Hyper-Kamiokande

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On behalf of the UK Hyper-K collaboration

NA61 – beyond 2020
April 28, 2017

ハイパーカミオカンデ
Hyper-Kamiokande

Outline

- The Hyper-K project in a Nutshell
- Beam studies
- T2K Flux Uncertainties
- Out-of-target Material
- Atmospheric Neutrinos
- Conclusions

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Hyper-Kamiokande Proto-Collaboration

- ~300 collaborators
- 75 institutions from 15 countries as of April 2017
- ~70% of collaborators from overseas Countries

- Next generation water Cherenkov detector
- Two staged detectors:
  - ➢ First detector in Japan → to build as soon as possible
  - ➢ Second detector possibly in Korea

Queen Mary University of London

The Hyper-Kamiokande Experiment

Hyper-Kamiokande is:

Multi-purpose experiment:

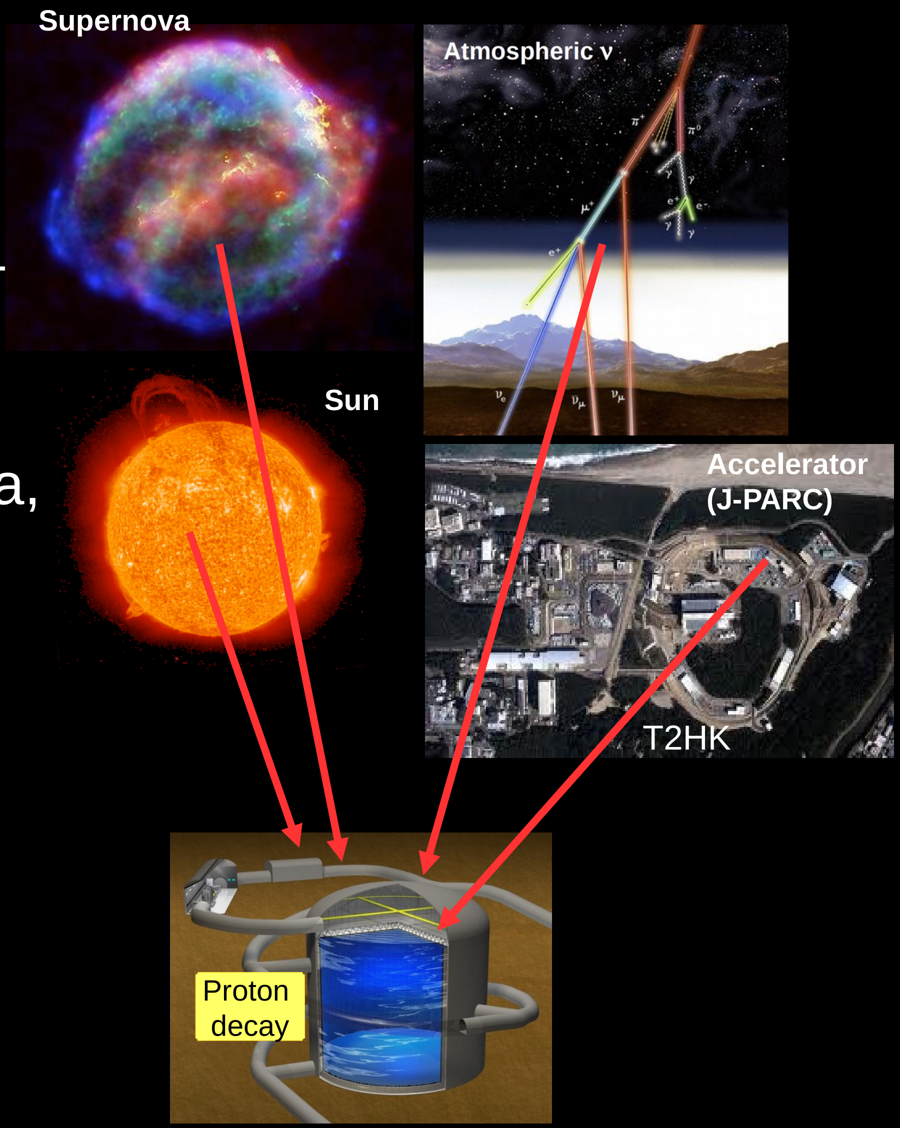
- Beam-physics (CP violation)
- High energy physics (Atmospherics – Δm^2_{32})
- Proton decays, new physics
- Astrophysics Observatory (Supernova, Solar neutrinos, Dark Matter, etc.)
- Neutrino Interactions

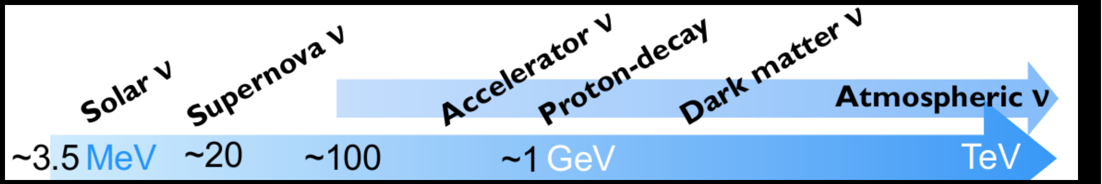
Detector:

- Water Cherenkov Technology: Japan (1st tank) and Korea (2nd tank)
- Near detectors (Neutrino interaction physics)

Pedigree:

- Based on the two-times Nobel Prize winner (Super)Kamiokande.
- 1 Breakthrough Prize





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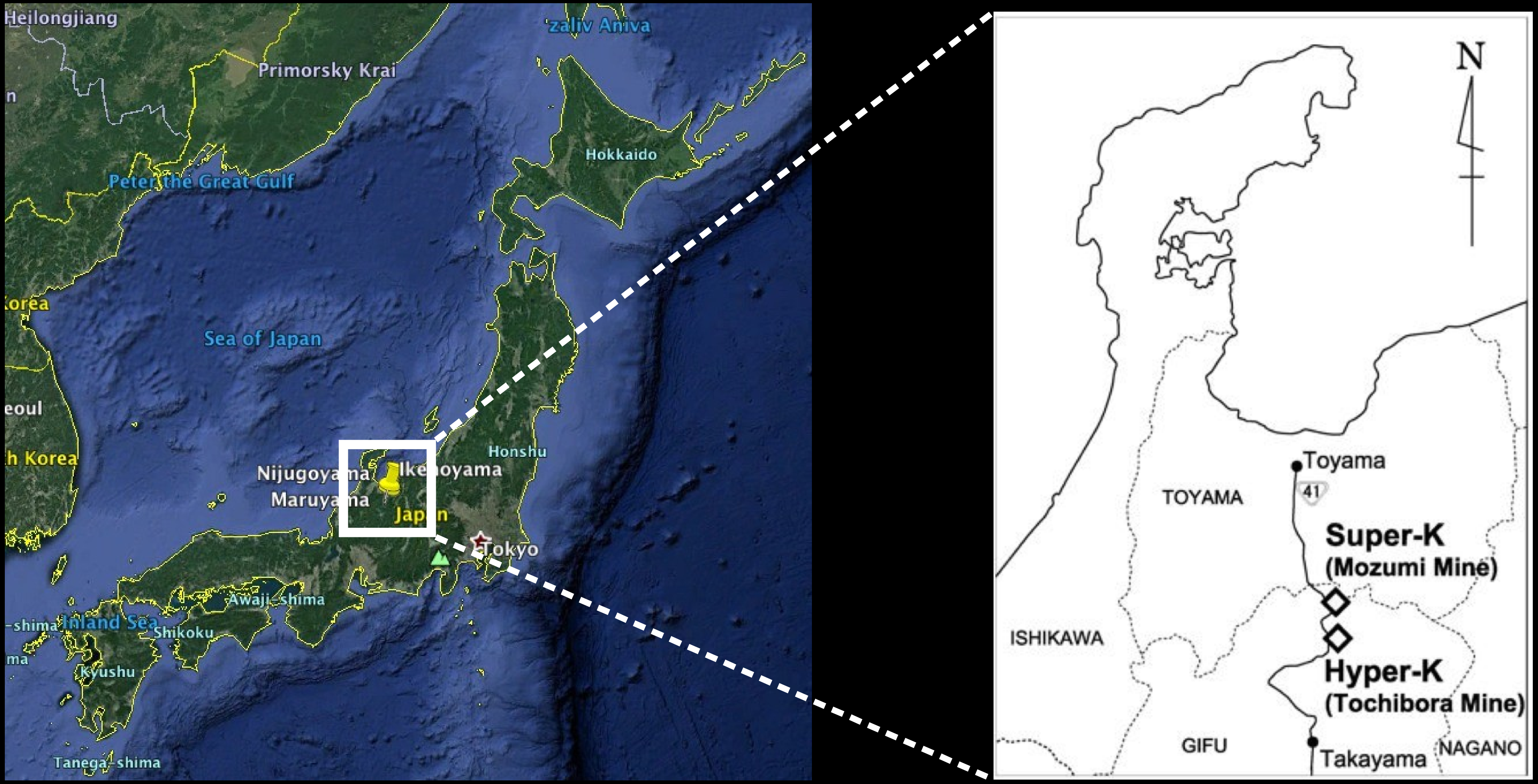
Physics programme spanning multiple fields.

Established, but new: Largest in the world, Gadolinium

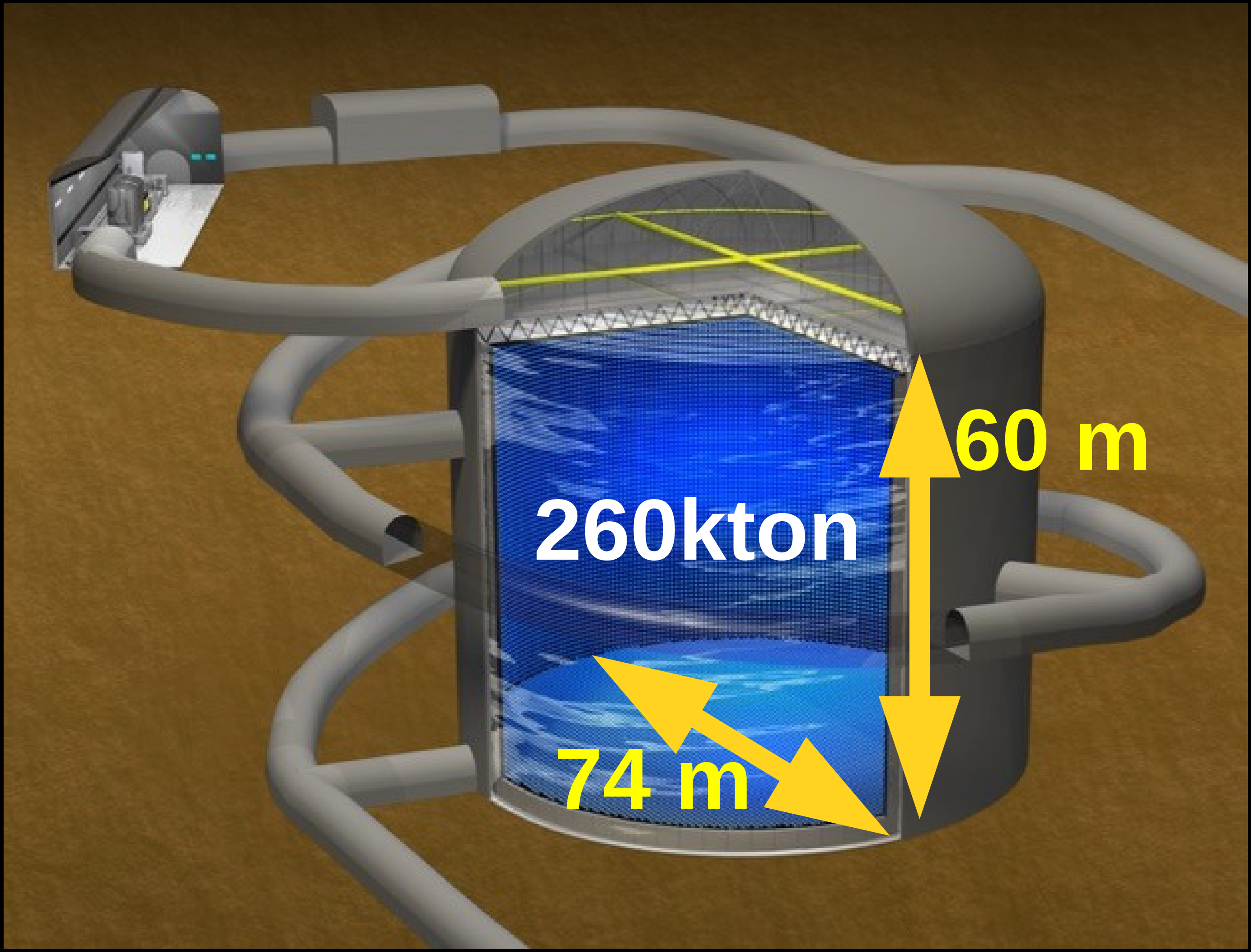
New: Gd for neutrino interactions, off-axis spanning, new TPCs

World-best high quality results

Detector Site



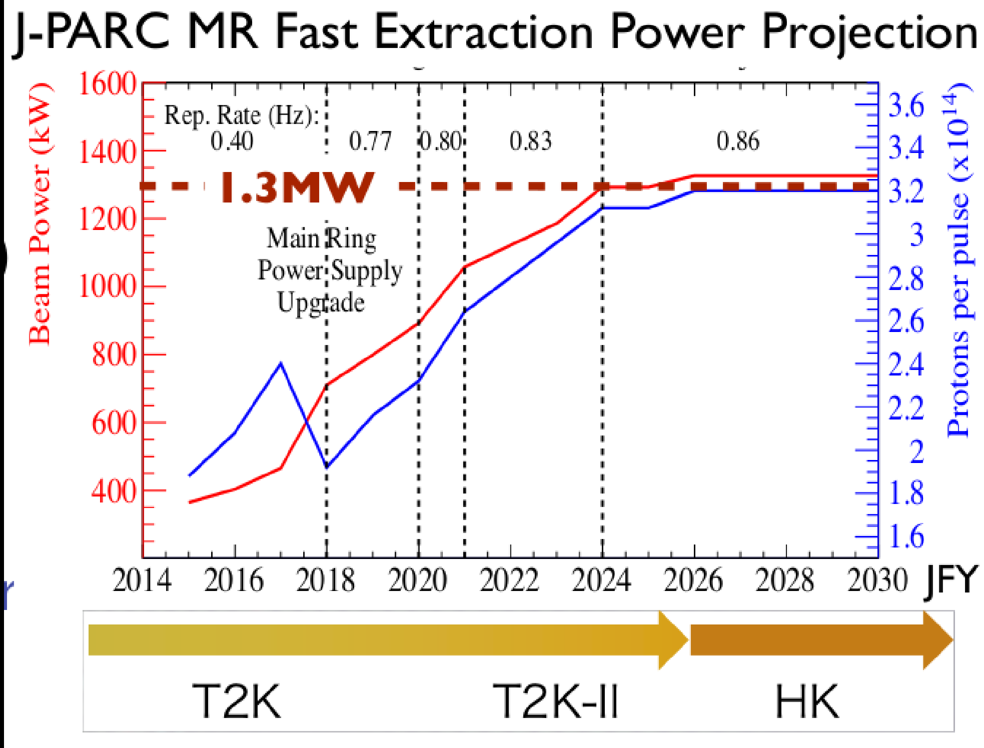
- The candidate site is located under Mt. Nijugo-yama
  - ~8km south from Super-K
- Identical baseline (295km) and off-axis angle (2.5deg) to T2K
- Overburden ~650m (~1755 m.w.e.)



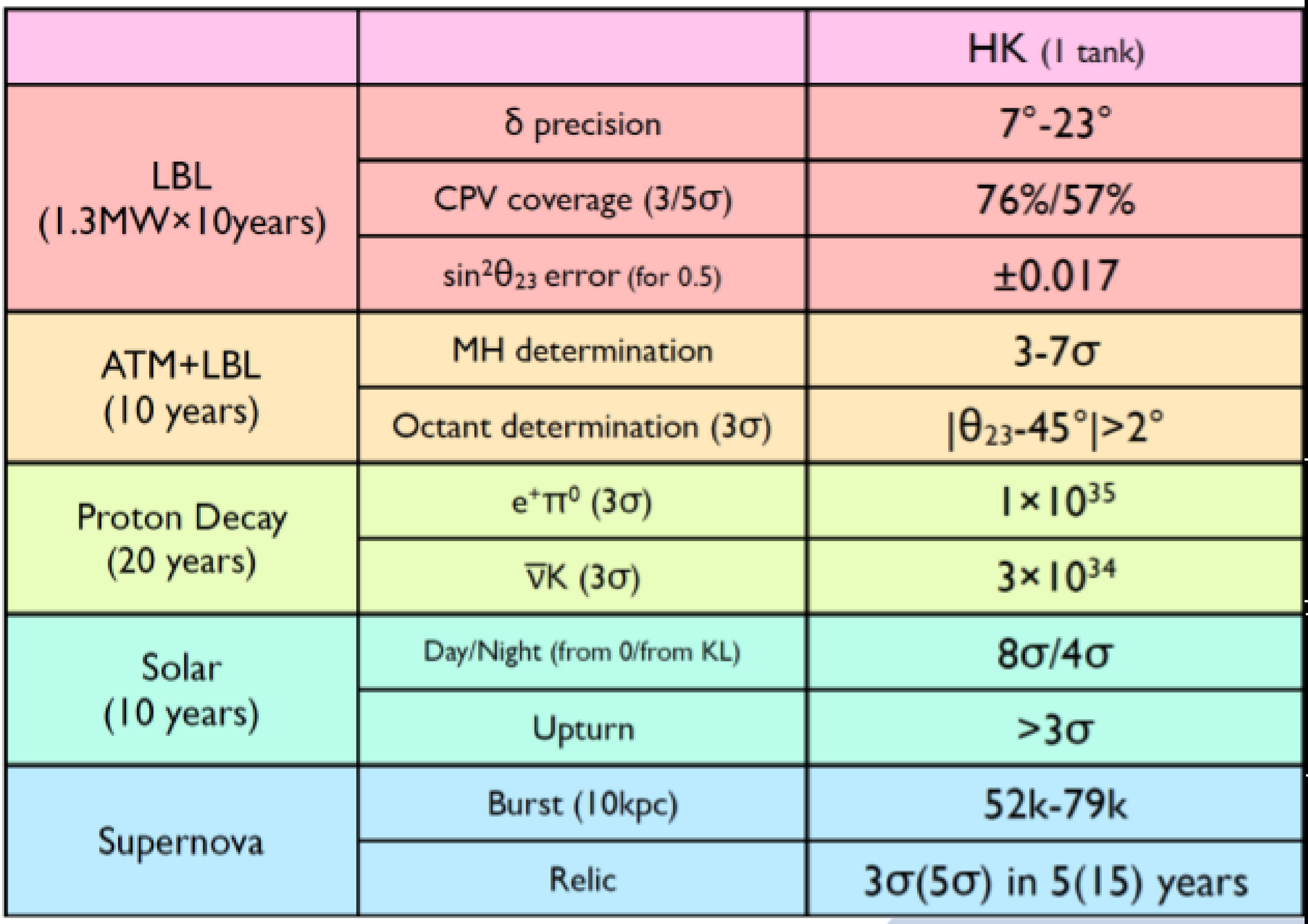
- Vertical-cylinder : H60m×Φ74m (X2 high pressure bearing)
- Total Mass 260kton
- Fiducial Mass 190kton, ~10 × Super-K
- 40,000 ID PMT (40% photocoverage)
- 6,700 OD PMT (nominal 8” PMTs)

Accelerator-Based Neutrinos

- High quality & high intensity neutrino beam
- 2.5 deg. off-axis narrow band neutrino beam (identical to T2K)
- Beam power: 1.3MW (before Hyper-K starts)
  - KEK Project Implementation Plan: top priority on 'J-PARC upgrade for Hyper-K'



Sensitivity of the experiment for 1 tank in Japan for 10 years



		HK (1 tank)
LBL (1.3MW×10years)	δ precision	7°-23°
	CPV coverage (3/5σ)	76%/57%
	$\sin^2\theta_{23}$ error (for 0.5)	±0.017
ATM+LBL (10 years)	MH determination	3-7σ
	Octant determination (3σ)	$\lvert\theta_{23}-45°\rvert>2°$
Proton Decay (20 years)	$e^+\pi^0$ (3σ)	1×10^{35}
	$\bar{\nu}K$ (3σ)	3×10^{34}
Solar (10 years)	Day/Night (from 0/from KL)	8σ/4σ
	Upturn	>3σ
Supernova	Burst (10kpc)	52k-79k
	Relic	3σ(5σ) in 5(15) years

Observing CP violation and best “disappearance” measurement

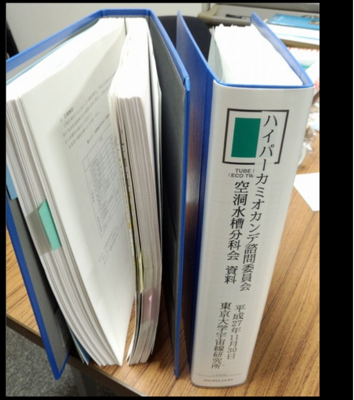
Atmospherics important for mass measurement.

Most of the final states being measured at HK

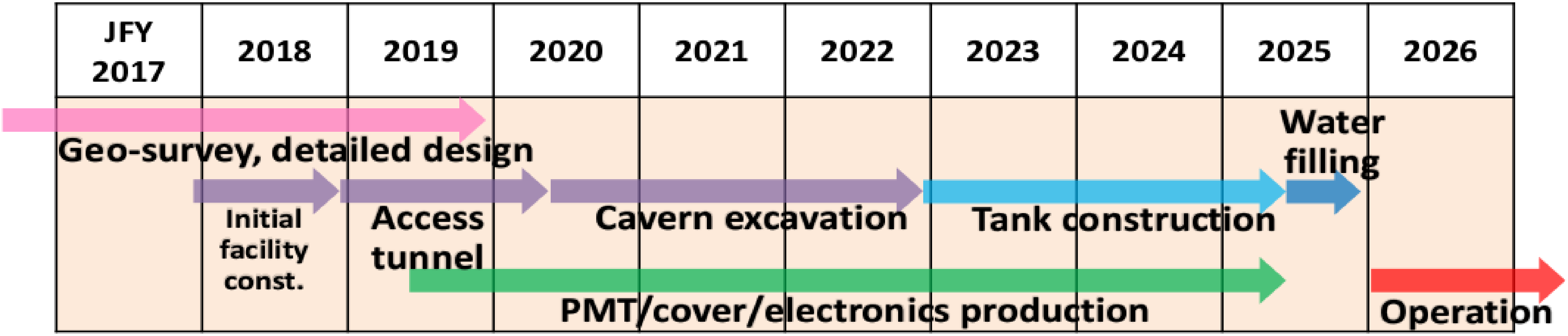
Addressing low energy physics thanks to 40% coverage.

Large statistics and proving important information to SN burst phases.

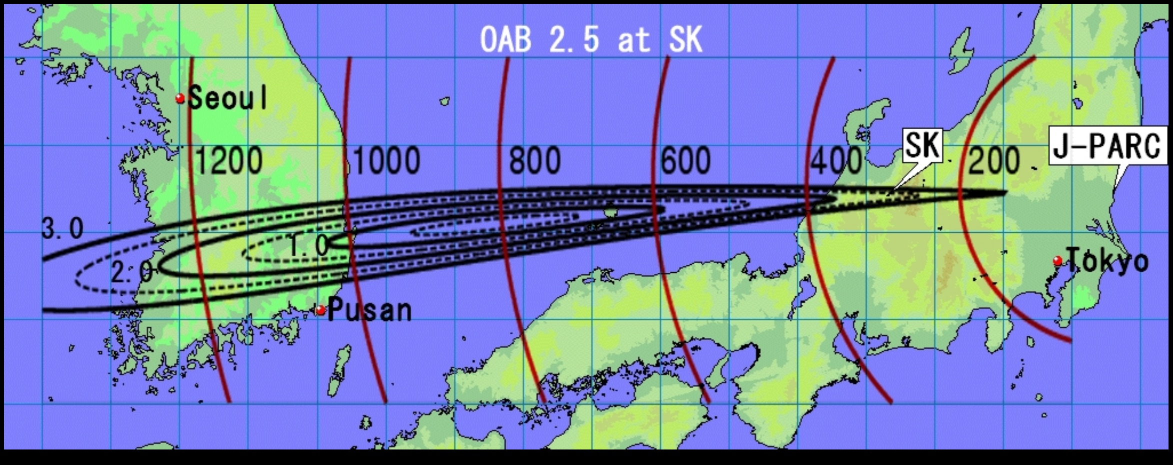
Project Status in Japan

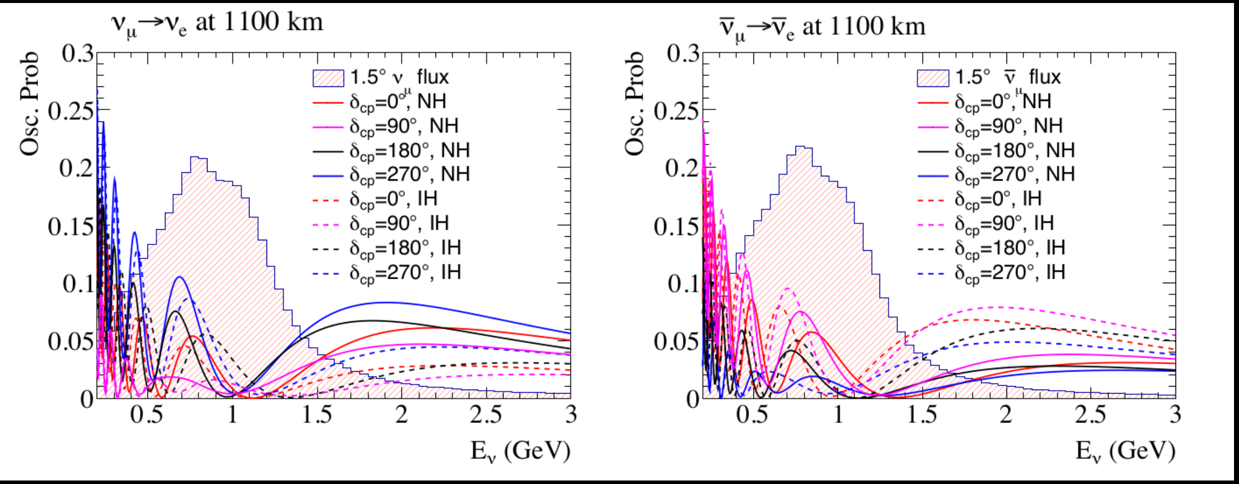


- “Hyper-K Design Report” released:
  - KEK preprint 2016-21, ICRR-Report-701-2016-1
- Strong commitment from host institutes:
  - ICRR, U. Tokyo and KEK (MoU for Hyper-K)
- Strong support from Japanese communities
  - Cosmic-ray (CRC) and high-energy (JAHEP)
- Science Council of Japan selected Hyper-K as one of the top priority large-scale projects in ‘Master Plan 2017’
- MEXT (funding agency) will soon release the official ‘Roadmap 2017’
  - Hyper-K is selected in the preliminary version of the Roadmap released on July 18, 2017
- Budget request being submitted, aiming to begin the construction in JFY 2018 & begin operation in JFY 2026



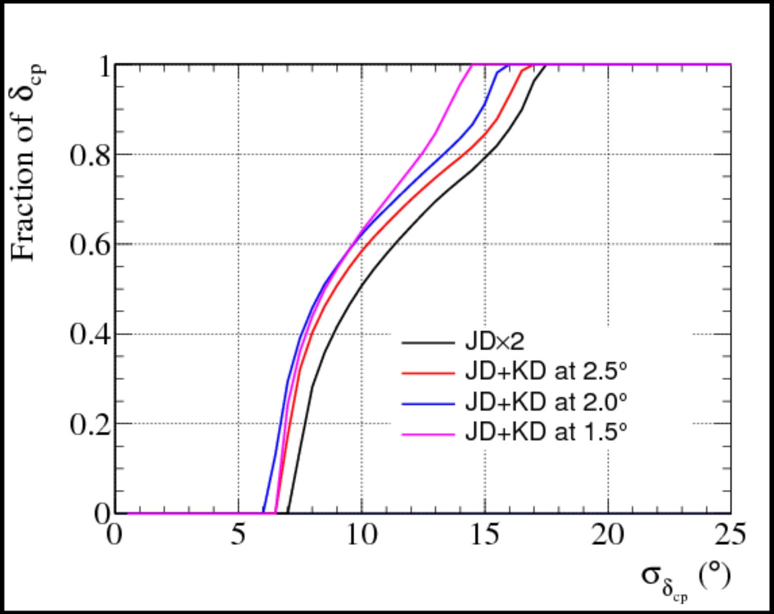
Second Hyper-K Detector in Korea





Second tank in Korea leads to:

- First, second and even third oscillation maximum.
- Breaking oscillation parameter degeneracy.
- Sensitivity to the mass hierarchy w/ beam.



- Feasibility studies started.
- Several possible sites in Korea are being investigated. Main candidate Mt. Bisul (1.3deg off-axis angle).

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Upgrade to 1.3MW

- Proposal is to increase the beam power by increasing the pulse frequency.
- This is good as the thermal shocks from the beam will not be any worse than current design (3.3x10^{14} ppp).

- However, we need to increase the cooling capacity for 1.3MW to remove the extra heat load.

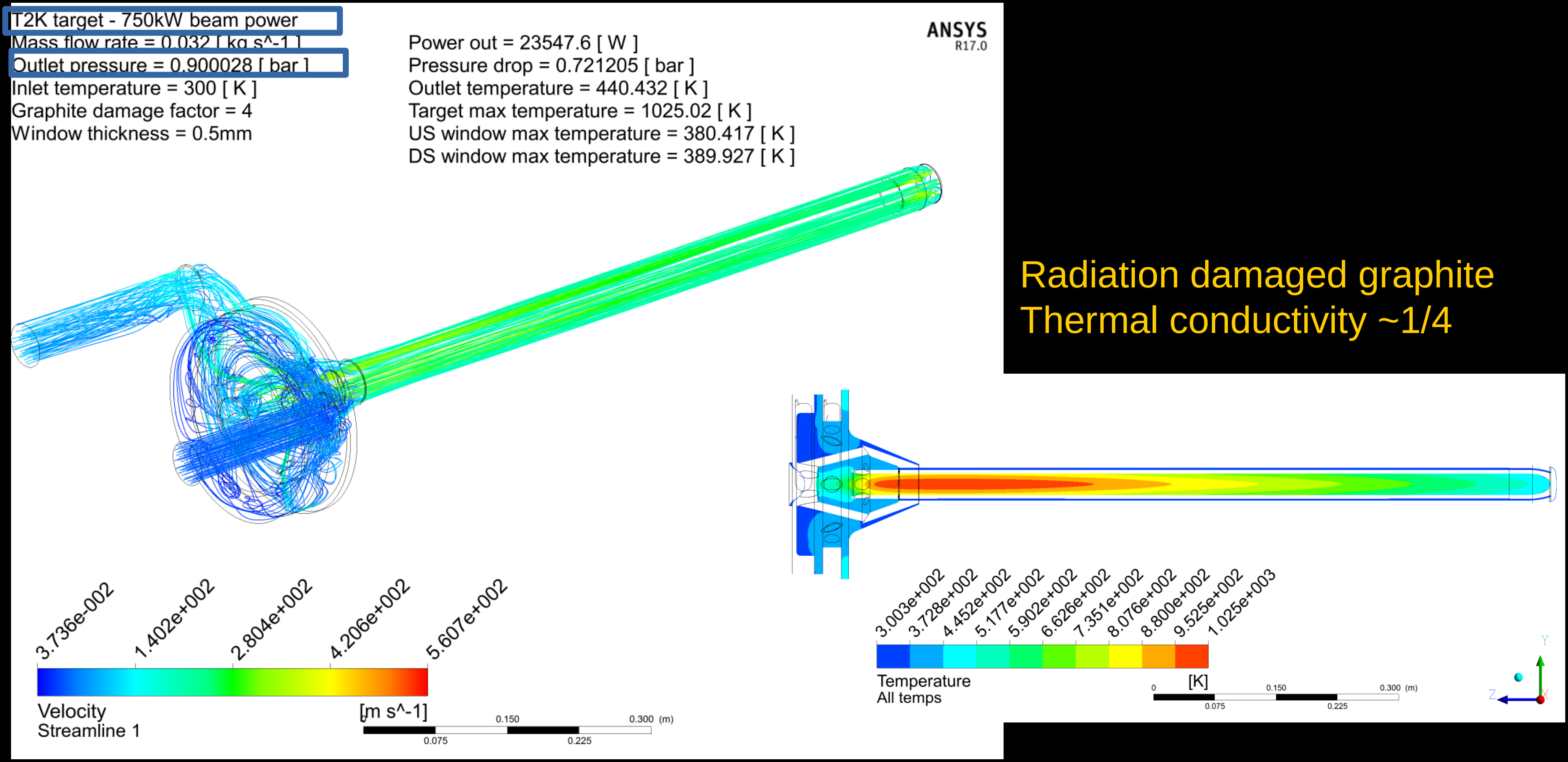
- Just increasing the mass flow rate leads to high pressure drops and velocities in the target approaching the speed of sound in Helium (Mach 1)

- Proposal is to increase the system pressure and make only minimal changes to the target structure.
- Changes are mainly to reduce pressure stresses in a few locations.
- There are options to make other changes such as replace the 2mm graphite tube with a 0.5mm titanium one.

Conjugate Heat Transfer analysis

Current design & Parameters

32g/s @ 1.6bar (0.9barG outlet) – 750kW beam power



T2K target - 750kW beam power
Mass flow rate = 0.032 [kg s^-1]
Outlet pressure = 0.900028 [bar]
Inlet temperature = 300 [K]
Graphite damage factor = 4
Window thickness = 0.5mm

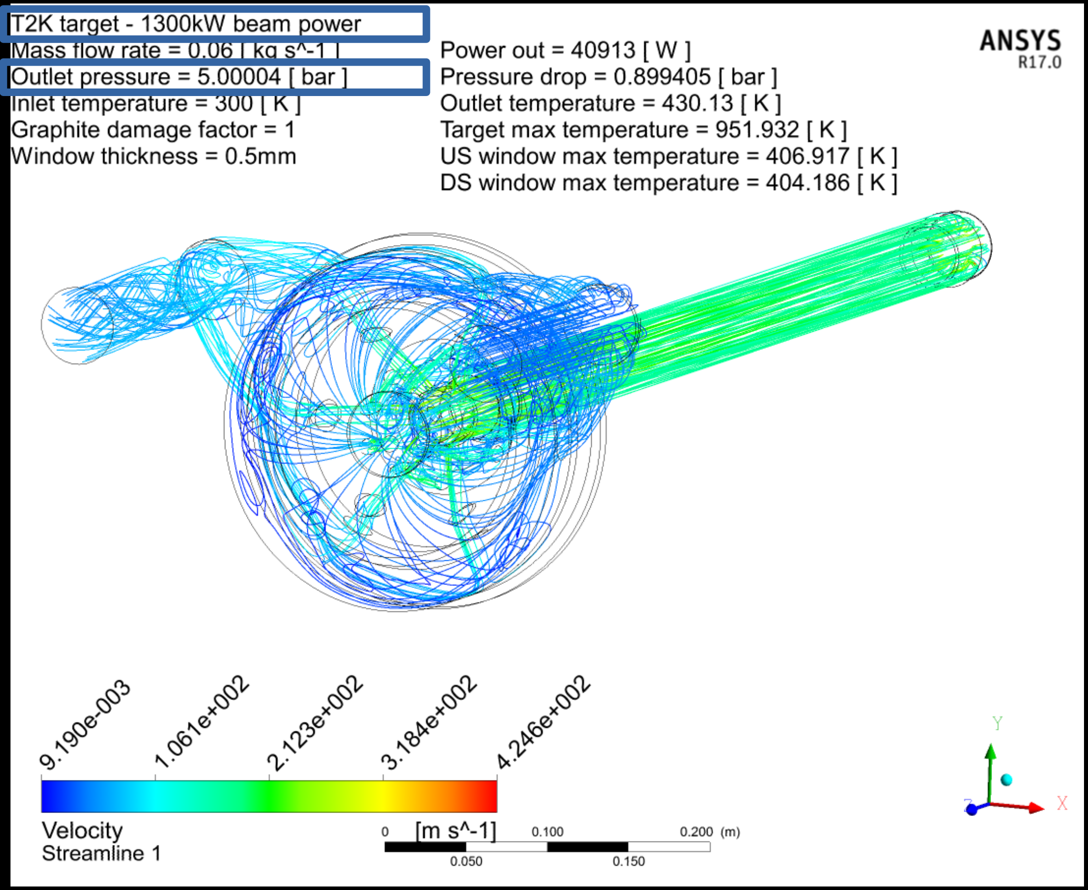
Power out = 23547.6 [W]
Pressure drop = 0.721205 [bar]
Outlet temperature = 440.432 [K]
Target max temperature = 1025.02 [K]
US window max temperature = 380.417 [K]
DS window max temperature = 389.927 [K]

Radiation damaged graphite
Thermal conductivity ~1/4

Conjugate Heat Transfer analysis

Increased beam power, flow rate & pressure

60g/s @ 5.9bar (5barG outlet) – 1.3MW beam power

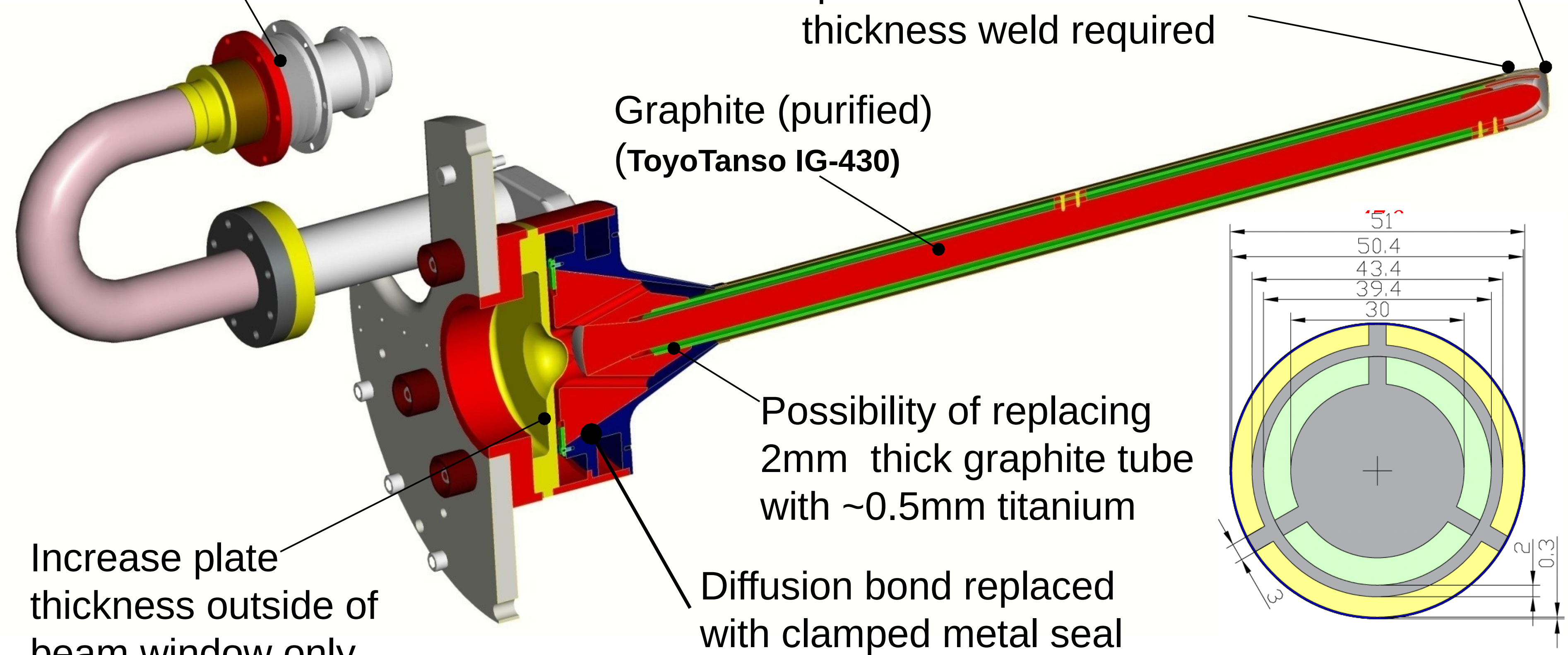


T2K target - 1300kW beam power
Mass flow rate = 0.06 [kg s^-1]
Outlet pressure = 5.00004 [bar]
Inlet temperature = 300 [K]
Graphite damage factor = 1
Window thickness = 0.5mm

Power out = 40913 [W]
Pressure drop = 0.899405 [bar]
Outlet temperature = 430.13 [K]
Target max temperature = 951.932 [K]
US window max temperature = 406.917 [K]
DS window max temperature = 404.186 [K]

- By increasing the outlet pressure to 5 bar the pressure drop of the system become comparable to the 750kW design.
- Steady-state operating temperature are also similar to current design at 750kW.
- Beam power scheduled to reach/exceed 750kW in 2018-2020.
- Upgrade to target required by 2020

Currently foreseen design modifications for 1.3MW operation



New isolator and bellows required for higher pressure

DS window shape change to reduce pressure stress

Full penetration full and full thickness weld required

Graphite (purified)
(**ToyoTanso IG-430)**

Possibility of replacing 2mm thick graphite tube with ~0.5mm titanium

Increase plate thickness outside of beam window only

Diffusion bond replaced with clamped metal seal

NOTE: Beam windows and outer tube 0.5mm Titanium

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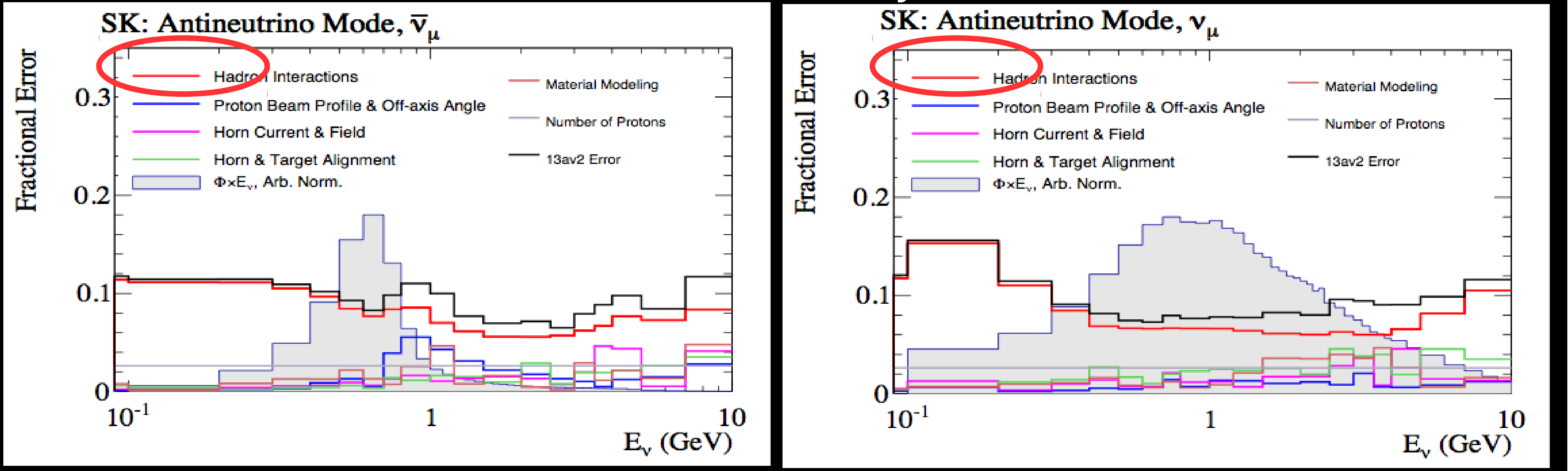
T2K Flux Uncertainties

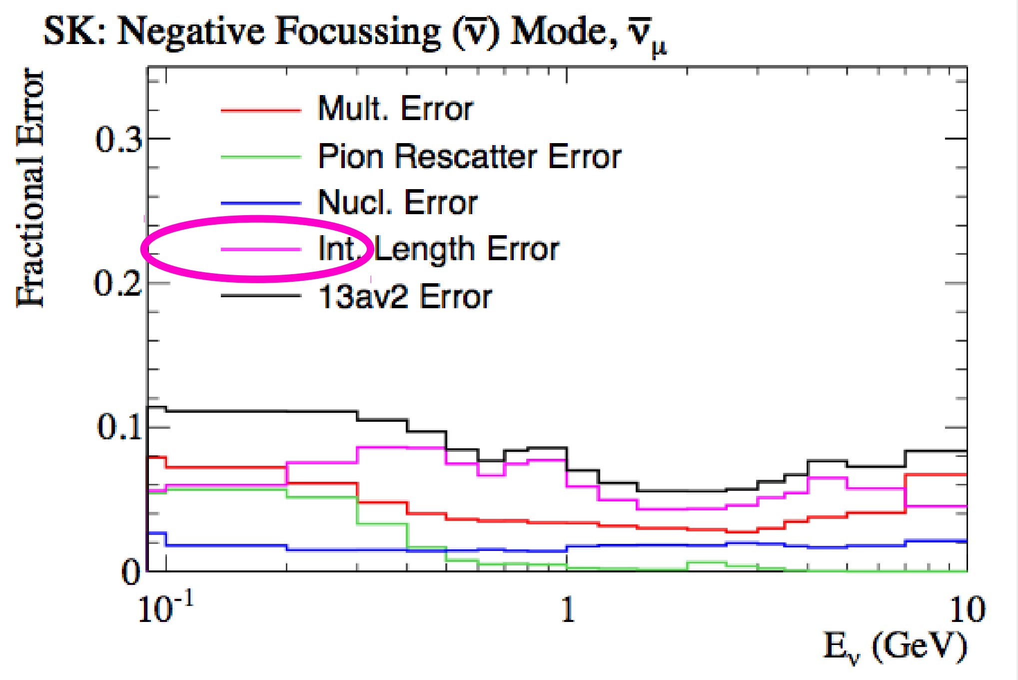
T2K Preliminary

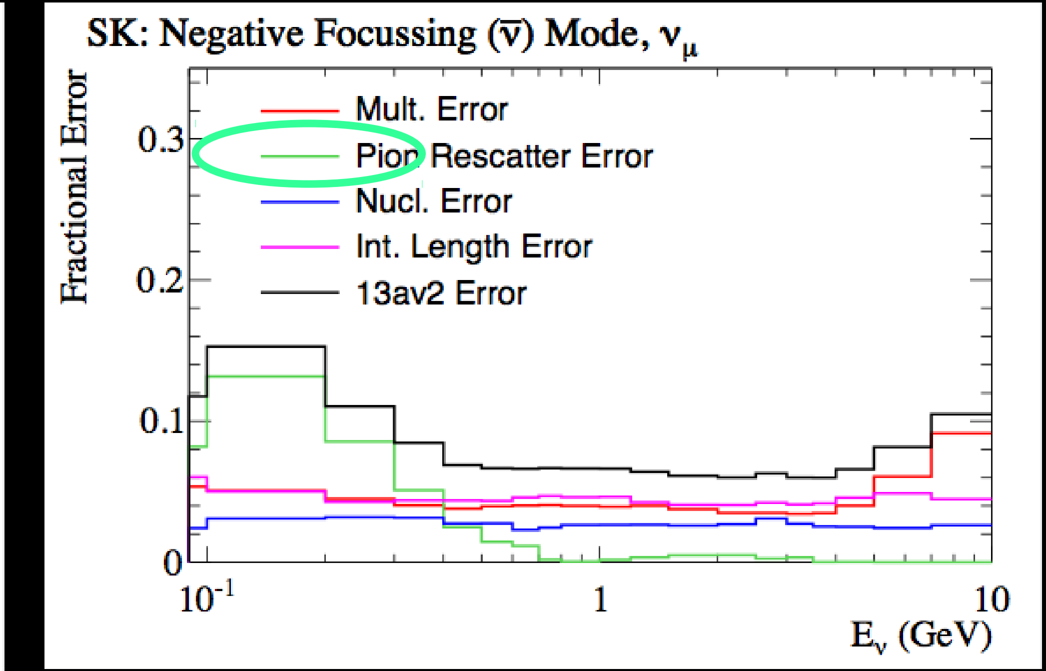


- The hadron interaction uncertainties are dominant for both the right-sign and wrong-sign flux

- Alignment and focussing uncertainties are also significant on the high energy side of the flux peak

Hadron Interaction Modelling


SK: Negative Focussing ($\bar{\nu}$) Mode, $\bar{\nu}_\mu$


SK: Negative Focussing ($\bar{\nu}$) Mode, ν_μ

- For right-sign flux, the interaction length error is the dominant error in the hadron interaction modelling

- For the wrong-sign flux, the pion re-scattering error becomes dominant at low energy. Contributions to the total error from interactions outside of the target.

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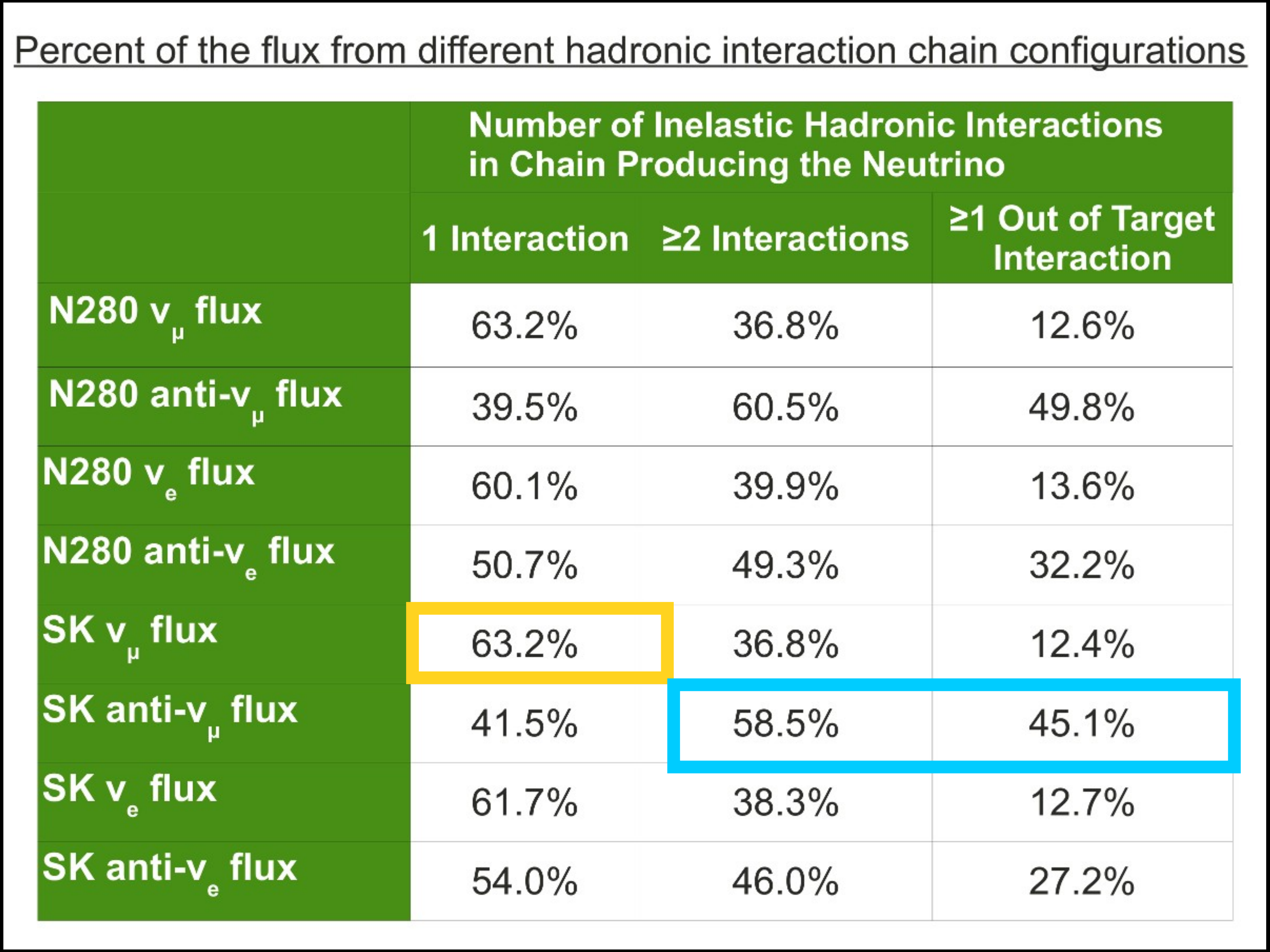
Interation Breakdown in T2K



Percent of the flux from different hadronic interaction chain configurations

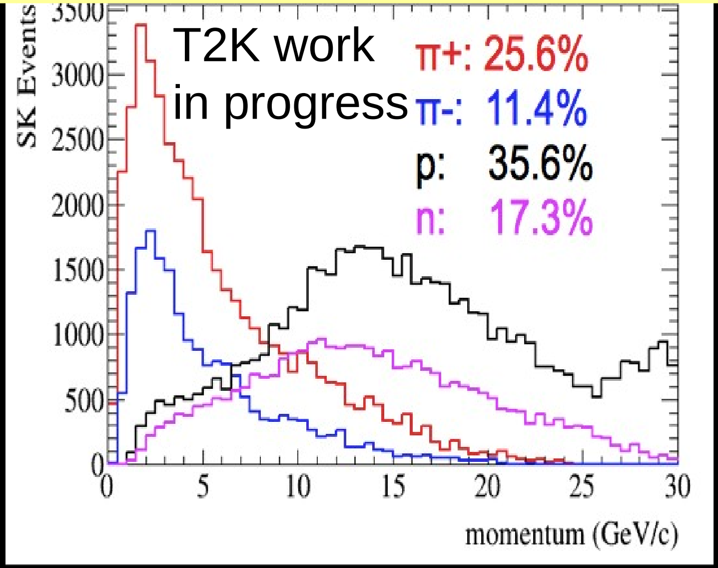
	Number of Inelastic Hadronic Interactions in Chain Producing the Neutrino		
	1 Interaction	≥2 Interactions	≥1 Out of Target Interaction
N280 ν_{μ} flux	63.2%	36.8%	12.6%
N280 anti-ν_{μ} flux	39.5%	60.5%	49.8%
N280 ν_{e} flux	60.1%	39.9%	13.6%
N280 anti-ν_{e} flux	50.7%	49.3%	32.2%
SK ν_{μ} flux	63.2%	36.8%	12.4%
SK anti-ν_{μ} flux	41.5%	58.5%	45.1%
SK ν_{e} flux	61.7%	38.3%	12.7%
SK anti-ν_{e} flux	54.0%	46.0%	27.2%

63% of the flux comes from primary proton interactions

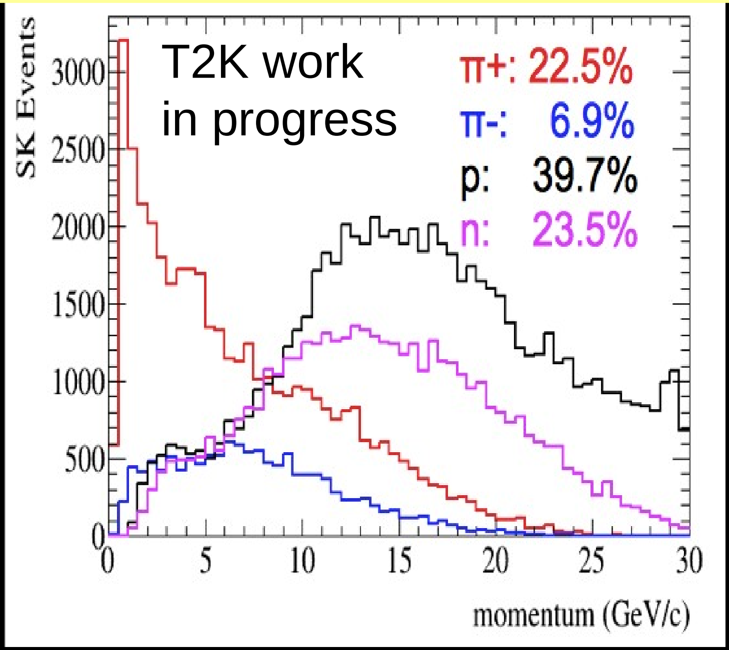
Almost half of wrong-sign flux from interactions in horns or decay volume wall

Out-of-Target Interactions

SK νe Parent Hadron momentum for Al Interactions



SK νe Parent Hadron momentum for Fe Interactions



- Interactions in horns (top) and decay volume walls (bottom) include protons and pions
- T2K tunes with existing hadron interaction data and assumptions for target nucleus and center of mass energy scaling
- Hyper-K can benefit from new measurements:
  - p+Al and p+Fe in the 5-30 GeV/c range
  - π+Al and π+Fe in the 1-15 GeV/c range

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Atmospheric Neutrinos for HK

- Hadron production measurements are important for atmospheric neutrino oscillation measurements in two (broad ways):

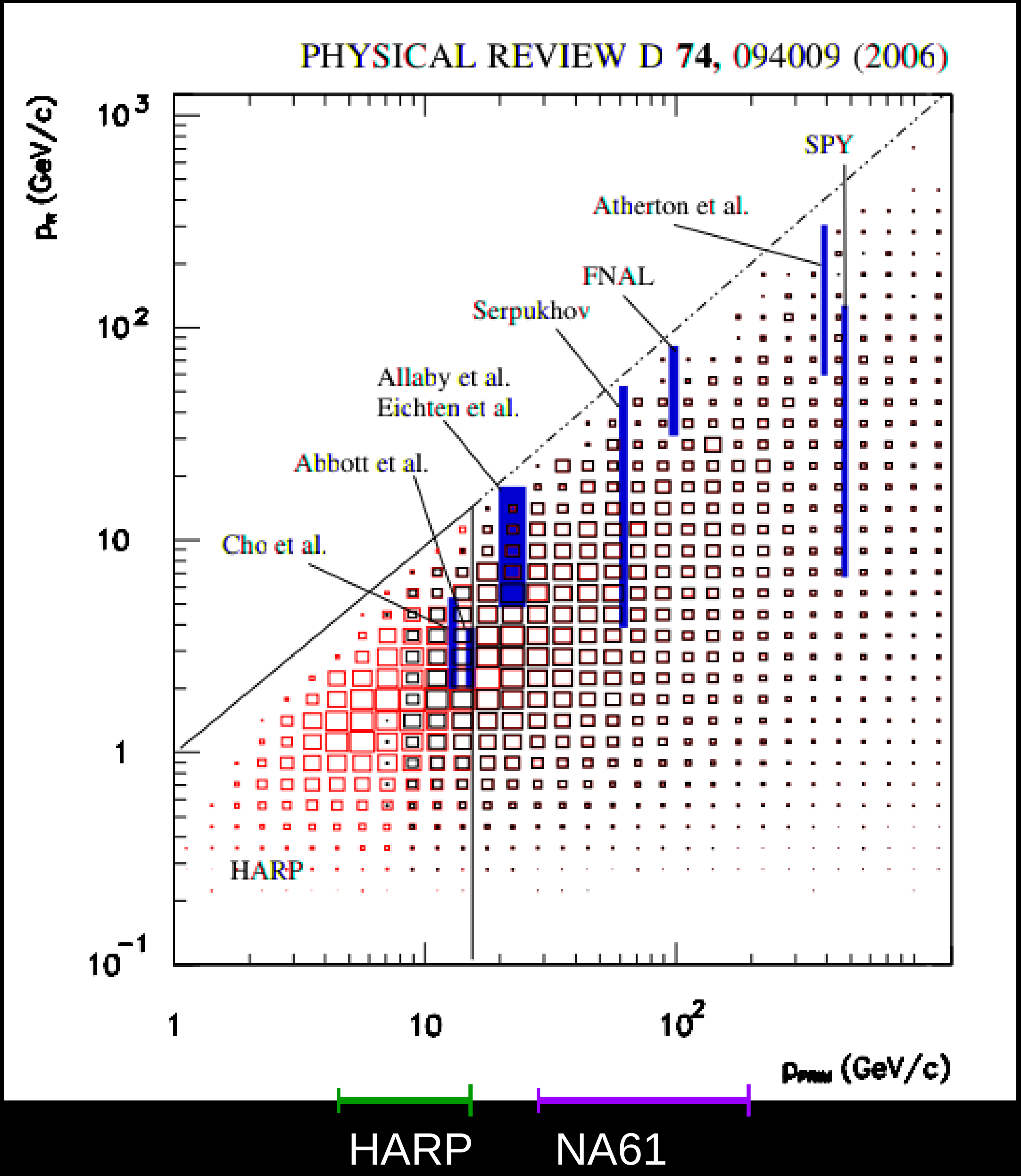
  - Used in estimation of hadron yields from primary cosmic ray interaction
    - Mesons produced in the decays/interactions of create the atmospheric neutrino flux. Hadron production uncertainties translate (directly) into errors on the (absolute) neutrino flux

  - Used in the calculation of products and rate of interaction of particles escaping the primary neutrino vertex
    - Secondary interactions in an atmospheric neutrino detector change the visible topology of an event, introducing uncertainties in oscillation parameter measurements

In the following we assume:

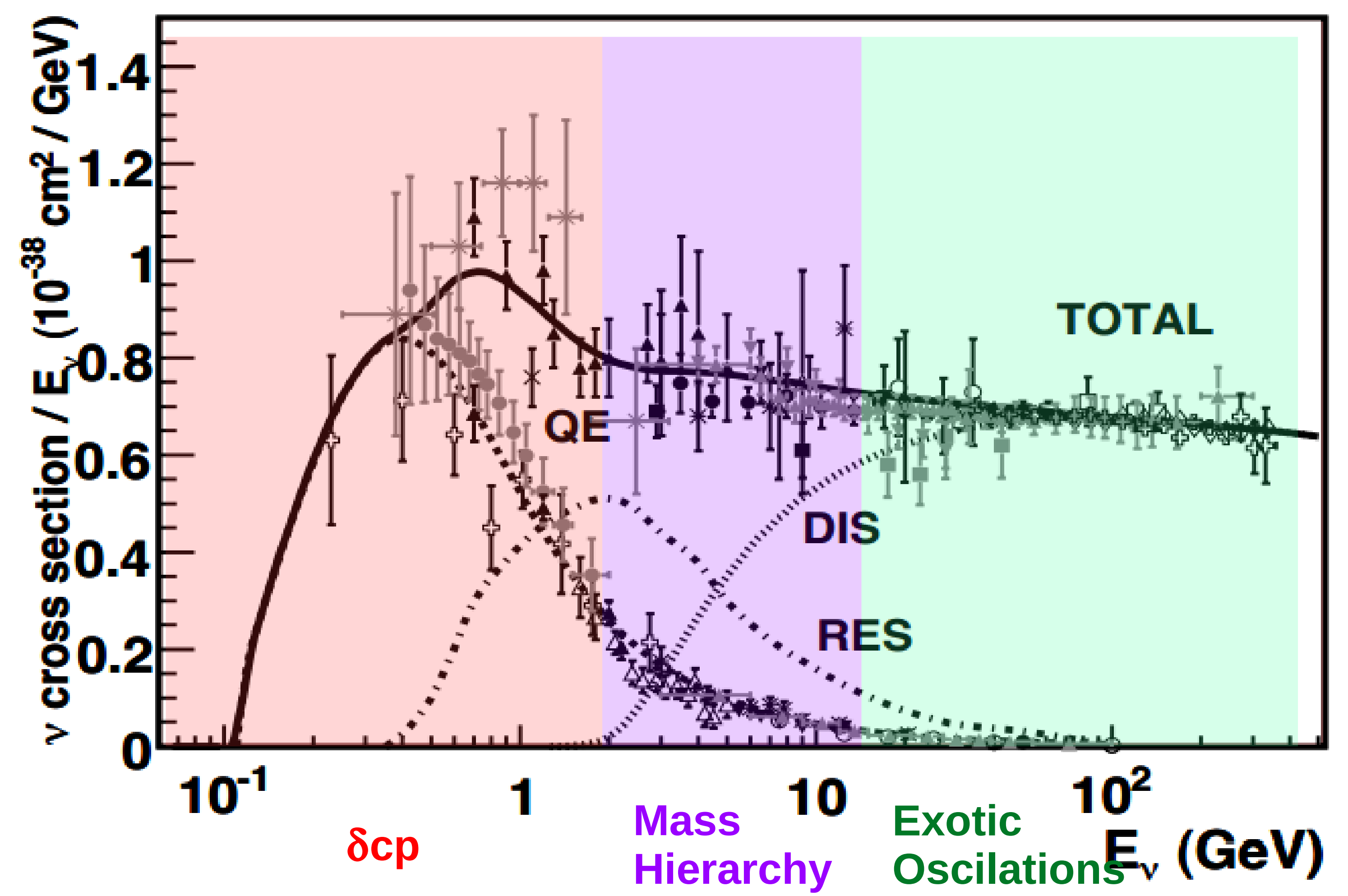
- Super-K = 306 kton yr exposure
- Hyper-K = 5.6 Mton yr exposure of SK detector

Hadronic Production



- Phase space for generating ***contained*** neutrino interactions
  - E_n (ν_μ) < 1 GeV
- Red : high geomagnetic latitude
- Black: low geomagnetic latitude
- Existing hadron production measurements use C, Be, Al, B
- However atmosphere is composed of O and N, so some extrapolation is required
- Improved phase space coverage by recent experiments not (yet!) included in models

Neutrino Interactions Relevant for Atmospheric Neutrinos

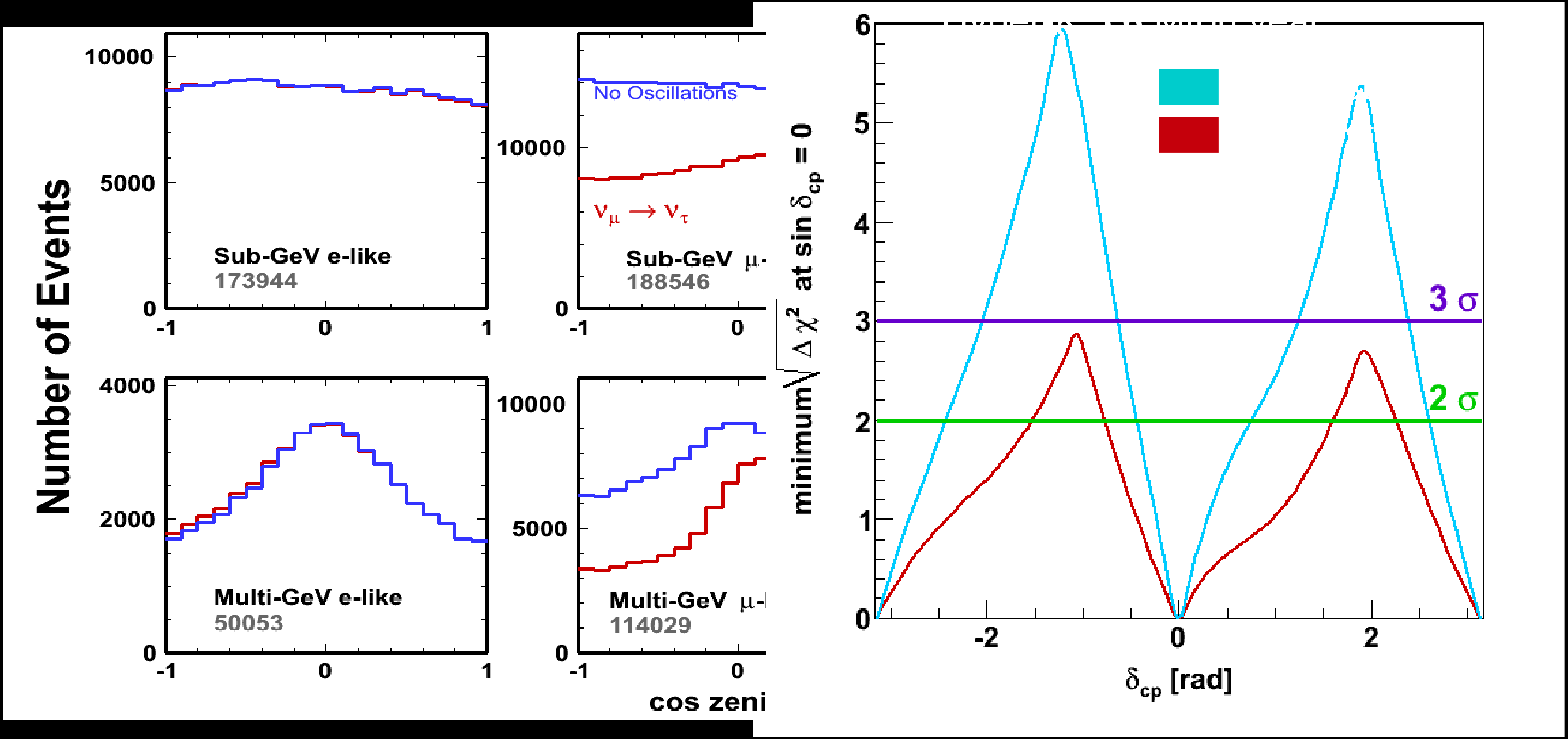


δcp

Mass Hierarchy

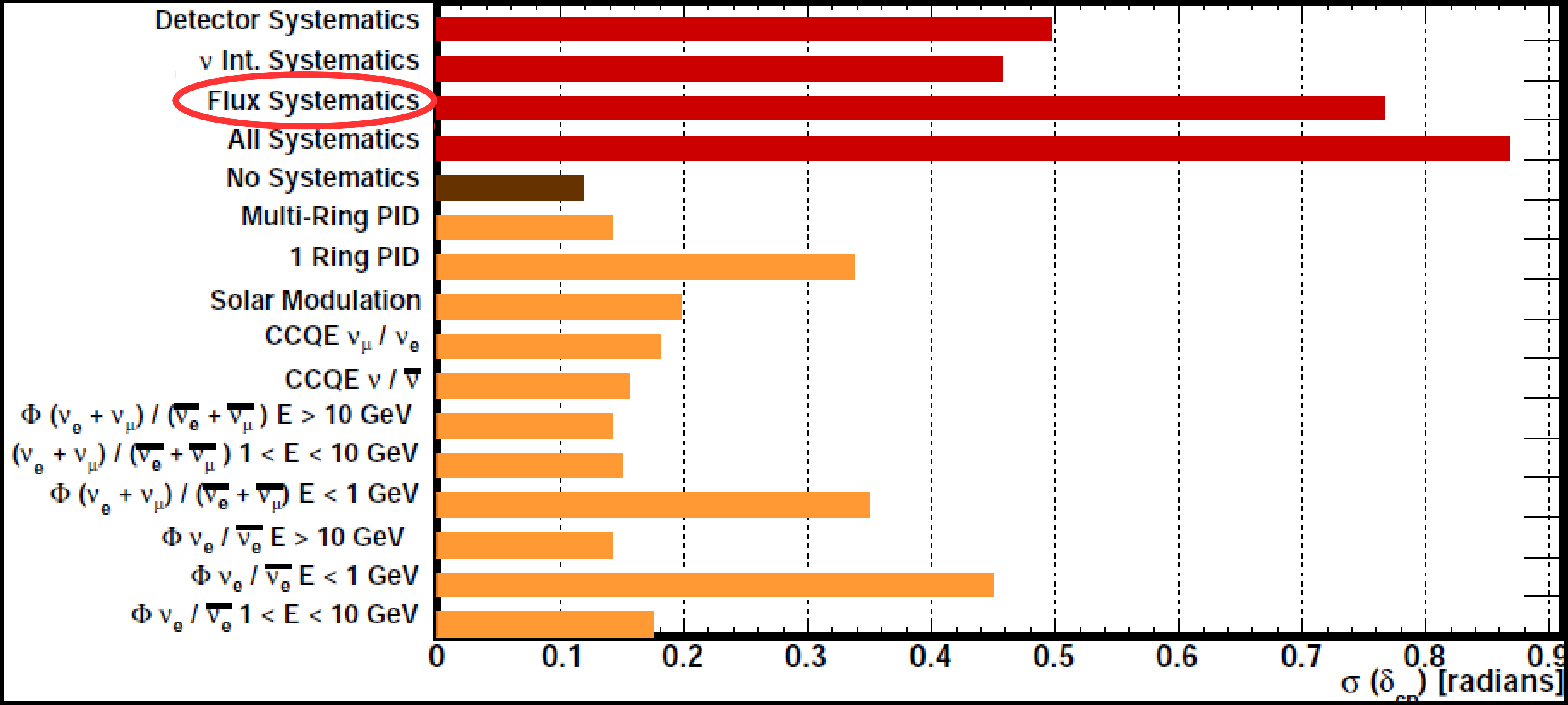
Exotic Oscillations

HK Sensitivity to δ_{CP} with ATMν



- Despite ample statistics in sensitive samples, limited sensitivity to CP-violation with atmospheric ν alone
- Impact of systematic errors is large
  - Poor angular resolution of low energy neutrinos also problematic

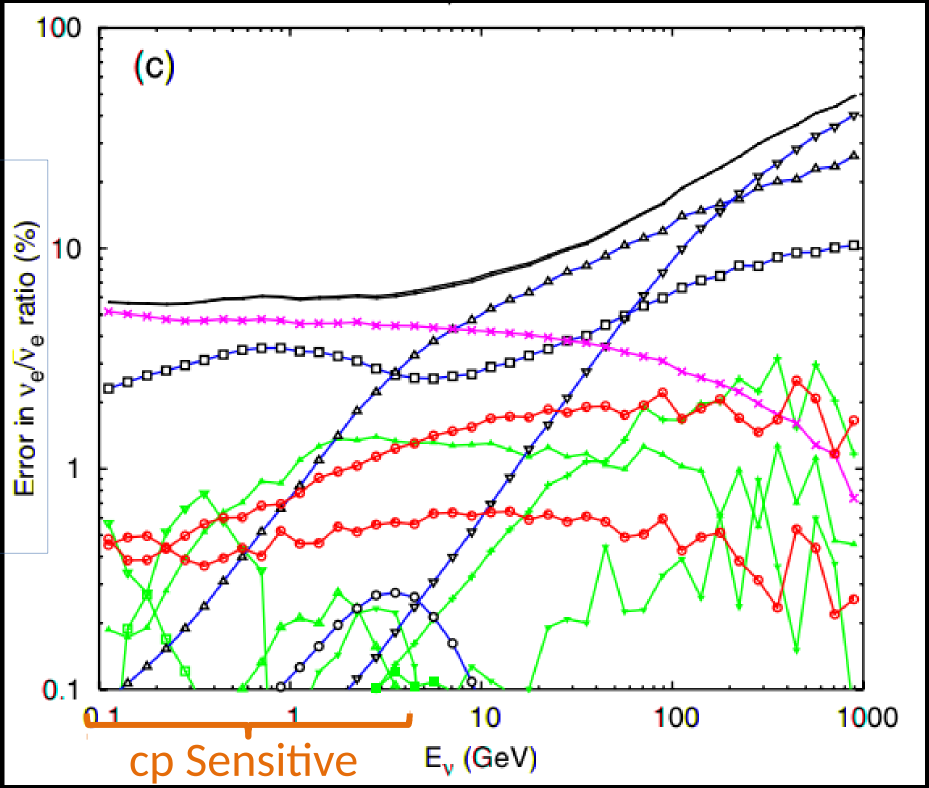
HK Sensitivity to δ_{CP} with ATM ν



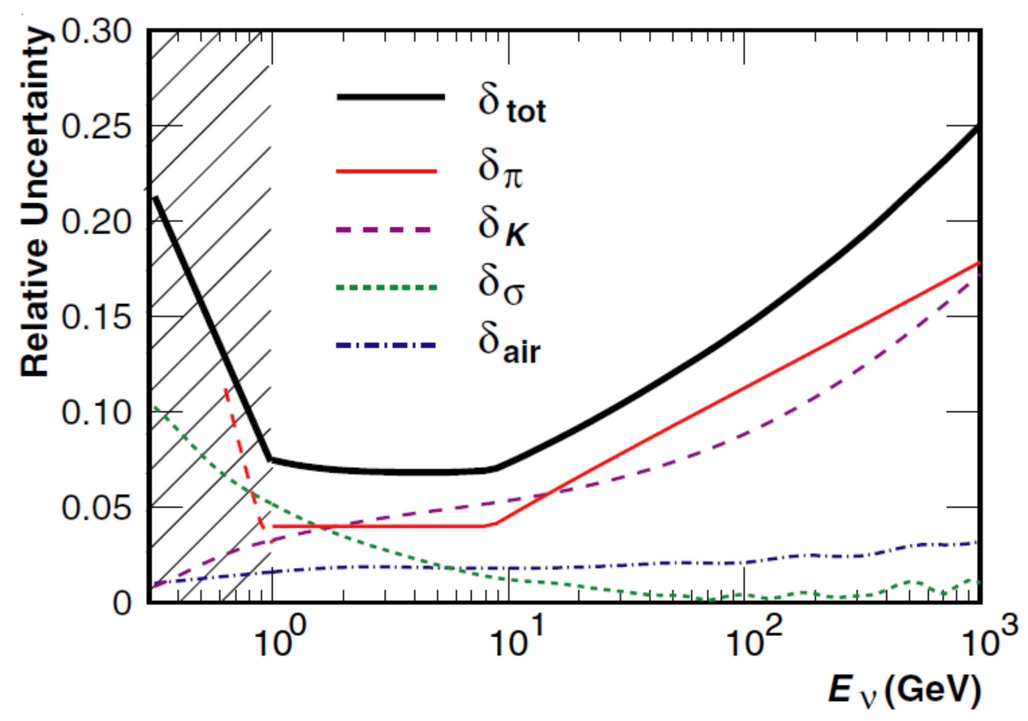
- Generally sensitivity is affected by systematics directly connected to the low energy neutrino flux
  - To a lesser extent the low energy interaction model:
    - CCQE $\nu/\bar{\nu}$: 5~15% below 500 MeV, CCQE ν_μ/ν_e : 2~10% below 500 MeV
- Note that the detector performance also becomes important
  - Single ring mis-PID uncertainty is 1~2% below 1330 MeV

Systematic Errors

Bartol Flux Model



Honda Flux Model

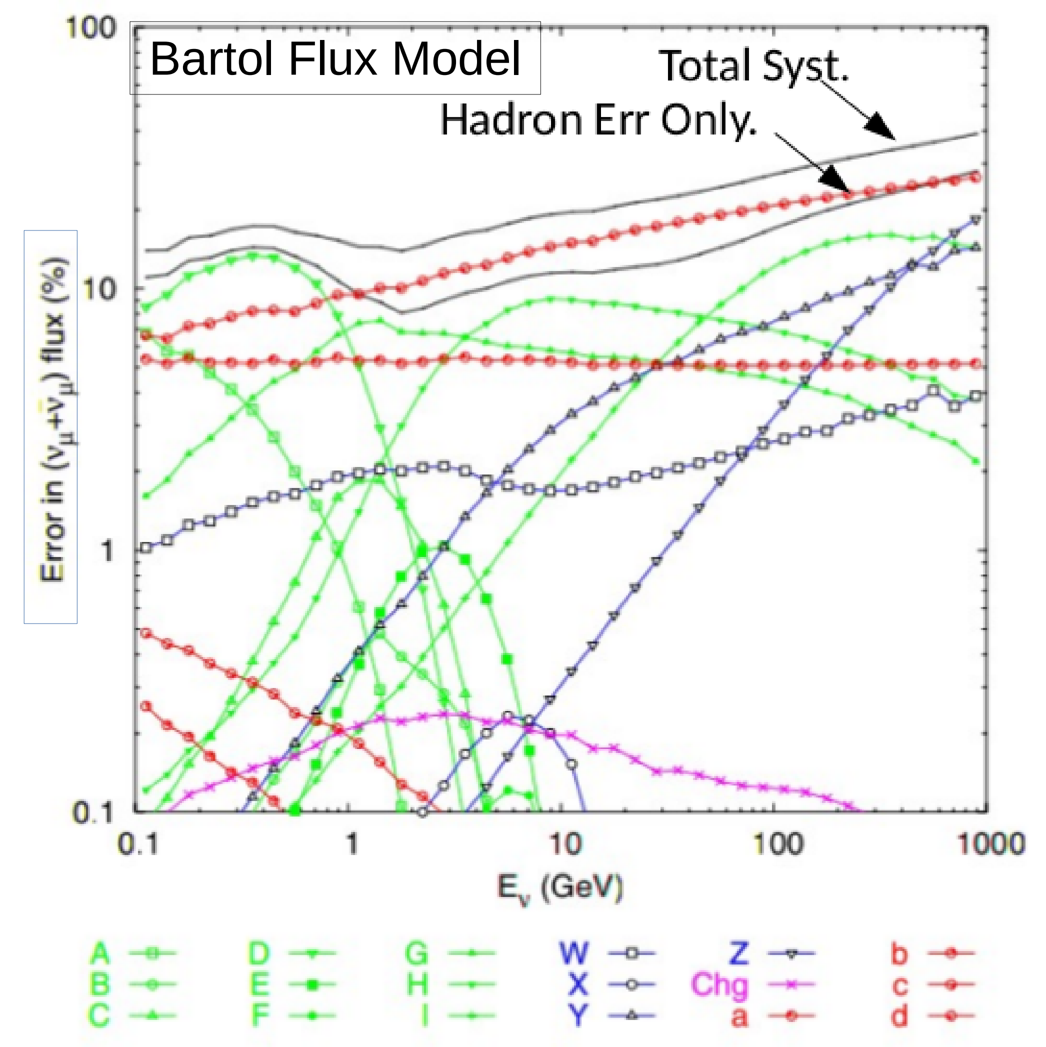


- At low energies the uncertainty is dominated by:
  - Kaon production uncertainty at modest projectile energies (Ei)
  - Uncertainty in the charged pion ratio uncertainty

- Absolute uncertainty is based on residual data/MC differences after muon tuning procedure
  - Ratio systematics are formed from the spread in alternative interaction models under the same tuning procedure

Higher Energy Neutrinos

- Atmospheric neutrinos also have sensitivity to exotic oscillations at high energies, where the absolute flux is important. NA61 measurements above O(10) GeV (secondary pion and kaon momenta above 10 GeV) can help in this regime.



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- Hyper-Kamiokande is a next general multi-purpose detector.
- Similar configuration as T2K with a much higher beam power (starting with 1.3MW) and ~10times larger far detector.
- NA61 studies can be very useful
  - Target: expected minimal changes to the current one but new measurements with new target can be provided.
  - Out-of-target material systematics would benefit from
    - **p+Al and p+Fe in the 5-30 GeV/c range**
    - **π+Al and π+Fe in the 1-15 GeV/c range**
  - A study of the atmospheric events:
    - Low (O(10Ge)) will help measurements of CP violation with ~1 GeV neutrinos
    - Higher energy neutrino flux (abs norm) produced from Kaon parents will improve sensitivity to standard and exotic oscillations in neutrino telescopes