Status of the ALICE TPC upgrade

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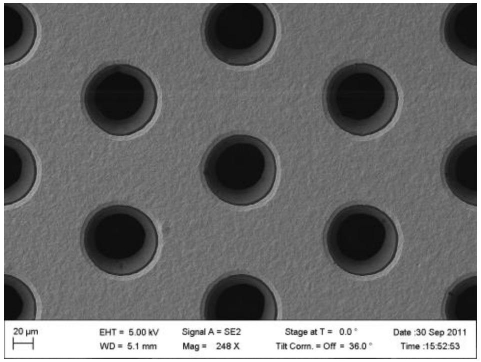
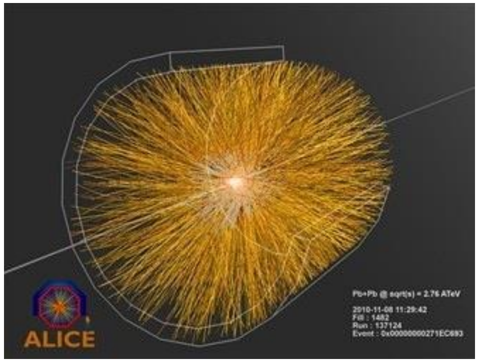
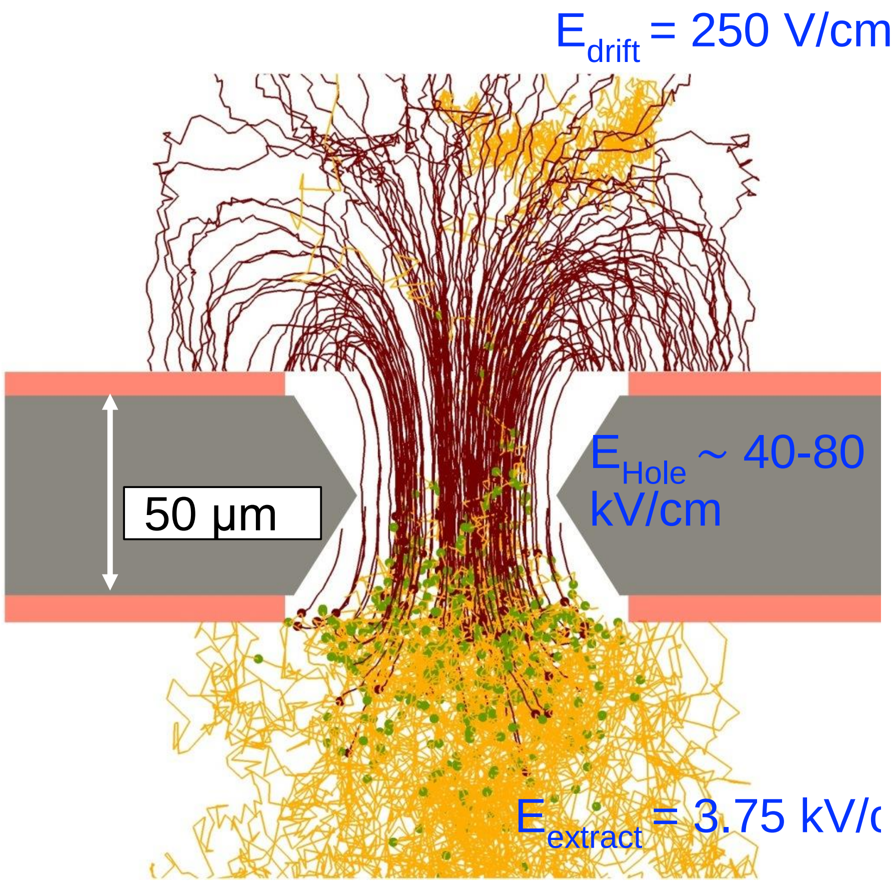


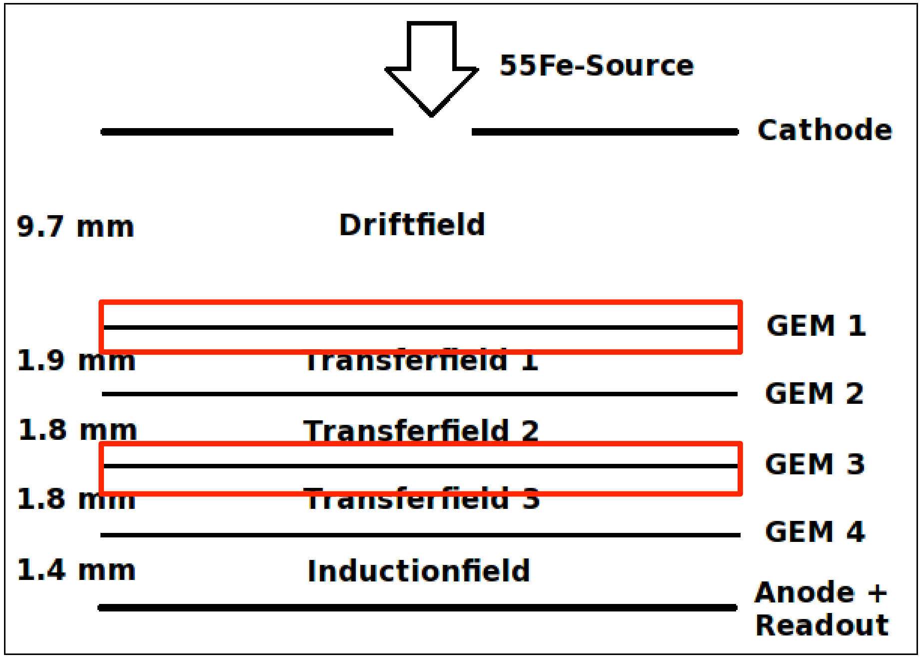


Outline

- **Motivation for the GEM upgrade**
- Ion backflow, energy resolution and discharge probability
- Full production
  - GEM Production and QA
  - Framing
  - Chamber assembly
- Summary

Ion Backflow Suppression





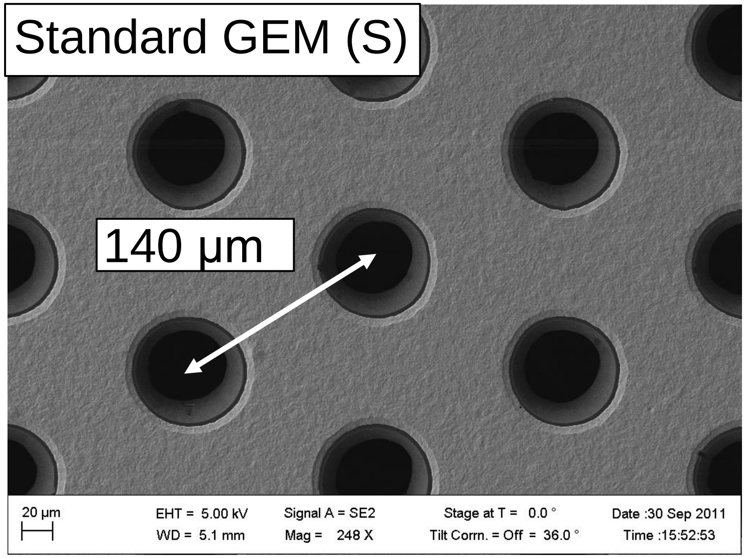
Ion Backflow suppression of a GEM ~ 10^{-1} for a single GEM
~ 10^{-2}-10^{-3} for a GEM stack

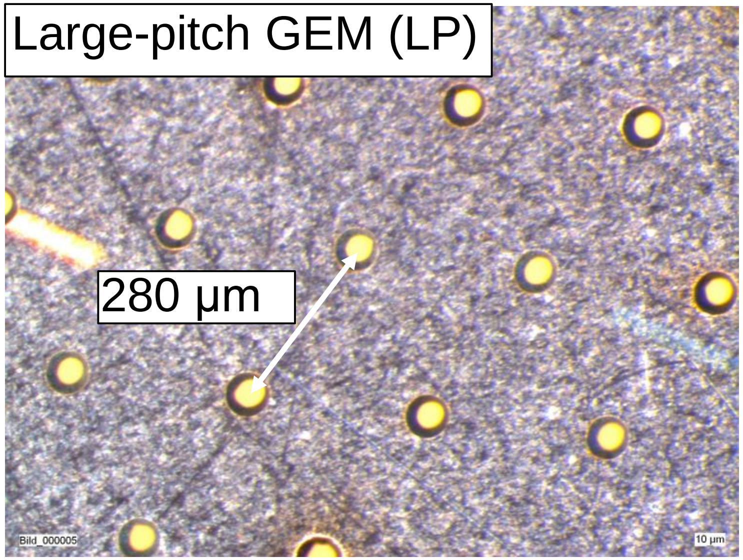
Asymmetric field configuration can be repeated in a GEM stack !

$E_{drift} < E_{T1}, E_{T2} < E_{T3}$

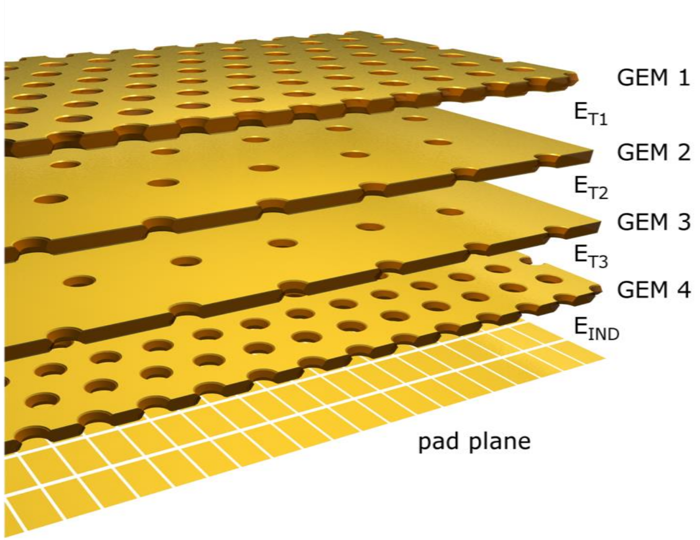
$\Delta U_{G1} < \Delta U_{G2} < \Delta U_{G3} < \Delta U_{G4}$

Properties of a GEM foil



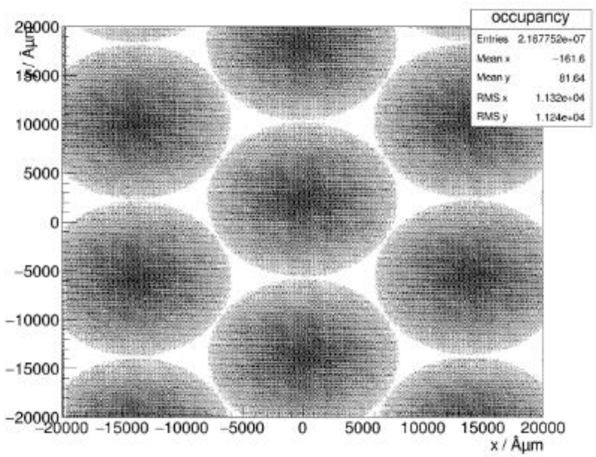


- Requirements could not be fulfilled with a triple GEM (S-S-S) setup
- New readout chambers employ standard pitch (S) and large pitch GEM foils in a S-LP-LP-S configuration
- HV configuration has to be optimal for ion back flow, energy resolution and low discharge probability at the same time

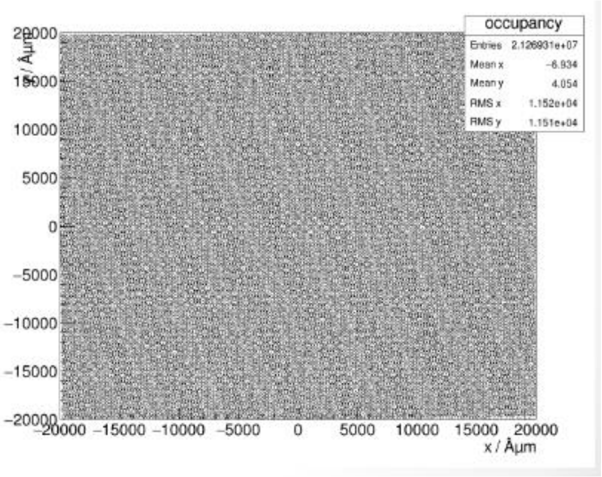


Rotation of Foils

Foils rotated 1°



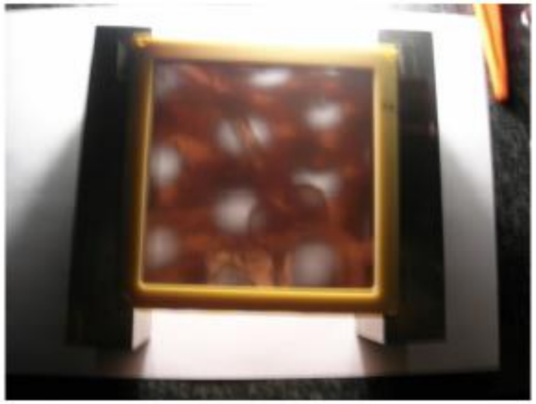
Foils rotated 90° to each other



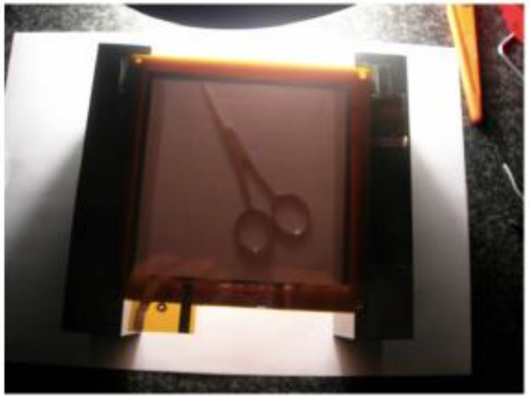
Alignment of the GEM foils

- Alignment between the GEMs crucial → uniform IB
- Rotation makes the S, LP foils unique (G1 ≠ G4, G2 ≠ G3
- To decrease the IB further than with the IB optimised electric field configuration → use GEM foils with different geometries (different optical transparencies)

Foils not rotated



Foils rotated 90° to each other



- Motivation for the GEM upgrade
- **Ion backflow, energy resolution and discharge probability**
- Full production
  - GEM Production
  - Framing
  - Chamber assembly
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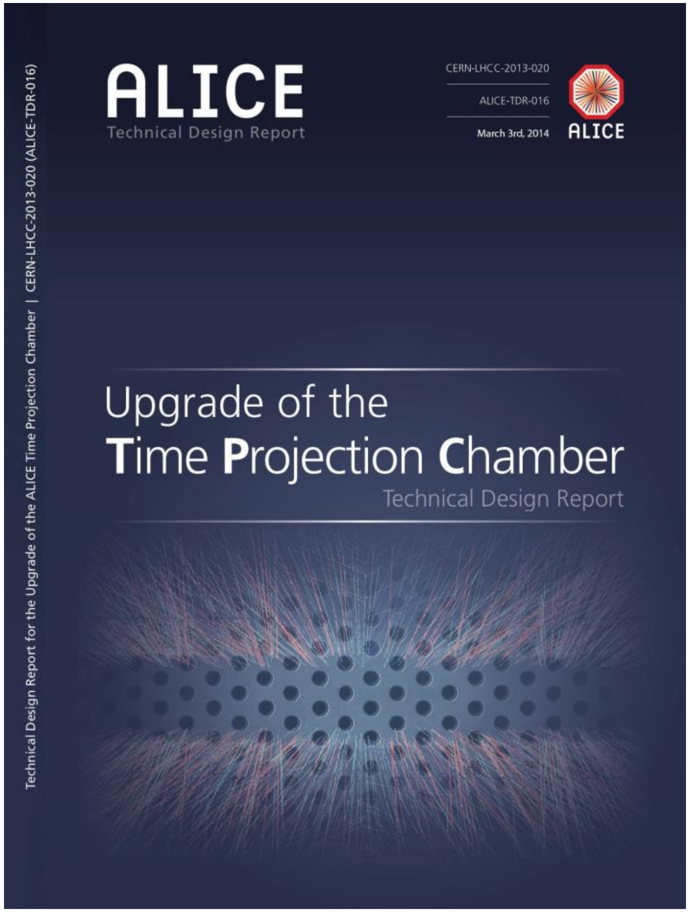
Upgrade TDR of the ALICE TPC



CERN-LHCC-2013-020
Addendum:
CERN-LHCC-2015-002

Requirements for the upgrade GEM based TPC of ALICE

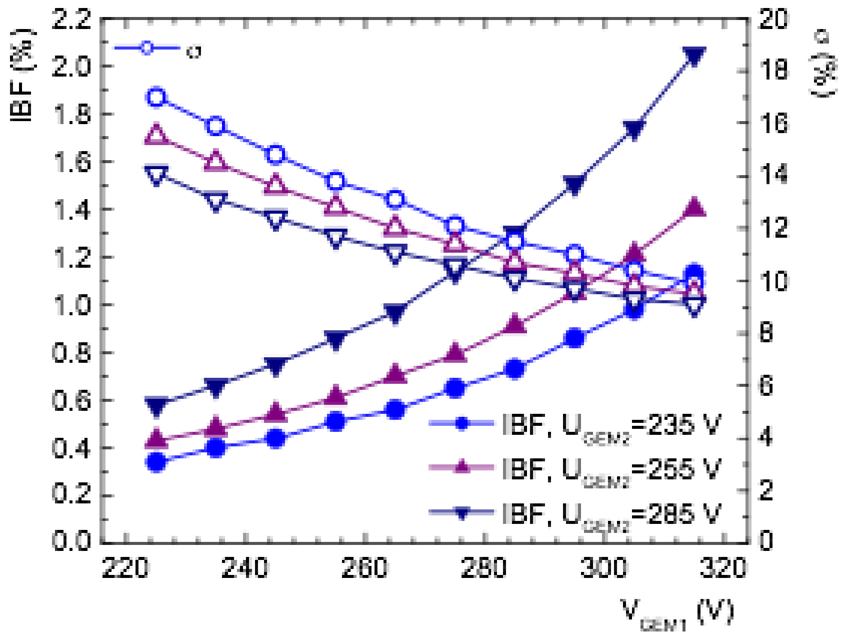
- Drift field: 0.4 kV/cm
- Detector gas: Ne-CO_2-N_2 (90-10-5)
- Effective gas gain: 2000
- S/N ratio ~ 20
- IB: < 1 %
- ε: < 20
- σ/E (5.9 keV): < 12 %
- Low discharge probability
- Operation at 50 kHz (Pb-Pb)

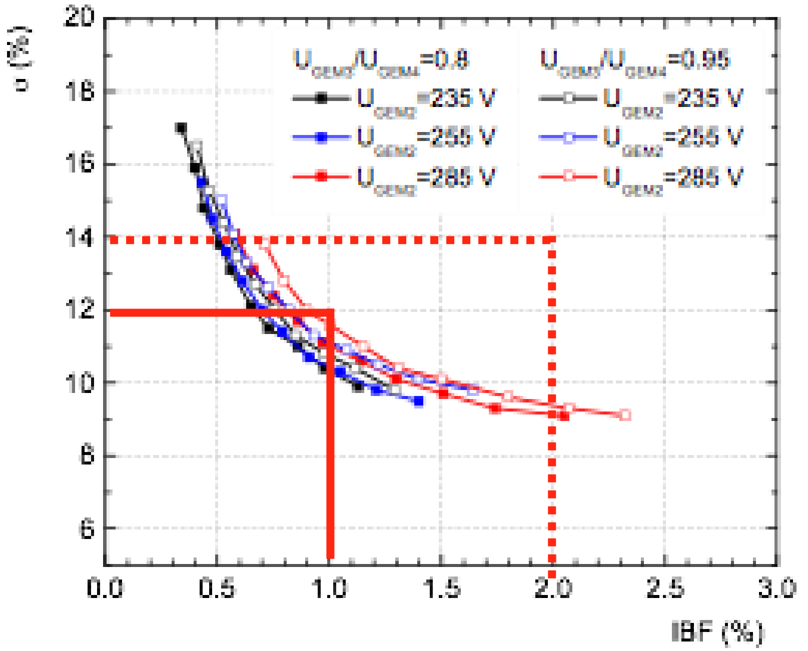
Ion Backflow
IB := Ratio of I_{Cath} / I_{Anode}

Number of back drifting ions / e^-_{prim}
ε := IB*gain - 1

Baseline solution for IB and Energy-resolution

(S-LP-LP-S)



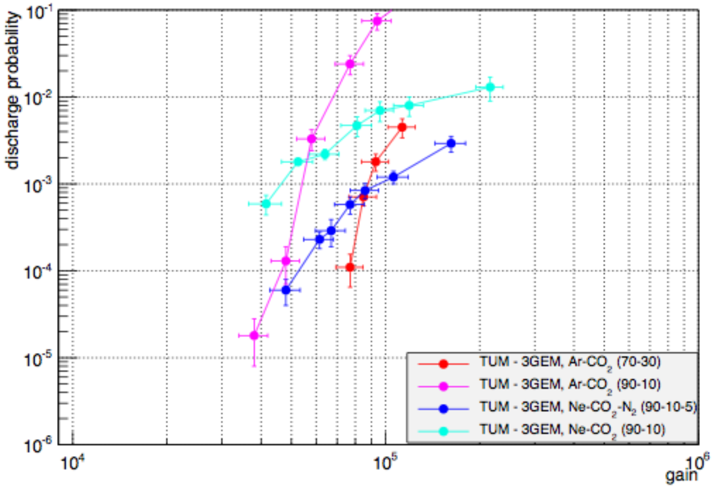


Optimisation of two parameters at the same time is conflicting:

- Best Value IB ~ 0.6 % at an energy resolution of σ/E < 12 %
- Upgrade goals have been reached with some margin for fine tuning (in case needed for the stability)
- Much larger phase space has been scanned no significant improvements (no order of magnitude) are expected

Discharge Probability

(S-LP-LP-S)



Stable operation under LHC conditions

- Discharge probability studies (TUM, CERN):
  - $< 10^{-10}$ (4GEM, measured with alpha particles)
  - $(6 \pm 4)\times10^{-12}$ (hadron beam at the SPS)
- Discharge propagation studies
- HV system stability (CERN, IKF, TUM)
- Charge density studies
  (see P. Gasik, A. Mathis, L. Fabbietti, J. Margutti NIM A870 (2017) 116)
- See presentation of P. Gasik

	S-S-S	S-S-S-S		S-LP-LP-S		
	'standard' HV G = 2000	IB = 2.0% G = 2000	IB = 0.34% G = 1600	IB = 0.34% G = 3000	IB = 0.34% G = 5000	IB = 0.63% G = 2000
^{220}Rn $E_\alpha = 6.4$ MeV rate = 0.2 Hz	$\sim 10^{-10}$			$< 2\times10^{-6}$	$< 7.6\times10^{-7}$	
^{241}Am $E_\alpha = 5.5$ MeV rate = 11 kHz						$< 1.5\times10^{-10}$
^{239}Pu+^{241}Am+^{244}Cm $E_\alpha = 5.2$+5.5+5.8 MeV rate = 600 Hz		$< 2.7\times10^{-9}$	$< 2.3\times10^{-9}$	$(3.1\pm0.8)\times10^{-8}$		$< 3.1\times10^{-9}$
^{90}Sr $E_\beta < 2.3$ MeV rate = 60 kHz					$< 3\times10^{-12}$	

- Motivation for the GEM upgrade
- Ion backflow, energy resolution and discharge probability
- **Full production**
  - **GEM Production**
  - **Framing**
  - **Chamber assembly**
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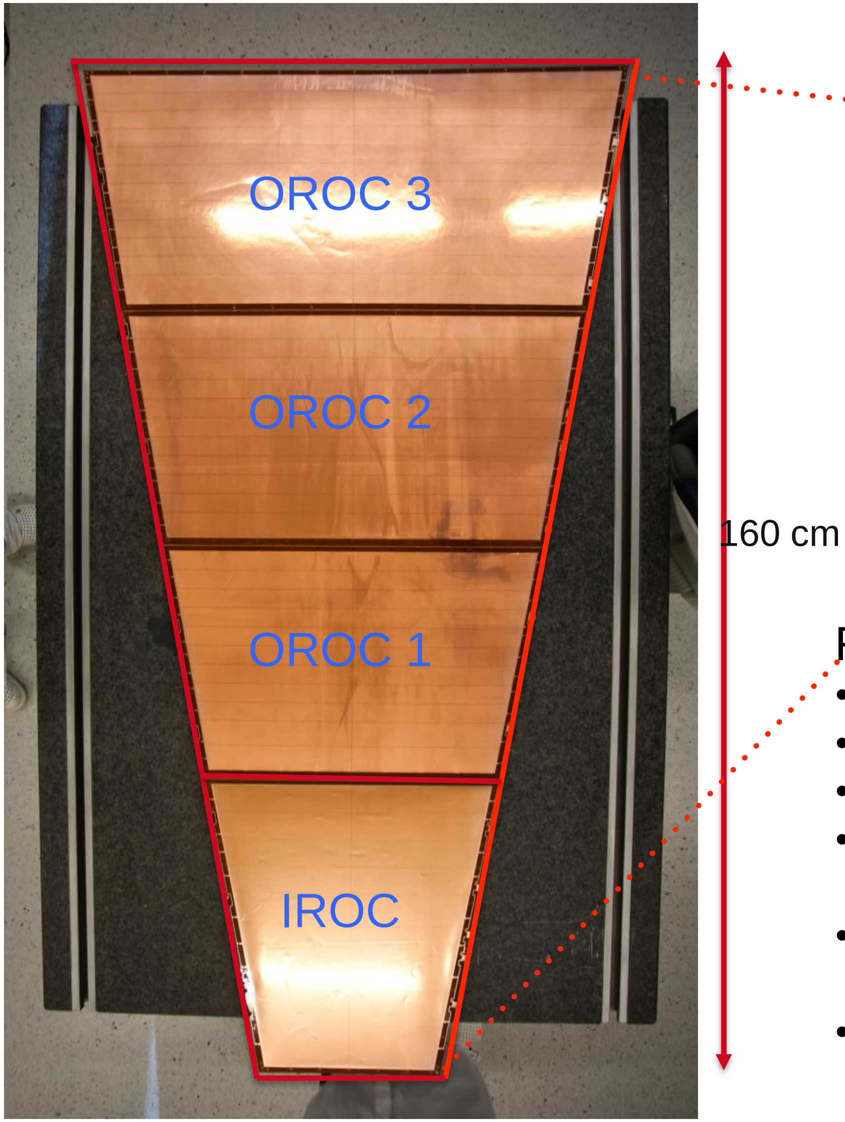
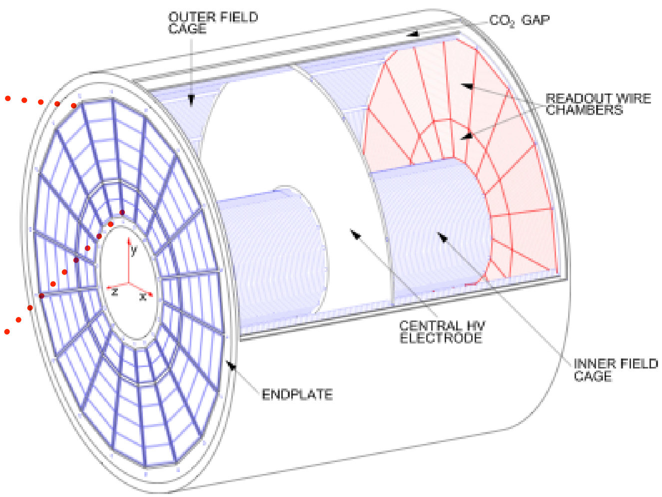
The TPC upgrade with GEMs





Replace 72 Readout Chambers in total !

- Each IROC consists of 4 GEMs
- Each OROC consists of 3x4 GEMs
- 576 GEM foils
- (+ spare chambers, plus yield not 100 %, rather ~90 %)
- → The quality of at least 720 GEM foils has to be assured
- → 40 IROC and 40 OROC fully qualified chambers have to be delivered (640 GEM foils)

TPCU milestones

- R&D and Prototyping — 2012-2015
- LHCC approval — June 2015
  (TDR, TDR Addendum, TDR Addendum UCG)

– Engineering design Review (EDR) — November 2015

– Training (School of ROCs, Visits at all institutes, etc.)

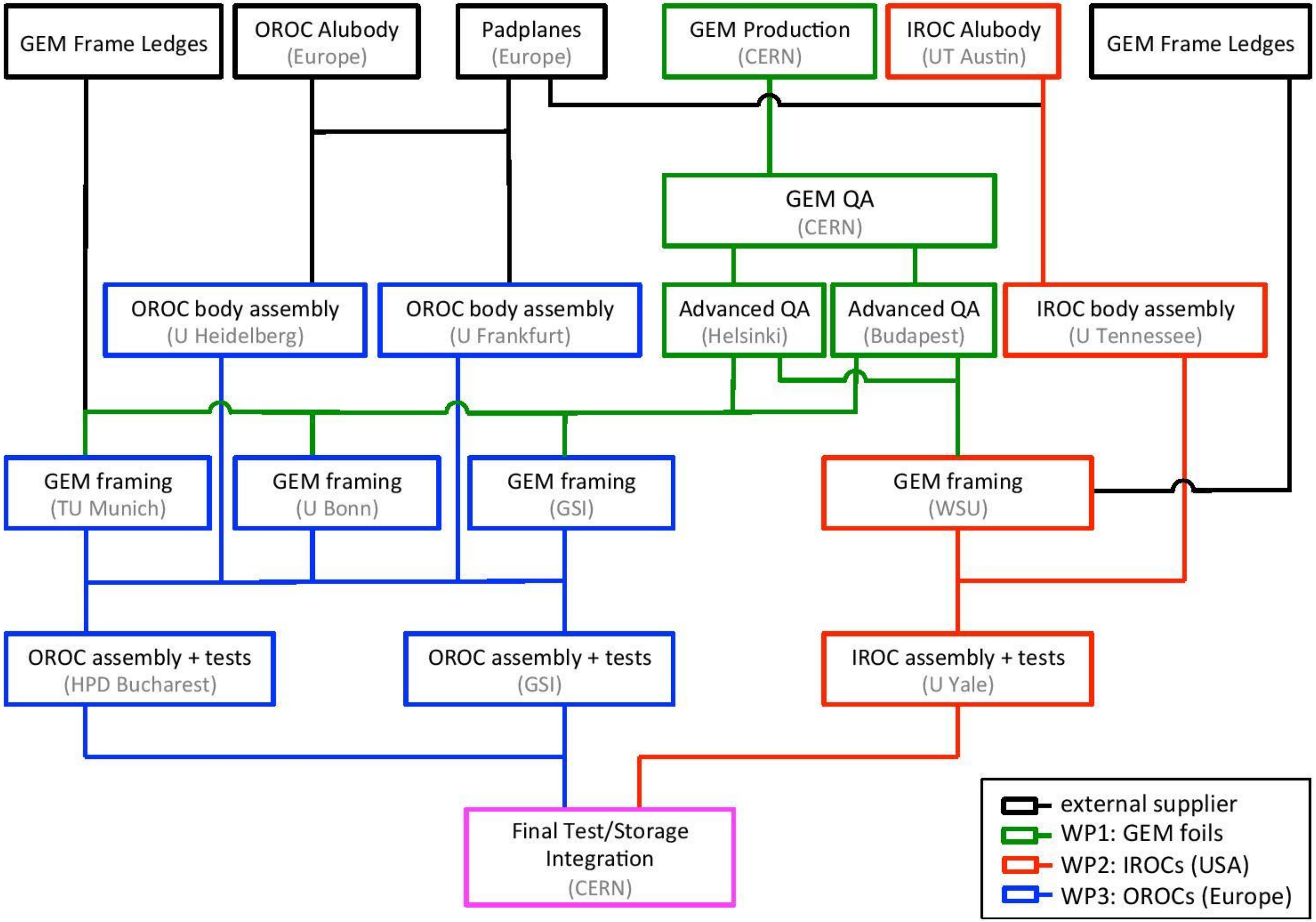
- GEM and chamber final design review — June 2016
- Pre-production: — finalized
- Production Readiness Review (PRR) — 10^{th} March 2017

– - full characterization of the final-design (aka PRR) chambers

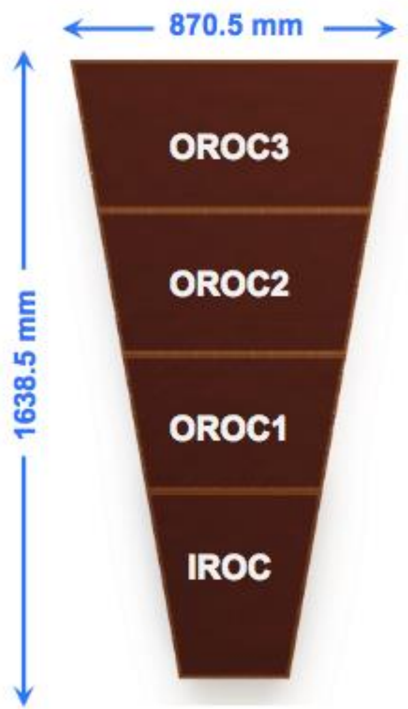
– Mass production (40x IROCs + 40x OROCs) — Q2.2017 – Q3.2018

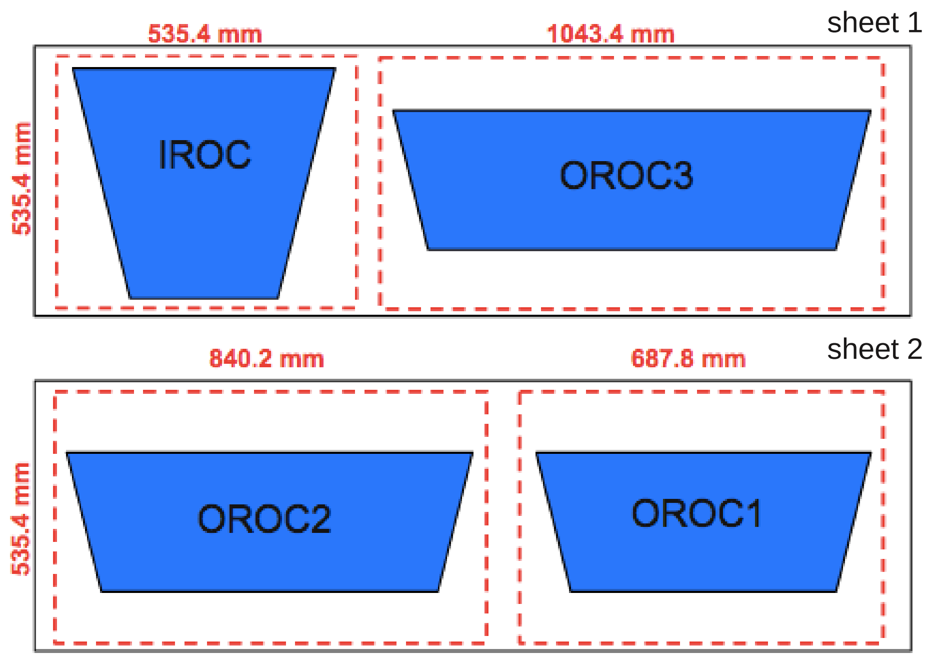
– ROC tests at LHC — Q2.2017 – Q3.2018

Participating Institutes



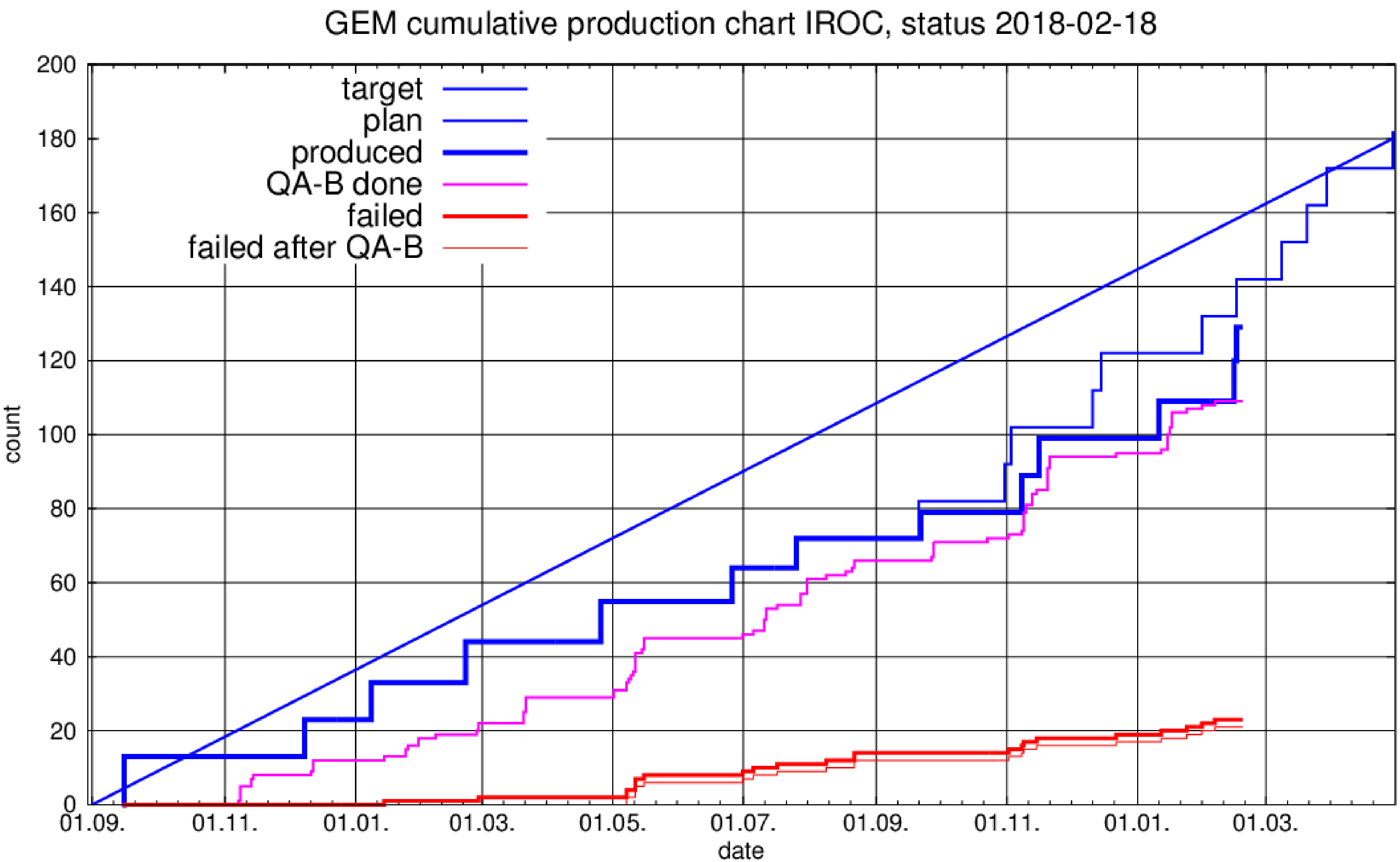
GEM production at CERN





- GEM production at CERN
  - 144 GEMs of each type: IROC, OROC 1, 2, 3
  - 720 individual GEMs (including 10 % spares) = 2 x 180 sheets (IROC + OROC3, OROC1 + OROC2)
  - Each type has 4 flavours (G1, G2, G3, G4), which are unique

GEM Production Progress



GEM Production Progress

ROC GEM Foils	Total (produced)	QA-B done	QA-B passed	failed	failed (w/o 5)	Sliding Yield	Sliding Yield (w/o 5)
IROC	129	109	88	23	17	0.807	0.844
OROC1	124	124	107	17	13	0.863	0.895
OROC2	115	115	107	8	5	0.930	0.957
OROC3	132	111	94	17	15	0.847	0.865
Total	**500**	**459**	**396**	**65**	**50**	**0.863**	**0.891**

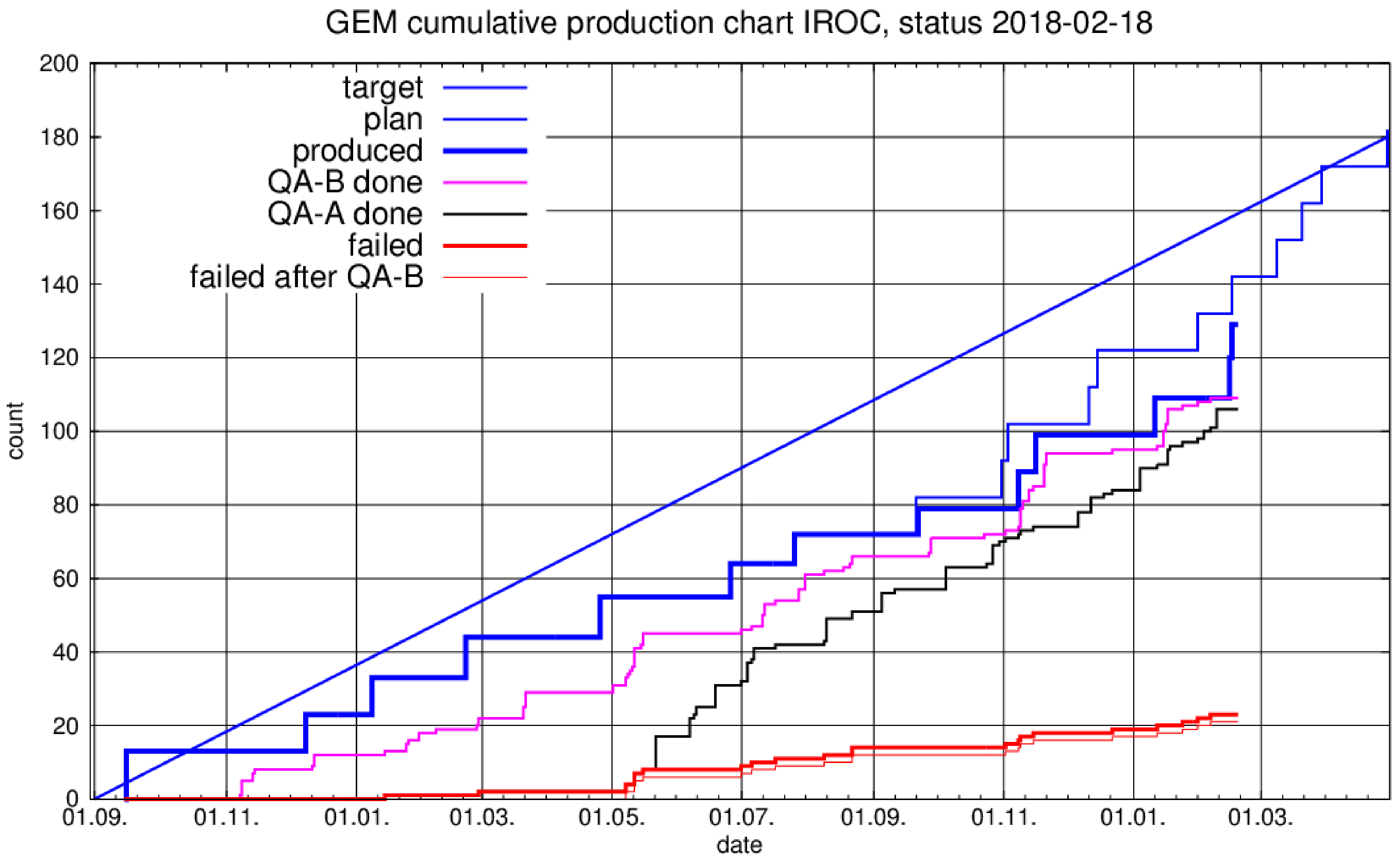
- February 2018: 500 foils produced (target: 720 = 640+80 spares)
- GEM production: Original end of production was planned end of april, now in may
- Projected yield: ~ 90% (constantly monitored)
- Yield might be too tight → 720 produced GEM foils might not be sufficient to finish ROC production
- 80 GEM foils on top of the 720 → 800 (need 640 GEMs for 40+40 ROCs)
- Very powerful database system is in place
- Keeps track of all GEMs, components and QA results

GEM Production Progress

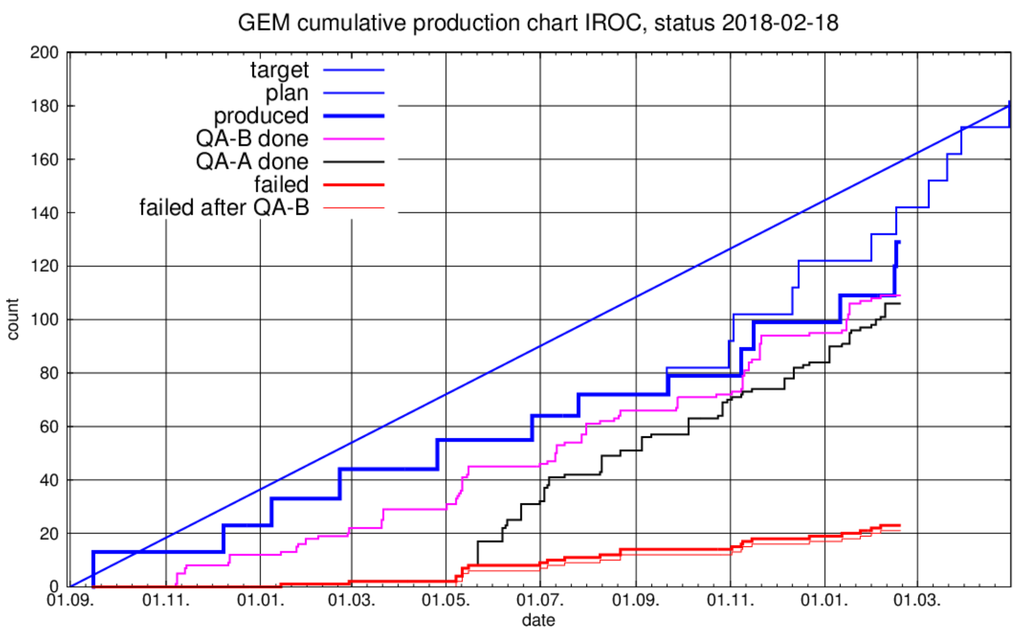
2018-02-15	IROC					OROC1					OROC2					OROC3				
flavor	G1	G2	G3	G4	sum	G1	G2	G3	G4	sum	G1	G2	G3	G4	sum	G1	G2	G3	G4	sum
QA-B done	30	30	29	31	120	34	30	31	29	124	29	31	30	26	116	32	29	27	33	121
produced	30	27	27	25	109	34	30	31	29	124	28	31	30	26	115	29	25	26	31	111
QA-B passed	20	25	25	16	86	29	25	26	27	107	25	30	30	23	108	23	21	24	26	94
QA-B yield	0.67	0.93	0.93	0.64	0.79	0.85	0.83	0.84	0.93	0.86	0.89	0.97	1.00	0.88	0.94	0.79	0.84	0.92	0.84	0.85
QA-A done	29	25	24	24	102	30	27	29	25	111	26	27	24	23	100	26	20	24	26	96
QA-A passed	19	23	22	15	79	25	22	24	23	94	23	26	24	20	93	20	16	22	21	79
QA-A yield	0.66	0.92	0.92	0.62	0.77	0.83	0.81	0.83	0.92	0.85	0.88	0.96	1.00	0.87	0.93	0.77	0.80	0.92	0.81	0.82
framed, ok	18	20	21	15	74	21	21	23	22	87	22	23	23	19	87	16	17	19	18	70

- GEM flavours are unique G1, G4 (S) and G2, G3 (LP) can not be exchanged (rotation)
- Lowest number of GEM flavours defines the number of chambers, that can be build
- Information from database and personal communication helps to equalize the flavours.
- Close contact to CERN PCB workshop allows to react on the flavor mismatch from batch to batch
- Keeping track of all GEM flavours is crucial

GEM Production Progress



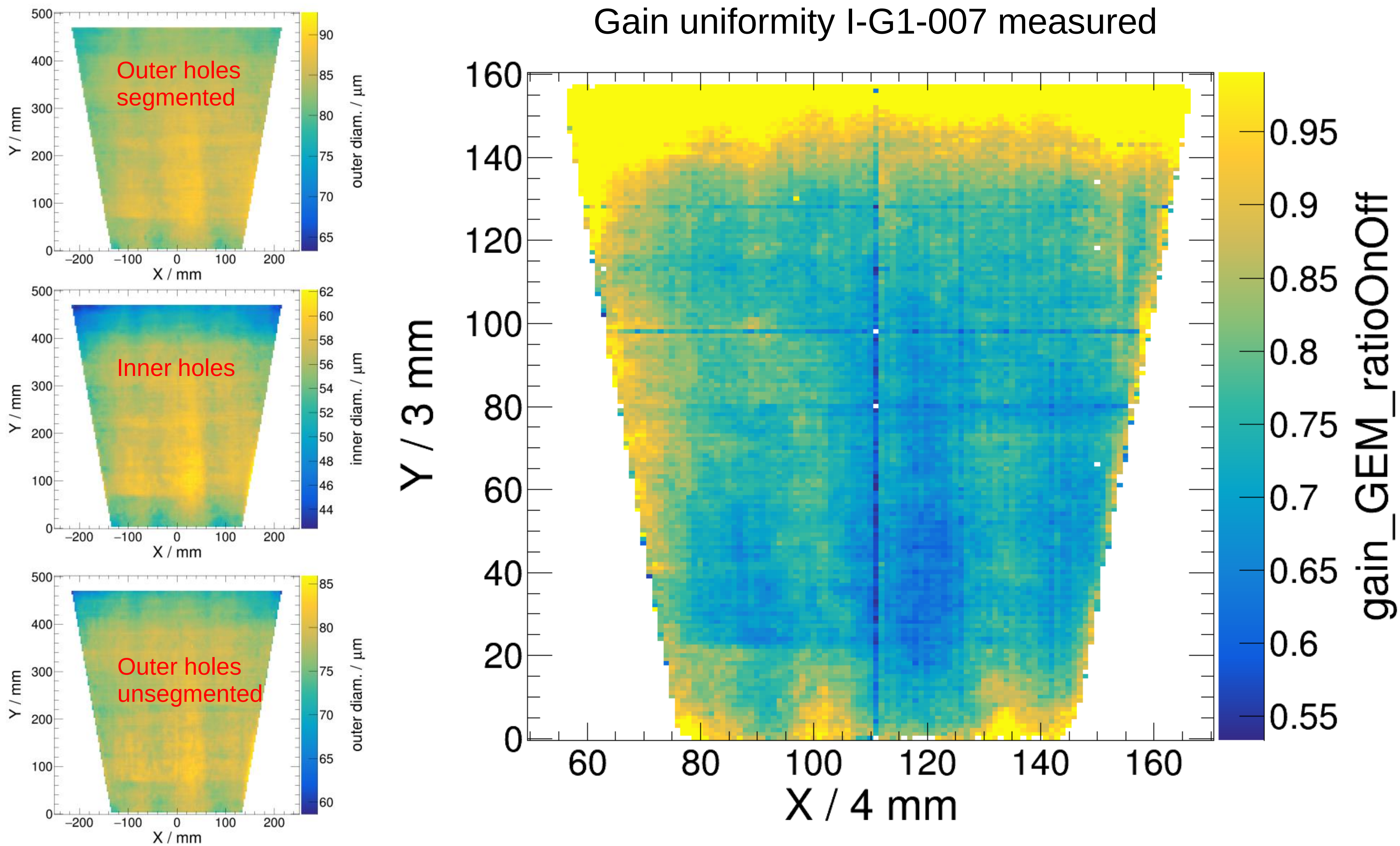
GEM Production Progress



Traffic Light	(green)	(yellow)	(orange)	(red)	
IROC	**48**	**25**	**6**	**23**	**102**
OROC1	**28**	**56**	**10**	**17**	**111**
OROC2	**45**	**26**	**9**	**8**	**88**
OROC3	**20**	**50**	**9**	**17**	**96**
Total	**141**	**157**	**34**	**65**	**397**

- February 2018: ~ 400 foils tested for Advanced QA, ~ 86 % of all GEM tested at CERN
- Advanced QA consists of
- high definition optical scan,
- Small part of GEM foils test gain uniformity
- long term leakage current measurement

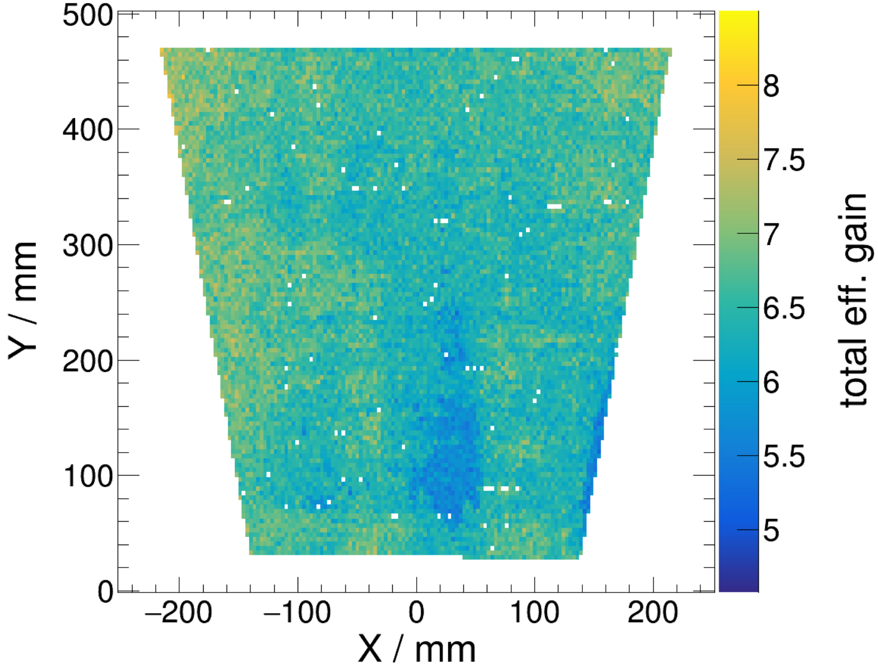
- Classification according an extended traffic light system
- So far all GEM foils except Red are used
- Connect performance of single GEMs and chamber gain uniformity (ongoing), see next slides



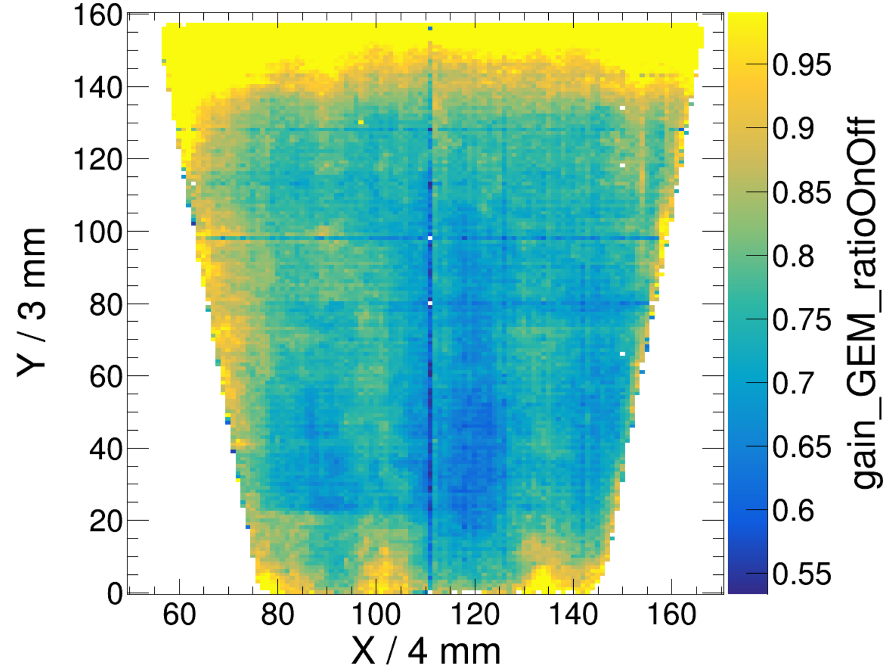
Outer holes segmented
Y / mm
X / mm
outer diam. / µm
Inner holes
inner diam. / µm
Outer holes unsegmented
Gain uniformity I-G1-007 measured
Y / 3 mm
X / 4 mm
gain_GEM_ratioOnOff

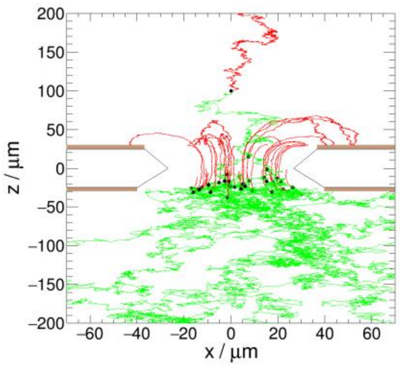
GEM Production Progress

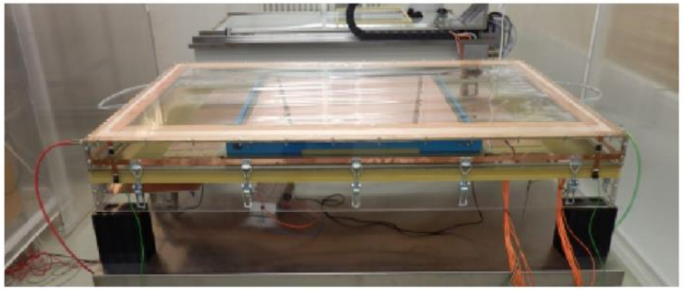
Gain uniformity I-G1-007 simulated



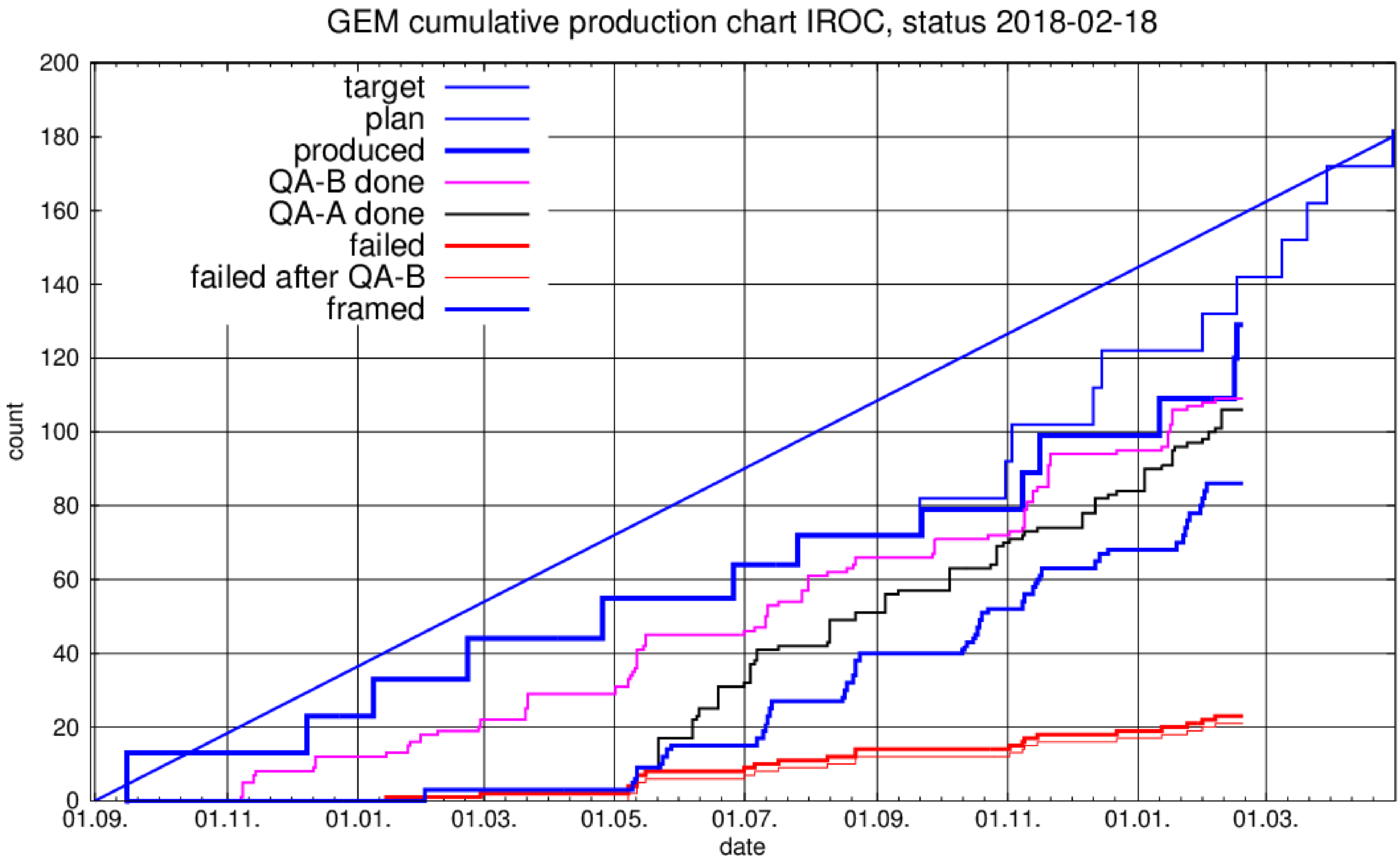
Gain uniformity I-G1-007 measured



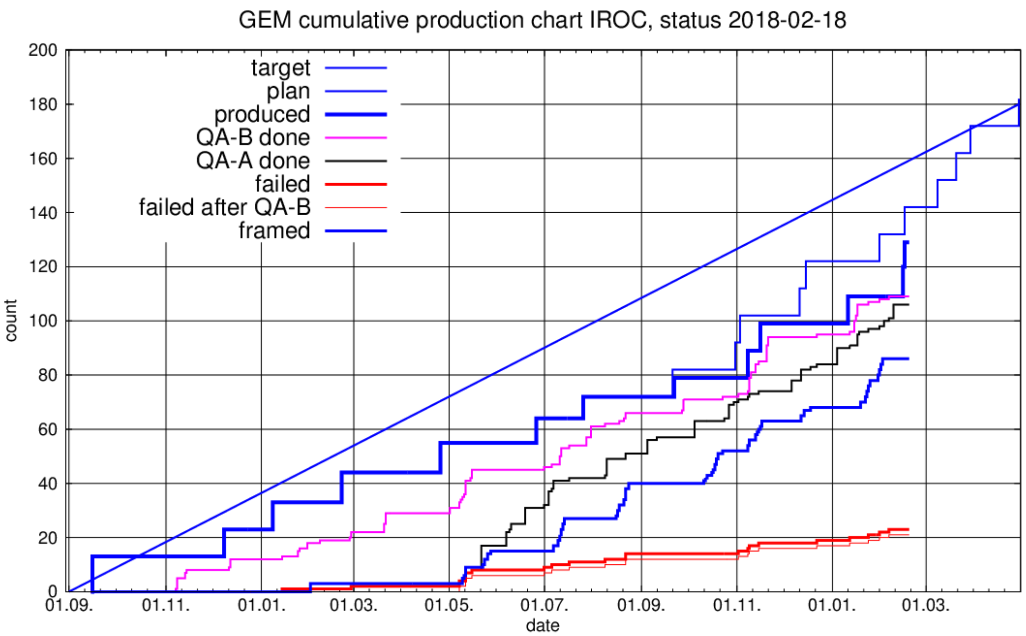




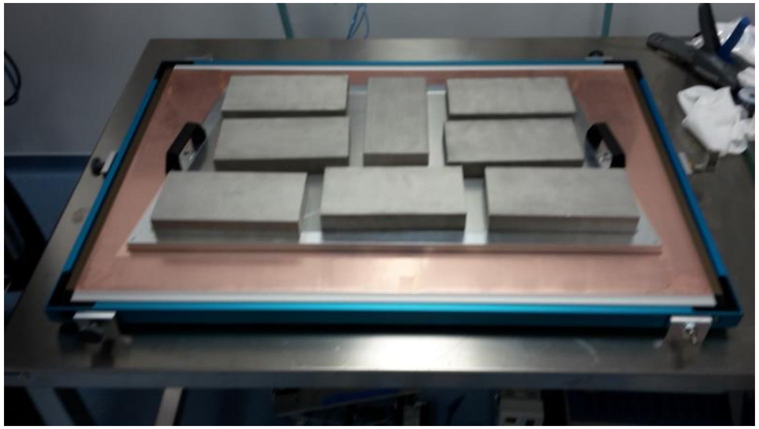
GEM Production Progress

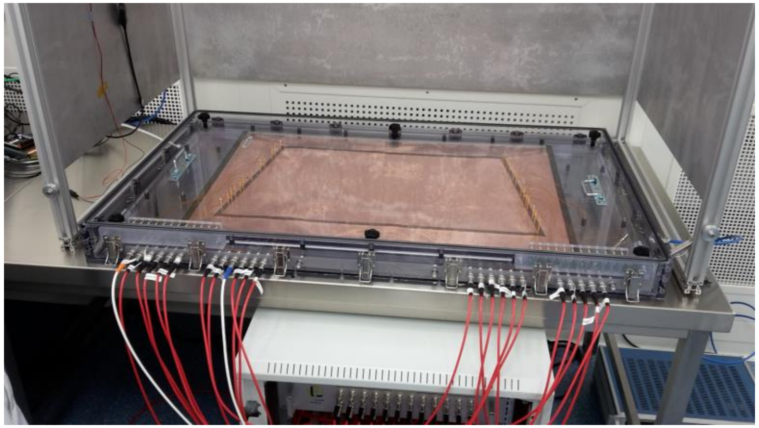


GEM Production Progress



- February 2018: ~ 340 GEM foils glued on frame
- For all GEM foils I_{Leak} has been measured twice (before and after framing glueing)
- ~ 74 % of all GEMs tested at CERN already glued to a GEM frame
- Quality of the glueing procedure constantly monitored at the framing and the assembly centres (feedback to the framing centres)
- Also GEM framing enters in the database





TPCU Production Status

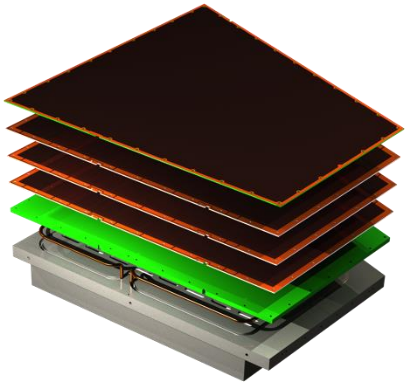
- **Production of 40x IROCs and 40x OROCs chambers is ongoing**
  - Almost all components in hand
  - GEM production continues until May 2018
  - All chambers assembled until Q4.2018

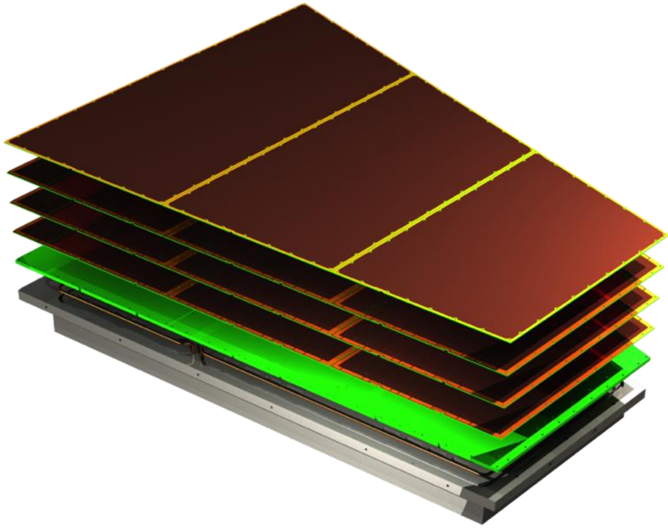
ROC components	Needed	Produced	Fraction (%)
Al-bodies	80	65	81
Padplanes	160	160	100
FEC connectors	15'000	15'000	100
HV cables	1'300	1'300	100
GEMs*	720 (10% spares)	500	69
GEM frames**	640	590	92

** PCB workshop will continue GEM production, if needed (manpower booked)*
*** Extra spare frames ordered recently*

Assembly step	Goal	Assembled	Fraction (%)
Chamber bodies (IROC/OROC)	40/40	21/15	45
Padplane + FEC connectors (IROC/OROC)	40/120	40/120	100
GEM framing	640	340	53
Assembled Chambers (IROC/OROC)	40/40	11/9***	25

**** 10/7 fully commissioned*





TPCU Production Status

	2017																									
	51	52	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
					Jan.18				Feb.18				Mar.18					Apr.18				May.18				Jun.18
Batch	DB		#27					#25	#28	#30				#32		#34				#36	#38					
IROC	99		109					119	129	139				149		159					179					
QA at CERN [20/w]				(10)			WGC		(10)	(10)	(10)				(10)	(10)				WGC	(10)	(10)				
Transportation [+1 w]						(10)	-->				18	12		18			18						22			
QA BUDAPEST [25/m]	18		18					10				18					18						18			
Transportation to US [+1 w]					18					10					18					18						18
IROC framing [4/w]	68					18					10					18					18					
Transportation in US [+1 w]							18					10						18					18			
GEMs	6/9/9/5				4x GEM4						3x GEM4				#27 1x GEM4			#25 and #28 has 10 GEM4s								
IROC Assembly [2/3w]	7			8+9			10+11			12+13			14+15			16+17			18+19			20+21+22			23+24	
IROC to CERN																										

		2018																							
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
					Jul.18				Aug.18				Sep.18					Oct.18				Nov.18			
Batch																									
IROC																									
QA at CERN [20/w]																									
Transportation [+1 w]																									
QA BUDAPEST [25/m]			16																		TS3		Pb-Pb		
Transportation to US [+1 w]						16																			
IROC framing [4/w]	18						16																		
Transportation in US [+1 w]			18						16																
GEMs																									
IROC Assembly [2/3w]		25+26+27			28+29			30+31+32			33+34			35+36+37			38+39+40								
IROC to CERN																									

TPCU Production Status

	2017	2018																																																
	51 52	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
				Jan.18				Feb.18				Mar.18					Apr.18				May.18				Jun.18					Jul.18				Aug.18				Sep.18					Oct.18					Nov.18		
Batch	DB		-->	#26				#29			#31			#33			#35		#37				#39																											
OROC1	114			124				134			144			154			164		174				184																											
QA at CERN [20/w]	5				(10)	WGC			(10)			(10)	WGC		(10)		WGC	(10)	WGC	(10)			WGC	(10)																										
Transportation [+1 w]					(3)	(7)				9			9			9			9		9				9	7																								
QA HELSINKI [25/m]	16	8		(8)		3 avail.		6	(4)		6			(9)			(9)			(9)			(9)				(9)			(10)																TS3		Pb-Pb		
Transportation in EUR [+1 w]		9		-->	9	8			9			9				9			9			9			9				9			10																		
OROC framing [4/w] (per site)	68+6		9		5		10		WGC	9		WGC	9		WGC		9		WGC	9		WGC	9		WGC	9		WGC		9		WGC	10																	
Transportation in EUR [0-1 w]			9-GSI		-->	9-HPD	9-GSI		6-HPD		9-GSI			9-HPD				9-GSI			9-HPD			9-GSI			9-HPD				9-GSI			10-HPD																

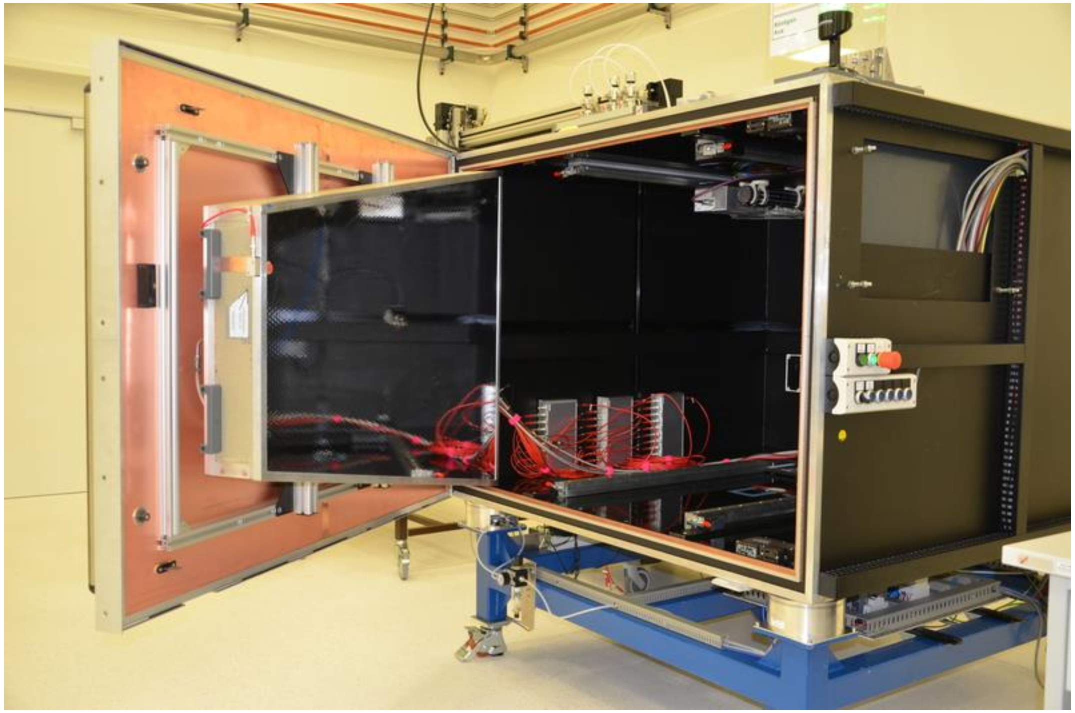
	2017	2018																																																
	51 52	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
				Jan.18				Feb.18				Mar.18					Apr.18				May.18				Jun.18					Jul.18				Aug.18				Sep.18					Oct.18					Nov.18		
Batch	DB		-->	#26				#29			#31			#33			#35		#37				#39																											
OROC2	106		116					126			136			146			156		166				176																											
QA at CERN [20/w]						9				(10)		(10)	WGC			(10)	WGC	(10)	WGC			(10)	WGC	(10)																										
Transportation [+1 w]							9				9		9				9		9				9		9	6																								
QA BUDAPEST [25/m]	21	1		9		5			15					12						18						18					12															TS3		Pb-Pb		
Transportation in EUR [+1 w]					9		6			9		6				9				9		9				9		9				9	6																	
OROC framing [4/w] (per site)	71+9		9			9		6			9		6		WGC		9		WGC		9		9		WGC		9		9		WGC		9	6																
Transportation in EUR [0-1 w]			8-HPD		--> 9-GSI			9-HPD		6-GSI			6-HPD		9-GSI				9-HPD				9-GSI		9-HPD				9-GSI		9-HPD			9-GSI	6-HPD															

	2017	2018																																																
	51 52	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
				Jan.18				Feb.18				Mar.18					Apr.18				May.18				Jun.18					Jul.18				Aug.18				Sep.18					Oct.18					Nov.18		
Batch	DB	#27					#25	#28	#30				#32		#34				#36	#38																														
OROC3	103	113					123	133	143				153		163				173	183																														
QA at CERN [20/w]	8		(10)			WGC		(10)			(20)		WGC	(10)		(10)	WGC				(10)	(10)	WGC																											
Transportation [+1 w]					(6)	(11)			9			18			9		9					9	9	7																										
QA HELSINKI [25/m]	18	9	(9)		5	9			(8)			12			(9)			(9)			(9)				(15)			(11)		(5)																TS3		Pb-Pb		
Transportation in EUR [+1 w]				9	-->		9			9			9			9			9			9			9			9			9	7																		
OROC framing [4/w] (per site)	58+7		7		9			9			9			9			9			9			9			9			9			9		7																
Transportation in EUR [0-1 w]					7-GSI		9-HPD		9-GSI			9-HPD			9-GSI			9-HPD			9-GSI			9-HPD			9-GSI			9-HPD			9-GSI	7-GSI																

	2017	2018																																																
	51 52	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
				Jan.18				Feb.18				Mar.18					Apr.18				May.18				Jun.18					Jul.18				Aug.18				Sep.18					Oct.18					Nov.18		
GEMs (GSI)	16/16/16			17/15/18			26/24/18			35/30/27			35/30/27			35/39/36			44/39/36			44/48/45			53/48/45			53/57/54			62/57/54			62/66/63																
OROC (GSI)			3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		19		20															
GEMs (HPD)	8/8/8			20/25/19			29/34/28			35/34/28			44/40/37			44/40/37			44/49/46			53/49/46			53/58/55			62/58/55			62/67/64			72/73/71												TS3		Pb-Pb		
OROC (HPD)			1		2		3		4		5		6		7		8		9		10		11+12		13+14		15+16		17+18		19+20																			

Final Chamber Performance

1. Chamber commissioning at the assembly sites
2. Stability tests at LHC



LIST OF TESTS

1. Gas tightness (< 0.5 ml/h)
2. Gain curve
3. Gain uniformity (<20 %)
4. IBF uniformity (IBF = 0.7%, Δε < 20%)
5. Full X-ray irradiation (10 nA/cm^2) for 6h

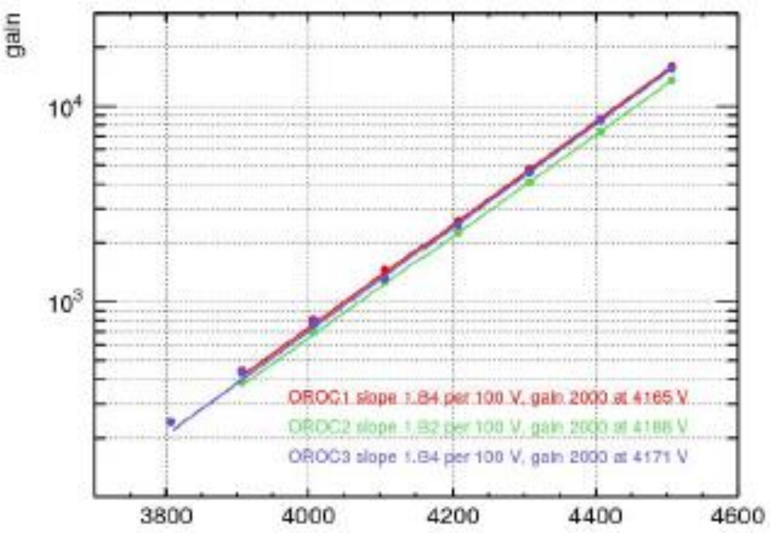
Gas: Ne-CO_2-N_2 (90-10-5)

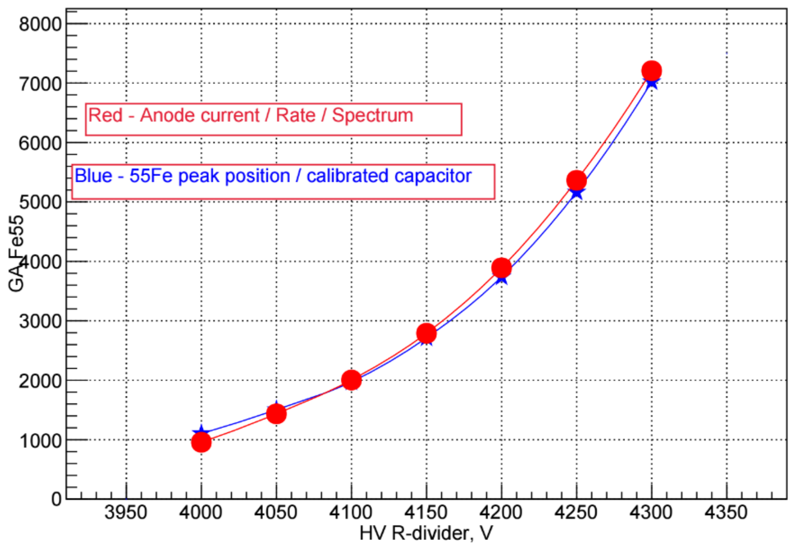
HV: resistor chain

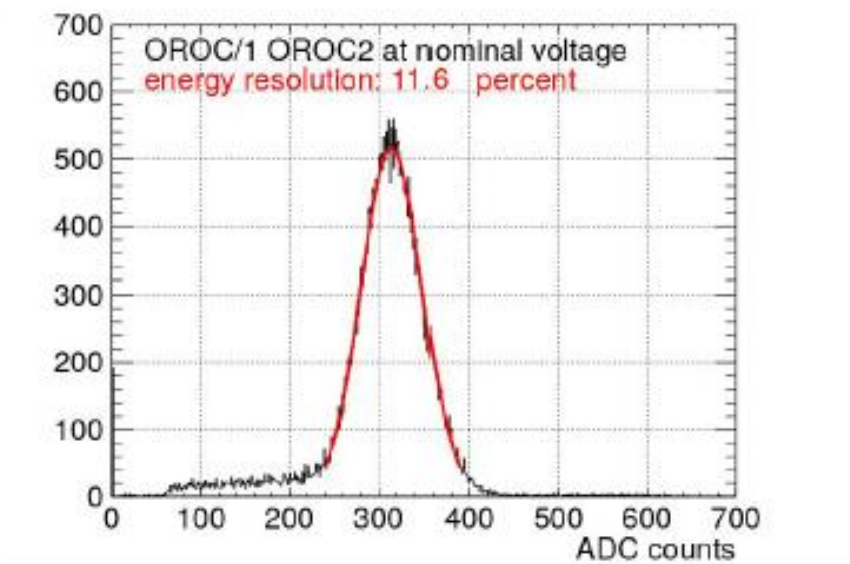
Settings: GEM1/2/3/4 = 270/230/288/359 V T1/T2/T3/IND = 4/4/0.1/4 kV/cm

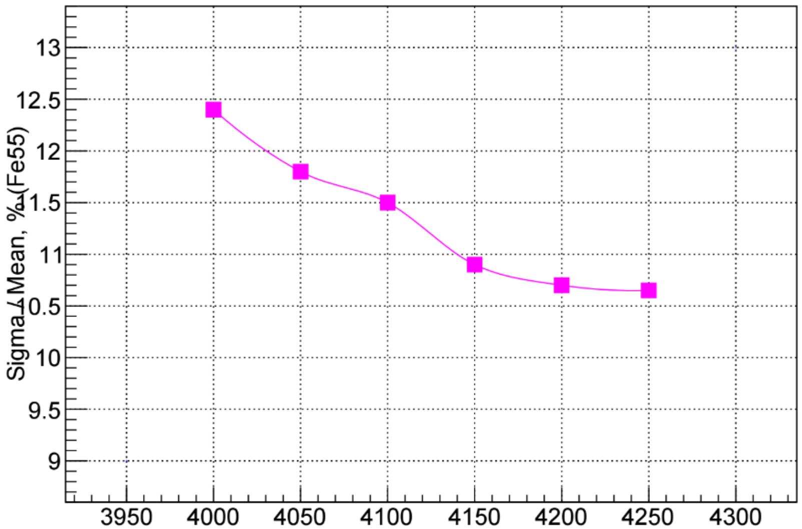
Readout: single channel pre-amplifier + shaper + ADC, amperemeters

Production Progress



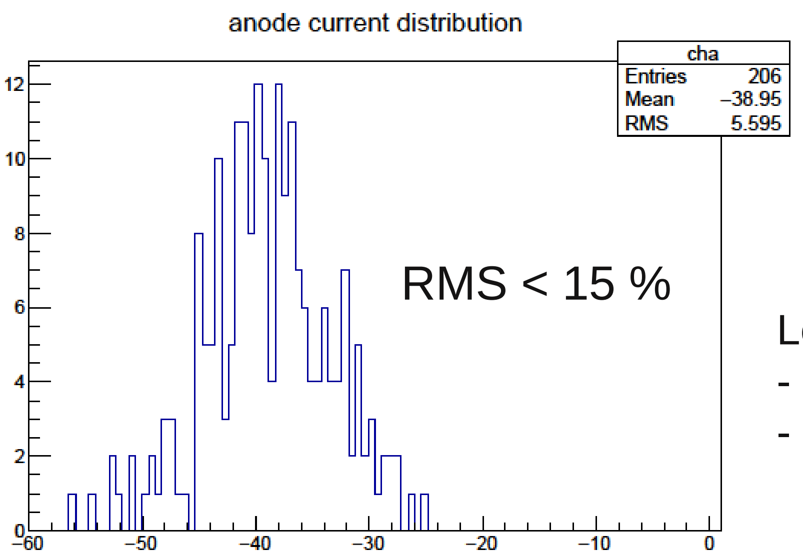


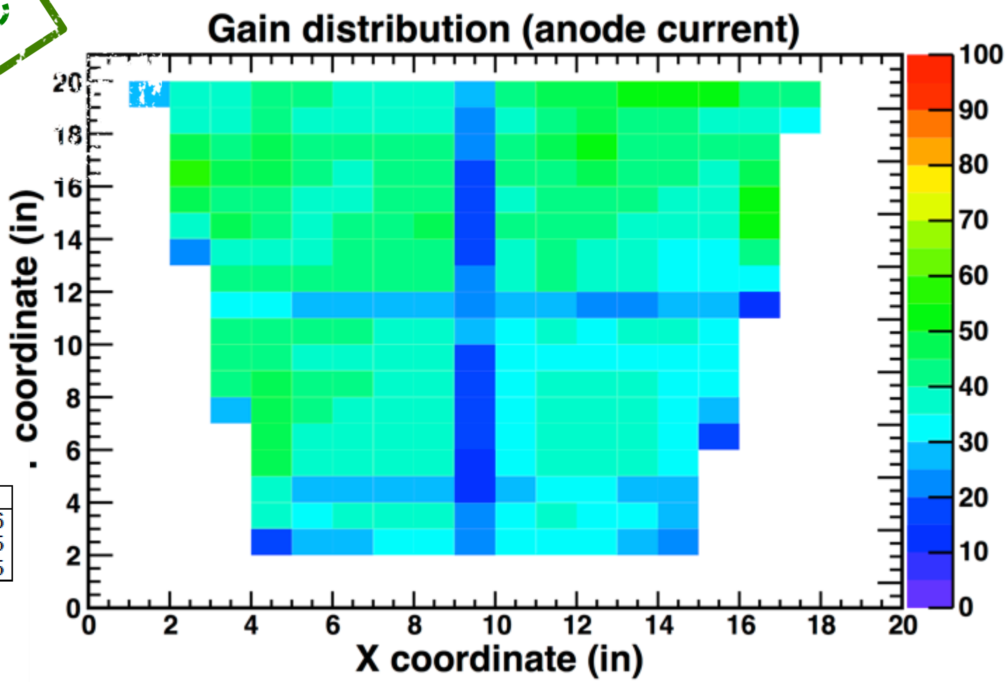




Gain Map

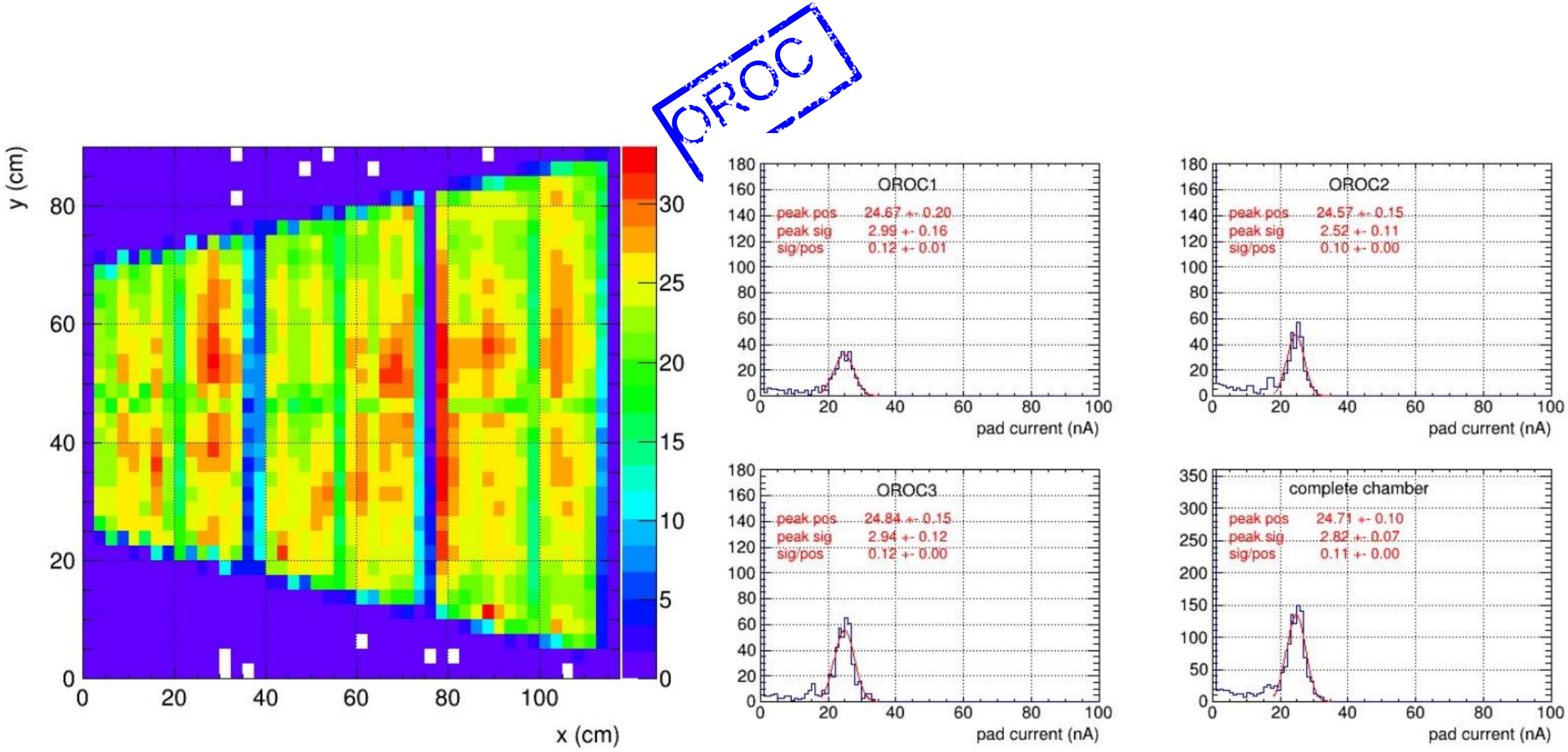
- Effective gain ($G_{eff} = \frac{I_{anode}}{eN_{ion}R}$)
- Performance within specs:
  - gain uniformity < 20%
- 10 IROCs within specs





Low-gain bins not included in 1D distribution
- spacer
- measurement edges (non-active area)

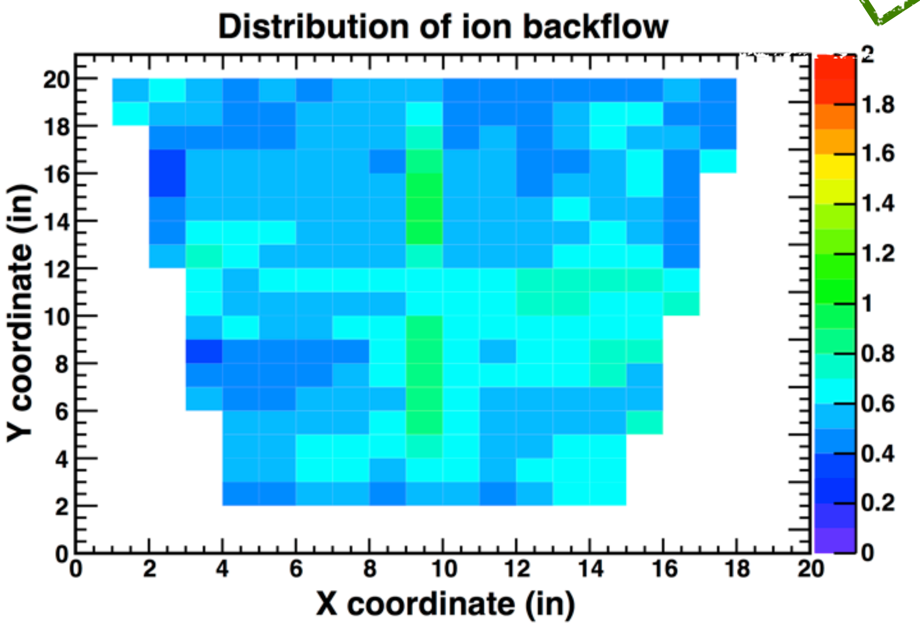
Gain Map

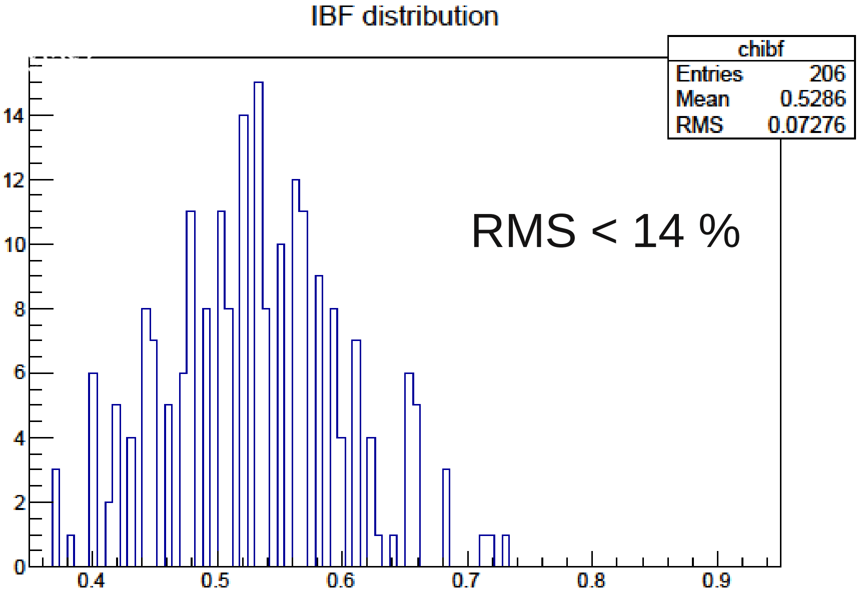


- Gain uniformity RMS well below ≤ 20% (within the specs)
- OROC3 non-uniformity correlates with a single foil hole-size distribution – investigation ongoing

Ion Backflow

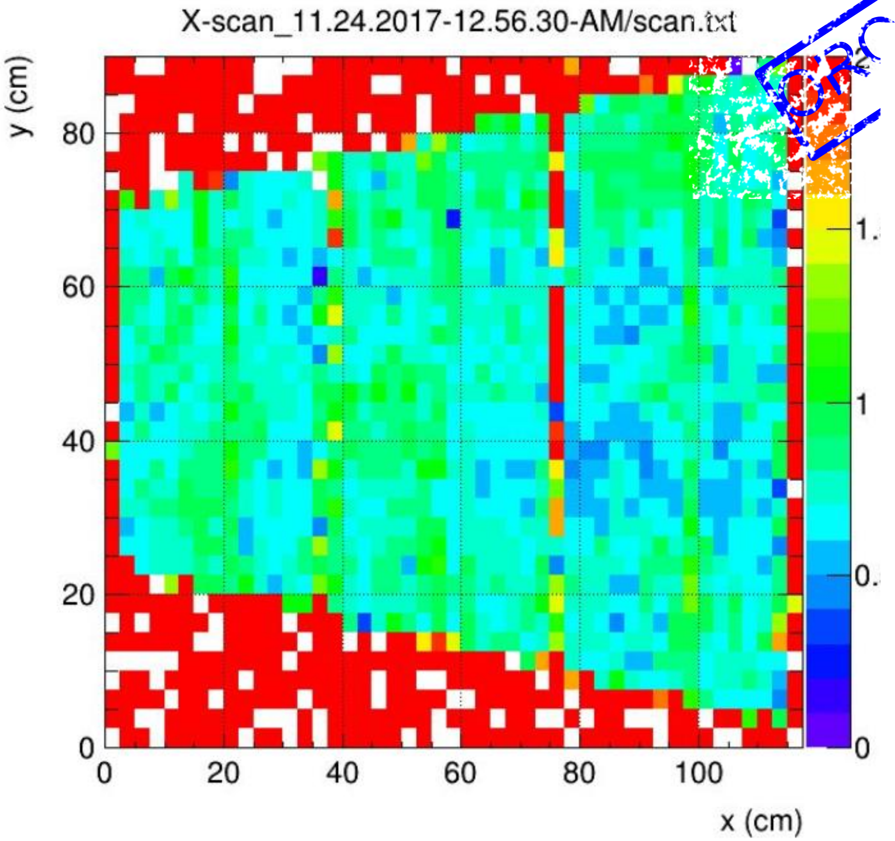
IROC

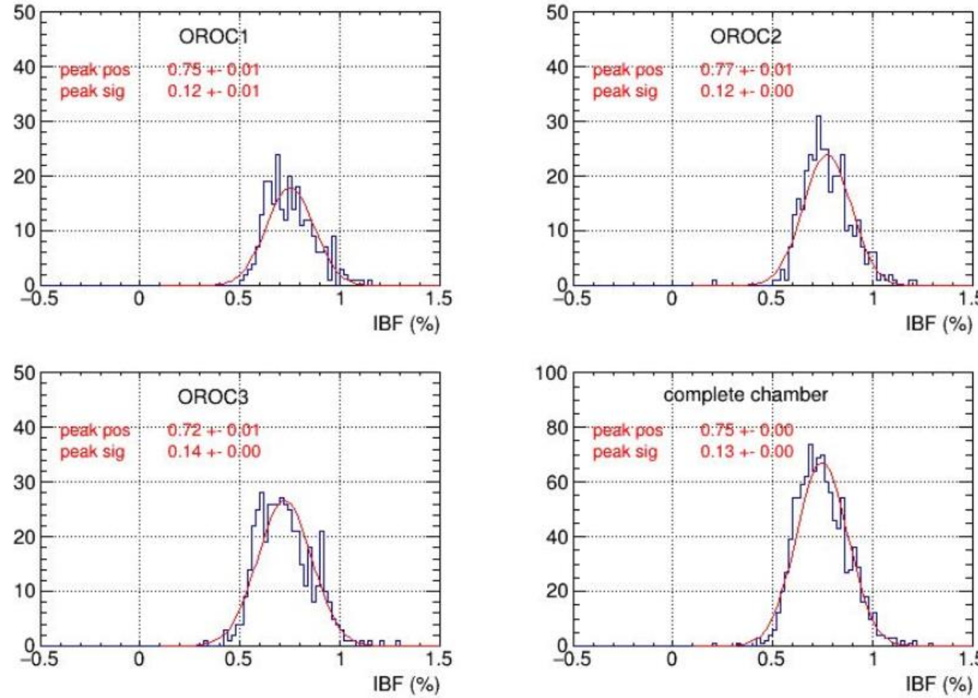




- Ion Backflow ($G_{eff} = \frac{I_{anode}}{e\, N_{ion} R}, IB = \frac{I_{cathode}}{I_{anode}} = \frac{(1+\epsilon)}{G_{eff}}$)
- Performance within specs. $IB < 1$ %
- Mean value in agreement with IB < 0.7% measured with 10x10 cm^2 GEMs at $G_{eff} = 2000$
- For the final TPC performance (space charge distortions) → ϵ uniformity!
- 18 segments means 18 times 10x10 cm^2 detectors (In total 206 individual measurements)
- Mean value in good agreement with the R&D results

Ion Backflow

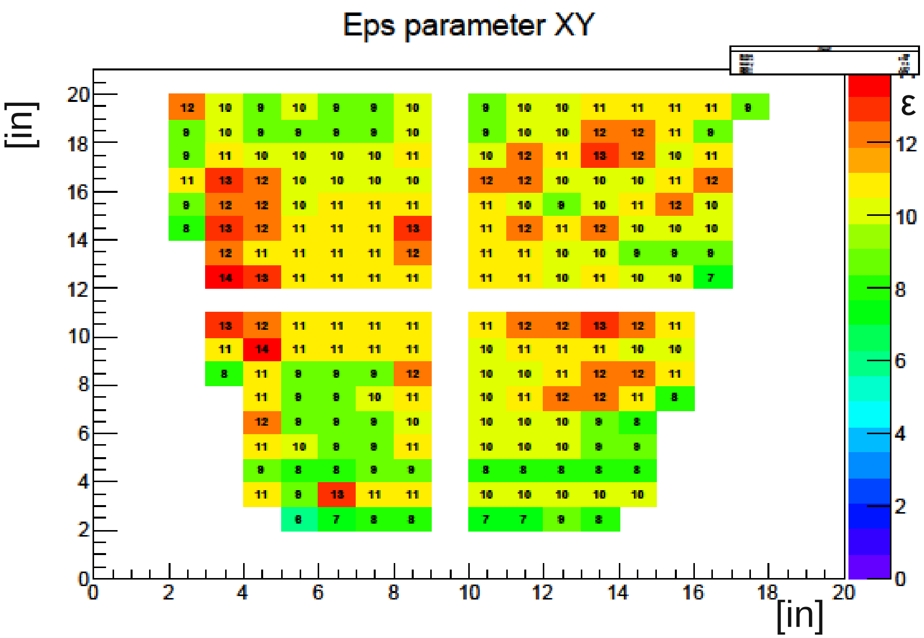


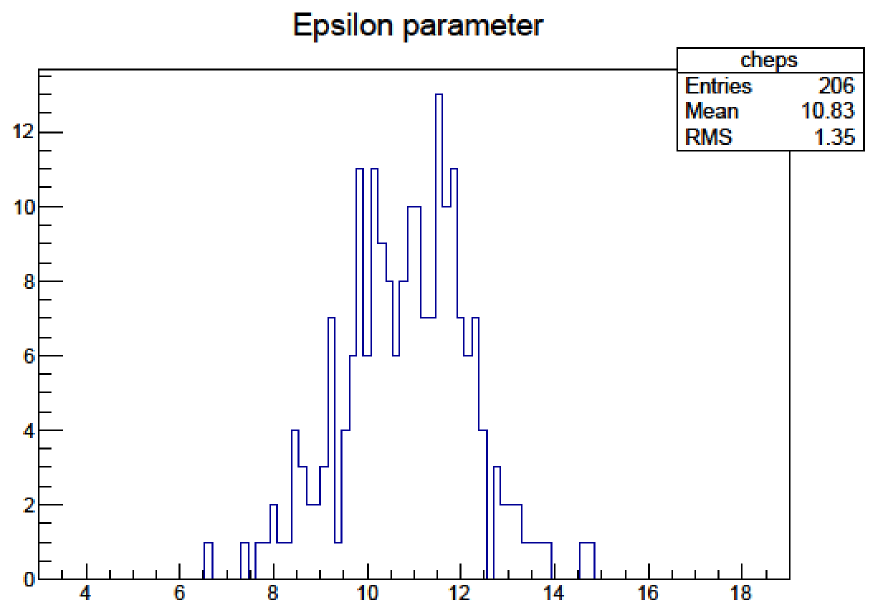


- Ion Backflow ($G_{eff} = \frac{I_{anode}}{e\, N_{ion} R}, IB = \frac{I_{cathode}}{I_{anode}} = \frac{(1+\epsilon)}{G_{eff}}$)
- Performance within specs. IB < 1 %
- Mean value in agreement with IB ~ 0.7% measured with 10x10 cm^2 GEMs at G_{eff} = 2000
- This is the area of 66 times 10x10 cm^2 detectors (in total ~ 900 individual measurements)

ε-Map

IROC

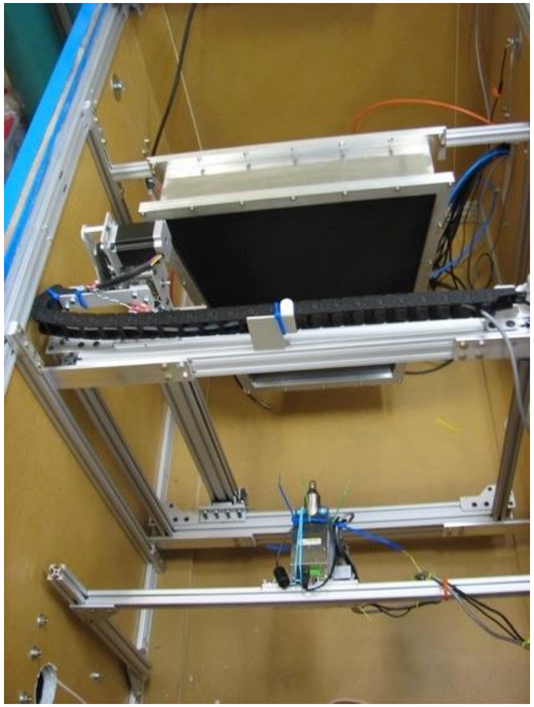




- Epsilon proportional to the cathode current:
- $G_{eff} = \frac{I_{anode}}{e\,N_{ion}R}, IB = \frac{I_{cathode}}{I_{anode}} = \frac{(1+\epsilon)}{G_{eff}}, \varepsilon = \frac{I_{cathode}}{(eN_{ion}R)} - 1$
- Performance within specs:

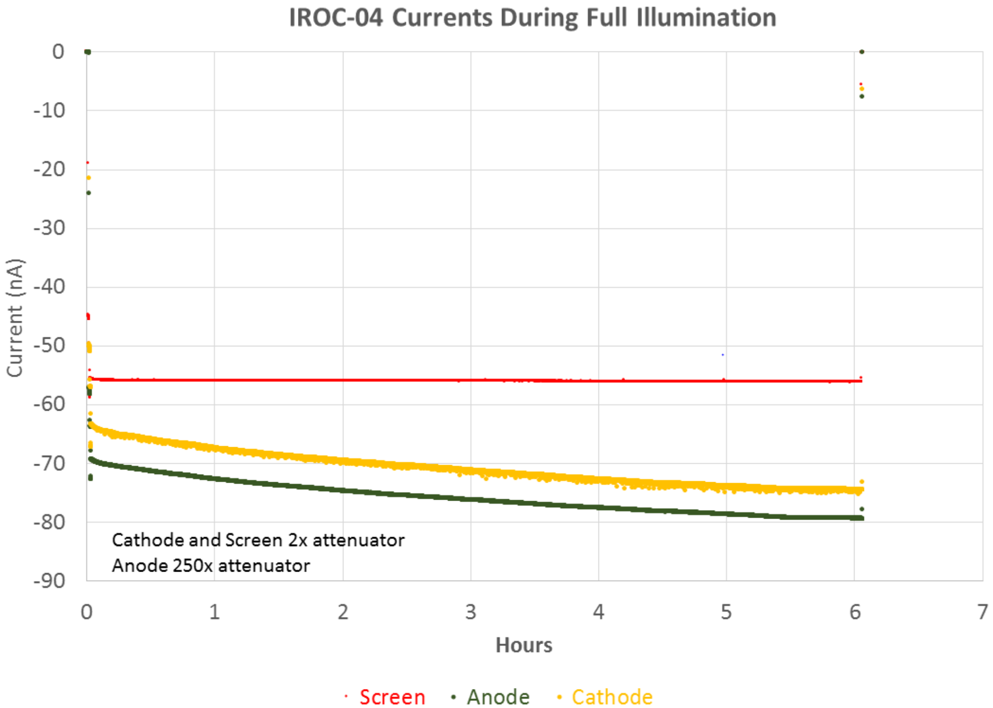
  - gain uniformity RMS < 20%; epsilon RMS < 20%
- The calibration procedure has been demonstrated to work for effective non-uniformities of ε ~25%

Full Irradiation with X-Rays



- Induce 10 nA/cm^2 current (expected in Run 3) at the pad plane after amplification G = 2000 for 6h
- Cathode/Anode current read with pA-meter

- Cathode/anode currents go directly to zero after X-ray off
- No energy resolution deterioration after the test
- Leakage current of all foils <0.5 nA after the test
- no discharge recorded during 6 hours of full irradiation



Commissioning Procedure

- Well established acceptance criteria
- Similar setups in all three assembly sites (Uni Yale, GSI Darmstadt, HPD Bucharest)
- Possible to assemble and commission 2-3 IROCs/month and 4 OROCs/month

- Acceptance criteria upon arrival at CERN:
  - Capacitance, resistance measurements
  - Leakage current at 350 V in dry gas
  - Full voltage in dry gas
  - Part of the chambers will be tested at LHC
  - All tests documented in the database

Chambers in the Database

part	item	batch	sent		date	location	QA status	link	comment
			from	to					
IROC chamber	IROC/01					Yale		X	
IROC chamber	IROC/03					CERN		X	
IROC chamber	IROC/04					CERN		X	
IROC chamber	IROC/05					CERN		X	
IROC chamber	IROC/06					Yale		X	
IROC chamber	IROC/07					Yale		X	
IROC chamber	IROC/08					Yale		X	
IROC chamber	IROC/09					Yale		X	
IROC chamber	IROC/10					Yale		X	
IROC chamber	IROC/11					Yale		X	
IROC chamber	IROC/12					Yale		X	
IROC chamber	IROC/13					Yale		X	
IROC chamber	IROC/14					Yale		X	
IROC chamber	IROC/15					Yale		X	

14 items

Chambers in the Database

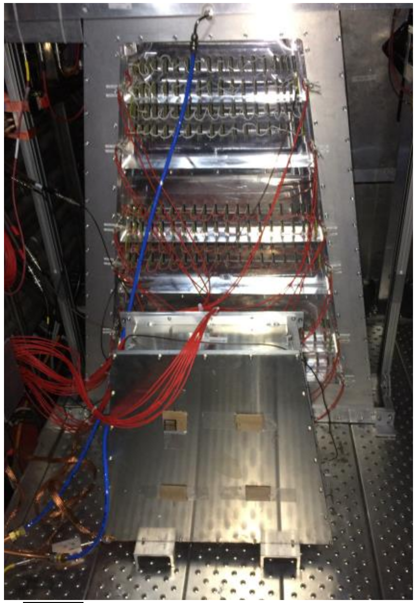
part	item	batch	sent		date	location	QA status	link	comment
			from	to					
OROC chamber	OROC/01					CERN		X	PRR (aka FINAL) OROC
OROC chamber	OROC/02					GSI		X	At the beginning of commissioning, 2 kV applied by mistake to pads.
OROC chamber	OROC/03					Bucharest		X	former OROC 23
OROC chamber	OROC/04					Bucharest		X	repaired HV-cable GEM 4 TOP (-1160V) tested at -3500V --> 75pA
OROC chamber	OROC/05					GSI		X	two discharges during HV-wire irradiation (at a wrong position), no discharges in a second test
OROC chamber	OROC/06					GSI		X	O3-G1-012 touched, replaced with O3-G1-016
OROC chamber	OROC/07					Bucharest		X	
OROC chamber	OROC/08					Bucharest		X	
OROC chamber	OROC/09					Bucharest		X	
OROC chamber	OROC/10					GSI		X	bump in gain map
OROC chamber	OROC/11					GSI		X	
OROC chamber	OROC/12					GSI		X	
OROC chamber	OROC/13					HD		X	
OROC chamber	OROC/14					HD		X	
OROC chamber	OROC/15					HD		X	
OROC chamber	OROC/16					HD		X	
OROC chamber	OROC/17					HD		X	

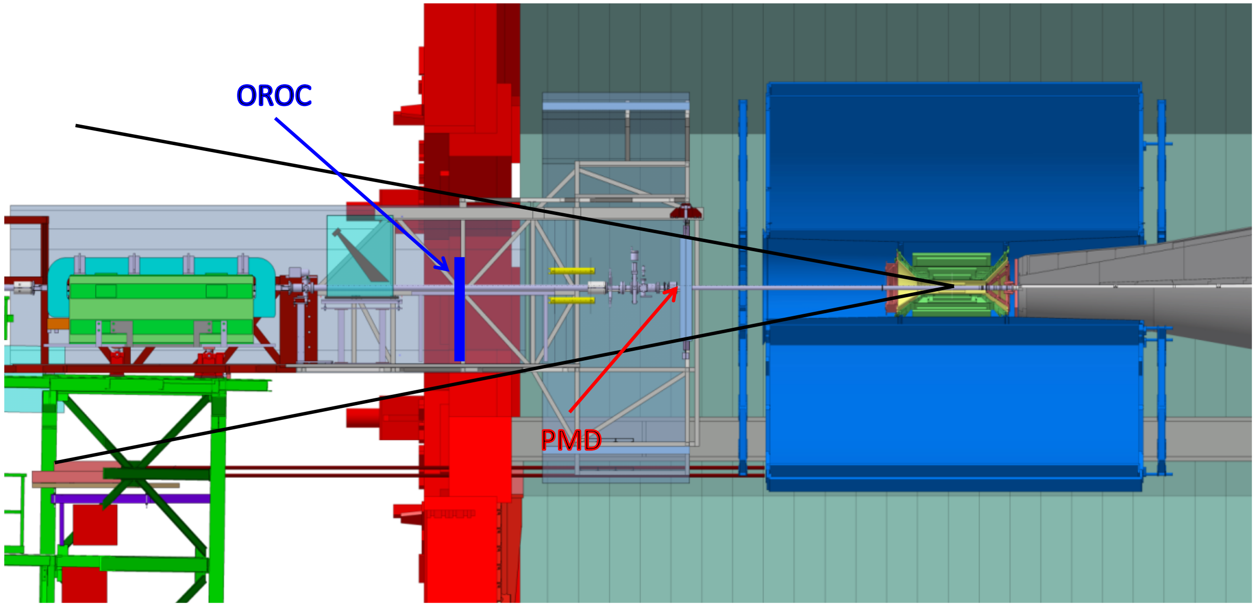
17 items

ROC test at P2

Goals:

- Test IROCs and OROCs under radiation conditions that are comparable to Run 3
- Practice HV hardware and control tools – complex system
- Optimize operational point: HV settings, decoupling resistors, trip settings





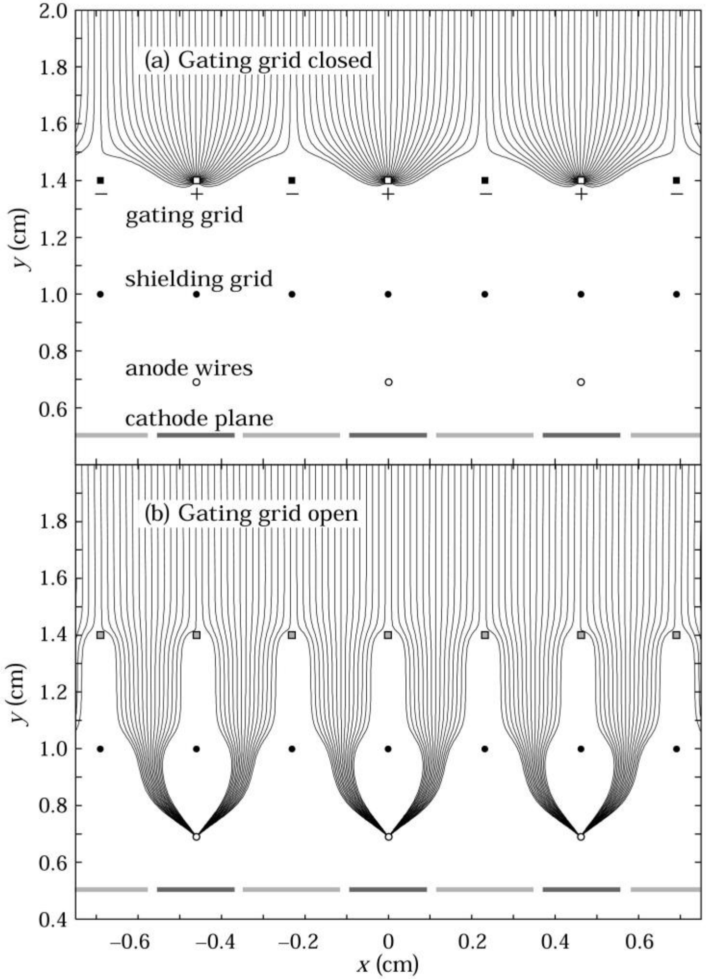
- IROC and OROC are placed in a miniframe, close to the beam pipe, between PMD and compensator magnet
- In 150kHz pp, **direct** load on ROCs in this position is comparable to that on ROCs installed in the TPC in Run 3
- HV supply in CR4, control from ALICE Control Room

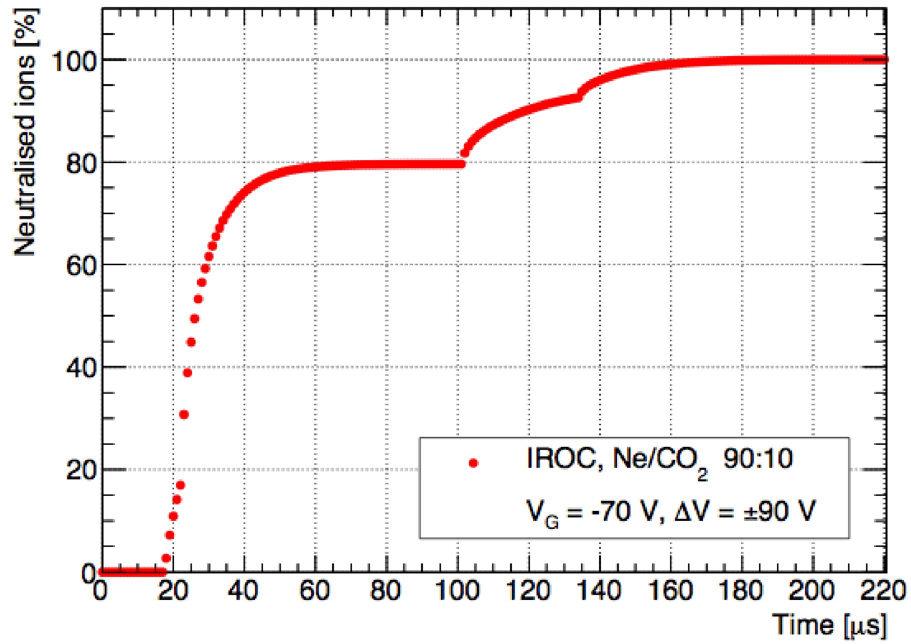
Summary & Outlook

- We have come a long way from R&D to full production
- Intensive R&D lead to the 4-GEM configuration, fulfilling all requirements
- We are in full production mode now, but the end of production is already near
- Results from R&D (10x10 cm^2) phase in good agreement with the results of the final chambers
- Full production:
  - GEM production and QA-B on track 500 out of 720 produced (more than 2/3)
  - GEM QA-A 400 out of 720 (55 % done already)
  - GEM framing 340 out of 640 (~ 50 %)
- ROC production/qualification on schedule, until Q3.2018
- OROC at LHC running stable. More chambers to be tested in the upcoming months
- LHC Long Shutdown 2 in 2019-2020: chamber and FEE installation, commissioning will be soon the crucial challenge
- RD51 and CERN PCN workshop were with us and part of everything during the whole time
- Your are/were gratefull for all you advice, comments and criticism
- Thank you all a lot that you contributed in such an active way !!!

Backup

Advantages and Limitations of a TPC





- Ion Backflow suppression of a MWPC with a Gating grid ~ 10^{-5}
- 100 μs electron drift time + 200 μs to neutralise all ions
- Total cycle time ~ 300 μs limits the maximal readout rate to ~ 3 kHz (in p-p)
- Trigger Rate ~ 600 Hz for Pb-Pb (300 Hz in Run 1)

00:00 → 00:20 **1. Chamber body assembly** — 20m
- body assembly 27...

00:20 → 00:40 **2a. HV cables and HV plugs assembly** — 20m
- Feedthroughs 27.0...

00:40 → 01:00 **2b. Padplane test** — 20m
- padplane 2702201...

01:00 → 01:20 **3. Working with GEMs**
- Savoir Vivre 27.08.2...

01:20 → 01:40 **4. Optiguard frame installation**
- optiguard 27.08.20...

01:40 → 02:00 **5. GEM packing/unpacking**
- Packing-Unpacking ...

02:00 → 02:20 **6. Coarse optical check**
- coarse optical chec...

02:20 → 02:40 **7. HV test**
- GEM HV test 23.10...

02:40 → 03:00 **7a. HV test in the PCB wokrshop**
- GEM HV test in PC...

03:00 → 03:20 **8. Optical scanning**
- GEM_OSS_test_v1...

03:20 → 03:40 **9. GEM frame assembly**
- frame assembly 27...

03:40 → 04:00 **10. GEM framing**
- gem framing 27.08...

04:00 → 04:20 **11. ROC assembly**
- ROC assembly 23.1...

04:20 → 04:40 **12. ROC commissioning** — 20m
- ROC commissionin...

04:40 → 05:00 **13. ROC acceptance** — 20m
- ROC acceptance 28...

ALICE

FRAME ASSEMBLY

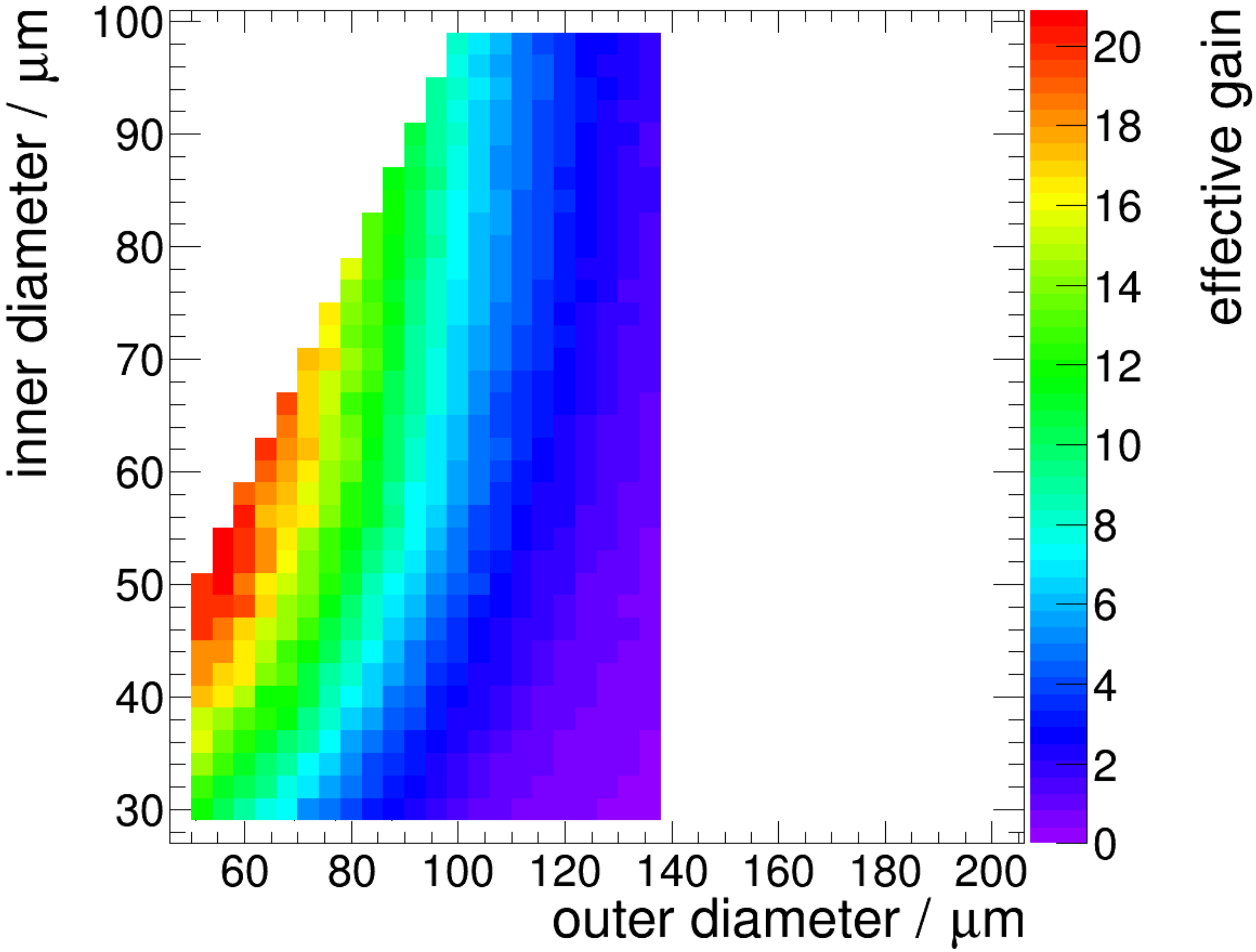
FRAME LEDGES CLEANING

1. Check ledges under the microscope
2. Document possible damages
3. Remove overhanging glass fibers with sand paper (see picture)
4. Clean in an ultrasonic bath for at least 5 minutes. For example:
   - Bath 1 with isopropanol for pre-cleaning – 5' (or pre-clean with iso-propanol manually)
   - Bath 2 with isopropanol for final cleaning – 3'-5' and let isopropanol drain
   - Bath 3 with distilled water – 3' and let water drain
5. Blow dry with nitrogen
6. Check ledges again under the microscope
7. Put ledges into the dry cabinet. Leave them (at least) over night for drying before the final assembly.

C.Ittar, M.Ball

ALICE

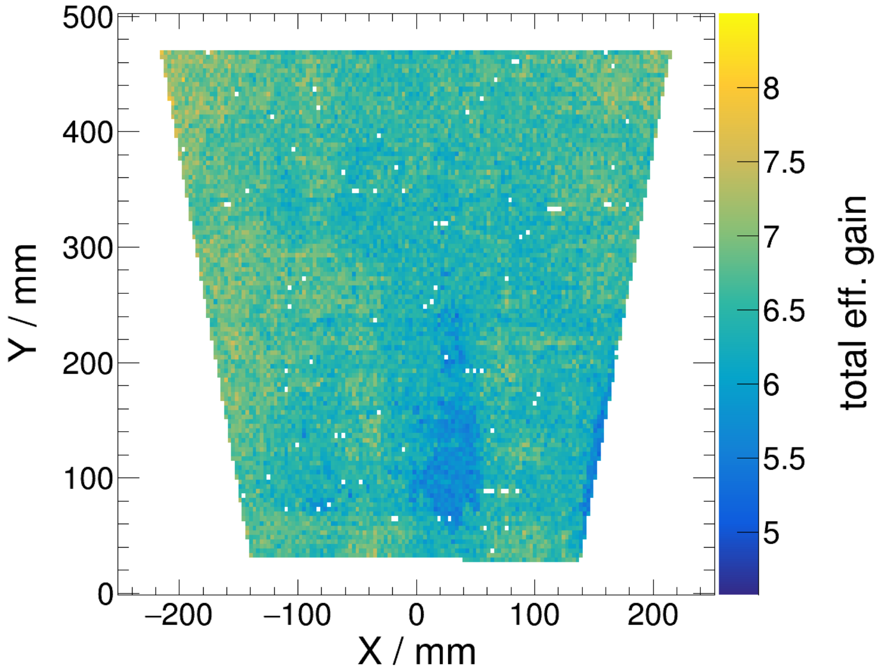
Offse

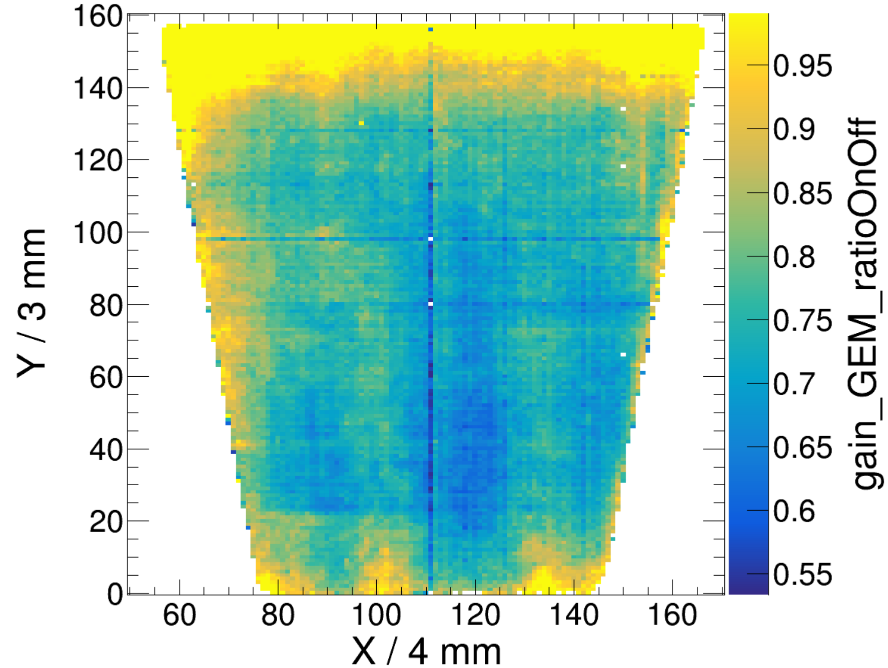


A Large Ion Collider Experiment

ALICE

Simulation vs. measurement





(1) Simulation

(2) Measurement

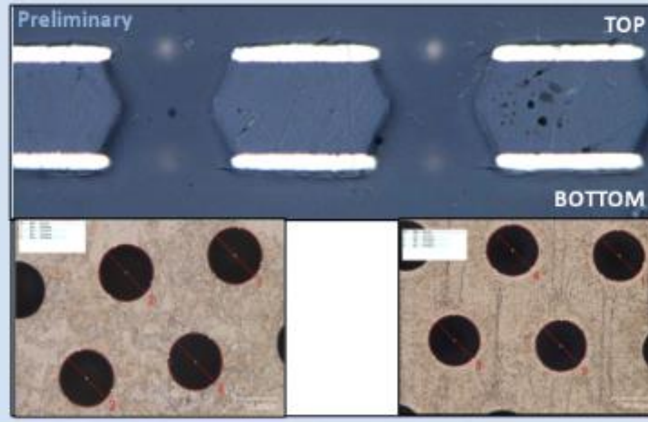
GEM foils geometries

Double-mask technique:

- *"Standard" for small areas (≤ 40x40 cm^2)*
- *Gives a perfect bi-conical shape*

Diameters	cross section optical microscopy	
Hole location	Diam. [μm]	Err. [μm]
Top	70.1	± 0.2
Middle	49.1	± 1.2
Bottom	69.4	± 0.8

Preliminary

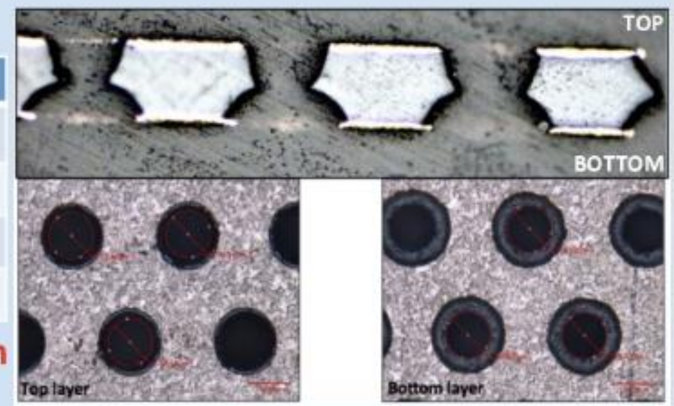


Single-mask technique:

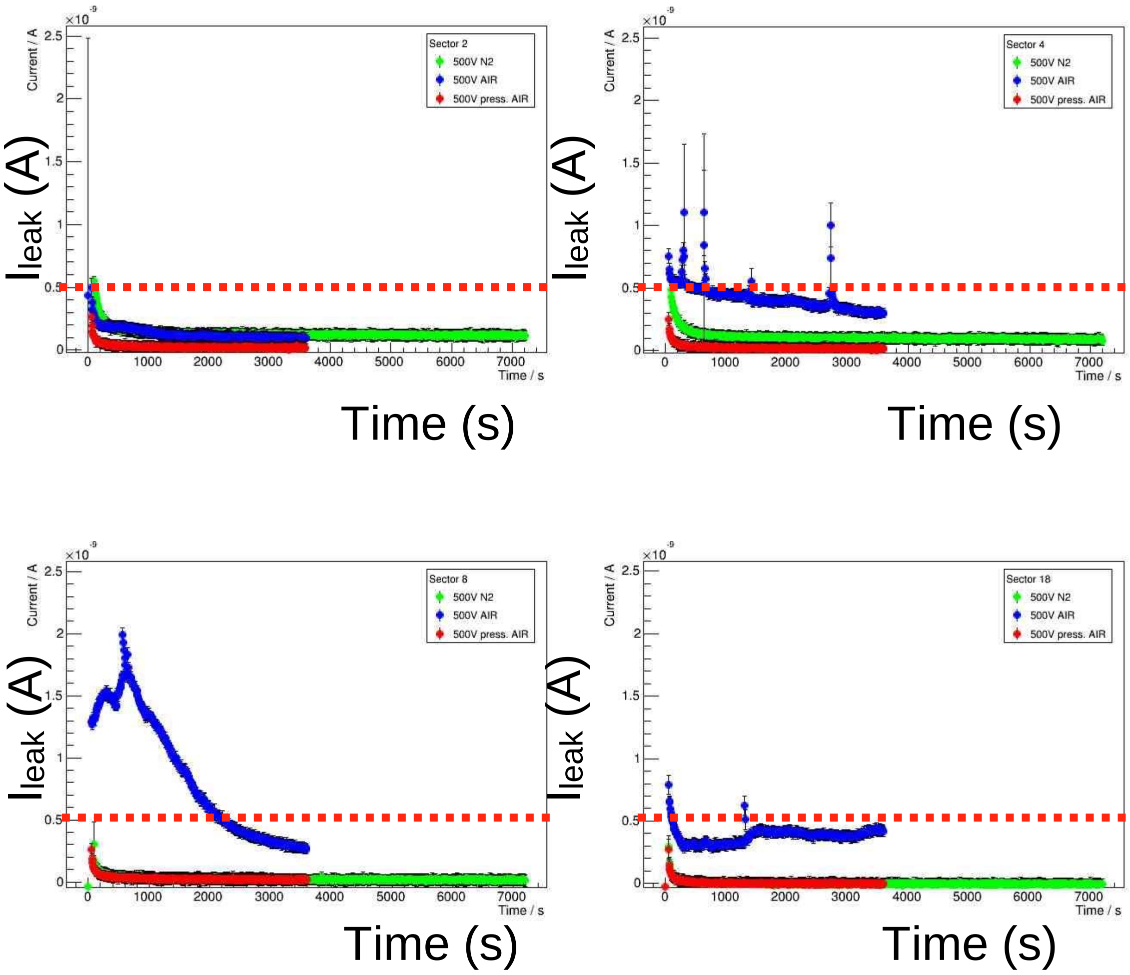
- *Suitable for large areas*
- *Gives a "asymmetric" bi-conical shape*

Diameters	digital microscopy		cross section optical microscopy	
Hole location	Diam. [μm]	Err. [μm]	Diam. [μm]	Err. [μm]
Top	73.8	± 3.3	71.0	± 2.1
Middle	51.3	± 2.7	52.8	± 5.4
Bottom	85.5	± 4.1	86.1	± 4.9

- **How does this asymmetry affect the operation of the detectors ?**

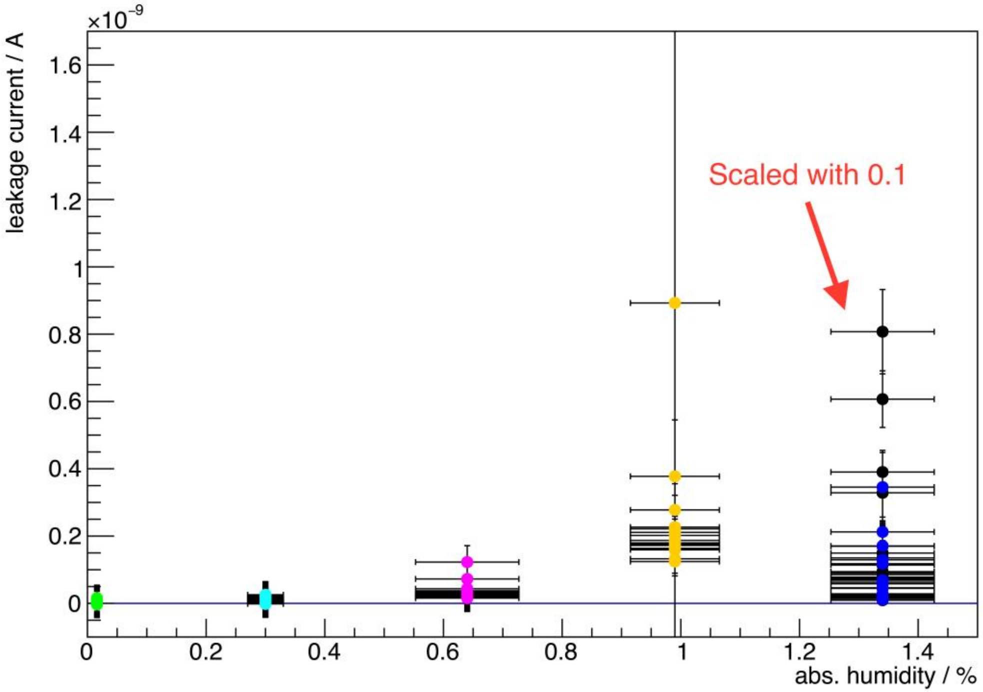


I_{leak} current measurements



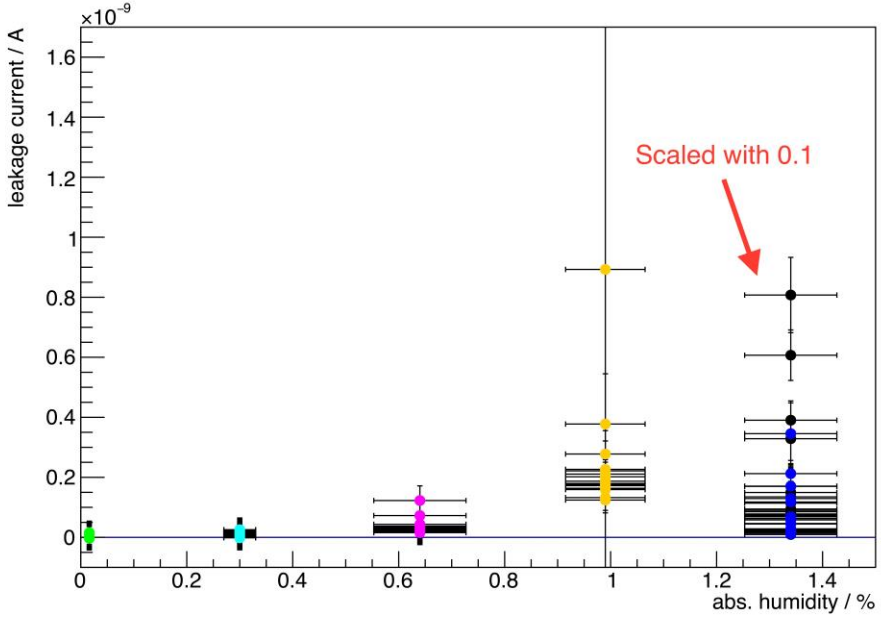
- Strong non linear humidity dependent > 0.6 % abs. humidity. Problematic if room air conditions are not under control. Typical room air conditions (0.8-1.5 %) abs humidity
- Variance of leakage current between segments is large in humid conditions. Reason unknown.
- I_{leak} variations of different segments could not be related to optical or stability measures
- After additional HV cleaning in humid condition most sectors show lower leakage currents
- Constant QA threshold in uncontrolled humidity conditions can not be used as a quality criteria.

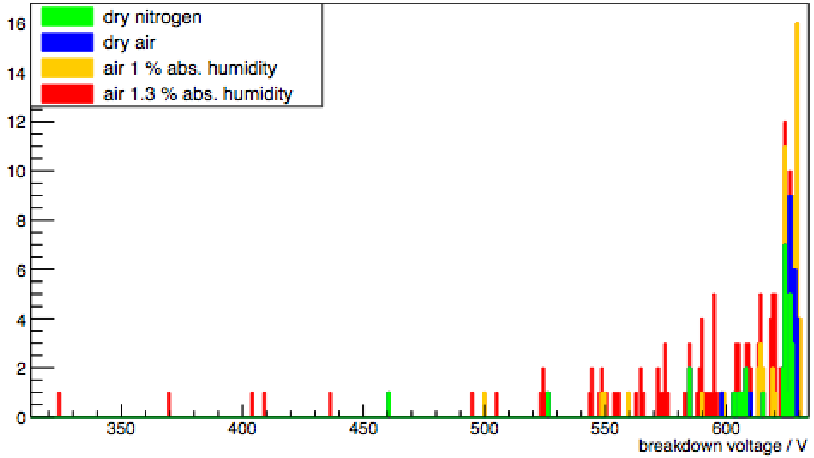
I_{leak} current measurements



- Strong non linear humidity dependent > 0.6 % abs. humidity. Problematic if room air conditions are not under control. Typical room air conditions (0.8-1.5 %) abs humidity
- Variance of leakage current between segments is large in humid conditions. Reason unknown.
- I_{leak} variations of different segments could not be related to optical or stability measures
- After additional HV cleaning in humid condition most sectors show lower leakage currents
- Constant QA threshold in uncontrolled humidity conditions can not be used as a quality criteria.

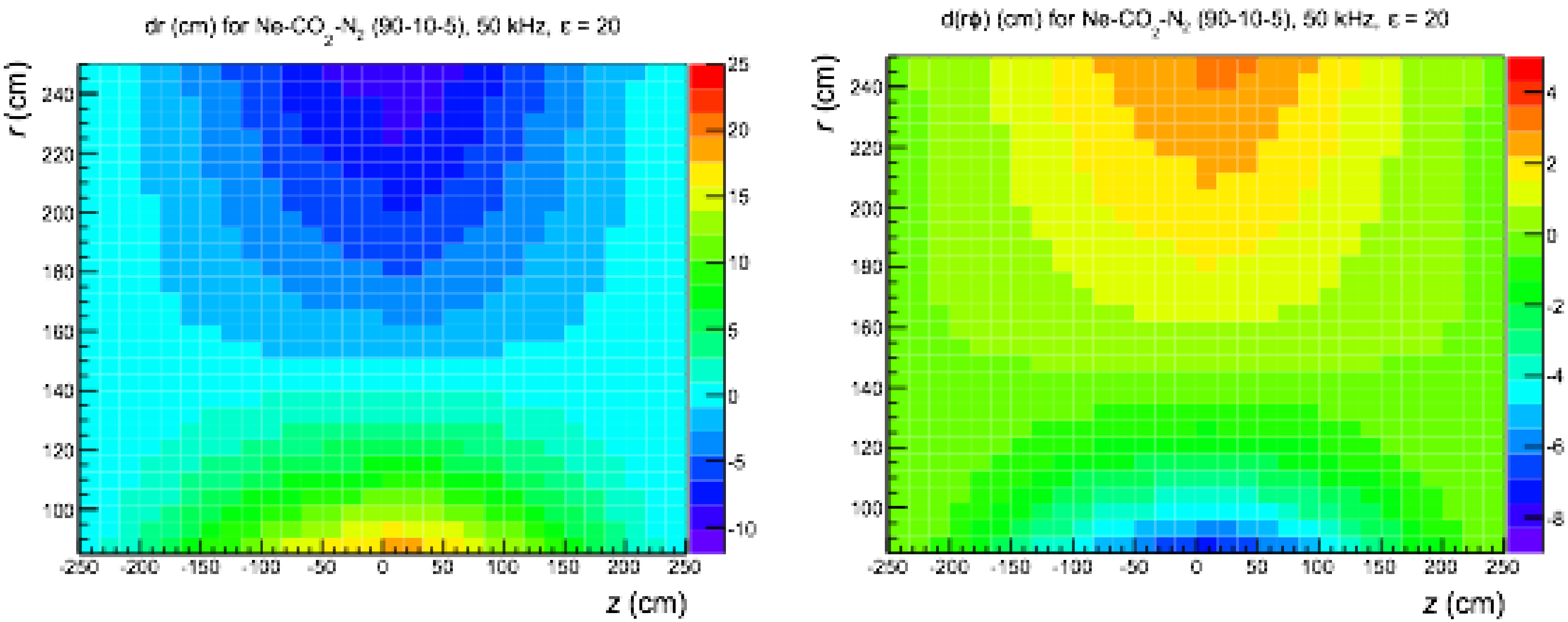
I_{leak} current measurements



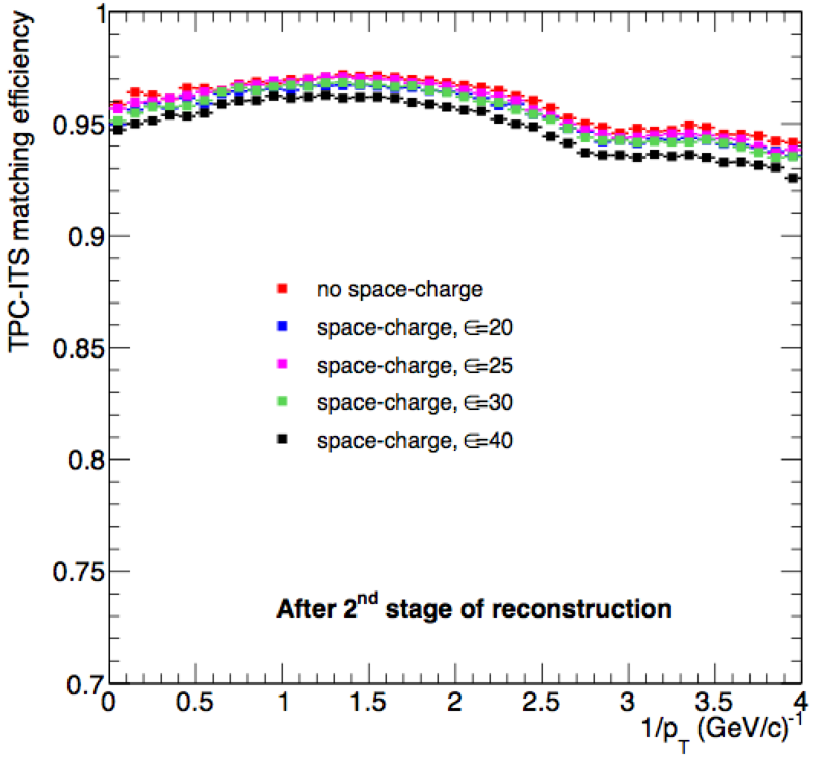


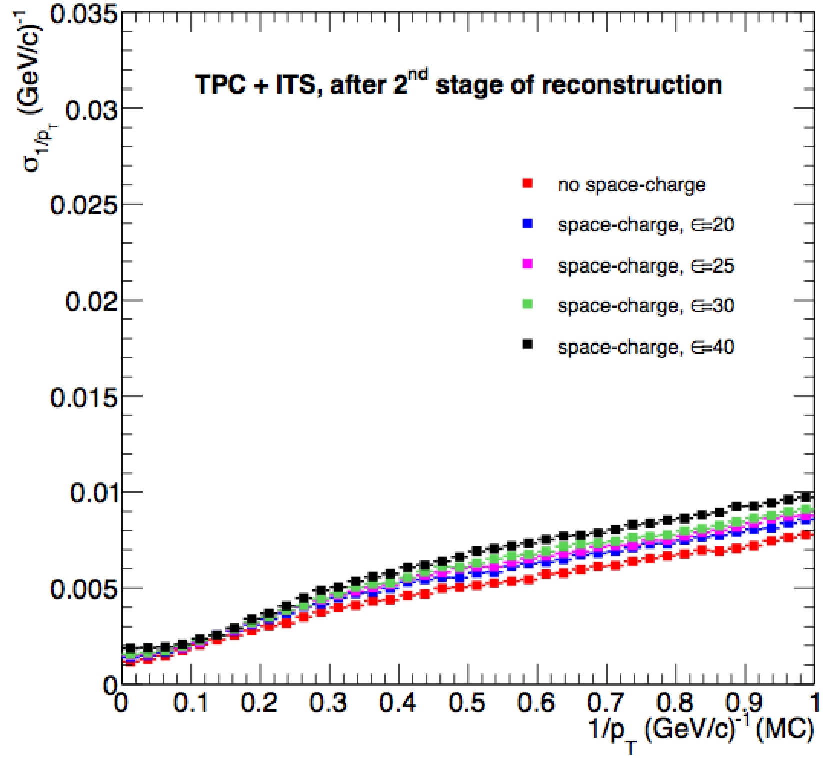
- Number of discharges rise with humidity
- Has also be observed in "M. C. Altunbas et al. Construction, test and commissioning of the triple-GEM tracking detector for COMPASS. Nucl. Instrum. Meth., A490:177-203, 2002."
- Observation contradicts expectation from gas properties GEM is not parallel plate capacitor → electrode quantities change e.g. dielectric constant, surface conductivity → behaviour not fully understood
- GEMs show some training effect (breakdown voltage increasing with number of tries). So far a clear quality criteria could not be derived. Currently sparks are detected. Foils are excluded if sparking continues after long term tests and sparks appear at the same position (red light)
- Avoid sparking → avoid humidity

Space-Charge Effects at ALICE



- Ions from 8000 events pile up in the drift volume at 50 kHz Pb-Pb collisions ($t_{d,ion}$ = 160 ms)
- Total number of ions in drift volume strongly depends on *IB*: $n_{tot} = n_{ion} * IB * G_{eff}$; $\varepsilon = IB * G_{eff} - 1$
- 1% of IB at G_{eff} = 2000 (ε = 20)
    - distortions up to dr ≈ 20 cm and d$r\varphi$ ≈ 8 cm (at small r and z)
    - well below 10 cm for the largest part of drift volume
- Corrections to $\mathcal{O}(10^3)$ are required for final calibration (to the level of intrinsic resolution, $\sigma_{r\varphi}$~ 200 μm)
- 2-stage calibration and reconstruction scheme





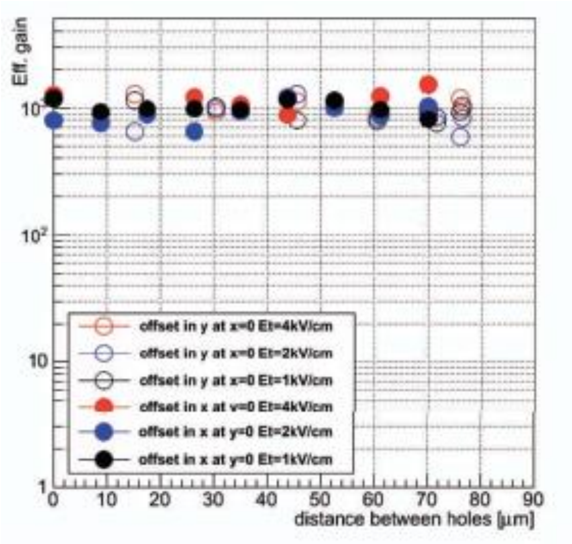
Testing limits of calibration procedure at up to twice the nominal ion density ($\varepsilon = 40$)

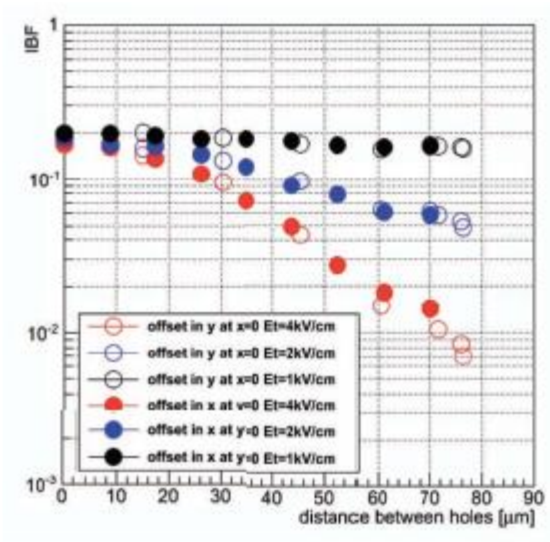
– tracking efficiency not compromised

– slight decrease in p_t resolution at low momenta

- does not compromise physics program

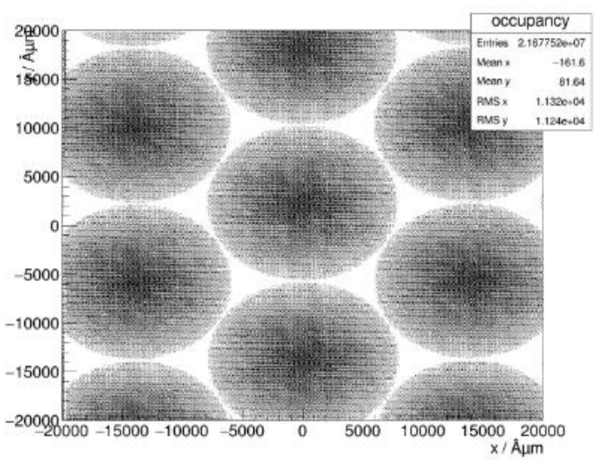
Rotation of Foils



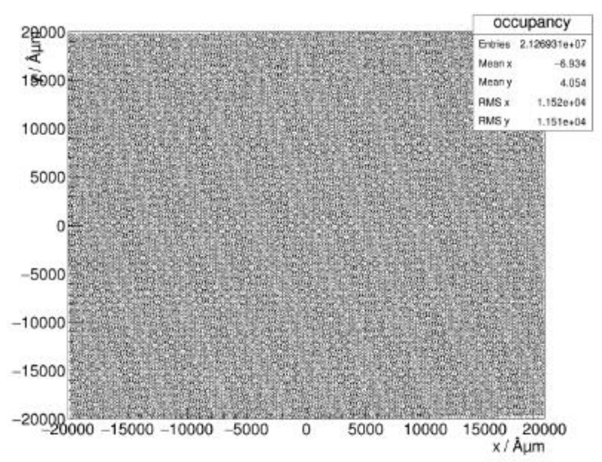


- Effective gain independent of hole alignment
- Ion backflow highly dependent on hole alignment

Foils rotated 1º

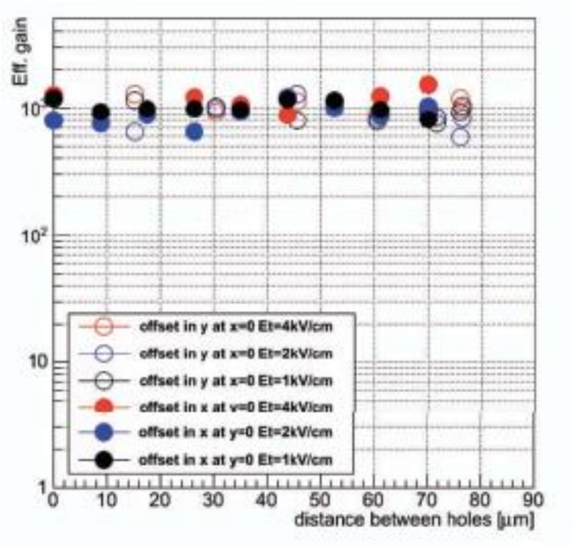


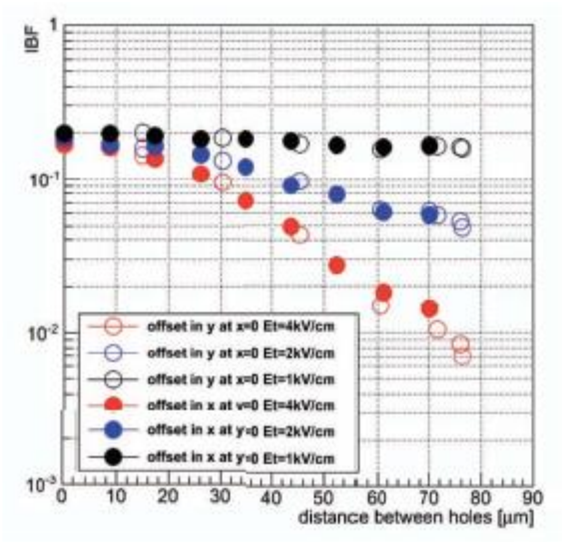
Foils rotated 90º to each other



- Effect of rotation of GEM to each other
- Ion backflow distributed uniform and reproducable

Rotation of Foils

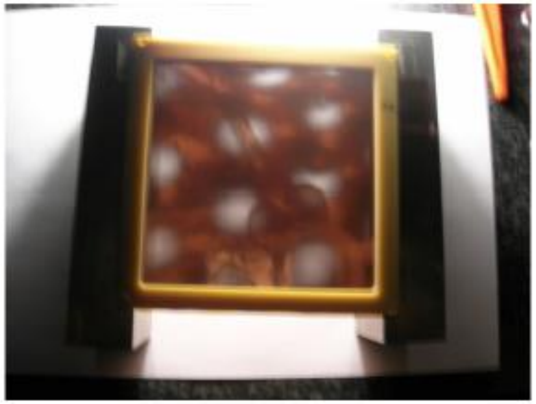


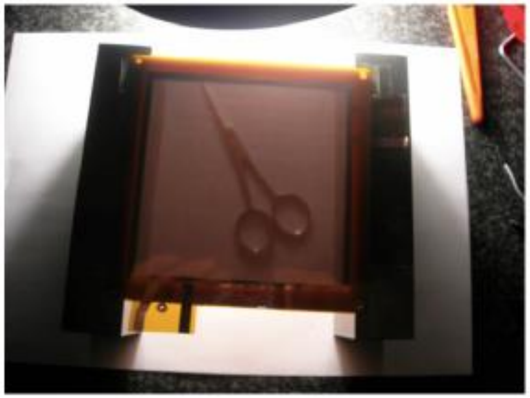


Foils not rotated

Foils rotated 90º to each other

- Effective gain independent of hole alignment
- Ion Backflow highly dependent on hole alignment

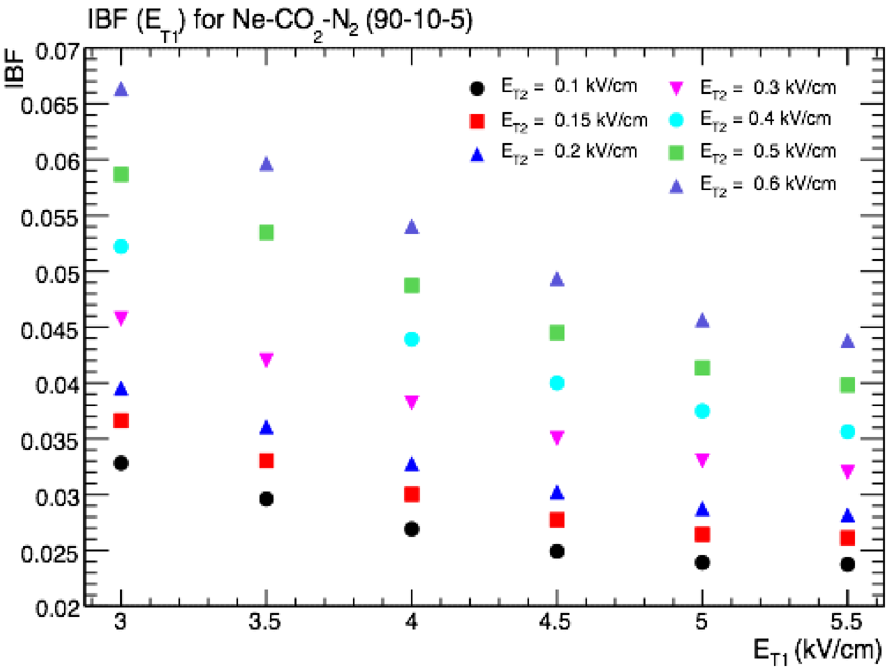


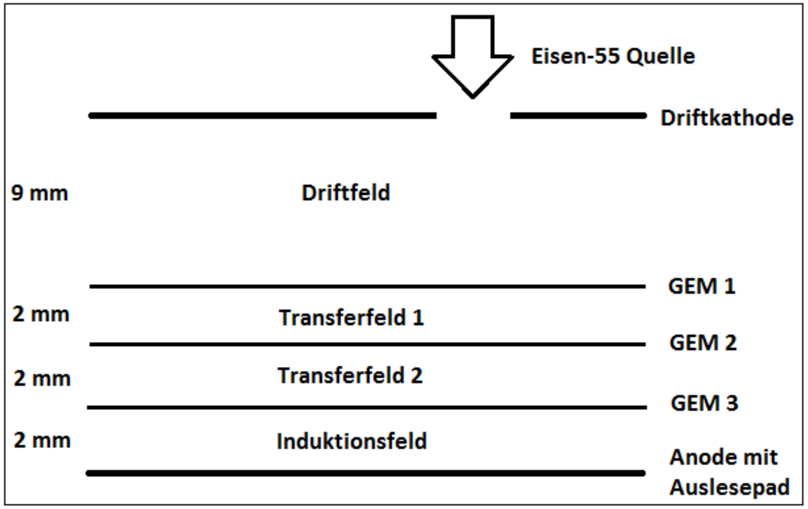


- Effect of rotation of GEM to each other
- Ion backflow distributed uniform and reproducable

Limit of a triple GEM setup

CERN-LHCC-2013-020





Asymmetric field configuration can be repeated in a GEM stack !

$E_{drift} < E_{T1}, E_{T2} < E_{ind}, \Delta U_{G1} < \Delta U_{G2} < \Delta U_{G3}$

Limitations of a triple GEM setup

- Ion Backflow was measured with triple GEM stack. Best value achieves was around 2.5 % at a gain of 2000 $\rightarrow \epsilon \sim 50$
- Asymmetric field configuration separates Gain of GEM_3 from Gain of $GEM_1 + GEM_2$ $\rightarrow$ higher discharge probability

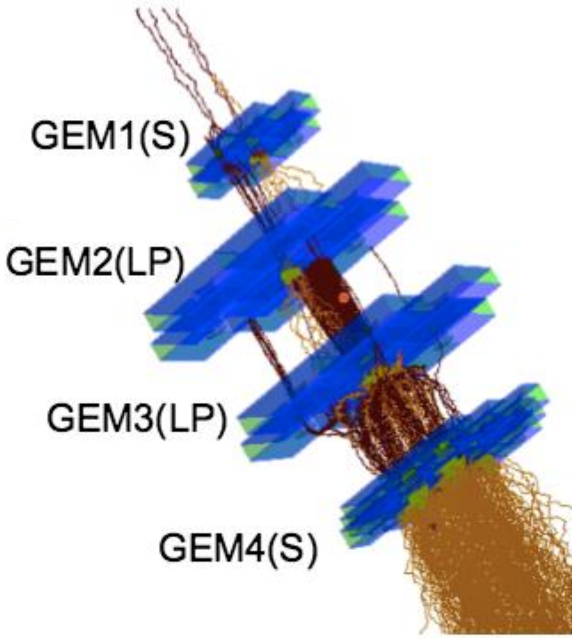
Electron transport properties for IB optimised HV settings

ε_{coll} = collection efficiency

ε_{extr} = extraction efficiency

M = gas multiplication factor

$G_{eff} = \varepsilon_{coll} \times M \times \varepsilon_{extr}$ = effective gain



	ε_{coll}	$n_{e,in}$	M	n_{e-ion}	ε_{extr}	$n_{e,out}$	G	$n_{ion,back}$	fraction of total IBF (sim.)	fraction of total IBF (meas.)
GEM1 (S)	1	1	14	13	0.65	9.1	9.1	3.6 (28%)	40%	31%
GEM2 (LP)	0.2	1.8	8	12.7	0.55	8	0.88	3.3 (26%)	37%	34%
GEM3 (LP)	0.25	2	53	104	0.12	12.7	1.6	1.3 (1.3%)	14%	11%
GEM4 (S)	1	12.7	240	3053	0.6	1830	144	0.84 (0.03%)	9%	24%
Total				3183		1830	1830	9 (0.28%)		

Ion trapping with GEMs

Electron transport properties for IB optimised HV settings

ε_{coll} = collection efficiency

ε_{extr} = extraction efficiency

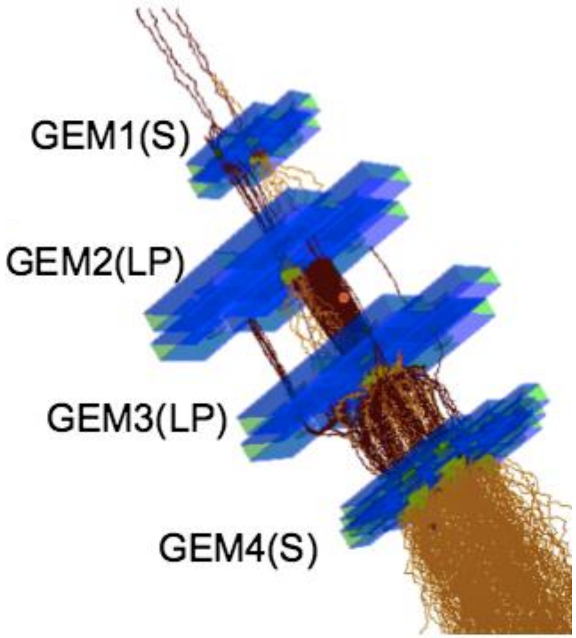
M = gas multiplication factor

$G_{eff} = \varepsilon_{coll} \times M \times \varepsilon_{extr}$ = effective gain

$n_{e\text{-}ion}$ = number of produced e-ions pairs

$n_{ion,back}$ = number of ions drifting back into the drift volume (ε)

$$IB = (1+\varepsilon)/G_{eff}$$



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Ion trapping with GEMs

ALICE UNIVERSITÄT BONN

Electron transport properties for IB optimised HV settings

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$G_{eff} = \varepsilon_{coll} \times M \times \varepsilon_{extr}$ = effective gain

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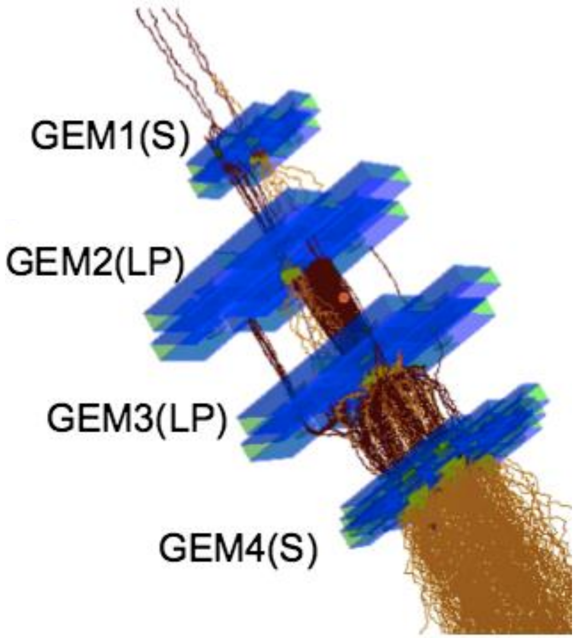
fraction of total IB: simulation vs. experiment



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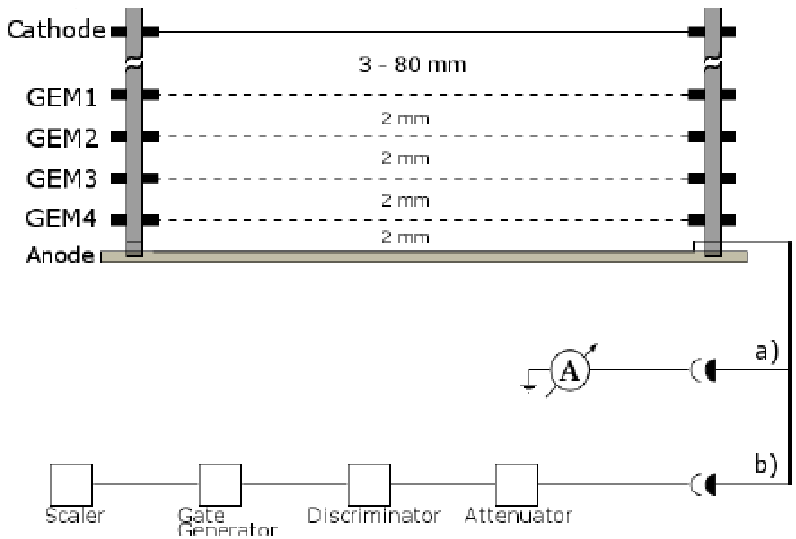
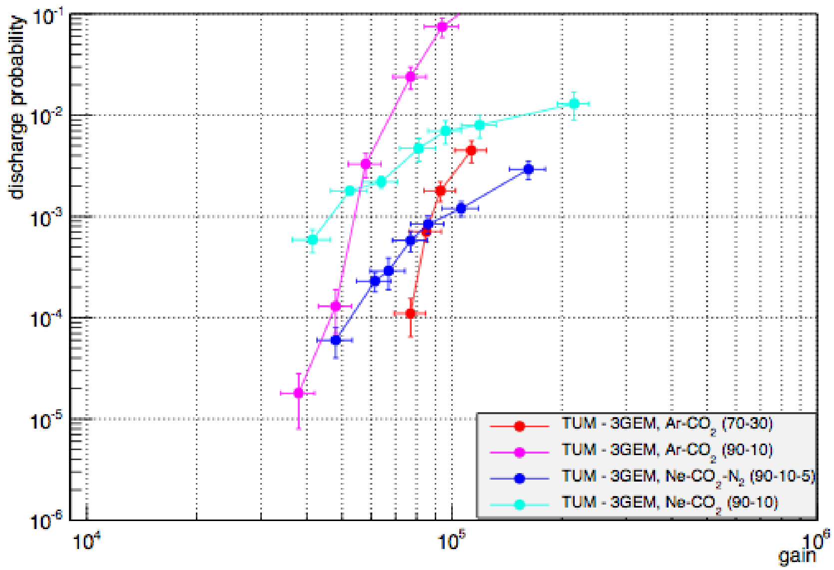
Triple GEM discharge probability
(S-S-S)

Triple GEM stack in standard settings





Optimisation of two parameters at the same time is conflicting:

- ^{220}Rn source, randomly distributed in the detector
- Measurement for TPC gas mixtures: Ar-CO_2 (90-10), Ne-CO_2 (90-10), Ne-CO_2-N_2 (90-10-5)
- Different slopes for Ar- and Ne-based gas mixture
- Clear influence of additional quencher

Goals of the QA

- QA of the CERN workshop:
  - Deliver GEM foils within specification agreed upon in collaboration document
- Basic QA (CERN):
  - Reject malfunctioning GEM foils at the earliest possible stage
  - Give fast feedback to the producer (CERN)
  - First reference (to identify e.g. defects coming from transport)
- Advanced QA:
  - Additional quality selection (hole size distributions, defect classification, gain uniformity prediction, long term stability)
  - Provide additional criteria to select the best foils
  - Provide additional information for the producer to improve/optimise the production process
- Basic QA (Framing-, Assembly sites)
  - Continuous quality monitoring
  - Shows if the basic HV stability is kept after each additional production step

Extended Traffic Light System

- Red Light:
  - GEM did not pass Basic QA (most important HV stability) → Reprocessed
  - Not (necessarily) permanent
- Orange Light
  - Basic QA passed → HV stability ok
  - Hole size distributions: both inner or outer holes show an asymmetry
  - Target design values for hole (inner outer deviate more than 10 μm)
- Yellow Light:
  - Basic QA passed → HV stability ok
  - Hole size distributions: either inner or outer holes show an asymmetry
  - Predicted gain spread larger than 10 % (RMS), long term HV stability acceptable
- Green Light
  - Passed all basic and advanced QA criteria
  - Basic HV stability is kept after all processing steps

Advanced QA

Advanced QA consists of:

- High definition optical scan including the determination of 1-dim and 2-dim hole size distributions and map of optical defects
- Gain uniformity measurements of statistically significant sample of GEM foils
- Correlation of gain uniformity and hole size distribution is used to predict the gain uniformity of each GEM foil
- $I_{leakage}$ measurements for at least five hours, data is stored in a leakage current file with common data format
- Determination and classification of defects (in preparation)

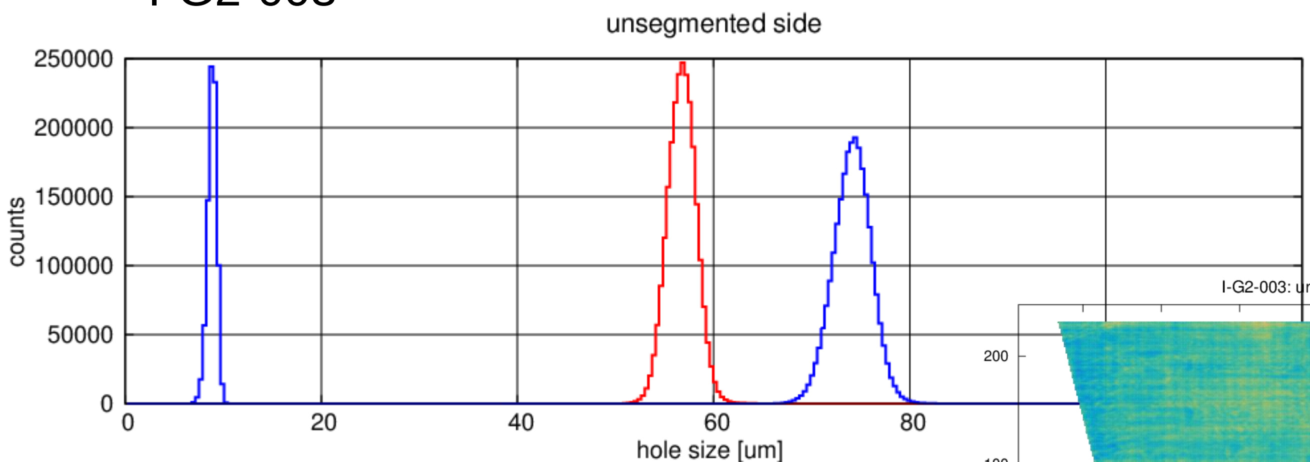
10	QA-B	**I_leak histo data**	01_O2-G1-001_N2_corrected.txt evaluate	2	2017-08-11 16:22:15	no comment | avg all segments 10.7, sparks: 0 ok	Viktor	file	
12	12	**hole size distribution**	O2-G1-001_1D.txt evaluate 1D		2017-06-09 11:44:02	no comment | avg all segments 10.7, sparks: 0	Marton	file txt	
13	13	**hole size data 2D**	O2-G1-001_2D.txt evaluate 2D		2017-06-09 11:44:43	no comment | avg all segments 10.7, sparks: 0	Marton	file txt	
15	QA-A	**long term leakage current data**	O2-G1-001-20170504-15-42_sectors.txt evaluate	2	2017-06-29 14:11:17	no comment | avg all segments 3.4, sparks: 0 sticky rolled after shorted sector, looks better although many sparks	Marton	file txt	
20	20	**frame glueing** comment if not perfect (wrinkels?)						eq	
25	25	**quality**	B	2	2017-06-10 23:01:47	Also slight problems from the HV, had to sticky roll it, but came back alive.	Marton	le C	
submit		darker field: mouse hover for more explanations							

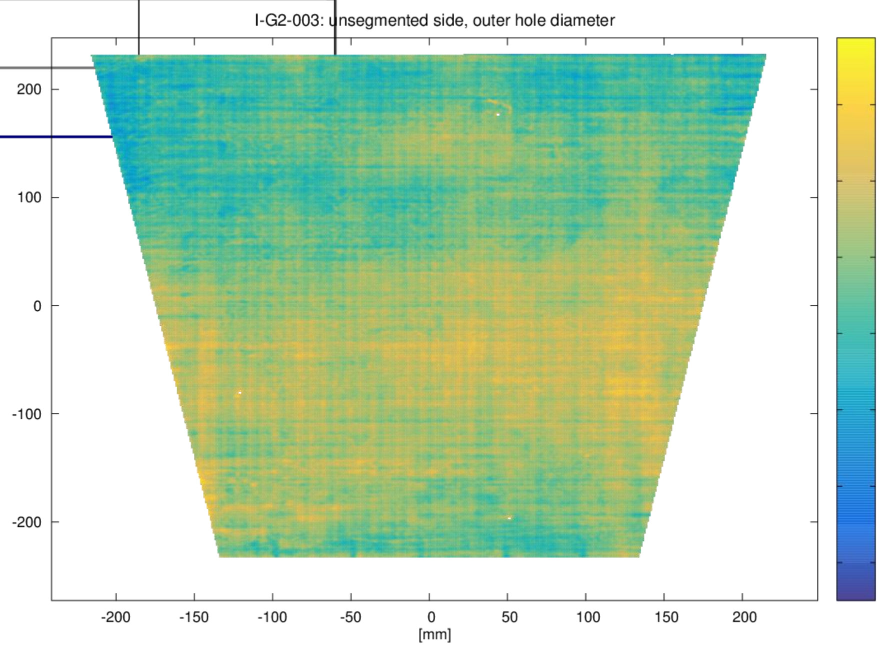
All values in µm

Green GEM foil:

	Segmented Side			Unsegmented Side	
inner (RMS)	outer (RMS)	rim (RMS)	inner (RMS)	outer (RMS)	rim (RMS)
56.6 (1.54)	74.7 (1.54)	9.0 (0.58)	56.6 (1.57)	73.9 (1.94)	8.7 (1.94)

I-G2-003





- Long term I_{leak} ok
- Hole size distribution uniform
- Mean values of the inner, outer holes close to the target values

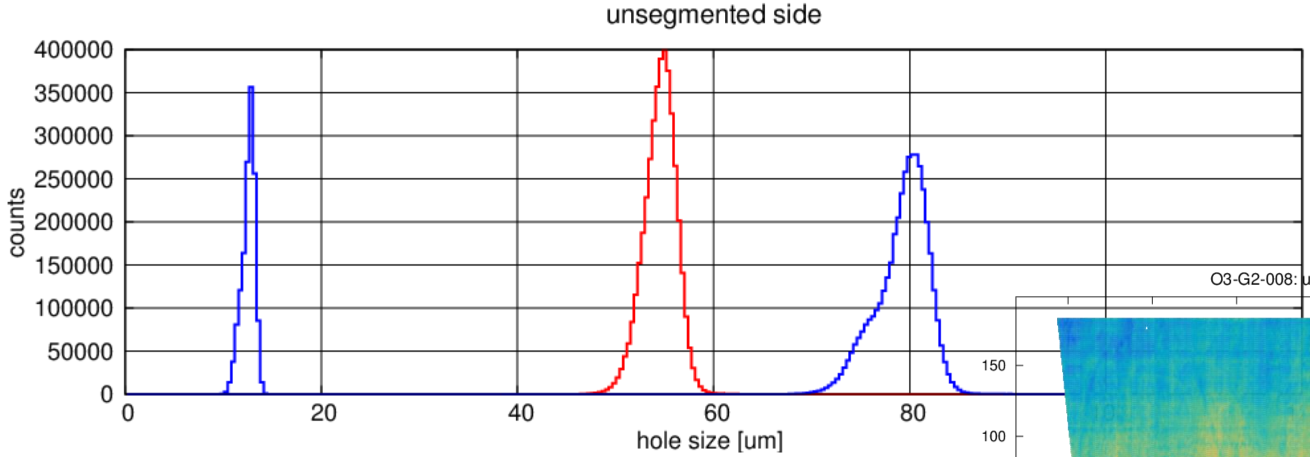
Advanced QA

All values in μm

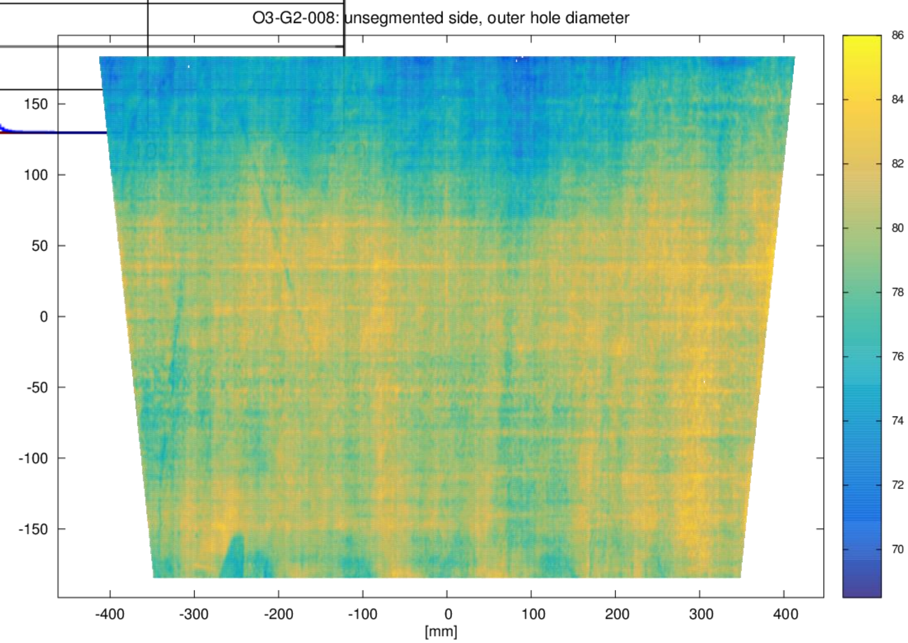
Yellow GEM foil:

Segmented Side			Unsegmented Side		
inner (RMS)	outer (RMS)	rim (RMS)	inner (RMS)	outer (RMS)	rim (RMS)
54.6 (1.72)	80.5 (1.57)	13.0 (0.49)	54.3 (1.67)	79.1 (2.64)	12.4 (0.68)

O3-G2-008



- Long term I_{leak} ok
- Hole size distribution not (always) uniform
- Mean values of the inner, outer holes within 5-10 μm of batch average



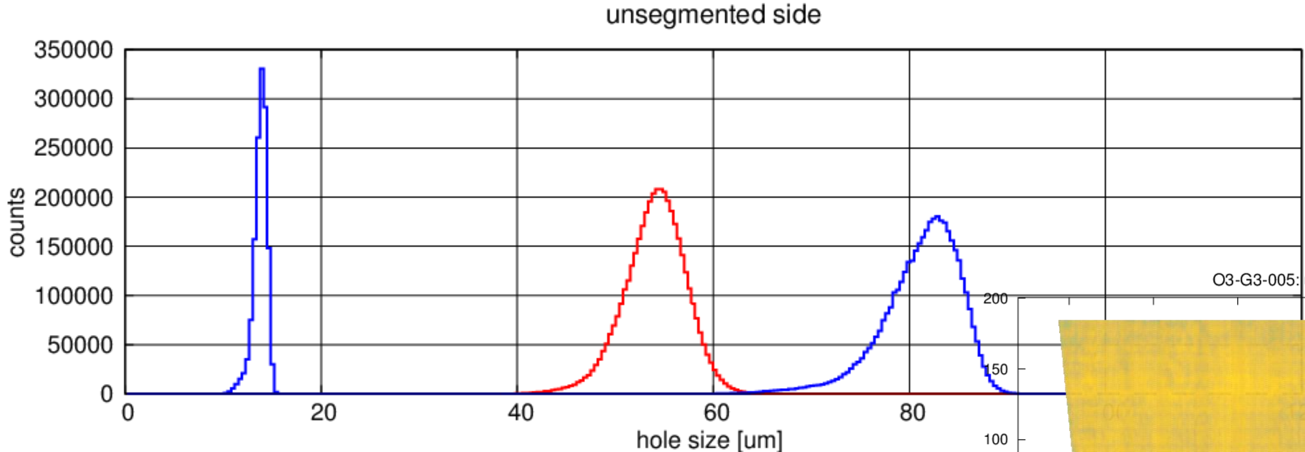
Advanced QA

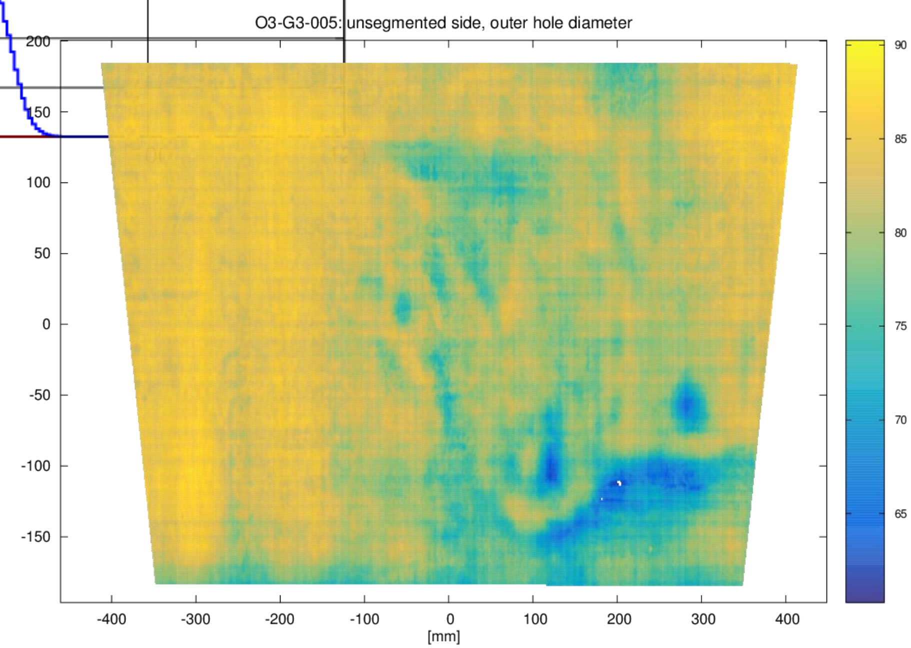
All values in µm

Orange GEM foil:

Segmented Side			Unsegmented Side		
inner (RMS)	outer (RMS)	rim (RMS)	inner (RMS)	outer (RMS)	rim (RMS)
53.9 (3.14)	77.3 (2.92)	11.7 (0.52)	53.8 (3.16)	81.0 (4.02)	13.6 (0.71)

O3-G3-005





- Long term I_{leak} ok
- Hole size distribution of segmented and unsegmented side not uniform
- Mean values of the inner, outer holes bigger than 10 µm of batch average

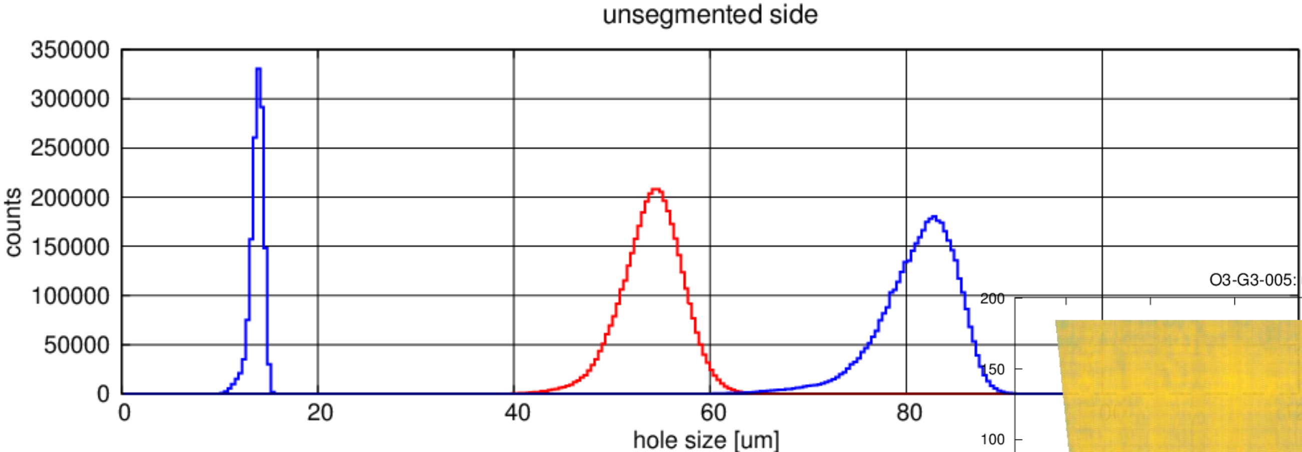
Advanced QA

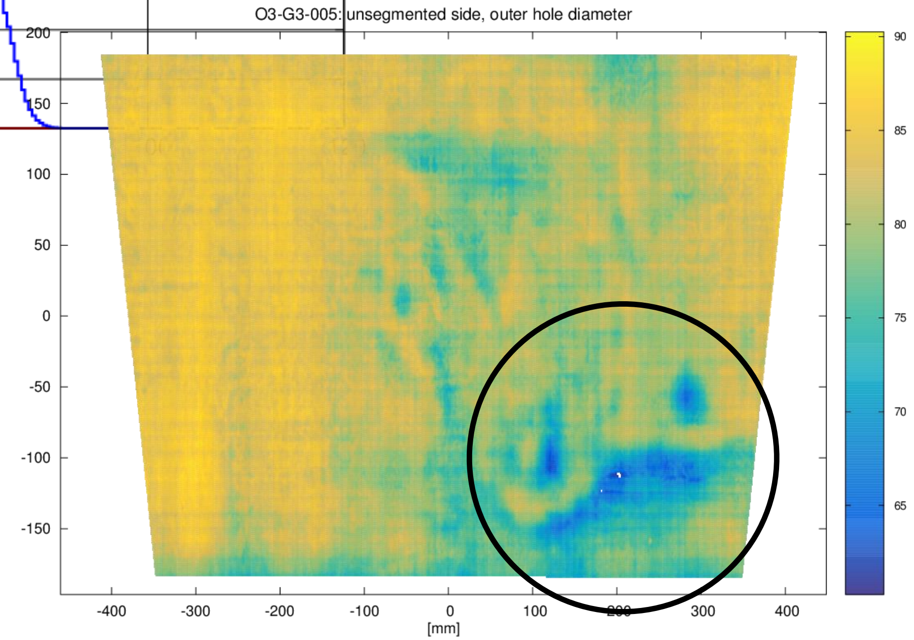
All values in μm

Orange GEM foil:

	Segmented Side			Unsegmented Side		
	inner (RMS)	outer (RMS)	rim (RMS)	inner (RMS)	outer (RMS)	rim (RMS)
	53.9 (3.14)	77.3 (2.92)	11.7 (0.52)	53.8 (3.16)	81.0 (4.02)	13.6 (0.71)

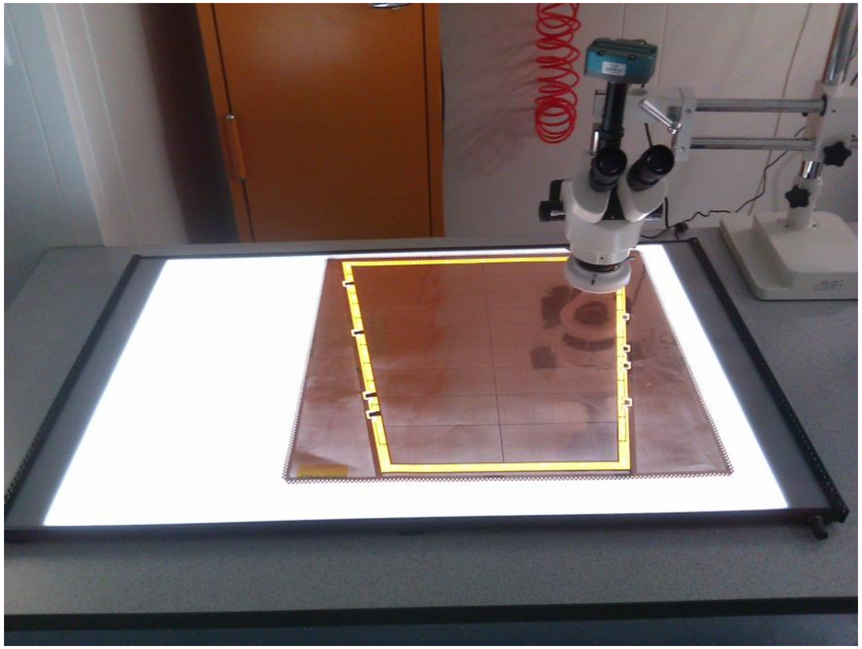
O3-G3-005

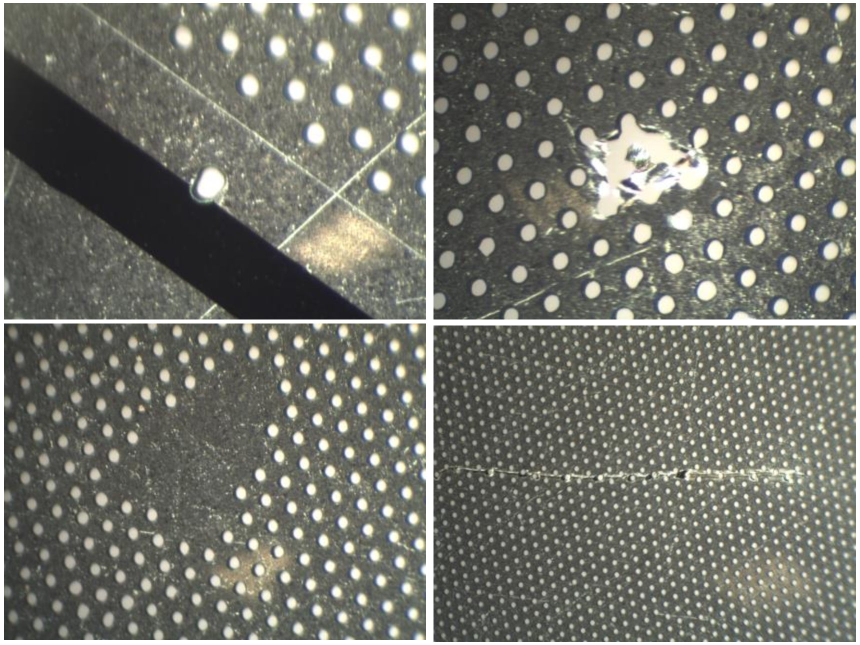




- Long term I_{leak} ok
- Hole size distribution of segmented and unsegmented side not uniform
- Mean values of the inner, outer holes bigger than 10 μm of batch average

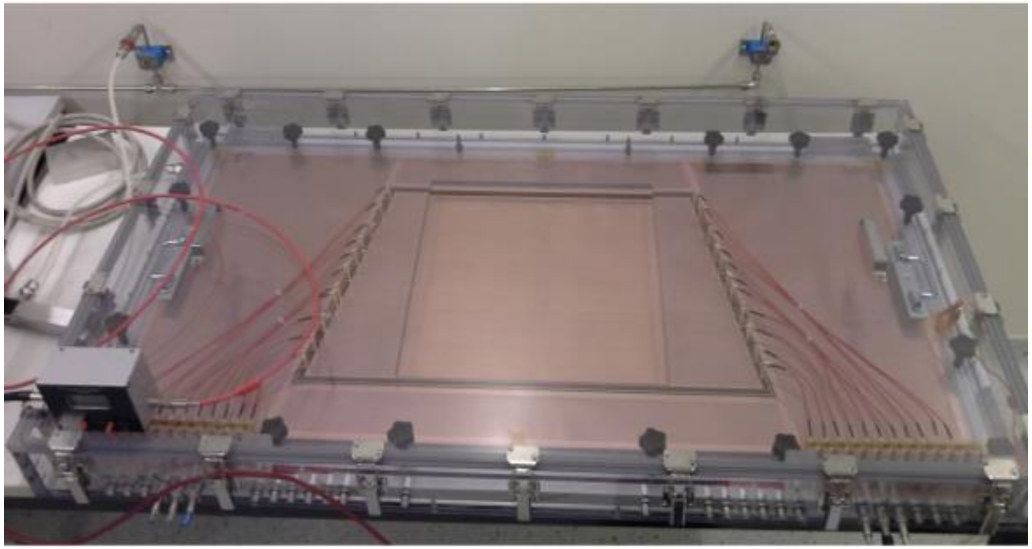
Basic QA

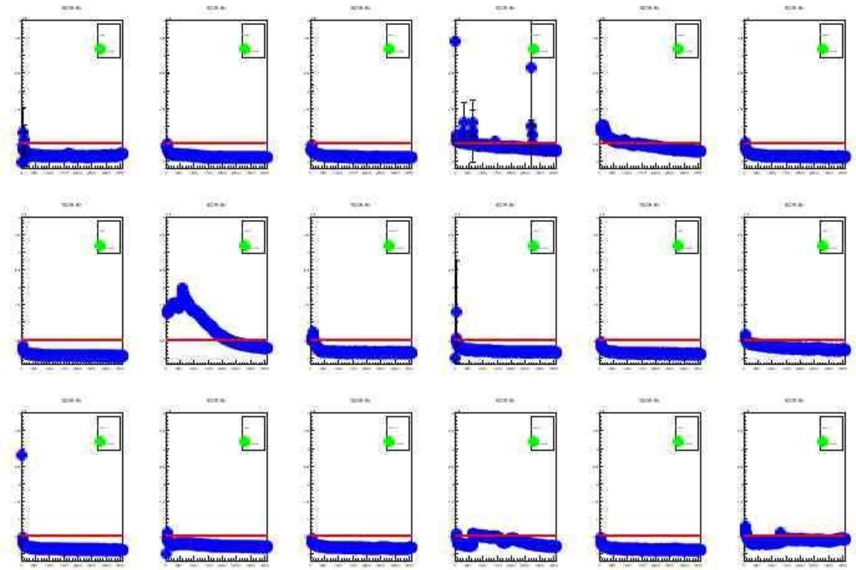




- Repeat coarse optical inspection and cross-check with known defects from the database

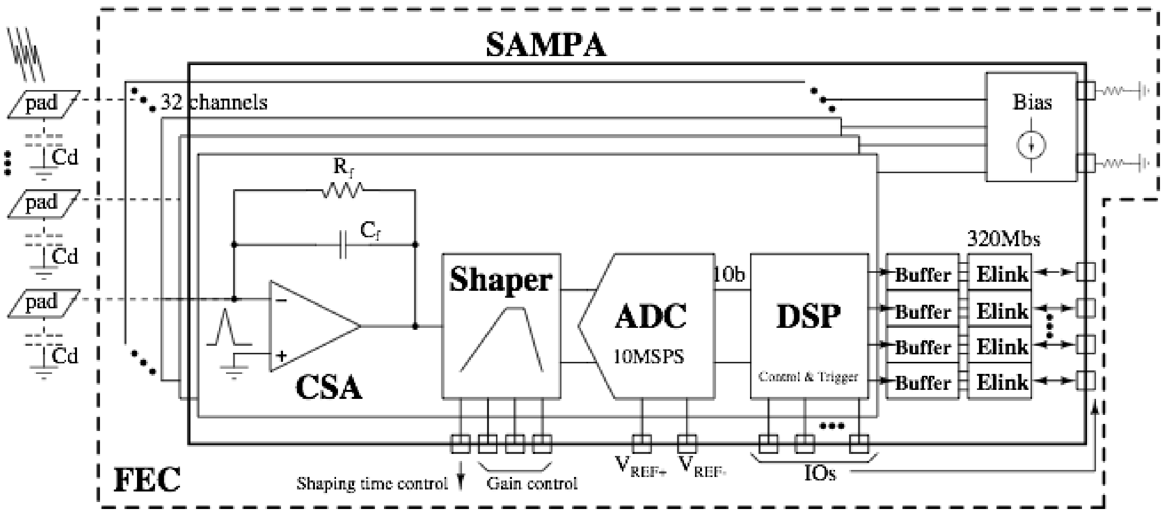
Basic QA

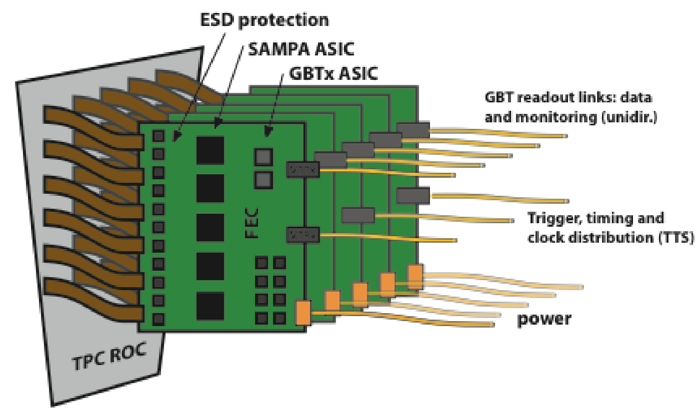




- Repeat coarse optical inspection and cross-check with known defects from the database
- We have to monitor the I_{leak} for each individual HV segment to fall below a specific value (0.5 nA/segment). I_{leak} will be measured before and after the framing

Electronics





New FE ASIC “SAMPA” (130 nm TSMC CMOS)

- Positive or negative input
- Programmable conversion gains and peaking times
- Different readout modes: triggered, continuous with DSP, continuous with DSP by-pass

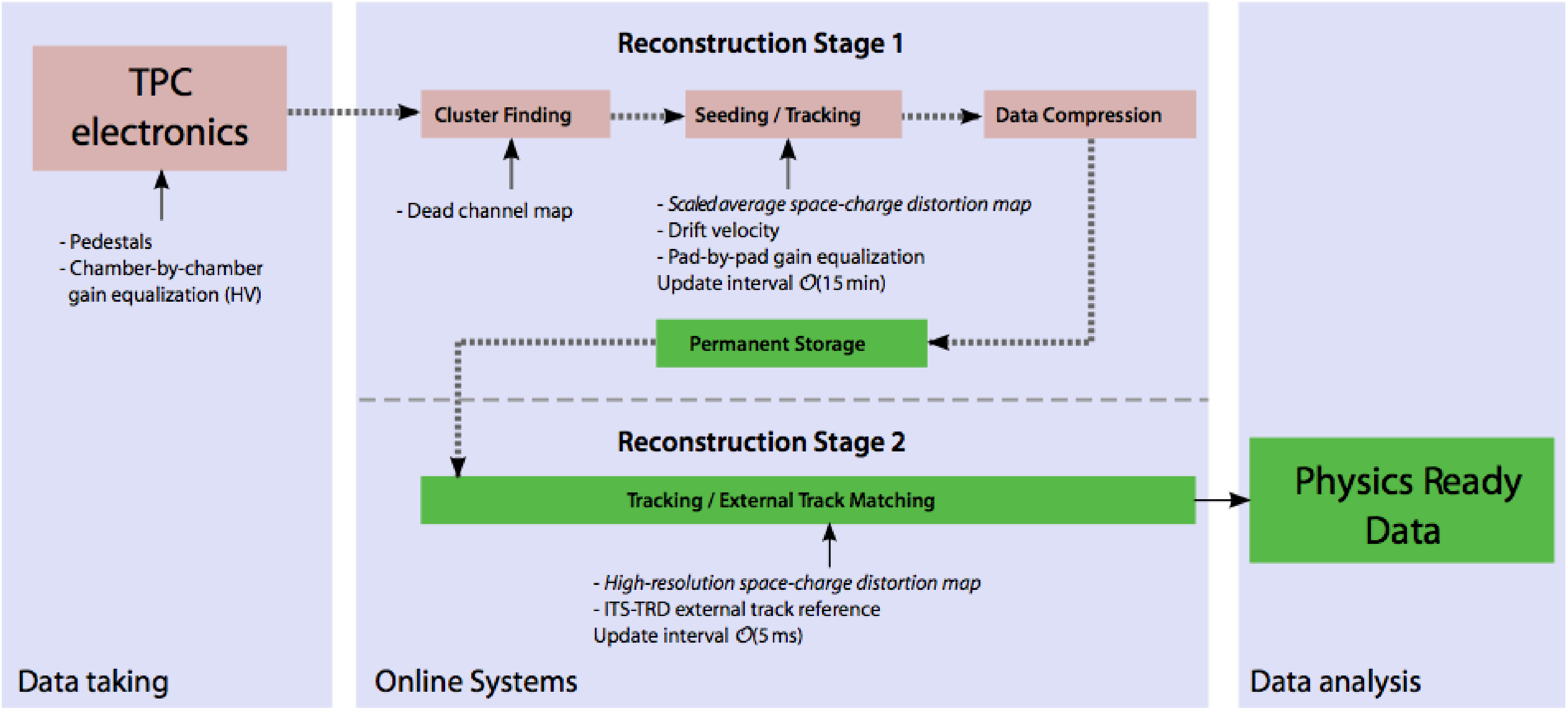
For required Signal-to-Noise ratio excellent noise figure of 670e^{-} (as currently) is needed

All ADC values are read out: data output for 50 kHz Pb-Pb collisions ≈ 6.55 TByte/s

Baseline correction and data compression off detector

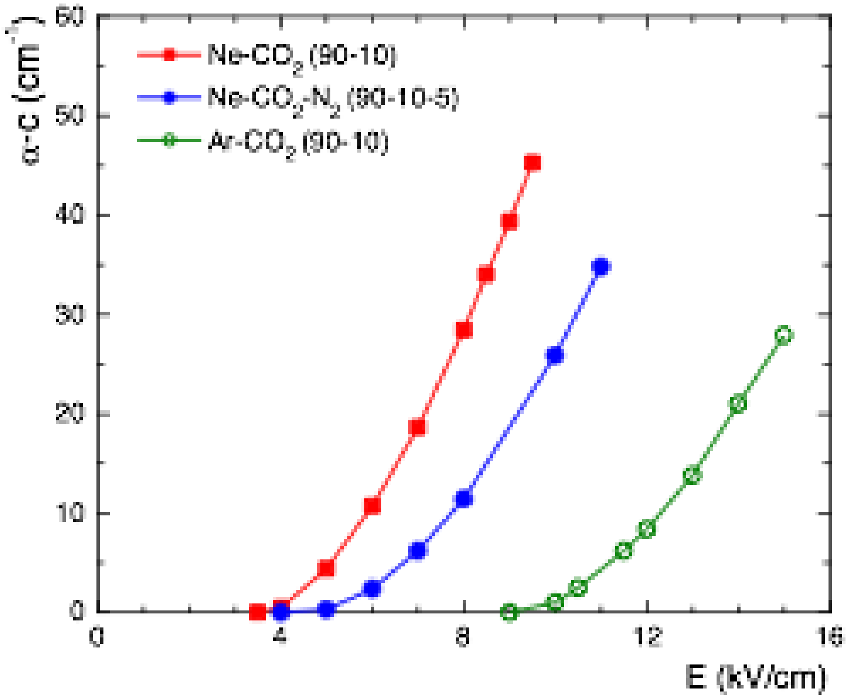
Use CERN developed GBT and Versatile Link for readout

Reconstruction Strategy



Two-stage reconstruction scheme:

- Cluster finding, cluster to track association: 1 TB/s → 50 GB/s, scaled averaged space charge distortion map
- Tracking, ITS-TRD track matching, high-resolution space-charge corrections for full distortion calibration → O(200 μm) in rϕ



Gas	v_d (cm/μs)	D_L ($\sqrt{cm}$)	D_T ($\sqrt{cm}$)	$\omega\tau$	W_i (eV)	N_p (cm^{-1})	N_t (cm^{-1})
Ne-CO_2-N_2 (90-10-5)	2.58	0.0221	0.0209	0.32	37.3	14.0	36.1
Ne-CO_2 (90-10)	2.73	0.0231	0.0208	0.34	38.1	13.3	36.8
Ne-CF_4 (90-10)	8.02	0.0152	0.0131	1.77	37.7	15.7	42.7
Ne-CF_4 (80-20)	8.41	0.0131	0.0111	1.84	37.3	20.5	54.1
Ar-CO_2 (90-10)	3.31	0.0262	0.0221	0.43	28.8	26.4	74.8

Gas Choices of the ALICE TPC:

- **RUN 1:** Ne-CO_2 (90-10)
  TPC with gating grid, space charges only from the primary ions produced in the drift volume
- **Run 2:** Ar-CO_2 (90-10)
  TPC with gating grid, focus on stability of operation
- **RUN 3:** Ne-CO_2-N_2 (90-10-5)
  TPC with GEM amplification system, focus on fast ion drift velocity v_{ion}(Ar) ~ 600 cm/s, v_{ion}(Ne) ~ 1600 cm/s, E_{trans} is in ~ 4 kV/cm (Townsend coefficient), increases probability for traversing discharges, limits the field settings