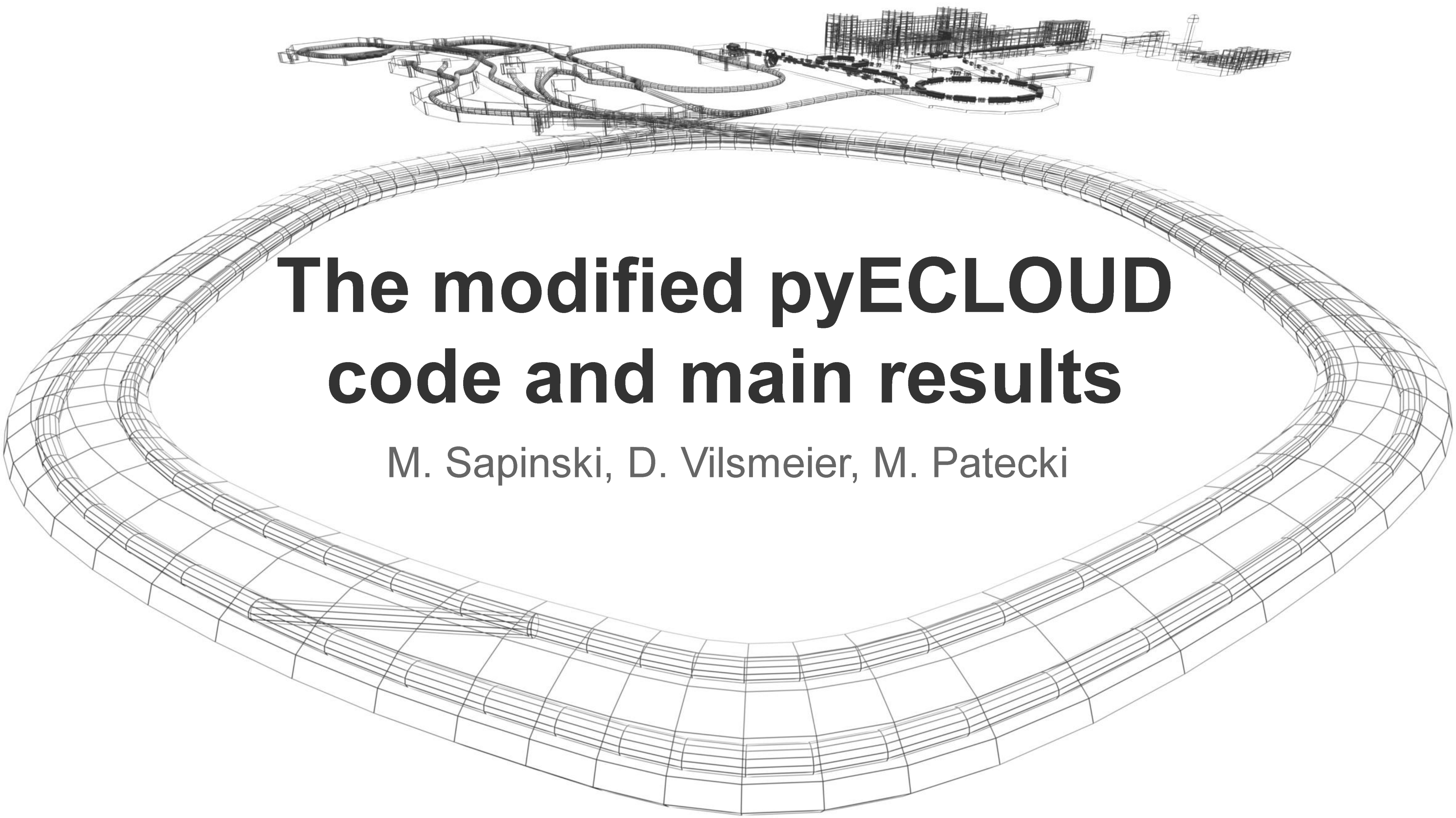


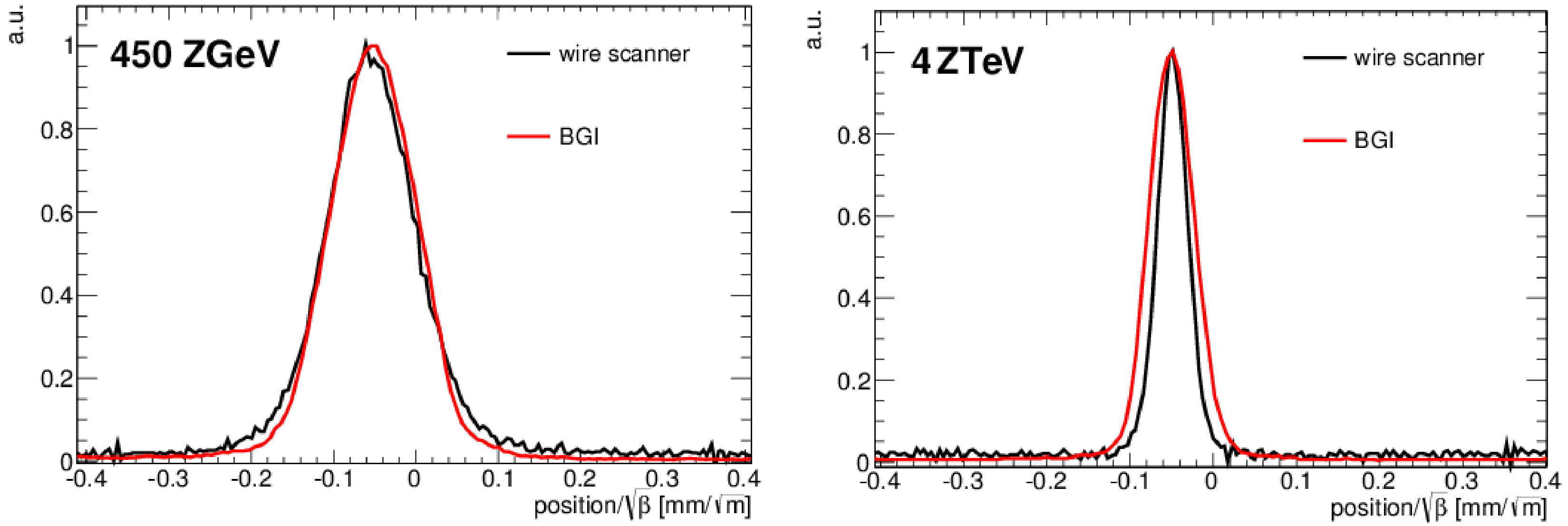
The modified pyECLOUD code and main results

M. Sapinski, D. Vilsmeier, M. Patecki

- 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

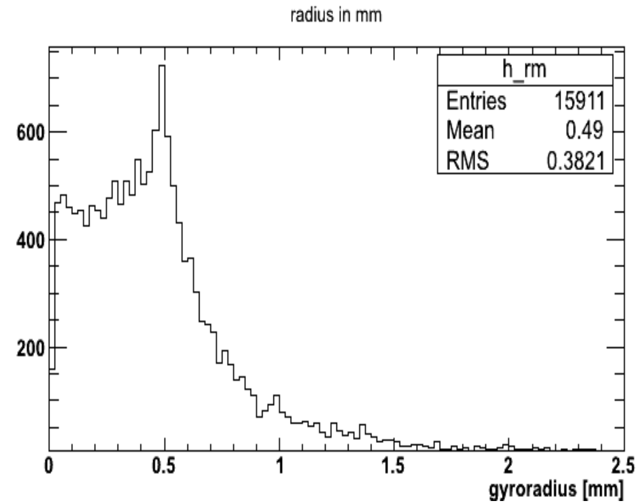
- Various possible reasons for broadening were investigated
  1. Detector tilt – excluded
  2. MCP/phosphor nonuniformity – excluded
  3. PSF of the imaging system
  4. Large electron gyroradius
  5. Beam space charge
- Ad 3: the PSF could be corrected in quadrature:

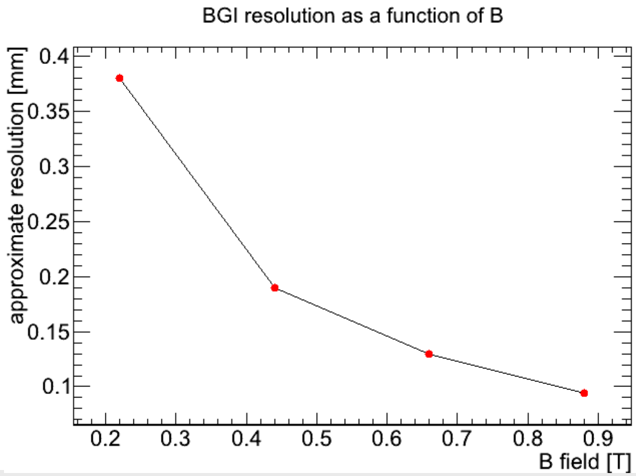
$$\sigma_{beam} = \sqrt{\sigma^2_{BGI} - \sigma^2_{PSF}}$$

  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



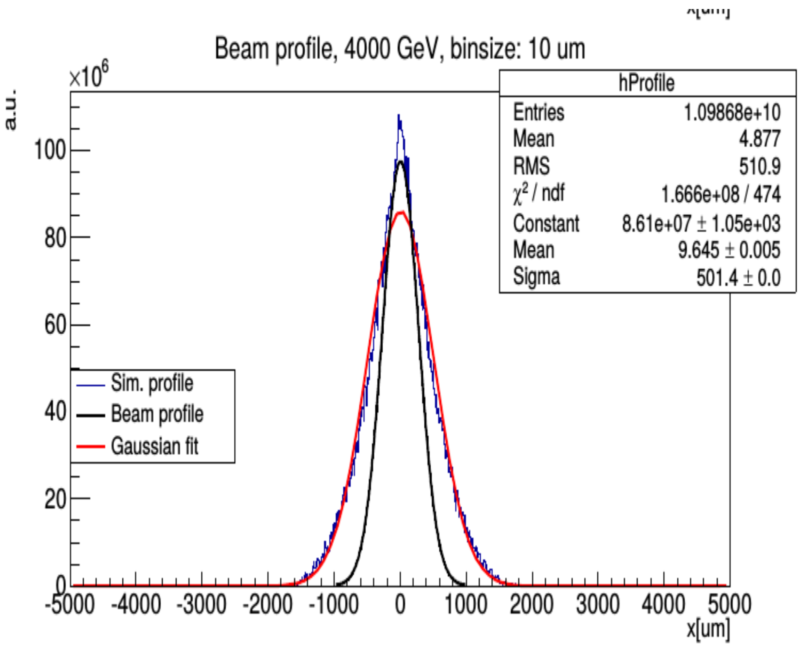


The story - pyECLOUD

- 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:

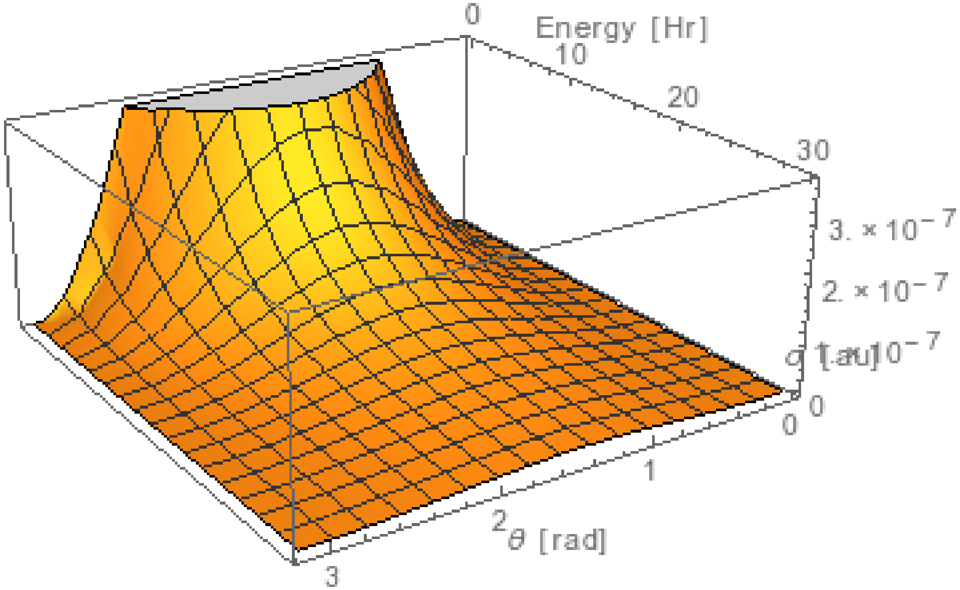
  Profile distortion by beam space charge in Ionization Profile Monitors, CERN-THESIS-2015-035 and HB2014 proceedings: *Investigation of the effect of beam space-charge on electrons in ionization profile monitors*, HB2014, MOPAB42

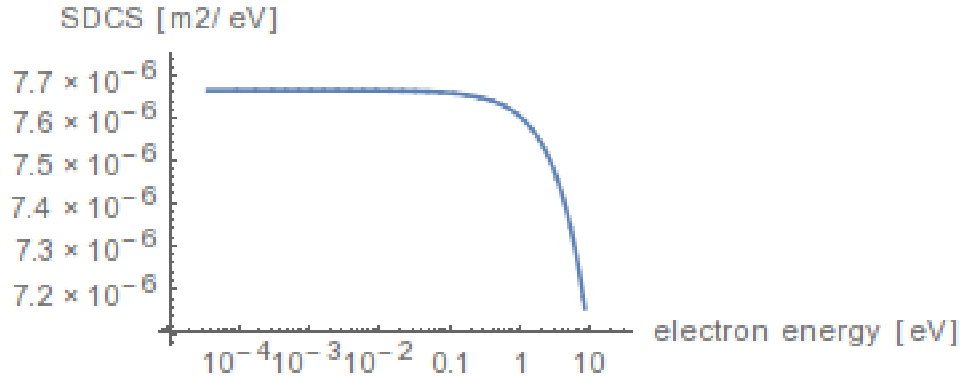
DDCS

- 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:

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

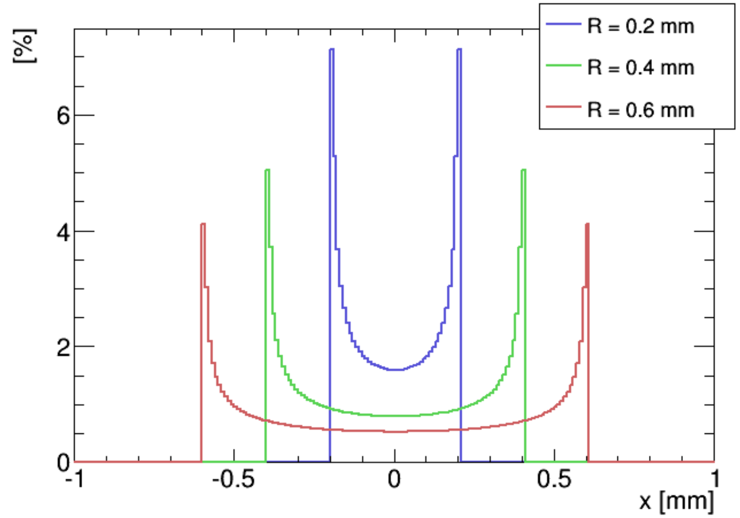
DDCS

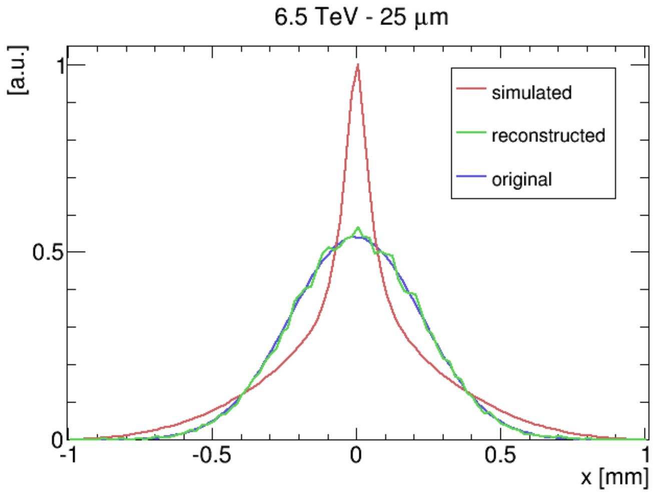

Energy [Hr]
0
10
20
30
3. × 10⁻⁷
2. × 10⁻⁷
σ [au]
0
0
1
2
3
θ [rad]

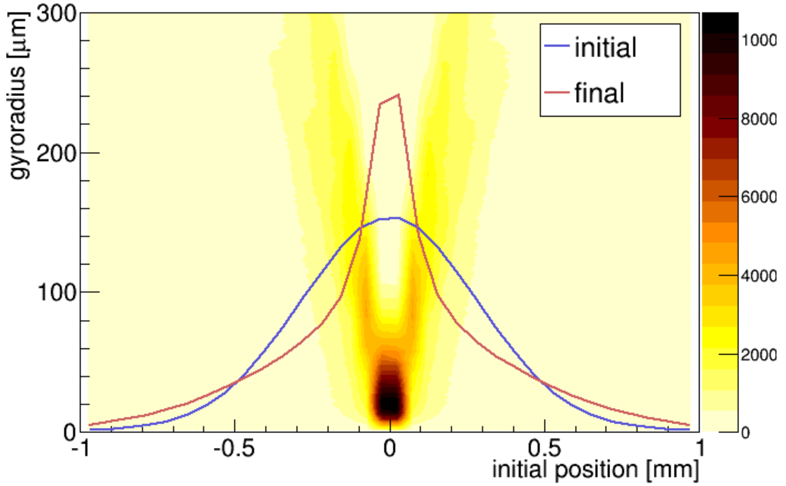

SDCS [m2/ eV]
7.7 × 10⁻⁶
7.6 × 10⁻⁶
7.5 × 10⁻⁶
7.4 × 10⁻⁶
7.3 × 10⁻⁶
7.2 × 10⁻⁶
electron energy [eV]
10⁻⁴ 10⁻³ 10⁻² 0.1 1 10

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 wit 25 um resolution, a very good correction is possible







Summary

- pyECLOUD 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.