For the JUNO Collaboration

Optimisation of the Top Tracker veto detector in the JUNO experiment

Master thesis defence

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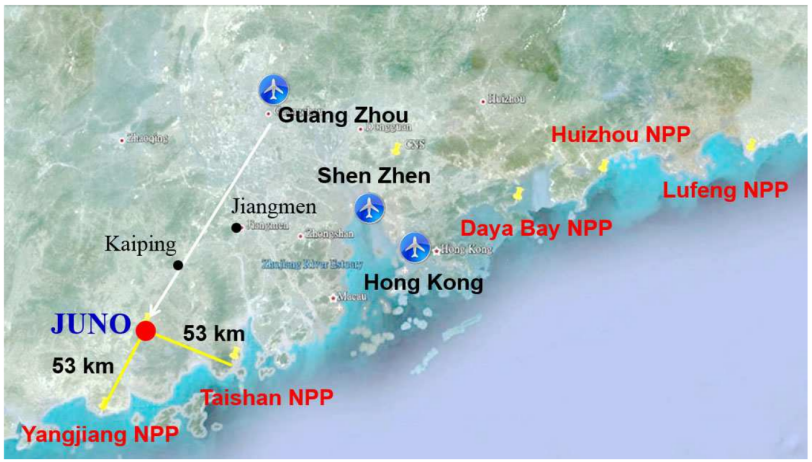
under tutorship of Dr. Cécile Jollet-Meregaglia

June 14, 2016

Goal of my internship

- JUNO experiment: detects $\bar{\nu_e}$
- **Background** cosmic muons $\Rightarrow$ $^9Li/^8He$ isotopes
- Muons detected by Cerenkov central detector and plastic scintillator detector (Top Tracker)

Goal: Optimize the muon reconstruction with the Top Tracker



Overview of presentation

1. Neutrino oscillations now
2. JUNO detector
3. Muon veto detector
4. Top Tracker
5. Results and conclusion

Neutrino oscillations

Pontecorvo-Maki-Nakagawa-Sakata matrix and oscillations parameters

PMNS matrix

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \overbrace{\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

PMNS contains:

- $\cos\theta_{ij}$
- $\sin\theta_{ij}$
- $e^{-1\delta}$

$\{i; j\} = 1, 2$ or 3

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Probability of oscillation:

$$P_{(\nu_\alpha \to \nu_\beta)} = |\langle \nu_\beta | \nu_\alpha(t) \rangle|^2$$

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Probability of oscillation:

$$P_{(\nu_\alpha \to \nu_\beta)} = |\langle \nu_\beta | \nu_\alpha(t) \rangle|^2$$

- $\Delta_{ij} = \frac{\Delta m^2_{ij} L}{4E}$
- $\Delta m^2_{ij} = m^2_i - m^2_j$
- L=baseline (distance)
- E=energy

$$P_{(\bar{\nu}_e \to \bar{\nu}_e)} = 1 - \sin^2 2\theta_{12} c^4_{13} \sin^2 \Delta_{21} - \sin^2 2\theta_{13} \left(c^2_{12} \sin^2 \Delta_{31} + s^2_{12} \sin^2 \Delta_{32} \right)$$

Known values

Parameter	Best fit	1σ	Best fit	1σ
	Normal mass ordering ($m_1 < m_2 < m_3$)		Inverted mass ordering ($m_3 < m_1 < m_2$)	
Δm^2_{21}	7.54×10^{-5} eV^2	3.2%	7.54×10^{-5} eV^2	3.2%
$\lvert\Delta m^2_{31}\rvert$	2.47×10^{-3} eV^2	2.4%	2.42×10^{-3} eV^2	2.5%
$sin^2\theta_{12}$	0.308	5.5%	0.308	5.5%
$sin^2\theta_{13}$	2.34×10^{-2}	8.3%	2.40×10^{-2}	8.5%
$sin^2\theta_{12}$	0.437	6.4%	0.455	19%
δ(rad)	4.37	23%	4.12	24%

From combined studies of several groups [1]

[1] F.Capozzi, G.L. Fogli, E.Lisi, A.Marrone, D.Montanino and A.Palazzo, *Phys. Rev. D 89 (2014)* [arXiv:1312.2878 [hep-ph]]
D.V.Forero, M.Tortola and J.W.F.Valle, *Phys. Rev. D 90 (2014)* [arXiv:1405.7540 [hep-ph]]
M.C.Gonzalez-Garcia, M.Maltoni and T.Schewtz, *JHEP 1411 (2014)* [arXiv:1409.5439 [hep-ph]]

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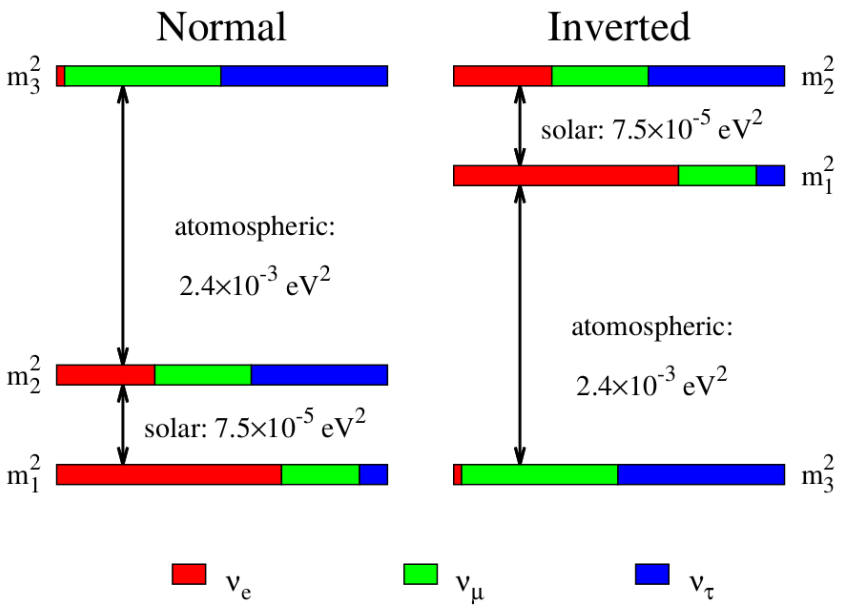
Sign ? + or - ?

Known values

Two orders of magnitude between Δm^2_{32} and Δm^2_{12}!



$$P_{(\bar{\nu_e}\to\bar{\nu_e})} = 1 - cos^4\theta_{13}sin^2 2\theta_{12}sin^2\Delta_{12}$$
$$- sin^2 2\theta_{13}\left(sin^2\Delta_{31} + sin^2\theta_{12}sin^2\Delta_{12}cos2\Delta_{12}\right)$$
$$\pm sin^2 2\theta_{13}sin^2\theta_{12}sin2\Delta_{12}sin2|\Delta_{13}|$$

Known values

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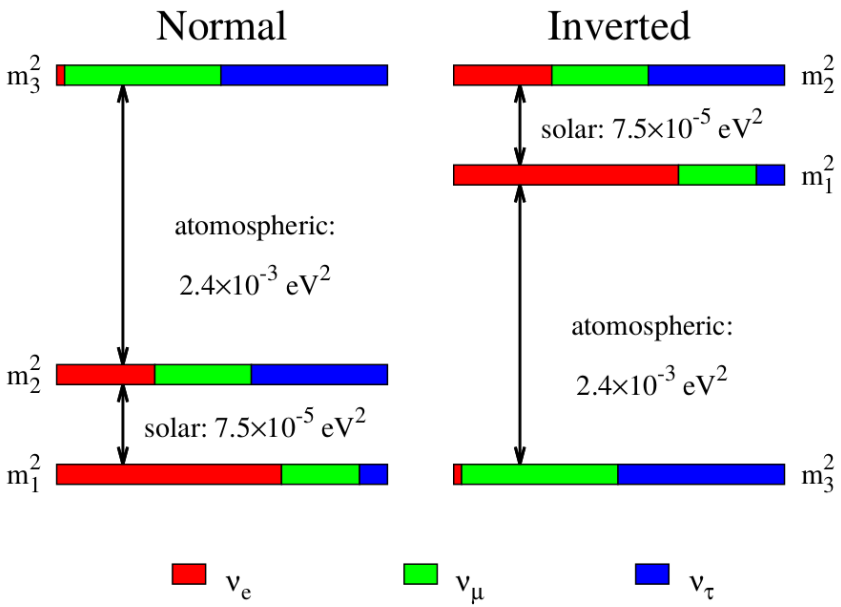

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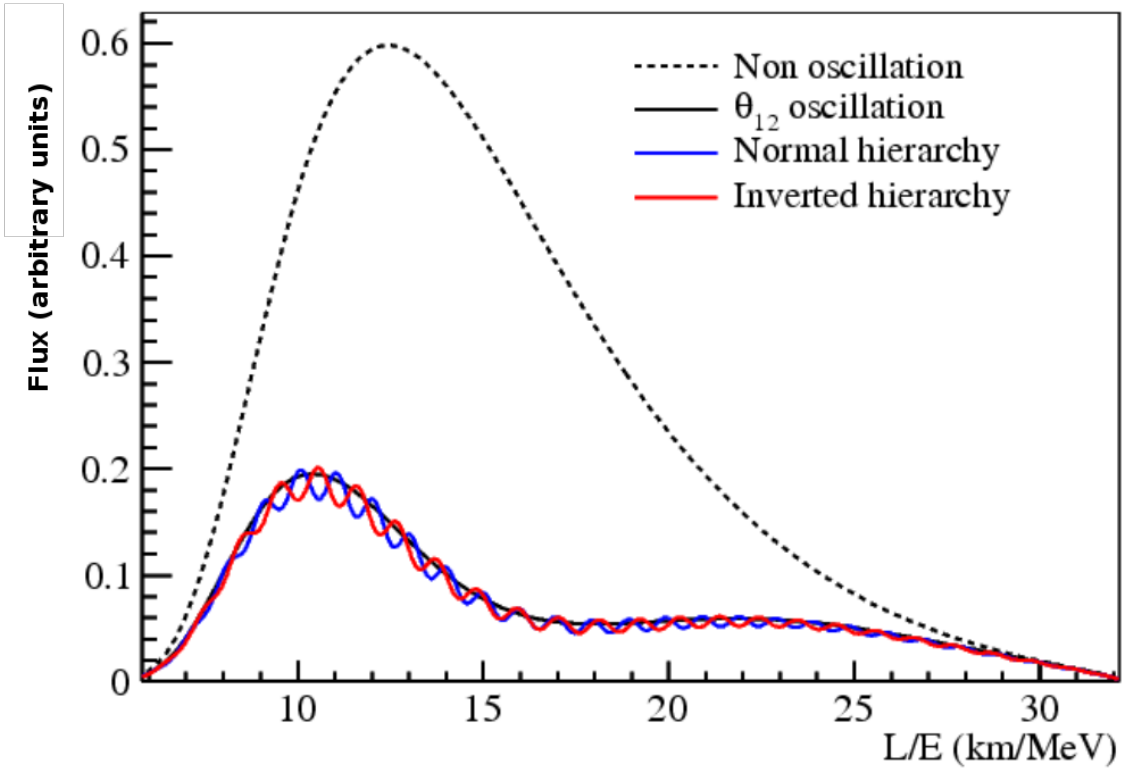
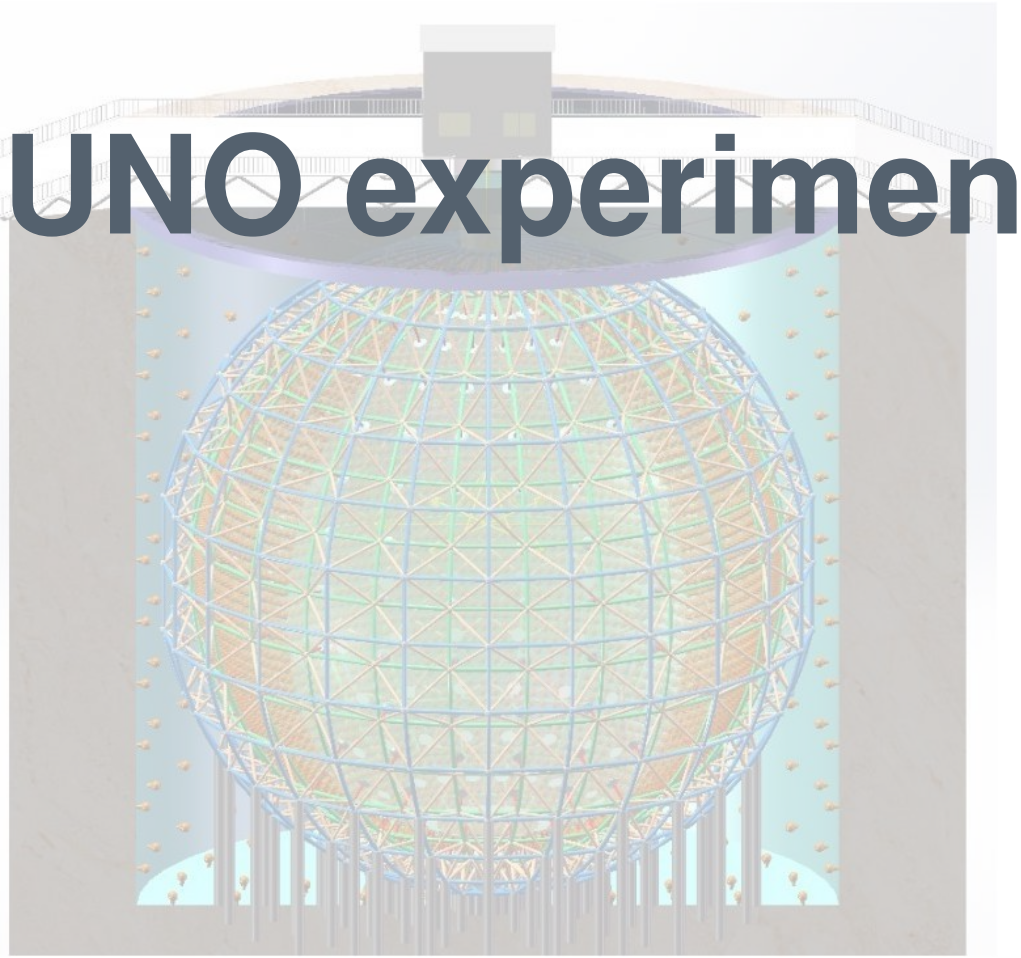
Mass hierarchy in JUNO



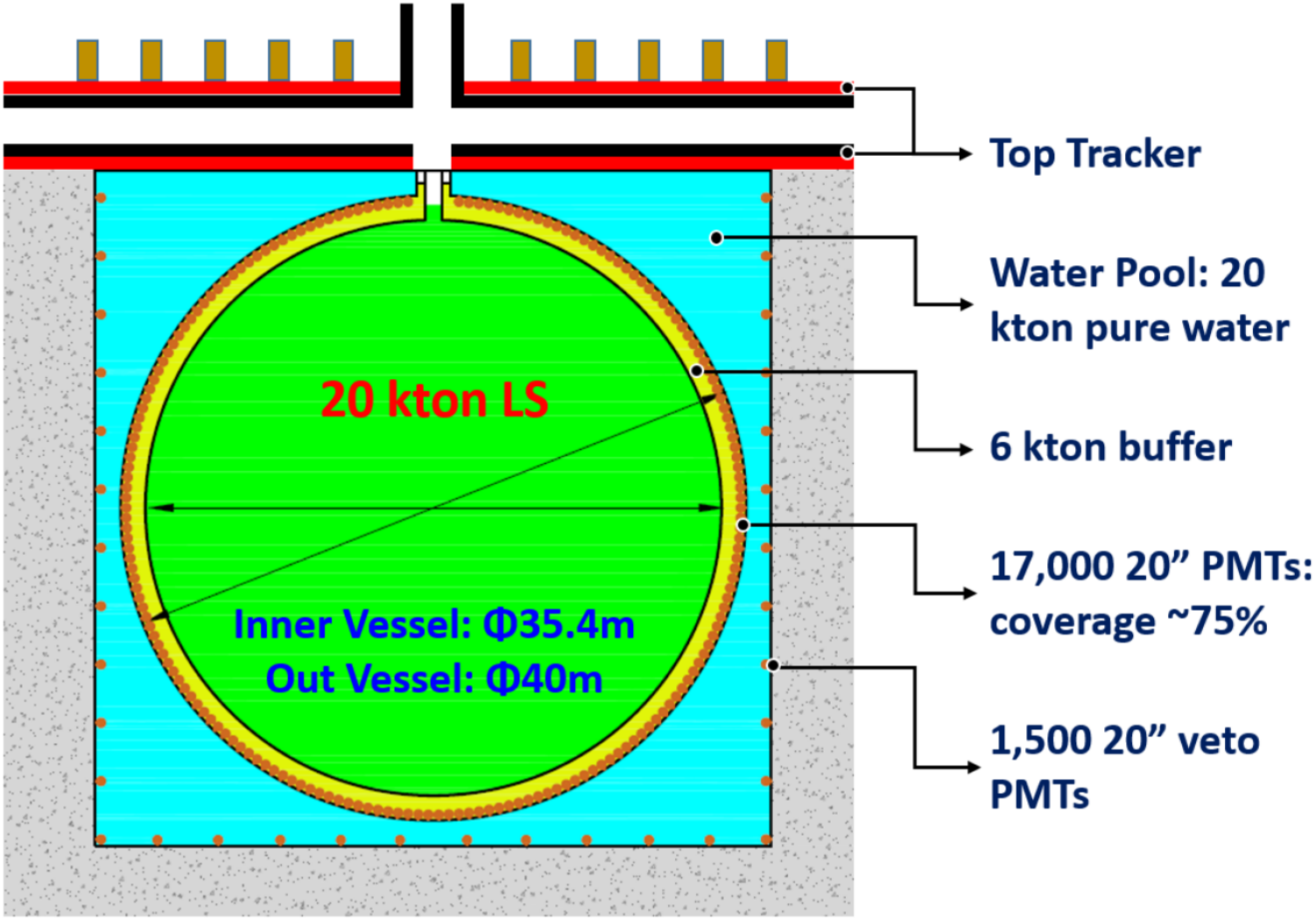
- Distance: 53 Km from nuclear reactors
- **Energy: need** $3\%/\sqrt{E}$ **precision**

Liang Zhan, Yifang Wang, Jun Cao, Liangjian Wen, *Phys. Rev. D 78 (2008)* [arXiv:0807.3203[hep-ex]]
Liang Zhan, Yifang Wang, Jun Cao, Liangjian Wen, *Phys. Rev. D 79 (2009)* [arXiv:0901.2976[hep-ex]]

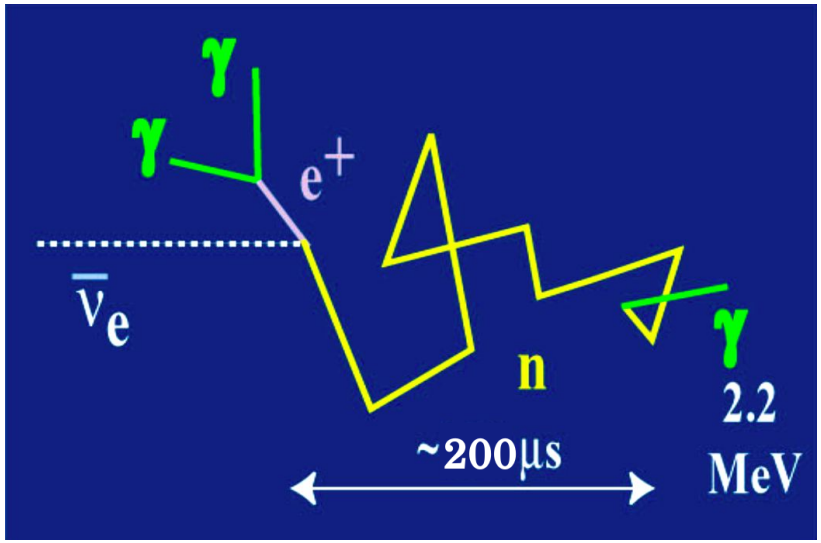
JUNO experiment



General presentation



Inverse β decay events signature



$$\bar{\nu_e} + p \rightarrow e^+ + n$$

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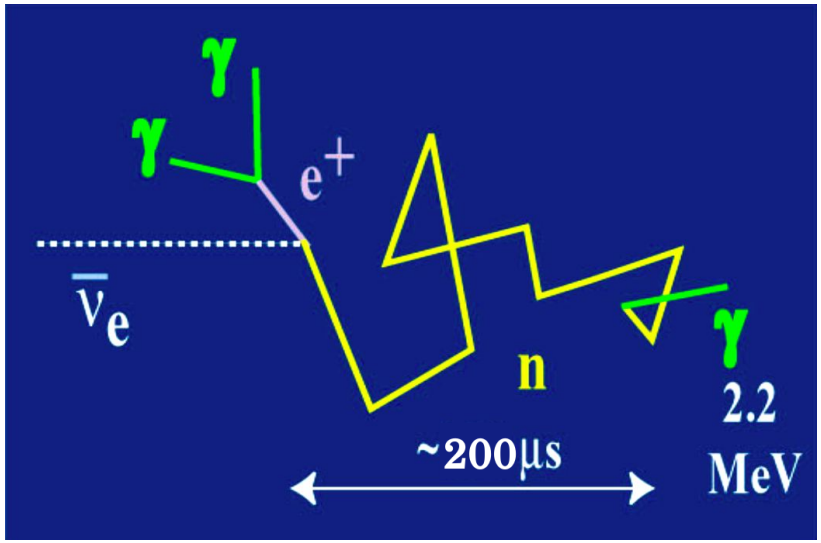

$$\bar{\nu_e} + p \rightarrow e^+ + n$$

Background: cosmogenic isotopes from cosmic muons

$^9Li/^8He$ decay through $\beta - n$:
β mimics e^+ and n... mimics n.

Impact on statistics

Expectations

83 Inverse β Decay (IBD) events per day **VS** 84 $^{9}Li/^{8}He$ events per day.
Need to tag background!

Impact on statistics

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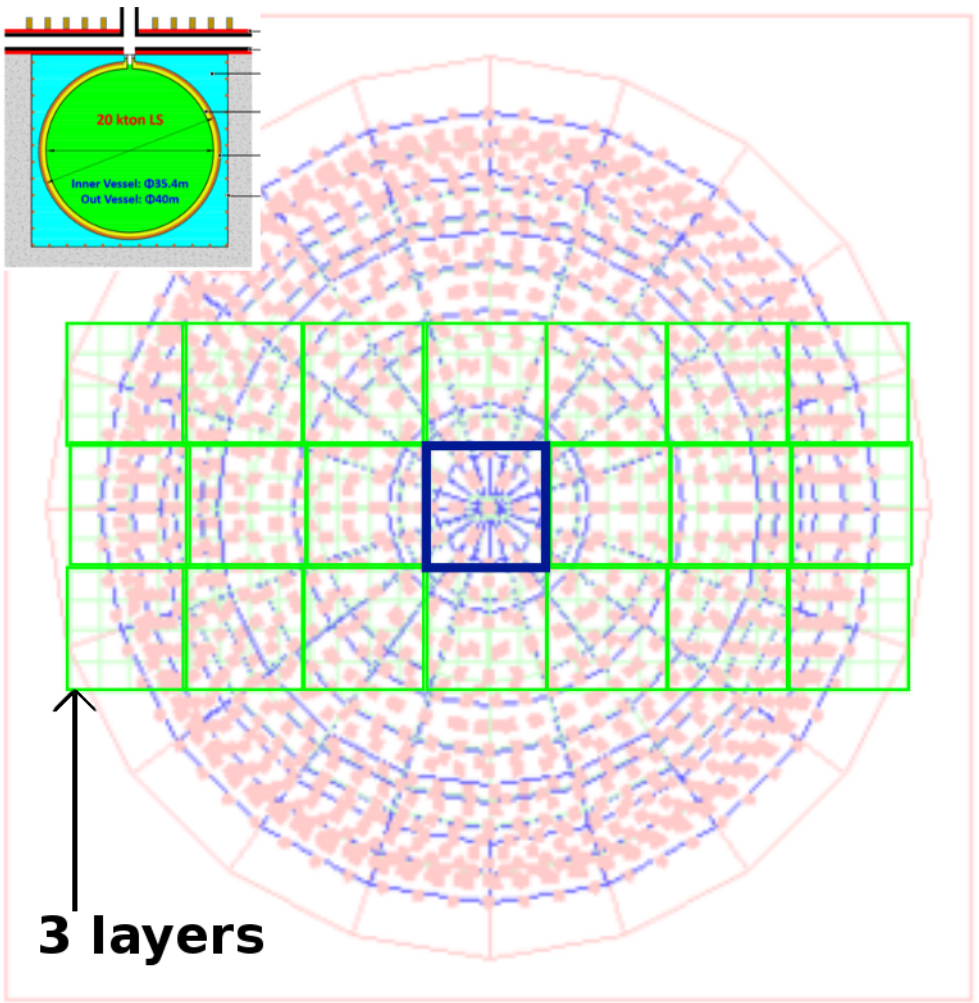
83 Inverse β Decay (IBD) events per day **VS** 84 $^{9}Li/^{8}He$ events per day.
Need to tag background!

Half life : 178 ms and 119 ms
$\rightarrow$ veto all detector for 1.2 s? **Too long**.
$\rightarrow$ Reconstruct path of muons and veto a volume around it
$\rightarrow$ Need a good precision in reconstruction!

Muon veto detector

Central detector to tag muons



Central detector:

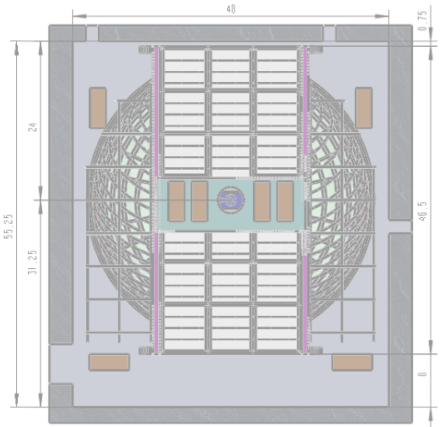
- 99% tagging efficiency for single muons
- Reconstruction algorithm complicated

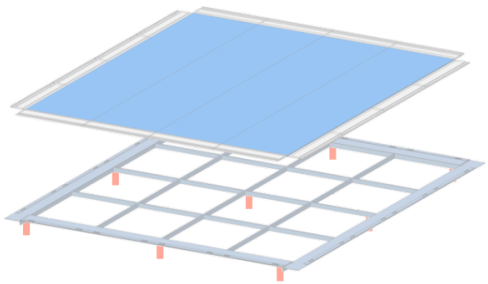
Top Tracker:

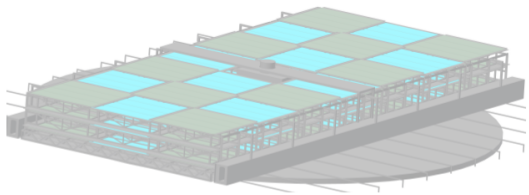
- Plastic scintillator detector from OPERA
- Well-known technology
- Efficiency around 90%
- Covers one diameter $\Rightarrow$ symmetry

$\Rightarrow$ **Validate tracking from central detector**

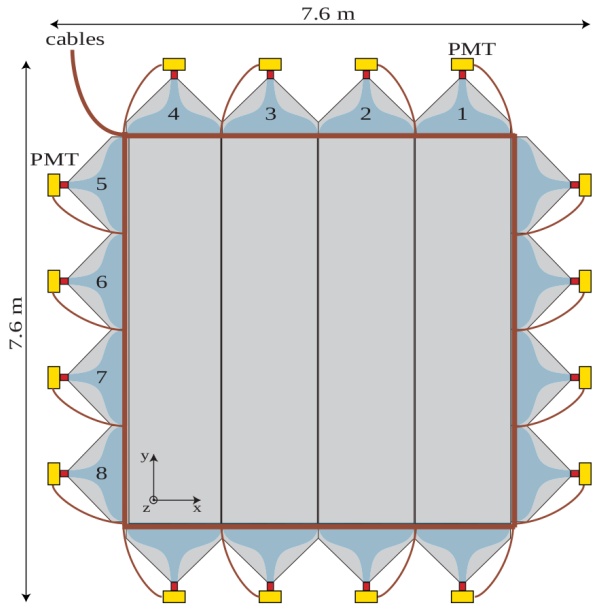
Top Tracker in details





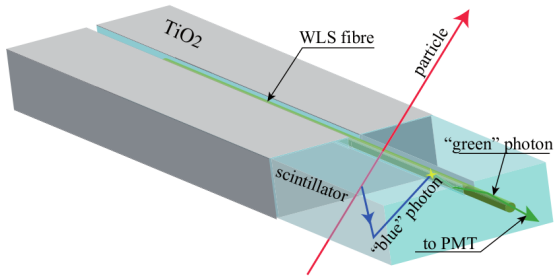


OPERA Target Tracker reconverted

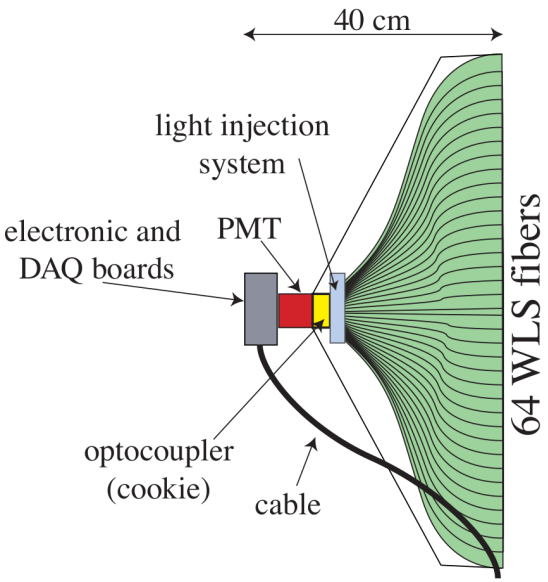


- TT = 62 walls
- Wall = 2×4 modules
- Module = 64 strips

- Strip = plastic+wavelength shifting fiber
- 6.7 m × 26.4 mm
- Detection on **both sides** by Photo Multiplier Tubes (PMs)



Optical cross talk



- PM = pixels
- $\Rightarrow$ 1 PM per module

One PM reads 64 strips

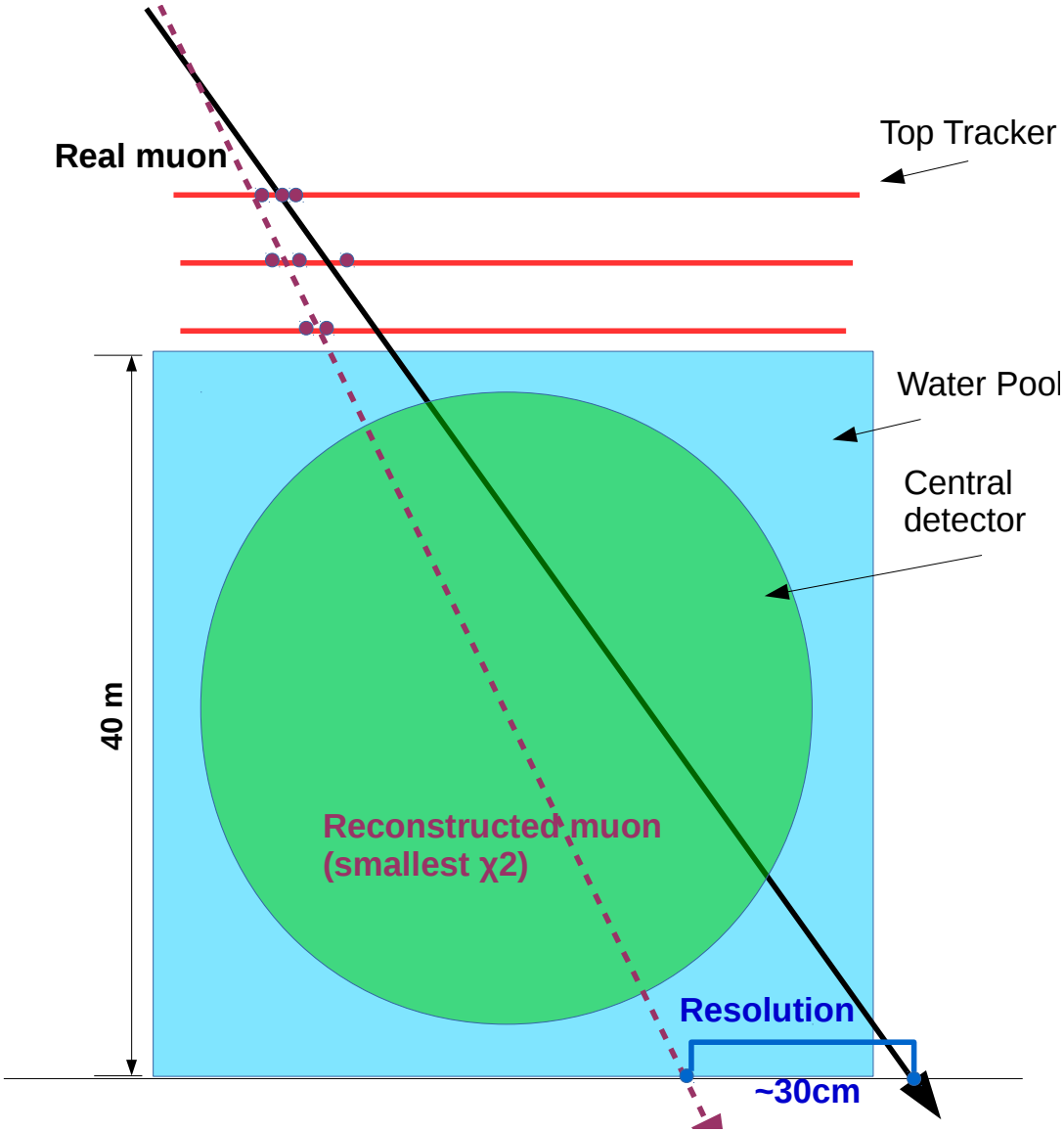
57	58	59	60	61	62	63	64
49	50	51 15	52 16	53 17	54	55	56
41	42 6	43 7	44 8	45 9	46 10	47	48
33	34 -2	35 -1	36 0	37 1	38 2	39	40
25	26 -10	27 -9	28 -8	29 -7	30 -6	31	32
17	18	19 -17	20 -16	21 -15	22	23	24
9	10	11	12	13	14	15	16
1	2	3	4	5	6	7	8

- Photon can trigger wrong channel
- $\Rightarrow$ Can loose position information

Top Tracker performance

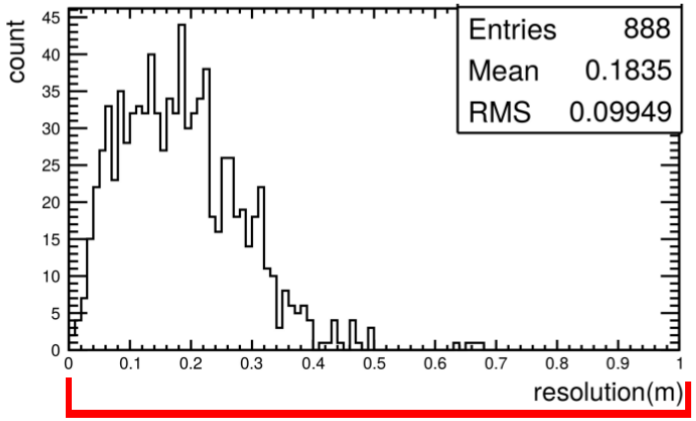
Simulation done with GEANT4 and analysis with ROOT

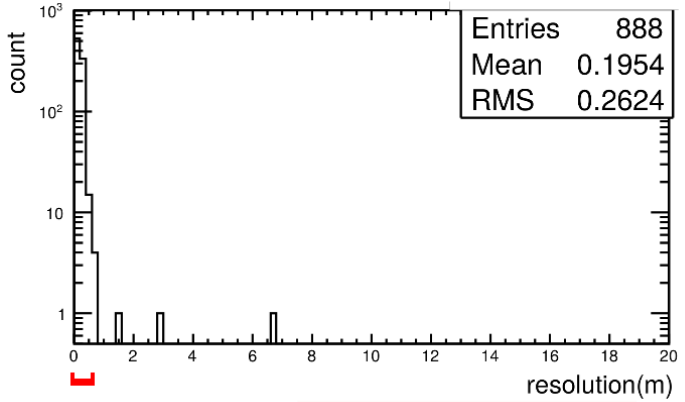
Resolution : definition



Resolution : impact of cross talk

Without cross talk :





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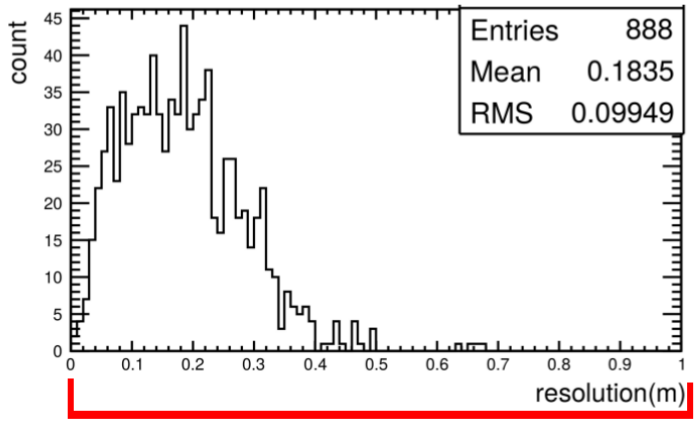
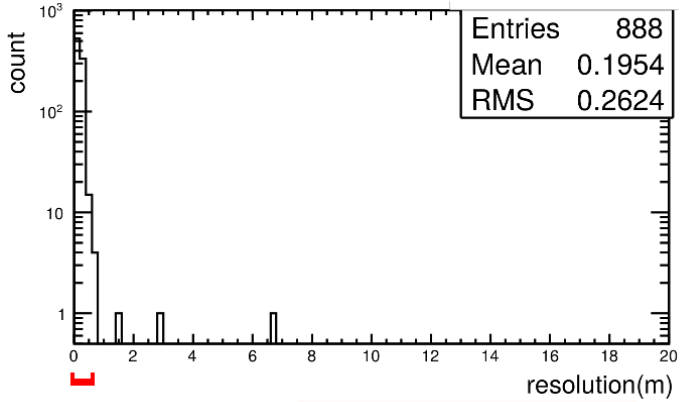
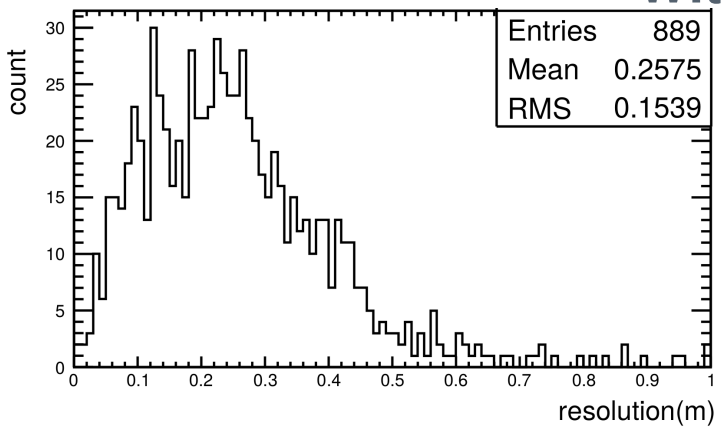
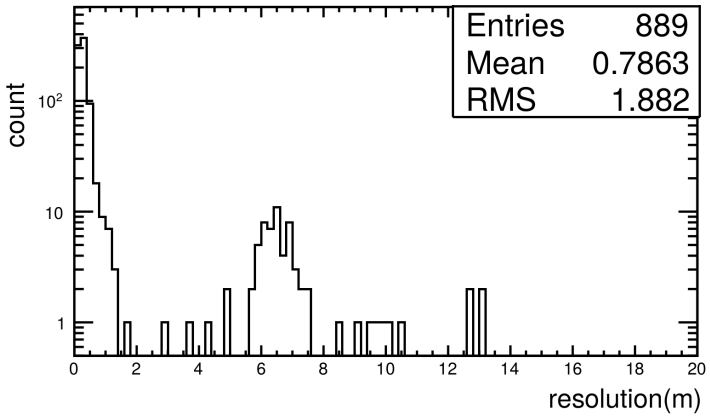




With cross talk :





Mean resolution : 18±10 cm → 25±15 cm

Events with resolution > 60 cm : 0.14±0.05% → 2.12±0.2%

Cross talk filter

1–Who is real in the module?

Strip with max left+right photo electrons

2–Cross talk Criteria

- Geometric
- Number of photo electrons : cross talk = stochastic

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Define a coefficient

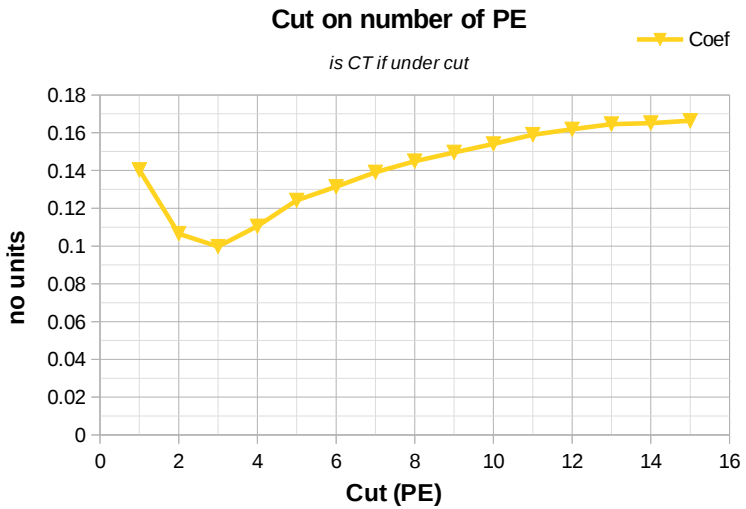
$$coef = \frac{\text{False positive}}{\text{efficiency}}$$

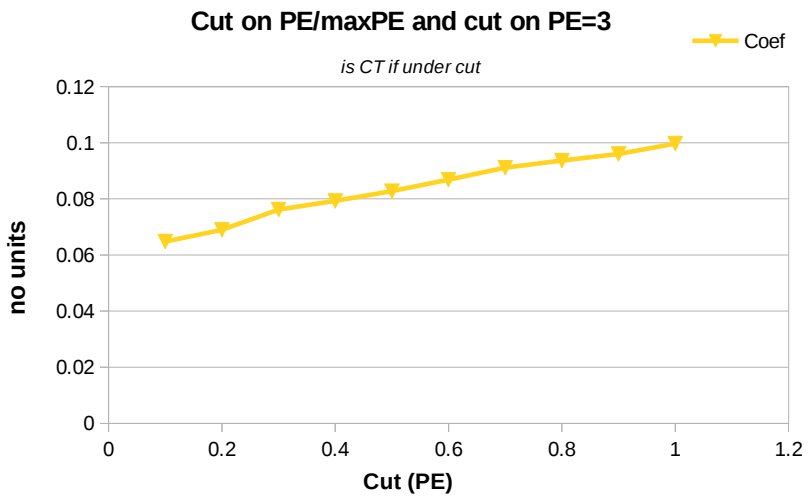
Small coef means more cross talk tagged and less good events killed

Test criteria

Hit=photo electrons on right PM and left PM

$\Rightarrow$ **Criteria**: left+right, left$\times$right, $\frac{\text{left}-\text{right}}{\text{left}+\text{right}}$, $\frac{\text{left}+\text{right}}{\text{(left+right) of real hit}}$





Resolution after filter

Best criteria :

Geometric **and** left+right < 3 PE **and** sum/sum max < 0.3

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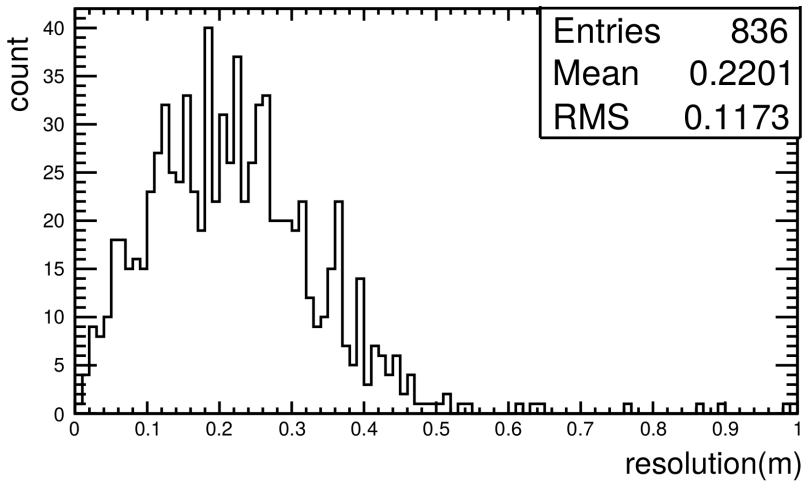
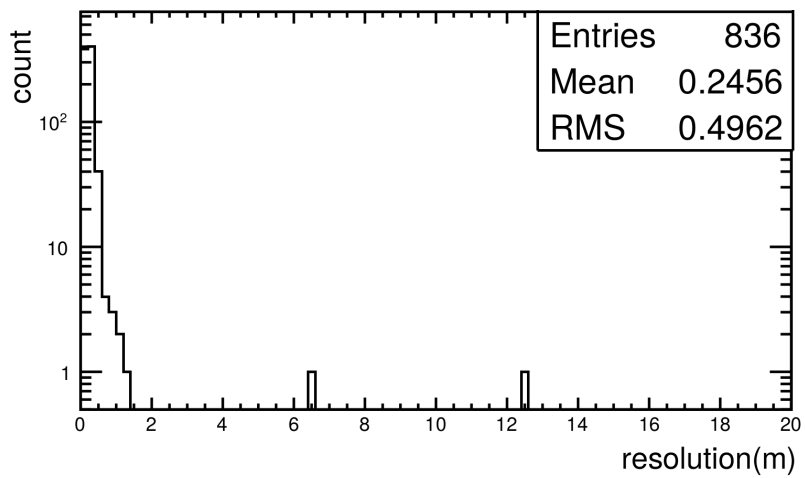




Results

Mean resolution : 22±11 cm

Events with resolution > 60cm : 0.16±0.06%

1.7±0.8% loss of muon tagging efficiency

$^9Li/^8He$ rates

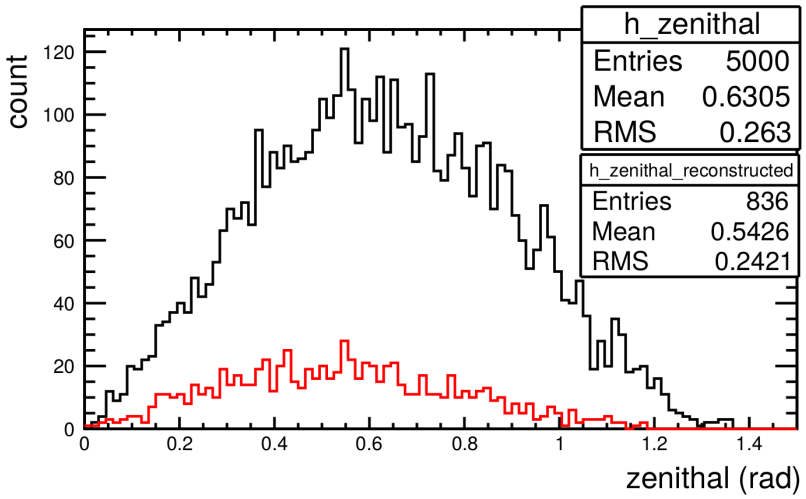
Rate of $^9Li/^8He$: $R_{Li} = \sum_{i=1}^{N} \left(E_i^{0.74} \times Length\right) \frac{0.0215}{time}$

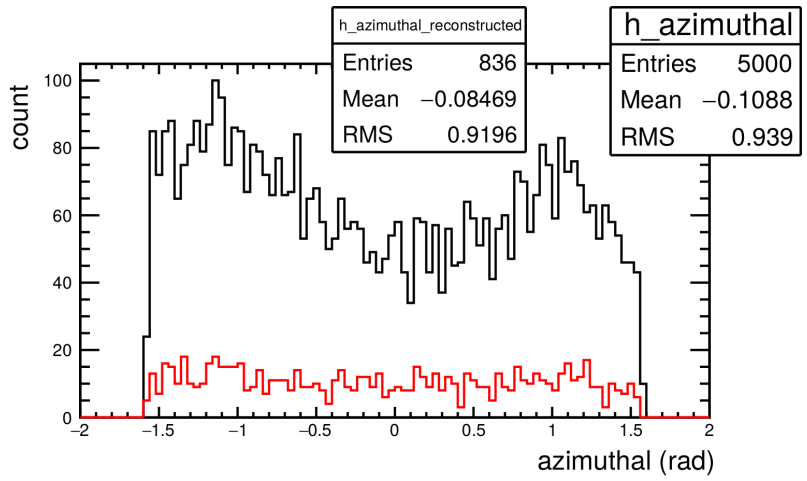
	R_μ (Hz)	$^9Li/^8He$ per day
central detector	3.7	85.9
central detector and TT	1.1(30%)	25.8(30%)

$\Rightarrow$ 30% of muons cut out with a volume of 3 m radius

$\Rightarrow$ Limit = geometric acceptance

Angular distributions





⇒ No straightforward deduction of total muon distribution from Top Tracker

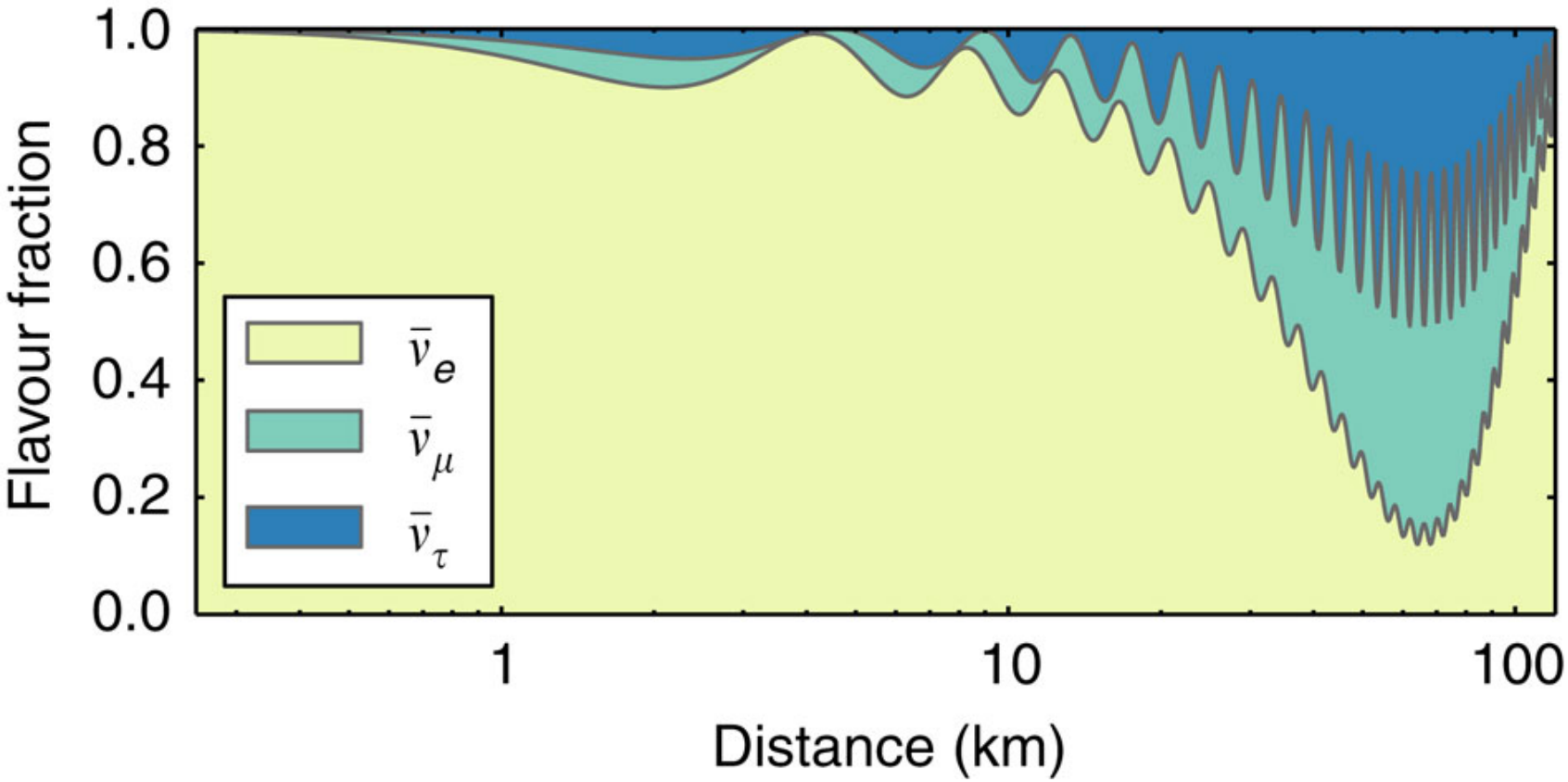
⇒ But no dead angles: can use TT to validate central detector tracking and extrapolate to whole detector

Conclusion

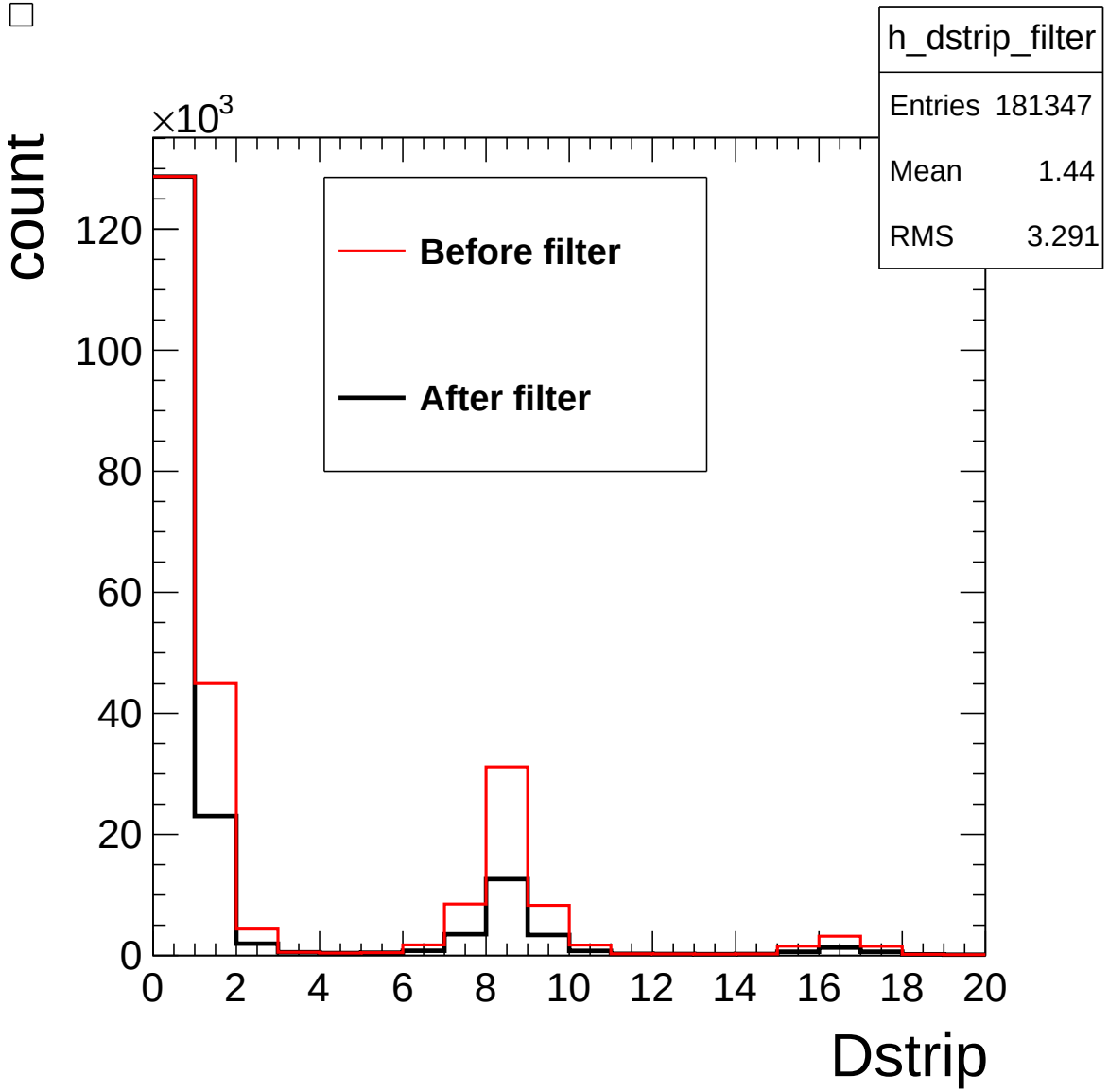
- Spatial resolution: 22±11 cm (18 ± 10 without cross talk)
- Number of bad events: 0.16±0.06% (0.14±0.05% without cross talk)
- 1.7±0.8% loss of muon tagging efficiency could be harmful for $^{9}Li/^{8}He$ tagging
- Angular reconstruction: more work needed
- Next step: reconstruct showering muons

Thanks for your attention!

Neutrino oscillation probability



Relative strip difference



Liquid Scintillator

- ionisation process: 10^4 $\gamma_{uv-blue}$/MeV
- Solvent: Linear alkyl benzene (LAB)
- Scintillating fluor: PPO (2,5− diphenyloxazole) at 3 g/L
- Wavelength shifter: Bis−MSB at 15 mg/L
- Light yield: Minimum of 1,100 photoelectrons per MeV
- Transparency: Attenuation length at 430 nm: > 22 m