Status of R&D of the ALICE TPC upgrade with GEMs

23 Apr 2013

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for the ALICE TPC collaboration

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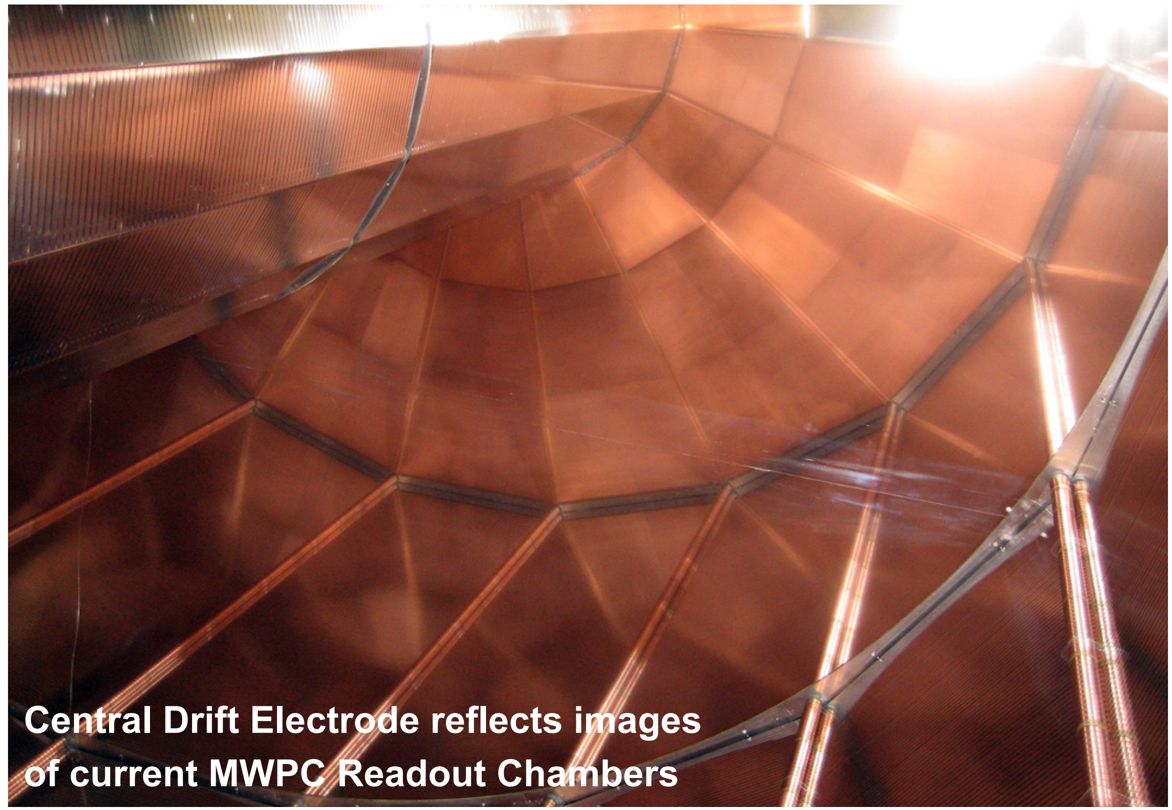
TPC upgrade strategy

- Replace MWPCs with GEMs
  - Continuous readout without Gating Grid
  - IBF suppression with multi-GEMs
  - Preserve current performance at 50 kHz

  ⇒Target: IBF < 0.25% at gain 2000



- Single mask method to produce large-size GEM foils
- Splicing of foils for larger Outer Read-Out Chambers

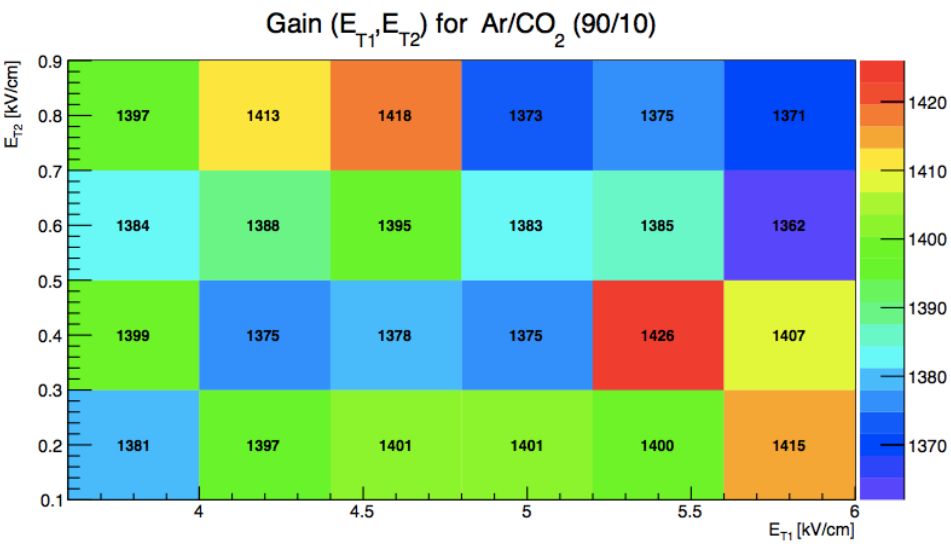
IBF in Ar/CO_2 90/10

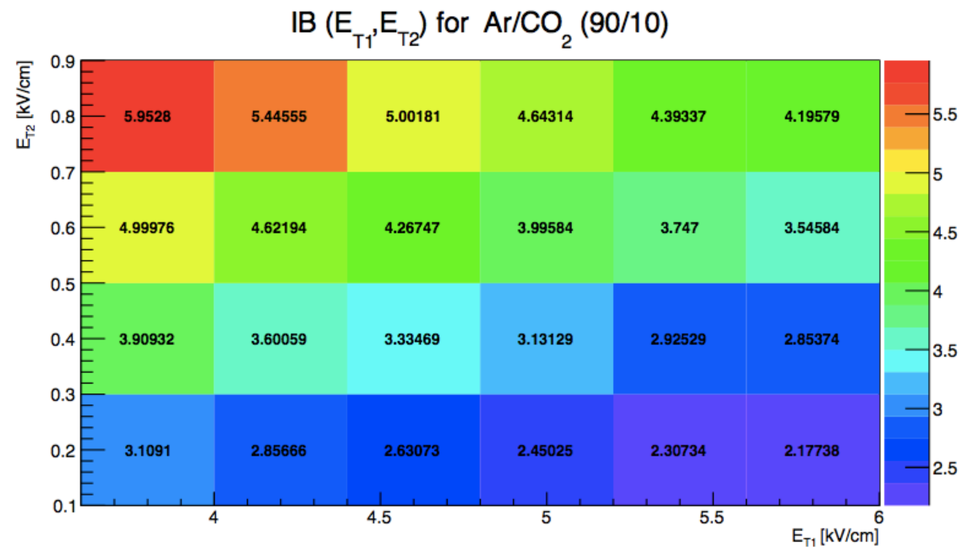
- Systematic measurements at TUM
- Gain kept ~constant using V_{GEM3}

For Ar/CO_2 90/10

GEM voltage settings		*Detector field settings*	
GEM1	300 V	E_{Drift}	0.4 kV cm^{-1}
GEM2	335 V	E_{T1}	5.8 kV cm^{-1}
GEM3	steerable	E_{T2}	0.2 kV cm^{-1}
		E_{Ind}	4.5 kV cm^{-1}

varied





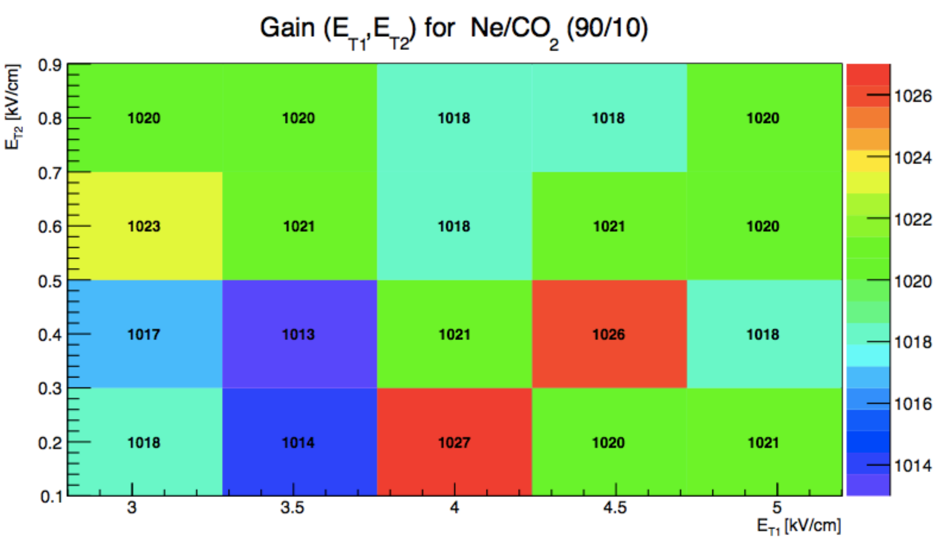
- Preliminary measurements: Requirements not met

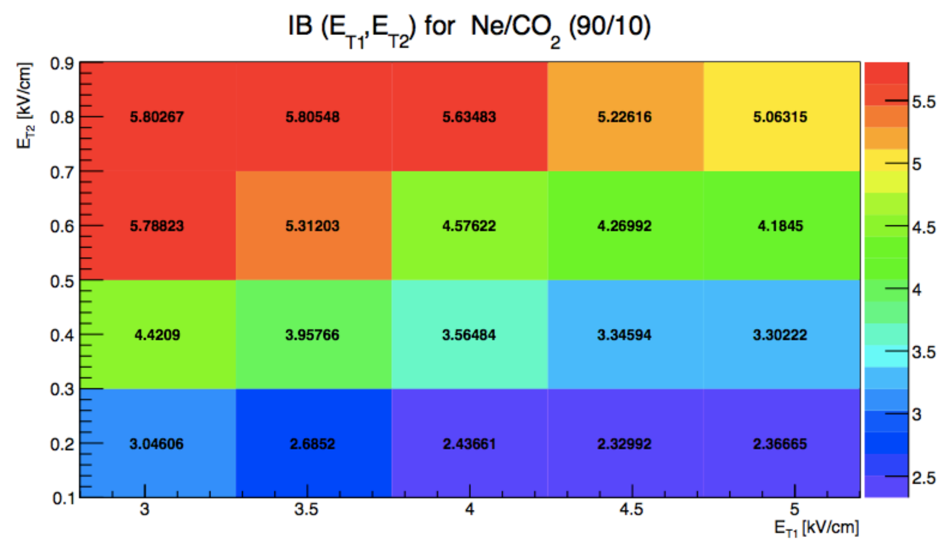
IBF in Ne/CO_2 90/10

- Systematic measurements at TUM
- Gain kept ~constant using V_{GEM3}

For Ne/CO_2 90/10

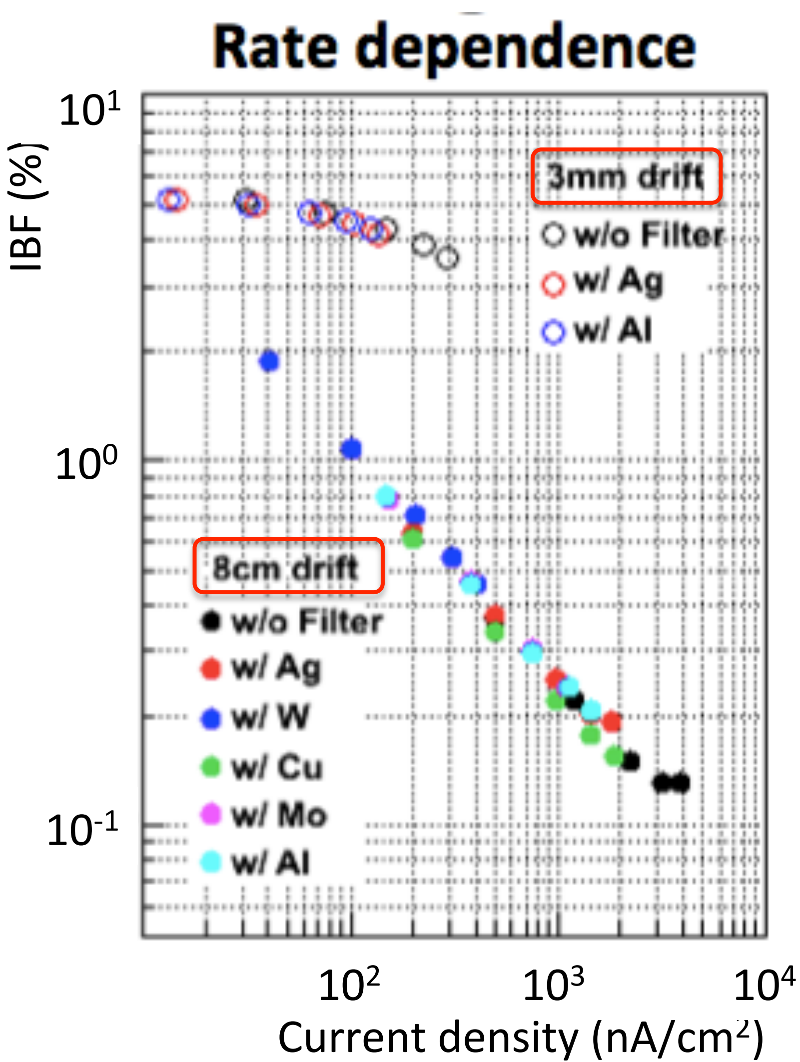
GEM voltage settings		*Detector field settings*		
GEM1	245 V	E_{Drift}		$0.4\,\mathrm{kV\,cm^{-1}}$
GEM2	255 V	E_{T1}	varied	$5.0\,\mathrm{kV\,cm^{-1}}$
GEM3	steerable	E_{T2}		$0.2\,\mathrm{kV\,cm^{-1}}$
		E_{Ind}		$3.8\,\mathrm{kV\,cm^{-1}}$





- Preliminary measurements: Very similar to Ar/CO_2

Influence of space charge and drift distance



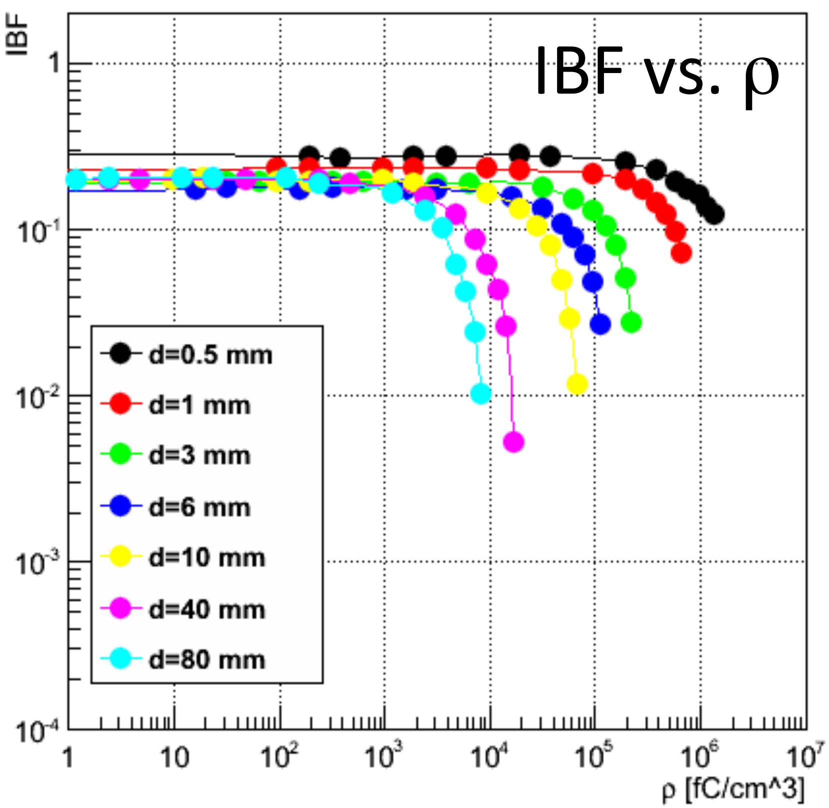
- Measurements show discrepancy for different drift distances (d=8cm and 3mm)
  - With short drift space (3 mm) almost no rate dependence
  - With long drift space (8 cm) IBF reduces and depends on rate
- What is the possible cause?

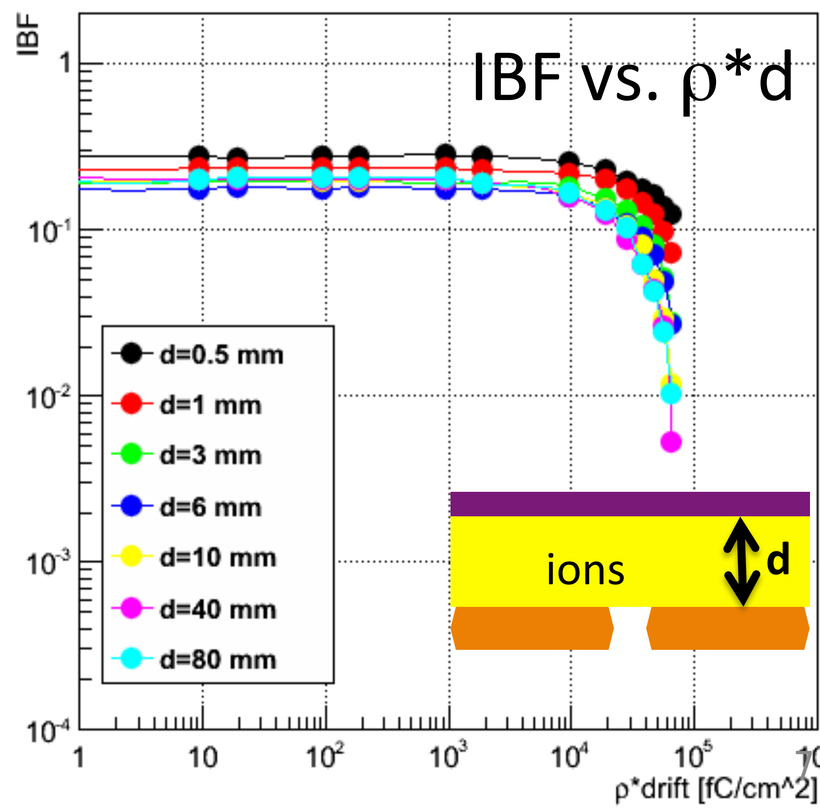
⇒Simulation studies (T. Gunji)

Simulations: IBF vs. space-charge

- Various uniform ion densities at various drift distance
- Space-charge starts to influence IBF at lower density for longer drift distance. ρ*d > 10^4 [fC/cm^2] at E_d=0.4kV/cm

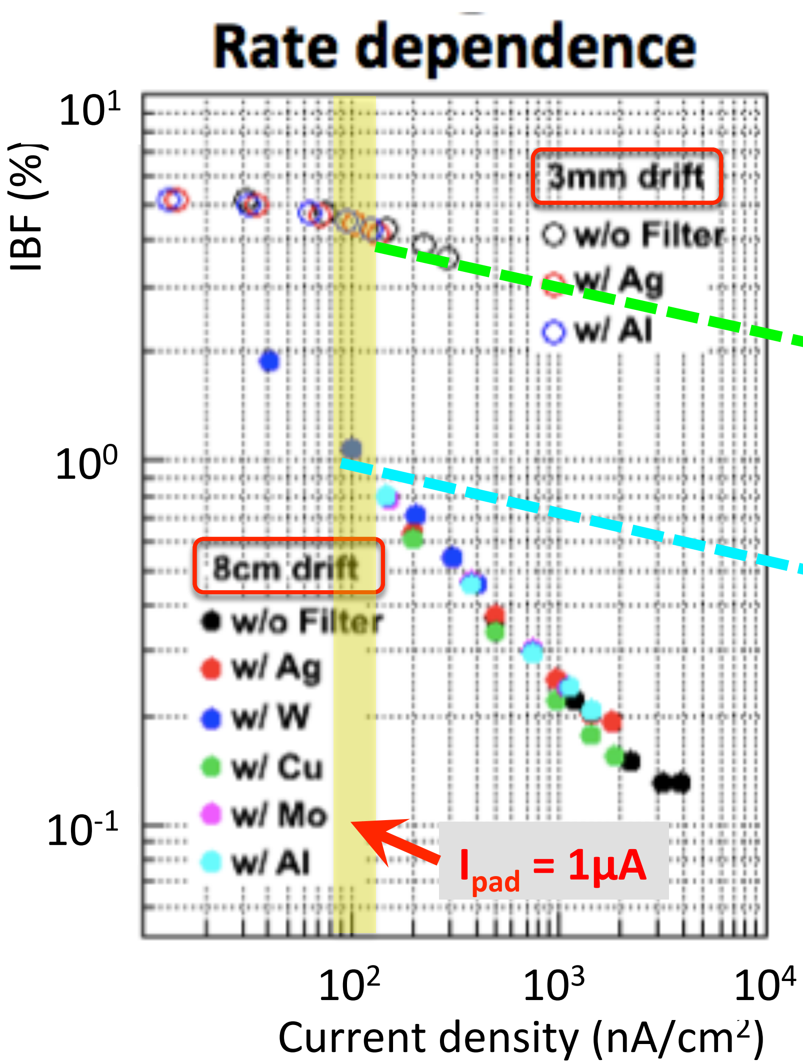
Field above top GEM changes as $E(z) = E_d - \rho/\varepsilon * d + 2\rho/\varepsilon * z$

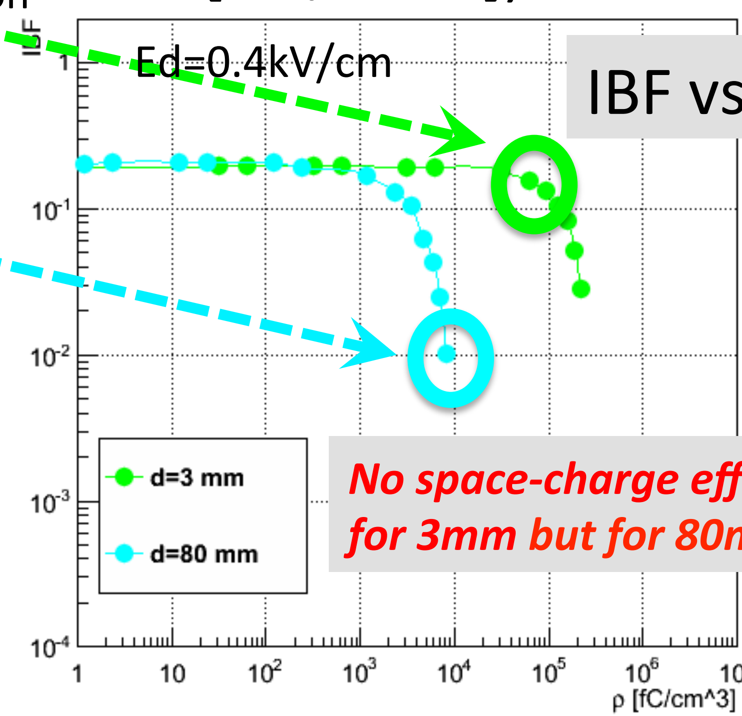




Comparison with measurements

- I_{pad} = 1uA ⇒ I_{drift} = 10nA (d=80mm), 40nA (d=3mm)
- $\rho_{ion} = I_{drift}/(Au_{ion})$ = 2.2×10^4 (80mm), 8.8×10^4 (3mm) [fC/cm^3] with $A=\pi r^2$ with r=0.5cm, v_{ion}=0.57 [cm/msec])

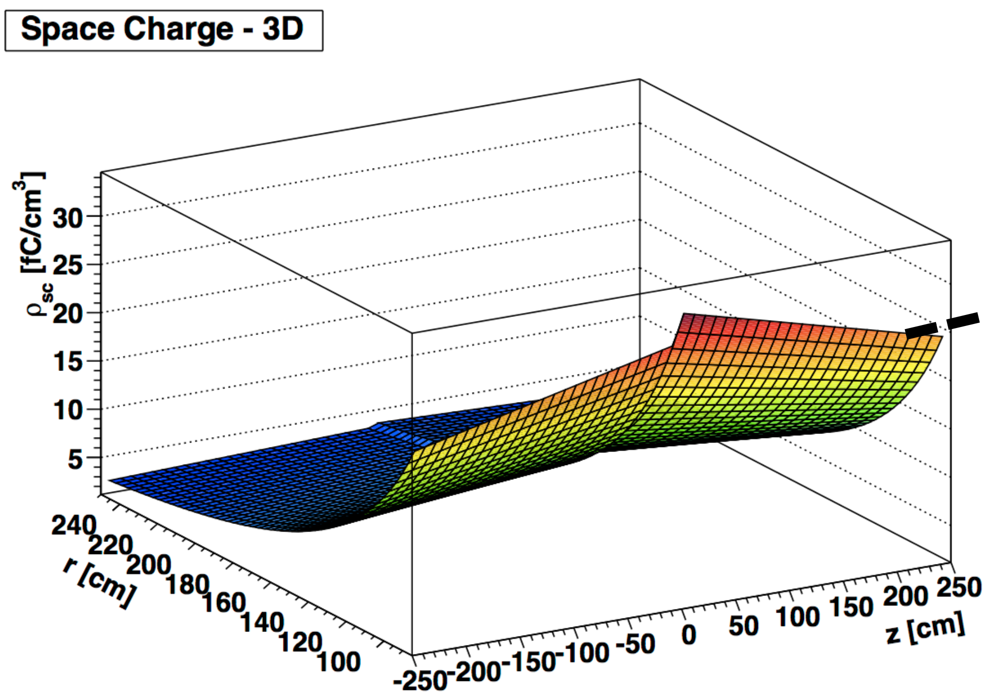


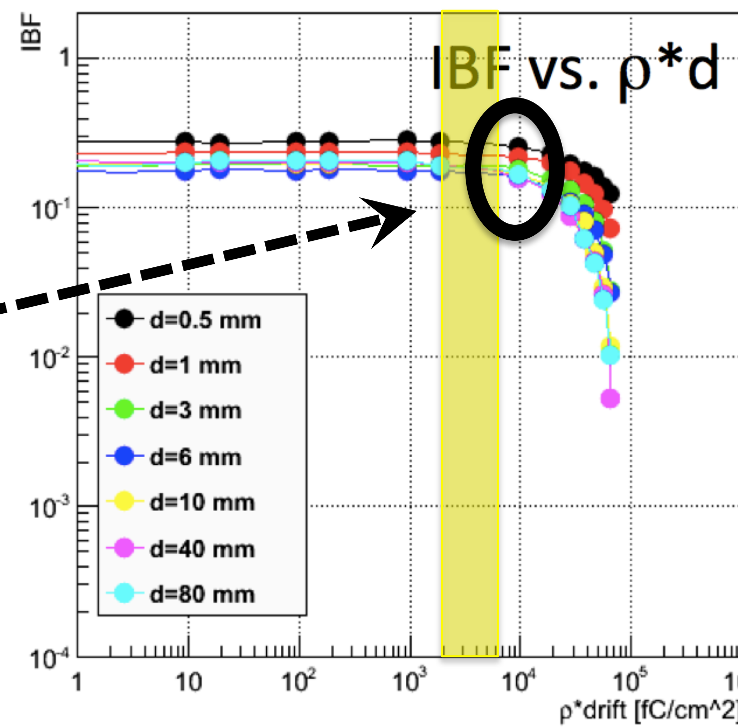


No space-charge effect for 3mm but for 80mm!!

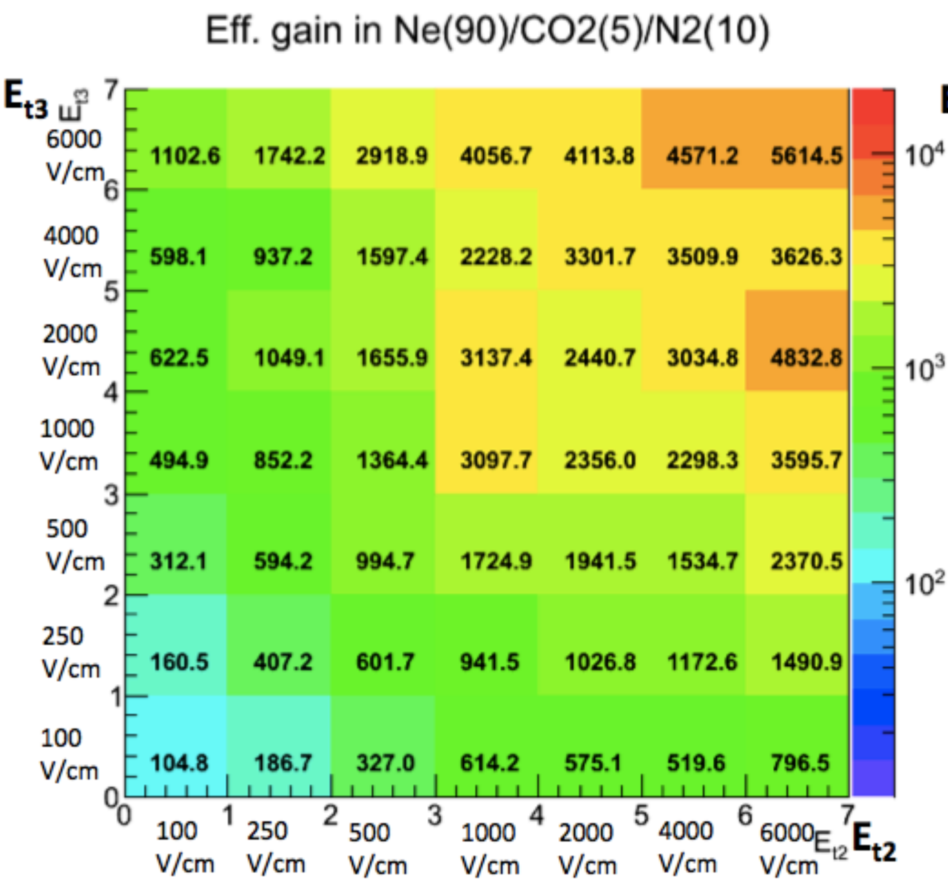
Expectation in ALICE (at 50kHz Pb-Pb)

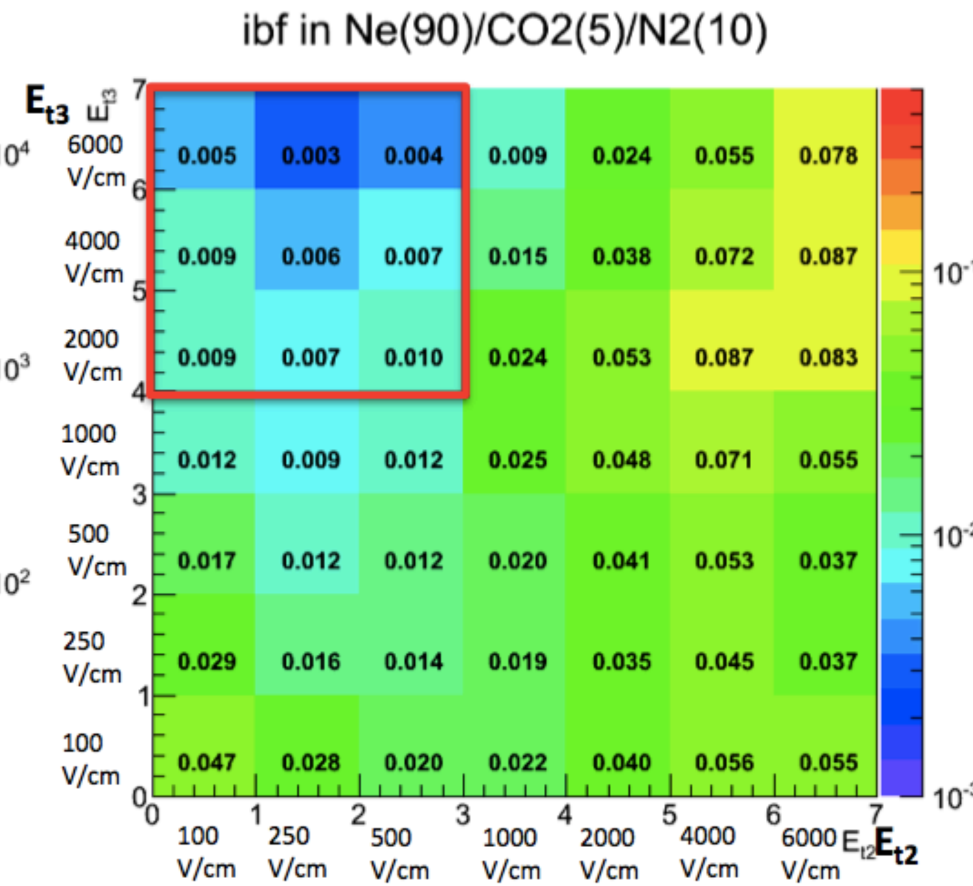
- Ion density: $\rho_{ion} < 30$ fC/cm^3 in drift space (Ne/CO_2, $\varepsilon=5$)
  - $\rho_{ion} \times d < 7.5\times10^3$ fC/cm^2 $< 10^4$ fC/cm^2
- No effect of space charge on IBF is expected.





Simulations: 4GEM stack

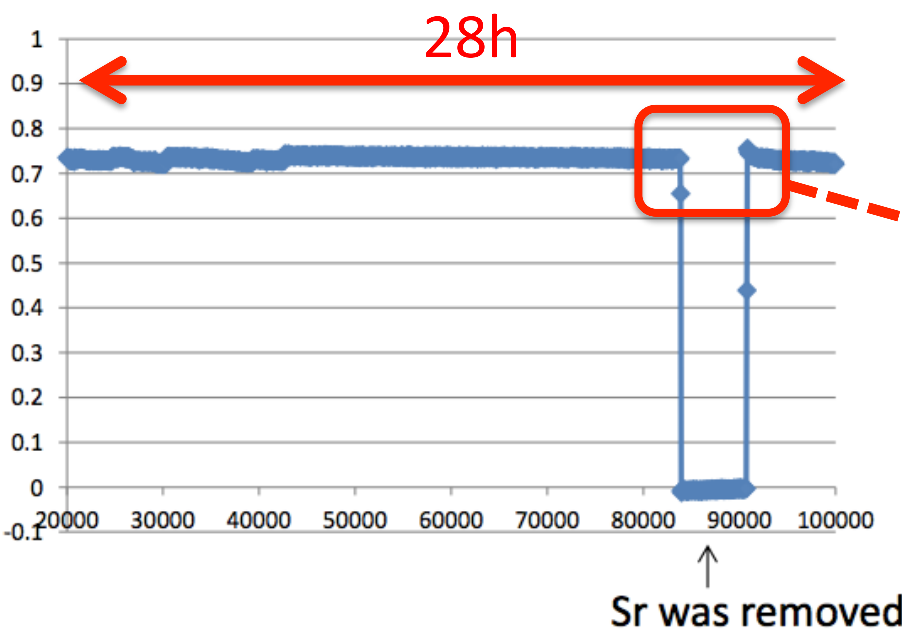


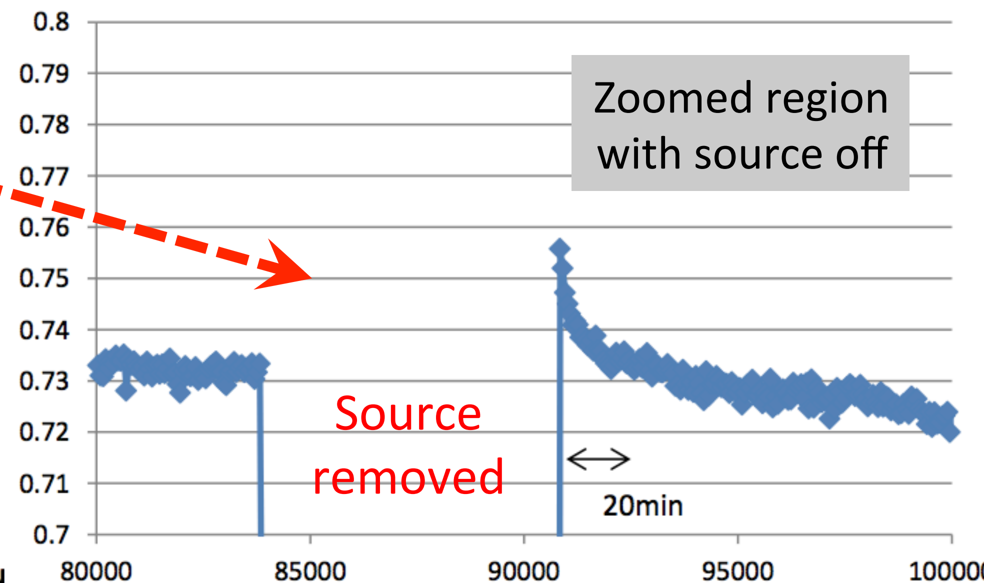


- IBF improvement by factor 2 to 4: 0.3-1% at high E_{T3} and low E_{T2}
  - V_{GEM1}=230V, V_{GEM2}=260V, V_{GEM3}=275V, V_{GEM4}=310V
  - E_{T2} and E_{T3} scan with E_{T1}=4 kV/cm, Ne/CO2/N2

Gain Stability measurements

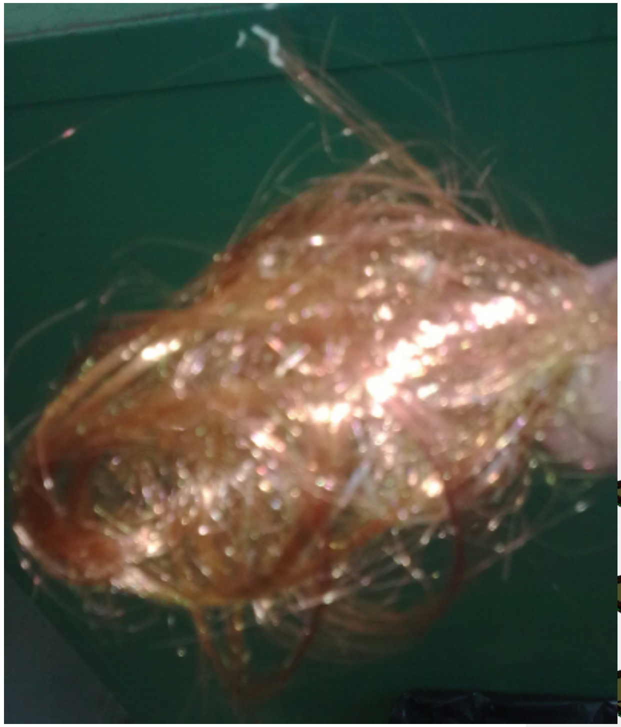
- Gain stability measurement with ^{90}Sr source
- Triple single-mask 3GEM (10×10 cm^2), cylindrical holes
- Single-wire counter as reference for P/T correction
- Stability between ± 2% (gain 1200) and ± 1.4% (gain 1800)

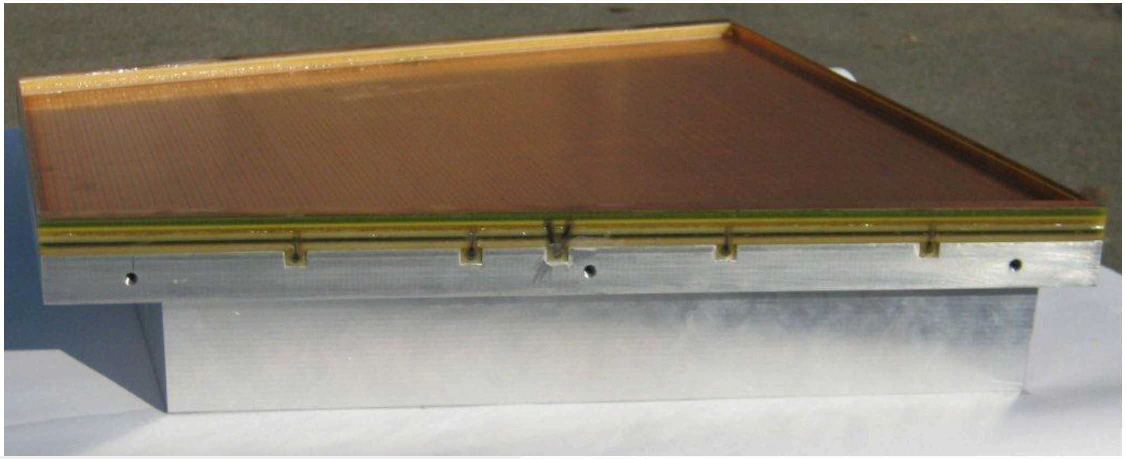


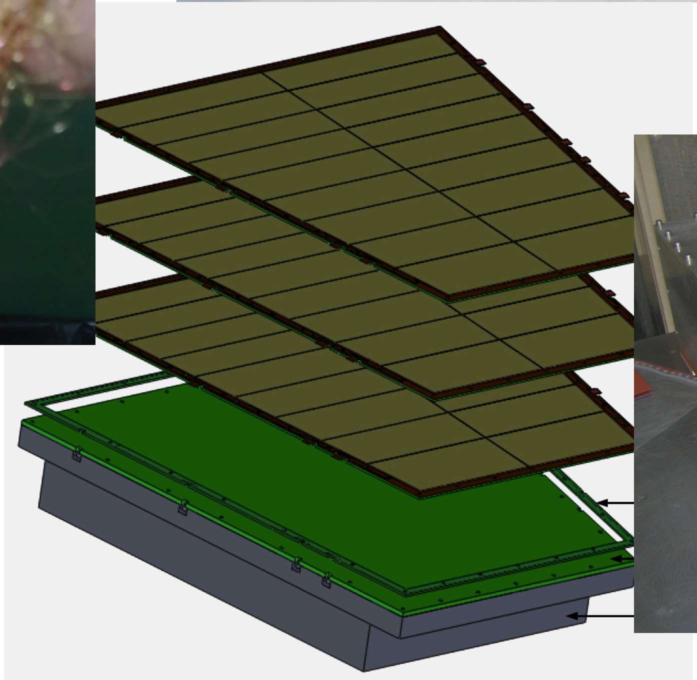


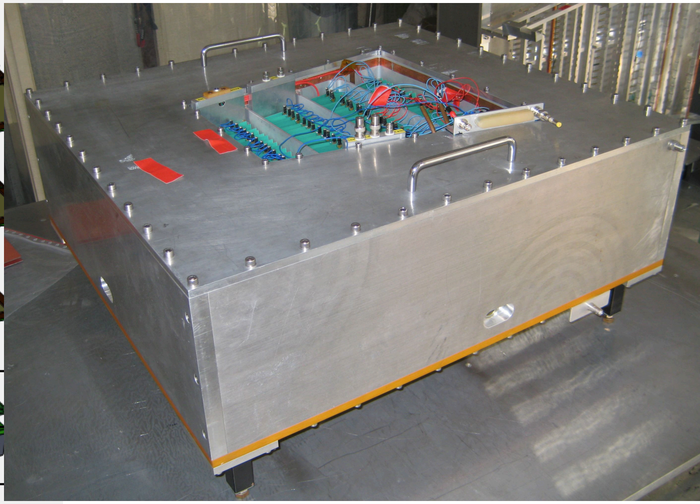
See also: V. Peskov, "Stability tests of GEMs with cylindrical holes for ALICE TPC upgrade", Mon 14:00

First full size prototype



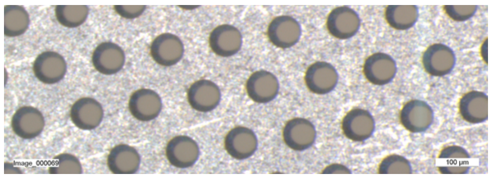




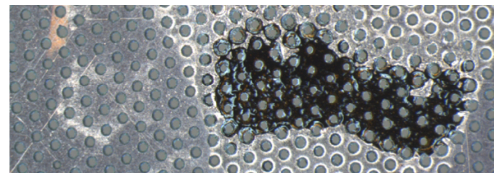


- Wires were removed from a TPC spare IROC and 3 single-mask GEM foils installed
- Test box was modified for test beam

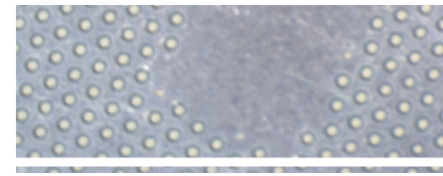
Foil quality



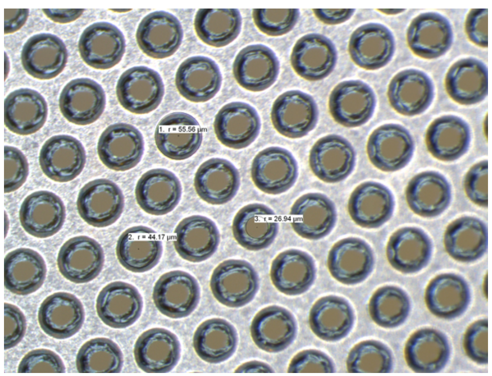
outer hole diameter varies with the position



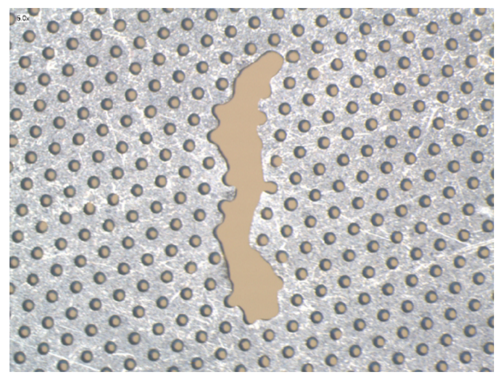
big holes



missing holes



(due to the electrochemical protection)



(defects in mask, dirt, . . .)

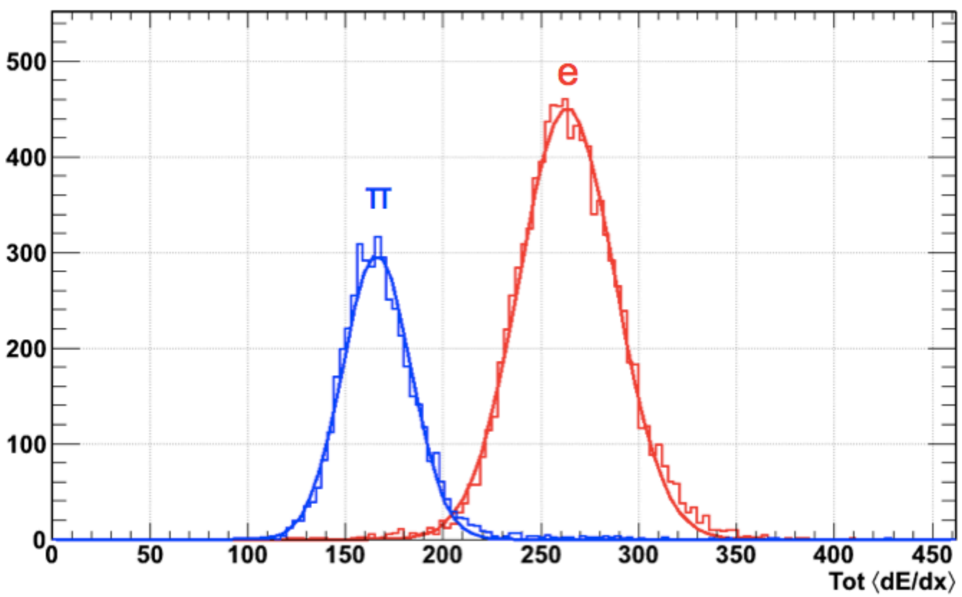
(no mask for etching of bottom side

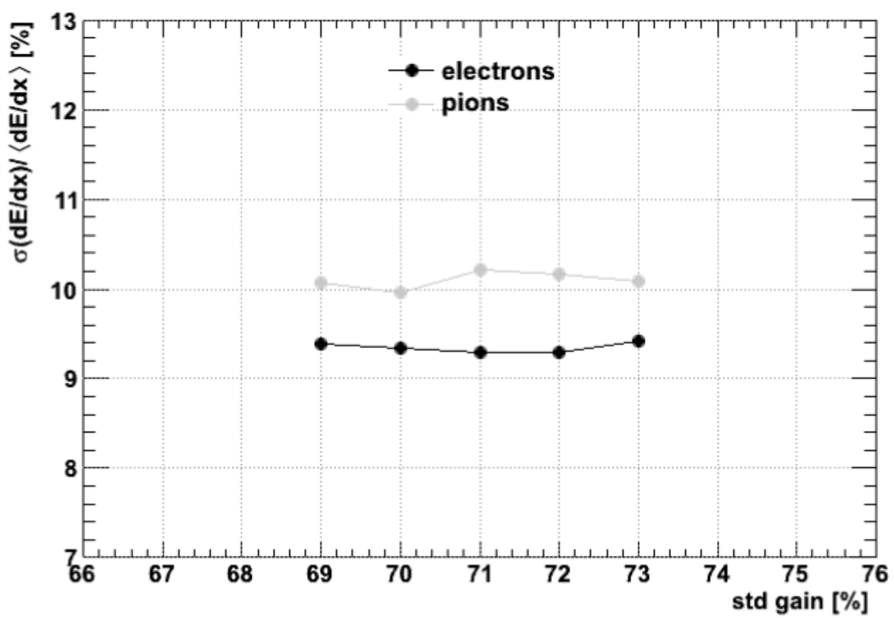
- Several defects visible before assembly ☹

See also: P. Gasik, "Quality control experience with foils of the ALICE TPC prototype", Wed 14:20

Test Beam Results: dE/dx (1)

- Measure dE/dx mean, sigma and separation power of identified electrons and pions over 64 pad rows
- Expected resolution with MWPC: 9-10%
- For standard HV settings (not optimised for IBF) performance is equal to MWPC

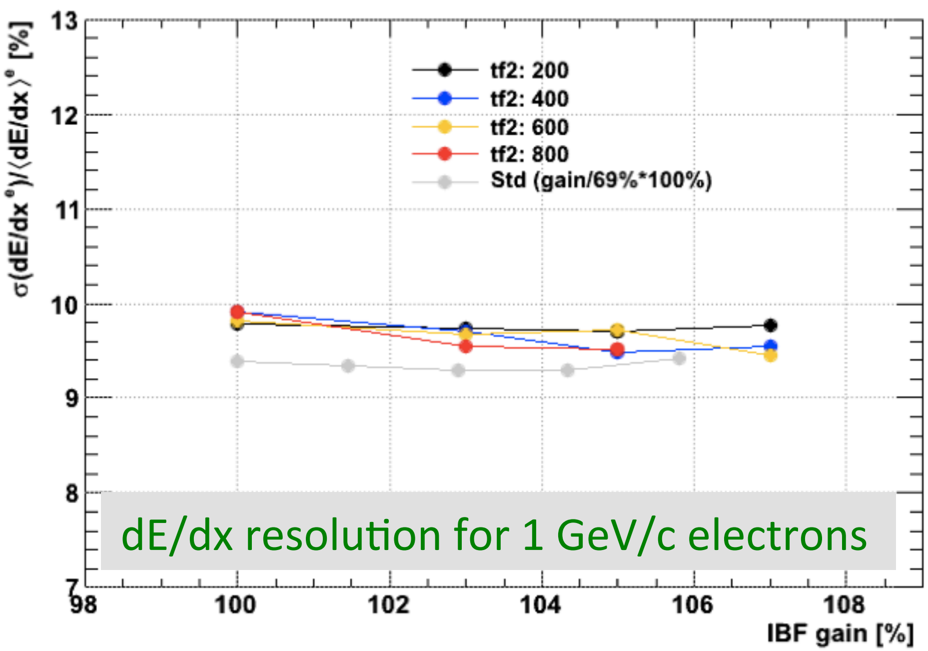




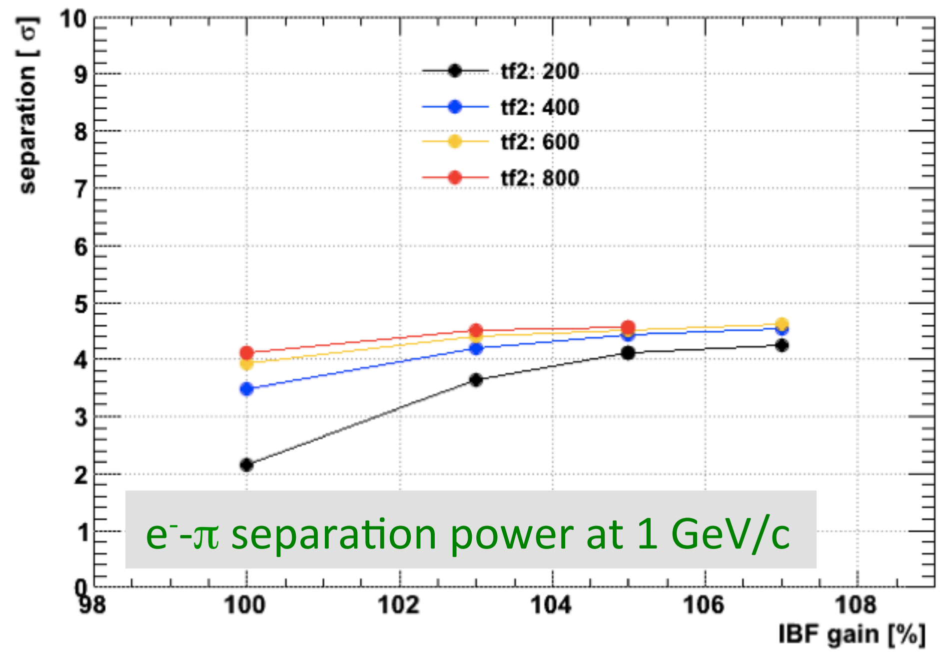
Test beam at the CERN PS in Nov 2012

Test Beam Results: dE/dx (2)

- Comparison of (preliminary) IBF settings to standard settings
- dE/dx performance of the upgraded TPC is preserved
- Gas density correction still to be done



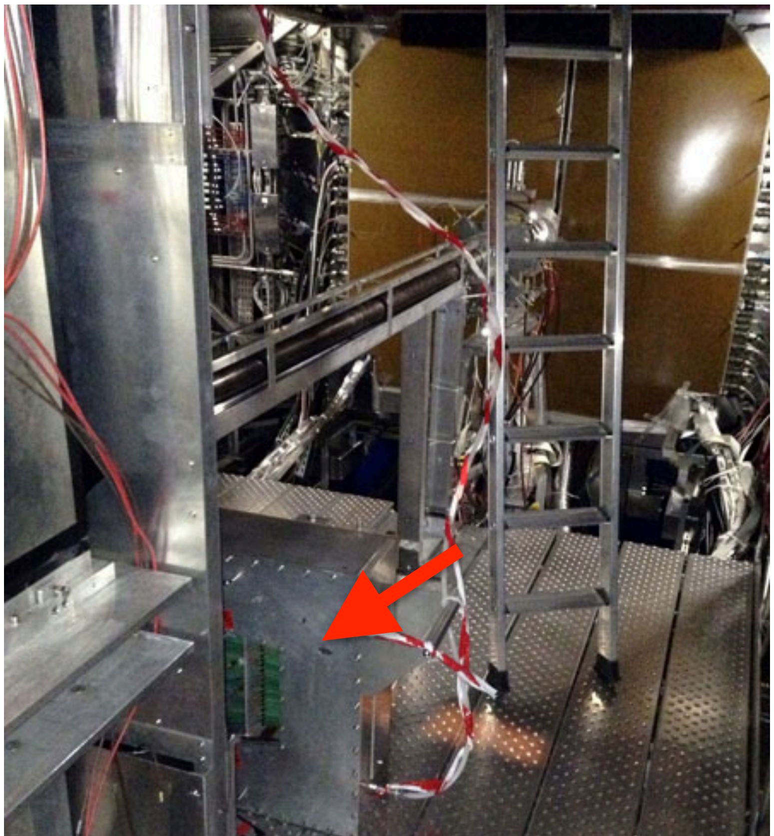
dE/dx resolution for 1 GeV/c electrons



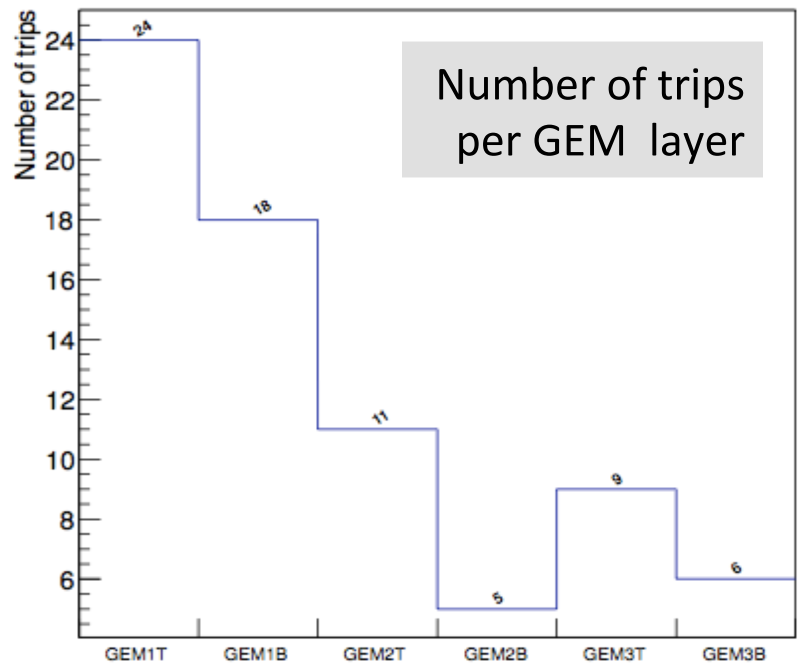
e^--π separation power at 1 GeV/c

Test beam at the CERN PS in Nov 2012

Test Beam Results at LHC



Prototype installed under the LHC beam pipe during the p-Pb run in Feb 2013



Number of trips per GEM layer

- Several trips occurred, and a few shorts developed
- No correlation found with beam conditions (as e.g. with the TPC)

⇒ Operational stability not consistently demonstrated

See also: P. Gasik, "Quality control experience with foils of the ALICE TPC prototype", Wed 14:20

Further activities

- Prepare new (1 or 2) prototypes (Inner Read-Out Chamber), with new foils
  - foils being inspected
- Design Outer Read-Out Chamber prototype
  - splicing of 2 foils needed
- Consider new pad planes and chamber bodies
  - perhaps with alternative pad patterns (chevron)
- Exotic foil pattern, ageing tests, etc

Common FEE for ALICE upgrade

1. Front-end ASIC for TPC and Muon arm (possibly more)
   - Based on existing TPC PASA/ALTRO chips
   - Support for continuous and triggered readout
   - Adjustable polarity and sensitivity
   - Reduced power consumption (<15mW/ch)
2. Read-out unit for TPC, ITS and Muon arm (possibly more)
   - Backwards compatible with current DDL readout
   - Requirement: At least radiation tolerant
   - Current options studied:
     1. Radiation tolerant FLASH-based FPGA (Microsemi Smartfusion2) with 10Gbps optical read-out (DDL3) or
     2. Radiation hard ASIC (GBT) with read-out at lower bandwidth (4.8Gbps versatile link)

Summary & Conclusions

- IBF requirement: 0.25% IBF at gain=2000
  - 3GEM seems not to satisfy requirements
  - Main R&D direction now: 4GEM and larger pitch GEMs
- R&D: IBF depends on rate and drift distance
  - Confirmed by simulations
  - IBF reduction due to space charge
  - No effect can be expected in ALICE
- Gain stability requirement met: 3GEM stack stable within ± 2% over days
- Performance requirement met:
  - Energy resolution comparable to the current TPC (MWPC)
  - Position and momentum resolution OK (from MC)

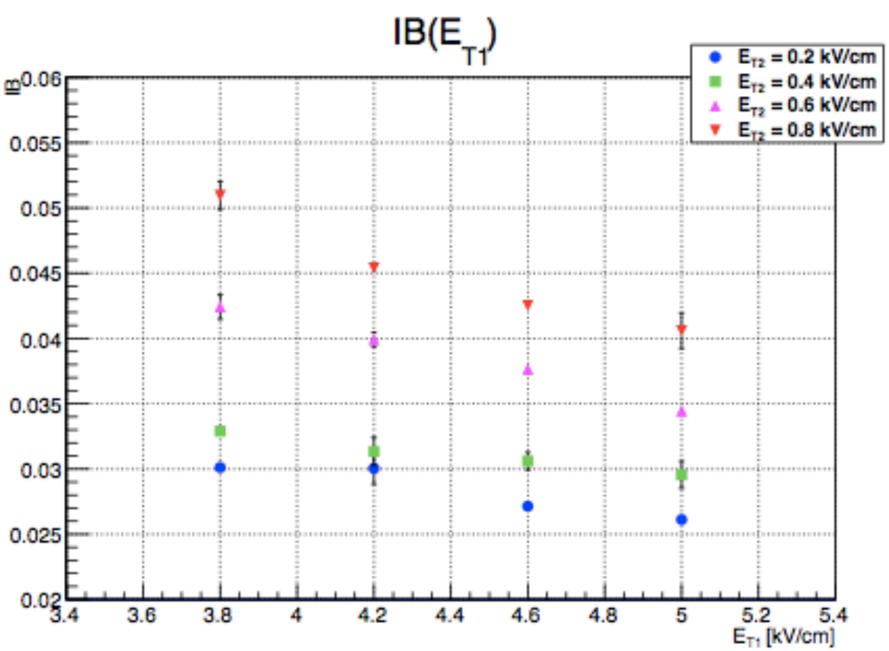
More

IBF in Ar/CO_2 90/10

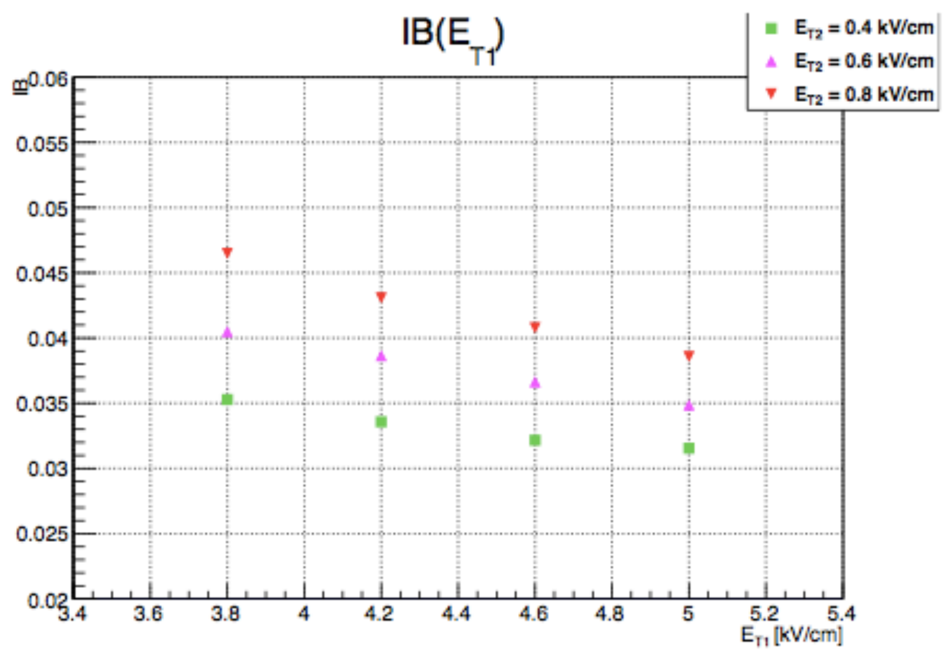
- Systematic measure-ments at TUM
- Gain not constant
- **Similar results for Xray and 55Fe**

For Ar/CO_2 90/10

GEM voltage settings		*Detector field settings*		
GEM1	300 V	E_{Drift}		$0.4\,\mathrm{kV\,cm^{-1}}$
GEM2	335 V	E_{T1}	varied	$5.0\,\mathrm{kV\,cm^{-1}}$
GEM3	380 V	E_{T2}		$0.2\,\mathrm{kV\,cm^{-1}}$
		E_{Ind}		$4.5\,\mathrm{kV\,cm^{-1}}$



X-ray gun (I=5 µA, U=30 kV)



^{55}Fe source

	TPC		MCH	
	Now	**Upgrade**	**Now**	**Upgrade**
Polarity	Pos	Neg	Pos	Pos
Detector capacitance [pF]	12 – 18	12 – 18	40 – 80	40 – 80
Peaking time [ns]	160	160	1200	160
Shaping order	4^{th} order	4^{th} order	2^{nd} order	4^{th} order
Sensitivity [mV/fC]	12	9	4	3
Gas gain	~4.000	1.000 – 2.000	~20.000	~20.000
Noise (electrons)	750e-@ 25pF	600e-@ 25pF	≤ 1000e-@40pF ≤ 1800e-@80pF	≤ 1000e-@40pF ≤ 1800e-@80pF
Linear Range (V)	2	1.2	2.5	1.2
Linear Range (fC)	170	170	625	420
Signal coding	10 bits	10 bits	11 bits	10 or 11 bits
Power consumption (mW per ch)	~35 (PASA +ALTRO)	< 15	13	< 15
Channel per chip	16	32	64	32 or 64
Chan per readout link	2.304 – 3.200		~50.000	