New TPCs for the upgrade of the T2K near detector

Marco Zito

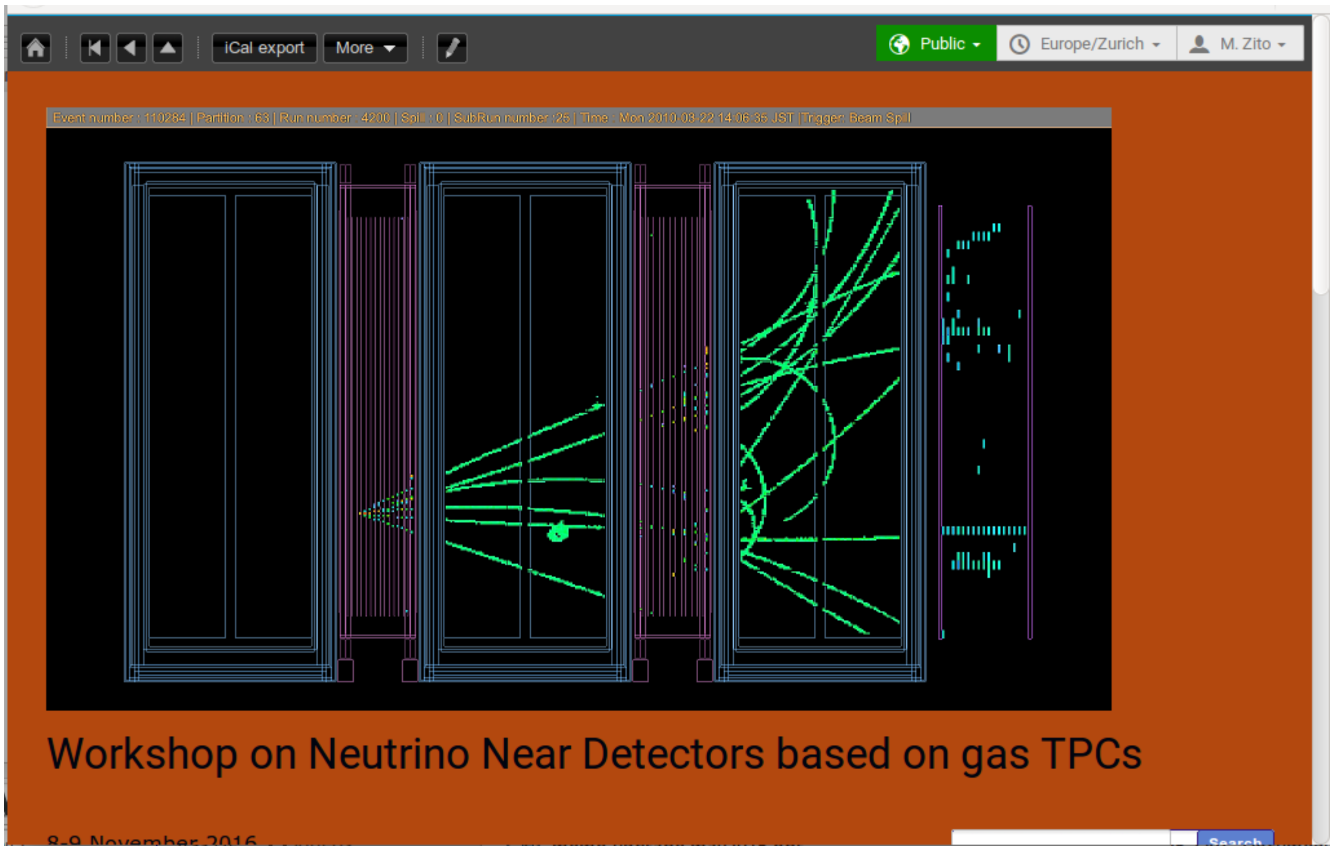
IRFU/SPP CEA Saclay

8th Int. Symposium on TPC for low energy rare event detection

Paris, December 5 2016

TPC-based near detectors for long baseline neutrino experiments

Workshop at CERN Nov 8-9 2016



https://indico.cern.ch/event/568177/

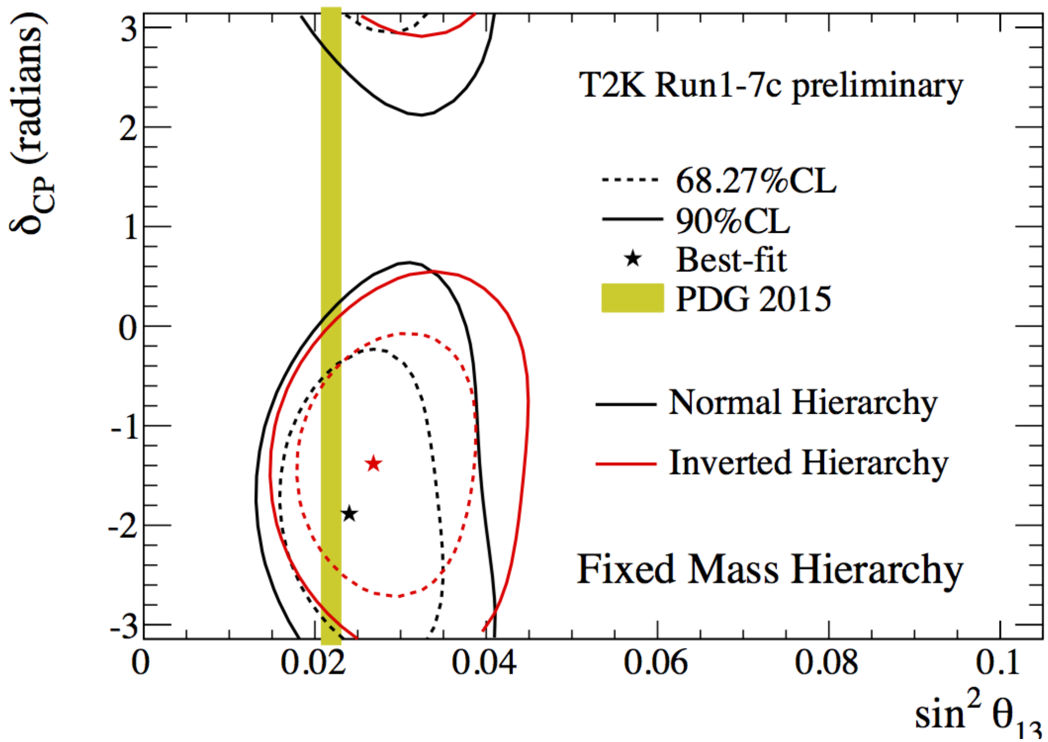
Apologies if your talk of interest is not covered here

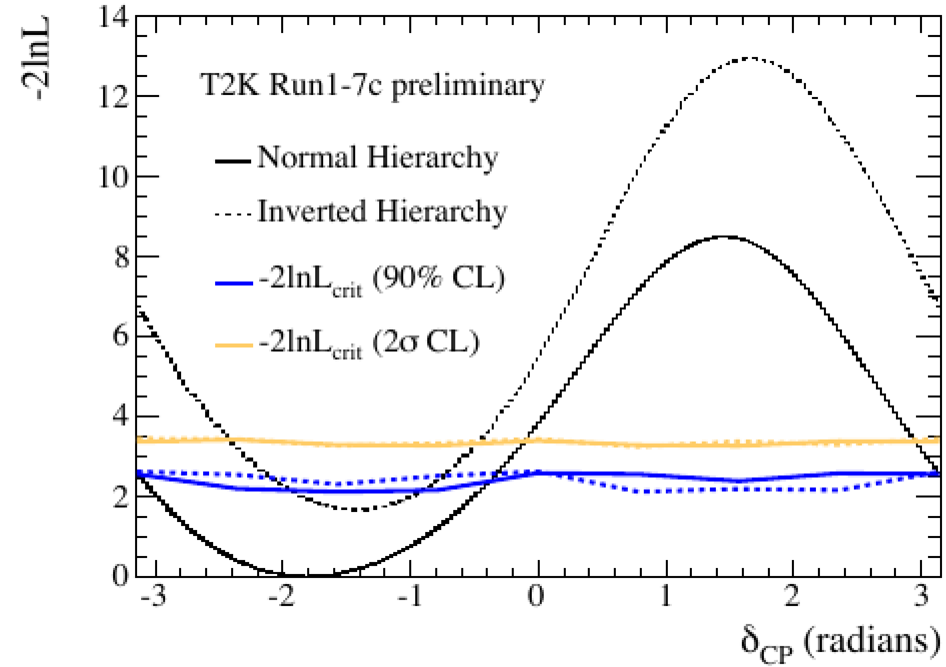
Motivations

- TPCs are in use with success in the near detector ND280 of T2K, and are envisaged for the DUNE near detector
- Recent development in neutrino oscillations (measurement of the θ_{13} angle, recent search for CP violation) stimulate even further this domain
- The new long baseline programs (Hyper-Kamiokande, DUNE) are a HEP priority for the next decade
- Recent progress in MPGD, electronics etc. enable more advanced performance
- A High Pressure TPC could be the ultimate detector for the study of neutrino-nucleus interactions

19% of full data set: 50 %nu, 50%antinu

T2K first search for CP violation





	$\delta_{cp} = -\pi/2$ (NH)	$\delta_{cp} = 0$ (NH)	$\delta_{cp} = +\pi/2$ (NH)	$\delta_{cp} = \pi$ (NH)	Observed
ν_e	28.7	24.2	19.6	24.1	32
$\overline{\nu}_e$	6.0	6.9	7.7	6.8	4

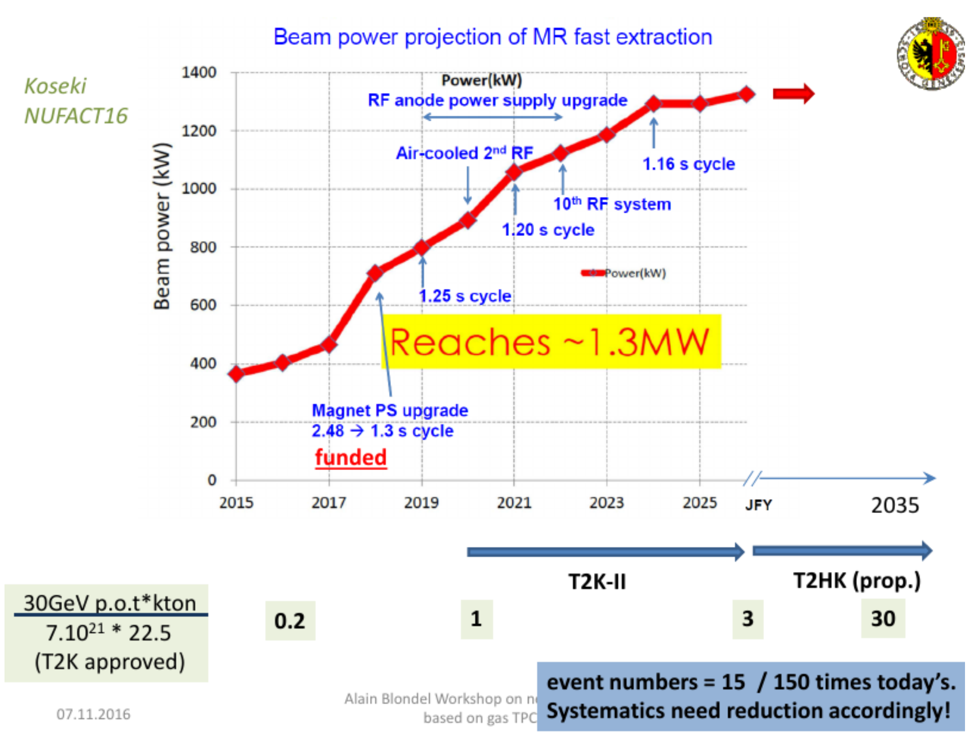
2016 x5 2021 x4 2025 x20

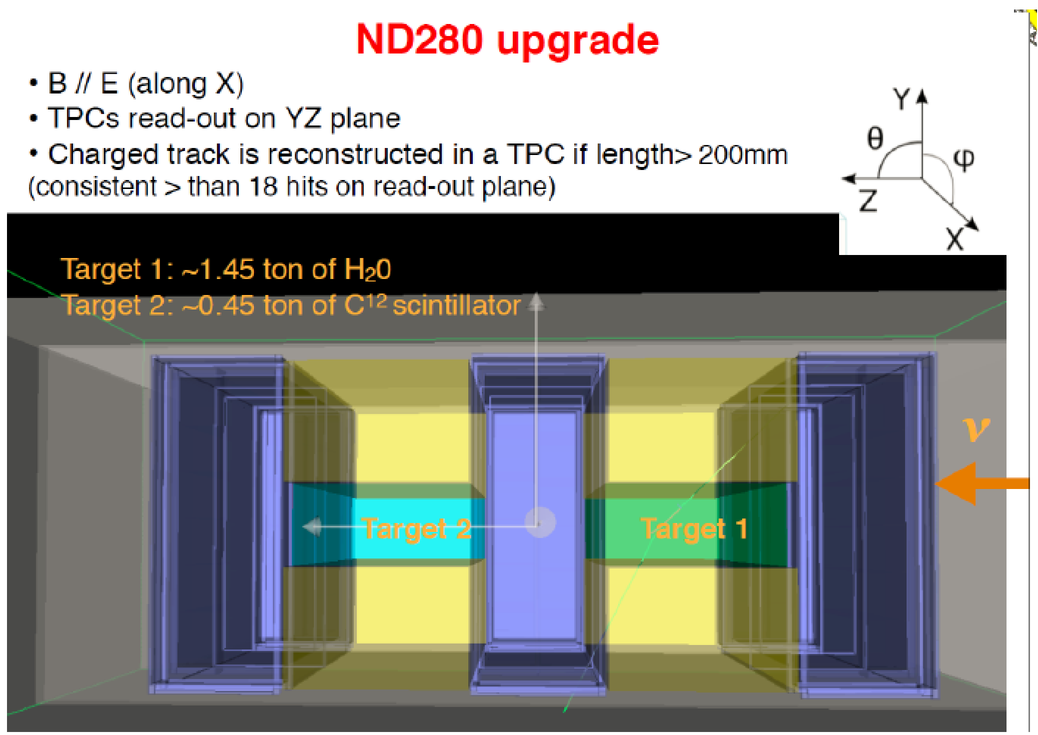
T2K-I T2K-II HK

A. Blondel

T2K-II phase and TPC-based ND upgrade

- T2K aims to continue data-taking from 2021 to 2025
- 400 nue appearance events at the far detector
- Needs to reduce the systematic uncertainties to 3-4%
- Upgrade of the near detector to be installed in 2020





Goal of this workshop:

-- Collaboration/synergy to develop state-of-the-art techniques
-- Acquire experience by building the required TPCs
  -- Start with ND280 upgrade (normal pressure)
  -- R&D for longer time scale HP TPCs
  -- CERN natural base and support for EU groups
  -- International collaboration (Europe, Japan, Russia, US +...)

-- More practically, review projects and ideas
  -- identify areas of expertise (or lack thereof)
  -- who does what etc...
  -- agree on terms for SPSC proposal to be discussed tomorrow
  -- agree on terms for e.g. EU funding proposal

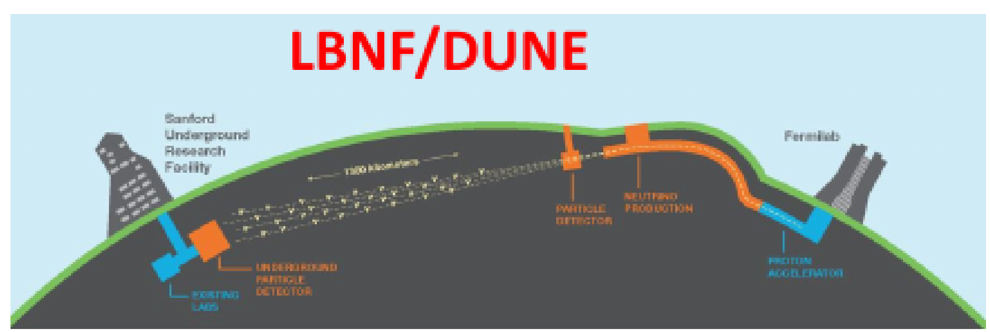
M. Nessi

ν future landscape (oscillation physics)

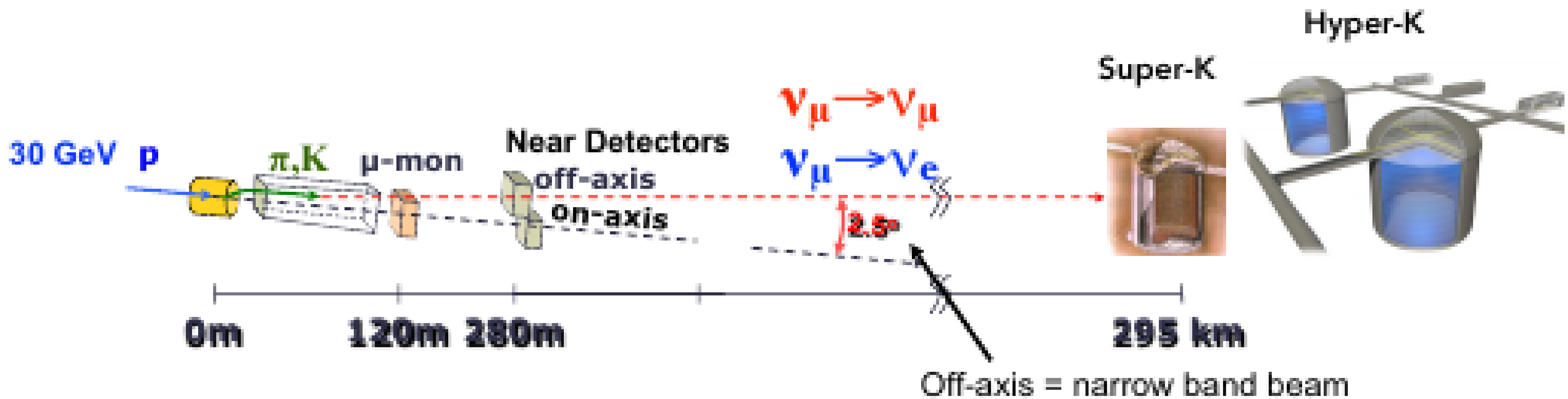
Neutrino Platform at CERN

T2K

SBN (short baseline)



T2K/HYPER-K OVERVIEW



Key Features:

Predominantly muon (anti)neutrino beam (~99%) with neutrino/antineutrino selected by horn polarity

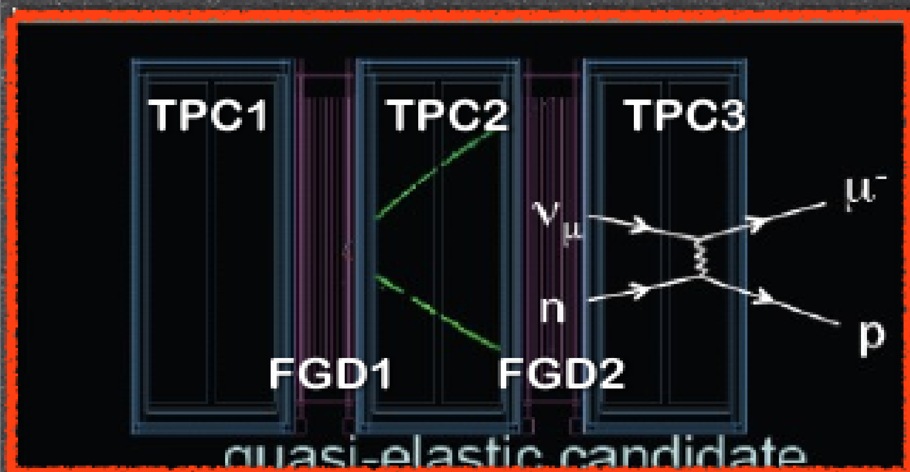
Off-axis narrow beam with a peak energy at the first oscillation maximum (600 MeV) at 295 km

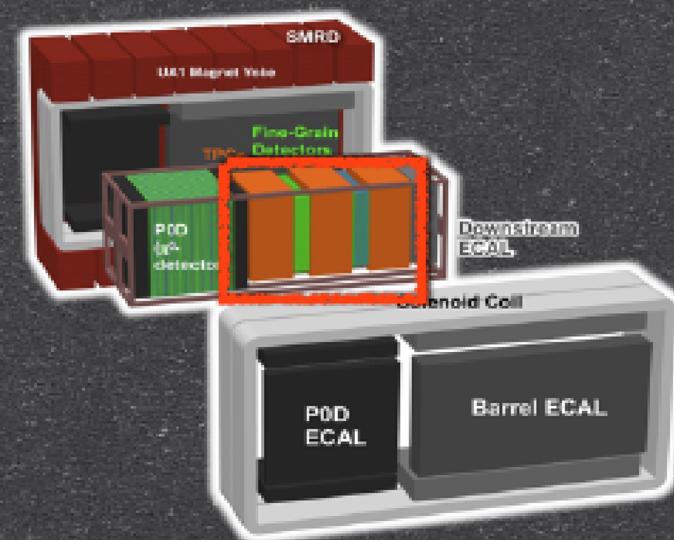
Near detectors to measure neutrino event rates before oscillations

Water Cherenkov far detectors Super-K (T2K) and Hyper-K

Goals of ND280

Tracker





- Constraint the ν_μ and ν_e spectra before the oscillations
- Measure neutrino cross-sections
- Measure background processes to the oscillation analyses (π^0, CC1π, etc)

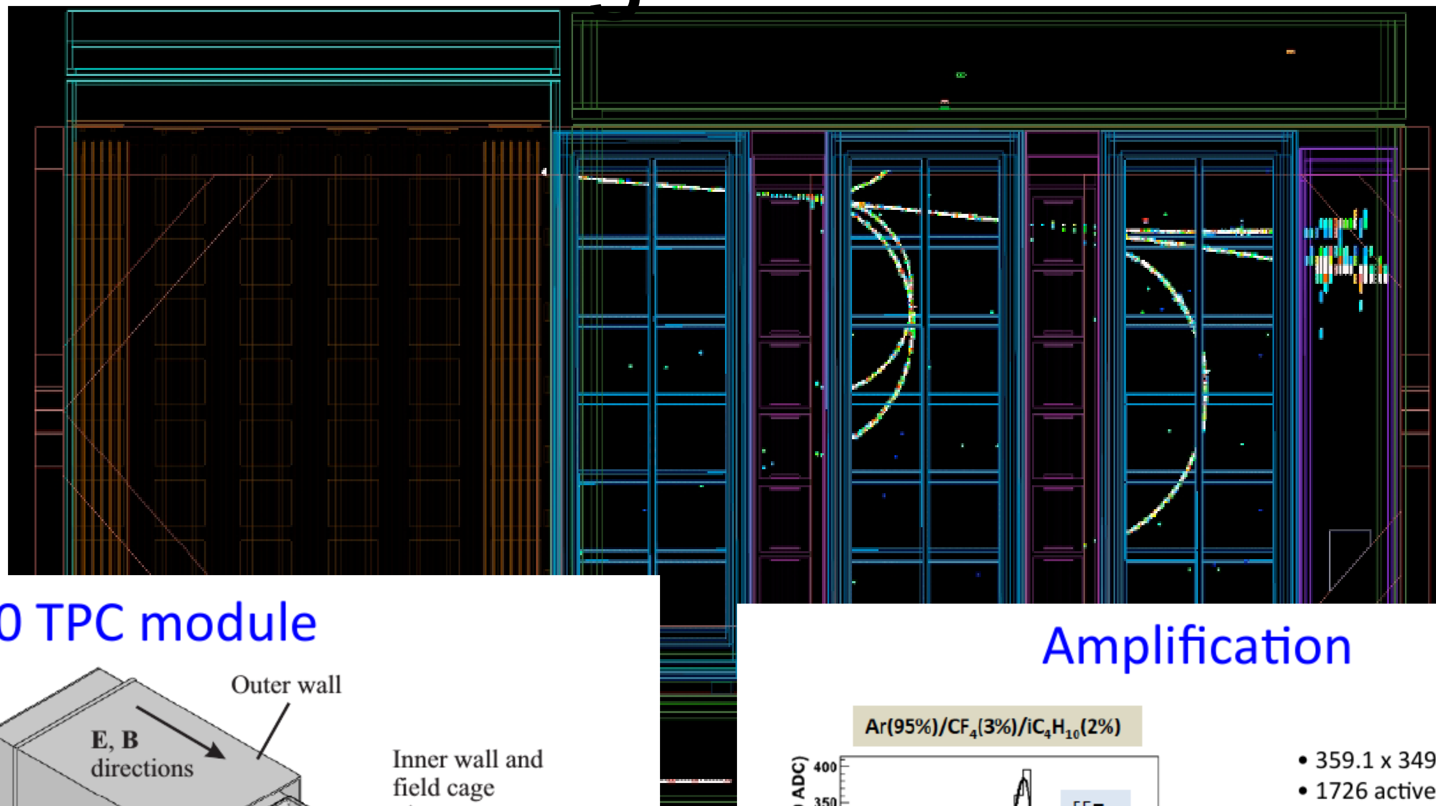
The existing TPC of the T2K near detector

Requirements and TPC motivations

From a slide ~ 11 years ago

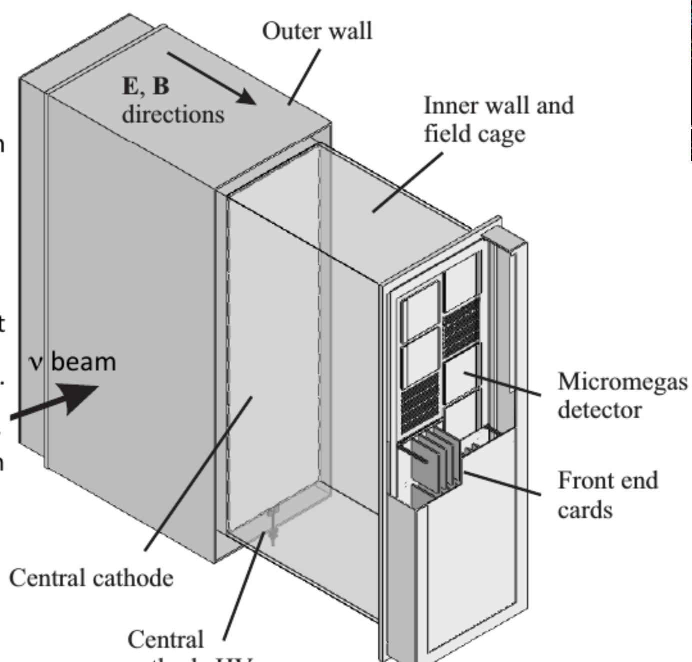
Resolution: σ ~ 500μm	Any decent tracker could do
Particle ID: e/μ/p	TPC !
Avg momentum < 1GeV/c	As-light-as-possible: TPC
Mild magnetic field	Low diffusion gas
Low track density	Few tracks per event → no need for small pads
Broad angle range for e and μ, + very large angle p	Dependency of σ from track angle → MPGD amplification → Squared (or almost) pads

The existing T2K ND TPC

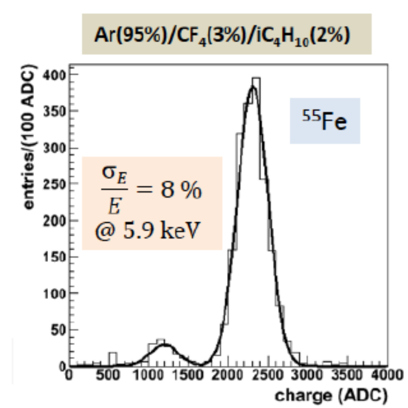


ND280 TPC module

- Outer volume (*2.5 x 2.5 m2 in the plane perpendicular to the neutrino beam direction, and 0.9*m along the beam direction
- Active volume 1*.8 x 2.2 x0.7 m3*
- Gas mixture: *Ar,iC$_4$H$_{10}$,CF$_4$ (95/2/3)*
- The central cathode is set at moderately high potential (close to 25 kV).
- The outer box is separated from the inner box by a gap of 6.8 cm on the sides and top and 11.8 cm on the bottom.
- Pad plane made by tiles of MM readout modules

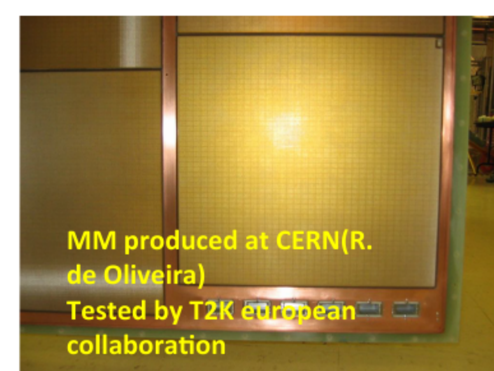


Amplification



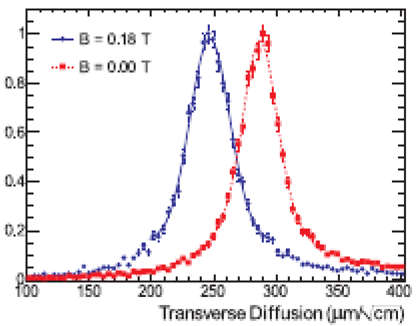
- 359.1 x 349.3 mm2
- 1726 active pads.
- 9.8 x 7.0 mm2
- 128 μm amplification gap.
- 72 modules for 3 TPC´s.

- TPC Gas: Ar(95%) CF$_4$(3%) iC$_4$H$_{10}$ (2%)
- Gain: 1500 @ 27.4 kV/cm
- Drift Velocity : 7.8 cm/μs
- Drift field: 279 V/m

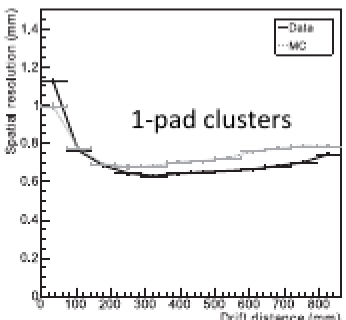


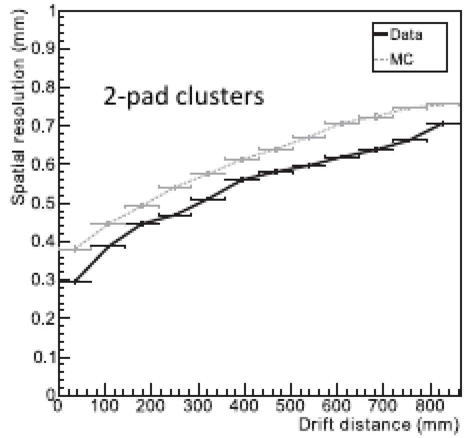
Performance

E. Radicioni

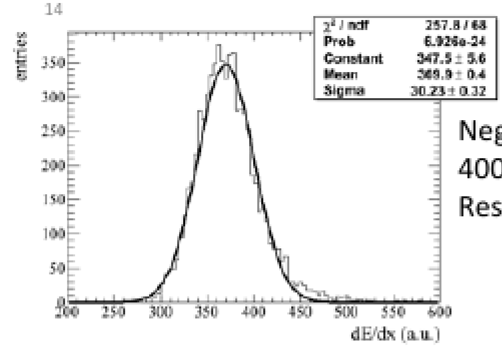


Likelihood fit: takes into account (and fits) transverse diffusion



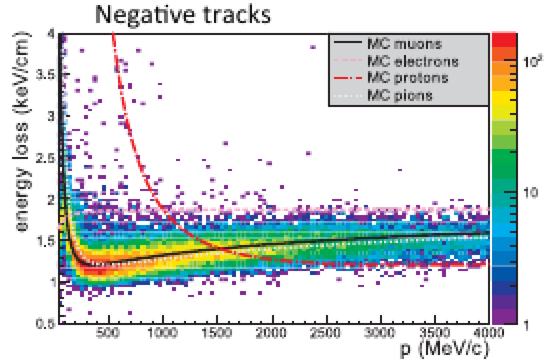


Performance

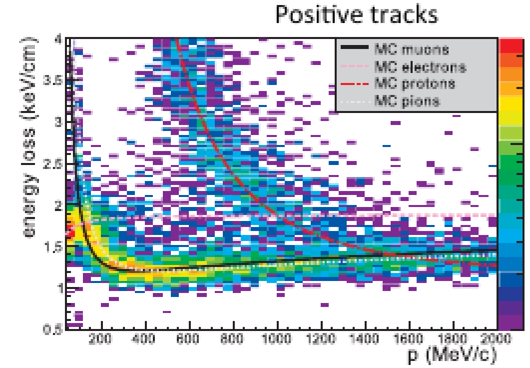


Negative tracks
400 MeV/c < p < 500 MeV/c
Resolution: better than 8%

Negative tracks



Positive tracks



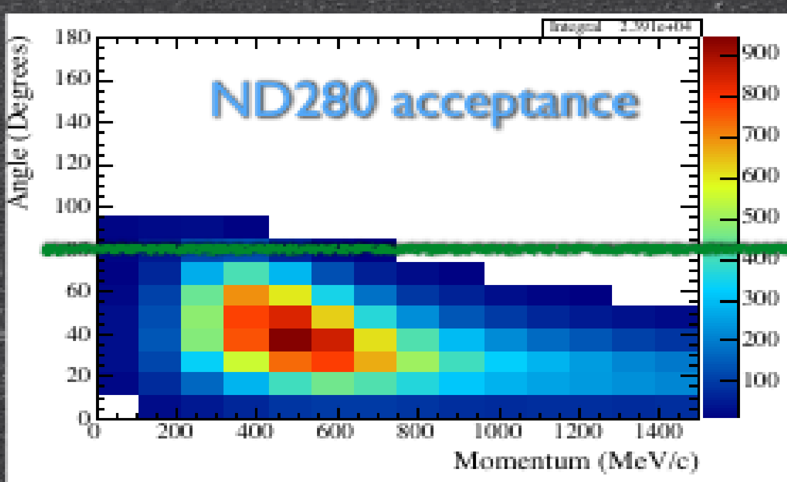
Lessons learned

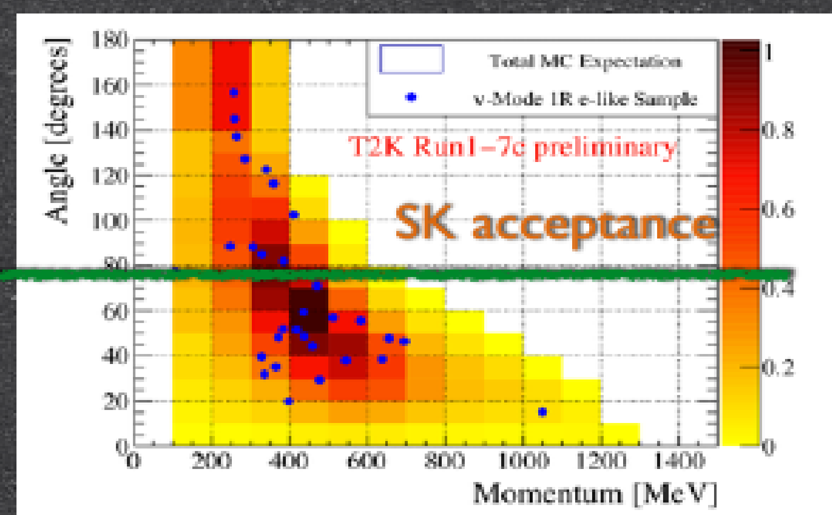
- Resolution: pad charge sharing limitations
  - resistive readout planes not realistic 10 years ago
- Complexity
  - Dual-layer field-cage designed for never-used HV values → acceptance lost (dead space and material in walls)
    - 200 MeV/c cutoff for muons
    - large-angle protons undetected most of the time
  - gas system for dual-volume field-cage
    - involved manpower and issues with long-term maintenance
- Track length, dE/dx resolution
  - it is OK for 3 σ separation of e/μ
  - increase track length, if possible
- dynamic range with heavily ionizing tracks
- delicate relative alignment of the MM modules
  - → larger modules now possible

Personal point of view

Angular acceptance

- One of the main limitation of current ND280 analyses is that it only select forward-going muons
- In SK the acceptance is flat with respect to the lepton angle and events with backward leptons are also selected
- Currently we constraint the models in the forward region and we let the model constraint the backward region → model dependent





16

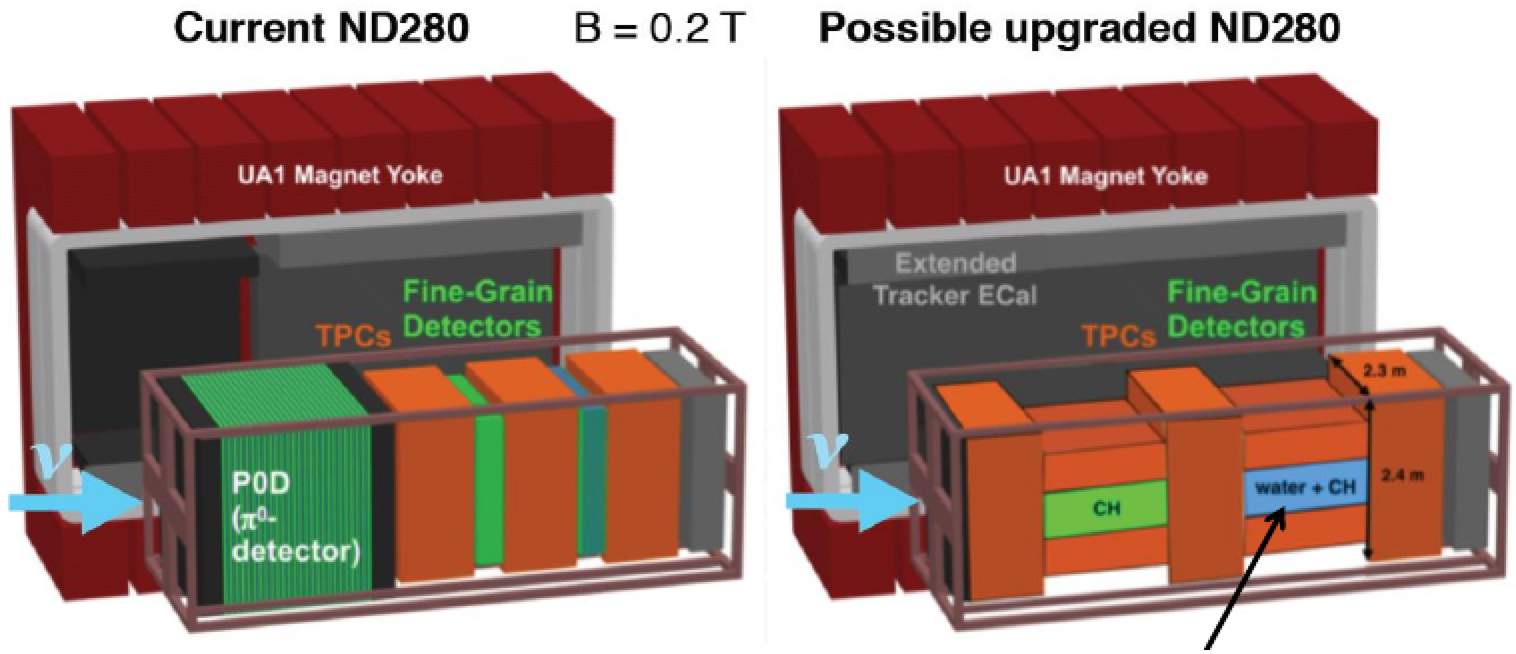
M. Hartz

T2K SYSTEMATIC ERRORS

arXiv:1609.04111

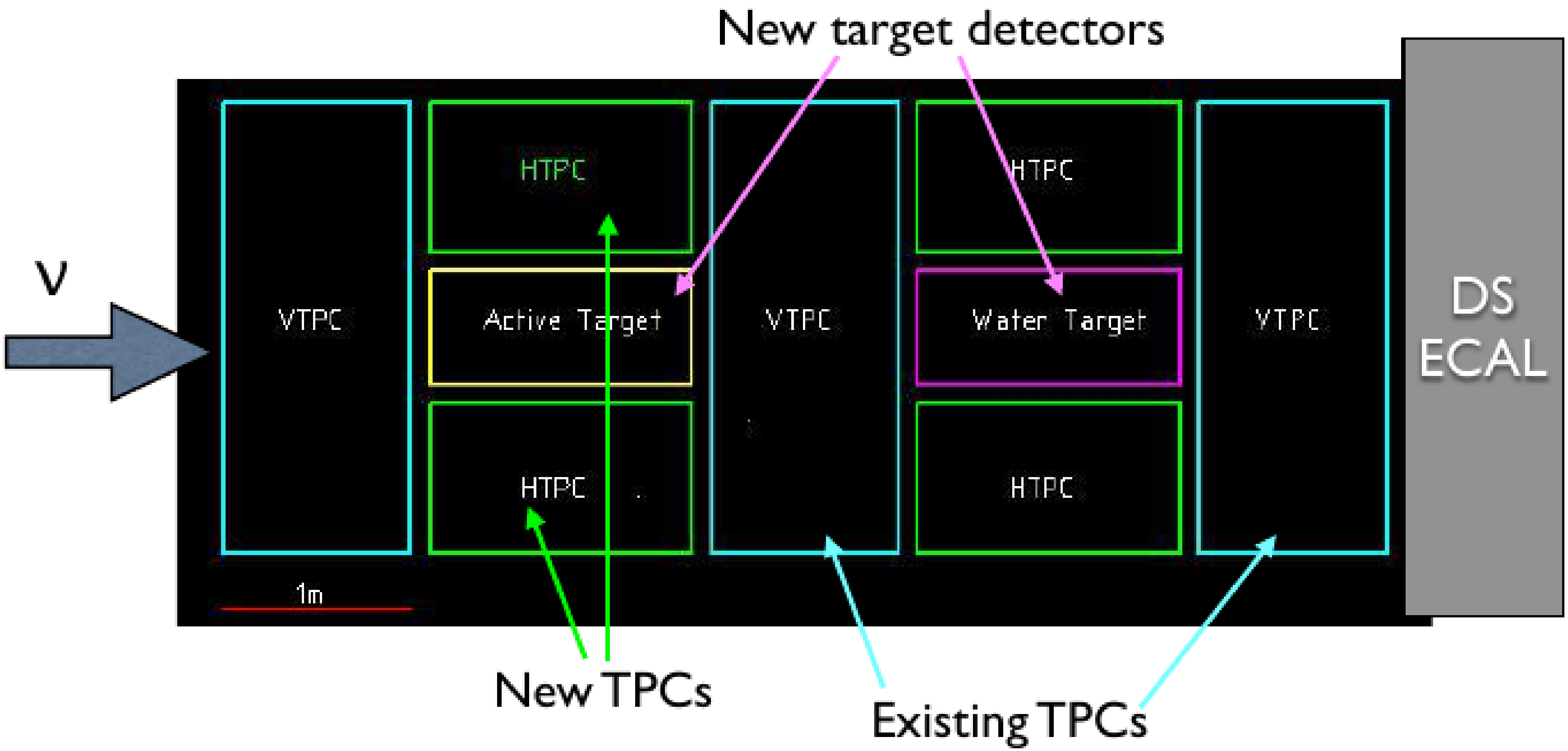
	$\delta_{N_{SK}}/N_{SK}$ (%)				
	1-Ring μ		1-Ring e		
Error Type	ν mode	$\bar{\nu}$ mode	ν mode	$\bar{\nu}$ mode	$\nu/\bar{\nu}$
SK Detector	3.9	3.3	2.5	3.1	1.6
SK Final State & Secondary Interactions	1.5	2.1	2.5	2.5	3.5
ND280 Constrained Flux & Cross-section	2.8	3.3	3.0	3.3	2.2
$\sigma_{\nu_e}/\sigma_{\nu_\mu}$, $\sigma_{\bar{\nu}_e}/\sigma_{\bar{\nu}_\mu}$	0.0	0.0	2.6	1.5	3.1
NC 1γ Cross-section	0.0	0.0	1.5	3.0	1.5
NC Other Cross-section	0.8	0.8	0.2	0.3	0.2
Total Systematic Error	5.1	5.2	5.5	6.8	5.9
External Constraint on θ_{12}, θ_{13}, Δm^2_{21}	0.0	0.0	4.1	4.0	0.8

New atmospheric-pressure TPCs for T2K



The "reference design"

Inside calorimeter and magnet (seen from side)



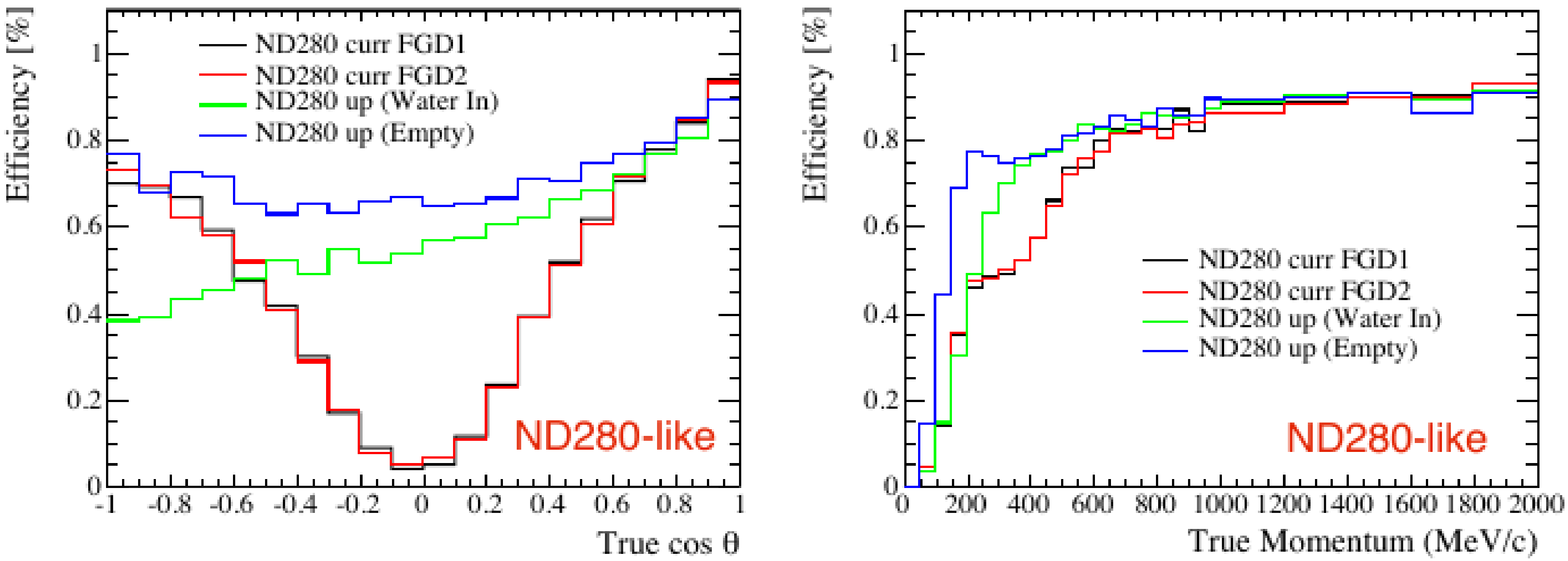
+scintillator planes around TPCs for timing

Reconfiguration + new detectors to cover full cosθ

Following talks assume this configuration

7

ND280 upgrade performance

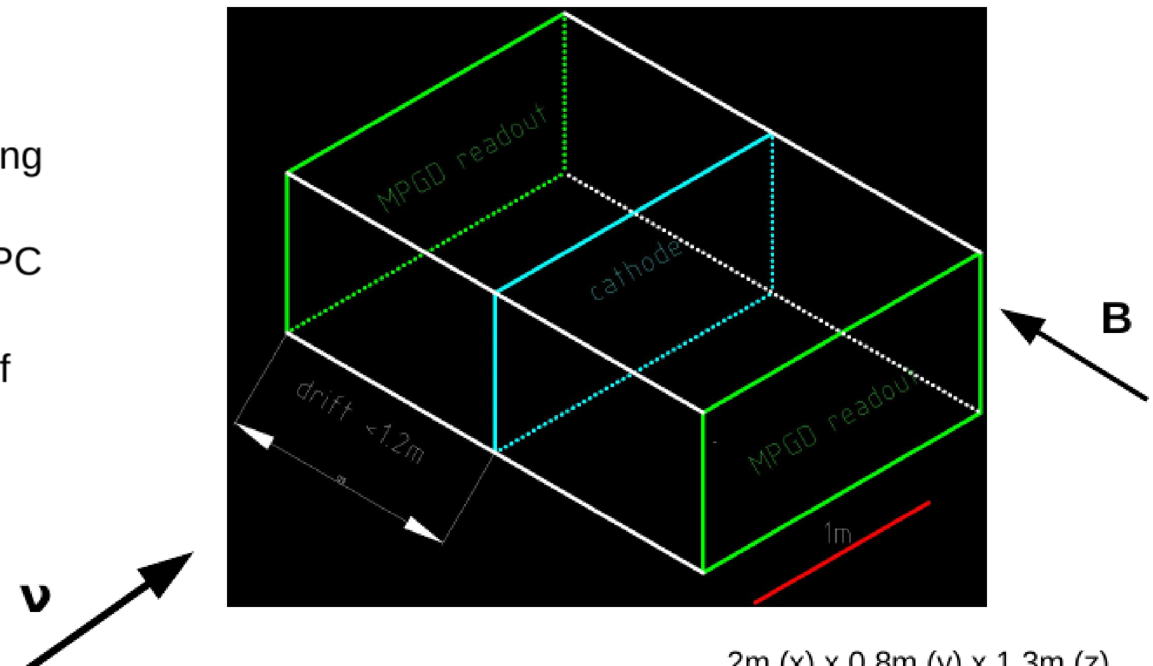


- Horizontal targets and new TPCs can measure very well the high angle region both for Water-in and Water-out WAGASCI targets
- At cosΘ~0 the efficiency is improved to >50% for water-in, ~70% for water-out
- Also momentum threshold is lower with the new configuration

New TPC for T2K Near Detector

Requirements for the new TPC

- Momentum resolution: same as for the existing TPC 10% at 1 GeV
- dE/dX resolution: same as for the existing TPC ~8% for a MIP gives ~ 4 σ e – μ separation
- This can be satisfied with a tracking length of ~70 cm for a vertical track
- And a similar pad size (~1 cm**2)



2m (x) x 0.8m (y) x 1.3m (z)

Parameter	Value	Comment
Overall dimensions	2 (x) x 0.8 (y) x 1.3 (z) m**3	4 identical TPC
Volume	2.1 m**3	Each
Drift Length	90 cm	Cathode in the middle
Pad area	~1 cm**2	
Sensitive area tot	7.3 m**2	Tot 4 TPC
N MM	~ 66	Tot 4 TPC with MM ~35x35 cm**2 each
N channels	7.3 10**4	Tot 4 TPC

Components of the new TPC

We had a full session with talks by

- I. Giomataris(CEA) MPGD
- F. Cadoux(Geneva Un.) Mechanical structure
- R. Guida (CERN), Gas system
- D. Calvet (CEA), M. Ziembicki (Warsaw), A. Oskarsson (Lund): Electronics
- J. Steinmann (RWTH Aachen) TPC Calibration
- Y. Kudenko (INR Moscow) TOF counters

How to improve the spatial resolution?

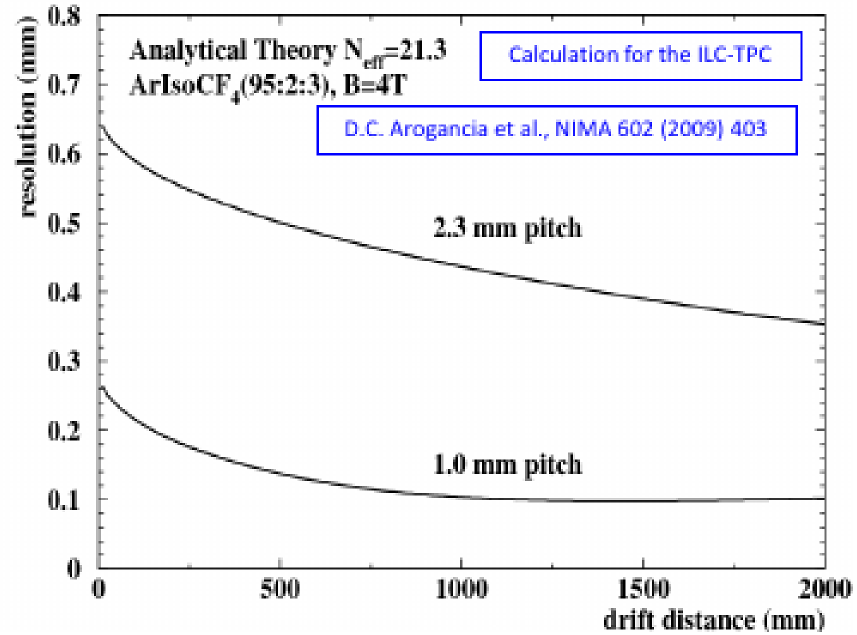
- Spatial resolution σ_{xy}:
  - limited by the pad size (s_0 ~ width/√12)
  - charge distribution narrow ($RMS_{avalanche}$ ~ 15 µm)

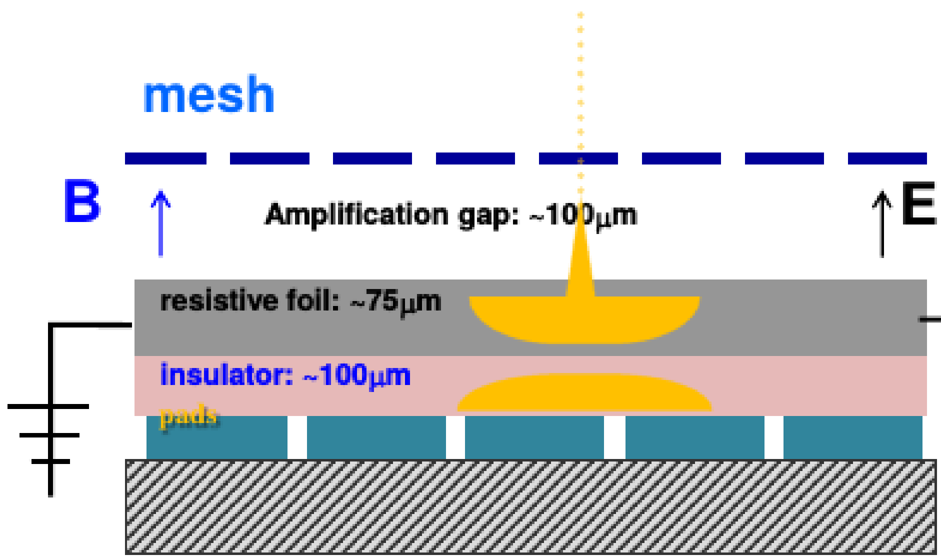
→ 1. Decrease the pad size: narrowed strips, pixels

→ - single electron efficiency
- Large number of read-out pixels

→ 2. Spread charge over several pads: resistive anode

+ reduce number of channels, cost and budget
+ protect the electronics
– limit the track separation





Equation for surface charge density function on the 2D continuous RC network:

$$\rho(r,t) = RC/2t \; exp(-r\uparrow 2 \; RC/4t)$$

$\rho(r,t)$: the surface charge density
R: the surface resistivity of the resistive layer
C: the capacitance per unit area.

5

Fabricating large detector

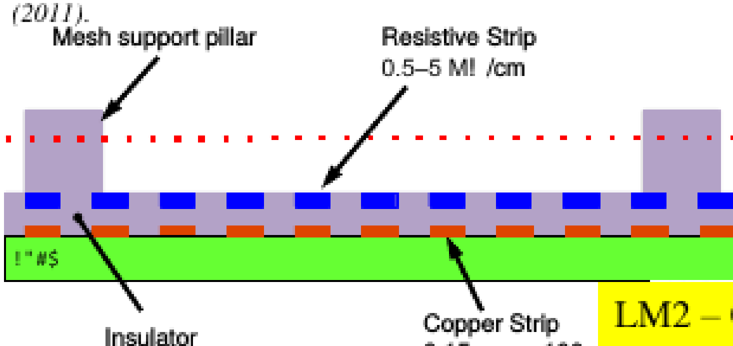
Construction of large chambers in ATLAS

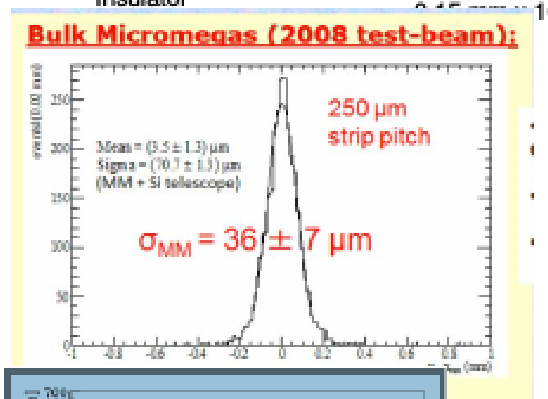
Goal : 1200 m2 total detector surface

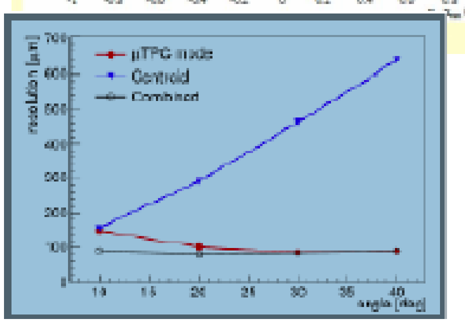
ATLAS Resistive strip technology

Joerg Wotschack, Mod.Phys.Lett. A28 (2013) 1340020

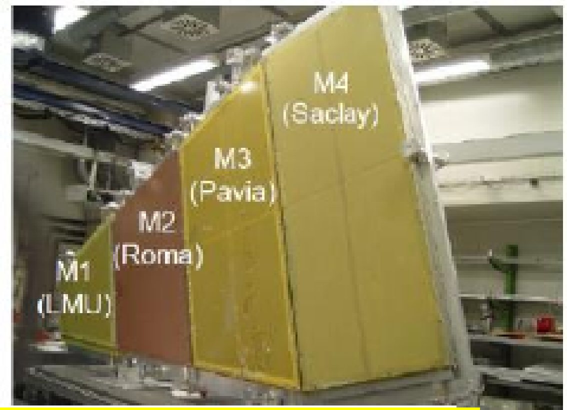
T. Alexopoulos, et al. Nucl. Instrum. Meth. A 640, 110-118, (2011).



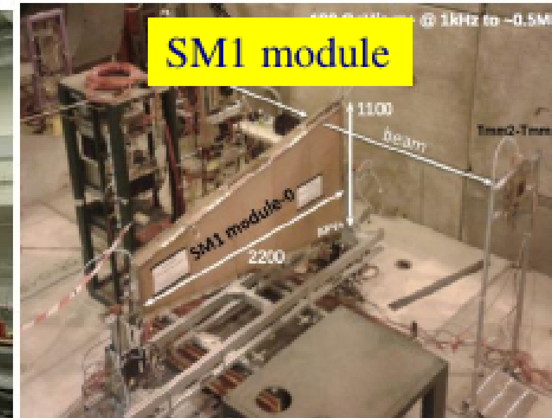




Industrialization is going on through ELVIA, ELTOS



SM1 module



LM2 – CERN / Dubna -Thessaloniki

SM2 – Germany

At Saclay the large clean room is ready and operational
First M0 module is under construction and soon will be tested

R. Guida

Gas systems for the LHC experiments

- The basic function of the gas system is to mix the different gas components in the appropriate proportion and to distribute the mixture to the individual chambers.
- 30 gas systems (about 300 racks) delivering the required mixture to the particle detectors of all LHC experiments.
- Gas mixture is the sensitive medium where the charge multiplication is producing the signal.
- Correct and stable mixture composition are basic requirements for good and stable long term operation of all detectors.

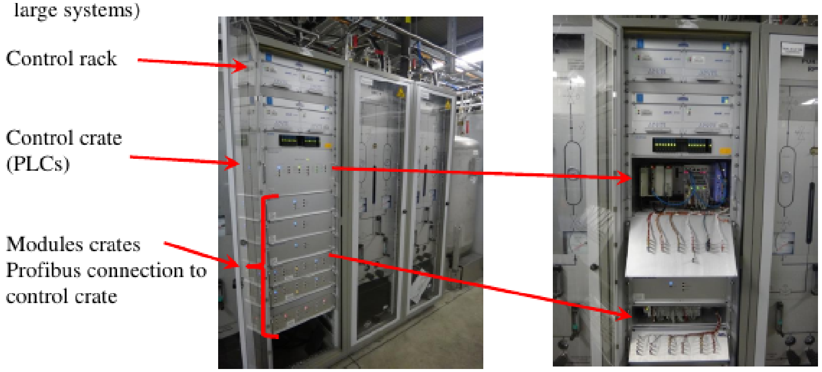
Summary of the sub-detector gas systems at the LHC experiments.

14 Closed loop detector gas system; 11 Single pass detector gas systems
3 Flushing systems for N_2, CO_2, and compressed air

LHC Point 1 ATLAS	LHC Point 2 ALICE	LHC Point 5 CMS and TOTEM	LHC Point 8 LHCb
MDT	TPC	DT	OT
CSC	TRD	CSC + CF_4 recovery	Muon MWPC
TGC	TOF	RPC	Muon GEM
RPC	HMPID	T1-CSC (Totem)	RICH1
TRT	CPV	T2-GEM (Totem)	RICH2
LUCID(*)	PMD	SX5 + 904(*) Mixers	
ID flushing	Muon Track.	ID Flushing	
TRT CO_2 Cooling	Muon Trig.		

phase and max modularity for large systems)

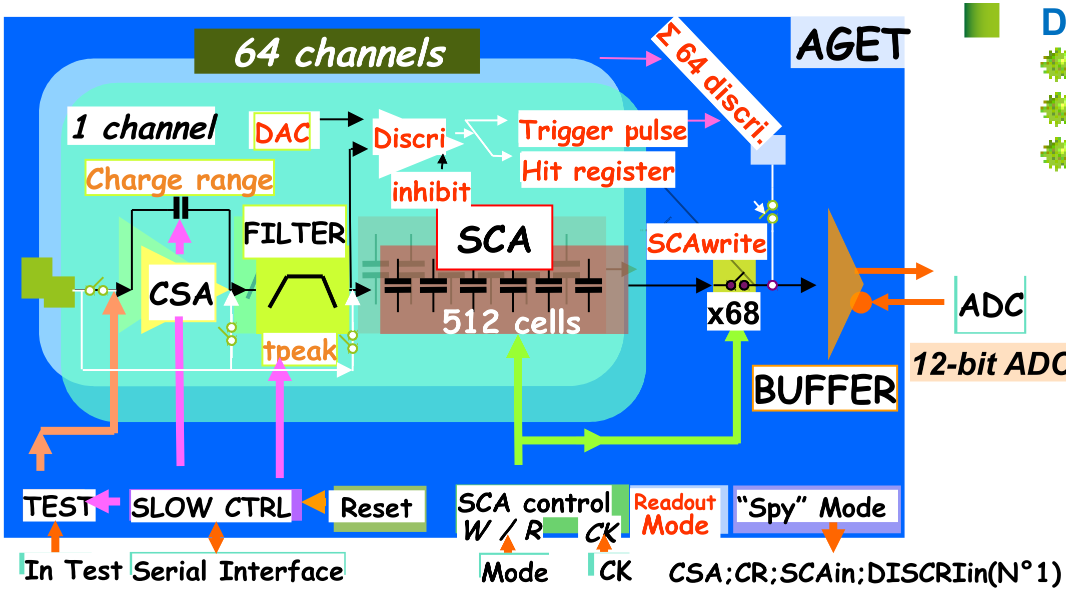
Modular system with these building blocks: Supply, monitor, mixer, purification, analysis



FRONT-END ASIC: FROM AFTER[1] TO AGET[2]

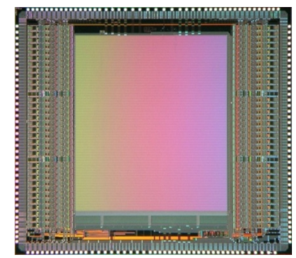
[1] built for the T2K neutrino oscillation experiment [2] Built by the GET collaboration for active target TPCs

D. Calvet



Design facts of AGET

- 0.35 µm AMS CMOS
- 28 x 28 mm 160-pin LQFP
- Pin-compatible with AFTER (8 channel less)



Main characteristics

- ~~72~~ 64* channels, pos/neg set by register, 120 fC to 10 pC (4 ranges), 100 ns-1 µs peaking (16 values)
- ~~511~~ 512 time-bin SCA. Sampling: 100 MHz max. Requires external ADC, 12 bit / 25 MHz max
- Self trigger: 1 discriminator per channel; Analog multiplicity signal. Can be used to make L1 trigger
- Hit Channel Register: hit pattern can be used to make L2 trigger. Hit pattern can be modified before SCA digitization, e.g. enable channels which are neighbor to hit channels
- SCA readout modes: all channels, hit channels only, channel set defined on-the-fly
- Optional internal charge sense amplifier and filter bypass for use with external preamplifiers
- SCA split mode: 2 banks of 256 time-bins. Can take 2 triggers close apart before digitization

* In red: differences between AFTER and AGET

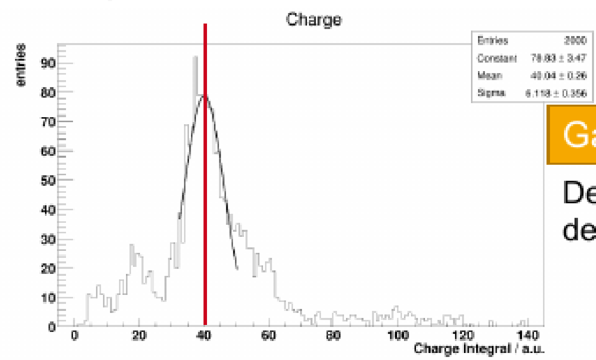
J. Steinmann

TPC calibration

Monitoring chambers for drift velocity and gain calibration

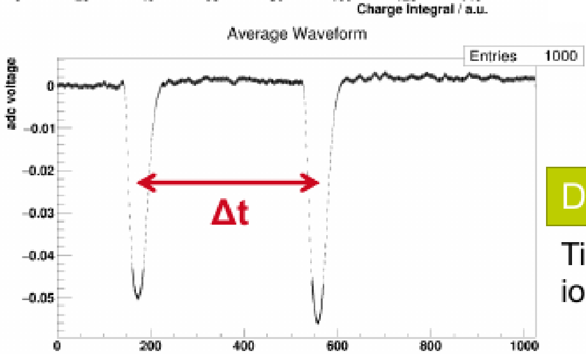
Gas Monitoring System (ND280)

- Two identical chambers for supply and return gas
- Sequential measurement of drift velocity and gain



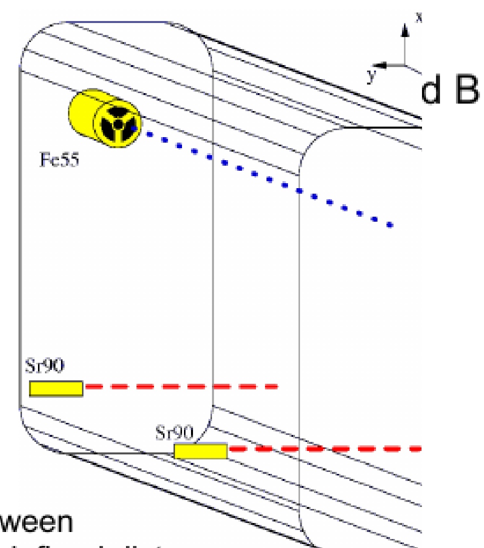
Gain Measurement

Detected charge from defined deposition

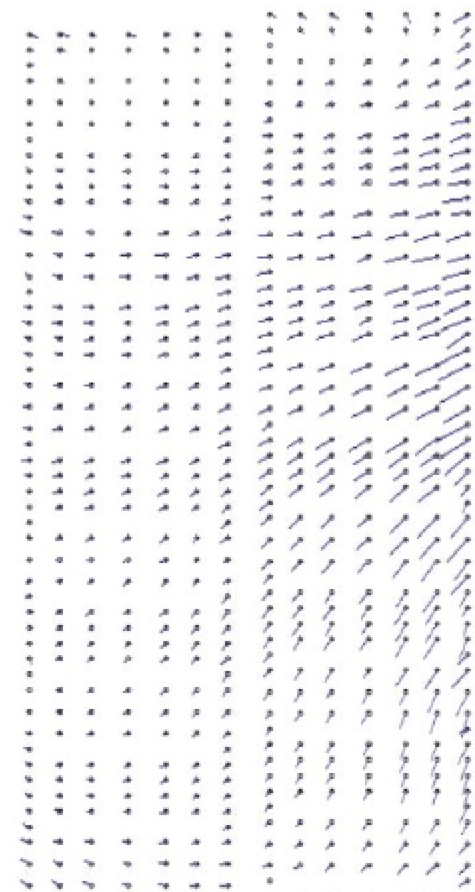


Drift Velocity

Time difference between ionization tracks of defined distance

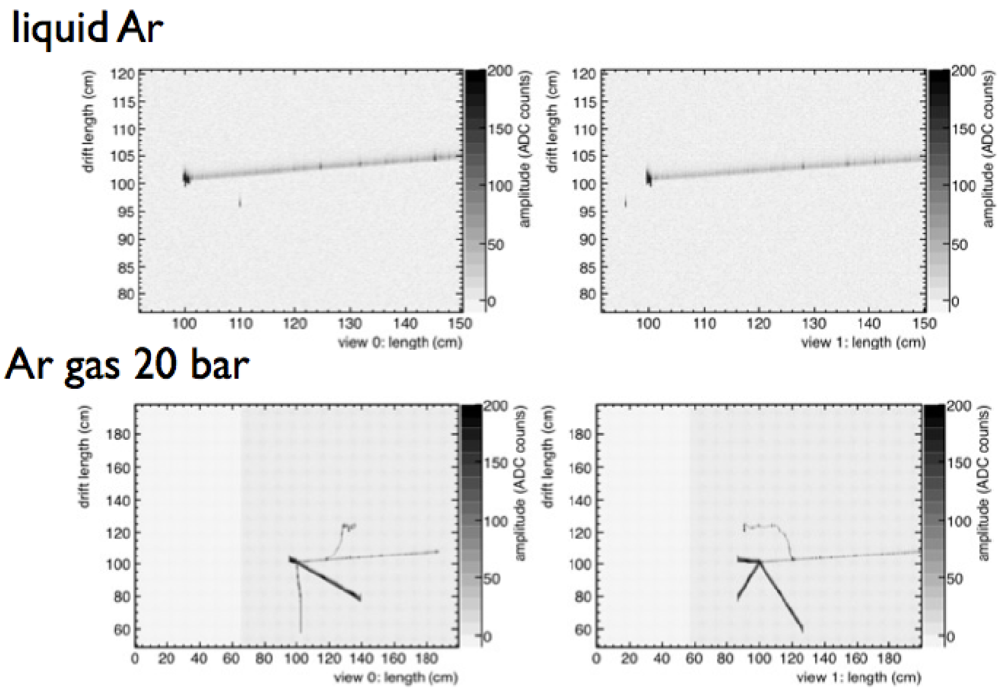


Laser calibration for E and B field distortions

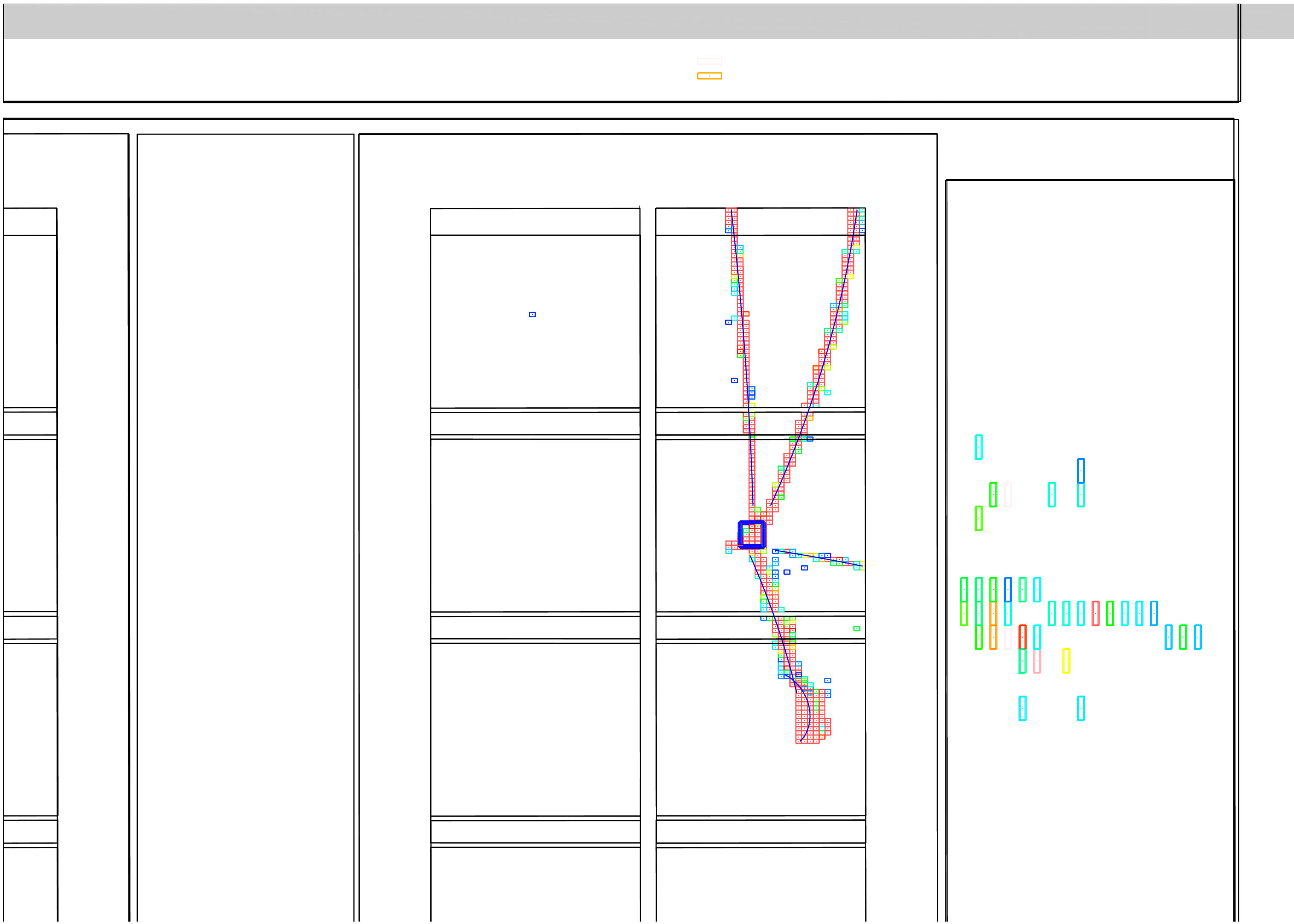


Displacement caused by B-field

A high pressure TPC for neutrino long baseline experiments



T2K TPC: ν interaction in the gas



HPTPC Event rates

CC-inclusive interactions per 10^{21} POT

Gas	mass, **40 m³** at 10 bar, 30 C	JPARC (0.6 GeV)	FNAL (2–4 GeV)*
He	63.6 kg	4.19E+03	1.46E+05
Ne	317 kg	2.10E+04	7.29E+05
Ar	636 kg	4.19E+04	1.46E+06
CF_4	1397 kg	9.23E+04	3.21E+06

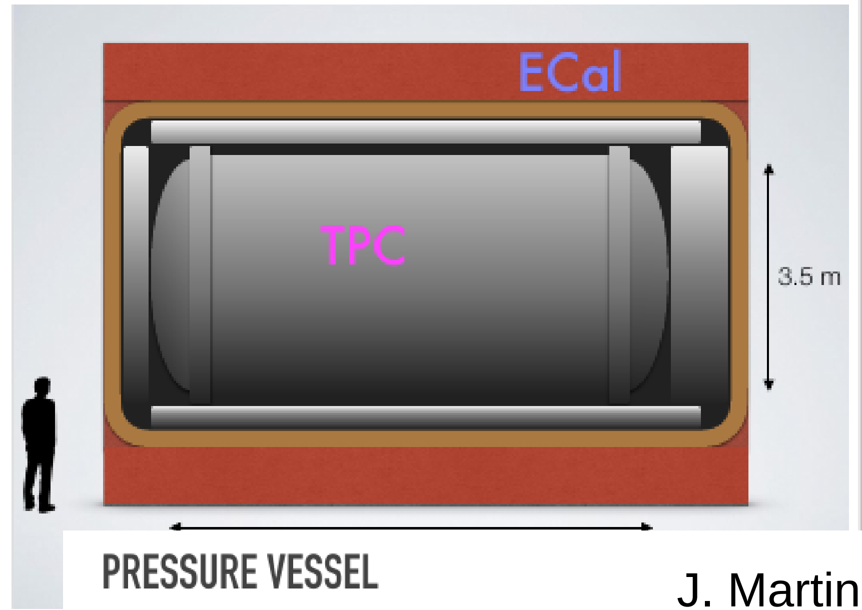
These J-PARC and FNAL numbers were calculated in a consistent manner.
*Using LBNE flux, c.2013

A. Kaboth

Gaseous Argon TPC

A high pressure TPC is under study as DUNE near detector

- 3.5 m x 6.5 m TPC
- Surrounded by an ECal



PRESSURE VESSEL

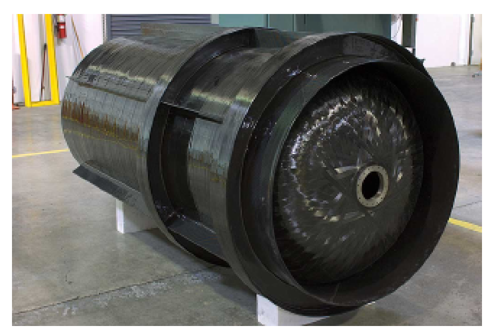
J. Martin-Albo

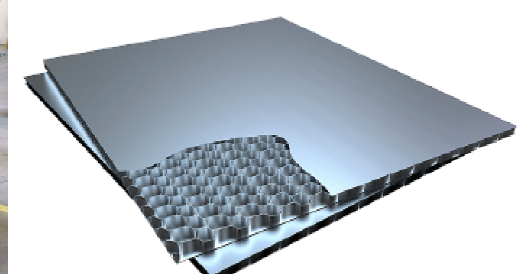
- Titanium alloy UNS-R56323
  - Wall thickness: barrel, 9 mm (0.25X_0); endcaps, 17 mm (0.5X_0).
  - Mass: ~13 tonnes.
- Stainless steel 304L
  - Wall thickness: barrel, 15 mm (1X_0); endcaps, 27 mm (2X_0).
  - Mass: ~20 tonnes.

Calculations by S. Cárcel (IFIC, Valencia) following ASME code and assuming torispherical endcaps.

PRESSURE VESSEL

J. Martin-Albo

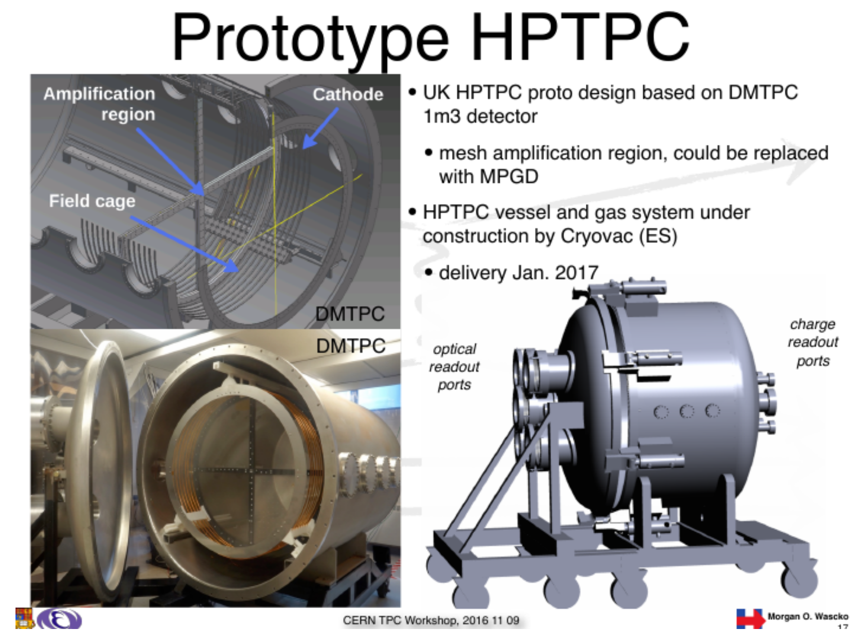




Possible lighter alternatives: composite materials or aluminium honeycomb?

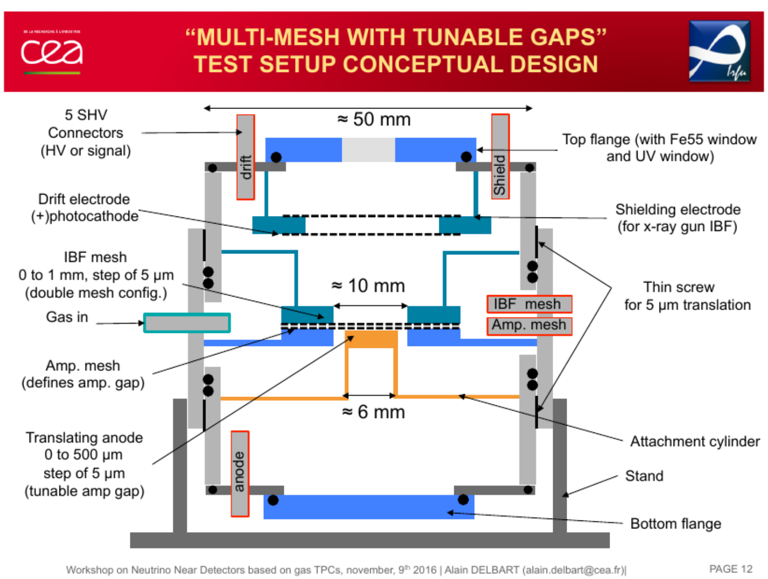
High pressure TPC

M. Wascko

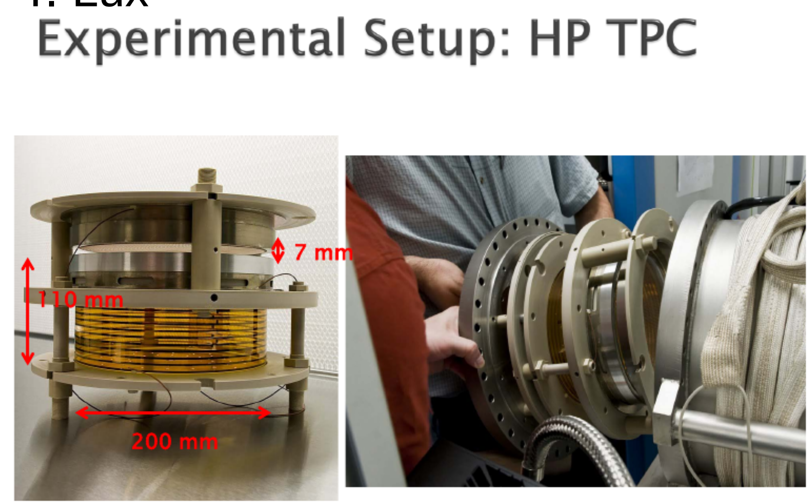


- HPTPC R&D in Spain for neutrinoless double beta decay (JJ Gomez Cadenas)
- HPTPC R&D in Japan for neutrinoless double beta decay (T. Nakaya)
- HPTPC R&D in Spain for DM (F. Iguaz-Gutierrez)
- HPTPC Studies for DUNE (J. Martin-Albo Simon)
- HPTPC R&D in UK for CPV (M. Wascko)
- HPTPC R&D in Spain for LB neutrinos (T. Lux)
- HPTPC R&D in France (A. Delbart)

A. Delbart

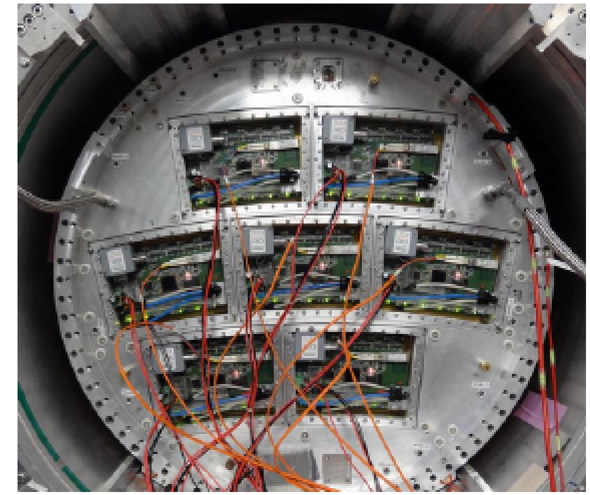


T. Lux



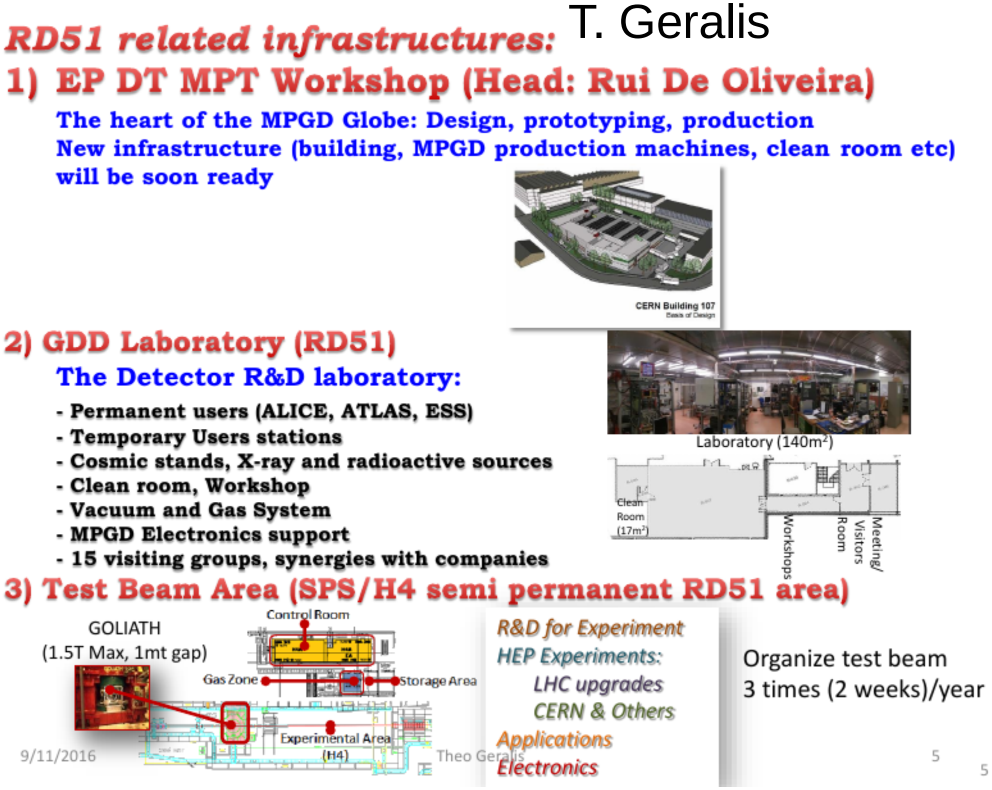
Facilities and ongoing R&D

F. Mueller

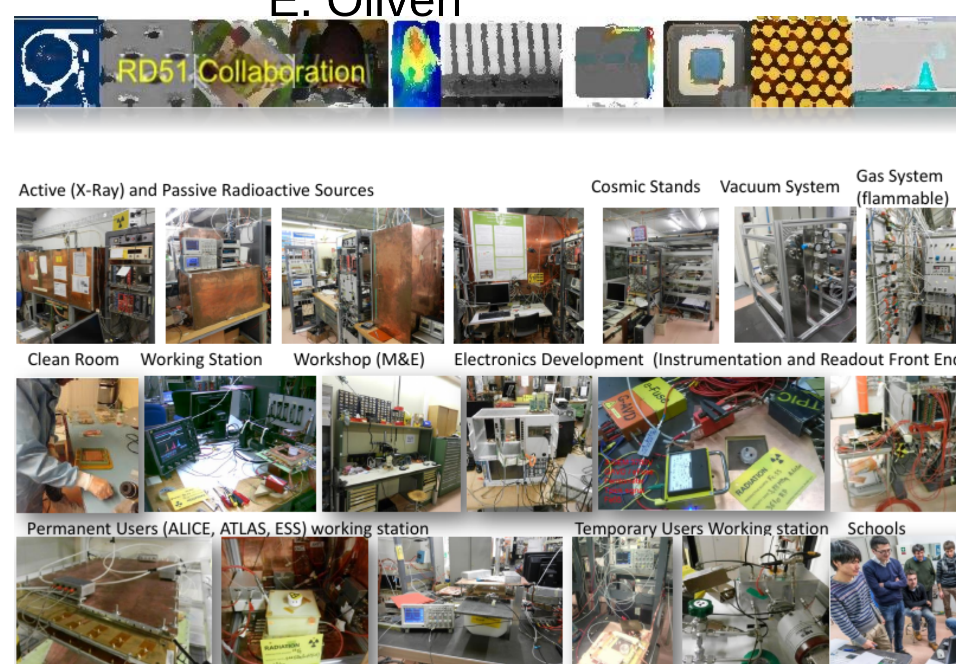


A session of the workshop was dedicated to the RD51 coll. and its facilities, and to ongoing R&D like the ILD TPC

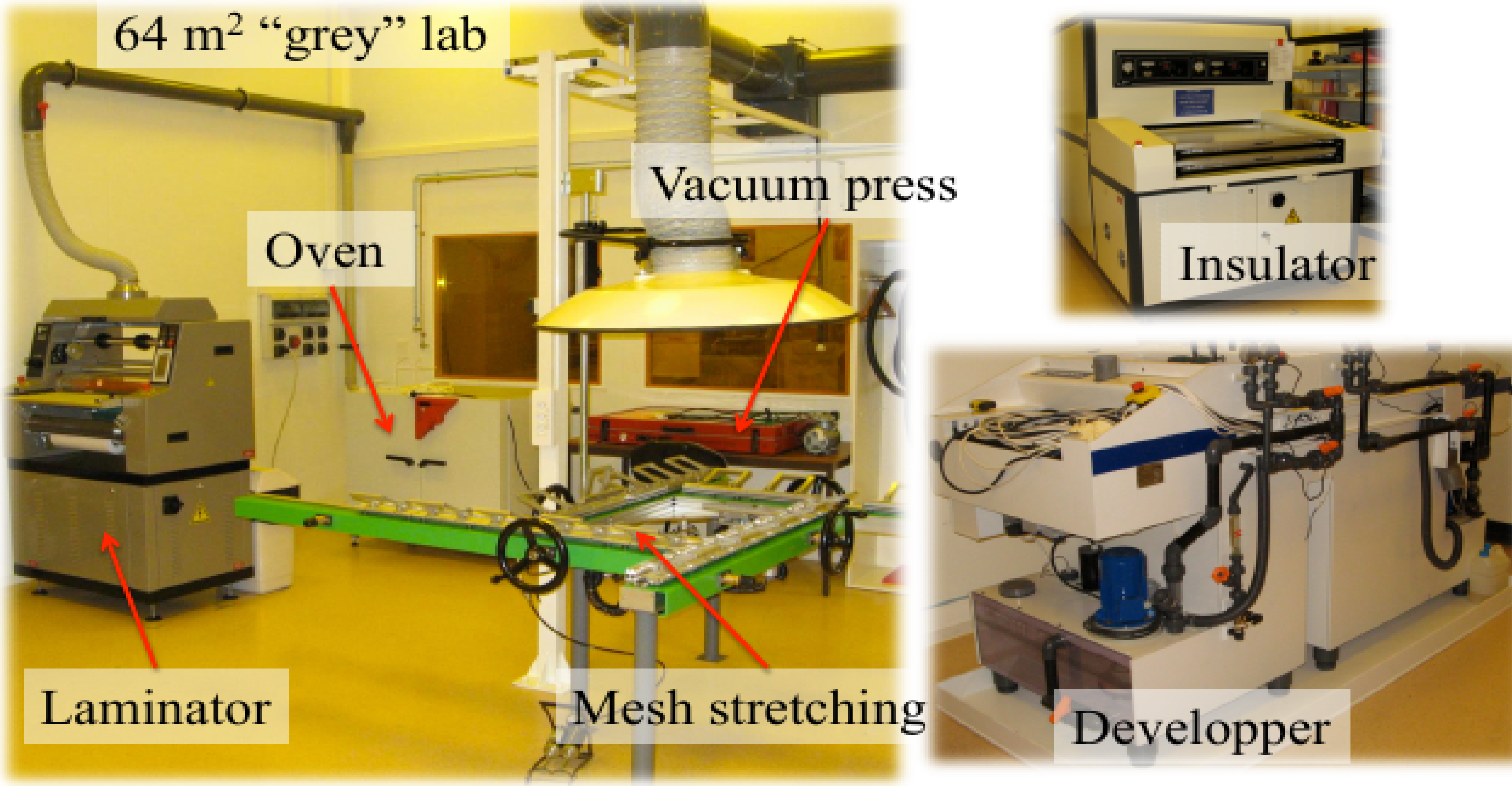
T. Geralis



E. Oliveri



THE IRFU / MPGD WORKSHOP



+ A screen printing machine for resistive coating on anode strips (up to 60x60 cm^2)
+ A 120 m^2 class 7 clean room (ATLAS/NSW), a 30 m^2 class 8 & a 20 m^2 class 7

The mesh stretching equipmentis for meshes sizes up to 1.5 x 1.5 m^2

Next steps

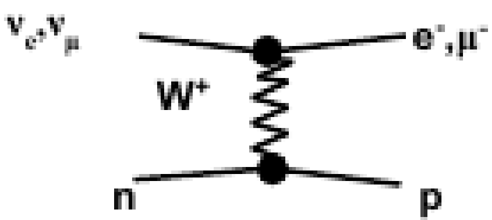
- An expression of interest on TPC-based near detector for neutrino experiment is in preparation, to be submitted to SPSC, in synergy with a High Pressure TPC R&D
- Next meeting in London in February-March 2017
- There are plans toward a prototype to be tested at CERN towards the end of 2017
- Wonderful opportunity to build a state-of-the-art TPC detector, learn about neutrino interactions and join the world-leading long-baseline experiment
- Please contact us if you are interested
- New collaborators are welcome!

Back-up slides

M. Hartz

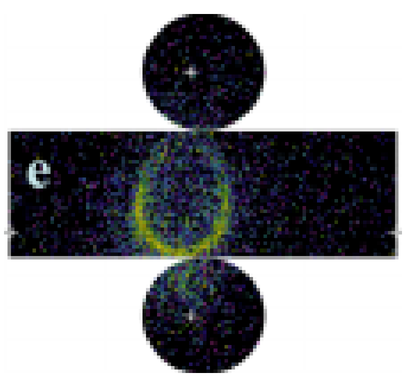
BEAM, OSCILLATIONS AND INTERACTIONS

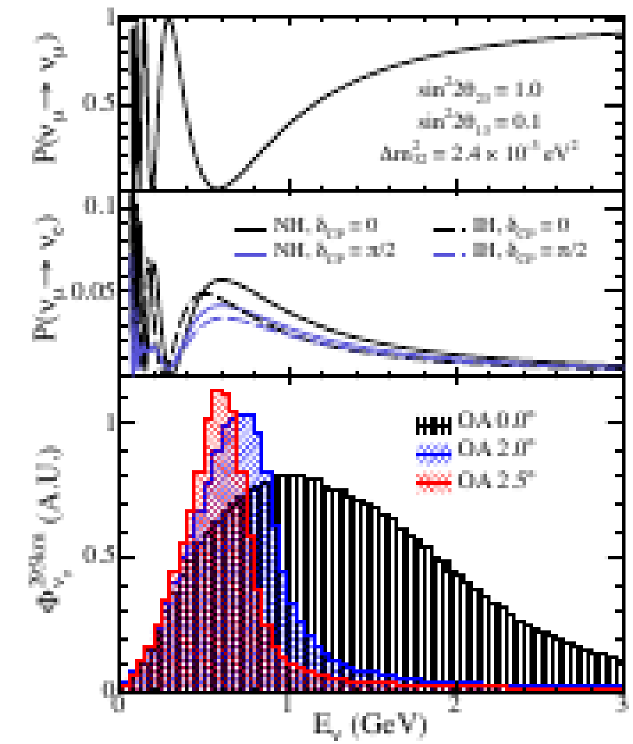
- Off-axis beam = narrow band spectrum peaked at first oscillation maximum
- Predominantly CCQE interactions at the peak energy:

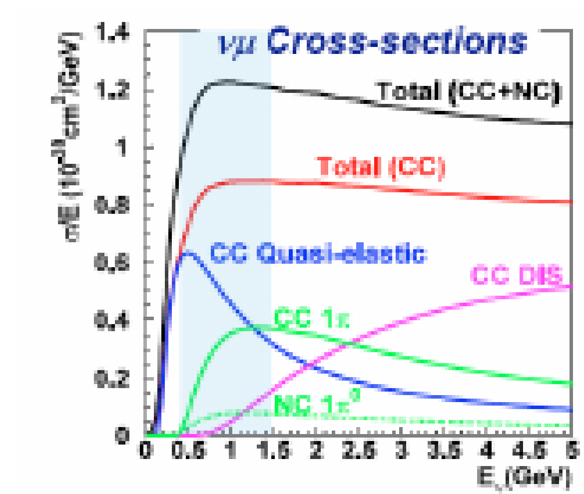


T2K signal at SK

- Signal candidates in water Cherenkov detector are single ring lepton candidates

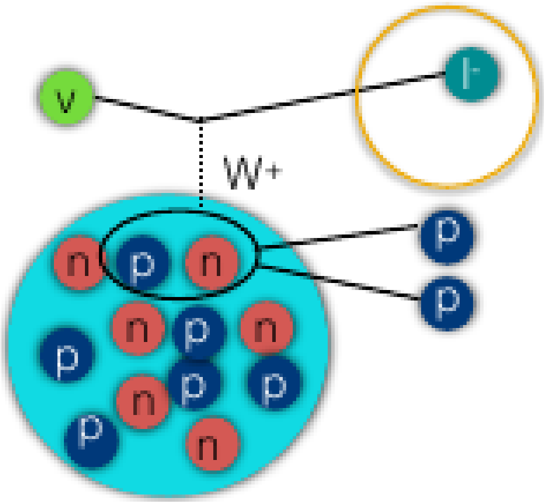






NON-CCQE INTERACTIONS

Can have CC interactions where only a lepton candidate is visible, but interaction was not CCQE

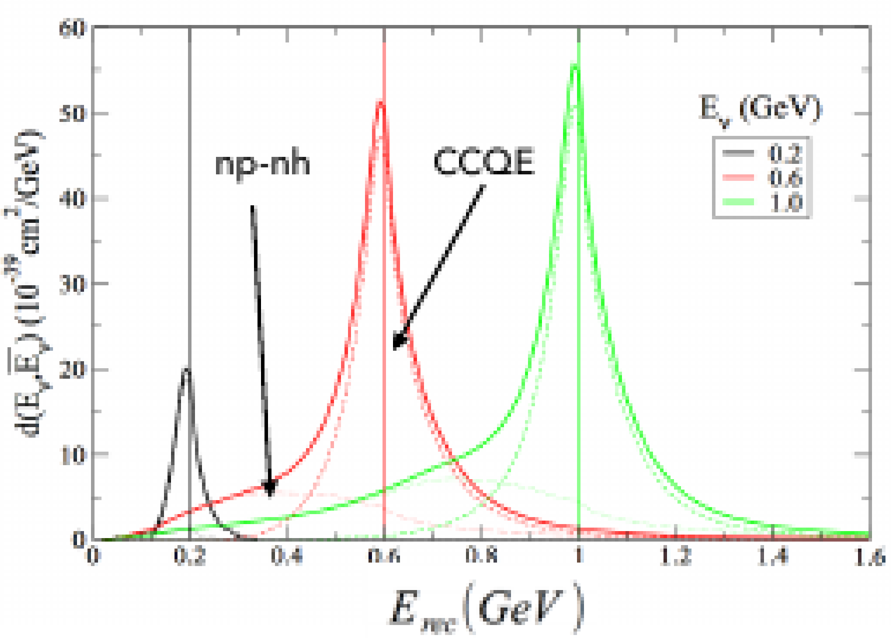


Example is np-nh (multi-nucleon) scattering processes

Can also happen when pion is produced and absorbed

These events have different final state lepton kinematics. If we infer the neutrino energy with CCQE assumption, bias is observed

Martini et. al.
Phys.Rev. D87 (2013) 013009



$$E_\nu^{rec} = \frac{2(m_n - V)E_\ell + m_p^2 - (m_n - V)^2 - m_\ell^2}{2(m_n - V - E_\ell + p_\ell \cos\theta_\ell)}$$

T2K-II: EXTENDED T2K OPERATION

T2K has received Stage-1 approval from the J-PARC PAC for program to extend operation to 2026: collect 20×10^{21} POT (~3 times original T2K proposal)

Expect beam power to reach 1.3 MV

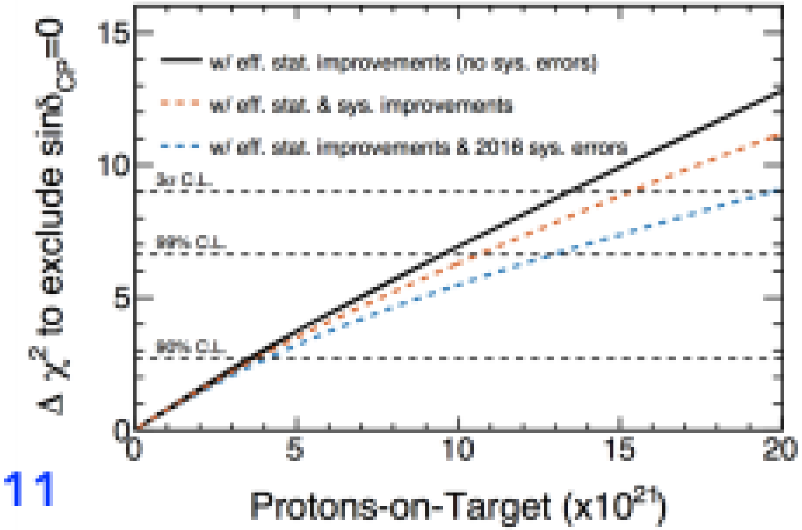
	True δ_{CP}	Total	Signal $\nu_\mu \to \nu_e$	Signal $\bar{\nu}_\mu \to \bar{\nu}_e$	Beam CC $\nu_e + \bar{\nu}_e$	Beam CC $\nu_\mu + \bar{\nu}_\mu$	NC
ν-mode	0	467.6	356.3	4.0	73.3	1.8	32.3
ν_e sample	$-\pi/2$	558.7	448.6	2.8	73.3	1.8	32.3
$\bar{\nu}$-mode	0	133.9	16.7	73.6	29.2	0.4	14.1
$\bar{\nu}_e$ sample	$-\pi/2$	115.8	19.8	52.3	29.2	0.4	14.1

Will collect ~500 electron neutrino and ~125 electron antineutrino candidates

3 sigma CP violation discovery potential for favorable value of $\delta_{cp}=-\pi/2$

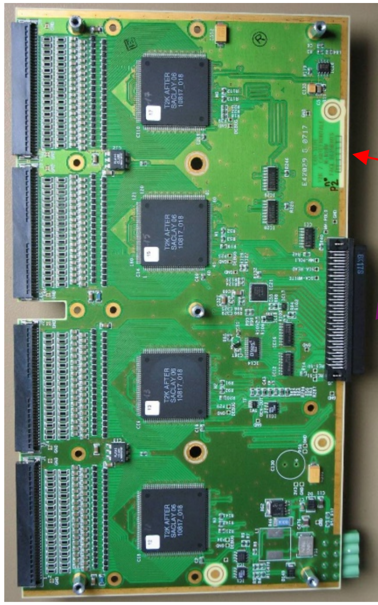
Reduction of systematic errors beyond current T2K errors can improve the experimental sensitivity

arXiv:1609.04111



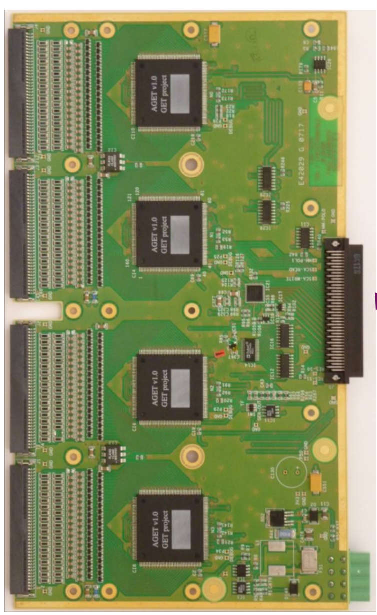
THE FEMINOS: AN EVOLUTIVE SYSTEM COMPATIBLE WITH AFTER AND AGET

D. Calvet



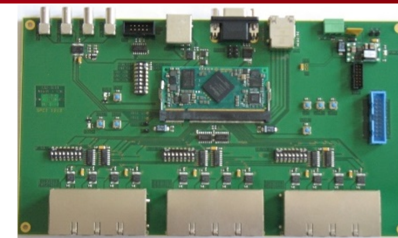
T2K FEC: 4 AFTER chips
288-channels

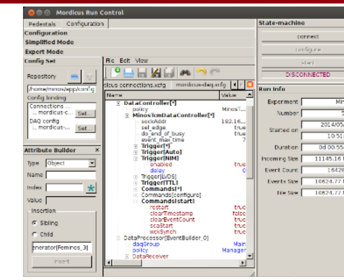
OR

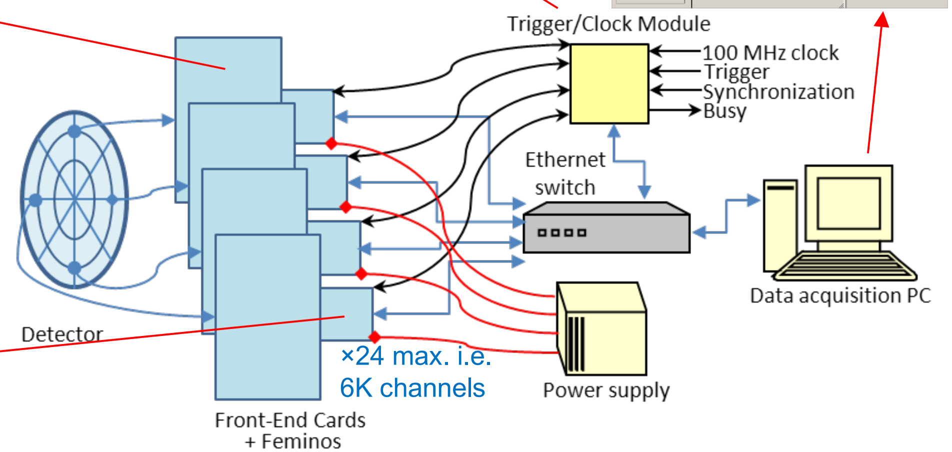


MINOS FEC: 4 AGET chips
(pin-compatible with AFTER)
256-channels

FEMINOS Board







- Main features
  - For small to medium scale systems 6K channels
  - Close to the lowest possible dead-time of AFTER and AGET to reach high event rate
  - External trigger or basic self trigger on multiplicity
  - Low cost system in a light infrastructure

- Feminos system used in ~10 different projects
- Production halted. Improved version being designed