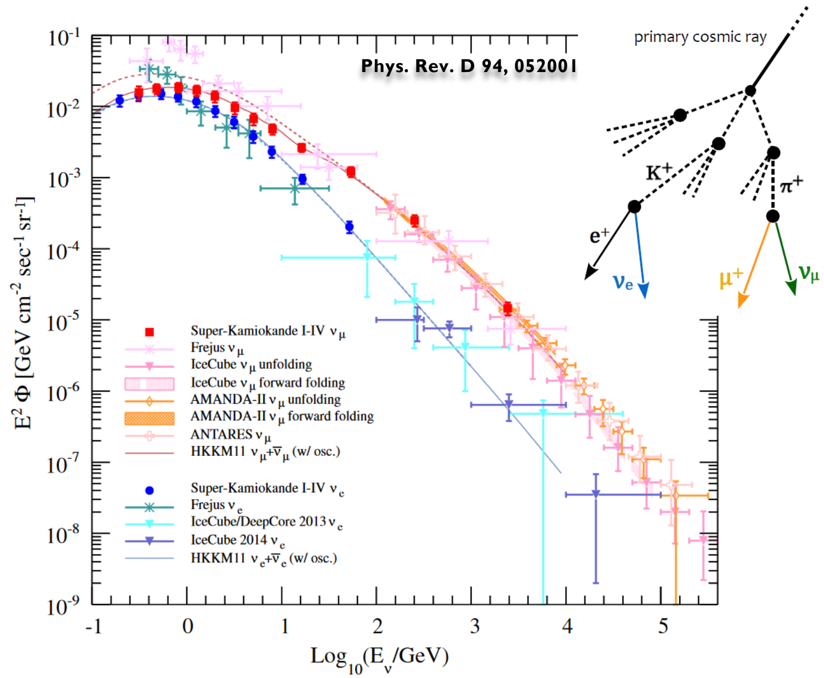
Single photon spectra with discrete front-end



ATMOSPHERIC NEUTRINOS

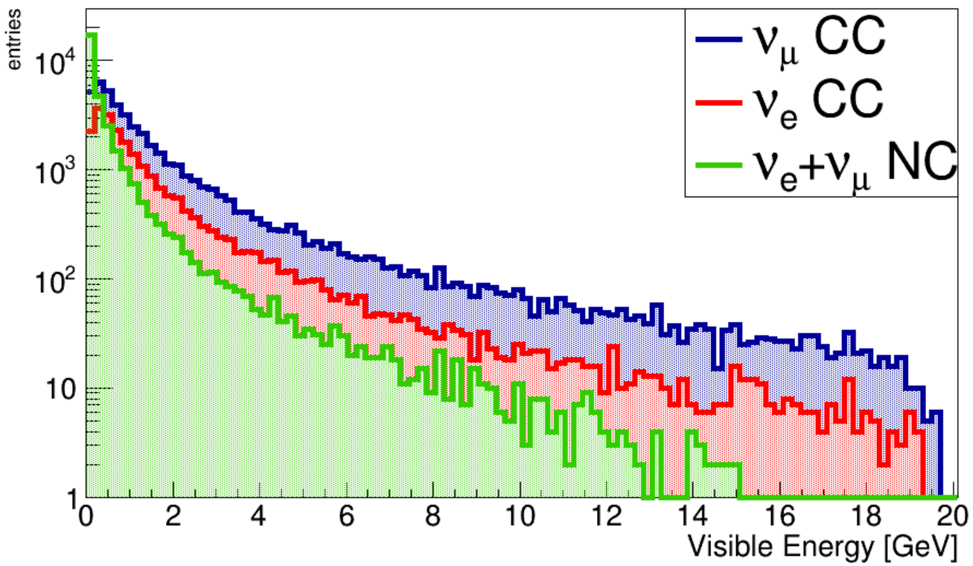
(giulio settanta)

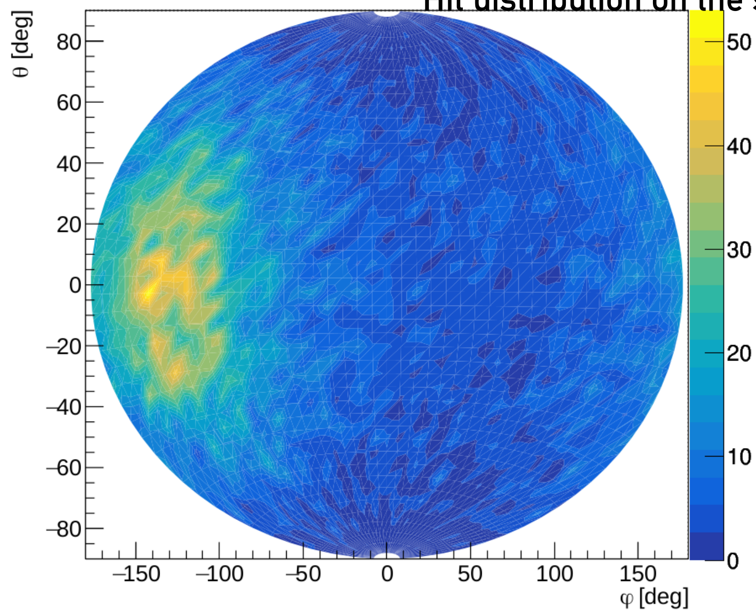
- Spectrum has been explored over a wide energy range
  - Some discrepancies survive at low energy
- ν_e and ν_μ have different flux
  - Different branching ratios of light mesons
  - ν_e from μ decay-in-flight are less abundant as the μ energy gets larger
- Present measurements come from Cherenkov detectors only
  - Which performances with a LS – based one?



MC simulations

HKKM14 flux model + GENIE (neutrino interactions) + GEANT4 (particle tracking)

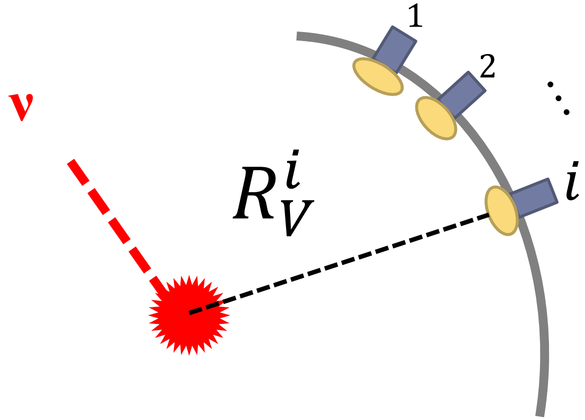




FLAVOR IDENTIFICATION

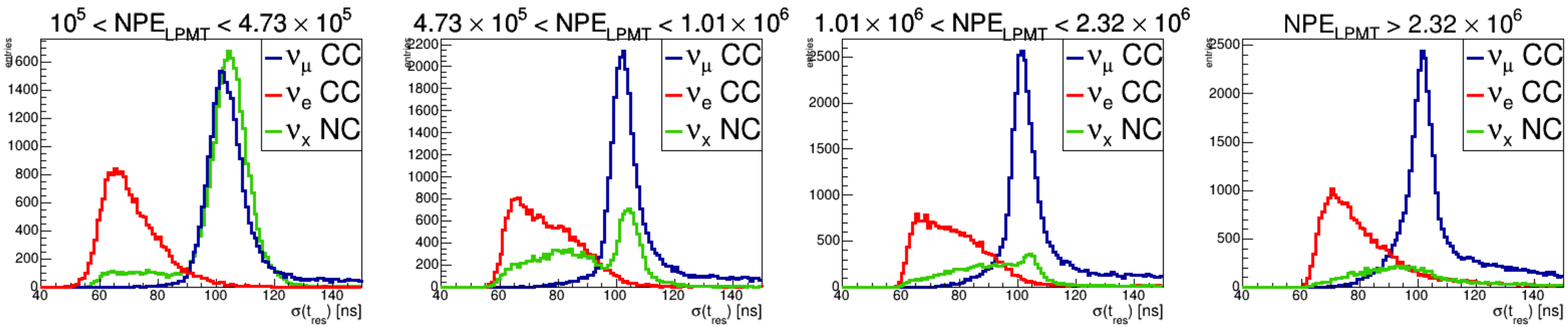
- A time residual – based variable tres is defined for each hit on the JUNO 3'' PMT system (small time resolution): $\rightarrow t^i_{res} = t^i_{hit} - \left(\frac{R^i_V \cdot n}{c}\right)$
  - σ = 1m gaussian smearing on the true vertex position to reproduce the experimental uncertainty conservatively
  - The new vertex is required to be within 16 m from the detector centre
  - σ = 4 ns gaussian smearing on the true vertex to simulate TTS
- Take the RMS of the profile → σ(tres)

t^i_{hit} : arrival time of the hit on the i-th PMT
R^i_V: vertex – i-th PMT distance



Cuts for ν_e: $\sigma(t_{res})$ < 75 ns
log(NPE_{LPMT}) > 5.0
EFF: ~30%   CONT: ~10%

Cuts for ν_μ : $\sigma(t_{res})$ > 95 ns
log(NPE_{LPMT}) > 5.7
EFF : ~30%   CONT: ~10%



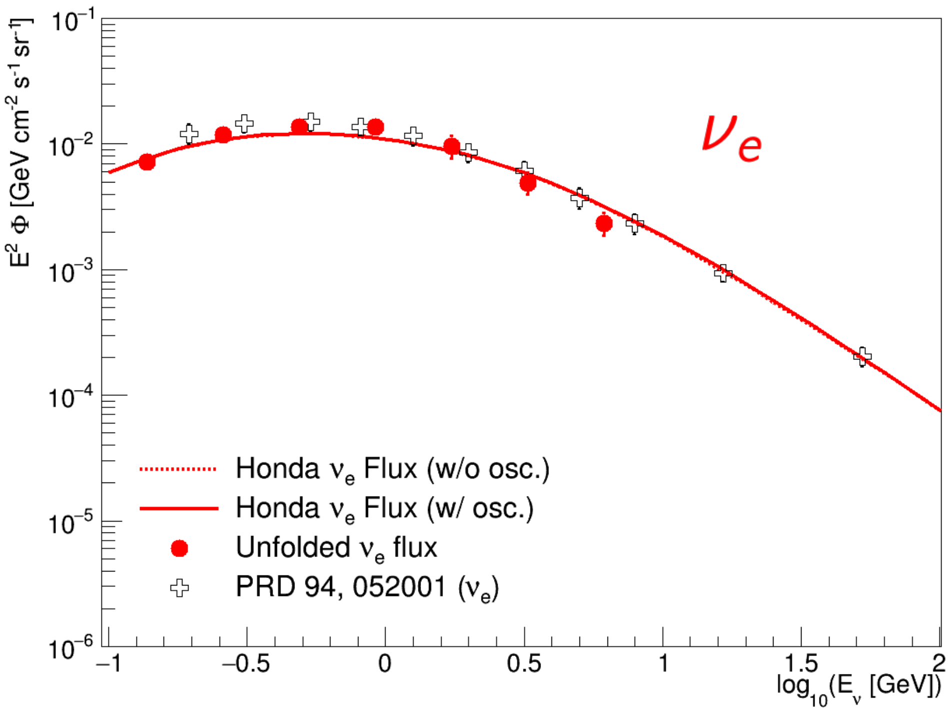
ATMOSPHERIC NEUTRINO FLUX

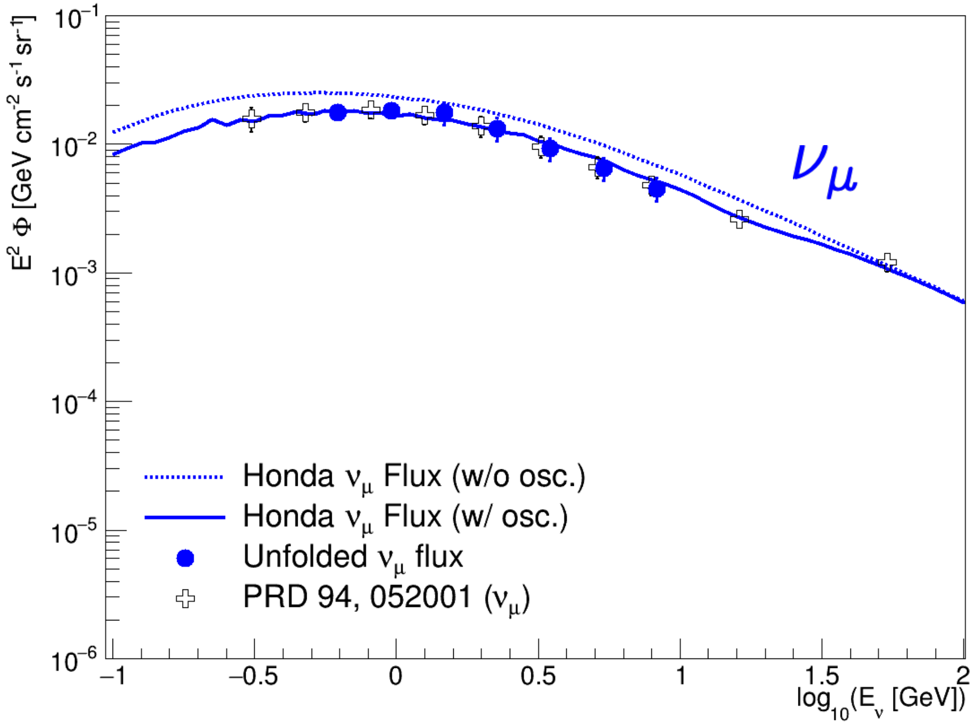
- Probabilistic unfolding algorithm to extract the spectrum (based on the Bayes theorem)

$$\boxed{P(E)^{\nu_\alpha}} = \mathrm{P}(\mathrm{E}|\mathrm{NPE}_{\mathrm{LPMT}})^{\nu_\alpha} \boxed{\cdot\, \mathrm{P}(\mathrm{NPE}_{\mathrm{LPMT}})^{\nu_\alpha}} \qquad \alpha = \mathrm{e},\mu$$

Unfolded spectrum — Detector observable

- 10.000 Events generated according to the HKKM14 flux model
- ~ <10 years of Detector live time
- Sys. Uncertainties ~ 20%
- Sensitive to oscillations





SUPERNOVA NEUTRINOS

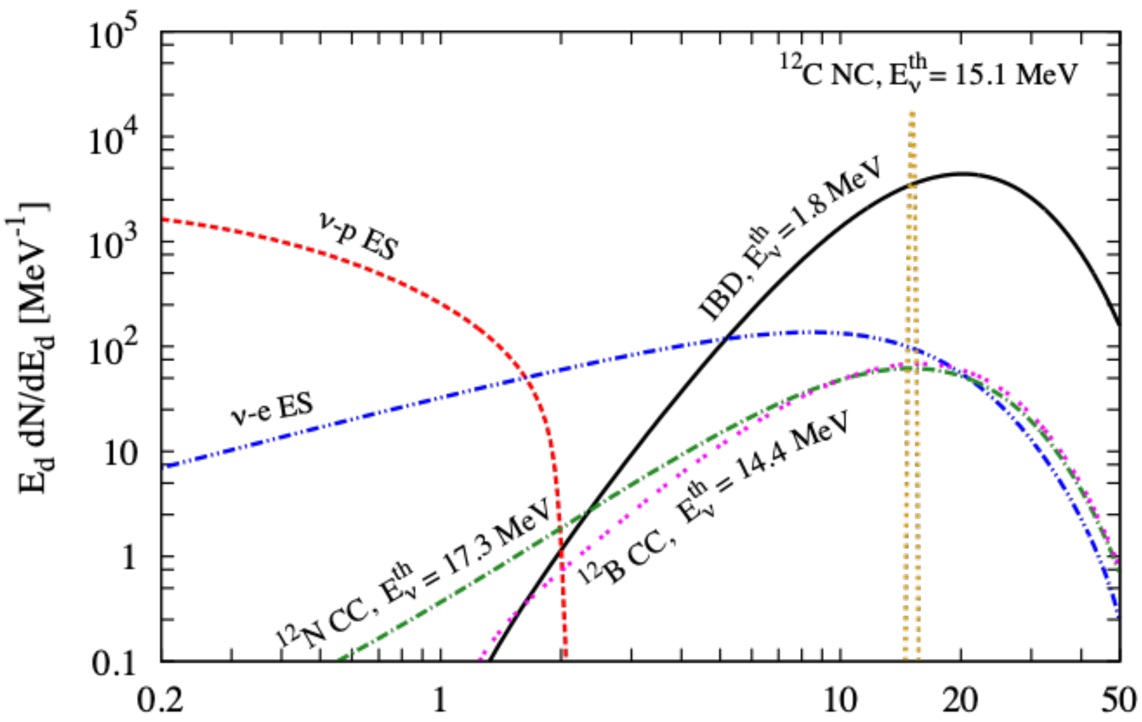
(cristina martellini)

- JUNO
- IBD is the golden channel at higher energies
- ν-p ES dominates at low energy

20 solar masses, d = 10 kph

- ~ 5000 IBD
- ~ 1500 ν-p ES
- 300 ν-e ES

Channel	Type	Events for different $\langle E_\nu \rangle$ values 12 MeV	14 MeV	16 MeV
$\overline{\nu}_e + p \to e^+ + n$	CC	4.3×10^3	5.0×10^3	5.7×10^3
$\nu + p \to \nu + p$	NC	0.6×10^3	1.2×10^3	2.0×10^3
$\nu + e \to \nu + e$	ES	3.6×10^2	3.6×10^2	3.6×10^2
$\nu + {}^{12}C \to \nu + {}^{12}C^*$	NC	1.7×10^2	3.2×10^2	5.2×10^2
$\nu_e + {}^{12}C \to e^- + {}^{12}N$	CC	0.5×10^2	0.9×10^2	1.6×10^2
$\overline{\nu}_e + {}^{12}C \to e^+ + {}^{12}B$	CC	0.6×10^2	1.1×10^2	1.6×10^2



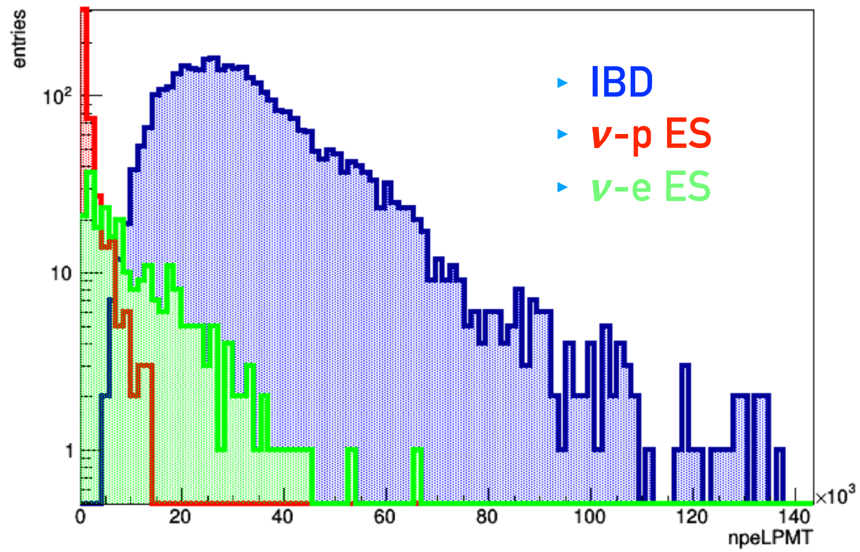
SUPERNOVA NEUTRINOS

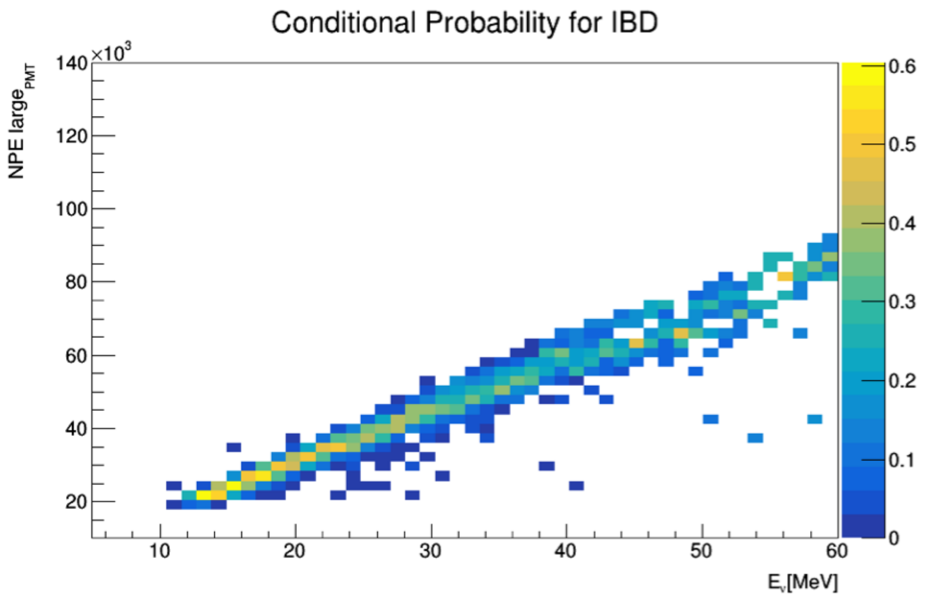
- Probabilistic unfolding algorithm to extract the spectrum

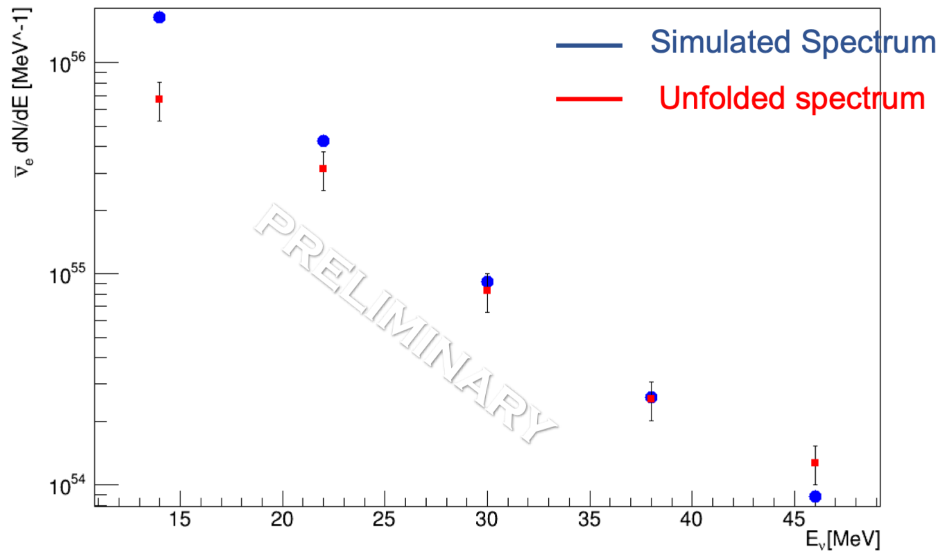
$$P_{IBD}(E_{\overline{\nu}_e}) \propto \int_{E_{min}}^{E_{max}} P_{IBD}(E_{\overline{\nu}_e}|E_0) \cdot P_{IBD}(E_0) \cdot dE_0$$

Detector response matrix

NPe as energy estimator

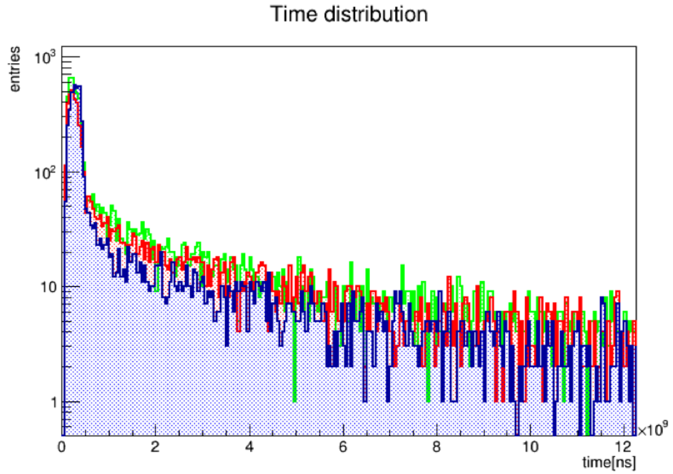


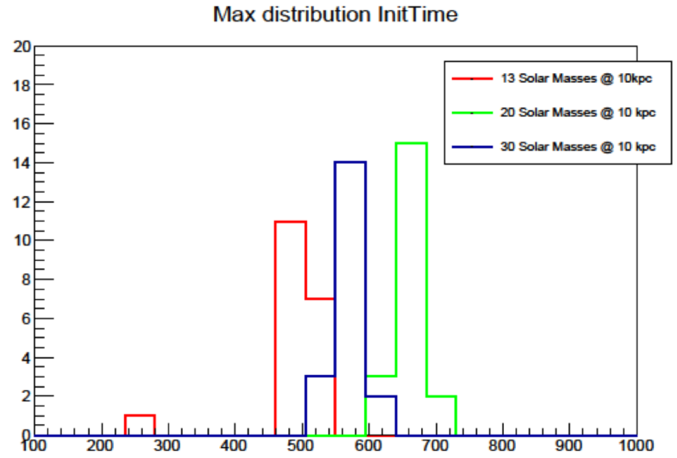


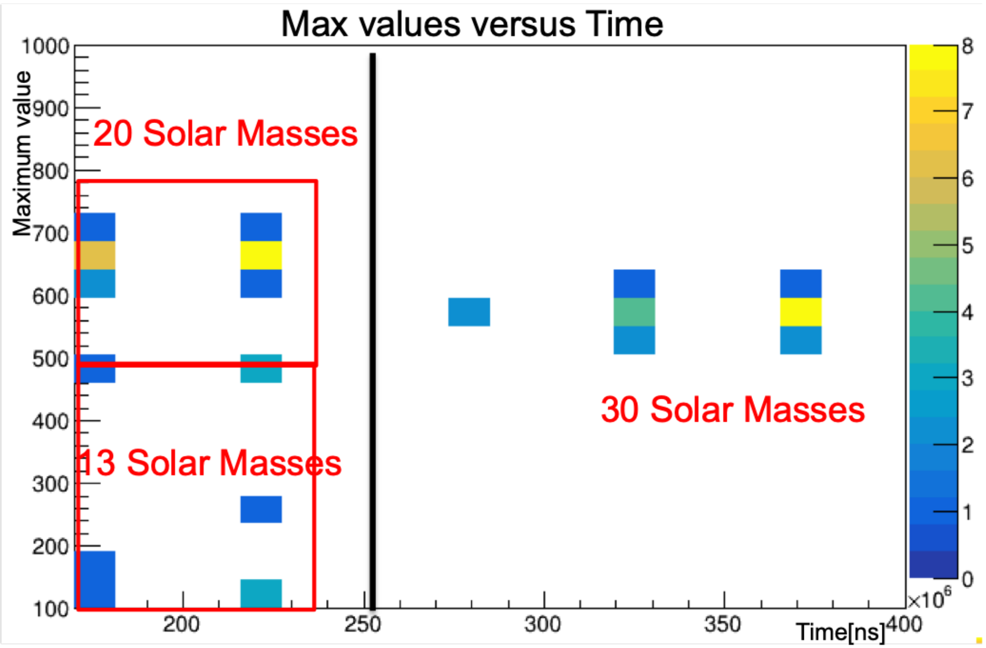


SUPERNOVA NEUTRINOS

- Unfold the SN properties (mass, distance) from the measured neutrino spectra
  - $M = 13_{M_\odot}$ $M = 20_{M_\odot}$ $M = 30_{M_\odot}$ D = 10 kpc



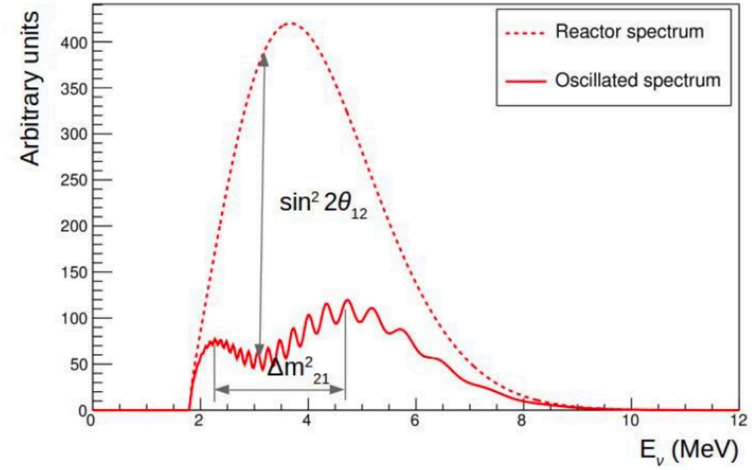




Neutrino Oscillation Parameters Analysis

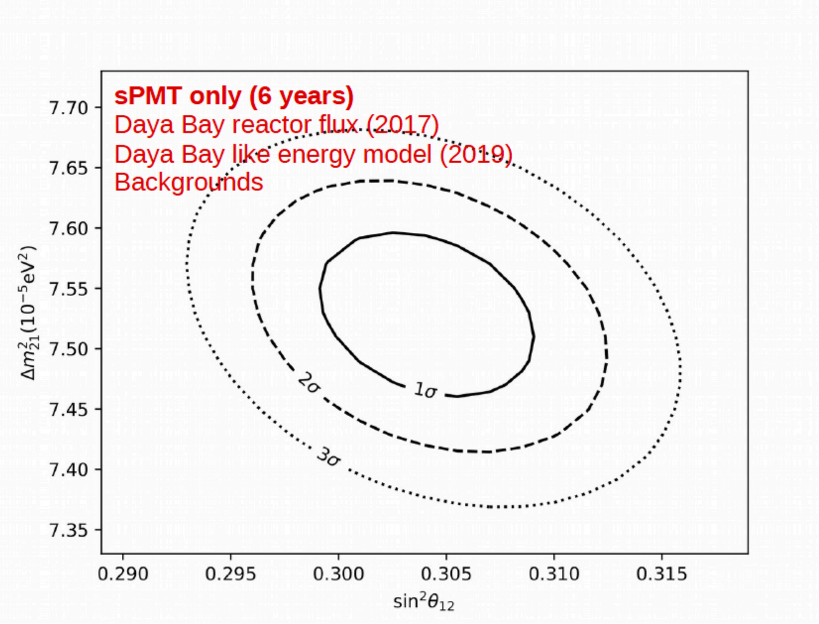
Yury Malyshkin

A new framework (**NODA** – Neutrino Oscillation Data Analysis) developed:
– for sensitivity studies
– for future data analysis



Physical goals:

- Update of sensitivities published in Yellow Book (2015):
  - State-of-the-art reactor flux uncertainties
  - Expected reactor flux uncertainties from TAO
  - More realistic energy model
  - Bin correlation treatment
  - …
- Solar Oscillation Parameters Measurement with the 3-inch PMT system:
  - Estimation of sensitivity
  - Investigation of complementarity to the 20-inch PMT



Collaboration with France and California groups

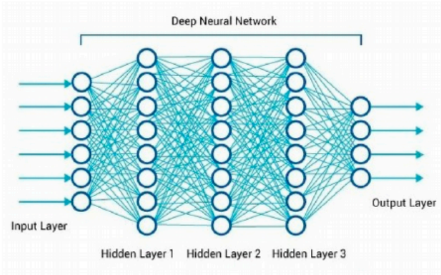
Machine Learning Techniques for Event Reconstruction

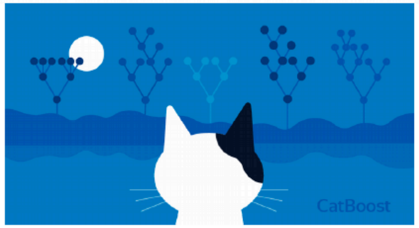
Yury Malyshkin

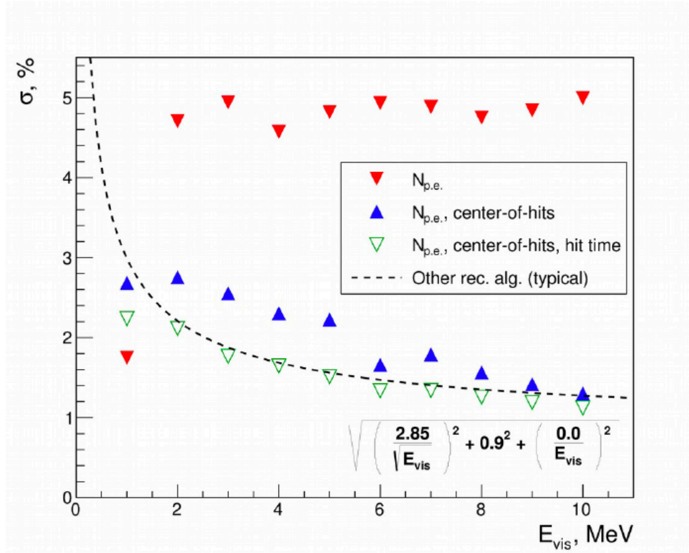
<u>Two techniques:</u>

– **Deep Neural Networks**
(with TensorFlow framework)

– **Boosted Decision Trees**
(with CatBoost framework)



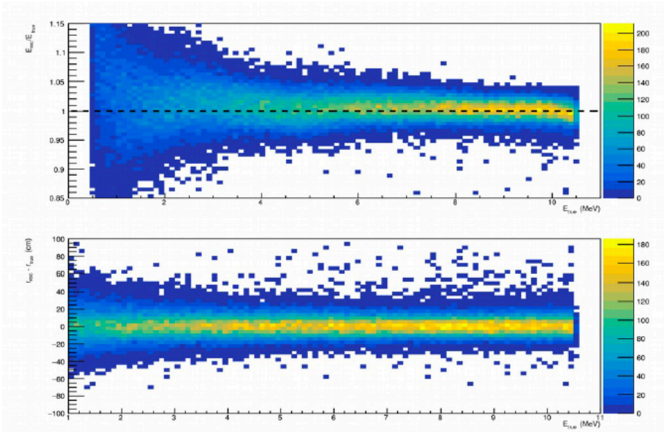




<u>Main directions:</u>

– **Energy** reconstruction
(to provide 3% @ 1 MeV resolution)

– **Vertex** reconstruction
(the goal is to reach several cm resolution)



<u>Advantages:</u>

– Effective use of input information

– Reconstruction speed

Collaboration with Padova and Moscow groups

2019:

JUNO: Completare il Trigger L2: long term test, DCS, recovery
JUNO: Atmosferici
TAO: elettronica classica: definire F/E analogica, parte digitale, temperatura, SiPM qualifica
TAO: simulazione

2020:

TAO: elettronica nuova: parte digitale,
TAO: pre-produzione F/E + SiPM
TAO: trigger + reco
JUNO: SN: completare la misura
JUNO: Computing

SiPM: HD imaging (automotive, green)
DAQ