Neutrinos in Japan

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The Group

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Ashley Greenall

Carl Metelko

Francis Bench

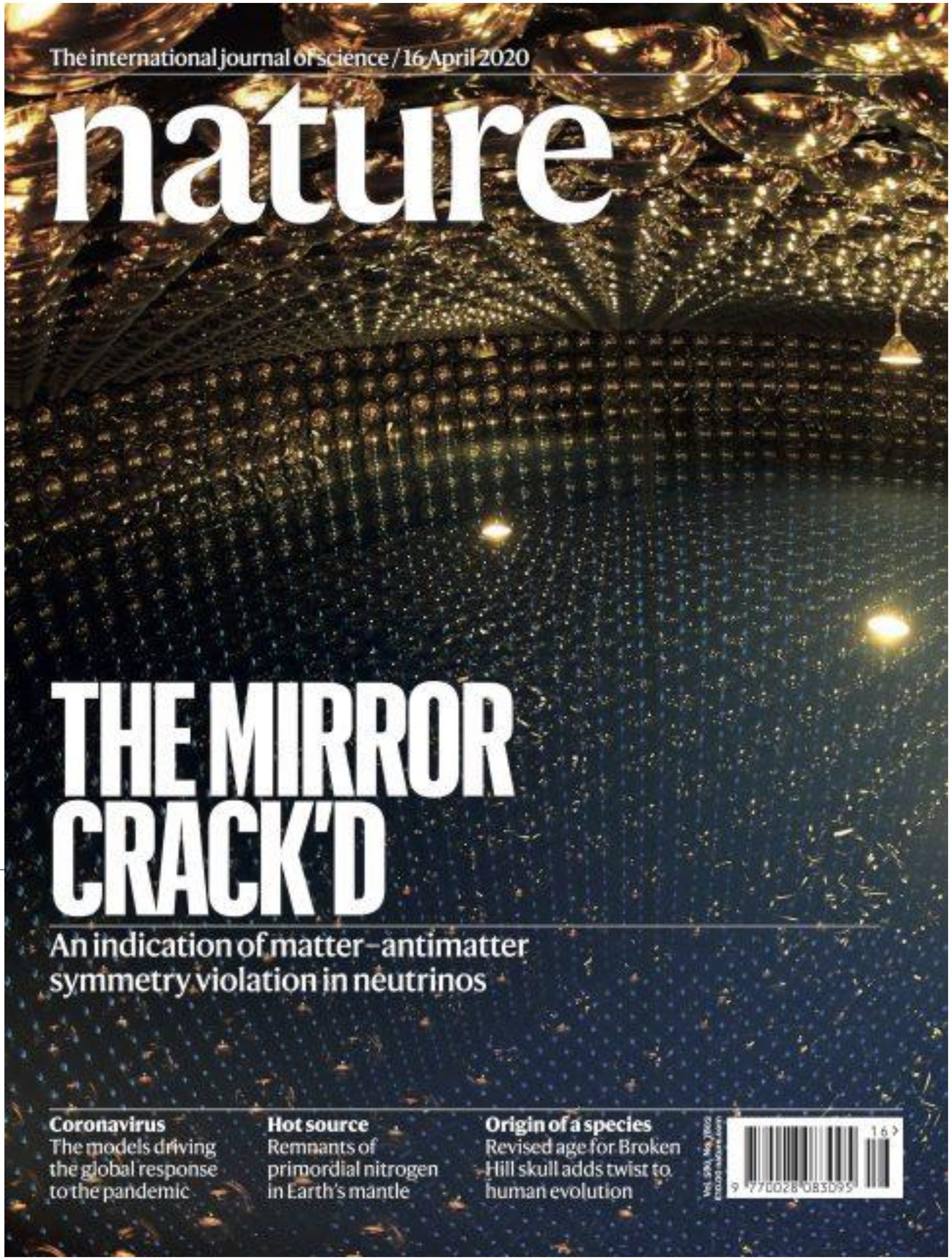
Gabriel Penn

Pruthvi Mehta

Jaiden Parlone

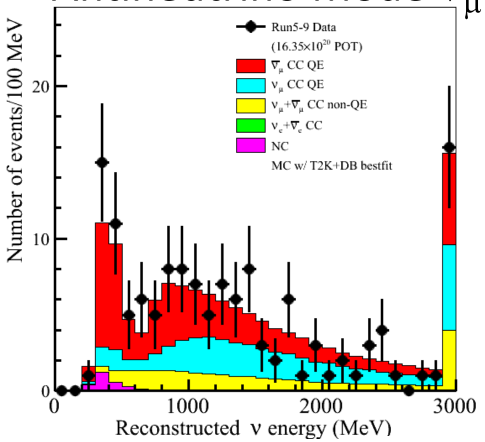
Adam Tarrant

T2K

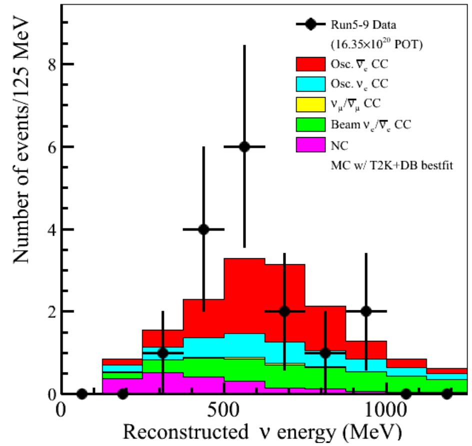

The international journal of science / 16 April 2020
nature
THE MIRROR CRACK'D
An indication of matter–antimatter symmetry violation in neutrinos
Coronavirus
The models driving the global response to the pandemic
Hot source
Remnants of primordial nitrogen in Earth's mantle
Origin of a species
Revised age for Broken Hill skull adds twist to human evolution

T2K Oscillation Results

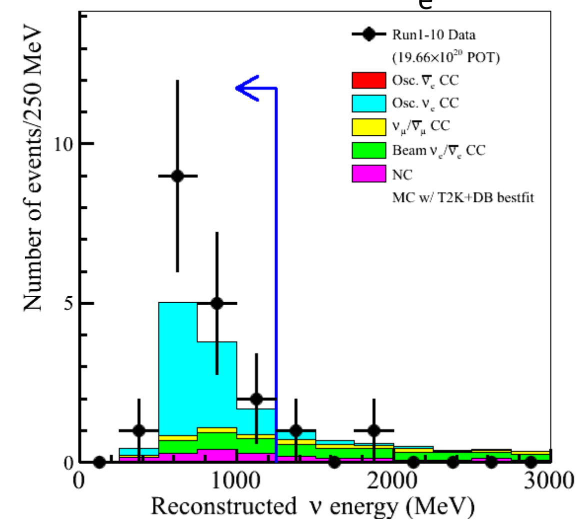
Antineutrino Mode ν_μ



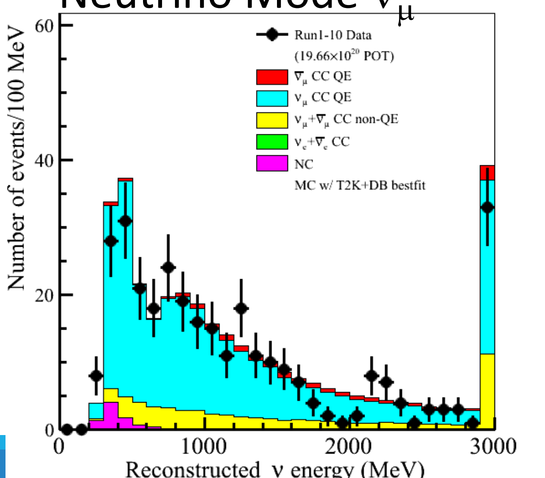
Antineutrino Mode ν_e



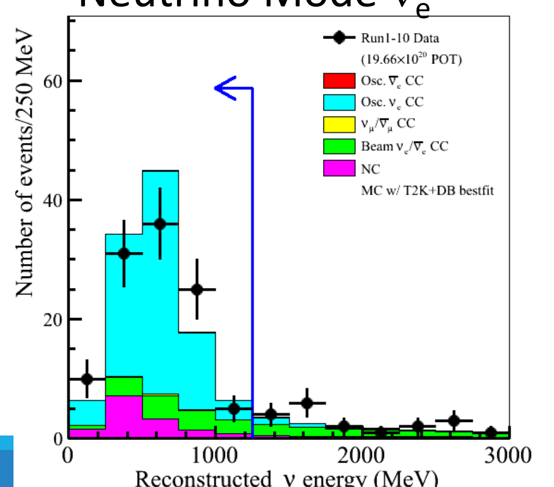
Neutrino Mode ν_e + 1de



Neutrino Mode ν_μ

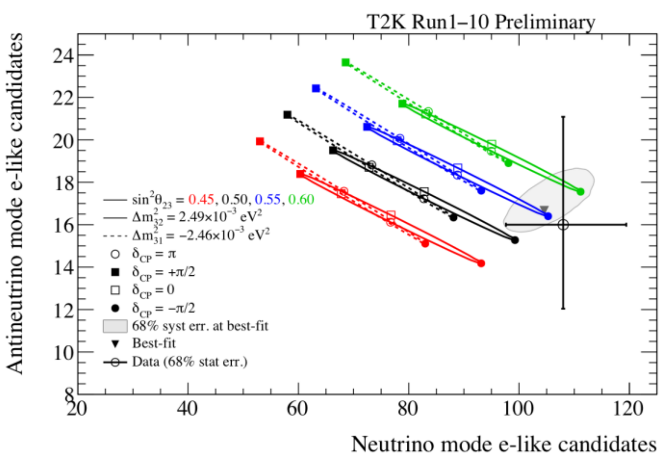


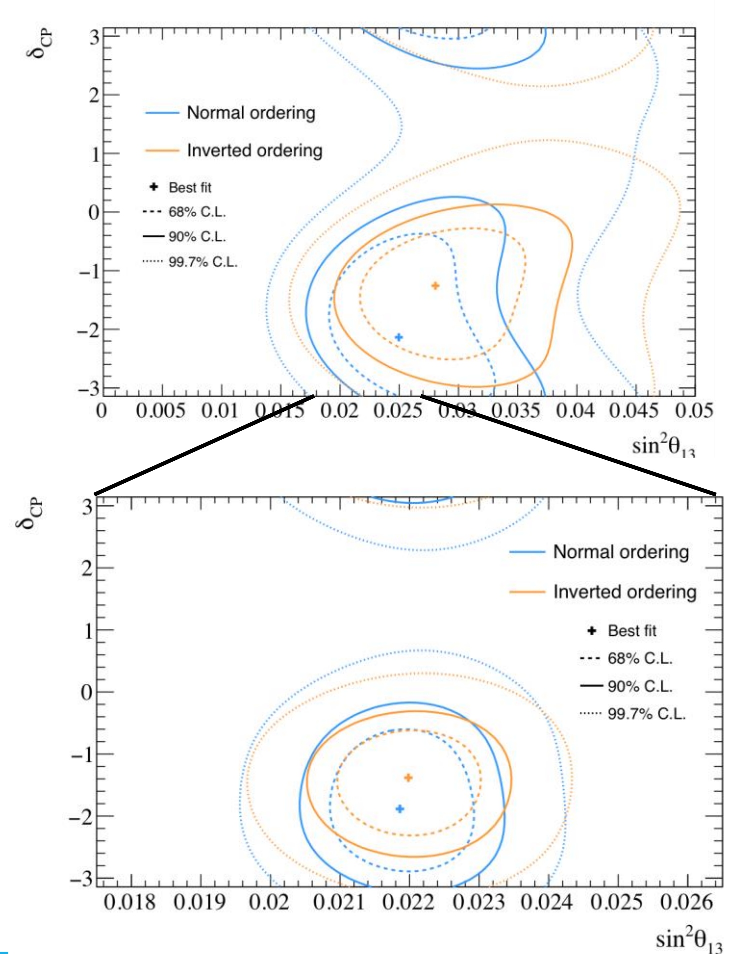
Neutrino Mode ν_e

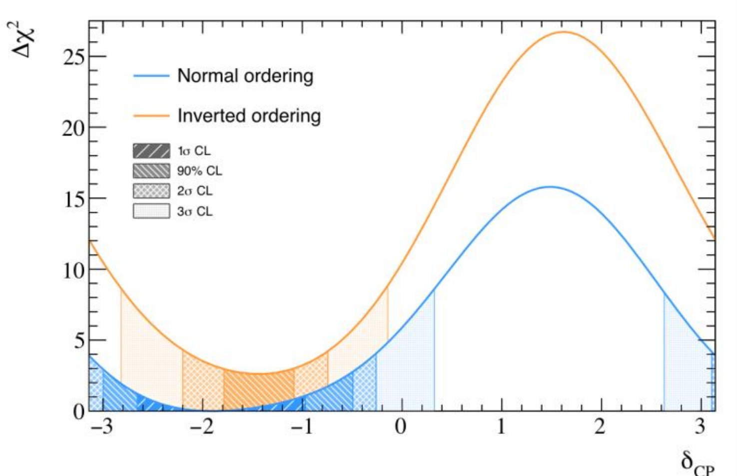


Oscillation Fits with VALOR
Costas Valor Lead
Francis, Jaiden

T2K Oscillation Results







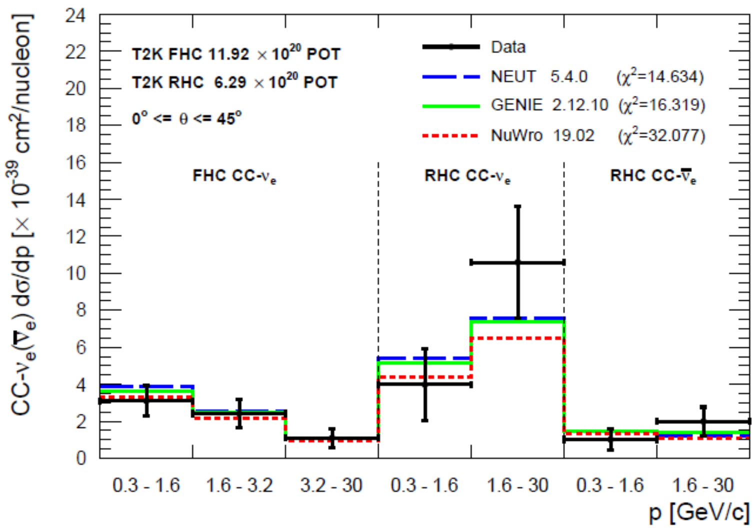
Cross Section Measurements

Completed publication of $\overline{\nu_e}$ cross section

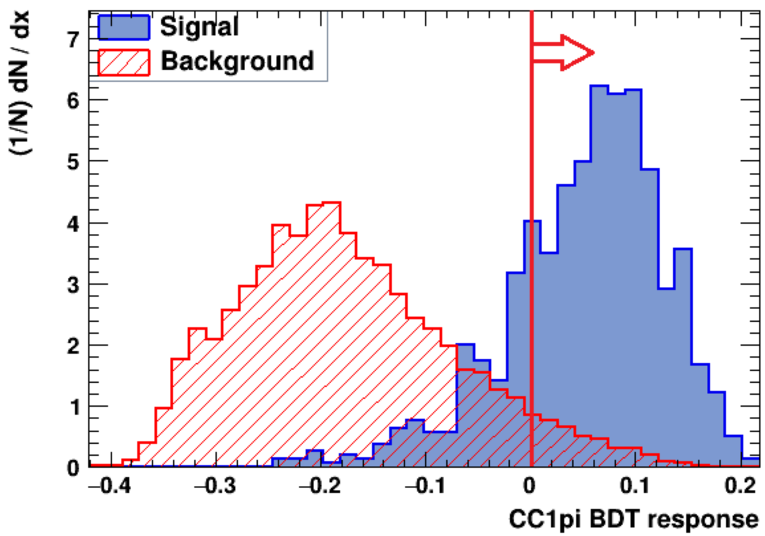
Change of focus to CC1π cross sections.

- Improved antineutrino selection
- CC1π1P transverse kinematic imbalance (TKI)

ν_e , $\overline{\nu_e}$ cross sections, Neil, George



Antineutrino CC1Pi BDT, Gabriel



Analysis and publication led by Ka Ming
Accepted by PRD today!

CC1π1P TKI

ν_μ CC1π^+ interaction on nucleus A with at least 1 proton in the final state

- $\nu_\mu + A \to \mu^- + \pi^+ + p + A'$

Kinematics sensitive to nuclear effects

Double transverse momentum imbalance δp_{TT}

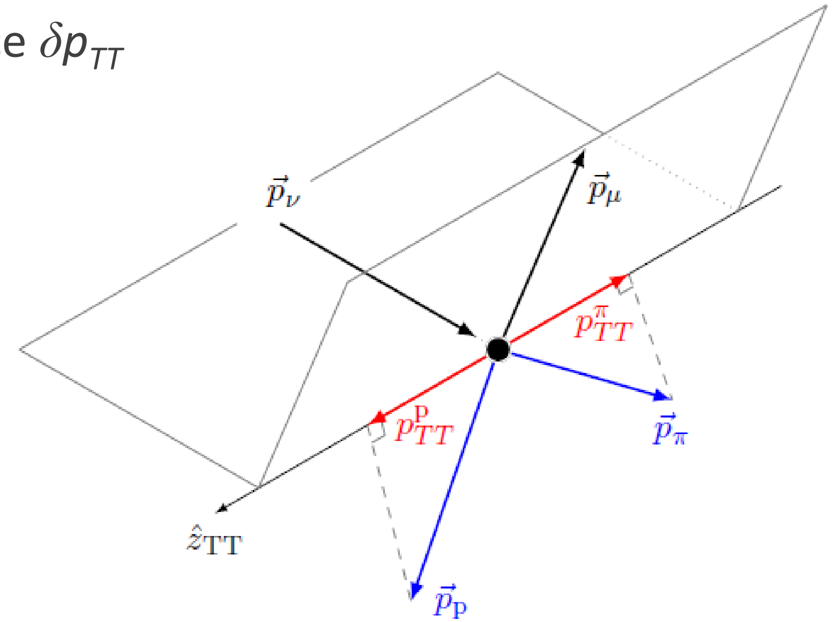
$$\delta p_{TT} = p_{TT}^{\pi} + p_{TT}^{\mathrm{p}} = \frac{\vec{p}^{\,\nu} \times \vec{p}_T^{\,\mu}}{\left|\vec{p}^{\,\nu} \times \vec{p}_T^{\,\mu}\right|} \cdot (\vec{p}_T^{\,\pi} + \vec{p}_T^{\,p})$$

δp_{TT} = 0 if no nuclear effects

Fermi momentum and FSI cause a broad spread

Other measures TKI also used

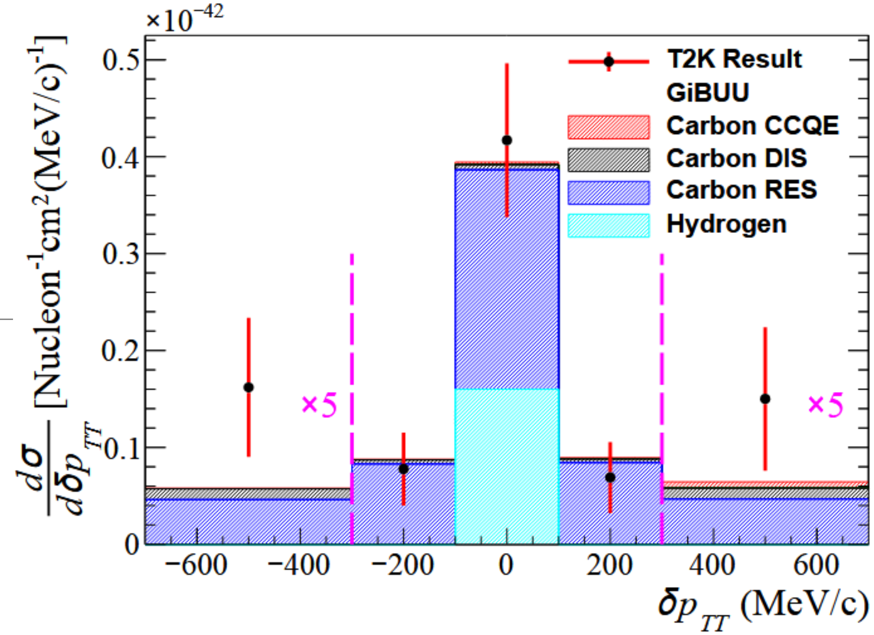
- Nucleon momentum
- Transverse boosting angle.

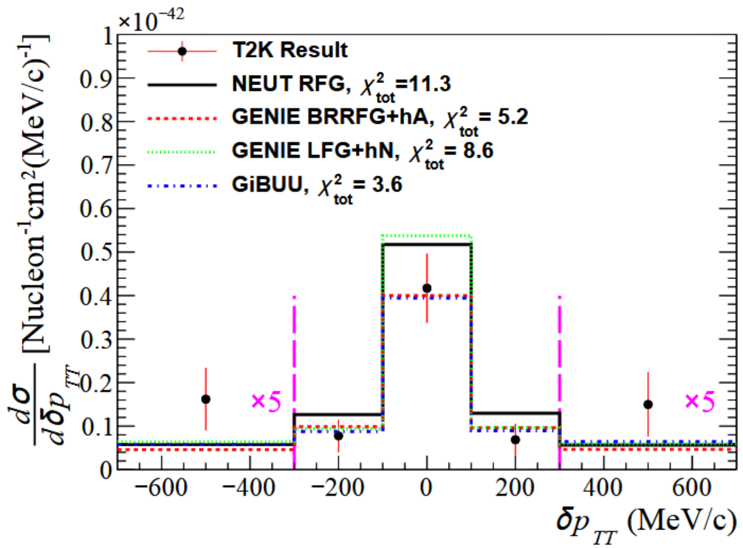


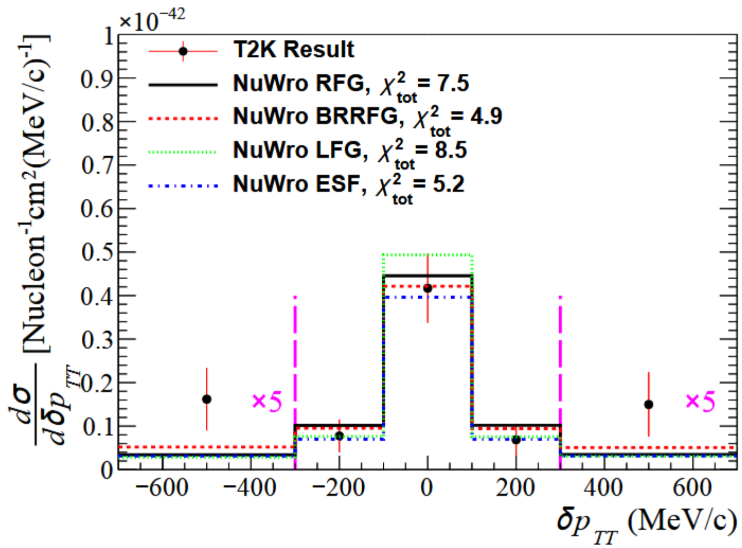
TKI Results

Model sensitivity comes mostly from central bins

Tail mostly contributed by FSI







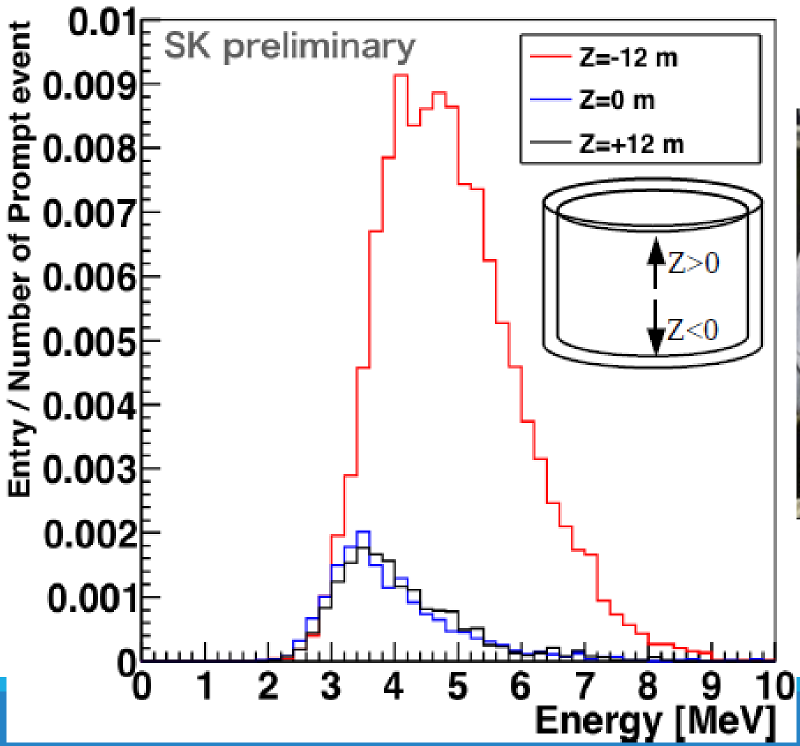
Super-K

SK-Gd

Gadolinium added to SK in July.

Start of new era for SK

AmBe Source Data

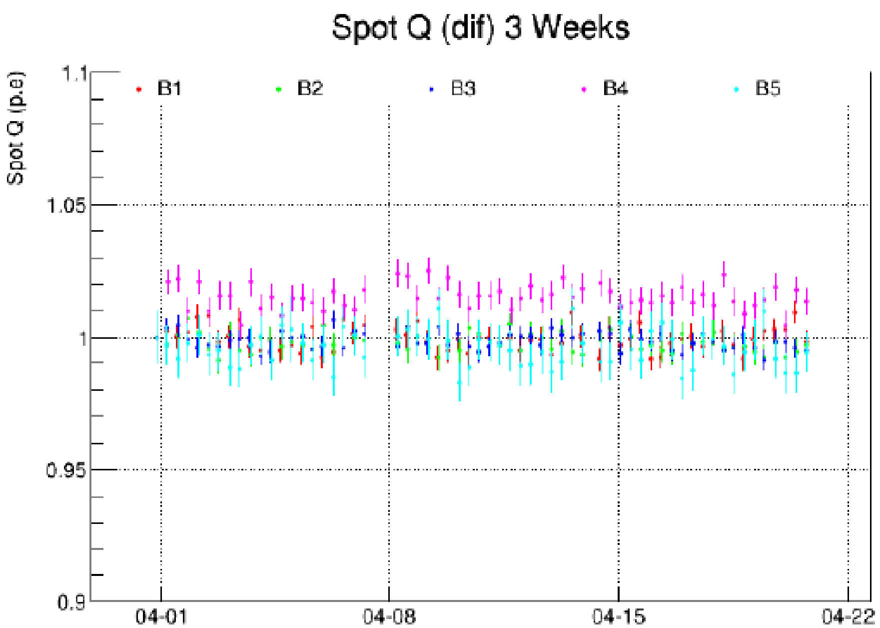


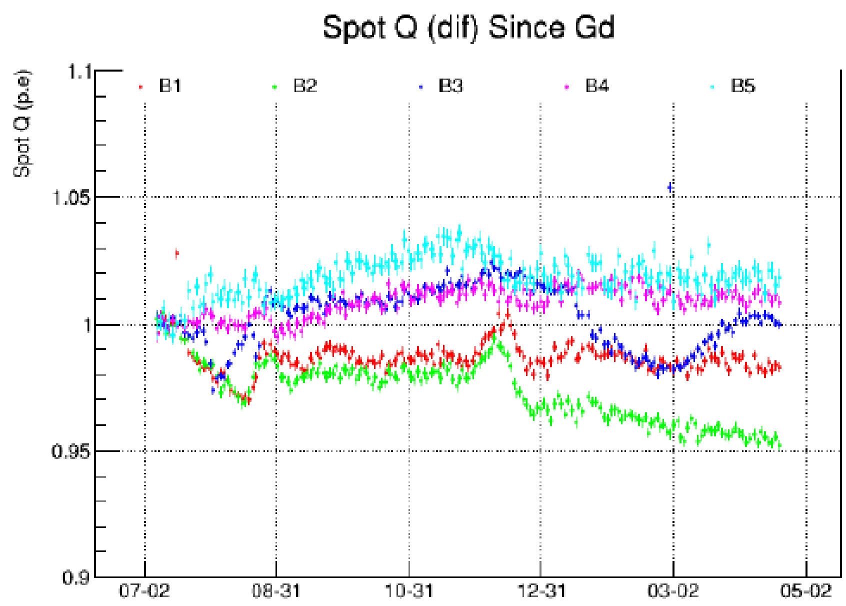
Light Injection

Our light injection system is used to monitor detector response during Gd loading and since.

Scattering measurement analysis under rapid development

Detector monitoring with the diffuser Pruthvi, Pablo, Neil



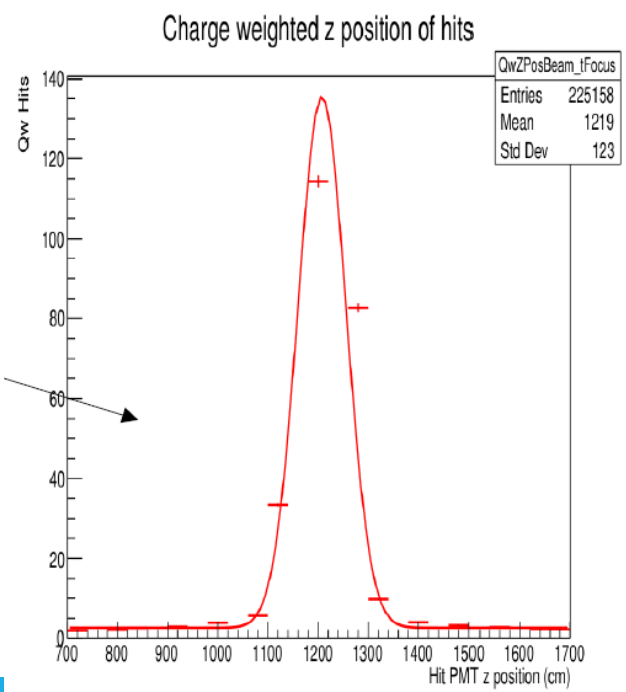


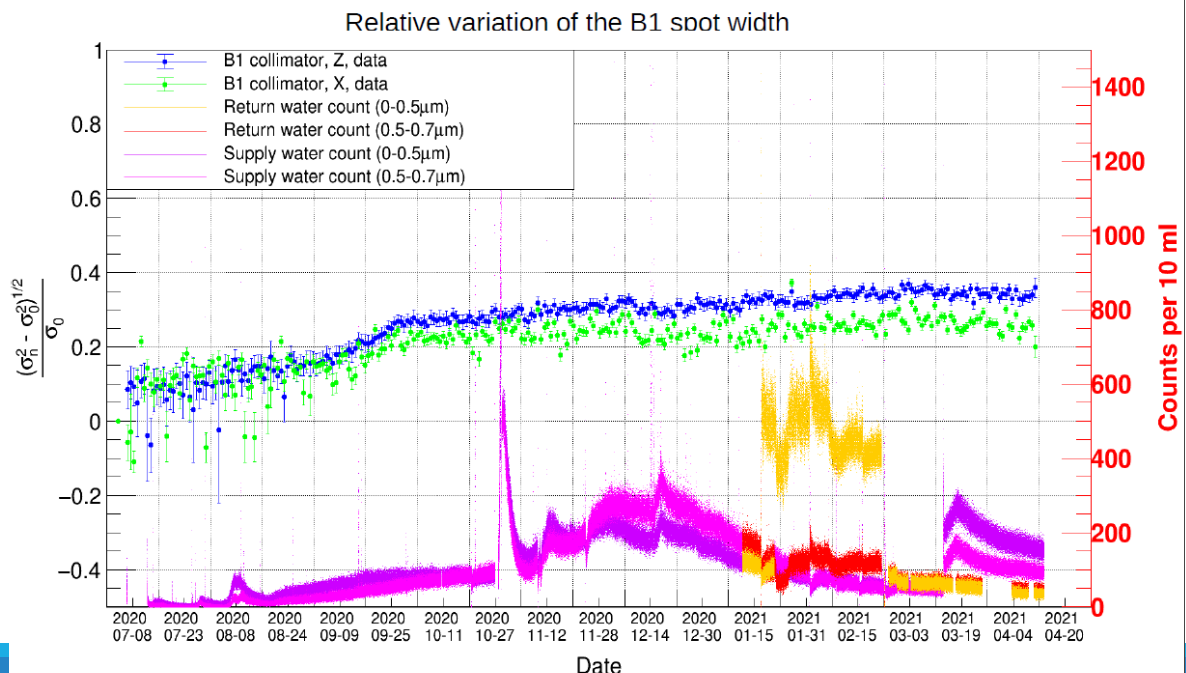
Scattering Measurement

New Scattering Monitor for symmetric scattering (Pablo)

Look at size of collimator spot

Compare to particle count measured in water.



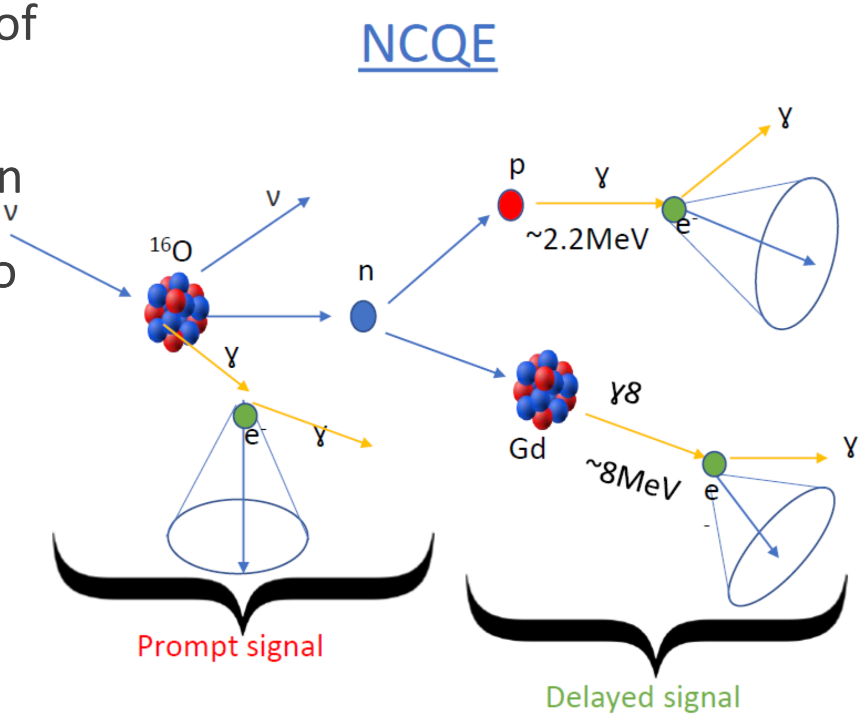


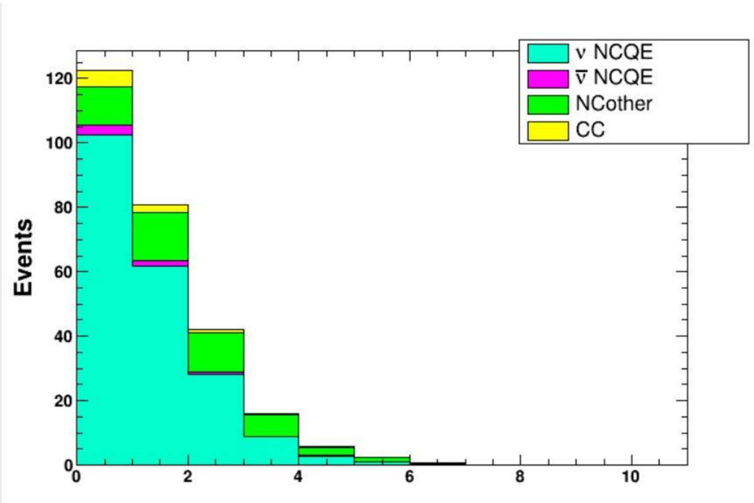
T2K NC-γ with neutrons

Observe NC interactions via deexcitation of excited nucleus.

Now can observe with neutron production

Background to diffuse supernova neutrino search





Detected Neutrons

Neutron Tag
Development: Pruthvi

Hyper-K

Hyper Kamiokande

2020 February : First year construction budget approved by Japanese Diet
2020 May: Univ. of Tokyo President and KEK Director General signed MOU

KEK will upgrade and operate the J-PARC accelerator to produce a high-intensity neutrino beam

The University of Tokyo will construct and operate the Hyper-Kamiokande detector

Hyper-K is under construction
Operation will begin in 2027

UK Budget Request with PPRP

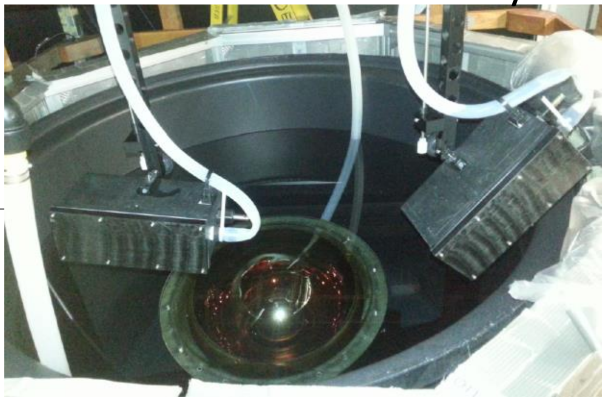
Neil: Far detector calibration group leader

Detector Calibration

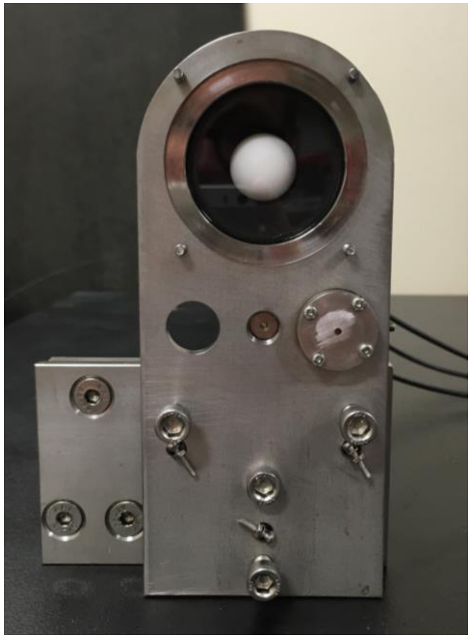
Wide programme of detector calibration to meet systematic needs

- Light Injection
- Diffuse Light source
- Electron LINAC (3-24 MeV)
- DT Generator – ^{16}N cloud
- CfNi Source
- AmBe Source
- Precalibration Programme

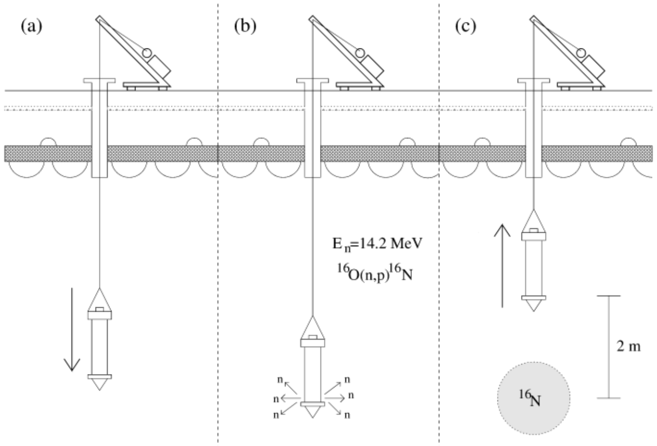
PhotoSensor Test Facility

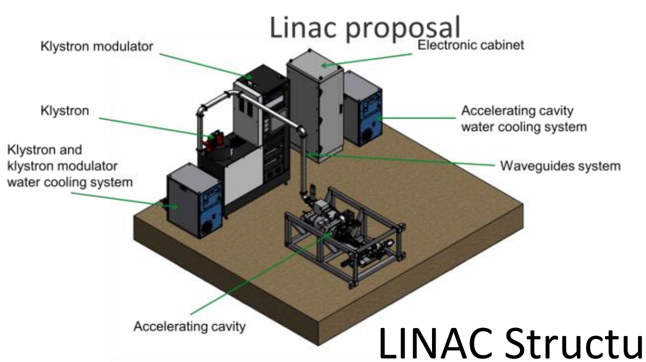


Light Injection Multi Injector



DT Operation





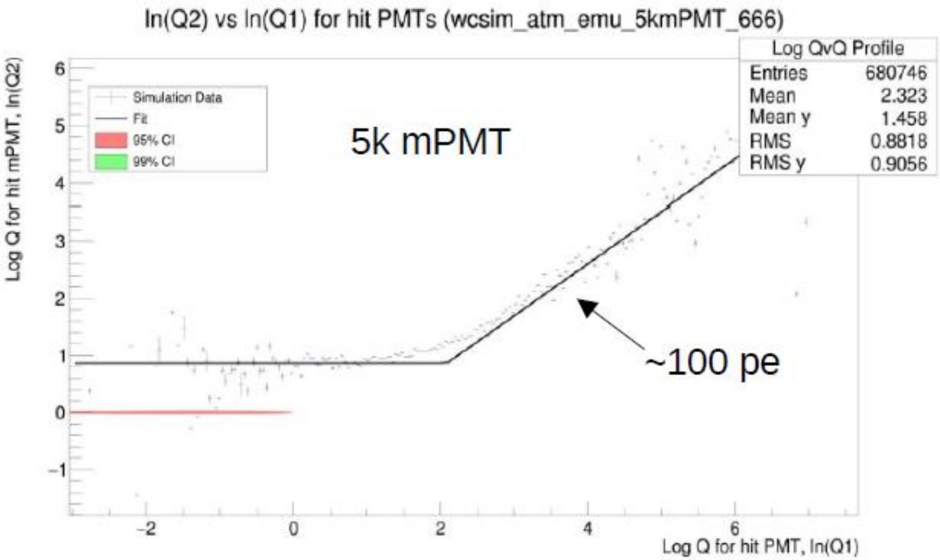
LINAC Structure

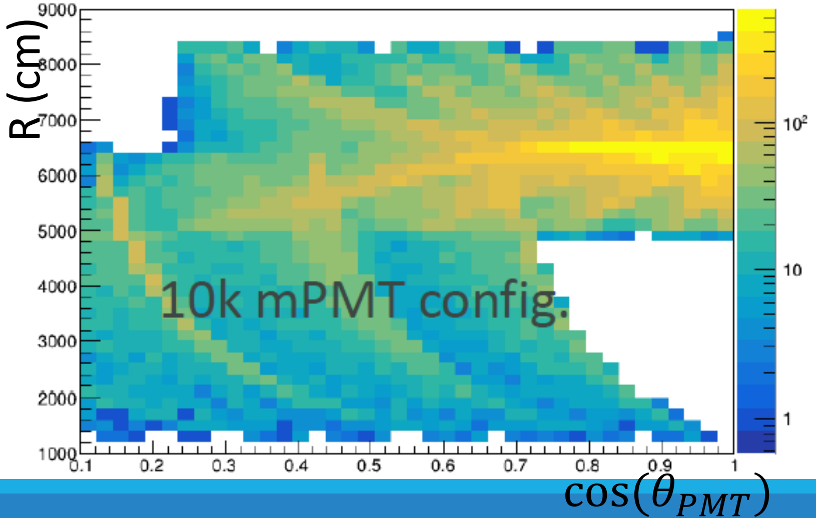
Calibration with mPMTs

New HK task force on calibration with mPMTs

Demonstrate benefit of mPMTs to HK

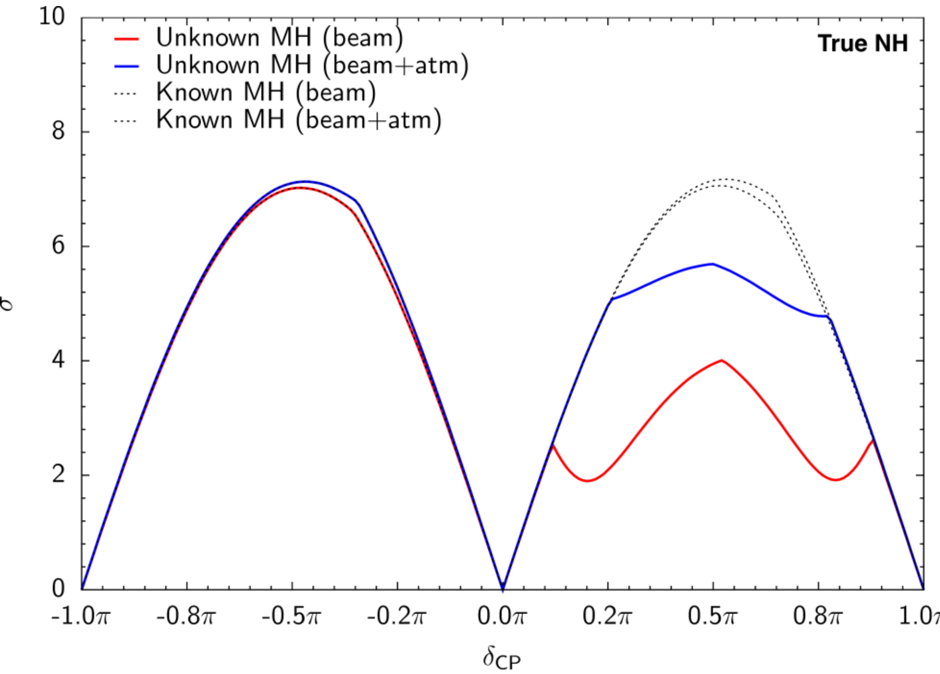
Neil (task force lead), Pablo, Ka Ming, Callum Seed (MPhys project)

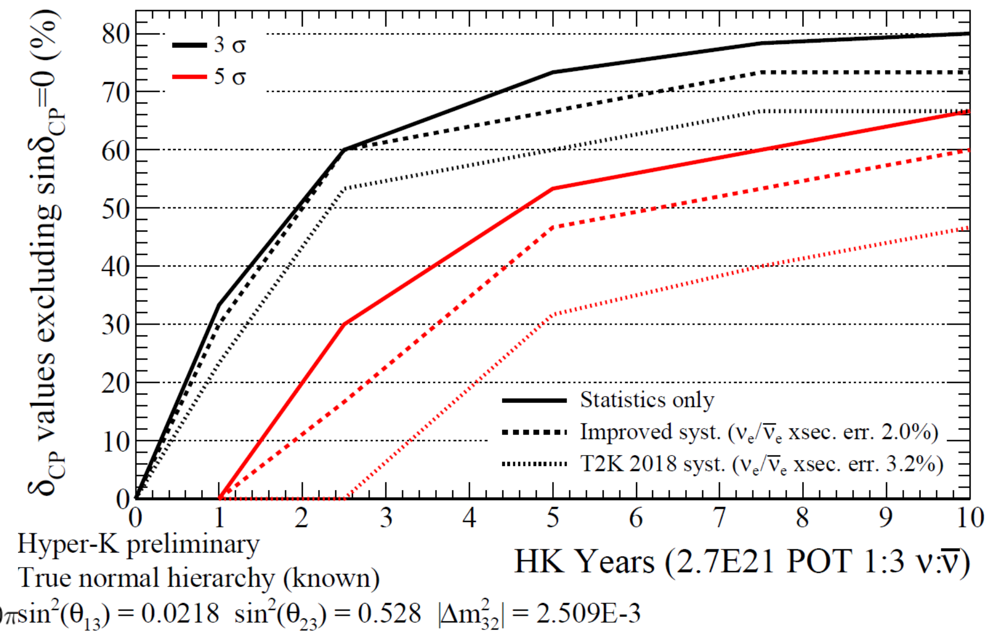




CP Violation Sensitivity

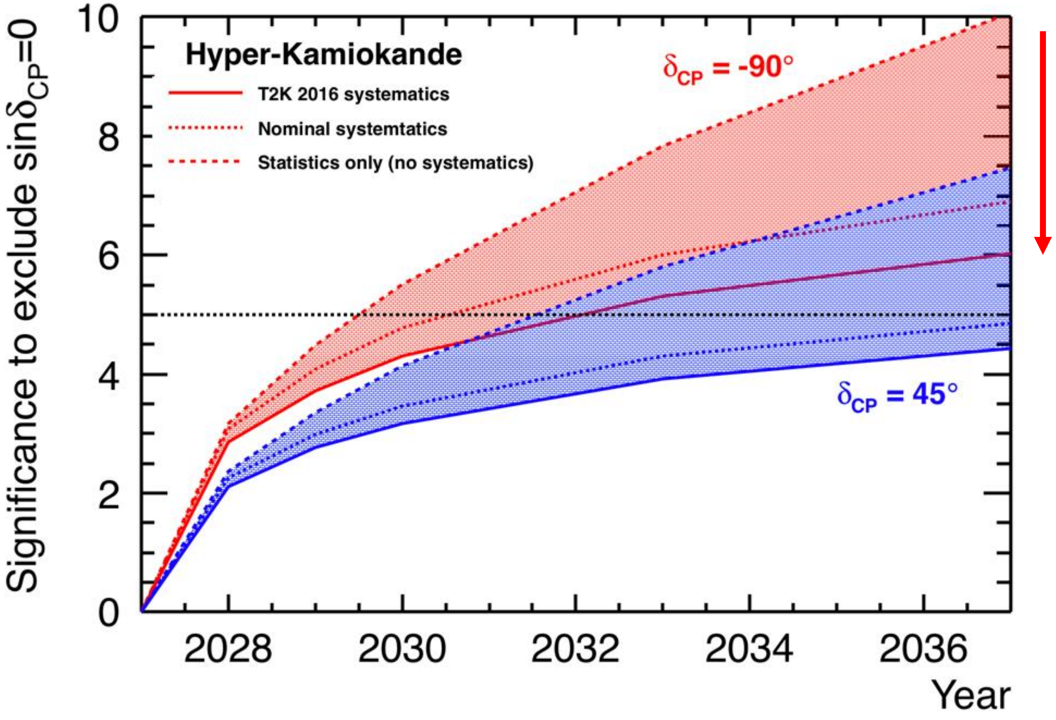
Exclusion for $sin\delta_{CP} = 0$





~8σ exclusion of $sin\delta_{CP} = 0$ at $\delta_{CP} = -90°$ (T2K favoured value)

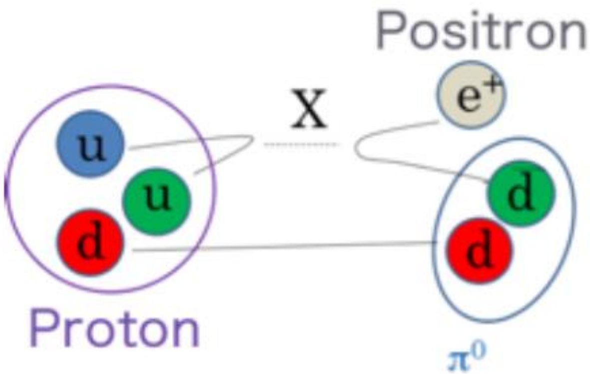
CP Measurement Prospects



Impact of Systematic Uncertainties
Statistics – T2K 2016
Shows importance of improved uncertainty estimations

Sensitivity depends on true value of δ_{CP}

Proton decay



Predicted by grand unification theories

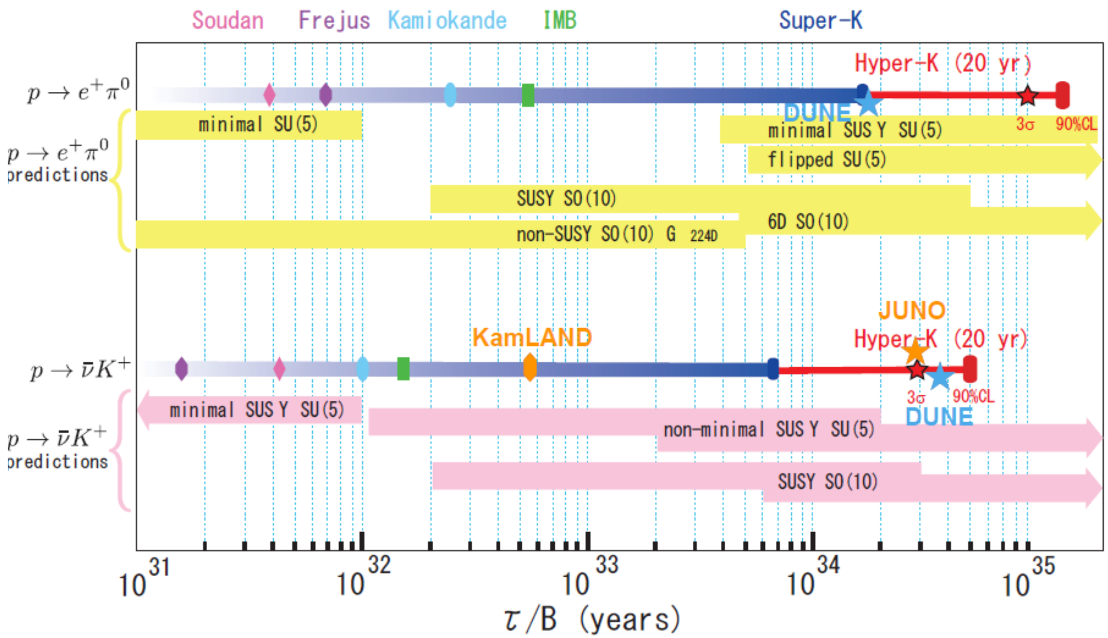
Suppressed by $\frac{1}{M_X^4}$

Many channels but $e^+\pi^0$ and $\bar{\nu}K^+$ are most common

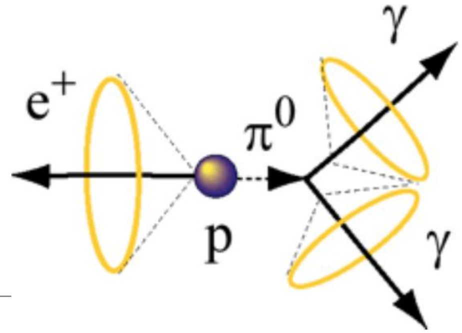
Rate is predicted by various GUT models and many have been rules out.

- Target 10^{35} years to significantly increase model coverage

The actual reason Kamiokande and IMB were built!

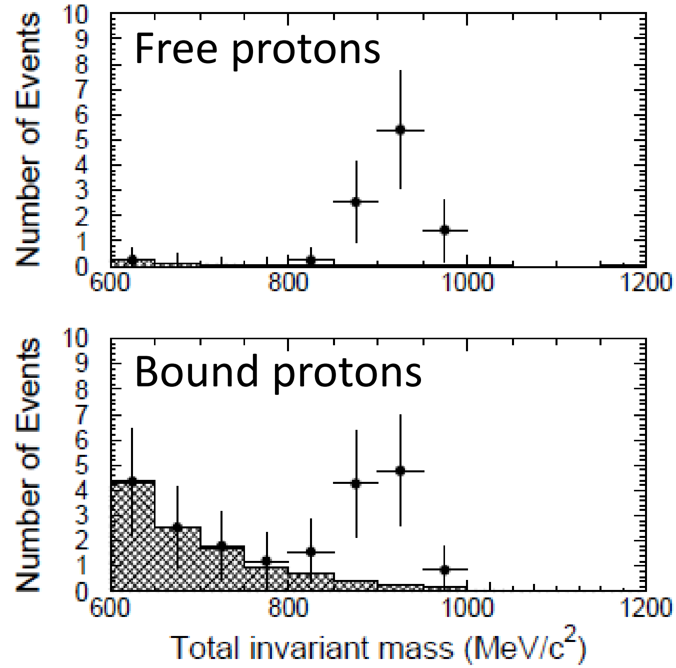


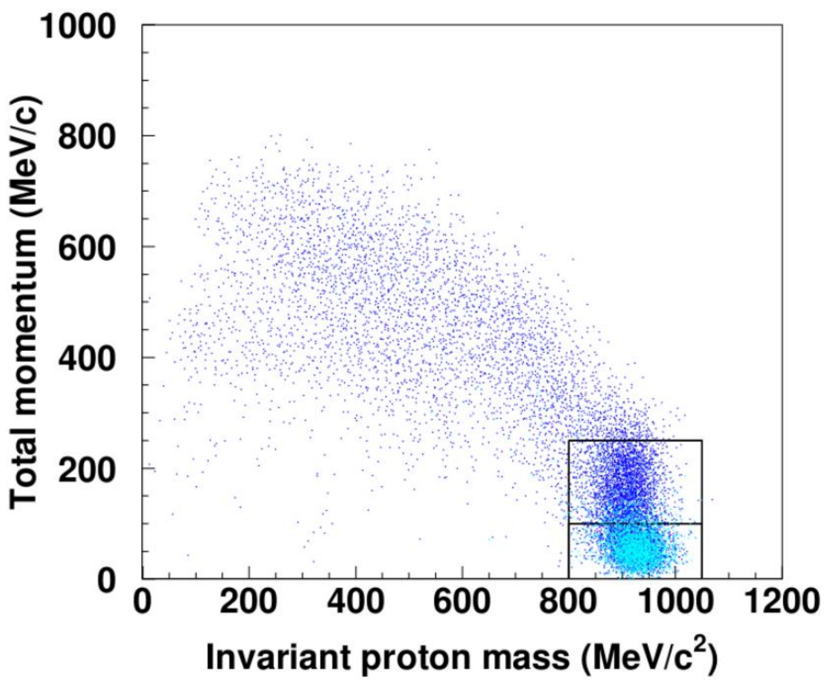
$p \rightarrow e^+\pi^0$



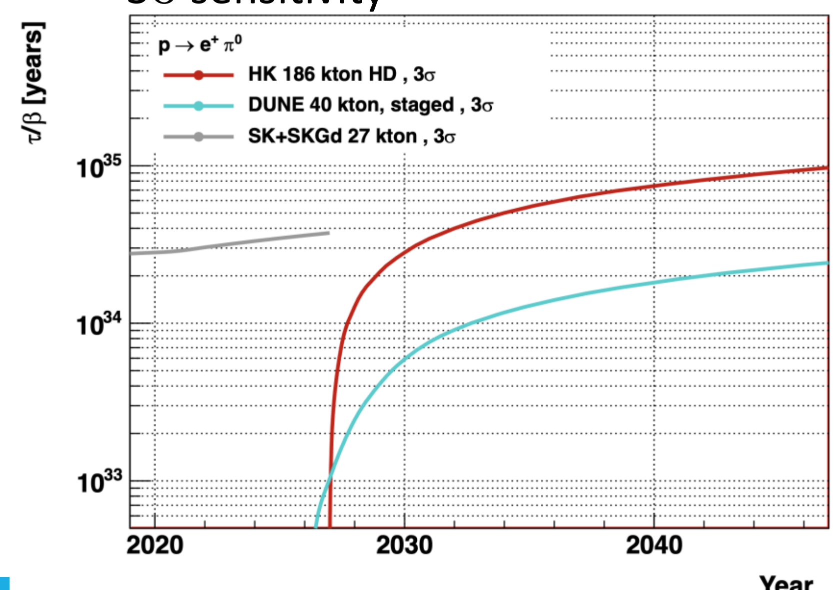
Very clean signal

- Background from atmospheric neutrinos reduced by neutron tagging to almost zero in signal box

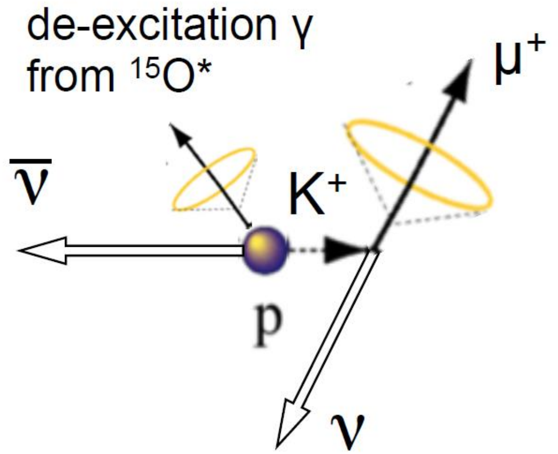




3σ sensitivity



$p \to K^+\bar{\upsilon}$

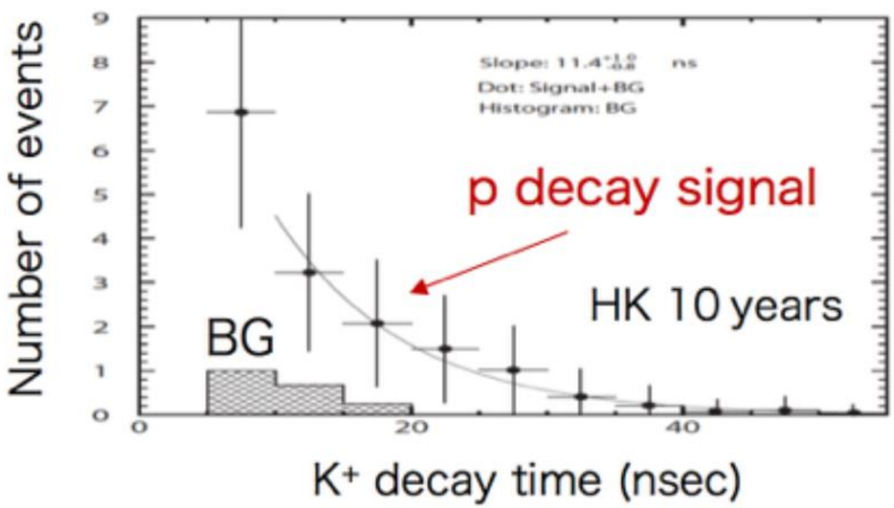


Clean signatures

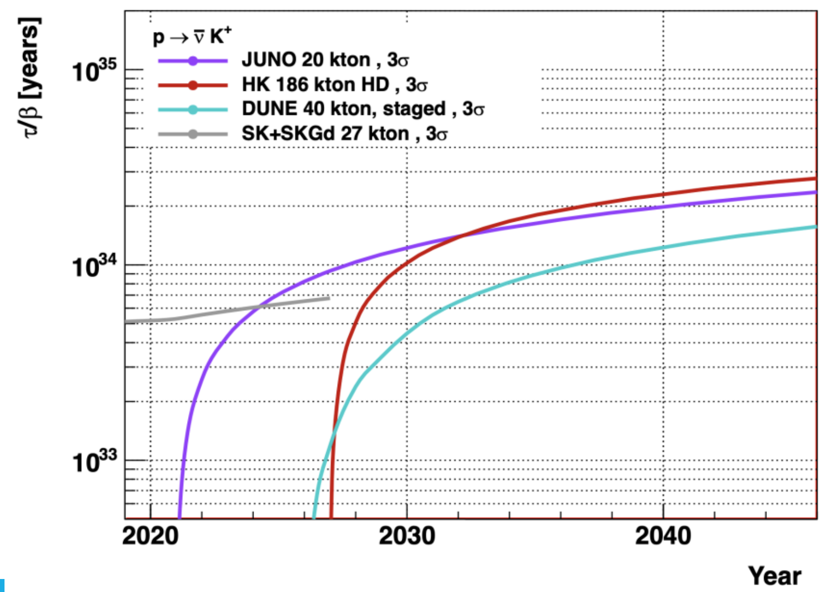
$K^+ \to \mu^+\nu$ (64%) 236 MeV μ^+

decay electron, 6MeV gamma

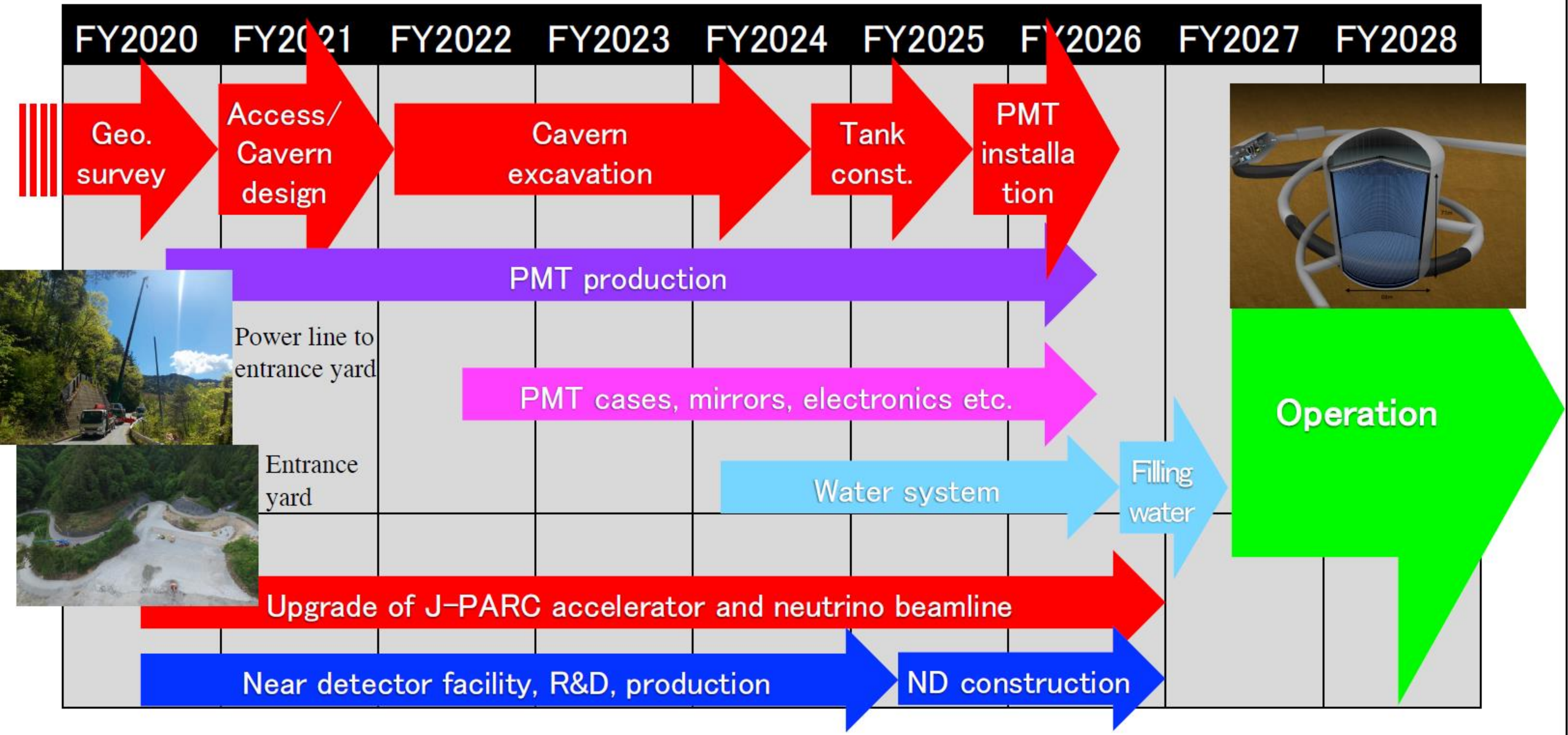
$K^+ \to \pi^+\pi^0$(21%) 205 MeV π^+ back to back



3σ sensitivity



Timeline



FY2020
FY2021
FY2022
FY2023
FY2024
FY2025
FY2026
FY2027
FY2028
Geo. survey
Access/ Cavern design
Cavern excavation
Tank const.
PMT installa tion
PMT production
Power line to entrance yard
PMT cases, mirrors, electronics etc.
Entrance yard
Water system
Filling water
Operation
Upgrade of J-PARC accelerator and neutrino beamline
Near detector facility, R&D, production
ND construction

Summary

HK is funded in Japan and will start in 2027

A new era for SK with SK-Gd

T2K continues to produce results and will be upgraded next year

- Beam Power
- ND280 Upgrade

Liverpool making key contributions to each

Backup

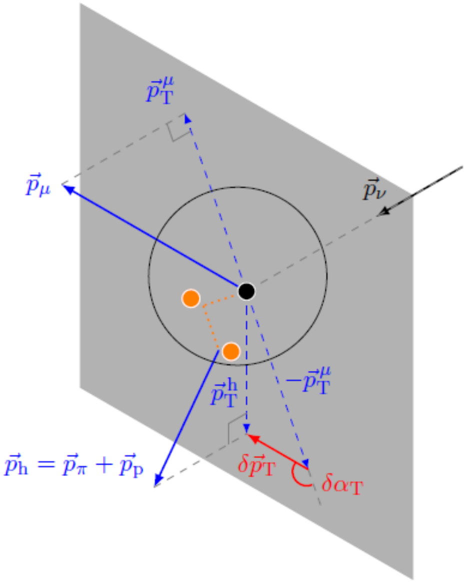
Measurement of TKI in CC1π^+Xp interaction at

ν_μ CC1π^+ interaction on nucleus A with at least 1 proton in the final state:

$$\nu_\mu + \mathrm{A} \rightarrow \mu^- + \pi^+ + \mathrm{p} + \mathrm{A}'$$

Initial nucleon momentum p_N (Phys. Rev. C **99**, 055504 (2019))

$$p_N = \sqrt{\delta\vec{p}_T^{\,2} + p_L^2} \quad \left\{ \begin{aligned} &\delta\vec{p}_T = \vec{p}_T^{\,\mu} + \vec{p}_T^{\,\pi} + \vec{p}_T^{\,\mathrm{p}} \\ &p_L = \frac{1}{2}\alpha - \frac{M_{\mathrm{A}'}^2 + \delta\vec{p}_T^{\,2}}{2\alpha} \\ &\alpha = M_{\mathrm{A}} + p_L^\mu + p_L^\pi + p_L^{\mathrm{p}} - E^\mu - E^\pi - E^{\mathrm{p}} \end{aligned} \right.$$



Probes the Fermi motion inside the nucleus

FSI shift the peak and cause a long tail

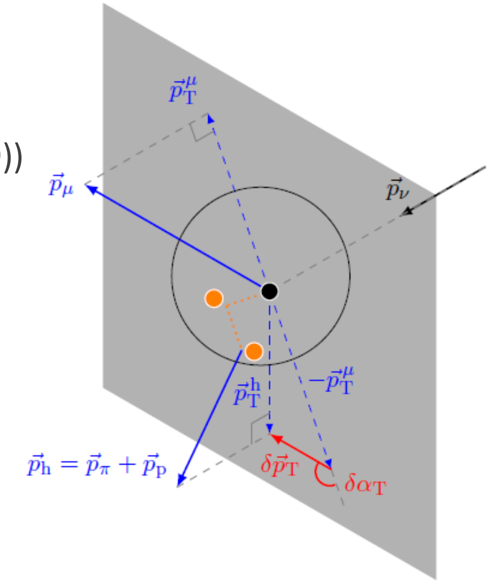
Measurement of TKI in CC1π^+Xp interaction at

ν_μ CC1π^+ interaction on nucleus A with at least 1 proton in the final state:

$$\nu_\mu + \mathrm{A} \rightarrow \mu^- + \pi^+ + \mathrm{p} + \mathrm{A}'$$

Transverse boosting angle $\delta\alpha_T$ (Phys. Rev. C **99**, 055504 (2019))

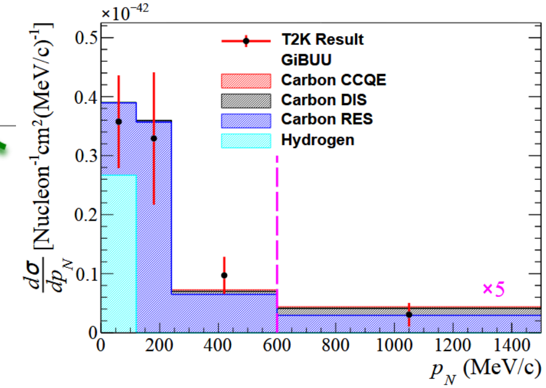
$$\delta\alpha_T = \cos^{-1}\frac{-\vec{p}_T^{\,\mu}\cdot\delta\vec{p}_T}{p_T^{\mu}\,\delta p_T}$$



Isotropic Fermi motion causes a flat distribution

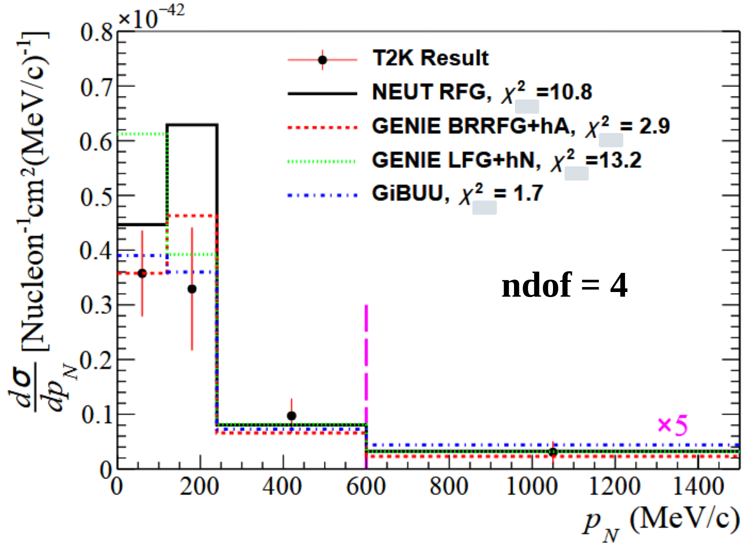
FSI slow down hadrons and skew towards $\delta\alpha_T$>90°

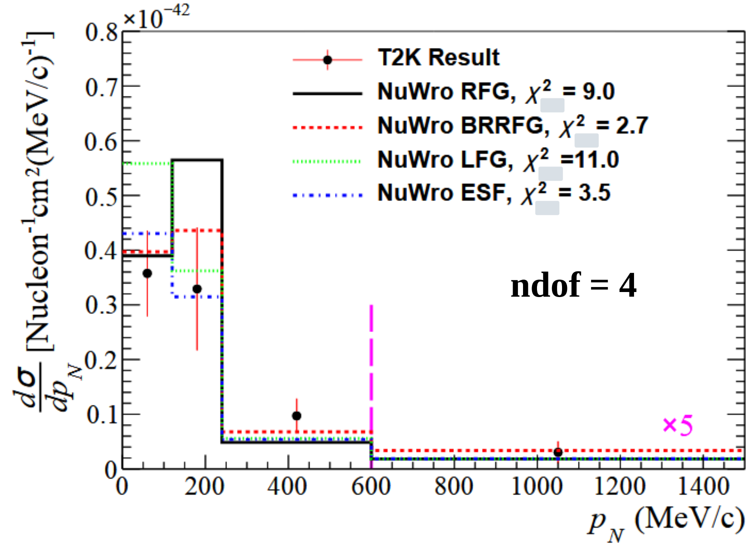
Results



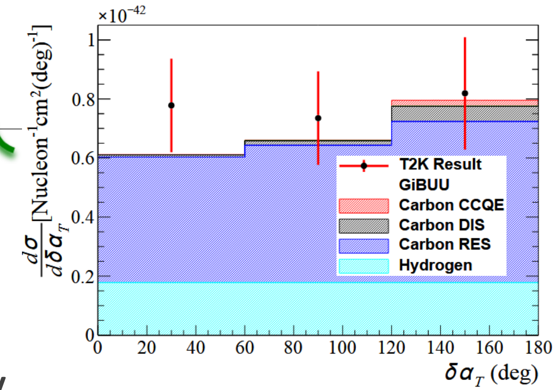
RFG and LFG models strongly disfavored at small p_N

Over-prediction in the peak region for all models





Results



Curvature strongly dependent on FSI

Current phase space restrictions limit our sensitivity