Monte-Carlo studies for the *ep*-elastic scattering

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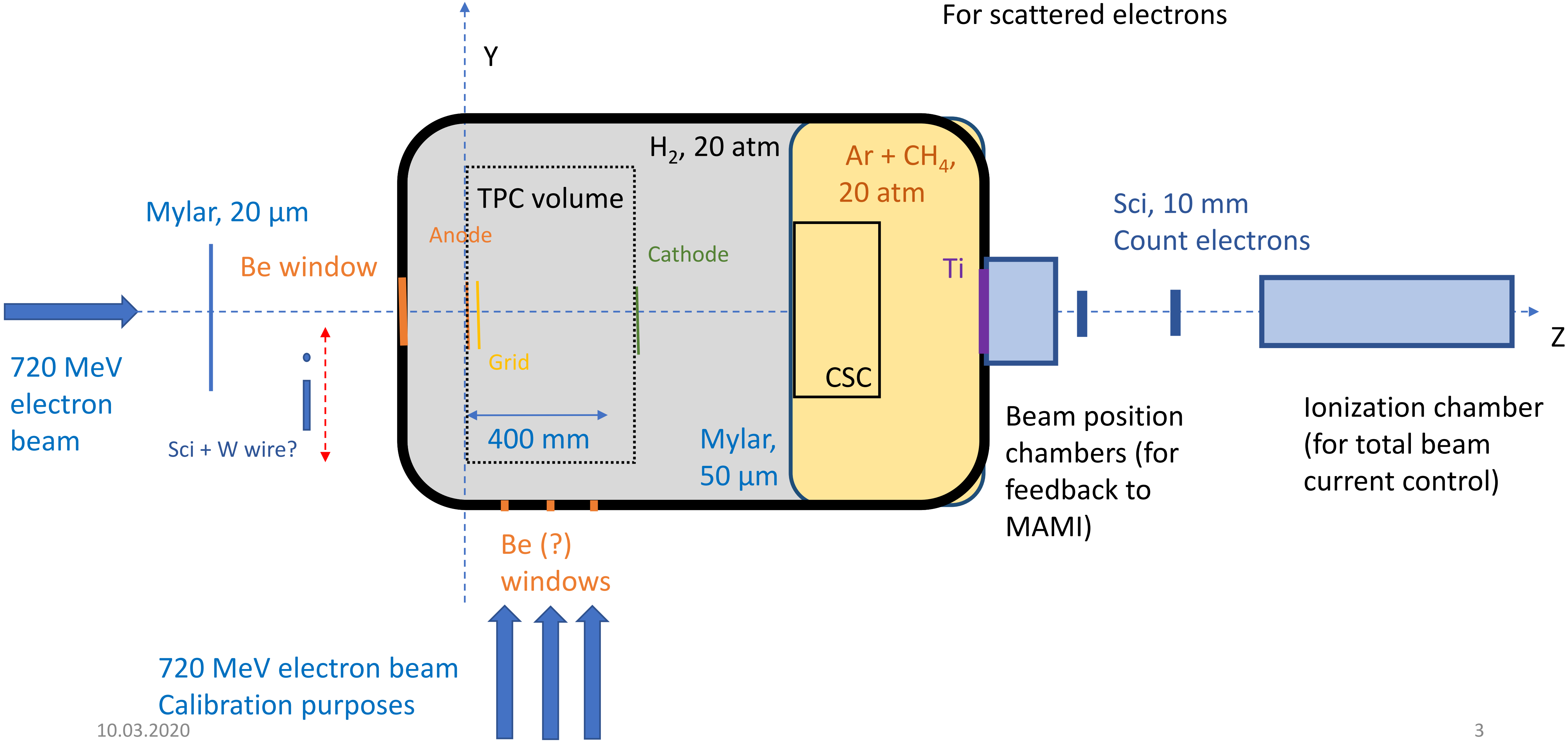
I’m going to discuss

- Some thoughts on what computer modelling of the *ep*-elastic scattering experiment should contain
- Which simplifications can be and are already done
- Which answers we’ve already gotten from Monte-Carlo (MC)

Note: Now MC is a bunch of different calculations made more like scripts, but not as a one big project (hope it will be changed soon).

A setup

CSC = Cathode Strip Chamber
For scattered electrons



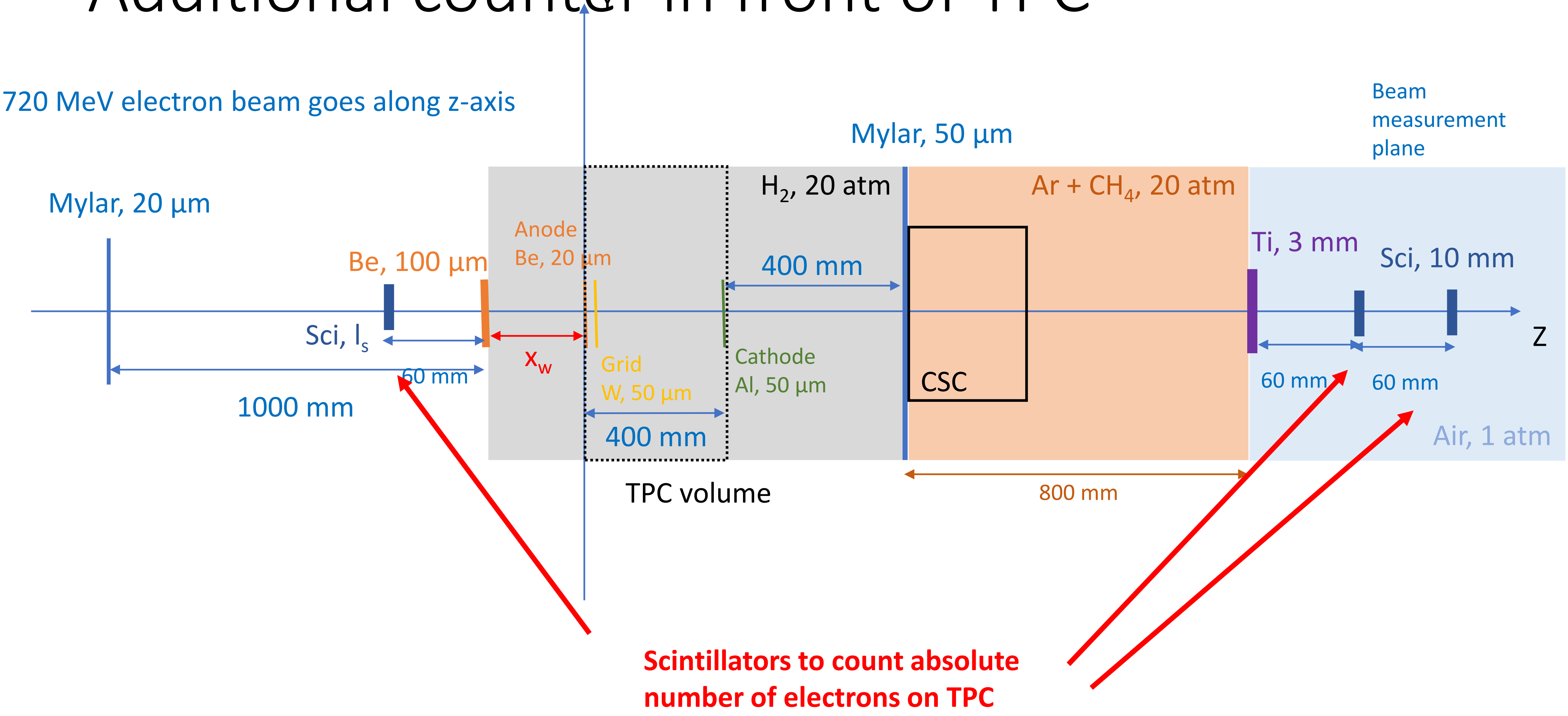
Run / detector conditions for MC

- Beam model
  - ***Time distribution for incoming electrons***; mean beam frequency – f_b;
  - 2D beam spatial distribution – $\text{Gaus}_x(\mu_{bx},\sigma_{bx})\times\text{Gaus}_x(\mu_{by},\sigma_{by})$
  - Beam direction distribution – $\text{Gaus}_p(\mu_{p\vartheta},\sigma_{p\vartheta})\times\text{Uniform}_{p\varphi}(-\pi,\pi)$
- Geant-4 (***detector model***) provides ionization
- TPC time resolution model
  - Drift velocities – W_{d1}, W_{d2}; ***Recombination***(r_{hit}, f_b); ***(x,y)-smearing***(r_{hit}, f_b)
  - **Accepting** due to not clean gas.
  - TDC parameters:
    - N_{ch}, Δt_{ch}; → t_i – TDC channel
    - Energy to TDC response – C_{TDC};
    - ***Noise spectrum***
  - Time-pulse function – $\delta_{Dirac}(t_i)$ → ***Some distribution***(t,t_i,T_j)

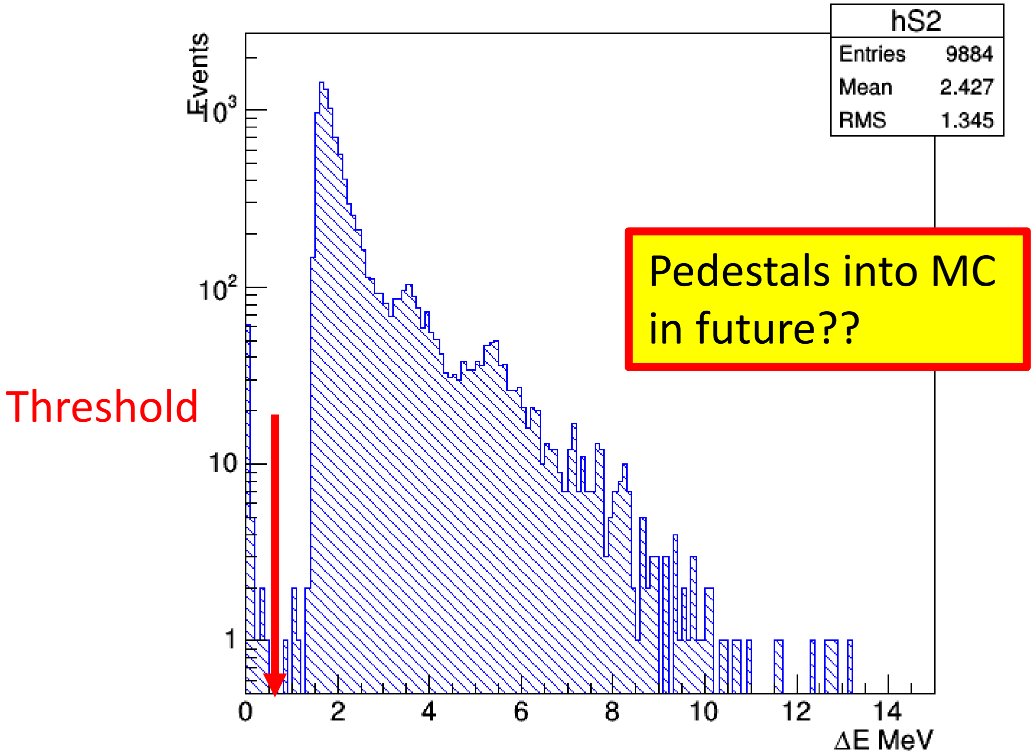
These conditions must be included into Monte-Carlo to have is as closer to the data as possible to mimic operation conditions as a function of (beam)time

Beam rate control with scintillators

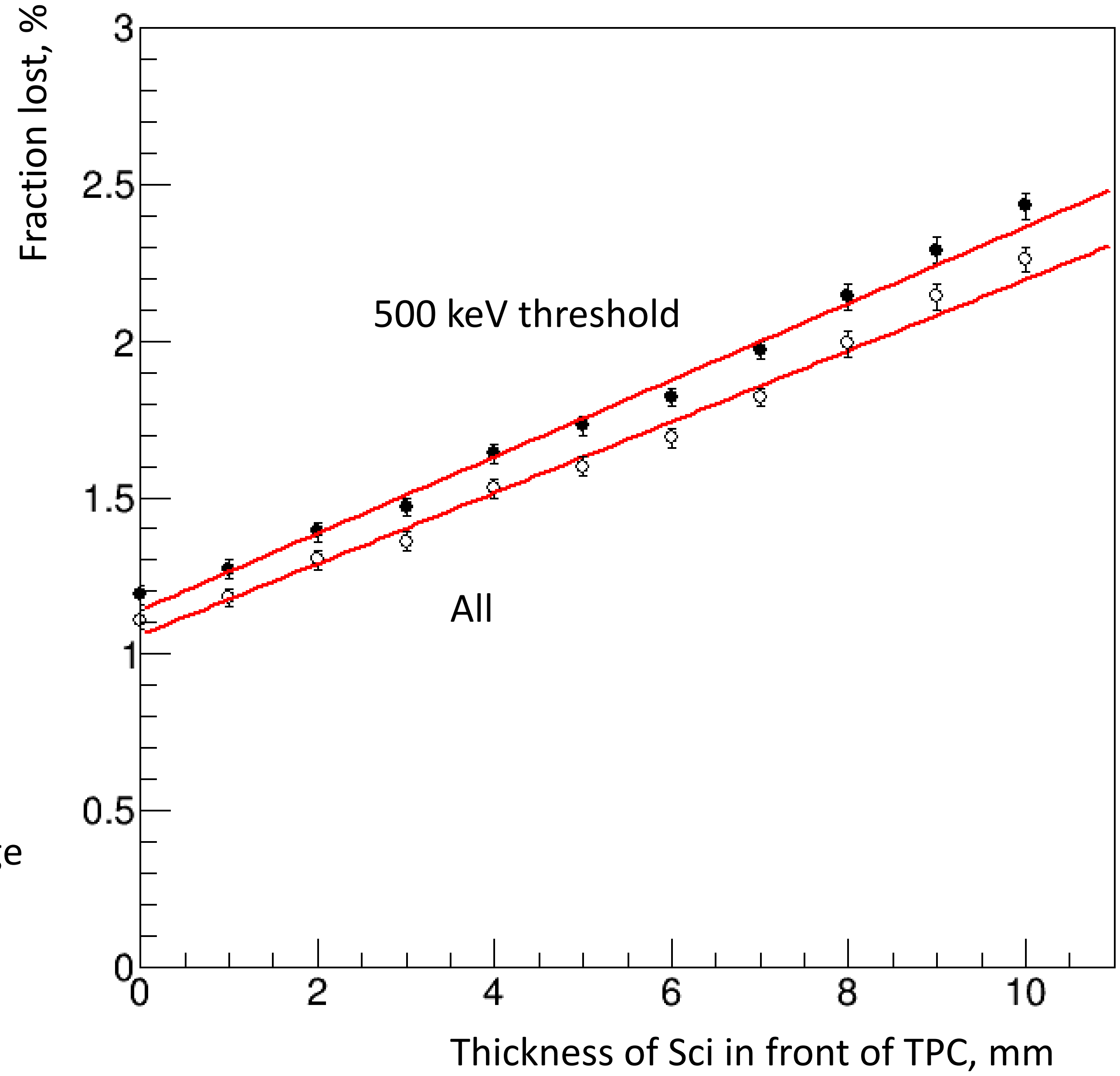
Additional counter in front of TPC



Energy loss in scintillator behind TPC



Fraction of electrons, which are lost in TPC



- Leaner approximation works but not perfect
- Seems it will underestimate zero-value is measurements will be done in 5-10 mm range and extrapolated into 0
- **Lost due Ar + CH4 gas!**

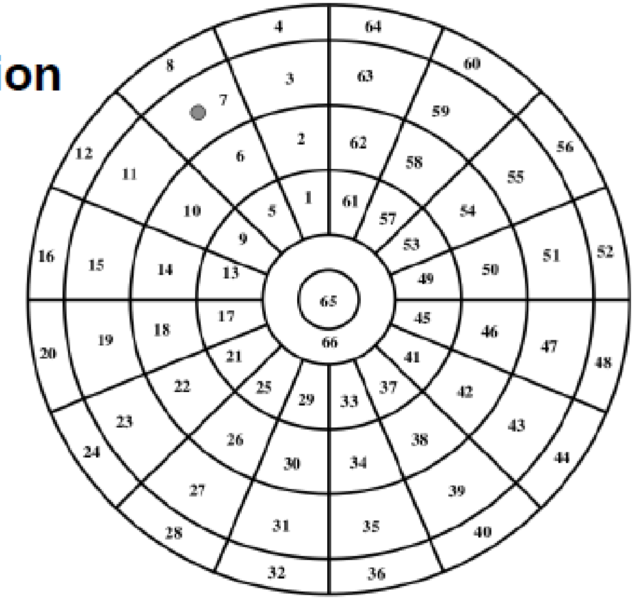
Alignment of scintillators

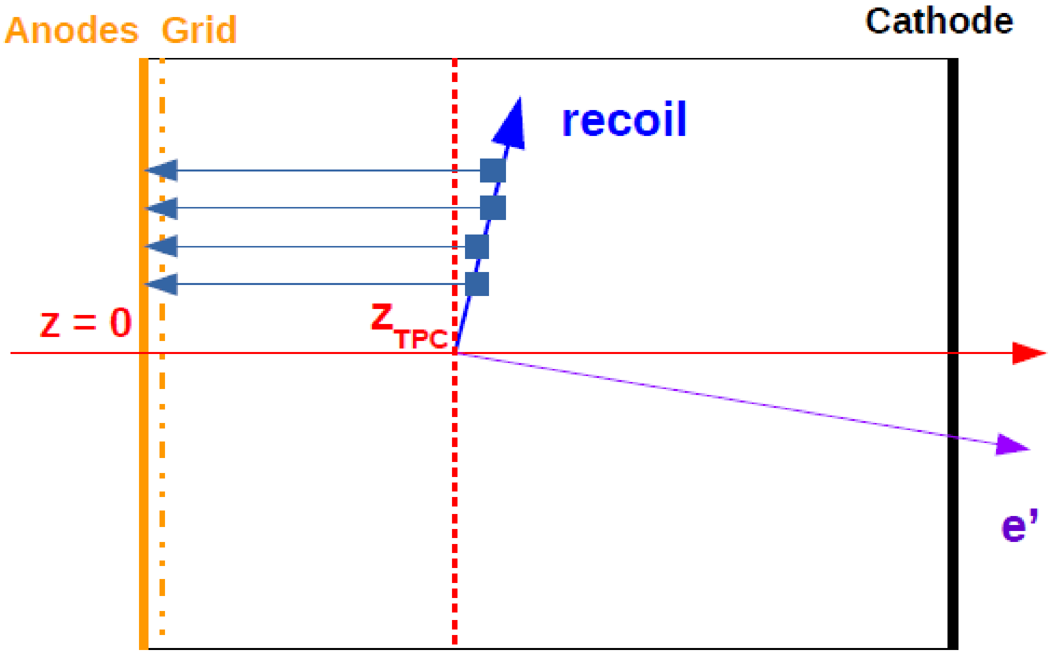
- Lost fraction doesn’t depend on small shifts (**<0,5 mm**) of scintillators along X and Y axes.
- Several positions were tested
    - Shift of one scintillator in X or X&Y direction
    - Shift of two scintillators in same (one) direction
    - Shift of two scintillator in opposite directions (one axis)
    - Shift in opposite directions for two axis
- No effect is found within uncertainties

TPC signal and noises

Simplifications (TPC-prototype example)

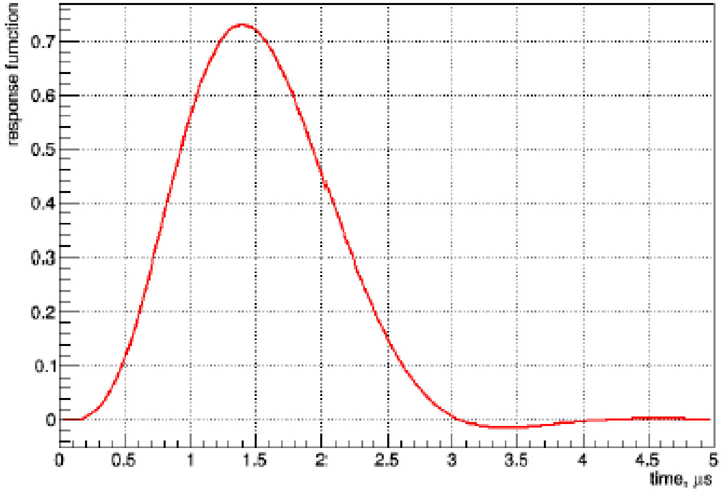
Anode segmentation





Need to be more realistic here

- **Uses G4 stepping action to keep as much information as possible**
- **All ionization energy deposited is projected on anodes: Time at anode = $(z-0.3)* W_1 + 0.3 / W_2$**
- **No losses during drift included**
- **Electronics response on delta-function at zero time, as in the test run**



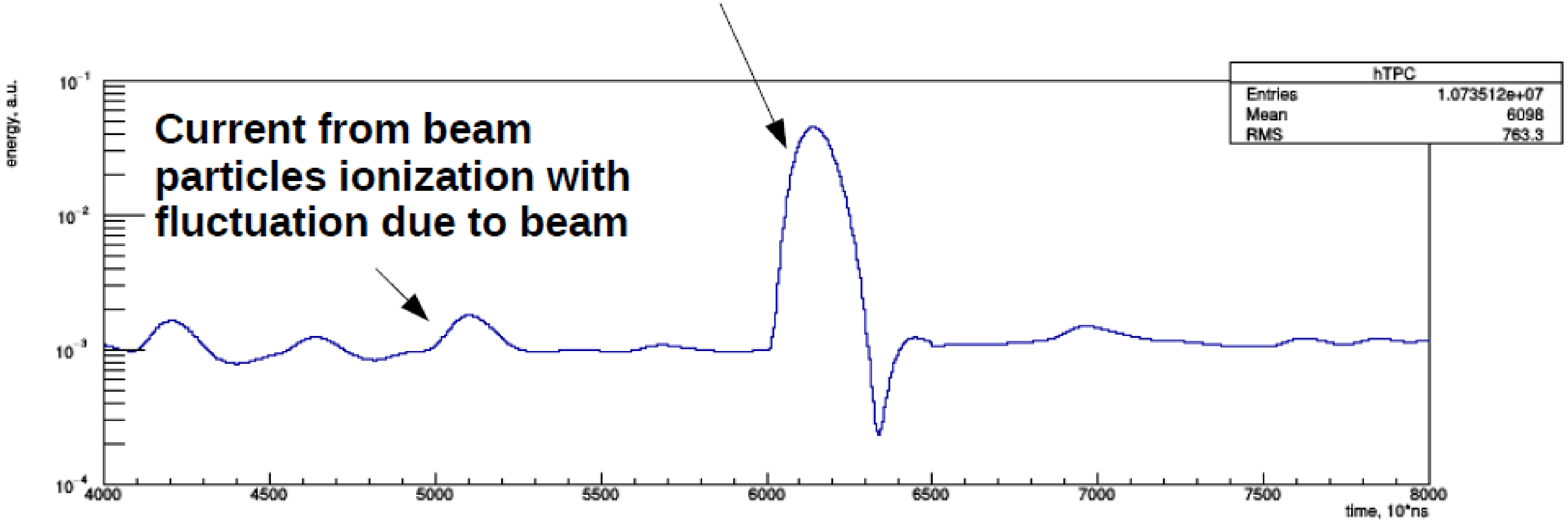
An example of simulated TPC signal

Beam intensity 300k electrons per second

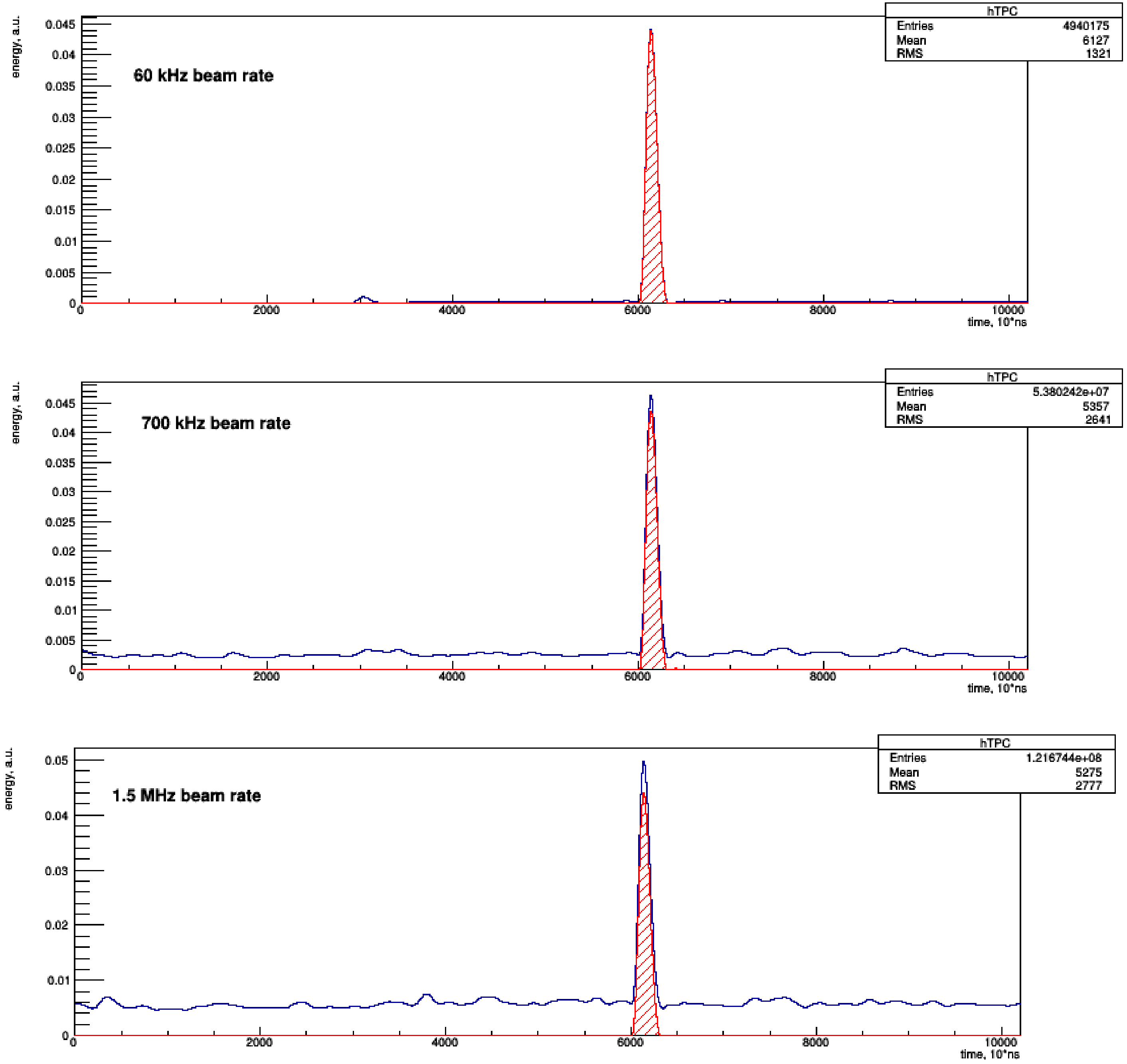
Central anode, Recoil energy 1.5 MeV

No electronic noise here

See some ideas on slide 11

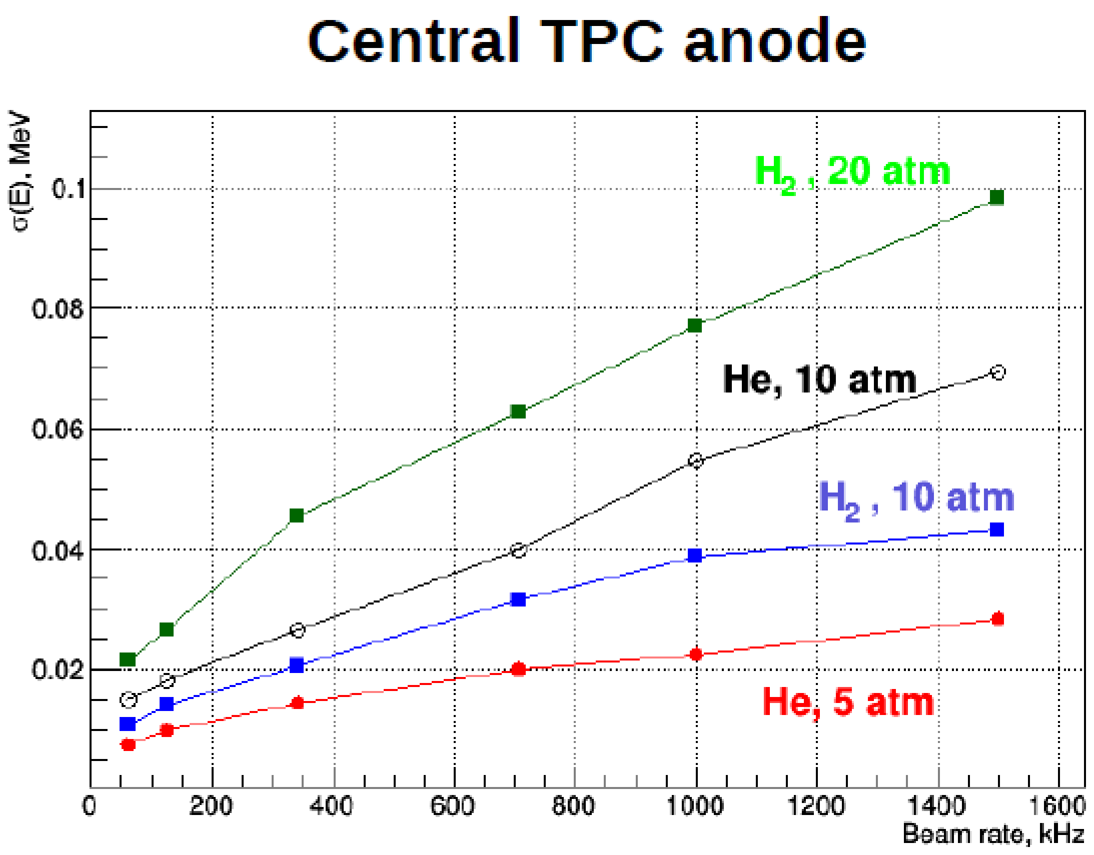


Resolution σ = 27 keV to be summed up with electronics noise of ~20-30 keV



Signal extraction should be the same for data and MC!

Energy resolution vs. Beam intensity



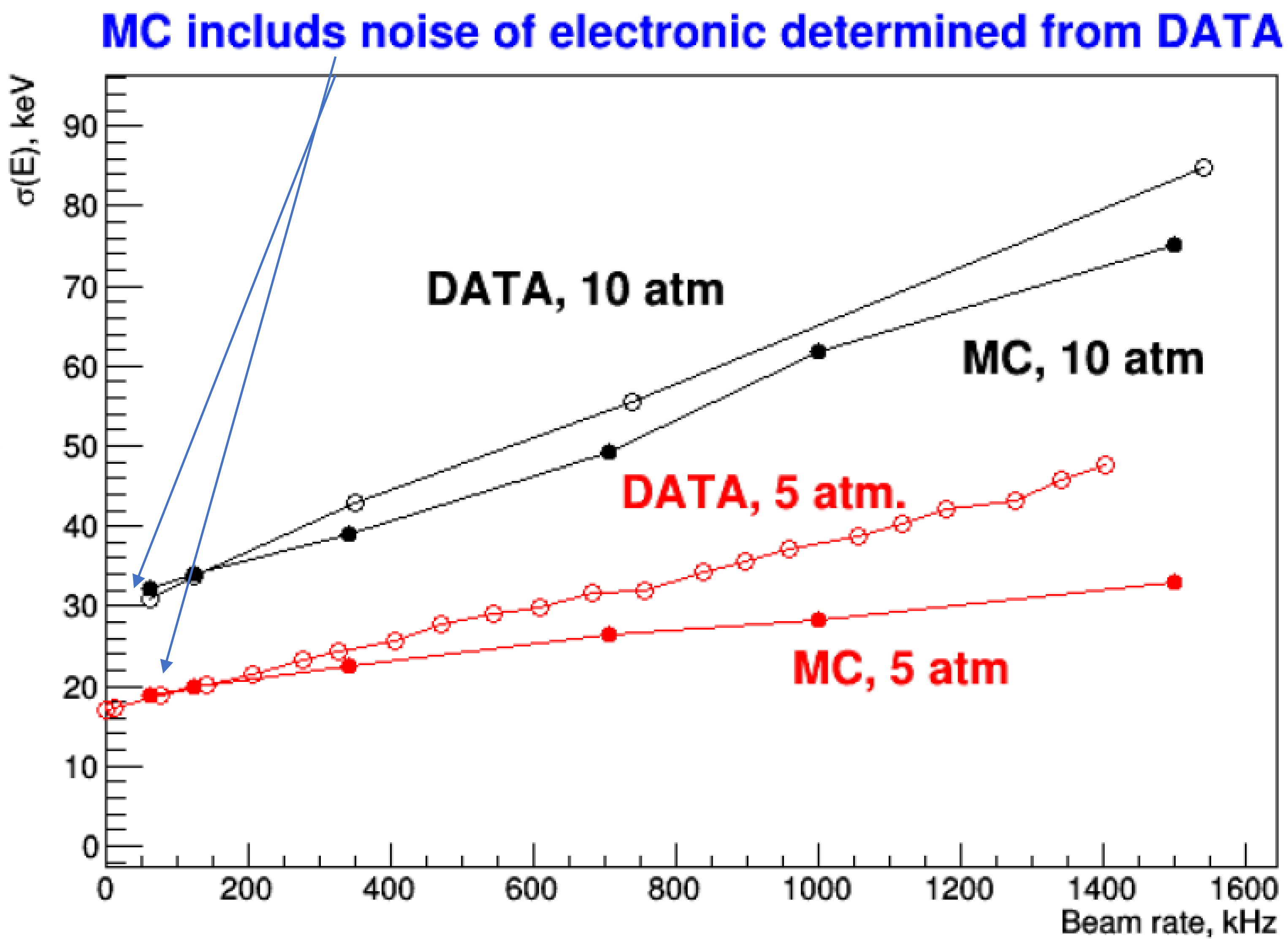
Beam noise is increasing (~as square root) with beam intensity

Beam noise (~linearly) increasing with the pressure of gas in TPC

Beam noise in Hydrogen is less than in 96% Helium + 4% Nitrogen gas mixture by factor ~1.5

Comparison of the experimental data with MC

Reasonable agreement

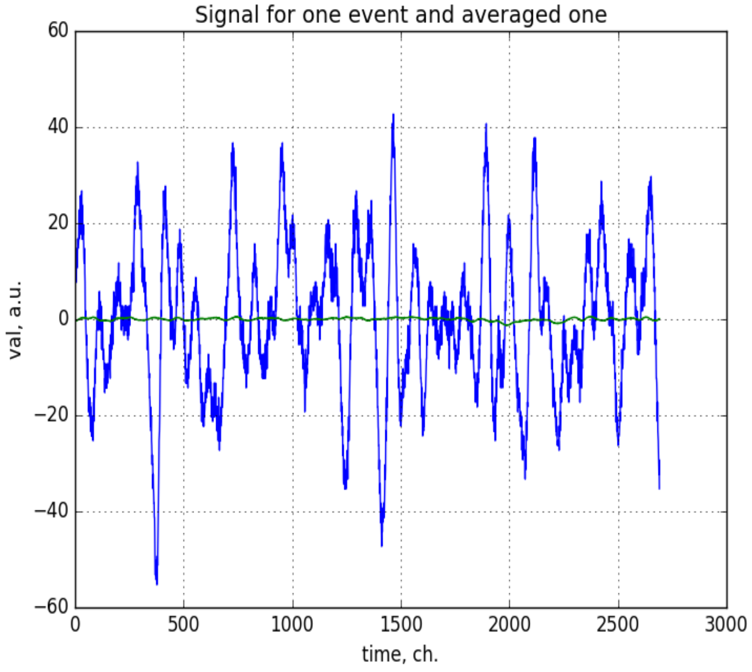


See more details https://github.com/aleksha/G4-Models/tree/master/Data/Noise

Further studies of noise + simulation

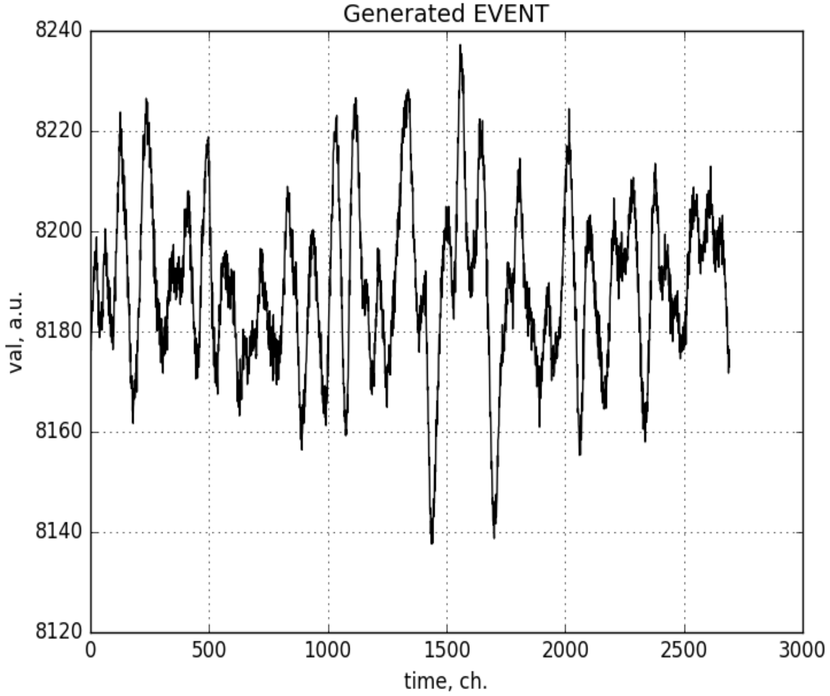
Still to be implemented
We can have noise as a function of time!

Noise in data (baseline corrected)



1. Obtain distribution for real and imaginary part of frequency spectra using Fourier transformation;
2. Fit these distributions using two gaussian hypotheses;
3. Generate random spectrum out of these distributions;
4. Use inverse Fourier transformation to obtain spectrum of generated events.

Generated noise

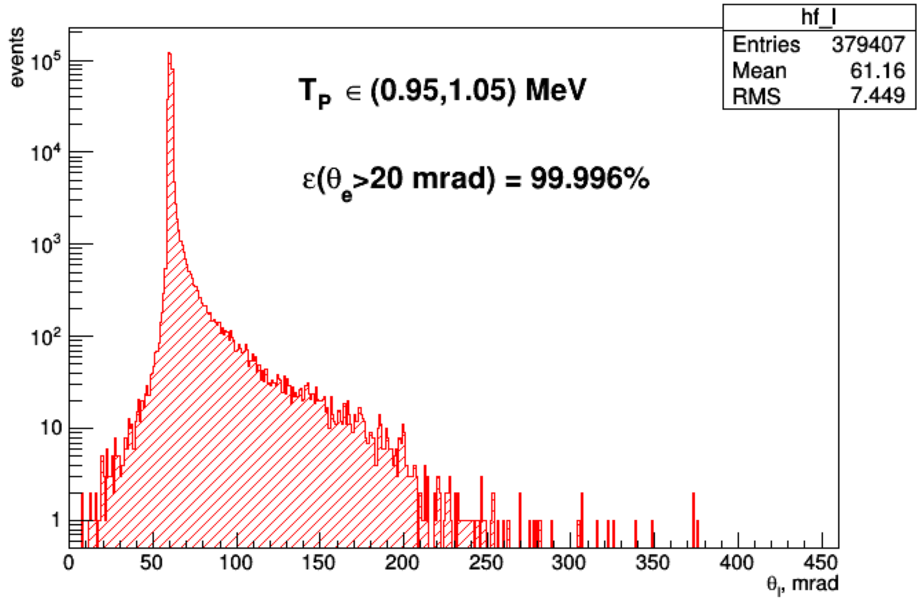


Event generators

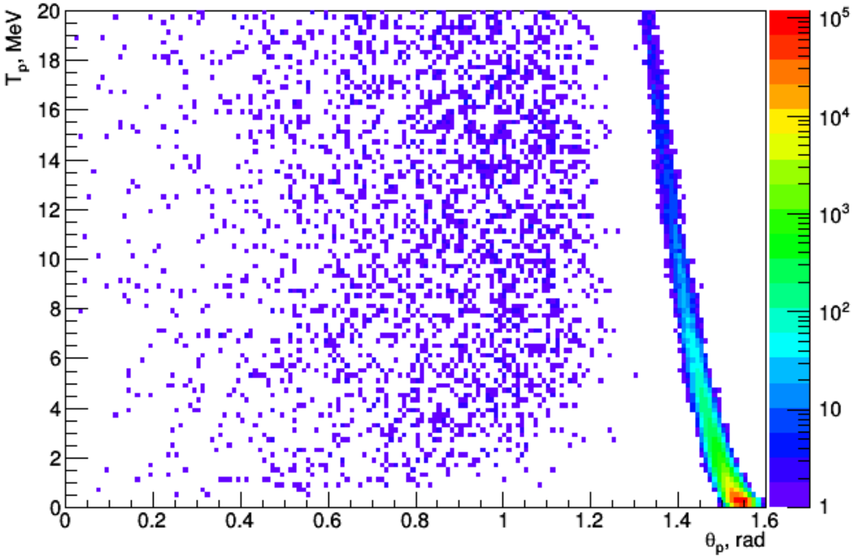
There will be no loss in central (not sensitive) part of CSC

Event generators

- ESEPP https://github.com/gramolin/esepp to account radiative corrections



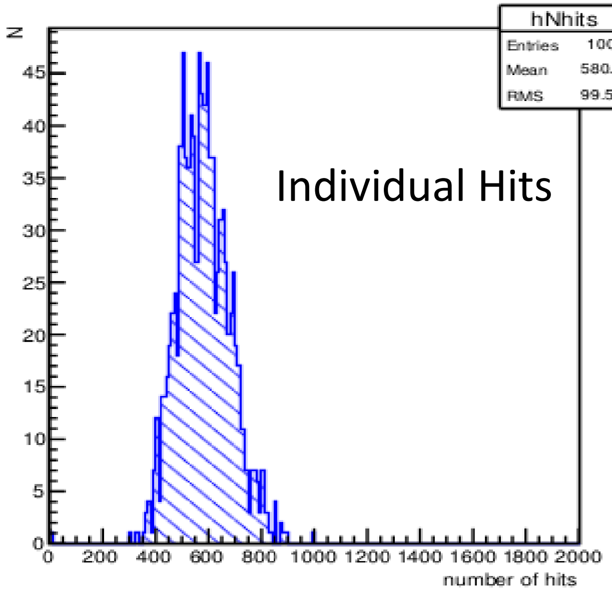
- "Handmade" Δ production generation for inelastic (there are more realistic approximation in PRad paper)

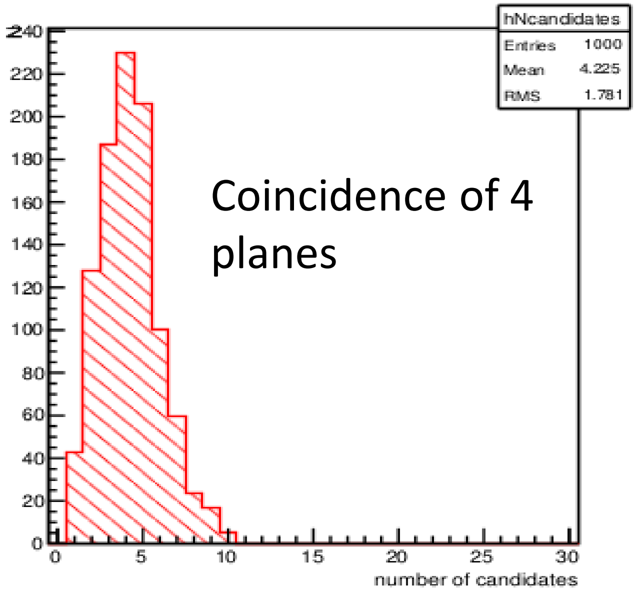


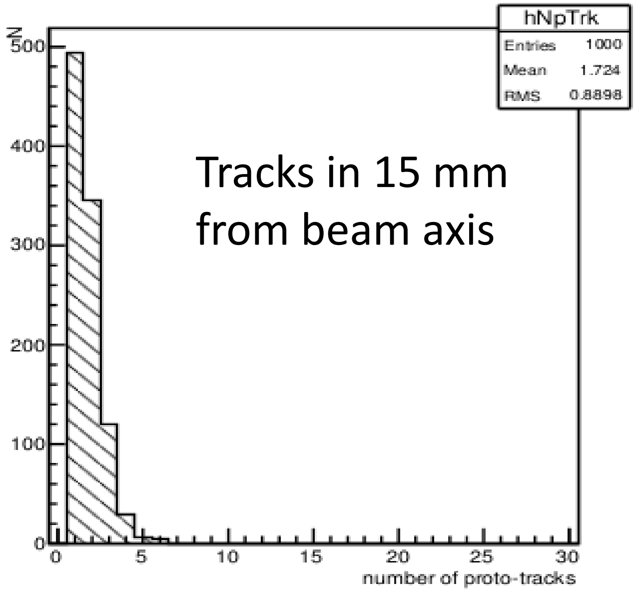
Correlation between T_p and electron and proton angle is powerful tool to reject inelastic background

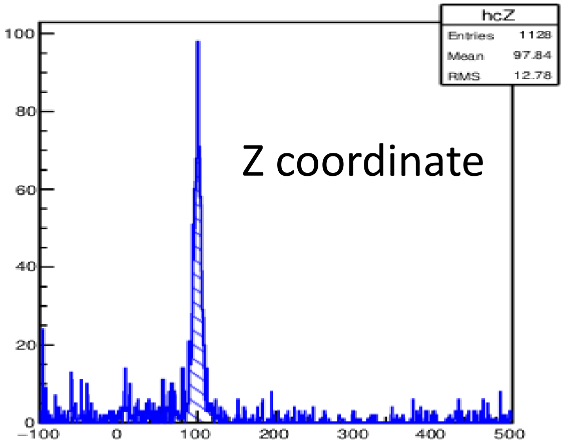
Tracking in CSC

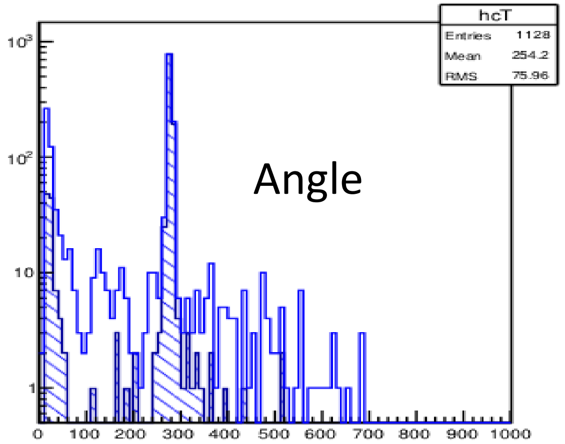
Scattered electron reconstruction (by CSC)







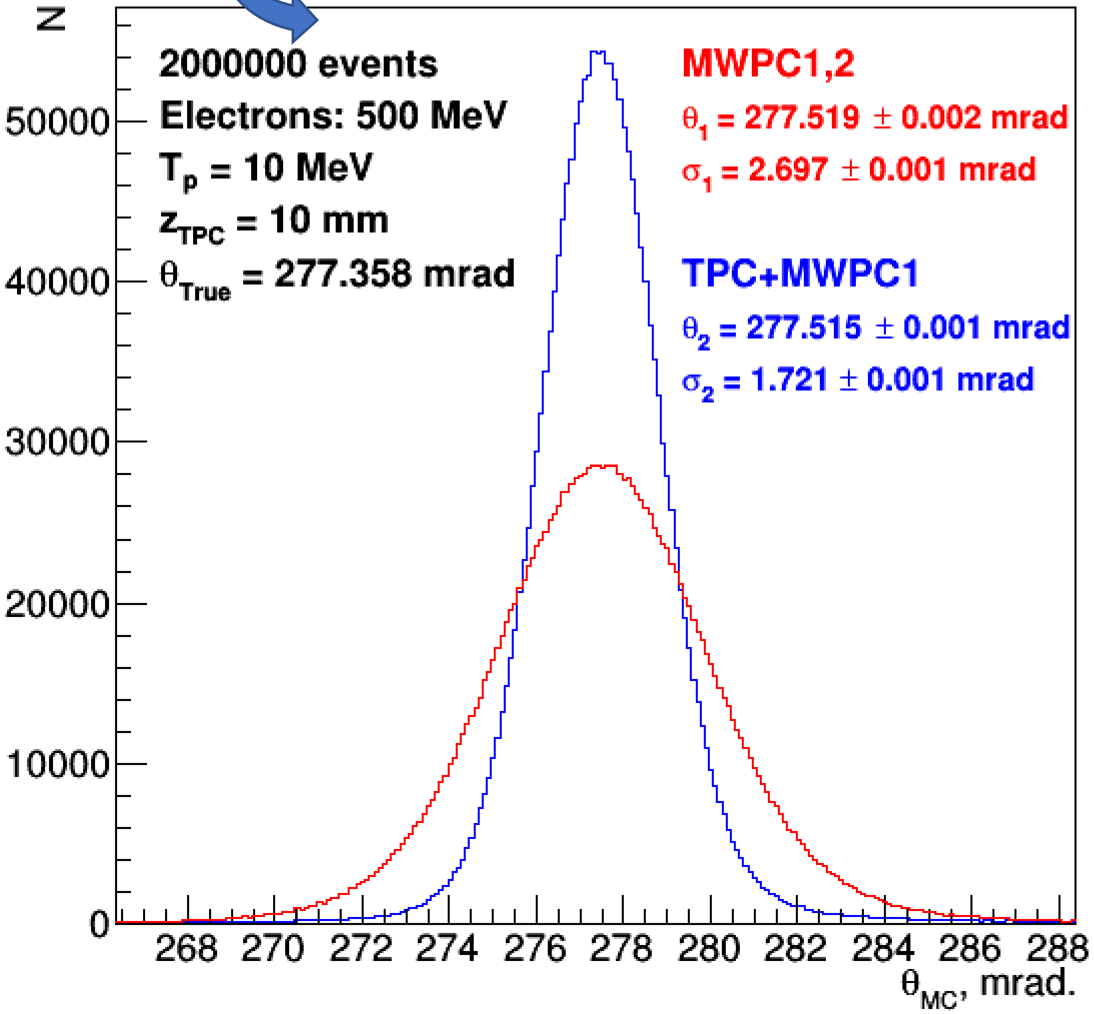


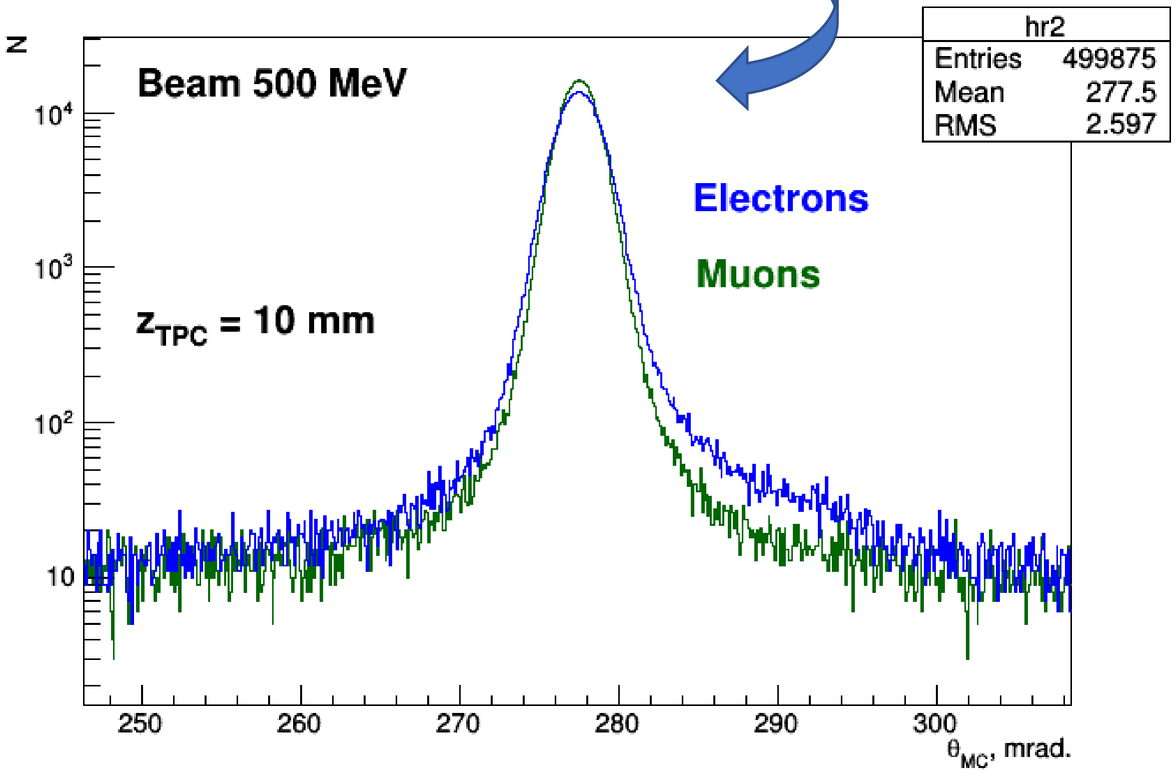


Beam frequency is 2 MHz

After proper incoming electron is found, angular resolution could be improved using time information (see next slide)

Angular resolution and Calibration





Does bremsstrahlung for scattered electron affect calibration? Faked it with muons and see!

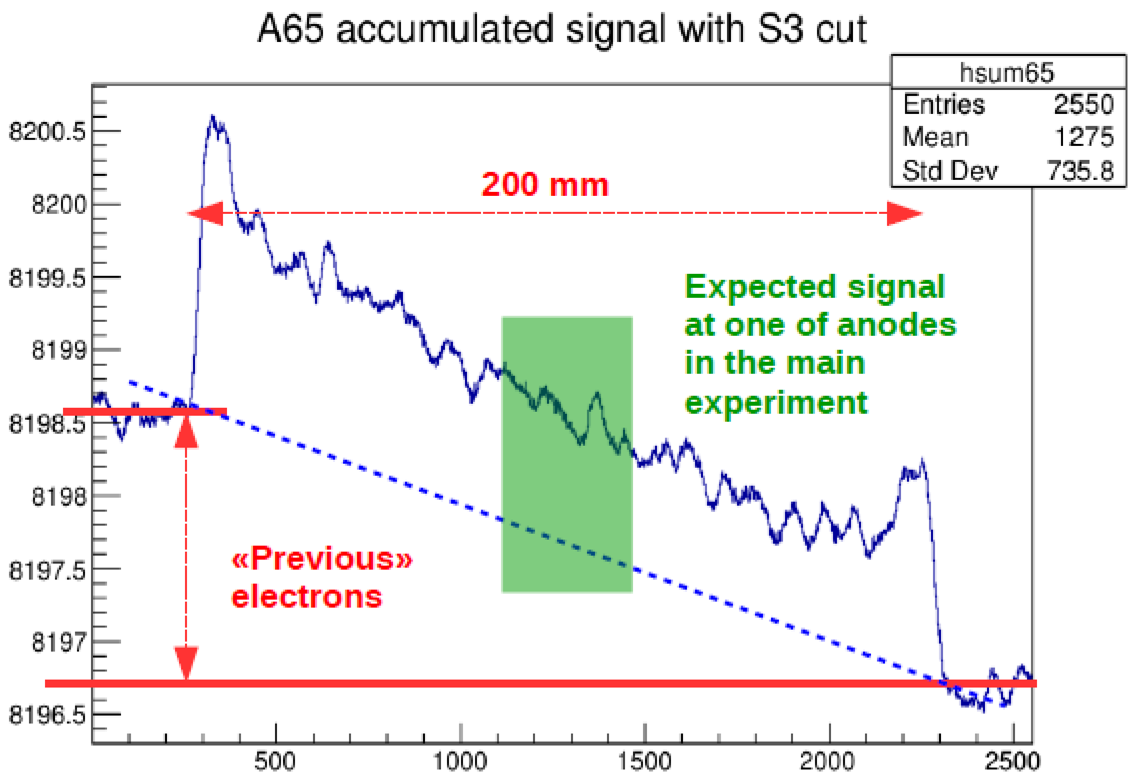
Peak position shift is small → Calibration is possible

Beam

Simplifications (beam)

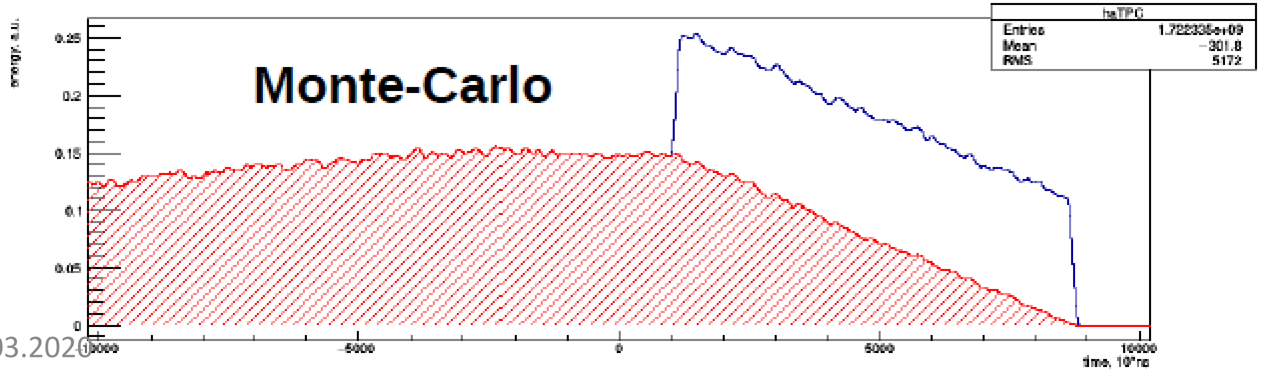
- Poisson time distribution for incoming beam electrons → time interval between beam electrons distributed as $\exp(-\Delta t/f_b)$.
- $\mu_{bx} = \mu_{by} = 0$ and $\sigma_{bx} = \sigma_{by} = \sigma_b$
- $\mu_{p\vartheta} = 0$

- **Note, that background for the event can be done as during simulation as well as constructed afterwards from single electrons.**



- Special low beam intensity run (18kHz)
- Accumulated signal from 36k events (~80 minutes).
- Events are taken if no electron in 70 μs time window (so-called protection after), but no protection before
- MC demonstrates linear behavior for the background

<u>Result:</u> accumulated signal could be used for drift time calibration in e^-p experiment (no recombination!)



For low frequencies Poisson distribution works, but it will be good to have some proofs for nominal f_b

Conclusions

- A lot of aspects of the Monte-Carlo for the proposed experiment were investigated
- They were rather answering on questions, which however demonstrated that the proposed experiment is feasible
- It’s time for the software project, which will join described ideas
- Propose to have special Monte-Carlo working group