A continuous-readout TPC for the ALICE upgrade

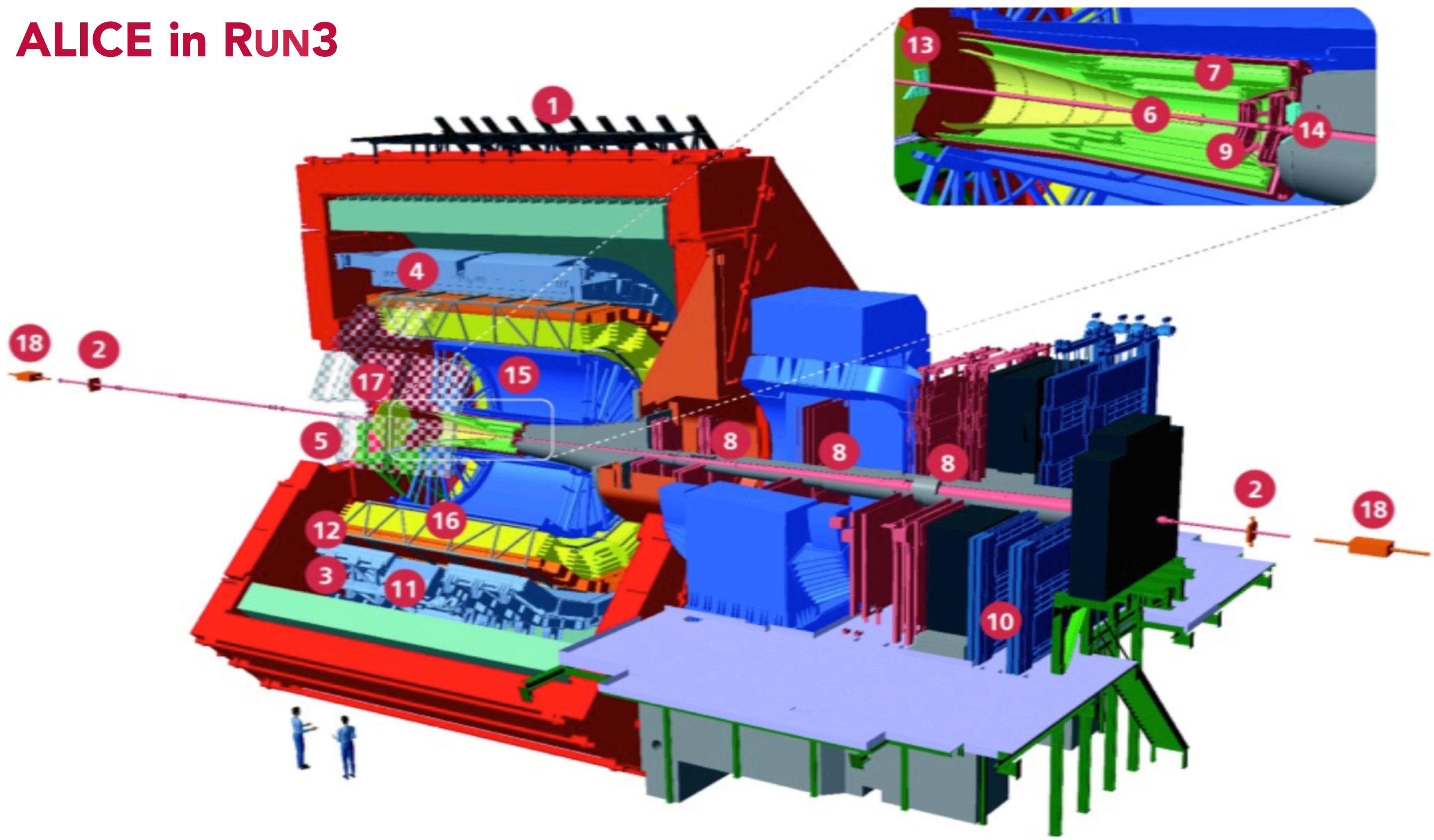
8th Jul 2017

Christian Lippmann
on behalf of the ALICE collaboration

ALICE experiment (1)

- The dedicated heavy-ion experiment at CERN LHC

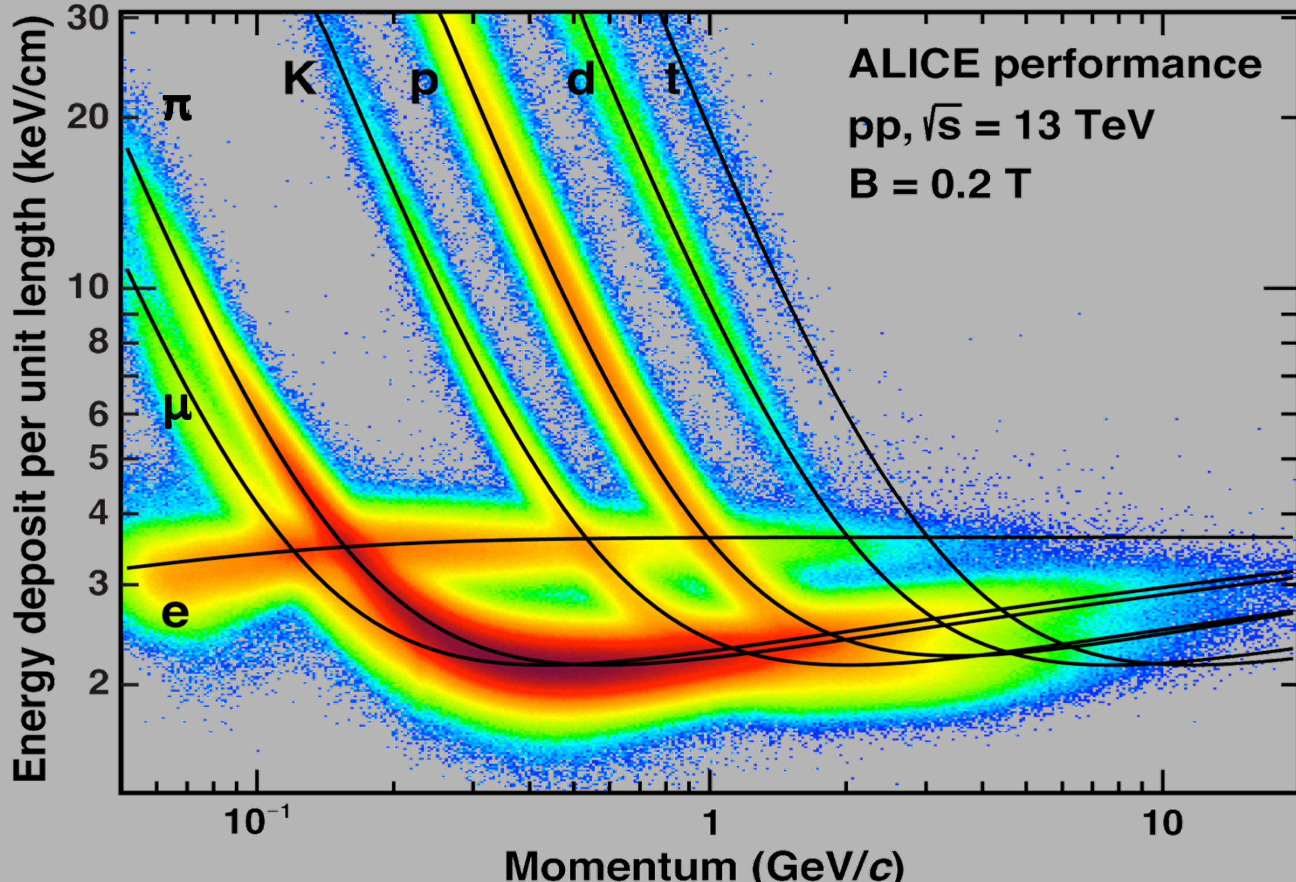
ALICE in RUN3



1. **ACORDE** | ALICE Cosmic Rays Detector
2. **AD** | ALICE Diffractive Detector
3. **DCal** | Di-jet Calorimeter
4. **EMCal** | Electromagnetic Calorimeter
5. **HMPID** | High Momentum Particle Identification Detector
6. **ITS-IB** | Inner Tracking System - Inner Barrel
7. **ITS-OB** | Inner Tracking System - Outer Barrel
8. **MCH** | Muon Tracking Chambers
9. **MFT** | Muon Forward Tracker
10. **MID** | Muon Identifier
11. **PHOS / CPV** | Photon Spectrometer
12. **TOF** | Time Of Flight
13. **T0+A** | Tzero + A
14. **T0+C** | Tzero + C
15. **TPC** | Time Projection Chamber
16. **TRD** | Transition Radiation Detector
17. **V0+** | Vzero + Detector
18. **ZDC** | Zero Degree Calorimeter

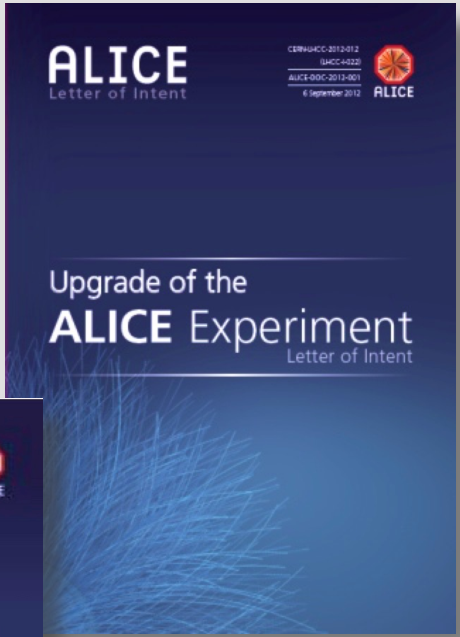
ALICE experiment (2)

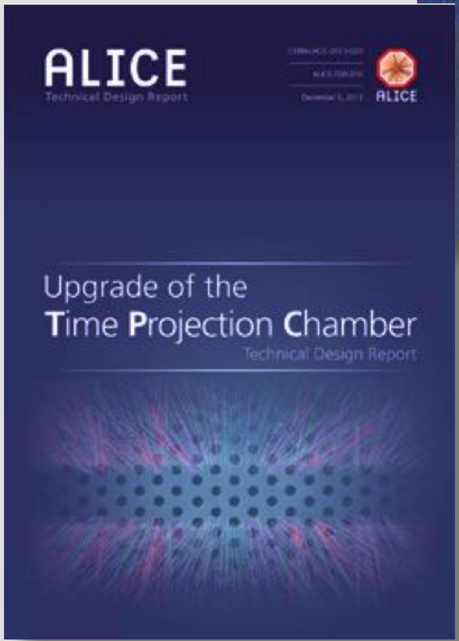
- Excellent performance in RUN1 (2009 - 2013) and RUN2 (2015-now)
- Time Projection Chamber (TPC) is main device for **tracking** and **PID** in central barrel



ALICE upgrade strategy (1)

- **Motivation:** Focus on high-precision measurements of rare probes at low p_T
  - Low signal-to-background ratio prevents selection with hardware trigger
  - Need to record large sample of events
- **Strategy:** Read out all Pb–Pb interactions at maximum interaction rate of 50 kHz
  - Factor 50 improvement with respect to now
- **When:** 2nd LHC Long Shutdown (LS2): 2019 & 2020





ALICE Upgrade Letter Of Intent:
https://cds.cern.ch/record/1475243

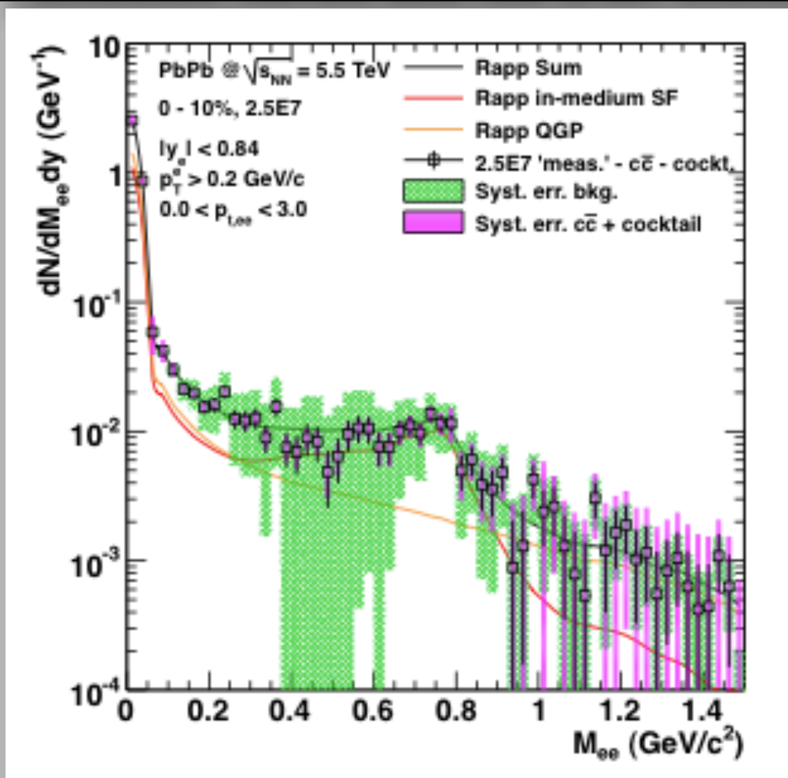
ALICE TPC Upgrade Technical Design Report (TDR):
https://cds.cern.ch/record/1622286

Addendum to the TDR:
https://cds.cern.ch/record/1984329

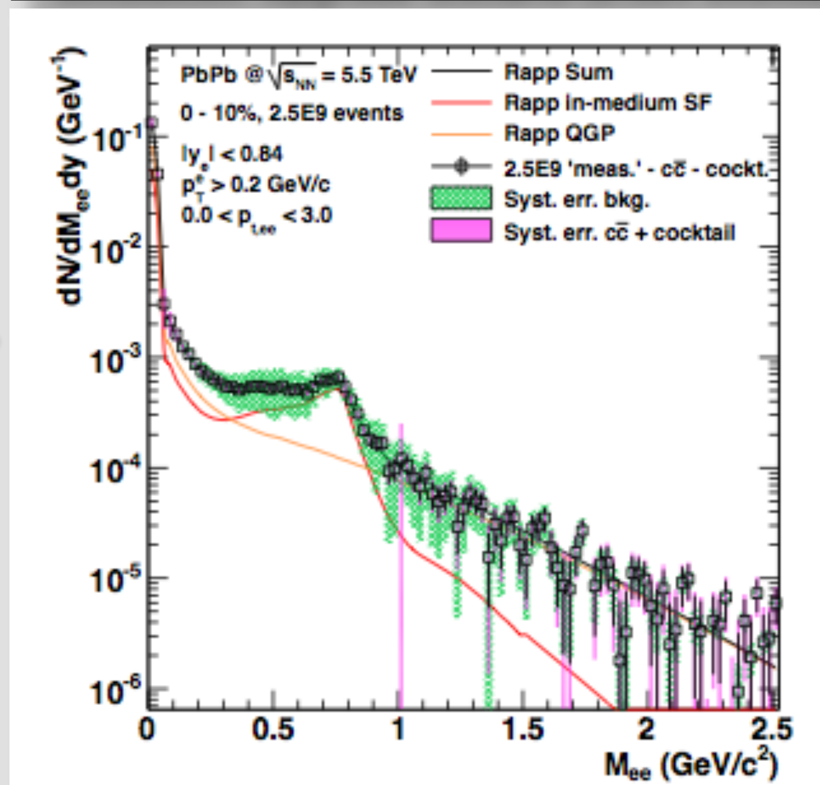
ALICE upgrade strategy (2)

- High-rate capability ➔ Increased statistics
- **Example**: Low-mass di-leptons after background subtraction

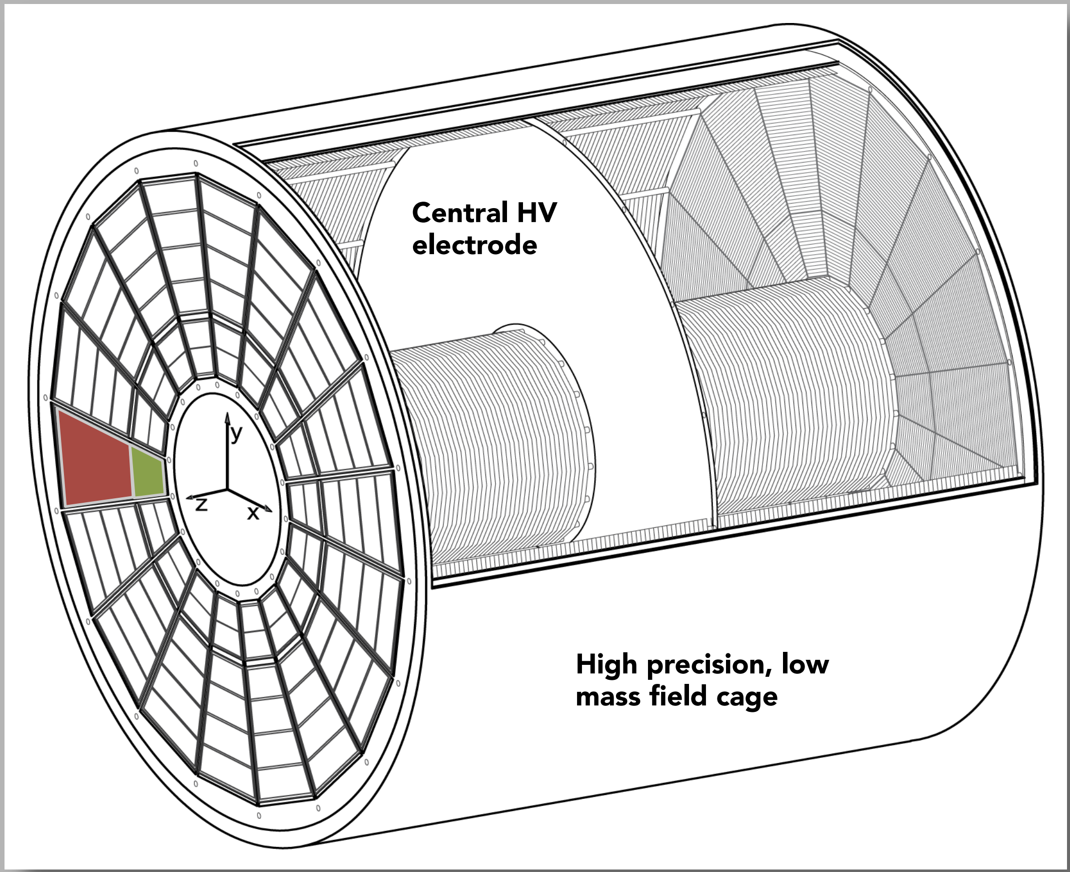
Simulation: Current data rate (2.5e7 events)



Simulation: Upgrade scenario (2.5e9 events)



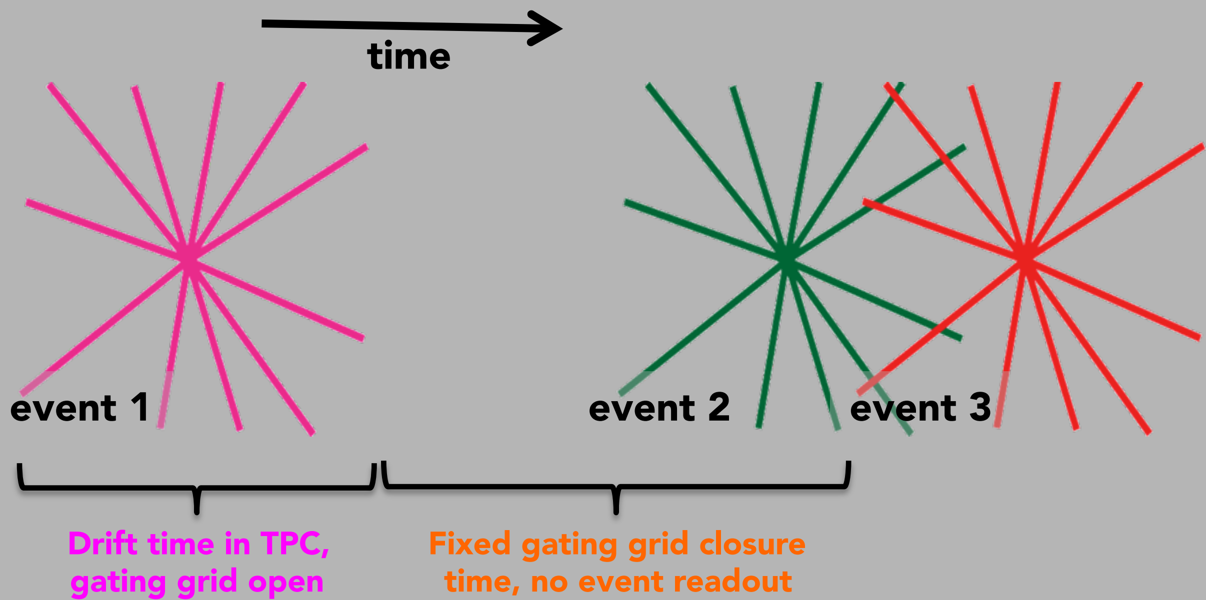
ALICE TPC overview



- Diameter: 5 m, length: 5 m
- Gas: Ne–CO_2–N_2, Ar–CO_2 in 2015 and 2016
- Max. drift time: ~100 μs
- 18 sectors on each side
- Inner and outer read out chambers: IROC, OROC

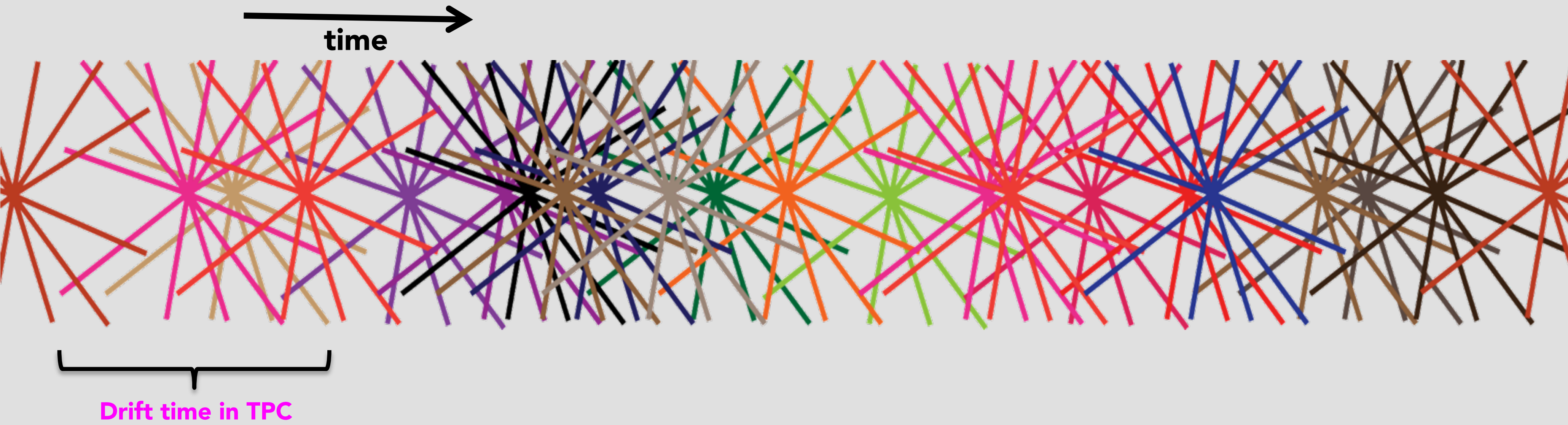
- Current detector (RUN 1, RUN2):
  - 72 MWPCs
  - ~550 000 cathode pads
  - Wire gating grid (GG) to block Ion BackFlow (IBF)
  - Rate limitation: few kHz

RUN 1 and 2: Gated operation



- Typical trigger rate in Pb–Pb: ~500 Hz
- Triggered operation with gating grid (GG)
- Ion backflow (IBF) suppression with gating grid: 10^{-5}
- Electron drift time: 100 μs + fixed closure time of the GG: 200 μs (400 μs for Ar mixture)
  - Intrinsic limitation of the readout rate to few kHz

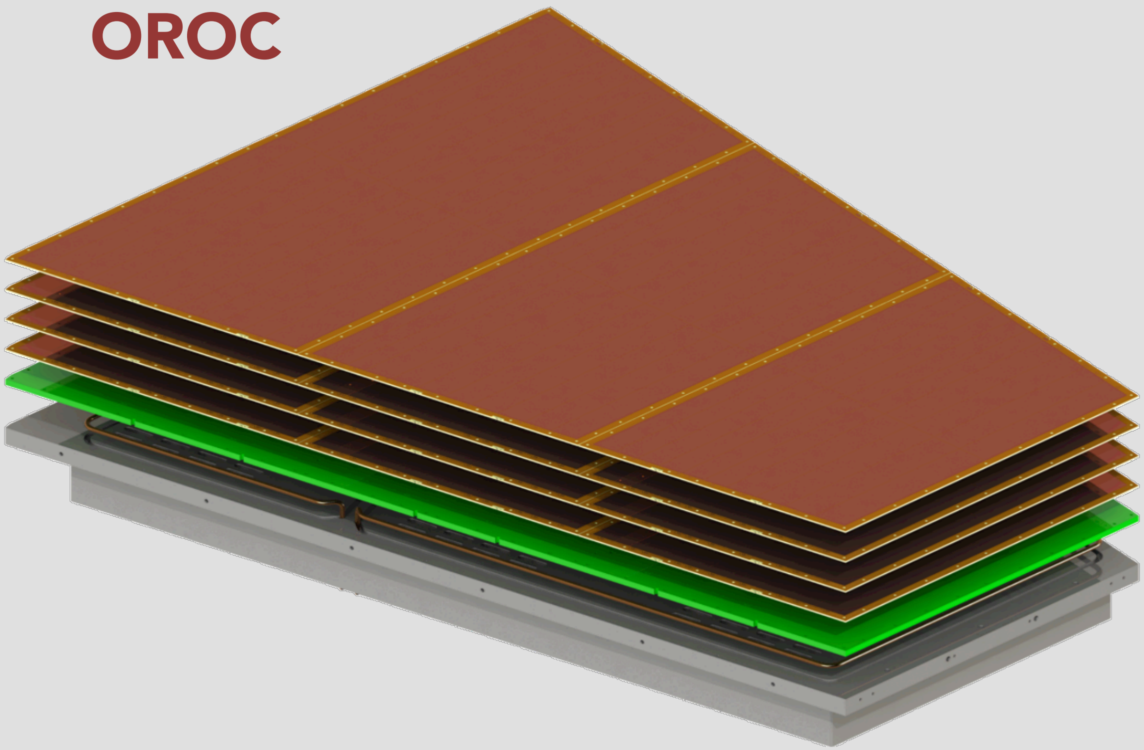
RUN3: Continuous operation

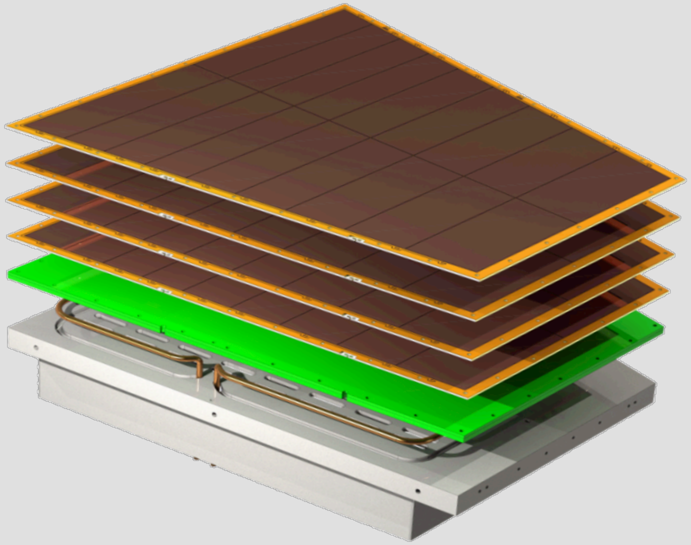


- 50 kHz Pb–Pb collisions with the goal to inspect them all!
- Average event spacing: ~20μs ➔ average pileup: 5 events
- Triggered operation does not make sense
- Minimize IBF without the use of a gating grid

➔ **Continuous read-out with GEMs (Gas Electron Multiplier)**

New Readout chambers



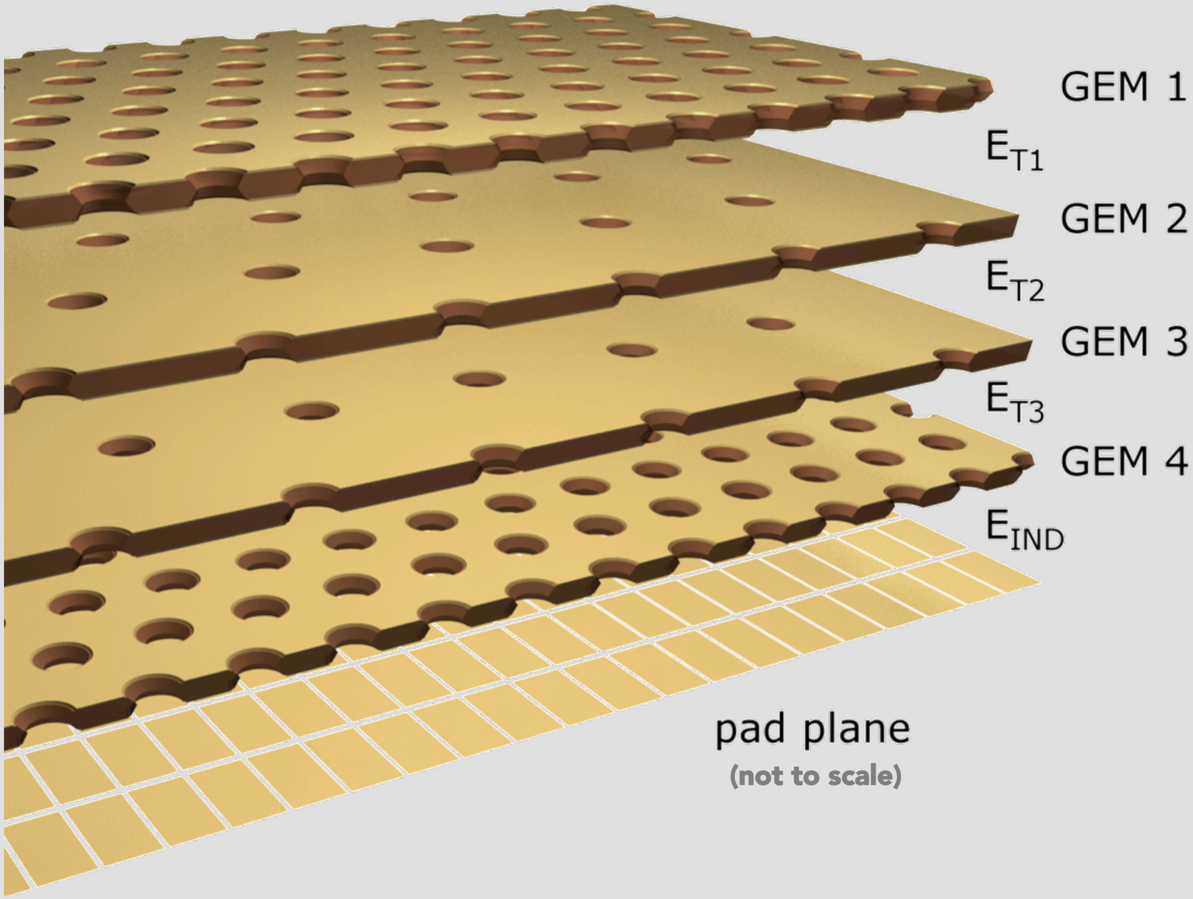


➔ **Continuous read-out with GEMs (Gas Electron Multiplier)**

GEM stack configuration (1)

Quadruple GEM stack in S-LP-LP-S configuration

- Combination of Standard (S) and Large Pitch (LP) GEM foils
- Highly optimized HV configuration
- Result of intensive R&D



GEM stack configuration (2)

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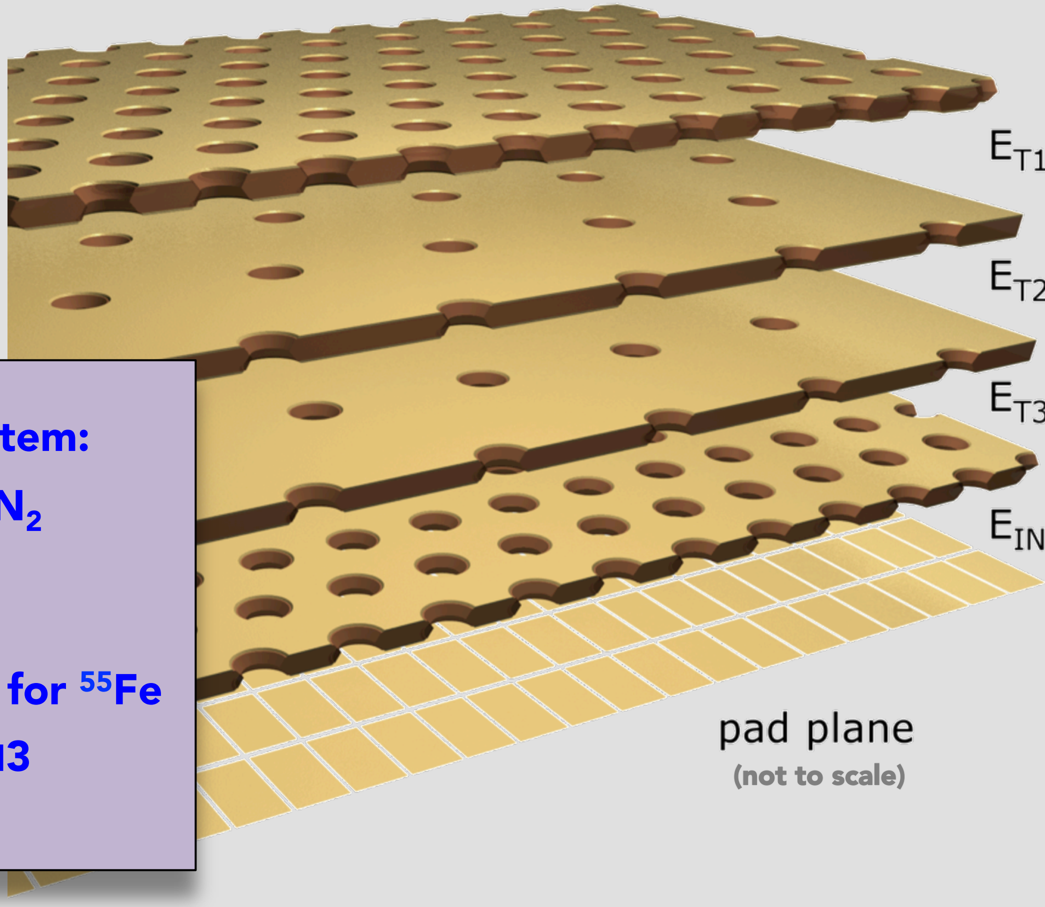
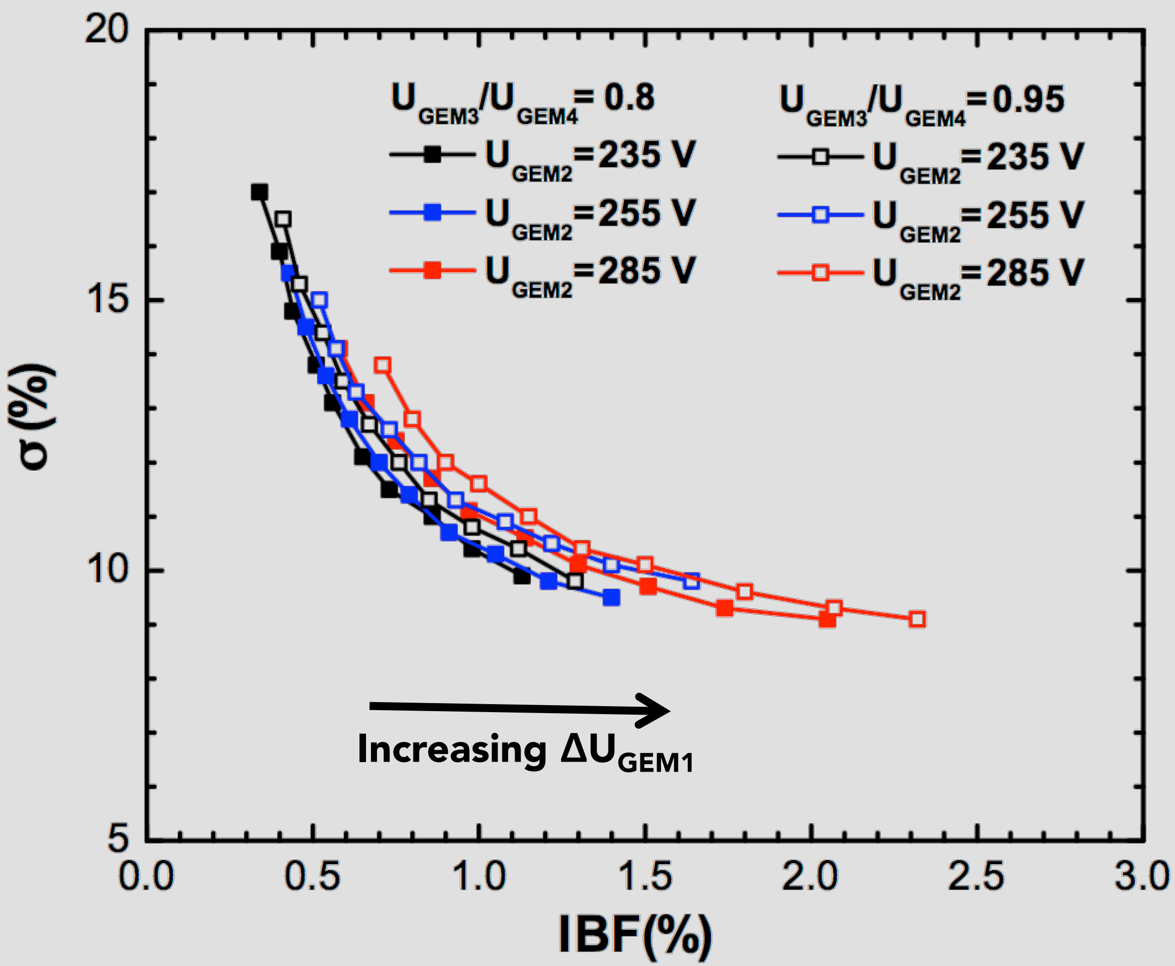


Requirements for GEM readout system:

- **Nominal gain** = 2000 in Ne-CO_2-N_2 (90-10-5)
- **IBF** < 1 % (→ ε = 20)
- **Energy resolution:** $\sigma_E / E < 12\%$ for ^{55}Fe
- **Stable operation** under LHC RUN3 conditions

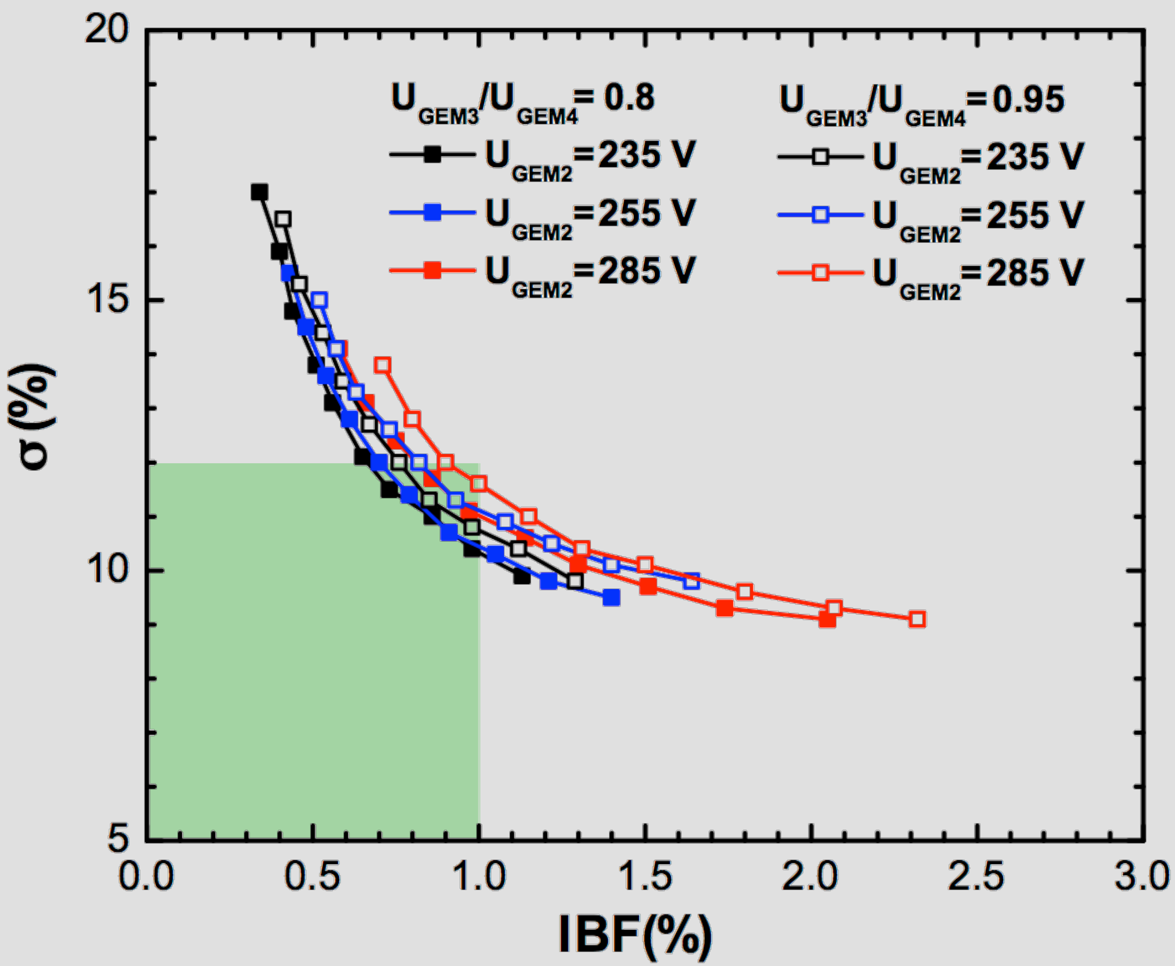
R&D highlights (1)

- **IBF and energy resolution have to be optimized in parallel**



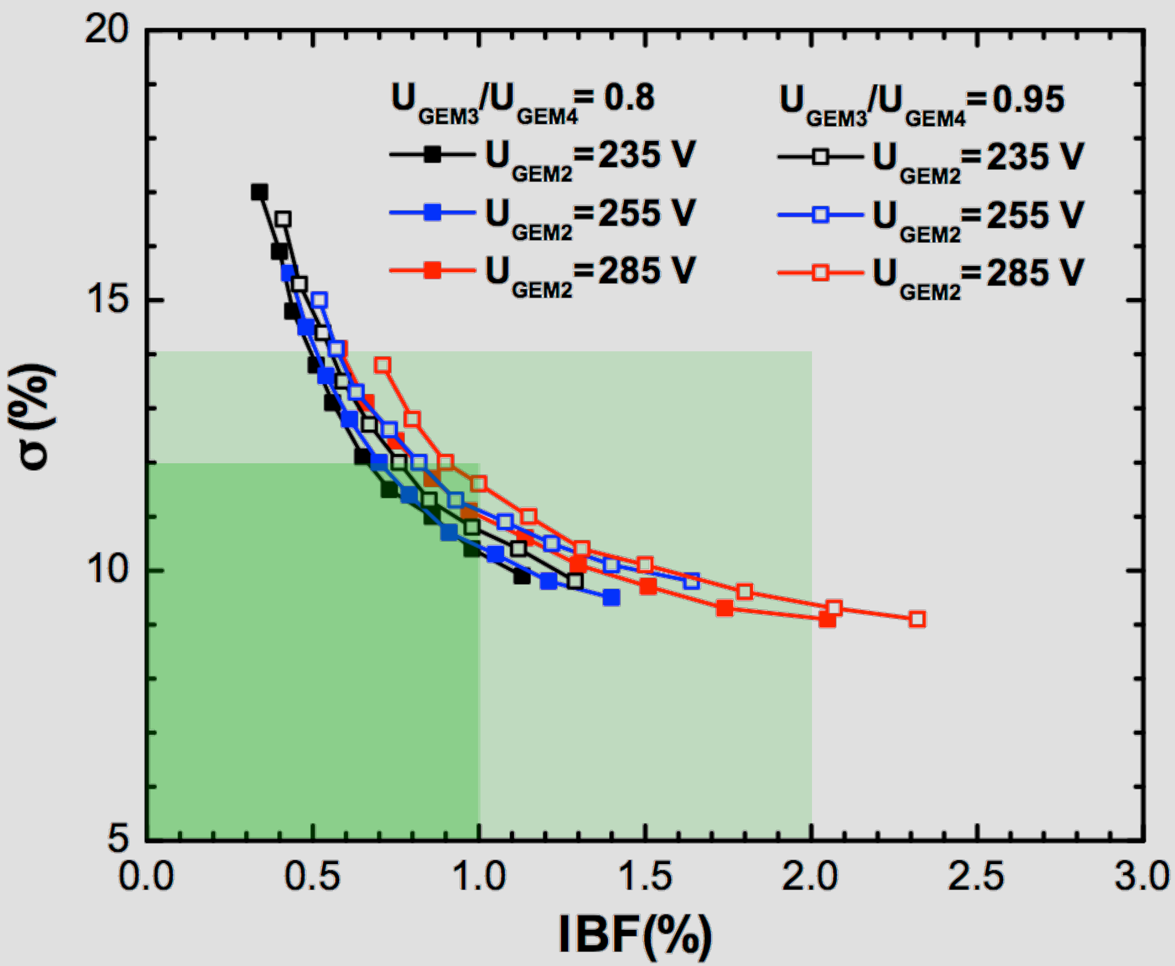
R&D highlights (2)

Conservative operational limits: IBF < 1 %, local energy resolution < 12 % for ^{55}Fe



R&D highlights (3)

Extended operational range: IBF < 2 %, energy resolution < 14 %



GEM foil QA (1)

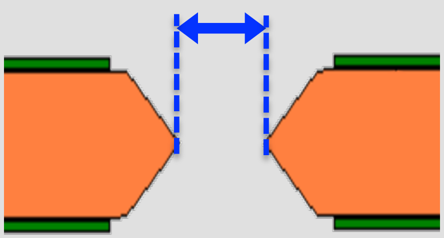
Multi-stage quality assurance (QA) using traffic light system (Bad / HV ok / Good)

1. **Basic QA at CERN**
   - Reject malfunctioning foils as early as possible
   - Fast feedback to the producer

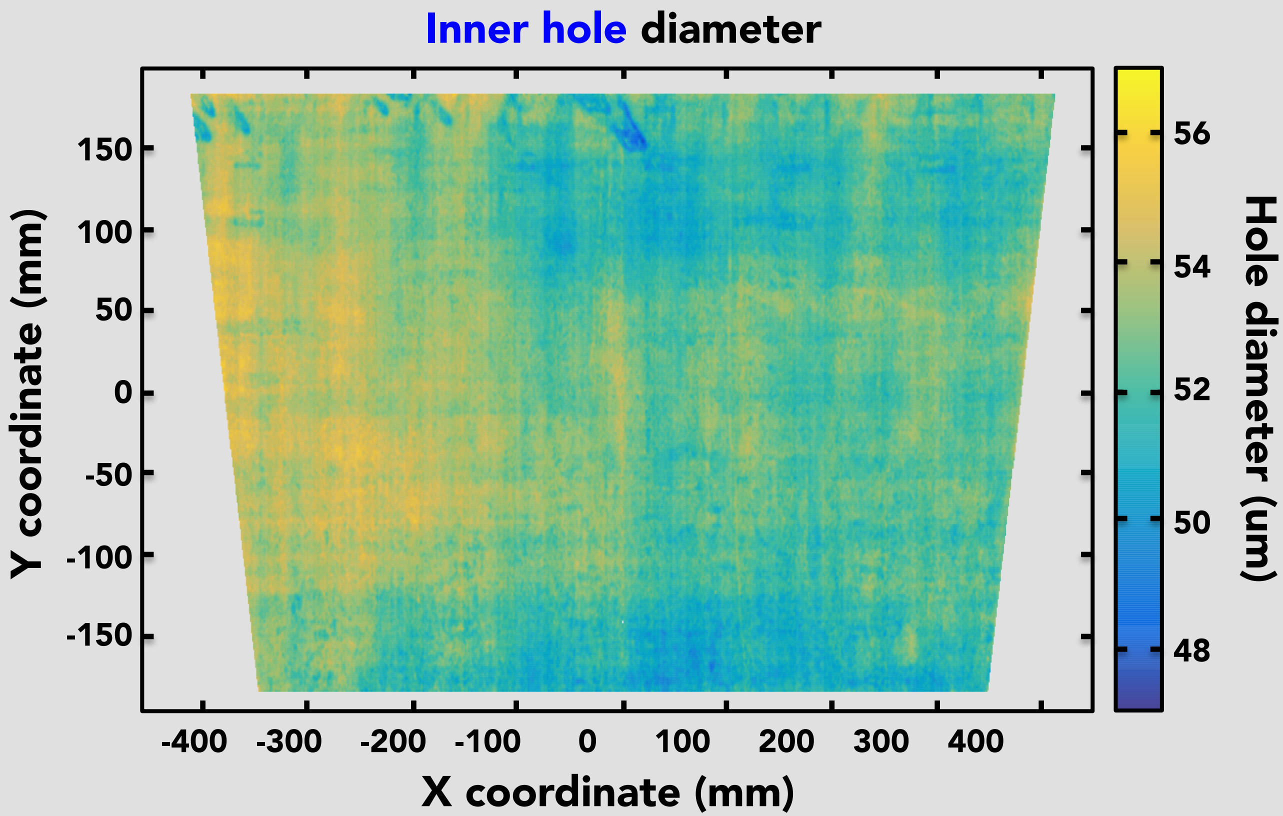
GEM foil QA (2)

Multi-stage quality assurance (QA) using traffic light system (Bad / HV ok / Good)

1. Basic QA at CERN
   - Reject malfunctioning foils as early as possible
   - Fast feedback to the producer
2. **Advanced QA**
   - **Hole size distributions**
   - **Gain uniformity prediction**



GEM hole cross-section



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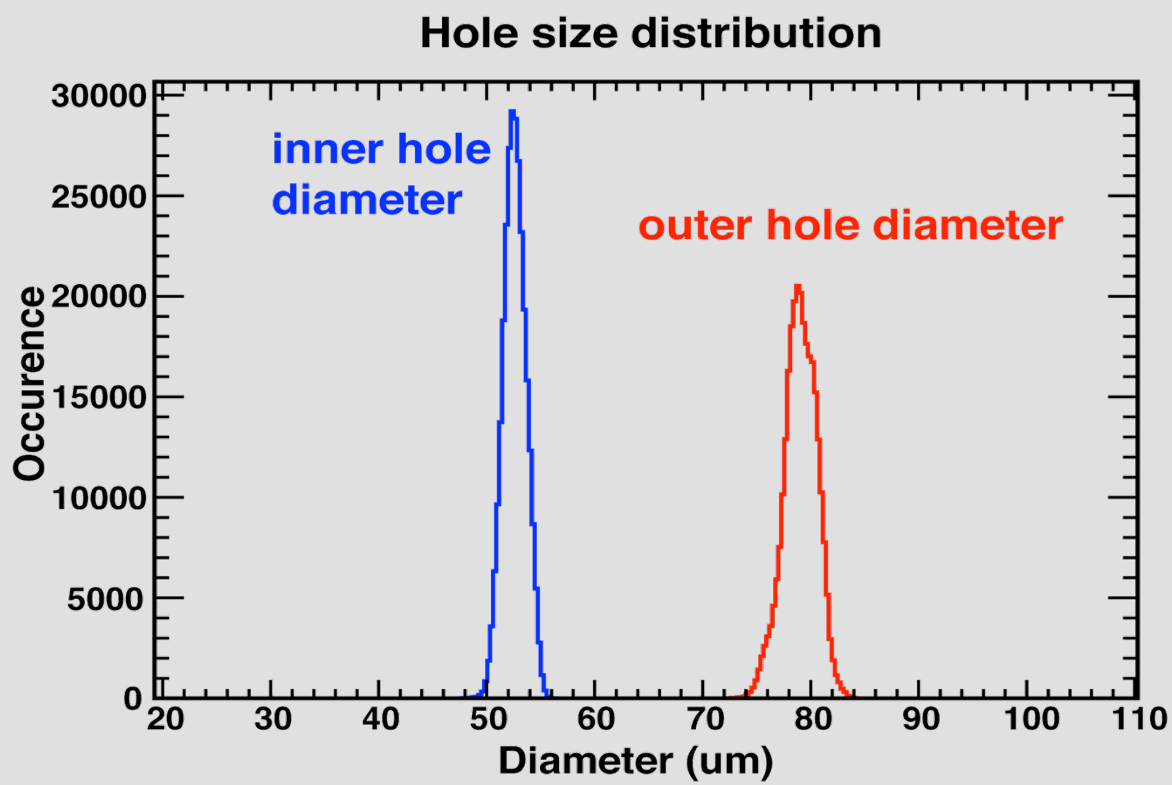
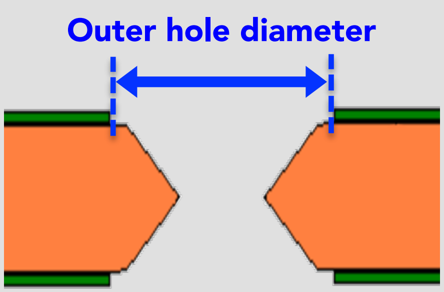




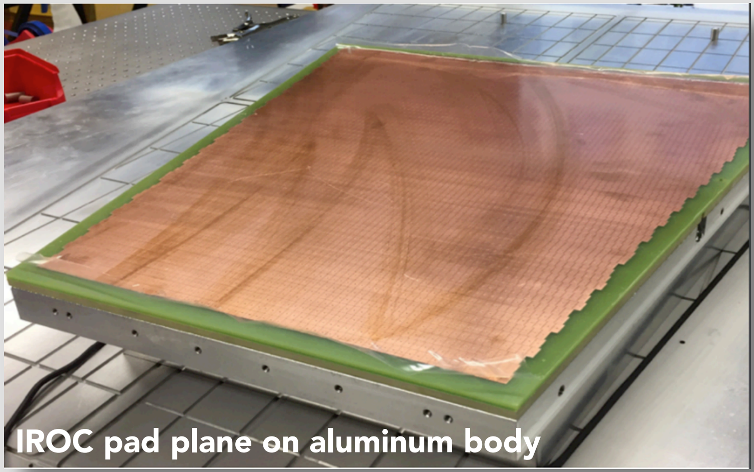
GEM hole cross-section

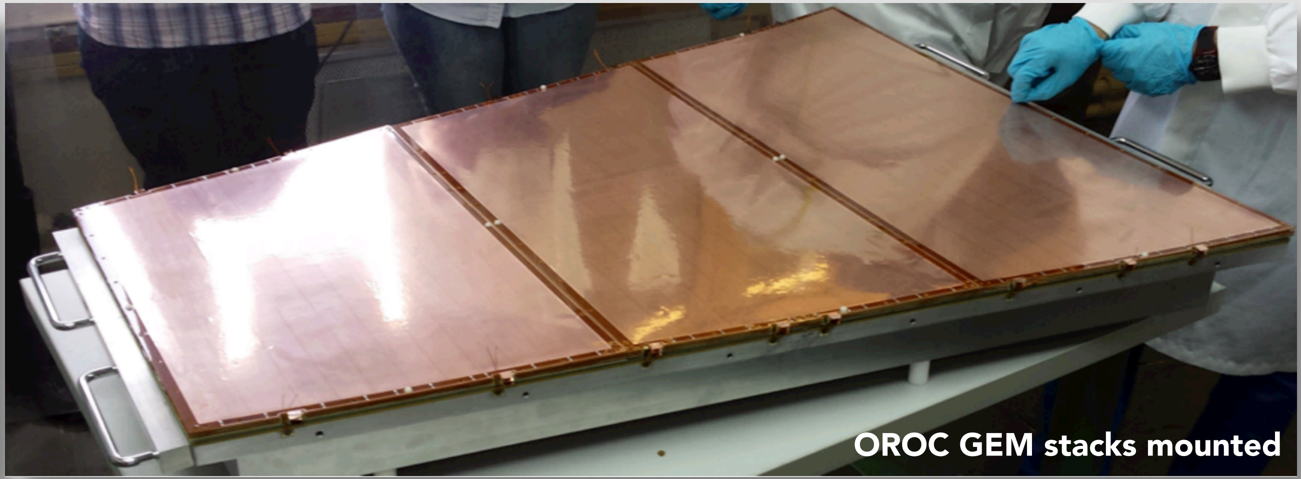
GEM foil QA (4)

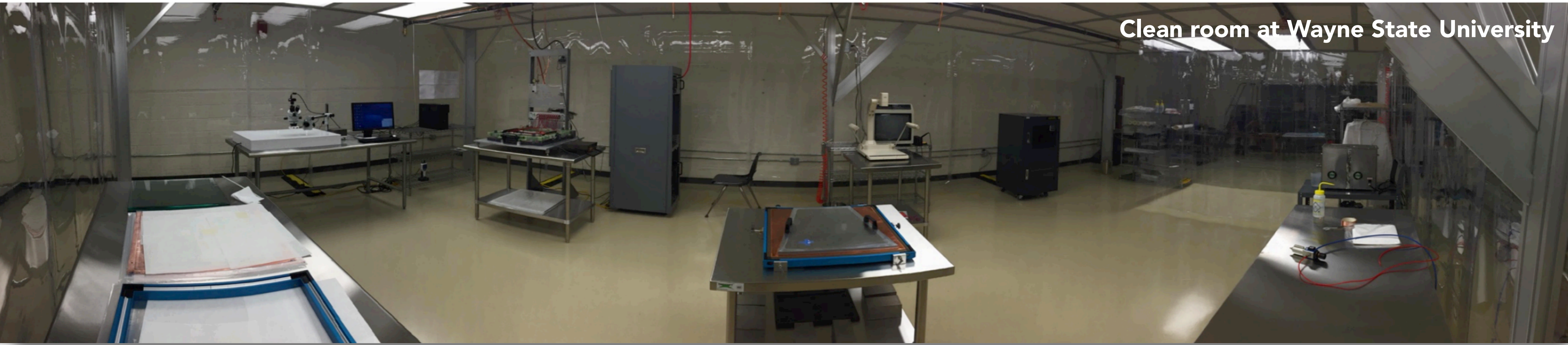
Multi-stage quality assurance (QA) using traffic light system (Bad / HV ok / Good)

1. Basic QA at CERN
   - Reject malfunctioning foils as early as possible
   - Fast feedback to the producer
2. Advanced QA
   - Hole size distributions
   - Gain uniformity prediction
3. Further QA steps at the framing and assembly sites
   - Continuous quality monitoring after each production step

ROC production







ROC characterization (1)

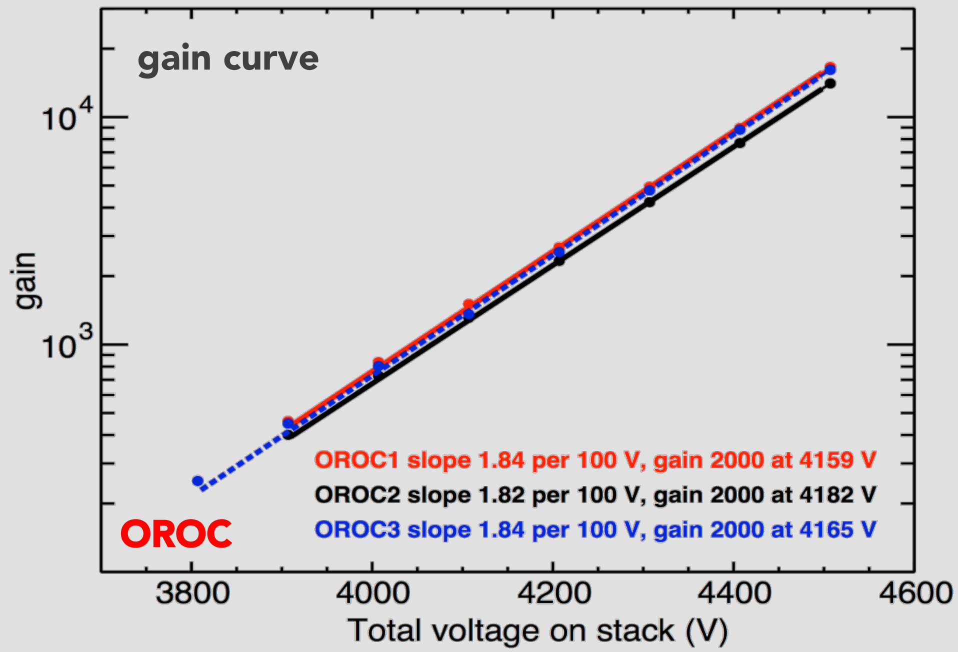
Final ROC characterization:

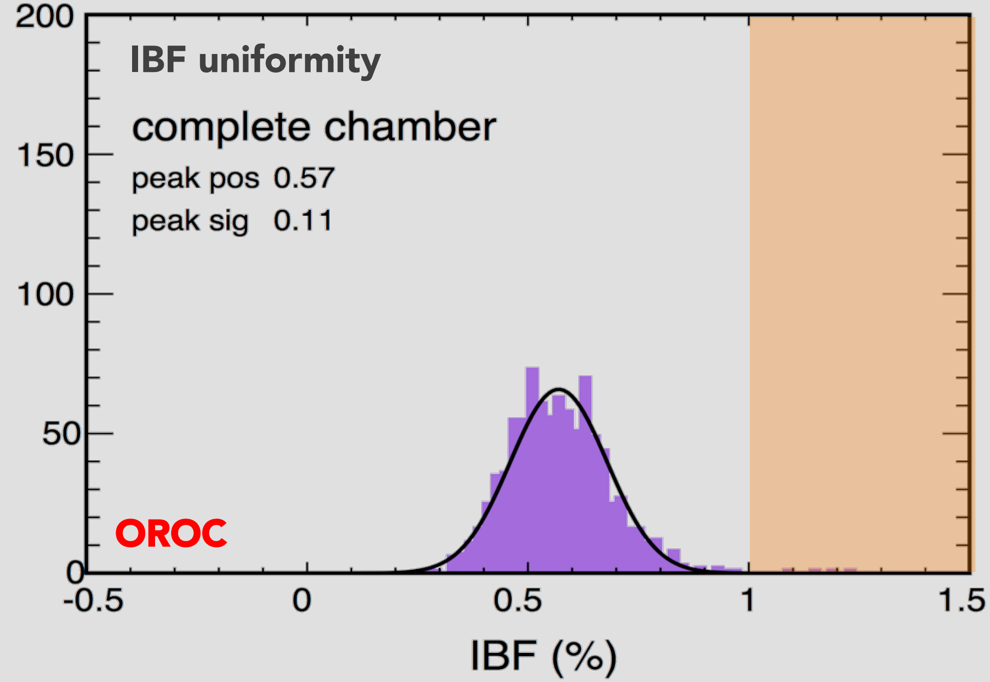
- ✓ Gas tightness (< 0.5 ml/h)
- ✓ Gain curve
- ✓ Gain uniformity (<20 %)
- ✓ IBF uniformity (IBF < 1 %, uniformity < 20%)
- ✓ Full X-ray irradiation for more than 6h (10 nA/cm^2 pad-plane current)

- ✓ **First production ROCs meet requirements**

ROC characterization (2)

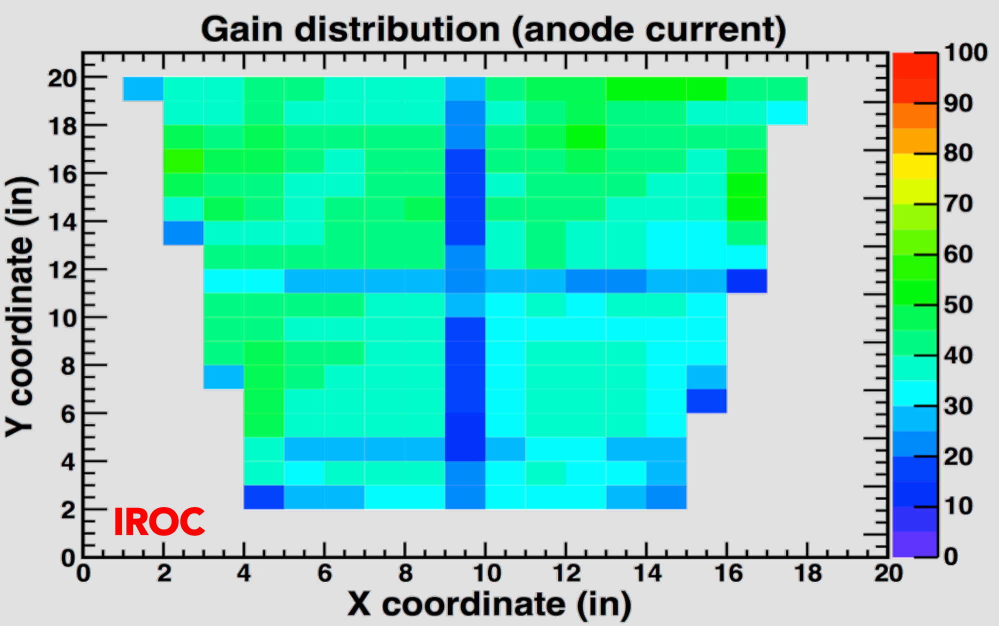
✓ **First production OROC meets requirements**



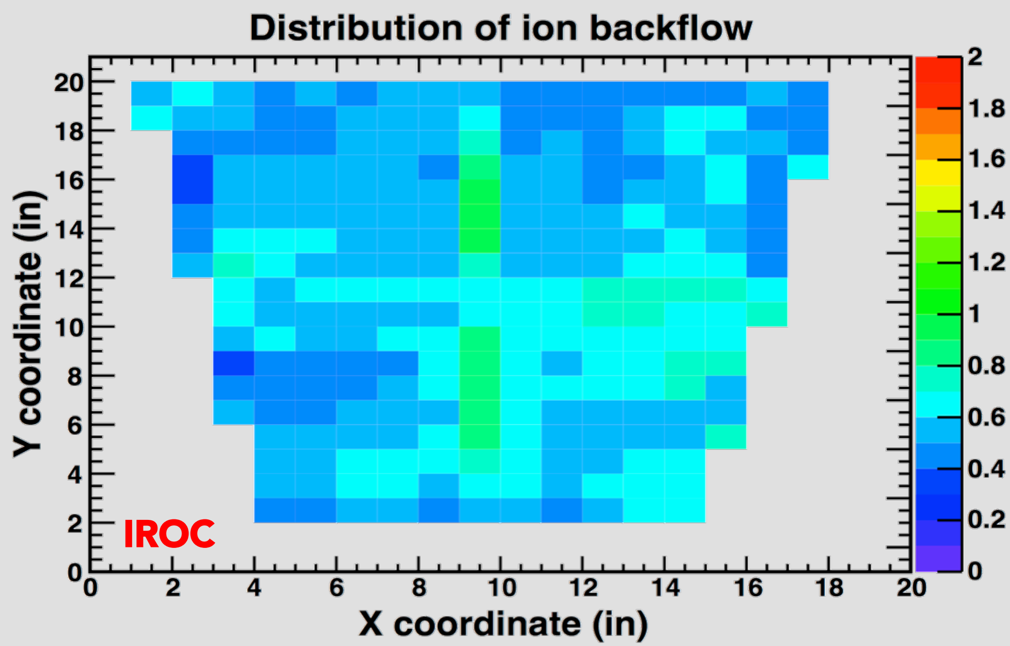


ROC characterization (3)

✓ **First production IROC meets requirements**

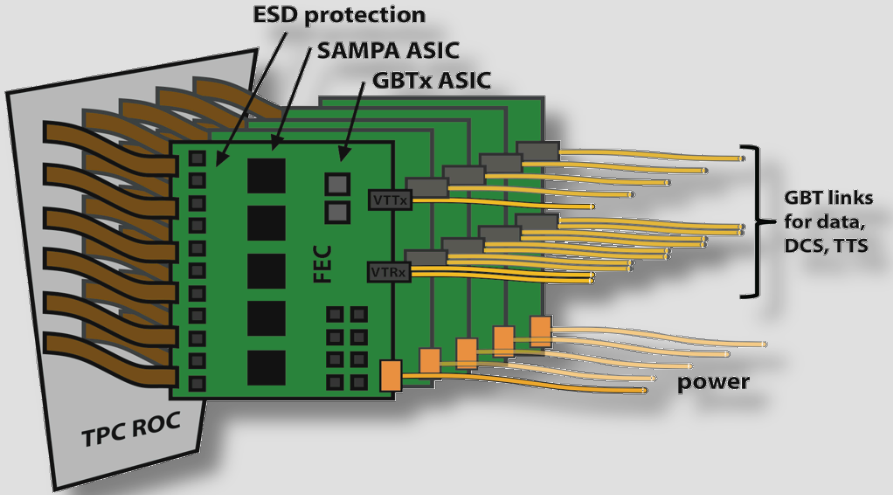


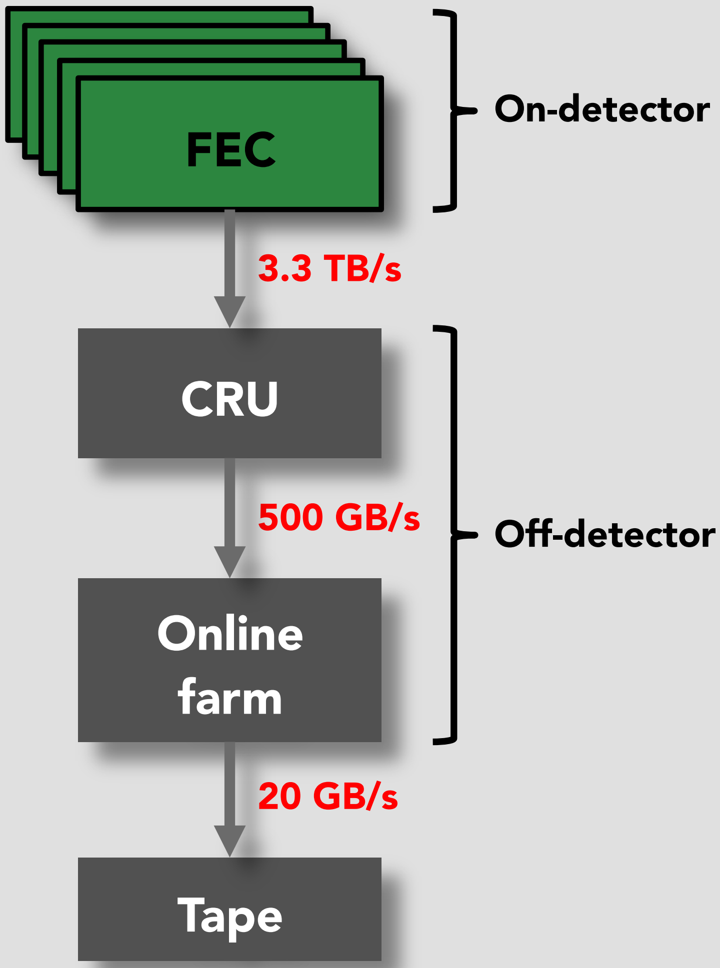
Systematic measurement effect: Apparent lower gain in region close to edges and GEM spacer frame



Readout strategy

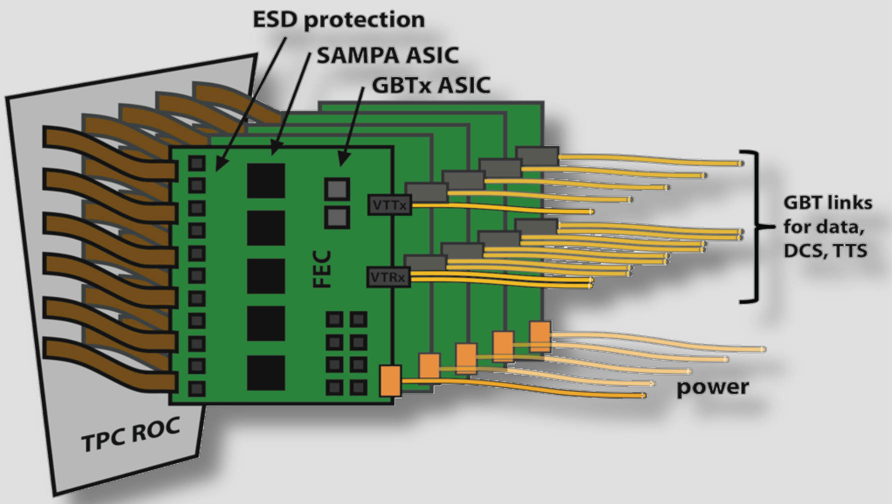
- Read all ADC values (no compression)
- Radiation hard data and control link: CERN GBT system
- Online data correction (baseline fluctuations, common mode effect) and cluster finding in CRU (FPGA based readout card)





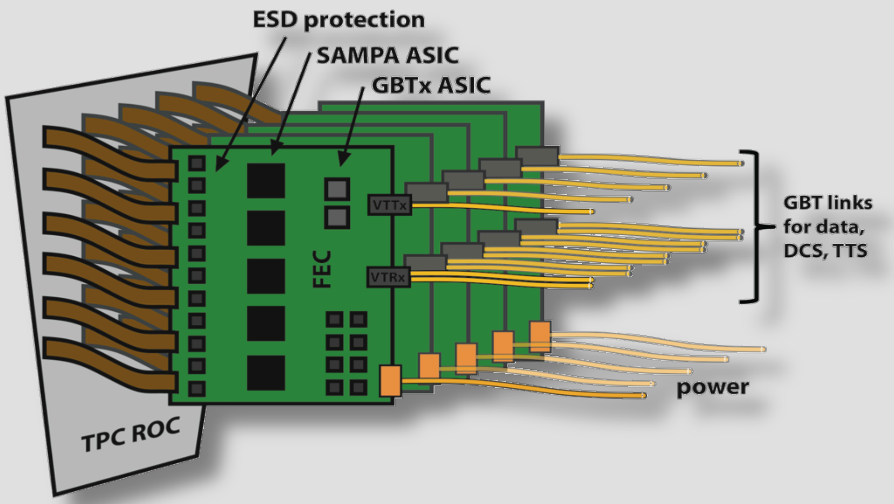
Readout electronics (1)

- **On the Front-End Card (FEC): New FE ASIC SAMPA (130 nm TSMC CMOS):**
  - Positive or negative input
  - Programmable conversion gains and peaking times
  - Readout modes: triggered or continuous
  - Digital Signal Processing (can be bypassed)



Readout electronics (2)

- On the Front-End Card (FEC): New FE ASIC SAMPA (130 nm TSMC CMOS):
  - Positive or negative input
  - Programmable conversion gains and peaking times
  - Readout modes: triggered or continuous
  - Digital Signal Processing (can be bypassed)

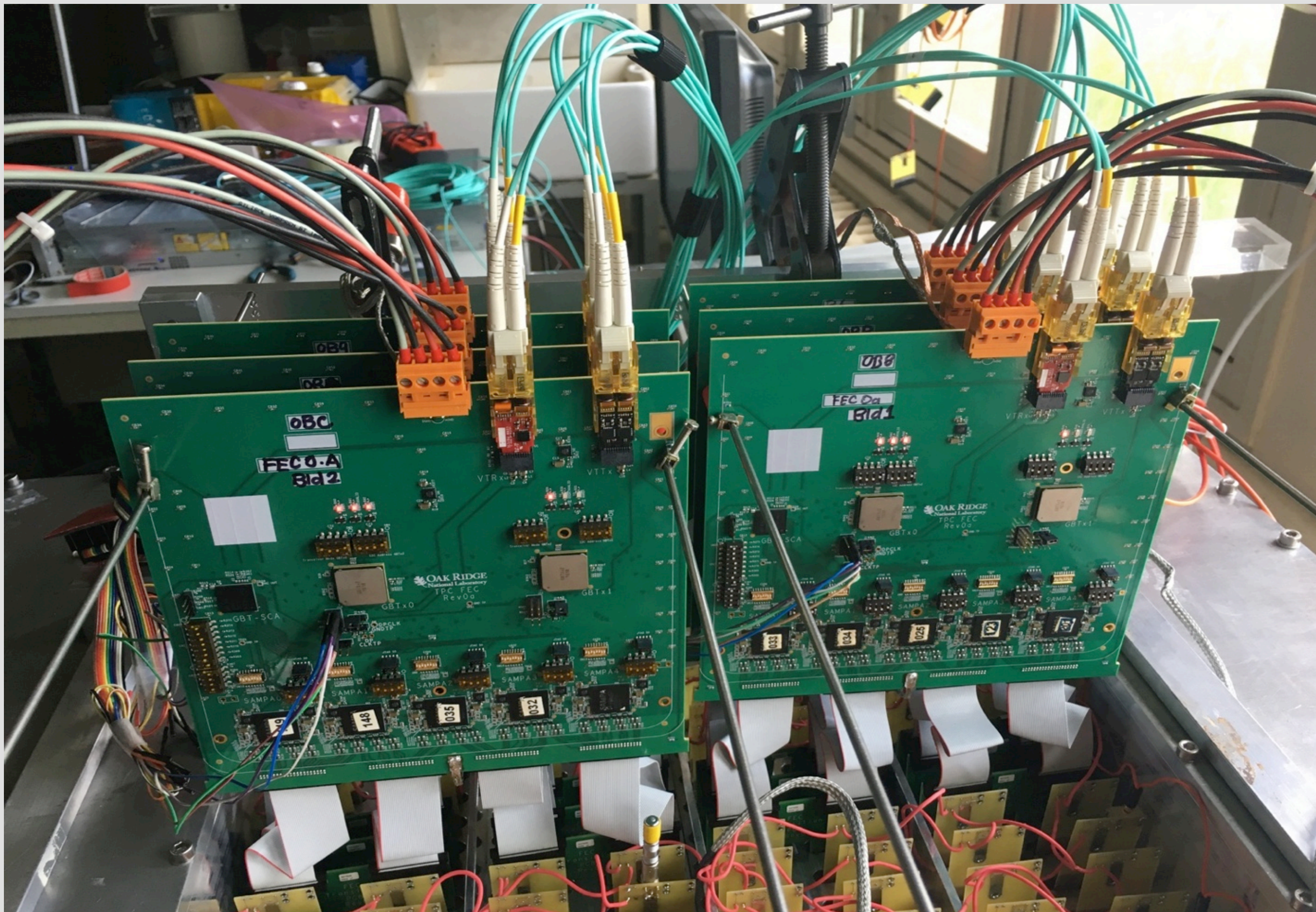


SAMPA requirements:

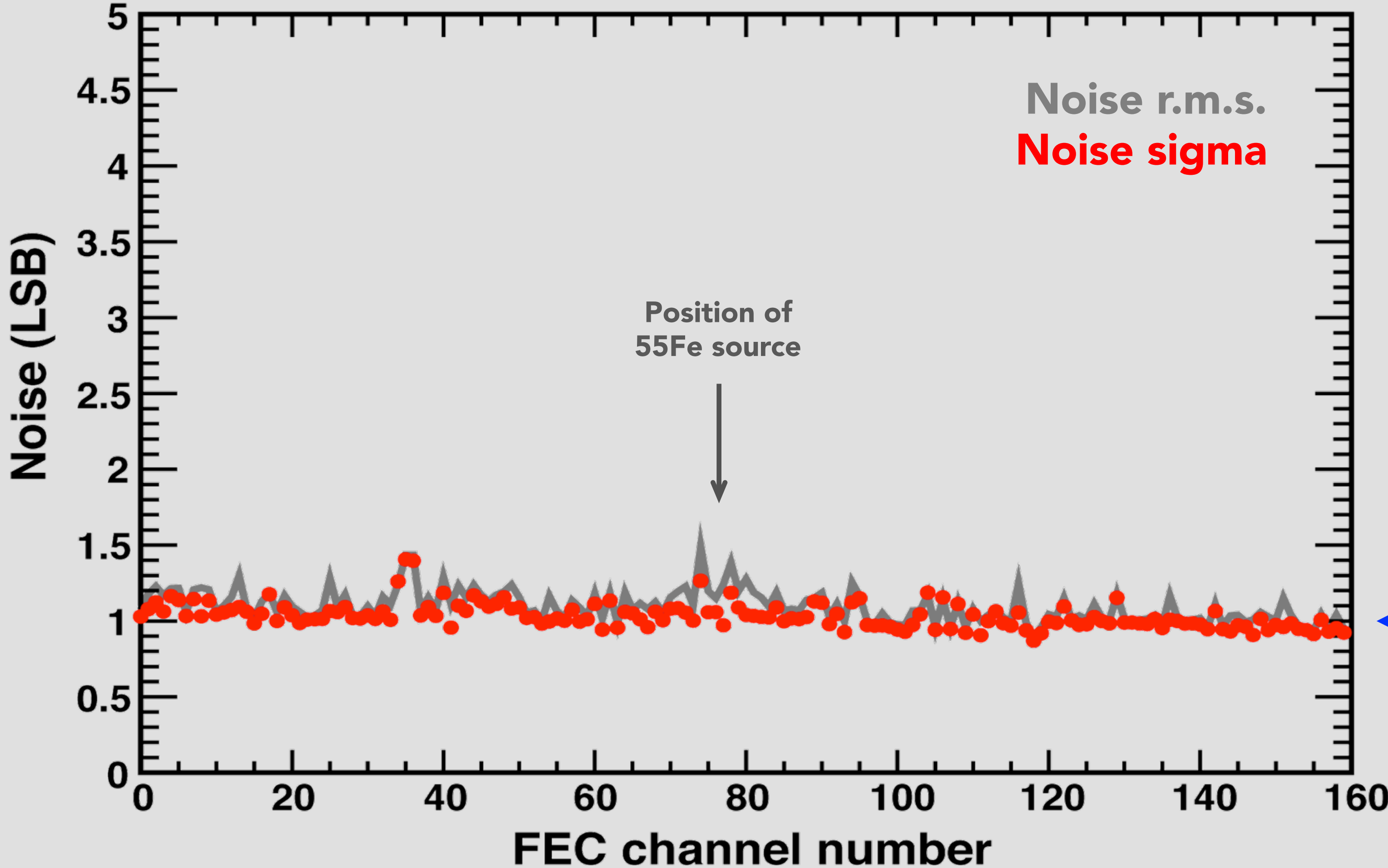
- Signal-to-noise ratio: 20:1 for IROC and 30:1 for OROC
- System noise (ENC): 670 e
- Conversion gain: 20 mV/fC
- Shaper peaking time: 160 ns
- Preamplifier saturation limit: > 10 nA
- ADC: 10 bit (ENOB>9.2), 5 MSPS

System integration

- **Front End Card prototypes (Rev 0a) on a GEM read-out chamber**



System noise

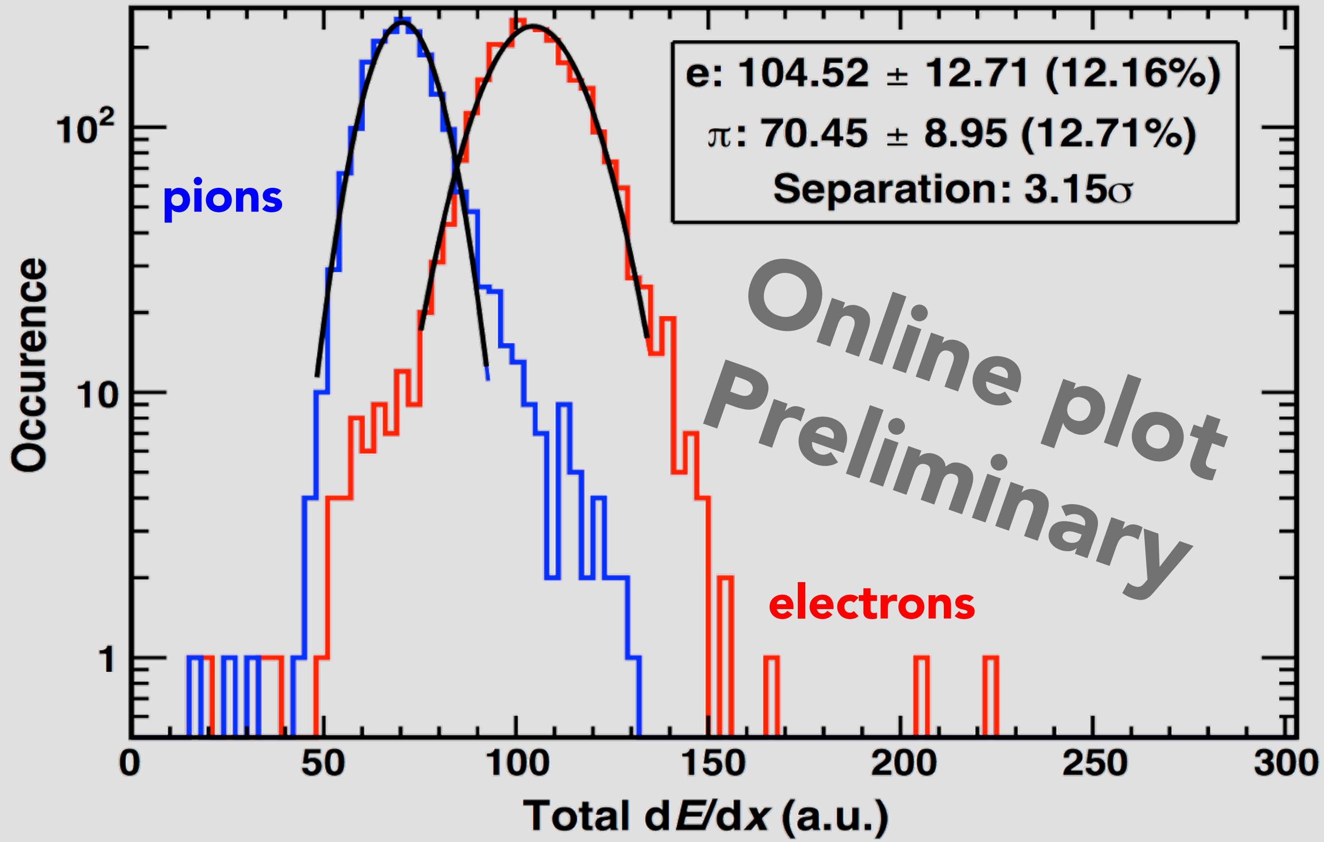


Required noise performance

1 LSB ≈ 670 e (ENC)

Performance in beam test

- Successful beam test at CERN PS in May 2017
- Example: Particle identification performance at 2 GeV/c



Summary and outlook

- Major upgrade of the ALICE experiment for installation in 2019/20
- Continuous TPC readout to inspect 50 kHz Pb–Pb collisions
- New TPC readout chambers based on quadruple GEM stacks
- Required performance (ion backflow, energy resolution, stability) achieved
- Extensive QA on produced GEM foils
- ROC assembly started
- New electronics for continuous readout
- Successful system tests

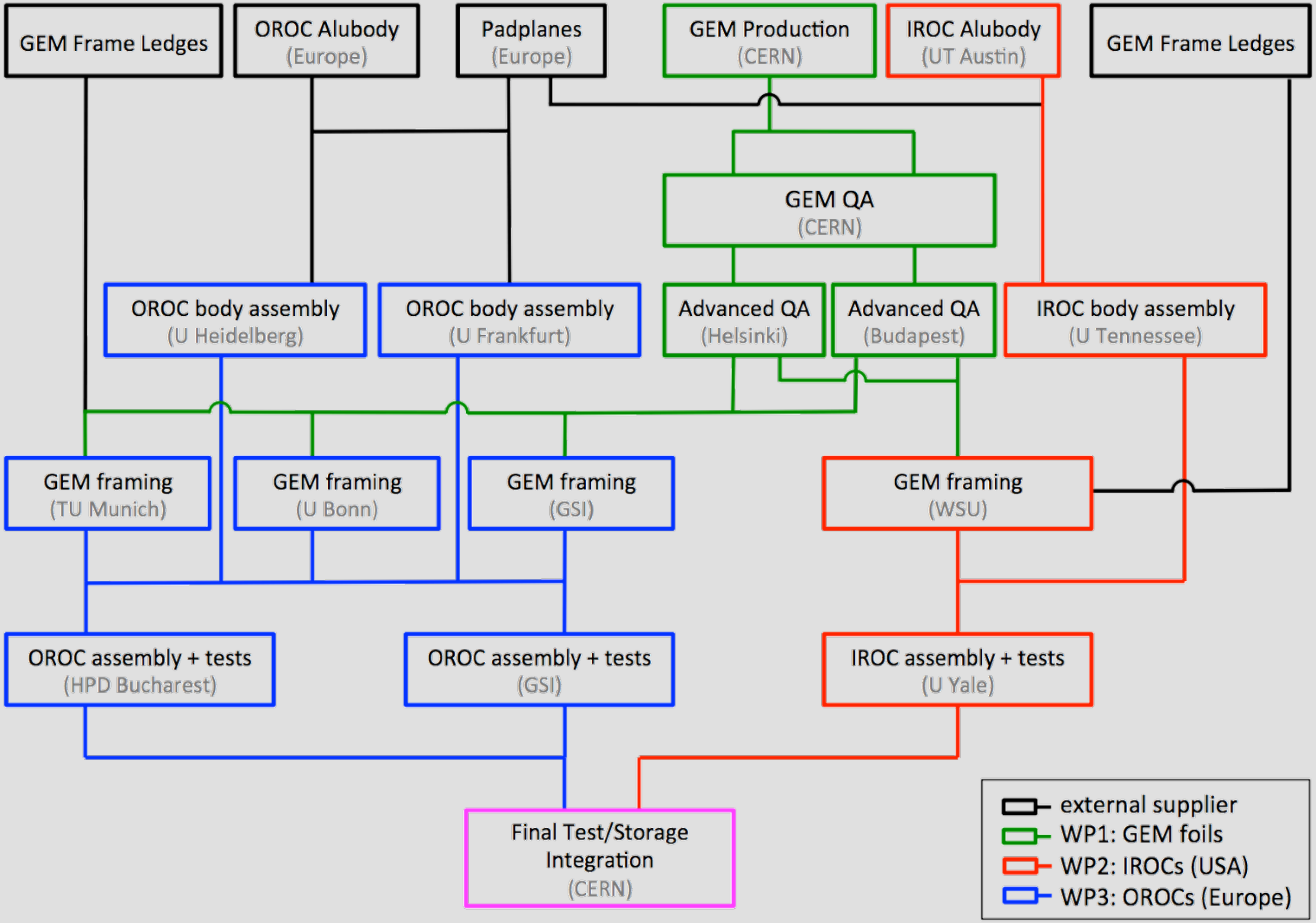
TPC team at the T10 beam line at CERN PS in May 2017

MORE

Milestones

Approval of the Technical Design Report (TDR)	June 2015
Readout chambers:	
• Engineering Design Review (EDR)	November 2015
• Readout Final Design Review	June 2016
✓ *Final design approved*	
• Production Readiness Review (PRR)	March 2017
✓ *Start of mass production*	
Front End Electronics:	
• Rev 0 schematic review	May 2016
• Rev 0 layout review	July 2016
• Rev 1 schematic review	March 2017
• Rev 1 layout review	April 2017
• EDR	October 2017
• PRR	August 2018
Installation:	
• Start of readout chamber installation	April 2019
• Start of FEE installation	August 2019

ROC assembly flow



FEE assembly flow