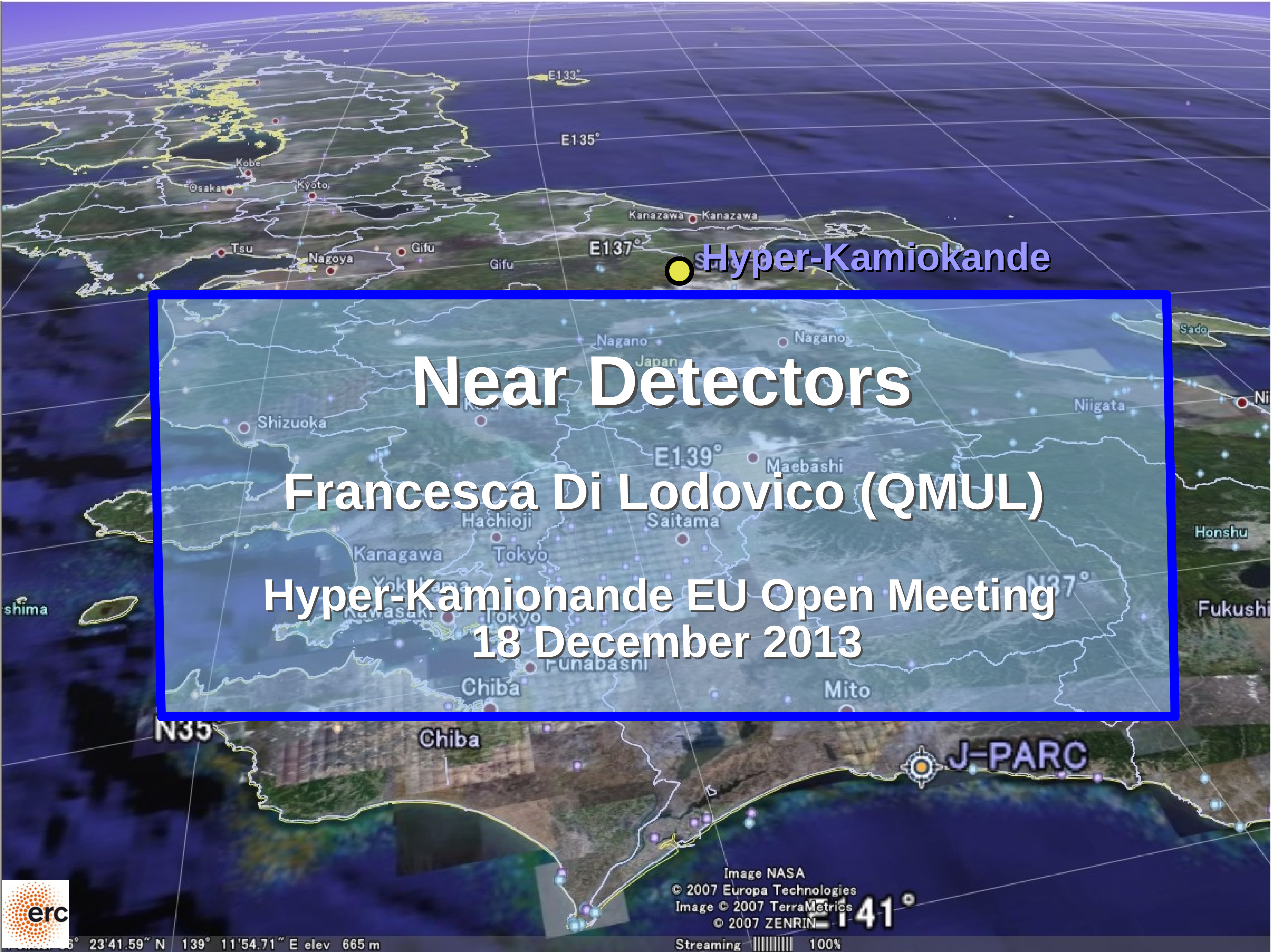


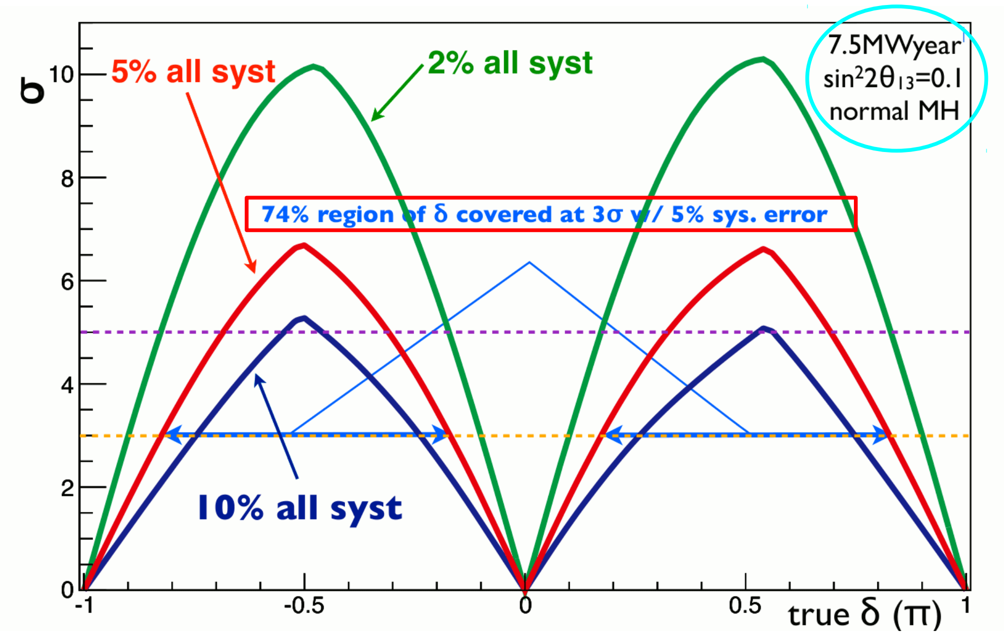

# Near Detectors

Francesca Di Lodovico (QMUL)

Hyper-Kamionande EU Open Meeting
18 December 2013

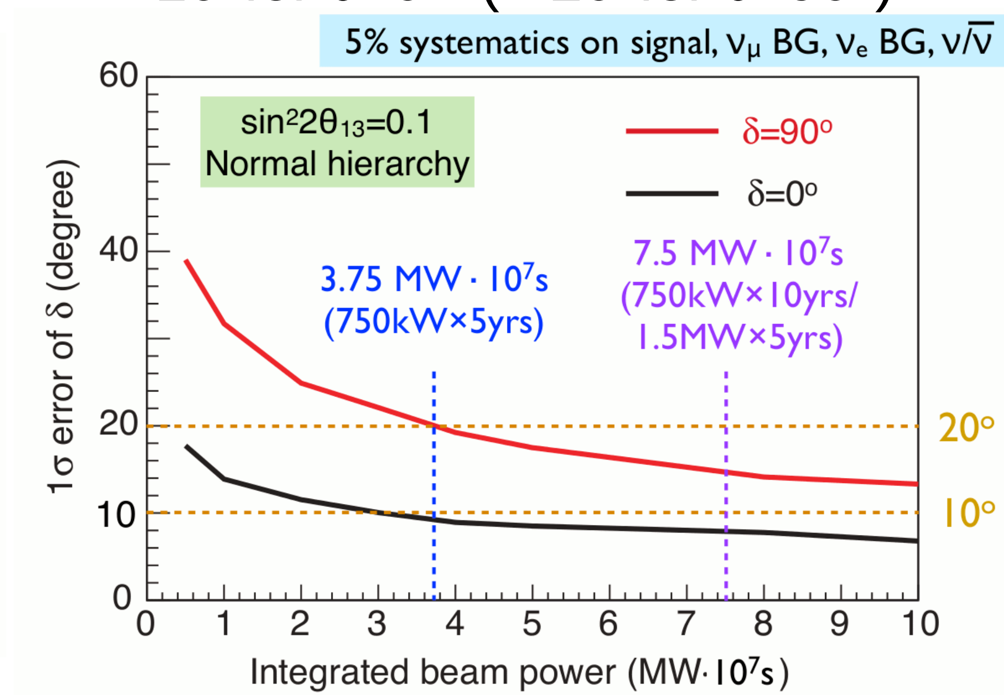
# Expected Sensitivity to CP Violation

**CPV discovery sensitivity** w/ mass hierarchy known.



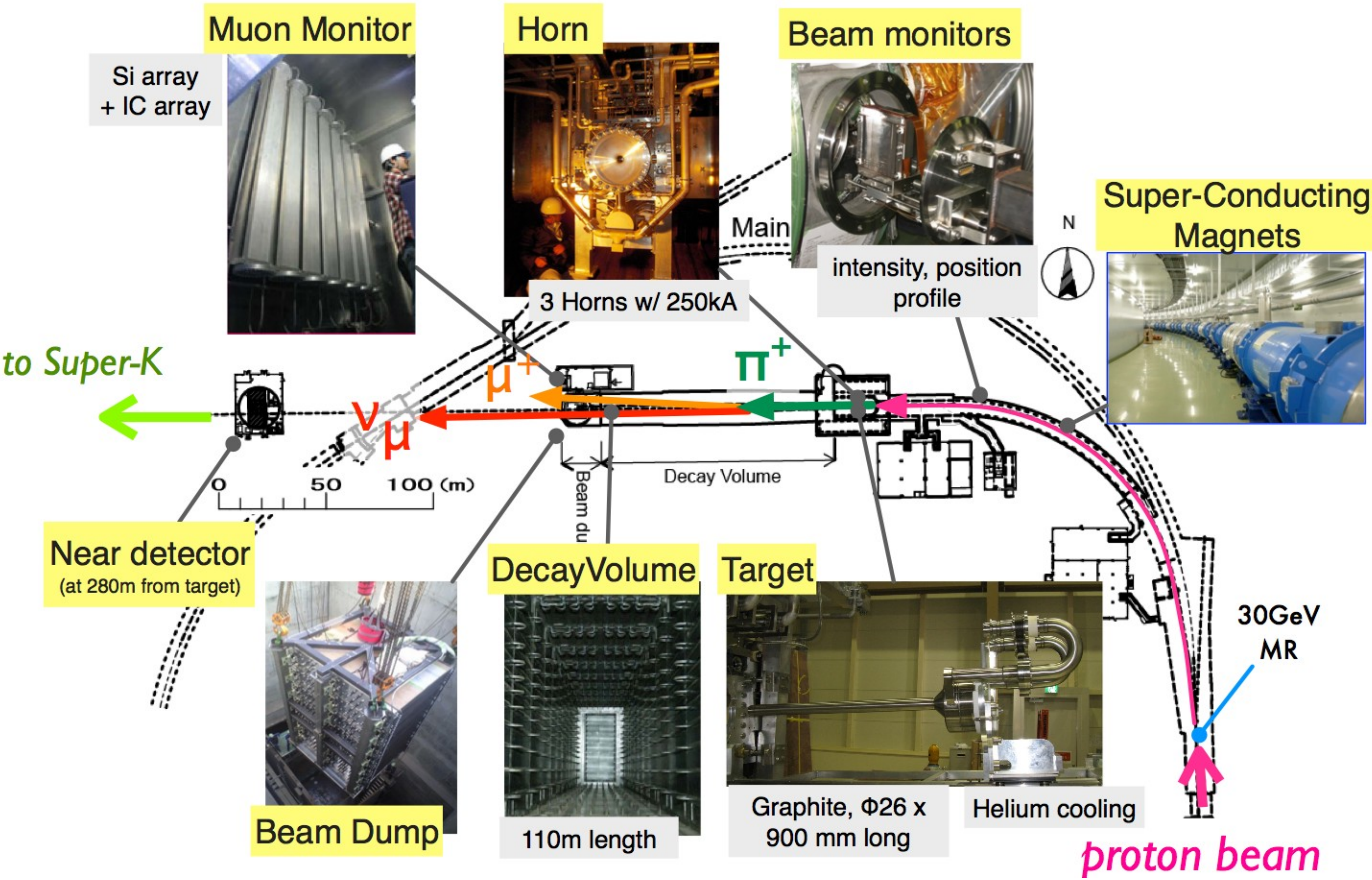

**δ precision**:

< 10°for δ=0° (< 20°for δ=90°)




- Assuming 5% nominal systematics and 0.750MW/y (3y ν-beam and 7y $\bar{\nu}$-beam), 74% region of δ can be covered at 3σ.
- It corresponds to a precision of < 10° for δ=0°.
- To achieve the full potential in CP violation measurement → systematic errors at 2% level.

# T2K Beam-line: our Starting Point



# Outline

- NA61/Shine
- (Upgraded) ND280
- Additional Near Detector
- 1kton Prototype

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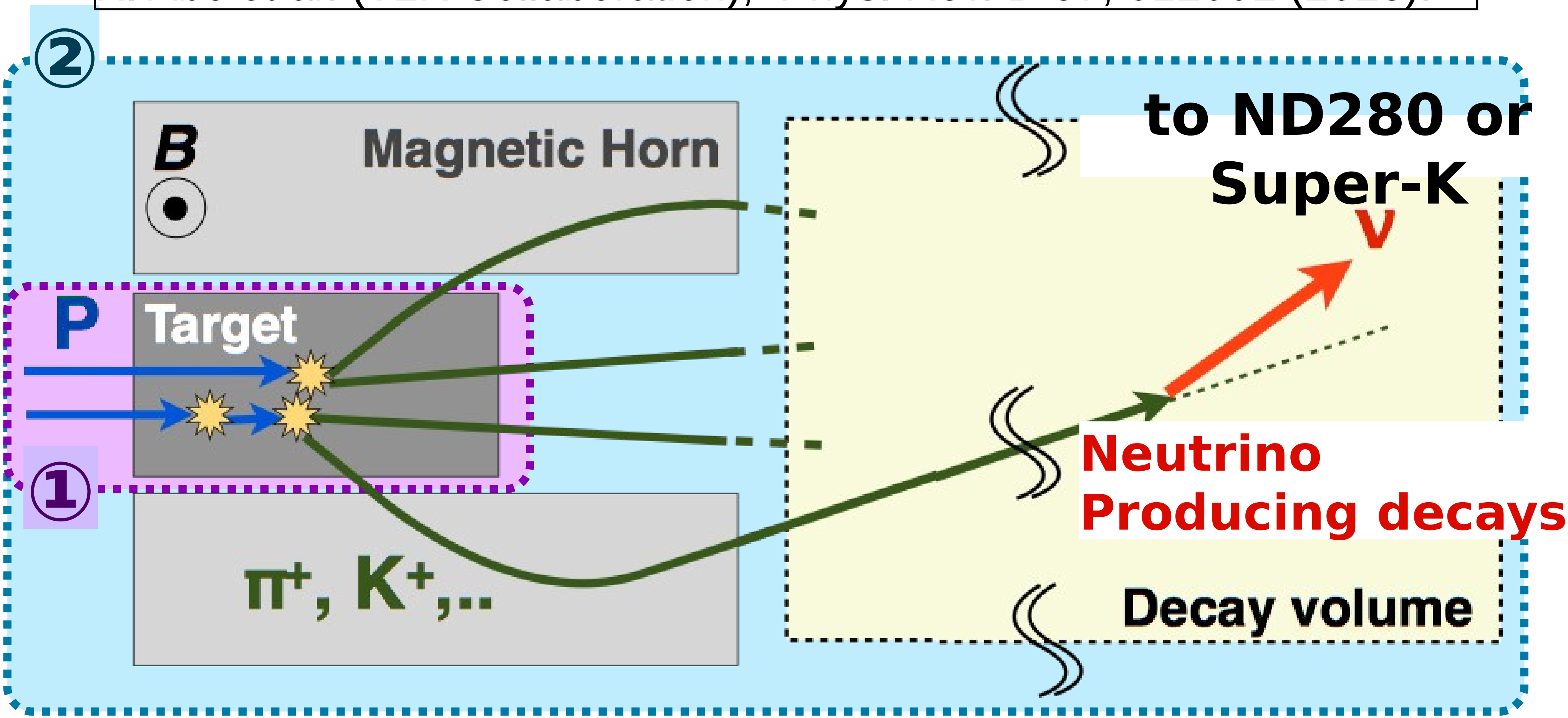
# Simulating neutrino flux

K. Abe *et al*. (T2K Collaboration), Phys. Rev. D 87, 012001 (2013).




1. p interaction inside the carbon target with FLUKA2008.3d
2. Tracking through horn fields and decay volume using GEANT3 with GCALOR

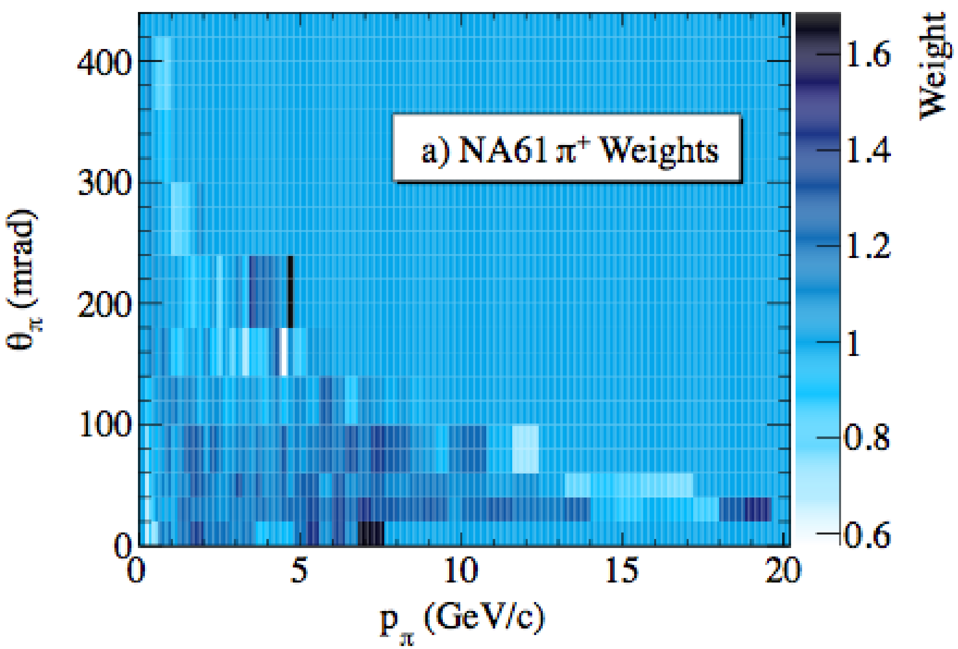
Calculate neutrino producing decays

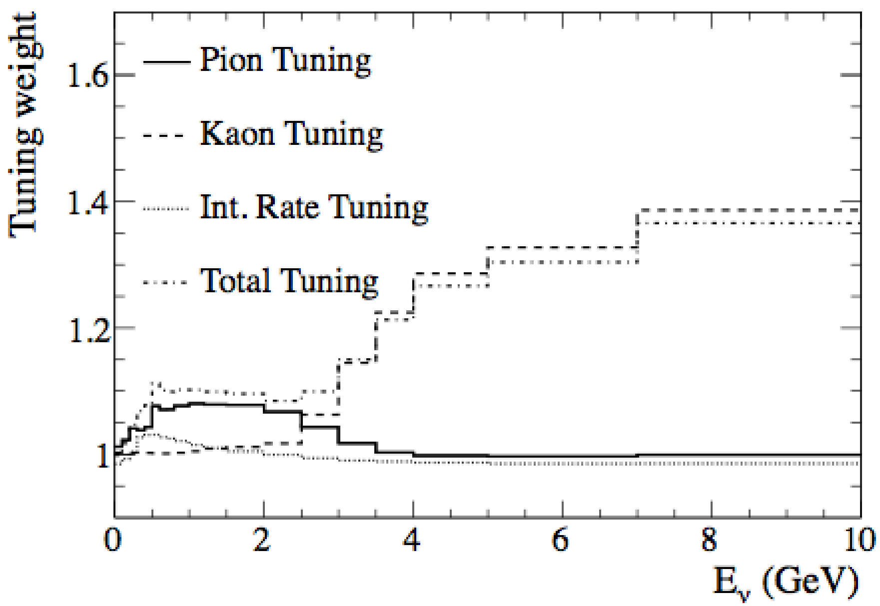
Estimate the flux at the near/far detector

# External Data and Flux

- Hadro-production simulated with FLUKA2008.3d, weighted so that interactions match external data **[1]**
  - NA61/SHINE (CERN) **[2][3]**, Eitchen *et al.* **[4]**, and Allaby *et al.* **[5]**

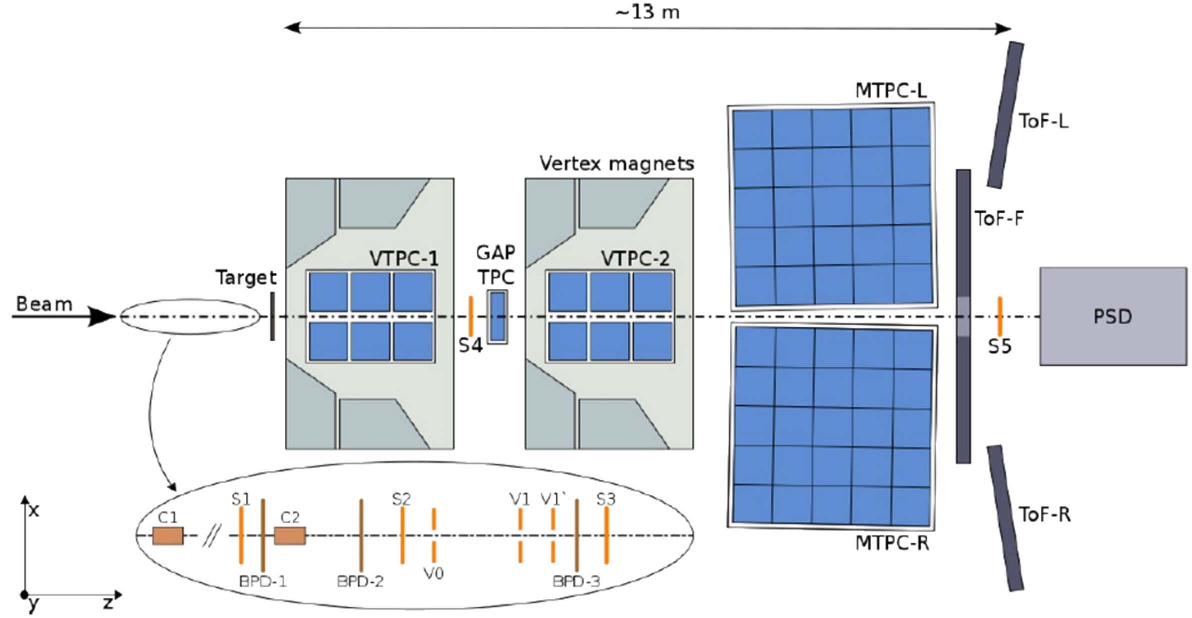

**[1]** K. Abe et al. (T2K Collaboration), Phys. Rev. D 87, 012001 (2013).
**[2]** N. Abgrall *et al*. (NA61/SHINE Collaboration), Phys. Rev. C 84, 034604 (2011)
**[3]** N. Abgrall *et al*. (NA61/SHINE Collaboration), Phys. Rev. C 85, 035210 (2012)
**[4]** T. Eichten *et al.*, Nucl. Phys. B 44 (1972)
**[5]** J. V. Allaby *et al.*, Tech. Rep. 70-12 (CERN,1970)

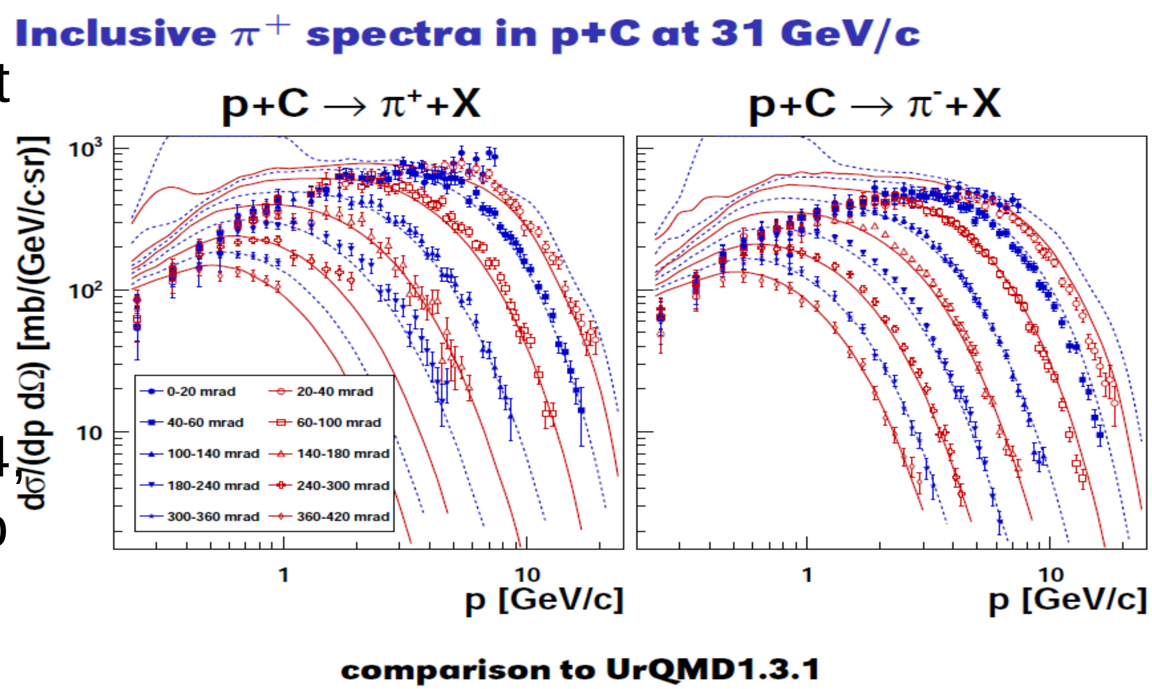



# NA61/SHINE

- Located at the CERN SPS (North Area, H2 beam line)
- Fixed target experiment on primary (ions) and secondary (ions, hadrons) beams




- Pion spectra in p+C interactions at 31 GeV/c are published:
  Phys. Rev. C84 (2011) 034604
- They are used to improve beam neutrino flux predictions
- Adjust models (UrQMD 1107.0374 Fritiof 1109.6768) used in neutrino and cosmic-ray experiments



# Outline

- NA61/Shine
- (Upgraded) ND280
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# Near Detector Constraint

Neutrino Flux Model:

- Data-driven: NA61/SHINE, beam monitor measurements
- Uncertainties: modeled by variation of normalization parameters (b) in bins of neutrino energy, flavor

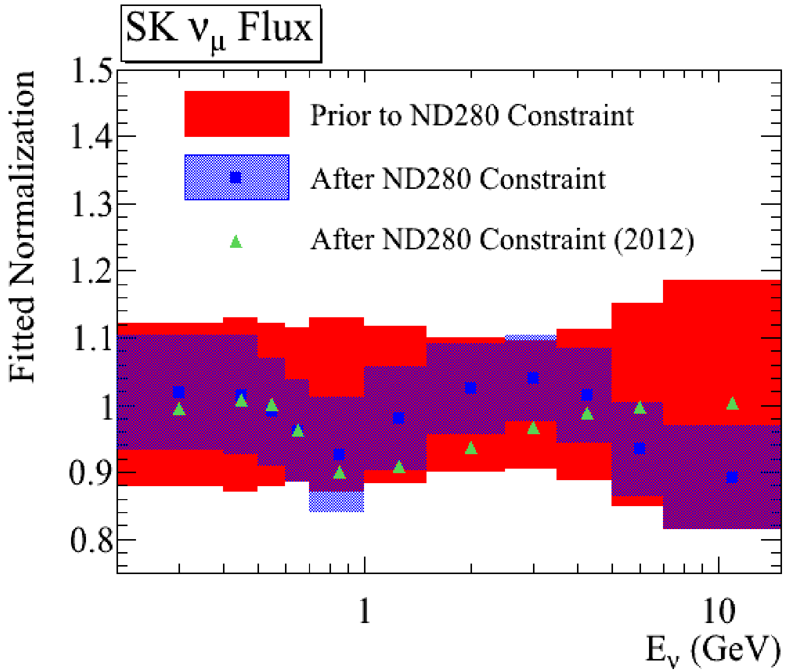
Neutrino Cross Section Model (NEUT):

- Data-driven: External neutrino, electron, pion scattering data
- Uncertainties: modeled by variations of model parameters ($M_A$, $p_F$, $E_b$) and ad-hoc parameters

Constraint from ND280 Data

- Data Samples enhanced in CC interactions with 0, 1 or multiple pions
- Fit to data constrains flux, b, and cross section, x=($M_A$, $p_F$, $E_b$, ad-hoc, etc.), parameters
- Constrained SK flux parameters and subset of cross section parameters are used to predict SK event rates

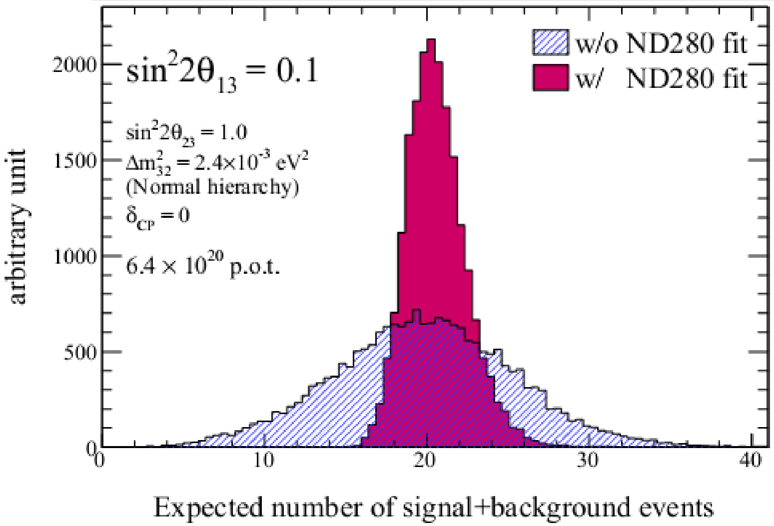
# Flux and X-Sections after Constraint

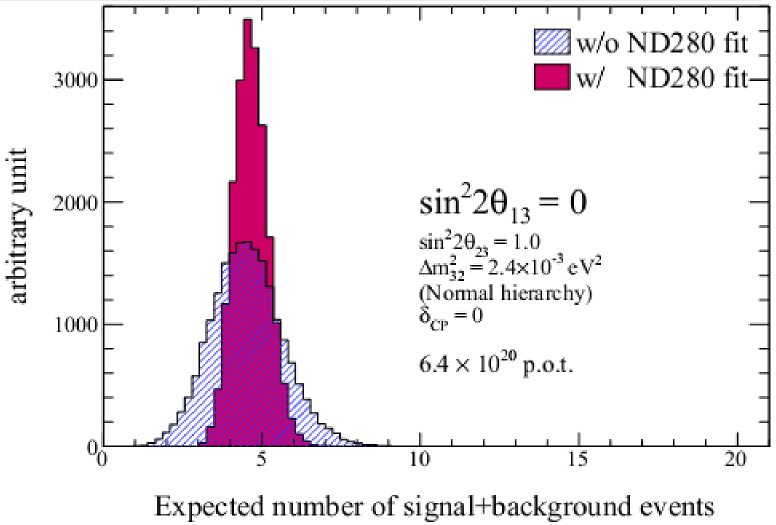



| Parameter | Prior to ND280 Constraint | After ND280 Constraint |
|---|---|---|
| $M_A^{QE}$ (GeV) | 1.21 ± 0.45 | 1.22 ± 0.07 |
| CCQE Norm.* | 1.00 ± 0.11 | 0.96 ± 0.08 |
| $M_A^{RES}$ (GeV) | 1.41 ± 0.22 | 0.96 ± 0.06 |
| CC1π Norm.** | 1.15 ± 0.32 | 1.22 ± 0.16 |

*For Eν<1.5 GeV **For Eν<2.5 GeV

Far detector prediction uncertainties after ND280 constraint



# T2K Systematic Errors

Oscillation analysis systematic uncertainties. Systematics for $N^{exp}_{SK}$ (%):

| | Error source | $\sin^2 2\theta_{13} = 0.1$ w/o ND280 fit | $\sin^2 2\theta_{13} = 0.1$ w/ ND280 fit | |
|---|---|---|---|---|
| From ND280 | Beam only | 11.4 | 7.4 | Flux error and part of cross section model constrained by near detector |
| | $M_A^{QE}$ | 20.7 | 3.1 | |
| | $M_A^{RES}$ | 3.2 | 1.0 | |
| | CCQE norm. ($E_\nu < 1.5$ GeV) | 9.0 | 6.2 | |
| | CC1$\pi$ norm. ($E_\nu < 2.5$ GeV) | 4.0 | 2.0 | |
| | NC1$\pi^0$ norm. | 0.6 | 0.4 | |
| SK only | CC other shape | 0.1 | 0.1 | |
| | Spectral Function | 5.9 | 5.9 | Modeling of initial state of nucleus |
| | $p_F$ | 0.1 | 0.1 | |
| | CC coh. norm. | 0.2 | 0.2 | |
| | NC coh. norm. | 0.2 | 0.2 | |
| | NC other norm. | 0.5 | 0.5 | |
| | $\sigma_{\nu_e}/\sigma_{\nu_\mu}$ | 2.8 | 2.8 | Uncertainty on $\nu_e$ xsection |
| | W shape | 0.2 | 0.2 | Behavior of Δ resonance in nuclear medium |
| | pion-less Δ decay | 3.6 | 3.6 | |
| | SK detector eff. | 2.4 | 2.4 | |
| | FSI | 2.3 | 2.3 | |
| | PN | 0.8 | 0.8 | |
| | SK momentum scale | 0.6 | 0.6 | |
| | Total | 27.2 | 8.8 | |

# On-going "New" Studies

Cross section measurements at ND280:

- Cross section studies in water using FGD2 and P0D

- Multi-nucleon activity at the vertex (FGD1)

- Inter-subsystem timing calibration:
  Expand angular coverage (backward tracks, MEC enhancement at high $Q^2$)

- CC1$\pi$ momentum measurement

Additional info for analysis from p beam test @ TRIUMF:

-Pion FSI and secondary interaction study (DUET)

-Pion beam on WC

# ND280 Upgrade for T2K (T2HK)

- Several studies being performed for a possible upgrade → beneficial for T2HK as well. Undergoing study.

- Water target with vertex information
  - water based scintillator for P0D/FGD
  - high pressure TPC, fiber tracker:
    - close to Oxygen, much lower energy threshold
  - water detector at the basement (B2) of ND280

- Enhancement on side/backward going tracks
  - Trip-t electronics upgrade or better calibration

- Neutrino-nucleon cross section for model input
  - D2O and CH2 targets for FGD/P0D

# ND280 Capability by End of T2K

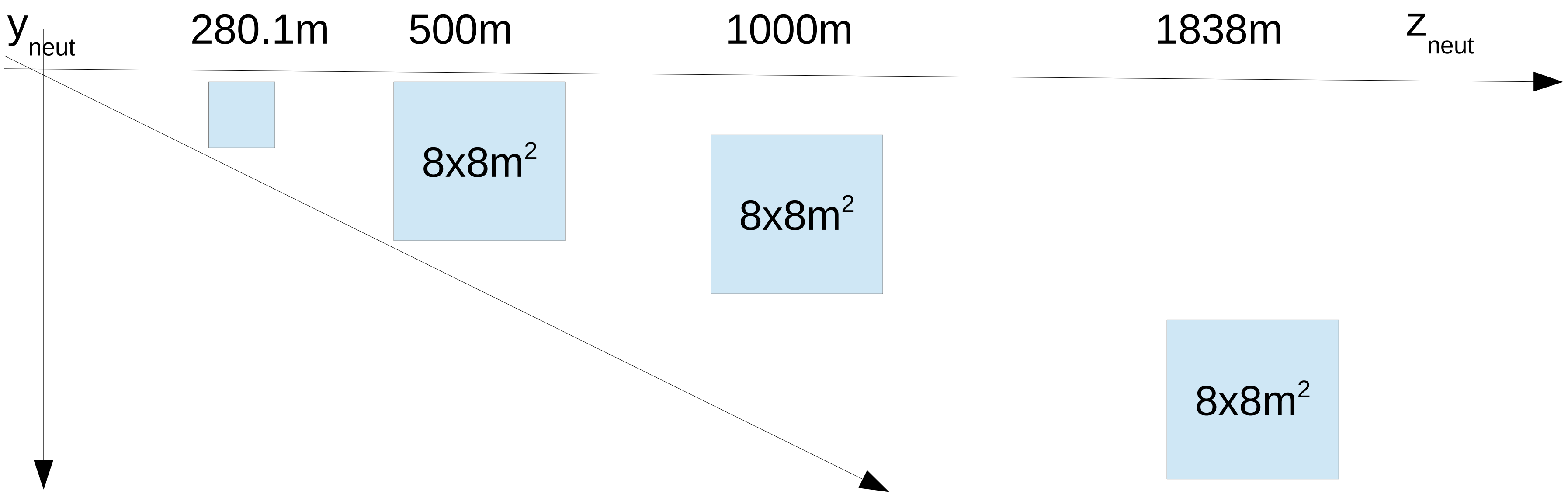
- We need to consider the ultimate capabilities and limitations of ND280 in several areas to stimate further upgrades and new ND needs.
- But, it is not obvious how to estimate the future errors on neutrino interactions and cross section.

- We will expect to have completed the following measurements before HK:
  - Measurements on oxygen
  - Irreducible uncertainty in 280m → 295km flux extrapolation
  - Measurement of the $\nu_e$ contamination and xsection
  - Measurement of NC backgrounds
  - Coverage at large $Q^2$ phase space
  - Right-sign/wrong-sign separation in anti-nu mode

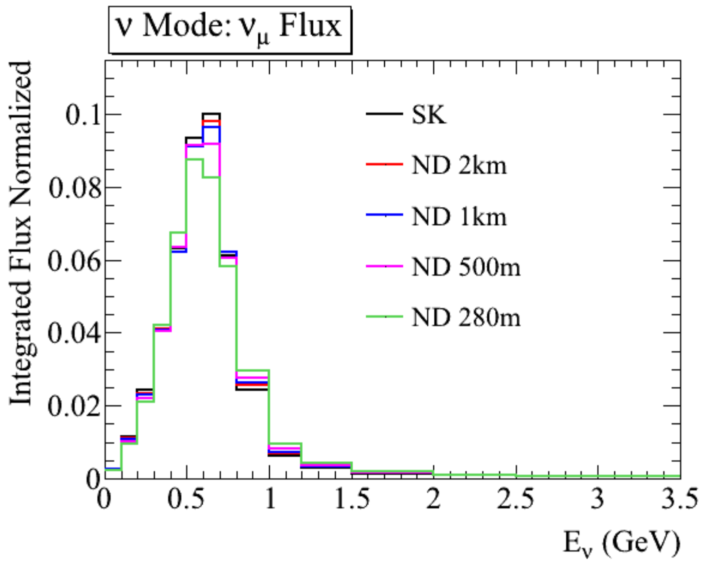
# Outline

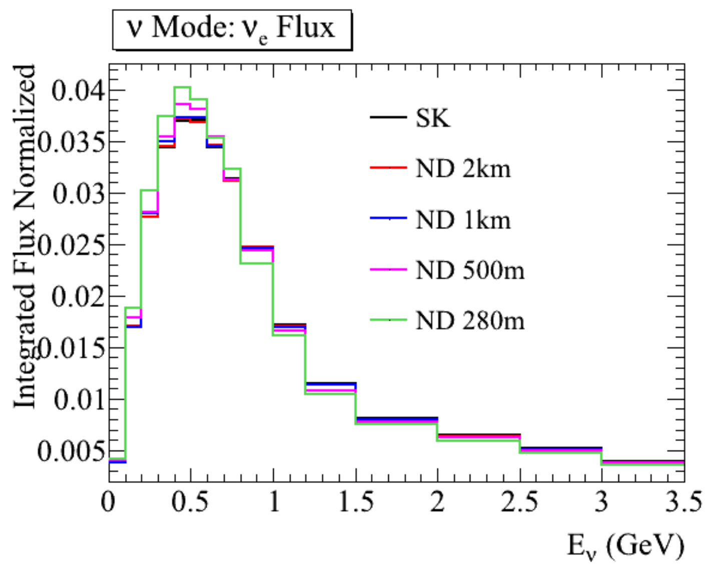
- NA61/Shine
- (Upgraded) ND280
- Additional Near Detector
- 1kton Prototype

# Neutrino Flux




- Beam flux available at different beam planes.
- Ongoing studies on beam errors.

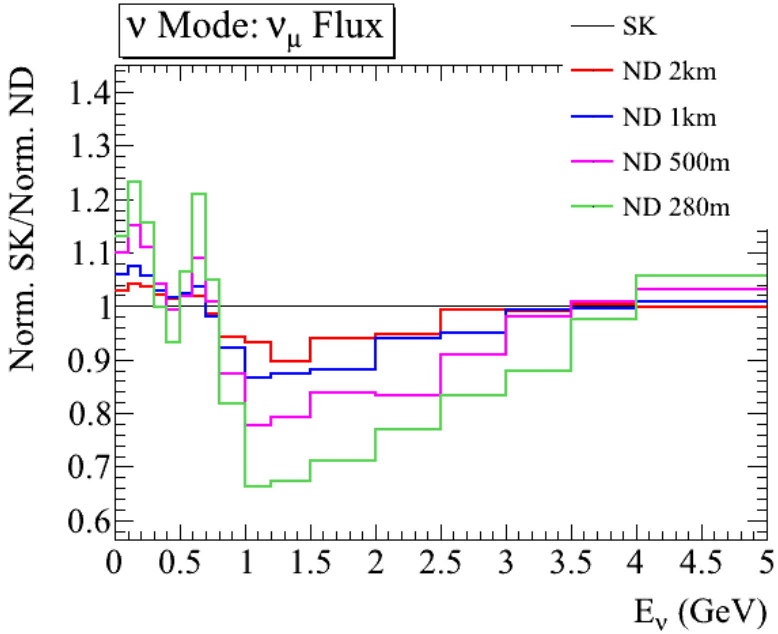


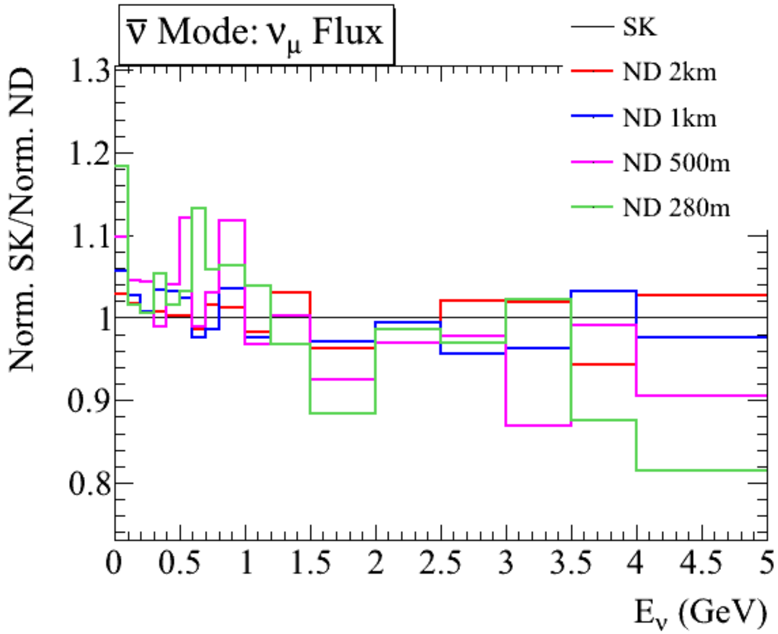



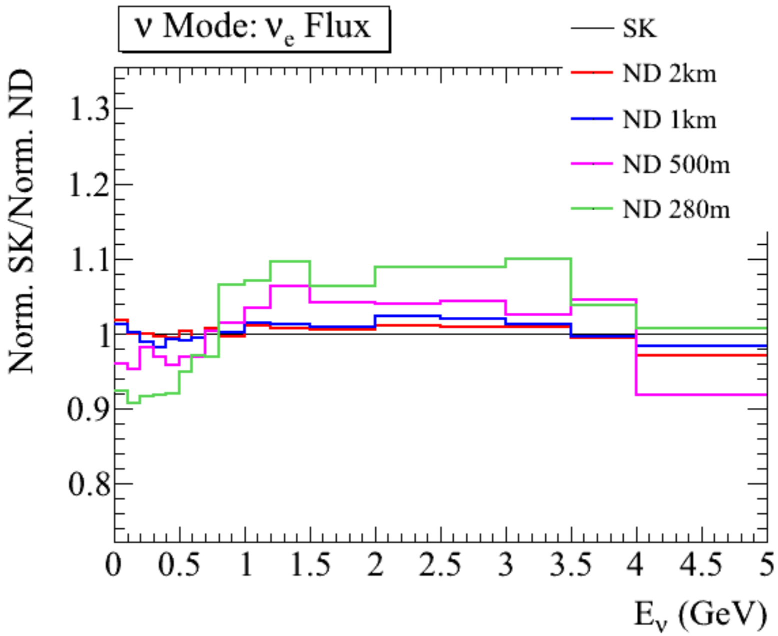

M. Hartz

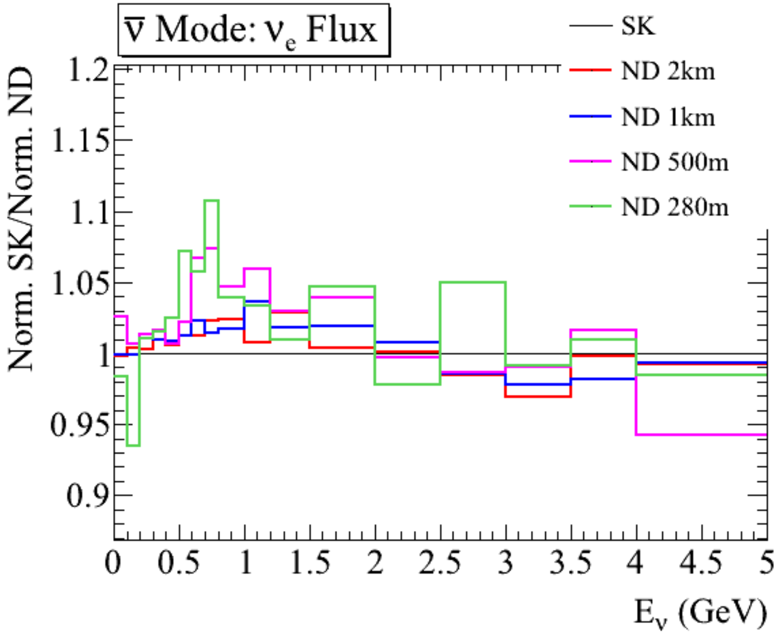
# Far/Near Ratio

M. Hartz



# Additional Near Detector Sites

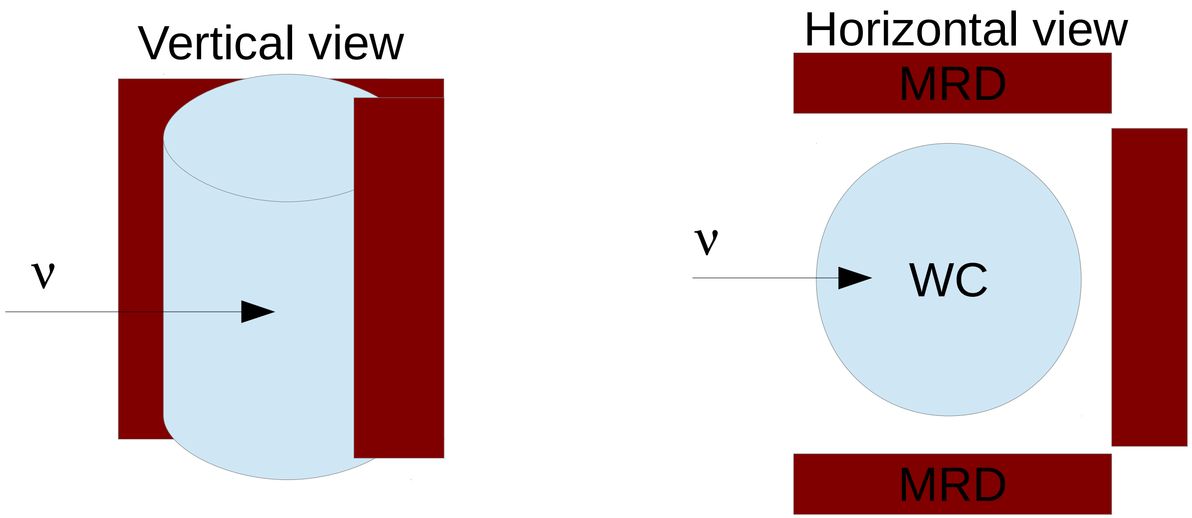

~2.8km 2km 1.2km from the target ND280 Neutrino Target

- Investigation of possible sites just started.
- Original T2K proposal included a 2km site along Tochibura direction.
- In the case we will choose Mozumi we will need a new location a bit more distant than ~2km (eg 2.8km). To be looked at.
- 2006 civil construction cost at 2km: ~$11.2M (T. Kajita)
- We will need to buy the land and estimate the costs.

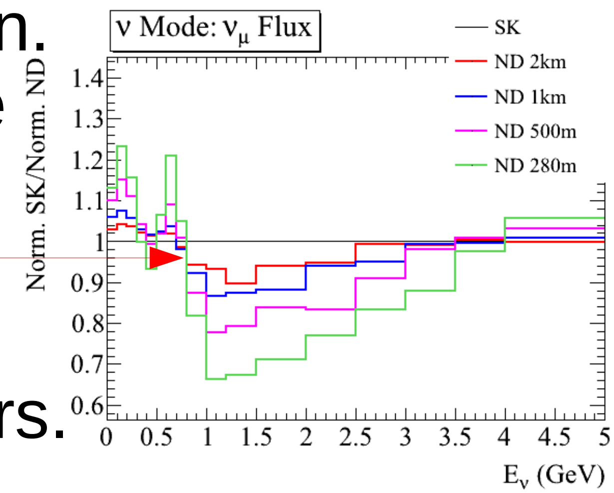
# Additional Near Detector

- Adopted technology is WC.
- Advantages:
  - Same detector as far detector → minimize error propagation.
- Location:
  - More distant from target than 280m, to minimize the near to far flux extrapolation.
- Currently two approaches:
  - New Near Detector (UK, more contributions welcome)
    - Nominal 1kton at 2km
    - Currently, size and location being optimized
  - Water Column (M. Hartz, M. Wilking)
    - Currently, location being optimized

# New Near Detector

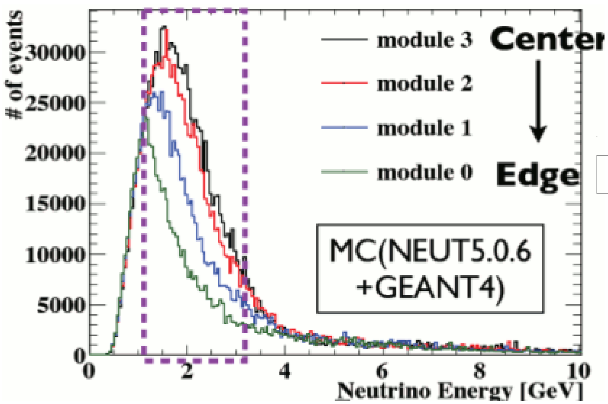


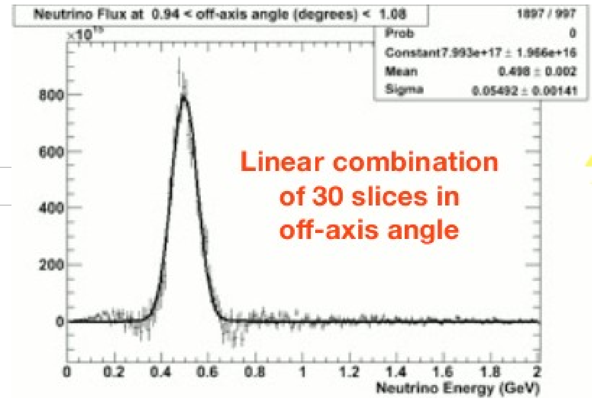

- “Nominal” 1kton, size 11mx11m as K2K 1kton.
- Muon Range Detector (MRD) to measure the muon energy.
- “Nominal” local baseline at 2km.



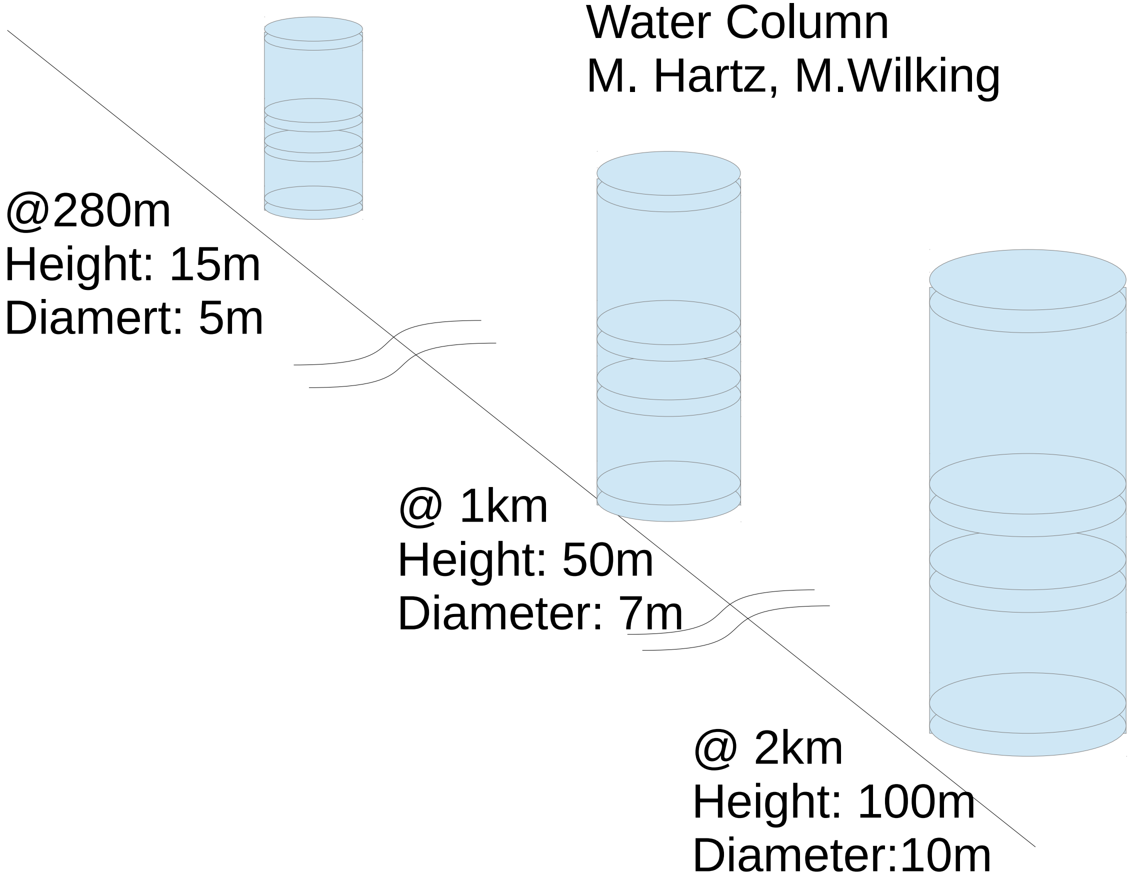

- Ongoing work on studying cross section errors.
- Coming soon studies of pile-up, OOFV, sand muons.
- Sensitivity studies under-way optimize the size and location of the detector.

# Water Column




Water Column
M. Hartz, M.Wilking



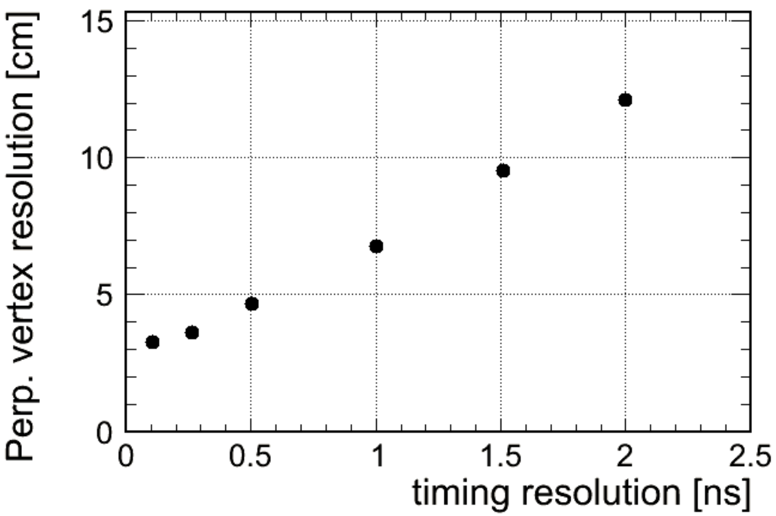

- Minimize dependence on neutrino interaction sampling the beam at several off-axis angles.
- Favoured <1km baseline from engineering point of view.
- Possibly add brine (Konaka) around detector to stop muons.

# New Near Detector Technologies: LAPPD*s Approach

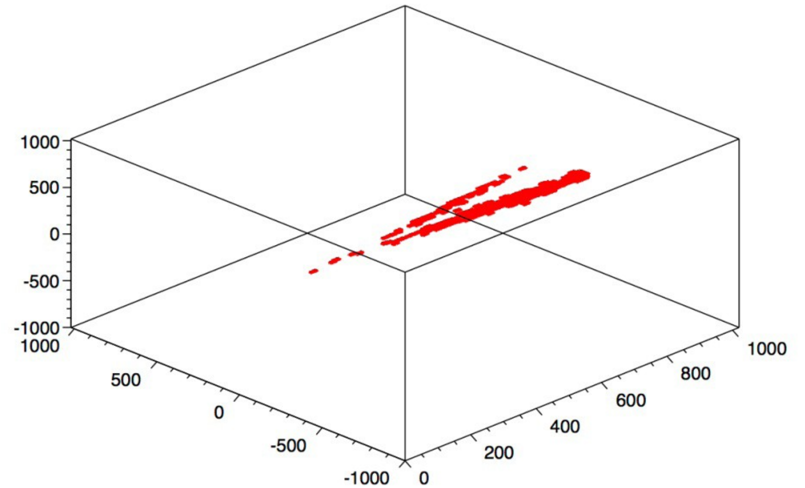
UK exploring

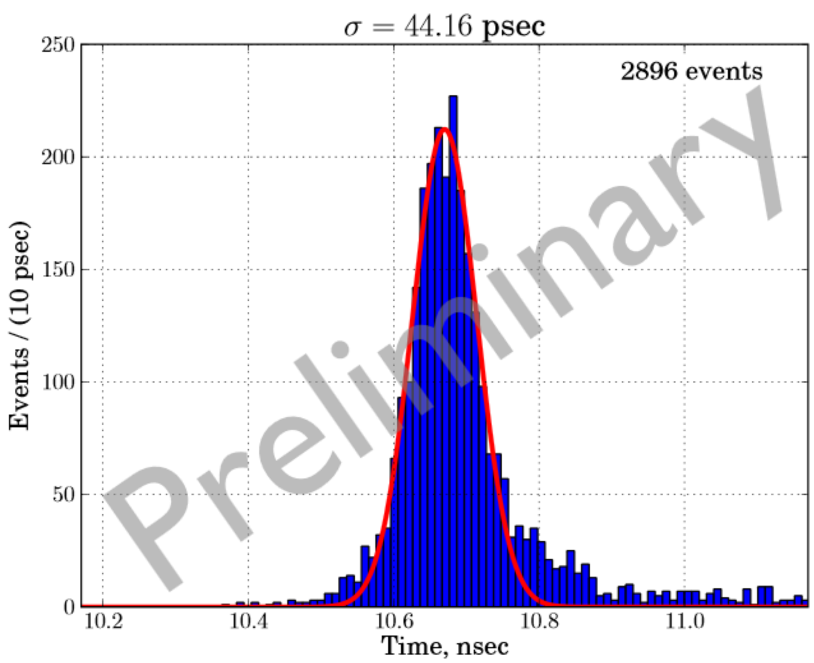
Currently limited by PMT transit time spread to 2-5ns (per photons)
LAPPD collaboration has shown the benefit of sub-ns resolution
–Improved vertex resolution
–Improved pattern recognition

T. Xin, I Anghel, M. Wetstein, M. Sanchez




Reconstructed 1.5 GeV Pi0 (geant)



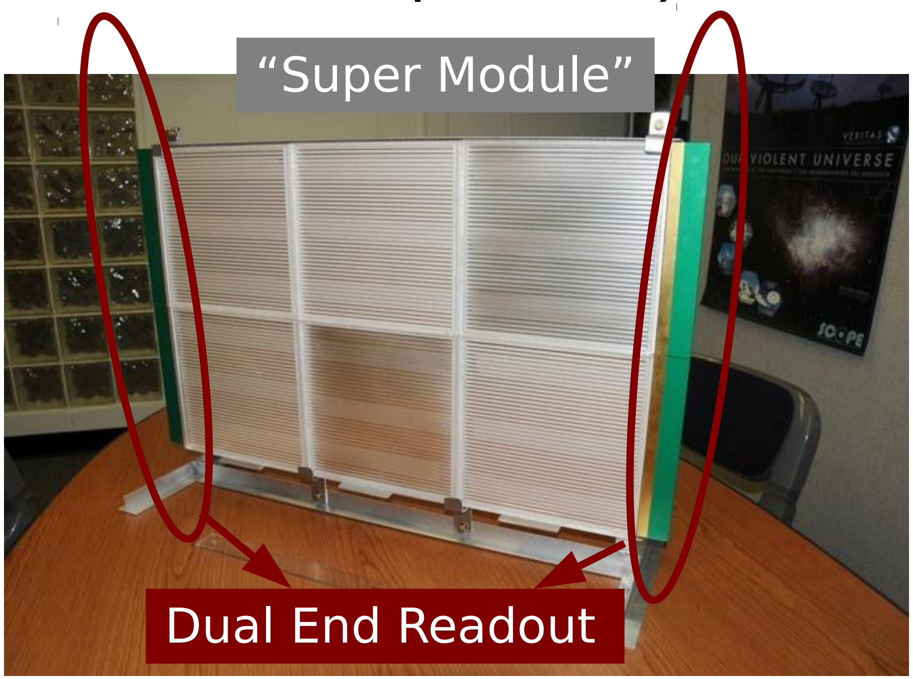

*Large Area Picosecond Photo-Detector

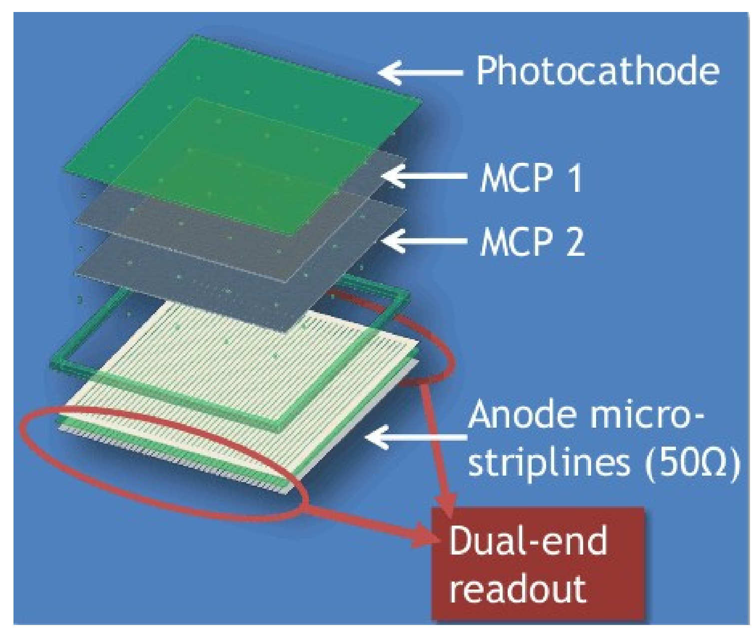
# LAPPDs Approach

Development of large-area, relatively inexpensive Micro-Channel Plate (MCP) photo-detectors

- 8” x 8” phototubes = ‘tile’ (large active area)
- Gain >= 106with two MCP plates
- Transmission line readout –no pins!
- Fast pulses + low TTS ~30ps

Currently transitioning from development through commercialization. First test in a WC tank: Annie (Atmospheric Neutrino Neutron Interaction Experiment)



# Outline

- NA61/Shine
- (Upgraded) ND280
- New Near Detector (NND)
- 1kton Prototype

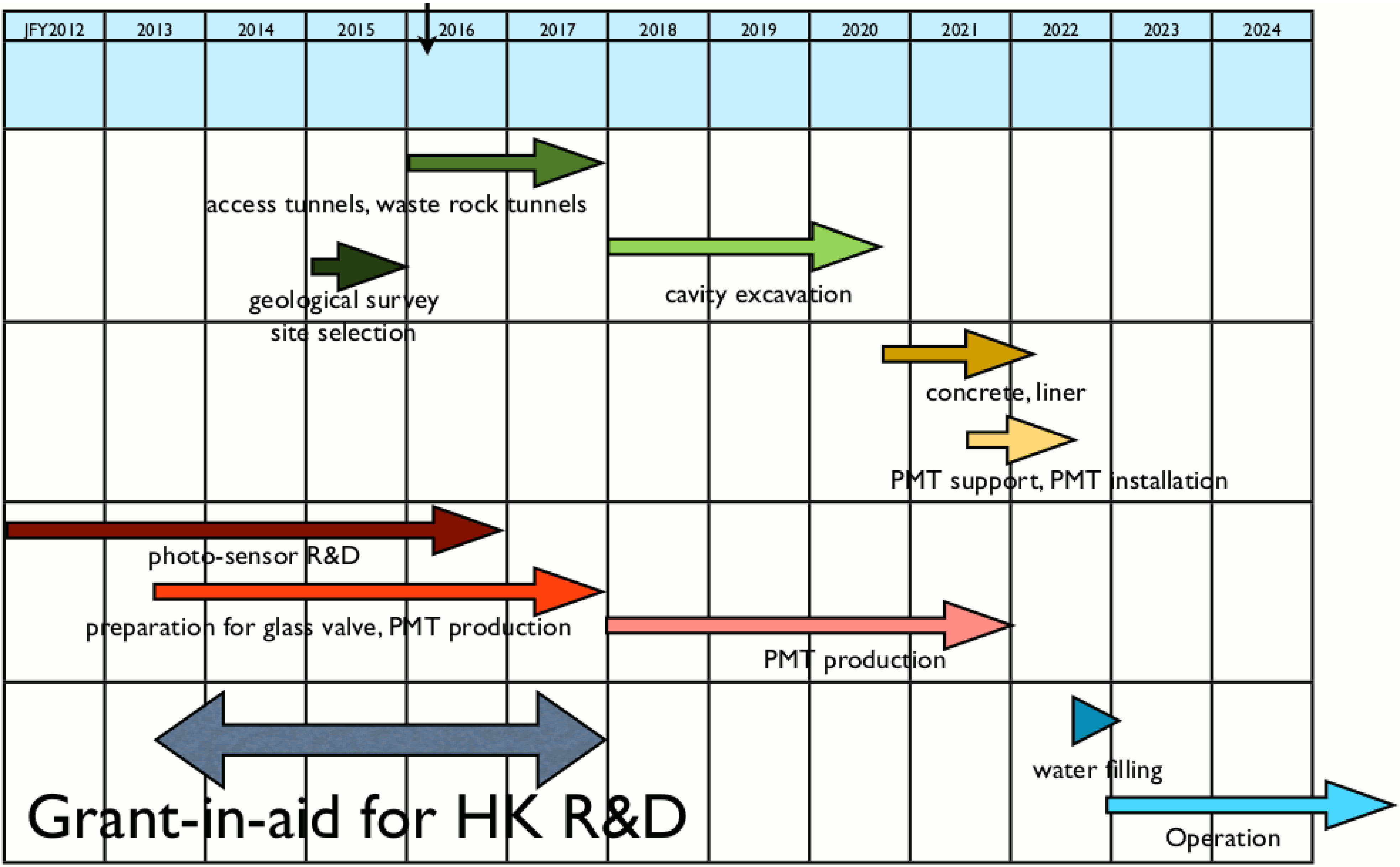
# 1 kton WC Prototype Detector

Japan, 2013/06: Awarded grant-in-aid for ~$1.2M.

Goals of the Prototype Detector (Shiozawa):

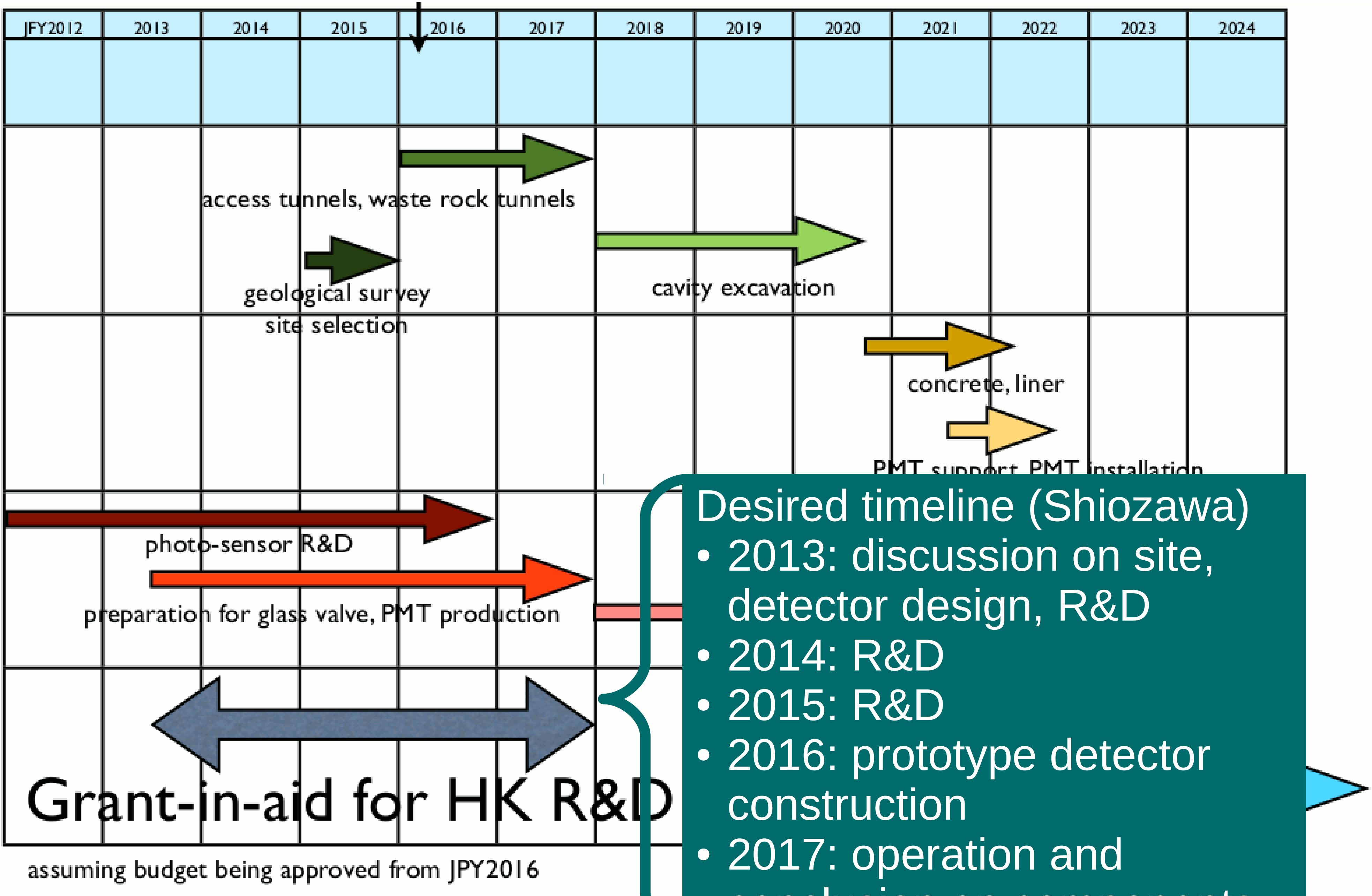
- Final test of O(100) photo-sensors
  - give green signal to the mass production
- Feasibility study of HK water sealing
  - Polyethylene linear construction and hole check, drain water structure, penetrating anchors...
- Other possible items to be tested
  - DAQ electronics (under water?)
  - Outer detector photo-sensors
  - Automated calibration system
  - Other elements, e.g. black sheet, Tyvek sheet, PMT covers, PMT support structure ...

# Timeline




assuming budget being approved from JPY2016

# Timeline



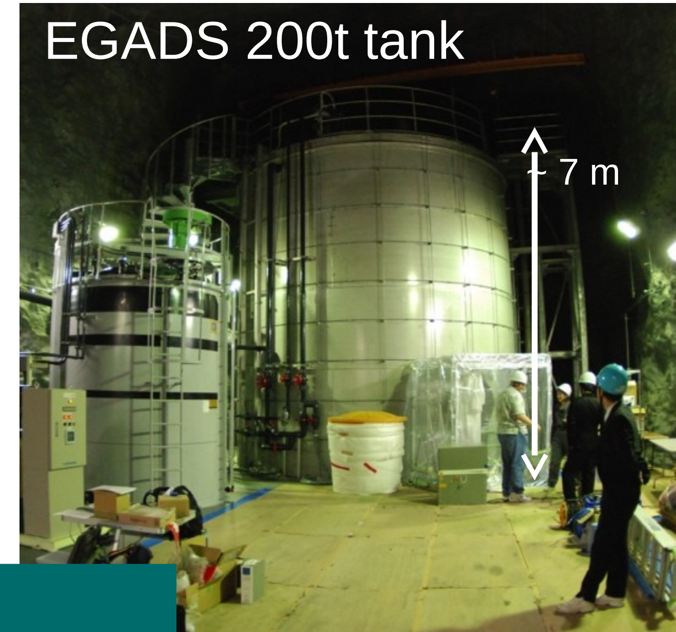

Desired timeline (Shiozawa)

- 2013: discussion on site, detector design, R&D
- 2014: R&D
- 2015: R&D
- 2016: prototype detector construction
- 2017: operation and conclusion on components

# Locations


- Kamioka option:
  - use of EGADS tank (200ton) at Kamioka mine (ID sensor x 180, OD sensor x 60) or new detector at Kamioka mine (new cavity cost ~$1.5M)
- K2K option:
  - 1 kton @KEK. ~600 photosensors can be tested. Water system is there.
- Tokai option:
  - It can potentially used a T2K/HK ND.
  - New hole to be escavated.
- Escavation costs, crane, other utilities not covered in grant-in-aid
- Welcome international contributions in part of the photosensors, electronics, DAQ, water system if needed..

# Locations

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  - It can potentially …
  - New hole to be …
- Escavation costs … overed in grant-in-aid
- Welcome international contributions in part of the photosensors, electronics, DAQ, water system if needed..

Tokai option:
- Hole could be re-used in the future for the NND.
- We may potentially get some physics for T2K.
- Logistically the most difficoult to organize.

# Conclusions

# Conclusions

- Several detector are complementary to achieve the best physics from Hyper-Kamiokande

- NA61/SHINE (or equivalent future experiment) needed for beam hadronization studies.

- ND280 detector will be upgraded for T2K, possible further upgrades for T2HK

- Additional near detector beyond ND280 being investigated (NND, and Water Column)

- 1kton WC prototype approved and being used for testing PMT and new ideas.