Ageing of the scintillator detectors of the T2K off-axis and on-axis detectors, ND280 and INGRID

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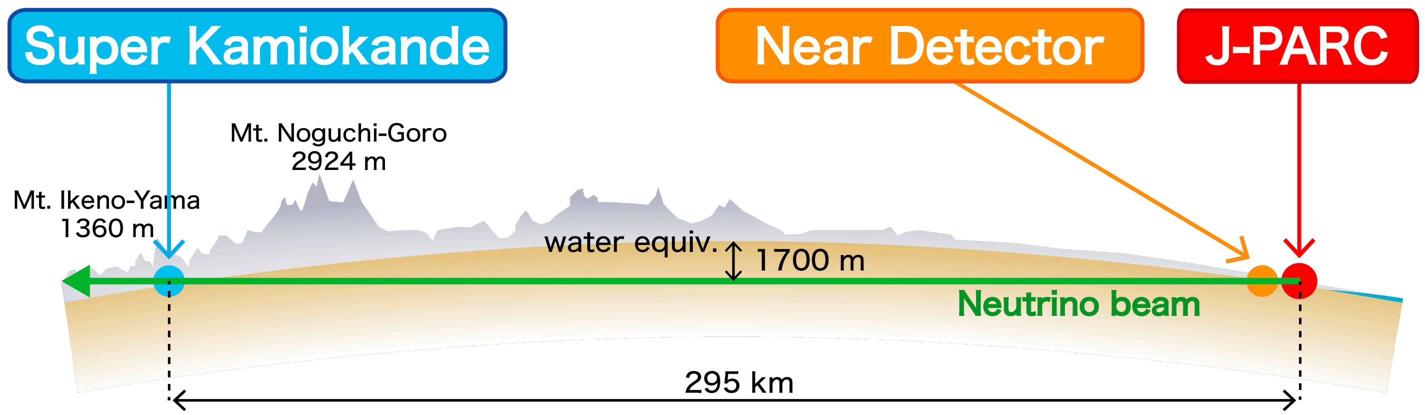
Motivation

- Plastic scintillators coupled with wavelength shifting (WLS) fibres and silicon photomultiplier readouts are widely used in various applications
  - Neutrino physics, LHC experiments, medical use detectors etc.
- Long-term operation study is beneficial for understanding detector performance
- **The T2K neutrino experiment**
  - Collecting data for over 10 years
  - Near detector complex with multiple scintillator bar designs
  - Great source of data for such study!

T2K experiment

Tokai-to-Kamioka long-baseline neutrino experiment

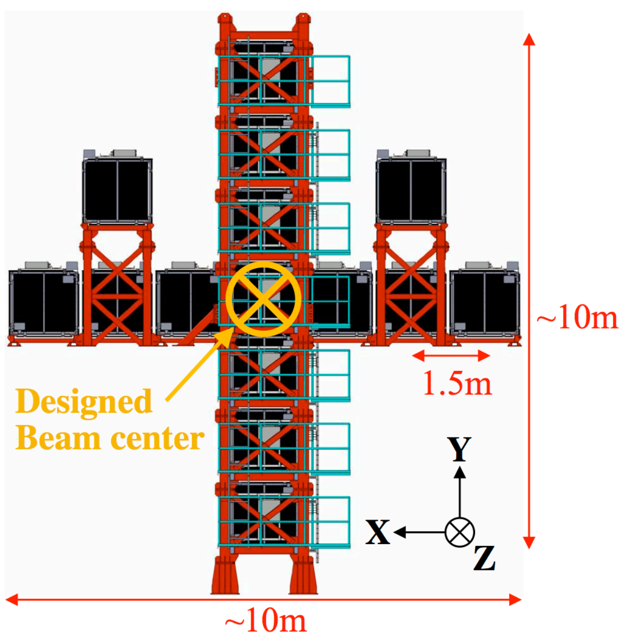
Leading results for $\nu(\bar{\nu})$ oscillations in appearance/ disappearance channels



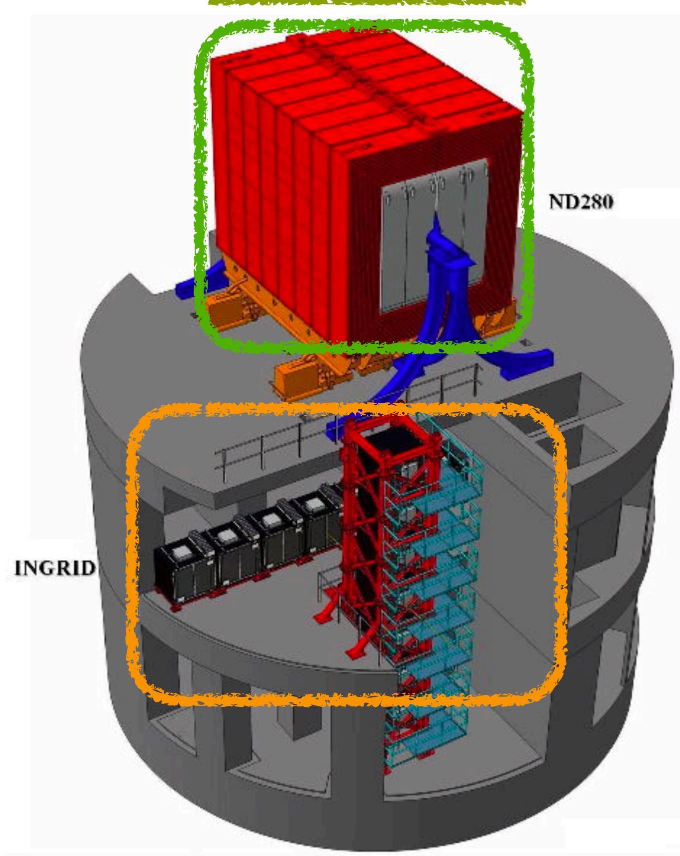
More on T2K analysis results and performance in talks by J.Walsh, S.Kasetti, M.Guigue etc.

Near Detector

INGRID

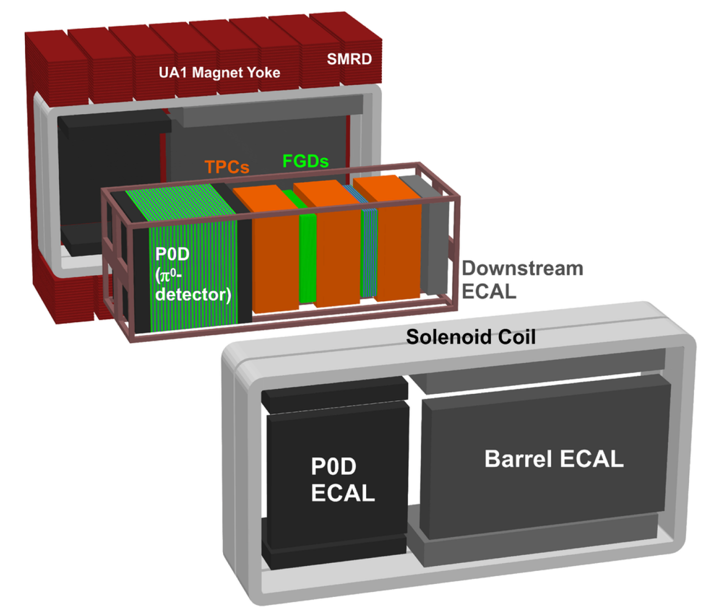


- On-axis detector
- Beam direction and rate stability monitor
- Day-by-day measurements
- ~ 9,500 scintillator bars



“Off-axis” concept: 0.6 GeV peak beam tuned for 1st osc. maximum at SK point

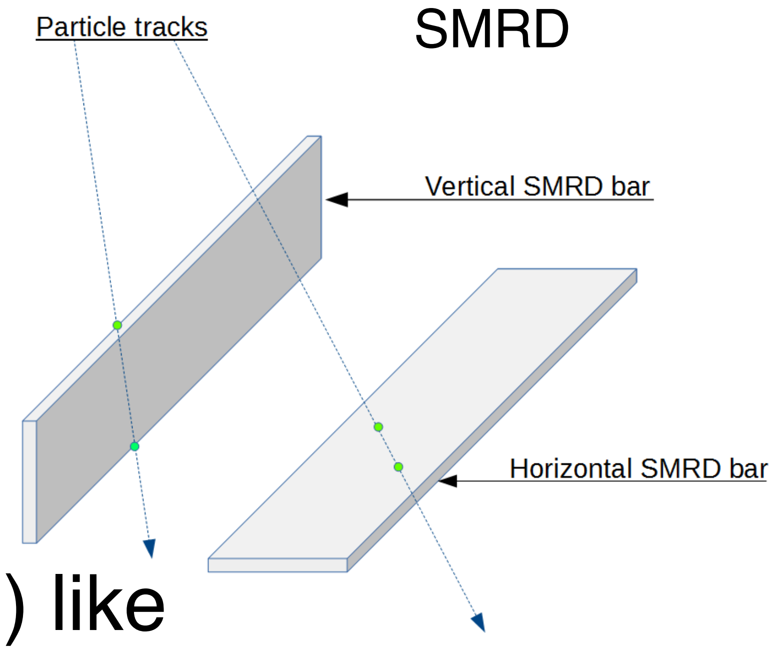
ND280

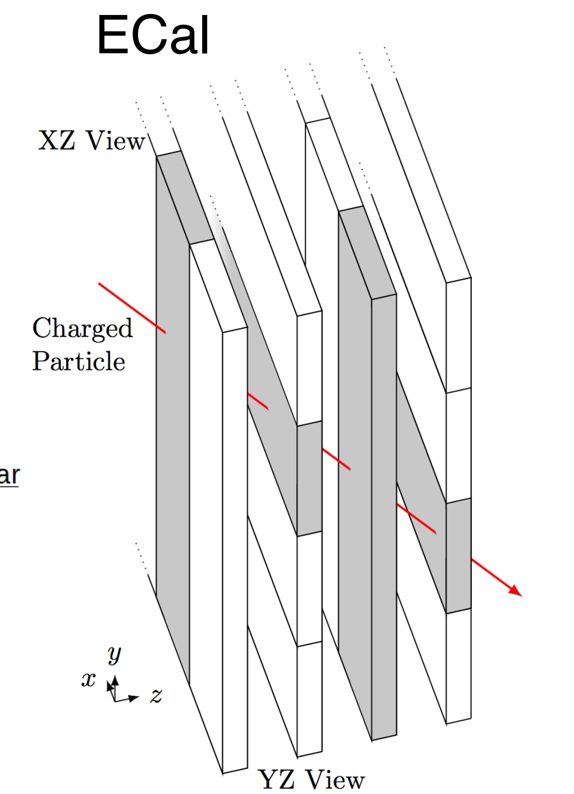


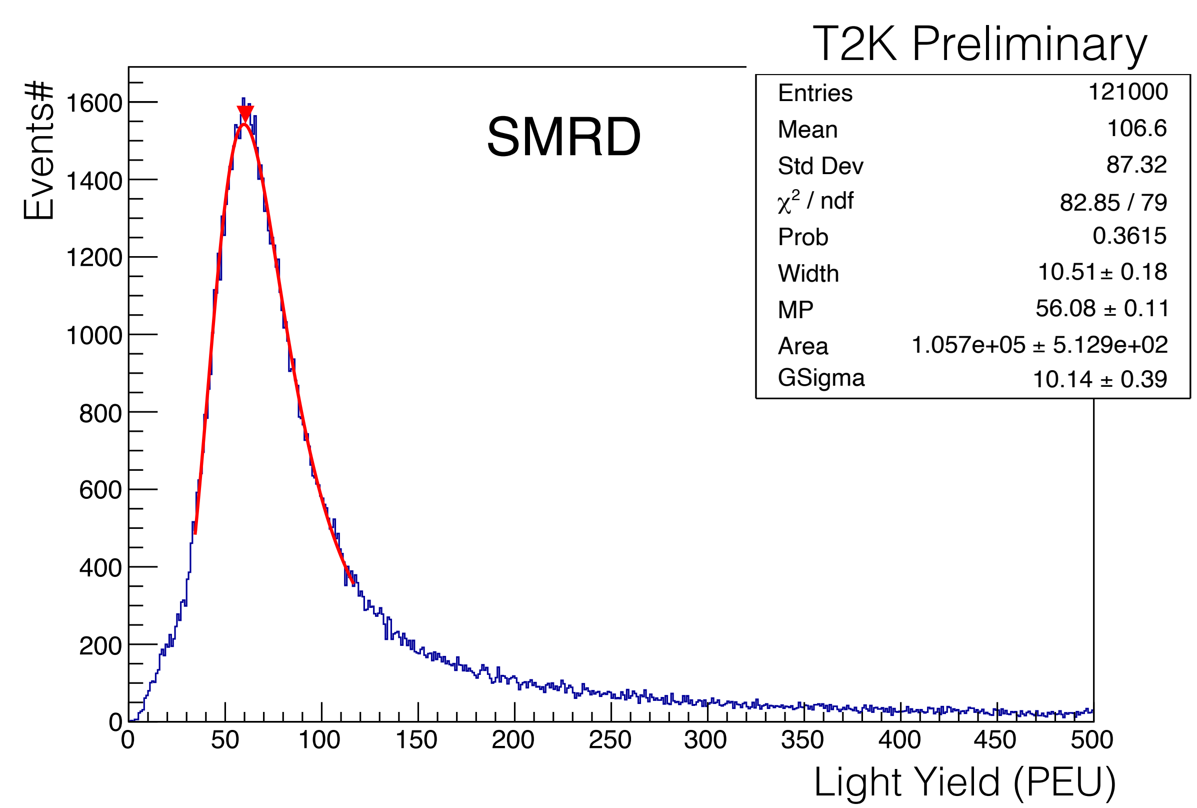
- Off-axis detector
- Constrains flux and cross-section uncertainties in the oscillation analysis
- ~36,000 scintillator bars
- Overall ~64,000 SiPMs in ND280 and INGRID

Analysis method

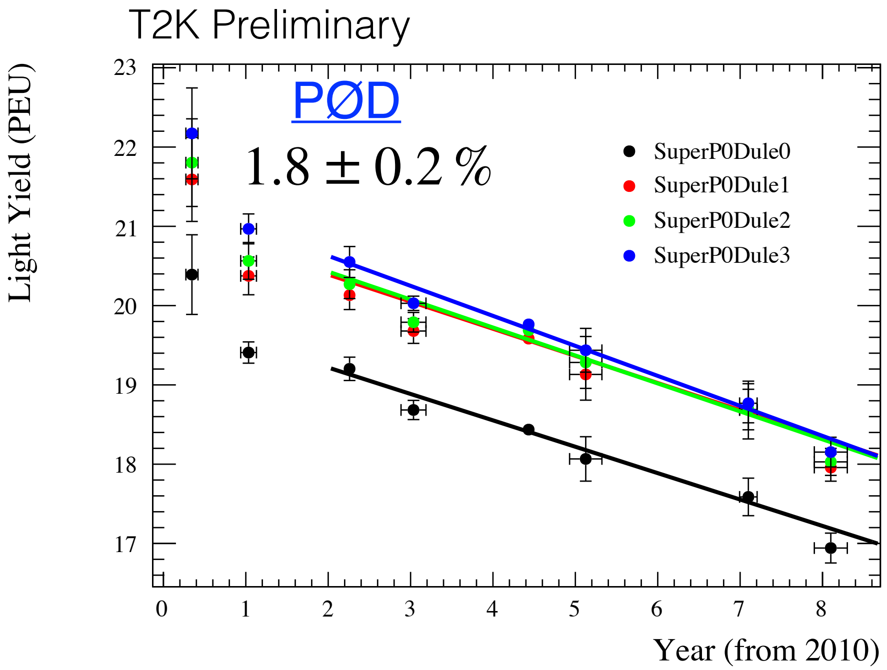
- Light yield (LY) corrected for
  - Attenuation in fibre
  - Detector specific calibration
  - Track angle correction
- Used minimum ionising particle (MIP) like tracks from cosmic rays (ECal, INGRID) or ν interactions (PØD, FGD, SMRD)
- Fitted with Landau-Gauss convolution to get most probable value (MPV)
- MPV distribution over time fitted with linear function
- Due to detector construction current study doesn't separate between a [counter, WLS fibre and SiPM]()

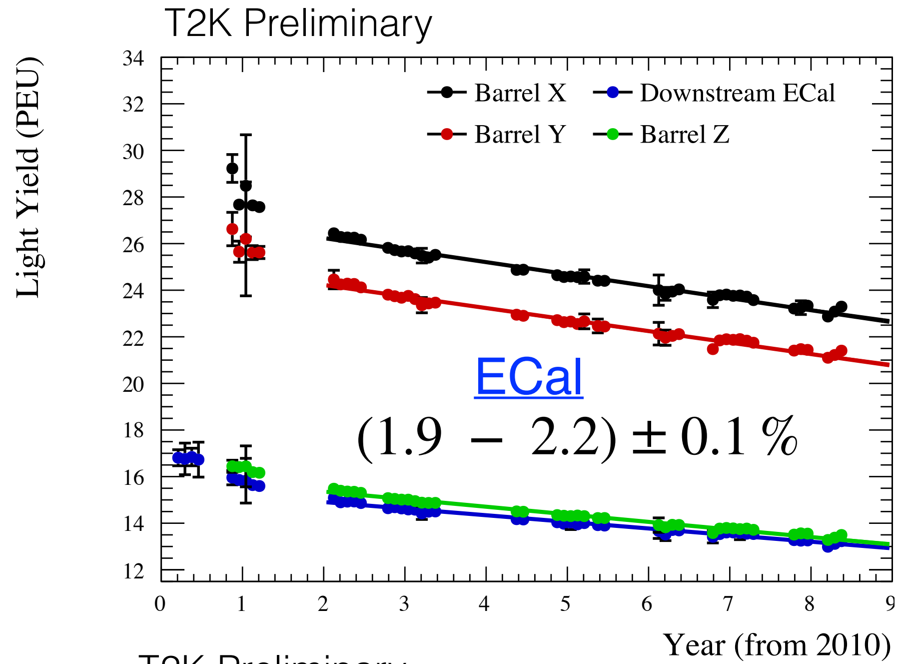


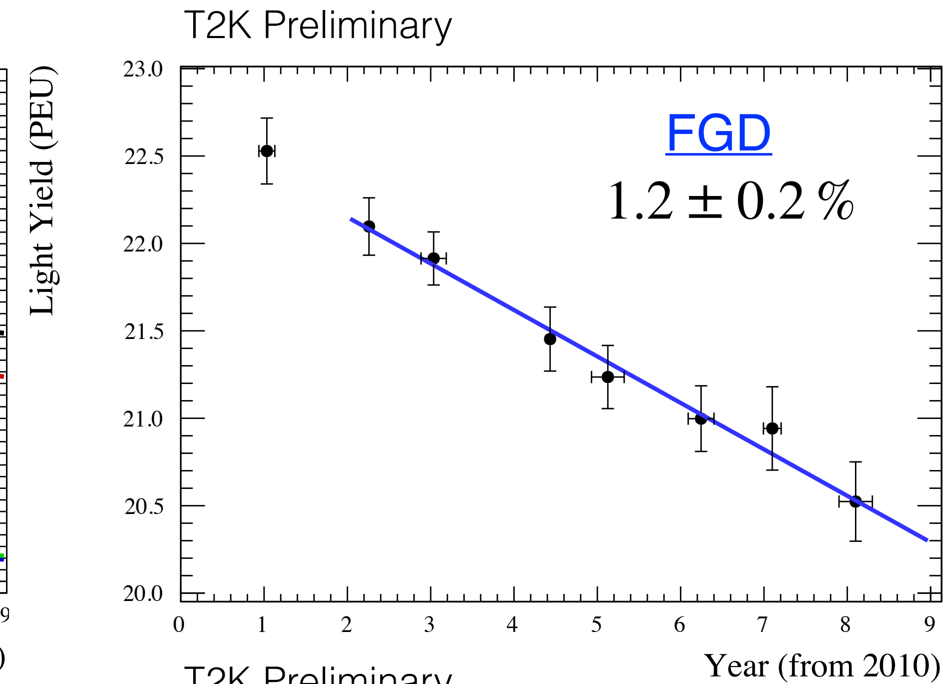




Ageing analysis results



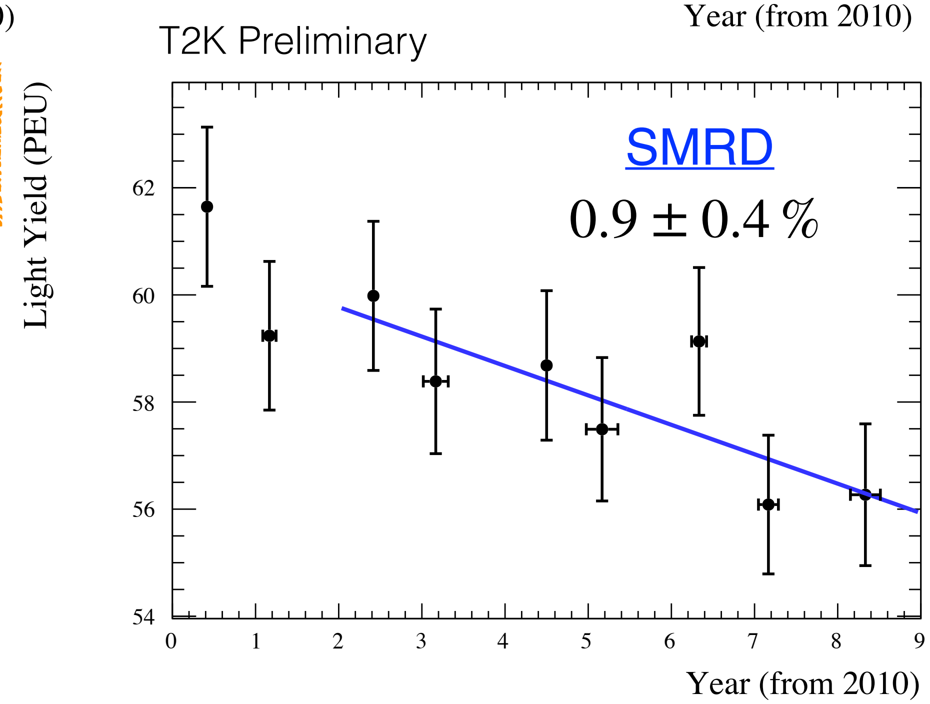


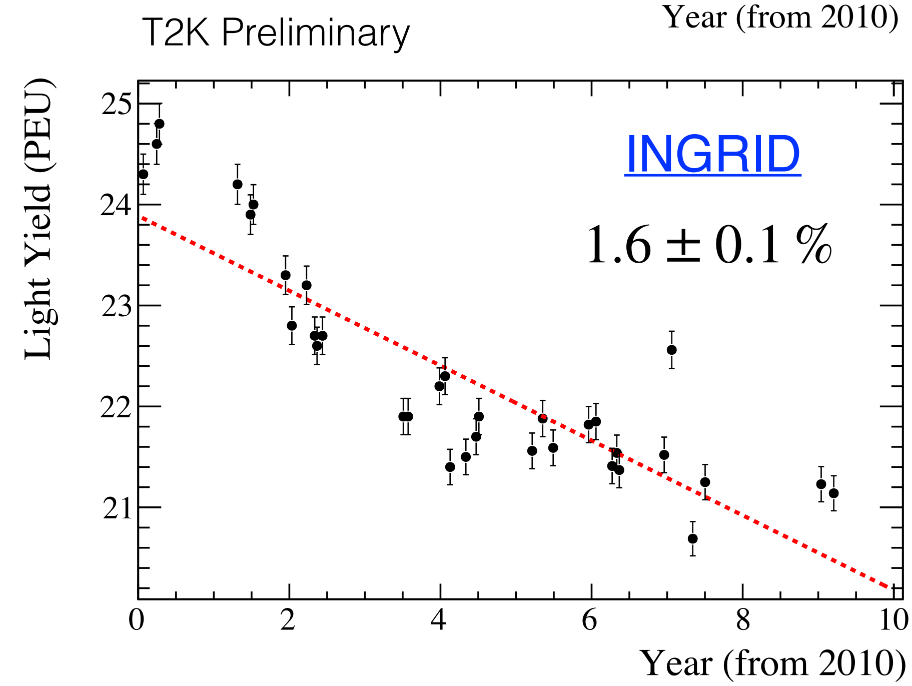


Linear fit function

$$Light\ Yield\,(Year) = A - B * Year$$

Exclude first two years data for ND280 detectors due to different calibration





Ageing constants

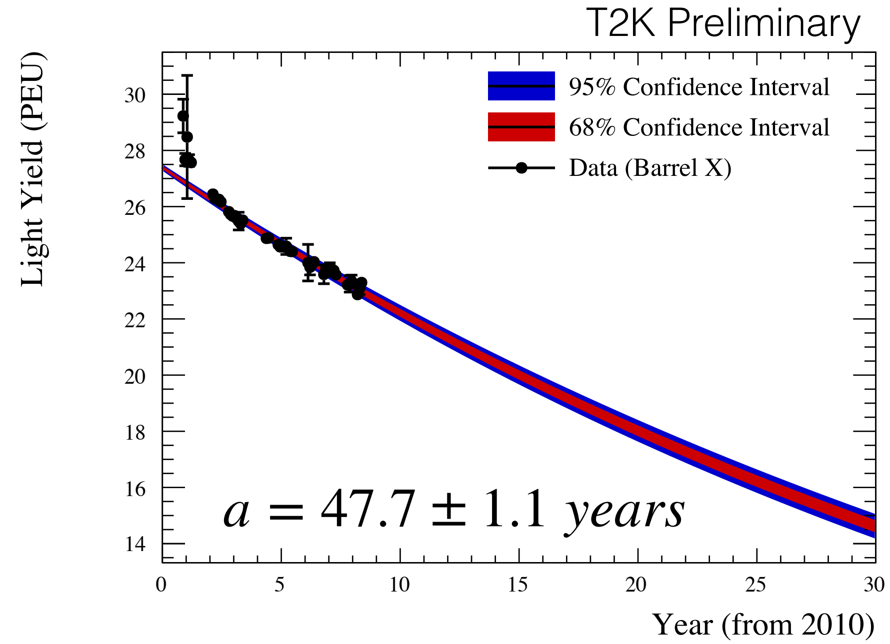
Sub detector	Annual Light Yield Reduction (%)
PØD	1.8 ± 0.2
FGD	1.2 ± 0.2
ECal	$(1.9 - 2.2) \pm 0.1$
SMRD	0.9 ± 0.4
INGRID	1.6 ± 0.1

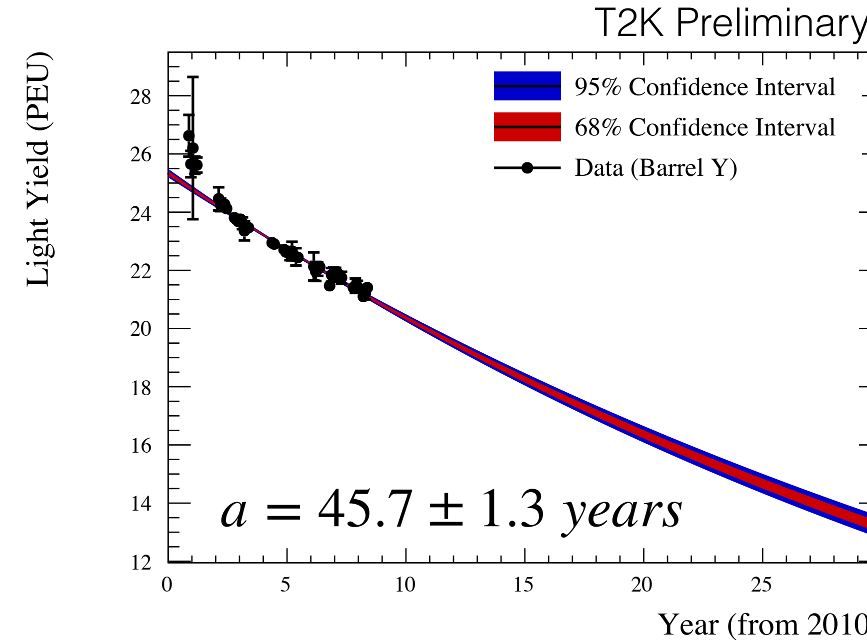
- **Typical ageing about 1-2% per year**
- **Good agreement for PØD, ECal, FGD and INGRID (same composition)**

Projected response

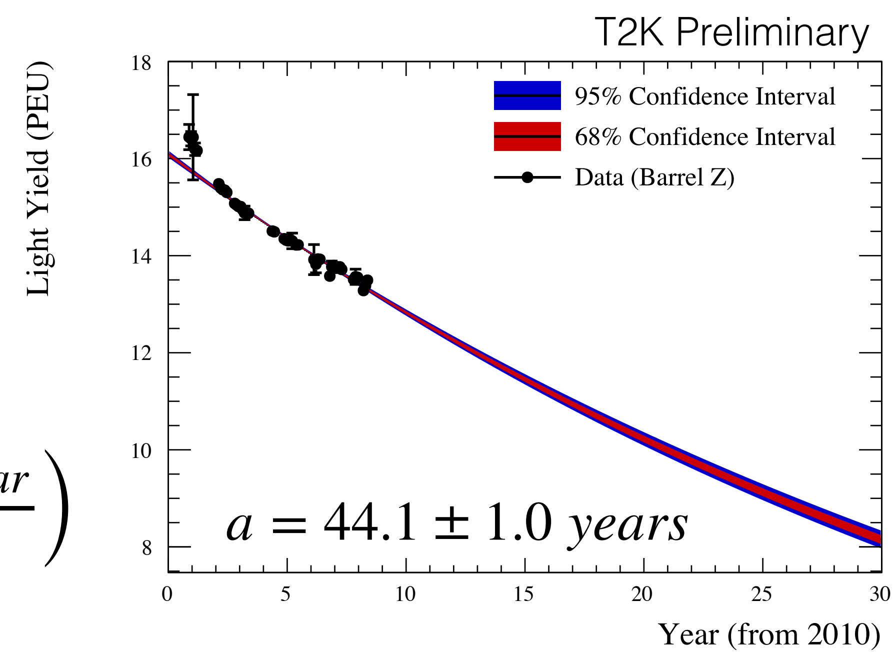
- ECal bars with double end readout record lowest MPV
- ECal can be used to project the “worse” future response of ND280 scintillators
- This study uses exponential fit
  - Better describes data on longer time scale

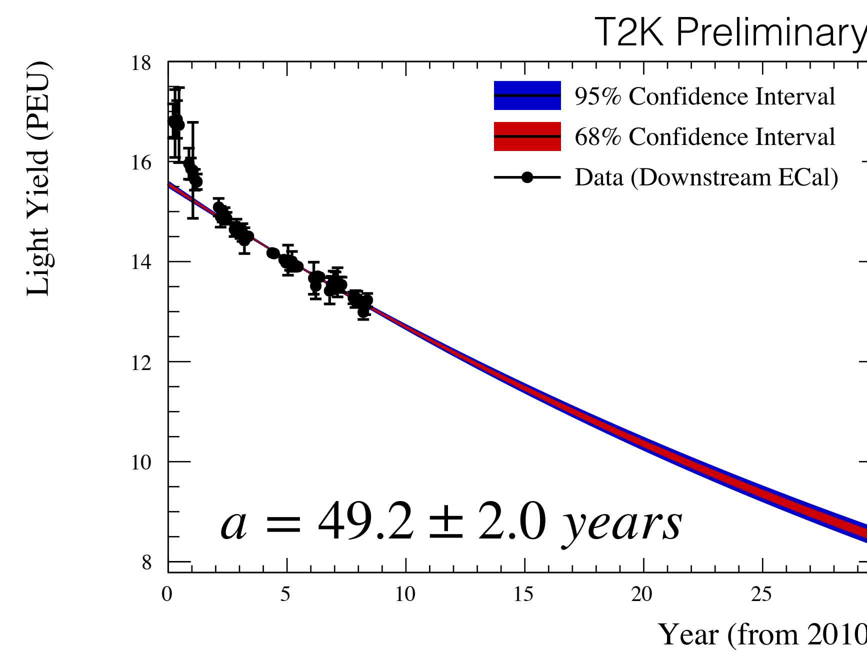
$$Light\ Yield\,(Year) = A\exp\left(\frac{-Year}{a}\right)$$





- Projection of the light yield up to 2040
  - ND280 and INGRID to be used for T2K-II, T2HK



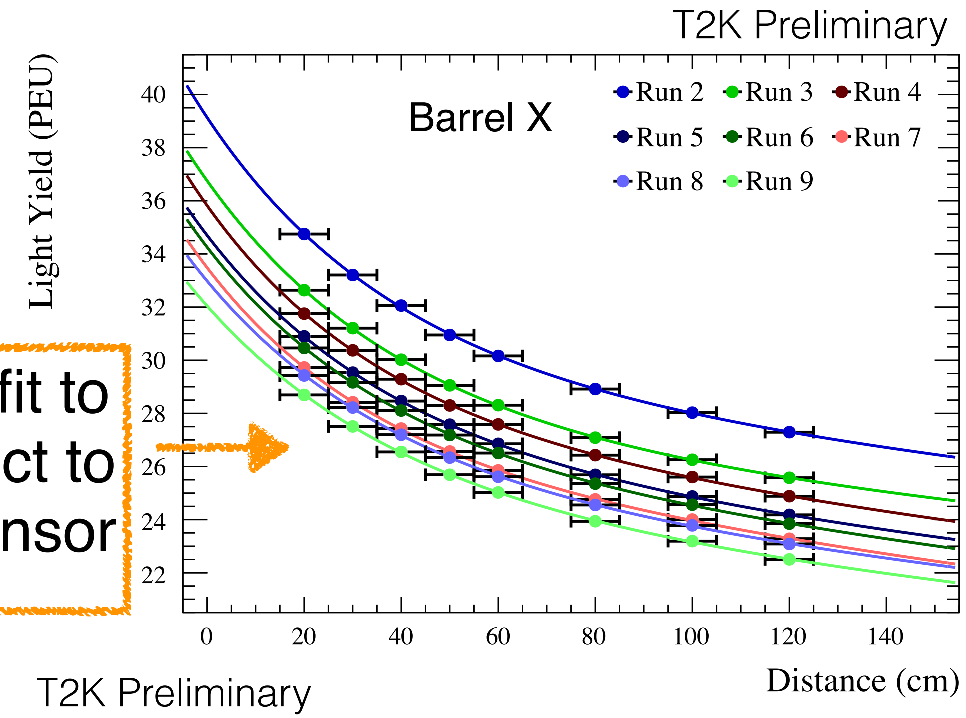


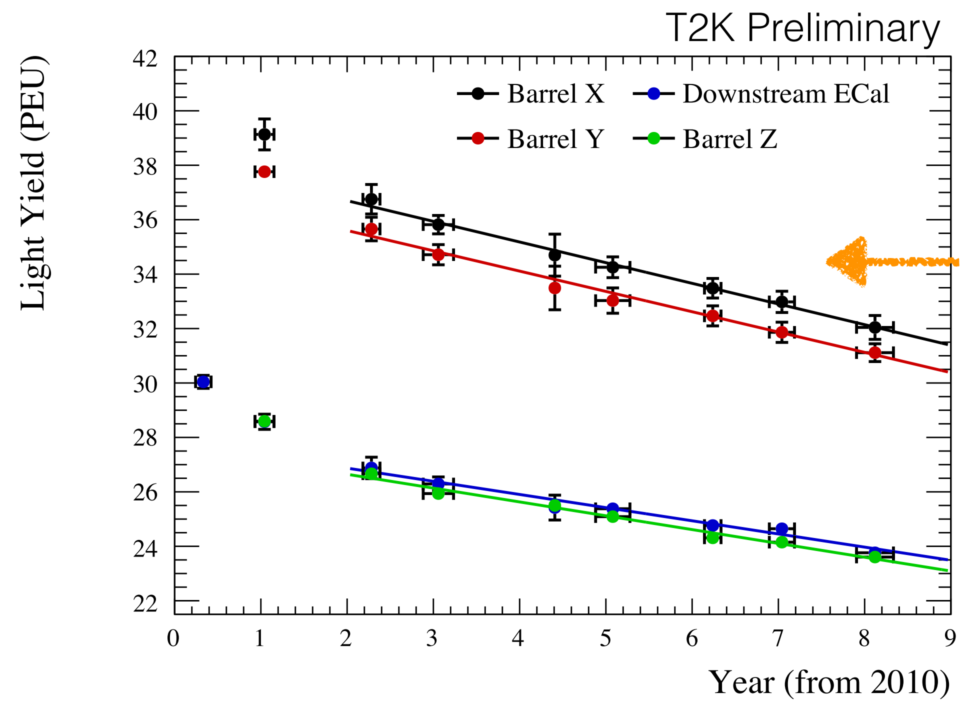
- **Response drops by ~50% over 30 years**
  this still remains above corrected charge threshold (5.5PEU)

Separate fibre and scintillator ageing study

- Without attenuation correction MIP MPV can be extracted at different point from MPPC
- Fitting this data as a function of time allows to calculate MIP MPV at 0cm from the sensor
  - Removes fibre effect
- Degradation rates (with and without fibre effect) are consistent ~1σ

Double exponential fit to MIP MPV with respect to the distance from sensor





Linear fit for MIP MPV at 0 cm from sensor over 10 years

ECal Bar Type	Readout Type	A (PEU)	B (PEU/yr)	Annual Light Yield Reduction (Reference (%)
Barrel X	Single-ended (mirrored)	38.22 ± 0.49	0.76 ± 0.09	2.07 ± 0.25 (1.98 ± 0.04)
Barrel Y	Single-ended (mirrored)	37.10 ± 0.46	0.75 ± 0.08	2.11 ± 0.23 (2.02 ± 0.05)
Barrel Z	Double-ended	27.66 ± 0.18	0.51 ± 0.03	1.91 ± 0.11 (2.15 ± 0.07)
Downstream	Double-ended	27.84 ± 0.32	0.48 ± 0.05	1.79 ± 0.18 (1.87 ± 0.07)

Summary

- Studied the rate of ageing for the T2K near detector complex scintillators with ~10 years of data collection
- Observed annual light yield degradation:
  - ECal,PØD, and INGRID (identical material, all produced at Fermilab) **1.6%-2.2%**
  - FGD (Canada) and SMRD (Russia) **1.2%** and **0.9%** respectively
- Results are comparable with similar studies by MINOS experiment - **1.2 % per year**
- Inconsistent with MINERvA study (was performed on a smaller time scale) **7.5% per year**
- Results of the study will be used to:
  - Predict long term performance of the detector
    - Parts of current T2K detector setup will be used for T2K-II/T2HK
  - Correct signal reconstruction methods
    - Already applied in reconstruction for INGRID and ND280 detectors
  - Take into account for new generation of the detectors
    - SuperFGD, WAGASCI, Baby-MIND in T2K/T2K-II /T2HK

Thank you!
(Official T2K publication in preparation, stay tuned)

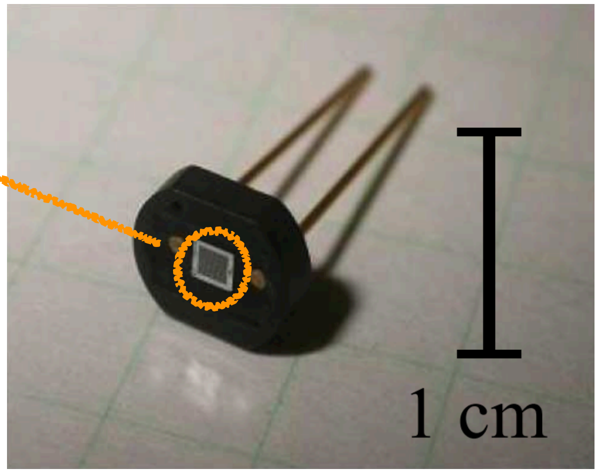
Backup

Scintillator detectors in T2K

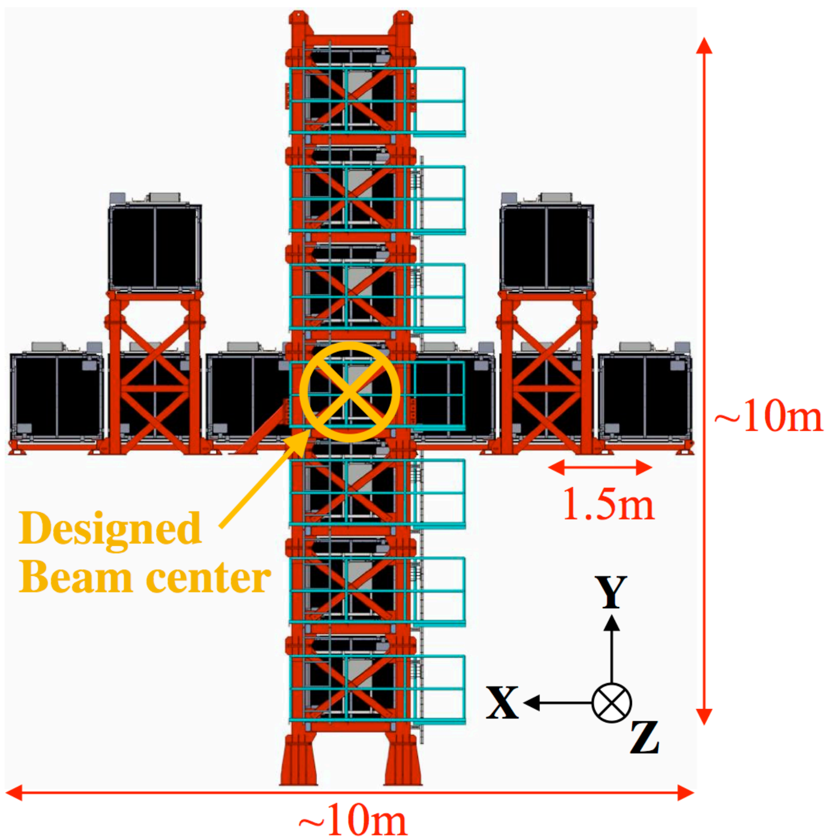
- Plastic scintillator bars of various profiles and sizes*
  - ~ 9,500 in INGRID and ~ 36,000 in ND280
- All using 1mm Kuraray Y11(200) WLS fibre
  - Glued into the bar or coupled through an air gap
- Read-out via [customised Hamamatsu MPPC]() (SiPM) (S10362-13-050C)
  - First time used 64,500 SiPMs
  - Overall failure rate is 0.5%

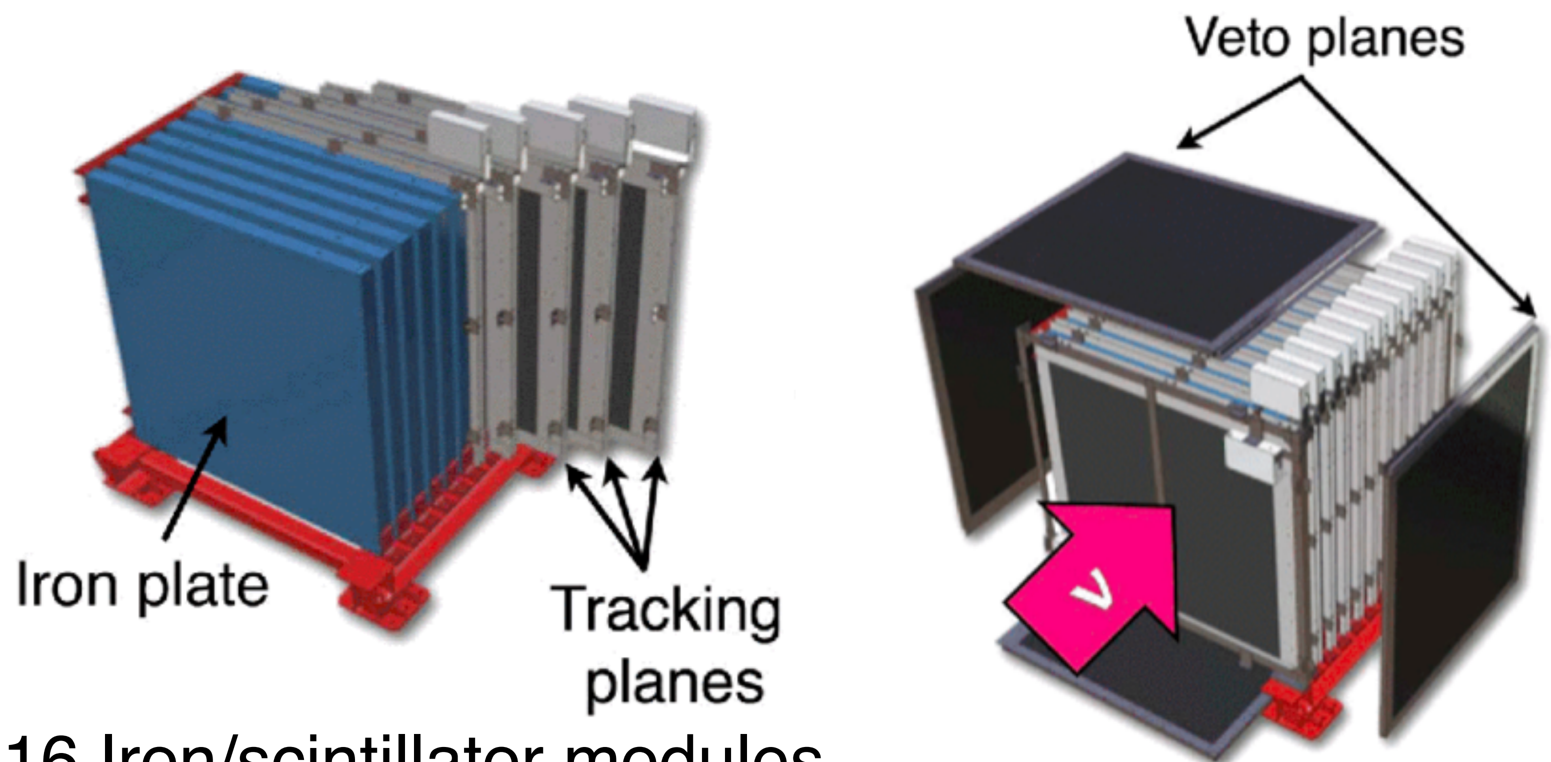
667 APD pixels (each pixel 50x50 μm^2)

Enlarged sensitive area 1.3x1.3 mm^2



INGRID



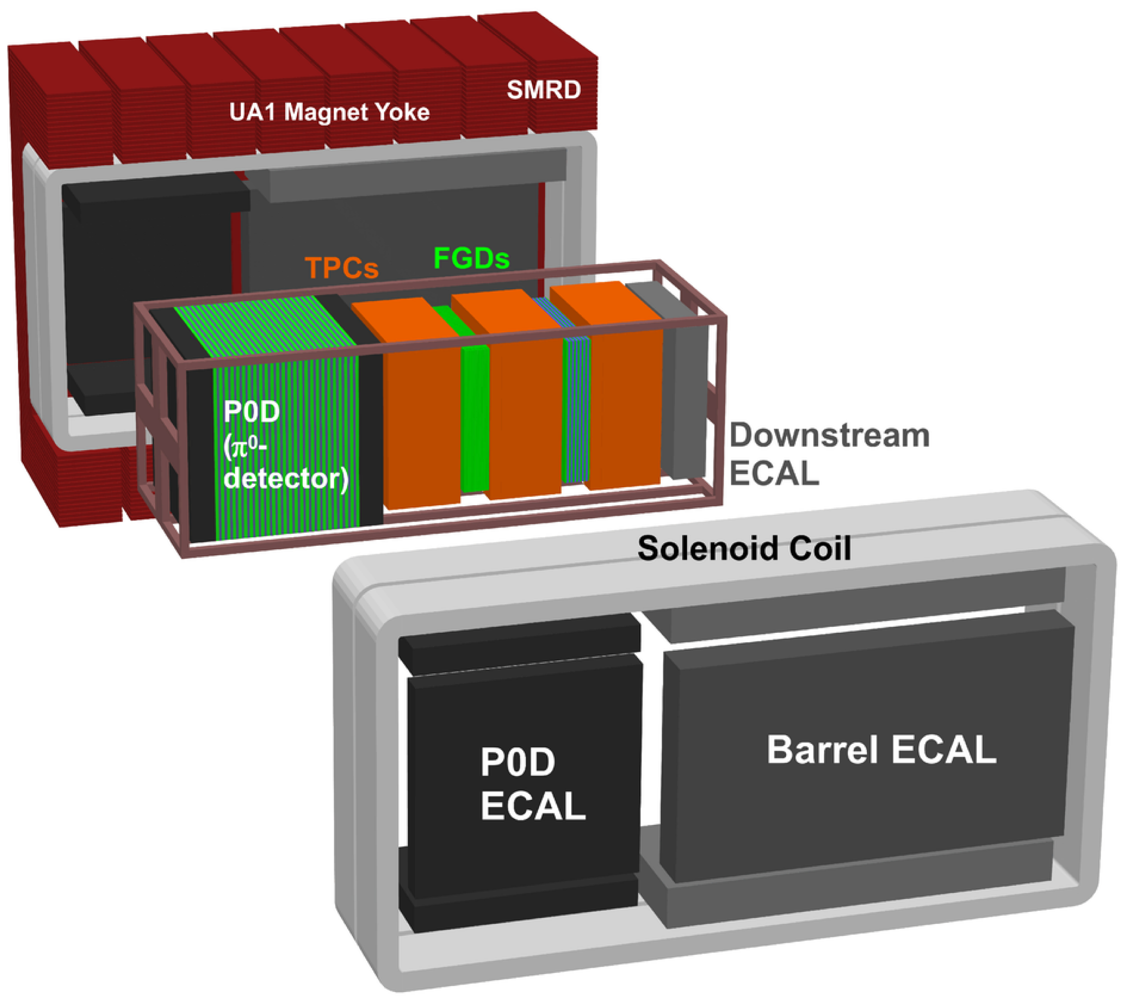


- On-axis detector
- Beam direction and rate stability monitor
- Day-by-day measurements

- 16 Iron/scintillator modules
- 11 tracking scintillator planes per module (placed perpendicular to beam direction)
- 24 horizontal and 24 vertical bars per plane
  - Bars in a plane are glued to each other
- Each bar is 1203 mm long with a 50x10 mm^2 cross section
- On one end readout. Other end is mirrored
- Fibre coupled to scintillator through air gap

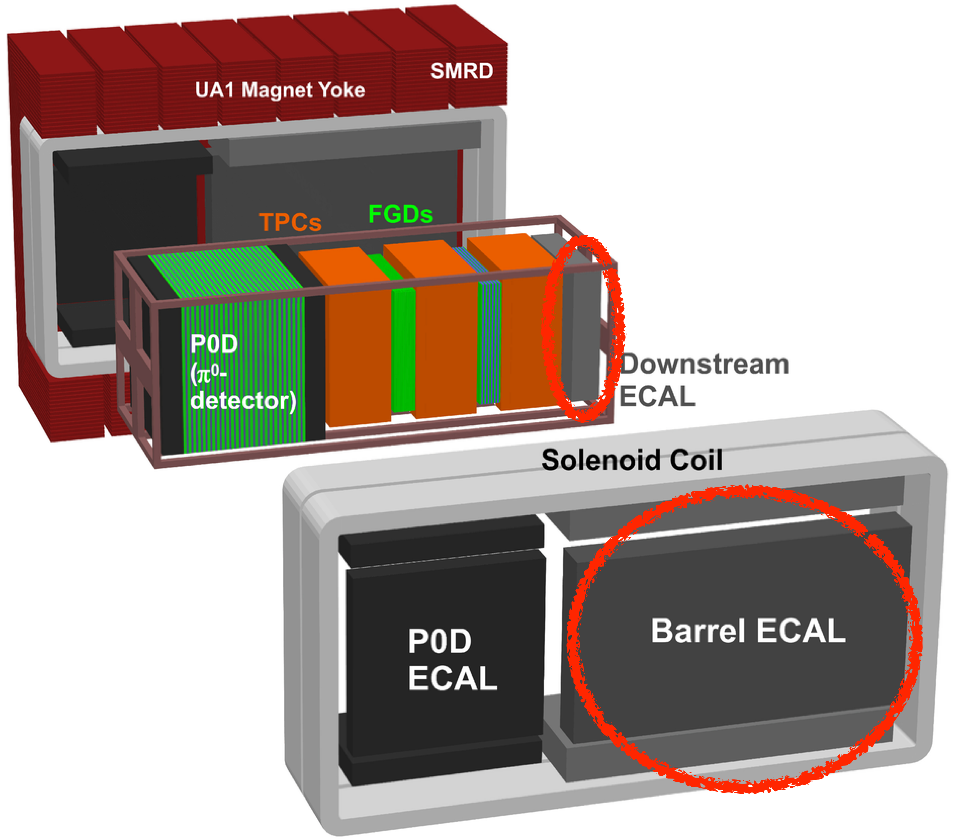
ND280 complex

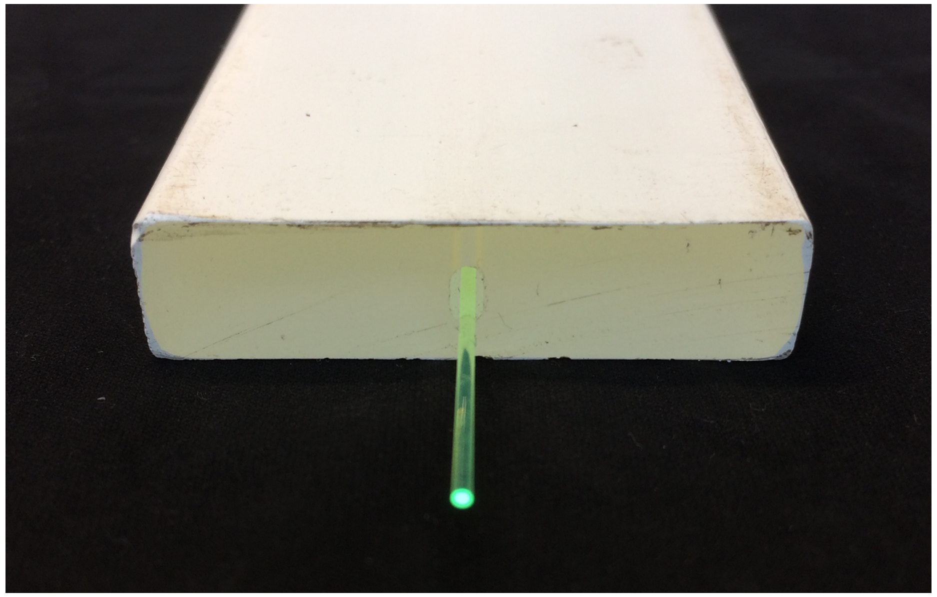
- Sub-detectors in 0.2T magnetic field:
  - Tracker:
    - Fine grained detectors (FGD)
    - Time-projection chambers (TPC)
  - Electromagnetic calorimeter (ECal)
  - Side muon range detector (SMRD)
  - Neutral pion detector (PØD)
- Off-axis detector
- Constrains flux and cross-section uncertainties in the oscillation analysis



ND280: ECal

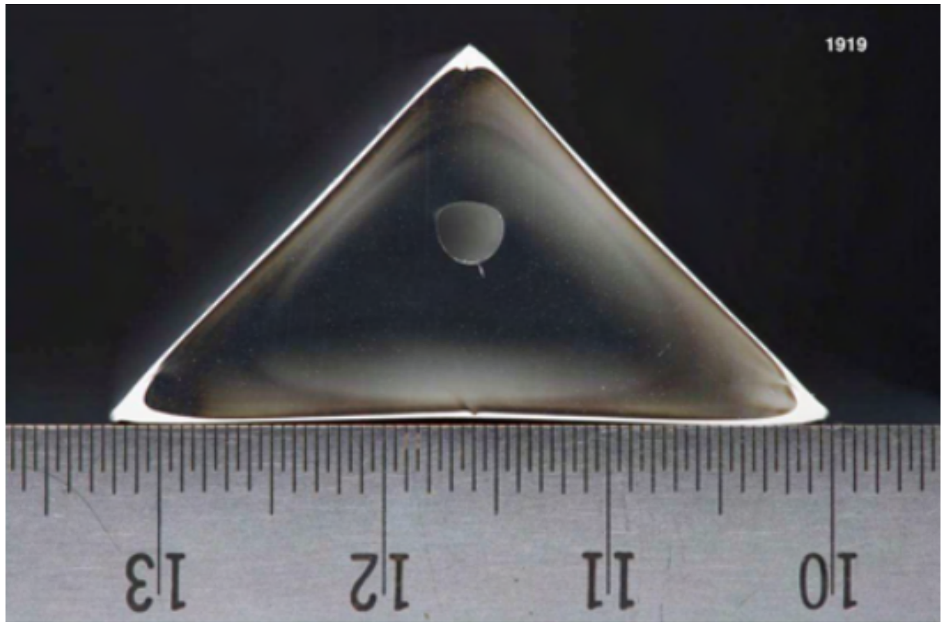
- Counters with 40x10 mm^2 cross section
- Three big modules with different lengths of the bars:
  - Barrel, Downstream(1700 bars of length 2000 mm) and PØD
    (latter is not used in this study)
  - Barrel divided into sub modules:
    X(6144 bars of length 1520 mm),
    Y(3072 bars of length 2280 mm),
    Z(3990 bars of length 3840 mm)
- Bars parallel (Z Barrel) or perpendicular (X,Y Barrel, Downstream) to the beam direction
- Readout from one end of the bar (both ends for Z Barrel and Downstream)
- Air gap coupling between WLS fibre and scintillator



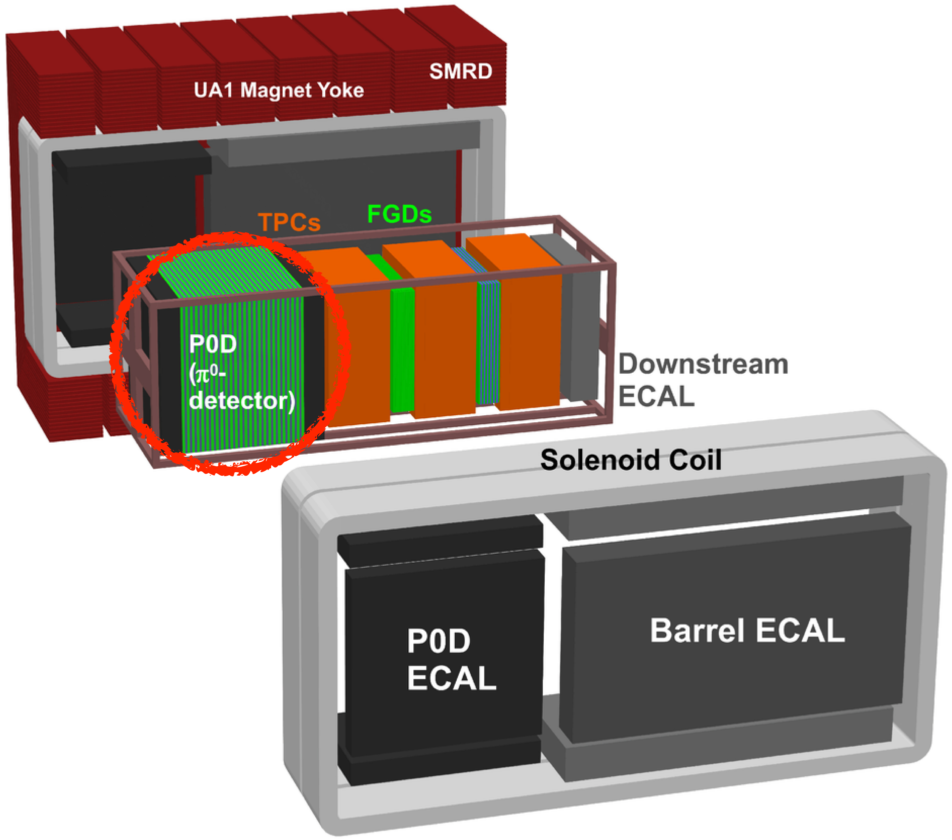


ND280:PØD

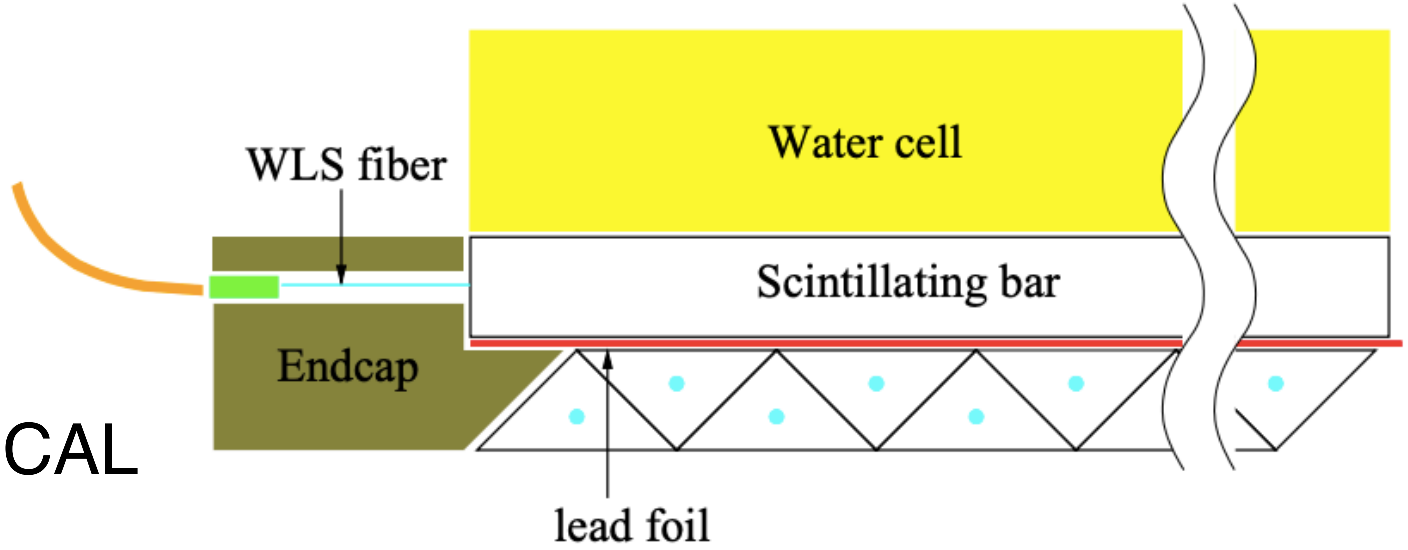
Design and composition is identical to MINERvA bars



- Triangular cross section (17 mm height and 33 mm width)
- Horizontal bars are 2133 mm long (134 bars in total)
- Vertical bars are 2272 mm long (127 bars in total)

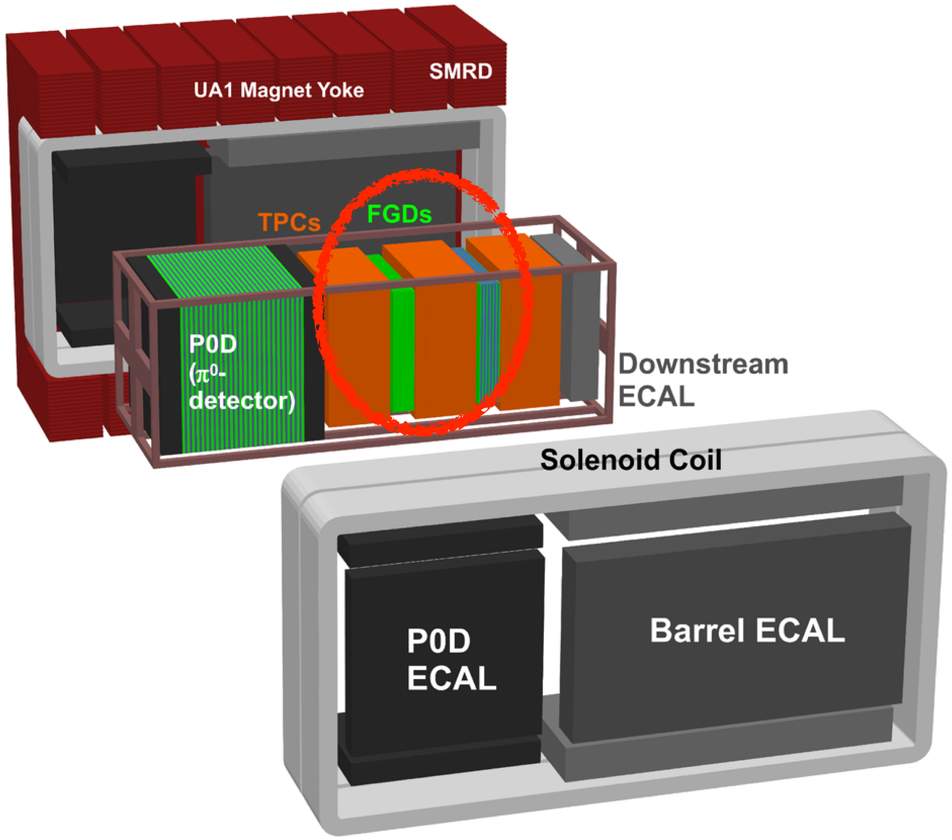


- Bars grouped into 40 modules(PØDules)
- All bars are placed perpendicular to the beam
- PØDules compose 4 SuperPØDules
- One end signal readout
- Another end is mirrored with vacuum deposition of aluminium
- Same MPPC/fibre coupling design as ECAL and INGRID

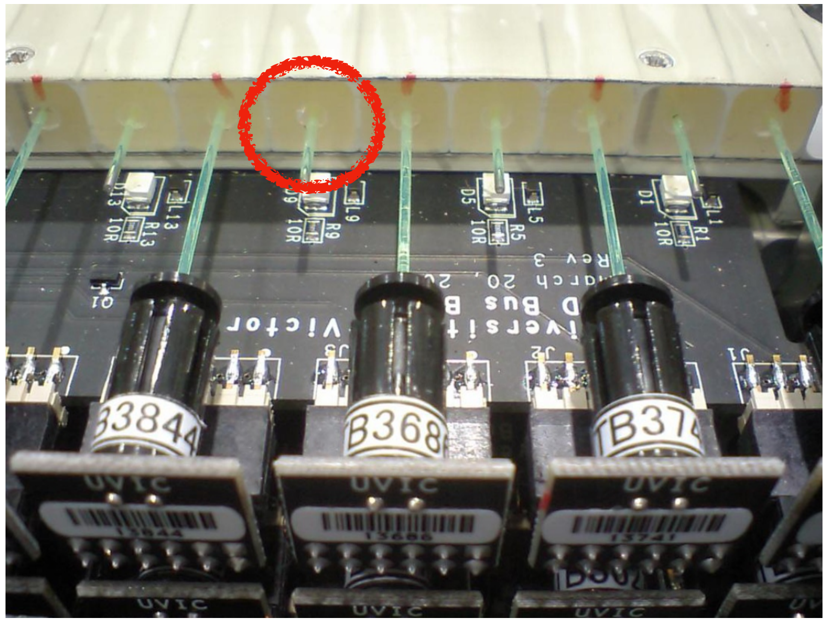


ND280:FGD

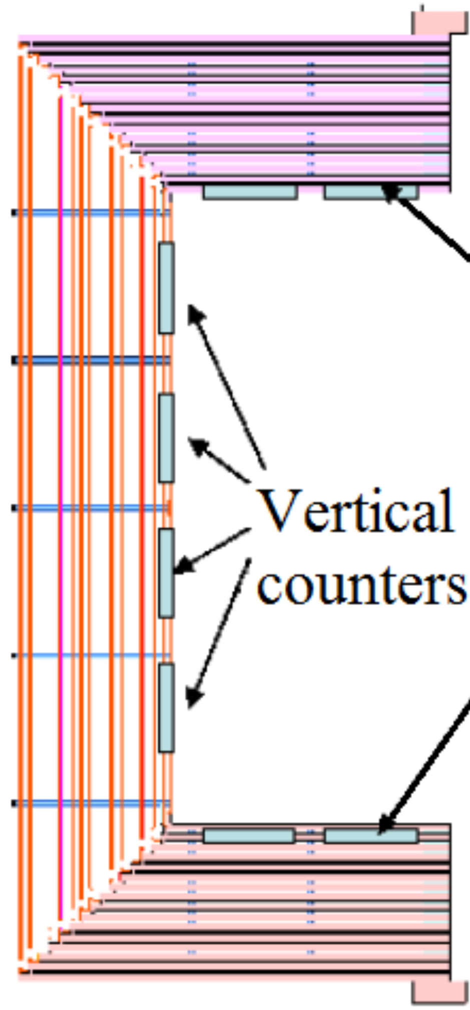
- Grouped in horizontal(vertical)layers of 192 bar each, perpendicular beam direction
- Two layers make a module (in two FGDs 22 modules in total)
- Within each layer alternate bars read from alternate ends
- Signal readout from one end only, the other end is mirrored
- Air gap coupling between fibre and bar

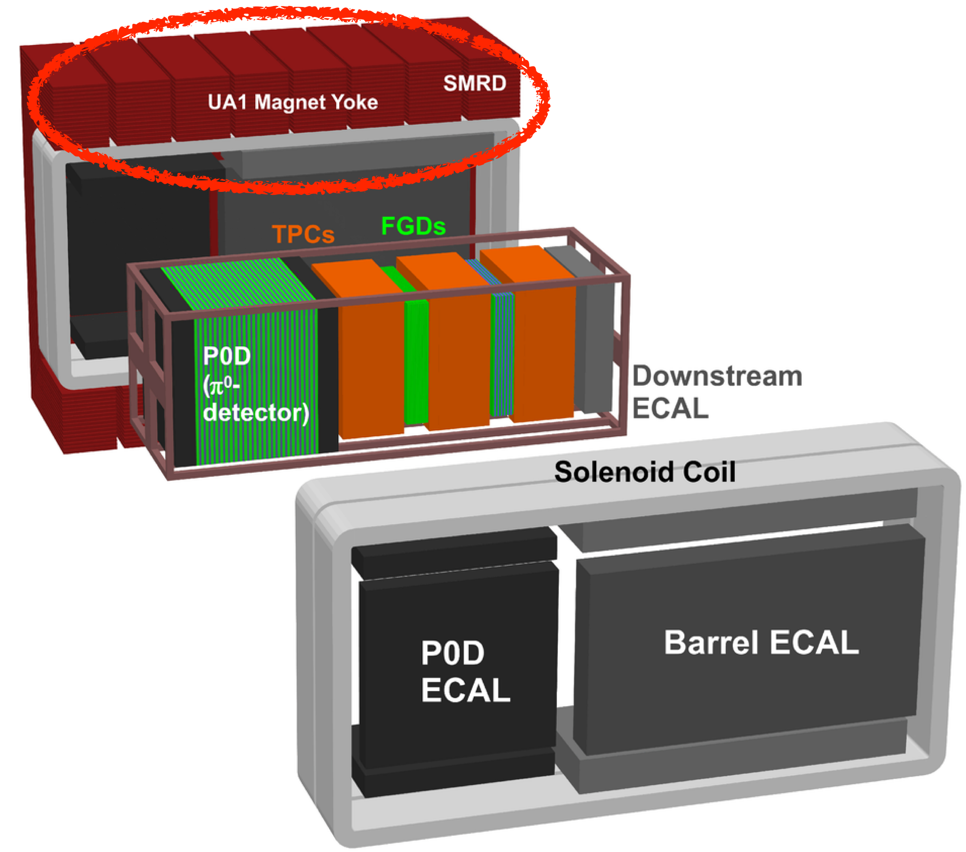


- Square profile scintillator bars (9.6 mm side, 1864 mm length)

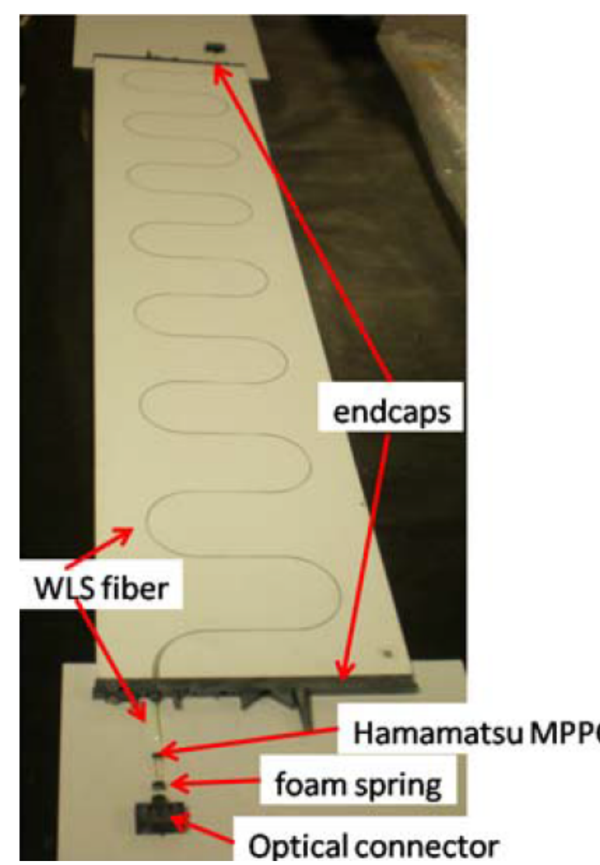


ND280:SMRD





- Vertical (7x175x185 mm²) (horizontal (7x167x185 mm²))bars
- Bars grouped by 4(5) in modules located in the magnetic flux return yokes
- In total SMRD consist of 404 modules



- S-shaped WLS fibre for better light collection
- Fibre is glued into the bar with optical glue
- Readout from the both sides of the counter
- Custom endcap at the end of the bar for better coupling between MPPC and fibre

Scintillator bars

- FGD, ECal, PØD and INGRID counters:
  - Polystyrene co-extruded with TiO_2
  - Doped with 1%PPO and 0.003% POPOP
- SMRD counters:
  - Extruded polystyrene
  - Outer surface etched by chemical reagent to provide reflective layer
  - Doped with 1.5% PTP and 0.01% POPOP
- PØD, ECal and INGRID bars produced at FNAL (2007-2009)
- FGD bars produced by Celco Plastic Ltd, Surrey, B.C.(2006)
- SMRD slabs produced by Uniplast, Vladimir, Russia (2007-2008)
- PØD, FGD,ECal,INGRID scintillators composition and production method are identical to ones of the MINOS experiment
- PØD bars are totally identical to bars used for MINERvA experiment