The JUNO neutrino oscillation experiment

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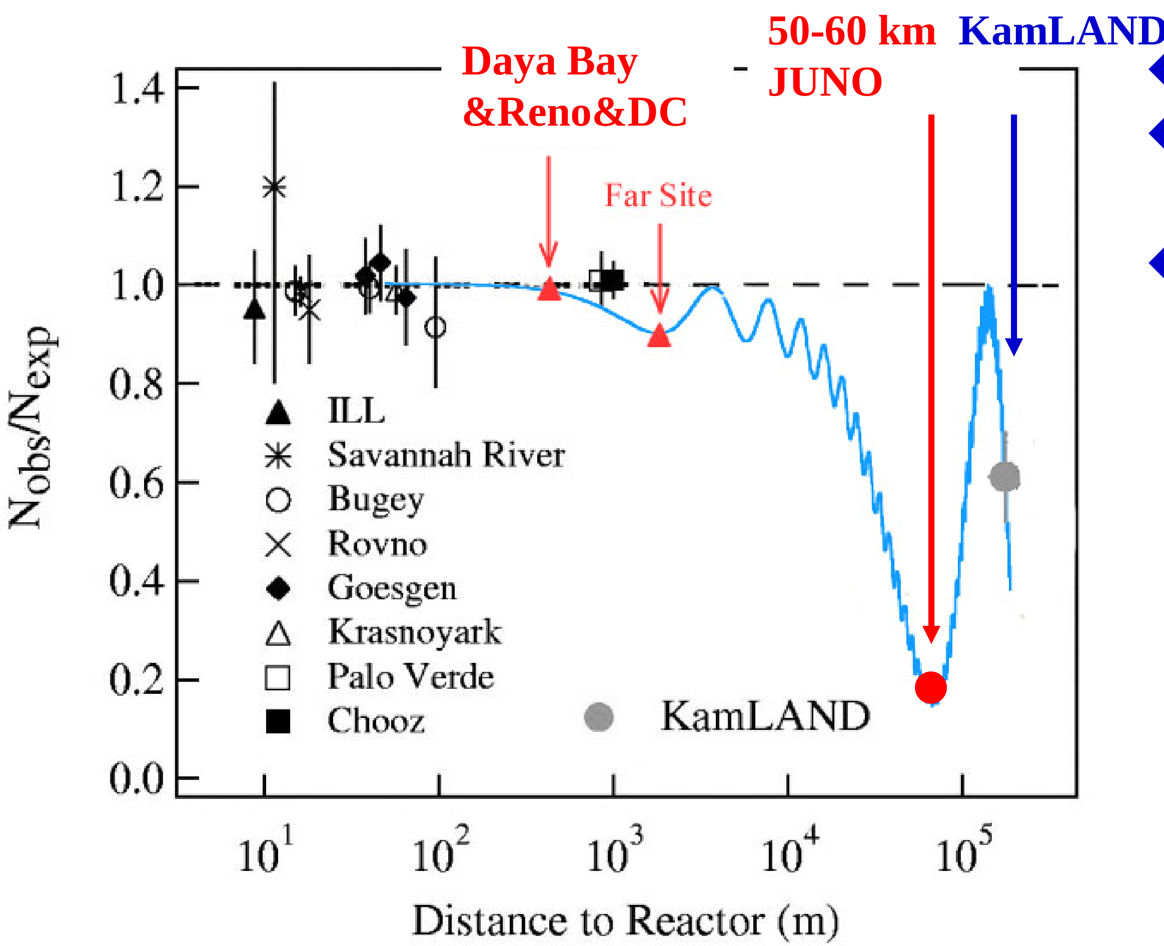
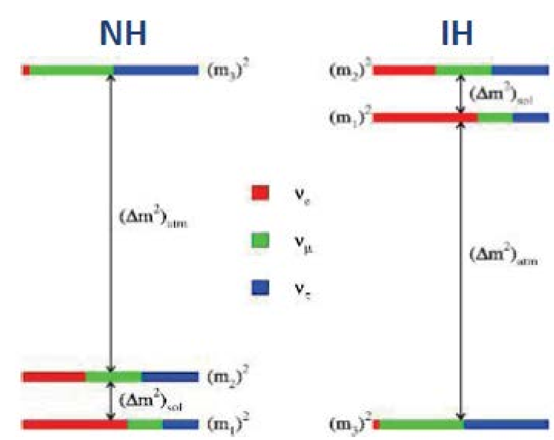
Troitsk, 9/10/2015

- Determination of the neutrino mass hierarchy with a large mass liquid scintillation detector located at medium distance – few tens of km – from a set of high power nuclear complexes
- Additional astroparticle program
- Requirement and technical features of the experiment

JUNO Experiment – physics summary

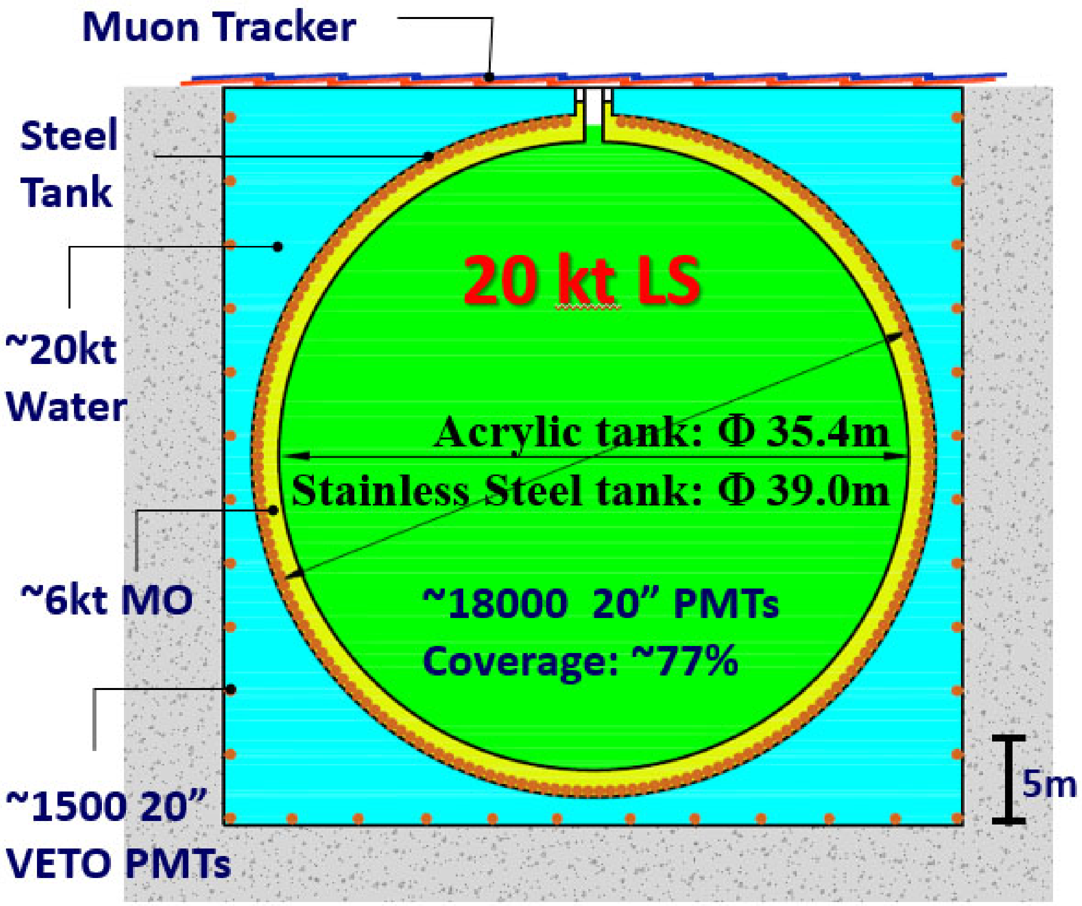


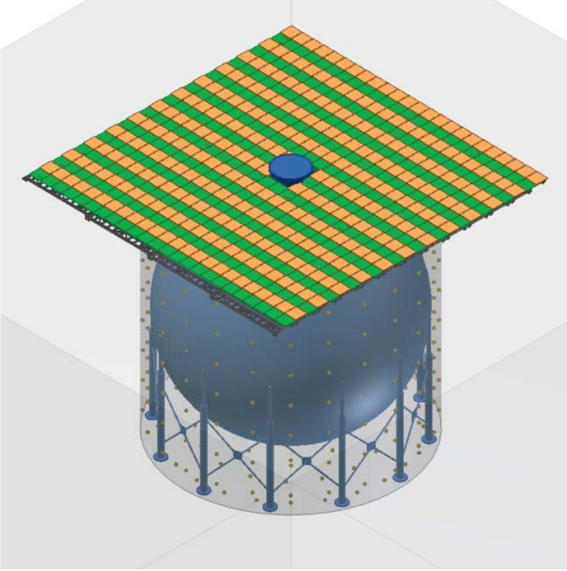
- **20 kton LS detector**
- **~3 % energy resolution-the greatest challenge**
- Rich physics possibilities
  - ⇨ **Mass hierarchy**
  - ⇨ **Precision measurement of 3 mixing parameters**
  - ⇨ **Supernovae neutrino**
  - ⇨ **Geoneutrino**
  - ⇨ **Sterile neutrino**
  - ⇨ **Atmospheric neutrinos**
  - ⇨ **Exotic searches**



The plan: a large LS detector

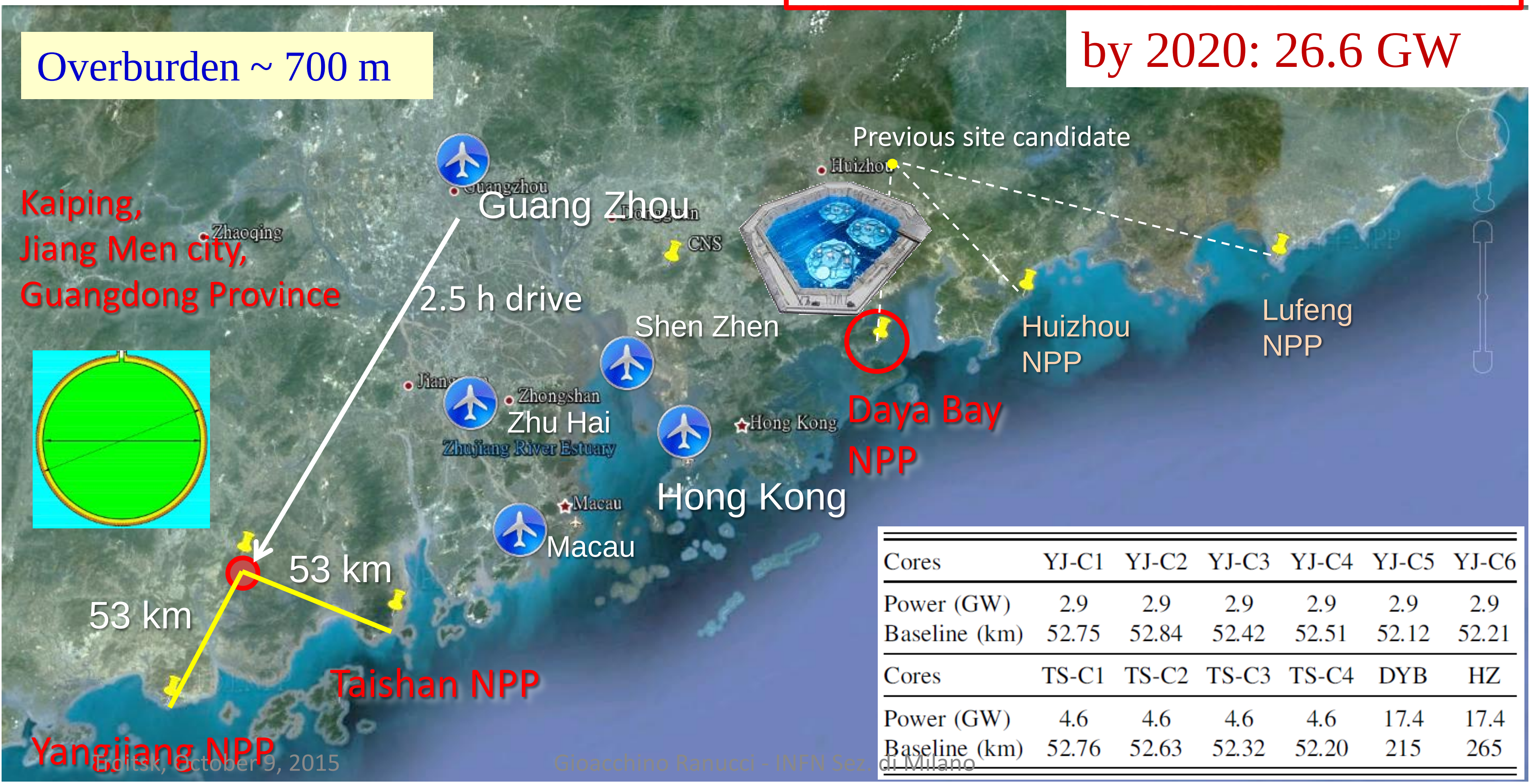
- LS large volume: ➔ for statistics
- High Light(PE) ➔ for energy resolution





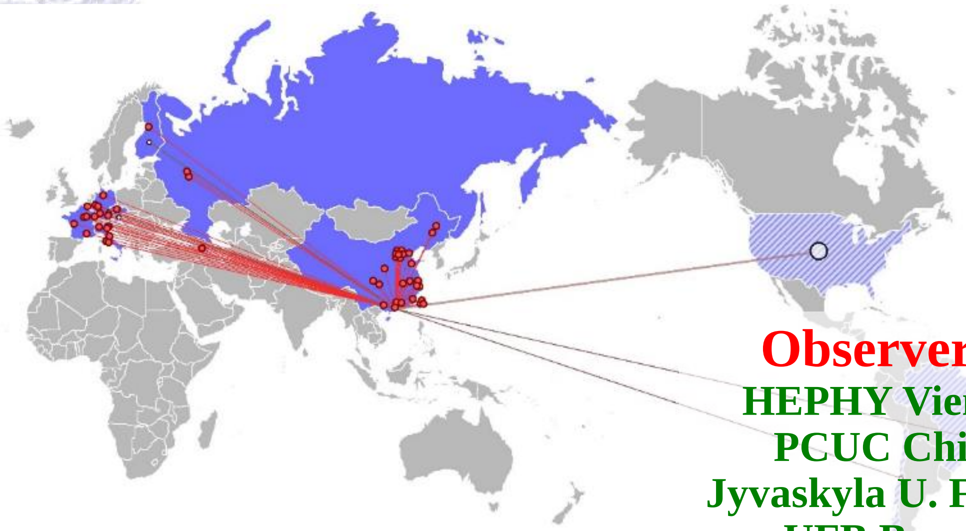
Location of JUNO

NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 GW



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 Collaboration



Observers:
HEPHY Vienna
PCUC Chile
Jyvaskyla U. Finlan
UFB Brazil
MSU Russia

Asia (28)

BNU
CAGS
CQ U
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ECUST
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Jilin U
Nanjing U
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Pekin U
Shandong U
Shanghai JTU
Sichuan U
SYSU
Tsinghua
UCAS
USTC
Wuhan U
Wuyi U
Xiamen U
Xi'an JTU

Europe (24)

France (5)
APC Paris
CPPM Marseille
IPHC Strasbourg
LLR Paris
Subatech Nantes
Finland (1)
U Oulu
Czech (1)
Charles U

Italy (7)
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Russia (2)
JINR
INR Moscow

Germany (6)
FZ Julich
RWTH Aachen
TUM
U Hamburg
U Mainz
U Tuebingen
Belgium (1)
ULB
Amenia (1)
YPI

America (3)

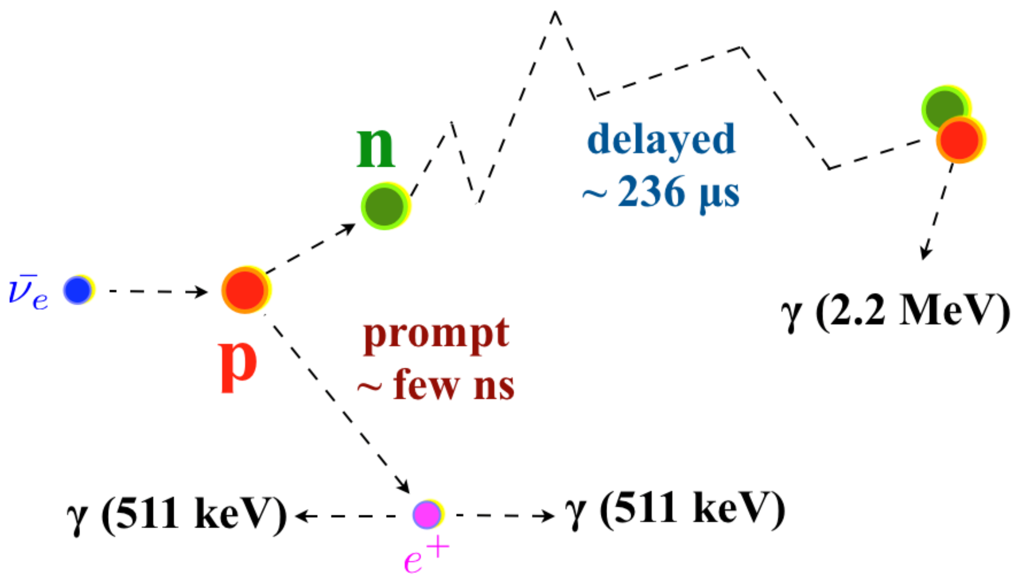
PCUC - Chile
Maryland U.- 2 groups

Method to infer the Mass Hierarchy

The determination of the mass hierarchy relies on the identification on the positron spectrum of the "imprinting" of the anti-ν_e survival probability

Detection through the classical inverse beta decay reaction (we use it in Borexino for the geo-neutrinos)

$$\bar{\nu} + p \rightarrow n + e^{+} \quad E_{\nu}>1.8 \text{ MeV}$$



The time coincidence between the positron and the γ from the capture rejects the uncorrelated background

The "observable" for the mass hierarchy determination is the positron spectrum

It results that $E_{vis}(e^+)=E(\bar{\nu})-0.8$ MeV

Method from Petcov and Piai, Physics Letters B 553, 94-106 (2002)

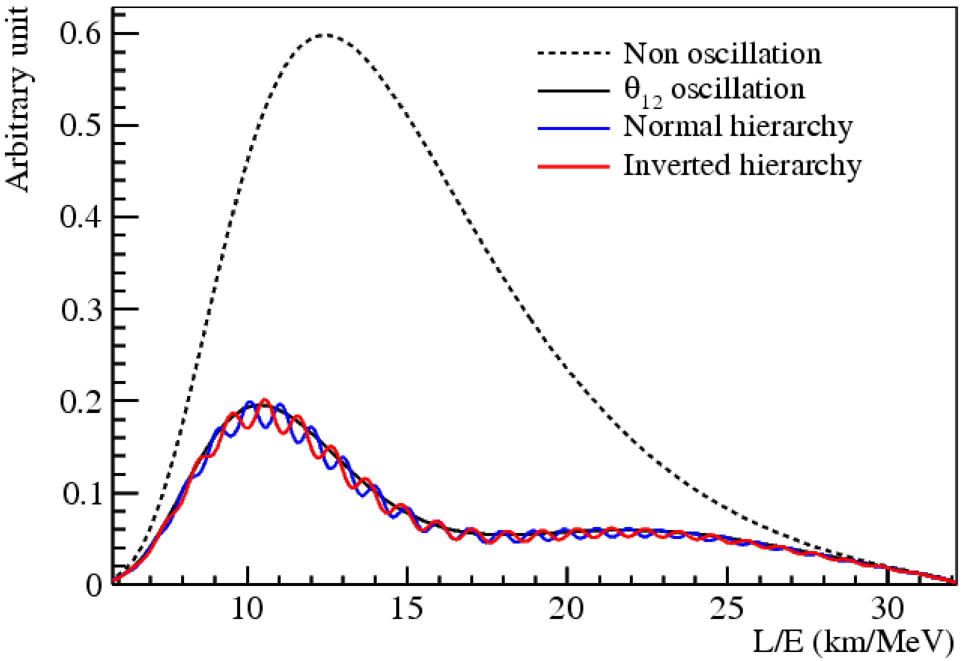
Survival probability

arXiv 1210.8141

$$P_{ee} = \left| \sum_{i=1}^{3} U_{ei} \exp\left(-i\frac{m_i^2}{2E_i}\right) U_{ei}^* \right|^2$$
$$= 1 - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2(\Delta_{21})$$
$$- \cos^2\theta_{12}\sin^2 2\theta_{13}\sin^2(\Delta_{31})$$
$$- \sin^2\theta_{12}\sin^2 2\theta_{13}\sin^2(\Delta_{32})$$

$$\Delta_{ij} \equiv \frac{\Delta m_{ij}^2 L}{4E_\nu}, \quad (\Delta m_{ij}^2 \equiv m_i^2 - m_j^2)$$

Or to make the effect of the mass hierarchy explicit, exploiting the approximation $\Delta m^2_{32} \approx \Delta m^2_{31}$:



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

+ NH
- IH

The big suppression is the “solar” oscillation → Δm^2_{21} , $\sin^2\theta_{12}$
The ripple is the “atmospheric” oscillation → Δm^2_{31} from frequency
MH encoded in the phase
“high” value of θ_{13} crucial

In engineering term

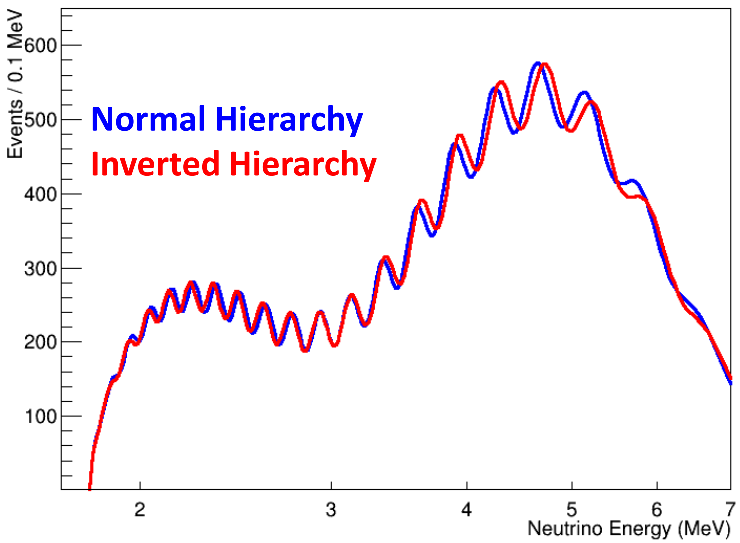
The problem is

A pattern recognition procedure

Coupled to a statistical inference method

Also solvable with a Fourier type approach

Neutrino & Positron Spectra



Spectrum in term of neutrino energy – no energy resolution

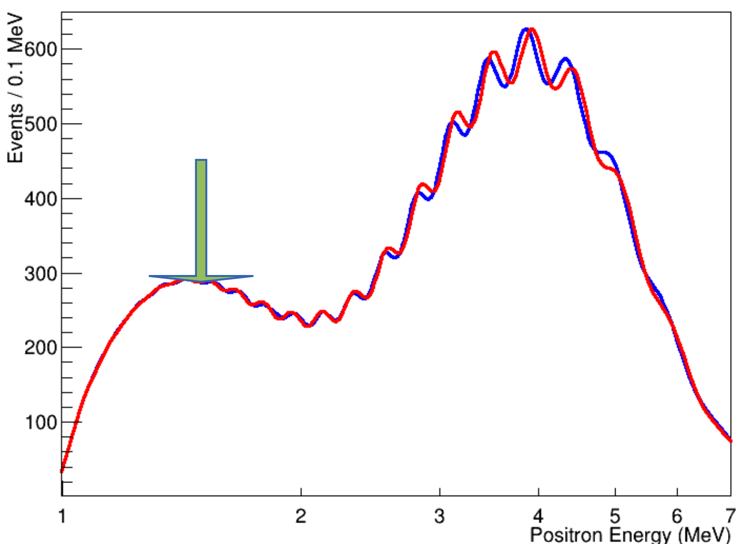
Exercise done by Marco Grassi post-doc INFN/IHEP at Beijing

Replicating sensitivity study in arXiv 1210.8141

- Three neutrino framework (no effective Δmee Δmμμ)
- Baseline: 50 km
- Fiducial Volume: 5 kt
- Thermal Power: 20 GW
- Exposure Time: 5 years
- more pessimistic than the JUNO values ▶ used to be in sync with paper

Visible energy due to inverse beta decay

- E(vis) ~ E(ν) – 0.8 MeV
- Assuming 3% / sqrt(E) resolution
- Assuming negligible constant term in resolution



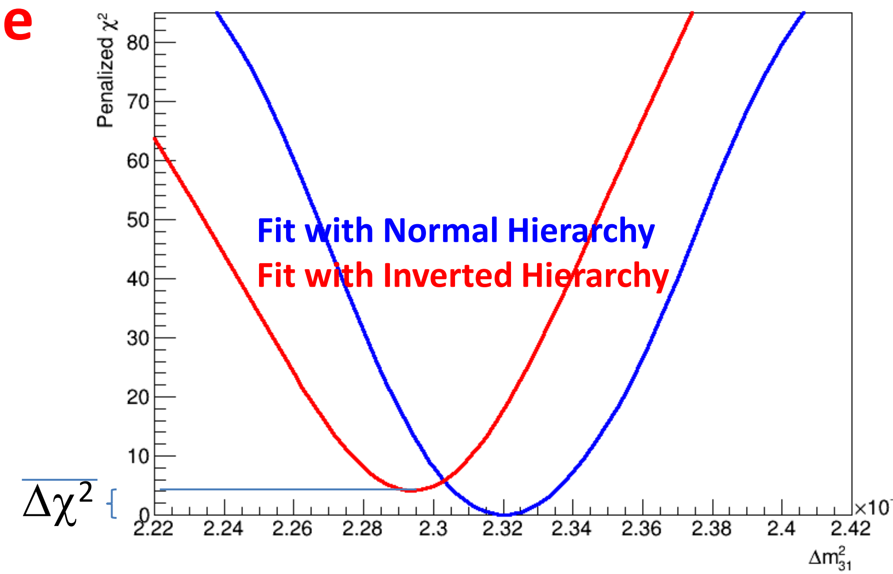
Spectrum in term of positron visible energy – with energy resolution

Example of χ^2 comparison – NH true

Numerical values as before
Scan of penalized (i.e. marginalized over the other minimization parameters) χ^2 vs. $|\Delta m^2_{31}|$

Case NH true- average spectrum
(no fluctuation –**Asimov data set**)
Test statistics → $\Delta\chi^2=\chi^2_{min}(NH) - \chi^2_{min}(IH)$

Fit NH minimum: $1.6\ 10^{-2}$ (practically 0)
FIT IH minimum: 4.0
$\overline{\Delta\chi^2}$ ~4.0

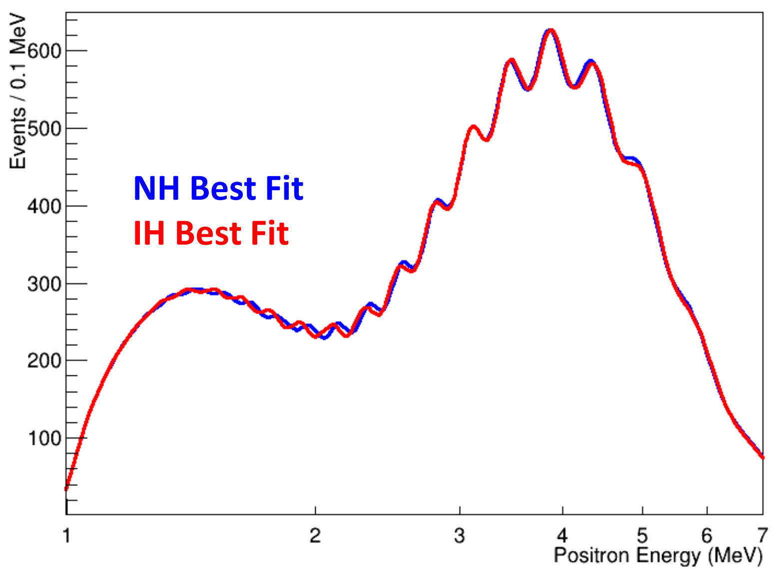


Comparison between IH/NH best fits

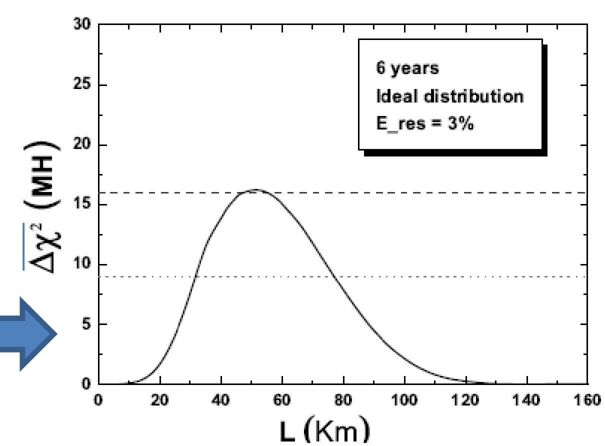
The best fit $|\Delta m_{31}|$ is different in the two cases

Fit almost succeeds in accommodating IH spectrum to NH data

The two solutions are fully degenerate but in a limited range of distances



Optimum distance to maximize $\overline{\Delta\chi^2}$



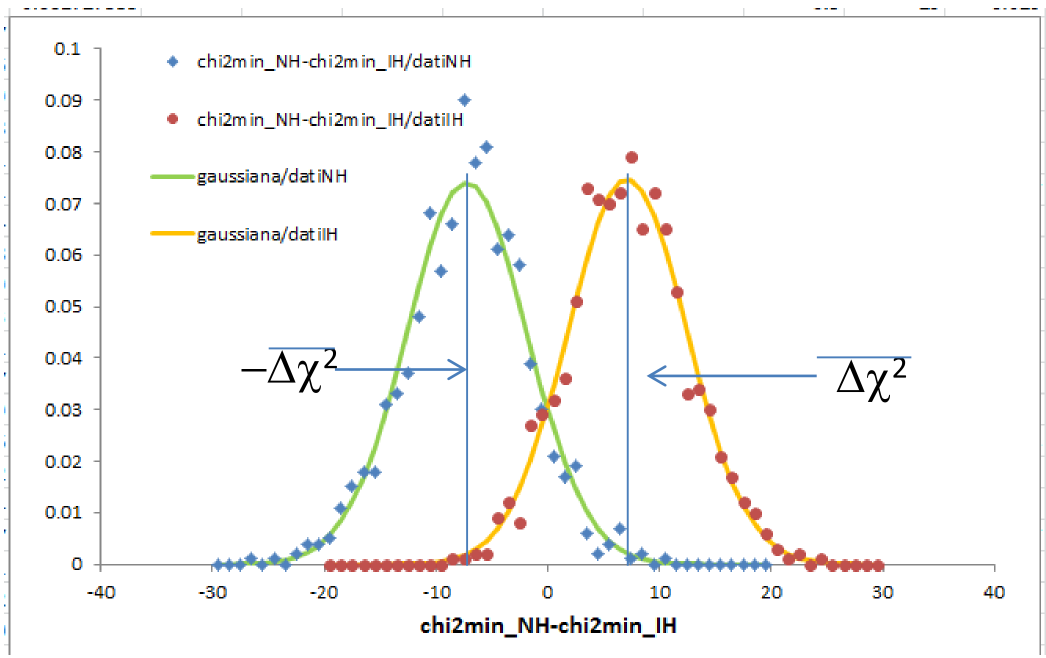
From arXiv:1303.6733v1 [hep-ex] JUNO
$\overline{\Delta\chi^2}$ can be as high as **16** @ 52 km

Distribution of the $\Delta\chi^2$ test statistics

So far only the mean value of the test statistics has been evaluated

Full distribution obtained taking into account the statistical fluctuations of the data

A Monte Carlo example



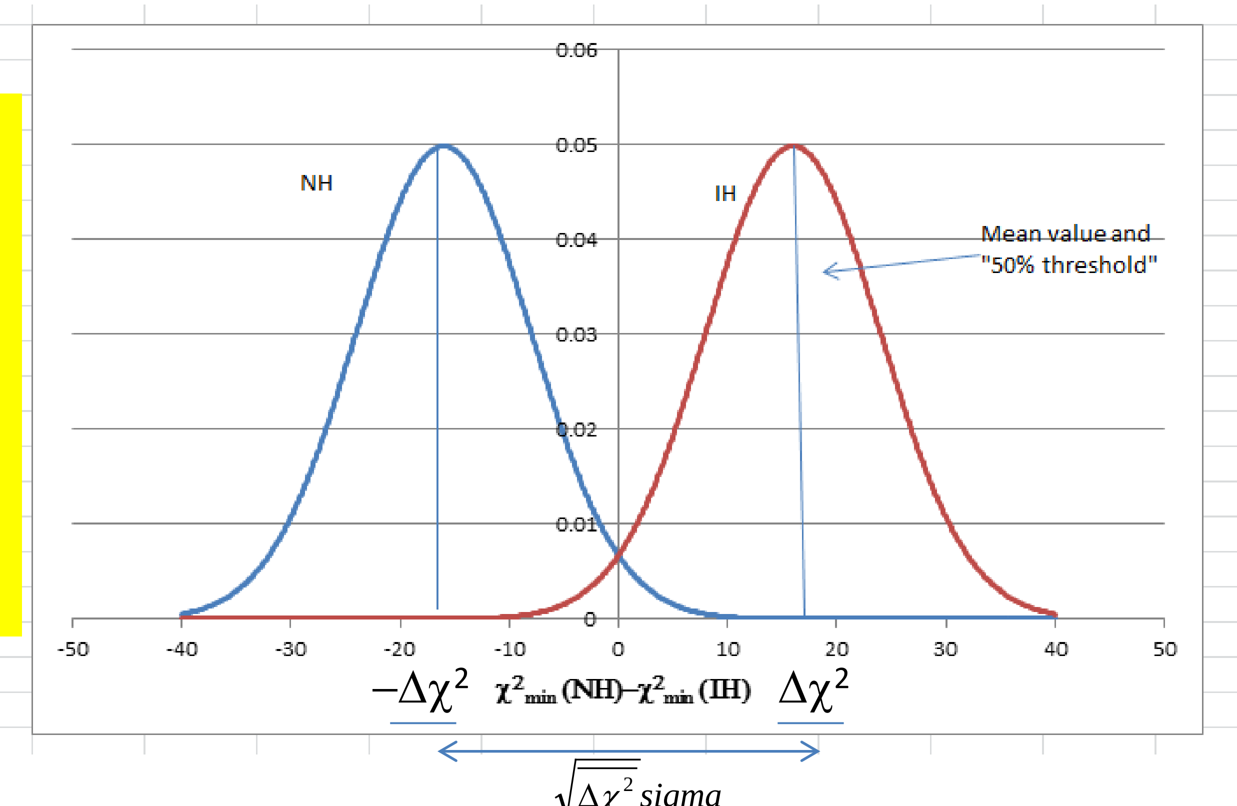
The actual distribution of the test statistics is a Gaussian centered on the absolute value of $\overline{\Delta\chi^2}$: yellow IH , green NH

The degree of overlap of the two Gaussian curves determines the "resolving" power of the experiment

How to quantify the discovery potential in term of number of sigma

- **Not unique answer**
- It depends upon the assumed framework (**frequentist or Bayesian**)
- However the actual information is fully encoded in the amount of overlap of the two Gaussian independently from how it is summarized as number of σ
- General result: sigma of each Gaussian = $2\sqrt{\Delta\chi^2}$ **arXiv: 1210.8141v2**

The mean value of the Gaussian curves is taken as representative of the **JUNO** capability at 52 Km arXiv:1303.673



The mean values of the two curves are displaced of exactly $\sqrt{\Delta\chi^2}\ sigma$

Frequentist considerations for the number of σ

The special relation between sigma and mean value of the two distributions implies that the median sensitivity according to the frequentist framework is automatically equal to

$$\sqrt{\Delta\chi^2}\sigma$$

This means that if the actual outcome of the experiment is more extreme than the expected mean value one get a positive indication for one of the two hierarchies (IH if the outcome is positive or NH if the outcome is negative) with a CL better than $\sqrt{\Delta\chi^2}\sigma$ i.e. with a probability of making a mistake (type I error according to the statistical terminology) equal to the corresponding one tailed p-value on the Gaussian curve

3 σ → p-value (1-0.9973)/2 instead of the more common 1-0.9973

In summary for JUNO

- If the outcome is as typically expected, the MH will be determined rather unambiguously
- Even better if there will be an upward fluctuation
- A downward fluctuation will produce an ambiguous result

With these characteristics JUNO declare a 4 σ sensitivity with the above meaning (spectrum with about 100000 events) →

Baseline: 52 km

Fiducial Volume: 20 kt

Thermal Power: 36 GW

Exposure Time: 6 years

Proton content 12% in mass , en. res. 3%

Alternative way to define the sensitivity: Bayesian approach

Given the same overlapped Gaussian curves a Bayesian methodology leads to less σ
This is only an apparent effect of the way adopted to communicate the same fact, i.e. how much the two Gaussians are overlapped , it is not a real decrease of sensitivity, which is determined by the intrinsic overlap independently of the metric adopted as its measure
However, this has created huge misunderstandings, as well as a lot of papers on the arXiv
For a specific outcome $\Delta\chi^2$ of the test statistics define the two a-posteriori probabilities

- For IH

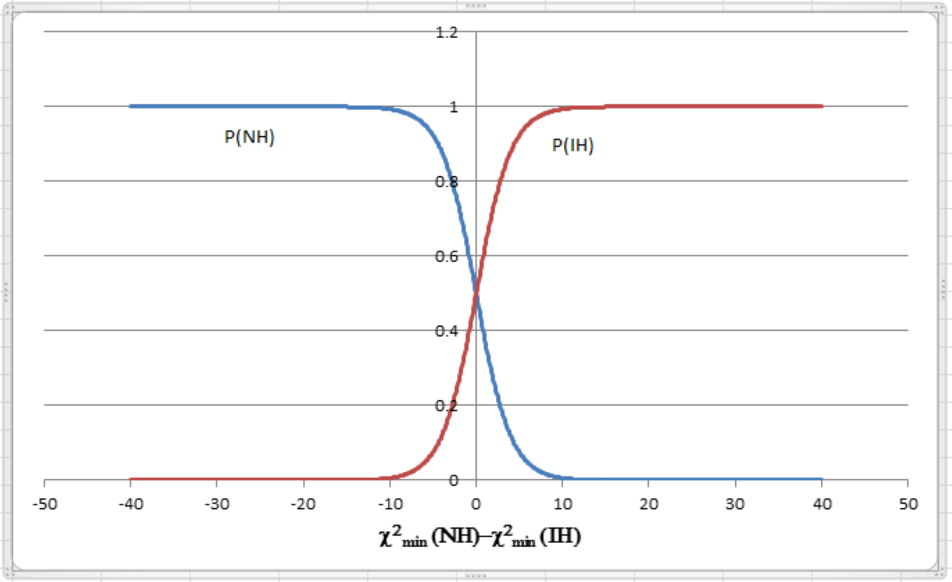
PIH=GIH($\Delta\chi^2$)/(GIH($\Delta\chi^2$)+GNH($\Delta\chi^2$))

- For NH

PNH=GNH($\Delta\chi^2$)/(GIH($\Delta\chi^2$)+GNH($\Delta\chi^2$))
Important result in **arXiv: 1210.8141v2**
they are invariant
Define

$$Paverage(IH) = \int_{-\infty}^{\infty} PIH(\Delta\chi^2)GIH(\Delta\chi^2)d\Delta\chi^2$$

And similarly for P*average* (NH)
(practically equal)

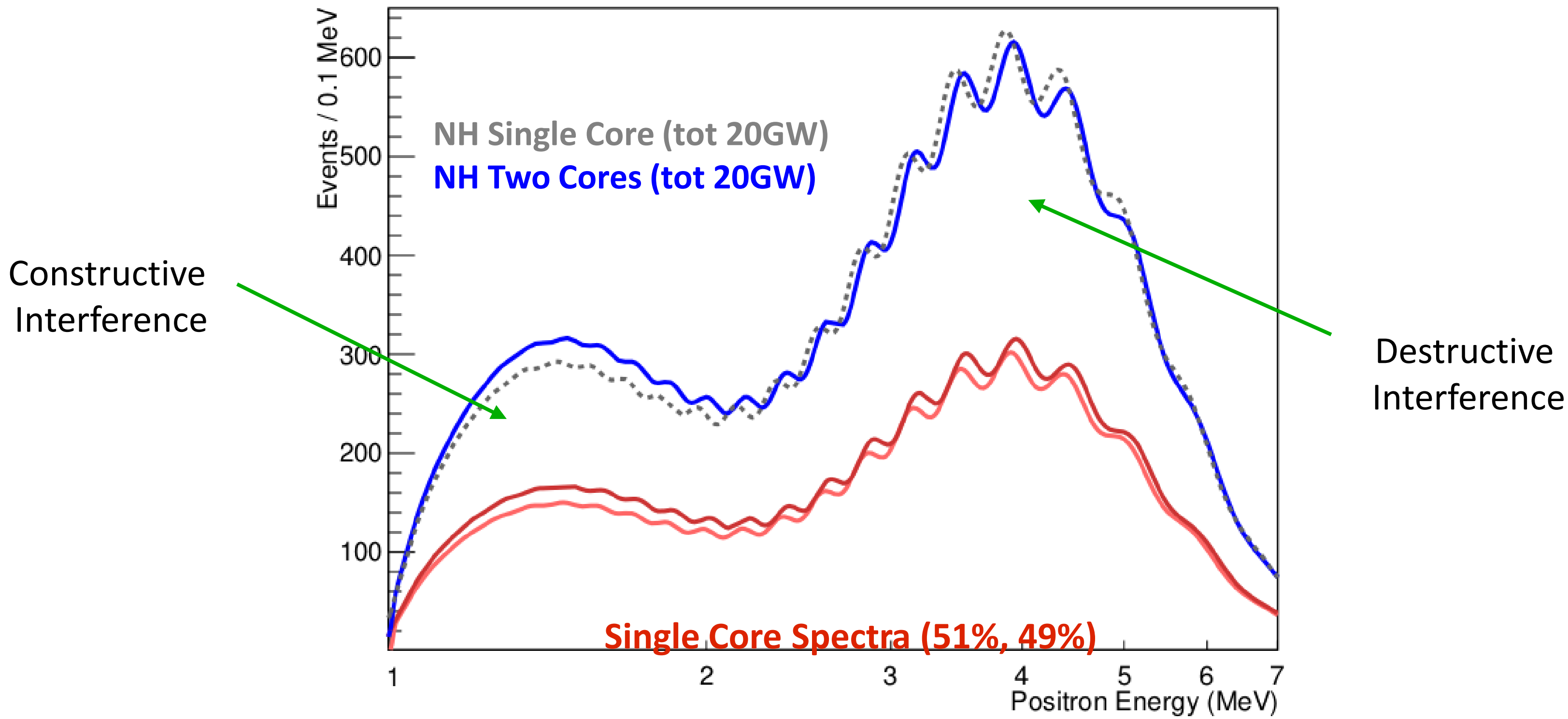


The two P*average* are converted in two tailed Gaussian p-values and in the corresponding number of σ $\rightarrow$ **for the same JUNO parameters this exercise leads to 2.1 σ**

Caveat: Multiple Cores

Reduction in sensitivity might arise from actual spatial distribution of nuclear reactor cores

Eg. two cores with 51% (49%) of tot. power, placed at 50 km (50.5km) distance from detector

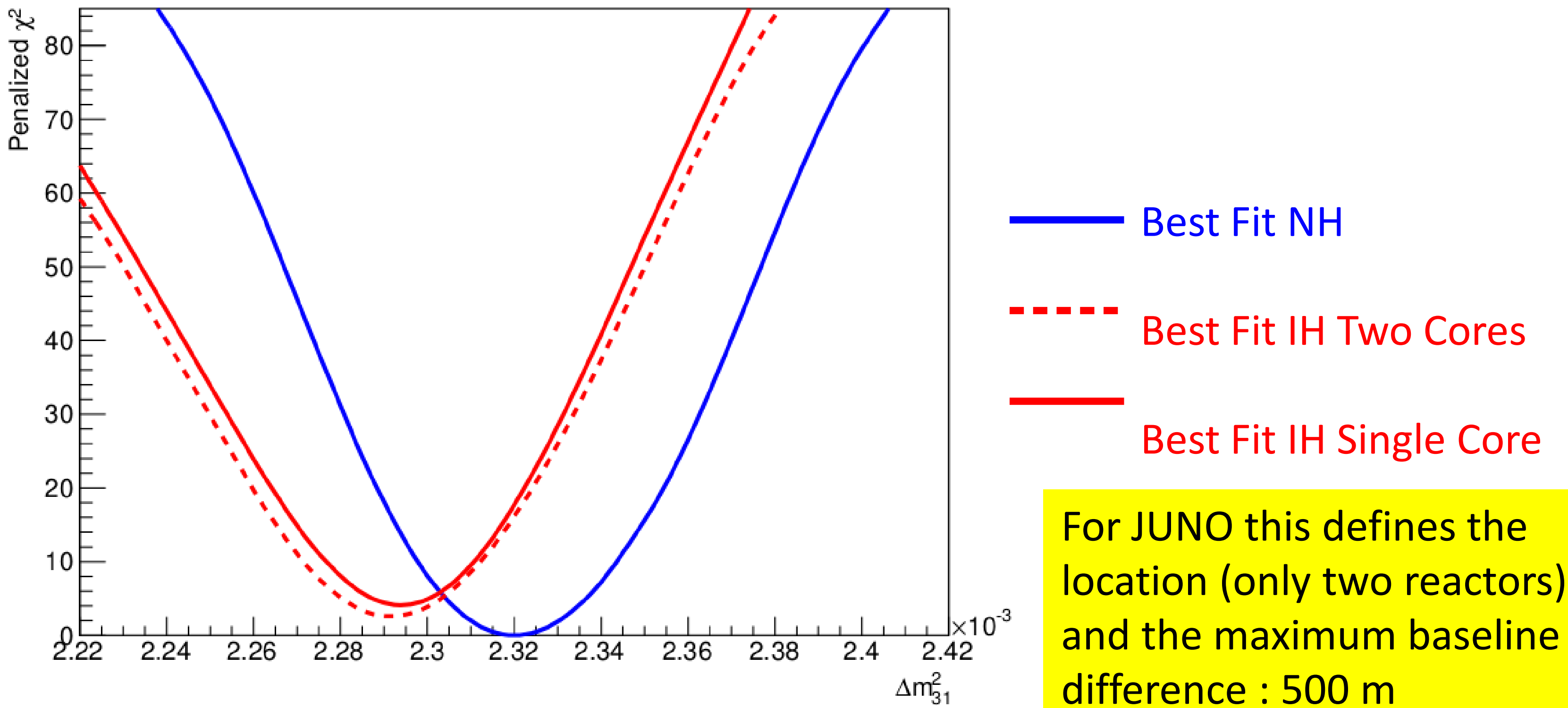


Baseline difference results in destructive interference in the most sensitive region of the spectrum

Important effect since JUNO will detect neutrinos from 10 cores

Multiple Cores: χ^2

Sensitivity loss is measured through the new χ^2 minimum



For JUNO this defines the location (only two reactors) and the maximum baseline difference : 500 m

$\Delta\chi^2$ between IH and NH in this numerical exercise is reduced from 4.0 to 2.6

In the JUNO set-up the spread of the cores is 500 m $\rightarrow$ $\Delta\chi^2$ reduction of about **5**

The other effects

- Adverse effect

Non linearity of the energy scale
This clearly impacts the ability to distinguish the true from false Hierarchy since distorts the experimental spectrum, therefore a very careful calibration is required better than 1% arXiv:1307.7419v3, as well as the long term stability of the detector (Borexino experience very promising, this is what we accomplished in the bulk of the FV , anyhow this is a challenge due to the large dimensions)

- Favorable element for analysis

Improved knowledge of $|\Delta m_{31}|$ by other experiments specifically T2K and NovνA ~1%

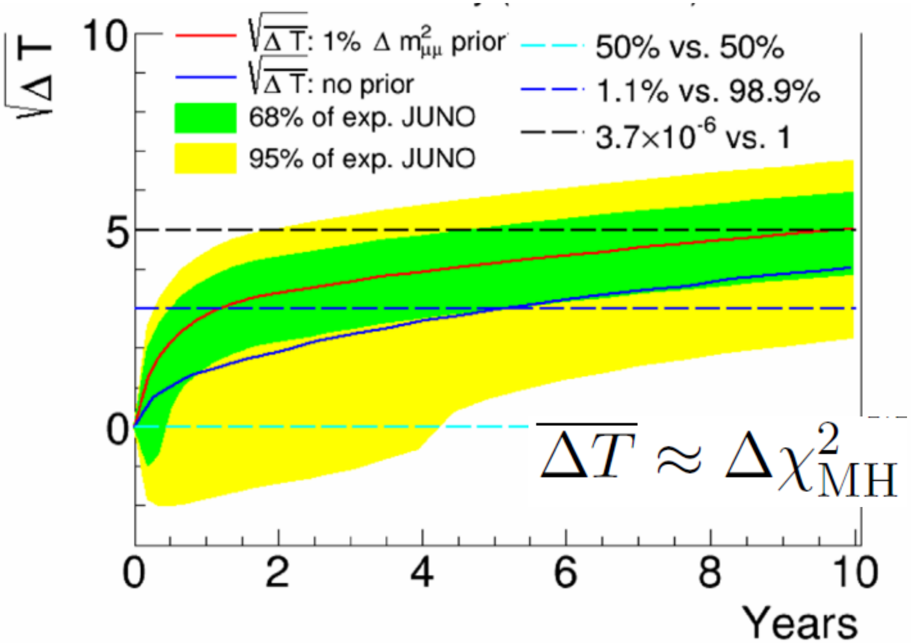
Exploited by adding a pull in the χ^2 definition thus increasing $\overline{\Delta\chi^2}$

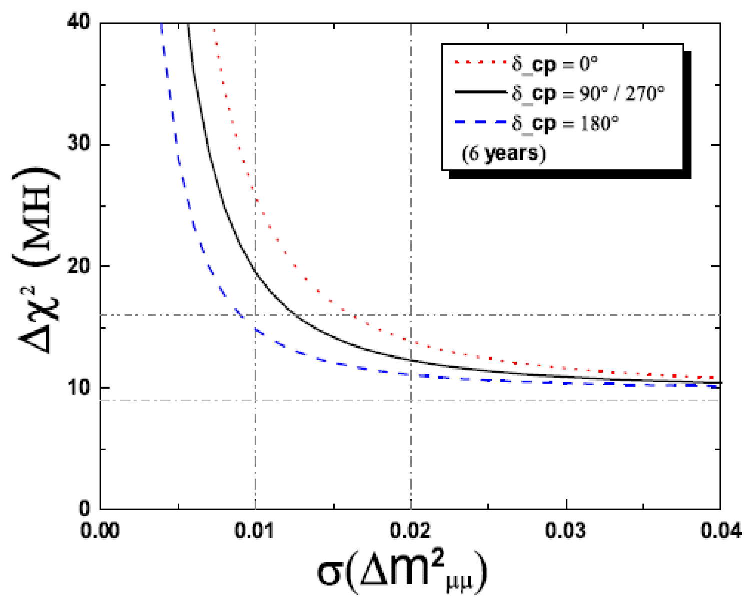
- In conclusion arXiv:1303.6733v1 demonstrates that JUNO can reach the value $\overline{\Delta\chi^2}$ in the range 15-20 ⇒ **crucially dependent upon the resolution (this assumes 3%) which is by far the challenge of the experiment**

Sensitivity on MH

PRD 88, 013008 (2013)	Relative Meas.	Use absolute Δm^2
Statistics only	4σ	5σ
Realistic case	3σ	4σ

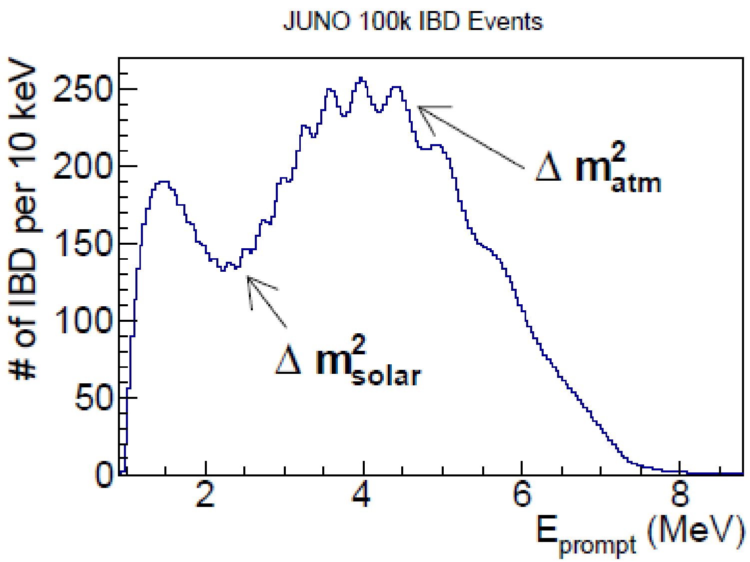
***JUNO* MH sensitivity with 6 years' data:**





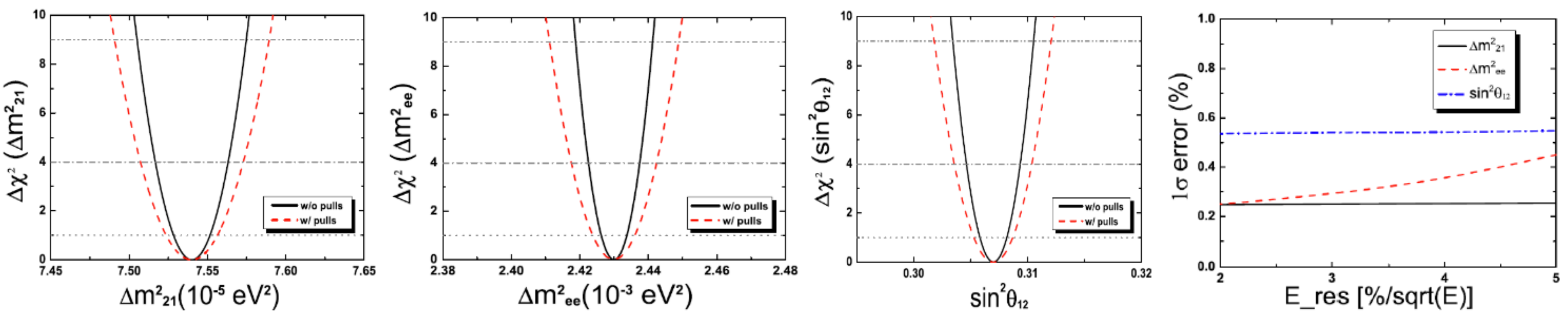
	Ideal	Core distr.	Shape	B/S (stat.)	B/S (shape)	$\lvert\Delta m^2_{\mu\mu}\rvert$
Size	52.5 km	Real	1%	4.5%	0.3%	1%
$\Delta\chi^2_{\mathrm{MH}}$	+16	−4	−1	−0.5	−0.1	+8

Precision Measurements



Probing the unitarity of U_{PMNS} to ~1% more precise than CKM matrix elements !

	Statistics	+BG +1% b2b +1% EScale +1% EnonL
$\sin^2\theta_{12}$	0.54%	0.67%
Δm^2_{21}	0.24%	0.59%
Δm^2_{ee}	0.27%	0.44%



0.16%→0.24% 0.16%→0.27% 0.39%→0.54%

E resolution

Correlation among parameters

Vast physics reach beyond Reactor Neutrinos

- **Supernova burst neutrinos**
- **Diffuse supernova neutrinos**
- **Solar neutrinos**
- **Atmospheric neutrinos**
- **Geo-neutrinos**
- **Sterile neutrinos**
- **Nucleon decay**
- **Indirect dark matter search**
- **Other exotic searches**

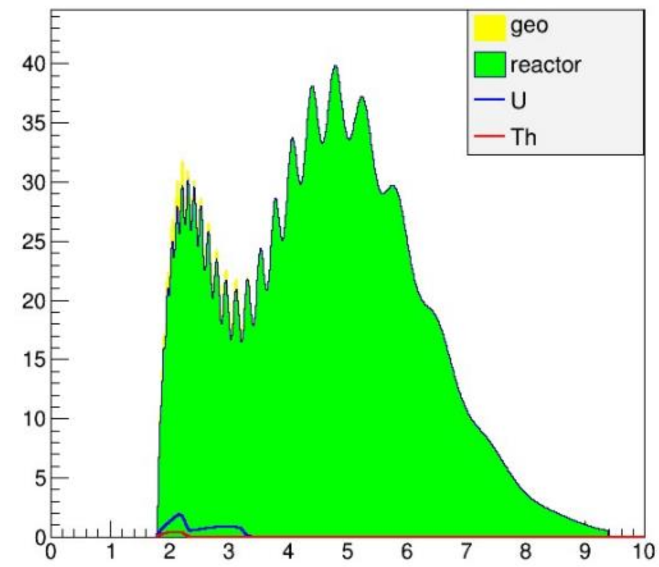
Geo-neutrinos

- **Geo-neutrinos**
  - Current results

    KamLAND: 30±7 TNU *(PRD 88 (2013) 033001)*

    Borexino: 38.8±12.2 TNU *(PLB 722 (2013) 295)*

    Statistics dominant
  - Desire to reach an error of 3 TNU
  - JUNO: 40 TNU, ×20 statistics
    - Huge reactor neutrino backgrounds
    - Need accurate reactor spectra



Source	Events/year
Geoneutrinos	408 ± 60
U chain	311 ± 55
Th chain	92 ± 37
Reactors	16100 ± 900
Fast neutrons	3.65 ± 3.65
^{9}Li - ^{8}He	657 ± 130
$^{13}C(\alpha, n)^{16}O$	18.2 ± 9.1
Accidental coincidences	401 ± 4

Combined shape fit of geo-ν and reactor-ν

	Best fit	1 y	3 y	5 y	10 y
U+Th fix ratio	0.96	17%	10%	8%	6%
U (free)	1.03	32%	19%	15%	11%
Th (free)	0.80	66%	37%	30%	21%

Supernova neutrinos

- Less than 20 events observed so far
- Assumptions:
  - Distance: 10 kpc (our Galaxy center)
  - Energy: 3×10^{53} erg
  - L_ν the same for all types
  - Tem. & energy

$T(\underline{\nu}_e) = 3.5$ MeV, $\langle E(\underline{\nu}_e)\rangle = 11$ MeV

$T(\nu_e) = 5$ MeV, $\langle E(\nu_e)\rangle = 16$ MeV

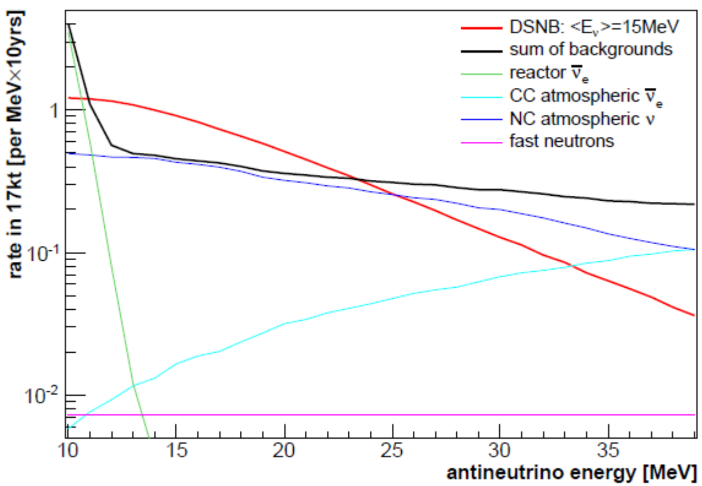
$T(\nu_x) = 8$ MeV, $\langle E(\nu_x)\rangle = 25$ MeV

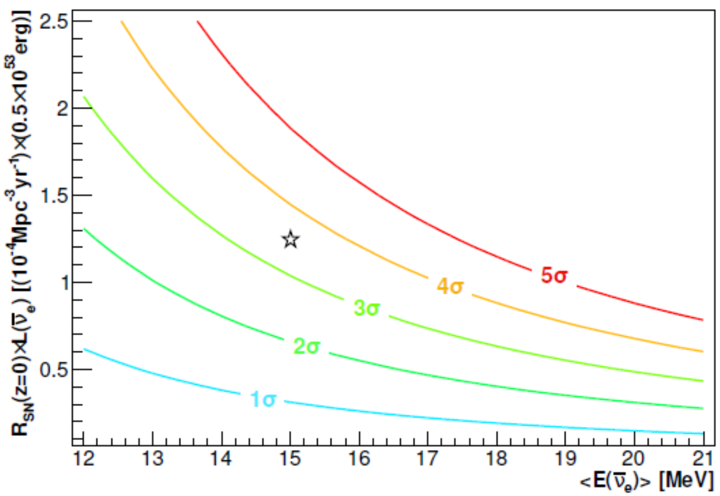
- Many types of events:
  - $\bar{\nu}_e + p \rightarrow n + e^+$, ~ 3000 correlated events
  - $\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B^* + e^+$, ~ 10-100 correlated events
  - $\nu_e + {}^{12}C \rightarrow {}^{12}N^* + e^-$, ~ 10-100 correlated events
  - $\nu_x + {}^{12}C \rightarrow \nu_x + {}^{12}C^*$, ~ 600 correlated events
  - $\nu_x + p \rightarrow \nu_x + p$, single events
  - $\nu_e + e^- \rightarrow \nu_e + e^-$, single events
  - $\nu_x + e^- \rightarrow \nu_x + e^-$, single events

Water Cerenkov detectors can not see these correlated events

Energy spectra & fluxes of all types of neutrinos

Diffuse Supernova Neutrino





- DSNB: Past core-collapse events
  - ⇨ Cosmic star-formation rate
  - ⇨ Core-collapse neutrino spectrum
  - ⇨ Rate of failed SNe

Item		Rate (no PSD)	PSD efficiency	Rate (PSD)
Signal	$\langle E_{\bar{\nu}_e} \rangle = 12\,\mathrm{MeV}$	12.2	$\varepsilon_\nu = 50\,\%$	6.1
	$\langle E_{\bar{\nu}_e} \rangle = 15\,\mathrm{MeV}$	25.4		12.7
	$\langle E_{\bar{\nu}_e} \rangle = 18\,\mathrm{MeV}$	42.4		21.2
	$\langle E_{\bar{\nu}_e} \rangle = 21\,\mathrm{MeV}$	61.2		30.8
Background	reactor $\bar{\nu}_e$	1.6	$\varepsilon_\nu = 50\,\%$	0.8
	atm. CC	1.5	$\varepsilon_\nu = 50\,\%$	0.8
	atm. NC	716	$\varepsilon_{\mathrm{NC}} = 1.1\,\%$	7.5
	fast neutrons	12	$\varepsilon_{\mathrm{FN}} = 1.3\,\%$	0.15
	Σ			9.2

10 Years' sensitivity

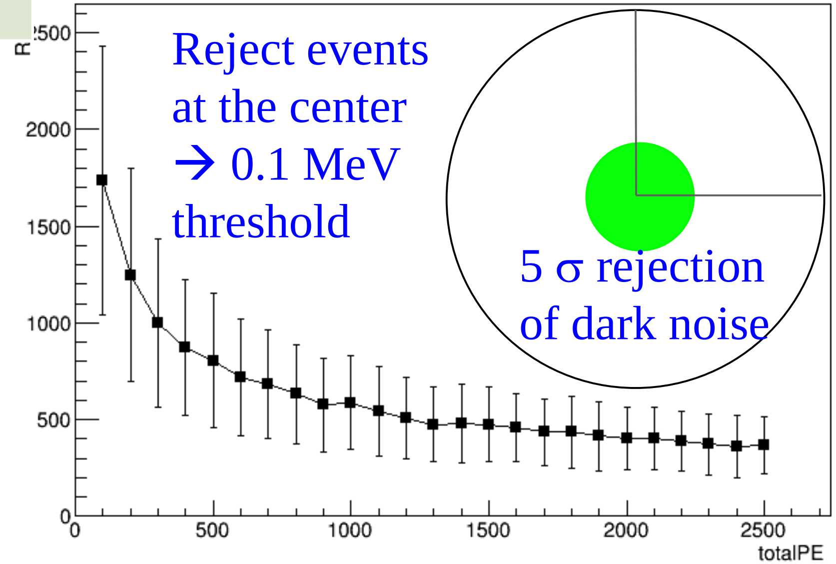
Syst. uncertainty BG	5 %		20 %	
$\langle E_{\bar{\nu}_e} \rangle$	rate only	spectral fit	rate only	spectral fit
12 MeV	$1.7\,\sigma$	$1.9\,\sigma$	$1.5\,\sigma$	$1.7\,\sigma$
15 MeV	$3.3\,\sigma$	$3.5\,\sigma$	$3.0\,\sigma$	$3.2\,\sigma$
18 MeV	$5.1\,\sigma$	$5.4\,\sigma$	$4.6\,\sigma$	$4.7\,\sigma$
21 MeV	$6.9\,\sigma$	$7.3\,\sigma$	$6.2\,\sigma$	$6.4\,\sigma$

Solar and other Physics

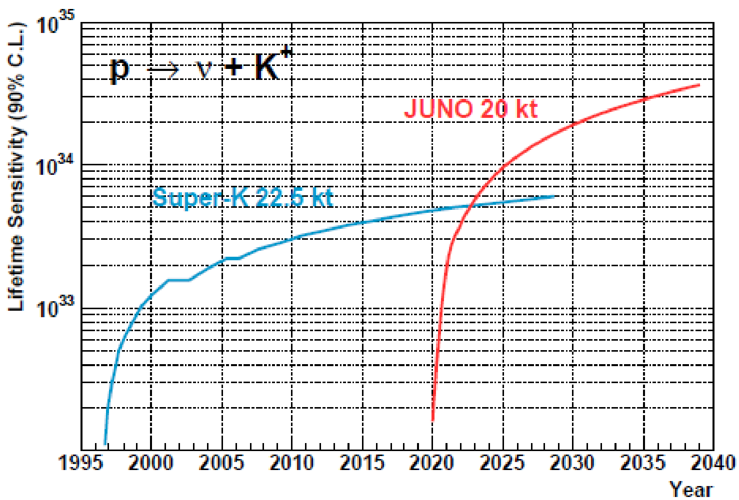
- **Solar neutrino**
  - ⇨ Metallicity? Vacuum oscillation to MSW?
  - ⇨ ^{7}Be and ^{8}B at JUNO

Liquid Scintillator	U238	Th232	K40	Pb210 (Rn222)	Ref.
No Distillation	10^{-15}	10^{-15}	10^{-16}	$1.4\cdot10^{-22}$	Borexino CTF, KamLAND
After Distillation	10^{-17}	10^{-17}	10^{-18}	10^{-24}	

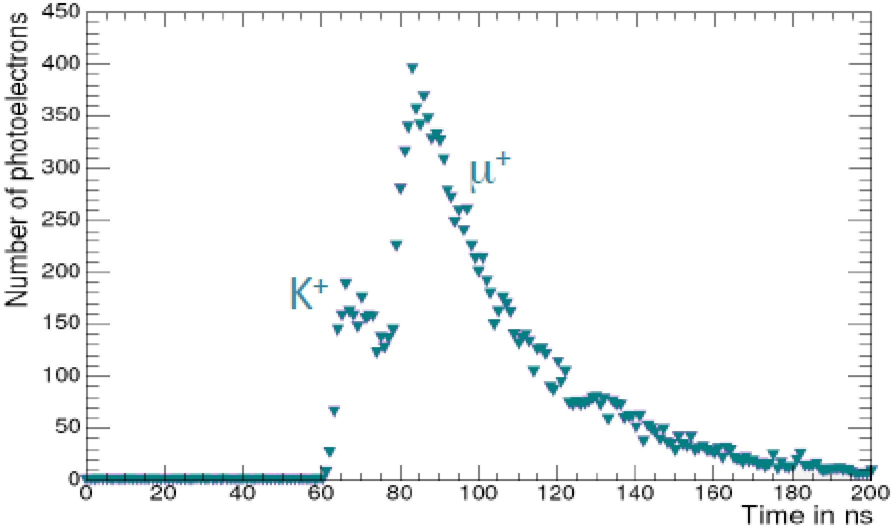
Source	Rate [cpd/1kt]
pp	1337
^{7}Be [line 0.384 MeV]	19
^{7}Be [line 0.862 MeV]	475
pep	28
^{8}B	4.5
^{13}N	25
^{15}O	28
^{17}F	0.7



- **Proton Decay, sterile, dark matter, etc.**



Proton decay into $K^+\overline{\nu}$



SUSY-favored decay mode

Signature $p \rightarrow K^+ \overline{\nu}$

$\hookrightarrow \mu^+\nu_\mu \,/\, \pi^0\pi^+$

→ kaon visible in liquid scintillator!

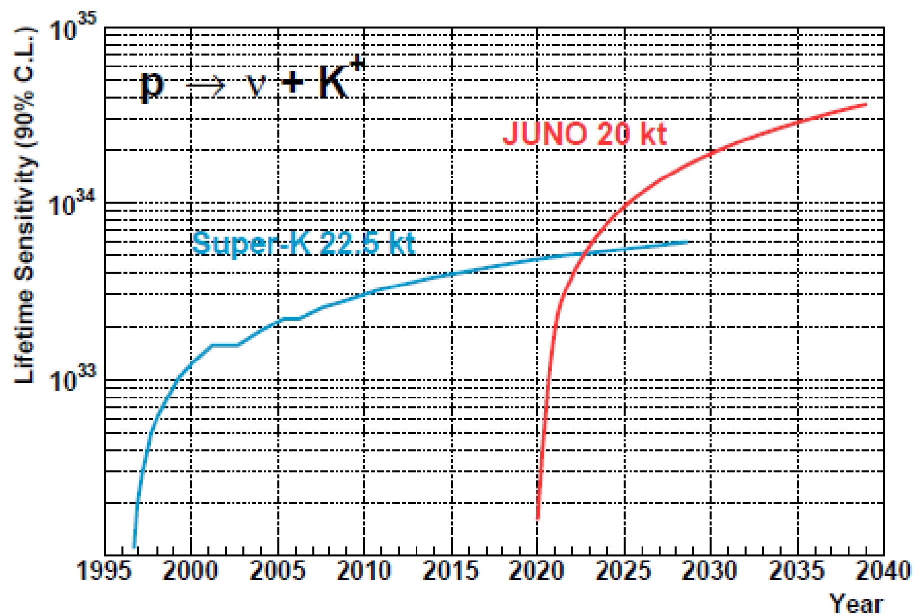
→ fast coincidence signature (τ_K = 13 ns)

→ signal efficiency: ~65% (atm. ν bg)

→ remaining background: <0.1 ev/yr

Limit if no event is observed in 10yrs (0.5 Mt·yrs):

$\tau_p >$ 2x10^{34} yrs (90%C.L.)



Physics at JUNO

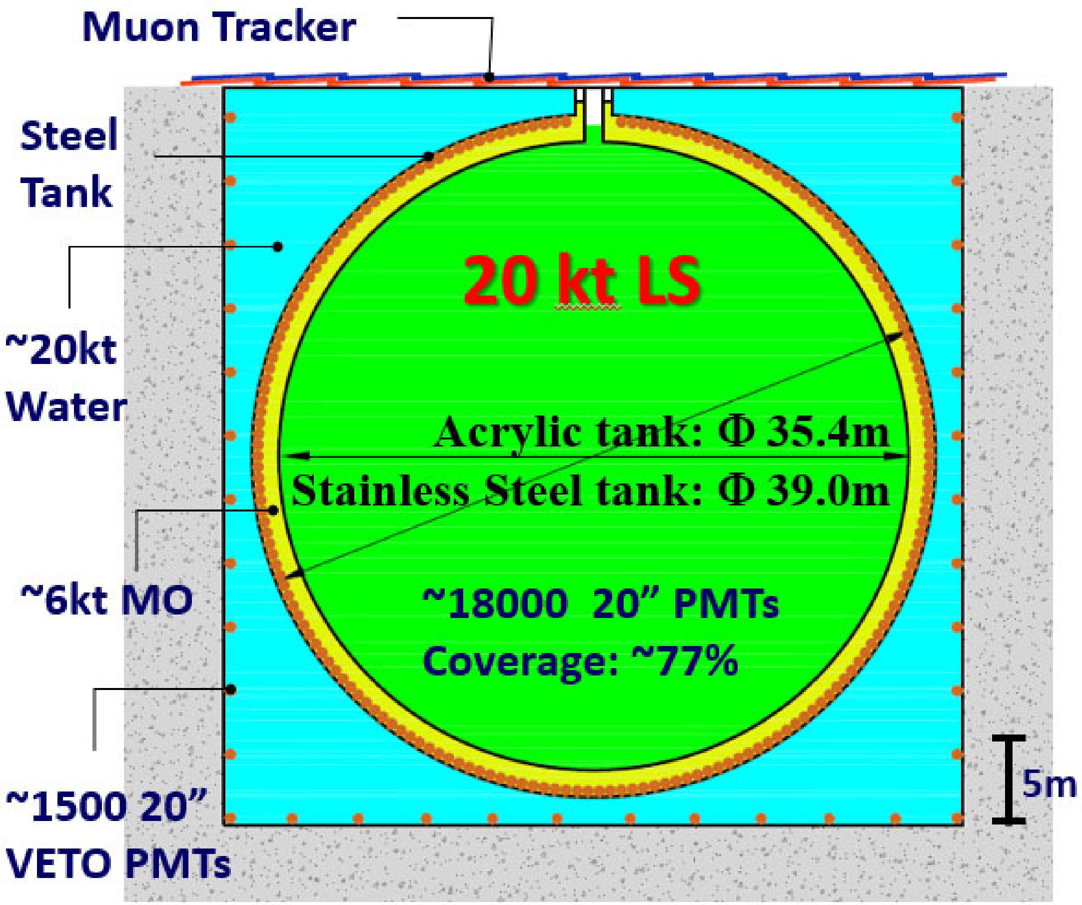
1. Introduction
2. Neutrino Mass Hierarchy
3. Precision Measurements of mixing parameters
4. Supernova burst neutrinos
5. Diffuse supernova neutrinos
6. Solar neutrinos
7. Atmospheric neutrinos
8. Geo-neutrinos
9. Sterile neutrinos
10. Nucleon decay
11. Indirect dark matter search
12. Other exotic searches
13. Appendix

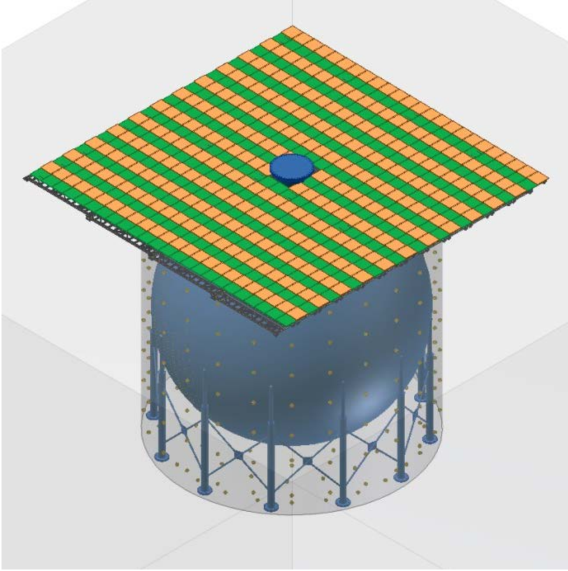
Yellow book

http://arxiv.org/pdf/1507.05613.pdf

The plan: a large LS detector

- LS large volume: ➔ for statistics
- High Light(PE) ➔ for energy resolution





[CDR](http://arxiv.org/abs/1508.07166)
http://arxiv.org/abs/1508.07166

Challenges

- Large detector: >10 kt LS
- Energy resolution: < 3%/√E ➔ ~1400 p.e./MeV

	Borexino	JUNO
LS mass	**~0.3 kt**	**20 kt**
Energy Resolution	**5%/√E**	**3%/√E**
Light yield	**500 p.e./MeV**	**~1400 p.e./MeV**

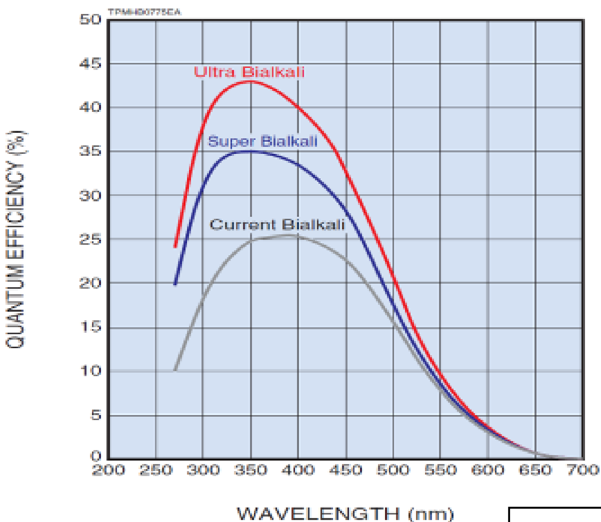
More photons, how and how many ?

- **Highly transparent LS:**
  - ⇨ **Target attenuation length: → 30m/34m (absorption-reemission helps a lot as shown by Borexino)**
- **High light yield LS:**
  - ⇨ **Borexino: 1.5g/l PPO → 5g/l PPO**
    about 30% more in the Light Yield
- **Photocathode coverage :**
  - ⇨ **Borexino: 33% → ~ 80%** $\times$ **2.3**
- **High QE "PMT":**
  - ⇨ **20" SBA PMT QE: 25% → 35% (Hamamatsu option)**
    or New PMT QE: 25% → 40% (China option)

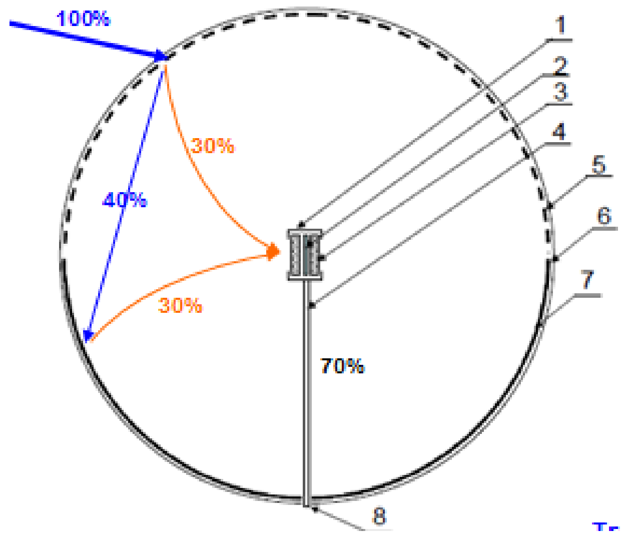
Alltogether these improvemente should ensure the desired LY and resolution - R&D ongoing to validate the various solutions

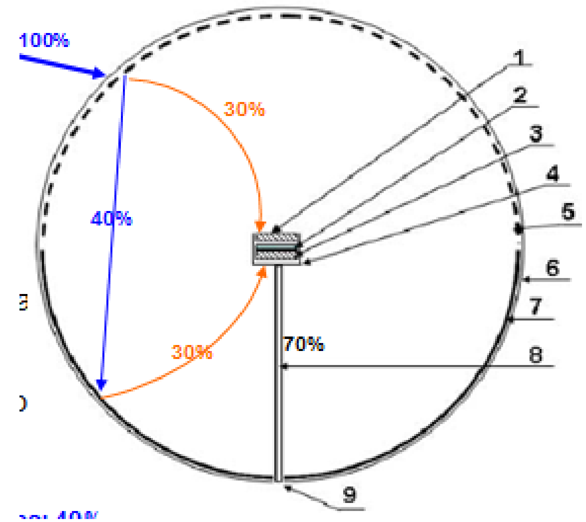
More Photoelectrons-- PMT

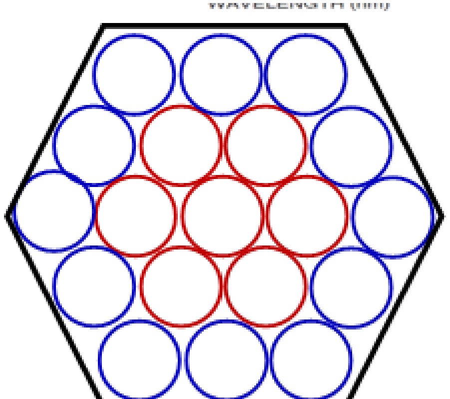
SBA photocatode



New type of PMT: MCP-PMT







Examples

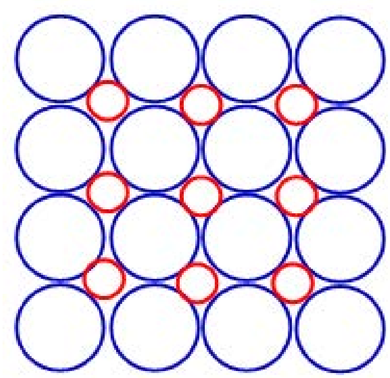
No clearance:

coverage 86.5%

1cm clearance:

coverage: 83%

Final coverage around 80%



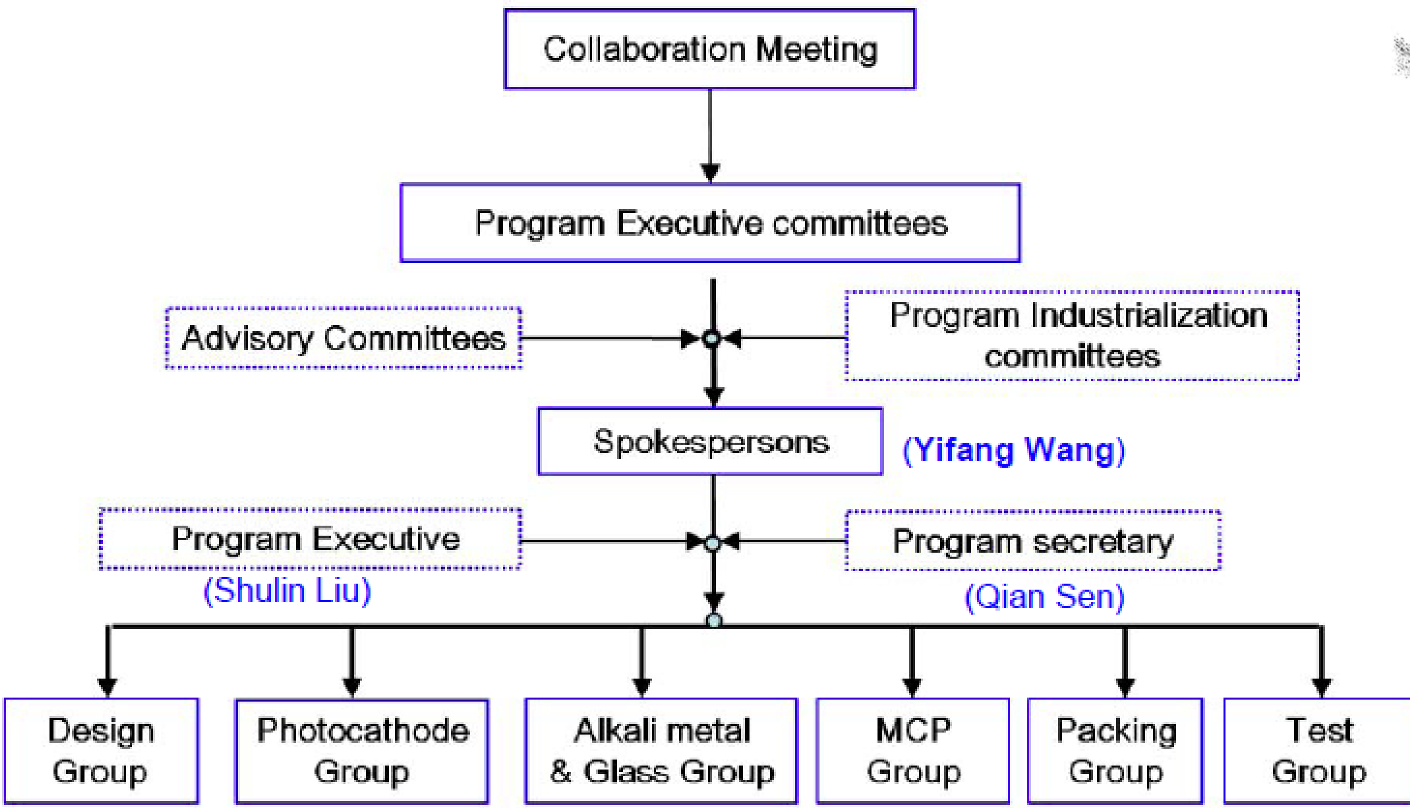
20" + 3" PMTs

3" PMTs Good for calibration, cosmic-rays & supernovae

Default solution if money available

A PMT R&D collaboration

Microchannel-Plate-Based Large Area Photomultiplier Collaboration (MLAPC)



中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

中国科学院西安光学精密机械研究所
XIAN INSTITUTE OF OPTICS AND PRECISION MECHANICS OF CAS

北方夜视技术股份有限公司
NORTH NIGHT VISION TECHNOLOGY CO.,LTD

海南展创光电技术有限公司
HZC PHOTONICS

中核（北京）核仪器厂
CNNC Beijing Nuclear Instrument Factory

宝光股份
BAOGUANG

南京大学

Main partner : North Vision

A new PMT factory in China

- **HZC bought Photonics PMT division four years ago. They have successfully produced first PMTs**

PHOTONIS → HZC PHOTONICS

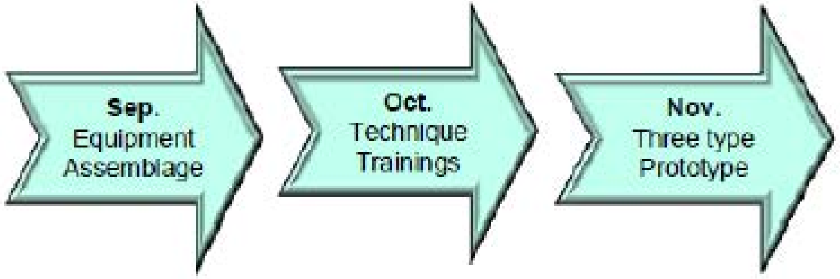
- Production Equipment for PMT;
- Patents and Technique documents;
- Technique Trainings;
- Technique Support for R&D;
- User authentication & product certification

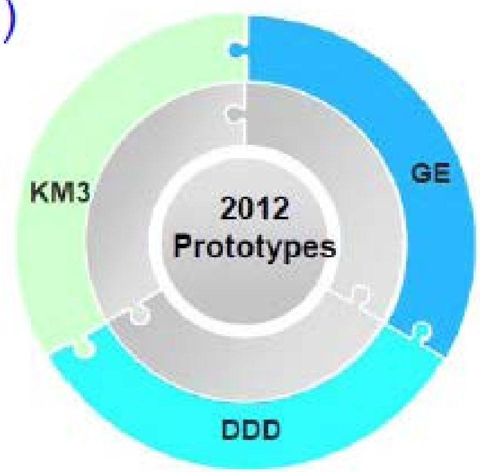
Office Building

Factory Building

HZC PMT plan

PMT Production Plan for the Market (2012)





PMT Prototype R&D Plan for the DayaBay II

3″ QE= 38.4%

XP53B20

+

8″ QE= 23.6%

XP1805

+

XP1807 12″ QE= 24%

=

20″ QE= 30%

Hamamatsu 20 inches device

Final selection procedure of the PMT for JUNO

Tender among the three mentioned Companies

- North Vision (China)
- HZC (China)
- Hamamatsu (Japan)

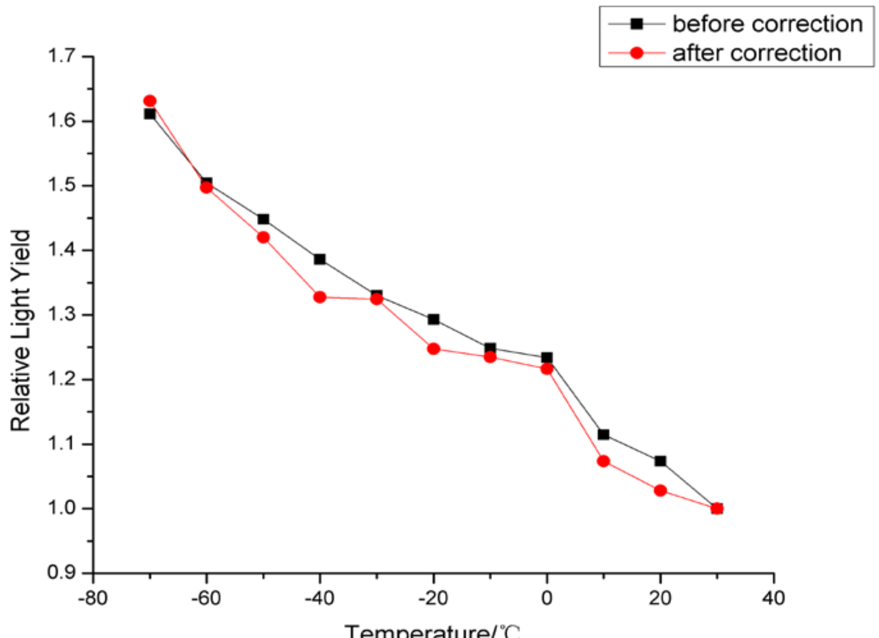
Selection Committee appointed in October

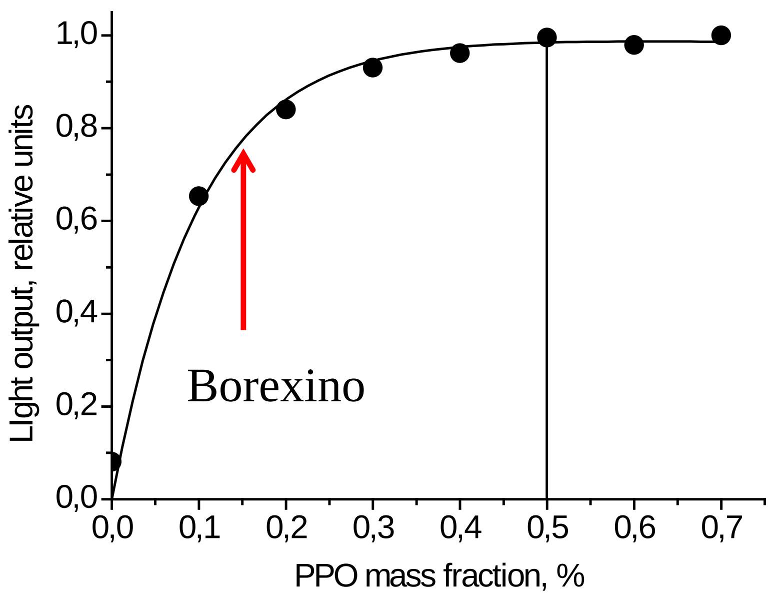
Final decision by December

More Photoelectrons-- LS

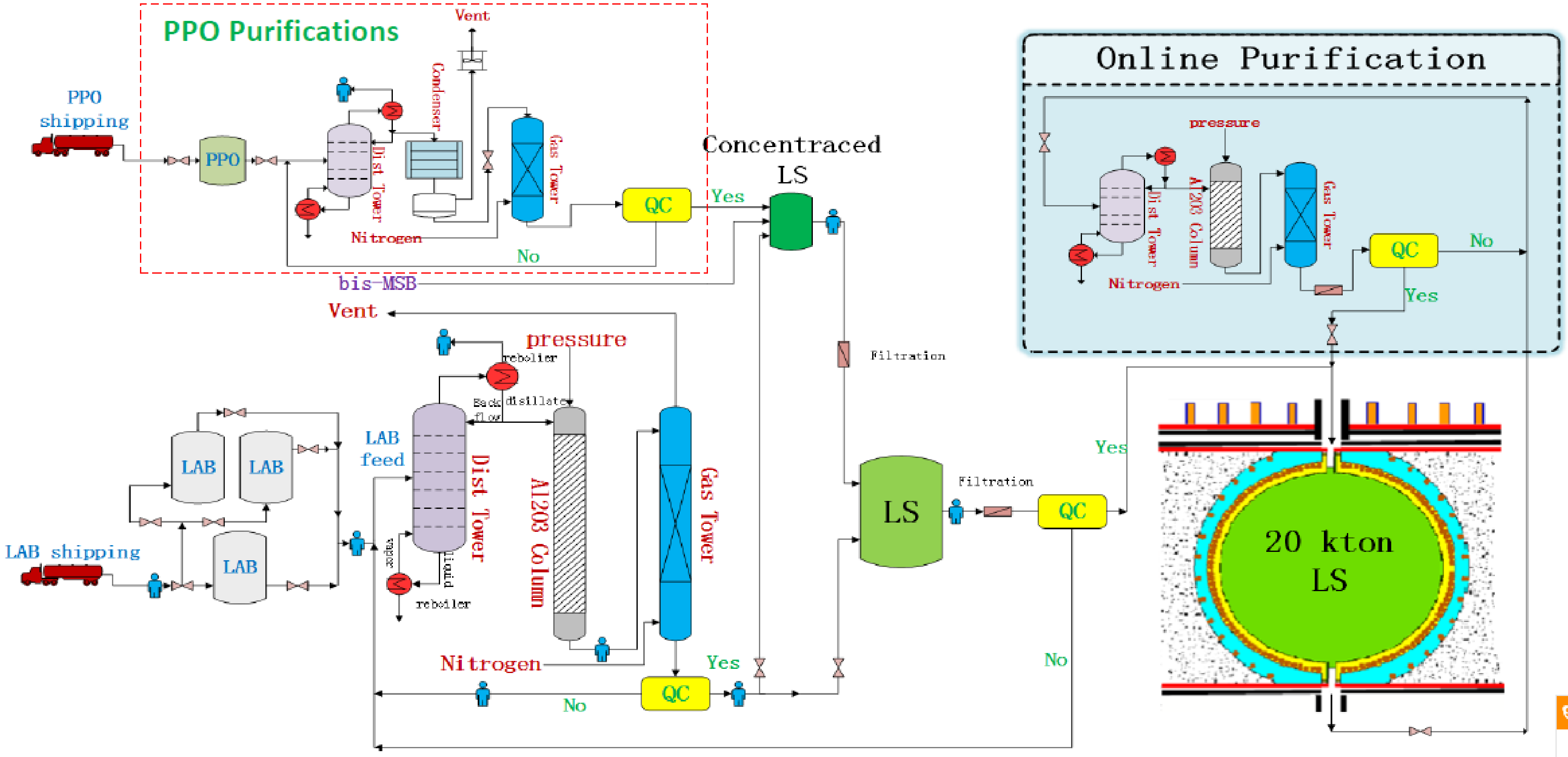
- **Longer attenuation length**
  - Improve raw materials (using Dodecane instead of MO for LAB production）
  - Improve the production process
  - Purification
- **Higher light yield**
  - Lower temperature
  - fluor concentration optimization

Linear Alky Benzene	Atte. Length @ 430 nm
RAW	14.2 m
Vacuum distillation	19.5 m
SiO_2 coloum	18.6 m
Al_2O_3 coloum	22.3 m



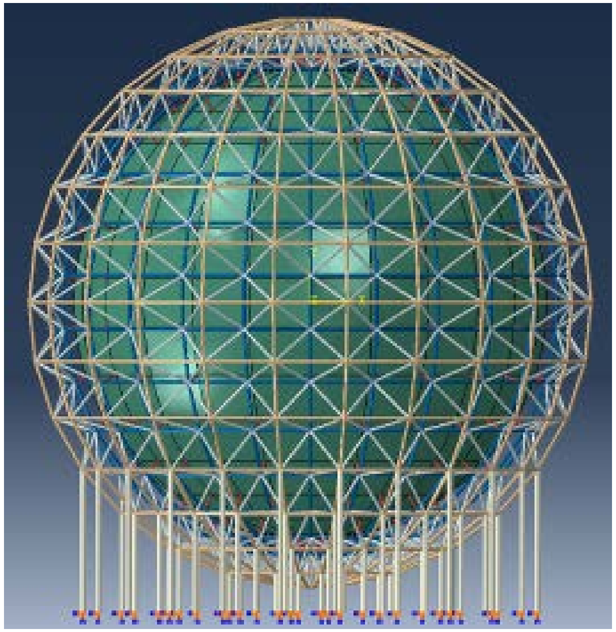


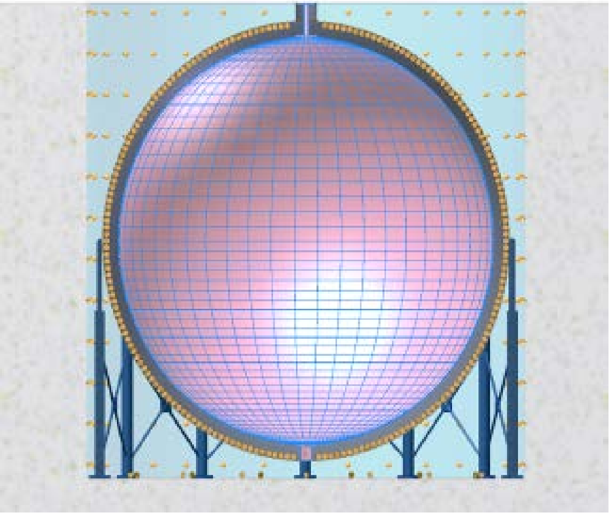
Jiangmen neutrino experiment
LS production-purification flow chart(primary)



Central Detector

- **Some basic numbers:**
  - ⇨ **20 kt liquid scintillator as the target**
  - ⇨ **Signal event rate: 40/day**
  - ⇨ **Backgrounds with 700 m overburden:**
    - ✓ **Accidentals(~10%), ^{9}Li/^{8}He(<1%), fast neutros(<1%)**
- **A huge detector in a water pool:**
  - ⇨ **Default option: acrylic tank(D~35m) + SS structure**
  - ⇨ **Backup option: SS tank(D~38m) + acrylic structure + balloon**
- **Issues:**
  - ⇨ **Engineering: mechanics, safety, lifetime, …**
  - ⇨ **Physics: cleanness, light collection, …**
  - ⇨ **Assembly & installation**
- **Design & prototyping underway**
- **Acrylic option definitively selected in July**





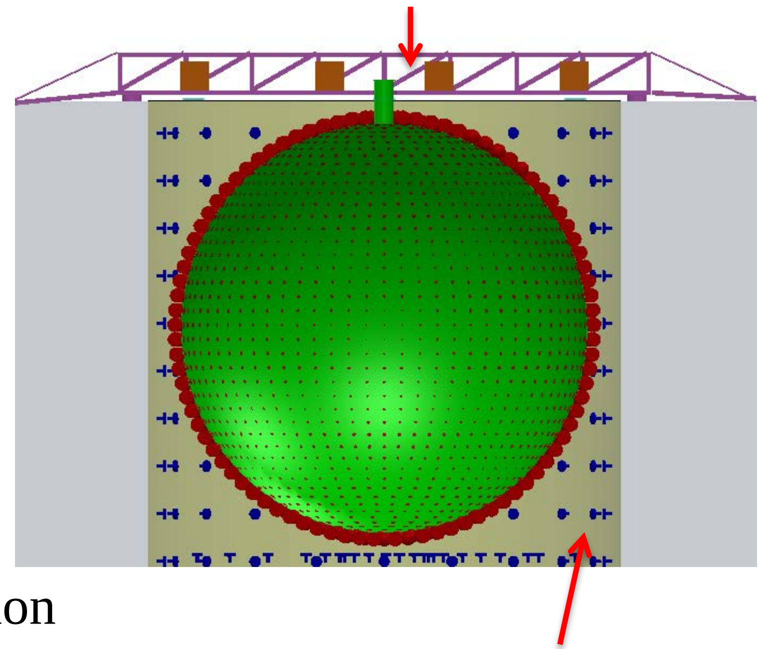
Veto Detectors

- Cosmic muon flux
  - Overburden：~700 m
  - Muon rate：**0.0031 Hz/m^2**
  - Average energy：214 GeV
- Water Cherenkov Detector
  - At least 2 m water shielding
  - ~1500 20”PMTs
  - 20~30 kton pure water
  - Similar technology as Daya Bay (**99.8% efficiency**)
- Top muon tracker
  - Muon track for cosmogenic bkg rejection
  - Decommissioned OPERA@Gran Sasso plastic scintillator

Muon multiplicity at JUNO

Multiplicity	1	2	3	4	5	6
Fraction	89.6%	7.7%	1.8%	0.6%	0.3%	0.07%

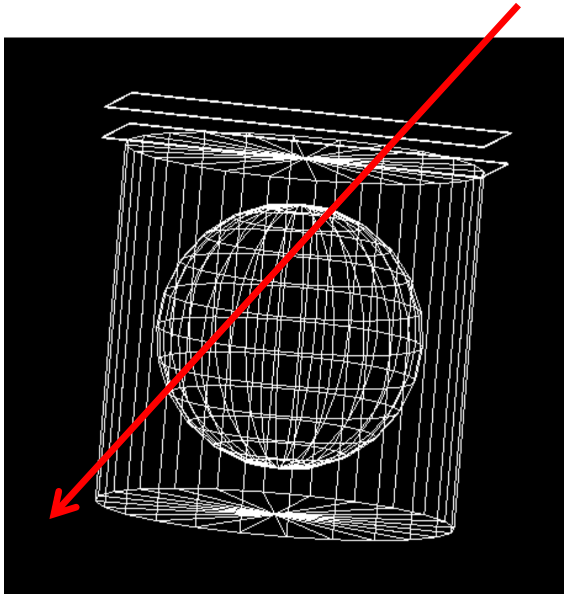
Top muon tracker

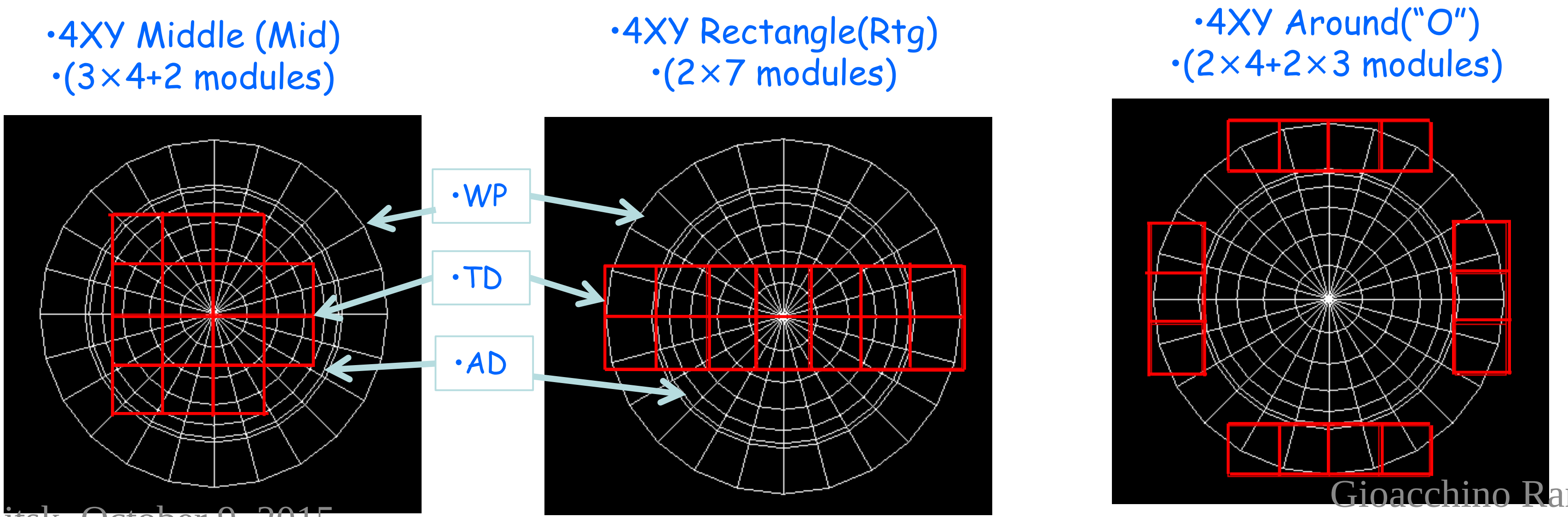


Water Cherenkov Detector

OPERA Target Tracker for the Top Tracker

- 56 x-y walls (6.7m×6.7m each)
- 14 TT stations, 4 walls each.
- each station is composed of 2 layers of 2 TT walls separated by 4 m distance.
- Distance of lowest and upper wall: 4 m
- Distance of lowest plane from water pool: 1 m.
- Different configurations (Middle, Rectangle, Around)
- Covered area is about 630m^2.





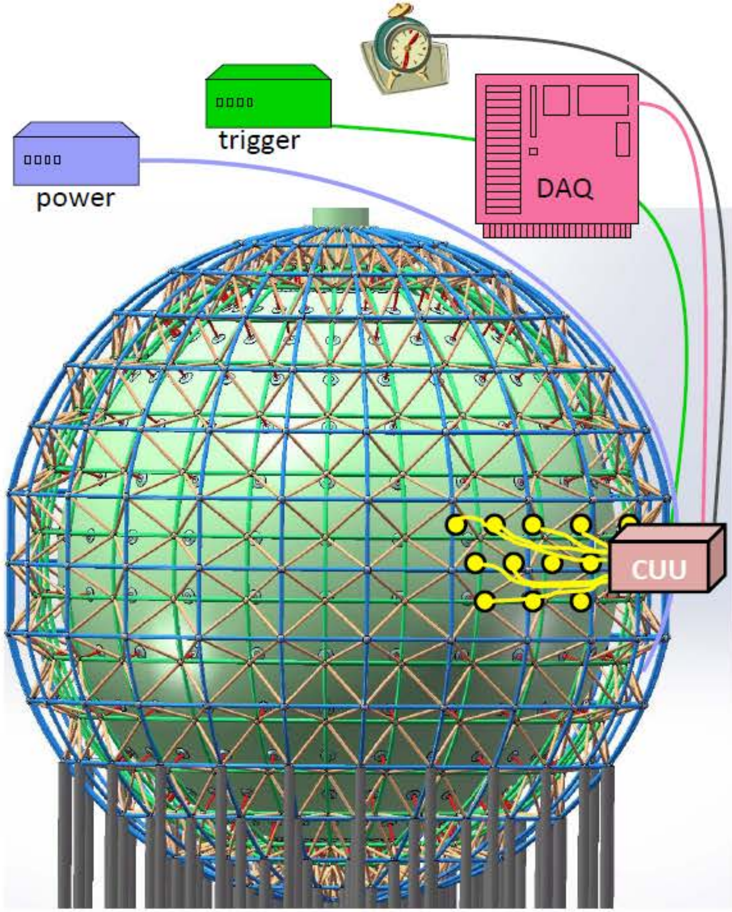
Dismounting schedule

- Dismounting schedule:
  - mid-2015: first OPERA super module (31 TT walls, 248 modules)
  - beginning 2016: second OPERA super module (31 TT walls, 248 modules)
  - storage of all TT modules in Gran Sasso in containers up to the moment all dismounting is finished
  - send all TT containers (10) to Kaiping ~Spring 2016 if storage buildings already available
- Mounting in JUNO: ~2019

Electronics, trigger, DAQ…

- FADC at 1GHz sampling rate for pattern recognition, more information for event reconstruction, better event quality, …
- Complicated trigger schemes should be available
- Supernova is an additional burden
- A challenge to DAQ since FADC is used
- Possible a new software scheme for neutrino experiments
- Design under finalization

The JUNO Central Detector Large-PMT Electronics



Main requirements

- ➜ all PMT FE electronics will be underwater
- ➜ 20 years lifetime
- ➜ no access possible after installation

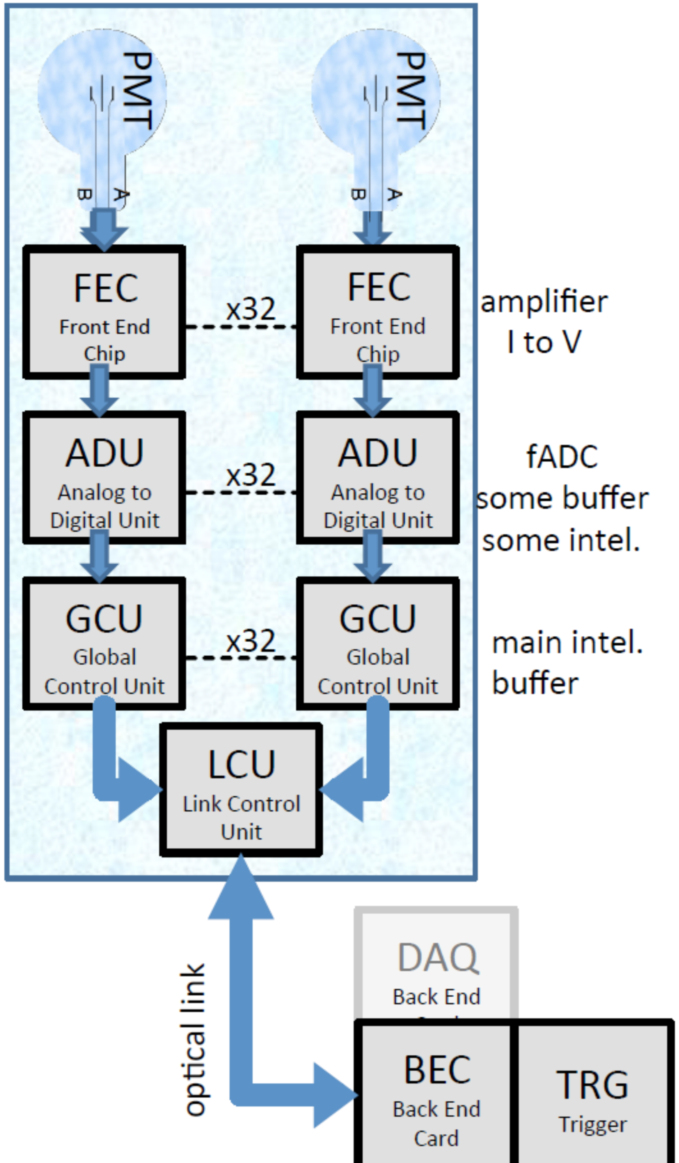
Under water (baseline option)

- ➜ ~ 16000 PMTs (Central Detector) + ~ 2000 PMTs (Water Cherenkov)
- ➜ PMT High Voltage
- ➜ FE electronics : signal amplification, ADC, digital processing and data reduction, trigger and digital data transmission

Above water (baseline option)

- ➜ DAQ back-end electronics, global trigger electronics, low voltage, clock & control and online DAQ farms

JUNO PMT Under Water Electronics



High Voltage

- ➜ baseline option : custom Cockcroft-Walton multiplier : convert AC low voltage to DC high voltage
- ➜ commercial system as backup option

Front End Card

- ➜ two ASICs R&D going on in Europe and China

Analog to Digital Unit

- ➜ two ASICs developments ongoing, keeping the commercial ADCs option as a backup

Global Control Unit

PD Interest

- ➜ the heart of the electronics : it gets the digitized waveform from the ADC, digital process the signal, and generates a trigger signal

Link Control Unit (Multiplexer)

- ➜ collects the signal from several GCU and transmits the digital data above water

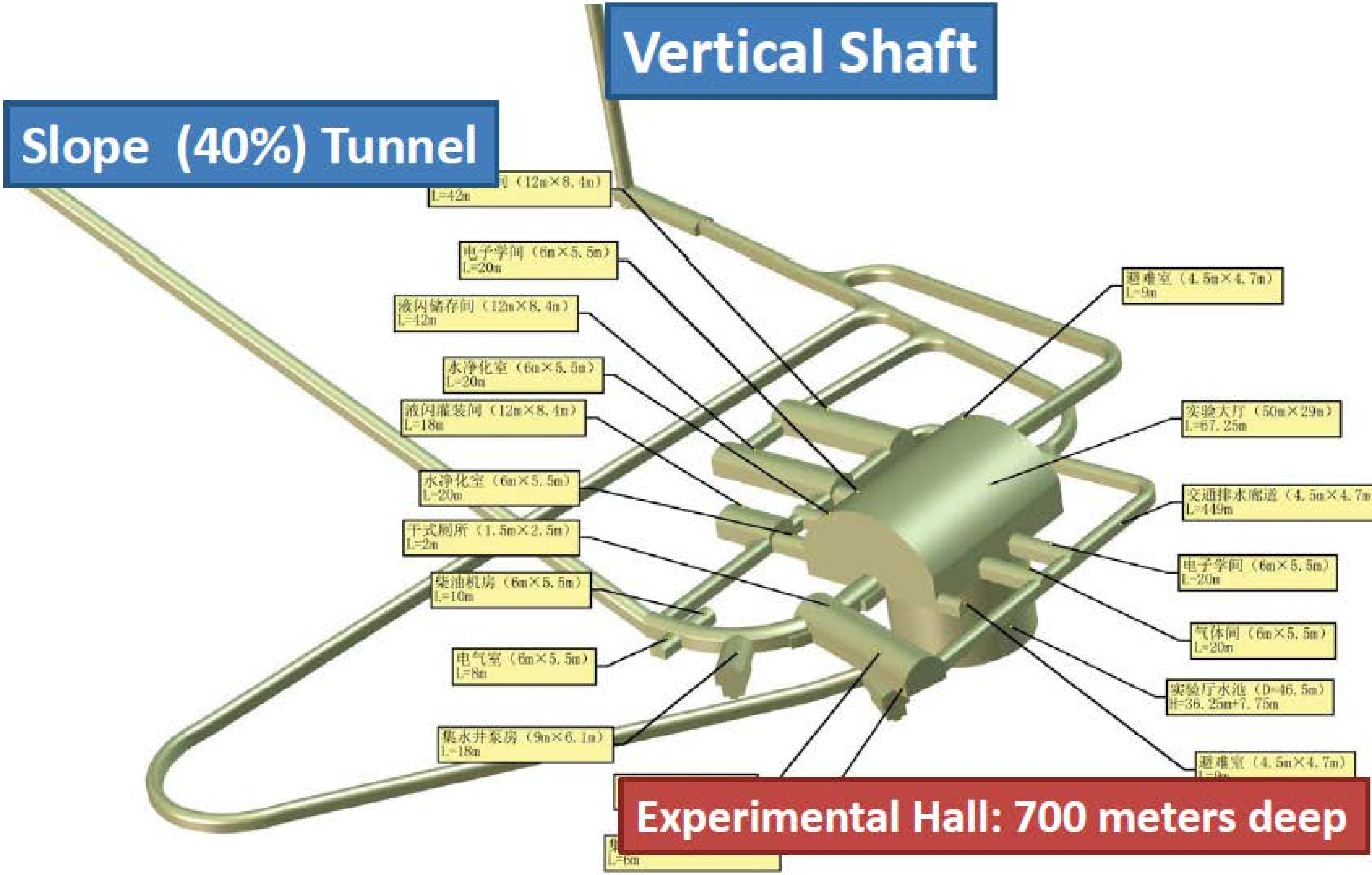
Calibration

- Fundamental
- Precision of the energy scale, resolution, stability, uniformity all essential ingredients to ensure the success of the measure
- Which type ? Movable arms? Entire volume or only vertical?
- Sub-marine type ?
- Need ideas and R&D
- A working group recently established

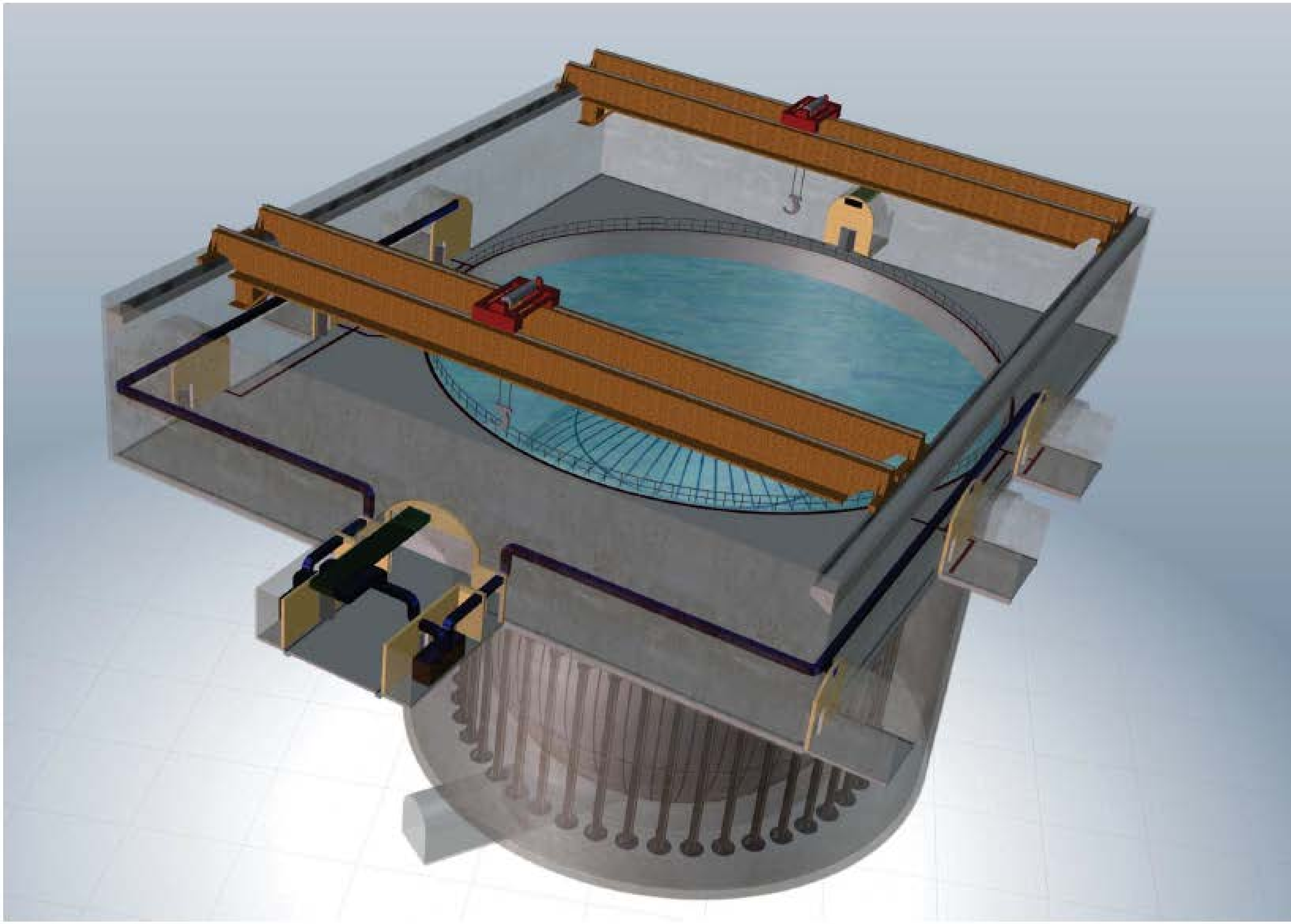
Open Tasks

- **Calibration:**
  - guided source insertion, LED, laser, CCD, …
- **3" PMT & electronics, cable，box,…**
- **LS filling**
- **Slow control**
  - PMT, water, environmental monitoring & control
- **DAQ: crates, server, router, software, …**
- **Offline farm, data storage/data center, software, …**
- **…**

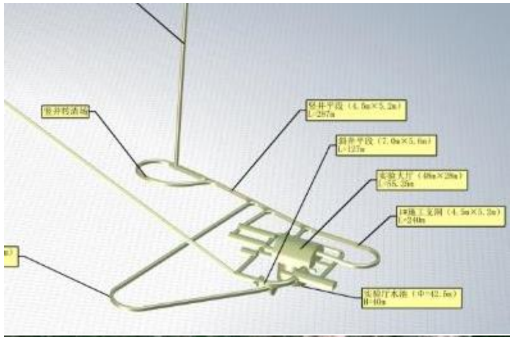
Underground Facility



Experimental Hall



Jan. 10, 2015



600 m vertical shaft
1300-m long tunnel(40% slope)
50-m diameter, 80-m high cavern


江门中微子实验建设启动会
Jiangmen Underground Neutrino Observatory
Civil Construction Kick-off Meeting
JUNO

Project Plan and Progresses

First get-together meeting

Funding(2013-2014) review approved

Geological survey and preliminary civil design

1st 20” MCP-PMT

Collaboration formed

Groundbreaking Ceremony

2013

Kaiping Neutrino Research Center established

Funding from CAS: “Strategic Leading Science & Technology Programme” approved (~CD1)

Yangjiang NPP started to build the last two cores

2014

Civil/infrastructure construction bidding

Civil design approved

- Civil construction：2015-2017
- Detector component production：2016-2017
- PMT production：2016-2019
- Detector assembly & installation：2018-2019
- Filling & data taking：2020

Management Structure

Spokesperson
- Yifang Wang (IHEP)

Deputy Spokesperson
- Gioacchino Ranucci (INFN-Milano)
- Jun Cao (IHEP)

Chair of the Institutional Board (IB)
- Marcos Dracos (IPHC/IN2P3)

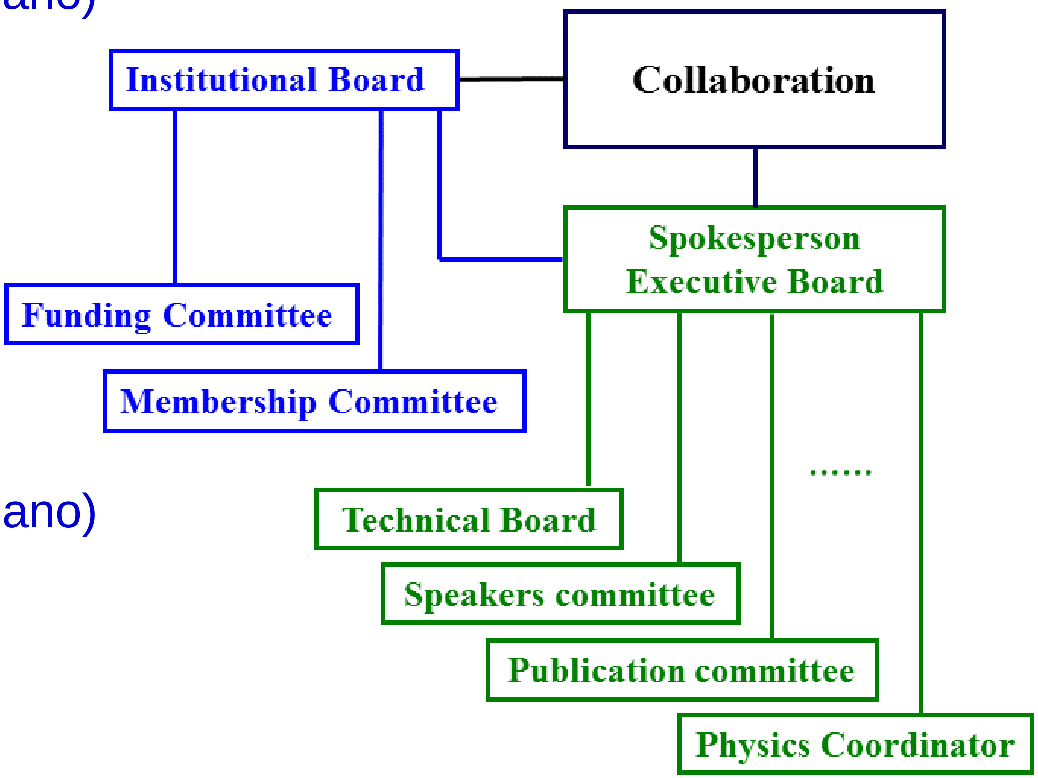
Executive Board (EB)
- Jun Cao (IHEP)
- Yee Hsiung (NTU)
- Jianglai Liu (STJU)
- Dmitry Naumov (JINR)
- Gioacchino Ranucci (INFN-Milano)
- Yifang Wang (IHEP)
- Michael Wurm (Mainz)
- Changgen Yang (IHEP)

Speaker's Committee (5)

Analysis Coordinator
- Liangjian Wen (IHEP)

Membership Committee (3)

Collaboration Organization



Project Management Team

- Project manager: Y.F. Wang
- Deputy manager: J. Cao, G. Ranucci
- Chief engineer: H.L. Zhuang, XXX
- Chief technical support：XXX, XXX
- Safety officer: XXX, XXXX
- L2 System manager (11):
  - Civil：X.N. Li
  - CD：Y.K. Heng，Y. Hsiung
  - VETO：M. Dracos，C.G. Yang
  - LS：L. Zhou，G. Rannucci
  - MCP-PMT: S.L. Liu
  - PMT(testing, potting, shielding, …): W. Wang, Z.H. Qin, Smirnov, XXXX
  - Electronics & Trigger & HV：X.S. Jiang，A. Stahl, D. Naumov
  - Calibration: J.L. Liu, S. Kettell
  - Integration: H.L. Zhuang, XXX
  - DAQ & Slow control：K.J. Zhu, A. Cabrera/S. Ducini
  - Offline & computing: W.D. Li，XXXX

Technical Board

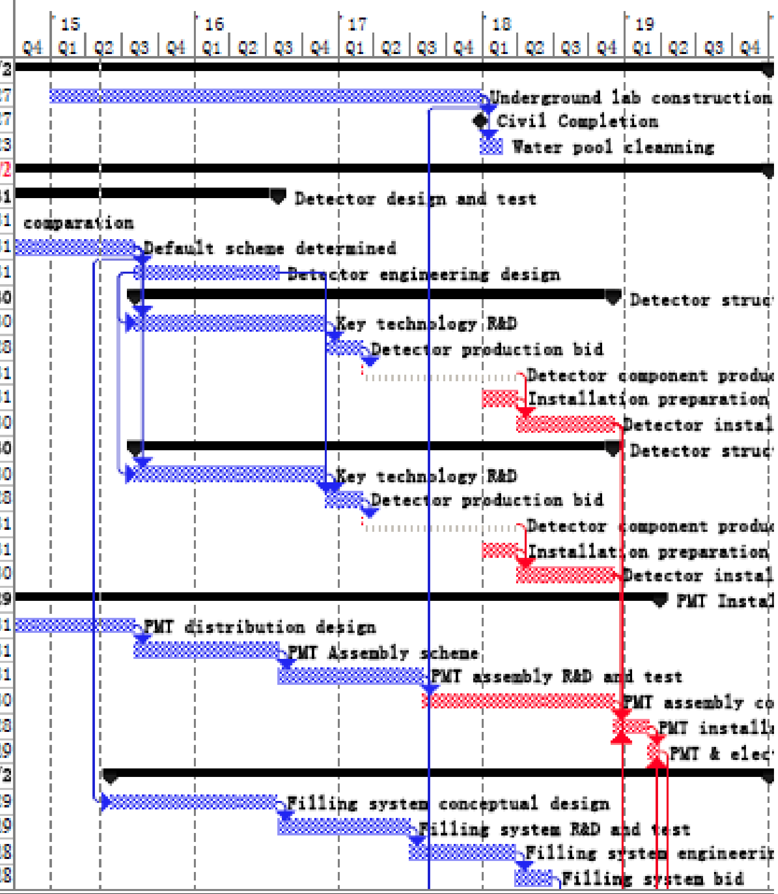
- Managers
- Chief engineers/tech. support
- safety officer
- One of L2
- Z. Wang, W.G. Li, W. McKeown, P. Lombardi, L. Oberauer, Z. Krumstein

Task Sharing in progress

- China:
  - Civil, CD, VETO, LS, PMT, electronics, DAQ, calibration, …
- France:
  - VETO: TTS scintillator & electronics, shipping
- Italy
  - LS: distillation, gas striping,
  - TTS: DAQ
  - Electronics
- Germany
  - electronics: FADC
  - LS: QCQA,
- Russia
  - PMT HV
  - TTS testing
  - TTS structure

Schedule

ID		任务名称	Duration	Start	Finish
1		JUNO	1832 days?	Mon 12/12/31	Thu 20/1/2
2		Underground lab construction	782 days	Thu 15/1/1	Wed 17/12/27
3		Civil Completion	0 days	Wed 17/12/27	Wed 17/12/27
4		Water pool cleanning	43 days	Thu 17/12/28	Fri 18/2/23
5		Central detector	1831 days?	Tue 13/1/1	Thu 20/1/2
6		**Detector design and test**	**934 days**	**Tue 13/1/1**	**Sun 16/7/31**
7		Scheme comparation	325 days	Tue 13/1/1	Mon 14/3/31
8		Default scheme determined	349 days	Tue 14/4/1	Fri 15/7/31
9		Detector engineering design	260 days	Mon 15/8/3	Sun 16/7/31
10		**Detector structure(Inner)**	**872 days**	**Tue 15/8/4**	**Fri 18/11/30**
11		Key technology R&D	348 days	Tue 15/8/4	Wed 16/11/30
12		Detector production bid	64 days	Thu 16/12/1	Tue 17/2/28
13		Detector component production	283 days	Fri 17/3/3	Sat 18/3/31
14		Installation preparation	65 days	Mon 18/1/1	Sat 18/3/31
15		Detector installation	175 days	Mon 18/4/2	Fri 18/11/30
16		**Detector structure(outer)**	**872 days**	**Tue 15/8/4**	**Fri 18/11/30**
17		Key technology R&D	348 days	Tue 15/8/4	Wed 16/11/30
18		Detector production bid	64 days	Thu 16/12/1	Tue 17/2/28
19		Detector component production	283 days	Fri 17/3/3	Sat 18/3/31
20		Installation preparation	65 days	Mon 18/1/1	Sat 18/3/31
21		Detector installation	175 days	Mon 18/4/2	Fri 18/11/30
22		**PMT Installation**	**1307 days**	**Tue 14/4/1**	**Fri 19/3/29**
23		PMT distribution design	349 days	Tue 14/4/1	Fri 15/7/31
24		PMT Assembly scheme	260 days	Mon 15/8/3	Sun 16/7/31
25		PMT assembly R&D and test	261 days	Wed 16/8/3	Mon 17/7/31
26		PMT assembly component bid and production	349 days	Wed 17/8/2	Fri 18/11/30
27		PMT installation	64 days	Mon 18/12/3	Thu 19/2/28
28		PMT & electronics joint test	21 days	Fri 19/3/1	Fri 19/3/29
29		**Filling System**	**1201 days?**	**Tue 15/6/2**	**Thu 20/1/2**
30		Filling system conceptual design	304 days	Tue 15/6/2	Fri 16/7/29
31		Filling system R&D and test	240 days	Mon 16/8/1	Thu 17/6/29
32		Filling system engineering design	196 days	Fri 17/6/30	Wed 18/3/28
33		Filling system bid	66 days?	Thu 18/3/29	Thu 18/6/28



JUNO Test Run on **Jan.2, 2020**

		Start	end	condition
1	Underground lab construction	2015.1.1	2017.12.27	
2	Water pool cleaning and CD construction preparation	2017.12.28	2018.2.23	1
3	CD & water poll equipment installation	2018.4.2	2018.11.30	2
4	PMT base(& to be sealed electronics) design finalized	2015.1.1	2016.9.30	
5	PMT base production and aging test	2016.10.1	2017.6.30	4
6	PMT bidding	2015.7.1	2015.12.31	
7	PMT mass production	2016.1.1	2018.8.31	6
8	PMT testing	2017.4.4	2018.11.30	
9	PMT potting and testing	2017.7.1	2018.11.30	5
10	CD & VETO PMT installation	2018.12.3	2019.2.28	
11	Readout electronics design finalized	2017.1.2	2017.5.31	
12	Readout electronics mass production	2017.6.1	2018.3.30	11
13	Readout electronics testing and aging	2018.4.1	2018.11.29	12
14	Readout electronics installation	2018.9.28	2019.2.28	
15	CD & water pool cleaning	2019.4.1	2019.4.30	
16	Water pool cover is placed	2019.5.1	2019.5.2	15
17	TTS supporting structure installation	2018.12.3	2018.12.21	16
18	TTS installation	2019.5.1	2019.7.30	17
19	AD & VETO water filling	2019.5.3	2019.7.2	18
20	LS filling	2019.7.3	2019.10.2	19
21	Test run	2019.11.5	2020.1.2	20

Conclusion

The vast potential physics reach of JUNO - MH determination and beyond - makes the experiment very attractive and one of he pillars of the next round of large liquid scintillator detectors worldwide

The perspectives for an Europen participation of significant impact are very promising, solidly grounded on previous expertise and well positioned in a larger Collaboration framework

New groups are eagerly needed and very welcomed