The ALICE Time Projection Chamber Upgrade

Presented by Charles Hughes on behalf of the ALICE Collaboration

Figure taken from
https://cds.cern.ch/record/2727174

Talk Contents

- TPC Upgrades
  - Physics motivation
  - Anatomy of the previous TPC
  - GEM foil upgrade
- Readout Chamber Construction
  - Assembly and testing IROCs at UTK
- Upgrade and Commissioning
  - GEM Chamber/FEC installation
  - Pre-Commissioning
  - Commissioning

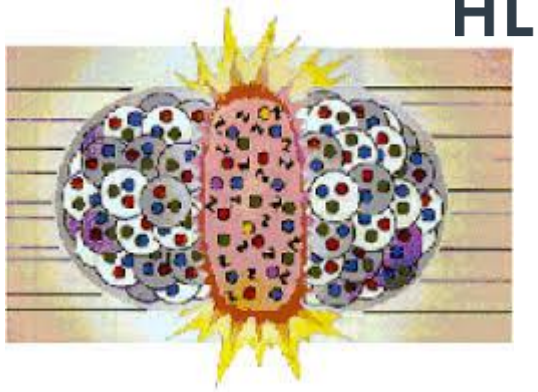
Figure taken from https://home.cern/news/news/experiments/alice-tpc-upgraded

PHYSICS MOTIVATION FOR UPGRADES

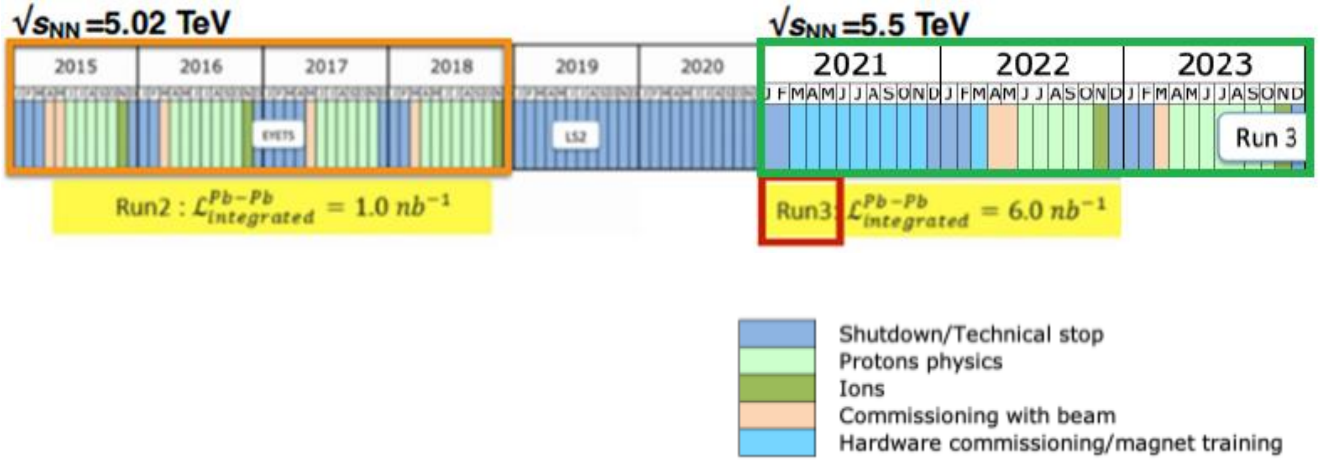
- Quark Gluon Plasma (QGP) - hot, thermalized partonic state of matter

- Wish to study QGP thermodynamic properties

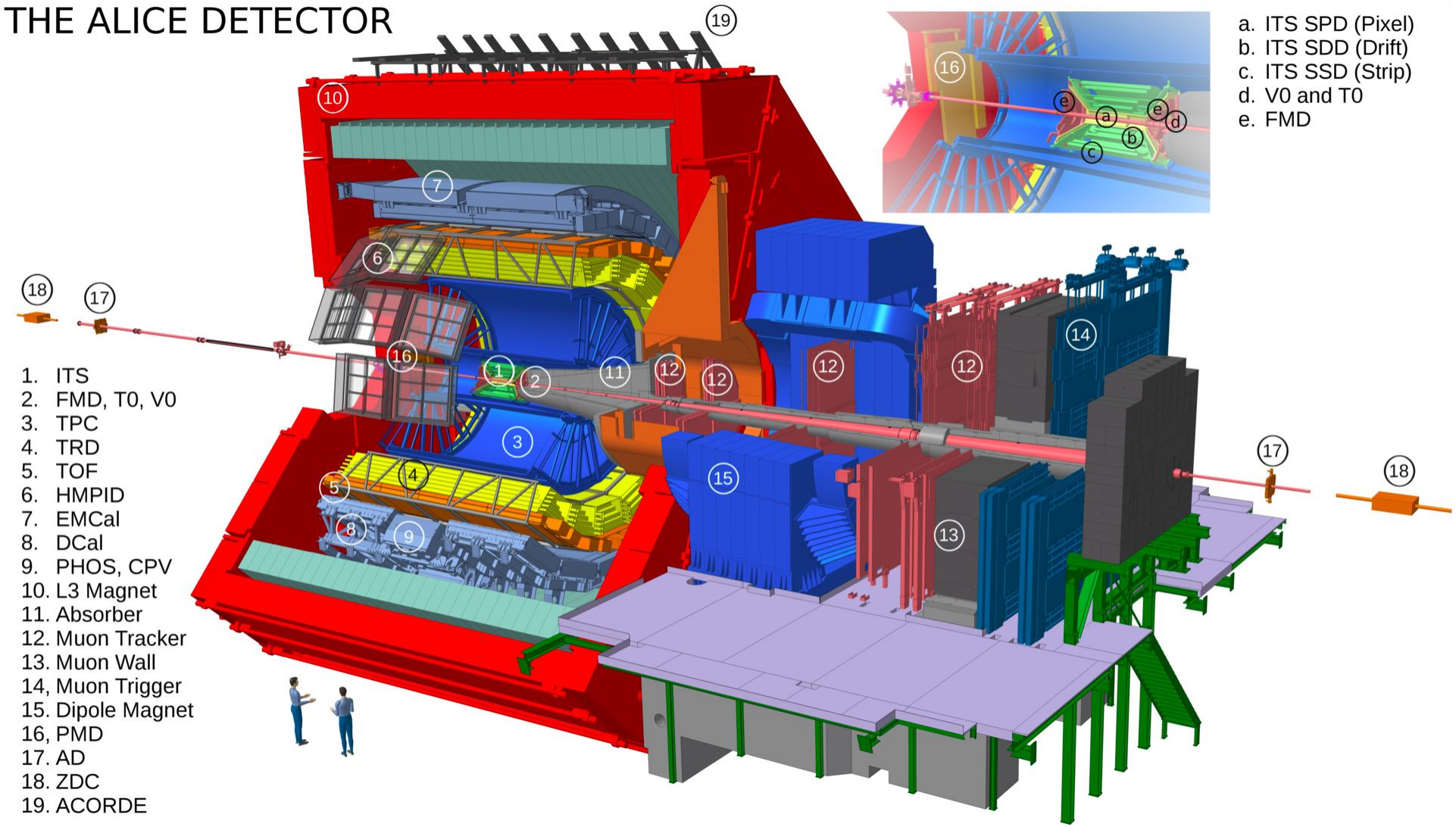
- Higher luminosity
  - More hard probes (increase in triggered data -> 10x)
  - More soft probes (increase in min. bias data -> 100x)



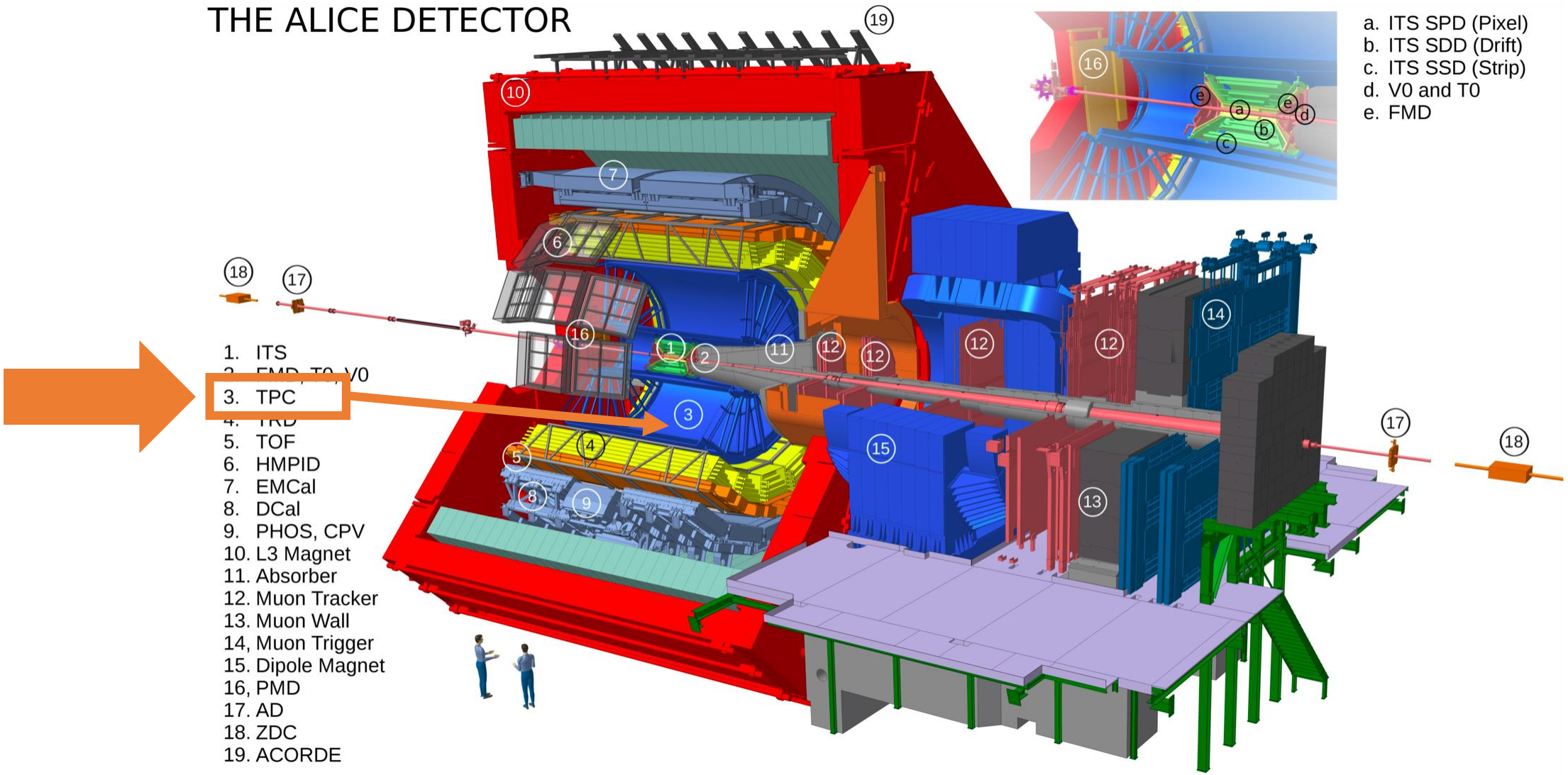
Run 3 Instantaneous Luminosity
-> 6 x 10^{27} cm^{-2} s^{-1}



A Large Ion Collider Experiment

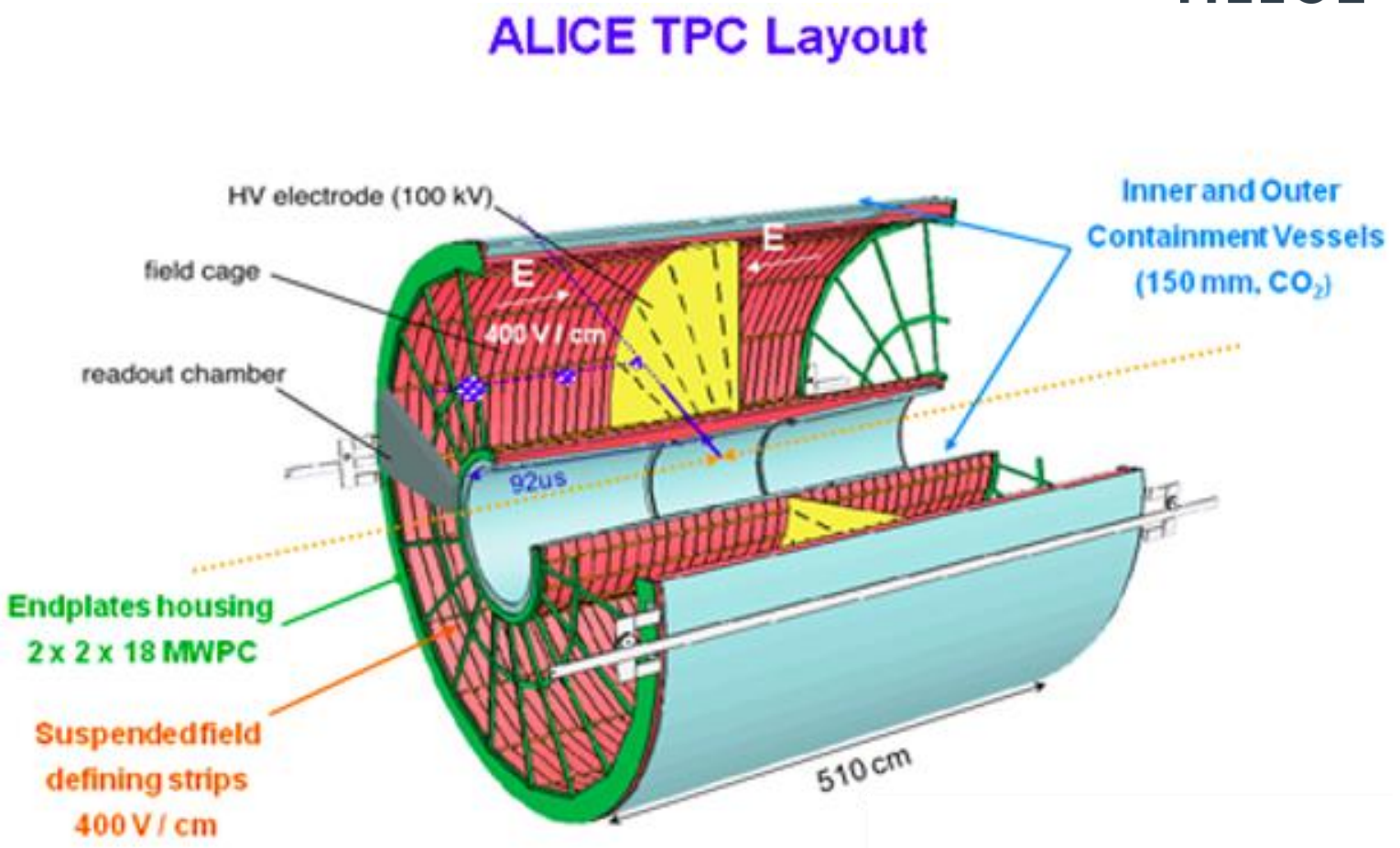


A Large Ion Collider Experiment

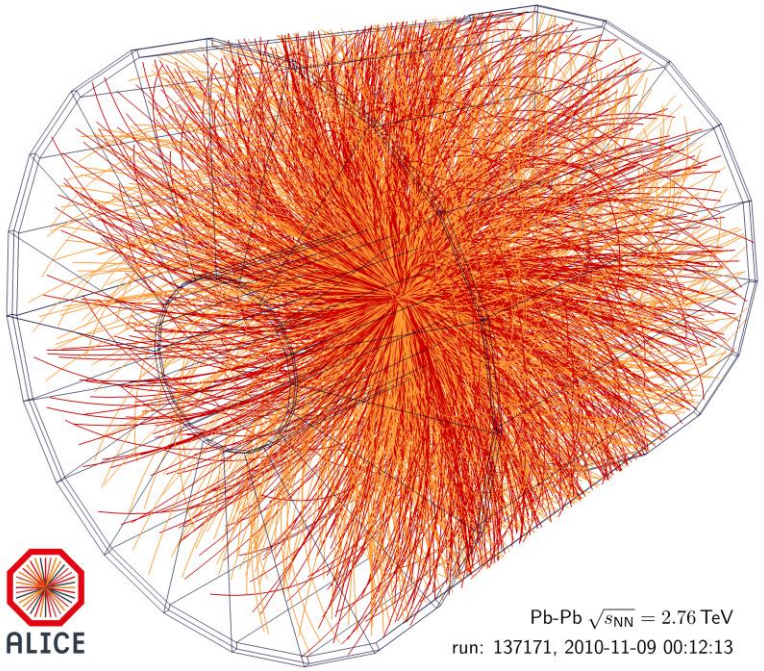


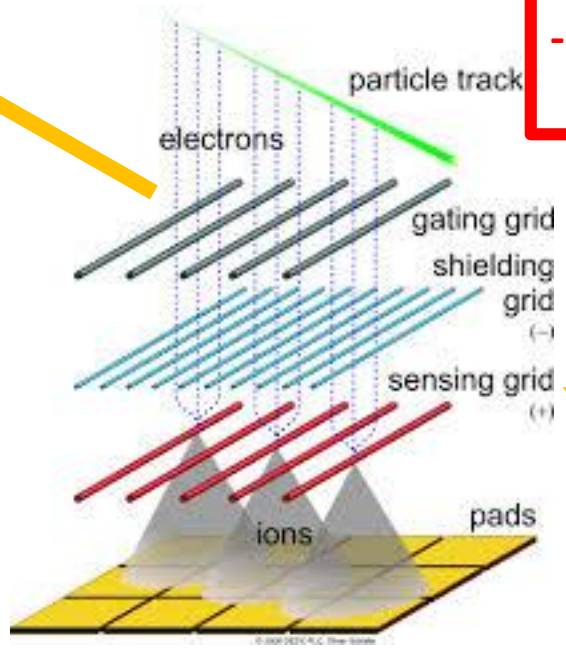
ALICE TIME PROJECTION CHAMBER

- Gaseous Drift Detector
- Used for tracking and PID
- MWPC + gating grid to reduce ionic backflow (previous technology)
- ~ 5 m diameter x ~ 5 m length
- 400 V/cm Electric Field
- Readout Chambers
  - Inner 18 x 2 (IROC)
  - Outer 18 x 2 (OROC)



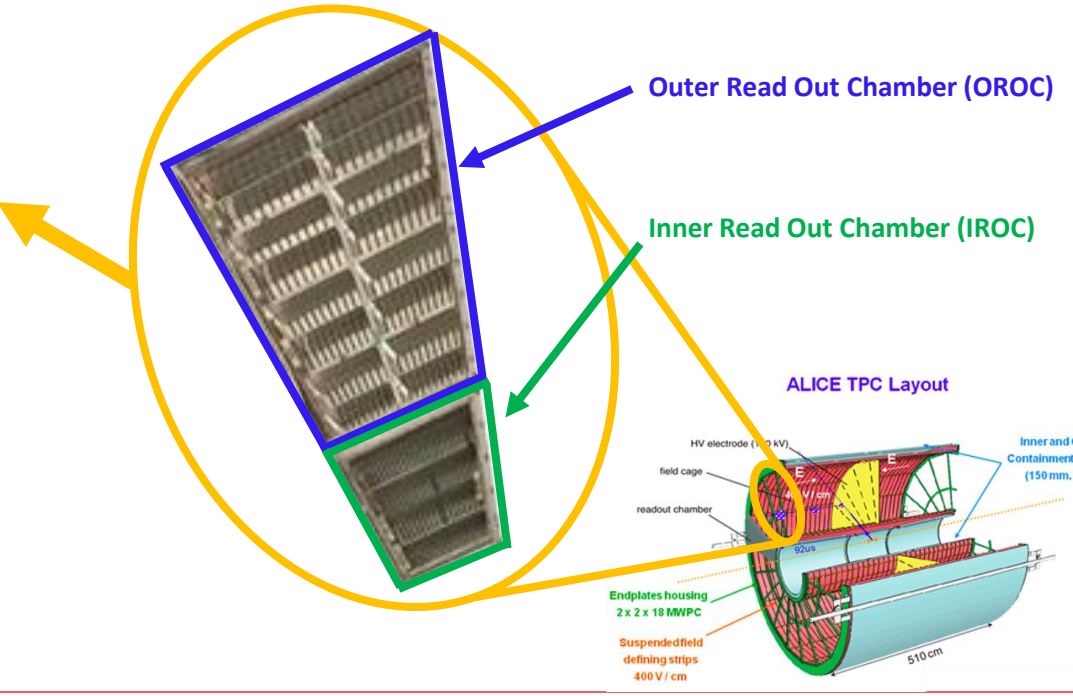
PREVIOUS TPC WORKING PRINCIPLE





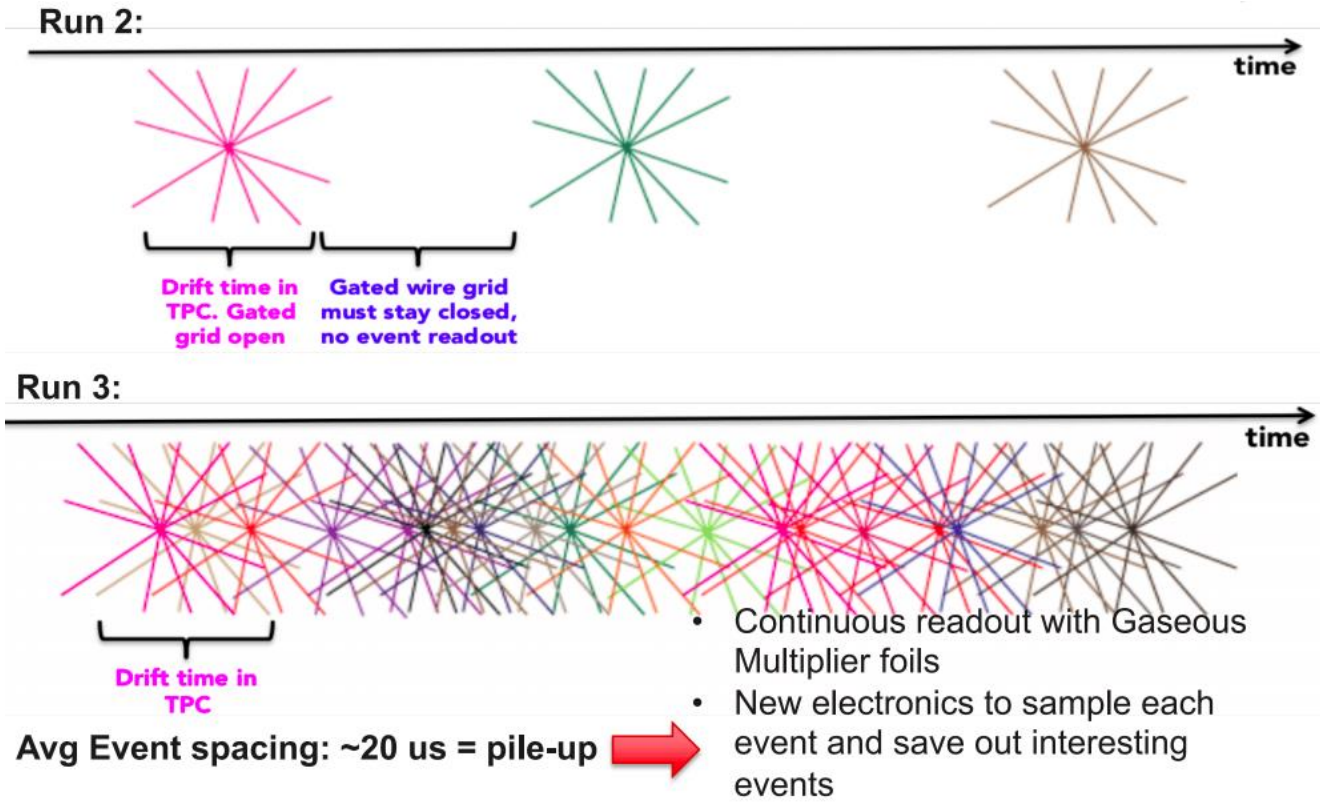
- Readout limited to ~ 3 kHz

- Dead Time: 92 µs (drift) + 280 µs (gating) ~ 400 µs



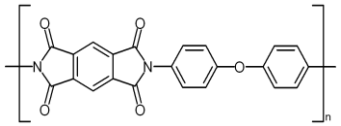
UPGRADING THE TPC

- ~ 3 kHz readout rate not enough to handle higher luminosity
- Heavy ion interaction rate to increase from 1 kHz to 50 kHz
- Eliminate ~400 μs dead time
- Replace MWPCs with GEM foils: 3kHz -> Continuous Readout



Gaseous Electron Multiplier (GEM) FOILS

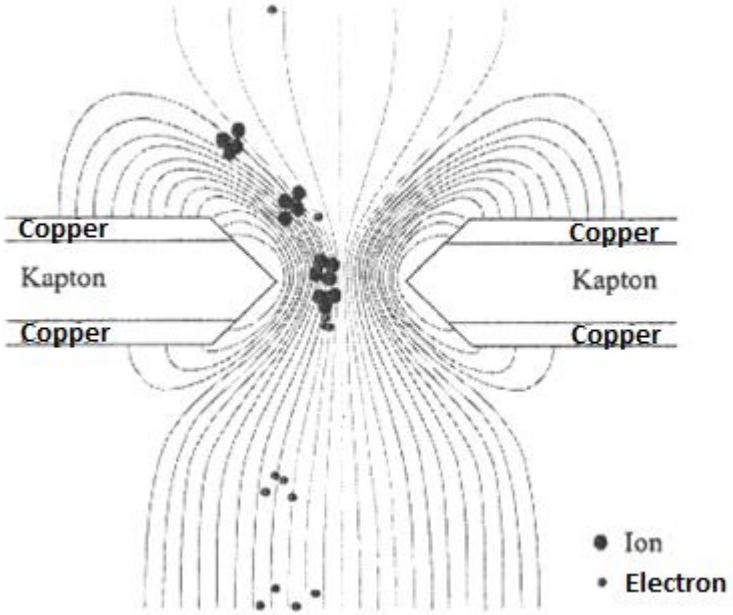
- Kapton Foil – Polyimide film insulator (poly-oxydiphenylene-pyromellitimide)

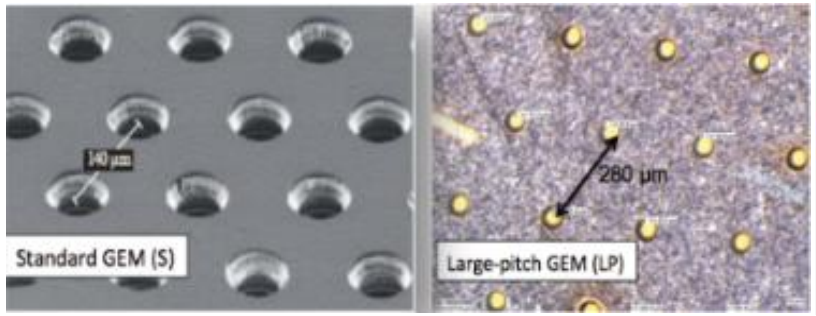


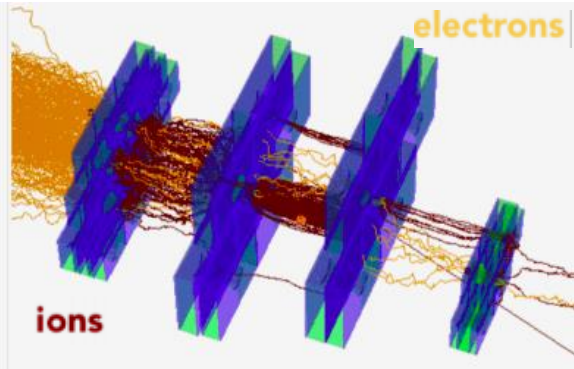
- Upper and lower copper conducting layer

- 70 µm diameter holes
  - etched with photo-lithography

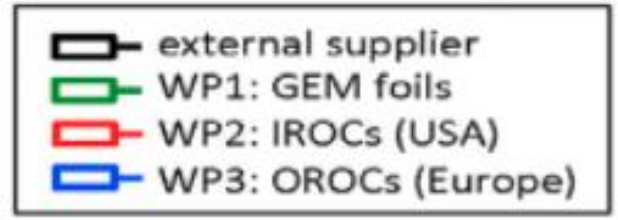
- 4 Layers of foil with varying GEM pitch
  - SP – LP – LP – SP



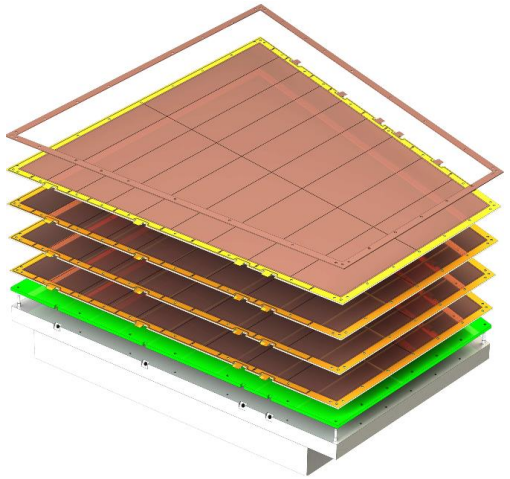




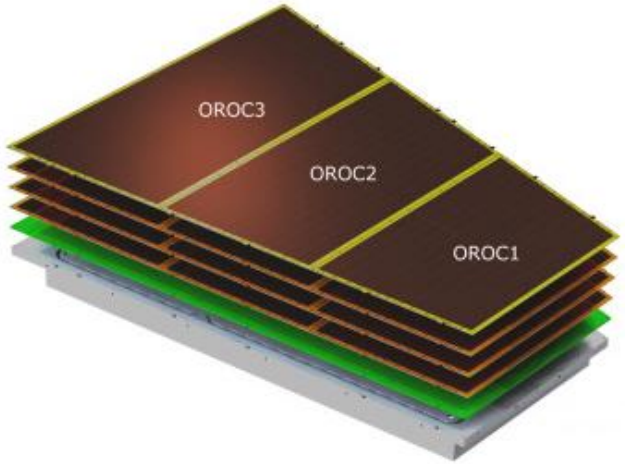
READOUT CHAMBER PRODUCTION



Inner Read Out Chamber

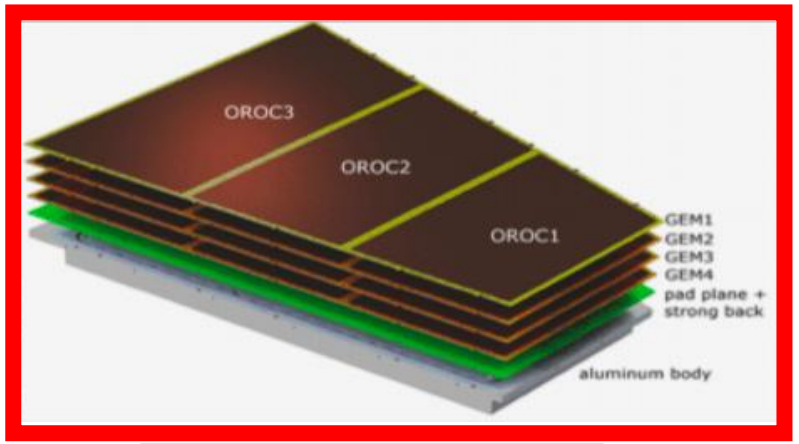


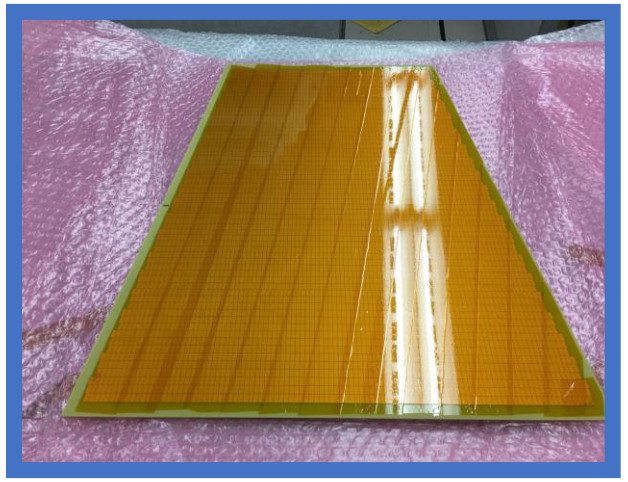
Outer Read Out Chamber

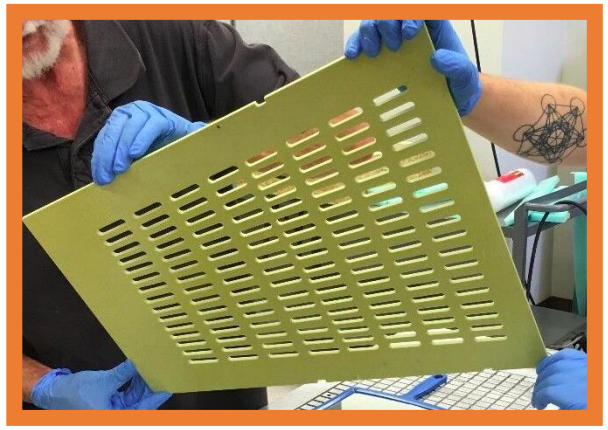


INNER READ OUT CHAMBER PRODUCTION

- Ingredients:
  - 4 GEM STACK
  - PAD PLANE (SENSORS)
  - ALUBODY
  - STRONG BACK

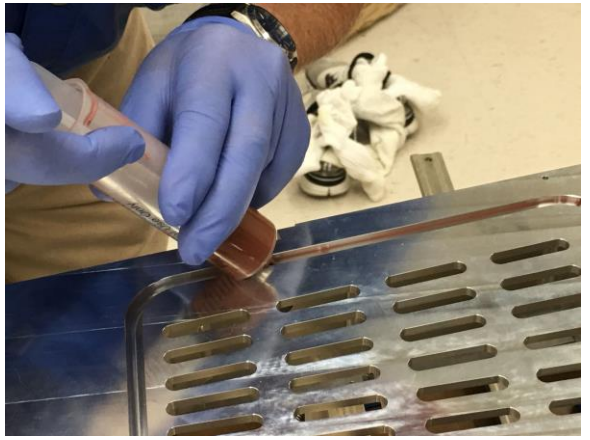
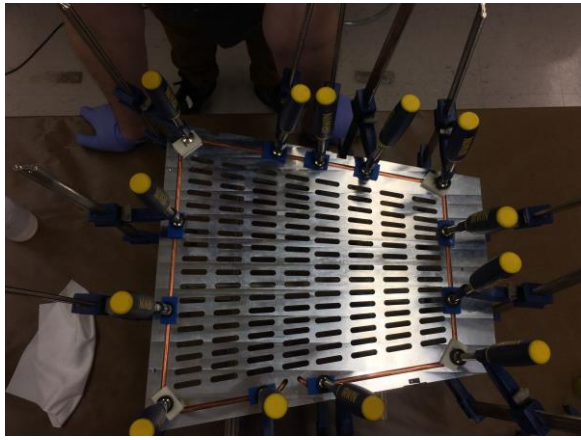


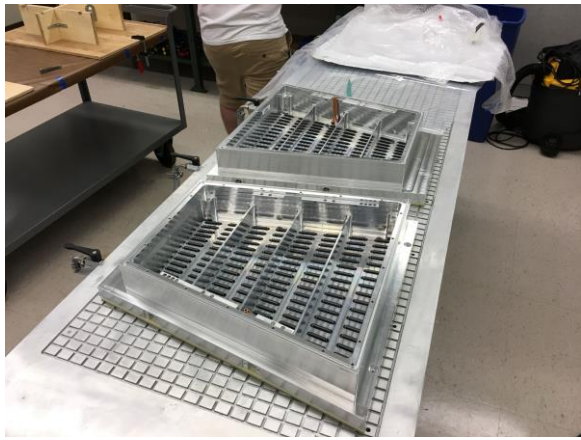




INNER READ OUT CHAMBER ASSEMBLY

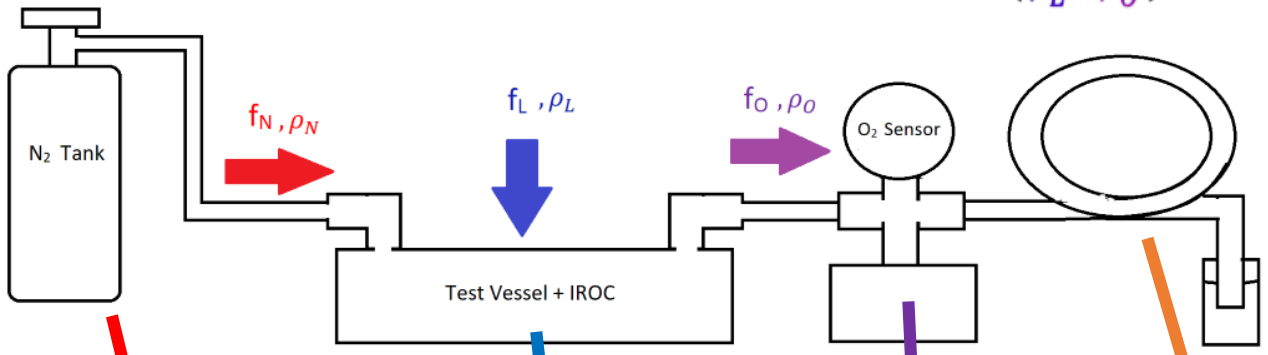
- Cooling System
- Epoxy:
  - Padplane + Strongback + Alubody
- HV connectors

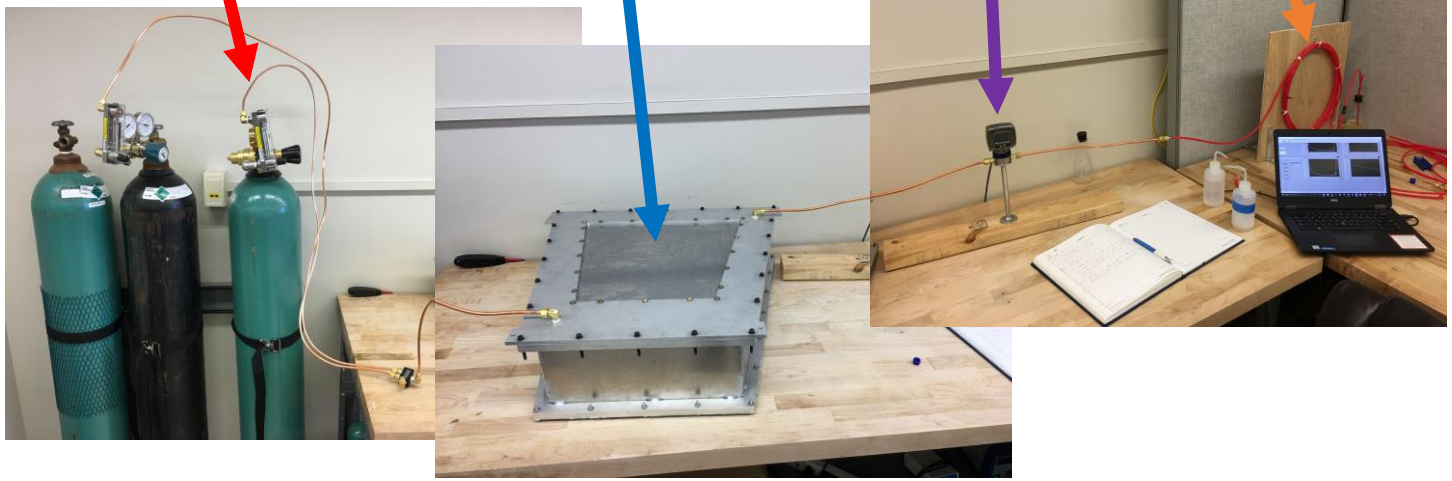




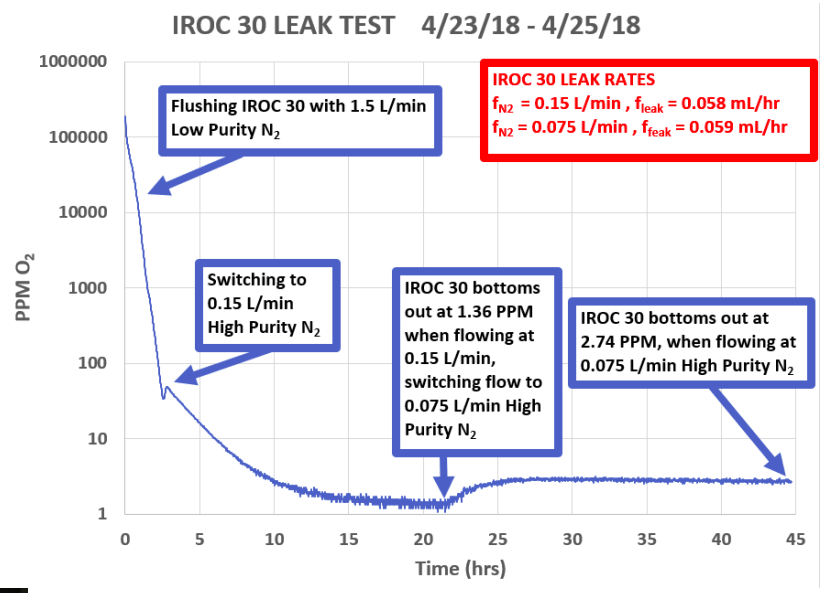



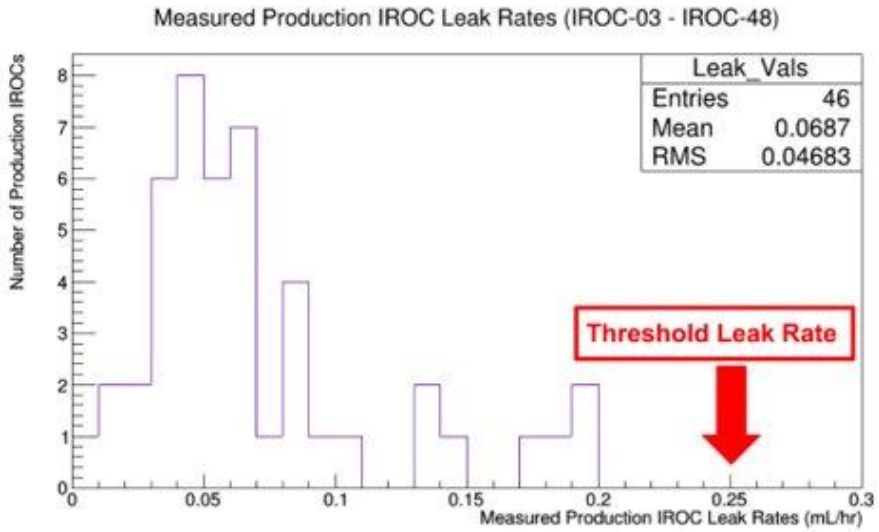
IROC LEAK TESTING

$$f_L = \frac{(\rho_O - \rho_N)}{(\rho_L - \rho_O)} * f_N$$



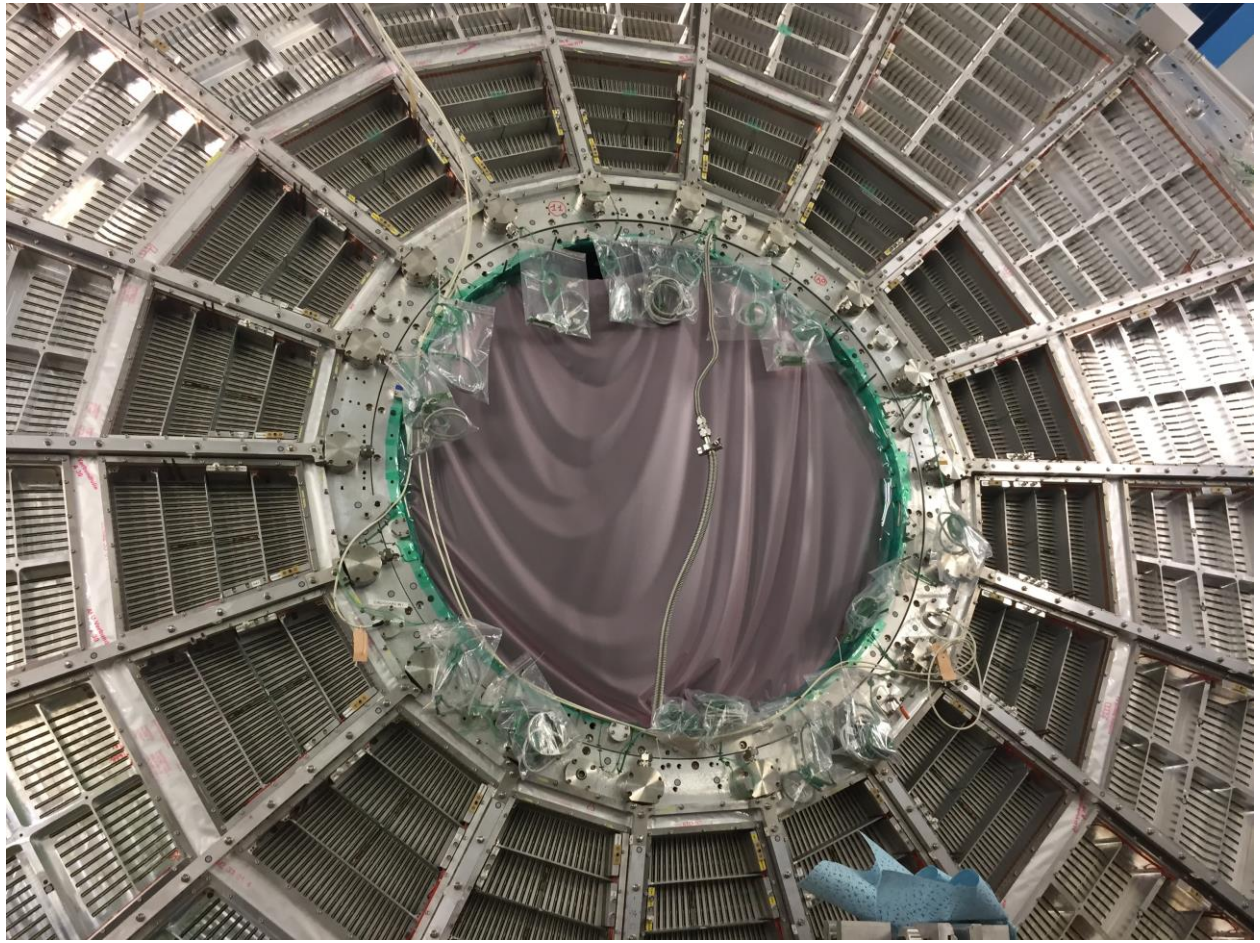






Switching Gears

- TPC Upgrade
  - Read Out Chamber Installation
  - Front End Electronics Card Installation
- Commissioning – 2 phases
  - Pre-Commissioning
  - Commissioning



TPC Upgrade

- Installation of GEM chambers
  - Above ground
- Mounting Tool
- Alignment of Chambers
  - Photogrammetry + shims
  - Measure once, remove shims
  - Machine shims down
  - Re-measure

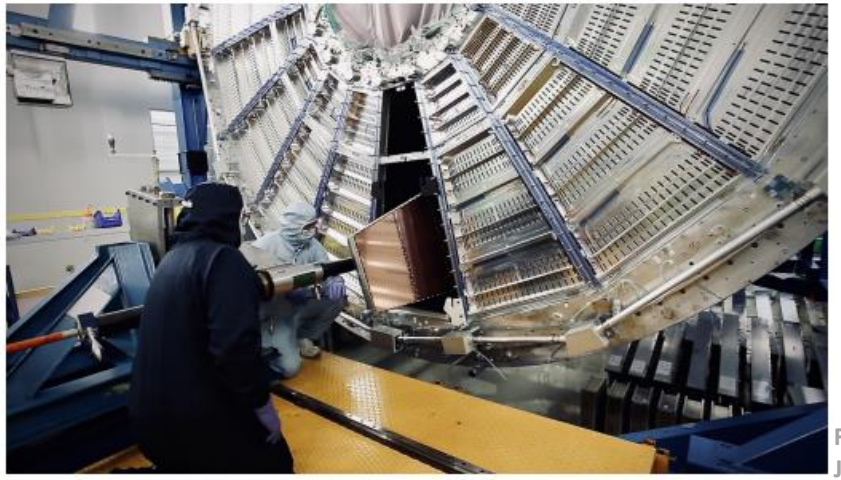


Figure taken from JINST 16 (2021) P03022

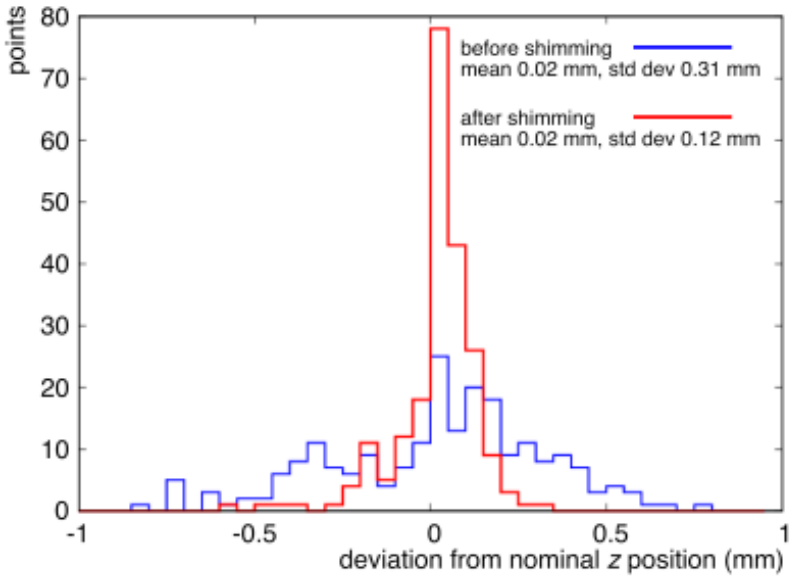


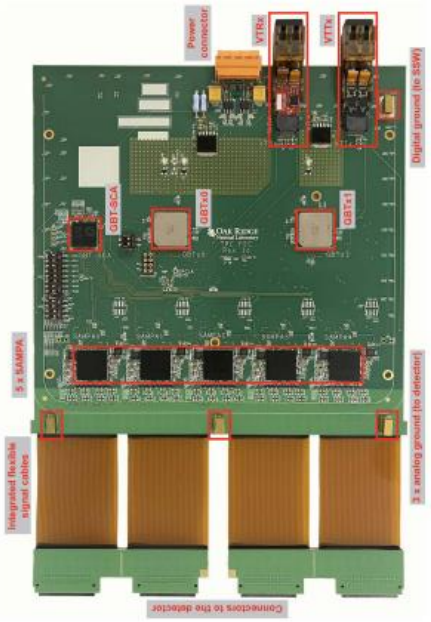
Figure taken from JINST 16 (2021) P03022

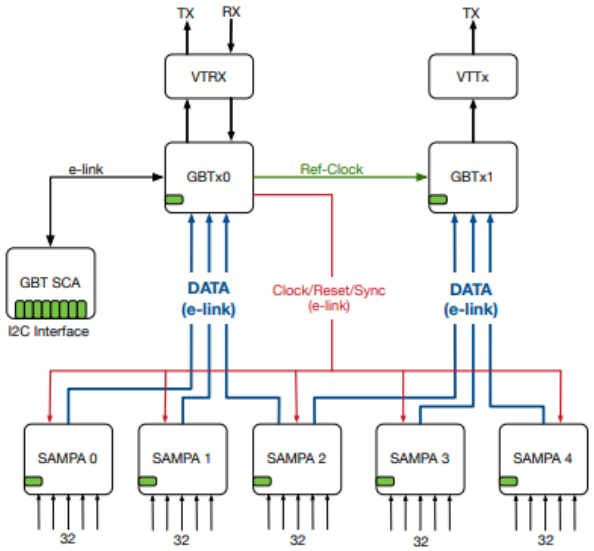
TPC Upgrade

- Installation of Front End Electronics Cards

- New Front End Electronics Cards

Figure taken from Torsten Alt – EP-ESE Seminar 5/21





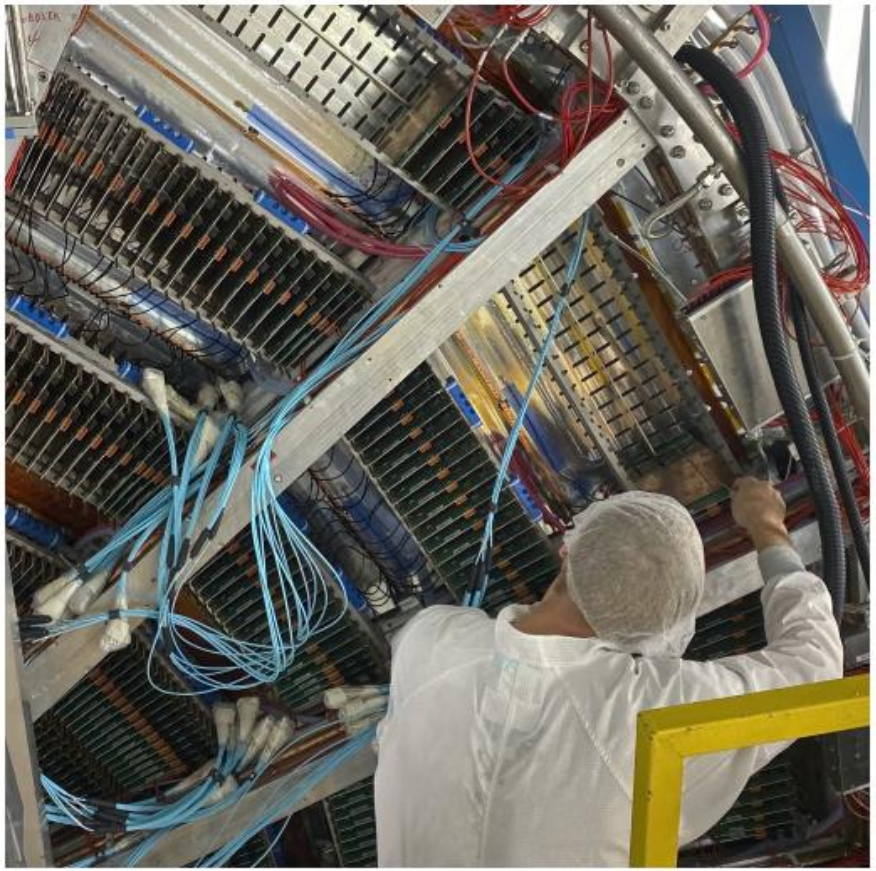
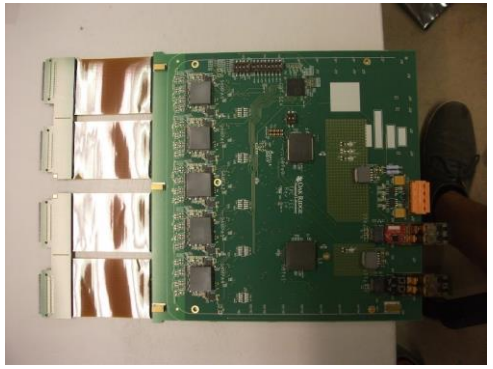


Figure taken from JINST 16 (2021) P03022

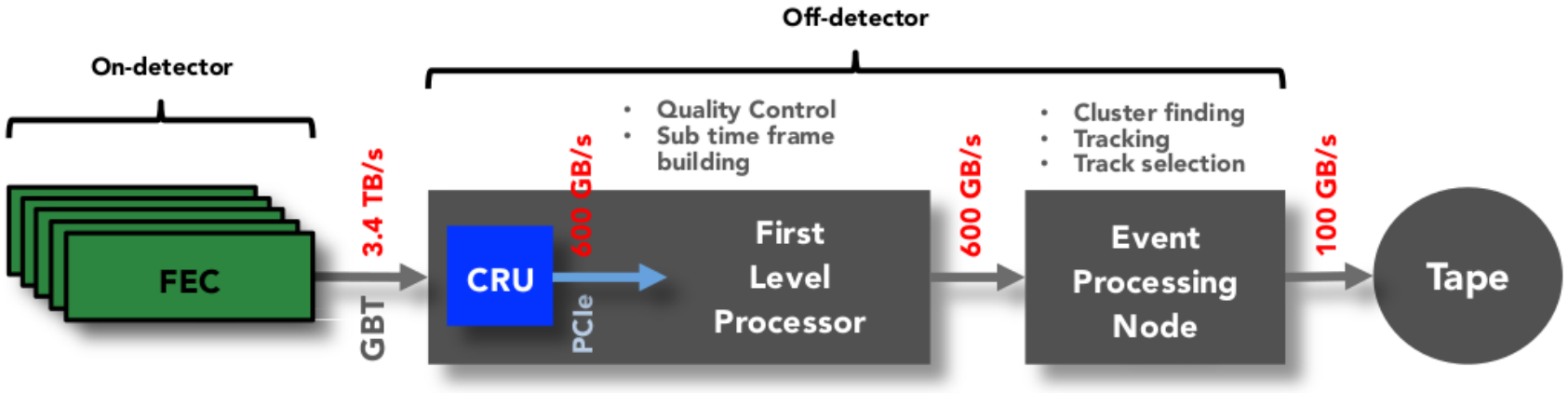
TPC Pre-Commissioning

- Data taking set up
- 2 sectors at a time only
- Total throughput = 3.4 TB/s (if all sectors active)



CR1 readout setup - FLPs and gateway

CR1 - Top to bottom: LTU, two EPNs, and FLP4



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TPC Pre-Commissioning

- Pedestal Runs
- Noise Assessment
- Pulser Runs
  - Pulse-shaping properties of electronics
- X-Ray Runs
  - Gain calibration
  - Stability under high radiation load
- Laser/Cosmic Runs
  - Drift calibration
  - Track reconstruction

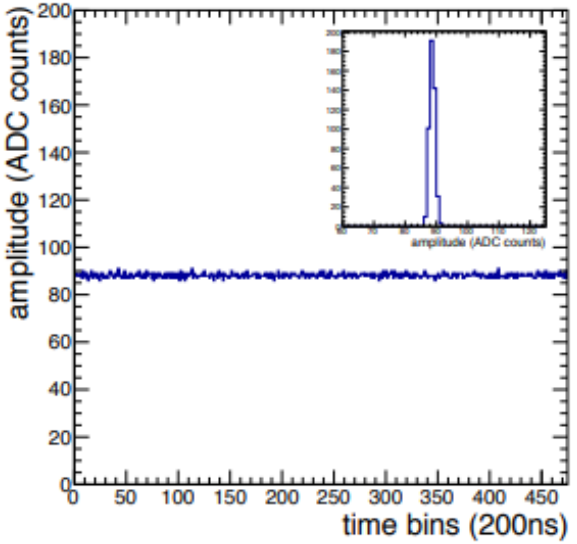


Figure taken from JINST 16 (2021) P03022

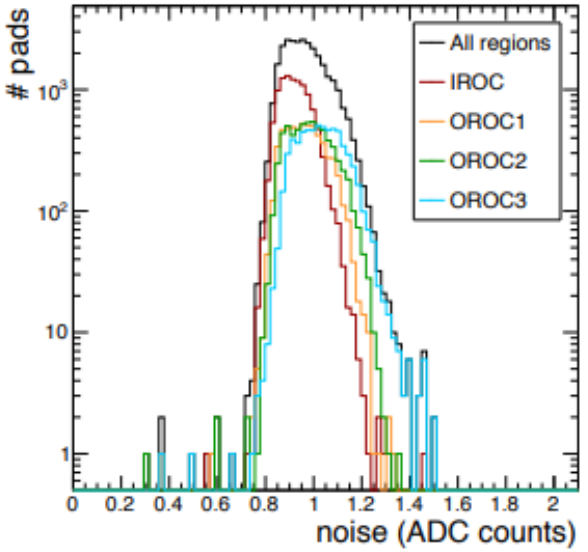


Figure taken from JINST 16 (2021) P03022

TPC Pre-Commissioning

- X-Ray runs
  - Amptek mini x-ray tube
  - Gain measurements
    - Nominal = 2000
    - Topological variation
  - ROC stability measurements

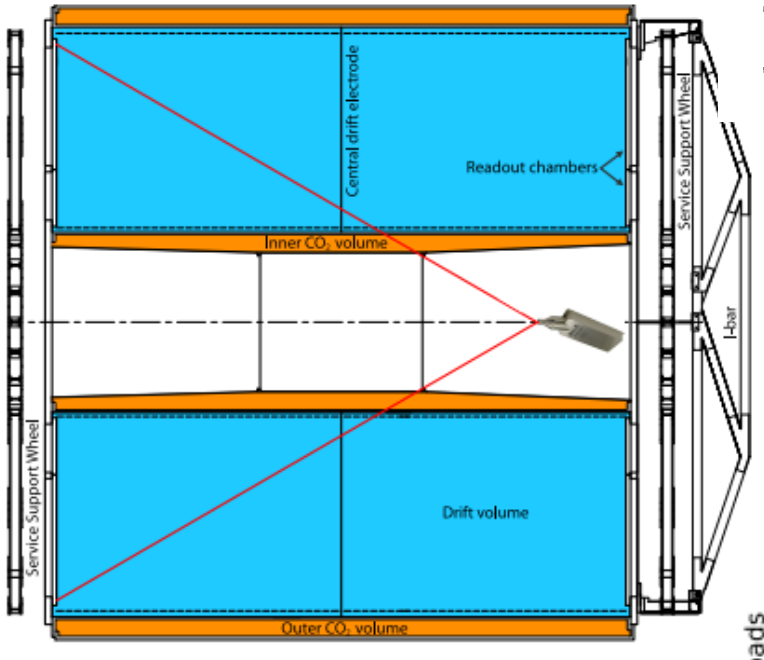


Figure taken from JINST 16 (2021) P03022

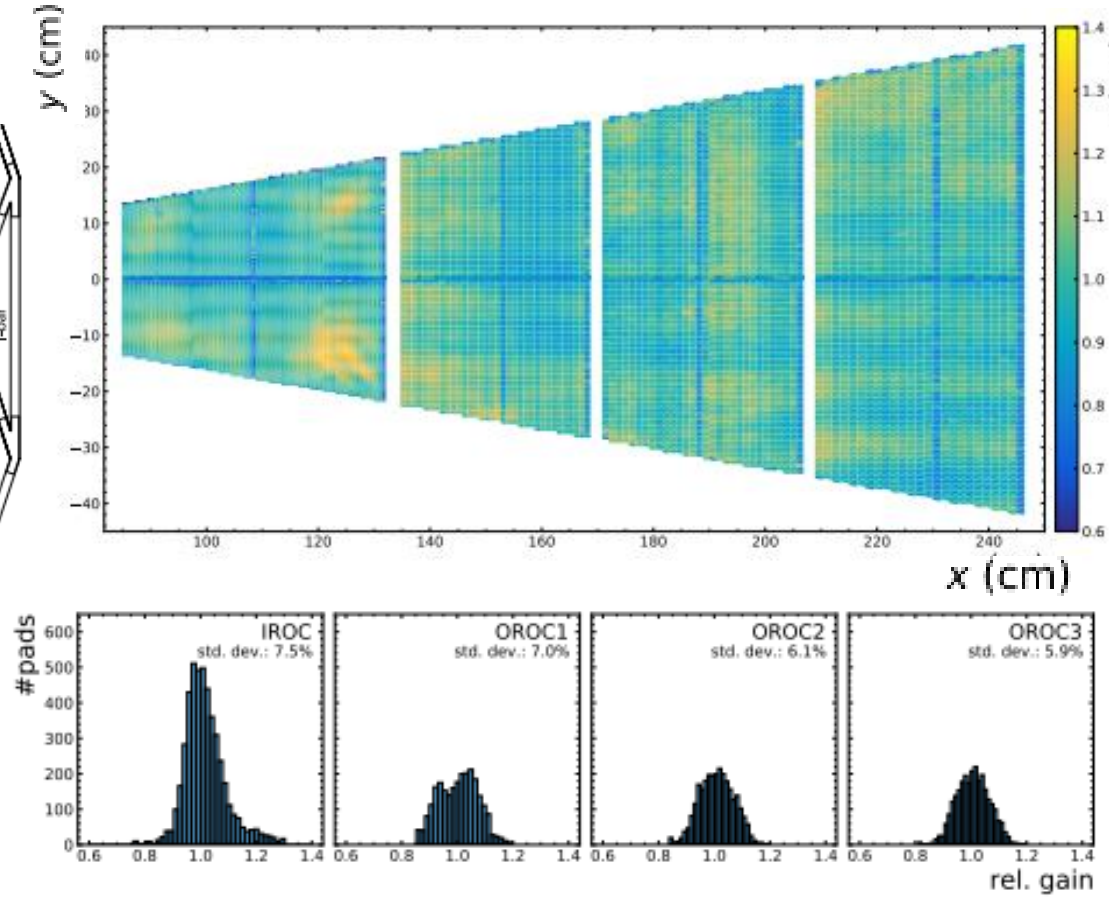


Figure taken from JINST 16 (2021) P03022

TPC Pre-Commissioning – Fully Assembled TPC

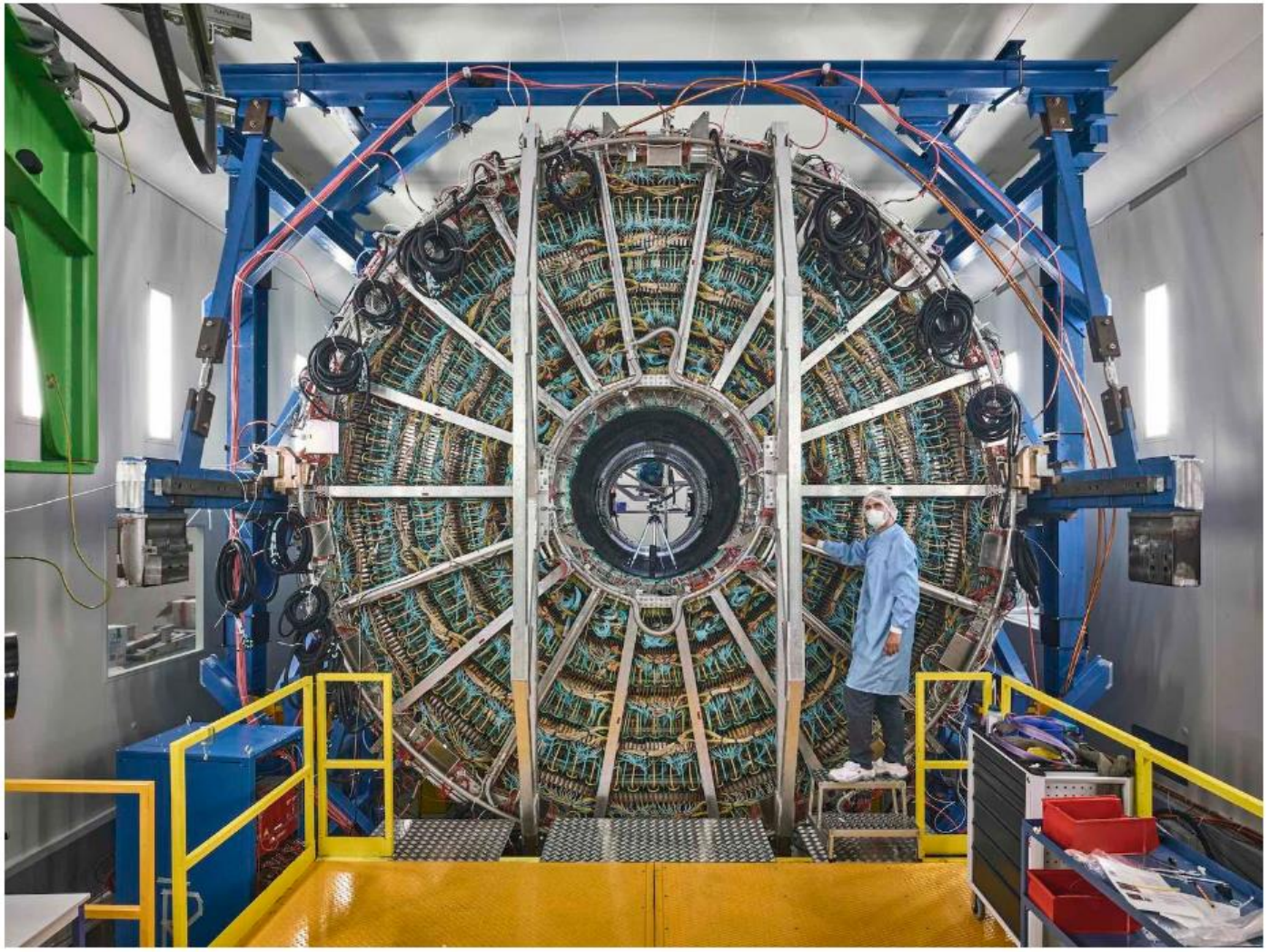


Figure taken from https://alice-collaboration.web.cern.ch/menu_proj_items/tpc

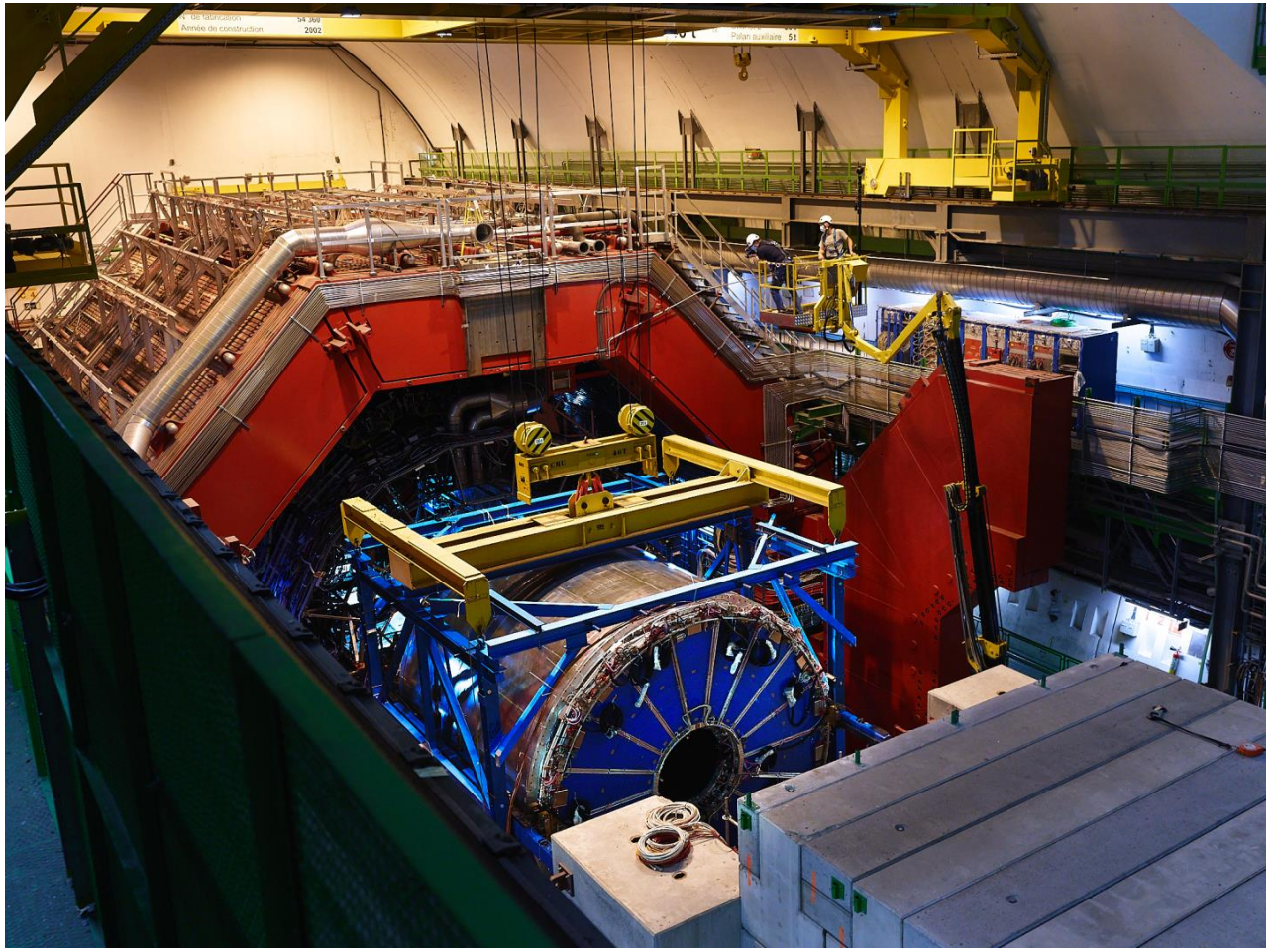
TPC Commissioning

https://videos.cern.ch/record/2729677

TPC Commissioning

- TPC back underground
- Stable Beams/Pilot Beam (late 2021)
- Overall Status

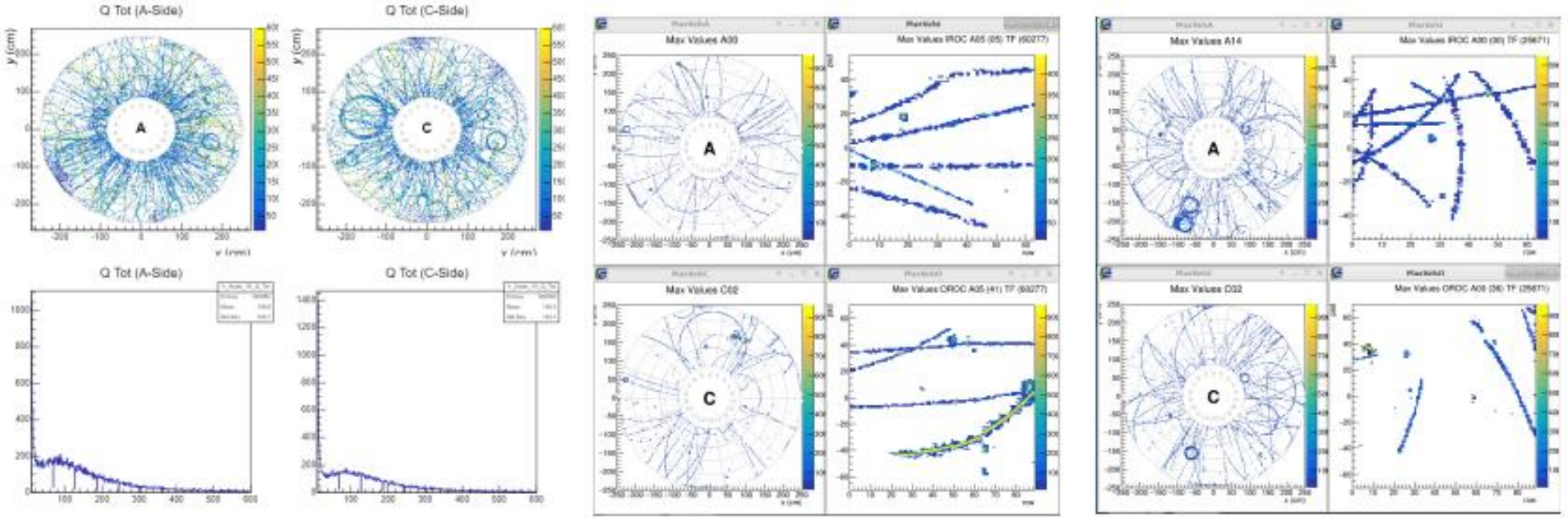
Figure taken from
https://cds.cern.ch/record/2727174



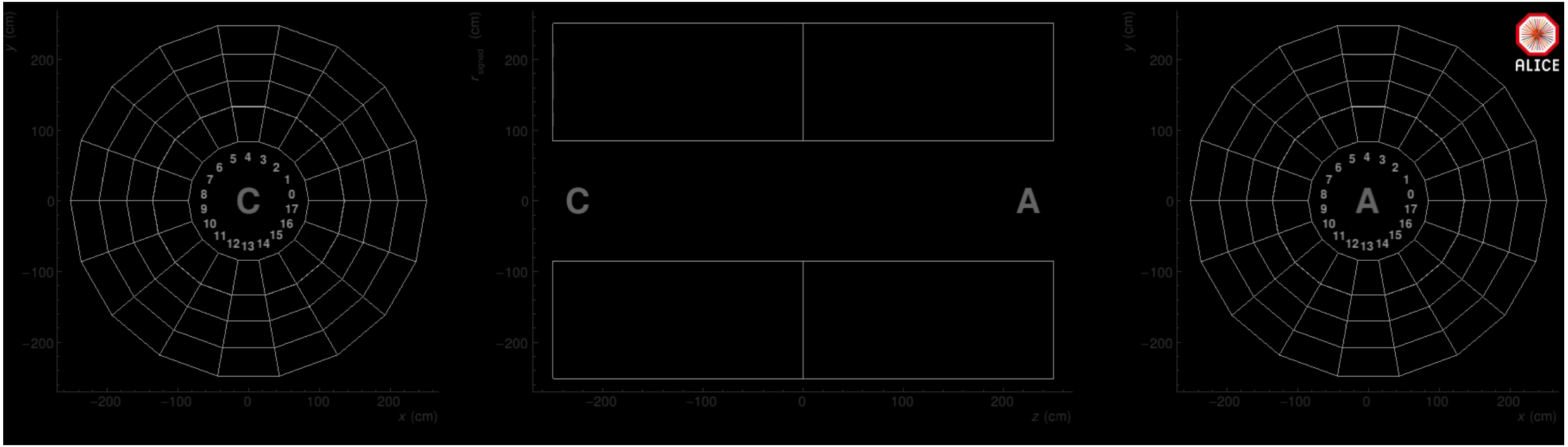
TPC Commissioning

- Stable Beams
  - Online Track Reconstruction
    - Tracks visible in online monitor

Figure taken from Robert Munzer
TPC Weekly Presentation



TPC Commissioning

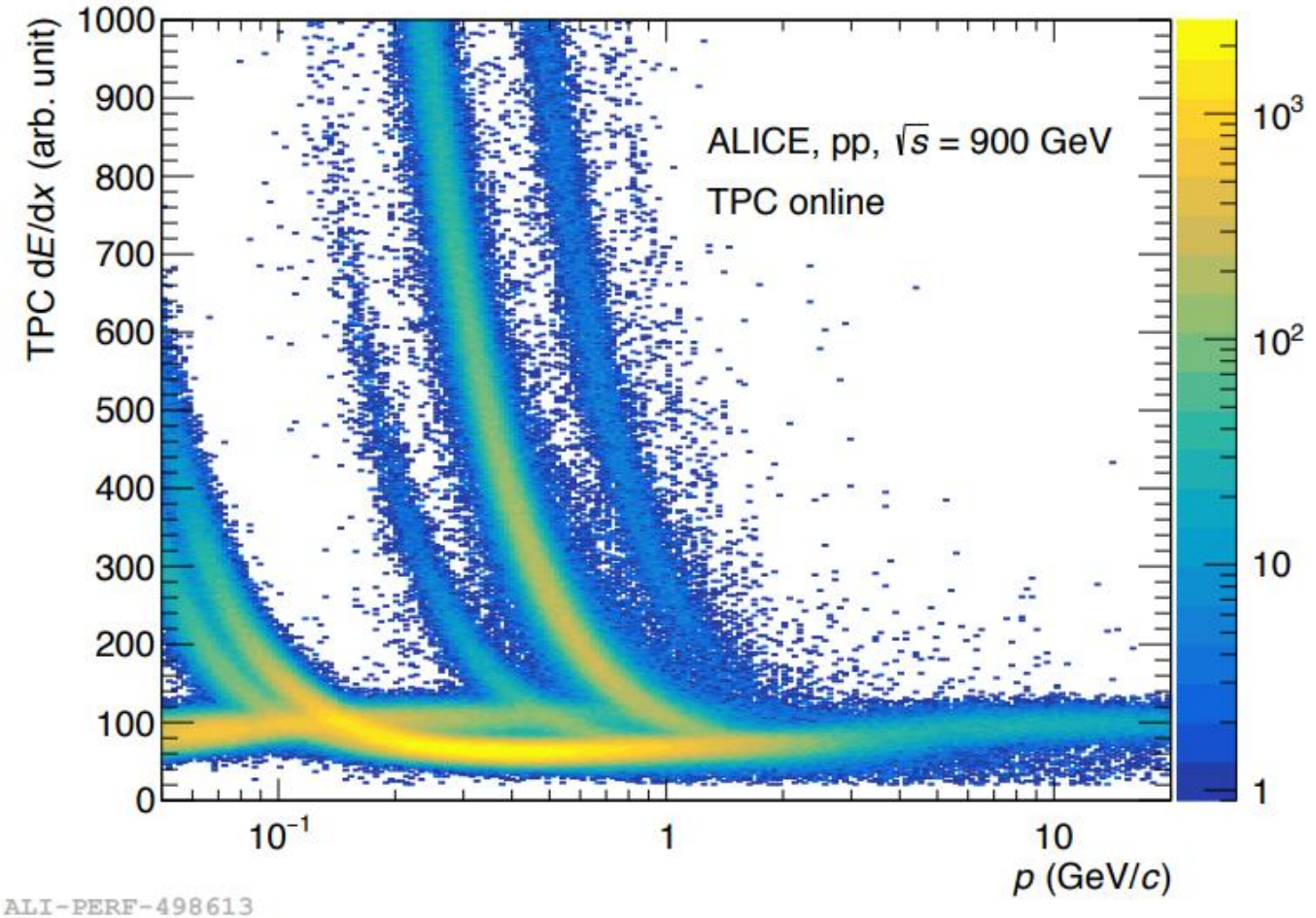


https://cernbox.cern.ch/index.php/s/xWLxU8N7SRAQqZ7

TPC Commissioning

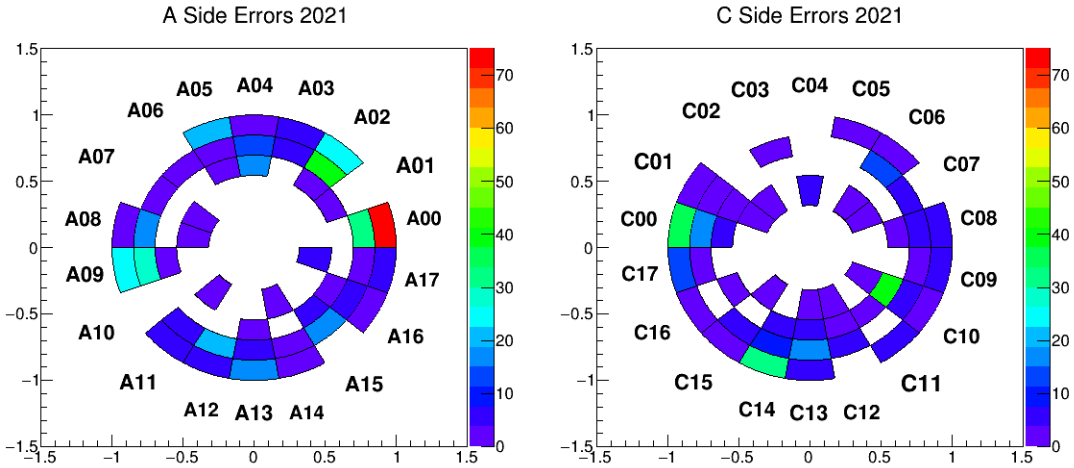
- Pilot Beam
  - Data processing chain stable
  - Online dE/dx
  - Stable operation of GEM chambers

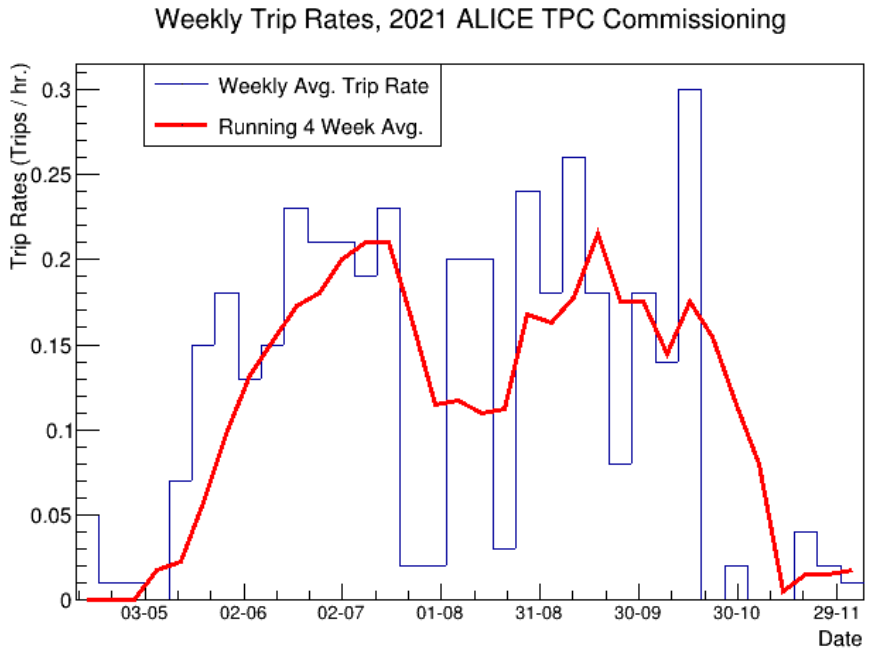
Figure taken from Christian Lippmann
https://alice-figure.web.cern.ch/node/20827



TPC Commissioning

- Stability
  - Analysis of High Voltage Trips
  - Initially High Trip Rate at start of 2021
    - 1 trip / 4 hrs.
  - Working Solution Found at end of 2021
    - **1 trip / 2 days**
    - Semi-Regular ramp down of GEM Voltage





SUMMARY & OVERALL STATUS

- ALICE: ~1 kHz interaction rate -> 50 kHz interaction rate (in heavy ion)

- ALICE TPC rebuilt
  - Replace MWPCs with GEM foils
  - New readout electronics

- ALICE TPC commissioned
  - Stable
  - Fully continuous readout
  - Online track reconstruction & dE/dx

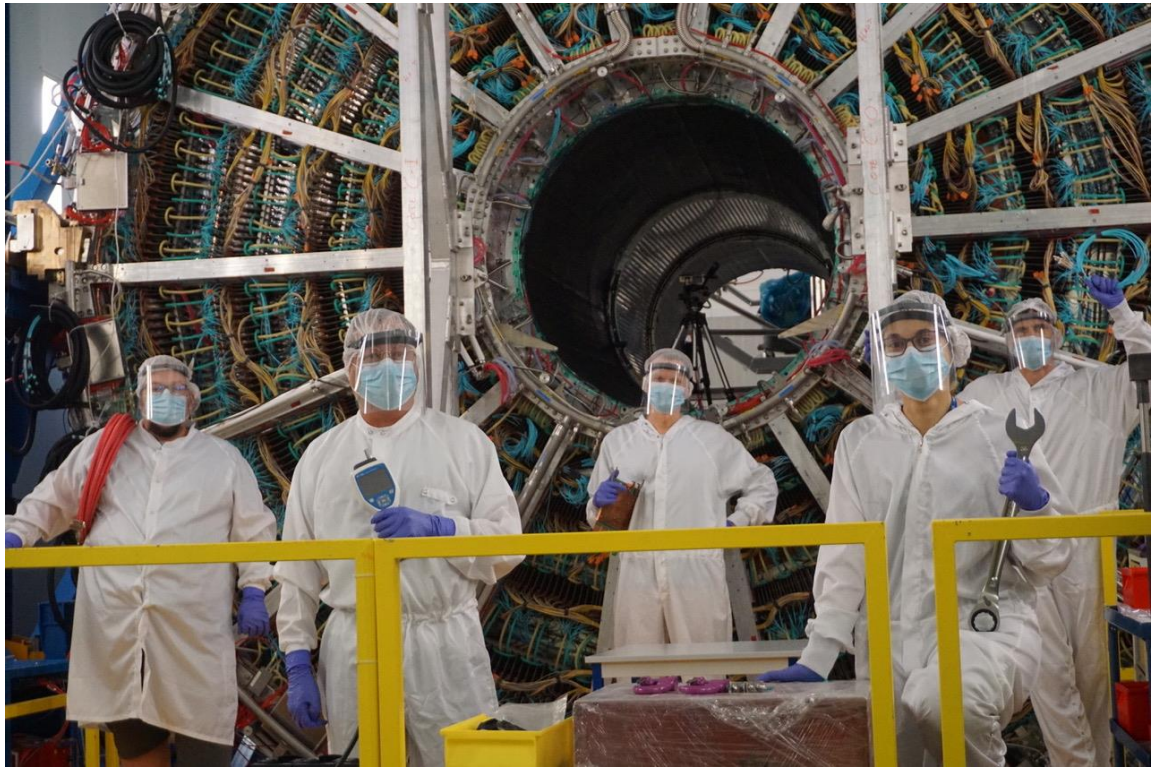
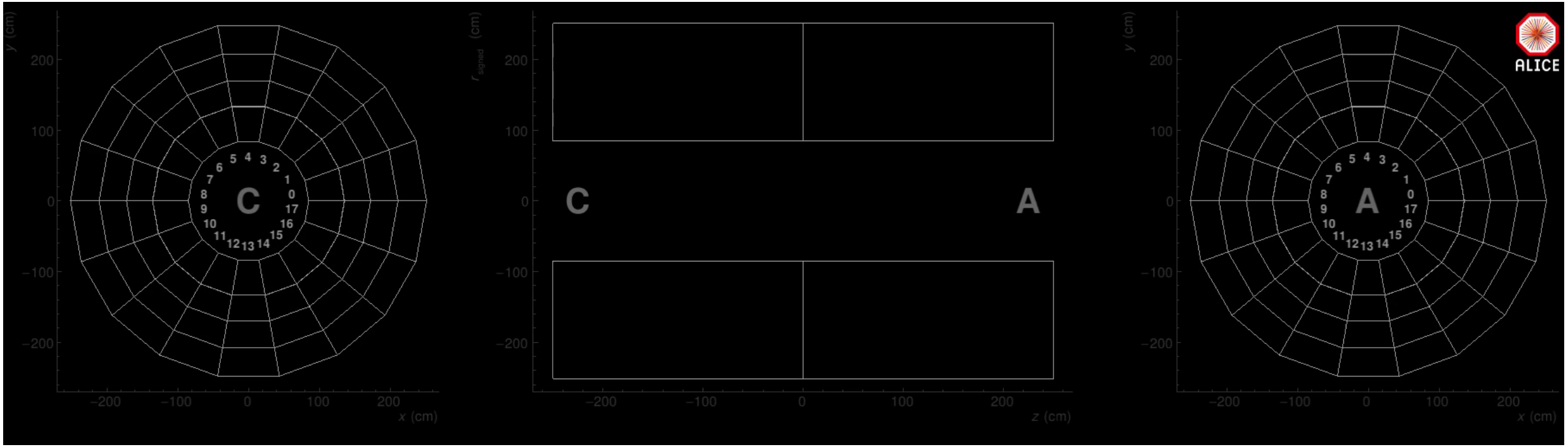


Figure taken fromhttps://alice-collaboration.web.cern.ch/menu_proj_items/tpc

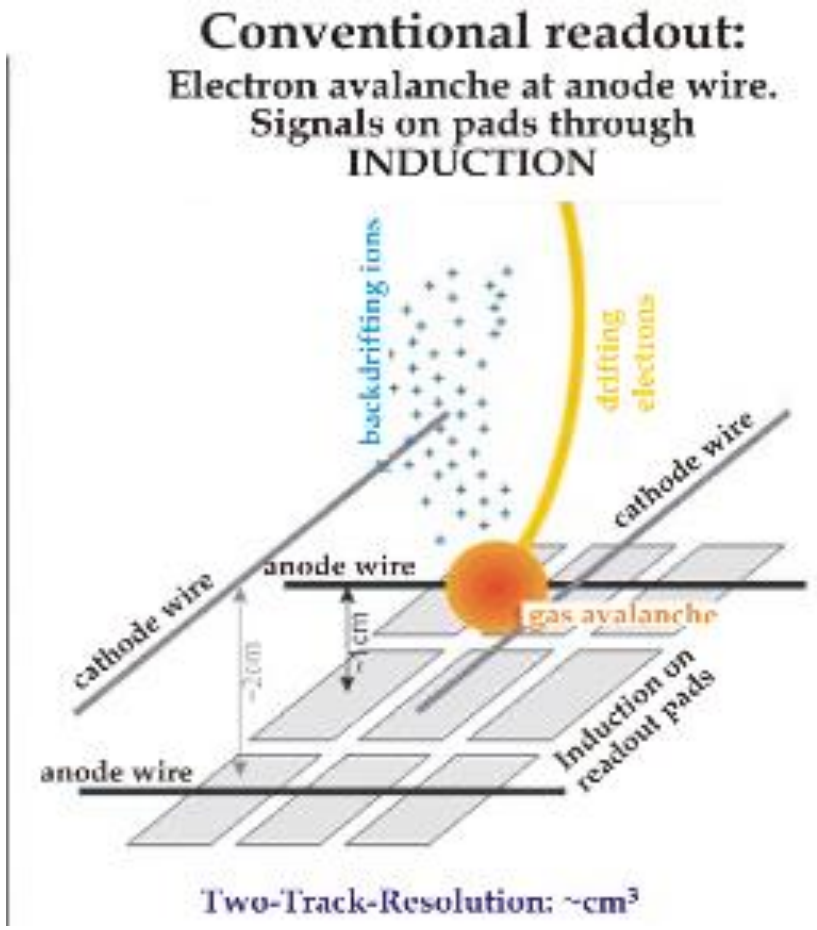
END

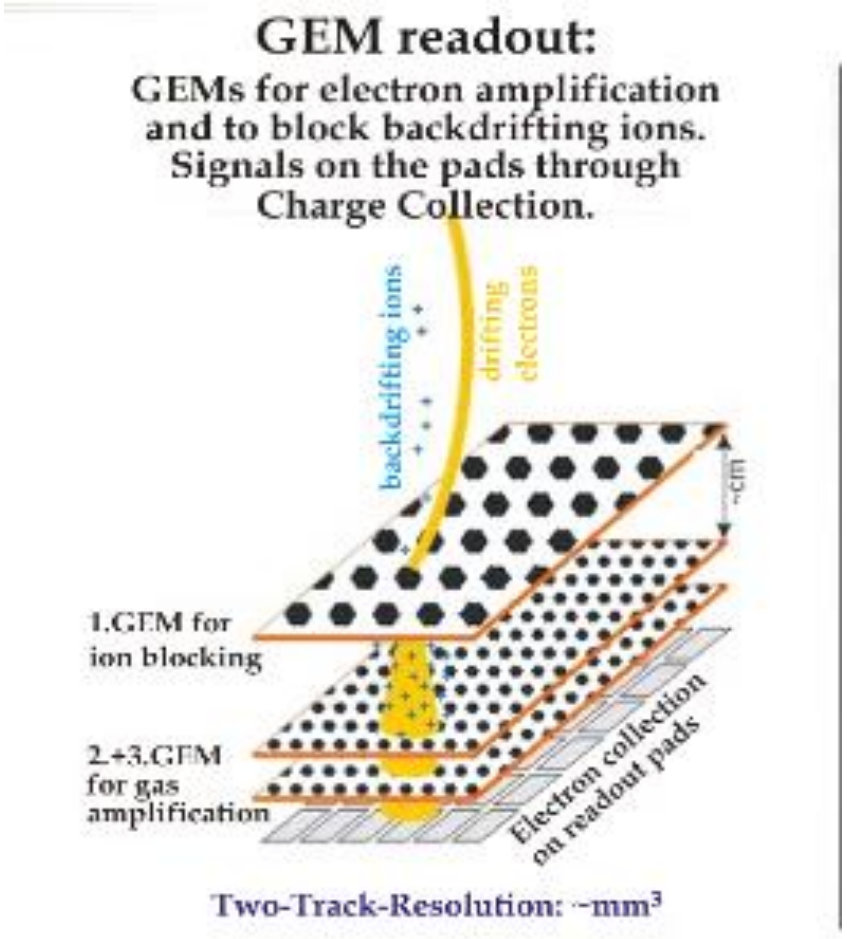


https://cernbox.cern.ch/index.php/s/xWLxU8N7SRAQqZ7

Backup

Comparison of old to new



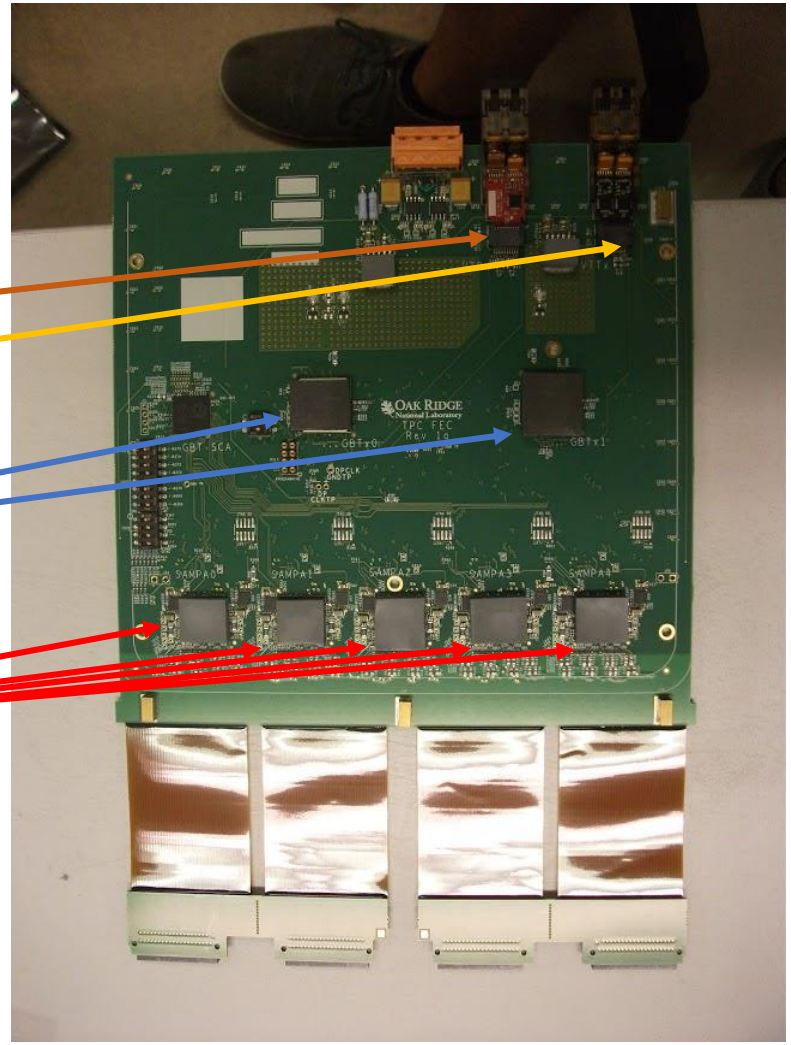


GEM Readout has a significant reduction in ionic backflow compared to the MWPC.

Reduction in backflow allows for CONTINUOUS READOUT !

TPC READOUT ELECTRONICS

- Prototyped at Oak Ridge National Lab in Tennessee
- 2 x Versatile Links
  - VTRx
  - VTTx
- 2 x GBTx ASICs
- 5 x SAMPA ASICs
- Thermal Pads + Copper Cooling Jacket



TPC READOUT ELECTRONICS

- 3276 Total FECs
- 91 FECs/TPC sector
- 524160 channels/FEC
- 1 GB/s/FEC output
- 3.3 TB/s total output

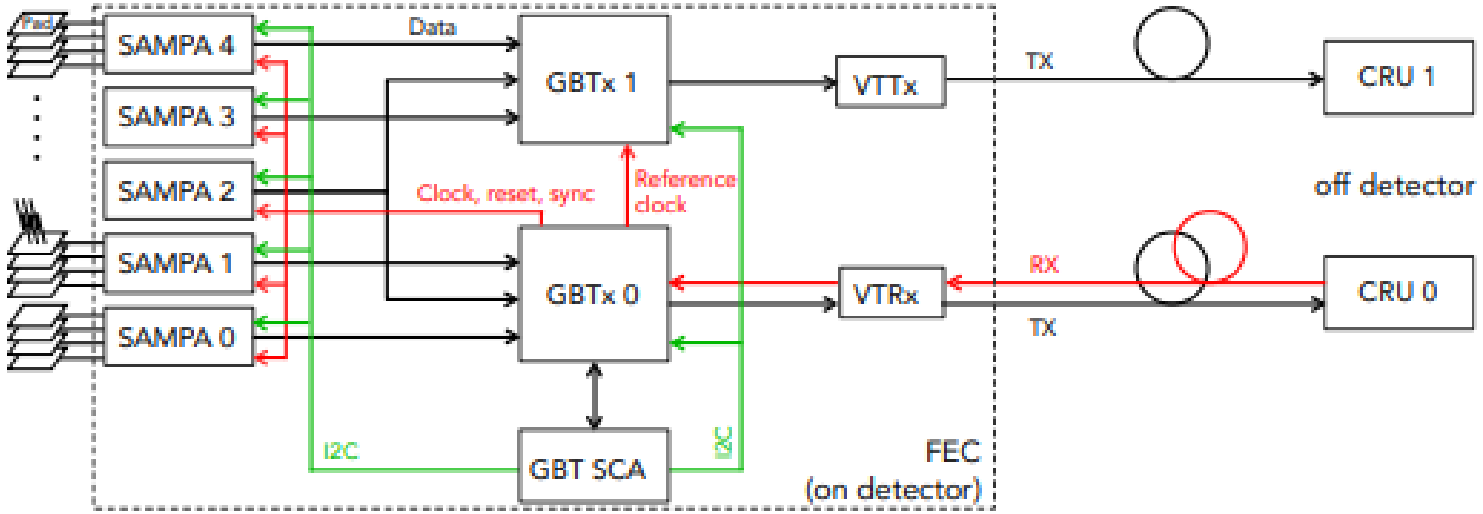


Figure 32. Schematic view of the TPC readout system. The different components are described in the text.

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SAMPA Chip Electronics (ALICE TPC FEC)

J. Adolfsson *et al* 2017 *JINST* 12 C04008

- Custom made ASIC
- 32 channels/chip, 10-20 Msamples/s
- USP (Sao Paulo, Brazil) & UNICAMP (Campinas Brazil) **among others**
- 1.6 Gbit/s

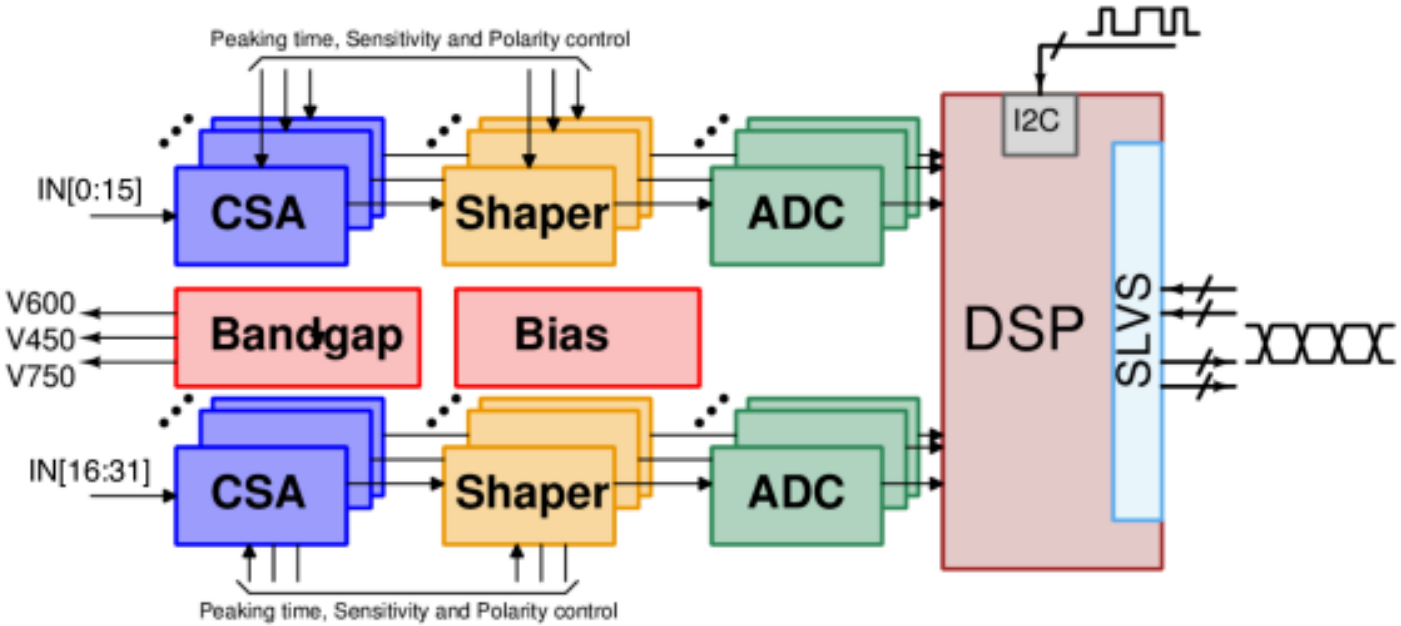

Figure 1. Sampa block diagram

Charge Sensitive Amplifier

Semi-Gaussian Shaper

10 bit Analogue to Digital Converter

Digital Signal Processor

SAMPA Chip Electronics (ALICE TPC FEC)

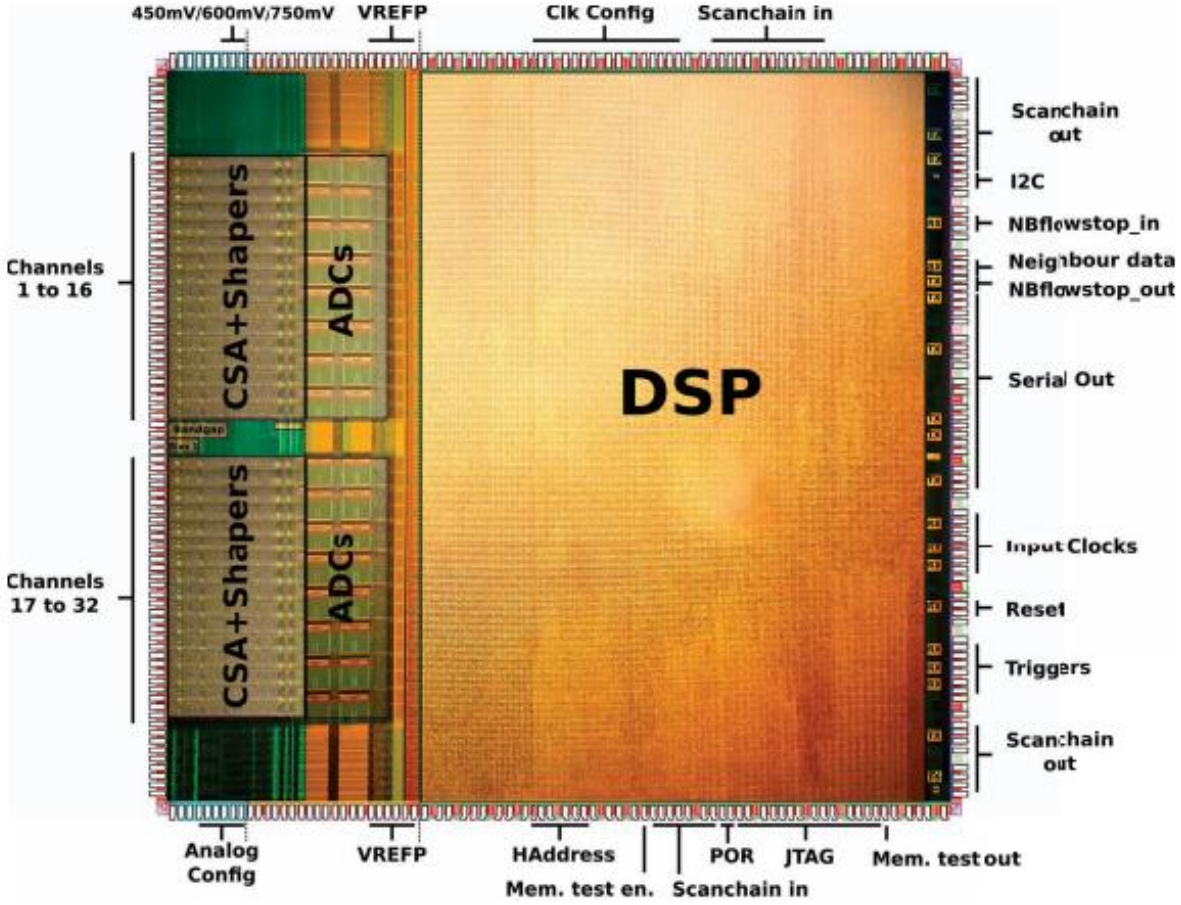

Figure 42. SAMPA chip layout. The placement of the individual functional blocks on the die is indicated, as well as the positions of some of the various input and output pins along the edge of the die.

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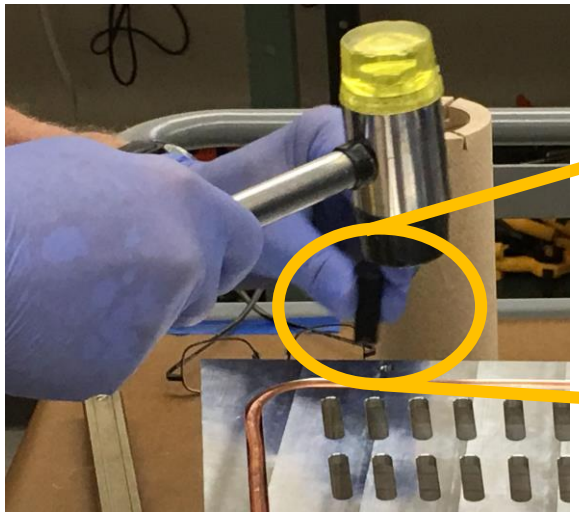
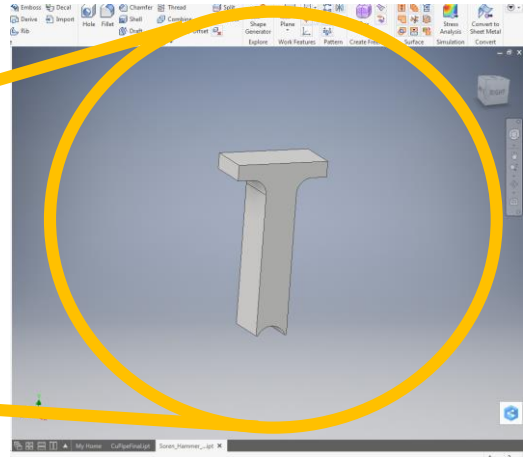
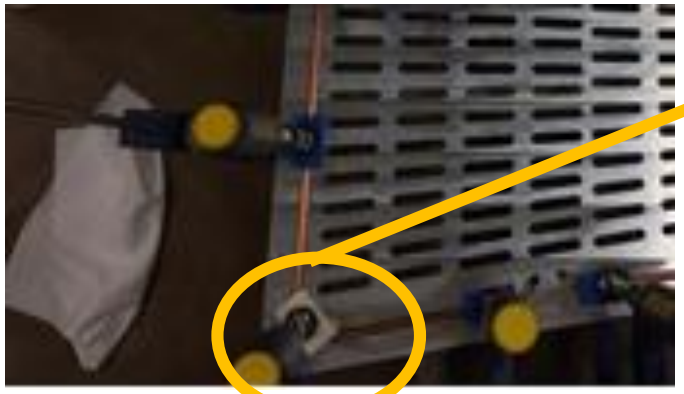
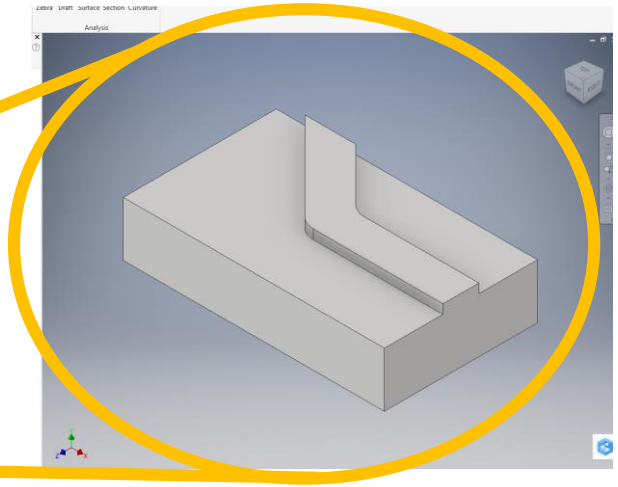
IROC Body Assembly

- Cooling System
- Copper Pipe
  - Bend into Shape
  - Tube Bender + Mallet + **3D printed “chisel”**
  - Epoxy + Clamps + **3D printed “jig” blocks** + time
- 3D printed parts
  - ABS Plastic



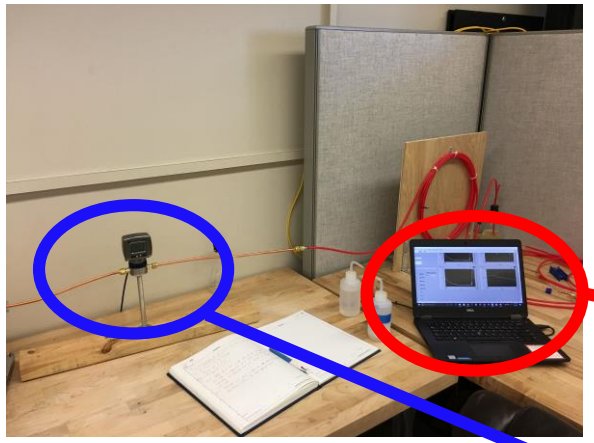


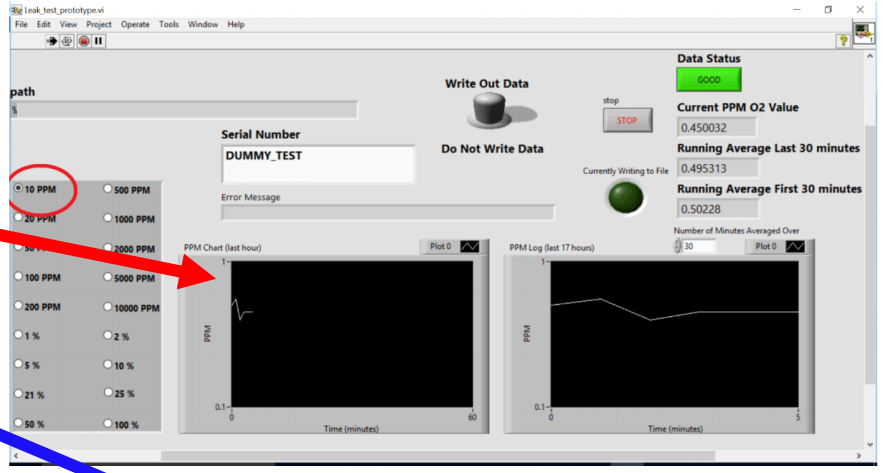


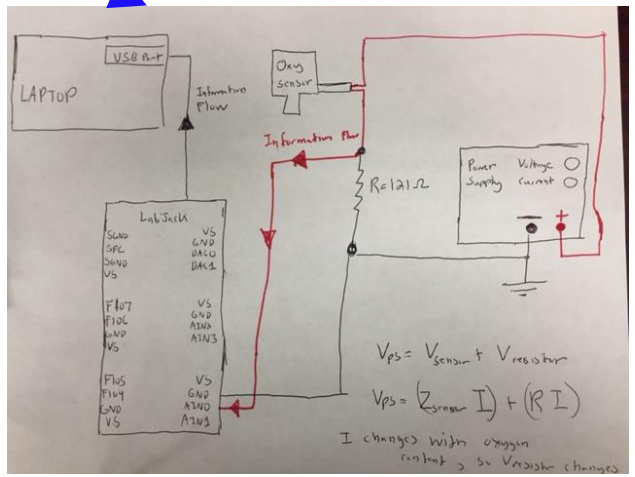


IROC Leak Testing

- **Oxygen Sensor**
  - Power Supply + GE OxyIQ + Resistor + LabJack DAQ
- **LabView Program**
  - Analyze from changes in Voltage across resistor

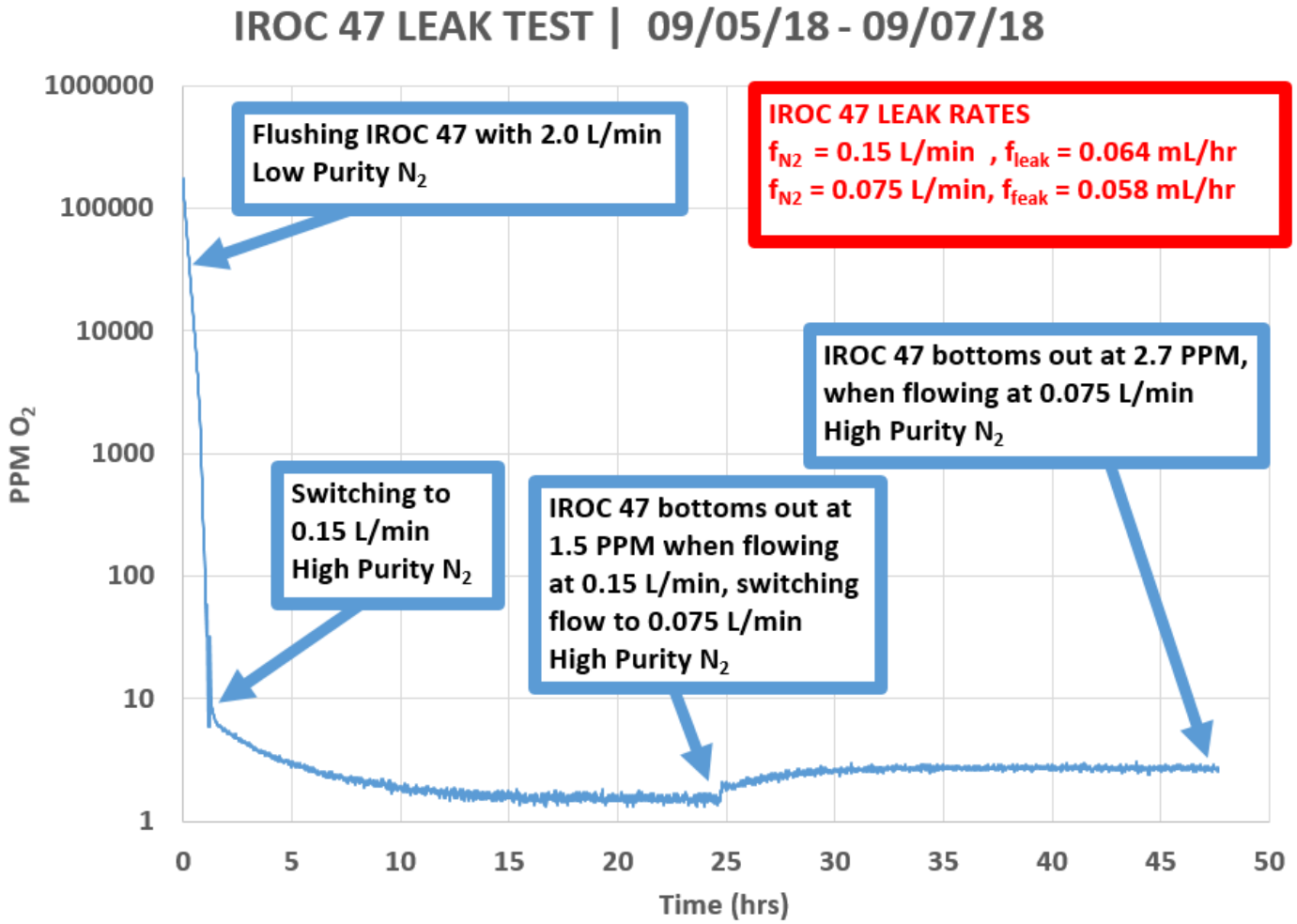






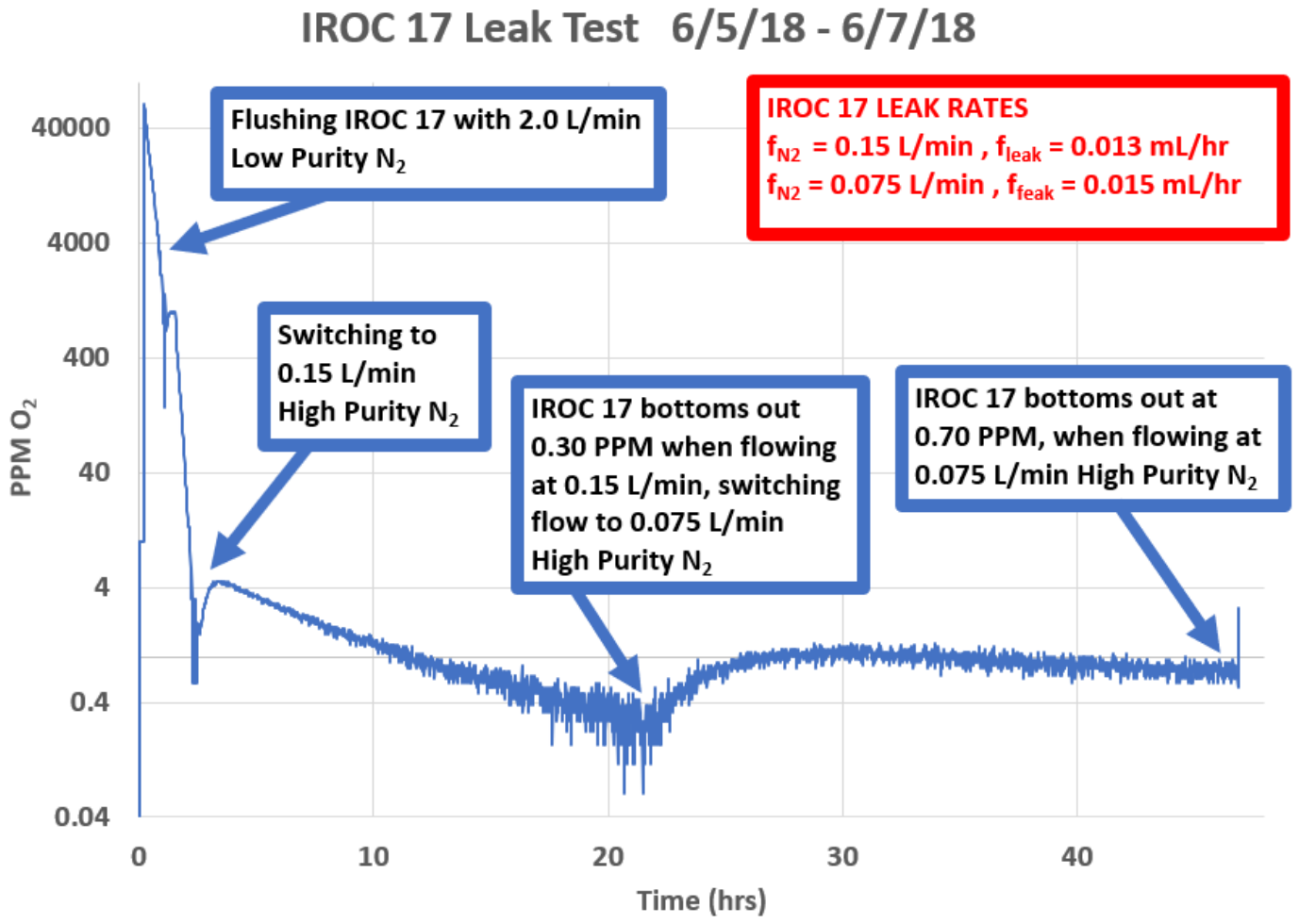
IROC Leak Testing

- Example Leak Test
- IROC 47



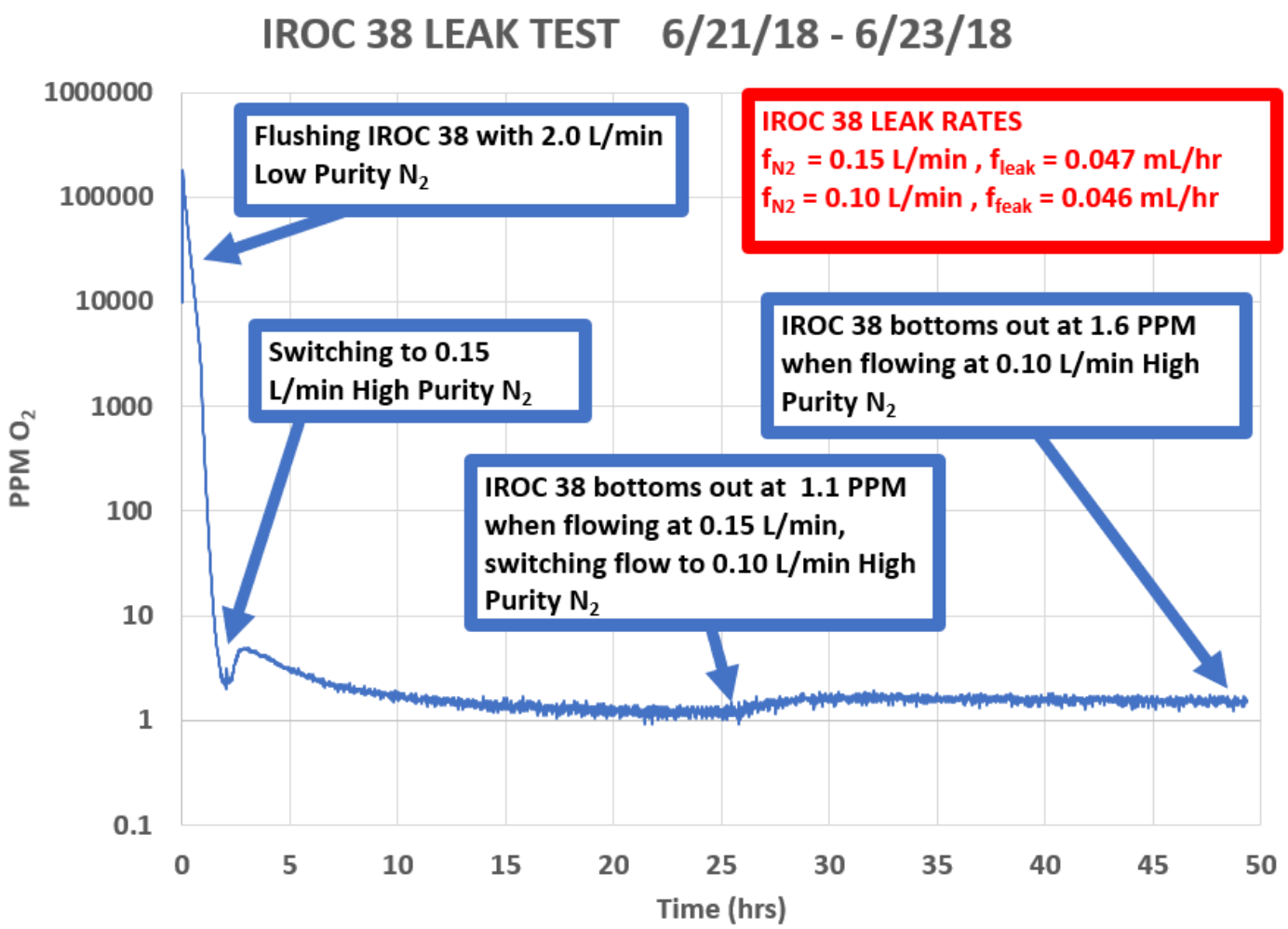
IROC Leak Testing

- Example Leak Test
- IROC 17



IROC Leak Testing

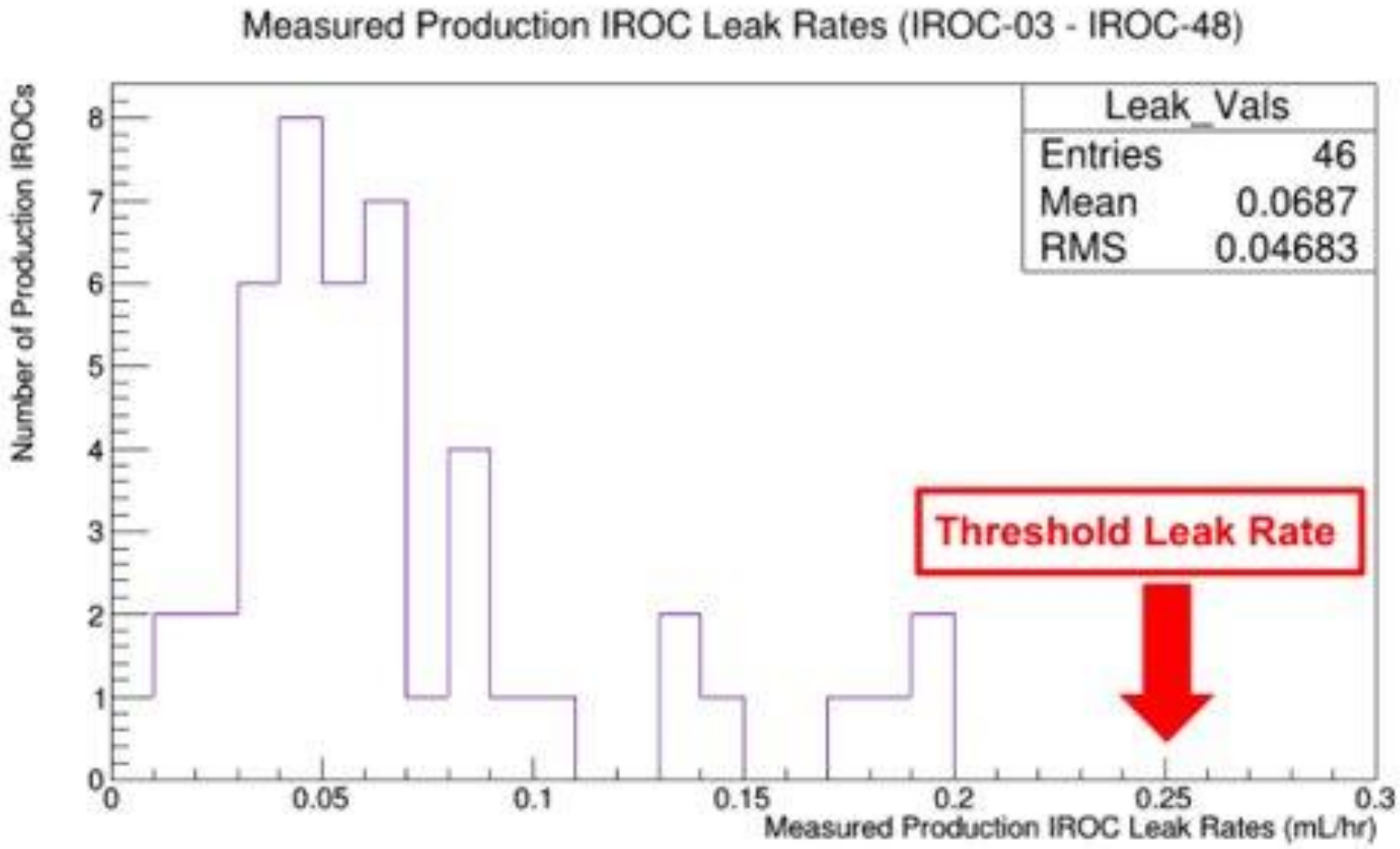
- Example Leak Test
- IROC 38



IROC Leak Testing

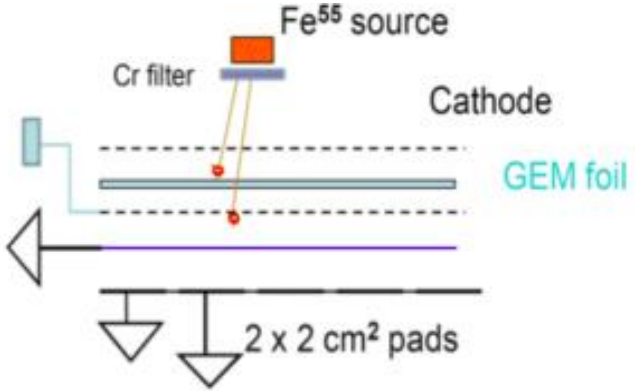
- Results

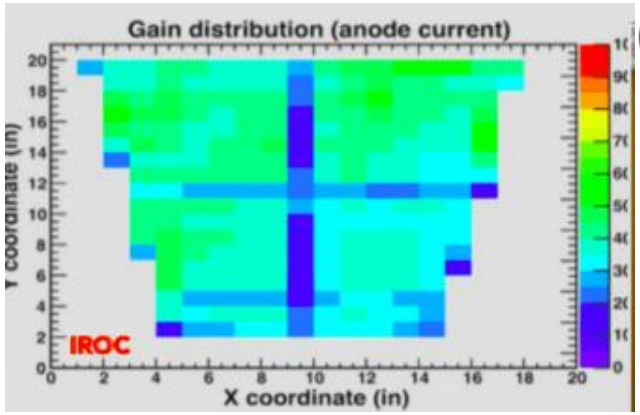
- All IROC's assembled at UTK **BELOW** design target leak rate (0.25 mL/hr)
  - Median = 0.056 mL/hr
  - Average = 0.069 mL/hr

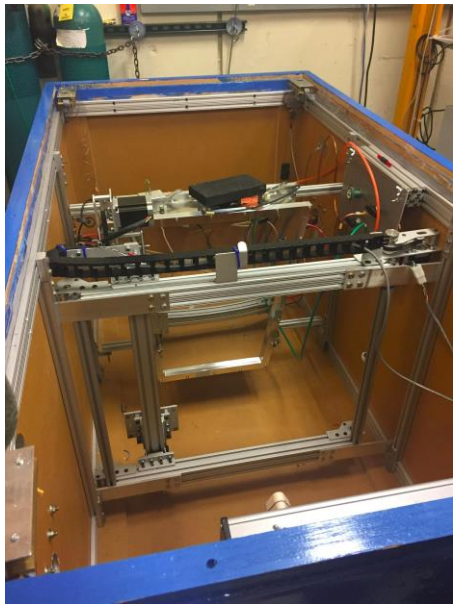


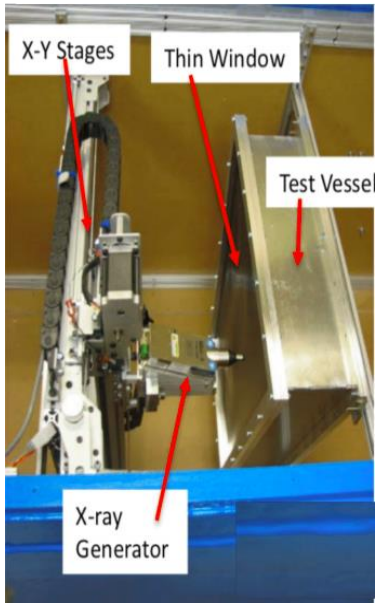
GAIN

- Full IROC Assembly
  - (IROC + GEM stack)
- Leak Test Full IROC Assembly
- Gain Testing (X-Ray Source)
- Ion Back Flow Testing (X-Ray Source)



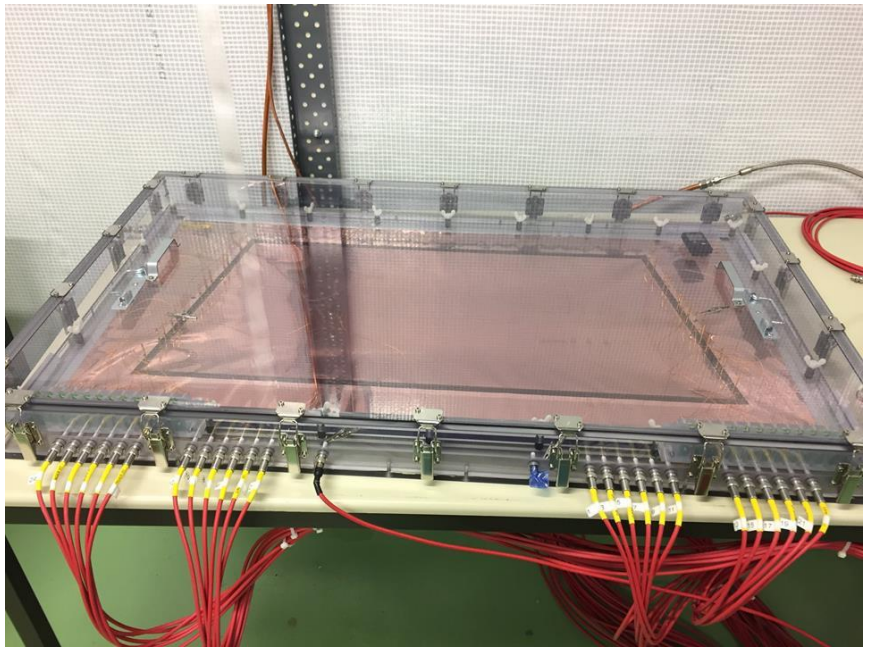


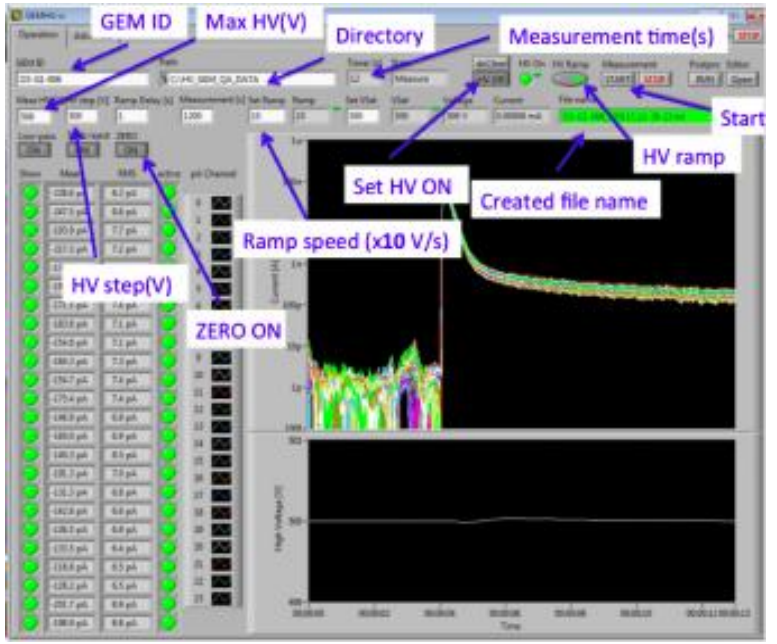




GEM QA: SPARK TEST

- Plexiglass HV drawer flushed with dry N_2
- Multichannel floating pico-ammeter for spark monitoring and current leak
- 10 nA rejection criteria





GEM QA: Foil Optical Test

- Optical Test
  - Searching for tears
  - Backlight + Camera

GEM QA: Foil Optical Test

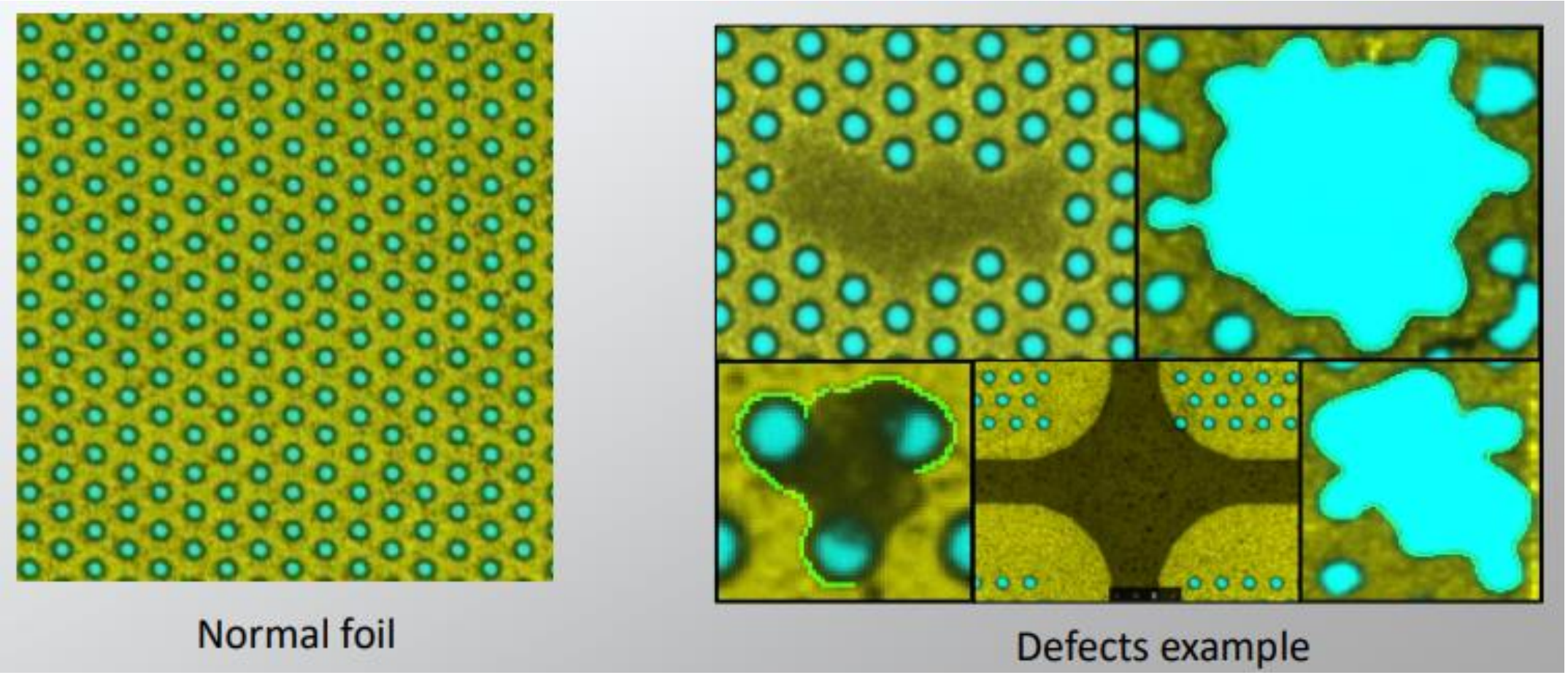
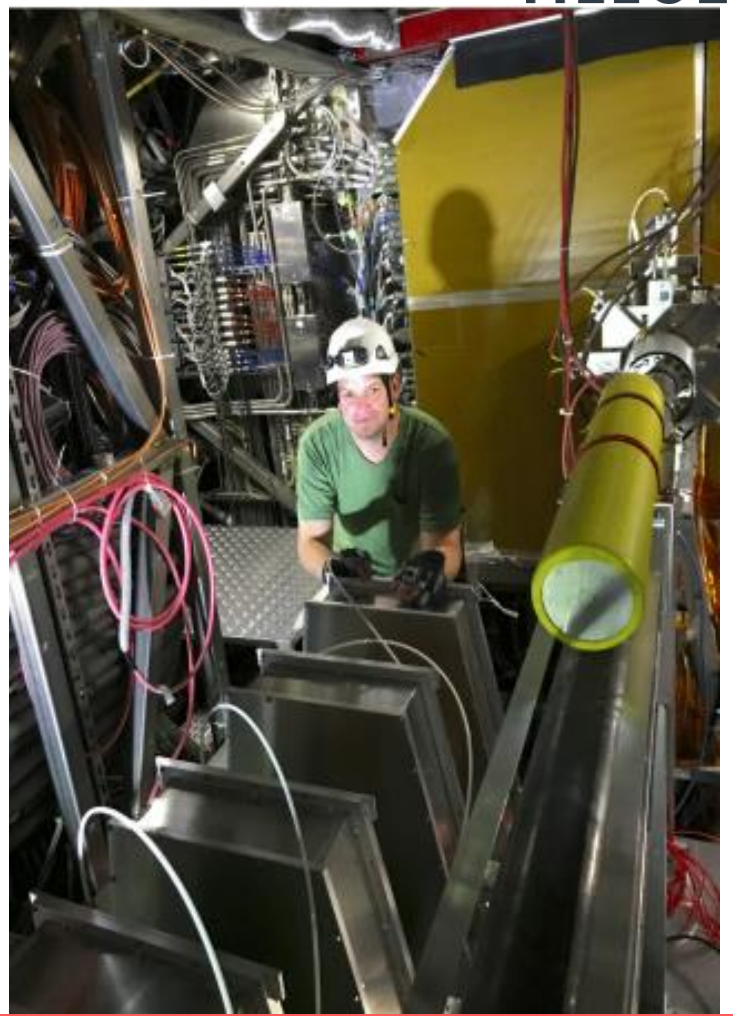


Figure taken from Adam Gera "Upgrade of the ALICE Time Projection Chamber for the LHC Run 3" https://indico.cern.ch/event/577856/contributions/3420142/attachments/1877395/3091970/Epshep2019_Adam_Gera_ALICE_TPC.pdf

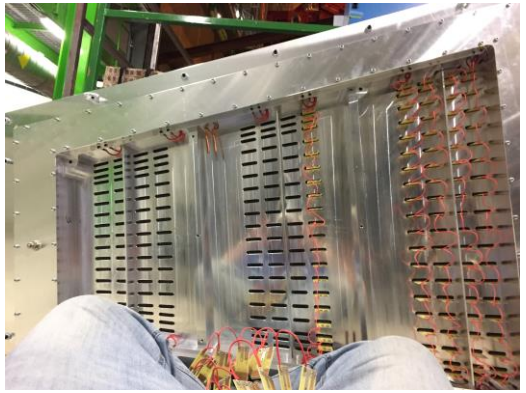
IN SITU ROC TESTING

- Real time spark rate monitoring as function of nominal GEM voltages
- Rocs just under beam line in front of PMD in mini-frame
- Tested during end of Run 2 in Fall 2018. Includes high luminosity pp run and PbPb run.
- Also tested in GIF++ facility before & after start of LS2



MISC. ALICE UPGRADE PICS (CA. 2018)

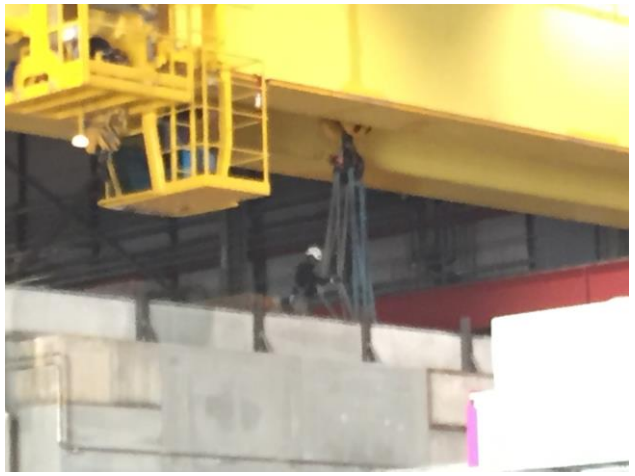
Close up of GEM foil holes



Putting Shorting Cards in OROC

Newly Arrived OROCs from GSI

ALICE Underground Cavern



Worker Sealing GIF++ facility

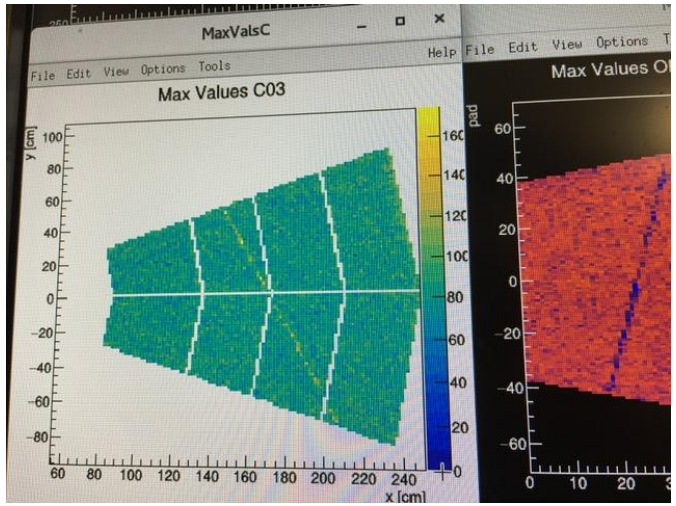
Preparing OROC for GIF++

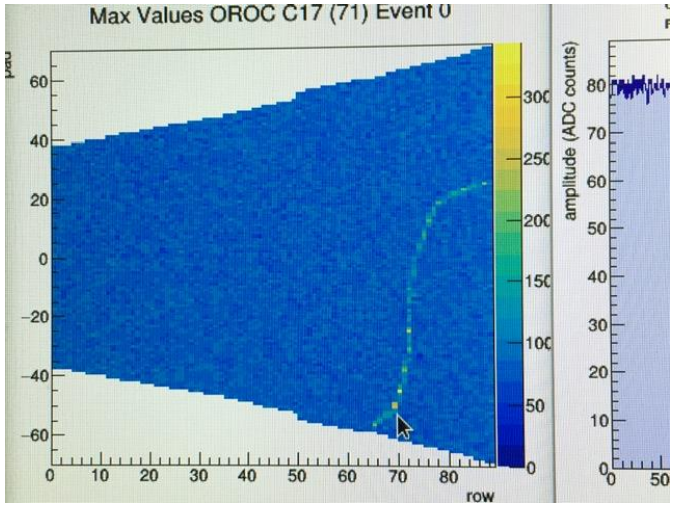
MISC. ALICE UPGRADE PICS (CA. 2019)

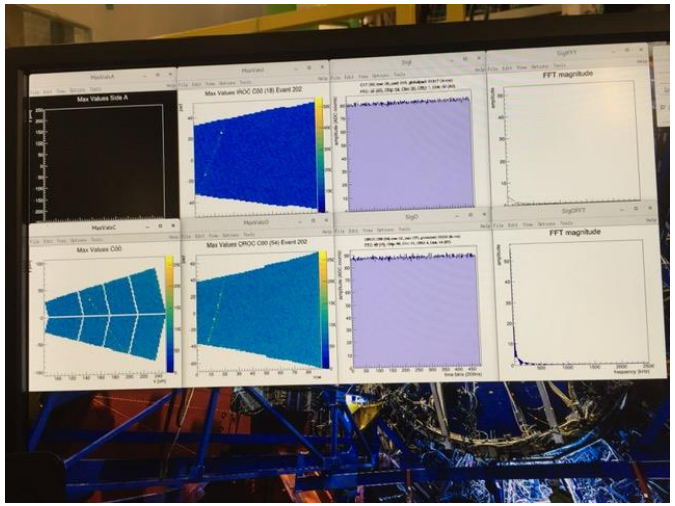
Thermal Pads on GBTx, SAMPAs, VTTx & VTRx, then seal w/ copper jacket

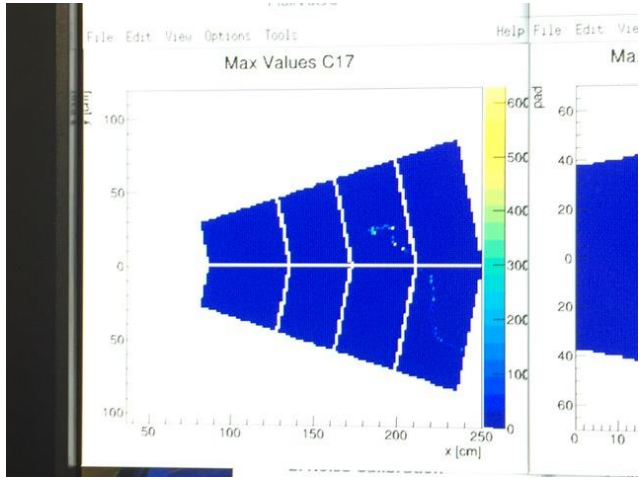
3276 Total Front End Electronics Cards
I did 700-800 personally

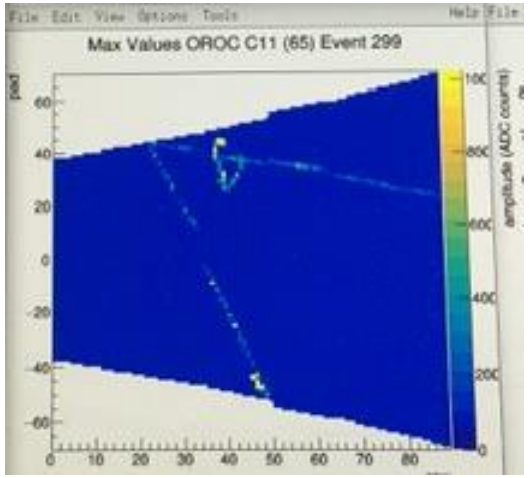
ALICE TPC PRE-COMMISSIONING - TRACKS

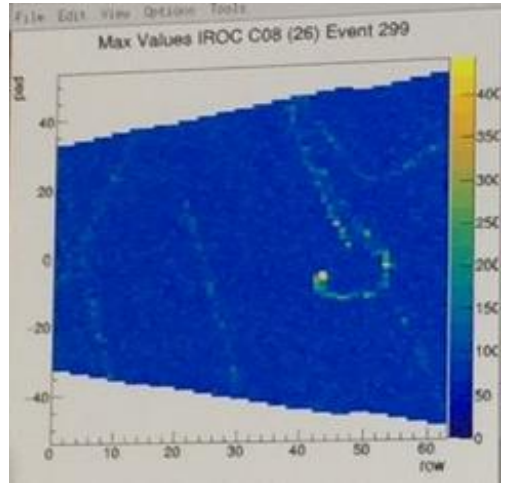












ALICE Design- RESOLUTION

- Design Resolution/IBF
  - Trade Off
  - Goal is IBF = 0.7 %, Res = 12 %
  - Resolution for Iron 55

Figure taken from ALICE TPC collaboration *et al* 2021 *JINST* 16 P03022

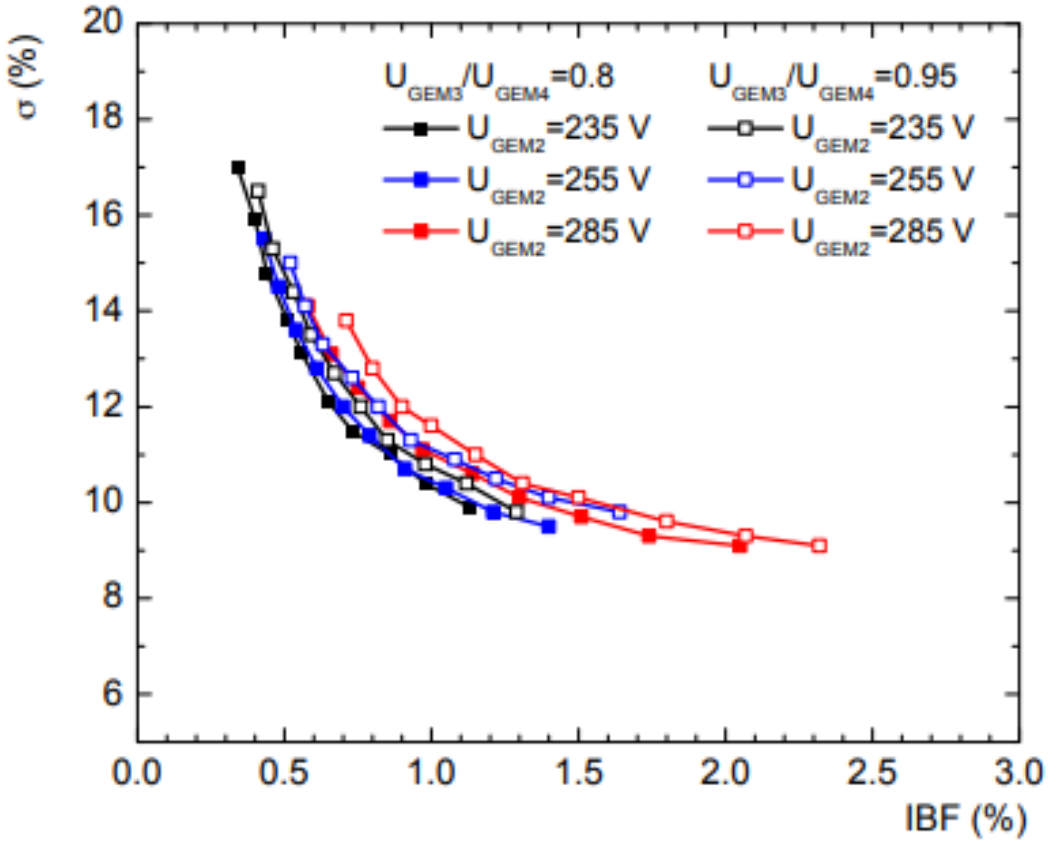


Figure 3. Energy resolution $\sigma(^{55}Fe)$ as a function of ion backflow (IBF) in a 4-GEM stack (S-LP-LP-S) in Ne-CO_2-N_2 (90-10-5). The gas gain is kept at 2000 in all measurements by adjusting the voltages on GEM 3 and GEM 4 at a fixed ratio of 0.8 or 0.95 (from [3]).

ALICE Design- Efficiency/Resolution

- Tracking Efficiency as a function of 1/pT
  - SNR = Signal to Noise Ratio
  - Effect of Varying ADC sampling frequencies
- Resolution as a function of 1/pT

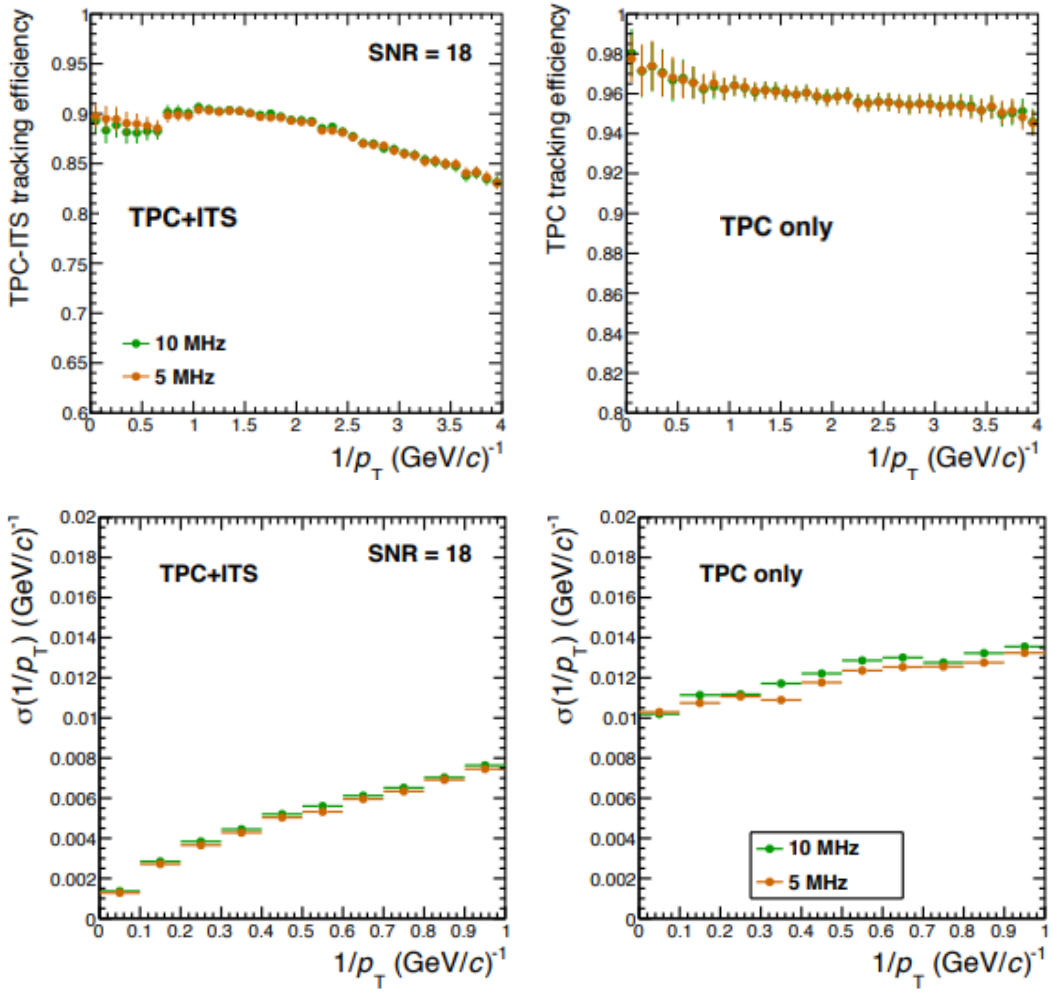


Figure taken from ALICE TPC collaboration *et al* 2021 *JINST* 16 P03022

ALICE TPC COMMISSIONING - RESOLUTION

- Overall spectrum looks good

- Resolution for Krypton calibration
  - 4-5 %

Figure taken from Robert Munzer / Torsten Alt
TB Meeting