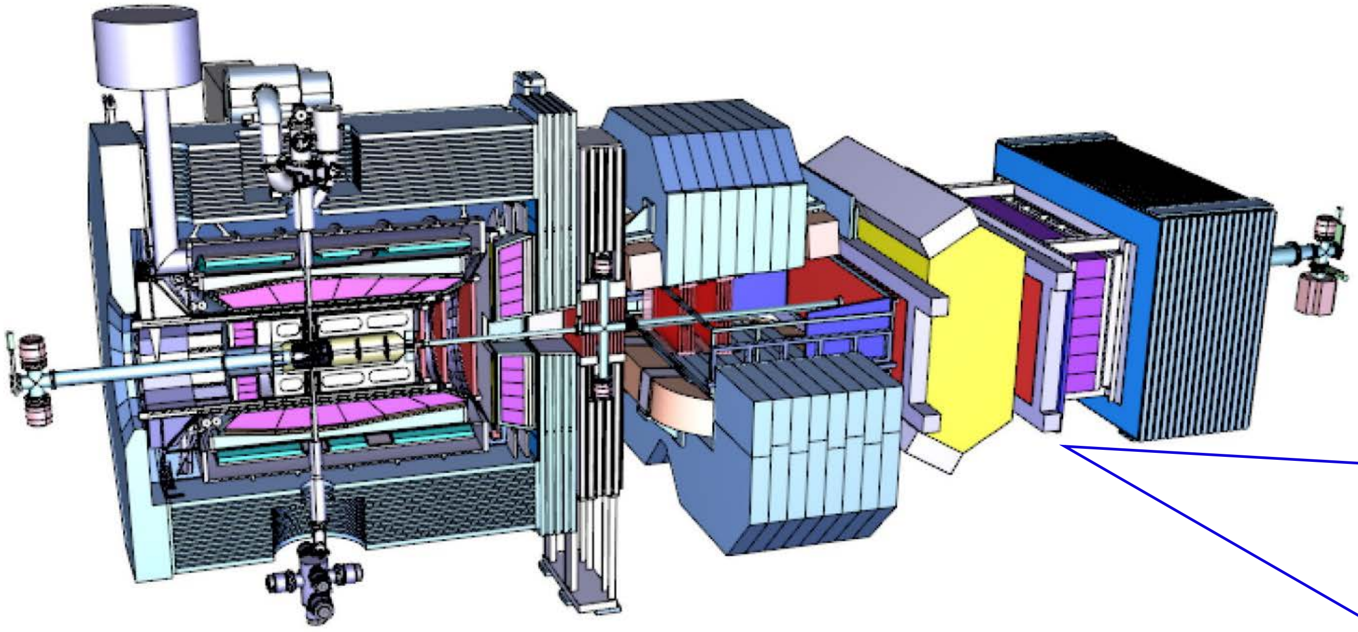
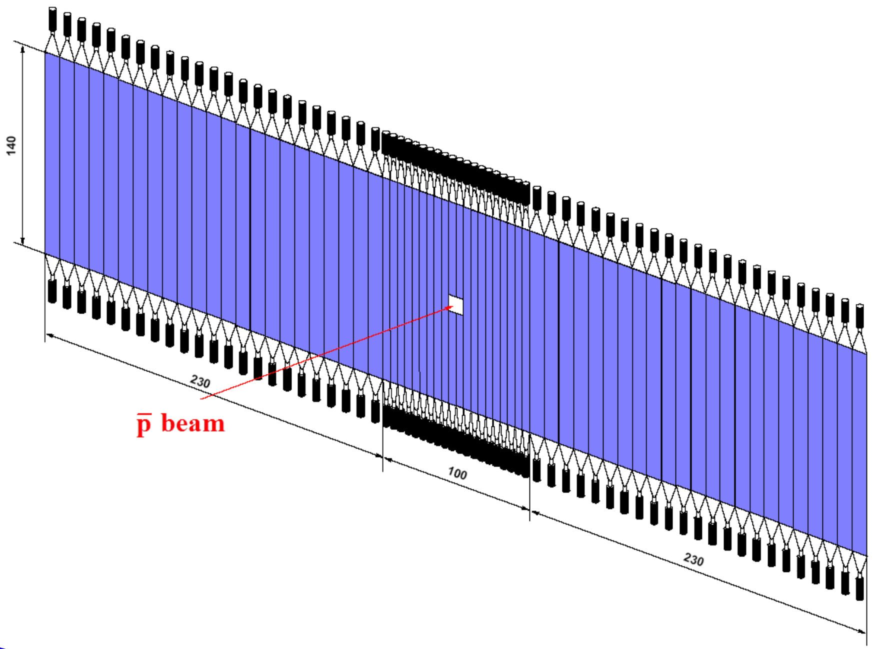
Simulation for FTOF detector

Overview of FTOF detector



66 scintillation counters: 20 counters in the central part and 46 counters in the side parts (23 counters in each side part)



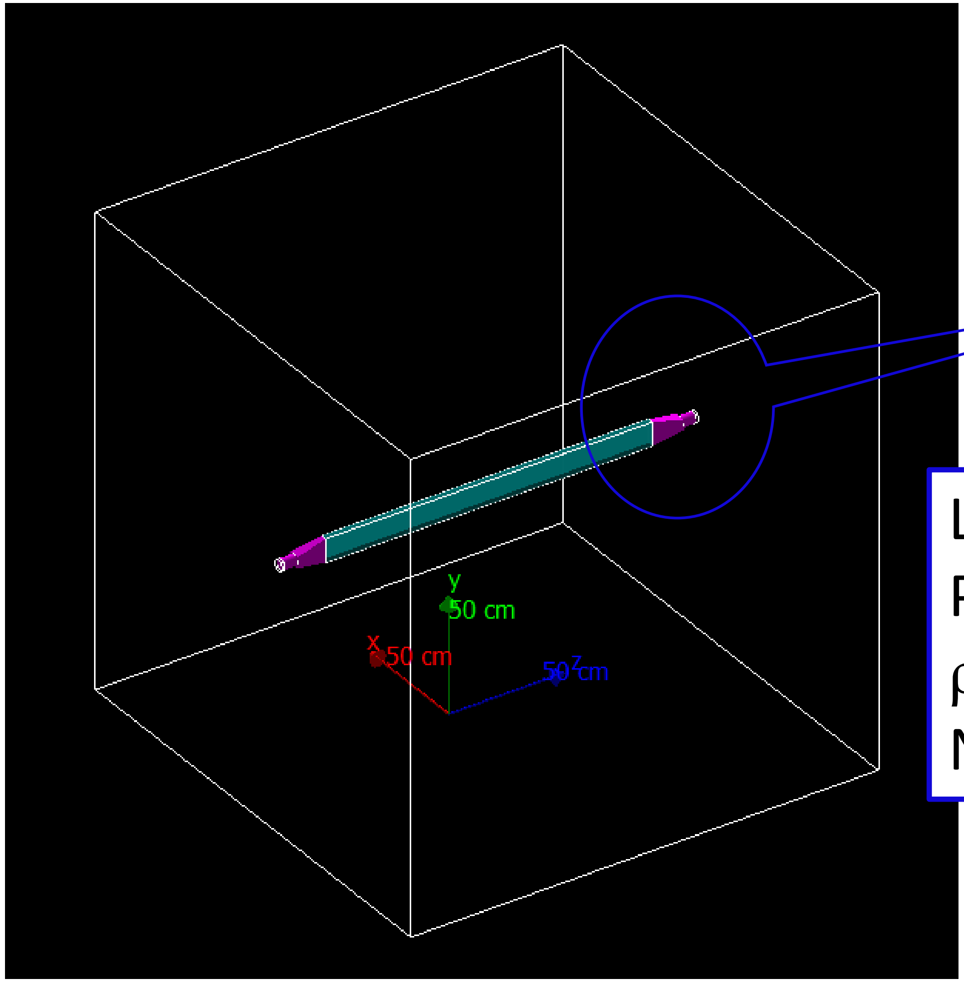
FTOF dedicated to measure the time of flight of forward particles emitted within the forward spectrometer acceptance with $-5° < \theta_y < 5°$ and $-10° < \theta_x < 10°$

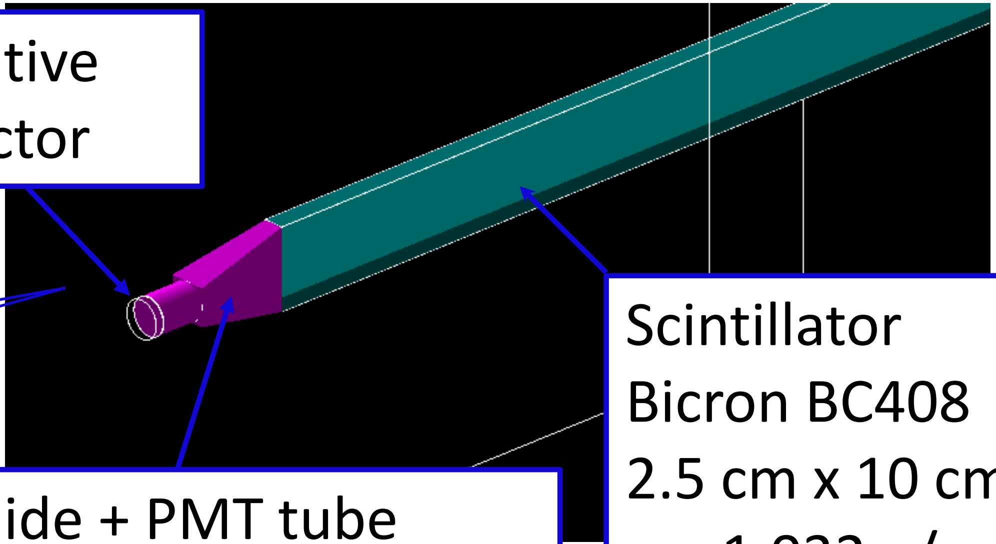
Time resolution in PANDAROOT

- Number of optical photons produced in scintillation process are very high (~ 10 000 per MeV of energy deposit)
- Propagating all of these photons are considerably slow down simulation

- Time resolution depend on:
  - Number of photons
  - Ratio of straight/reflected photons
- Parametrize time resolution as function of energy deposit (number of photons) and hit position (straight/reflected photons ratio)
- In PANDAROOT hit time smeared with parametrized time resolution

Geometry





Sensitive detector

Scintillator
Bicron BC408
2.5 cm x 10 cm x 140 cm
ρ = 1.032 g/cm3
N(C) = 276, N(H) = 250

Lightguide + PMT tube
Plexiglas
ρ = 1.18 g/cm3
N(C) = 5, N(H) = 8, N(O) = 2

Scintillator and lightguide wrapped by mylar foil

Relevant processes for optical photons

Needed material properties:

- atomic composition of the materials used
- refractive index
- absorption length
- scintillation yield (slow/fast)
- scintillation time constant (slow/fast)

To simulate the behavior of the time resolution for TOF bar, optical processes provided by GEANT4 have to be understood:

Process and Geant4 source

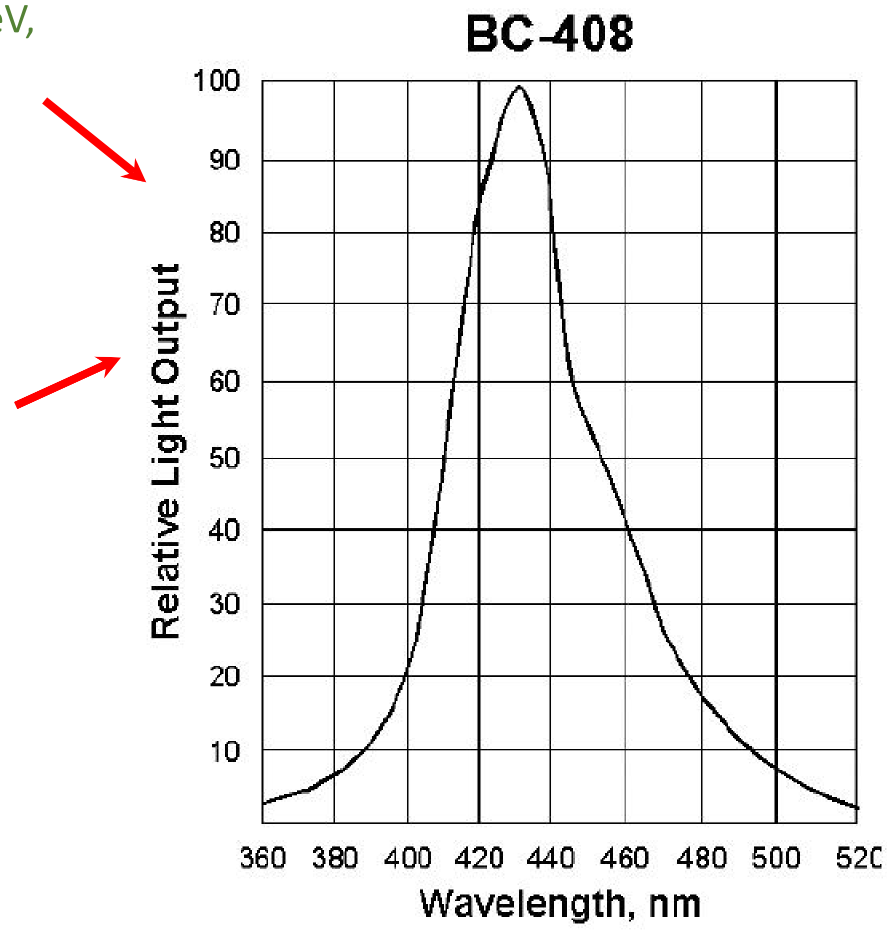
- OpAbsorption processes/optical -> G4OpAbsorption
- OpRayleigh processes/optical -> G4OpRayleigh
- Cerenkov processes/electromagnetic/xray -> G4Cerenkov
- Scintillation processes/electromagnetic/xray -> G4Scintillation
- OpBoundary processes/optical -> G4OpBoundary

Scintillation

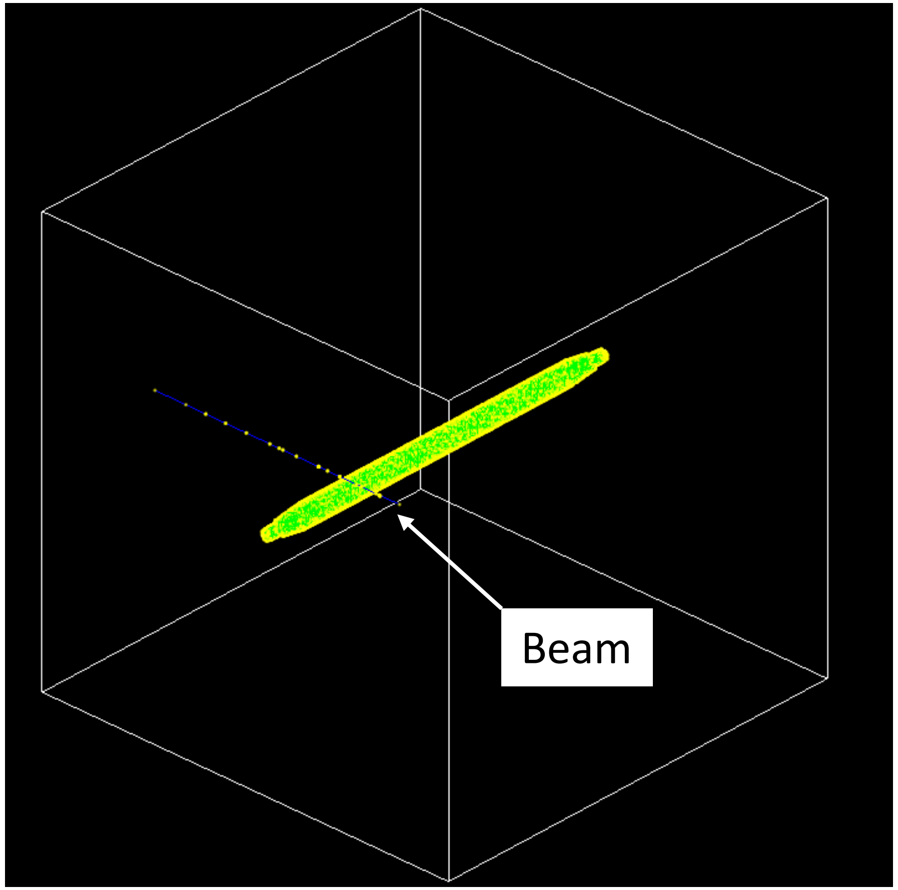
```
G4double PhotonEnergy[nEntries] = { 3.4439*eV, 3.3508*eV, 3.2626*eV, 3.1954*eV,
3.1790*eV, 3.0995*eV,  3.0612*eV, 3.0387*eV, 3.0239*eV, 2.9875*eV,  2.9660*eV,
2.9519*eV,  2.9241*eV, 2.8833*eV, 2.8766*eV, 2.8371*eV,  2.8177*eV, 2.8113*eV,
2.7923*eV, 2.7798*eV, 2.7551*eV, 2.7308*eV,  2.6952*eV, 2.6835*eV,  2.6491*eV,
2.6379*eV, 2.5992*eV, 2.5829*eV,  2.5302*eV, 2.5148*eV,  2.4796*eV, 2.4310*eV,
2.3842*eV, 2.08*eV };

G4double ScintillBC408[nEntries] = { 0.03, 0.04, 0.06, 0.1, 0.11, 0.21, 0.3, 0.4, 0.50,
0.70, 0.80, 0.84, 0.9, 0.98, 0.99, 0.9, 0.85, 0.8, 0.70, 0.60, 0.54, 0.50, 0.42, 0.4, 0.3,
0.26, 0.2,  0.17,  0.12, 0.1, 0.07, 0.04, 0.025, 0.0  };

myMPT1->AddConstProperty("SCINTILLATIONYIELD",12800./MeV);
myMPT1->AddConstProperty("RESOLUTIONSCALE",1.0);
myMPT1->AddConstProperty("FASTTIMECONSTANT", 2.1*ns);
myMPT1->AddConstProperty("SLOWTIMECONSTANT",21.*ns);
myMPT1->AddConstProperty("SLOWSCINTILLATIONRISETIME",0.9*ns);
myMPT1->AddConstProperty("FASTSCINTILLATIONRISETIME",0.9*ns);
myMPT1->AddConstProperty("YIELDRATIO",1.0);
```



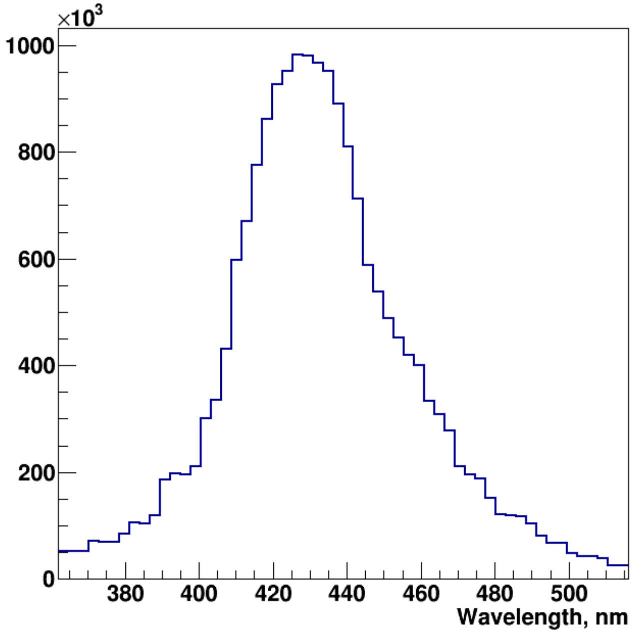
Optical photons simulation

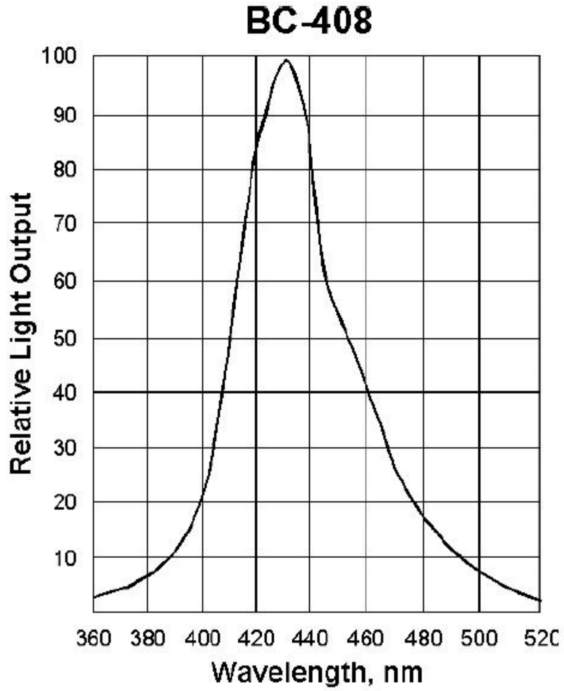


Hit 1000 protons with energy 500 MeV, beam shifted by 40 cm to left side (take ~14 hours to simulate propagation of all photons)

Produced photons 83.89 M

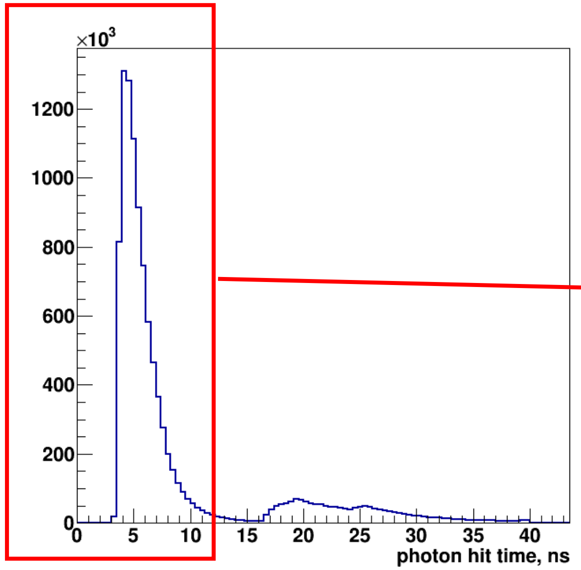
Detected (both sides) 19.47 M (10.65M left and 8.81M right)

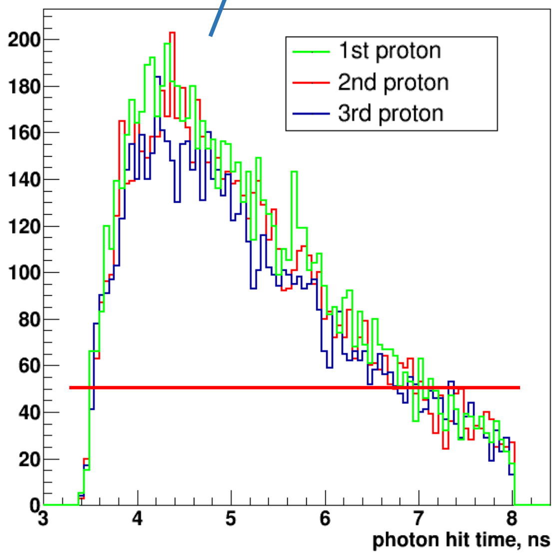


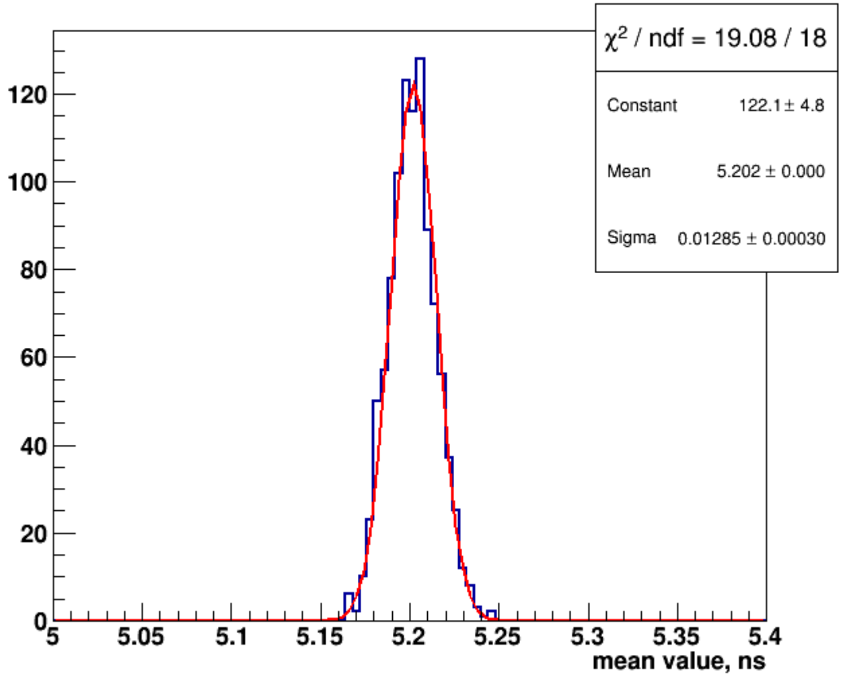


Time resolution (left side)

Number of photons per one proton ~10 000







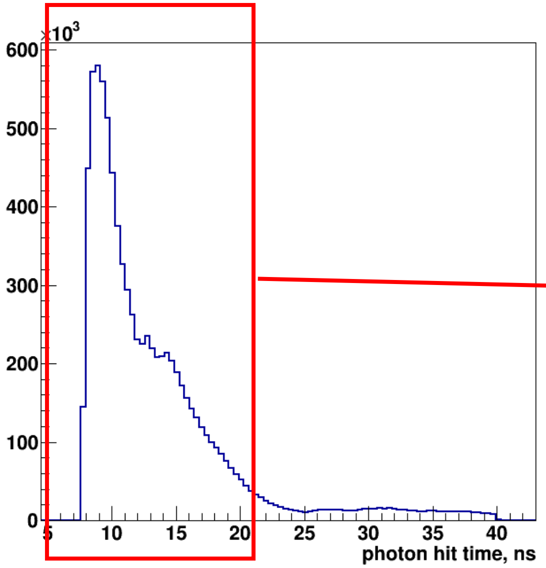
Scintillator time resolution can be calculated as width of the distribution of photons mean time over threshold (calculated for photons from one primary).

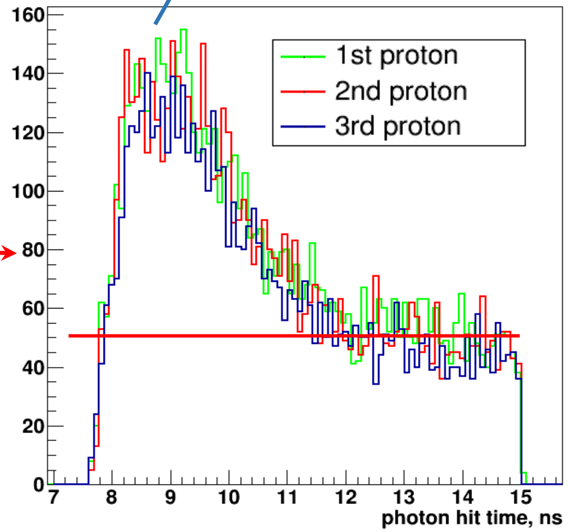
Number of photons are statistically fluctuating, so peak position also fluctuating from one primary to another

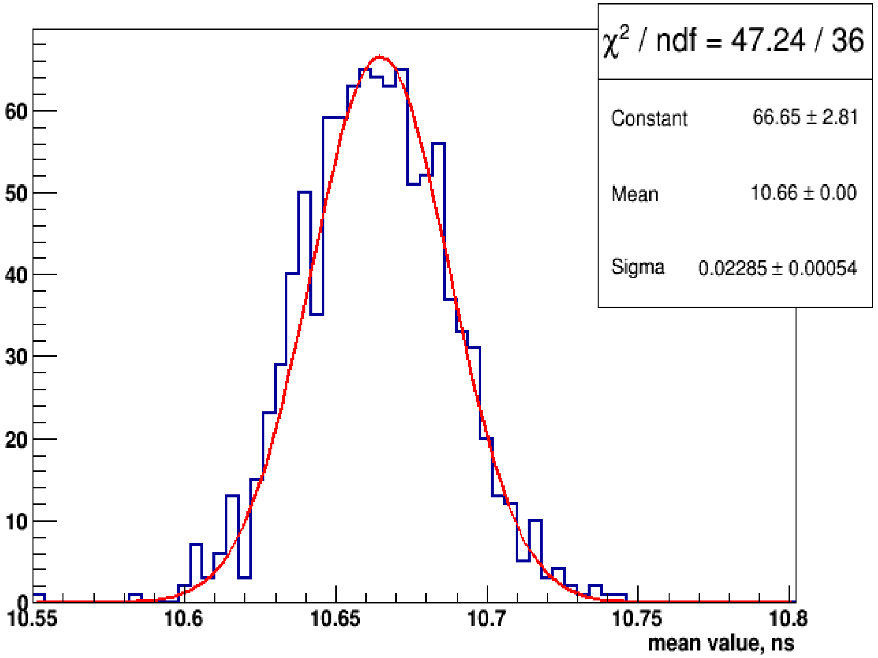
For protons with energy 500 MeV and hit position close to the counter, the own scintillator resolution ~13 ps

Time resolution (right side)

Number of photons per one proton ~8 500







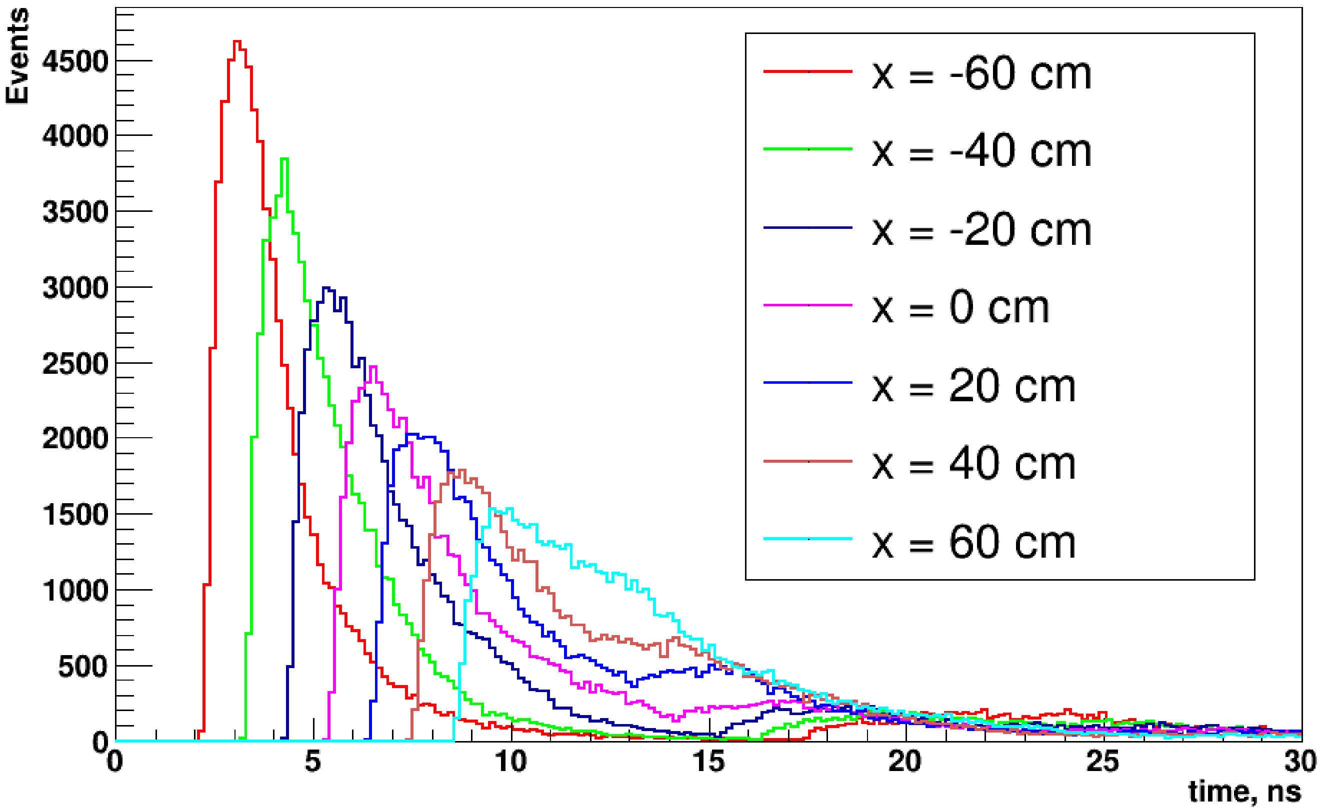
Scintillator time resolution also depend from straight/reflected photons ratio. For higher number of reflected photons resolution became worst.

For protons with energy 500 MeV and hit position far from the counter, the own scintillator resolution ~23 ps

Total time resolution = Scintillator + PMT + readout
from experiment we got 70 ps

PMT gain fluctuation (HV, temperature etc.)

Time signal



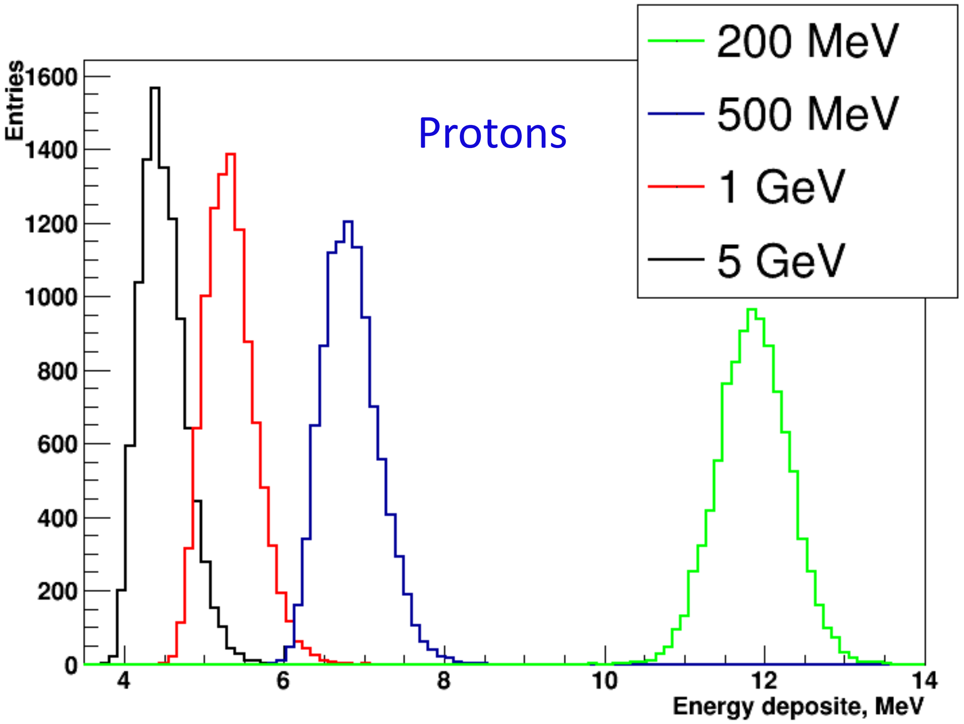
Hit position 0 cm correspond to middle of the TOF bar, -60 cm means 10 cm from left side and 60 cm means 130 cm from left side.

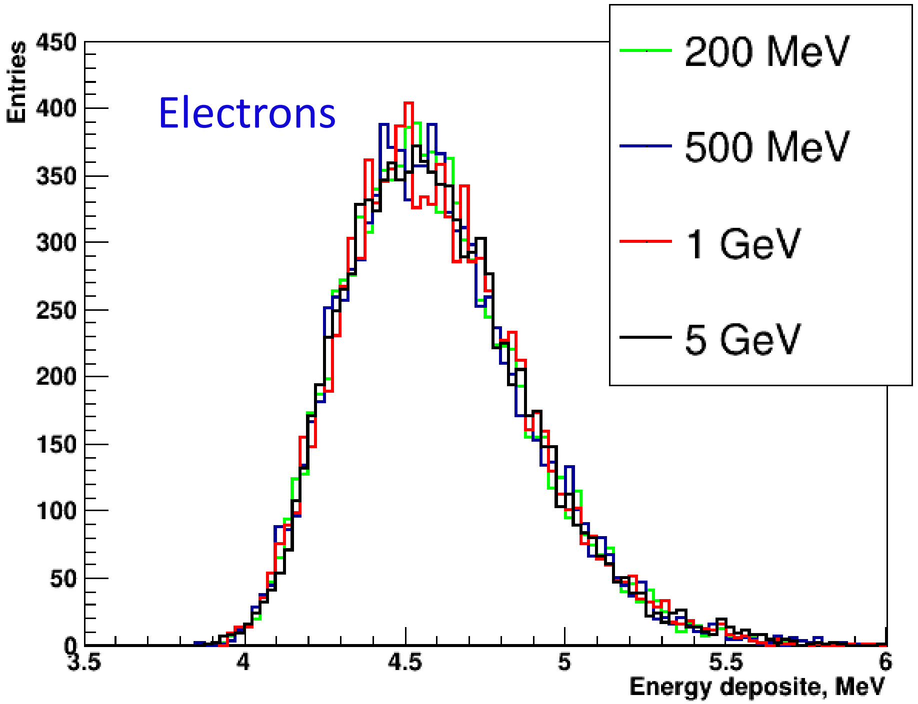
When hit position far from counter photons time distribution became more wide, rising edge is not as sharp as for closest position → time resolution get worse.

Total time resolution = Scintillator1 + Scintillator2

From test experiment we got 70 ps

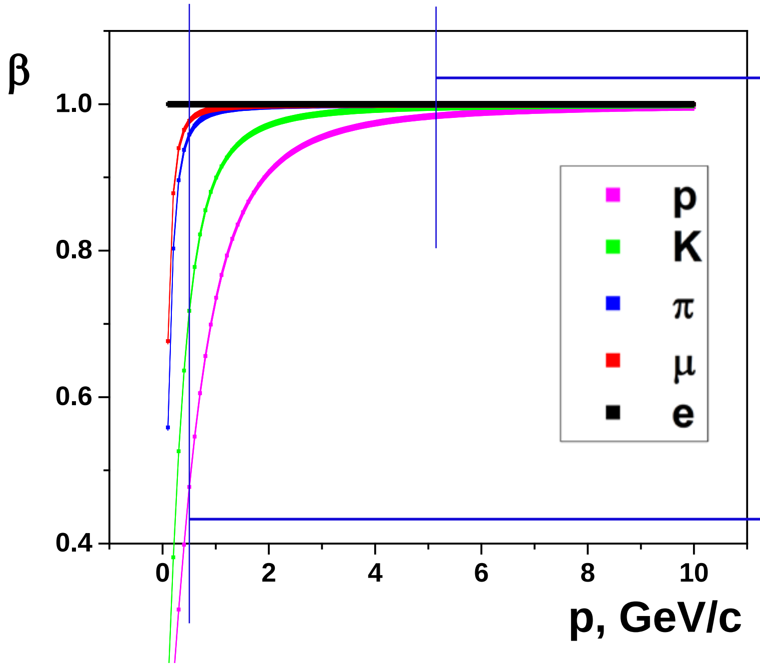
Energy deposit

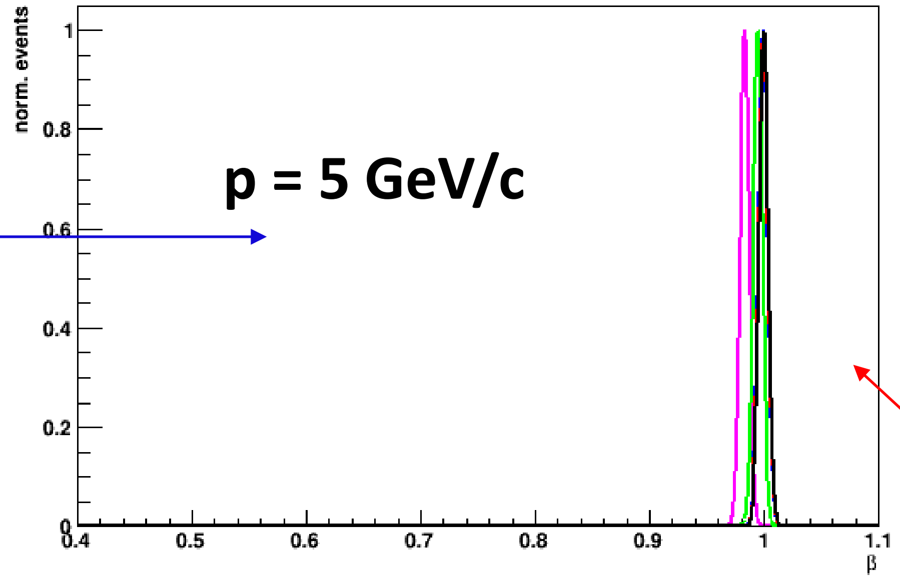


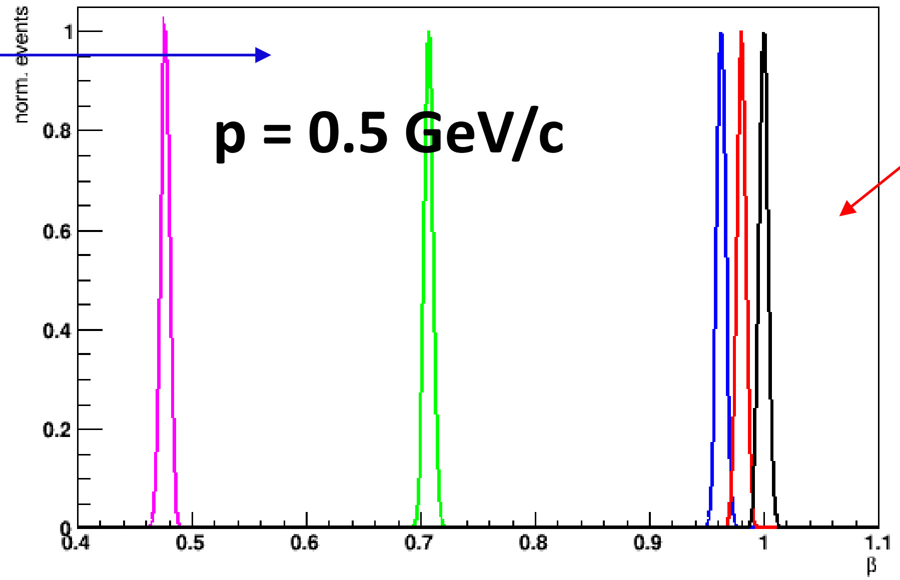


All electrons are reenergizes are relativistic and energy deposited does not depend from energy
Energy deposite distribution is not Landau distribution due to thickness of plastic

TOF PID in PANDA ROOT







p.d.f for different particle types

$$\beta = \frac{L}{ct^{TOF}}$$

β is not a constant for given particle and momentum due to TOF (70 ps), momentum and track length resolutions.

t0 determination

"Offline" t0

$$t_1^{TOF} = t_0 + \frac{L_1}{c\beta_1} = t_0 + \frac{L_1}{c}\frac{\sqrt{p_1^2 + m_1^2}}{p_1}$$

$$t_2^{TOF} = t_0 + \frac{L_2}{c\beta_2} = t_0 + \frac{L_2}{c}\frac{\sqrt{p_2^2 + m_2^2}}{p_2}$$

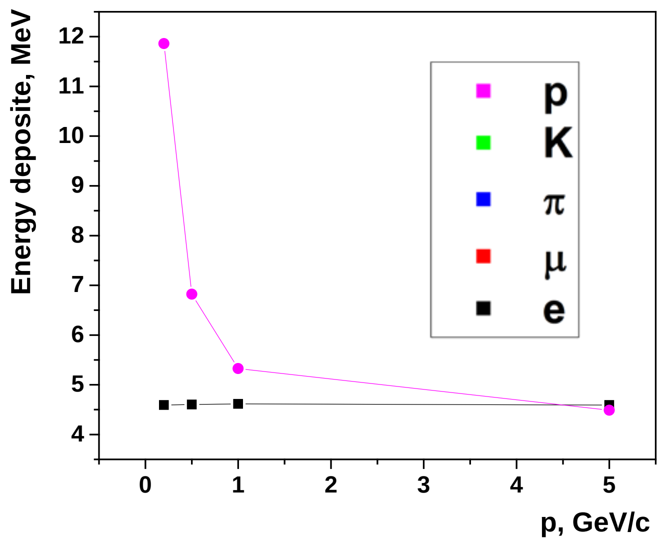
………

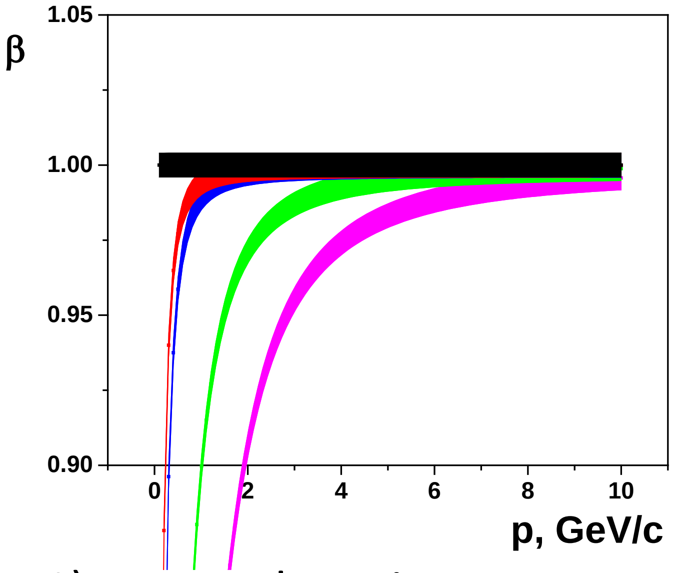
$$t_n^{TOF} = t_0 + \frac{L_n}{c\beta_n} = t_0 + \frac{L_n}{c}\frac{\sqrt{p_n^2 + m_n^2}}{p_n}$$

} TOF hits

- L and p provided by tracking
- m can be only m_p, m_K, m_π, m_μ or m_e
- Loop over all possible combination and find right one

"Online" t0





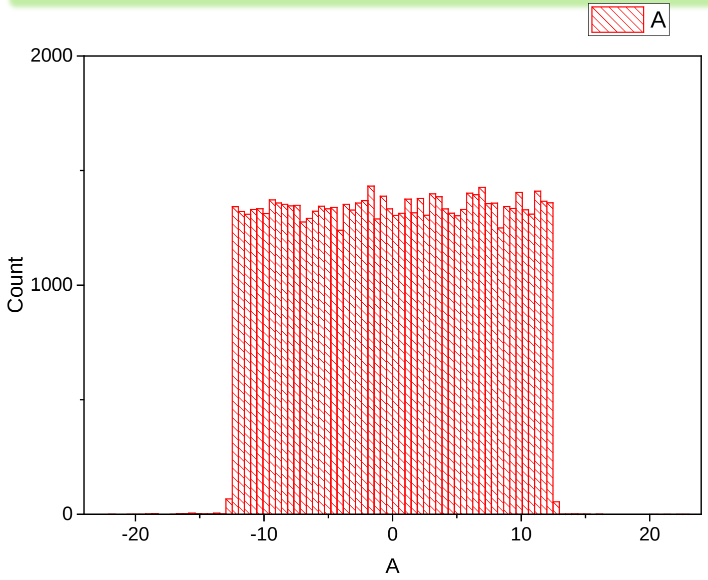
For high relativistic particles (β ≅ 1) energy deposit not depend from particle type. For 2.5 cm plastic Edep = 4.6 MeV.

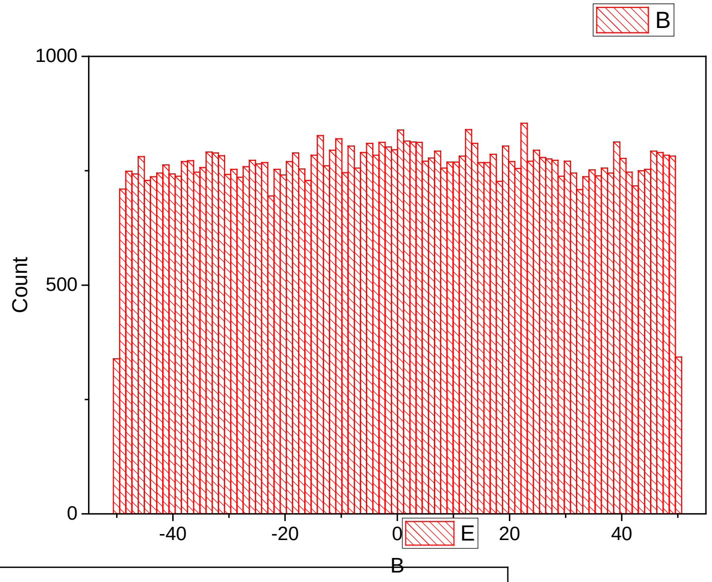
If for one hit Edep ≅ 4.6 MeV, so β ≅ 1 and t_0 can be calculate $t_0 = t^{TOF} - L/c$ assuming track as straight line

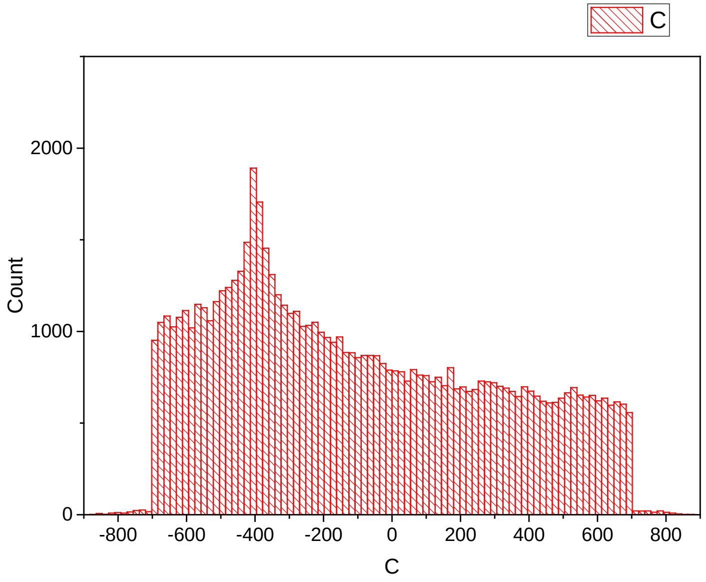
Outlook

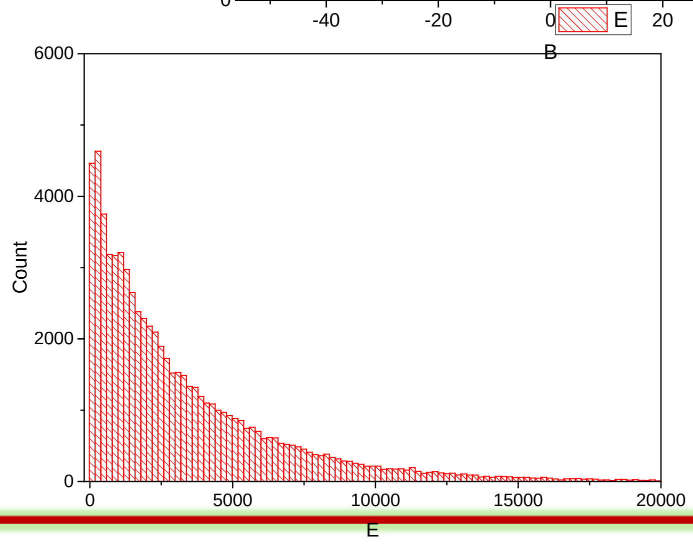
- These simulation studies continue:
  - Add PMT to simulation
  - Parametrize time resolution as function of the energy deposit and hit position
  - Include parametrized time resolution to PANDAROOT
  - Macros for t0 determination

Hits position









PID with time of flight

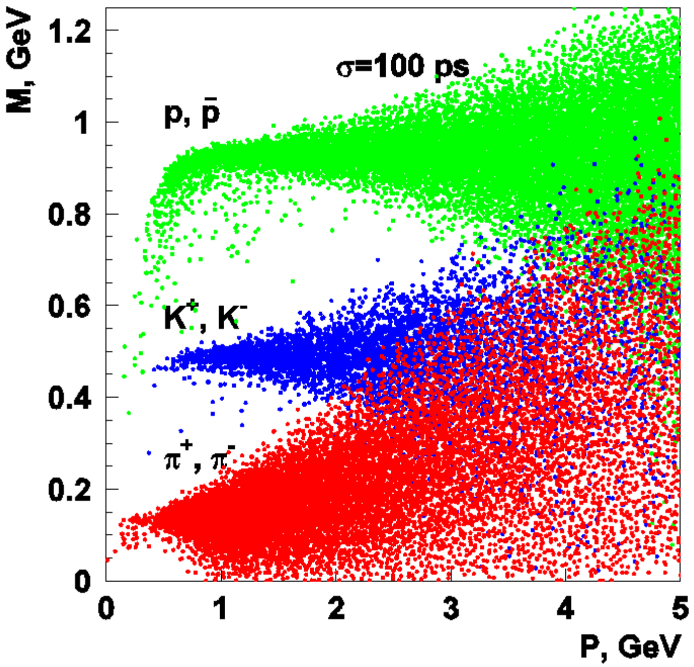
$$m = \frac{p}{c}\sqrt{\frac{t^2c^2}{L^2} - 1}$$

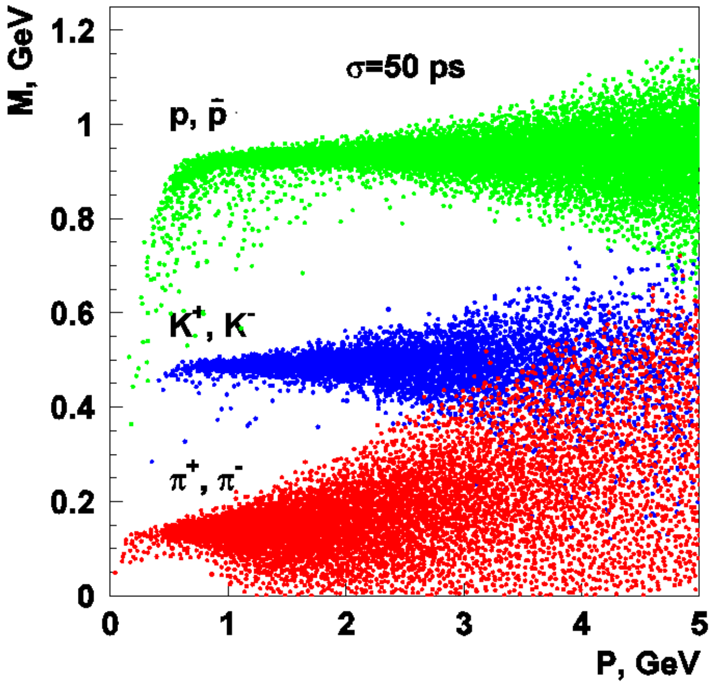
L - track length

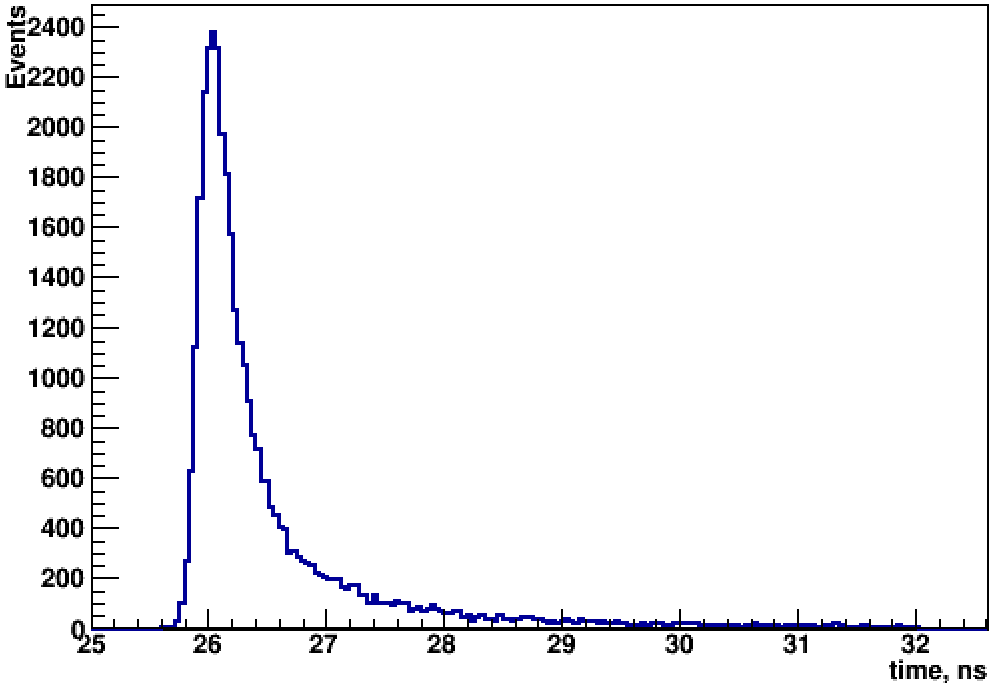
t – TOF time

$$\frac{\delta m}{m} = \sqrt{\left(\frac{\delta p}{p}\right)^2 + \gamma^4\left(\frac{\sigma_{TOF}}{t}\right)^2}$$

Main contribution is σ_{TOF} due to relativistic γ - factor



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time, ns