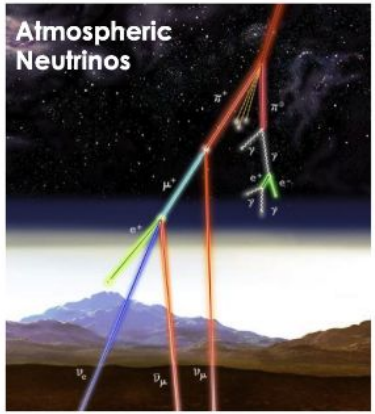
Neutrinos @LLR: introduction to the group activities

Margherita for the LLR Neutrino group

Neutrinos @LLR

Neutrino: a multi-source particle



Natural

Geo-(anti)neutrinos

Supernova neutrinos

Solar Neutrinos

Artificial

Our group focuses on the studies of two kind of neutrino sources

T2K

Neutrinos from accelerator

Study neutrino properties (oscillations)

Give access to the CP asymmetry in the lepton sector

SUPER SK

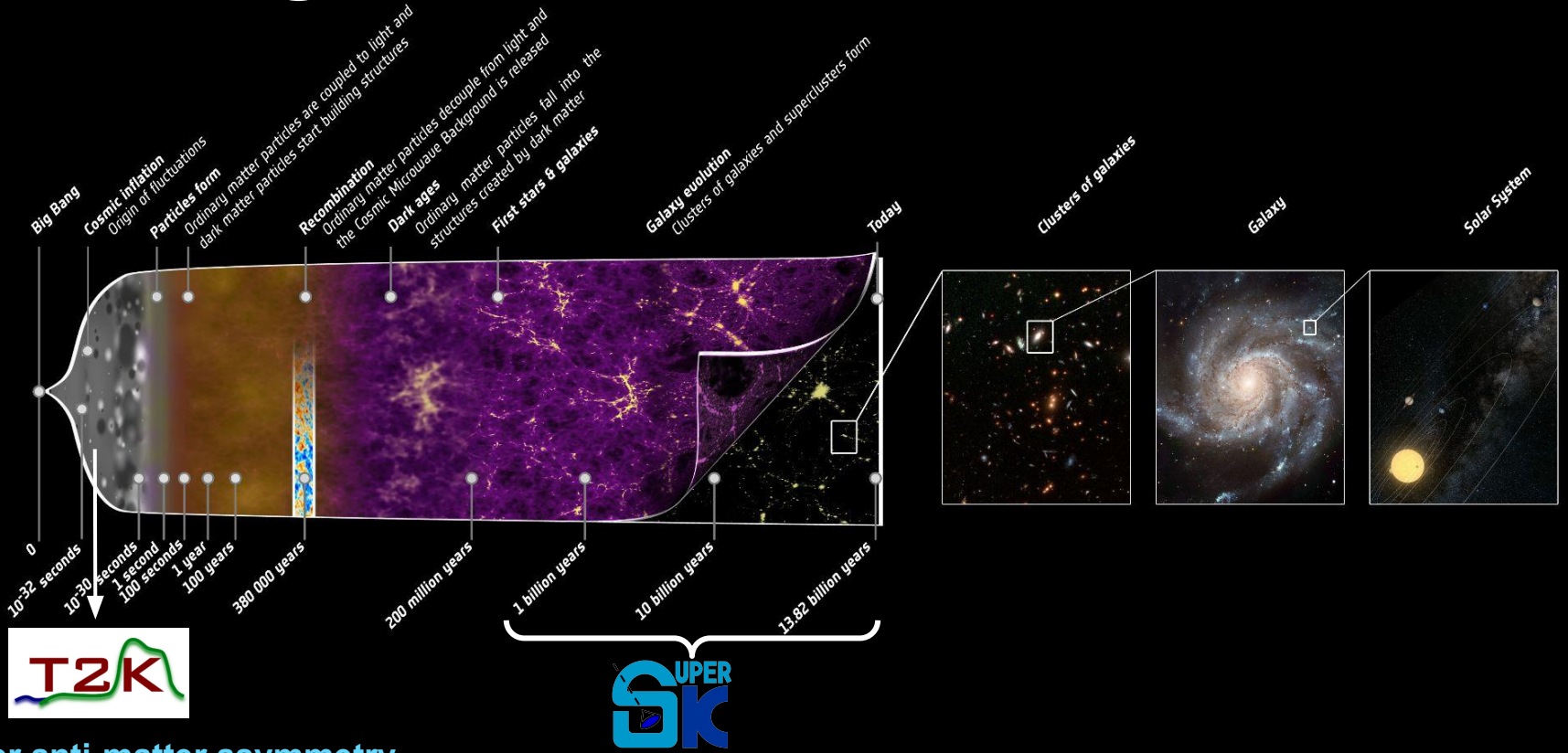
Neutrinos from old Supernovae

use ν as a probe of astrophysical objects

Give access to star/BH formation rate

cosmological implications

Neutrinos @LLR



T2K

matter anti-matter asymmetry

SUPER SK

DSNB, SN neutrinos

Neutrino: a special particle to study

Neutrino oscillations: while travelling from the source to the detector point, a neutrino created with a certain flavor has a certain probability to convert into another neutrino flavor

Neutrino: a special particle to study

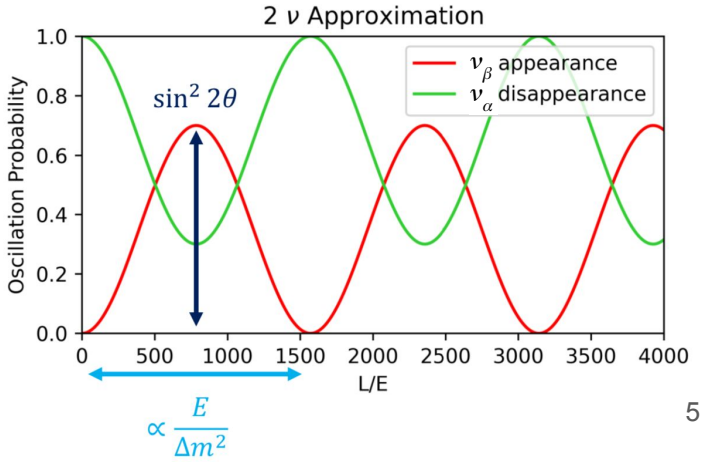
Neutrino oscillations: while travelling from the source to the detector point, a neutrino created with a certain flavor has a certain probability to convert into another neutrino flavor

SOURCE [Sun, reactor, accelerator] → ν_α → ν_β → DETECTOR

$$P(\nu_\alpha \to \nu_\beta) = \sin^2 2\theta \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

Neutrinos, and anti-neutrinos, exist in **3 flavors**: ν_e ν_μ ν_τ
The flavor mixing is only possible if neutrinos have masses
Oscillations happen because what propagate are the **mass-eigenstates ν_i**, related to the **flavor eigenstates** via the **PMNS mixing matrix**

$$|\nu_\alpha\rangle = \sum_i U^*_{\alpha i} |\nu_i\rangle$$



Neutrinos and the matter/anti-matter asymmetry

The complete three flavor case:

More details in the slides from 2021 LLR biennale

atmospherics + accelerator | reactor + accelerator | solar + reactor

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{CP}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Basically, if δ_{CP} != 0 && δ_{CP} != π , we expect $P(\nu_\alpha \to \nu_\beta) \neq P(\overline{\nu}_\alpha \to \overline{\nu}_\beta)$

CP violation!

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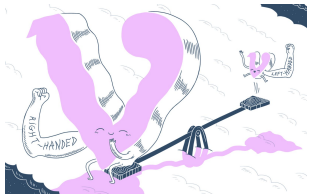
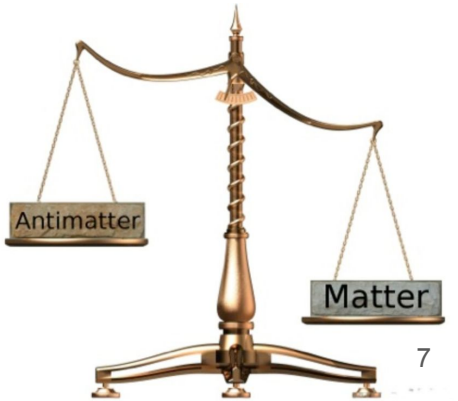


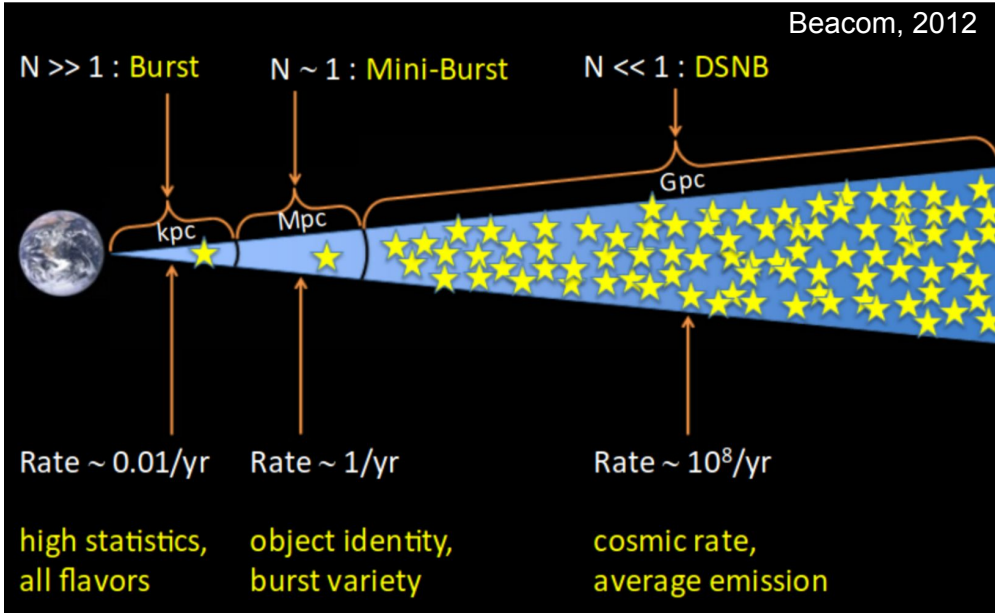
This means that matter and anti-matter could behave differently in the lepton sector.

Under certain assumptions, included the existence of super heavy neutrinos, this can translate in the **leptogenesis**, i.e. why leptons won over anti-leptons

Under additional conditions, leptogenesis could generate also **baryogenesis**, thus explaining why matter won over anti-matter… that is why we exist now!



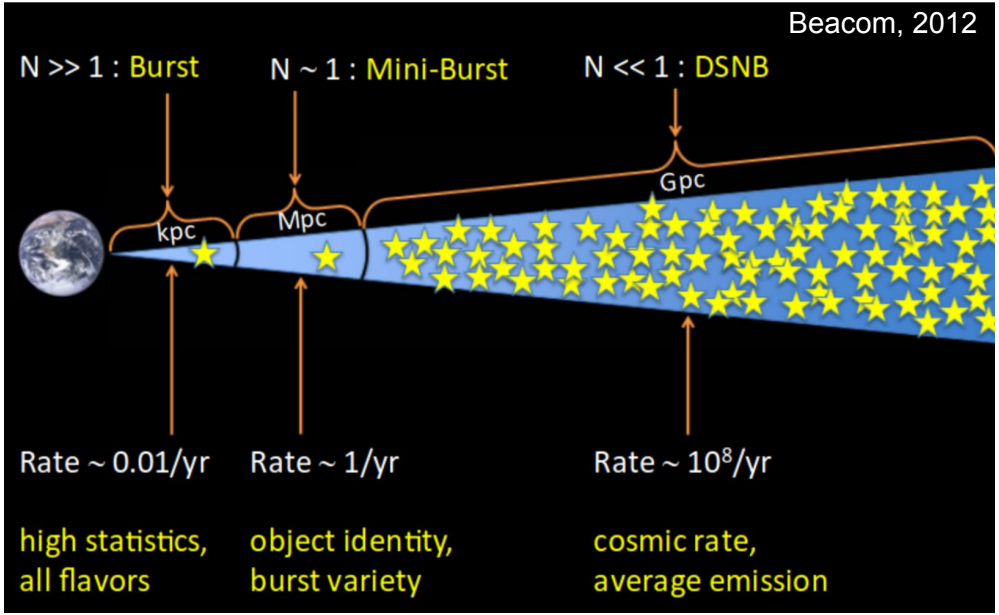
Neutrino: a unique probe of astrophysical objects - DSNB



Expected one supernova per second in observable Universe

Since ν travel freely across the Universe, could we look for past SN neutrinos? This is the Diffuse Supernova Neutrino Background!

Neutrino: a unique probe of astrophysical objects - DSNB



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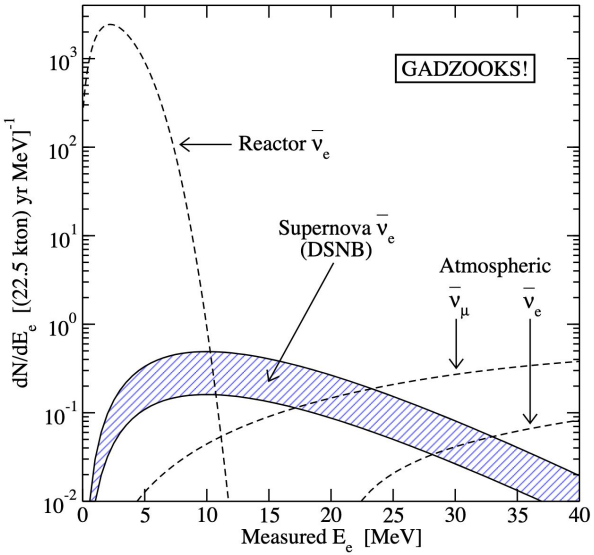
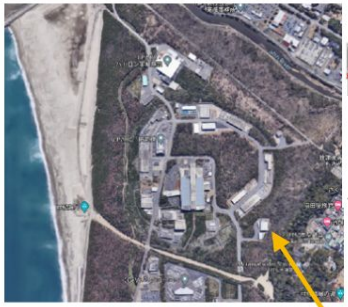
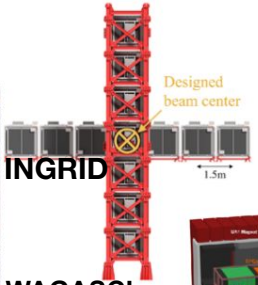


Phys.Rev.Lett. 93 (2004) 171101

DSNB study can shed light on many astrophysical aspects like BH formation rate, star formation rate.

Neutrinos @LLR : T2K &...





INGRID

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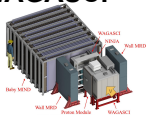
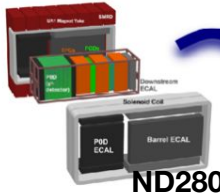
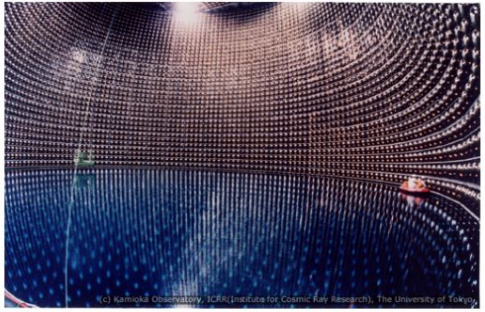




ND280

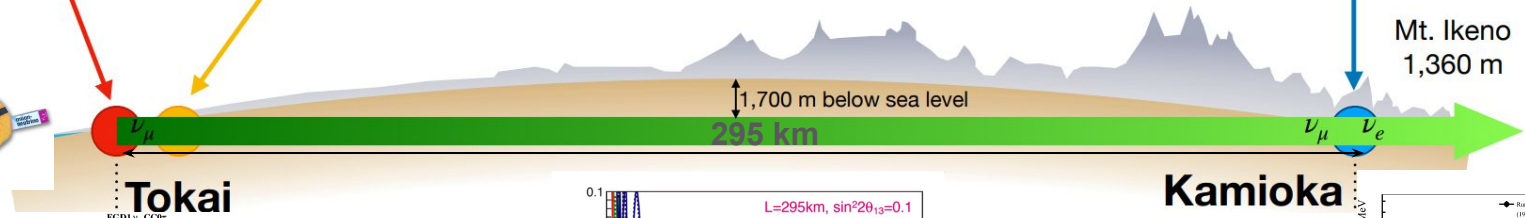
T2K



J-PARC

Near Detectors

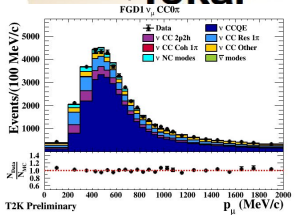
Super-Kamiokande

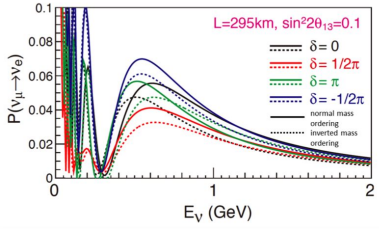


Tokai

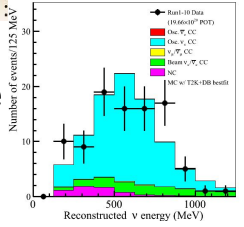
Kamioka

ν_μ beam

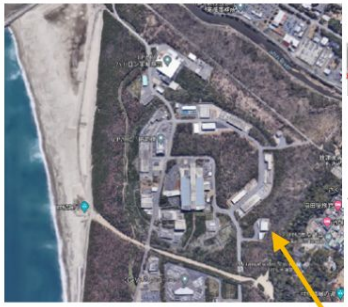


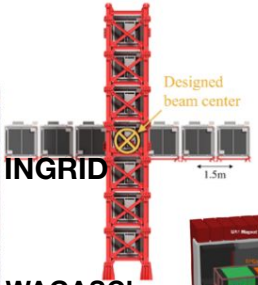


ν_e appearence

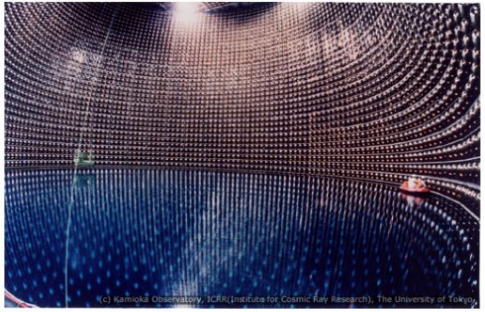


Neutrinos @LLR : T2K &...





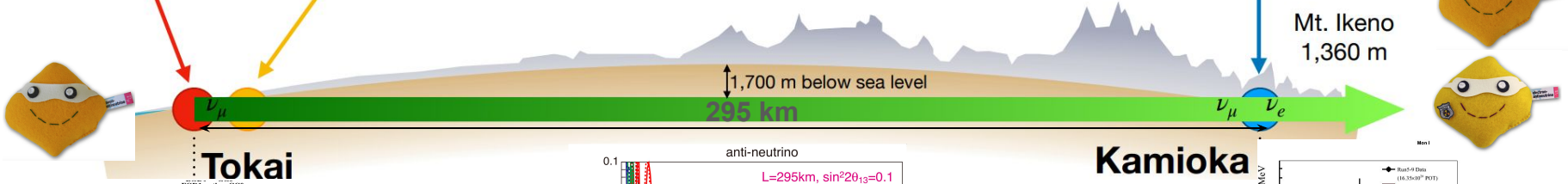
T2K



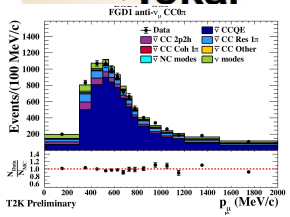
J-PARC

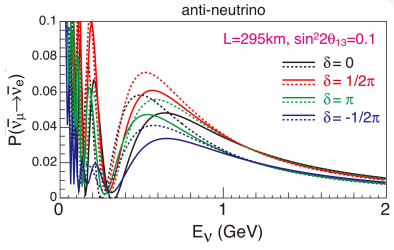
Near Detectors

Super-Kamiokande

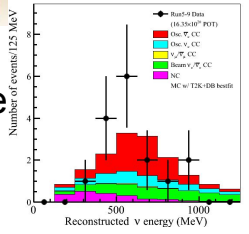


$\bar{\nu}_\mu$ beam



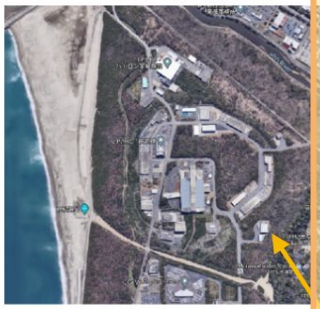


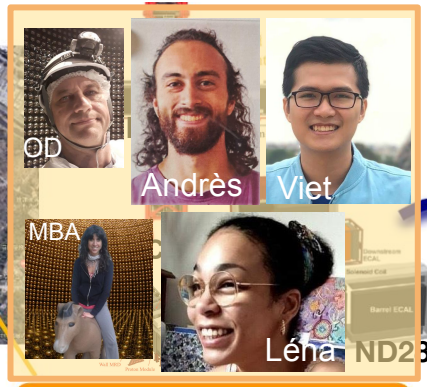
$\bar{\nu}_e$ appearence



Neutrinos @LLR : T2K &...

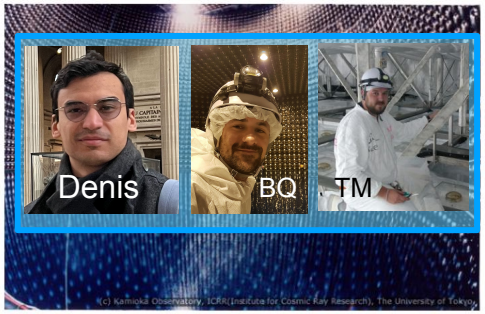
Hardware + xsec/OA analyses





T2K

OA analysis



J-PARC

Near Detectors

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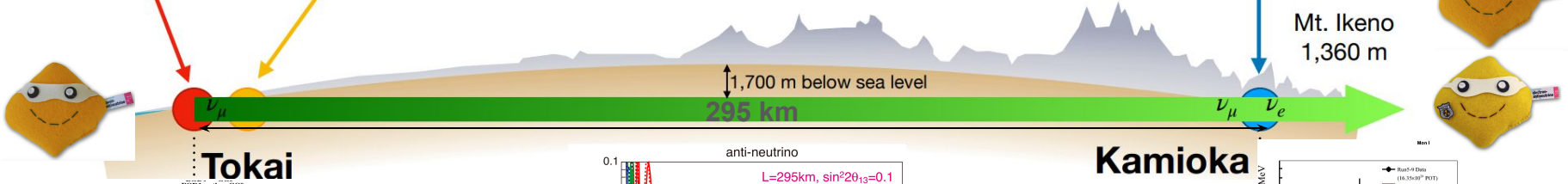

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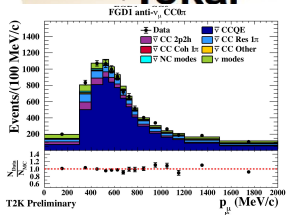

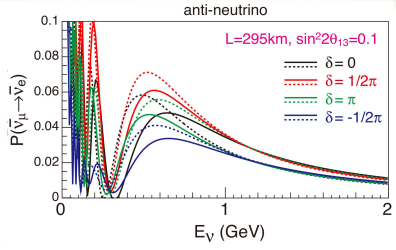

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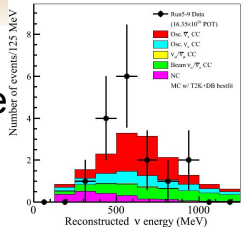
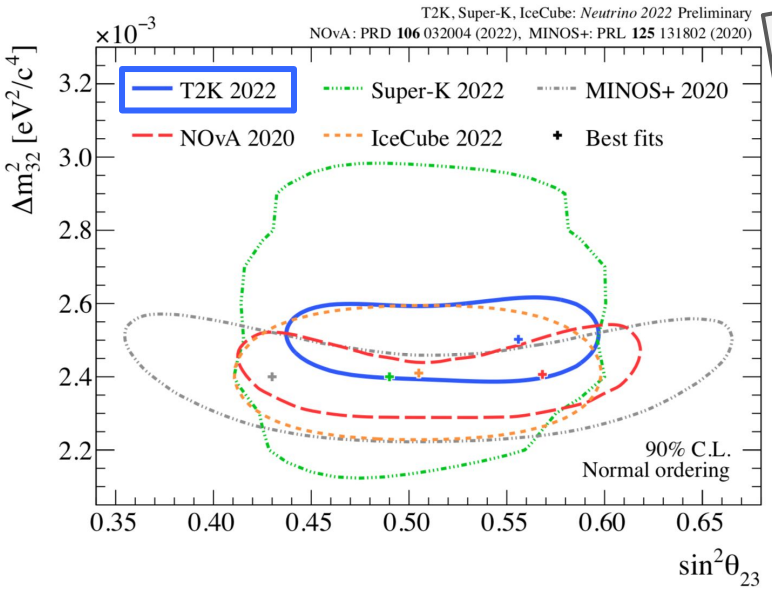


Most recent T2K results on oscillation parameters

As presented at NEUTRINO 2022

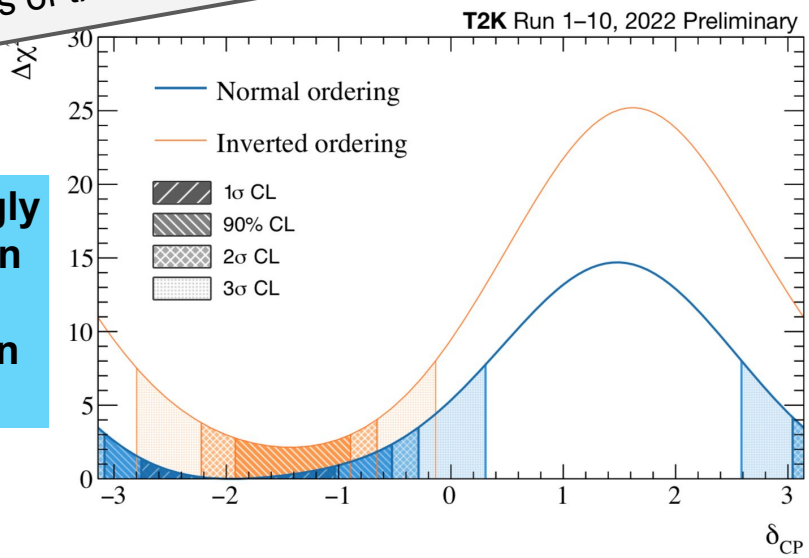


World leading measurement of the atmospheric parameters!

Still compatible with both octants, slightly preferring the upper one

See updates of this in Denis' talk!

LLR strongly involved in 2024 Oscillation analysis!



CP conservation excluded at 90%

Large region of δ_{CP} values excluded at 3σ

Preference for ~maximal CP violation ($\delta_{CP}\approx-\pi/2$)

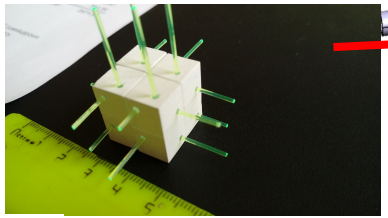
Preference for Normal Ordering

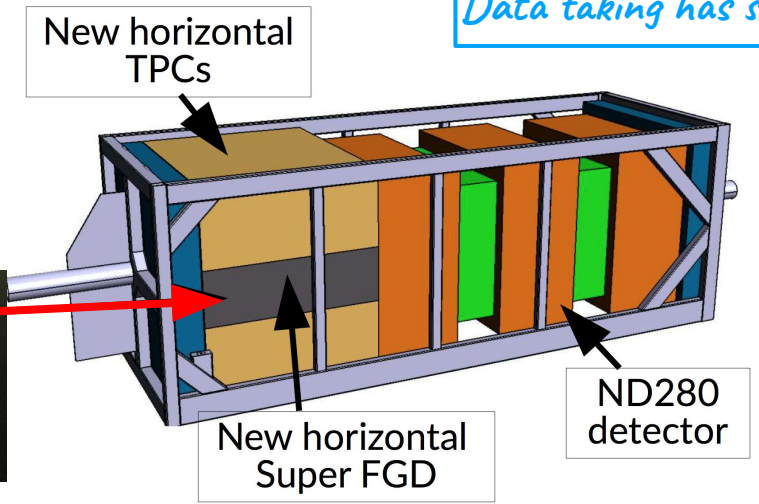
T2K phase II: ND280 Upgrade

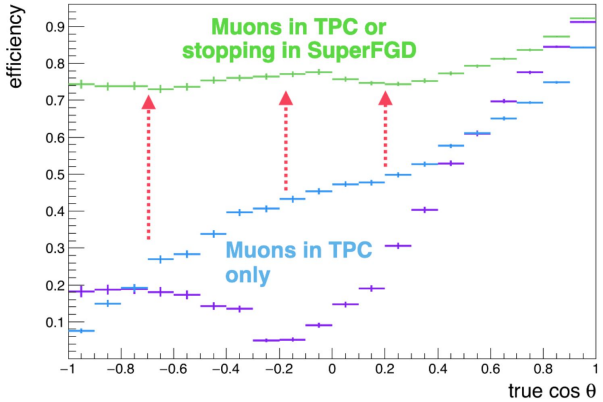
P0D replaced with a totally active target
SuperFGD: segmented 1cm^3 cubes FGD
Sandwiched by 2 TPCs

Data taking has started !

2 millions of 1cm^3 cubes.
Optical fibers in 3 directions







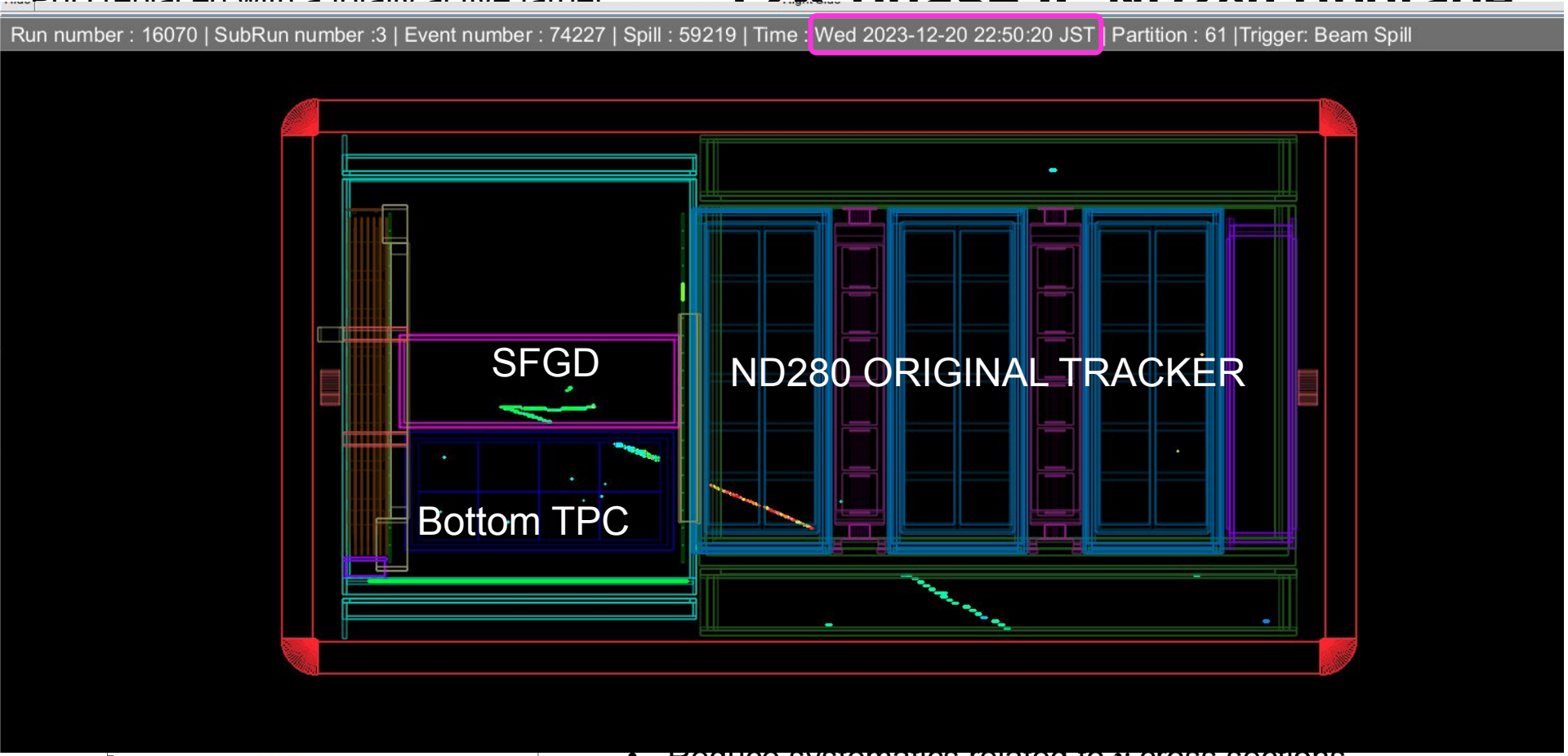
Improvements w.r.t. current ND280:

- vertex reconstruction
- Acceptance 4π
- Low momentum protons (p_p>300MeV)
- Vertex activity
- Neutron detection
- Reduce systematics related to ν cross sections

Installation almost complete (>70%) @JPARC!!!!

T2K phase II: ND280 Upgrade

- P0D replaced with a totally active target



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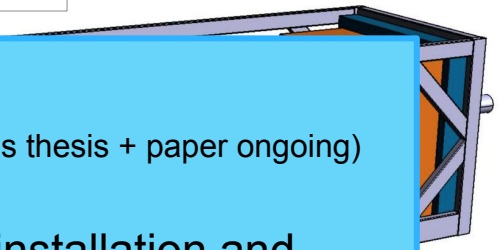
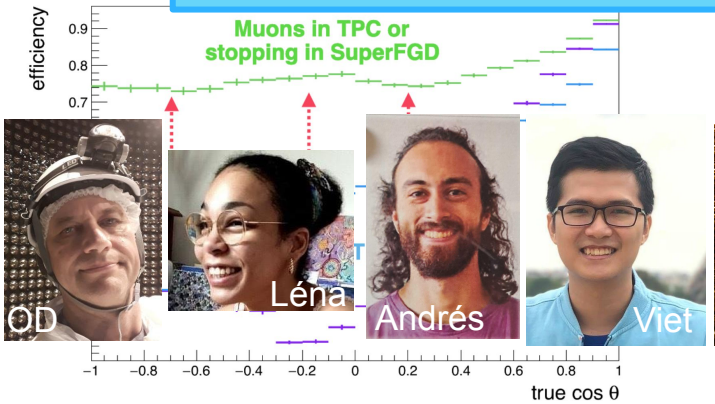
New horizontal TPCs



STRONG PARTICIPATION OF THE LLR:

- **Sensitivity studies** (Phys. Rev. D **105**, 032010, Jaafar's thesis + paper ongoing)
- **Software development** (GUNDAM)
- **SuperFGD electronics**: design, production, installation and commissioning ⇒ **strong involvement of physicists + service électronique + service mécanique**

See Viet's talk in a moment!



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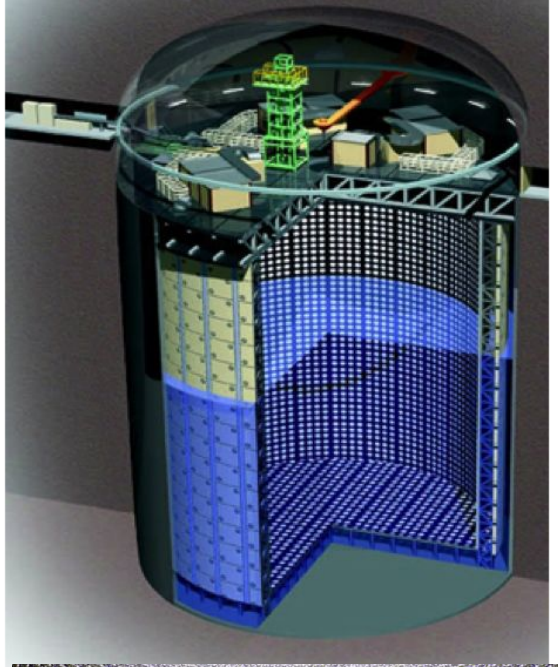
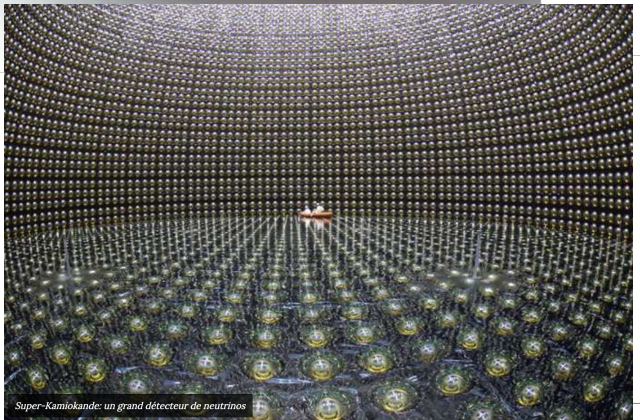
Super Kamiokande

SK is a 50 kton water Cherenkov detector

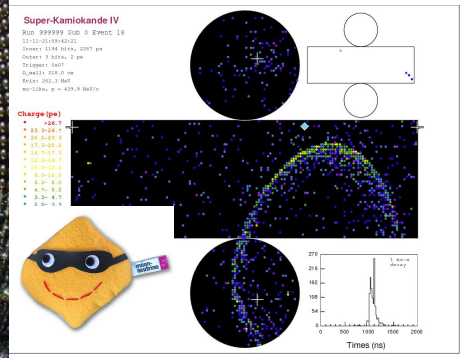
Inner detector ~11000 20 inch PMTs

Outer detector ~2000 8 inch PMTs

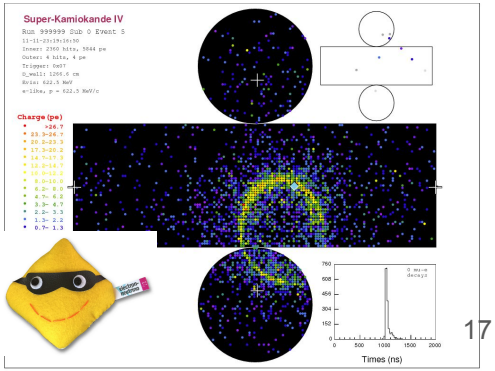


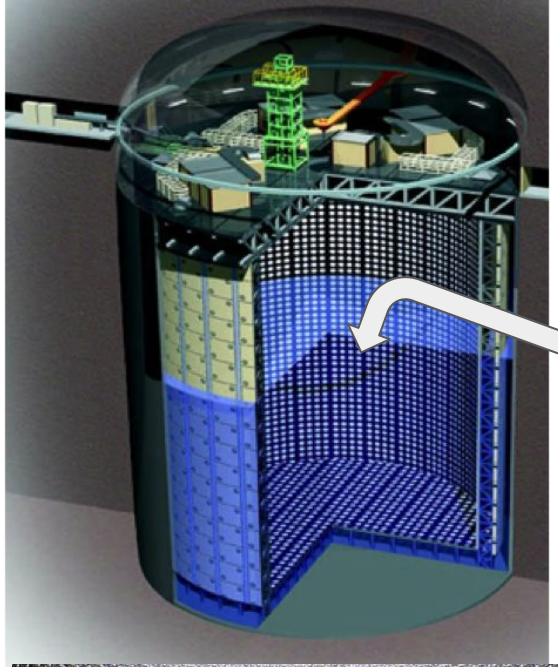


ν_μ CCQE interaction



ν_e CCQE interaction





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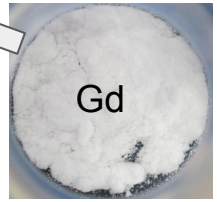
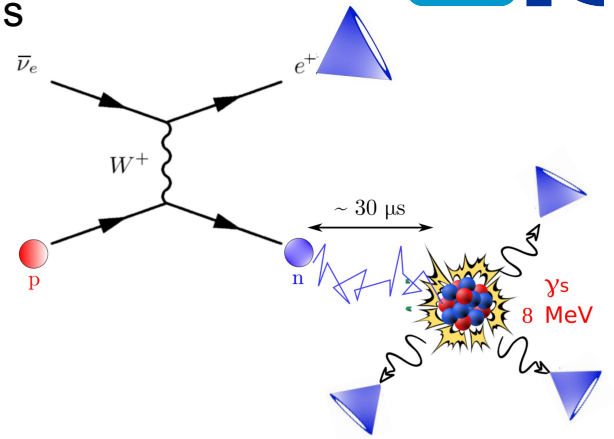
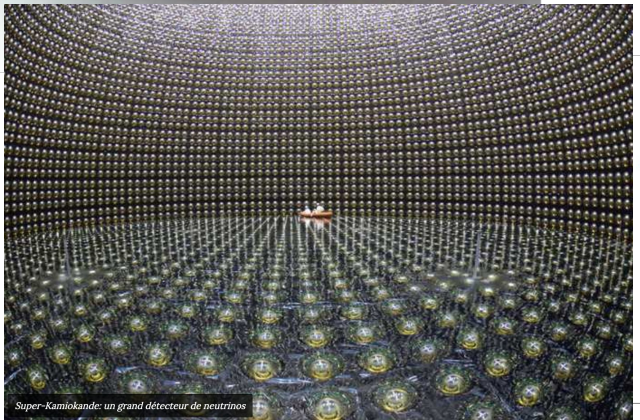
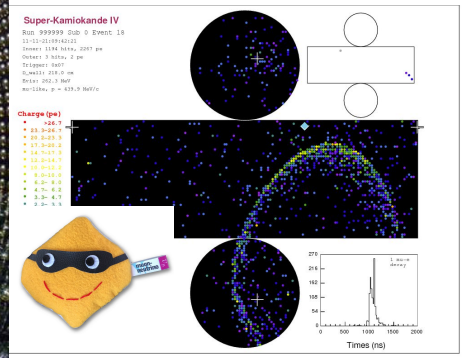


Gadolinium added since 2019 (???) to increase neutron capture rate ⇒ **strong participation of LLR in the hardware work!**

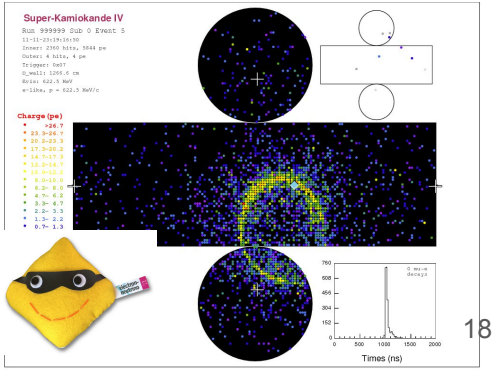


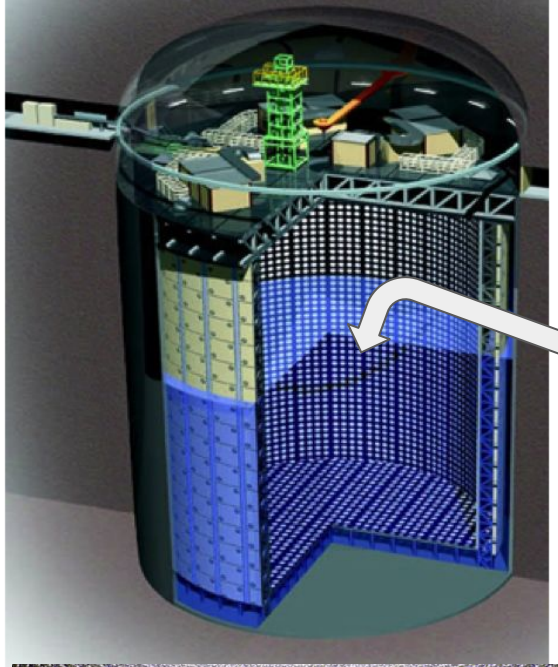


ν_μ CCQE interaction



ν_e CCQE interaction





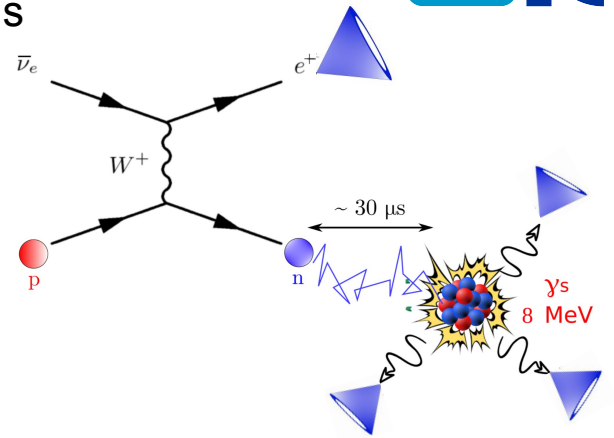
Super Kamiokande

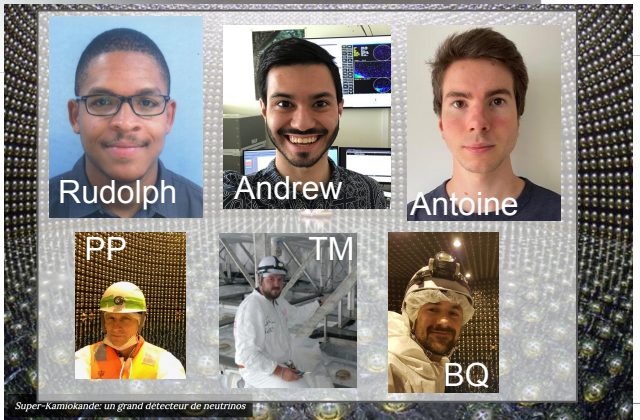
SK is a 50 kton water Cherenkov detector

Inner detector ~11000 20 inch PMTs

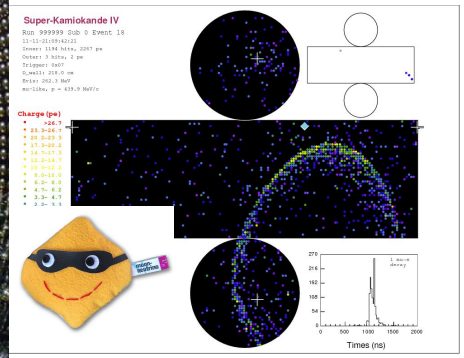
Outer detector ~2000 8 inch PMTs

Gadolinium added since 2019 (???) to increase neutron capture rate ⇒ **strong participation of LLR in the hardware work!**

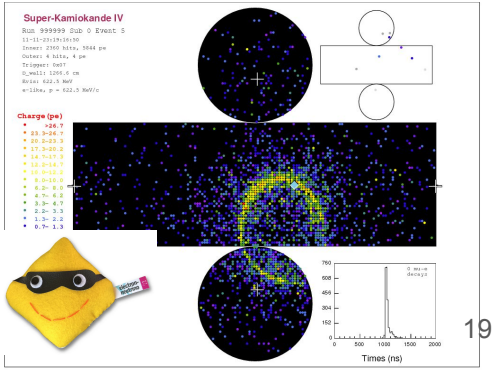




ν_μ CCQE interaction



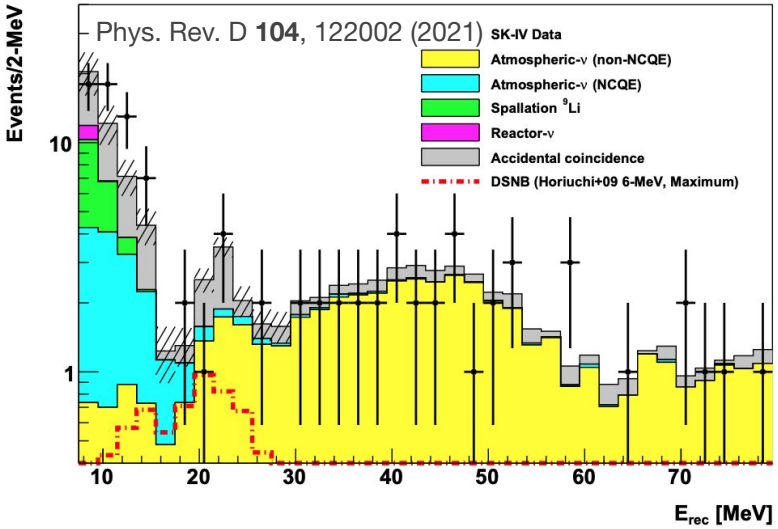
ν_e CCQE interaction



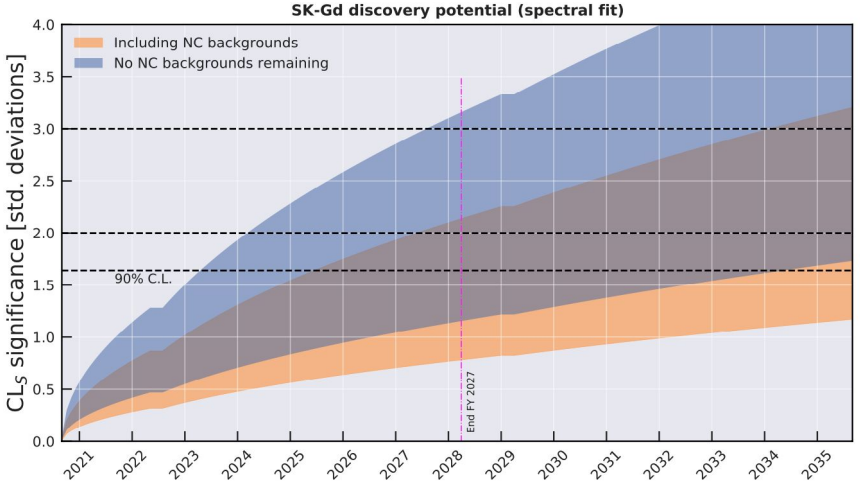
Diffuse Supernovae Neutrino Background @LLR

LLR leader of DSNB analysis since 2019: 2 papers w/o Gd already out, preparing new analysis with more sophisticated neutron and prompt tagging

Rate analysis (model independent), before Gd era

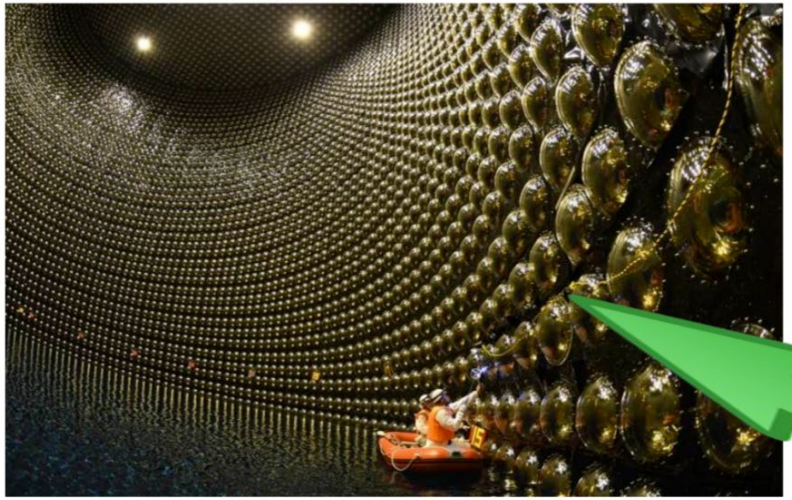


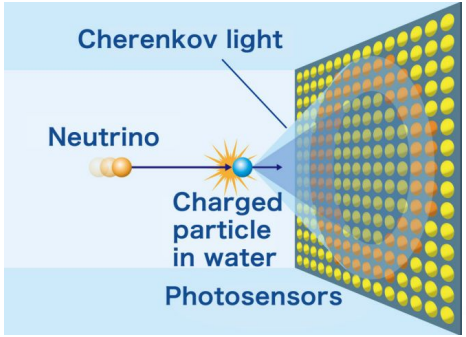
Sensitivity studies for the Gd era (model dependent analysis)



See updates in Antoine's talk!

The Kamiokande series





Super-Kamiokande

KamiokaNDE

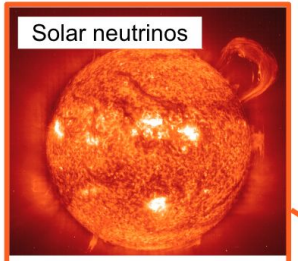
Hyper-Kamiokande

Moving to Hyper-Kamiokande

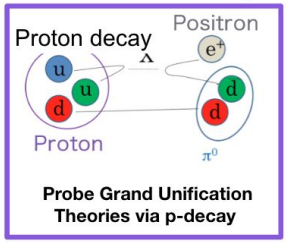
[T2K + SUPER SK] × 8 =

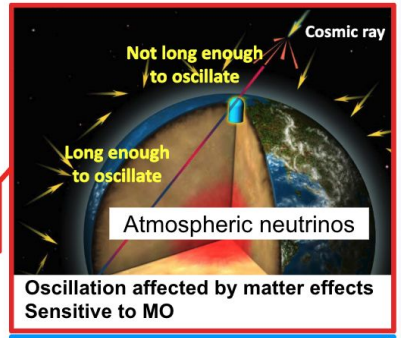
Hyper-Kamiokande

Hyper-Kamiokande physics program

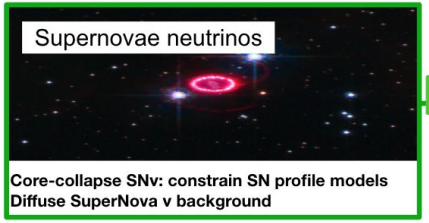


Survival probability up-turn
Solar/reactor tension
hep neutrinos

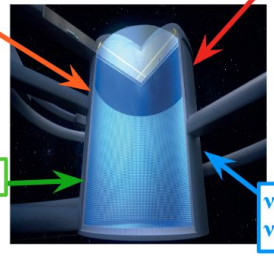




Oscillation affected by matter effects
Sensitive to MO

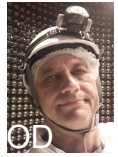


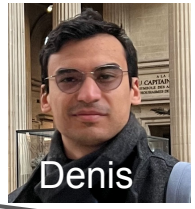
Core-collapse SNv: constrain SN profile models
Diffuse SuperNova ν background



The future and bigger synthesis of T2K and SK physics

Observe CP violation for leptons at 5σ
Precise measurement of δ_{CP}





See Denis' presentation in a moment!

Much more details in Benjamin's presentation at last CS