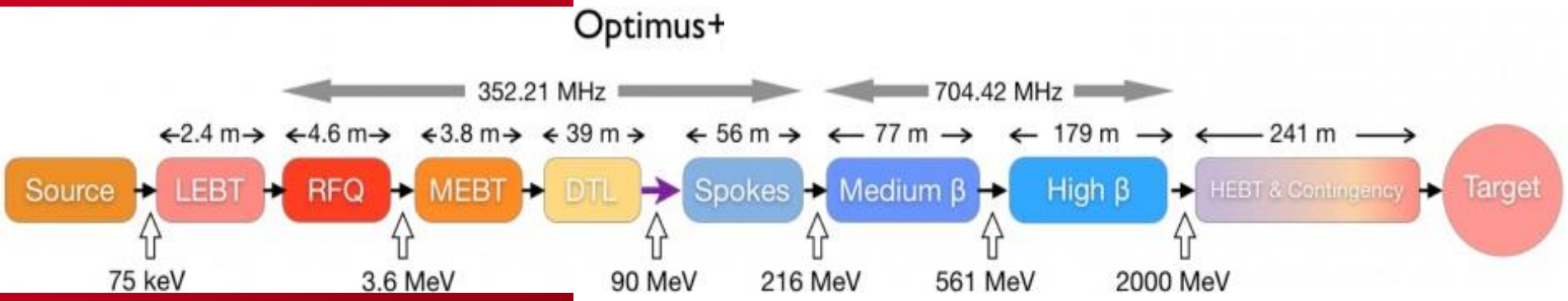
DE LA RECHERCHE À L'INDUSTRIE

CEA – Saclay

COLD NPM ELECTRIC FIELD UNIFORMITY



P. Abbon, F. Belloni, F. Benedetti, G. Coulloux, C. Lahonde-Hamdoun, P. Le Bourlout, Y. Mariette, J. Marroncle, J.P. Mols, V. Nadot, L. Scola (CEA)

Cyrille Thomas (ESS)

BI FORUM #4

www.cea.fr

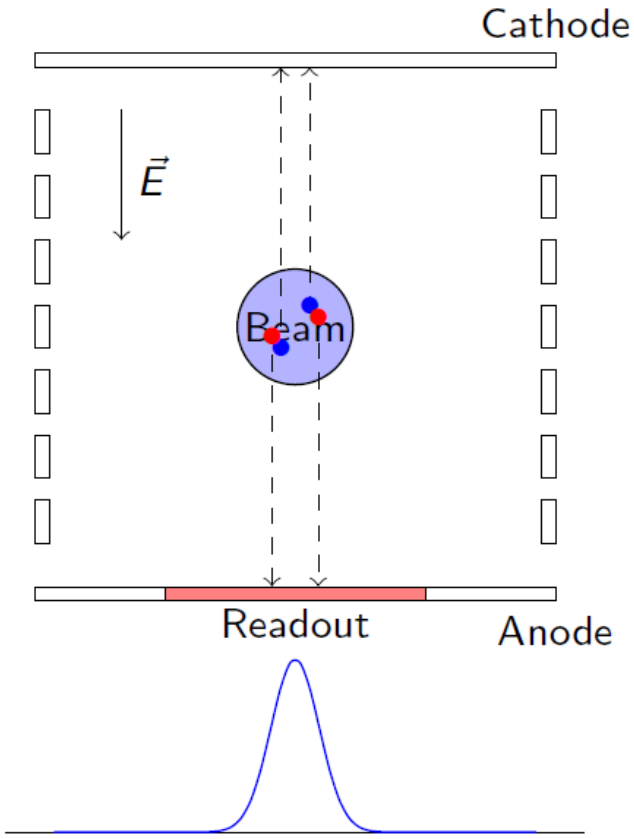
WHY UNIFORMITY IS IMPORTANT ?

ESS Requirements

- The transverse beam profile shall be measured with a total measurement error:
  - in the RMS extension of the beam of less than ±10%
  - in the 95% extension of the beam of less than ±10%

Real IPM: profile distortion !

- Space charge & initial momentum
  - See talk of Francesca Belloni (BI Forum #3)
- Electric field uniformity
  - Not parallel plate ➔ Side effect
  - Detector geometry
  - Vacuum vessel geometry
  - And etc.



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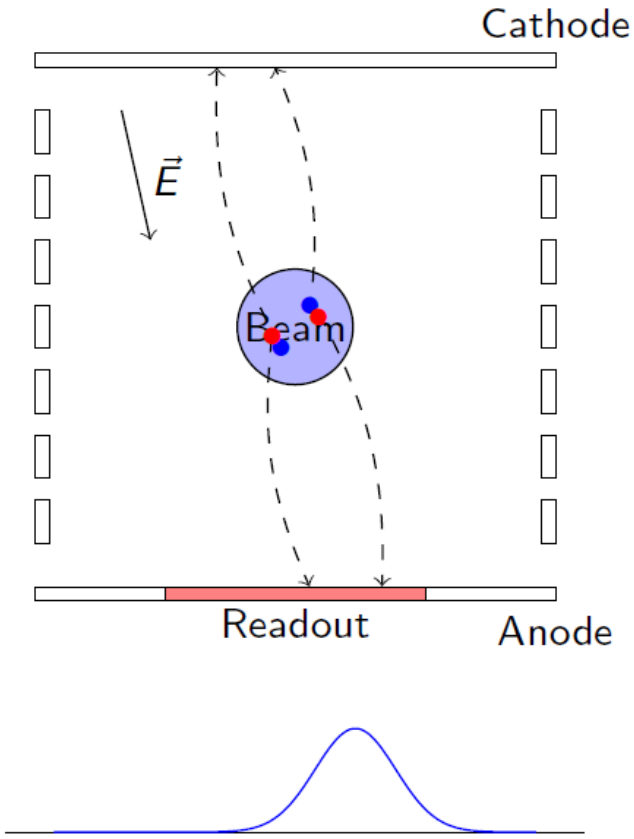
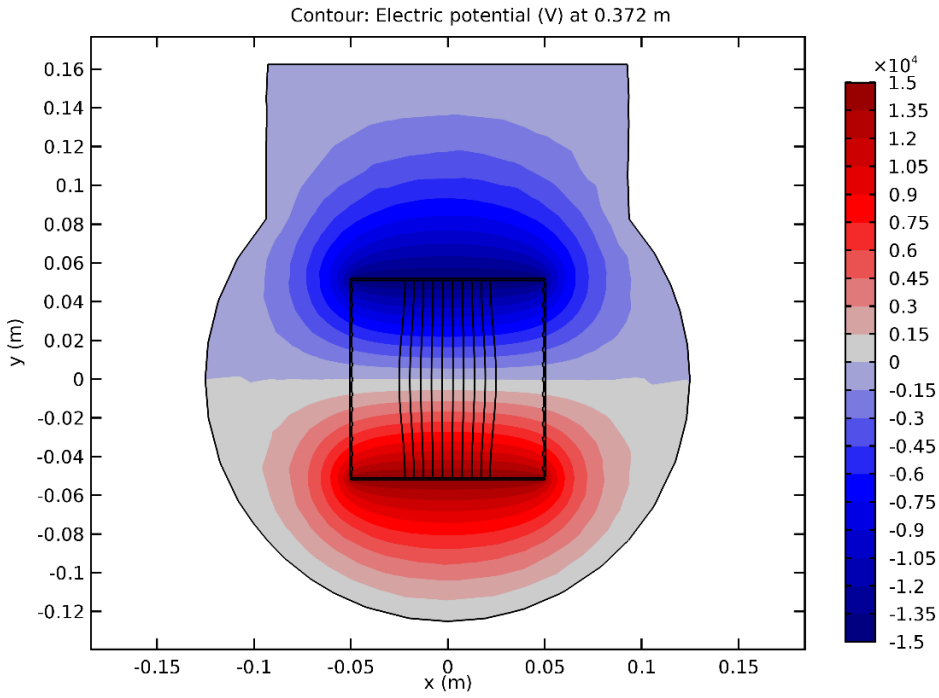
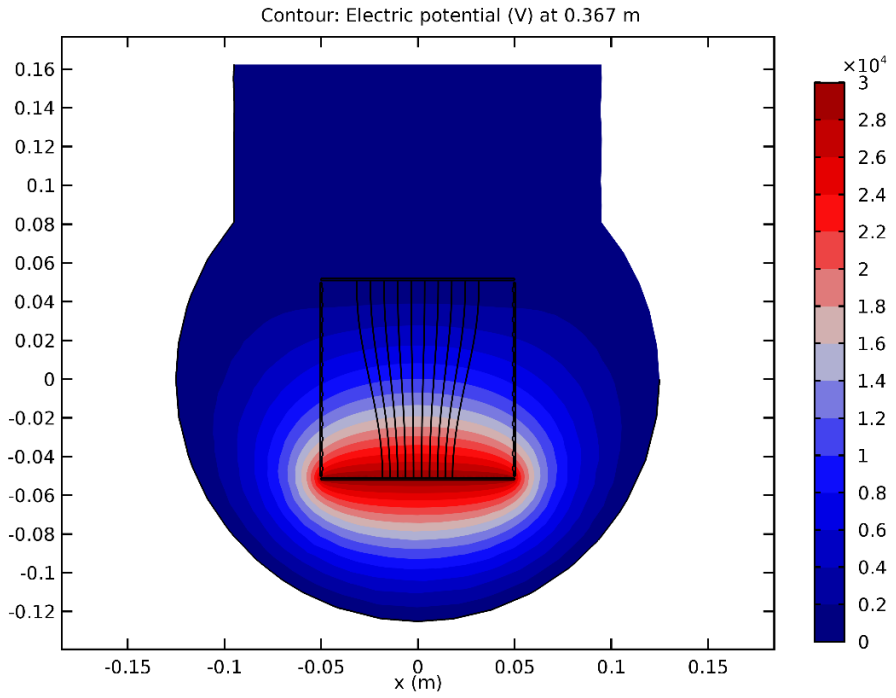


PROBLEMS (1/2)

2 types of IPM

- Asymmetric
- Symmetric

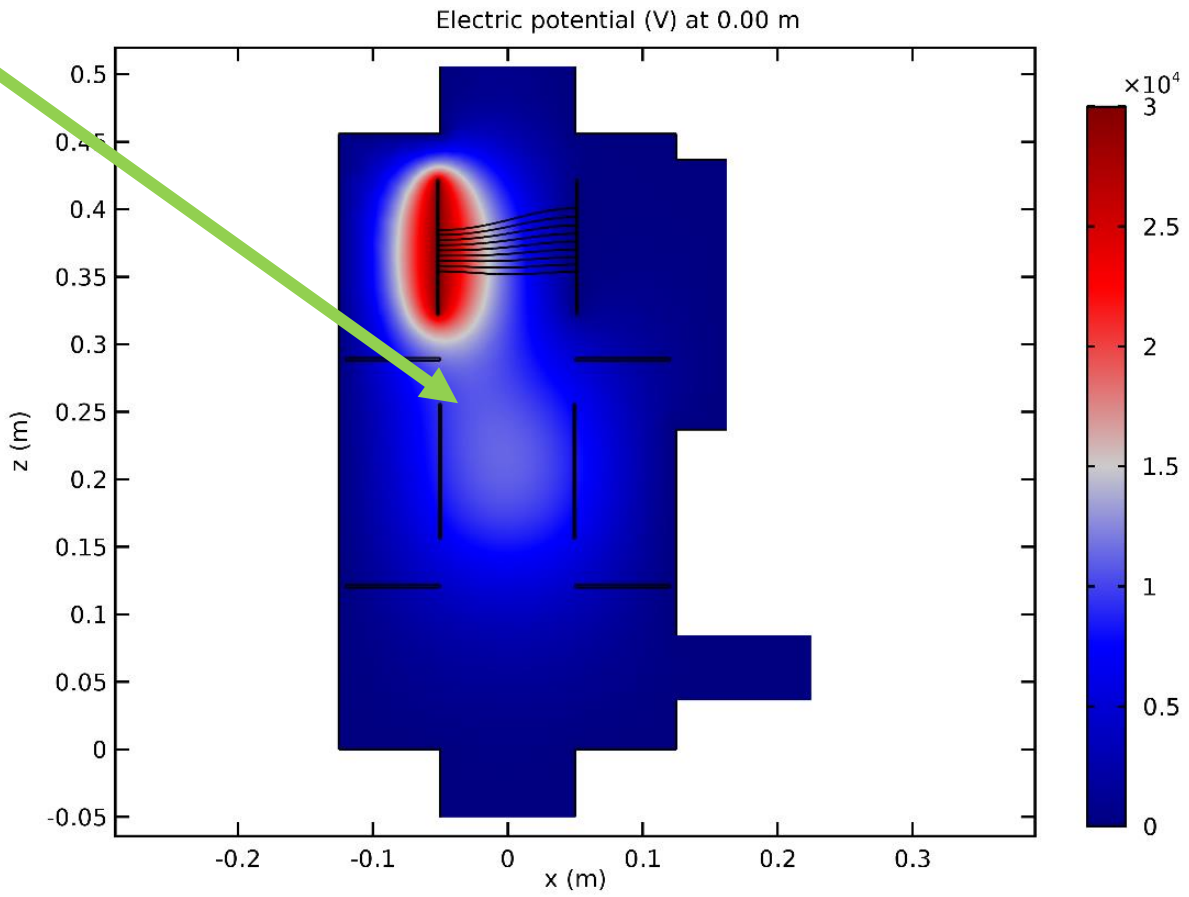




PROBLEMS (2/2)

A NPM = IPM X + IPMY

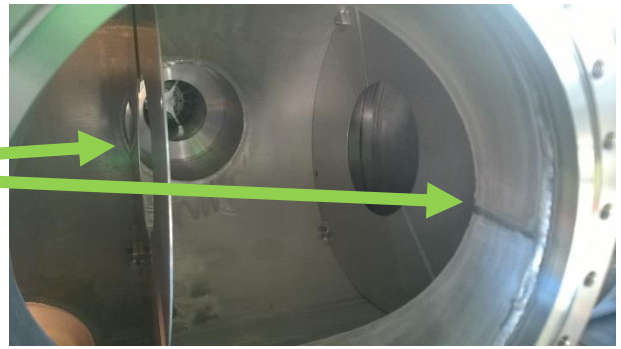
- Cross interaction

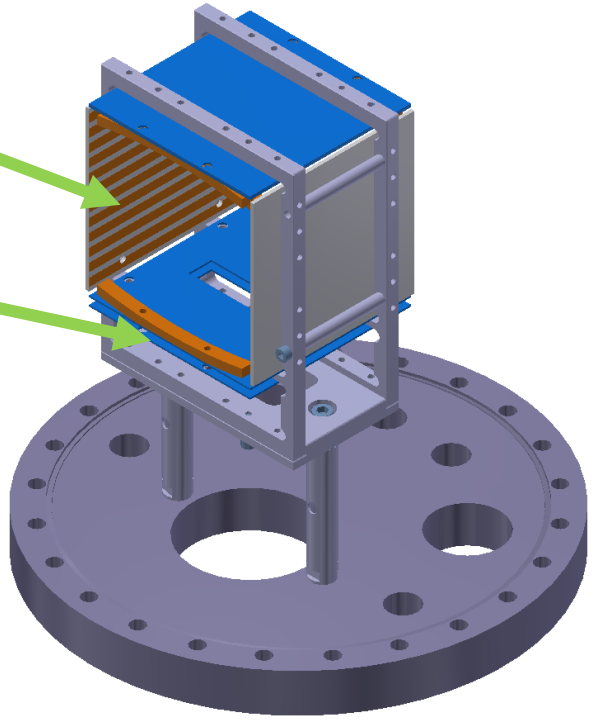


HOW TO CORRECT ELECTRICAL FIELD ?

3 main leverages

- Disks
  - Shield IPM from each other
  - Independent systems
- Field correctors
  - Correction in transversal direction
- Curved electrodes
  - Increase the shielding effect
  - Correction in longitudinal direction

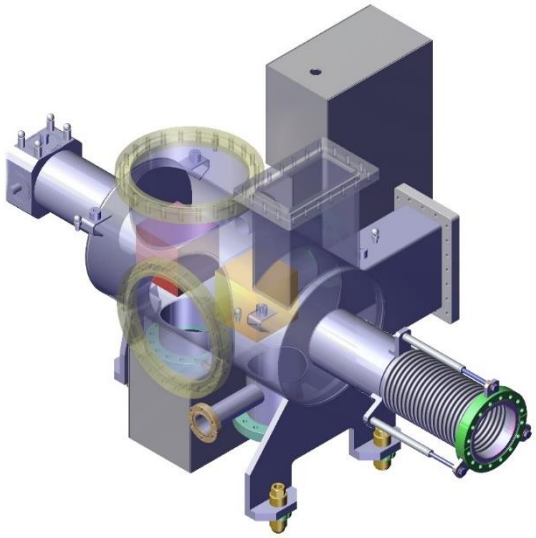


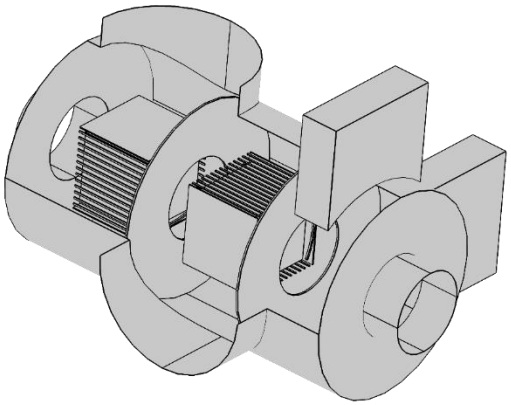


SIMULATIONS SETUP

COMSOL

- All-in one Finite Element Method software
  - Geometry construction (1D, 2D, 3D)
  - Mesh generation
  - Boundaries Condition
  - Solution solver
  - Visualization
- Support different type of solver/physic
  - Static/Temporal
  - Optimization
- Drawbacks
  - Sometimes, it looks like a black box
  - Segmented product
  - Export data to other software





HOW TO QUANTIFY UNIFORMITY ?

Criteria

- 3D vector data are difficult to represent directly
  - Go back to 2D
  - Streamlines
- Find a way to quantify the uniformity

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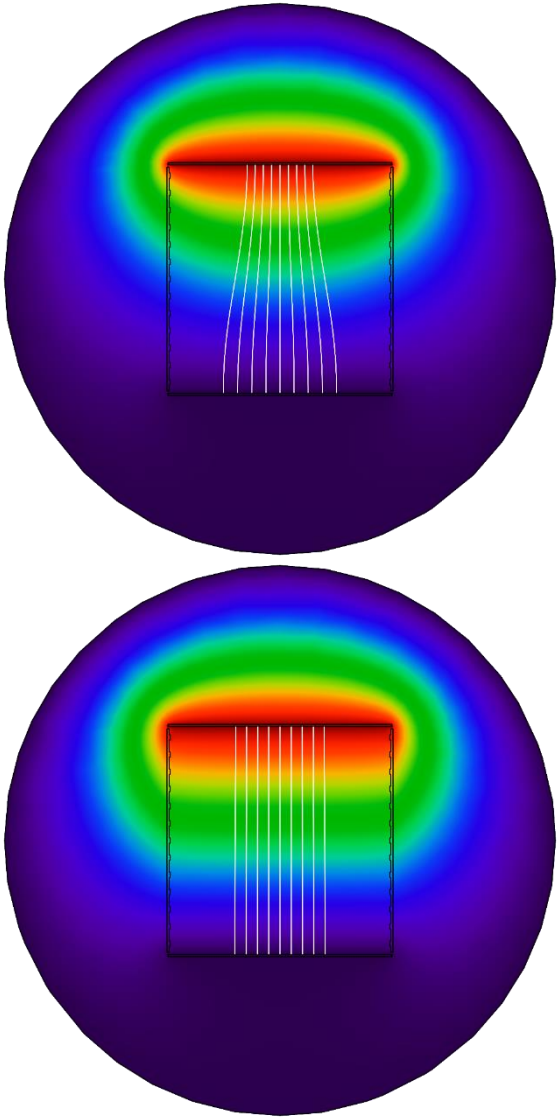
Image

1. Plot an image from the solution

- Advantages
  - Simple, include in COMSOL
- Drawbacks
  - How to quantify/compare



HOW TO QUANTIFY UNIFORMITY ?

Criteria

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  - **Go back to 2D**
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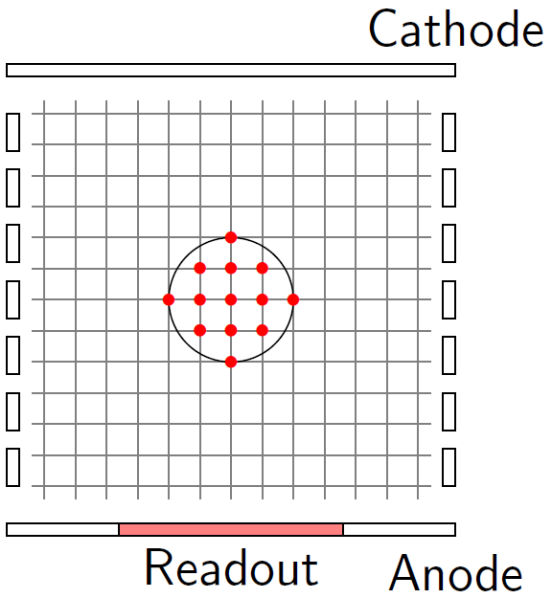
Statistical

1. Make a slice in Z direction
2. Calculate the quadratic mean value of E field in the area close by to the beam
3. Sweep over Z

- Advantages
  - Quadratic ➔ No compensation
  - Error FEM solver only

- Drawbacks
  - Quadratic ➔ Lost sign



HOW TO QUANTIFY UNIFORMITY ?

Criteria

- 3D vector data are difficult to represent directly
  - Go back to 2D
  - **Streamlines ➔ Particles tracking in our case**
- Find a way to quantify the uniformity

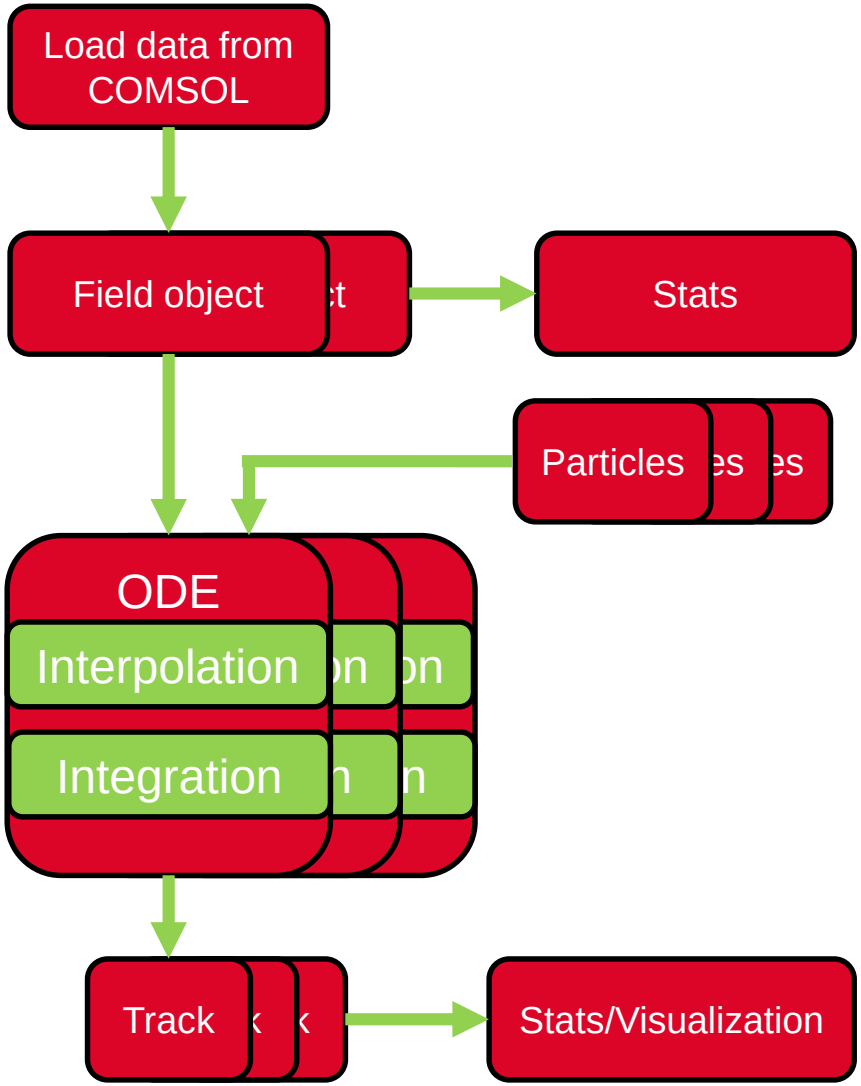
Particle tracking

1. Draw randomly (or not) particles and store the initial position
2. Integrate the equation of motion w.r.t the Lorentz equation
3. Store the final position

- Advantages
  - That's all we want
- Drawbacks
  - Error: FEM+Interpolation+Integration

- $\vec{F} = q \cdot \vec{E} + \vec{v} \times \vec{B}$
  - Non relativistic in range of a IPM
  - No magnetic field in our case but possibility to add one (background)
- Interpolation on scattered data
  - Radial Basis Function
  - Nearest Neighbors
  - Delaunay Triangulation

ANALYSIS WORKFLOW



Goals

- Load data from COMSOL and create n field objects (can be electric or magnetic)
- Perform stats computation on these fields
- Generates particles and tracks them
- Different ODE solvers and interpolation methods
- With reasonable time of computation

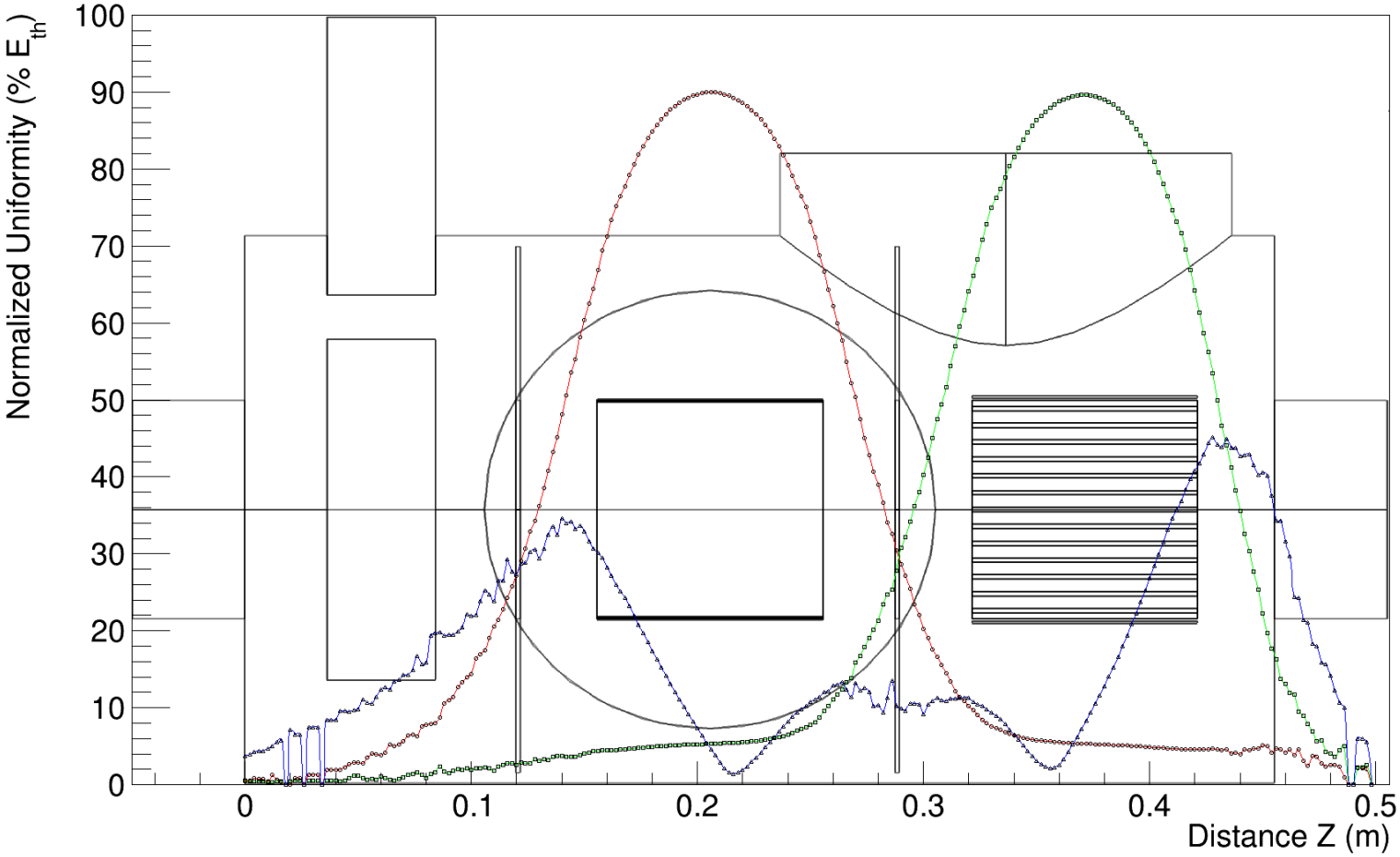
Third Party libs used

- Boost
  - ODE integration
  - Random generation
- Nanoflann for k-Nearest Neighbors search
- Intel TBB for parallelization
- VTK and ROOT for visualization

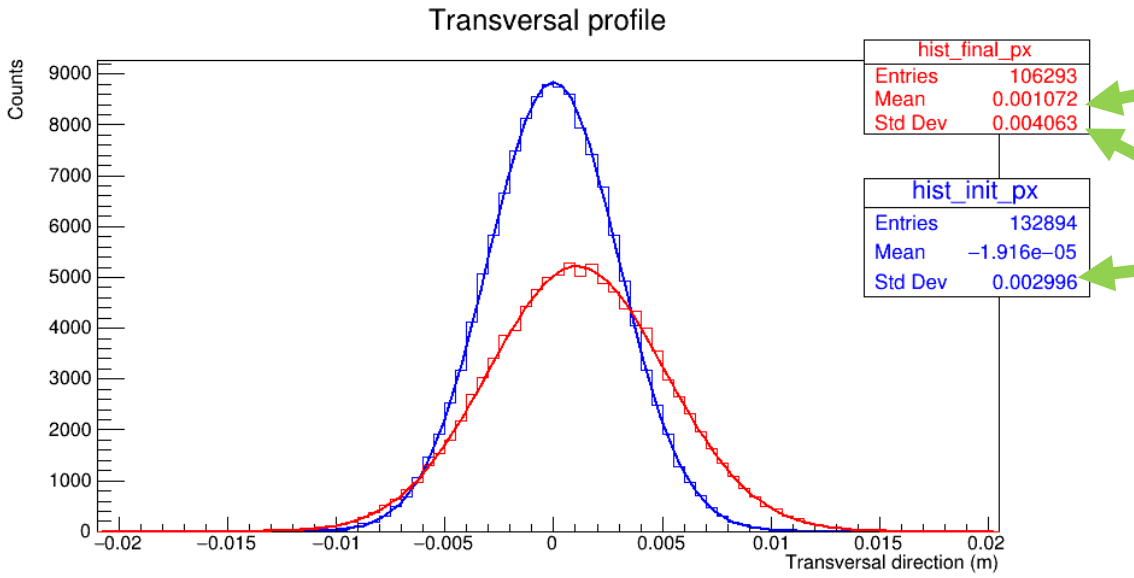
ASYMMETRIC IPM

ASYMMETRIC WITHOUT ANY CORRECTION

Electrical Field normalized by $E_{Th} = 3 \cdot 10^5\ V/m$ inside a circle of $6 \cdot \sigma_{beam} = 18\ mm$ radius

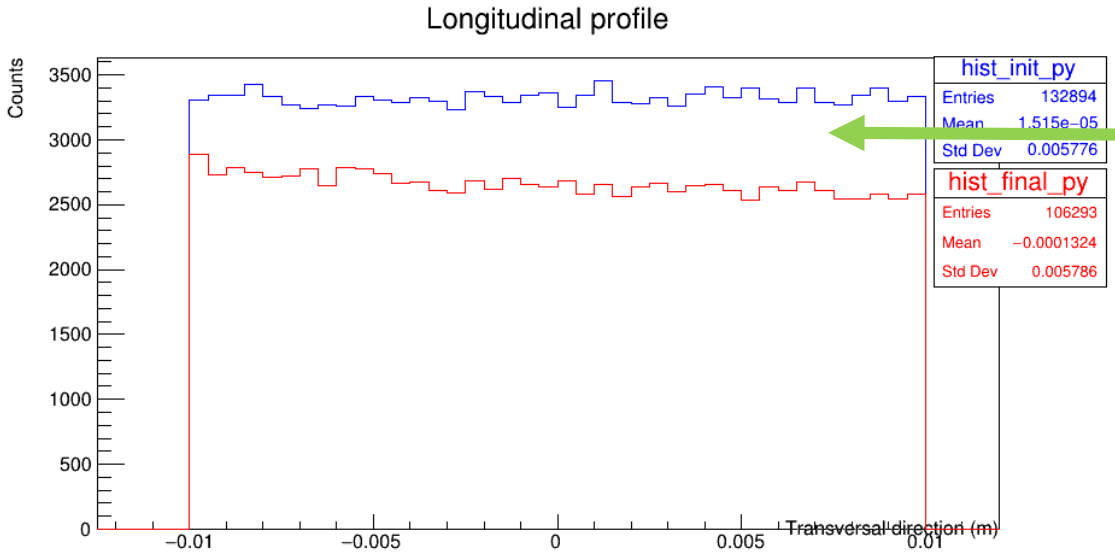


TRACKING ASYM. WITHOUT ANY CORRECTION



Shift

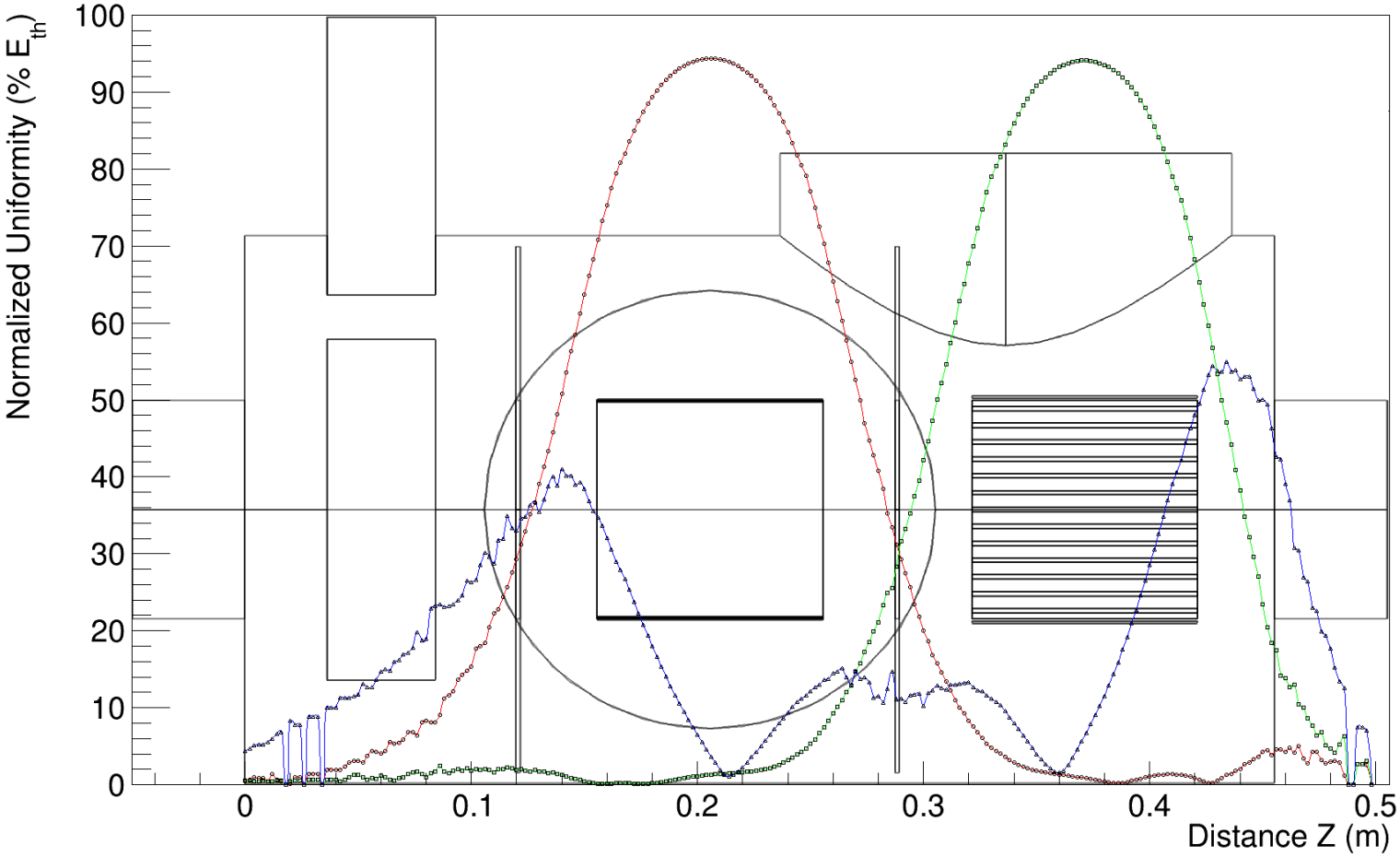
Error on profile: +35%
Not acceptable !
Due to defocusing effect of asymmetric



21% of initial particles are “lost” also due to defocusing effect.

ASYMMETRIC (CORRECTORS)

Electrical Field normalized by $E_{Th} = 3 \cdot 10^5\ V/m$ inside a circle of $6 \cdot \sigma_{beam} = 18\ mm$ radius



ASYMMETRIC (DISKS + CORRECTORS)

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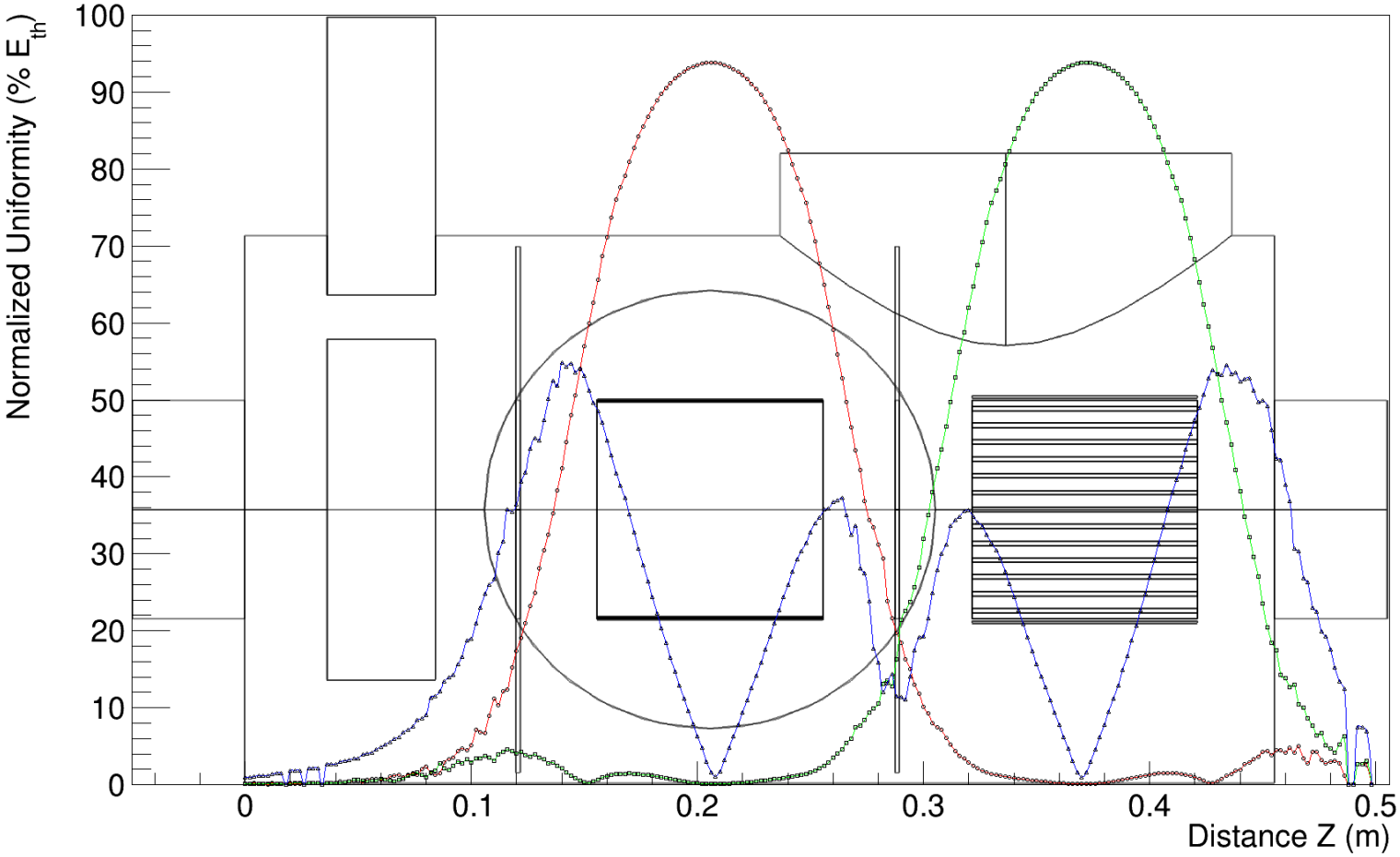
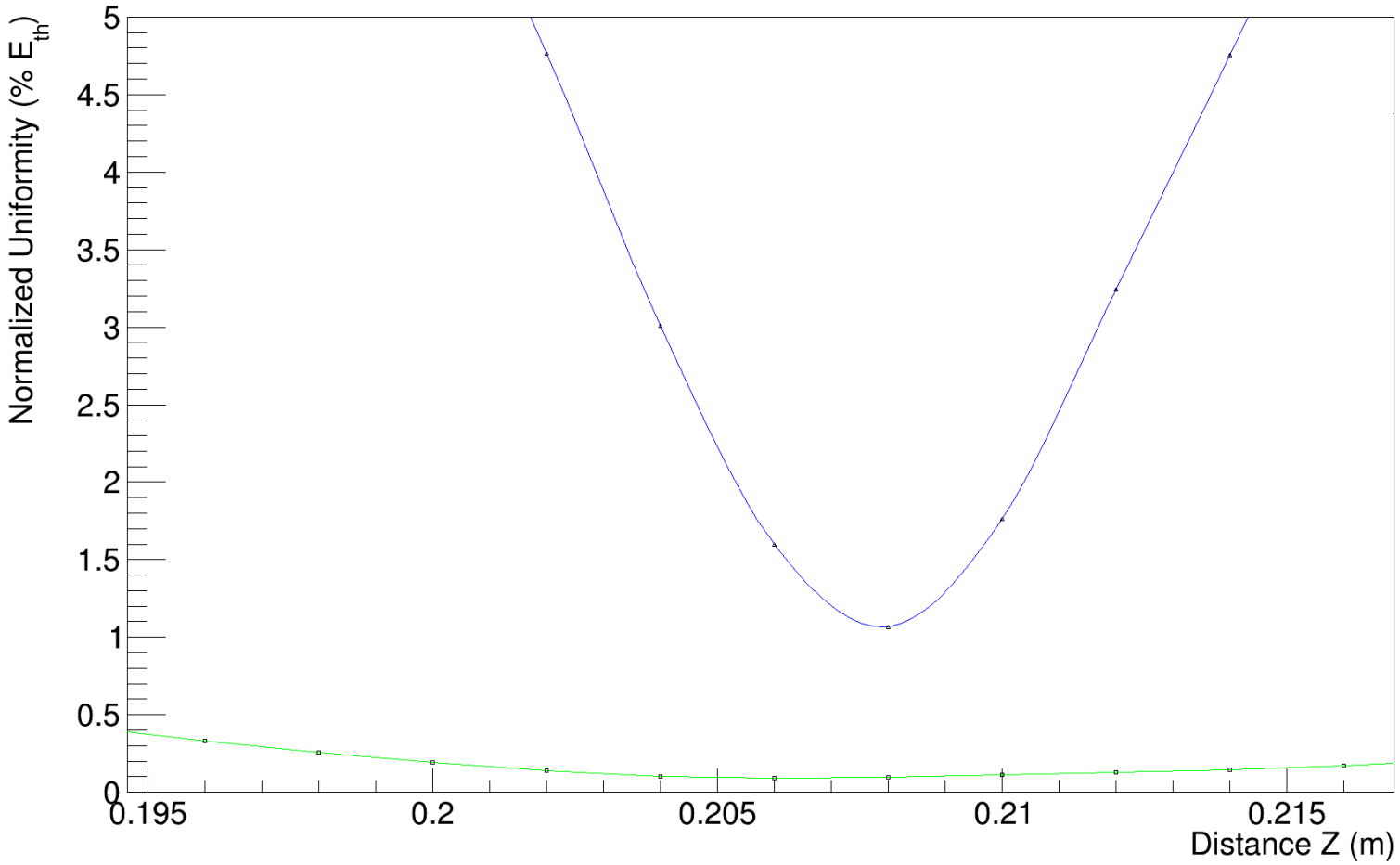


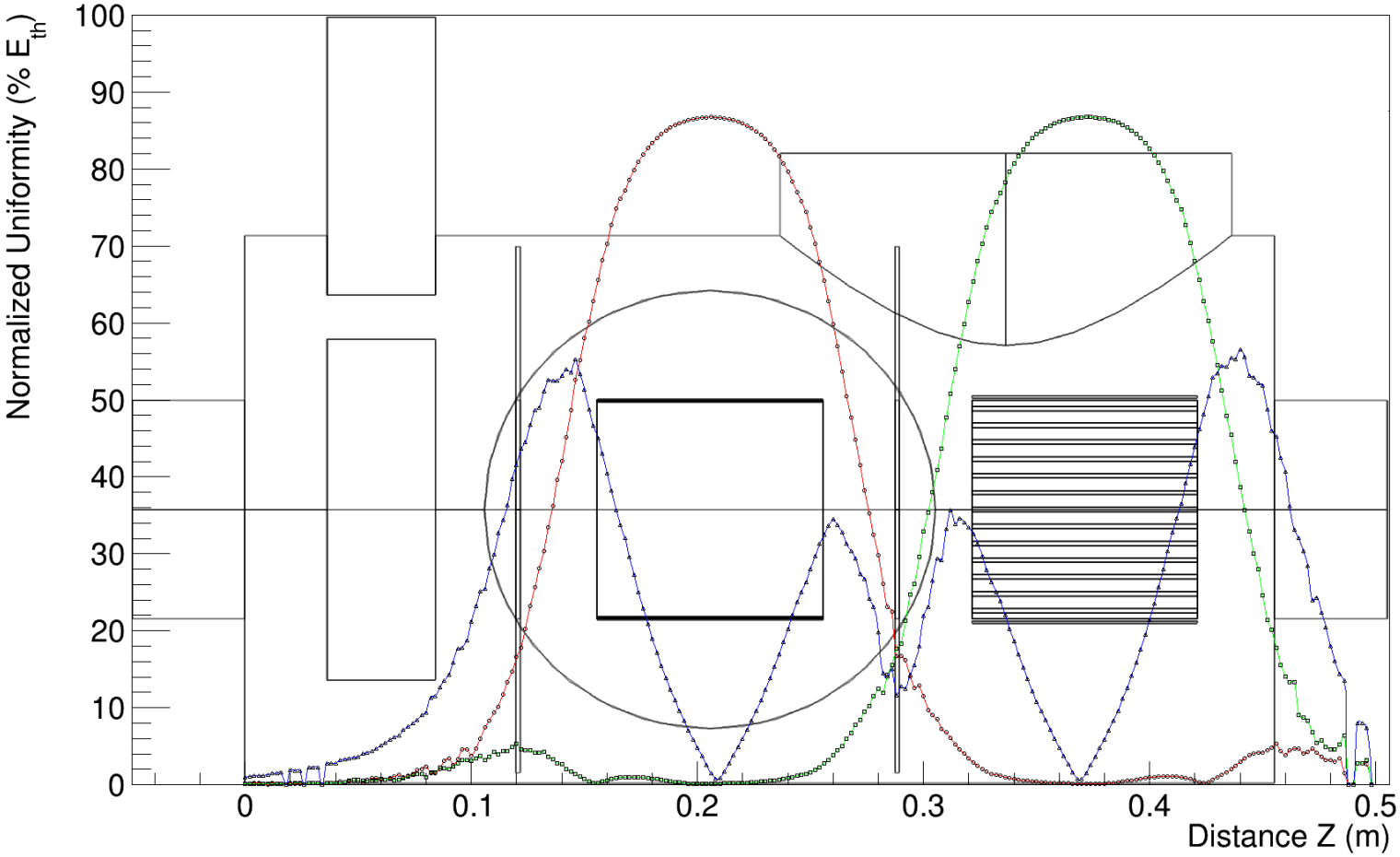
ASYMMETRIC (DISKS + CORRECTORS) ZOOM

Electrical Field normalized by $E_{Th} = 3 \cdot 10^5\ V/m$ inside a circle of $6 \cdot \sigma_{beam} = 18\ mm$ radius



ASYM. (DISKS + CORRECTORS + CURVED)

Electrical Field normalized by $E_{Th} = 3 \cdot 10^5\ V/m$ inside a circle of $6 \cdot \sigma_{beam} = 18\ mm$ radius



ASYM. (DISKS + CORRECTORS + CURVED) ZOOM

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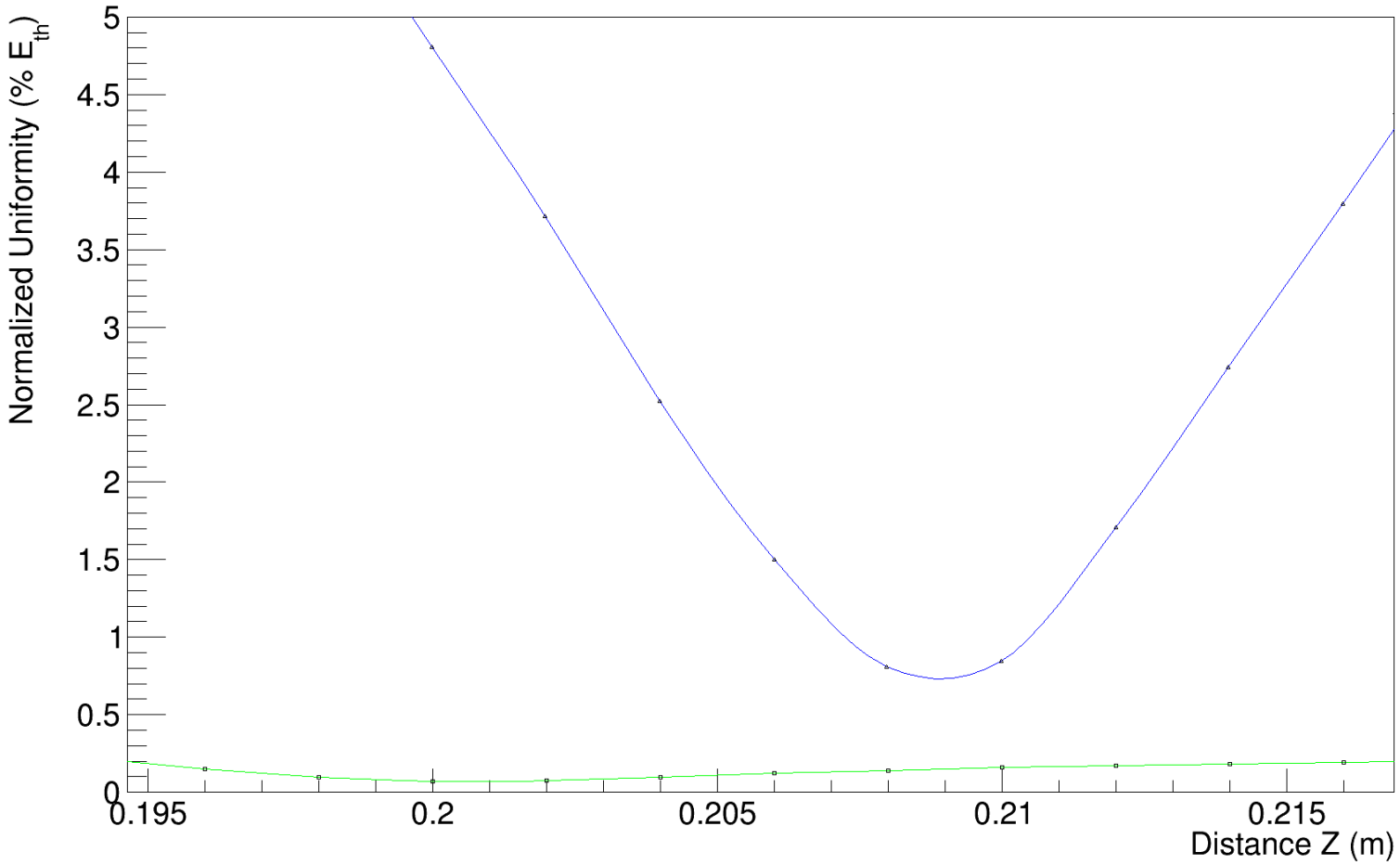
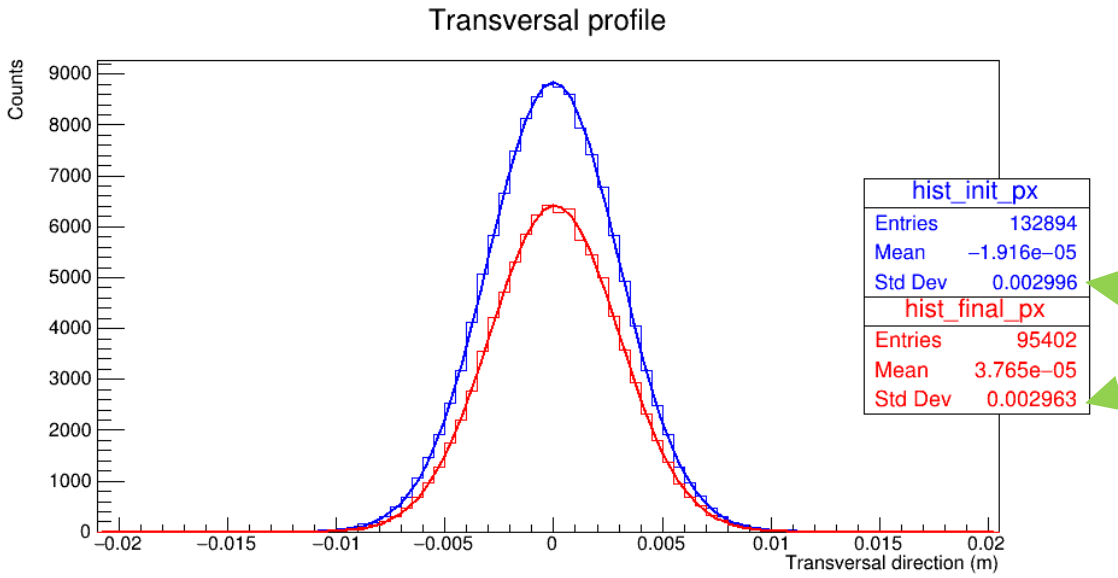
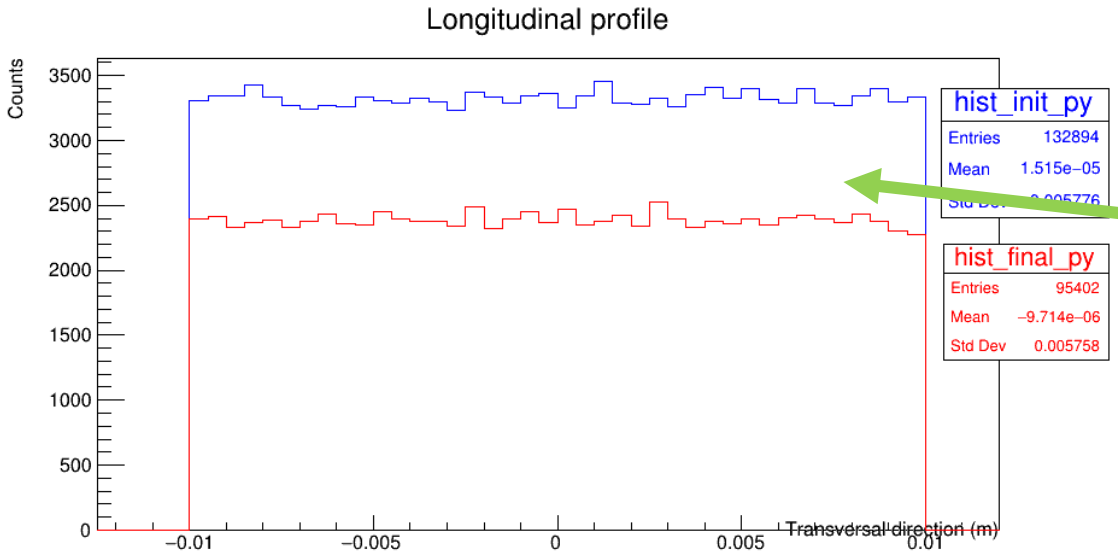


TRACKING ASYM. (DISKS + CORRECTORS)



No more shift

Error on profile: 1,1%

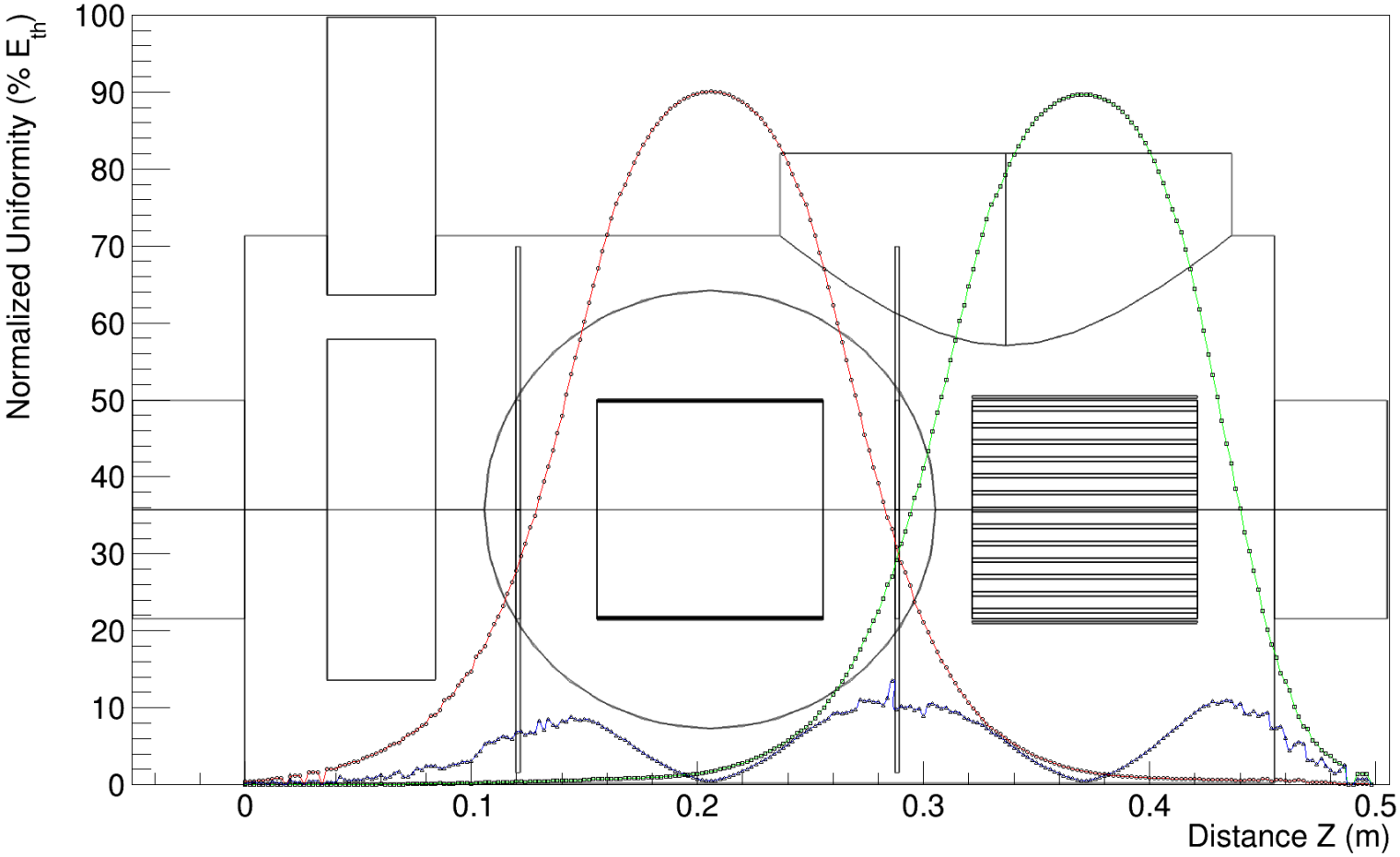


But now 29% of initial particles are “lost”

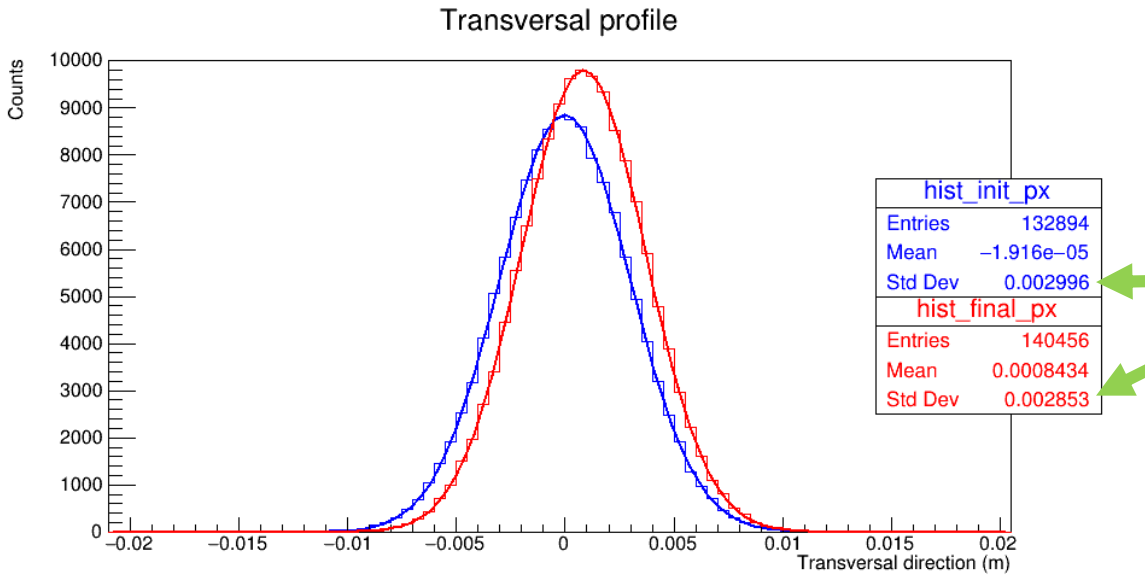
SYMMETRIC IPM

SYMMETRIC (WITHOUT ANY CORRECTION)

Electrical Field normalized by $E_{Th} = 3 \cdot 10^5\ V/m$ inside a circle of $6 \cdot \sigma_{beam} = 18\ mm$ radius



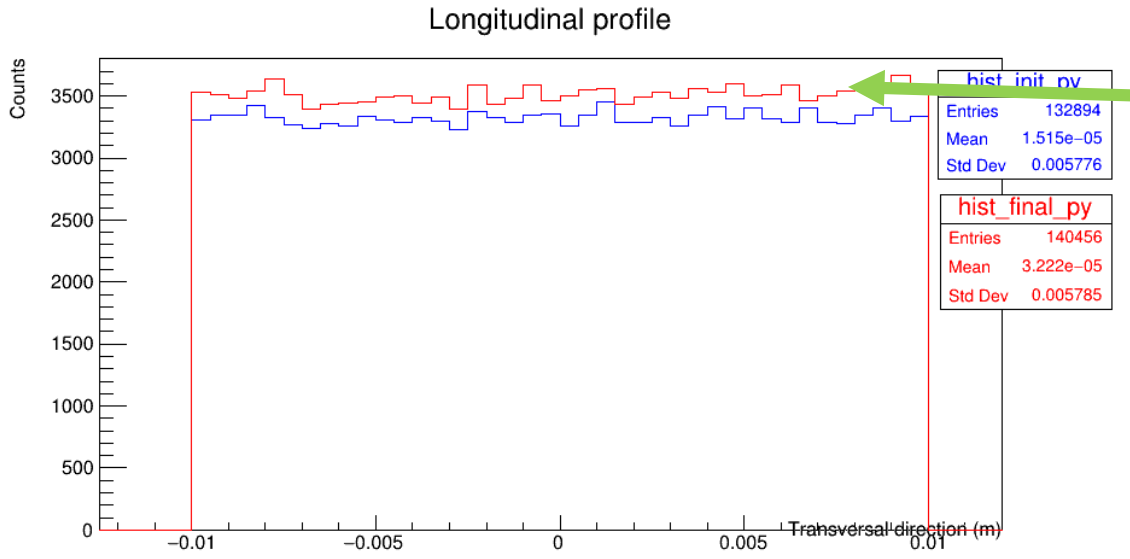
TRACKING SYM. (WITHOUT ANY CORRECTION)



Small shift

Error on profile: -4%
Without correction !

Due to focusing effect of symmetric

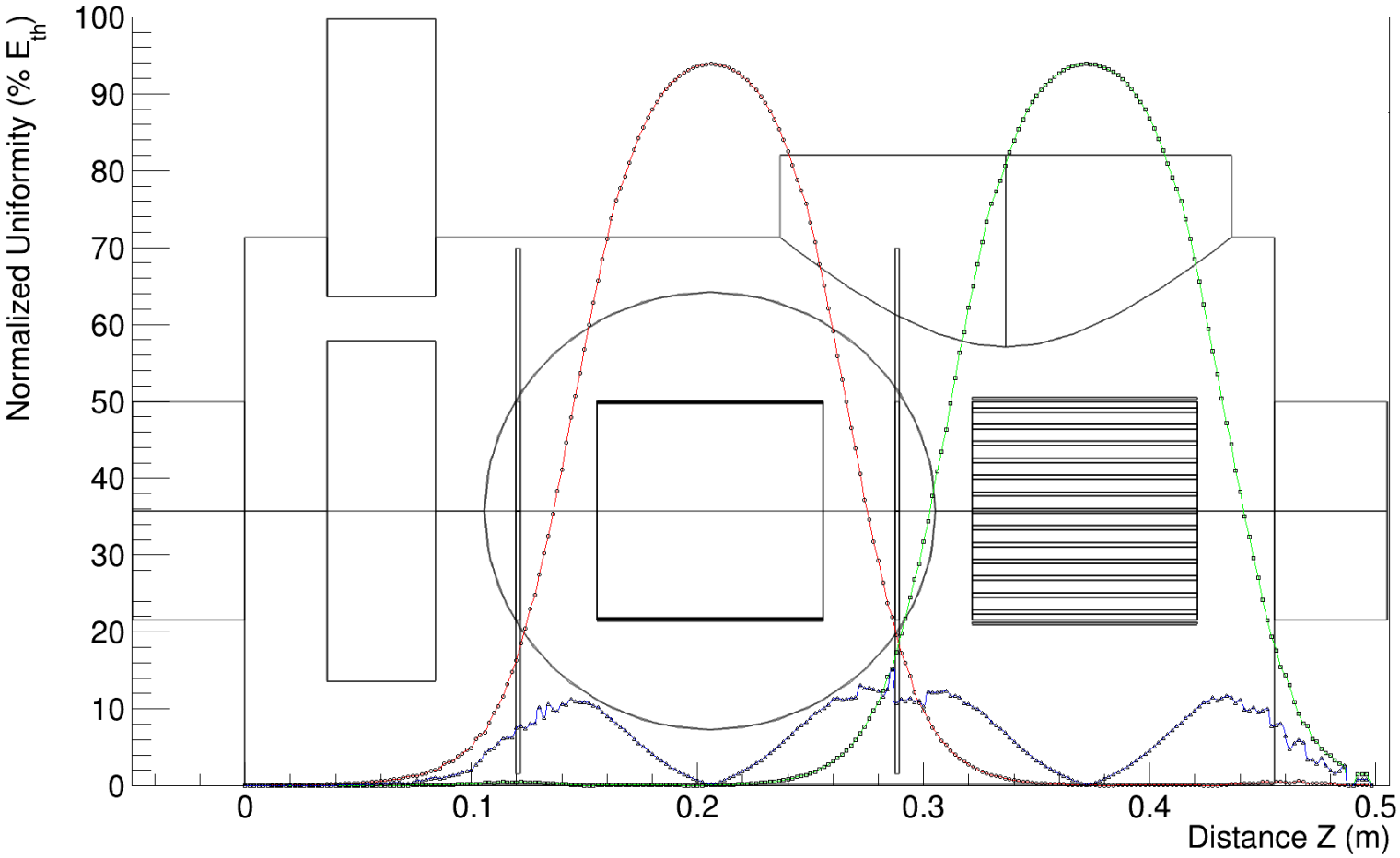


5% more particles

Due to focusing effect of symmetric

SYMMETRIC (DISKS + CORRECTORS)

Electrical Field normalized by $E_{Th} = 3 \cdot 10^5\ V/m$ inside a circle of $6 \cdot \sigma_{beam} = 18\ mm$ radius



SYMMETRIC (DISKS + CORRECTORS) ZOOM

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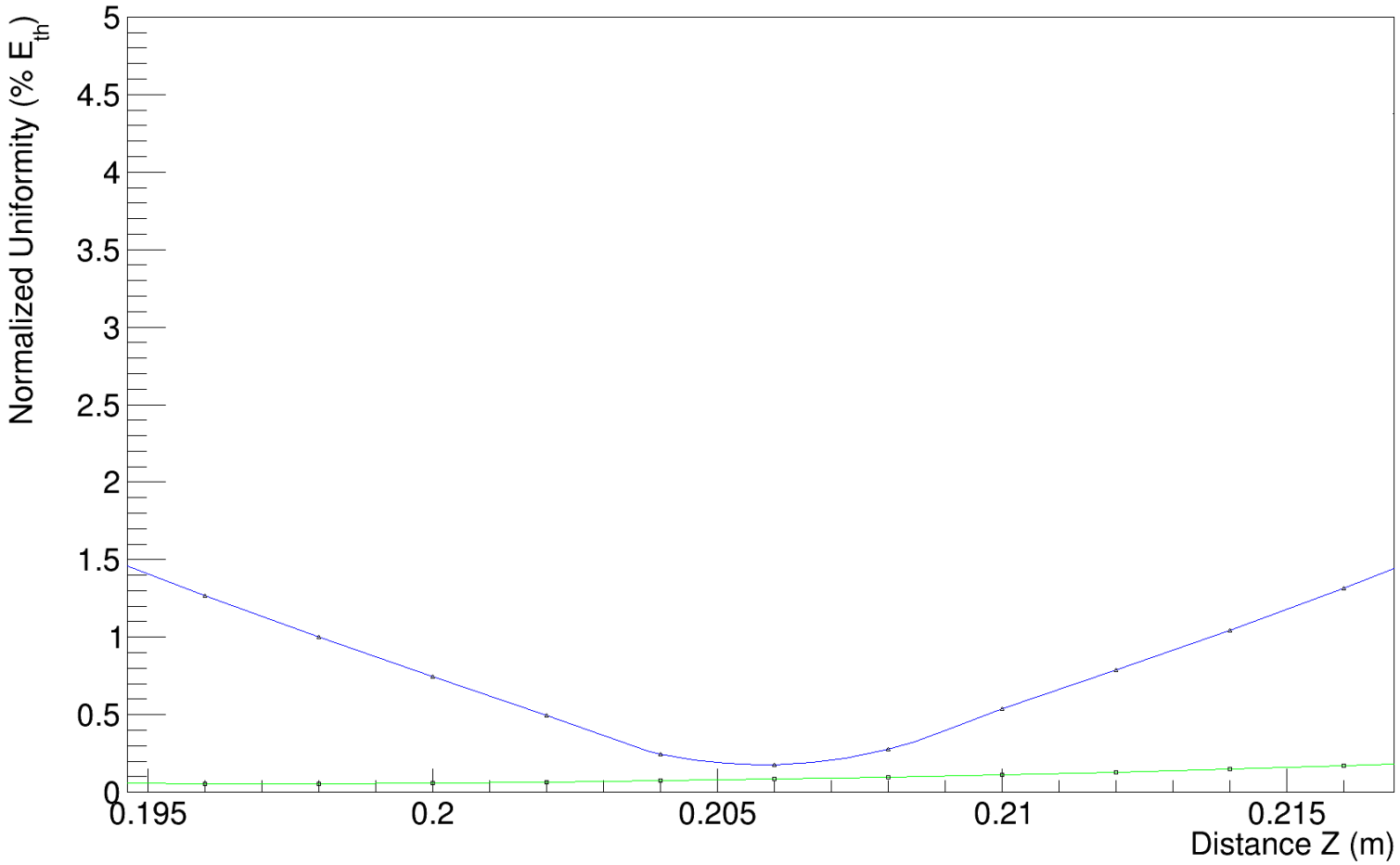
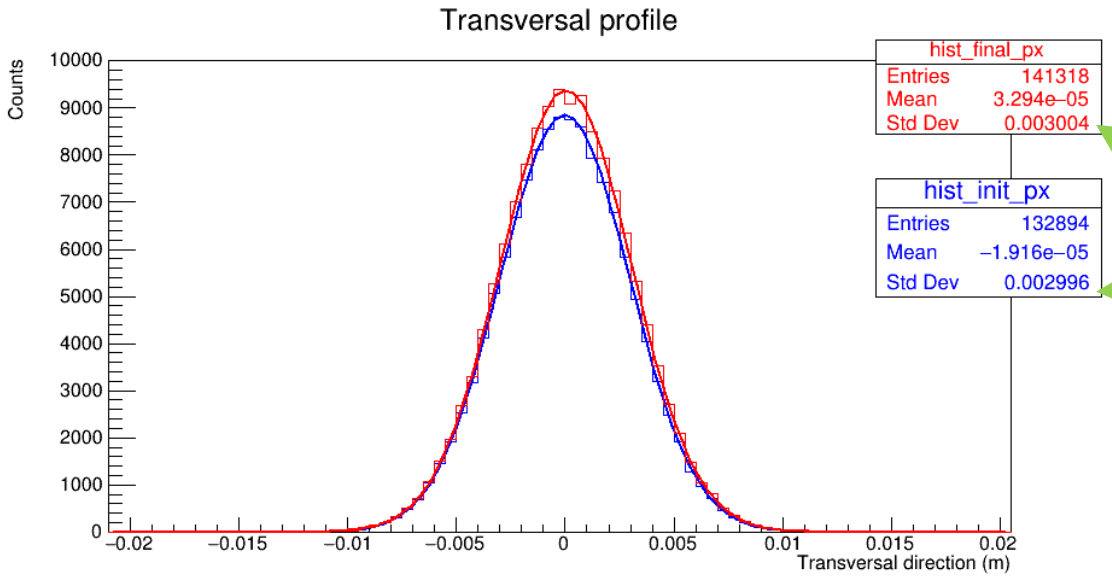
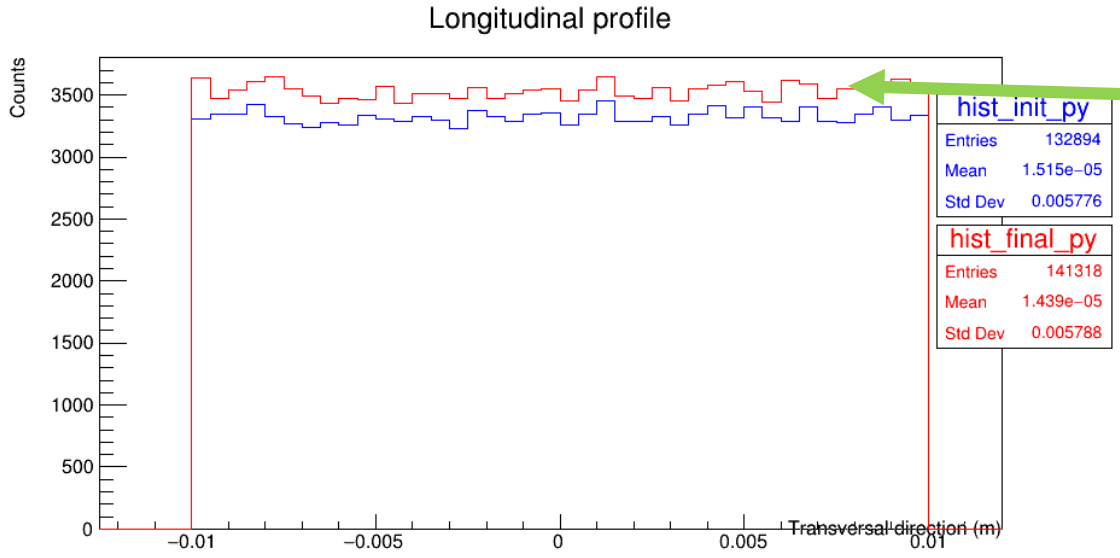


TRACKING SYM. (DISKS + CORRECTORS)



No more shift

Error on profile: +0.2%



5% more particles

CONCLUSIONS & OUTLOOKS

Conclusions

- The uniformity unlike other phenomena can be “hardware” corrected
- Correctors are mandatory in order to perform a good uniformity
- Disk are the easiest and efficient way to isolate IPM
- Curved electrodes may not be useful since our IPM are “big”

Outlooks

- Add “noise” to simulation
  - Magnetic background
  - Other BI systems
  - Etc.
- Investigate more on error in analysis process
- Continue to improve and keep up to date the simulation model/analysis code

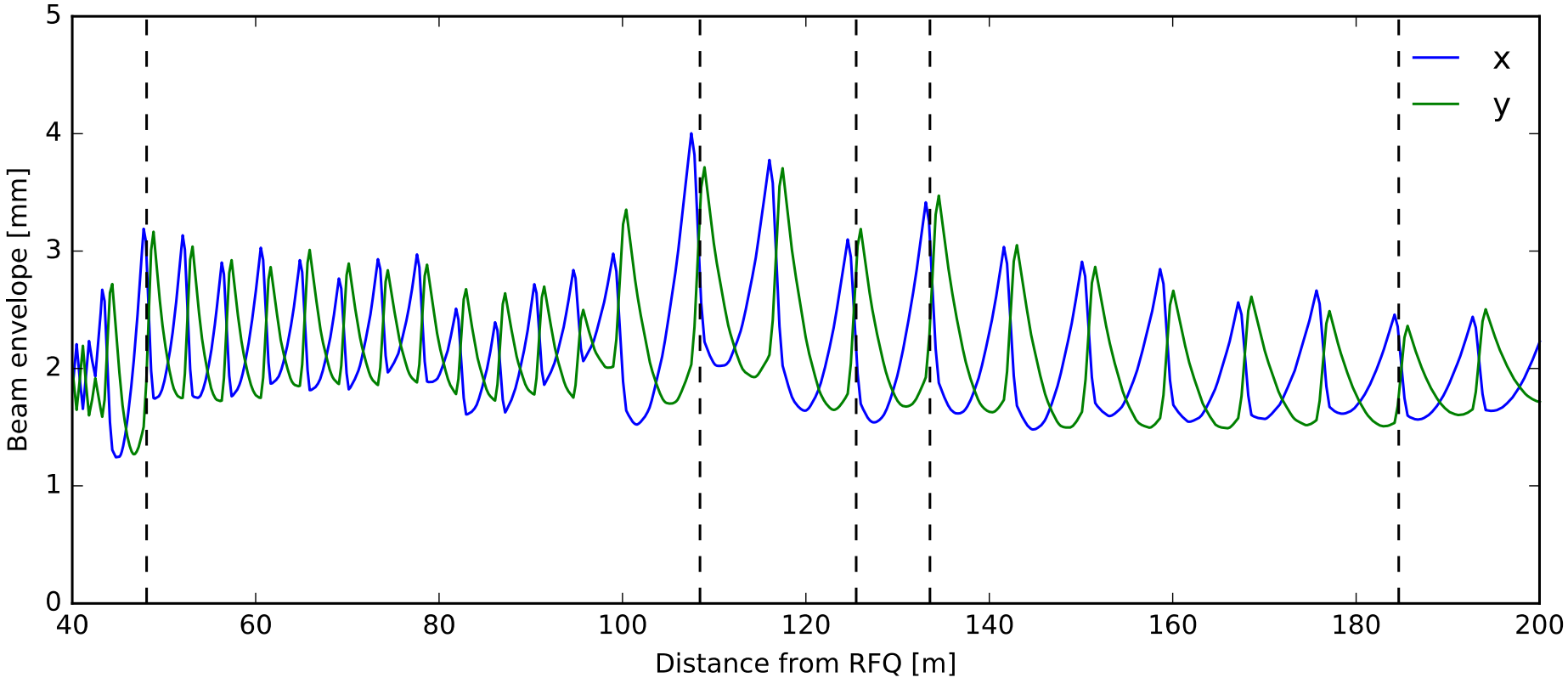
THANK FOR YOU ATTENTION

-

QUESTIONS ?

BACKUP SLIDES

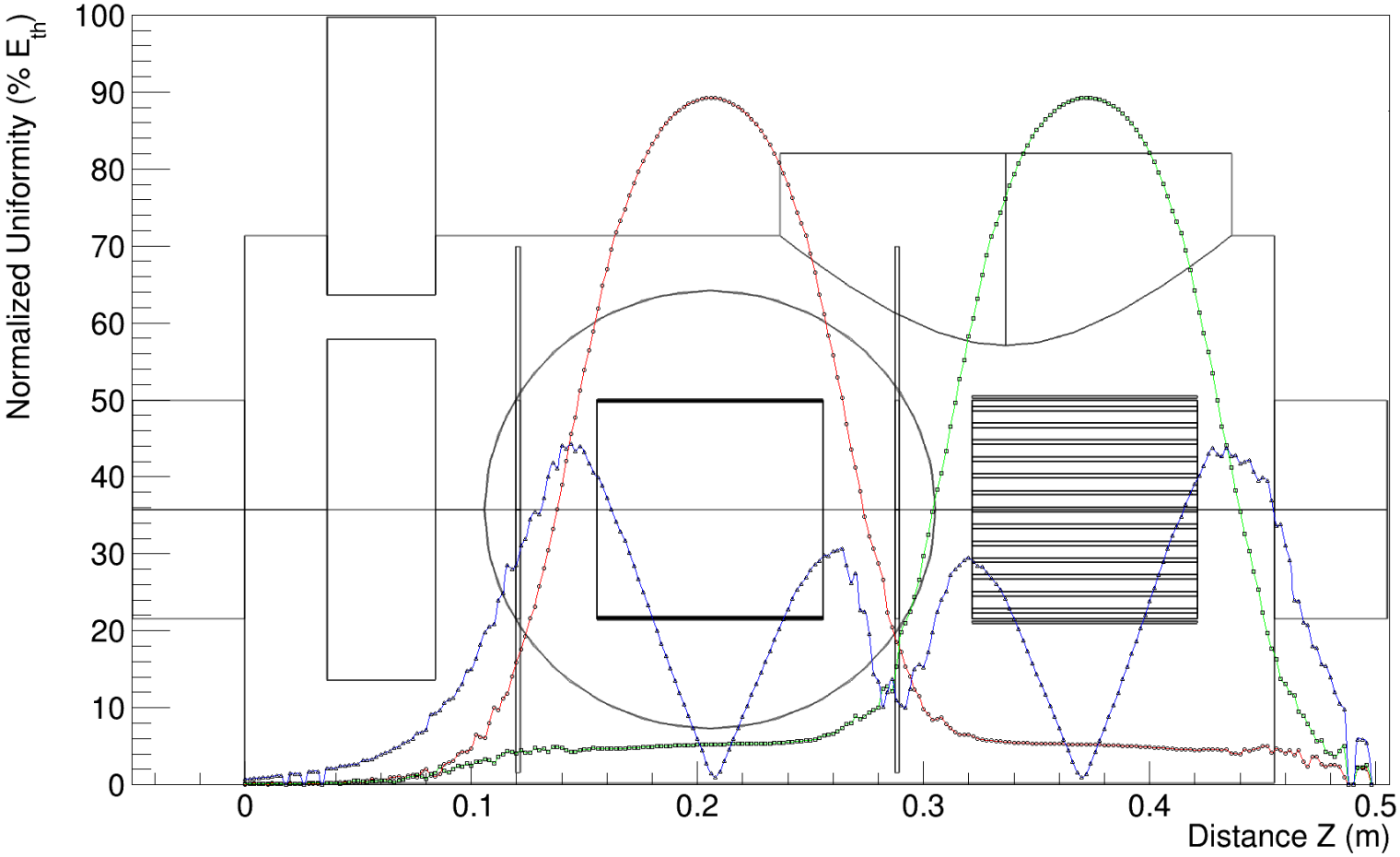
BEAM PHYSICS – BEAM ENVELOPES



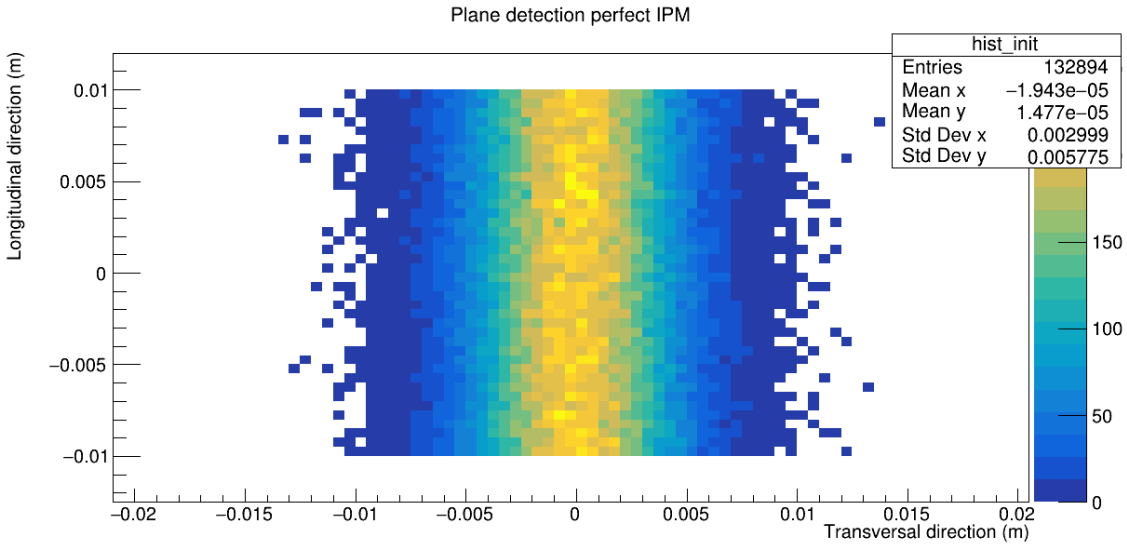
NPM locations in cold linac

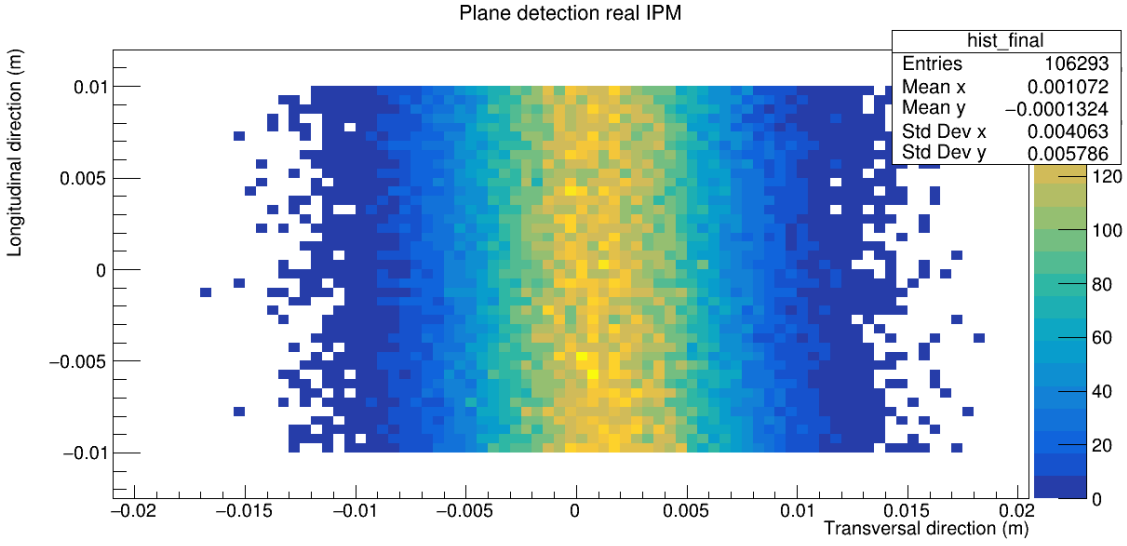
ASYMMETRIC (WITH DISKS)

Electrical Field normalized by $E_{Th} = 3 \cdot 10^5\ V/m$ inside a circle of $6 \cdot \sigma_{beam} = 18\ mm$ radius



TRACKING ASYM. WITHOUT ANY CORRECTION





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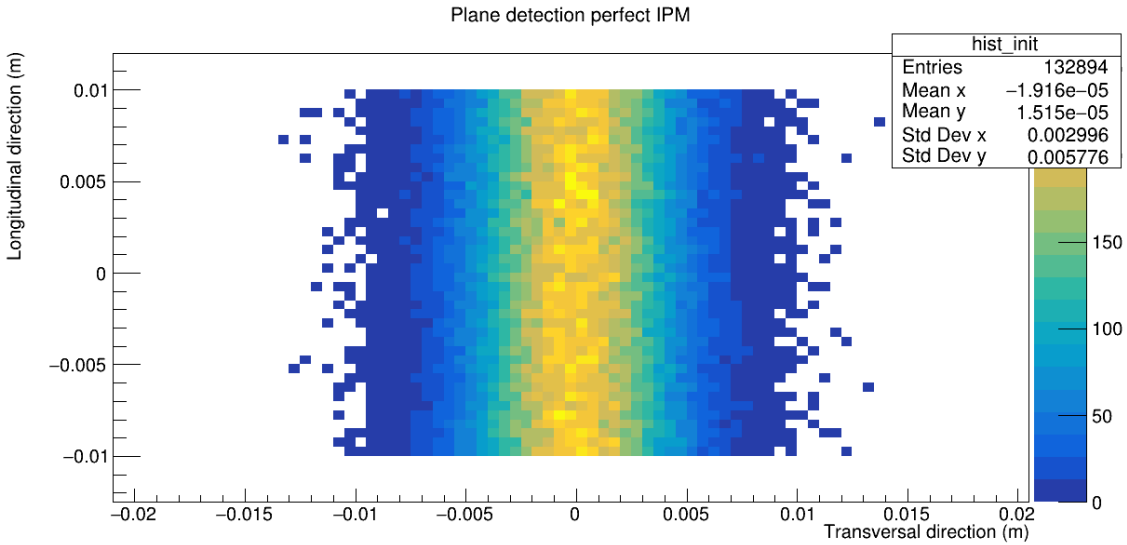
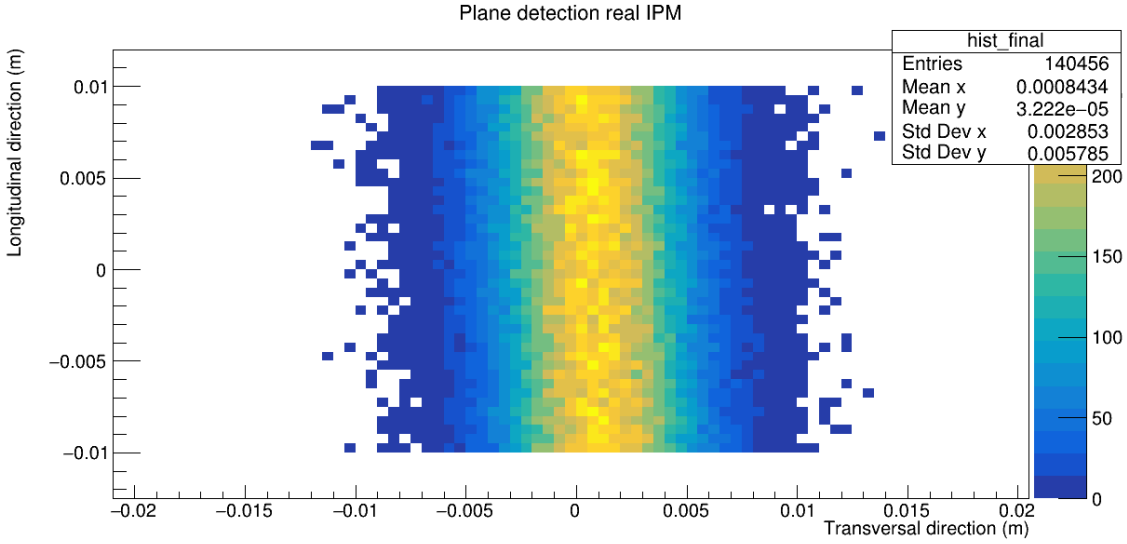
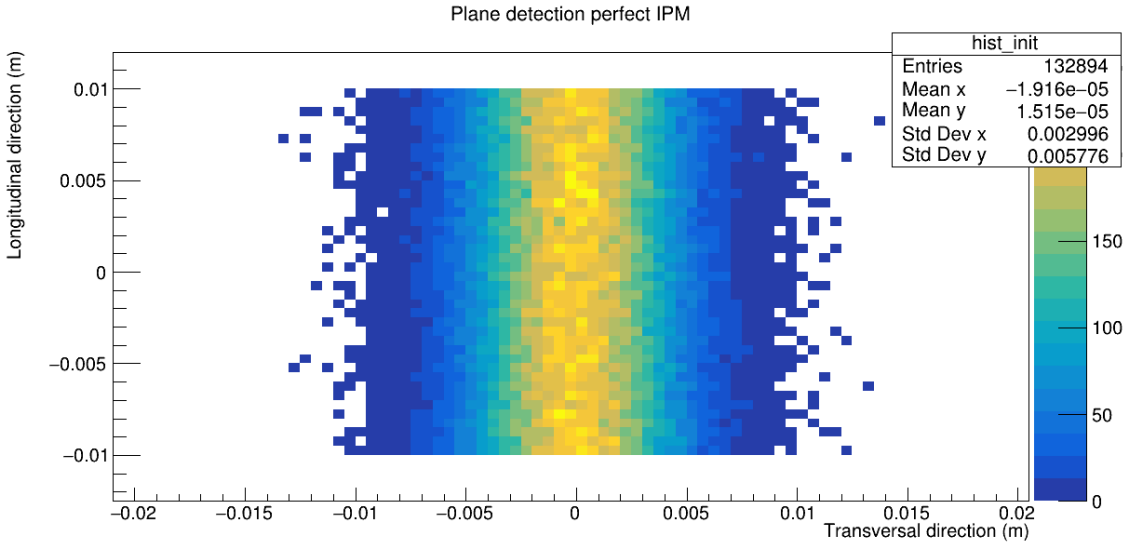
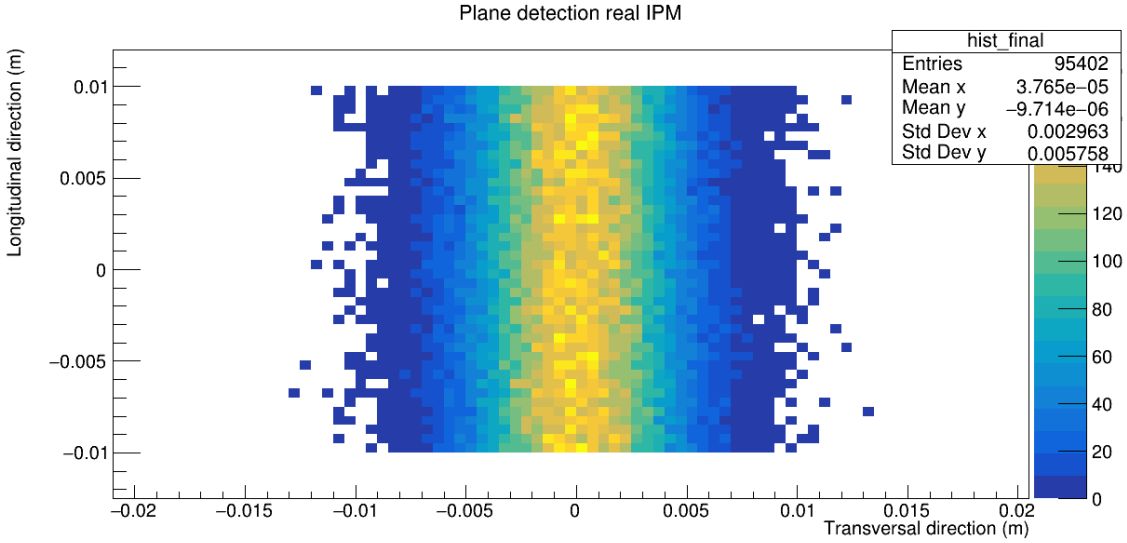




TRACKING ASYM. WITH CORRECTIONS





TRACKING SYM. WITH CORRECTIONS