

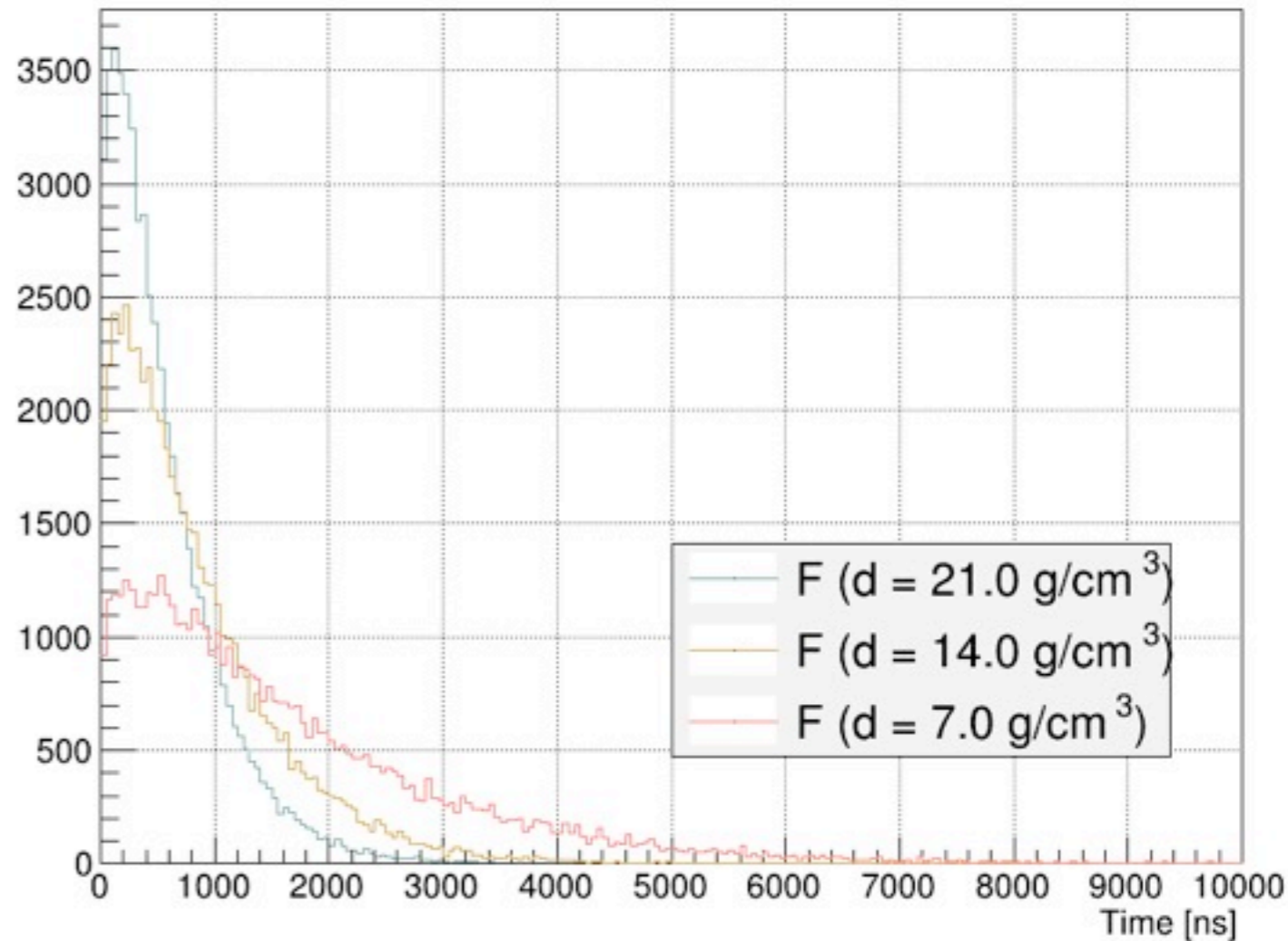
Progress Report

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July 19th, 2013

Creation time of photons from neutron capture in F (5 GeV pi-)

| Density (g/cm ³) | # of photons (avg. per evt.) | # of atoms/cm ³ (x 10 ²³) | # of atoms*cross section (x 10 ²¹) |
|------------------------------|------------------------------|--|--|
| 7.0 | 53.835 | 2.22 | 2.13 |
| 14.0 | 54.509 | 4.44 | 4.26 |
| 21.0 | 54.260 | 6.66 | 6.39 |

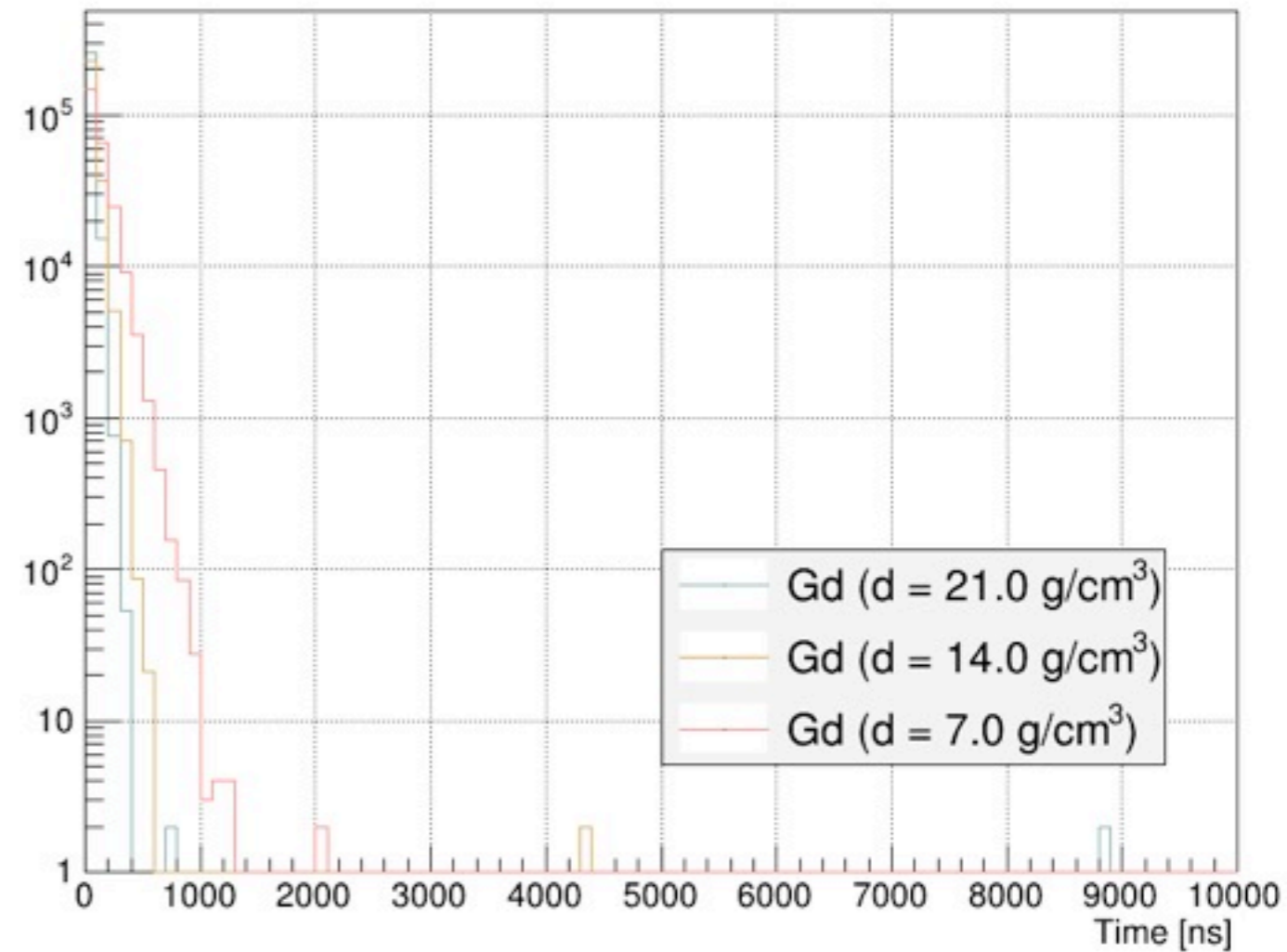
Density ~ 1.696 g/cm³ (@ 293K)
Molar mass ~ 18.99 (g/mol)
Neutron capture cross section -> 0.0096



Creation time of photons from neutron capture in Gd (5 GeV pi-)

| Density (g/cm ³) | # of photons (avg. per evt.) | # of atoms/cm ³ (x 10 ²³) | # of atoms*cross section (x 10 ²¹) |
|------------------------------|------------------------------|--|--|
| 7.0 | 252.373 | 0.268 | 1,313,200 |
| 14.0 | 268.195 | 0.554 | 2,714,600 |
| 21.0 | 273.233 | 0.804 | 3,940,628 |

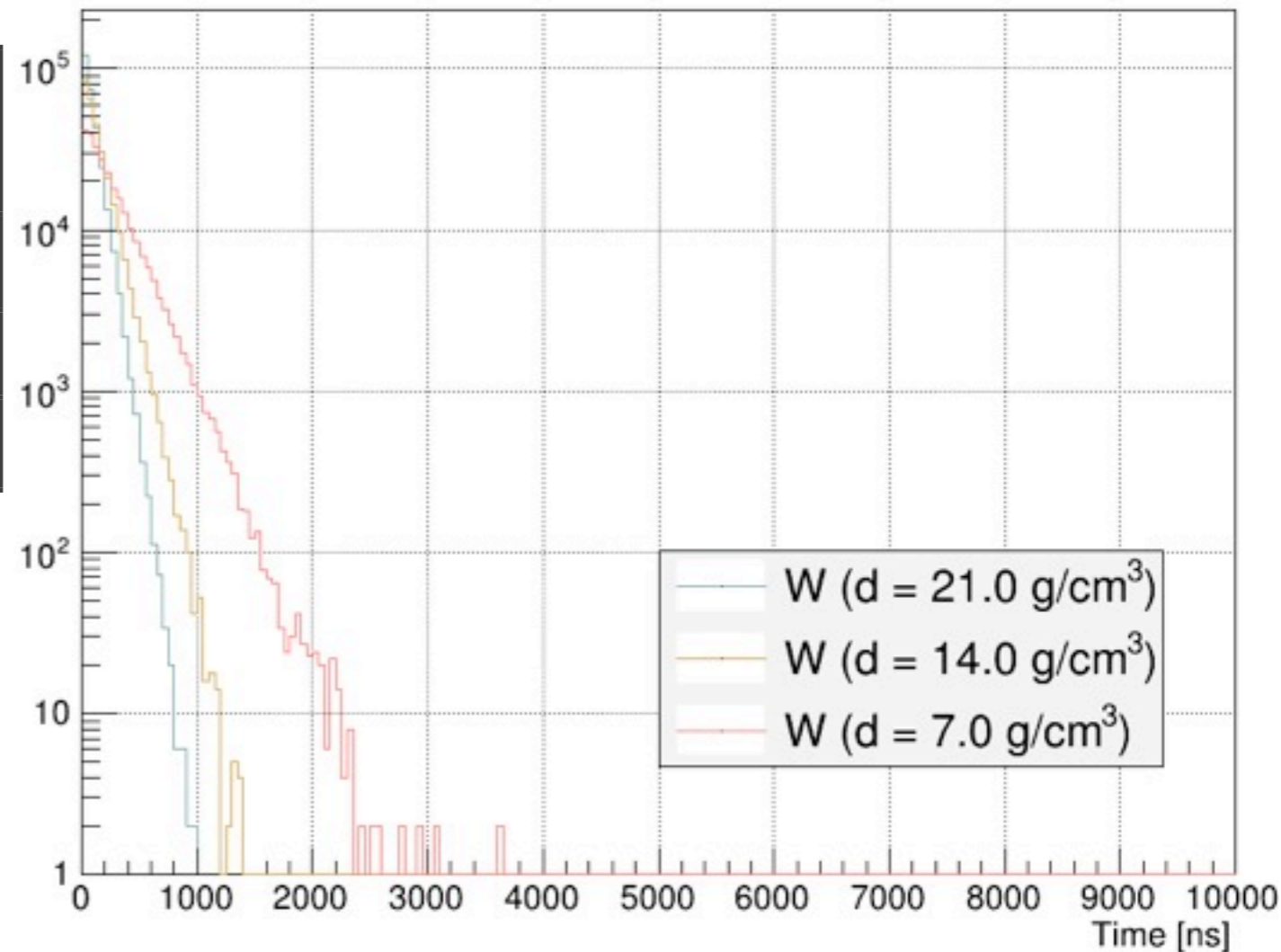
Density ~ 7.90 g/cm³
 Molar mass ~ 157.25 (g/mol)
 Neutron capture cross section -> 4.9 x10⁴
 (barn)



Creation time of photons from neutron capture in W (5 GeV pi-)

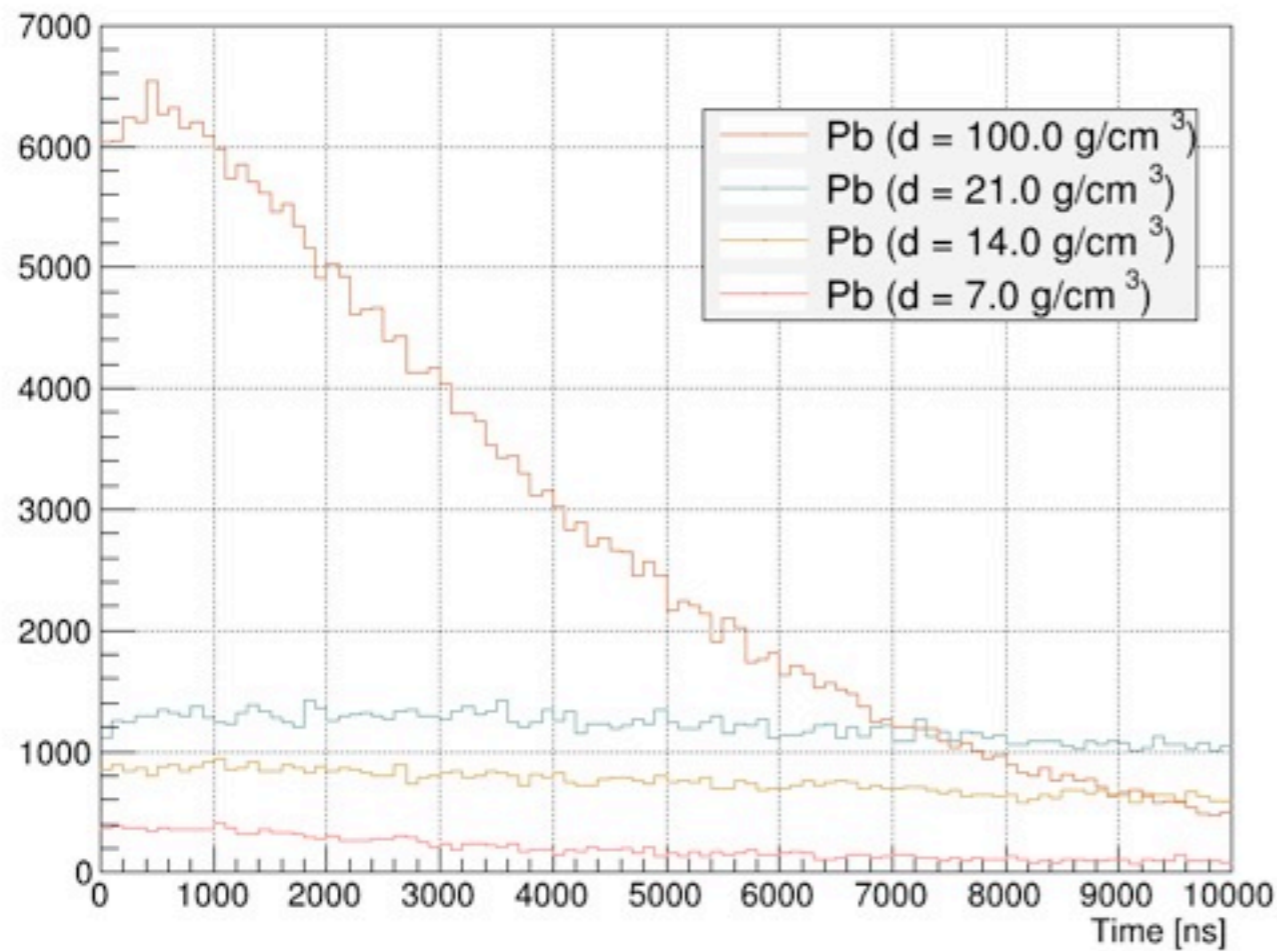
GeV pi-)

| Density (g/cm ³) | # of photons (avg. per evt.) | # of atoms/cm ³ (x 10 ²³) | # of atoms*cross section (x 10 ²¹) |
|------------------------------|------------------------------|--|--|
| 7.0 | 265.204 | 0.223 | 411.12 |
| 14.0 | 288.757 | 0.458 | 844.552 |
| 21.0 | 294.481 | 0.687 | 1266.82 |



Density ~ 19.25 g/cm³
Molar mass ~ 183.8410 (g/mol)
Neutron capture cross section -> 18.44 (barn)

Creation time of photons from neutron capture in Pb (5 GeV pi-)



| Density (g/cm ³) | # of photons (avg. per evt.) | # of atoms/cm ³ (x 10 ²³) | # of atoms*cross section (x 10 ²¹) |
|------------------------------|------------------------------|--|--|
| 7.0 | 19.655 | 0.21 | 3.59 |
| 14.0 | 75.11 | 0.406 | 6.94 |
| 21.0 | 120.807 | 0.610 | 10.43 |
| 100.0 | 284.377 | 2.90 | 49.59 |

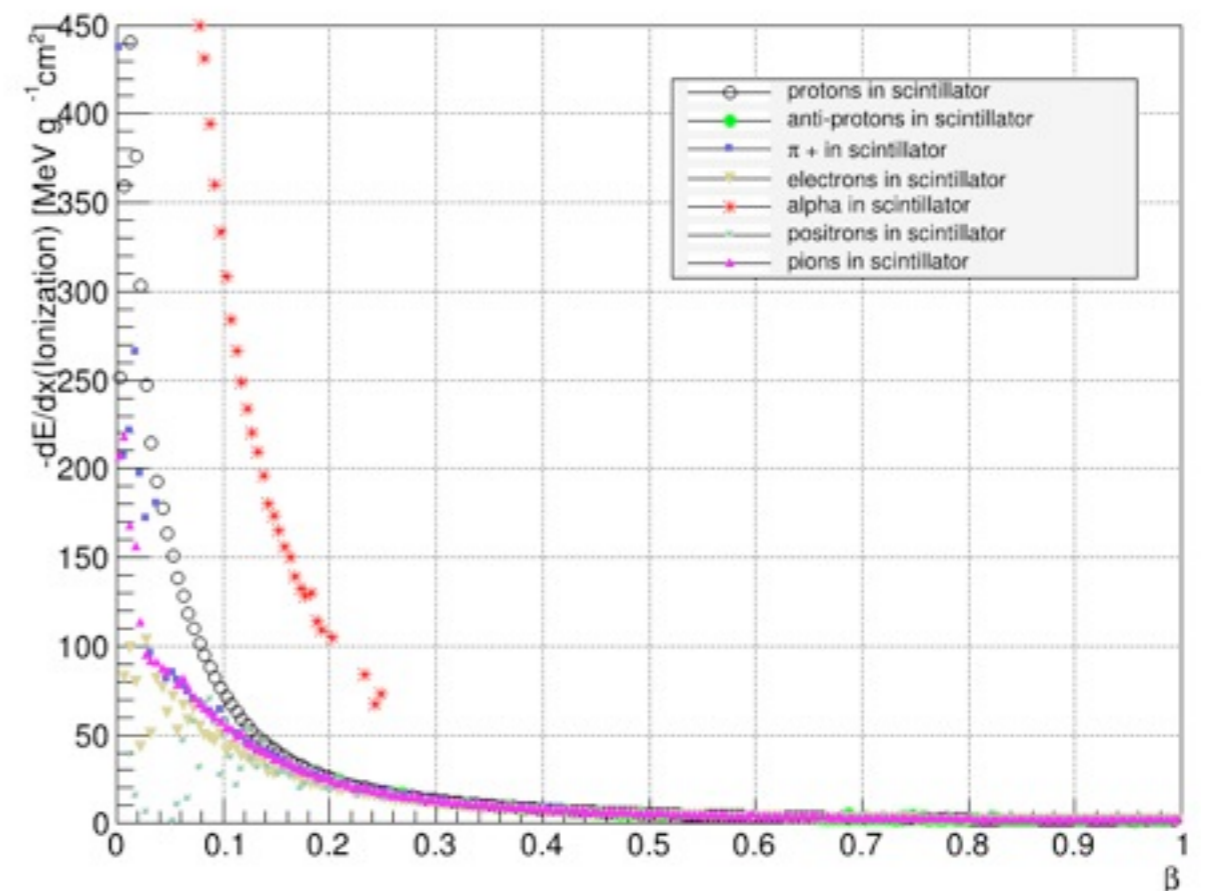
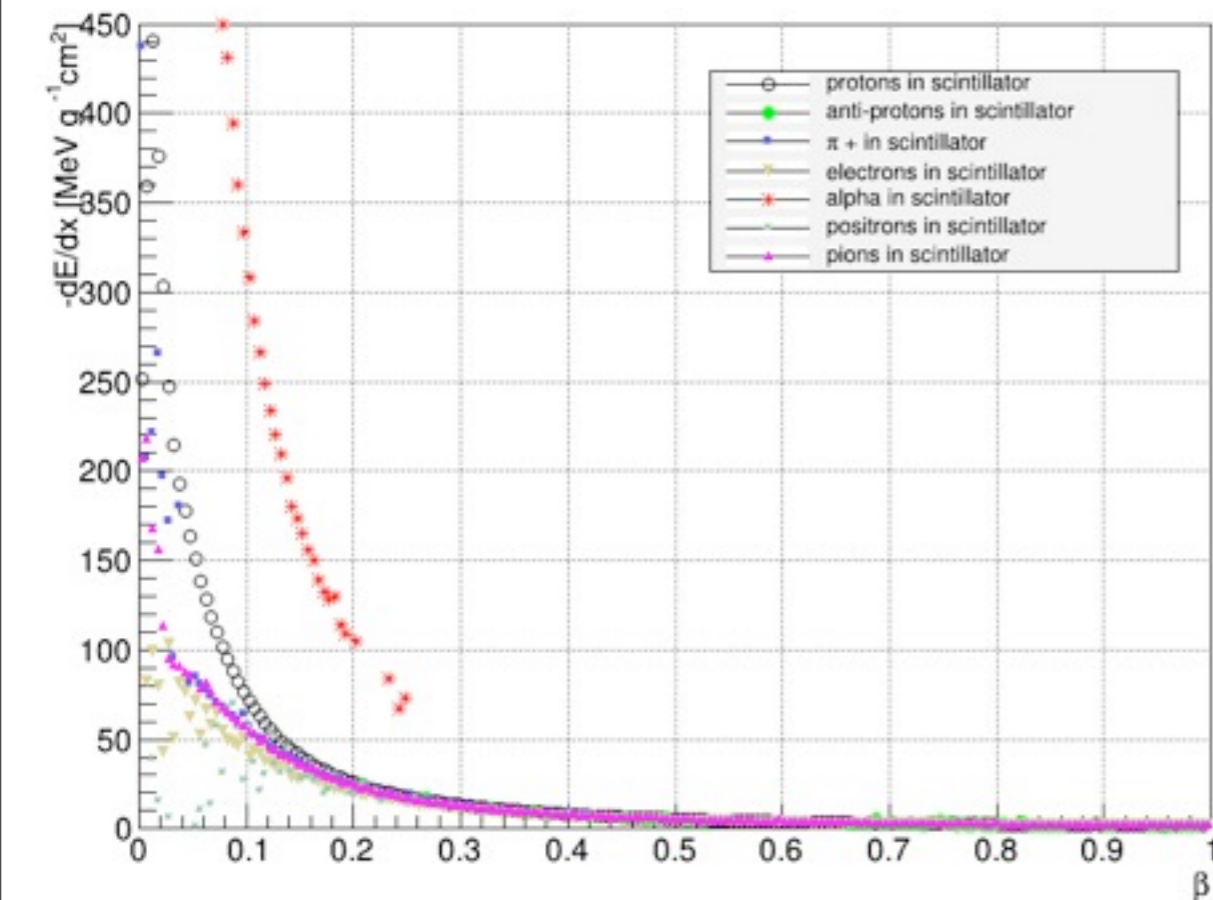
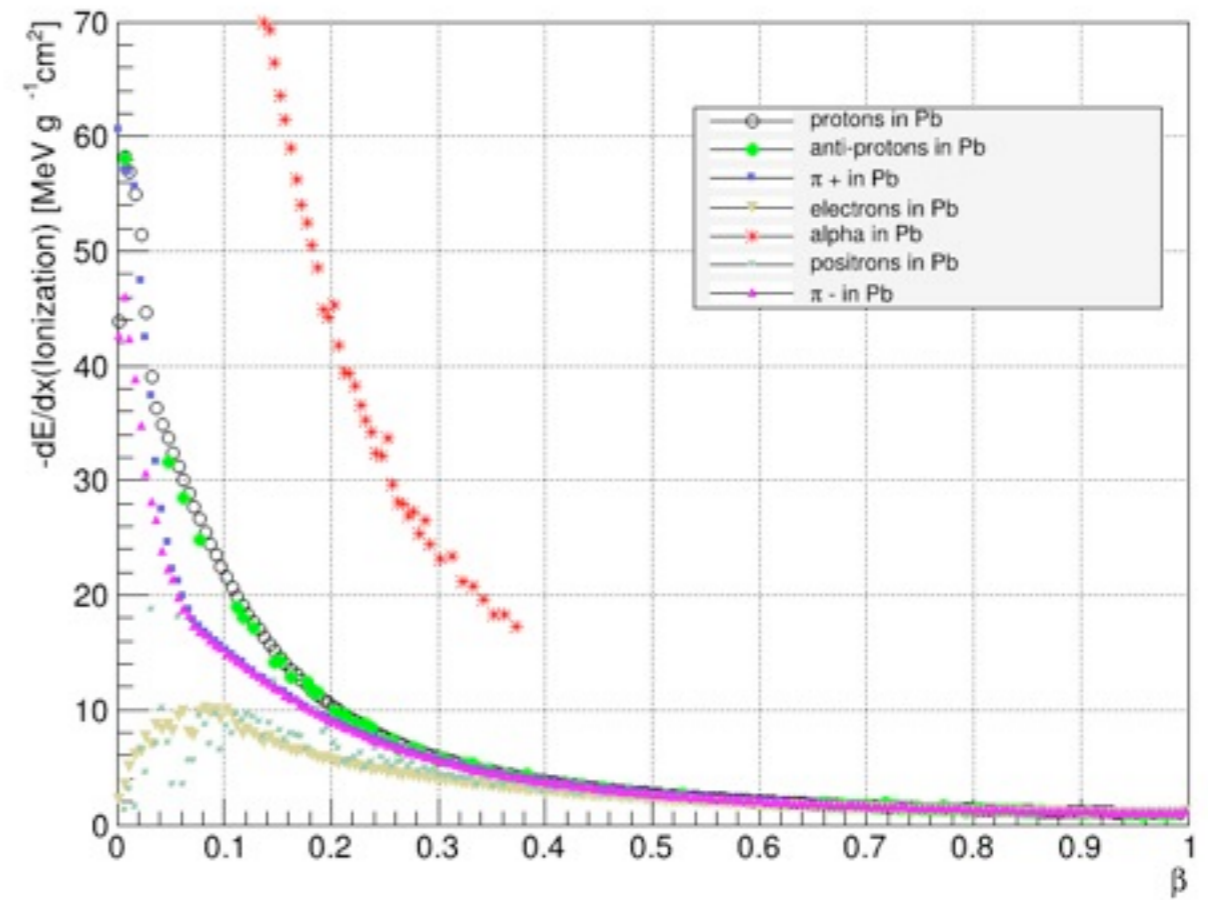
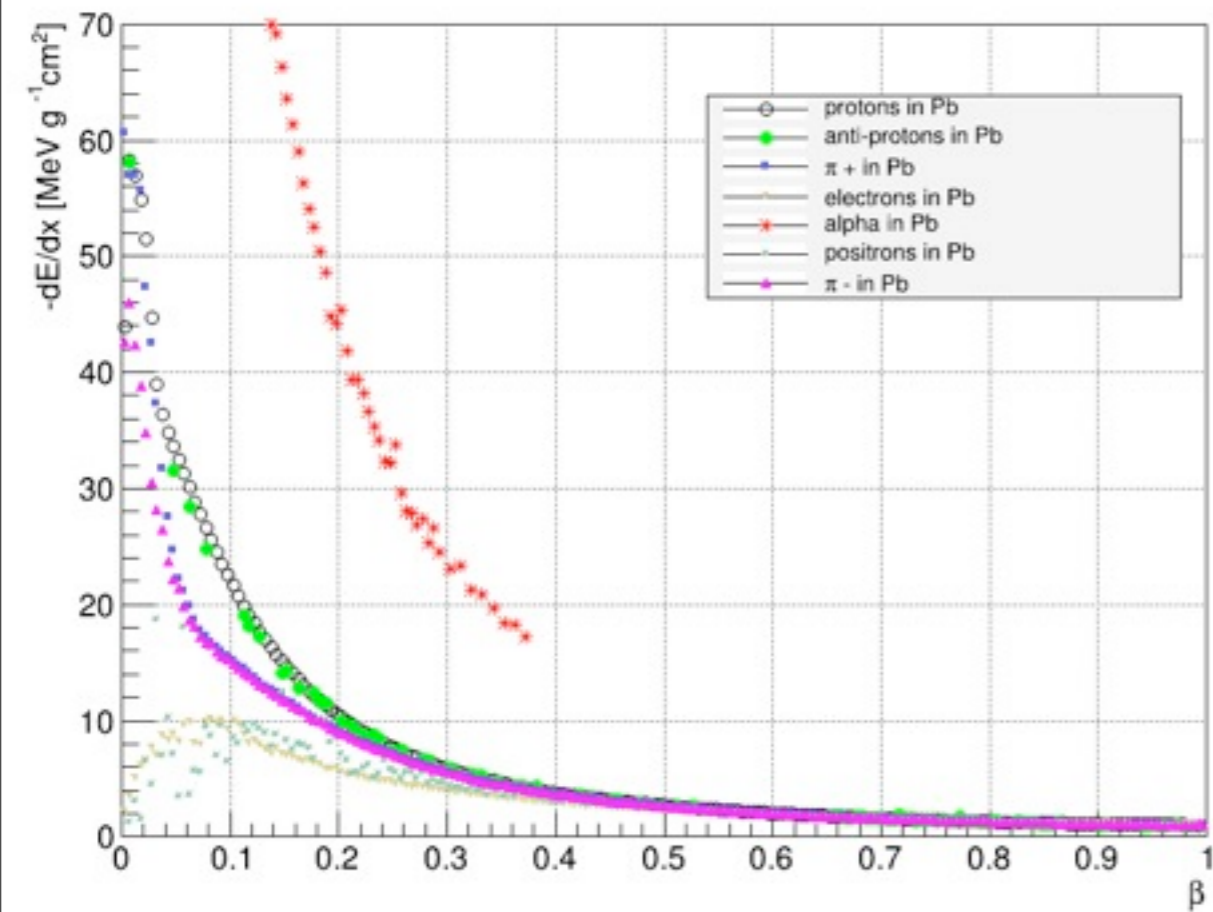
Density ~ 11.34 g/cm³
 Molar mass ~ 207.21 (g/mol)
 Neutron capture cross section -> 0.171 (barn)

| | # of photons (avg. per evt.) | # of atoms/cm ³ (x 10 ²³) | # of atoms*cross section (x 10 ²¹) |
|------------|---------------------------------|--|--|
| 7.0 (Pb) | 19.655 | 0.21 | 3.59 |
| 14.0 (Pb) | 75.11 | 0.406 | 6.94 |
| 21.0 (Pb) | 120.807 | 0.610 | 10.43 |
| 100.0 (Pb) | 284.377 | 2.90 | 49.59 |
| 7.0 (W) | 265.204 | 0.223 | 411.12 |
| 14.0 (W) | 288.757 | 0.458 | 844.552 |
| 21.0 (W) | 294.481 | 0.687 | 1266.82 |
| 7.0 (Gd) | 252.373 | 0.268 | 1,313,200 |
| 14.0 (Gd) | 268.195 | 0.554 | 2,714,600 |
| 21.0 (Gd) | 273.233 | 0.804 | 3,940,628 |
| 7.0 (F) | 53.835 | 2.22 | 2.13 |
| 14.0 (F) | 54.509 | 4.44 | 4.26 |
| 21.0 (F) | 54.260 | 6.66 | 6.39 |

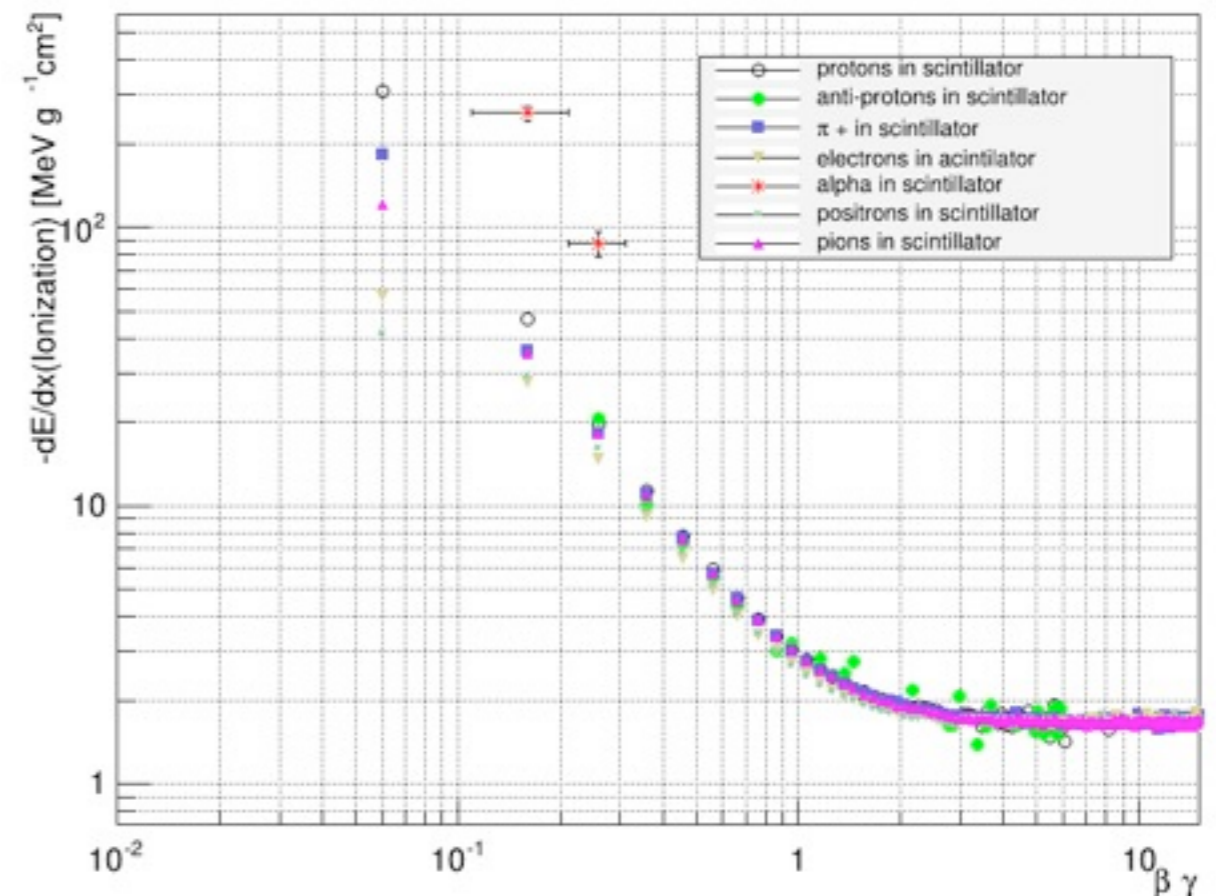
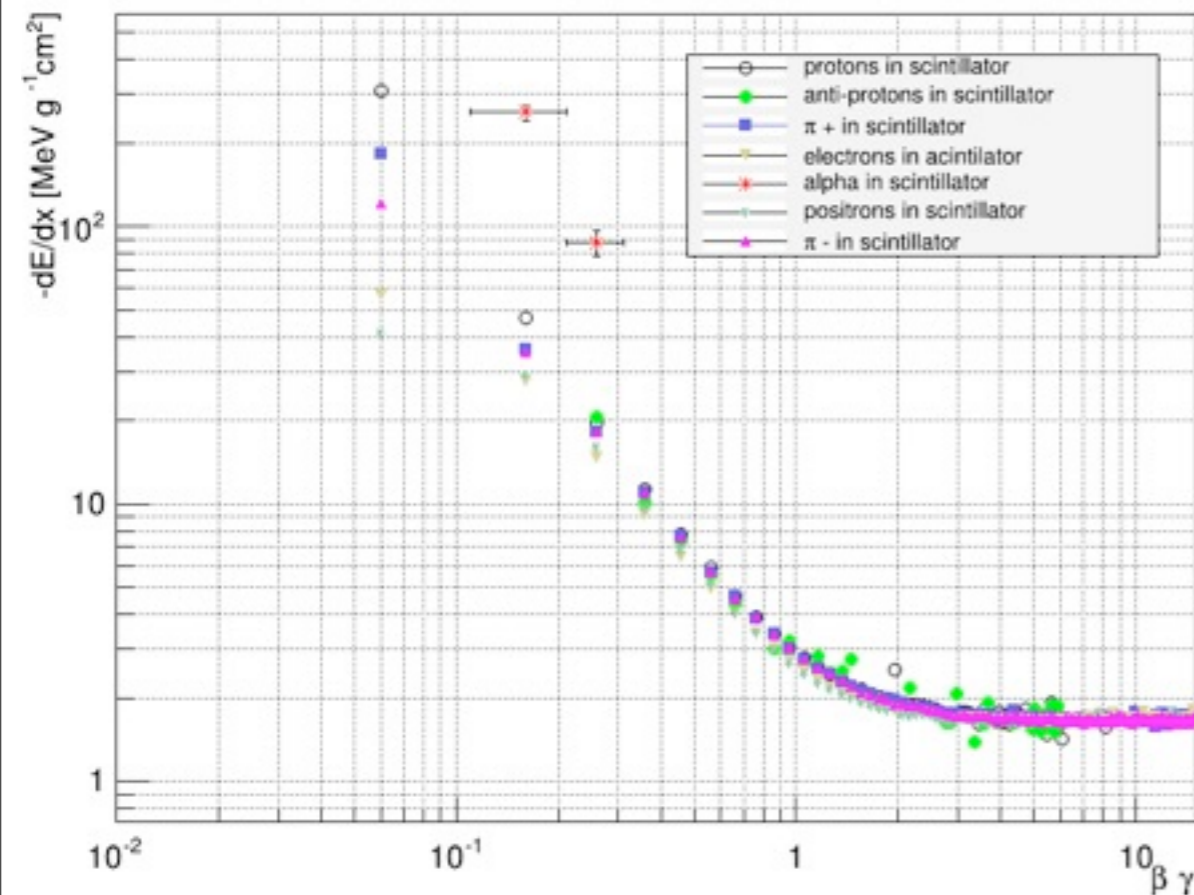
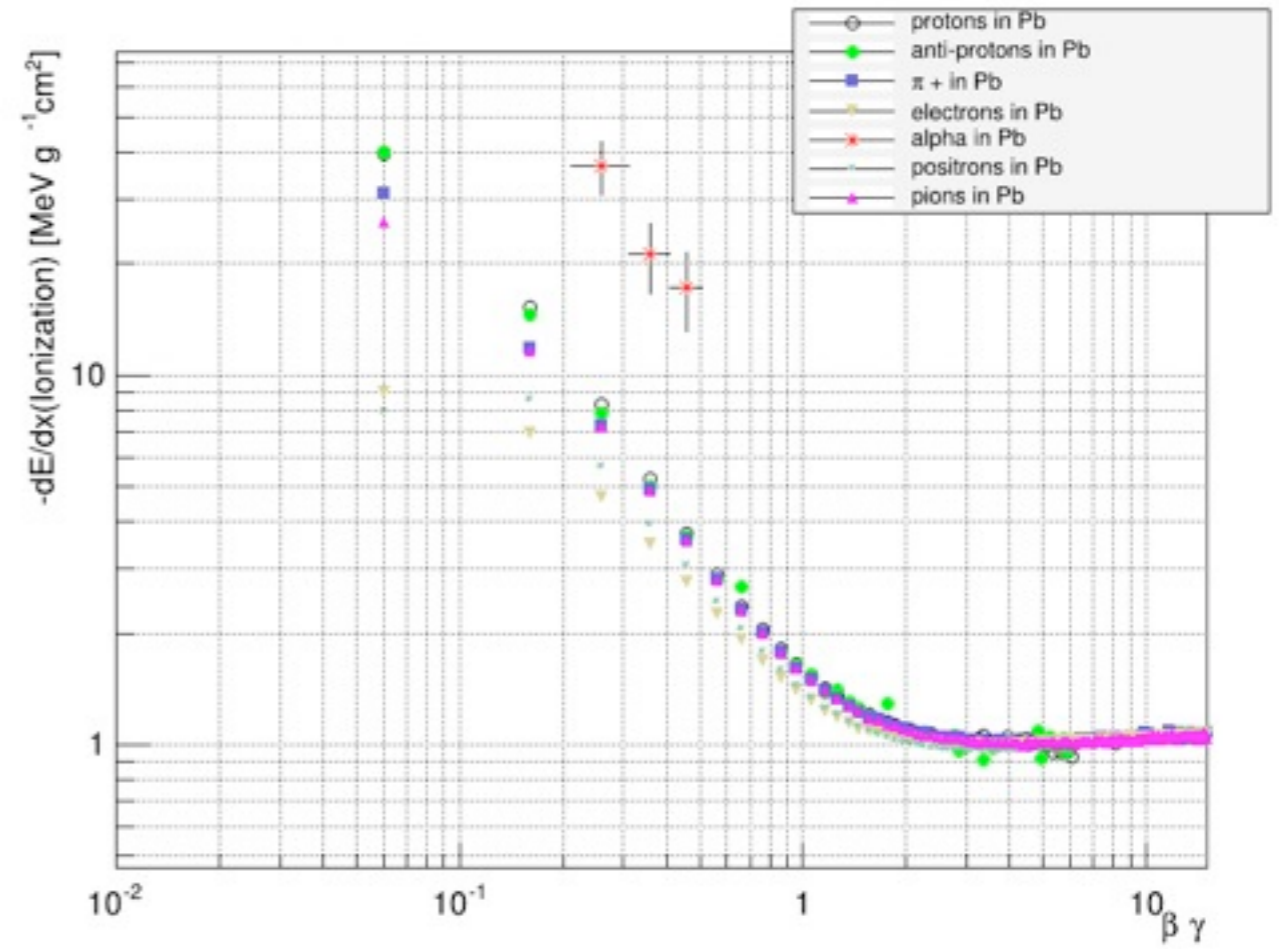
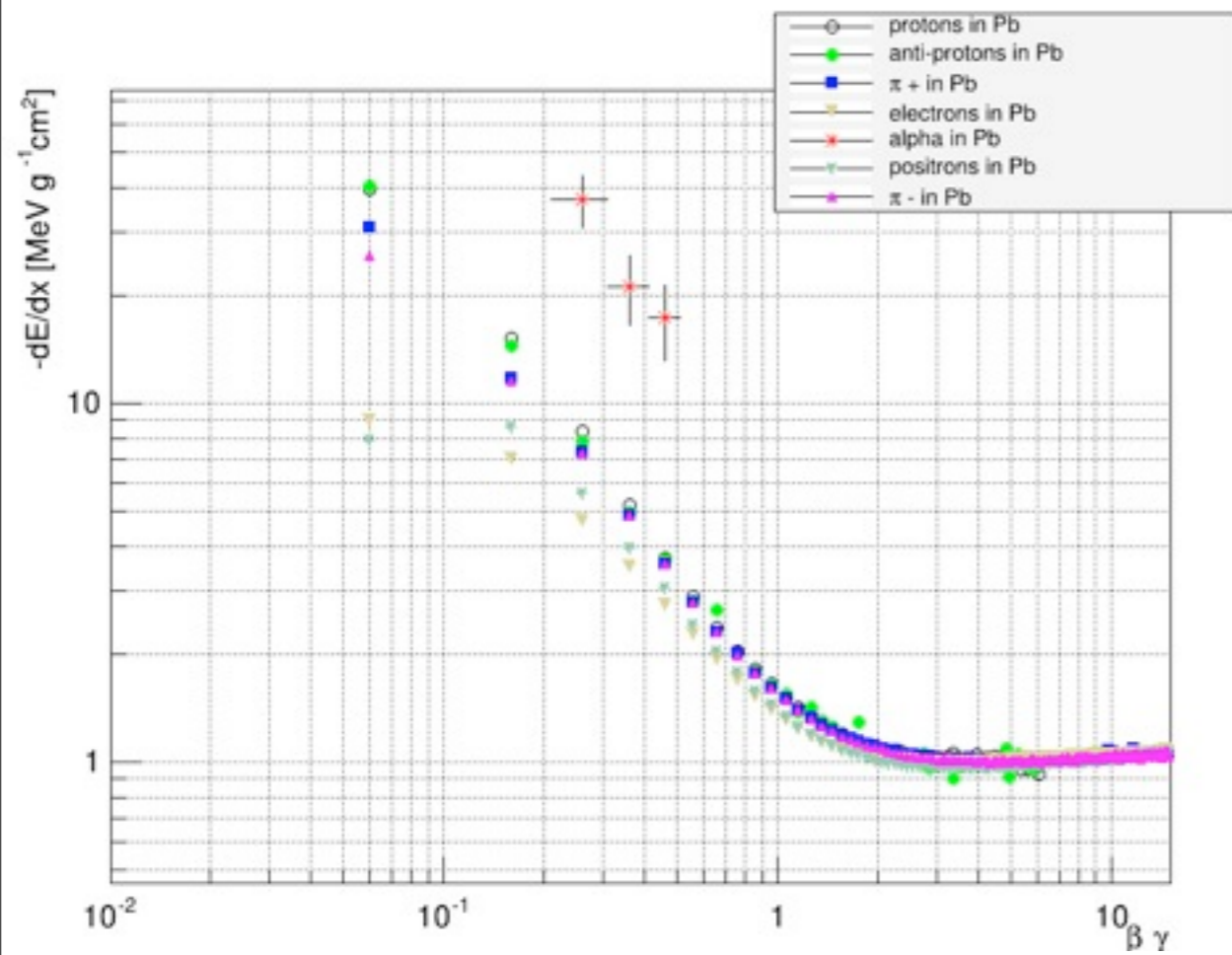
dE/dx for charged particles

Pb4mm + Scint1mm
15 GeV incident pi-

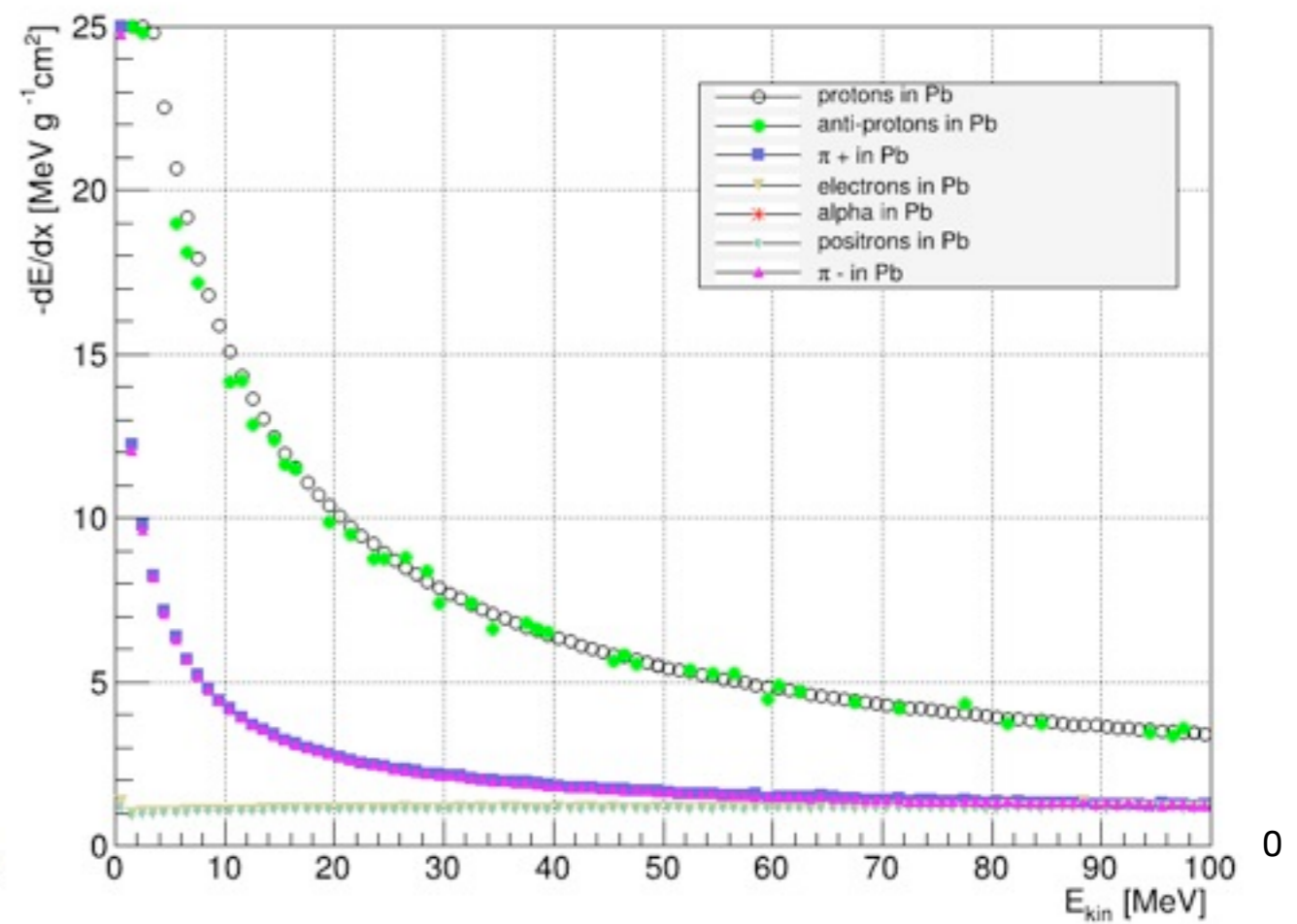
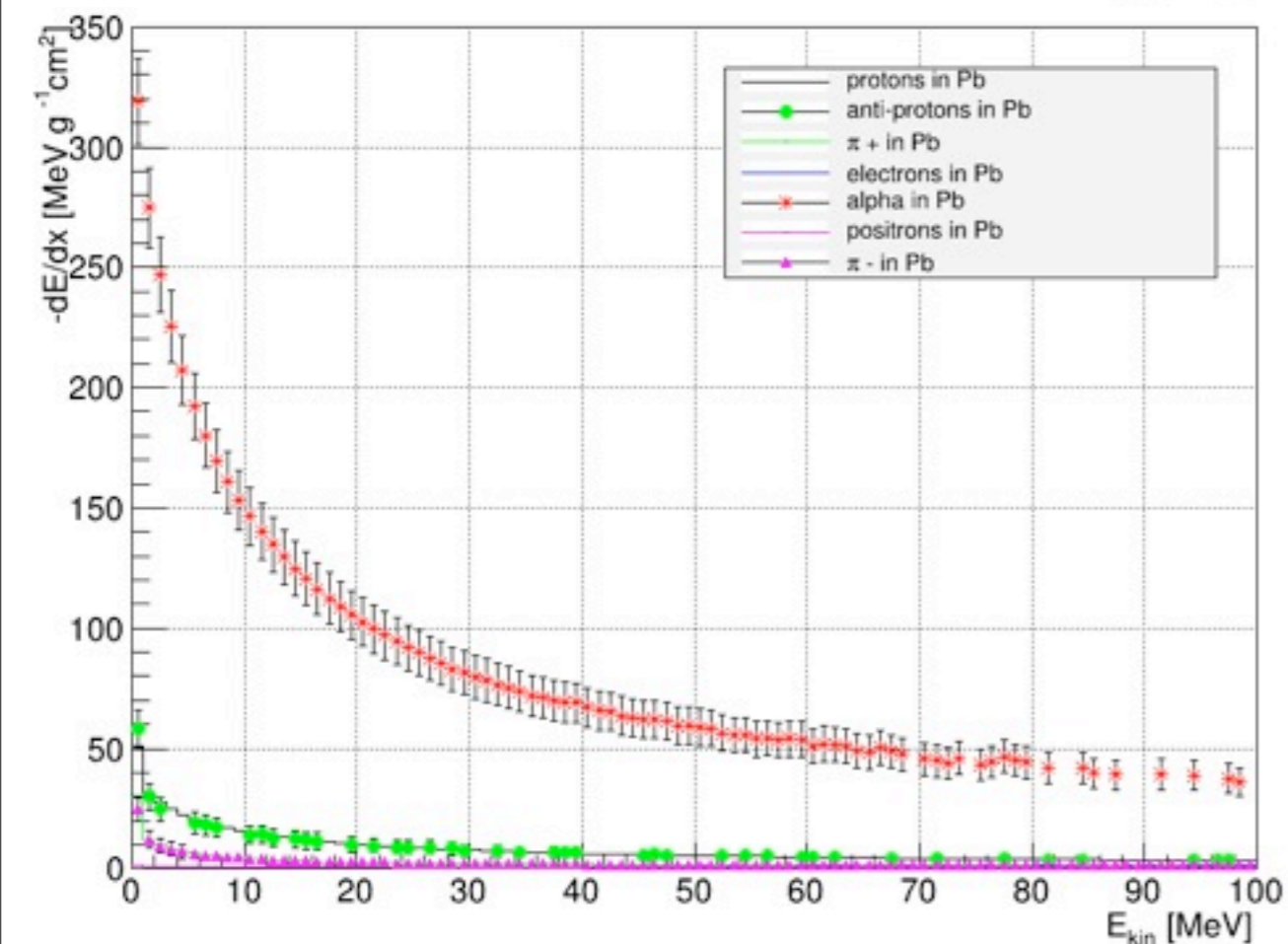
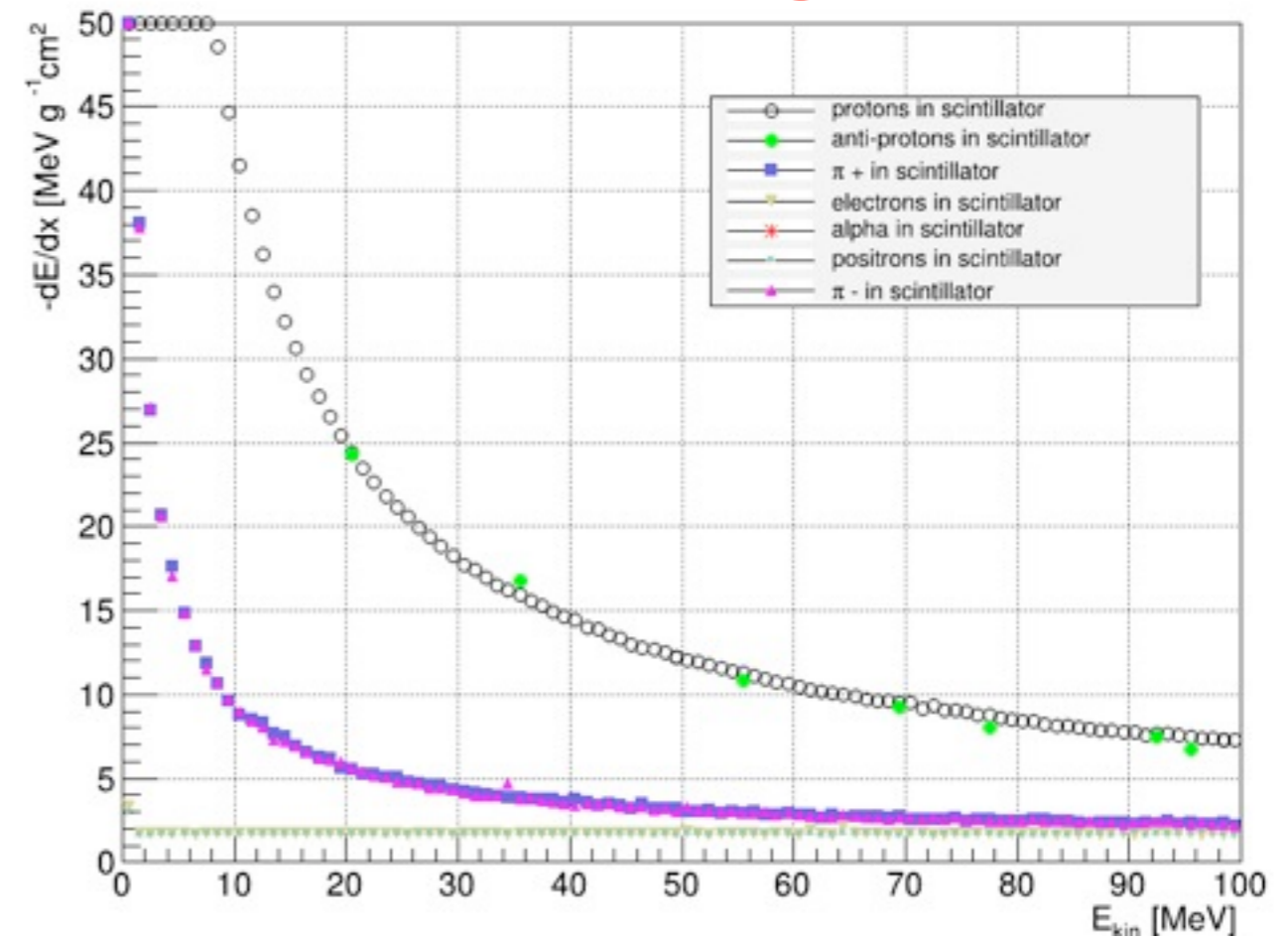
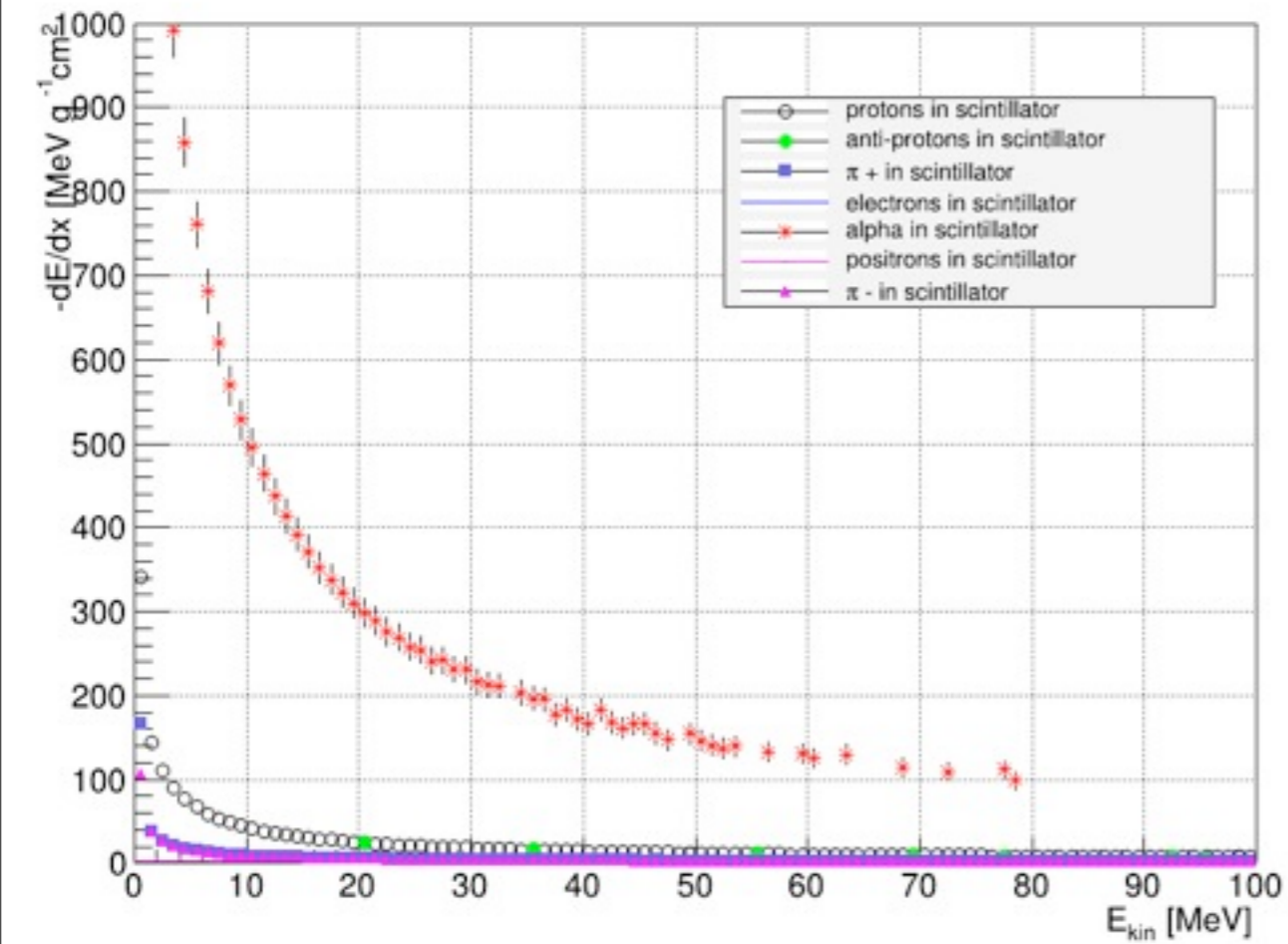
dE/dx as a function of beta for charged particles



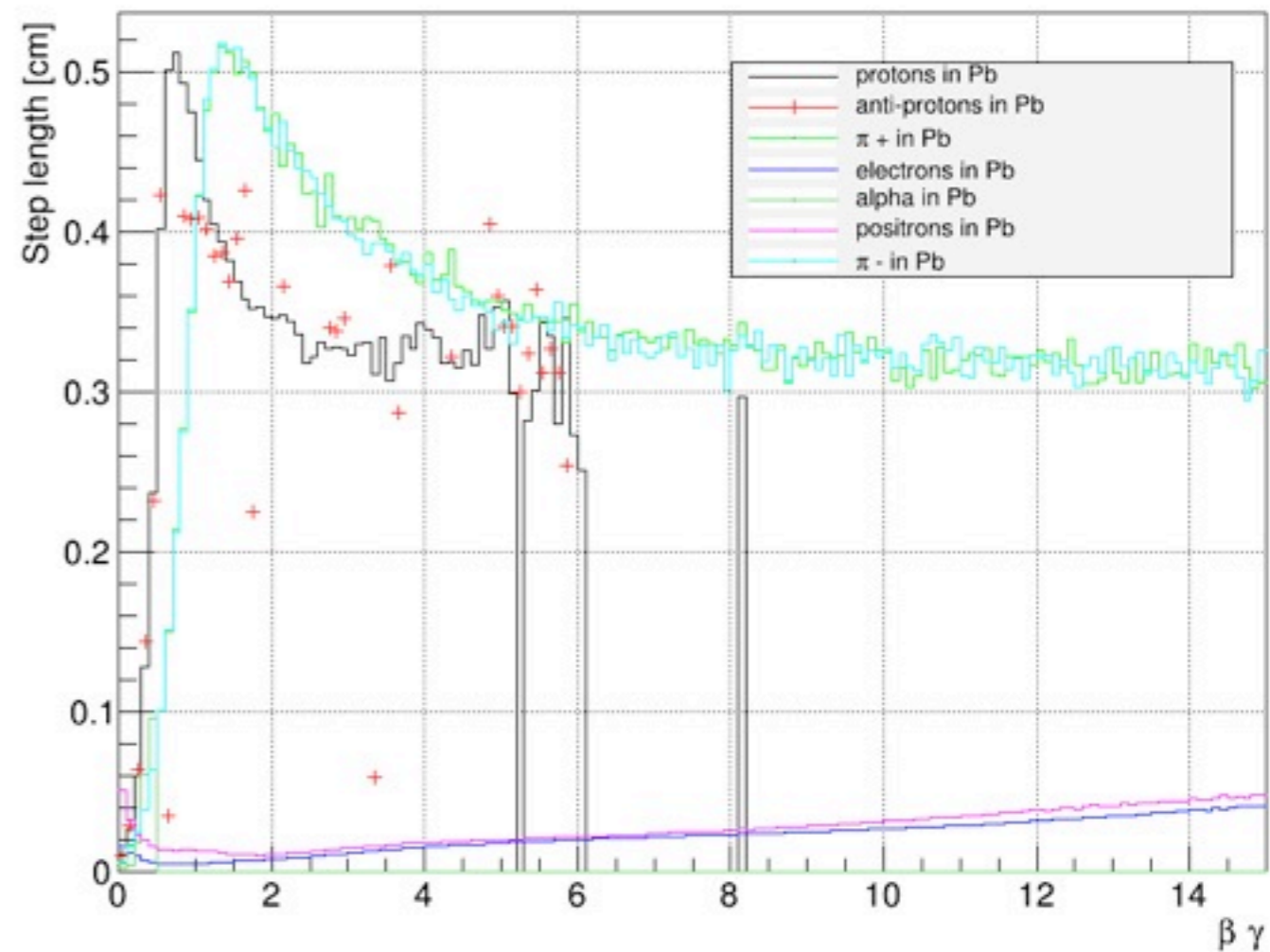
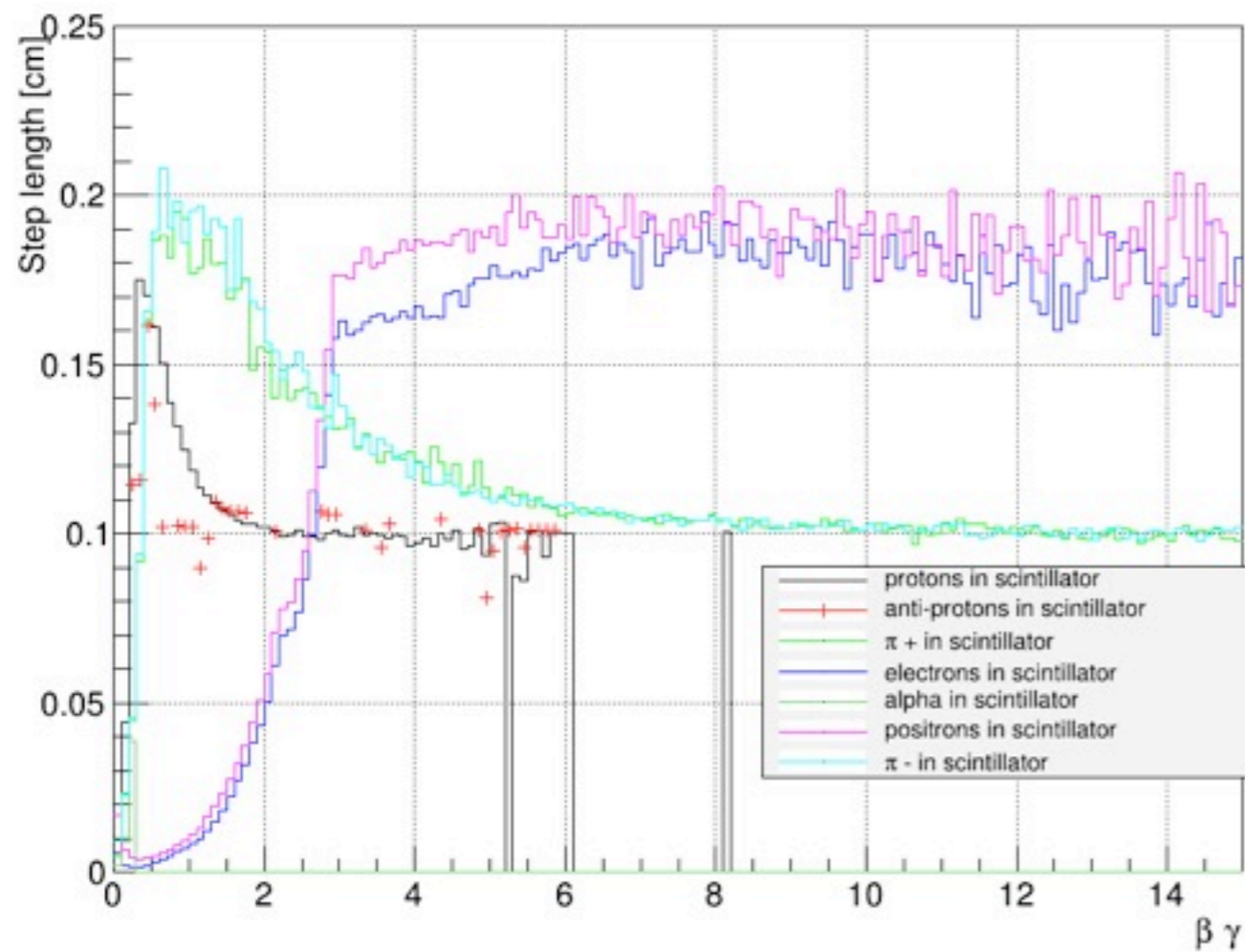
dE/dx as a function of beta*gamma for charged particles



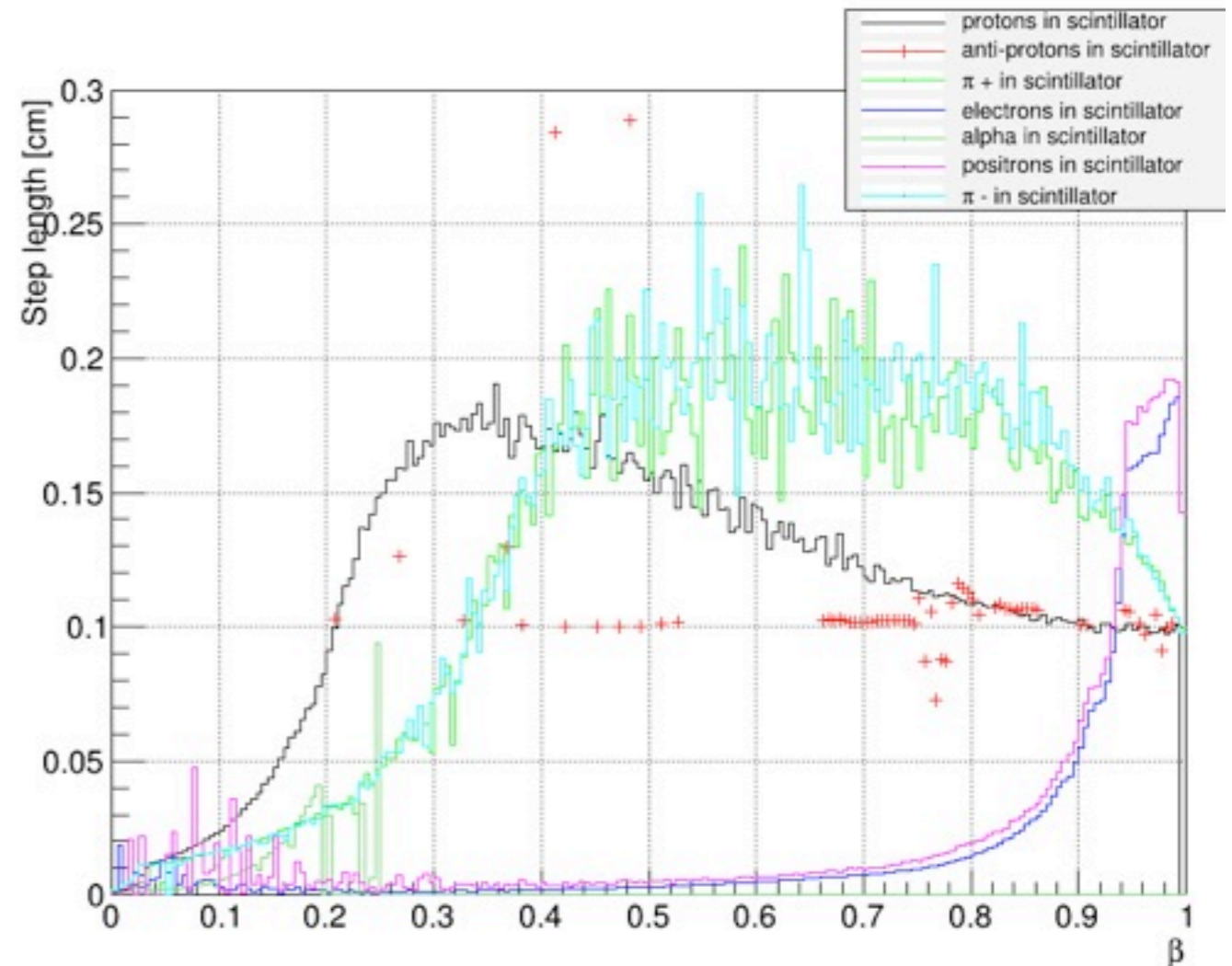
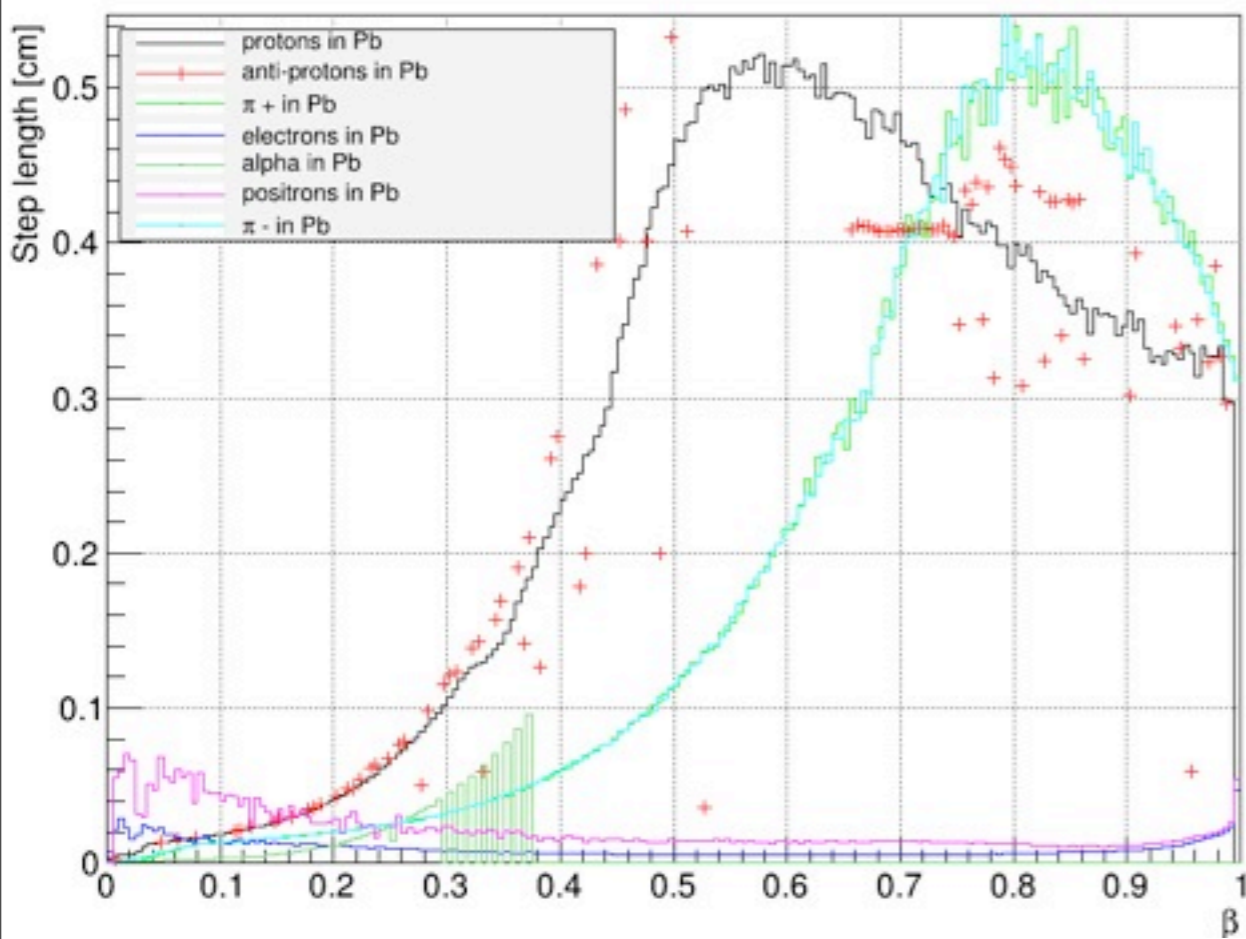
dE/dx as a function of E_{kin} for charged particles



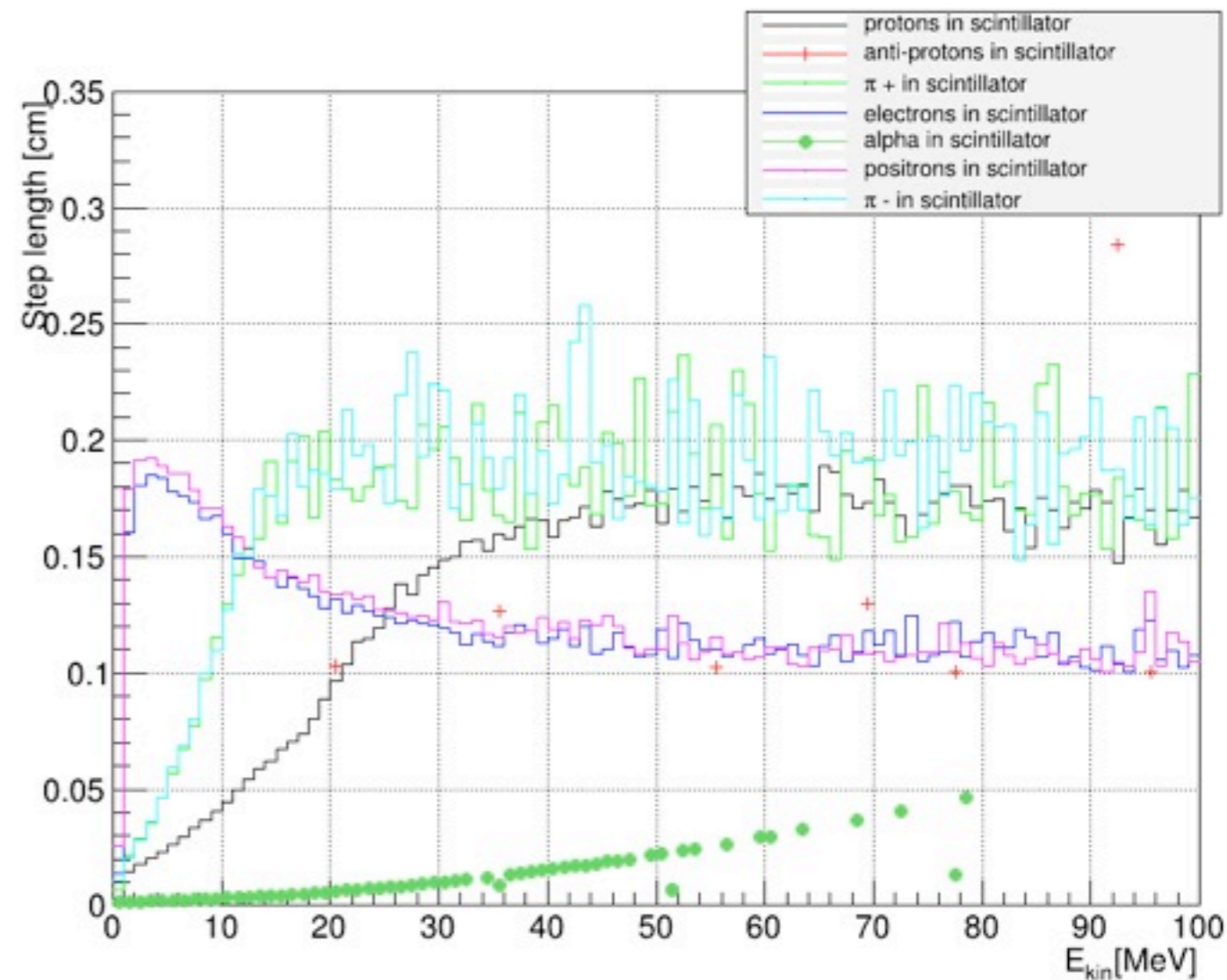
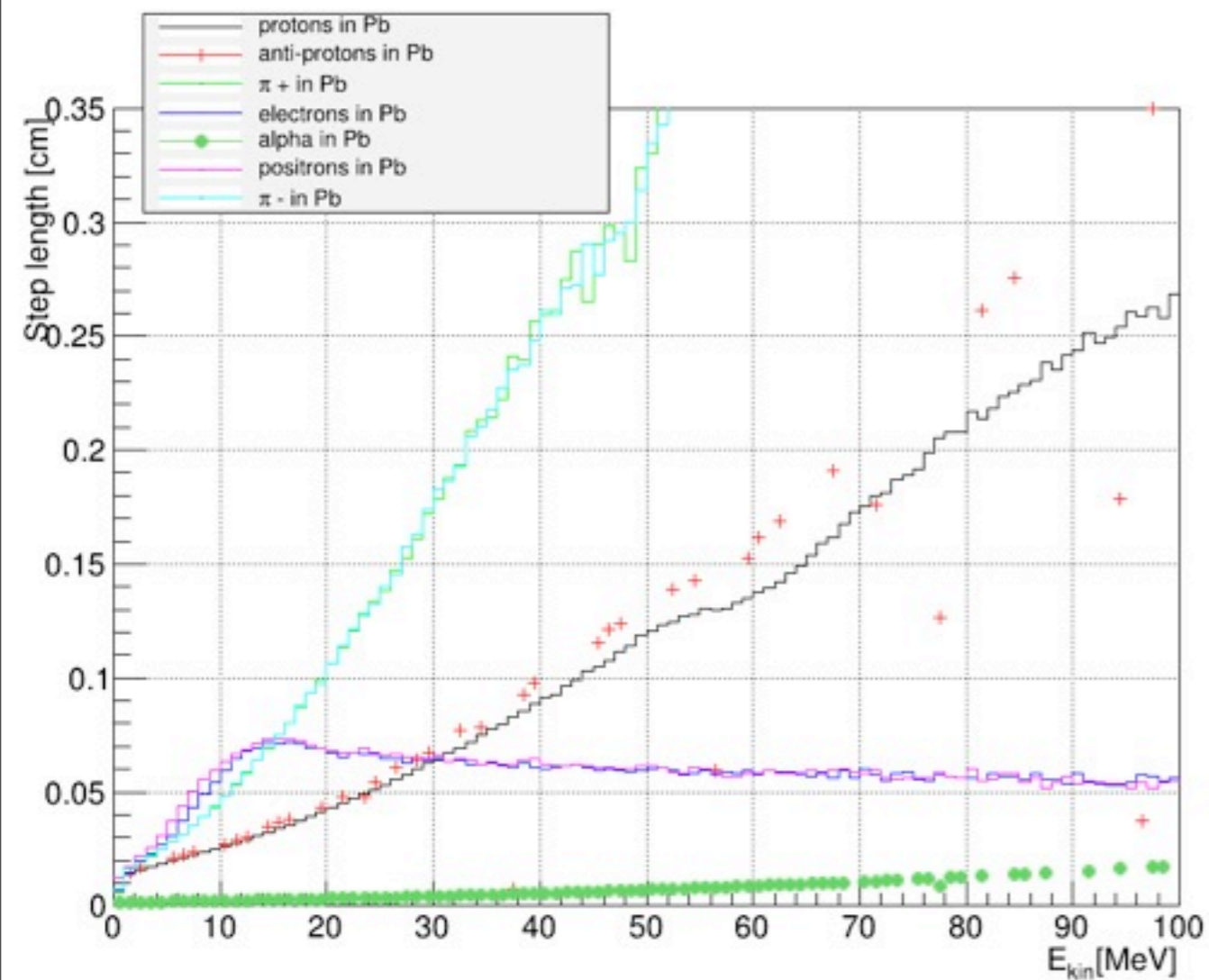
Step length as a function of beta*gamma (15 GeV incident pi-)



Step length as a function of beta (15 GeV incident pi-)



Step length as a function of kinetic energy (15 GeV incident pi-)



Birks attenuation

- Empirical formula for the light yield per path length as a function of the energy loss per path length for a particle traversing a scintillator.
- Heavily ionizing particles produce less light.

$$\frac{dL}{dr} = \frac{S \cdot dE/dr}{1 + c_1 \cdot dE/dr + c_2 \cdot (dE/dr)^2}$$

$$c_1 = 1.29 \times 10^{-2} \text{ g} \cdot \text{cm}^{-2} \cdot \text{MeV}^{-1}$$

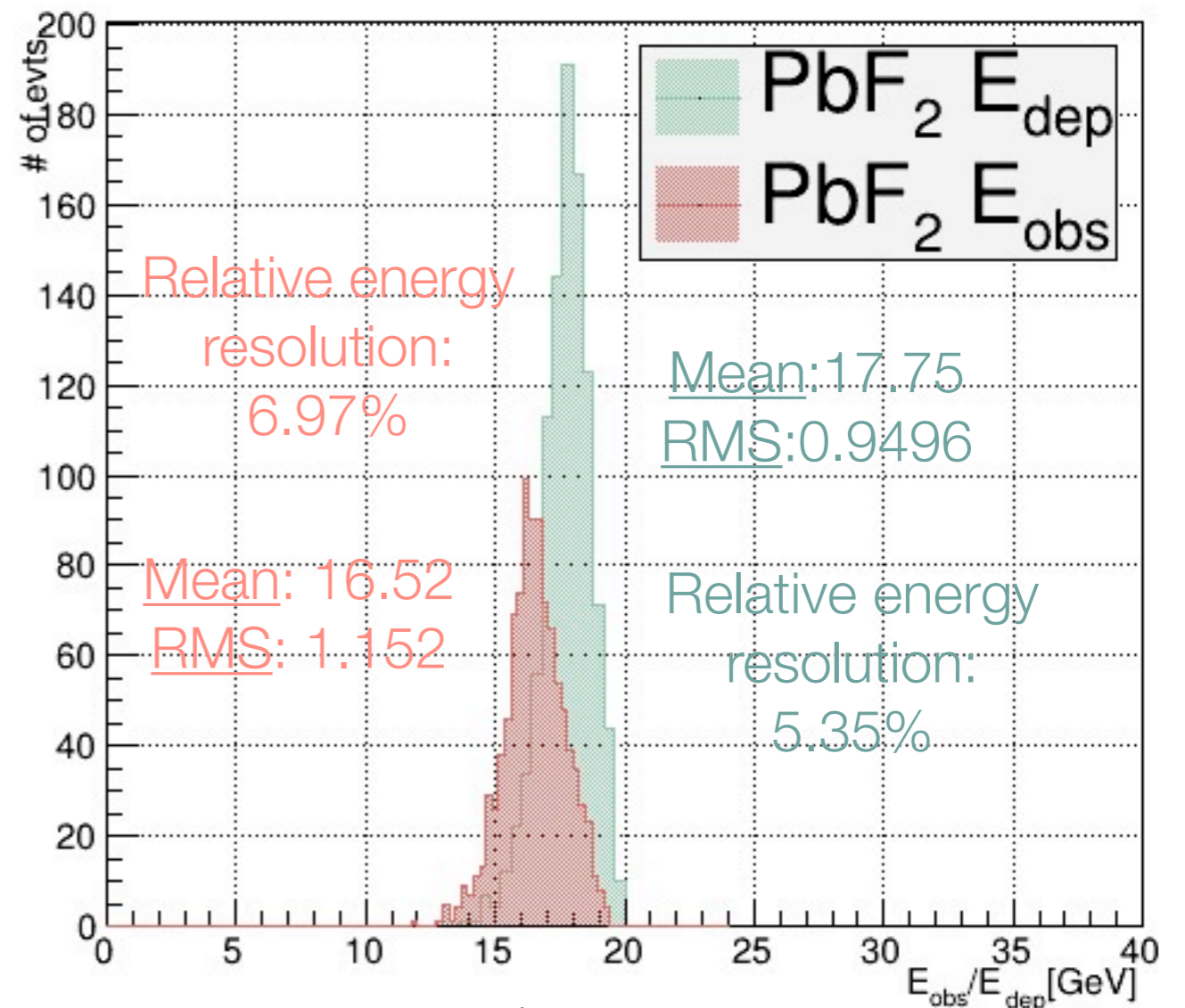
$$c_2 = 9.59 \times 10^{-6} \text{ g}^2 \cdot \text{cm}^{-4} \cdot \text{MeV}^{-2}$$

$$S = 1$$

Values used by ATLAS TileCal and CMS HCAL (also default in Geant3)

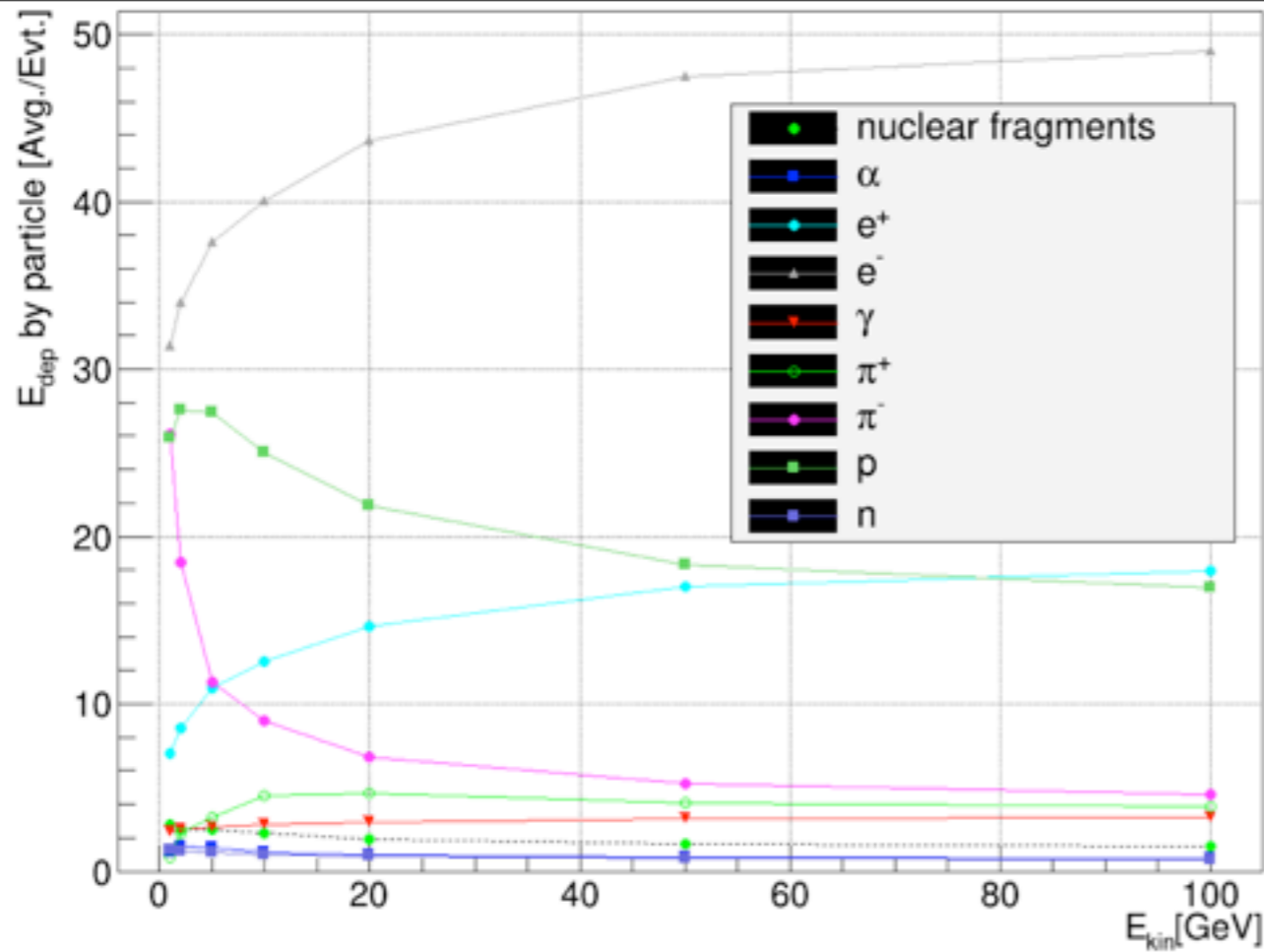
where:

- E_{dep} -> energy deposited in the entire calorimeter volume.
- E_{obs} -> observed energy after applying Birks suppression
- S -> scintillation efficiency (1)
- c_1, c_2 -> Birks constants
- dL/dx -> light output

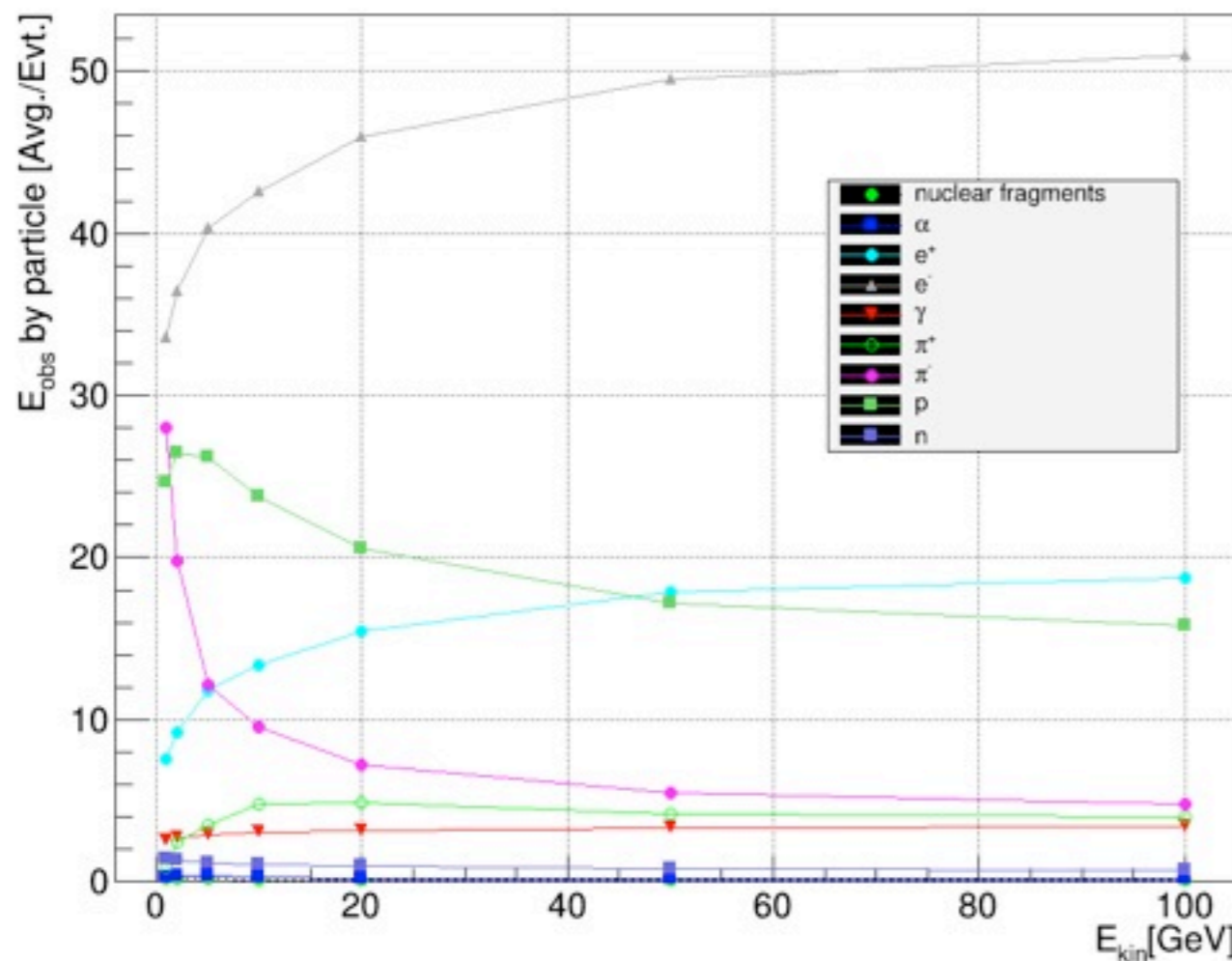


- > 20 GeV incident pi-
- > 1,000 events
- > FTFP_BERT Physics list₁₄
- > PbF2 gdml

Contribution to energy deposition/observed energy by particle (%)

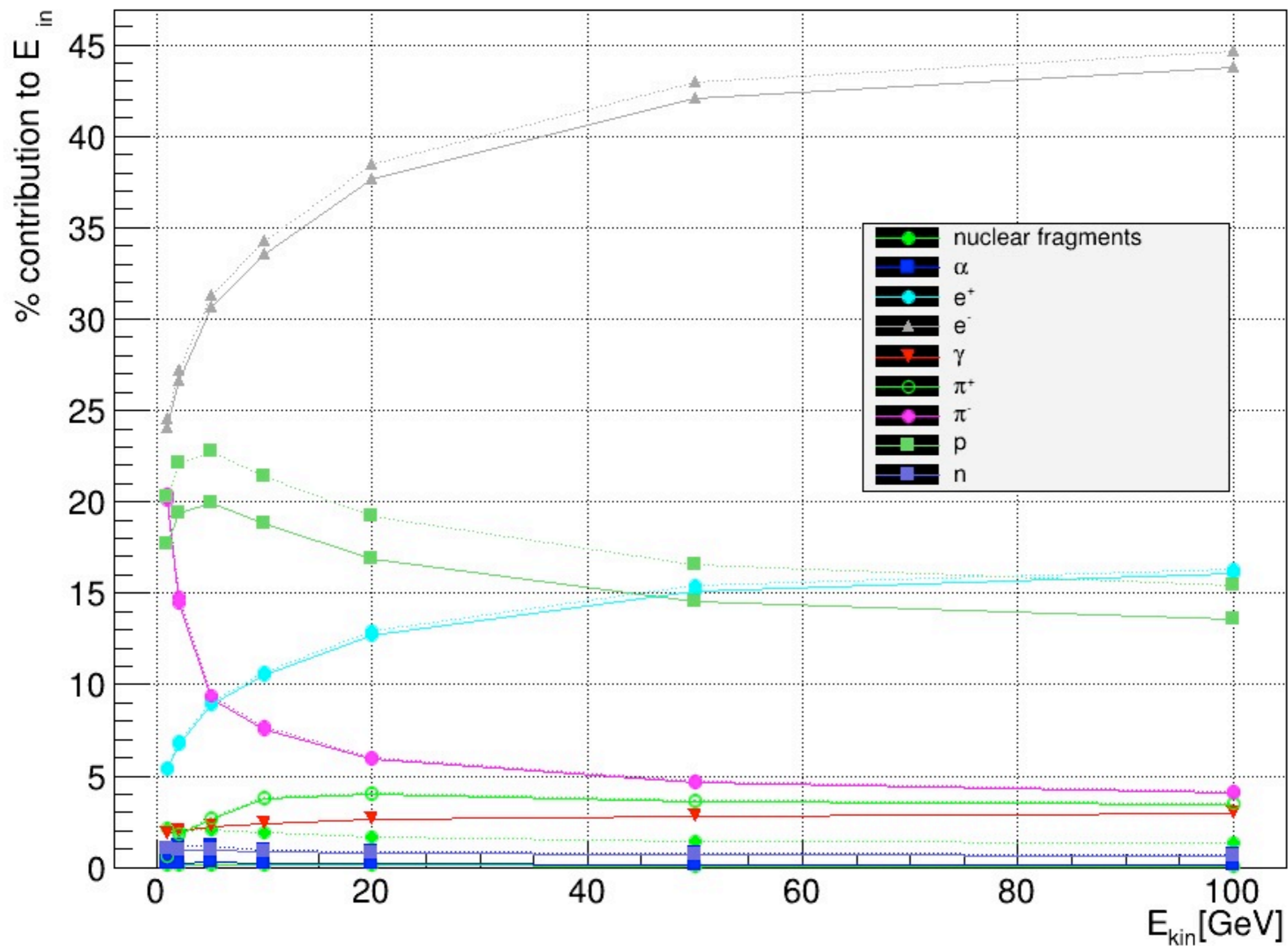


- ➔ Contribution from protons is suppressed.
- ➔ Overall, contribution from electrons is increased after considering Birks suppression.



- > Incident pi-
- > 1,000 events
- > FTFP_BERT Physics list₁₅
- > PbF2 gdml

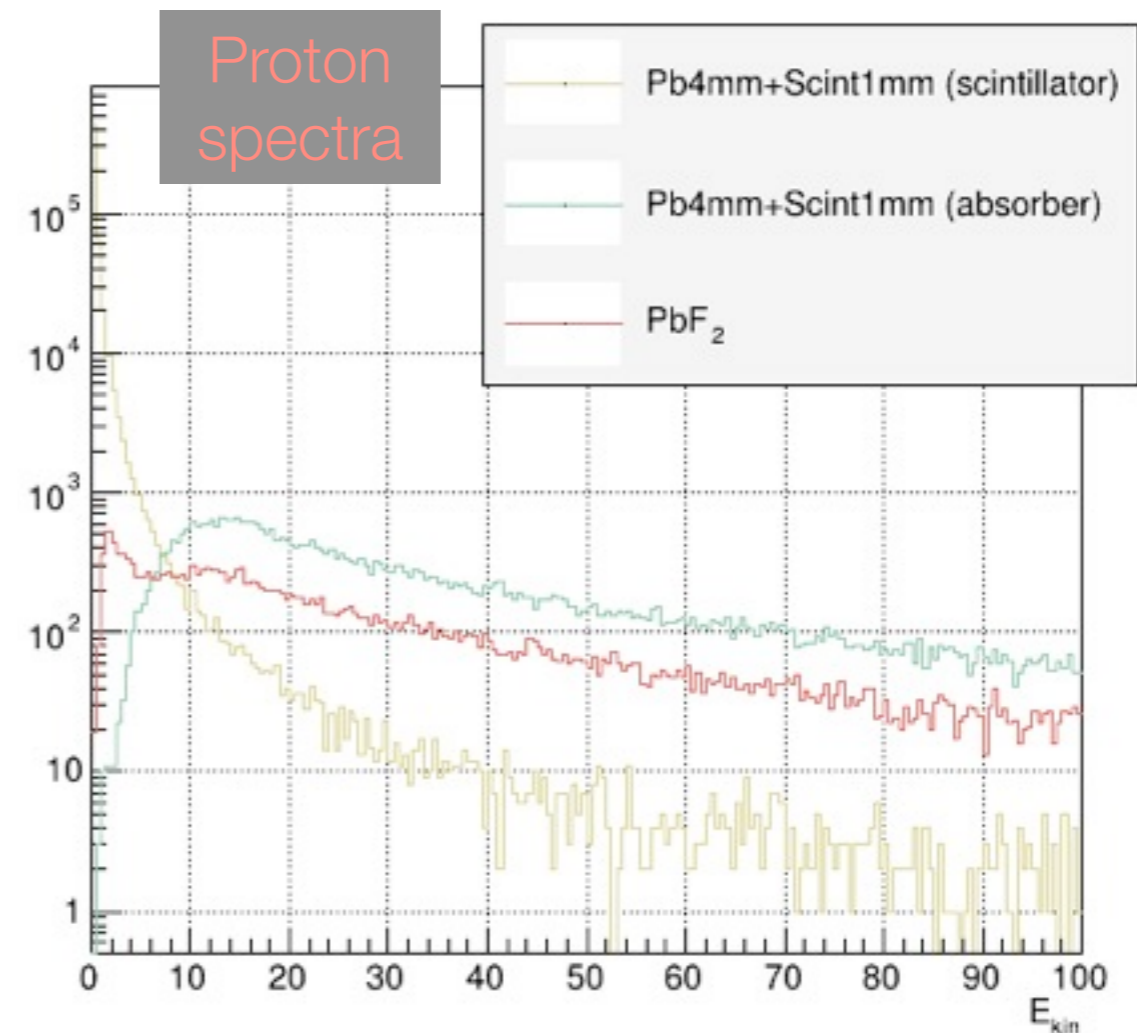
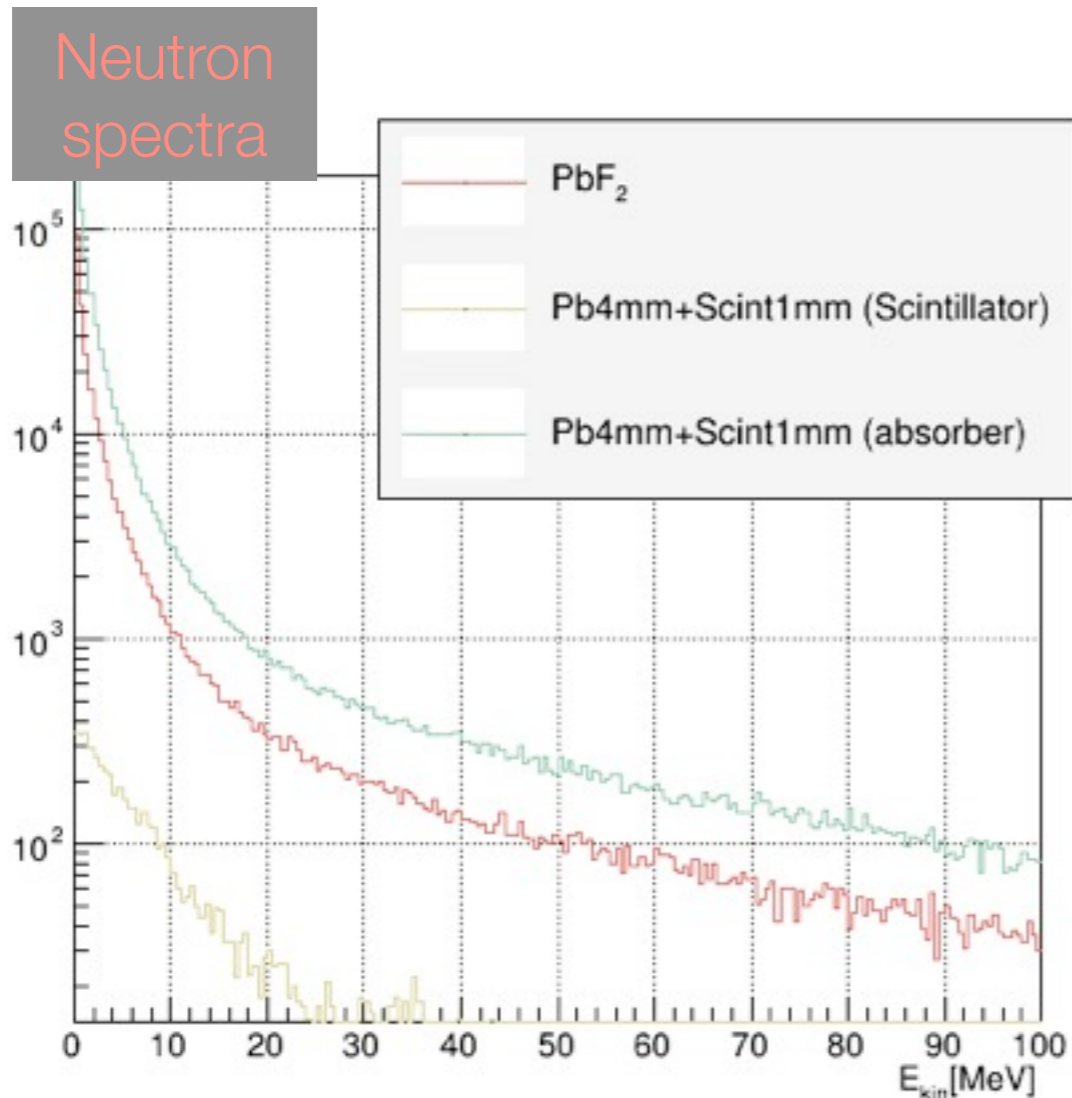
Contribution to incoming energy by particle



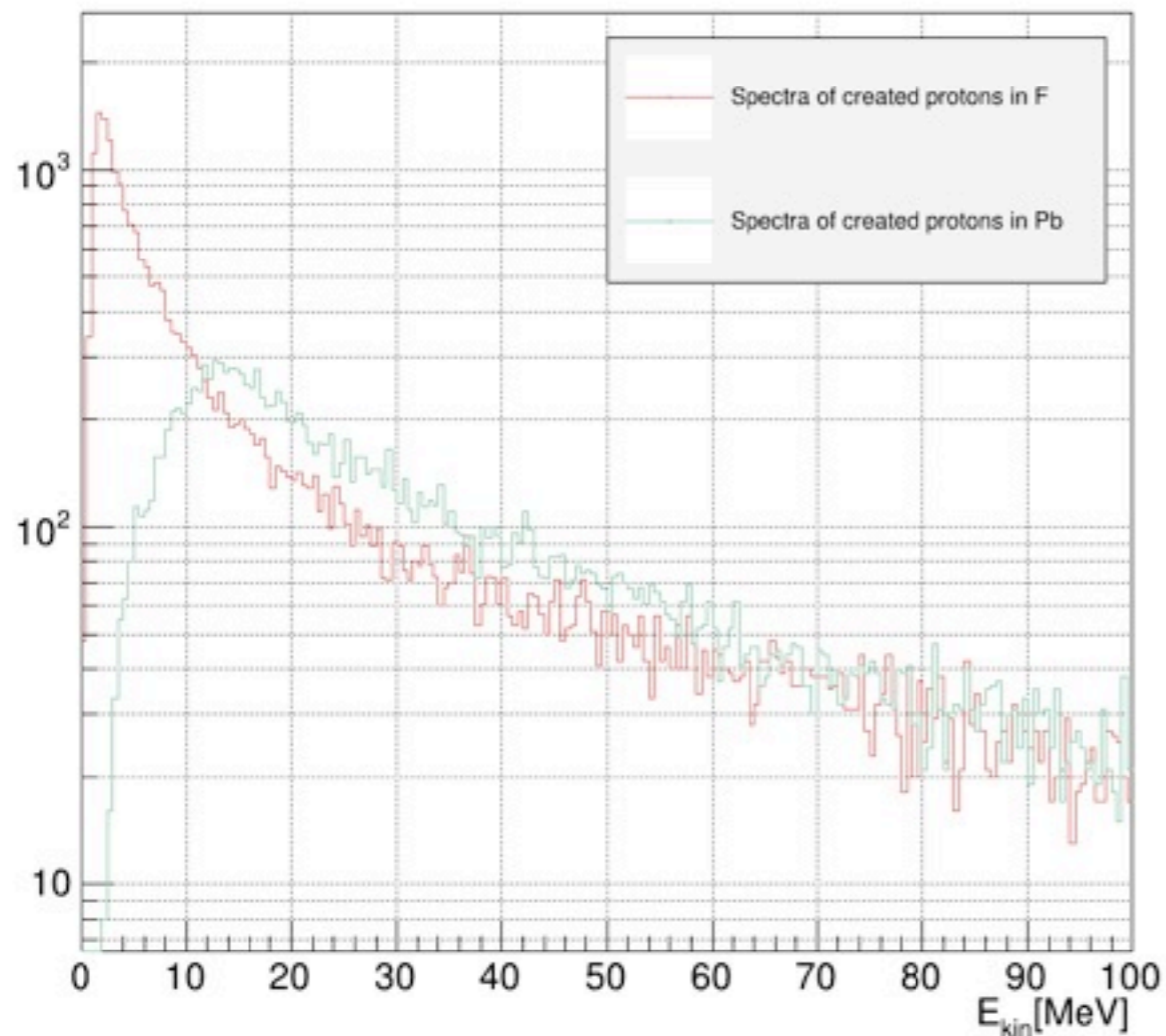
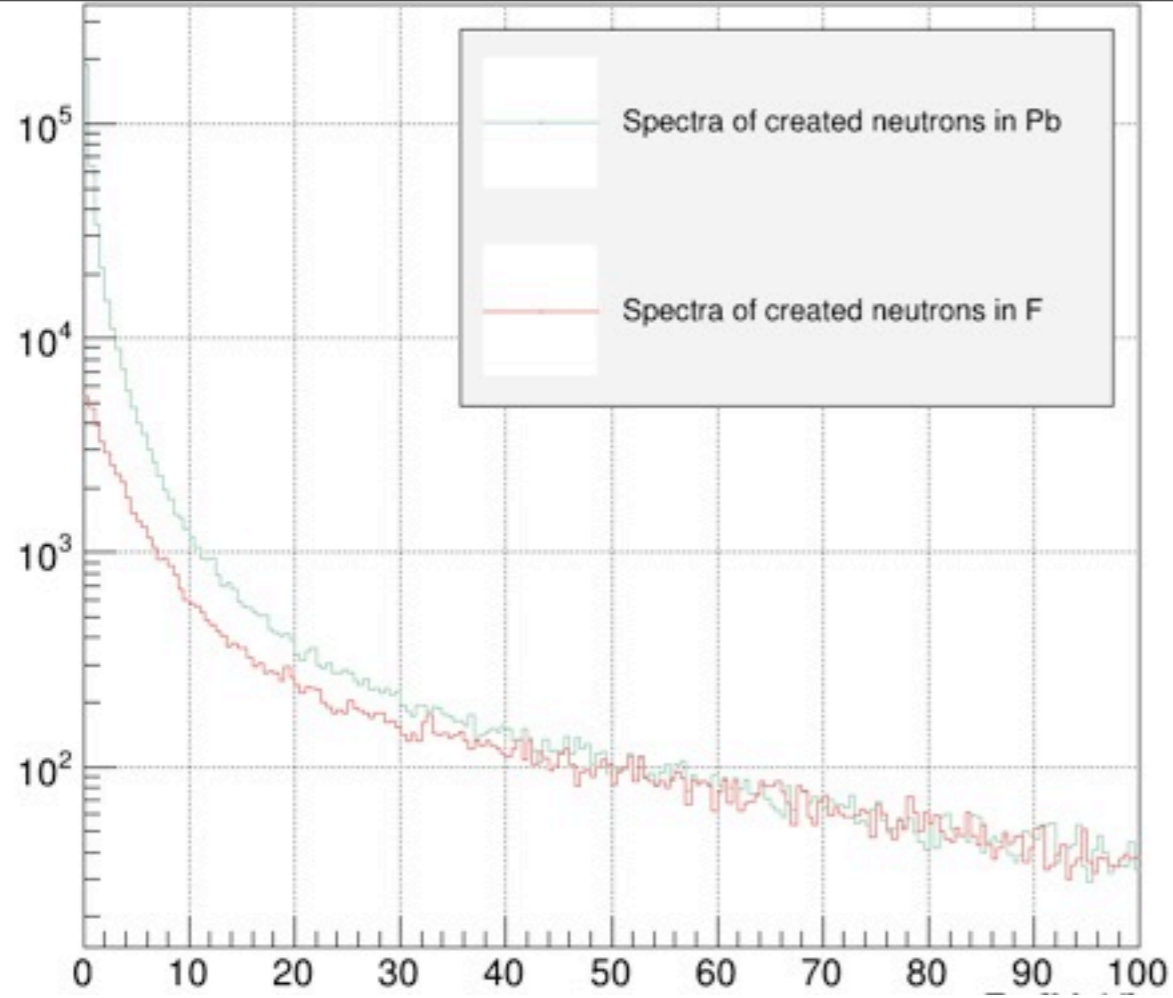
| Material | # of neutrons [avg. per evt.] | # of protons [avg. per evt.] |
|------------------------------|----------------------------------|---------------------------------|
| PbF2 | 279.82 | 24.339 |
| Pb4mmSc1mm (scintillator) | 6.385 | 545.747 |
| Pb4mmSc1mm (Pb) | 781.696 | 49.849 |

Proton/neutron spectra (5 GeV pi⁻)

- ➔ Two components from nuclear spallation processes in PbF2?
- ➔ More neutrons are created in Pb + Scint



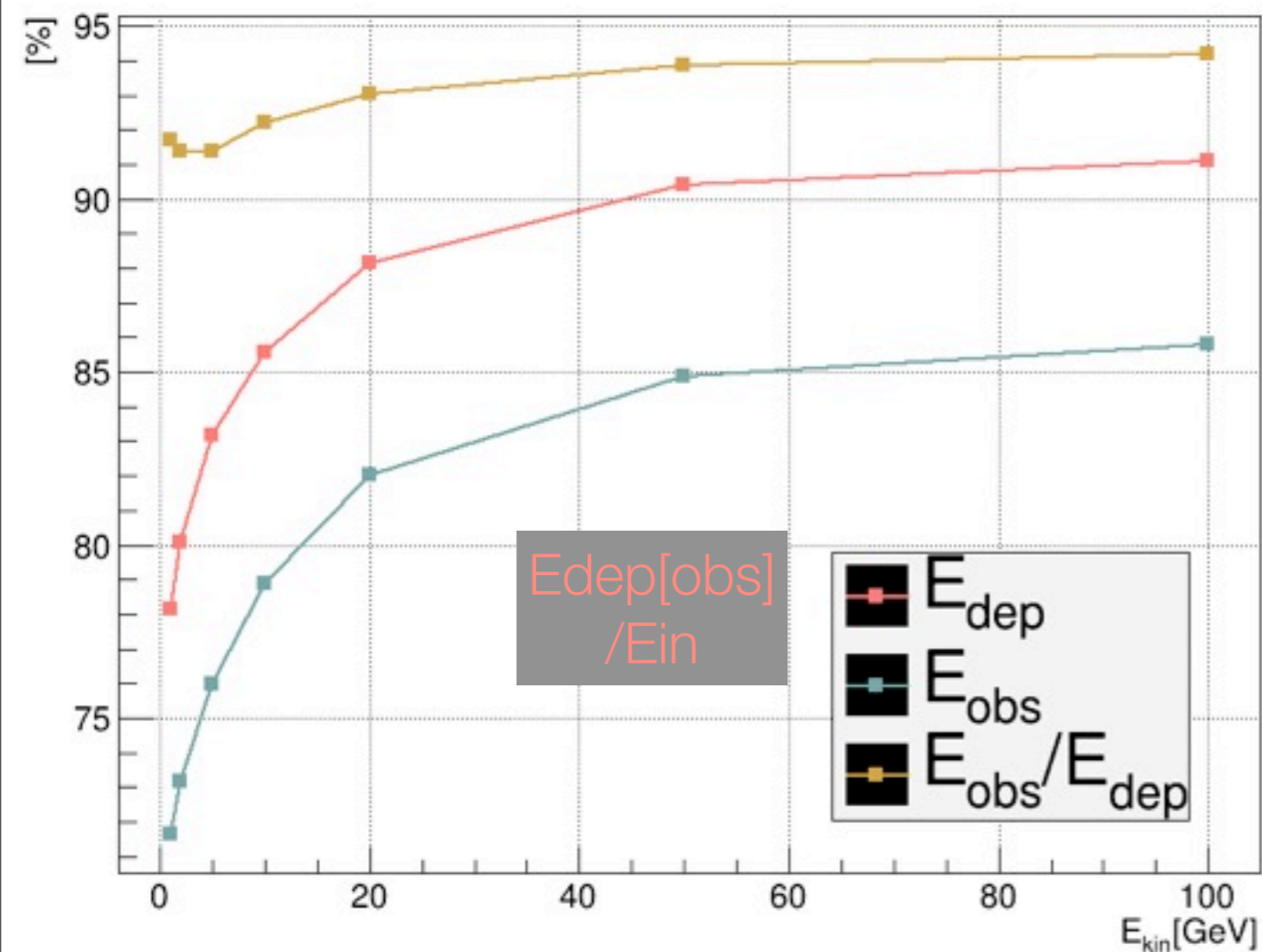
Proton/neutron spectra (5 GeV pi-)



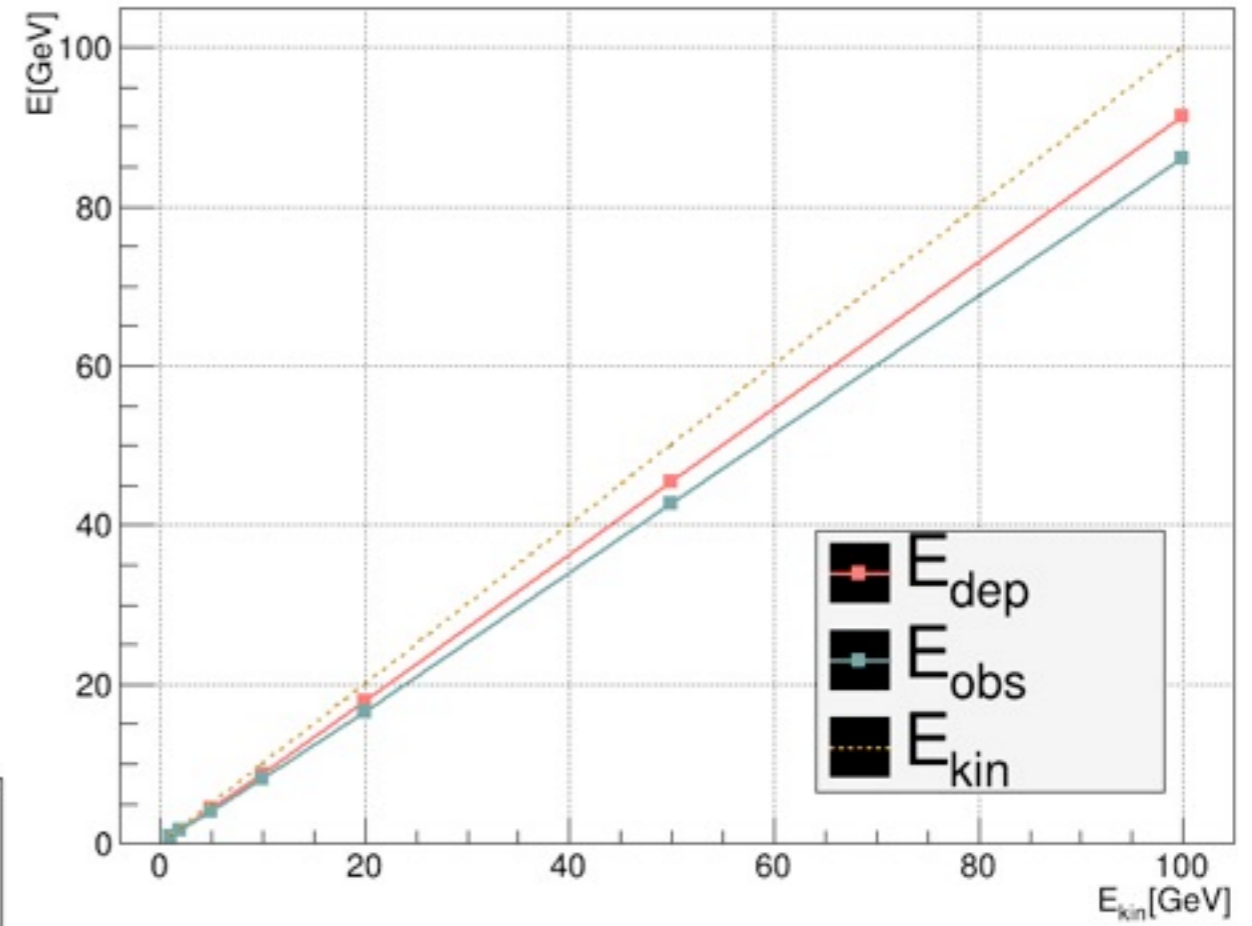
| Material | # of neutrons (avg. per evt.) | # of protons (avg. per evt.) |
|----------|-------------------------------|------------------------------|
| Pb | 419.641 | 21.54 |
| F | 69.11 | 30.426 |

Energy response in PbF2 for incident pi-

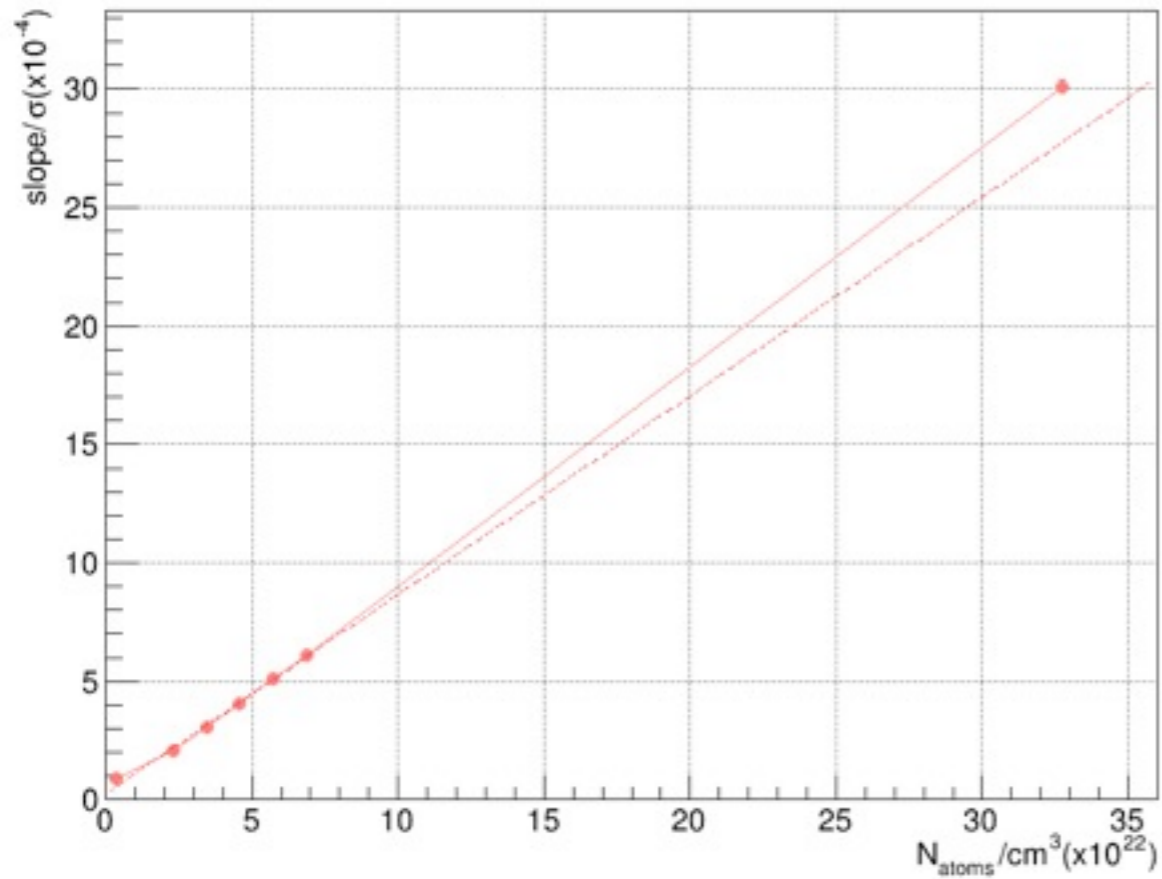
Ratio of energy deposited/observed to E_{in} as a function of E_{kin}



Energy deposited/observed as a function of E_{kin}



Exponential slope of time distribution of neutron capture gammas as a function of # of atoms in W



Exponential slope of time distribution of neutron capture gammas as a function of cubed root of # of atoms in W

