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# CALORIMETRY OF MULTI-GEV WAKEFIELD ACCELERATORS

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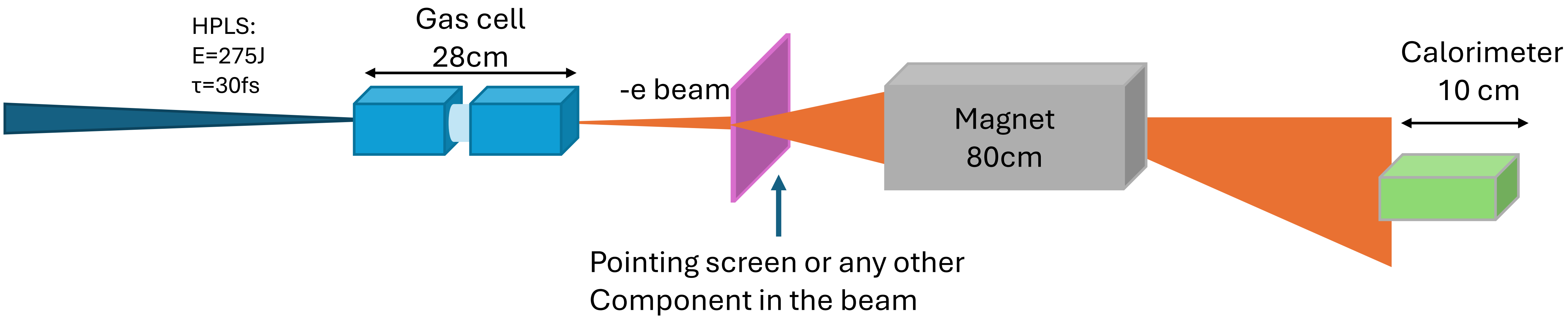
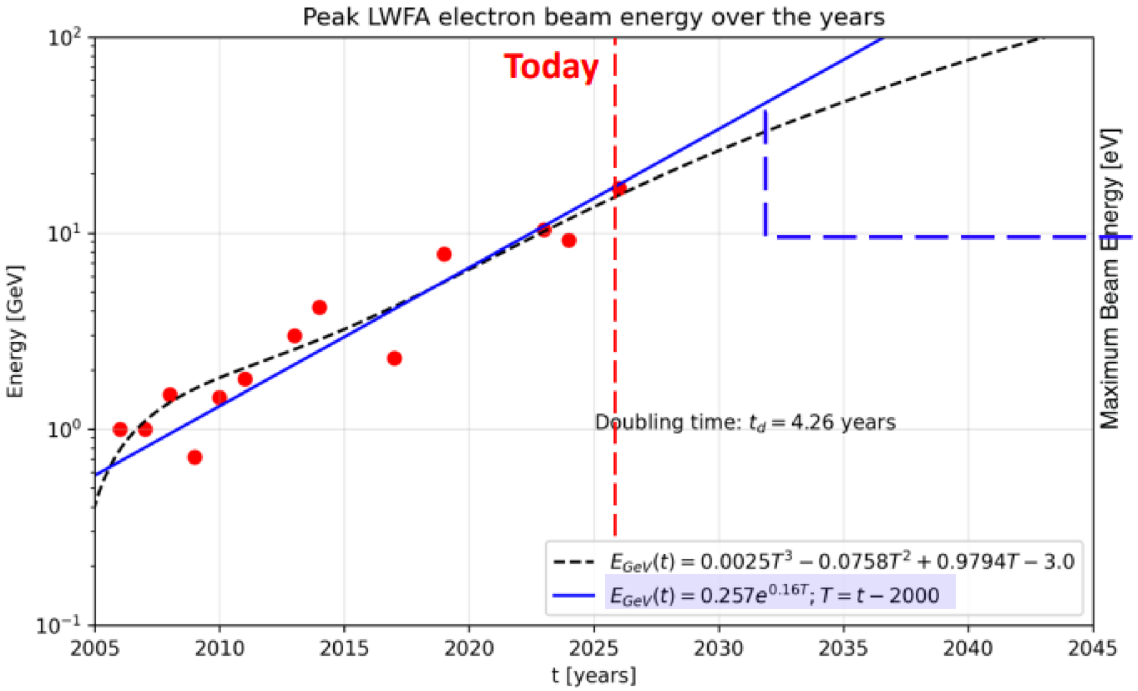
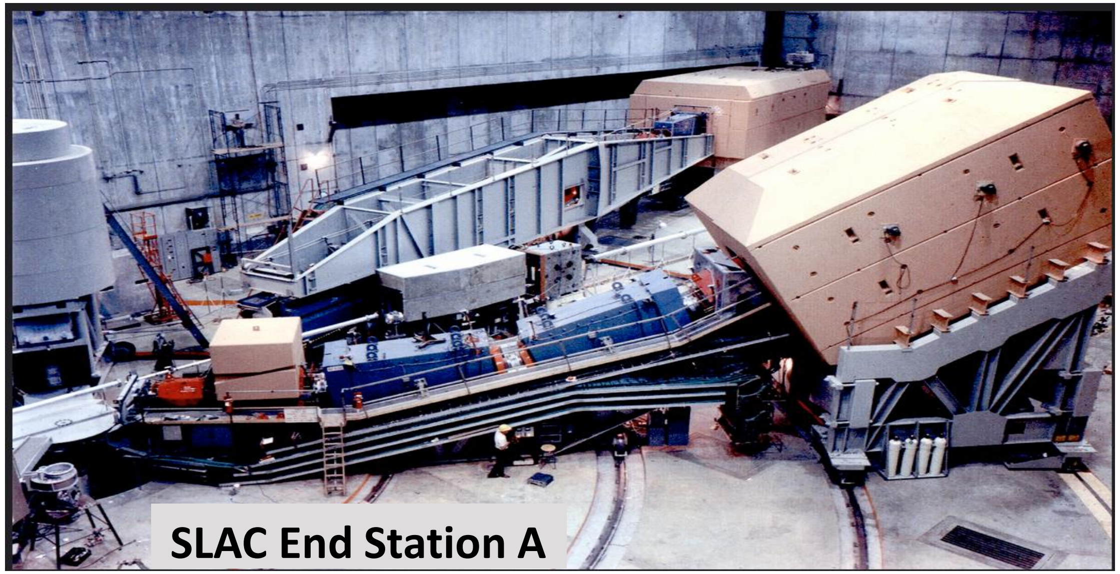


# Need of new diagnostics for MPW facilities




*"Diagnostics should be compact, affordable and in one shot"*
M. C. Downer.

As showed by C. Hojbota on yesterday's plenary, 100GeV could be achieved in the next decade.

# EM Calorimetry Basics: radiation-matter interaction

When electrons go through a material, they lose energy due Bremsstrahlung, producing photons, and ionization. The subsequent photons interact the material as well via Photoelectric effect, Compton Scattering and Pair production. These photon process also generate electrons that are able to interact with the material. The result of an electron or a photon traveling in a material ends up in a particle cascade. This type of cascade is called Electromagnetic (EM) cascade.

When talking about EM calorimetry, there are two important concepts [1],[2].

Radiation length:

Characteristic length at which an electron going through a material loses all but 1/e of its Energy.

$$X_0 \sim 180 \frac{A}{Z^2} \text{ [g/cm2] for } Z \geq 13.$$

Critical energy:

Critical energy is the energy at which an electron loses as much energy in collisions as in radiation. This is the energy at which the multiplication process is almost stopped (pair production), and Compton scattering and photoelectric effect are the main mechanisms.

$$\epsilon_c \sim \frac{550}{Z} \text{ [MeV]}$$

An additional unit to characterize the transverse evolution of the cascade is the Moliere radius.

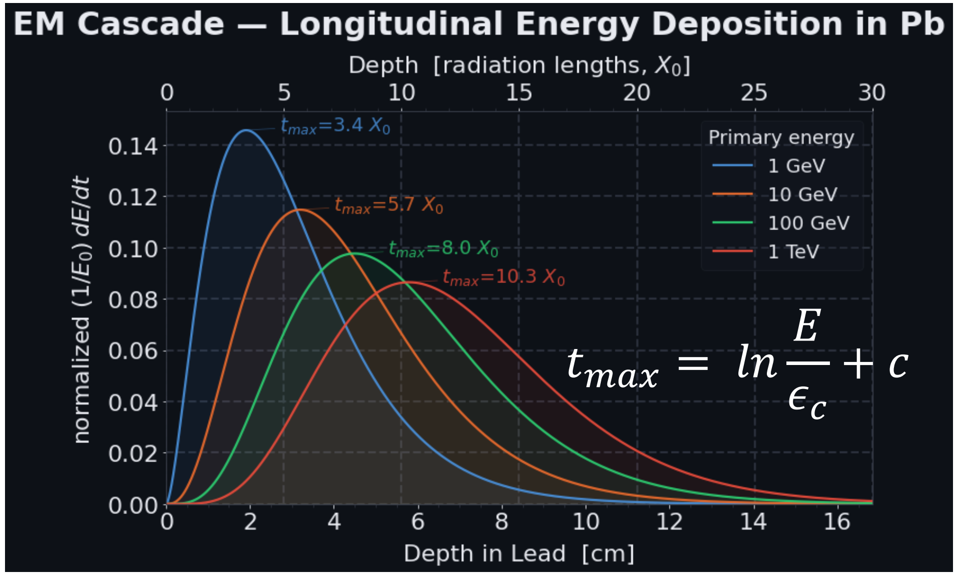
$$R_m = \frac{21.2[MeV]}{\epsilon_c} X_0$$

[1] C. Leroy and P.G. Rancoita, Rep. Prog. Phys. 63 (2000) 505–606
[2] R. Wigmans, Calorimetry – energy measurement in particle physics, 2nd edition, Oxford University Press (2017 )

# EM Calorimetry Basics: Shower development

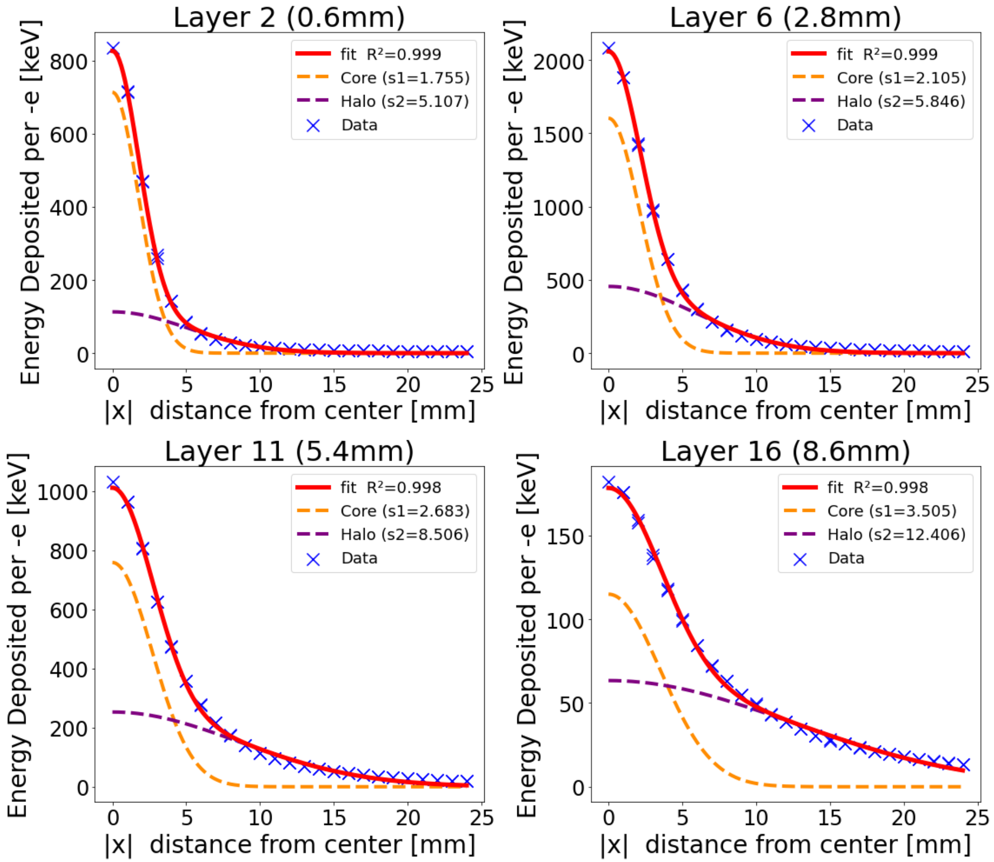
The energy distribution profile generated by a single particle with energy, $E_0$, is described longitudinally by a gamma distribution, $\mathcal{L}(t)$. Transversely, the shower has a narrow high-energy core and a wide lower-energy halo [2]. This behavior can be modelled by a double gaussian, $\mathcal{R}(r,t)$. So, the shower is $\mathrm{F}(\mathrm{r},t) = \mathcal{L}(t)\mathcal{R}(r,t)$ :

$$\mathcal{L}(t) = E_0 \frac{b(bt)^{\alpha-1}e^{-bt}}{\Gamma(\alpha)}$$




$$\mathcal{R}(r,t) = A_c e^{-r^2/2\sigma_c^2} + A_h e^{-r^2/2\sigma_h^2}$$

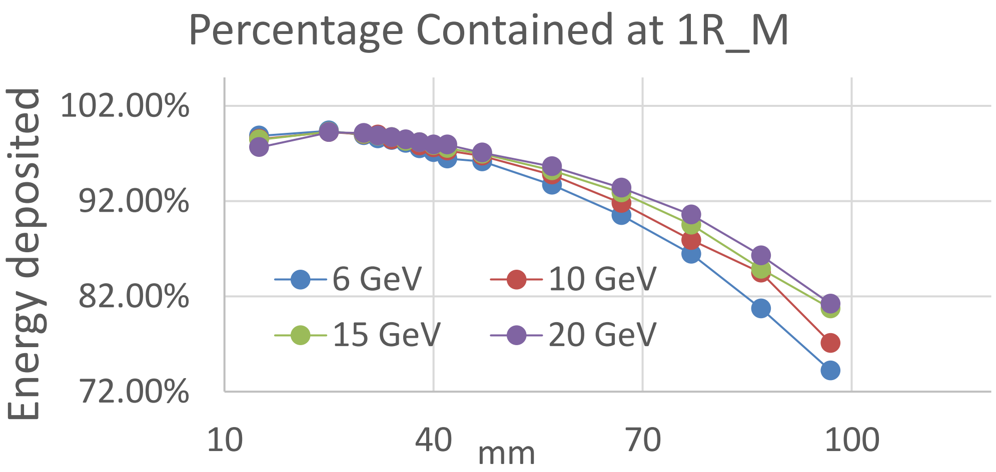
Transverse Profiles for a 10GeV electron

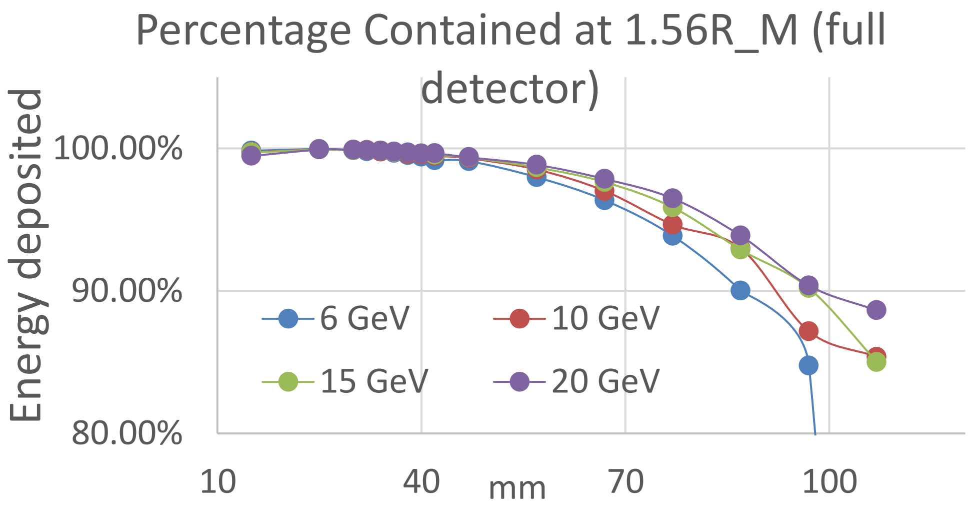


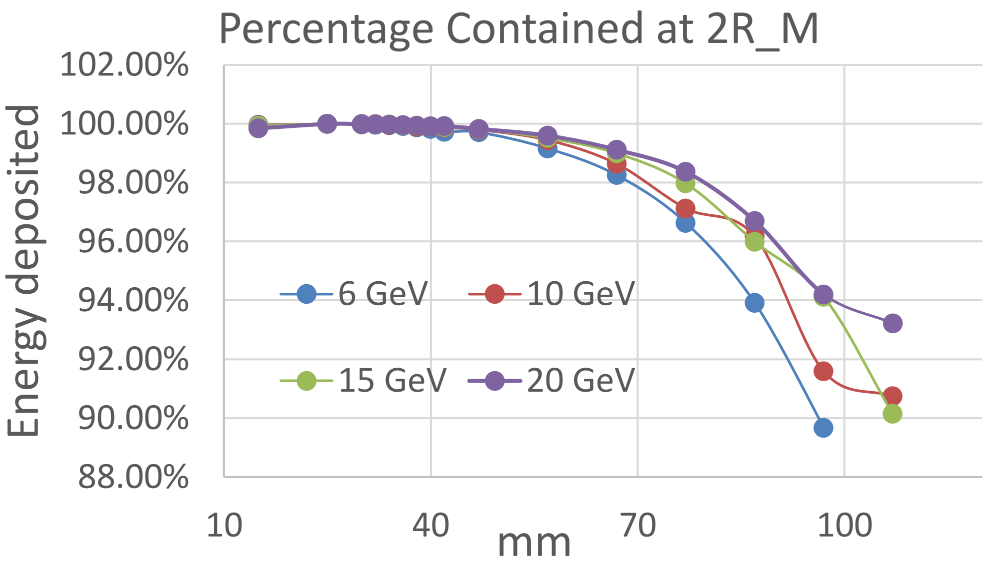

*Radial evolution is commonly modelled by a double exponential decay. In this case, Gaussians work since electrons got scattered by a beam block and multi-ple Lanex screens along the beam path

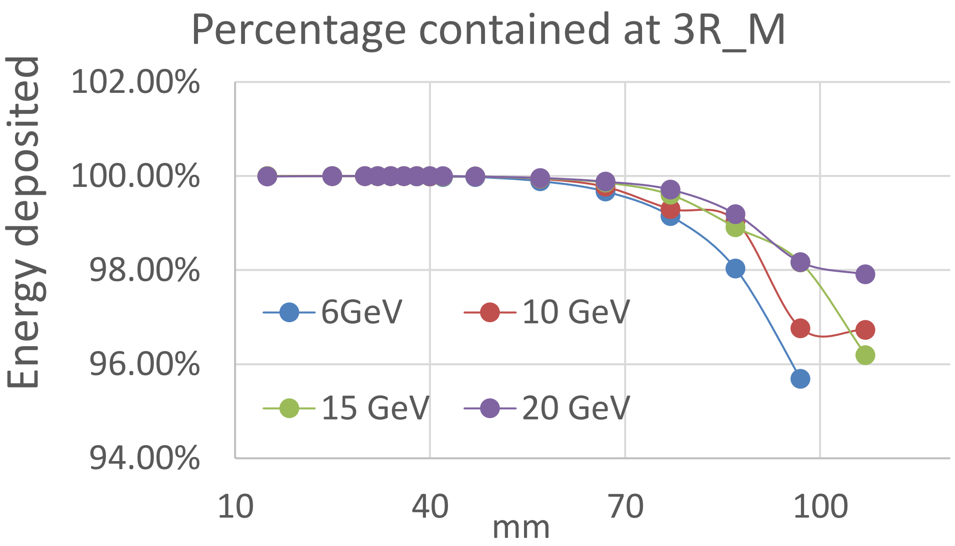
# EM Calorimetry Basics: Lateral Shower Containment

$$R_m = \frac{21.2[MeV]}{\epsilon_c} X_0$$

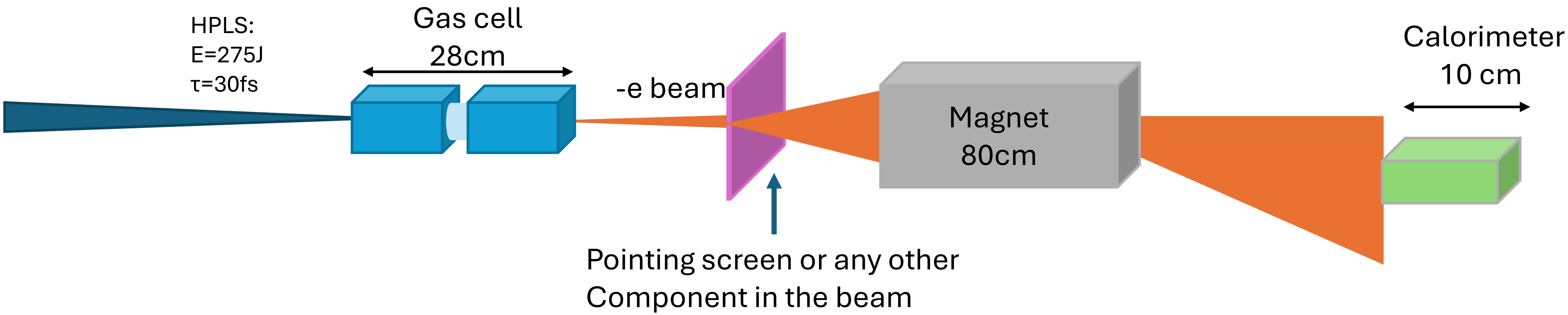


# Dealing with bunches




the total transverse profile will then be the convolution of $G(r_0) * F(r,t)$, so:

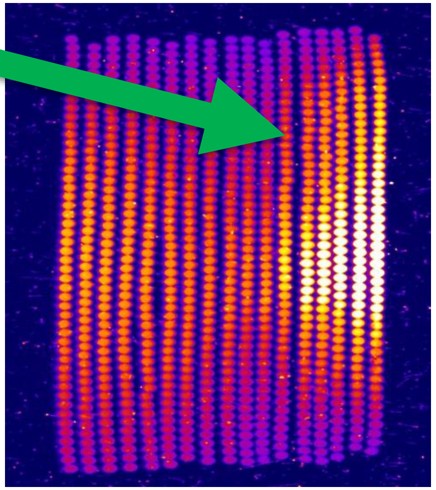
$$\Phi(r,t) = \int G(r_0)F(|r - r_0|, t)rdrd\theta$$

Will depend on elements in the beam path
from experiment to experiment.

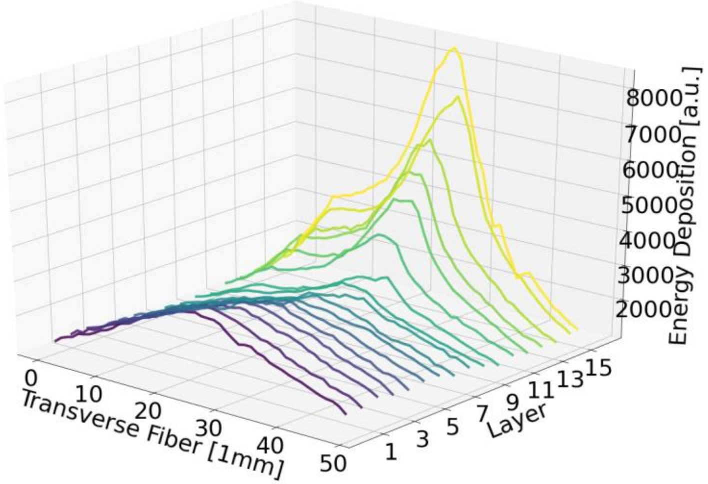
# Scintillator-based calorimeters

Bremsstrahlung

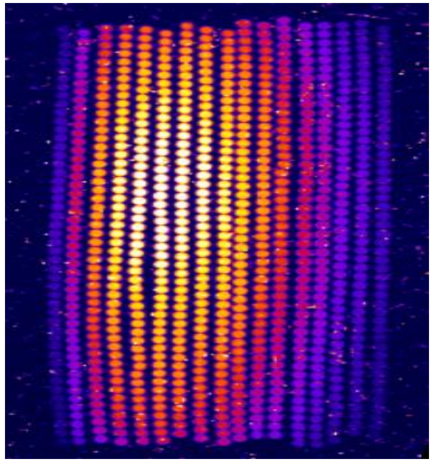
Betatron



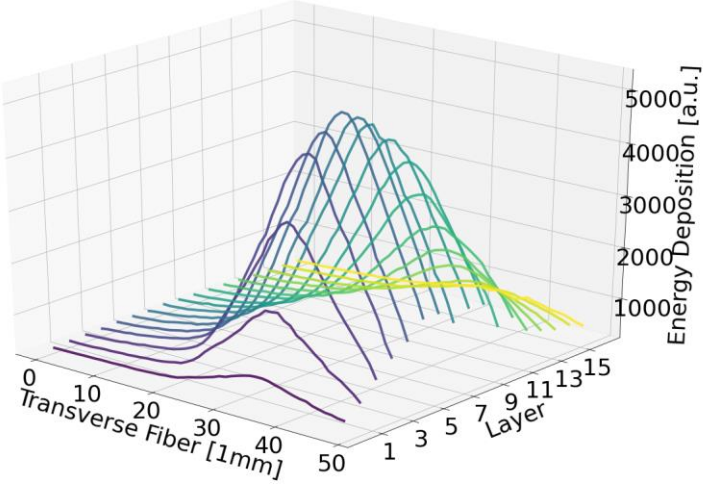
3D Experimental Photon Profile




Electrons

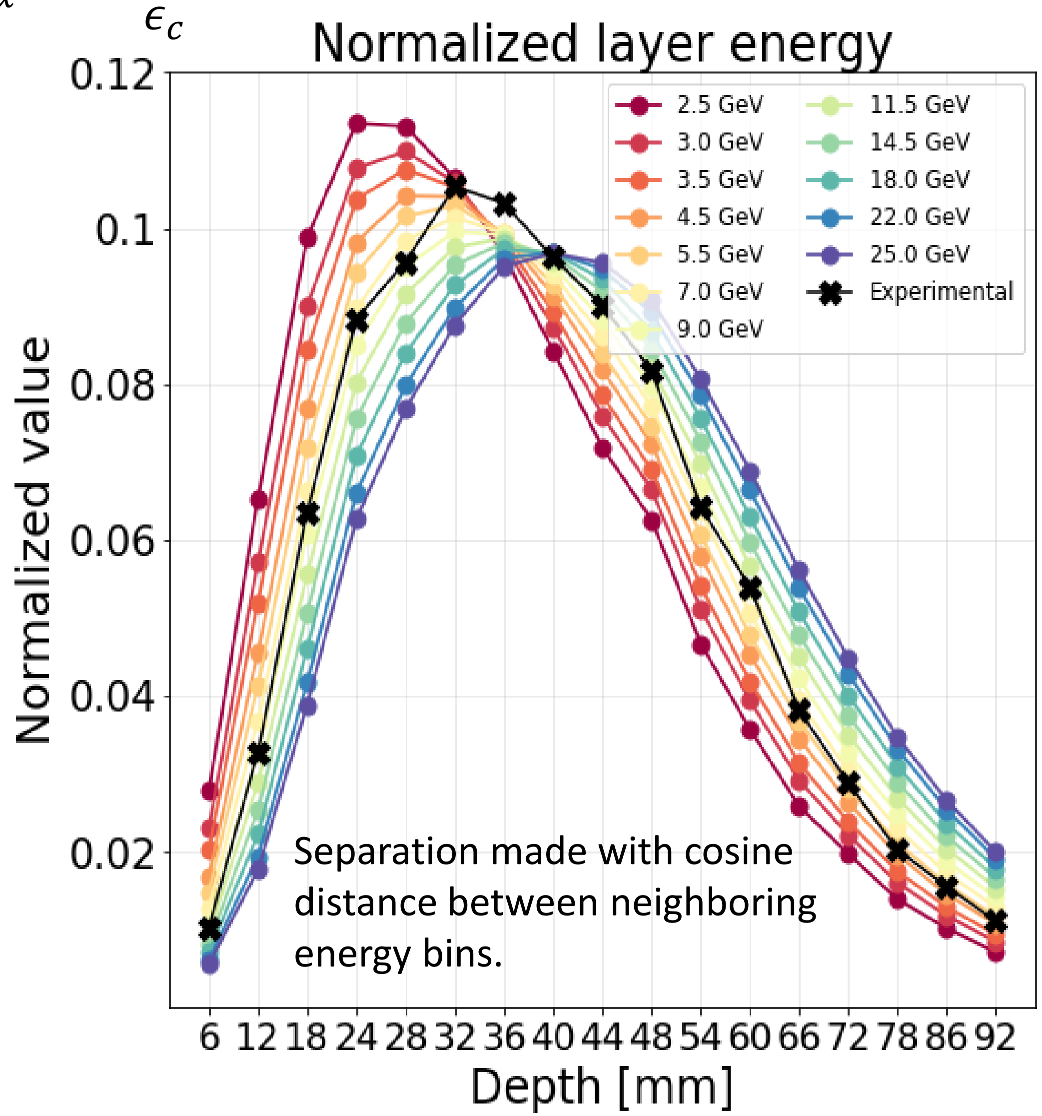


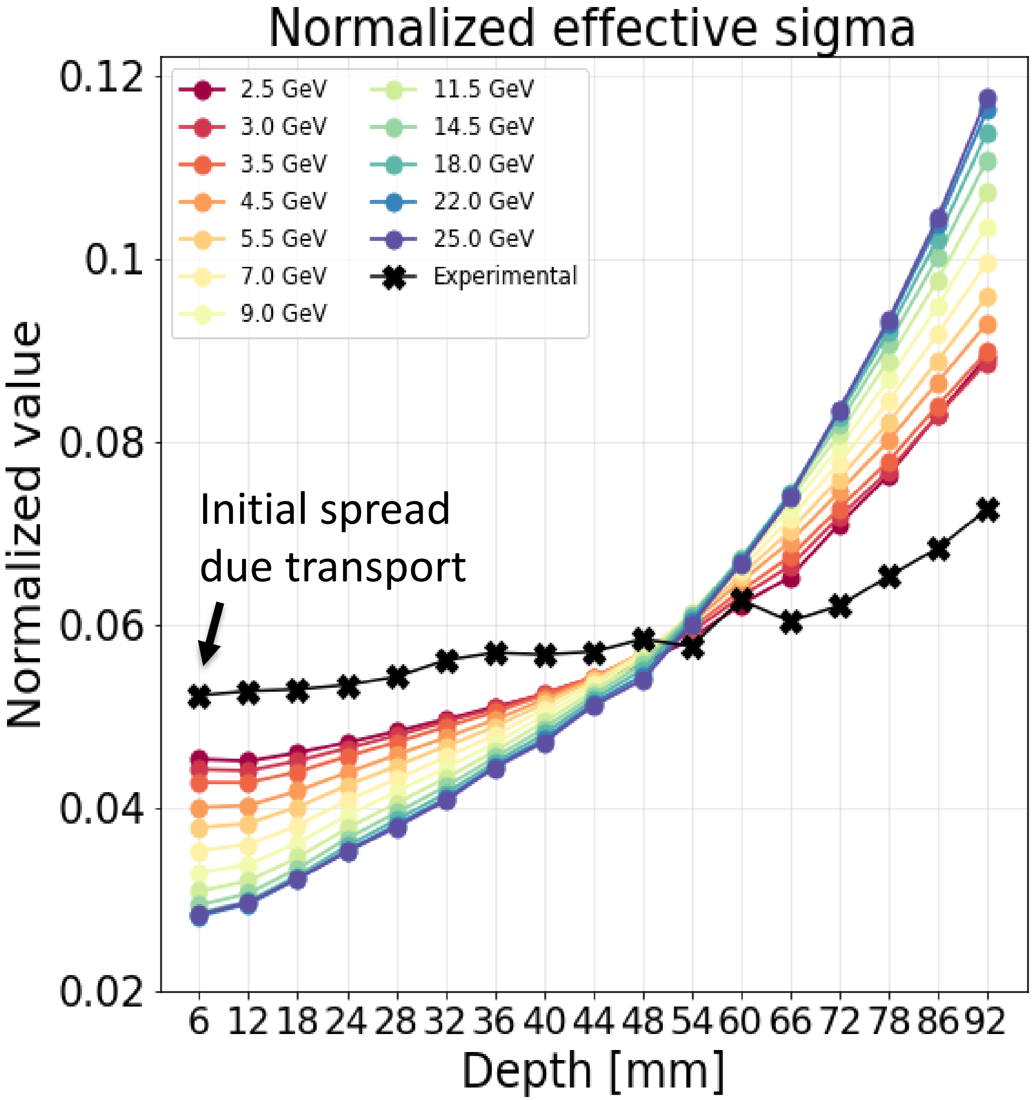
3D Experimental Electron Profile



$$t_{max} = ln\frac{E}{\epsilon_c} + c$$

# Response at optimal energy separability



# Fitting Strategy

**Integral response** – total energy deposited, $R_{int}$, in layer, $l$, by a single electron with energy $E_j$

$$R_{int}(E_j, l) = \sqrt{2\pi}(A_C\sigma_C + A_h\sigma_h)$$

**Sigma response** – *effective* lateral (weighted average) width, $R_\sigma$, at layer, $l$, broadened by a beam divergence $\sigma_{beam}$

$$R_\sigma(E_j, l, \sigma_{beam}) = \frac{A_C\sqrt{\sigma_C^2 + \sigma_{beam}^2} + A_h\sqrt{\sigma_h^2 + \sigma_{beam}^2}}{A_C + A_h}$$

The predicted profiles are weighted sum over the energy grid $w_j$

$$\hat{m}_{int}(l) = \sum_j w_j \cdot R_{int}(l, E_j), \quad \hat{m}_\sigma(l) = \sum_j w_j \cdot R_\sigma(l, E_j, \sigma_{beam})$$

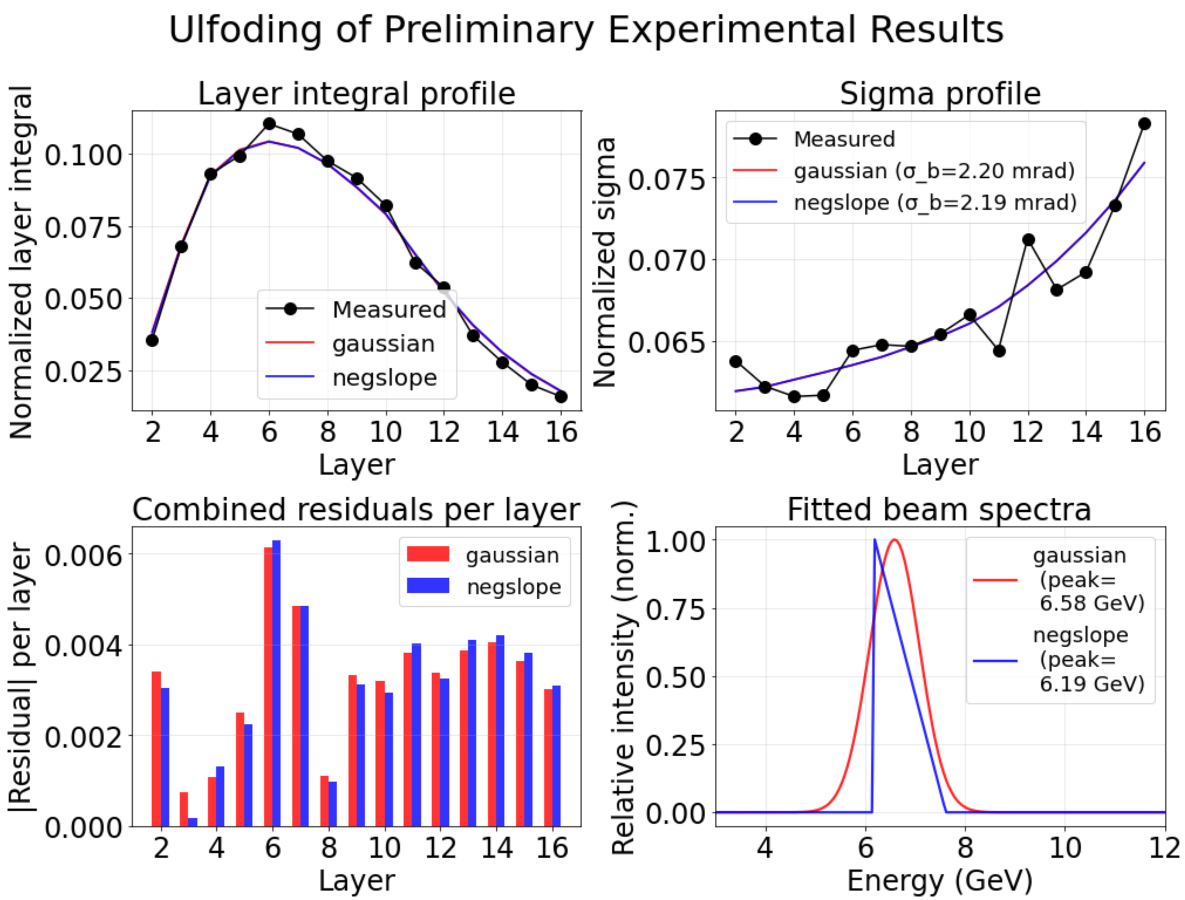
For the experimental data, the measured profiles are $m_{Exp\_int}(l)$ and $\sigma_{meas}(l)$. The fitting is the minimized combined residual, $Re_{int}$ ,between measured and predicted profiles

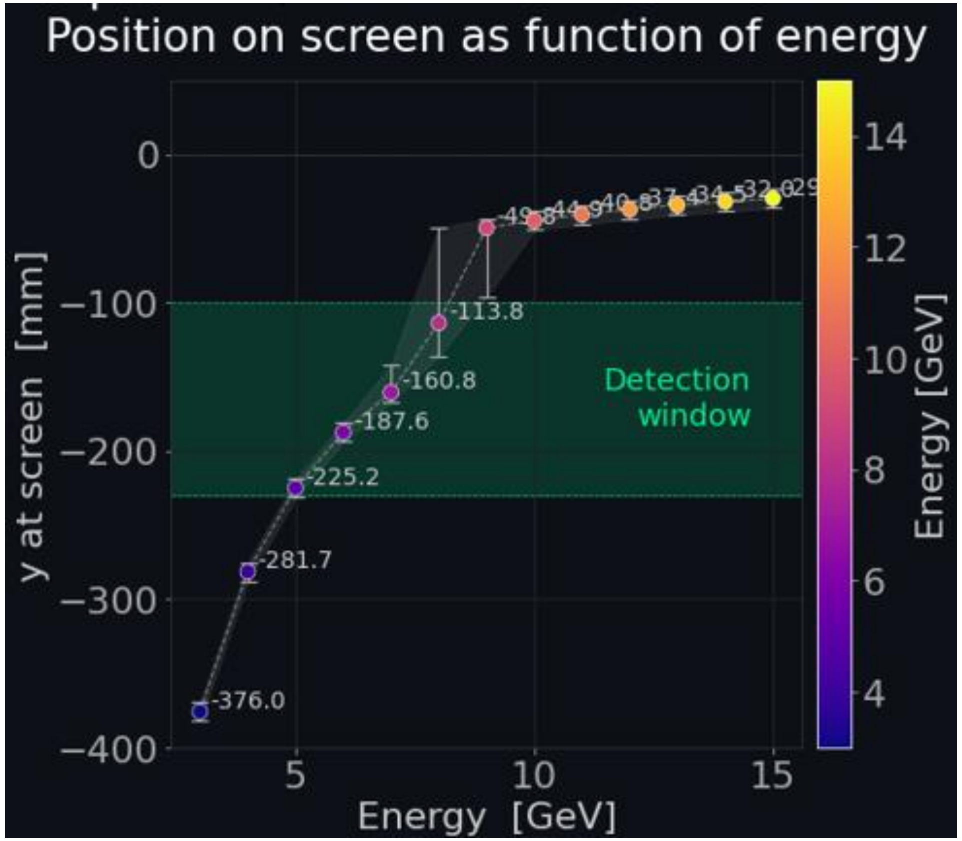
$$Re_{int}(E_0, \sigma_{beam}) = \boxed{\sum_l \left(\hat{m}_{int}(l) - m_{Exp\_int}(l)\right)^2} + \delta \cdot \boxed{\sum_l \left(\hat{m}_\sigma(l) - \sigma_{meas}(l)\right)^2}$$

Integral (longitudinal) Transverse evolution

where $\delta$ is a weight factor ($\delta = 1$ if longitudinal and sigma weight the same).

# Preliminary Results



# Conclusions & Outlook

- Sampling calorimeters are well-suited for the detection of Multi-GeV beams from next-generation laser-plasma wakefield accelerators, offering a compact alternative where conventional magnetic spectrometers become impractical.

- Preliminary unfolded results from ELI-NP indicate electron energies between 5 GeV and 8 GeV, consistent with the calorimeter's physical detection window. These results used a parametric model to guide the unfolding. A model-free approach is being considered (Covariant Matrix optimization or Bayes-based for example).

- Calorimeters also act like beam dumps or muon converters, and provide secondary measurements of the beams, so why not use them?

## Acknowledgments

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