Studies of angular effects in recombination in ICARUS data

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1. Aim

- Provide test of **angular dependence of recombination effect** in ICARUS data.
- Follow and compare to the paper from ArgoNeuT: arXiv:1306.1712

important note for discussion: data selection method can remove the angular effect

2. Reconstruction: the same for MC and data

3. Calculation procedure

4. Results for protons and pions. (muon sample can be later)

Data

- protons and pions from secondary interactions in CNGS events

Simulation-FLUKA

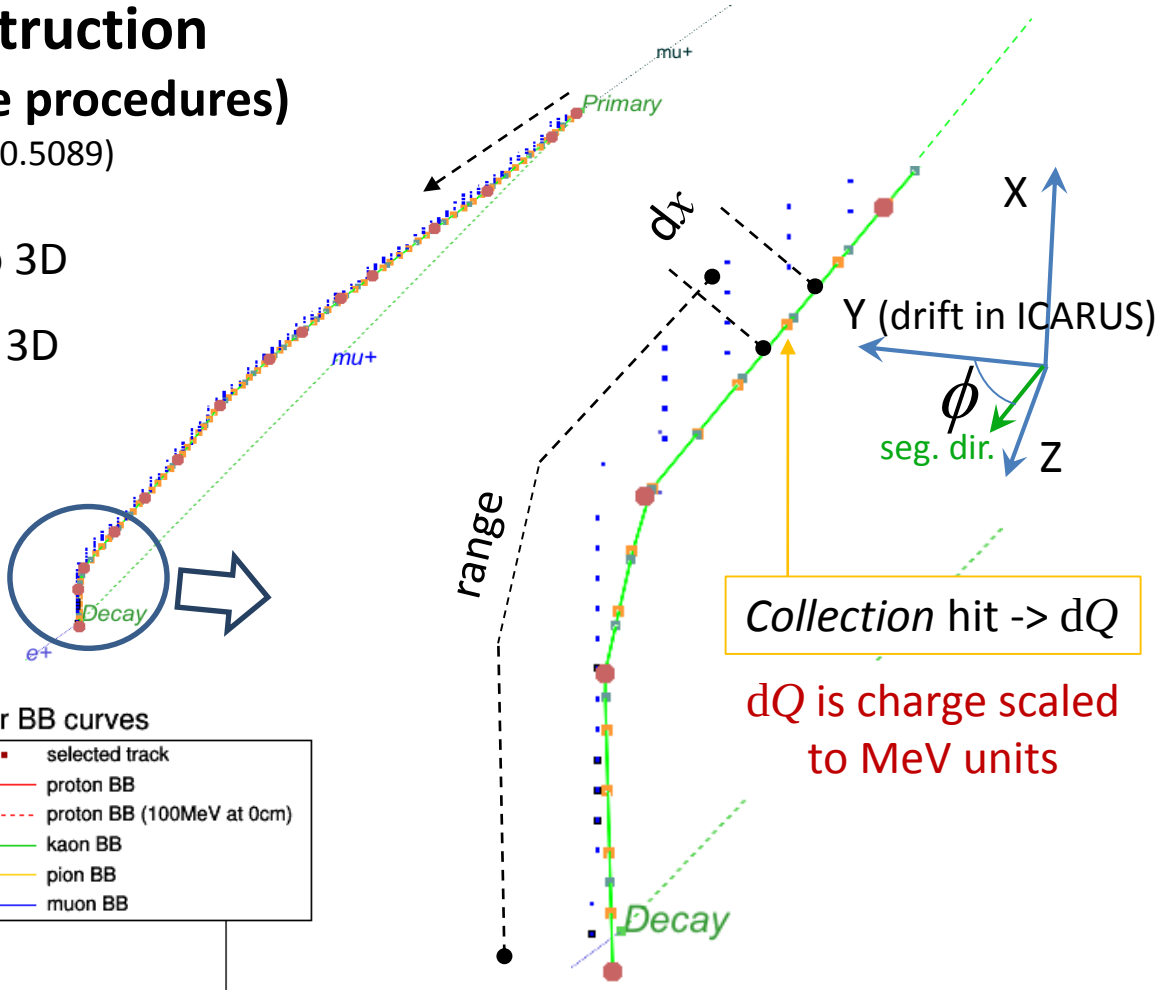
- isotropic initial directions, E_k corresponding to ~40cm range
- no decay products simulated for pions (stop point not confused)
- selected stopping protons (not reinteracting)
- FULL detector simulation (projection, electronics, noise)

Simulated tracks – reconstruction

(apply to data exactly the same procedures)

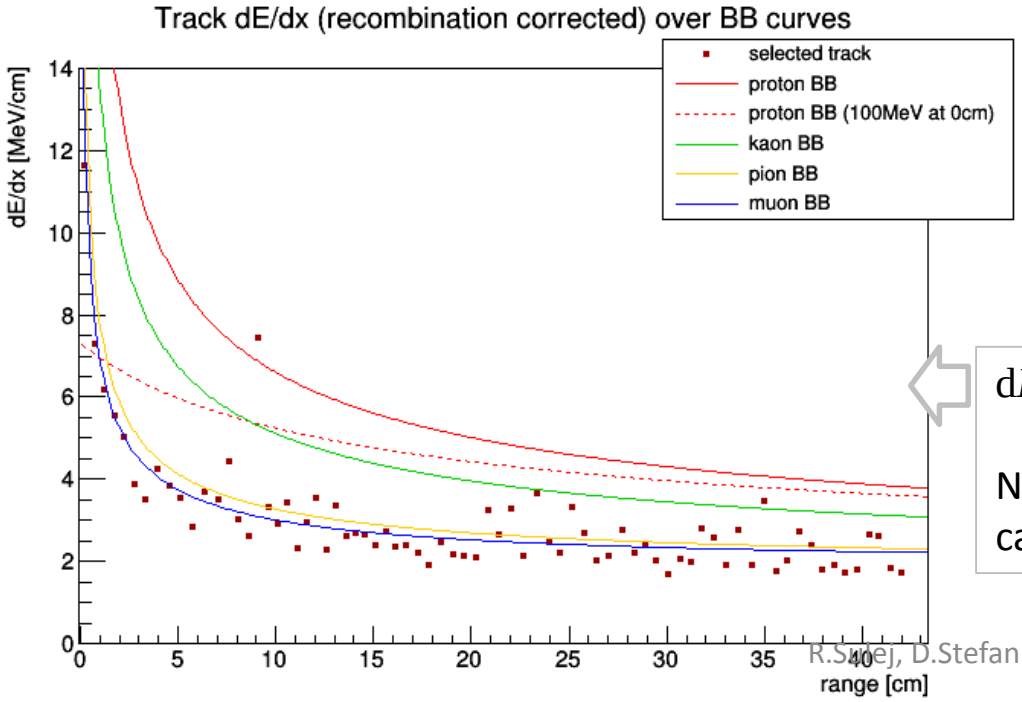
2D->3D and calo as in AHEP paper (arXiv:1210.5089)

- *Collection* hit projected to 3D
- *Induction* hit projected to 3D
- MC cell 3x3x3mm
- PLA node
- reco track



Collection hit -> dQ

dQ is charge scaled to MeV units



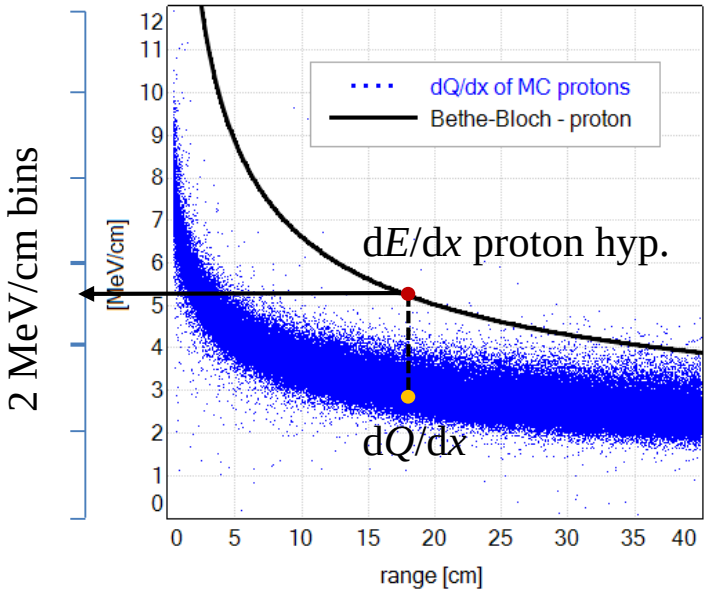
dE/dx here = dQ/dx corrected with Birks formula

Note: we use uncorrected dQ/dx values to calculate all **ratios on next slides**.

Calculations:

For each data point, on each track:

1. Take **[d*Q*/d*x*; *range*; ϕ]** data point.
2. Take **d*E*/d*x*** from proton Bethe-Bloch curve corresponding to ***range***.
3. Put ratio **d*Q*/d*x* / d*E*/d*x*** in the histogram for each 2 MeV/cm bins according to **d*E*/d*x***, for one of **ϕ bins**:
   - **90° – 70° (reference for the two below)**
   - **70° – 50°**
   - **50° – 30°**



Calculate mean value for each **d*Q*/d*x* / d*E*/d*x*** ratio bin, for each **ϕ bin**: reproduces recombination factor vs. hypothetical dE/dx at given angle w.r.t. drift direction.

Calculate **final result**: ratio between

- **<d*Q*/d*x* / d*E*/d*x*> at 70° – 50°** and the reference **<d*Q*/d*x* / d*E*/d*x*> at 90° – 70°**
- **<d*Q*/d*x* / d*E*/d*x*> at 50° – 30°** and the reference **<d*Q*/d*x* / d*E*/d*x*> at 90° – 70°**

Apply procedure to MC (no angular dep. in recombination) to quantify systematics due to reconstruction.

Apply procedure to data: is there any dependence or all the final ratios are flat at 1.0?

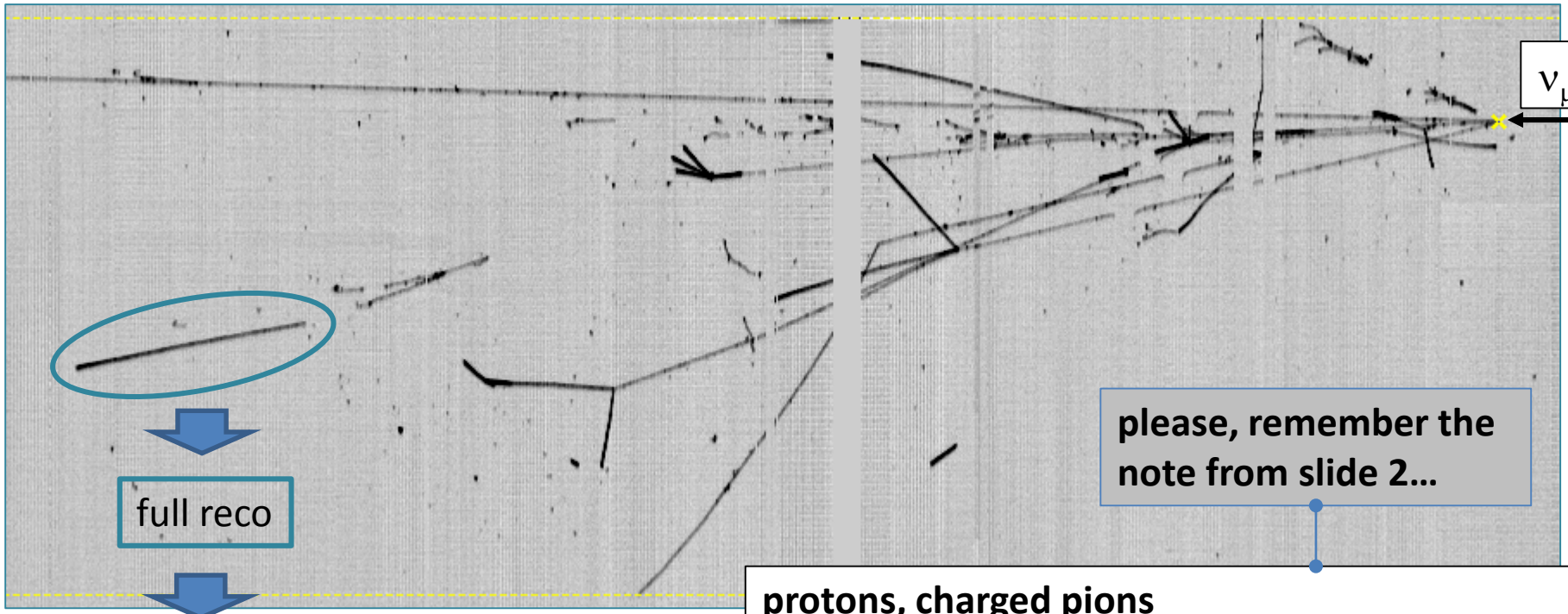
Last dE/dx points on the track:

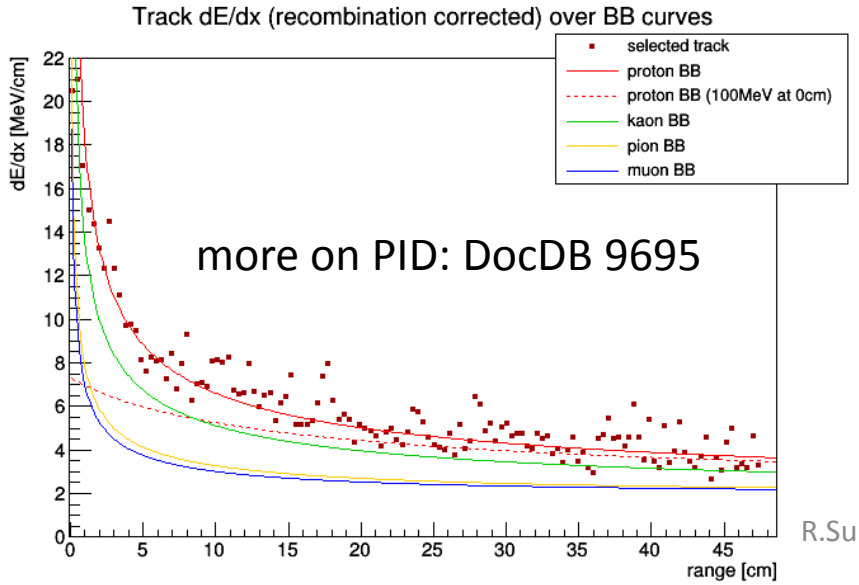
- near to the stop point, high ionization, **very steep** theoretical BB curve => any slight error in the residual range estimation has strong effect on $(dQ/dx)_{reco}/(dE/dx)_{BB}$
- sources of the *range* measurement error:
  - actual trajectory details may be not represented well if last 1-2 hits describe turning track – more likely for **pions/muons** which are lighter
  - **protons** may reinteract at small E_k instead of ranging out (this we can exclude in MC)
    - only neutrals produced, proton „dissapears"
    - secondaries short and visible only as increase of ionization
  - uncertainty due to ***not reaching*** or ***overshooting*** the last visible hit
- **for today** we decided not to correct the range from the 3D reconstruction algorithm (more explanation on slides later).

Overall systematic errors of *final ratios* based on MC reconstruction:
(plots on next slides)

- **protons: 1.0 ± 0.01**
- **pions: 1.0 ± 0.05**

Samples of protons, pions and muons in data





protons, charged pions

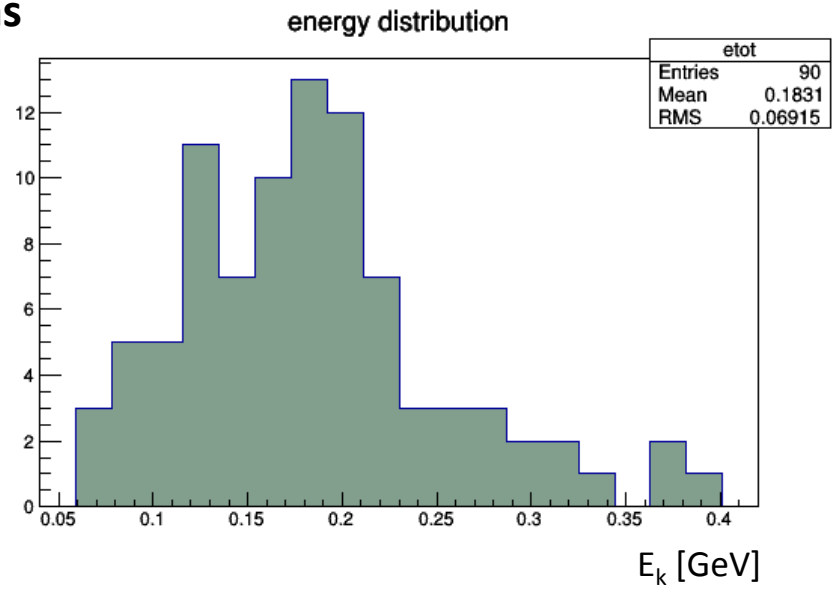
- from secondary interactions in CNGS events
- must match **stopping** p or π particle pattern
- thus PID is not confused between p and π
- μ's are ~not produced in sec. interactions

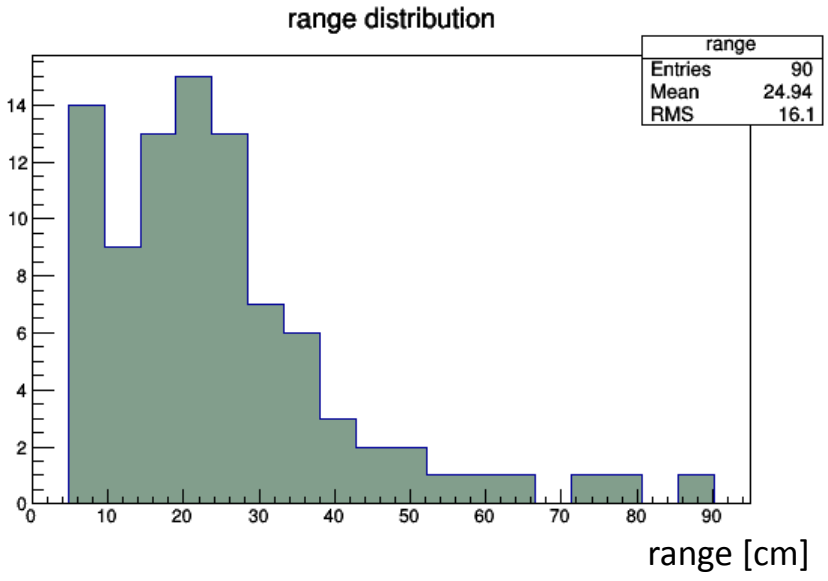
muons (not today, ϕ is 90-70° in 1k trks, 100trks 70-50°)

- from primary interactions in ν_μ CC events
- over 2.5m lenght with no inelastic scattering
- μ's are ~always stopping
- ~3% π cont. with the above conditions

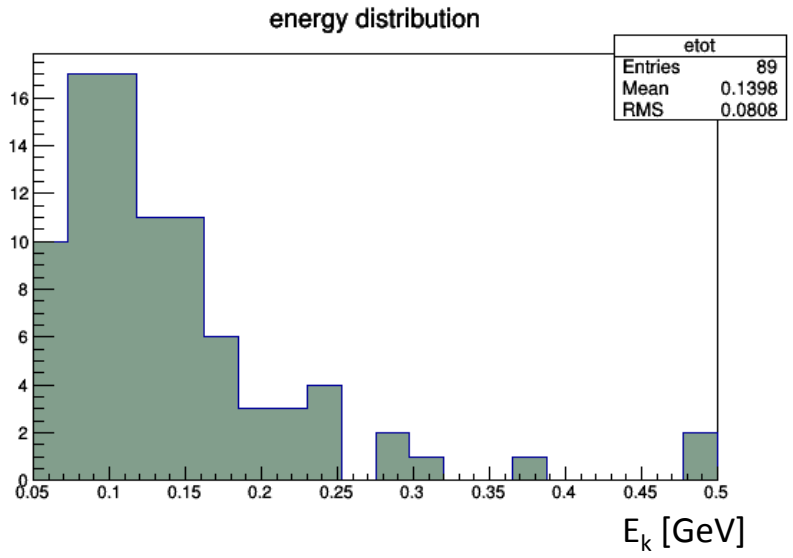
Samples of protons and pions in data

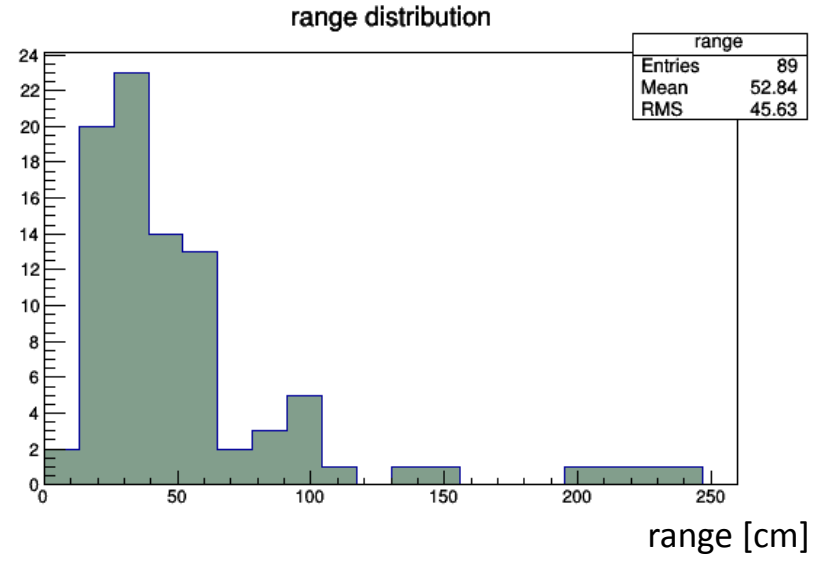
protons





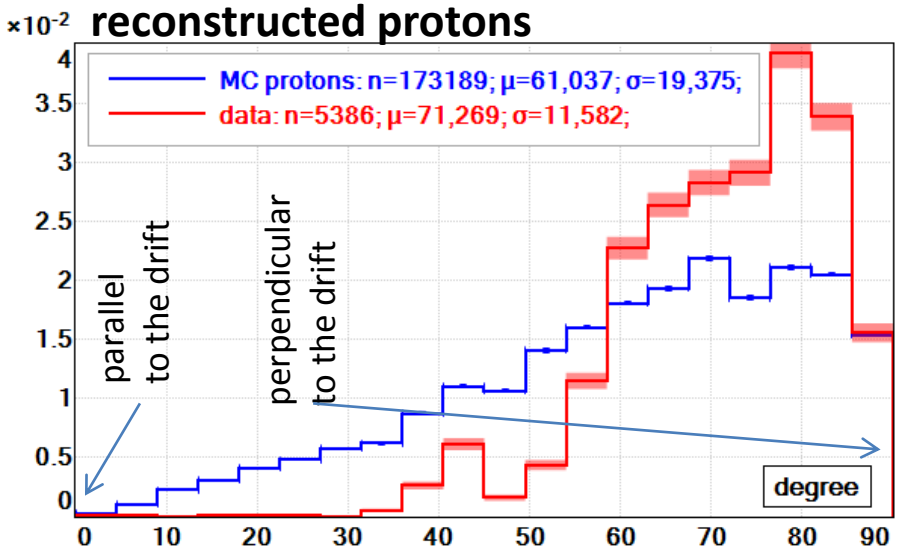
pions

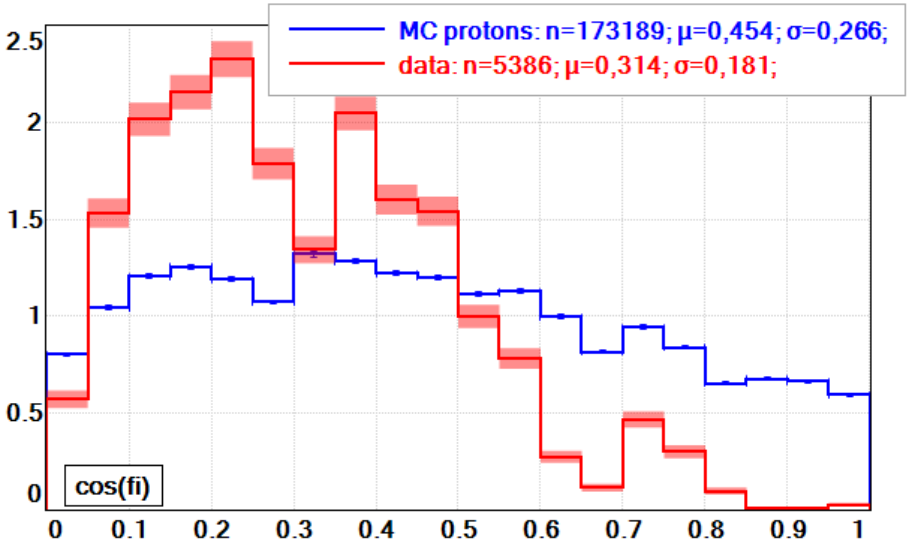




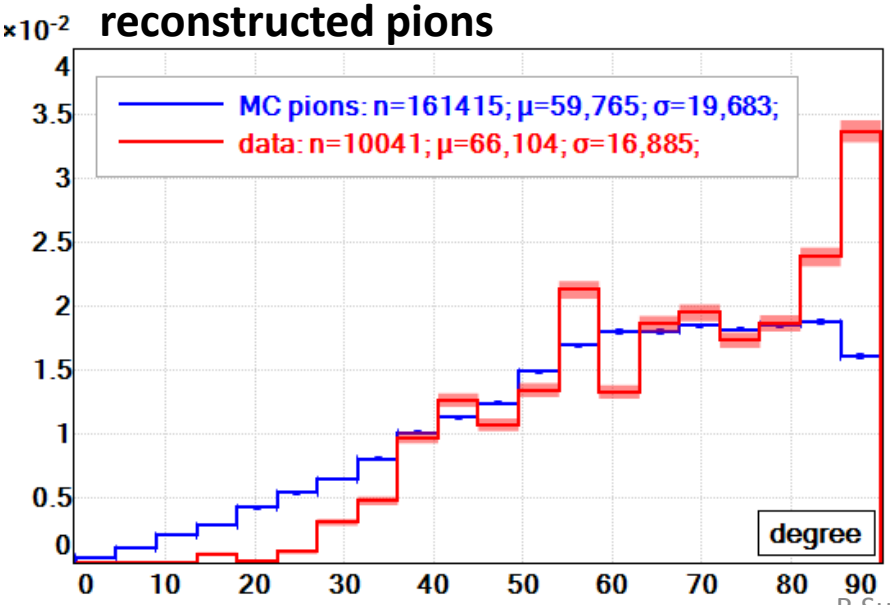
Protons and pions – segment angles w.r.t the drift direction

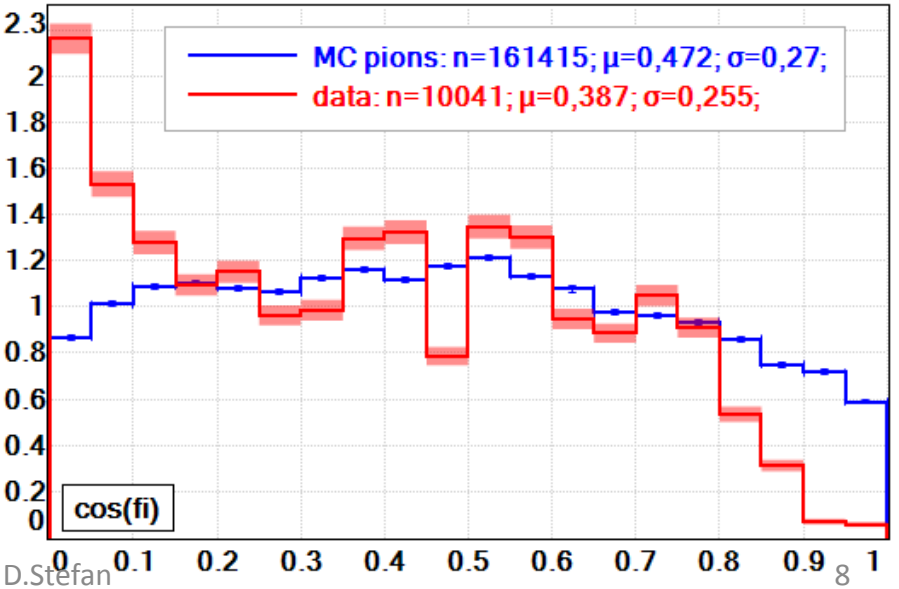
reconstructed protons





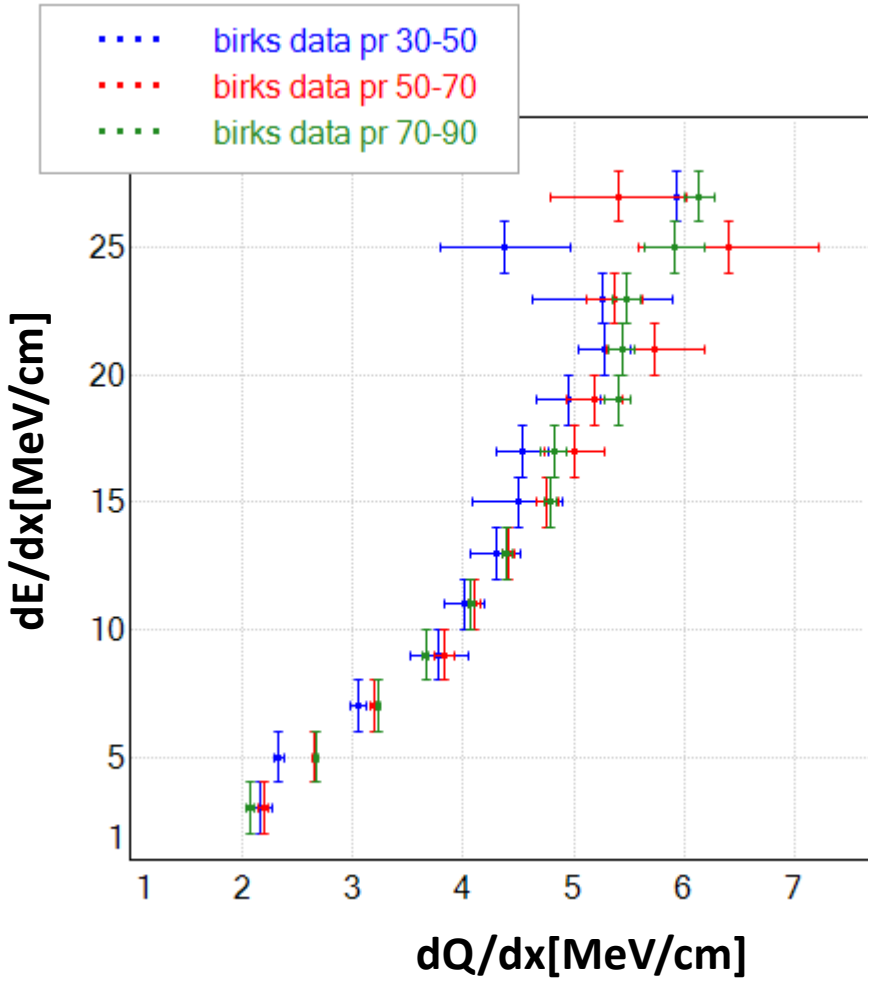
reconstructed pions



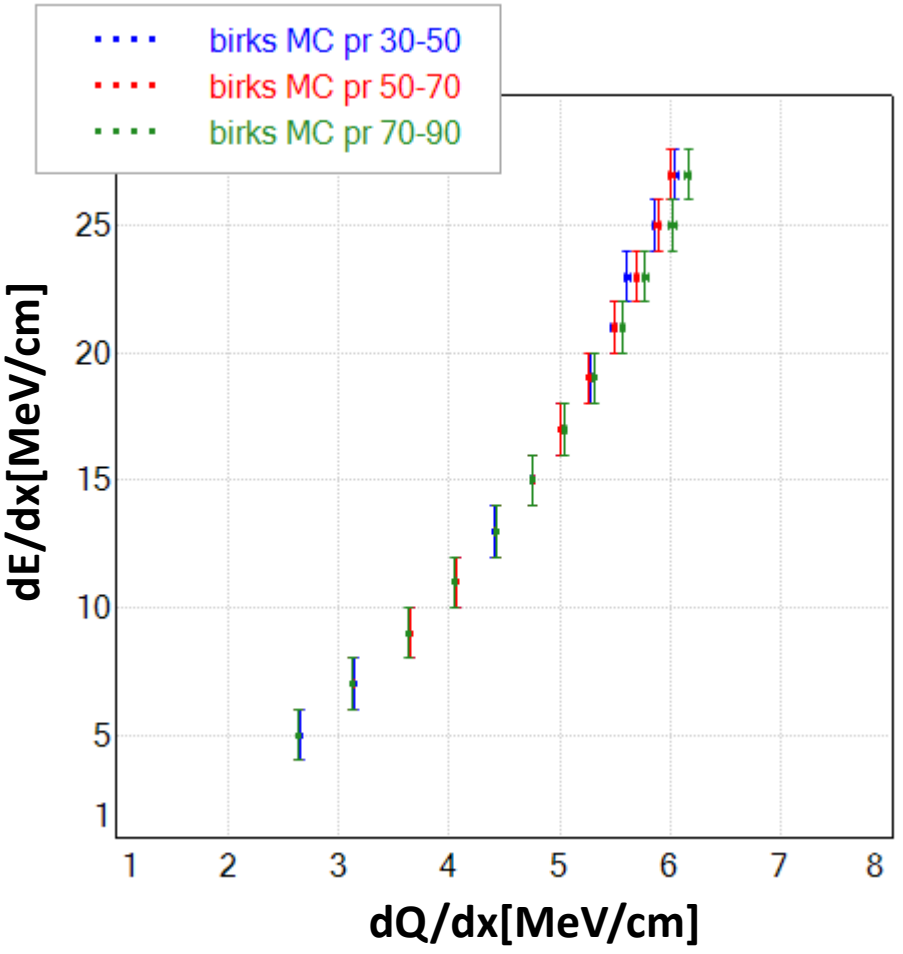


Birks relation showed on proton sample

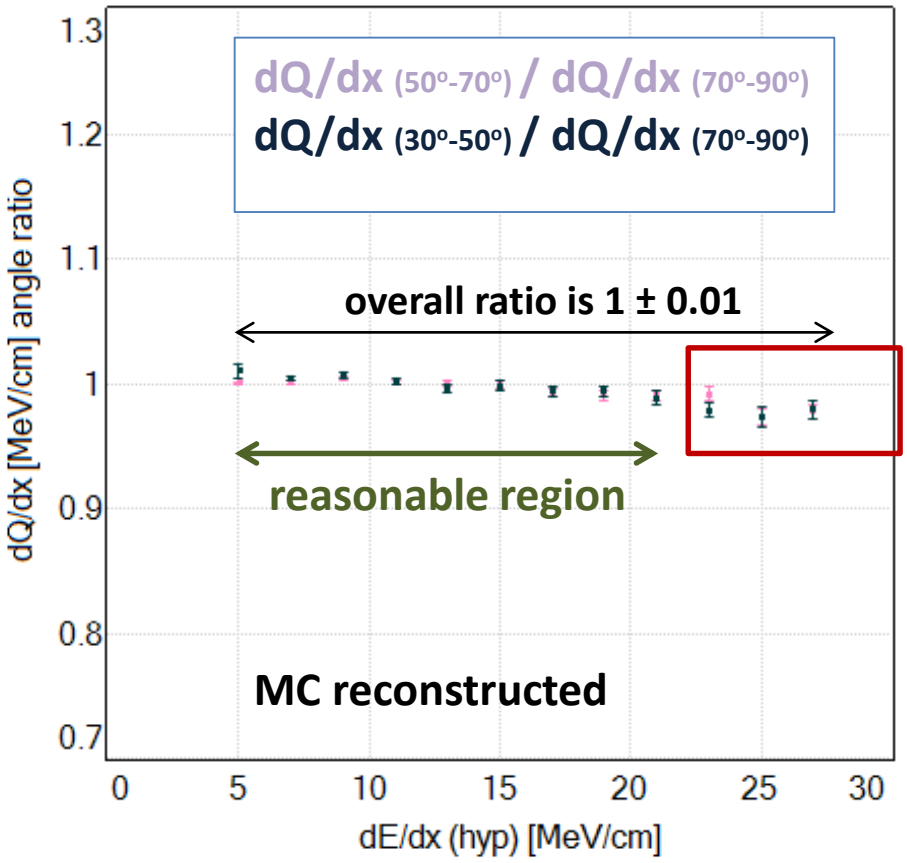
data reconstructed

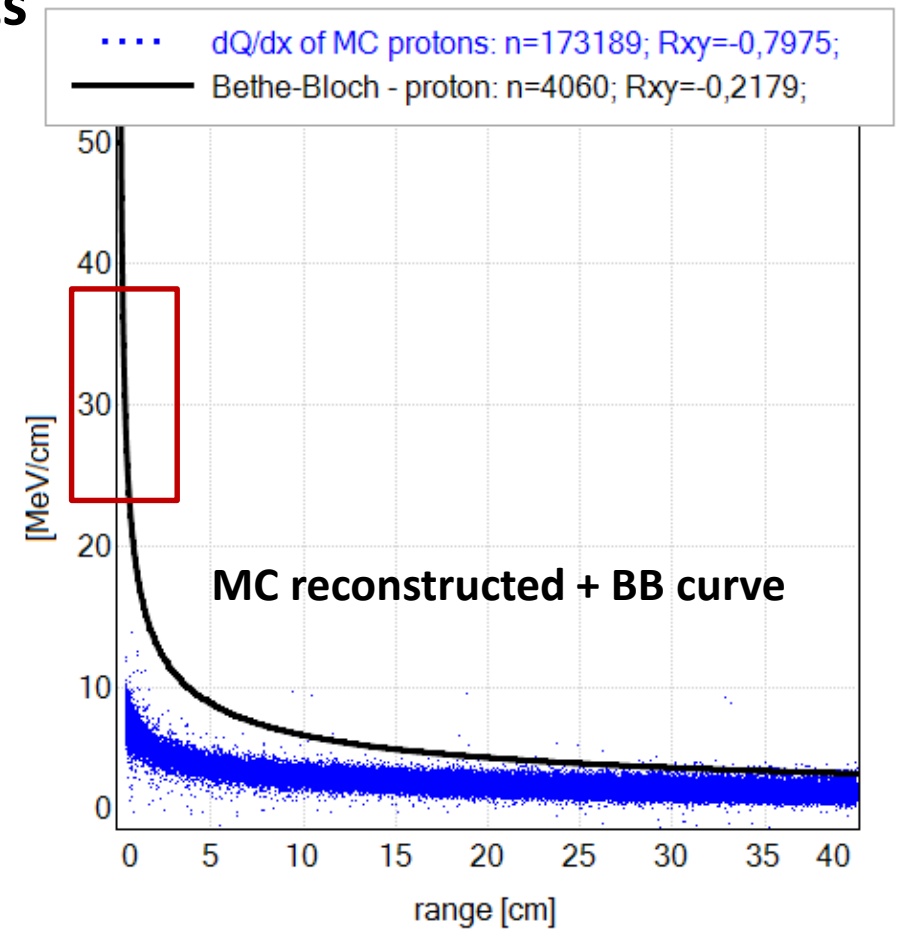


MC reconstructed



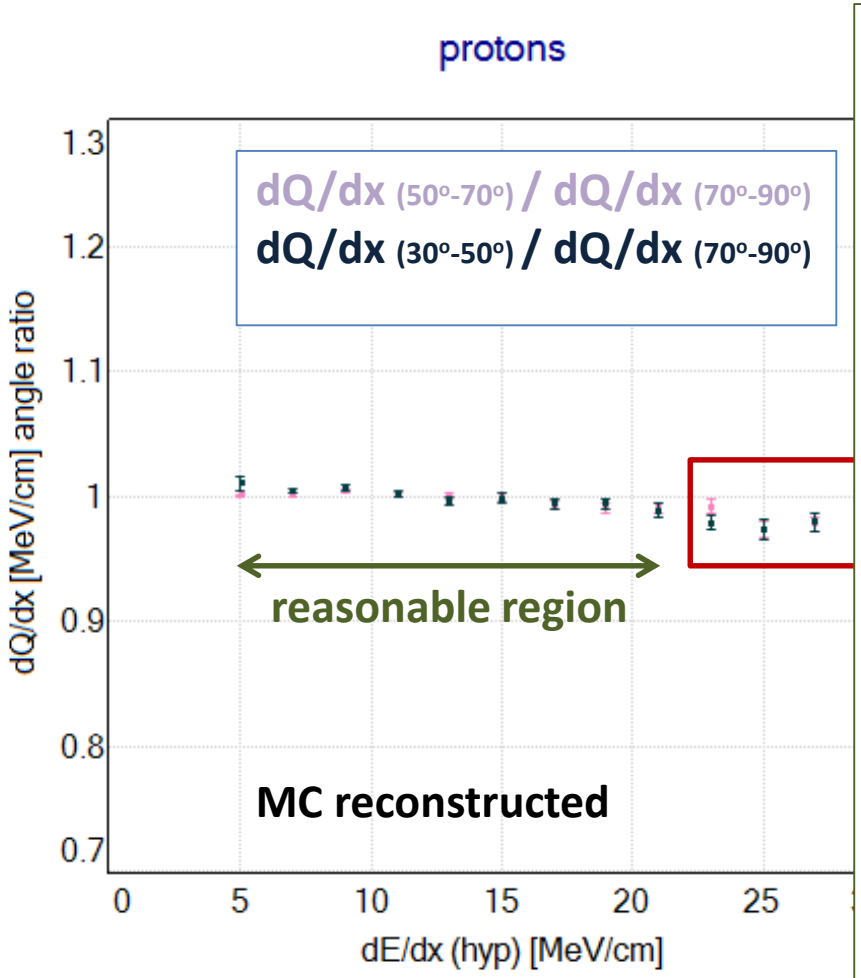
MC reconstructed protons - results

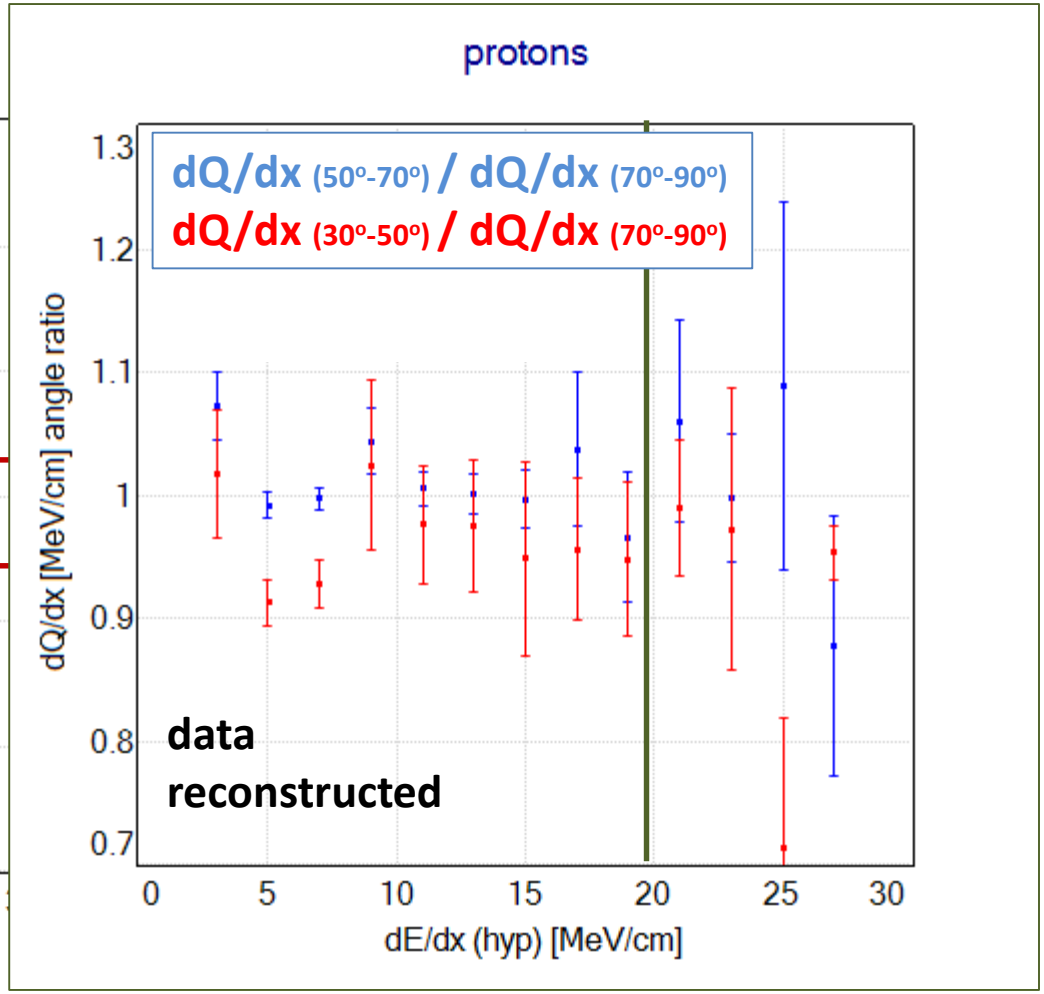




dQ/dx computed in 3 different ranges of angles:
50-70 degree w.r.t drift direction
30-50 degree w.r.t drift direction
70-90 degree w.r.t drift direction.
Plot shows the ratio of dQ/dx (50-70 deg.) / dQ/dx (70-90 deg.) – violet color
and dQ/dx (30-50 deg.) / dQ/dx (70-90 deg) – dark blue color

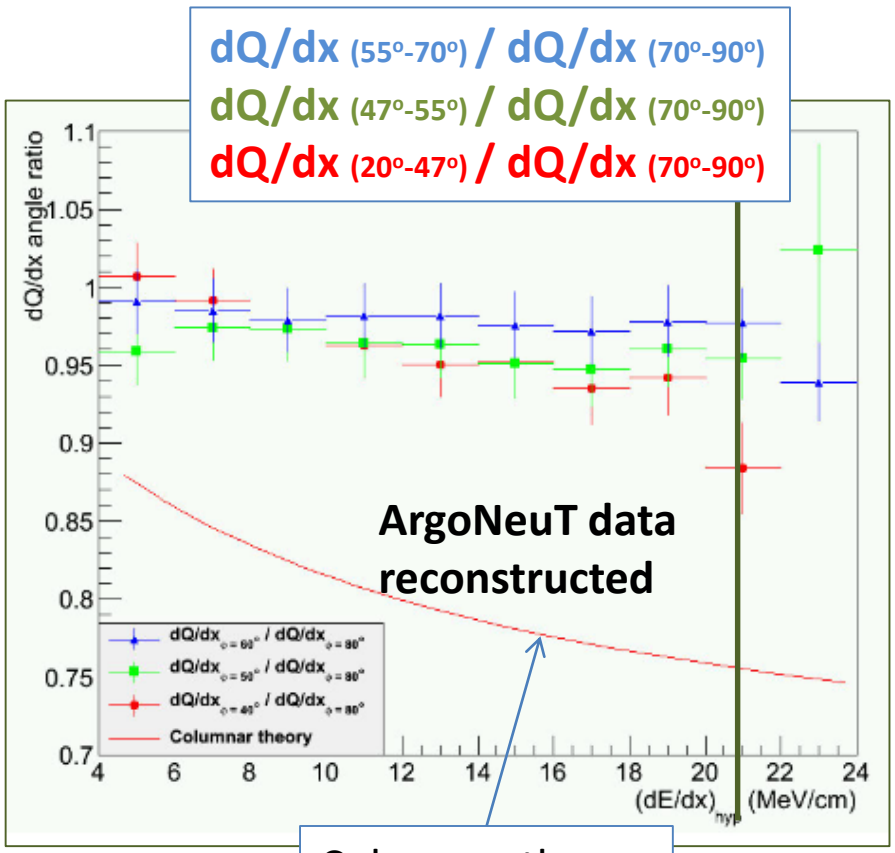
Both MC and data reconstructed protons results



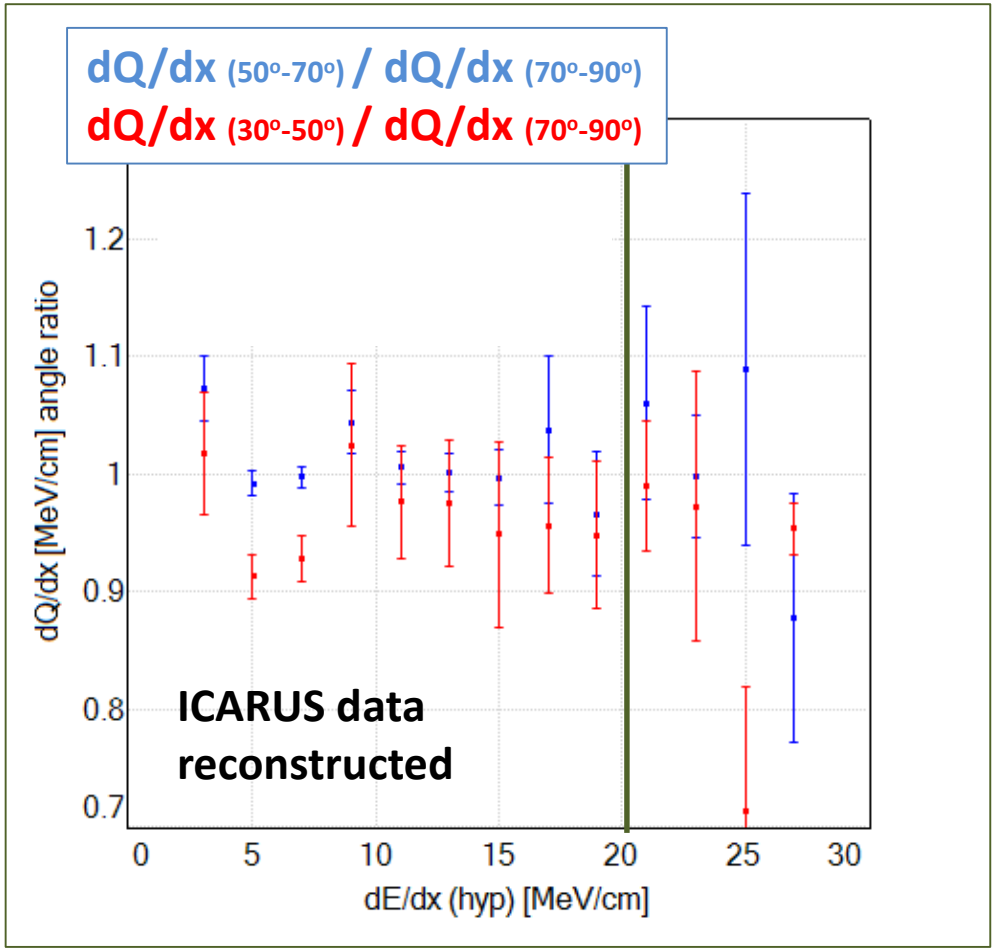


90 protons that are stopping
Problem: very low statistics… it could be possible to enrich the sample

ICARUS-ArgoNeuT protons data comparison

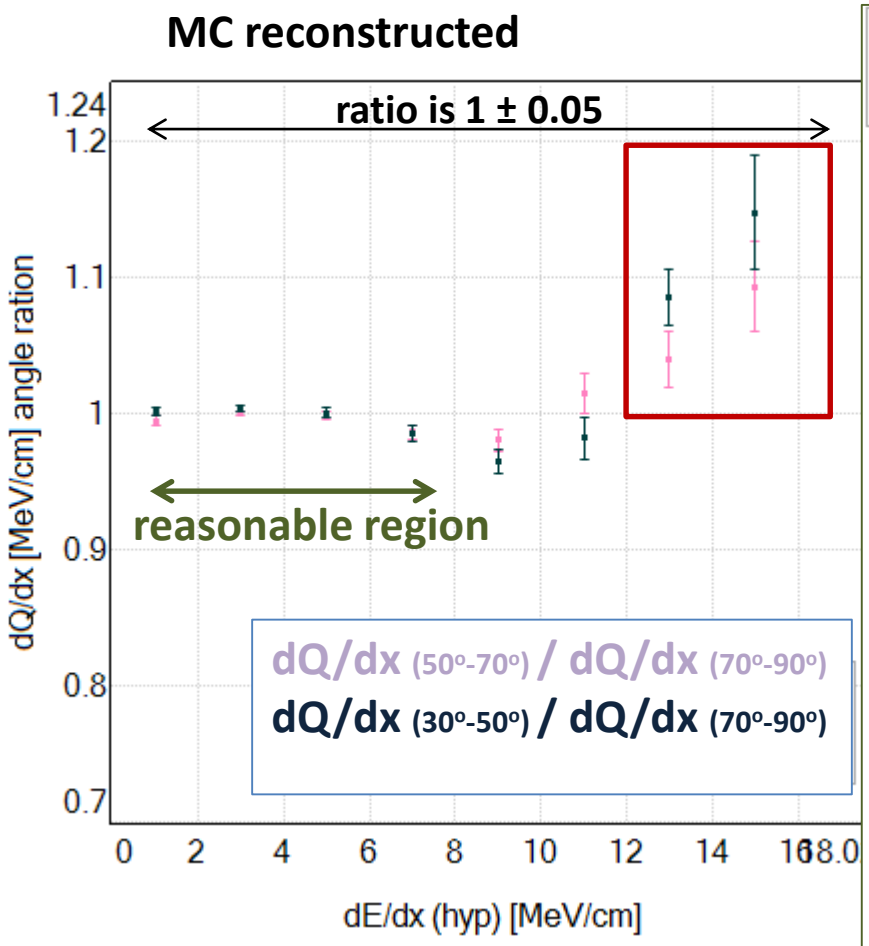


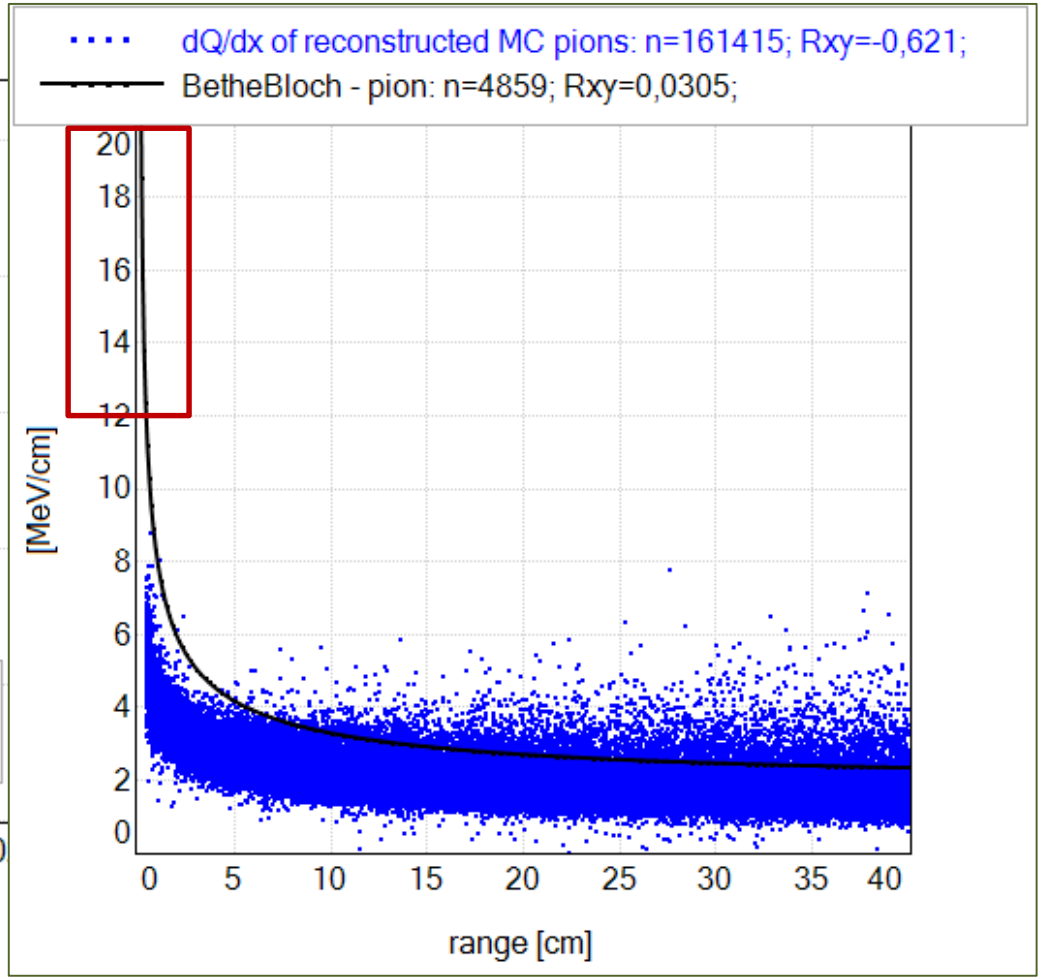
Columnar theory



arXiv:1306.1712 – ArgoNeuT paper

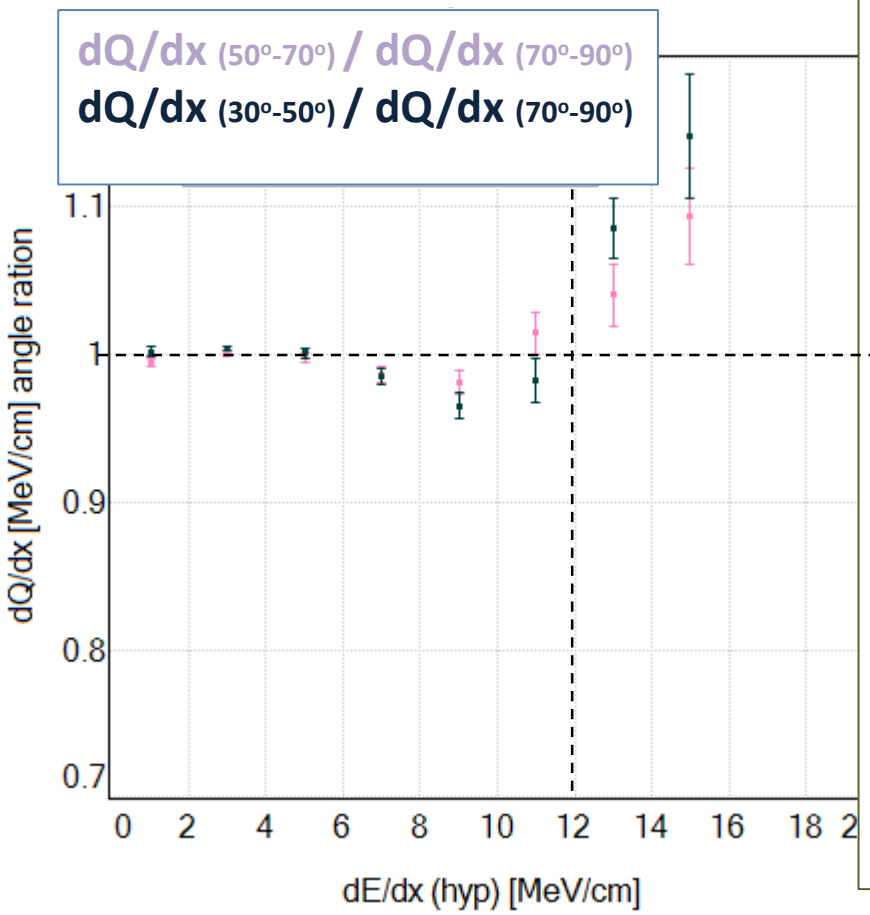
MC reconstructed pions - results



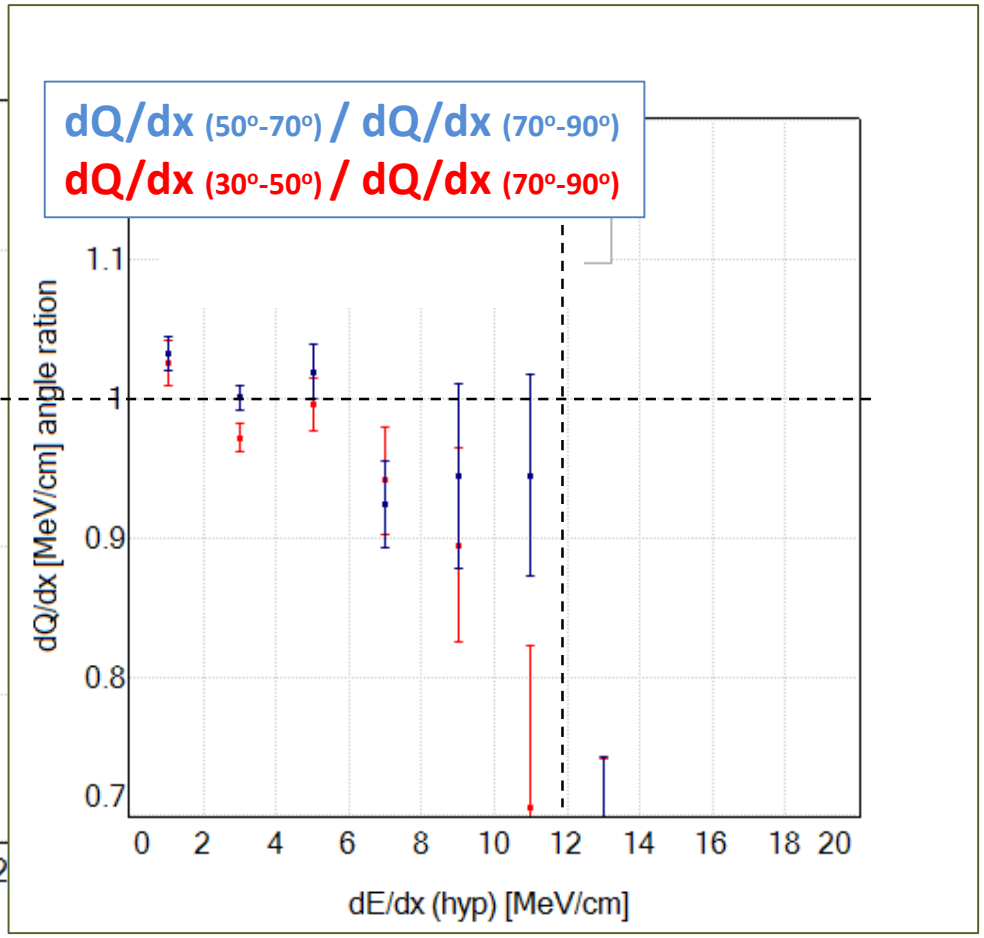


Both MC and data reconstructed pions results

MC reconstructed



Data reconstructed



Pions are lighter than protons, like scattering and decaying…

Conclusion - 1

- The effect, if exists, probably is small but we can still investigate by increasing the sample of protons and pions.

- If needed we can use also long muons produced in CNGS beam using ν_μ CC interactions (angular distribution narrow, only ϕ = 50°-70° possible).

- Important: PID is selecting what looks like stopping proton with no angular effects.
  - there are protons which are not ranging out;
  - if stopping protons are attenuated due to ϕ, they are mixed with the above;
  - this is what we may consider important to investigate.

For discussion…

Just to try, we have made attempt on presently used sample:

- less strict selection of stopping protons
- more reinteracting protons, hope that change is the same in every direction
- not „Bethe-Bloch” at all
- still far from PID = pion