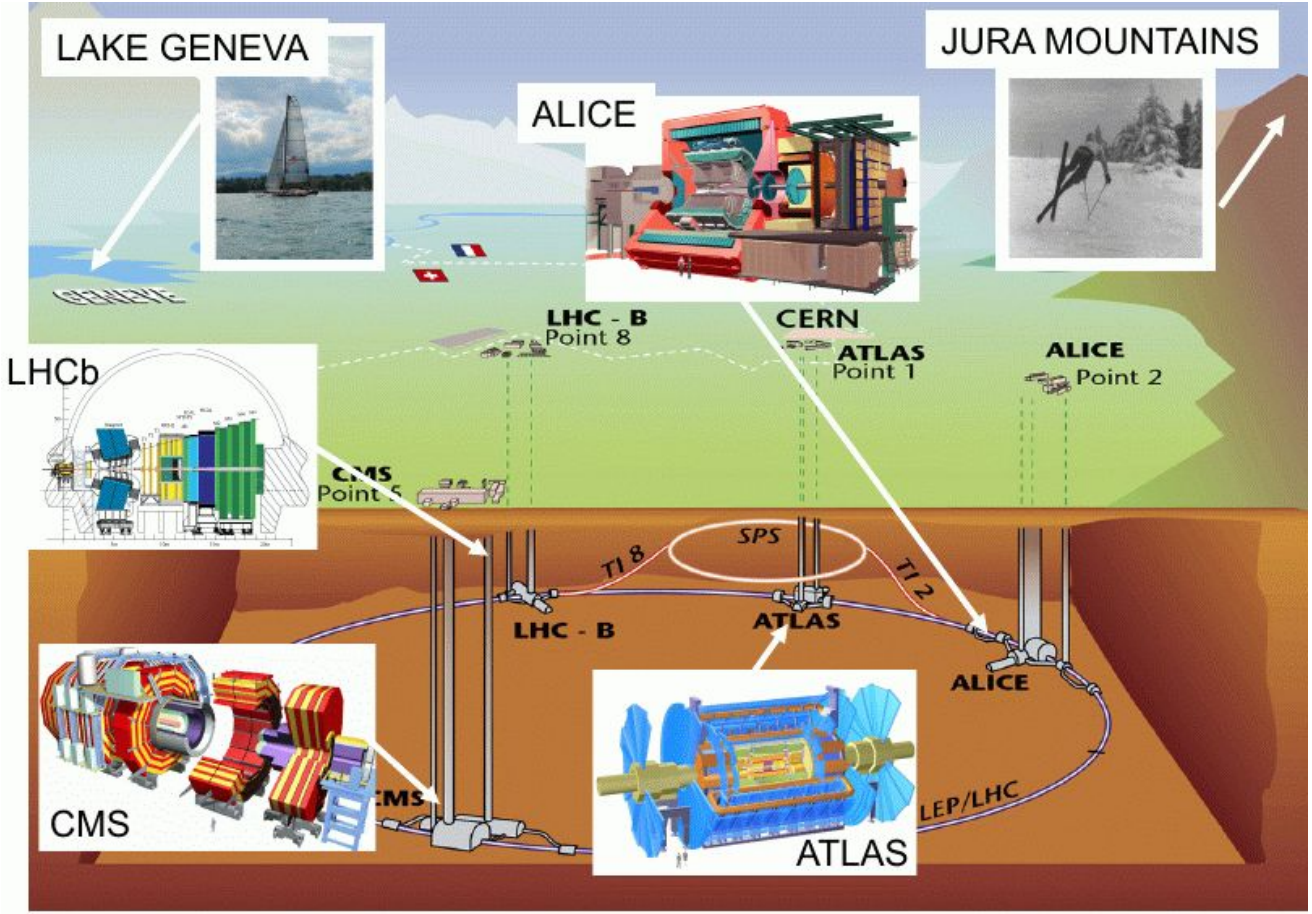
(W)hole new field

or

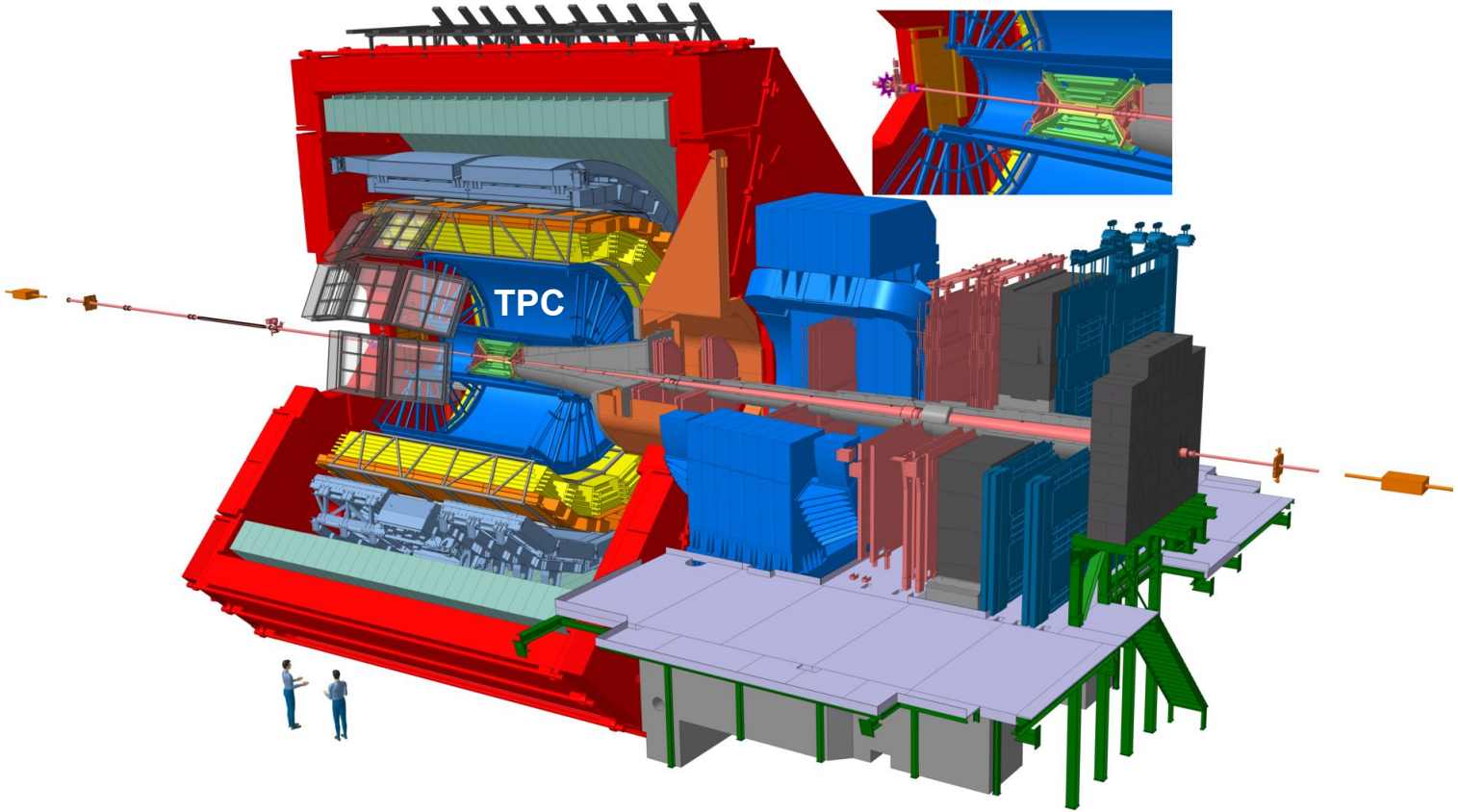
the new GEM TPC of ALICE

Dariusz Miśkowiec, GSI Darmstadt
for the ALICE Collaboration

Large Hadron Collider at CERN

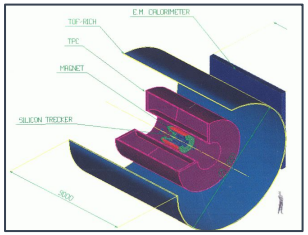


A Large Ion Collider Experiment at CERN

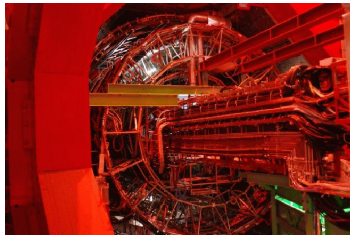


ALICE timeline

~1990 inception



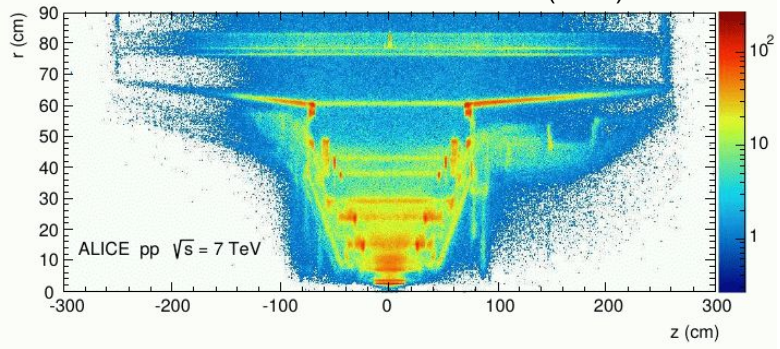
1995-2008 construction



IJMPA 29 (2014) 1430044

2009-2013 LHC Run 1: Pb-Pb, p-Pb, pp at 50% energy

2015-2018 LHC Run 2: Pb-Pb, Xe-Xe, p-Pb, pp at 93% energy



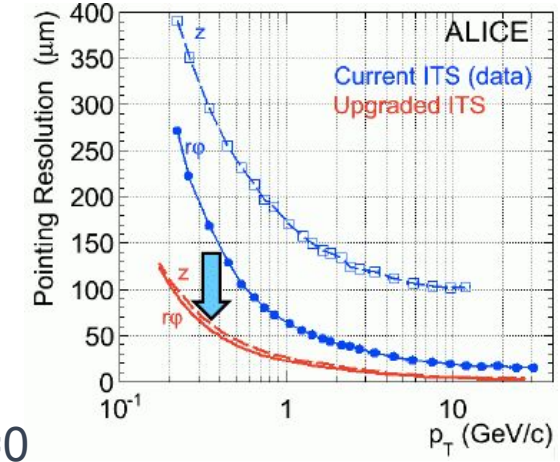
2021-2023 LHC Run 3: increased luminosity and 93-100% energy

plan for Run 3

- improve statistics of minimum-bias Pb-Pb collisions by a factor of 100 by speeding up the Time Projection Chamber

triggered operation with maximum Pb-Pb readout rate of 500 Hz → **continuous readout of minimum-bias Pb-Pb interactions at 50 kHz**

- improve tracking resolution at low p_T by a factor of 3 by reducing the radius and amount of material in the Inner Tracking System



With higher statistics and better resolution, study

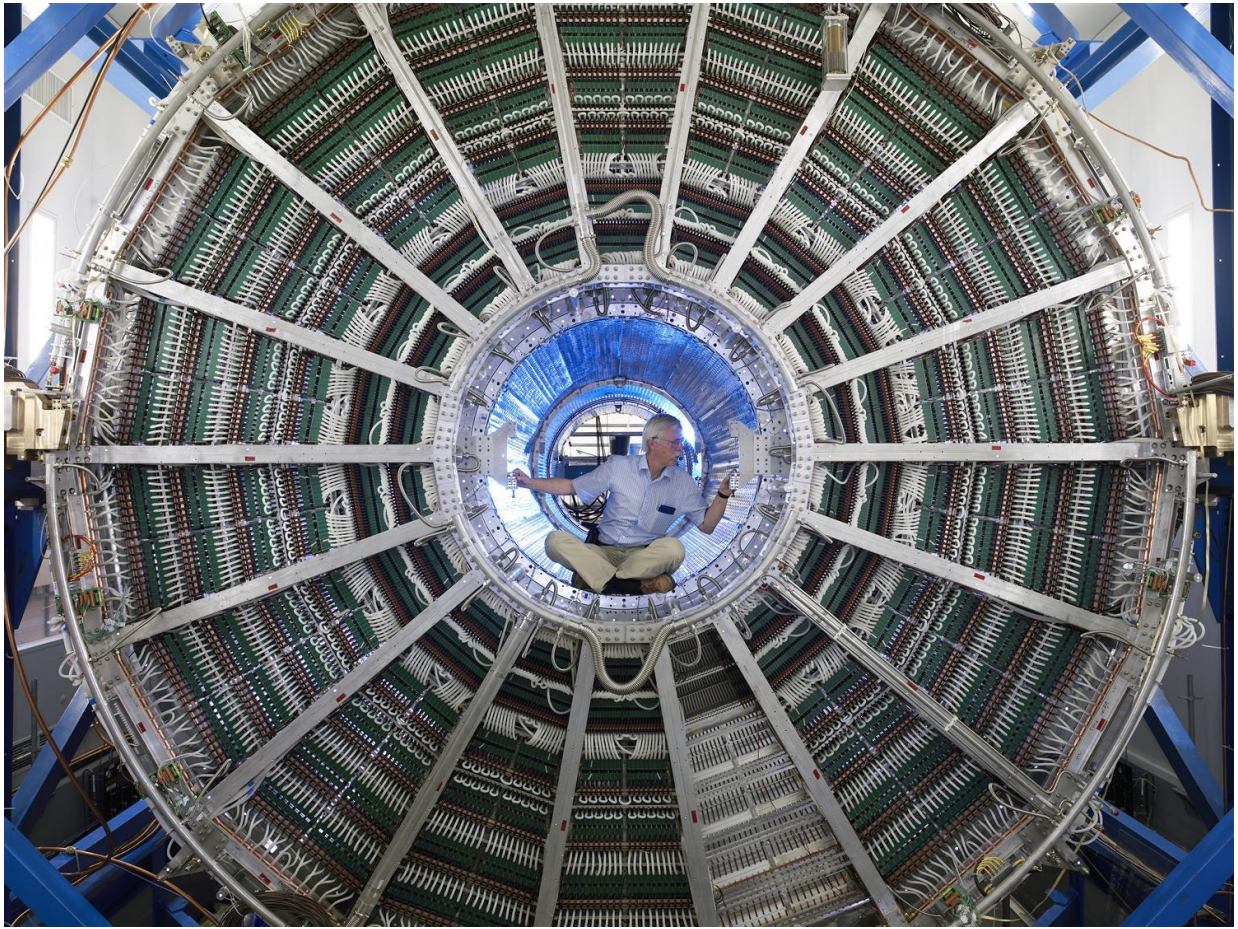
- open charm and beauty at low p_T, J/ψ down to p_T=0
- photons, thermal dileptons, vector mesons
- light nuclei and exotica

this talk is about

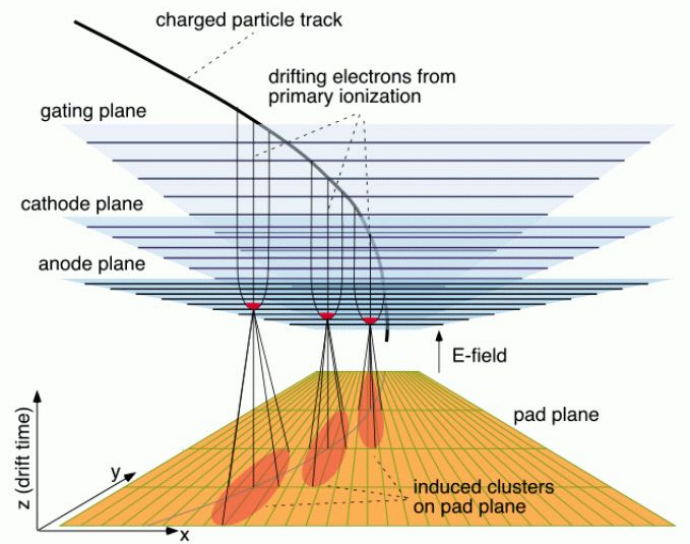
Assembly and test of the new GEM chambers
(Outer Readout Chamber = OROC)
for the ALICE TPC

(involvement of the GSI Darmstadt)

ALICE Time Projection Chamber in 2006



Time Projection Chamber



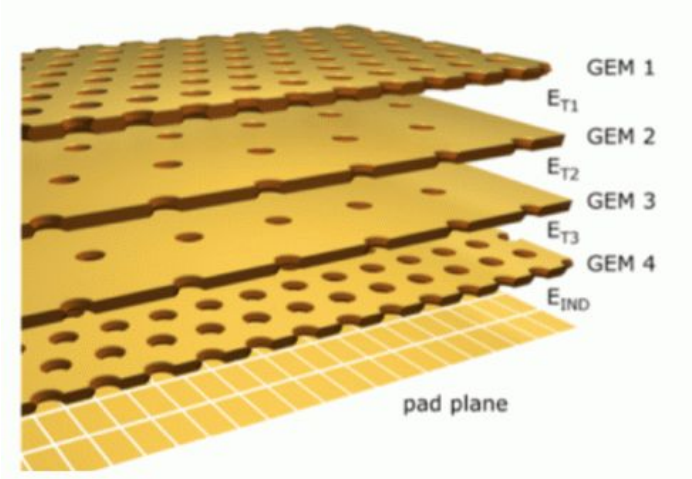
gating grid closes 100 μs after the trigger and stays closed for 180 μs to keep ions off the drift volume → maximum event-taking rate of 3.5 kHz

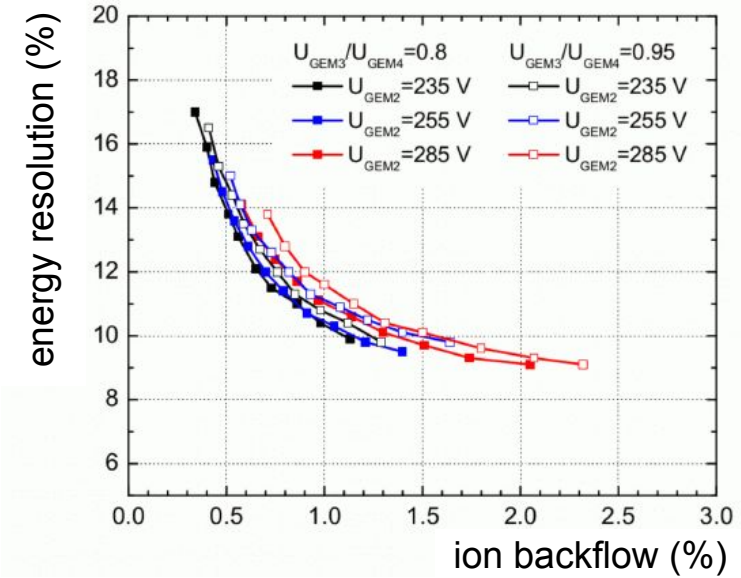
LHC Run 3 will offer 50 kHz of Pb-Pb

solution for the rate limitation

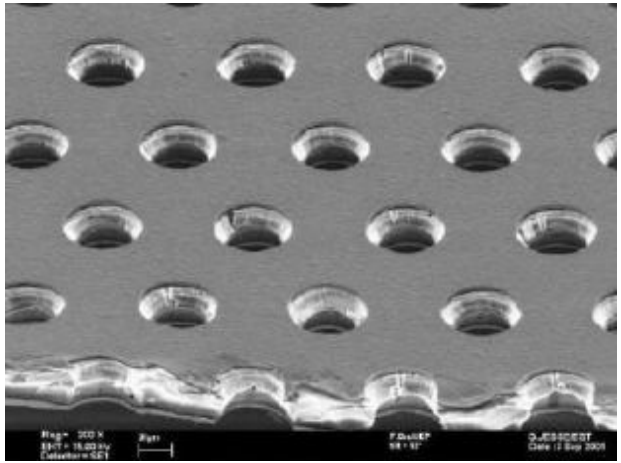
- remove gating grid
- use several amplification stages, keep total gain low, reduce ion backflow (IBF) by the choice of electric fields

implementation: 4 Gas Electron Multiplier (GEM) foils





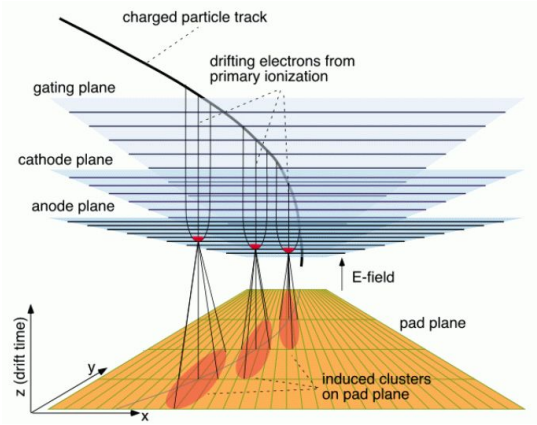
Gas Electron Multiplier foils

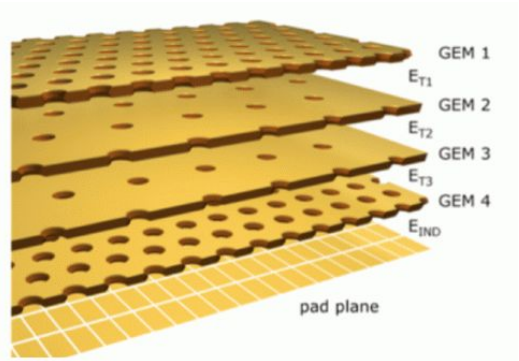


thin (50 μm) insulating foil with many small (diameter 70 μm) holes
5 μm copper coating on both sides
voltage (~300 V) across (between top and bottom copper layers)

→ high electric field inside holes
→ electrons ionize gas atoms while passing through holes
→ signal amplification

comparison between wire chambers and GEM chambers

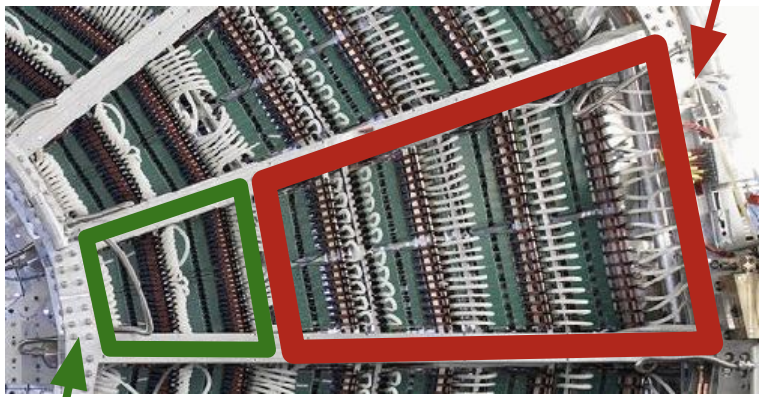




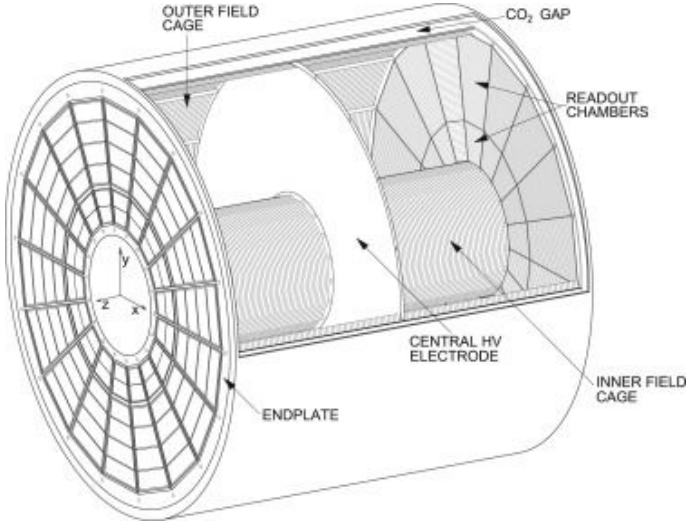
	wire chamber		GEM chamber
	grid open	grid closed	
gain	8000	0	2000
ion backflow	0.13	<0.0001	<0.01

upgrade of the TPC

Outer Readout Chamber (OROC)

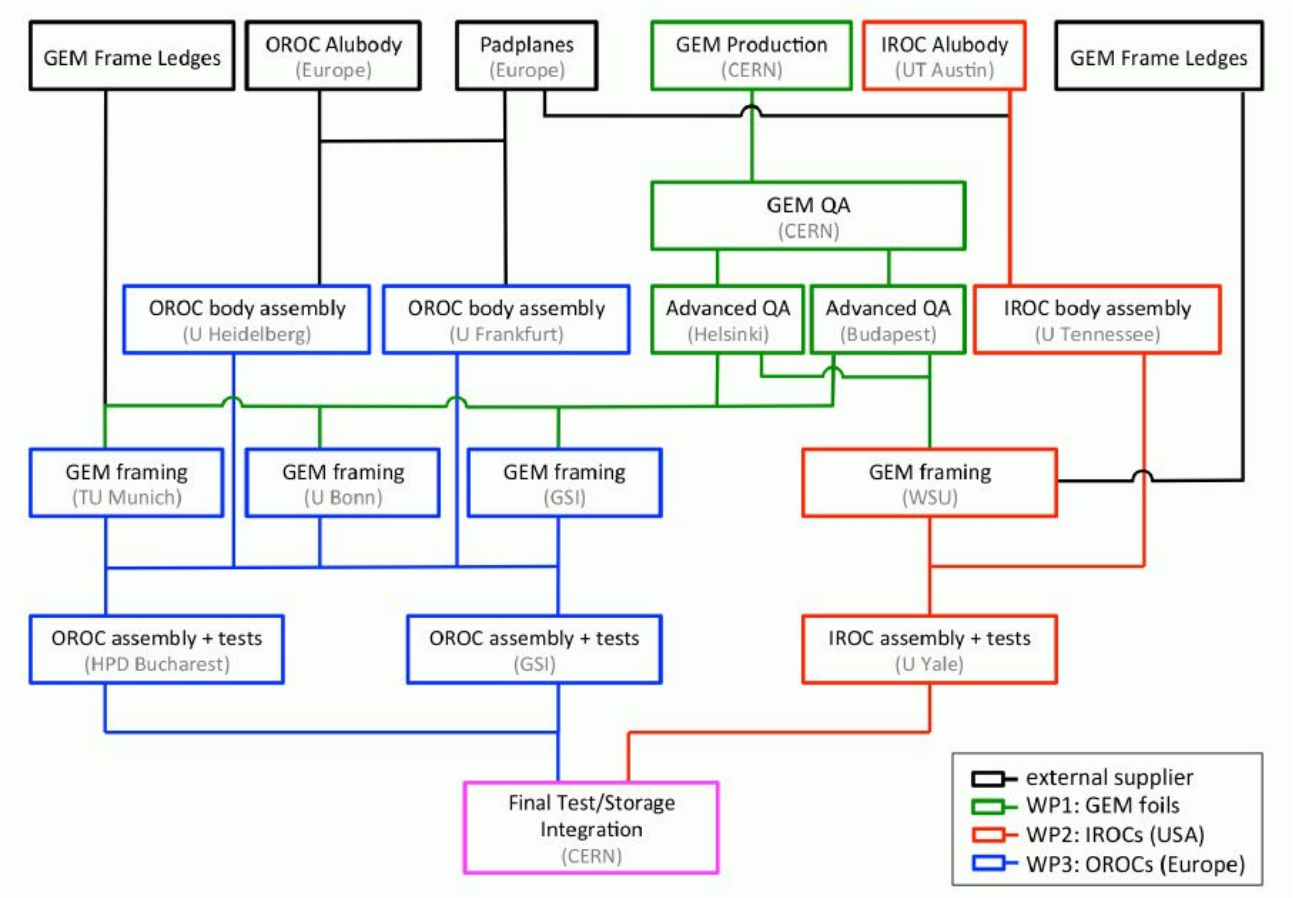


Inner Readout Chamber (IROC)

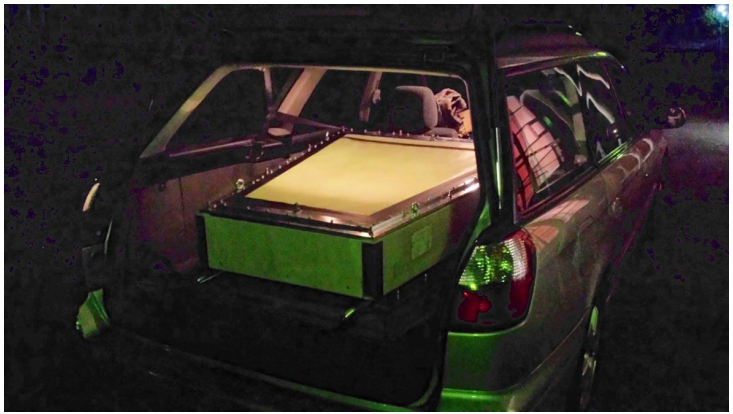


36 IROCs and 36 OROCs to be replaced with new GEM chambers
GSI assembling 20 OROCs

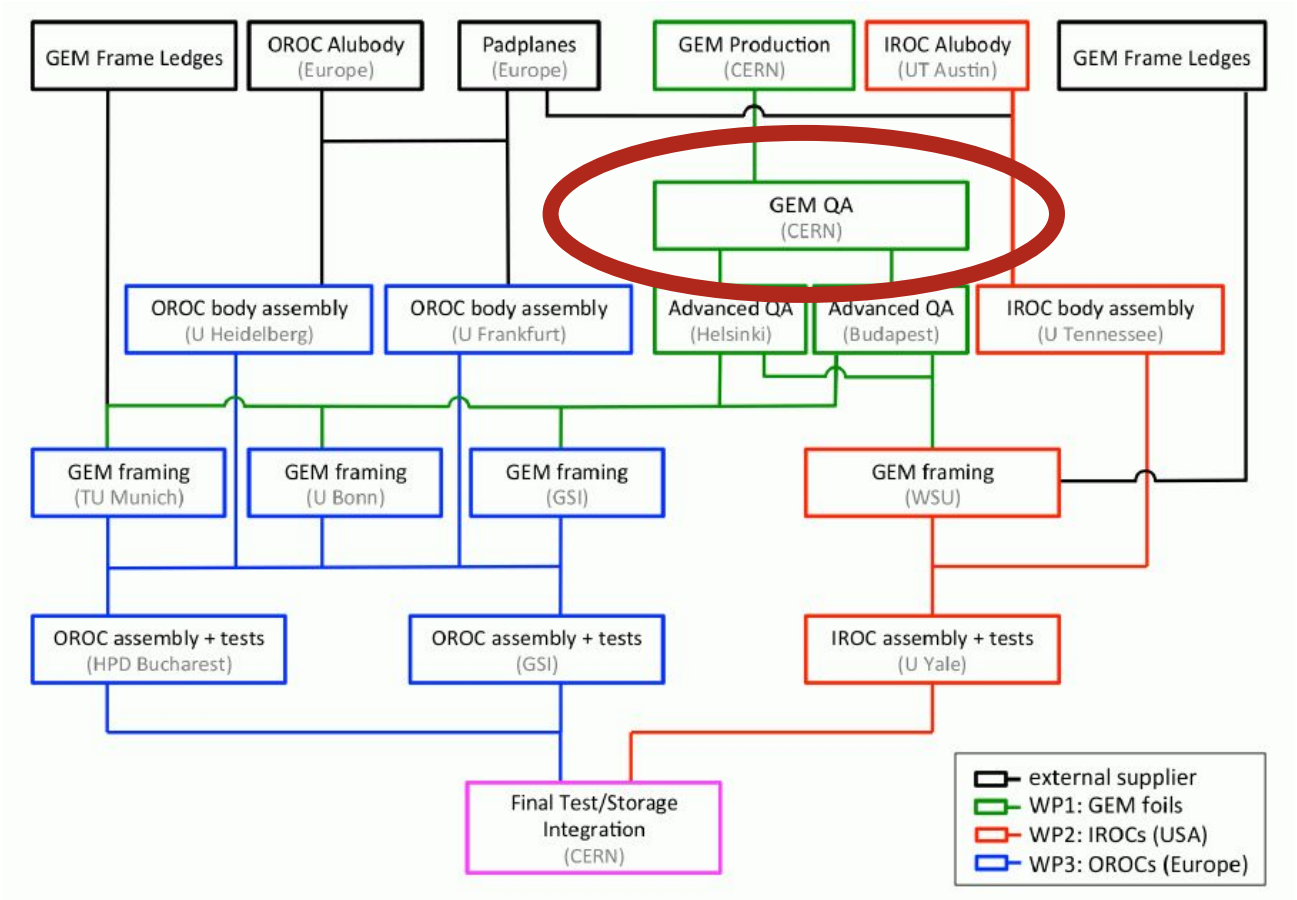
ALICE TPC upgrade project structure



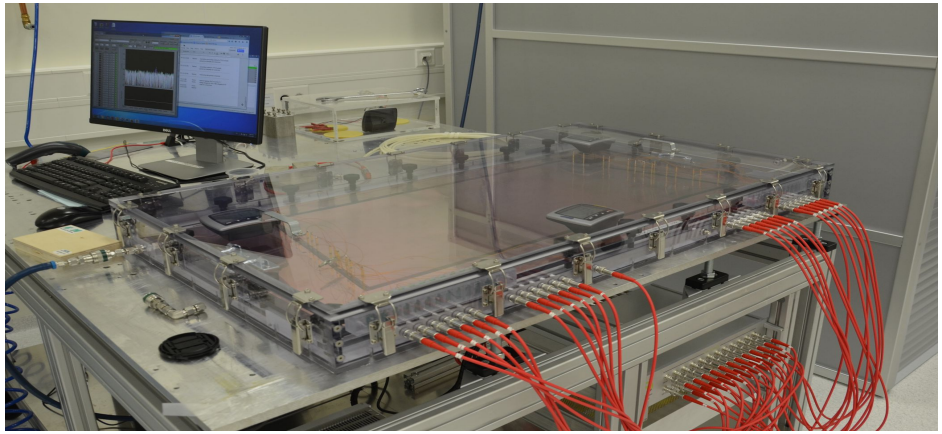
ALICE TPC upgrade - a very logistic-intensive project

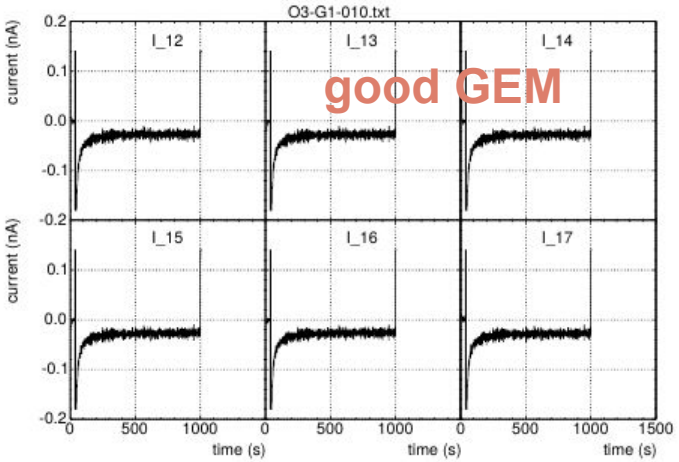


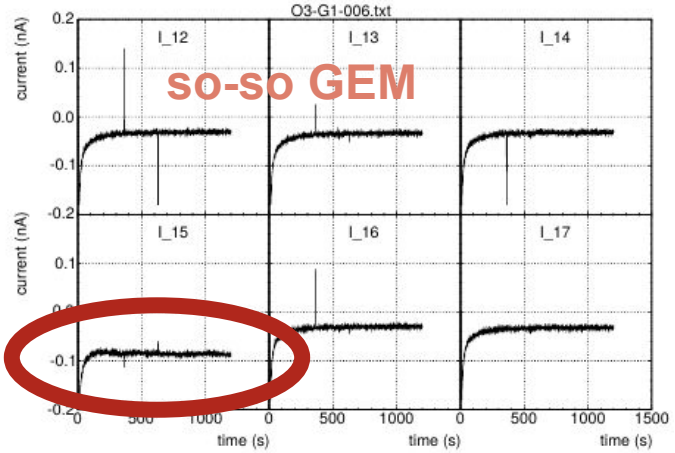
ALICE TPC upgrade project structure



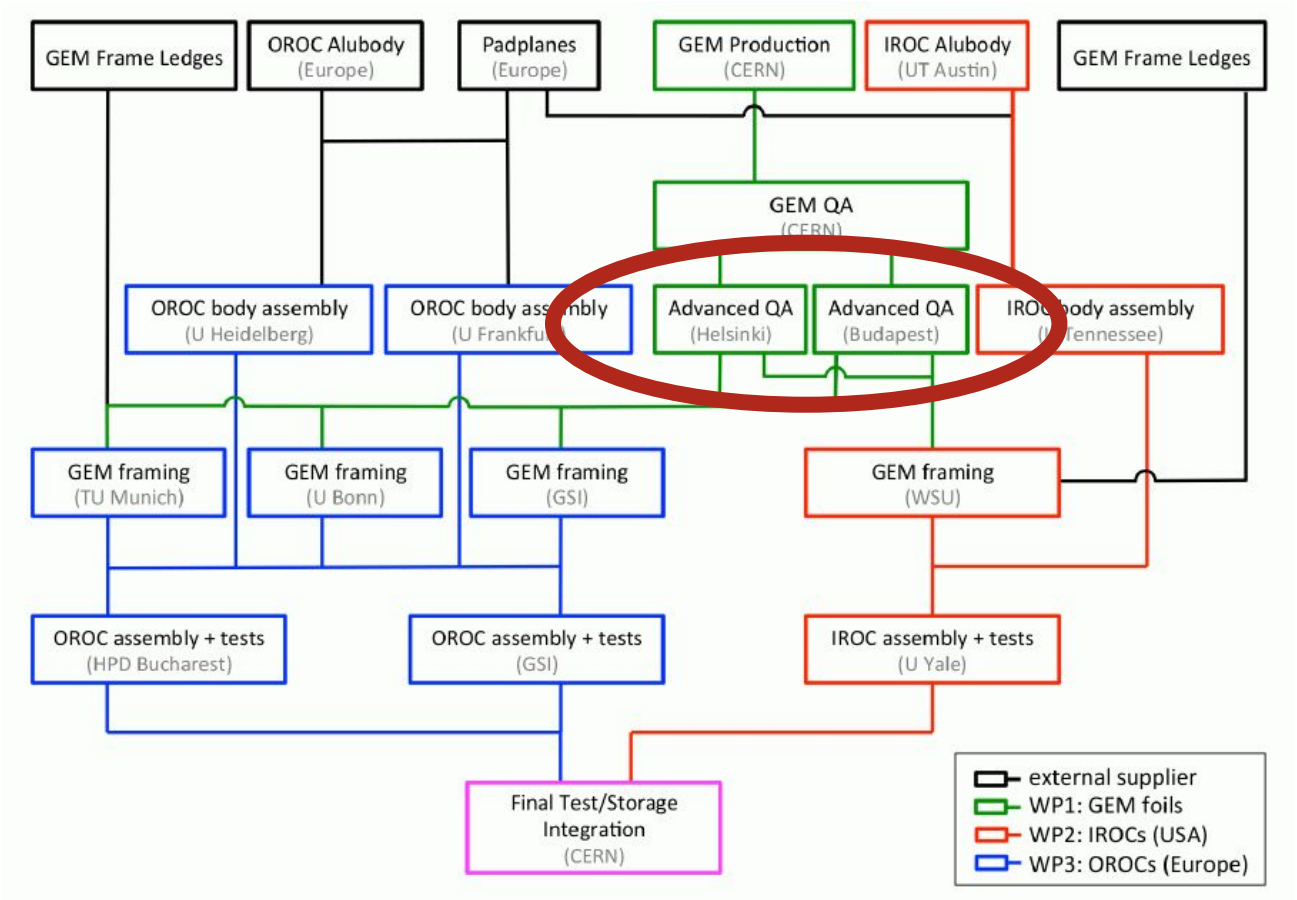
basic GEM test: leakage current at 500 V





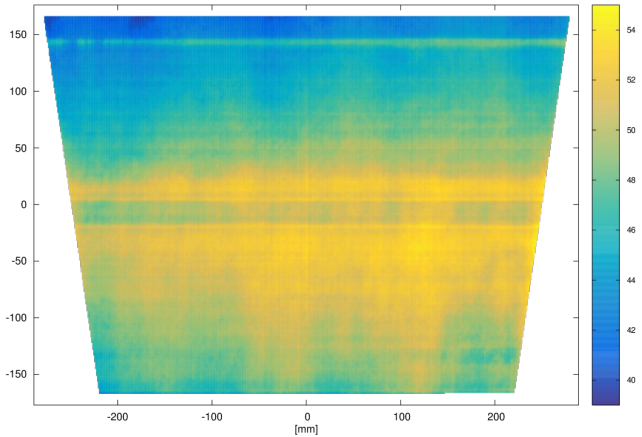


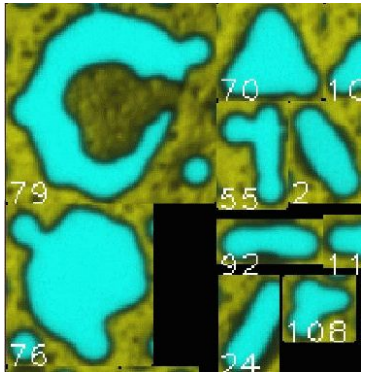
ALICE TPC upgrade project structure



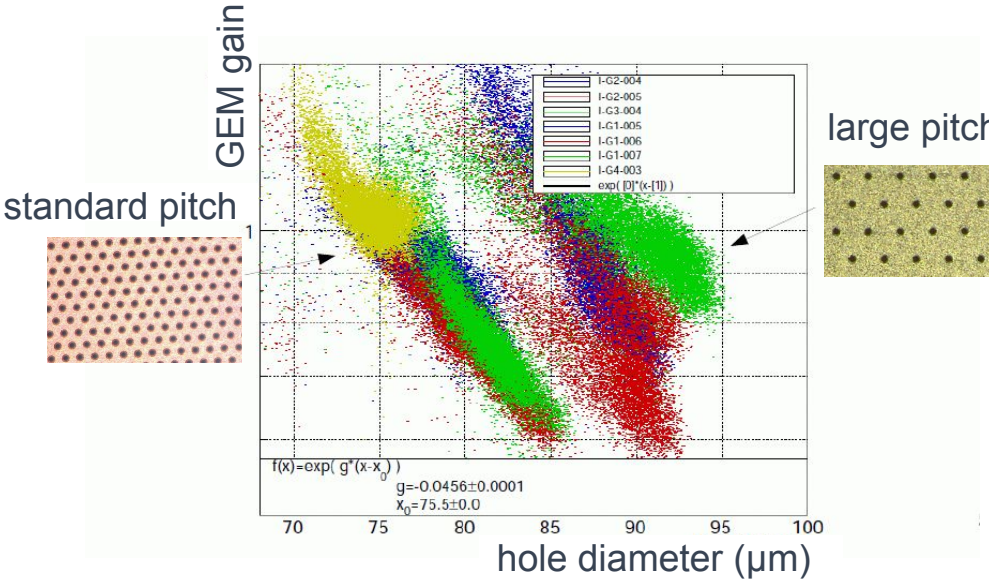
advanced GEM tests: optical scan

hole-size map





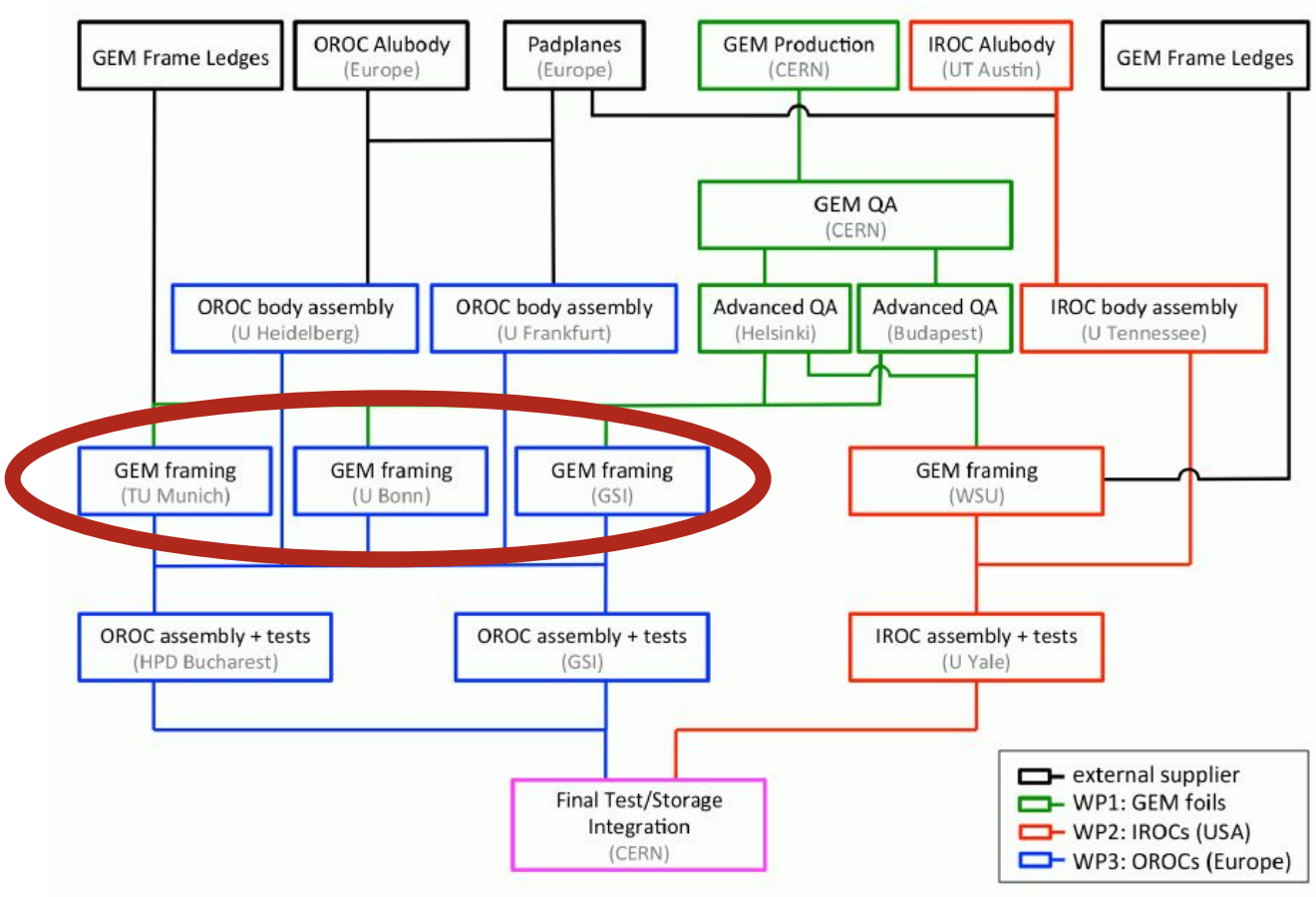
etching defects



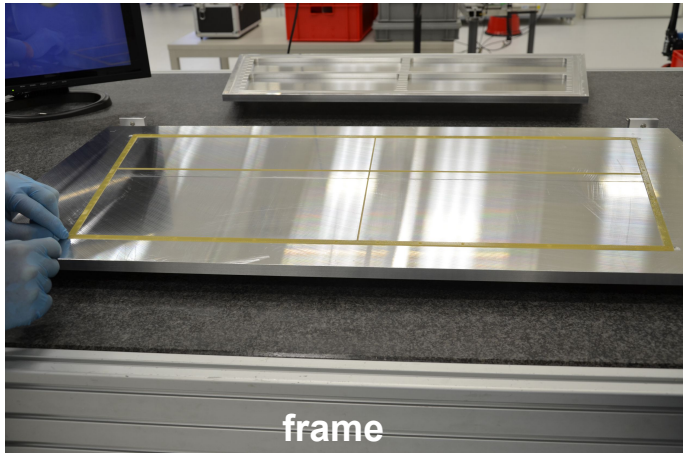
clear anticorrelation between hole size and single-GEM gain

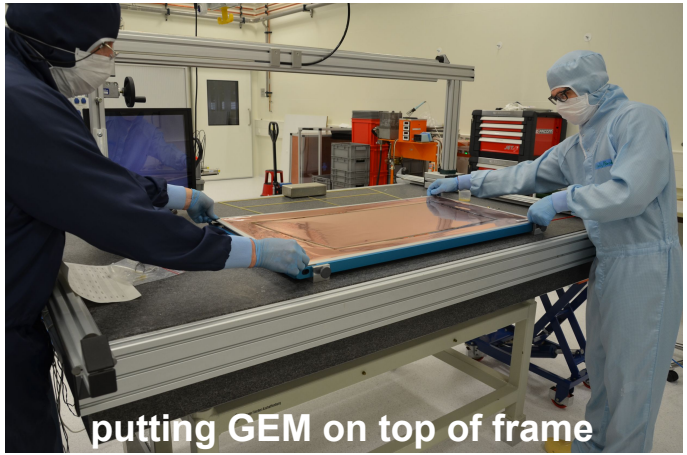
...gets lost once several GEMs are stacked together

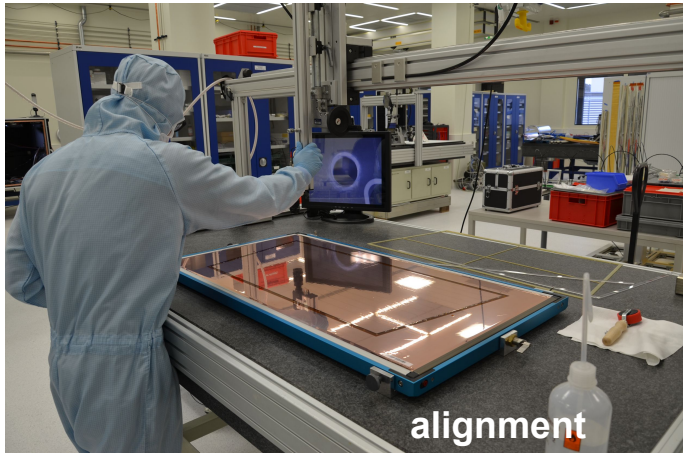
ALICE TPC upgrade project structure

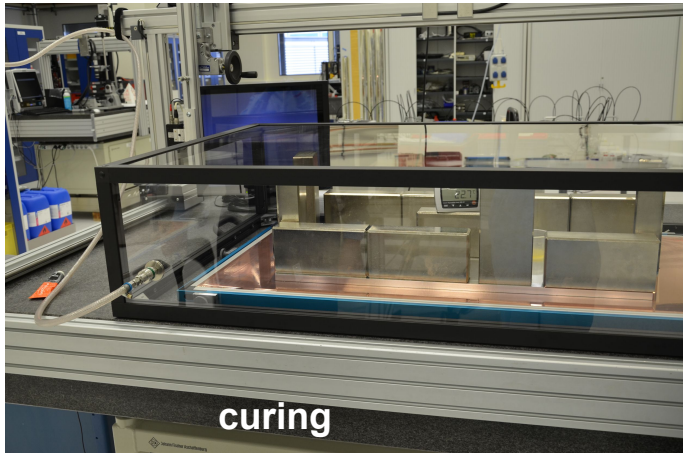


GEM framing









GEM database documenting 923 foils

Home | Category: OROC | Stock | Shipping | Information | logged in: Dariusz

ALICE TPC production database

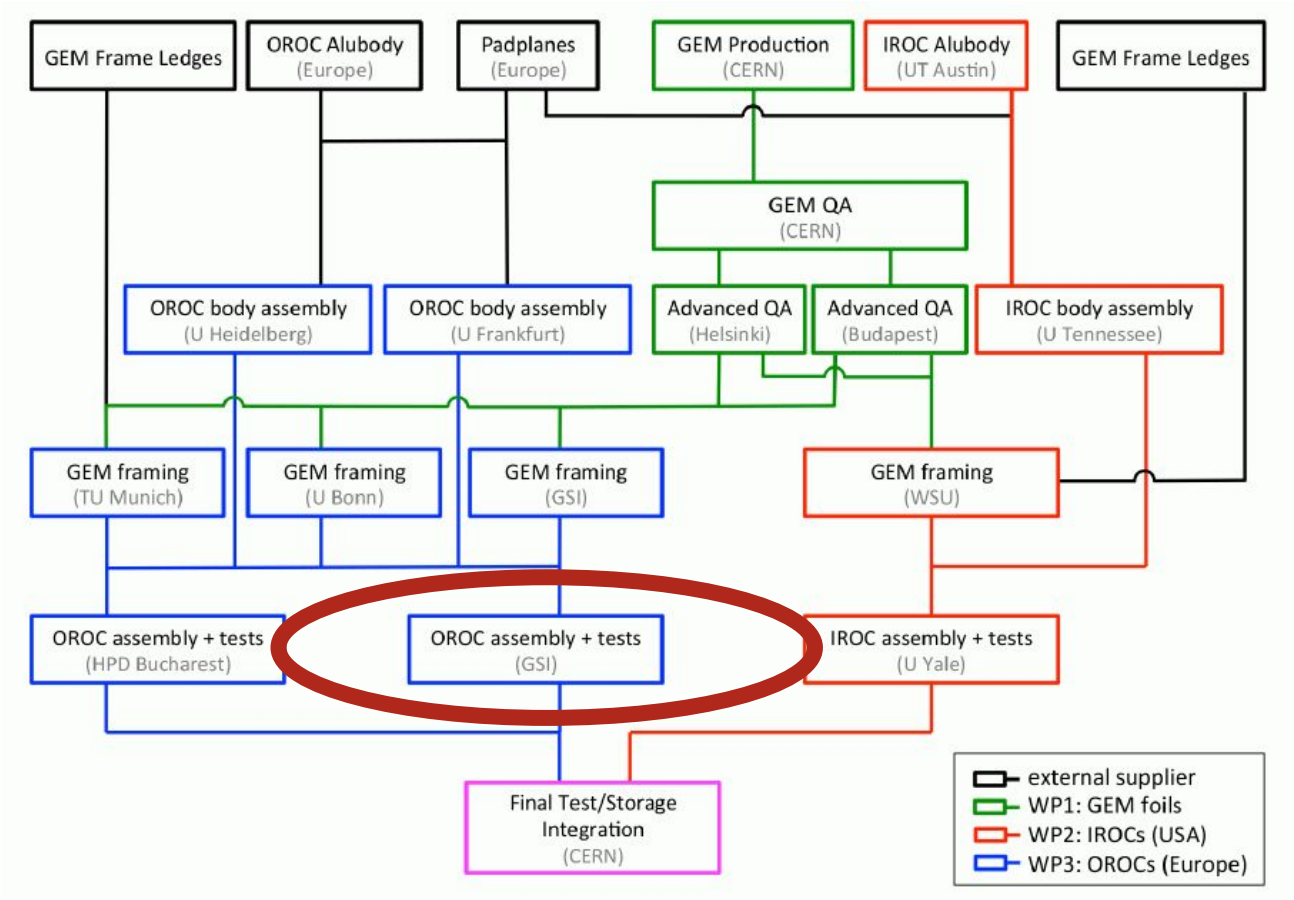
Show selected stock items link to bookmark this selection

Selection — specific QA step selection: off / not done / passed / failed

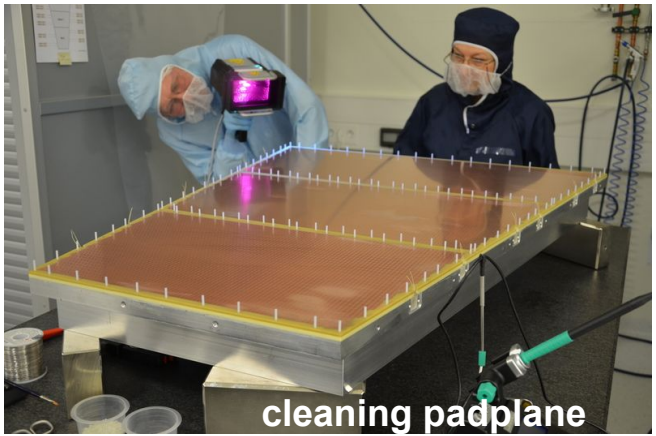
category	part	batch	type	QA status	serialno/bc wildcards %, _	sent?	select location or 'used'	search string within comment regular expressions accepted
OROC	OROC3 GEM foil	any	all types	any				

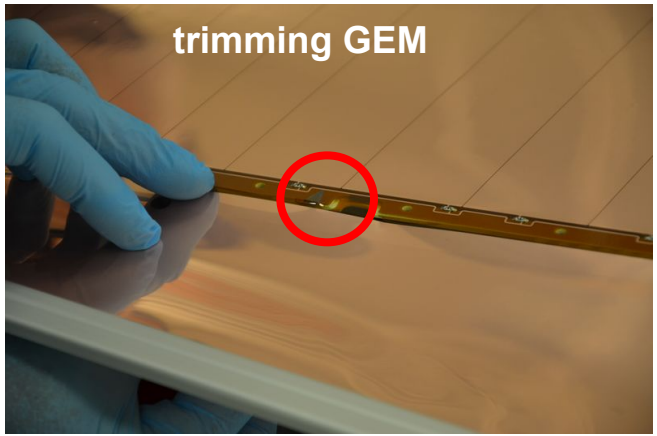
part	item	batch	sent from	sent to	date	location or link to parent	QA status			link	comment
OROC3 GEM foil	O3-G1-001	5				OROC/02	A	20.07.17	CERN	X	
OROC3 GEM foil	O3-G1-002	5				OROC/01	3	15.01.17	CERN	X	
OROC3 GEM foil	O3-G1-003	5				OROC/04	B	30.01.18	CERN	X	
OROC3 GEM foil	O3-G1-004	7				Bonn	QA-A	05.11.18	CERN	X	
OROC3 GEM foil	O3-G1-005	7				GSI	3	17.01.17	CERN	X	GSI: GEM stripped from frame
OROC3 GEM foil	O3-G1-006	7				GSI	QA-A	23.11.18	CERN	X	GSI long term tested
OROC3 GEM foil	O3-G1-007	8				OROC/35	B	19.12.18	CERN	X	GSI long term tested. from CERN
OROC3 GEM foil	O3-G1-008	8				OROC/05	C	30.10.17	CERN	X	GSI tested, framed, tested

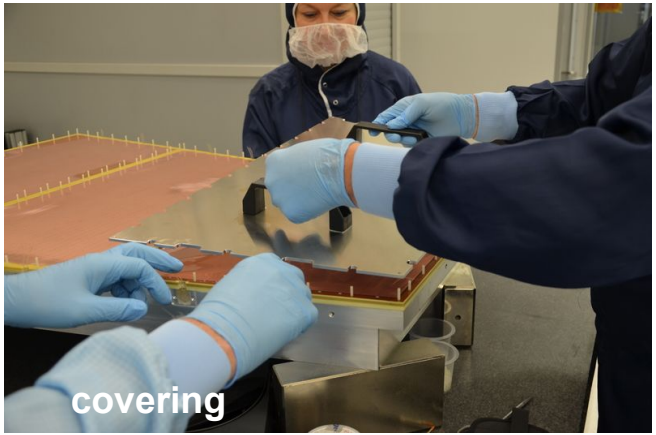
ALICE TPC upgrade project structure



OROC assembly





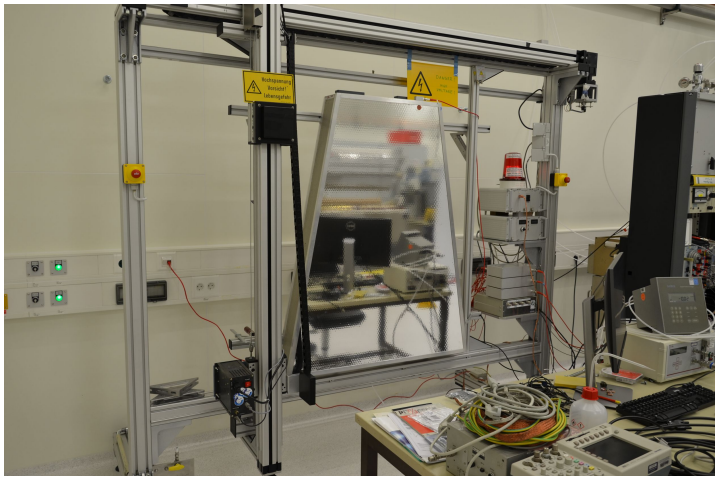

covering


soldering HV connections

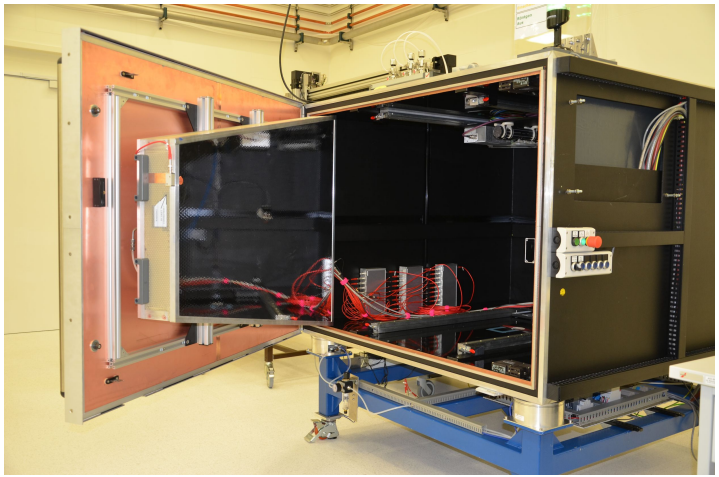

SUPER DRY
tightening nylon screws


SUPER DRY
done

OROC tests at GSI

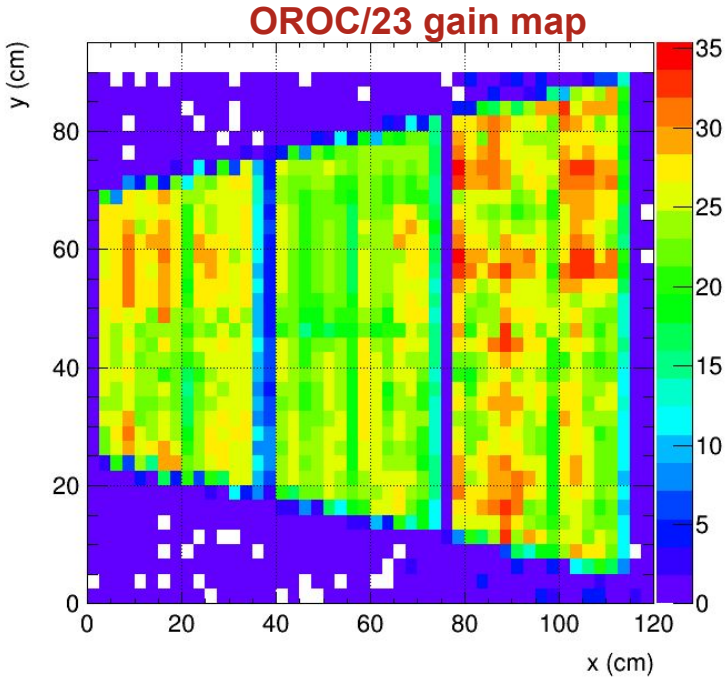


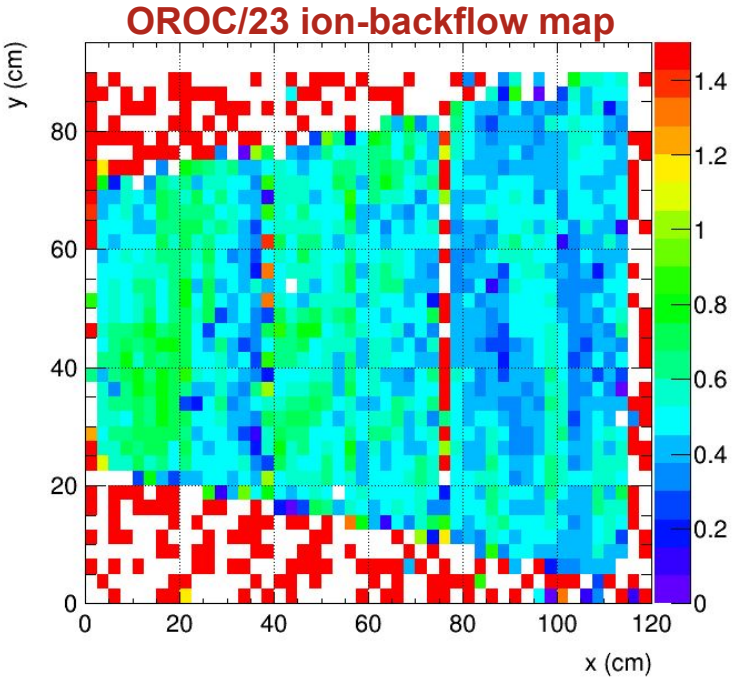
moving x-ray gun at 10 kV
moving ^{55}Fe source of 6 keV x-rays
monitoring currents of padplane and cathode



two x-ray guns at 60 kV, full illumination
monitoring currents of padplane and cathode

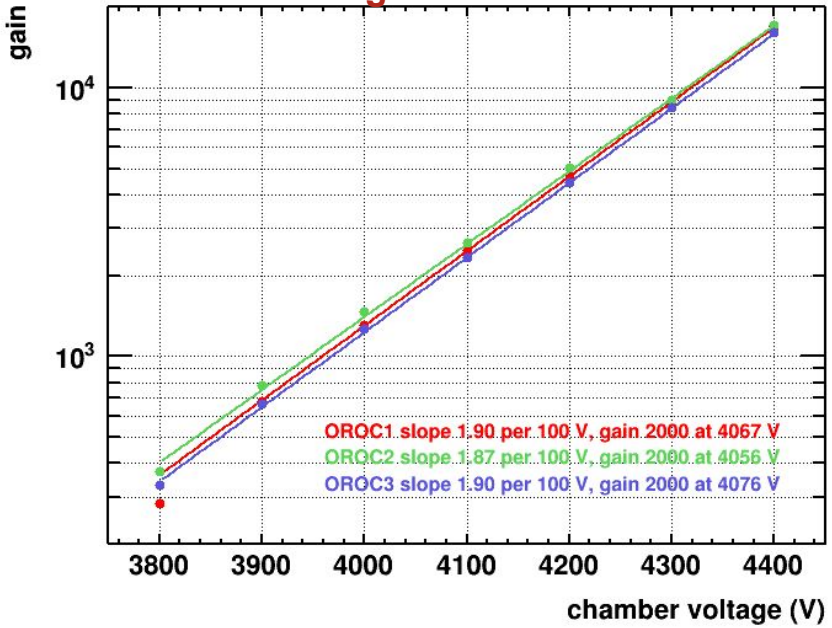
OROC tests



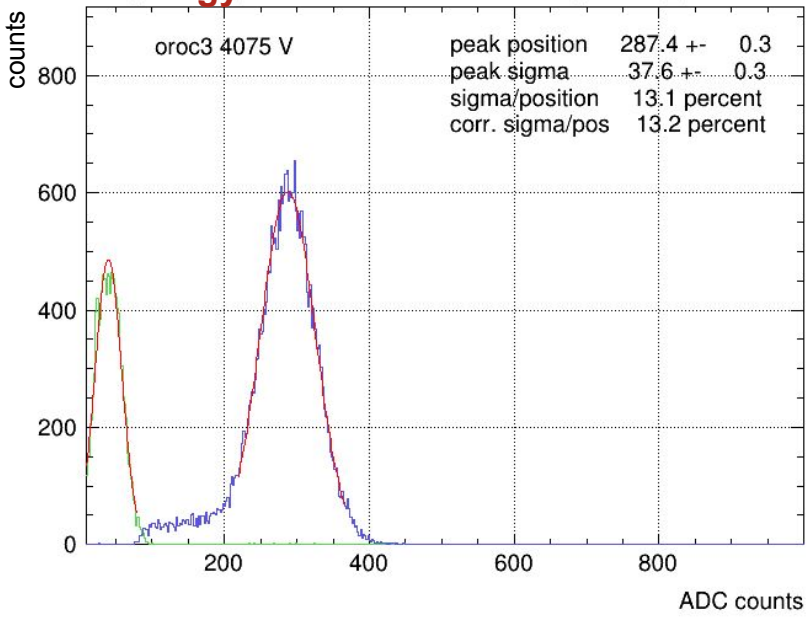


- gain uniformity 11% (standard deviation), requirement <20%
- average ion backflow 0.5%, requirement <1%

gain curves

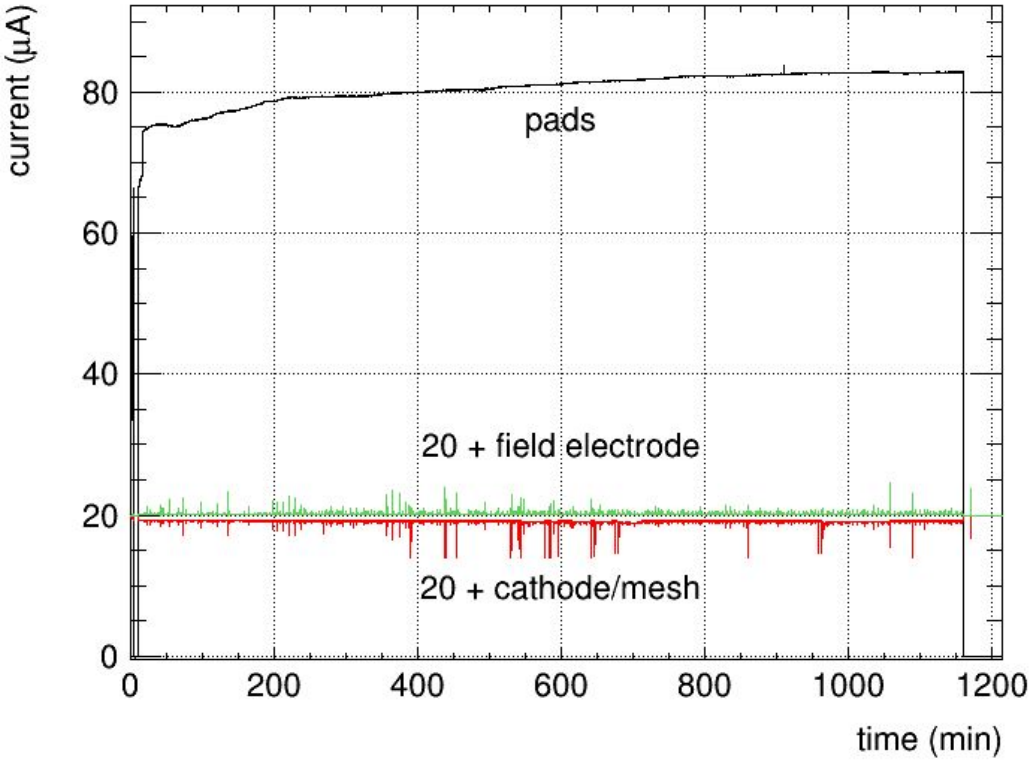


energy resolution with ^{55}Fe source



- gain exponential within 300-15000, nominal gain 2000
- energy resolution 12-14%, requirement <12%

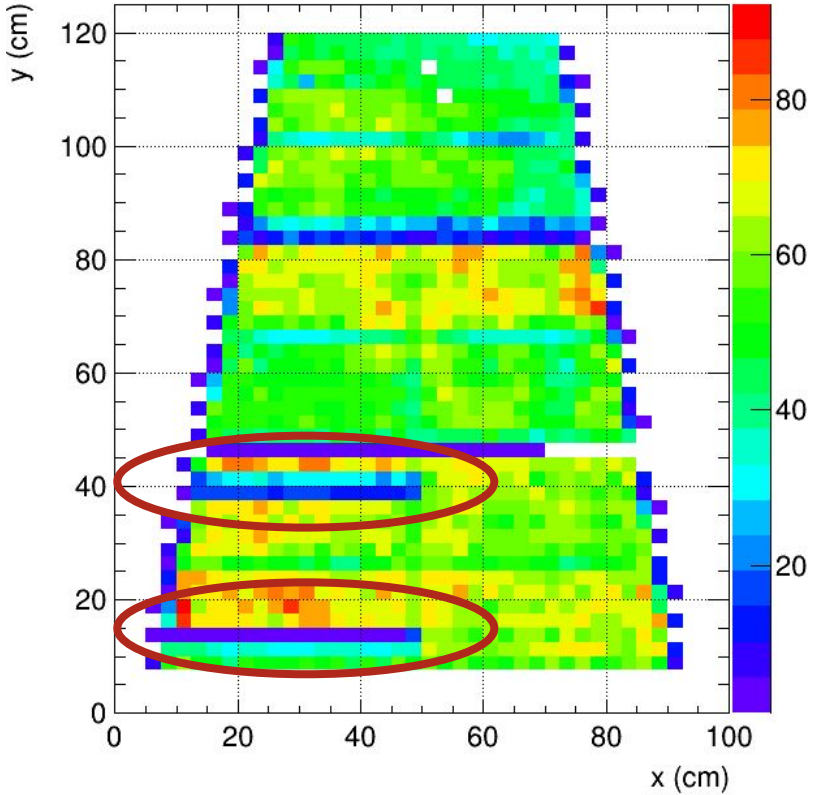
full illumination with x-rays, pad current 10 nA/cm^2



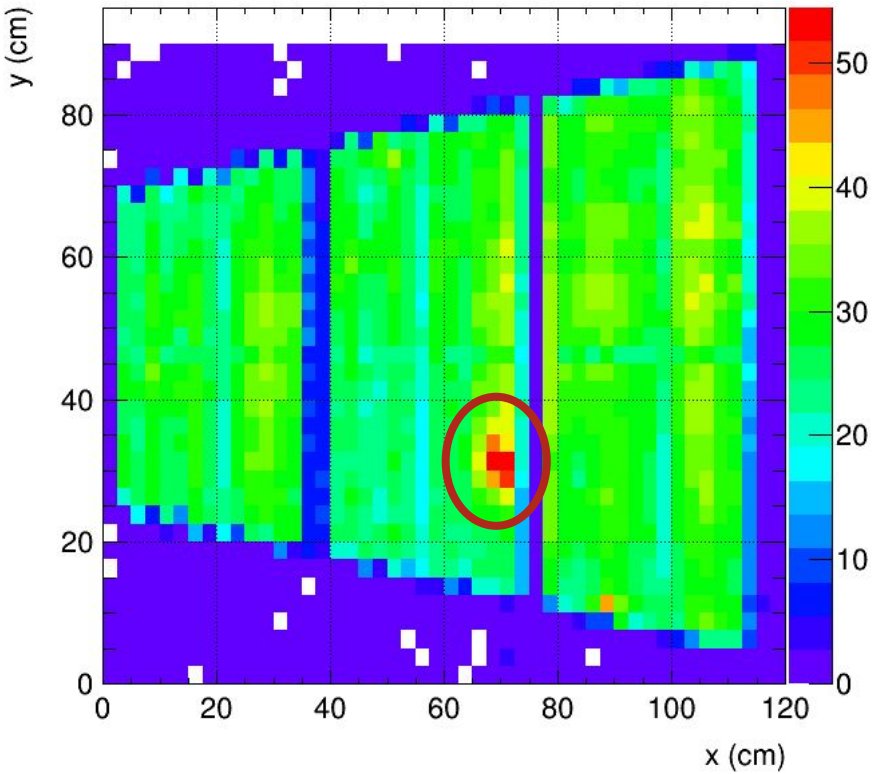
long x-ray irradiation at high intensity, chamber stable

encountered problems

OROC/00 missing segments

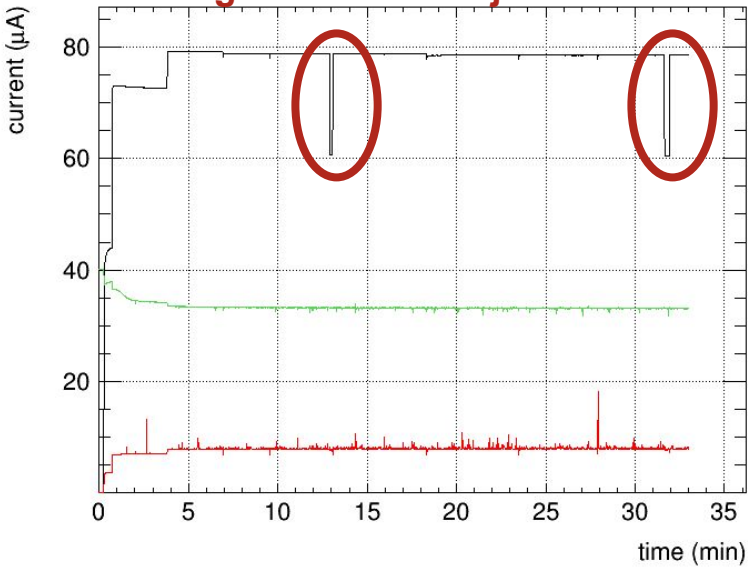


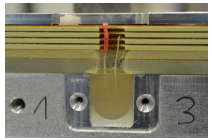
OROC/10 gain hotspot



encountered problems

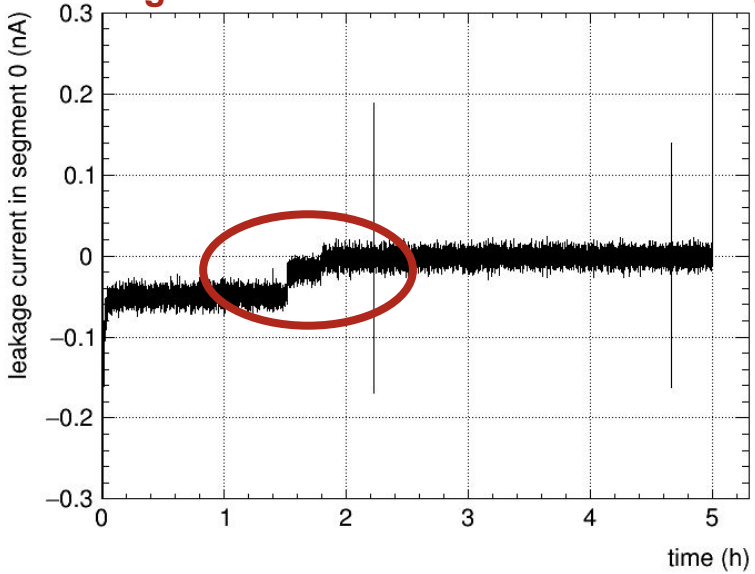
discharges between adjacent HV wires





2.1 kV between GEM3 top
poor fix of the GEM1 top wire

leakage current test sensitive to room light

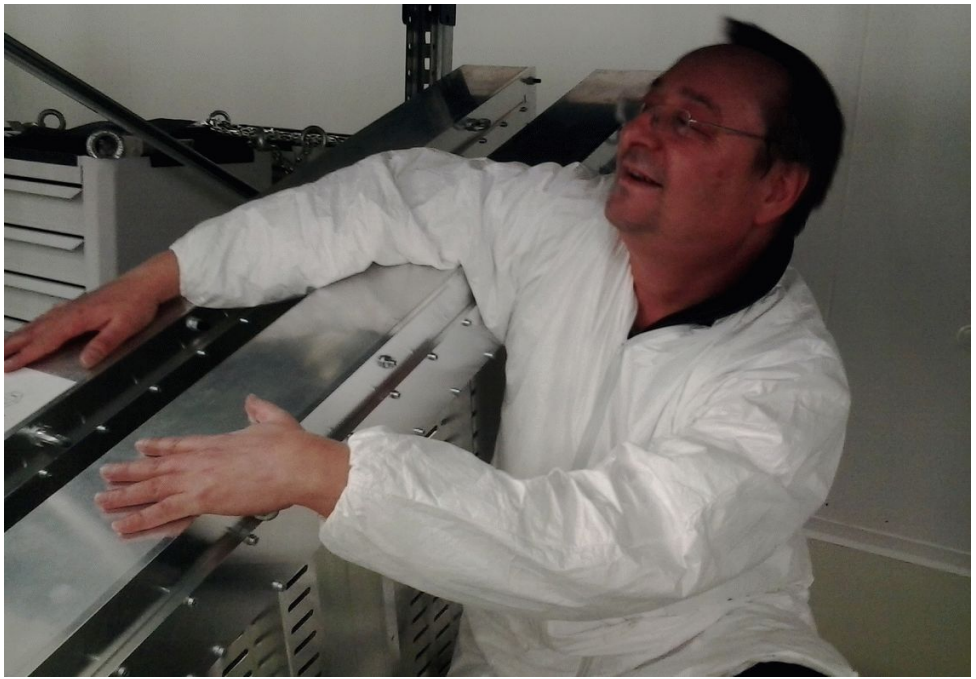


not really a problem

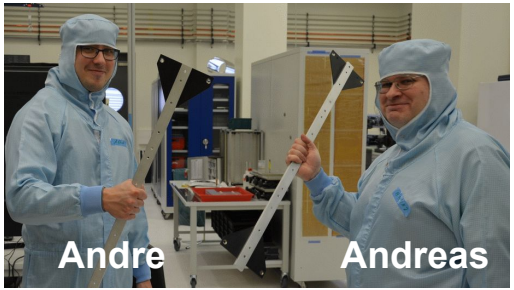
completion of the OROC assembly and tests

- 2015 planning
- 2016 planning and preparing
- 2017 3 OROCs assembled
- 2018 17 OROCs assembled

last OROC shipped to CERN in October 2018, one month before the start of the shutdown



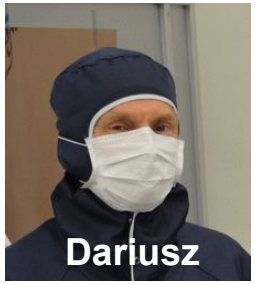

Alena


Andre
Andreas


Bernd


Bogdan


Daniel


Dariusz

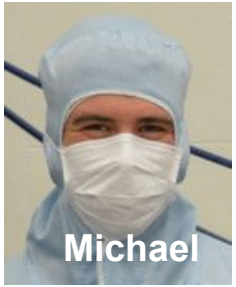

Holger


Joerg

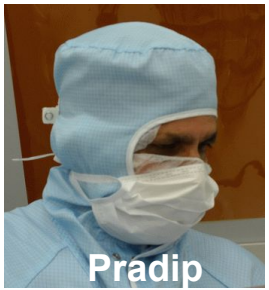

Lilit


Lukas


Manuel


Michael

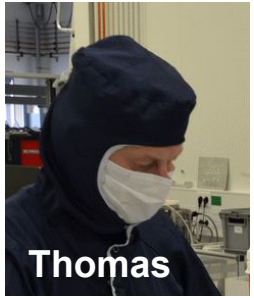

Pascal


Pradip

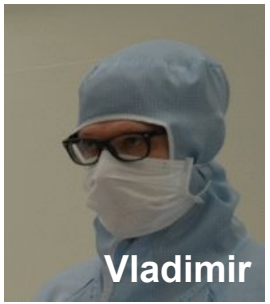

Rajendra


Sebastian


Silvia


Thomas

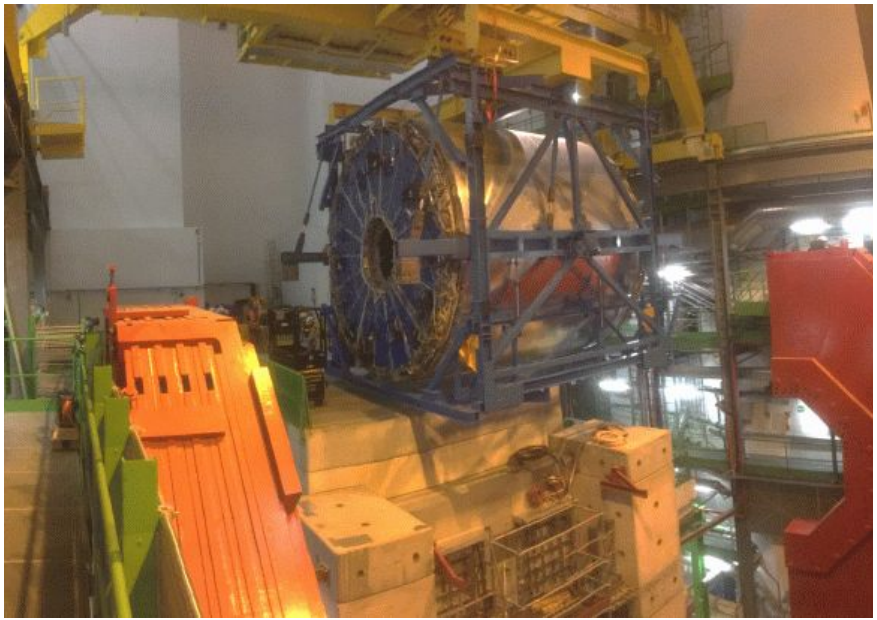

Thomi


Vladimir

And what is happening now?

OROC installation in 2019

TPC extracted (Jan-Feb)



… and brought to the surface (Mar)


Tue 5 Mar
before removal of the services/electronics and cleaning

in the cleanroom

chamber extraction video https://youtu.be/6nENACC8BhY


Jul 2019, side A completely
equipped with GEM chambers

personal summary: how well did things work?

what	expectation	reality
bringing life into things ("Frankenstein effect")	put things together, apply HV, wake them up to live	yes!
flushing volumes with gas	rest gas = exp(-t/tau)	so-so
building tight volumes	you can debug by sniffing	sniffing worked only for big holes
keeping things clean	if you keep things clean, nothing can happen	if you keep things clean, you reduce the probability that something happens
electric discharges in equipment	just keep distance and isolation, then OK	calculate and test carefully, use a safety margin, then OK
electric discharges in gas	absent	statistical

bringing life into things ("Frankenstein effect")

But life functions very differently from the standard condensed-matter fare of metals or superconductors, which are “dead” things whose behaviors are predetermined. Living creatures can respond in seemingly disparate ways to the same stimulus. “Biological systems have this feedback loop that makes them very difficult to analyze using standard differential equations,” Goldenfeld says, adding that he doesn’t yet know how to address that problem.

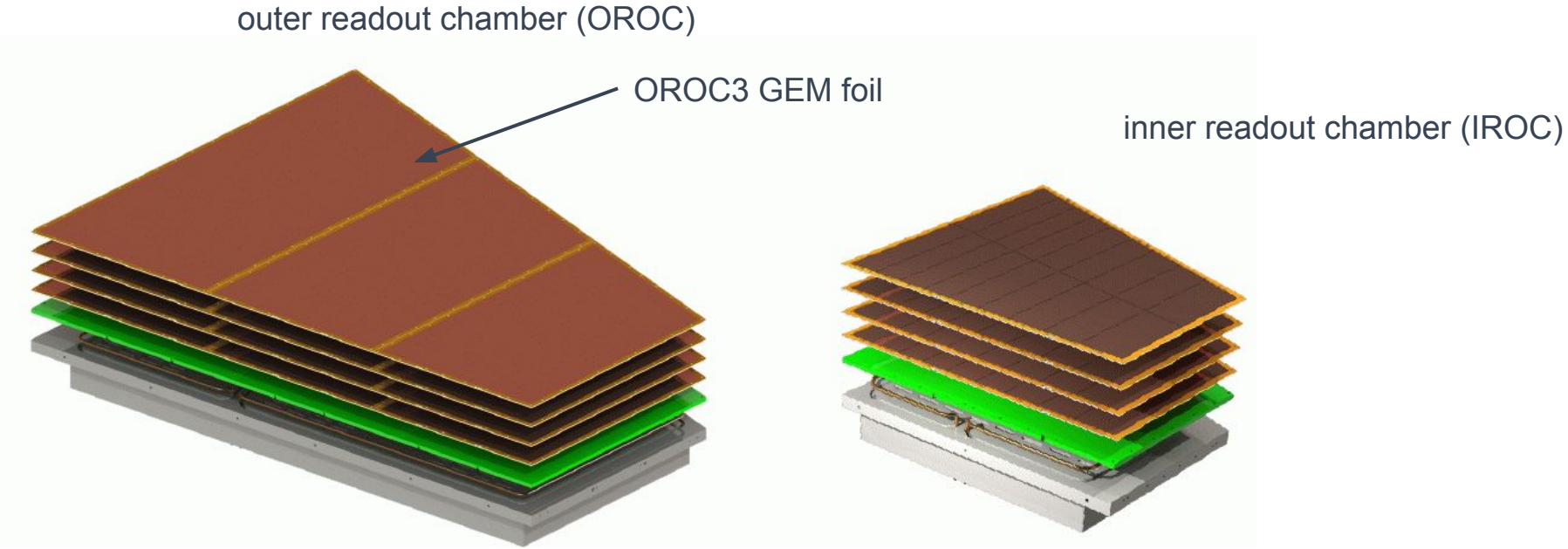
APS Physics, "Life is Physics", January 11, 2019

following this definition, gaseous chambers are living beings

under HV, they always wake up

backup

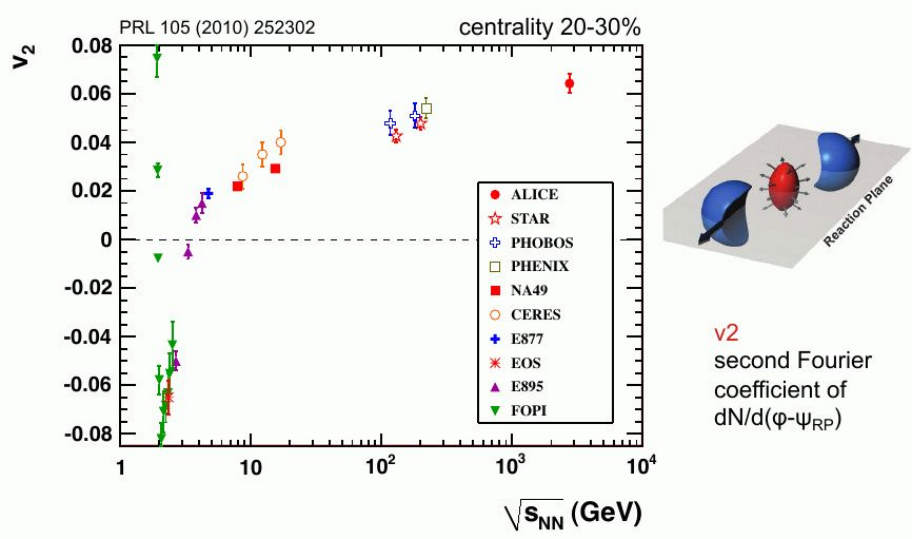
ALICE Time Projection Chamber upgrade 2019



GSI contribution:

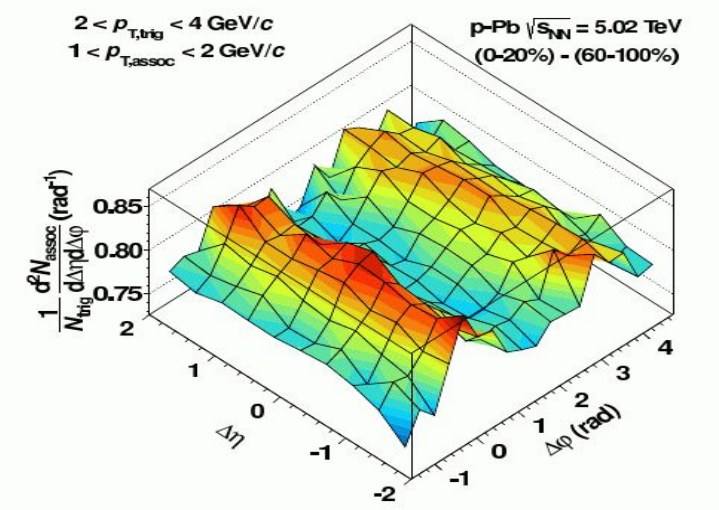
- frame 160 OROC3 GEM foils (= 100% of all)
- assemble and commission 20 OROCs (= 50% of all)

ALICE highlights from Run 1 and 2 (personal selection)



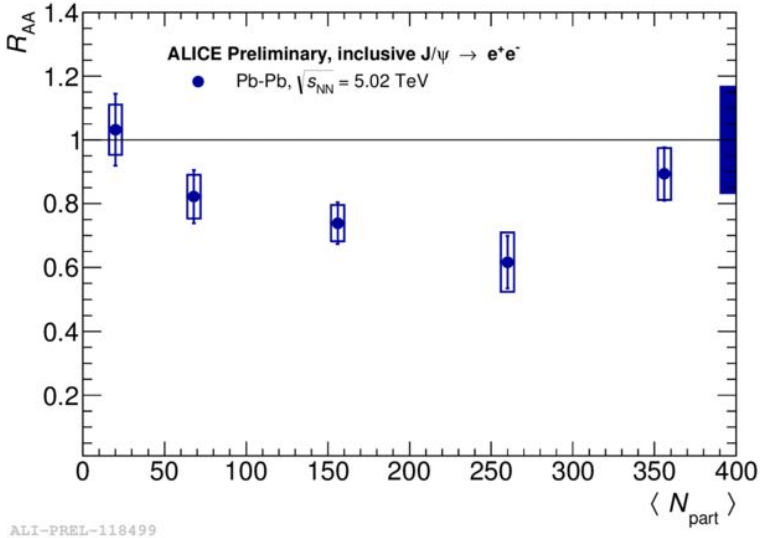
v2
second Fourier coefficient of $dN/d(\varphi-\psi_{RP})$

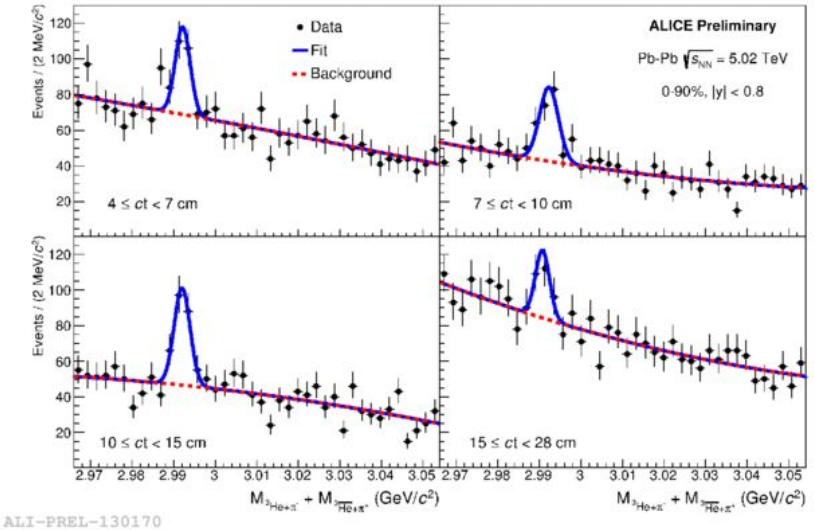
PLB 719 (2013) 29



flow continues at high energy
QGP is NOT a gas of free quarks

collectivity in violent pp and pA collisions (modification of p_T spectra, elliptic flow, p_T dep. of HBT radii) → QGP in small systems?





J/ψ enhancement in central Pb-Pb collisions: c + anti-c coalescence

light nuclei and exotica production (eg. hypertriton ${}^{3}_{\Lambda}\mathrm{H}$)

Collectivity in pp has been predicted!

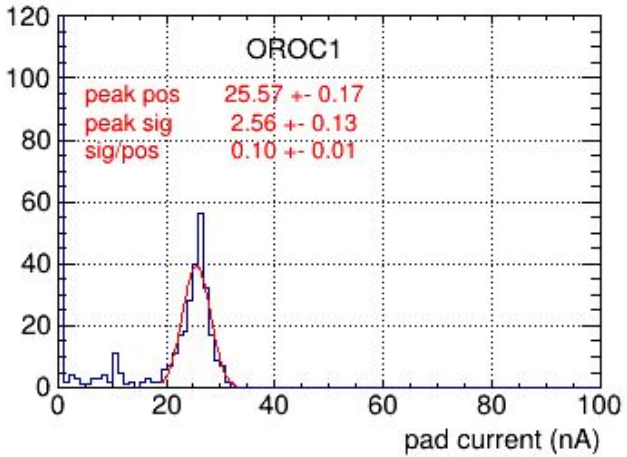
Quark Matter 2008, Jaipur, panel discussion with Blaizot, Kharzeev, Mueller, Schukraft

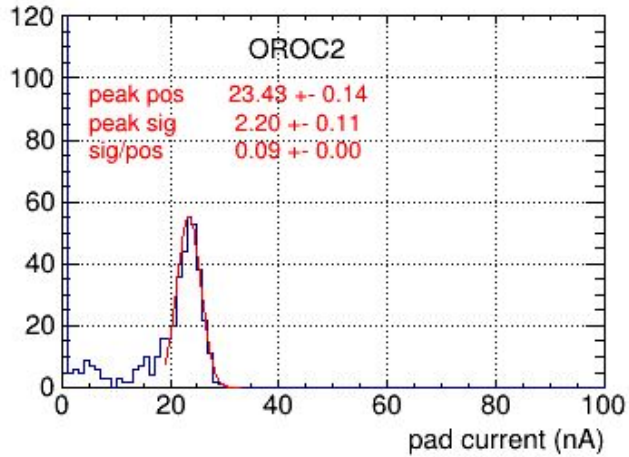
Jurgen Schukraft:

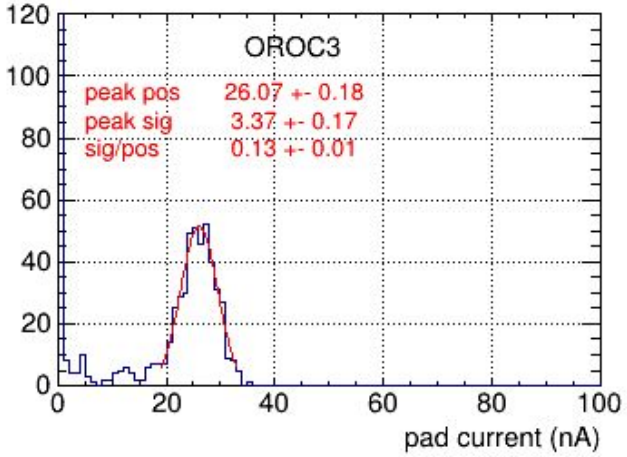
- Multiplicity distribution at LHC
  - ⇨ quite respectable particle densities
    - $dN_{ch}/d\eta \sim 50 - 100$ can be reached !
    - > central S+S @ SPS, mid-central Cu-Cu @ RHIC
  - ⇨ naïvely, energy density $\varepsilon > 5 - 10$ GeV/fm^3
    - $\tau_0 = 1$ fm, V = 5 fm^3
- even protons get obese these days
  - ⇨ p@LHC ~ small (but very dense) nucleus@SPS

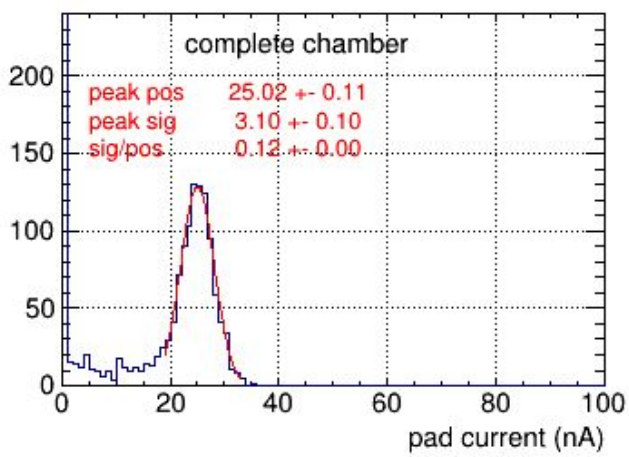
	SPS	RHIC	LHC
# of partons in proton $3 + \int g(x > 2\text{GeV})$	4	10	**30**

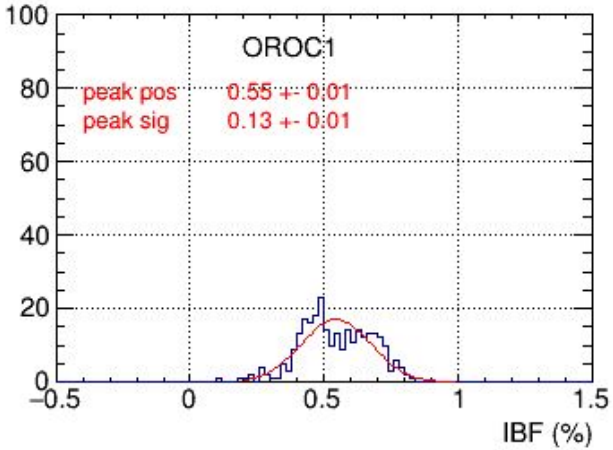
- 'QGP' physics with protons
  - ⇨ at least: onset of hadronic FS interactions
  - ⇨ maybe: collective hadronic/partonic dynamics
  - ⇨ why not: the QGP, mini serving

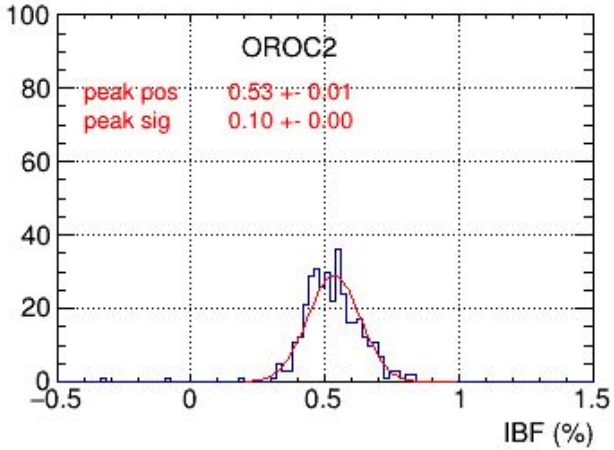

OROC1
peak pos 25.57 +- 0.17
peak sig 2.56 +- 0.13
sig/pos 0.10 +- 0.01
pad current (nA)

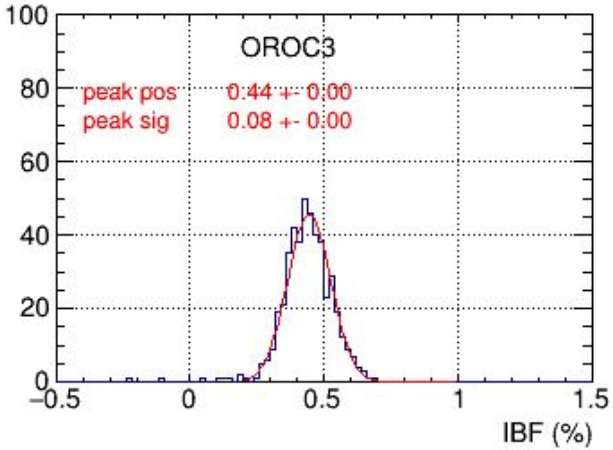

OROC2
peak pos 23.43 +- 0.14
peak sig 2.20 +- 0.11
sig/pos 0.09 +- 0.00
pad current (nA)

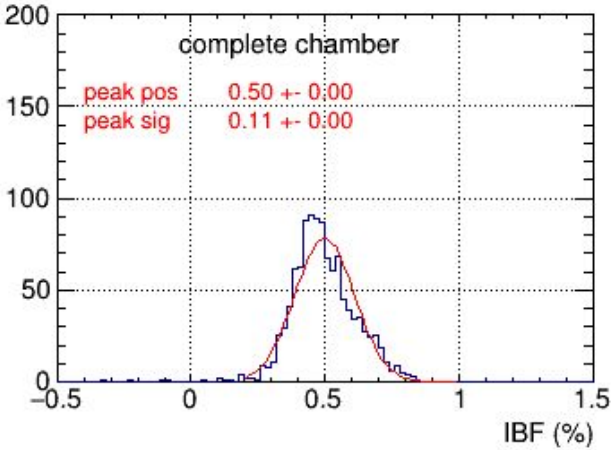

OROC3
peak pos 26.07 +- 0.18
peak sig 3.37 +- 0.17
sig/pos 0.13 +- 0.01
pad current (nA)


complete chamber
peak pos 25.02 +- 0.11
peak sig 3.10 +- 0.10
sig/pos 0.12 +- 0.00
pad current (nA)


OROC1
peak pos 0.55 +- 0.01
peak sig 0.13 +- 0.01
IBF (%)


OROC2
peak pos 0.53 +- 0.01
peak sig 0.10 +- 0.00
IBF (%)


OROC3
peak pos 0.44 +- 0.00
peak sig 0.08 +- 0.00
IBF (%)


complete chamber
peak pos 0.50 +- 0.00
peak sig 0.11 +- 0.00
IBF (%)

test run with open GG

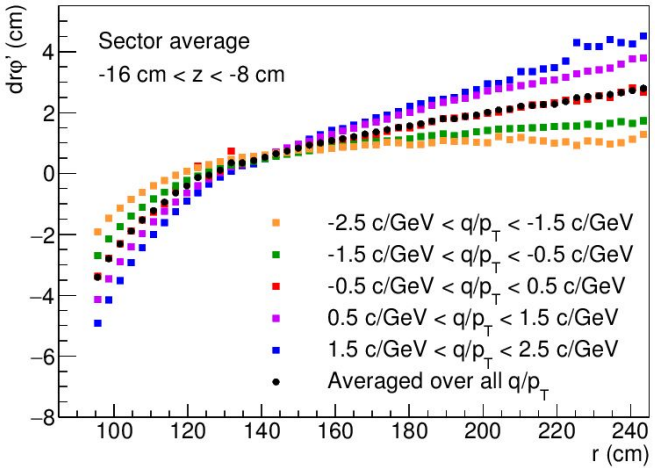
Ernst Hellbär, Marian Ivanov

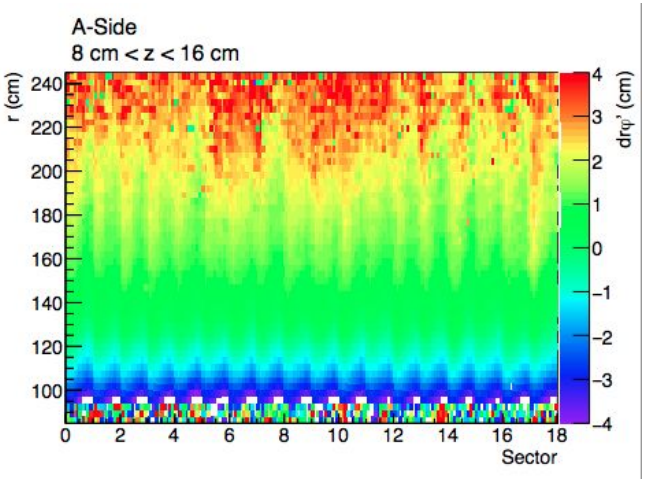
analysis of the special run with open GG taken in pp collisions at 200 kHz

- IBF = 13% (compare to ~0.01% with closed GG, ~1% with four GEMs)
- ε = 900 (compare to ~1 with closed GG, 20 with four GEMs)

⇒ space charge comparable to Pb-Pb in Run 3

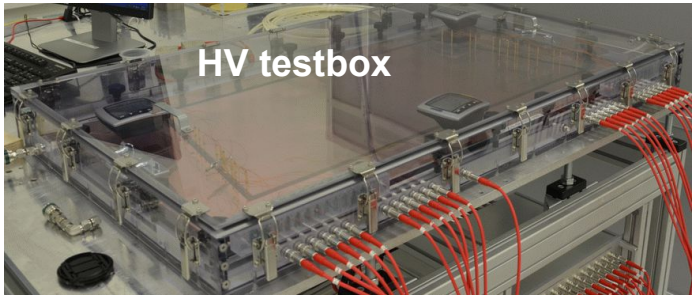
azimuthal distortions observed

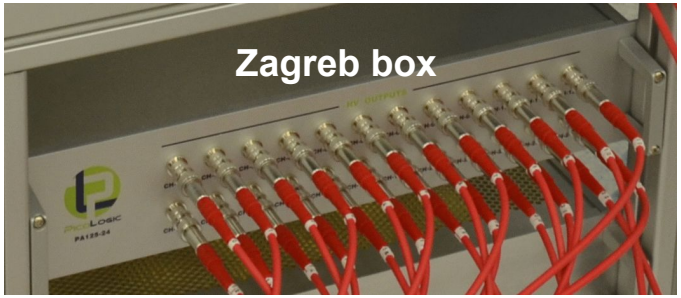


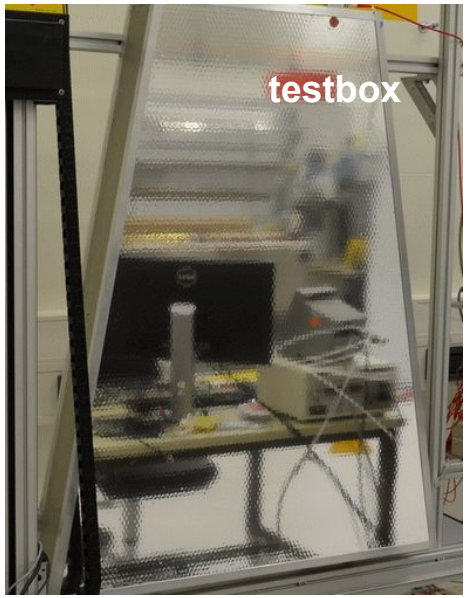


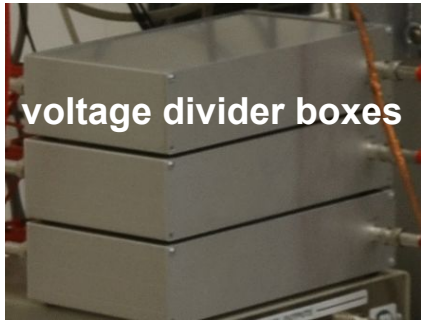
observed distortions agree with simulations with $\varepsilon \approx 15$

project equipment









LHC long-term schedule