REGISTRATION OF THE TRANSITION RADIATION WITH GaAs DETECTOR: DATA/MC COMPARISON

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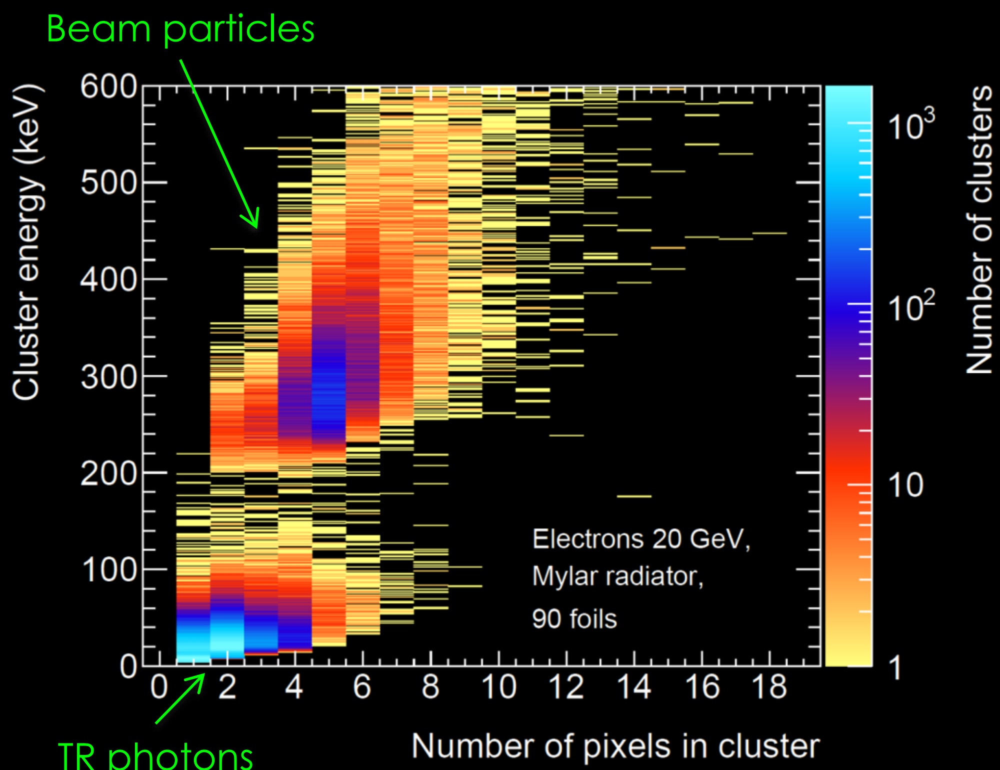
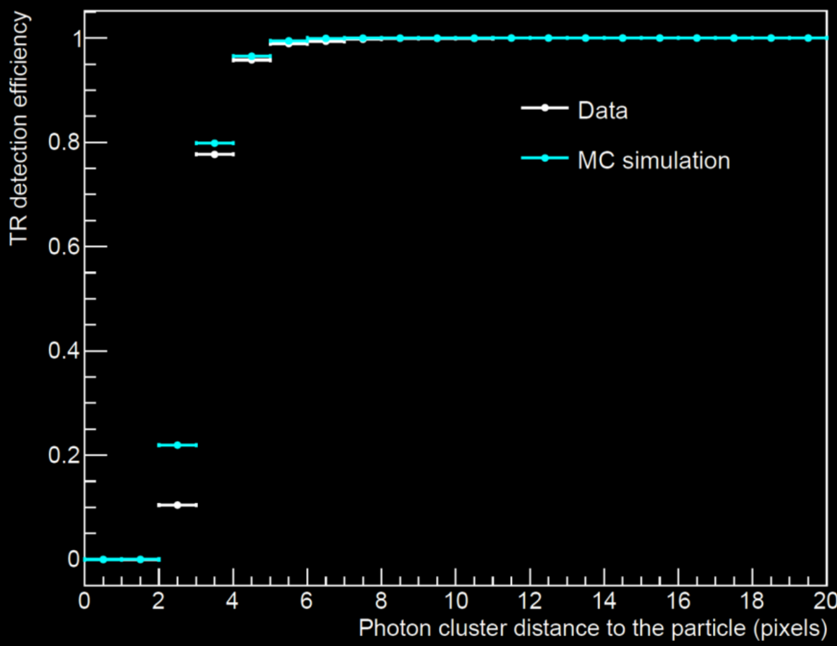
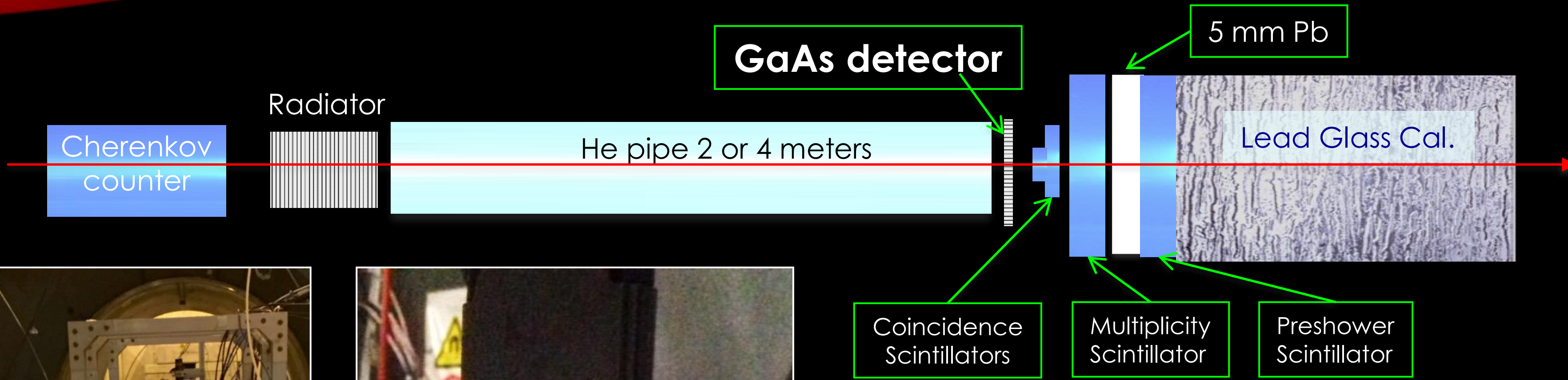
WHY GaAs?

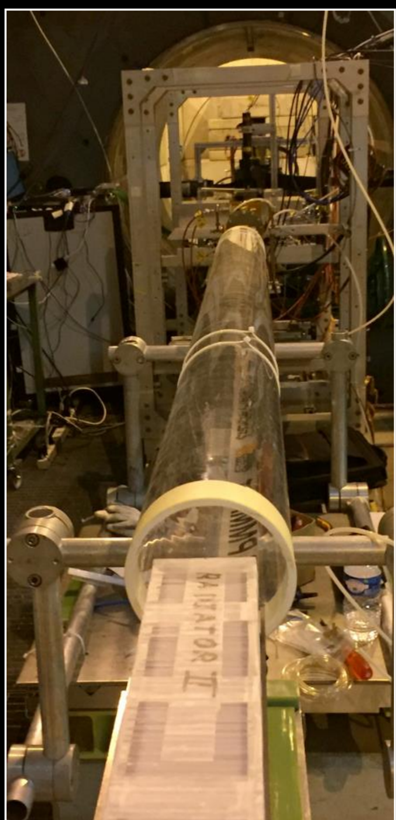
- For pixel detectors, CdTe chip can be the best, but it has huge fluorescent yield (84%) and fluorescence photons have a large mean path in the detector (110 um).
- Si detectors are very good, but only for low energy part of TR spectrum.
- GaAs material is the optimum one for low and high energy part of TR spectrum. Fluorescence photons have small mean path (15.5 and 40 um).

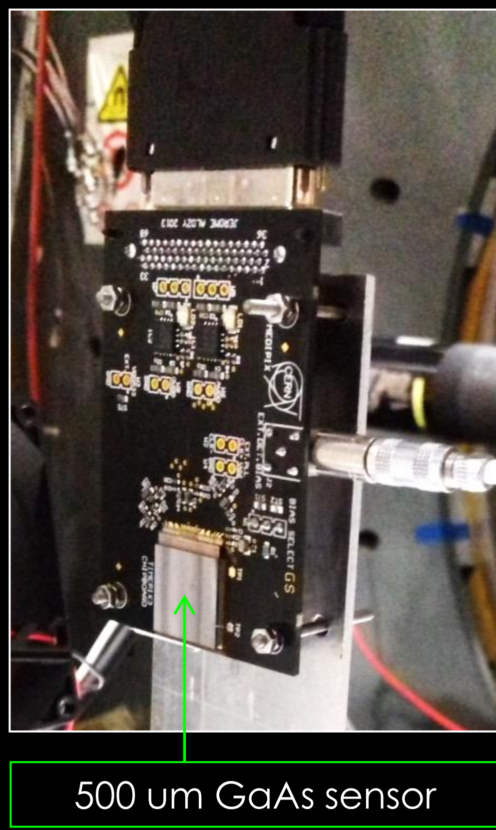




GaAs DETECTOR SETUP







- Experimental studies were carried out at the CERN SPS NA facility with 20 GeV/c electrons and muons from 120 to 290 GeV/c using different types of radiators.
- Radiators have multi-foil structure – in this talk, only 30 or 90 Mylar foils of 50 μm thickness, spaced by 2.97 mm, are considered.
- 500μm thick GaAs sensor bonded to the Timepix3 chip was used as detector.
- In order to perform consistent DATA/MC comparison, the relevant MC simulation tool is required.

MC: GENERATION OF TR

- In order to generate transition radiation (TR) photons, the information about TR properties for chosen radiator configuration is required.

- Energy-angle dependencies of TR are calculated with the following expression [1]:

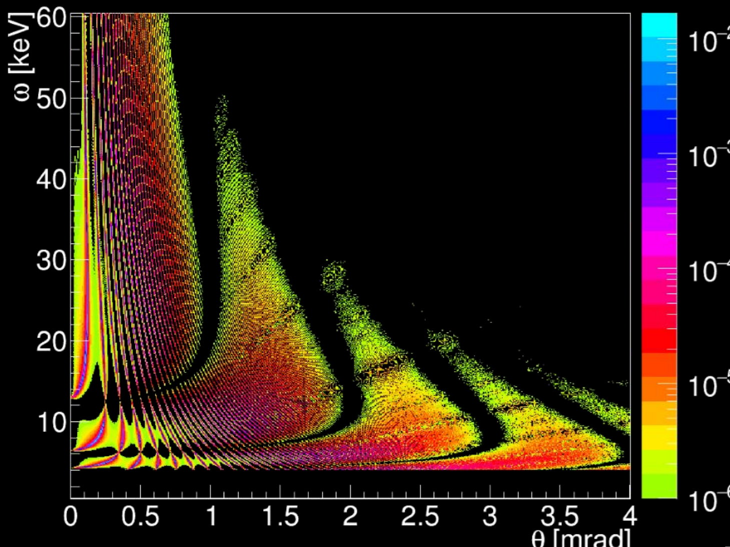
$$\frac{d^2 N_\gamma}{d\omega d\theta} = A\omega\theta^3 \left(Z_f - Z_g\right)^2 sin^2\left(\frac{l_f}{Z_f}\right) \frac{sin^2\left(N\left(\frac{l_f}{Z_f} + \frac{l_g}{Z_g}\right)\right)}{sin^2\left(\frac{l_f}{Z_f} + \frac{l_g}{Z_g}\right)},$$

where $Z_{f,g} = \left(\frac{4hc}{\omega}\right)\left(\gamma^{-2} + \theta^2 + \left(\frac{\omega_{f,g}}{\omega}\right)^2\right)$ and $A = 0.0300525$ is an effective constant.

- The ROOT histograms with 600x600 bins are generated for all radiators and energies and used as input.

- By using TH2::GetRandom2() method we can obtain energy and angle of generated TR photon.

$$N_\gamma = \sum_{x\ bins} \sum_{y\ bins} \frac{N_\gamma^{(x,y)}}{\Delta\omega\Delta\theta};$$



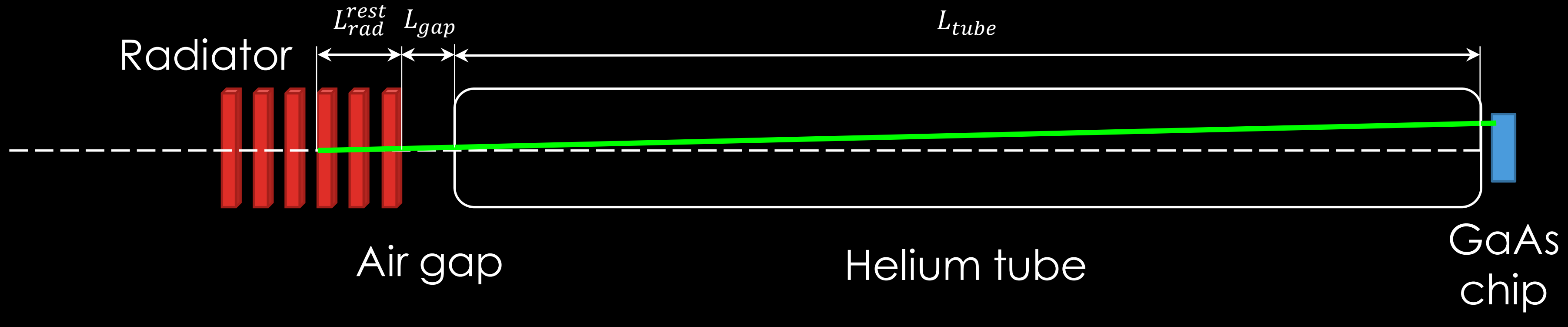
[1] M. L. Cherry *et al.* 1974 *Phys. Rev. D* **10** 3594

MC: TR PHOTON EMISSION

- The number of TR photons produced in each event is extracted from a Poisson distribution with a mean value N_γ.
- The index number of foil where the photon is produced is generating randomly.
- Photon is assumed to be produced <u>at the end of the radiator foil</u>.
- Thus the photon birth length can be calculated as follows:

$$L_\gamma = L_{rad}^{rest} + L_{gap} + L_{tube};$$

- L_{gap} is run-dependent - for TestBeam 2018 it varies from 3 to 6 mm.
- L_{tube} = 2014 or 4028 mm.



MC: MULTIPLE SCATTERING

- Multiple scattering was modeled based on the approximation suggested by PDG [2].
- The polar angle of the scattered particle is extracted from a Gaussian distribution with a sigma given by the expression:

$$\sigma_{MS} = \frac{13.6\,MeV}{\beta cp} Z \sqrt{\frac{l}{X_0}} \left(1 + 0.038 \ln\left(\frac{l}{X_0}\right)\right),$$

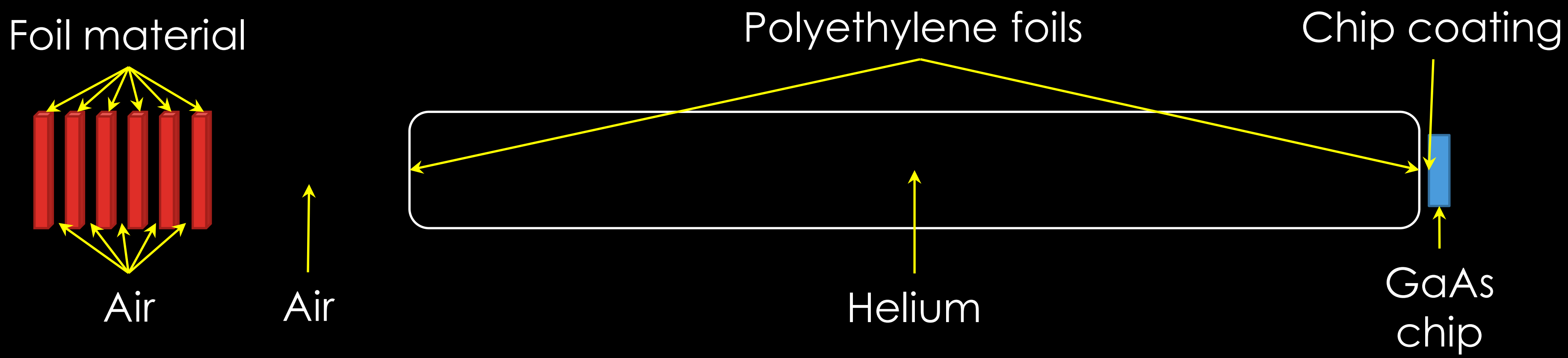
where p, βc and Z are the momentum, velocity and the charge number of the incident particle, respectively; l is the thickness of the material; X_0 is the radiation length of the material.

- The impact point of the particle on the detector plane is obtained using the space angle and the distance L between the radiator and the detector, and assuming an azimuthal angle symmetry of the scattering process with respect to the beam direction (Z-axis).
- The coordinate differences between the particle impact point and its position without scattering are then added to the photon impact point coordinates.

[2] http://pdg.lbl.gov/2005/reviews/passagerpp.pdf

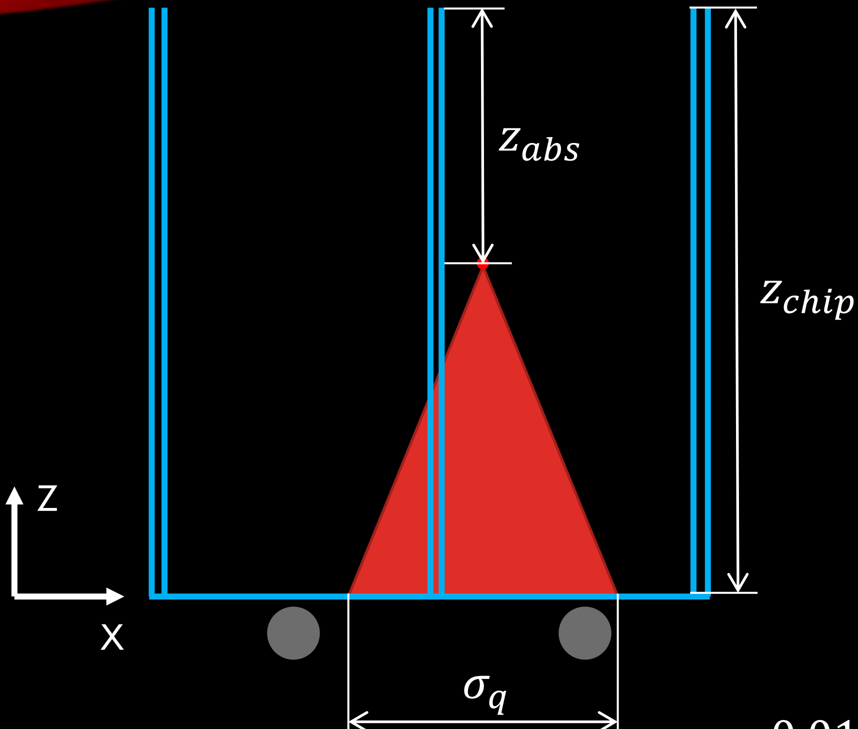
MC: ABSORPTION SCHEME

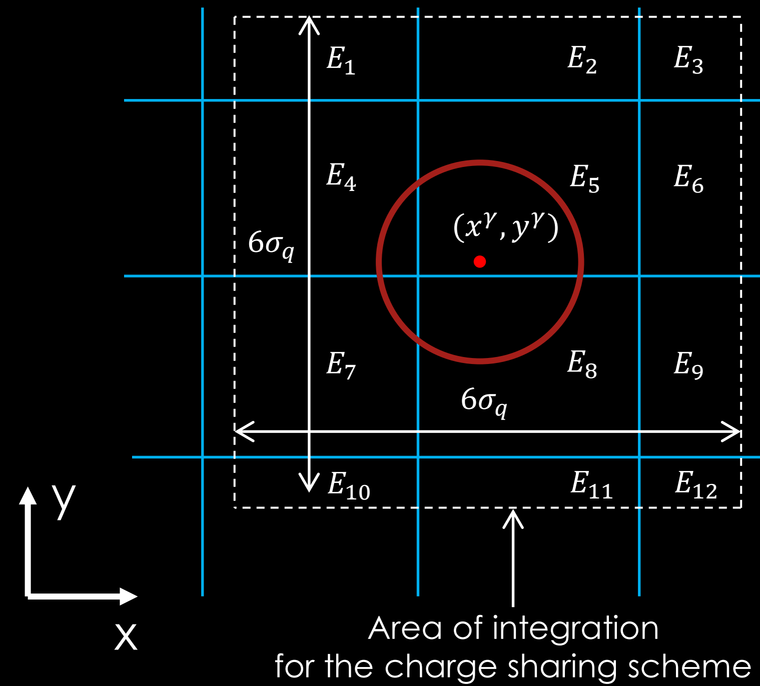
- Absorption is emulated based on the absorption probability $p = 1 - e^{-l_{mat}\,\mu(E,mat)}$;
- The values of the absorption lengths $\mu(E, mat)$ were calculated using the mass absorption coefficients taken from the NIST reference database [3].
- Polyethylene foils at the edges of the helium tube assumed to be 20 um thick.
- GaAs chip coating is represented by 1 um of nickel.
- The dead layer of the chip is represented by 3 um of GaAs.
- The thickness of the GaAs chip is set to 500 um.



[3] https://www.nist.gov/pml/x-ray-mass-attenuation-coefficients

MC: PHOTON REGISTRATION

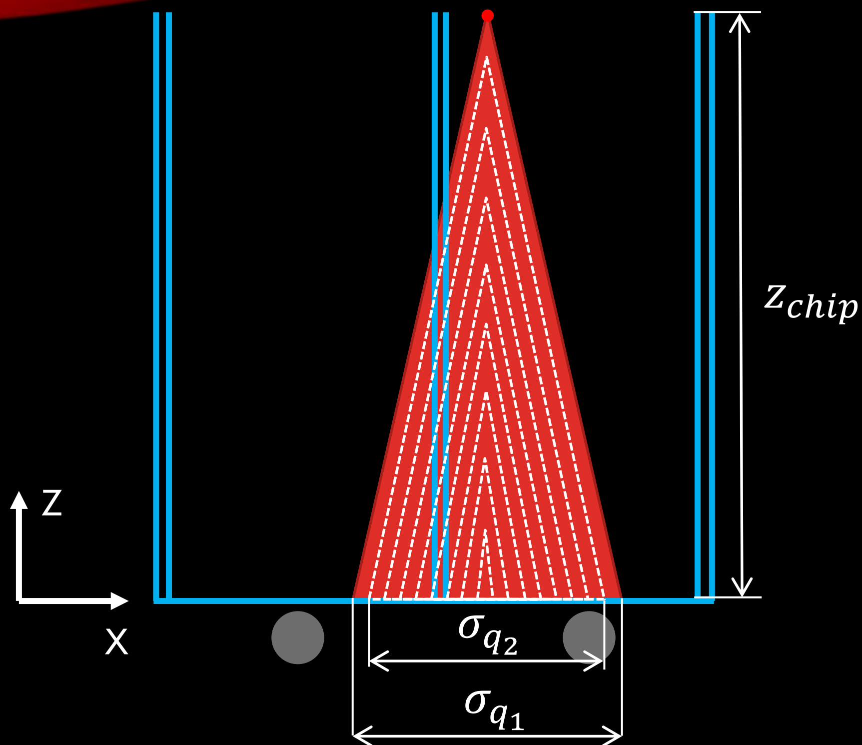


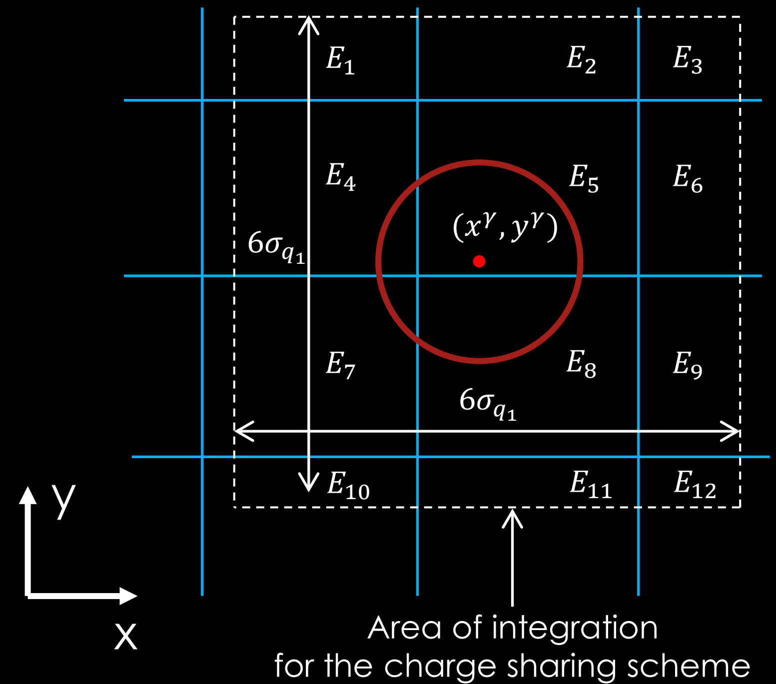


$$\sigma_q = 0.014(z_{chip} - z_{abs}) + 2\mu m;$$

- After the coordinates of photon is generated, the simulation of absorption depth in chip is performed.
- The total charge collected by the chip is described by the Gaussian PDF with the sigma σ_q.
- The average electronics threshold used in the TestBeam studies was equivalent to 4.2 keV.
- After the charge is collected by each pixel, the electronics noise is added by smearing the energy associated to each pixel using a Gaussian distribution with a σ_{noise} of 426 eV (100 primary electrons).

MC: PARTICLE REGISTRATION



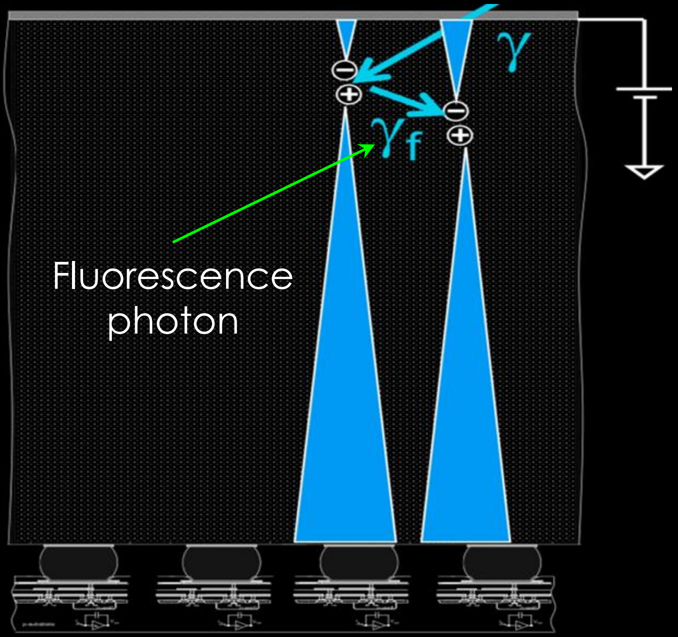


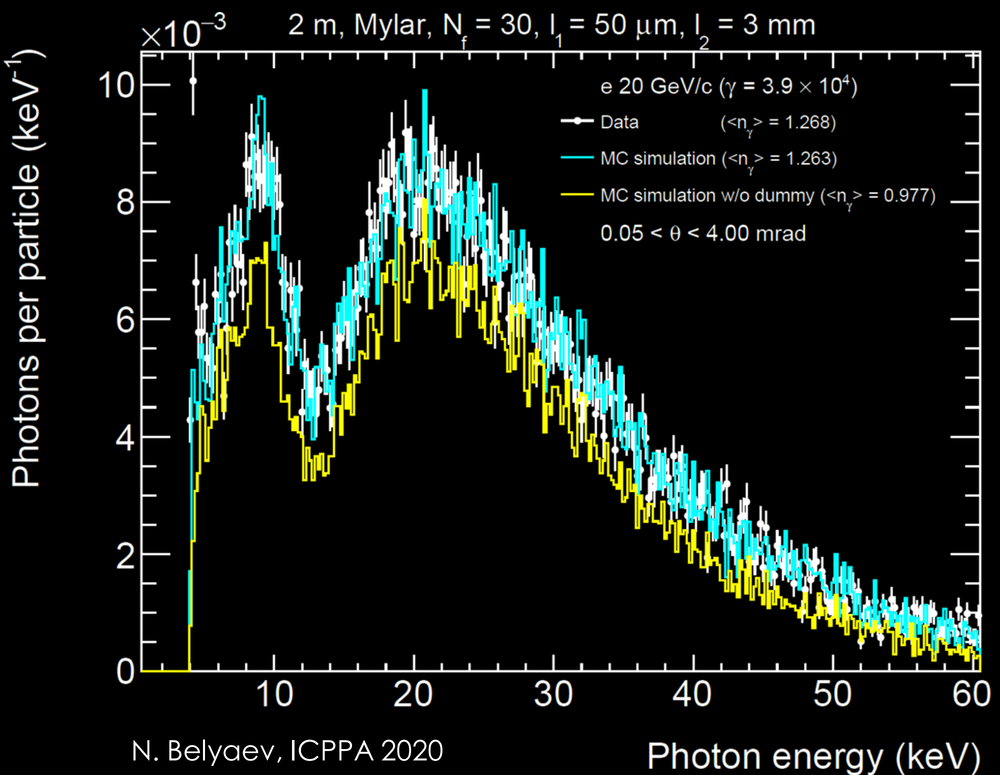
- In case of particle registration $\sigma_q = \sigma_q(z)$ and the total charge is the sum over the set of 2D-Gaussians with all possible values from $\sigma_q(z) \in [2\mu m; 9\mu m]$.
- Summation step was fixed as $50\mu m$ over Z-axis.
- Energy deposition of the particle was taken based on the Landau PDF with the parameters obtained from the data.

MC: ADDITIONAL EFFECTS

- Several additional important effects are taken into account, namely:

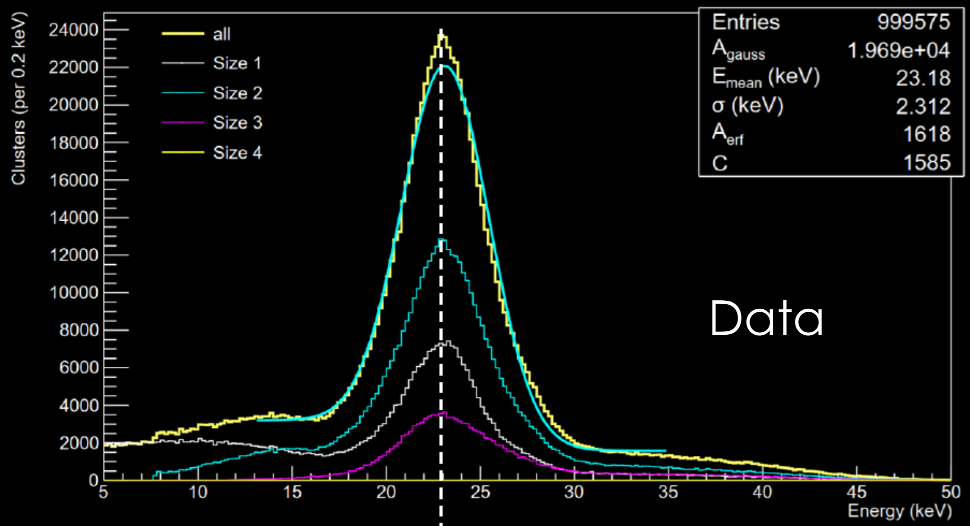
1. Both GaAs sensor materials have about 50% yield of fluorescent photons with energies of 9.2 keV (Ga) and 10.5 keV (As). These photons have 40.6 um and 16.6 um absorption lengths, respectively, and may escape from the main cluster area producing separate clusters.

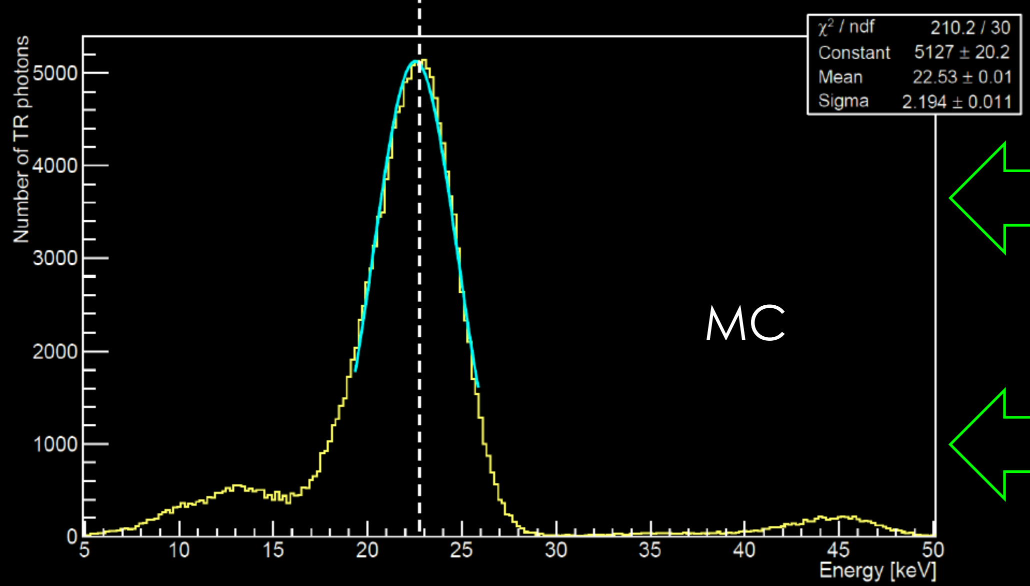




2. Secondary processes lead to a production of photons and delta electrons along the beam line. To take them into account, special runs with a "dummy" radiator (3 mm thick polyethylene slab) were taken. Clusters obtained in these runs were added to those obtained in the simulations.

MC: ADDITIONAL EFFECTS





3. The calibration procedure similar to one performed in data was carried out. The real detector was calibrated pixel-by-pixel using fluorescence lines and γ -rays of different elements, namely:

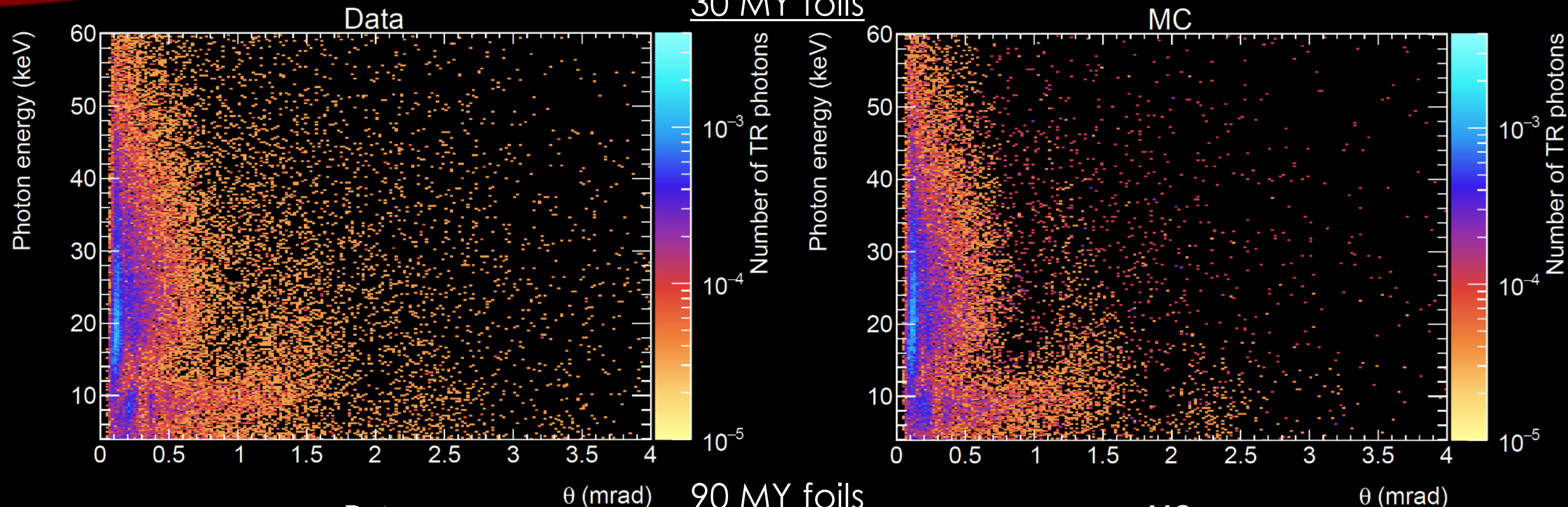
$$Fe \ (E_\gamma = 5.95\ keV)$$
$$Cu \ (E_\gamma = 8.05\ keV)$$
$$Zr \ (E_\gamma = 15.77\ keV)$$
$$Cd \ (E_\gamma = 22.70\ keV)$$
$$^{241}Am \ (E_\gamma = 59.50\ keV)$$

In the MC, the data-driven correction to the peak position is applied.

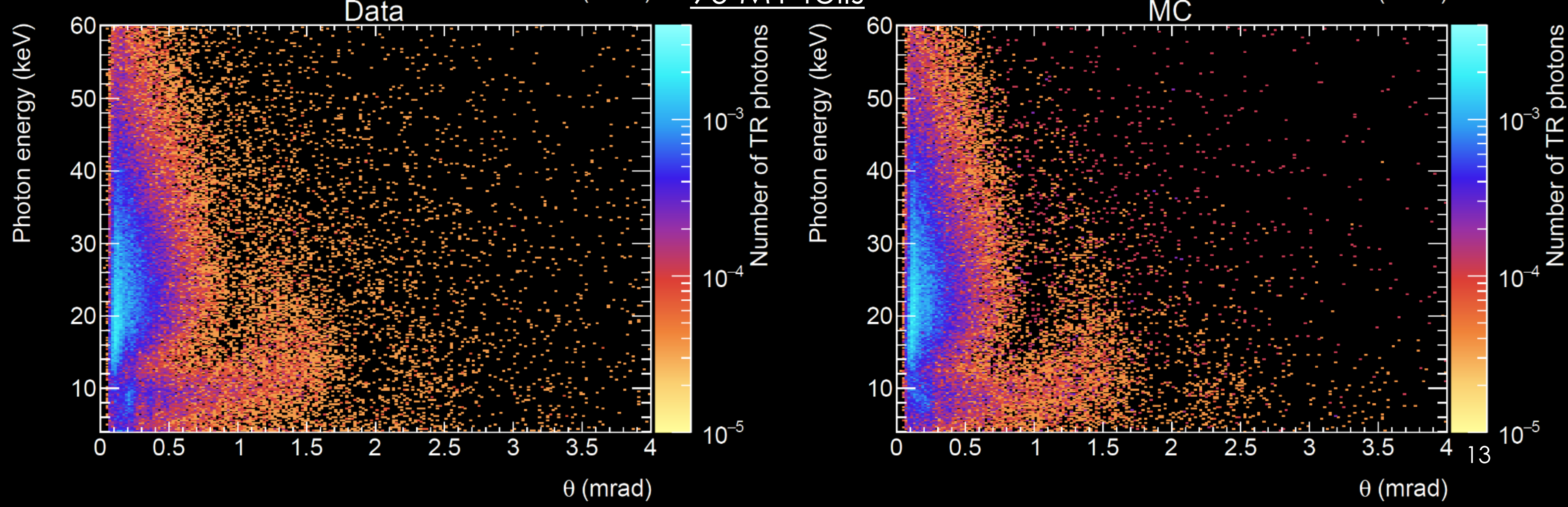
4. In order to simulate relatively large leakage current in GaAs detectors, signals which passed the threshold criteria were smeared further with the Gaussian distribution with a σ_{leak} of 1.2 keV.

DATA/MC COMPARISON

30 MY foils



90 MY foils



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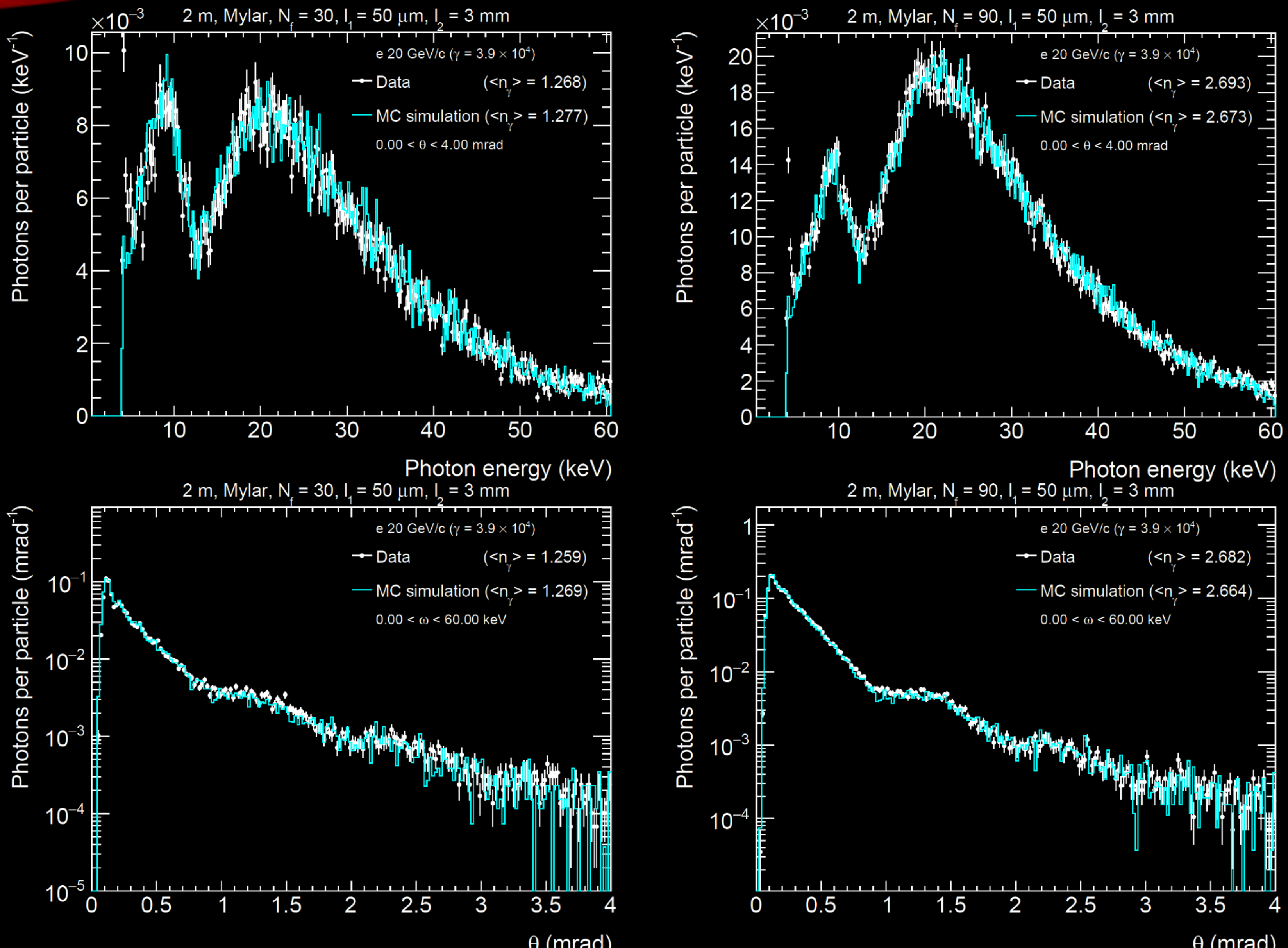

DATA/MC COMPARISON

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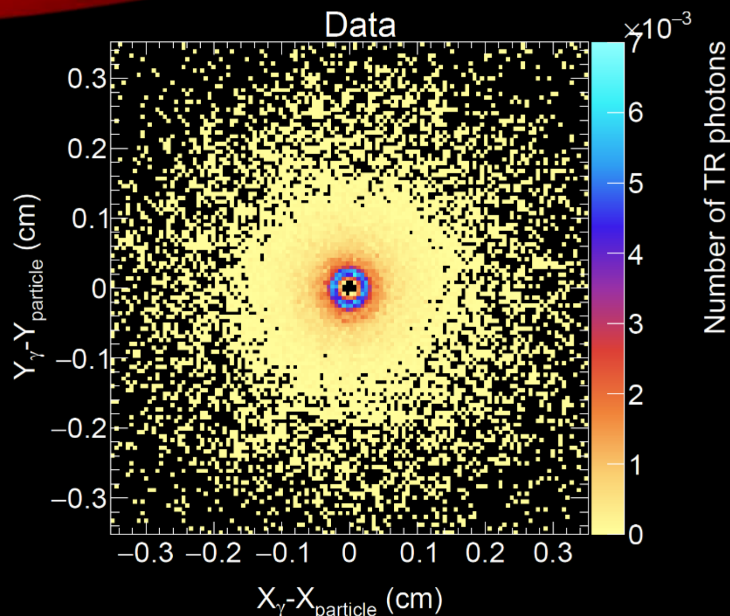
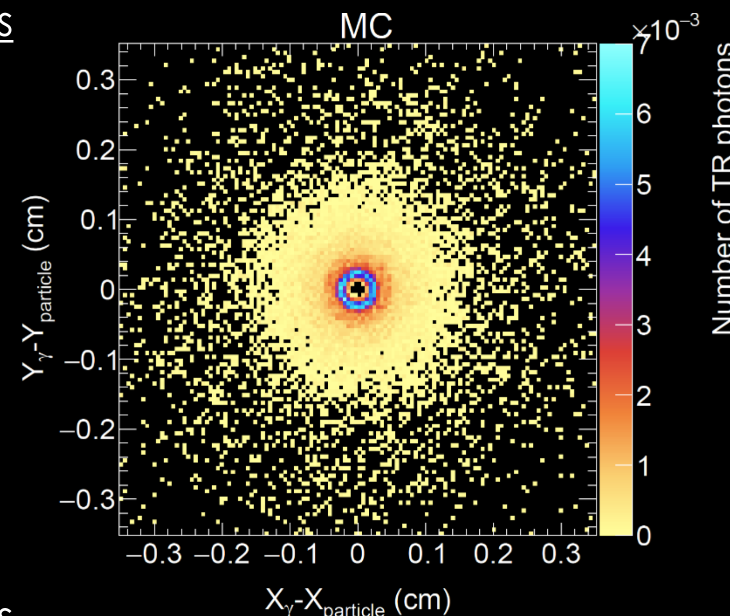
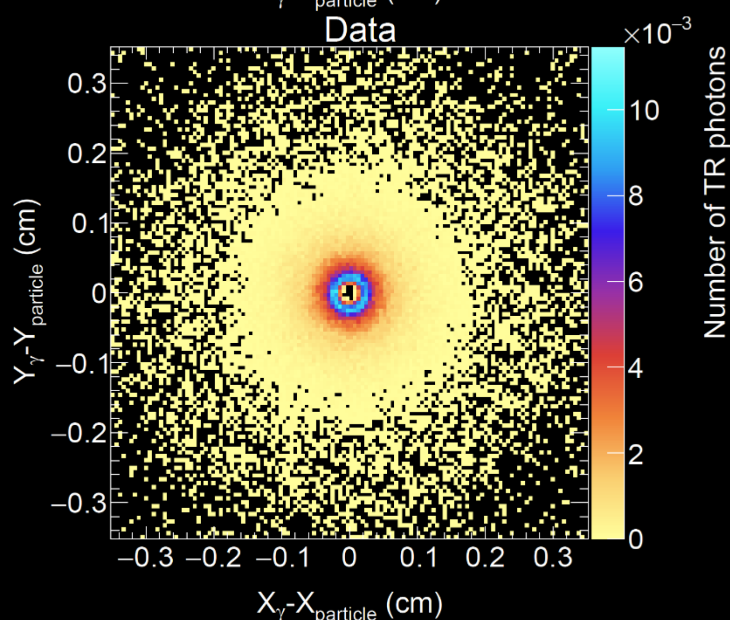
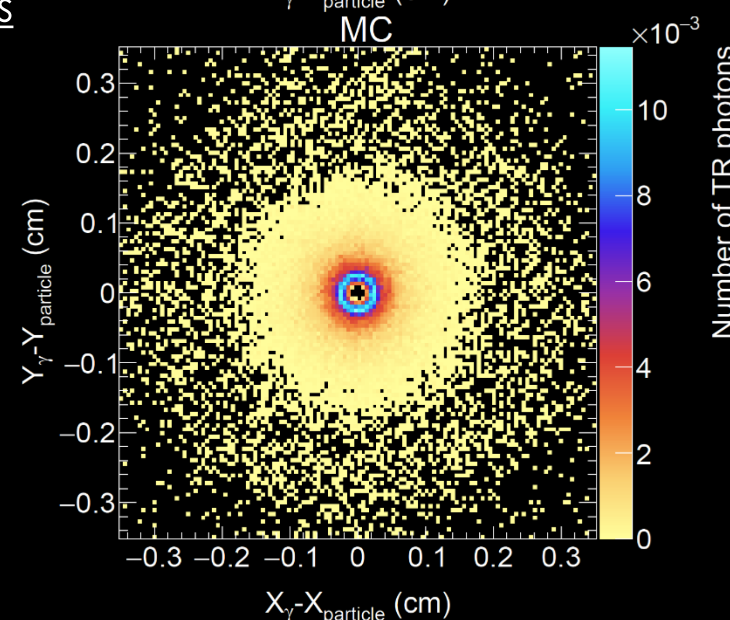




90 MY foils





DATA/MC COMPARISON

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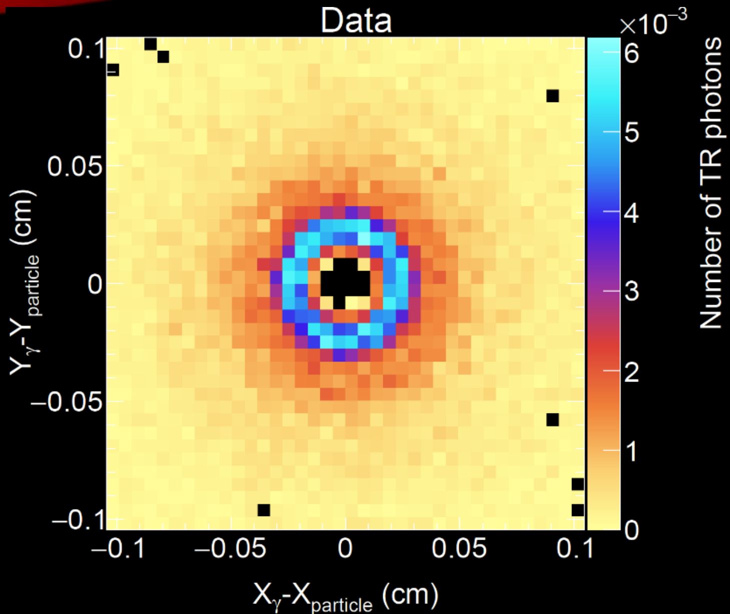
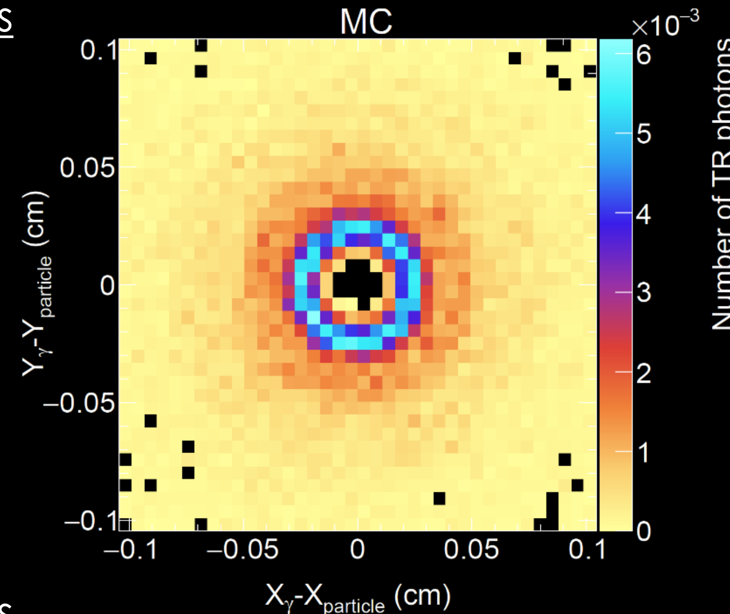
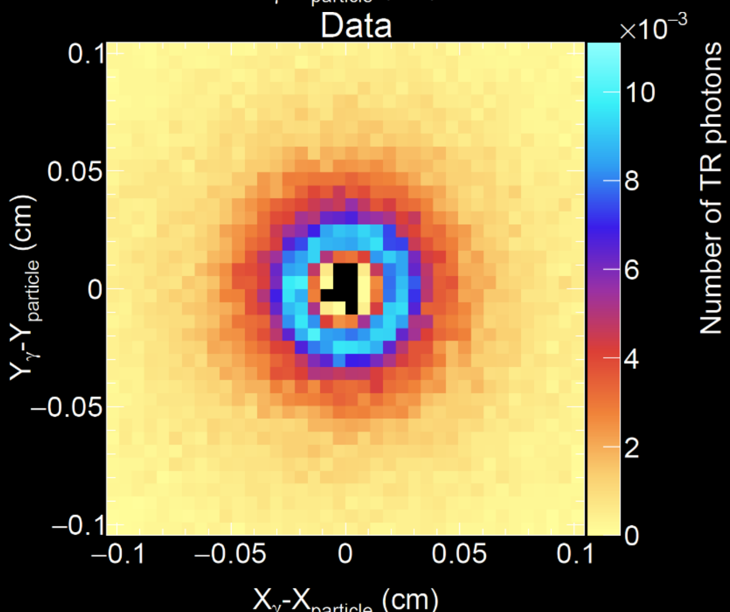
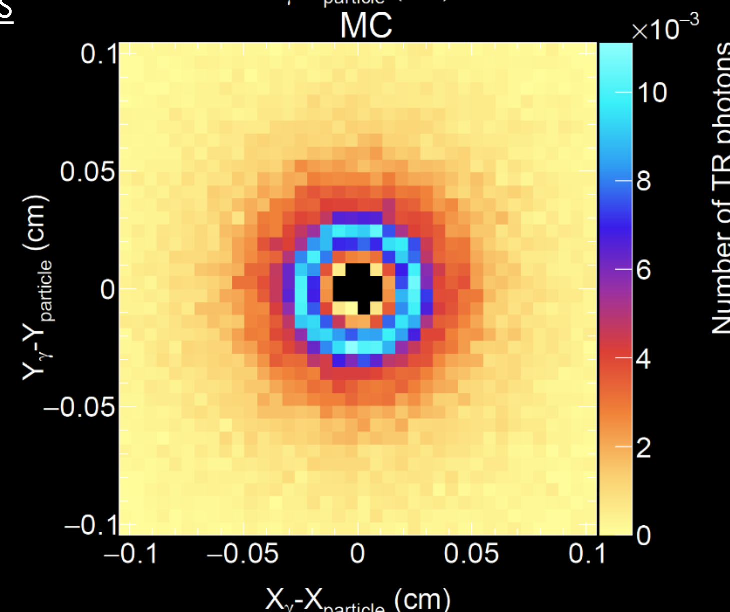




90 MY foils





CONCLUSION

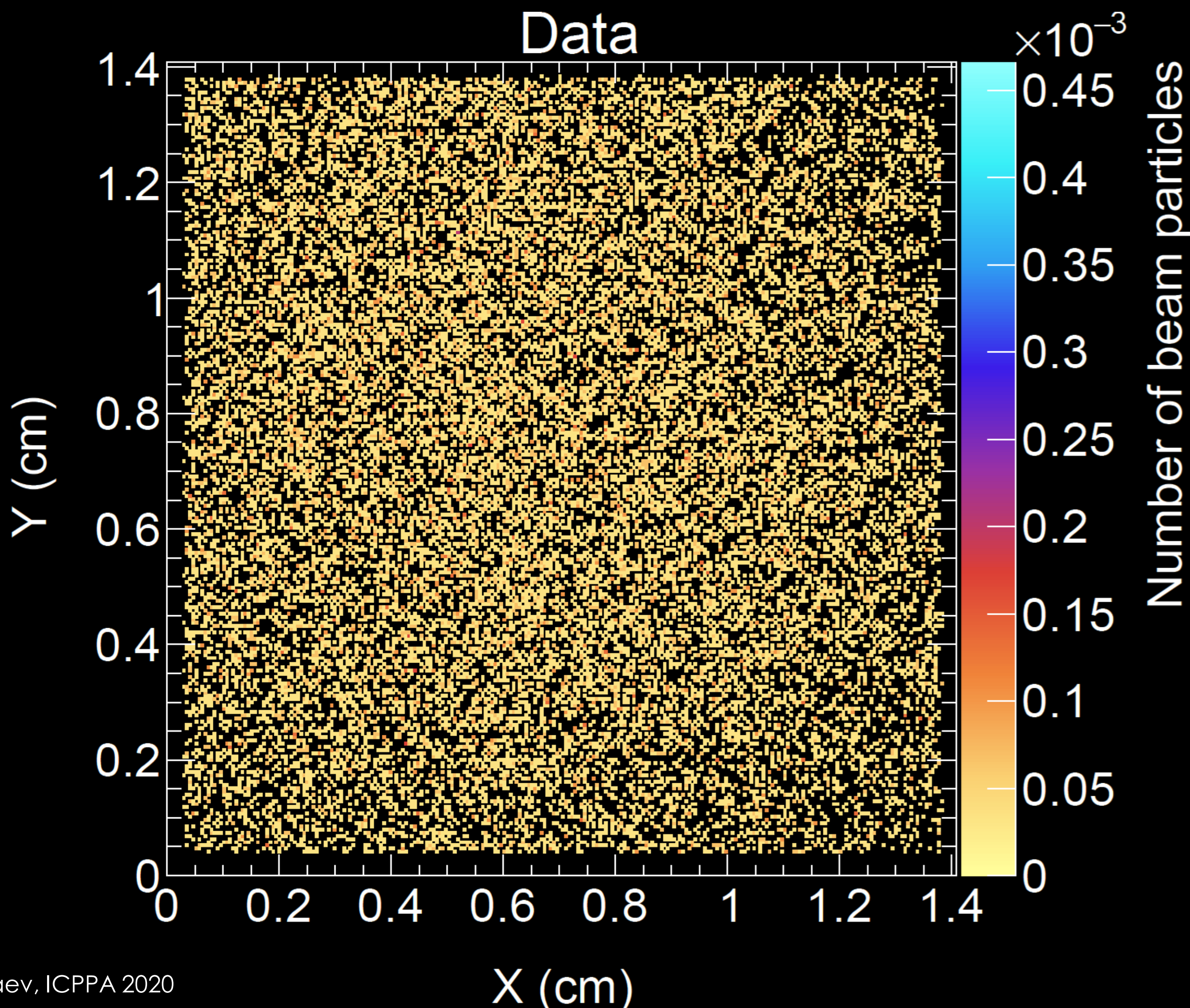
- Standalone Python-based simulation tool was created to perform the Monte Carlo simulation for Si and GaAs detector experiments.
- Many different detector effects are taken into account: geometry effects, absorption, detector resolution, Compton effect, fluorescence emission, charge sharing, multiple scattering etc.
- Great Data/MC agreement was achieved for all the radiators used during the TestBeam 2018 experiment at the CERN SPS North Area.
- The developed MC tool allows to study different radiator configurations and/or different detector parameters for better understanding of the transition radiation effects and proposing the future experiments setups.
- The following papers were published considering Si and GaAs detectors:

1. E. J. Schioppa, F. Dachs, J. Alozy, N. Belyaev, M. Campbell, M. Cherry *et al.* 2019 *NIM* A **936** 523-526.
2. F. Dachs, J. Alozy, N. Belyaev, B. L. Bergman, M. Beuzekom, T. R. V. Billoud *et al.* 2020 *NIM* A **958** 162037.
3. J. Alozy, N. Belyaev, M. Campbell, M. Cherry, F. Dachs, S. Doronin *et al.* 2020 *NIM* A **961** 163681.

THANKS FOR YOUR ATTENTION!

BACKUP

BEAM PARTICLE PROFILES



BEAM PARTICLE PROFILES