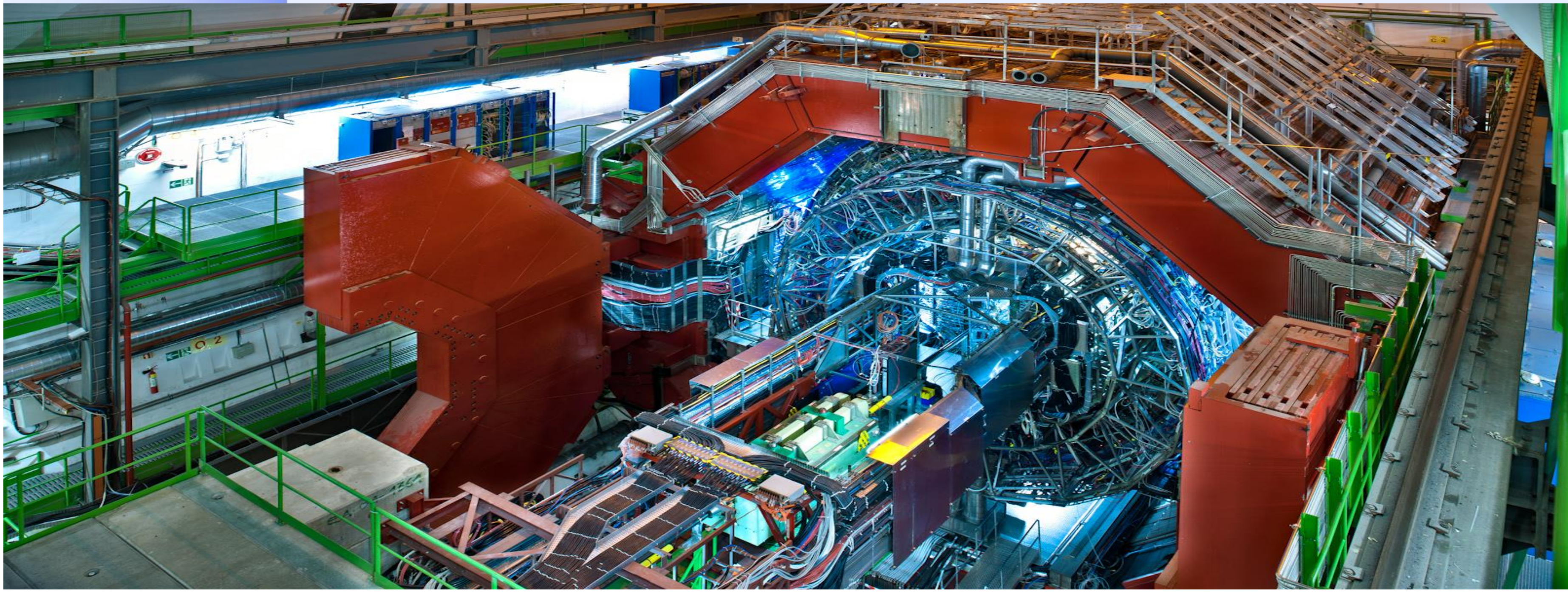
Десятые Черенковские чтения

Новые методы в экспериментальной ядерной физике и физике частиц

Москва, ФИАН, 18 апреля 2017 г.



Быстродействующие черенковские детекторы для триггерной и времяпролетной систем супердетектора АЛИСЕ Большого адронного коллайдера ЦЕРН

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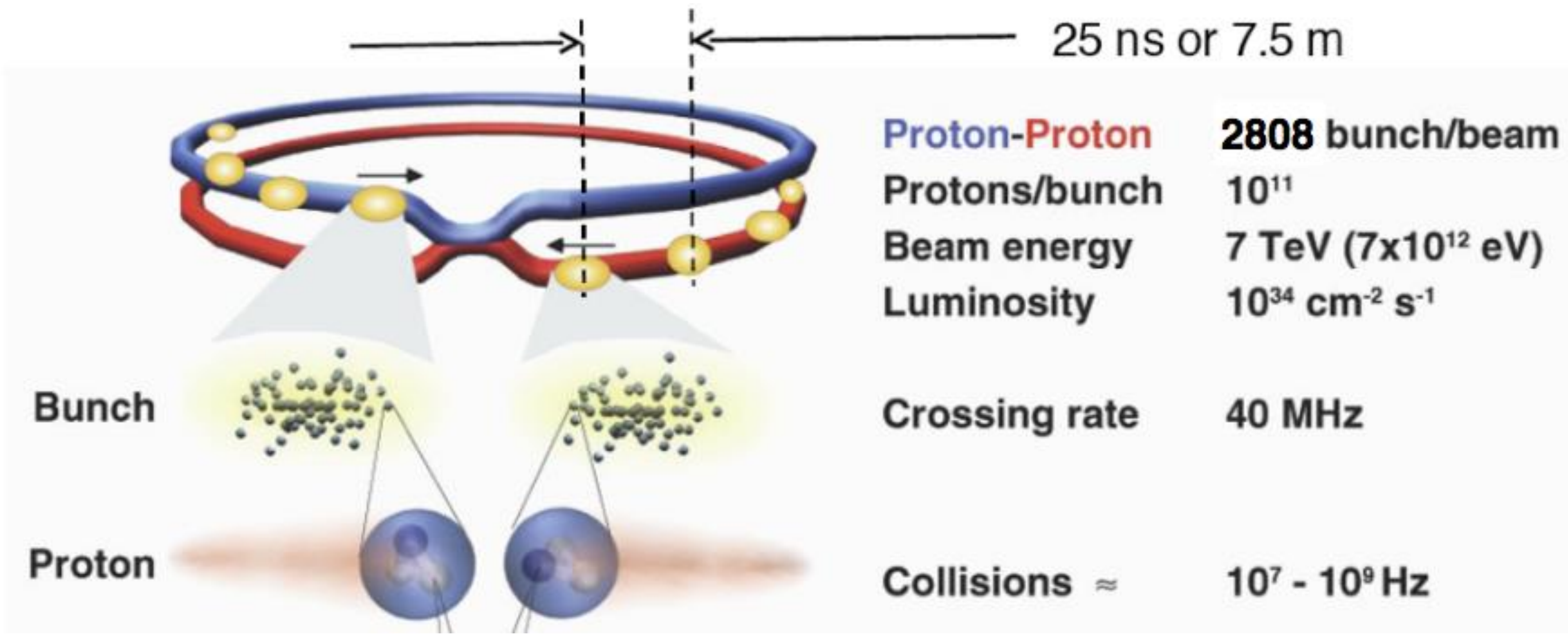
Outline

- **Experiment ALICE**
- **Cherenkov Detector T0**
- **LHC injectors upgrade during** LS2 (2019 – 2020)
  - Impact on ALICE detectors
- **Concept and functionality of FIT**
- **Performance of the prototypes**
  - Cherenkov radiator + MCP-PMT
- **Conclusion**

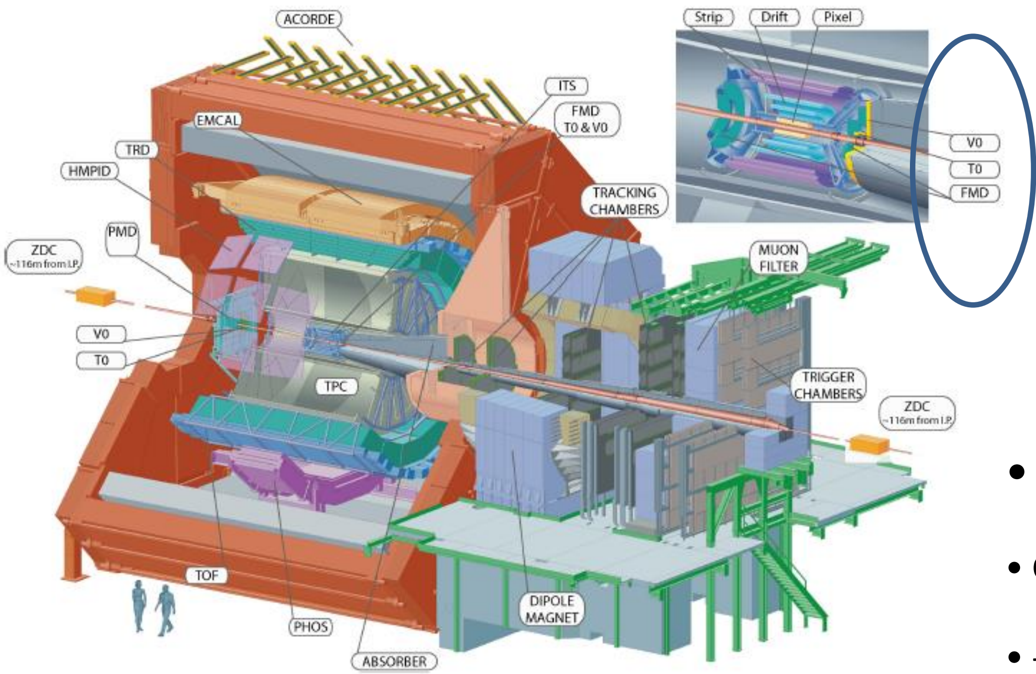
Эксперименты на LHC

Эксперименты на LHC

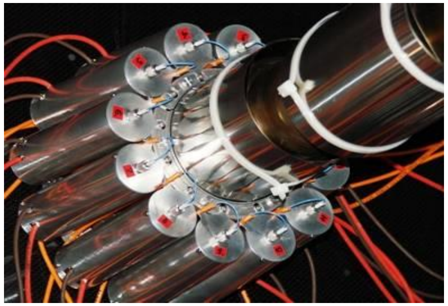
Filling scheme



The present ALICE detector



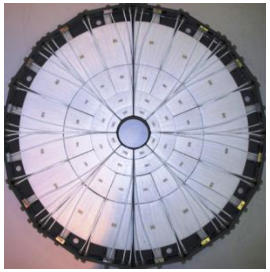
Current T0



- T0 consists of two arrays, placed on the opposite sides of the IP
- Cherenkov radiators, each coupled to PMTs (12 per module)
- $-5 < \eta < -4.5$, $2.9 < \eta < 3.3$

Time resolution of ~ 40ps for protons and ~25ps for PbPb collisions

Current V0



- V0 consists of two arrays of 32 scintillating counters
- Installed on opposite sides of IP
- Scintillators coupled to PMTs by fibers

$-3.7 < \eta < -1.7$, $2.8 < \eta < 5.1$

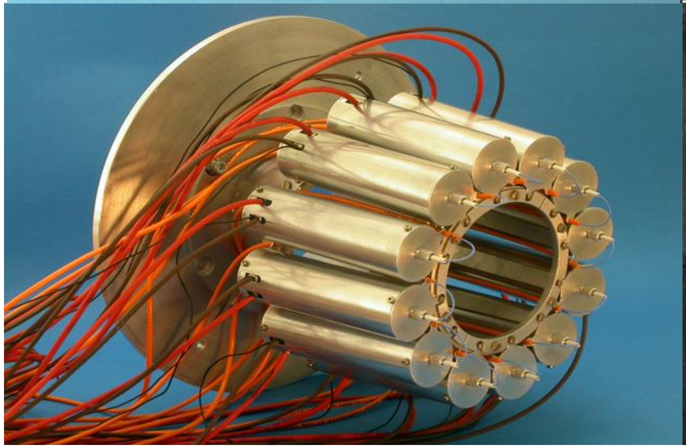
Time resolutions of about 450 ps and 350 ps are achieved for V0-A and V0-C

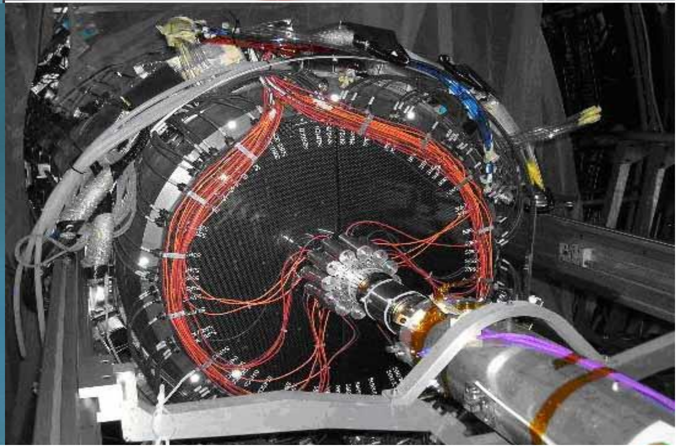
V0 & T0 Provide triggers, luminosity monitoring, background reduction, collision time (for PID), centrality, and event plane determinations

Design considerations

- detectors **on both sides** of the interaction point
- **compact design** (minimal space on RB 26 side)
- time resolution of **about 50 ps**;
- position resolution (along the beam direction) **≈ 1 cm**;
- **laser calibration** system;
- total dead time of **less than 25 ns**;
- maximum rate (bunch crossing) of **40 MHz**;
- operation in the magnetic field of **up to 0.5 Tesla**;
- radiation hardness **up to 500 krad**;
- reasonable **multiplicity resolution** for charged particles.

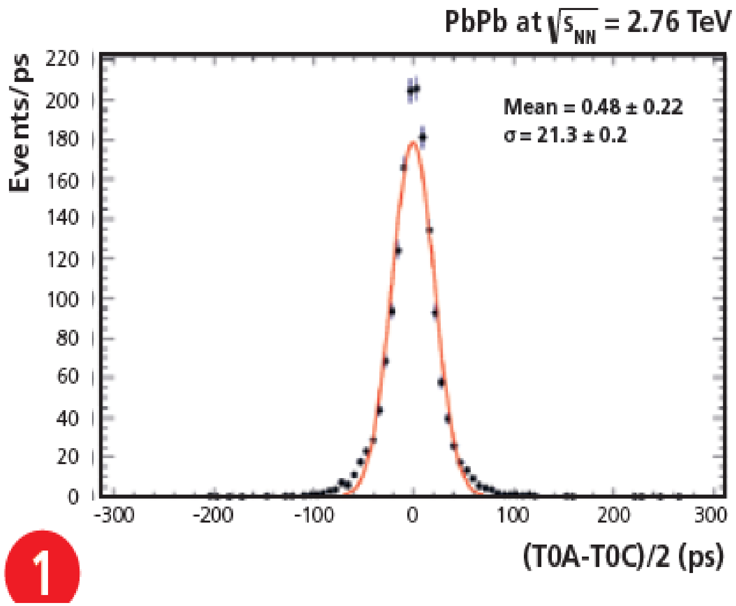
T0-C & T0-A production





WORKING ON T0 DETECTOR

Detector performance



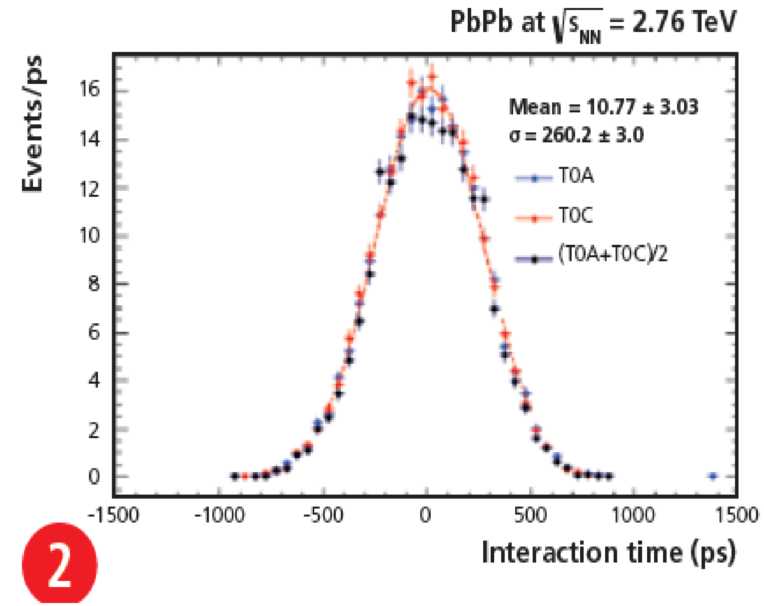
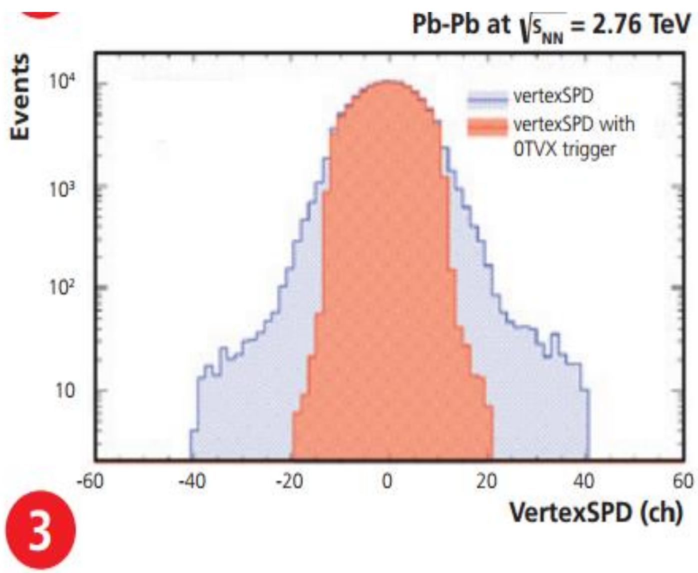


Figure 1 shows the time distribution of (T0A-T0C)/2 after slewing and vertex correction. The time resolution of the T0 detector is ~ 25 ps

Figure 2 shows the time distribution of the summed arrival times inT0A and T0C (interaction time) in Pb-Pb collisions at $\sqrt{S_{NN}}$ = 2.76 TeV.

Detector performance



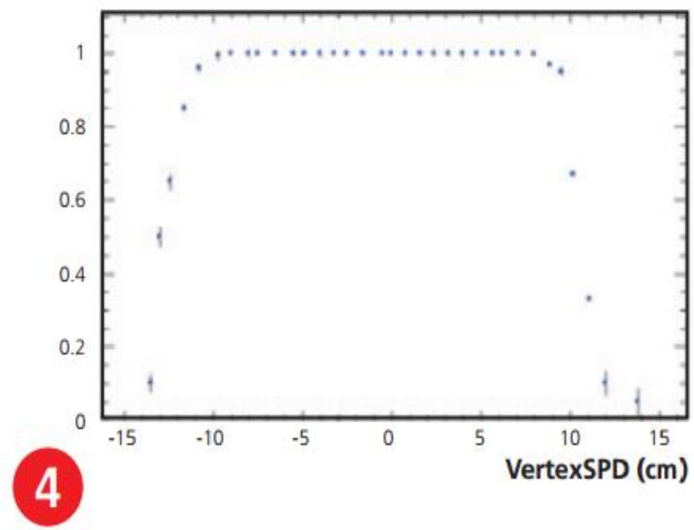
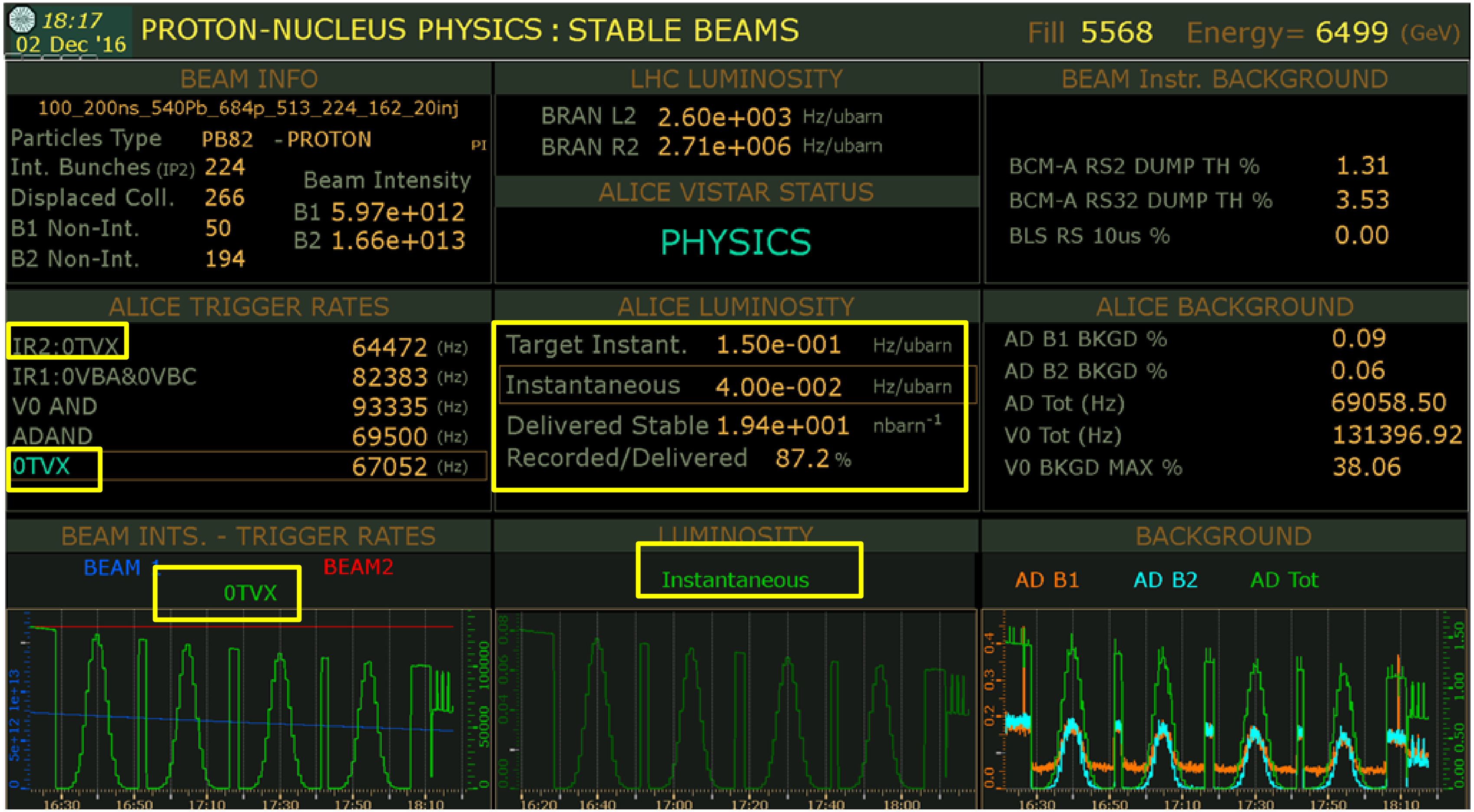


Figure 3 : Background rejection by T0

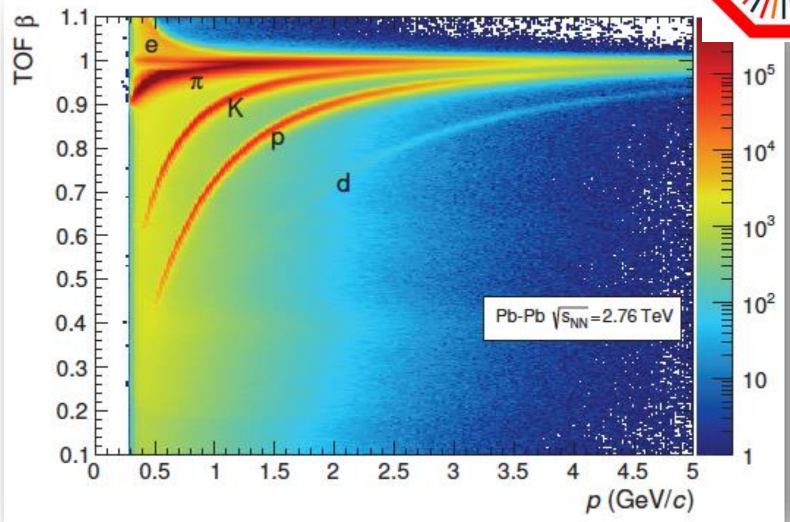
Figure 4 : T0 vertex trigger efficiency during Pb-Pb runs at $\sqrt{s_{NN}}$ = 2,76 TeV for central and semi-central events (0-50%)

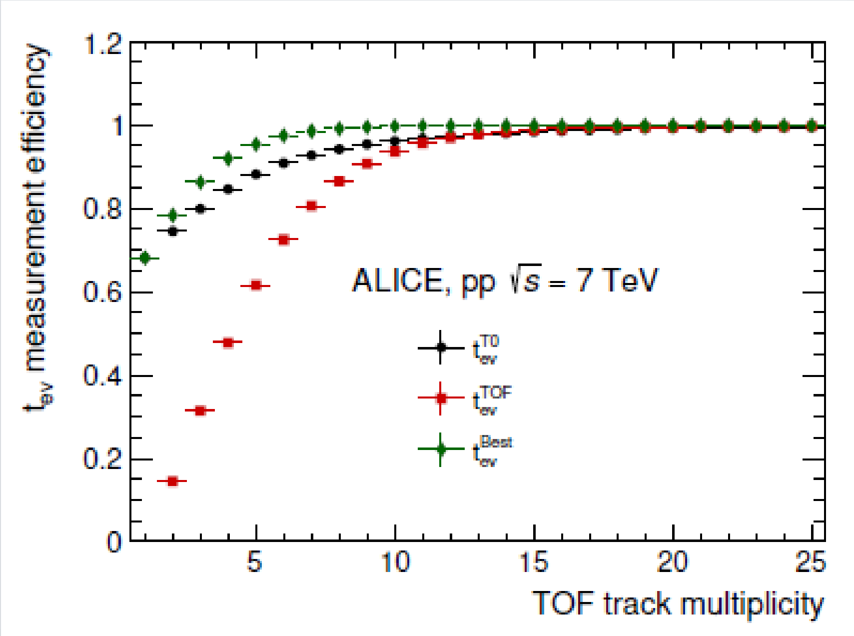
Luminosity monitoring by T0 trigger signal (OTVX)



Luminosity determination in ALICE at the LHC is based on visible cross sections measured in van der Meer (vdM) scans . The visible cross section is seenby a given detector (or set of detectors) with a given trigger condition is a fraction of the total inelastic interaction cross section.

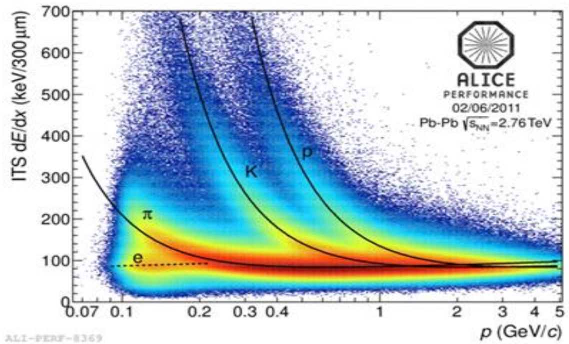
Measurement of the event collision time for particle identification via the time-of- flight technique



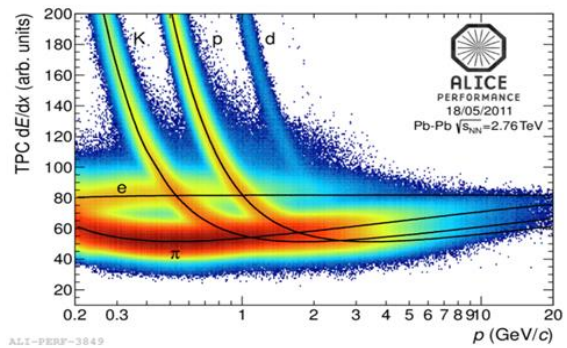


In pp collisions, for very low multiplicity events, the current T0 detector can provide a t_{ev} measurement with an efficiency of the order of 70% that increases with the track multiplicity. At the same time, for all events having high multiplicity, the $t^{TOF}{}_{ev}$ method is able to provide a t_{ev} measurement.

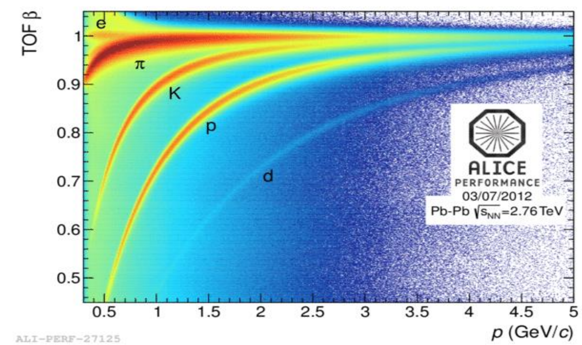
ALICE PID



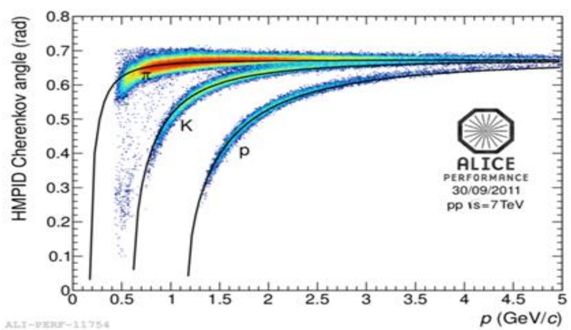
ITS standalone tracker,
PID (pT<200MeV) – energy loss in the silicon;



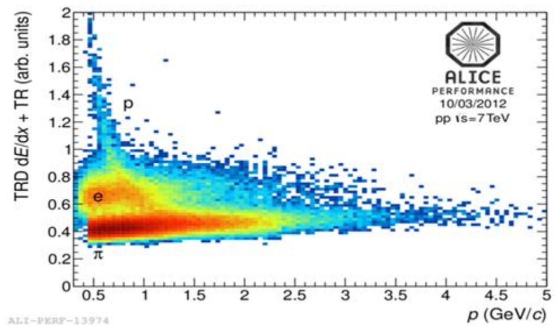
TPC main tracking system
PID - energy loss in the gas
pT 0.1-1GeV/c



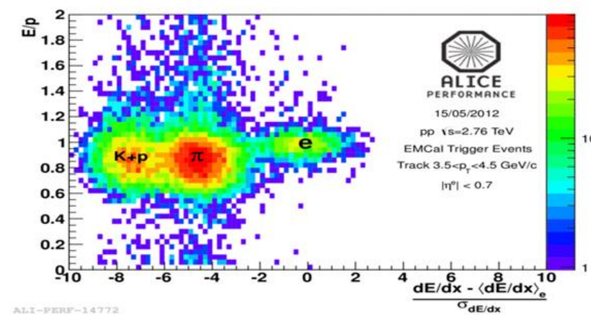
TOF
resolution ~85 ps (Pb-Pb);
π-k separation up to 2.5GeV/c;
protons-4GeV/c



HMPID
Cherenkov angle measurement
PID p_T 1 -5 GeV/c



TRD
Electron and hadron identification via TR + energy loss in the gas ;
pT>1GeV/c



***E/p* from calorimeters (EMCAL, PHOS)**
Electron identification

LHC injectors upgrade (After the Long Shutdown 2019-2020)

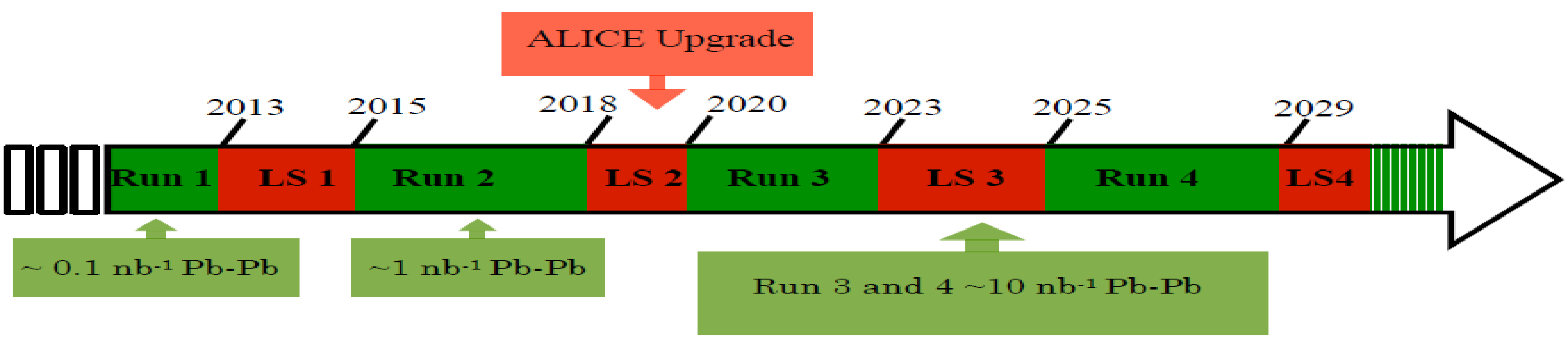
- **Increase in luminosity**

  LHC target luminosity *Pb-Pb* $L = 6 \times 10^{27} cm^{-2} s^{-1}$

  corresponding to collision rates of 50 kHz

  and >200 kHz for pp and p-Pb

- **25 ns bunch spacing option for RUN3 and RUN4**



Upgrade Strategy for ALICE at High Rate

- **Physics plans focused on rare processes where ALICE is unique**

  - Low-pT heavy-flavour mesons and baryons

  - Low-pT charmonia (J/ψ and ψ (2S))

  - Low-mass dileptons
- **Rate limits of current setup (500 Hz of Pb-Pb events)**
- **Detector upgrades**
- **New readout and trigger system**

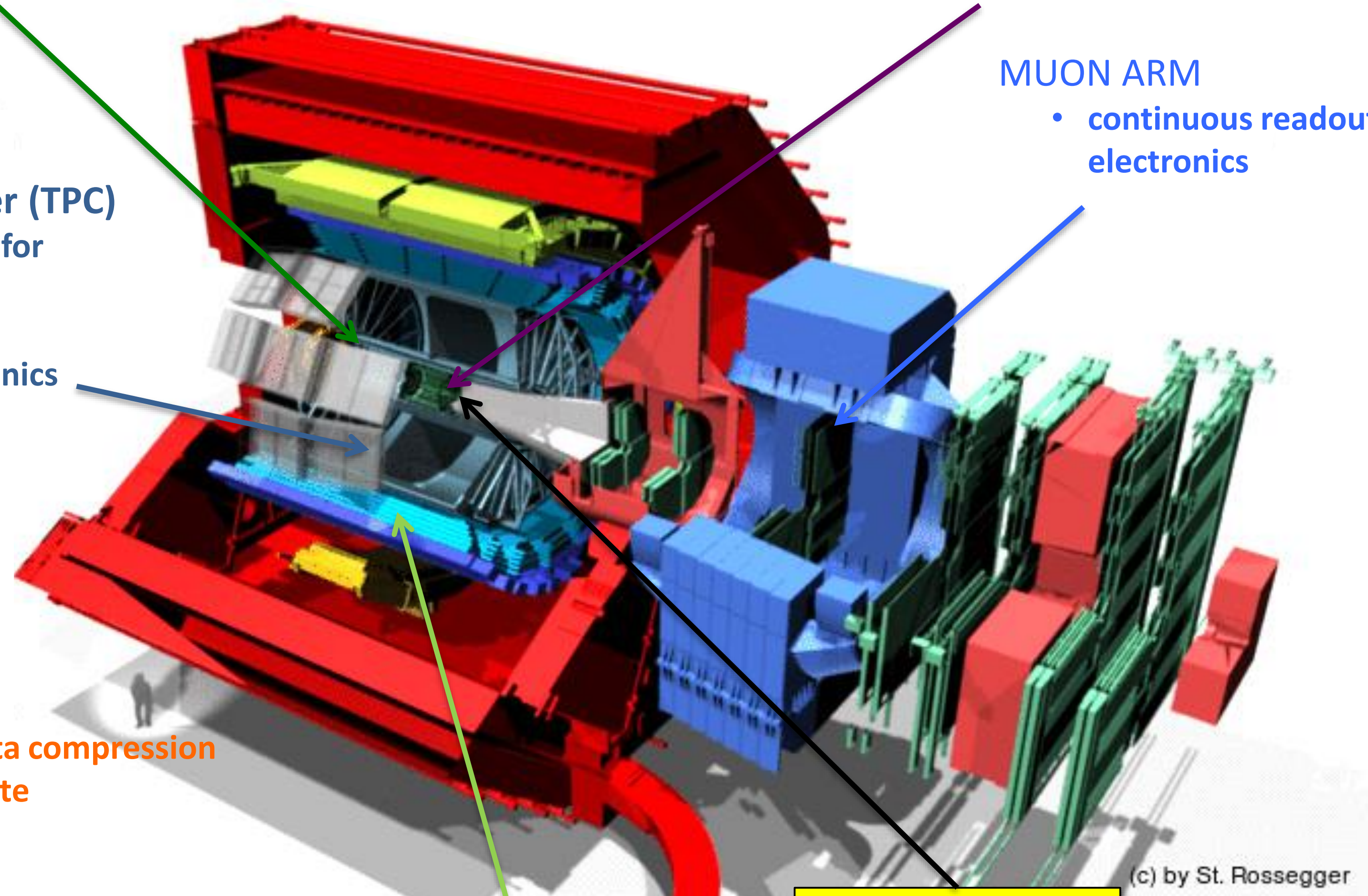
The Future : ALICE upgrade Program

New Inner Tracking System (ITS)
- **improved pointing precision**
- **less material -> thinnest tracker at the LHC**

Muon Forward Tracker (MFT)
- new Si tracker
- Improved MUON pointing precision

MUON ARM
- **continuous readout electronics**

Time Projection Chamber (TPC)
- **new GEM technology for readout chambers**
- **continuous readout**
- **faster readout electronics**



New Central Trigger Processor

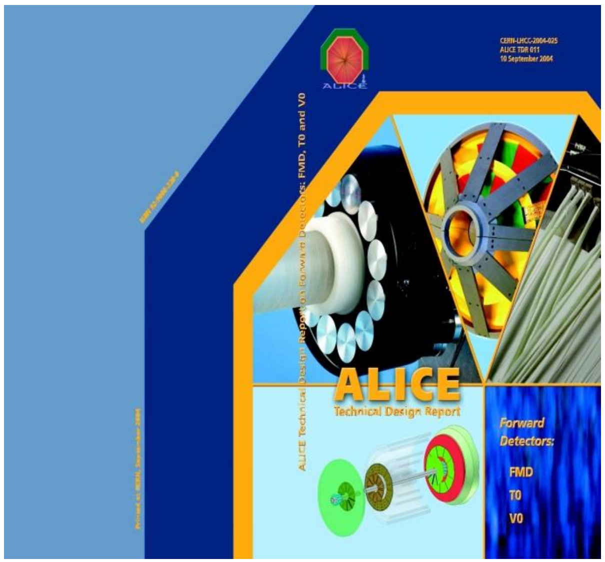
Data Acquisition (DAQ)/ High Level Trigger (HLT)
- **new architecture**
- **on line tracking & data compression**
- **50kHz Pb-Pb event rate**

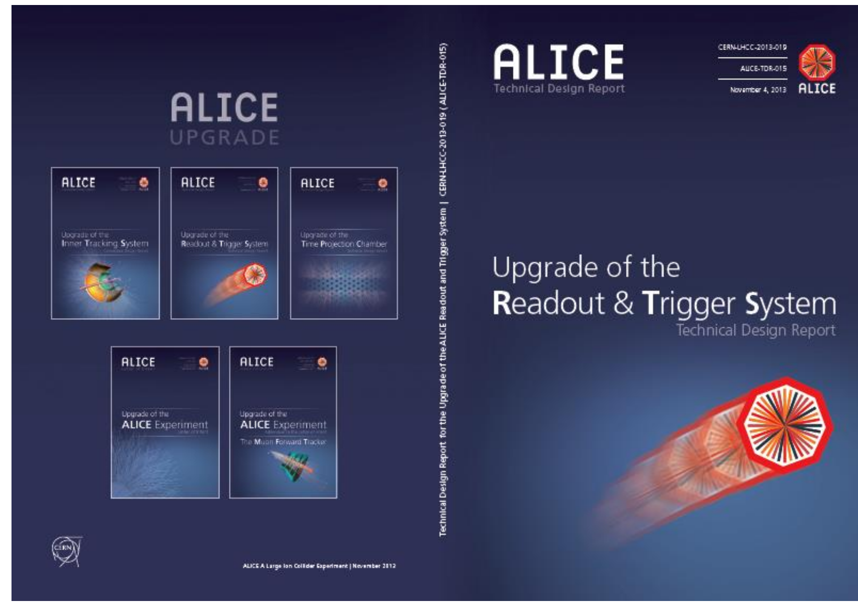
TOF, TRD
- Faster readout

New Trigger Detectors (FIT)

Fast Interaction Trigger

replaces 3 detectors in ALICE: T0, V0, and FMD





https://cds.cern.ch/record/781854/files/lhcc-2004-025.pdf

https://cds.cern.ch/record/1603472/files/ALICE-TDR-015.pdf

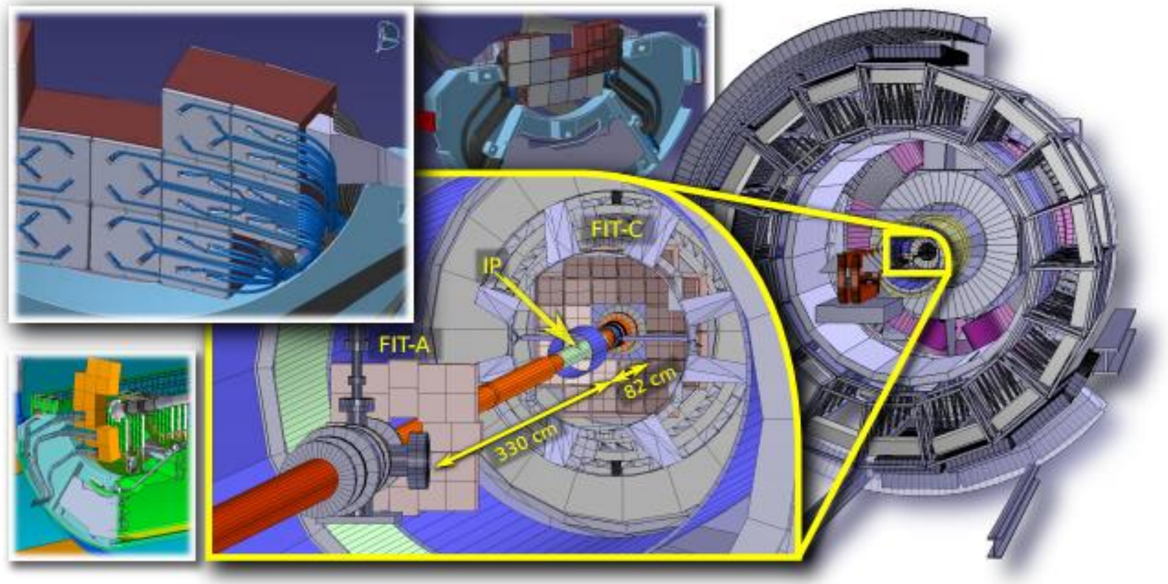
FIT will consist of two arrays of Cherenkov radiators with MCP-PMT sensors (T0+) and of a single, large-size scintillator ring (V0+)

(**FIT = T0+** and **V0+** for ALICE after LS2)

Why ALICE needs FIT:

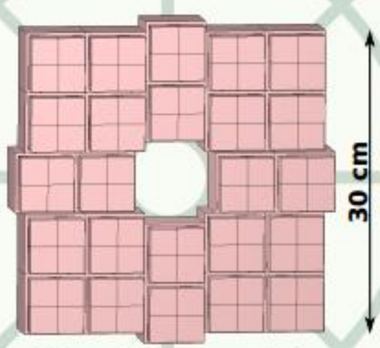
- Luminosity **monitoring** & **feedback** to LHC
  - Essential for the operation of ALICE
- Fast Interaction **Trigger**
  - Online Vertex determination
  - Minimum Bias and centrality selection
  - Rejection of beam/gas events
  - Veto for Ultra Peripheral Collisions
- Collision **time** for Time-Of-Flight particle ID
- **Multiplicity** → **Centrality** and **Event Plane**

Location of FIT arrays within ALICE



Geometry of FIT arrays

FIT A-side



T0A+: $3.8 \lesssim \eta \lesssim 5.4$

V0+: $2.2 < \eta < 5.1$

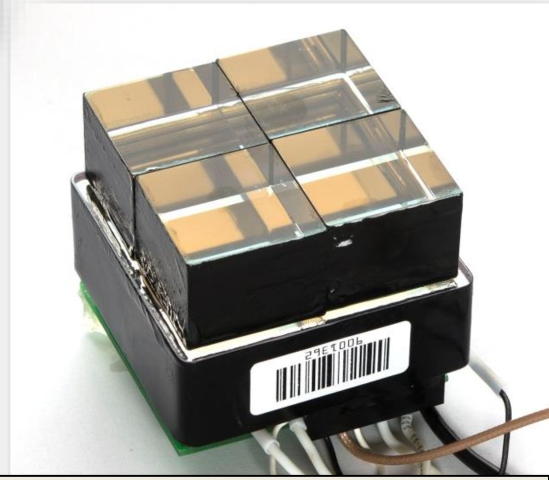
V0+ diameter: 148 cm

FIT C-side

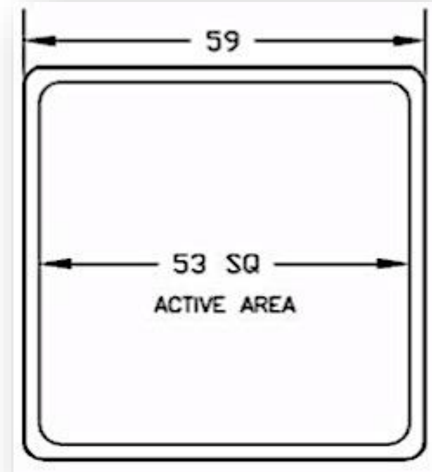
T0C+: $-3.3 \lesssim \eta \lesssim -2.2$

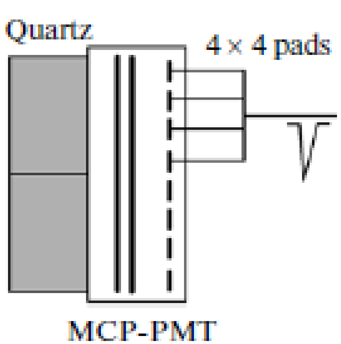
Prototype of T0+ module

PLANACON® **XP85012** + quartz radiators



Time resolution < 20 ps





<u>MCP-PMT :</u> The MCP-PMT XP85012 with 64 anode pads is transformed into the 4channel photo detector by merging 16 pads (4 × 4) of each cell into a single channel

The main problems

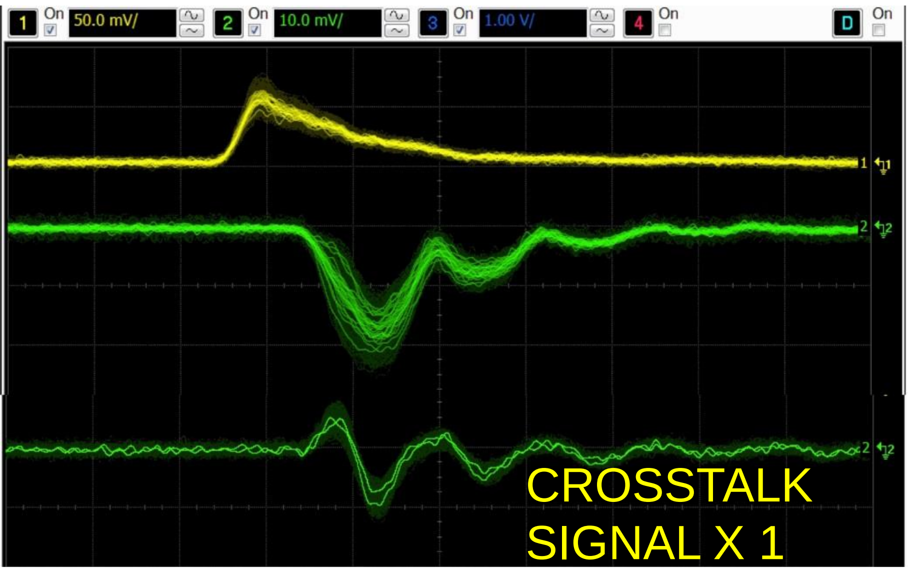
with a Standard PLANACON® XP85012

- 64 individual anodes (sectors) are connected to the common output. The anode – MCP capacitance creates inversed (positive) **crosstalk** which distorts time measurements when more than one quadrant is hit.
- To collect signals from each quadrant we need to attach an additional PCB. This increases inductance and capacitance of the traces and distorts the shape of the signal. It also makes signal shape **dependent on the coordinates**.
- The total **capacitance** of the anode system for one quadrant is about 80 pF.
- **Different trace lengths** for individual anodes decrease the MCP time resolution.

Laser tests of the modified PLANACON

Three quadrants are open to laser pulses. One quadrant is covered.

Standard XP85012 Modified



The leading edge is unstable, depends on charge distribution between individual anodes of the three illuminated quadrants. Oscillation on the trailing edge can be seen. The crosstalk signal is large.

Signals from the 3 illuminated quadrants are stable and without oscillations. The crosstalk signal (on the darkened quadrant) is now ~5x smaller and has only a negative component. There is no time shift. The trailing edge is 1.5x shorter.

Our solution

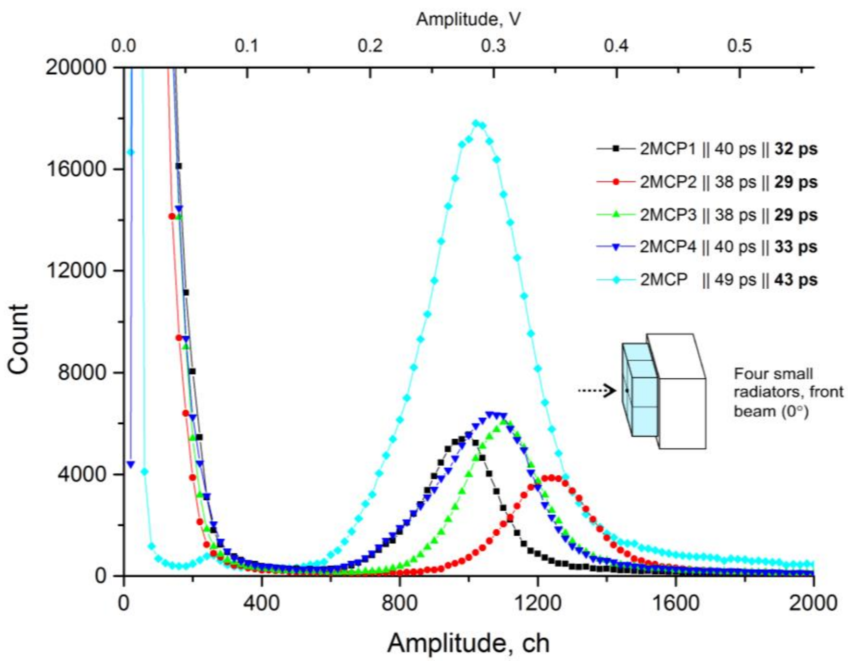
to Modify PLANACON® XP85012

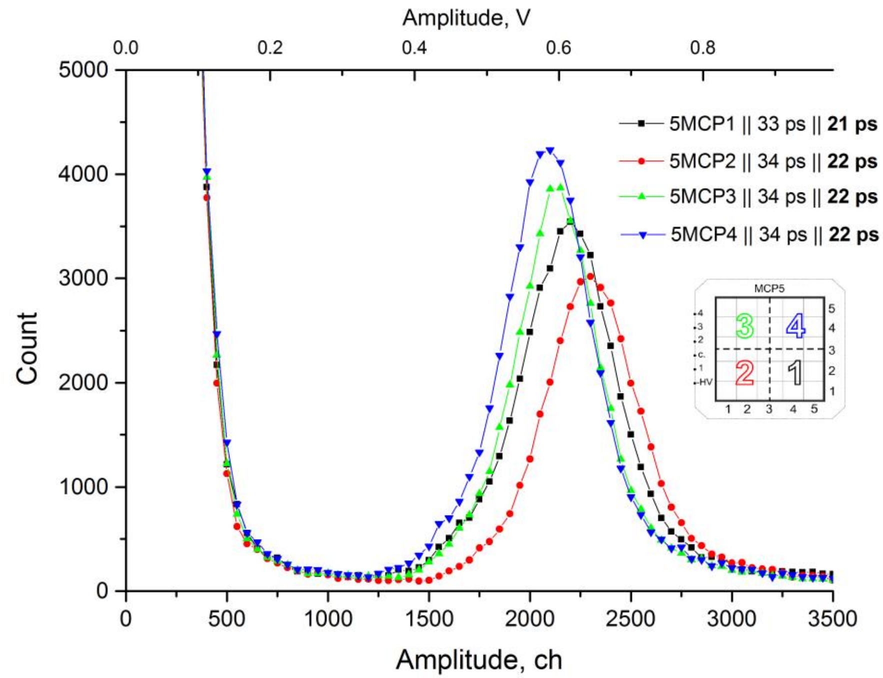
- New PCB for XP85012 was designed and manufactured at Institute of Nuclear Research and assembled to a new PLANACON by Photonis
- The **modified PLANACON**
  - – Eliminated the “positive crosstalk”.
  - – Increased signal amplitude for a given MCP gain*
  - – Eliminated additional PCB
  - – Reduced the size of the unit
  - – Improved time resolution and signal shape stability

*now the anode capacitance is 30 pF/quadrant, 2 pF between quadrants

Beam tests of the modified PLANACON

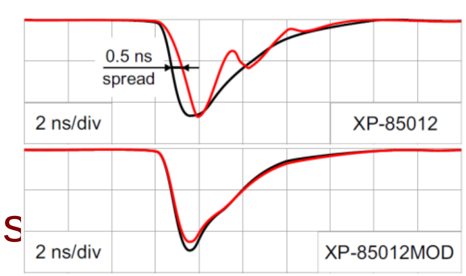
Standard XP85012 Modified





As measured in **June 2015**
Standard XP85012

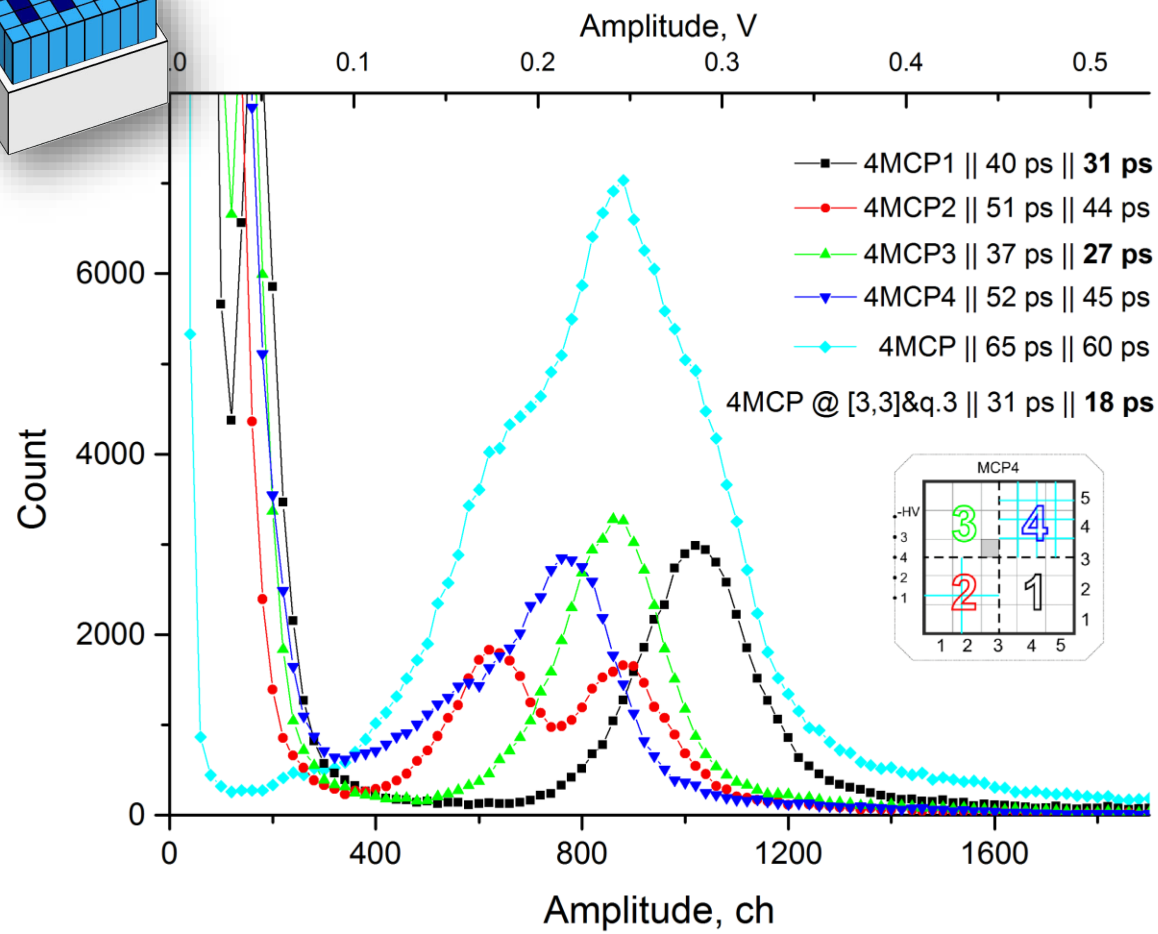
- MCP amplification 10^6
- Amplitude ~1100 channels
- Time resolution ~**30 ps**



As measured in **October 2015**
Modified XP85012

- MCP amplification 10^6
- Amplitude ~2100 channels
- Time resolution **~22 ps**

Radiator granularity results (October 2015 data)



Results for the **repaired NBI MCP** with different combinations of fragmented radiators.

4MCP1-radiator- 1/4

4MCP2-radiators 4/16 new

4MCP4-radiators 16/64

4MCP3-radiator 1/4

Conclusion - Reproducible results for quadrants with default radiators (#1, #3) comparing to June 2015 data.

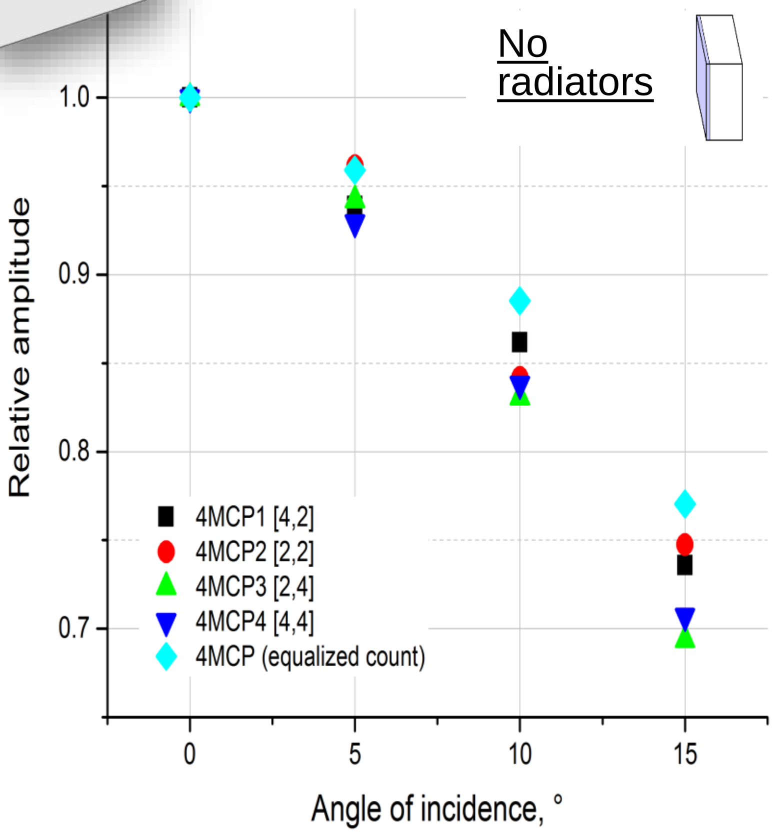
- No benefit in further segmentation of radiators;

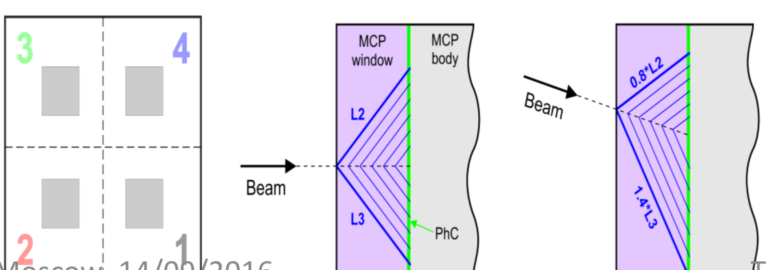
- Best timing for 4 default radiators;

-Perfect pulse shape and largest amplitude for 4 default radiators;

As measured in June 2016 beam test

Amplitude vs impact angle of MIPs





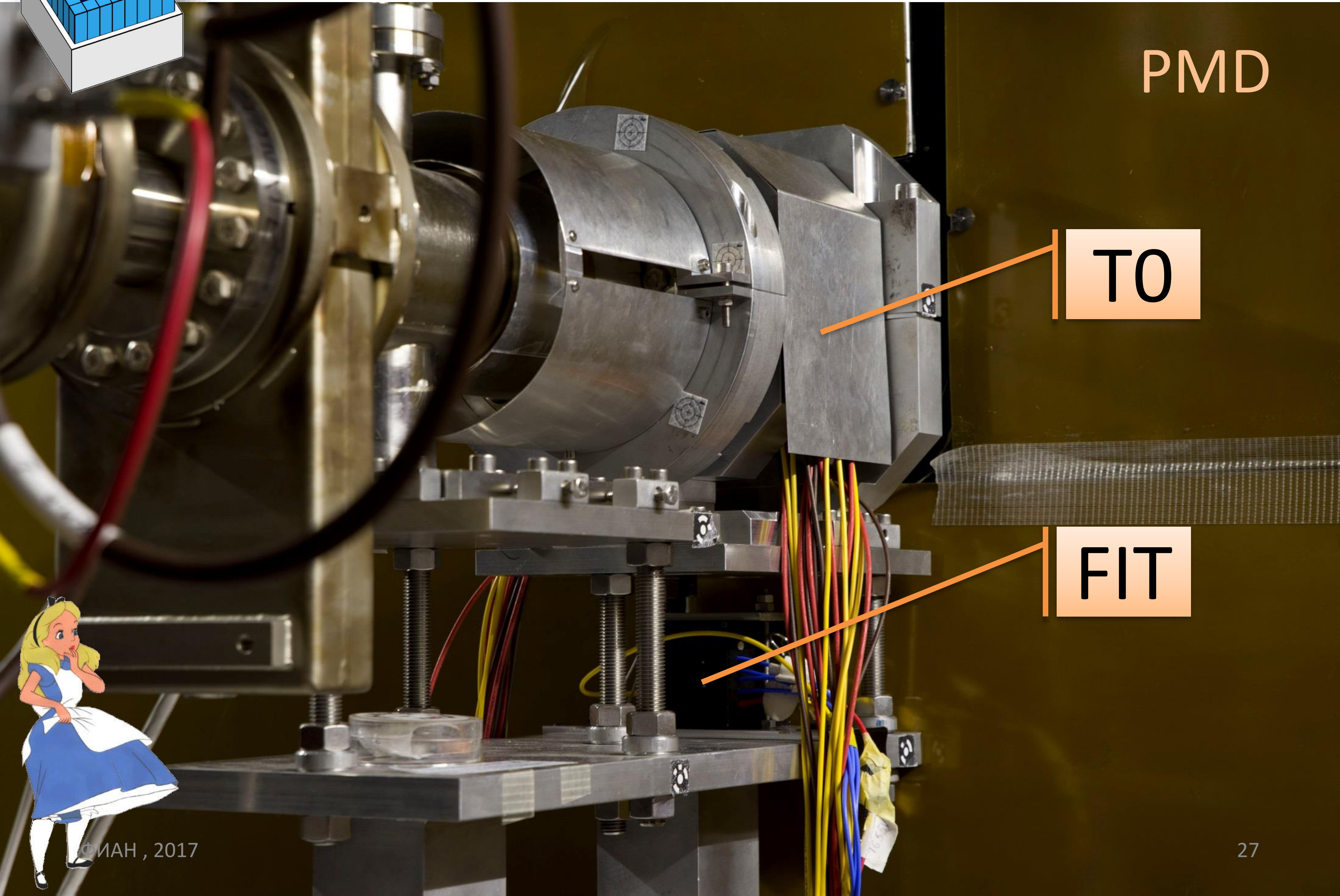
If T0+ at side C is flat, particles would hit the radiators under the corners of up to **12.6°**.

For some reason **amplitude decreases with the impact angle of MIPS increase** even for the central pixel events in the MCP window (no radiators).

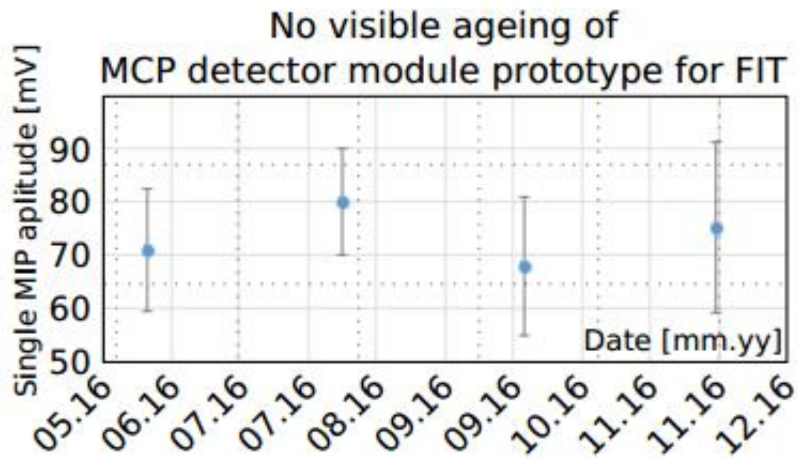
<u>Many variable/unknown parameters could act here:</u>

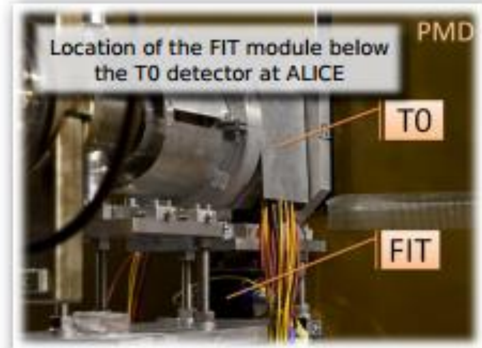
- Q.E. variation for oblique photons;
- unclear reflectivity of PhC-window border;
- quartz transparency for VUV-light at short distances, etc.

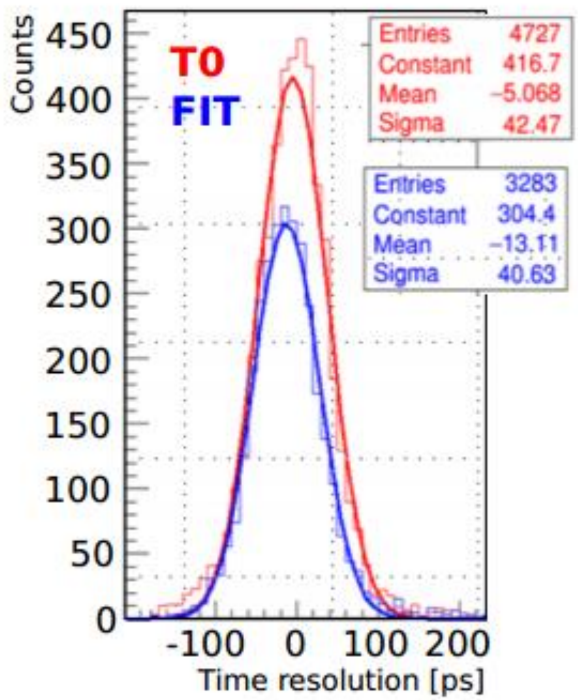
FIT module installed in ALICE

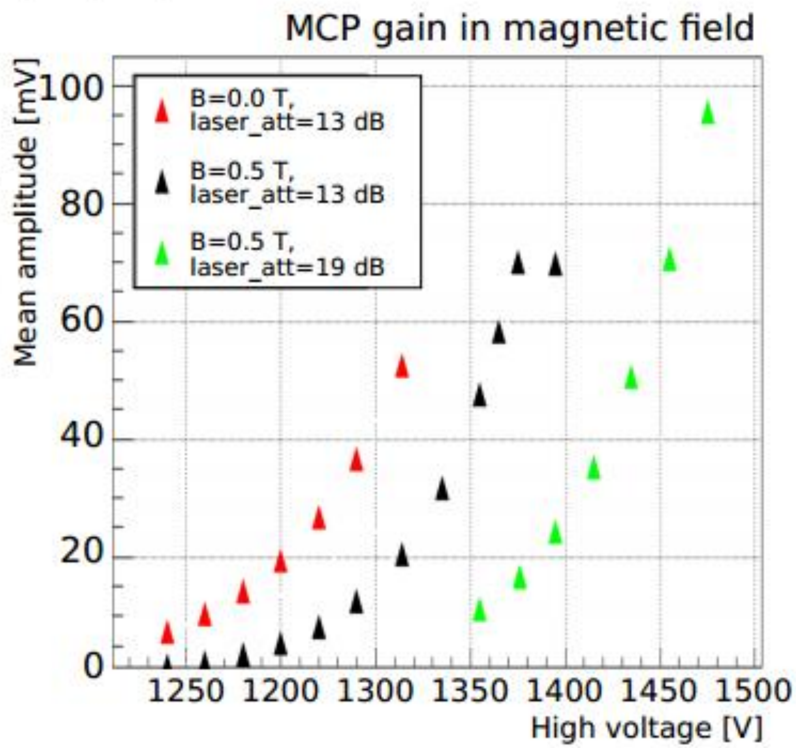


FIT module test with LHC beams









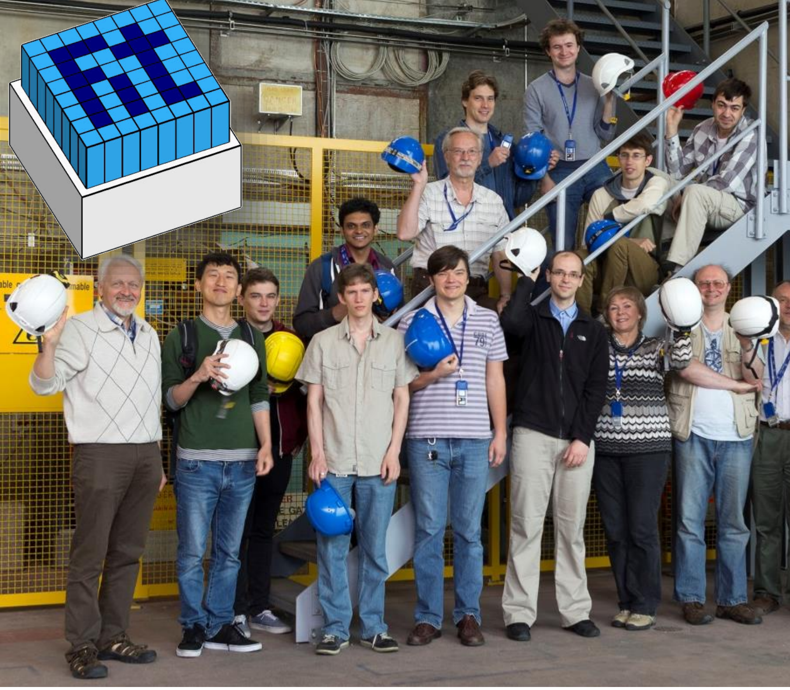
Conclusions

› During the upcoming Long Shutdown 2 (2019-2020) ALICE is going to upgrade several of the key detectors including the Fast Interaction Trigger (FIT).

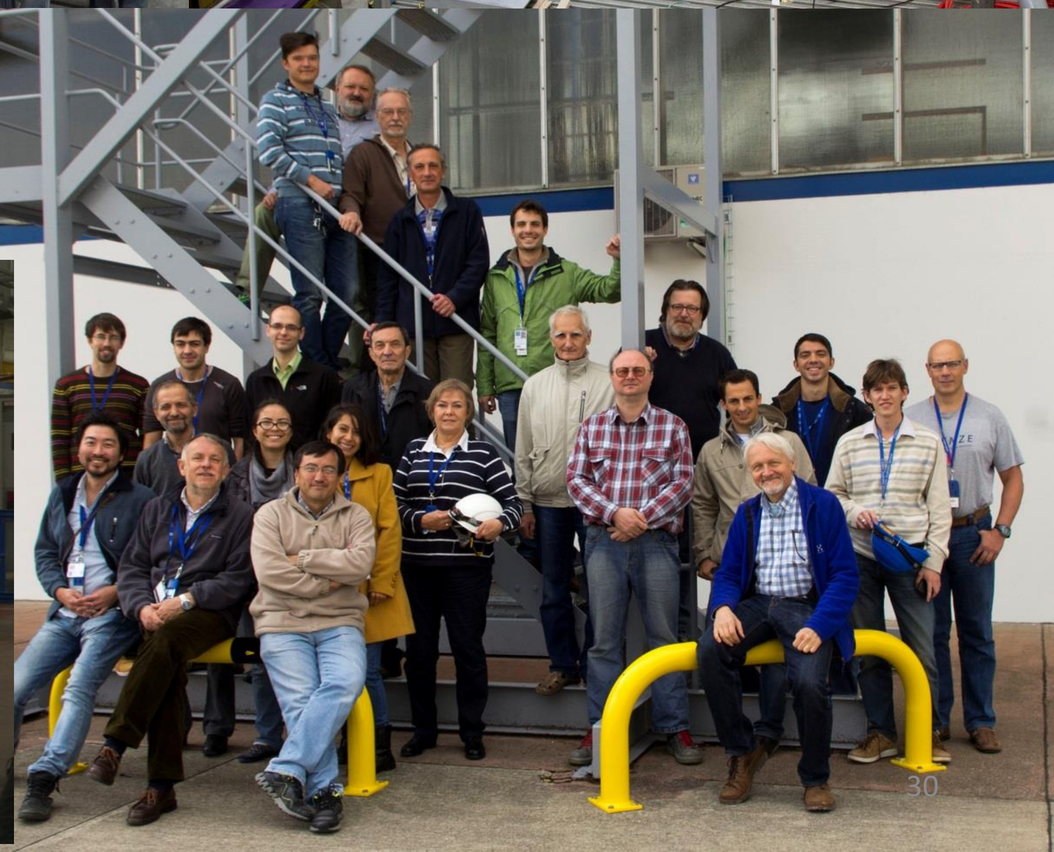
› FIT will consist of two arrays of T0+ modules (quartz Cherenkov radiators coupled to MCP-PMTs) and one V0+ (segmented scintillator ring).

› T0+ prototype with a modified PLANACON XP85012 sensor routinely achieves $\Delta T \sim 40$ ps during the tests at ALICE in 2016

› The R&D is currently focused in defining plans for detector integration into ALICE, multichannel readout electronics prototyping and detector module testing performed with the real-life conditions at ALICE.



FIT collaboration
during PS beam tests
~50 people, 14 institutes, 6 counties



Thank you for your attention!

BACKUP SLIDES

Russian participation in the upgrade of ALICE detector

Results of 2014 – 2016 and future plans

Fast Interaction Trigger FIT

FIT-T0C and FIT-T0A are very well advanced:

- We have optimized the segmentation quartz radiator
- The vendor for the photo sensor has been chosen
- The optical fibres, signal and HV cables have been chosen and approved
- FIT T0+ prototype has been extensively tested at PS and in the actual location inside ALICE, next to T0A, with the actual LHC beam.
- **During FIT Design Review on 16 June 2016** the milestones, cost estimate, man power and budget resources were considered

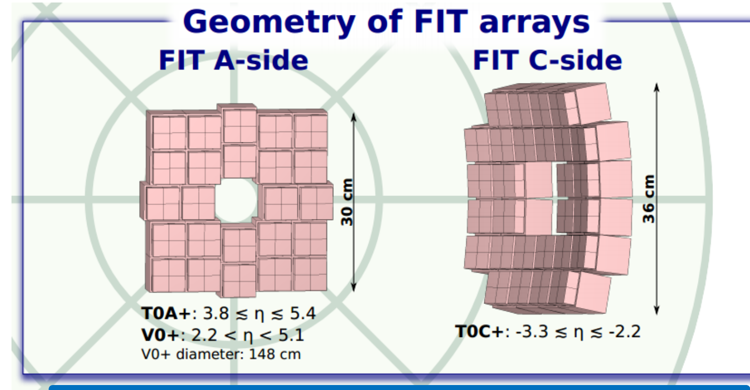
Plans for 2017-2020:

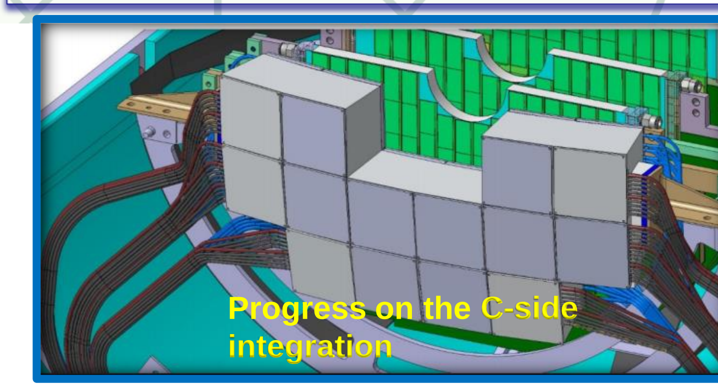
- Development and production of the FIT detector mechanical design for integration within ALICE
- Assembling and testing Cerenkov modules
- Development and production of integrated electronic modules, including elements of FE electronics, trigger and readout electronics

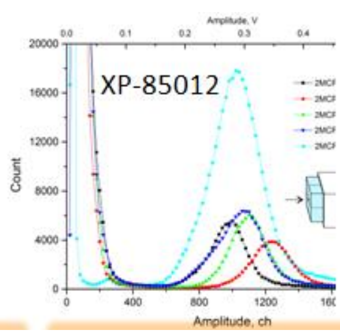
EDR (Engineering Design Review at CERN) **FIT-C detector (6/17), FIT-A detector (12/17), Electronics (9/17)**

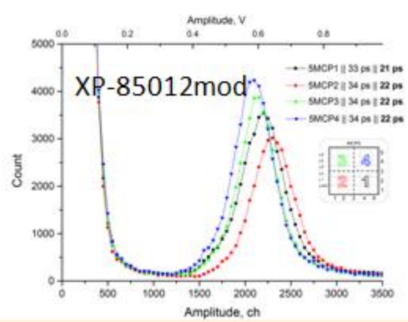
PRR (Production Readiness Review at CERN) **Electronics (12/18)**

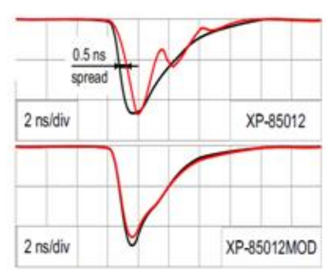
Installation and commissioning finalized (12/20)

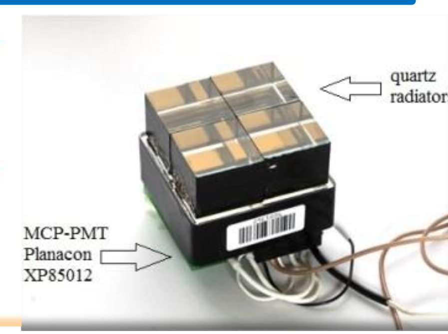






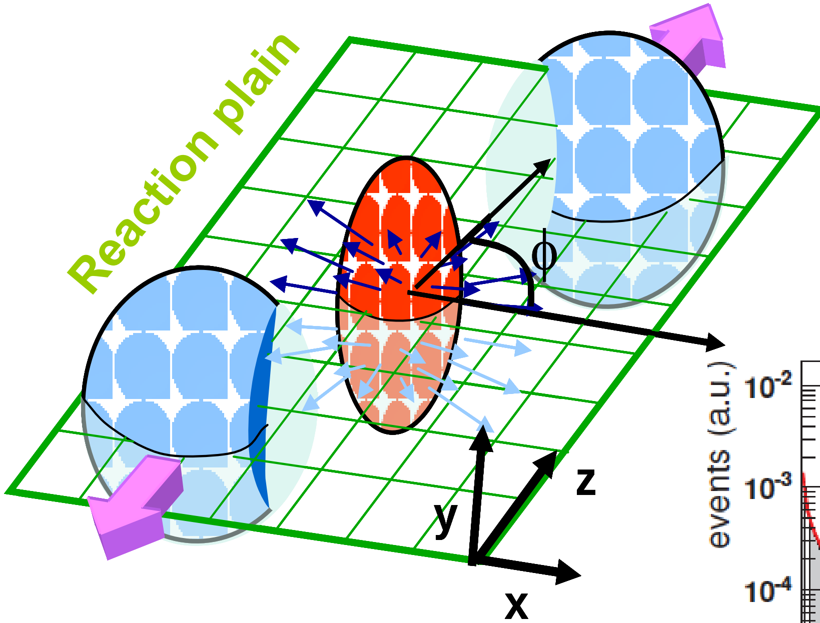




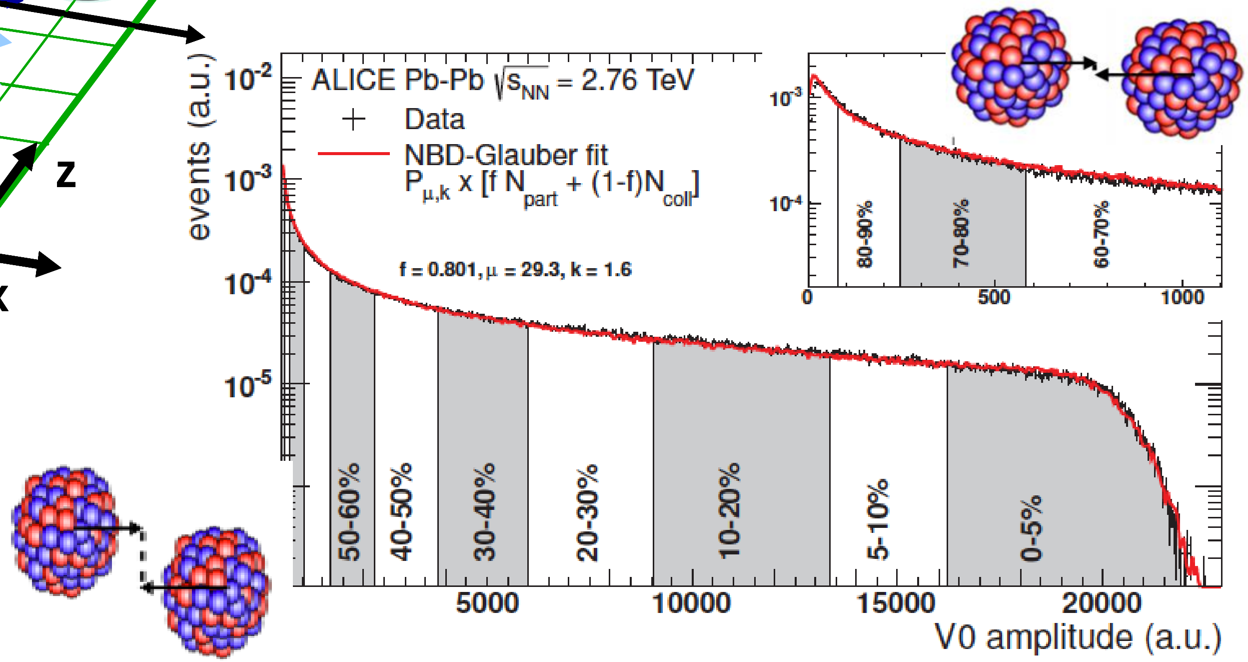


Significant achievements in FIT timing resolution

Why FIT should maximize acceptance:

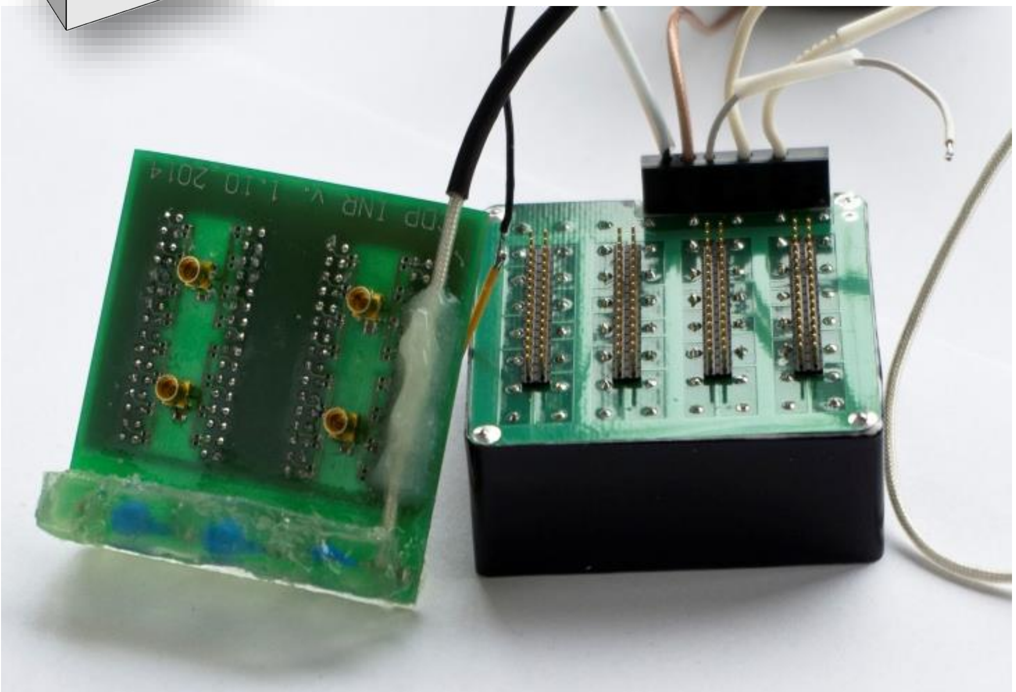


$$\frac{dN}{d\phi} = 1 + v_2 \cos(2(\phi - \Psi_{RP})) + \ldots$$

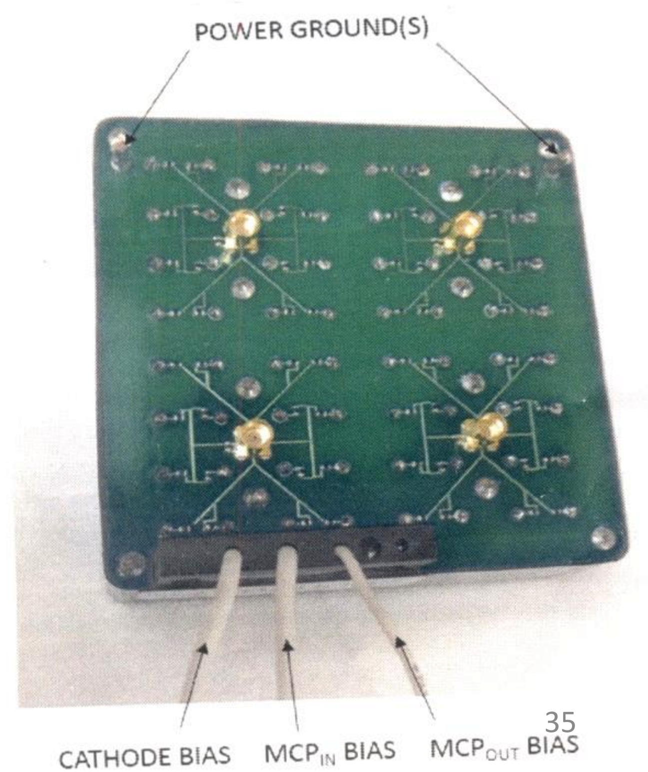


FIT should be as large as possible within the available space inside ALICE!

Standard XP85012 **Modified**

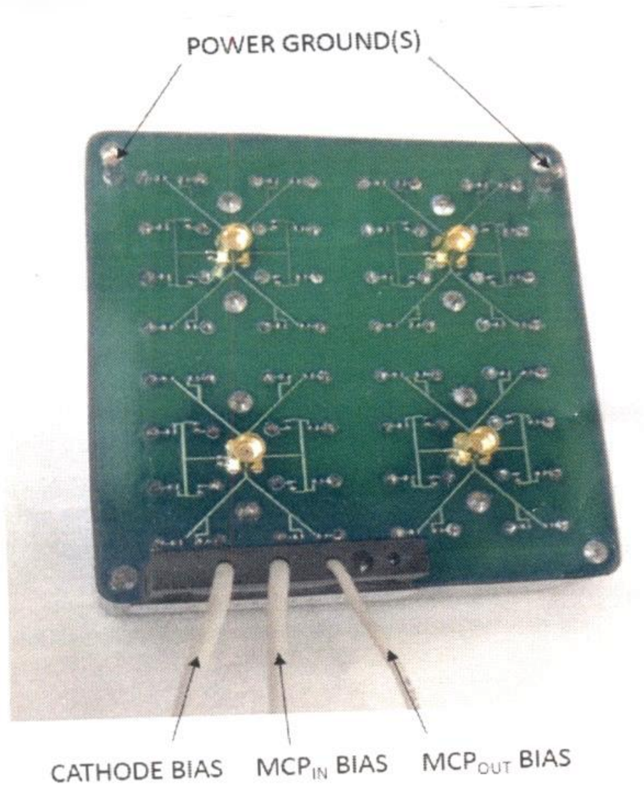


Modified variant has RF grounded MCP out electrode, reduced anode-ground capacitance, and equalized propagation time from individual anodes to the output connectors.



Standard off-the-shelf PLANACON® has a common output and uses non-RF connectors for anode outputs

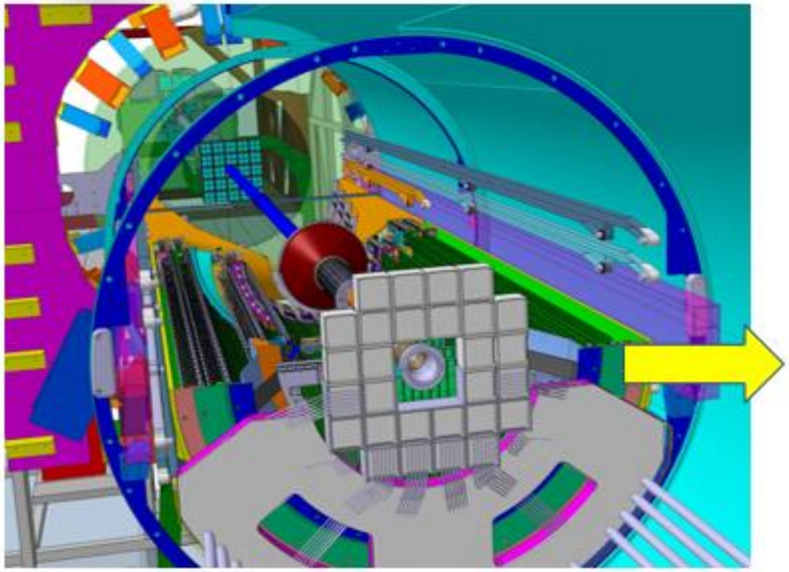
Modified PLANACON® XP85012 version 2

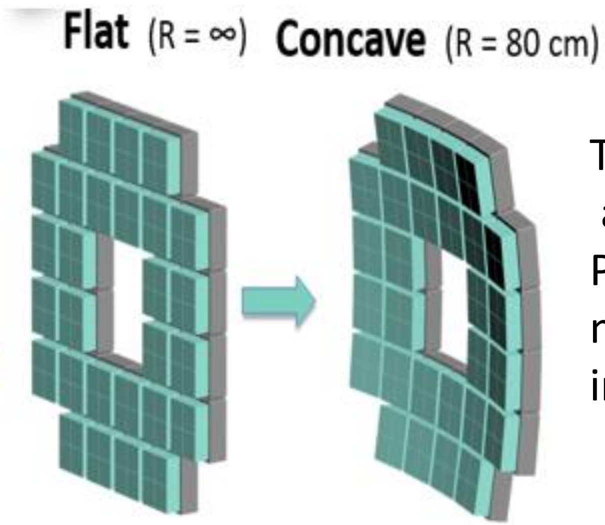


Changes from Version 1 :

- Reduced size of the HV port, optimized HV divider placement
  Result: Assembled detector module length decreases ~10 mm to 67 mm
- MCP plates resistance decreased ~3 times to 16 -17 Mohms
  Result:
  - Dynamic range increases at least 2 times, now covers FIT requirements.
  - All MCP internal time constants are reduced in 3 times.
  - 40 MHz burst repetition rate test passed.
  - Average 1 MHz interaction rate test to be finished, preliminary – passed.
- Minor changes of the PCB
  Result:
  - Electrical crosstalk between quadrants now is less than optical one.

FIT configuration T0C+



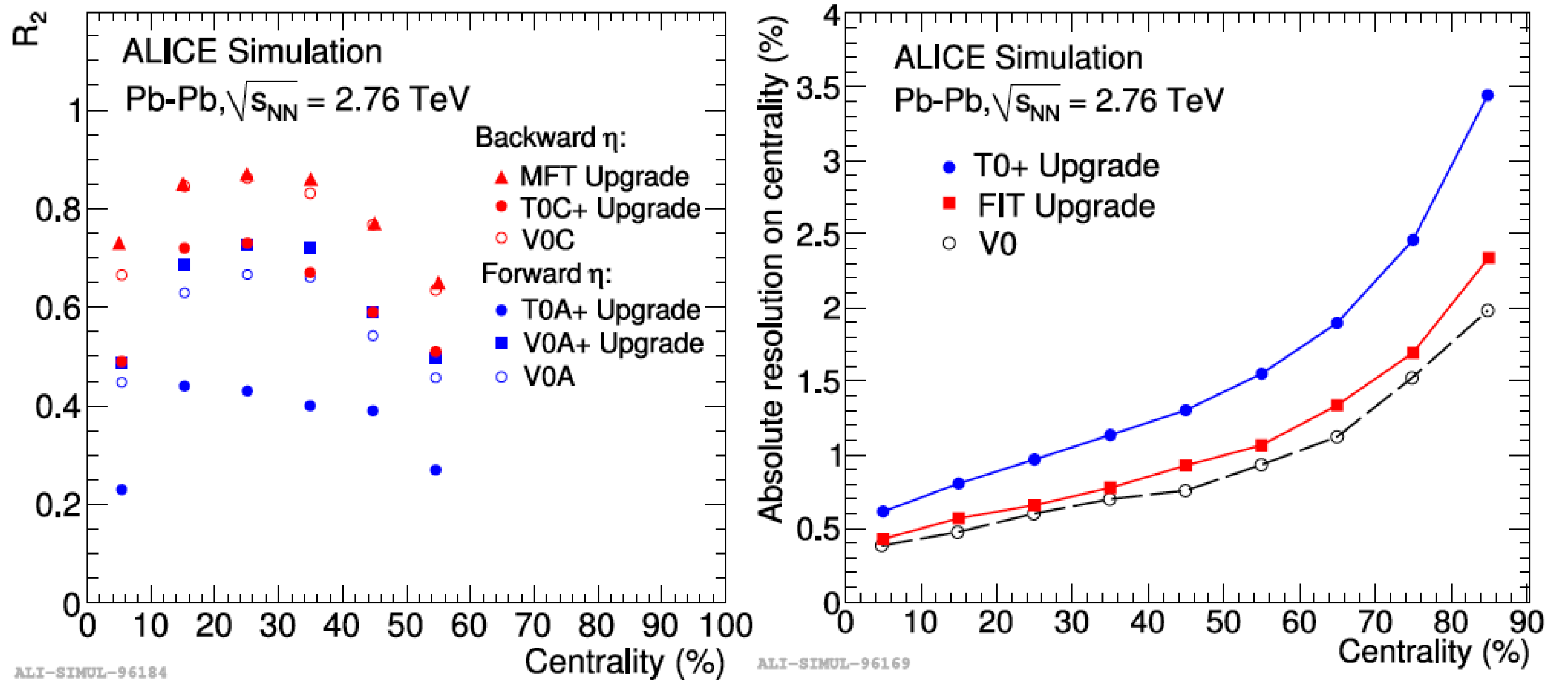


The distance between IP and **T0C+** is only 80 cm
Performance of the T0+ module depends on the impact angle of MIPs

Concave geometry is now possible due to the thinning of the MCP-PMT sensor

Importance of V0+

FIT simulation results
Event plane & centrality resolution



New Modified XP85012-V2

PHOTONIS

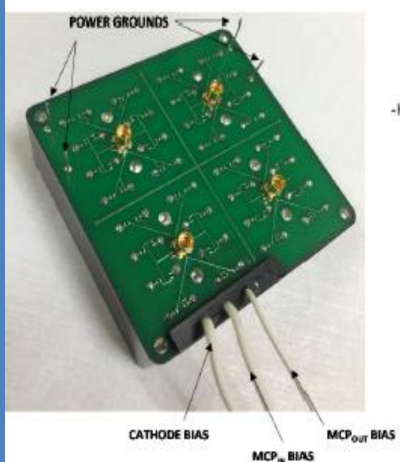
Tube Type: XP85012/A1-Q - PROTO
Serial #: 9002059
Date: 18-Apr-16

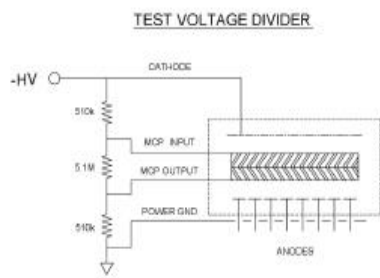
NOTES:
* No Internal Limiting Resistors on HV connections
* Custom Electrode and Signal Connections

DC TEST DATA

Cathode (white)	68	µA/lm
Cathode (blue)	9.9	µA/Blm
Overall HV for 10^5 gain	1505	V
Overall HV for 10^6 gain	1800	V
I_{dark} (@10^5 gain)	0.4	nA
I_{dark} (@10^6 gain)	4	nA
MCP resistance	16	Meg-Ω

CAUTION:
* Never Expose to Helium or Hydrogen Gas
* Cathode at Negative High Voltage ONLY.
* Max DC Anode Current = 3µA
* Maximum Overall Voltage Using Test Divider = 2.0 KV
* Maximum MCP Voltage= 1.8 KV





PHOTONIS

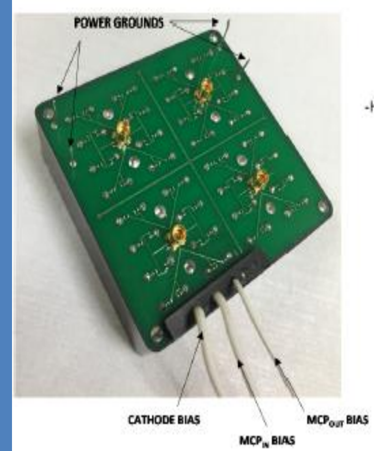
Tube Type: XP85012/A1-Q - PROTO
Serial #: 9002060
Date: 18-Apr-16

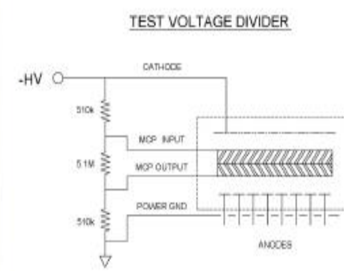
NOTES:
* No Internal Limiting Resistors on HV connections
* Custom Electrode and Signal Connections

DC TEST DATA

Cathode (white)	71	µA/lm
Cathode (blue)	9.8	µA/Blm
Overall HV for 10^5 gain	1655	V
Overall HV for 10^6 gain	1590	V
I_{dark} (@10^5 gain)	0.3	nA
I_{dark} (@10^6 gain)	4	nA
MCP resistance	16.5	Meg-Ω

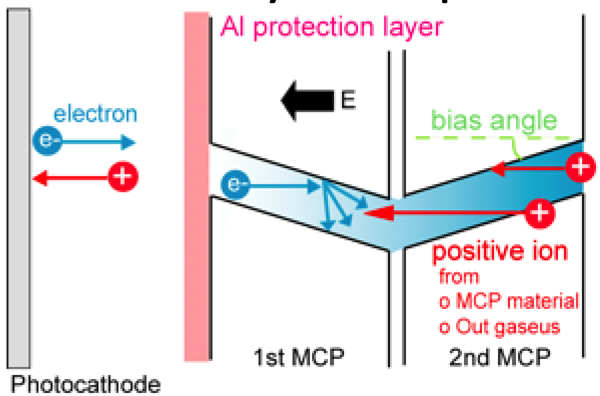
CAUTION:
* Never Expose to Helium or Hydrogen Gas
* Cathode at Negative High Voltage ONLY.
* Max DC Anode Current = 3µA
* Maximum Overall Voltage Using Test Divider = 2.0 KV
* Maximum MCP Voltage= 1.8 KV

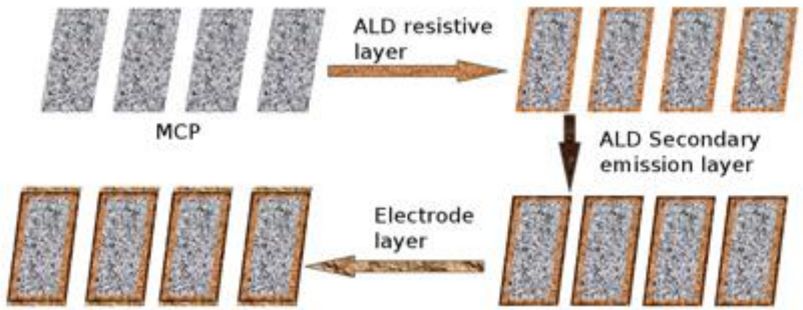




Big progress in MCP technology
(since the initial R&D for ALICE)

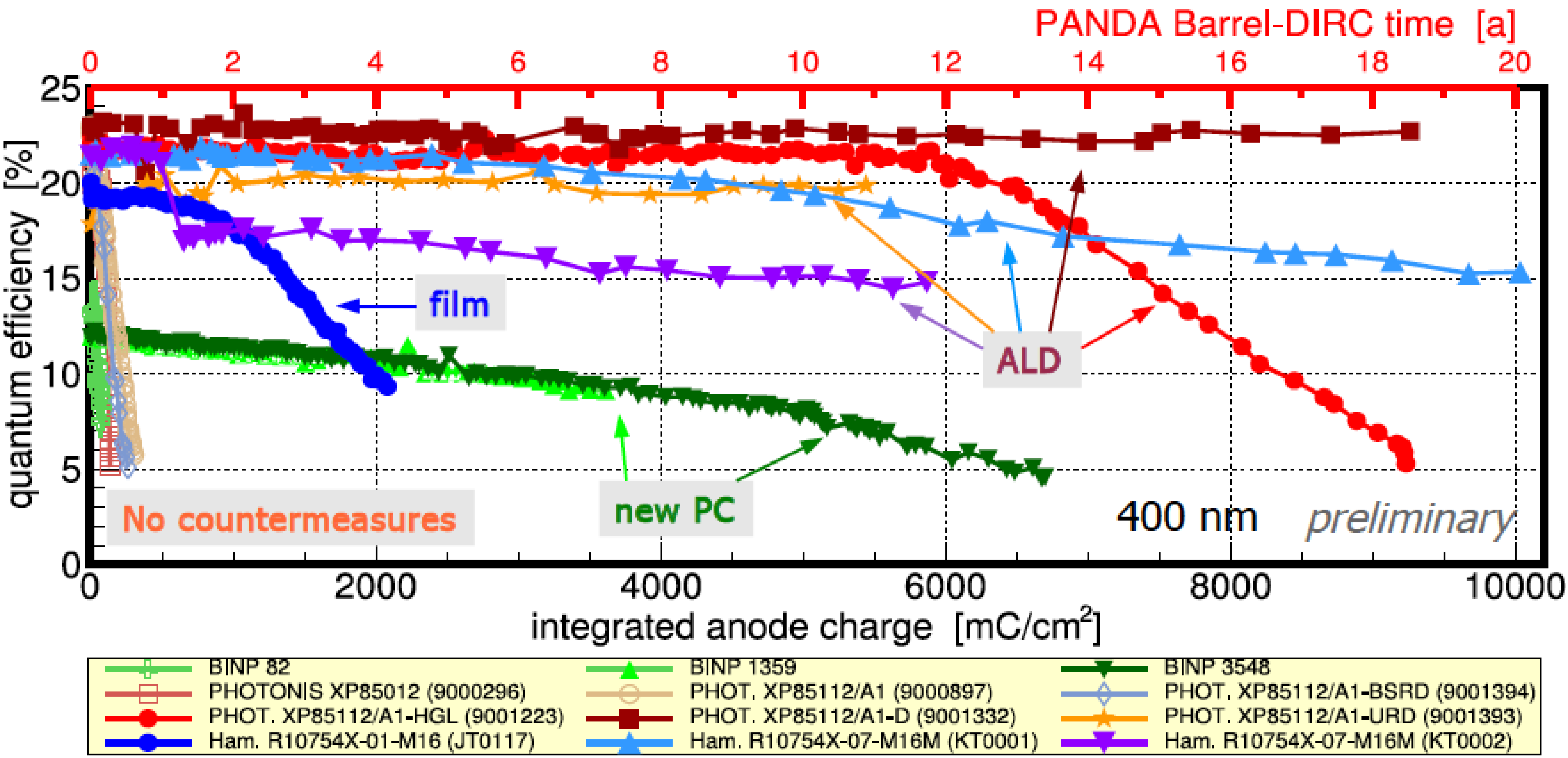
- Appearance of <u>commercially available</u> MCP-PMTs (Hamamatsu, Photonis USA, BINP)
- Significant and ongoing <u>improvement in lifetime</u>:
  - **A**tomic **L**ayer **D**eposition technology [NIM A639 (2011) 148]





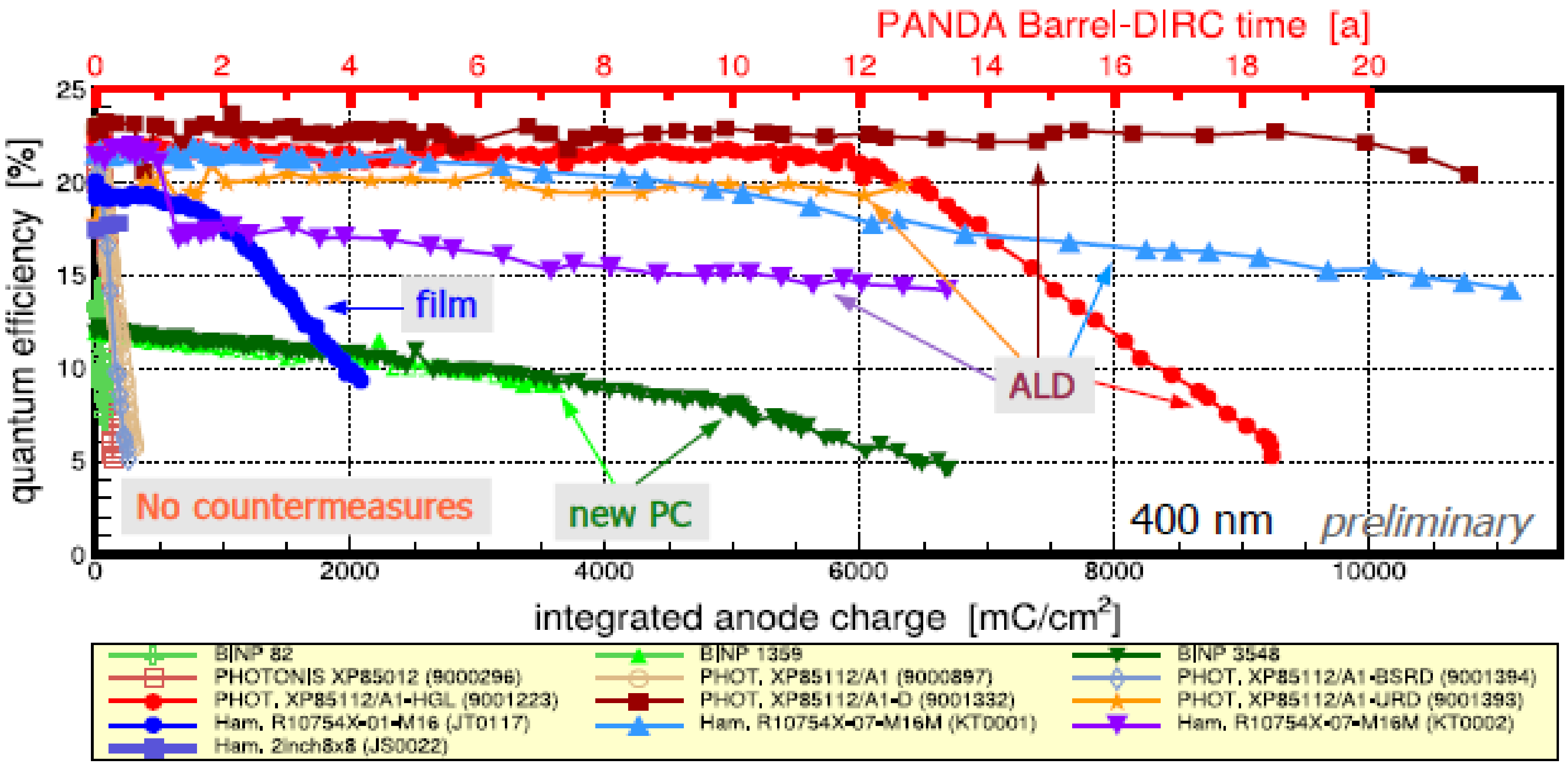
  - Modified photocathodes [JINST 6 C12026 (2011)]
  - Reduced outgassing (borosilicate glass)

Lifetime of MCP-PMTs (Nov. 2015)



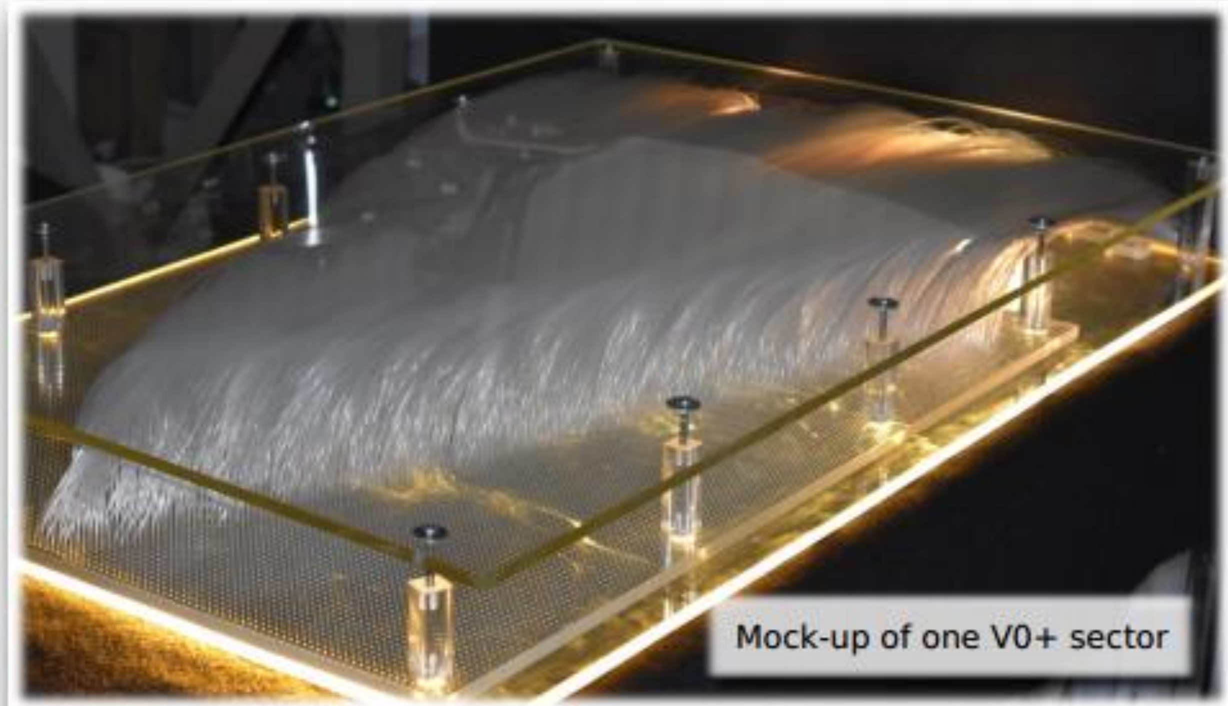
- Hamamatsu film MCP-PMT: Q.E. drops beyond 1 C/cm^2
- Photonis 9001332: no Q.E degrading observed yet up to >9 C/cm^2
- MCP-PMTs with ALD layers: **very good performance to >5 C/cm^2**

Lifetime of MCP-PMTs (Feb. 2016)



- Hamamatsu film MCP-PMT: Q.E. drops beyond 1 C/cm^2
- Photonis 9001332: no Q.E degrading observed up to 10 C/cm^2
- MCP-PMTs with ALD layers: **very good performance to >6 C/cm^2**

FIT = T0+ and V0+



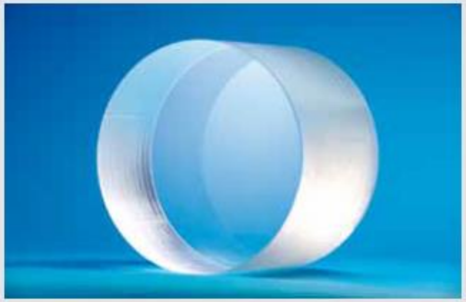
T0+ → modular detector:
- Improved T0
- Rectangular quartz radiators
- New sensors MCP-PMT
- Larger acceptance
- More channels
- Upgraded electronics and readout

V0+ → sectored detector:
- Improved V0
- Faster plastic scintillator
- Monolithic structure
- Reduced fiber length
- New sensor (SiPM or MCP-PMT)
- New electronics and readout

Spectrosil® 1000

Application:
- Semiconductor industry

Characteristics:
- Highest chemical purity
- Free of bubbles and inclusions
- Superior transmission in UV and IR
- Attractive performance/cost ratio



Spectrosil® 1000 synthetic fused silica is manufactured using an environmentally friendly process resulting in a glass of exceptional purity and excellent visual quality.

Spectrosil® 1000 has been designed for the highest demanding semiconductor applications. Spectrosil® 1000 is chlorine-free, free of bubbles and inclusions, and provides an ultra-high purity which makes it one of the cleanest materials available.

Quartz components made from Spectrosil® 1000 eliminate the risk of contamination in plasma etch applications and sensitive deposition processes such as ALD.

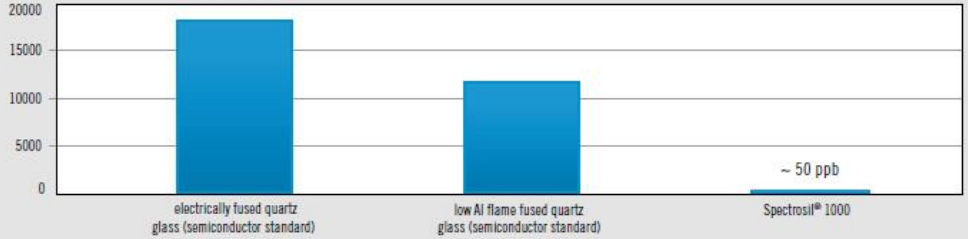
In addition the superior transmission characteristics make it the ideal material for use in modern UV and IR assisted processes.

Sizes for 300 and 450 mm semi-conductor tools available.
Max diameter of round ingots:
- up to 380 mm – direct fused ingots
- 420 – 700* mm – reflow ingots

*Larger sizes available on request

Comparison of typical level of metal impurities measured in high quality quartz glass types

Sum of Al, Ca, Cu, Fe, Na, K, Li, Mg, Ti in ppb.



Quark-Gluon Plasma

- Quark-Gluon Plasma (QGP): phase of deconfined quarks and gluons
- QGP behaves as a perfect fluid
  - Well described by ideal hydrodynamics
  - Viscosity near quantum lower limit ($\eta/s > 1/4\pi$)
- Phase transition near 170 MeV
- Crossover or 1st-order phase transition between QGP and hadron gas
- Critical point?
  - RHIC Energy Scan