Reconstruction of β: analysis of n=1.03, n=1.05 and n=1.33 radiators

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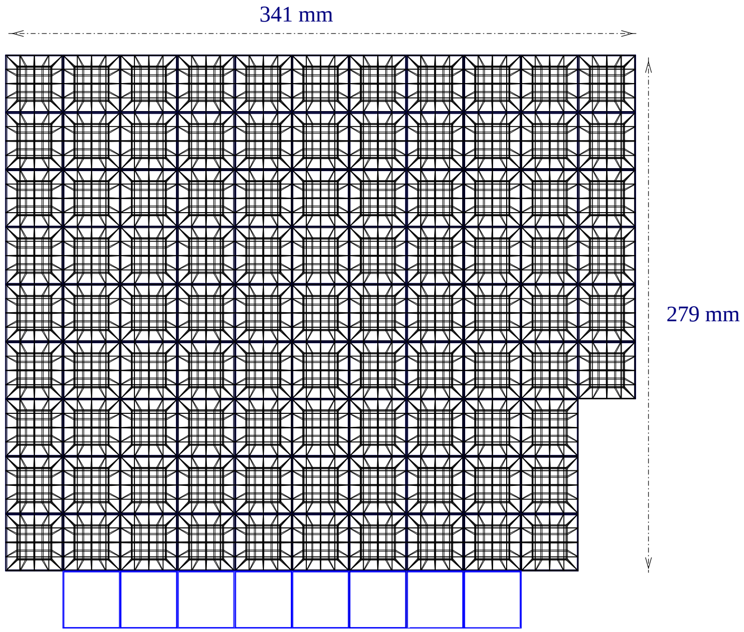
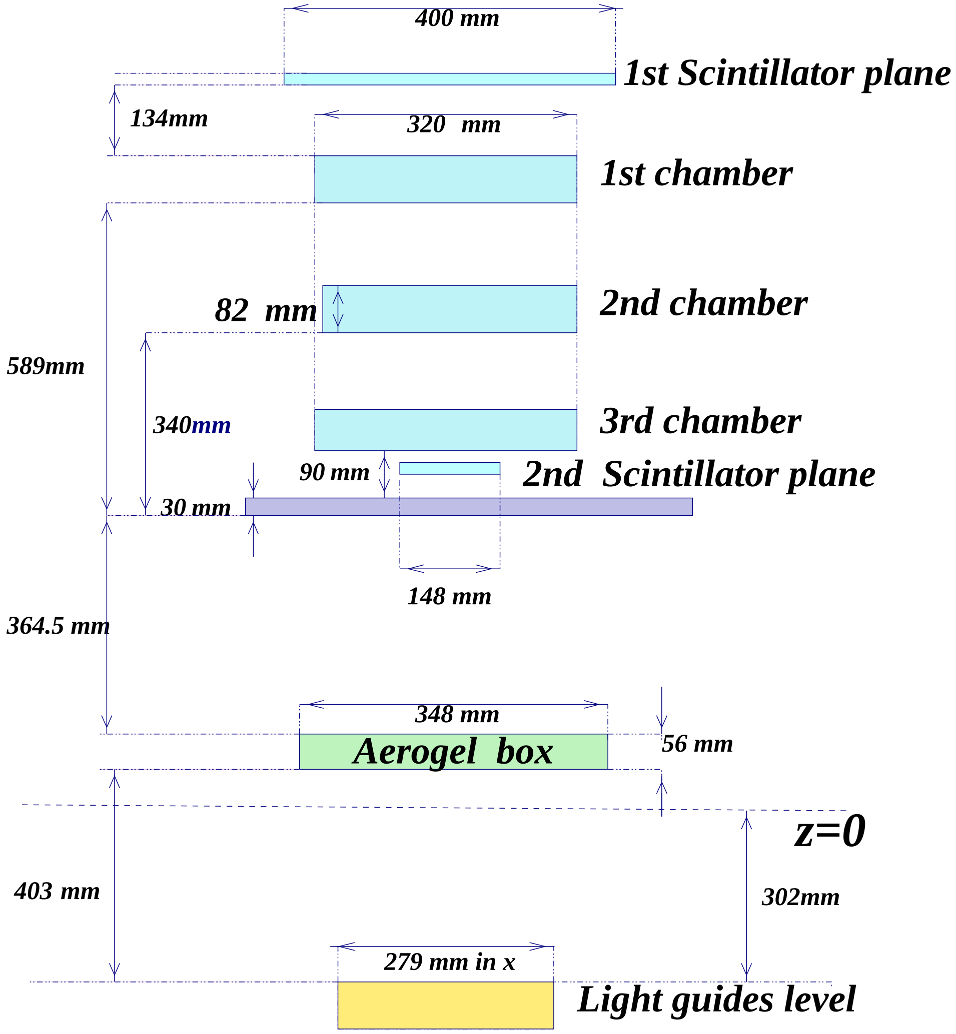
- Setup and runs description.
- PMTs calibration and alignment procedures.
- Event selection.
- Number of hits.
- β reconstruction algorithms.
- Reconstruction results.
- Towards data/MC agreement for aerogel.
- Conclusions/Petitions.

Setup description

- Wire chambers and scintillators planes on top of radiator.
- PMT array geometry:





Adapted from Borges, Barao

Runs descriptions

`The trigger rate is ∼ 0.5 Hz`

`For the MC the simulated spectrum is muons at sea level.`

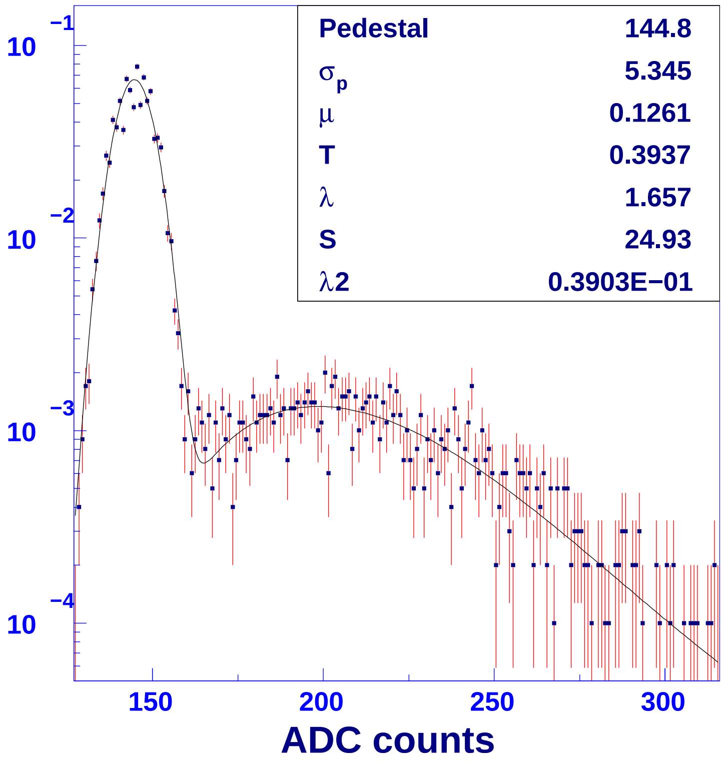
- **Radiator:** 3 cm of aerogel n=1.03
  - **Data:** run21: ∼200000 evts
  - **MC:** 100 Kevts

    Clarity: 0.0041 $cm^{-1}\mu m^{4}$
- **Radiator:** 2cm of aerogel n=1.05
  - **Data:** run 26: ∼150000 evts
  - **MC:** 100 Kevts

    Clarity: 0.0091 $cm^{-1}\mu m^{4}$
    n simulated: 1.0488
- **Radiator:** 0.5 cm of NaF n=1.33
  ($10 \times 10 cm^{2}$ tile)
  - **Data:** run29: ∼700000 evts
  - **MC:** 200 Kevts

- All the aerogels with polyester supporting foil.
- NaF without supporting foil.
- All the runs aligned.
- Common PMT calibration for all the runs with noisy channel suppression for each run.

PMTs calibration



- Gain: $\approx S(1+\lambda)$
- Single P.E. resolution: $\approx S\sqrt{\lambda}$
- Mean number of p.e.: μ

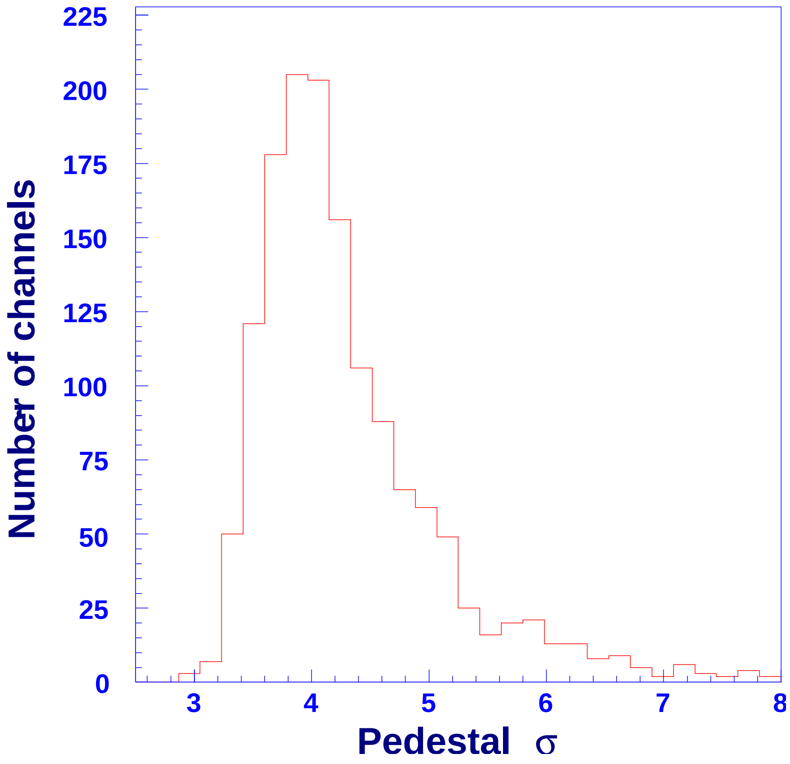
Fit to the convolution of several distributions:

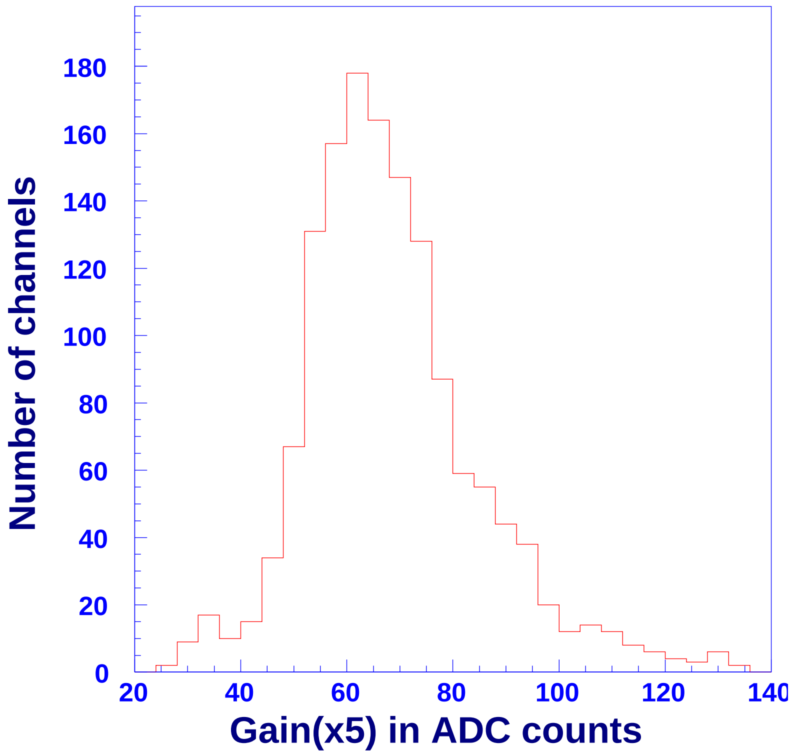
1. Pedestal: Gaussian.
2. Single p.e.: Described by the approximate distribution

$$P(x) \simeq e^{-\lambda}\delta(x) + (1-e^{-\lambda})\frac{e^{-\lambda}}{S\lambda}\frac{\lambda^{\frac{x}{S}}}{\Gamma(\frac{x}{S})}\theta(x)$$

The calibration resulted in

- Mean pedestal width: ~ 4 ADC counts.
- Mean gain ($\times 5$): ~ 67 ADC counts.
- $\sim 1\%$ of negative pedestals
- $\sim 9\%$ of double peaked pedestals

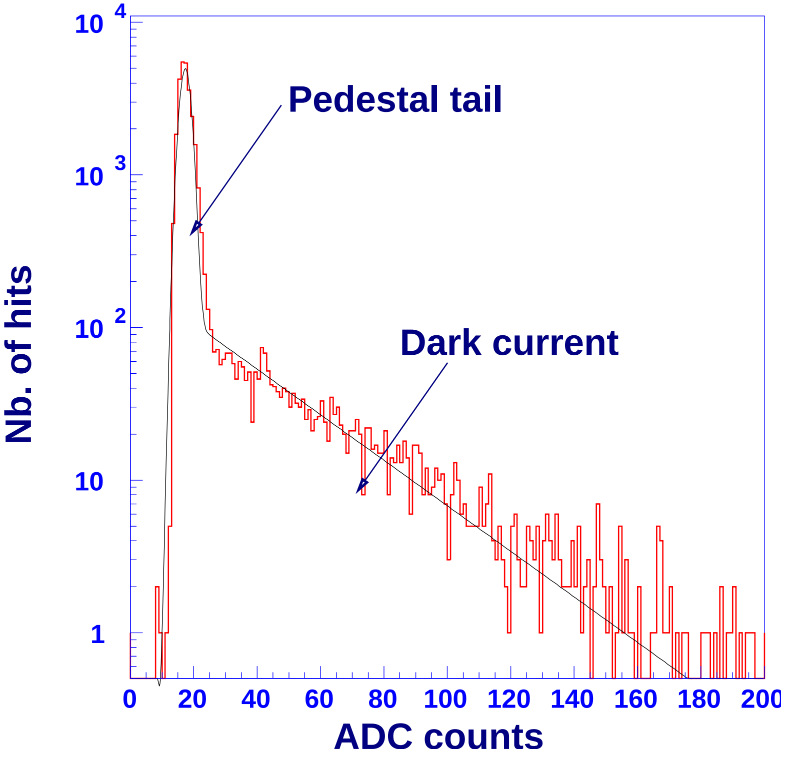


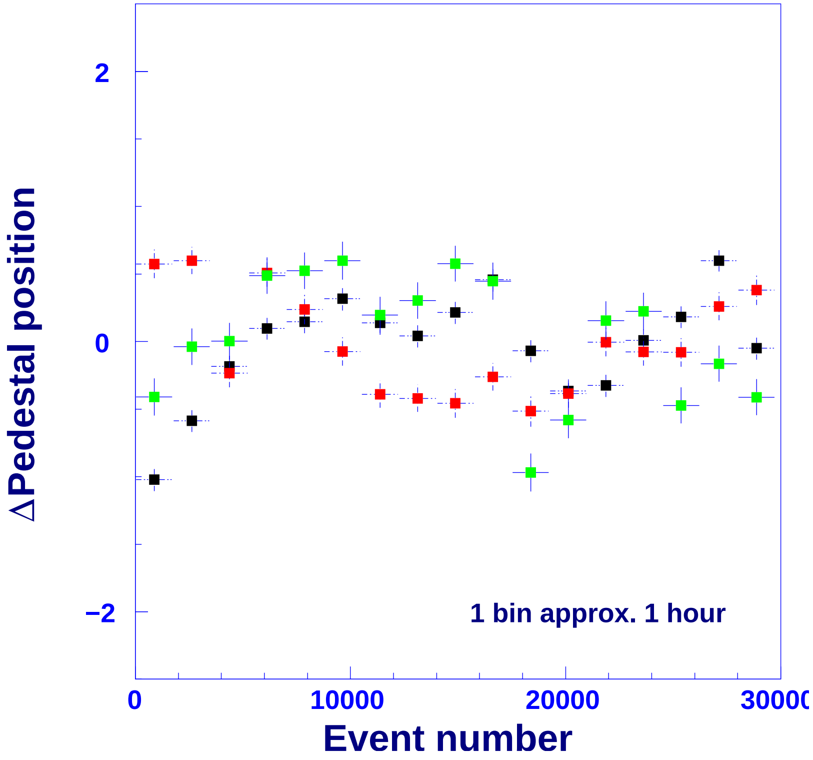


- **Pedestals stability:** in 19 hours is in the range ±1ADC counts.

- **PMTs dark current:** yields $\sim 4 \times 10^{-5}$ hits per event per channel.

- **Pedestal tails ($> 4\sigma$):** yields $\sim 8 \times 10^{-5}$ hits per event per channel.

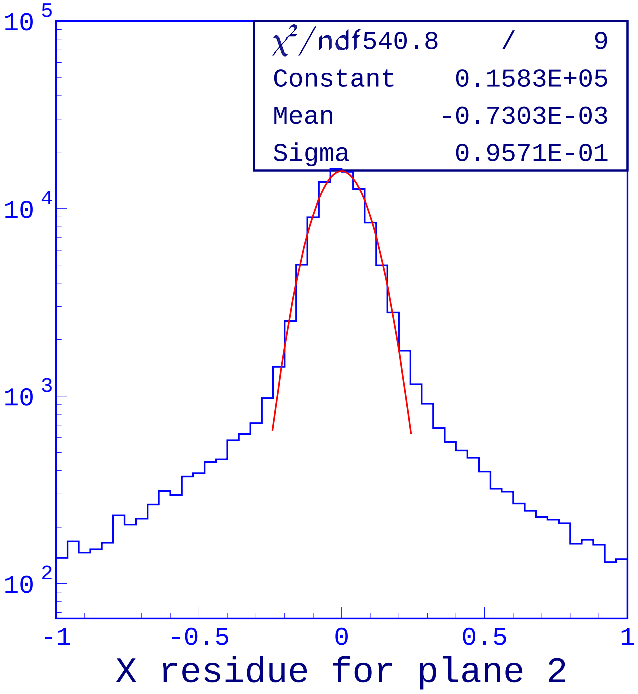


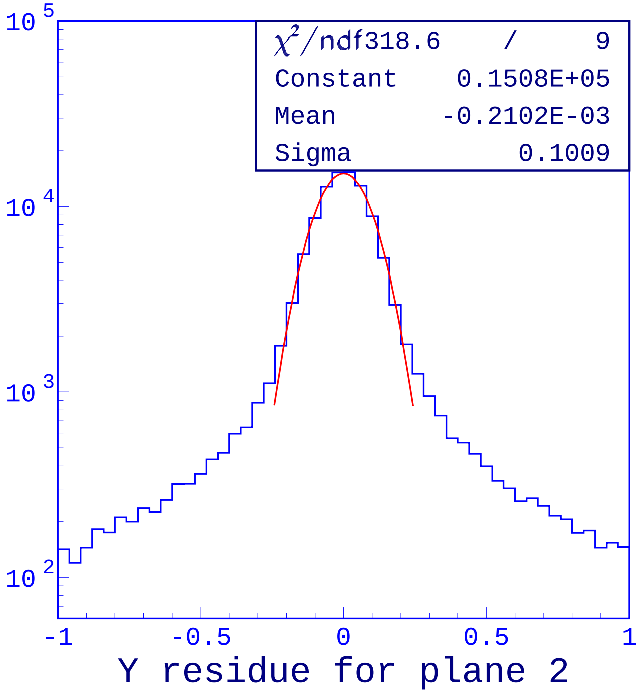


Wire Chamber alignment

Procedure:

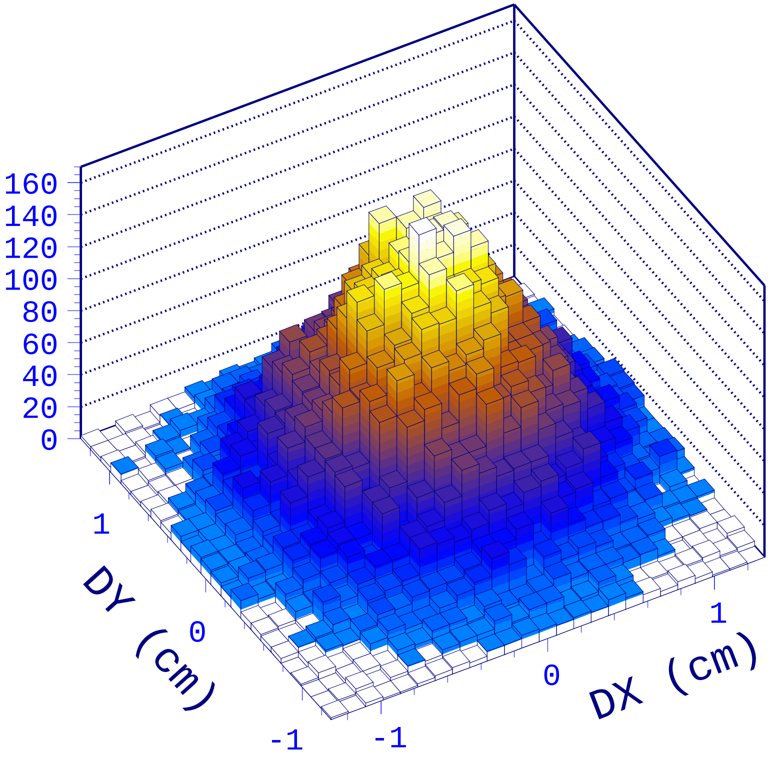
- Wire chamber signals are fitted to a line.
- The residues for each plane are computed.
- The local position or all planes is shifted according to the peak of the residues associated to it.





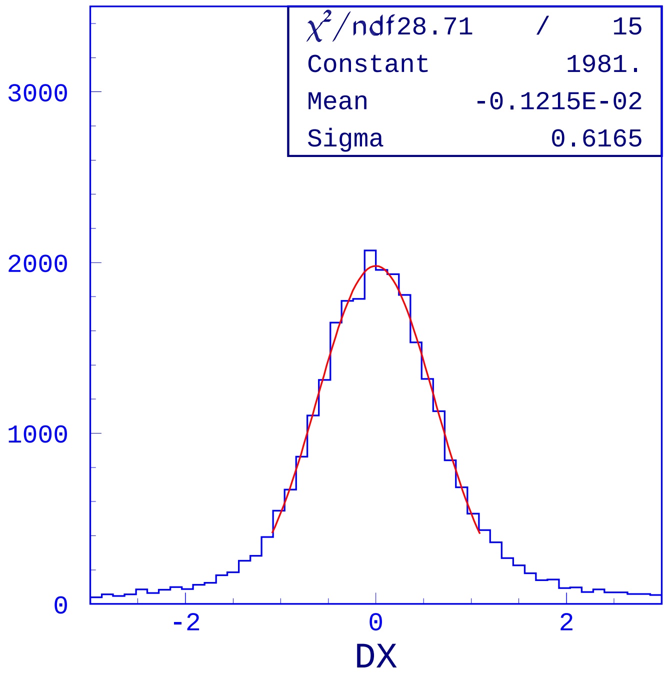
Wire Chambers/RICH alignment

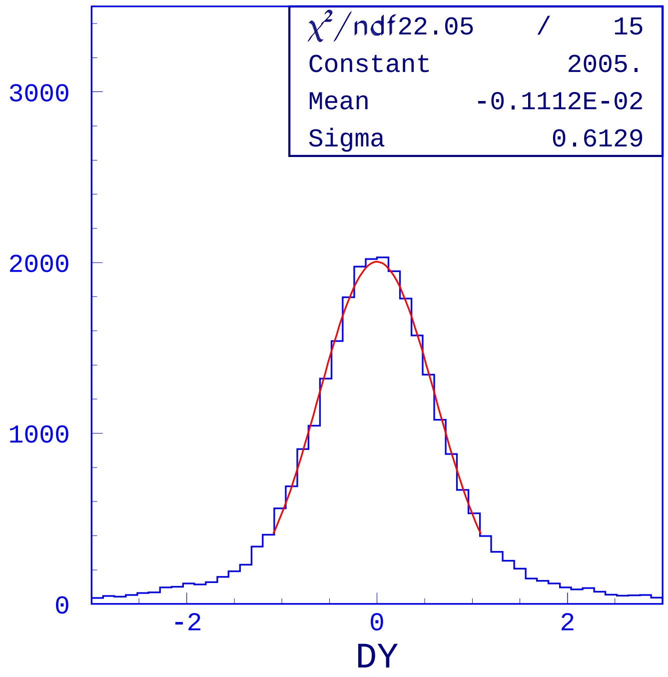
- It relies in the RICH capacity to determine the light guide crossed by the particle.
  - **From MC:** $\sigma_x^{RICH} \simeq \sigma_y^{RICH} \approx 0.4cm$.
  - It present a small bias if the tracks are not homogeneously distributed in ϕ.

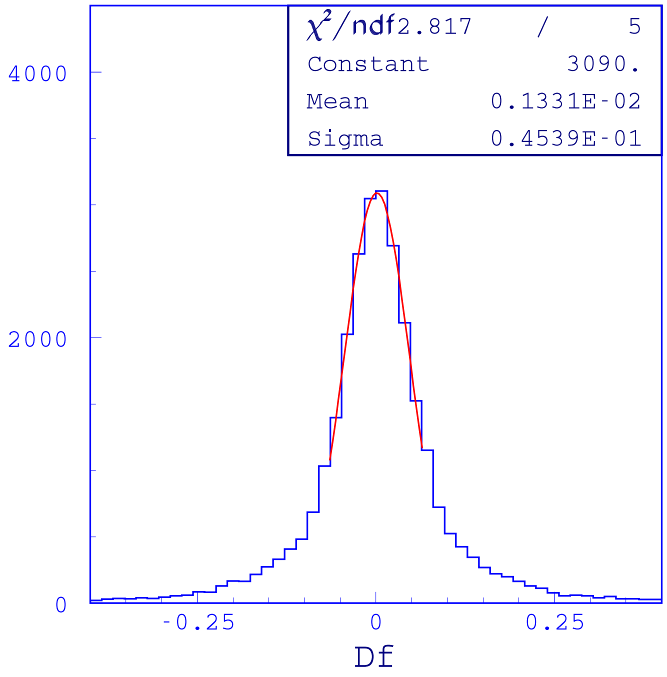


Procedure

- Compute the extrapolation of the track to the PMT matrix.
- Within a given region around this point ($\sim$ 1/2 PMT size), choose the hit with largest number of p.e.
- If this number is large enough ($\geq$ 3p.e.), compute:
  1. Distance in X to the track point.
  2. Distance in Y to the track point.
  3. Difference in $\tan^{-1}\frac{Y}{X}$ for the track point and the chosen one.

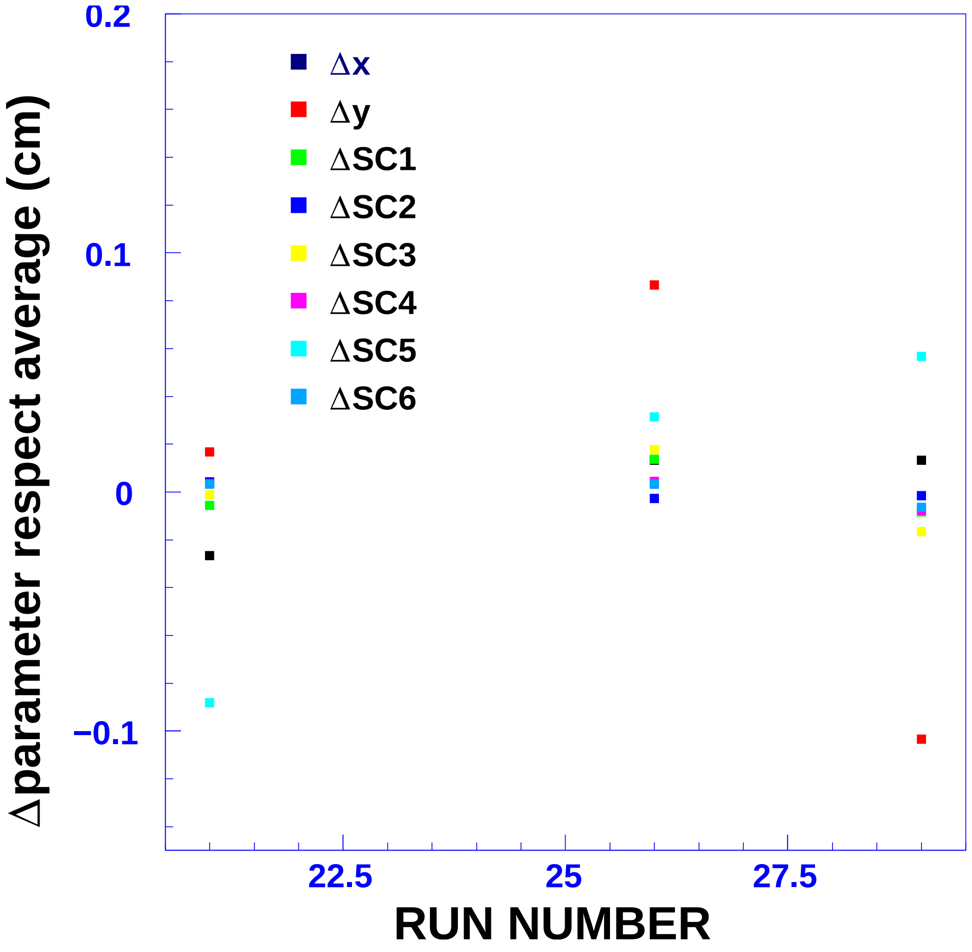






- All the aligned differences are compatible with zero.
- The $RICH \oplus WC$ resolution is $\sim$ 0.6cm.

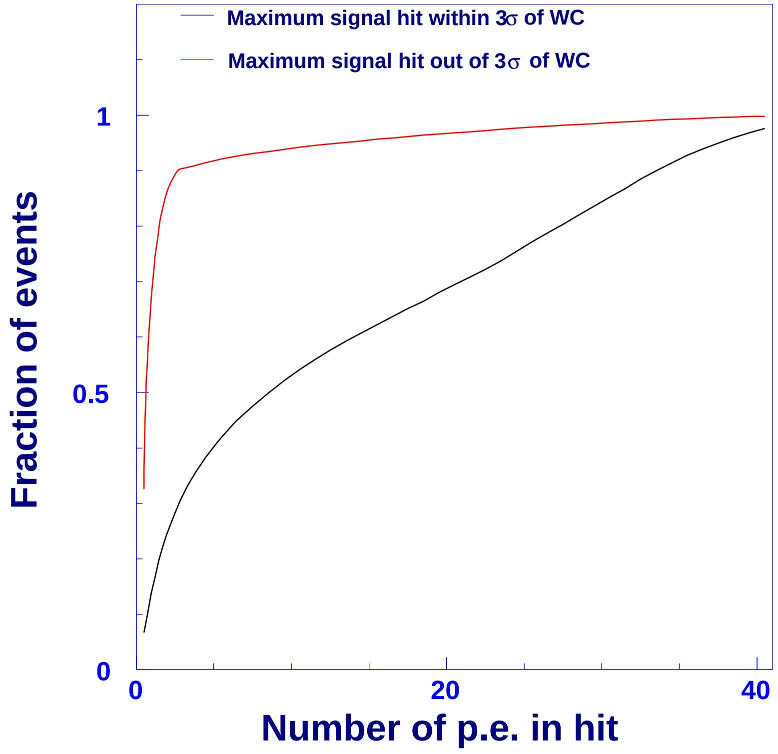
Alignment stability

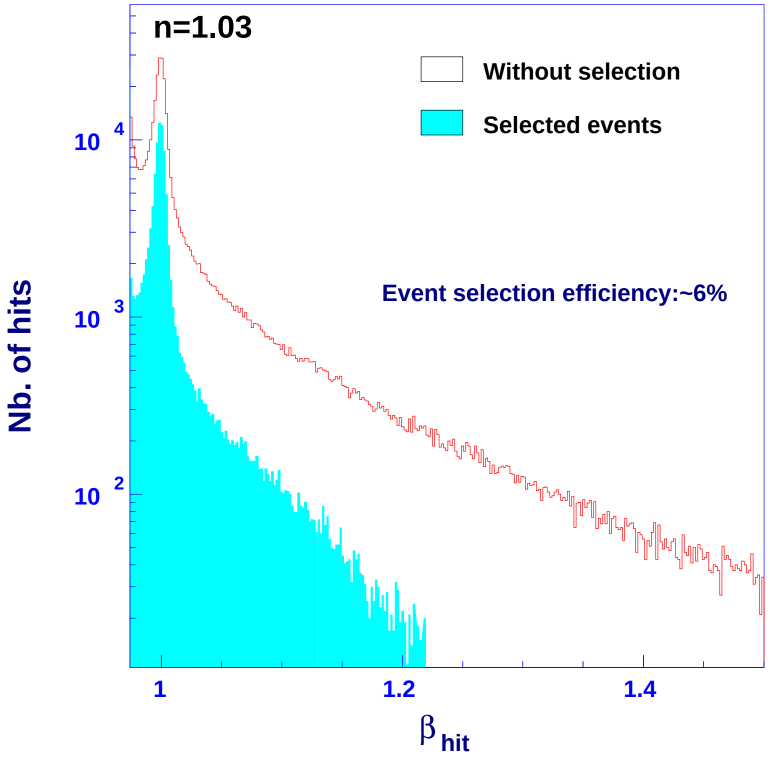


- From one run to other the alignment parameters change in the range ±1mm.

Track selection

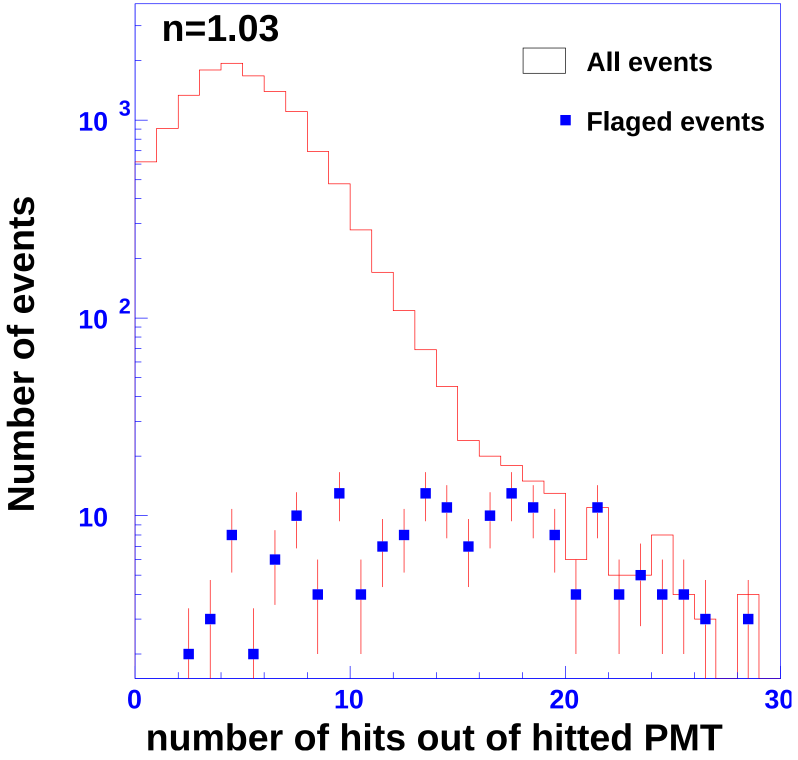
- To ensure a well reconstructed track we proceed as in the alignment study, but we are more careful in choosing the signal threshold for the hit matching the track: signal>6 p.e.
- Only tracks with a hit with a signal above the threshold matching the track are selected.
  - Strong matching criteria: Distance from track extrapolated point to selected hit $< 1\sigma_{RICH \oplus WC}$.
- Finally a loose χ^2 cut in the track is applied.





Event selection

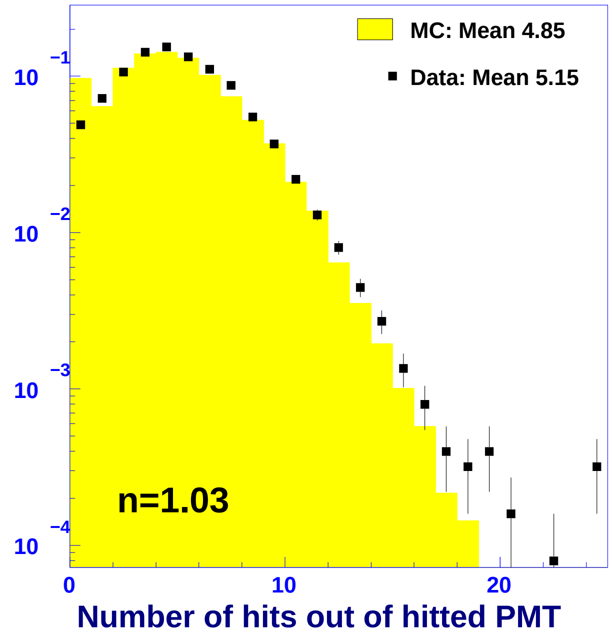
Further refinements are achieved by event selection:

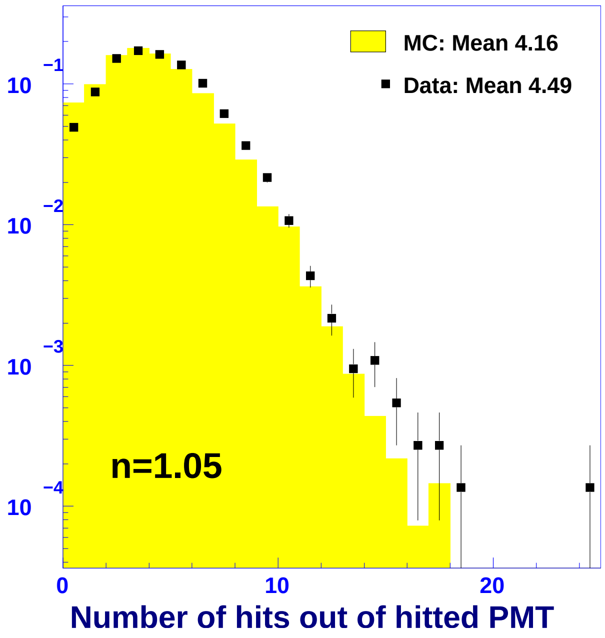


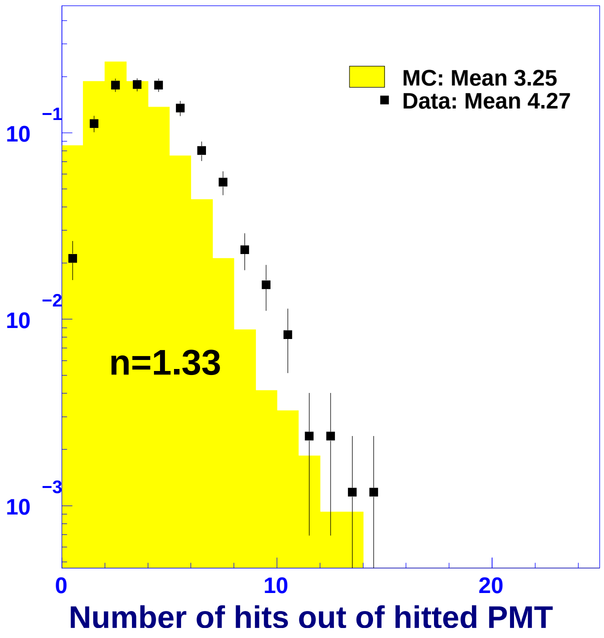
- Events with possibility of confusion of the hit due to the crossing of the particle are flagged.

Number of hits

- Very good agreement between data and MC for aerogel.
- For NaF there is an extra 30% amount of hits respect MC.







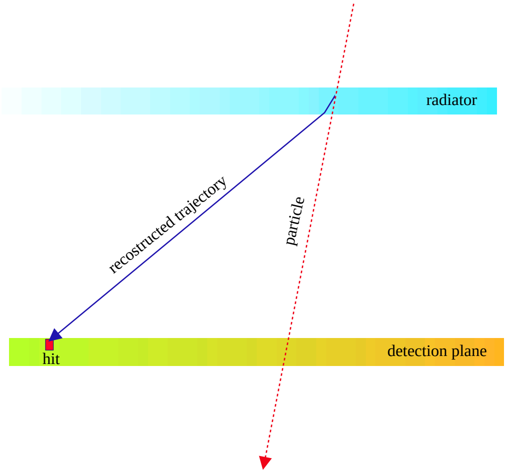
β reconstruction algorithm

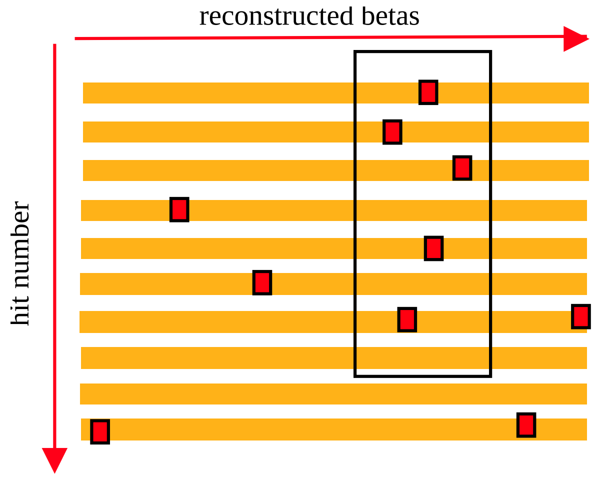
Two closely related algorithms implemented in the prototype reconstruction:

- **Reconstruction with track parameters.**
  - Implemented in AMS software too.
  - Very tested.
  - Robust and fast as far as the tracks parameters are well known.
    - ▷ ≈140 times faster than Tracker reconstruction for protons.
- **Reconstruction without track parameters.**
  - Not implemented int the AMS software.
  - Not very tested (but working).
  - ≈ 146 times slower than the reconstruction with known track parameters

Reconstruction with track parameters

1. Back trace: Find all the photons trajectories compatible with each hit and assign a β to each trajectory.
   - Semi analytical solving of propagation equation.
   - Assume a common emission point for all the photons: mean emission point of the detected photons.
2. Fast search of most the probable common β for all the reconstructed trajectories with noise reduction and ambiguity solving:
   - Look for the cluster of β values such that:
     - For each hit, only the trajectory with the associated β closer to the cluster center is considered.
     - Only the β closer than $3 \times \sigma(\beta\ hit)$ to the cluster center are considered.
   - Only the cluster with the bigger number of β values is retained.
   - The reconstructed particle β is the mean value of the cluster.





Reconstruction without track parameters

1. For a set of points over the radiator estimates the particle direction assuming that it passes by this point.
    - Currently it assumes that the particle passes through the light guide associated with the channel with bigger number of p.e.
2. If the estimated track is within the geometrical acceptance: reconstruct β.
3. Select the track with the best reconstructed β.

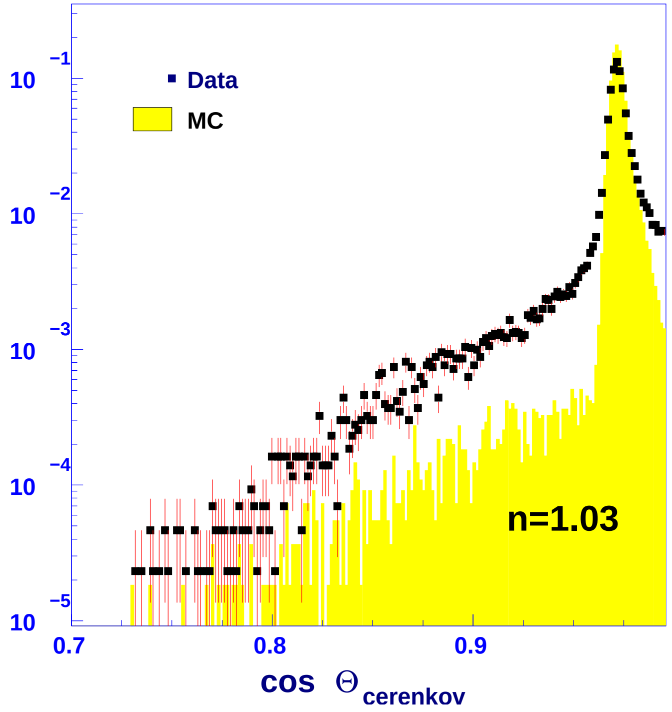
The uncertainty of the PMT behaviour when it is crossed by a charged particle is a source of uncertainty in the resolution for the current implementation of the algorithm.

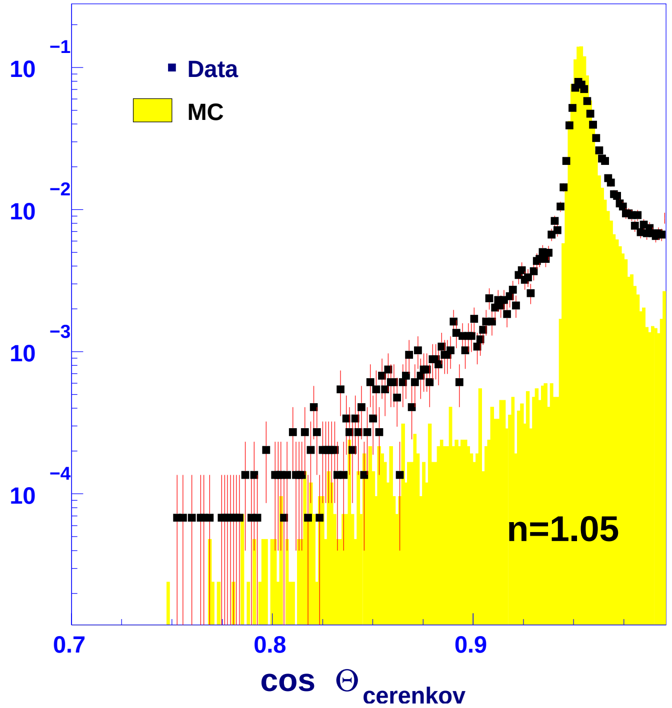
Track known: all β_{hit} spectrum

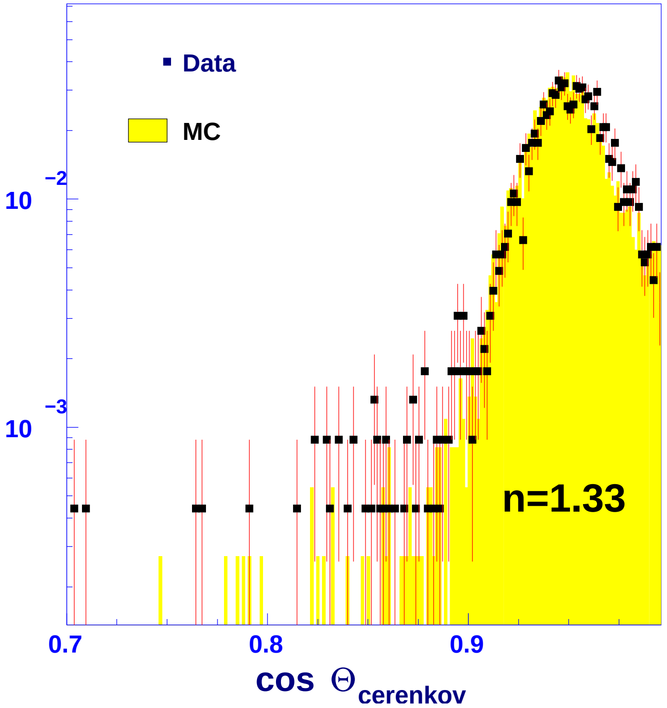
For aerogel there are two main differences between data and MC:

- The background in data is larger than in MC.
- The Čerekov peak width is larger in data than in MC.

This disagreement is larger for n=1.05. Apparently this does not happen for NaF.

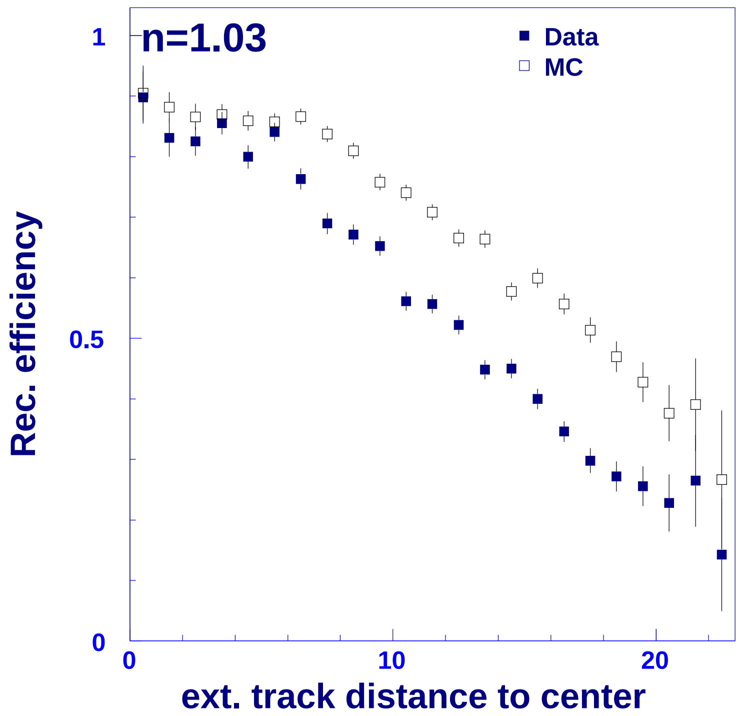


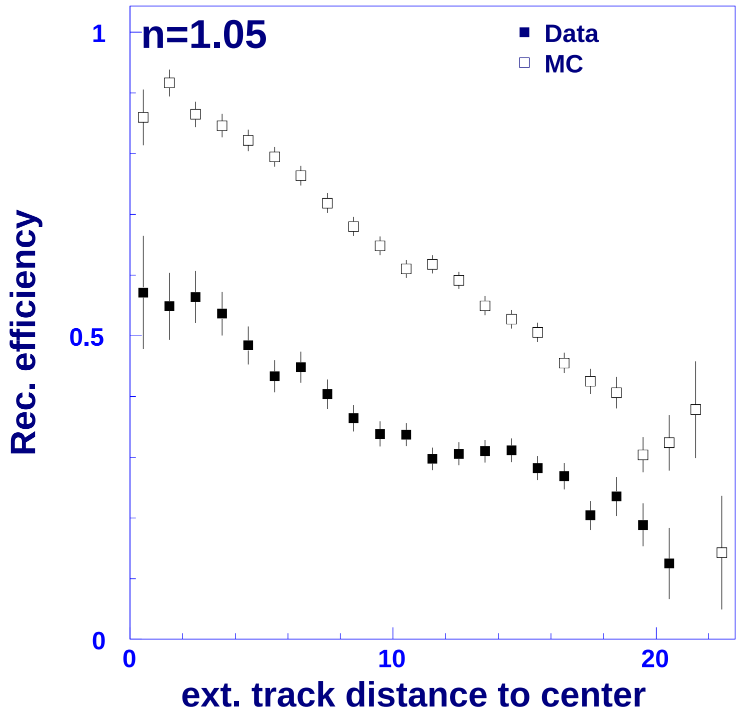


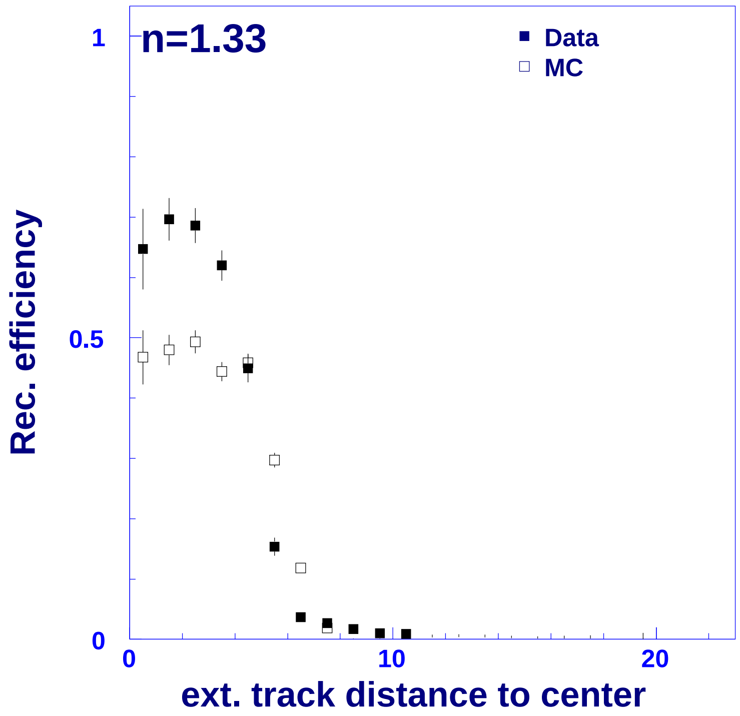


Track known: reconstruction efficiency

- Good agreement with MC for 1.03:
  - 1.03: Small disagreement due to ~ 1 hit of difference.
- Large disagreement for 1.05, to be investigated further.
- Disagreement in NaF compatible with excess of hits in the ring, could be due to geometry (still to be checked).

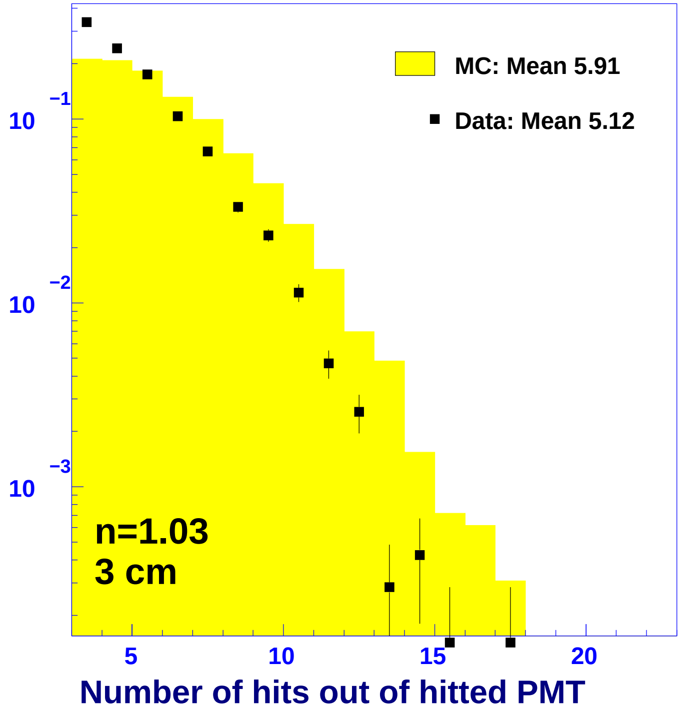


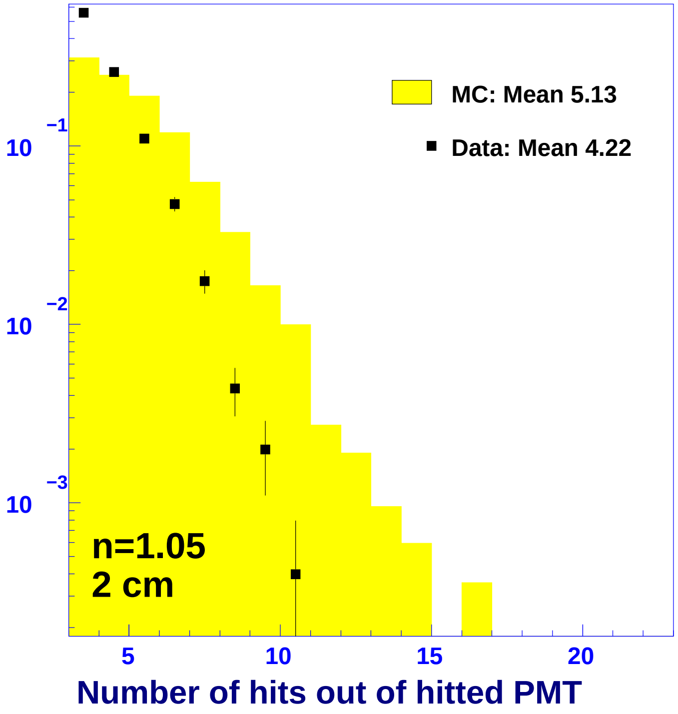


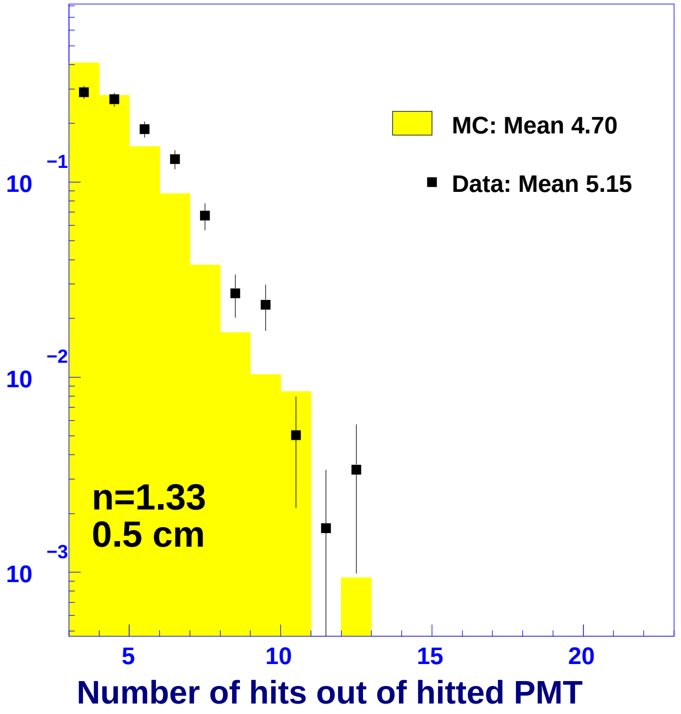


Track known: hits in ring

- There is an important defect of hits associated to a ring for aerogel in data respect MC. The disagreement for n=1.05 is quite worse than for n=1.03.
- For NaF this difference is a small excess of hits in the ring of data respect MC .





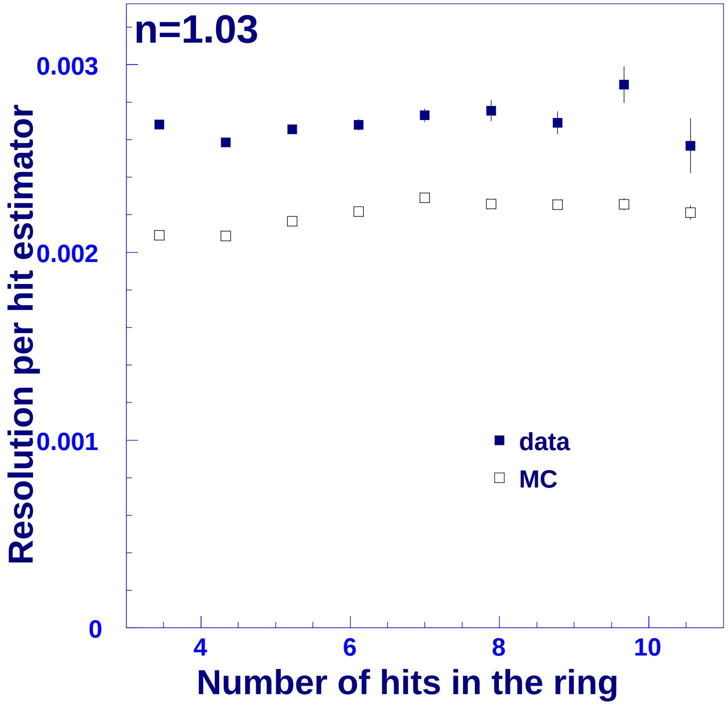


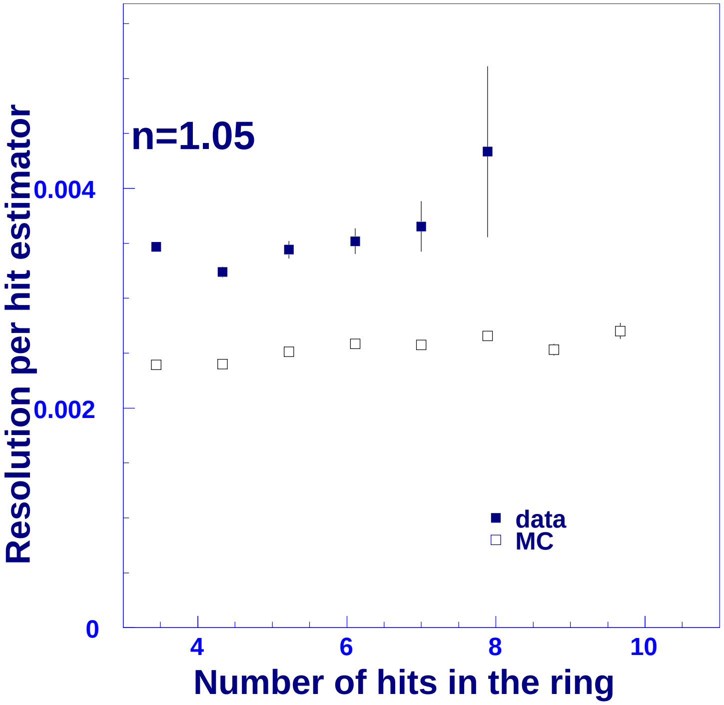
Track known: resolution per hit

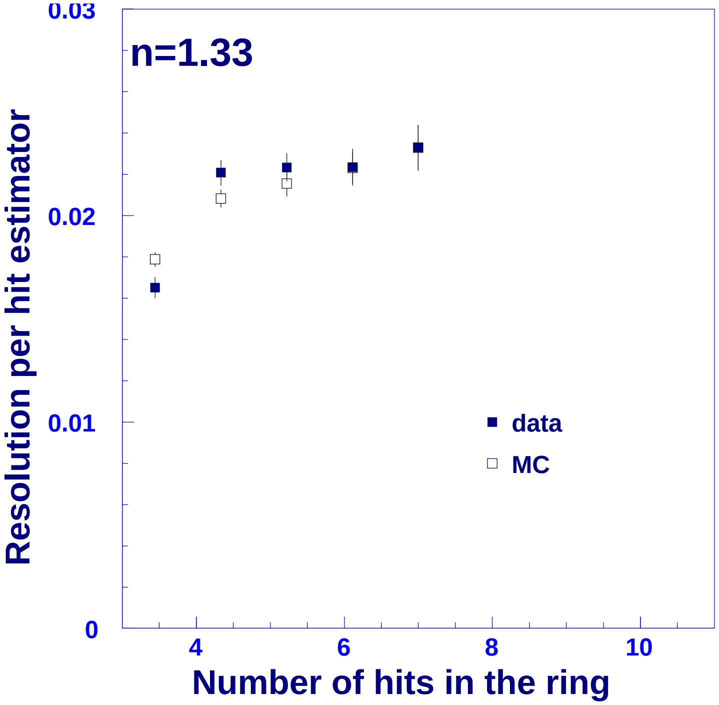
- Estimated as

$$\lim_{n_{used}\to\infty}\sqrt{\frac{n_{used}}{n_{used}-1}}\,\sigma(\beta_{event}-\beta_{hit})$$

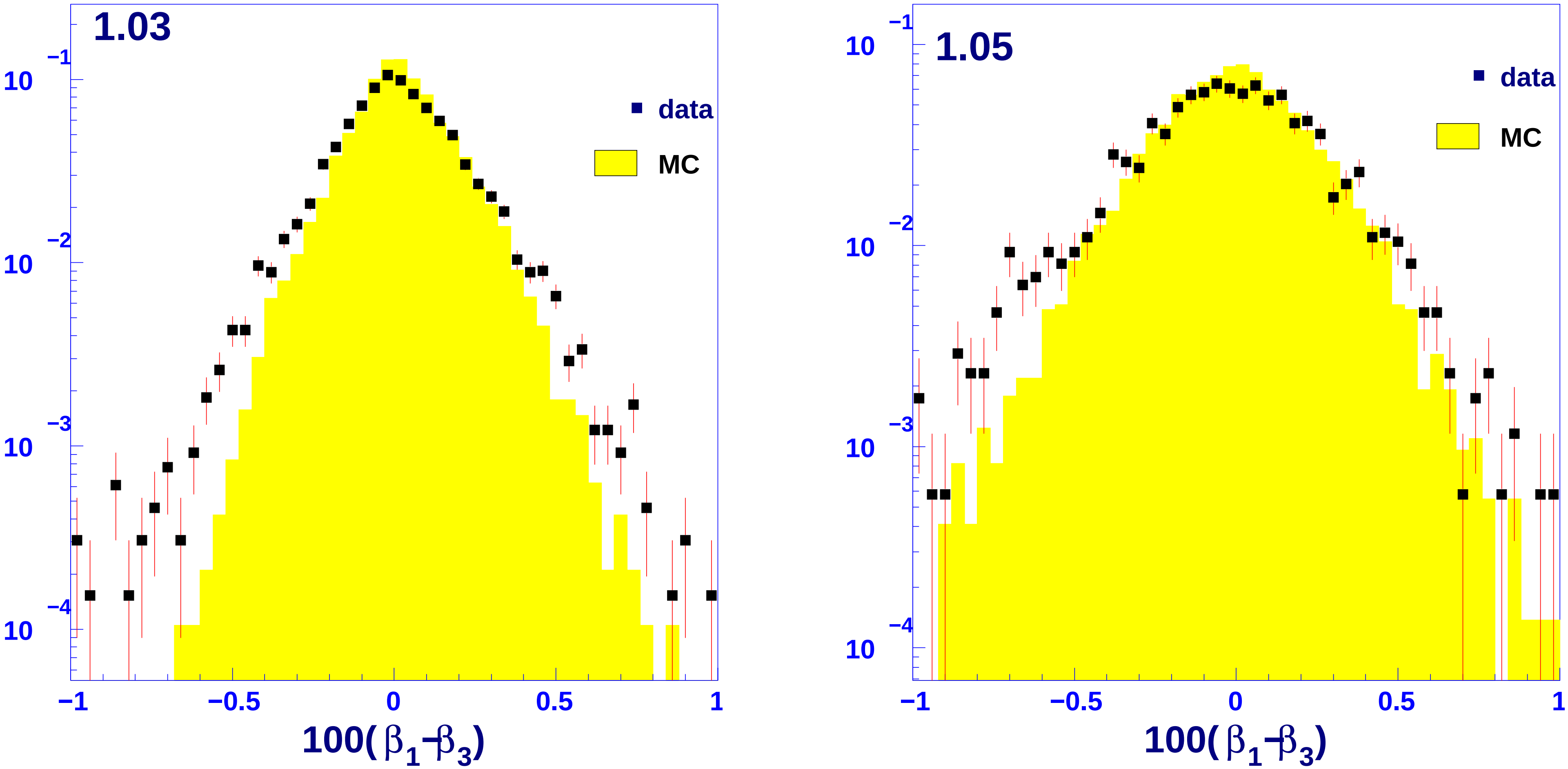
- $\approx$ 25% of disagreement for n=1.03
- Roughly 40% for n=1.05, but not conclusive due to the lack of hits.
- Very good agreement for NaF





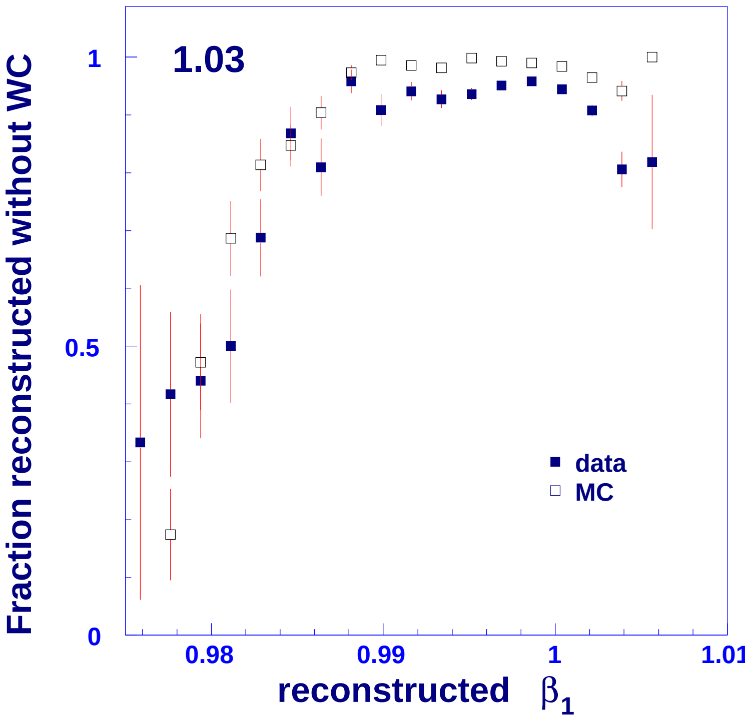


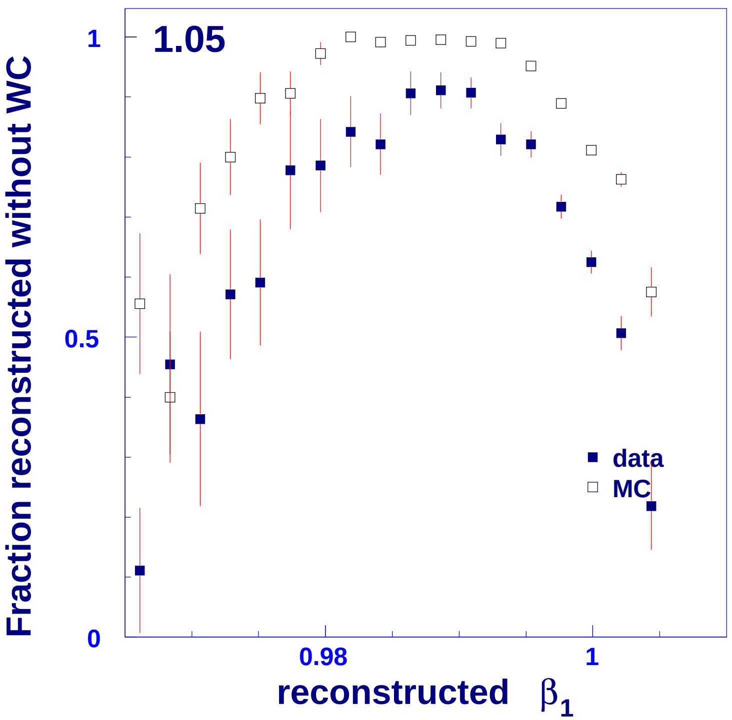
Track unknown: correlation with 'track known' rec.



- New reconstruction only working for aerogel runs.
- Reconstructions difference are within $\approx 2\sigma$ of the reconstruction using the wire chambers for data and MC.

Track unknown: reconstruction efficiency

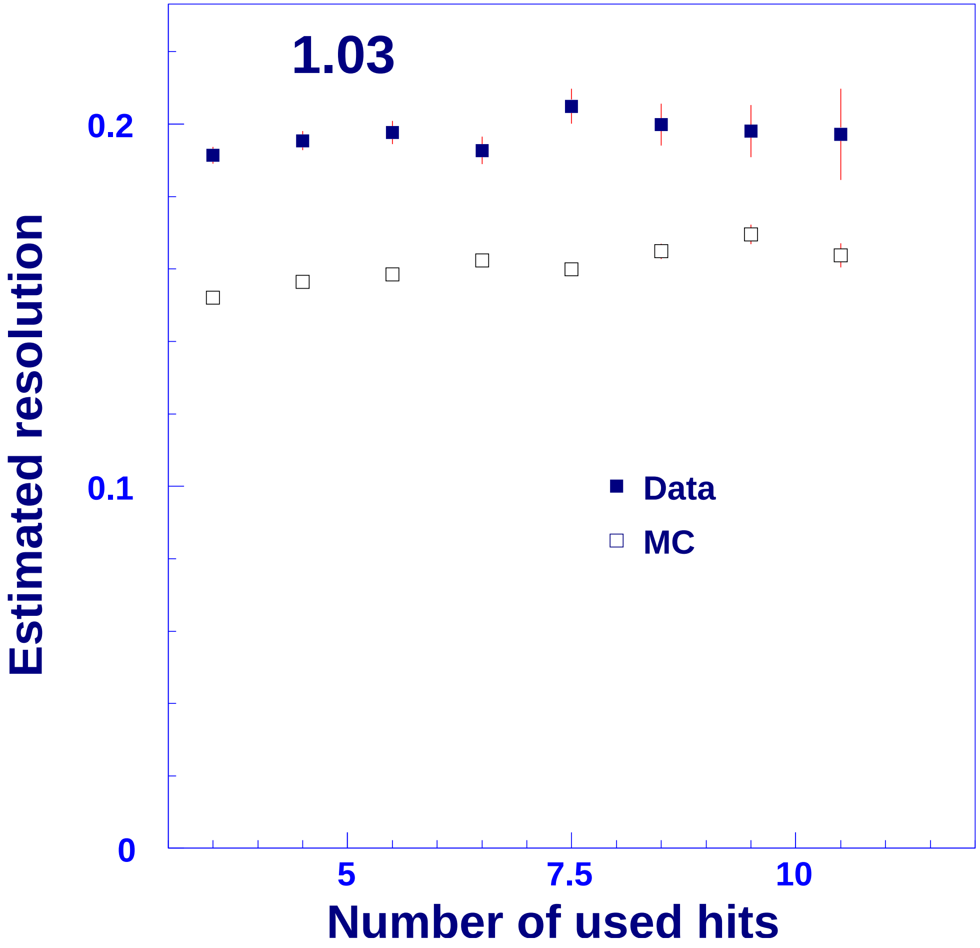


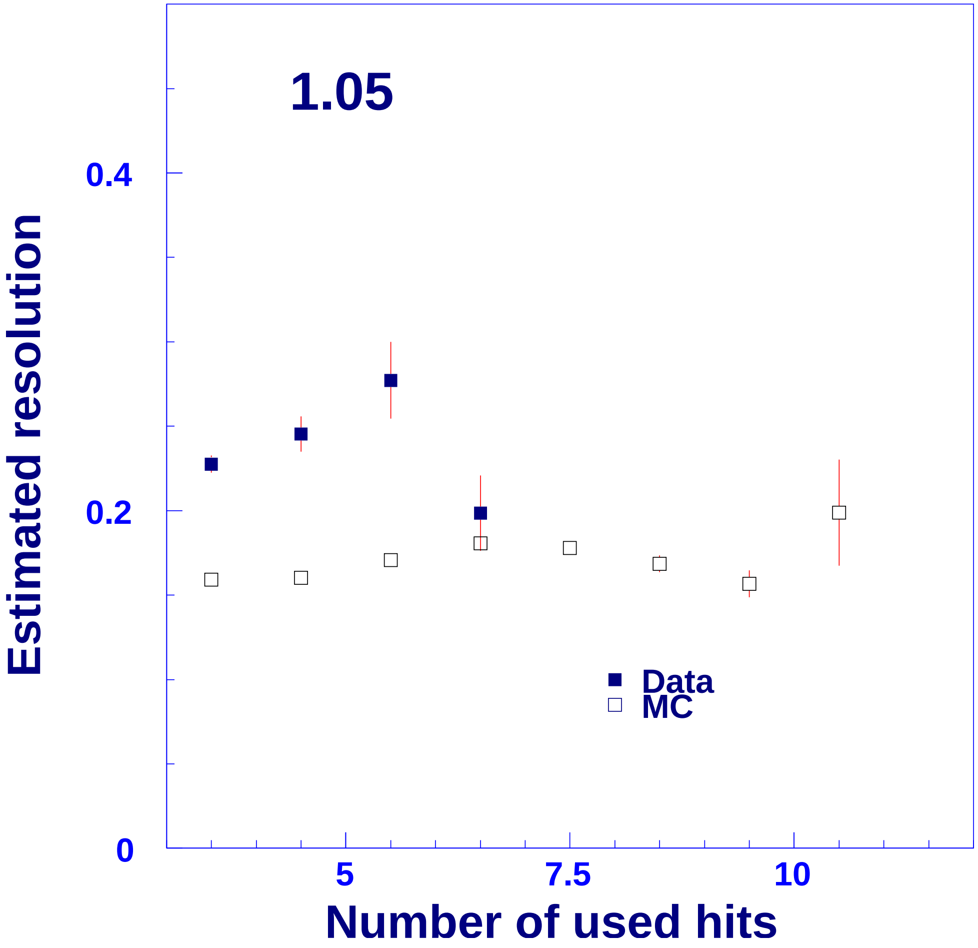


- The reconstruction without wire chambers has a strong dependence in the fraction of ring detected. This explain the decrease for large β in the efficiency.

- The reconstruction efficiency for n=1.05 is smaller than the expected. This is due to the small mean number of hits per ring on data respect the MC.

Track unknown: resolution per hit (%)





- For n=1.03, the disagreement between data and MC is similar to the one of the reconstruction using the wire chambers.
- For n=1.05, apparently the disagreement is similar too. However the small number of hits per rings makes it difficult to give a precise number.

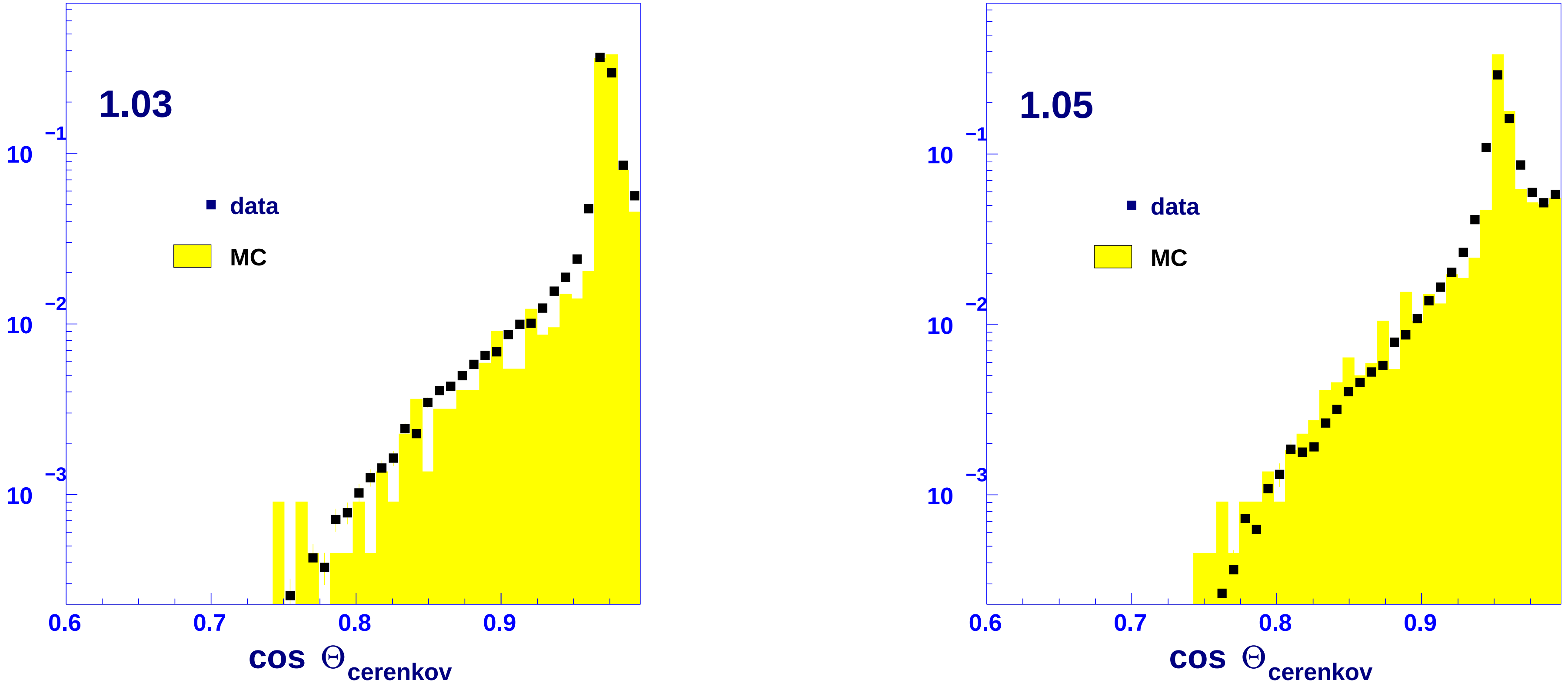
Summary of differences

We can summarize the previous results as:

- For aerogel the background is larger than the expected.
  This difference is such that:
  - The total number of hits agrees in data and MC.
  - The number of hits in the ring is smaller in data.

  thus pointing to a migration from the population of hits in the ring to the background.
  Apparently this does not happen for NaF.
- The resolution per hit for aerogel is worse than expected.

Background excess



- The background and (partly) the difference in the resolution can be parametrized as a scattering process over imposed to the Rayleigh with:

`n=1.03`

- Mean free path: 2 cm
- $\frac{d\sigma}{d\Omega} \propto \frac{G_{\sigma=0.5}(\theta)}{sin\theta}$

`n=1.05`

- Mean free path: 1 cm
- $\frac{d\sigma}{d\Omega} \propto \frac{G_{\sigma=0.5}(\theta)}{sin\theta}$

The necessary scattering lengths ratio is compatible with the values obtained from the clarity:

$$L_{scattering}(\lambda) = \lambda^4 Clarity^{-1}$$

- n=1.03 (Cl=0.0042): $L_{scattering}(400nm) \approx 6cm$
- n=1.05 (Cl=0.0091): $L_{scattering}(400nm) \approx 3cm$

However the cross section is different:

$$\frac{d\sigma_{rayleigh}}{d\Omega} \propto 1 + cos^2\theta$$

The deterioration of the resolution is, at least partly, due to this effect.

Need to be measured!!!

Conclusions

- NaF resolution agrees with MC.
  So light guide angular inefficiency is well reproduced in MC. not clear.
- NaF photon yield is larger than expected.
  This to be understood.
- Agreement for n=1.03 is better than for n=1.05 (but note the acceptance and radiator thickness differences). However the source of both disagreements seems to be similar:
  - Aparently it is not the wire chambers, as we see it using the independent algorithm.
  - It is not the light guides or PMT, as we do not see it for NaF.
  - The stacking cannot be responsible for all the effect as for n=1.05 the stacking is smaller but the disagreement is larger.
  - The disagreement could be due to a very forward scattering process.
  - We have not idea of the contribution due to the polyester foil!!

Petitions

- Set of measurements of the aerogels forward scattering angular distribution to determine if the new scattering process is really there.
- Set of runs without the polyester.
- Run of n=1.03 (at least) without stacking.
- Run with n=1.05 with 3cm of thickness and/or smaller drift distance.
- Measurement of light guides properties.