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pCT feasibility studies

simulation suit and first results

Introduction

We want a software toolkit able to perform feasibility studies with:

- A CMOS based tracker ⟶ to identify tracks pathway along a phantom
- A Scintillator detector ⟶ to associate a reconstructed energy to each trajectory.

General idea:

- Describe a 'flexible' geometry in GEANT4.
- Process the energy deposits in each sub-detector (CMOS/SciDet) independently to add detector related effects.
- Provide a 'flexible' event generator.
- Store the output in a handy way.
- Do some analysis.

Where are we now?

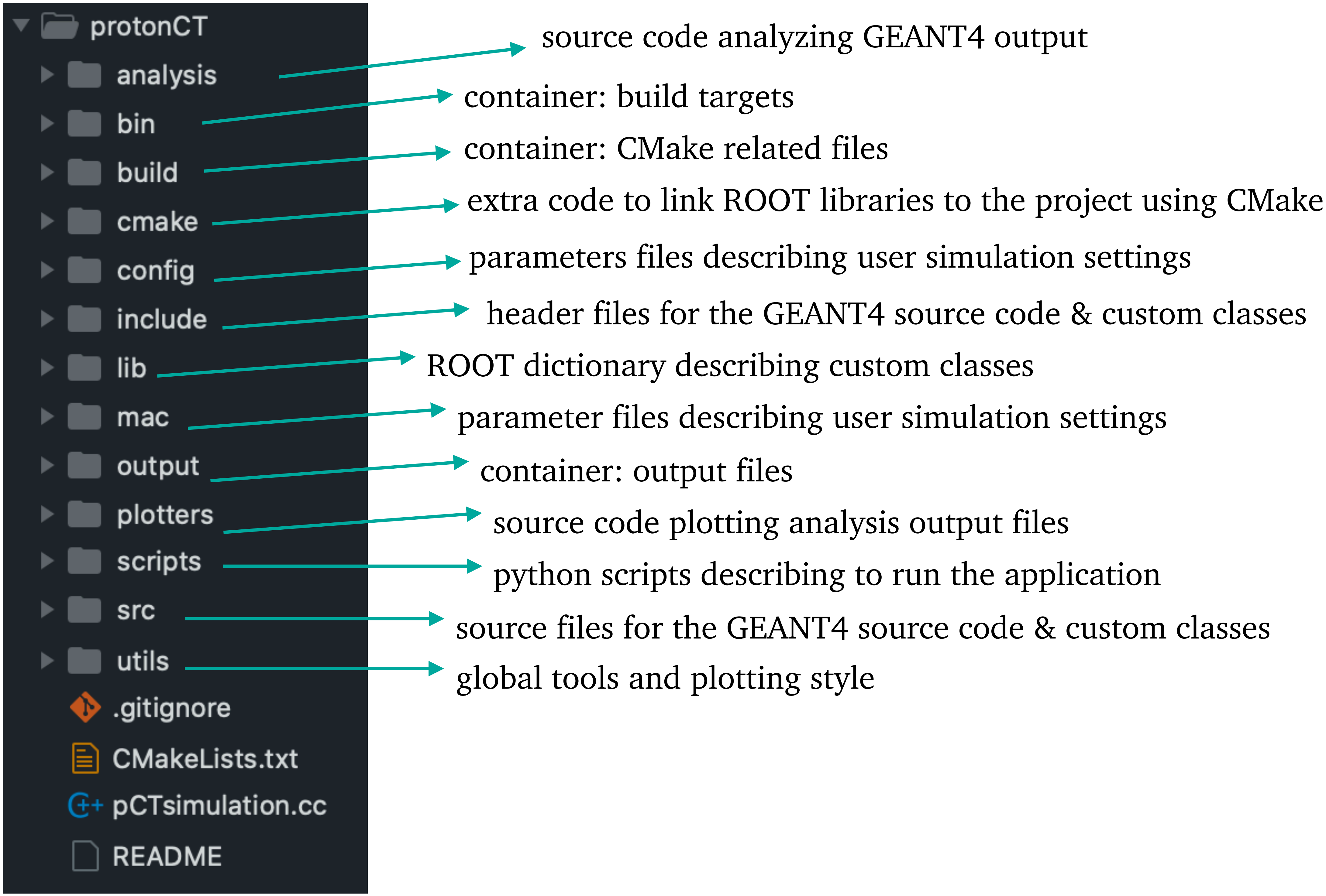
Framework Overview

Institut de Física d'Altes Energies

EXCELENCIA SEVERO OCHOA

Barcelona Institute of Science and Technology

The repo: https://github.com/granadomarc/protonCT



Geometry

CMOS:

As it is now (default), the tracker consists on:

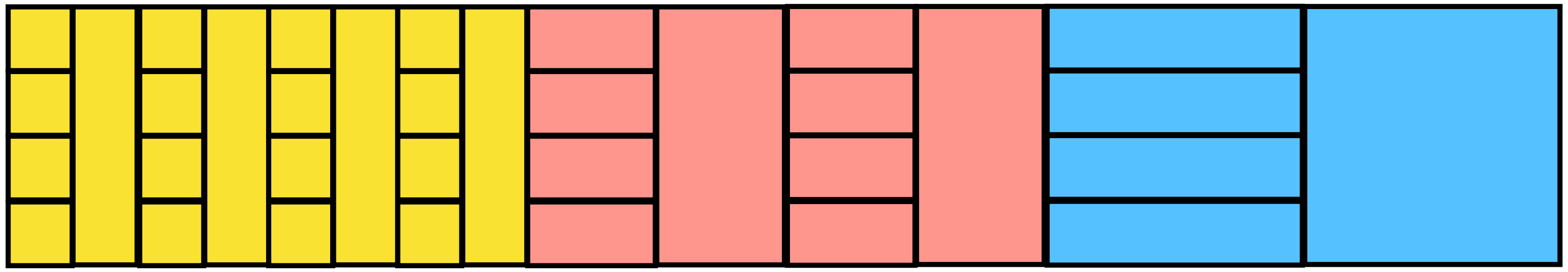
- 3 tracker planes of 448x 224 pixels of $40\mu m$ x $36\mu m$.
  Each plane is sub-divided in two layers of different thickness (the CMOS sensitive layer $25\mu m$ + substrate $75\mu m$).
  In total ~0.1mm of Silicon along beam direction.

SciDet:

As it is now (default), the Scintillator Detector consists on:

- 10 bars per layer, 200 layers. Each layer is $30x30mm^2$. Even (odd) layers are read in XZ (YZ).
  Each bar thickness is set to be 3mm (default is squared bars).
- The constructor allows placing several Scintillator Detector of different thicknesses very easily.

Namely, thing like this:



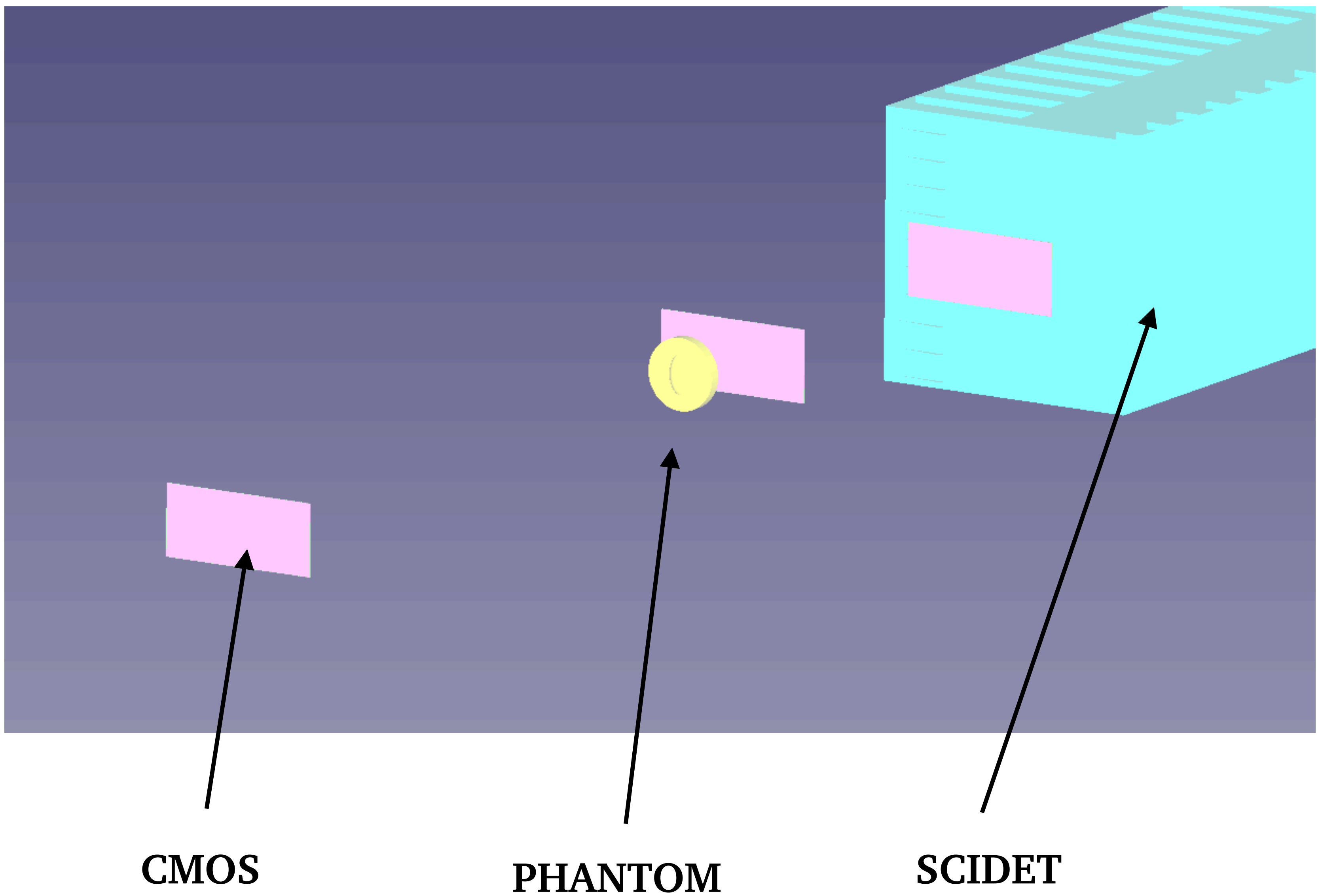
- Each bar has two volumes, an inner core, and an external shell of variable thickness to study coating related effects.

Geometry

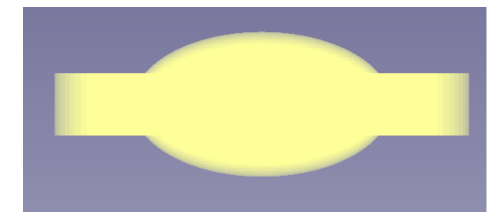
Phantom:

Currently there is a test phantom between the first 2 tracker layers. We can describe any shapes we want.

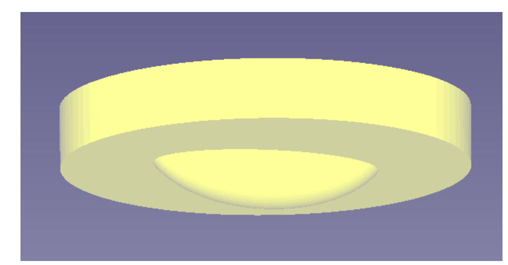
Overall geometry:



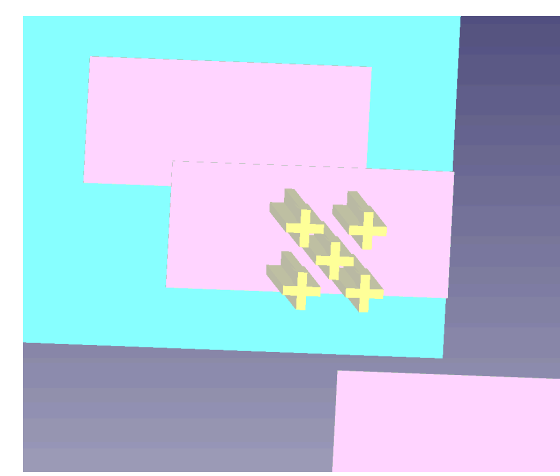
PHANTOM TOP VIEW



PHANTOM TOP VIEW + ROTATION



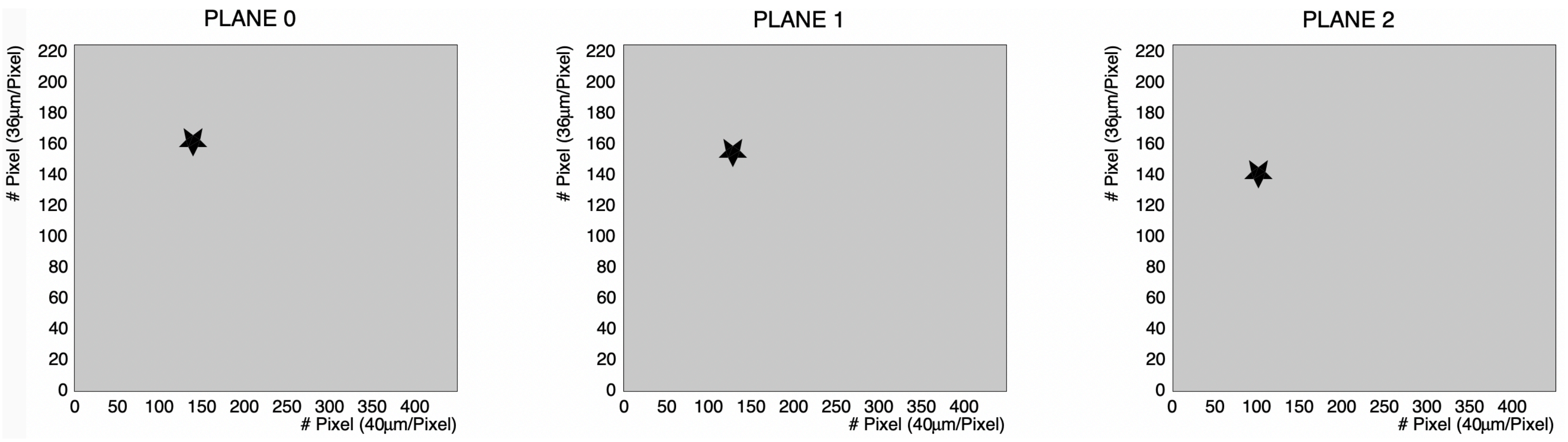
CROSSES PHATOM

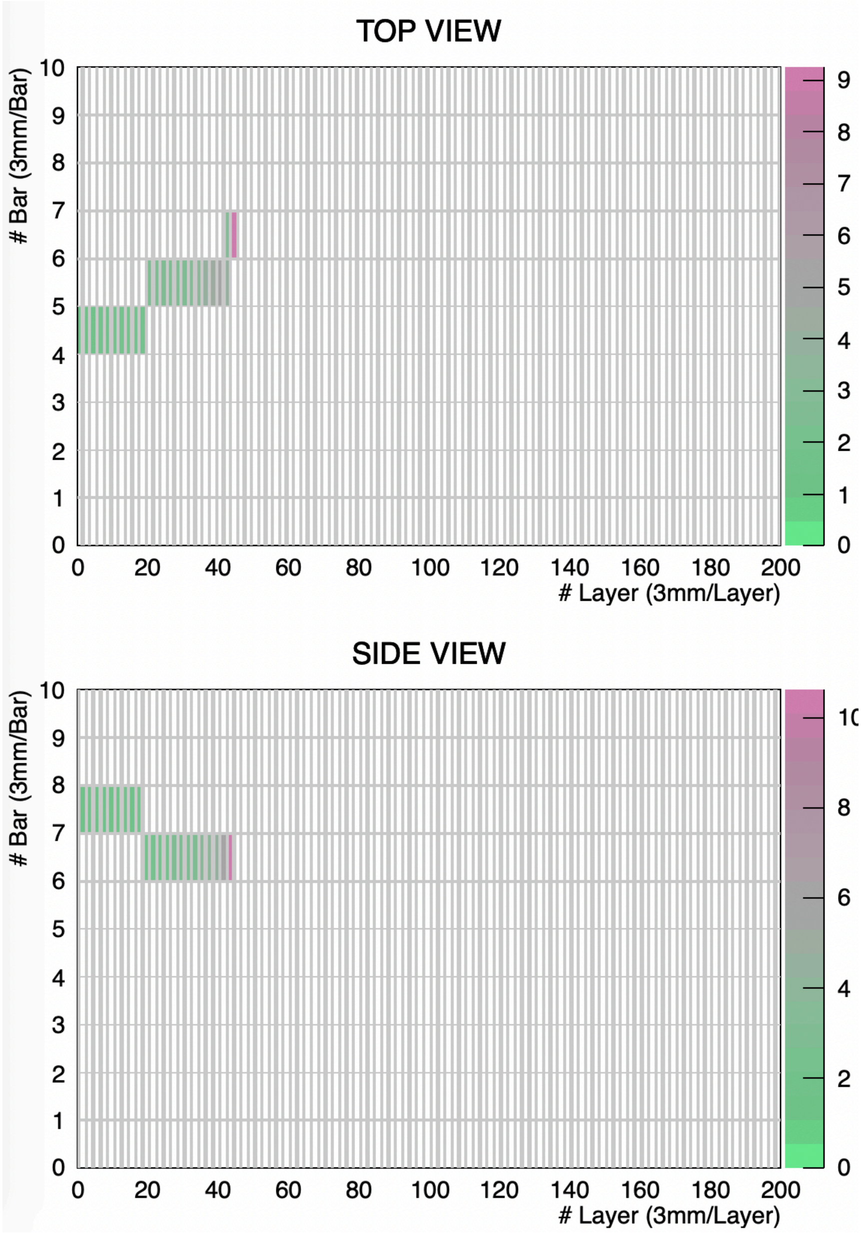


Event Displays

While working with a new detector event displays can help to identify bugs/problems unexpected behaviour and get a feeling on the physics we measure.

The /analysis folder includes a templateAna in which an interactive event display allows to see event by event data.





the pixels are actually so small that a bigger star is placed on top of the fired pixels.

The GEANT4 output

The output contains:

- The configuration parameters used for the simulation (layers, pixels, pitch, distances…)
- A complete map of <plane, CMOS hits>.
- A complete map of <bar, SciDet hits>. Each SciDet hit contains trackID info of all contrubutors to its edep.
- A map of <true trackID, true track kinetic energy>.

In the future we can include

- Information about the phantom
- trackID info of all contributors to the edep in each pixel.

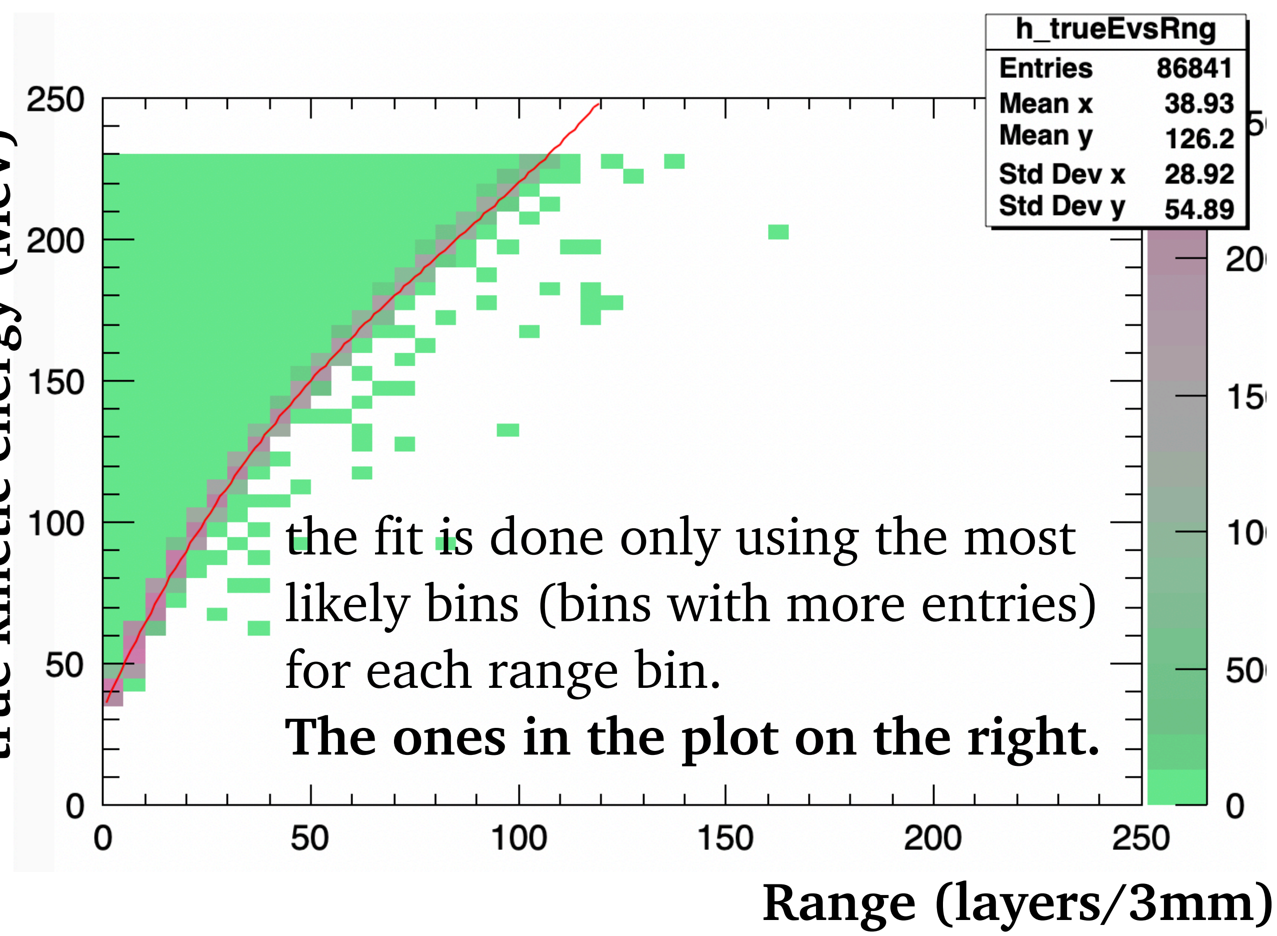
SciDet analysis

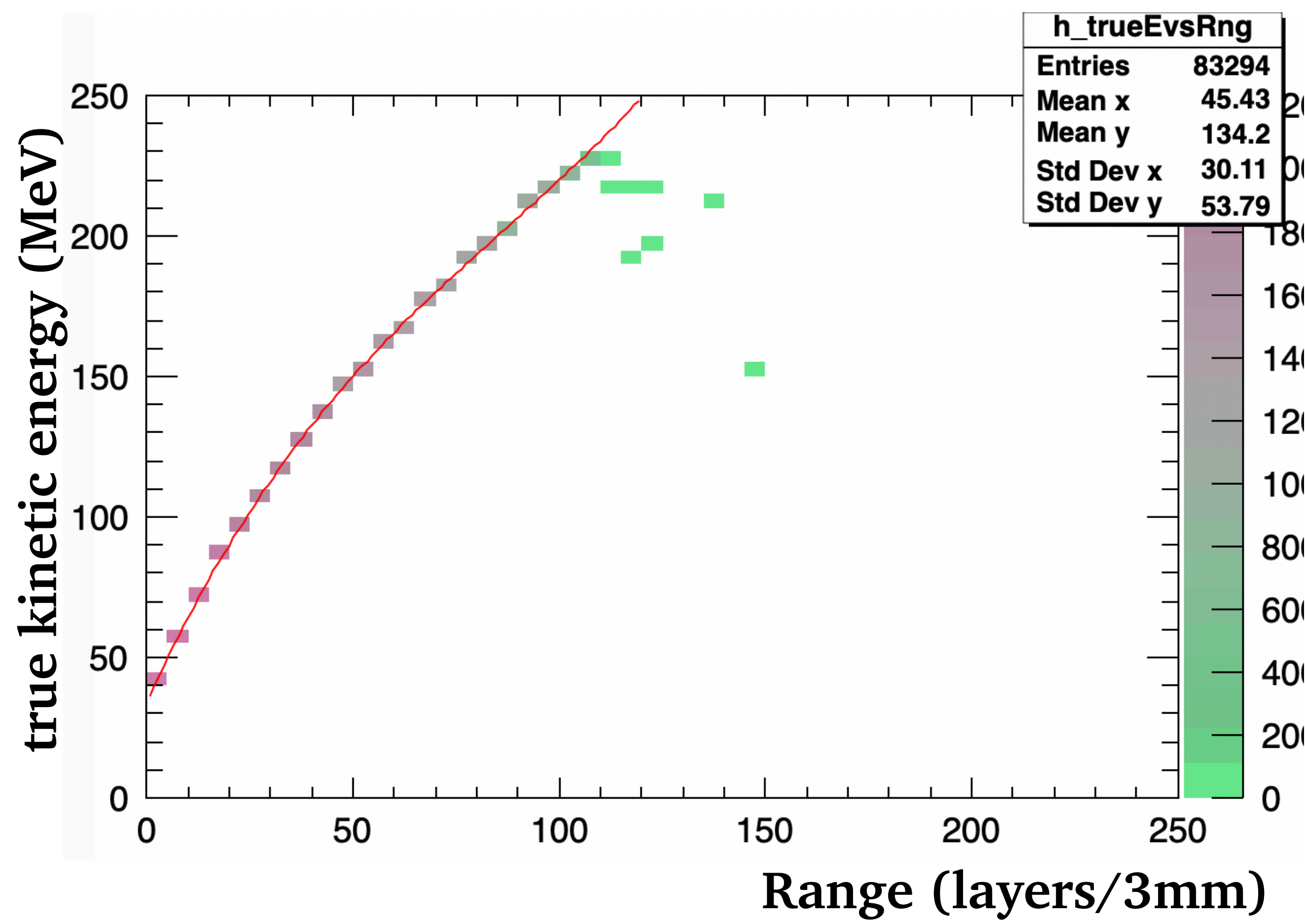
Idea:

- Study the reconstructed energy resolutions using different methods.

Steps:

A) compute a relation between true energy and a reconstructed measurable amount





This can be done in the same way using the measured light (SciDet as calorimeter).

Range computation and 3D tracking algorithm:

- For each set of 2 layers, build a XYZ point. (X,?,Z) + (?,Y,Z+1) —> (X,Y,Z+0.5).

Can be expanded to be used together with tracker to build N separated 3D tracks

We can compute the range in many ways either as:

- $Z_{fin} - Z_{ini}$ (good assuming high straightness, not true for low energy)

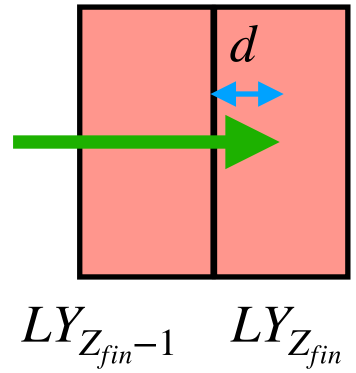
using this one so far

- $\textbf{EuclidianDist}(XYZ_{ini}, XYZ_{fin})$ (good for straight tracks not perpendicular to SciDet layers)

- $\sum_i \textbf{EuclidianDist}(XYZ_i, XYZ_{i+1})$ (good even for not straight tracks)

Idea to have better resolution that that of barWidth/sqrt(12): (to be checked)

- $\sum_i \textbf{EuclidianDist}(XYZ_i, XYZ_{i+1}) + \textbf{RngCorr}(LY_{Z_{fin}-1}, LY_{Z_{fin}})$



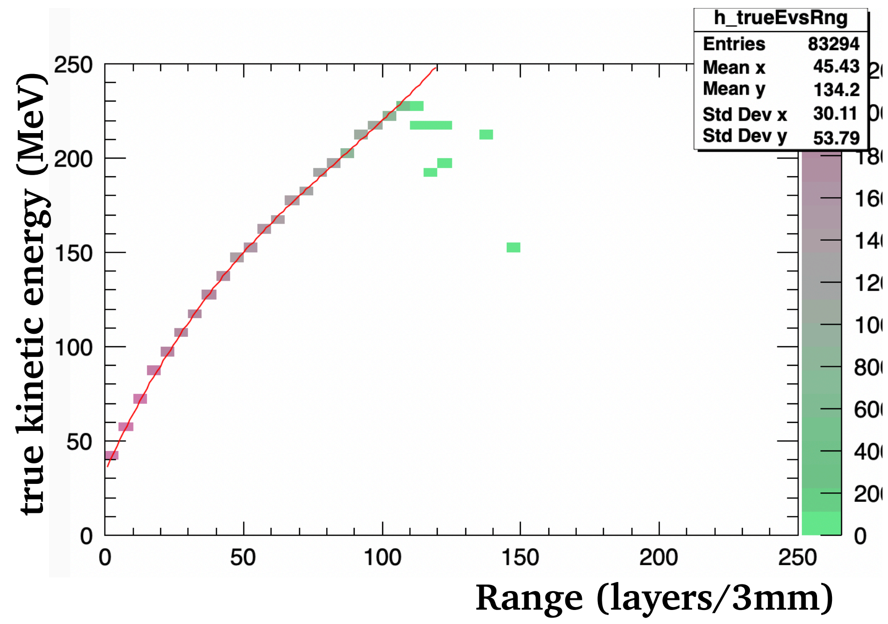
Use light yield (LY) in last 2 layers to extract distance d

We may not have all the LY info for al channels to reduce data flow

Out of the different range definitions we can define proton straightness:

$$\textbf{EuclidianDist}(XYZ_{ini}, XYZ_{fin}) / \sum_i \textbf{EuclidianDist}(XYZ_i, XYZ_{i+1})$$

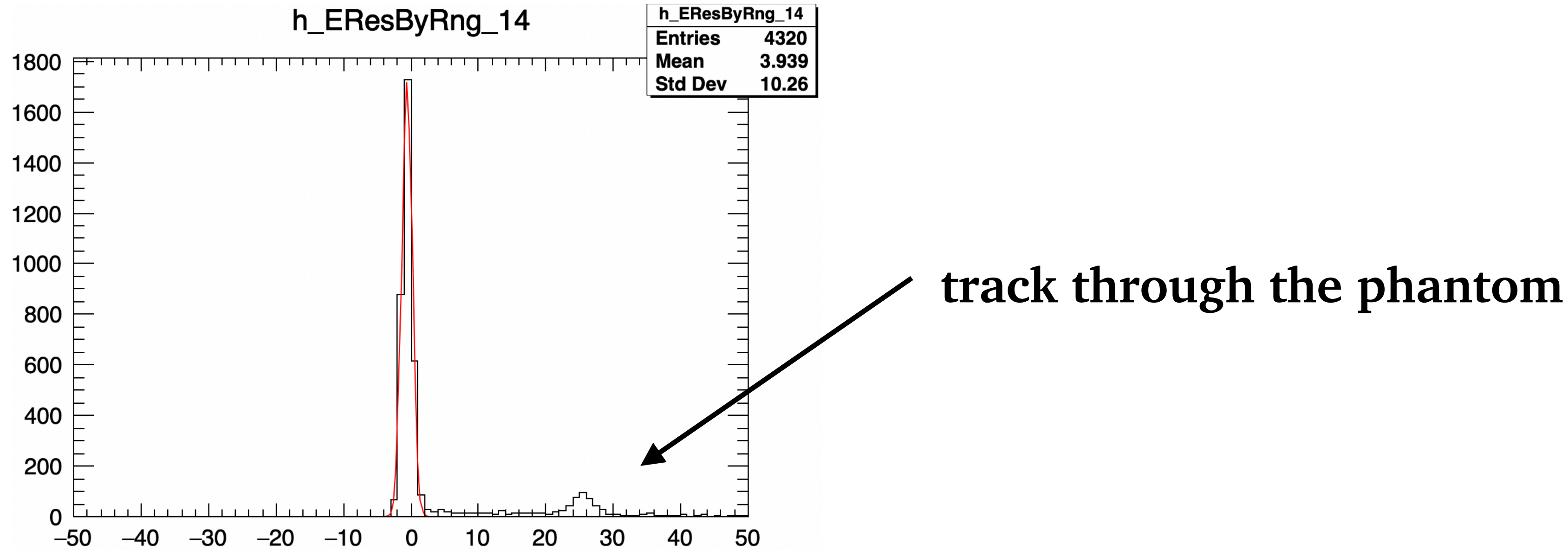
First SciDet analysis



Steps:

B) For each measured value, use the fit to compute the reconstructed energy.
Then we compute how much is the distance from the true and the reco as $E_{resolution} = 100 * \frac{E_{true} - E_{reco}}{E_{true}}$

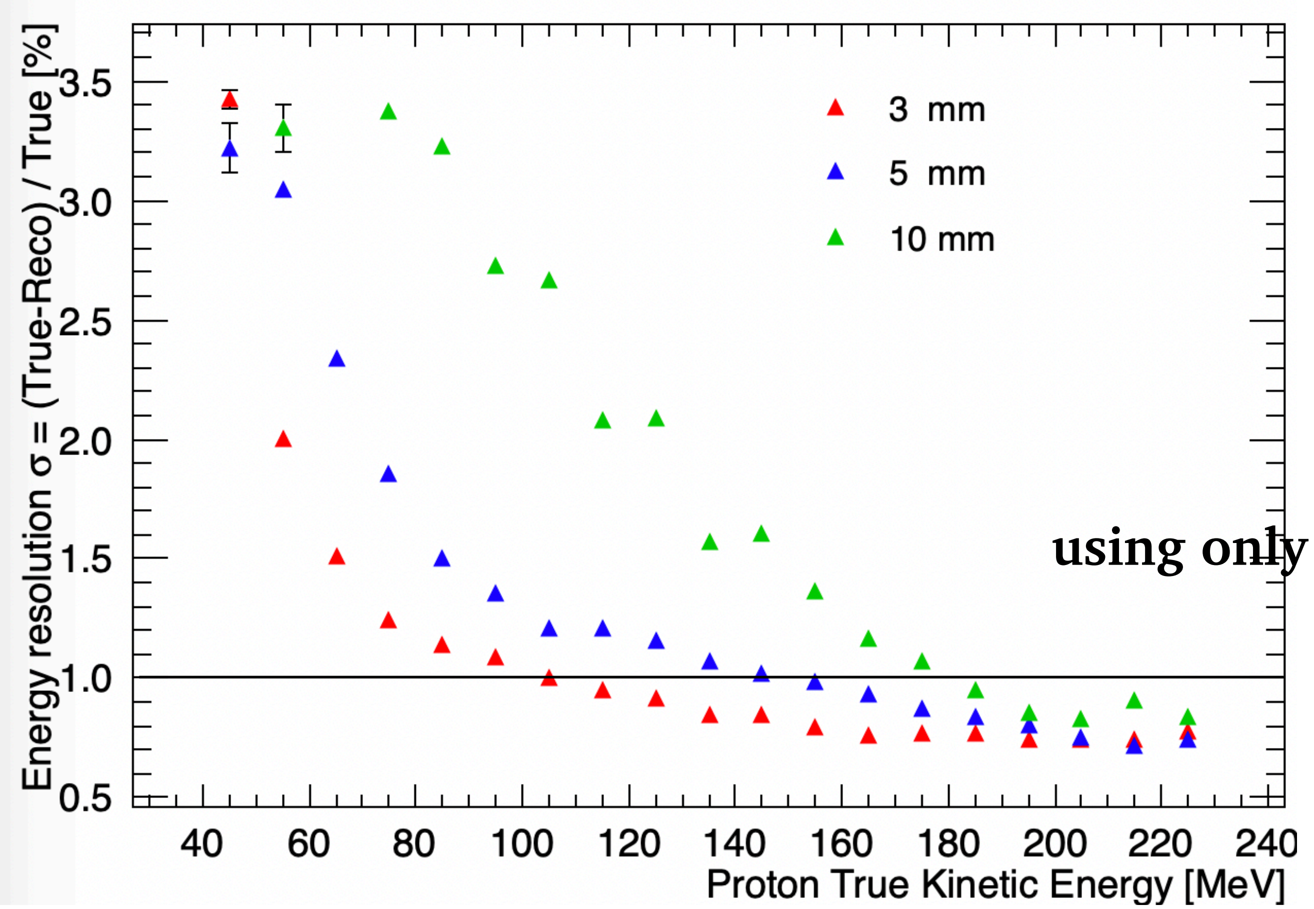
C) define bins of true kinetic energy (I am using 25MeV). For each bin, fill a histogram with $E_{resolution}$



First SciDet analysis

D) Fit a gaussian to each histogram, and extract the sigma, $\sigma_{E_{resolution}}$.

$\sigma_{E_{resolution}}$



using only SciDet (no phantom)

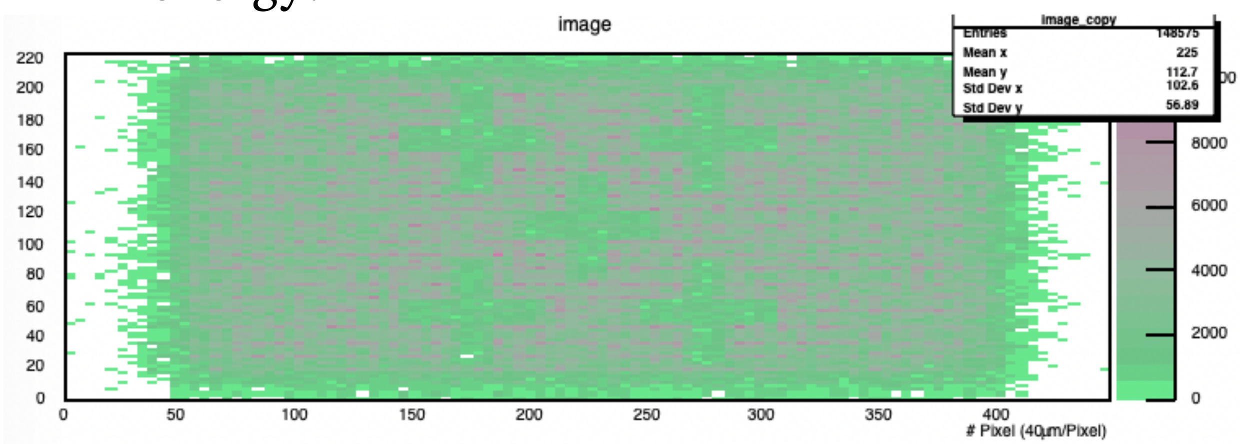
true initial kinetic energy

Phantom 'Imaging'

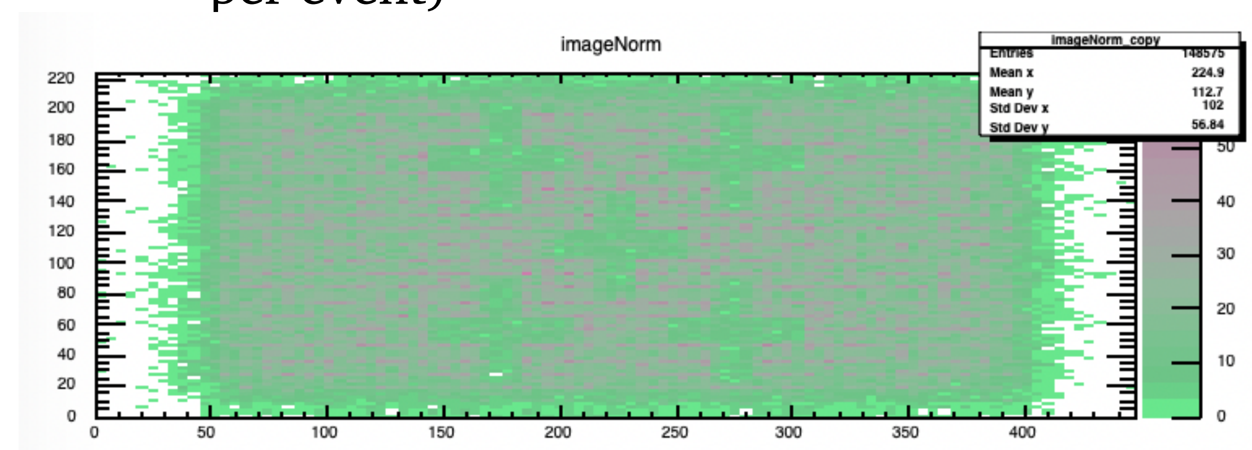
E) Since we have a method (preliminary, but just to show the whole working chaing) to assocaite to each proton a reco energy, **we can produce some phantom imaging**!

Example made with 180 MeV protons and 'only' 100k events and 10k 'effective' pixels.

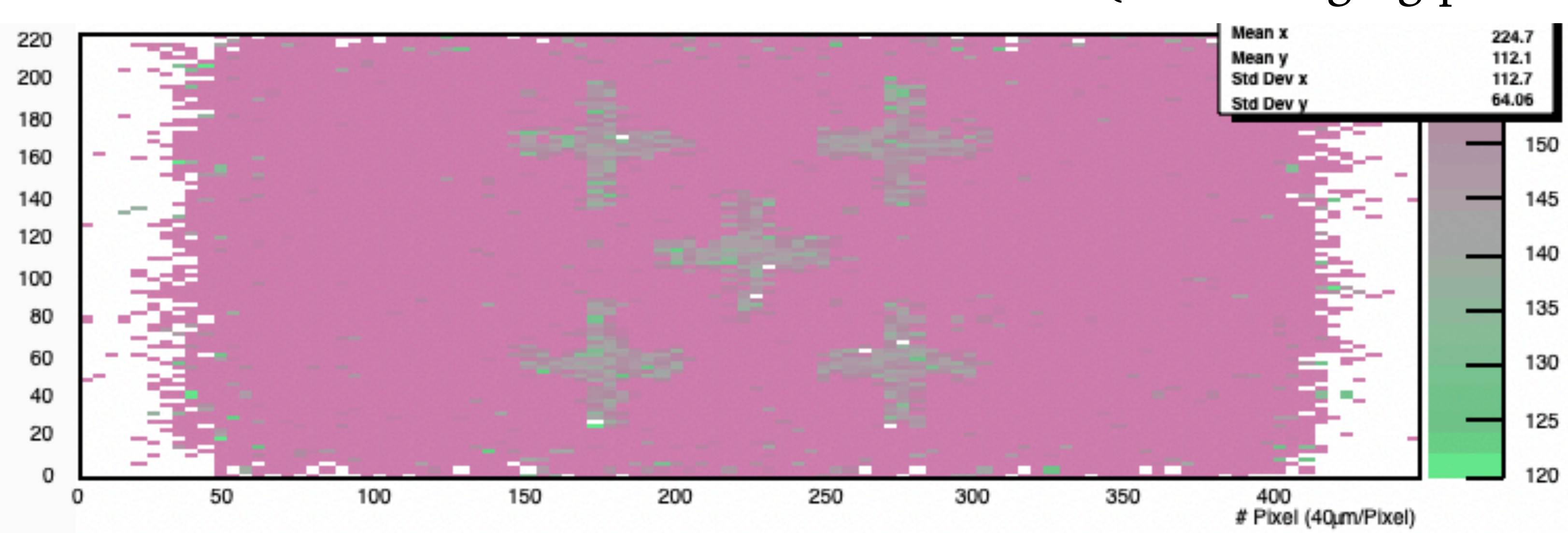
1) First plane tracker X and Y, filling histogram with reco energy:

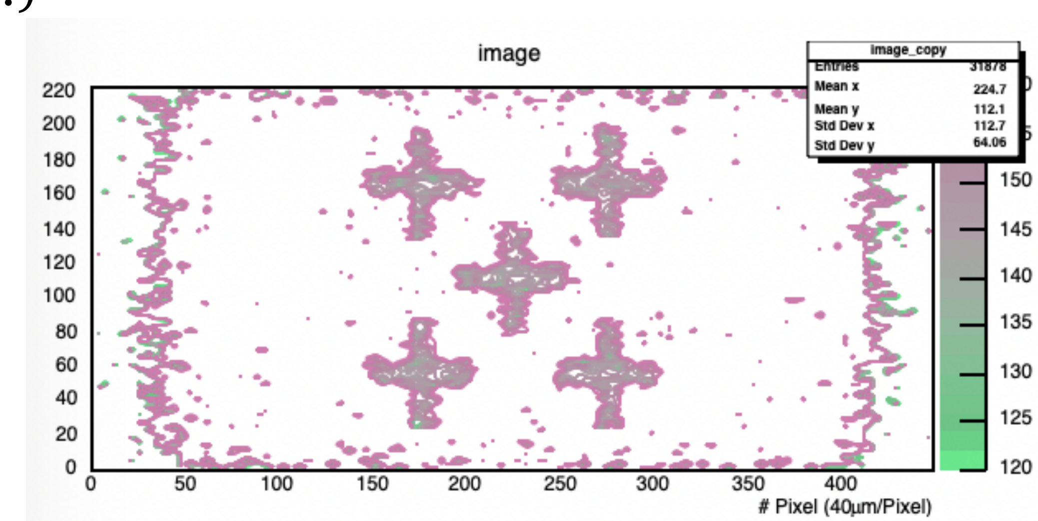


2) First plane tracker X and Y, filling histogram with counts (1 per event)



3) Divide 1 and 2 to get mean momentum in each bin (I am merging pixels…)

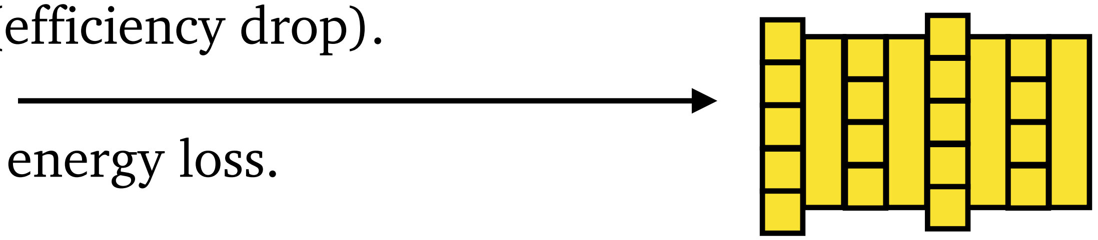




Next Steps

The whole chain is ready for massive analysis.

- Study best way to reconstruct the energy.
  - Different ways to measure the range
  - Range corrections
  - Range vs Calorimetry.
- Study energy resolution vs bar thickness.
  - Including multi-thickness approaches.
- Study role of bar coating. Microns can account for substantial volume percentage of the detector.
  - Track holes (efficiency drop).
  - Layers shift.
  - Calorimetric energy loss.



- Tracking analysis. Study track separation for more than 1 proton. (we need to optimize plane - SciDet distance).
- Efficiency analysis. If we apply some cuts, how much events do we loss (does some extra cuts improving the resolution are worth it?)
  - How many protons do not cross all CMOS planes
  - How many protons are not contained in the detector FV
  - How many times we find track holes.
  - Efficiency vs straightness and resolution vs straightness…