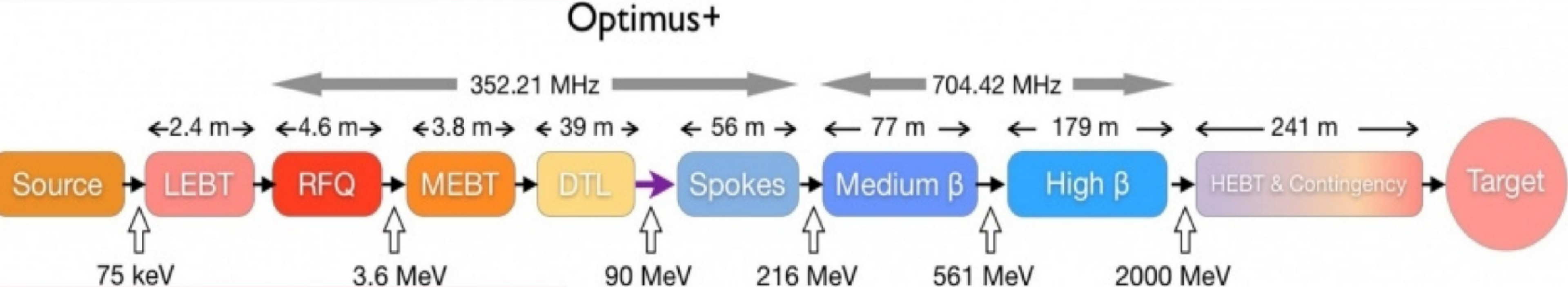
NPM beam test with conductive strips Read-out: results and conclusion



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Overview

- Read-outs:
  - Geometry
  - Electronic

- Measurement campaigns:
  - Set-ups
  - Results
  - Issues of the second campaign for the strip read-outs

- Space charge effects:
  - Main results
  - Final tables

- Background:
  - Simulations on-going

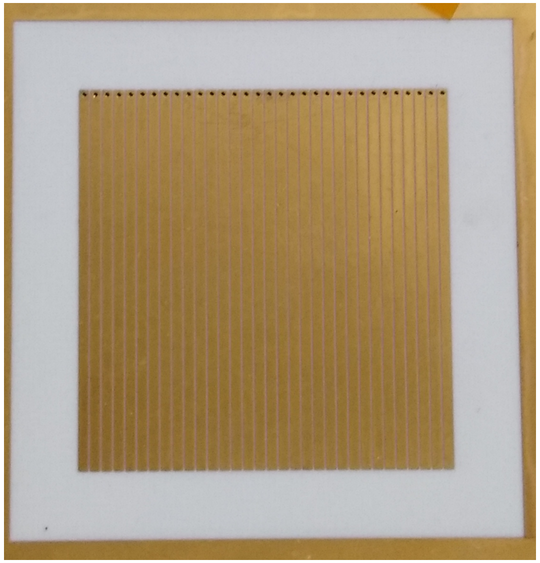
- Final remarks

Strip read-outs

Strip read-outs

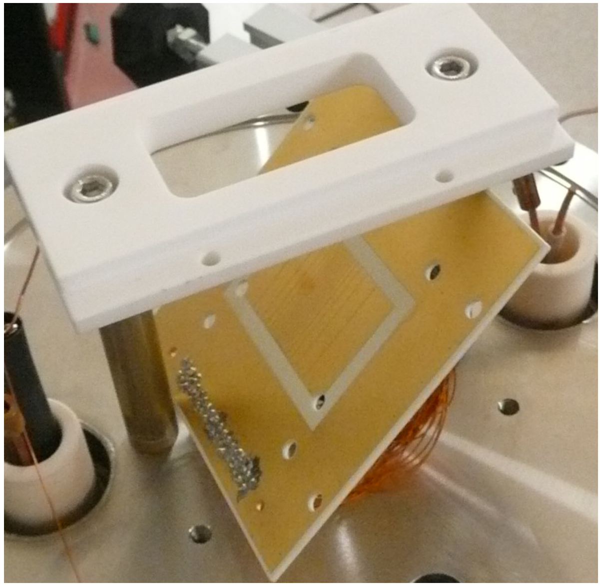
- "Linear strips" : all the strips have the same width.

  - material: Cu on ceramic
  - strip number: 32
  - strip length: 30 mm
  - strip width: 0.8 mm
  - inter-strip distance: 120 µm
  - read-out limits: [-14.66,+14.66] mm
  - read-out extension: 29.32 mm

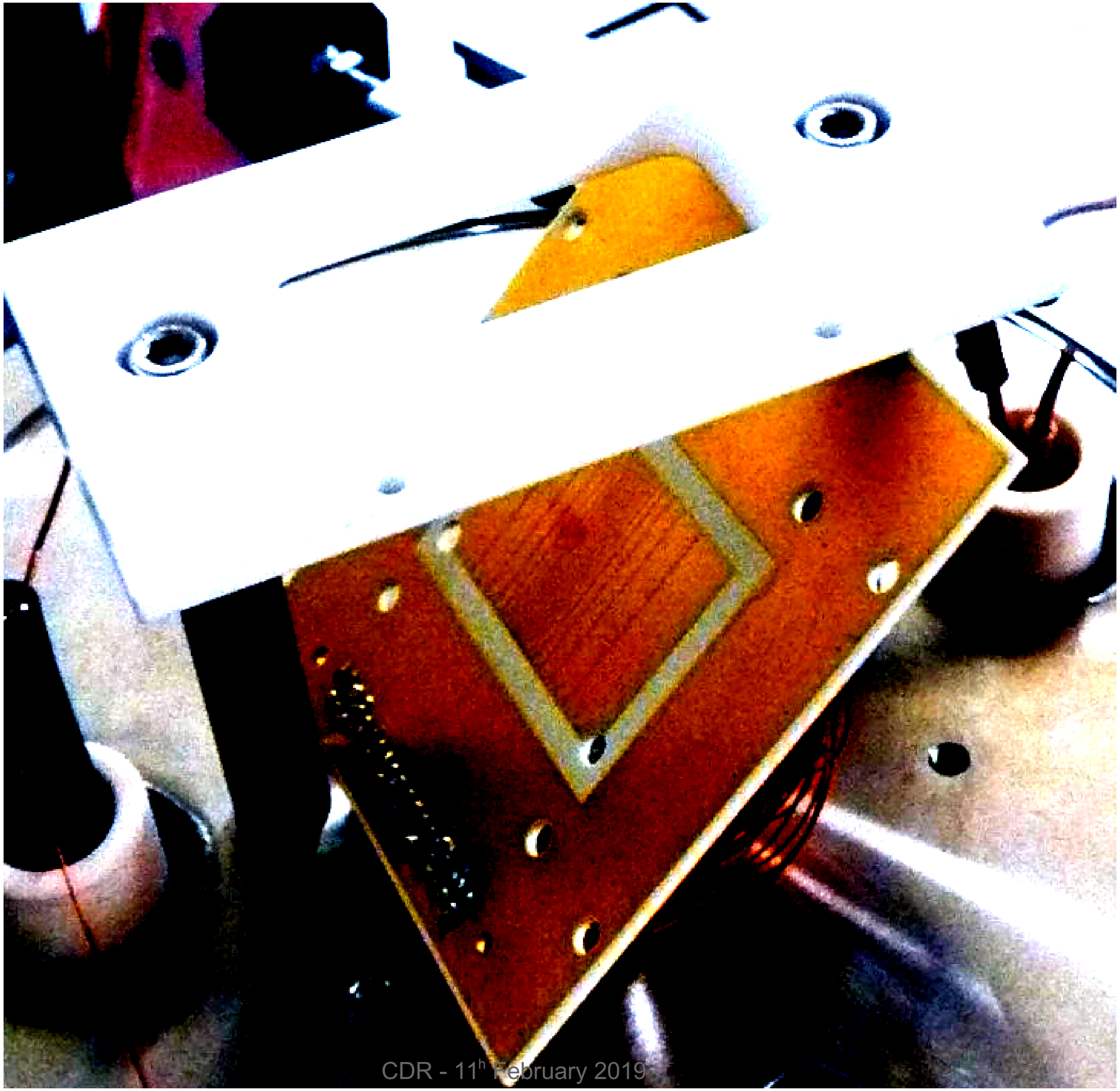


- "Gaussian strips" : variable width size, larger on tails.

  - material: Cu on ceramic
  - strip number: 18
  - strip length: 30 mm
  - strip width: 0.8 mm (center) to 9 mm (tails) [9 – 5 – 3 – 2 – 1.5 – 1 – 0.9 – 0.8 – 0.8 - 0.8 – 0.8 – 0.9 -1 – 1.5 – 2 – 3 – 5 – 9] mm
  - inter-strip distance: 120 µm
  - read-out limits: [-25.02,+25.02] mm
  - read-out extension: 50.04 mm



Zoom on gaussian strips read-out



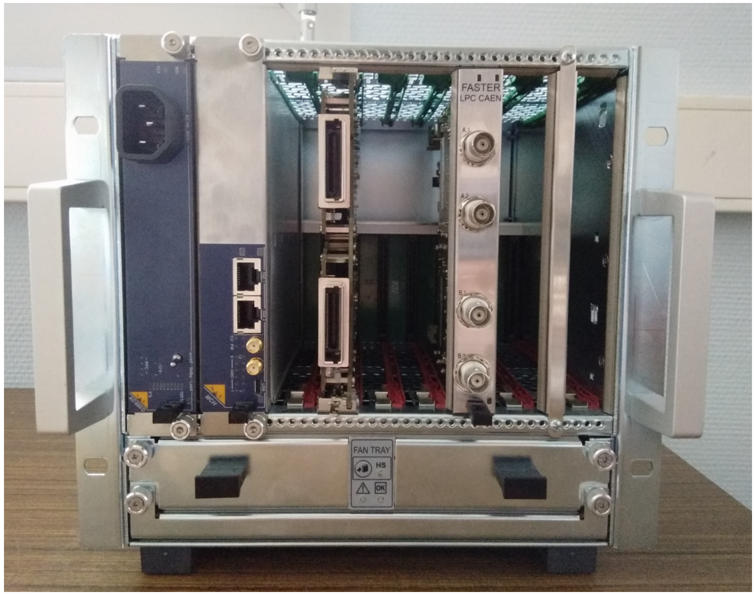
Electronics (1/5)

FASTER : Fast Acquisition System for nuclEar Research

- Modular digital acquisition
- Possibility of handling up to some hundreds of detectors
- Freedom in set-up building options: µTCA or NIM standards
- Ethernet gigabit connection
- Developed by LPC Laboratoire de physique corpuscolaire of Caen (France) by the group of David Etasse

Our set-up consisted of:

- 1 µTCA Crate
- 1 motherboard *syroco_amc_c5*
- 2 daughterboards *caramel*
- 1 motherboard *syroco_amc*
- 2 daughterboards *caras*



Electronics (2/5)

- motherboard *syroco_amc_c5*
  - FPGAs
  - 1 and 10 Gbe connection
  - Synchronized by an external clock

- daughterboard *caramel*
  - 32 channels
  - Integrating I-to-V conversion front-end
  - Adjustable integrating time from 10 μs to 1 ms
  - Programmable full scale: 3 pC – 12 pC

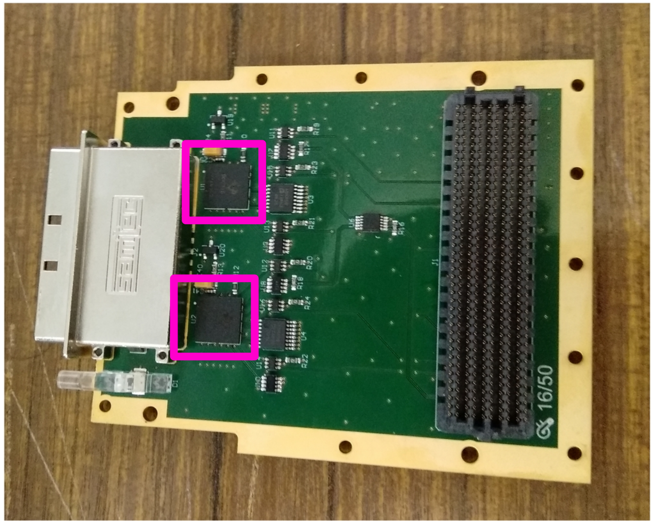
⇓

No negative charges

⇓

Offset necessary

2 × DDC316 chips from Texas Instruments



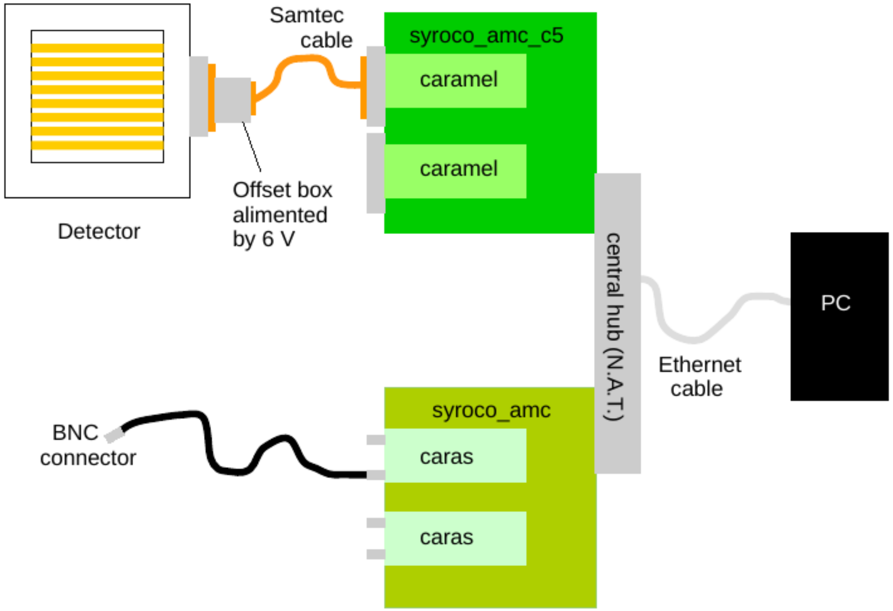
Electronics (3/5)

- motherboard *syroco_amc*
  - FPGAs
  - Synchronized by an external clock

- daughterboard *caras*
  - 2 channels
  - ± 1.15 V dynamic range
  - Input Offset adjustable by software (-1.1V , 1.1V)
  - Bandwith: 100 MHz

Electronics (4/5)

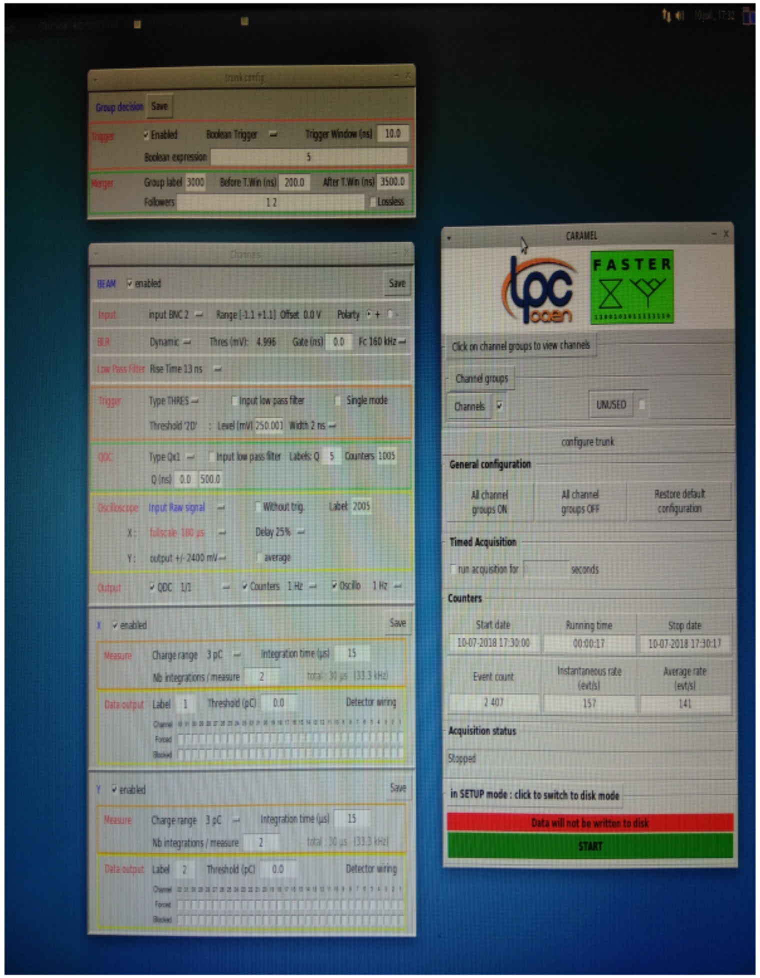
➢ Hardware scheme



The 2 motherboards are independent

- the DDC316 continuously integrate the current
- trigger coincidence by software interface
  (more go-no-go recording than real trigger)

➢ GUI



Group decision Save
Trigger ☑ Enabled Boolean Trigger Trigger Window (ns) 10.0
Boolean expression 5
Merger Group label 3000 Before T.Win (ns) 200.0 After T.Win (ns) 3500.0
Followers 1 2 ☐ Lossless

BEAM ☑ enabled Save
Input input BNC 2 Range [-1.1 +1.1] Offset 0.0 V Polarity ● + ○ -
BLR Dynamic Thres (mV): 4.996 Gate (ns) 0.0 Fc 160 kHz
Low Pass Filter Rise Time 13 ns
Trigger Type THRES ☐ Input low pass filter ☐ Single mode
Threshold '2D' : Level (mV) 250.001 Width 2 ns
QDC Type Qx1 ☐ Input low pass filter Labels: Q 5 Counters 1005
Q (ns) 0.0 500.0
Oscilloscope Input Raw signal ☐ Without trig. Label 2005
X : fullscale 100 µs Delay 25%
Y : output +/- 2400 mV ☐ average
Output ☑ QDC 1/1 ☑ Counters 1 Hz ☑ Oscillo 1 Hz

X ☑ enabled Save
Measure Charge range 3 pC Integration time (µs) 15
Nb integrations / measure 2 total : 30 µs (33.3 kHz)
Data output Label 1 Threshold (pC) 0.0 Detector wiring
Channel
Forced
Blocked

Y ☑ enabled Save
Measure Charge range 3 pC Integration time (µs) 15
Nb integrations / measure 2 total : 30 µs (33.3 kHz)
Data output Label 2 Threshold (pC) 0.0 Detector wiring
Channel
Forced
Blocked

Click on channel groups to view channels
Channel groups
Channels ☑ UNUSED ☐
configure trunk

General configuration
All channel groups ON | All channel groups OFF | Restore default configuration

Timed Acquisition
☐ run acquisition for seconds

Counters
Start date 10-07-2018 17:30:00
Running time 00:00:17
Stop date 10-07-2018 17:30:17
Event count 2 407
Instantaneous rate (evt/s) 157
Average rate (evt/s) 141

Acquisition status
Stopped

in SETUP mode : click to switch to disk mode
Data will not be written to disk
START

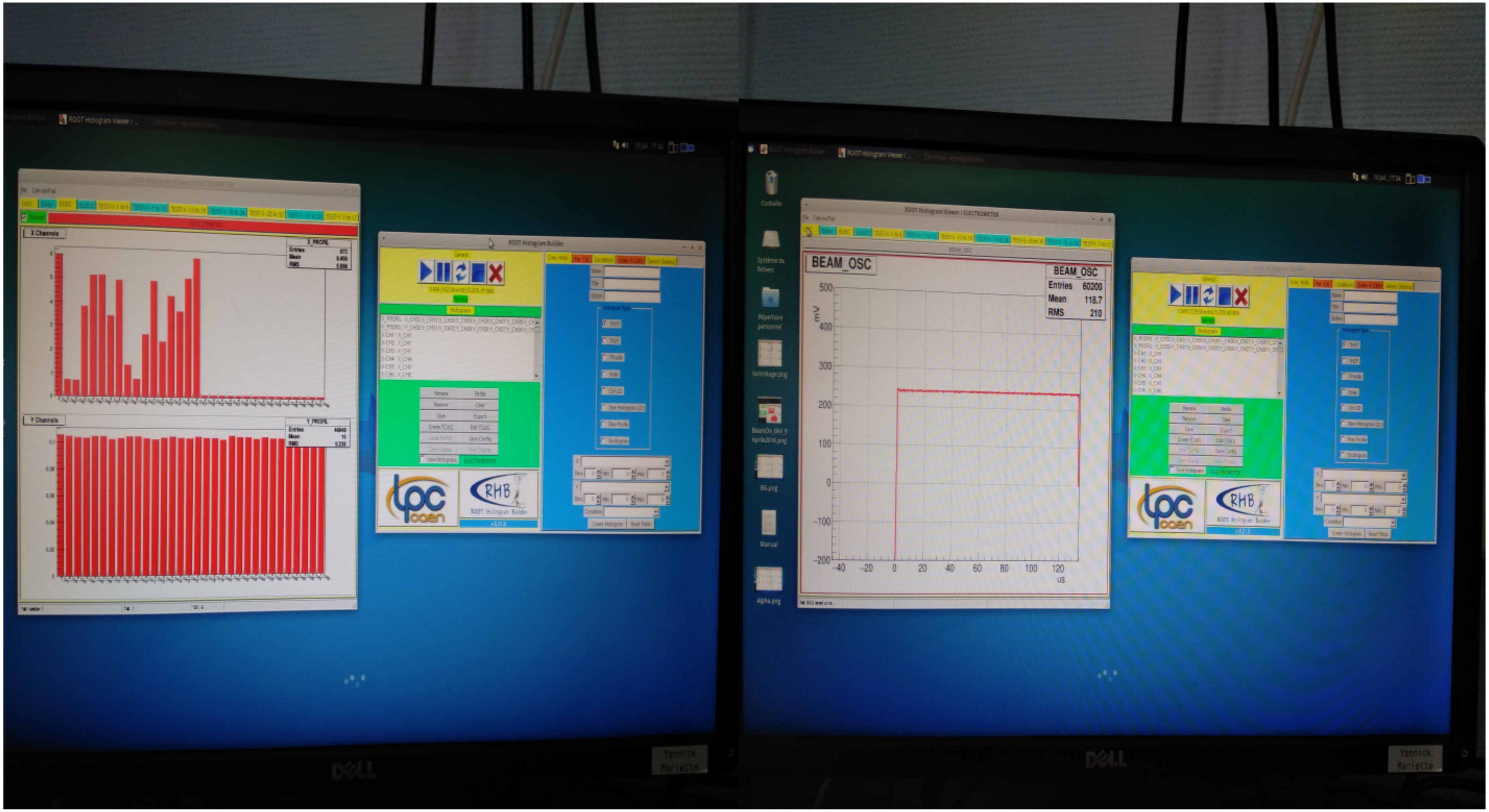
➢ Software requirement

Ubuntu Linux

- supported on 14.04
- to be released for 16.04

Electronics (5/5)

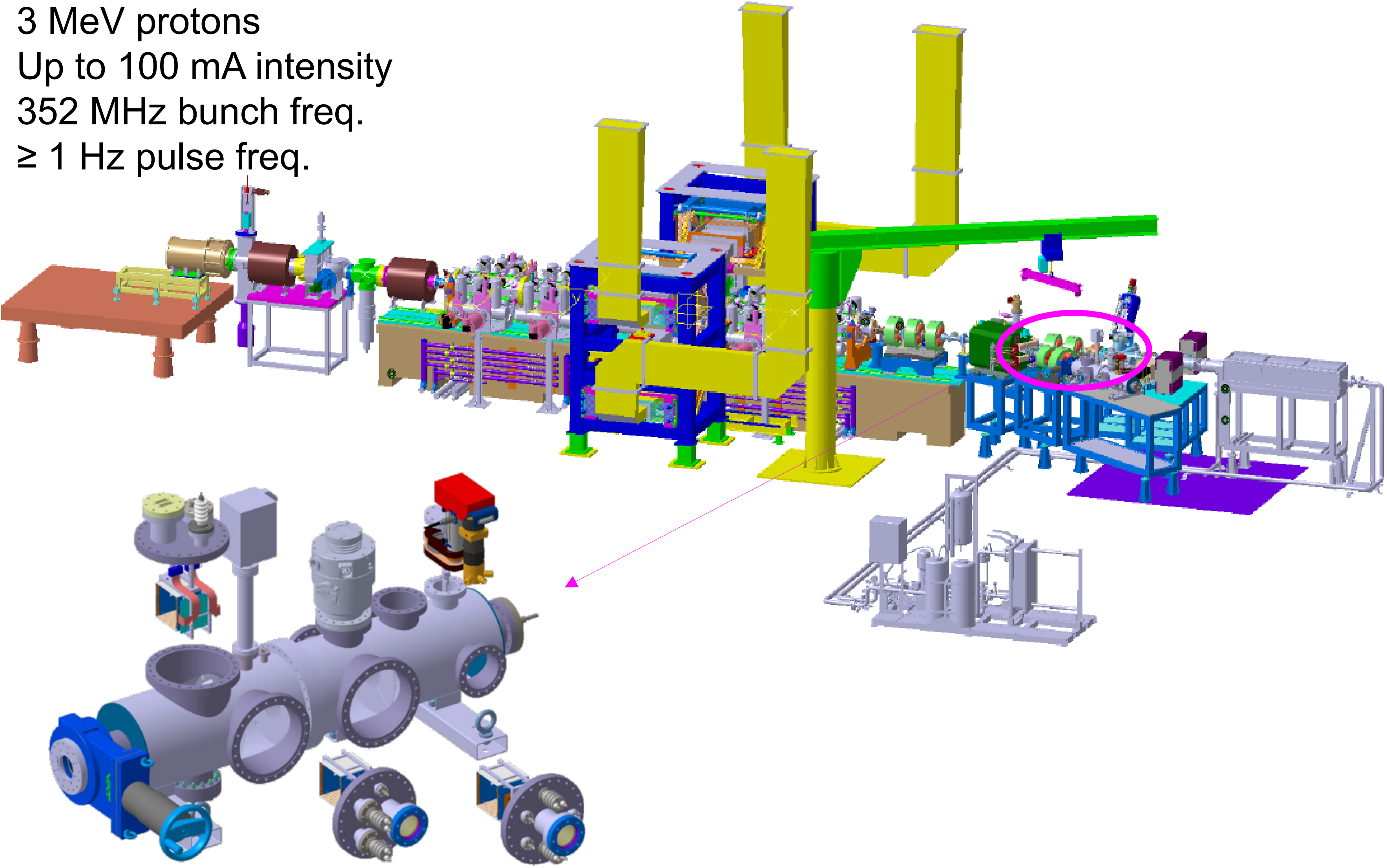
- RHB (Root Histogram Builder)



Measurement campaigns

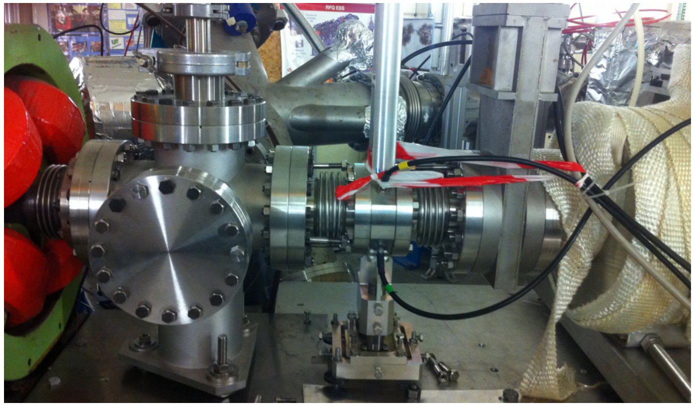
TESTS at IPHI

- 3 MeV protons
- Up to 100 mA intensity
- 352 MHz bunch freq.
- ≥ 1 Hz pulse freq.

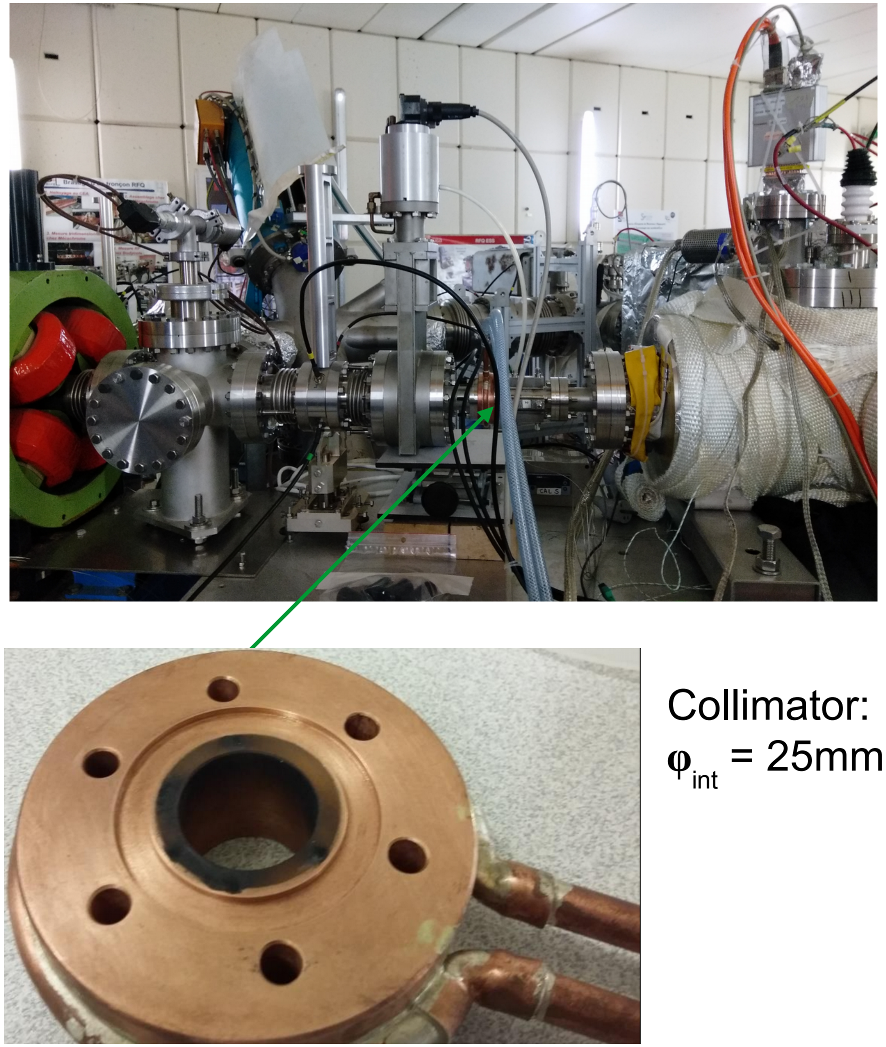


Difference between the 2 campaigns

1st campaign



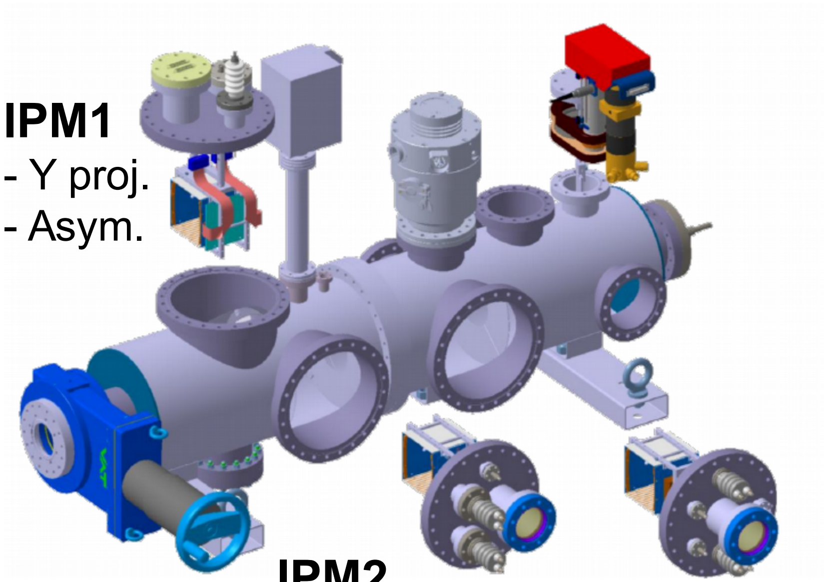
2nd campaign



Collimator:
φ_{int} = 25mm

Difference between the 2 campaigns

1st campaign



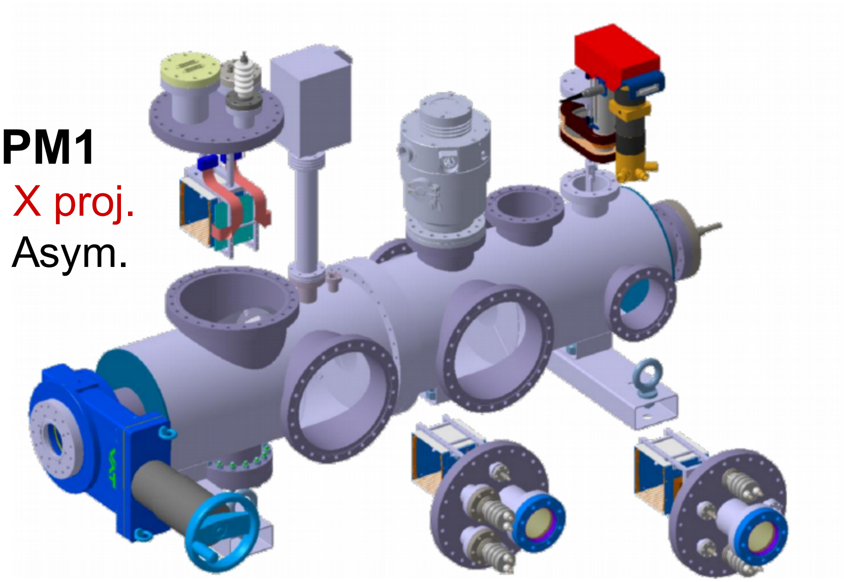
IPM1
- Y proj.
- Asym.

IPM2
- Y proj.
- Asym./Sym.

IPM3
- Y proj.
- Asym.

IPM1: Linear strips +/- mcp
IPM2: Optical read-out (mcp + camera)
IPM3: Gaussian strips alone

2nd campaign



IPM1
- X proj.
- Asym.

IPM2
- Y proj.
- Asym./Sym.

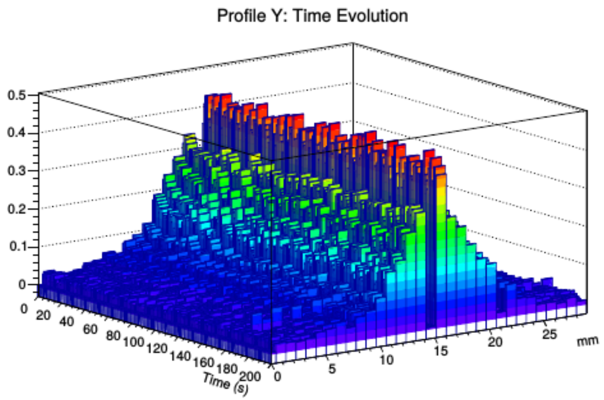
IPM3
- Y proj.
- Asym.

IPM1: Gaussian strips alone
IPM2: Optical read-out (mcp + camera)
IPM3: Linear strips alone

1st Campaign: linear + mcp (1/7)

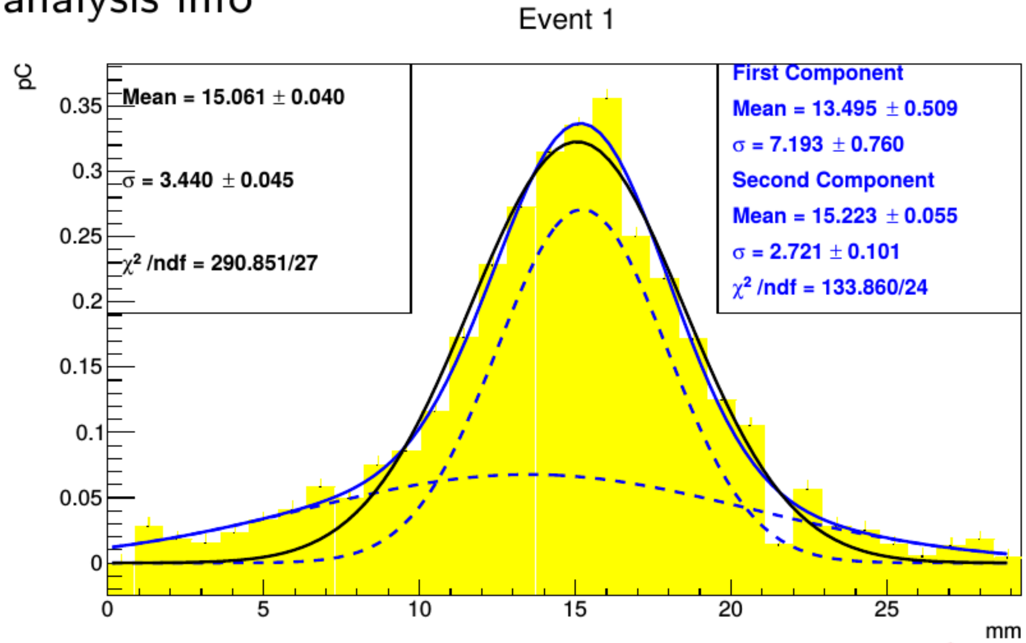
Run info

- Run started at 14:47:18
- Run ended at 14:50:39
- ddp between electrodes: + 7 kV
- $\Delta V_{mcp} = 650/2$ V
- $I \approx 32$ mA



Some analysis info

- Central strip signal (dead) replaced with average of 2 nearby strip signal
- With N. Chauvin we had seen the beam has 2 components looking like:
  - a narrow Gaussian (second component) superimposed to
  - a large Gaussian background (first component)
- Two data analysis were performed:
  - treating the profile as a single Gaussian
  - treating the profile as the sum of two Gaussians



Single Gaussian : $\sigma = 3.440 \pm 0.045$ ($\chi^2_{red} \approx 10.8$)

Double Gaussian, 2nd component : $\sigma = 2.721 \pm 0.055$ ($\chi^2_{red} \approx 5.6$)

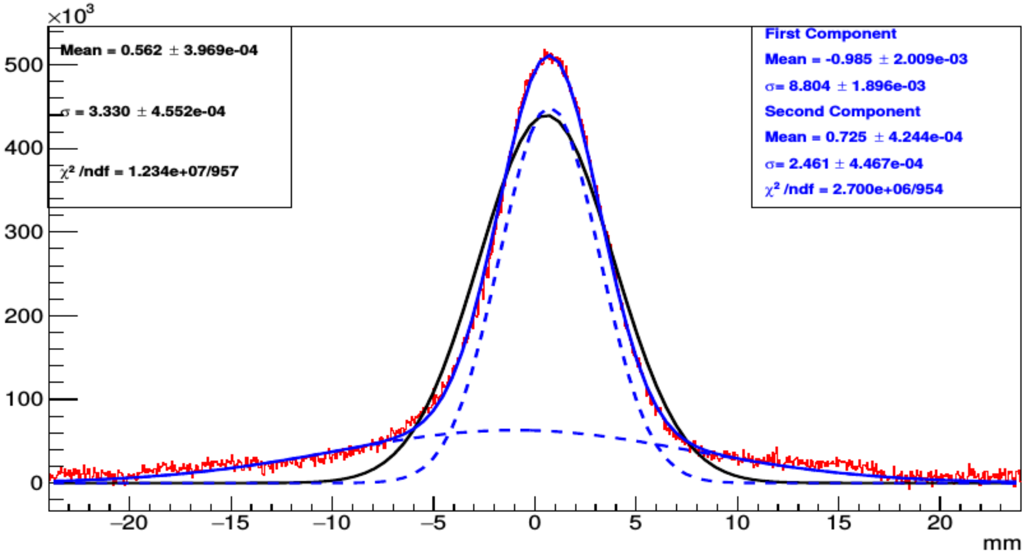
1^{st} Campaign: linear + mcp (2/7)

Camera (IPM2) signal formation

- The proton beam ionizes the gas: electrons and ions are created
- Electrons and ions drift in opposite directions ($\vec{E}$)
- Electrons or ions hit the MCP
- Electrons are emitted
- The electrons hit a phosphorus screen
- Photons are emitted
- The photons hit the silicon matrix of the camera
- Camera specs: 960 x 600 pixels, 11.72 μm pixel side

Camera run to compare to strip run:

- Run ended at 14:50
- Run duration: 90 s
- Filename: aprem_005.h5
- ddp between electrodes: + 7 kV
- $V_{mcp} = 587$ V
- $I \approx 32$ mA



Single Gaussian :

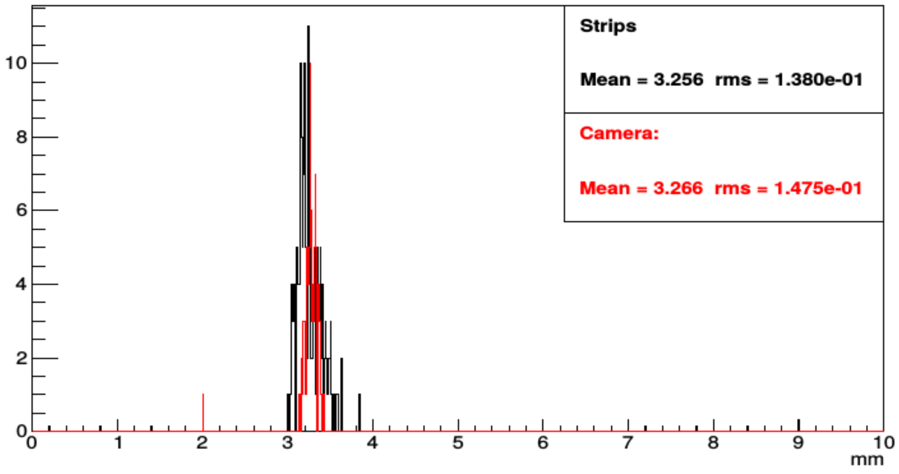
$$\sigma = 3.330 \pm 4.552 \cdot 10^{-4} \; (\chi^2_{red} \approx 12894)$$

Double Gaussian, 2^{nd} component :

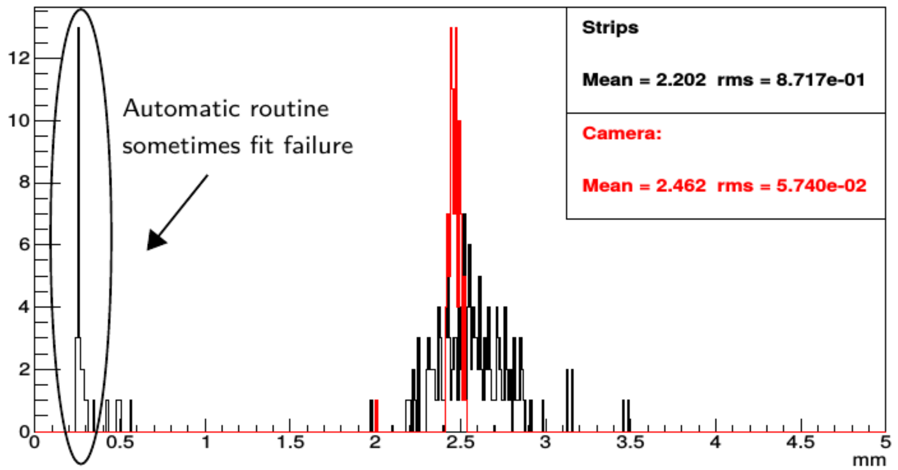
$$\sigma = 2.461 \pm 4.467 \cdot 10^{-4} \; (\chi^2_{red} \approx 2830)$$

1st Campaign: linear + mcp (3/7)

Comparison of the histograms of the σ values obtained by the fits. Here below is the result when **a single Gaussian** is used to fit the data



Histograms of the σ values of the **second Gaussian component** (= the narrower) when two Gaussians are used to fit the data.



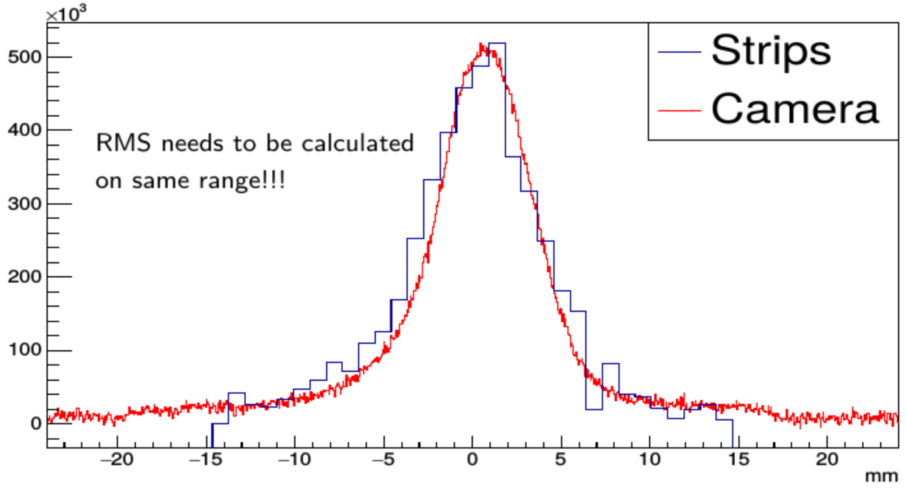
Automatic routine sometimes fit failure

Comments on the fits:

- Single Gaussian:
  - does not account for the tails.
  - $\chi^2_{red} \not\to 1$
- Two Gaussians:
  - Several misfits (24% here, up to 82% for other runs)
  - $\chi^2_{red} \not\to 1$

$\Downarrow$

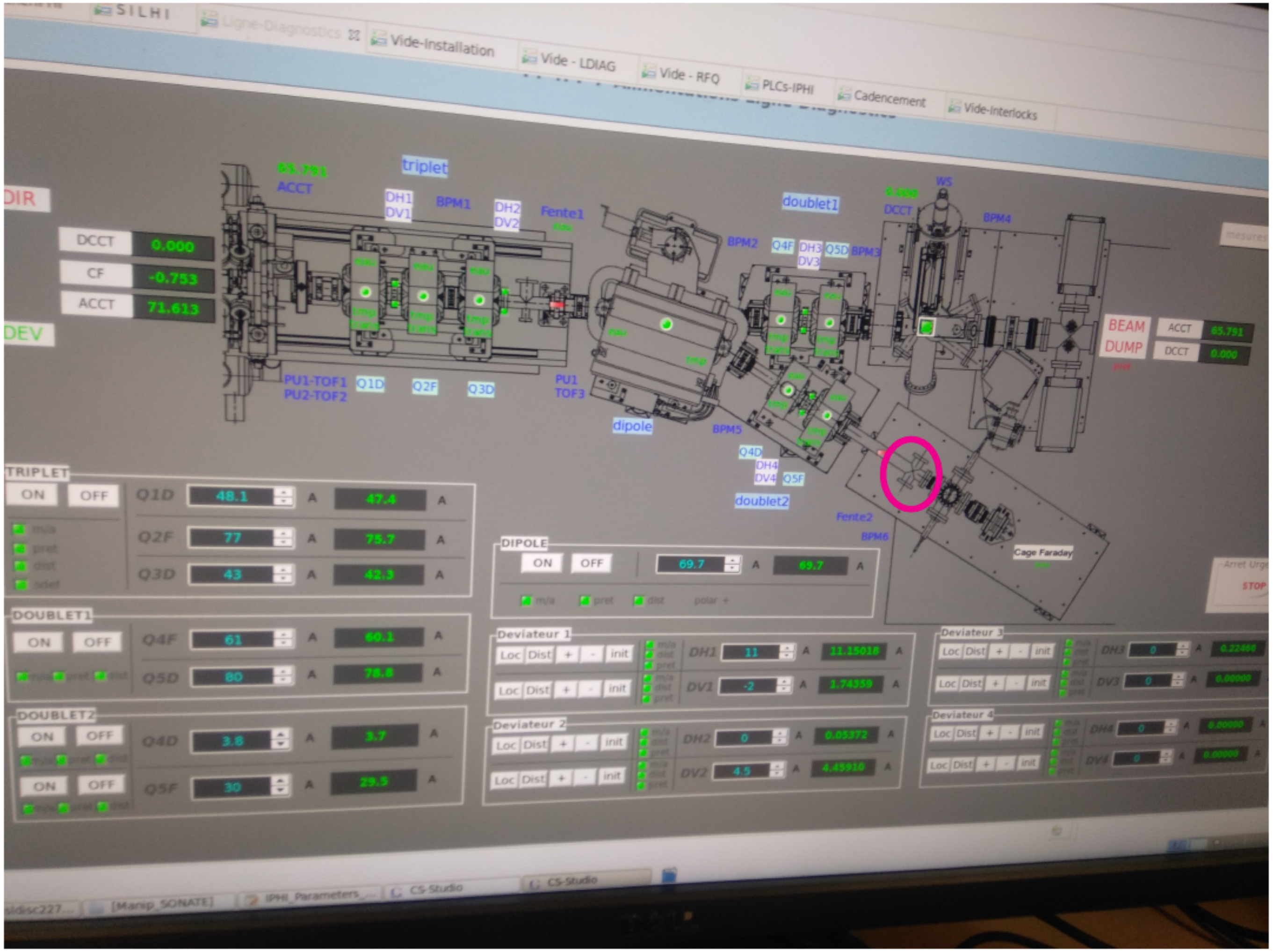
The profile can not be described by Gaussians.
A better estimation of the width of the profile
is given by the RMS.



RMS needs to be calculated on same range!!!

1^{st} Campaign: linear + mcp (4/7)

BPM 6



DCCT 0.000

CF -0.753

ACCT 71.613

ACCT 83.791

DCCT 0.000

BEAM DUMP: ACCT 65.791, DCCT 0.000

TRIPLET

Q1D 48.1 A 47.4 A

Q2F 77 A 75.7 A

Q3D 43 A 42.3 A

DOUBLET1

Q4F 61 A 60.1 A

Q5D 80 A 78.8 A

DOUBLET2

Q4D 3.8 A 3.7 A

Q5F 30 A 29.5 A

DIPOLE

69.7 A 69.7 A

Deviateur 1

DH1 11 A 11.15018 A

DV1 -2 A 1.74359 A

Deviateur 2

DH2 0 A 0.05372 A

DV2 4.5 A 4.45910 A

Deviateur 3

DH3 0 A 0.22460 A

DV3 0 A 0.00000 A

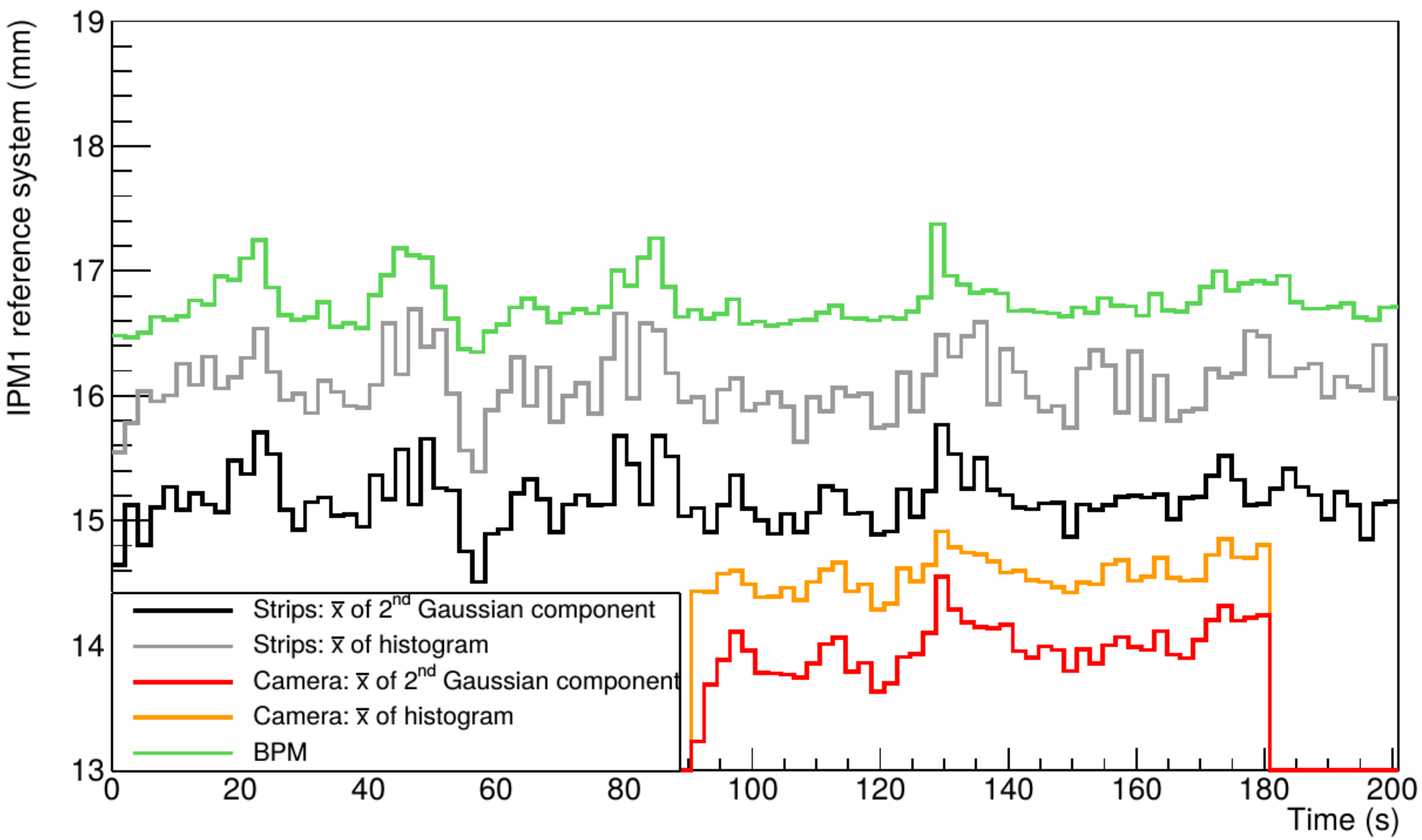
Deviateur 4

DH4 0 A 0.00000 A

DV4 0 A 0.00000 A

1st Campaign: linear + mcp (5/7)

Compare the center of charge

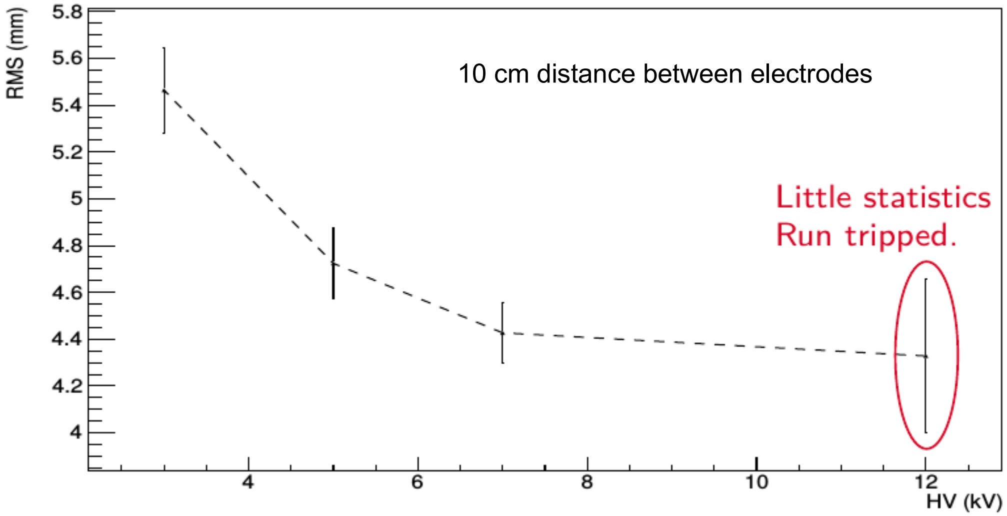


Signals vertically shifted for better visualization

1st Campaign: linear + mcp (6/7)

Runs 2, 7, 8 and 15

- $I \approx 32$ mA
- $\Delta V_{mcp} = 700/2$ V
- Run 2: HV in the cage = + 7 kV
- Run 7: HV in the cage = + 5 kV
- Run 8: HV in the cage = + 3 kV
- Run 15: HV in the cage = + 12 kV

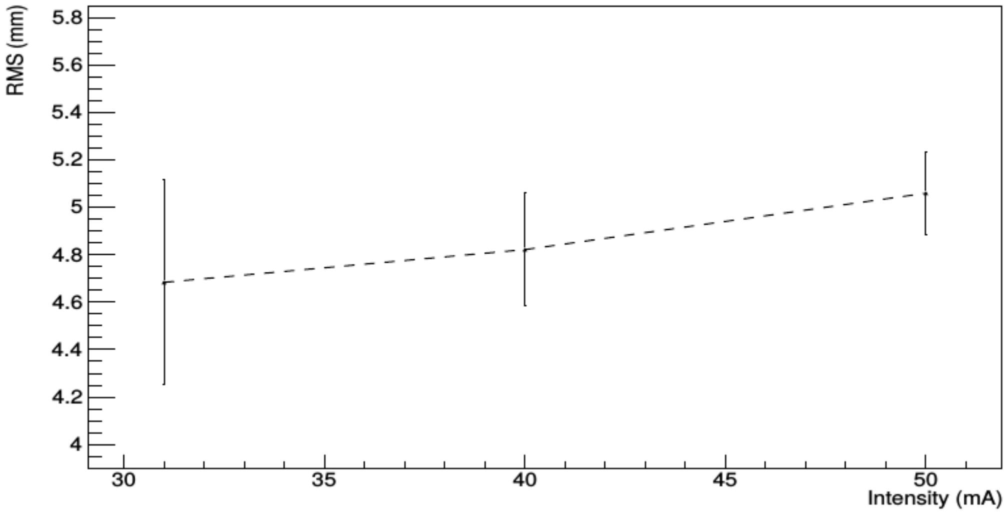


10 cm distance between electrodes

Little statistics
Run tripped.

Runs 9, 10 and 11

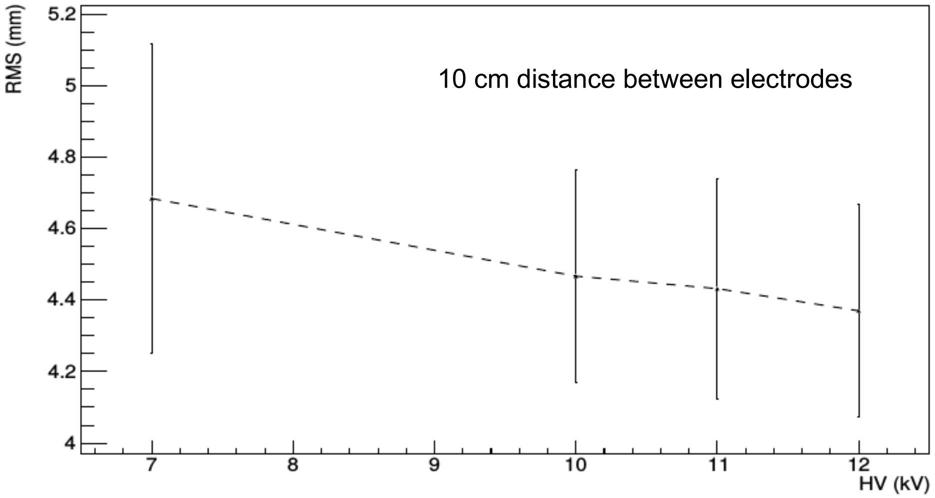
- HV in the cage = + 7 kV
- $\Delta V_{mcp} = 600/2$ V
- Run 9: $I_p = 50$ mA
- Run 10: $I_p = 40$ mA
- Run 11: $I_p =$ 31-32 mA

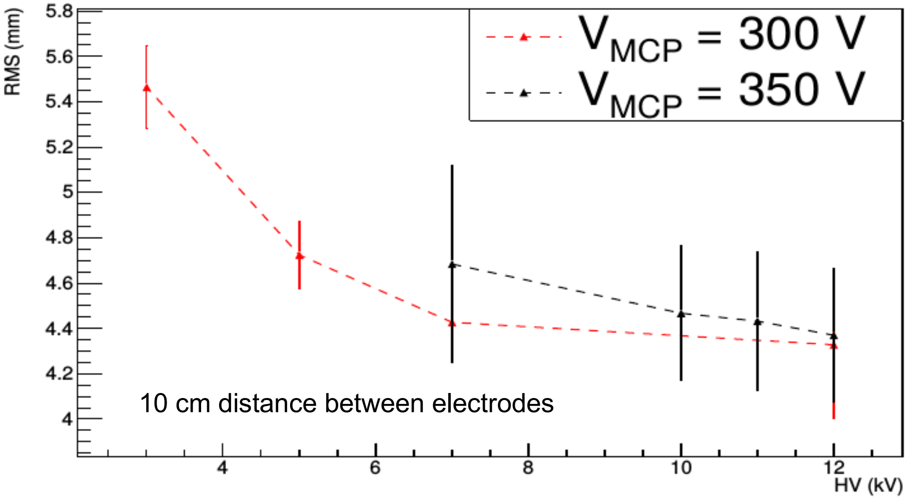


1^{st} Campaign: linear + mcp (7/7)

Runs 11, 12, 13 and 14

- I ≈ 32 mA
- $\Delta V_{mcp} = 600/2$ V
- Run 11: HV in the cage = + 7 kV
- Run 12: HV in the cage = + 10 kV
- Run 13: HV in the cage = + 11 kV
- Run 14: HV in the cage = + 12 kV

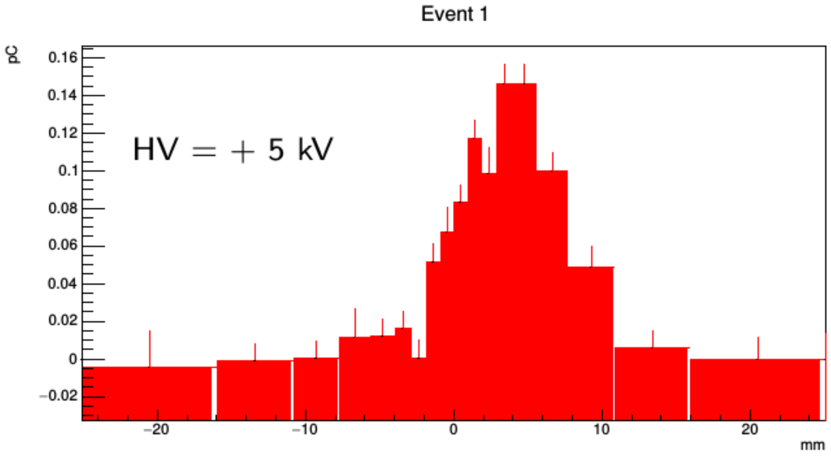




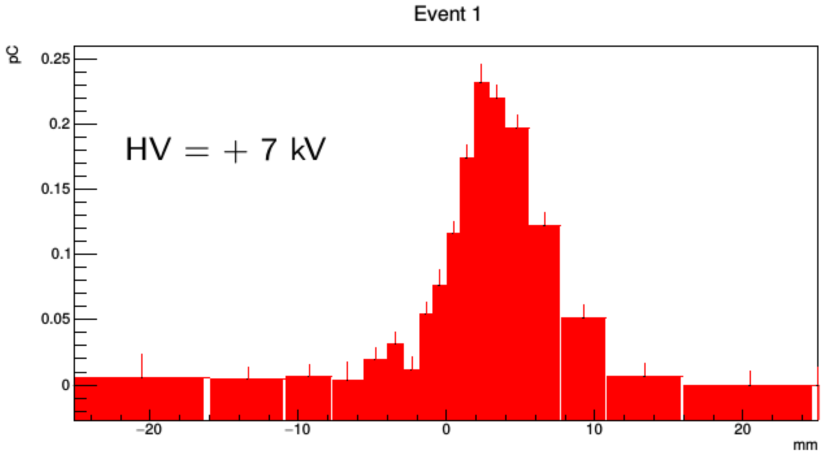
The curves of the RMS as a function of the voltage applied in the cage is different for $V_{MCP} = 300$ V and $V_{MCP} = 350$ V.

1st Campaign: gaussian strips (1/2)

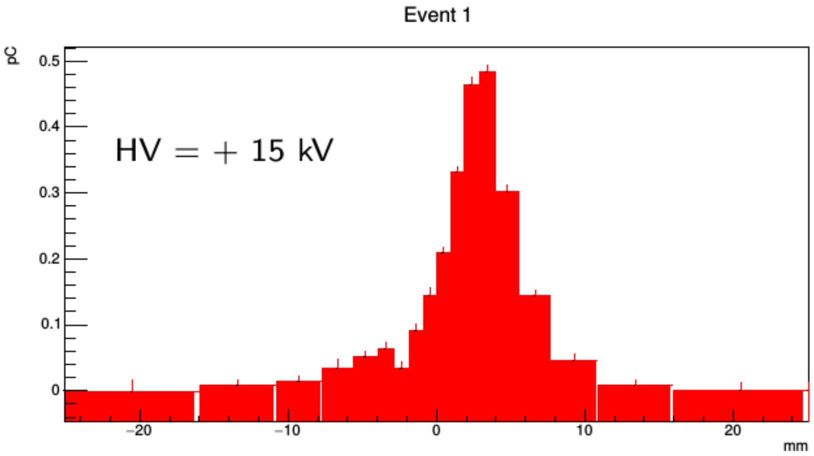
Results ($I_p = 30$ mA)


Event 1

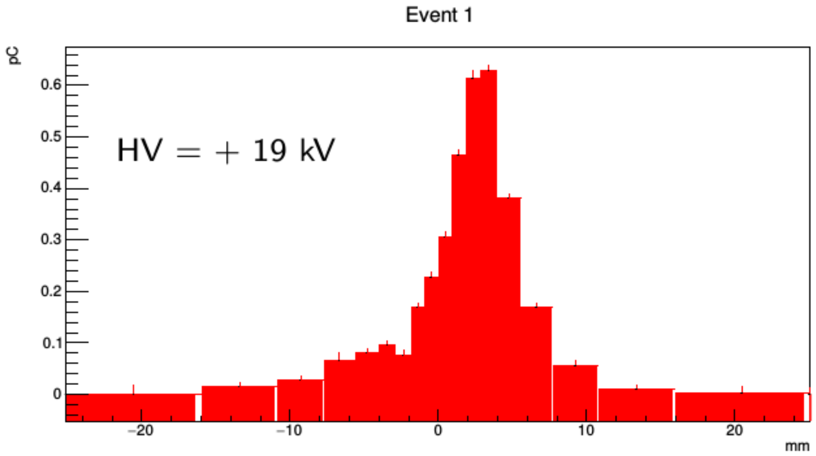
$HV = +5$ kV


Event 1

$HV = +7$ kV


Event 1

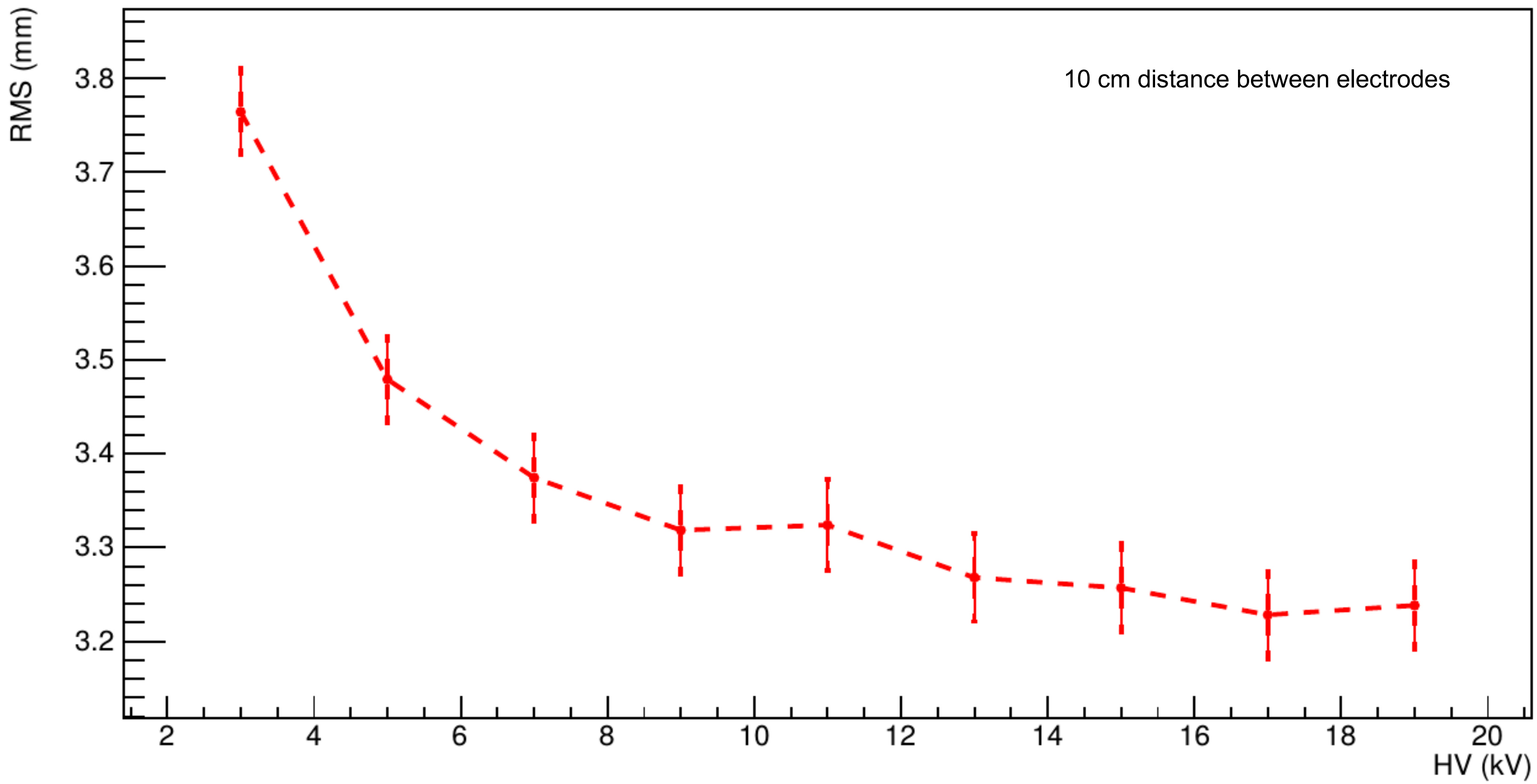
$HV = +15$ kV


Event 1

$HV = +19$ kV

1st Campaign: gaussian strips (2/2)

Results ($I_p = 30$ mA)



Few words about the SC effects (1/3)

Space charge effects

- In beam dynamics: Coulomb repulsion between the charges of a charged particle beam
- In a beam profile monitors: perturbation of the trajectory of a charged particle due to the elm field generated by a pulsed charged beam
  $\Rightarrow$ misreconstruction of the real beam profile

S.C. effects calculation

- Quantification of the deviation of a particle from its ideal trajectory
- Multivariable problem as a function of:
  - beam structure (energy, intensity, bunch frequency, beam width)
  - electric field strength
  - nature of the ionisation products (mass and charge)
  - momenta of the ionisation products at their creation
- In-house code:
  - developed at ESS (Cyrille Thomas, MATLAB)
  - CEA: - implementation of the code into C++
    - plug-in of external files: COMSOL electric fields (F. Benedetti)
      Garfield++ initial electron and ion momenta distributions

TraceWin

- Code to calculate the beam (ion/electron) dynamics in particle accelerators
  In simple world:
  - input: geometry of the beam line through analytic expression or field maps
    source particles
  - output: x,y,z, momenta and phase of the beam at the desired position

Few words about the SC effects (2/3)

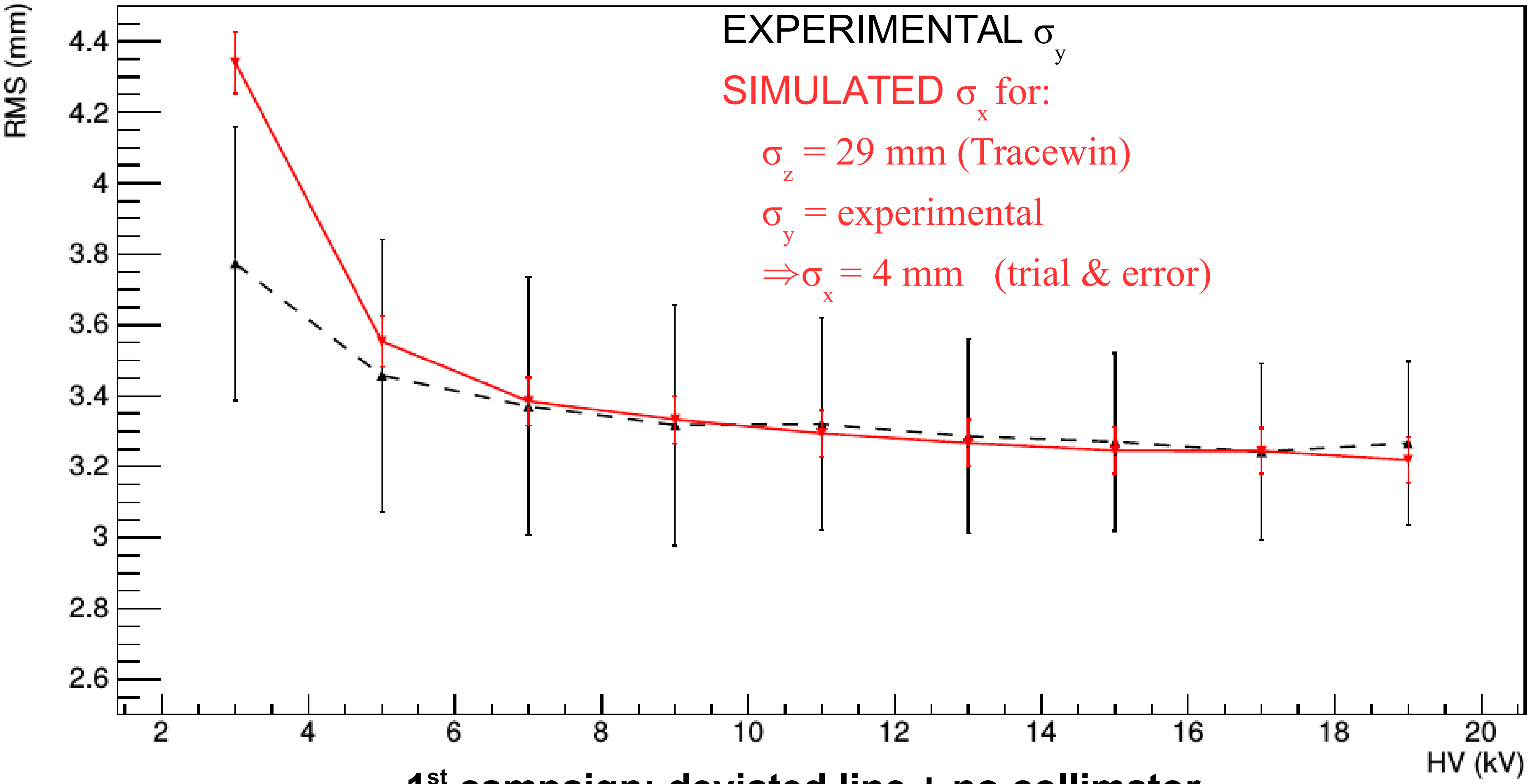
TRACEWIN:

- We asked for a beam of $\sigma_x = \sigma_y = 2.5$ mm or $\sigma_x = \sigma_y = 3$ mm
- We run TraceWin simulations and found the parameters giving such results
- For the configuration $\sigma_x = \sigma_y = 3$ mm it resulted $\sigma_z \sim 29$ mm (Tracewin)

IN-HOUSE SC EFFECT CODE:

- Unfortunately IPHI operators can not be sure of the beam size they provide
- We could measure the beam profile along Y (σ_y) for different voltages and I = 30 mA
- For σ_z we decided to enter in the simulations for the SC effect the Tracewin value
- We therefore tried to find the σ_x value making the simulations for the SC effect to collimate with the exp results

Few words about the SC effects (3/3)

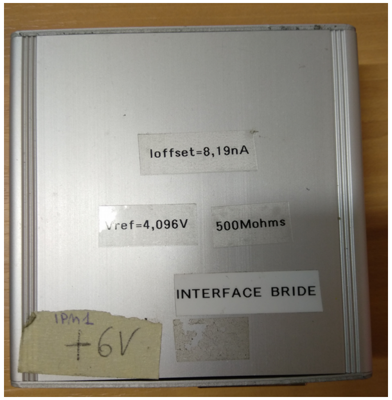


1st campaign: deviated line + no collimator

confirmed $\sigma_x > \sigma_y$

2^{nd} Campaign: detection limit (1/4)

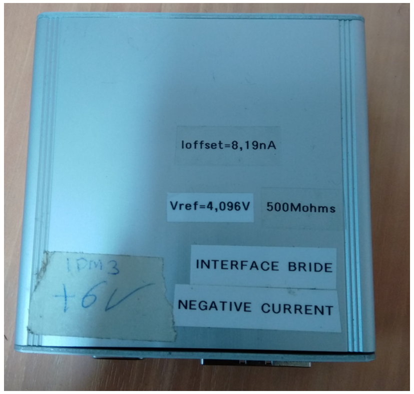
- Strip calibration :



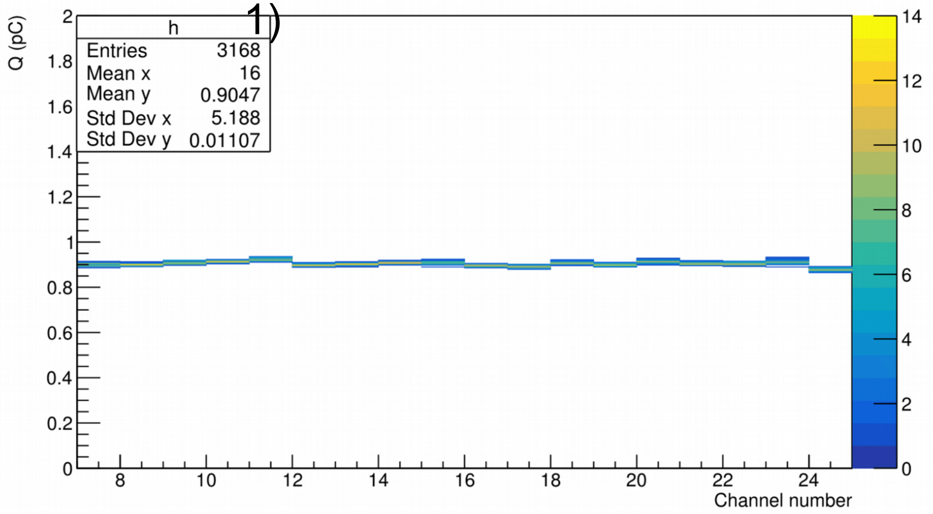
I_{offset} = 8.19 nA

$\text{Integration\_time}_{DAQ}$ = 100 µs

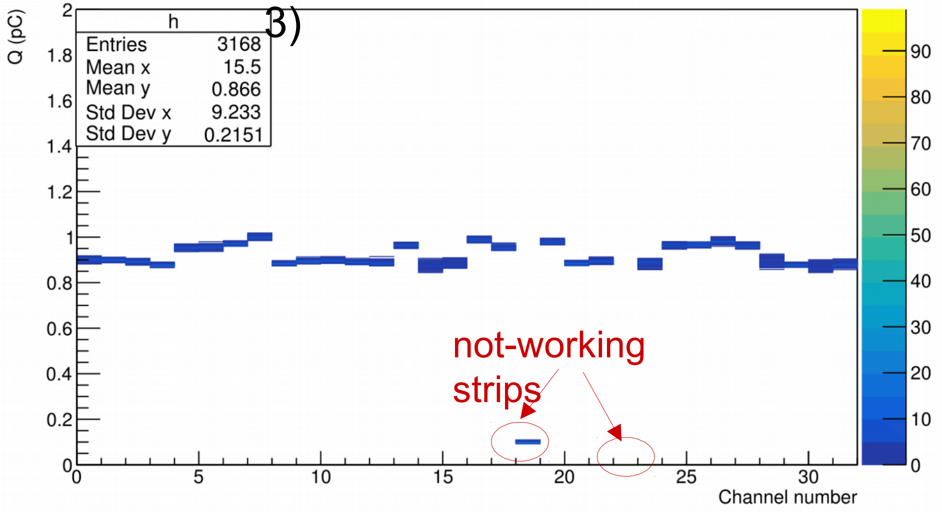
$$Q_i^{offset} = \int_0^{10^{-4}\ s} (8.19 \cdot 10^{-9}\ A)\ dt = 8.19 \cdot 10^{-13}\ C = 0.819\ pC$$



Gaussian read-out (IPM 1)

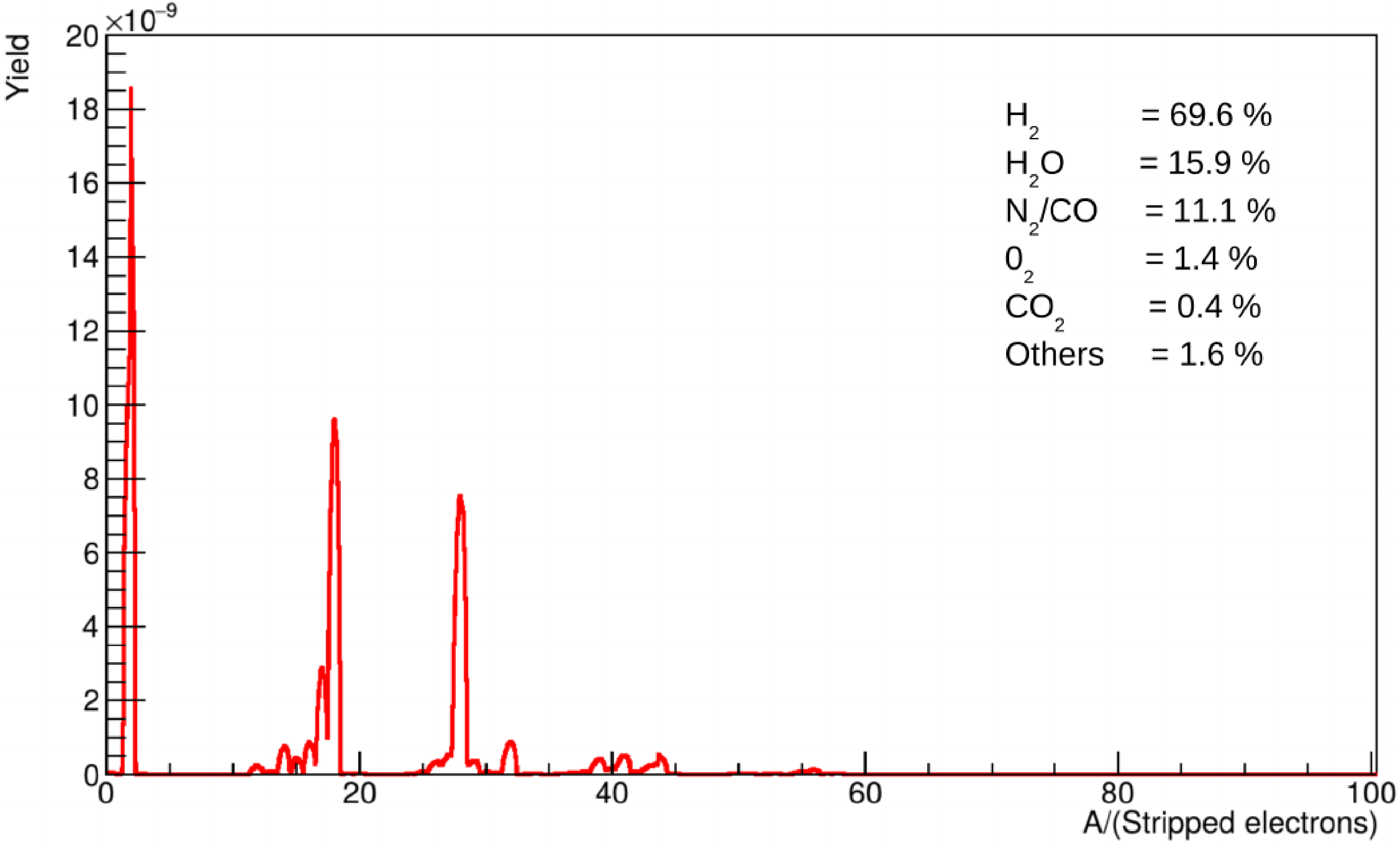


Linear read-out (IPM 3)



2^{nd} Campaign: detection limit (2/4)

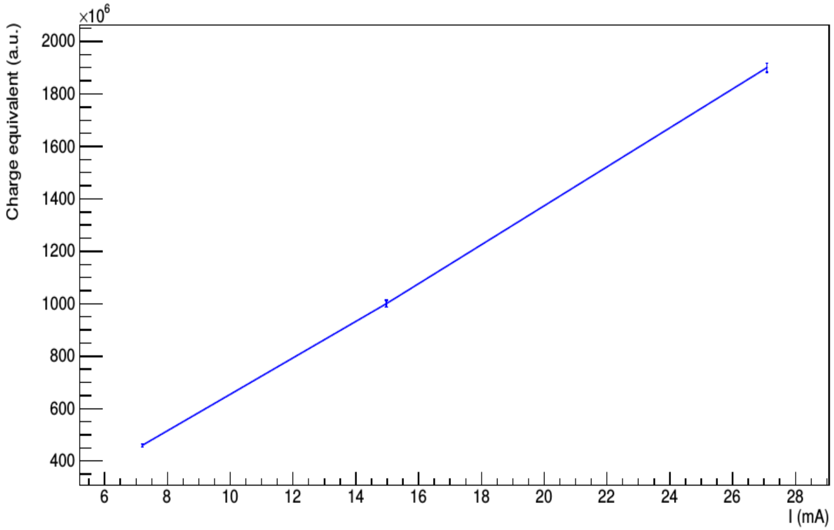
RGA: residual gas analyser (Hiden Analytical Hal-201-rc)

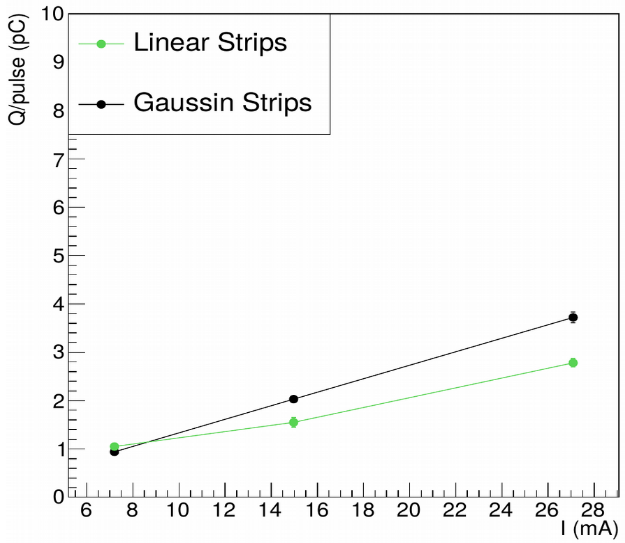


2nd Campaign: detection limit (3/4)

RUN	I (mA)	p (mbar)	GAUSSIAN STPs Q $\pm\sigma_q$ (pC/pulse)	LINEAR STPs Q $\pm\sigma_q$ (pC/pulse)	CAMERA Q $\pm\sigma_q$ (arb. unit)	EXPECT. B-B Q (pC/pulse)	EXPECT. G++ Q (pC/pulse)
1	7.2	$2.9\ 10^{-8}$	0.94 ± 0.06	1.05 ± 0.07	$4.6\ 10^{8} \pm 6.4\ 10^{6}$	0.119	0.119 *0.52
2	14.97	$7.5\ 10^{-8}$	2.03 ± 0.08	1.55 ± 0.10	$1.0\ 10^{9} \pm 1.3\ 10^{7}$	0.649	0.649*0.52
3	27.09	$6.6\ 10^{-8}$	3.72 ± 0.11	2.78 ± 0.09	$1.9\ 10^{9} \pm 1.7\ 10^{7}$	1.034	1.034 *0.52
~~4~~	~~44.6~~	~~$1.1\ 10^{-7}$~~	~~7.34 ± 0.17~~	~~5.72 ± 0.21~~	~~different gain~~	~~2.735~~	~~2.735*0.52~~

point at 44mA discarded because of no possibility of camera validation



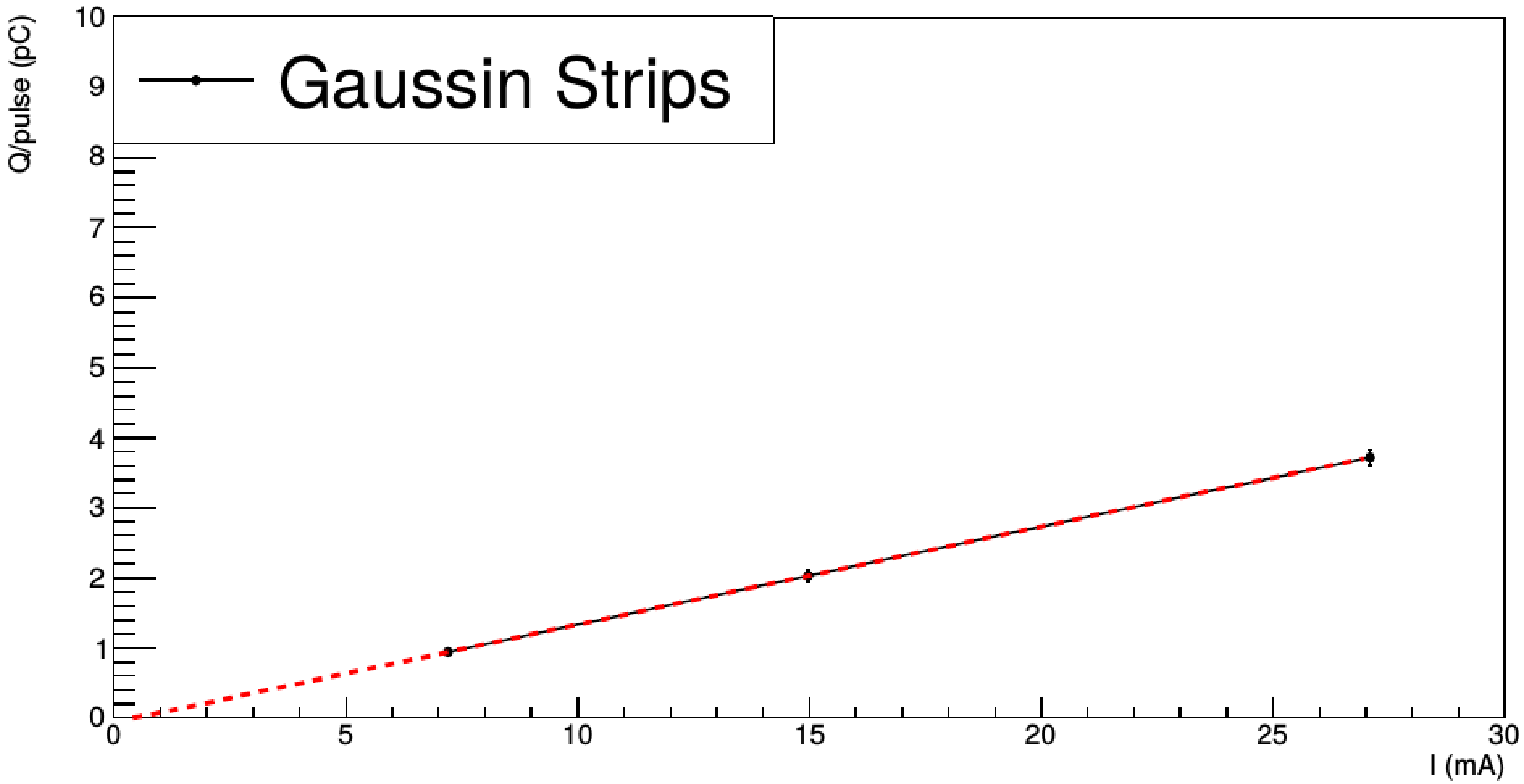


RUN	GAUSS/GAUSS	LINEAR/LINEAR	CAMERA/CAMERA	EXPECT./EXPECT.	INTENS./INTENS.
1/2	0.47 ± 0.02	~~0.68 ± 0.04~~	0.45 ± 0.01	0.18	0.48
2/3	0.55 ± 0.02	0.55 ± 0.02	0.54 ± 0.01	0.62	0.55
3/4	0.51 ± 0.01	0.49 ± 0.02	different gain	0.38	0.60

↑

Linear set discarded

2nd Campaign: detection limit (4/4)



Q = 0 ⇔ I = 0.5 mA

According to Bethe-Bloch Q= 0.5 mA , corresponds to 10^5 electrons/ions created per pulse. 10^5 electrons/ions created per pulse is also the charges expected in the Spoke section at ESS (at 90 MeV) according to Bethe-Bloch

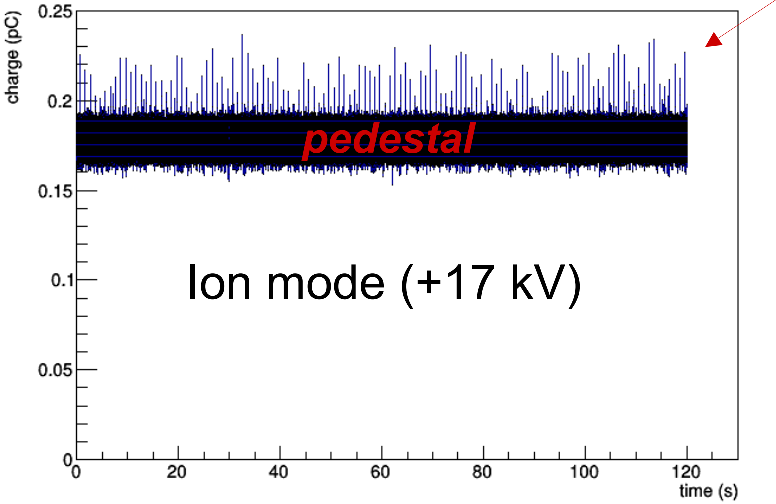
2nd Campaign: problems

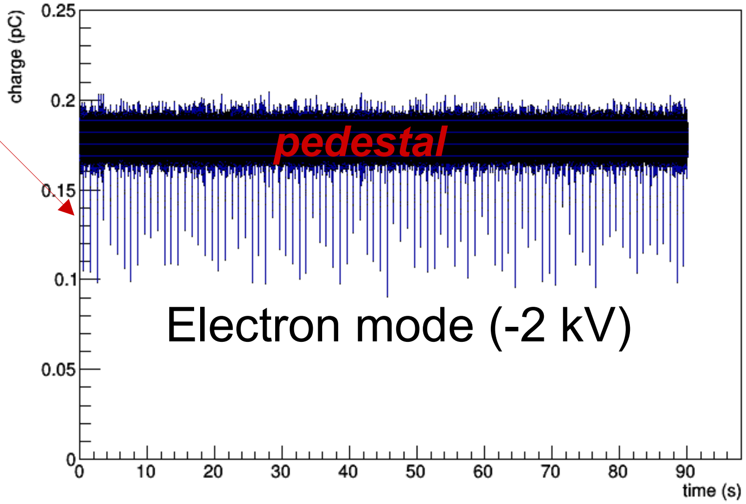
Few words about the signals :

The following pictures are plots of the signal in a single strip as a function of the time for:

- 1st campaign
- gaussian strips alone
- I = 30 mA
- strip number 12
- integration time DAQ = 30 μ s

signals



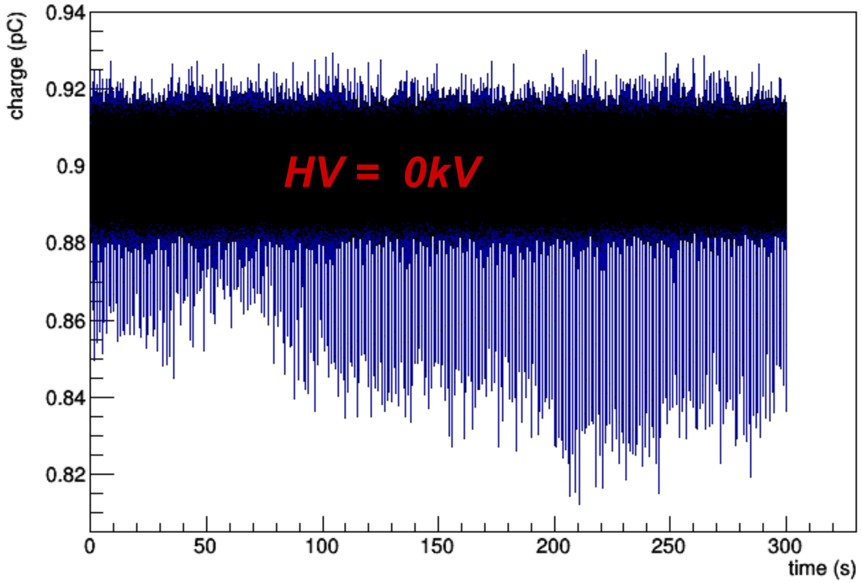


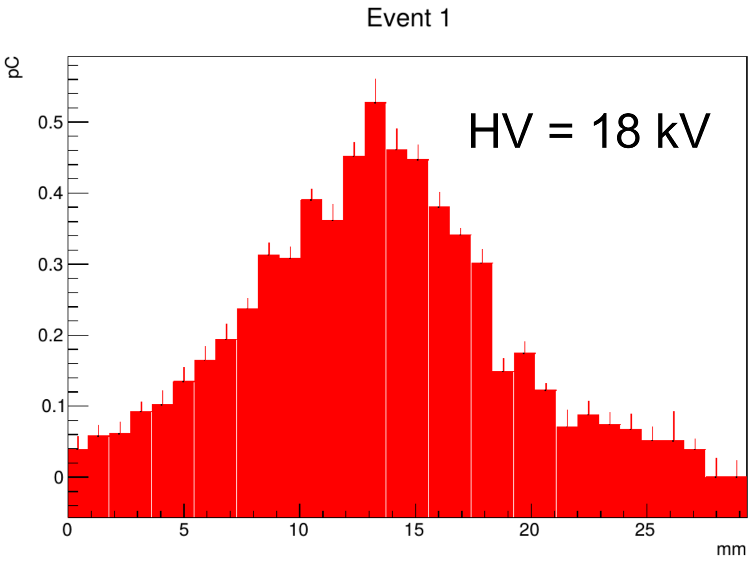
- visible pedestal (= offset+el. noise) and signals every 1 s (pulse ν = 1 Hz)
- positive charges moving towards the signal, result in a positive signal
- negative charges moving towards the strip, result in a negative signal

2nd Campaign: problems

- 2nd campaign
- gaussian strips alone
- I = 25 mA
- strip number 12
- integration time DAQ = 100 μ s

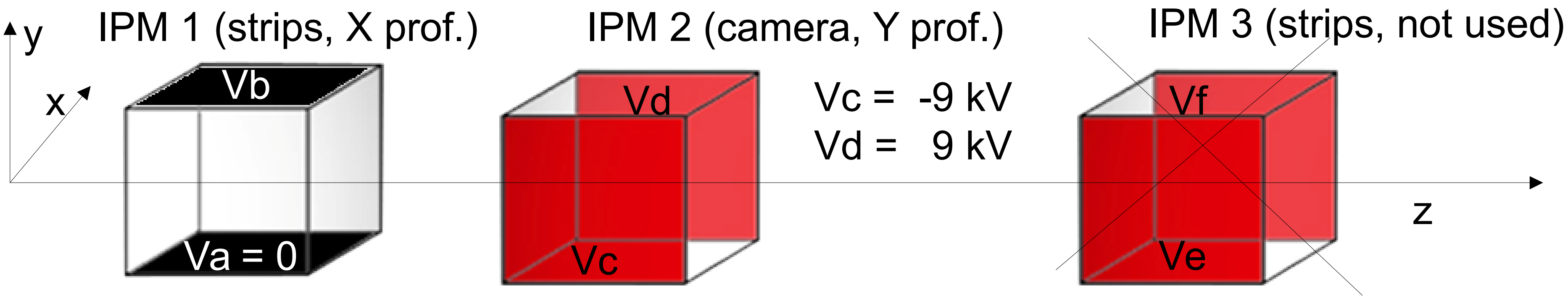
Normally you should collect no charges….but we see negative signals.





- The higher the beam intensity, the “higher” the negative signals (and changing beam intensity results in changing the beam dynamics … no proportionality)
- The lower the electric field, the lower the ion signal collected on the read-outs
- You can reconstruct the beam profile, but the trends of the RMS as a function of the beam intensity and HV are biased.

Electron background: 2nd campaign



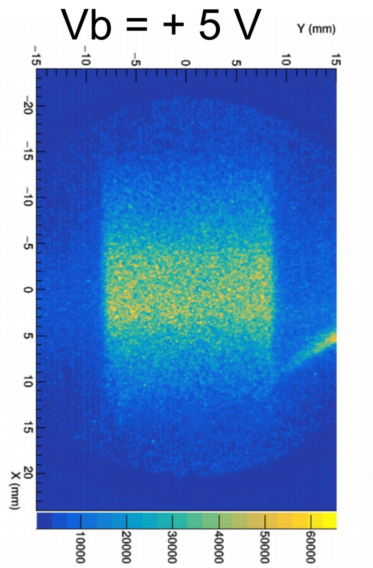
IPM 1 (strips, X prof.)

IPM 2 (camera, Y prof.)

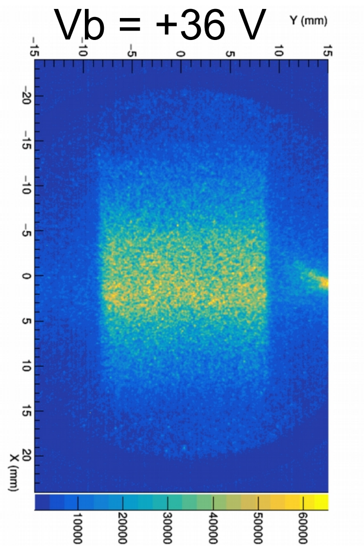
IPM 3 (strips, not used)

Vc = -9 kV
Vd = 9 kV

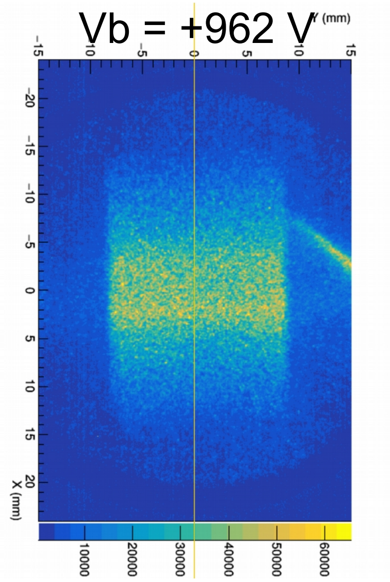
What you see in the IPM2 (camera), i.e. projection on Vd when:



Vb = + 5 V



Vb = +36 V

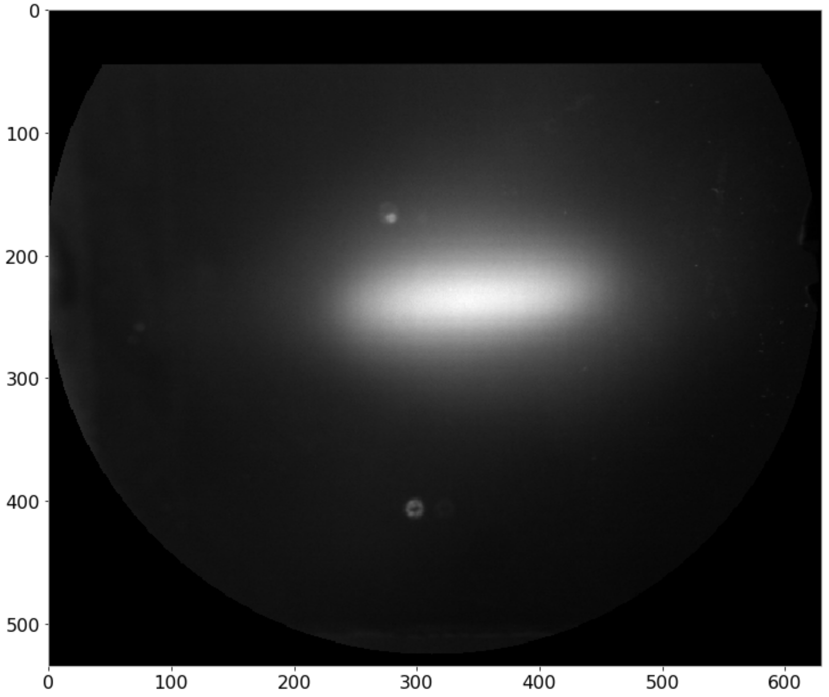


Vb = +962 V

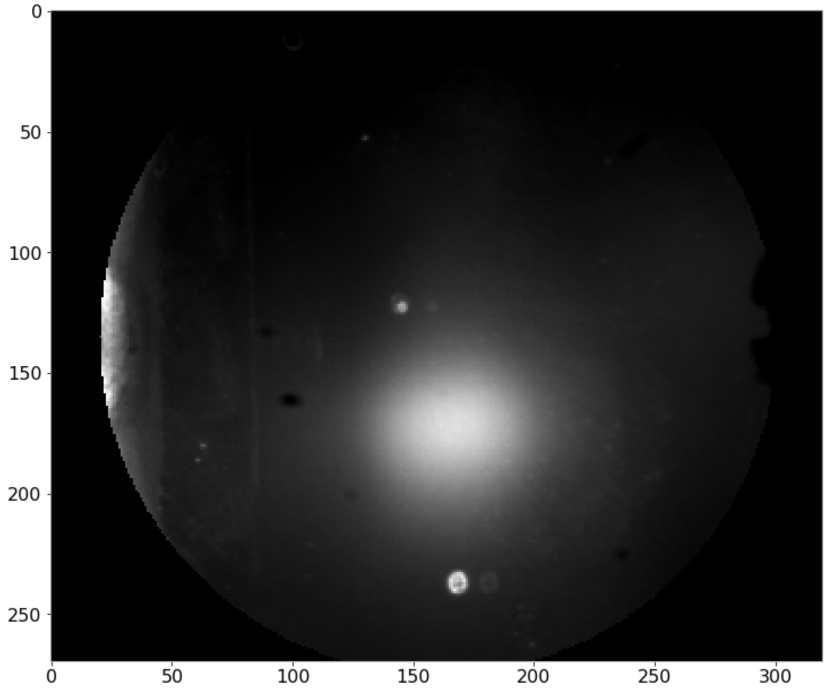
We saw an electron background component, as the beam s hitting somewhere

Electron background

1st campaign



2nd campaign

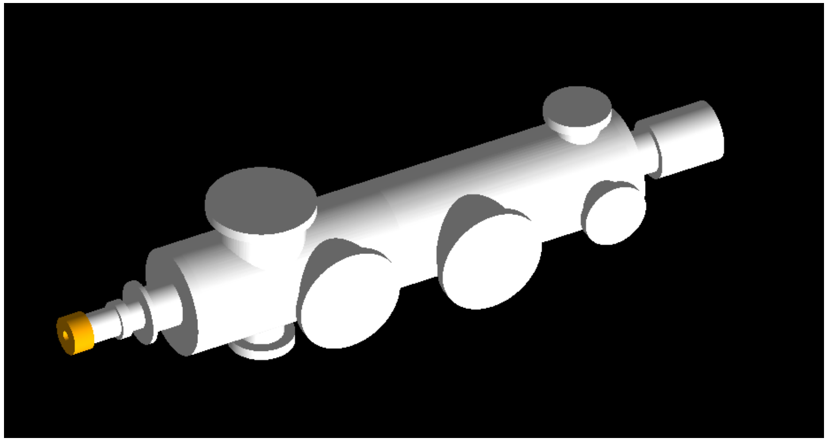


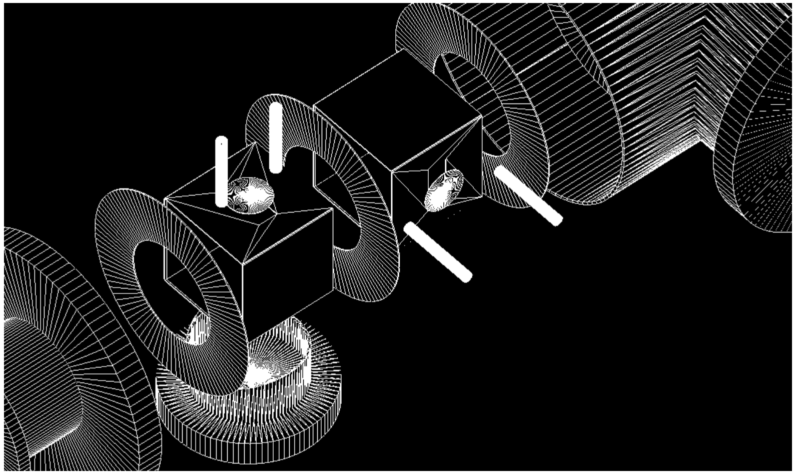
Electron background: 2nd campaign

In the second campaign there was a collimator of (which blackened) . Could it be the source of additional electron background?

GEANT4 simulations BUT

- simple model with few elements
- no idea of beam width and divergence before the collimator
- too few particles shot wrt particles in the beam (much higher statistics needed)





Electron background: 2nd campaign

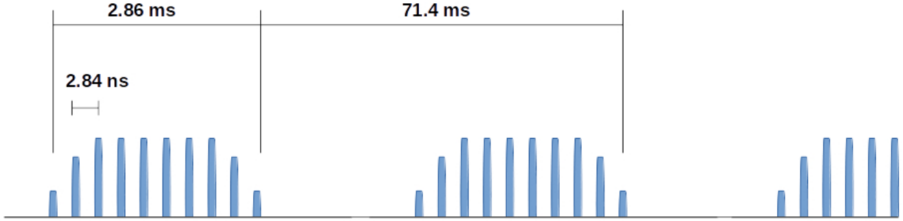
- From the simulations: most of the electrons have energies in the range [100 eV, 10 keV] BUT there is a threshold on the minimum energy creation

- Still opened issue. Possible cause:
  - electrons created by the presence of the collimator and entering the chambers?
  - negative signal induced in the ground of the strip detector through common mechanical ground due to charges hitting the collimator or the chamber?
  - in the first campaign we had protected the read-outs with mylar foils, in the second no

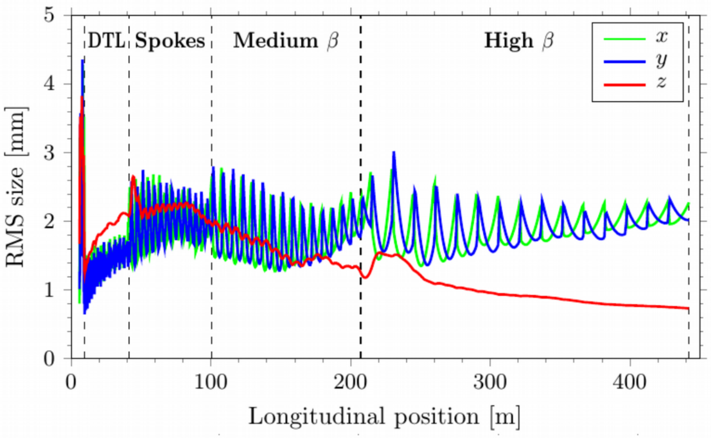
Space charge effects: main results

Parameters on which SCE depends

- Beam “structure” (intensity, spatial spread, energy)?
  - Energy: [90, 2000] MeV
  - Current peak: 62.5 mA
  - Pulse length: 2.86 ms
  - Pulse frequency: 14 Hz (duty cycle 4%)
  - Bunch frequency: 352.31 MHz

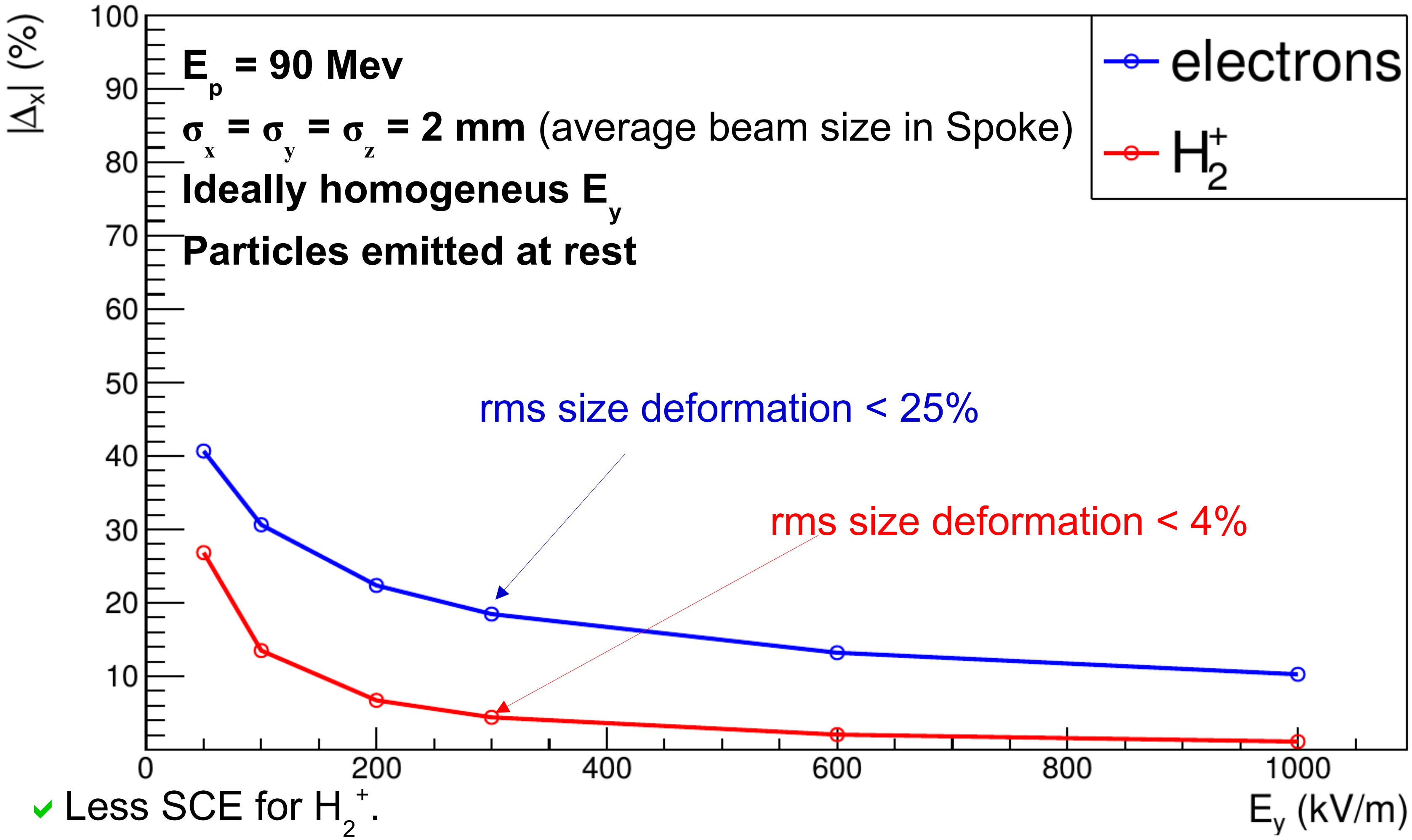


  - σ_x: [1.4 , 3] mm
  - σ_y: [1.4 , 3] mm
  - σ_z: [0.8 , 2.8] mm



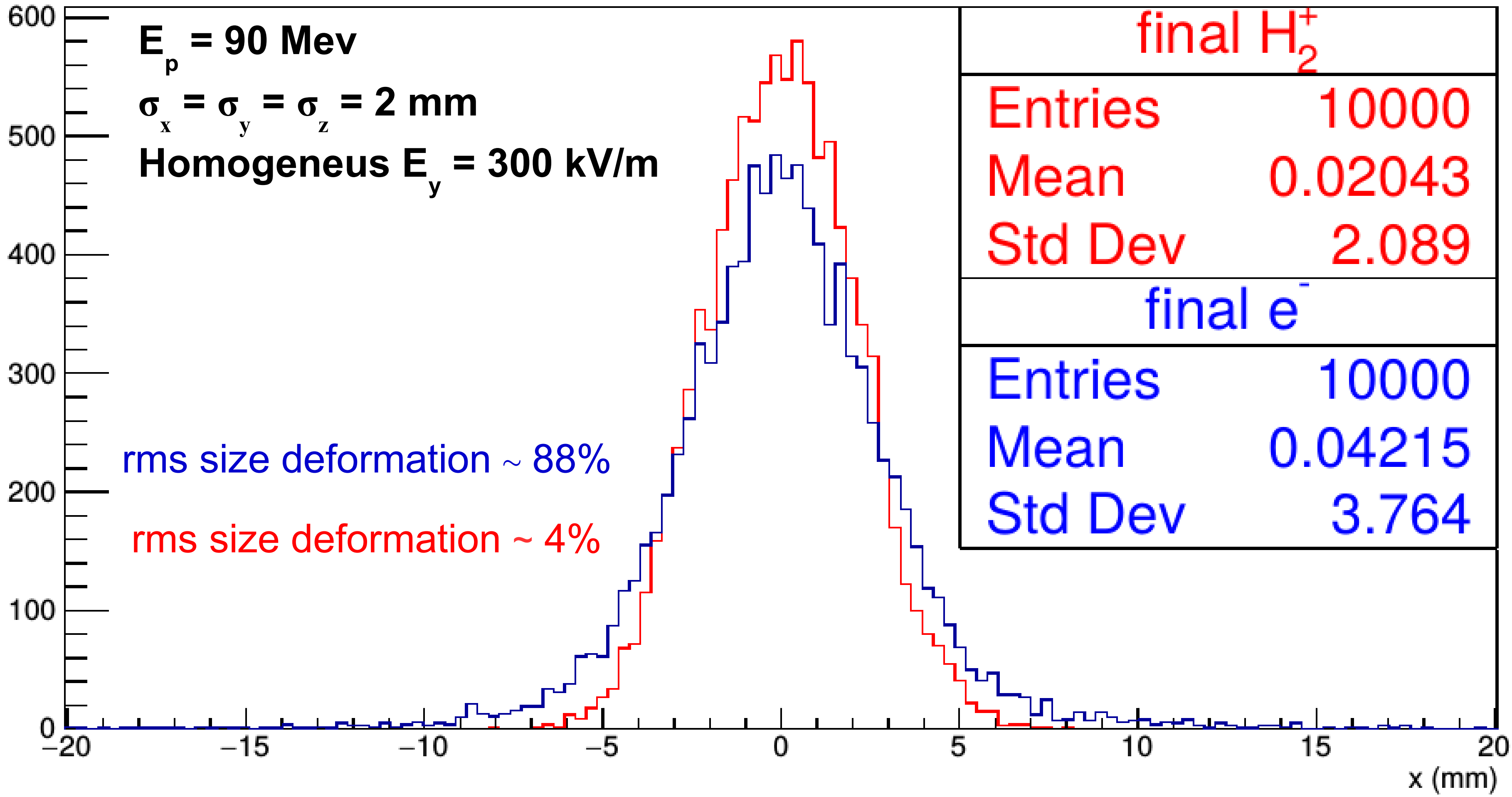
- E field?
- Nature of the tracked ion ⇒ residual gas composition?
  - Nominal gas composition: H_2 (79%), CO (10%), CO_2 (10%), N_2 (1%)
- Initial momenta distribution of electrons/ionised molecules?

SC @ ESS: electric field influence



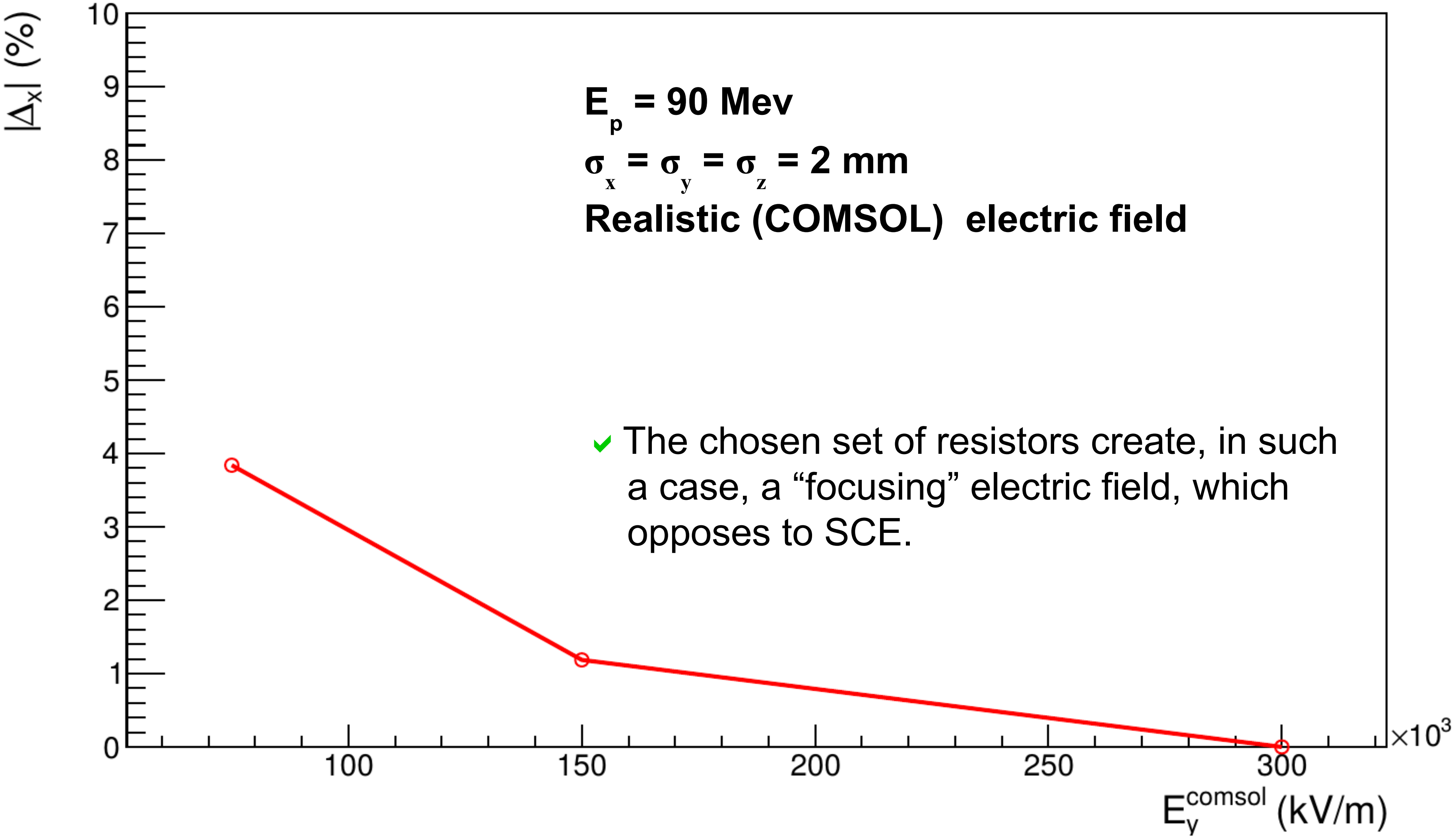
- ✓ Less SCE for H_2^+.
- ✓ Less SCE for higher electric fields (but if too high, you reverse the trend).
- ✓ Much higher HV needed in electron config. to achieve the same as in ion config.

SC @ ESS: Initial momenta influence



✓ Less SCE for H_2^+.

Electric field homegeneity influence



E_p = 90 Mev

$\sigma_x = \sigma_y = \sigma_z = 2$ mm

Realistic (COMSOL) electric field

- ✓ The chosen set of resistors create, in such a case, a “focusing” electric field, which opposes to SCE.

Lessons learnt from simulations

TO MINIMIZE THE SCE

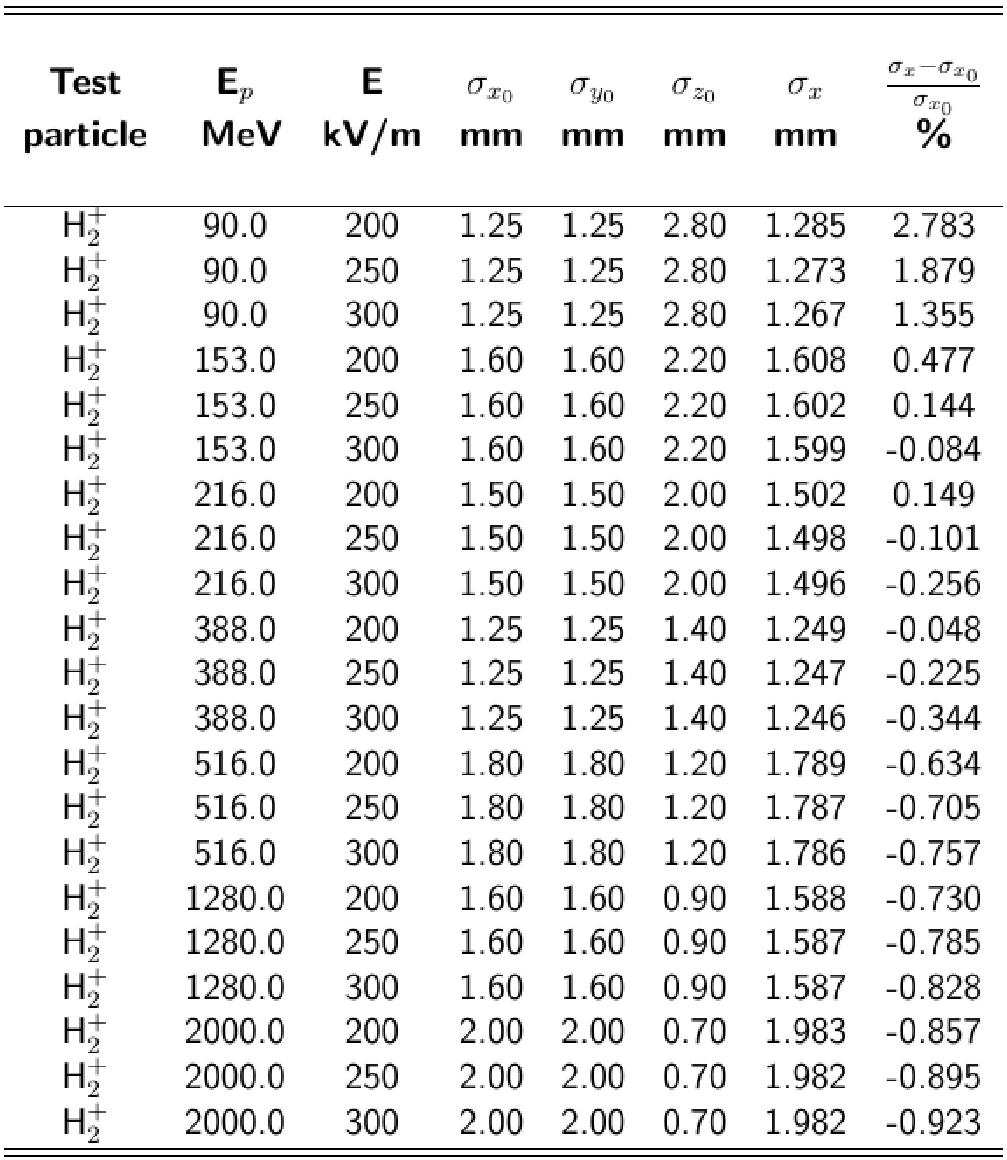
- IPM used in ion configuration
- Initial momenta distribution unimportant only for massive ionization products
- High electric field

IF MEASURES TO MINIMIZE THE SCE ARE FOLLOWED, NO CORRECTION IS NEEDED TO MEET THE L4 ESS REQUIREMENTS

REMINDER:

the total measurement error in the RMS extension of the beam must amount to less than ± 10%. (L4 ESS requirement)

Expected SC @ ESS



Test particle	E_p MeV	E kV/m	σ_{x0} mm	σ_{y0} mm	σ_{z0} mm	σ_x mm	$\frac{\sigma_x-\sigma_{x0}}{\sigma_{x0}}$ %
H_2^+	90.0	200	1.25	1.25	2.80	1.285	2.783
H_2^+	90.0	250	1.25	1.25	2.80	1.273	1.879
H_2^+	90.0	300	1.25	1.25	2.80	1.267	1.355
H_2^+	153.0	200	1.60	1.60	2.20	1.608	0.477
H_2^+	153.0	250	1.60	1.60	2.20	1.602	0.144
H_2^+	153.0	300	1.60	1.60	2.20	1.599	-0.084
H_2^+	216.0	200	1.50	1.50	2.00	1.502	0.149
H_2^+	216.0	250	1.50	1.50	2.00	1.498	-0.101
H_2^+	216.0	300	1.50	1.50	2.00	1.496	-0.256
H_2^+	388.0	200	1.25	1.25	1.40	1.249	-0.048
H_2^+	388.0	250	1.25	1.25	1.40	1.247	-0.225
H_2^+	388.0	300	1.25	1.25	1.40	1.246	-0.344
H_2^+	516.0	200	1.80	1.80	1.20	1.789	-0.634
H_2^+	516.0	250	1.80	1.80	1.20	1.787	-0.705
H_2^+	516.0	300	1.80	1.80	1.20	1.786	-0.757
H_2^+	1280.0	200	1.60	1.60	0.90	1.588	-0.730
H_2^+	1280.0	250	1.60	1.60	0.90	1.587	-0.785
H_2^+	1280.0	300	1.60	1.60	0.90	1.587	-0.828
H_2^+	2000.0	200	2.00	2.00	0.70	1.983	-0.857
H_2^+	2000.0	250	2.00	2.00	0.70	1.982	-0.895
H_2^+	2000.0	300	2.00	2.00	0.70	1.982	-0.923

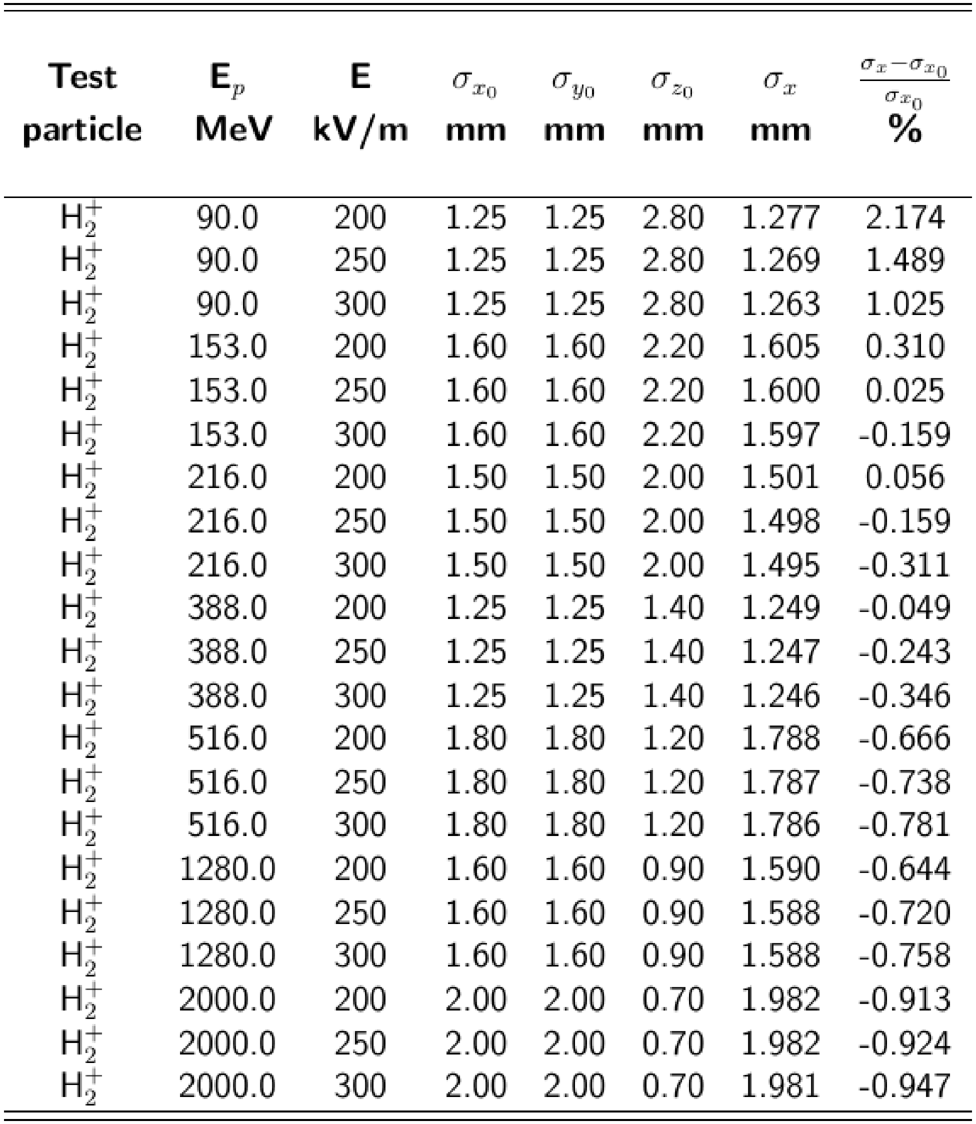
IPM 1: Y projection

- Proton energies:

  Start of Spoke = 90 MeV
  Middle of Spoke = 153 MeV
  End of Spoke = 216 MeV
  Middle of MB = 388 MeV
  End of MB = 516 MeV
  Middle of HB = 1280 MeV
  End of HB = 2000 MeV

- Realistic el. Field
- Initial momenta considered
- Uncertainty on simulations ~ 2%
- No detector resolution considered

Expected SC @ ESS



Test particle	E_p MeV	E kV/m	σ_{x_0} mm	σ_{y_0} mm	σ_{z_0} mm	σ_x mm	$\frac{\sigma_x-\sigma_{x_0}}{\sigma_{x_0}}$ %
H_2^+	90.0	200	1.25	1.25	2.80	1.277	2.174
H_2^+	90.0	250	1.25	1.25	2.80	1.269	1.489
H_2^+	90.0	300	1.25	1.25	2.80	1.263	1.025
H_2^+	153.0	200	1.60	1.60	2.20	1.605	0.310
H_2^+	153.0	250	1.60	1.60	2.20	1.600	0.025
H_2^+	153.0	300	1.60	1.60	2.20	1.597	-0.159
H_2^+	216.0	200	1.50	1.50	2.00	1.501	0.056
H_2^+	216.0	250	1.50	1.50	2.00	1.498	-0.159
H_2^+	216.0	300	1.50	1.50	2.00	1.495	-0.311
H_2^+	388.0	200	1.25	1.25	1.40	1.249	-0.049
H_2^+	388.0	250	1.25	1.25	1.40	1.247	-0.243
H_2^+	388.0	300	1.25	1.25	1.40	1.246	-0.346
H_2^+	516.0	200	1.80	1.80	1.20	1.788	-0.666
H_2^+	516.0	250	1.80	1.80	1.20	1.787	-0.738
H_2^+	516.0	300	1.80	1.80	1.20	1.786	-0.781
H_2^+	1280.0	200	1.60	1.60	0.90	1.590	-0.644
H_2^+	1280.0	250	1.60	1.60	0.90	1.588	-0.720
H_2^+	1280.0	300	1.60	1.60	0.90	1.588	-0.758
H_2^+	2000.0	200	2.00	2.00	0.70	1.982	-0.913
H_2^+	2000.0	250	2.00	2.00	0.70	1.982	-0.924
H_2^+	2000.0	300	2.00	2.00	0.70	1.981	-0.947

IPM 2: X projection

- Proton energies:

  Start od Spoke = 90 MeV
  Middle of Spoke = 153 MeV
  End of Spoke = 216 MeV
  Middle of MB = 388 MeV
  End of MB = 516 MeV
  Middle of HB = 1280 MeV
  End of HB = 2000 MeV

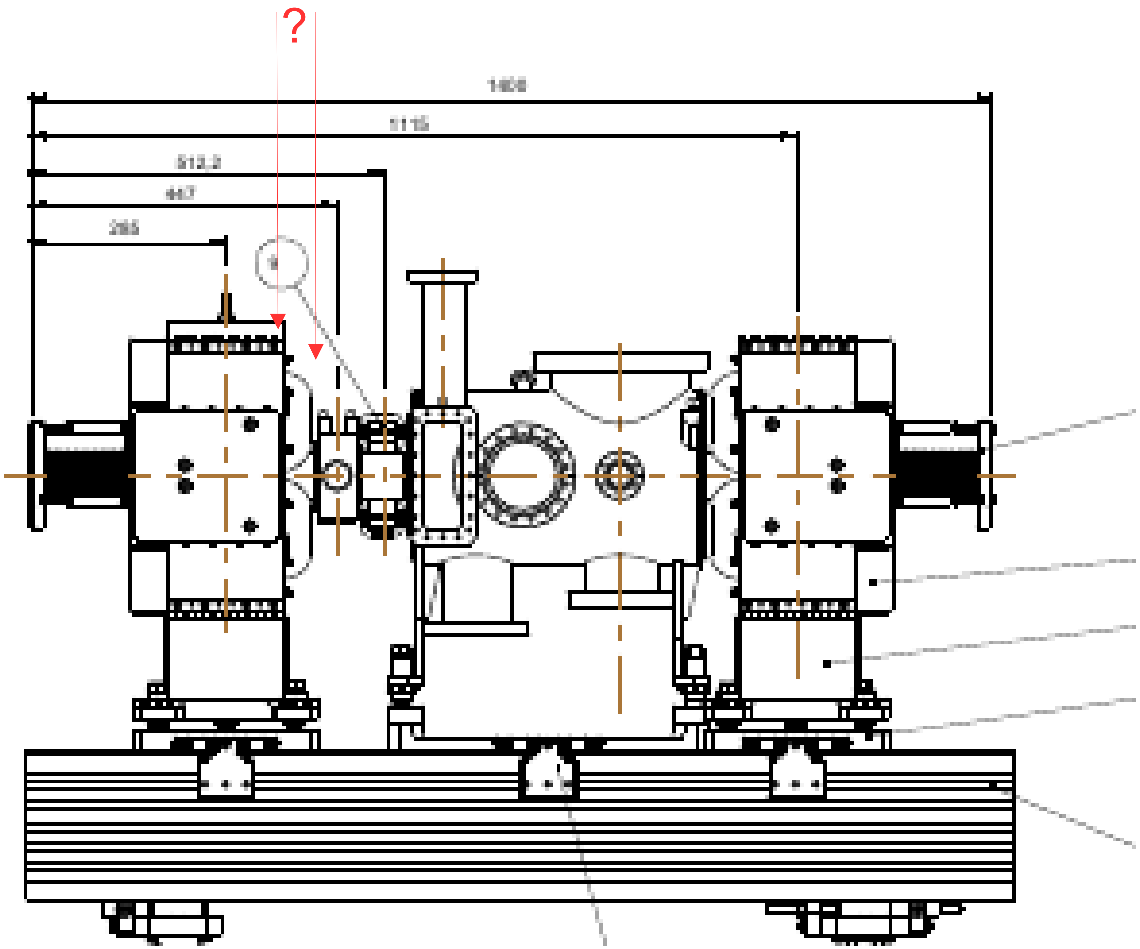
- Realistic el. Field
- Initial momenta considered
- Uncertainty on simulations ~ 2%
- No detector resolution considered

Background: on-going simulations

Background @ ESS

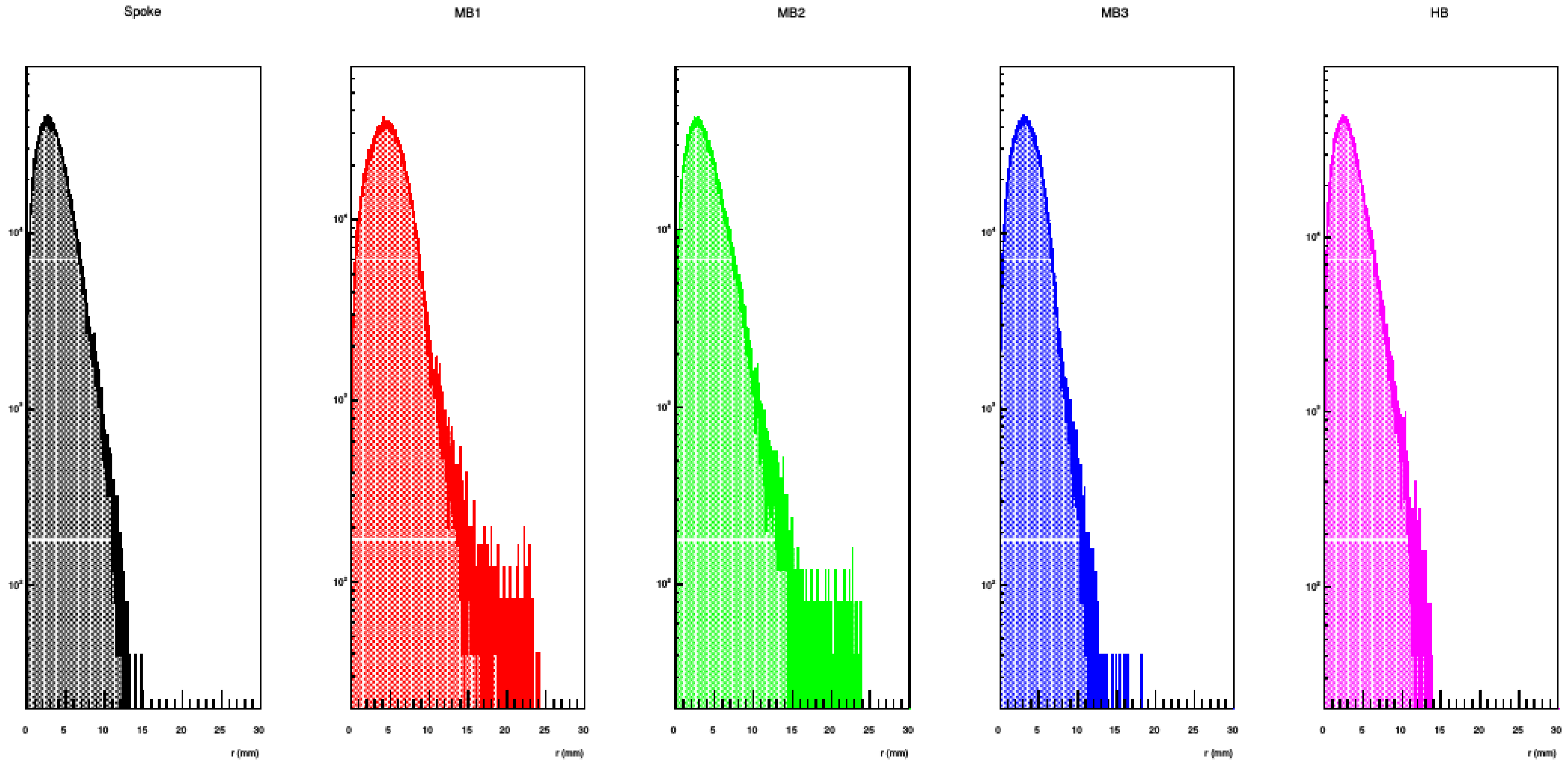
- File provided by ESS (Yngve) containing , at the quadrupole plane, for each surviving proton:

x, x’, y, y’, z, z’, phase, t, E, losses

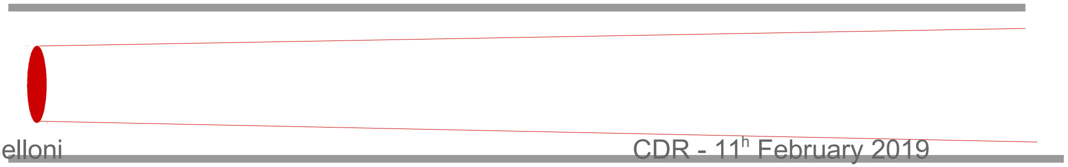


Background @ ESS

- Look at particle distribution at the magnet plane ($r^2 = x^2 + y^2$)



- Look at the maximum cos(theta) at which particles are shoot.
- Add r_{max} from previous slide to the displacement expected at the end of the tube



- Tube radius r = 25 mm
- Tube length L = 170 mm
- $h_{max} = r_{max} + L \sin(theta)$

Background @ ESS

SPOKE: h_{max} = 14.6682 mm + 2.16039 mm < 25 mm
MB1 : h_{max} = 24.0782 mm + 2.0599 mm > 25 mm
MB2 : h_{max} = 23.8285 mm + 2.14193 mm > 25 mm
MB3 : h_{max} =18.2402 + 1.35979 mm < 25 mm
HB : h_{max} =13.8893 mm + 1.02233 mm < 25 mm

Maximum radius and maximum angle not correlated (i.e. not found for the same proton), therefore on the left is the worst case scenario in case of correlation

- Implementation of the ESS chamber MCP disks and tube between quadrupole and the chamber

- GEANT4 Simulations run for the MB2 section. No particle hits the MCPs.

Geometry oversimplified ⇒ necessity to run the simulations with more materials implemented and with other input particles (gammas)

Final remarks

Main conclusions

- Read-outs:
  - mcp necessary for the ESS beam conditions
  - advisable to use mcp + camera since already implemented in EPICS

- Measurement campaigns:
  - Second campaign affected by huge negative signals. On-going investigations through simulations (collimator? Mylar foils?)

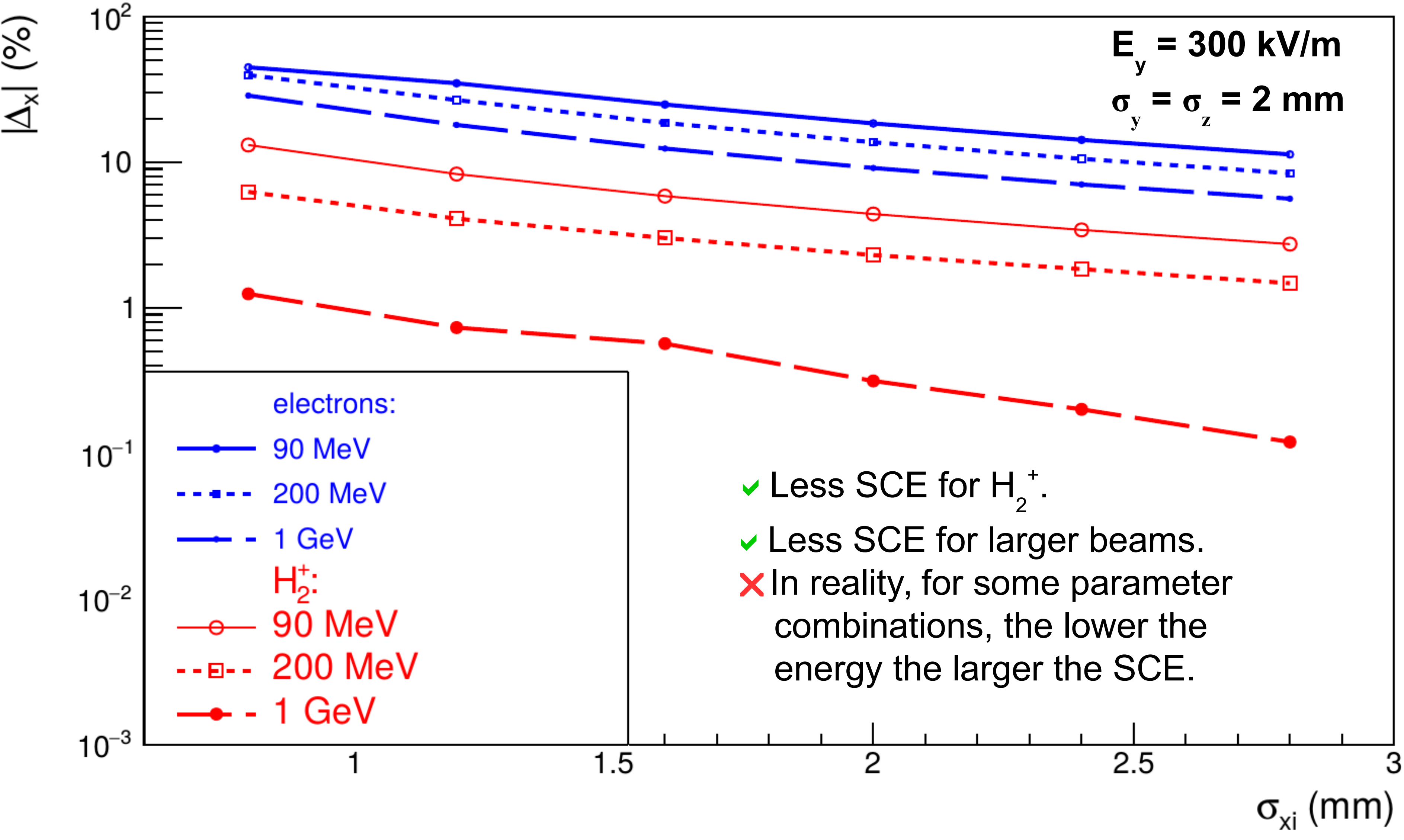
- Space charge effects:
  - Necessary to work ion mode
  - Advisable to use electric field of 250 kV/m in ion mode
  - If electron mode chosen, too high electric field necessary

- Simulations of background
  - On-going.

Conclusions:

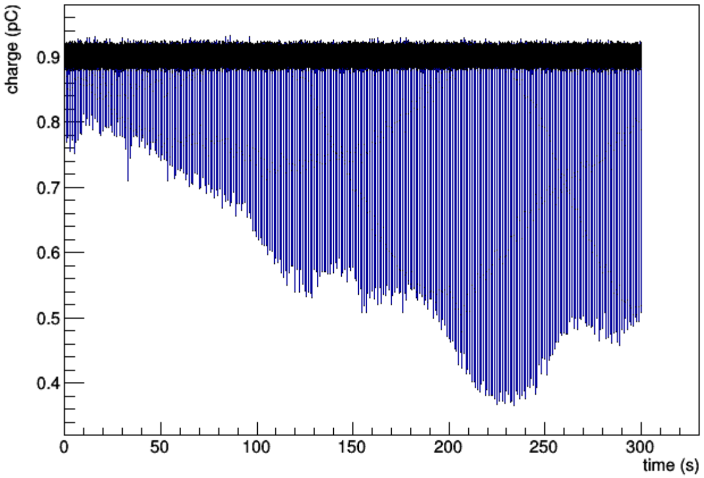
THANK YOU FOR YOUR ATTENTION

SC @ ESS: beam energy influence

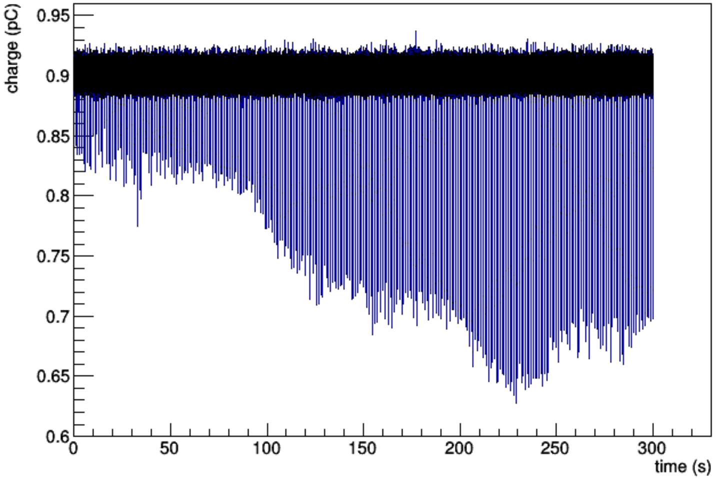


- ✓ Less SCE for H_2^+.
- ✓ Less SCE for larger beams.
- ✗ In reality, for some parameter combinations, the lower the energy the larger the SCE.

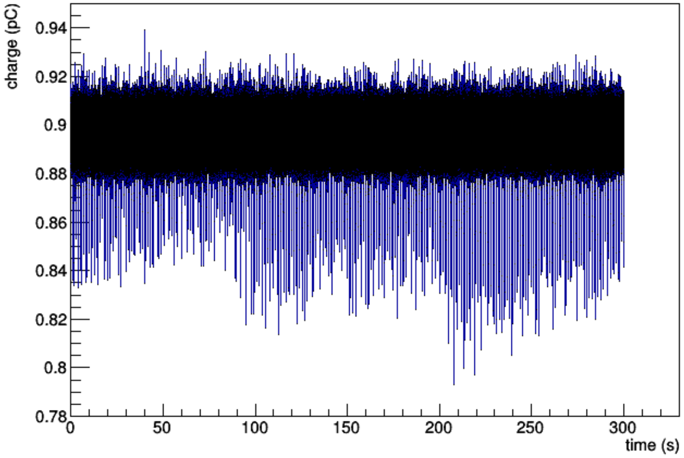
Channel 7



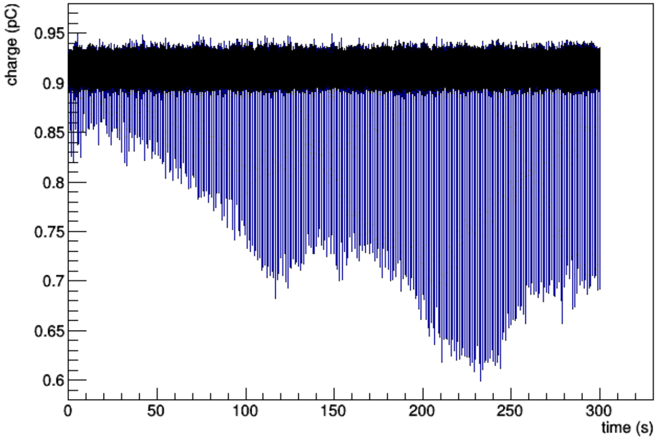
Channel 8



Channel 16

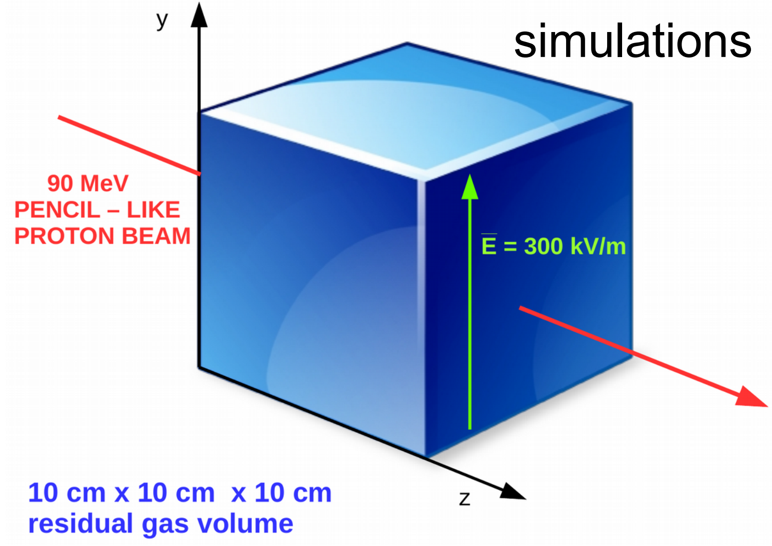


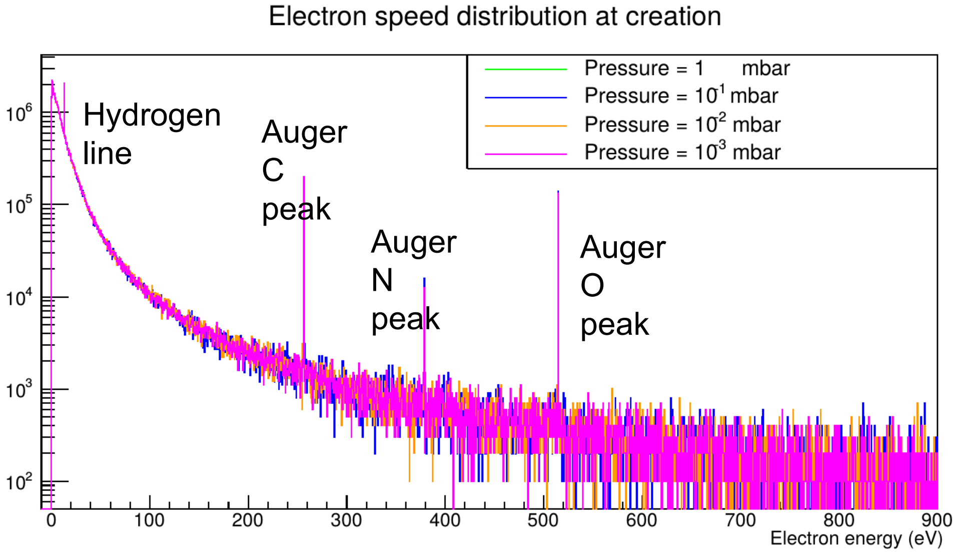
Channel 24



SC @ ESS: initial p influence (1/2):

GARFIELD++ simulations





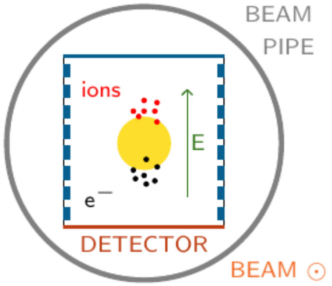
Electrons:

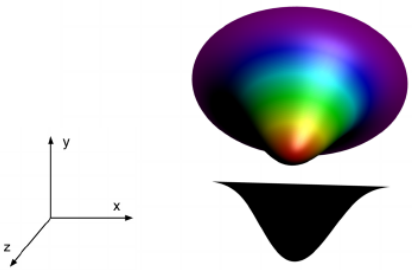
- Azimuthal angle φ uniformly sampled in [0, 2π)
- Emitted preferentially orthogonally to the z axis
- Ionised molecules (assumption): $v_e = \frac{m_{ion}}{m_e} v_{ion}$

Working principle and issues:

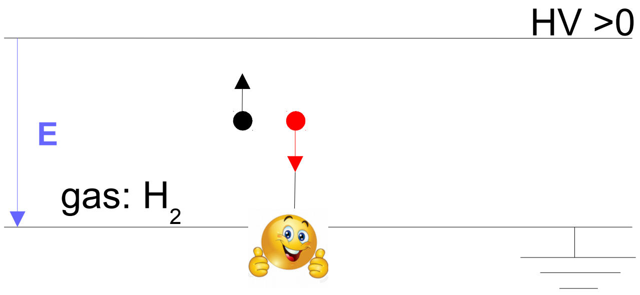
IPM: Ionisation Profile Monitor

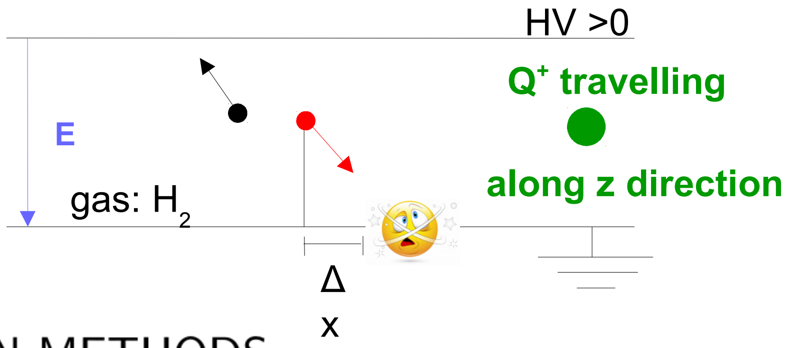
- The proton beam ionises the residual gas
- E separates e$^-$/ionised molecules
- Charge collection on read-out





SPACE CHARGE EFFECTS:





Q^+ travelling

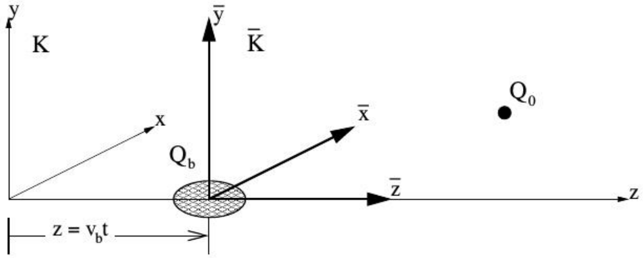
along z direction

POSSIBLE CORRECTION METHODS

- Add magnetic field ✗
- High electric field ✓ ✗
- Software correction ✓

Space charge effect estimation:

General idea:



R. Wanzenberg, "Nonlinear Motion of a Point charge in the 3D Space Charge Field of a Gaussian Bunch"

- A Gaussian bunch with charge Q_b is moving with velocity v_b along the z-axis in the lab. frame K.
- The bunch is at rest w.r.t. the co-moving frame K.
- The Φ generated by Q_b is calculated in the co-moving frame → $\nabla^2\Phi(\bar{x},\bar{y},\bar{z}) = -\frac{1}{\epsilon_0}\rho(\bar{x},\bar{y},\bar{z}).$
- The E field generated by Q_b is calculated in the co-moving frame → $\bar{\boldsymbol{E}} = -\boldsymbol{\nabla}\Phi$
- Through Lorentz transformations, the E field in K is translated into an electromagnetic field in K.

$$\boldsymbol{E} = \begin{pmatrix} E_x \\ E_y \\ E_z \end{pmatrix} = \begin{pmatrix} \gamma_b \bar{E}_x \\ \gamma_b \bar{E}_y \\ \bar{E}_z \end{pmatrix}, \quad \boldsymbol{B} = \begin{pmatrix} -\gamma_b \beta_b \bar{E}_y/c \\ \gamma_b \beta_b \bar{E}_x/c \\ 0 \end{pmatrix} = \frac{\beta_b}{c}\begin{pmatrix} -E_y \\ E_x \\ 0 \end{pmatrix}.$$

- **F** = Q_0(**E** + **v** x **B**) ⇒ acceleration ⇒ speed ⇒ displacement … therefore trajectory of Q_0 in the elm field generated by Q_b.

Remind:

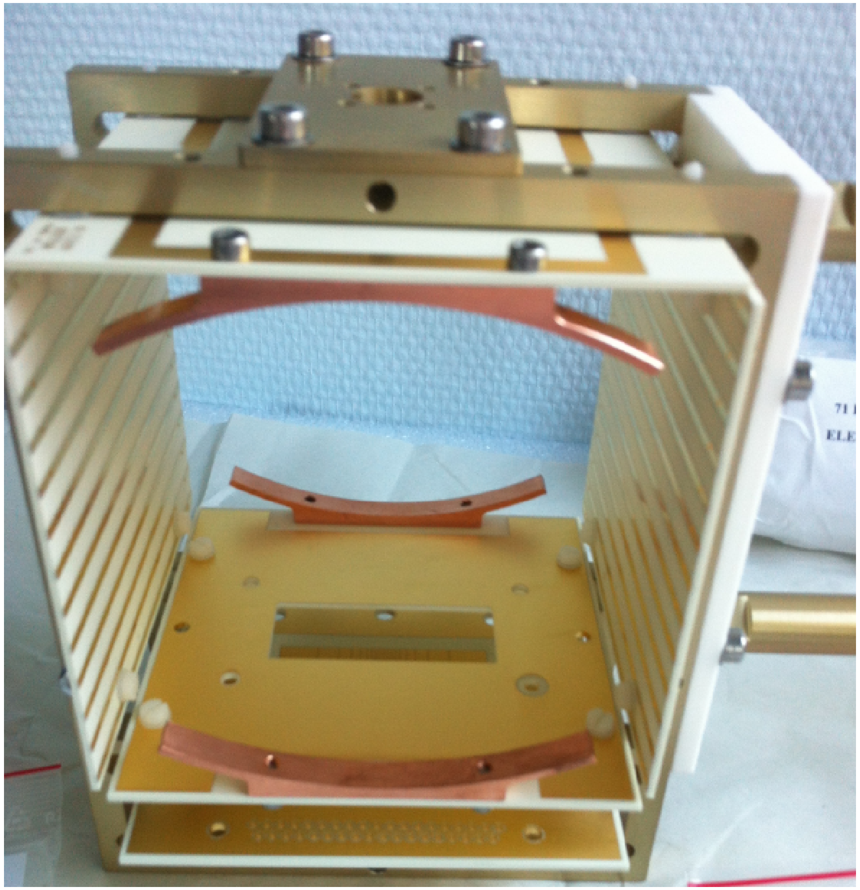
- The Coulomb interaction between the ionisation charges is neglected ($Q_{\text{proton bunch}}$/ $Q_{\text{ionisation charges}} \geq 10^4$)

Space charge effect estimation:

Implementation (ESS core + CEA development & optimisation):

- 10^4 test particle Q_0 are generated in the center of the IPM [at rest or with momentum]
- The test particles are generated following a Gaussian distribution σ_x, σ_y, and σ_z which reflects the beam width along x,y and z
- The test particles are tracked as previously described [External electric field ideally perfect or COMSOL generated]
- The SCE is given by the difference between the initial and final RMS of the Q_0 distribution

Electric field homegeneity influence:



COMSOL simulations of the El field in the IPM:

- The value of the resistors was optimized with COMSOL in order to get the best electric field uniformity
- Different sets of resistors were chosen for different potential difference configurations