Multiphysics simulation of the Heavy Ion Detector of the upgraded Recoil Filter Detector using Geant4 and SIMION

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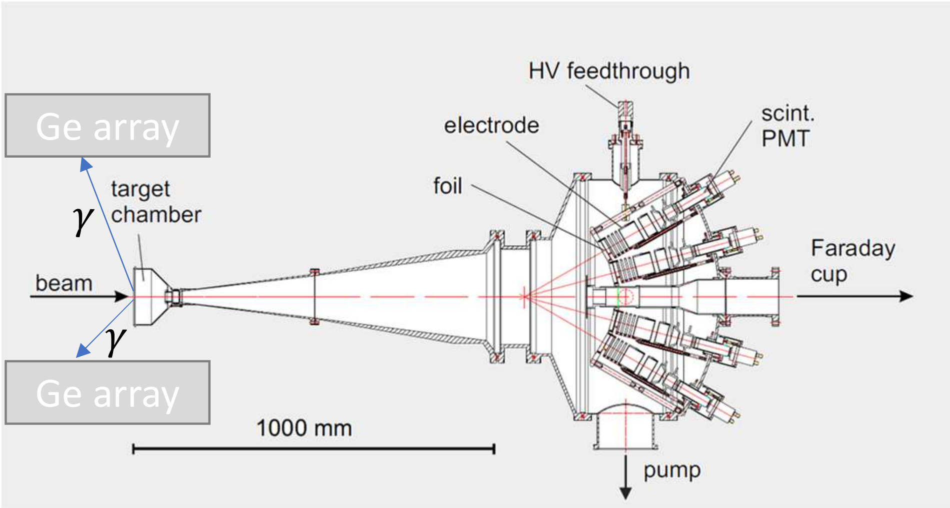
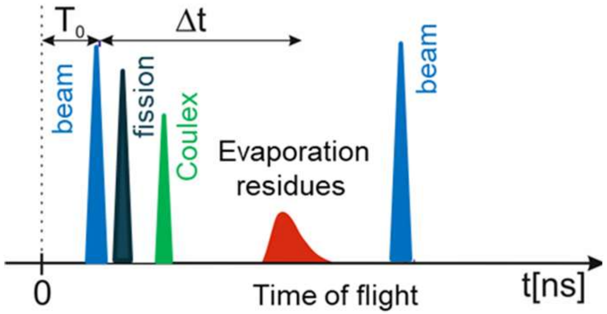
SONATA BIS, NCN grant No. 2023/50/E/ST2/00621

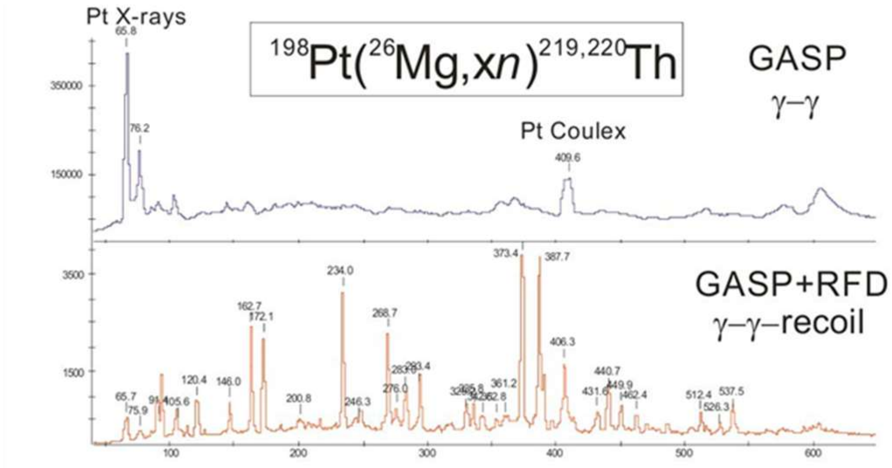
NATIONAL SCIENCE CENTRE POLAND

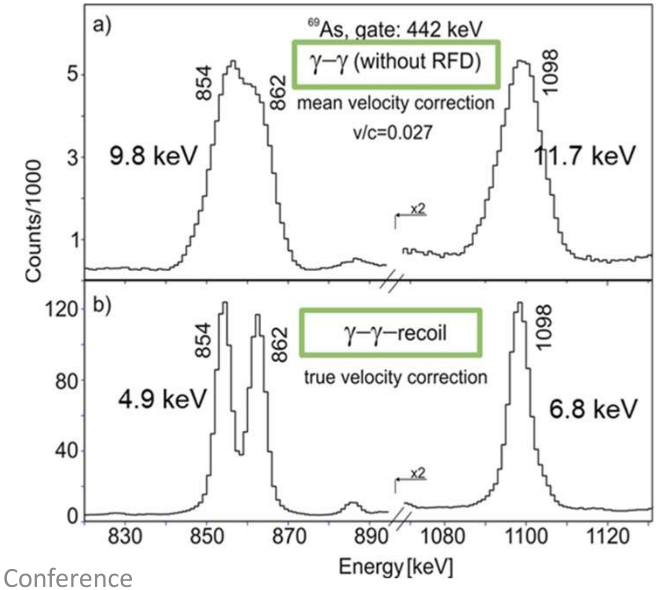
UNIVERSITY OF WARSAW

1. The RFD detector









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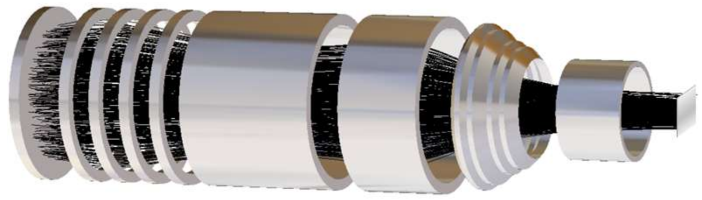
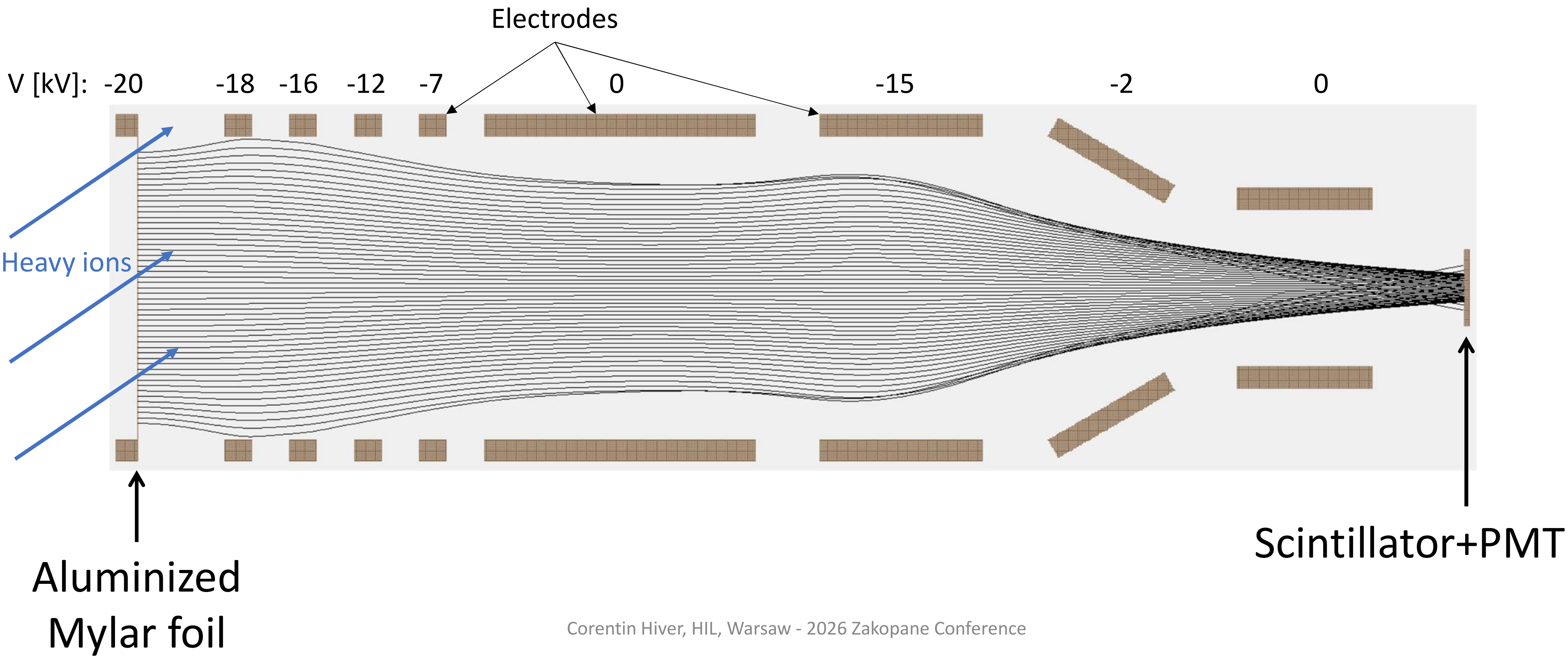




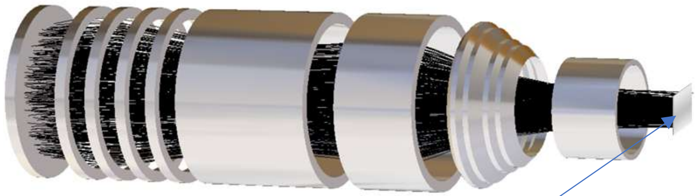
2. Upgrade

- The original setup showed several limitations:
  - Limited counting rate (scattered beam in inner detectors)
  - Limited fluence (regular pauses needed)

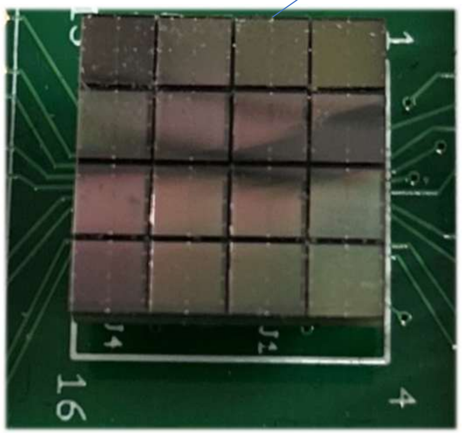
- The update consists in replacing the PMT by a SiPM array
  - →Intrisic segmentation
  - →Increased counting rate
  - →Decreased fluence per cell

- Integration at Heavy Ion Laboratory in Warsaw for experimental campaign in 2027-2028 with EAGLE and DIAMANT

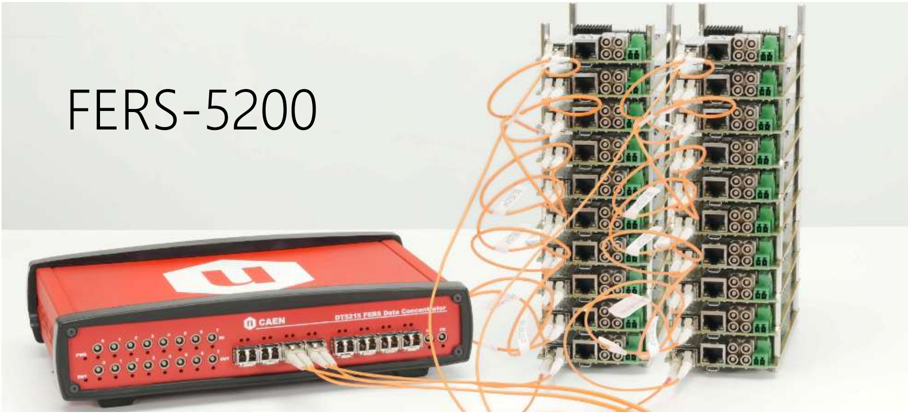
2. Upgrade



MICROFJ-30035-TSV-TR from onsemi



SiPM array of 16 cells
3x3 mm each



New electronics from CAEN

- Dedicated ASIC for SiPM
- Can handle the 16x18 = 288 channels

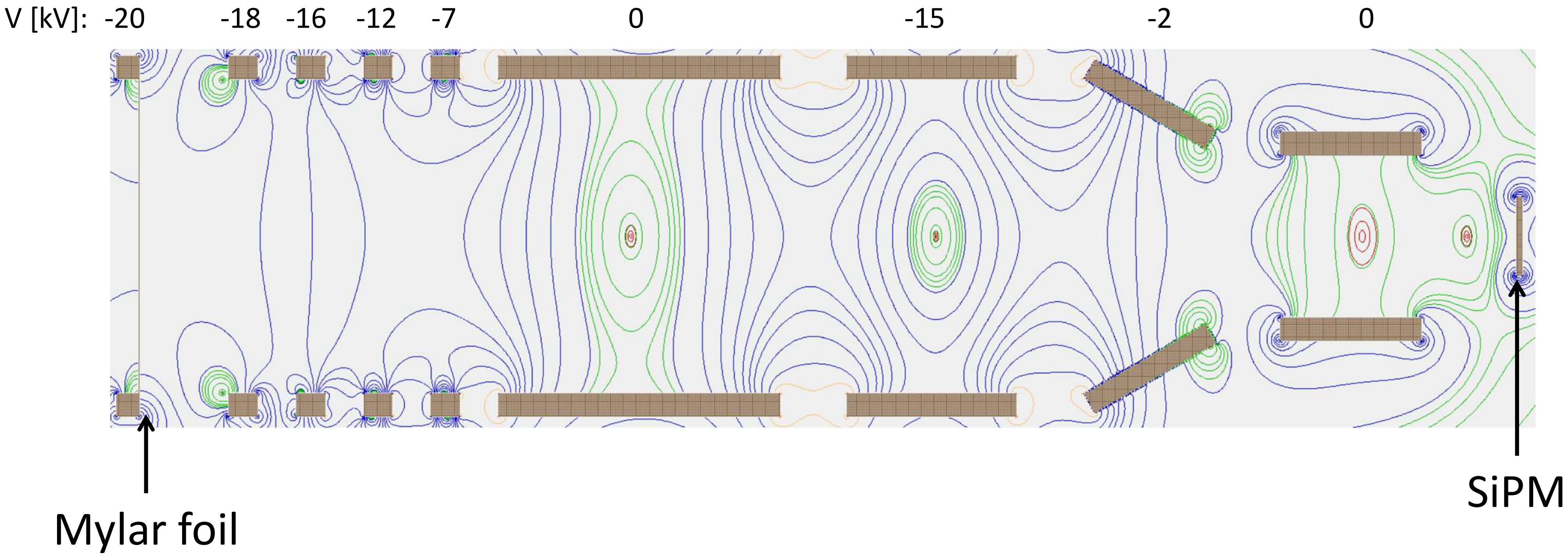
2. Upgrade

- Main question: will segmentation work as intended ?
- Two probable problems:
  - Light sharing between cells
  - Dispersion of electron bunches after acceleration

➢ Geant4 simulation for light propagation

➢ SIMION simulation for electron bunches focusing

3. SIMION simulation



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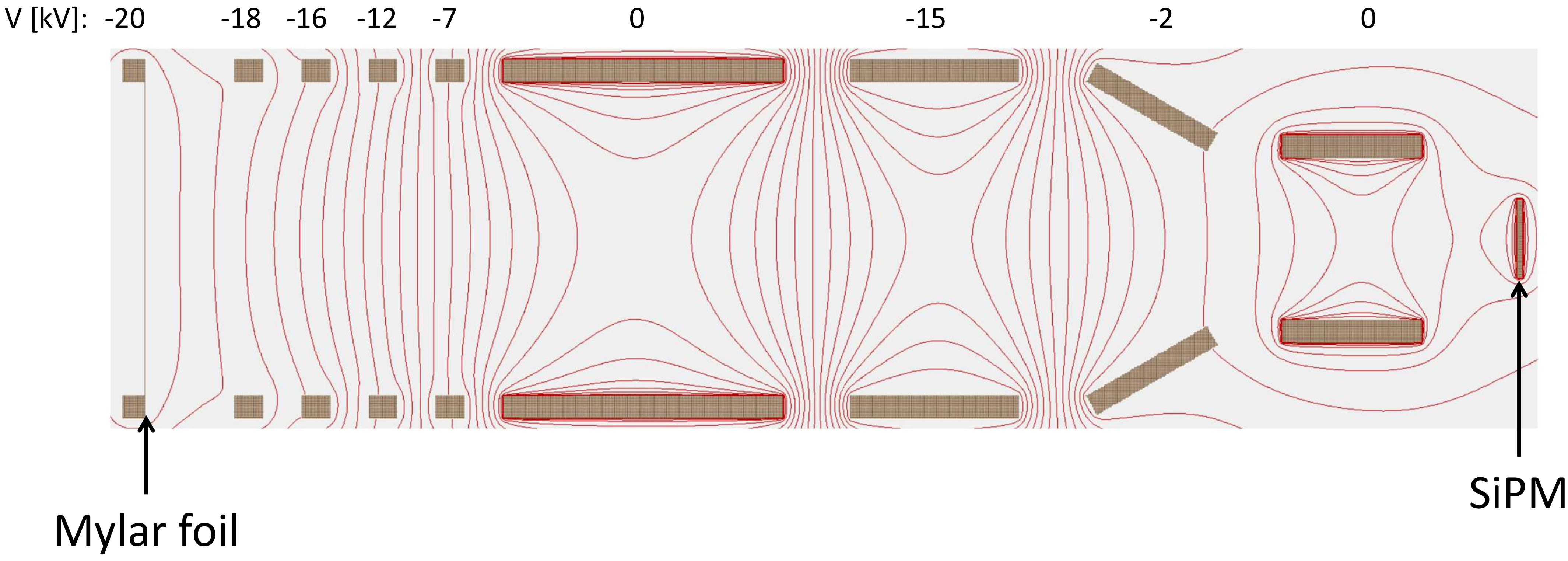

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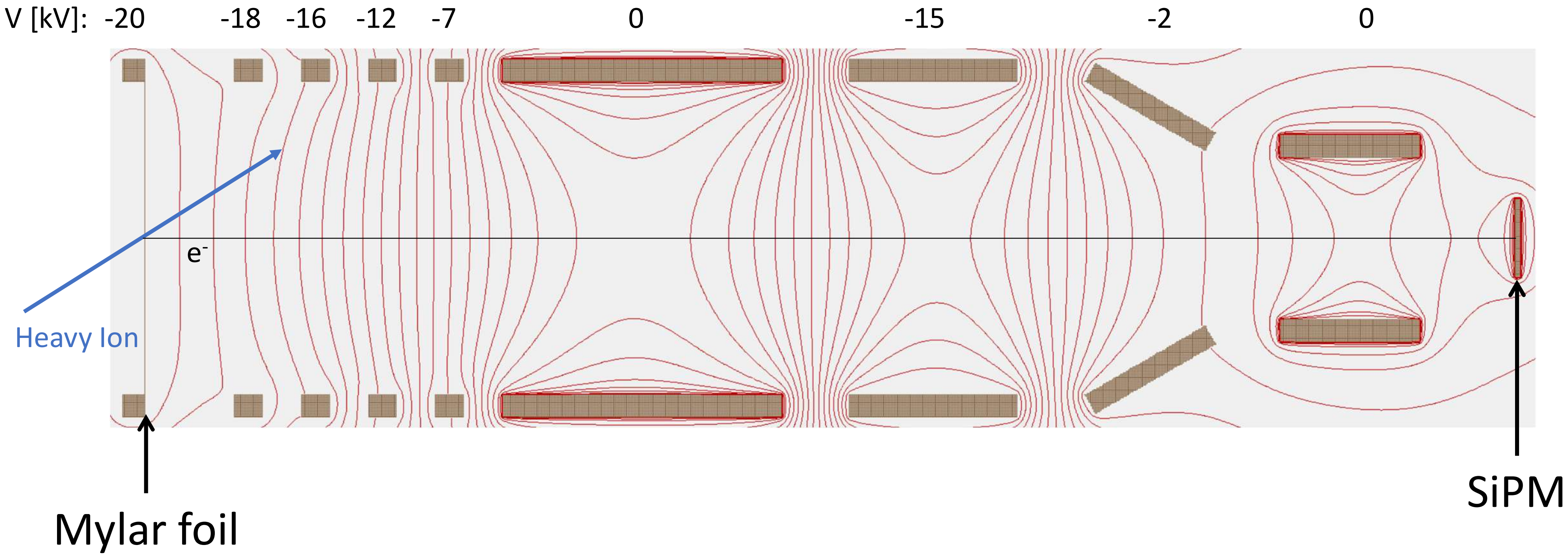

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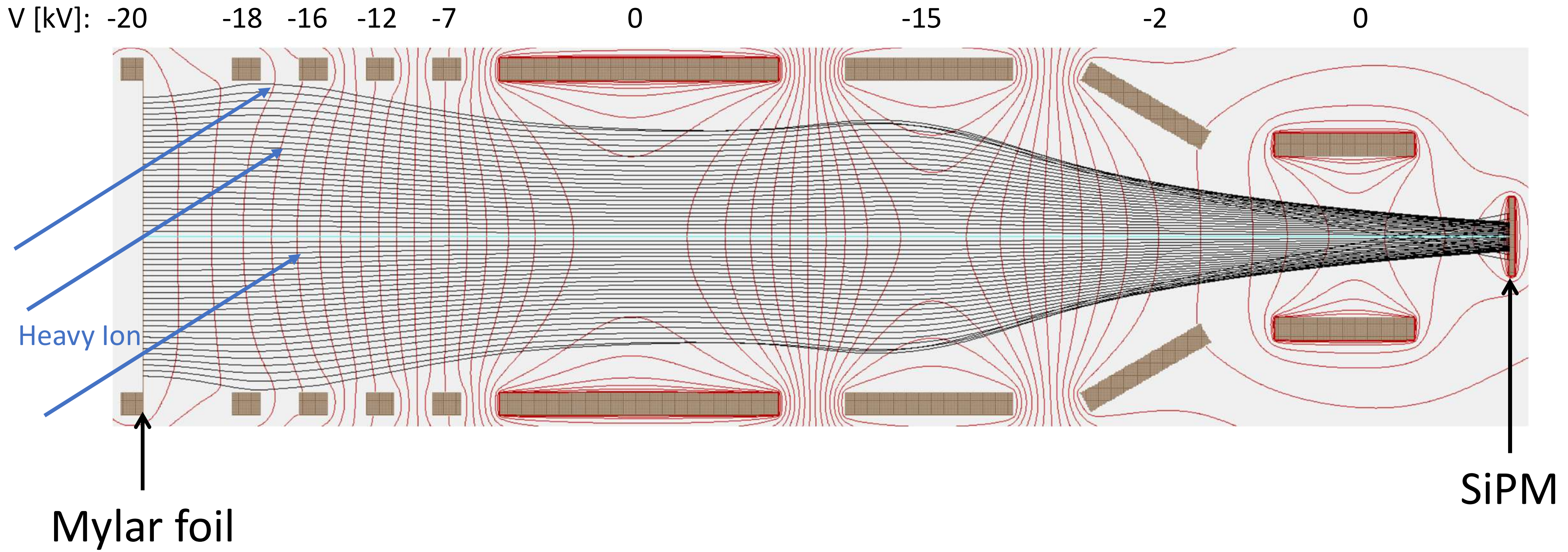

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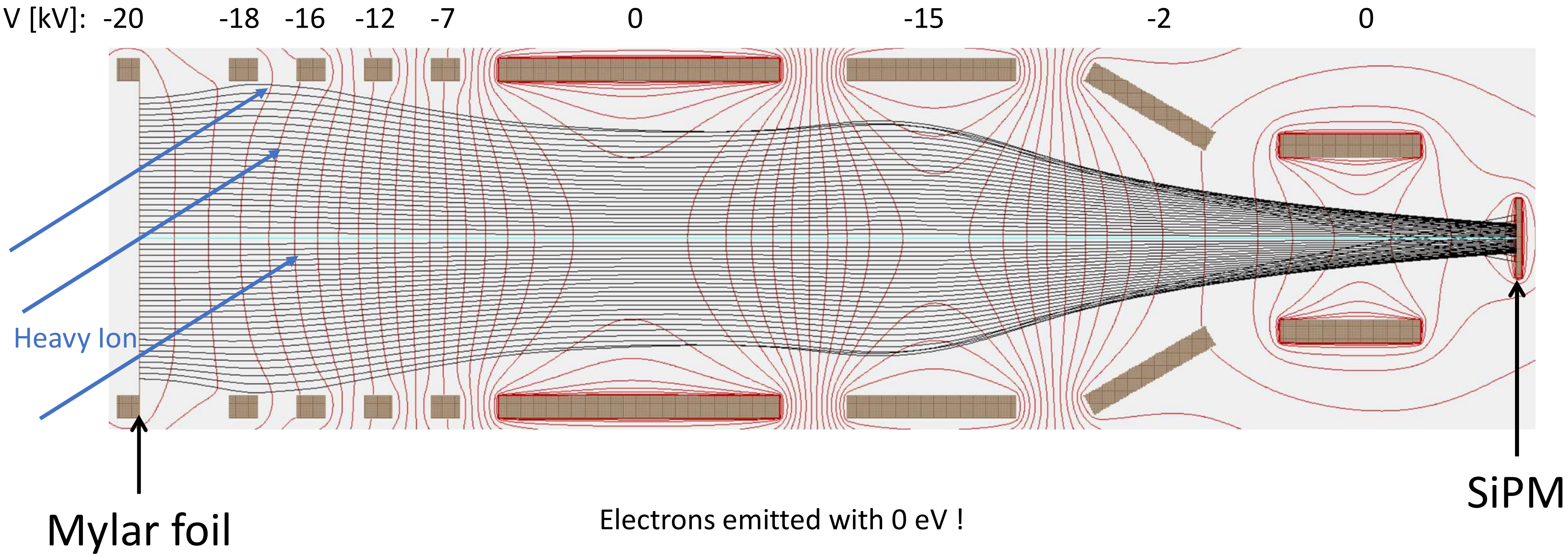
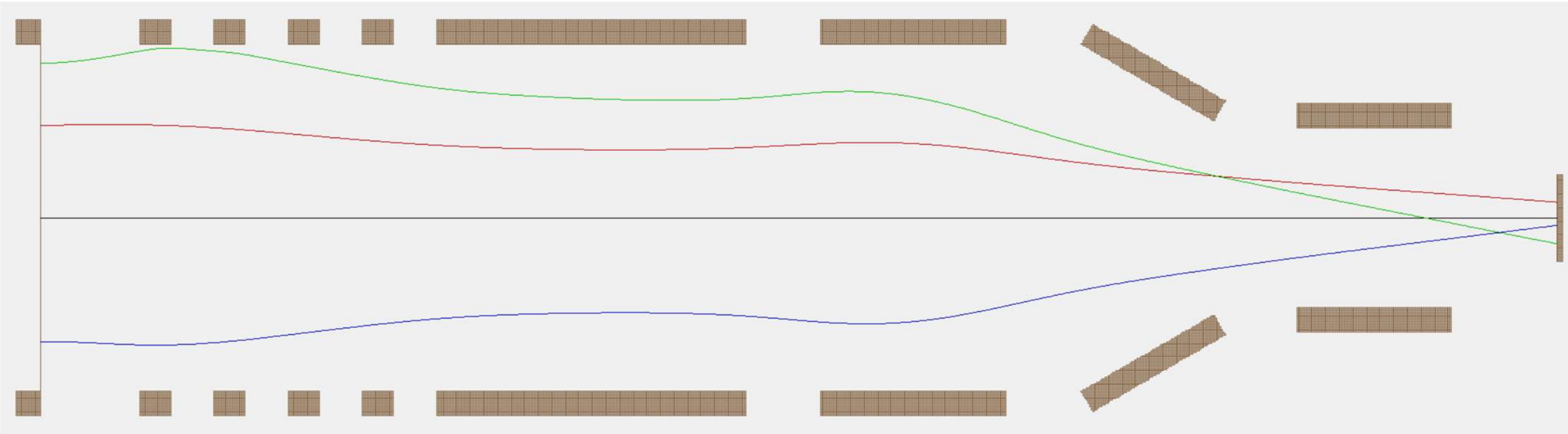


Electrons emitted with 0 eV !

3. SIMION Simulation

Let’s study the impact of the initial energy on the distribution of 4 typical bunches
Lambertian emission + 0 eV:



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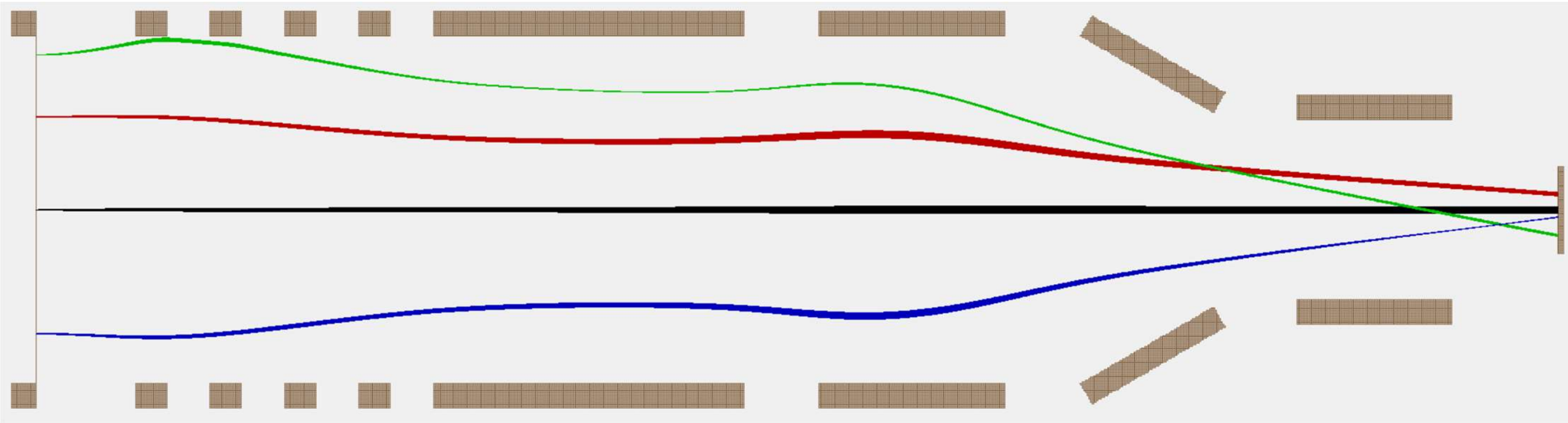
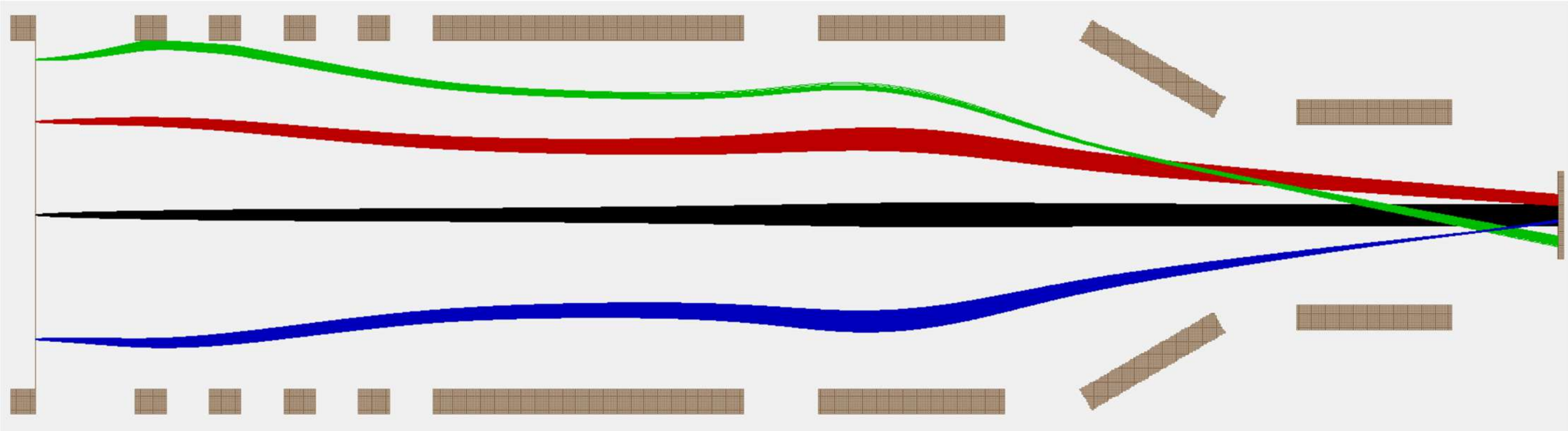
Let’s study the impact of the initial energy on the distribution of 4 typical bunches
Lambertian emission + 0.1 eV:



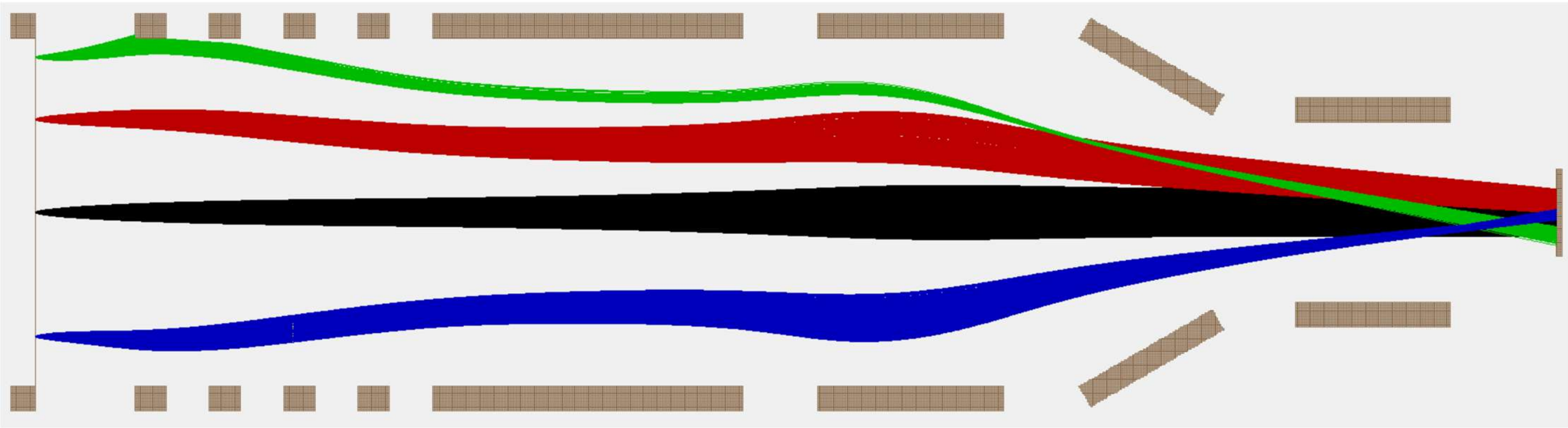
3. SIMION Simulation

Let’s study the impact of the initial energy on the distribution of 4 typical bunches
Lambertian emission + 1 eV:



3. SIMION Simulation

Let's study the impact of the initial energy on the distribution of 4 typical bunches
Lambertian emission + 5 eV:



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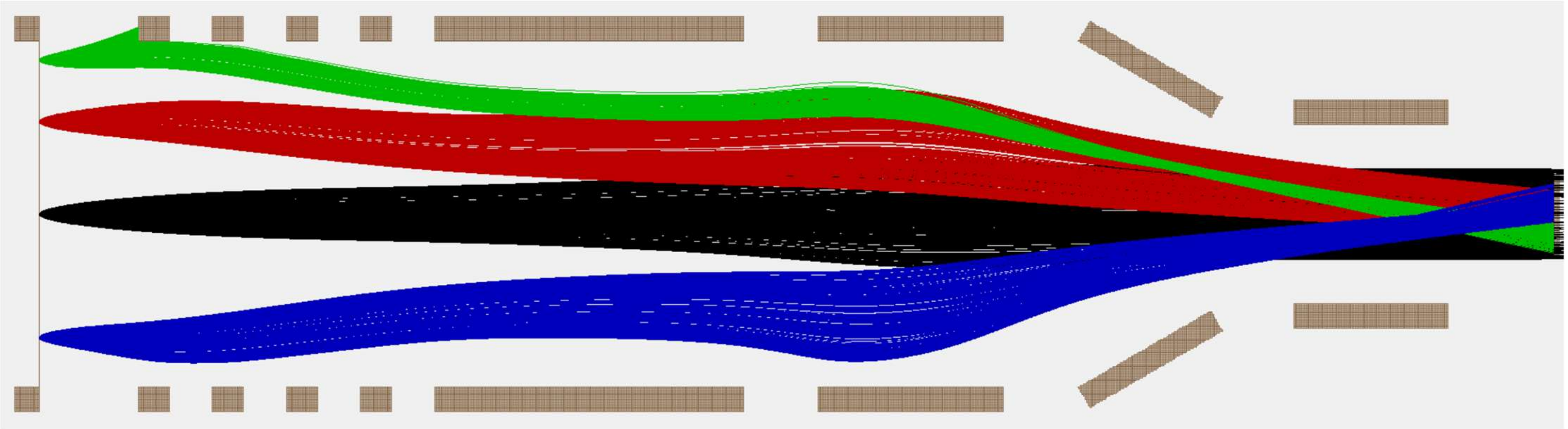
Let's study the impact of the initial energy on the distribution of 4 typical bunches
Lambertian emission + 20 eV:



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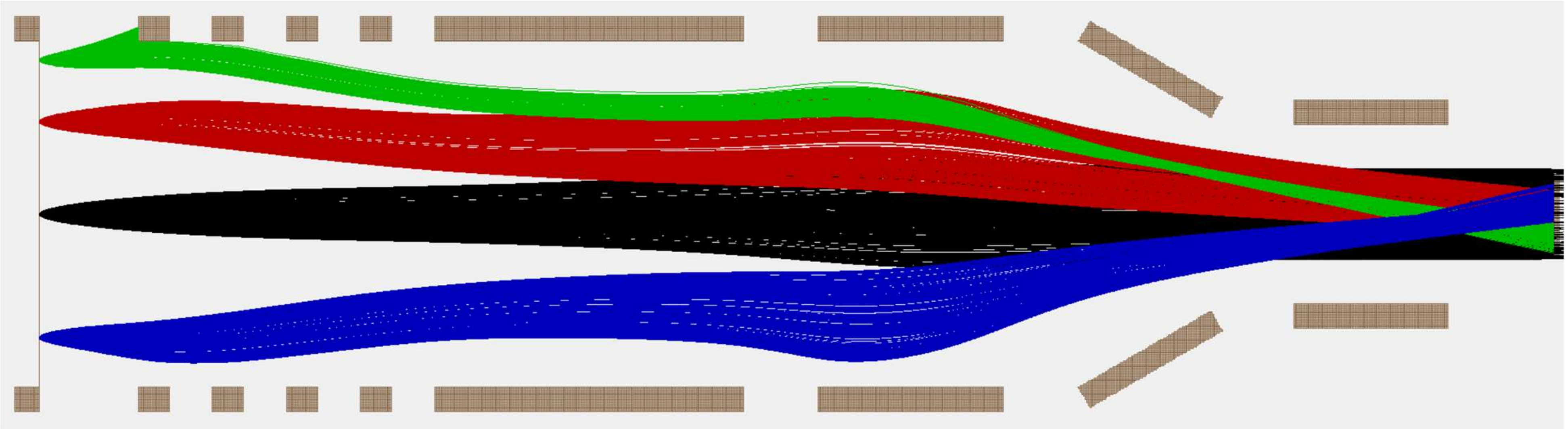

Correct modelisation of the kinetic energy emission needed !

4. Kinetic electron emission in Mylar

- How many electrons are generated in Mylar ?

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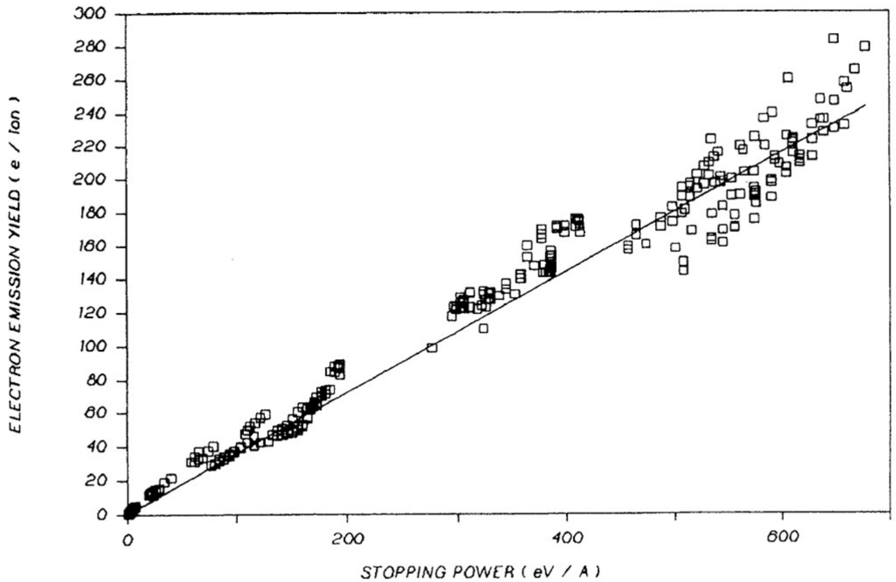
Sternglass proportionality theory :

$$N_{e^-} \propto stopping\ power$$



Clouvas, A., et al. *Physical Review B* 48.10 (1993): 6832

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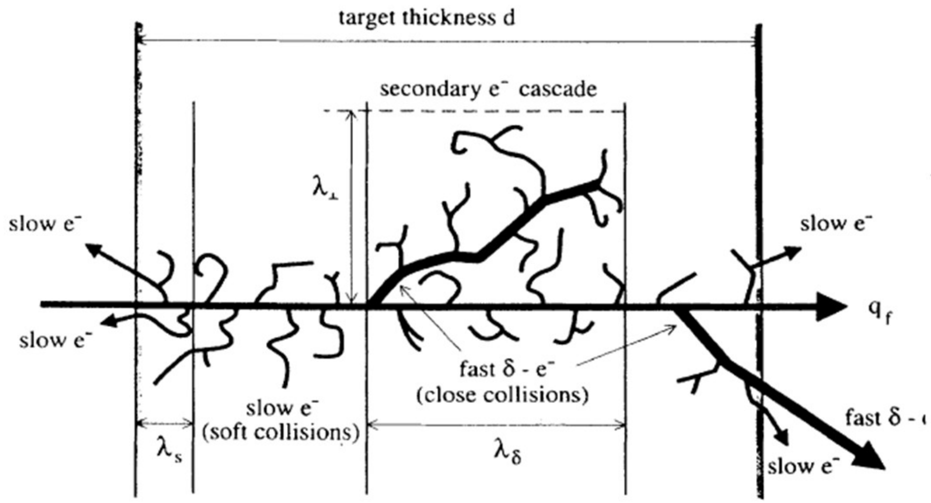
Spectrum with 2 components: fast δ electrons + slow electrons (<100 eV)



Rothard, Hermann, et al. *Physical Review A* 51.4 (1995): 3066.

4. Kinetic electron emission in Mylar

- How many electrons are generated in Mylar ?
- What energy spectrum have these electrons ?

Delta electrons:

- 1-10 per event
- High energy -> not focused by the lense
- Directional emission and ions not in direction of the SiPM
- Low geometrical efficiency

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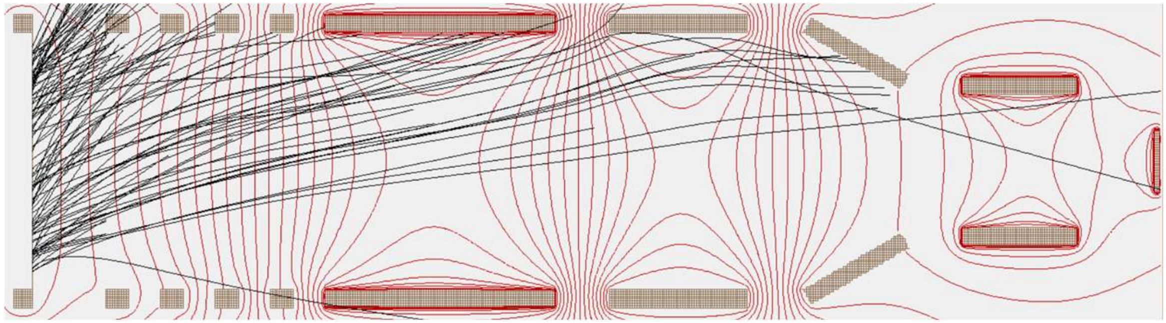
- Directional emission and ions not in direction of the SiPM
- Low geometrical efficiency
- ➢ Neglected in the simulation



4. Kinetic electron emission in Mylar

- How many electrons are generated in Mylar ?
- What energy spectrum have these electrons ?

Low-energy electrons:
Chung–Everhart equation:

$$f(E) = 4\phi^2 \times \frac{E}{(E+\phi)^4}$$

With:

ϕ: surface work

$$E_{max} = \frac{\phi}{3}$$

For aluminum:

$$\phi \approx 4\ eV$$

$$E_{max} = 1.3\ eV$$

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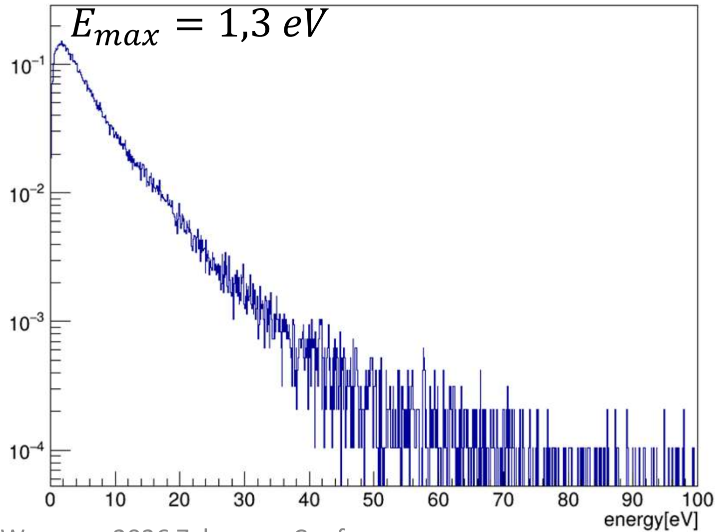
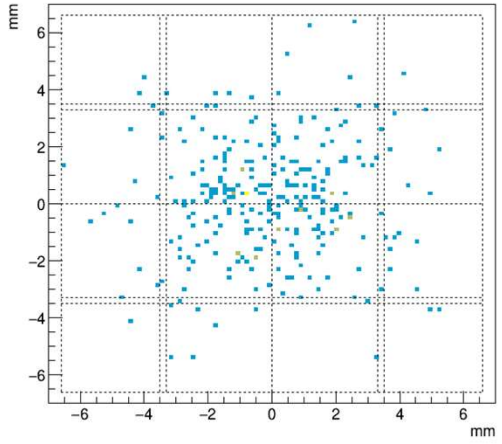


4. Kinetic electron emission in Mylar

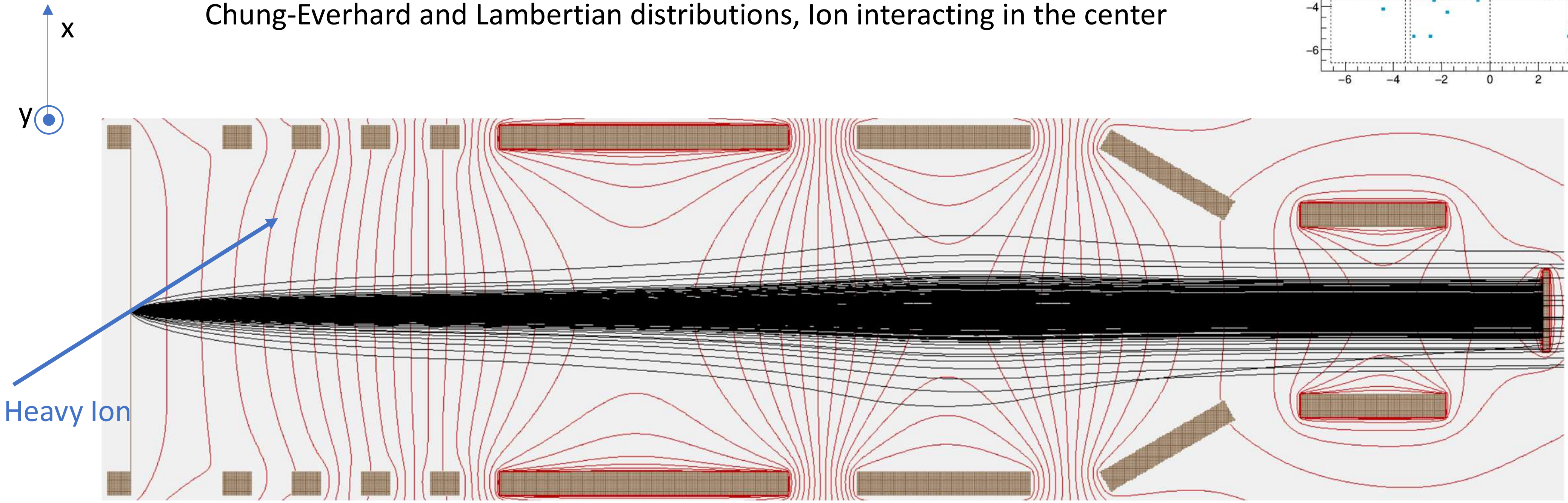
- Profile of electron emission after ion interaction:
  - Source considered as point-like
  - Following a Chung-Everhart distribution
  - Isotropical generation -> Lambertian emission
  - Typical bunches of 200 electrons

5. Realistic SIMION simulation

Electron hitmap



Chung-Everhard and Lambertian distributions, Ion interacting in the center



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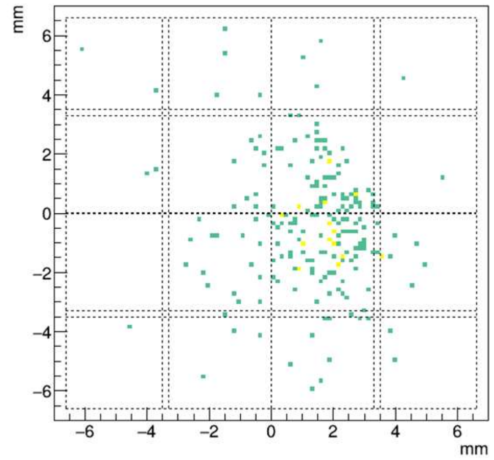
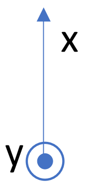
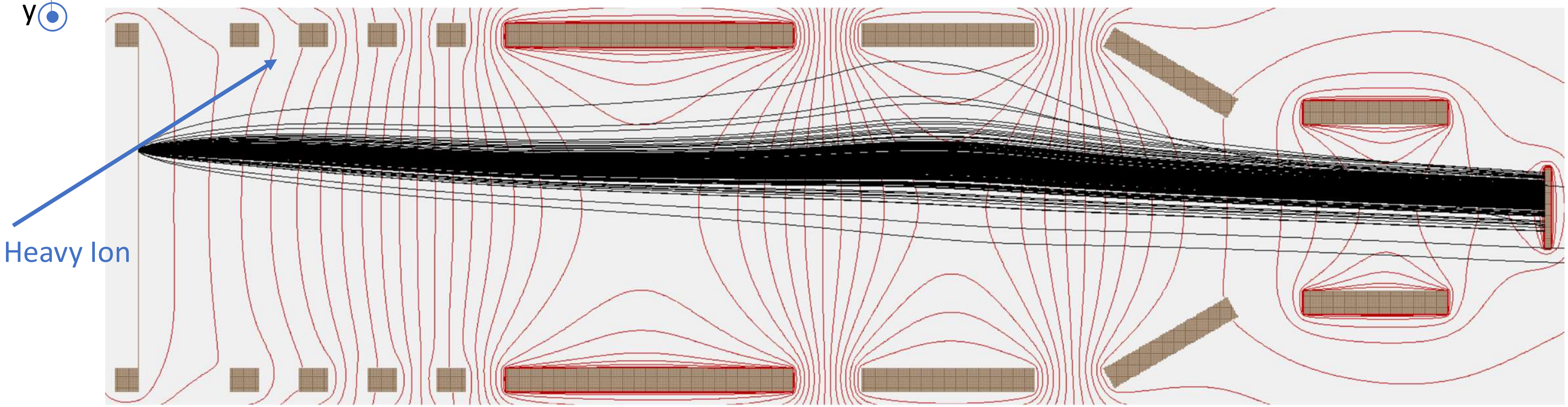


Chung-Everhard and Lambertian distributions, Ion interacting at (10;0)





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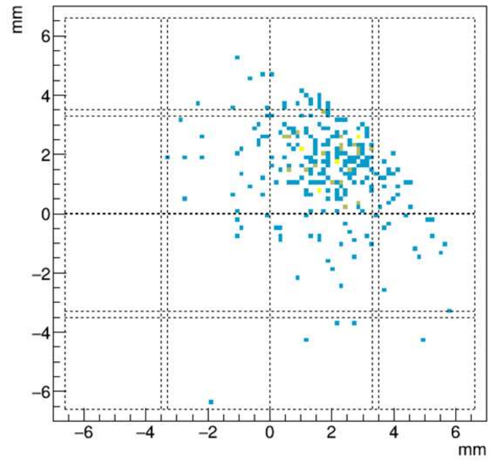

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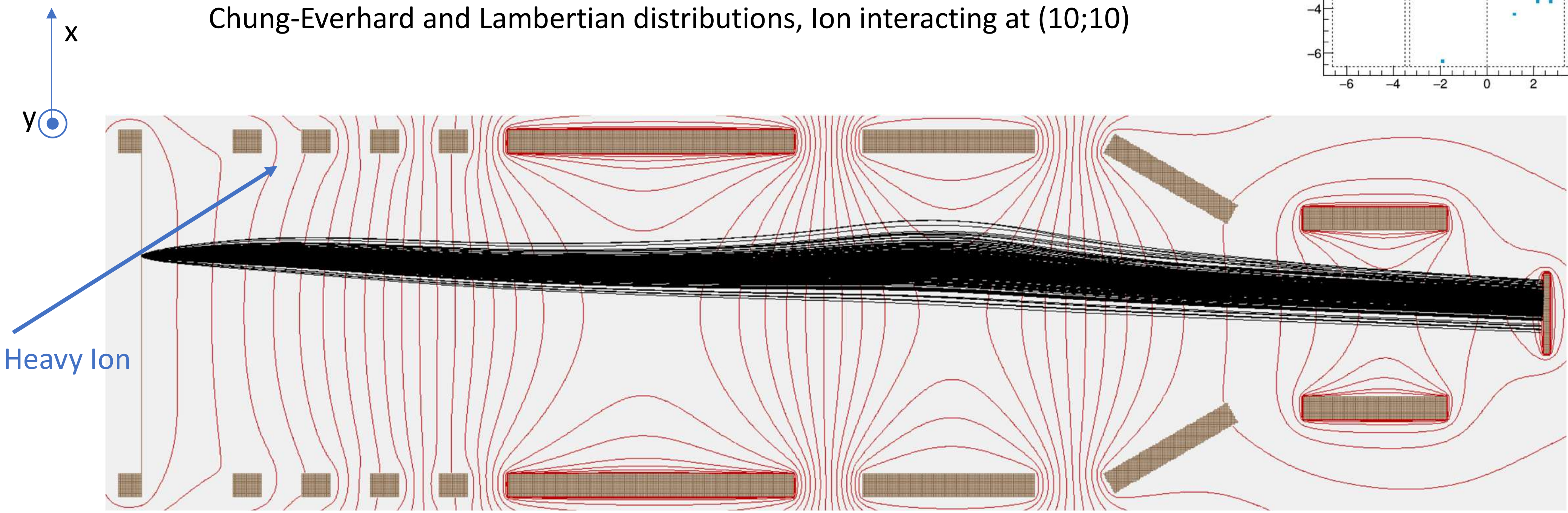

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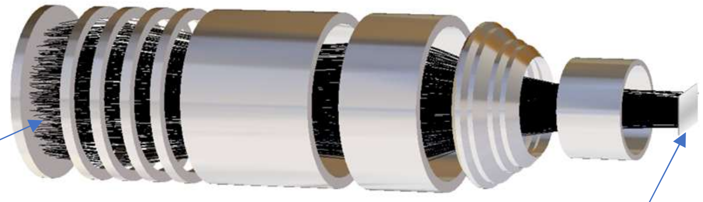
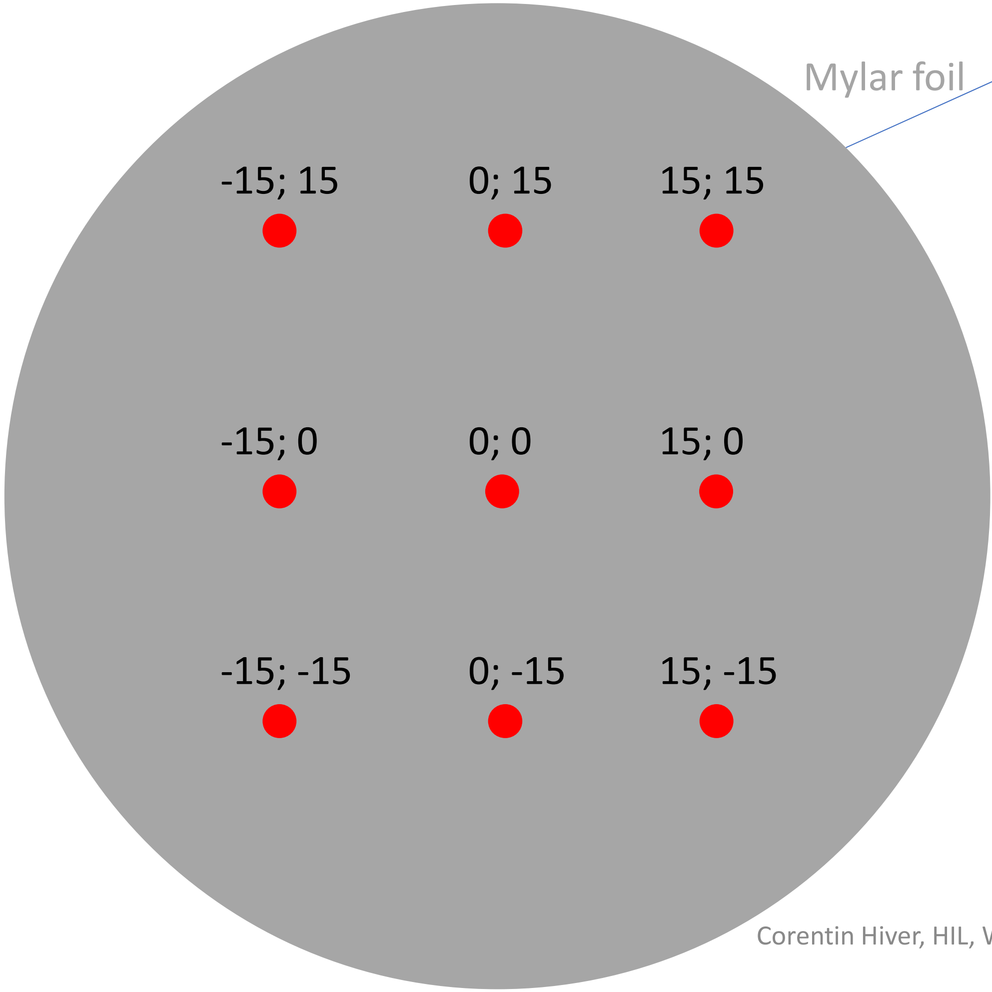
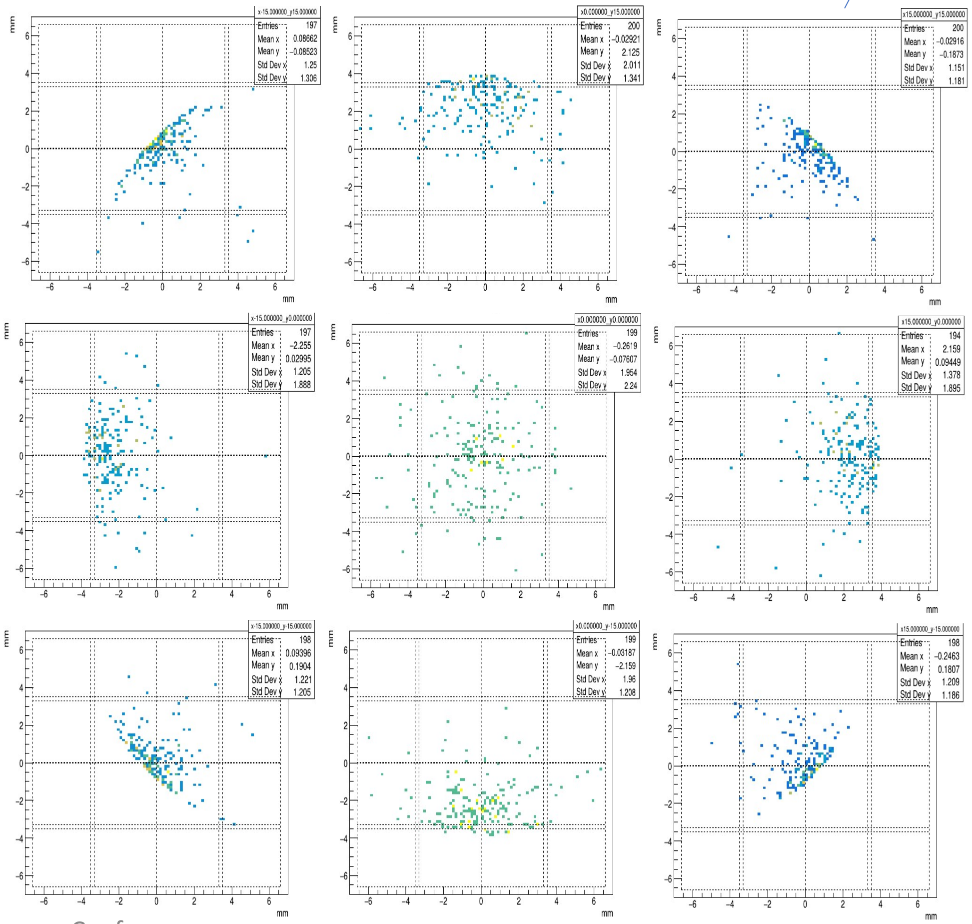
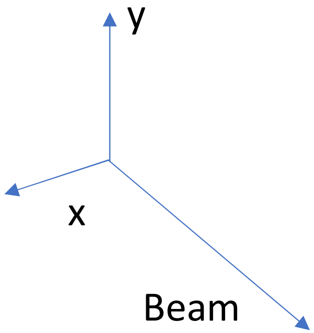


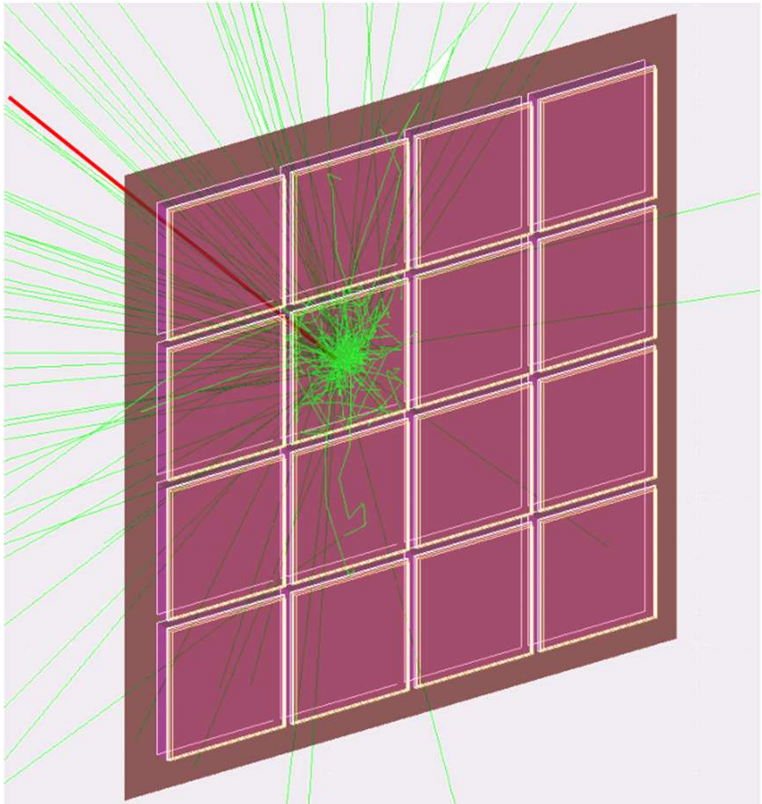


Focus

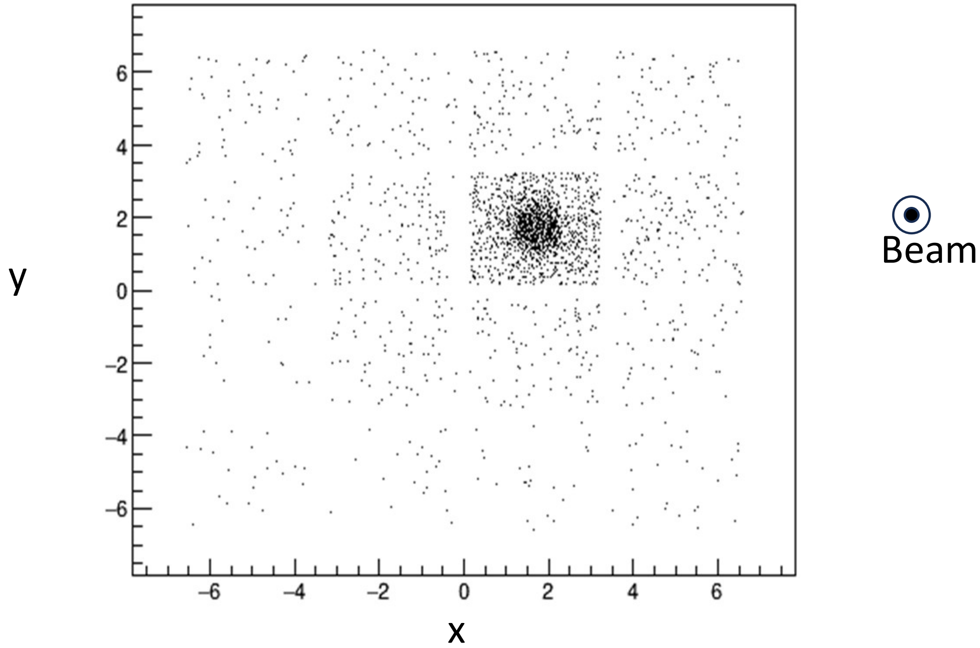


6. Geant4 simulation



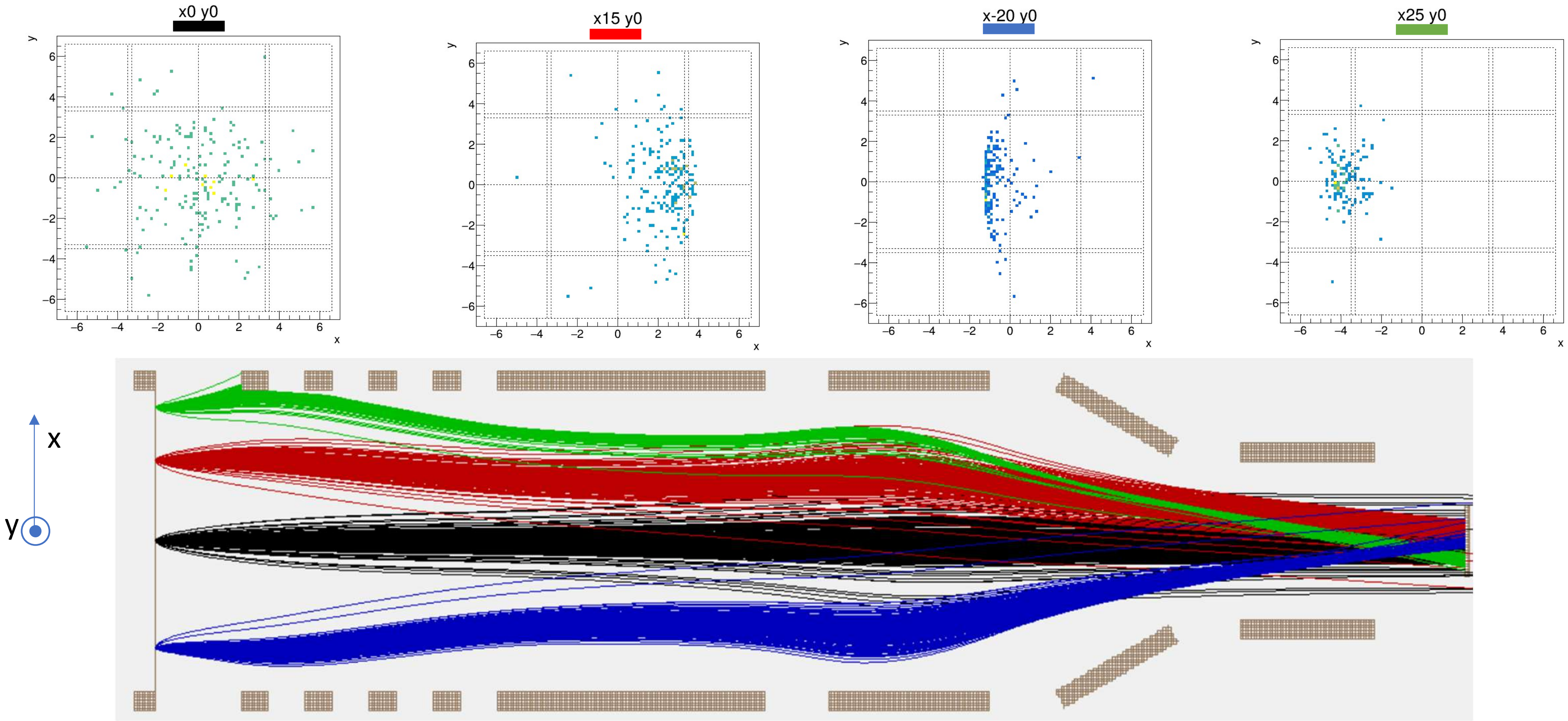


Scintillation hitmap on SiPM
for 200 electrons interacting at the same point:



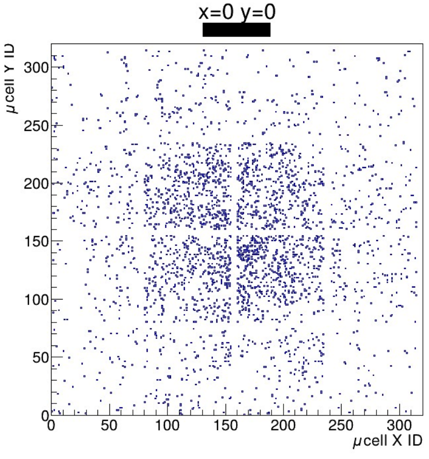
6. Geant4 simulation

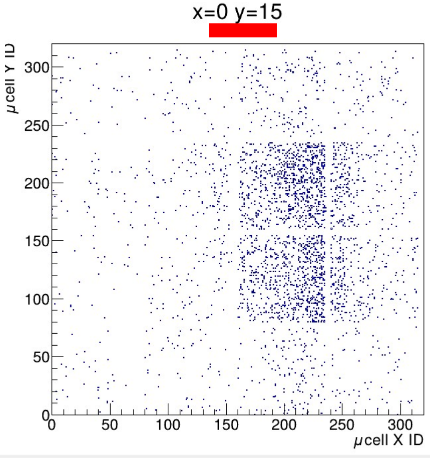
Electron hitmap of a bunch in the scintillator

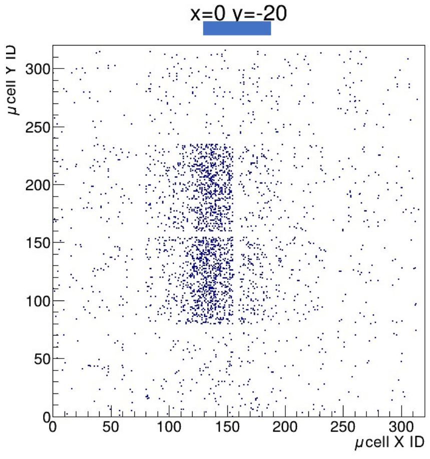


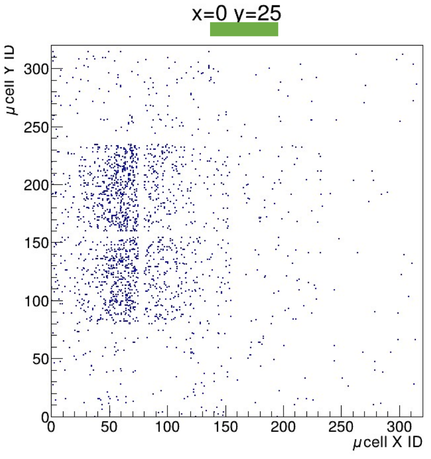
6. Geant4 simulation

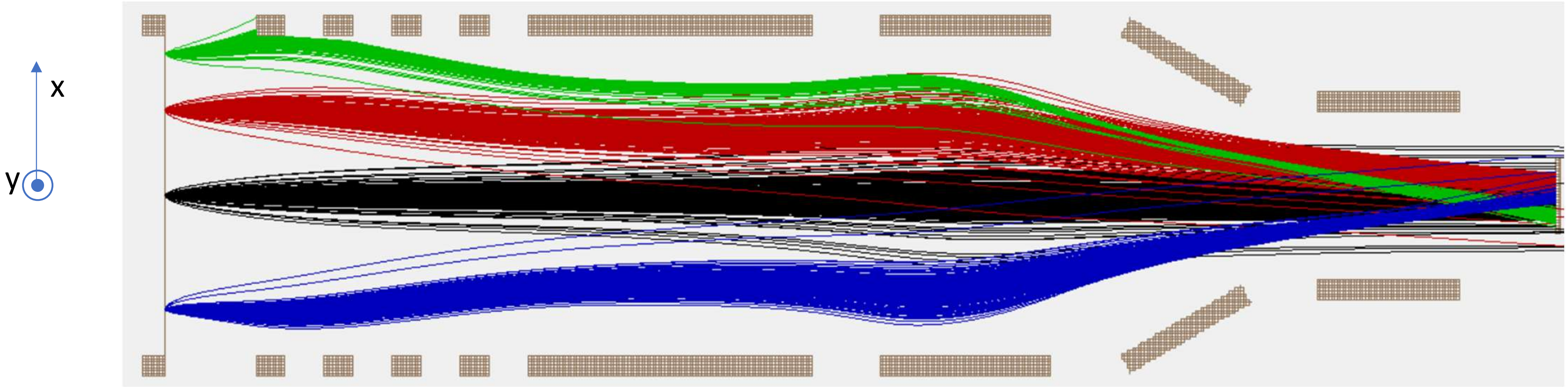
Scintillation photon in the SiPM











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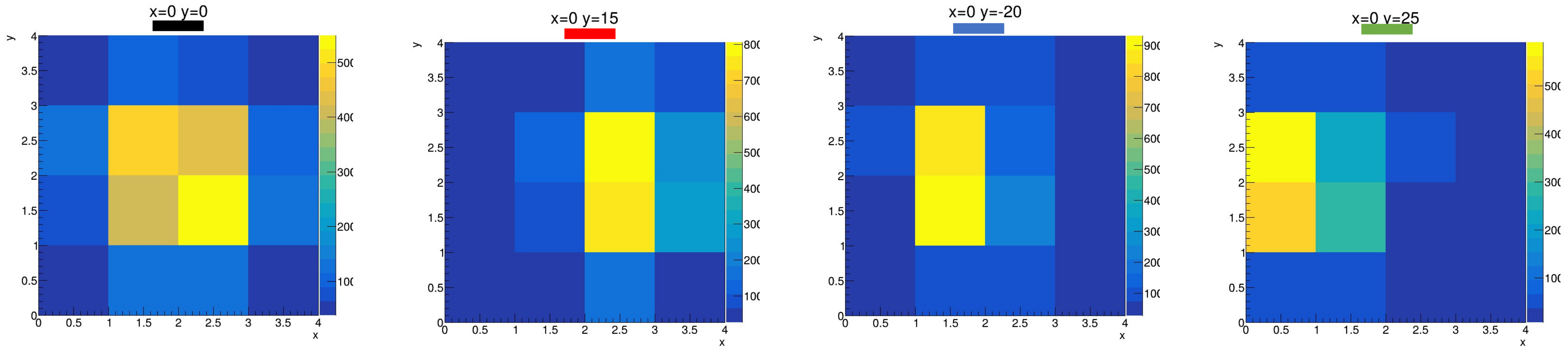

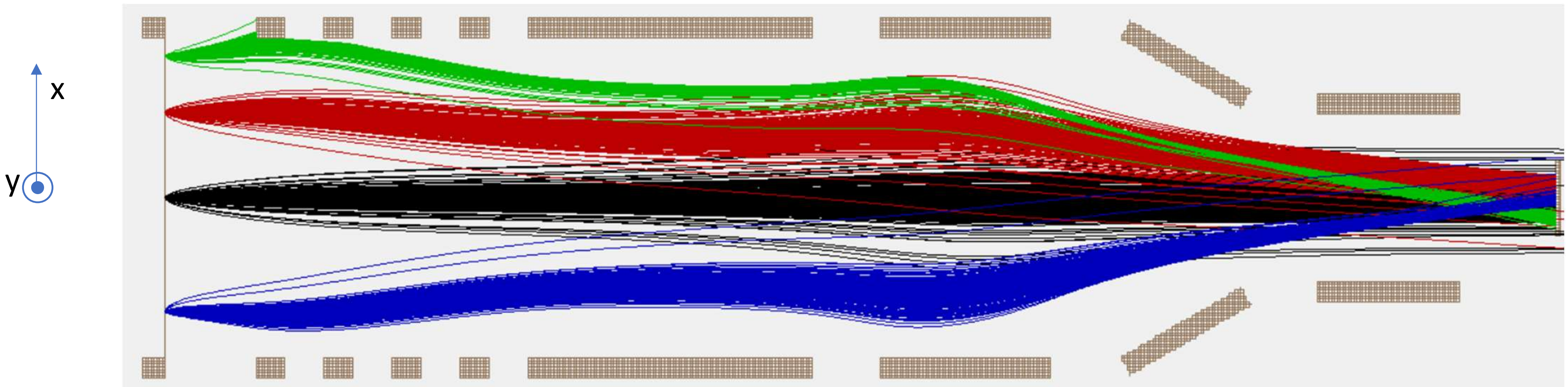

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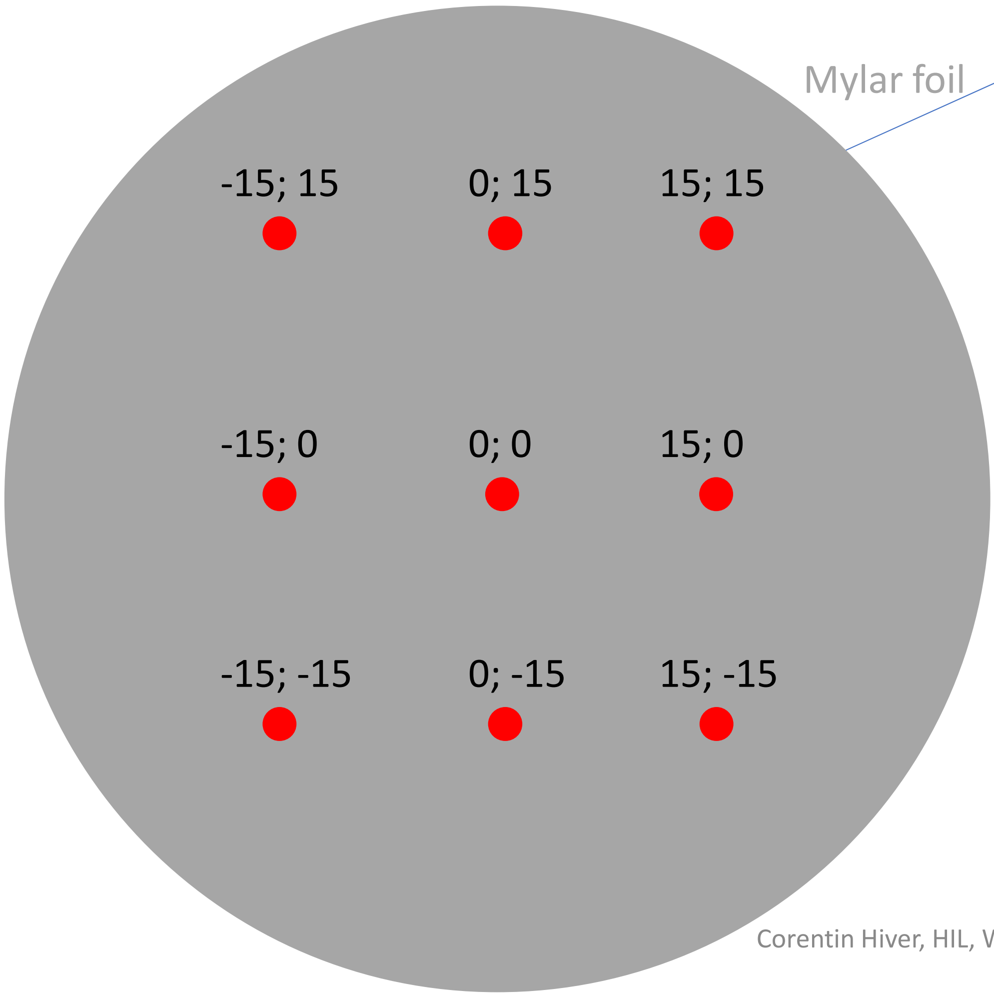
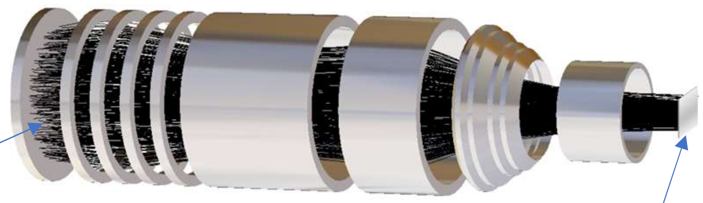
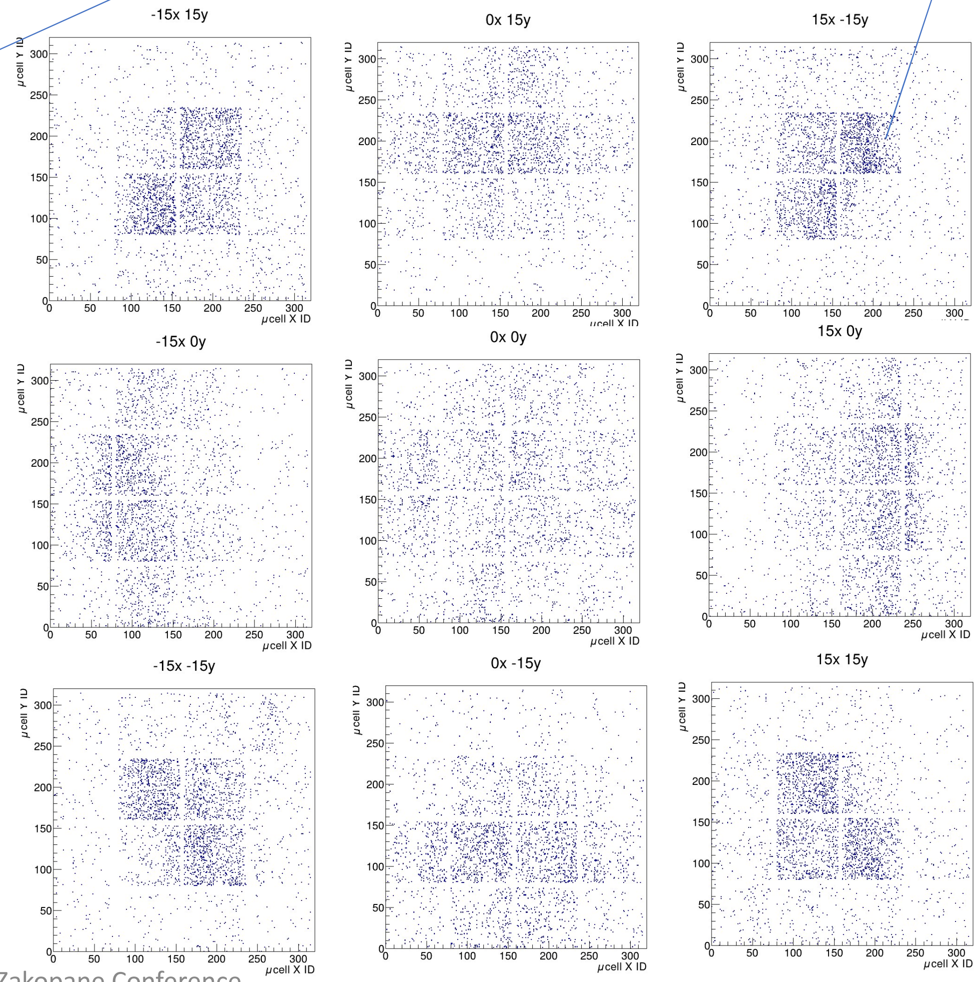


Focus





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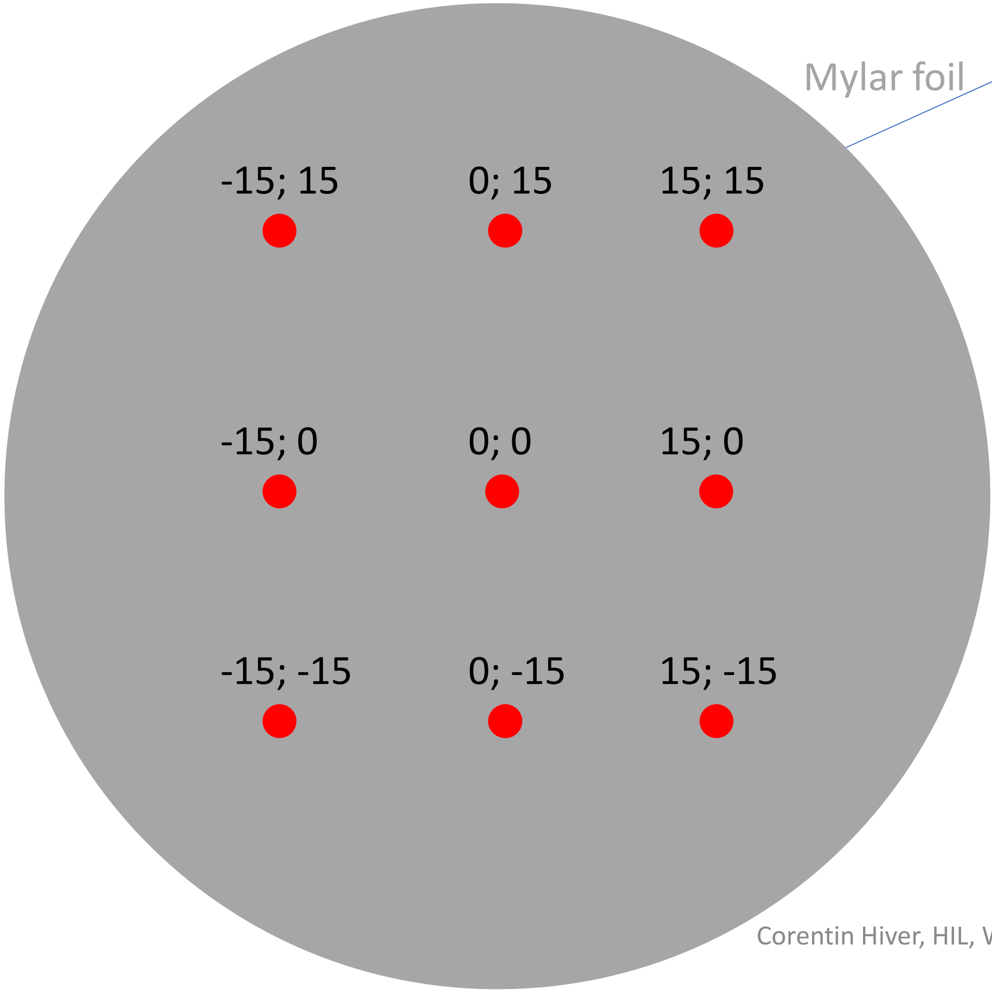

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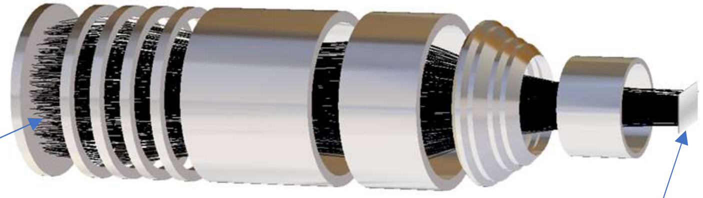
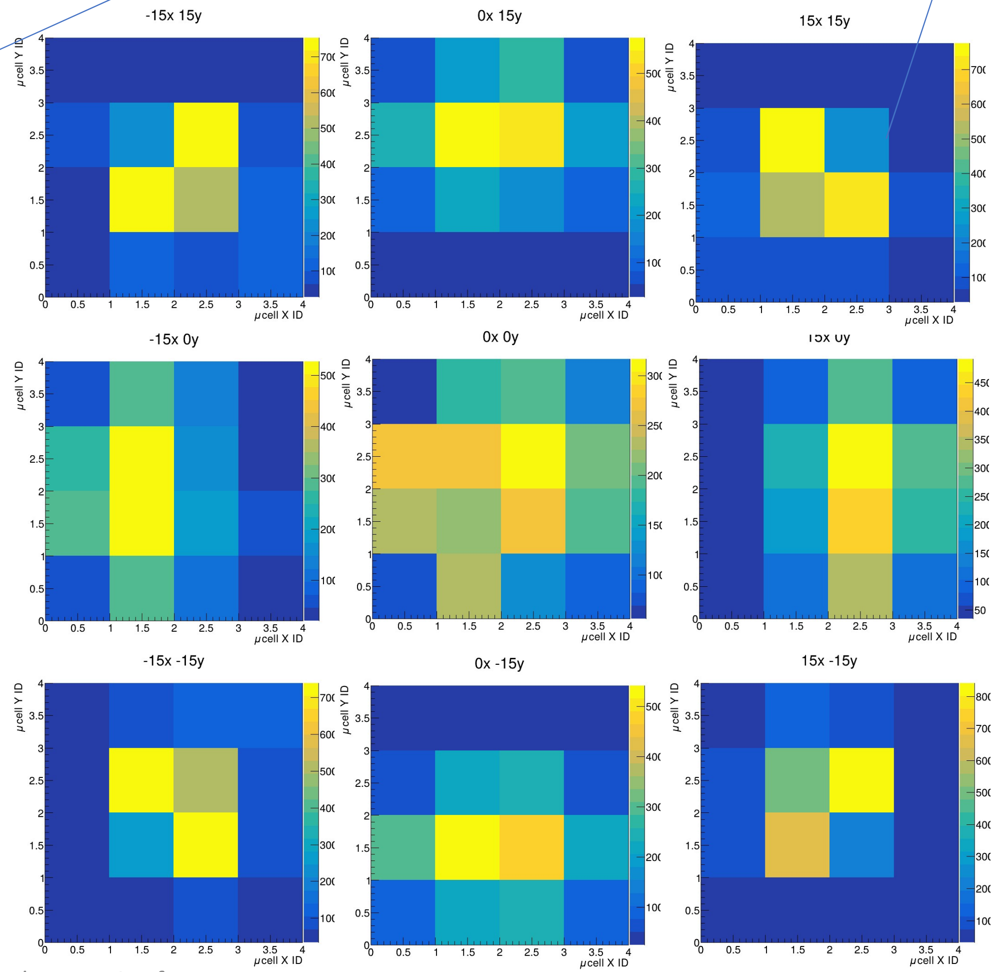




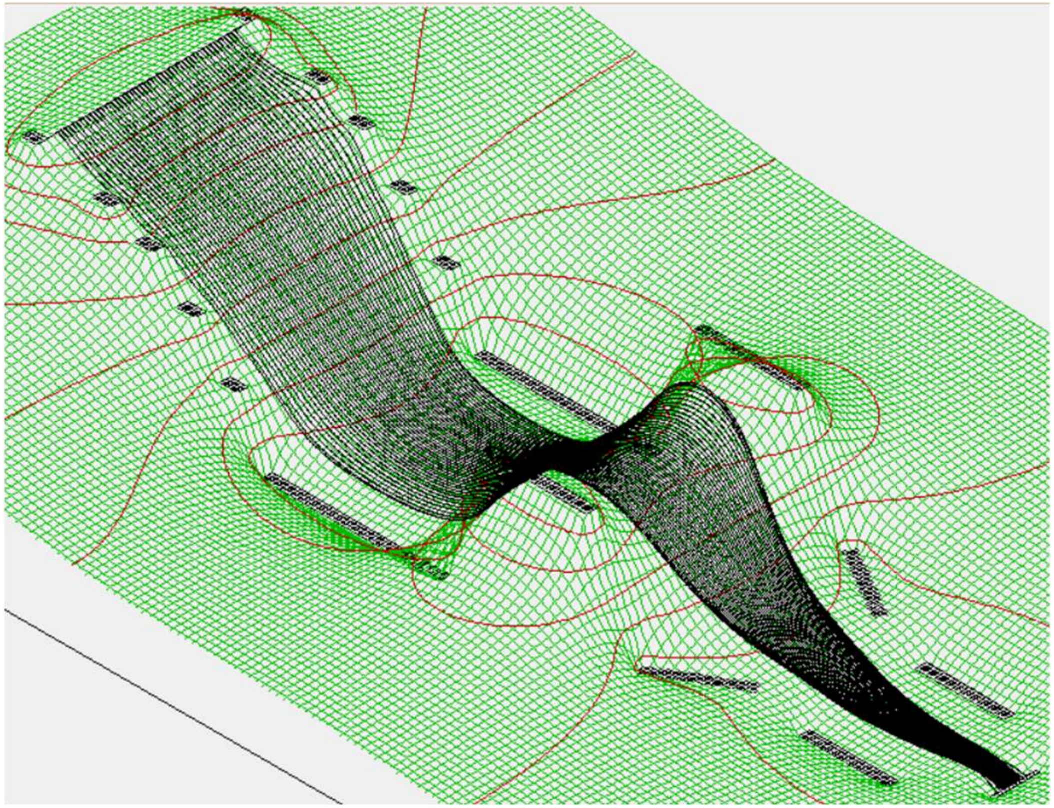
Conclusion

- Simulations help understanding the detector’s behavior
- Segmentation not as performant as forseen, but could be used for other purpose (background rejection, scattered beam rejection, ….)
- Simulations allow future investigations for optimisation: SiPM cell size, number, focusing…

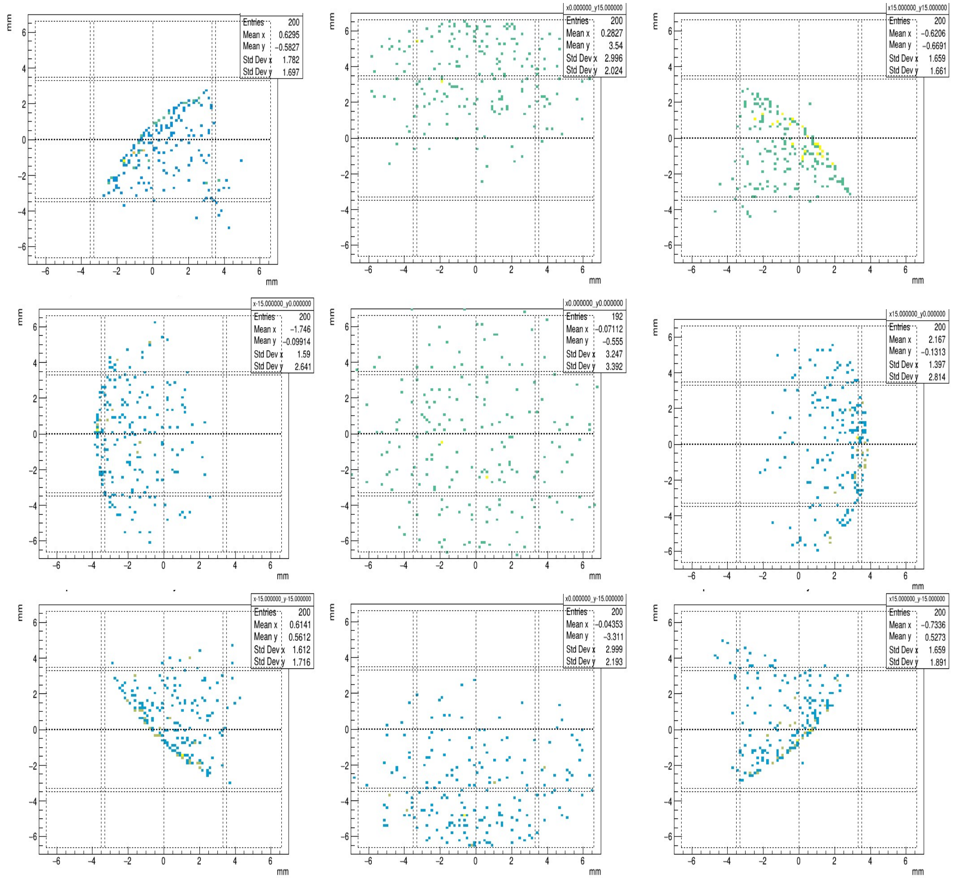
Conclusion

Next steps:

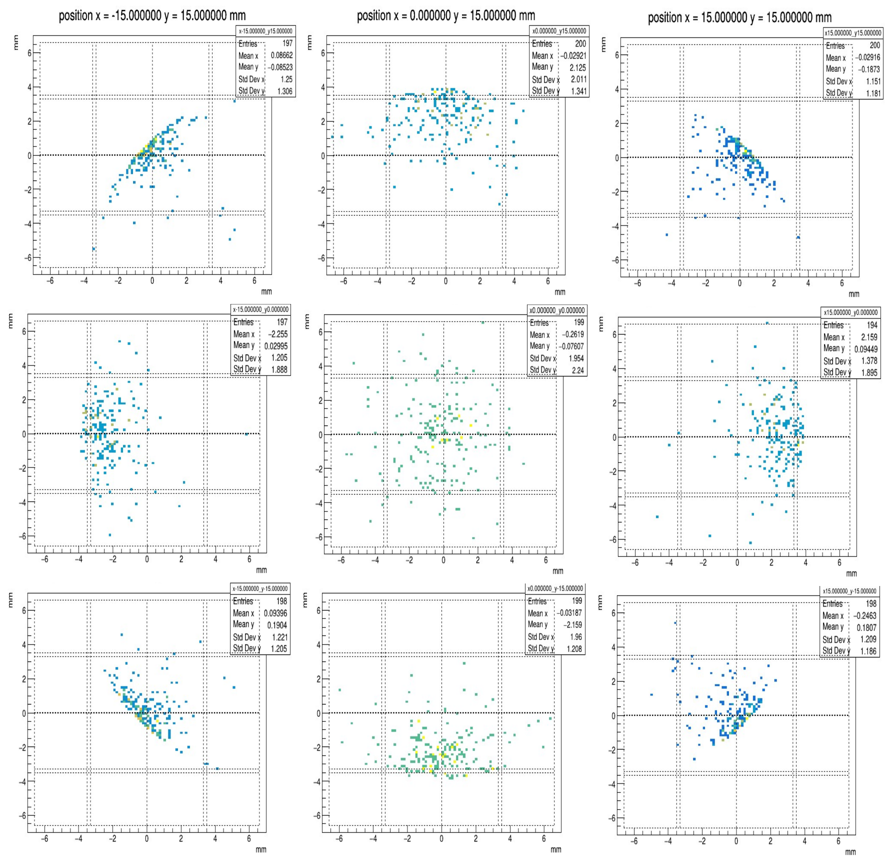
- Investigate focusing lens :
  - Potential field optimisation
  - Geometrical optimisation
- All-in-one Geant4 simulation:
  - Include focusing lens response function (Neural Network? Potentials?)
  - Include the full-scale detector
- Compare the detector with real-life data
- Integration at Heavy Ion Laboratory for experimental campaign in 2027-2028 with EAGLE and DIAMANT



5 eV



Chung-Everhar



4. Kinetic electron emission in Mylar

- How many electrons are generated in Mylar ?
- What energy spectrum have these electrons ?

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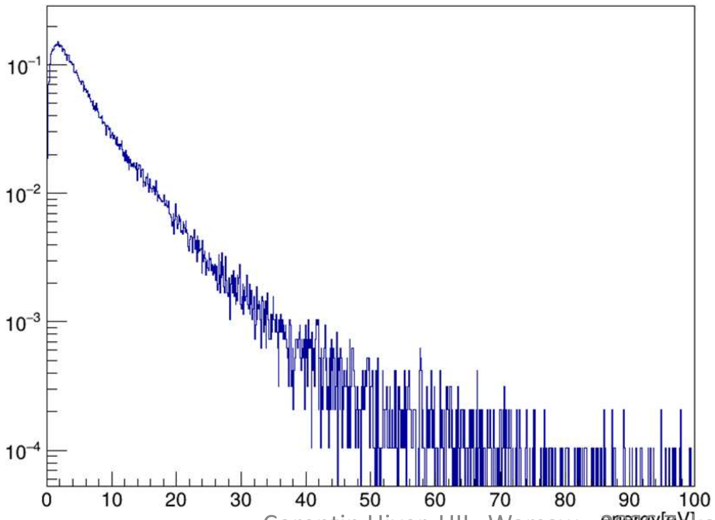
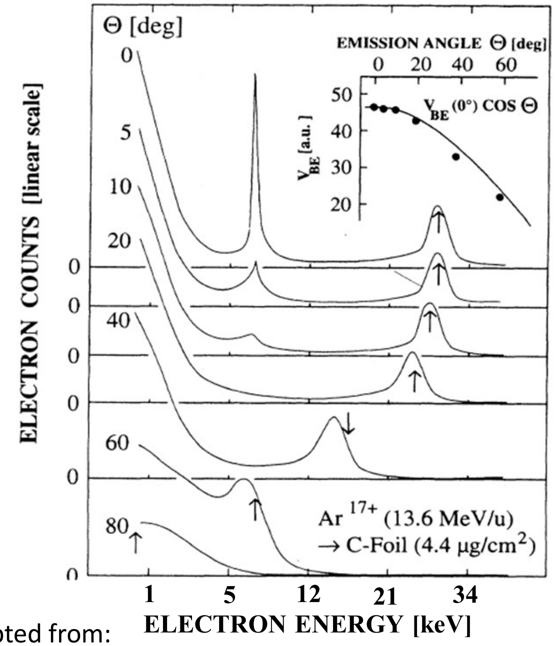


δ electrons:



Adapted from:
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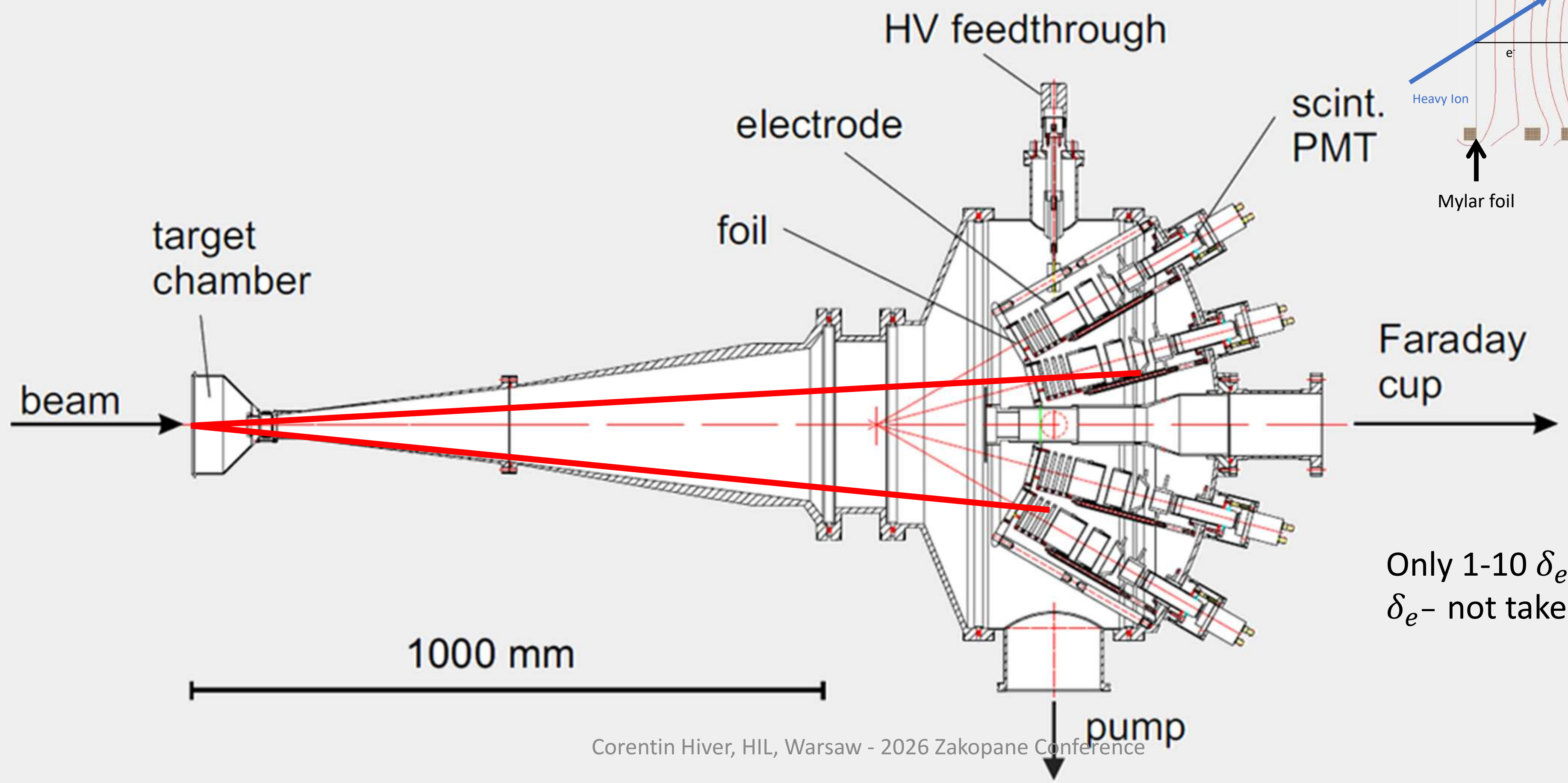
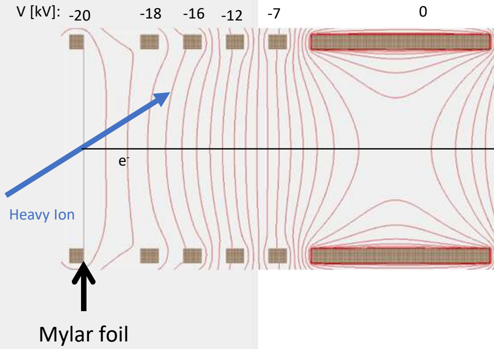




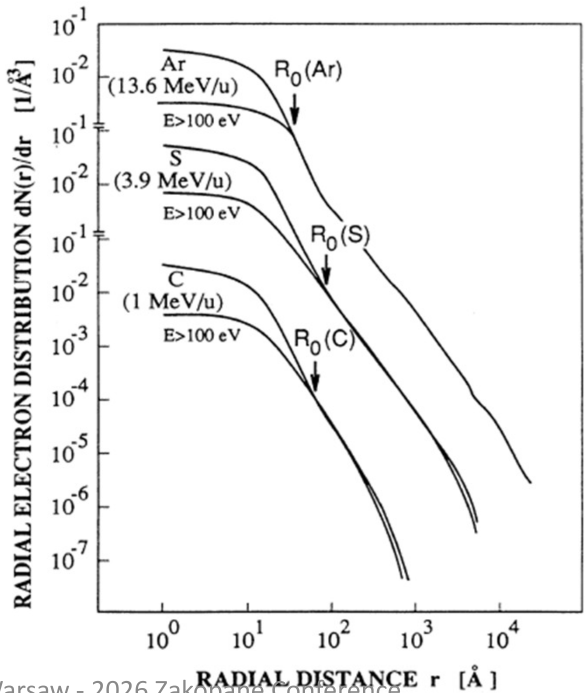
Only 1-10 δ_{e^-}, poorly focused

δ_{e^-} not taken into account !

4. Kinetic electron emission in Mylar

- How many electrons are generated in Mylar ?
- What energy spectrum have these electrons ?
- Where are they created ?

Vast majority of electrons created within 10-100 nm around the point of interaction.



Rothard, Hermann, et al. *Physical Review A* 51.4 (1995): 3066.