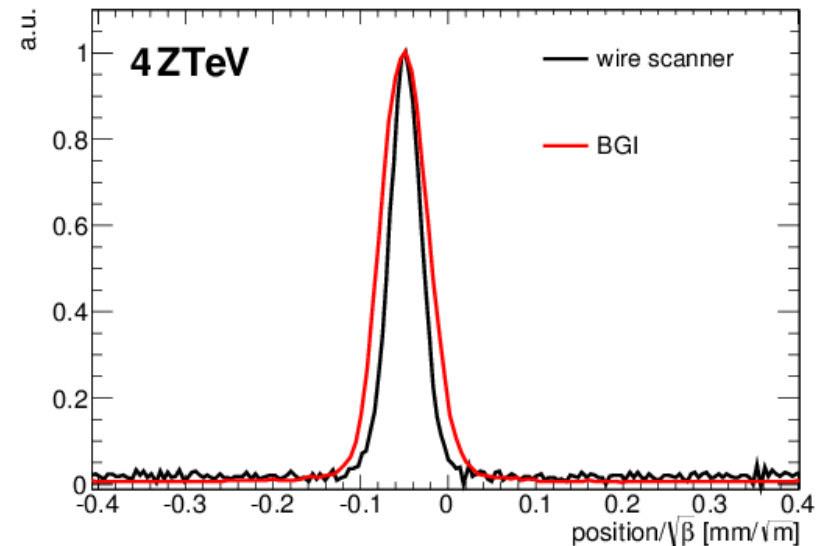
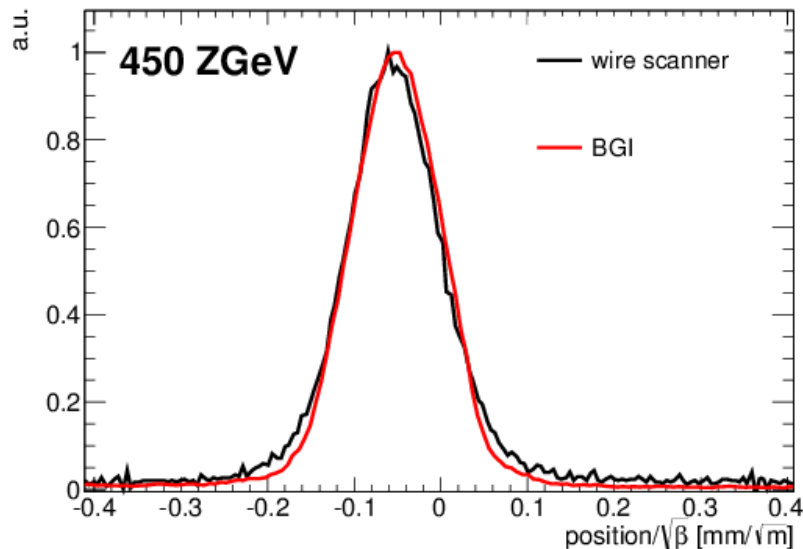


The modified pyECLLOUD code and main results

- The story of space charge in LHC IPM.
- Ionization Double Differential Cross Section investigation.
- Correction procedure investigation.
- Summary.

The story - data

- In 2011 I've spend a lot of time trying to calibrate – with beam - LHC IPM. Results were confusing (from *The First Experience with LHC Beam Gas Ionization Monitor*, proceedings of IBIC12 TUBP61, CERN-ATS-2012-286):



- The profile at high energy was always broader than expected.

The story – chasing the broadening

- Various possible reasons for broadening were investigated

1. Detector tilt – excluded
2. MCP/phosphor nonuniformity – excluded
3. PSF of the imaging system
4. Large electron gyroradius
5. Beam space charge

- Ad 3: the PSF could be corrected in quadrature:

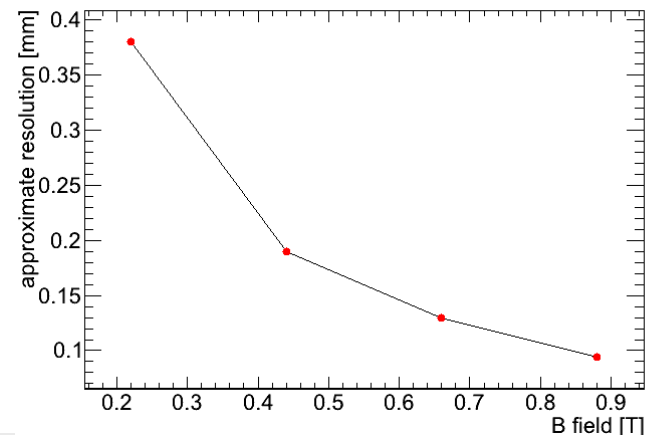
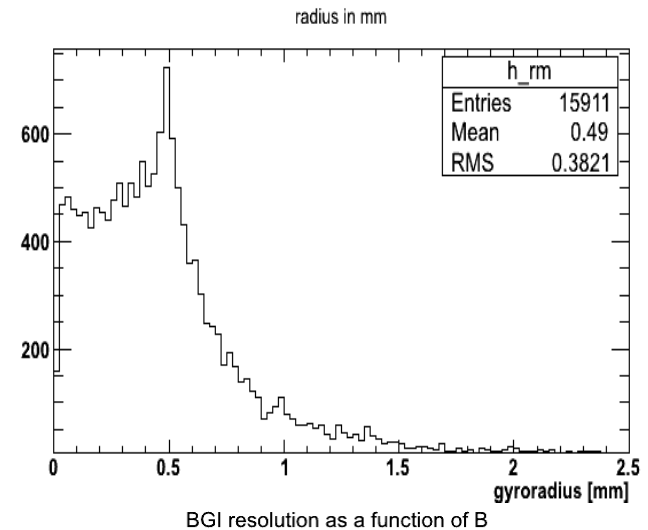
$$\sigma_{beam} = \sqrt{\sigma_{BGI}^2 - \sigma_{PSF}^2}$$

but σ_{PSF} was obviously not constant during the ramp

- Ad 4: I have tried to simulate electron trajectories using Geant4 (which suppose to give DDCS).

The story – Geant 4

- *Geant4 simulations of electron trajectories in BGI, EDMS 1182412*
- Main results:
 - large gyroradius due to cross-section “cutoff” at 100 eV
 - this turned out to be **false** – Geant4 cannot simulate low energy electrons
 - Increase of electric field did not help to reduce observed beam profile distortion, **only increase of magnetic field helped.**
 - Geant4 cannot simulate beam space charge

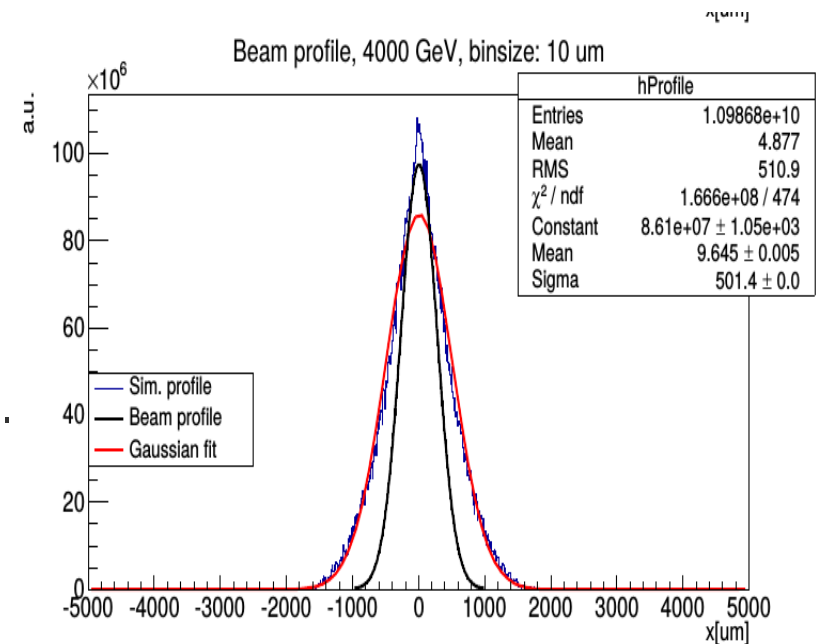


The story - pyECLOUD

- In early 2012 we were looking with Marcin Patecki how to simulate beam space charge.
- After ‘CCC discussion’ with Giovanni Iadarola we decided to try with pyECLOUD. Giovanni modified his code to include uniform electric and magnetic fields.
- Results are published in Marcin’s thesis: *Analysis of LHC Beam Gas Ionization monitor data and simulation of the electron transport in the detector*, Politechnika Warszawska/CERN-THESIS-2013-155
- At that time we still used incorrect DDCS from Geant4 (trying to modify physics list), but having serious doubts about it, we repeated all simulations with zero initial velocities.
- Thesis publishes also an interesting attempt to estimate theoretically the effect of the bunch field on electron movement by Giuliano Franchetti (something to be followed up).

The story – pyECLOUD results

- Profile distortion is clearly due to **beam space charge**
 - Initial velocities play secondary role.
 - For lead beam the distortion should be much smaller (2011 observations not explained).
 - Increase magnetic field to 1T would suppress the effect from beam space charge.
 - No simple correction procedure found (despite considerable effort)



Dominik and DDCS

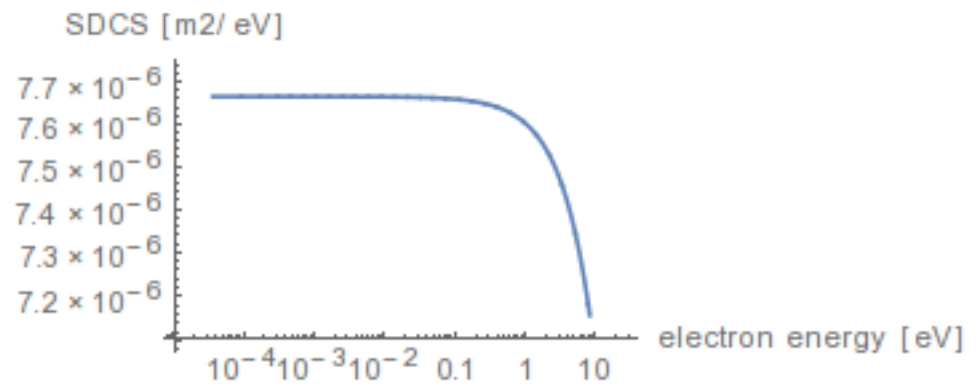
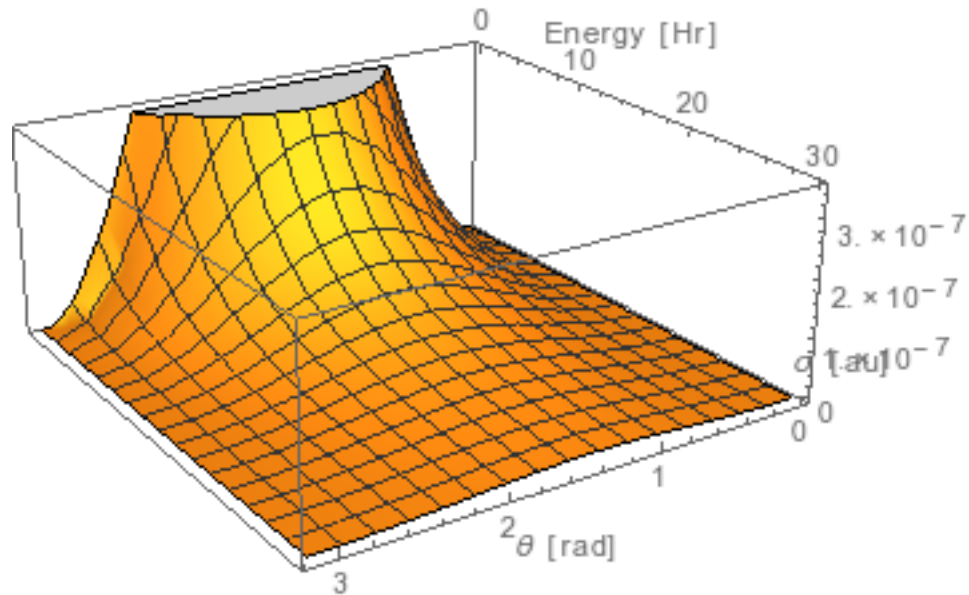
- Dominik Vilsmaier continued Marcin's study focusing on:
 - Proper Double-Differential ionization cross section (DDCS).
 - Beam profile correction procedure.
- Dominik's work is documented in his thesis:
Profile distortion by beam space charge in Ionization Profile Monitors, CERN-THESIS-2015-035 and HB2014 proceedings: *Investigation of the effect of beam space-charge on electrons in ionization profile monitors*, HB2014, MOPAB42

DDCS

- In general it is not an easy to calculate DDCS for low energy (1 eV) electrons. Also a very few measurements exist!
- Lot of work, especially for fast projectiles, were done in last years by A. Voitkiv (MPI Heidelberg).
- One of his papers he gives DDCS for He⁺ ionization by relativistic projectiles:

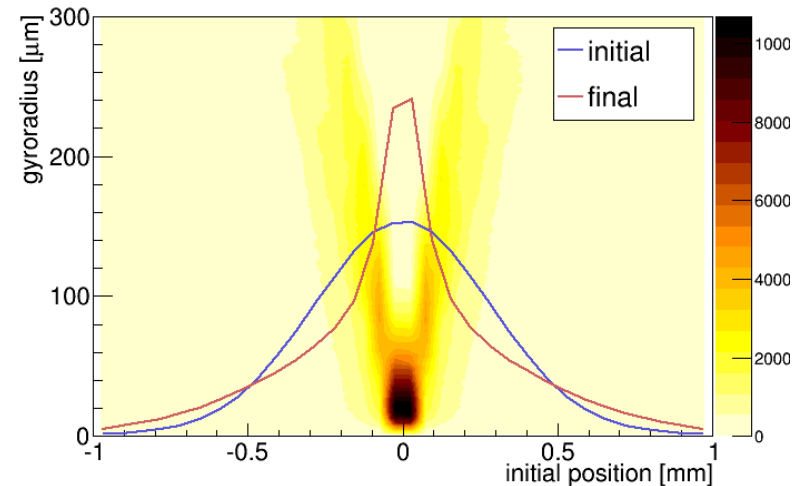
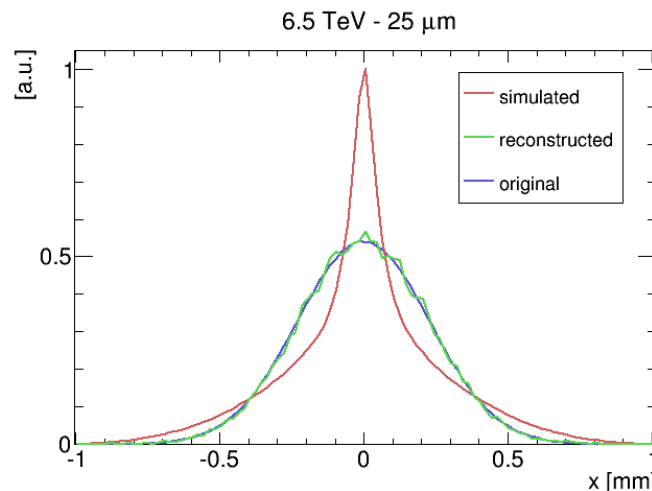
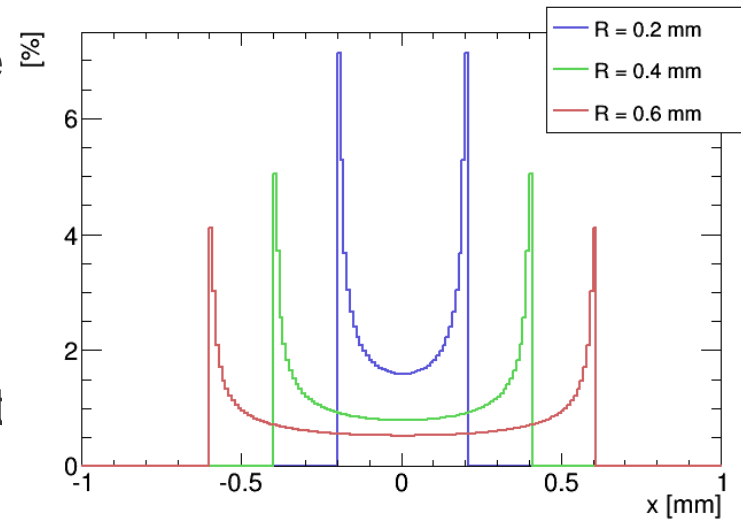
$$\frac{d^2\sigma_{He}^{(1+)}}{dE d\Omega} = 2 \times 2^8 \frac{Z^2}{v^2 Z_t^4} \frac{1}{(1 + 2E/Z_t^2)^5} \frac{\exp\left(-\frac{4 \arctan \sqrt{2E/Z_t^2}}{\sqrt{2E/Z_t^2}}\right)}{\left(1 - \exp\left(-\frac{2\pi}{\sqrt{2E/Z_t^2}}\right)\right)} \left(\sin^2 \theta \ln \eta_{He} + \frac{\cos^2 \theta}{\gamma^2} \right. \\ \left. - 0.5 \sin^2 \theta + \frac{8\sqrt{2E}}{v} \cos \theta \left(1 - \frac{v^2}{2c^2}\right) \sin^2 \theta \ln \eta_{He} + \frac{2ZZ_t}{v^2 \gamma^2} \cos \theta \ln^2 \eta_{He} \right) \quad (38)$$

DDCS



Correction procedure

- For a given electron gyroradius – the PSF is known and could be deconvoluted
- “Electron sieve” (or a slit) is needed
- Dominik shows that using sieve able to reconstruct electron gyroradius with 25 μm resolution, a very good correction is possible



Summary

- pyECLLOUD is a good tool, but has 2 main limitations:
 - Assumes relativistic beams by neglecting longitudinal component of the fields
 - External fields are uniform (no field map)
- Precise knowledge of Double Differential Cross Section maybe not often required (when beam space charge dominates), but when required is quite tricky.
- Stronger magnetic field is an obvious but expensive solution to space charge problem.
- Correction procedure based on “electron sieve” theoretically works, technical implementation needs still a lot of work.