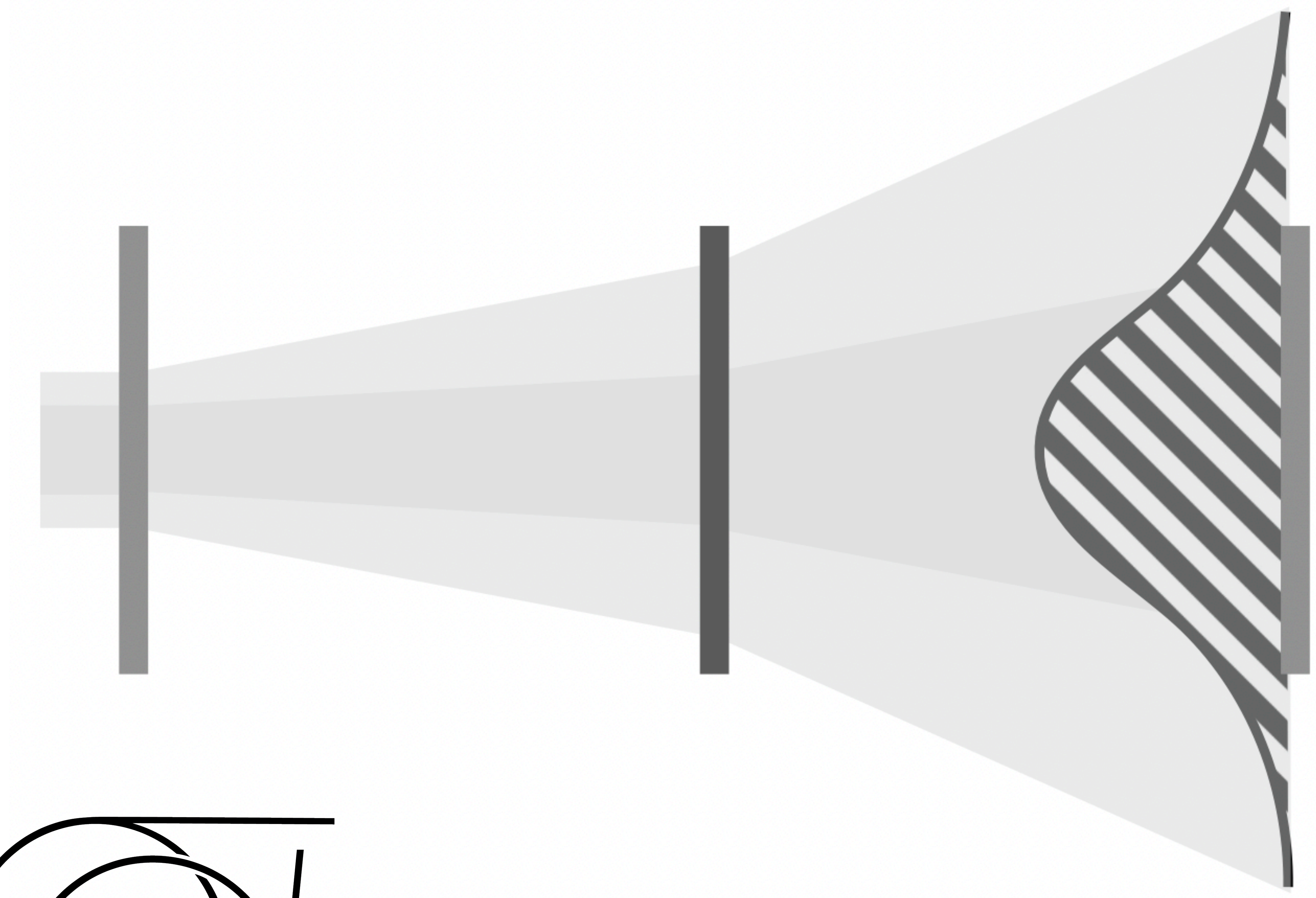
PS Testbeam at T9
MALTA/ATLAS

Brian Moser and Simon Koch
on behalf of the testbeam crew

PS and SPS users meeting

25/05/2023



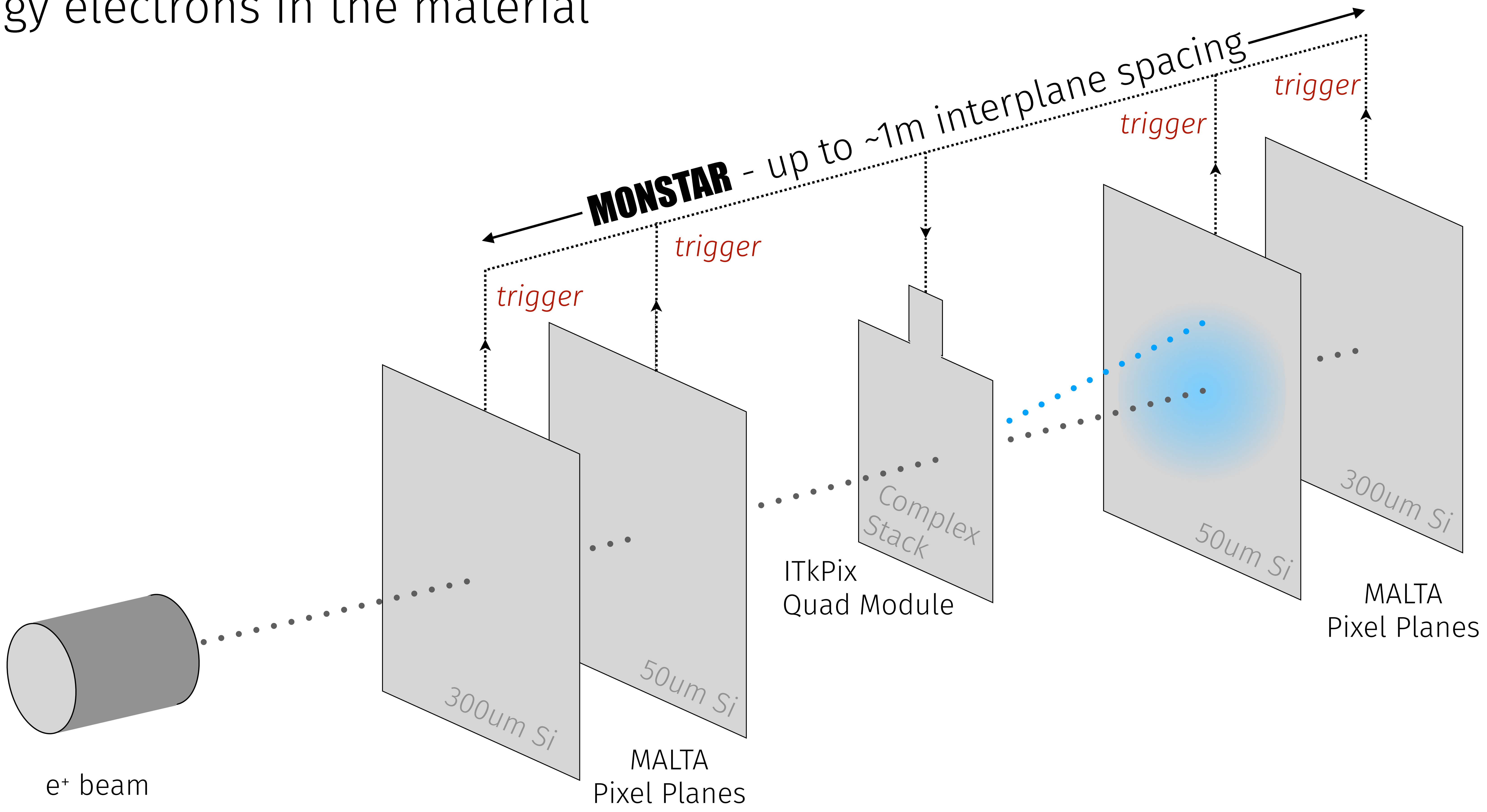
ATLAS EXPERIMENT

UNIVERSITY OF OXFORD

CERN

Context

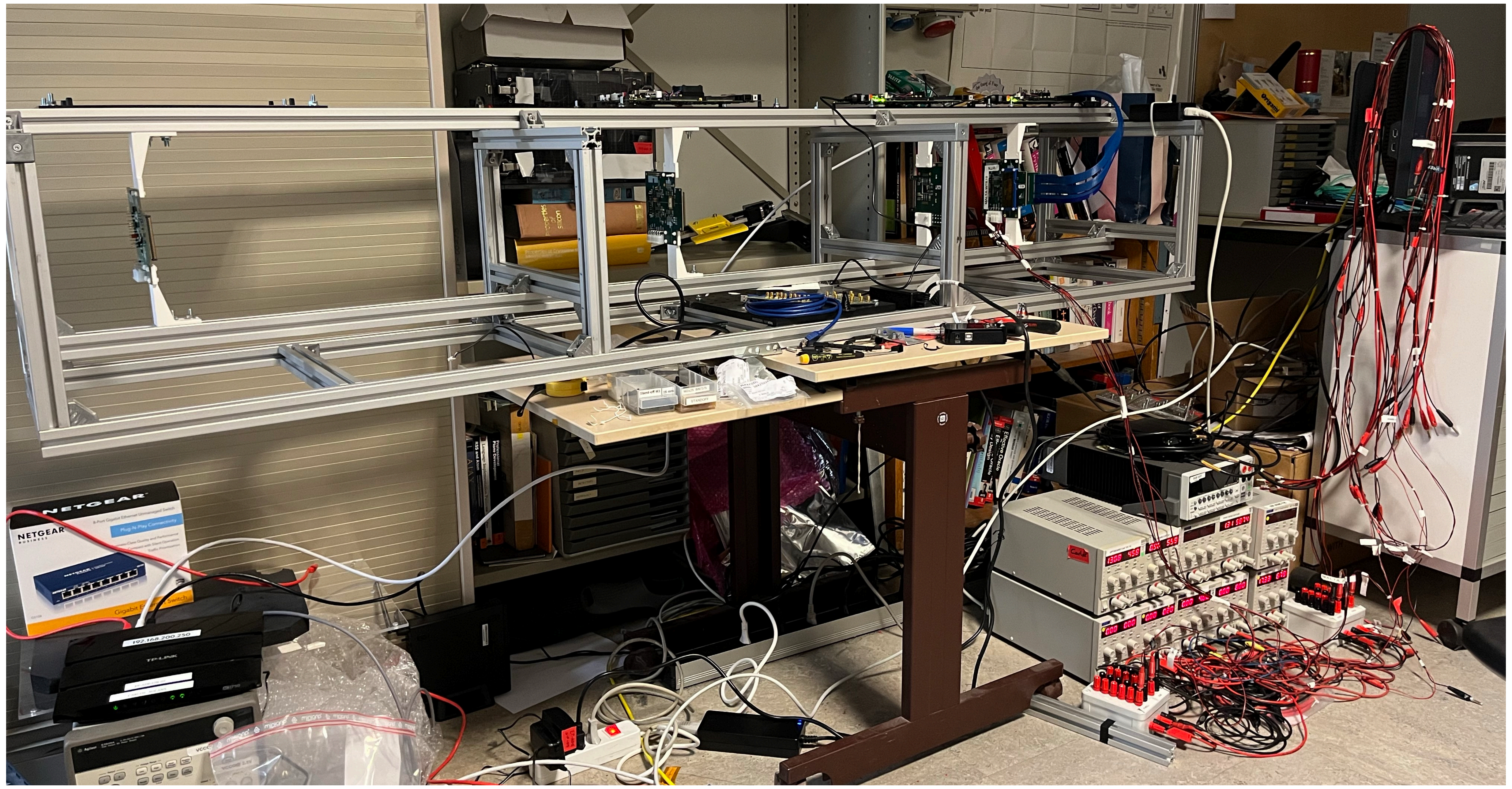
- Want to measure the **radiation length** of an ATLAS ITk pixel quad module via multiple scattering of low energy electrons in the material



- Goal: create a 2D map of how much material is in the quad module as a function of (x, y)

Our telescope

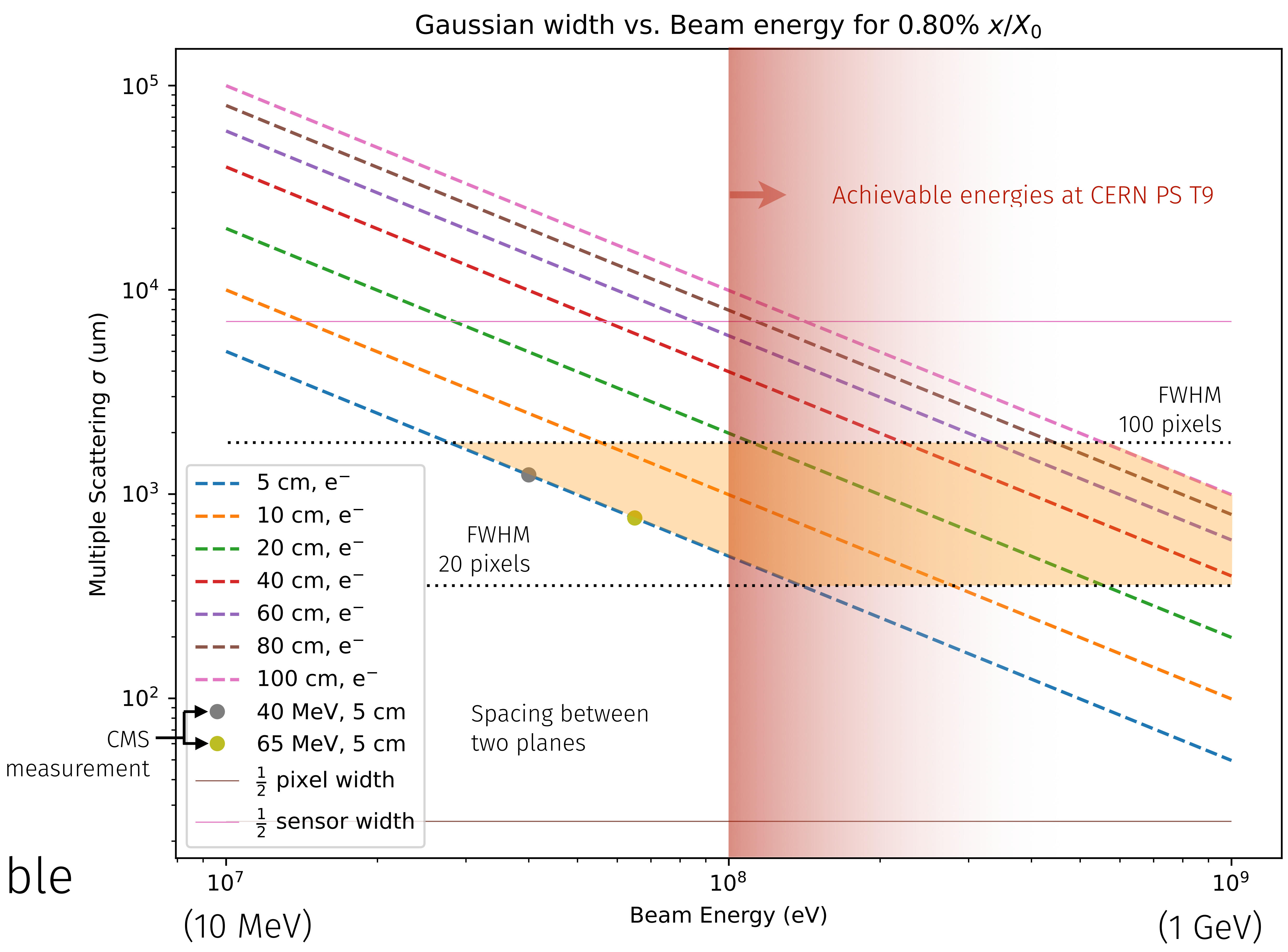
- **Dimensions**: ~ 2m length x 0.4m width x 0.5m height
- Telescope planes from MALTA Monolithic HVCMOS modules (excellent timing and low material)
- ITkPix quad module mounted on a linear stage in the center (to scan different points)



- The usual of-telescope services: power supplies, DAQ server, …
- No HV needed, max. Voltage to deplete the sensor is 50V (μA current)

Our requirements

- **Beam requirements**:
  - Pure electrons (or positrons) at a rate of 10k-50k/spill (we are flexible with the beam energy to match the desired rate)
  - Energy between 100-500 MeV for normal data taking, as high as possible for alignment runs
  - Δp/p ~ 5% would be desirable
  - Already had useful discussion with Dipanwita about the T9 possibilities
  - Prefer to operate with beam pipe in place if possible
- **Other requirements:**
  - 1 DESY table for our telescope
  - 1 regular table for off-telescope services
  - N2 supply for the telescope at max 120l/h
  - Spill timing signal, if possible (not mandatory, more nice to have)

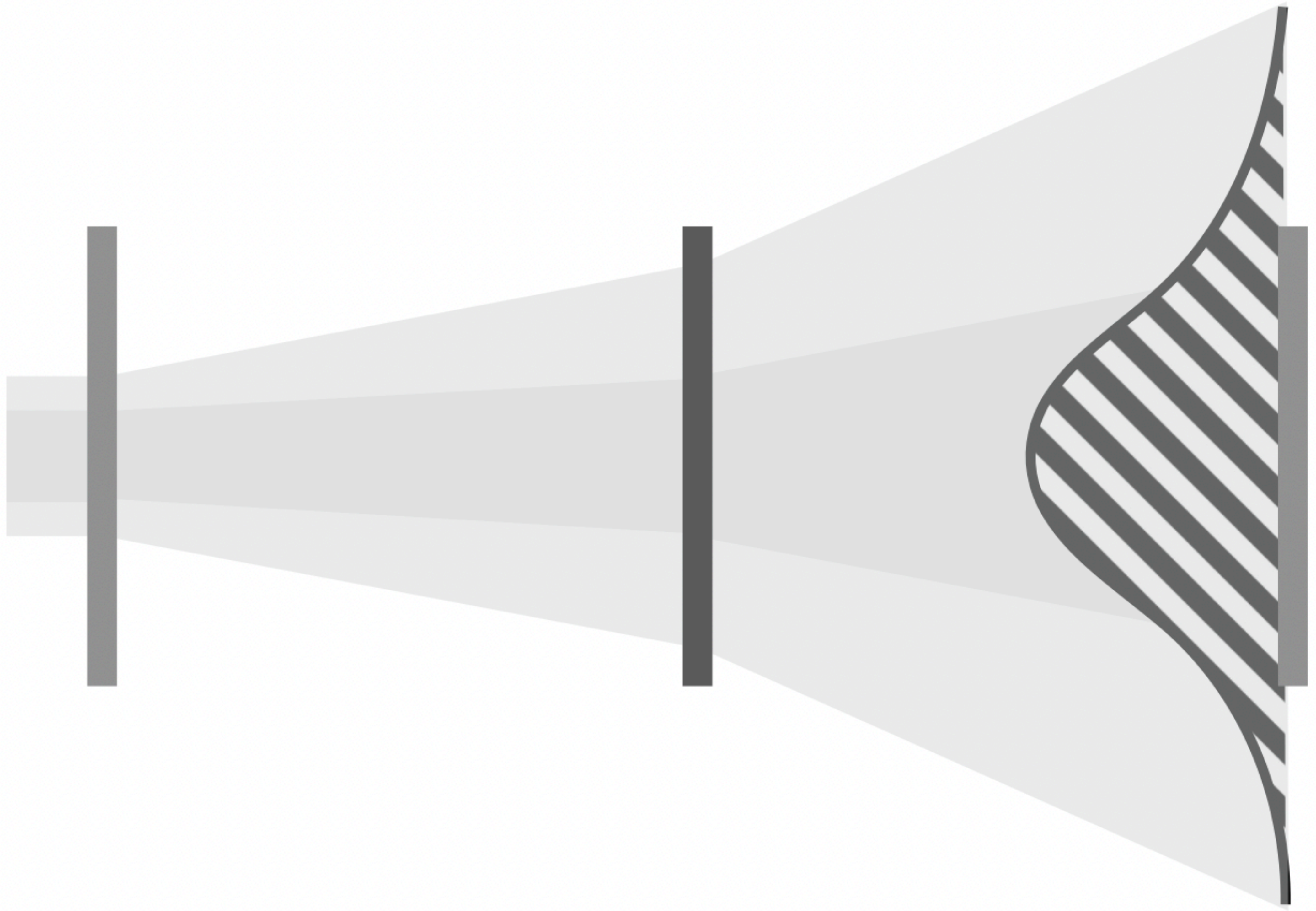


Contact persons

- Main contact person:
  - Ignacio Asensi (ignacio.asensi@cern.ch)

- Responsible for the measurement:
  - Brian Moser (brian.moser@cern.ch)
  - Simon Koch. (simon.florian.koch@cern.ch)

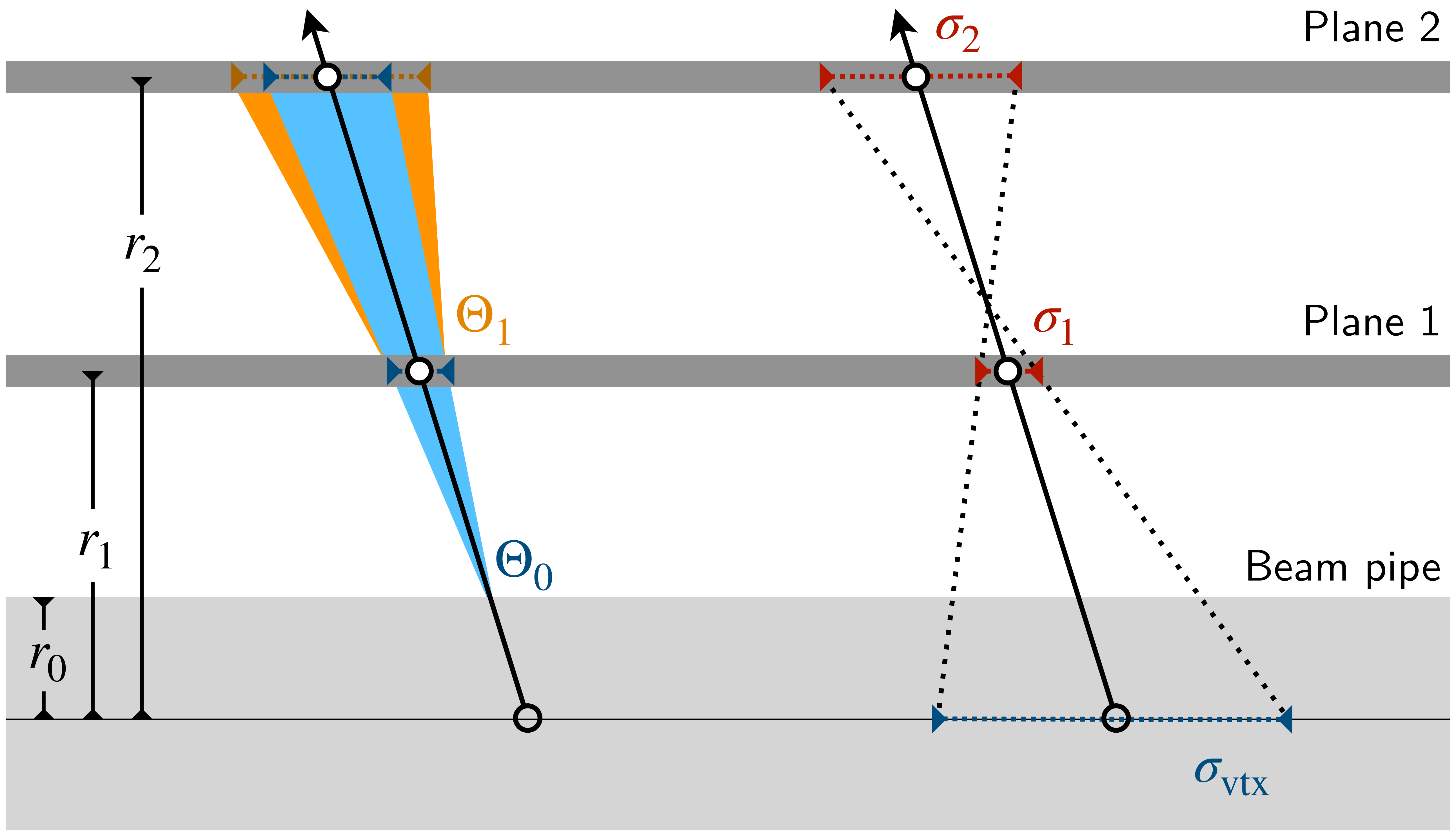
Backup

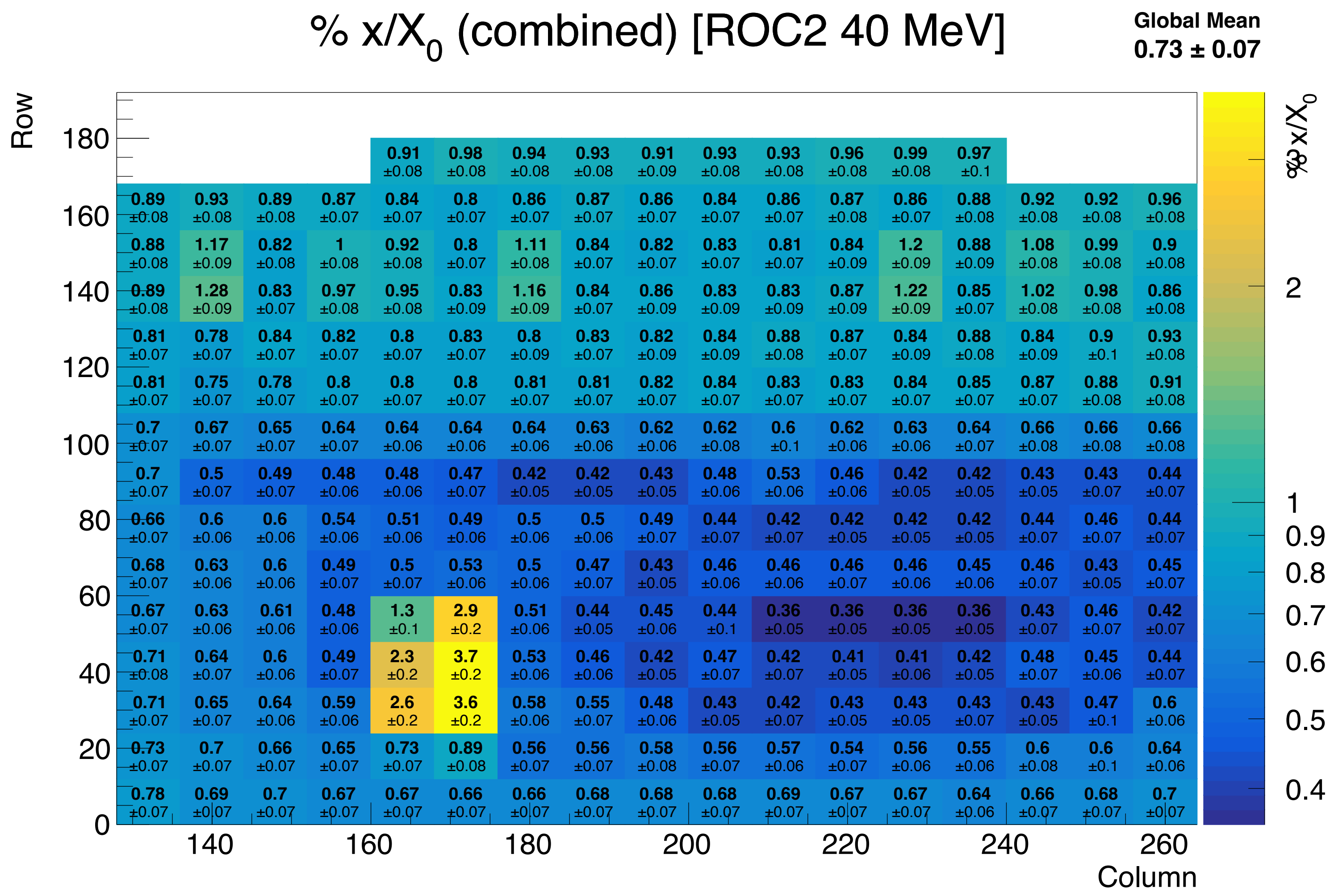


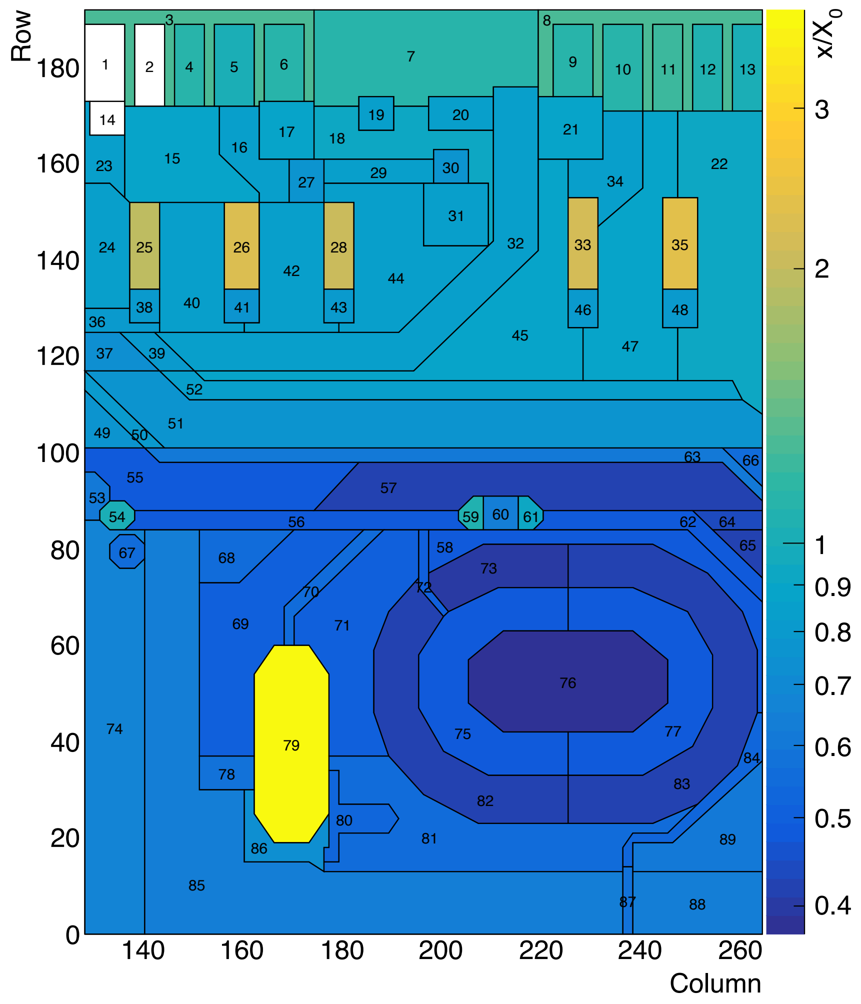
Context

- Material budget of tracking detectors heavily influences uncertainties on vertexing precision, and detrimental material effects such as photon conversion
  - Implications for **b-tagging**, coping with the **higher pileup from HL-LHC**
- Traditionally, material budget is only **estimated** during R&D, and measured in calibration runs of the detector
- Measurements tend to deviate from estimates by O(10-20%) in calibration runs
- An attempt at a **testbeam measurement** via multiple scattering in a CMS pixel module at the PSI PiE1 beam showed promising results…

**M. Backhaus, B. Ristic, S. Koch, et. al.*
Plots taken from my MSc Thesis





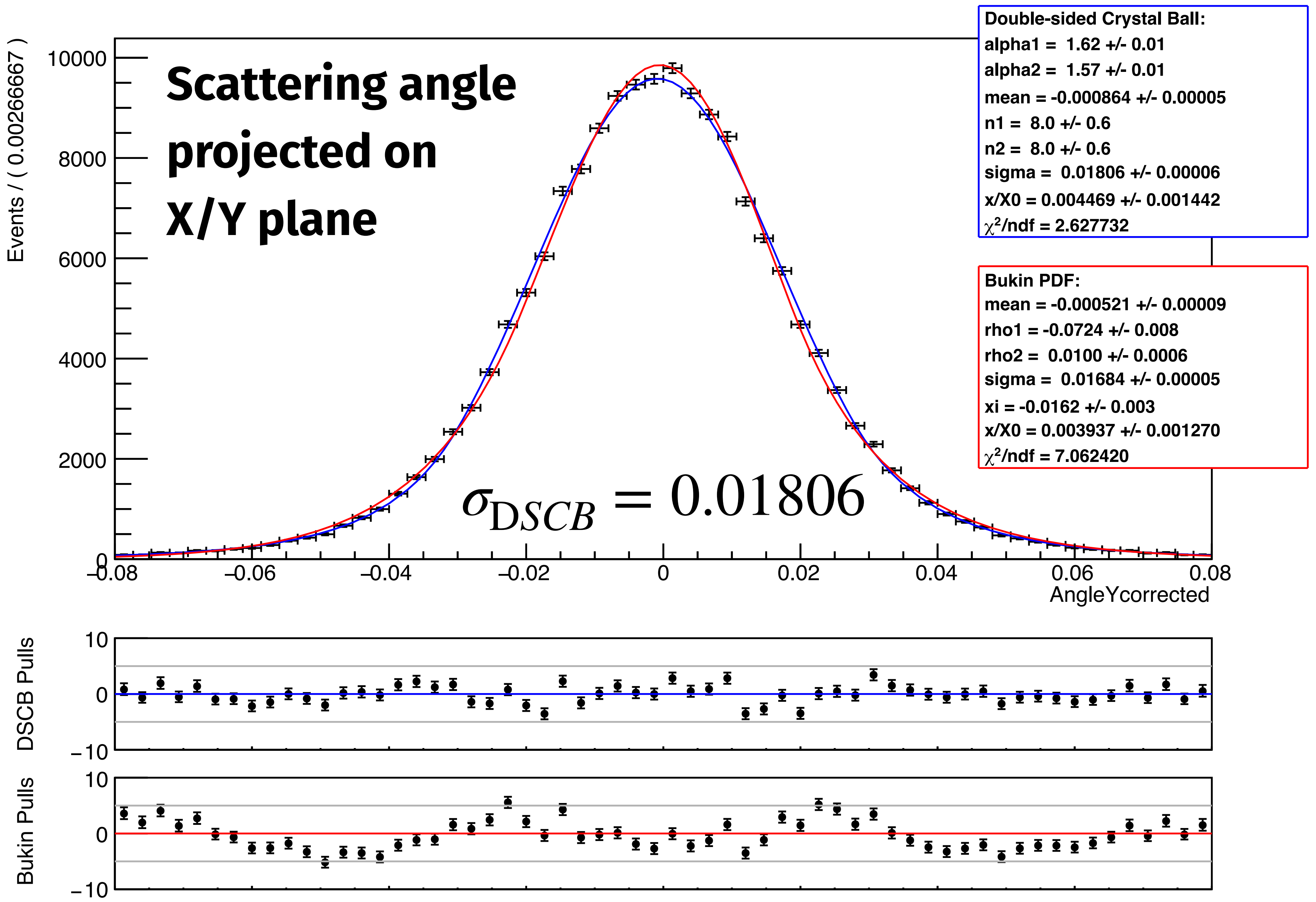


Multiple scattering of low-energy particles

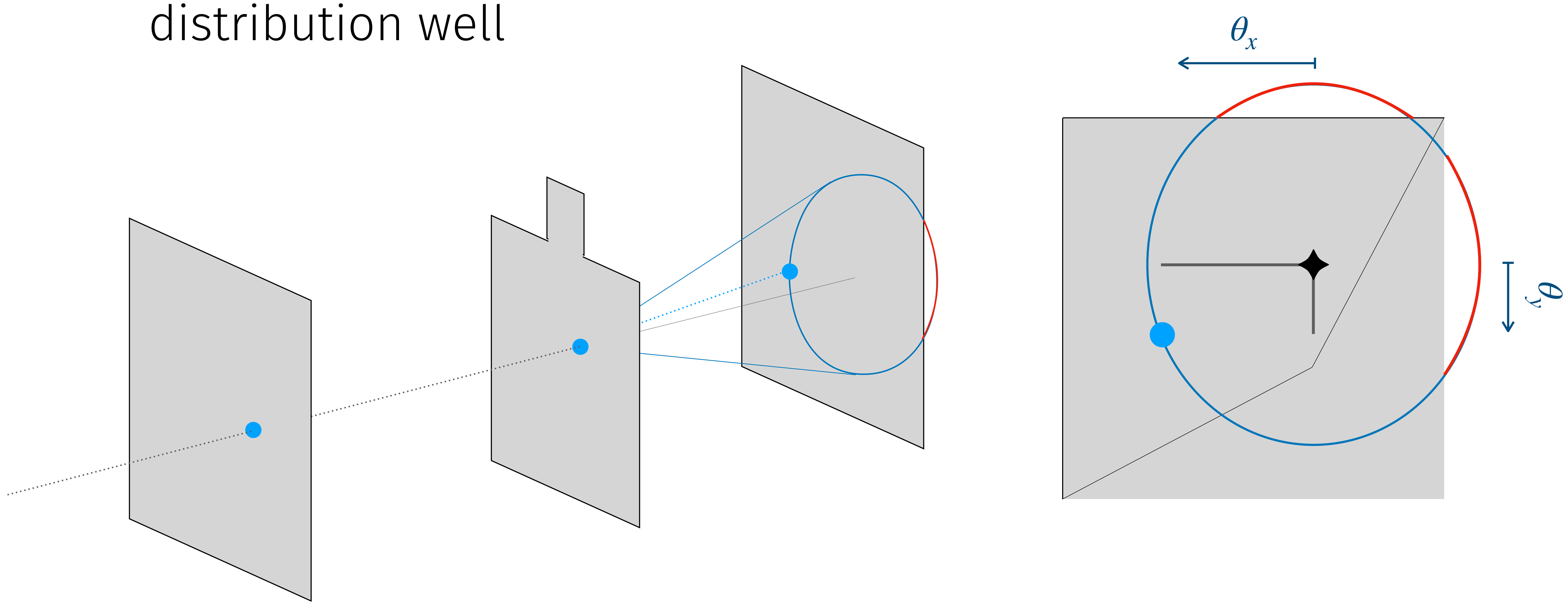
- Molière theory gives a precise description of multiple small-angle scatters in materials at low energy
  - Highland et. al. produced a simplified "gaussian fit" for the projected scattering angle distribution. Lynch & Dahl's refinement is the generally accepted modern approximation used (see PDG)

$$\theta^{\mathrm{rms}}_{\mathrm{plane}} = \frac{13.6\,\mathrm{MeV}}{\beta c p} z^2 \sqrt{x/X_0}\,\left(1 + 0.038\ln(x/X_0)\right)$$

- MS is gaussian with "single-hard-scatter" Rutherford tail ($\sim \theta^{-4}$)
  - A double-sided crystal ball (DSCB) fits the projected angle distribution well



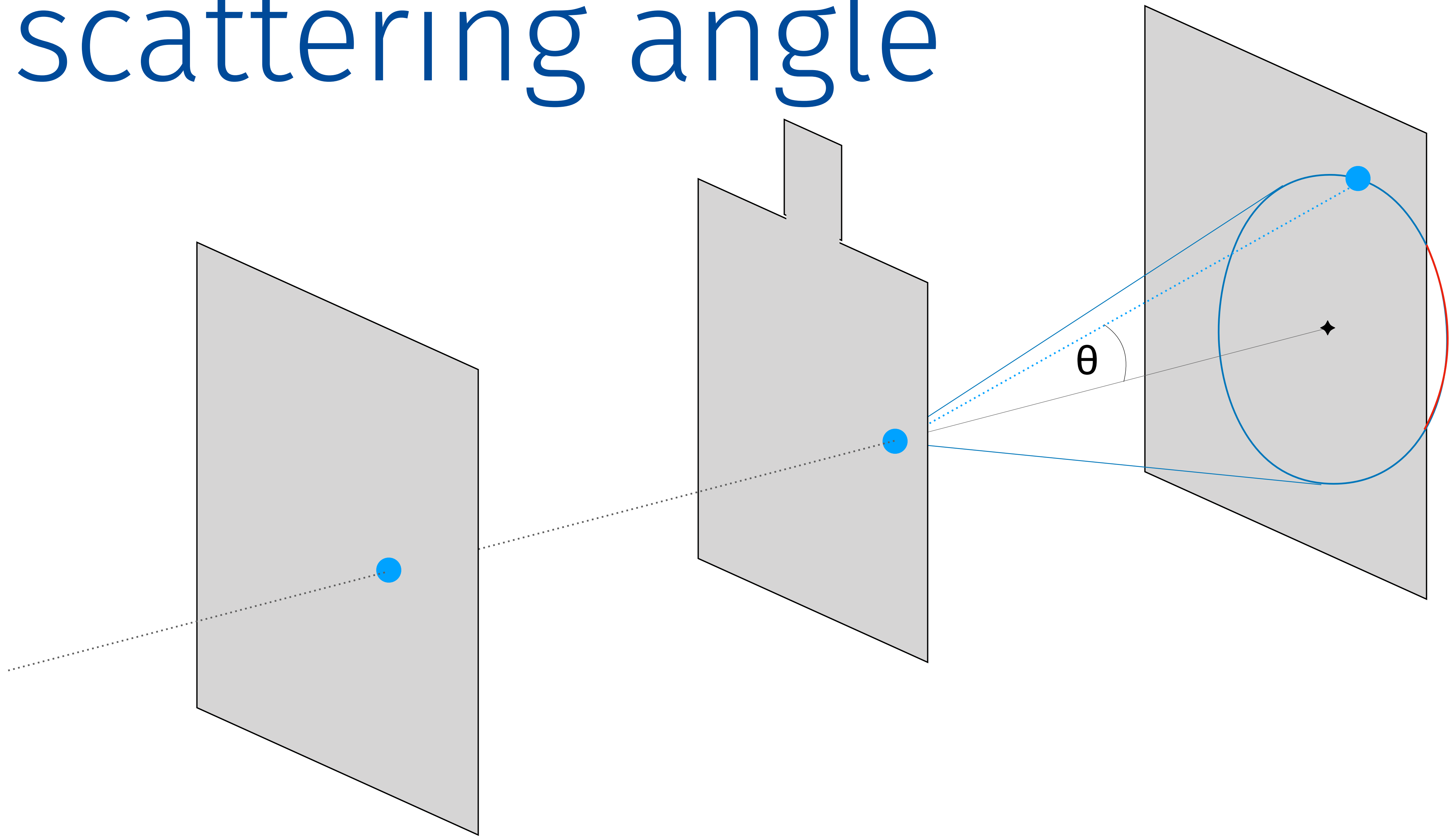
**Data from (yet to be published) CMS measurement*



The idea: measure the scattering angle of an active pixel plane within a telescope, using at least two other planes

Another approach: global scattering angle

- There is more data we can use - the phi-symmetric "global" scattering angle
- Some questionable assumptions and "hacking" of statistical distributions give a surprisingly good fit to global angle data
- Benefit (in CMS measurement): non-directionality - resistant to boundary effects



Aside: Deriving the global angle fit

Let us assume θ_x, θ_y are independent ~gaussian random variables, and $\theta^2 \approx \theta_x^2 + \theta_y^2$ (small angles)

$$\theta_x \sim \sigma \cdot \mathcal{N}(0,1)$$

$$\theta_x^2 \sim \sigma^2 \cdot \chi^2(1) = \sigma^2 \cdot \Gamma(\frac{1}{2},2) = \Gamma(\frac{1}{2},2\sigma^2)$$

$$\theta^2 \approx \theta_x^2 + \theta_y^2 \sim \Gamma(\gamma = 1, \beta = 2\sigma^2)$$

Now we can fit a gamma function to the square of the phi-symmetric "global" scattering angle in data

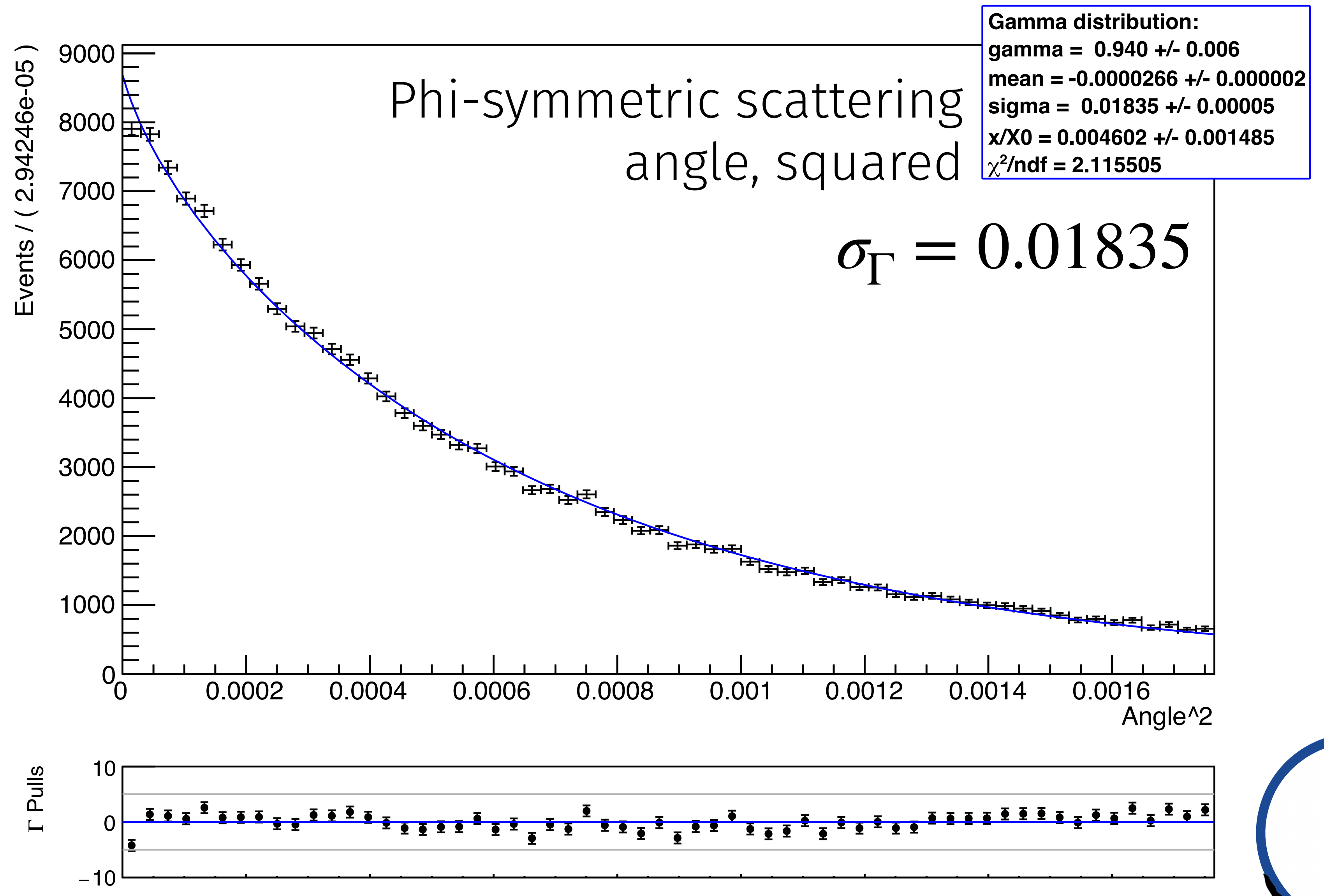
But θ_x , θ_y are not truly independent - can include this in fit by relaxing constraint on γ, but keeping the expectation value constant

$$\mathrm{E}\left[\Gamma(\gamma,\beta)\right] = \gamma \cdot \beta$$

$$\mathrm{E}\left[\Gamma(1,2\sigma^2)\right] = 2\sigma^2$$

$$\mathrm{E}\left[\Gamma(\gamma,2\sigma^2/\gamma)\right] = 2\sigma^2$$

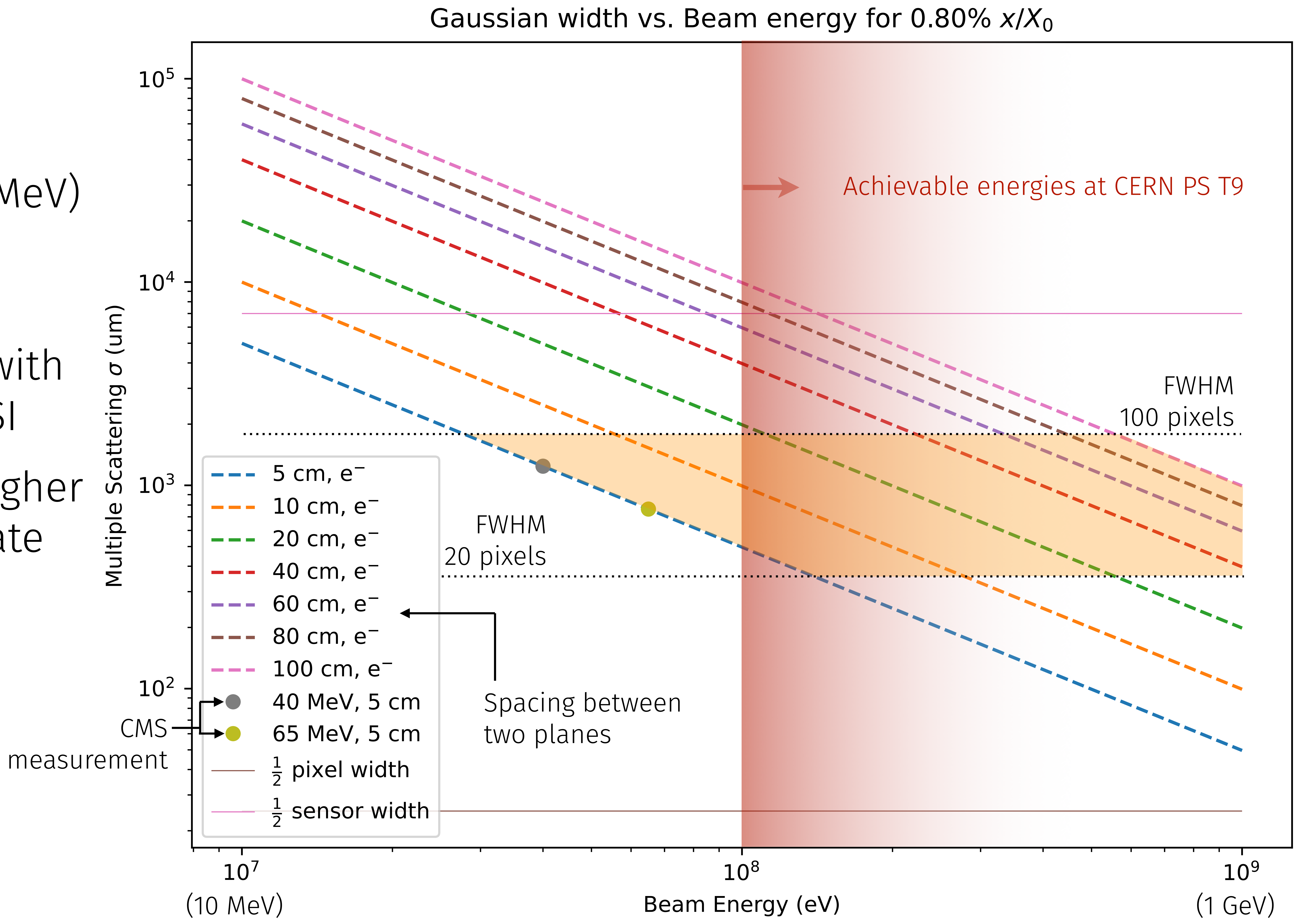
$$(\text{let } \gamma \in [0.5,1])$$



*Data from (yet to be published) CMS measurement

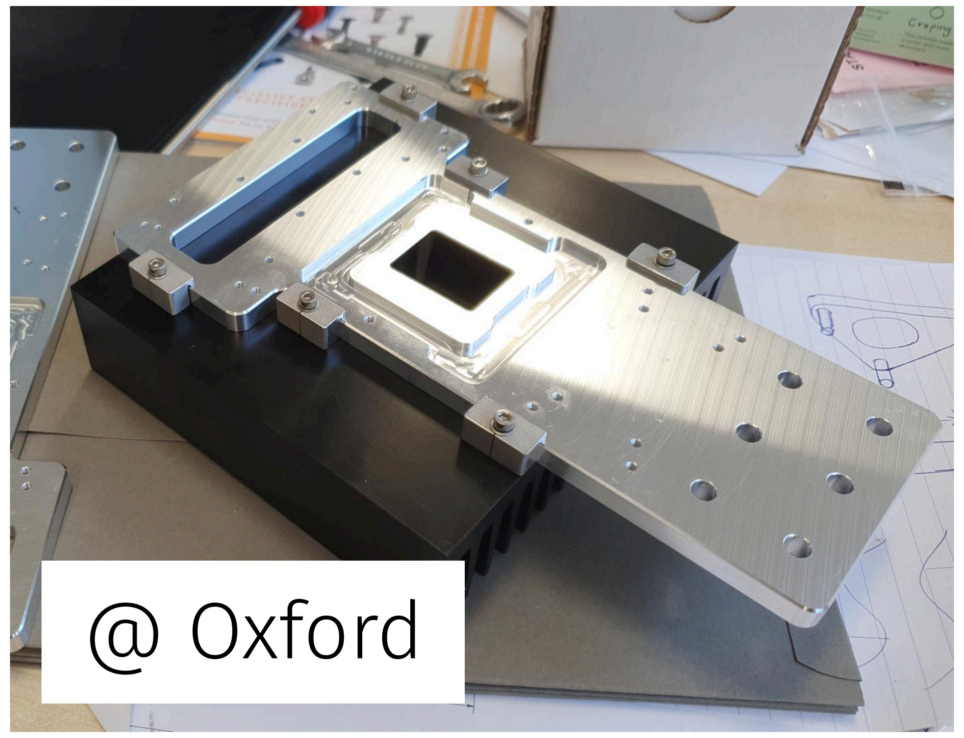
Suitable beams

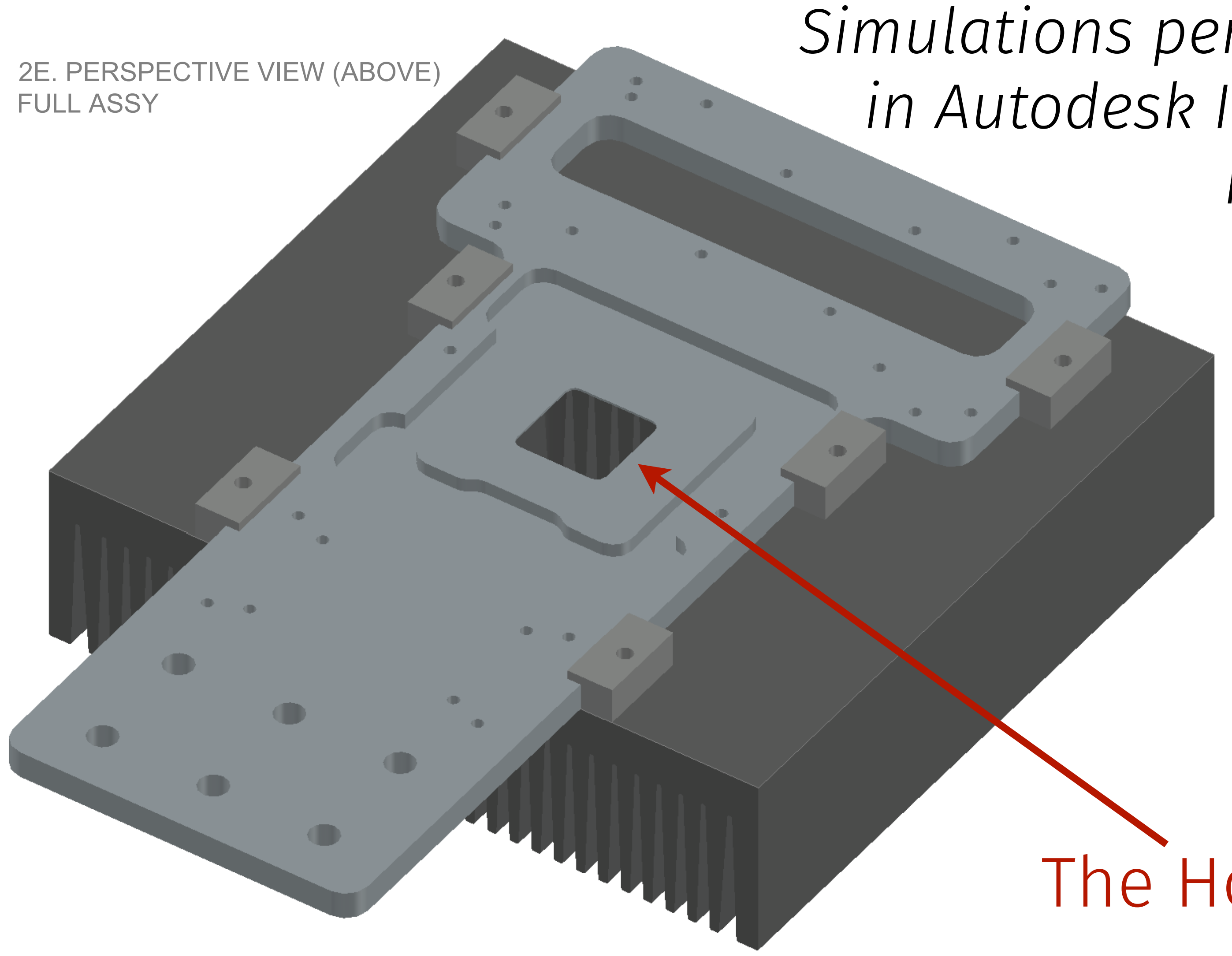
- The measurement is only viable at a relatively low energy range - O(10-1000 MeV) for “moderate” telescope lengths
- CMS measurement done with 40-65 MeV positrons at PSI
- CERN beamlines are all higher energy, but can compensate with longer telescope to “exaggerate” scattering
- We are also sensitive to the purity of the beam (targeting e-), and the width of the momentum band



Thermal Considerations

- An ITkPix quad outputs up to 12W of power as heat, but temperature should stay < 40°C
- We designed mechanics for the quad based on one used by the ITkPix testbeam group, which has been manufactured by the Oxford mechanical workshop (many thanks!)
- FEA simulations show viability for 20×20 and 30×30 mm holes
- Fall-back solution with Peltier elements under consideration





Simulations performed in Autodesk Inventor Nastran