Jinping Neutrino Experiment and DSNB (SRN) with slow liquid scintillator

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(for the research group)

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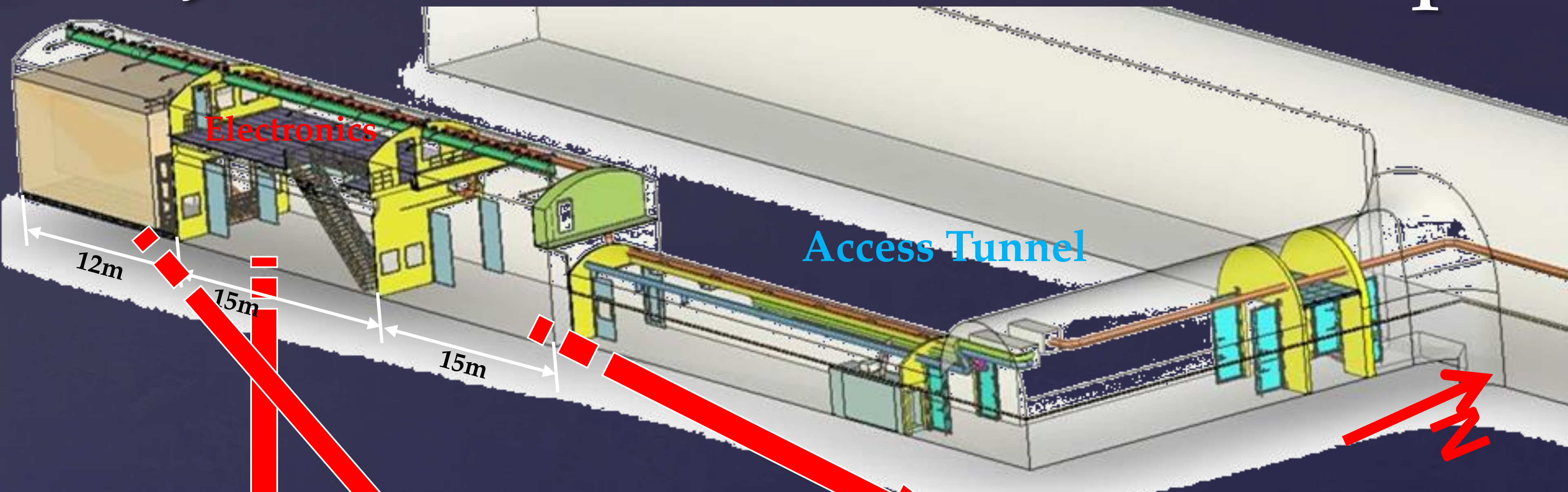
Location of CJPL

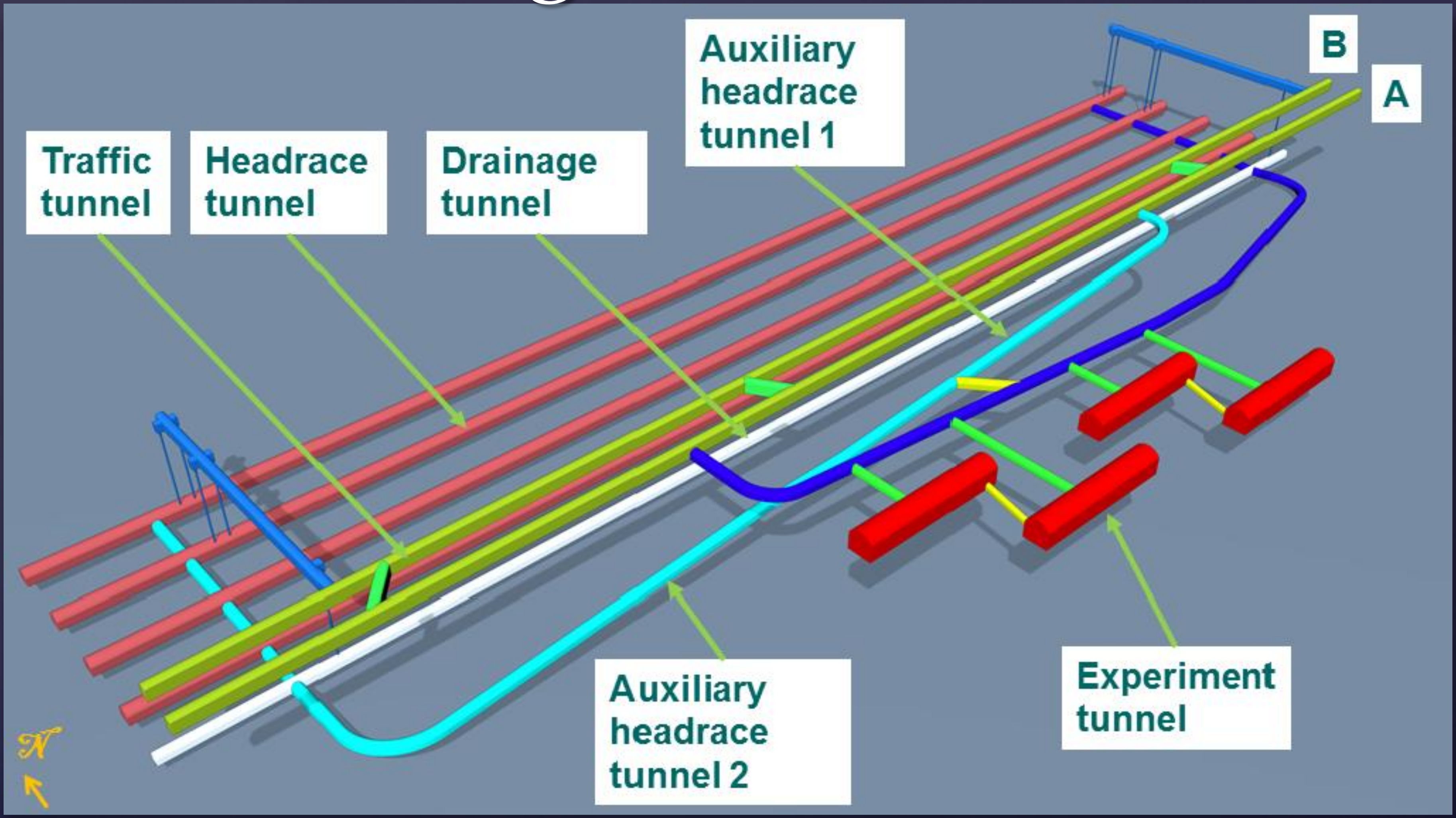
Travel:

1. To Xichang airport by air (from Beijing, Shanghai, etc.)
2. To Jinping laboratory by car (<2 hours)

CJPL-I and Dark Matter Exp.



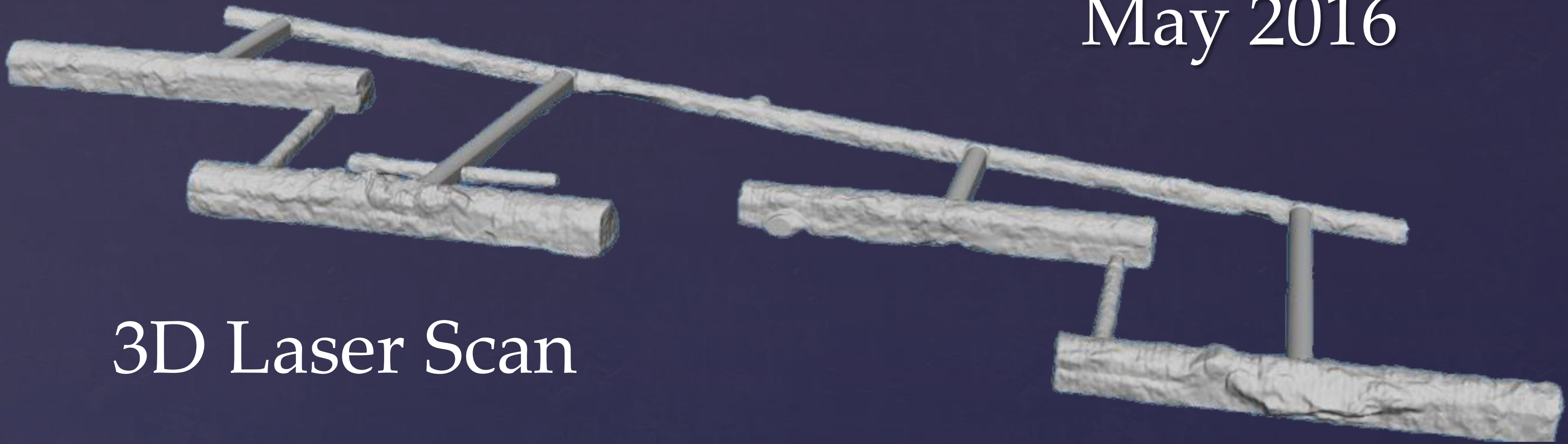
Design of CJPL-II



	CJPL-I	CjPL-II
Rock Work	4000 m^3	131000m^3

CJPL Current status

May 2016

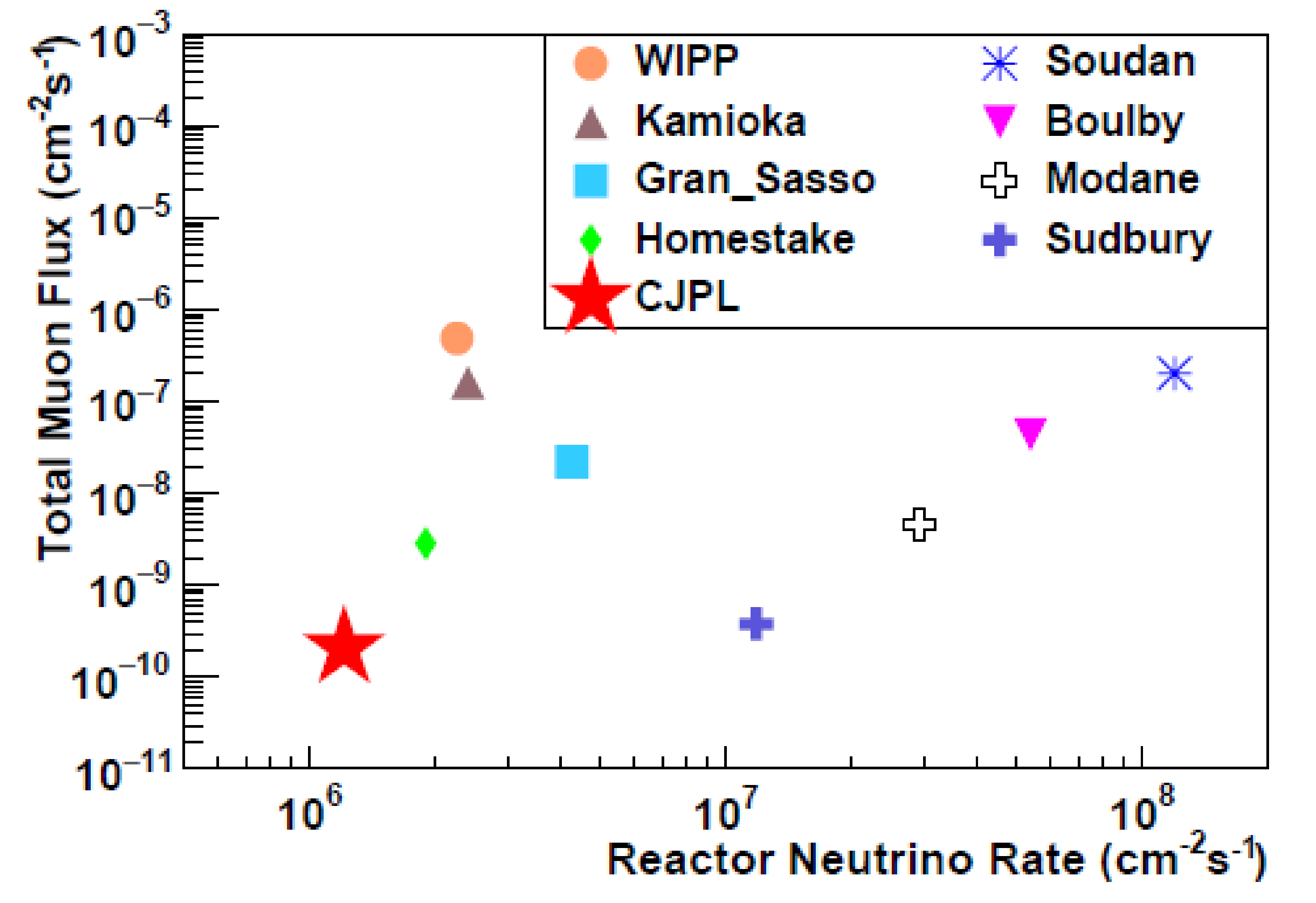


3D Laser Scan

CDEX foundation pit

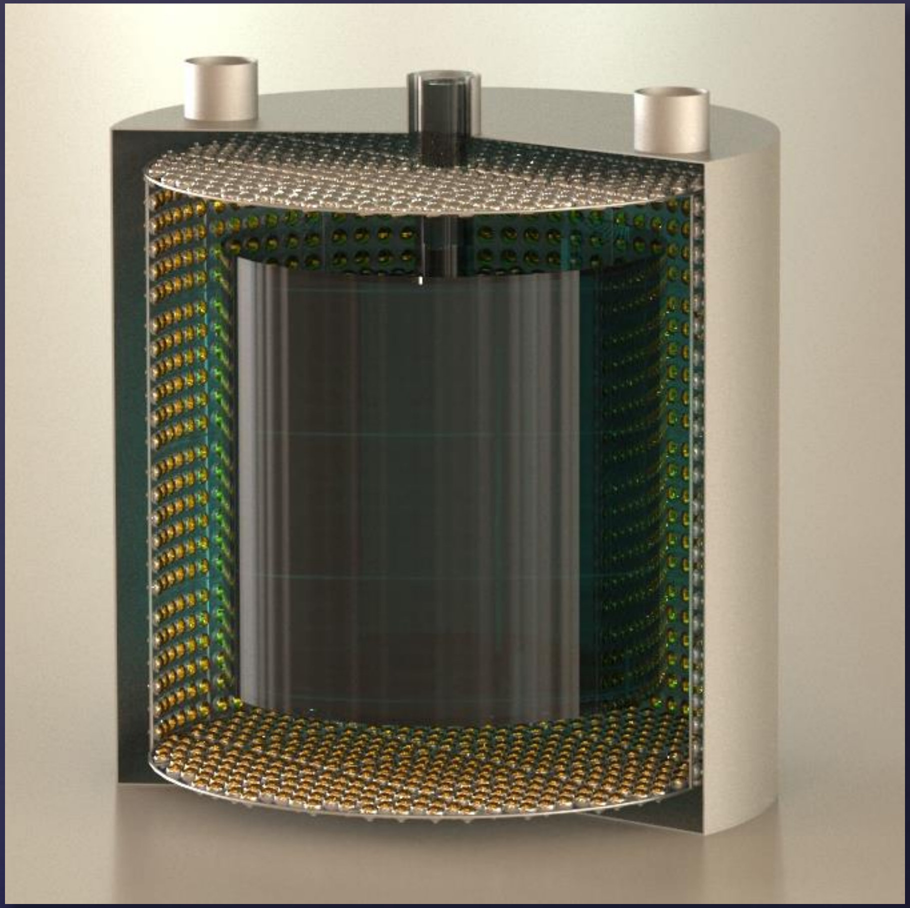
PandaX foundation pits

Ideal Low Bkg. Laboratory



→Overburden 2400 m←

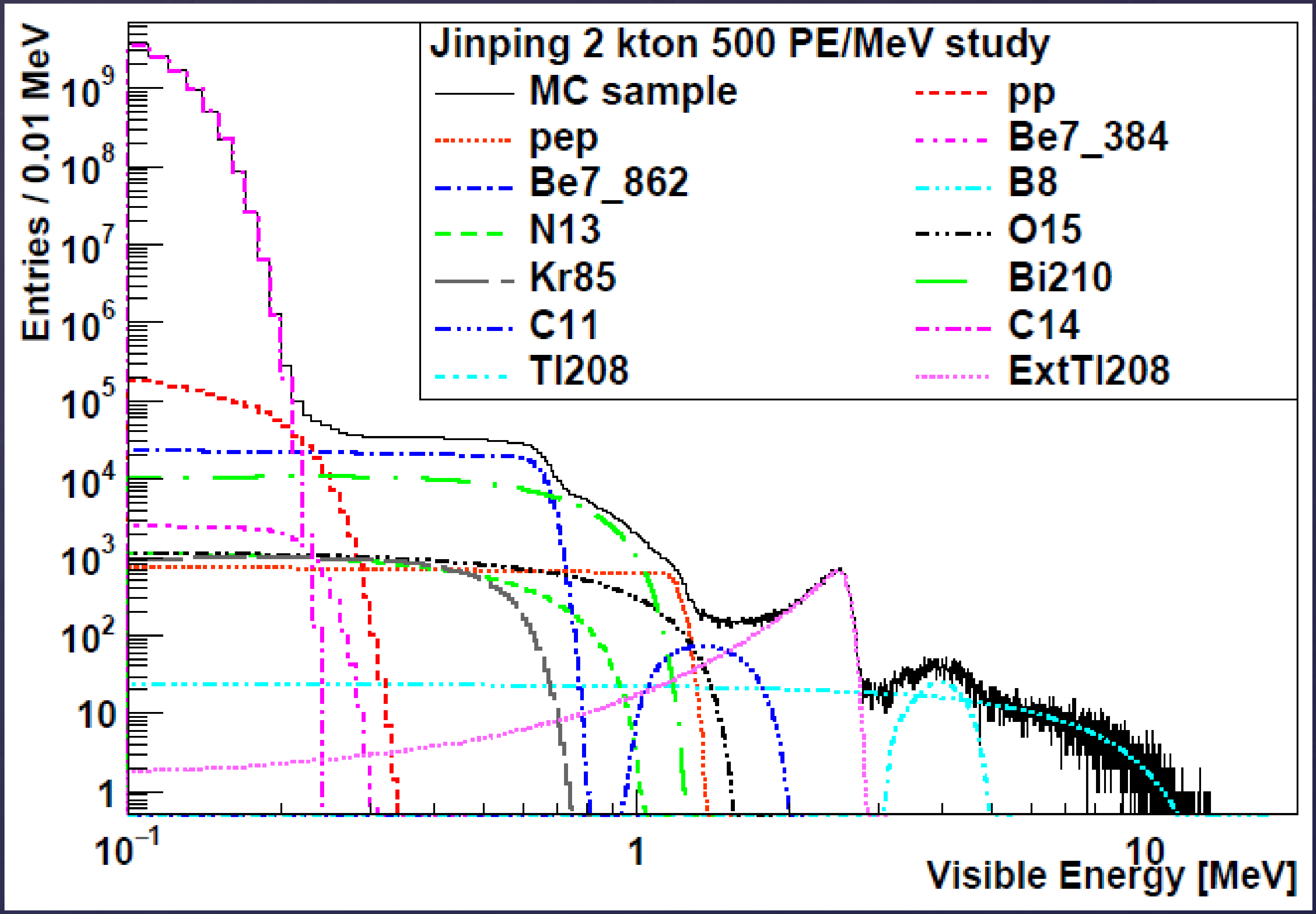
Jinping Neutrino Experiment



Or spherical detector
Or a single detector

- TWO detectors
- Total fiducial mass 2000 tons (solar), 3000 tons (geo, supernova)
- Liquid scintillator or slow liquid scintillator
- ~20 m for height and diameter for each
- Light Yield>500 PE/MeV

Solar Neutrinos

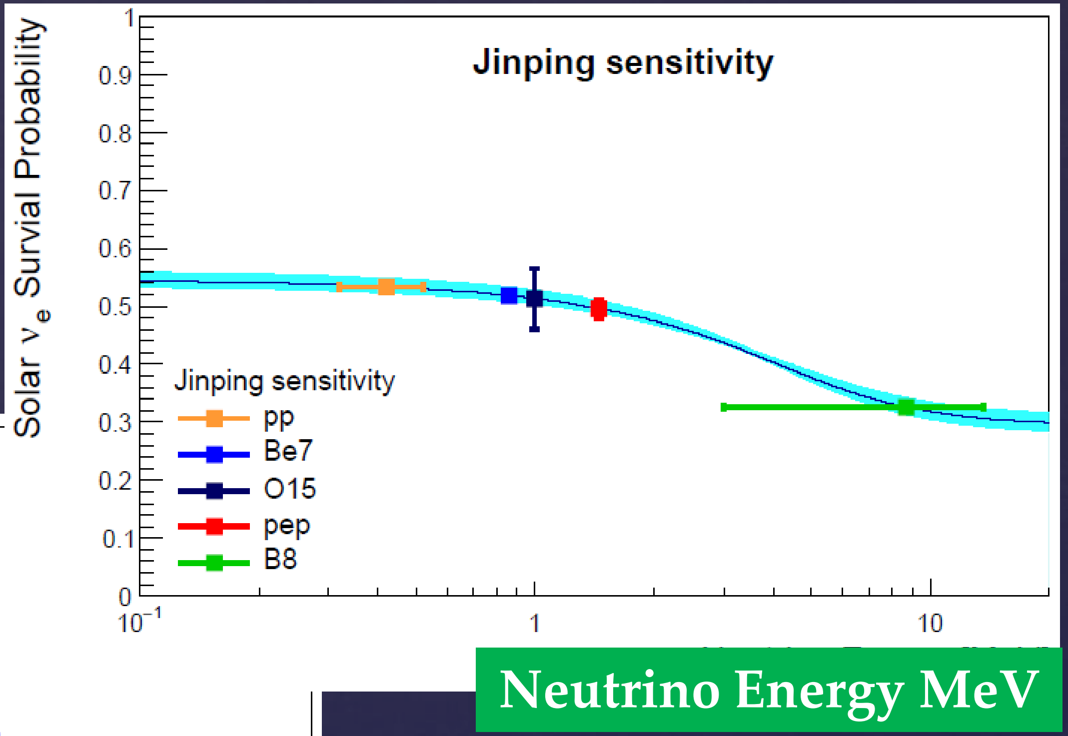


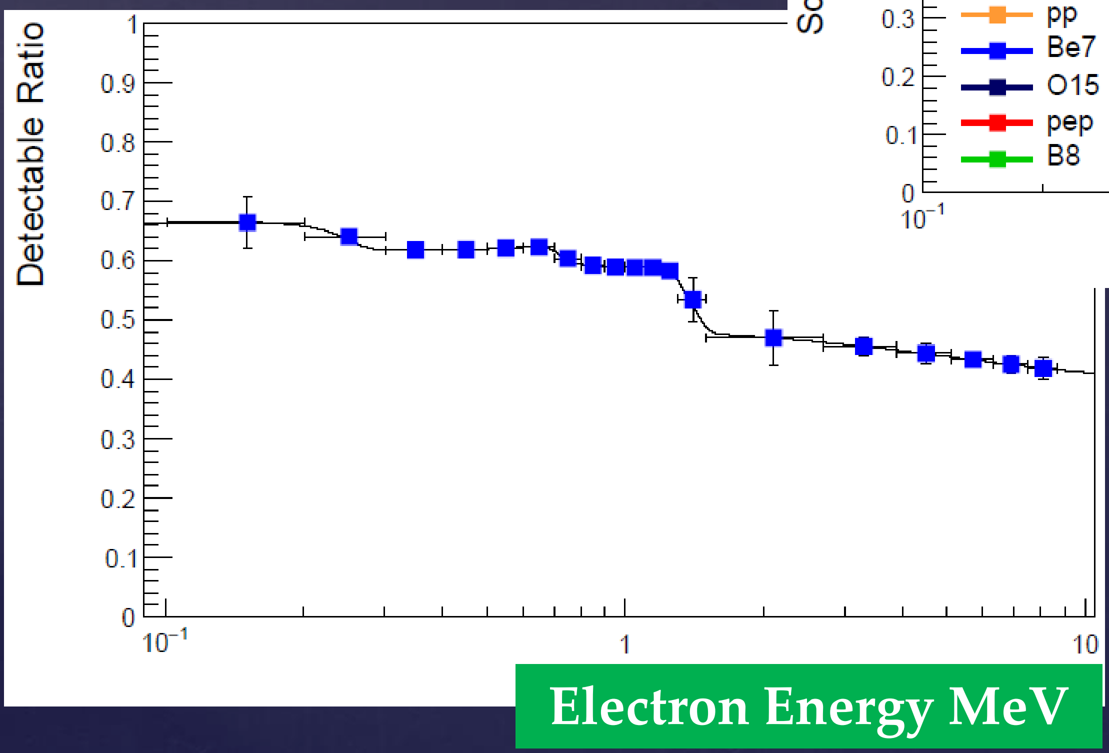
Simulation study with Borexino and Jinping assumptions.

Various target mass and resolutions studied.

Solar Neutrinos Oscillation

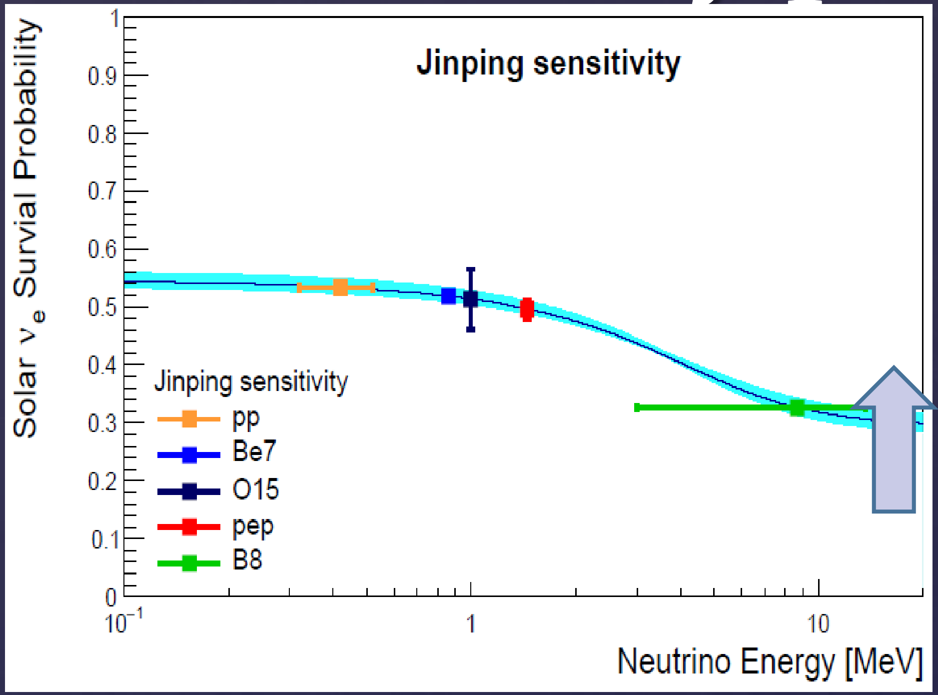
Constrain neutrino oscillation upturn in Solar density





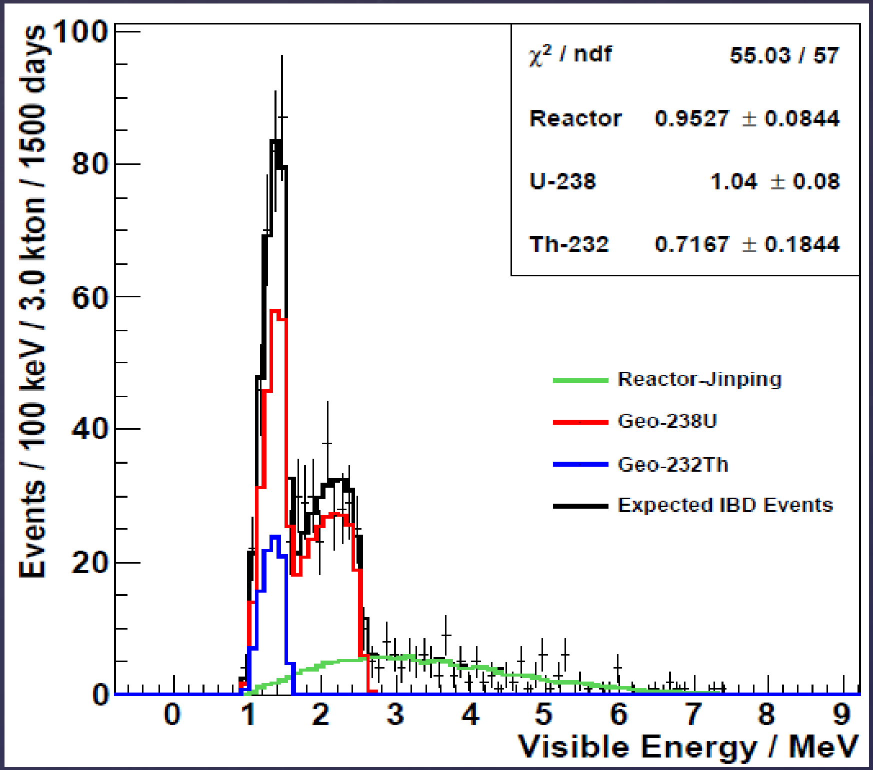
Reject or discover new physics (sterile, NSI, CPT)

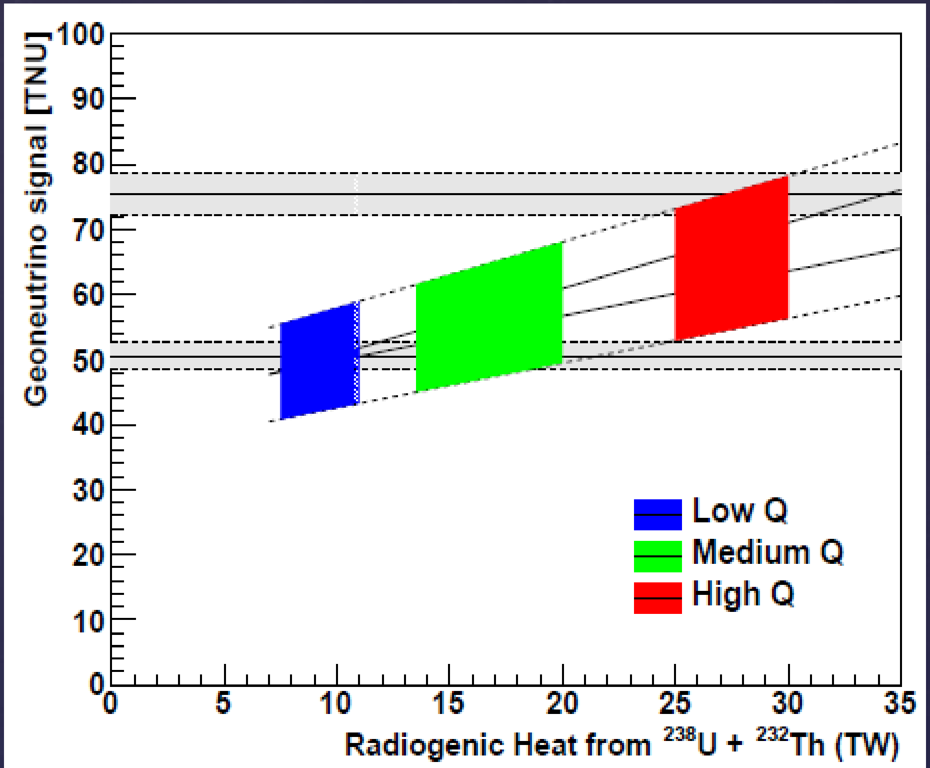
Discover CNO neutrino Address metallicity problem



- Precise measure of all components
- Expected to discover CN ν
- O-15 precision 10%
- Direct proof for metallicity problem

Geoneutrinos



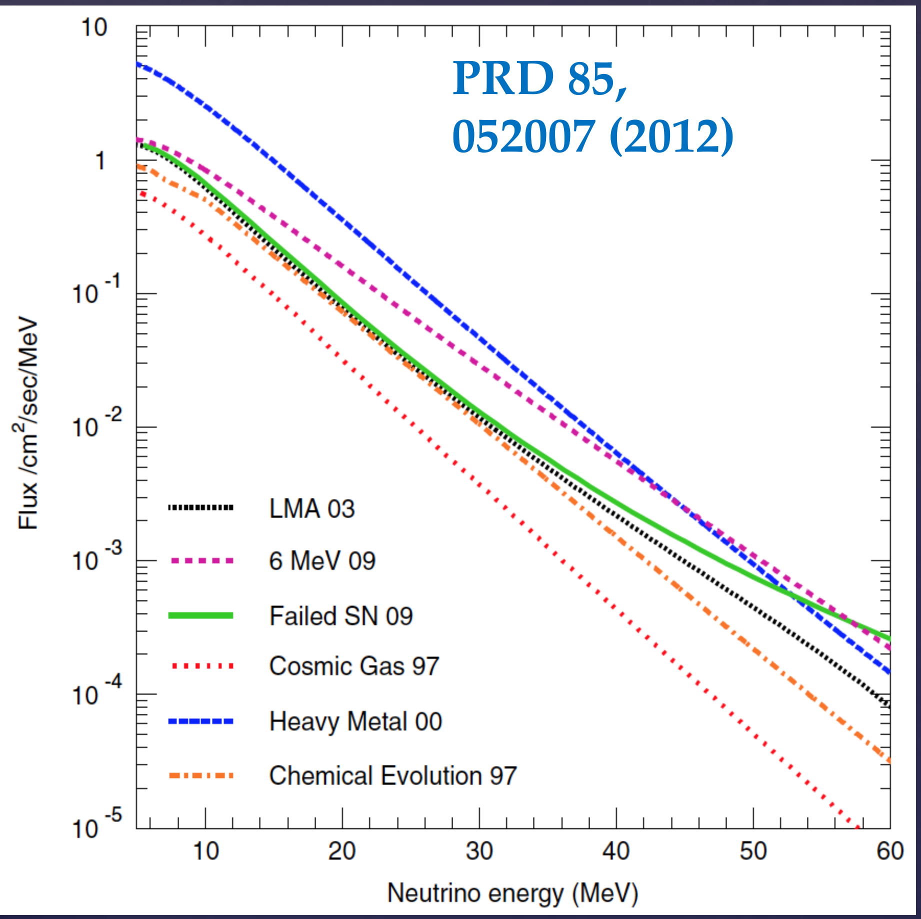


- U geoneutrino spectrum
- Th geoneutrino spectrum
- Th/U ratio ~ 10%
- Geo-reactor

- Address mantel contribution
- Geoneutrino flux prediction at Jinping

Sci. Rep. 6, 33034 (2016)

SRN spectrum



$$\frac{d\phi(E)}{dE} = \int R_{ccSN}(z)\frac{dN(E')}{dE'}(1+z)\left|\frac{dt}{dz}\right|dz$$

1. R_{ccSN} - supernova rate (known with precision)
2. dN/dE' - neutrino spectrum (Some knowledge)
3. Others: redshift or constant

SRN Detection

- Equal amount for each flavors;
- SRN are identified primarily through IBD interactions in a hydrogen-rich detector

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

$$\rightarrow + p \rightarrow D + \gamma\ (2.2\ MeV) \quad (200\ \mu s)$$

$$\rightarrow + Gd \rightarrow Gd^* \rightarrow Gd + \gamma\text{'s}\ (8\ MeV) \quad (30\ \mu s)$$

✓ Liquid scintillator – KamLAND [scintillation light]
✓ Water – SuperK w/ or w/o neutron tagging [Cherenkov light]
✓ Gd-Water - Super K with neutron tagging [Cherenkov light]

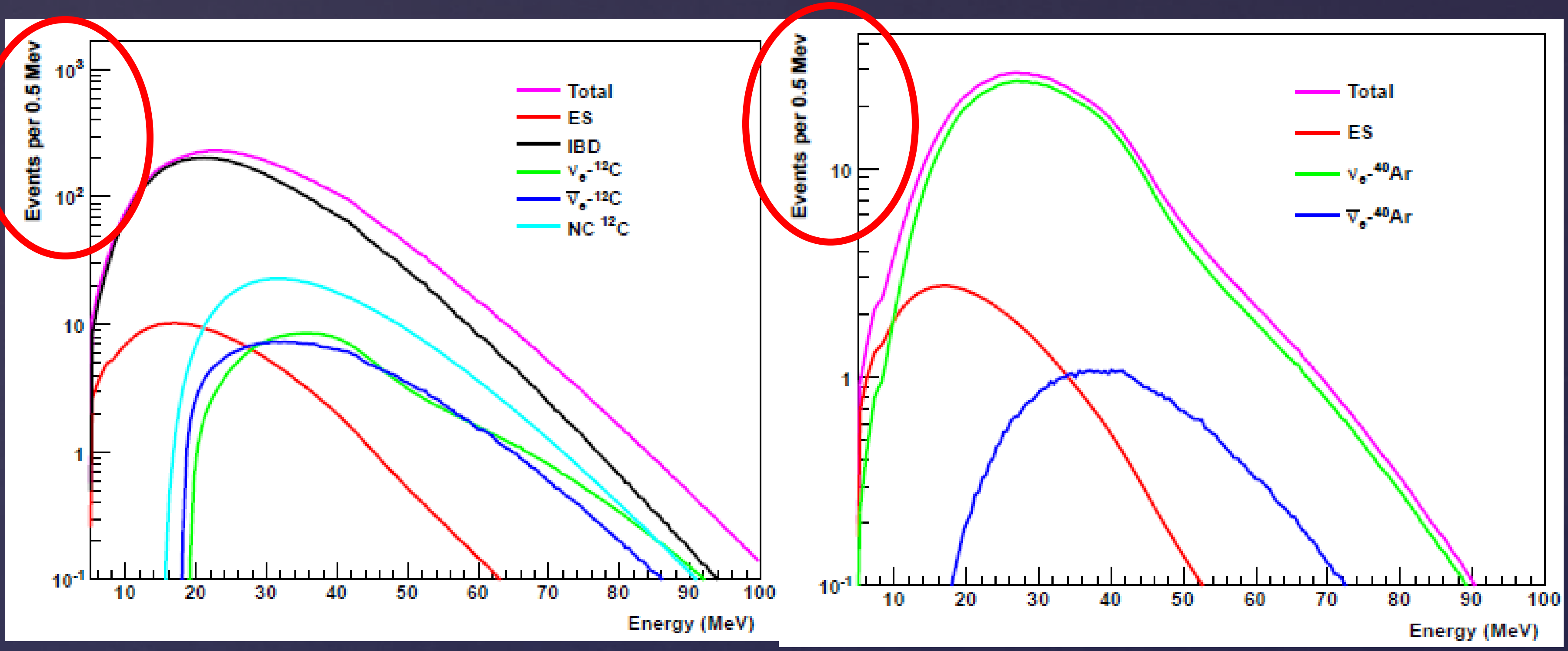
- LAr-TPC - DUNE

  Elastic scattering

$$\bar{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{Cl}^*$$

$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$

Statistical comparison for H or Ar



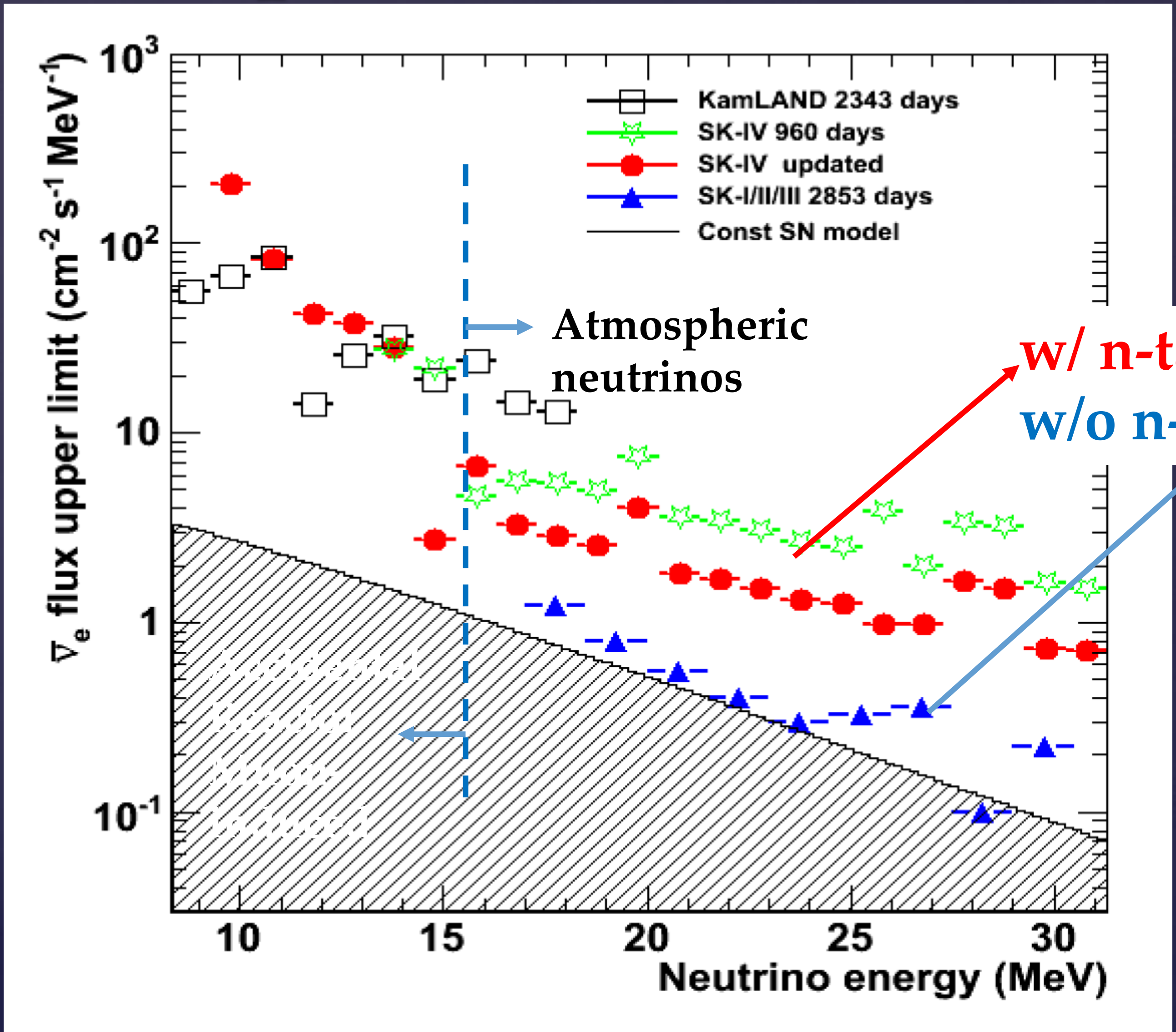
50 kt LS

17 kt LAr

Water case is similar with LS

arxiv:1205.6003

Experimental results



Super K result

w/ n-tag ~1900 days
w/o n-tag 2853 days

KamLAND result can be found at Astrophys. J. 745, 193 (2012)

Backgrounds for SRN detection

Site dependent:

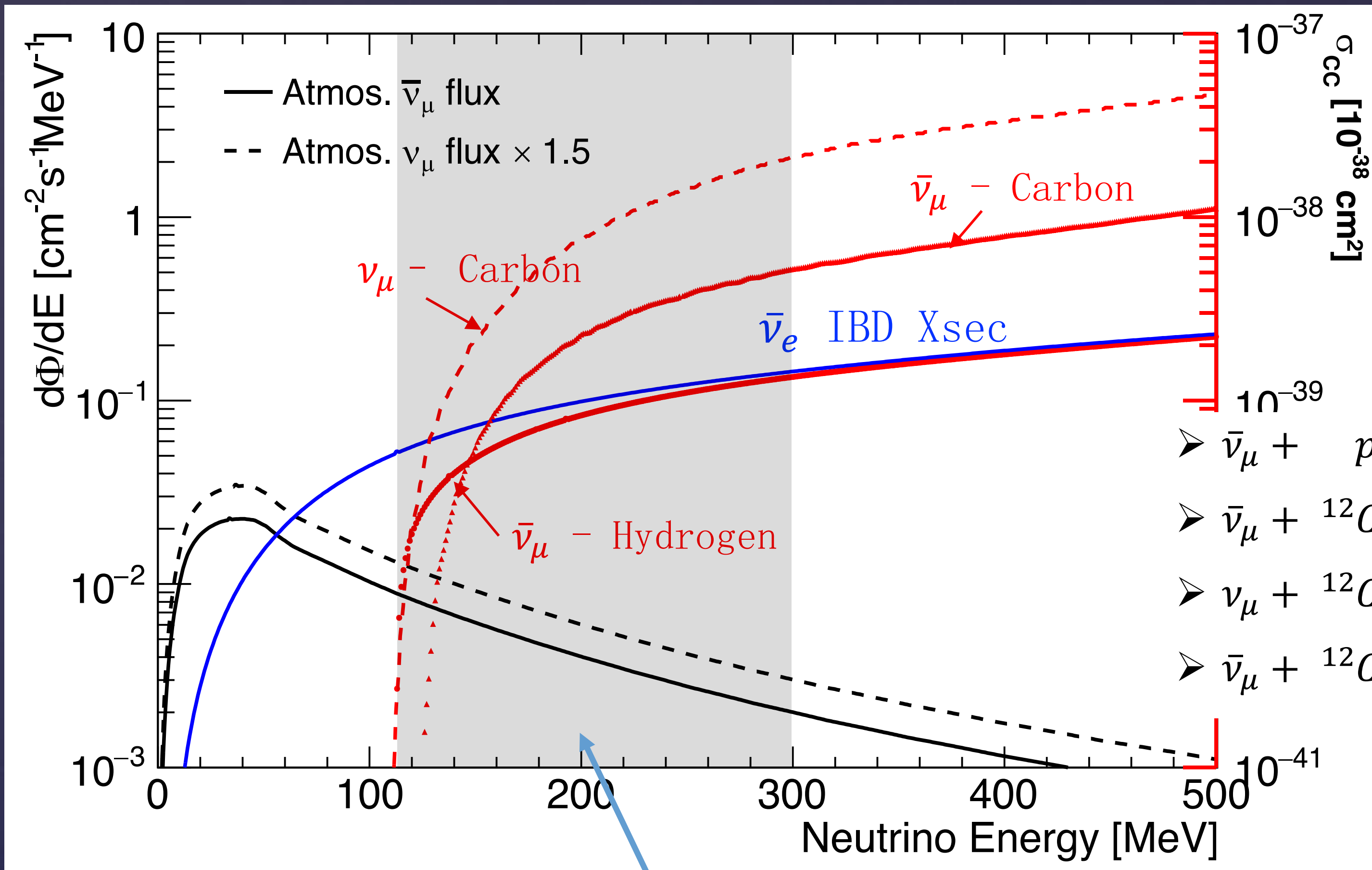
- ✓ Reactor neutrino E < 10 MeV
- ✓ Cosmogenic muons, Li9/He8 E < 15 MeV

Irreducible:

- ✓ Atmospheric ν_e background, E> 25-30 MeV

=> Signal window [10, 30] MeV

Atmospheric $\bar{\nu}_\mu/\nu_\mu$ charged current (CC) Bkg.

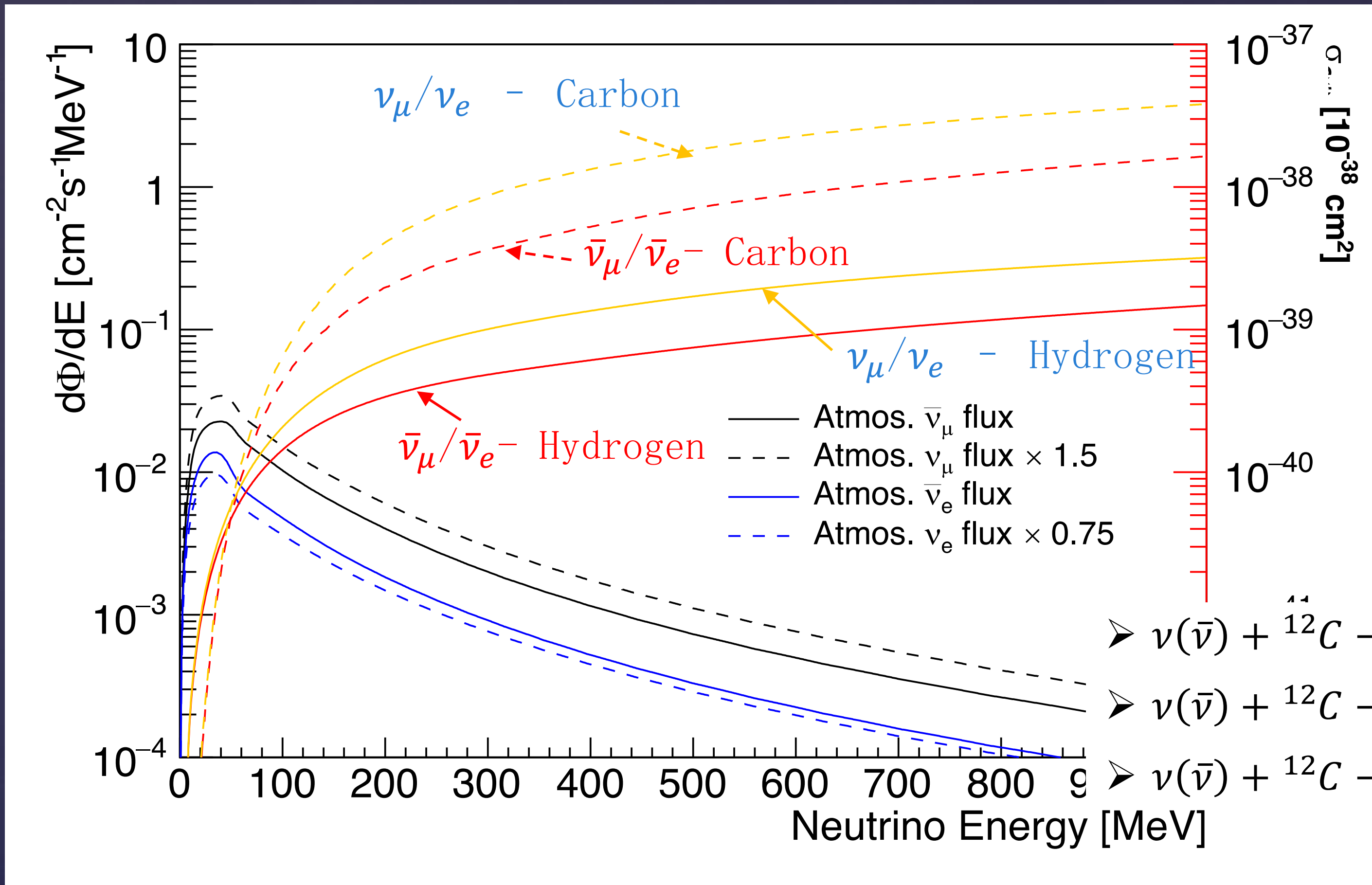


- ✓ Total CC cross section
- ✓ Quasi-elastic scattering (QES) dominated < 500 MeV

- $\bar{\nu}_\mu + p \rightarrow \mu^+ + n$
- $\bar{\nu}_\mu + {}^{12}C \rightarrow \mu^+ + n + {}^{11}B(+\gamma)$
- $\nu_\mu + {}^{12}C \rightarrow \mu^- + n + {}^{11}N$
- $\bar{\nu}_\mu + {}^{12}C \rightarrow \mu^+ + n + {}^{7}Li + \alpha$

Shaded area: Atmospheric $\bar{\nu}_\mu/\nu_\mu$ CC background responsible for 10-30 MeV SRN detection

current (NC) Bkg.



- ✓ Total NC cross section
- ✓ NC elastic scattering dominated
- ✓ Quite a few percent resonant/coherent single π production and ν–e scattering

- $\nu(\bar{\nu}) + {}^{12}C \rightarrow \nu(\bar{\nu}) + n + {}^{11}C + \gamma$
- $\nu(\bar{\nu}) + {}^{12}C \rightarrow \nu(\bar{\nu}) + n + {}^{10}B + p$
- $\nu(\bar{\nu}) + {}^{12}C \rightarrow \nu(\bar{\nu}) + n + {}^{6}Li + \alpha + p$

<1 GeV Atmospheric $\nu/\bar{\nu}$ NC background responsible for 10-30 MeV SRN detection

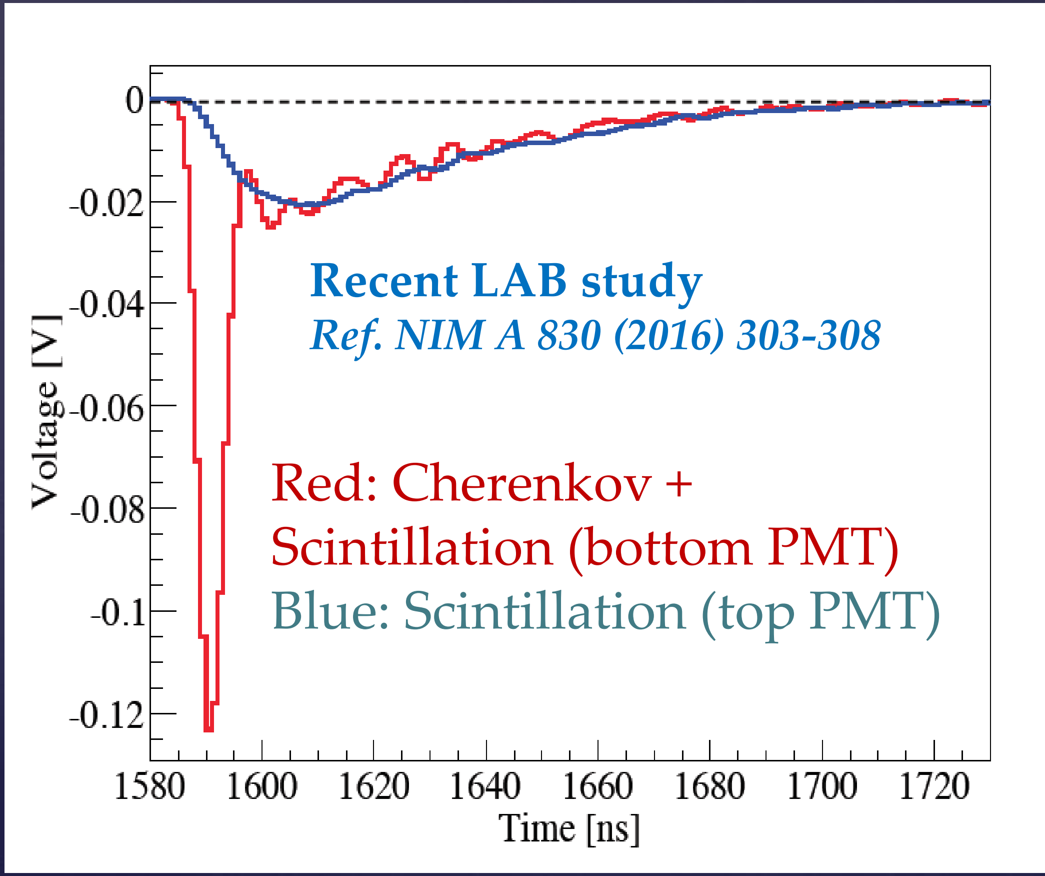
Key issues on SRN detections

	effi	Atmos. CC	Atmos. NC	Optical
LS	~90%	triple coin. from $\mu^{\pm}$, decay $e^{\pm}$, and neutron capture. $\mu^{\pm}$ visible in 10-30 MeV	Energetic neutrons from high energy atmos. Neutrinos	Scintillation
water w/o n-tag	~75%	Decay $e^{\pm}$ from invisible $\mu^{\pm}$, $\mu^{\pm}$ invisible in 10-30 MeV	Secondaries (decays) of n or $\pi^{\pm}/\pi^{0}$ below Cherenkov threshold or different hit pattern	Cherenkov
water w/ n-tag	~13%	Reduced a lot by neutron tagging. The efficiency is increased a lot in Gd-water.	Further reduced by neutron tagging.	
Gd-water	~70%			

- Green: advantage / Blue: disadvantage

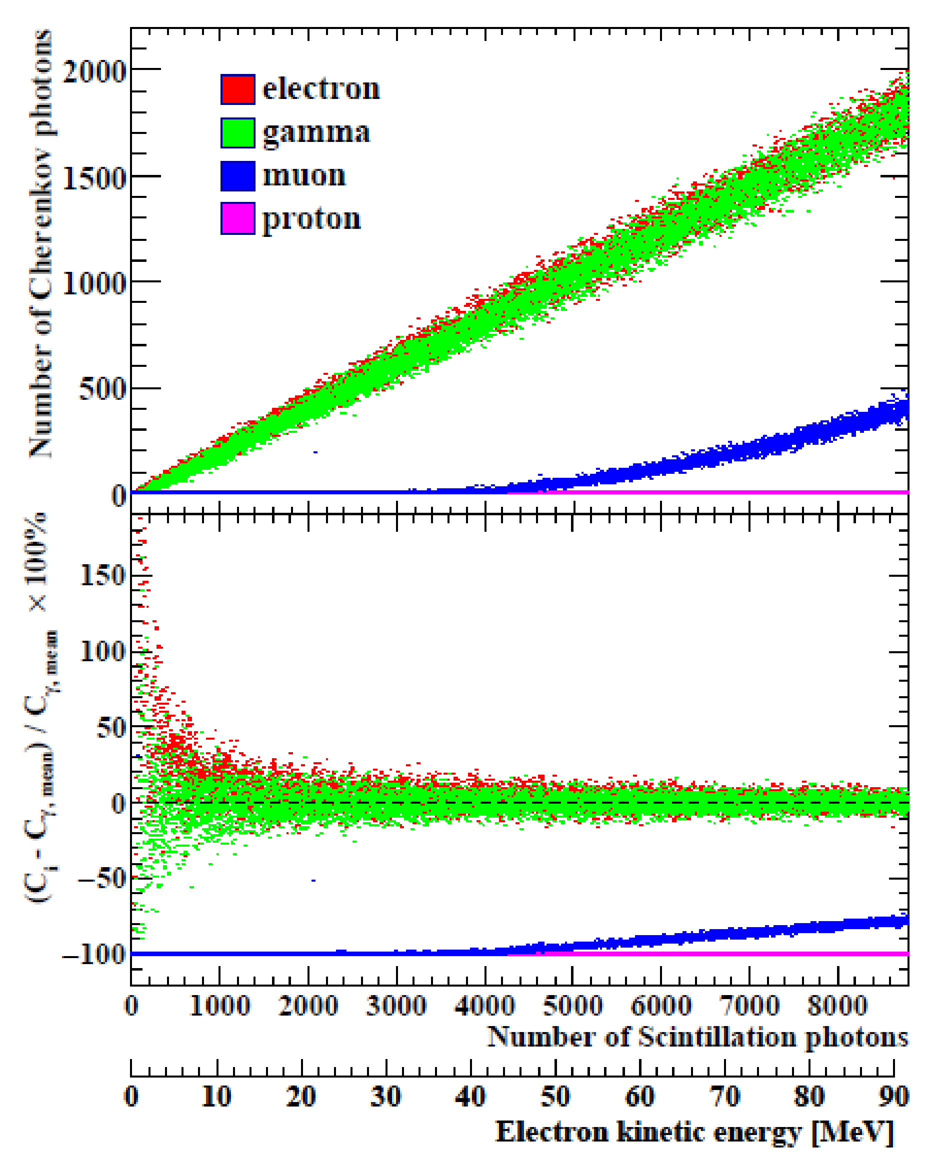
Slow liquid scintillator candidate - LAB

- Other candidates: oil-based or water-based
- Feature: scintillation components slow enough
- Distinguish Cherenkov and scintillation



- **Rising time (τ_r): 7.7 ± 3.0 ns**
- **Decay time (τ_d): 36.6 ± 2.4 ns**
- **PMT time resolution: ~2ns**
- **Scintillation light yield: ~1000/MeV**

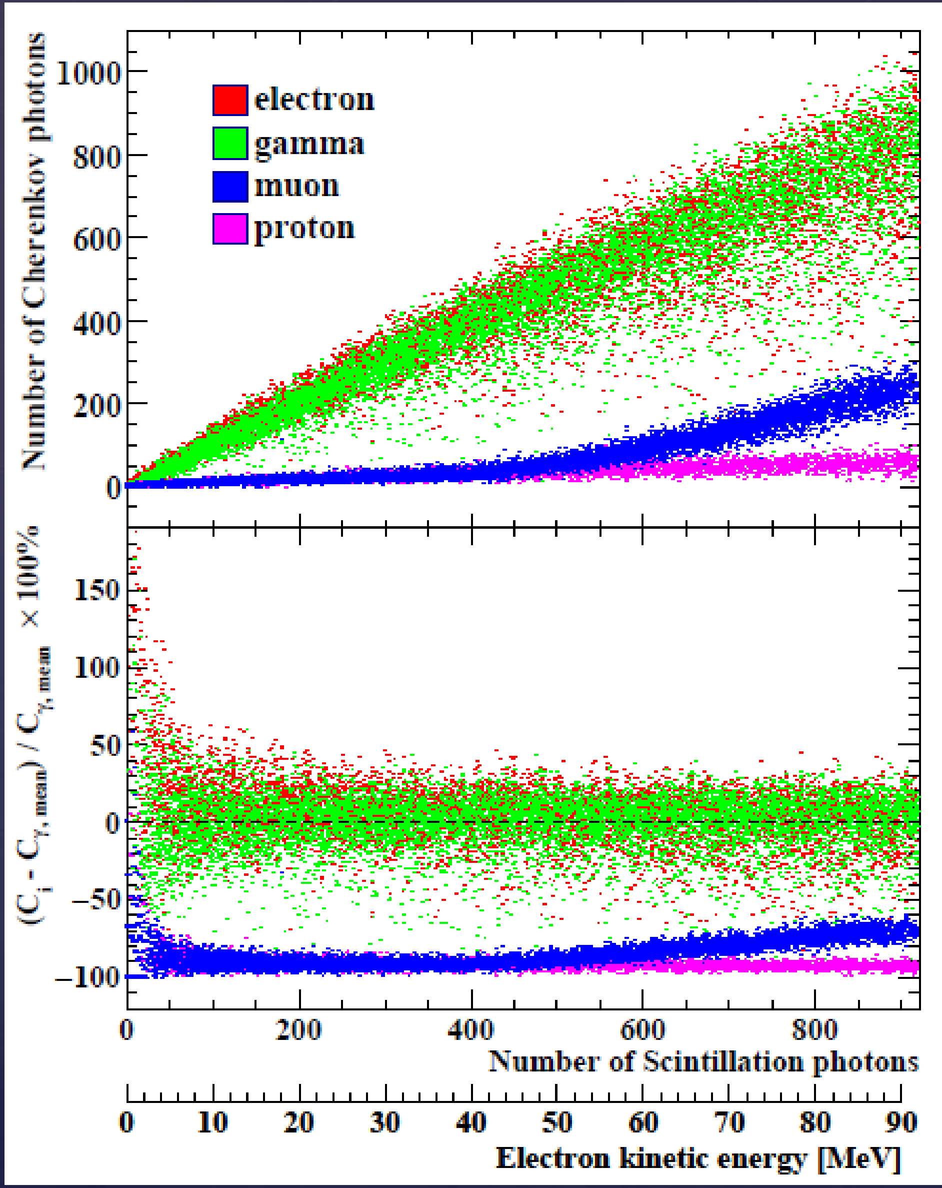
Separation of particles with LAB



Simulation of all types of particles

- Geant4 true information
- 10% QE efficiency for all photons
- No other detector effect

Separation of particles with LAB



More realistic:

- 10 ns cut for Cherenkov counting
- Attenuation in a 10-m R detector (Eff: 10% for S and 50% for C)
- 10% efficiency for all photons

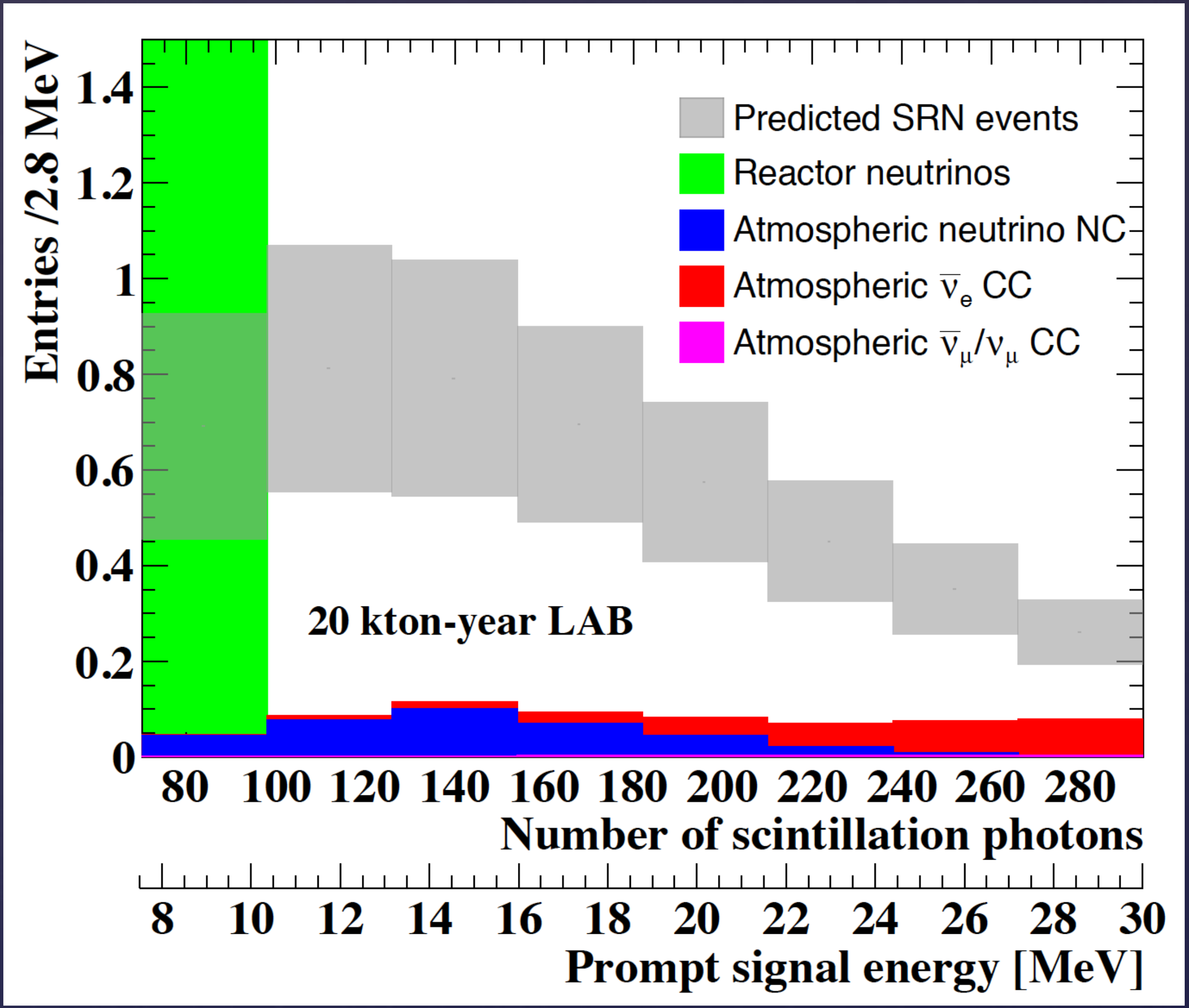
Simulation study

- [Detector response] Use LAB, PID in the realistic case
- [Signal flux] HBD model for SRN prediction
- [Background flux] Atmospheric neutrino flux
  - > 100 MeV (Honda)
  - < 100 MeV (Barr), basically for atmos. $\bar{\nu}_e$, ($\bar{\nu}_\mu/\nu_\mu$ CC interaction threshold ~105 MeV, NC neutron mainly contributed from >100 MeV atmos. flux)
  - MSW effect considered, which would reduce the flux of $\bar{\nu}_\mu/\nu_\mu$ by 30%-50% in the interested energy range for SRN study
- GENIE cross sections for neutrino interactions
- *Simulation validated by KamLAND SRN result (2012)*

Suppression of Atmos. nu backgrounds

- CC background is suppressed as liquid scintillator to tag muon
  - $\bar{\nu}_\mu + p \rightarrow \mu^+ + n$
  - $\bar{\nu}_\mu + {}^{12}C \rightarrow \mu^+ + n + {}^{11}B(+\gamma)$
  - $\nu_\mu + {}^{12}C \rightarrow \mu^- + n + {}^{11}N$
  - $\bar{\nu}_\mu + {}^{12}C \rightarrow \mu^+ + n + {}^{7}Li + \alpha$
- NC background is suppressed with particle id for electron and neutron recoils and others
  - $\nu(\bar{\nu}) + {}^{12}C \rightarrow \nu(\bar{\nu}) + n + {}^{11}C + \gamma$
  - $\nu(\bar{\nu}) + {}^{12}C \rightarrow \nu(\bar{\nu}) + n + {}^{10}B + p$
  - $\nu(\bar{\nu}) + {}^{12}C \rightarrow \nu(\bar{\nu}) + n + {}^{6}Li + \alpha + p$

Result in a 20 kton-year detector



Environmental background at Jinping level

Comparison with other techniques

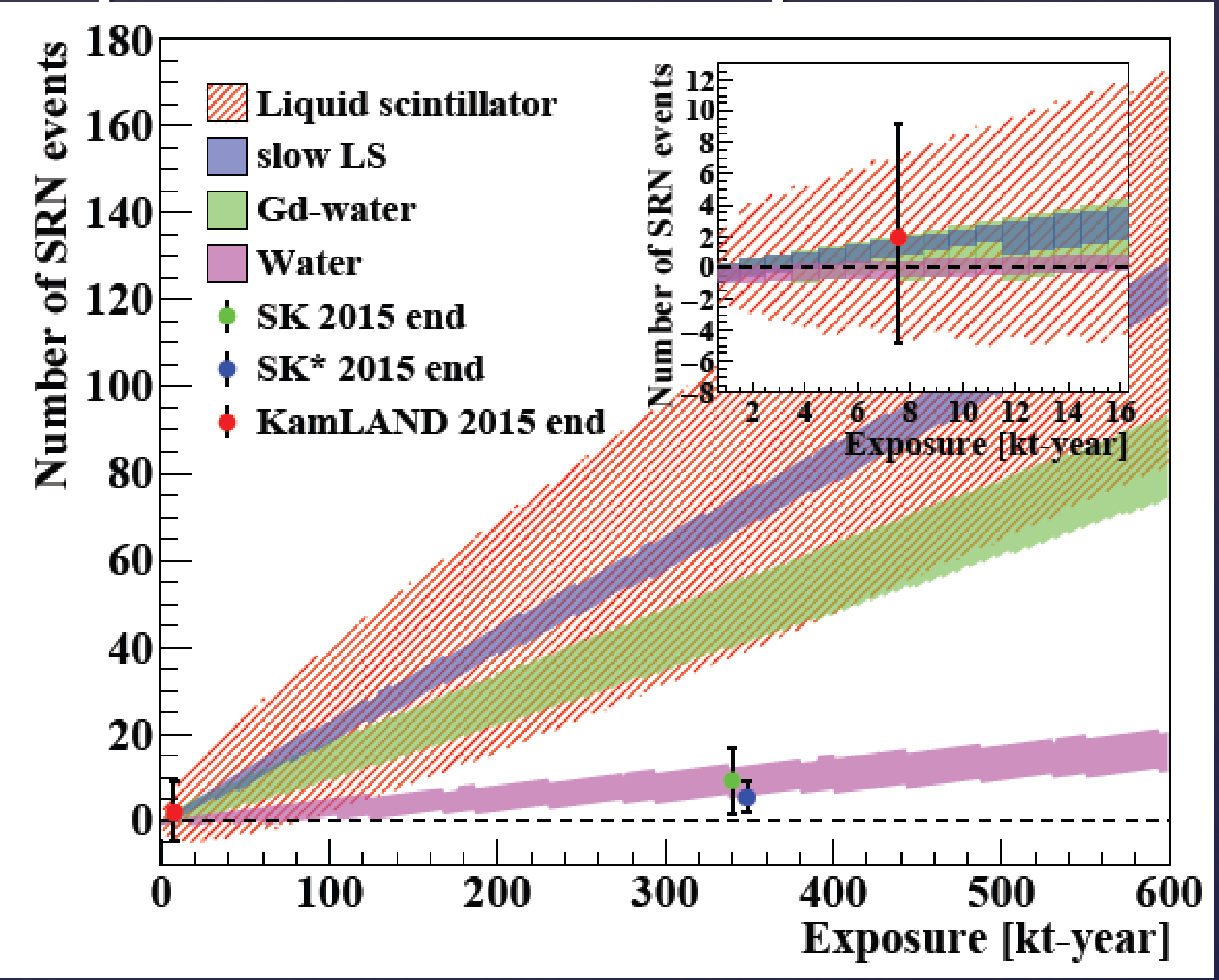
20 kton-year	water [a]	Gd-w [a]	LS	slow LS
Atmos. $\bar{\nu}_e$	0.040	0.21	0.28	0.26
Atmos. $\bar{\nu}_\mu/\nu_\mu$ CC	0.33	1.8	3.6	0.025
Atmos. NC	0.095	0.49	62	0.35
Total backgrounds	0.47	2.5	66	0.64
Signal[b]	0.54	2.8	4.2	4.1
Signal efficiency	13%	70%	92%	90%
S/B	1.1	1.1	0.064	6.4

[a] with neutron tagging.
[b] HBD model; water and Gd-w results corrected by a factor ~0.9 due to the different fraction of free protons in water from that in LAB.

Note:

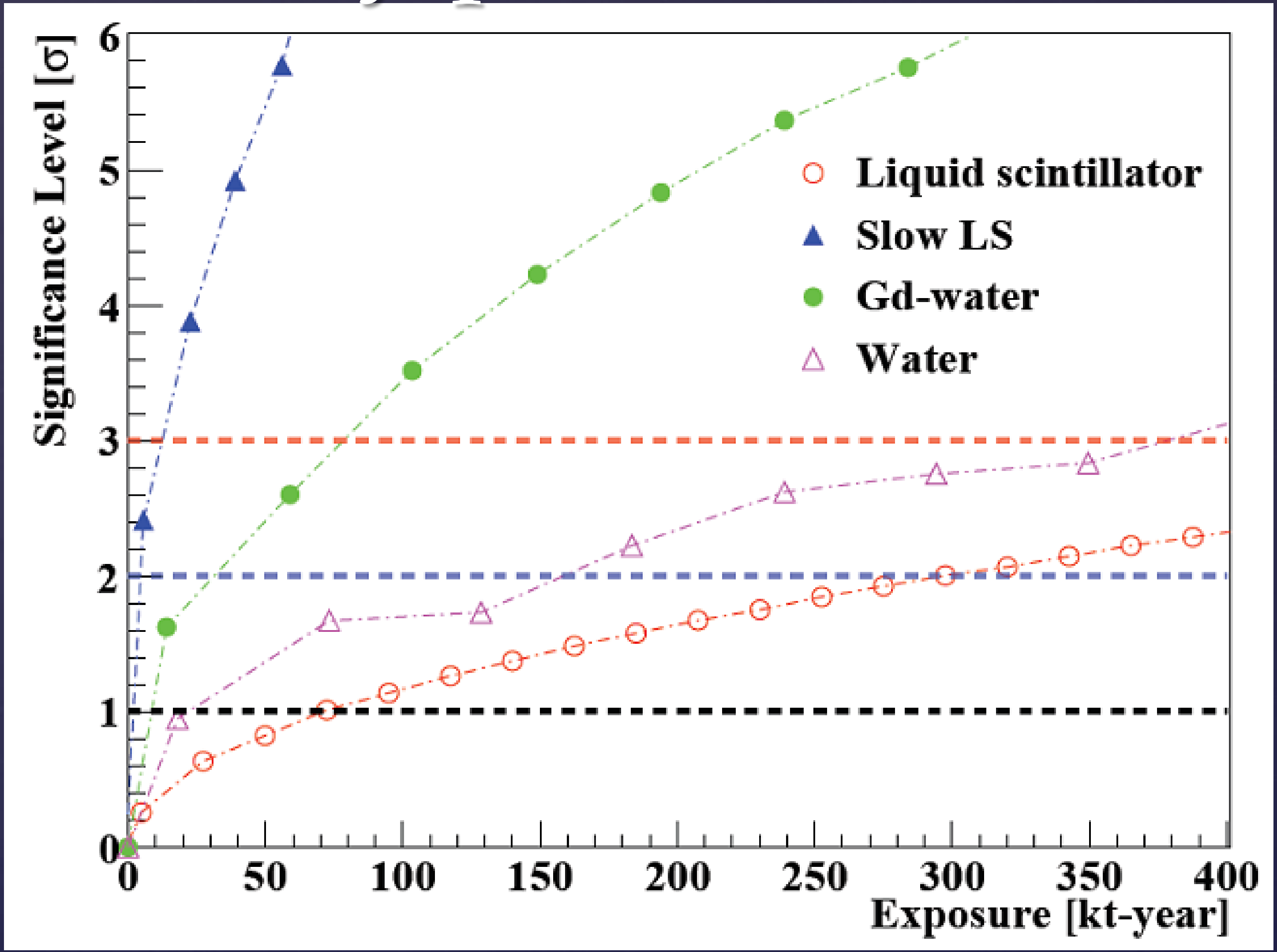
1. Traditional PSD in LS should improve the LS result.
2. For LAr, we expect the same S/N and Eff.

Comparison in a plot

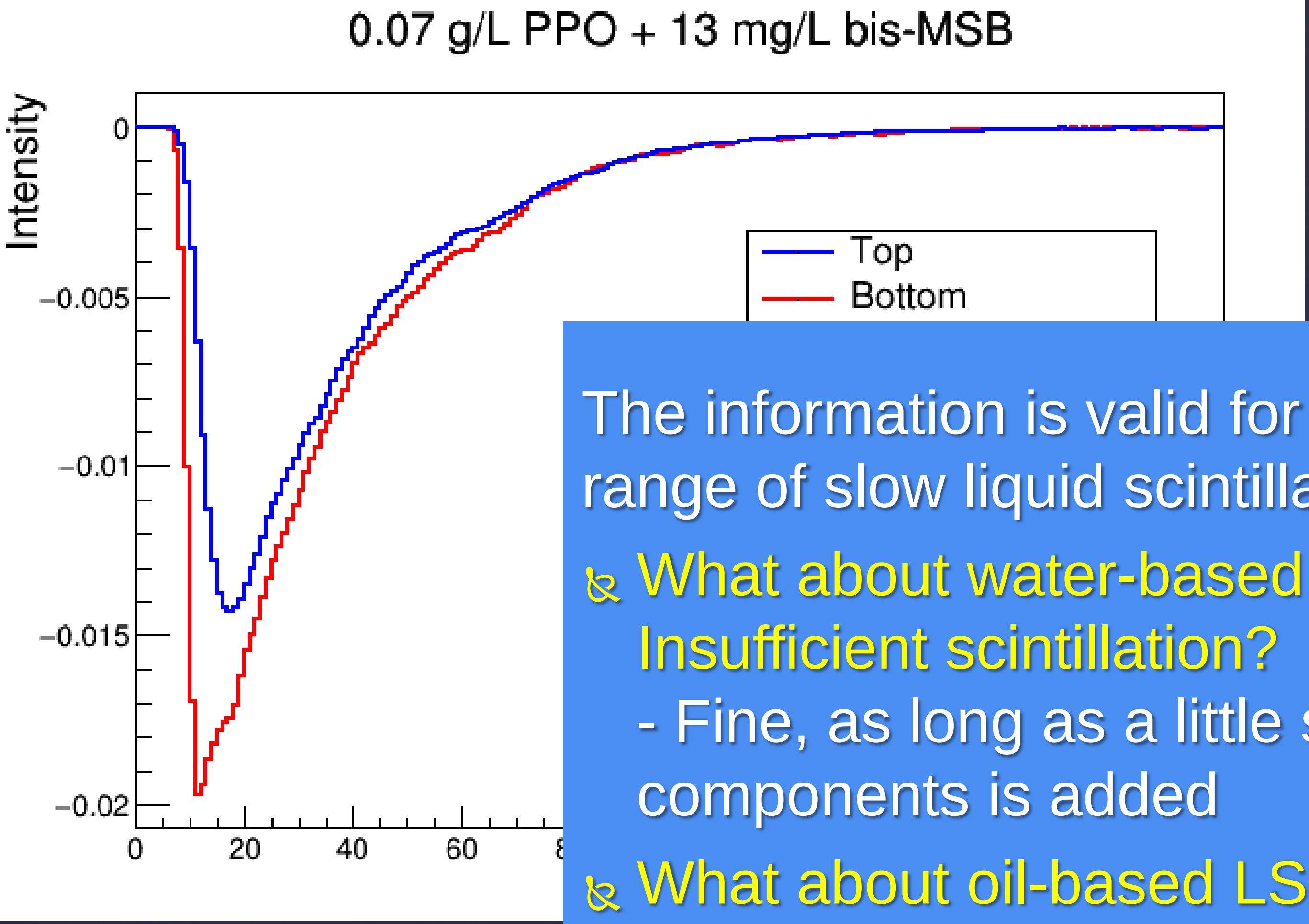


Band is background only uncertainty at 1 sigma

Discovery potential



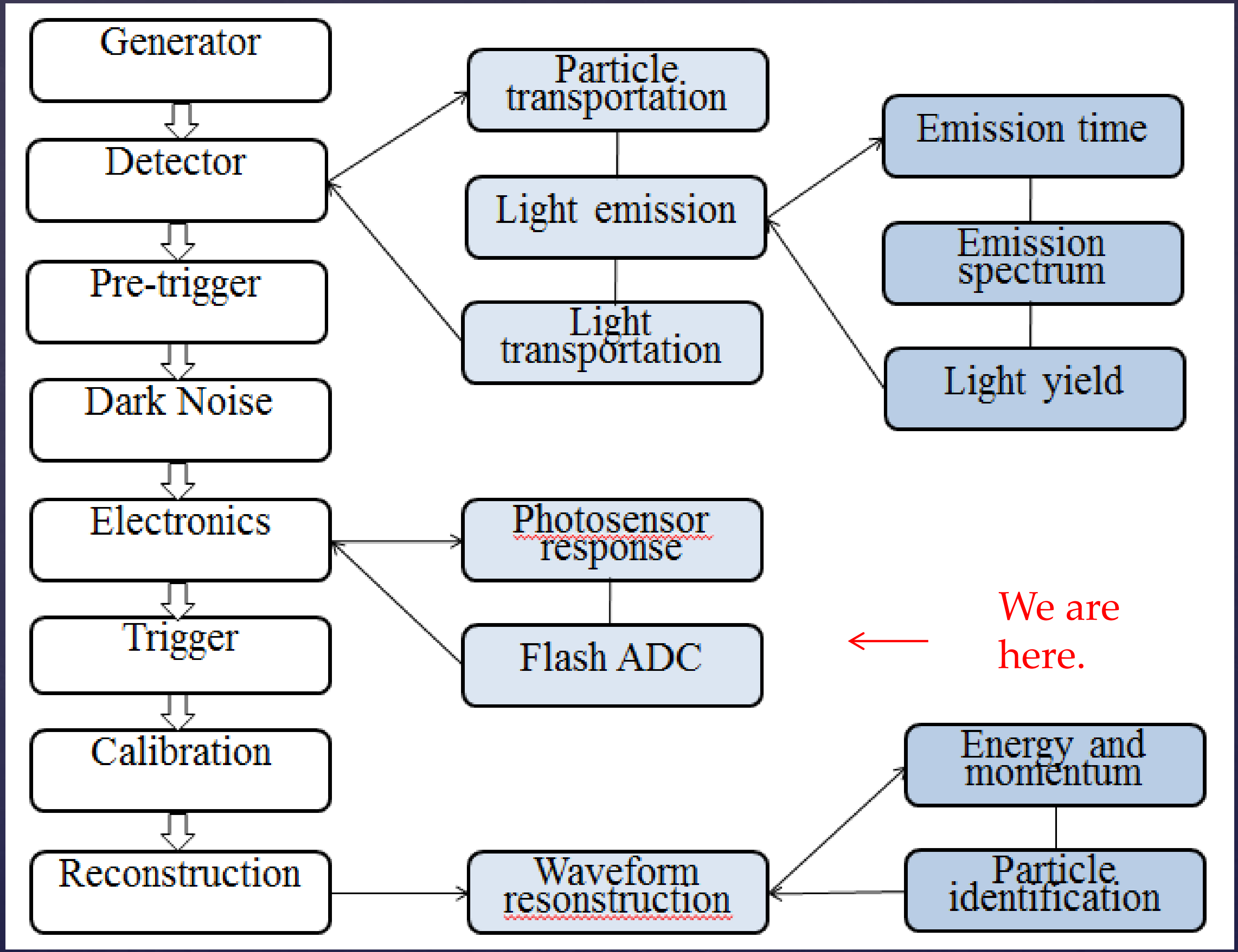
Final comments on the result

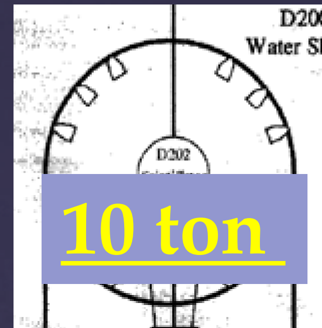


The information is valid for a wide range of slow liquid scintillators.

- What about water-based LS? Insufficient scintillation?
  - Fine, as long as a little scintillation components is added
- What about oil-based LS? Separation is poor
  - A little separation is still needed.

Jinping Simulation & Analysis





2025, physics results

18-20: TDR

2020: kilo-ton detector

16-18: CDR

2017-18: 10 ton prototype

14-15: LOI

2016: 1 ton prototype

2014-15: 20 L Slow liquid scintillator

2014-15: Physics potential study

Thank you

More detail of the Jinping Neutrino Experiment can be found at
http://jinping.hep.tsinghua.edu.cn