JUNO and RENO-50

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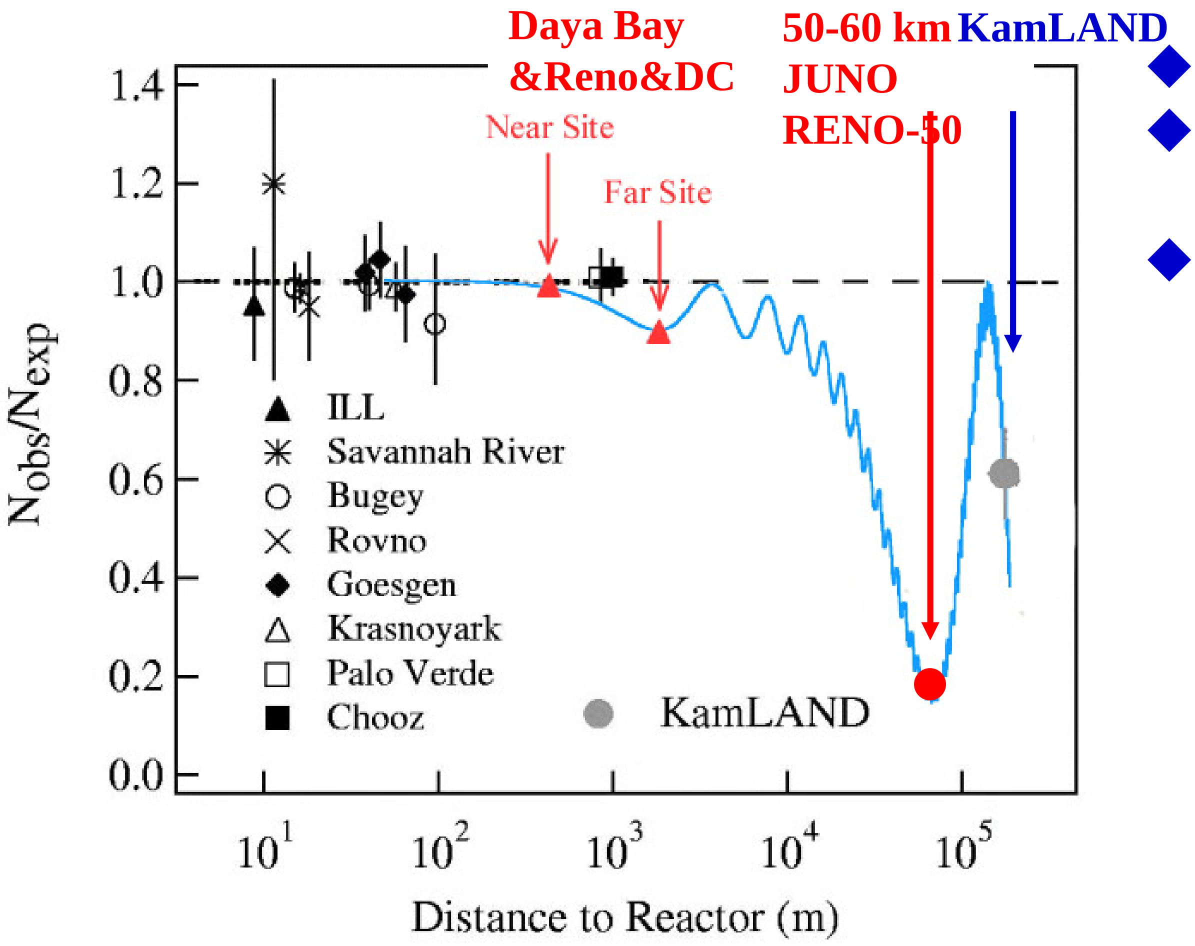
INFN - Milano

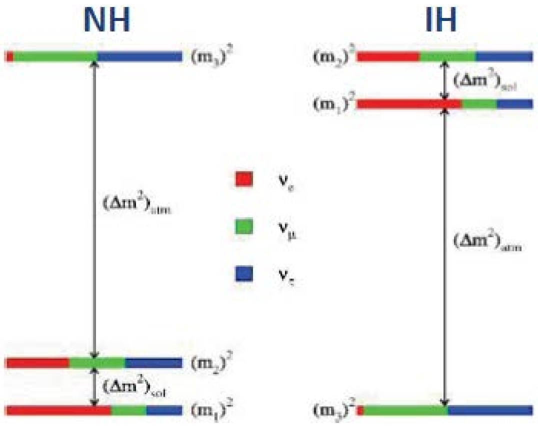
25th International Workshop on Weak Interactions and Neutrinos (WIN2015)
June 8–13, 2015, MPIK Heidelberg, Germany

- 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
- Precise measurements of oscillation parameters
- Additional astroparticle program
- Requirements and technical features of the experimental approach

JUNO Experiment – physics summary

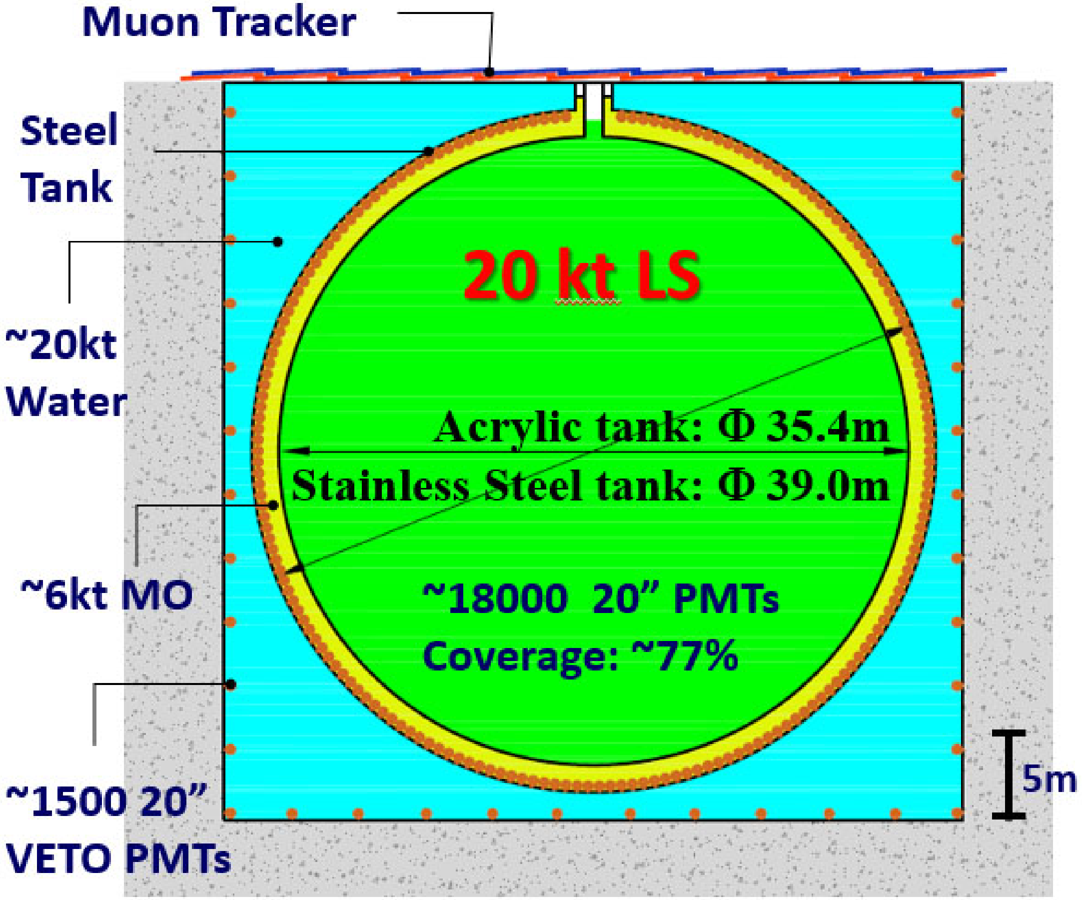


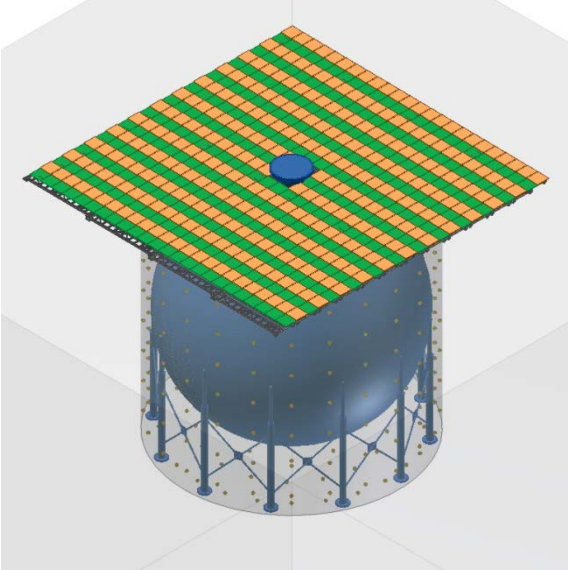
- **20 kton LS detector**
- **~3 % energy resolution-the greatest challenge**
- Rich physics possibilities
  - ⇨ **Mass hierarchy**
  - ⇨ **Precision measurement of 3 mixing parameters**
  - ⇨ **Supernovae neutrino**
  - ⇨ **Geoneutrino**
  - ⇨ **Sterile neutrino**
  - ⇨ **Atmospheric neutrinos**
  -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

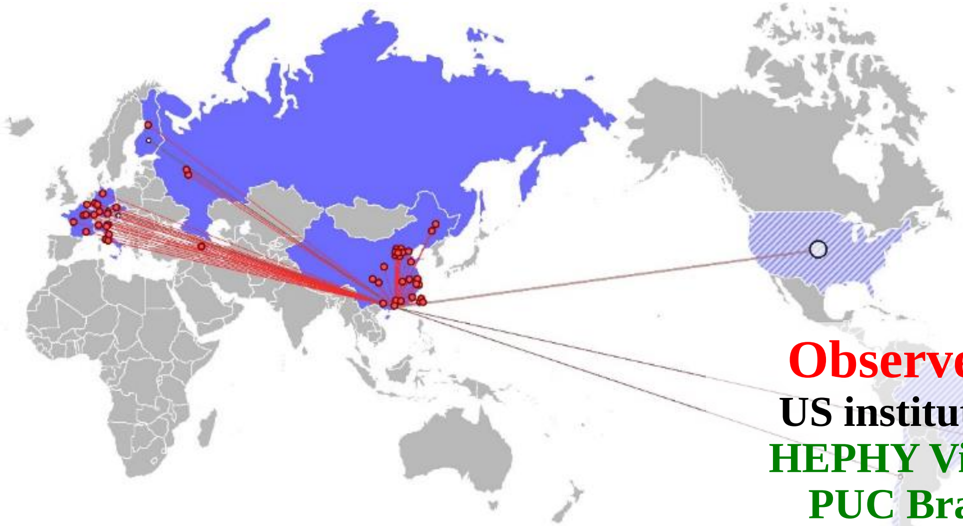
by 2020: 26.6 GW

Overburden ~ 700 m

Kaiping,
Jiang Men city,
Guangdong Province

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:

US institutions

HEPHY Vienna

PUC Brazil

PCUC Chile

Jyvaskyla U.

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

Europe (23)

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

Italy (6)
INFN-Frascati
INFN-Ferrara
INFN-Milano
INFN-Padova
INFN-Perugia
INFN-Roma 3
Russia (2)
JINR
INR Moscow

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

MH and Survival probability

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

arXiv 1210.8141

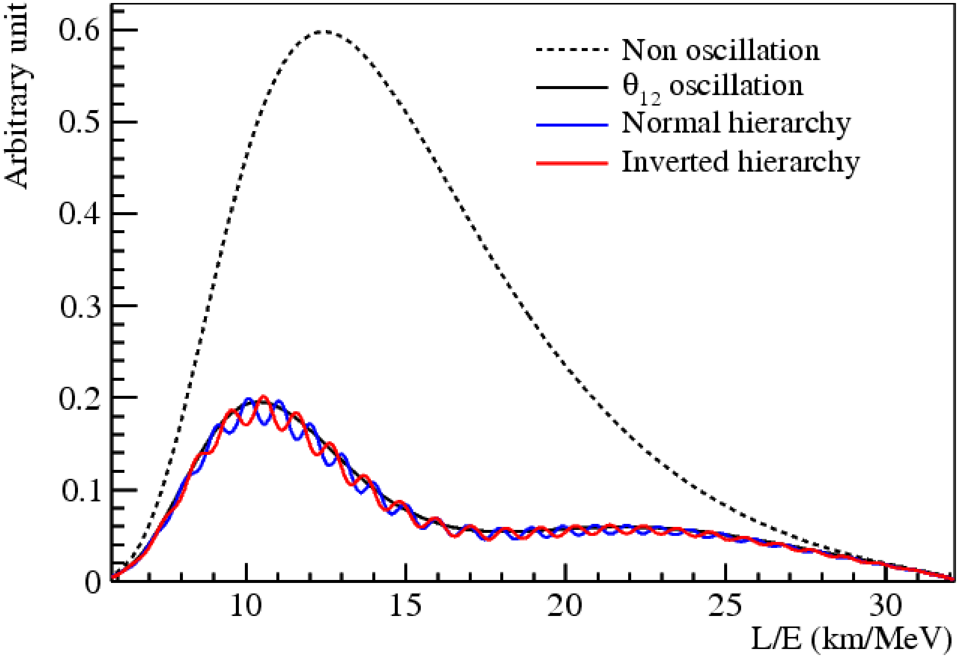
$$P_{ee} = \left| \sum_{i=1}^{3} U_{ei} \exp\left(-i\frac{m_i^2}{2E_i}\right) U_{ei}^* \right|^2$$

$$= 1 - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2(\Delta_{21})$$

$$- \cos^2\theta_{12}\sin^2 2\theta_{13}\sin^2(\Delta_{31})$$

$$- \sin^2\theta_{12}\sin^2 2\theta_{13}\sin^2(\Delta_{32})$$

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



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

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

$$- \sin^2 2\theta_{13}\sin^2(|\Delta_{31}|)$$

$$- \sin^2\theta_{12}\sin^2 2\theta_{13}\sin^2(\Delta_{21})\cos(2|\Delta_{31}|)$$

$$\pm \frac{\sin^2\theta_{12}}{2}\sin^2 2\theta_{13}\sin(2\Delta_{21})\sin(2|\Delta_{31}|),$$

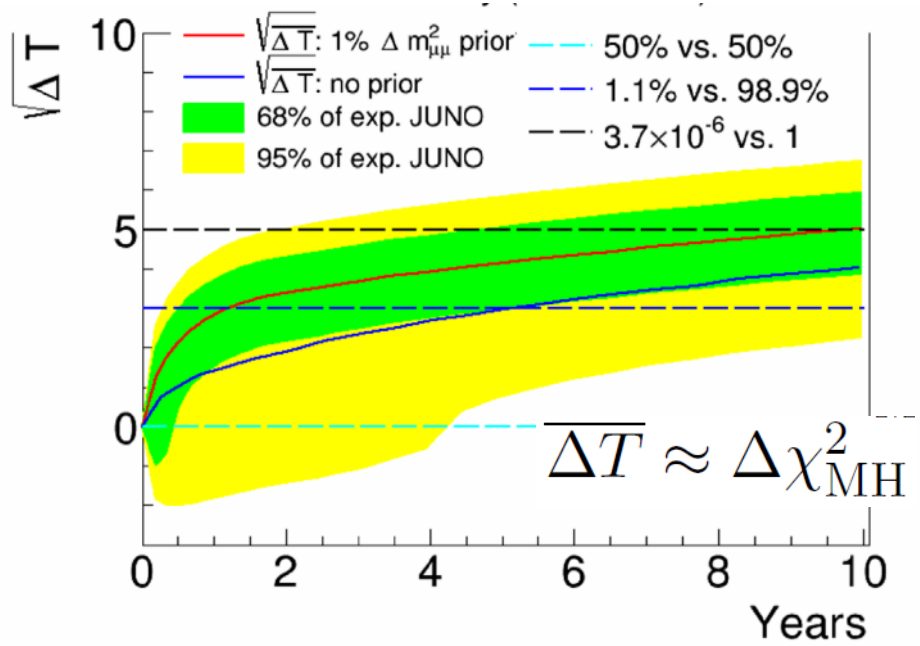
+ NH
- IH

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

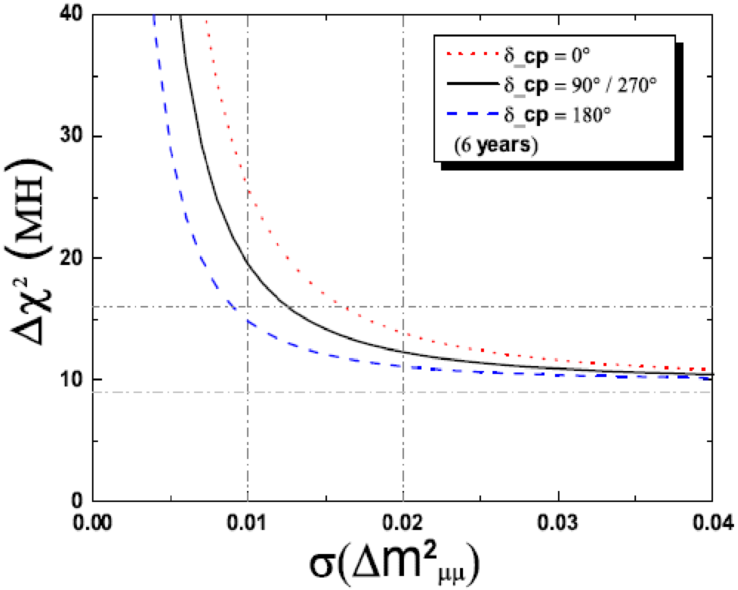
Sensitivity on MH

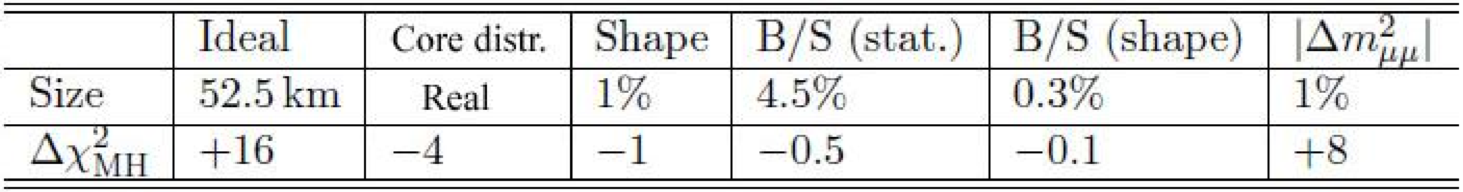
PRD 88, 013008 (2013)	Relative Meas.	Use absolute Δm^2
Statistics only	4σ	5σ
Realistic case	3σ	4σ

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



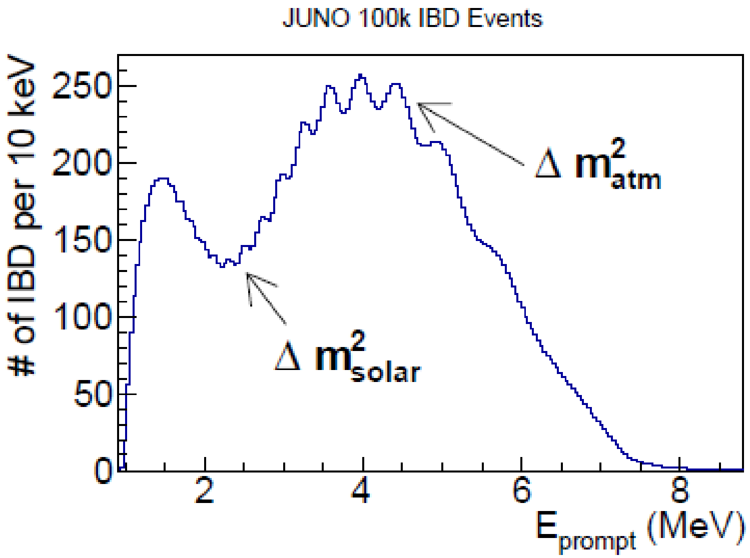
$$\overline{\Delta T} \approx \Delta\chi^2_{\rm MH}$$





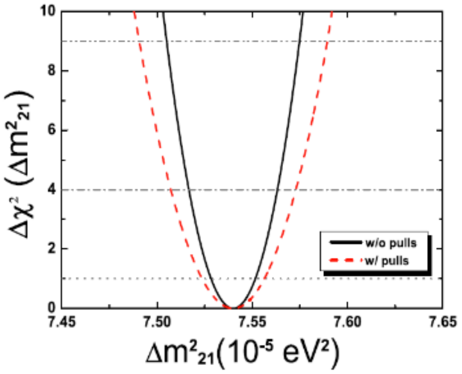
	Ideal	Core distr.	Shape	B/S (stat.)	B/S (shape)	$\lvert\Delta m^2_{\mu\mu}\rvert$
Size	52.5 km	Real	1%	4.5%	0.3%	1%
$\Delta\chi^2_{\rm MH}$	$+16$	-4	-1	-0.5	-0.1	$+8$

Precision Measurements

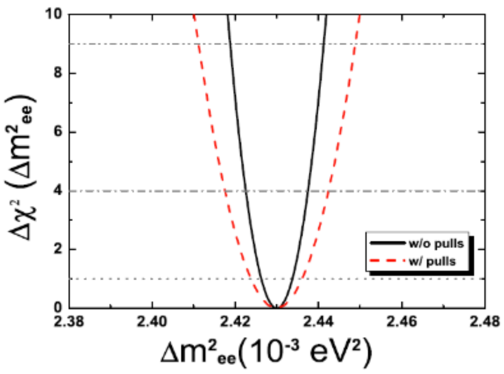


Probing the unitarity of U_{PMNS} to ~1% more precise than CKM matrix elements !

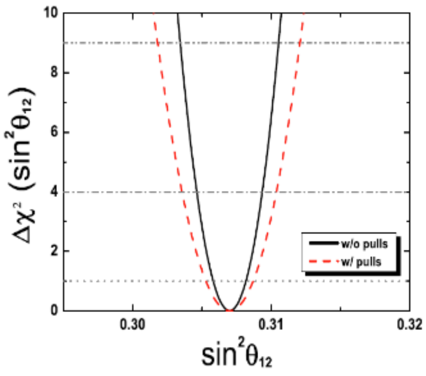
	Statistics	+BG +1% b2b +1% EScale +1% EnonL
$\sin^2\theta_{12}$	0.54%	0.67%
Δm^2_{21}	0.24%	0.59%
Δm^2_{ee}	0.27%	0.44%



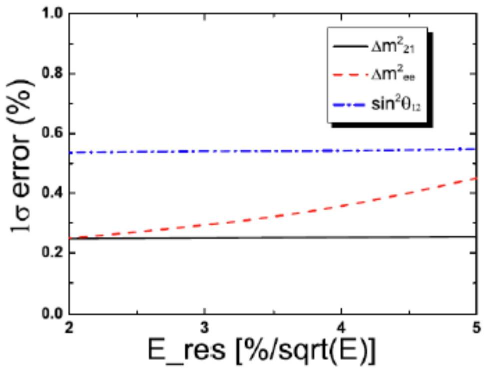
0.16%→0.24%



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**

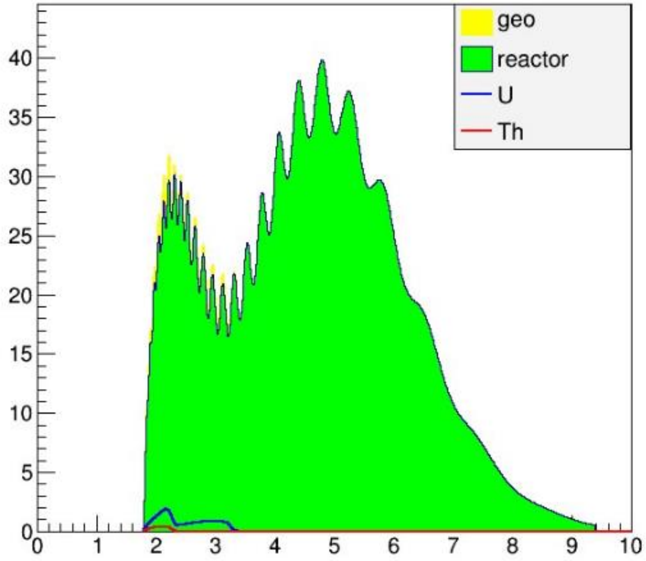
Geo-neutrinos

- **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
$^{13}\mathrm{C}(\alpha, n)^{16}\mathrm{O}$	18.2 ± 9.1
Accidental coincidences	401 ± 4

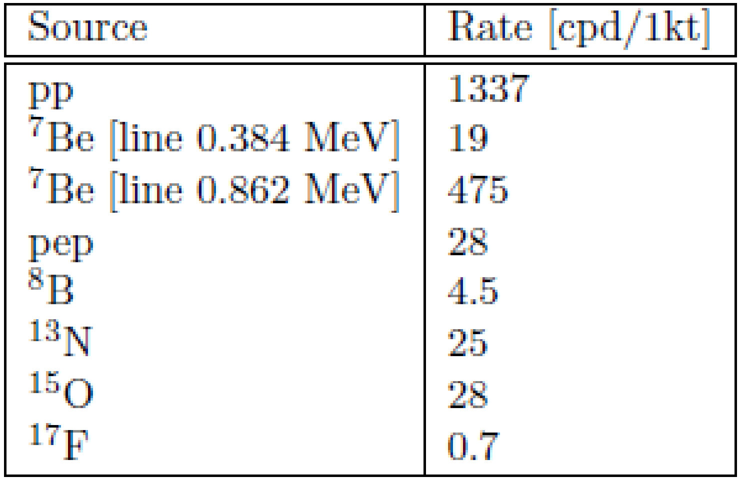
Combined shape fit of geo-ν and reactor-ν

	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%

Solar and other Physics

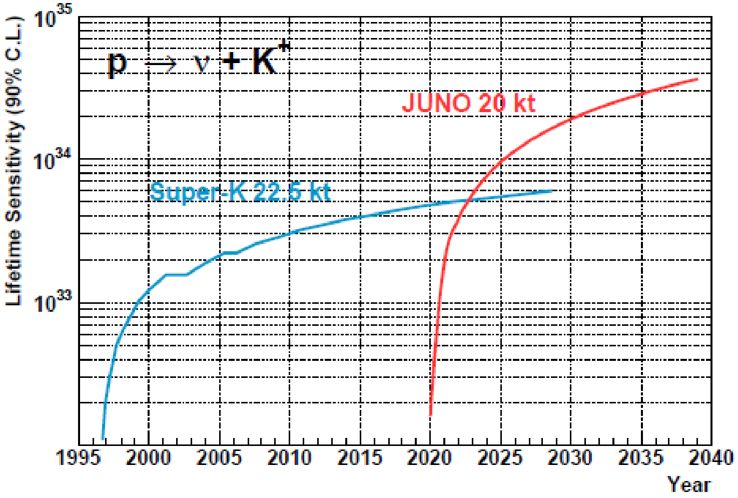
- **Solar neutrino**
  - ⇨ Metallicity? Vacuum oscillation to MSW?
  - ⇨ ^{7}Be and ^{8}B at JUNO

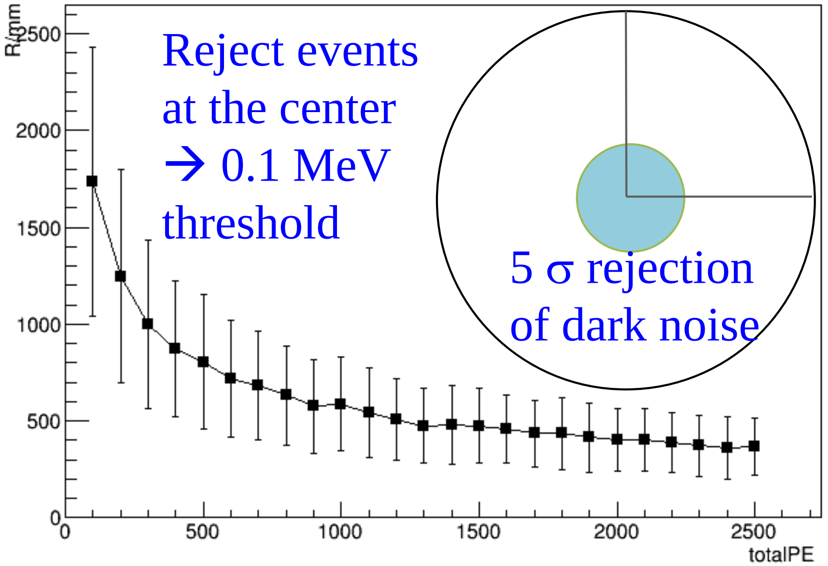
Liquid Scintillator	U238	Th232	K40	Pb210 (Rn222)	Ref.
No Distillation	10^{-15}	10^{-15}	10^{-16}	$1.4 \cdot 10^{-22}$	Borexino CTF, KamLAND
After Distillation	10^{-17}	10^{-17}	10^{-18}	10^{-24}	



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.**





Reject events at the center → 0.1 MeV threshold

5 σ rejection of dark noise

Challenges

- Large detector: >10 kt LS
- Energy resolution: < 3%/√E ➔ ~1300 p.e./MeV

	Borexino	JUNO
LS mass	**~0.3 kt**	**20 kt**
Energy Resolution	**5%/√E**	**3%/√E**
Light yield	**500 p.e./MeV**	**~1300 p.e./MeV**

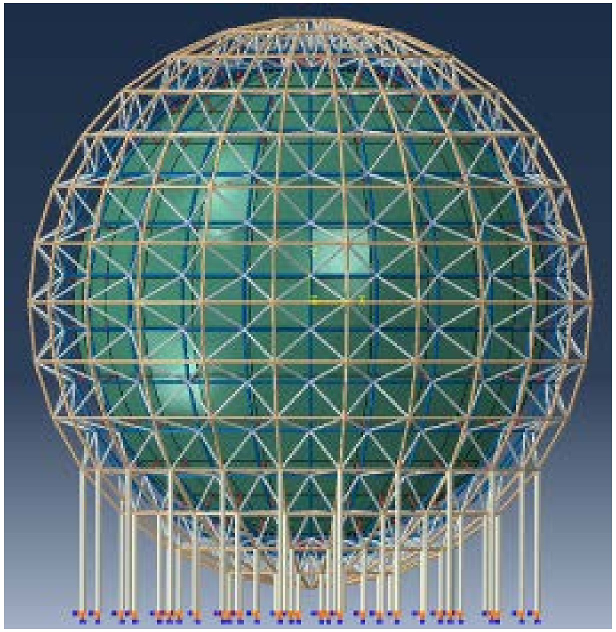
More photons, how and how many ?

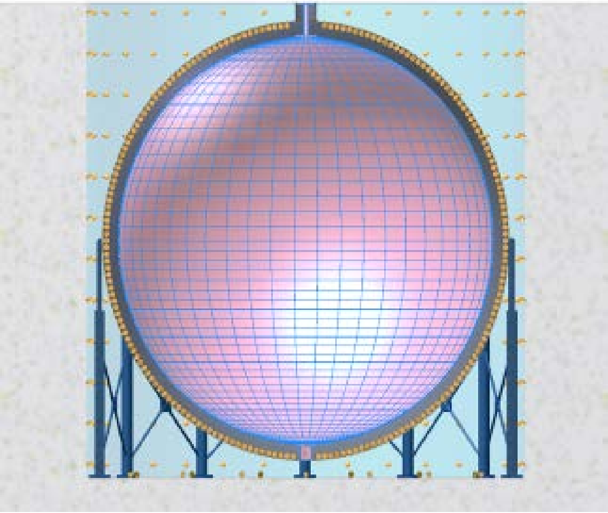
- Highly transparent LS:
  - **Target attenuation length: → 30m/34m (absorption-reemission helps a lot as shown by Borexino)**
- High light yield LS:
  - **Borexino: 1.5g/l PPO → 5g/l PPO**
    about 30% more in the Light Yield
- Photocathode coverage :
  - **Borexino: 33% → ~ 80% × 2.3**
- High QE "PMT":
  - **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

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



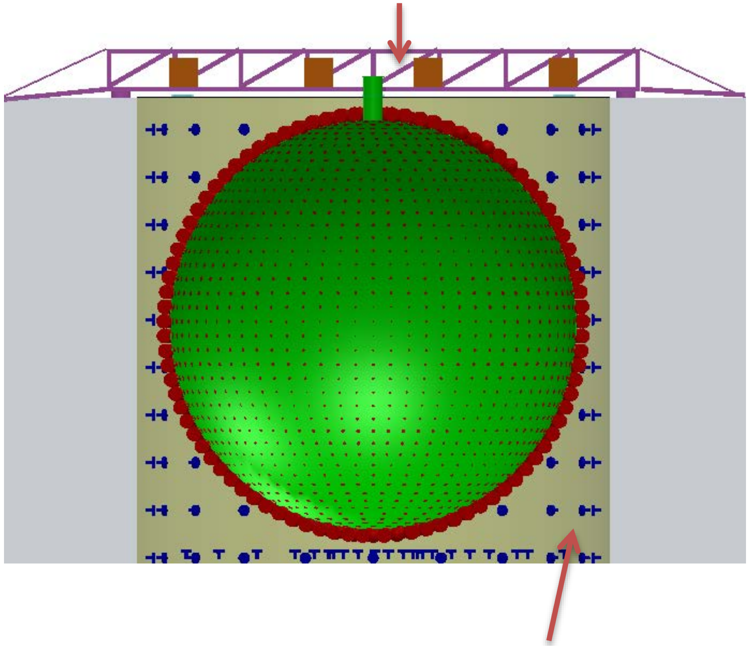


Veto Detectors

- 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 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

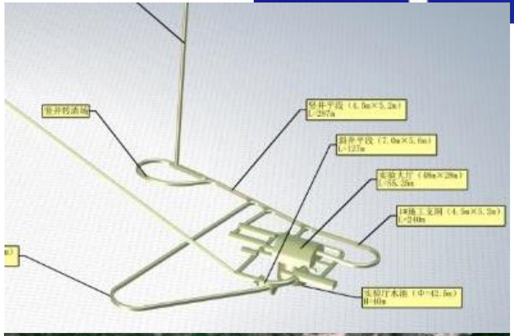
江门中微子实验建设启动会

Jiangmen Underground Neutrino Observatory

Construction Start-up Meeting

广东省.开平市.金鸡镇

Jan. 10, 2015



600 m vertical shaft

1300-m long tunnel(40% slope)

50-m diameter, 80-m high cavern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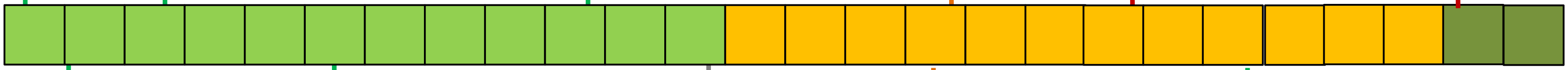
Project Plan and Progresses



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)

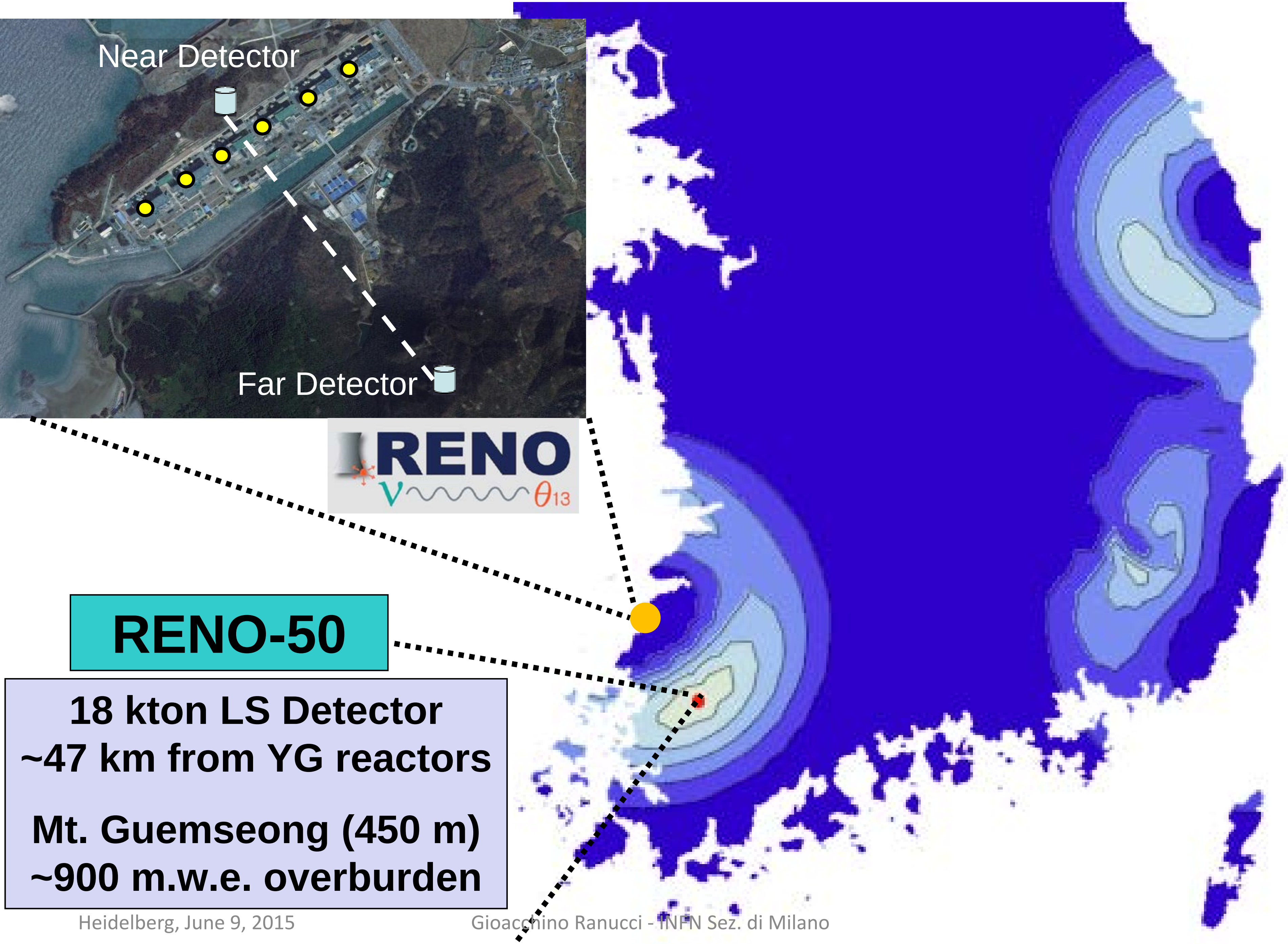
Yangjiang NPP started to build the last two cores

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



RENO-50

18 kton LS Detector
~47 km from YG reactors

Mt. Guemseong (450 m)
~900 m.w.e. overburden

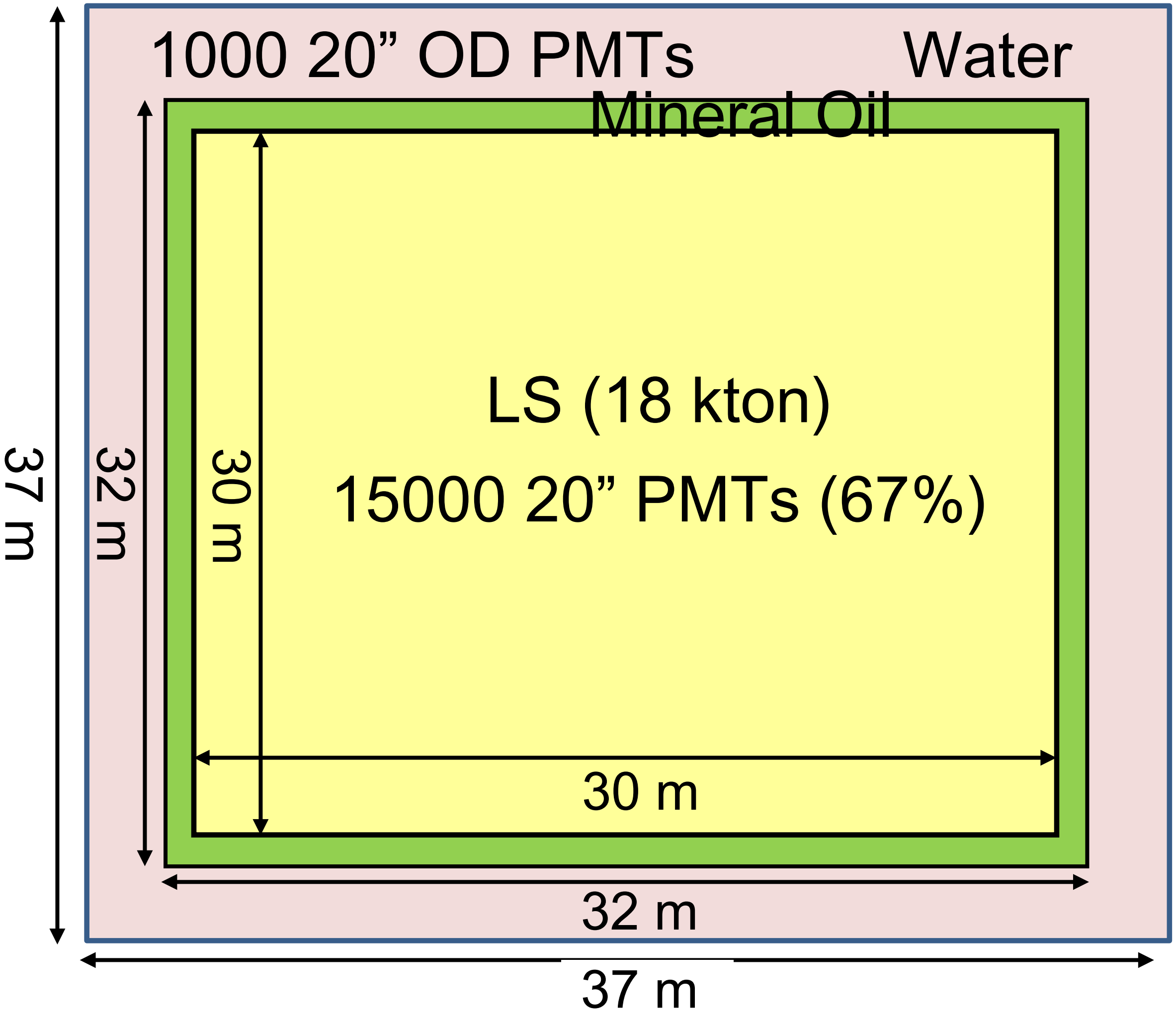
RENO-50 Candidate Site

Mt. GuemSeong

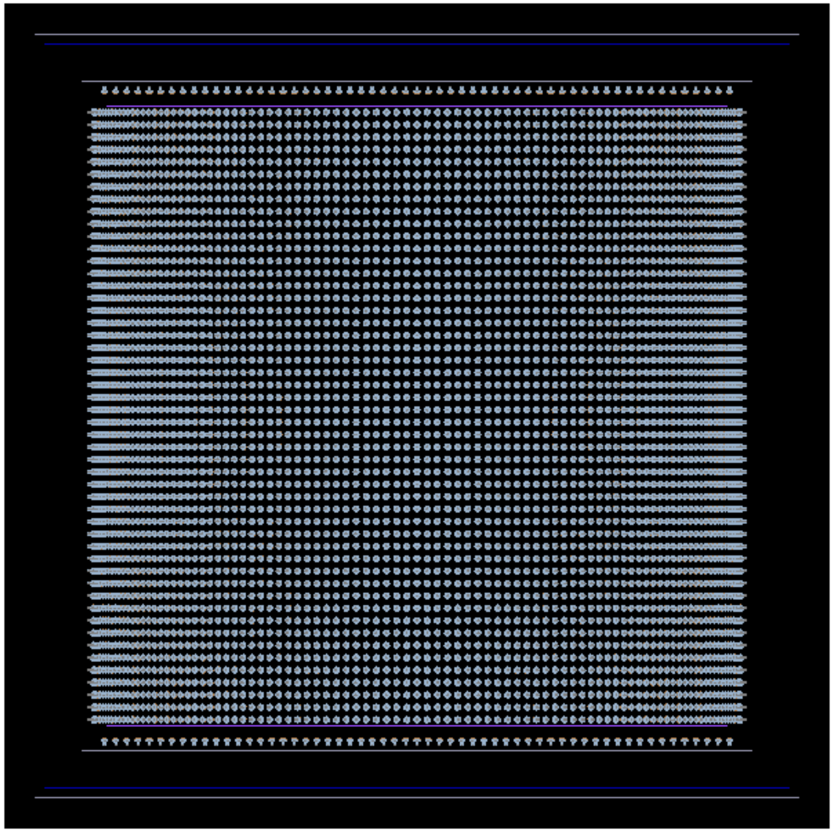
Altitude : 450 m

RENO-50 Candidate Site

Conceptual Design of RENO-50



MC Simulation of RENO-50



- R&D with optimization of detector design by a MC study

- Increase of photosensitive area up to ~60% using 15,000 20” PMTs to maximize the light collection

- PMT arrangement scheme.

- Barrel : 50 raw * 200 column
- Top & Bottom: 2500 PMTs for each region

Target : Acrylic, 30m*30m

Buffer : Stainless-Steel, 32m*32m

Veto   : Concrete, 37m*37m

Schedule

- 2015 : Group organization
  Detector simulation & design
  Geological survey
- 2016 ~ 2017 : Civil engineering for tunnel excavation
  Underground facility ready
  Structure design
  PMT evaluation and order,
  Preparation for electronics, HV, DAQ & software tools,
  R&D for liquid scintillator and purification
- 2018 ~ 2020 : Detector construction
- 2021 ~ : Data taking & analysis

Conclusion

The vast potential physics reach of very large liquid scintillator detectors - MH determination and beyond - makes such a technology very attractive and one of the pillars of the next round of massive detectors planned worldwide for the ultimate quest of the neutrino oscillation properties

JUNO has already established a solid program and a large Collaboration toward the goal of data taking start-up in 2020

RENO-50 plans to join the experimental effort one year later