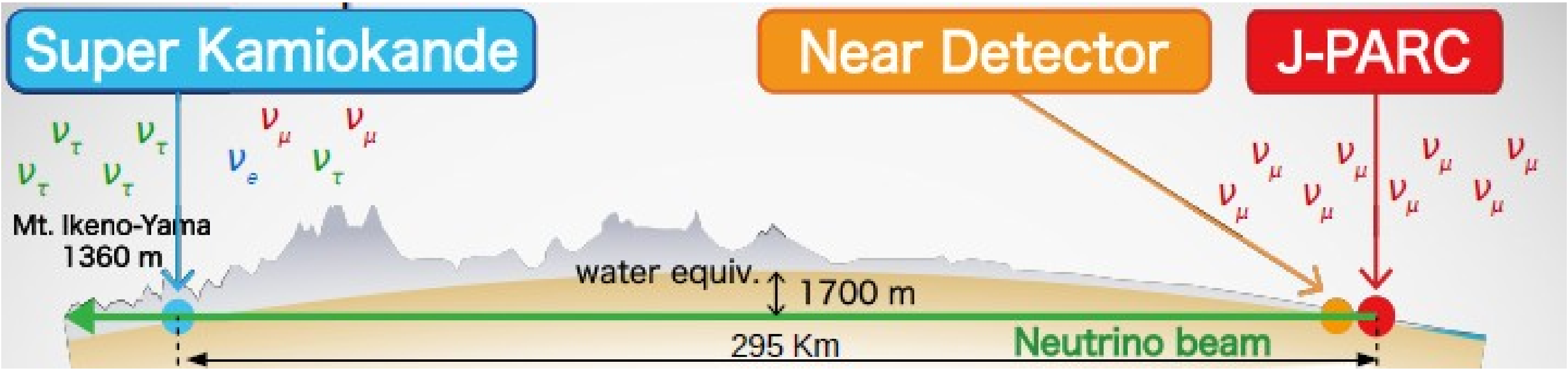
# Prospettive esperimenti T2K & SuperKamiokande

G.Collazuol – CdS INFN PD - 2018/7/9

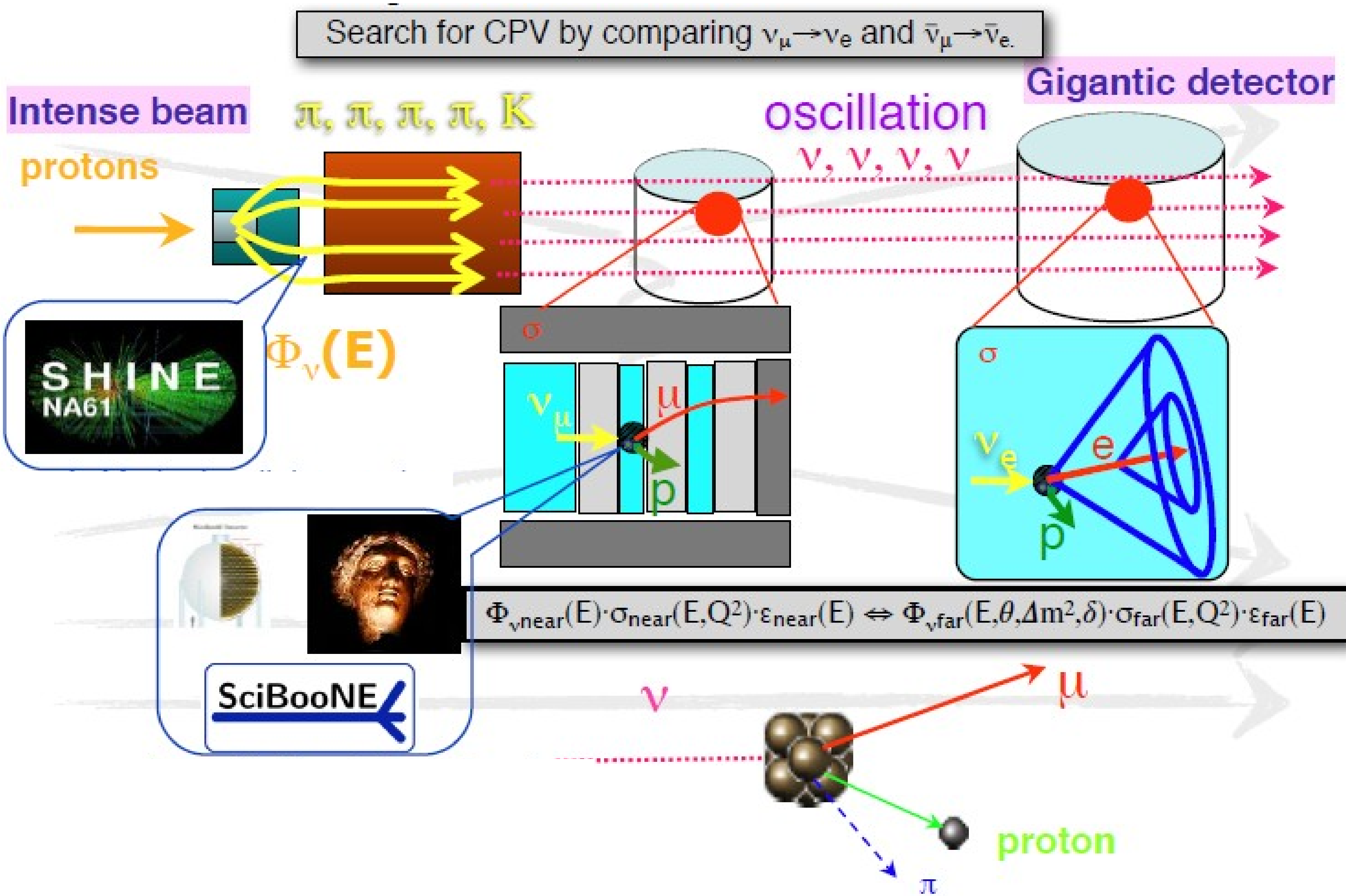



## L'attuale gruppo locale

Staff: **G.C.** (T2K&SK), **M.Laveder**(T2K), **A.Longhin**(T2K), **M.Mezzetto** (T2K)
Post-doc: **A.Ajmi** (T2K&SK)
Dottorandi: **F.Iacob** (T2K&SK), **M.Pari** (T2K),

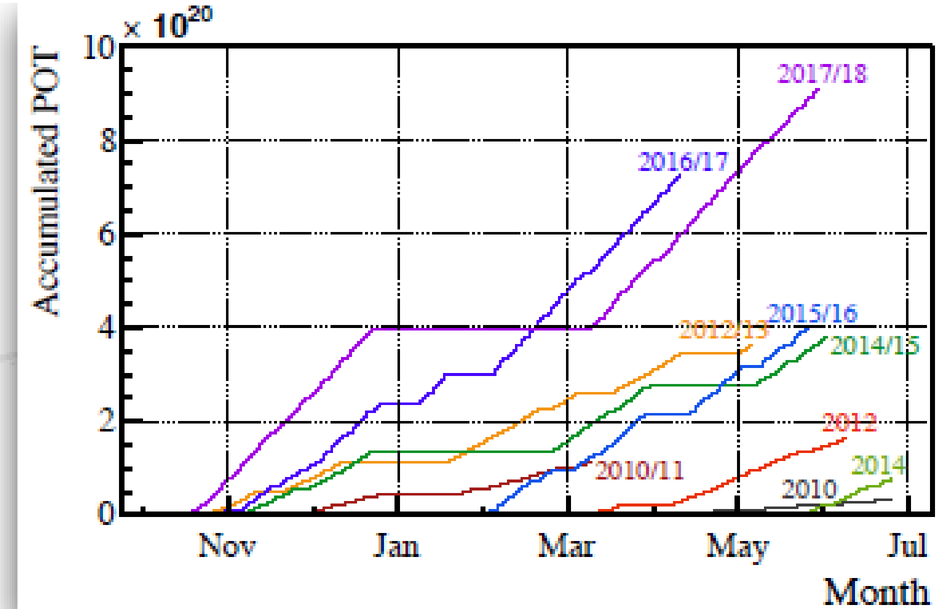
In collaborazione per T2K-upgrade @ LNL: **M.Cicerchia, F.Gramegna, T.Marchi**

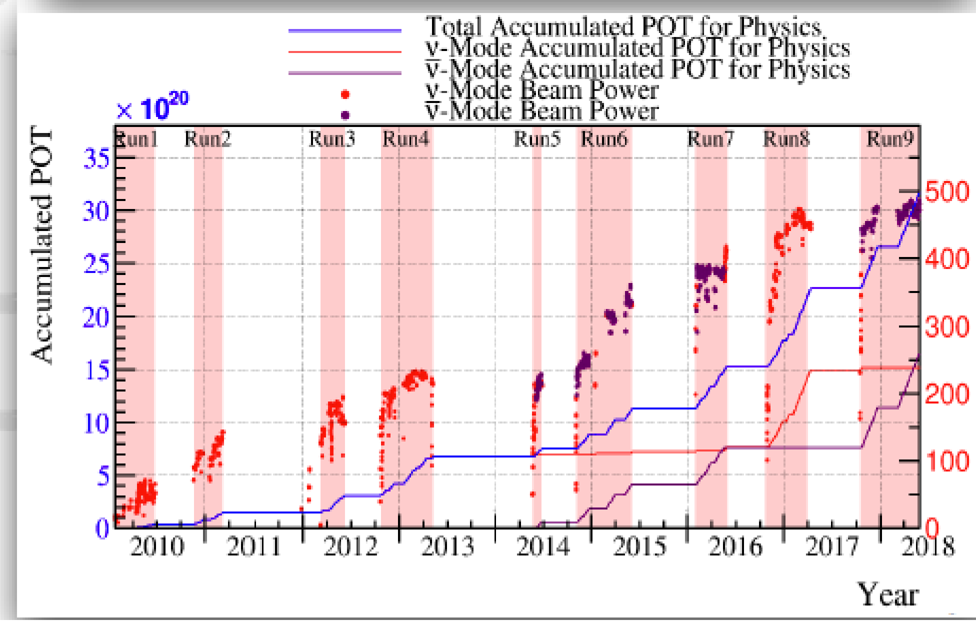
# T2K experimental strategy



# Protons on Target

- Milestones this year: J-PARC
  - **exceeded 3×10$^{21}$ POT;**
  - **achieved 500 kW beam power!**
- Beam delivery summary
  - **3.16×10$^{21}$ POT TOTAL**
  - 1.51×10$^{21}$ POT ν-mode (FHC)
  - 1.65×10$^{21}$ POT ν̄-mode (RHC)
  - Beam operated stably at **485 kW**!
  - **More than double ν̄ data set in 2017/18!**
- Analysis results presented this Summer
  - 1.49×10$^{21}$ POT ν-mode
  - 1.12×10$^{21}$ POT ν̄-mode (*)
- Stable neutrino rates and beam direction demonstrated by INGRID and MUMON




(*) +50% increase in anti-nu mode wrt 2017 results

# T2K Oscillation & CPV results

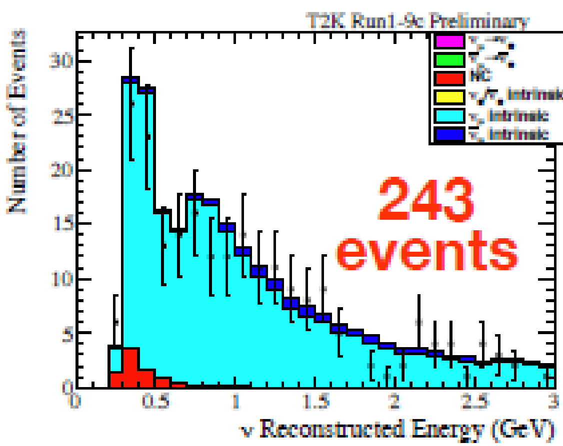
## 5 CC event samples (in SuperK) → oscillation parameters

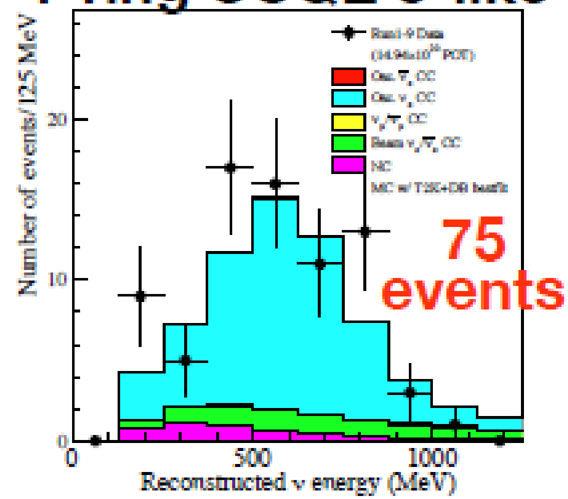
1-ring CCQE μ-like

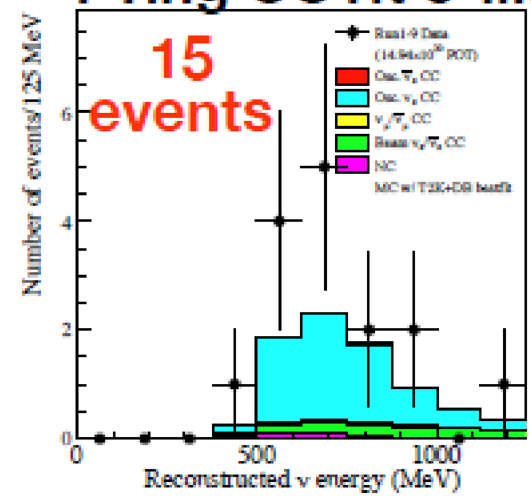
1-ring CCQE e-like

1-ring CC1π e-like

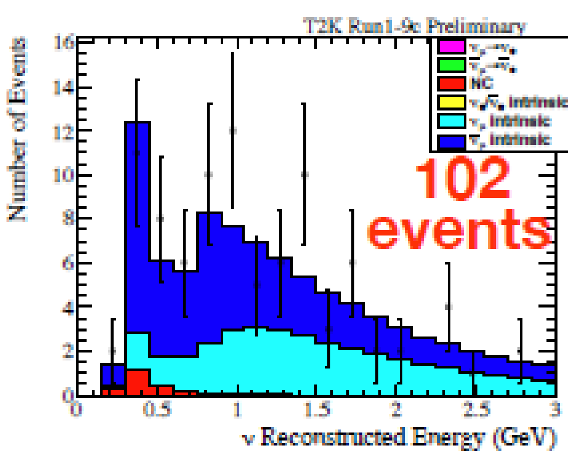
ν-mode

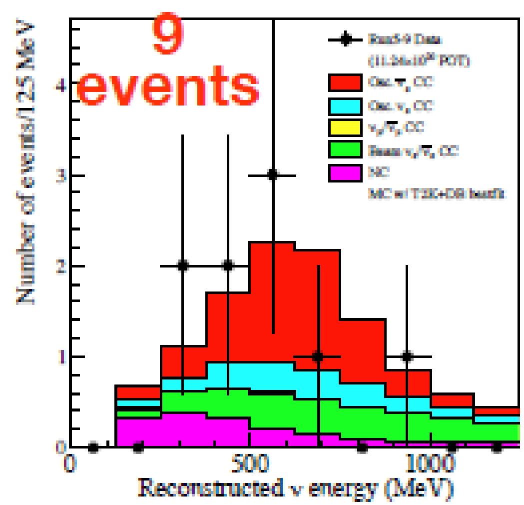



$\bar{\nu}$-mode




**MC assumption**

- $\delta = -1.601$
- Normal hierarchy
- $\sin^2\theta_{23} = 0.528$
- $\sin^2\theta_{13} = 0.0219$

# T2K Signal & Background summary

| | Expected | | | | | | | Data |
|---|---|---|---|---|---|---|---|---|
| | $\nu_\mu+\bar{\nu}_\mu$ CC | Beam $\nu_e+\bar{\nu}_e$ CC | NC | BG total | $\nu_\mu\to\nu_e$ | $\bar{\nu}_\mu\to\bar{\nu}_e$ | MC total | |
| $\nu_e$ CCQE | 0.269 | 8.79 | 4.21 | 13.3 | 58.5 | 0.79 | 72.2 | 75 |
| $\bar{\nu}_e$ CCQE | 0.093 | 2.65 | 1.58 | 4.32 | 2.01 | 5.40 | 11.7 | 9 |
| $\nu_e$ CC1$\pi$ | 0.164 | 0.926 | 0.383 | 1.47 | 5.64 | 0.007 | 7.13 | 15 |

| | Expected | | | | | | | Data |
|---|---|---|---|---|---|---|---|---|
| | $\nu_\mu+\bar{\nu}_\mu$ CC non-QE | $\nu_e+\bar{\nu}_e$ CC | NC | BG total | $\nu_\mu$ CCQE | $\bar{\nu}_\mu$ CCQE | MC total | |
| $\nu_\mu$ CCQE | 36.8 | 0.080 | 8.31 | 45.1 | 210.6 | 12.2 | 268.0 | 243 |
| $\bar{\nu}_\mu$ CCQE | 16.2 | 0.010 | 2.37 | 18.6 | 25.4 | 48.7 | 92.7 | 102 |

Background (MC) Signal (MC) Data

# T2K Observed vs Predicted

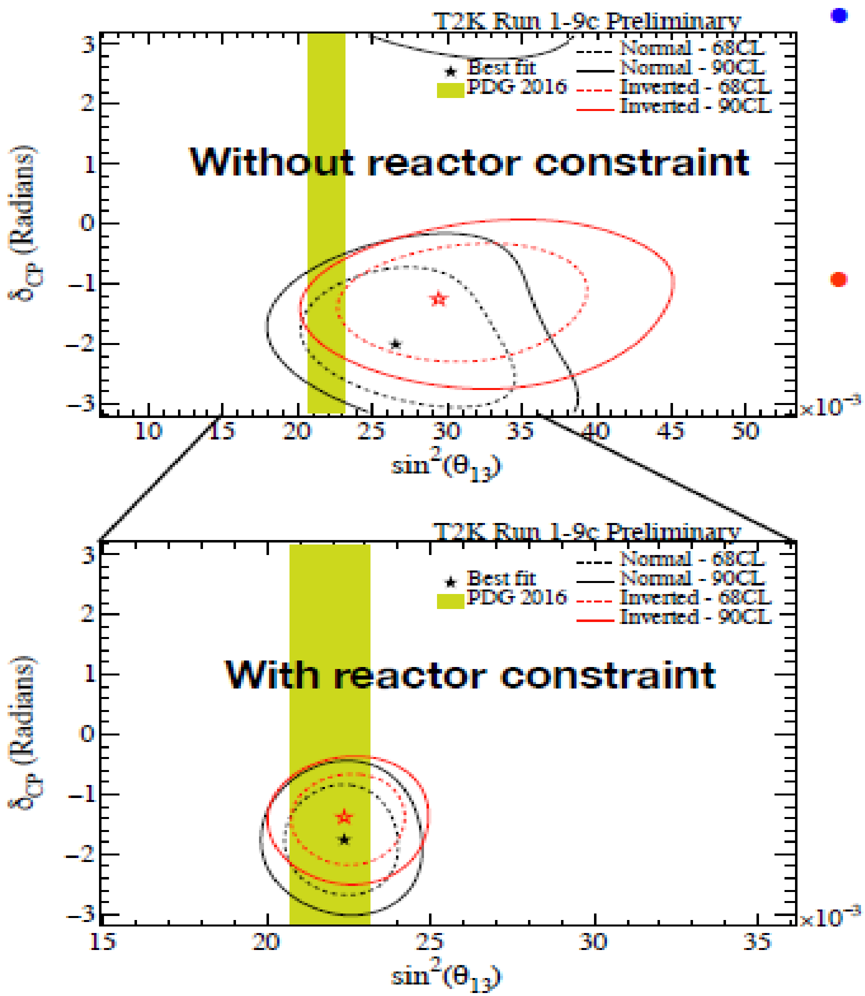
| Sample | Predicted rates | | | | Observed rates |
|---|---|---|---|---|---|
| | $\delta=0$ | $\delta=\pi/2$ | $\delta=\pi$ | $\delta=-\pi/2$ | |
| $\nu$-mode CCQE 1-ring $\mu$-like | 268.2 | 268.5 | 268.9 | 268.5 | 243 |
| $\nu$-mode CCQE 1-ring e-like | 61.6 | 50.1 | 62.2 | 73.8 | 75 |
| $\nu$-mode CC1$\pi$ 1-ring e-like | 6.0 | 4.9 | 5.8 | 6.9 | 15 |
| $\bar{\nu}$-mode CCQE 1-ring $\mu$-like | 95.3 | 95.5 | 95.8 | 95.5 | 102 |
| $\bar{\nu}$-mode CCQE 1-ring e-like | 13.4 | 14.9 | 13.3 | 11.8 | 9 |

- Predicted $\nu_e$ and $\bar{\nu}_e$ appearance event rates change by $\delta_{CP}$
  - $\delta= -\pi/2$ gives higher (smaller) event rates for $\nu_e$ ($\bar{\nu}_e$) appearance signal
  - Observed event rates prefer $\delta=-\pi/2$

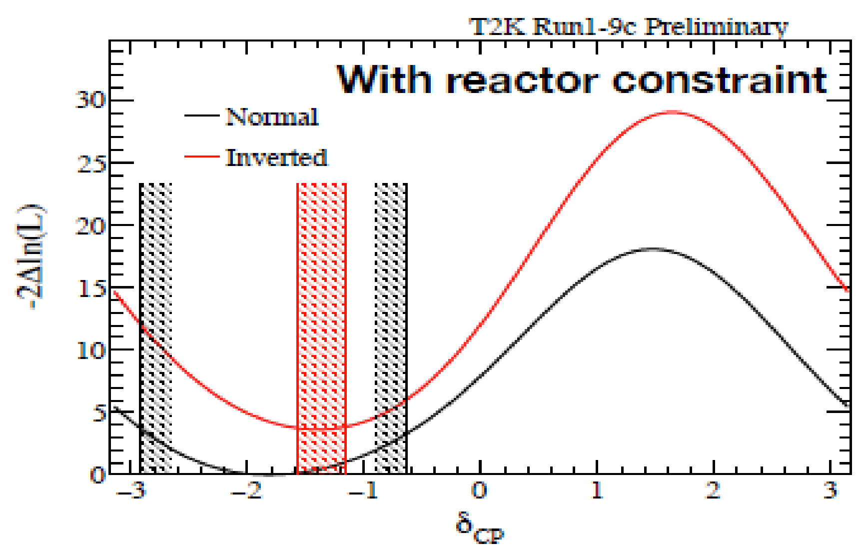
# T2K Oscillation & CPV results

ν-appearence larger than expected
anti-ν-appearence smaller than expected

} data favour largest CPV with $\delta_{CP} \sim -\pi/2$




- **2σ interval calculated with Feldman&Cousins method**
  - **NH : [-2.914, -0.642]**
  - **IH : [-1.569, -1.158]**
- **CP conserving values (0, ±π) outside of 2σ region for both hierarchy**



# Contributi T2K-Padova

- Misure sezioni d'urto

 - Inclusive cross sections of anti-$\nu\mu$ CC at ND280
(A.Longhin, A.Ajmi) → key ingredients for Oscillation Analysis

 - Measurements O(n,$\gamma$) reactions → NC QE cross-sections T2K/SK
(G.Collazuol) → SN Relics, Sterile neutrino, direct Dark Matter

- Convenership gruppo cross-sections (A.Longhin)

- Presa dati:

- Data Quality Expert Task (A.Ajmi)

- turni DAQ, Shift-Leader e Operazioni TPC

- Review di note interne/papers

# Prospettive → T2K-II

# Beam and Near Detector upgrade

T2K-II extension proposal (arXiv:1609.04111):

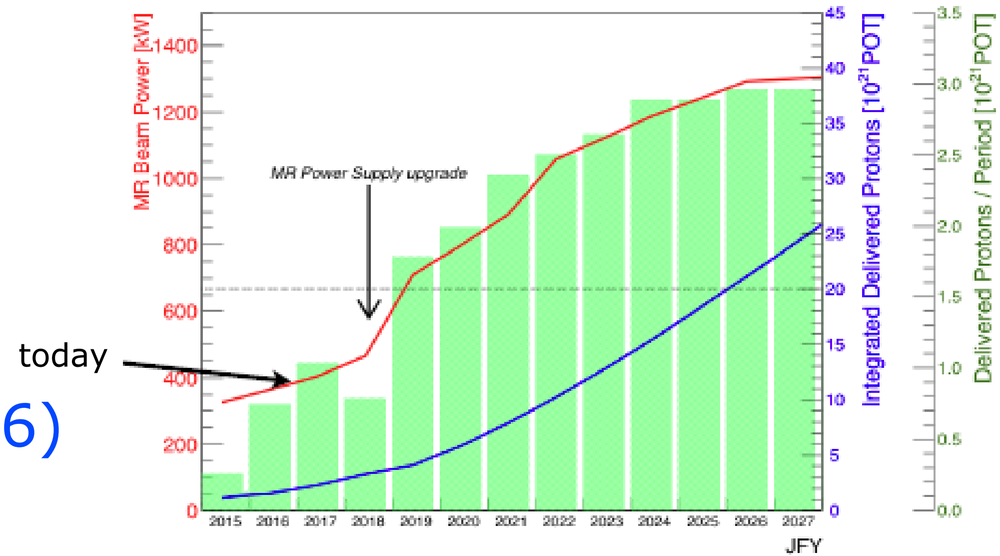
- Aim at 3σ CPV sensitivity or CPC exclusion (w/ favorable param.)
- Accumulate $20\times10^{21}$ pot by 2026 (x3 original T2K program)

Mandatory (for high stat)

- High Intensity Neutrino beam

→ **Accelerator/Beam-line Upgrade** approved

→ gradual increase of power to 1MW (1.3MW) by 2021 (2026)




Mandatory (at high stat)

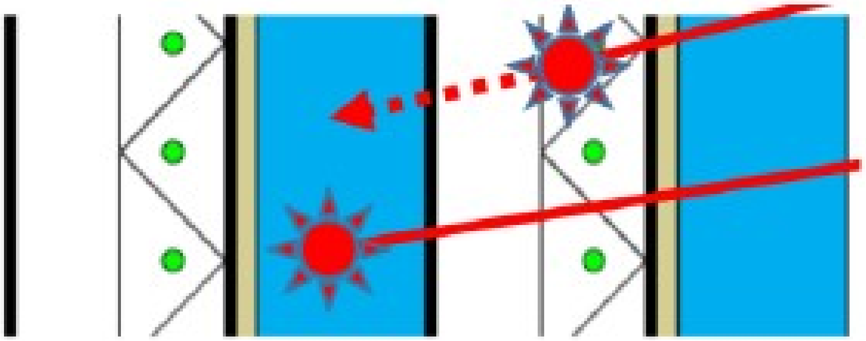
- Reduce systematic error & cross-section model dependence

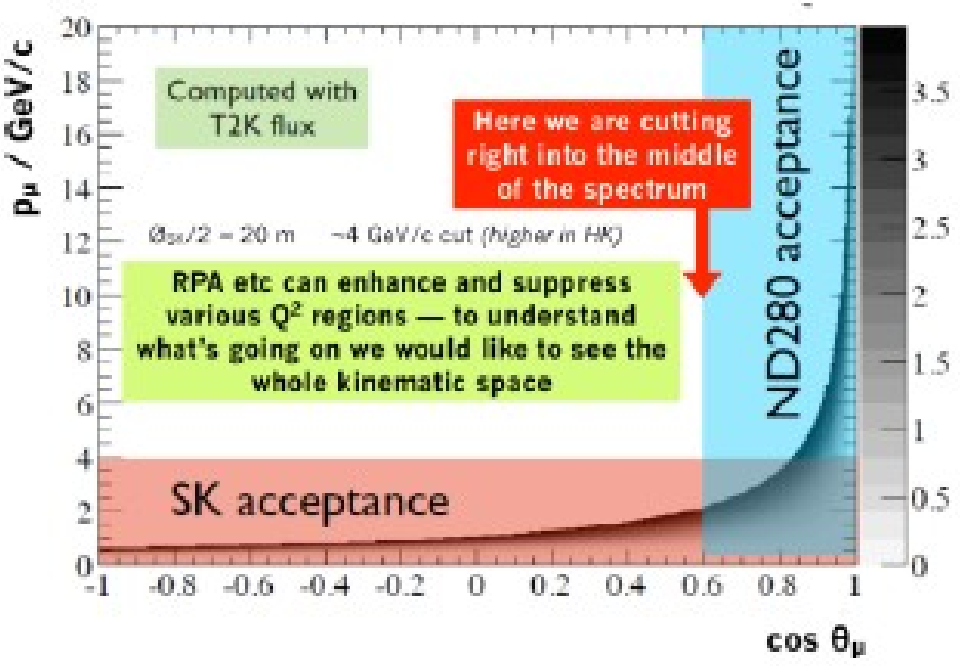
→ **Near Detector Upgrade** → stage 1 approval by PAC ok
Technical Design Report (end 2018) for stage 2 approval

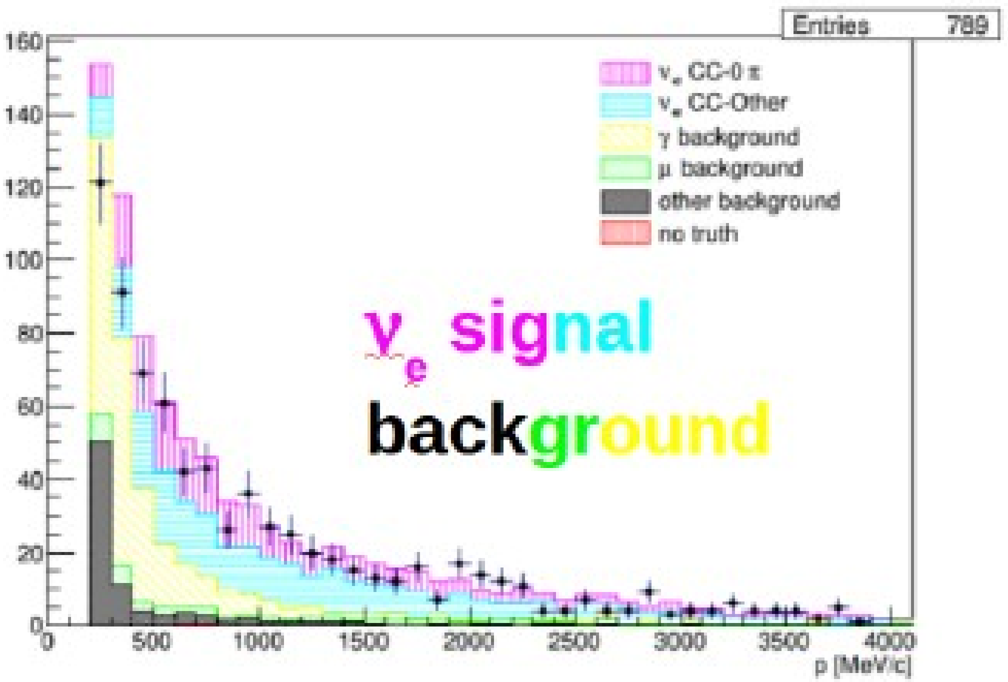
# Prospettive → T2K-II

## Near Detector limitations

- Different target
  - large migrations between scintillator and water layers. Ambiguity on the target nucleus
- Different Acceptance (Model dependence)
- External backgrounds (especially for $\nu_e$!)





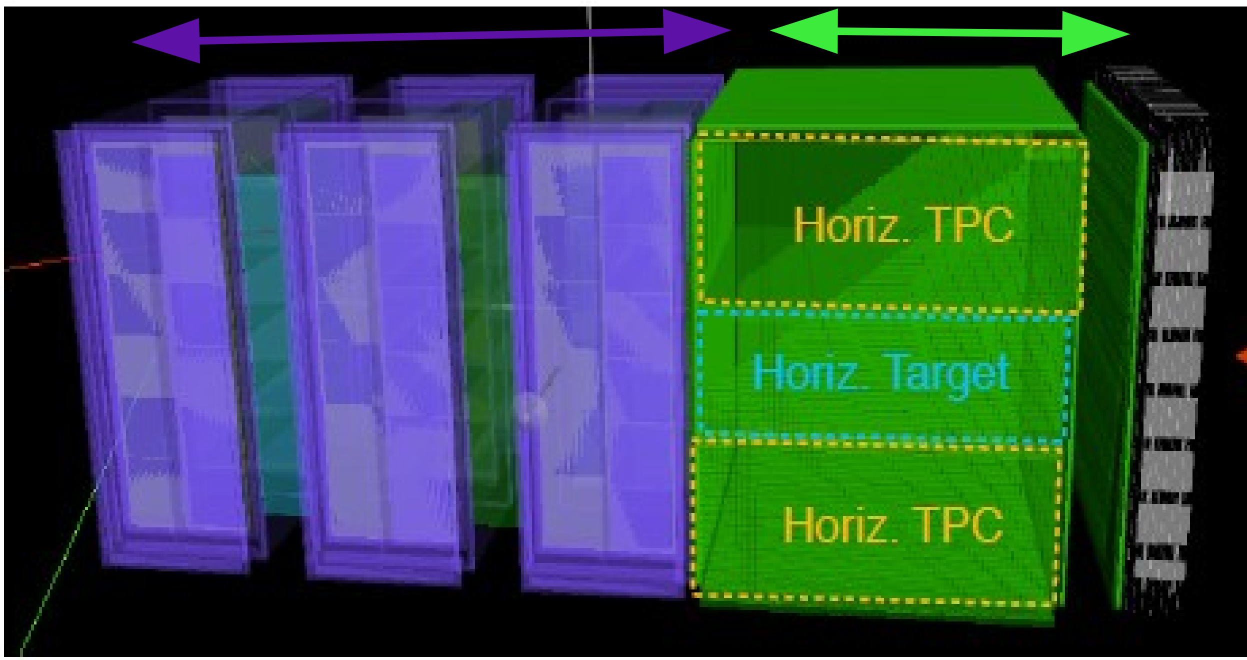
# Prospettive → T2K-II

# Near Detector upgrade

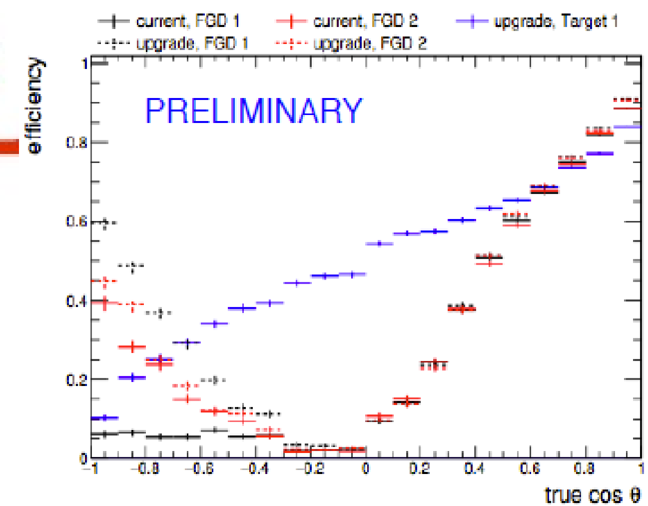
same as present

new detectors:

- 2 horizontal TPCs
- scintillator / water target
- TOF detectors




ν




**2017 Jan:** CERN-SPSC-EOI-015: improvement of ND toward T2K-II (and Hyper-K) aiming to be part of the CERN neutrino platform

**2017:** design studies → submitted Proposal to CERN SPSC + supported as a neutrino platform project

**2018:** Prototype TPC (field cage, micromegas), testbeam @ CERN, TDR by end 2018

**2019-2020:** Production, integration at CERN, System test

**Aiming for installation in 2021 at JPARC**

# The T2K-ND280 upgrade proposal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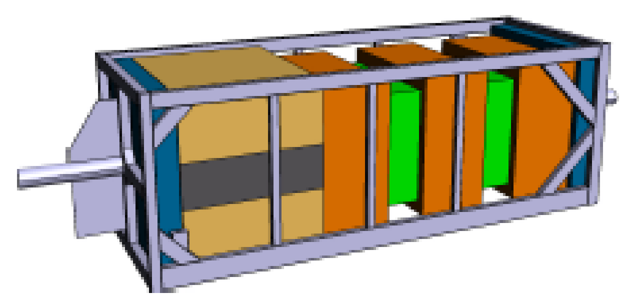
**Abstract**

The T2K experiment established the $\nu_\mu \to \nu_e$ appearance with only 10% of the original beam request of $7.8 \times 10^{21}$ 30 GeV protons on target (p.o.t.). In view of the J-PARC program of upgrades of the beam intensity, the T2K-II proposal requires to run up to $20 \times 10^{21}$ p.o.t., i.e. an increase of the exposure by a factor 10. The Hyper-K proposal consists in a further increase by a factor 10 of the far detector mass. Facing the potential increase of statistics by two orders of magnitude, it is of great importance to undertake a vigorous program of near detector upgrades, with the aim of reducing the statistical and systematic uncertainties at the appropriate level of 3-4% or less on the prediction of the $\nu_\mu \to \nu_e$ and $\bar{\nu}_\mu \to \bar{\nu}_e$ appearance signals in the far detector. In February 2017 the T2K Collaboration launched the program of upgrade for the off-axis magnetic near detector of the T2K experiment (ND280). This report presents a baseline proposal, which achieves a much better uniformity of acceptance as function of polar angle, by reconfiguring the geometry with a fully active scintillator detector acting as neutrino target, disposed along the plane including both the beam direction and the magnetic field. The favoured option for this detector is the Super-FGD concept, consisting of small scintillator cubes each read-out by three WLS fibers. Two new TPCs cover the large angles and time-of-flight detectors allow rejection of out of fiducial volume events. First results of performance are given showing a significant reduction of the uncertainties.

# ND280 Upgrade
# contributi Padova - Legnaro

Impegno per le HA-TPCs

- G.Collazuol (co-project leader HA-TPC w/ M.Zito,CEA)
- A.Pepato, G.Cogo, M.Romanato,
- A.Longhin, F.Iacob, M.Pari

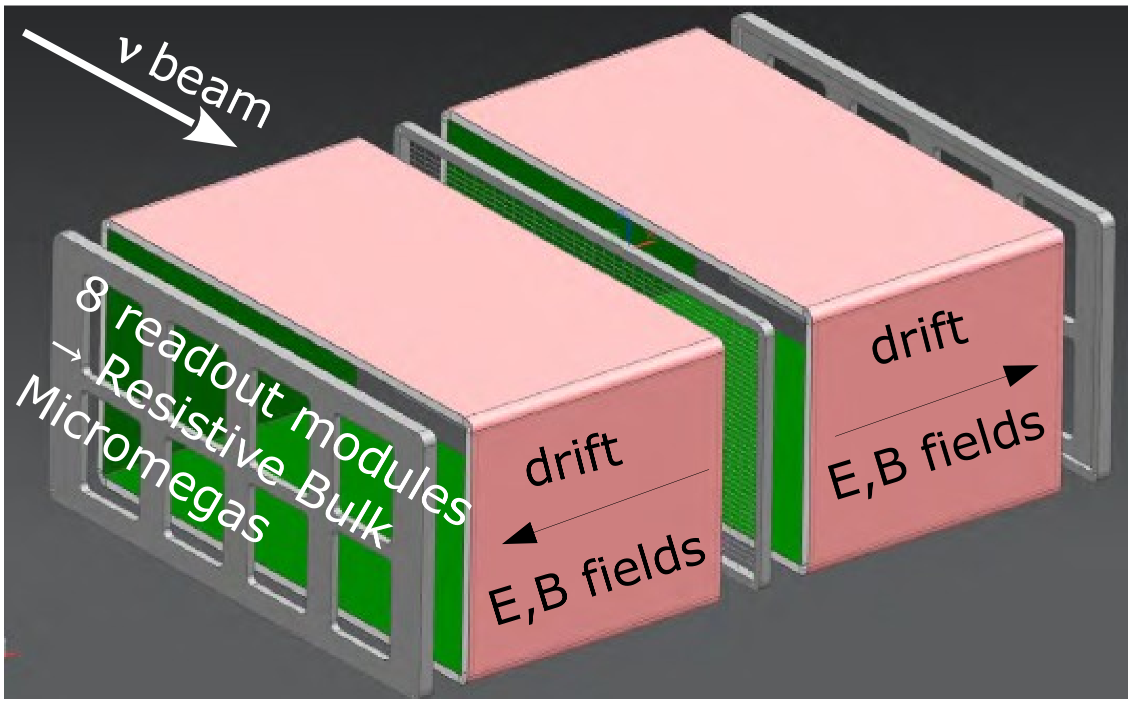
in collaborazione colleghi INFN LNL

- M.Cicerchia, F.Gramegna, T.Marchi

(coinvolti in ND208-upgrade)

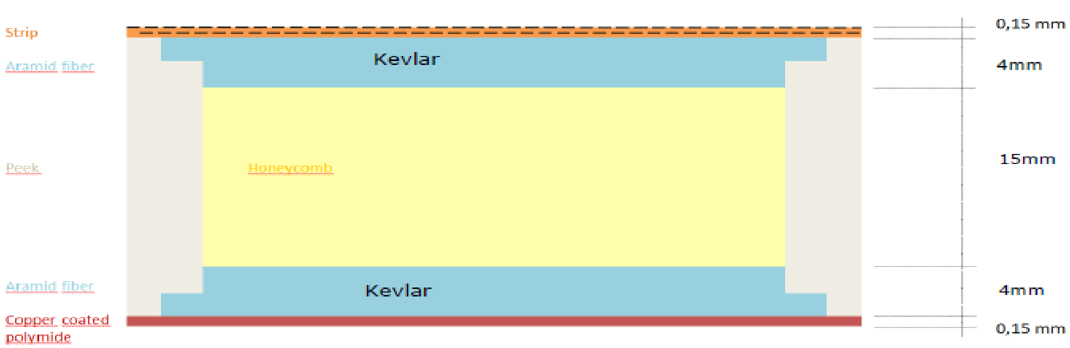
- proposta e disegno Field Cage HATPC in materiali compositi
- test beam at CERN 2018 e test beam 2019
- test e simulazioni Resistive Bulk Micromegas in sinergia con progetto Active Target TPC per SPES (LNL)

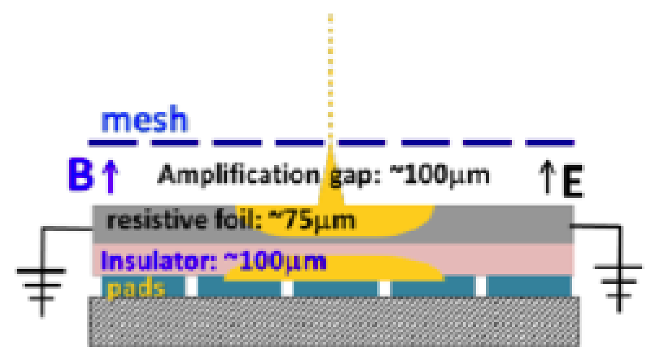
# ND280 Upgrade
## new High Angle TPCs




| Parameter | Value for 1 TPC |
|---|---|
| Dimension | 1.8(x) x 0.8(y) x 2.0(z) $m^3$ |
| Volume | 2.9 $m^3$ |
| Drift Length | 90 cm |
| Pad area | ~1 $cm^2$ (~2 $cm^2$ resistive MM) |
| Sensitive area | 3.2 $m^4$ |
| # MM | 16 (50x50 $cm^2$ each MM) |
| # channels | 3.2x$10^4$ |

Thin Field Cage walls (composite materials)




Resistive Bulk MicroMegas (charge spread, intrinsic spark protection)

# ND280 Upgrade
## TPC Prototype

Sezione INFN di Padova fortemente coinvolta in TPC-upgrade project

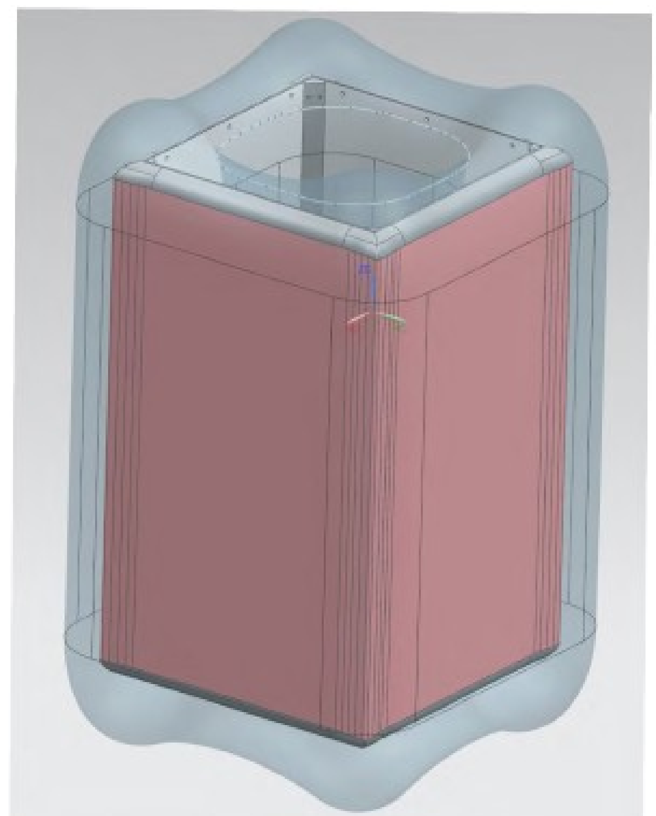
In particolare per il disegno e la costruzione della Field Cage

Towards a mold tecnical design and a detailed procedure definition for the composite building process

INFN Padova: G.Cogo
A.Pepato
M.Romanato

→ ongoing iterations with
+ INFN Bari: Cosimo Pastore
+ IFJ: Henry Przybilski
+ IFAE: Julia Mundet

G.Collazuol 2018/6/7
TPC upgrade meeting

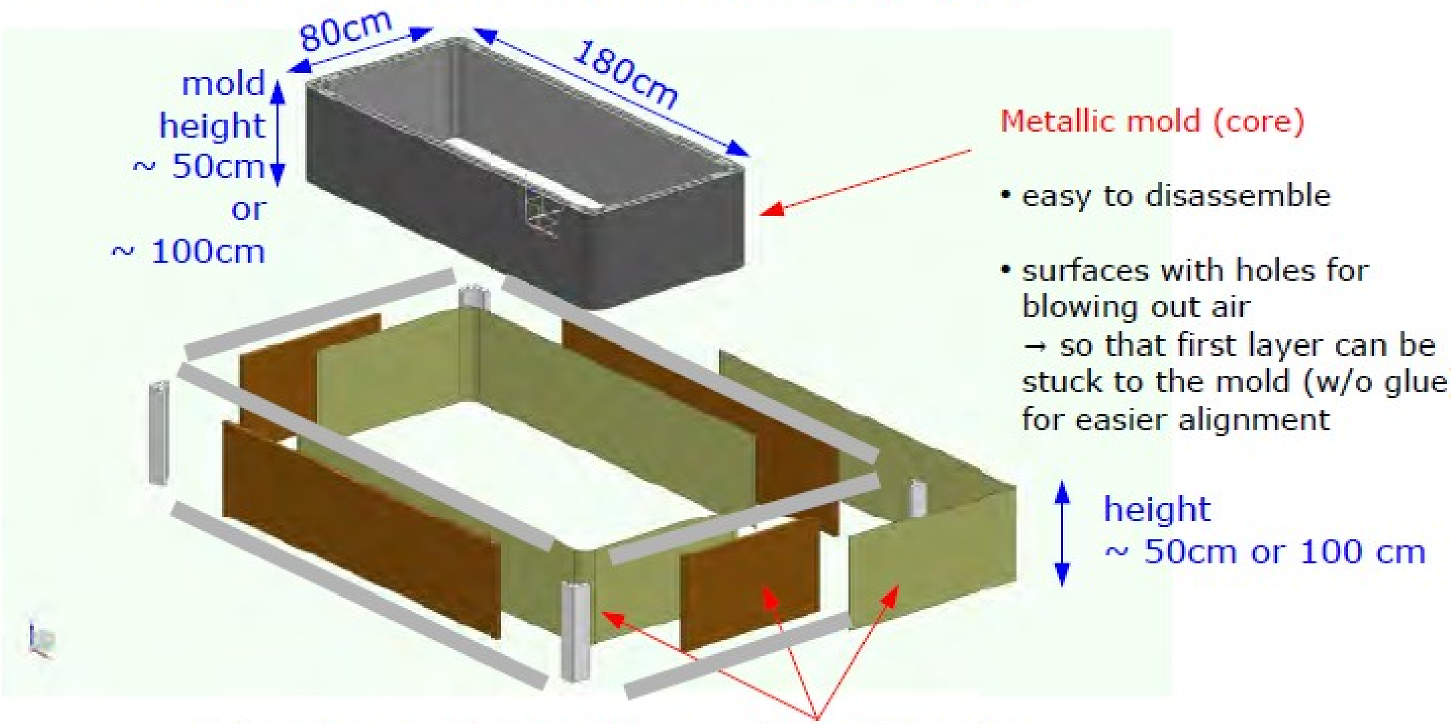


Primo passo e` stata la definizone della tecnologia ed il disegno della FC per PROTOTIPO di TPC

→ si prevede di avere il prototipo funzionante al CERN entro la fine del 2018

# ND280 Upgrade
## TPC Prototype

1 - ... details about how to build a box

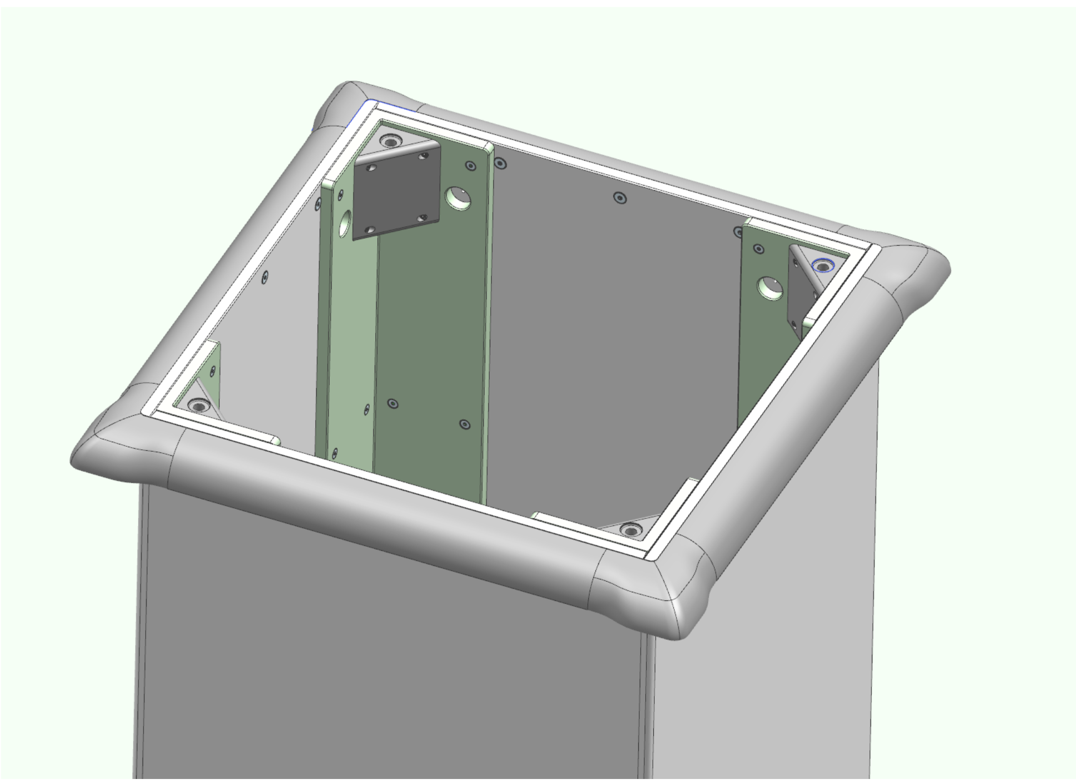


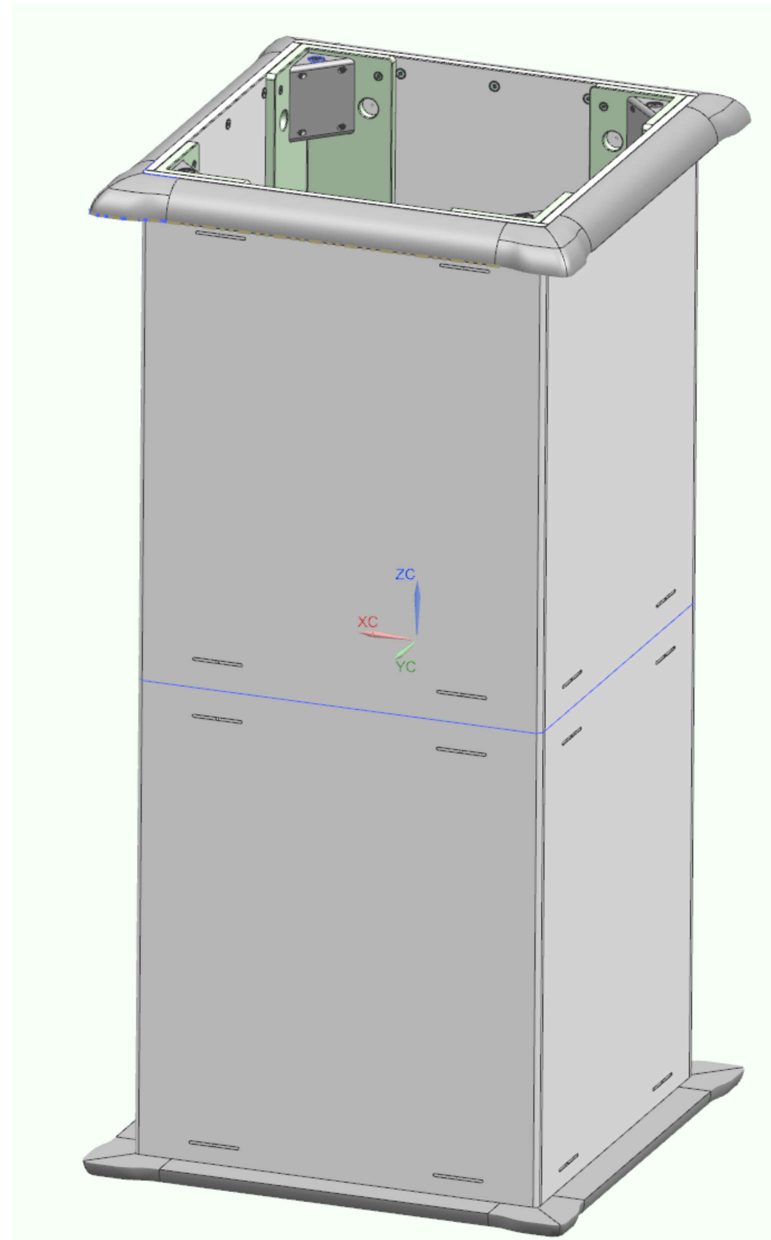

Various layers to be wrapped around the mold one by one

- the following layers should be continuos
  - foils w/ strips → minimizing strip junctions
  - kapton foils → better insulation but ok w/ joints
  - structural peels (carbon-fiber or kevlar) → mechanical properties
- discontinuos layers
  - panels (HC)
  - corners (PEEK) + bars at edges (PEEK)

# ND280 Upgrade
## TPC Prototype

Lo stampo per processare il composito

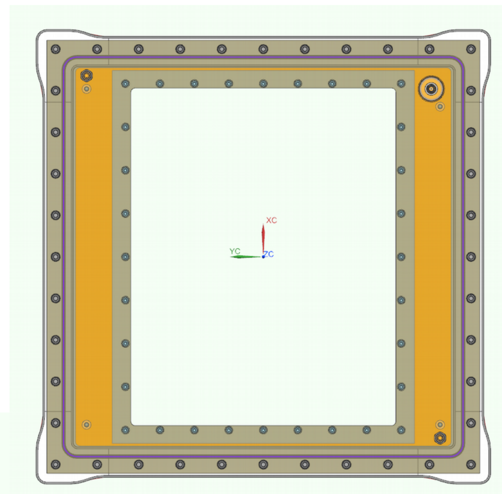


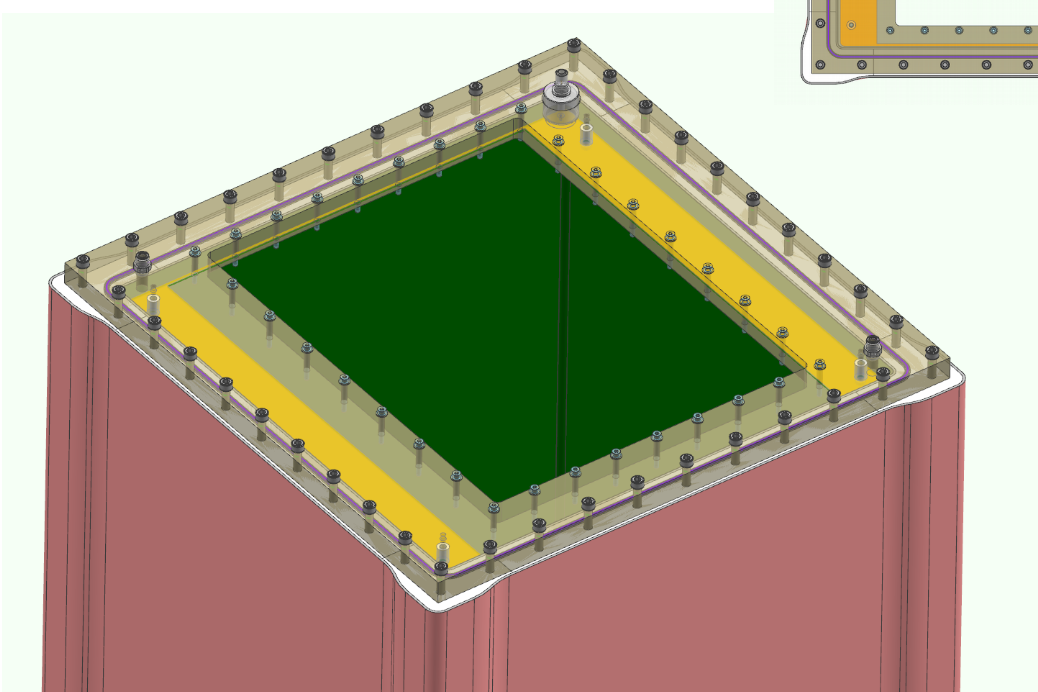


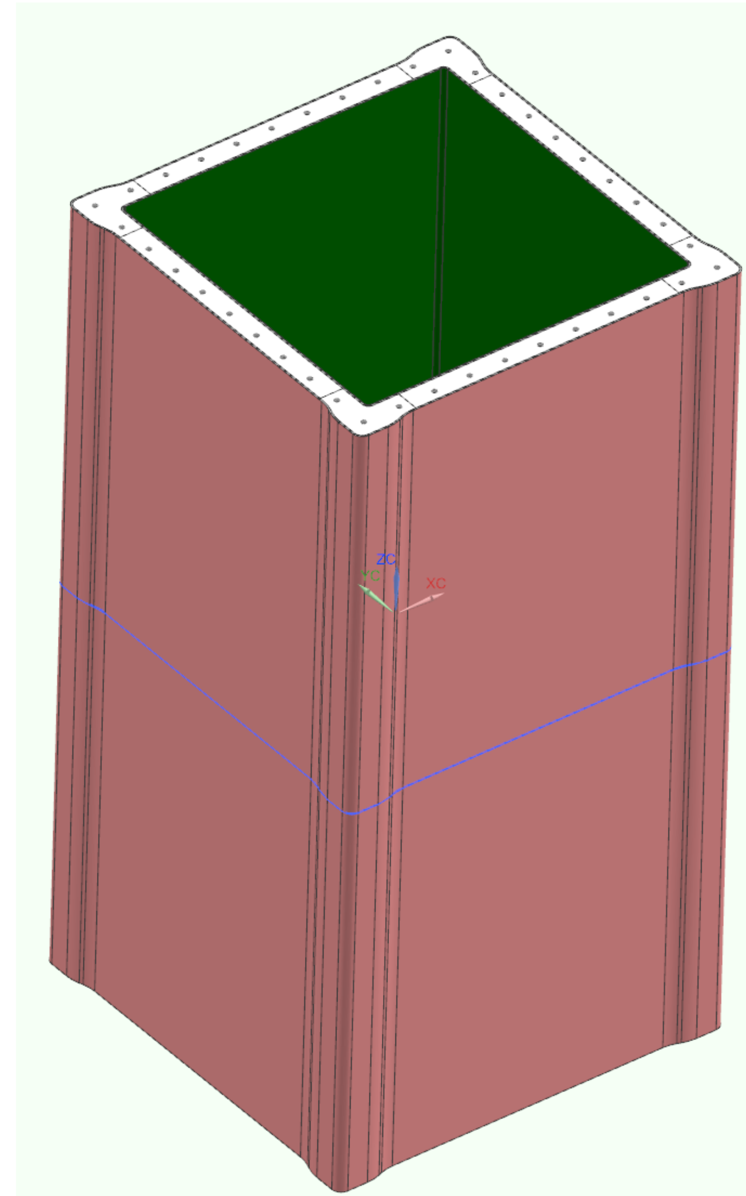
# ND280 Upgrade

# TPC Prototype

Field cage e Anode plate







→ disegno pronto per la produzione dello stampo @ INFN Bari
→ produzione del composito @ NEXUS (Barcellona)

# Esperimento SuperK

Dal 2017 l'INFN partecipa all'esperimento Super-Kamiokande
→ nuovi canali di fisica senza acceleratori (astrofisica, p decay, …)
→ nuove tecniche sperimentali WC → neutron tagging con Gd

La collab. SuperK ha deciso di svuotare e riempire il tank in 2018
- riparare perdite vessel e sostituire fototubi non funzionanti
- preparare la nuova fase di presa dati con Gadolinio
- campagna di misura campo magnetico e direzione dinodi
- installazione nuovi sistemi di calibrazione

→ prima meta` 2018: presa dati SK e T2K
→ da giugno a dicembre → operazione di "refurbishing"

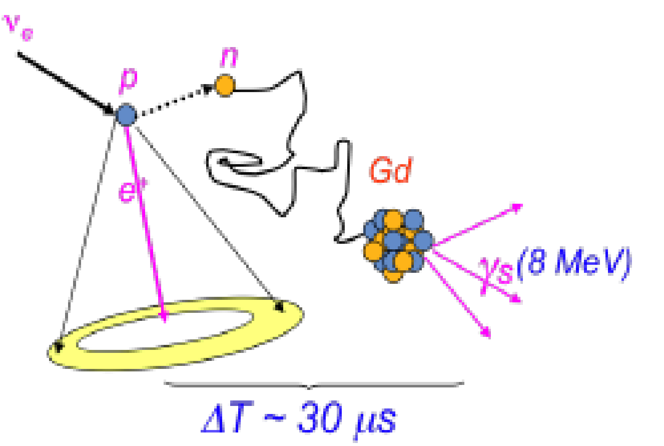
# Prospettive → SuperKGd

Adding 0.2% (mass) of Gd2(SO)3 to SuperK water will allow to detect with high efficiency (> 80%) neutrons produced in interactions by exploiting neutron capture resulting in gamma ray cascade (~8MeV in total)

→ anti-neutrino tagging at inverse $\beta$ reaction

→ $\nu$ / anti-$\nu$ discrimination

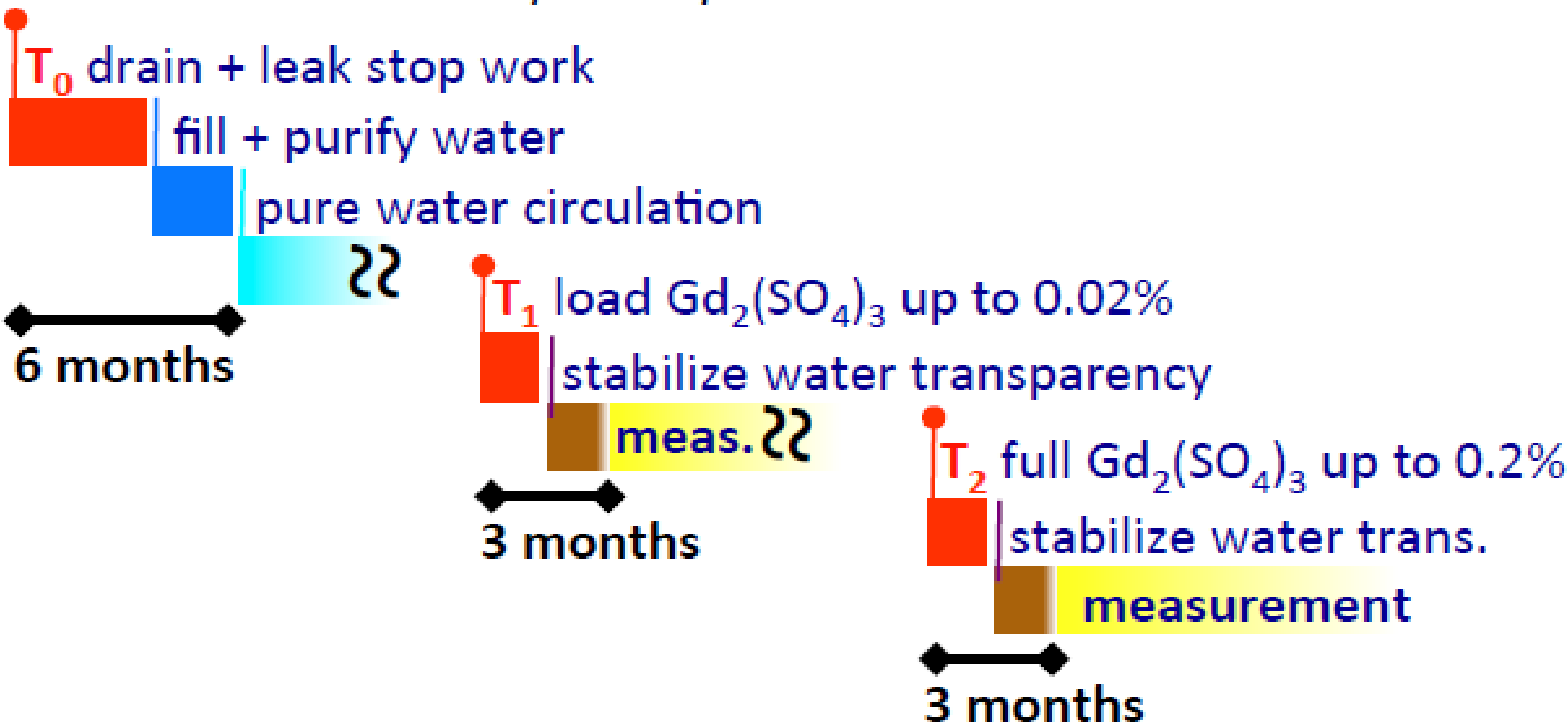
→ neutron veto




- discovering DSNB (much reduced bkg)
- improved pointing accuracy for SN ($\nu$e)
- SN early warning
- sensitive to reactors anti-$\nu$e
- improvements of CPV with Oscillation
- n-veto → improvements in $\nu$–Atm. and p-decay

# Prospettive → SuperKGd

**SuperK-Gd time line** → *3-phase procedure:*




decision about when to trigger it ($T_0$) taken jointly by T2K and SK:

→ proposed to start refurbishment **by middle 2018**

→ final decision will be made at J-PARC PAC meeting (July 24-26)

Further key items:

- refurbishment / leak stop
- the new water system

# Contributi SuperK-Padova

- Partecipazione Low Energy Physics group
  - Responsibility WIT trigger system (A.Ajmi)
  - Solar neutrino analysis (A.Ajmi)
  - anti-neutrino tagging w/ neutron capture (F.Iacob)

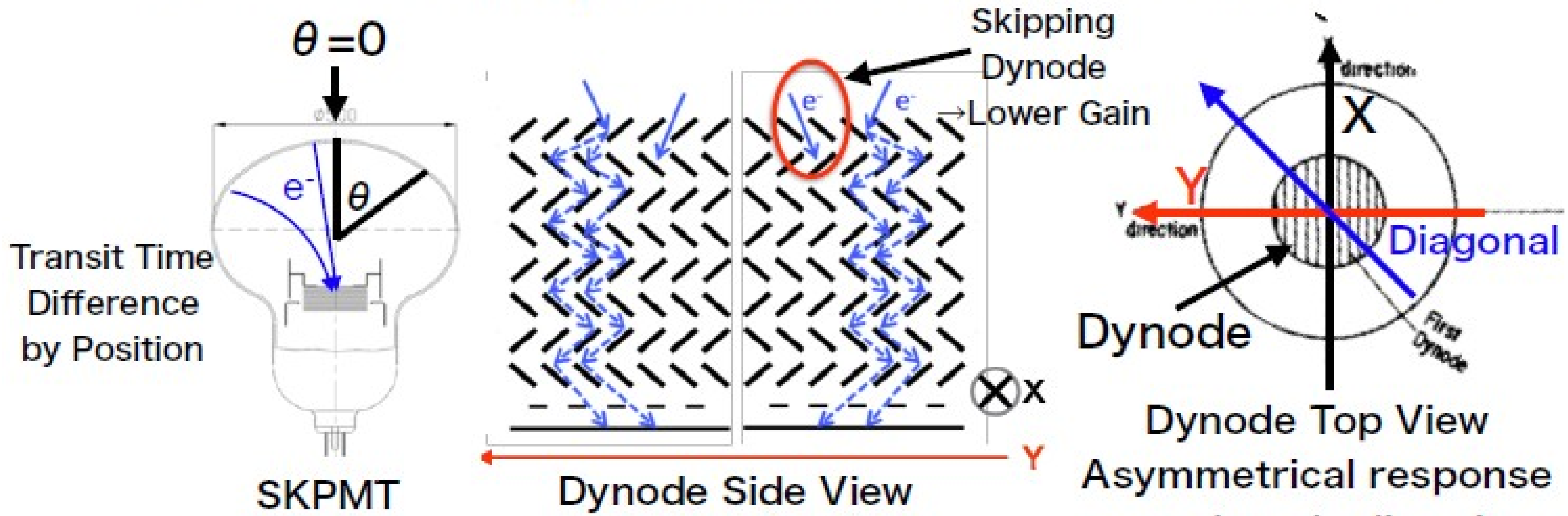
- SK-Calibration
  - misura campo magnetico residuo e direzione dynodi PMT (Inner) (F.Iacob, G.Collazuol,)
  - studies of gamma cascade from Gd(n,$\gamma$) capture (A.Ajmi, G.Collazuol)
  - studies for a new SK-LINAC beam monitor (progetto INFN Rm/Ba) (tesi Laurea Magistrale F.Iacob)

- data taking / shifts
  - Tank Open Work (2018) - regular shifts (2018 e 2019)

# B field measurement & dynode orientation

3

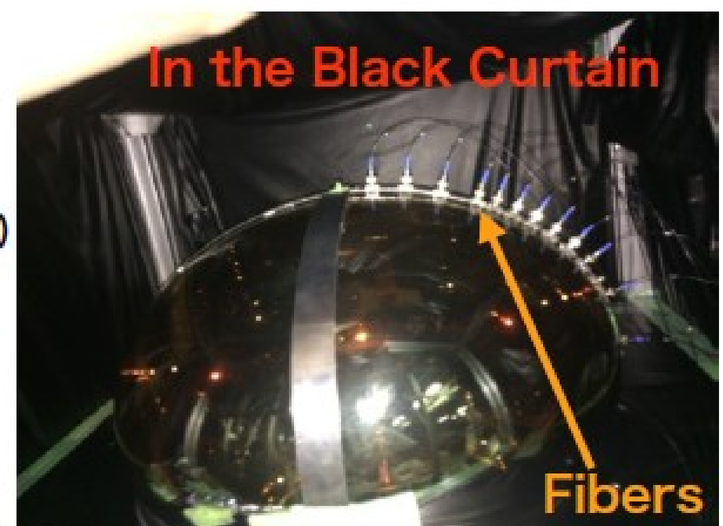
## Non-uniformity Measurement @Kamioka




1st: GJ4211 (Prod. 1992)

2nd: AB9289 (Prod. 1997)

- Magnetic Field: Controlled by coils for (X,Y,Z).
  - Applied (0,0,0), (50,0,0), (0,50,0), (0,0,50), (50,50,0), (0,50,50), (50,0,50) in mG (2nd PMT)
- Scan Direction:X,Y,D(Diagonal) Direction
- Scan Position:PMT Zenith Angle $\theta$=0~40 (10° step), 40~80 (5° step) and 90°
- Fiber by fiber difference about light intensity (~10%) is measured in advance.

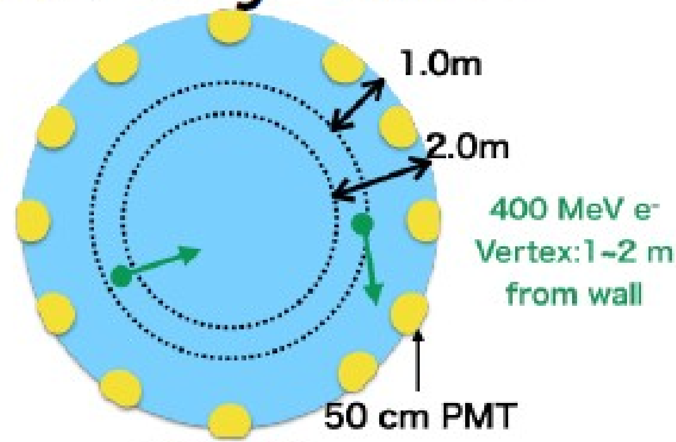


# B field measurement & dynode orientation

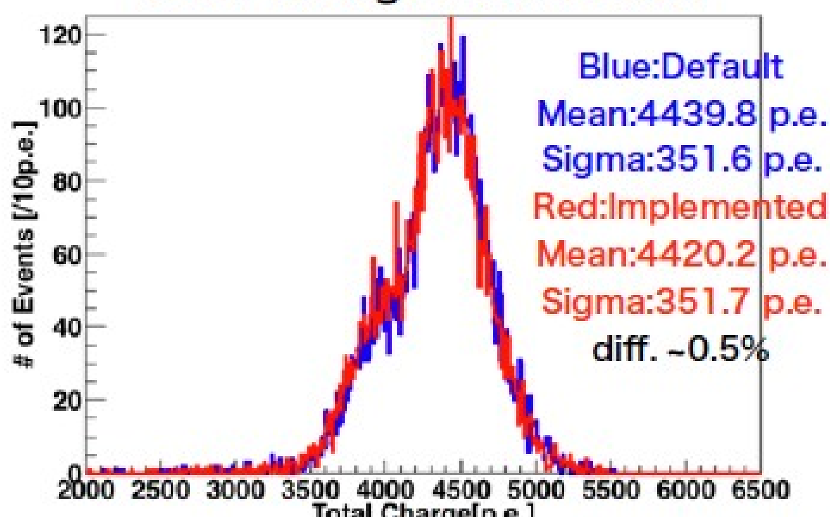
# Impact Estimation by MC

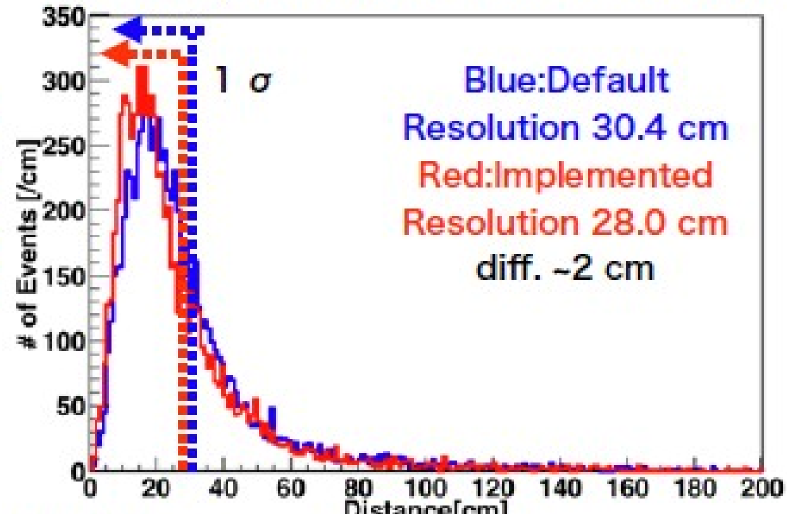


- Default MC assumes PMT uniform responses.
- Implemented only **non-uni.** based on measurement data. (Corrected TQ bias made by this implementation. Detail in back up.)
- Generated same particle gun events (near the wall) with default and implemented MC and compared detector responses.




SK Top View



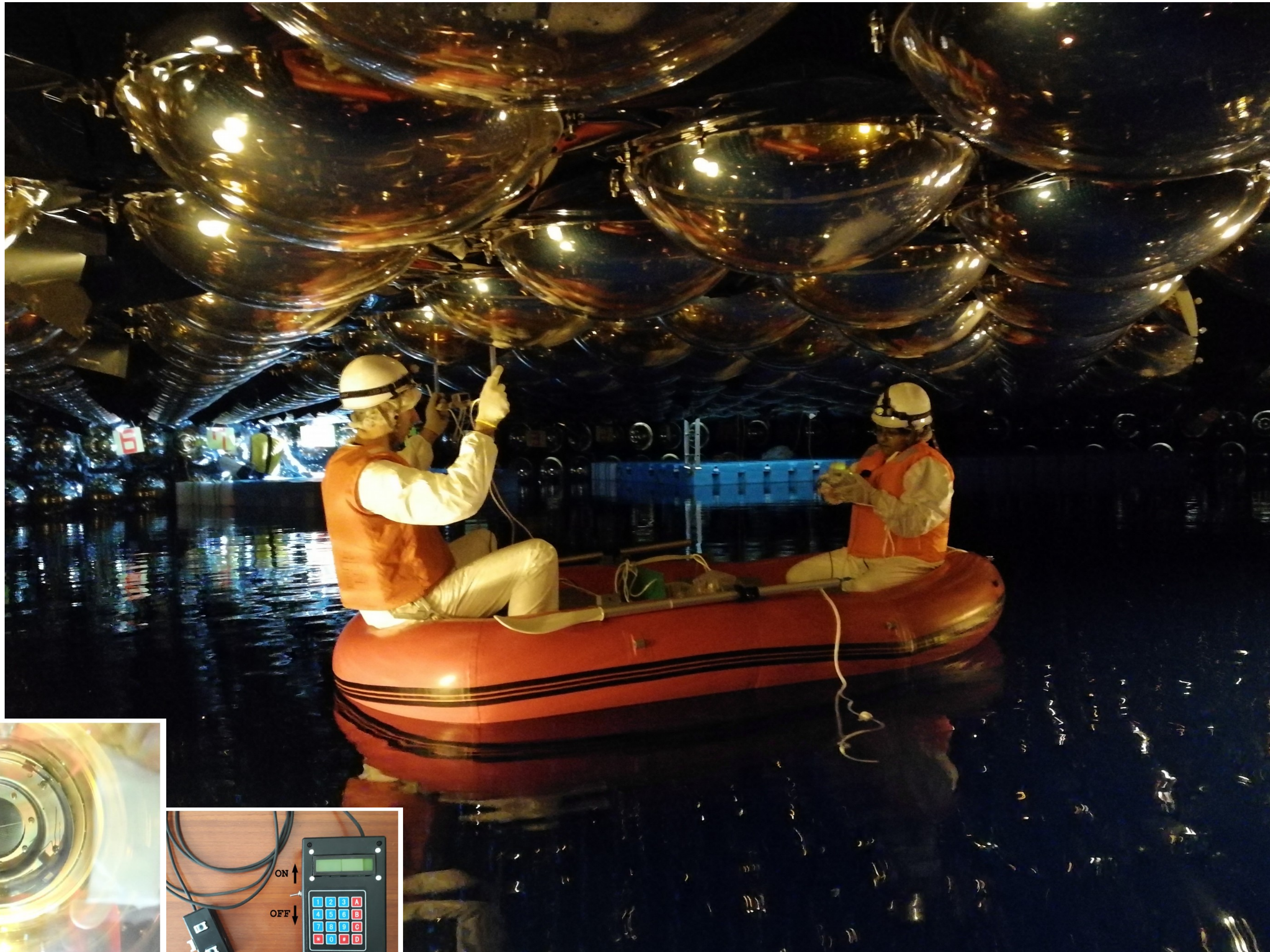




Charge shift : < ~1% shift (cf:ATMPD E-scale error~2%)

Vertex: ~2 cm shift (cf:Vertex resolution ~30 cm)

→ Aiming at expanding fiducial volume
via reconstruction with most detailed information

# B field measurement & dynode orientation



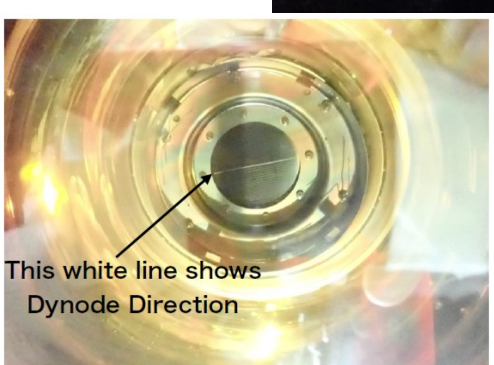
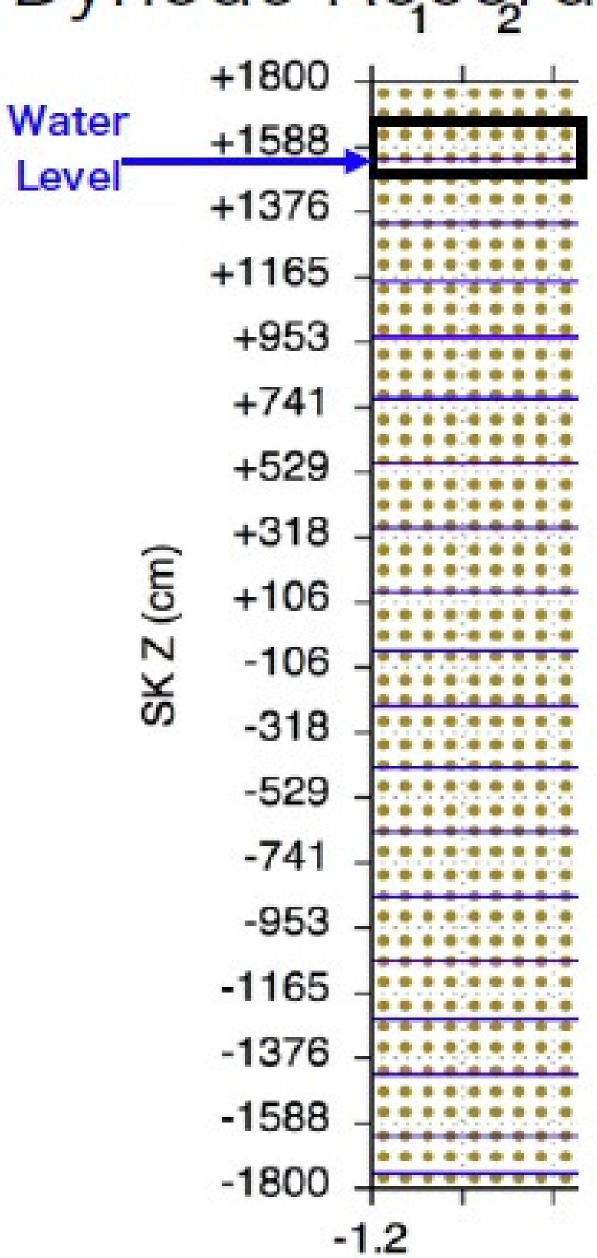
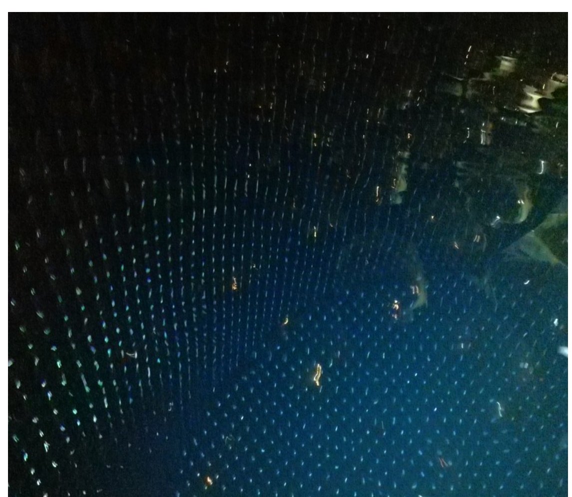




FIGURE 1: *Overview: probe box, user interface box, ON/OFF switch positions.*

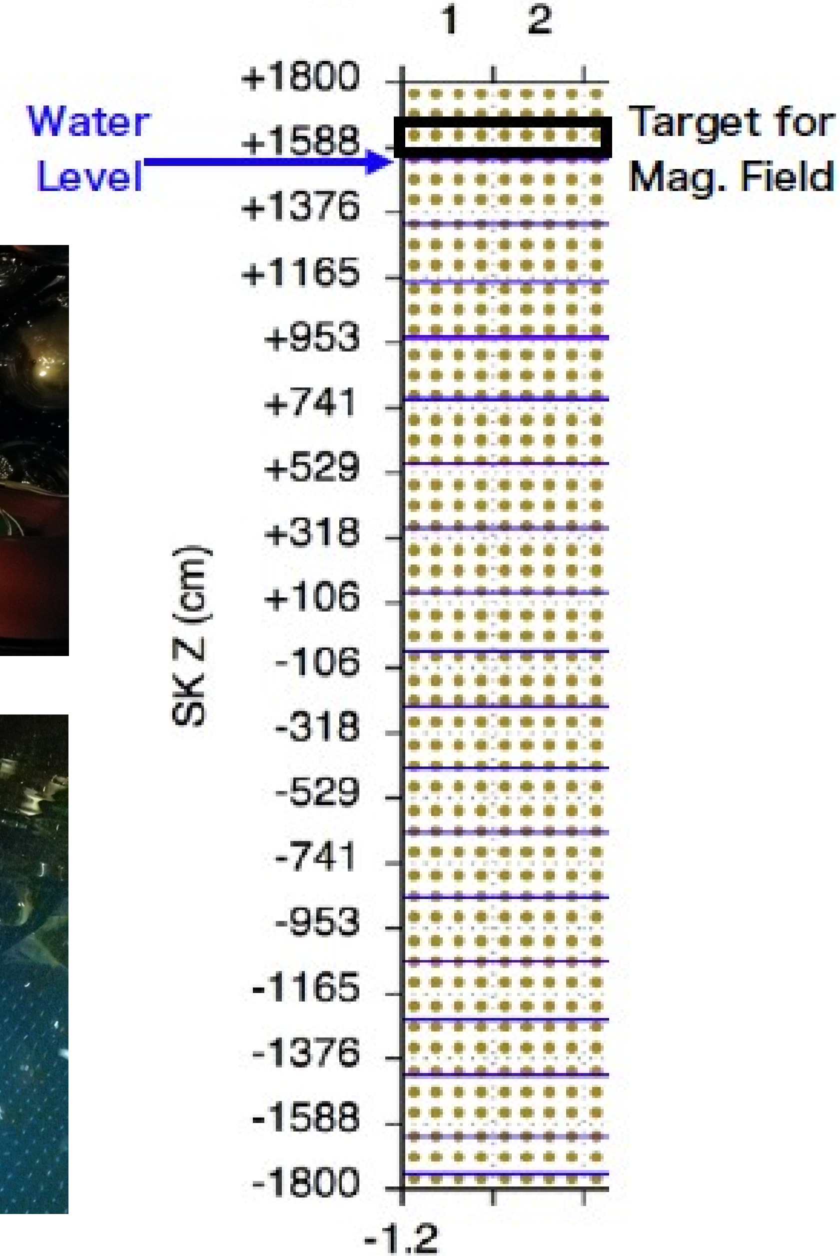
# B field measurement & dynode orientation

## Dynode Recording



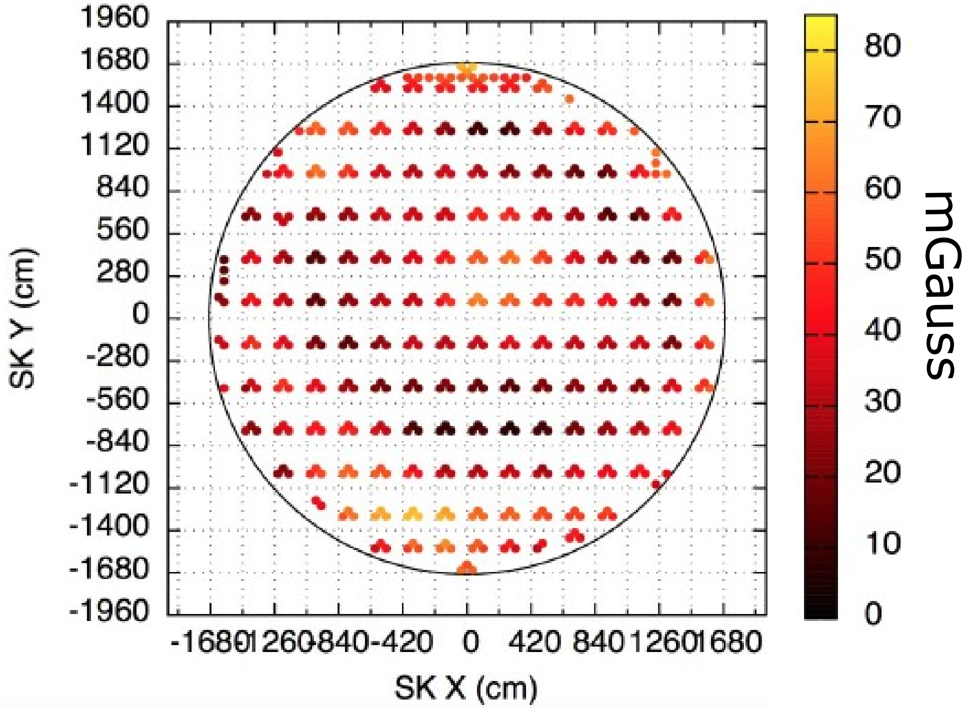



## Mag. Field

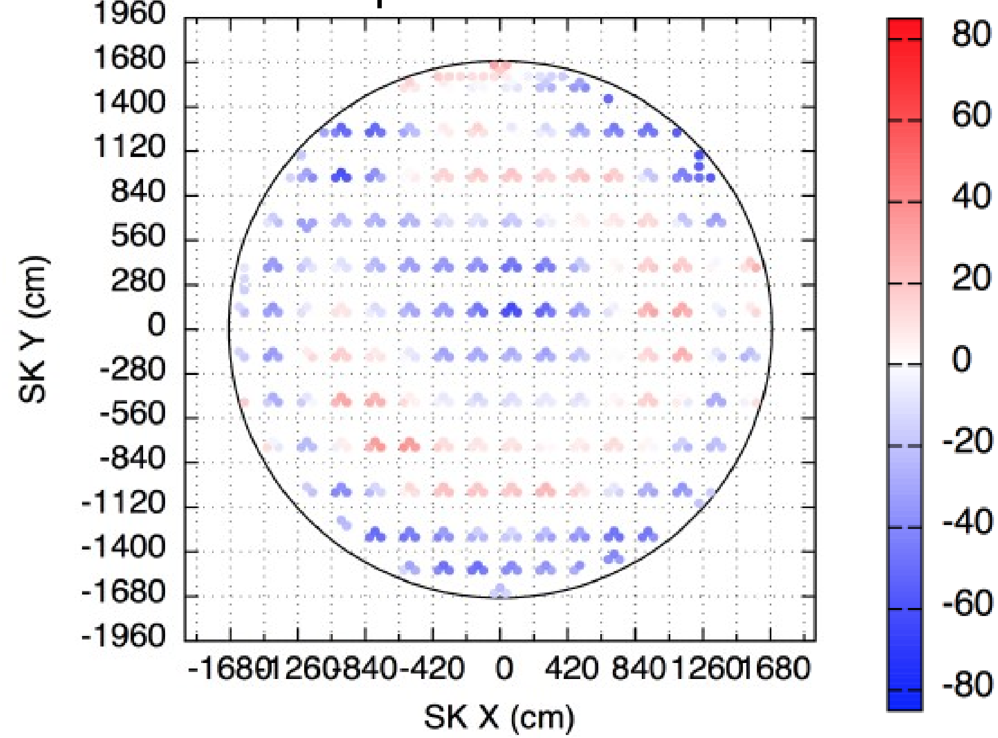


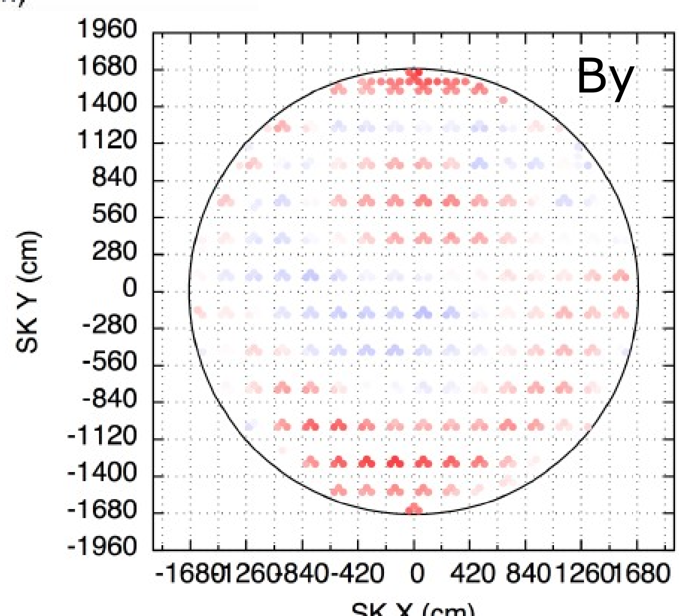
# B field measurement - TOP PMTs

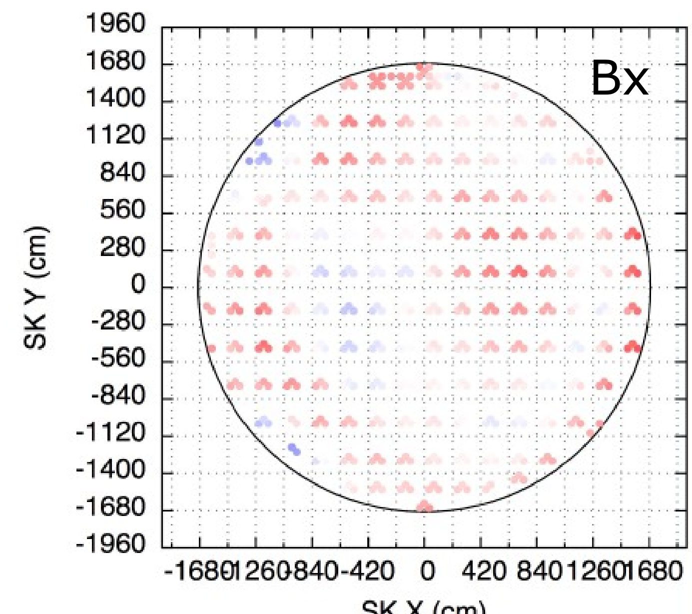
B field module




Bz component



# ANNRI experiment @ JPARC

## Analysis of Gd(n,$\gamma$) reaction with $^{155}$Gd, $^{157}$Gd and $^{Nat}$Gd targets at JPARC-ANNRI & Development of Gd(n,$\gamma$) decay model for Gd-doped n/$\nu$-detectors


**Ali Ajmi**[1,2]

*on behalf of* **ANNRI-Gd** *Collaboration*

(**T.Tanaka**[1], M.Sakuda[1], P.Das[1], R.Dir[1,4], W.Focillon[7], M.Gonin[7], K.Hagiwara[1], Y.Koshio[1], S.Lorenz[1,5], T.Mori[1], T.Kayano[1], I.Ou[1], M.Reen[1], T.Sudo[1], Y.Yamada[1], G.Collazuol[2], H.Harada[3], N.Iwamoto[3], A.Kimura[3], S.Nakamura[3], T.Yano[6], M.Wurm[5])

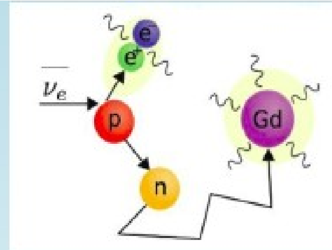
[1] *Okayama University,* [2] *INFN-Padova,* [3] *JAEA,* [4] *SRM U.,* [5] *Mainz U.,* [6] *Kobe U.,* [7] *Ecole Polytechnique*

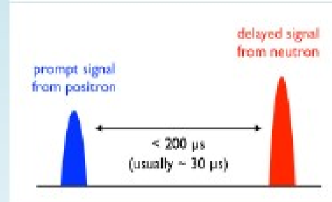

ICHEP2018-Seoul, July 05, 2018

ANNRI-Gd Collaboration

# ANNRI experiment @ JPARC

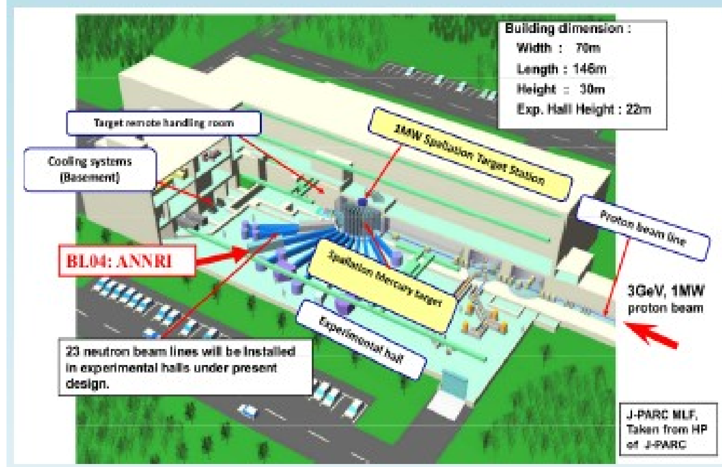
- Detection of $\bar{\nu}_e$ via IBD: $\bar{\nu}_e + p \rightarrow e^+ n$ vital to $\nu$-detectors, with reduced background from $\nu_\mu$QE, $\nu_e$ES etc.
- Pair of prompt and delayed coincidence signature offers tremendous bkg. suppression.
- Thermal neutrons captured in the medium: $\gamma$-emission.
  by proton $\rightarrow$ 2.2MeV $\gamma$ in $\sim$200$\mu$s;
  by Gd $\rightarrow$ $\sim$8MeV $\gamma$ in $\sim$30$\mu$s.




- Cross section of thermal n-capture on natural Gd $\sim$49000b, while $\sim$0.3b on water(p). Presence of Gd enhances $\bar{\nu}_e$ signal selection drastically.
- For data-analysis, $\gamma$ rays from n-capture need to be studied, hence simulation of these $\gamma$-rays in the detector (specially with partial energy deposition) is essential.

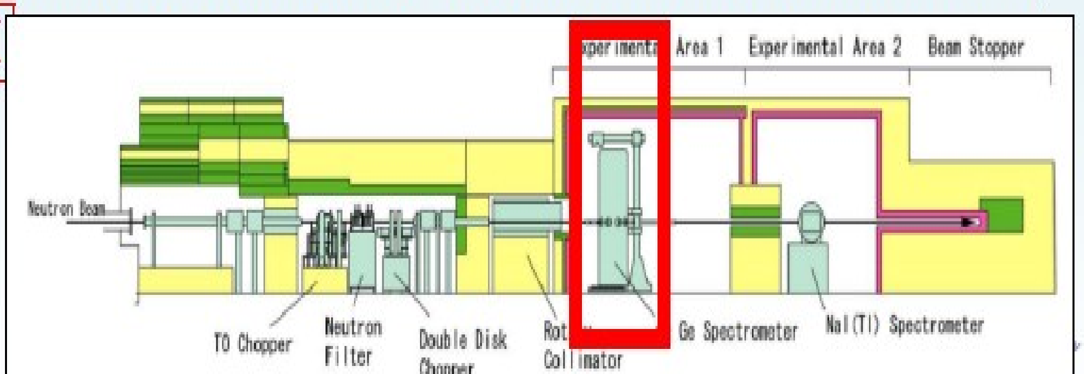
## Experimental Facility:




- 3 GeV proton beam of 300kW at . JSNS, JPARC-MLF complex.
- Incident on mercury target at 25 Hz (double-bunch mode: 100ns wide, 599 ns apart)$\rightarrow$ spallation neutron beam source
- Be, Fe reflectors confine neutrons from escaping otherwise.
- Moderated by supercritical hydrogen, deliver n-beam of about $1.5 \times 10^7$/cm$^2$/s (1meV-10eV).

- BL04: Accurate Neutron-Nucleus Reaction Measurement Instrument,

ANNRI



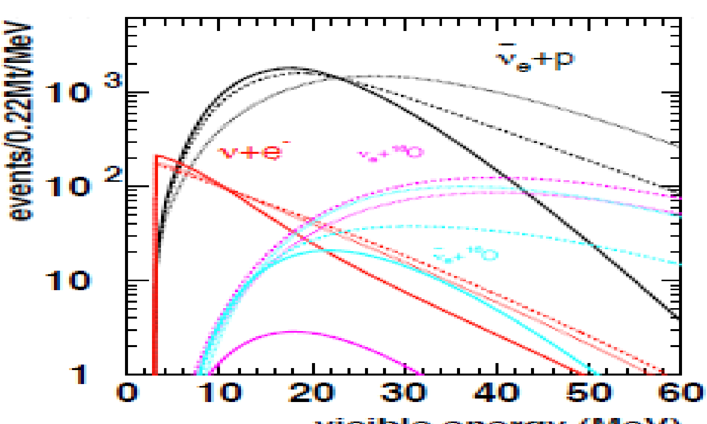
# SK LowE activities

New Responsibility of WIT DAQ system at SK:

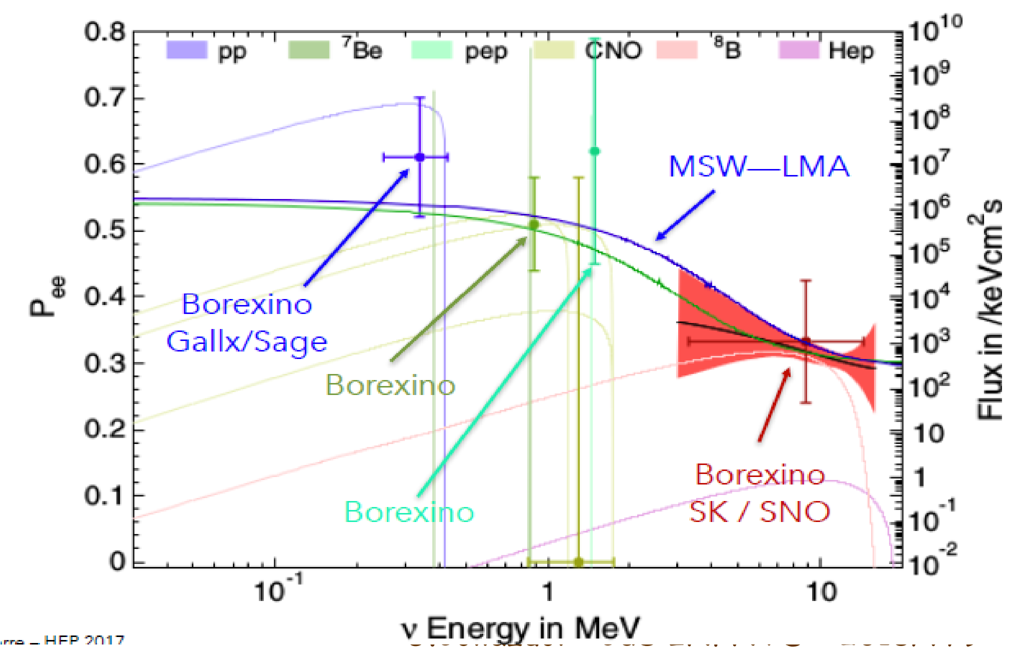
WIT: Wideband Intelligent Trigger System records the SK data with lower energy threshold (→ 2.2MeV) and higher efficiency

The low energy range of SK data is subjected to large statistics → very high trigger rate
($\gamma$ from rocks, spallations, NC, solar $\nu$, DSNB...) → multiplicity trigger not enough
WIT is the shadow-DAQ of SK → online software trigger system
(data with a lower PMT cut → fast vertex fitting algorithm)

WIT is crucial to many physics channels: for instance
→ more efficient detection of SN $\nu$
→ measure more low E 8B $\nu$ flux
→ studies of matter effects in day/night asymmetry vs $\Delta m_{21}^2$




Test of the Mikheyev-Smirnov-Wolfenstein Large Mixing Angle model



# Anagrafica e Richieste 2018

**Anagrafica 2018**

G.Collazuol 60% (+10% ENUBET)
A.Ajmi (PD) 100%
F.Iacob (PhD) 100%
M.Pari (PhD) 30% (+70% ENUBET)
M.Laveder 60%
A.Longhin 30% (+70% ENUBET)
M.Mezzetto 80% (+10% ENUBET)

Totale 4.6 FTE (+ 1.5 ENUBET)

INFN-LNL:
M.Cicerchia (PhD → AssegnistaJ) 60%
F.Gramegna 10%
T.Marchi 10%

**Richieste 2018**

Missioni interne 4k€
Missioni estero 80k€
- shifts e meetings T2K & SK
- test TPC at CERN

Costruzione apparati 60k€ (?)
- HA-TPC

Consumabile 10k€
- RMM ed elettonica TPC
- setup calibrazione TPC

**Richieste Servizi Sezione 2018**

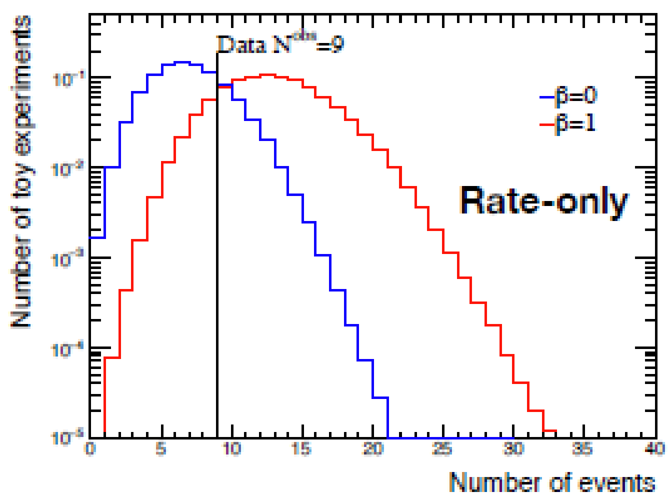
- U.Tecnico: 3 mu per disegno Field Cage TPC finali
- O.Meccanica: 1 mu per test deformazione piani stampo TPC finale
- S.Elettronica: 1 mu per elettronica TPC

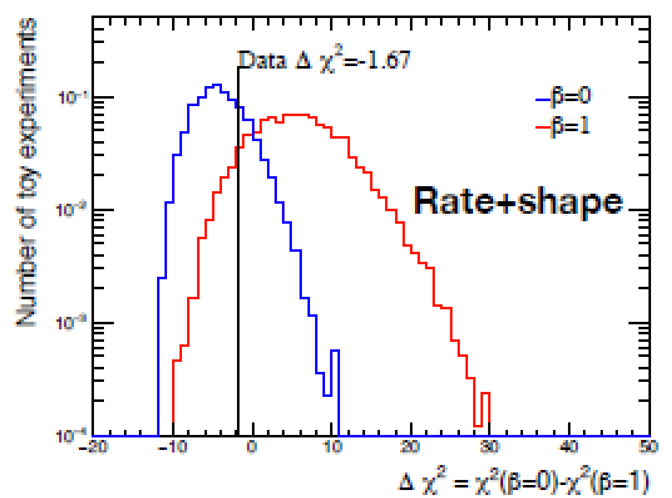
# Additional Material

# anti-$\nu_e$ Appearance Search

- $\bar{\nu}_e$ appearance is not discovered yet
- Hypothesis test with $P(\bar{\nu}_\mu \to \bar{\nu}_e) = \beta \cdot P_{PMNS}(\bar{\nu}_\mu \to \bar{\nu}_e)$
  - β=0 : no $\nu_e$ appearance
  - β=1 : consistent probability with PMNS matrix
- Two analysis methods : rate-only and rate + shape
  - Both analyses indicate no conclusive results

| Rate-only analysis | | | Rate+shape analysis | | |
|---|---|---|---|---|---|
| Nobs | $\beta$=0 p-value | $\beta$=1 p-value | $\Delta\chi^2_{obs}$ | $\beta$=0 p-value | $\beta$=1 p-value |
| 9 | 0.219 | 0.213 | -1.67 | 0.233 | 0.087 |



T2K for

# Bayesian Analysis

- Oscillation parameters were extracted using Bayesian approach
- Posterior probabilities for mass hierarchy and $\theta_{23}$ octant
  - Data prefer normal hierarchy and upper octant ($\sin^2\theta_{23}>0.5$)

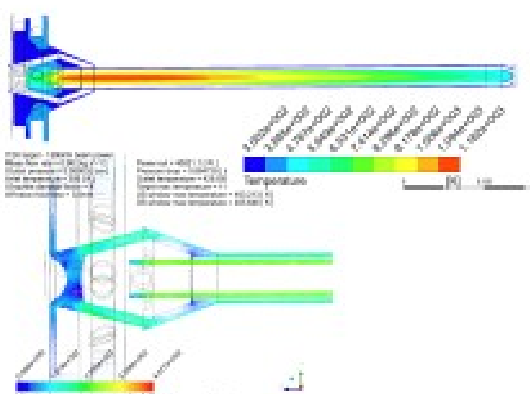
| | $\sin^2\theta_{23}<0.5$ | $\sin^2\theta_{23}>0.5$ | Sum |
|---|---|---|---|
| NH ($\Delta m^2_{32}>0$) | 0.204 | 0.684 | 0.888 |
| IH ($\Delta m^2_{32}<0$) | 0.023 | 0.089 | 0.112 |
| Sum | 0.227 | 0.773 | 1 |

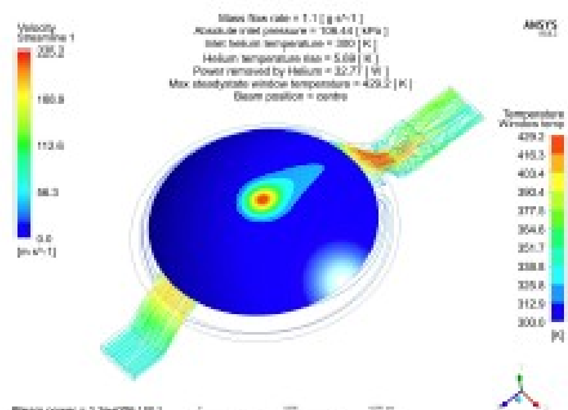
# Prospettive → T2K-II

## Beam-line upgrade

- **Beamline upgrade to accommodate 1.3 MW beam**
  - DAQ and horn power supply upgrade for higher repetition rate (~1Hz)
  - Target/beam window upgrade for high intensity beam
  - Cooling improvement for secondary beamline
  - Reinforce radioactive water disposal
  - New radiation-robust beam monitors
- **Beamline upgrade TDR submitted to KEK**
  - Review meeting in June

WSEM Mounted on Mover 13 /






# Pubblicazioni ultimo anno

- "Measurement of $\nu$ and anti-$\nu$ oscillations by the T2K experiment including a new additional sample of anti-$\nu_e$ interactions at the far detector"
arXiv:1707.01048 [hep-ex]. Submitted to **PRD**

- "Measurement of anti-$\nu_\mu$ and $\nu_\mu$ charged current inclusive cross sections and their ratio with the T2K off-axis near detector"
arXiv:1706.04257 [hep-ex]]. Submitted to **PRD**

- "Measurement of the single $\pi^0$ production rate in neutral current neutrino interactions on water"
[arXiv:1704.07467 [hep-ex]]. Accepted by **PRL**

- "Updated T2K measurements of $\nu_\mu$ and anti-$\nu_\mu$ disappearance using 1.5 $10^{21}$ protons on target.
[arXiv:1704.06409 [hep-ex]]. Accepted by **PRL**

- "Search for Lorentz and CPT violation using sidereal time dependence of neutrino flavor transitions over a short baseline.
**Phys Rev D**95 (2017) 11 111101

- "Combined Analysis of Neutrino and Antineutrino Oscillations at T2K"
**Phys Rev Lett** 118 (2017) 15 151801

- "Physics Potentials with the Second Hyper-Kamiokande Detector in Korea"
arXiv:1611.06118 [hep-ex]. Submitted To **PTEP**

- "Proposal for an Extended Run of T2K to 20 $10^{21}$ pot"
arXiv:1609.04111 [hep-ex]]. Submitted to **PTEP**

- "T2K and Beyond"
**Adv High Energy Phys** 2016 (2016) 5496103

- "Sensitivity of the T2K accelerator-based neutrino experiment with an Extended run to to 20 $10^{21}$ pot"
arXiv:1607.08004 [hep-ex]

- "TITUS: the Tokai Intermediate Tank for the un-oscillated Spectrum"
arXiv:1606.08114 [physics.ins-det]

- "First measurement of the muon neutrino charged current single $\pi$ production cross section on water with the T2K near detector"
**Phys Rev D**95 (2017) 1 012010

- "Measurement of Coherent p+ Production in Low Energy Neutrino-Carbon Scattering"
**Phys Rev Lett** 117 (2016) 19 192501

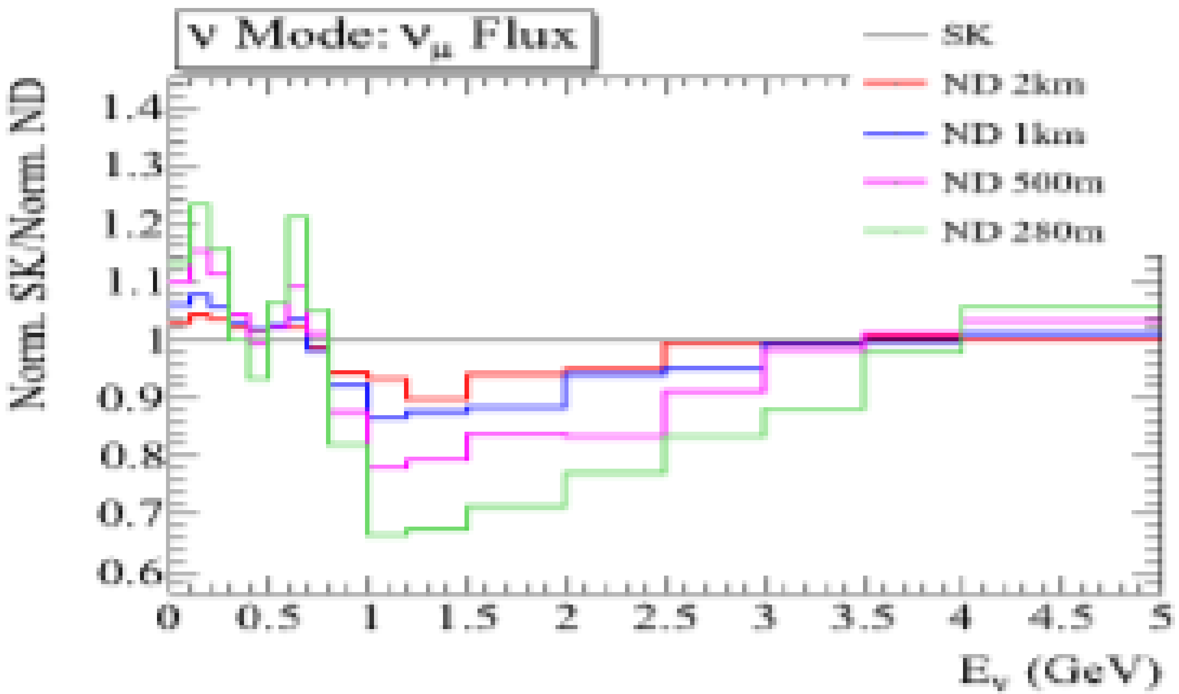
- "Measurement of double-differential $\nu\mu$ charged-current interactions on $CH_8$ without pions in the final state using the T2K off-axis beam"
**Phys Rev D**93 (2016) 11 112012

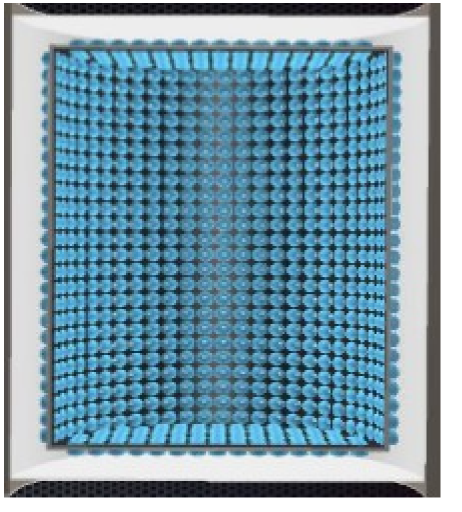
# Prospettive → T2K-II
# Intermediate Detector (IWCD)

Water Cherenkov detector at ~1-2 km being investigated for T2K-II/HK

- Same detector principle as Far detector
- Far/Near errors cancellation
- Off-axis angle spanning orientation
- Gd loading
- Construction 2020-23

- Active surface:
  40% surface coverage
- New sensor:
  Multi-PMT
  (INFN-TRIUMF collab.)



→ G.C. co-convener of the Calibration WG

# Prospettive → T2K-II
# Near Detector upgrade - WPs

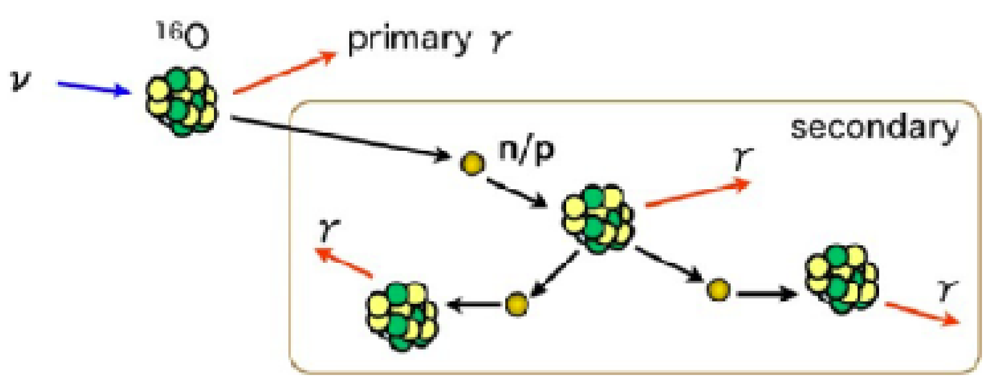
- WP1 Mechanical design and integration (Marcela, Davide)
- WP2 TPC field cage and gas vessel (Emilio, Gianmaria Collazuol)
- WP3 TPC Readout technology (A. Delbart, CERN)
- WP4 TPC electronics and DAQ (D. Calvet, Andrzej Rychter)
- WP5 Gas system and calibration (Blair, CERN)
- WP6 Scintillator-based trackers (Japan+LLR)
- WP7 TOF system (Yury)
- WP8 Test beam measurements (Federico, Stefania)
- WP9 High Pressure TPC (Asher, Morgan)
- WP10 Simulation and optimization studies (Davide)
- WP11 Physics studies (Sara, Claudio)
- WP12 DAQ (G. Barr)
- WP13 Software( Y. Uchida)

11

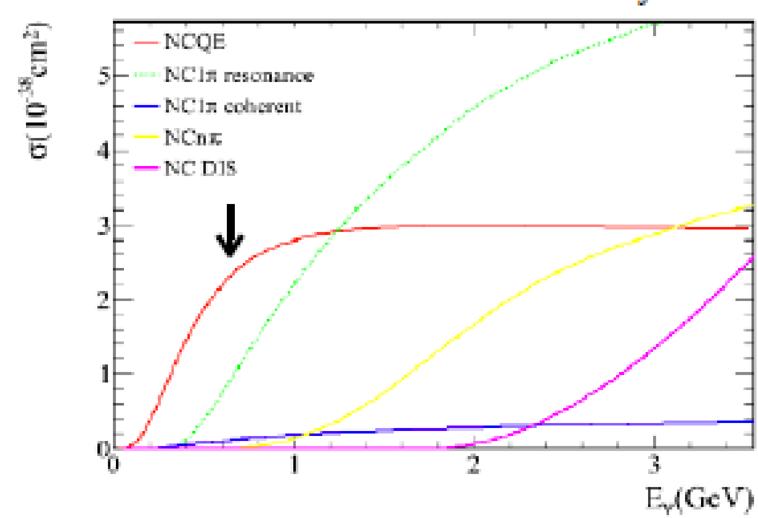
# Prospettive → T2K-II

## Neutral Current Quasielastic Interaction

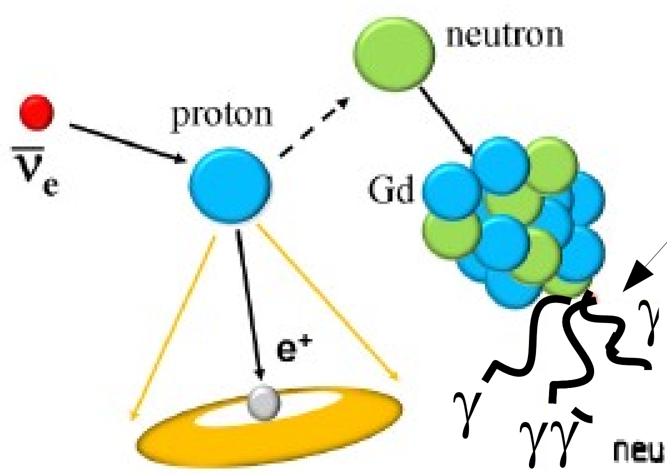
- NCQE cross section is important for several physics searches at (T2K-)SK.
  - **Supernova Relic Neutrino**
  - **Sterile Neutrino**
  - **Dark Matter**
- The signal at SK is "γ-rays" from excited oxygen or nitrogen (or others).
  - At T2K energy region, quasielastic process is dominant.




Calculation by NEUT

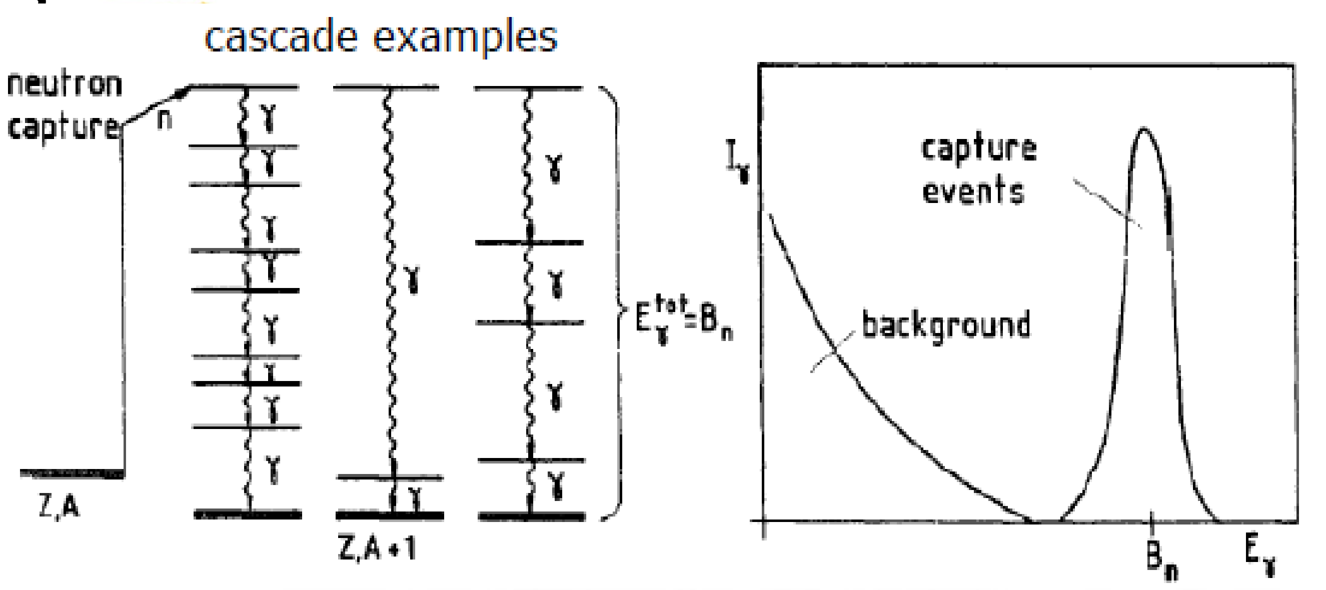


# Anti-neutrino detection efficiency




**Cascade from n capture on Gd**

- TOTAL ENERGY
  - ~ 7.9MeV from $^{157}$Gd (80.5%)
  - ~ 8.5MeV from $^{155}$Gd (19.3%)
- <MULTIPLICITY> ~ 4



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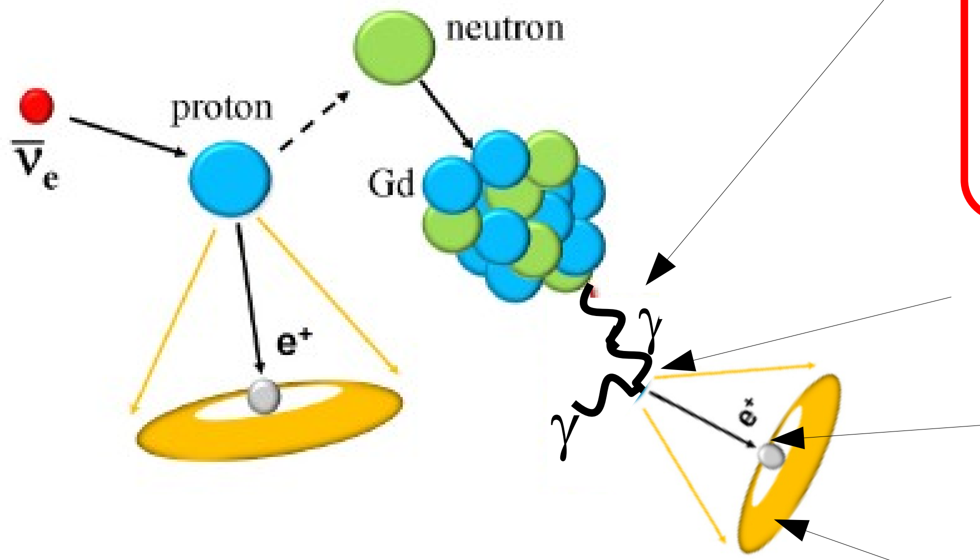


**Cascade from n capture on Gd**

- TOTAL ENERGY
  - ~ 7.9MeV from $^{157}$Gd (80.5%)
  - ~ 8.5MeV from $^{155}$Gd (19.3%)
- <MULTIPLICITY> ~ 4

1) visible Energy $E_{vis}$ ~ 4Mev
2) large fluctutations of $E_{vis}$ rms 2MeV
3) threshold to see each electron ~ 1MeV

- neutron tagging Efficiency $\varepsilon$ ~ 80%
- large uncertainty in $\varepsilon$ determination

**BUT $\varepsilon$ must be determined with high accuracy (sub % level) in order not affect high precision neutrino measurements**

**We aim at**

**1) measuring** $\gamma$ **cascades** from n capture on Gd

**2) tuning** proper **models** for use in SK detector

# Neutron capture on Gd

1) **data**

Very deeply studied process, since early 60-ies...
... but main focus at **cross sections** and **nuclear structure**

- missing reliable spectroscopic information below separation energy
  ie in the region 4-8MeV
  → see eg *Chyzh et al Phys. Rev. C 84 (2011) 01406*
- missing accurate data high $\gamma$ multiplicity at high E resolution
  → no published accurate data with Germanium detector arrays

Note: high multuplicity cascades are very relevant to SK because on average $\gamma$s (ie Compton scattered electrons) are nearer to Cherenkov thresholds → main contribution to inefficiency

2) **models**

Among lots of analytical or Monte Carlo based models of $\gamma$ cascade DICEBOX code is potentially very accurate (based on "Extreme Statistical Model", *F.Becvar, Nucl. Instr. & Meth A417*)
→ contacts with DICEBOX authors (M.Krticka) for collaboration

Note: all models implemented within GEANT4 quite unsatisfying