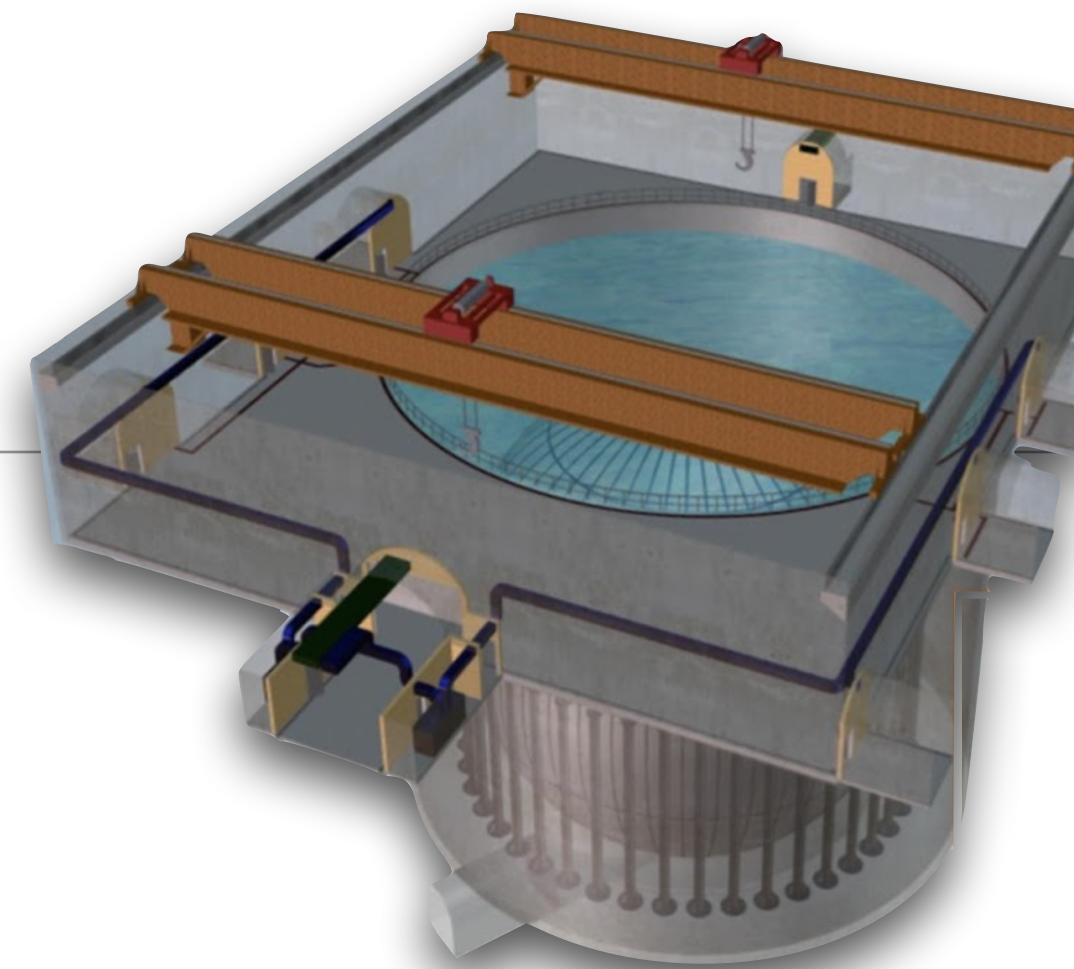
11th France China Particle Physics Laboratory Workshop
MAY 22-25, 2018 - MARSEILLE, FRANCE

The JUNO experiment : physics perspectives and status

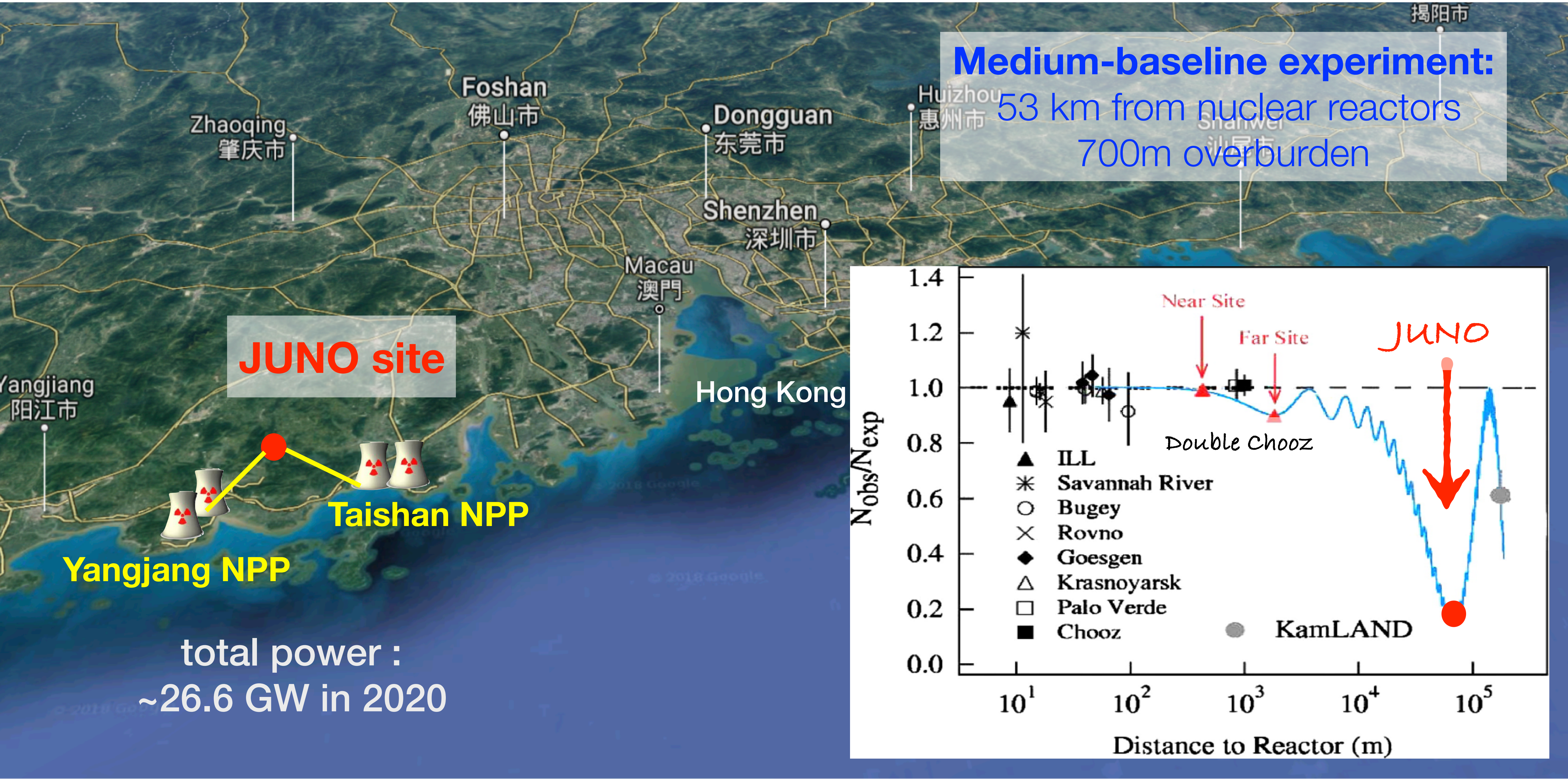


Mariangela Settimo for the JUNO Collaboration
SUBATECH, CNRS-IN2P3, Nantes (France)

CNRS IN2P3 Les deux infinis · Subatech · IMT Atlantique Bretagne-Pays de la Loire École Mines-Télécom

The Jiangmen Underground Neutrino Observatory

A challenging goal: the **neutrino mass hierarchy**

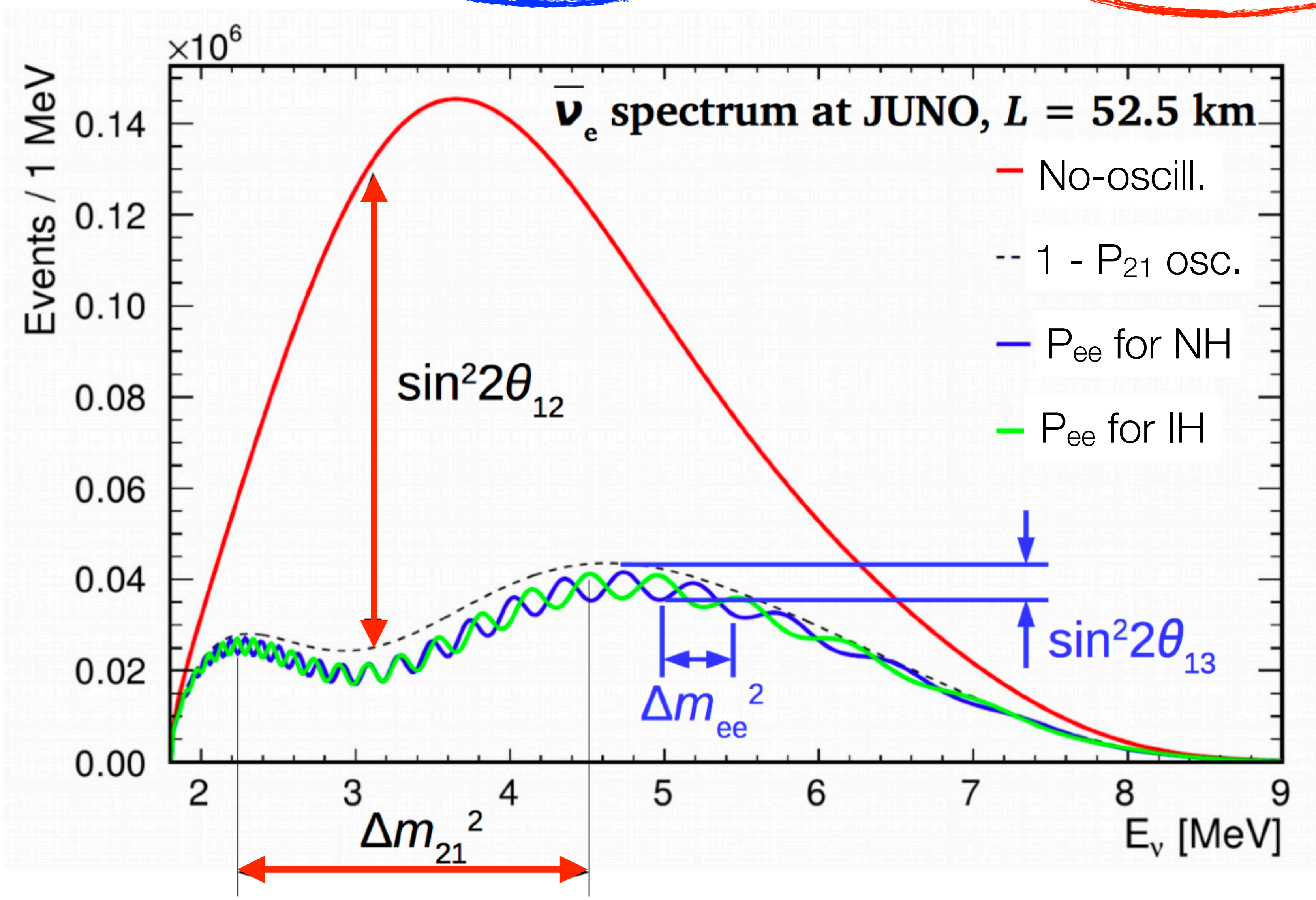


The biggest liquid scintillator experiment ever built

Sensitive to two oscillations -> first time!

Neutrino oscillation from $\bar{\nu}_e$ disappearance

$$P(\nu_e \to \nu_e) = 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{32} L}{4E_\nu}\right) - \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m^2_{21} L}{4E_\nu}\right)$$



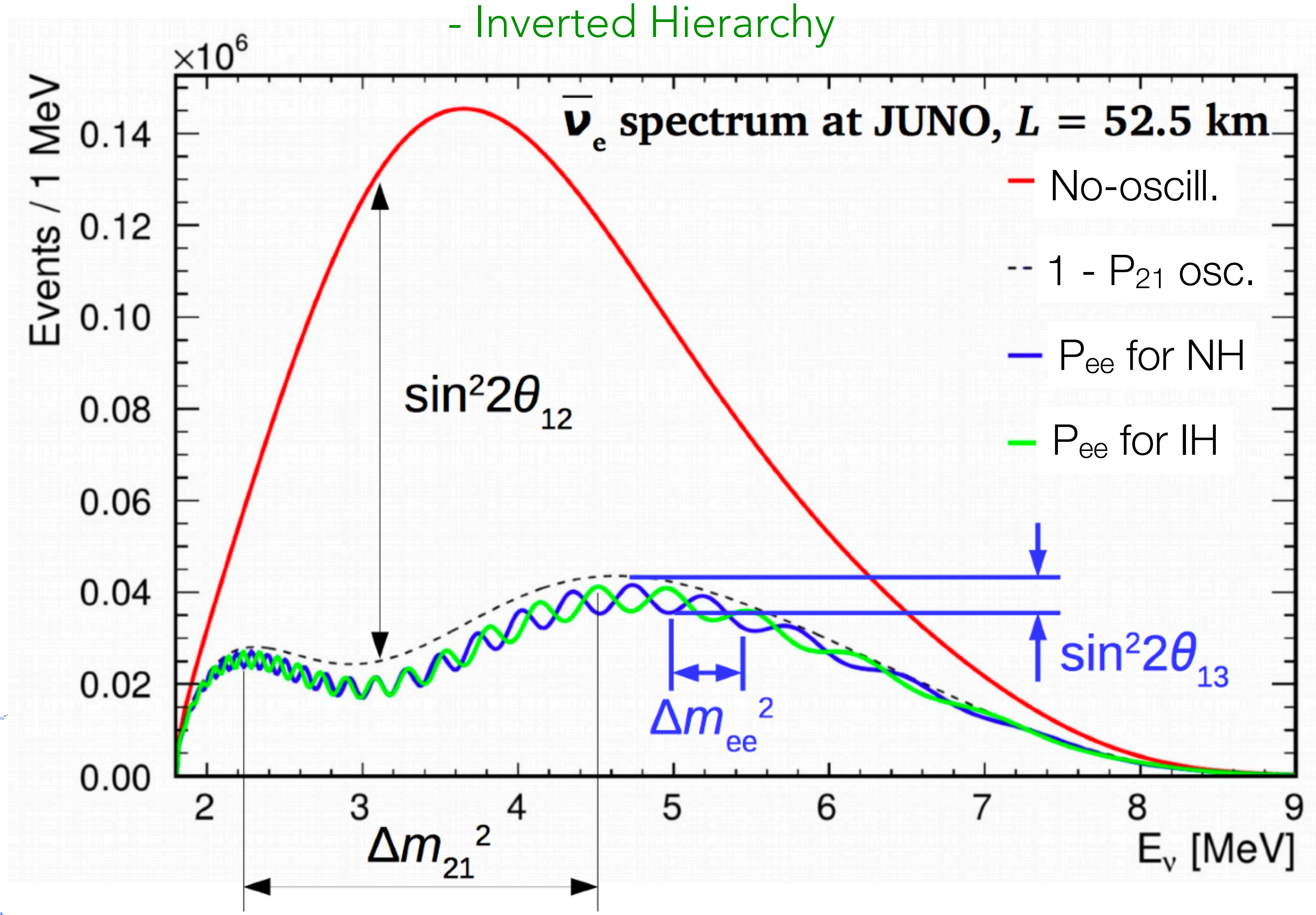
See A. Cabrera's talk

Neutrino oscillation from $\bar{\nu}_e$ disappearance

$$P_{ee} = 1 - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2(\Delta_{21}) \pm \frac{\sin^2\theta_{12}}{2}\sin^2 2\theta_{13}\sin(2\Delta_{21})\sin(2|\Delta_{31}|) \text{ - } \ldots$$

+ Normal Hierarchy

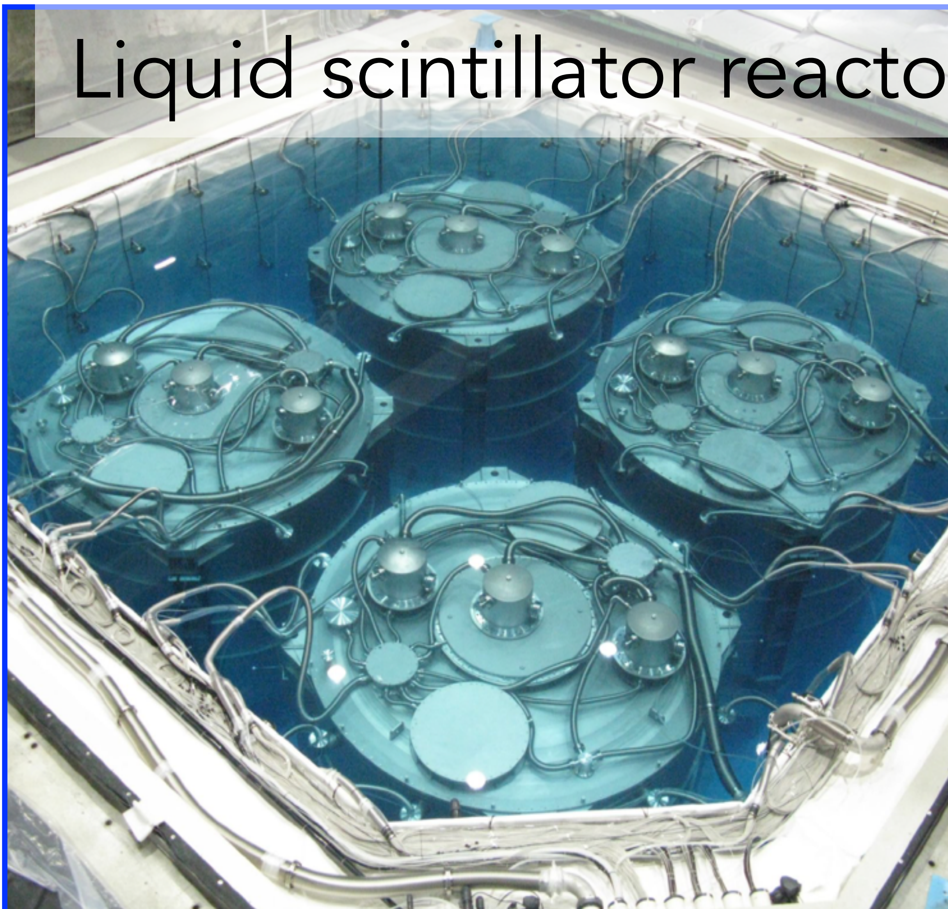
- Inverted Hierarchy



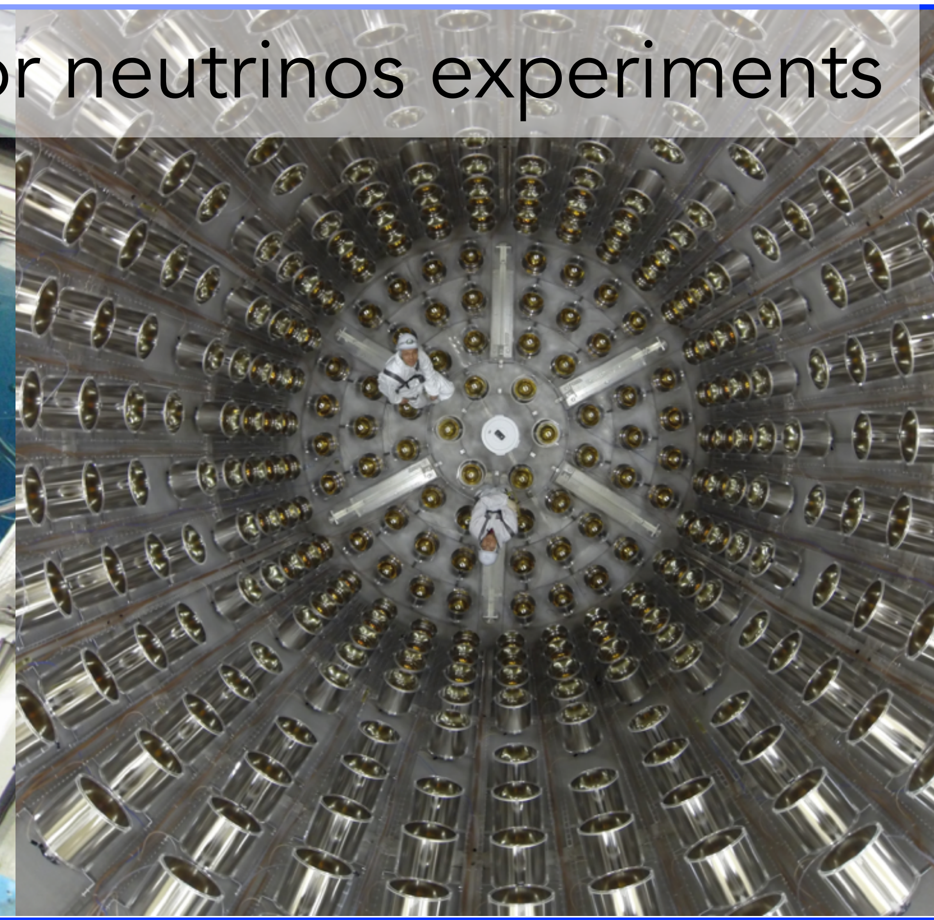
- Excellent **energy resolution** (3%/√E) and **energy scale accuracy** (1%)
- Precise detector **position** and NPP **baselines difference** (< 500m)

How the detector works?

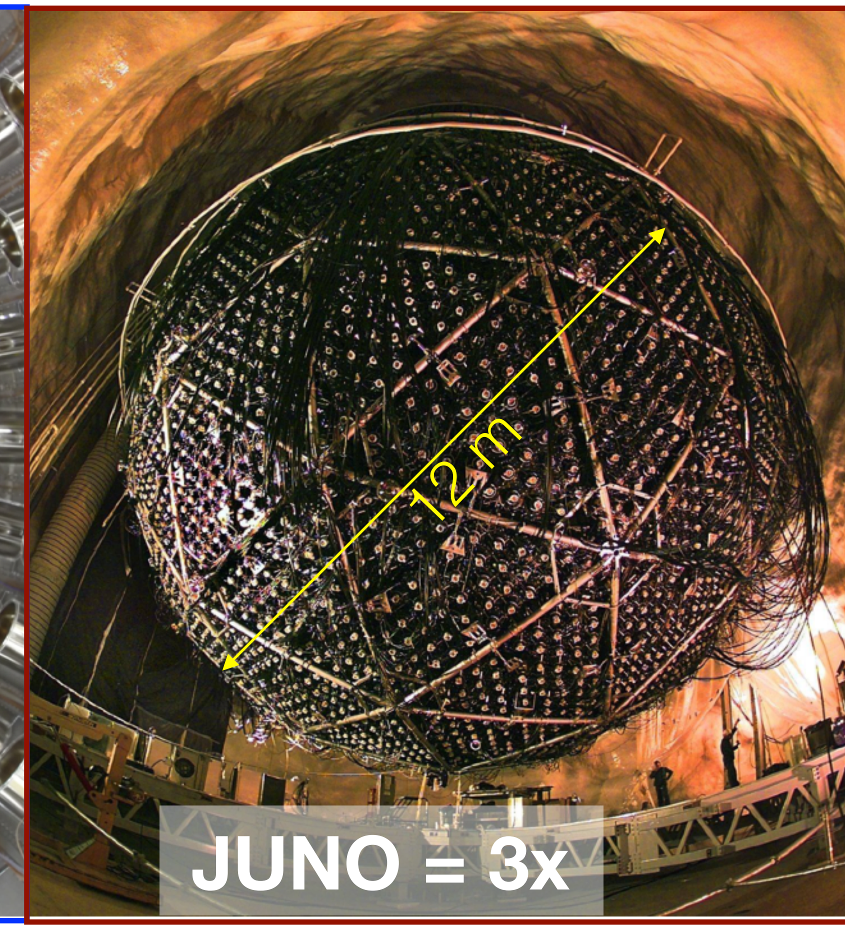
Liquid scintillator reactor neutrinos experiments



Daya Bay, China



Double Chooz, France



SNO, Canada

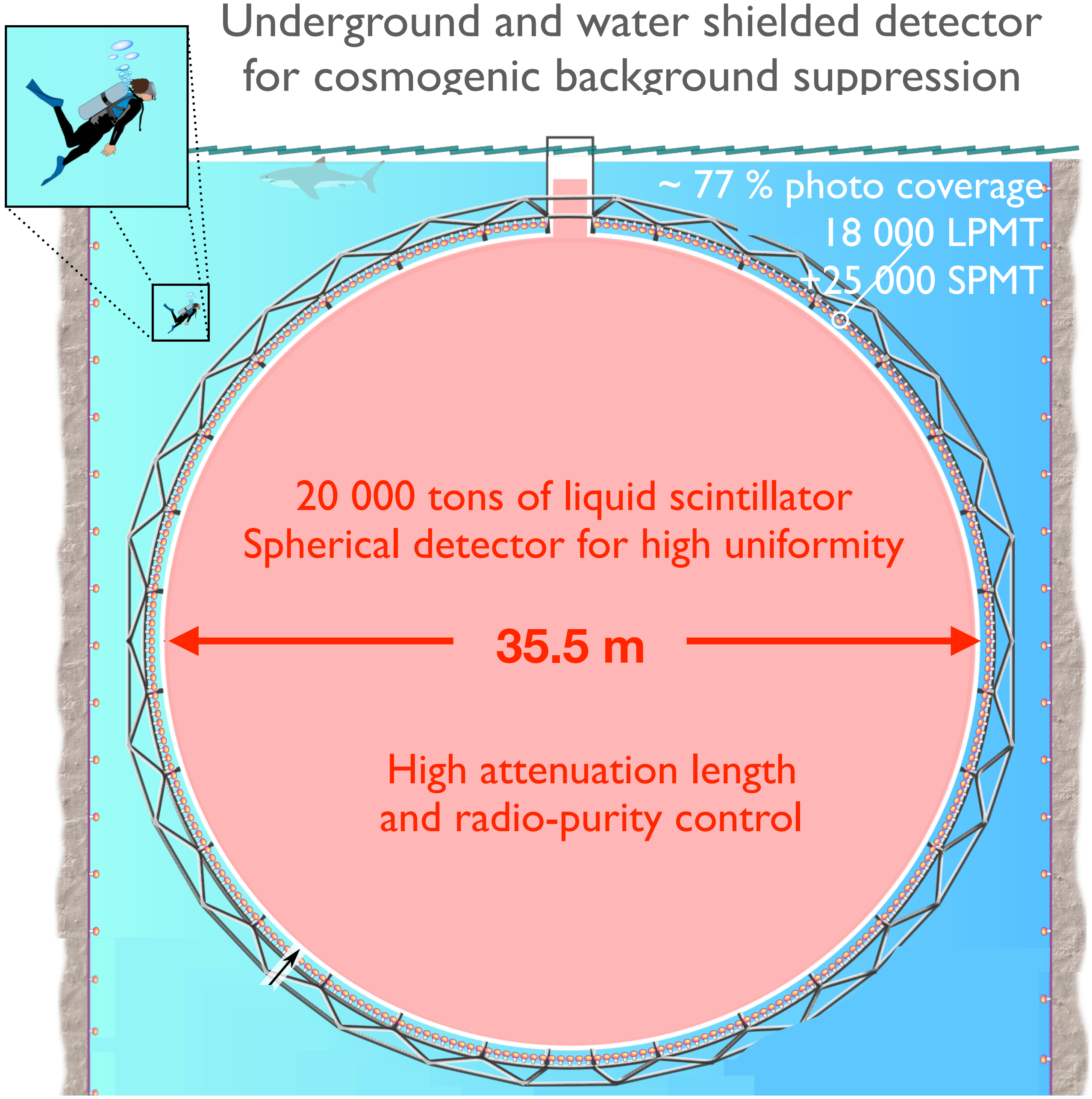
Capitalize on previous experiences to reach :

1. Large statistics
2. Unprecedented resolutions

A well known detection technique

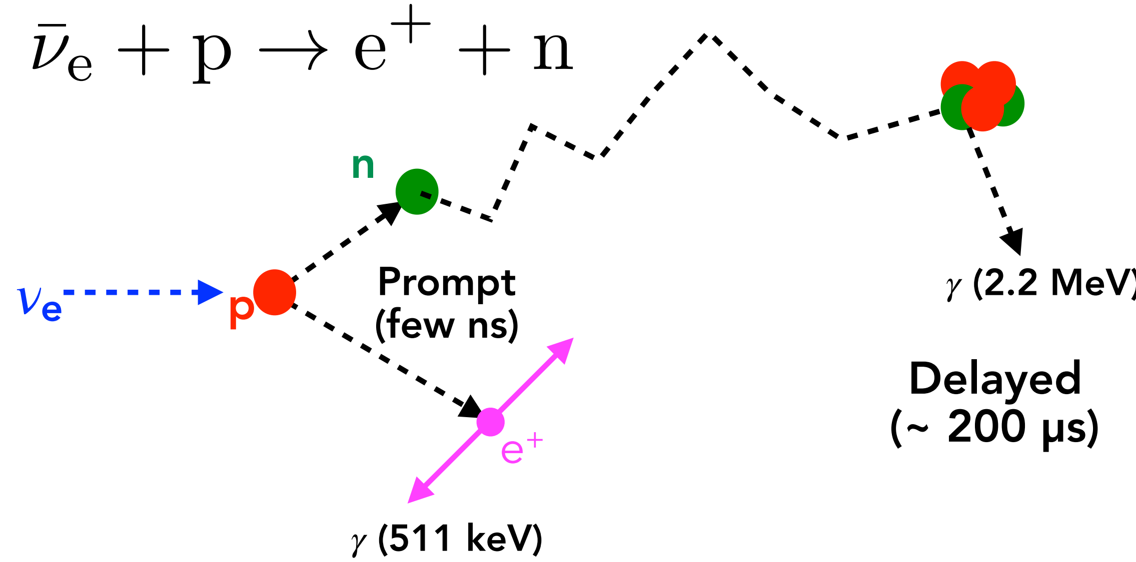
Liquid Scintillator (Anti)neutrino Detector

Underground and water shielded detector for cosmogenic background suppression



Neutrino detection via
Inverse Beta Decay

$$\bar{\nu}_e + p \rightarrow e^+ + n$$



E_{thr} = 1.8 MeV

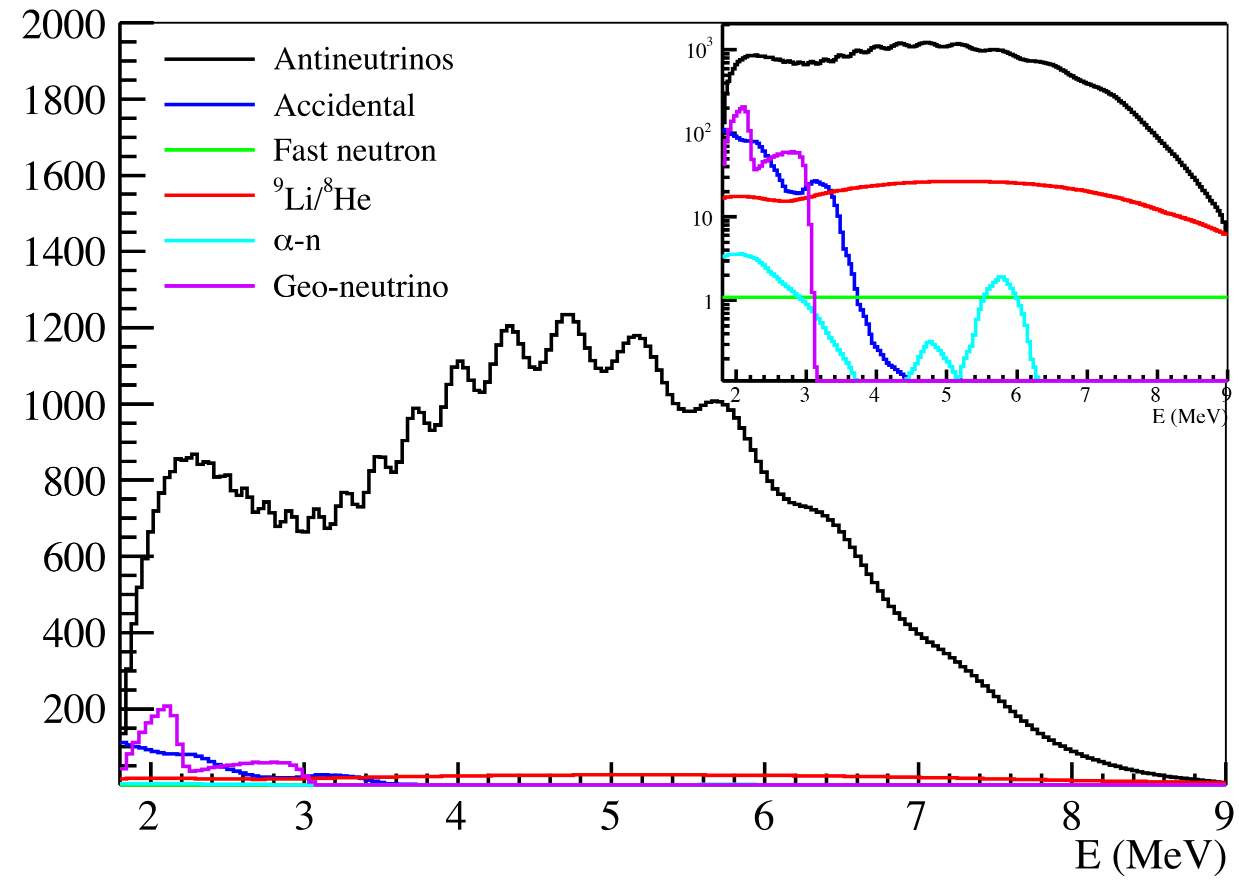
$E_\nu = E_{vis} + 0.8$ MeV

Time coincidence between the prompt and delayed signals to select IBD and reject background

Some numbers: signal and background events

Background sources

- Accidentals (material radioactivity)
  - *Radio-purity control*
  - *Fiducial volume cuts*
  - *distance on the prompt-delayed pair*
- Cosmogenic (^{9}Li/^{8}He)
  - *Muon reconstruction/veto*
- Geo-neutrino



Event rate per day

signal

<table>
<tr><th>Selection</th><th>IBD efficiency</th><th>IBD</th><th>Geo-νs</th><th>Accidental</th><th>^{9}Li/^{8}He</th><th>Fast n</th><th>(α, n)</th></tr>
<tr><td>-</td><td>-</td><td>83</td><td>1.5</td><td>$\sim 5.7 \times 10^4$</td><td>84</td><td>-</td><td>-</td></tr>
<tr><td>Fiducial volume</td><td>91.8%</td><td>76</td><td>1.4</td><td rowspan="3">410</td><td>77</td><td rowspan="5">0.1</td><td rowspan="5">0.05</td></tr>
<tr><td>Energy cut</td><td>97.8%</td><td rowspan="3">73</td><td rowspan="3">1.3</td><td rowspan="3">71</td></tr>
<tr><td>Time cut</td><td>99.1%</td></tr>
<tr><td>Vertex cut</td><td>98.7%</td><td>1.1</td></tr>
<tr><td>Muon veto</td><td>83%</td><td>60</td><td>1.1</td><td>0.9</td><td>1.6</td></tr>
<tr><td>Combined</td><td>73%</td><td>60</td><td colspan="5">3.8</td></tr>
</table>

See F. Perrot's talk

The JUNO detector

Calibration room

Muon Veto Detector

E. Baussan's talk

Top Tracker

Water pool + PMTs

35 kt ultra-pure water

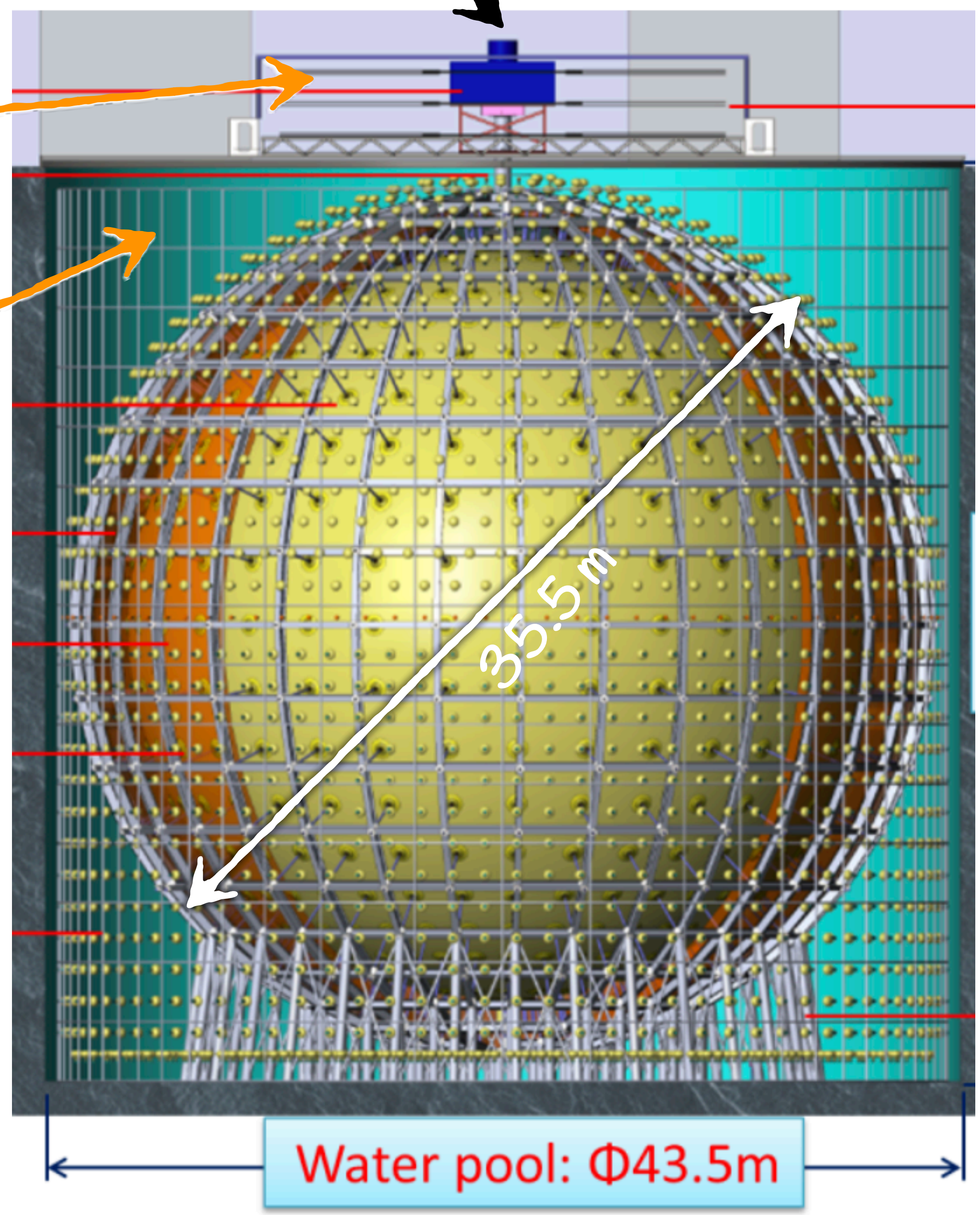
2000 LPMTs (20″)

Acrylic Sphere

(35.5 m diameter)

Steel Truss

Mechanical support for acrylic sphere and PMTs

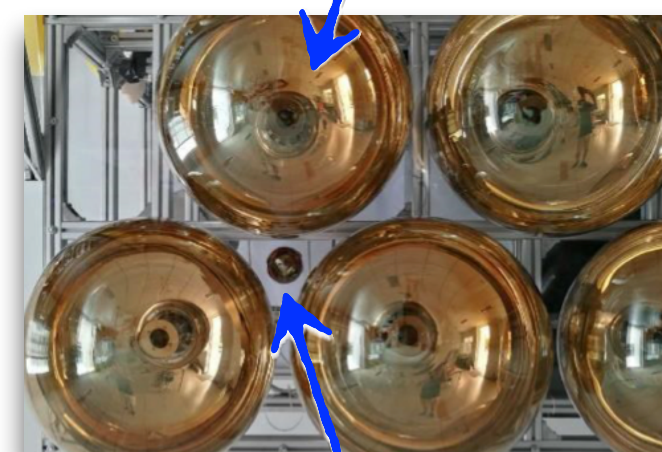


Central Detector

20kt Liquid Scintillator

17000 Large PMT

(20″ diameter)



25000 Small PMT

(3″ diameter)

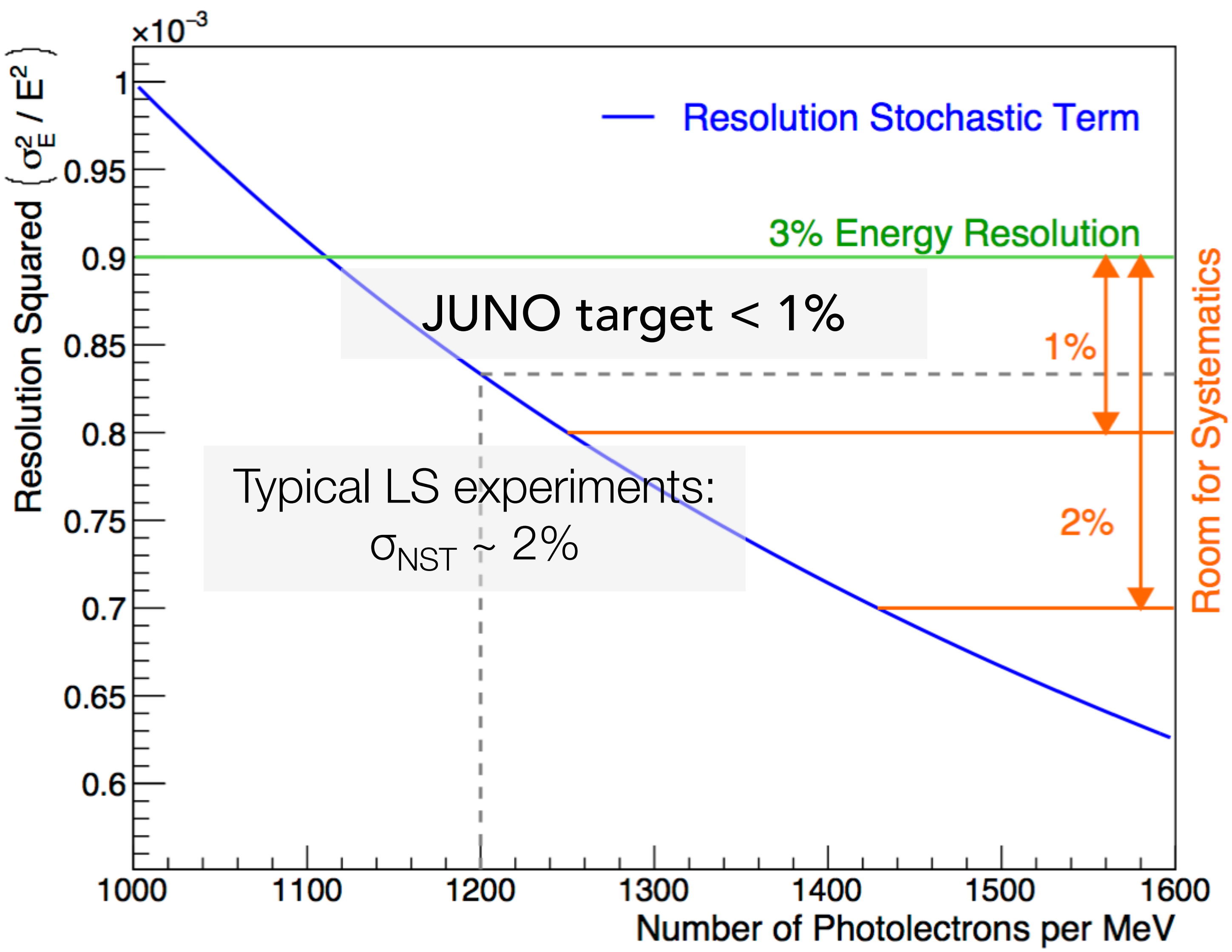
C. Cerna's talk

How to fulfill the energy resolution requirements

$$\frac{\sigma_E}{E} = \sqrt{\left(\frac{a}{\sqrt{E}}\right)^2 + b^2 + \left(\frac{c}{E}\right)^2}$$

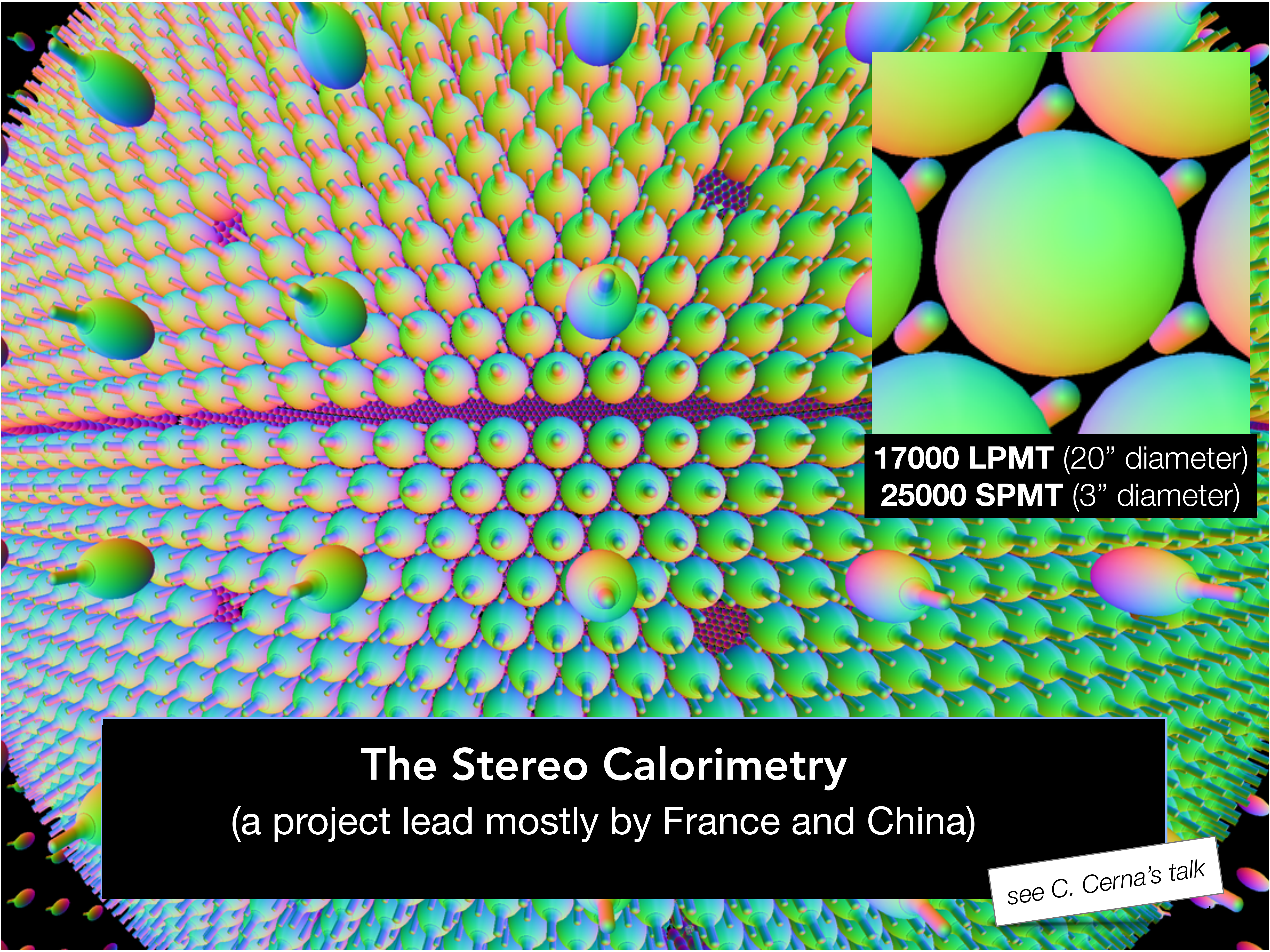
stochastic term → Maximise detected light → **Large photo-coverage, high QE, Transparent scintillator**

non-stochastic term → Control of systematics → **Stereo Calorimetry (20″ PMTs + 3″ PMTs)**



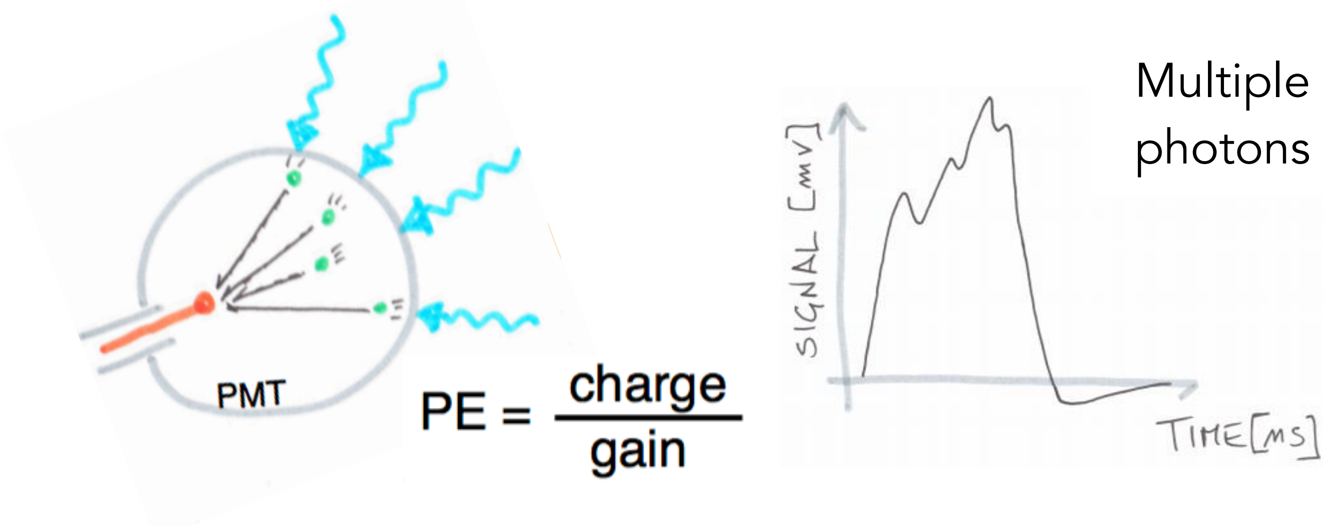
Unprecedented resolutions

Drive the detector design


17000 LPMT (20” diameter)
25000 SPMT (3” diameter)
The Stereo Calorimetry
(a project lead mostly by France and China)
see C. Cerna’s talk

Looking at the same events with different instruments

Large PMT (20”) 1200 P.E./MeV



Multiple photons

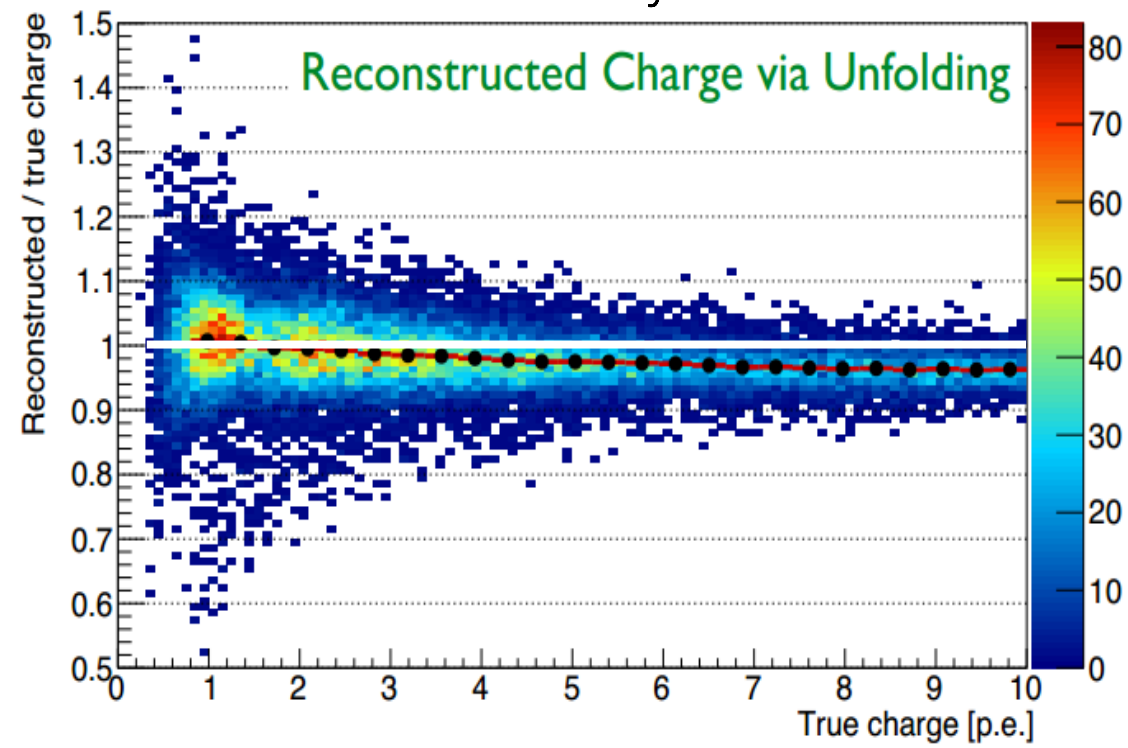
$$PE = \frac{charge}{gain}$$

charge integration (over a wide signal range)

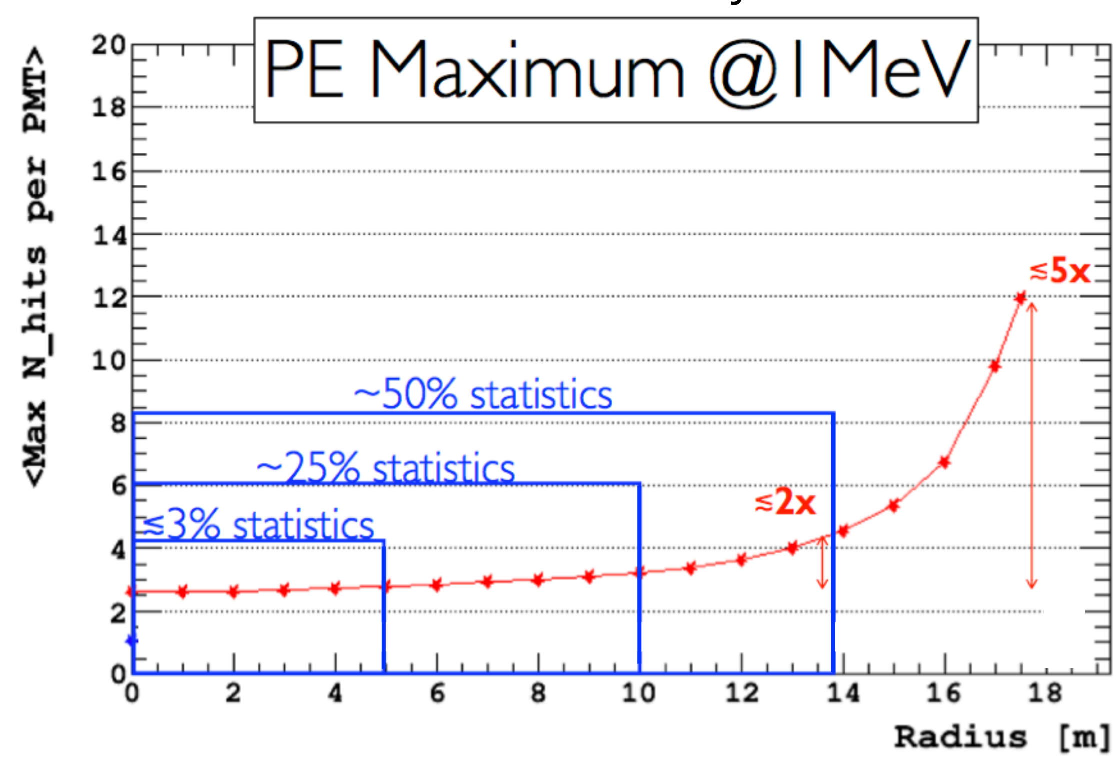
Non-linearity and non-uniformity effects

Difficult to get rid off with calibration

non-linearity effect



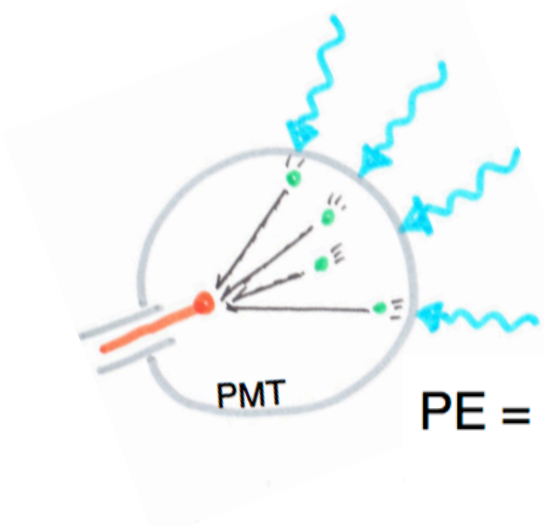
Non-uniformity effect



Looking at the same events with different instruments

Large PMT (20”)

1200 P.E./MeV



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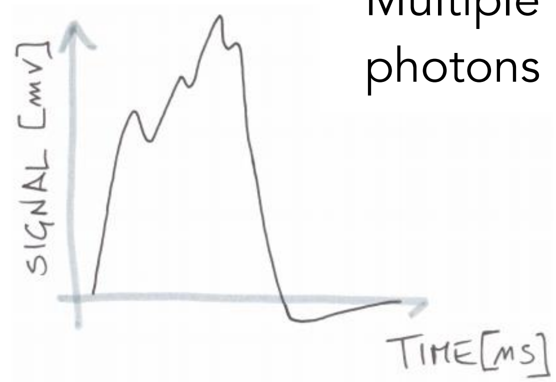

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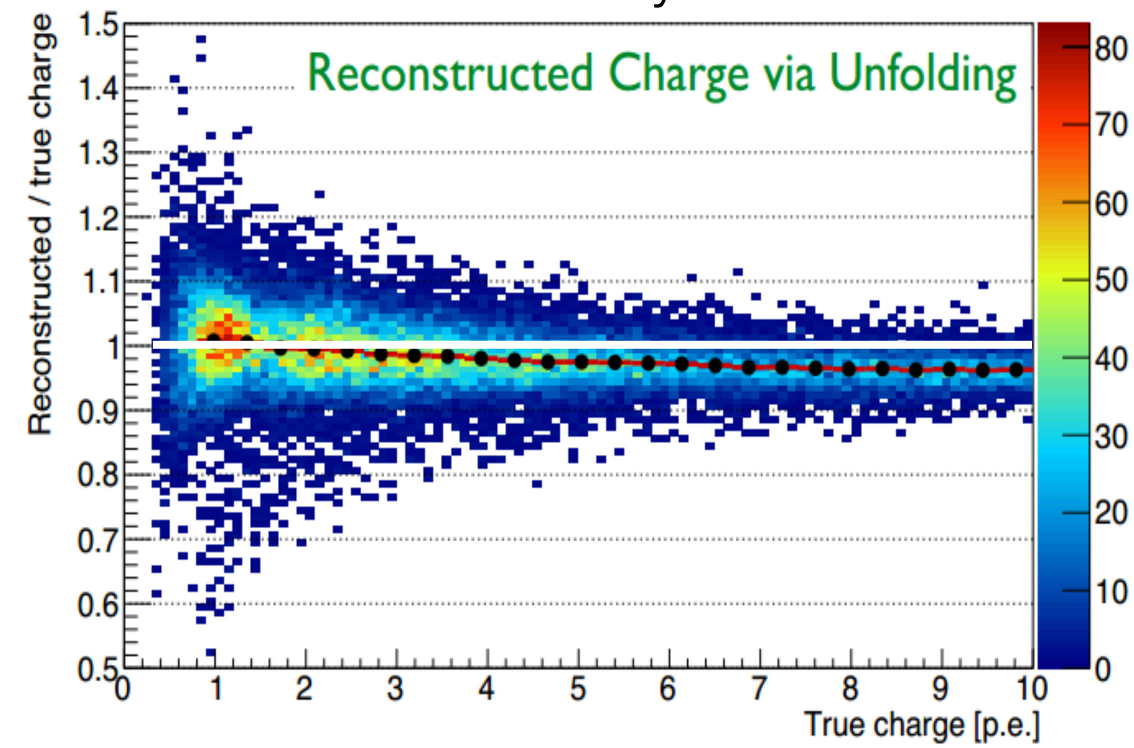
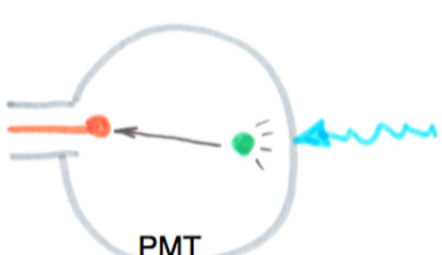


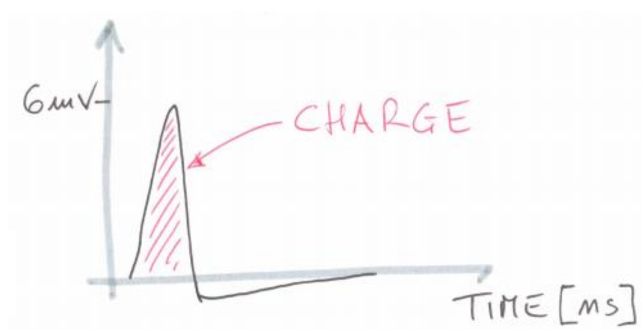
Small PMT (3”)

Photo-coverage ~ 2%

~ 35 P.E./MeV



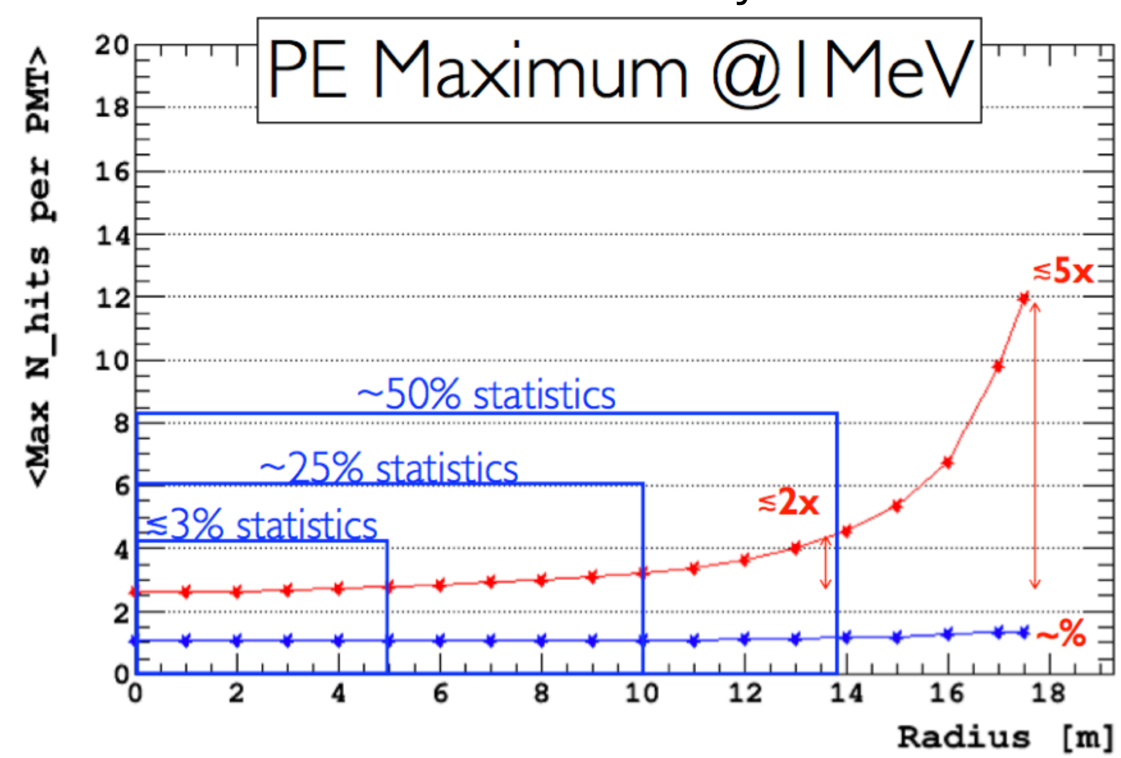
PE = hit



Predominantly working in **photon counting** mode

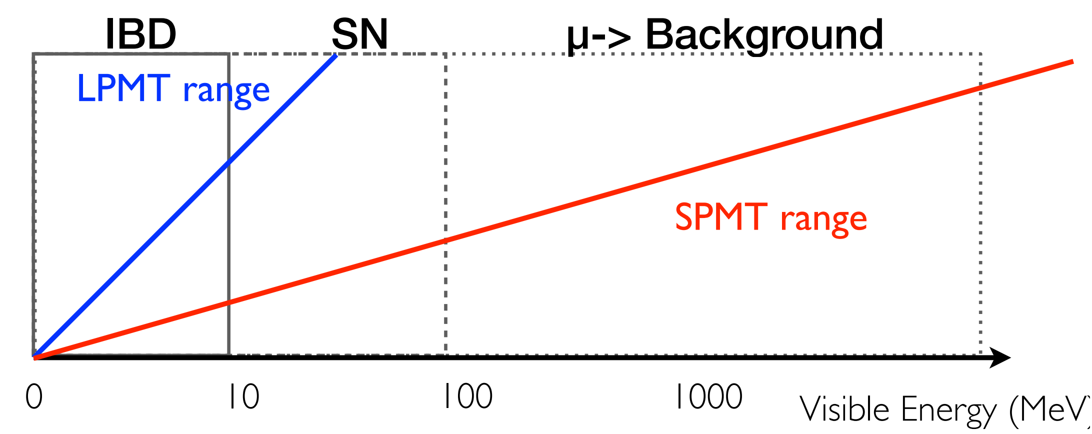
Negligible “non-linearity” and “non-uniformity” effects

Non-uniformity effect

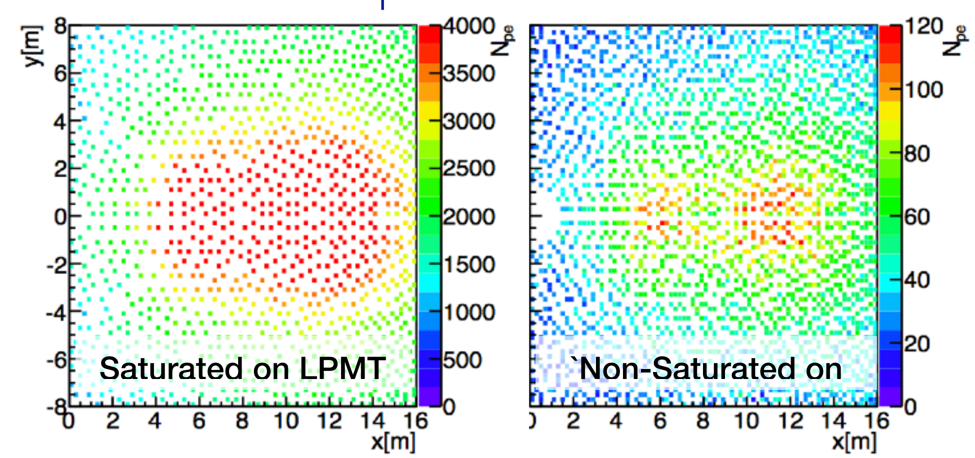


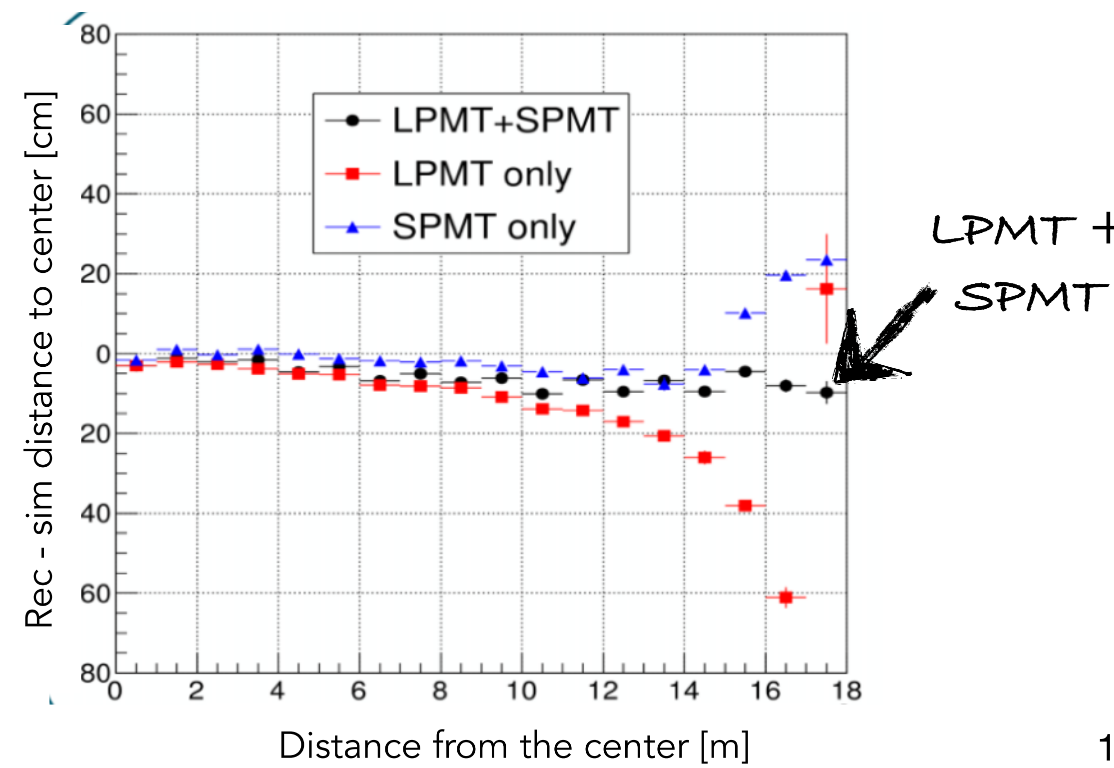
SPMT as "aider" of the LPMT

- Breaks the non-linearity/non-uniformity degeneracy for high precision calorimetry
- Enlarge energy range (LPMT saturation)
- Improve central-detector μ-reconstruction
  → Aide ^{9}Li/^{8}He tagging/vetoing



Example of double-muons event





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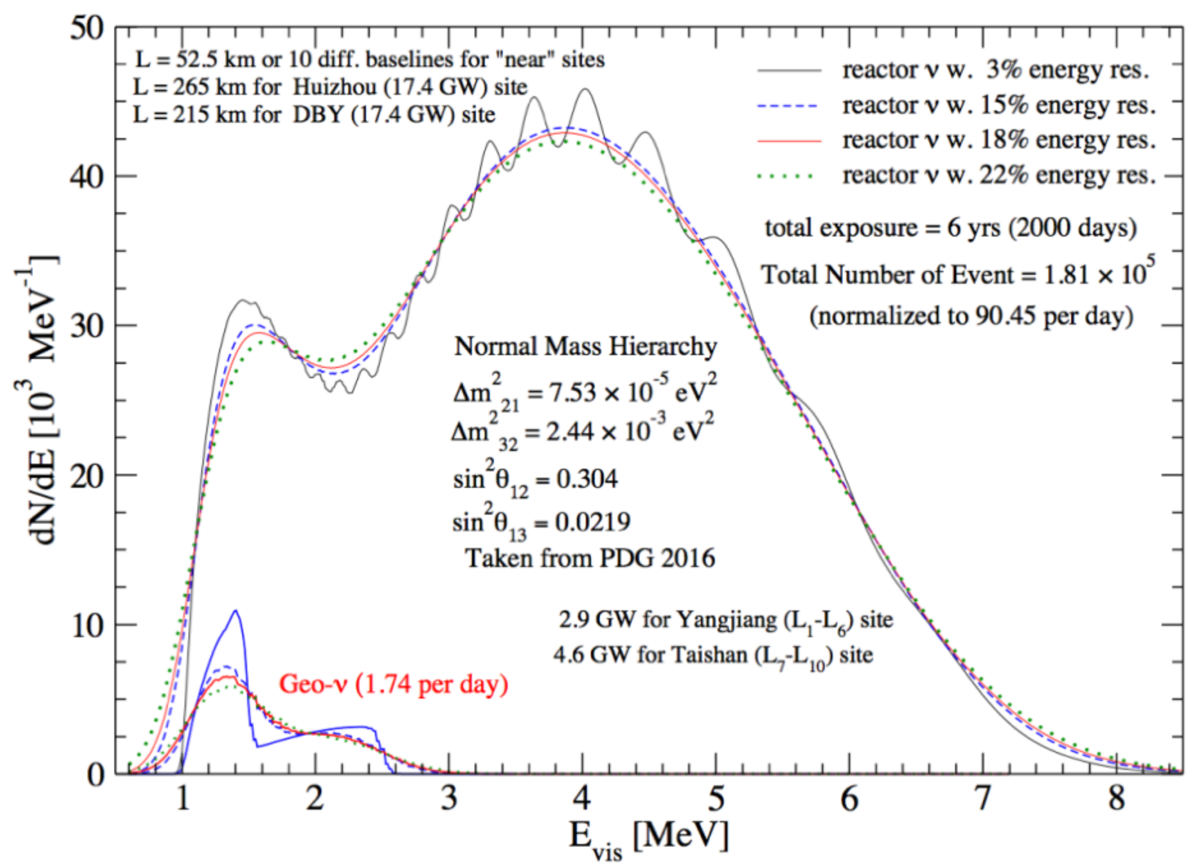
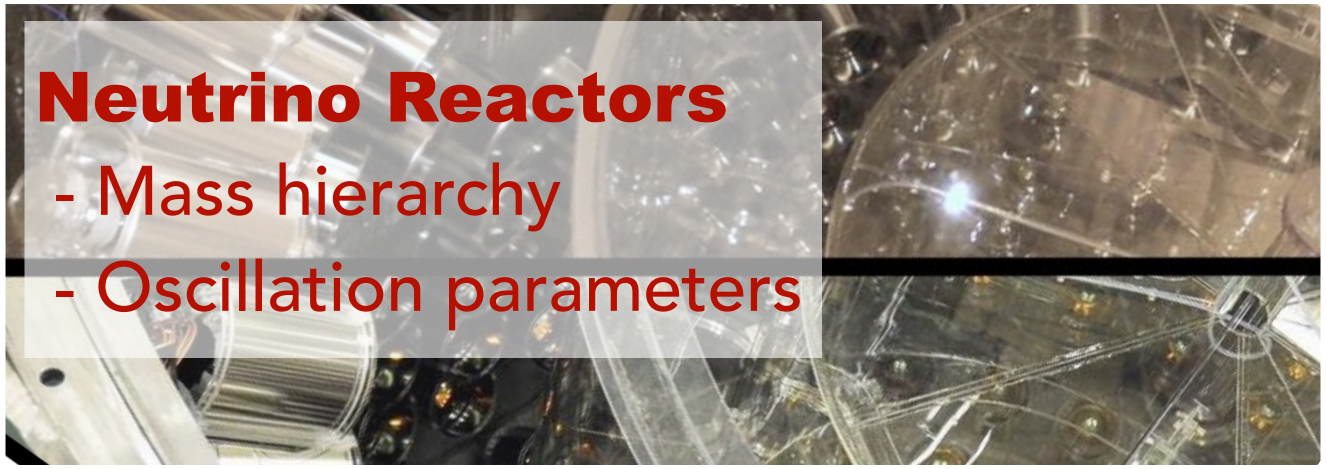
- Breaks the non-linearity/non-uniformity degeneracy for high precision calorimetry
- Enlarge energy range (LPMT saturation)
- Improve central-detector μ-reconstruction
  → Aide ^{9}Li/^{8}He tagging/vetoing
- Stand-alone physics e.g. measurement of solar oscillation parameters
  → Ensure accurate physics results and validate energy scale
- High rate Supernova pile-up (if very near)
  → Minimise bias in absolute rate & energy spectrum

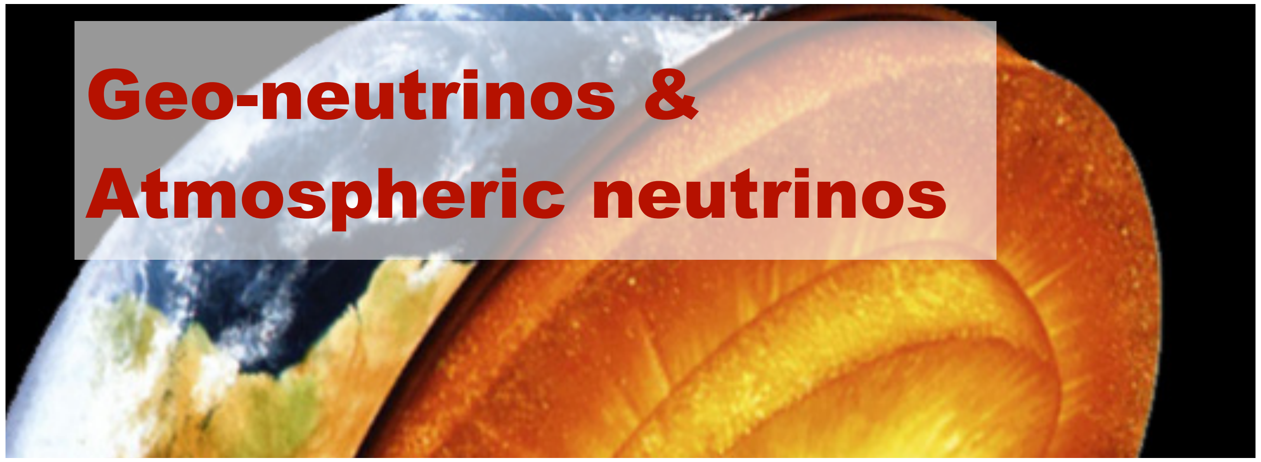


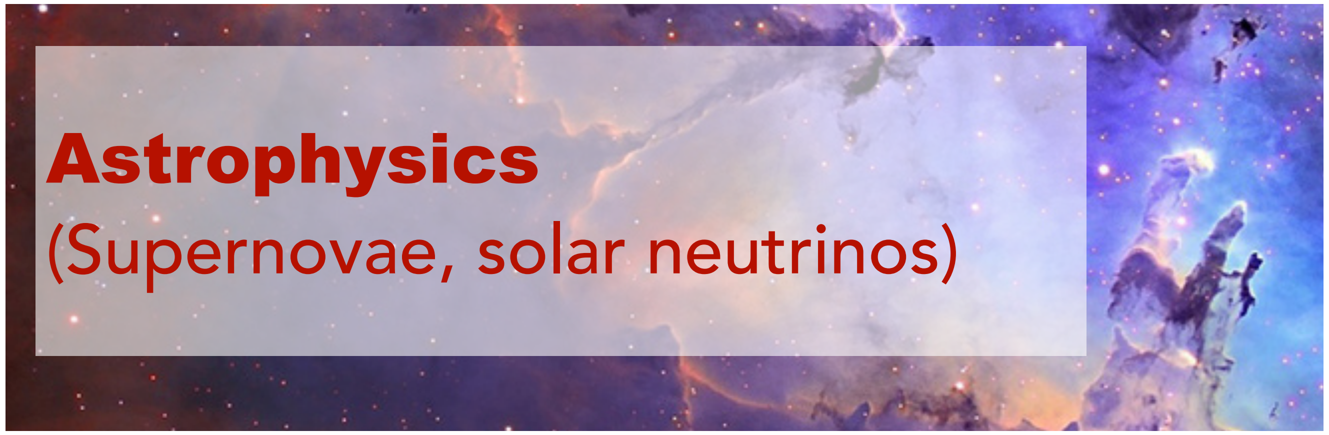
Solar parameter measurement with 25k SPMTs is comparable with LPMTs and will at least improve the current sensitivities down to 0.5-1%

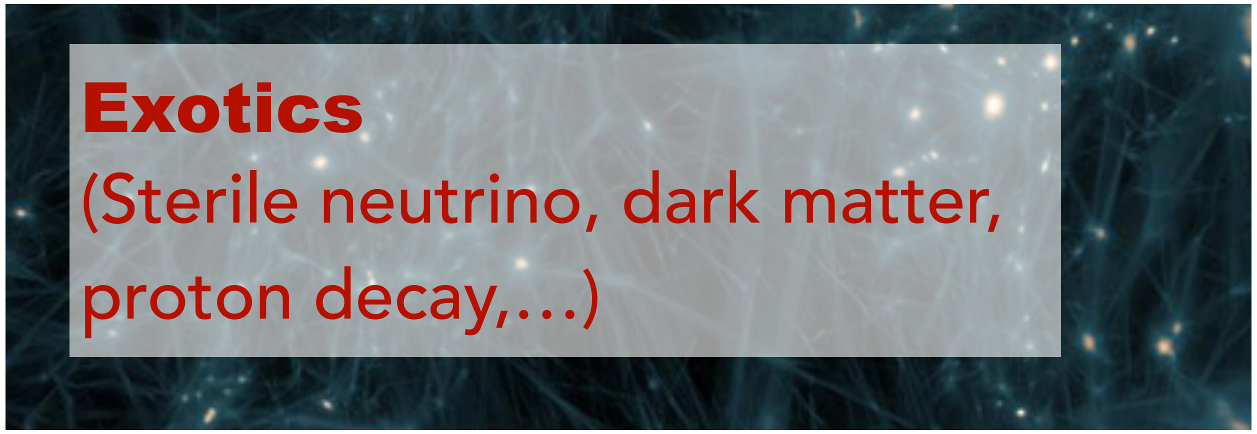
Can use solar oscillations to compare the SPMT and LPMT energy scales (→ **internal redundancy check!**)

A vast physics program





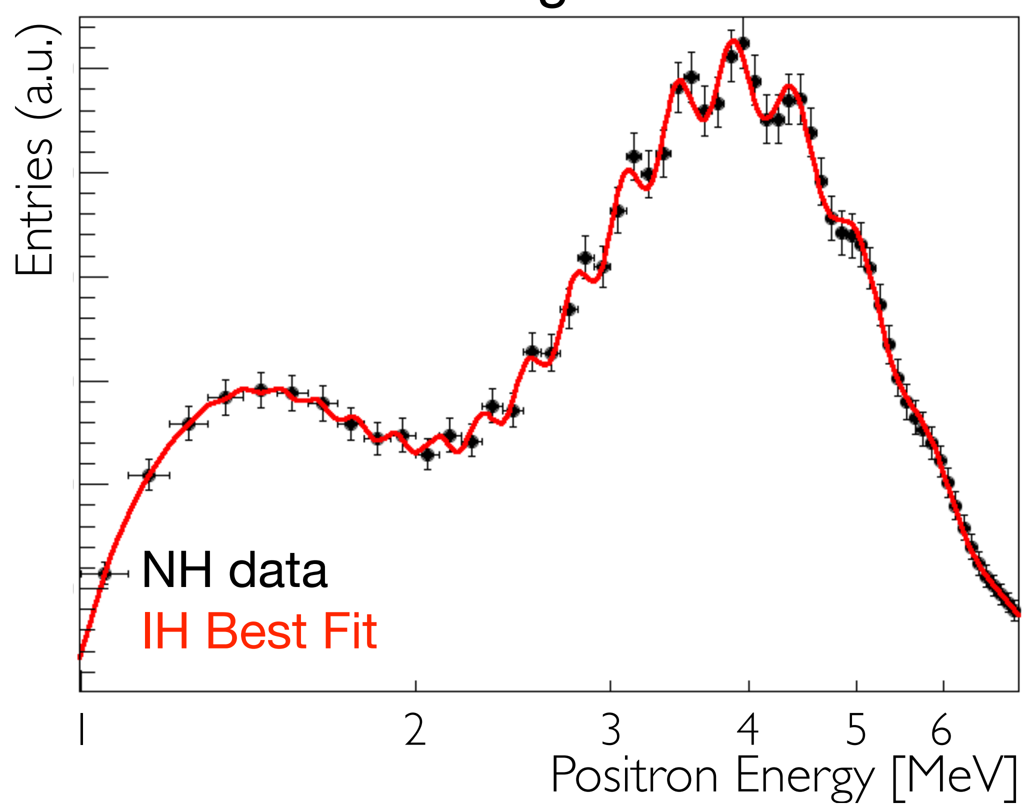




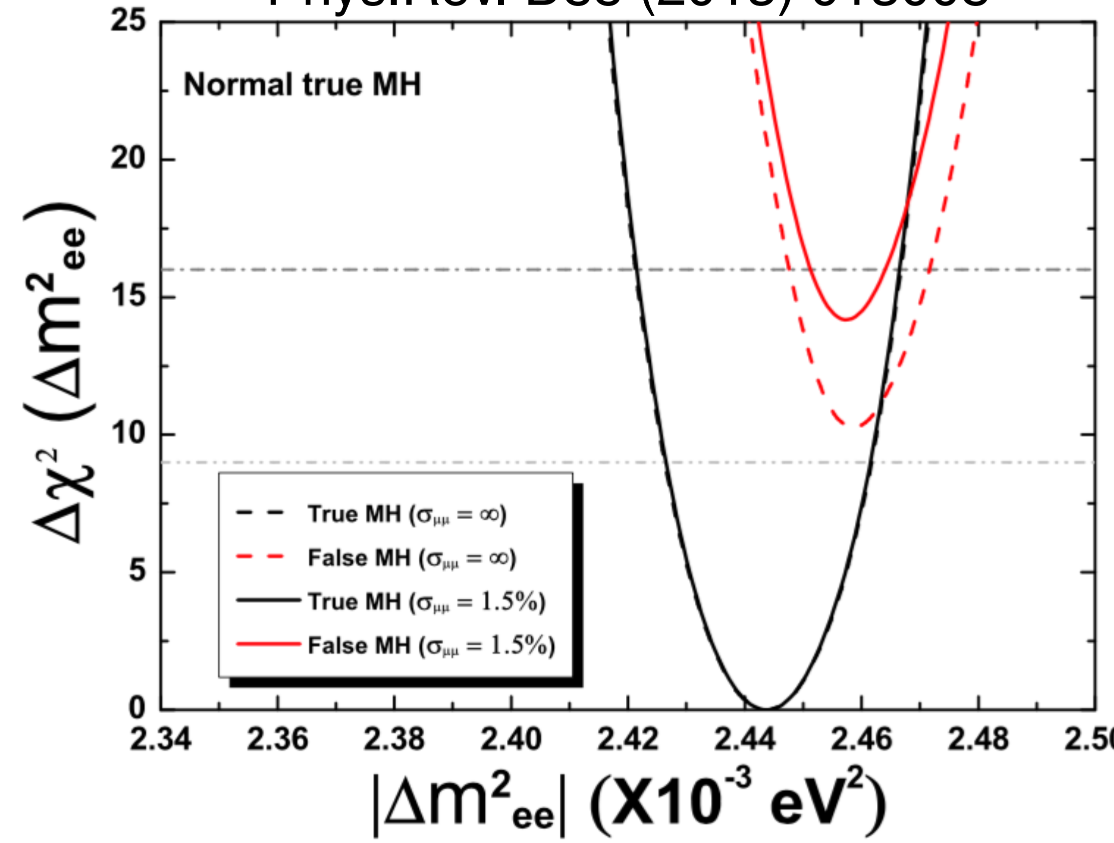
Details in J. Phys. G 43 (2016) no.3, 030401

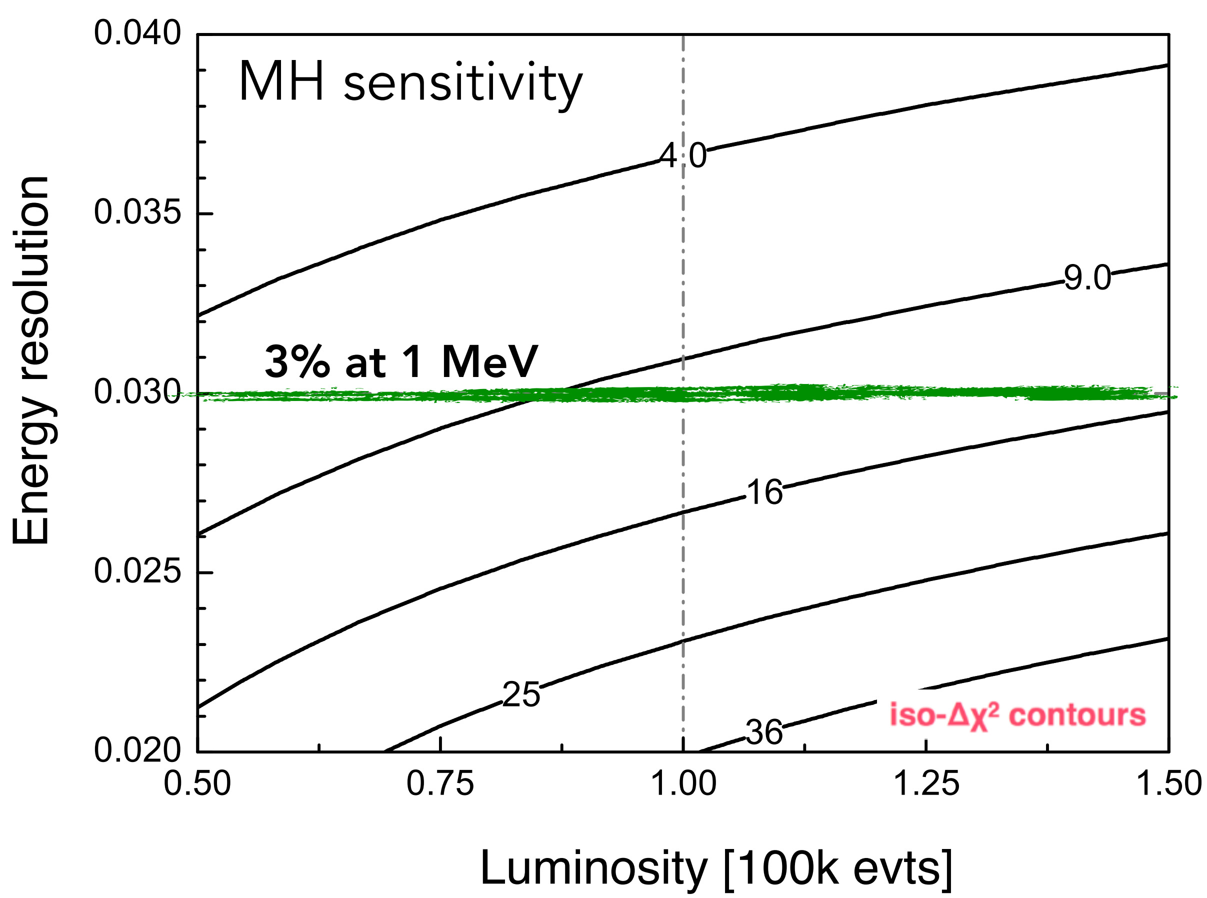
JUNO sensitivity to Mass Hierarchy

Fit model against data



Phys.Rev. D88 (2013) 013008





Mass Hierarchy Sensitivity

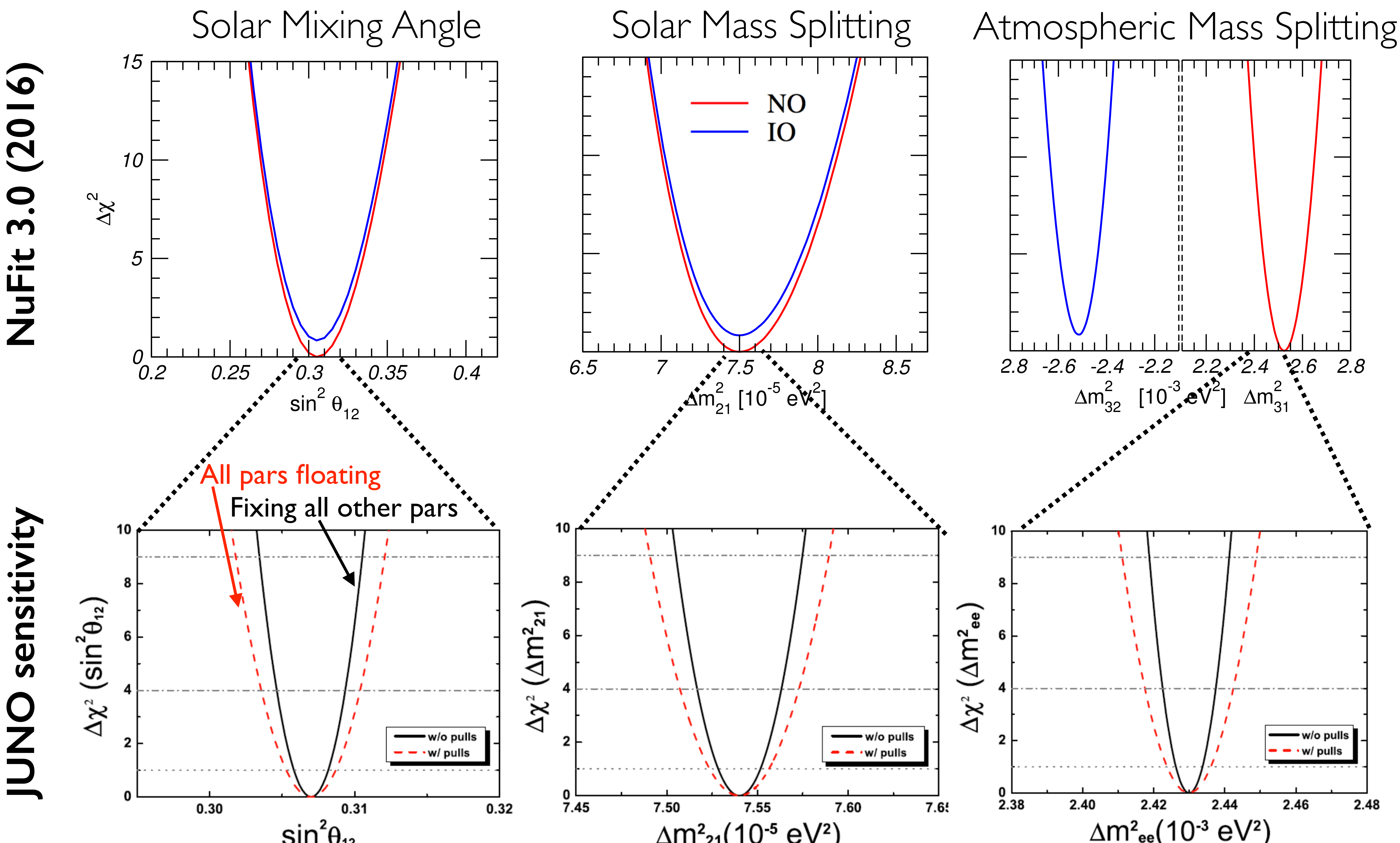
100k signal events (20kt x 36GW x 6 years)

$\Delta\chi^2$: Fitting wrong model - Fitting correct one

······ Unconstrained (JUNO only) $\Delta\chi^2 \sim 10$

—— Using external $\Delta m_{\mu\mu}$ (1.5% precision) from long baseline exps: $\Delta\chi^2 \sim 14$

Sensitivity to the Oscillation Parameters



$\sin^2(\theta_{12})$: 4.1% —> 0.54%

Δm^2_{21} : 2.6% —> 0.24%

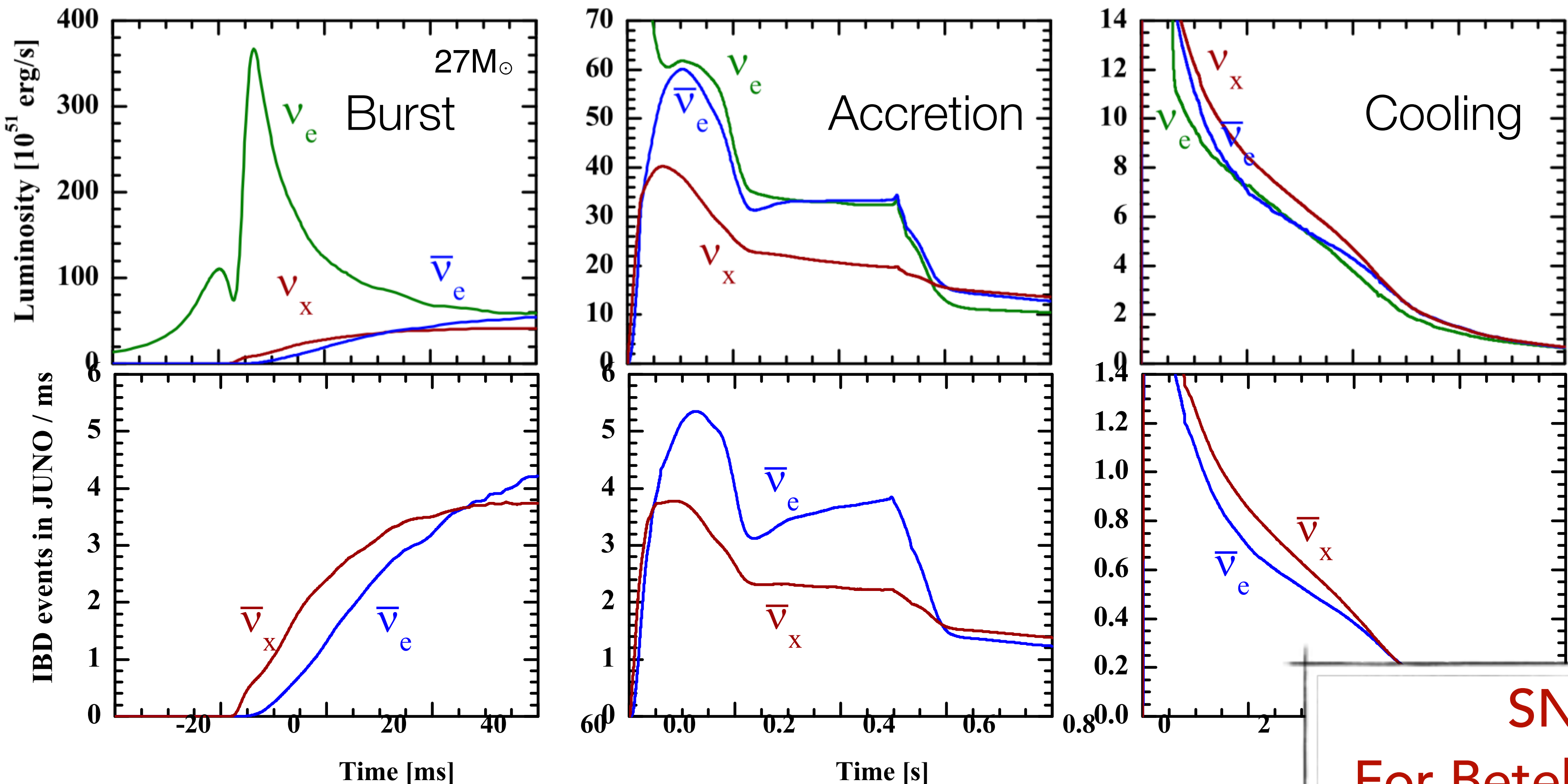
Δm^2_{ee}: 0.27%

SN explosion rate in our Galaxy ~ 1/30-40 yr.
Must not be missed!

JUNO one of the best supernova neutrino detectors

Supernova Neutrino Burst

- **Huge amount of energy (3×10^{53} erg) emitted as neutrinos in < 10 s**
- Unique astrophysics implications from the measured spectra



Process		Events (14 MeV)
$\bar{\nu}_e + p \to e^+ + n$	(CC)	5.0×10^3
$\nu + p \to \nu + p$	(NC)	1.2×10^3
$\nu + e \to \nu + e$	(ES)	3.6×10^2
$\nu + {}^{12}C \to \nu + {}^{12}C^*$	(NC)	3.2×10^2
$\nu_e + {}^{12}C \to e^- + {}^{12}N$	(CC)	0.9×10^2
$\bar{\nu}_e + {}^{12}C \to e^+ + {}^{12}B$	(CC)	1.1×10^2

SN @10 kpc ~ 10^4 events

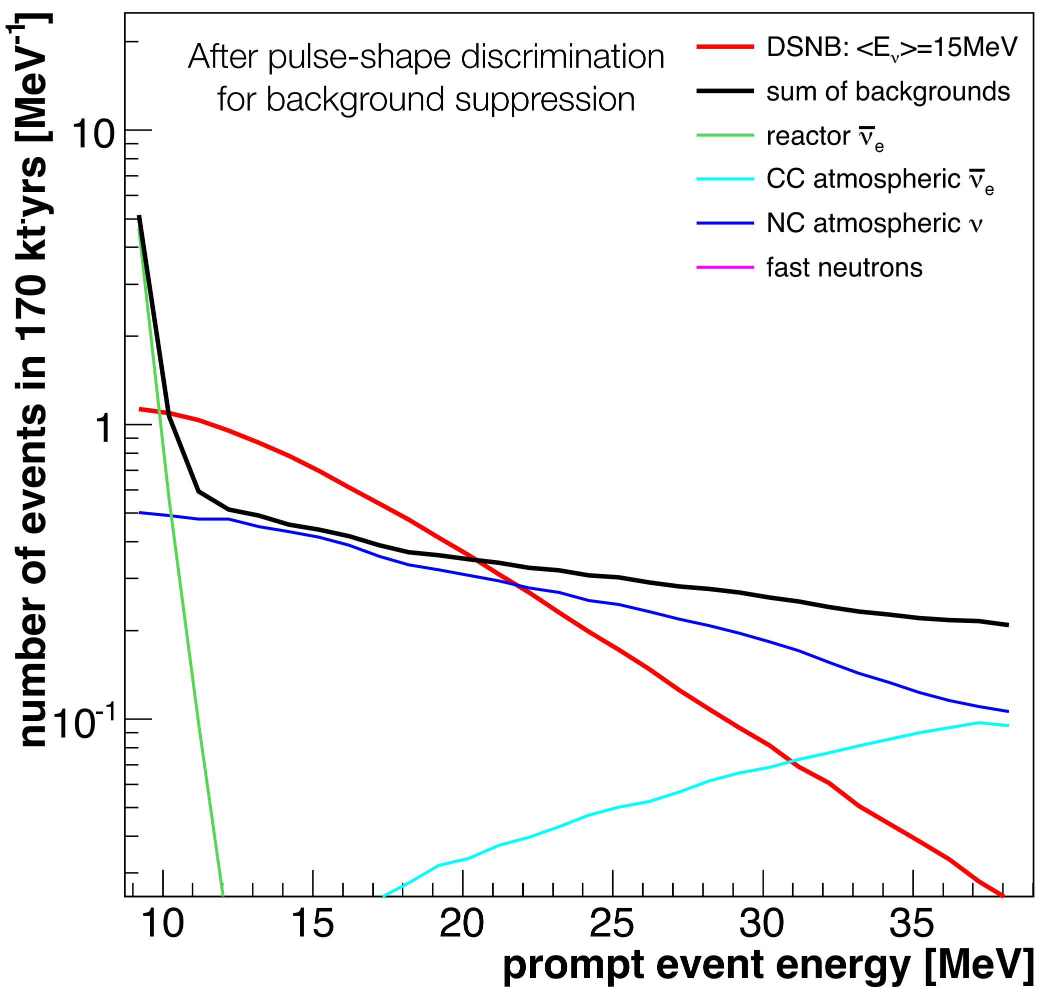
For Betelgeuse (0.2 kpc) ~ 10^7 events

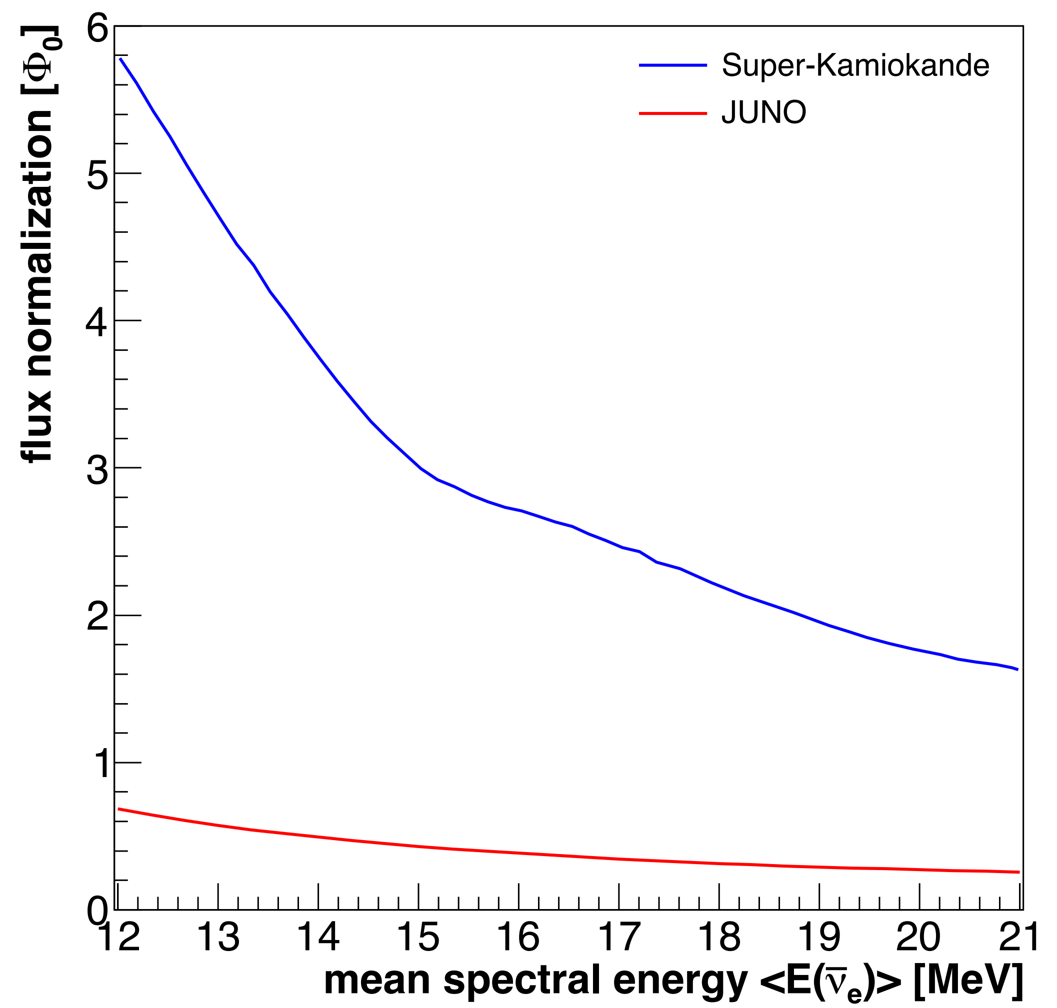
- **DAQ system must handle exceptionally high trigger rates**
  - Dedicated trigger for LPMT
  - SPMT system working in ``deadtime-less” mode *(see C.Cerna’s talk)*

Diffuse Supernova Neutrino Background (DSNB)

Integrated neutrino flux from all past core-collapse events

- cosmic star formation rate, average core-collapse spectrum, rate of failed SNe.





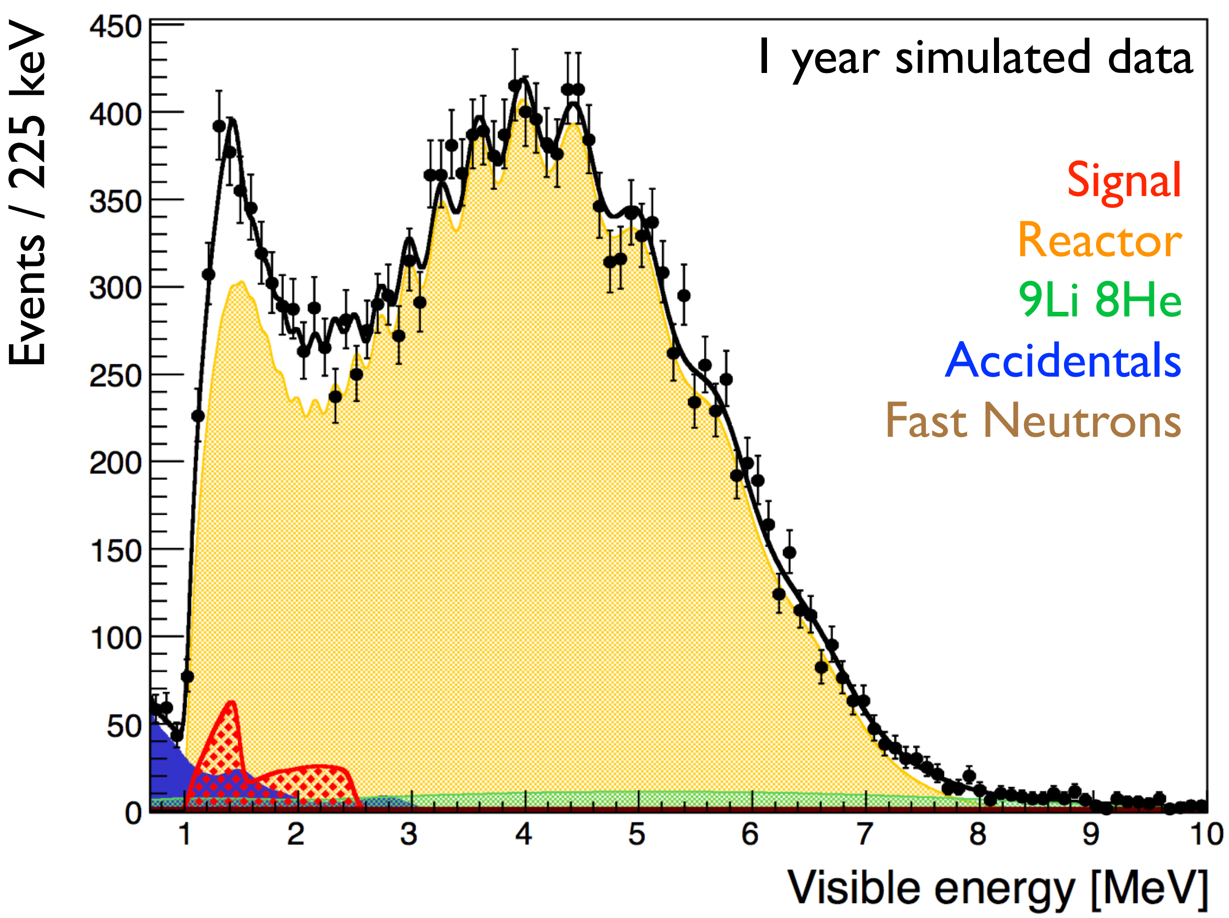
- **3 σ expected for observation after 10 years** (for most favorable DSNB parameters) **or tight exclusion limits** (if no-positive signal)

Geo-neutrinos

Earth's surface heat flow: 46 ± 3 TW. ν from U/Th decay chains to understand:

- **Earth's formation and evolution**
- **crust and mantle composition**
- **mantle convection** (driver of plate tectonics)

- 17-25% uncertainty on geo-ν (U + Th) flux from KamLAND + Borexino data



JUNO will collect ~ 400 events/yr
(largest sample so far ~ 150 events)

- geo-ν detection by IBD. **Reactor-ν as main background source**

- Signal extracted by a template fit.

Estimated uncertainties on (U+Th) flux:

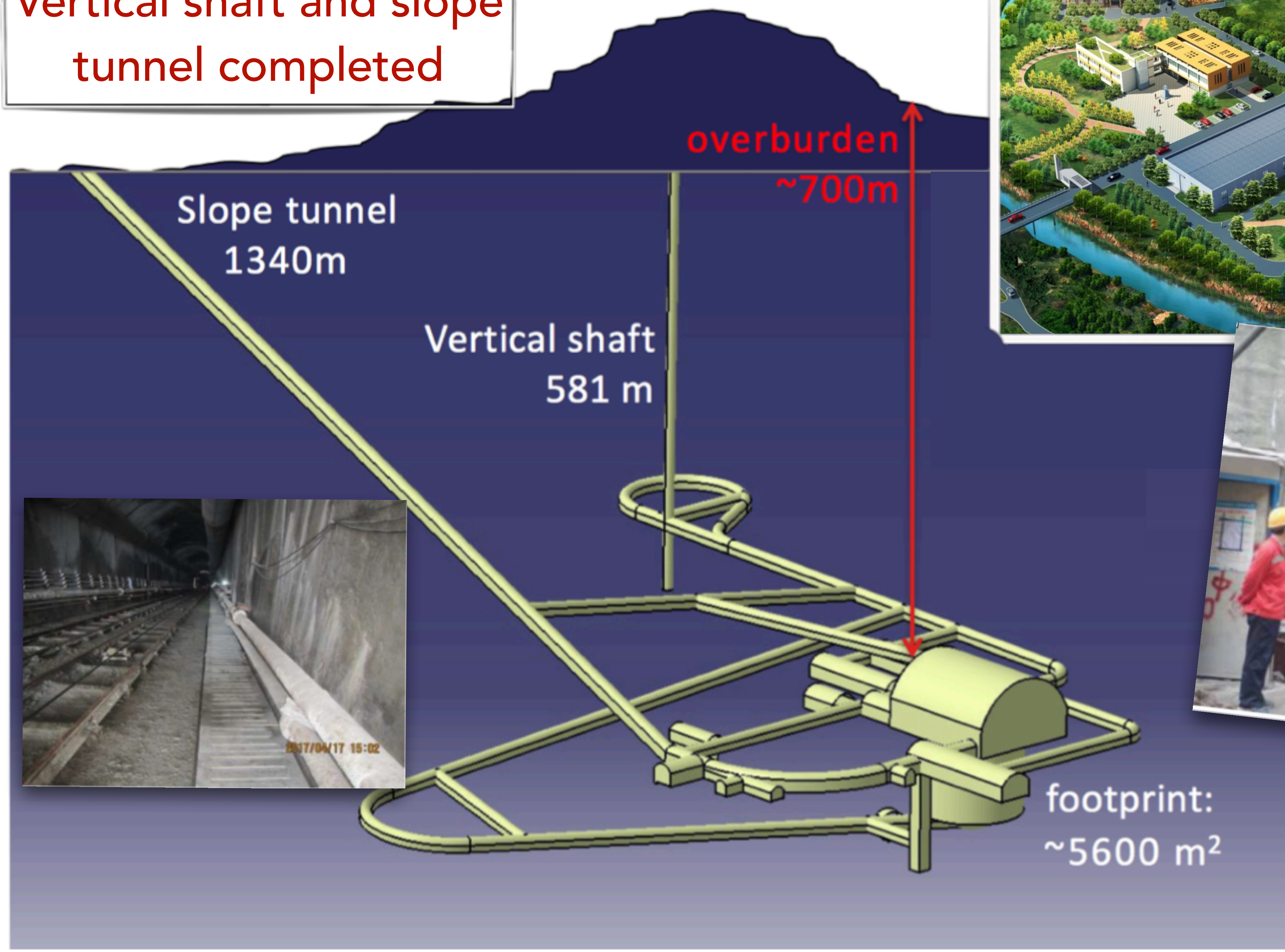
17% after 1 year, 6% in 10 years

DETECTOR STATUS

Civil Construction continuing …

A new underground lab under construction with infrastructures on surface

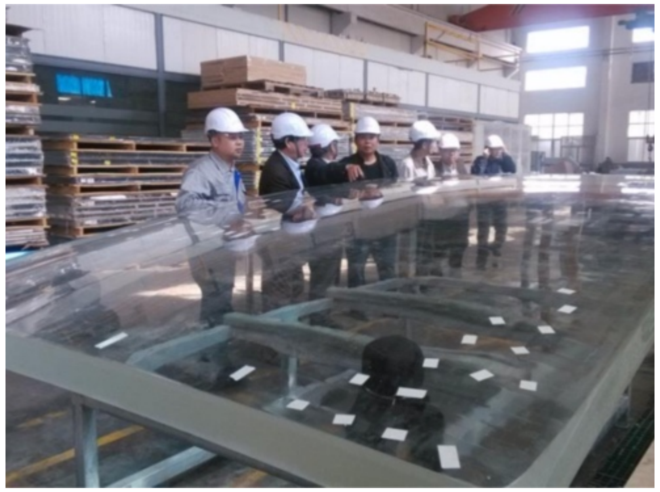
Vertical shaft and slope tunnel completed



Some main steps towards JUNO….

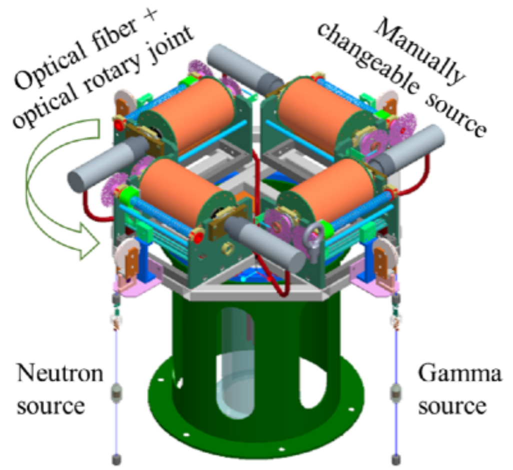
Acrylic sphere
a 4 m prototype in progress

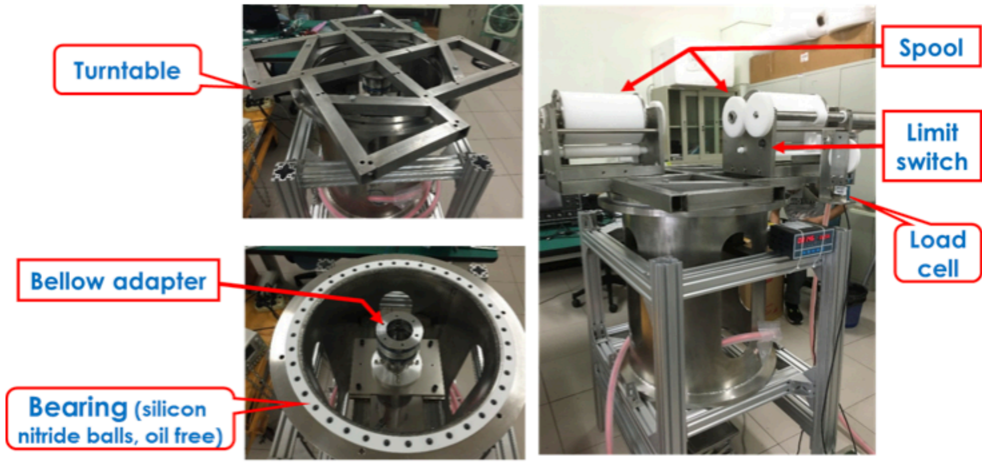
Steel structure
CD,VETO structure design completed
Bidding completed and contract signed


Acrylic panel

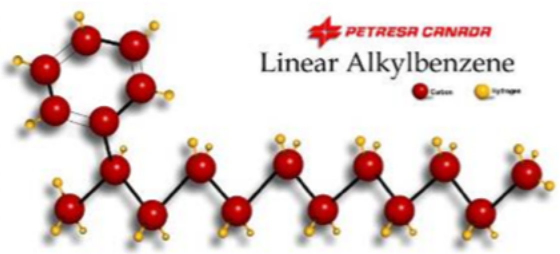

Onsite assembly

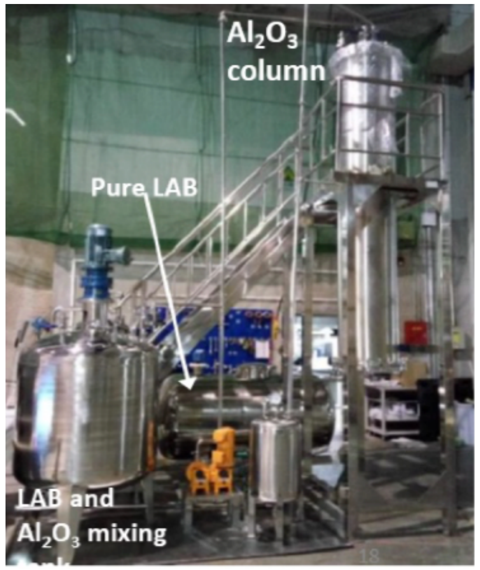
Calibration systems
4 sub-systems designed





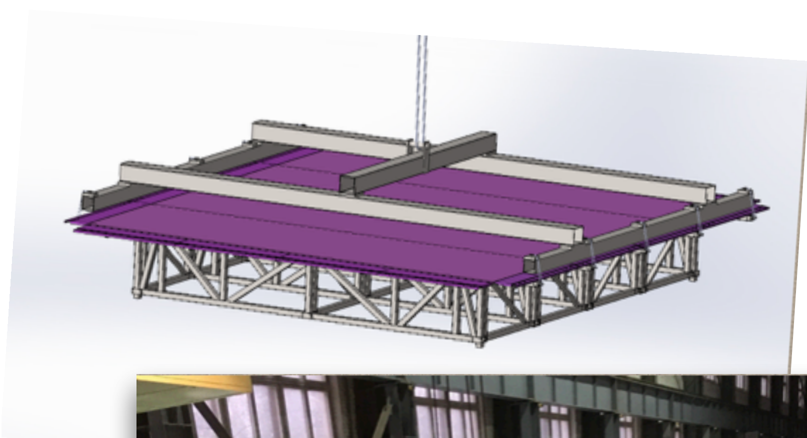
Liquid Scintillator
Progresses in LS choice (yield, contamination studies), distillation plant and purification system.





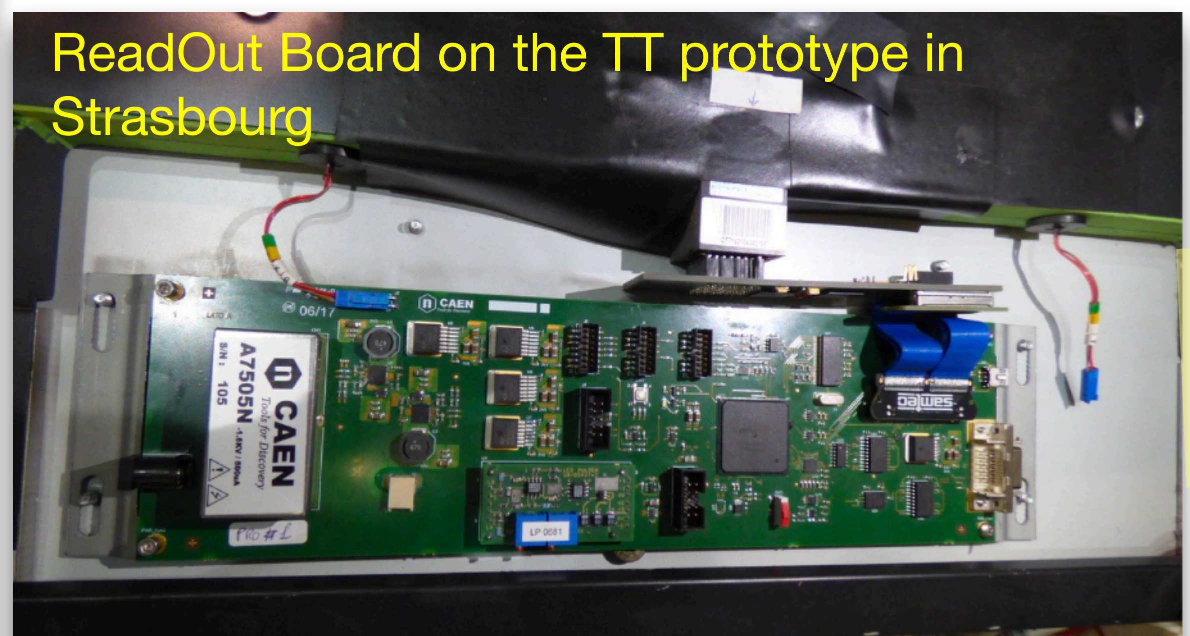
Some main steps towards JUNO: **the Top Tracker**

- The design of the TT mechanical support validated with the prototypes.
- The assembly procedure elaborated and approved by Chinese side



the 7 containers in the stockage hall

- TT shipped to China



ReadOut Board on the TT prototype in Strasbourg

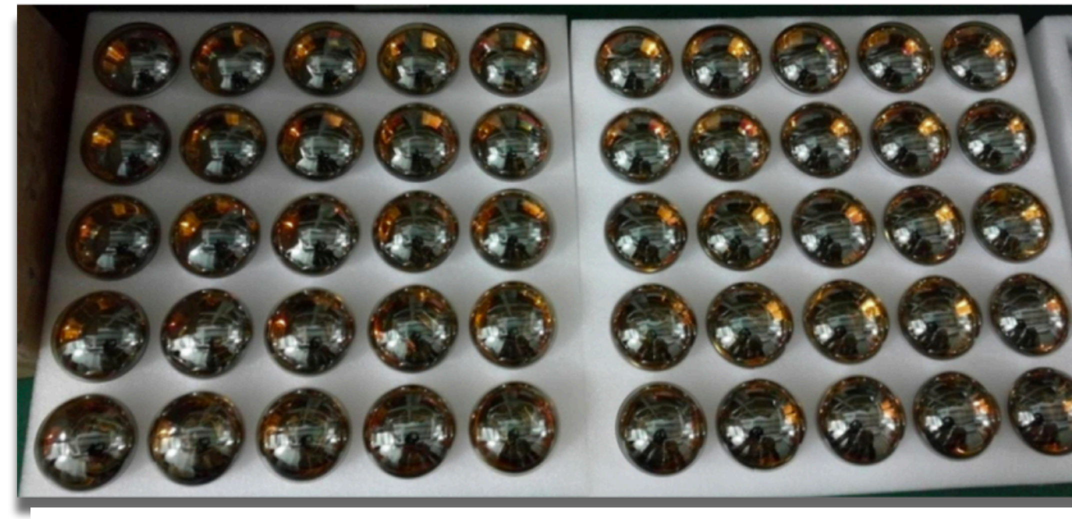
details in E. Baussan's talk

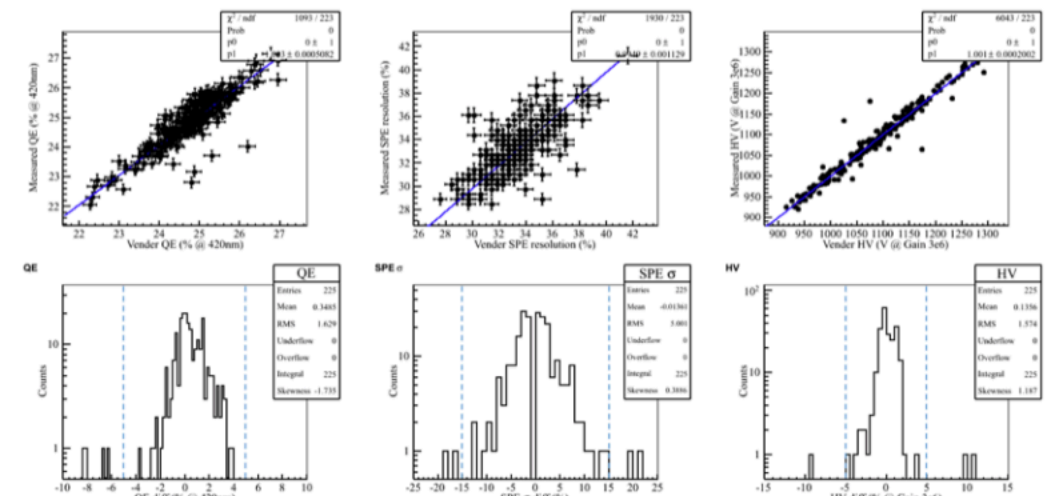
Some main steps towards JUNO: **the SPMTs**

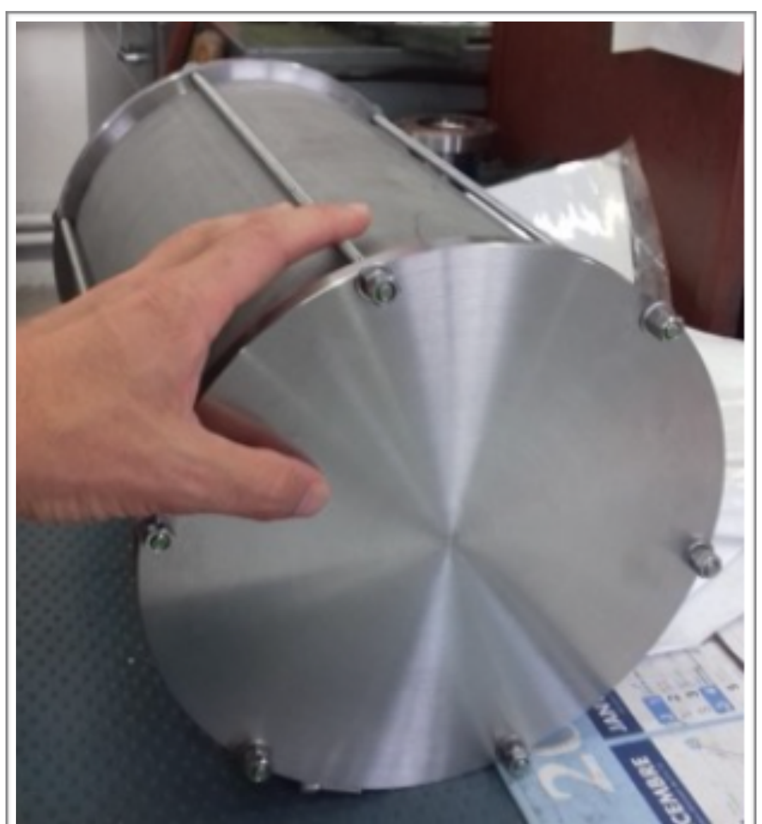
- **SPMTs** bidding in 2017 (HZC selected)
  - Production and acceptance tests started
  - ~3000 PMTs produced and tested @ HZC

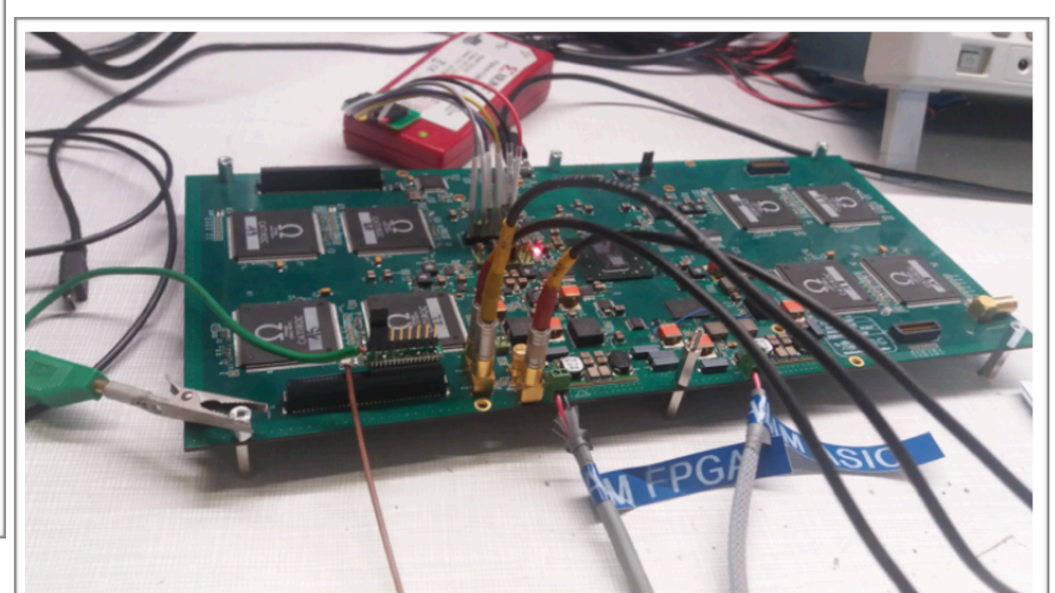
  A 10% sample tested at IHEP (good agreement)

- **PMT potting, cabling and connectors**
- **HV, Electronics:** board ready and under test
- **underwater boxes**: design and prototypes









... much more in C. Cerna's talk

Some main steps towards JUNO: the LPMTs

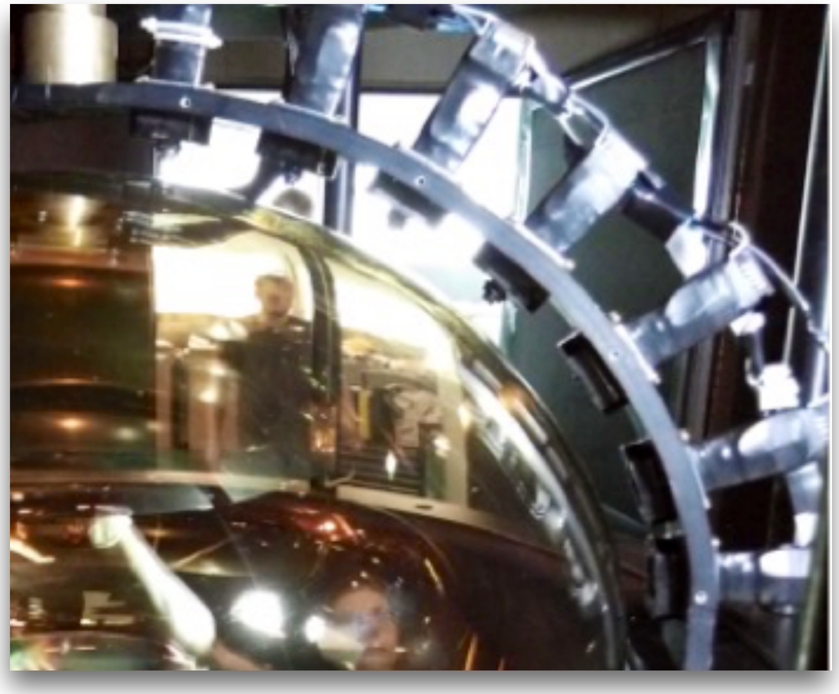
LPMT (20”) production and testing started

~ 6000 LPMT delivered

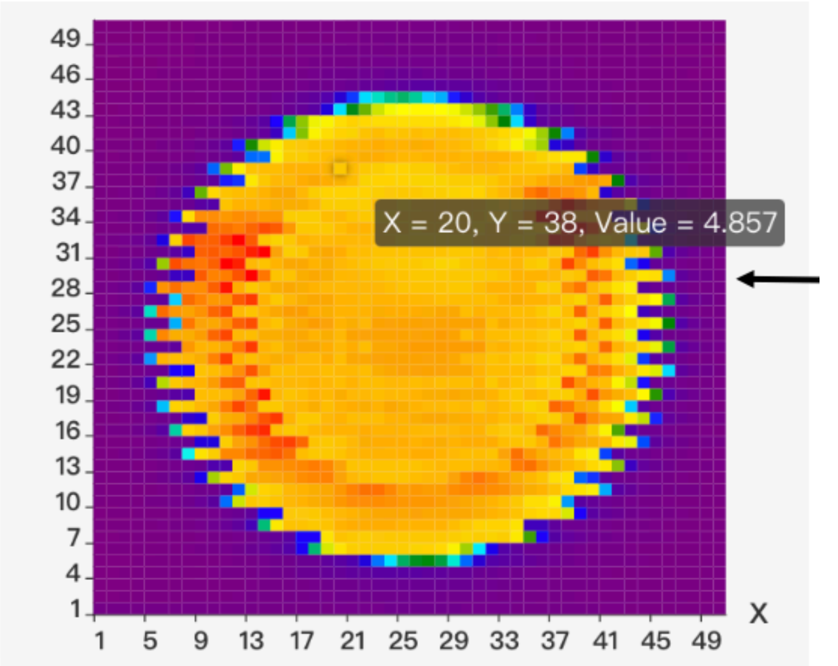
Electronics design defined, v0 production and testing in progress

Scanning stations for LPMT

Uniformity scan station

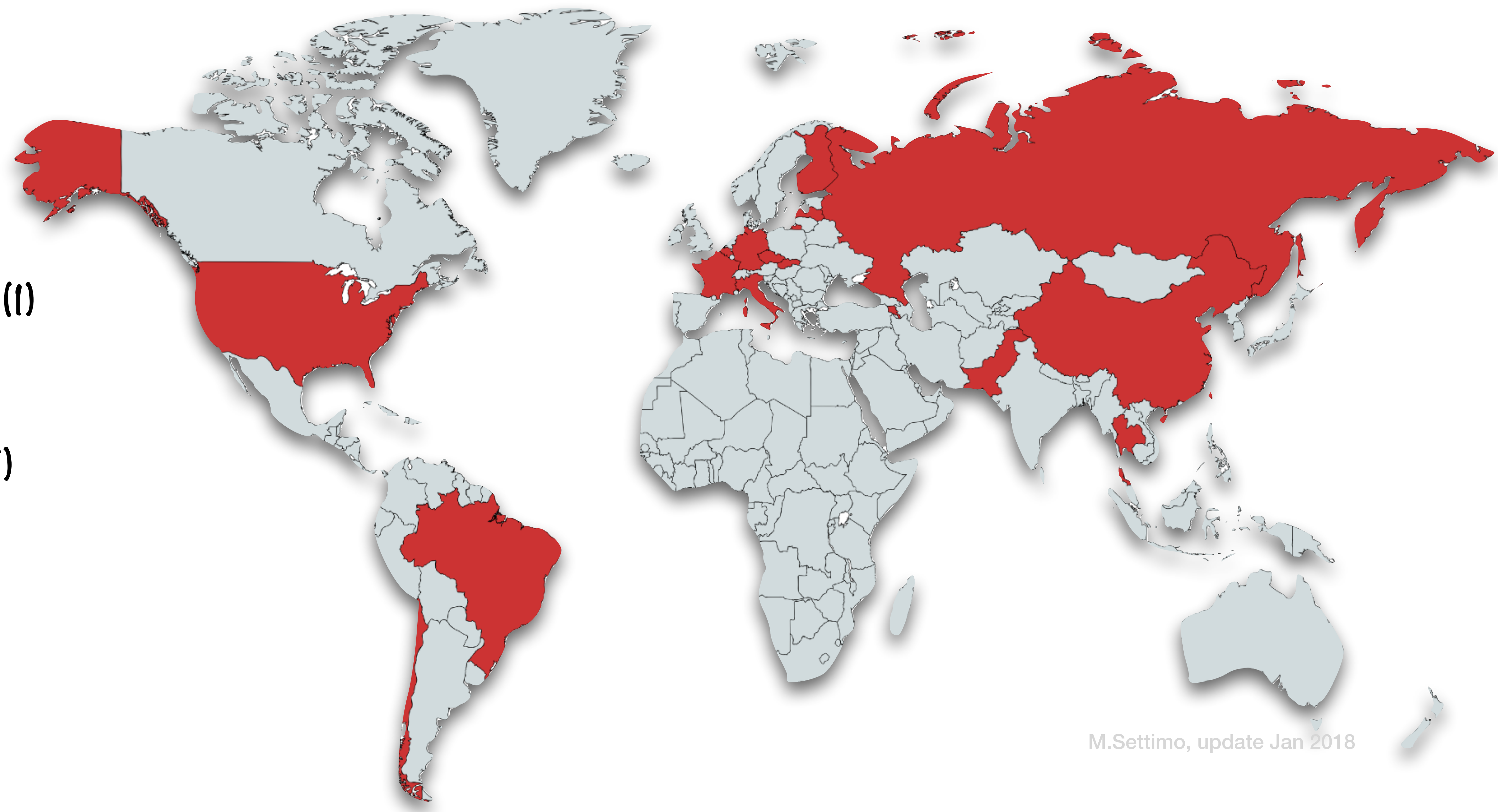


Example of uniformity test



An international collaboration

Armenia (1)
Belgium (1)
Brazil (2)
Chile (2)
China (30)
Czech Rep. (1)
Finland (1)
France (5)
Germany (7)
Italy (8)
Latvia (1)
Malaysia*
Pakistan (1)
Russia (3)
Slovakia (1)
Taiwan (3)
Thailand (3)
USA (2)



17 countries, 72 institutions (+ 4 observers)
~ 550 collaborators

(*) Observers

Conclusions

JUNO unprecedented **large & high precision-calorimetry** liquid scintillator detector

Experiment	Daya Bay	BOREXINO	KamLAND	JUNO
Target mass	20 ton	~ 300 ton	~ 1 kton	**20 kton**
Optical coverage	12%	34%	34%	**75%**
Light yield	160 p.e./MeV	500 p.e./MeV	250 p.e./MeV	**1200 p.e./MeV**
Energy resolution	7.5%/√E	5%/√E	6%/√E	**3%/√E**
Energy calibration	1.5%	~ 1%	2%	**< 1%**

Multi-purpose experiment :

- reactor ν : Mass Hierarchy sensitivity, < 1% precision on the oscillation parameters
- ``non-reactor" ν: A vast program for (supernova physics, geo-neutrinos, solar ν, …)

Many progresses on going on civil and detector construction

Several sub-projects based a very close and successful collaboration between China and France


July 17-21,2017,IHEP Beijing
Summer fashion 2017


Winter fashion 2018
Nanjing, Jan 2018
Thank you