SUPER-FRS TRACKING of HEAVY IONS at FAIR with a TWIN GEM-TPC

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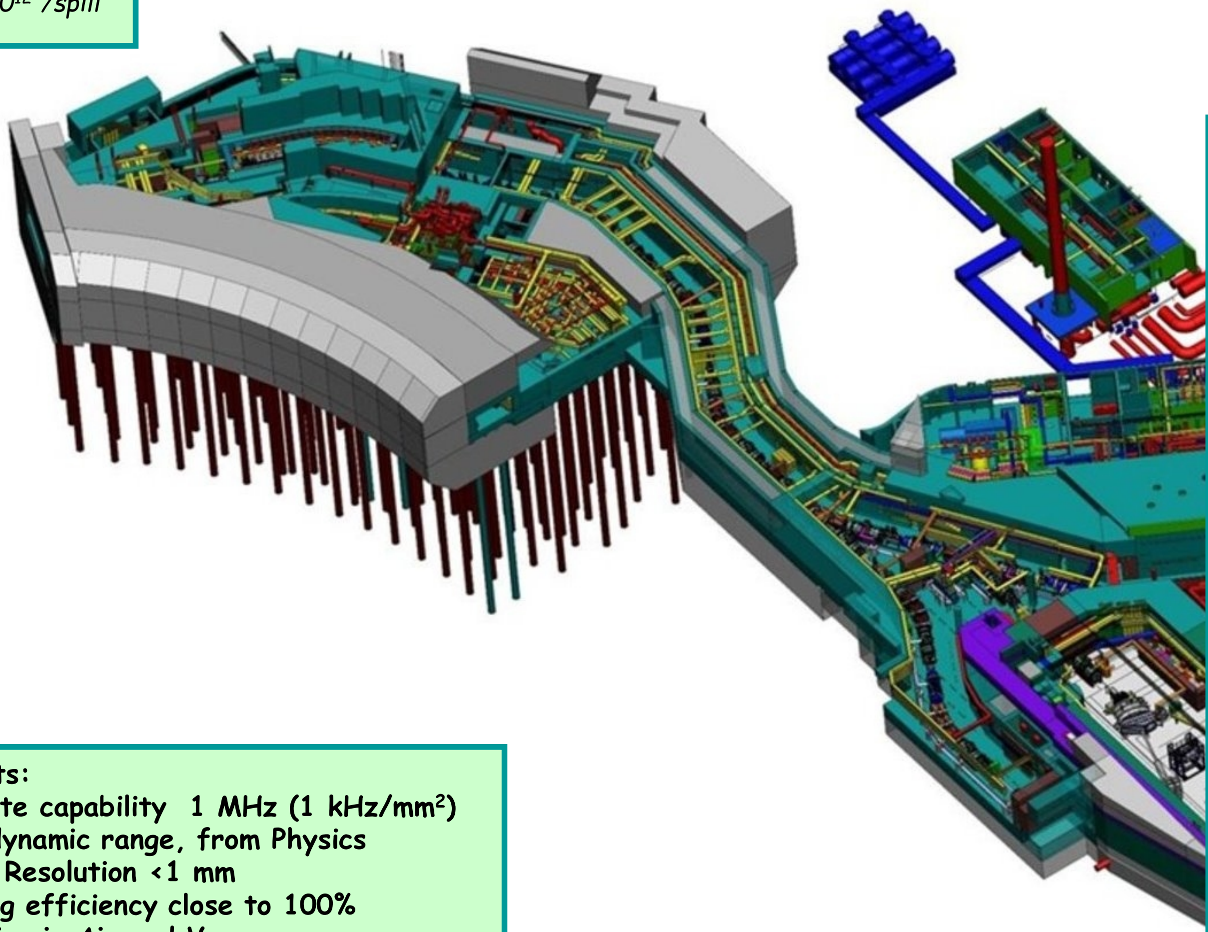
OUTLINE

1. Introduction and Motivation
2. Research & Development Phase
3. Consolidation of the Final Prototype
4. Conclusions

INTRODUCTION & MOTIVATION

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



@DMU-GSI, @FSB-FAIR

THE PROJECT TIMELINE

The R&D and Design can be finalized by:

Q3/2022

Mass production:

Q1/2023 – Q4/2024

Part of the Finnish Contribution will be in Diagnostic systems, which is a work package dedicated to provide 36 GEM-TPC detectors.

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

RESEARCH & DEVELOPMENT PHASE

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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

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[a] Helsinki Institute of ...
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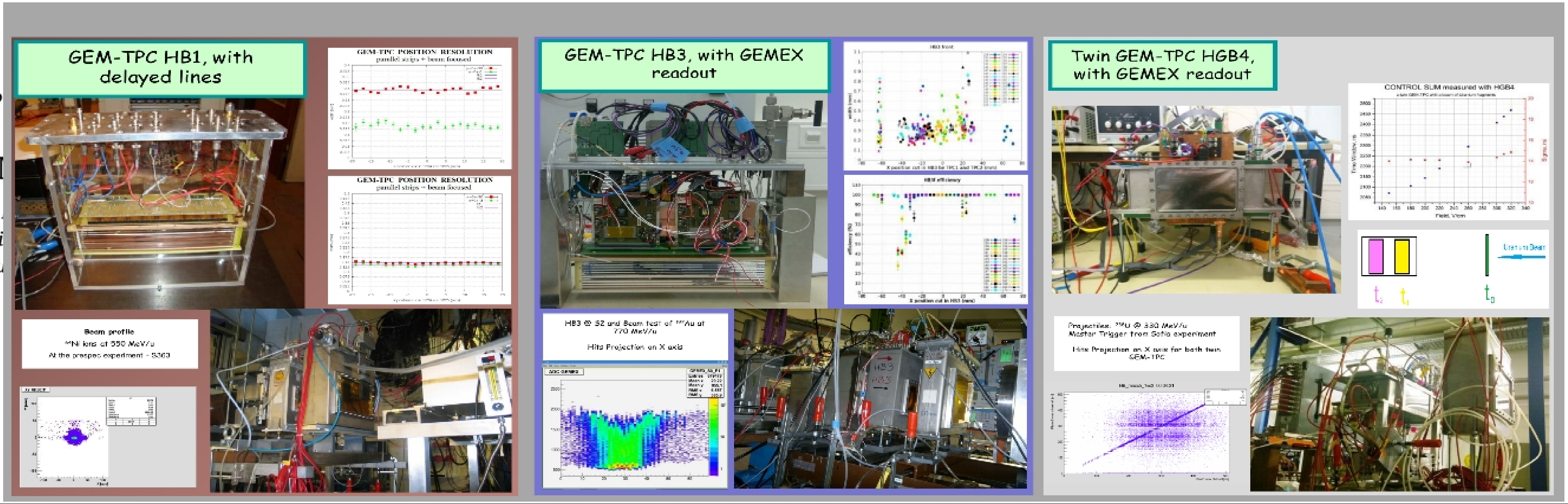
[c] GSI Helmholtzzentru...



RESEARCH & DEVELOPMENT PHASE

Projectile (Energy)	GEM-TPC (Half)	Energy deposited, MeV (in 2.5 cm of P10 gas at 1 atm) Mean	RMS
Protons	1st	$36.7\ 10^{-3}$	$3.3\ 10^{-3}$
(50 MeV)	2nd	$37.4\ 10^{-3}$	$3.1\ 10^{-3}$
^{12}C	1st	$240.2\ 10^{-3}$	$38.7\ 10^{-3}$
(660 MeV/u)	2nd	$241.4\ 10^{-3}$	$39.2\ 10^{-3}$
^{124}Xe	1st	20.1	$343.3\ 10^{-3}$
(660 MeV/u)	2nd	20.2	$349.6\ 10^{-3}$
^{238}U	1st	82.6	6.0
(300 MeV/u)	2nd	84.0	6.1

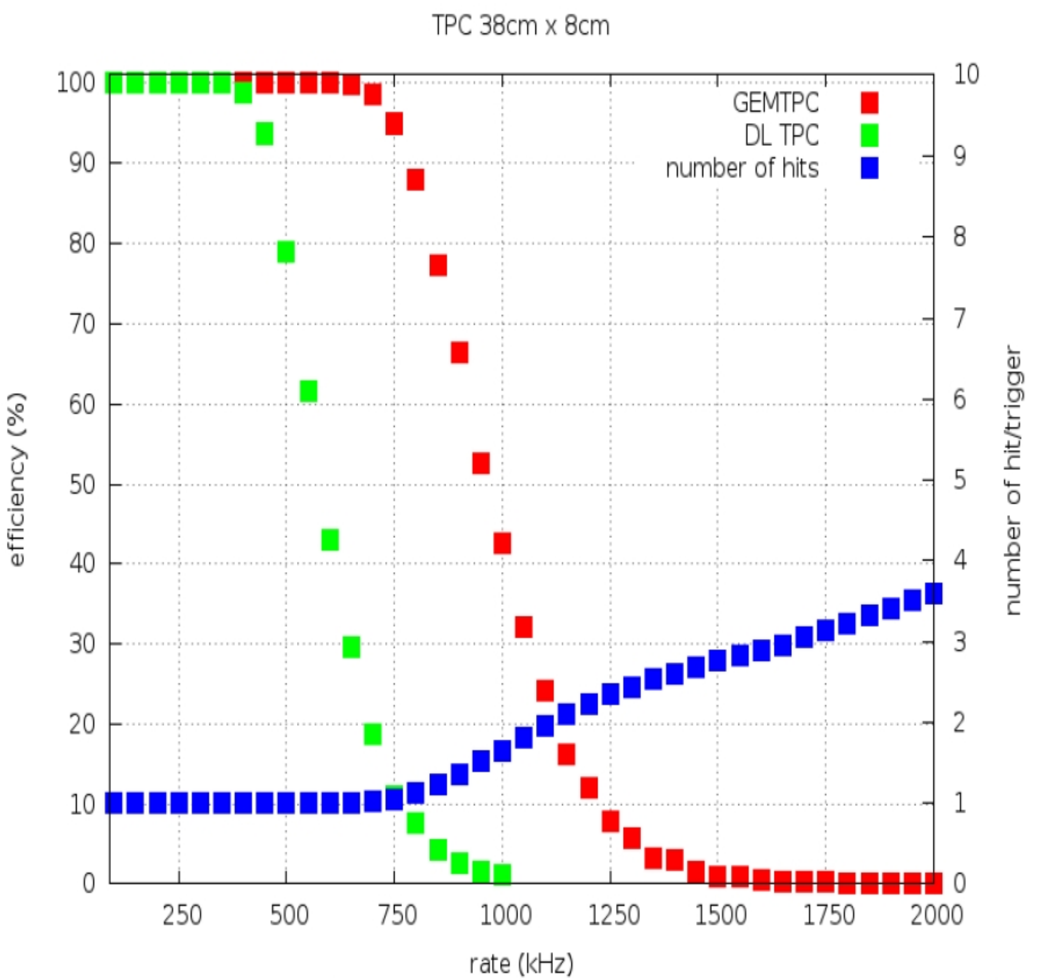
RESEARCH & DEVELOPMENT PHASE

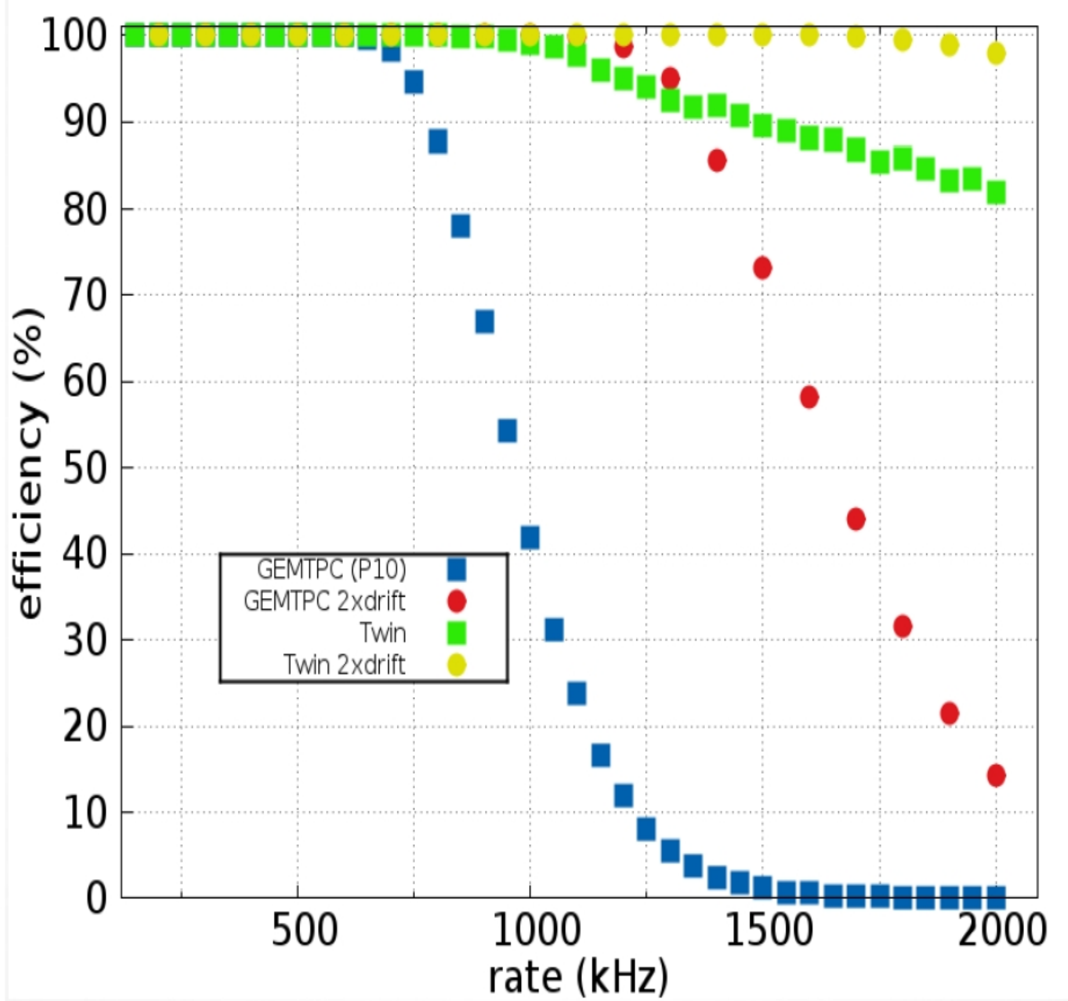
Summary:

- The GEM-TPC **concept** was tested and performing very stable with good spatial resolution at close to 100% tracking efficiency

- Test beams with Primary projectiles of:
  - Protons at 50 MeV
  - Ni at 550 MeV/u
  - Au at 750 MeV/u
  - U at 330 MeV/u and 300 MeV/u
  - C at 660 MeV/u
  - Xe at 660 MeV/u
  - Fragments

RESEARCH & DEVELOPMENT PHASE





Courtesy of A. Prochazka

Efficiency Plots simulations for the GEM-TPC equipped with Delayed lines and with GEMEX readout for the case of P10 and a faster gas. The twin GEM-TPC using a 1.6 μs time window and a 21 ns check sum can reach 1.75 MHz

RESEARCH & DEVELOPMENT PHASE

Educated guess:

From Physics; the run with the largest Dynamic range requires:

The Sensitivty from: Ni: 56 fC up to U: 614 fC (in $ArCH_4$, Gain=1 and 3 cm thick gas)

U → 614 fC → 122 fC/strip [cluster:10 strips] (20%) → 153 fC (25%)

Ni → 56 fC → 11.2 fC/strip [cluster:10 strips] (20%) → 14.3 fC (25%)

In order to have some gain to steer the space chage/avalanche

A Gain of the order of = 10 is desired, which arrives to 1.5 pC/strip

RESEARCH & DEVELOPMENT PHASE

The Super-FRS GEM-TPC prototype development

TECHNICAL REPORT

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June 1, 2015

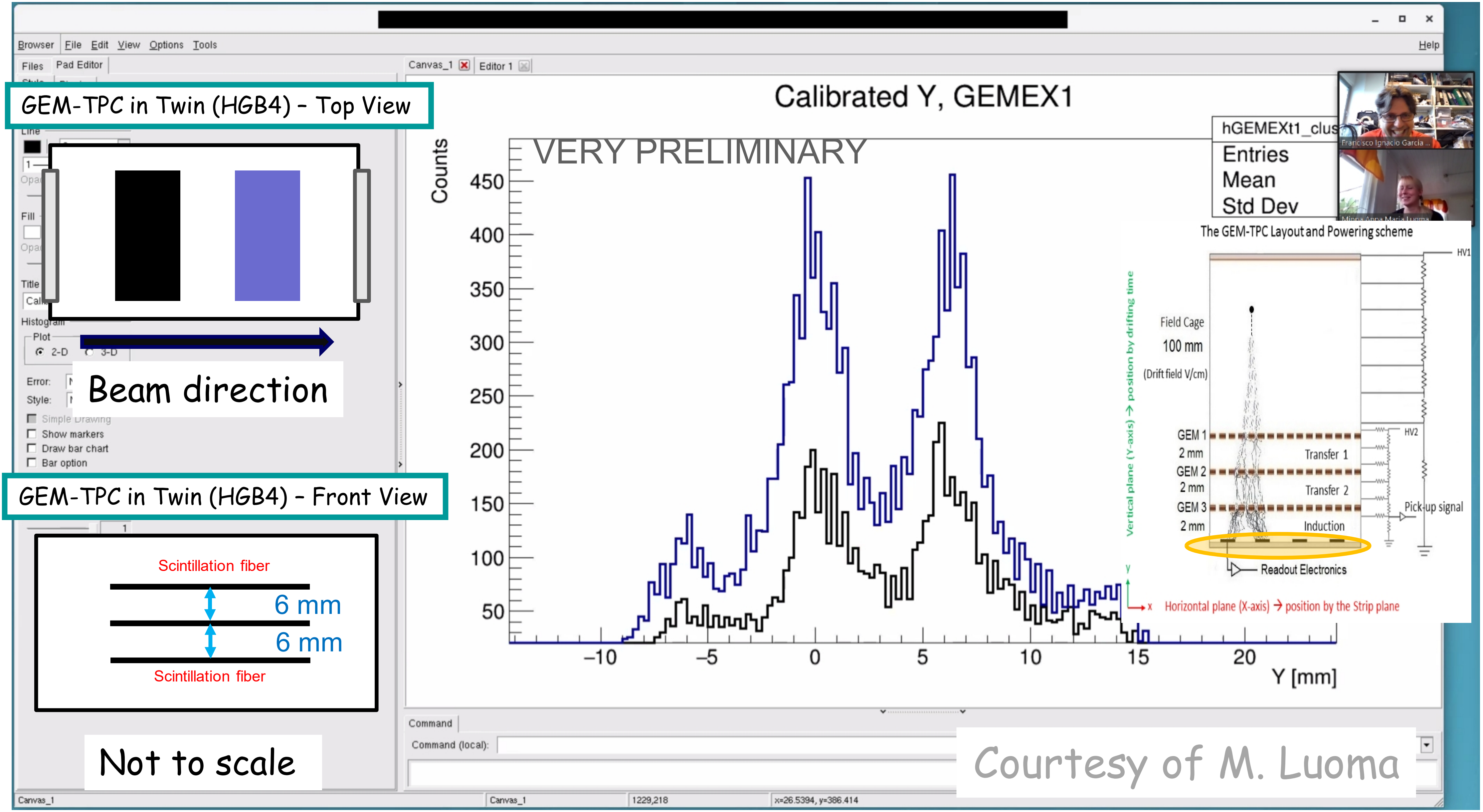
Contents

CONSOLIDATION of the FINAL PROTOTYPE

However, there are questions to be answered:

- Is the drift field uniform inside the two field cages which are in opposite directions (twin configuration)?
- Is the P10 - $ArCH_4$ (90/10%) gas mixture a solution for Super-FRS?
- Can we integrate the VMM3a/SRS into MBS?

CONSOLIDATION of the FINAL PROTOTYPE



CONSOLIDATION of the FINAL PROTOTYPE

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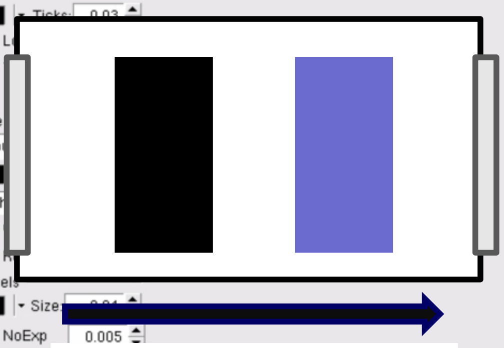
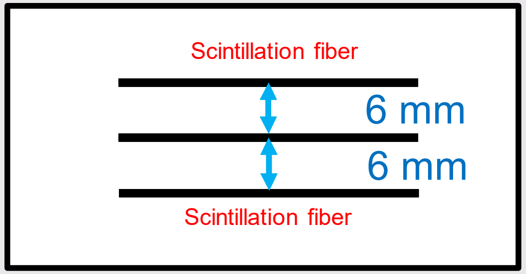
GEM-TPC in Twin (HGB4) – Top View

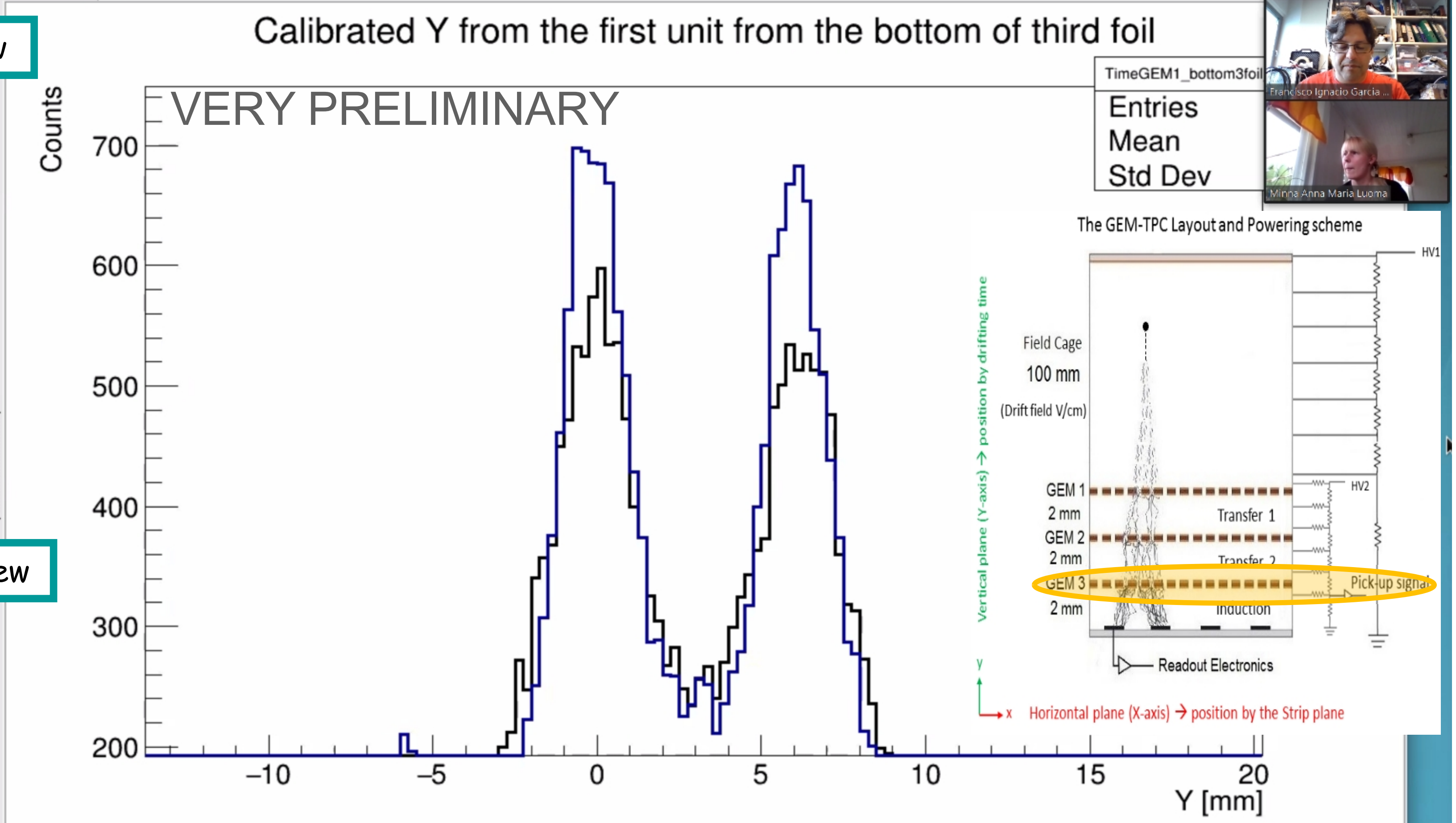


Beam direction

GEM-TPC in Twin (HGB4) – Front View



Not to scale



Courtesy of M. Luoma

CONSOLIDATION of the FINAL PROTOTYPE

- 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

CONSOLIDATION of the FINAL PROTOTYPE

Rate-capability of the VMM3a Front End in the RD51 Scalable Readout System

D. Pfeiffer[a,b,c,*], L. Scharenberg[b,d,*], P. Schwäbig[d,*], S. Alcock[a], F. Brunbauer[b], M. J. Christensen[e], K. Desch[d], K. Flöthner[b,f], F. Garcia[g], R. Hall-Wilton[a,c], M. Hracek[b,h], G. Iakovidis[i], D. Janssens[b,j], J. Kaminski[d], M. Lupberger[d,f], H. Muller[b,d], E. Oliveri[b], L. Ropelewski[b], A. Rusu[k], J. Samarati[a,b], M. van Stenis[b], A. Utrobicic[b], R. Veenhof[b,l]

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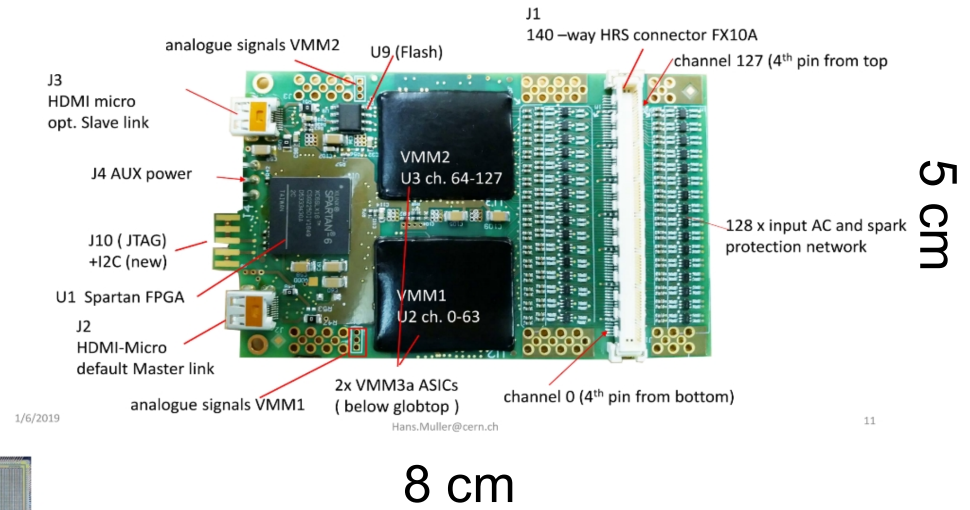
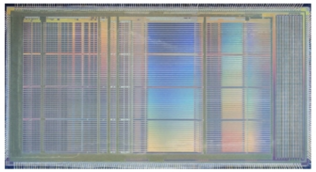
VMM hybrid (V4.0 2020)



VMM3a Specifications

- 64 channels
- Developed by BNL for ATLAS New Small Wheel Upgrade
- **High rate capability** → about 4 MHz/channel
- **Self triggered, continuous read-out**
- Integrated zero suppression
- 10-bit **charge information**
- 12+8-bit **time information** → O(ns) time resolution
- **Neighbouring logic**
- ...

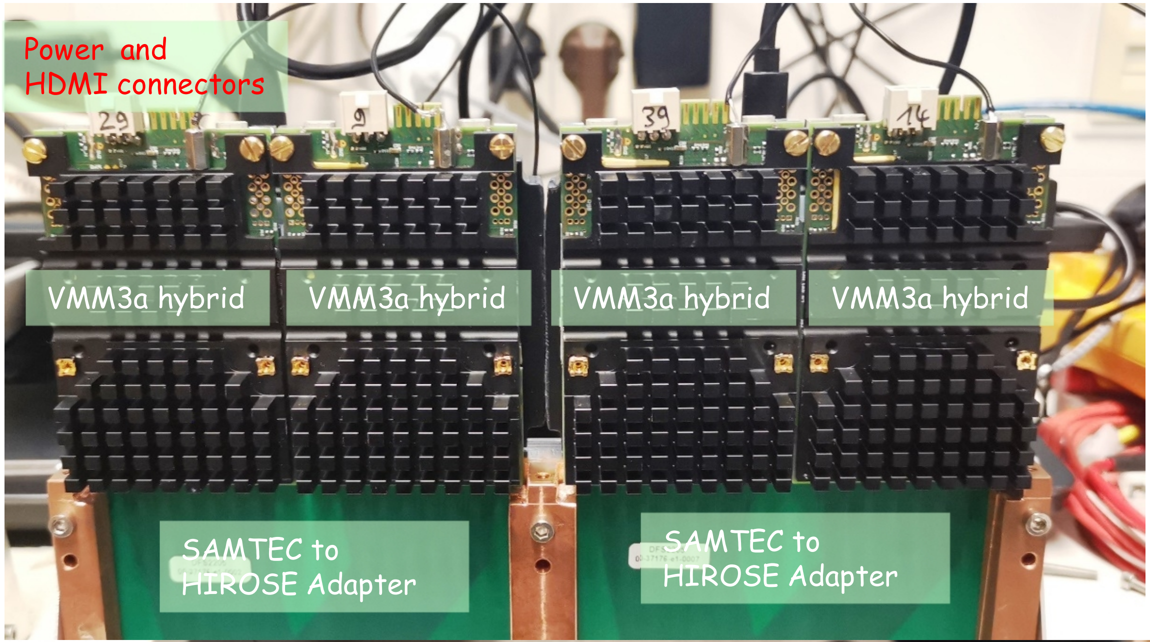


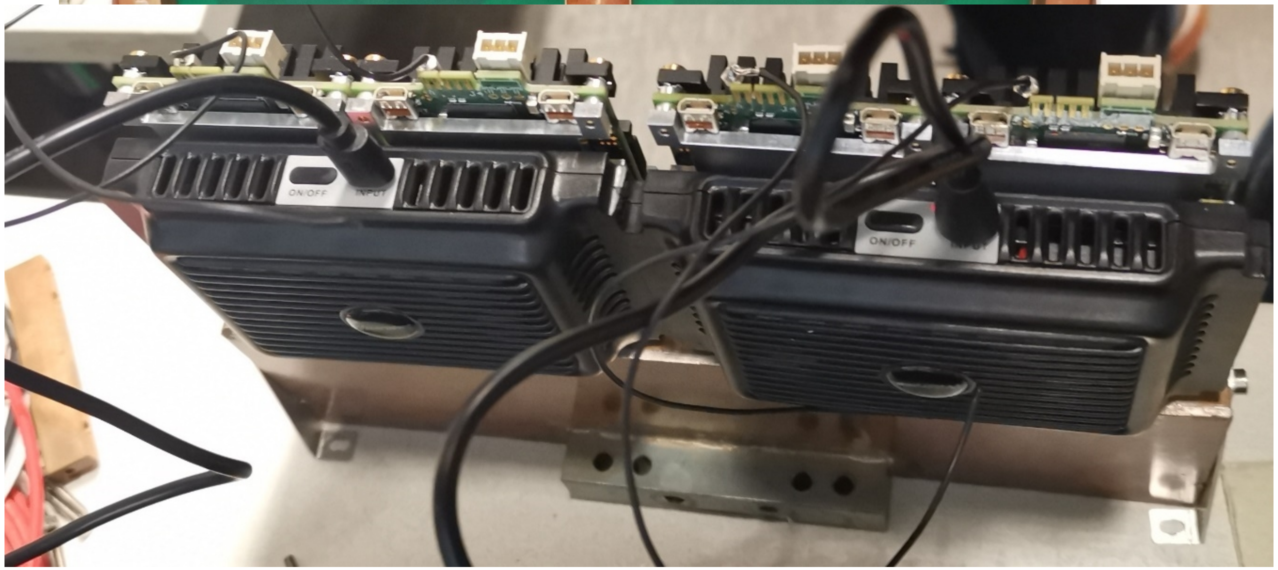
https://indico.cern.ch/event/757322/contributions/3394528/attachments/1838914/3014049/2019_05_06_Iakovidis_VMM.pdf

28 Feb 2020 L. Scharenberg @ INSTR20

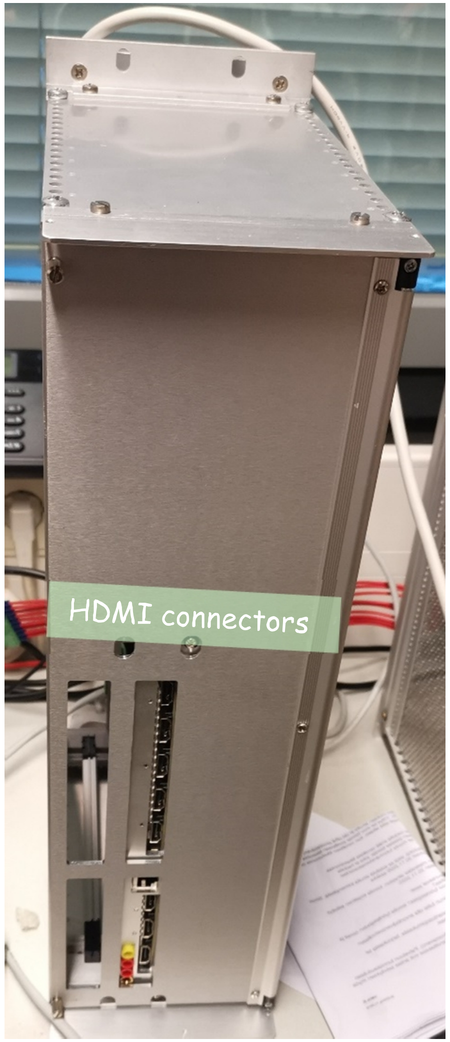
Cortesy of: H. Müller, L. Scharenberg, and D. Pfeiffer et al.

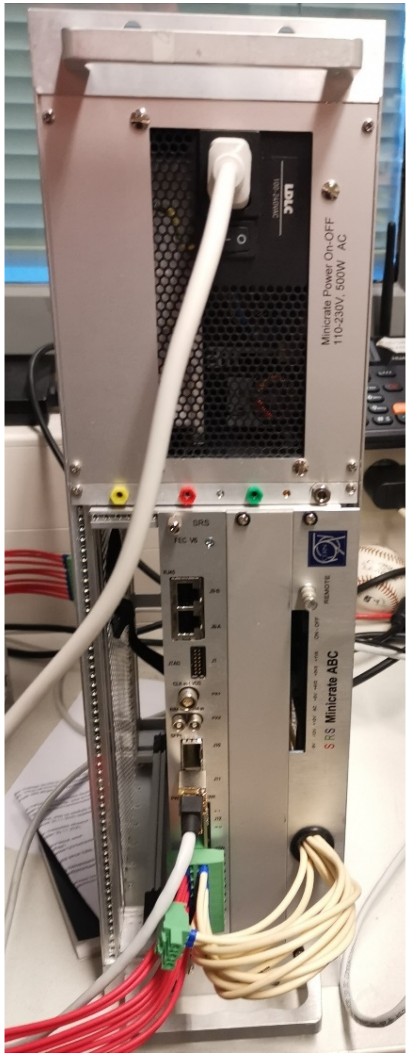
CONSOLIDATION of the FINAL PROTOTYPE





Create + SRS-FEC + DVM card





CONCLUSIONS

- The concept of a GEM based TPC in Twin configuration, at the Super-FRS for particle tracking has reach its final stage
- The TDR shows that the physics program of the Super-FRS in terms of tracking can be well covered by the detector developed during this R&D phase
- In publications have been reported results of the spatial resolution lower than 1 mm (125 μm - 700 μm) and tracking efficiency of close to 100% has been achieved for all projectiles tested for moderate rates
- Several groups at GSI started to work in the integration of the VMM3a/SRS to the existing local DAQs, which open an opportunity for synergies in our Finnish in-kind contribution

HELSINKI INSTITUTE OF PHYSICS

JYVÄSKYLÄN YLIOPISTO

Thank you for your Attention

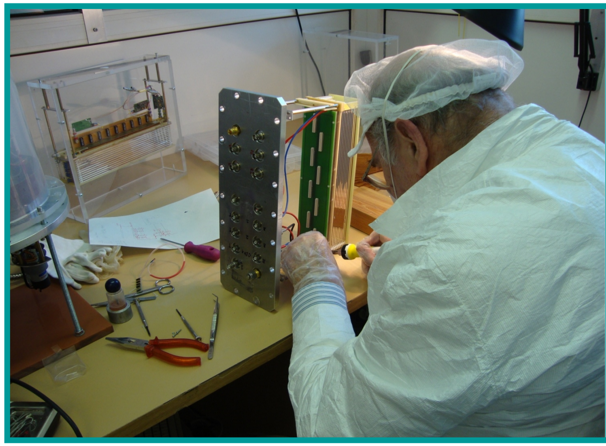
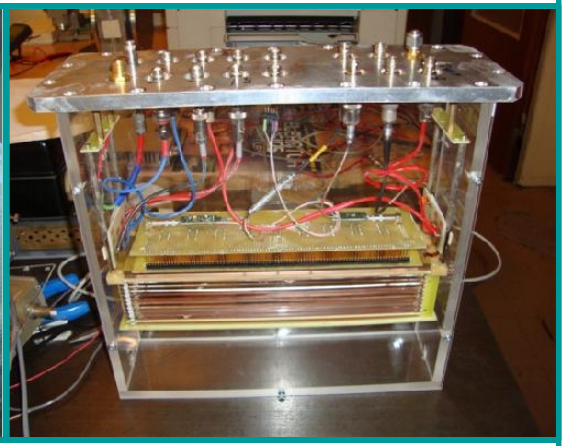
FAIR

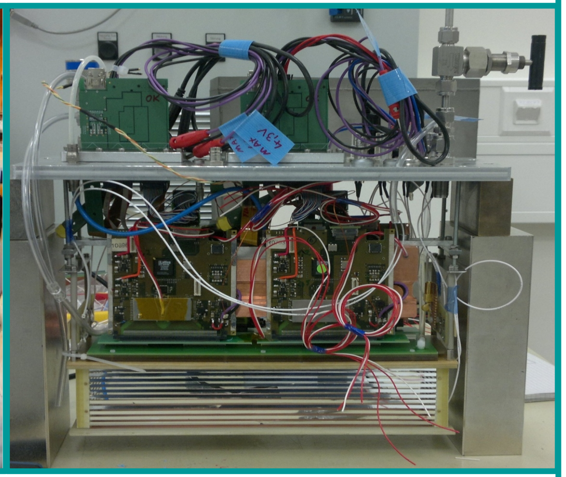
GSI

JOURNEY ACROSS THE GEM-TPC DEVELOPMENT

TO SUMMARIZE:

- **First meeting at Eurorib'08 with H. Simon**
- Meeting at HIP and GSI in Oct. 08 and Feb. 09
- Creation of Consortium: Comenius Univ. and Univ. of Helsinki Feb 09
- First visit to Bratislava, March. 09
- Design of GEM stack at HIP, April 09
- Production of GEM foils at CERN by R. Oliveira, Nov. 09
- Successful Tests of the First GEM stack, Dec. 09
- **Integration of the HB1, GEM-TPC, Feb. 10**
- **First Test Beam at GSI with HB1, GEM-TPC, Aug. 10**
- Meeting at HIP and NUSTAR meeting at GSI in Jan. 11 and Feb. 11
- Concept of GEM-TPC for SuperFRS presented to RD51, Apr, 11
- First discussions about twin TPC by B. Sitar, June 11
- NUSTAR meeting in Bucharest, Oct. 11
- **The twin GEM-TPC design starts by R. Janik, Jan. 12**
- NUSTAR meeting at GSI, Feb. 12
- Integration of GEMEX into HB2 and HB3, GEM-TPC, Apr. 12
- **Beam Test at GSI with HB2 and HB3, May. 12**

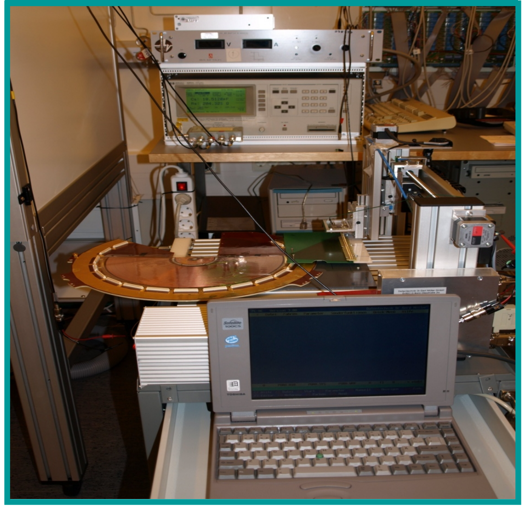



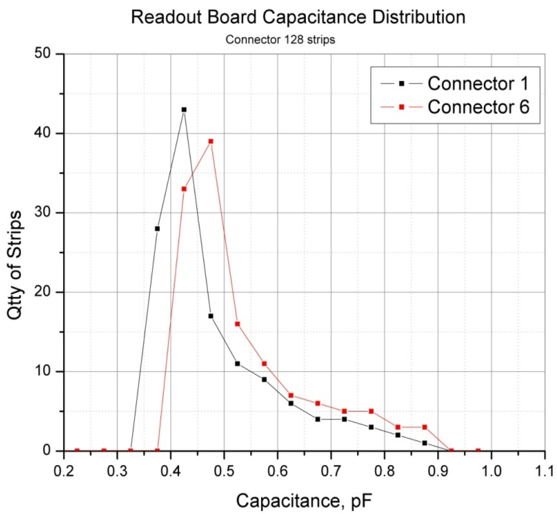


- The Spatial resolution requirements fulfilled
- The Rate capability increased, but yet no as required

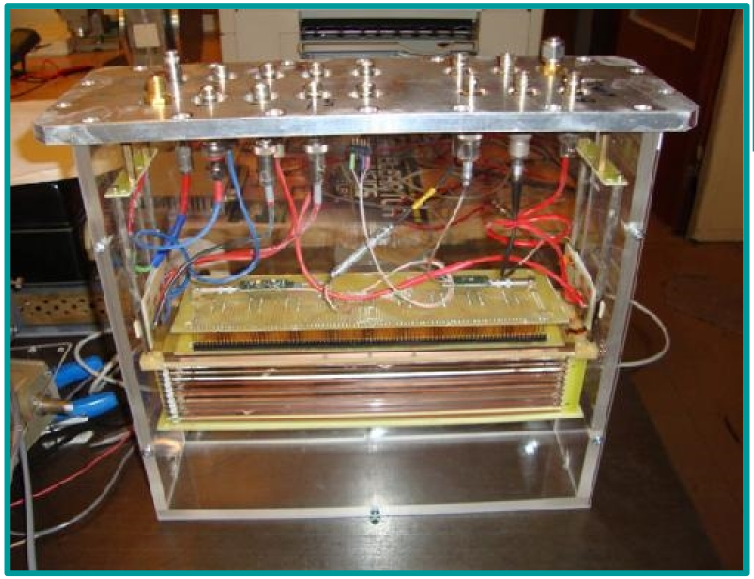
PROTOTYPE DEVELOPMENTS

Capacitance measurement setup

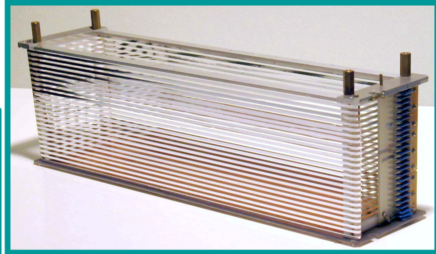




Flange of the GEM-TPC HB1, read out by delayed lines

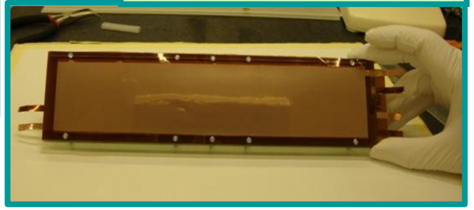


Comenius University - Bratislava

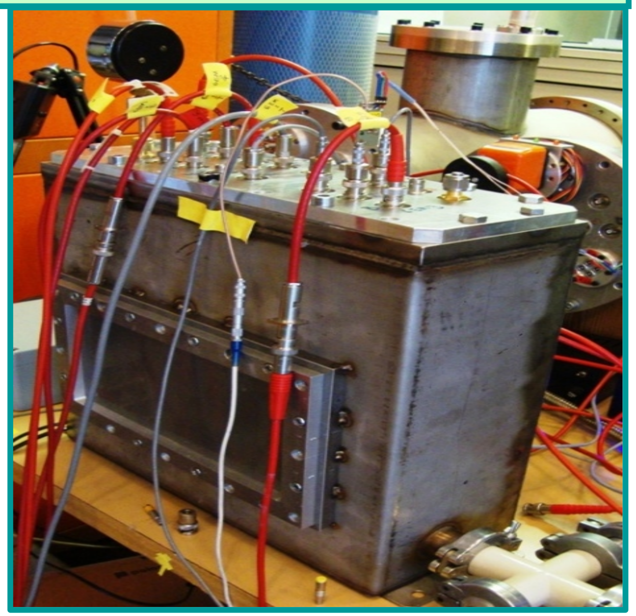


Field cage of 40 mm drift

Triple GEM stack

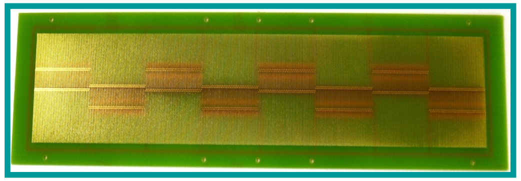


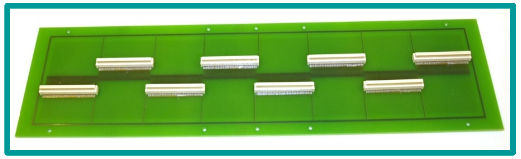
First GEM-TPC called HB1 detector (Helsinki Bratislava prototype 1)



Right: The electrodes of the board with strips of 200 μm width and 500 μm pitch

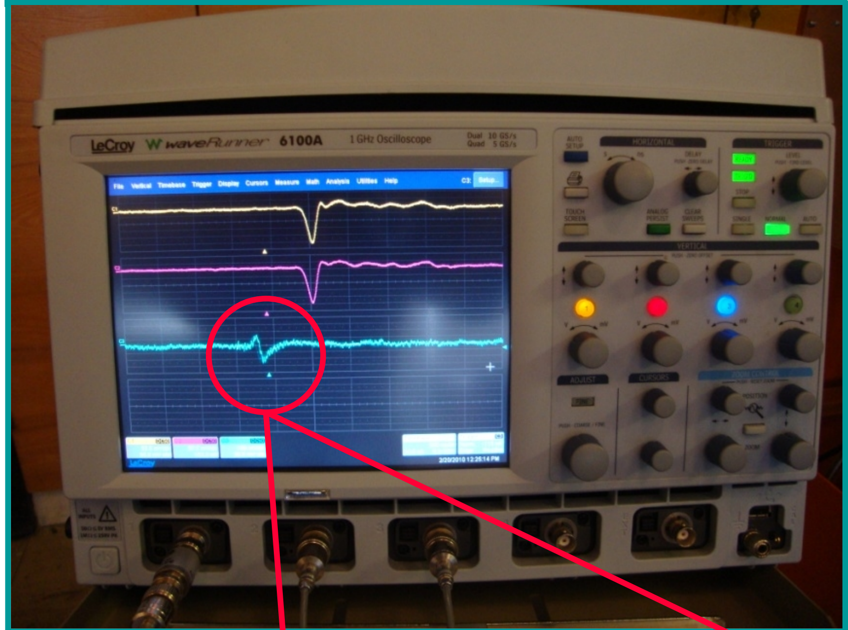
And 8 Header Panasonic connectors with 130 Pin each





JOURNEY ACROSS THE GEM-TPC DEVELOPMENT

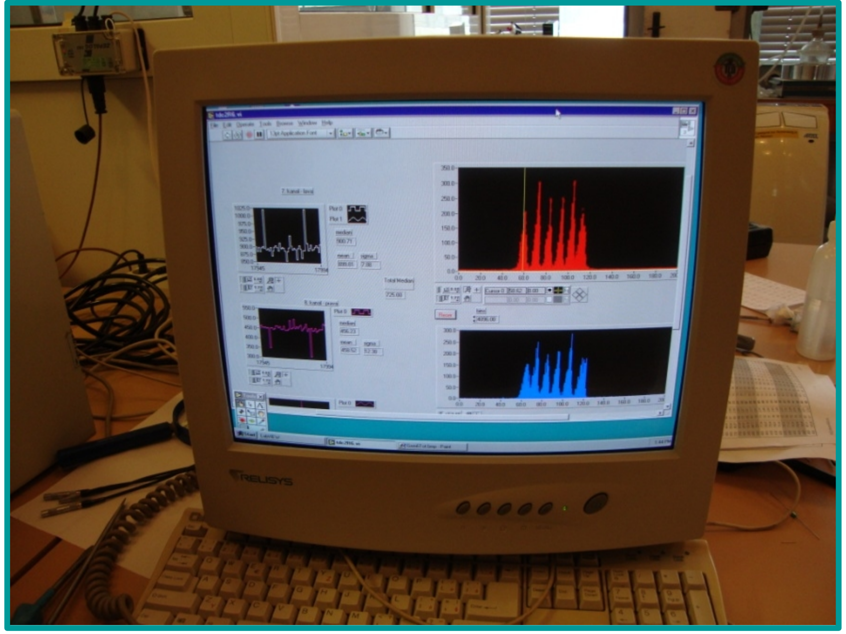
GEM-TPC test in lab at Comenius University



It can be observed:

- Signals from the delayed lines are very clean
- Same relative time between them
- Trigger signal bipolar, it can be that the 40% negative overshoot is due to e-transparency loses in the GEM 3

GEM-TPC tracking capabilities for ^{55}Fe



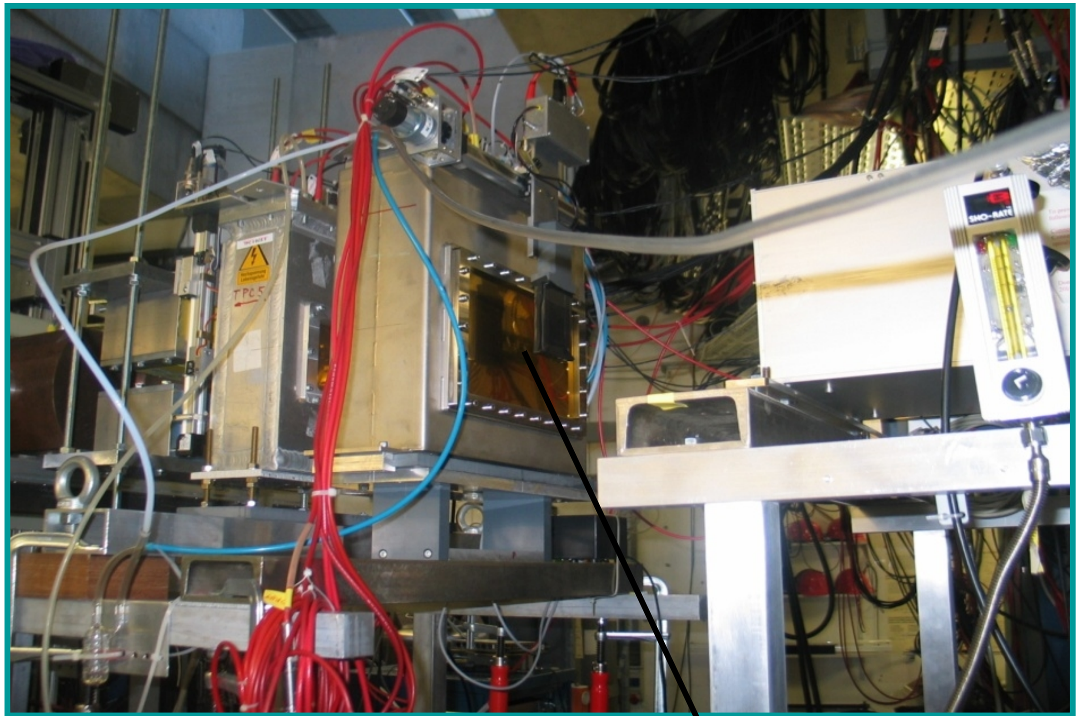
Trigger Signal before reshaping

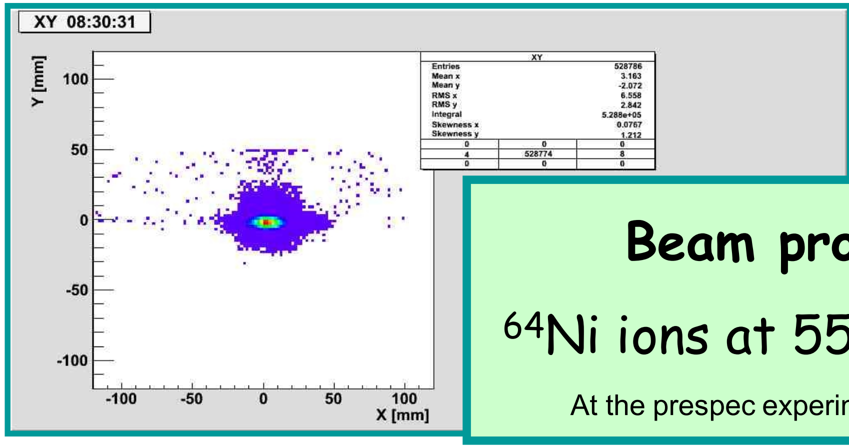
Trigger Signal with rise and decay time reshaped

In the picture above there are multiple picks from the different source positions.
The source was not very well collimated therefore a mm scale resolution on X was achieved and the trigger was taken from the bottom of the GEM3

FIRST GEM-TPC PROTOTYPE HB1 - TEST (cont.)

GEM-TPC Beam test at GSI - Darmstadt

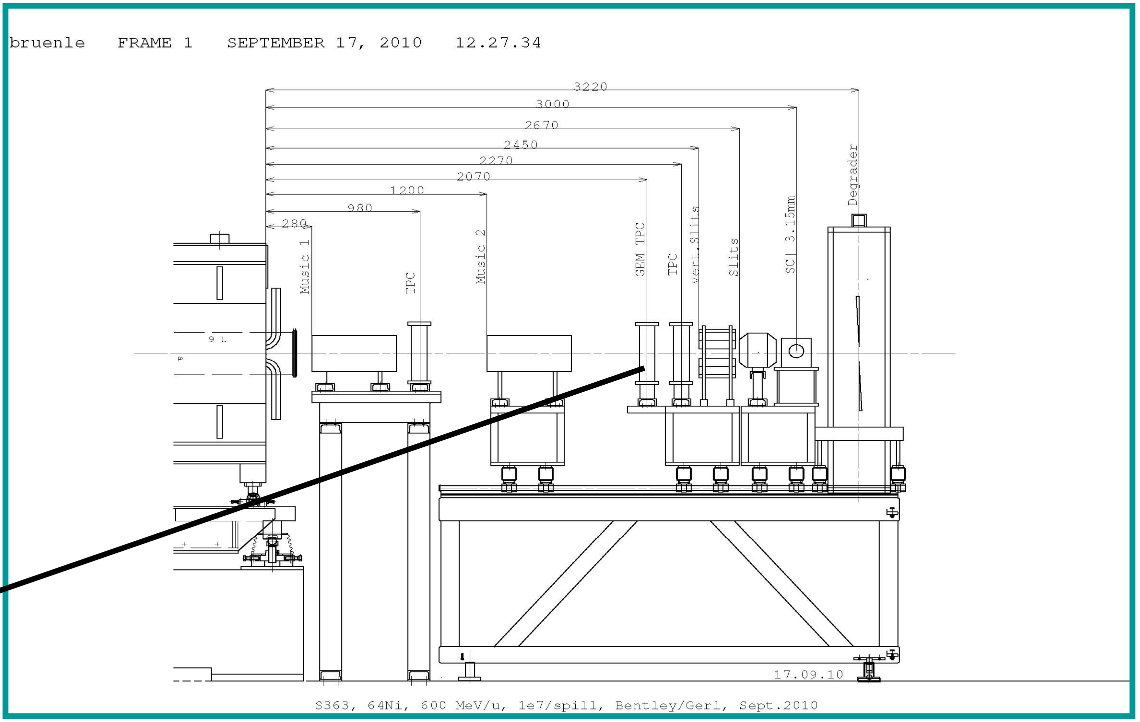


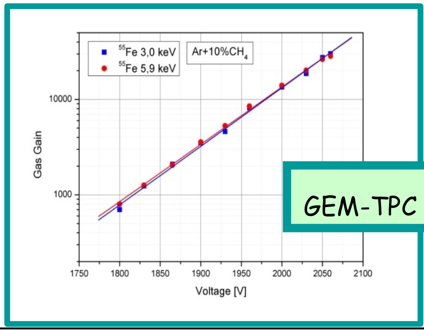


Beam profile

^{64}Ni ions at 550 MeV/u

At the prespec experiment - S363



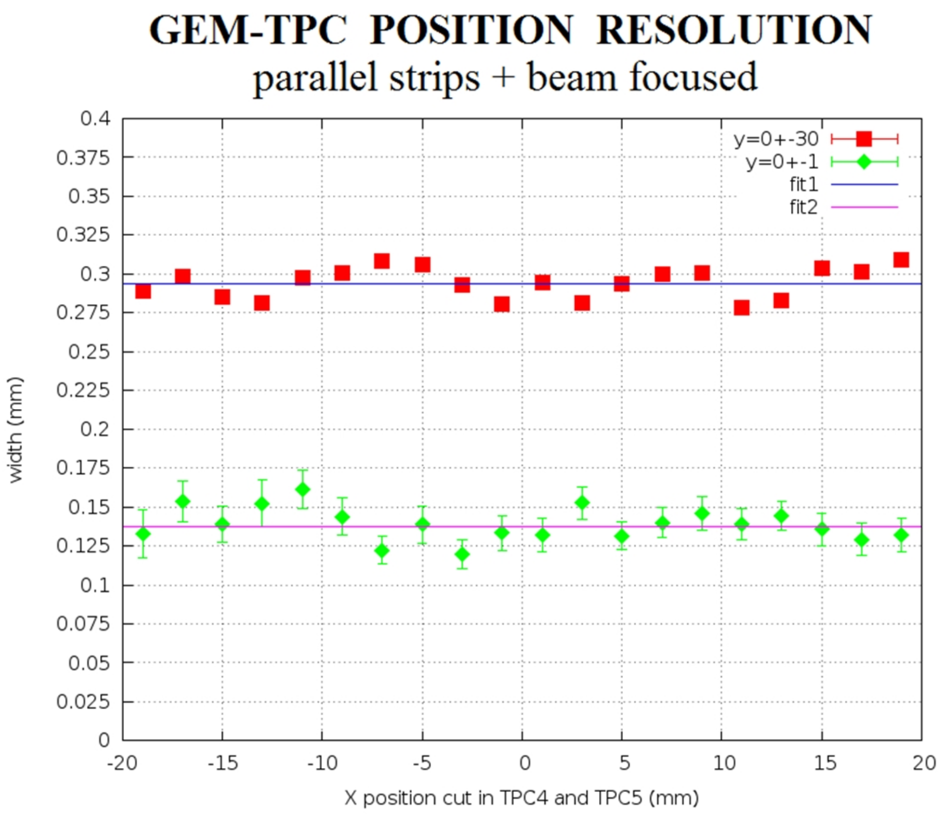


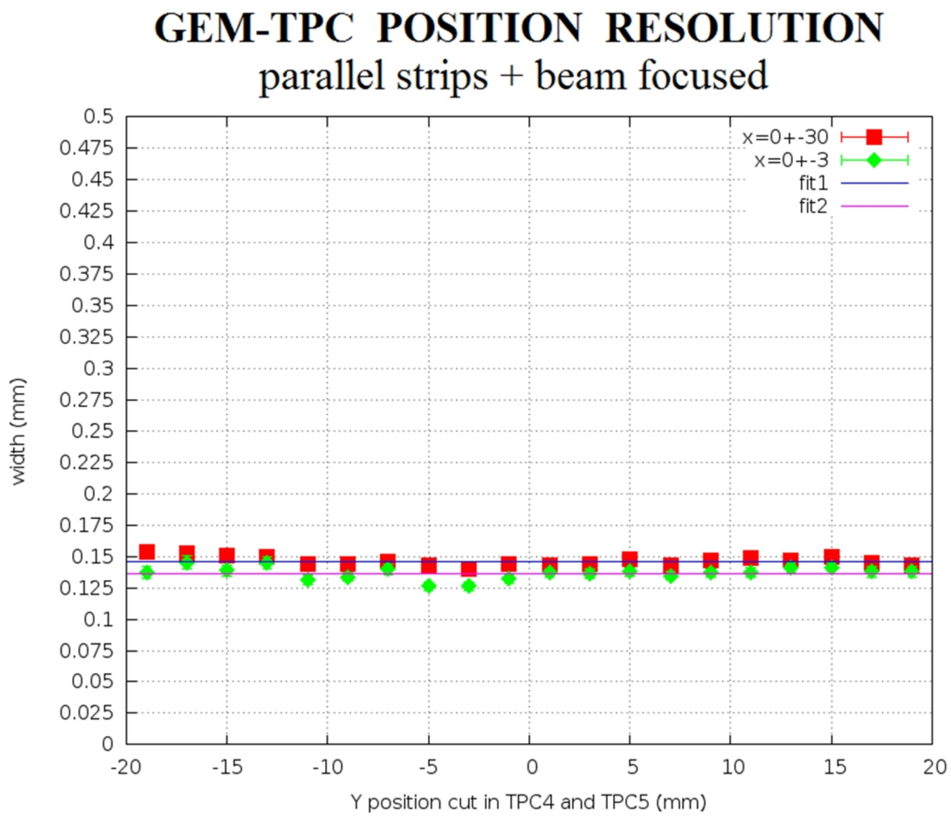
GEM-TPC Gain

GEM-TPC at S4

PROTOTYPE DEVELOPMENTS (cont.)

GEM-TPC Results for a Test Beam @GSI with ^{64}Ni ions at 550 MeV/u

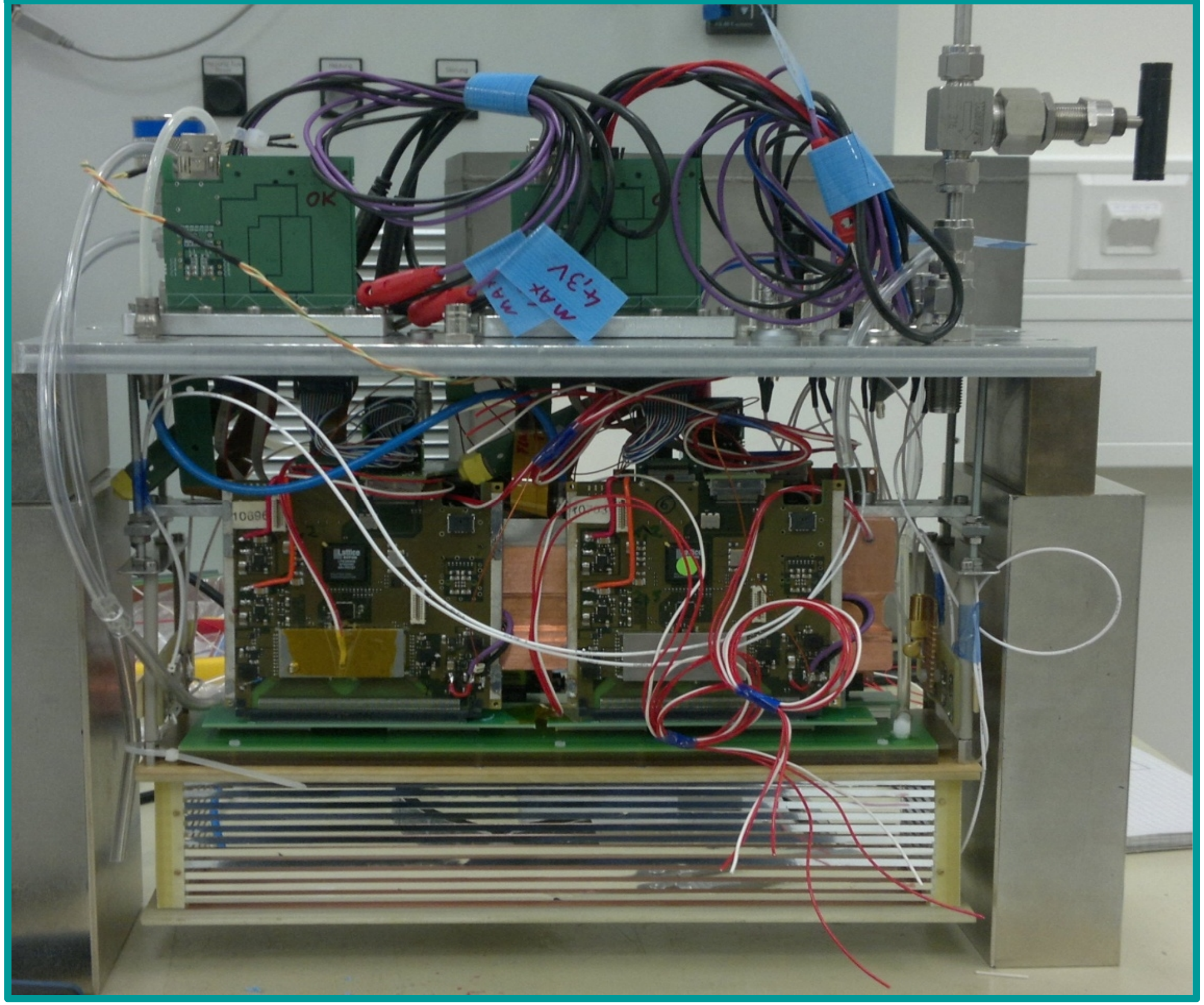




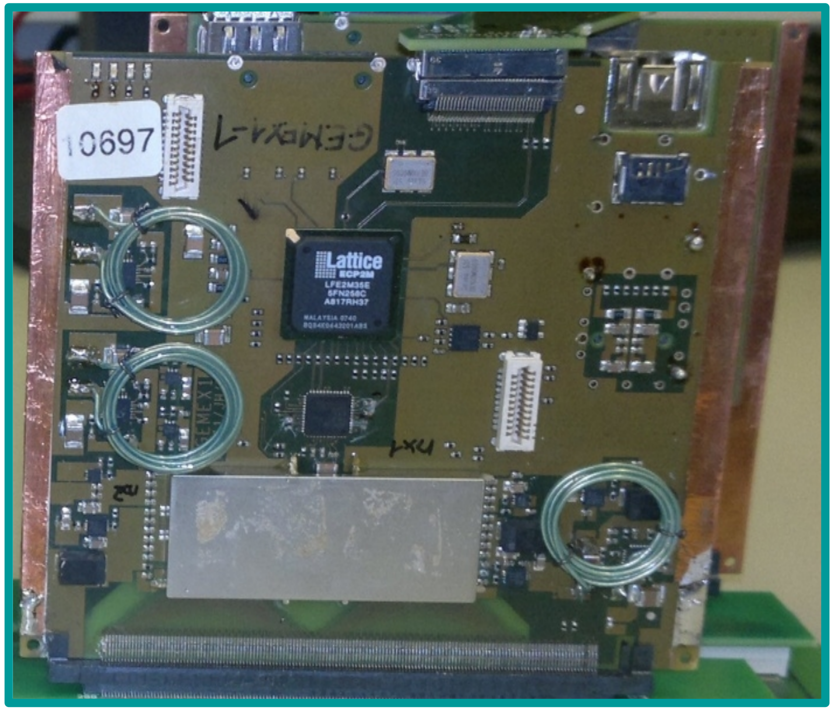
The GEM-TPC shows that the resolution in Y (Drift) reaches value around 130 μm and on X between 130 to 300μm

PROTOTYPE DEVELOPMENTS (cont.)

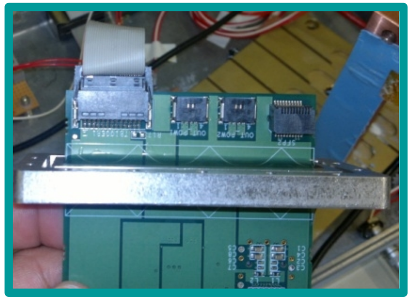
HB3 with four GEMEX cards



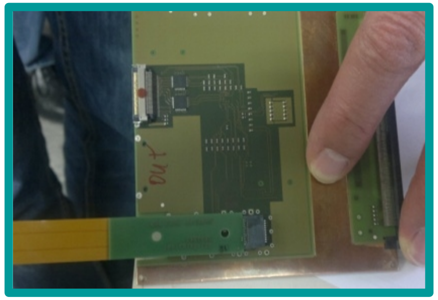
GEMEX cards provide by EE - GSI



Flange Adapter card

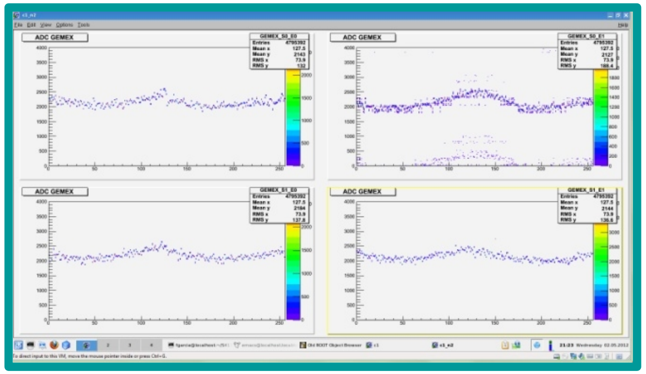


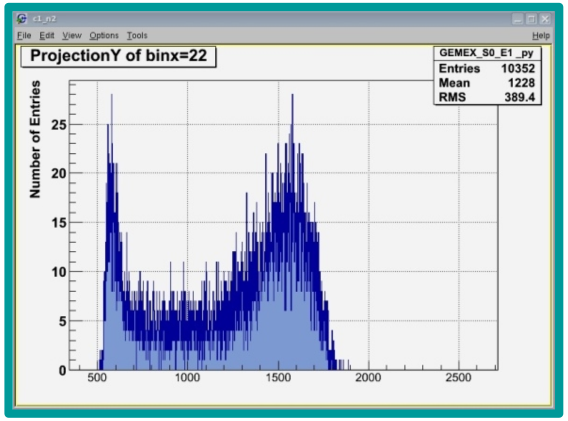
SFP to Copper inside the chamber



JOURNEY ACROSS THE GEM-TPC DEVELOPMENT

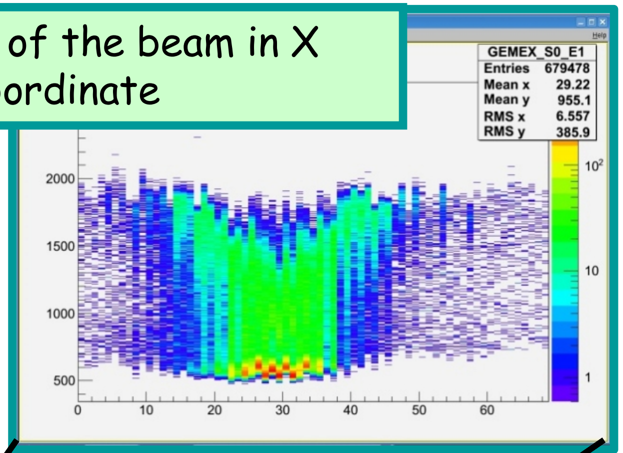
Pedestals of 4 GEMEX cards and Pulse Height distribution of one channel





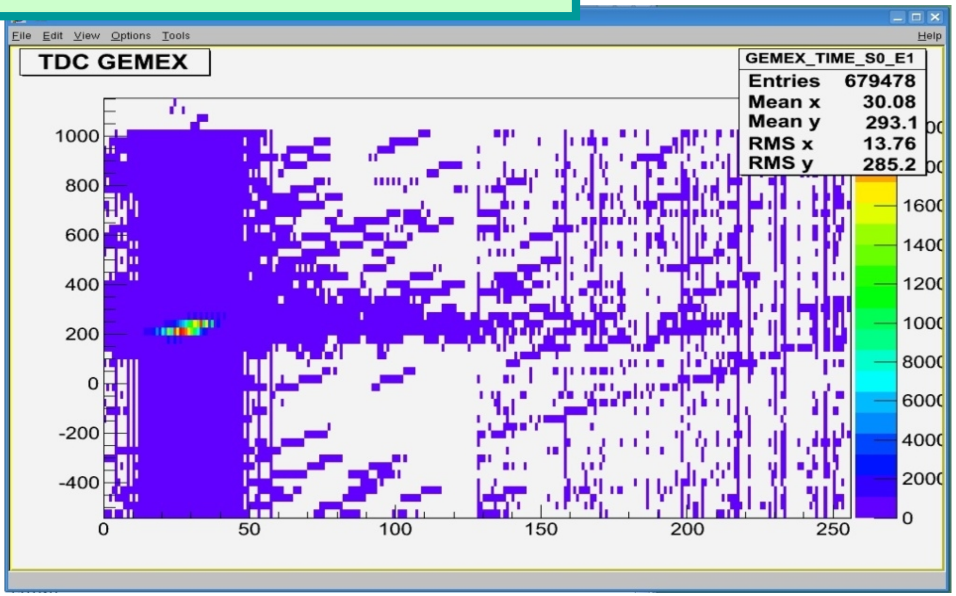
Projection of the beam in X coordinate

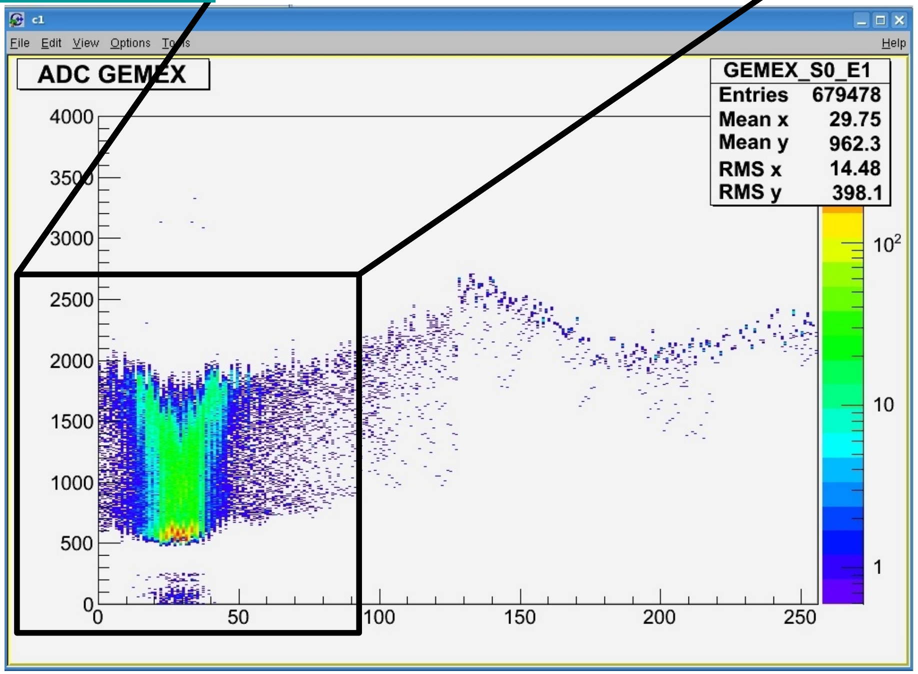
In X direction the beam size was of 7 mm. HB3 shows 15 channels at 0.5 mm per channel



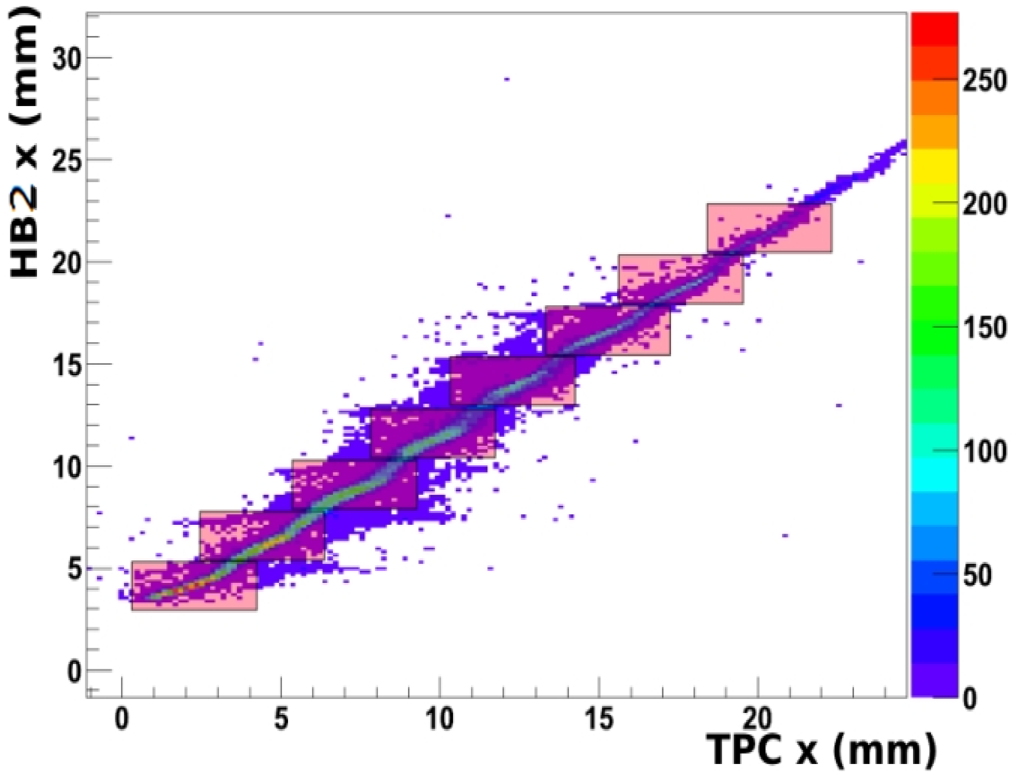
Projection of the beam in Y coordinate

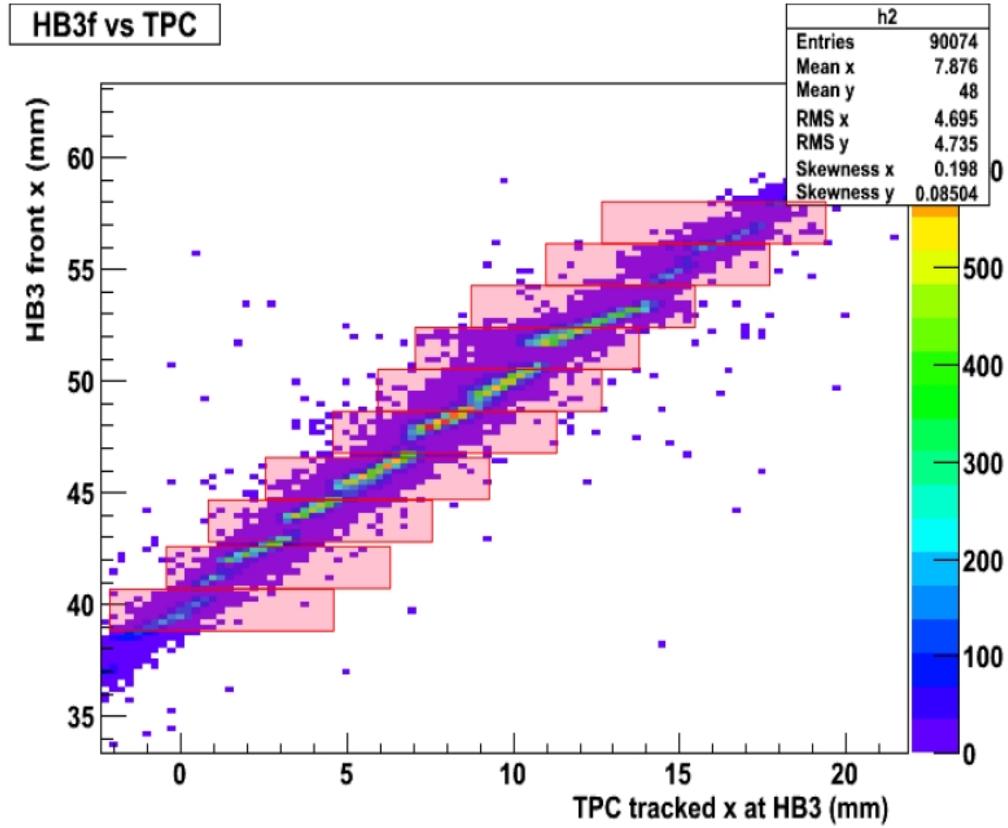
In Y direction the was at the center. HB3 shows 200 counts which is a systemic error to be corrected during data analysis





JOURNEY ACROSS THE GEM-TPC DEVELOPMENT

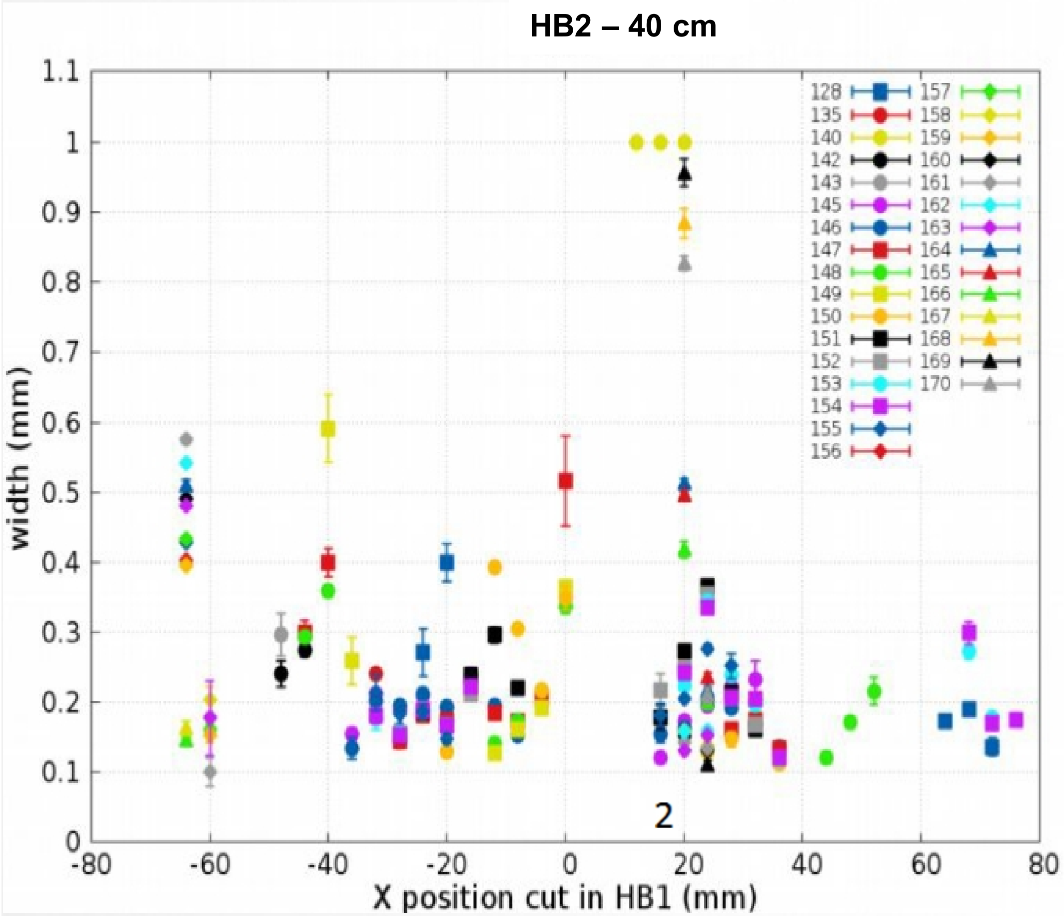


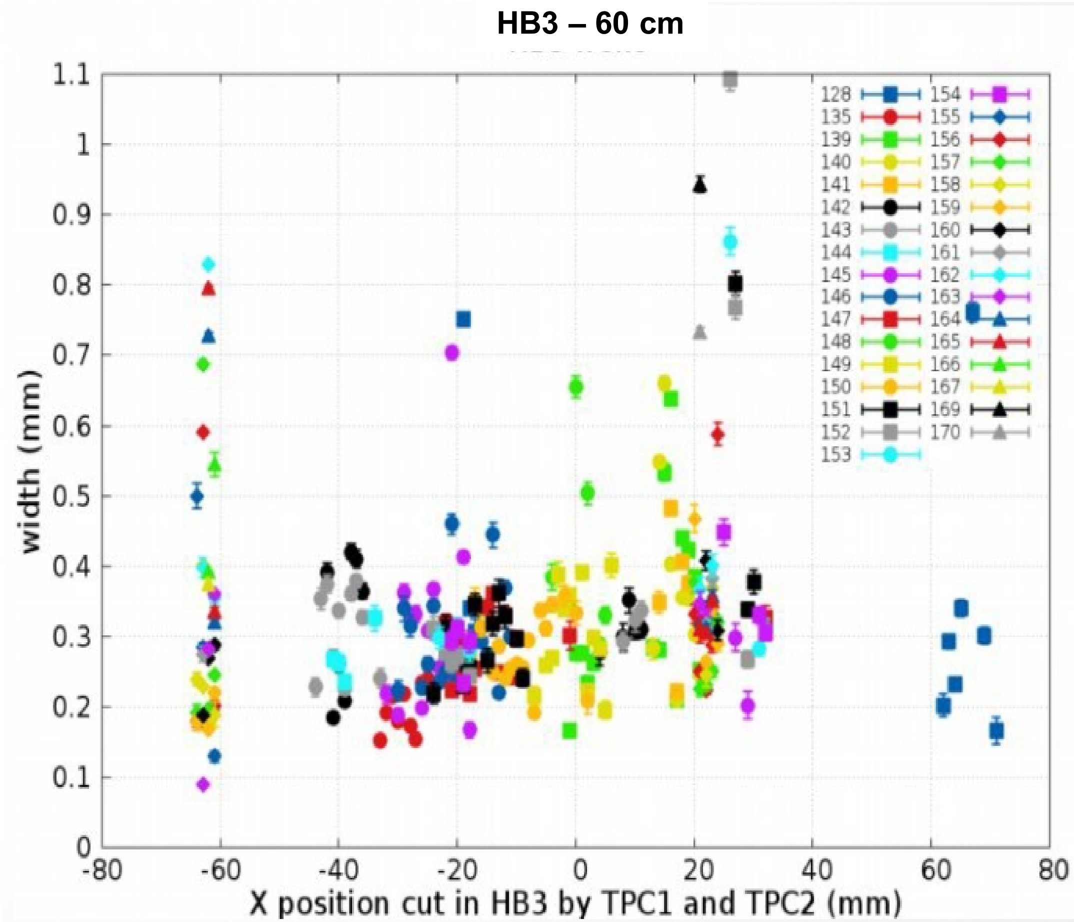


The nonlinearity for the HB2 and HB3 for the run 150. Variations are due to the fact that the baseline fluctuations were not monitored during the data taken.

PROTOTYPE DEVELOPMENTS (cont.)

HB2/HB3 @ GSI Test Beam with ^{197}Au at 770 MeV/u

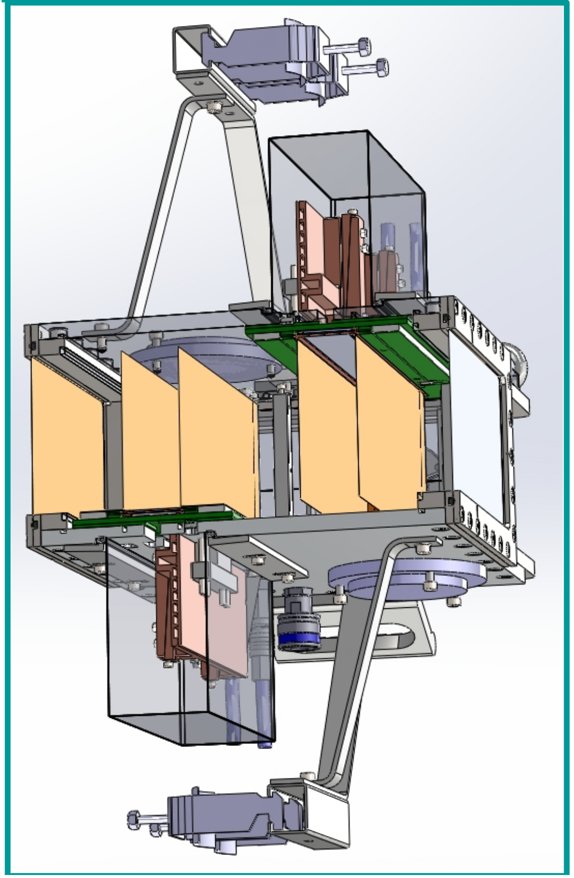


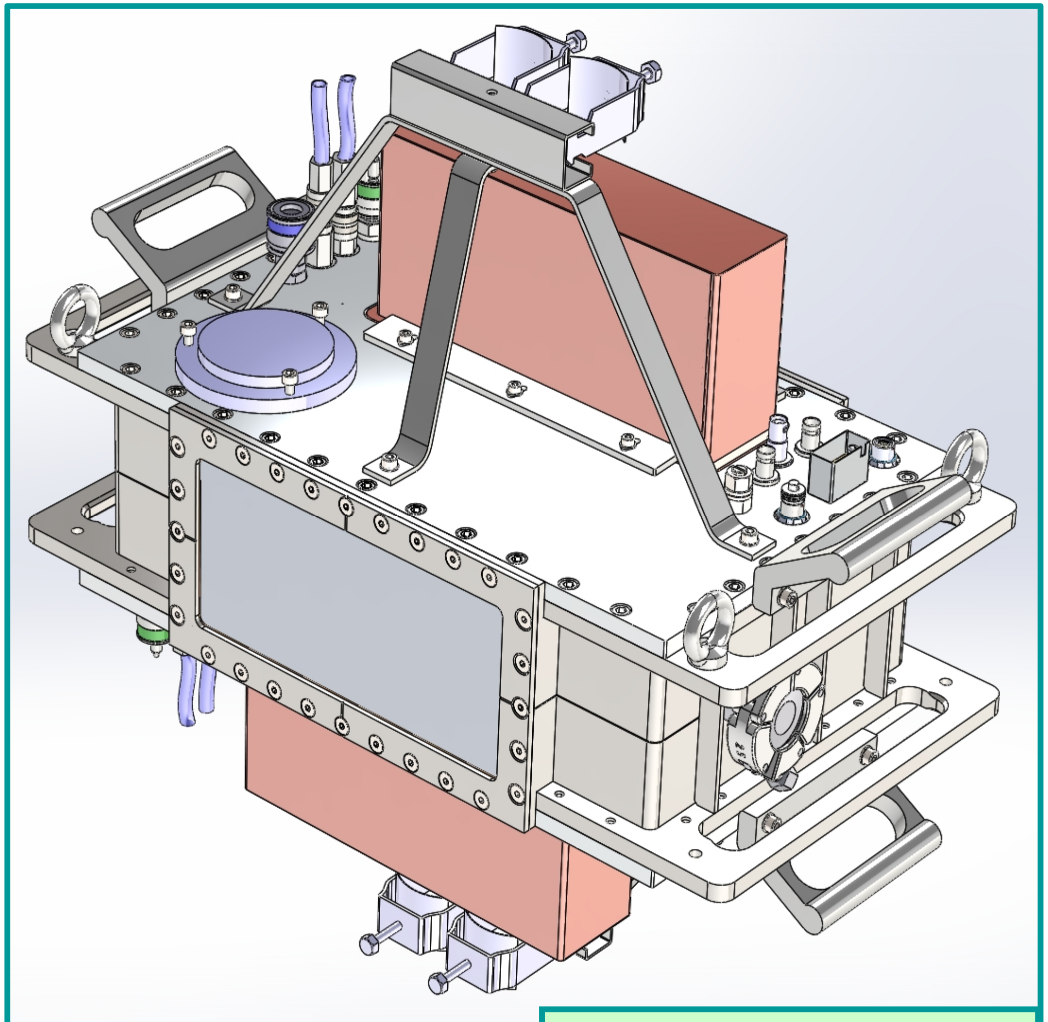


The position resolution in X coordinate for the HB2 (200 μm) and HB3 (300 μm) for most of the runs.

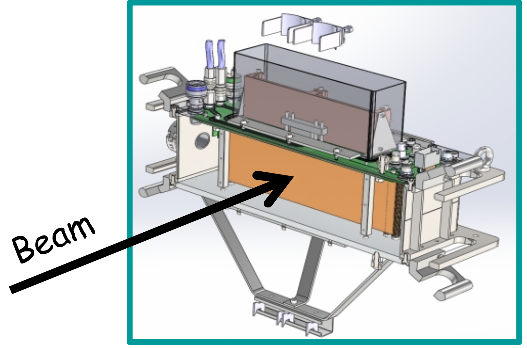
The HGB4 - Twin GEM-TPC Prototype

Lateral view

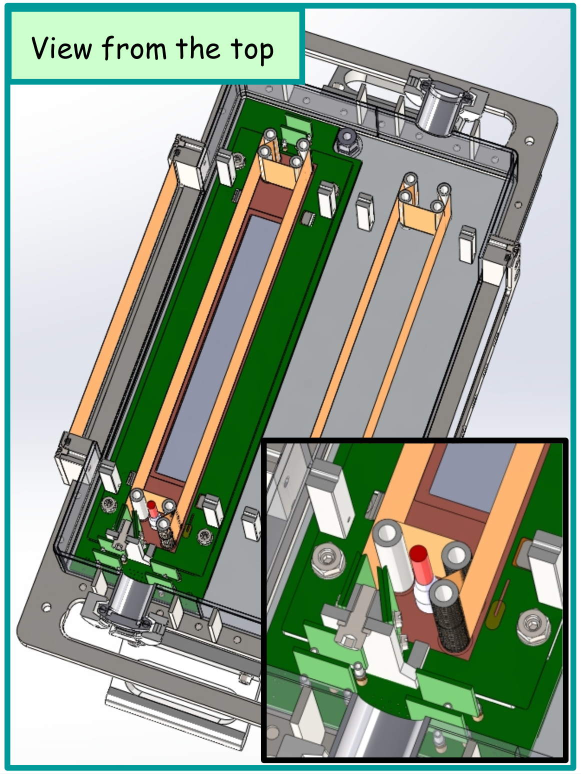




View beam downstream



View from the top



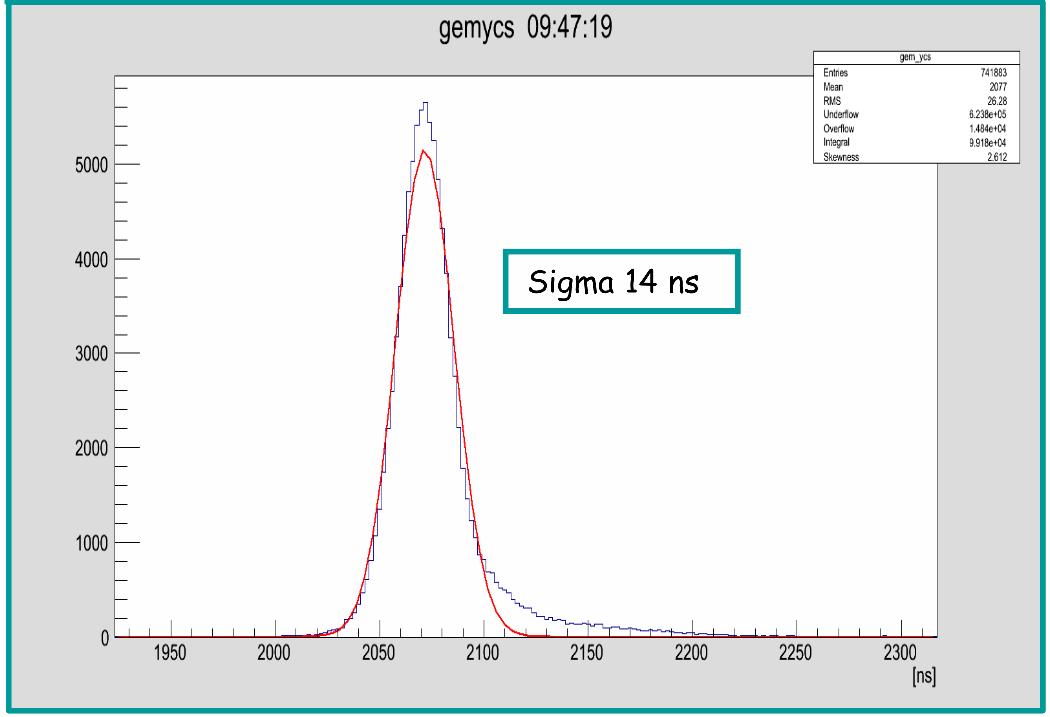
This GEM-TPC has a twin configuration, which means that two GEM-TPC are positioned back to back.

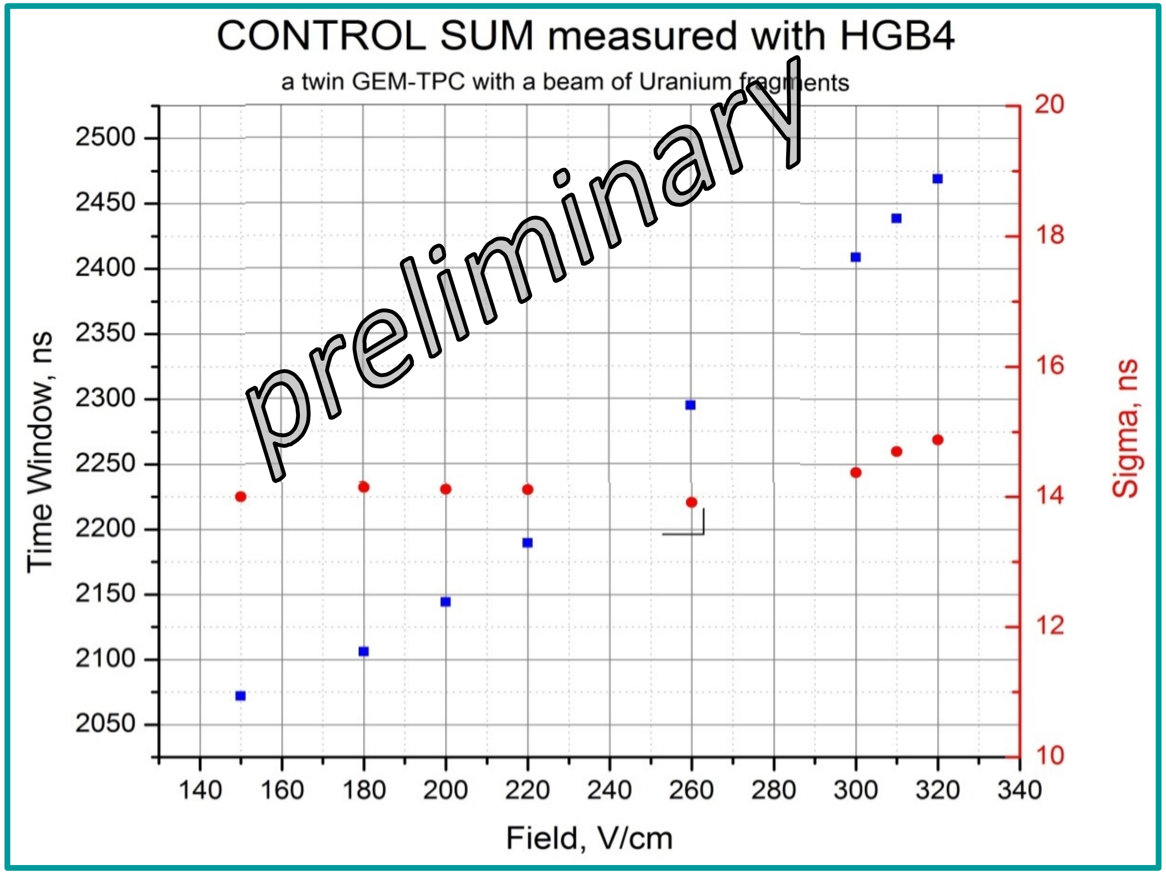
Courtesy of B. Voss

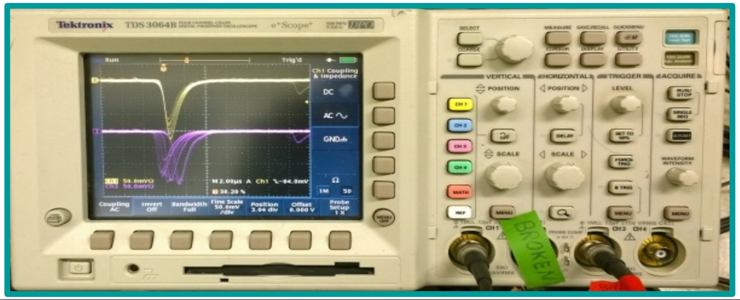
HGB4 CONTROL SUM

Projectiles: ^{238}U @ 330 MeV/u

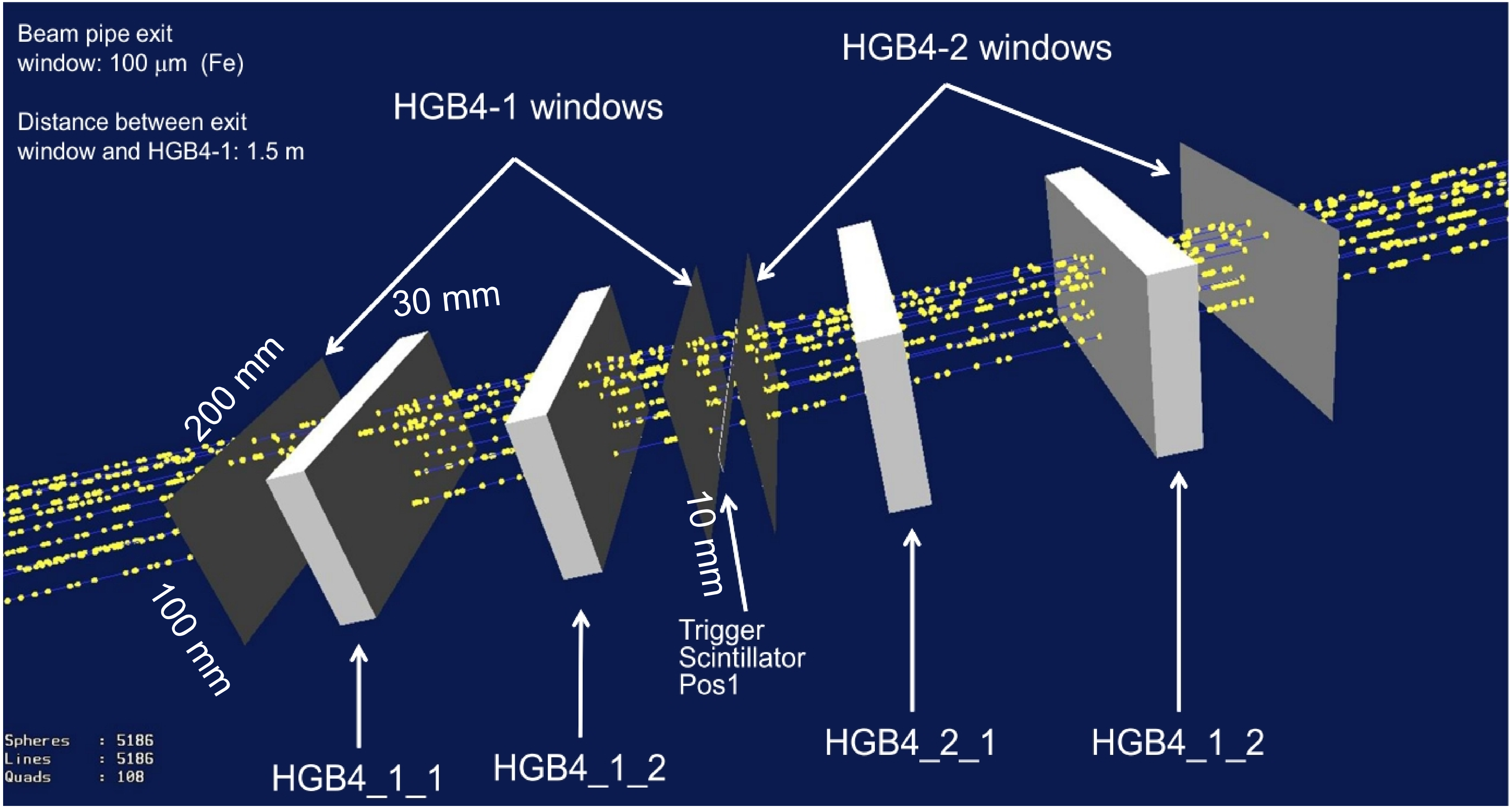
Hits distribution for a field of 150 V/cm



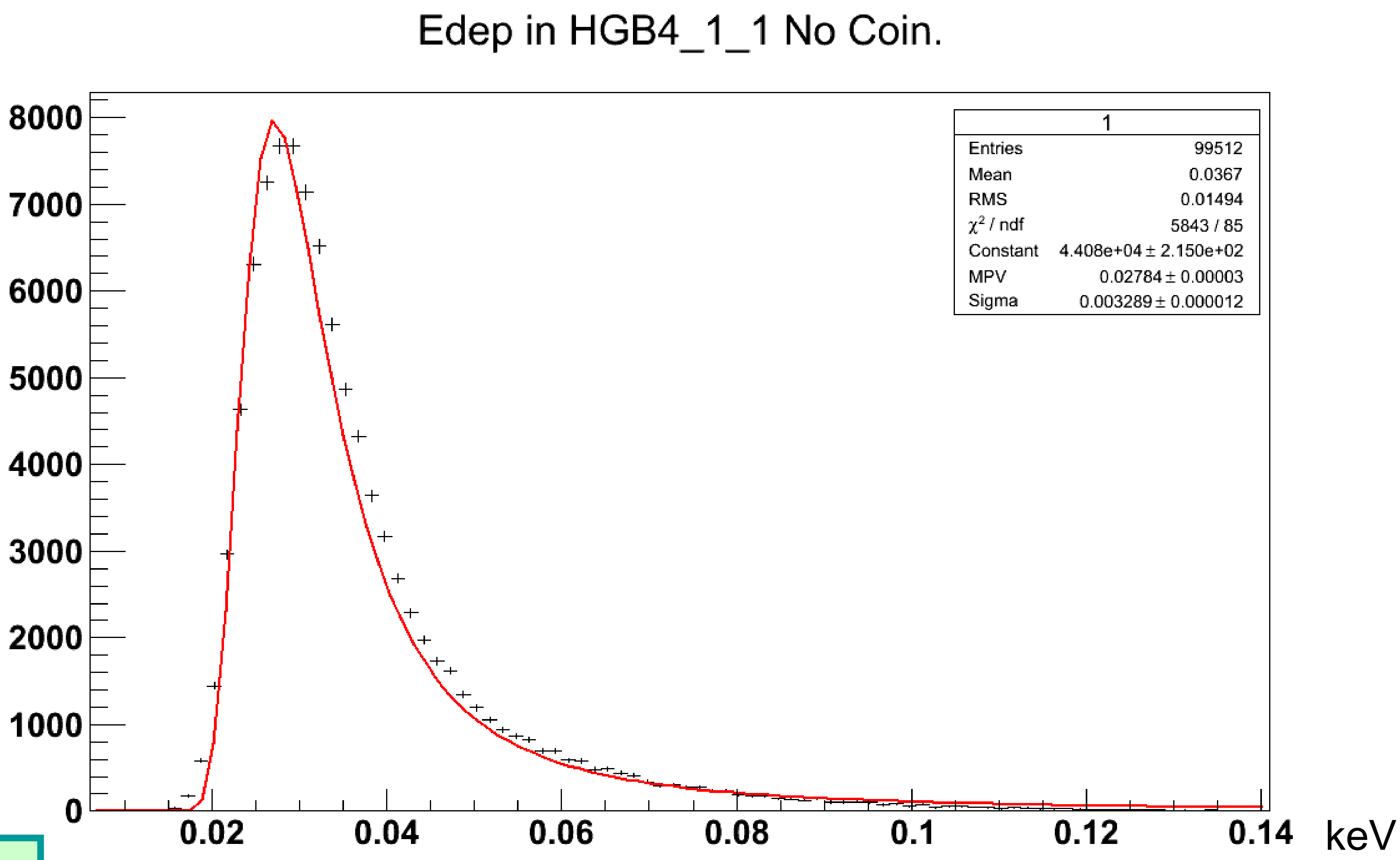




TEST BEAM - GEANT4 SIMULATIONS

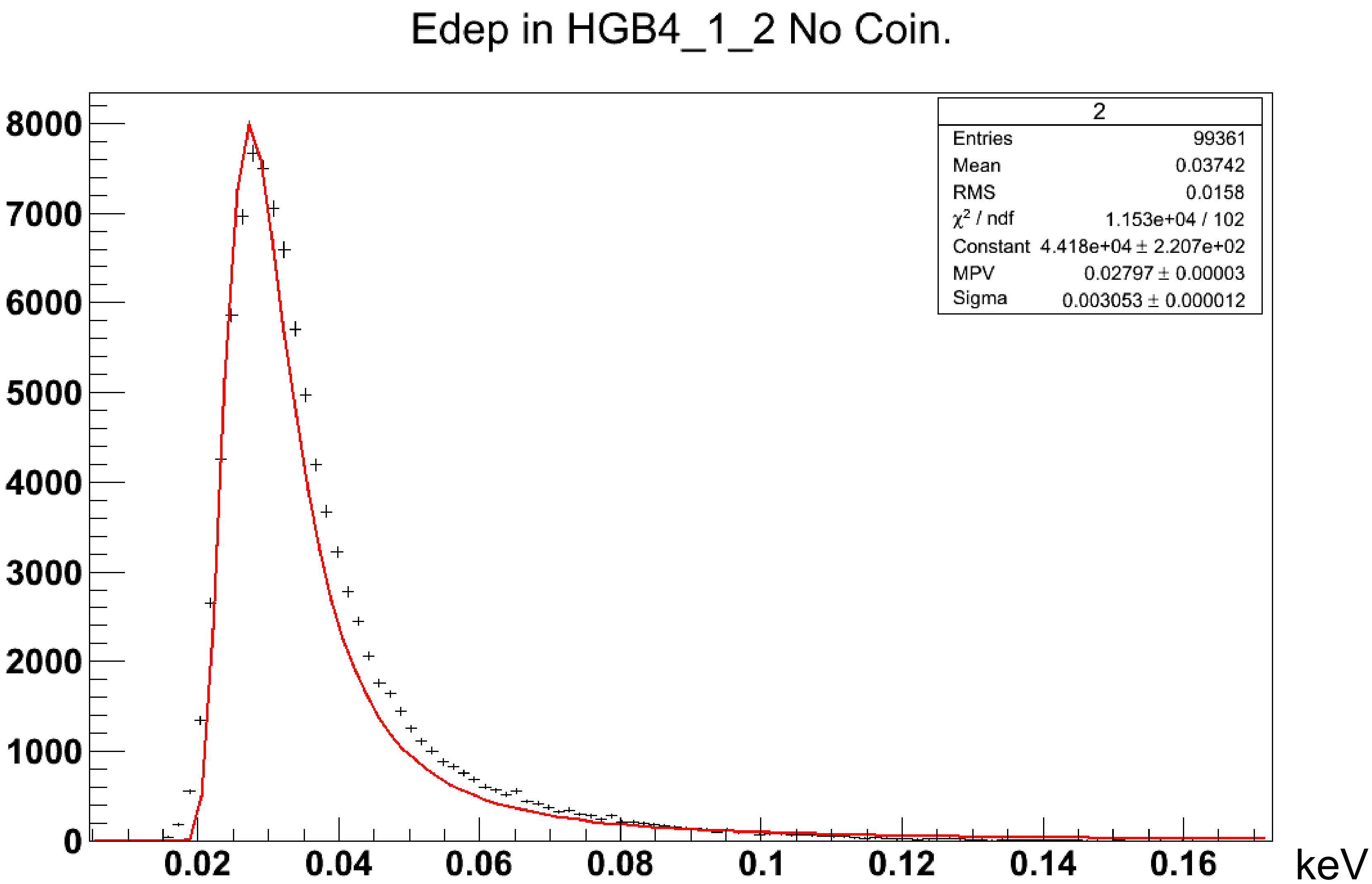


TEST BEAM - GEANT4 SIMULATIONS (cont.)



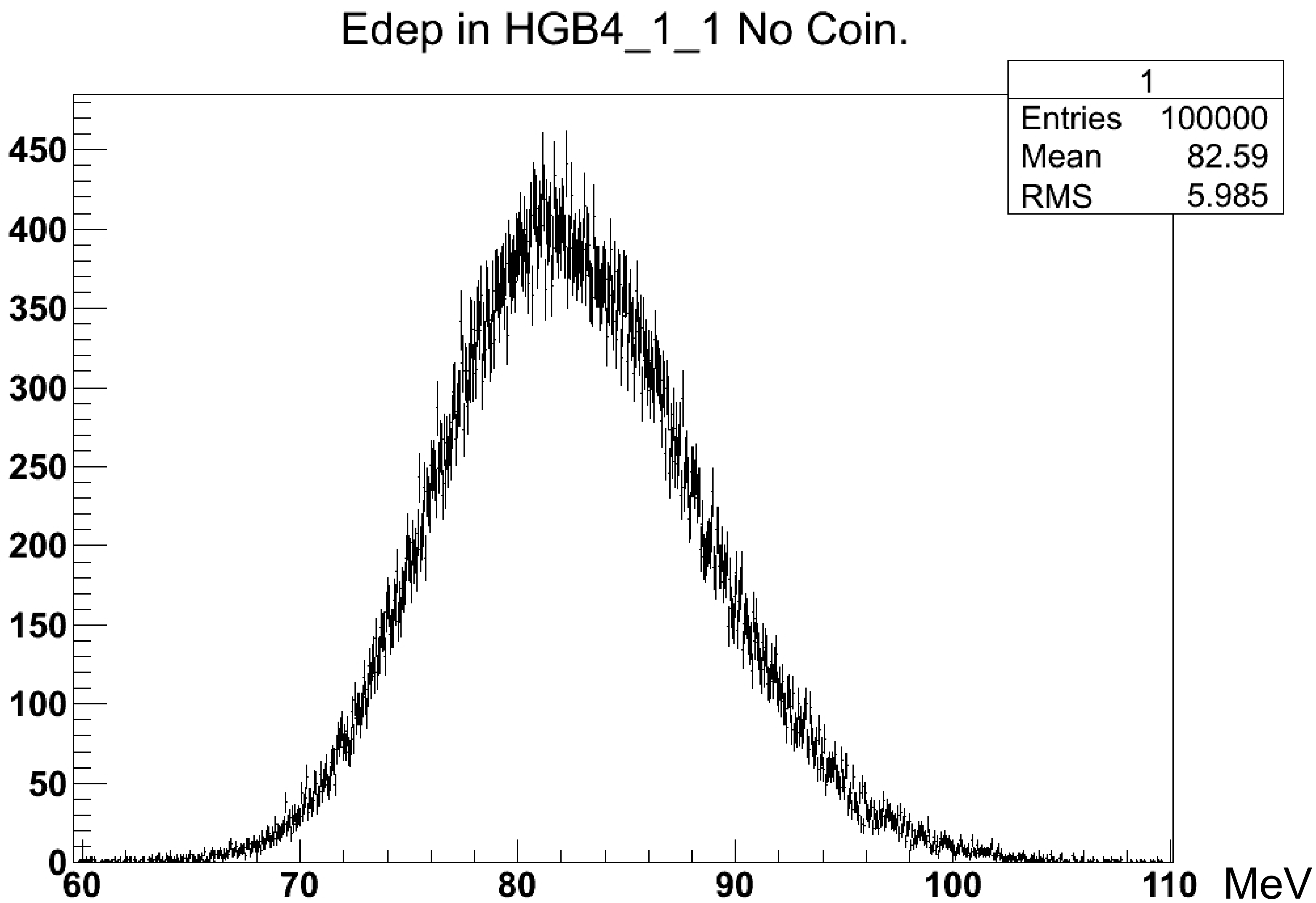
Protons

TEST BEAM - GEANT4 SIMULATIONS (cont.)



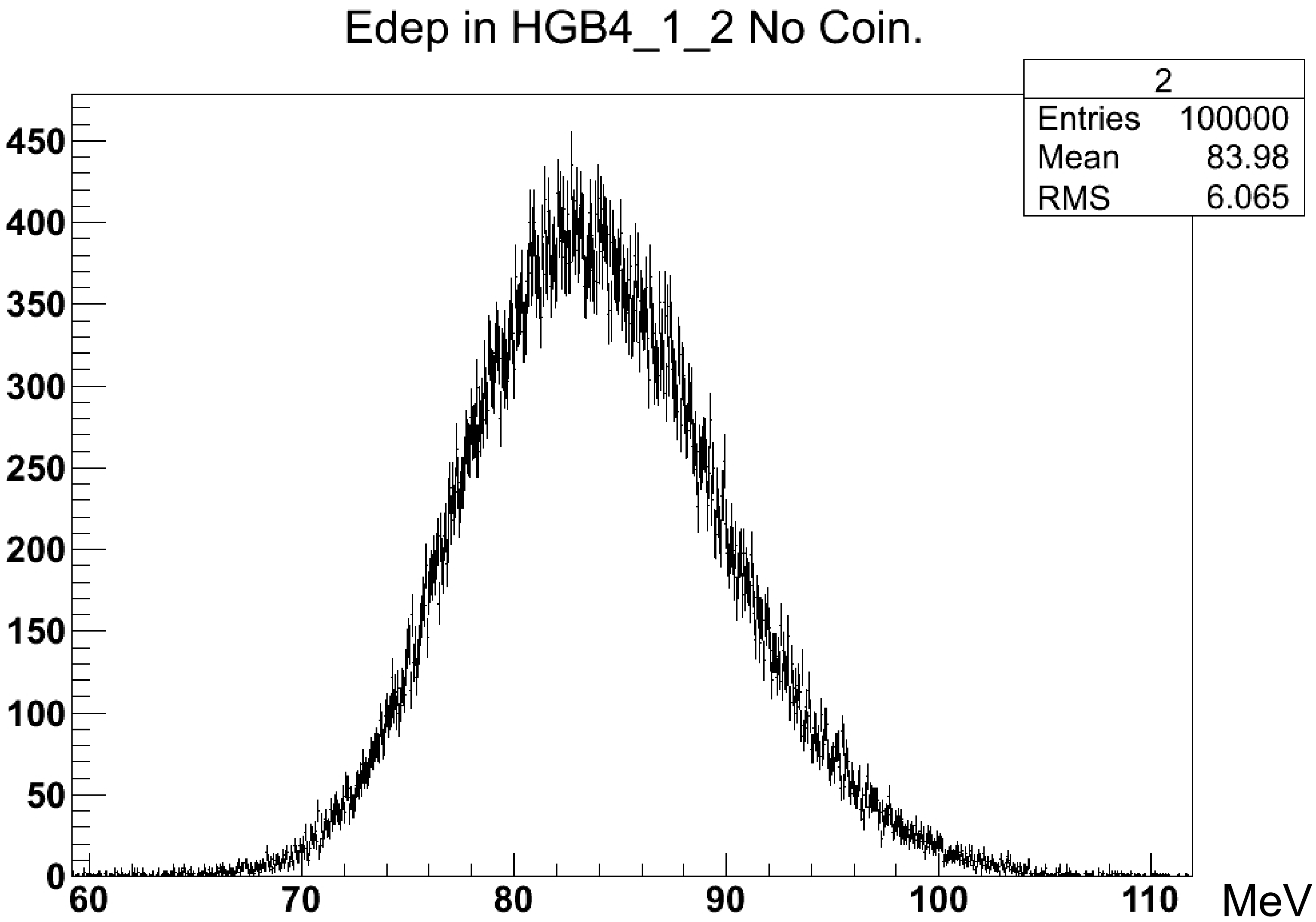
Protons

TEST BEAM - GEANT4 SIMULATIONS (cont.)



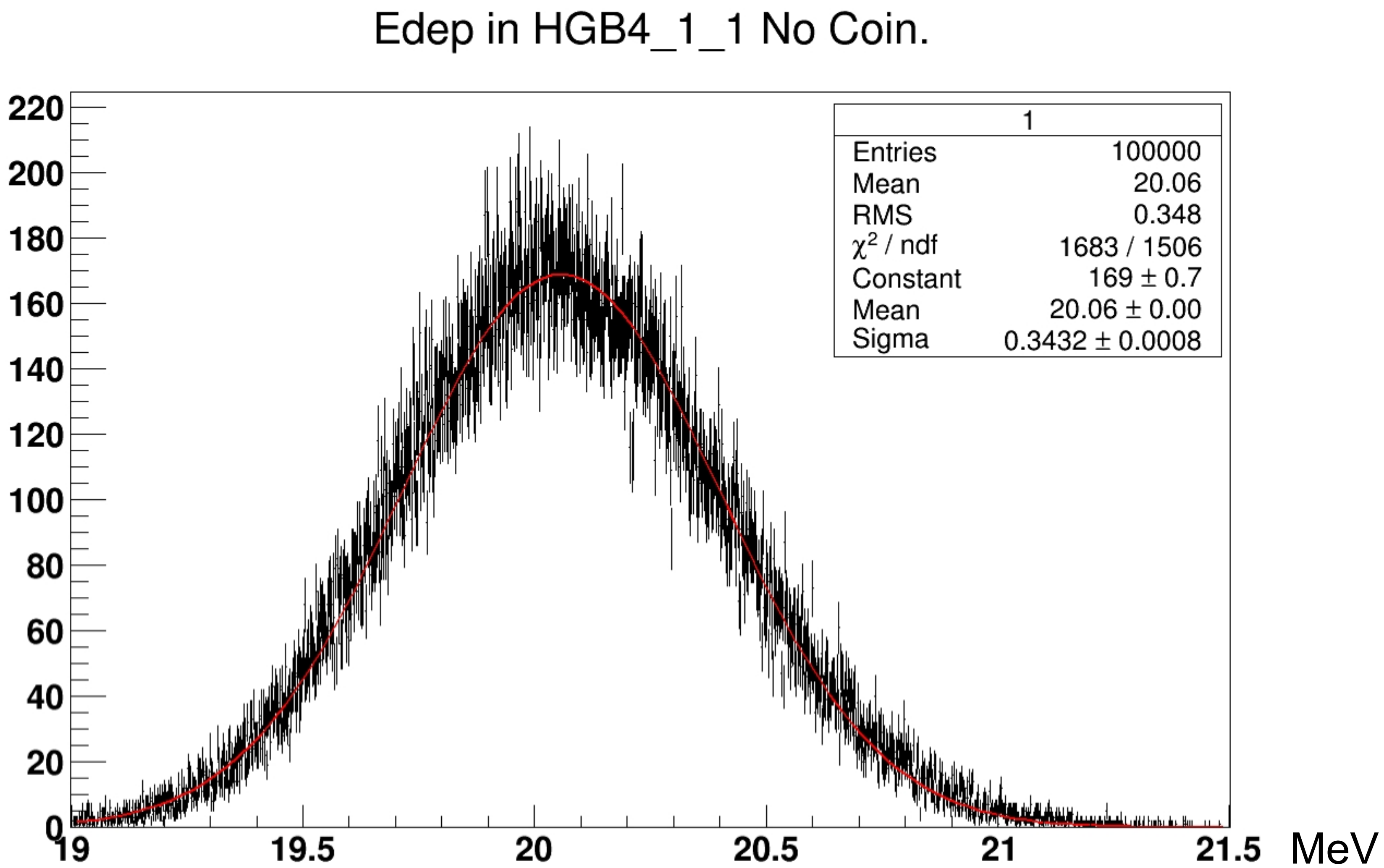
Uranium

TEST BEAM - GEANT4 SIMULATIONS (cont.)



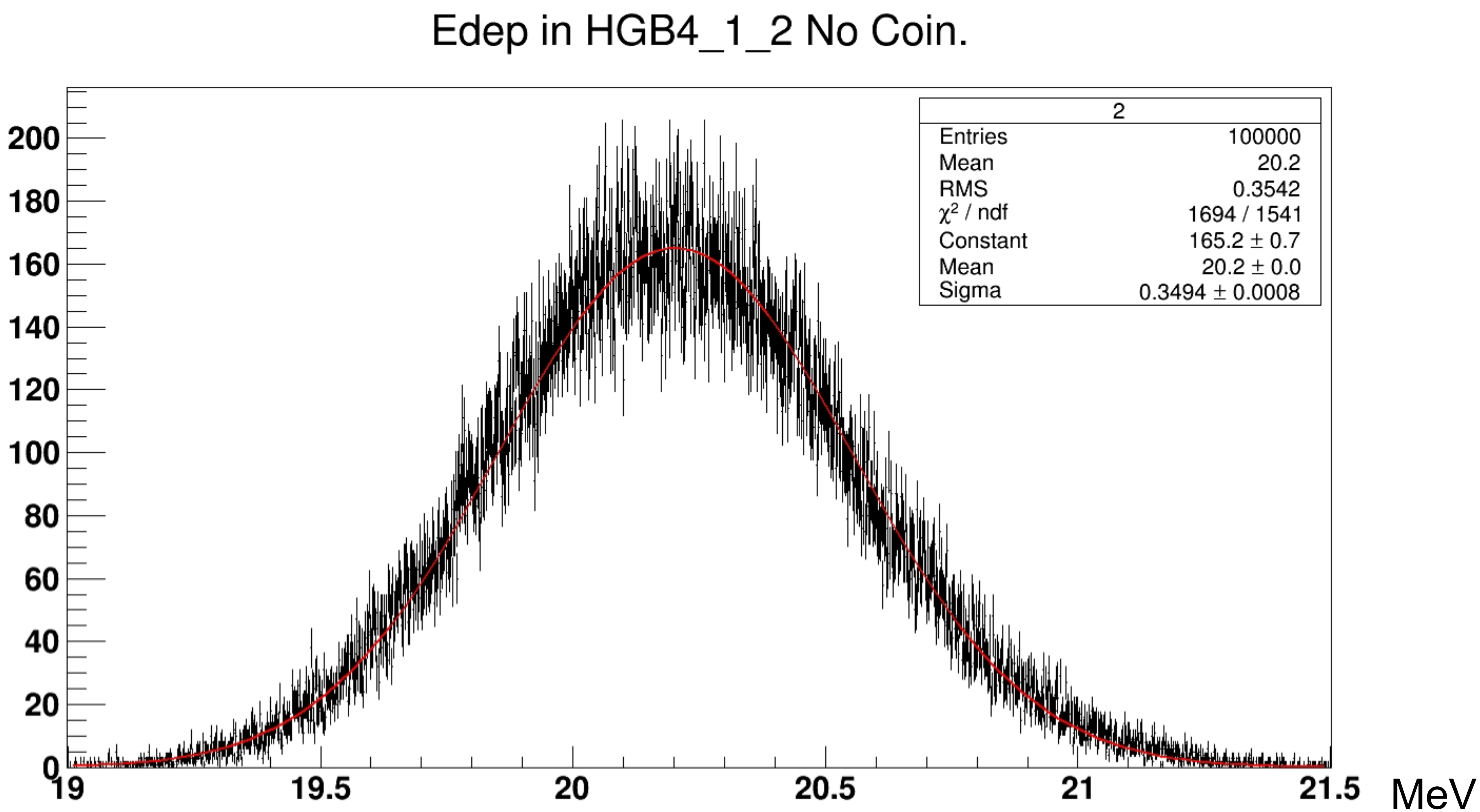
Uranium

TEST BEAM - GEANT4 SIMULATIONS (cont.)



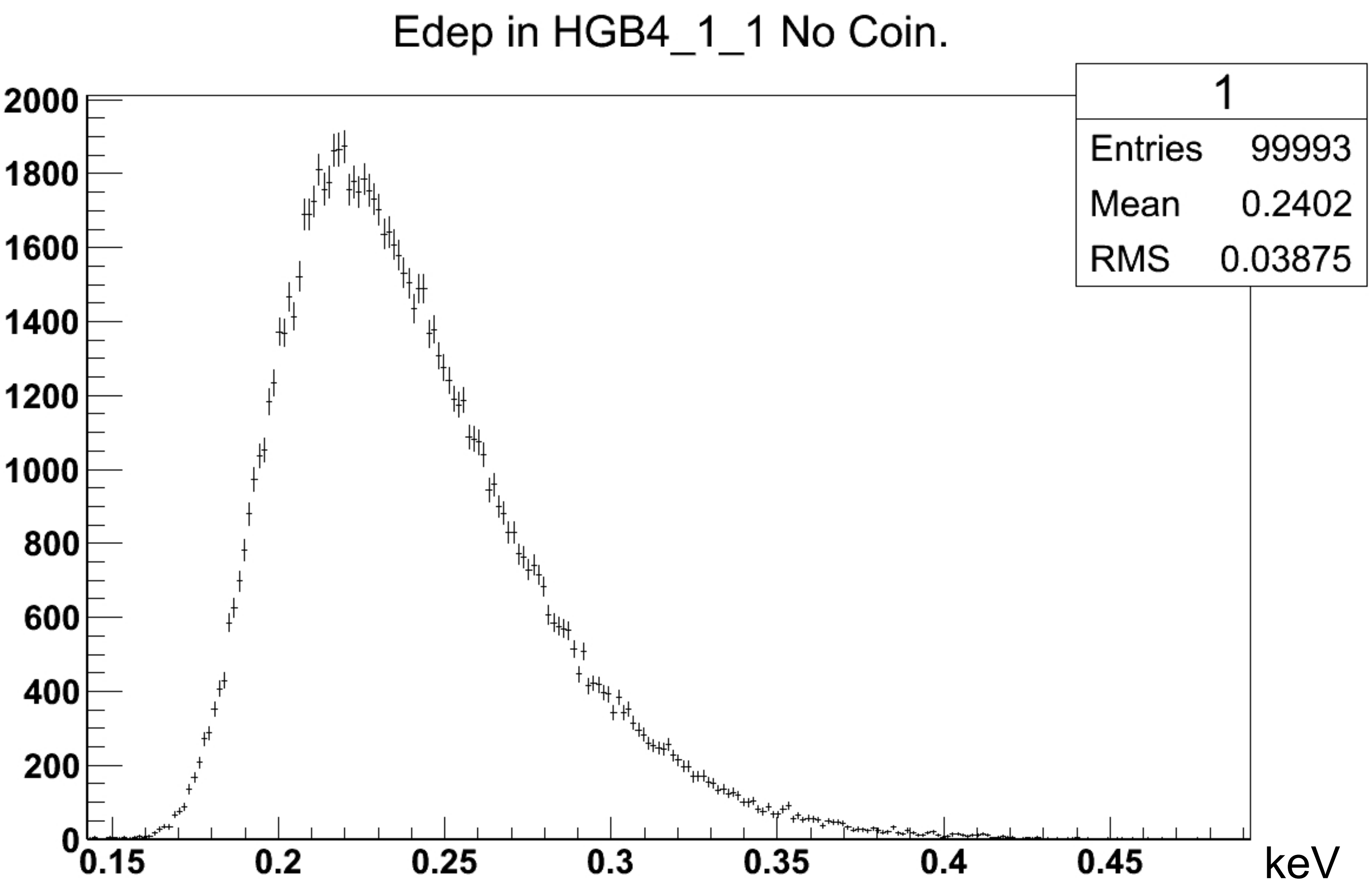
Xenon

TEST BEAM - GEANT4 SIMULATIONS (cont.)



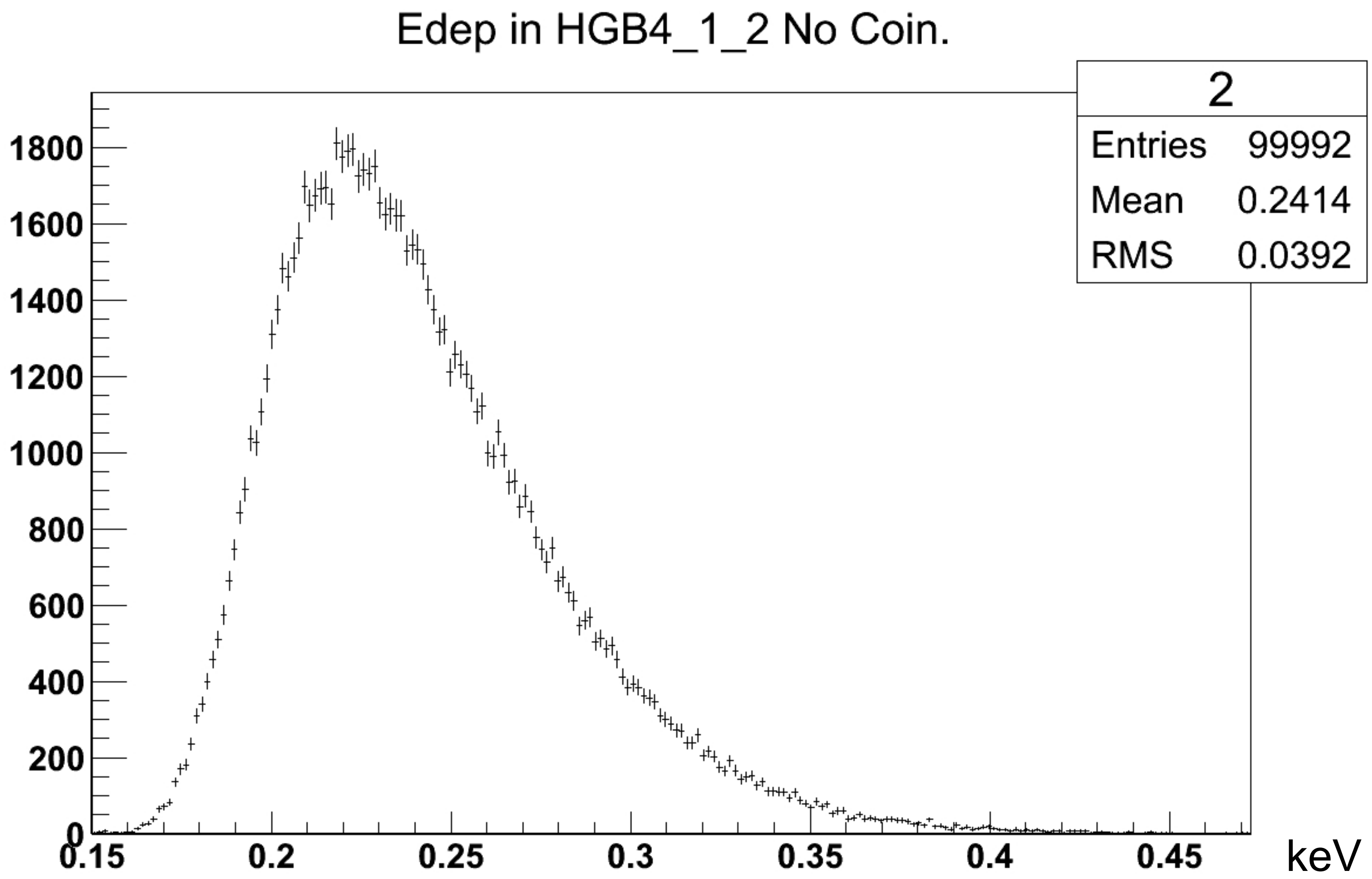
Xenon

TEST BEAM - GEANT4 SIMULATIONS (cont.)



Carbon

TEST BEAM - GEANT4 SIMULATIONS (cont.)



Carbon

TEST BEAM - GEANT4 SIMULATIONS (cont.)

Educated guess:

From Simulations:

$\Delta E \approx 20$ KeV (Landau distr.)

$N_{e\text{-}i\ pair} = 678$ e-

From Electronics:

$G = 2$ mV/fC

$\tau_{rise} = 120$ ns

From Oscilloscope:

$\Delta V = 40$ mV → 20 fC

20 fC = 125000 e-

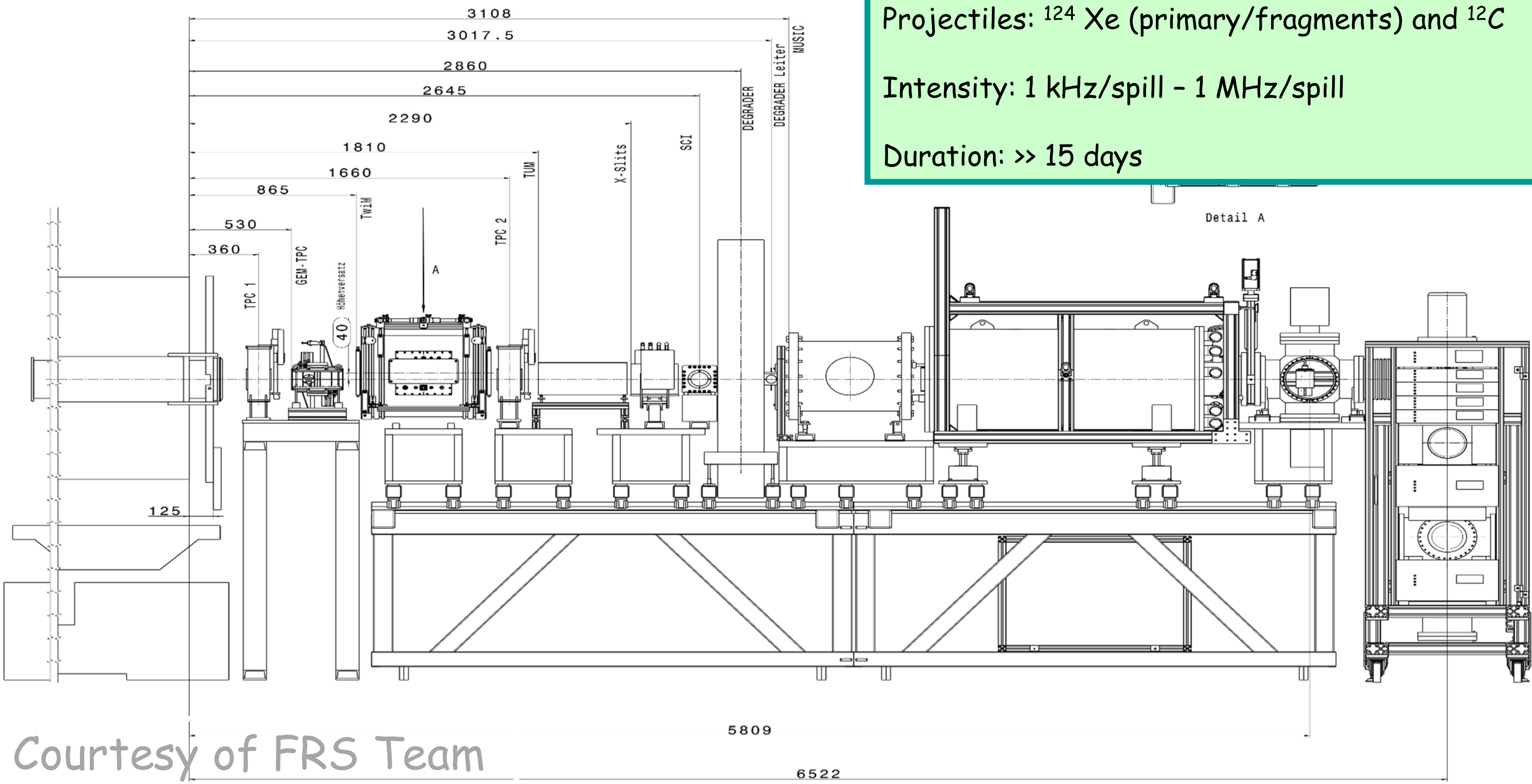
$Gain_{eff} = 184$ (per GEM-TPC)

BACKUP SLIDES

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

Intensity: 1 kHz/spill – 1 MHz/spill

Duration: >> 15 days



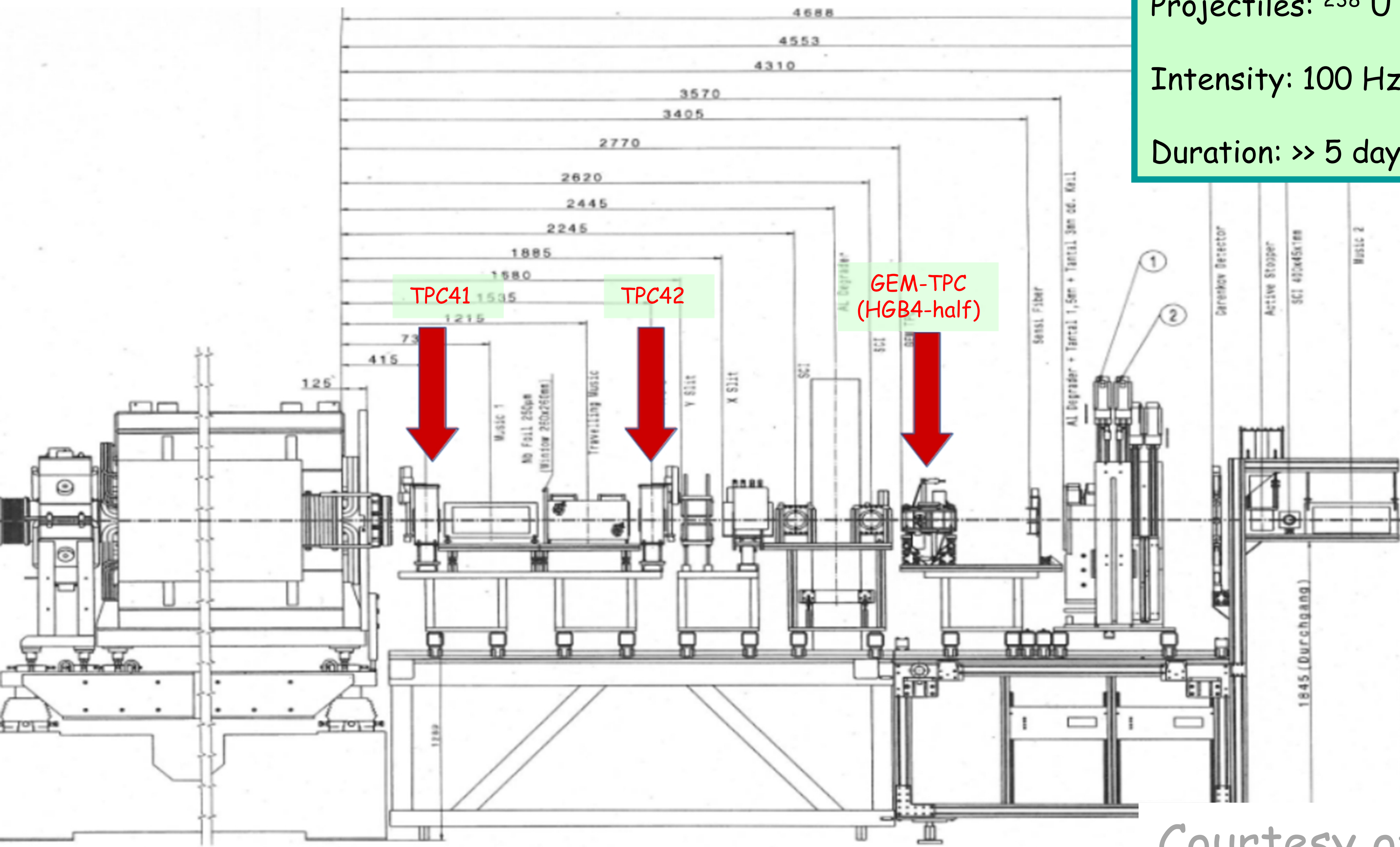
Courtesy of FRS Team

BACKUP SLIDES

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

Intensity: 100 Hz/spill – 1 kHz/spill

Duration: >> 5 days



Courtesy of FRS Team