Time-Projection-Chamber for MPD NICA

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On behalf of the TPC team

Laboratory of High Energy Physics, JINR, Dubna

NICA Days 2015

TPC TDR rev.02

TPC/MPD Collaboration JINR
Dubna, April 2015, rev.02

Time Projection Chamber for

Multi Purpose Detector at NICA

Technical Design Report (rev.02)

Laboratory of High Energy Physics, JINR, Dubna

A.Averyanov, A.Bajajin, V.F.Chepurnov, V.V. Chepurnov, G.Cheremukhina, S.Chernenko, O.Fateev, Yu.Kiriushin, A.Korotkova, F.Levchanovskiy, J.Lukstins, S.Movchan, S.Razin, A.Ribakov, V.Samsonov, S.Vereschagin, Yu.Zanevsky, S.Zaporozhets and V.Zruyev

http://nica.jinr.ru/files/mpd_tdr.htm and select MPD Time Projection Chamber Technical Design Report (pdf)

Dubna 2015

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The requirements on TPC

-efficient tracking up to pseudorapidity region lηl=1.2

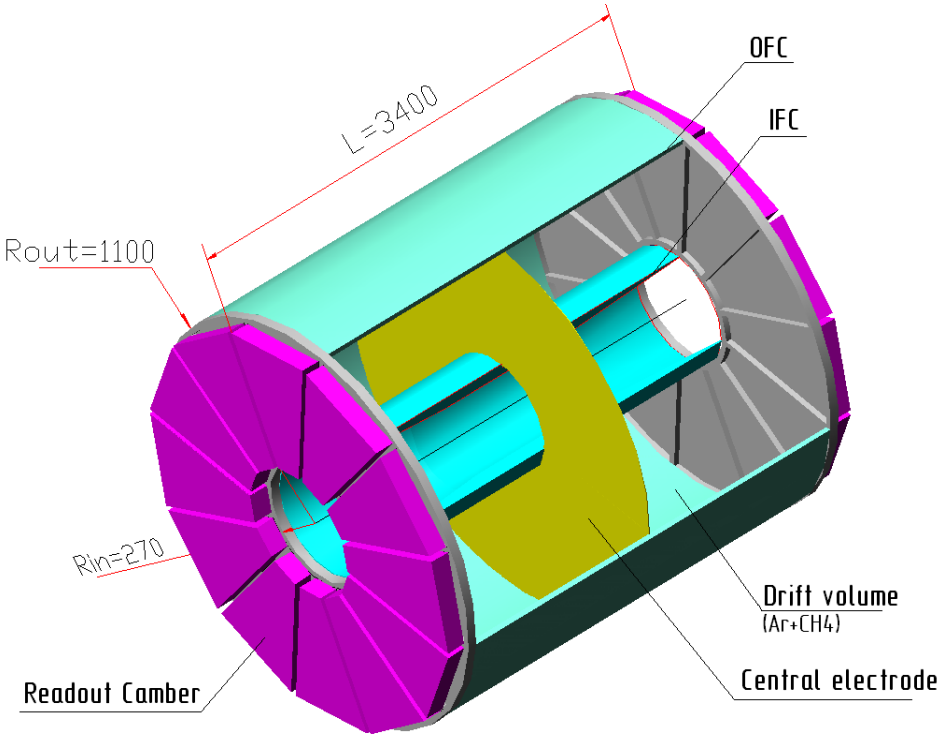
- the momentum resolution for charge particles ~2% at the transverse momentum of 300 Mev/c

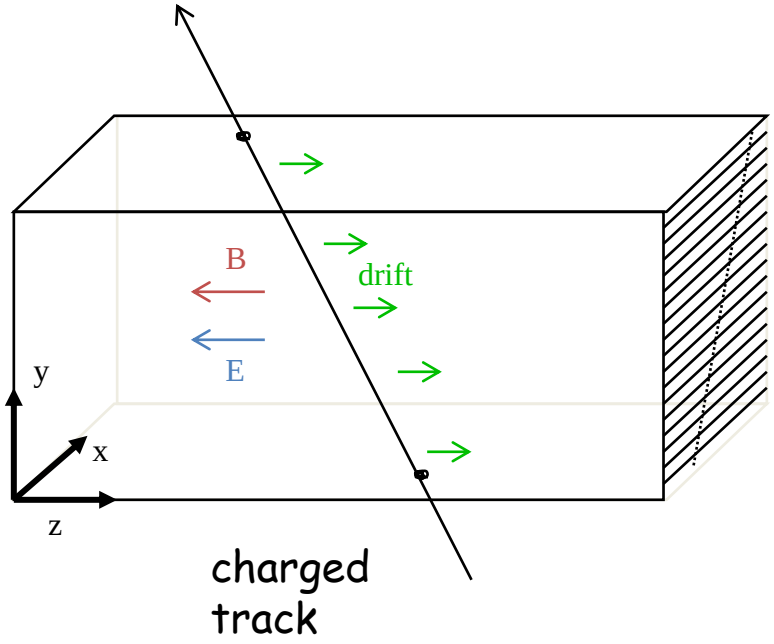
- the two-track resolution has to be about 1 cm

- a dE/dx resolution better than 8% is desirable for hadron and lepton identification

A design luminosity - 10^{27} cm^{-2} s^{-1} for Au+Au collisions
Interaction rate ~ 7 kHz

Time Projection Chamber Design





- **Track points recorded in 3-D (x, y, z)**
- **Particle Identification by dE/dx**
- **Large track densities possible**

- Only gas in active volume,
  small amount of material
- Long drift (~ 1.5 m)
  therefore
  slow detector (~30 μs)
  no impurities in gas
  uniform E-field
  strong & uniform B-field

3-D coordinates

- Z coordinate from drift time

- X,Y coordinates from pads

Amplitude on ith pad

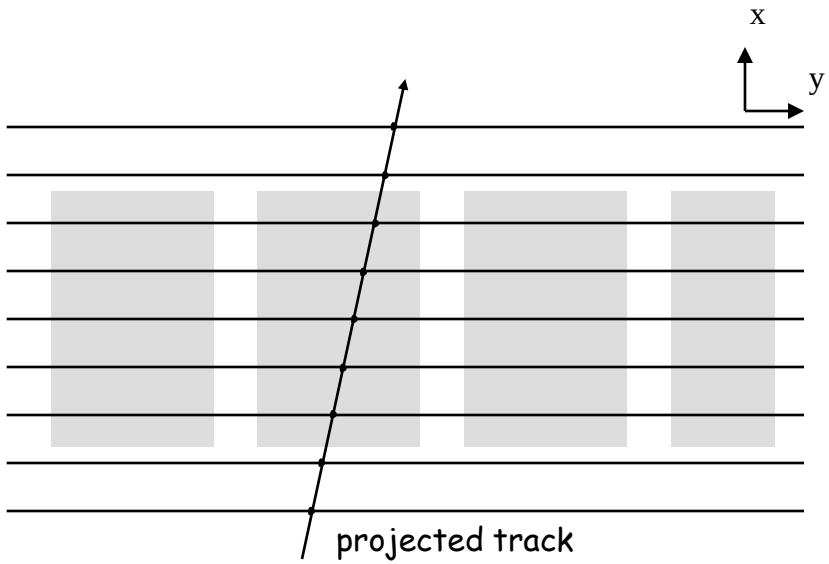
$$A_i = Ae^{(-(y-y_i)^2/2\sigma_{prw}^2)}$$

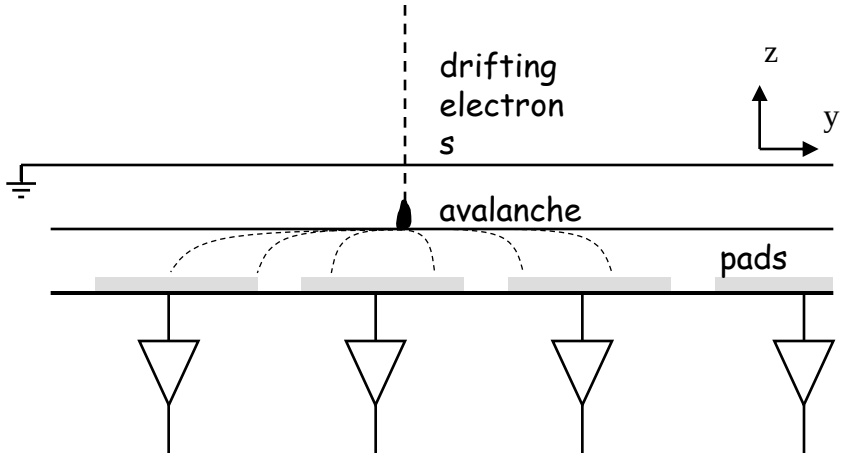
y avalanche position

y_i position of center of ith pad

σ_{prw} pad response width

- Measure A_i
- Invert equation to get y





Basic parameters of the TPC:

TPC length – 340cm
Outer radius – 140cm
Drift volume outer radius – 133cm
Inner radius – 27cm,
Drift volume inner radius – 34cm
Length of drift volume – 170cm
Electric field strength – 140V/cm
Magnetic field strength – 0.5 Tesla
Drift gas – 90% Argon + 10% Methane
Readout: 2x12 sectors (MPWC cathode pads
Number of pads ~ 100000
Pad size – 5x12mm, 5x18mm

Low material budget in barrel part,
max. transparency for forward tracking

Small distortions, $B_r/B_z < 5*10^{-4}$

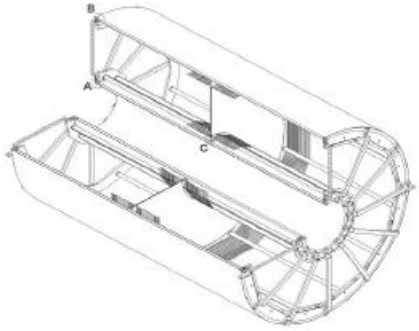


Fig.2a. Inner view of the TPC

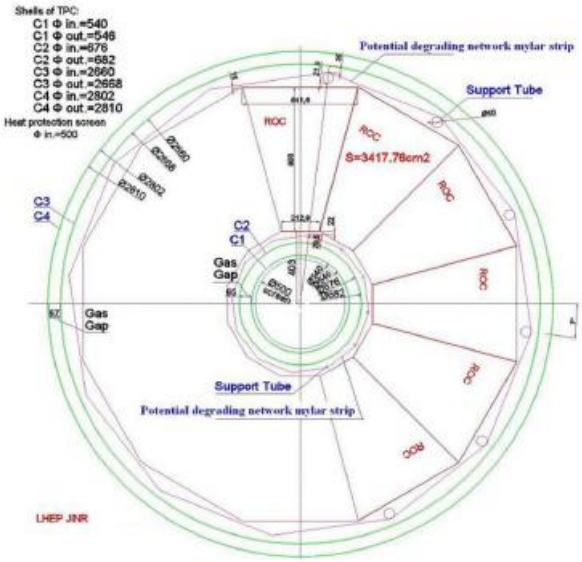
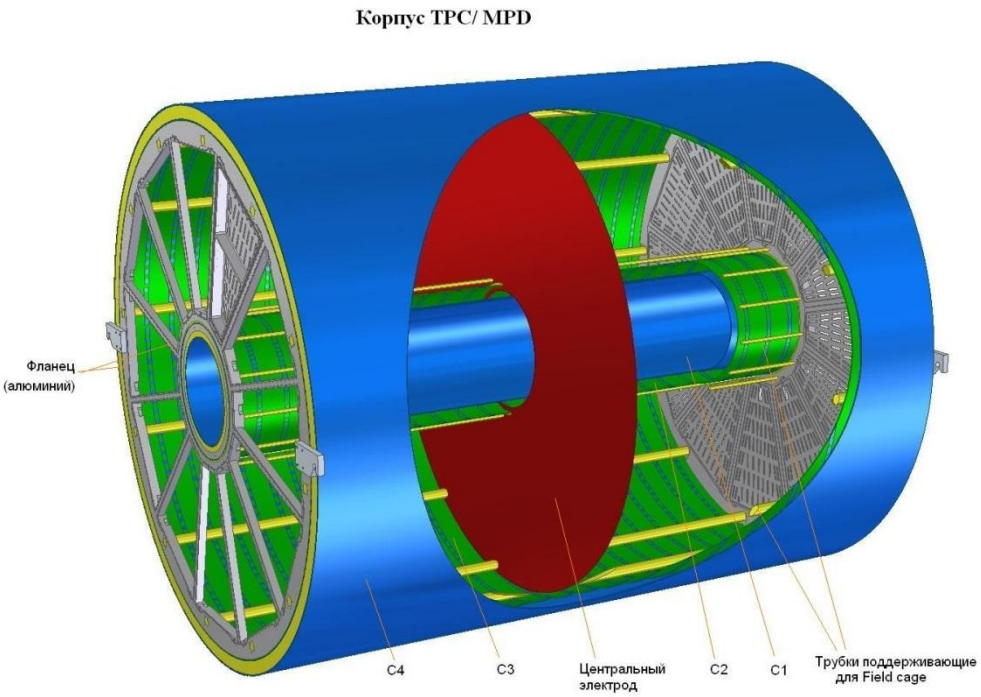


Fig.2b.The front view of the TPC

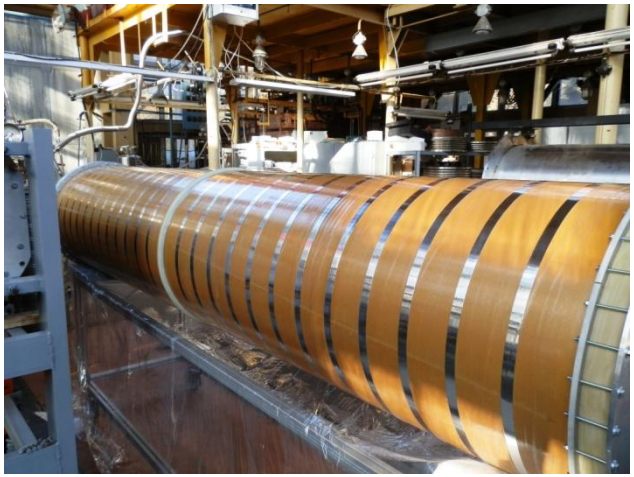
Main characteristics of TPC



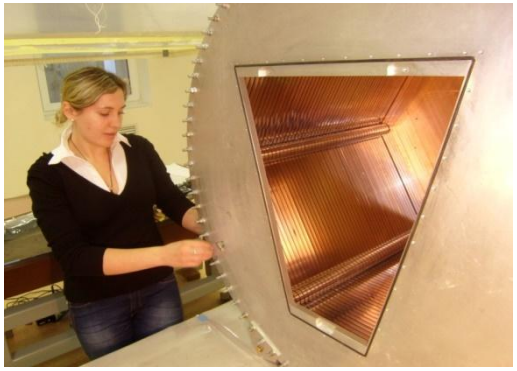
Item	Dimension
Length of the TPC	340cm
Outer radius of vessel	140cm
Inner radius of vessel	27 cm
Outer radius of the drift volume	133cm
Inner radius of the drift volume	34cm
Length of the drift volume	170cm (of each half)
HV electrode	Membrane at the center of the TPC
Electric field strength	~140V/cm;
Magnetic field strength	0.5 Tesla
Drift gas	90% Ar+10% Methane, Atmospheric pres. + 2 mbar
Gas amplification factor	~ 10^4
Drift velocity	5.45 cm/μs;
Drift time	< 30μs;
Temperature stability	< 0.5°C
Number of readout chambers	24 (12 per each end-plate)
Segmentation in φ	30°
Pad size	5x12mm^2 and 5x18mm^2
Number of pads	95232
Pad raw numbers	53
Pad numbers after zero suppression	< 10%
Maximal event rate	< 7 kHz (Lum. 10^{27})
Electronics shaping time	~180 ns (FWHM)
Signal-to-noise ratio	30:1
Signal dynamical range	10 bits
Sampling rate	10 MHz
Sampling depth	310 time buckets

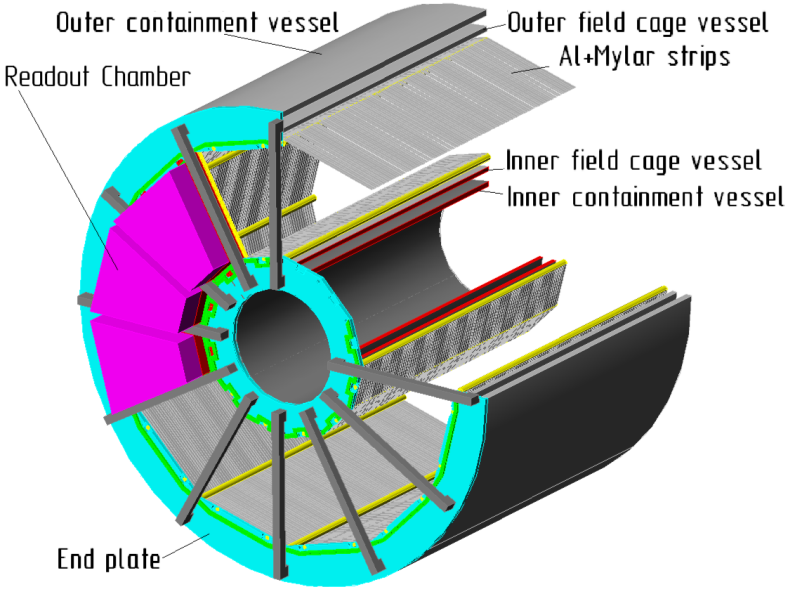
Gas tight containment cylinders C1-C4 production in Russian industry

- Material : Kevlar
- Thickness: 4 mm
- Length: 3.4 m
- Diameter: 2.8 m
- Deformation in operational position is less than 100 mkm



Uniform E-field creation system



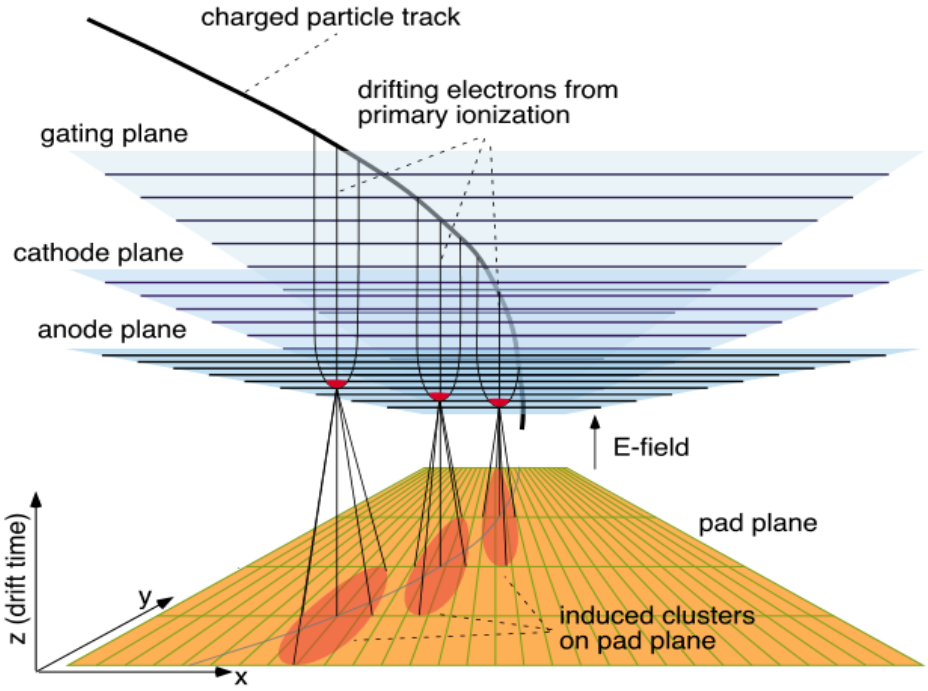


The non uniformity of the electric field inside the sensitive TPC volume has to be not more than 10^{-4} relative to nominal value (140V/cm P10 gas mixture)

TPC Readout

Readout Chambers

The wire chamber sectors (30° in azimuth) are mounted on each side of cylinder, on the end-cap wheels. In total - 24 chambers.



The overall area to be instrumented is ~ 8,0 m². The chambers will be conventional multiwire proportional chambers with cathode pad readout. To keep the occupancy as low as possible and to ensure the necessary d*E*/d*x* and position resolution, there will be ~ 100 000 readout pads with two different sizes varying from 0.5 cm² near the inner radius to 1.0 cm² near the outer radius.

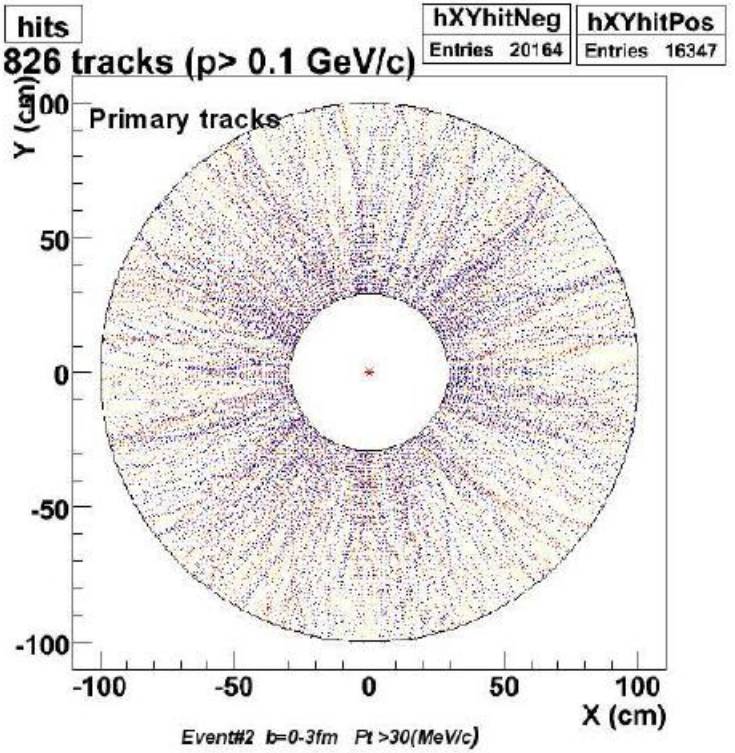
TPC SIMULATION (pad sizes)

Allison and Cobb relation

$$\frac{\Delta dE/dx}{dE/dx} = \frac{0.96}{2.35} N^{-0.46} l^{-0.32}$$

dE/dx ~7% ⟺ number $N = 40$ of pad rows, $l = 1.2$ cm the plength

16% tracks occupy the about 10 cm area around the inner field cage wall

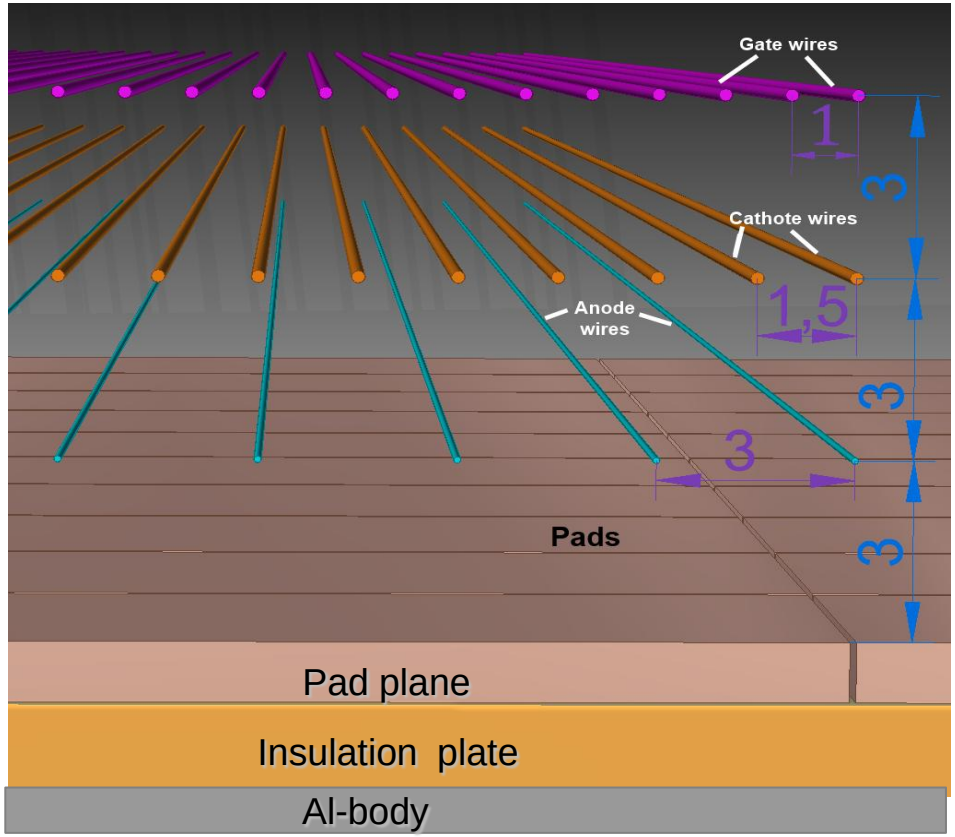


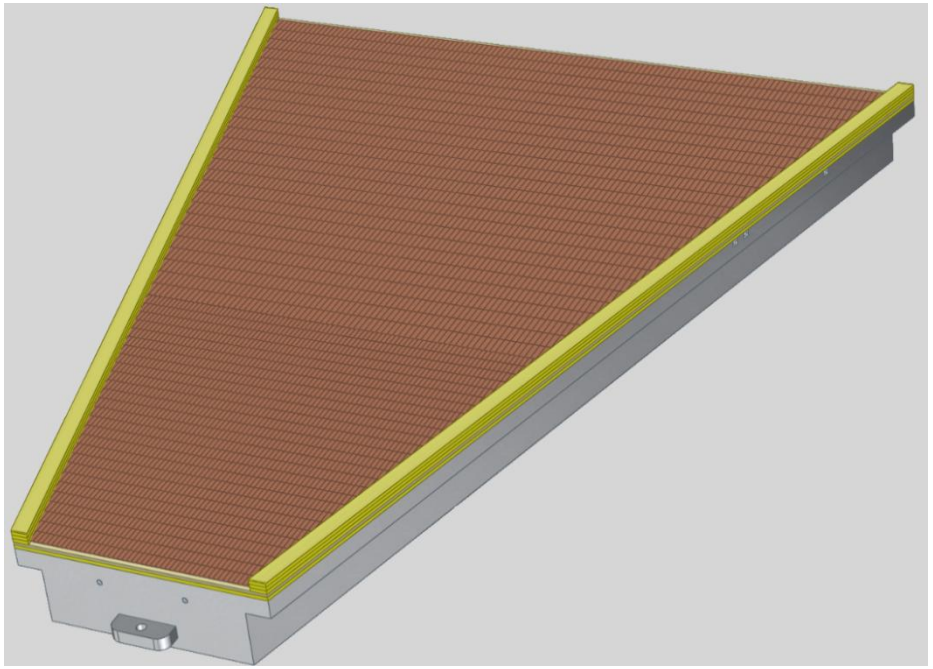
central $Au + Au$ collision at $\sqrt{s_{NN}} = 9\,GeV$

At least 41 rows of 12mm length has to be in the pad plane area

Readout chamber

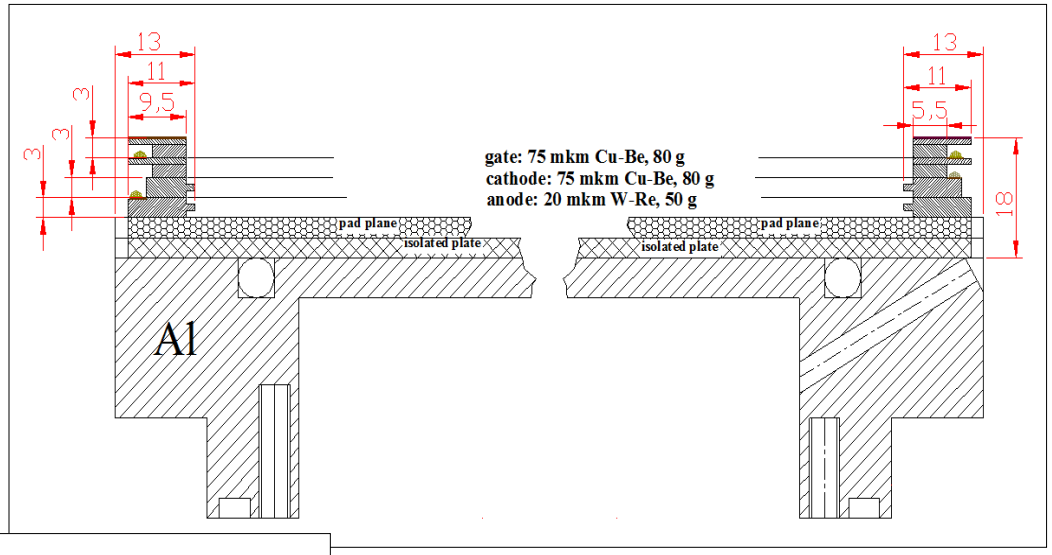
Structure of readout chamber:
- three wire planes
- pad plane
- insulation plate
- trapezoidal aluminum frame

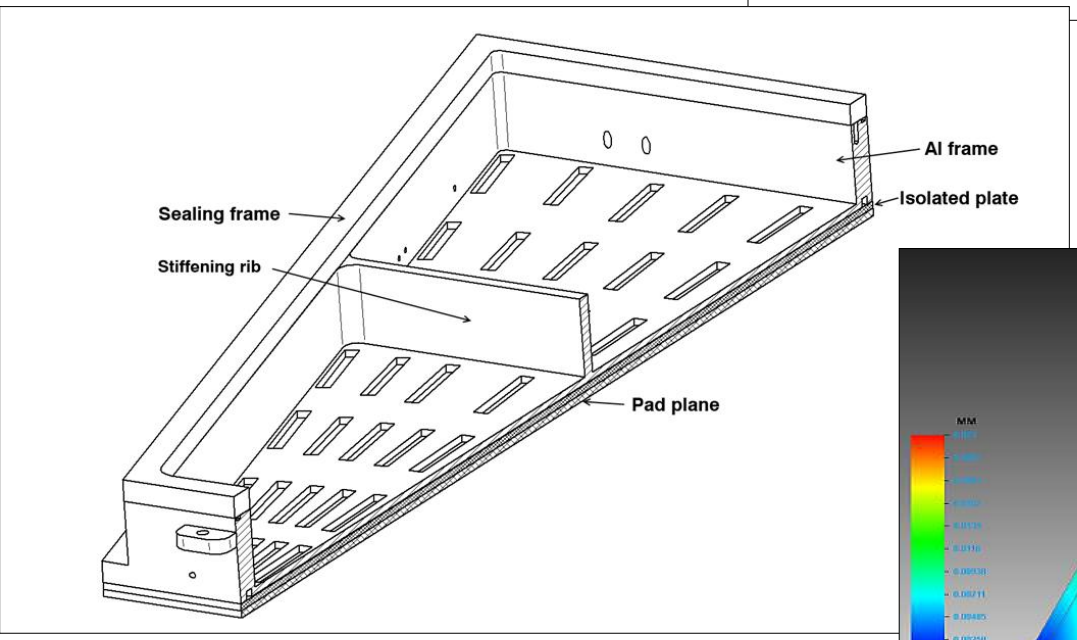


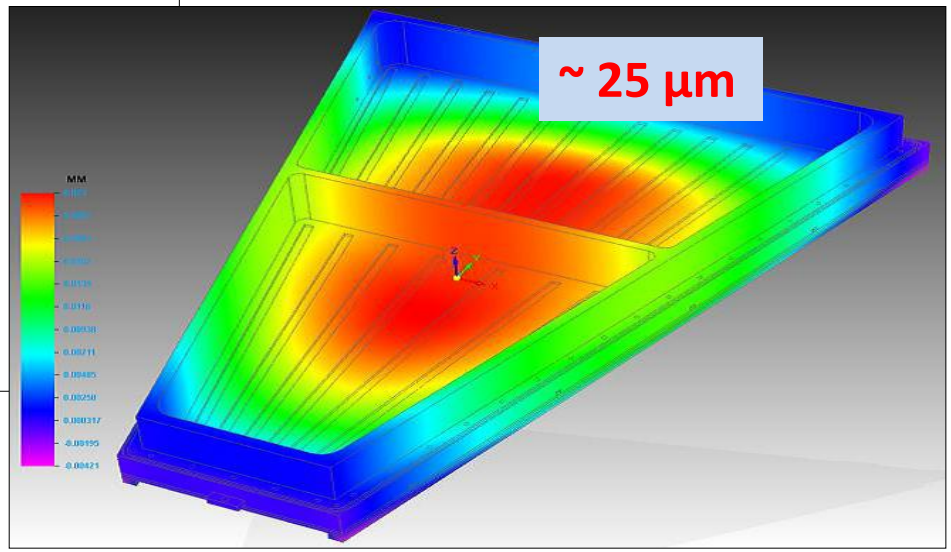


Pad structure
pad raw number 53
rectangle shape
- small pads 5×12 mm^2
- large pads 5×18 mm^2

Wires structure
- anode wire pitch 3 mm
- cathode wire pitch 1,5 mm
- gate wire pitch 1 mm
- wires gap 3 mm


13
11
9,5
3
3
3
13
11
5,5
18
gate: 75 mkm Cu-Be, 80 g
cathode: 75 mkm Cu-Be, 80 g
anode: 20 mkm W-Re, 50 g
pad plane
isolated plate
pad plane
isolated plate
Al


Al frame
Isolated plate
Sealing frame
Stiffening rib
Pad plane


~ 25 µm
MM

ROC chamber and Pad-plane status

Design of Read-Out Chamber (ROC) is defined

Structure of Readout Chamber:

- three wire planes
- pad plane
- insulation plate
- trapezoidal aluminum frame

Wire structure:

- anode wire (Ø=25 μm) pitch - 3 mm
- cathode wire (Ø=75 μm) pitch - 1.5 mm
- gate wire (Ø=75 μm) pitch - 1 mm
- wires gap - 3 mm

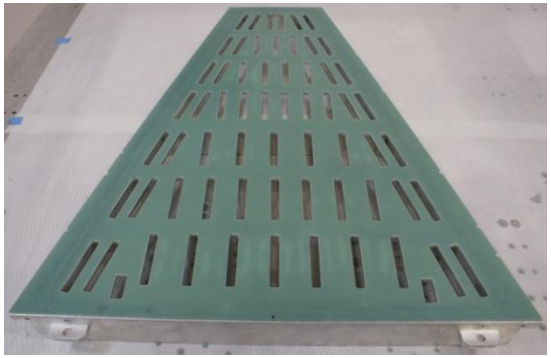
Pads:

- rectangular shape
- 27 rows of pad with size 5x12 mm² at inner area
- 26 rows of pad with size 5x18 mm² at outer area

Two prototypes of read-out chamber were constructed and tested

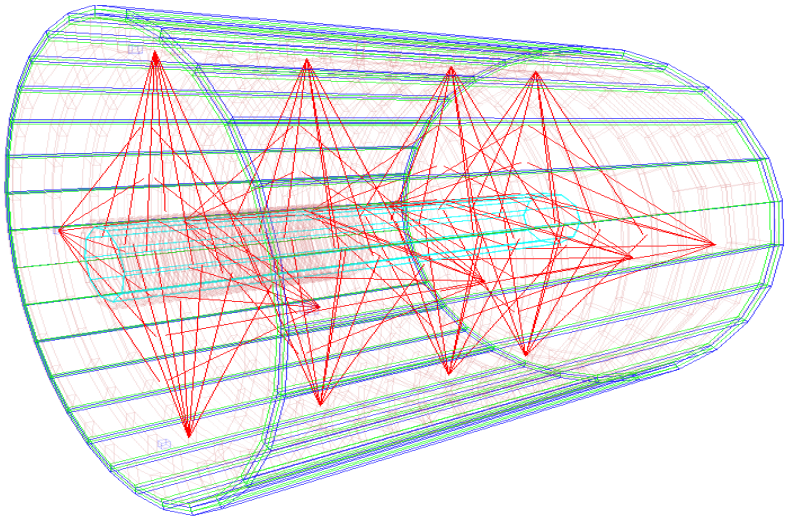
Serial read-out chamber (ROC) is designed and two prototypes are under construction

Pad-plane printed circuit board is developed and given into manufacture

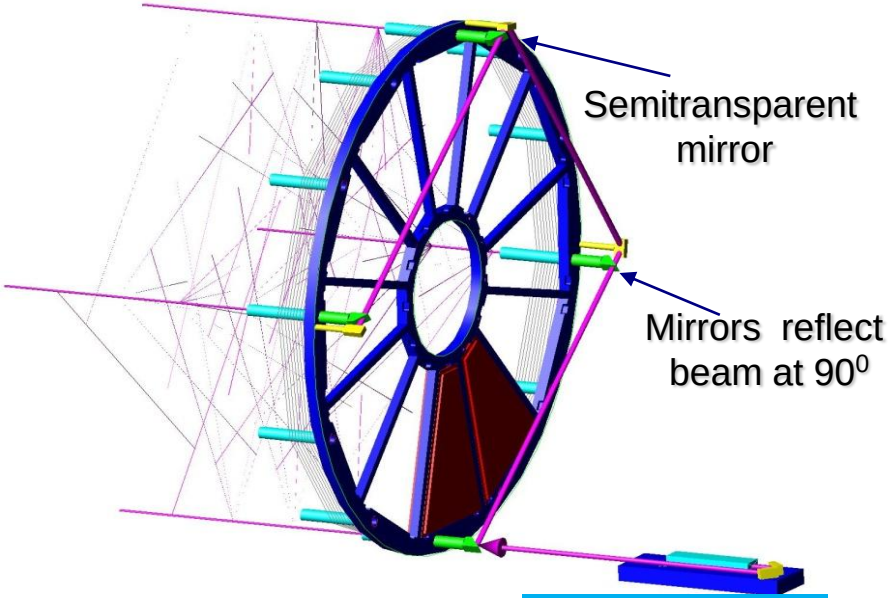


TPC Laser Calibration System

In order to minimize the error in the absolute position measurement by TPC, it is necessary to take into account both static and time-dependent distortions in the drift path of the ionization cloud. A calibration system that can reproduce fiducial tracks is needed to monitor the TPC performance. This calibration system will be based on the UV laser.



There are 224 laser beams whole TPCin

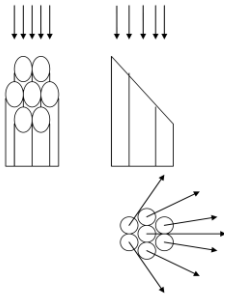


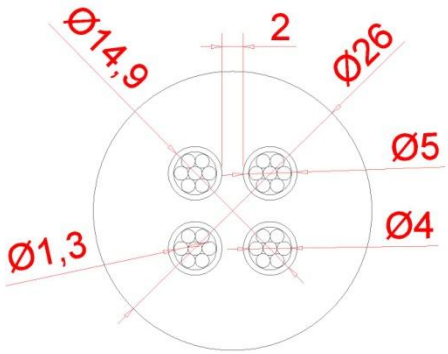
Laser *NL313-10*

Status of TPC calibration system

2 lasers are ordered

Set of mirrors

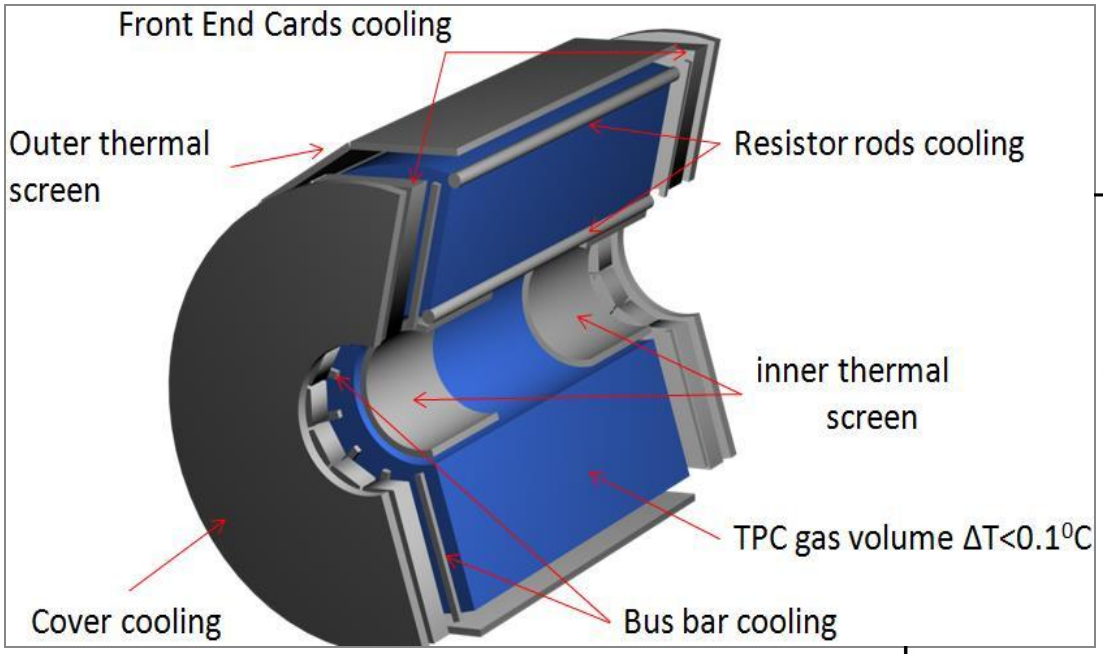


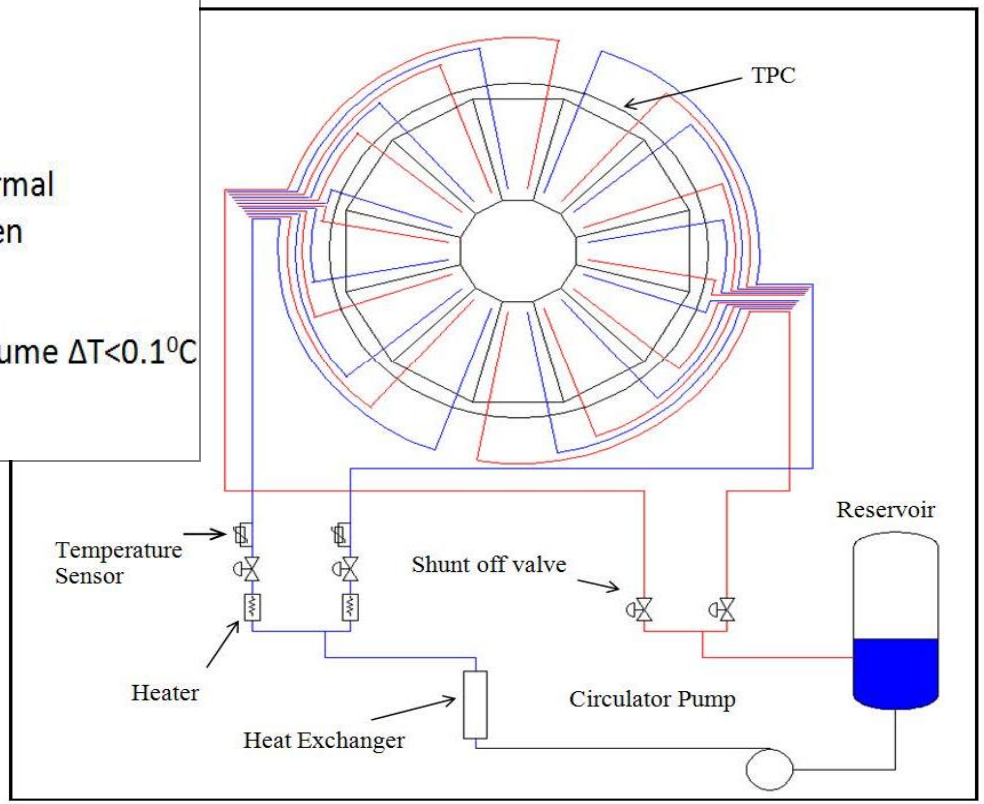


300 mirrors are ordered

Prototyping and design – in progress

TPC cooling system



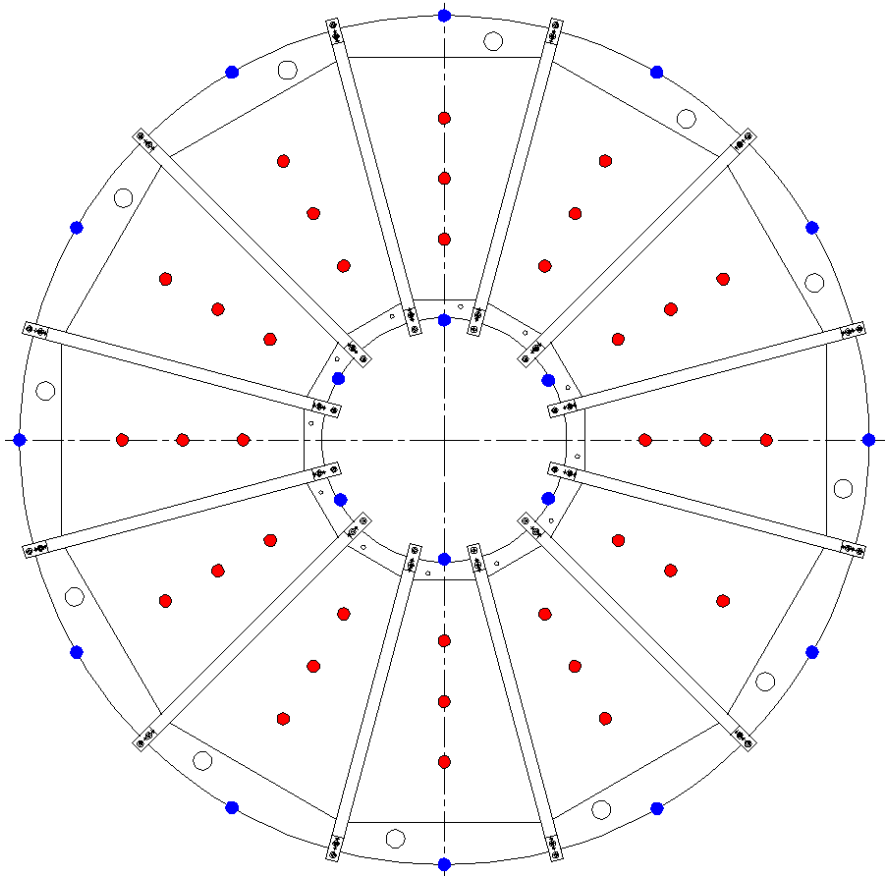


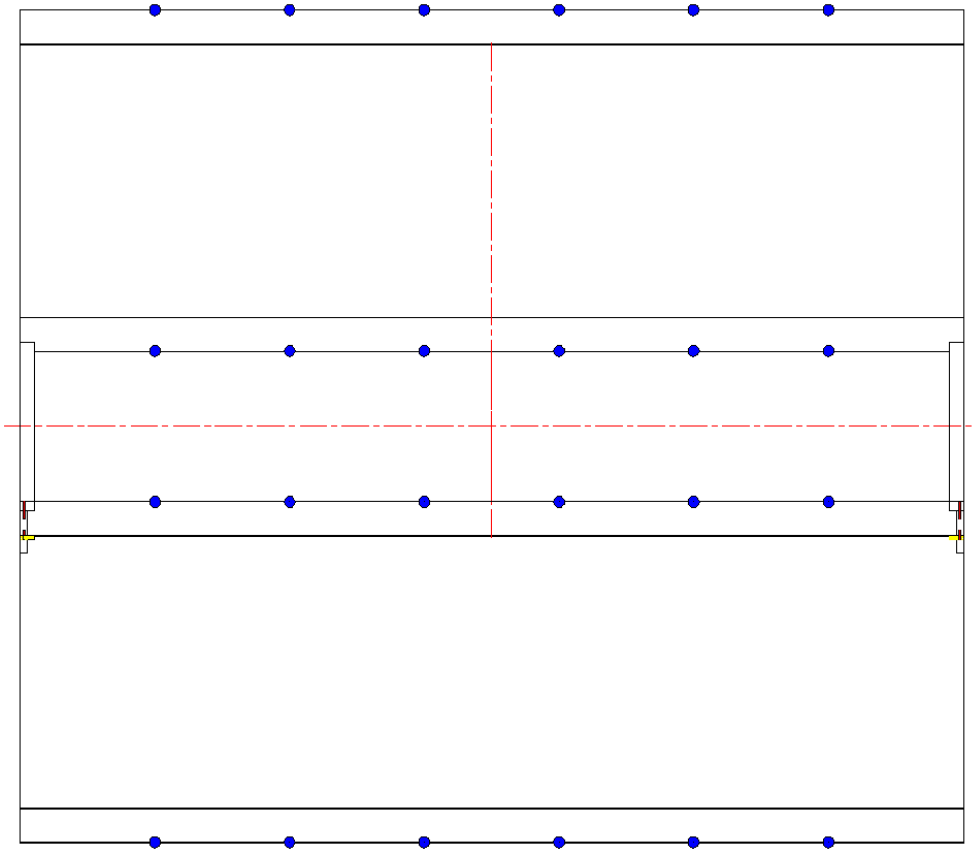
Number of Circuits:

- FEEC: 12+12
- ROC Covers: 2+2
- Therm screen: 12+6
- Resistor rods: 2+4

Total: 52

Temperature Monitoring

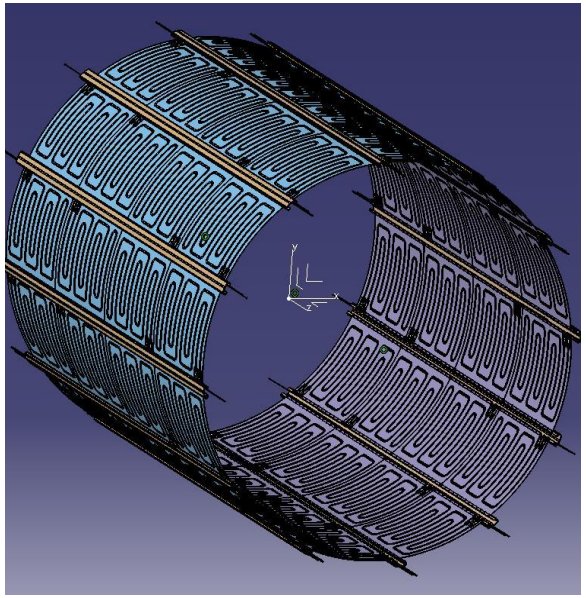


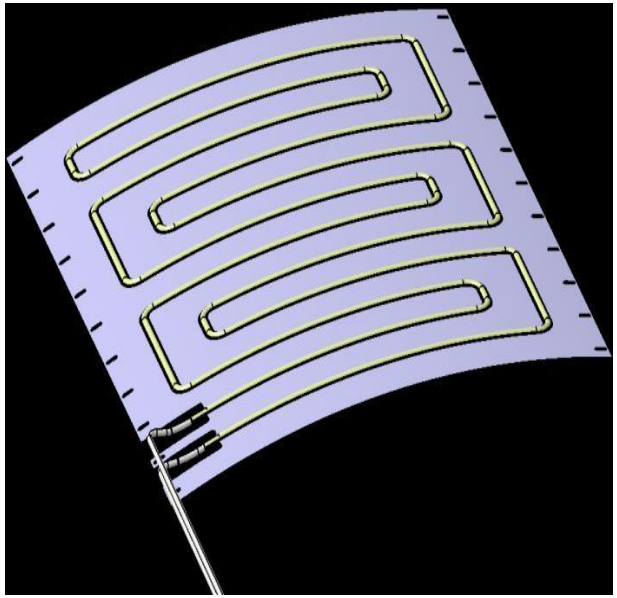


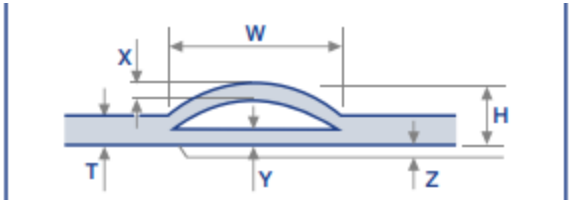
Sensors: **blue** – on the field cage, **red** on the chambers

Location	Outer Field cage	Inner Field cage	ROC modules
Number of the sensors	72	36	72

Status design of cooling system







W (mm)	H (mm)	T (mm)	X (mm)	Y (mm)	Z (mm)
9.0	3.0	1.5	0.6	0.9	0.4
10.0					
11.0					

in progress …

Weight ~ 2.7 kG
Weight+H2O ~ 3 kG
48 cooling plates (48*3) ~ 144 kG
Option 1: 48 cooling plates + steel supports (144+14*22) ~ 452 kG
Option 2: 48 cooling plates + Al supports (144+14*7.3) ~ 246 kG

TPC gas system

Requirements

90%Ar+10%CH_4

The drift volume is 18500 liters,
the insulating gaps – 4800 liters

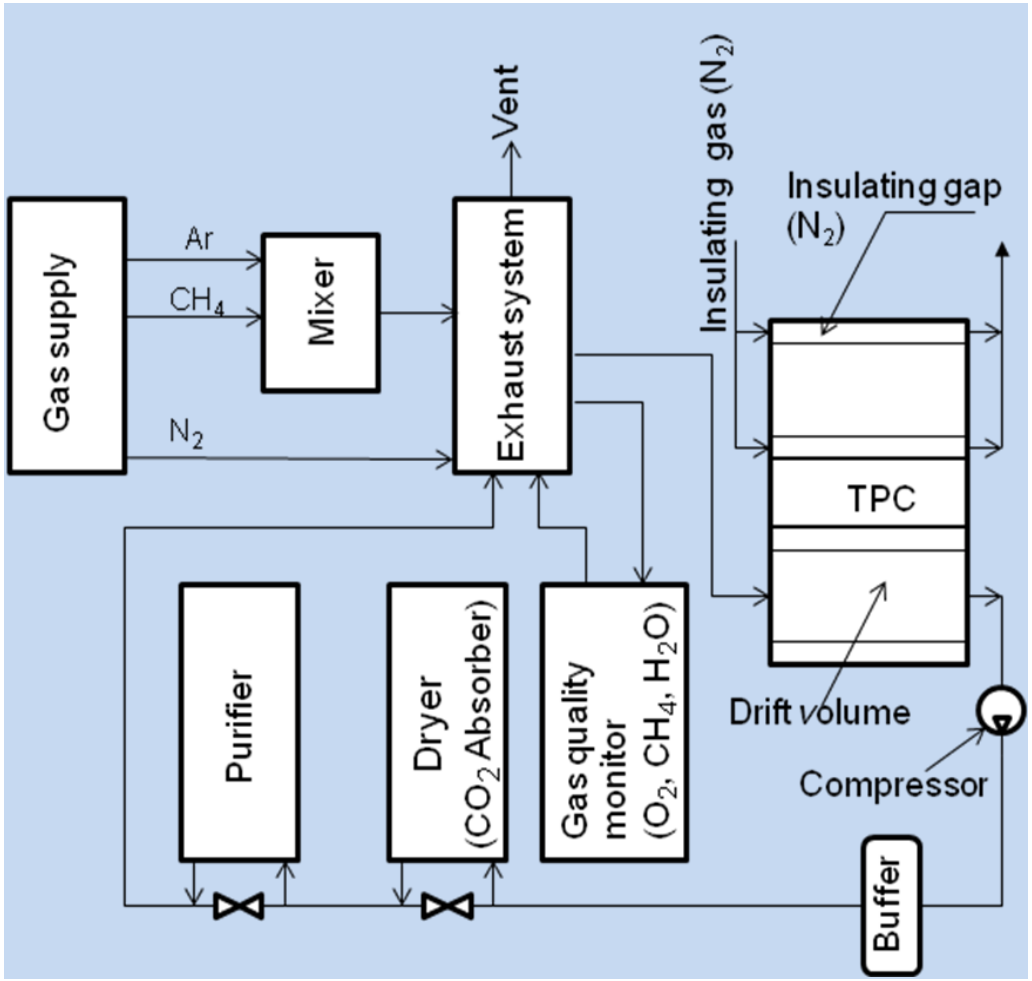
Hermetically closed-loop gas circulation system

Dryer and purification in return line
Continuous monitoring of gas gain and drift velocity – gas chromatograph

Gas mixture temperature control - 0.5 K

Internal TPC overpressure – not more 2 mbar
Recirculation flow - 3.8 m^3 /h

TPC gas system



Gas mixture	Ar + 10%CH_4
TPC gas flow, nominal	200 l/min
TPC overpressure	(2.0 ± 0.1)mBar
O_2 admixture	20 ppm
H_2O admixture	10 ppm
External loop, refresh gas rate	30 l/min
Fresh part of gas mixture add to external loop, range	(0-50) l/min
TPC isolating gas	N_2
N_2 gas flow	(5-20) l/min

Gas system technical design report is complete, the system is under construction. It will be ready in 2017.

TPC data rates

Trigger rate - N=7 kHz

hit size per track - 3.0 kB

- *signal shape - 5 byte/ch*
  *(3 ADC*10bit + time(10bit))*
- *per 1 "hit" on track - 5byte/ch* 6 pads*

= 30 byte

- *per track - 30x53(R-коор.) = 1.6 kByte*

up to 30x(53R+75φ)= 3.9 kByte

max rate per half TPC: 15 GB/sec

$3.0*10^3$ Byte x 500 tracks = 1.5 MB per ~ 100 µsec

TPC total data rate: 30 GB/sec

TPC data rate:

max **- 30 GB/sec** (1000 tracks per 100 µsec)

average - **10 GB/sec** ($2.5*10^6$ tracks/sec (350 tracks per 100 µsec))

Occupancy (for 1000 tracks): ~ 10 %

ROC chamber:

Each ***RCU output link speed***

Max **- 11.2 Gbit/sec**

average **– 4 Gbit/sec - OK!**

FE-RCU (62 pc FE per ROC chamber):

Each ***FE-RCU link speed:***

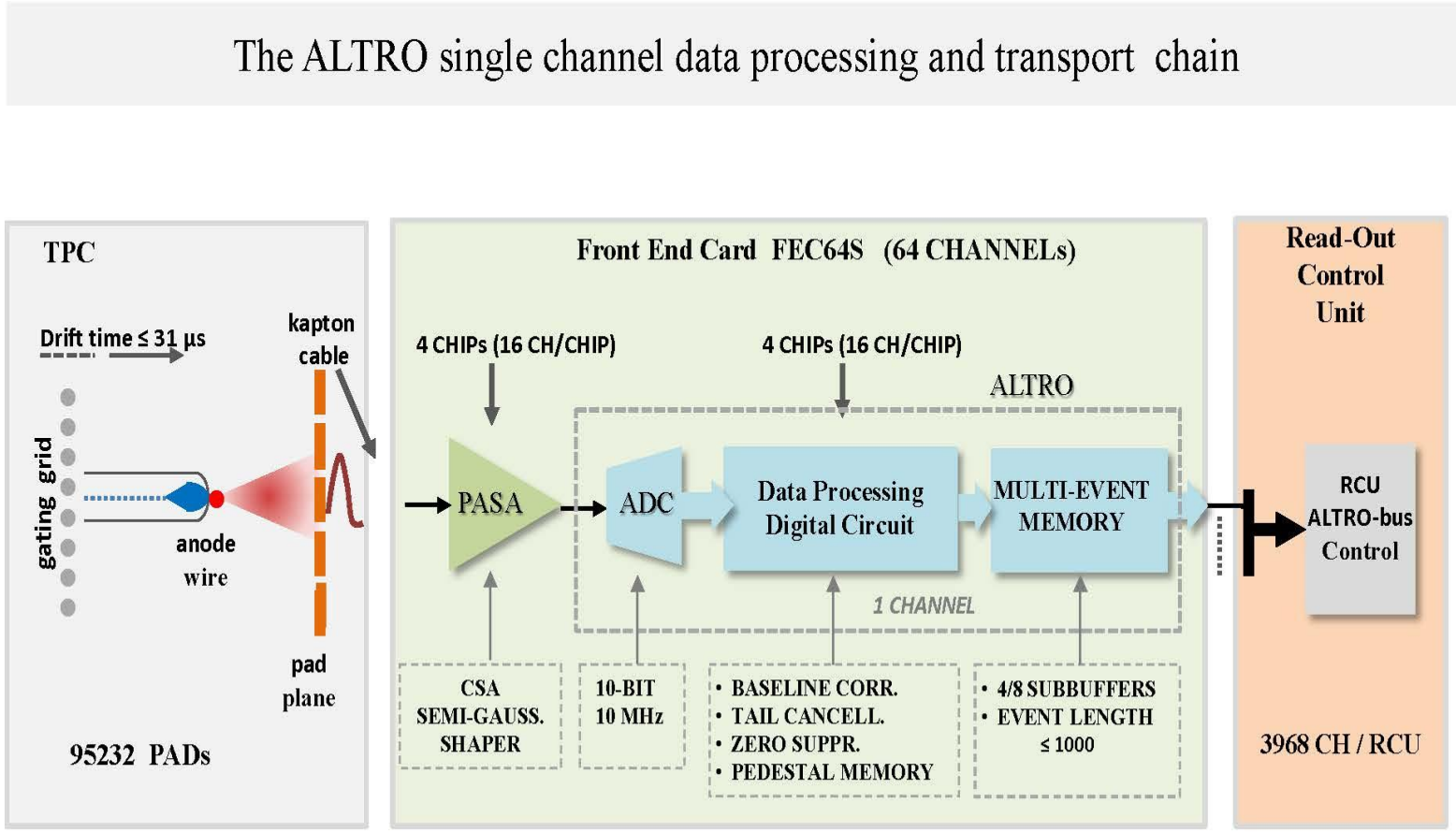
max **- 180 Mbit/sec - OK!**

average **– 65 Mbit/sec**

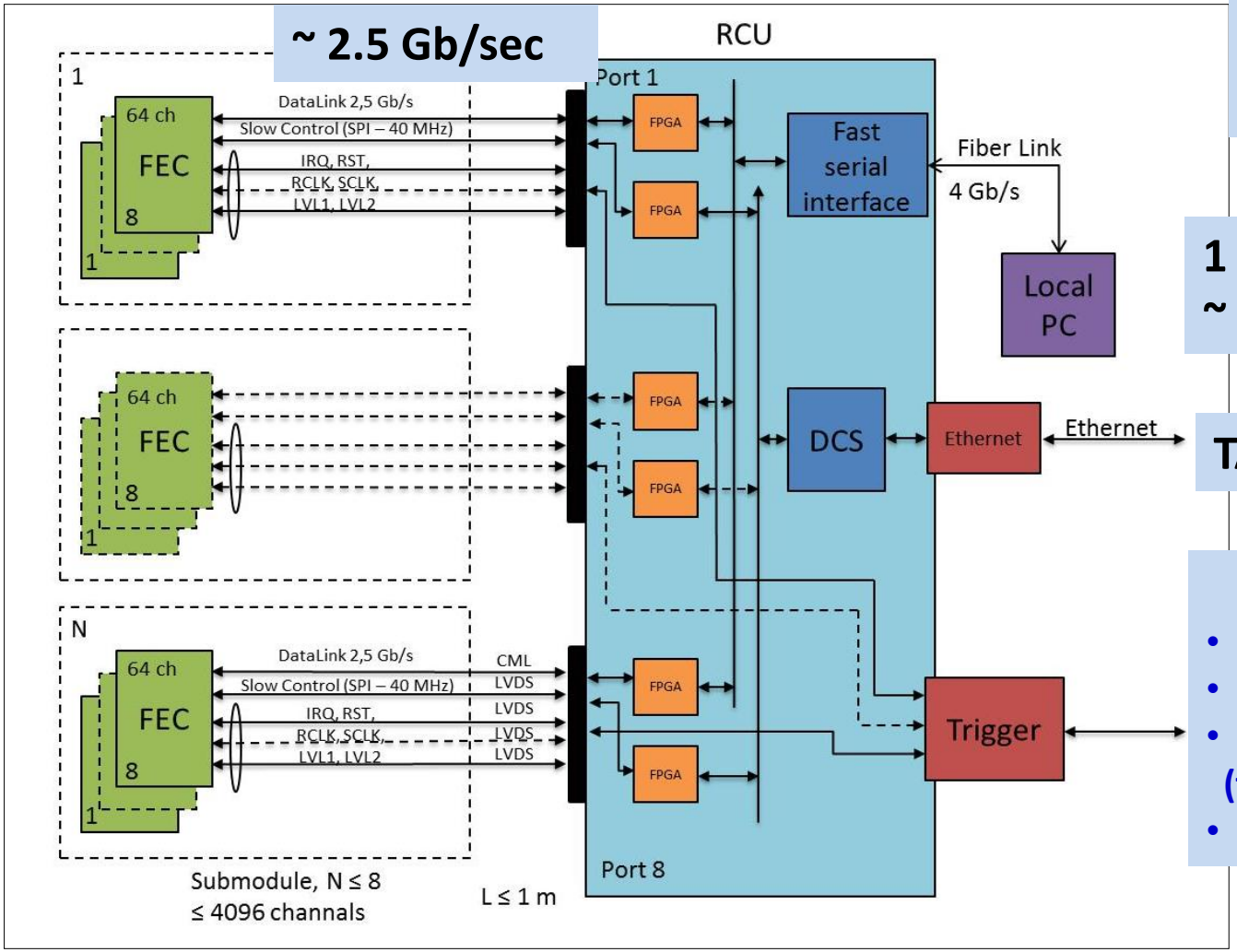
TPC electronics

Parameter	Value
Total number of channels	95 232
Signal to noise ratio, S/N	> 30:1 @ MIP (σ_{noise} < 1000e^-)
Dynamic Range	1000 (10 bits sampling ADC)
Shaping time	190 ns
Sampling	10 MHz
Tail cancellation	< 1% (after 1 μs)
Zero-suppression	up to 90%
Bandwidth	up to 10 GB/s @ TPC
Power consumption	100 mW/ch

FE electronics based on PASA and ALTRO ASICs



RCU controller



24 RCU / TPC
~ 10 GB/sec

1 RCU to DAQ:
~ 0.45 GB/sec

TANGO

LTU/TPC

- **Orbit number**
- **Bunch crossing #**
- **L0, L1, L2**

(timing/trigger/control)

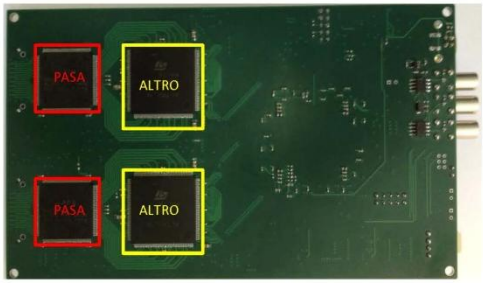
- **TPC busy**

FE card prototype (FEC-64)

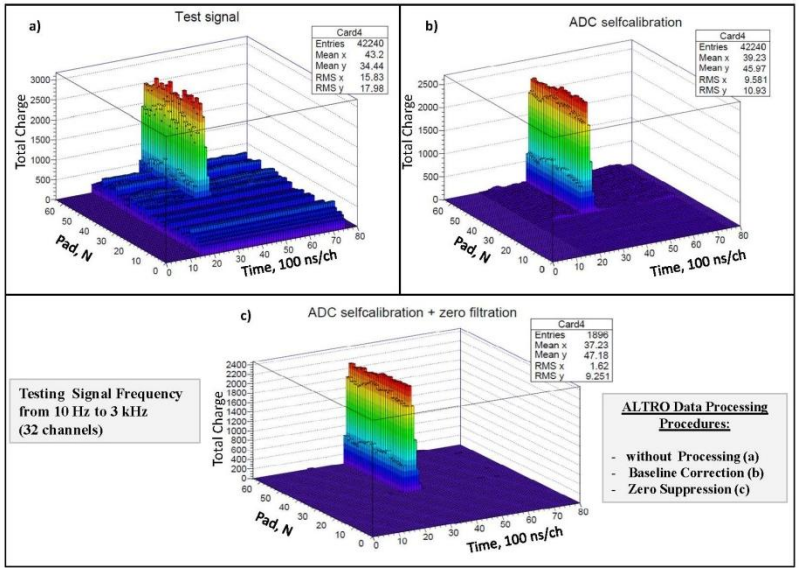
Top view

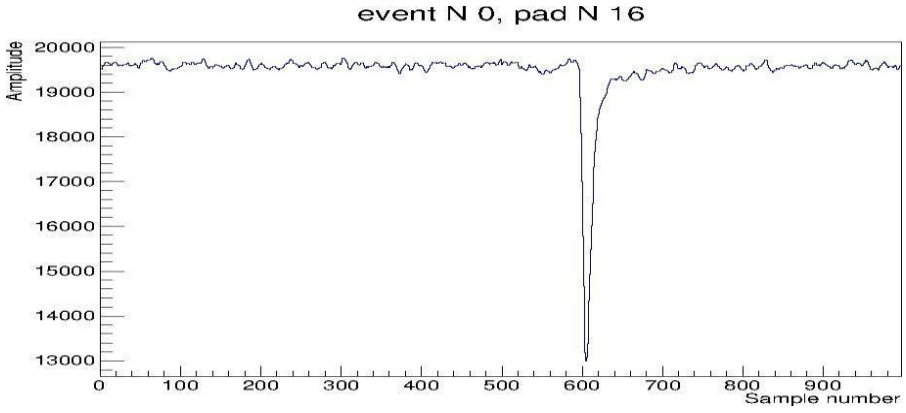
- ❖ 64 channels
- ❖ Signal to noise ratio, S/N – 30
- ❖ σ_{NOISE} < 1000e$^-$ (C=10-20 pF)
- ❖ Shaping time - 180-190 ns

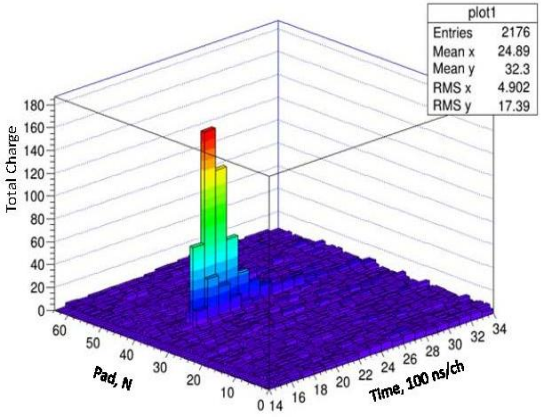
- ❖ Sampling clock – 0.5 – 25 MHz
- ❖ ALTRO bus speed 200 MB/s
- ❖ USB speed ~ 30 MB/s
- ❖ Dimensions - 100 x 170 mm²



Bottom view







FEE status

- ✓ **TPC FE electronics concept - done**
- ✓ **Engineering & Construction** of the 64-Channel Front-End Card based on the 16-channel analog-to-digital **ASIC ALTRO (Prototype FEC64) - done**
- ✓ **FEC64 Software** for study ASIC ALTRO functioning and debugging of FPGA digital logics - **done**
- ✓ **Testing of some FEC64** with Pulse Generator and on the TPC-prototype Readout Chamber with Fe-55 - **complete**
- ✓ **Engineering & Construction and Test** of the **serial** 64-Channel Front-End Card **FEC64S - in progress**
- ✓ **Engineering** of the Readout Controller **RCU - in progress**
- ✓ **Creation** of the FEC64S **Testing System** based on the development kit **'Cyclone-5 SoC' – in progress**

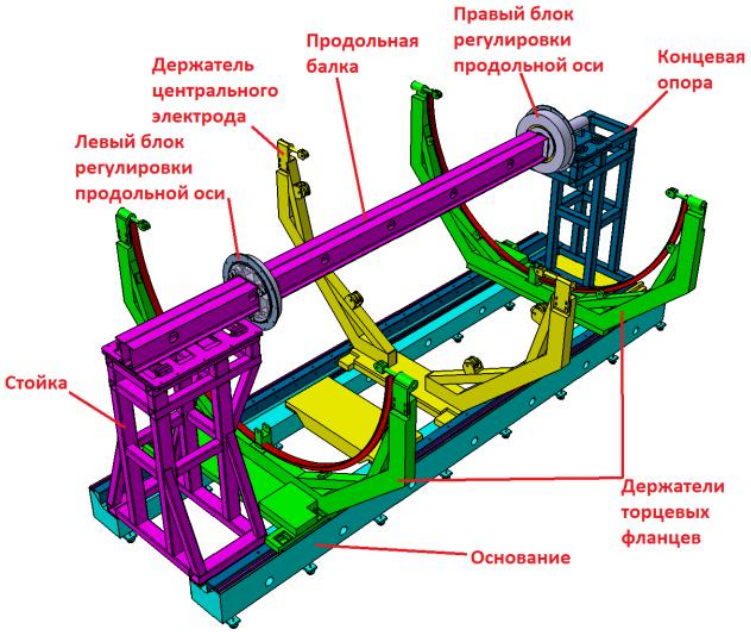
TPC assembly

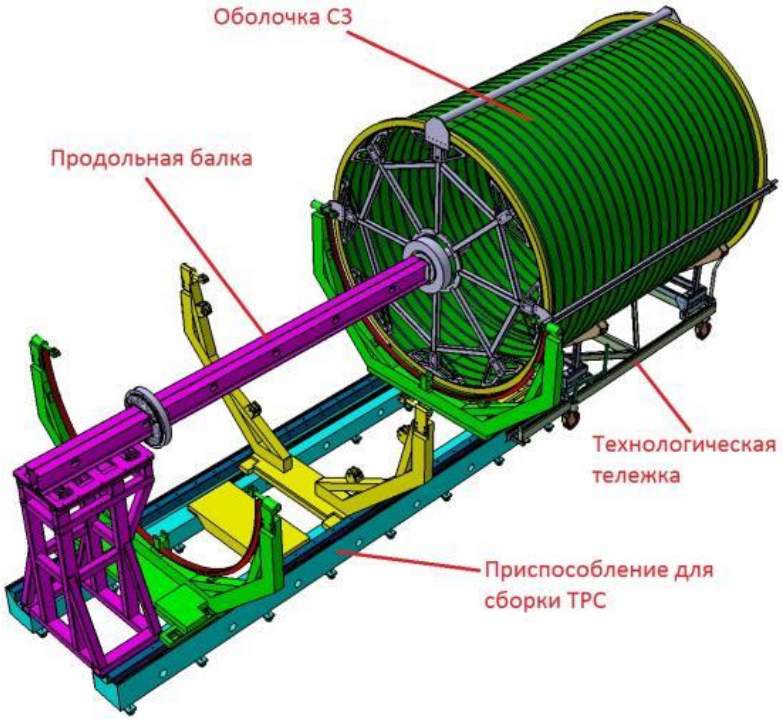
Bld.217

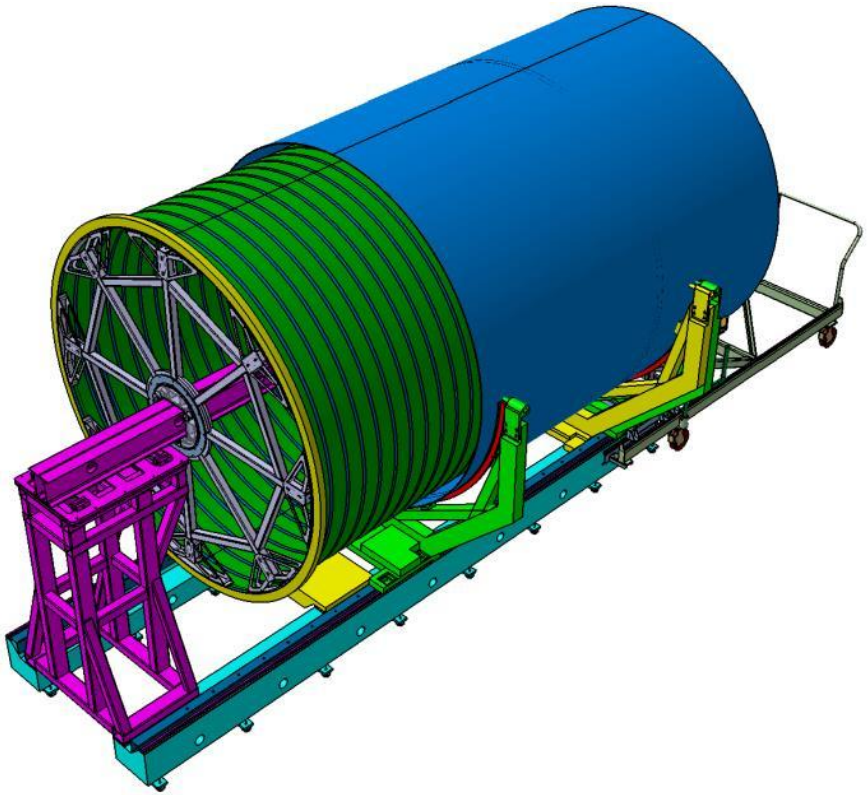
S = 84 m2 (ISO-8-9)
+ 2 rooms for equipment

Tools for TPC assembling

Status: under design







ROC chamber assembly hall

Gluing

Wiring

Test set up

Soldering

Time schedule

	Item	Date
1	Assembly TPC cylinders C1+C2	December 2015
2	TPC assembly hall ready	June 2016
3	TPC assembly (C1-C4 + HV electrode + field cage + 2 flanges)	December 2017
4	ROC chamber manufacture (26 pc)	2016 – 2017
5	Assembly ROC chamber (24pc) to TPC	Jan-June 2018
6	TPC electronics manufacture (FEC64S and RCU)	May 2018
7	Assembly FEC64S to ROC chamber	Sept– Dec 2018
8	TPC test with cosmic and laser calibration system	2018-July 2019
9	TPC transportation from Bld.217 to the MPD hall	August 2019
10	Installation TPC to MPD	Sept 2019
11	TPC gas and cooling systems assembly in the MPD hall	Jan – Sept 2019
12	TPC test inside MPD	Oct–Dec 2019 - 2020

Thank you for attention

Welcome to joint us for design and experiments at NICA accelerator complex with MPD

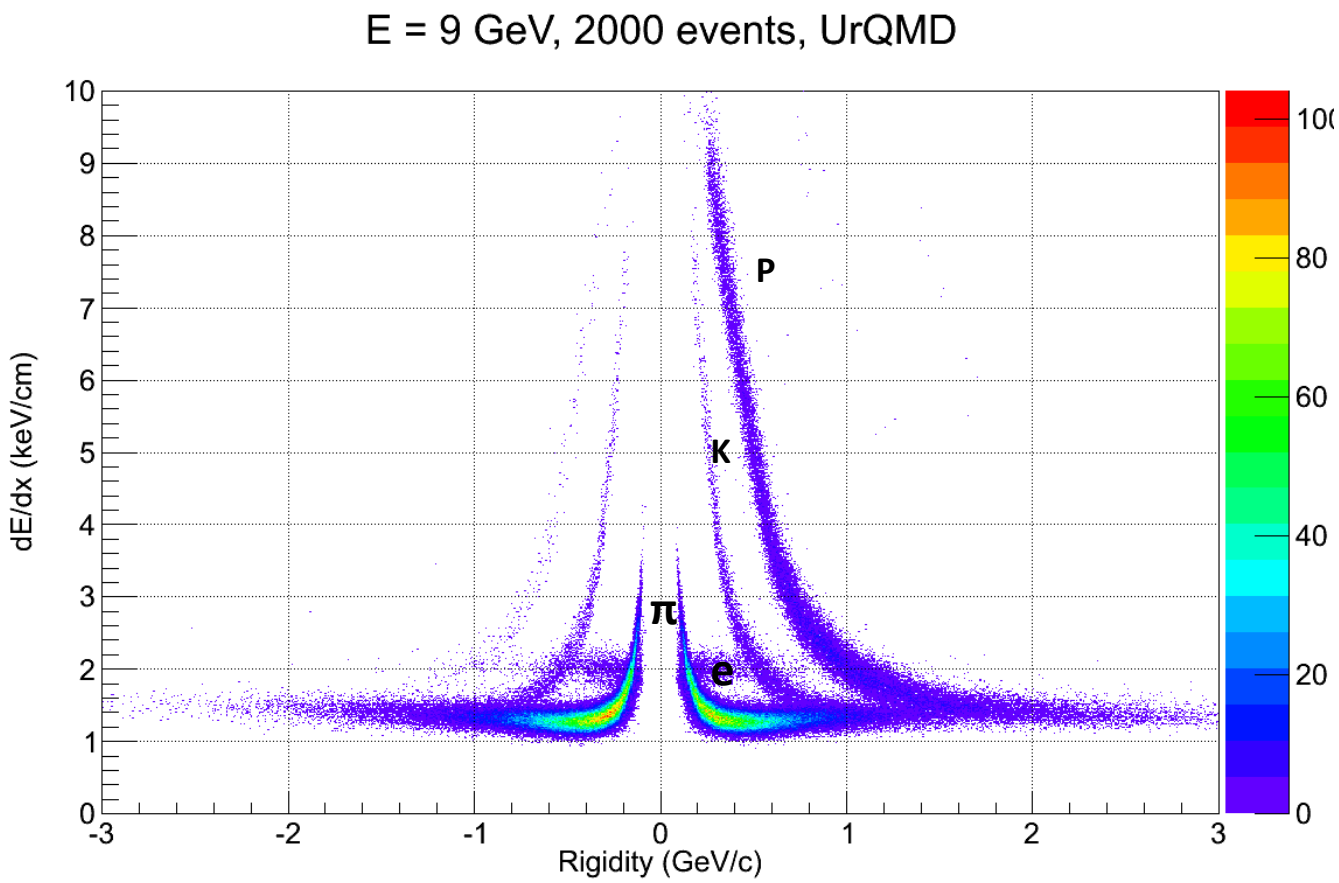
SPARE Slides

(TPC + termoscreen) radiation length

	Base line option			Upgrade
	for $\eta = 0$	for $\eta = 1.31$		
Air (beam pipe-C1) h=220 mm	0.073	0.146		
TPC shielding Al, h=0.1 mm	0.11	0.22		
C1 h=3 mm	0.80	1.6		
N_2 (gap C1-C2) h=63 mm	0.02	0.04		
C2 h=3 mm	0.8	1.6		
sum:	1.803	3.6		
TPC gas mixture L=1500 mm	1.171	0.984 (L=1260 mm)		
sum:		4.6		4.6
ROC			ROC	
1. Wires+gas	0.08		1.4 GEM foils Cu, 8x5µm=40 µm Kapton 4x50µm =200 µm	0.32
2. Pad plane h=3 mm	2.00		2. Pad plane h=1.5 mm	1.00
3. Insulating plate h=3 mm	1.55		3. Insulating plate h=1.5 mm	0.775
4. Al frame h=5 mm	5.62		4. Carbon panel h=25 mm	0.30

5. Epoxy glue (2x0.1mm)	0.056		5. Epoxy glue (2x0.1mm)	0.056
Air gap L=10 cm	0.03		Air gap L=10 cm	0.03
ROC sum:	9.34		ROC sum:	~2.5 - 3.72
FE (62 FE boards)			FE (based on SAMPA chip)	
PCB+components, 21 kG	21.13		all FE – single layer FE - 4 layers	1.0 5.0
FE Cooling			FE Cooling	
Cu radiators + H_2O, 14.4kG	36.00		Al pipes + plates on chips	2.5
Service wheel SSW Al, 10 kG	13.3			NO
TPC termoscreen Al + H_2O, h=1.5 mm	1.69		TPC termoscreen Al + H_2O, h=1.5 mm	1.69
Summary:	~86.1			~17.5

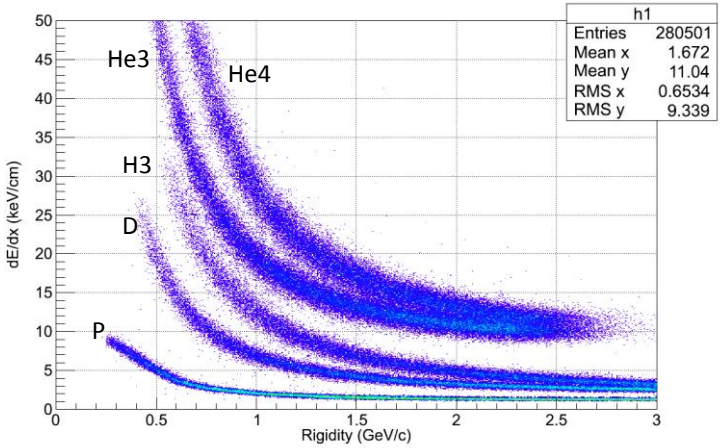
ENERGY LOSS

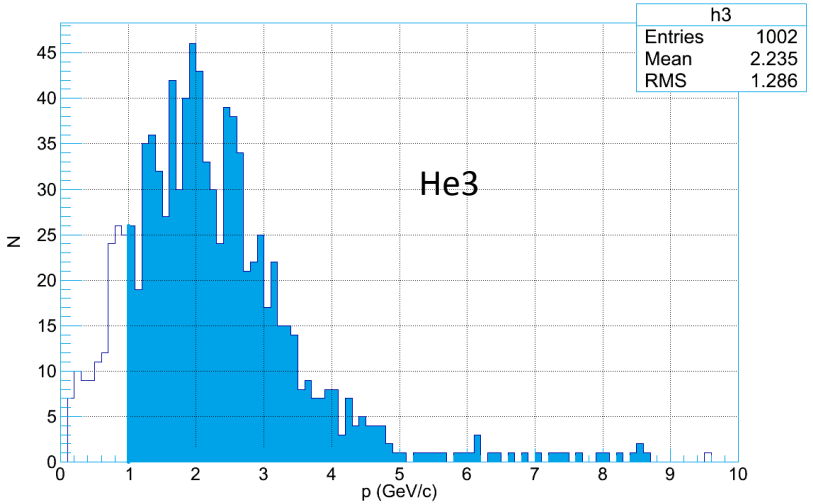


PID: Ionization loss (dE/dx)
Separation:
e/h – 1.3..3 GeV/c
π/K – 0.1..0.6 GeV/c
K/p – 0.1..1.2 GeV/c

The energy loss distribution in the MPD TPC

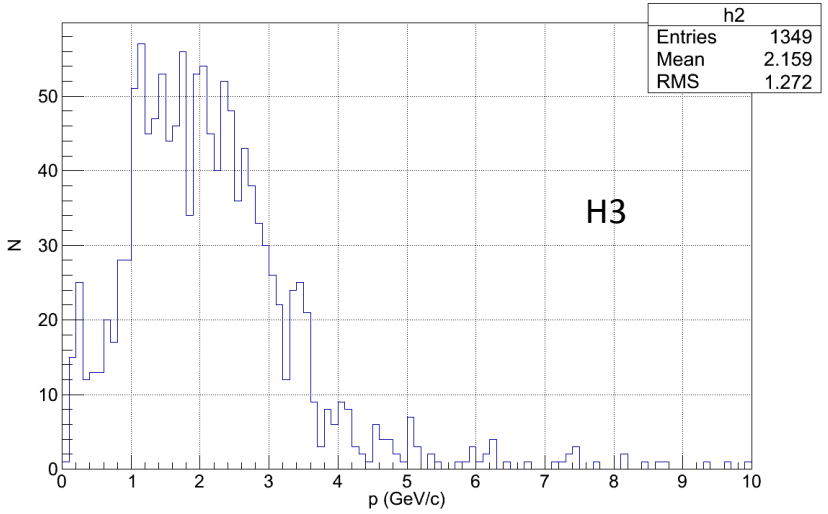
Light nuclei in TPC





TPC FEE input full scale amplifier ~ 250 fC
It is ~ 30-40 MIP energy loss

QGSM Au+Au central collision
9 GeV, b=1fm



TPC / MPD

Two-track resolution: The two-track resolution has to be such that HBT measurements with a resolution in relative momentum of a few (~ 5) MeV/*c* can be performed. This may require running at higher magnetic fields. Two Track resolution ~1 cm is expected.

Resolution d*E*/d*x*: For hadron identification d*E*/d*x* resolution of 8% is desirable, following the experience of NA49. Depending on the final particle multiplicity this can just be reached with the current design.

For TPC MPD
~ 6-7 % of *dE/dX* resolution is expected

- **π/K separation to 0,7 GeV/c (for TPC Alone)**
- **(π+K)/p to p ~ 1,2 GeV/c (for TPC Alone)**

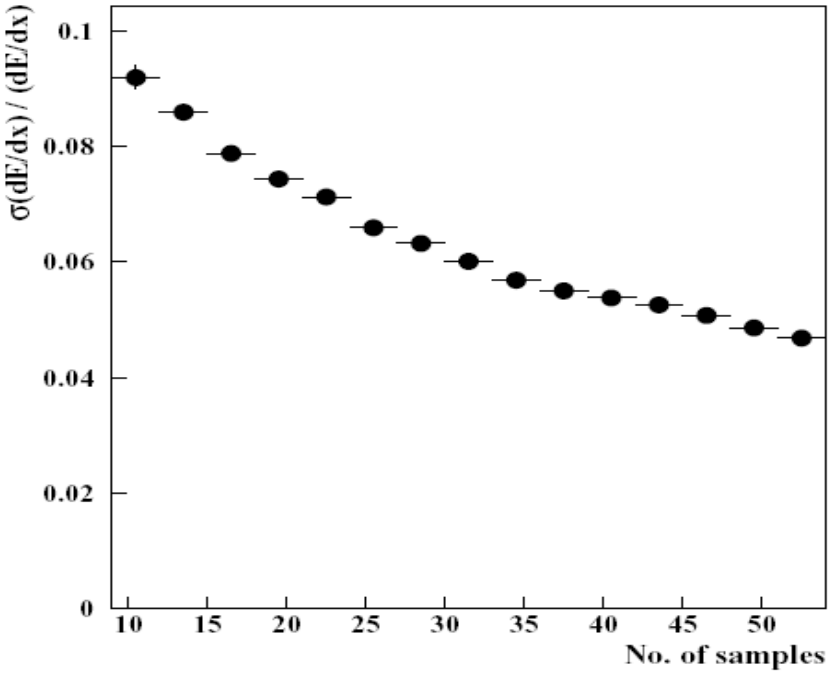
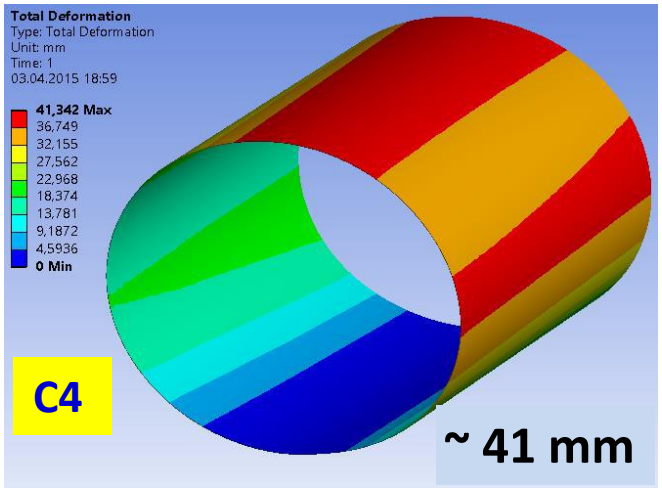
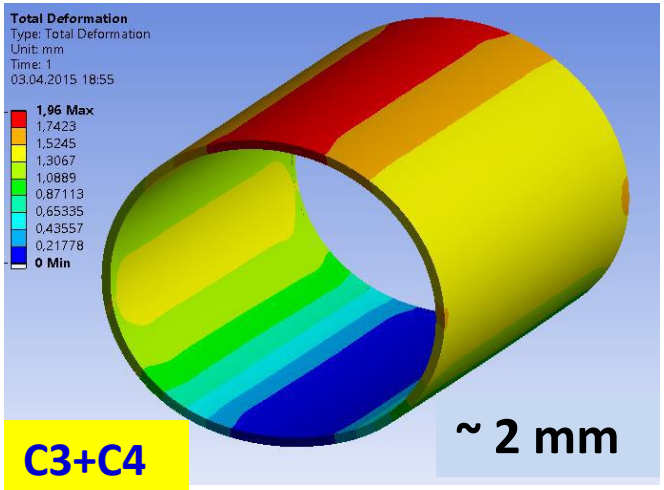
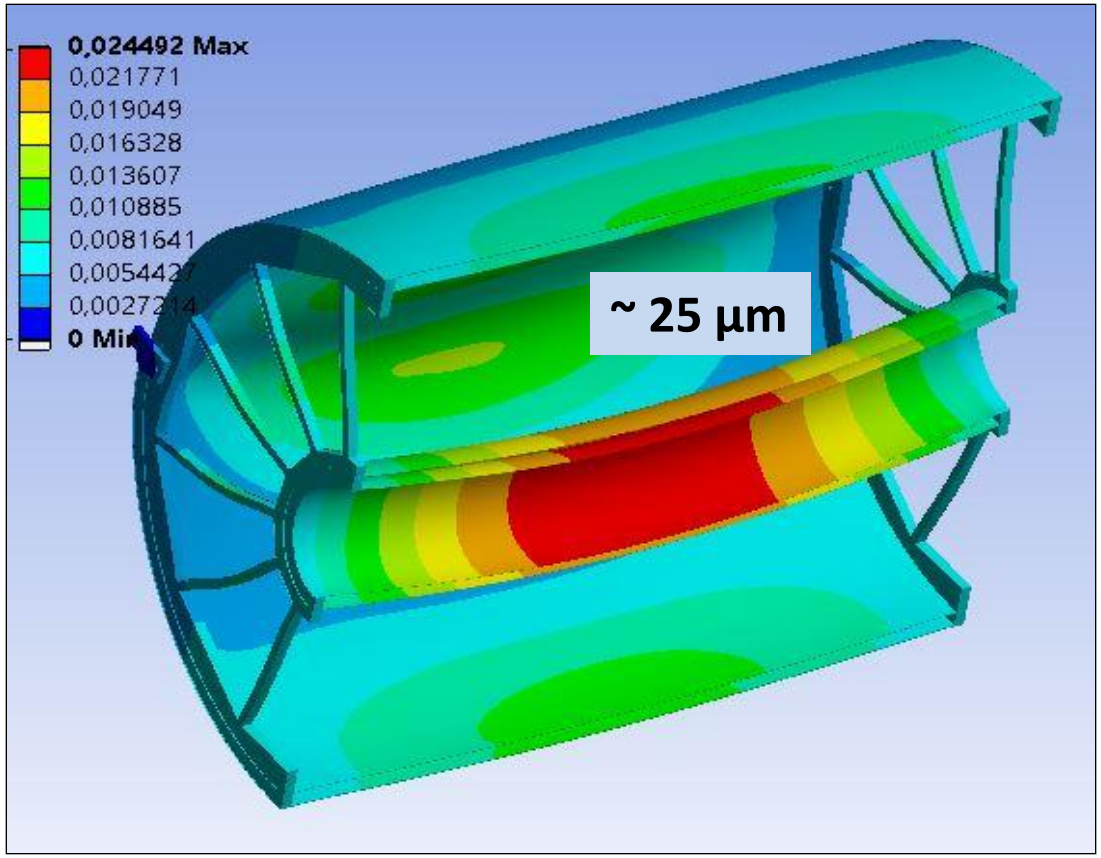


Figure 3.35: d*E*/d*x* resolution as a function of the number of samples in the NA35 TPC. Sample length 4 cm, gas Ar/CH_4 (91/9).

TPC deformation







TPC assembly must be done very carefully

TPC assembly hall (Bld.217)

Bld.217

S = 84 m2 (ISO-8-9)
+ 2 rooms for equipment

TPC integration to MPD (similar to *ALICE design*)

Laser calibration system – in progress

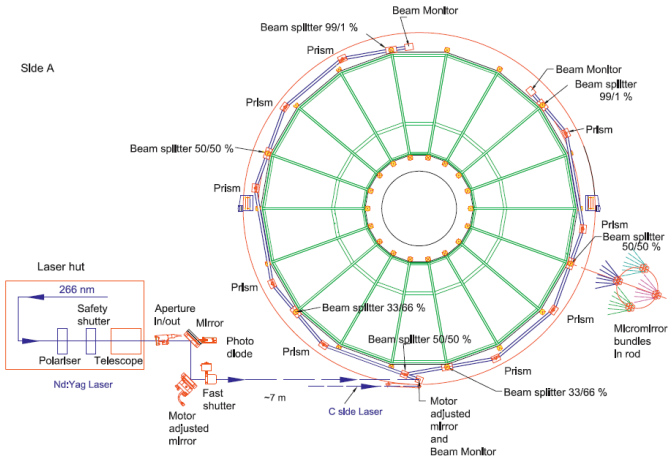


Fig. 46. Overview of the optical elements to guide the laser beam from the laser to the entrance windows in the TPC field cage. The A side system is shown; the C side system is obtained by mirror symmetry in a vertical plane along the TPC axis.

TPC alignment marks – not started

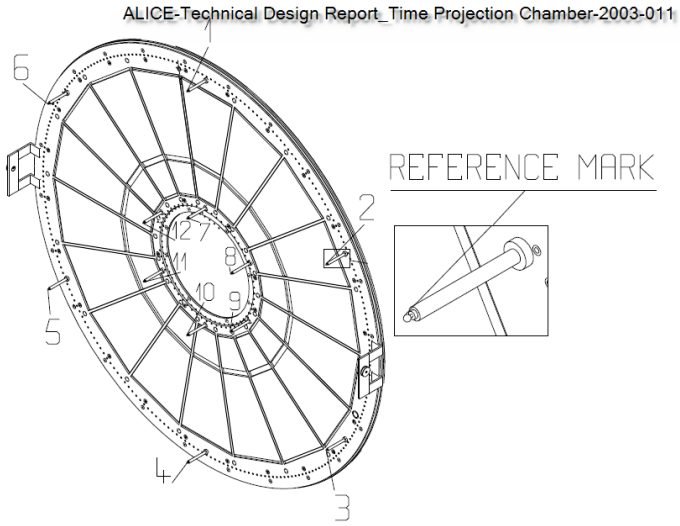


Figure 4.38: Reference marks distributed along the outer and inner circumference of the end-plate allow the orientation and planarity of the end-plate to be surveyed via photogrammetry.

TPC FE integration: service wheel (SSW) – design started