Neutron detection in a KLOE-based detector

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- Neutron β reconstruction
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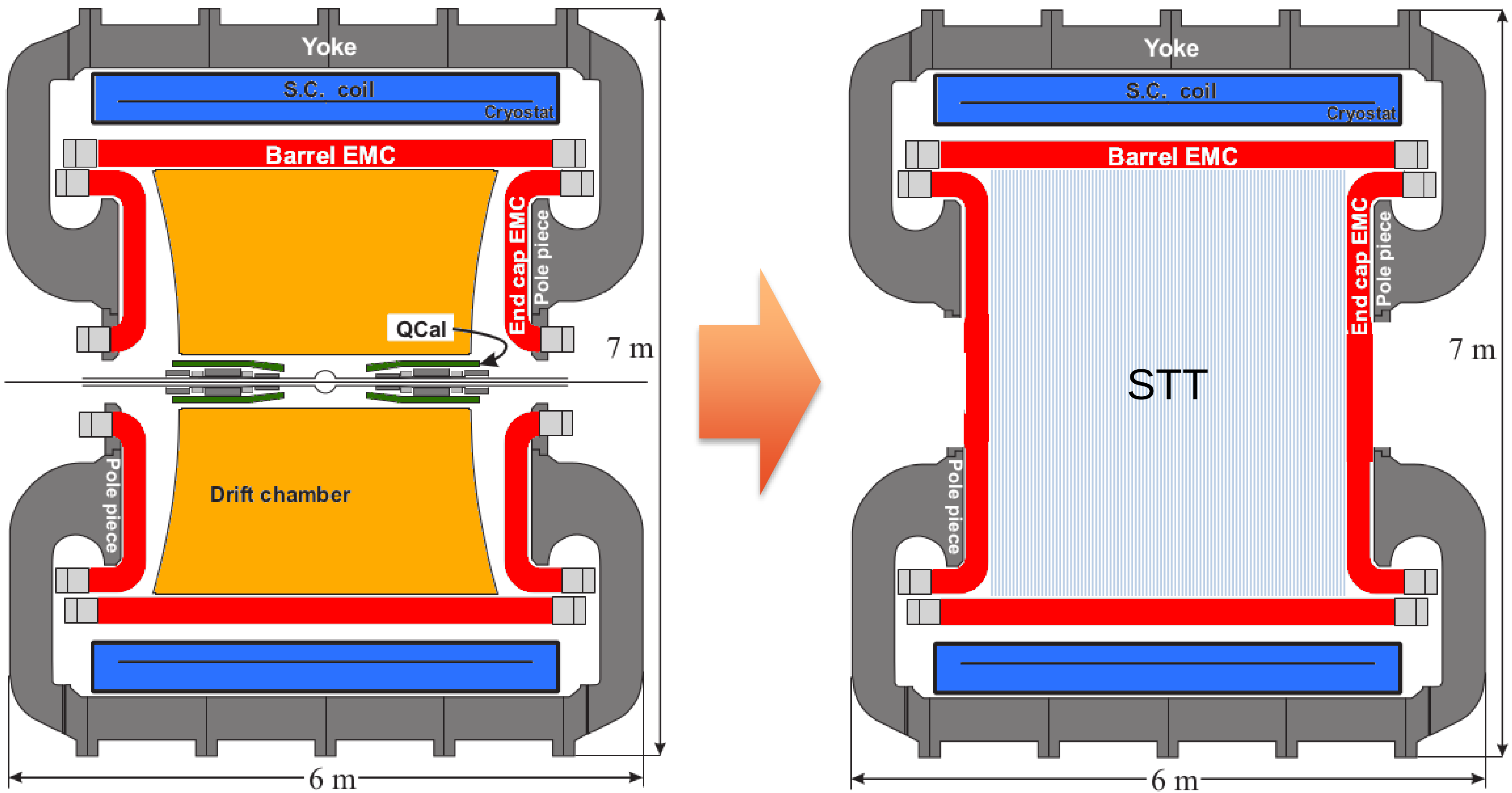
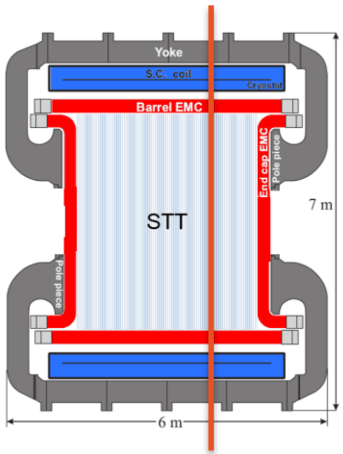
    - Combination of STT and calorimeter
- Neutron detection efficiency

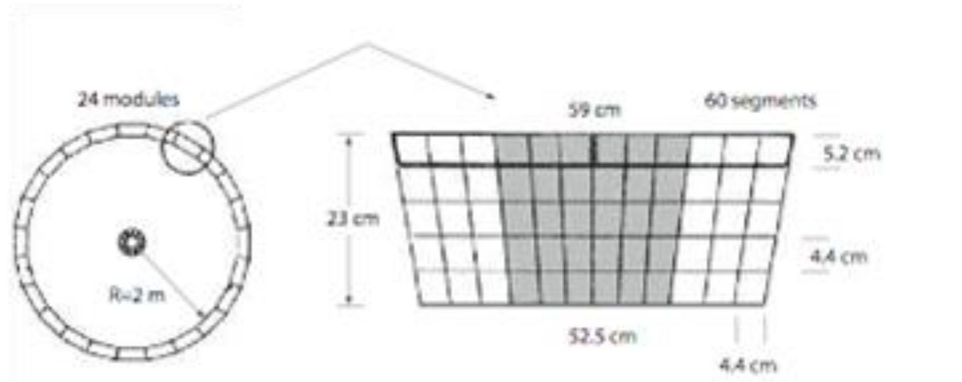
Detector geometry



Calorimeter segmentation

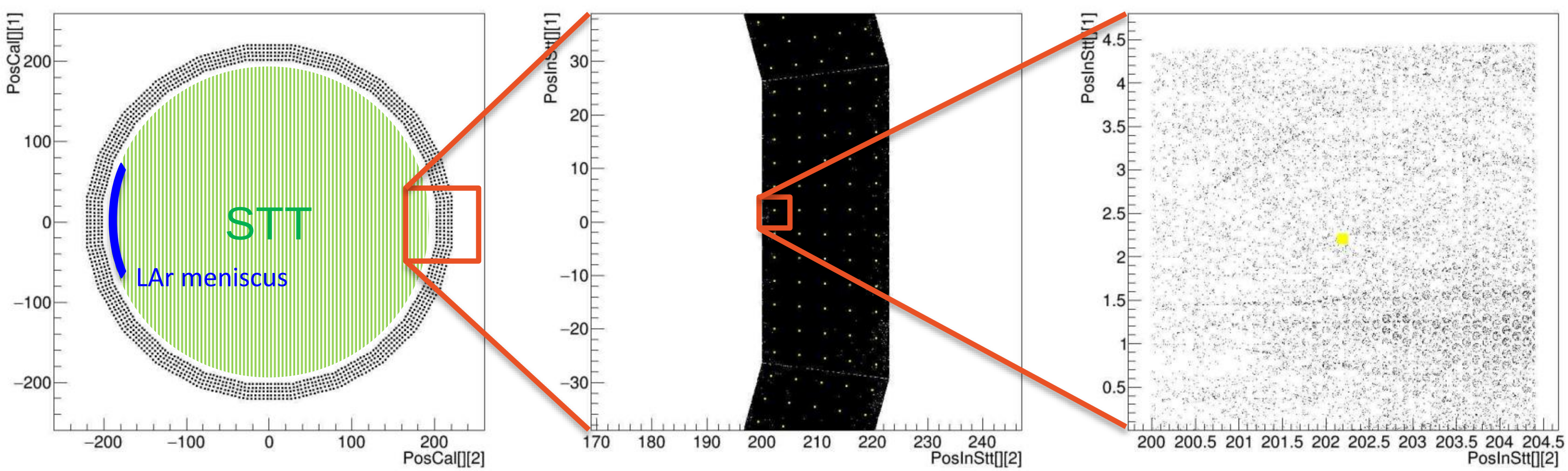


side view



KLOE calorimeter - readout segmentation (one end)

A cell is 430 cm long



Time resolution of the calorimeter

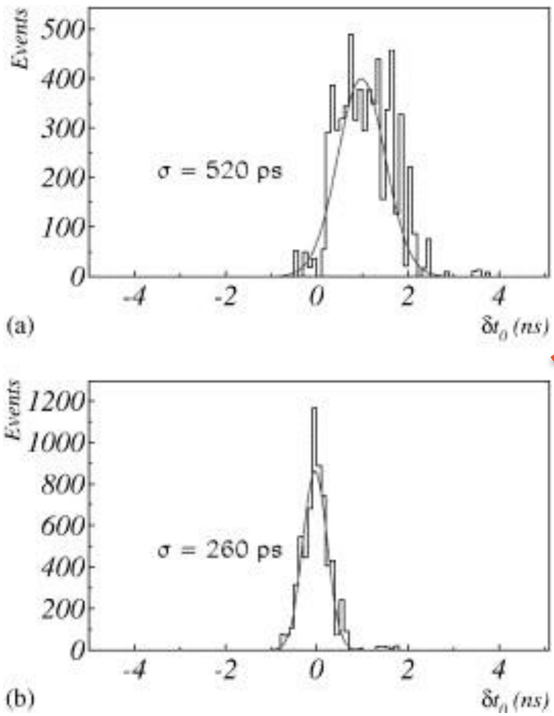


Fig. 29. Residual distributions before and after t_0 **corrections using cosmic ray particles**.

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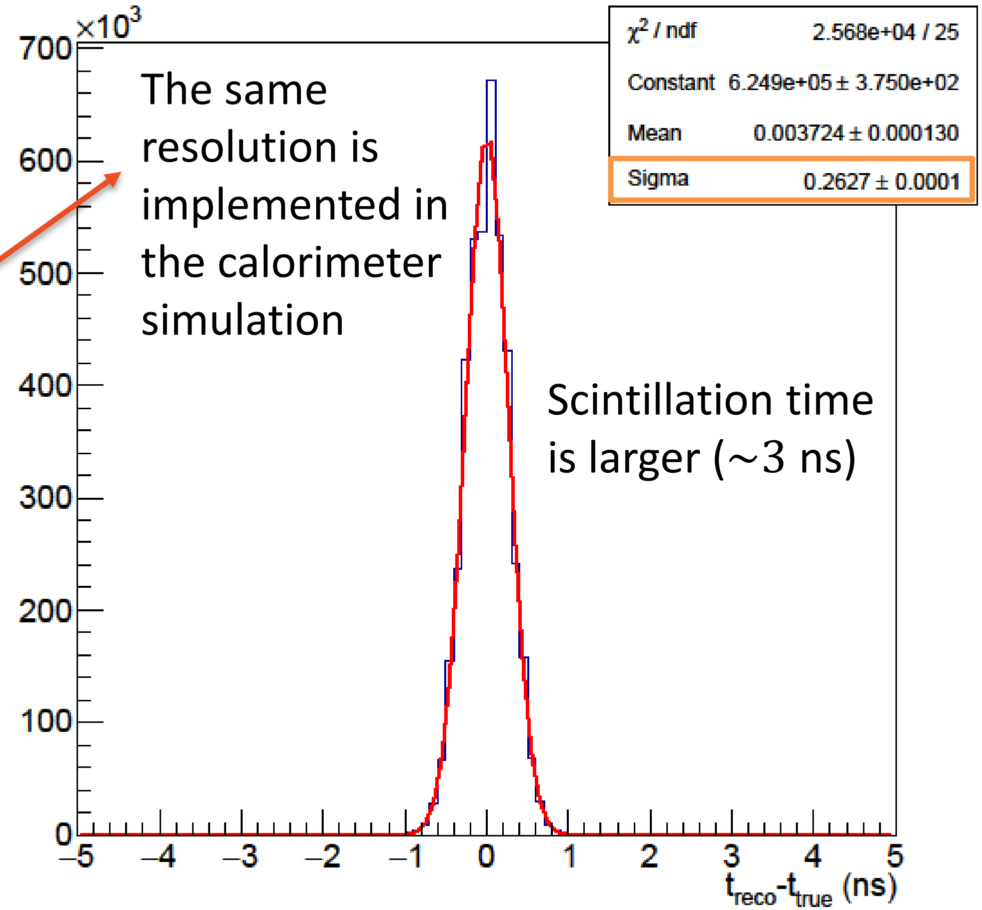


The same resolution is implemented in the calorimeter simulation

Scintillation time is larger (~3 ns)

Precise position obtained with internal tracker

Disclaimer

- This study assumes that the detected signal is caused by a neutron generated in the LAr meniscus, with known vertex
- This does not allow a test of PID capabilities of the detector
- It is possible to extract useful information on the features of expected signals
- Events causing hits in the endcaps are not considered at all (implementation of real geometry in the endcaps is not trivial)

Time of Flight (ToF) technique

- Kinetic energy is given by

$$E_{kin} = m_n(\gamma - 1)c^2 = m_n\left(\frac{1}{\sqrt{1-\beta^2}} - 1\right)c^2$$

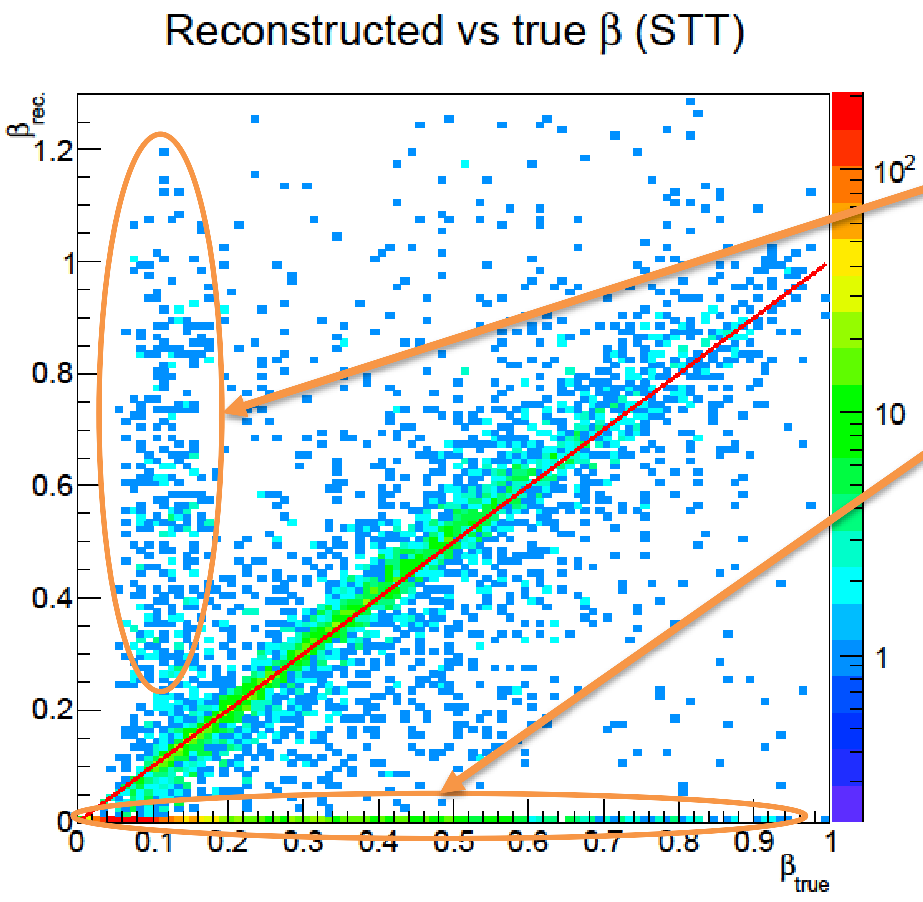
- Measuring β it is possible to calculate E_{kin}
- Measurement of β:
  - (x_v, y_v, z_v) vertex
  - (x_0, y_0, z_0) point used to calculate β
  - t_{reco} time corresponding to the event in (x_0, y_0, z_0)
  - $\beta = \frac{\sqrt{(x_0-x_v)^2+(y_0-y_v)^2+(z_0-z_v)^2}}{c\, t_{reco}}$

Time of Flight (ToF) technique

- In the STT
  - because of the very low threshold, one hit is usually sufficient to overcome the threshold
  - t_{reco} is the time corresponding to the first hit detected

- In the calorimeter
  - several hits are needed to deposit a sufficiently high energy and overcome the threshold
  - the time of each hit is weighted with the corresponding energy deposition
  - the time of an event in the cell is the weighted average of the times of the hits in the cell
  - t_{reco} is the time of the first cell above the threshold

β reconstruction in STT



Due to the initial neutron spectrum, which is highly populated around $\beta = 0.1$

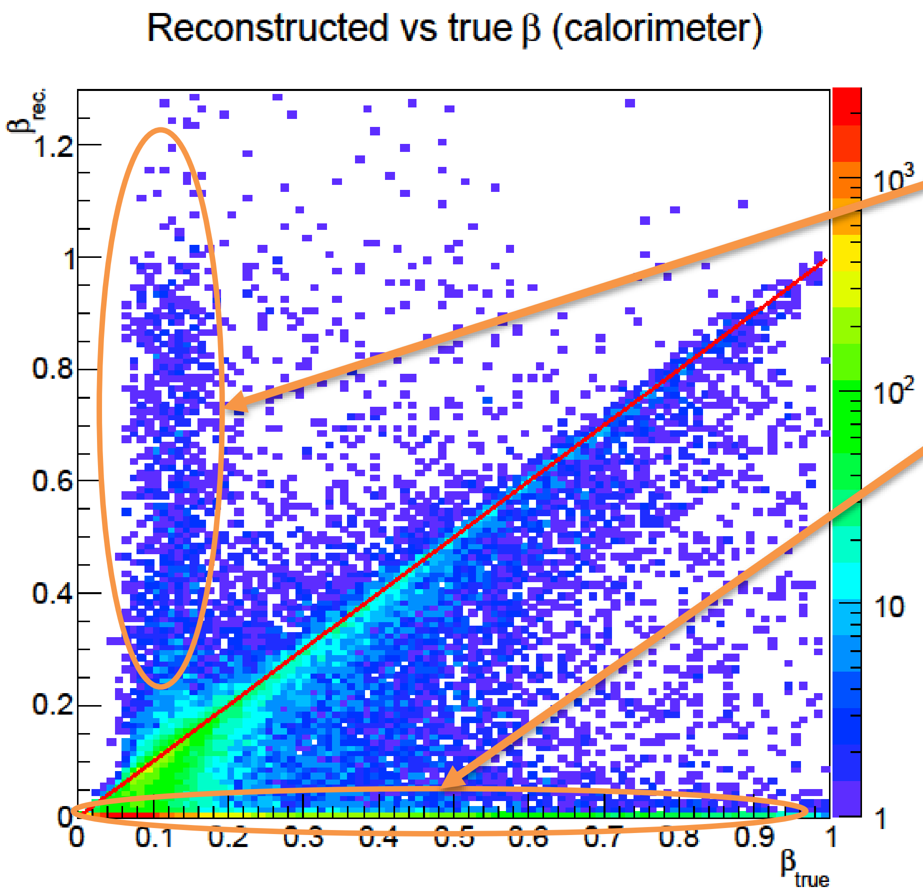
Due to neutron multiple scattering before detection

Energy threshold: 250 eV

Time resolution: 800 ps

Efficiency: 17%

β reconstruction in the calorimeter



Due to the initial neutron spectrum, which is highly populated around $\beta = 0.1$

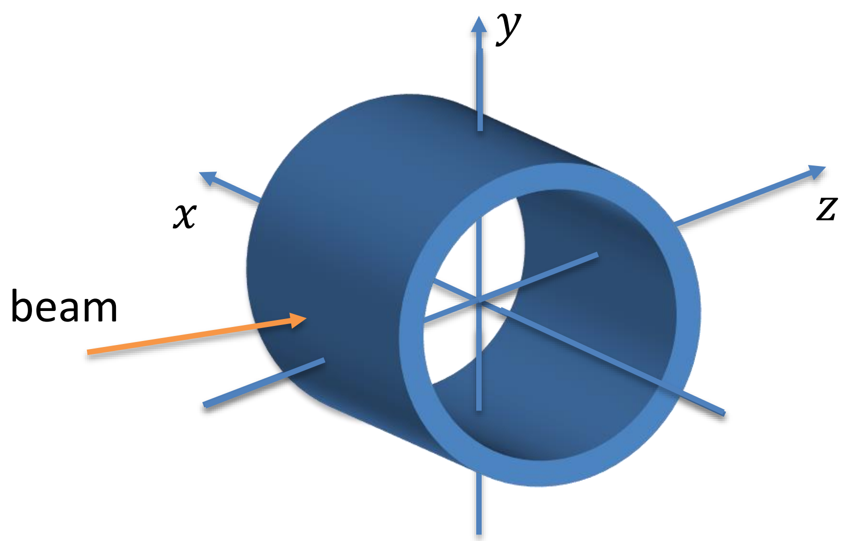
Due to neutron multiple scattering before detection

Energy threshold: 100 keV

Time resolution: 260 ps

Efficiency: 55%

Neutron signals in the calorimeter



Let me use this notation:

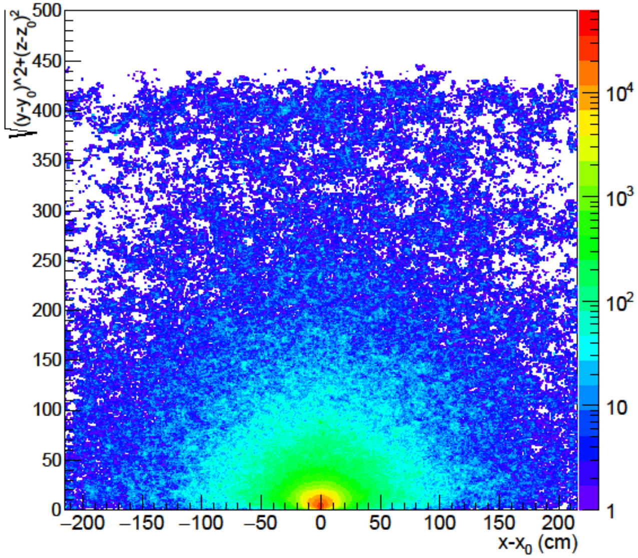
(x_0, y_0, z_0): point used to calculate β_{reco}

x: coordinate along the symmetry axis
y, z: coordinates on a plane $\perp$ to the symmetry axis

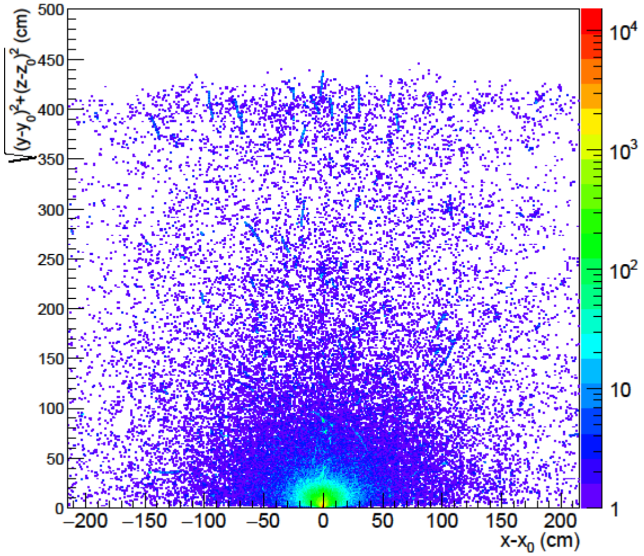
Neutron signals in the calorimeter

Number of hits as a function of $x - x_0$ and $\sqrt{(y-y_0)^2 + (z-z_0)^2}$

No threshold

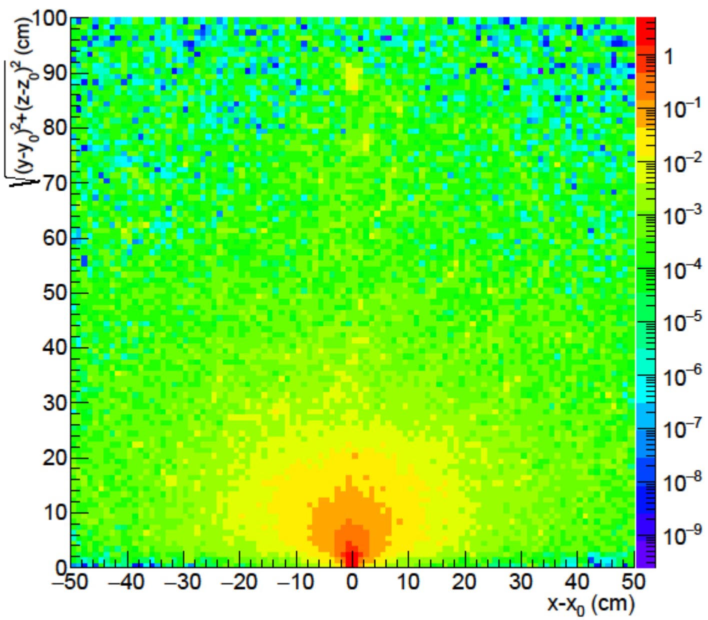


$E_{dep} > 50$ keV

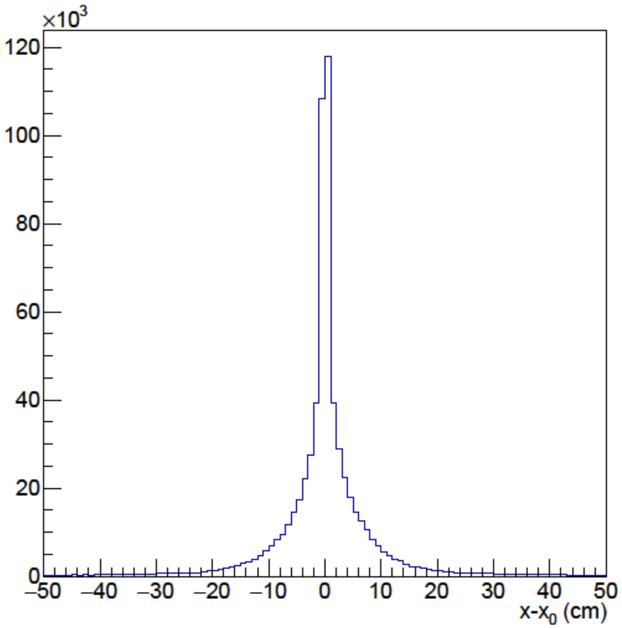


Neutron signals in the calorimeter

13 cells involved on average, but only 1 or 2 above threshold

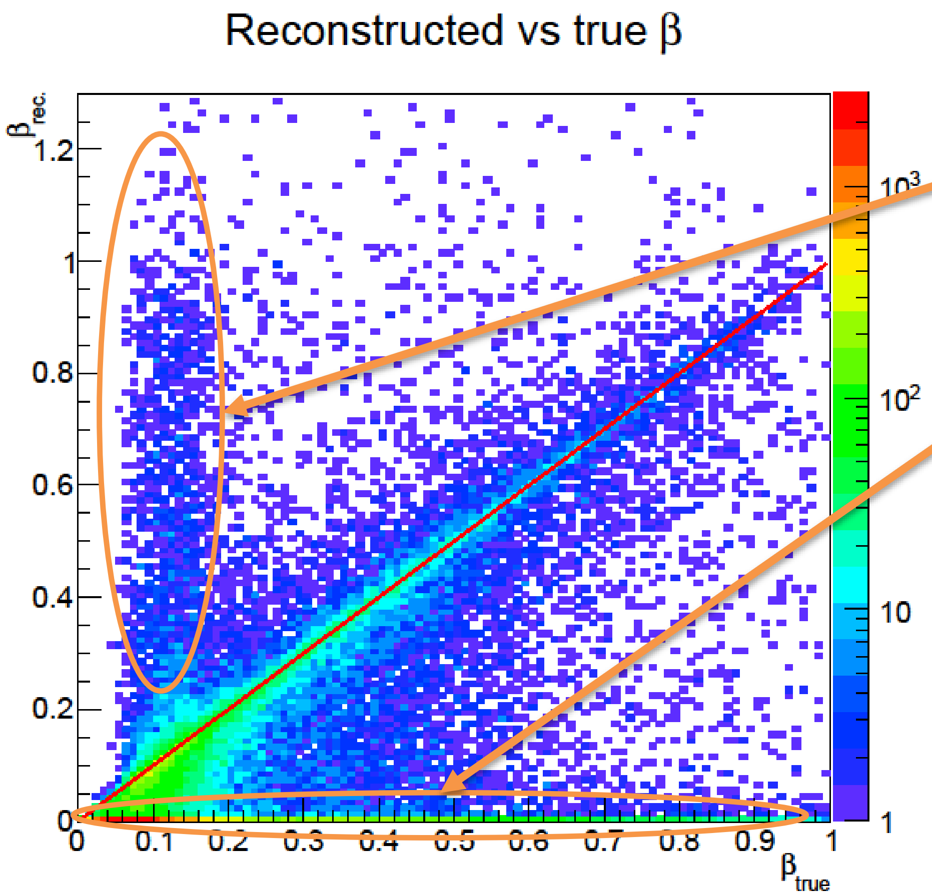


Sum of the energy deposited in all of the detected events, as a function of $x - x_0$ and $\sqrt{(y - y_0)^2 + (z - z_0)^2}$



Distribution of hits belonging to detected neutrons in a single cell, as a function of $x - x_0$

β reconstruction (combination)



Due to the initial neutron spectrum, which is highly populated around $\beta = 0.1$

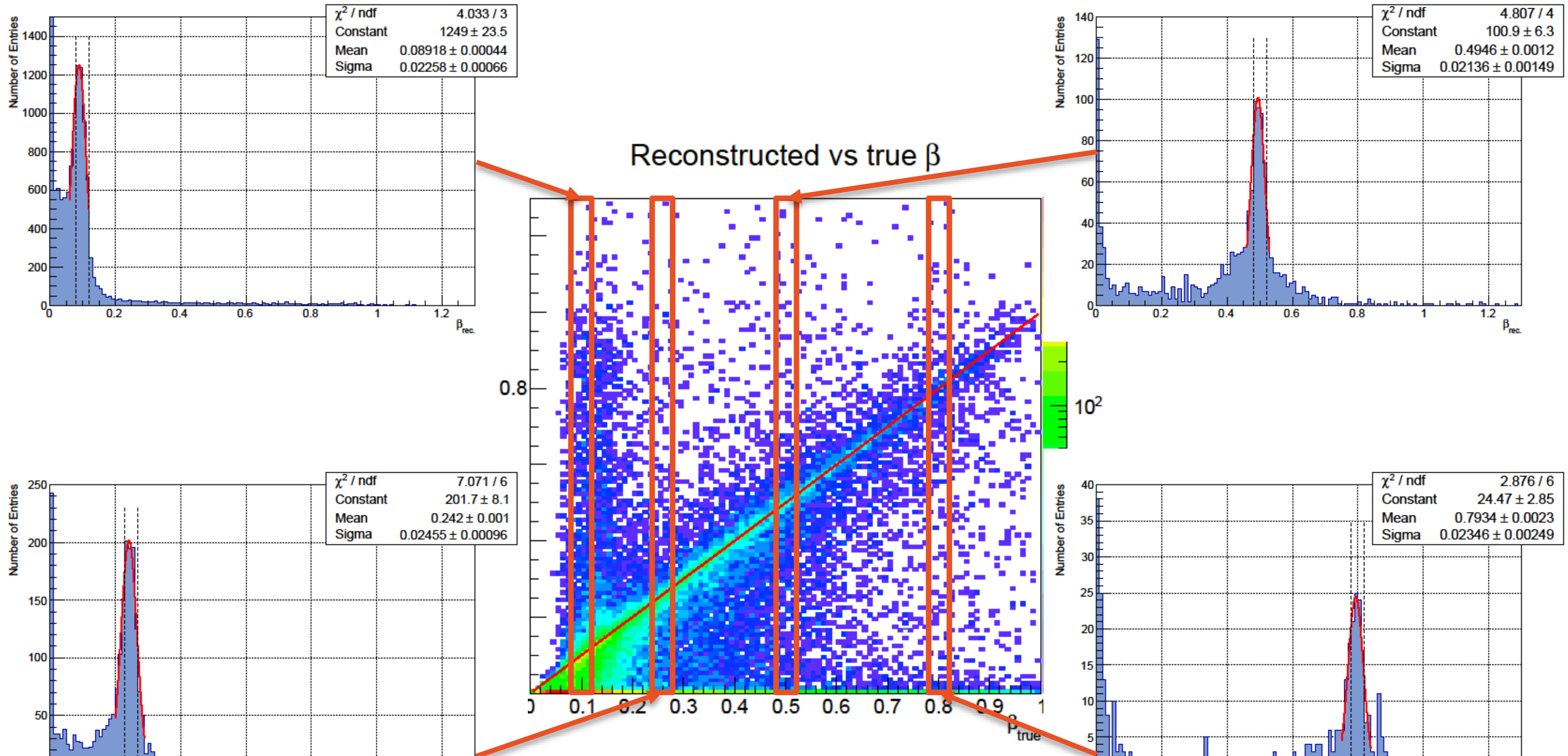
Due to neutron multiple scattering before detection

Energy threshold: STT: 250 eV
Calorimeter: 100 keV

Time resolution: STT: 800 ps
Calorimeter: 260 ps

Efficiency: 64% STT: 17%
Calorimeter: 55%

Sections of β_{reco} vs β_{true} @ different β_{true}



$\sigma_\beta \approx 0.023$

$\frac{\beta_{reco}-\beta_{true}}{\beta_{true}} < 0.30$ for 27% of the neutrons generated in ν interactions in LAr

(or for 60% of the neutrons with β_{reco}>0.01)

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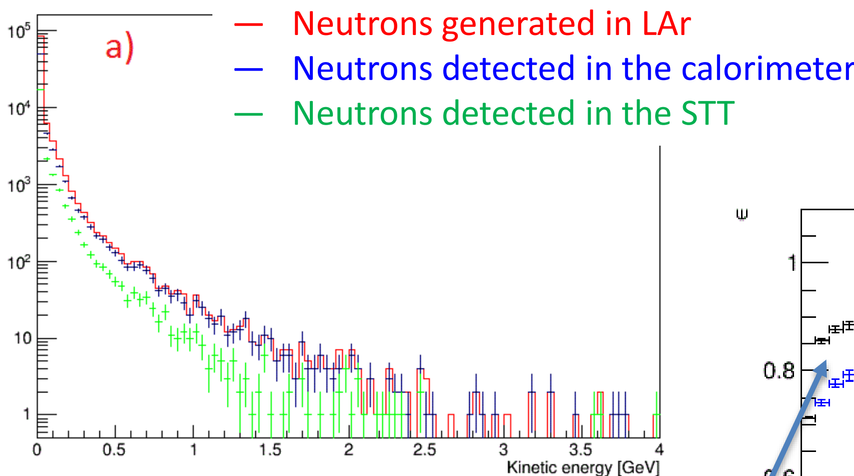
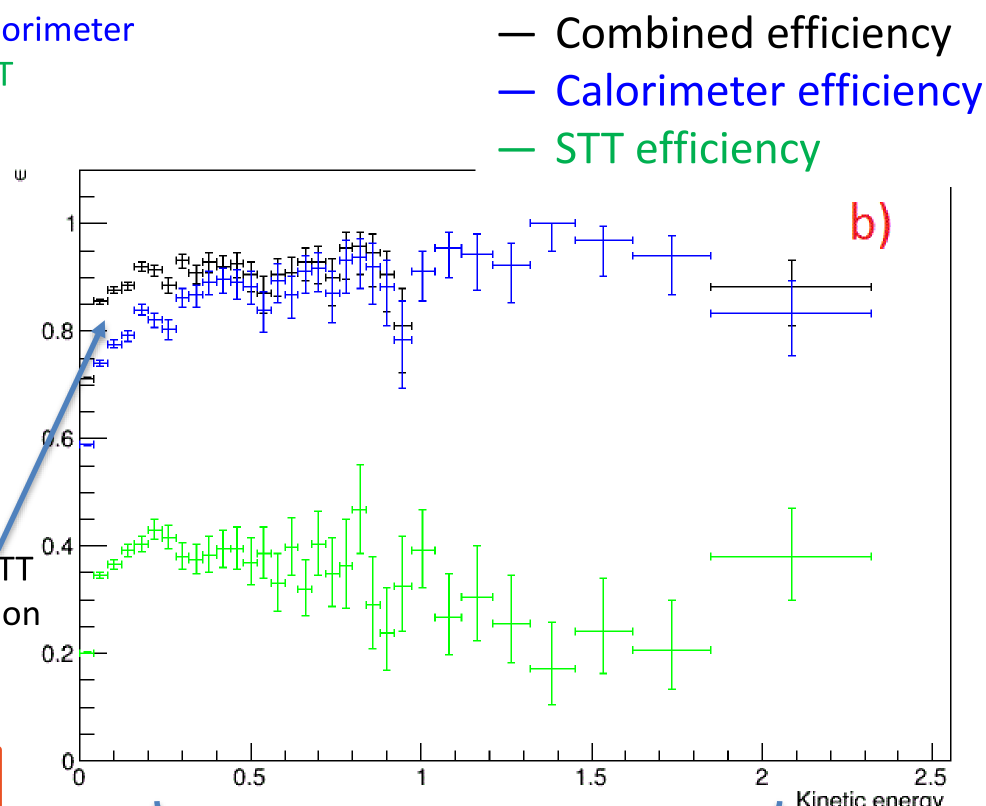
Neutron detection efficiency





Below $E_k \approx 400$ MeV the STT gives a significant contribution to the detection efficiency

Considering the whole spectrum of neutrons **generated in LAr**	STT: 17% Calorimeter: 55% Combination: 64%

Few neutrons, but very high efficiency (more than 80%)

Conclusions

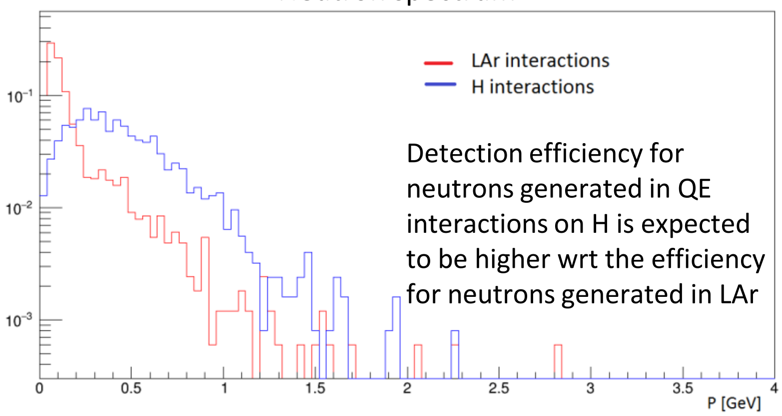
Present results

- Real calorimeter simulation, including
  - geometry
  - segmentation
  - time resolution
- Neutron β reconstruction in
  - STT
  - calorimeter
  - combination of the 2
- Basic topology

Outlook

- Calorimetric reconstruction
- Particle ID with the calorimeter
- Interactions on H
- …

Neutron spectrum



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Thanks for your attention!

…any questions?

Backup

Time of Flight (ToF) technique

- Distance of the hit from the PMTs:
  - d_1 PMT #1
  - d_2 PMT #2
- Speed of light in the fiber:
  - v_f
- Time resolution:
  - t_{res}
- Detection times for the couple of PMTs looking at the cell:
  - t_1 PMT #1
  - t_2 PMT #2
- Vertex known:
  - $t_v = 0$
  - (x_v, y_v, z_v) assumed known
- **Reconstructed detection time (calo)** → Energy weighting:
  - $\boldsymbol{t_{reco} = \frac{1}{2}\left(t_1 + t_2 - \frac{d_1+d_2}{v_f}\right) + t_{res}}$

$$\boldsymbol{t_{reco}^{cell} = 1/E_{cell} \sum_i t_{reco}^{i}\, E_i}$$

- Kinetic energy is given by

$$E_{kin} = m_n(\gamma - 1)c^2 = m_n\left(\frac{1}{\sqrt{1-\beta^2}} - 1\right)c^2$$

- Measuring β it is possible to calculate E_{kin}
- Measurement of β:
  - $(x_0, y_{,0}\, z_0)$ point used to calculate β
  - $\beta = \frac{\sqrt{(x_0-x_v)^2+(y_0-y_v)^2+(z_0-z_v)^2}}{c\, t_{reco}}$