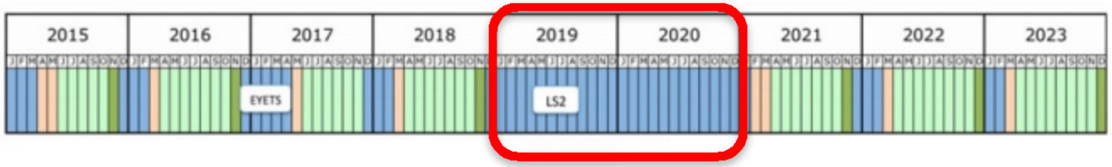
The ALICE TPC Upgrade Project

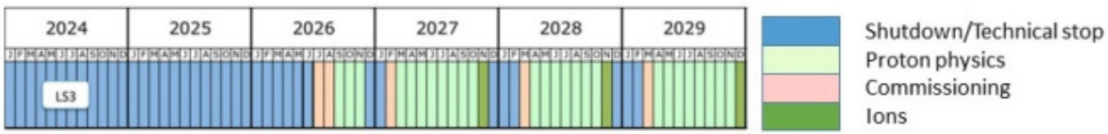
Richard Majka for the ALICE Collaboration*
Physics Department, Yale University,
New Haven, CT 06511, USA
richard.majka@yale.edu

*R. Majka supported by the US Department of Energy Office of Science

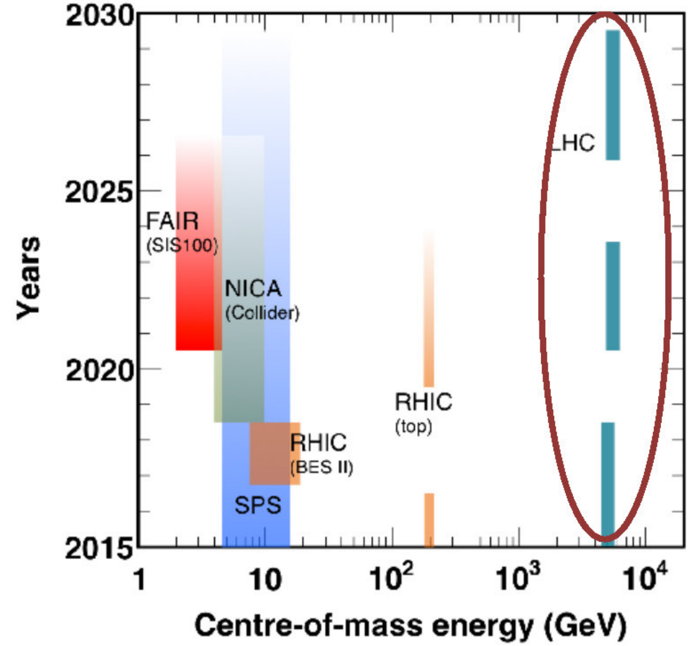
Upgrade of LHC injector chain - What and When

$\sqrt{s_{NN}} \sim$ 5TeV $\sqrt{s_{NN}}$ =5.5TeV





Heavy ions facilities up to 2030



- L_{int} 10^{27} $cm^{-2}s^{-1}$ → (goal) 6 10^{27} $cm^{-2}s^{-1}$

  Pb-Pb interaction rate: 8 kHz → **50 kHz**
- Besides Pb-Pb, p-Pb and pp at $\sqrt{s}$=5.5 TeV
- ALICE request: 10 nb^{-1} at B=0.5 T (+ 3 nb^{-1} at B=0.2 T)

LHC operates at higher energies and at vanishing baryon chemical potential
→ best suited for measurement of QGP properties
→ abundance of calculable QCD processes (heavy quarks)

LHC Upgrade → New Physics Opportunities for ALICE

- Study the **thermalization of partons** in the QGP, with focus on **charm and beauty** quarks at **low p_T**
  - secondary vertices
- Low-momentum **charmonia** dissociation (and regeneration?) to study deconfinement and medium temperature
- Production of **thermal photons** and **low-mass dileptons** emitted by QGP to study initial temperature and equation of state of the medium
  - exploit low p_T reach & PID of ALICE

Processes Cannot be selected at trigger level

Move from **1 kHz triggered** running in ALICE to **50 kHz Pb-Pb**

Record Everything!

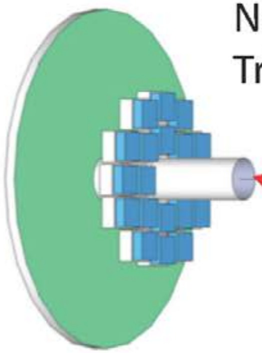
What will ALICE do to exploit these new physics opportunities?

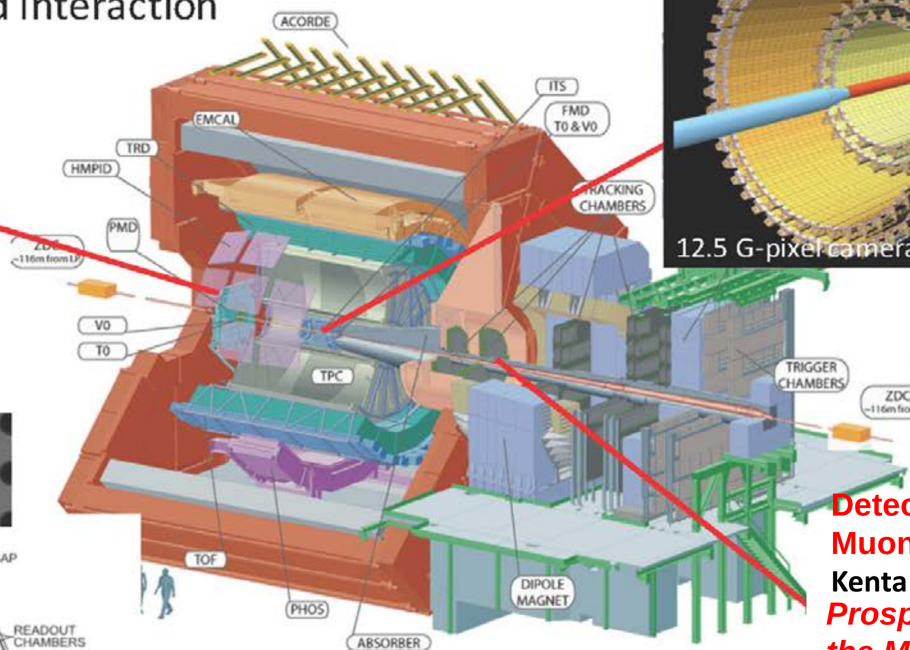
ALICE

Next Presentation, Paolo Martinengo

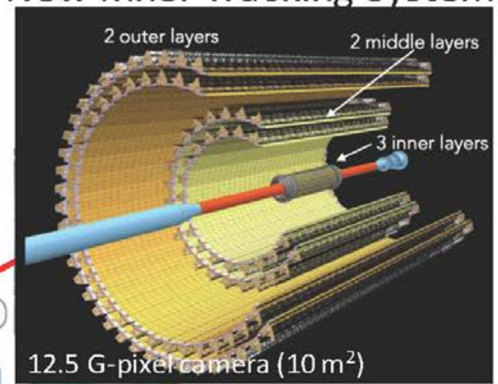
The new Fast Interaction Trigger detector for the ALICE Upgrade
Wladyslaw Henryk Trzaska, Poster

New Forward Interaction Trigger (FIT)



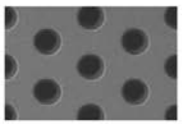


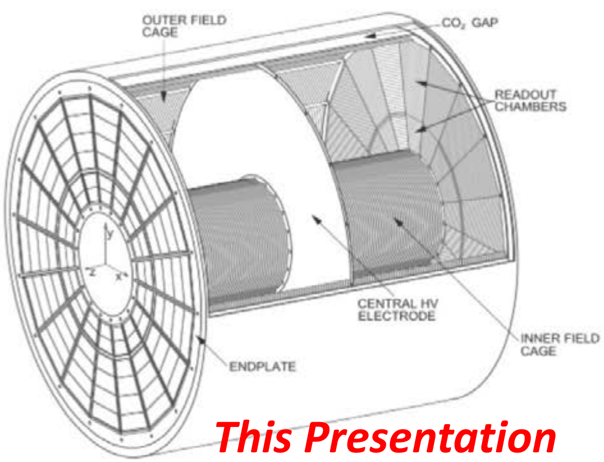
New Inner Tracking System (ITS)



Both based on Monolithic Active Pixel Sensors (MAPS)

TPC with GEM based readout



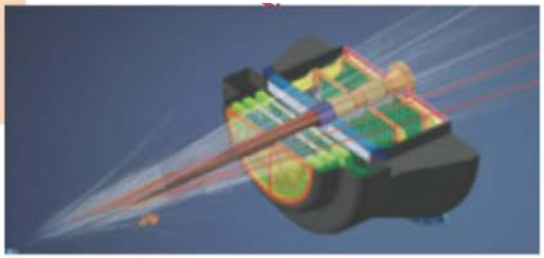


This Presentation

+ improved readout for TOF, ZDC, TRD, MUON ARM
+ new Central Trigger Processor
+ new DAQ/Offline architecture

Detector Control System of the new Muon Forward Tracker at ALICE
Kenta Shigaki, Poster

Prospects for ALICE physics with the Muon Spectrometer Upgrade and the new Muon Forward Tracker
Antonio Uras, Poster



Why We Need to Upgrade the TPC

Present TPC: Wire chamber end plates

- ***p* Resolution**: $\sigma_{pT}/p_T < 3.5\%$ at $p_T \cong 50$ GeV/c and below 1% at $p_T = 1$ GeV/c.
- **dE/dx resolution**: 5% (p-p) – 6.5% (central Pb-Pb) (158 max. samples)
- **Event rate: 1 kHz Pb-Pb** minimum bias

Want to be able to record **50 kHz Pb-Pb** collision rate and maintain the current performance

BUT

Drift time for ionization electrons from central electrode to end plate is $\mathcal{O}$**(100 μs)**
Drift time for ions from end plate to central electrode is $\mathcal{O}$**(160 ms)**

Build up of positive ions in the drift volume → electric field distortion → distortion of the ionization electron tracks as they drift to the end plates

Ions produced by charged particles traversing the detector are unavoidable – this is the signal

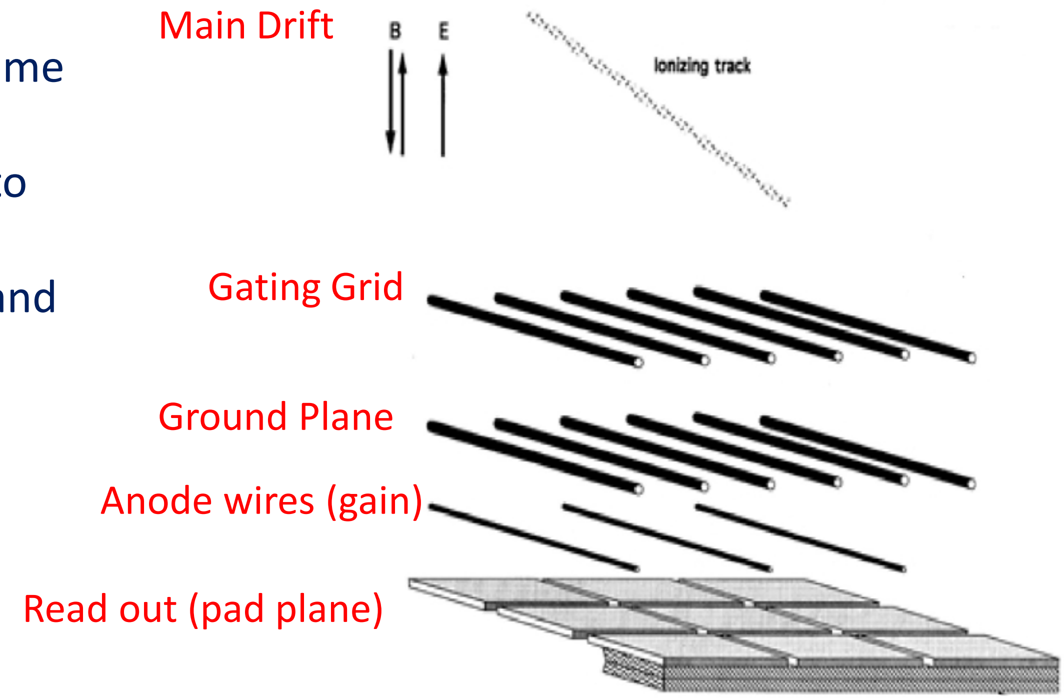
Ions from the gain structure - typically a few thousand times the initial ionization - **must be prevented** from getting to main drift volume

Usual Solution

Use a **gating grid** between the gain element and the drift volume

Gating grid is normally biased to prevent passage of charged particles (ionization electrons and ions)

TPC is run in **triggered mode**



- When a trigger occurs, gating grid is biased (opened) to allow passage of charged particles
- The grid is kept **open** for the time required to collect the ionization electrons $\mathcal{O}$**(100 μs)**
- In this time, no ions from the gain element (anode wires) can escape the gain region
- Grid then must be kept **closed** long enough to collect all ions $\mathcal{O}$**(300 μs)**
- Intrinsic dead time → **rate limitation ~ 3 kHz**

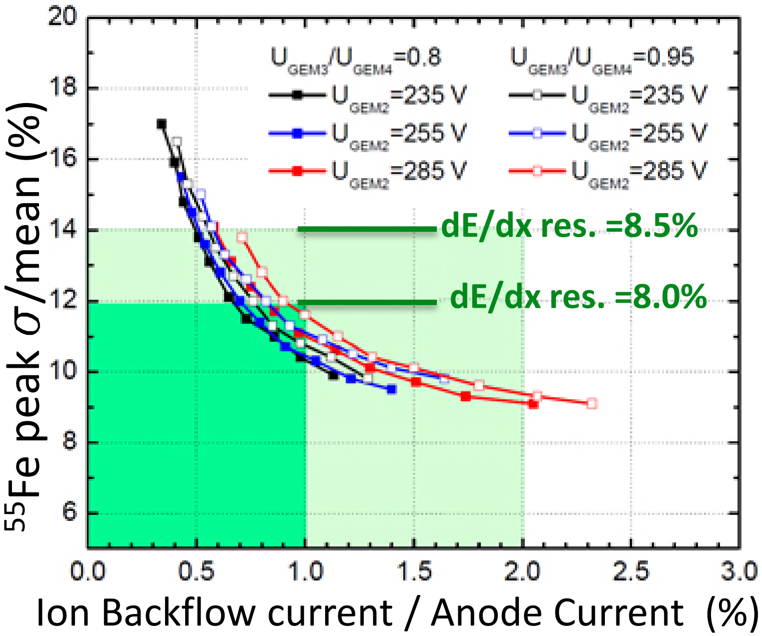
Eliminate the gating grid by exploiting the low Ion Back Flow (IBF) of Gas Electron Multipliers (GEMs)*

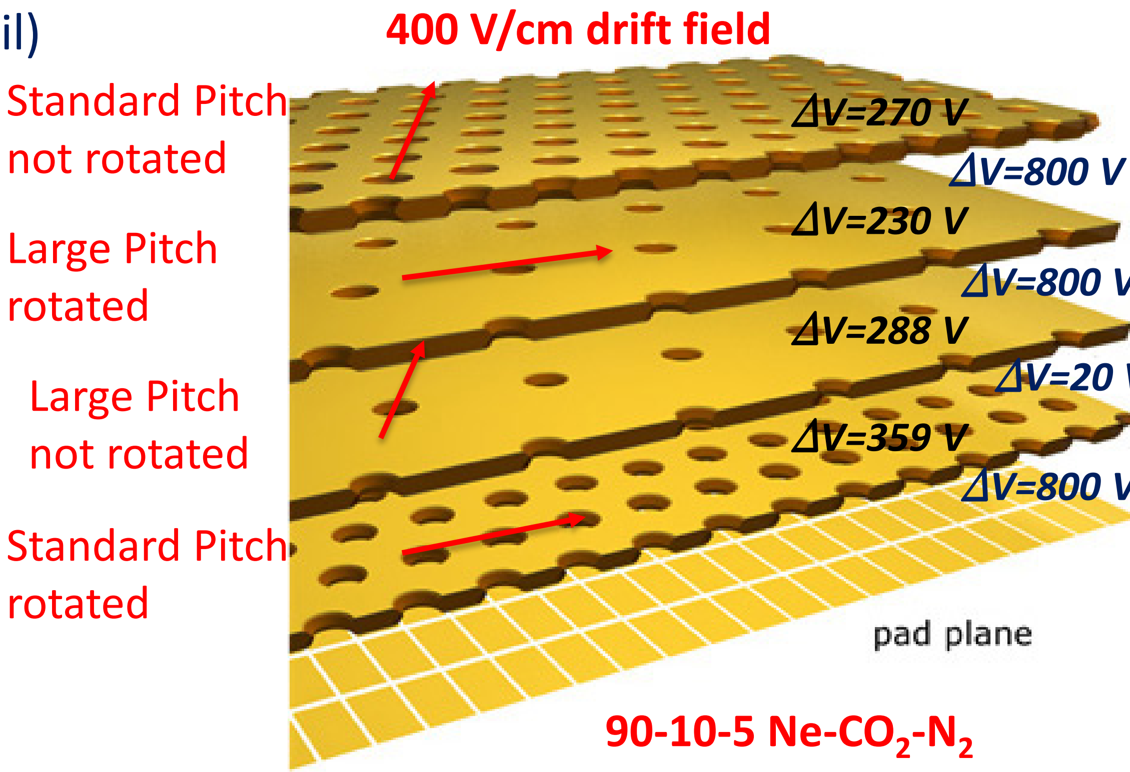
*B. Ketzer et al., Nucl.Instrum.Meth. A732 (2013) 237-240

Solution – Technology Choice

Several year R&D program developed a **solution** with 4-GEM chambers

- Different GEM hole patterns on each GEM helps to block ion backflow
- Tradeoff between energy resolution (large gain in first foil) and ion back flow (IBF) (small gain in first foil)





Eight voltages (ΔV on 4 GEMs and ΔV on 4 gaps) makes huge parameter space to scan

Curves of energy resolution vs ion backflow show a region that meets our design goals and a larger region that gives acceptable performance to meet the physics goals.

Calibration method for correcting space-charge distortions is **already in use** for the current run and handles variations even larger than we see in prototype chamber.

→**Poster:** ***Space-charge distortions in the ALICE TPC in RUN 2,*** **Ernst Hellbar**

Readout Chamber Design and Construction

ALICE TPC end plate readout is divided into 18 20° sectors on each end. Each sector has an inner chamber (IROC) and outer chamber (OROC). To maintain reasonable sizes for the GEM foils the OROCs are divided into 3 sections.

GEM foil sizes

- IROC: 467 (292) × 497 mm²
- OROC1: 595 (468) 362 mm²
- OROC2: 730 (596) × 380 mm²
- OROC3: 870 (730) × 398 mm²

GEM foil numbers

- 40 sectors (36 installed + 4 spare)
- 4 GEM stacks per sector
- 4 GEM foils per stack

= ***640 GEM foils***

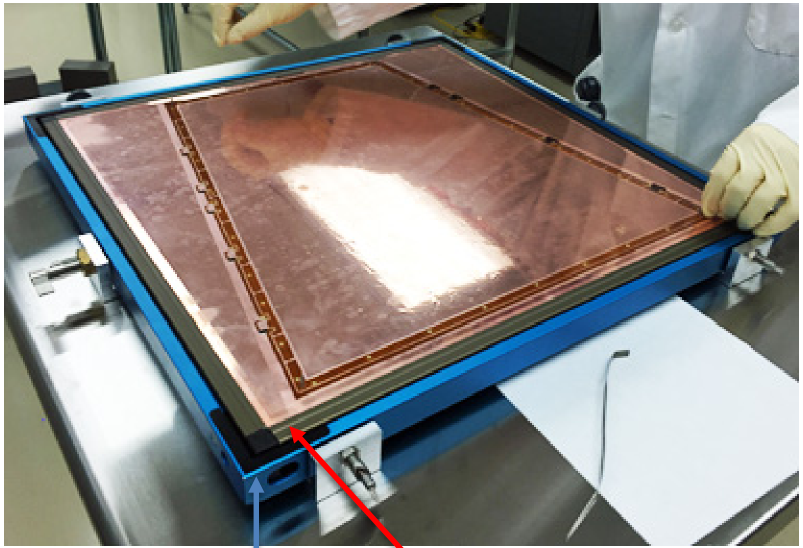
To accomplish this very large construction effort the project has been divided among several institutions

Division of Effort for ROC and Electronics Construction and Testing

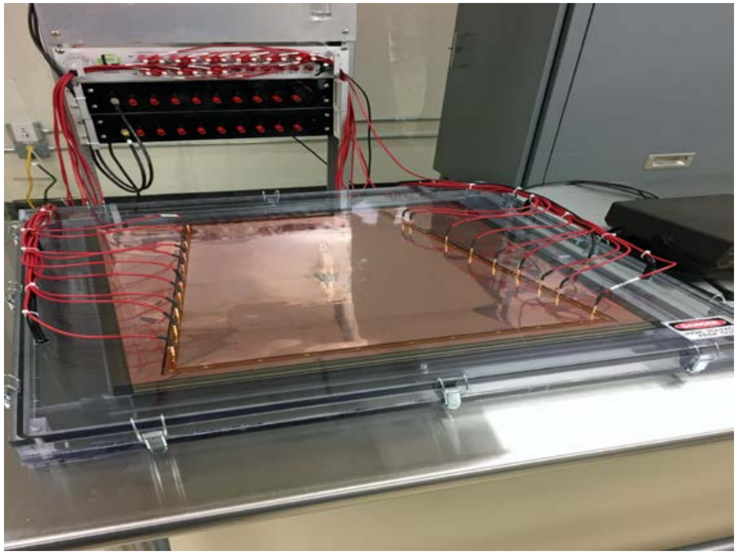
Managing **material flow** among many institutes is not a small part of the project. For ROC construction **Database** is used to track material location, status and archive QA+test data.

Foil Handling and Testing

Commercial stencil stretching frame used. The inner frame is used for handling foils until they are glued onto fiberglass frame.



- Foil mounted in inner frame as soon as it comes from CERN shop
- Stays with foil until foil is finally trimmed to final fiberglass frame
- Outer (blue) frame clamps inner frame and applies calibrated stretching force (Calibrated springs)

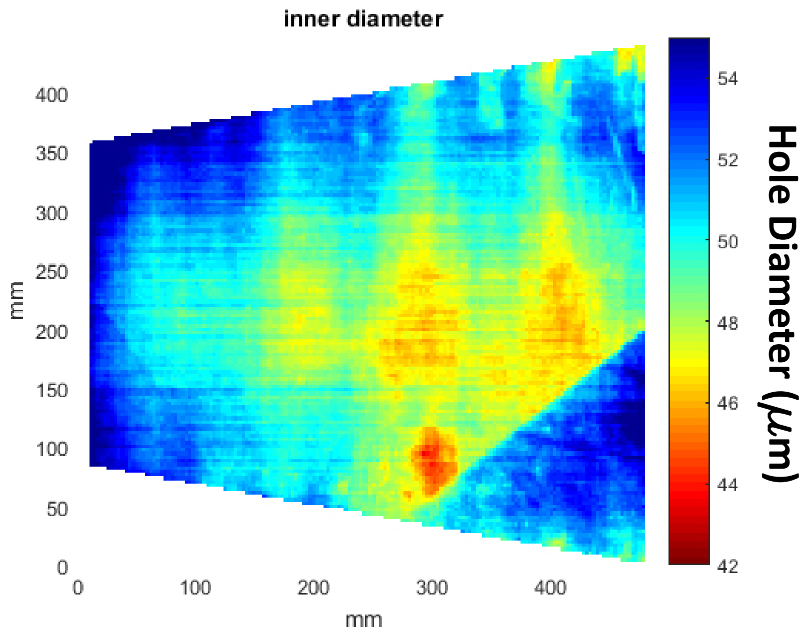


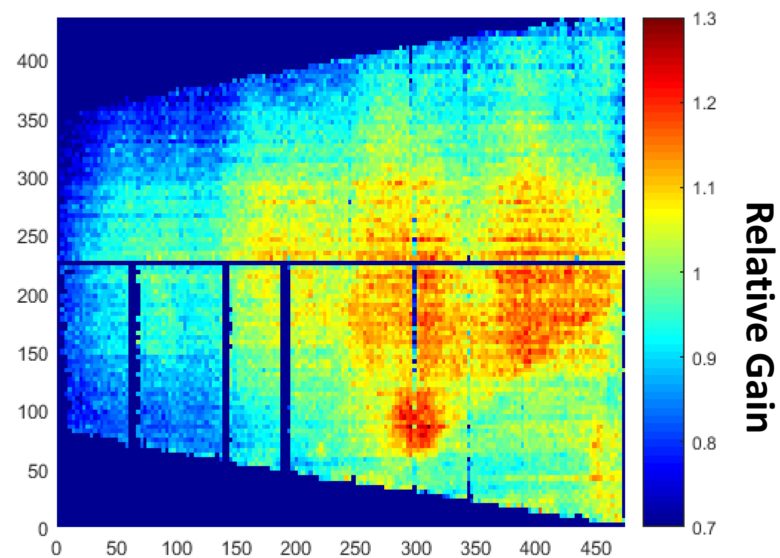
HV Testing:

- Plexiglass box can be flushed with dry nitrogen.
- Spring pins in lid connect to each of the foil HV segments
- Multichannel floating pico ammeter developed can measure leakage currents at HV down to a few pA
- Foils checked before leaving CERN, at advanced QA site, before and after framing and before mounting in chamber

Single Foil Advanced QA

- Two institutes have optical scanners and software to measure all inner (polyimide) and outer (copper) hole diameters.
- We also can map the gain across single foils.
- Training neural net software to predict the gain based on optical measurements.
- Clear correlation is seen and the optical scan is faster and easier to do.
- Every foil will be optically scanned and acceptance criteria established.

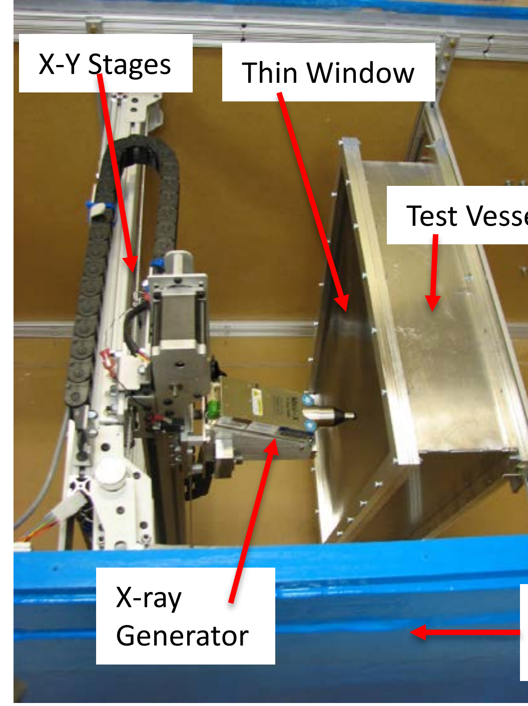


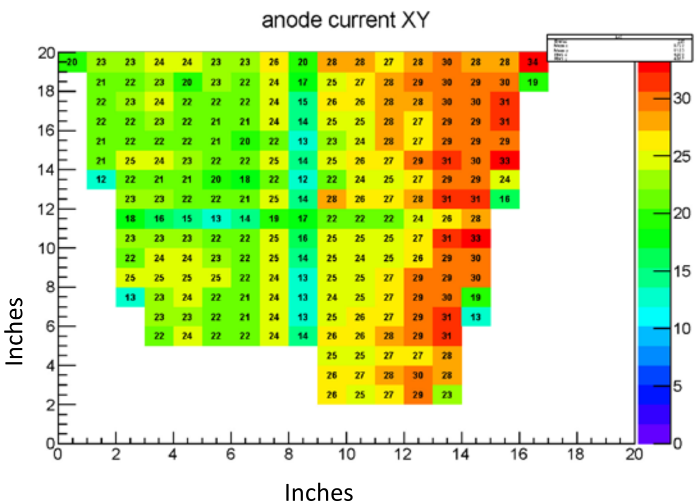


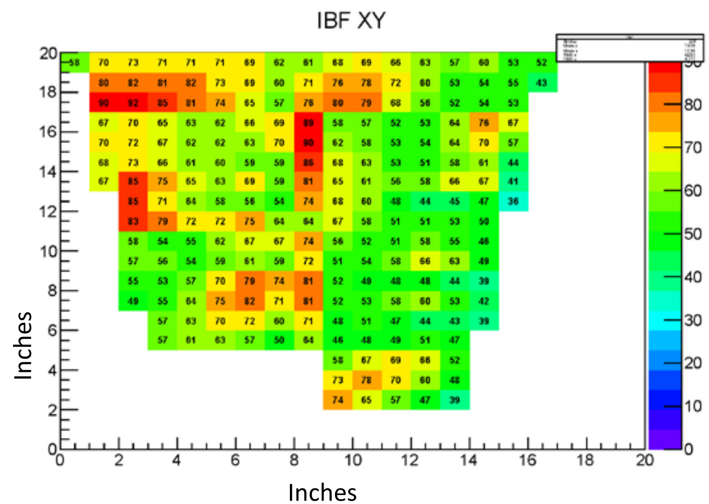
Scan shown is from "flawed" foil – useful to have larger range of hole sizes for neural net training

Assembled Chamber Testing and QA

- Gas tightness (monitor H_2O, O_2 in gas exit stream)
- Gain curve and gain at standard voltages (^{55}Fe peak)
- Stability – run for 2 days, monitor gain and any discharges
- Spatial map of gain and Ion Back Flow (IBF) – scan chamber with collimated X-ray source, measure anode and cathode currents at each location
- “Stress” test – illuminate full chamber with X-ray source to give 10 nA/cm^2 anode current (max. expected in operation at LHC). Monitor for discharges.





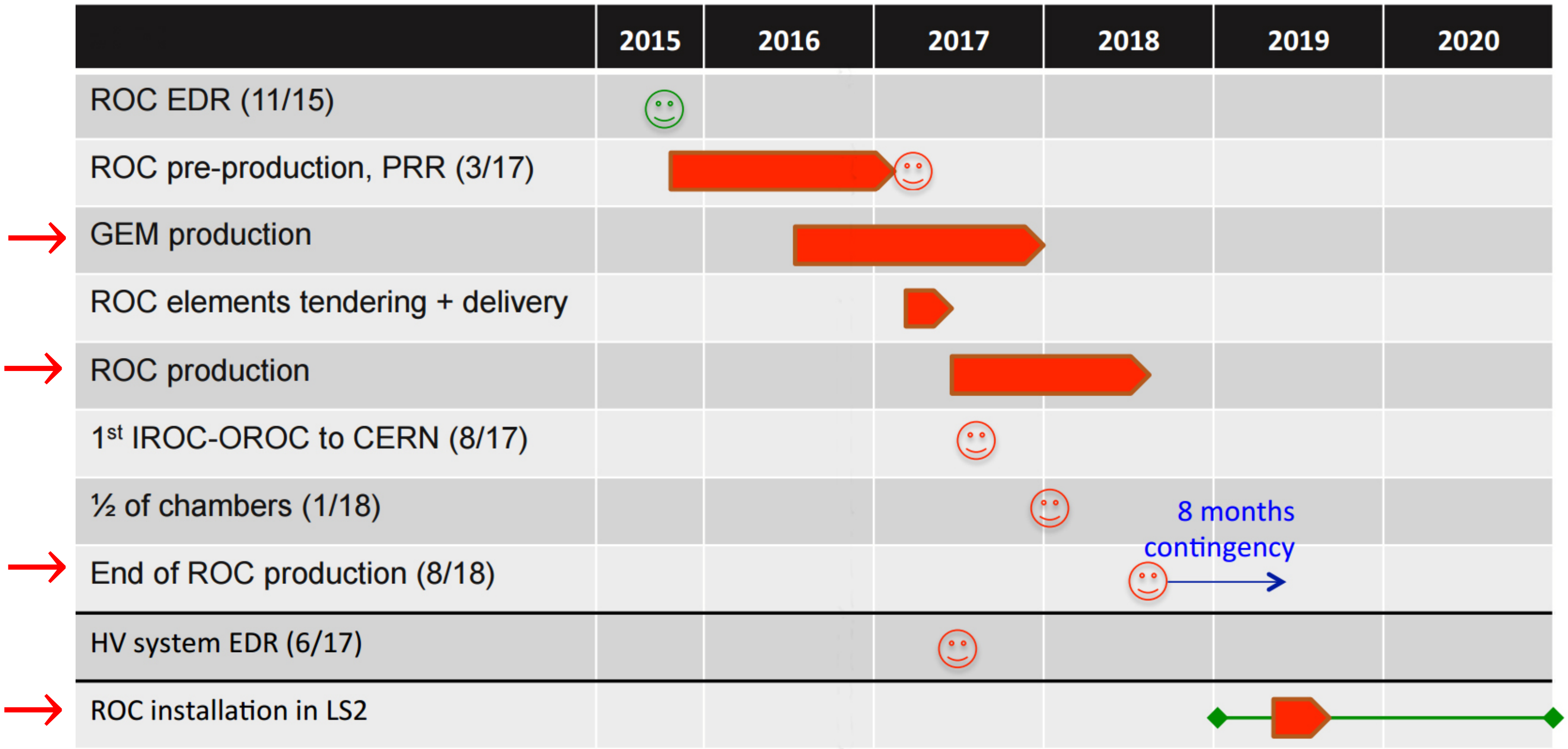


Scans from early prototypes used to tune procedure **Software Tools already in use** to deal with the distortions from this level of IBF*

Local IBF variation can be tolerated if the* ***pattern is stable in time**. Initial tests indicate that it is.*

Status and Schedule

- Two full prototype IROC and OROC chambers built using nearly final design and tested
- Changes made to design and to procedures
- Final-design parts ordered for 5 IROC and 5 OROC chambers
- Gain more experience before starting full production



New Front End Card (FEC) for TPC Upgrade readout - 5 x 10^5 Channels

Uses five ALICE custom-designed 32 channel ASICs (SAMPA) providing preamp/shaper/ADC and digital signal processing

- 3276 FECs will be installed, each with 160 channels using radiation tolerant components (rad tolerant to 5.6 kRad integrated dose)
- System continuously digitizes signals at 5 MHz* for 0.5 M TPC channels.
- FECs send digitized data over fiber optic links to ALICE Common Readout Units (CRU)

*Detailed simulations show that the TPC sampling rate can be lowered from the present 10 MHz to 5 MHz without compromising the physics performance.

>> Onboard front end zero suppression *not required*

Baseline correction and zero suppression can be done in a computer – much easier to program and change if needed.

SAMPA – Custom ASIC for TPC and Muon Tracking Chambers

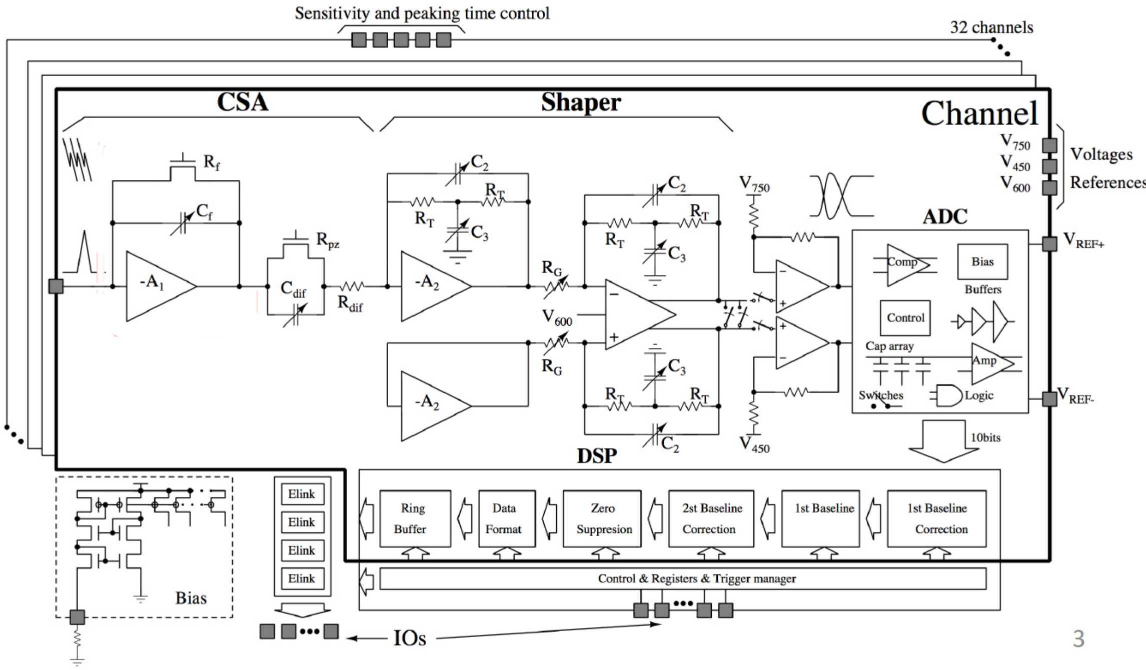
SAMPA = 32 channel chip – mixed analog and digital – also used for muon tracker upgrade

Development plan allows 3 cycles

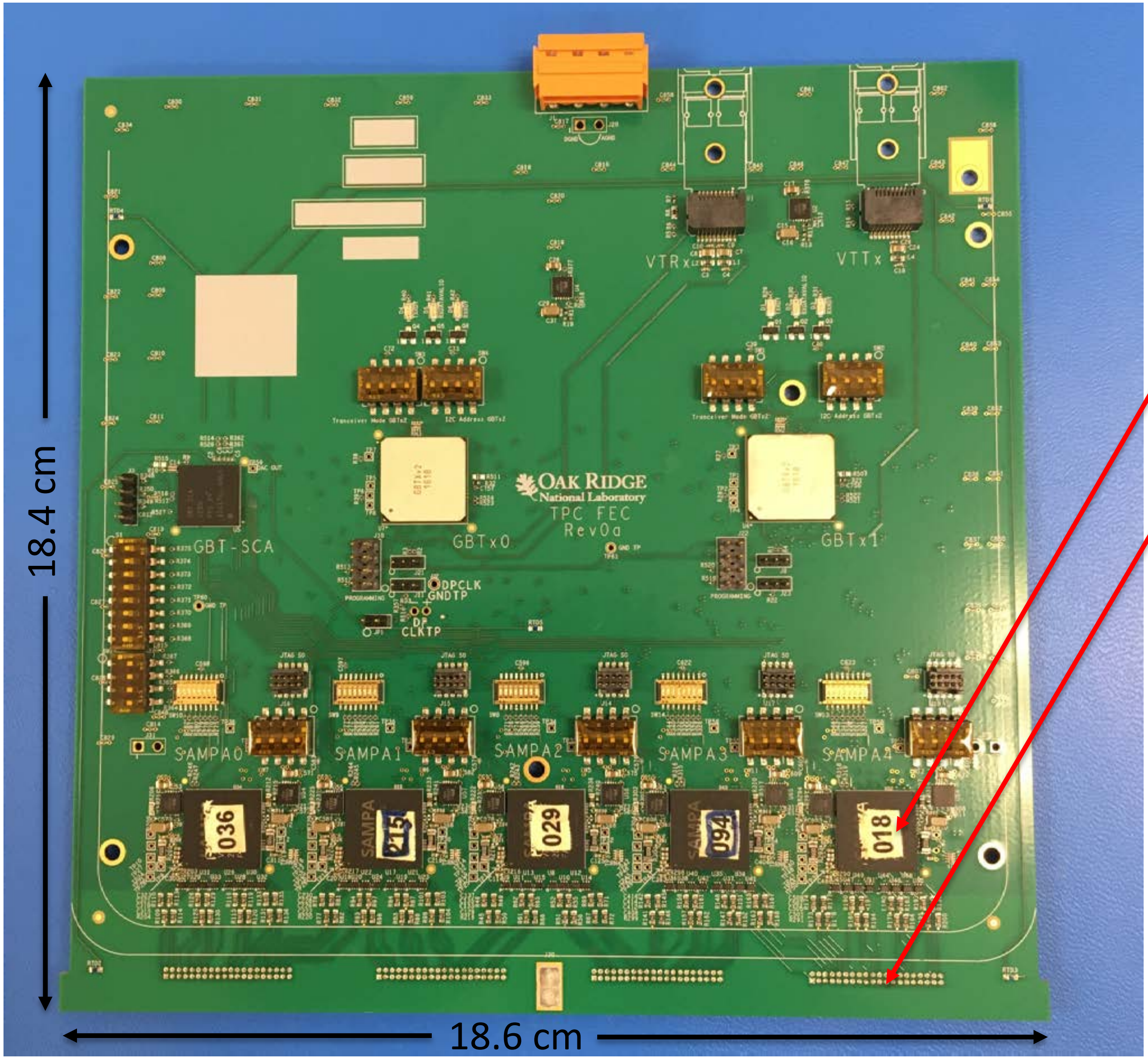
- Cycle 1 – functionality divided into 3 chips, lots of test features included
- Cycle 2 – all functions integrated into one chip
  - Delivered and tested. Noise performance looks very good - average 360 electrons on the bench
  - Some glitches in digital part found but workarounds have allowed functional front end cards (FEC) to be built
  - Test
- Cycle 3 – all fixes incorporated
- Submit this Spring
- Expect chips in Summer

Work already ongoing for final FEC design

- Test fully instrumented chamber



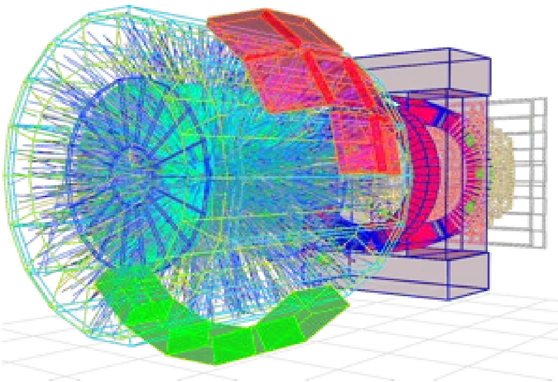
TPC Front End Card Prototype (Rev. 0a)



5 cycle 2 SAMPA chips

4 connectors for flat jumpers to connectors on pad plane

Note: Final FEC will be rigid-flex with a flex layer extending here to plug directly into pad plane connectors – no jumper cables needed



Data Compression

All this data pouring out of the front end has to be further compressed, monitored, used to feed calibrations back into compression, …

50 kHz

Reconstruction
Compression
Monitoring
Calibration

Storage

75 GB/s

3.2 TByte/s into PC farm

O^2 (Online Offline) System

Hardware and software developments ongoing

← PEAK OUTPUT
(20 GB/s average)

Summary

The ALICE collaboration is building a major upgrade for the ALICE TPC to be installed in the LHC Long Shutdown 2 (2019-2020)

This upgrade will allow operation in the high luminosity in LHC runs 3 and 4 (50 kHz Pb-Pb collision rate) while maintaining the current physics performance of the TPC.

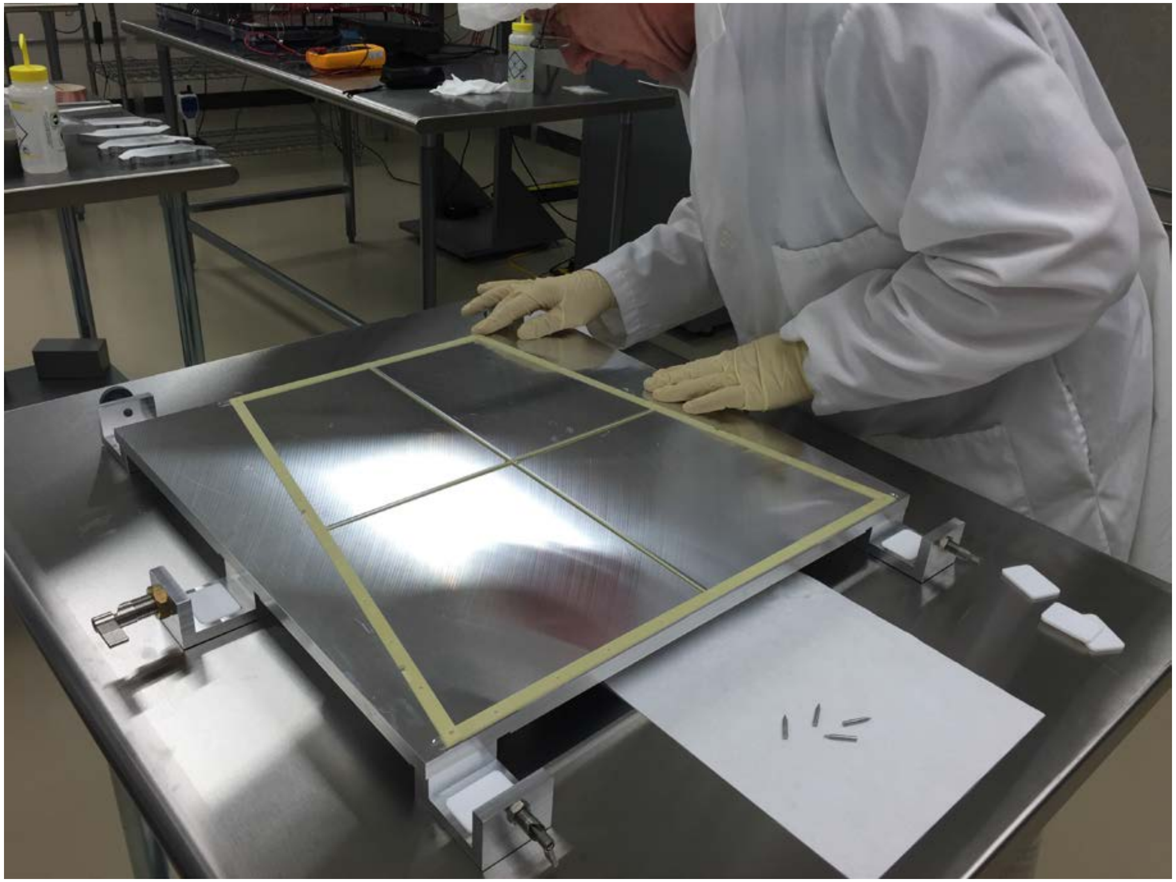
The upgrade involves:

- Replacing all readout wire chambers with quadruple-GEM chambers.
- The GEMs are designed to minimize ion back flow to allow continuous, ungated and untriggered readout.
- Replacing the front end electronics with electronics based on a new ASIC (SAMPA) designed to allow continuous readout
- Developing software to achieve compression of the 3.2 TB/sec raw data from the TPC

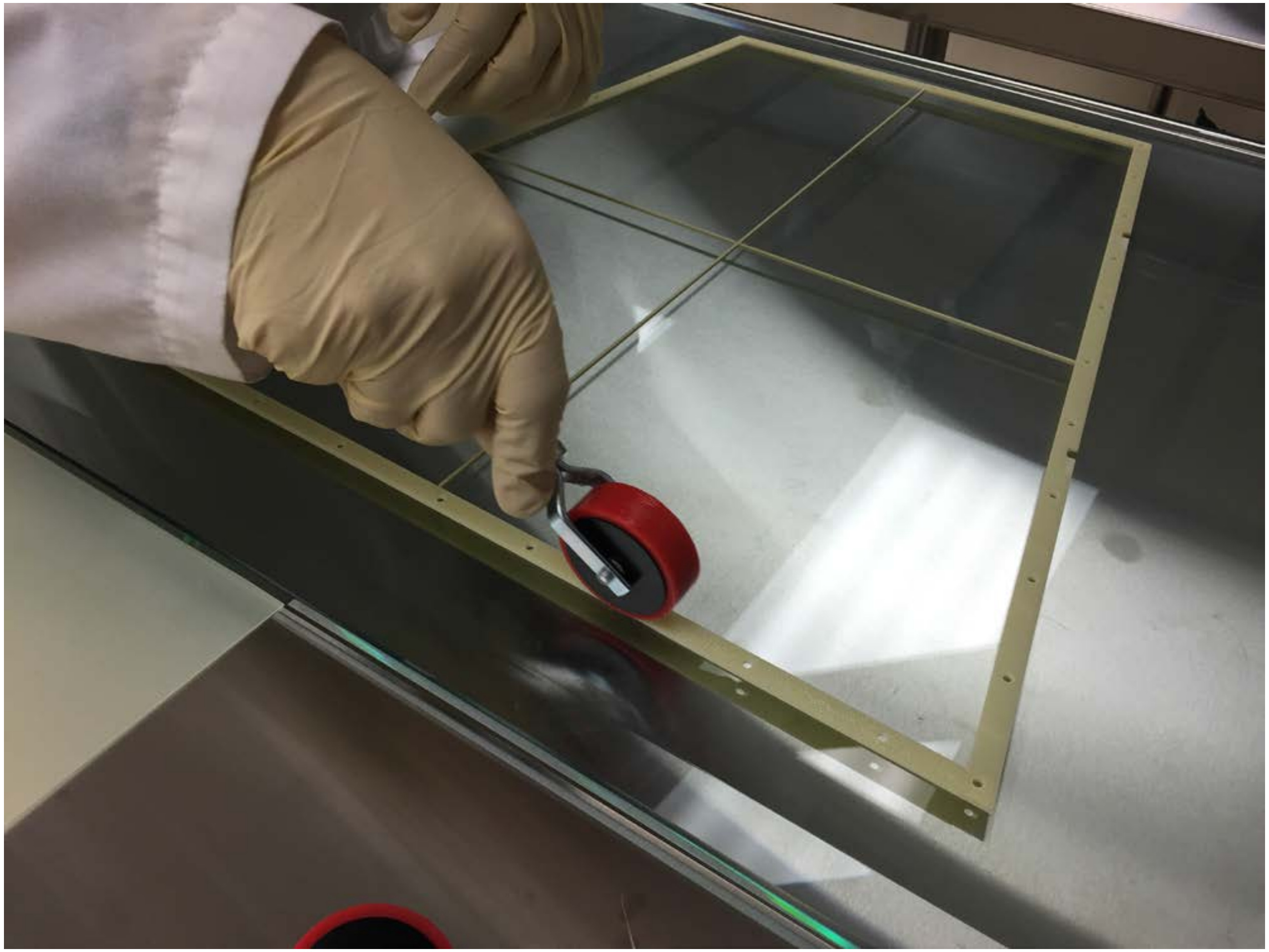
This upgrade will allow ALICE to record the full Pb-Pb luminosity and gather very high statistics data sets even for processes where a trigger is not possible.

Backup Slides

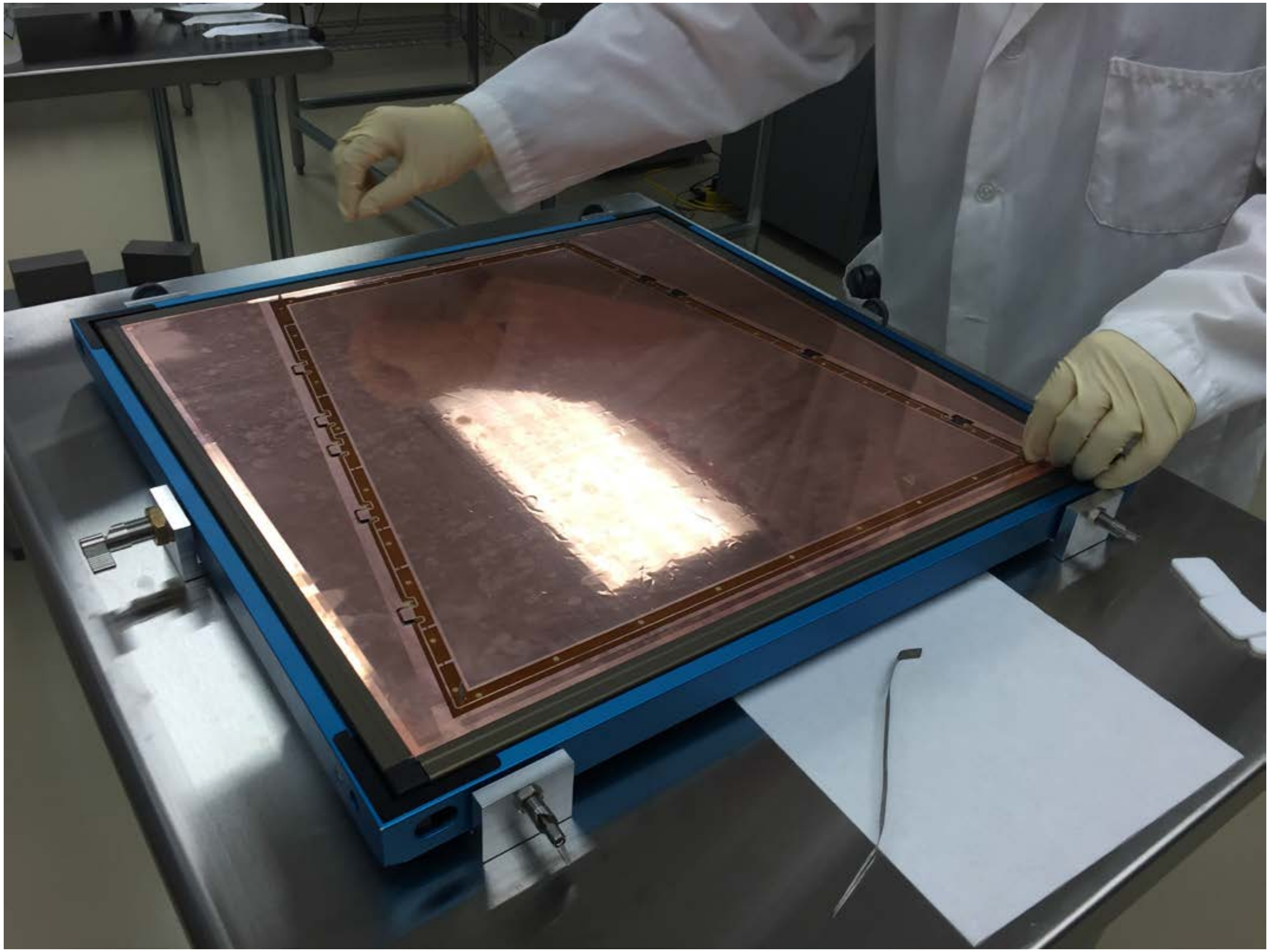
Frame in gluing fixture



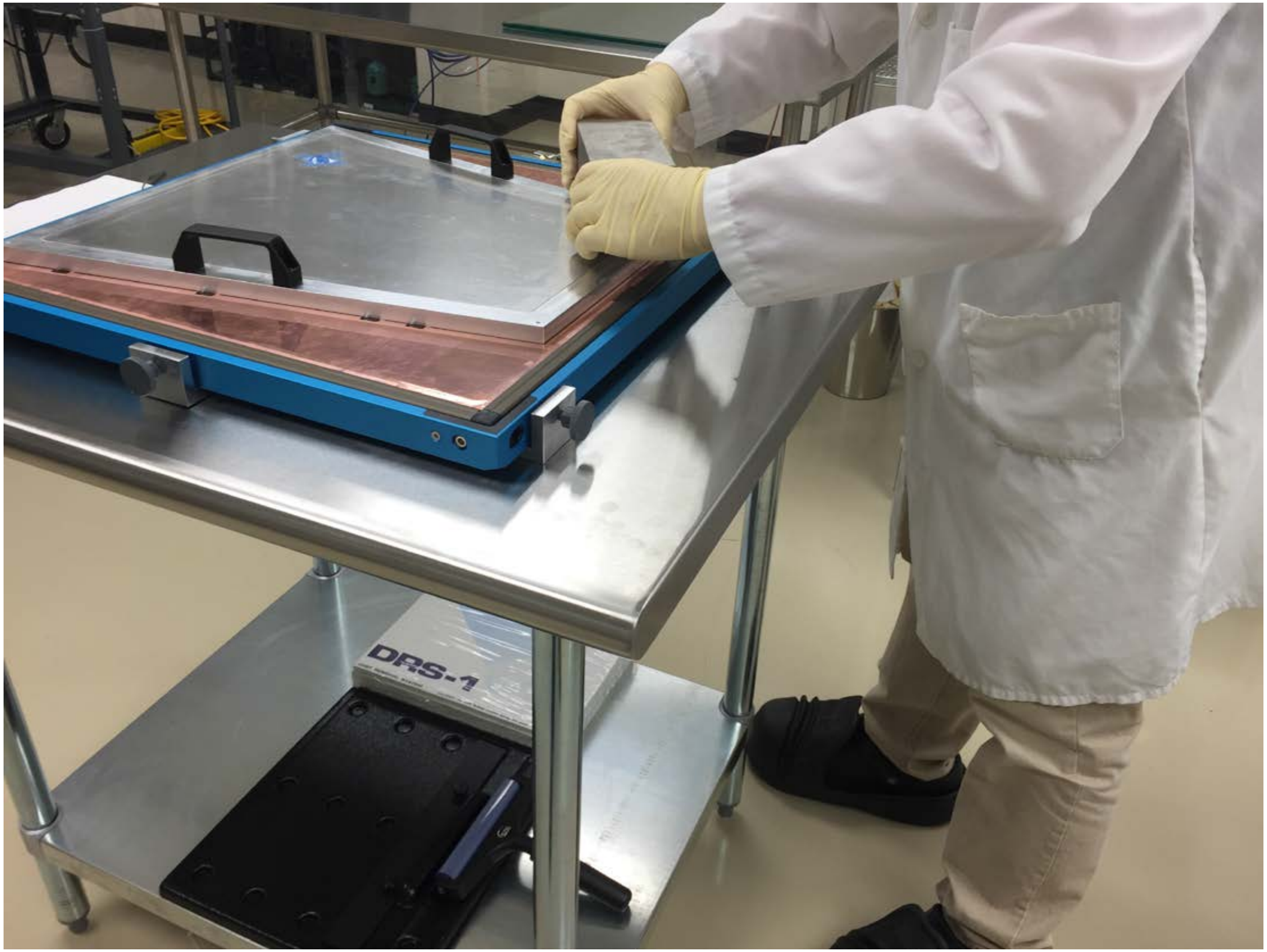
Using roller to apply epoxy



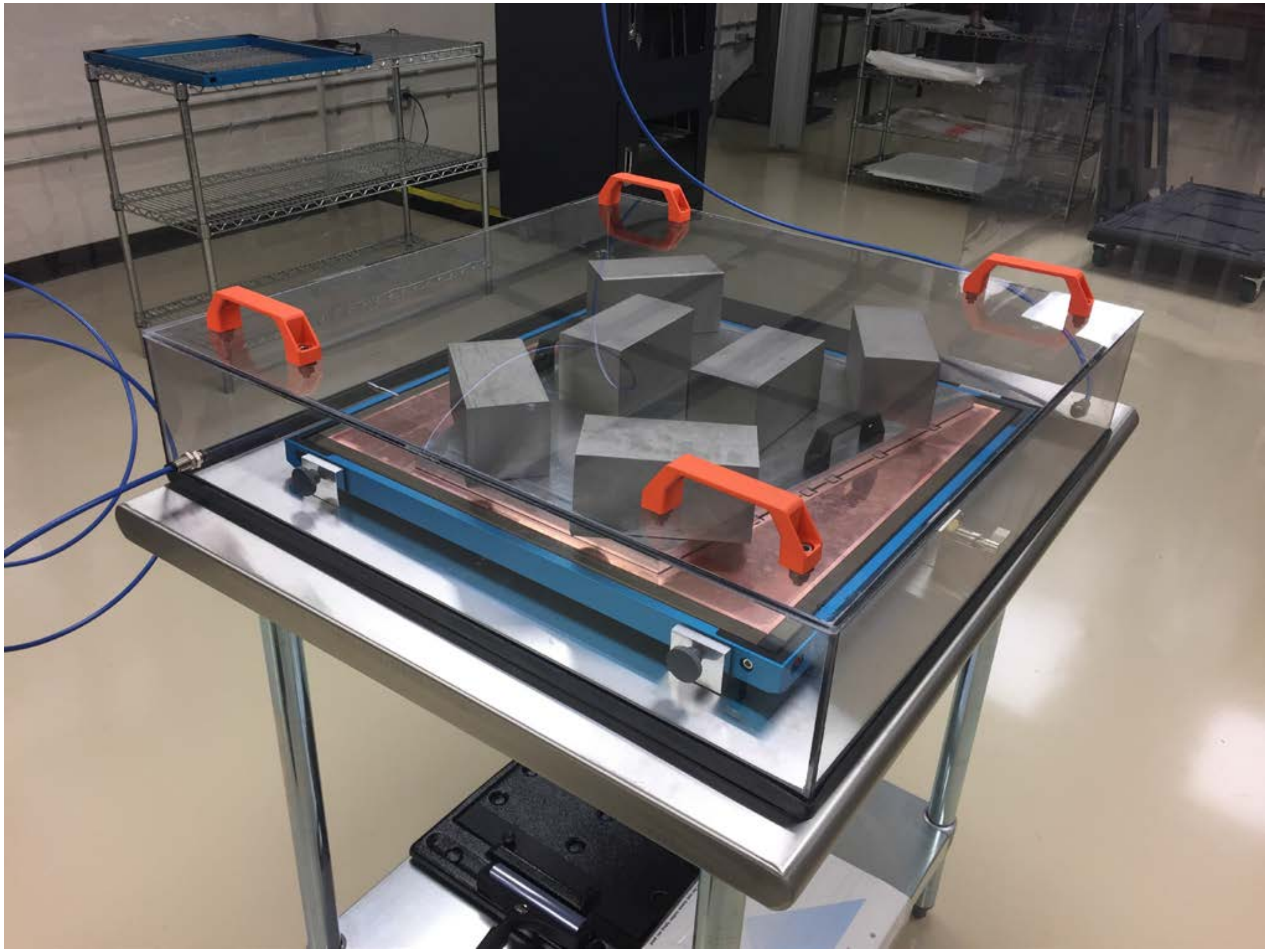
Foil in gluing fixture



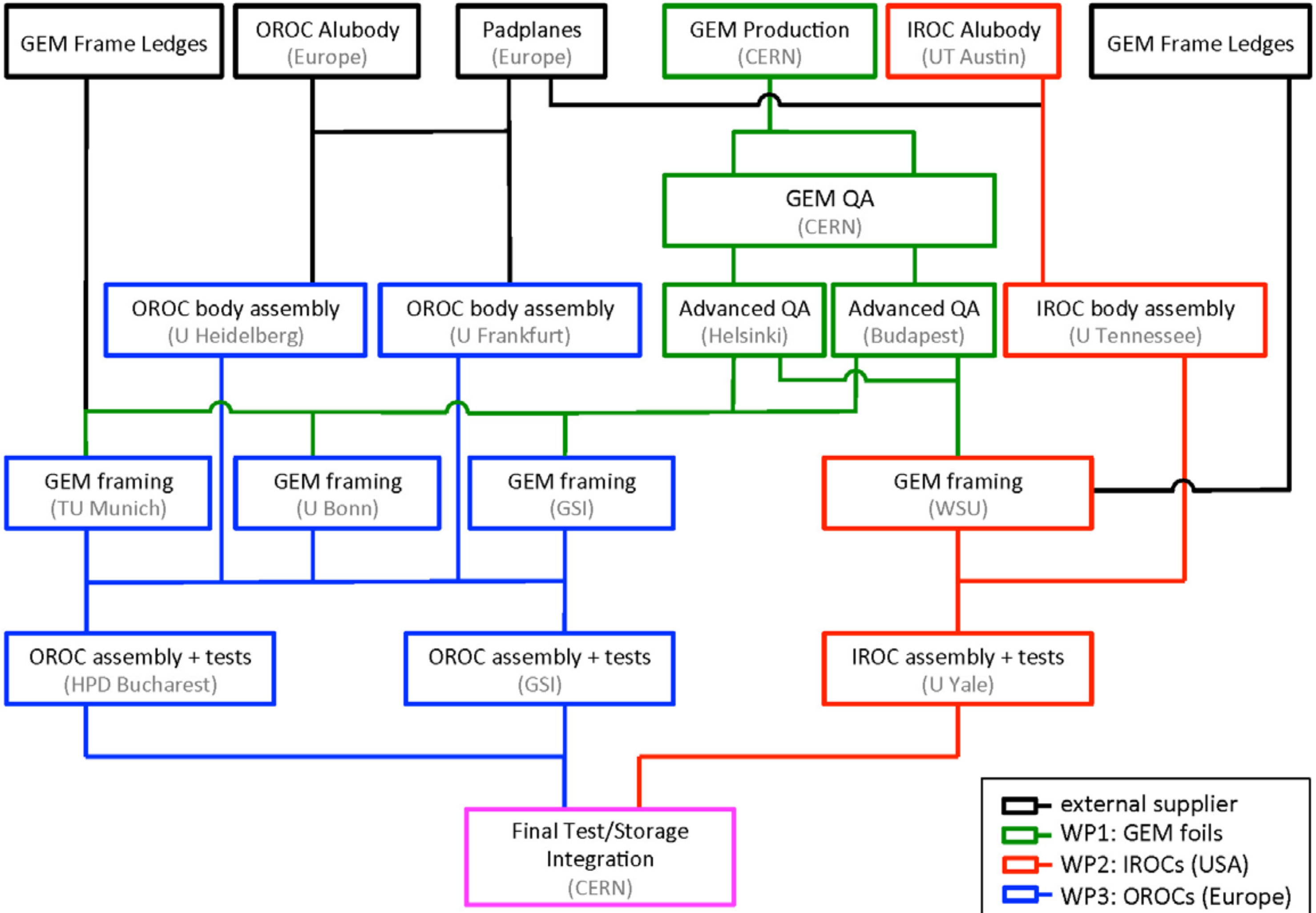
Pressure plate and SS bricks



Curing in dry atmosphere



Division of effort and material flow for ROC construction and testing.

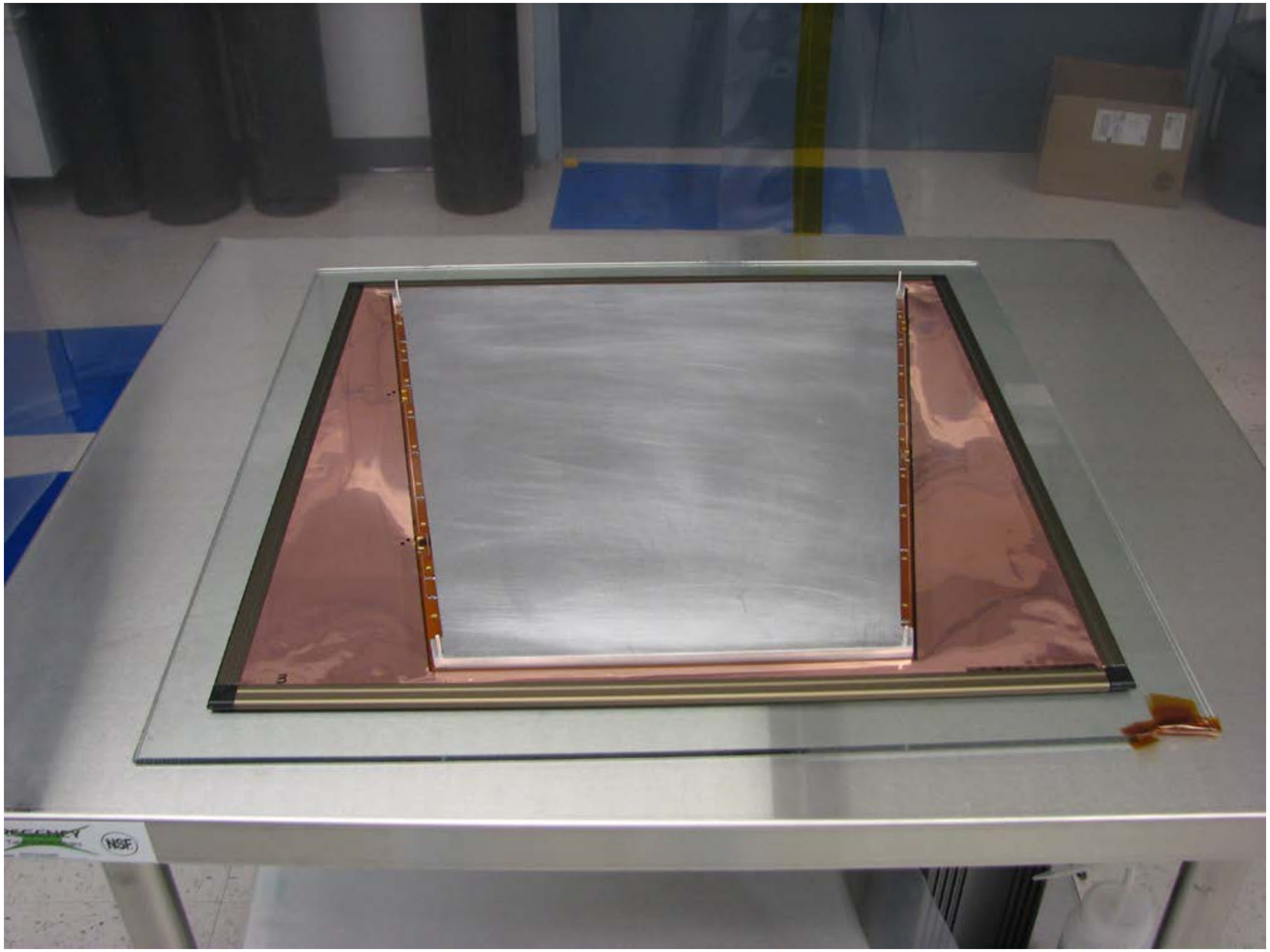


Managing material flow is not a small part of the project.
Database is in place and being used to track material location, status and archive QA+test data.

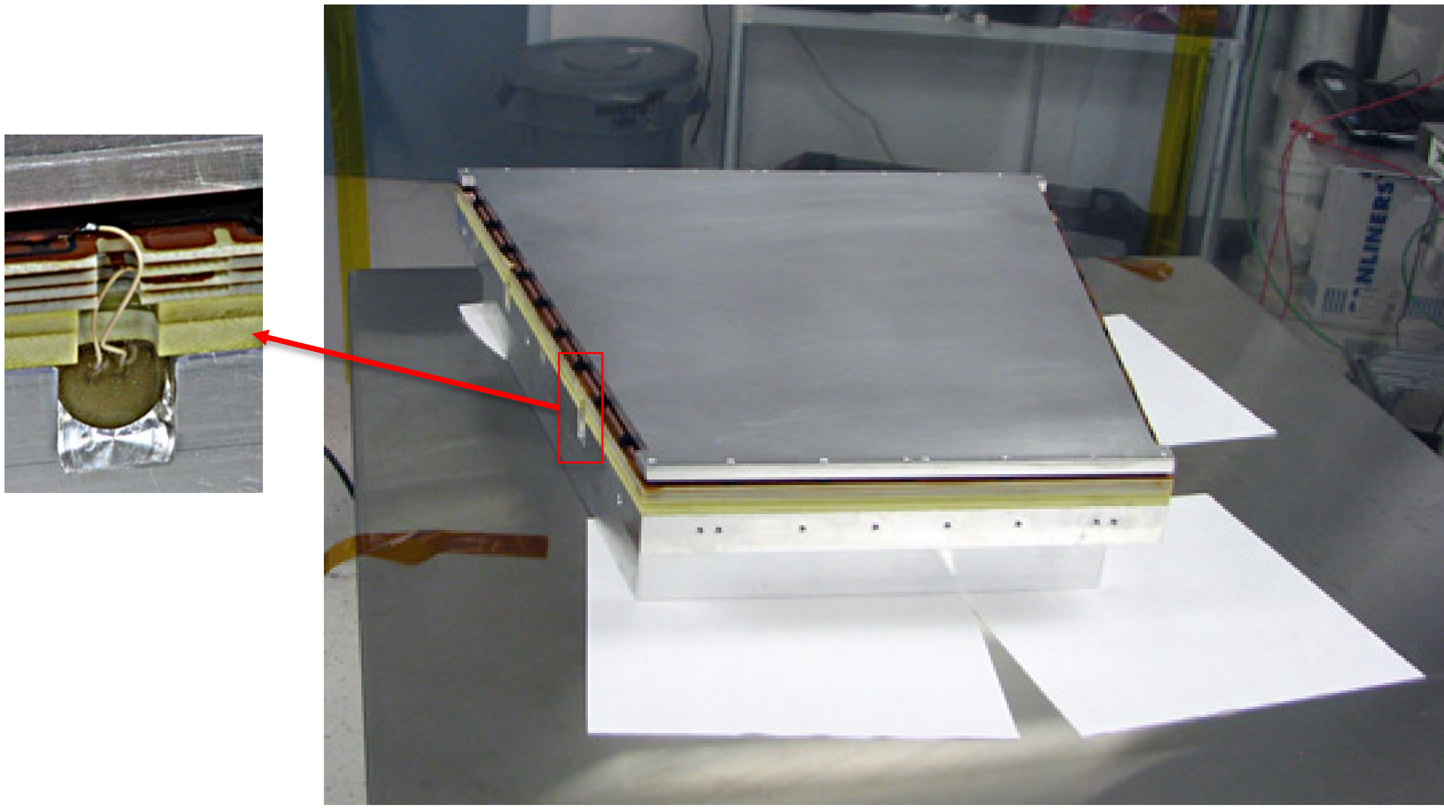
Foil trimming plate

Glass plate with hole matching alignment hole in corner of GEM foil and frame.

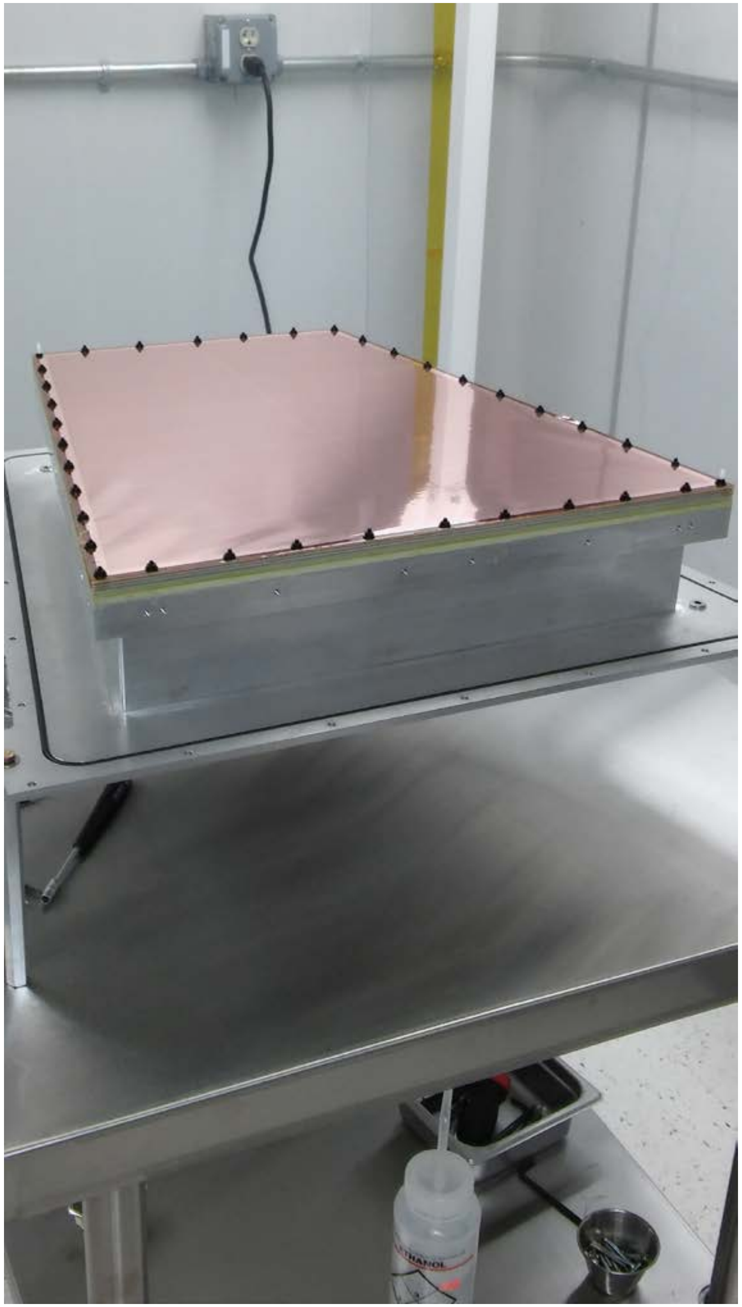
Dowel pins keep foil, frame and protective aluminum cover in place during trimming



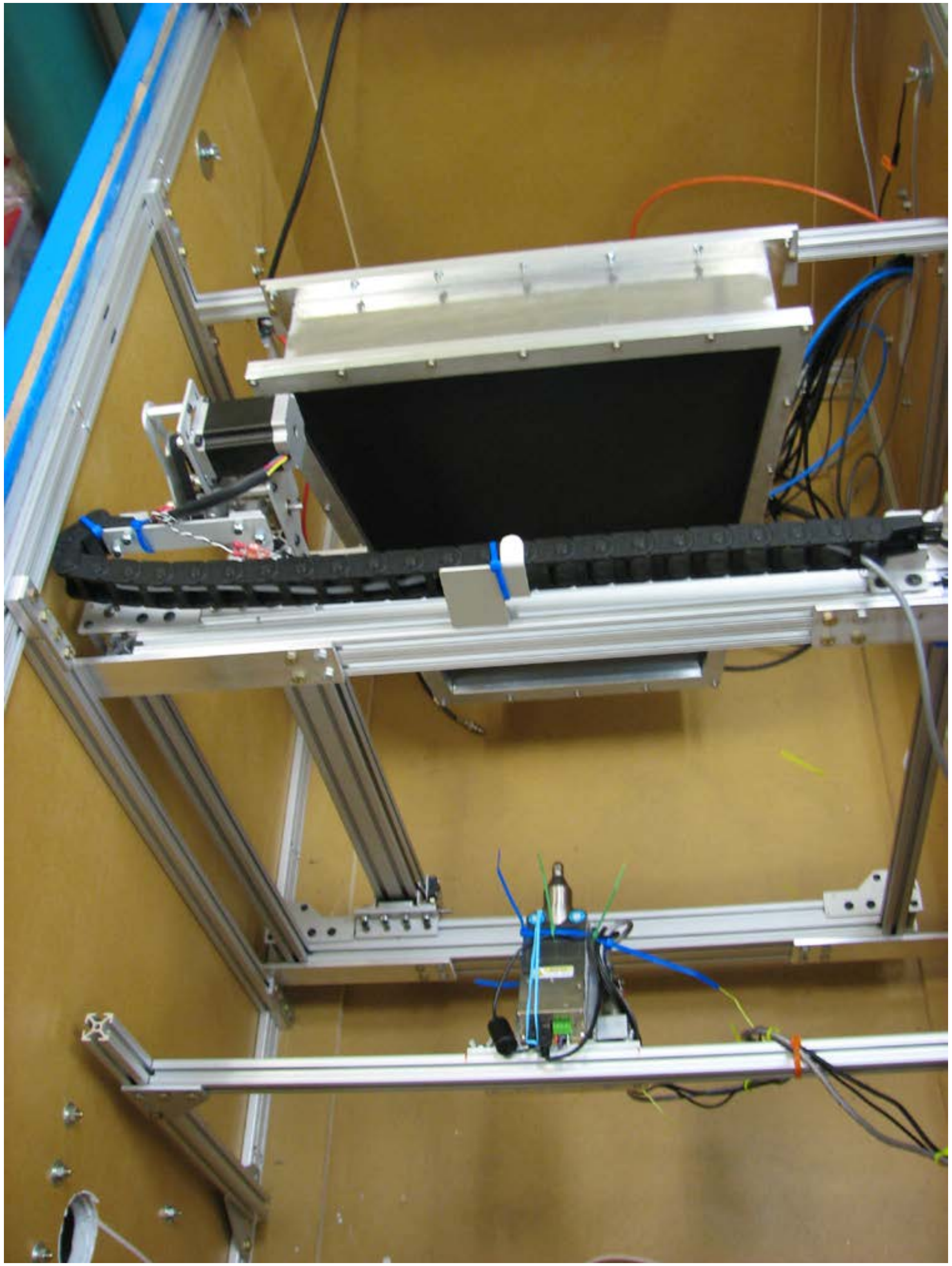
For assembly work, soldering HV leads to GEM's or when not necessary to have GEM exposed it is always kept covered.



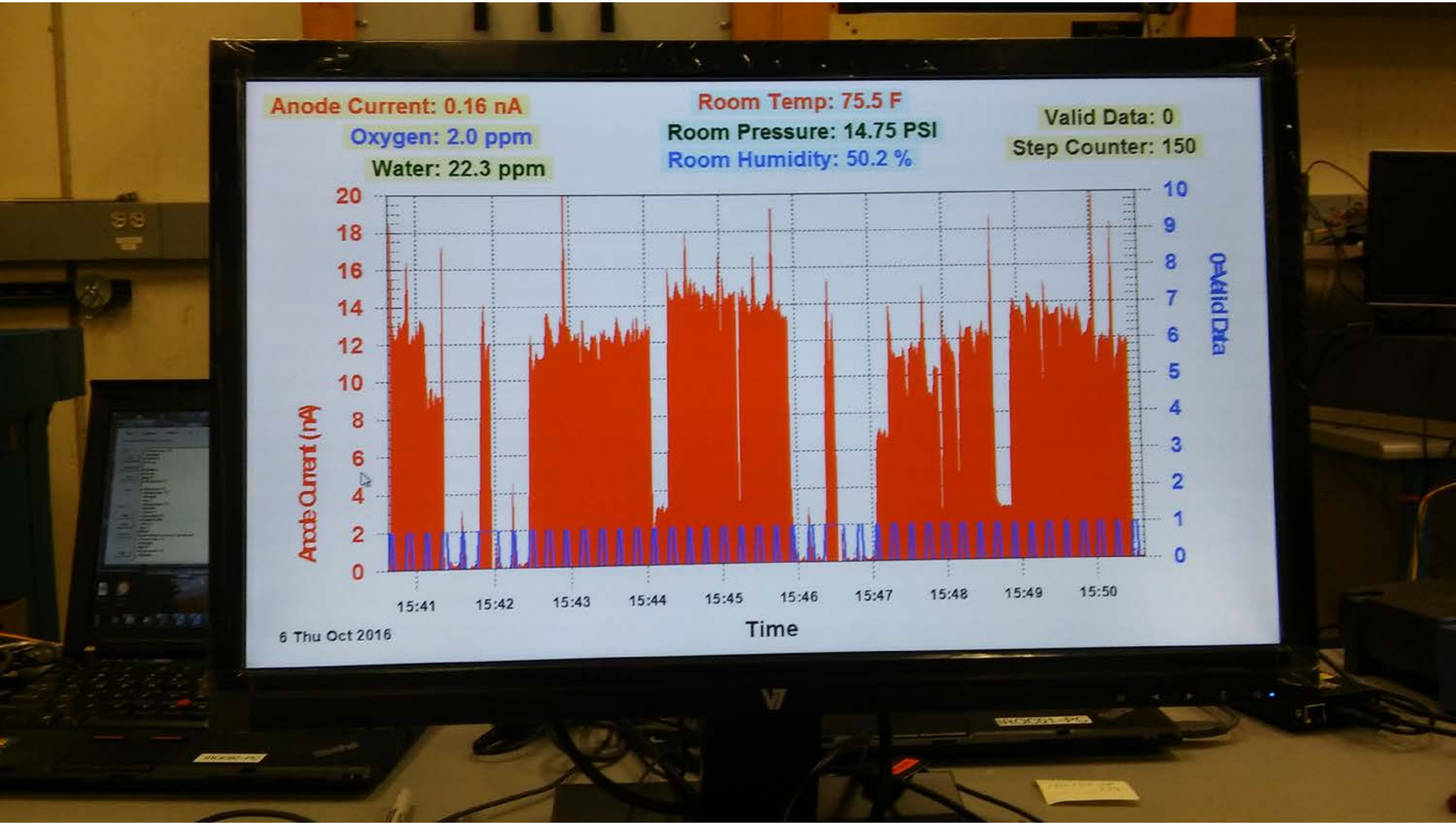
IROC foils assembled on pad plane, alubody, test vessel base plate.
Ready for test vessel cover.



X-ray generator mounted to illuminate full chamber



Typical live display while scanning chamber gain *vs* position



FEC Block diagram