The JUNO experiment

T2K-*JUNO*-HK group @ LLR

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R. Pain Visit

LLR, 26/05/2015

Neutrino Oscillation Matrix

Atmospheric+LBL | **Reactor+LBL** | **Solar**

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & e^{i\delta}\cos\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

θ_{atm} | θ_{13}, δ | θ_{sol}

SuperK., K2K, Minos

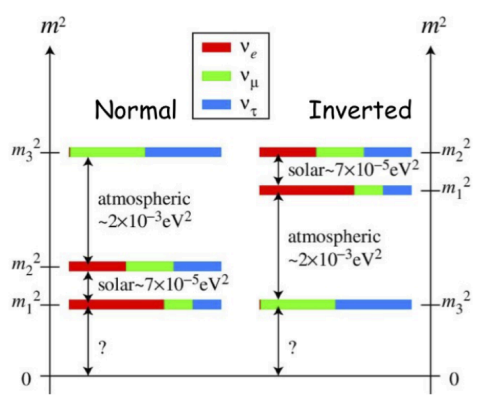
$\sin^2\theta_{23}$ (NH)= 0.44 (7%)
$|\Delta m^2_{31}|$=2.43 x10^{-3} eV^2 (3%)

Double Chooz, RENO, DayaBay, T2K

$\sin^2\theta_{13}$ (NH)= 0.023 (9%)

Homestake, Sage, Gallex/GNO
SuperK., SNO, Borexino, Kamland

$\sin^2\theta_{12}$ =0.308 (5%)
Δm^2_{21}=7.54 x10^{-5} eV^2 (3%)



Phys.Rev. D89, 093018 (2014)

δ_{CP} ?

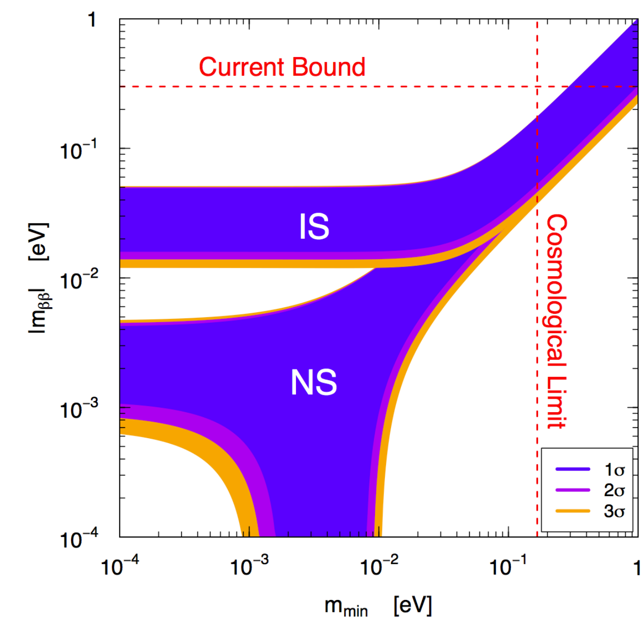
➔ Mass hierarchy ? ⬅

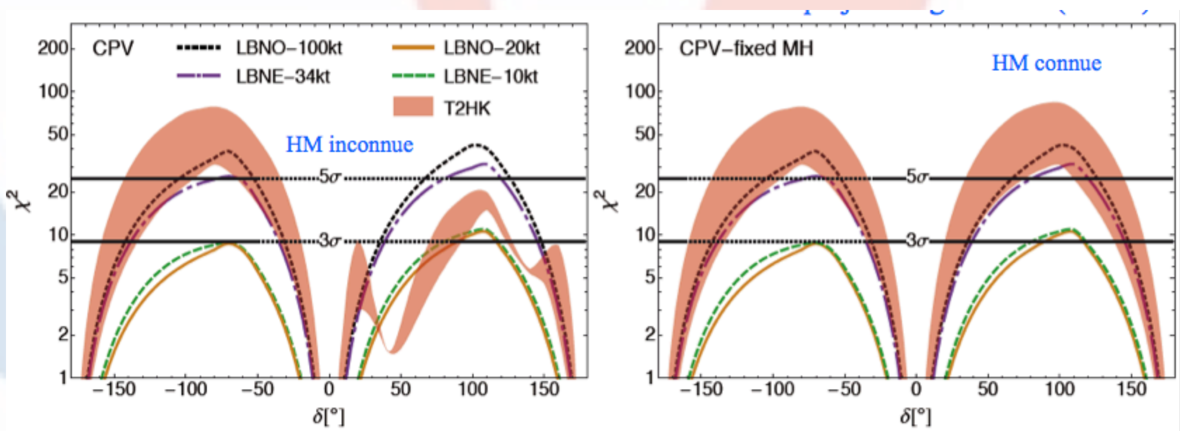
(Δm^2_{31} > 0 or < 0) **?**

Why the MH?

Mass Hierarchy (MH)

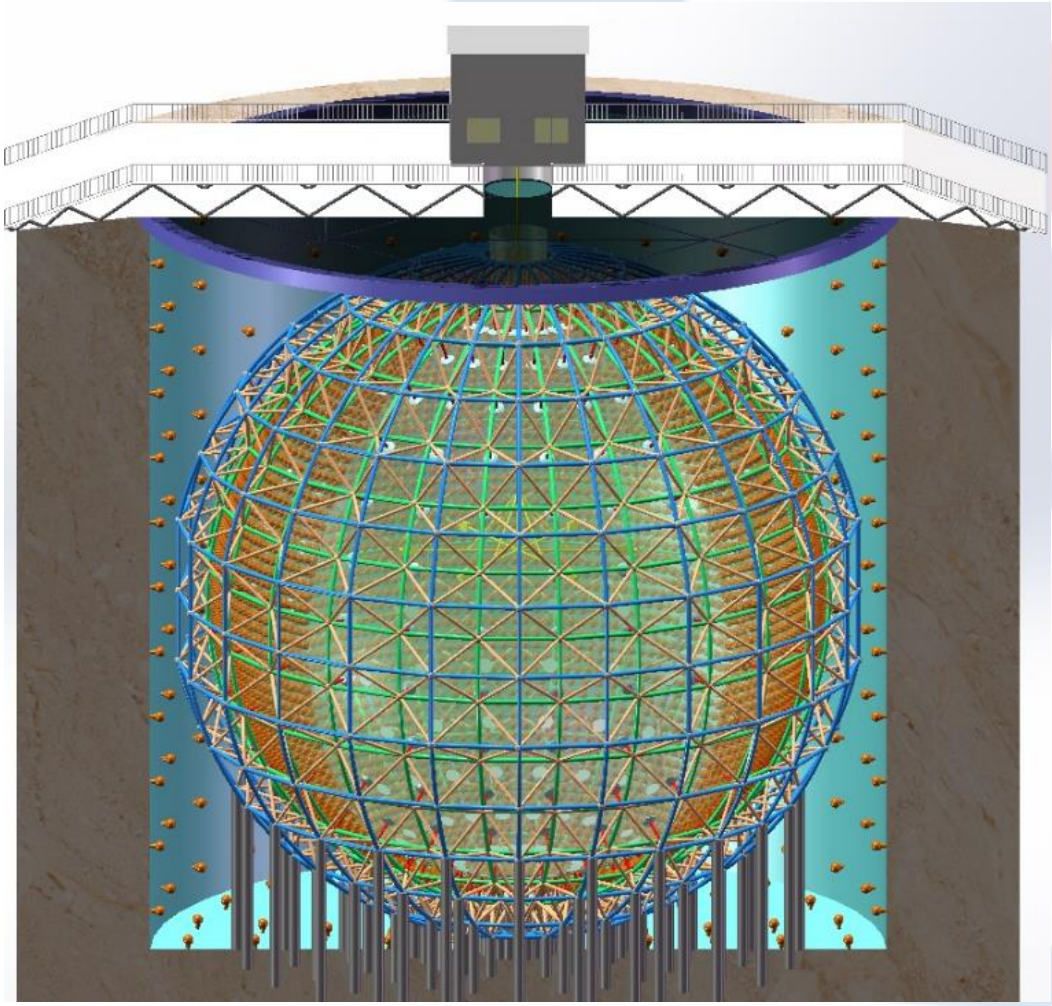
1. helps in to define the goal of searching for $\beta\beta0\nu$
2. Is crucial factor for measuring the lepton δ_{CP}
3. Is a key parameter of neutrino astronomy (supernova nucleosynthesis) and neutrino cosmology
4. …





The JUNO Experiment

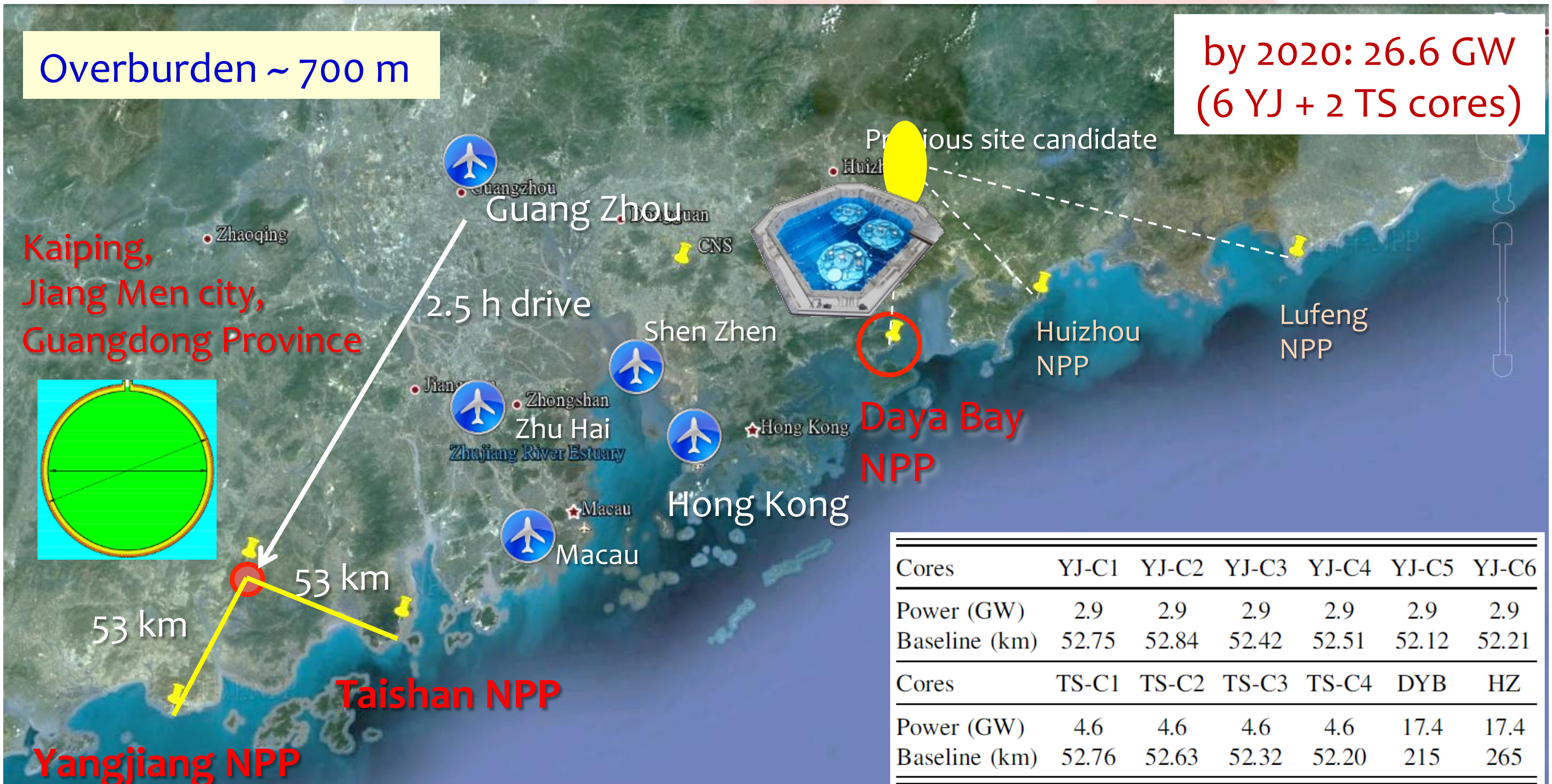
- Jiangmen Underground Neutrino Observatory, a multiple-purpose neutrino experiment, approved in Feb. 2013. ~ 300 M$.



- 20 kton LS detector
- 3% energy resolution
- 700 m underground
- Rich physics possibilities
  - Reactor neutrino for Mass hierarchy and precision measurement of oscillation parameters
  - Supernovae neutrino
  - Geoneutrino
  - Solar neutrino
  - Atmospheric neutrino
  - Exotic searches

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



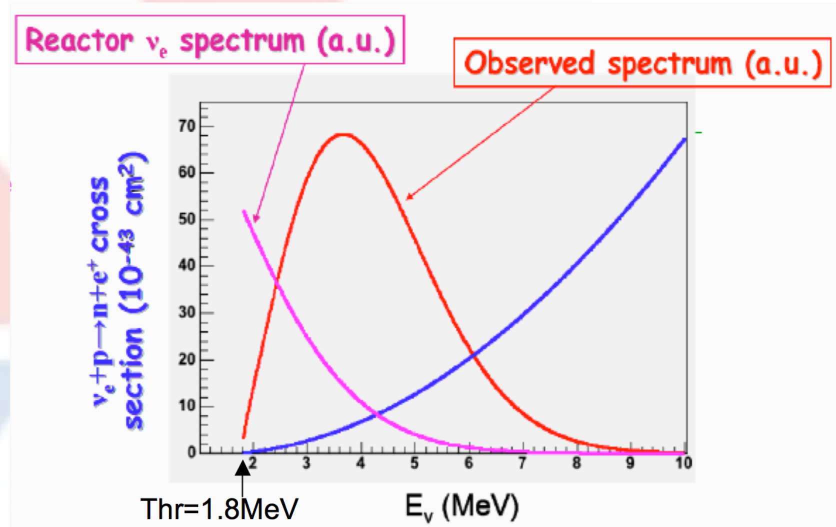
Cores	YJ-C1	YJ-C2	YJ-C3	YJ-C4	YJ-C5	YJ-C6
Power (GW)	2.9	2.9	2.9	2.9	2.9	2.9
Baseline (km)	52.75	52.84	52.42	52.51	52.12	52.21
Cores	TS-C1	TS-C2	TS-C3	TS-C4	DYB	HZ
Power (GW)	4.6	4.6	4.6	4.6	17.4	17.4
Baseline (km)	52.76	52.63	52.32	52.20	215	265

Antineutrino Detection

Anti-ν are observed via Inverse Beta Decay (IBD)

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

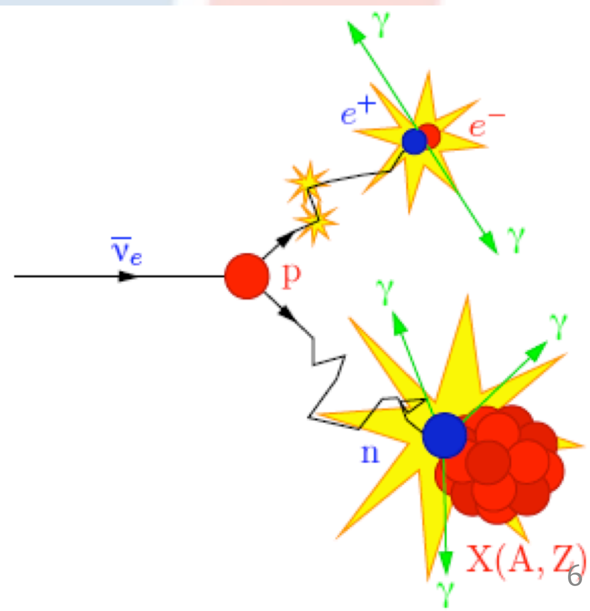
The energy spectrum is a convolution of flux and cross section (E_{thr} = 1.8 MeV)



Signal signature is given by**:**

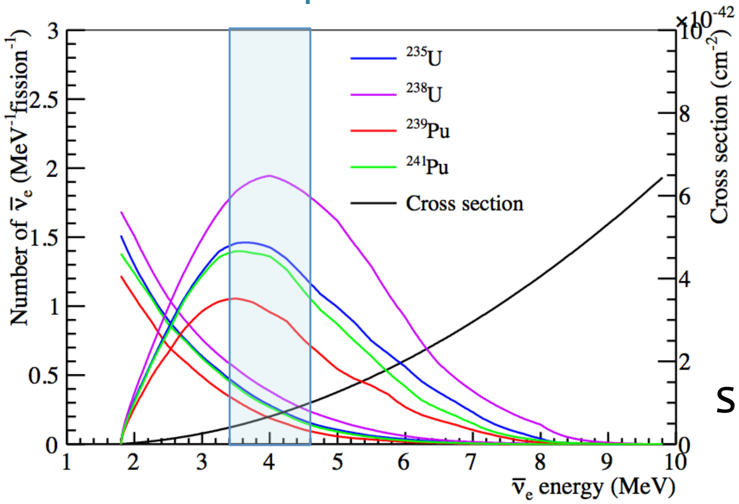
* **Prompt** photons from e⁺ ionisation and annihilation (1-8 MeV)
$E_{VIS} \approx E_\nu - (M_n - M_p) + m_e$

* **Delayed** photons from n capture on H: Δt~200μs, E=2.2MeV in about 1m

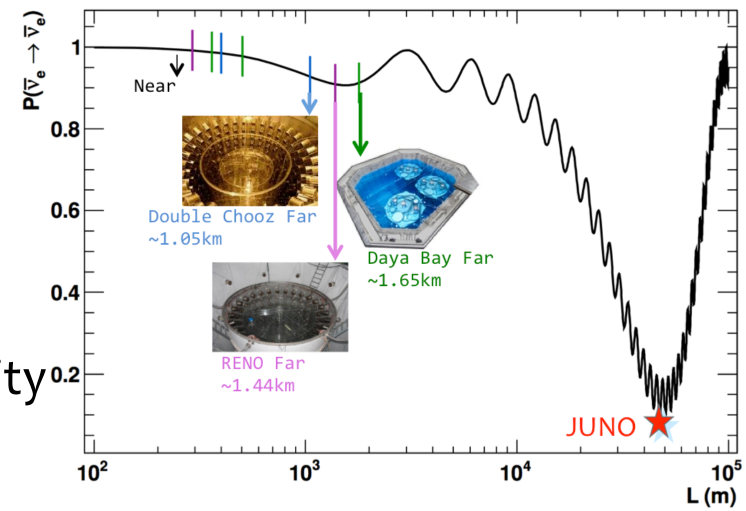


MH determination with reactor anti-ν (1)

<E> ~ 4MeV



Disappearence experiment ➔ survival probability

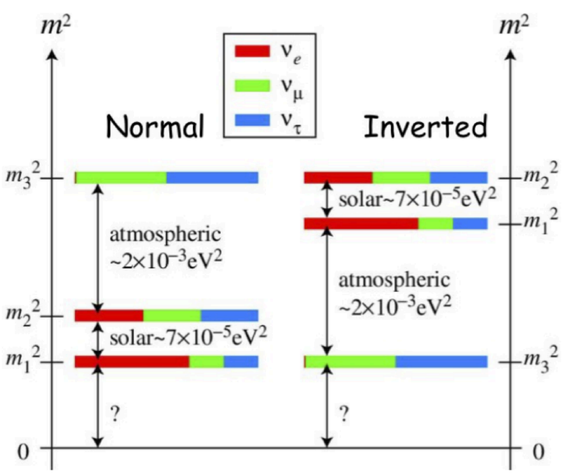


$$P_{\bar{\nu}_e \to \bar{\nu}_e}(L,E) = 1 - \sin^2 2\theta_{12} \cos^4 \theta_{13} \sin^2 \frac{\Delta m^2_{21} L}{4E} - \sin^2 2\theta_{13} \left[\cos^2 \theta_{12} \sin^2 \frac{\Delta m^2_{31} L}{4E} + \sin^2 \theta_{12} \sin^2 \frac{\Delta m^2_{32} L}{4E} \right],$$

3 oscillation frequencies:

- Low frequency Δm^2_{21} (~ 7.54 x10^{-5} eV^2)
- High frequencies: Δm^2_{31} and Δm^2_{32} (2.43 x10^{-3} eV^2)

MH determination with reactor anti-ν (2)



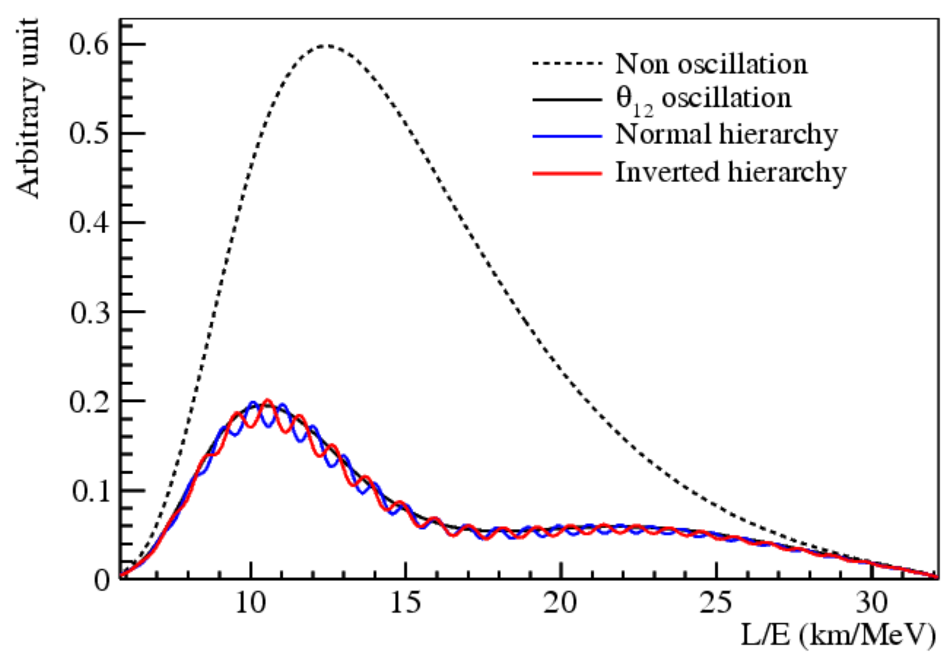
If $\mathrm{NH}: \Delta m^2_{32} > 0 \implies |\Delta m^2_{31}| > |\Delta m^2_{32}|;$

if $\mathrm{IH}: \Delta m^2_{32} < 0 \implies |\Delta m^2_{31}| < |\Delta m^2_{32}|.$

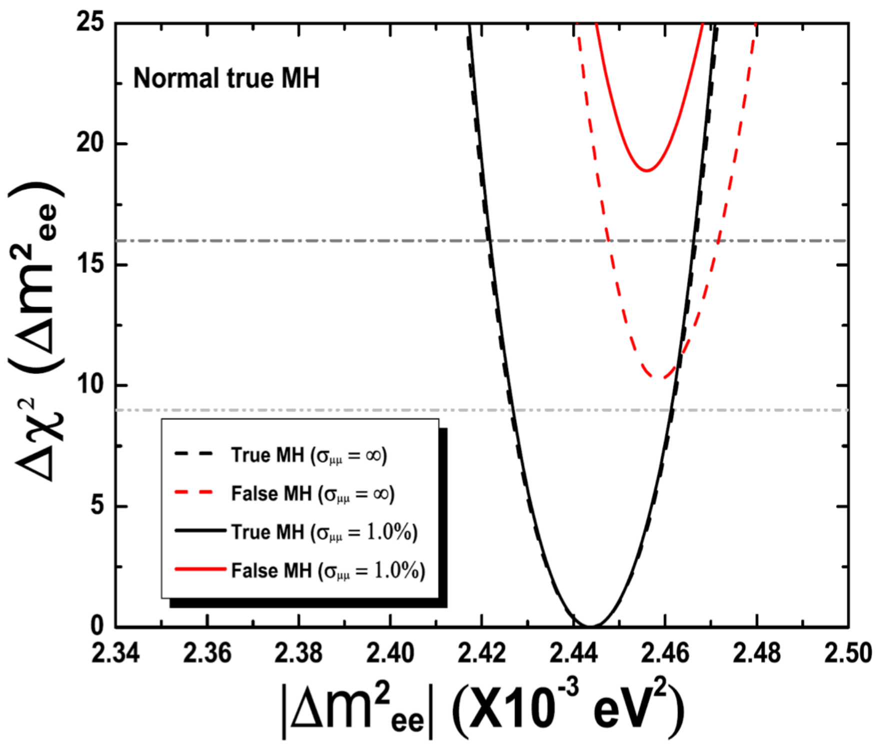
The goal is to determine the highest frequency

Shifted spectra by a phase ϕ, energy related

Precision energy spectrum measurement interference between the term in Δm^2_{31} and in Δm^2_{32}



MH sensitivity



Ingredients…

✓ 20kt valid target mass ⊕ 36GW reactor power ⊕ 6-years data

✓ 3% energy resolution ⊕ ~1% energy scale uncertainty assumed

✓ Systematics

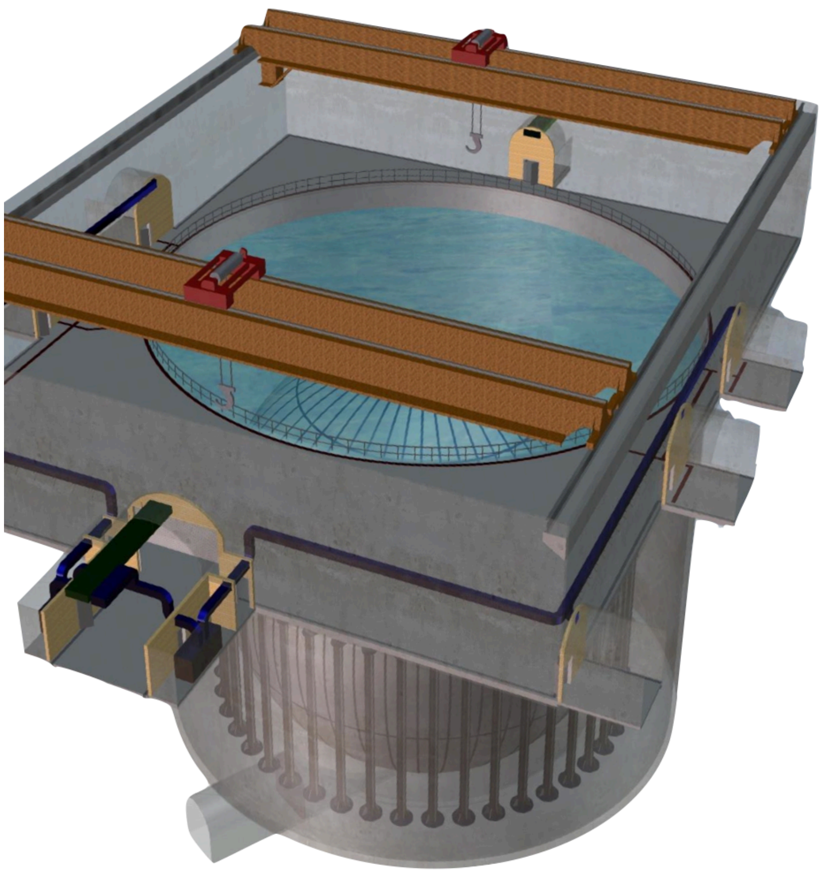
	Ideal	Real	Shape	B/S (stat.)	B/S (shape)	$\|\Delta m^2_{\mu\mu}\|$
Size	52.5 km	Tab. 2-2	1%	4.5%	0.3%	1%
$\Delta\chi^2_{\rm MH}$	+16	−4	−1	−0.5	−0.1	+8

- **~3σ** → spectral measurement with no Δm^2 external constraint
- **~4σ** → external Δm^2 measured to ~1% error

(ν_μ disappearance with ν-beam off-axis)

Δm^2 @~1% by T2K+NOvA combined analysis [1312 .1477]

σ_E: Fundamental design parameter

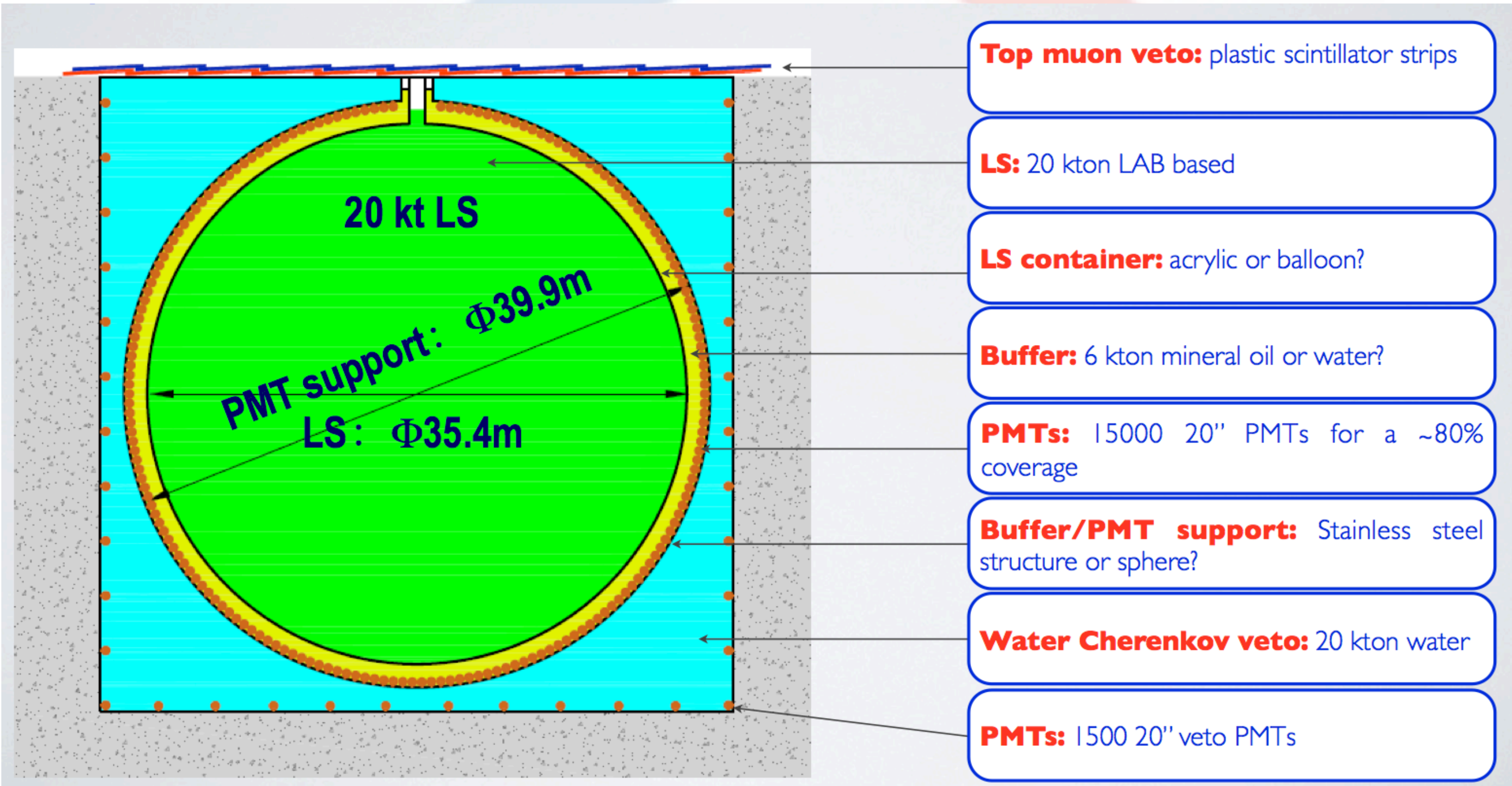


- ENERGY RESOLUTION : 3% @ 1MeV
- HUGE LIGHT YIELD
    - Highest light collection 1200 p.e./MeV
    - Highest photocathode coverage (~ 80%)
    - High detection efficiency PMTs (DE ~ 35%)
    - Attenuation length ~ 20m
- Detector uniform response and symmetrical (sphere)
- Low electronics & light noise (radio-purity)

- **Never achieved before!**

	KamLAND	Borexino	Daya Bay	JUNO
Mass [t]	~1000	~300	~170	20000
Energy resolution	6%/√E	5%/√E	7.5%/√E	3%/√E
Light yield [p.e./MeV]	250	500	200	1200

Detector Concept



Challenges:

- Engineering: mechanics, safety, lifetime, …
- PMT: high QE, high coverage
- LS: high transparency, low background

JUNO @ LLR

1. **Background reduction/control:**
   Top Tracker (simulation + electronics)
2. **Energy resolution optimisation:**
   Central Detector (simulation)

Cosmogenic Background

Cosmic μ flux @ JUNO

Overburden: ~700 m

$<E_\mu>$: 214 GeV

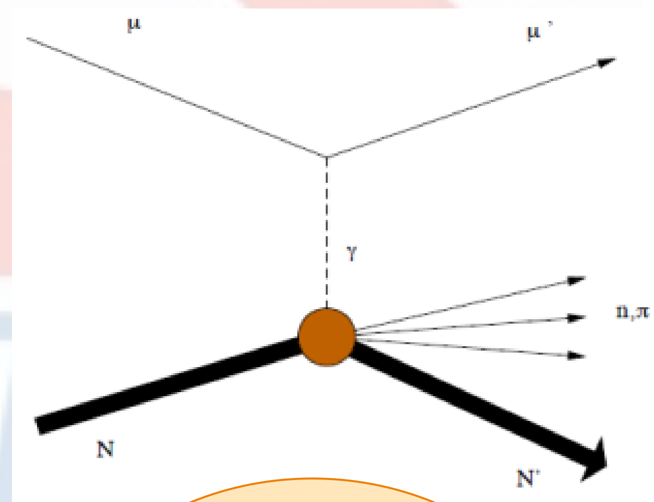
μ rate: 0.0031 Hz/m²

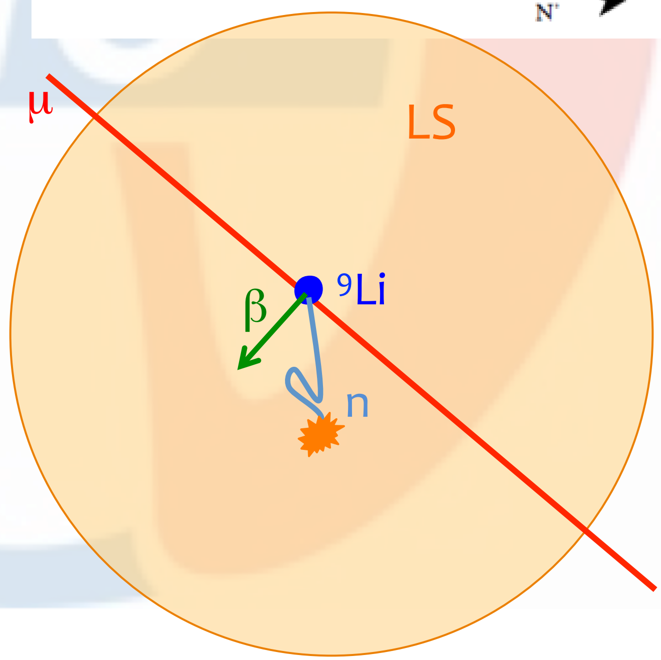
Expected μ in the CD: 3 Hz

Expected signal: 60-80/day

Isotopes	E^{β}_{max} (MeV)	$T_{1/2}$ (s)	Rate (per day)
^{6}He	3.51 (β^-)	0.807	544
^{7}Be	0.861 (β^-)	53.24 day	5438
^{8}Li	16.0 (β^-)	0.840	938
^{8}B	-	0.77	225
^{9}Li/^{8}He	13.6 (β^-+n)	0.18/0.12	94/ 11
^{9}C	16.0 (β^+)	0.13	30
^{10}Be	0.556 (β^-)	1.51e6 year	1419
^{10}C	3.65 (β^+)	19.3	482
^{11}Li	20.6	0.009	0.06
^{11}Be	11.5 (β^-)	13.8	24
^{11}C	0.96 (β^+)	1221	0.19 Hz
^{12}Be	11.7 (β^-)	0.021	0.45
^{12}B/^{12}N	16.0 (β^-)	0.02/0.01	965/17
^{13}B	13.4 (β^-)	0.017	12
^{13}N	1.20 (β^+)	9.965 min	19
^{16}N	10.42 (β^-)	7.13	13

MUON SPALLATION on ^{12}C





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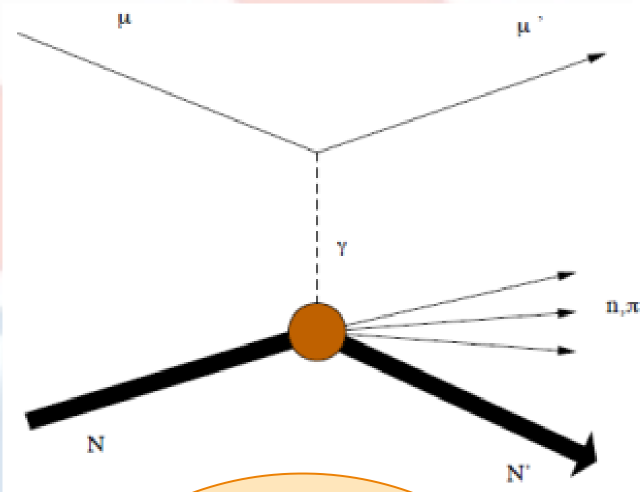
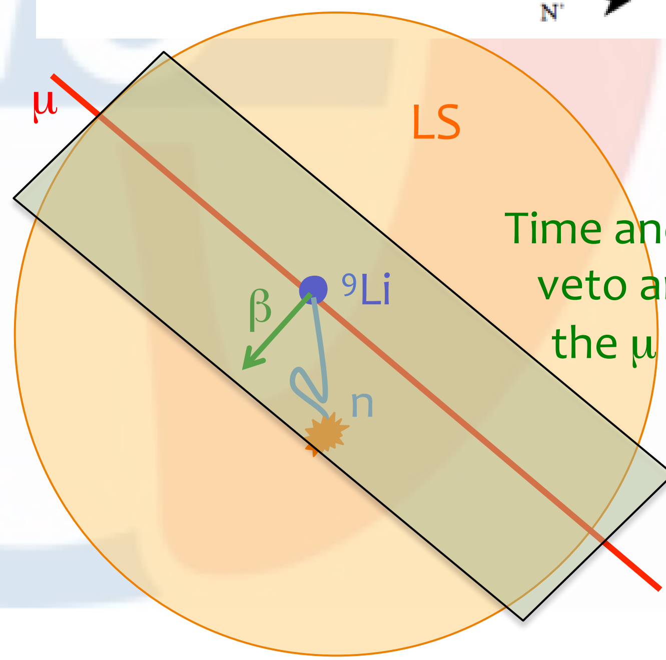


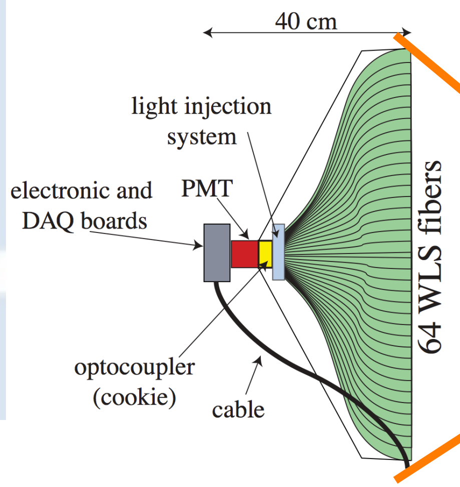


Muon Top Tracker using Opera

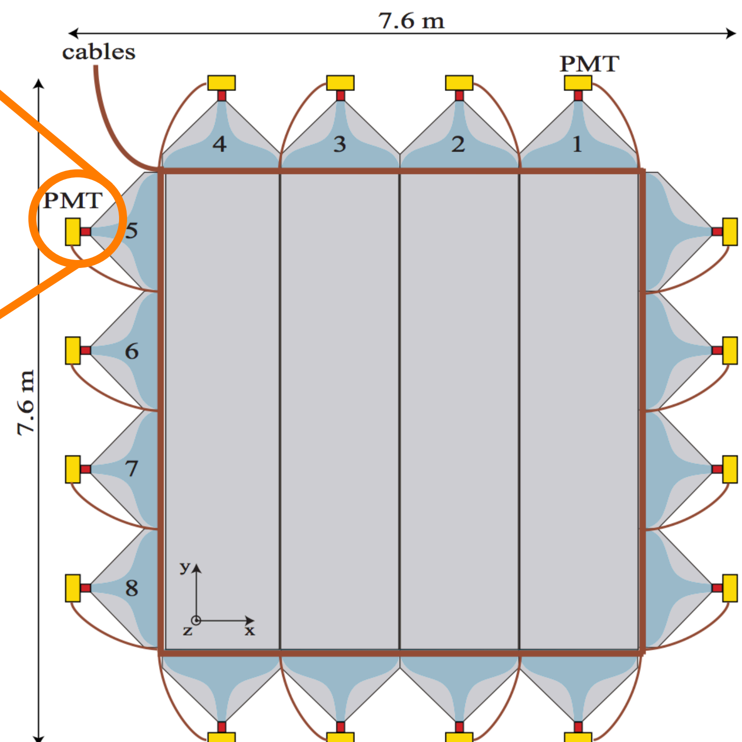
The JUNO cosmic muon tracker will help enormously to evaluate the contribution of the cosmogenic background to the signal.

The baseline of the JUNO Top Tracker is the OPERA Target Tracker (TT)

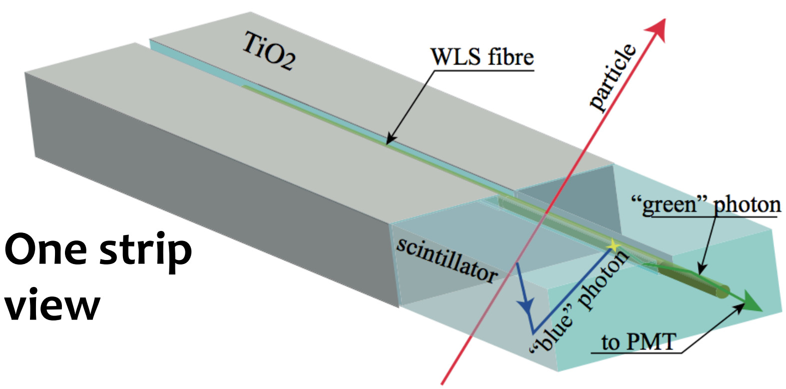
Multianode PMT



One Opera xy wall



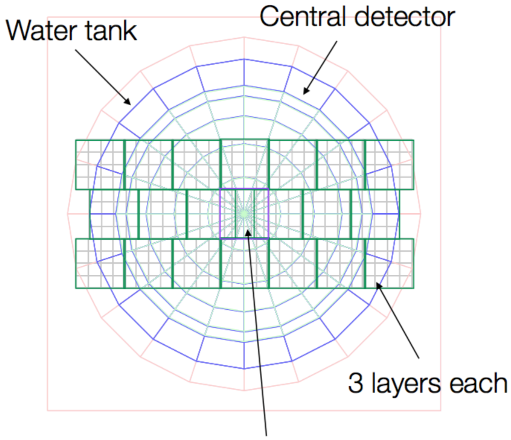
One strip view



Geometries (1)

3 walls

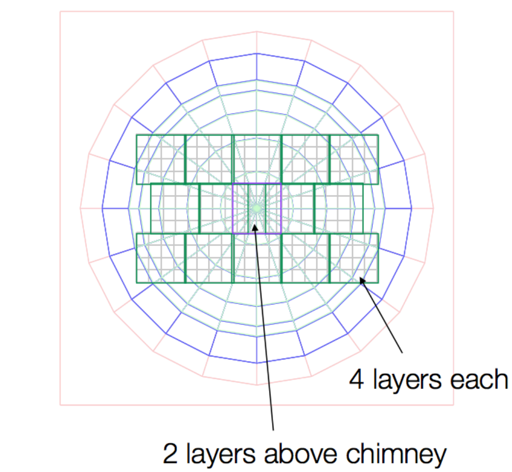
Vertical space between walls = 3 m (2 x 1.5 m)



62 walls

4 walls

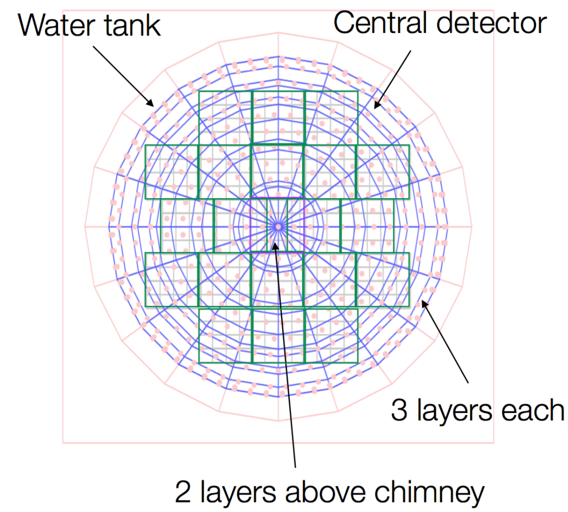
Vertical space between walls = 3 m (3 x 1 m)



58 walls

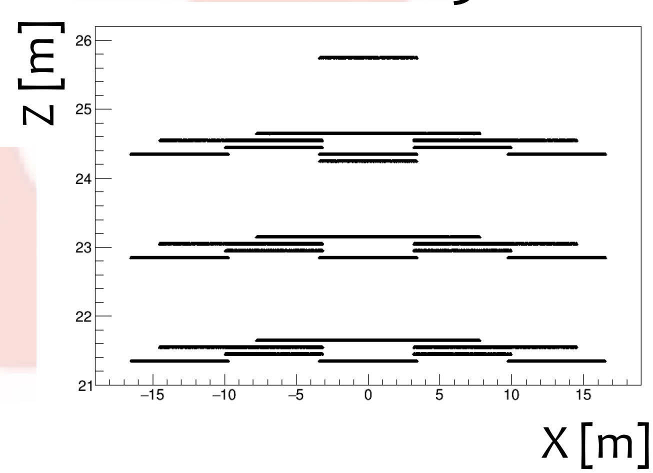
3 walls configuration 2

Vertical space between walls = 3 m (2 x 1.5 m)

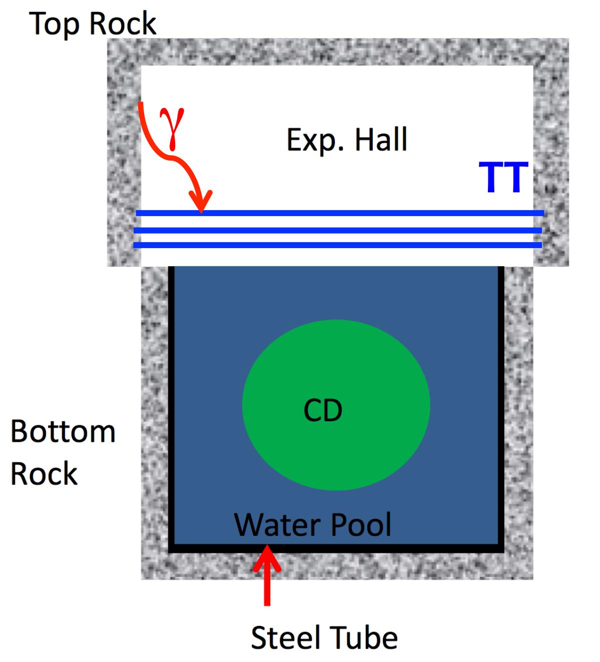


Three considered geometries with
3 layers v1
3 layers v2
4 layers

Side view of conf 3walls v2



Study on the Rock Radioactivity



Abundances measured on a rock sample from the JUNO site:

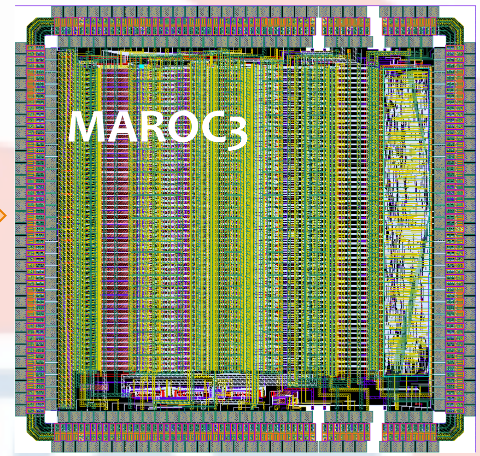
Element	Abundance	Rate
^{232}Th	~ 105 Bq/kg	1.11 x 10^{9} Hz
^{238}U	~ 110 Bq/kg	1.17 x 10^{9} Hz
^{40}K	~ 1340Bq/kg	1.42 x 10^{10} Hz

Fake muons estimation for different configurations and thresholds

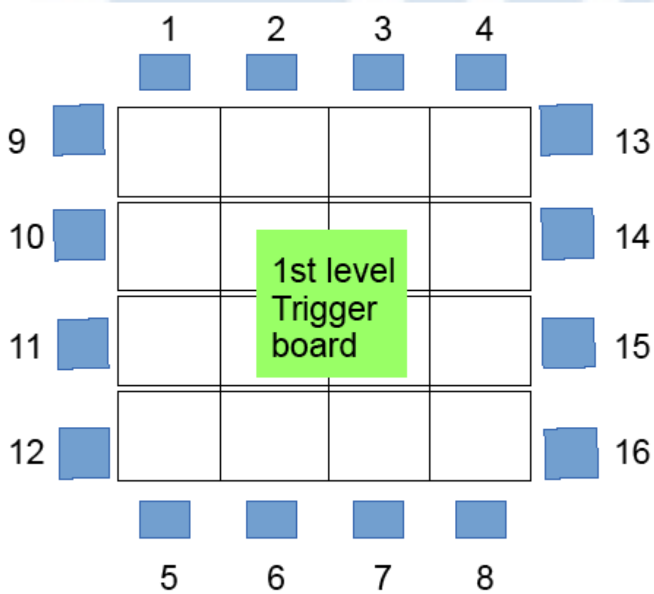
Config.	N xy coinc.	0.33p.e. OR	1 p.e. OR
3 layers	2	1.6E6 (μ: 2.72)	3.6E5 (μ: 2.72)
3 layers	3	21.1 (μ: 2.3)	2.2 (μ: 2.22)
4 layers	2	4.6E5 (μ: 2.02)	1.0E5 (μ: 2.01)
4 layers	3	15.0 (μ: 1.85)	1.4μ (μ: 1.83)

Read out and Trigger

RATES (Hz/PMT)		0,33 pe : L or R	1 pe : L or R
Plane 1		~ 53k	~ 36k
Plane 0		~ 48k	~ 33k

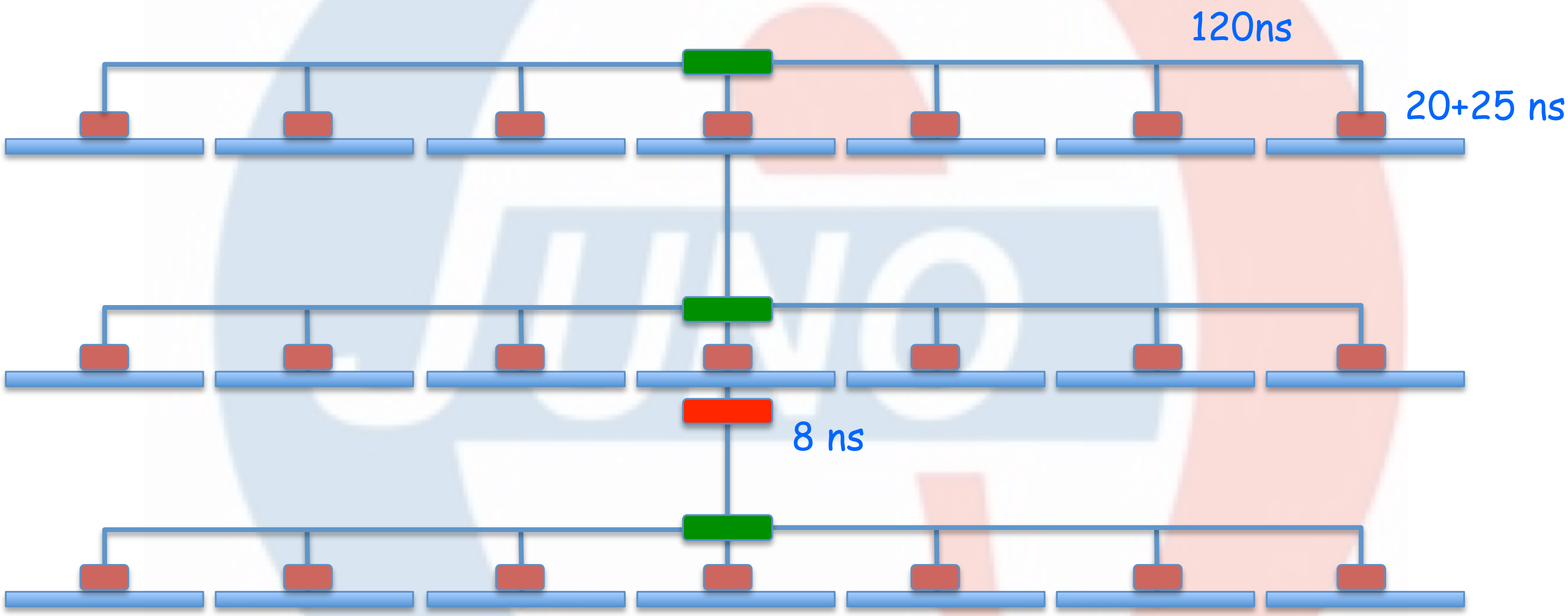


Multi Anode Read Out Chip v3



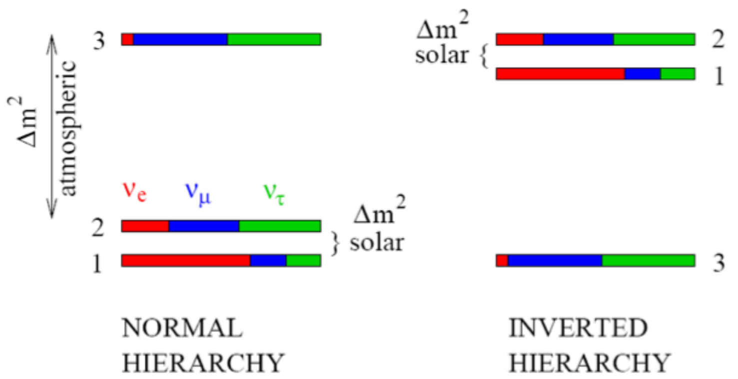
Development of an online "xy trigger" → rate reduction of a factor 10

Second Level Trigger ?



The challenge of the energy resolution

$\Delta m_{31}^2(IO) \neq \Delta m_{31}^2(NO) \Longrightarrow$ **δ~3%** (i.e. $\delta m^2/\Delta m^2$)



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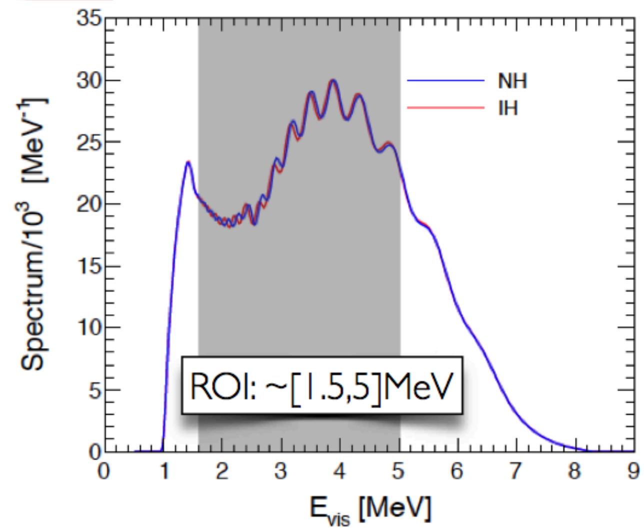


σ(E)/E ≲ 3% total
(→ including non-stochastic terms)

Generic form of σ_E

- a: statistical term
- b: constant term
- c: noise term

$$\frac{\sigma_E}{E} = \sqrt{\left(\frac{a}{\sqrt{E}}\right)^2 + b^2 + \left(\frac{c}{E}\right)^2} \simeq \sqrt{\left(\frac{a}{\sqrt{E}}\right)^2 + \left(\frac{1.6\, b}{\sqrt{E}}\right)^2 + \left(\frac{c}{1.6\,\sqrt{E}}\right)^2}$$

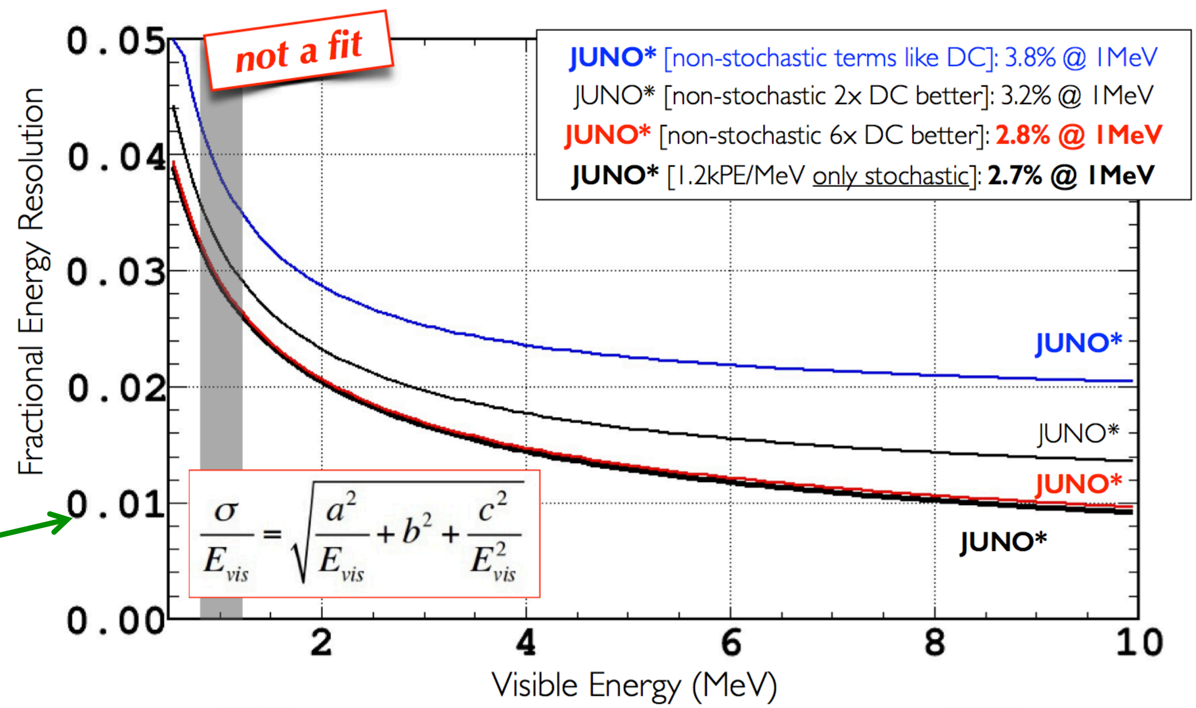
Requirement:

$$\sqrt{(a)^2 + (1.6 \times b)^2 + \left(\frac{c}{1.6}\right)^2} \leq 3\%$$

The energy resolution (goal 3% @ 1MeV)

Constant term 1.6 times more important than stochastic term ➔ systematic to be under control!

Exercise:
Extrapolation from Double Chooz



can we reach the σ(E)/E≤3%(total)?

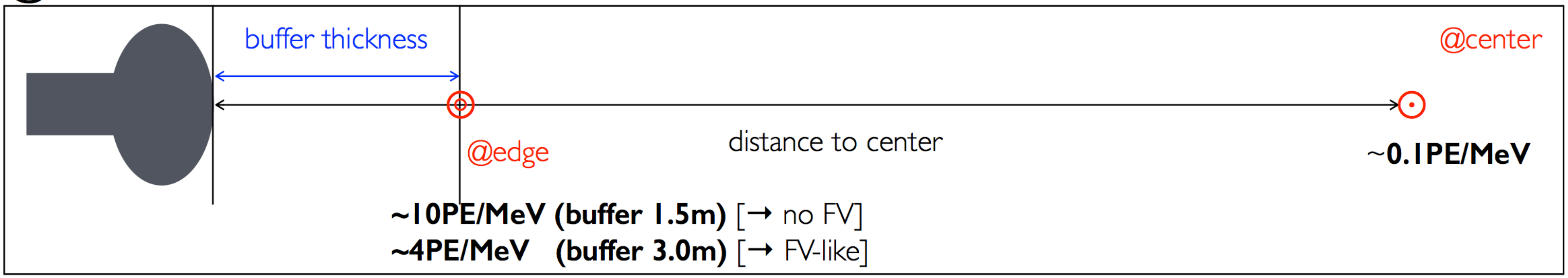
we reach σ(E)/E(stochastic)≤3%!! [i.e. 1.2kPE/MeV feasible by MC]

can we reach σ(E)/E(non-stochastic) improve by 4x wrt today's values?

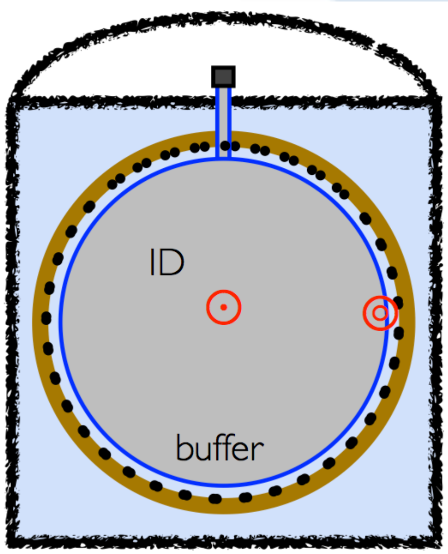
(current detector design→ good enough?)

Calorimetry regimes in JUNO

@1MeV



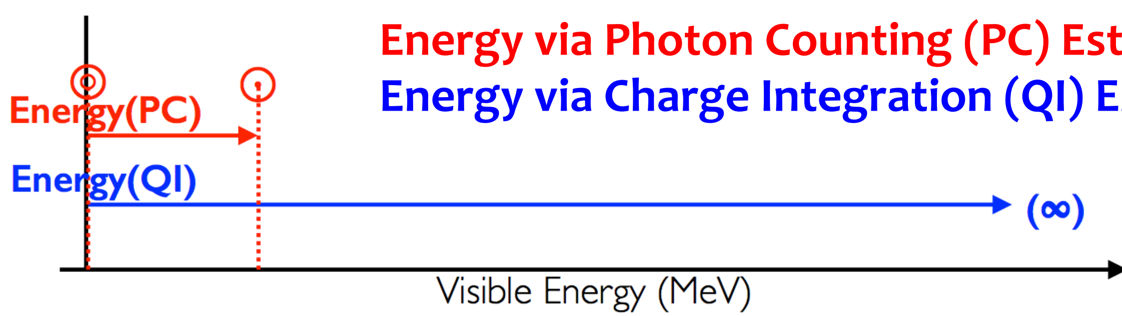
Illumination level per PMT varies by **~100x from center(⊙) to edge(◎)**
Ω (solid angle) effects [**20" PMT ⊕ huge Light Yield**]



Energy reconstruction effects (including readout effect)→ lead to large **non-linearity effects**

Strong dependence on the energy and on the position ➔ Non-linearity ⊕ Non uniformity

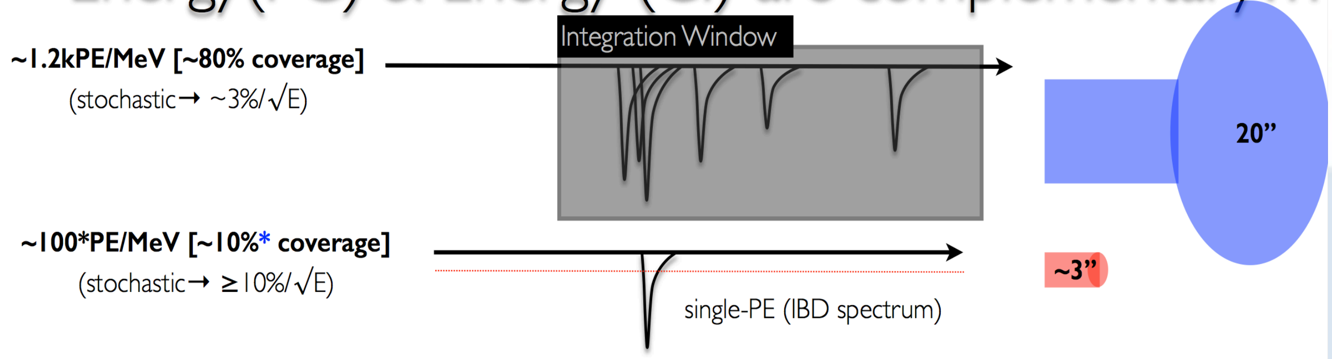
Energy via Photon Counting (PC) Estimator
Energy via Charge Integration (QI) Estimator

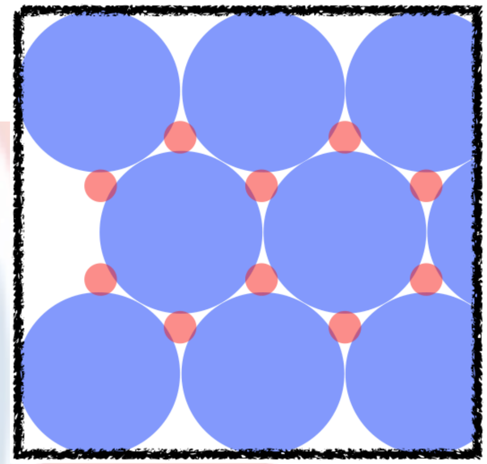


Multi-Calorimetry Proposal

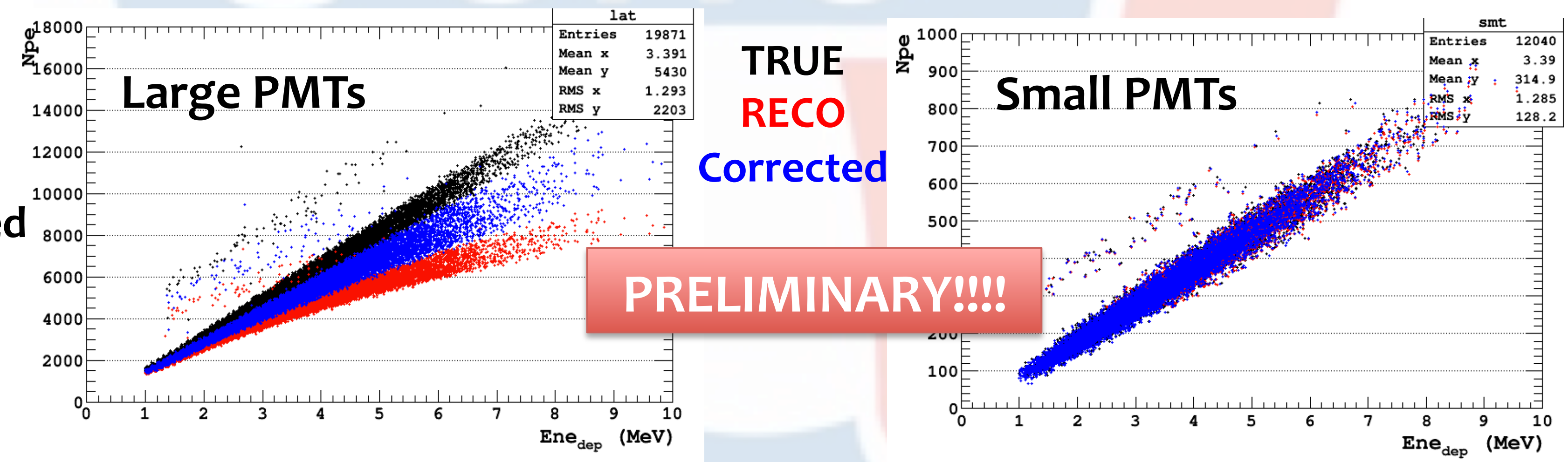
Adding 3 inch PMTs in the space between the « large PMTS»…

Energy(PC) & Energy (CI) are complementary…



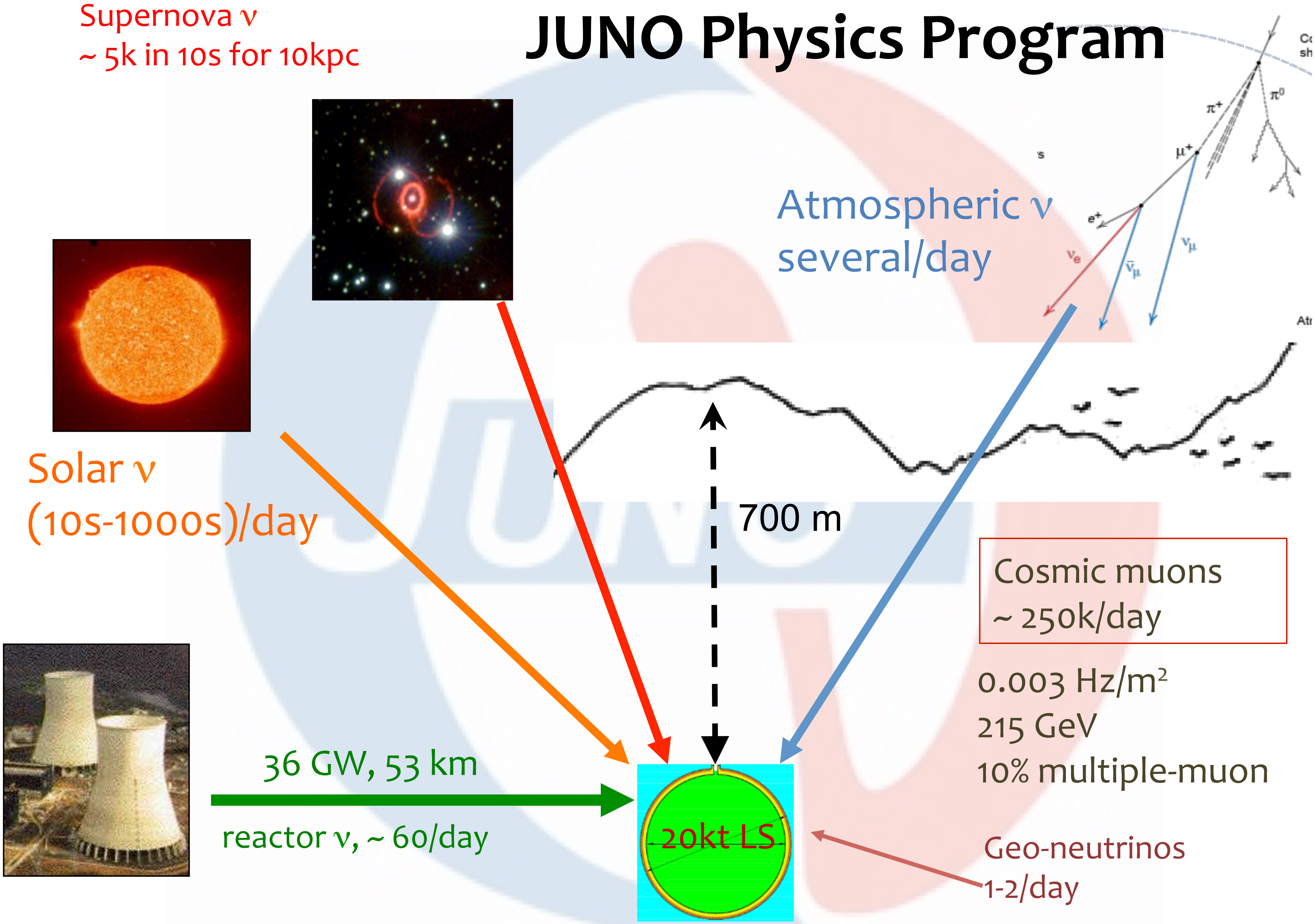


IBD unif. distributed



Energy linearity improvement by adding small PMTs

JUNO Physics Program



Summary: JUNO @

1. TT design optimisation	Done/ongoing
2. TT trigger design	Started
3. TT DAQ test setup (portable)	Started
4. 3” PMTs option study/optimisation	On going
5. Participation in the data analysis	Future