The UltraLow Material Budget GEM based TPC used for Tracking

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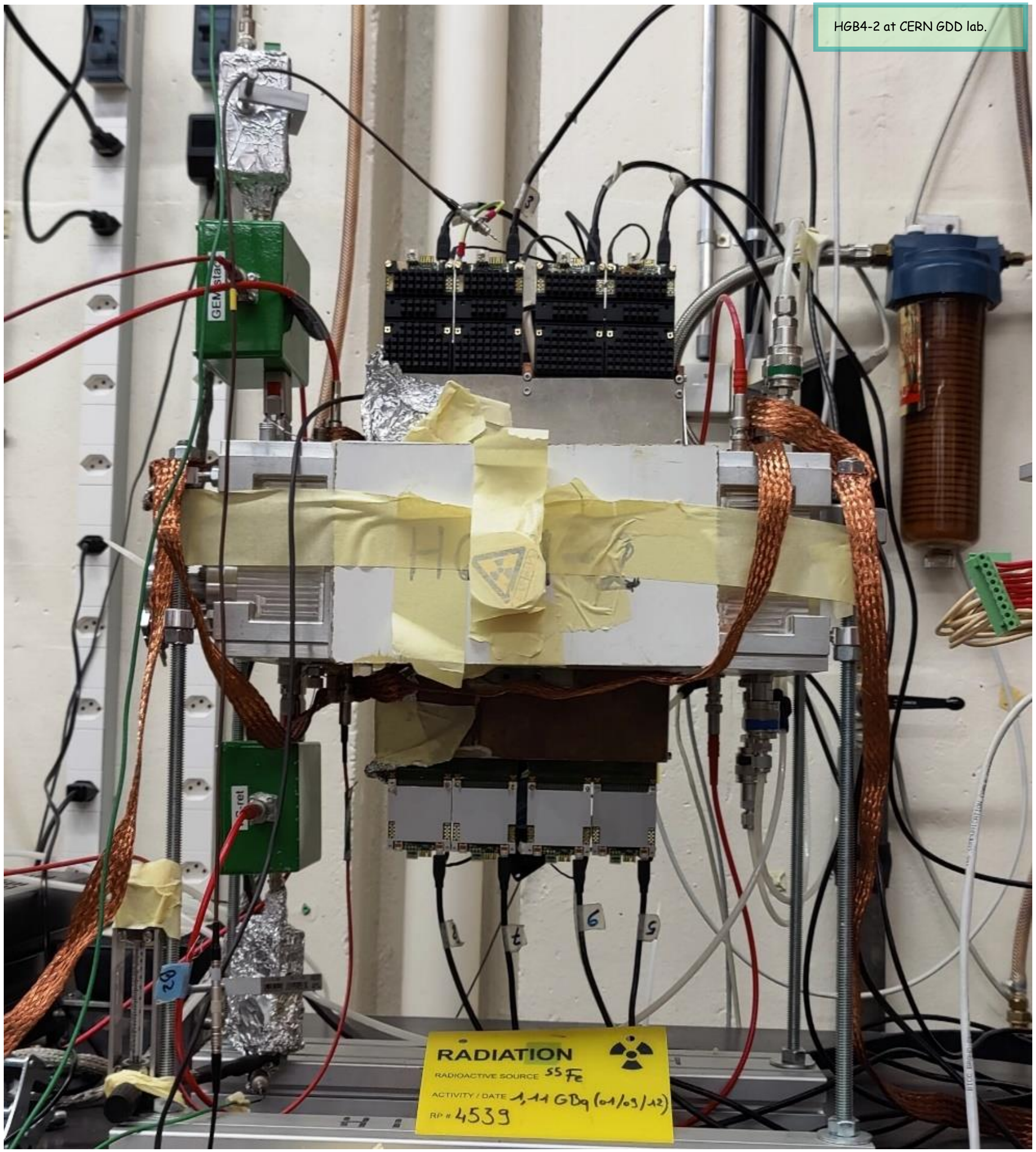
Outline

1. Introduction & Motivation
2. Tracking at different facilities
3. Test beam at the SPS - H4 beamline
4. Summary

INTRODUCTION

The GEM-TPC in twin configuration consists of two GEM-TPCs inside a single vessel. One of them is rotated 180º on the middle of the horizontal plane w.r.t. the other.

The **TWIN concept** was introduced in collaboration between the Helsinki and Bratislava group sometime ago to cope with tracking at high rate. By constraining the time of the signals on both GEM-TPCs the ambiguity of association of hits to single track is drastically reduced.



MOTIVATION

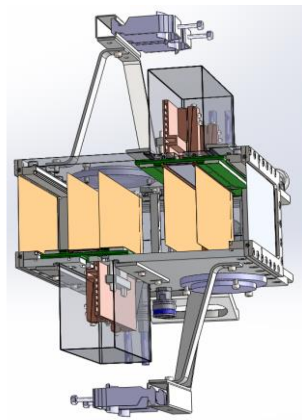
To perform tracking of particles with minimal distortions to its trajectory in high rate conditions.

Low material budget

$2.81e\text{-}3\ X/X_0$

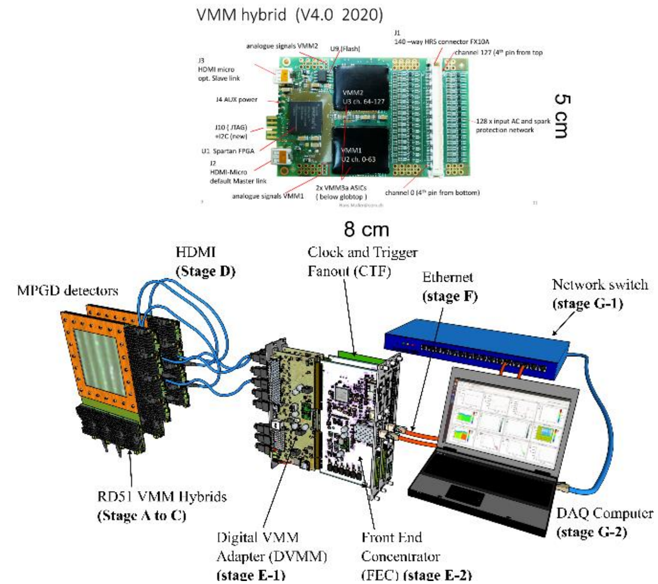
- *Main contribution from gas volume*
- *In contrast one triple GEM detector à la TOTEM will have 7.30e-3 x/x_0*

Tracking Reconstruction



The sum of drift time of both field cages represent the total drift, which is called the Control Sum

The VMM3a-SRS readout



- *Fast readout electronics with ~4 MHz per VMM3a.*
- *Time resolution O(2ns)*
- *Large Dynamic range*

TRACKING at DIFFERENT FACILITIES

At the FRS - GSI

Projectile:
Elements p – U
Energy up to 1.5 GeV/u
Intensity up to 10^{12} /spill

GEM-TPC PROTOTYPE for BEAM DIAGNOSTICS of Super-FRS in NUSTAR EXPERIMENT – FAIR FACILITY

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One major part of the FAIR facility will be the Super-FRS separator. The NUSTAR experiments will benefit from this separator, which will deliver an unprecedented range of radioactive ion beams (RIB). Helsinki Institute of Physics and Comenius University are in a joint R&D of GEM-TPC for the Super-FRS diagnostic chambers . The current status of the first prototype will be shown.

The GEM-TPC concept was introduced Presented in the NSS conference 2009 Orlando USA

The Super-FRS GEM-TPC prototype development
TECHNICAL REPORT

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June 1, 2015

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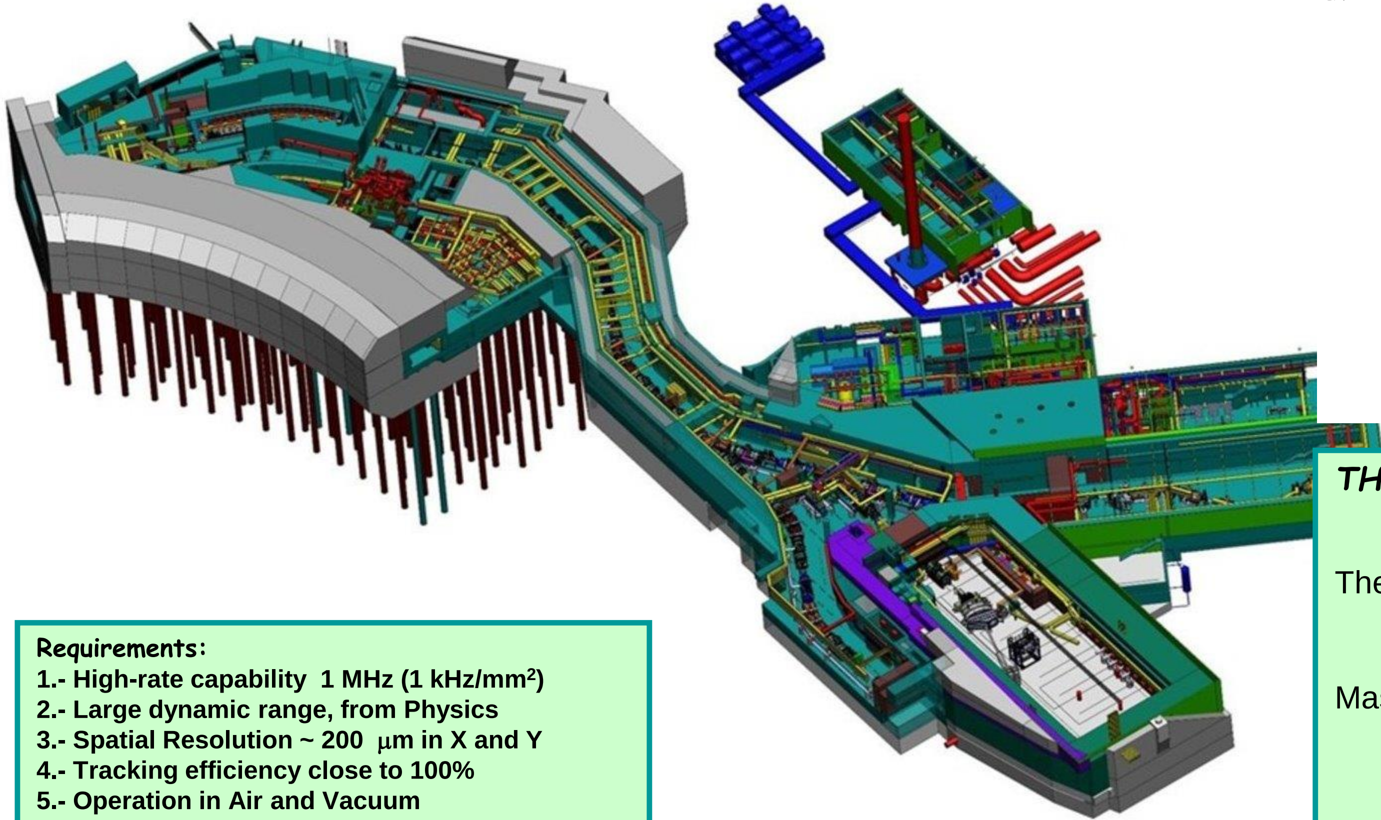

Requirements:
1.- High-rate capability 1 MHz (1 kHz/mm²)
2.- Large dynamic range, from Physics
3.- Spatial Resolution ~ 200 μm in X and Y
4.- Tracking efficiency close to 100%
5.- Operation in Air and Vacuum

@DMU-GSI, @FSB-FAIR

THE TIMELINE OF THIS PROJECT

The R&D and Design can be finalized by:

Q4/2024

Mass production:

Q1/2025 – Q1/2026

Part of the Finnish Contribution will be in Diagnostic systems, which is a work package dedicated to provide 14 GEM-TPC detectors.

Most Relevant Results at GSI

Test beam with ^{64}Ni ions: Spatial resolution 125 µm in X, 150 µm in Y → FRS S4 (2010)

Test beam with ^{197}Au ions: Spatial resolution 300 µm in X → FRS S4 (2012)

Test beam with Xe and C ions: Spatial resolution 188 µm in X, 147 µm in Y → FRS S4 (2016)

Test beam with U ions: Spatial resolution 740 µm in X → FRS S4 (2019)

For P10 ($ArCH_4$ 90/10) the tracking efficiency >95%

Nuclear Inst. and Methods in Physics Research, A 884 (2018) 18–24

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journal homepage: www.elsevier.com/locate/nima

A GEM-TPC in twin configuration for the Super-FRS tracking of heavy ions at FAIR

F. García [a,*], T. Grahn [a,b], J. Hoffmann [c], A. Jokinen [a,b], C. Kaya [c], J. Kunkel [c], S. Rinta-Antila [a,b], H. Risch [c], I. Rusanov [c], C.J. Schmidt [c], H. Simon [c], C. Simons [c], R. Turpeinen [a], B. Voss [c], J. Äystö [a,b], M. Winkler [c]

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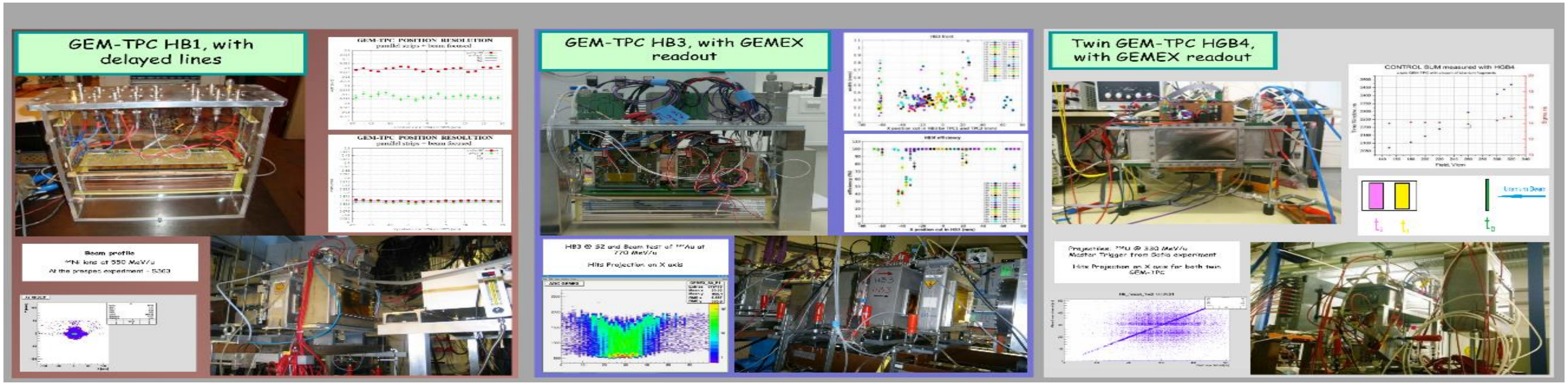


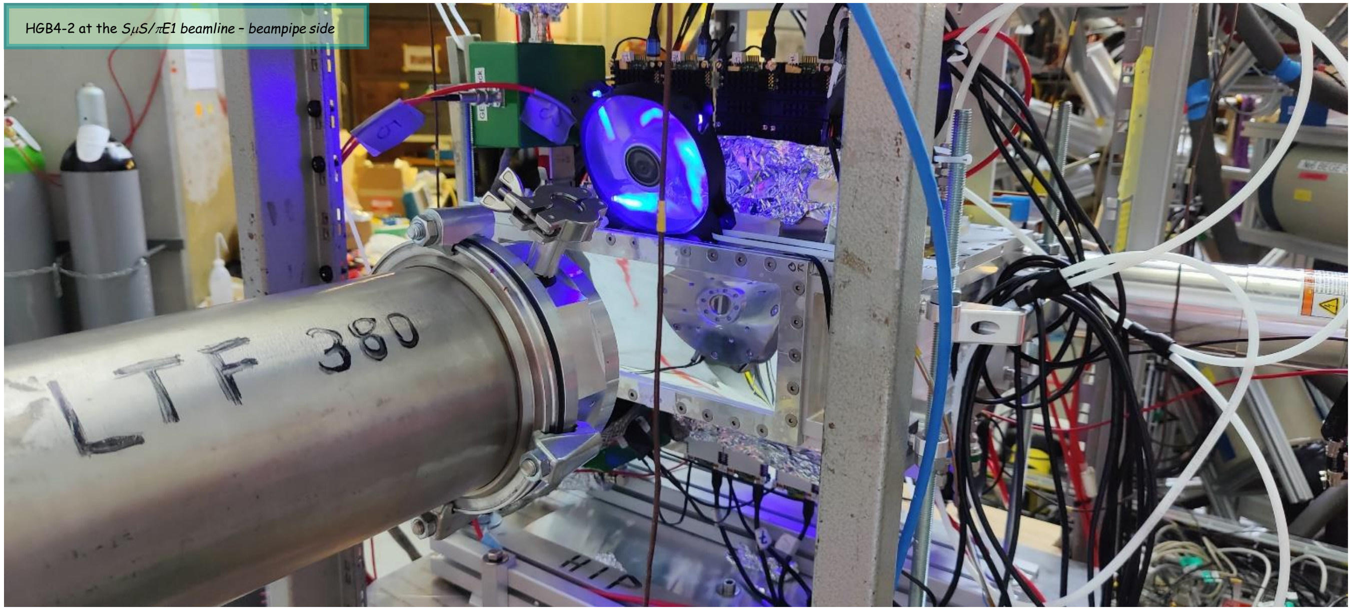
M. Luoma, F. Garcia et al., In-beam test results of the Super-FRS GEM-TPC detector prototype with relativistic uranium ion beam. NIMA, 1052 (2023) 168262.

TRACKING at DIFFERENT FACILITIES

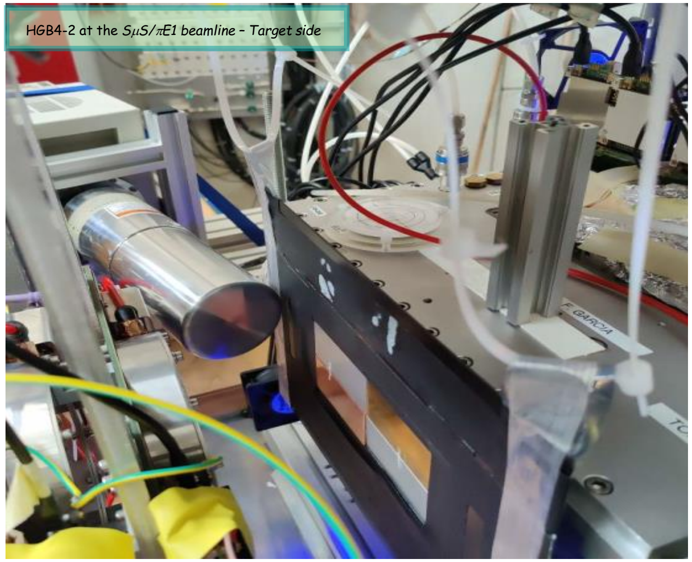
Projectile: μ
Momenta up to 60 MeV/c
Intensity up to 10^5 μ/sec

First campaign at the $S\mu S/\pi E1$ - PSI

HGB4-2 at the $S\mu S/\pi E1$ beamline - beampipe side



HGB4-2 at the $S\mu S/\pi E1$ beamline - Target side



Target with different materials

Successful Operation in:

In the first campaign in $ArCO_2$ (75/25)

In second campaign in $HeCO_2$ (90/10)

Combined Spatial Resolution:

For $ArCO_2$ (75/25) @ 40 MeV/c:

- *X* → 1.083 ± 0.113 mm
- *Y* → 1.357 ± 0.172 mm

For $HeCO_2$ (90/10): Analysis ongoing

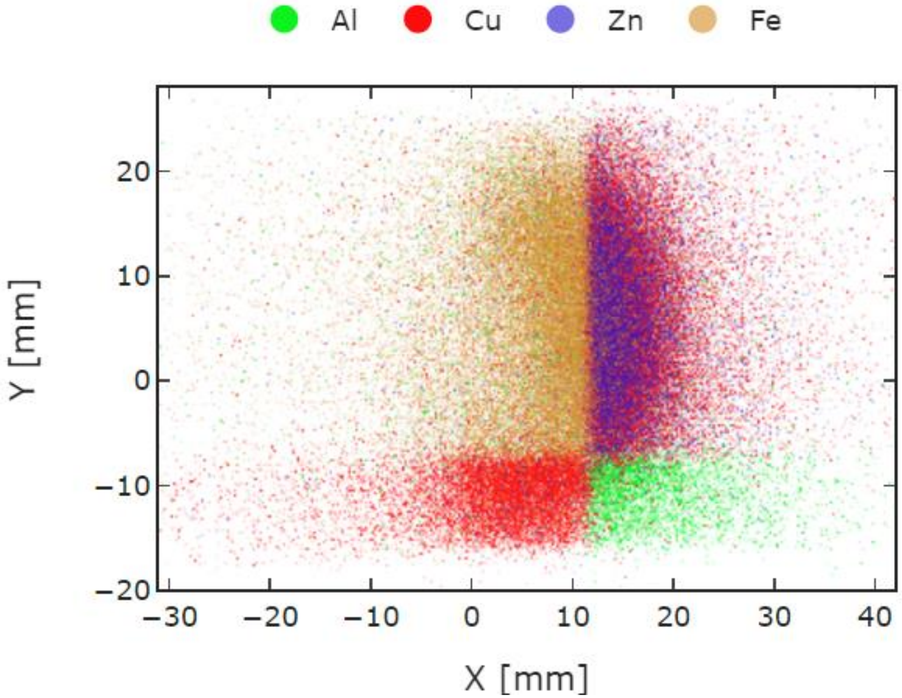
The Plans are:

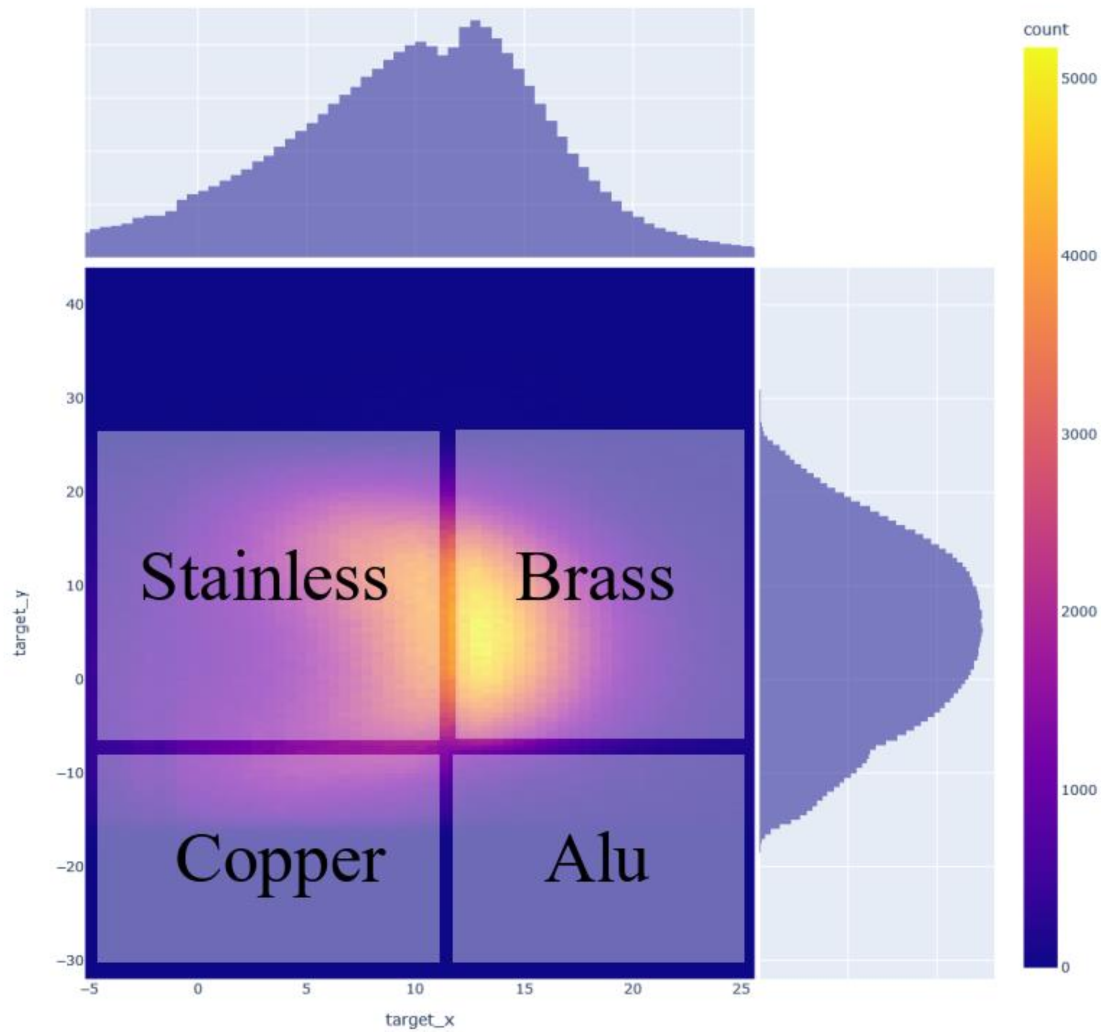
1. *Test the GEM-TPC with pixel readout.*
2. *Single GEM-TPC configuration.*
3. *Design a new miniaturized GEM-TPC for MIXE.*

Talk by: Xiao Zhao, A novel technology for element-sensitive 3D tomography

First campaign target Configuration:

- Stainless: Fe (66%), Cr (18%), Ni (12%)
- Brass: Cu (63%), Zn (37%)
- Copper (ETP): Cu (100%)
- Anticorodal: Al (97%)

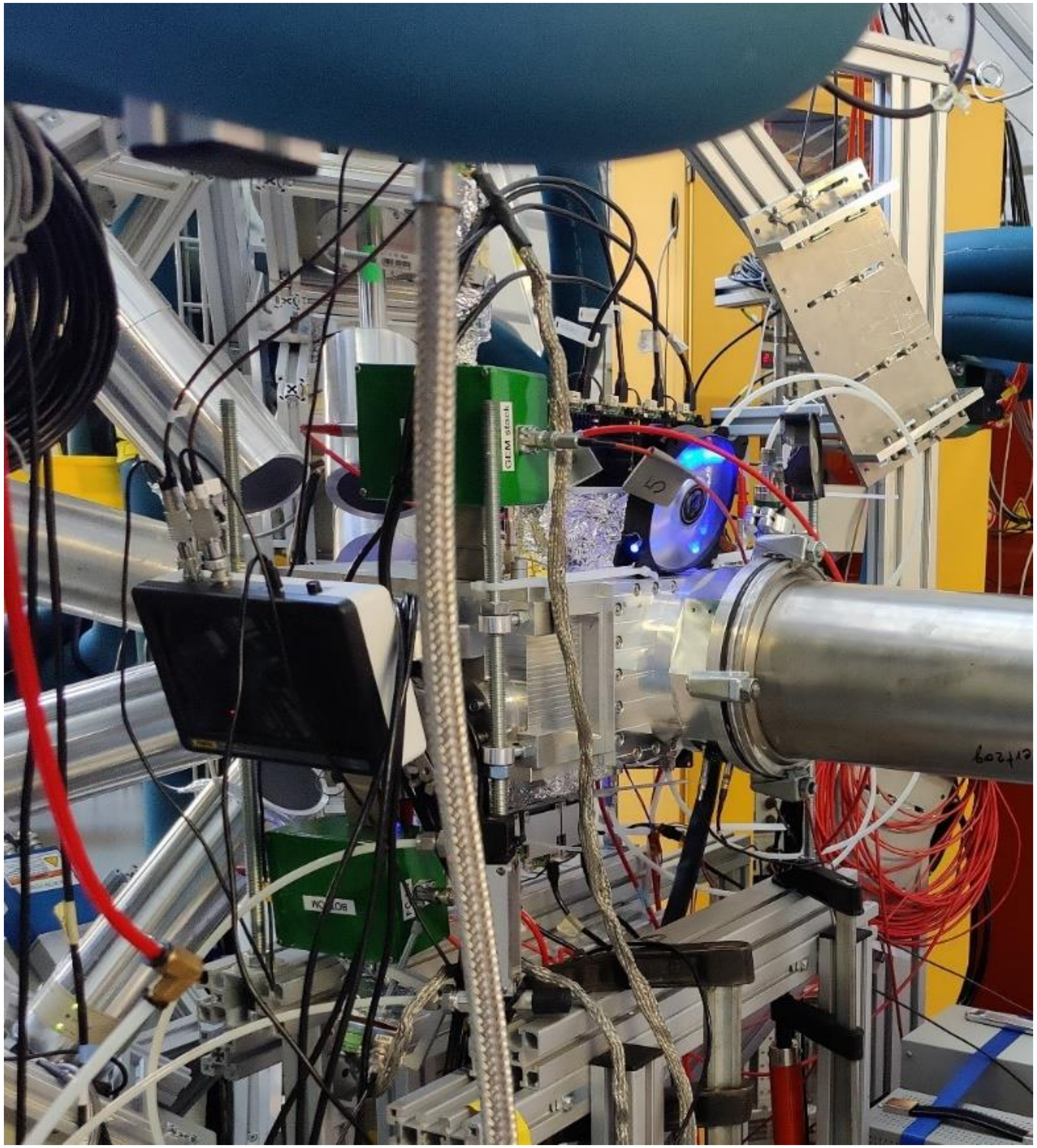




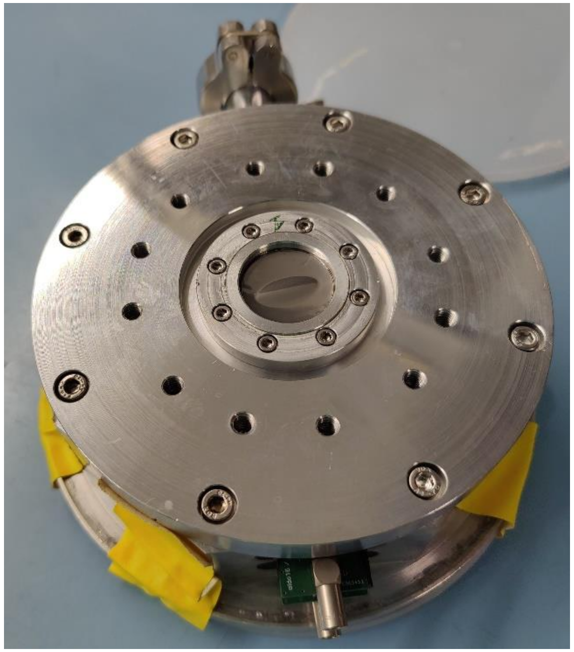
Talk by: Xiao Zhao, A novel technology for element-sensitive 3D tomography

The second campaign for GEM-TPC – HGB4 at SμS/πE1 - PSI

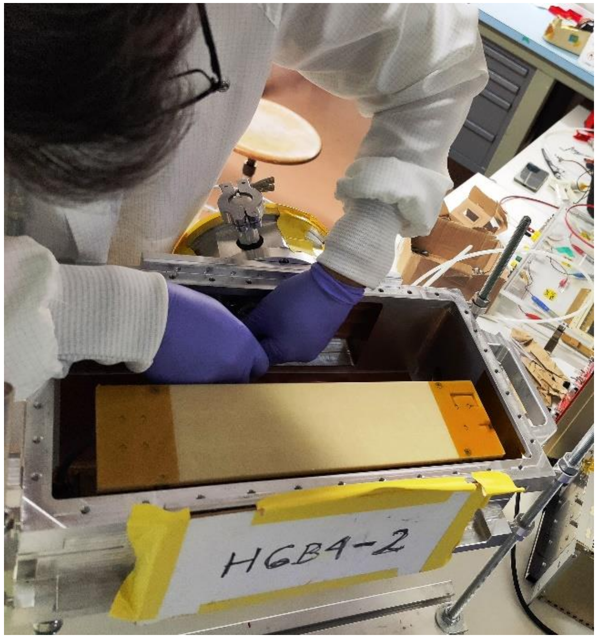
- The gas was changed by $HeC0_2$ (90/10).
- The GEM-TPC in twin configuration (HGB4-2) was flagged to the beam pipe.
- The target was refurbished.
- Ten (10) high purity Germanium detectors were added to the setup.

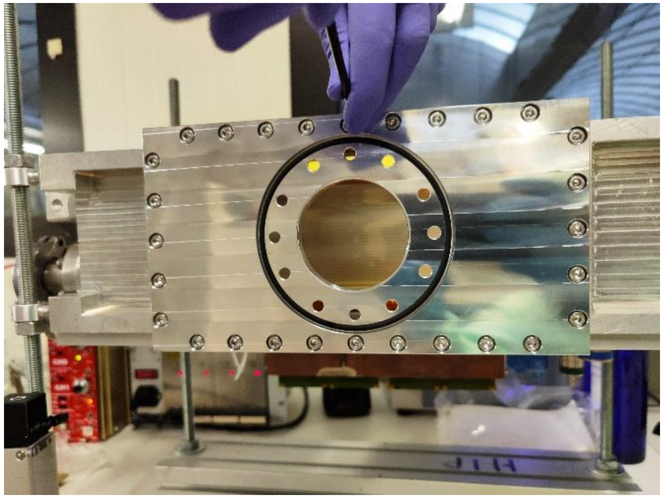


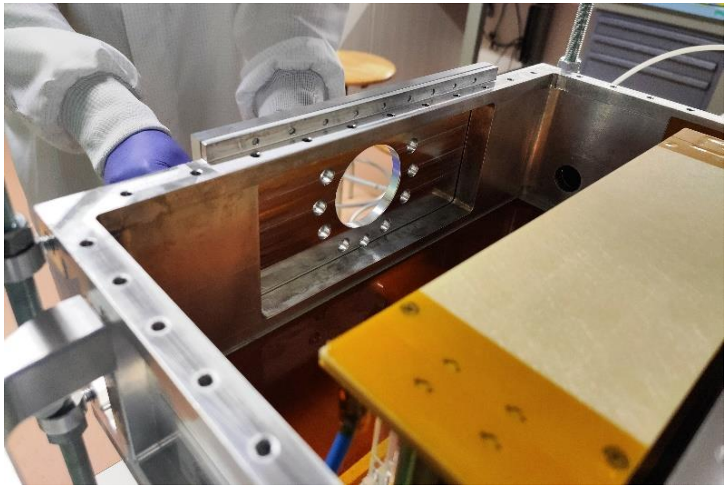
The second campaign for GEM-TPC - HGB4 at SμS/πE1 - PSI

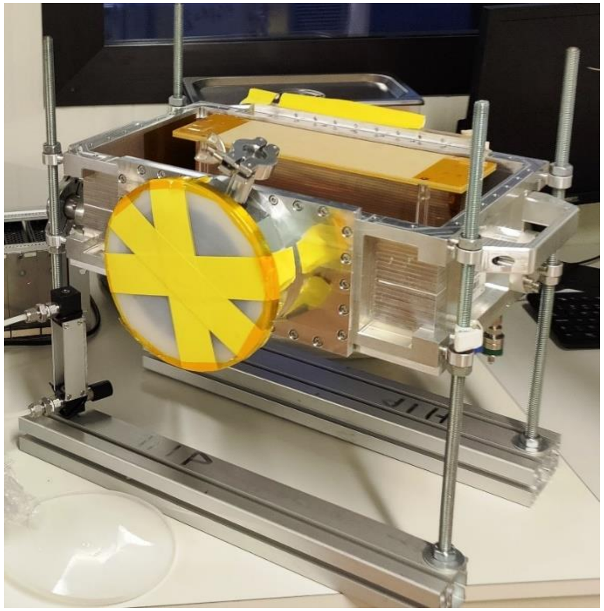


Procedure to flange the GEM-TPC in twin configuration (HGB4-2) to the beam pipe at SμS/πE1 - PSI .









TEST BEAM at the SPS – H4 Beamline

Particles: μ and π at 180 GeV/c

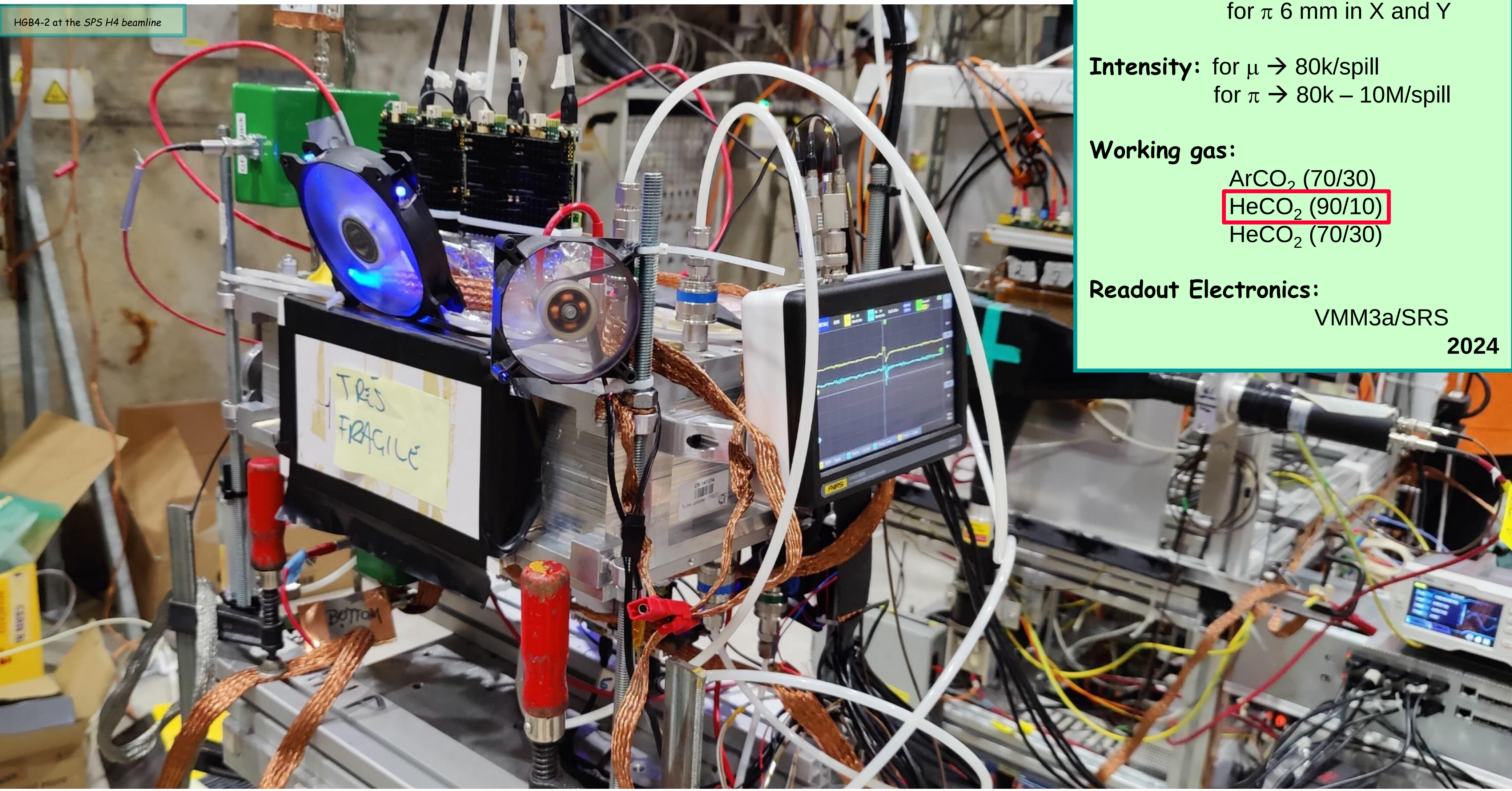
Beam spot: for μ 10cm in X and Y
for π 6 mm in X and Y

Intensity: for μ → 80k/spill
for π → 80k – 10M/spill

Working gas:
$ArCO_2$ (70/30)
$HeCO_2$ (90/10)
$HeCO_2$ (70/30)

Readout Electronics:
VMM3a/SRS

2024



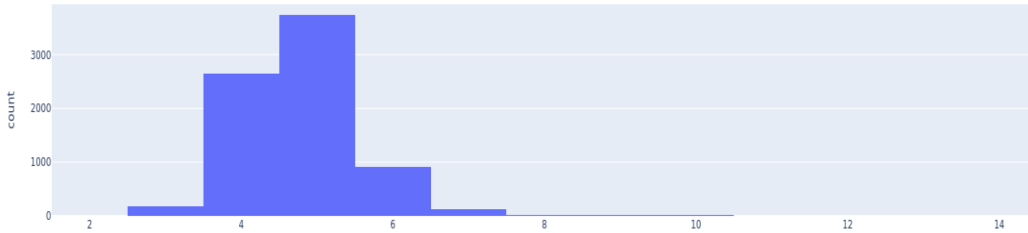
HGB4-2 at the *SPS H4 beamline*

TEST BEAM at the SPS - H4 Beamline

Cluster Strip multiplicity on $ArCO_2$ (70/30)

Cluster Strip multiplicity on $HeCO_2$ (90/10)

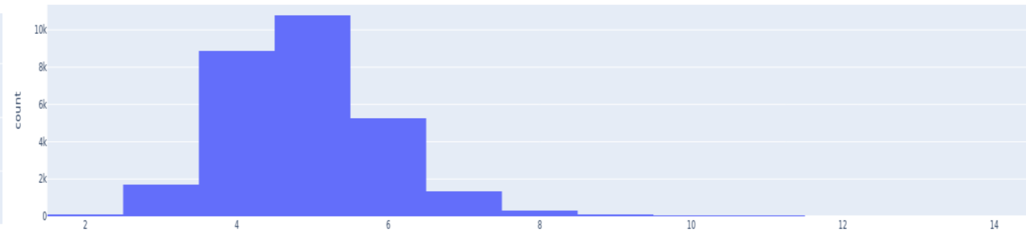
For Muons



strips

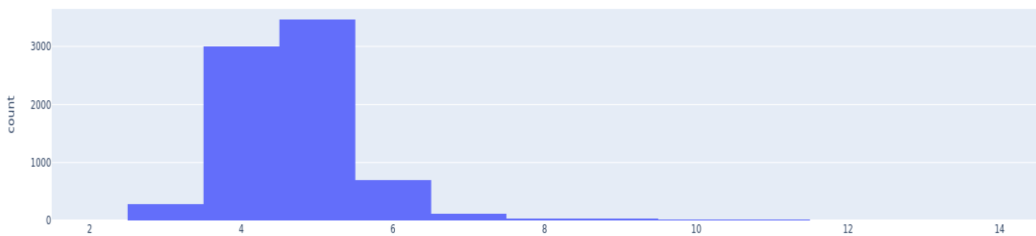
GEM-TPC, Top

For Muons



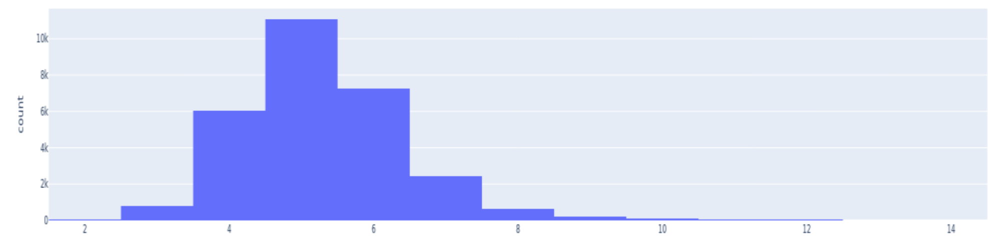
strips

GEM-TPC, Top



strips

GEM-TPC, Bottom



strips

GEM-TPC, Bottom

Cluster strip multiplicity is the quantity of strips fired in one reconstructed cluster

GEM-TPC Top:
Voltage at the Cathode: 6780 V
Voltage at the GEM Stack: 3200 V
Field in the Field Cage: 358 V/cm

GEM-TPC Bottom:
Voltage at the Cathode: 6680 V
Voltage at the GEM Stack: 3100 V
Field in the Field Cage: 358 V/cm

GEM-TPC Top:
Voltage at the Cathode: 5550 V
Voltage at the GEM Stack: 2150 V
Field in the Field Cage: 340 V/cm

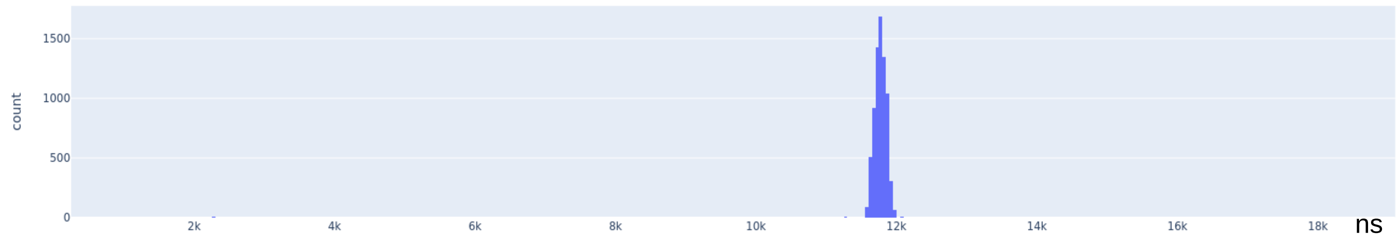
GEM-TPC Bottom:
Voltage at the Cathode: 5560 V
Voltage at the GEM Stack: 2160 V
Field in the Field Cage: 340 V/cm

TEST BEAM at the SPS - H4 Beamline

Cluster multiplicity

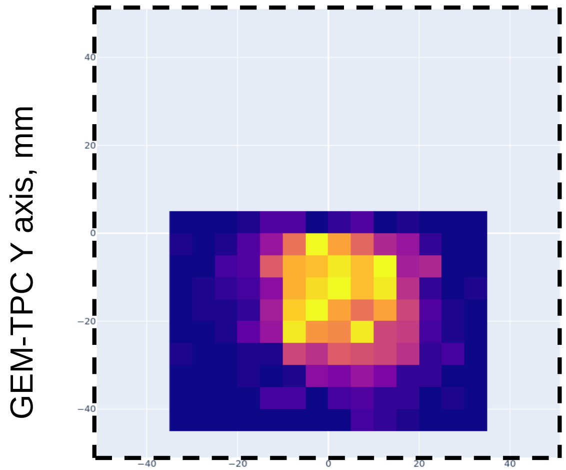
The cluster Multiplicity is the quantity of cluster within a full drift time

Total Drift Time – Control Sum



GEM-TPC, Top		GEM-TPC, Bottom	
Multiplicity	**Amount**	**Multiplicity**	**Amount**
0	0.345	0	0.351
1	0.407	1	0.406
2	0.157	2	0.153
3	0.045	3	0.043
4	0.018	4	0.016
5	0.029	5	0.031

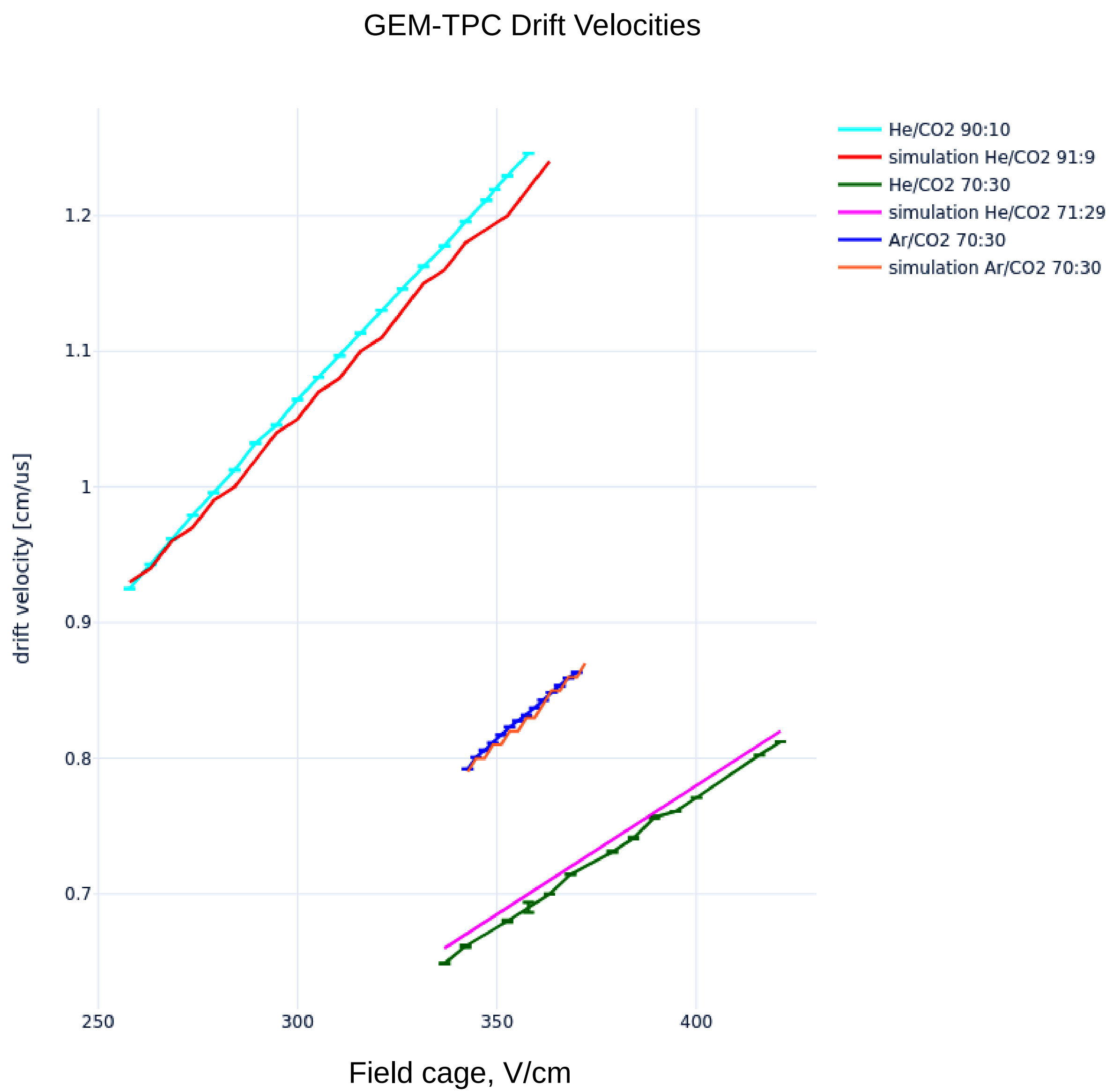
Beam Track Map



TEST BEAM at the SPS - H4 Beamline

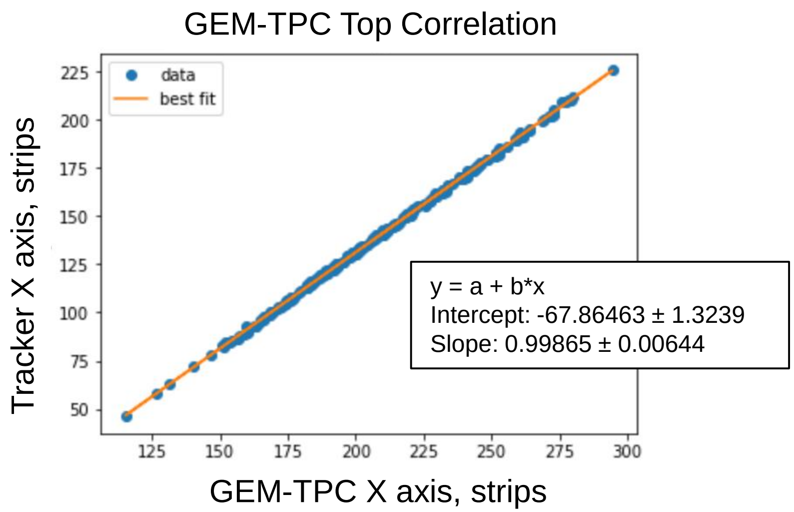
Drift Velocity Calibration

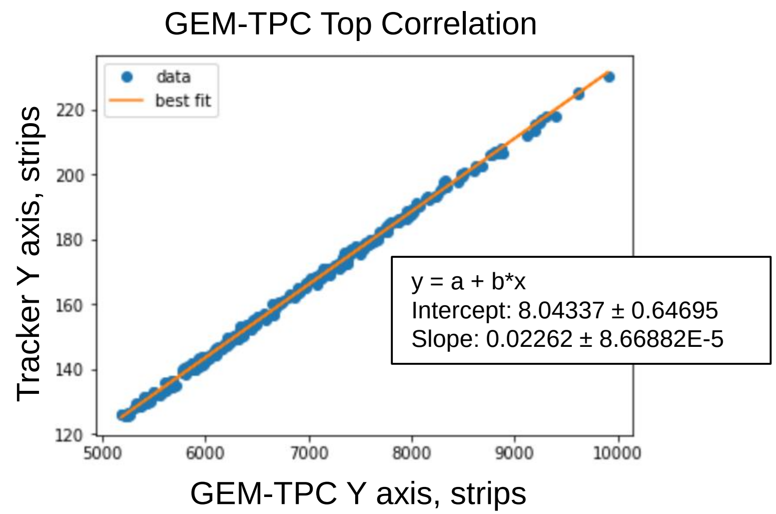
- By the use of scintillation grid detector:
- By the correlation of the hits from the tracker:
    - Prealigment.
    - Selection straight tracks (small χ^2).
    - Fine alignment.
    - Correlation of the GEM-TPC clusters to the first reference tracker plane in X and Y.



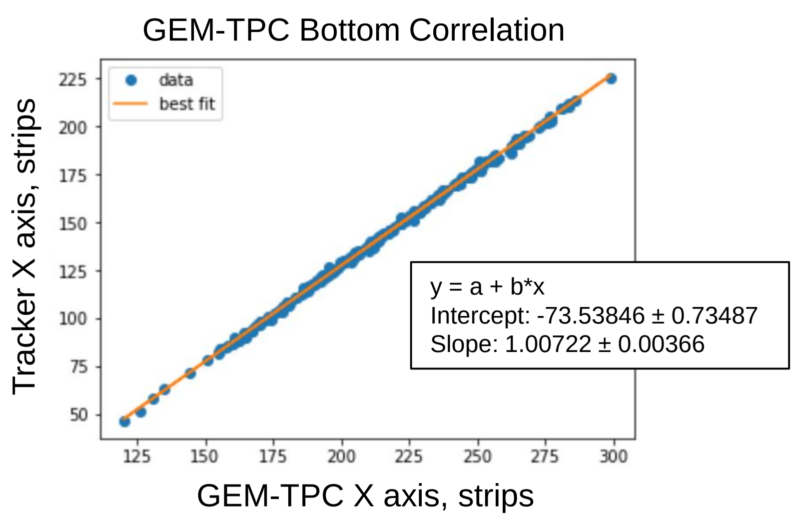
TEST BEAM at the SPS - H4 Beamline

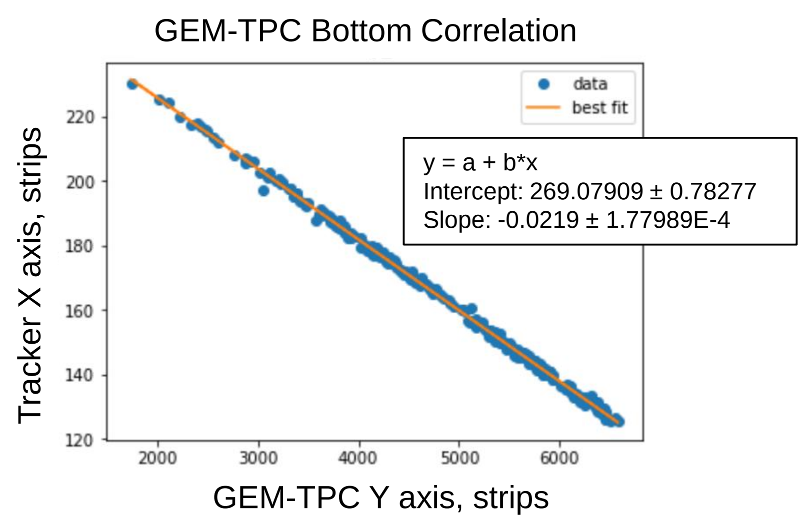
Correlation plot of the GEM-TPC Top vs Tracker:





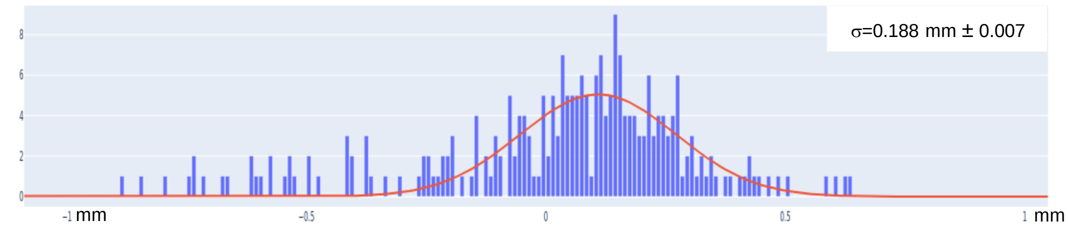
Correlation plot of the GEM-TPC Bottom vs Tracker:



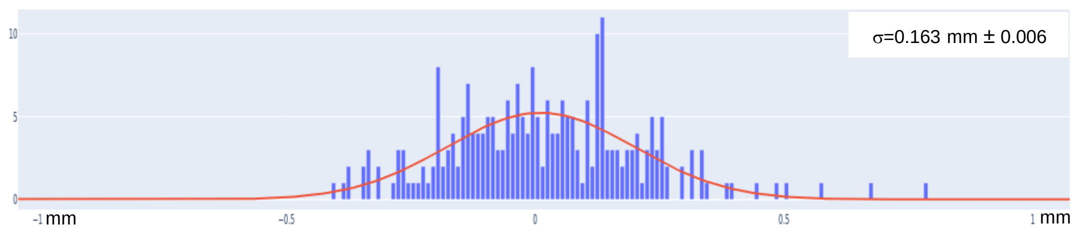


TEST BEAM at the SPS - H4 Beamline

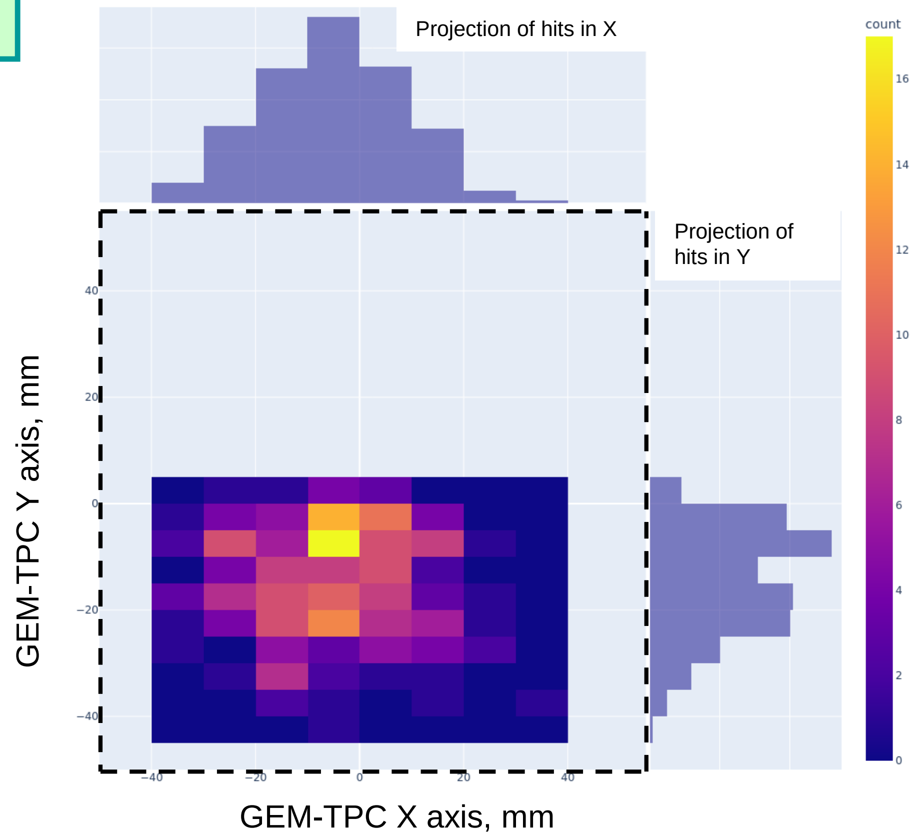
The hit map, residuals and the Control Sum for muons.

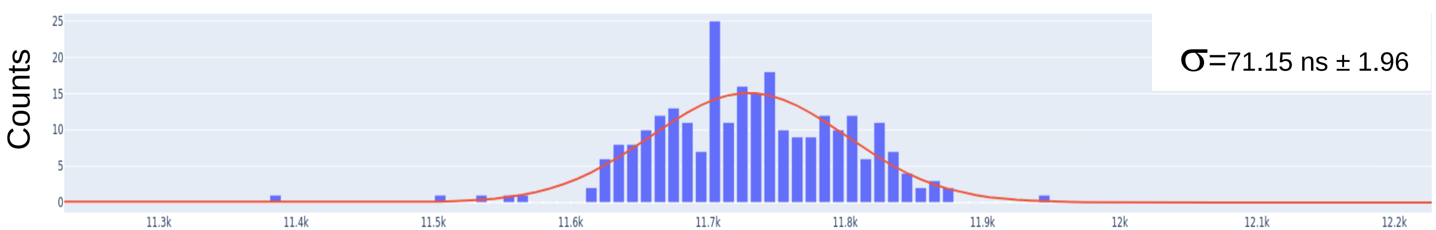


Residual Distribution X axis



Residual Distribution Y axis

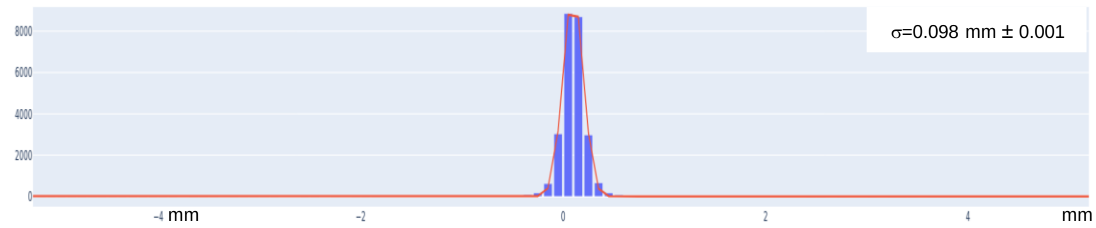




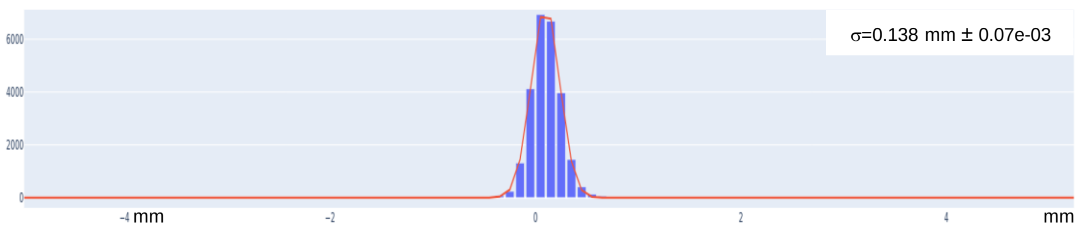
Drift time, ns

TEST BEAM at the SPS - H4 Beamline

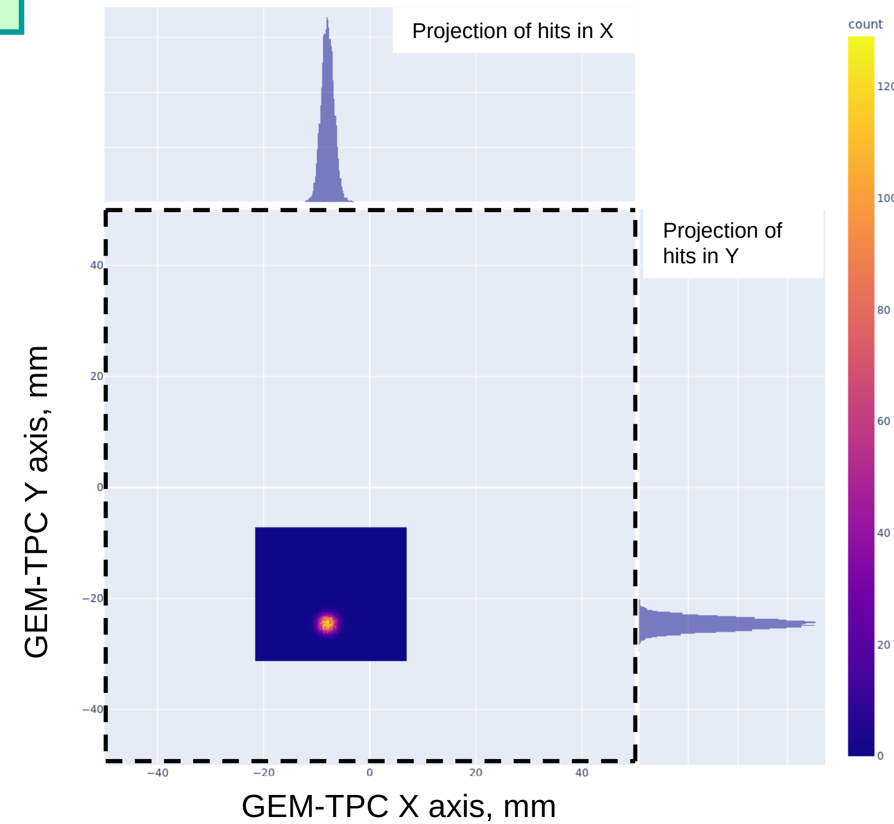
The hit map, residuals and the control sum for pions .

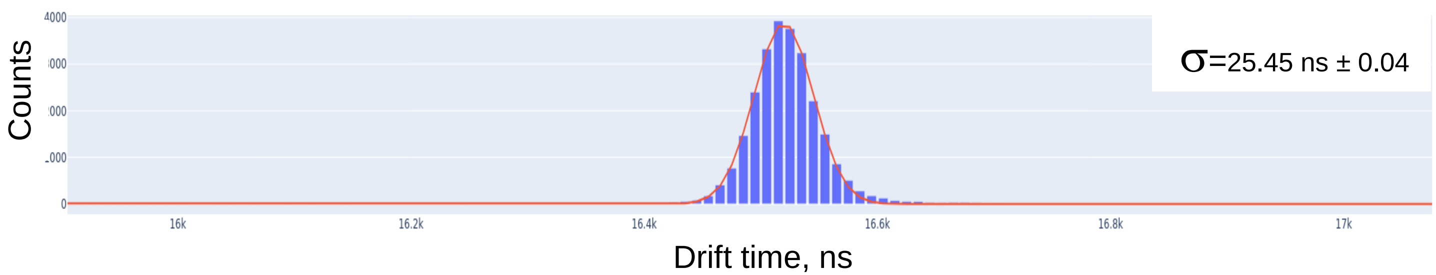


Residual Distribution X axis



Residual Distribution Y axis

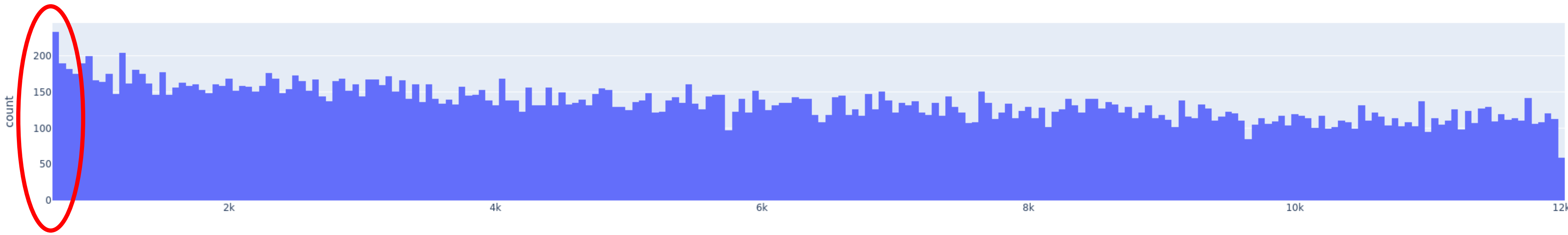




TEST BEAM at the SPS - H4 Beamline

Indications of rate capability by looking at the instantaneous peak rate on $ArCO_2$ (70/30)

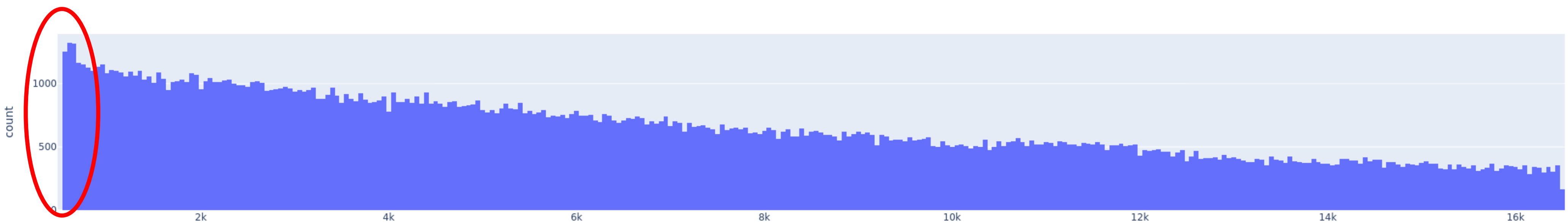
At ~ 677.66 ns → 1.48 MHz, O(10%) of the tracks



ΔT_0, ns

Indications of rate capability by looking at the instantaneous peak rate on $HeCO_2$ (70/30)

At ~ 524.44 ns → 1.91 MHz, O(10%) of the tracks

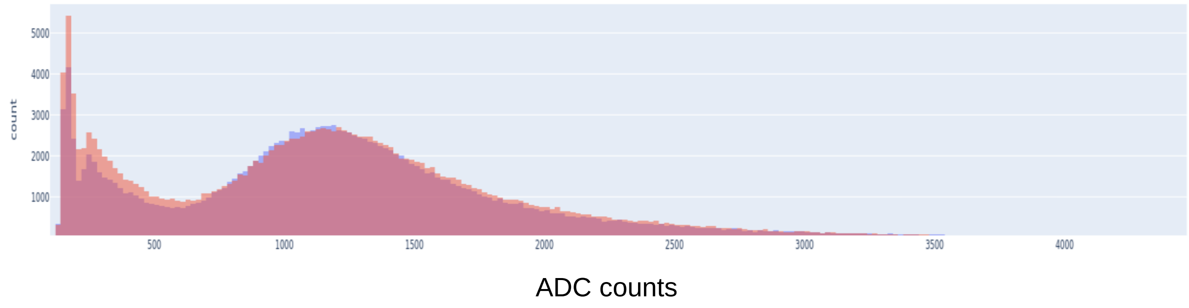


ΔT_0, ns

Cluster Charge Distribution

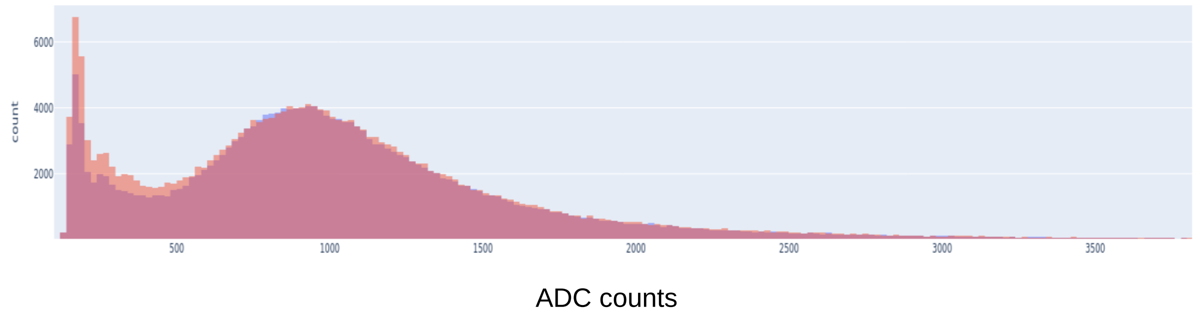
GEM-TPC, Muons

$ArCO_2$ (70/30)



GEM-TPC, Muons

$HeCO_2$ (90/10)

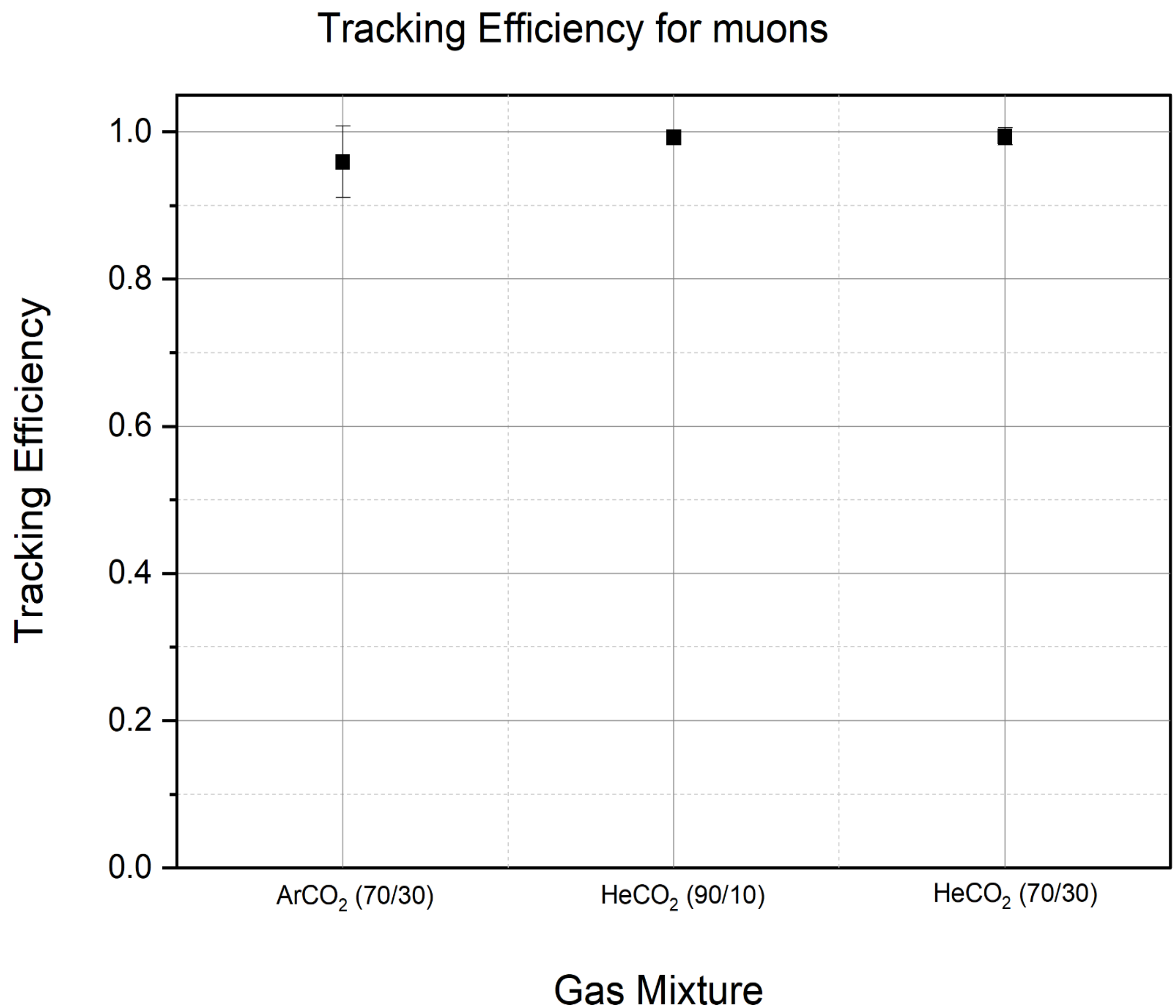


TEST BEAM at the SPS - H4 Beamline

Efficiency with fiducialization:

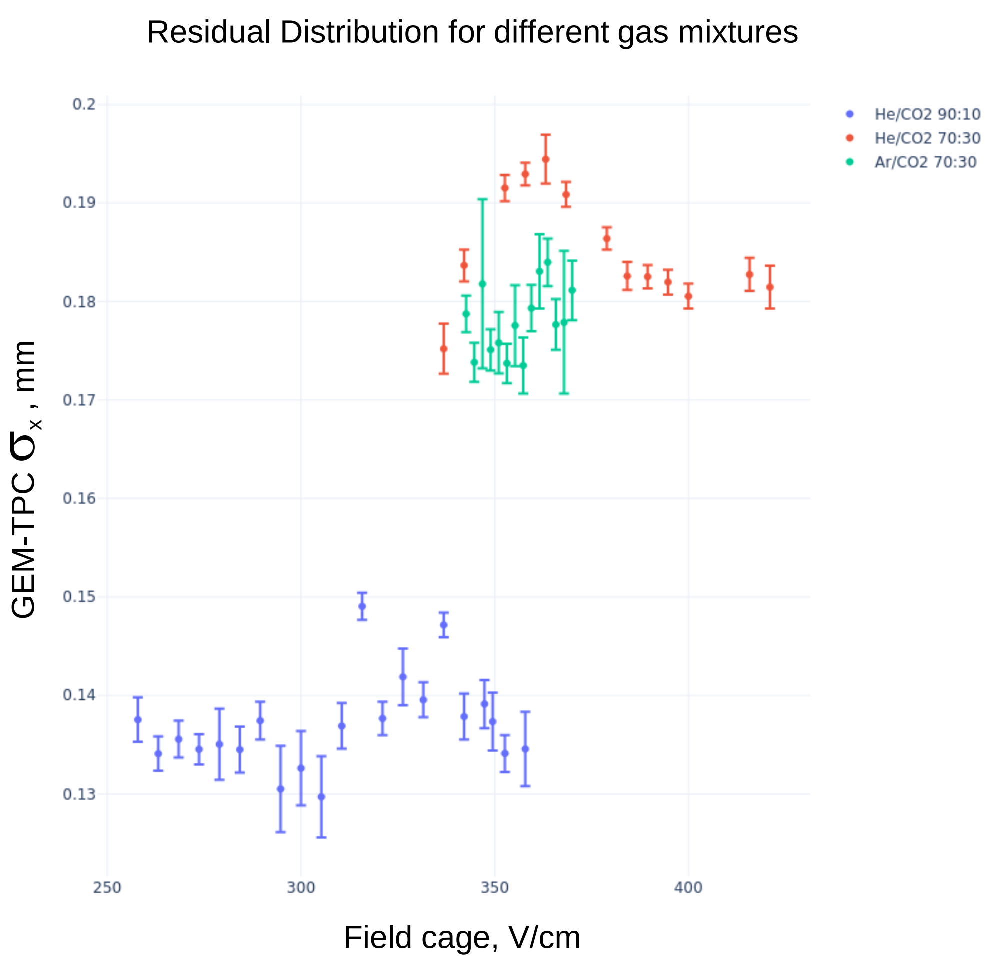
$$\varepsilon_{\text{HGB4-2}} = \frac{\#\,Tracks\ reco\ GEM{-}TPC}{\#\,Tracks\ reco\ Tracker}$$

- small χ^2 cut
- Fine alignment.
- Fiducialization:
  2 cm in X
  1 cm in Y

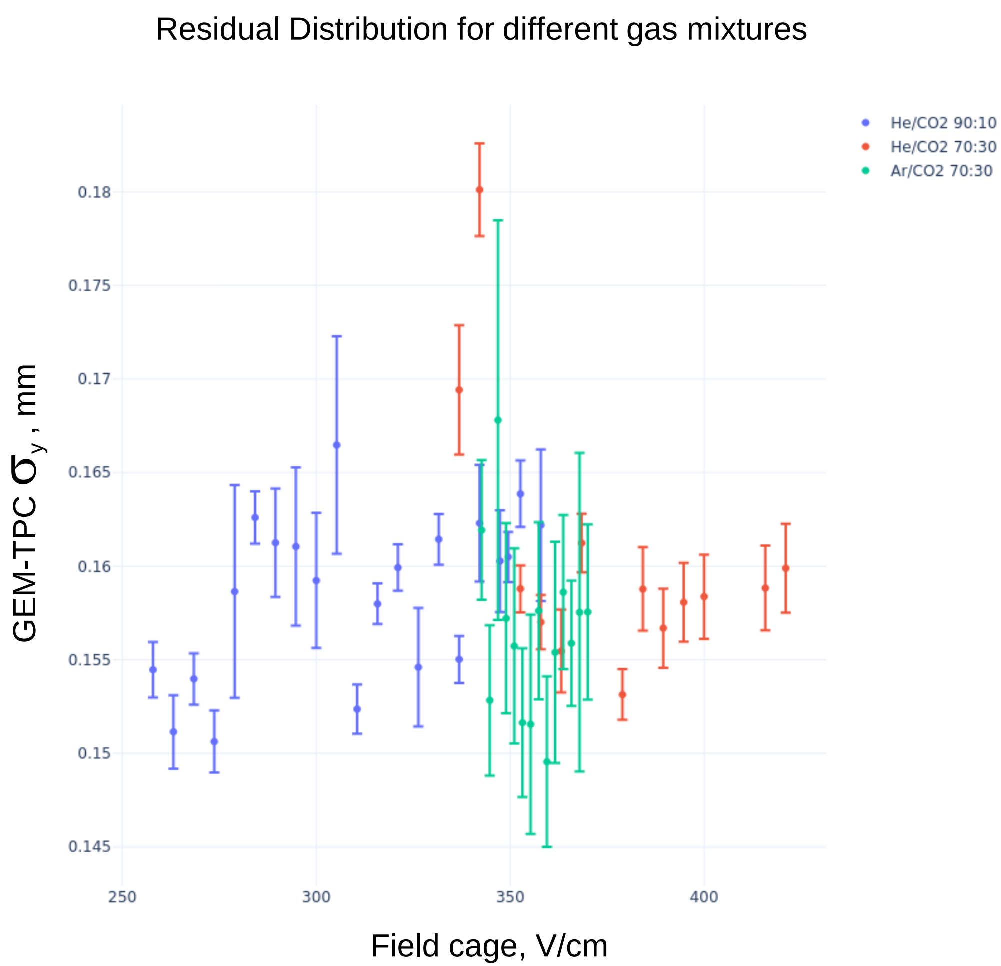


TEST BEAM at the SPS - H4 Beamline

Spatial resolution in X:



Spatial resolution in Y:

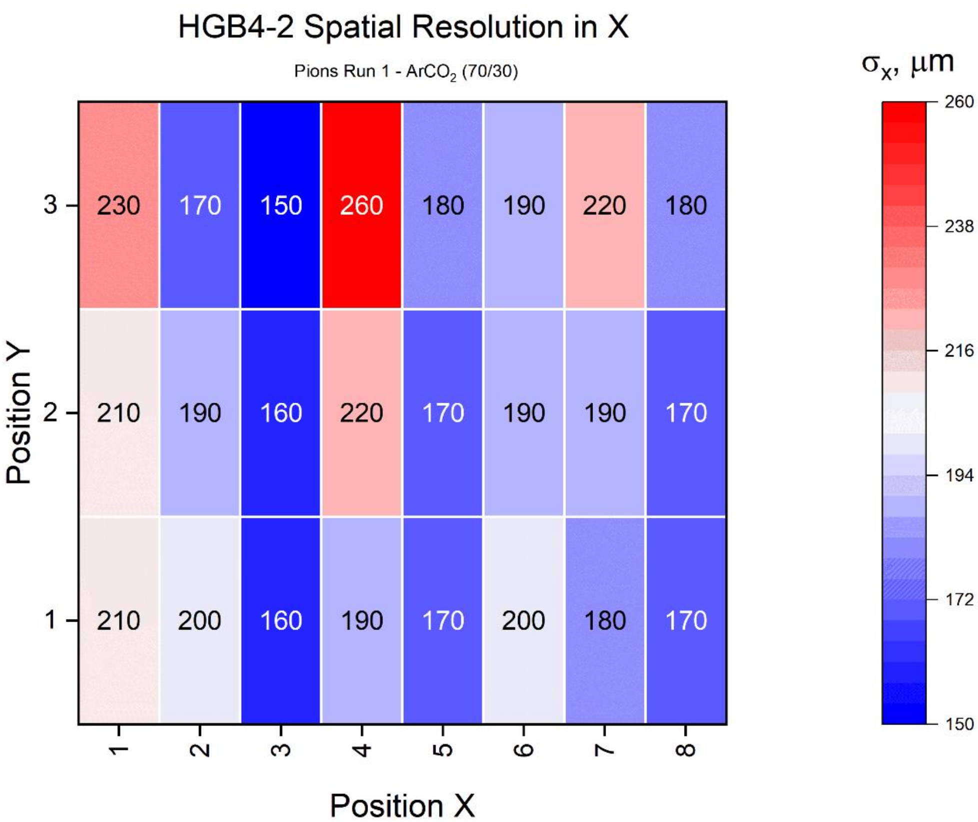


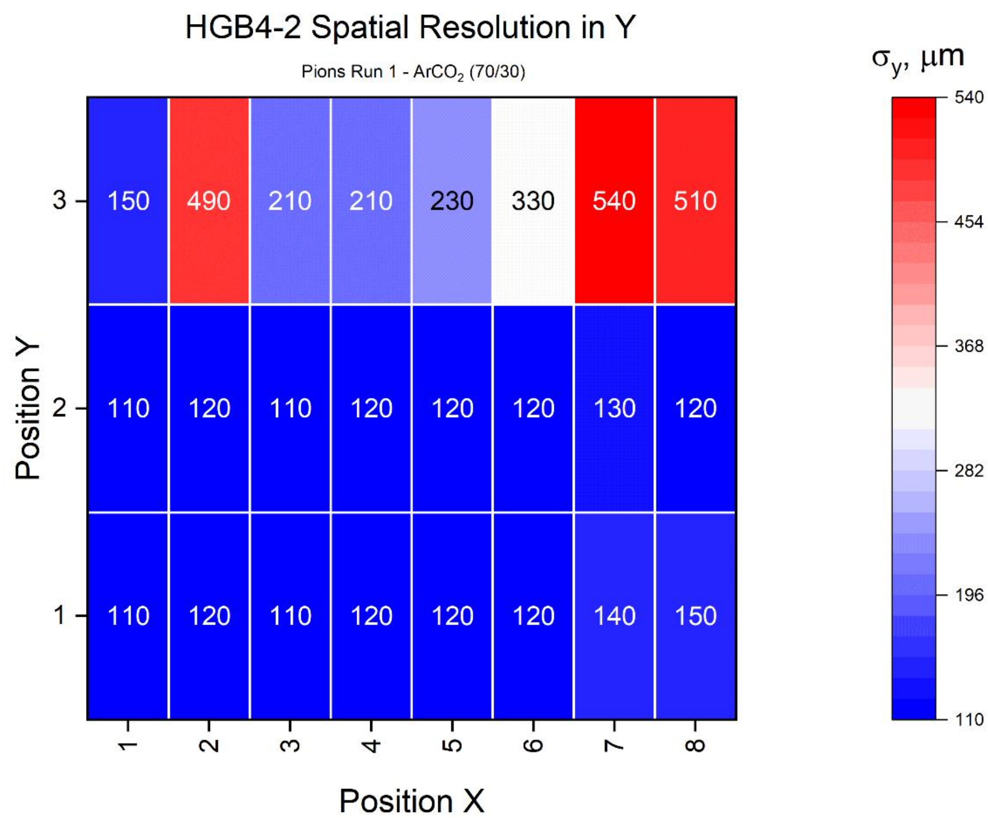
TEST BEAM at the SPS - H4 Beamline

Pions position scan for $ArCO_2$ (70/30) gas mixture

$$\sigma_{HGB4\text{-}2} = \sqrt{\sigma^2_{GEM-TPC} - \sigma^2_{Tracker}}$$

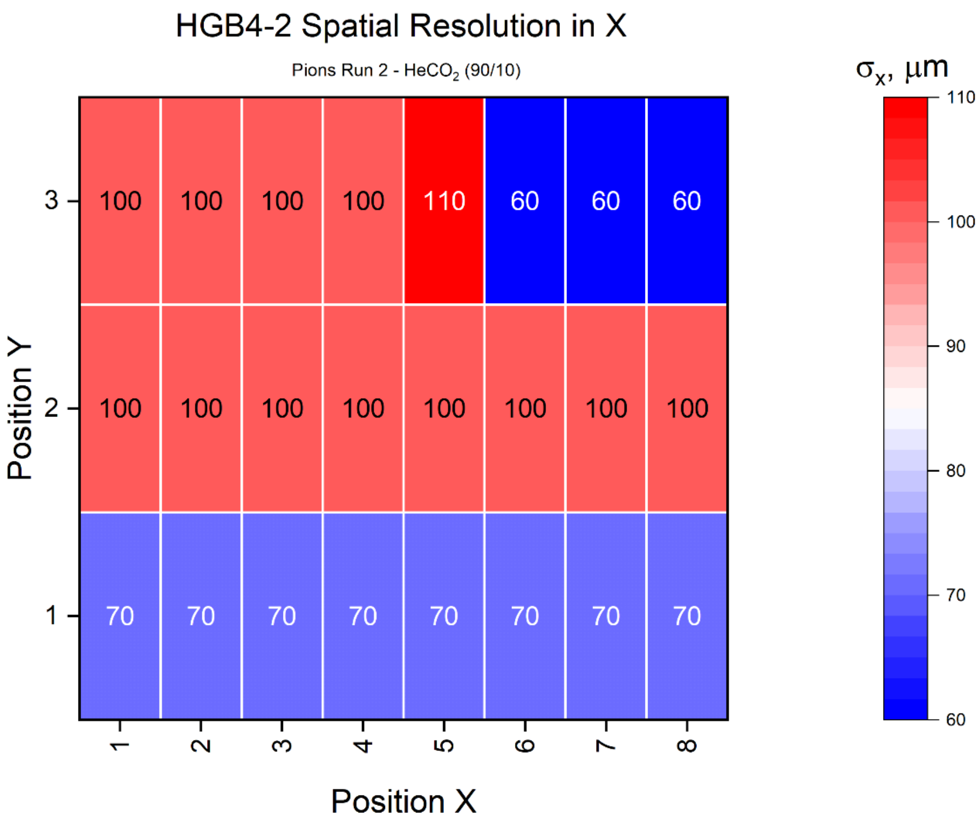
Becasue of small χ^2 cut the $\sigma^2_{Tracker} \cong 50\ \mu m$

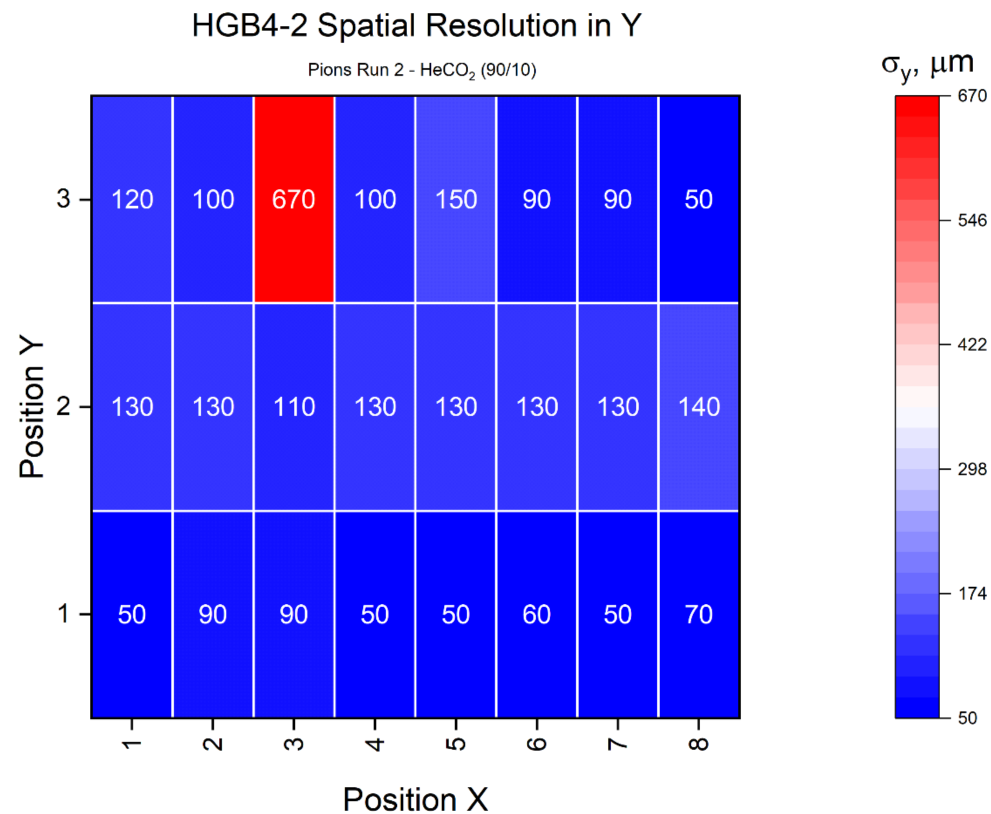




TEST BEAM at the SPS - H4 Beamline

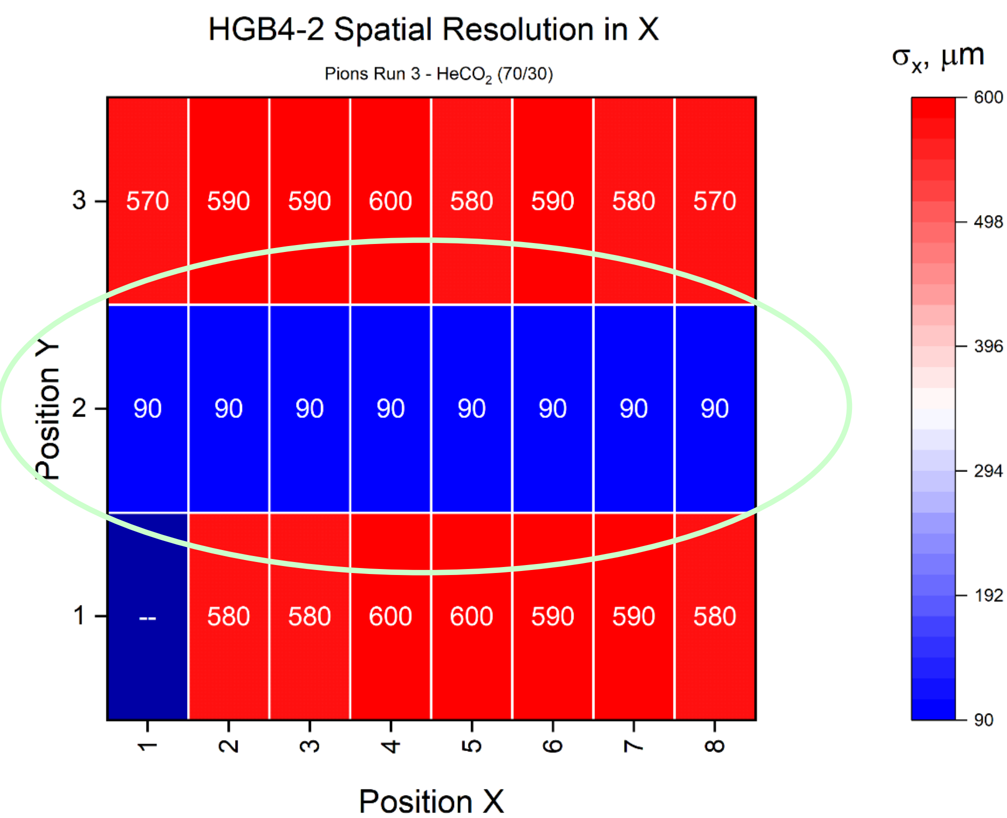
Pions position scan for $HeCO_2$ (90/10) gas mixture

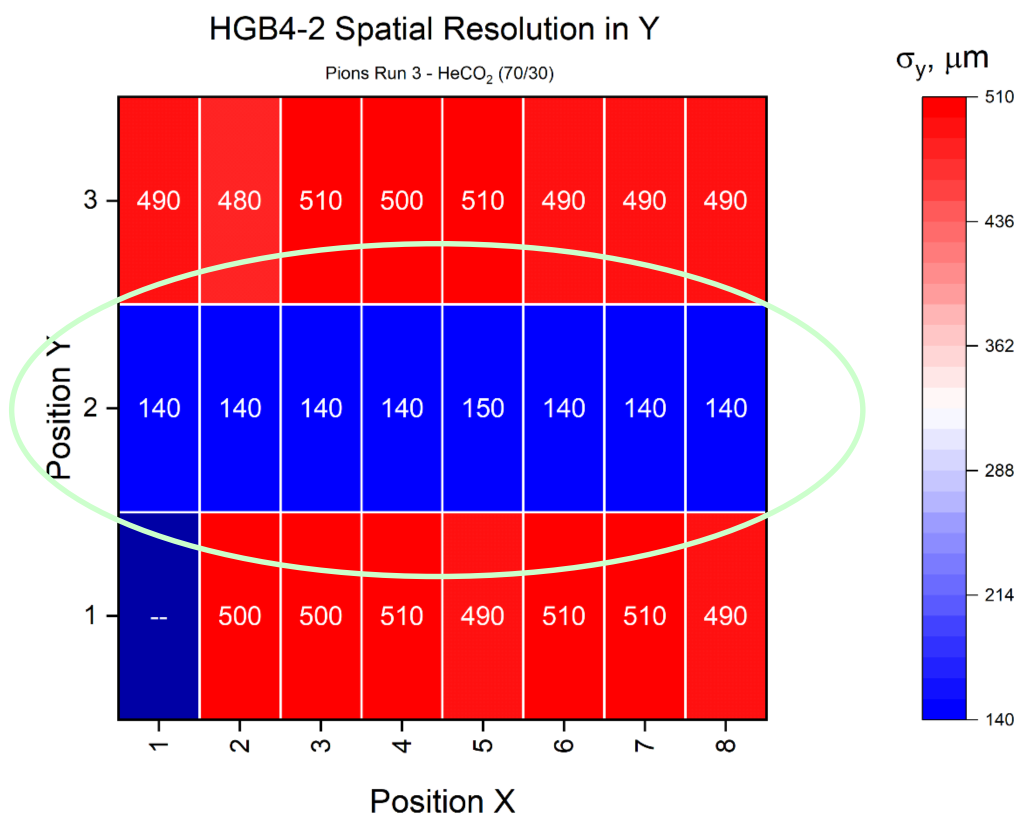




TEST BEAM at the SPS - H4 Beamline

Pions position scan for $HeCO_2$ (70/30) gas mixture





SUMMARY

- The synchronization of DAQs is very crucial and a paintful task, therefore work on a TLU-like unit for DRD1 is of utmost importance.

- The work of the GEM-TPC (HGB4-2) with $HeCO_2$ (90/10) show good stability and high spatial resolution. This changing of the gas was proposed to improve the spatial resolution for MIXE experiment.

- The use of Jupyter Notebooks provides a good platform for students to make important contributions to the analysis.

- The support given by the GDD lab during the integration of the VMM3a/SRS DAQ and the commission was indispensable for the success on these measurements.

- The RD51/DRD1 reference tracker has good operation stability and reliability, which was shown throughout the whole campaign.

Collaborators

Francisco, Bernhard, Xiao, Michael and Karl (left to right)

Akcknowledgements to all the collaborators in the GDD lab and RD51 test beam coordination especially to: **Eraldo, Max, Lucian, Dorothea, Hans, Yorgos, Alex, Benjamin and Miranda.**

To Collaborators at the Micro Pattern Technology Workshop: **Rui, Alexandra, Bertrand, Alexis, Antonio and Benilde.**

To collaborators at the Detector Laboratory at GSI: **Christian, Bernd, Holger, Jochen, Chan, Andrei, Christoph, Hennings, Jan and Nik.**

To collaborators at HIP: **Raimo, Jouni and Minna.**

Thank you for your Attention

BACKUP SLIDES

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 1052, July 2023, 168262

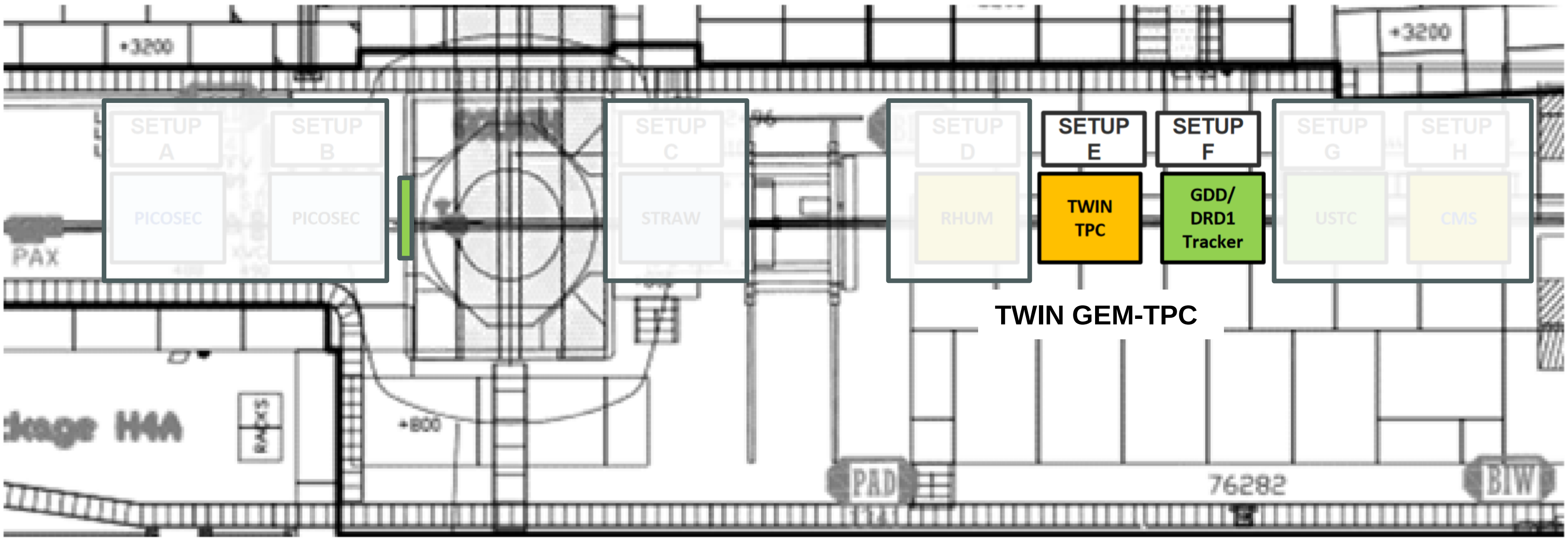
Full Length Article

In-beam test results of the Super-FRS GEM-TPC detector prototype with relativistic uranium ion beam

M. Luoma [a b], F. García [a], J. Äystö [a b], T. Blatz [c], D. Chokheli [d], H. Flemming [c], K. Götzen [c], T. Grahn [a b], A. Jokinen [a b], C. Karagiannis [c], N. Kurz [c], S. Löchner [c], C. Nociforo [c], S. Rinta-Antila [a b], C.J. Schmidt [c], H. Simon [c], R. Turpeinen [a], B. Voss [c], P. Wieczorek [c], M. Winkler [c]

TEST BEAM LAYOUT:

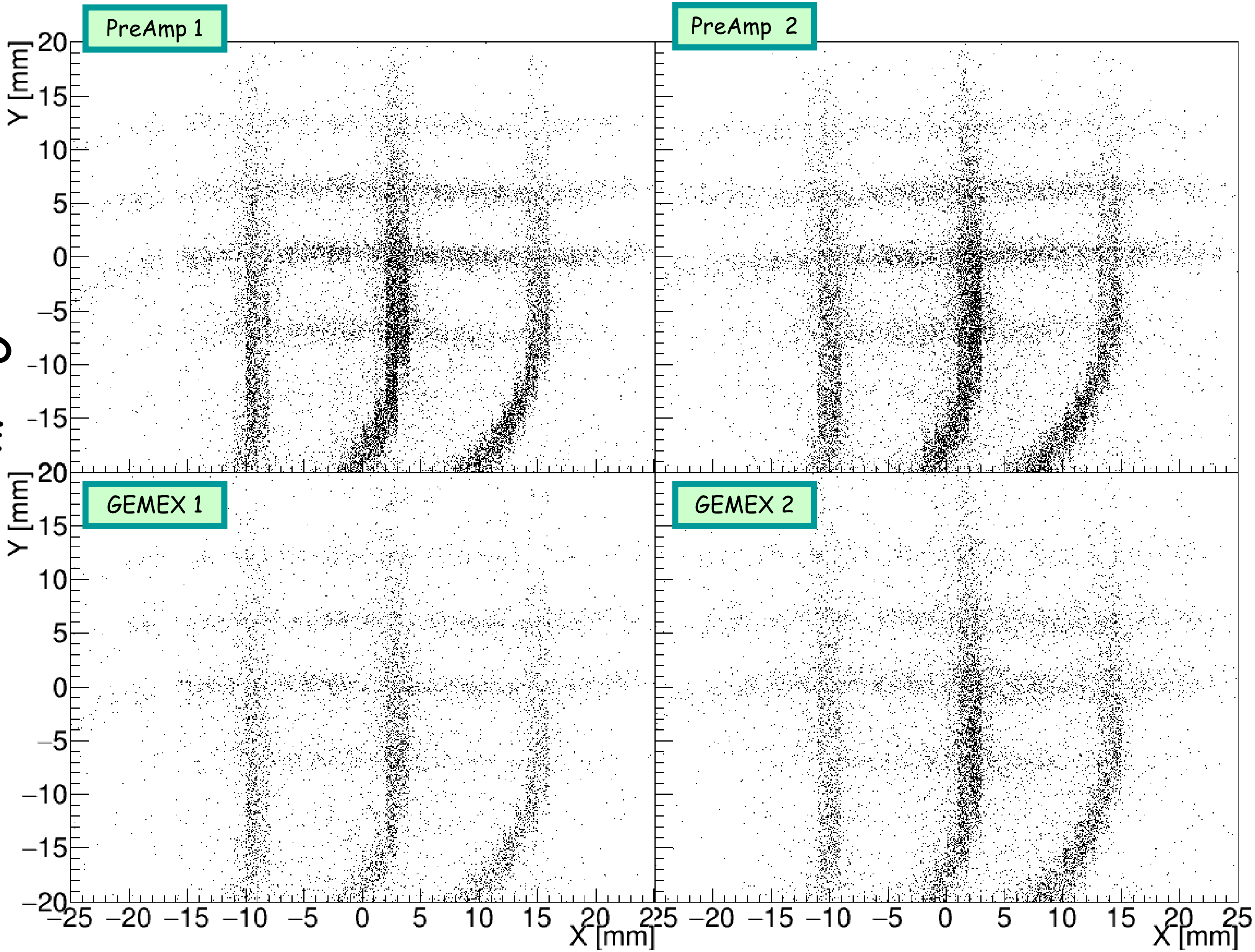
BEAM H4, PPE134 – INSTALLATION (DRD1, 10 April – 24 April)



- SETUP A, B: PICOSEC (F. Brunbauer, M. Lisowska)
- SETUP C: STRAW (T. Enik, K. Kuznetsova)
- SETUP D: RHUM (M. Iodice, G. Sekhniaidze)
- SETUP E: TWIN TPC (F. Garcia Fuentes)
- SETUP F: GDD/RD51 Tracker (K. Floethner)
- SETUP G: USTC (Y. Zhou)
- SETUP H: CMS ME0 (A. Pellecchia, P. Everaerts)

TWIN GEM-TPC

Reconstruction of the scintillation grid by the GEM-TPC

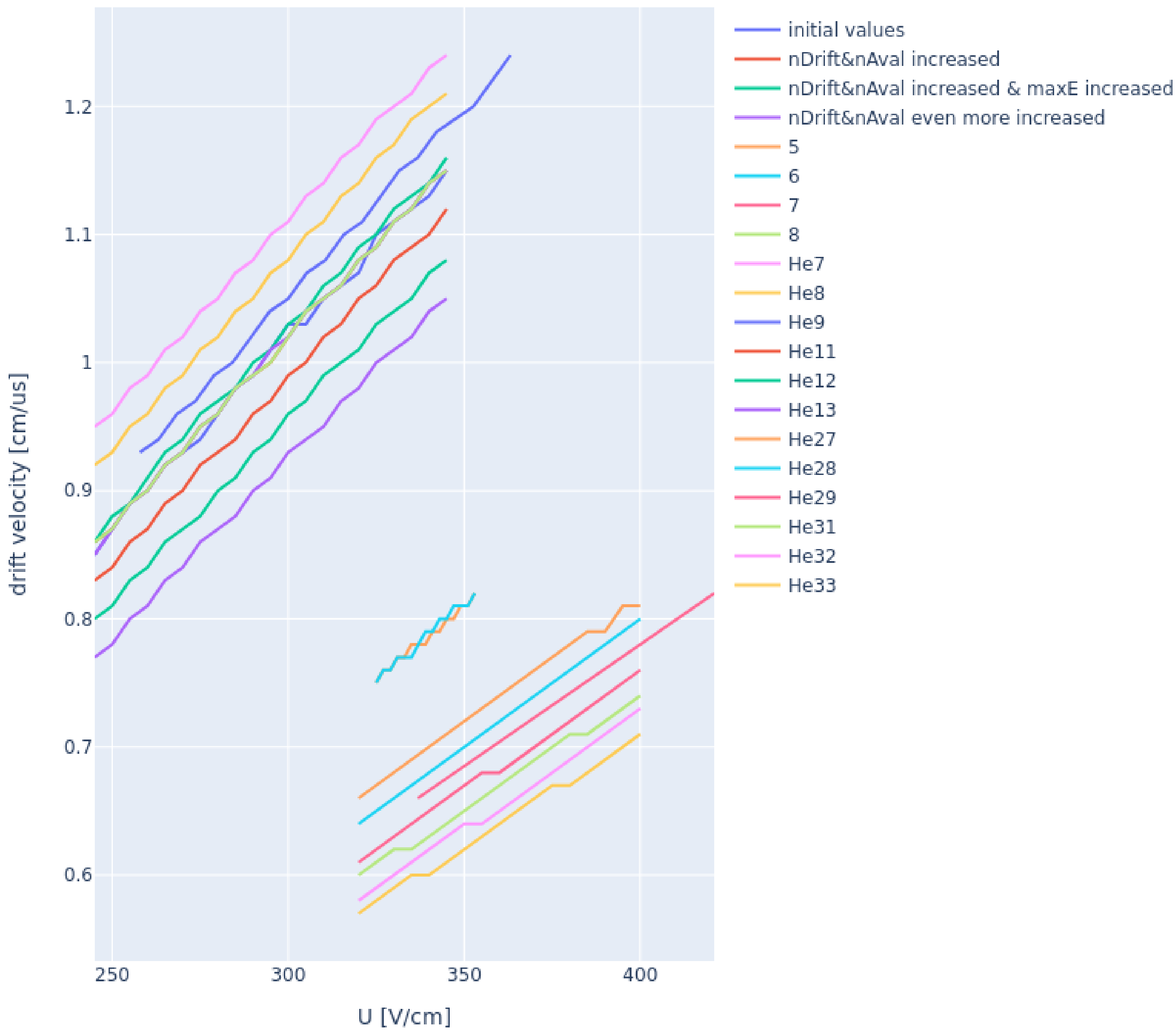


THE GRID IS RECONSTRUCTED AS IN THE REFERENCE ONE

NOTE:
One of GEM-TPC grid has been rotated 180°

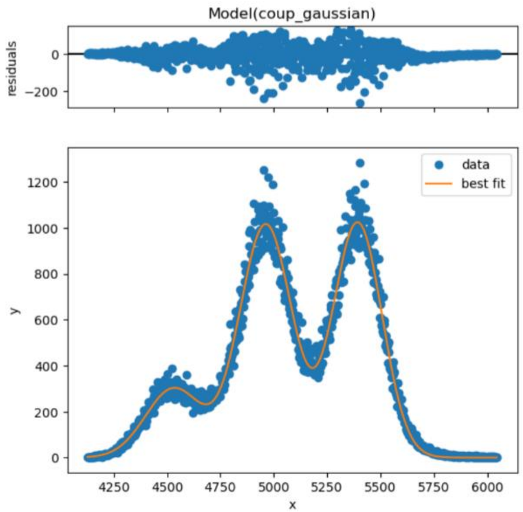
Drift Velocity Simulations:

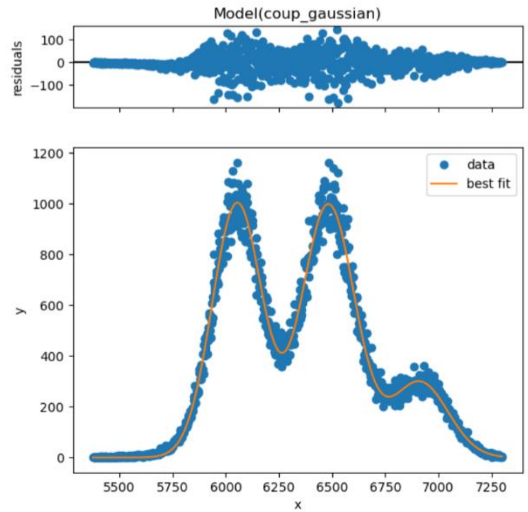
- $ArCO_2$ (70/30)
- $HeCO_2$ (70/30)
- $HeCO_2$ (90/10)

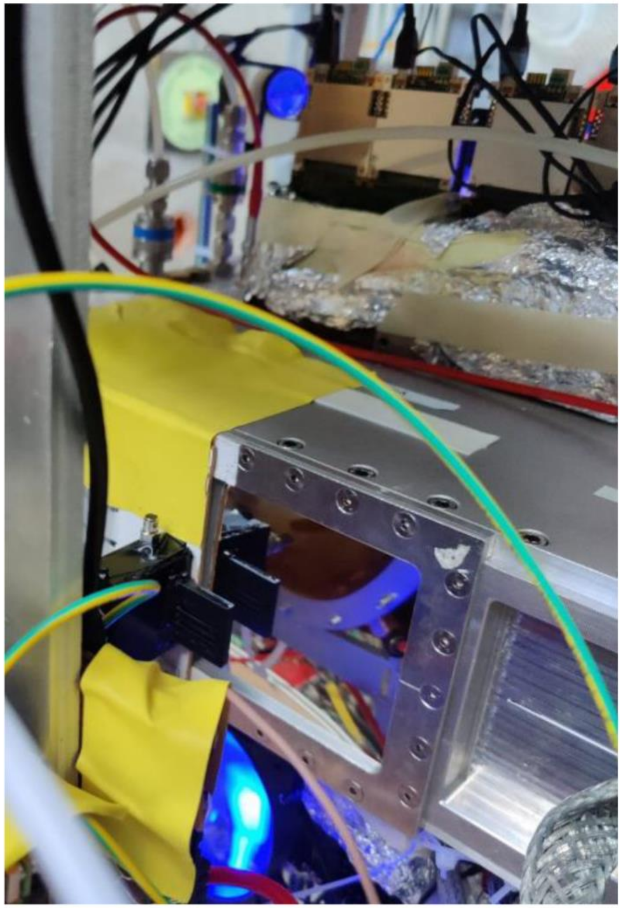


Drift time calibration – Fiber Detector

- Assembled, tested and mounted new detector
  - precision 3D printed (35um) mounting structure
  - 3 scintillating fibers in exactly 4mm distance
  - high speed SiPM premounted on readout board
- *Drift time calibration successful!*
  - cut on parallel tracks (constant sum of drift time)
  - drift velocity: (9.30 +/- 0.03) mm/us

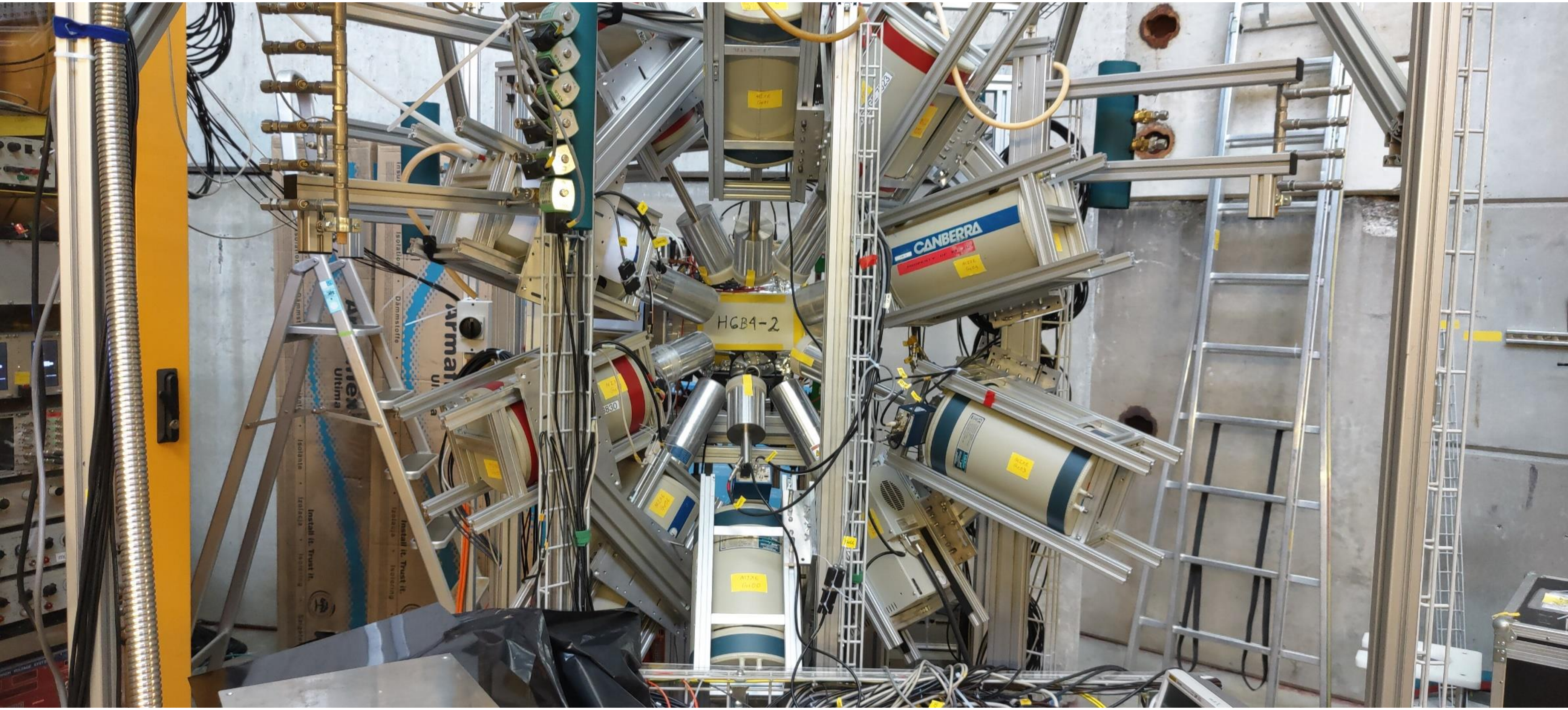






TEST BEAM at the SPS - H4 Beamline

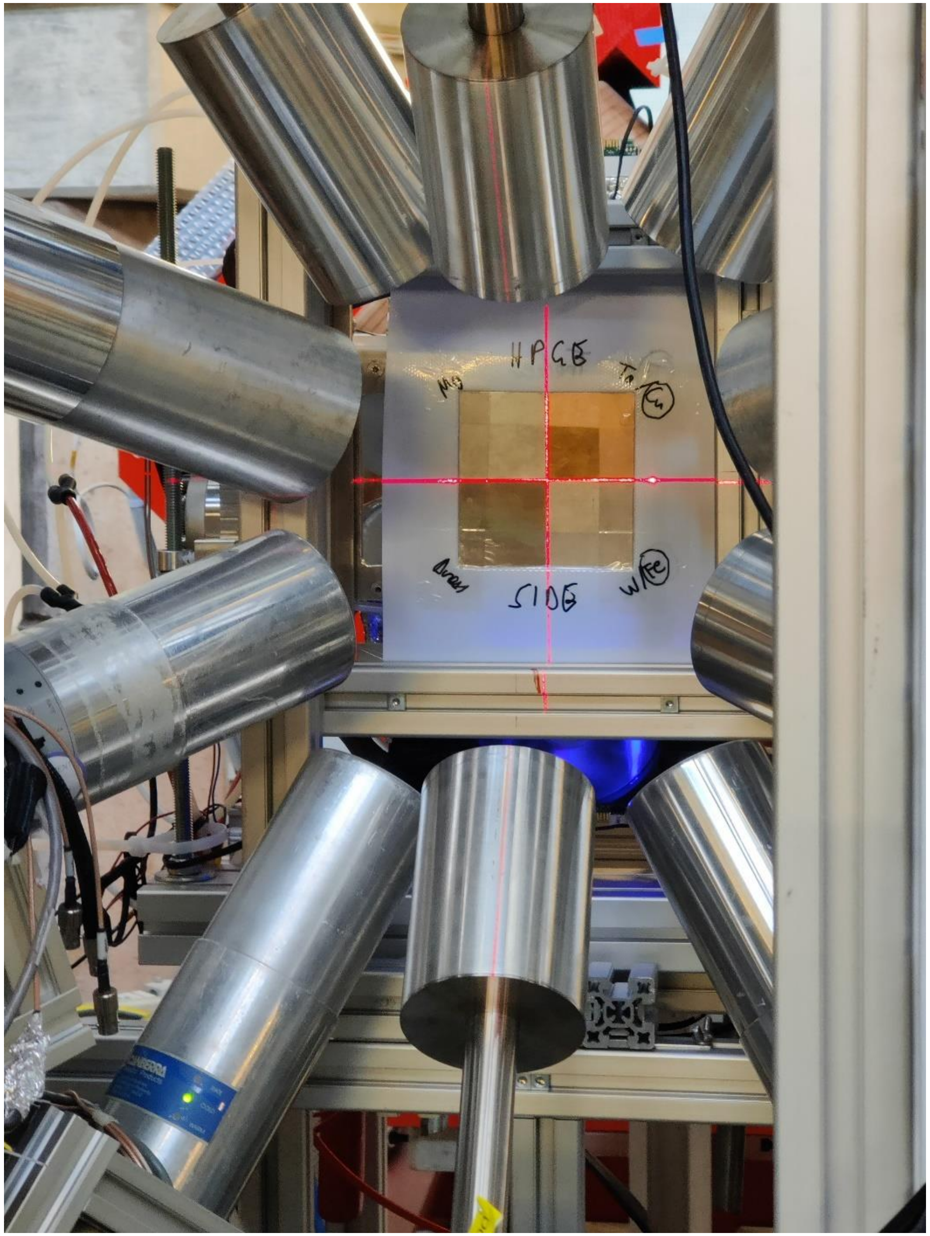
The second campaign for GEM-TPC - HGB4 at SμS/πE1 - PSI



The second campaign for GEM-TPC - HGB4 at the S SμS/πE1 - PSI

Target Configuration:

- Molybdenum
- Tantalium and Copper
- Tungten and Iron
- Brass: Cu (63%), Zn (37%)



Is the P10 GAS MIXTURE a SOLUTION for the SUPER-FRS?

- ❑ Until now the gas mixture used has been P10 - $ArCH_4$ (90/10%) → Which has a severe aging problems at high rate
- ❑ Next gas mixture will be: $ArCO_2$ 70/30% → for Testing whole system and Characterization
- ❑ Possible choice can be: $ArCO_2CF_4$ (45/15/40%)

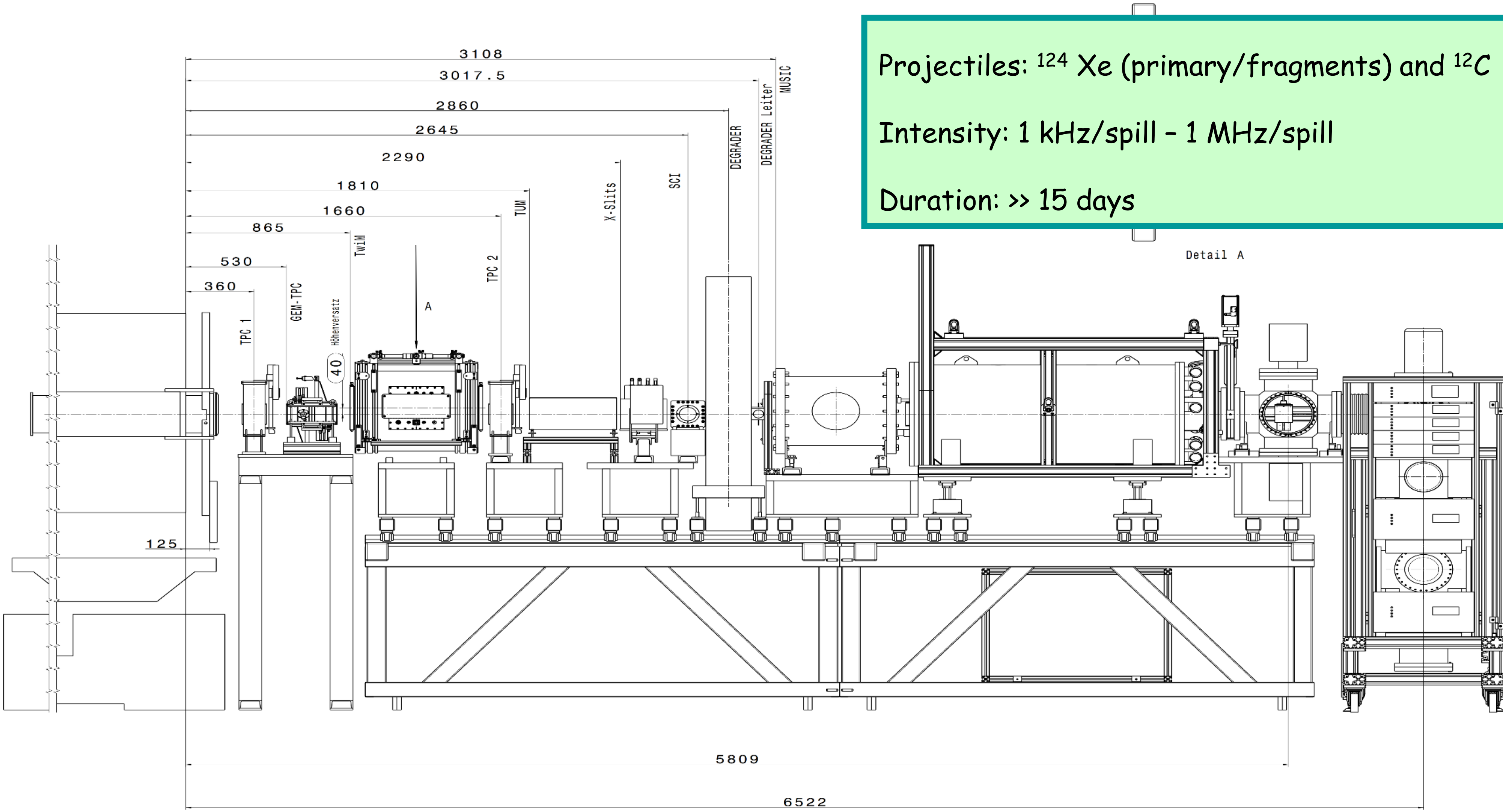
Gas mixture	Drift Field, V/cm	Drift Velocity, cm/μs	D_L, μm/ √D(cm)	D_T, μm/ √D(cm)	Drift Time, μs
P10	320	4.2	257.2	603.8	2
$ArCO_2$ (70/30)	600	1.5	150.1	134.0	6.6
$ArCO_2CF_4$ (45/15/40)	600	2.5	117.3	118.9	4

Most Relevant Results at GSI

Projectiles: ^{124}Xe (primary/fragments) and ^{12}C

Intensity: 1 kHz/spill – 1 MHz/spill

Duration: >> 15 days

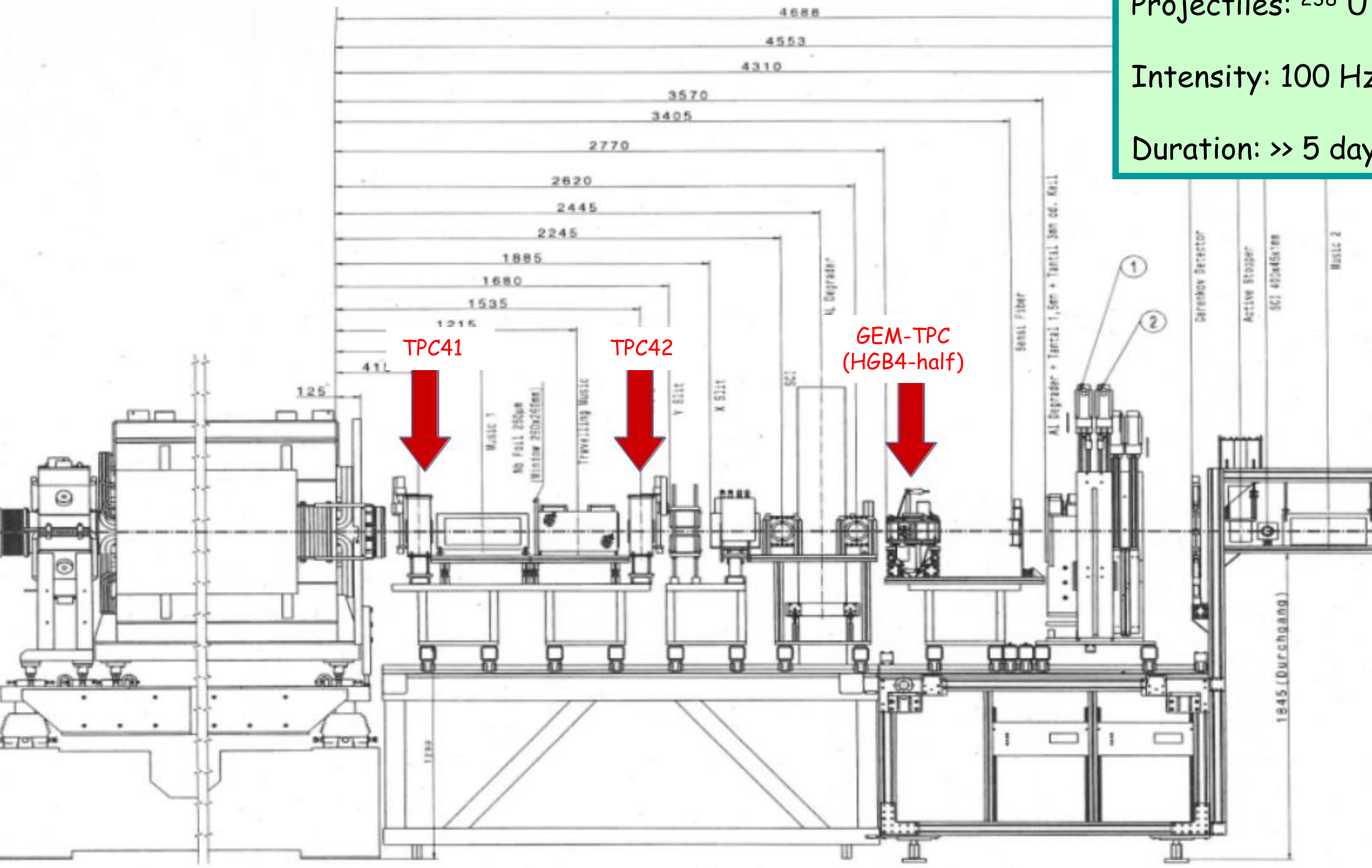


Most Relevant Results at GSI

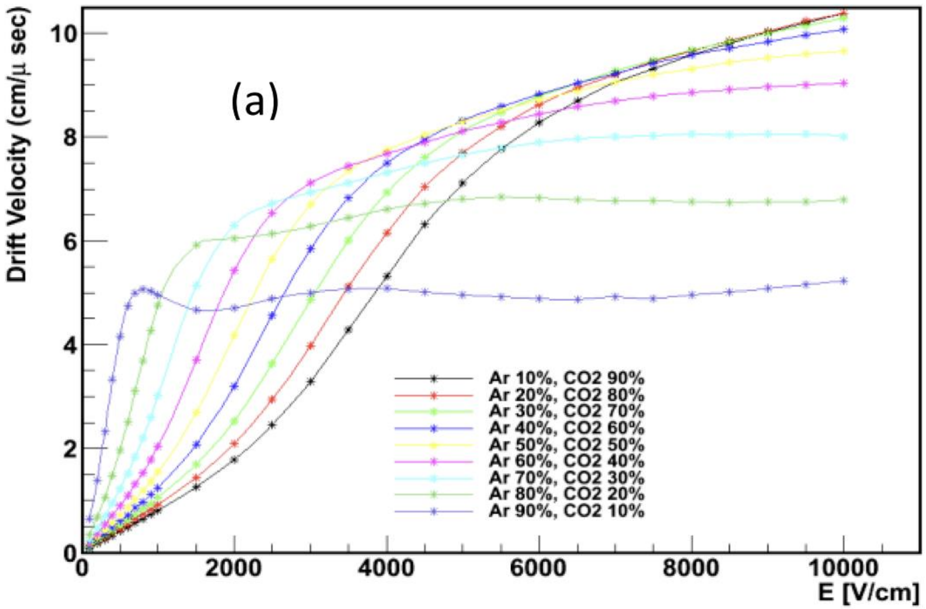
Projectiles: $^{238}U^{92+}$

Intensity: 100 Hz/spill – 1 kHz/spill

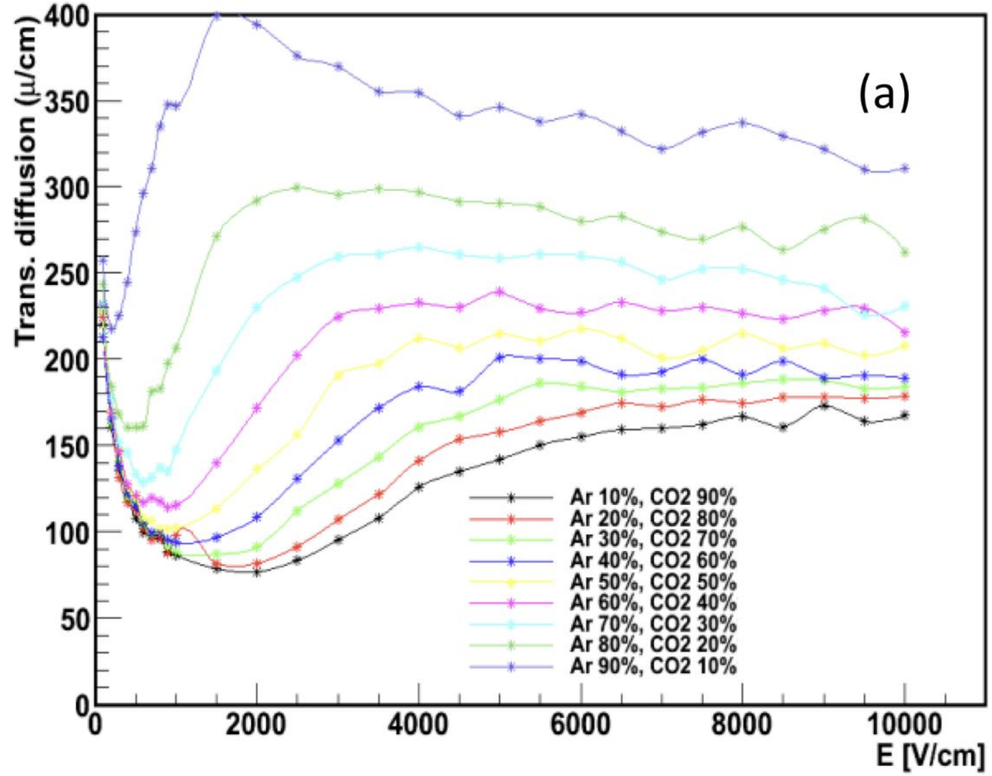
Duration: >> 5 days



$ArCO_2$

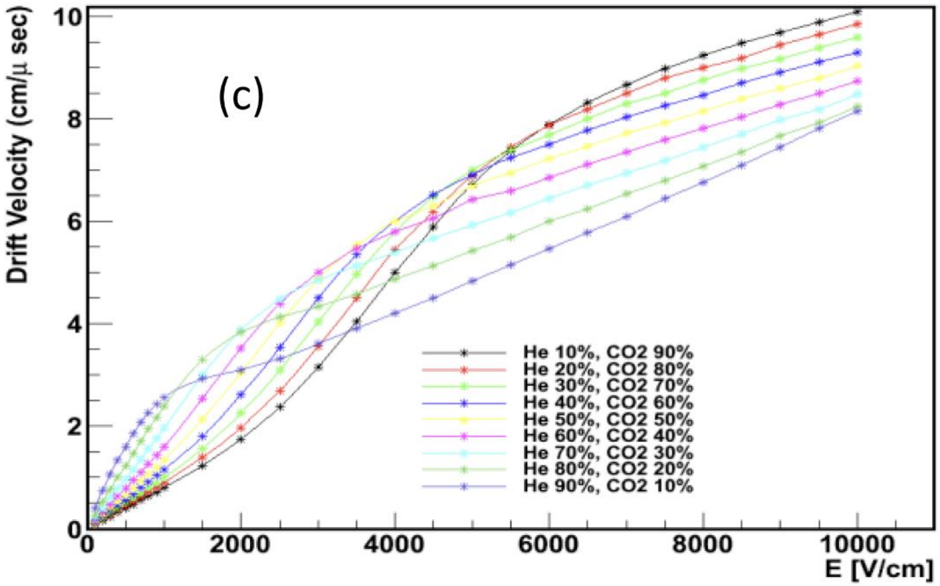


(a)
Drift Velocity (cm/μ sec)
E [V/cm]
Ar 10%, CO2 90%
Ar 20%, CO2 80%
Ar 30%, CO2 70%
Ar 40%, CO2 60%
Ar 50%, CO2 50%
Ar 60%, CO2 40%
Ar 70%, CO2 30%
Ar 80%, CO2 20%
Ar 90%, CO2 10%

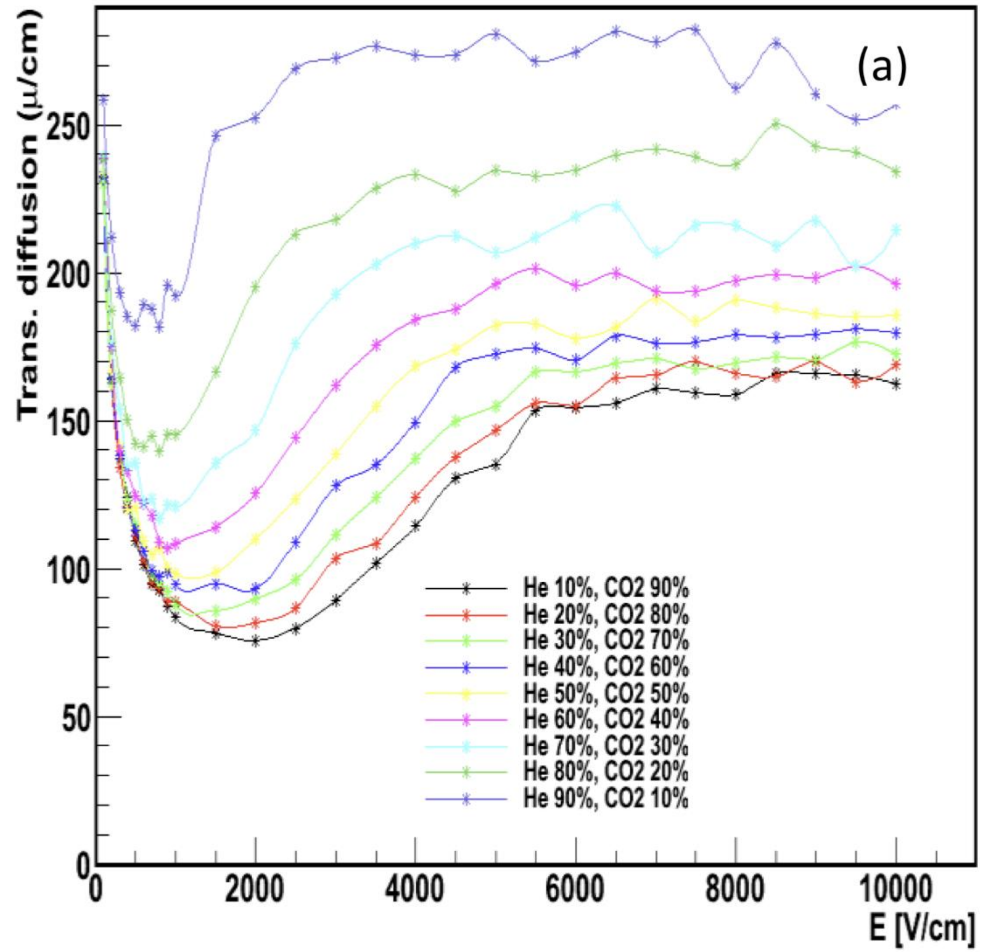


(a)
Trans. diffusion (μ/cm)
E [V/cm]
Ar 10%, CO2 90%
Ar 20%, CO2 80%
Ar 30%, CO2 70%
Ar 40%, CO2 60%
Ar 50%, CO2 50%
Ar 60%, CO2 40%
Ar 70%, CO2 30%
Ar 80%, CO2 20%
Ar 90%, CO2 10%

$HeCO_2$

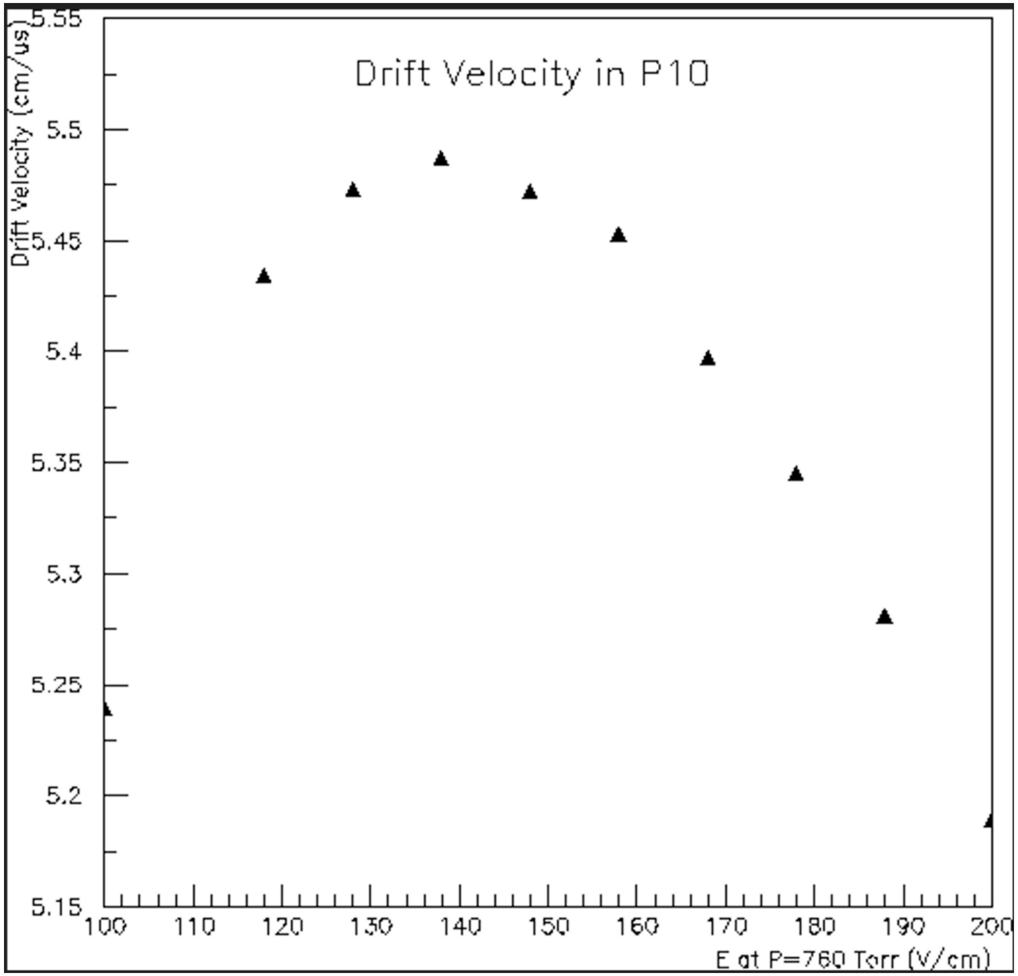


(c)
Drift Velocity (cm/μ sec)
E [V/cm]
He 10%, CO2 90%
He 20%, CO2 80%
He 30%, CO2 70%
He 40%, CO2 60%
He 50%, CO2 50%
He 60%, CO2 40%
He 70%, CO2 30%
He 80%, CO2 20%
He 90%, CO2 10%

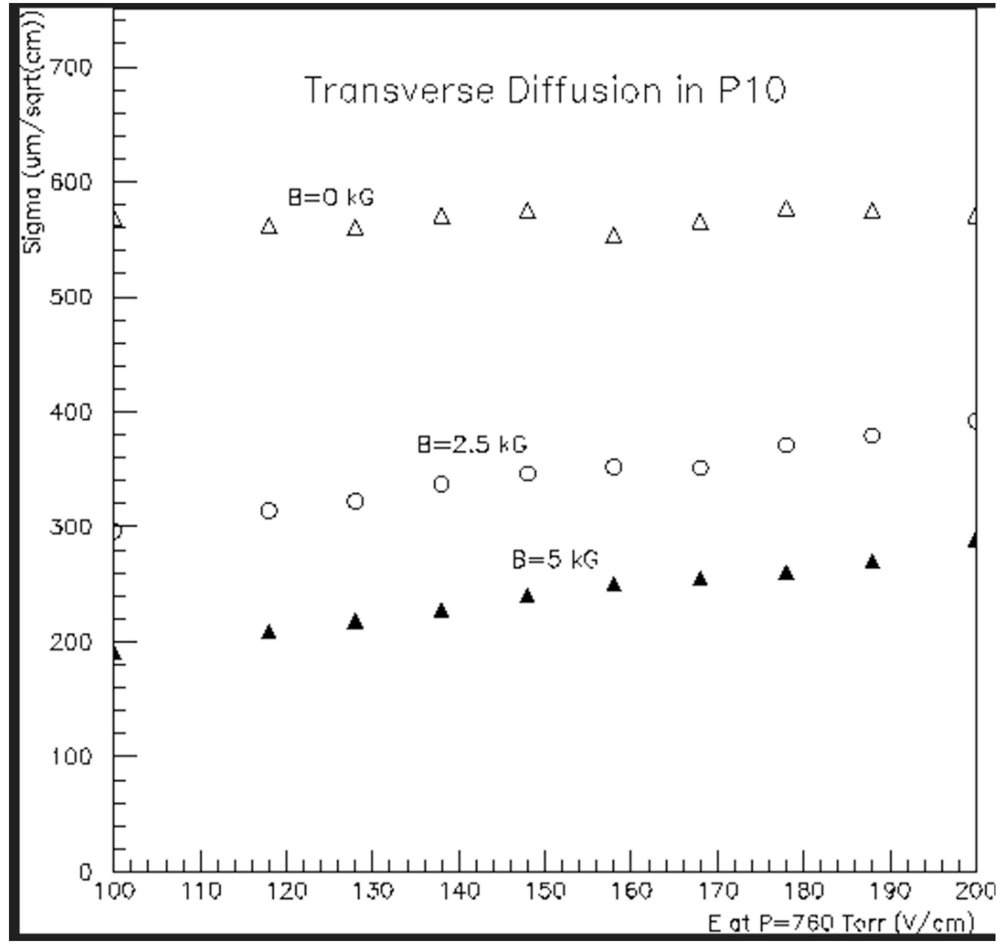


(a)
Trans. diffusion (μ/cm)
E [V/cm]
He 10%, CO2 90%
He 20%, CO2 80%
He 30%, CO2 70%
He 40%, CO2 60%
He 50%, CO2 50%
He 60%, CO2 40%
He 70%, CO2 30%
He 80%, CO2 20%
He 90%, CO2 10%

$ArCH_4$



Drift Velocity in P10
Drift Velocity (cm/us)
5.55
5.5
5.45
5.4
5.35
5.3
5.25
5.2
5.15
100
110
120
130
140
150
160
170
180
190
200
E at P=760 Torr (V/cm)



Transverse Diffusion in P10
Sigma (um/sqrt(cm))
700
600
500
400
300
200
100
0
B=0 kG
B=2.5 kG
B=5 kG
100
110
120
130
140
150
160
170
180
190
200
E at P=760 Torr (V/cm)

Existing - AIDA-2020

- Current production version
- 6 trigger inputs
- 4 DUT connections
  - LVDS on HDMI
    - But direction of each line can be swapped in hardware to allow different firmware mapping
- Low jitter clock
- Hardware permits optical distribution of clock/trigger
- In small desktop case or rack-mount case

This project has received funding from the European Union's Horizon 2020 research and inn

David Cussans,
https://indico.cern.ch/event/1323113/contributions/5823585/attachments/2836907/4959134/cussans_aida_tlu_bttb12_april2024.pdf