Standalone reconstruction with the AMS RICH detector: update

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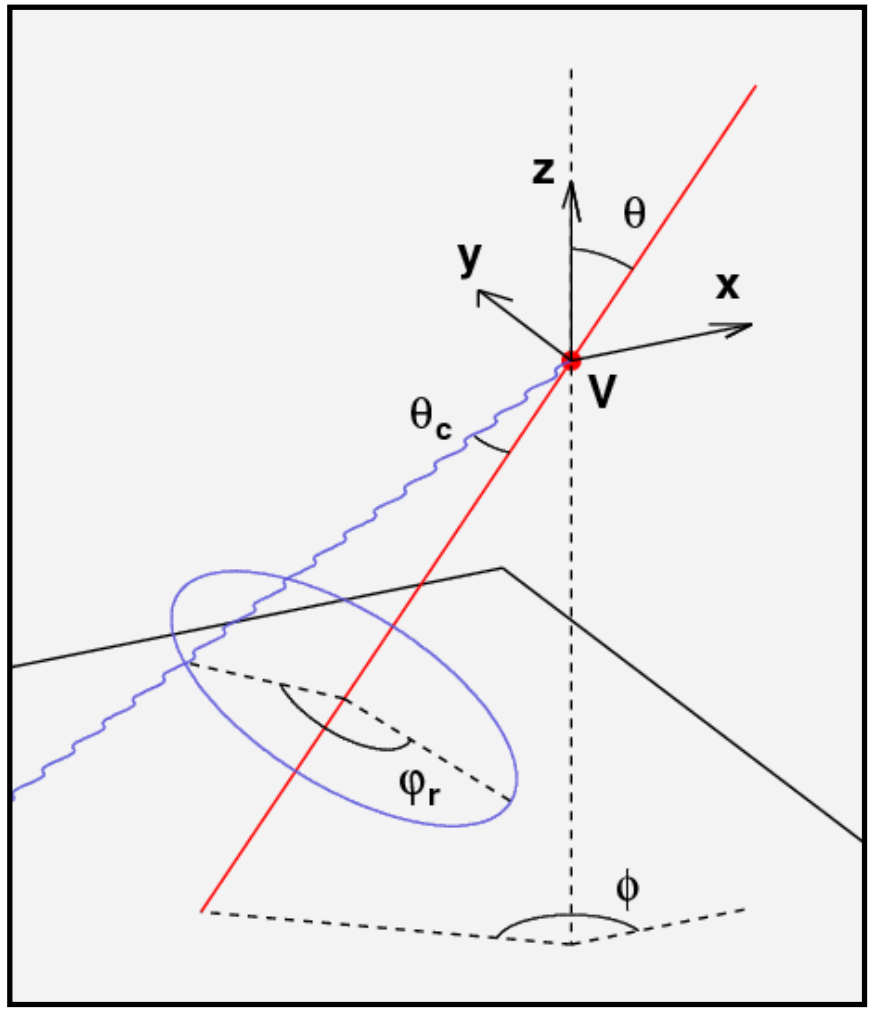
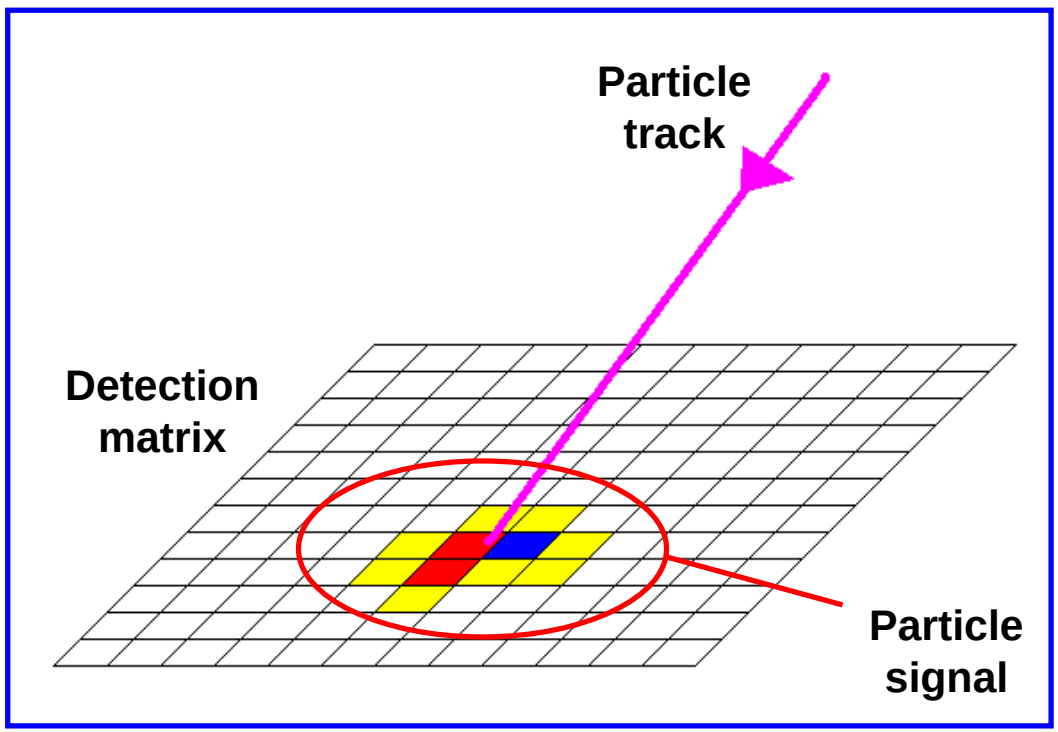
RICH standalone reconstruction

- Goal: event reconstruction using only data from the RICH detector
- No Tracker or TOF data used
- 5 parameters for reconstruction:
  - matrix impact point (x_{matrix}, y_{matrix}), θ, ϕ, θ_c
- Likelihood function used (similar to 1-parameter reconstruction)
- Sample used: proton events in the AMS-02 full simulation:
  - p > 10 GeV/c/nuc ($\beta \approx 1$)
  - p < 10 GeV/c/nuc ($\beta < 1$)



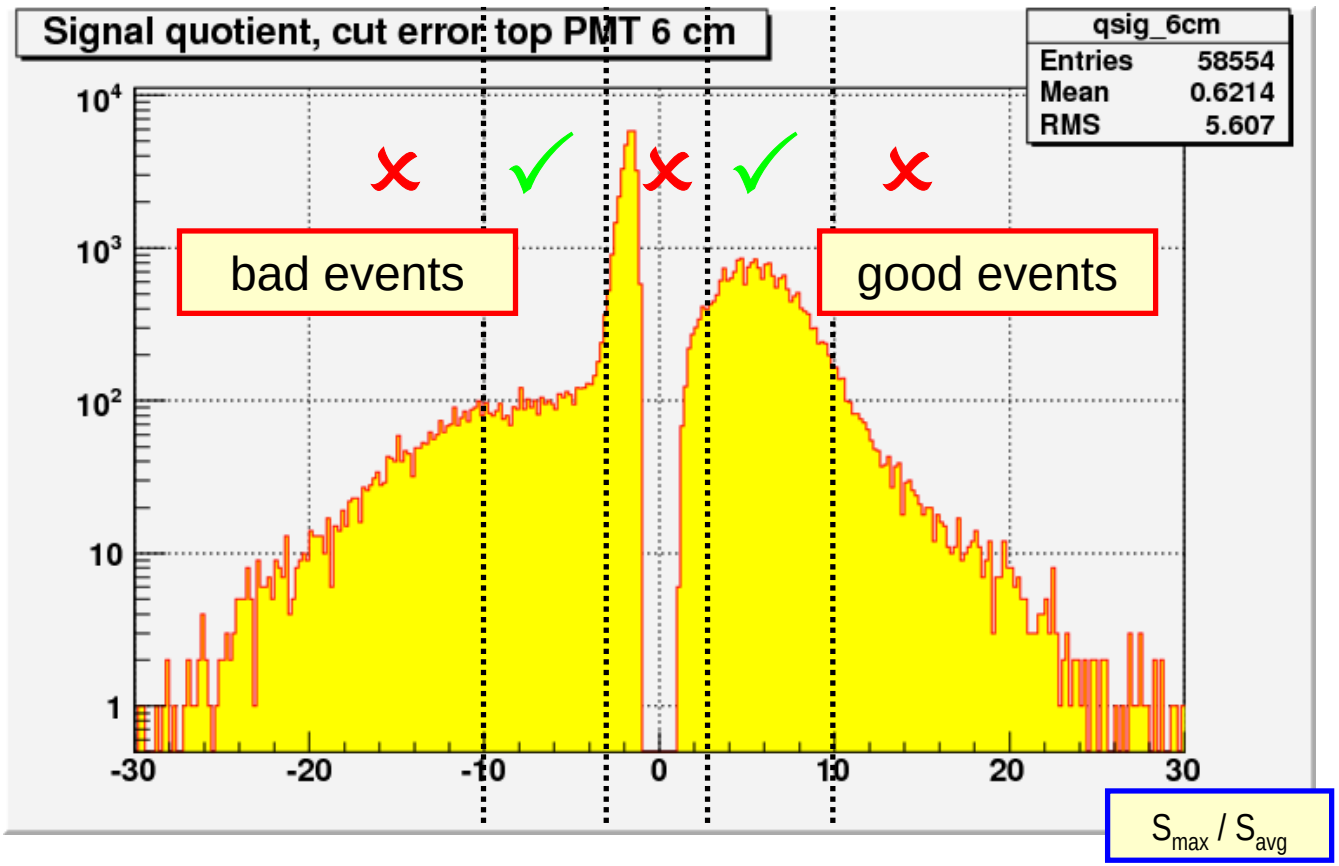
RICH standalone reconstruction

- PMT matrix crossing point identified by strong signal in matrix (much stronger than ring hits)
- Quality cuts for hint:
  - Quotient between strongest and average PMT signal must be higher than 3 and lower than 10
  - Strongest PMT signal must be higher than 6 p.e.



Quality cuts: signal quotient

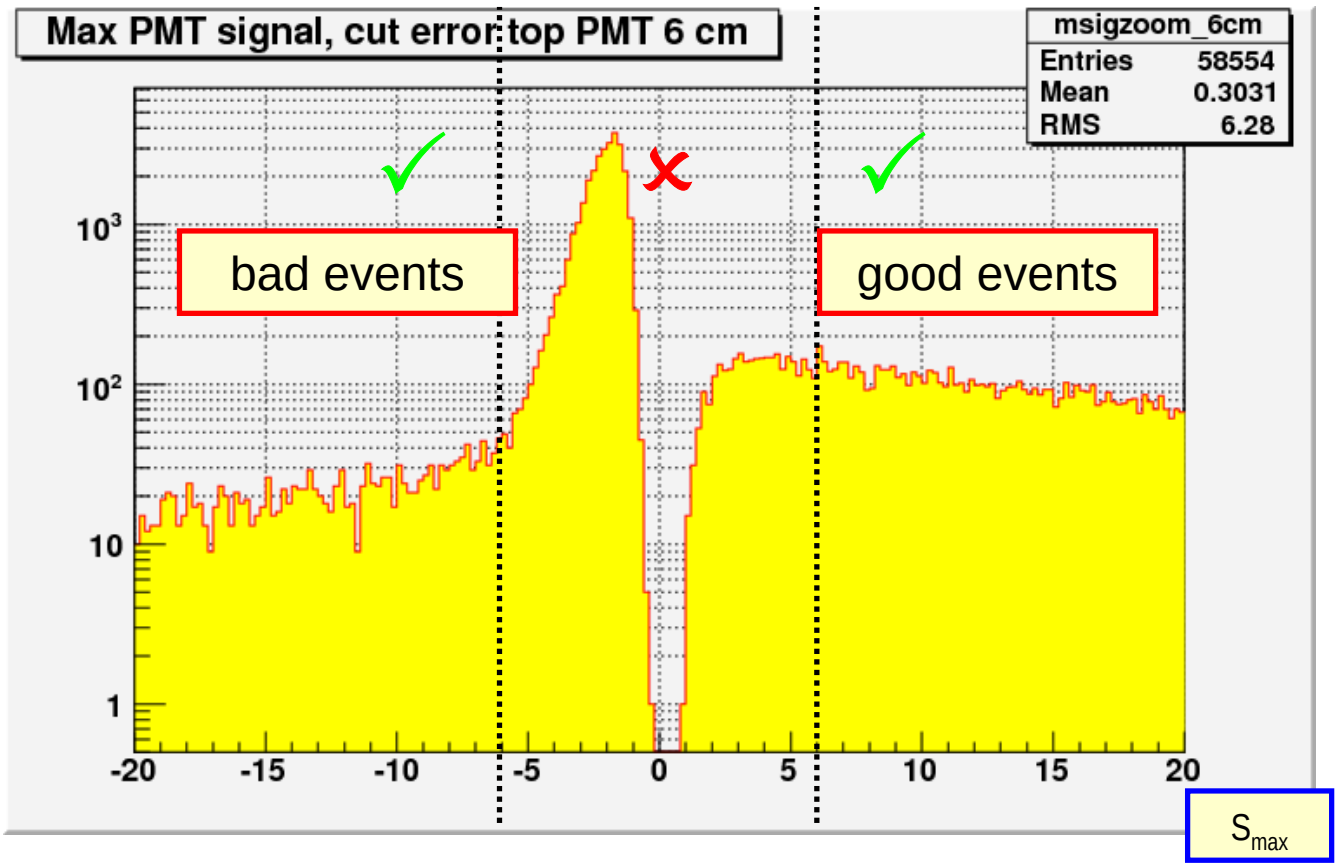
- $3 < S_{max} / S_{avg} < 10$
  - S_{max} = highest total signal in a PMT
  - S_{avg} = average signal in PMTs hit



good events defined as having hint < 6 cm from real crossing point

Quality cuts: strongest PMT signal

- S_{max} > 6 p.e.
  - S_{max} = highest total signal in a PMT



good events defined as having hint < 6 cm from real crossing point

Standalone reconstruction: new version

- Situation in May 2007:
  - Reconstruction performed starting from vertical hint (or almost vertical if impact signal was near the edge of the detection matrix) with $\beta = 1$
  - Large bias in track reconstruction towards smaller θ, combined with significant fluctuations in the reconstructed angle for events with similar inclination, made reconstruction impossible, at least for Z = 1

- First attempt: iterative method
  - Successive minimizations based on the result of the previous one:
    - Vertical hint for first iteration
    - After first iteration, hints uses θ, ϕ, θ_c from result of previous iteration
    - Same matrix impact point (from original hint) in all iterations
  - Results did not improve with respect to original method

Standalone reconstruction: new version

- New approach to standalone reconstruction: using several hints instead of only one, selecting best reconstruction by likelihood value and/or number of ring hits
  - Removes the implicit preference for vertical reconstructions and high velocity
  - Better coverage of parameter space
  - Drawback: much more time-consuming

Standalone reconstruction: new version

- Grid of hints in parameter space – hints are combinations of:
  - Different emission points in radiator
  - Different impact points in PMT matrix
  - Different Cerenkov angles

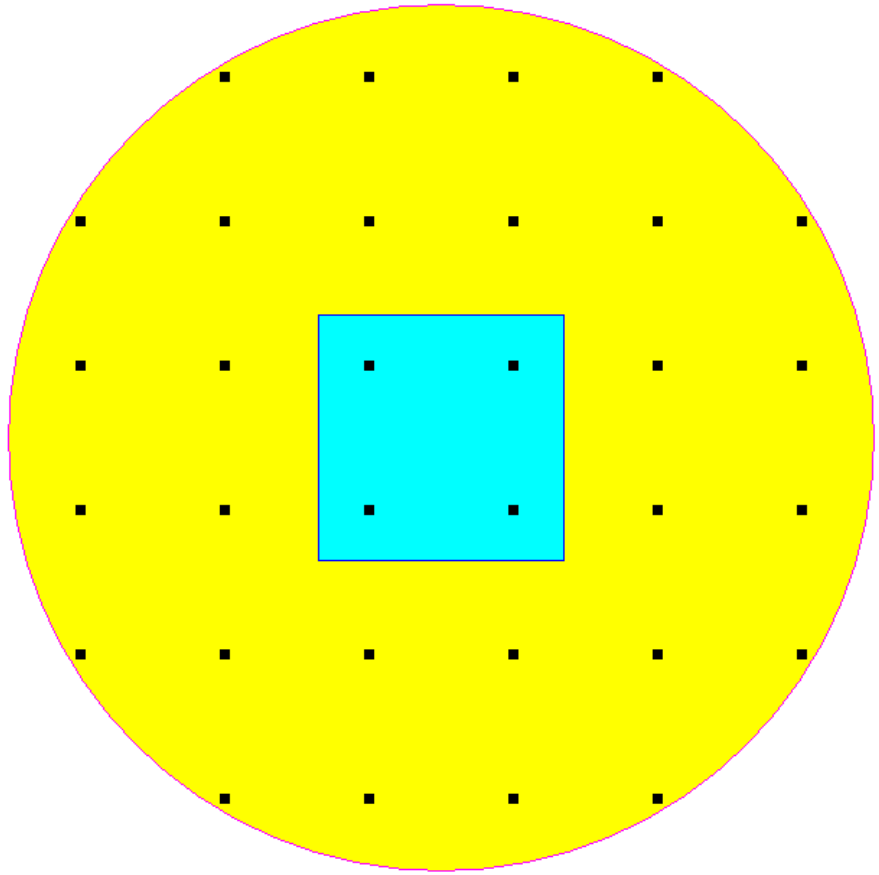
- Number of hints is large even if only a small number of values is considered for each parameter $\Rightarrow$ performing minimization from all hints might not be possible in practice

- Approach used here: likelihood is calculated for all hints but minimization is only applied to the most promising ones

- Several versions of this hint-grid procedure were tested, looking for a compromise between reconstruction quality and processing time

Standalone reconstruction: new version

- Version presented here uses:
  - 32 emission points, 28 aerogel + 4 NaF (square grid with 20 cm step, 6×6 points except corners)
    - points > 50 cm from vertical of matrix hint are discarded
  - 9 impact points (square grid with 1 cm step, 3×3 points where central point is matrix hint)
  - 5 Cerenkov angles correspondng to 68%, 76%, 84%, 92%, 100% of angle for $\beta = 1$

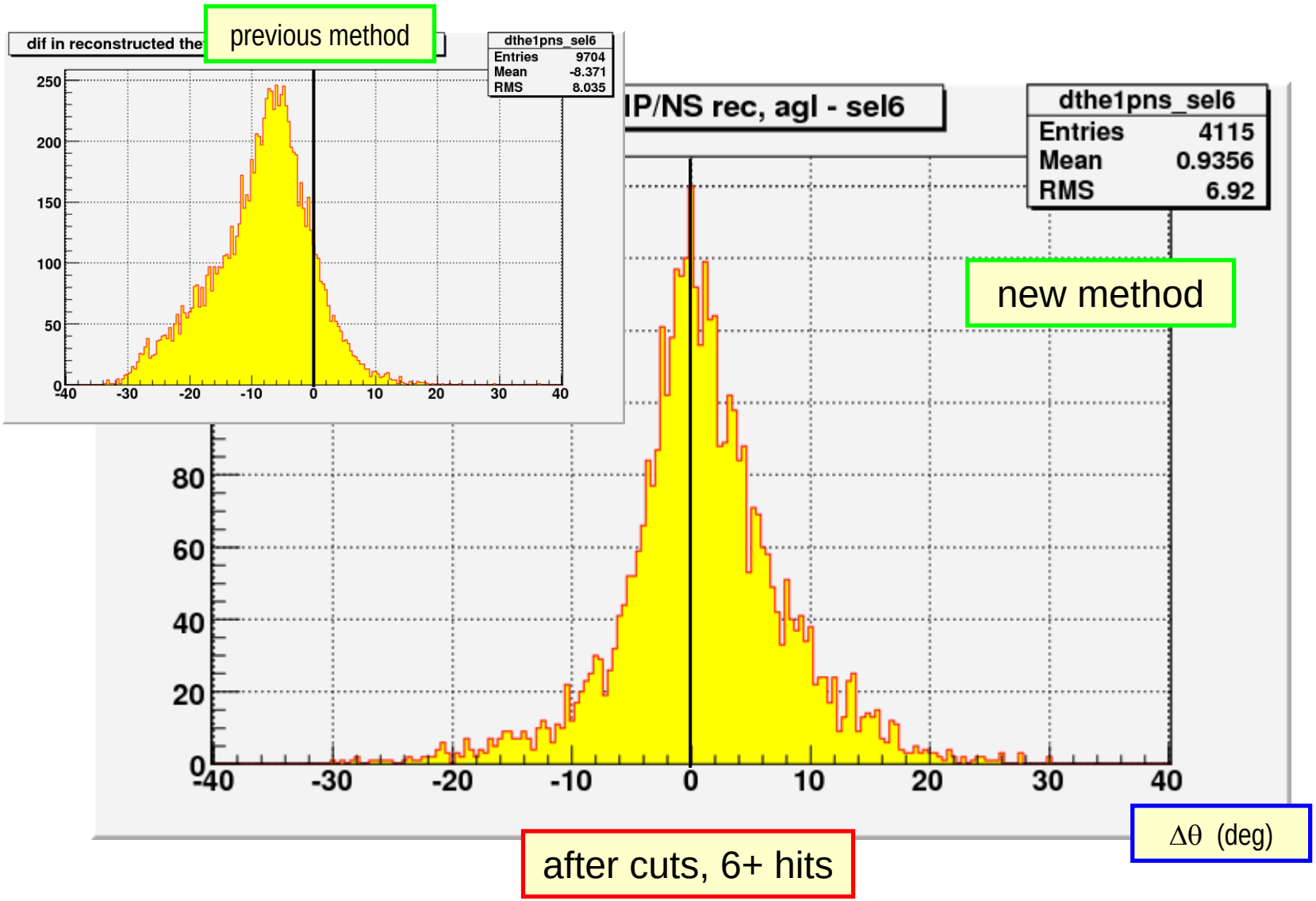


grid of emission points

Standalone reconstruction: new version

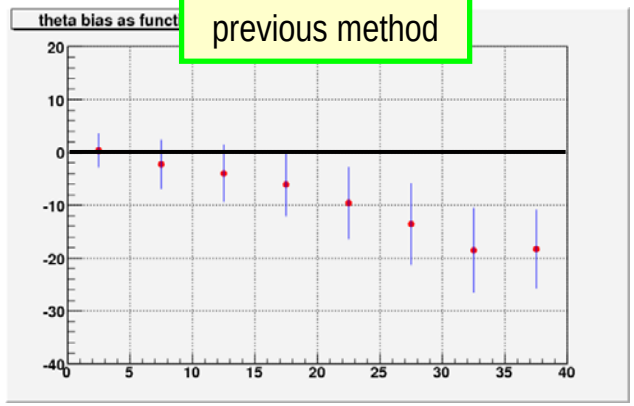
- Value of likelihood is calculated for all combinations of emission point, matrix impact point and Cerenkov angle
  - Effective depth of PMT impact signal (1.8 cm) is used
- Hints are sorted according to their likelihoods
- Best 50 hints are used as starting points for 5-parameter minimization procedures
- Results of 50 minimizations are sorted according to:
  - i) number of hits in ring
  - ii) likelihood value
- Result of best minimization is taken as final result of standalone reconstruction
- Same quality cuts of March/May version
- Applied to event sample with $\beta \approx 1$

Reconstruction quality: θ

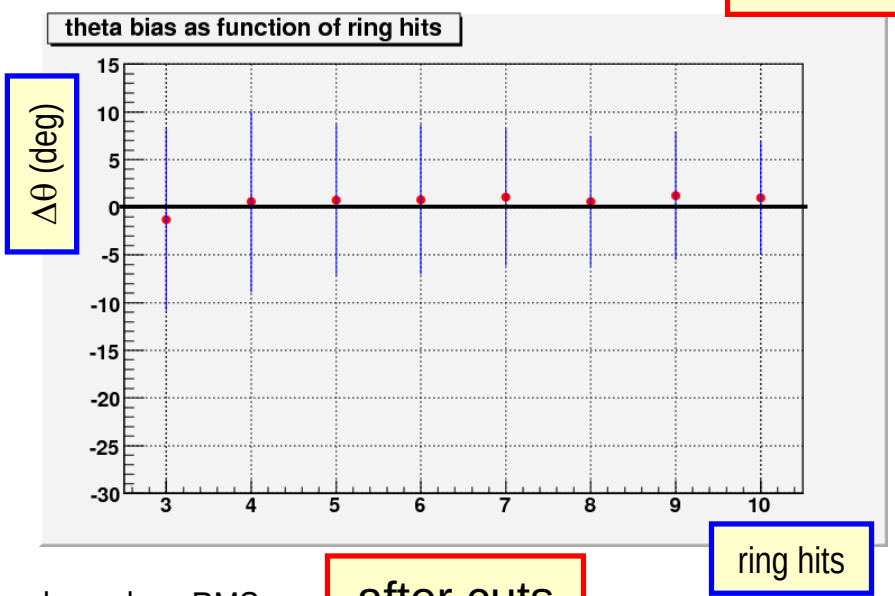


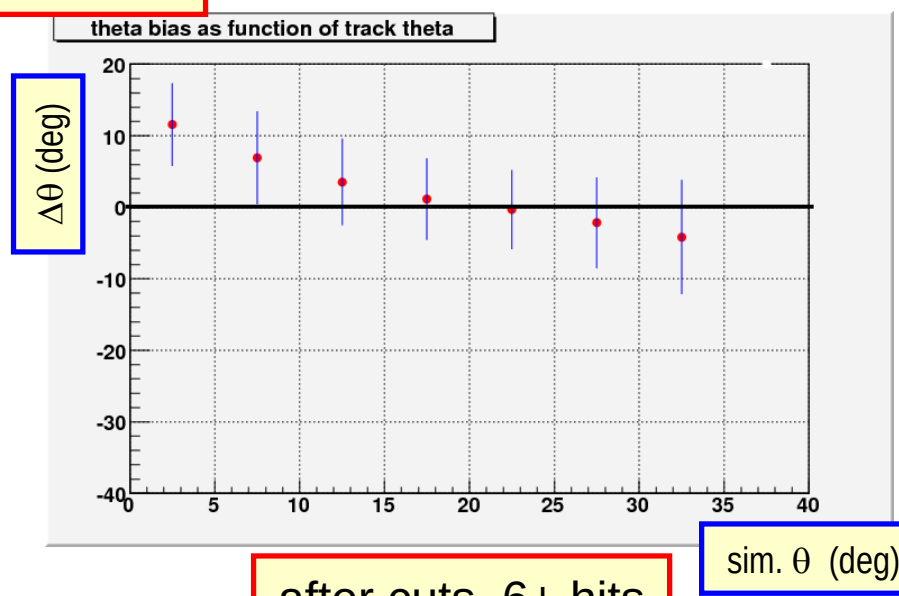
Reconstruction quality: θ, all events

- Average bias in θ reconstruction is now close to zero
  - Positive bias for small θ, negative bias for large θ
  - Reconstructed θ is, on average, close to simulated values
  - For a given angle, spread in reconstructed θ is ~5°



ALL EVENTS





after cuts

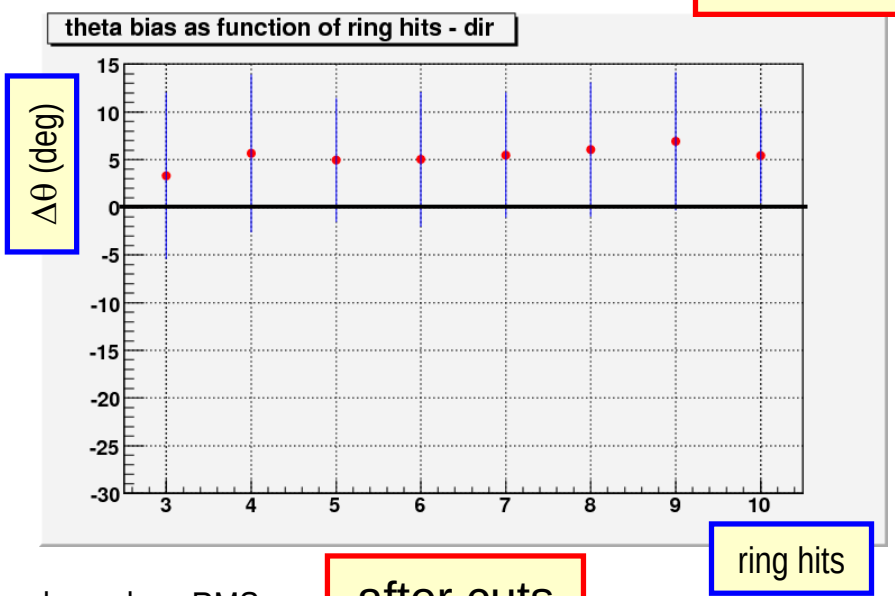
after cuts, 6+ hits

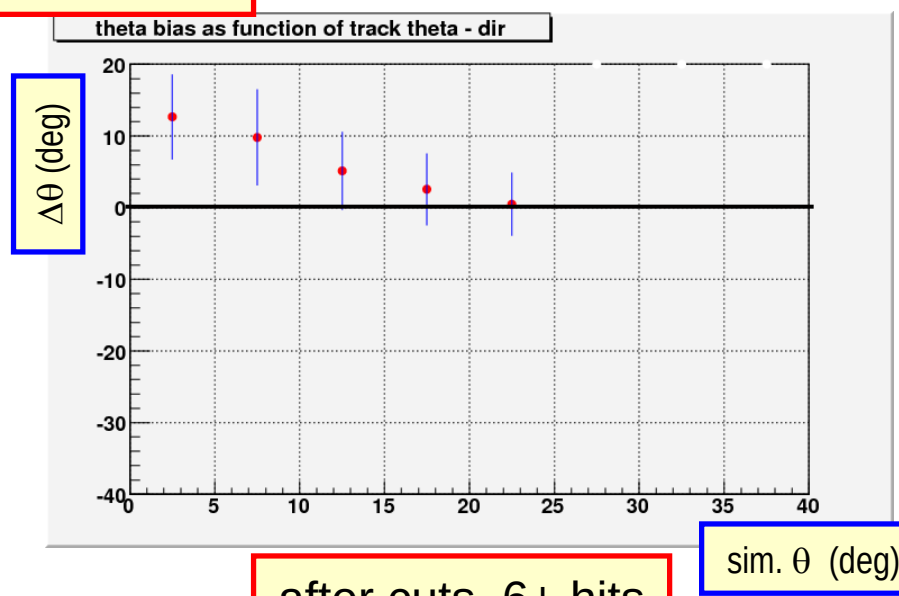
bars show RMS of distributions

Reconstruction quality: θ, direct events

- Direct events (r_{hint} < 42 cm):
  - Positive bias in θ: ~5°
  - Distribution as function of simulated θ shows that change in bias is due to smaller average θ (<θ>~12°): bias is similar for events with same angle

DIRECT EVENTS





after cuts

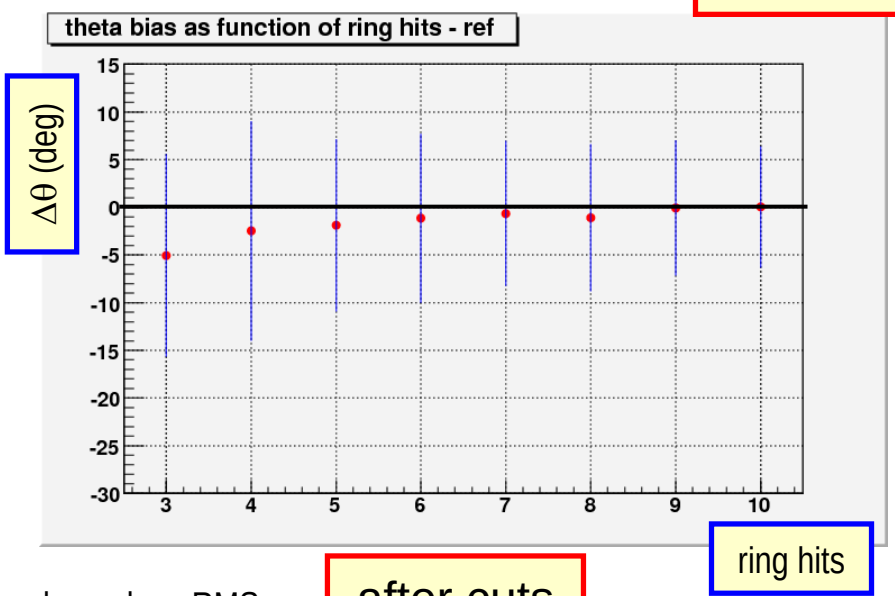
after cuts, 6+ hits

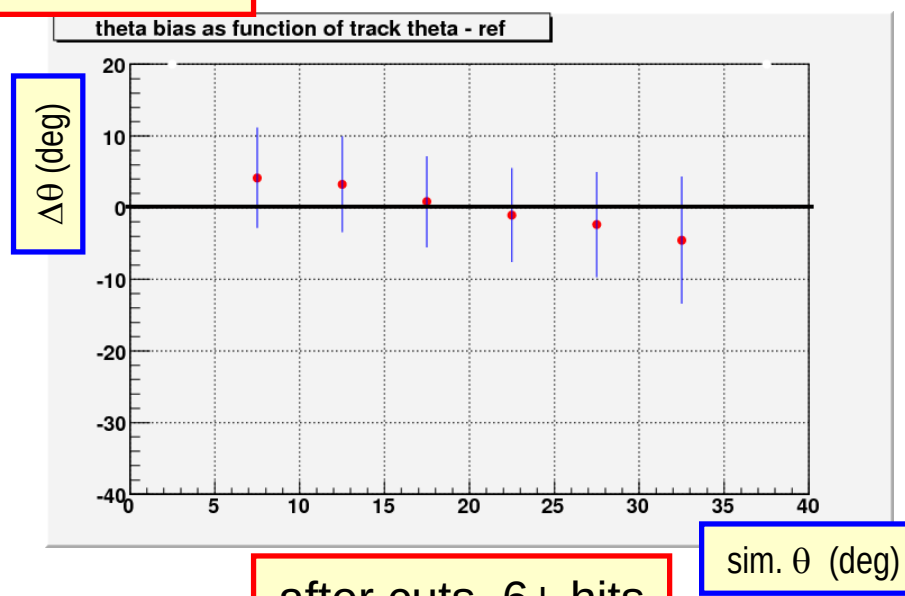
bars show RMS of distributions

Reconstruction quality: θ, mirror events

- Mirror events (r_{hint} > 55 cm):
  - Negative bias in θ, especially for events with few hits
  - Most events with a high number of hits come from this region due to their high acceptance
  - Again, similar bias for events with same angle

MIRROR EVENTS



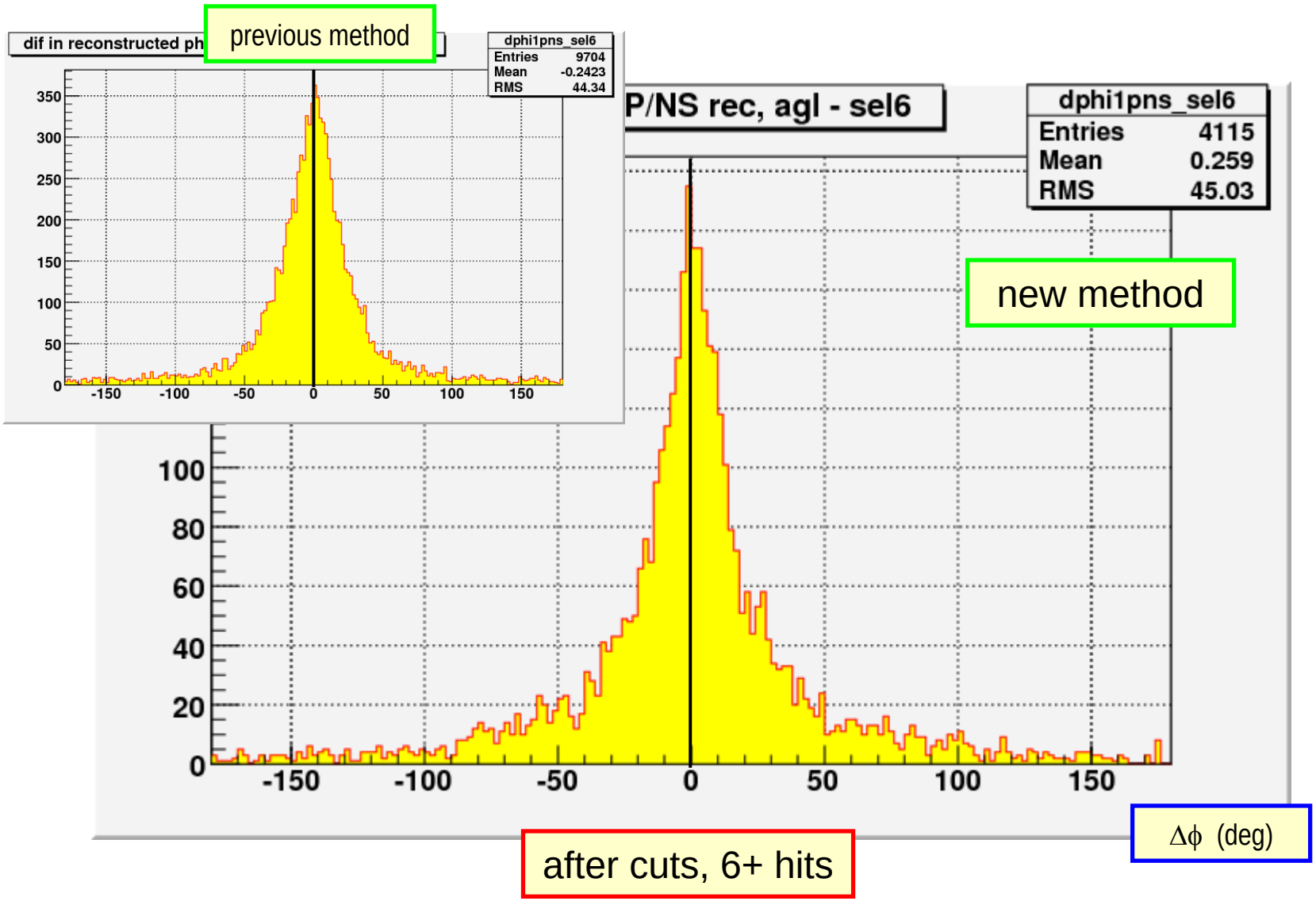


after cuts

after cuts, 6+ hits

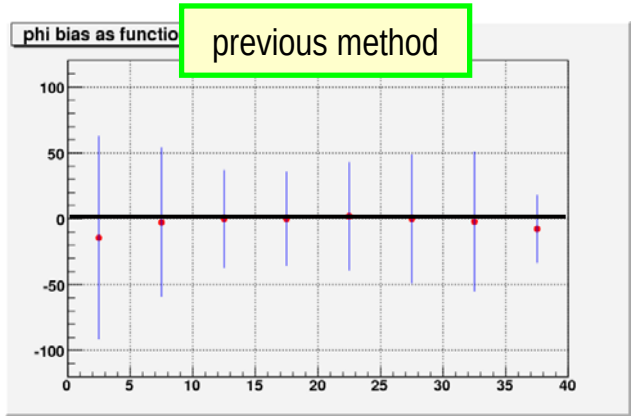
bars show RMS of distributions

Reconstruction quality: ϕ

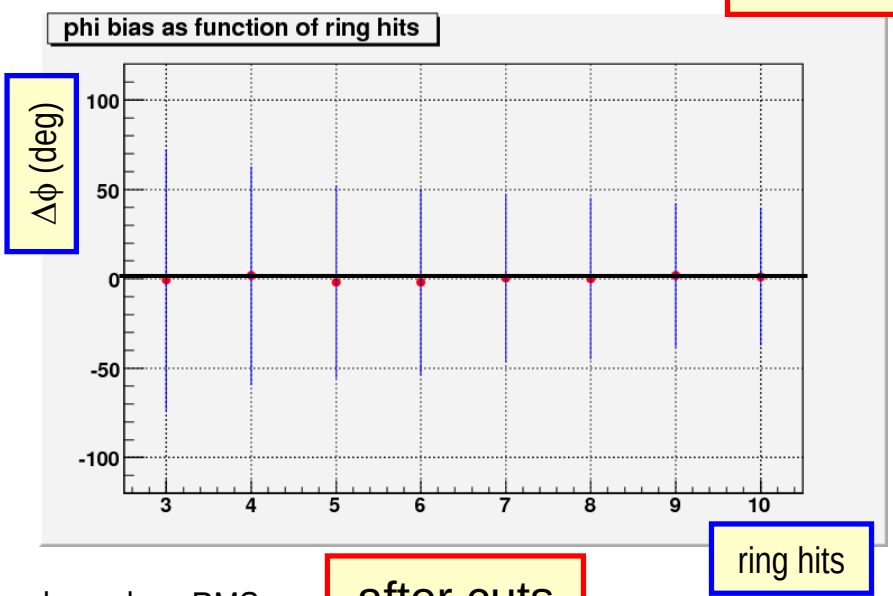


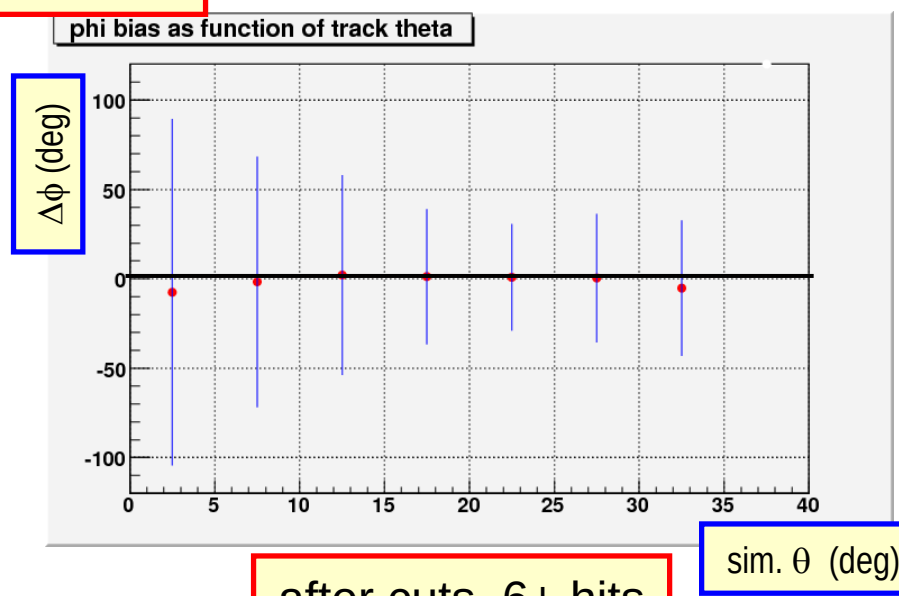
Reconstruction quality: ϕ, all events

- No bias in ϕ reconstruction
  - Spread decreases as number of hits increases
  - Mixed behaviour of ϕ spread as function of θ: decrease in 0°-20° region, stable for higher angles



ALL EVENTS





after cuts

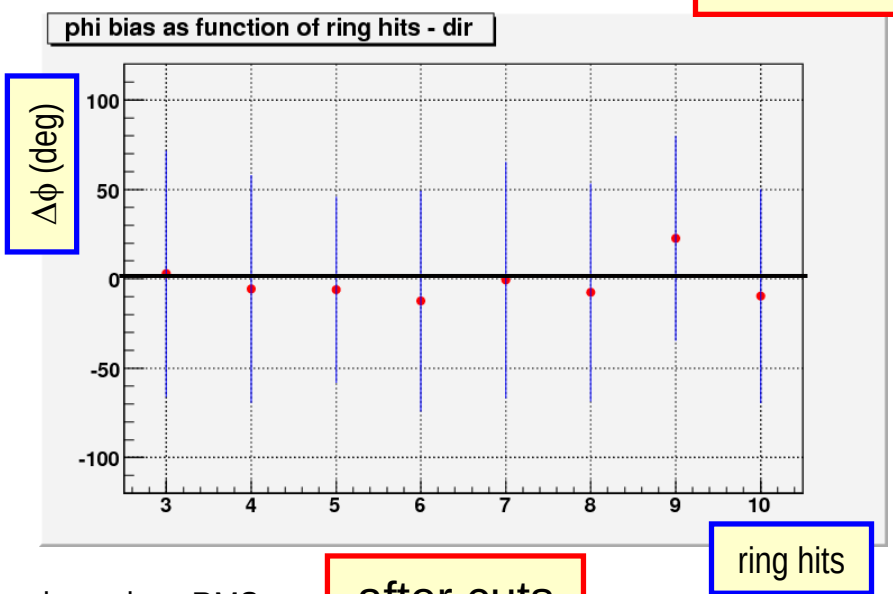
after cuts, 6+ hits

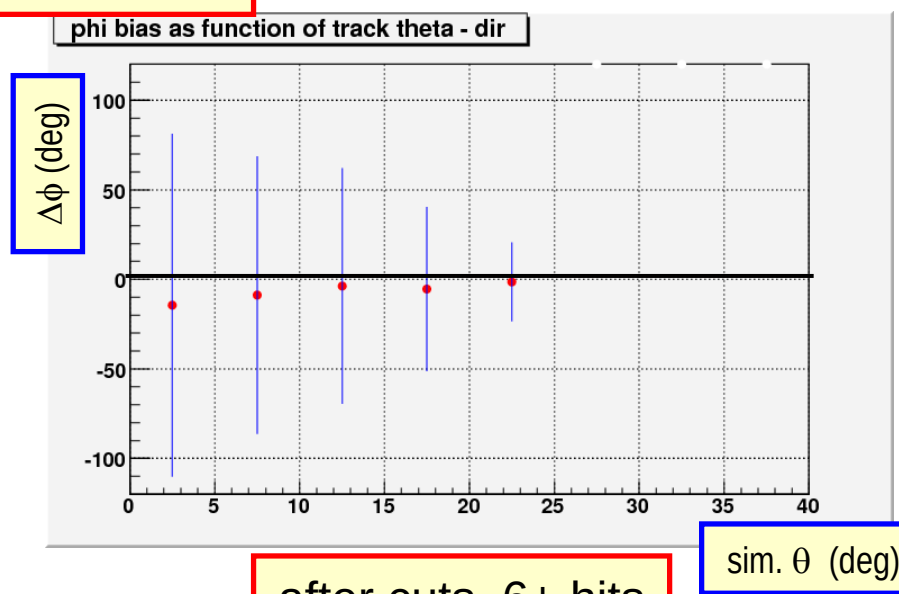
bars show RMS of distributions

Reconstruction quality: ϕ, direct events

- Direct events (r_{hint} < 42 cm):
  - Spread ~50° is almost independent of number of hits
  - ϕ spread decreases to ~30° for θ ~ 20° (no data available for higher θ in this region)

DIRECT EVENTS





after cuts

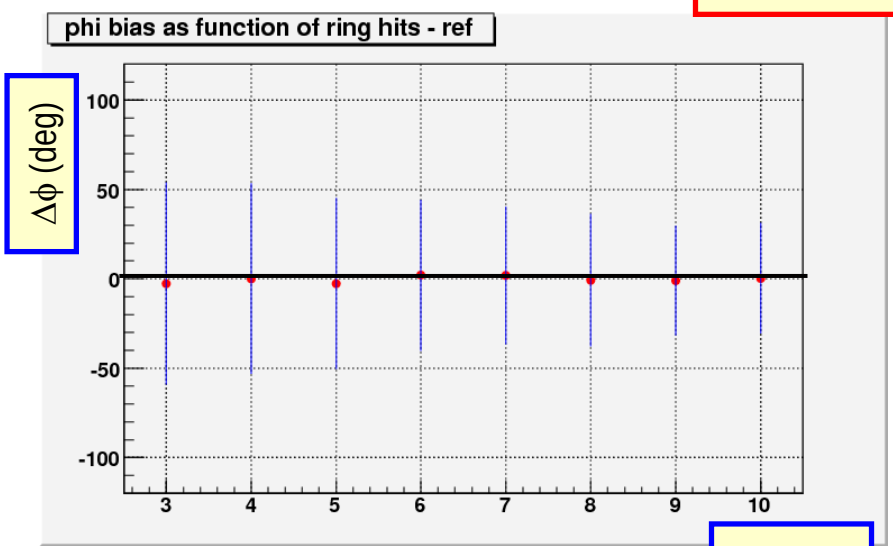
after cuts, 6+ hits

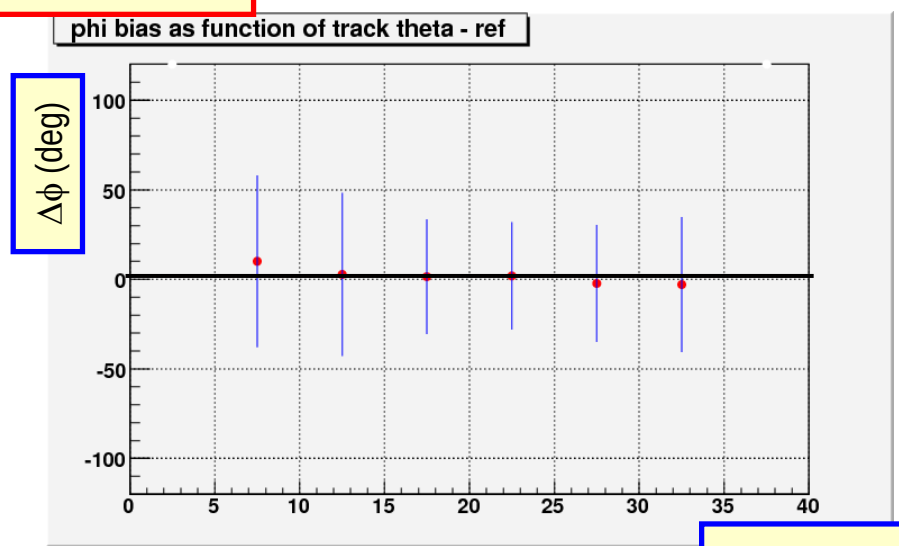
bars show RMS of distributions

Reconstruction quality: ϕ, mirror events

- Mirror events (r_{hint} > 55 cm):
  - Significant decrease in spread as number of hits increases
  - Mixed behaviour of ϕ spread as function of θ: increase in ϕ tails could be due to confusion between direct and reflected branches

MIRROR EVENTS



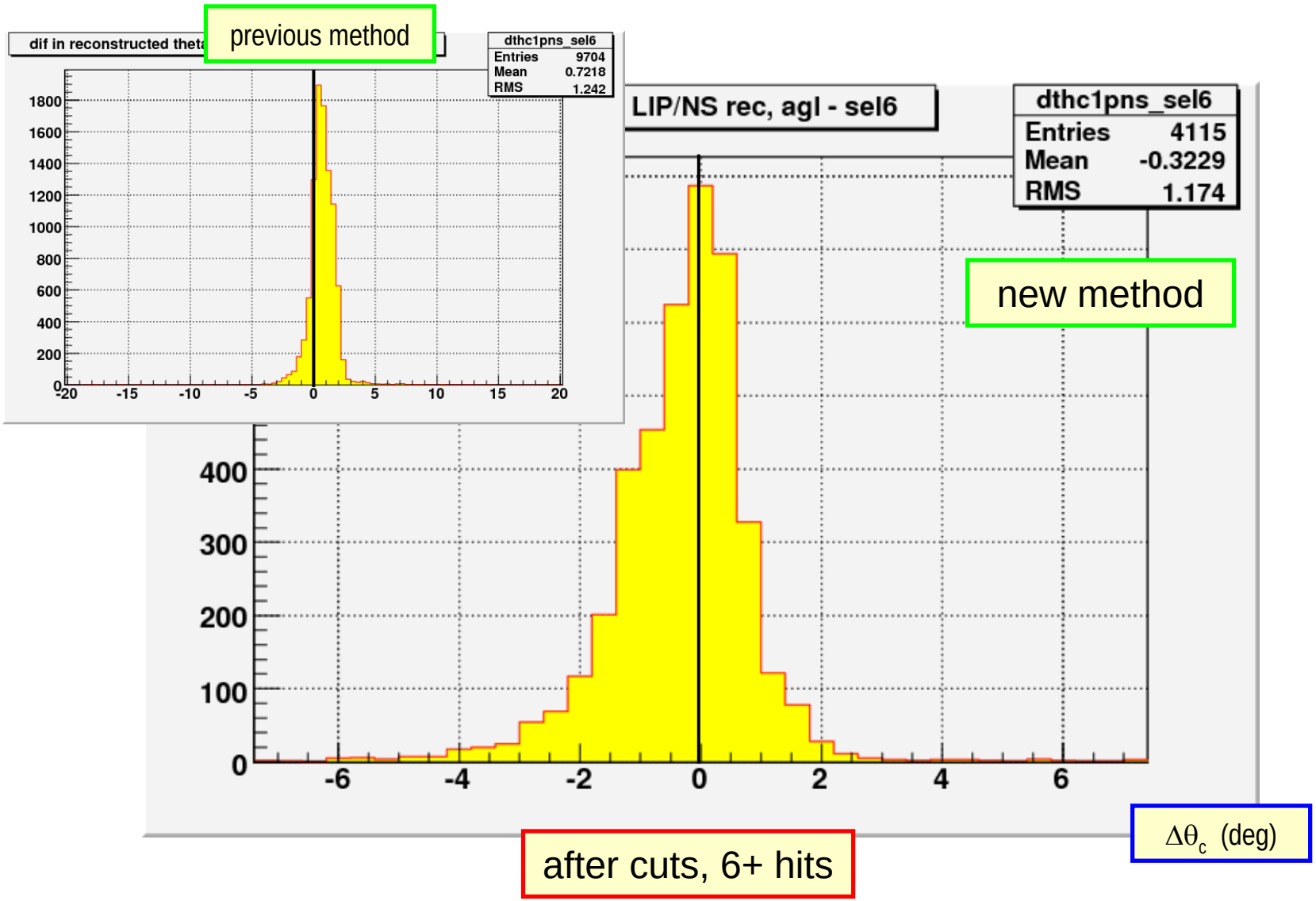


after cuts

after cuts, 6+ hits

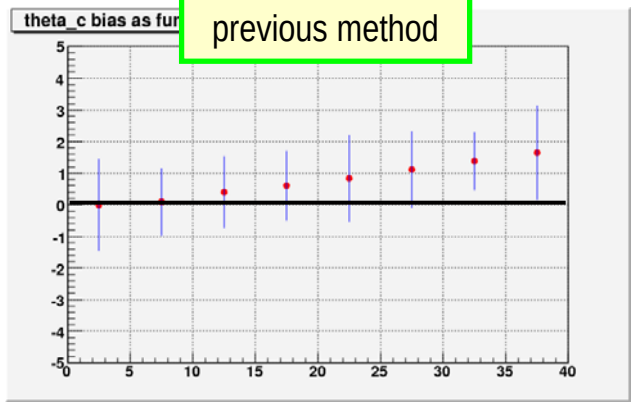
bars show RMS of distributions

Reconstruction quality: θ_c

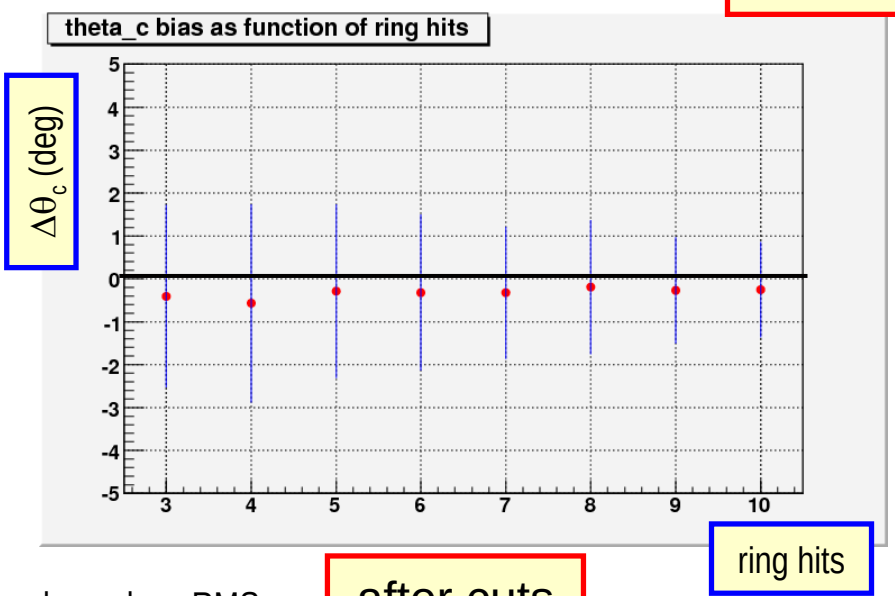


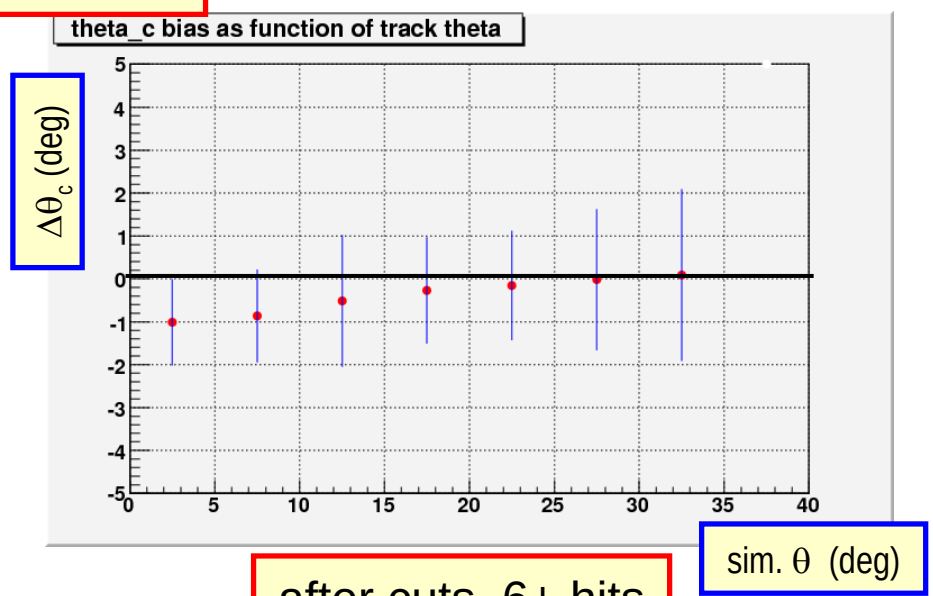
Reconstruction quality: θ_c, all events

- Visible bias in θ_c reconstruction
  - Difference between reconstructed and simulated angles peaks at zero, but left-hand tail is the largest one
  - Average bias of a few tenths of a degree, almost independent of number of ring hits
  - Larger bias (~1°) for vertical events, reaches zero for higher θ



ALL EVENTS





after cuts

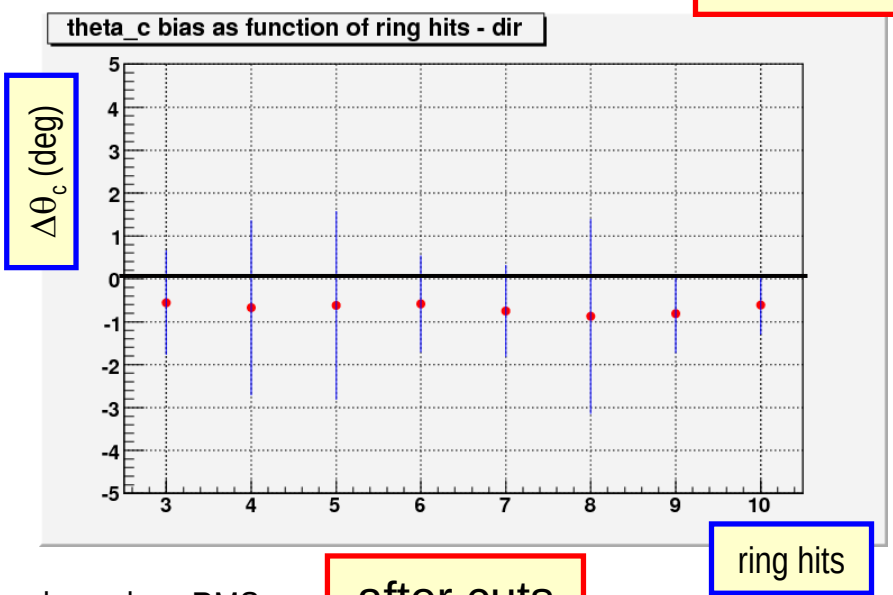
after cuts, 6+ hits

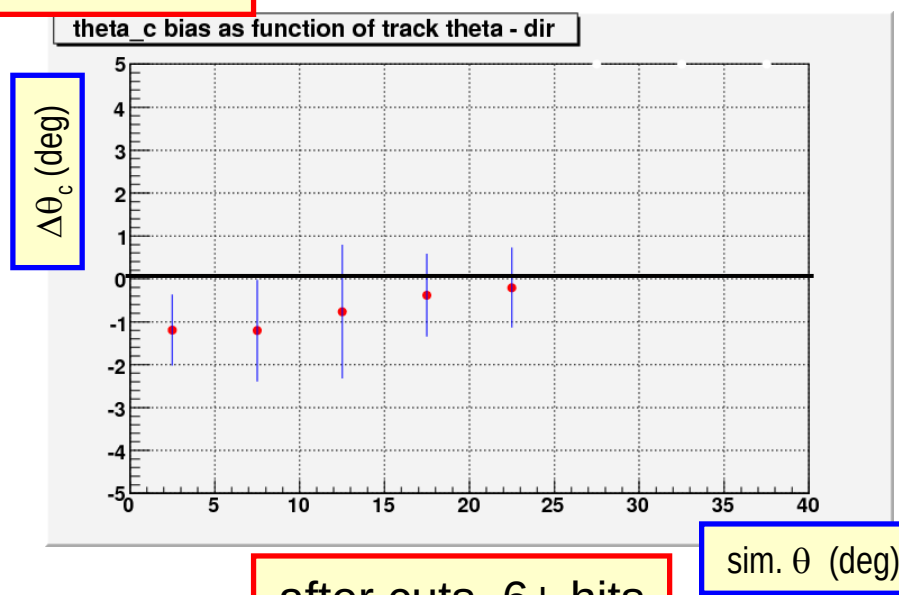
bars show RMS of distributions

Reconstruction quality: θ_c, direct events

- Direct events (r_{hint} < 42 cm):
  - Higher average bias, essentially due to lower θ
  - Average bias ~0.7°

DIRECT EVENTS





after cuts

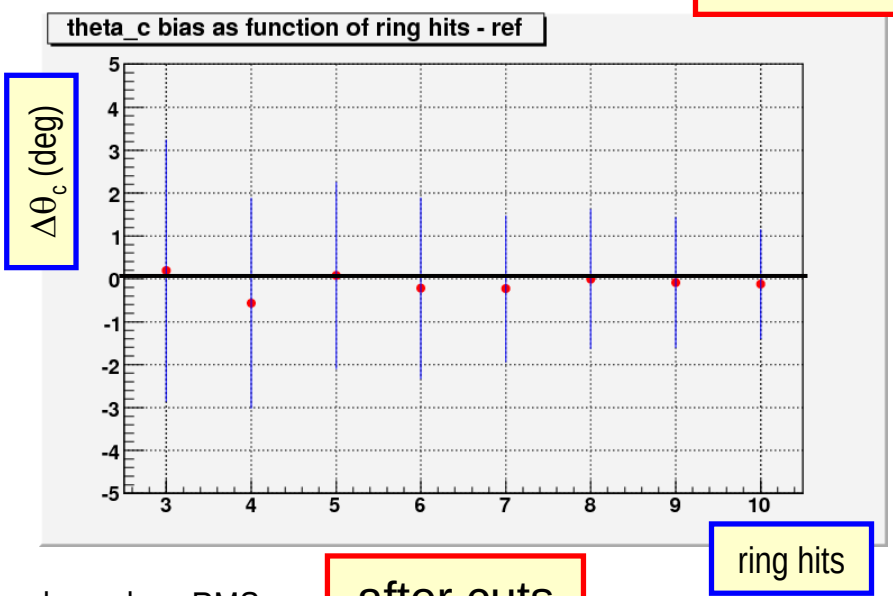
after cuts, 6+ hits

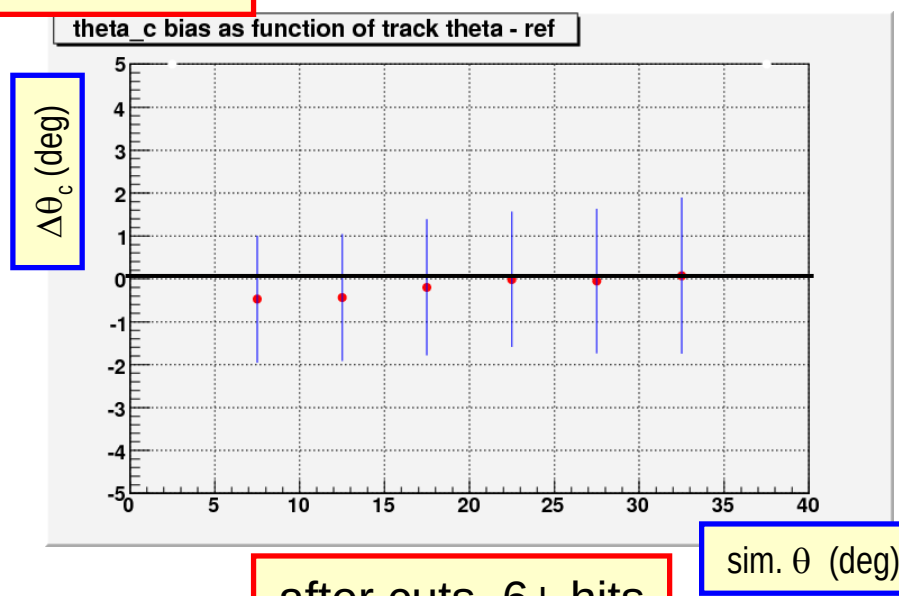
bars show RMS of distributions

Reconstruction quality: θ_c, mirror events

- Mirror events (r_{hint} > 55 cm):
  - Bias close to zero due to larger average θ
  - Evolution with θ similar to what is seen using all events

MIRROR EVENTS



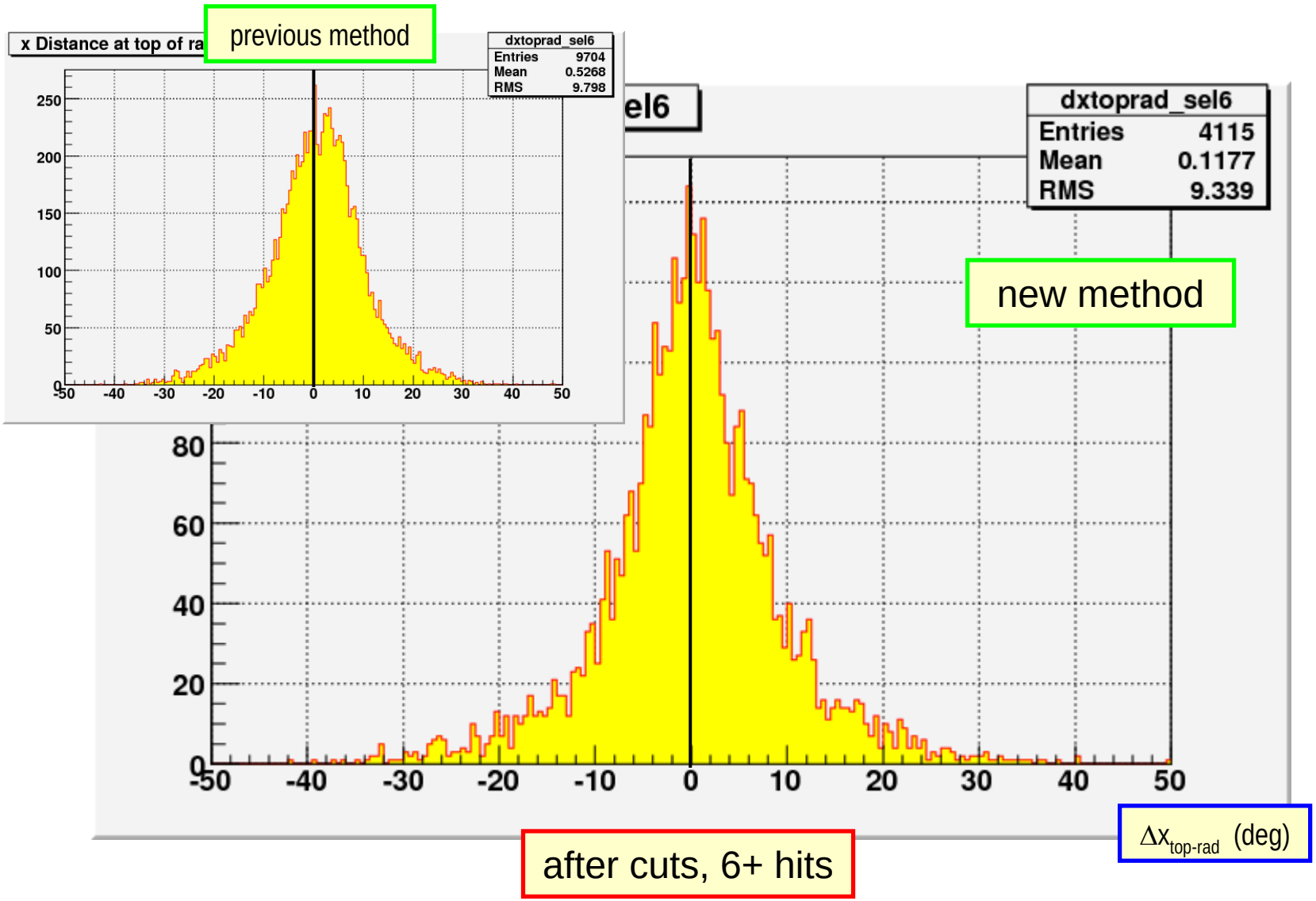


after cuts

after cuts, 6+ hits

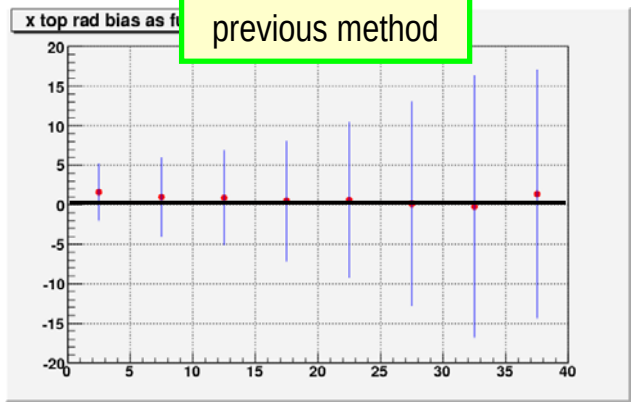
bars show RMS of distributions

Reconstruction quality: $x_{top\text{-}rad}$

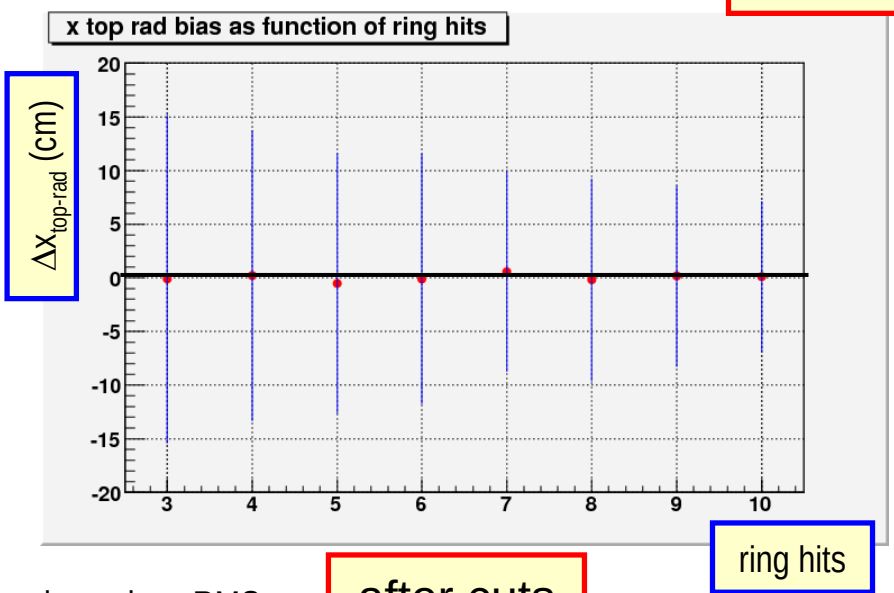


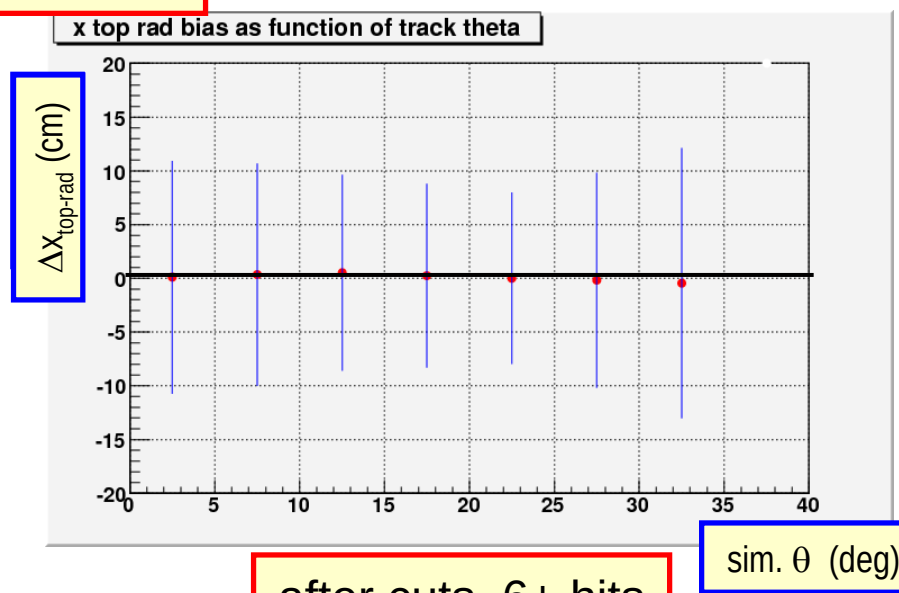
Reconstruction quality: $x_{top\text{-}rad}$, all evts

- x coordinate at top of radiator:
  - Spread becomes smaller as number of ring hits increases
  - Some change with theta: some reduction up to $\theta \sim 20°$, increase for higher angles
  - Similar results for $y_{top\text{-}rad}$



ALL EVENTS





after cuts

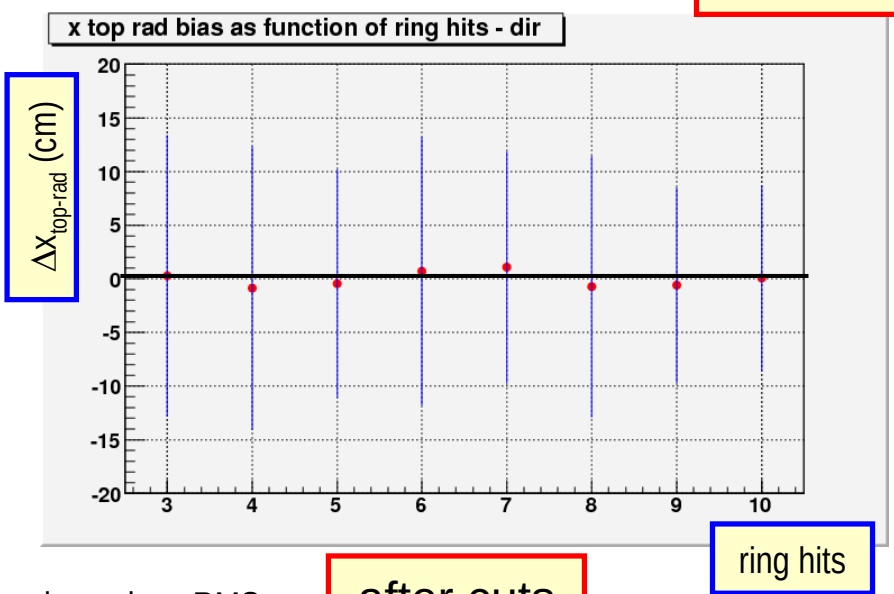
after cuts, 6+ hits

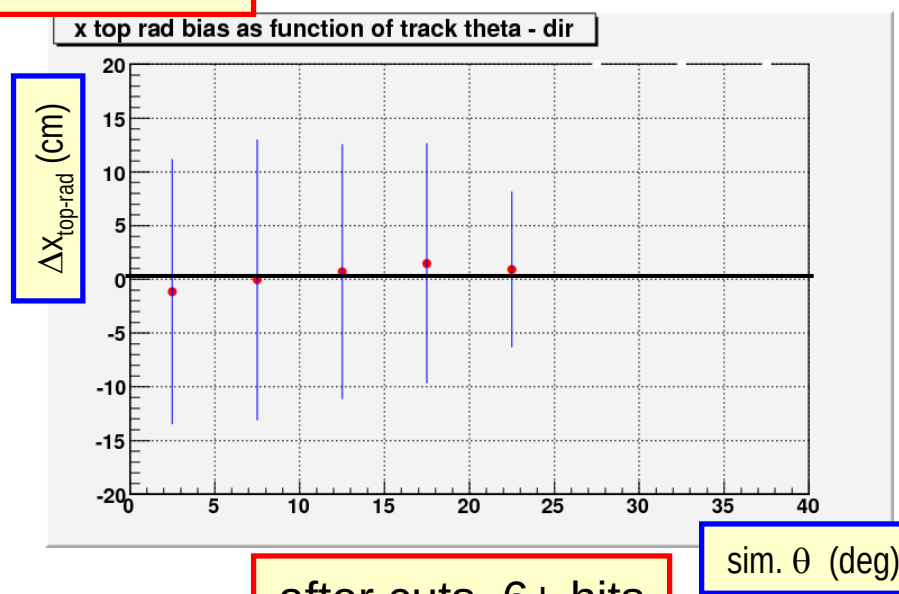
bars show RMS of distributions

Reconstruction quality: $x_{top\text{-}rad}$, dir evts

- Direct events (r_{hint} < 42 cm):
  - Similar spread for same number of hits
  - Larger spread than global sample at comparable θ regions due to lower number of hits

DIRECT EVENTS





after cuts

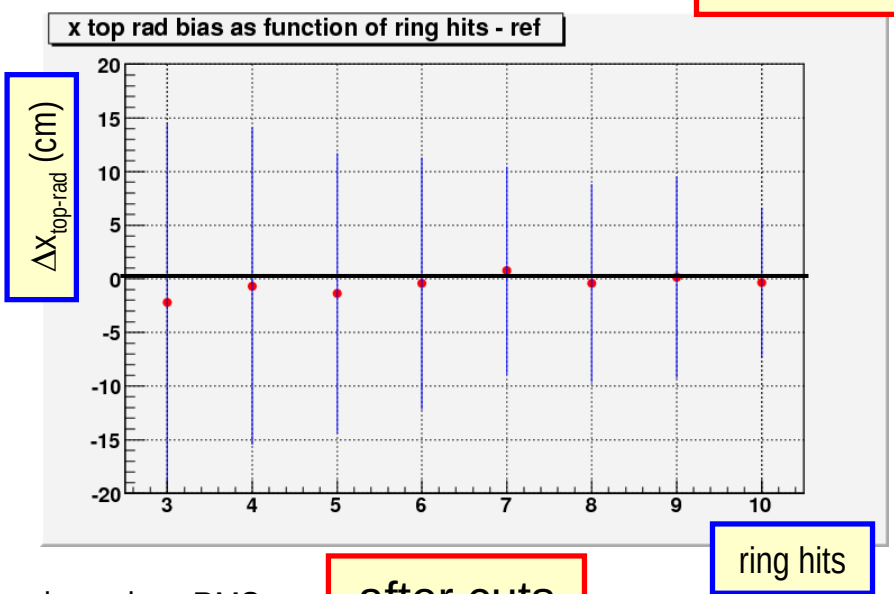
after cuts, 6+ hits

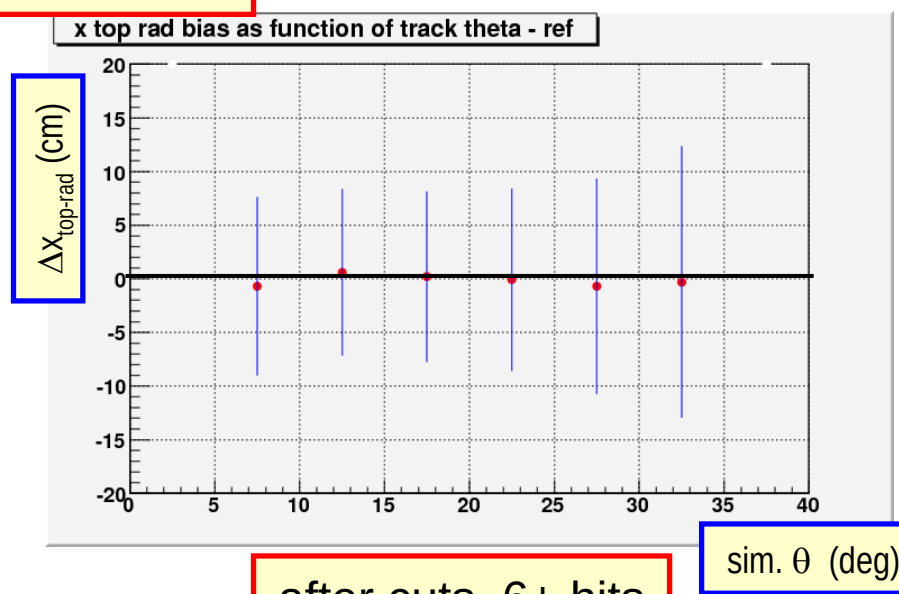
bars show RMS of distributions

Reconstruction quality: $x_{top\text{-}rad}$, mir evts

- Mirror events (r_{hint} > 55 cm):
  - Evolution with number of hits similar to what is seen using all events
  - Smaller spread than for direct events at similar θ (mirror events have higher number of hits)

MIRROR EVENTS



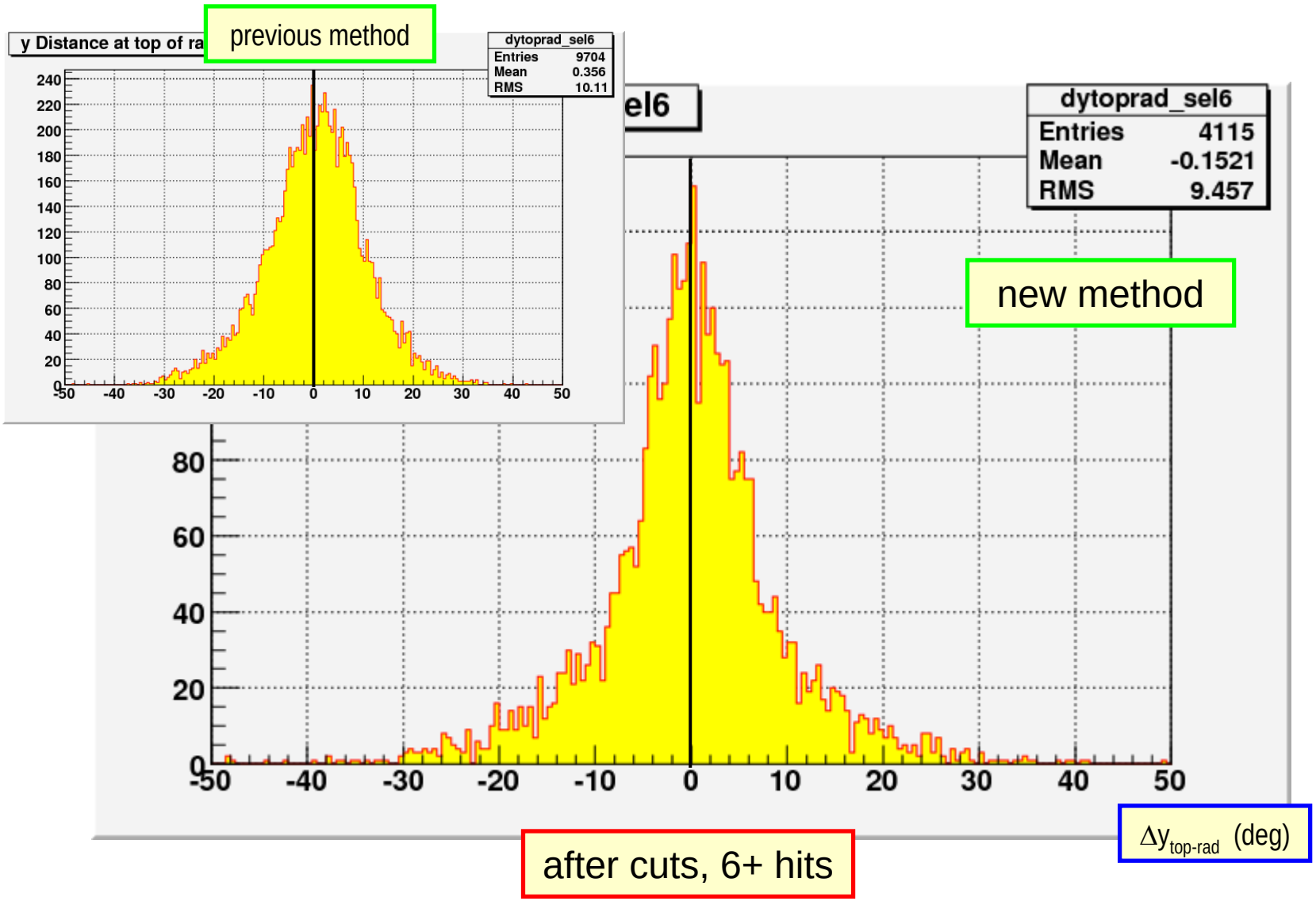


after cuts

after cuts, 6+ hits

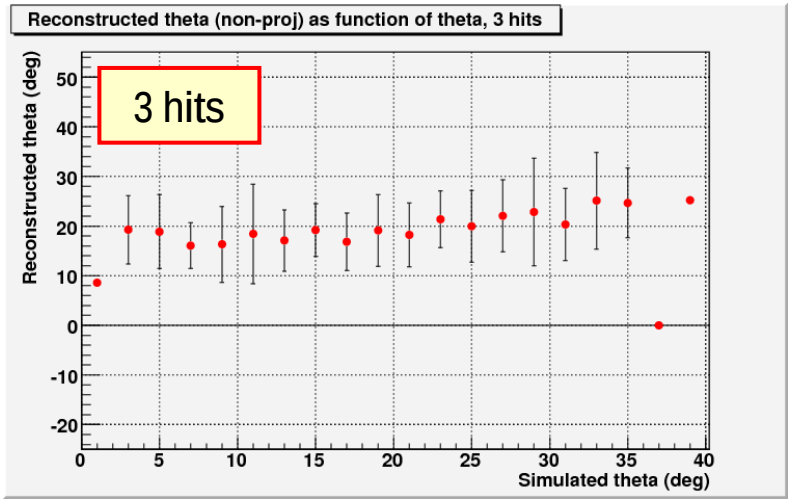
bars show RMS of distributions

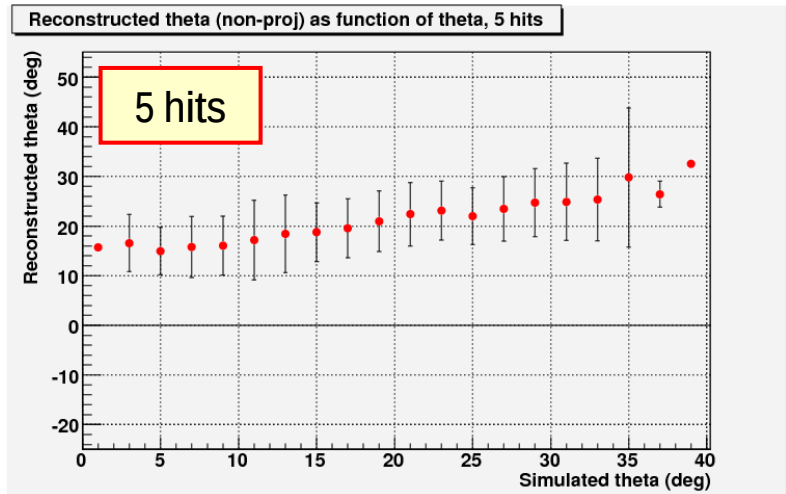
Reconstruction quality: $y_{top\text{-}rad}$

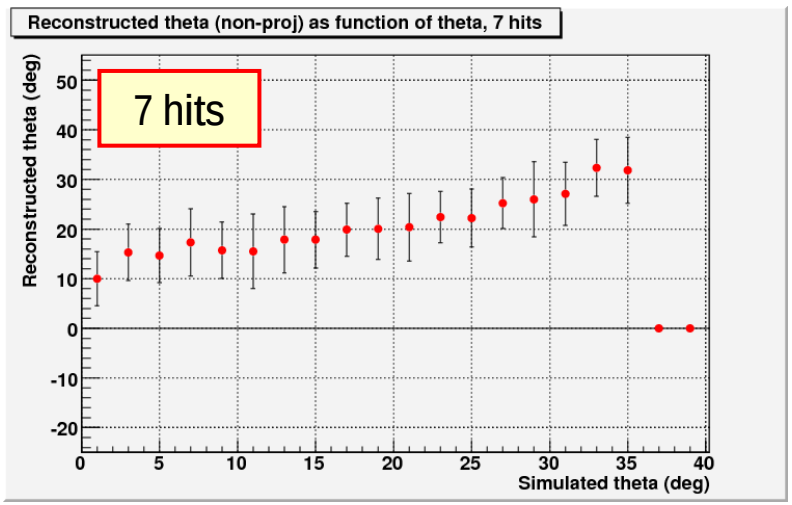


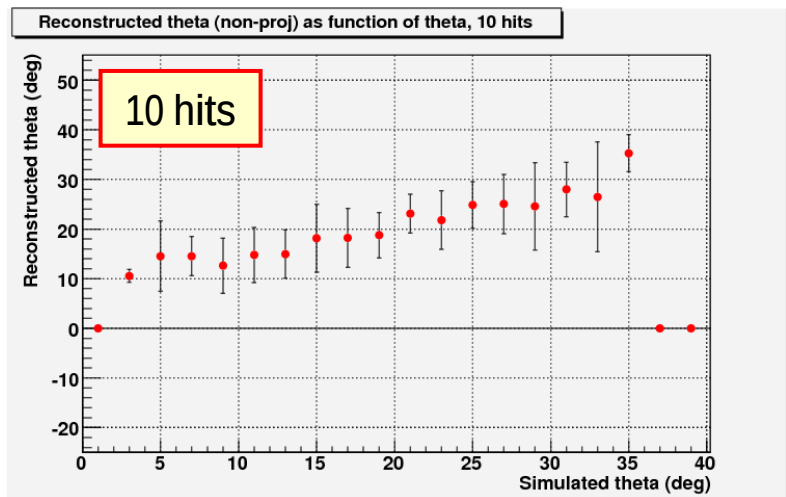
Reconstruction quality: θ (no. hits)

- Evolution of reconstructed θ for different numbers of hits:



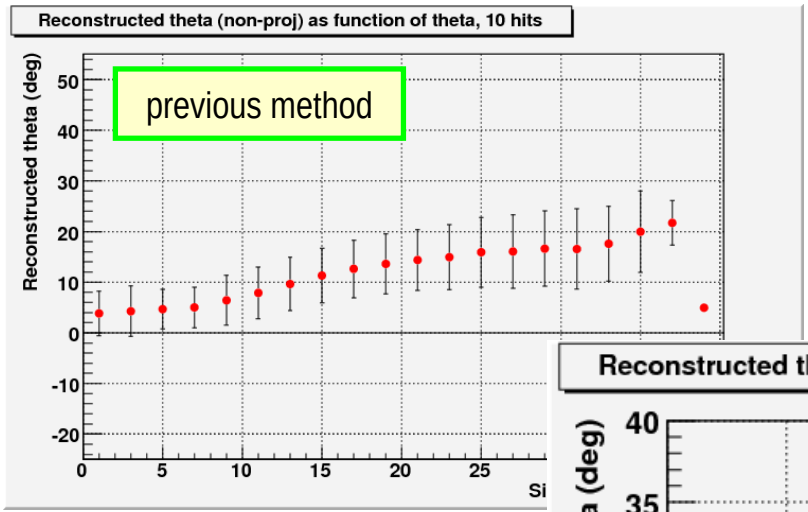




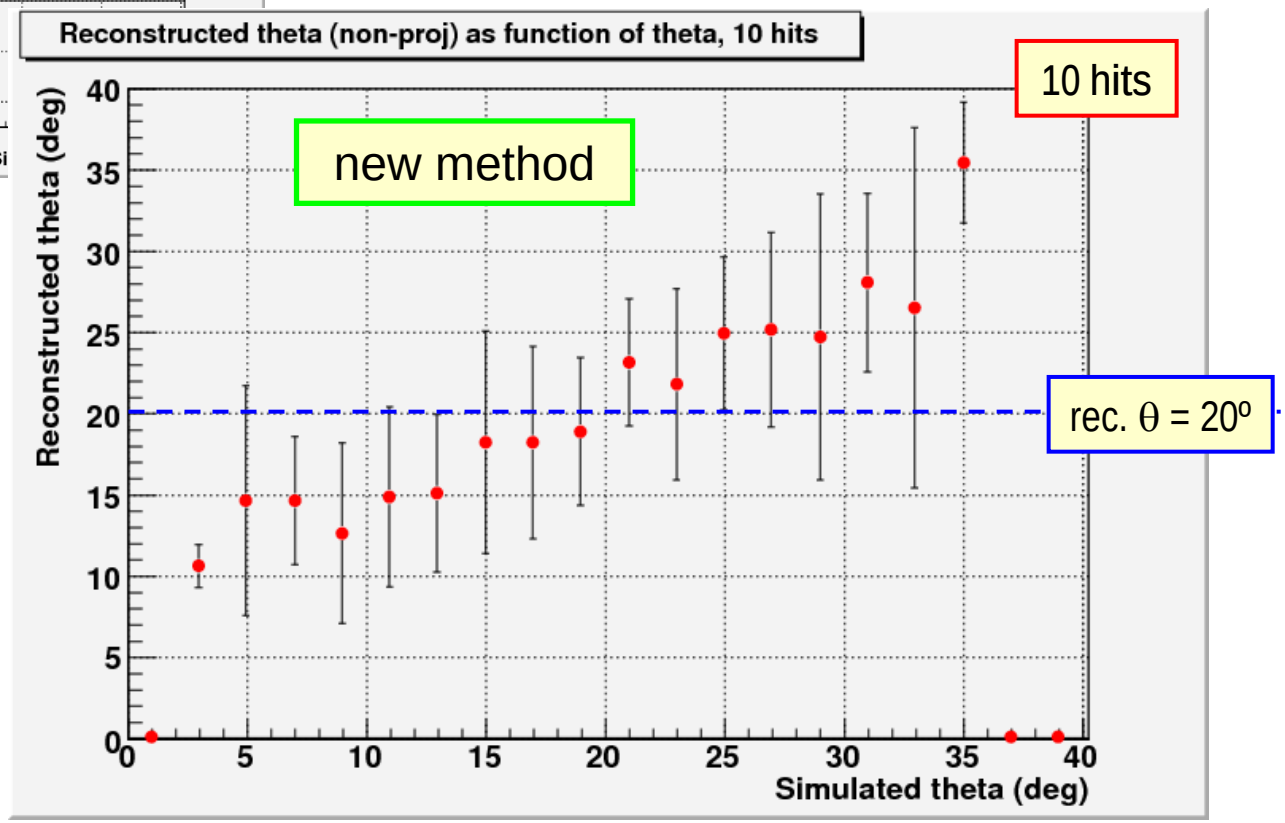


bars show RMS of distributions

Reconstruction quality: θ (no. hits)



- Evolution of reconstructed θ with simulated θ is still quite slow
- Even for 10 hits, a reconstructed value θ ~ 20º is within one standard deviation of the expected result for all angles in the 5º-30º range

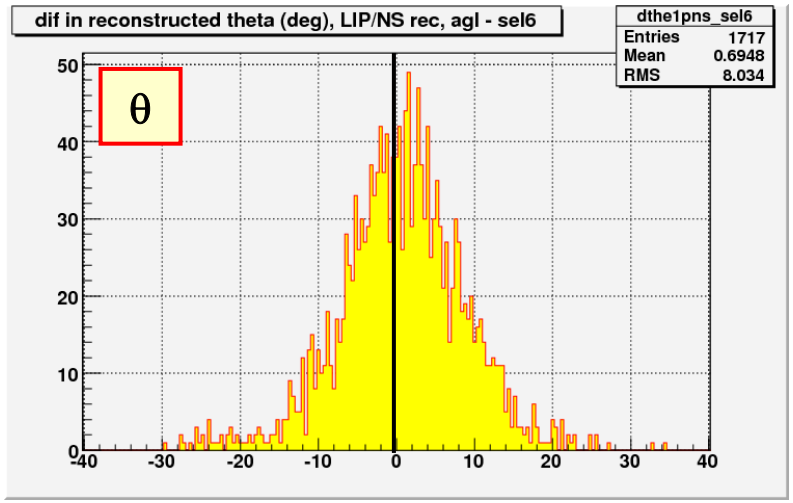


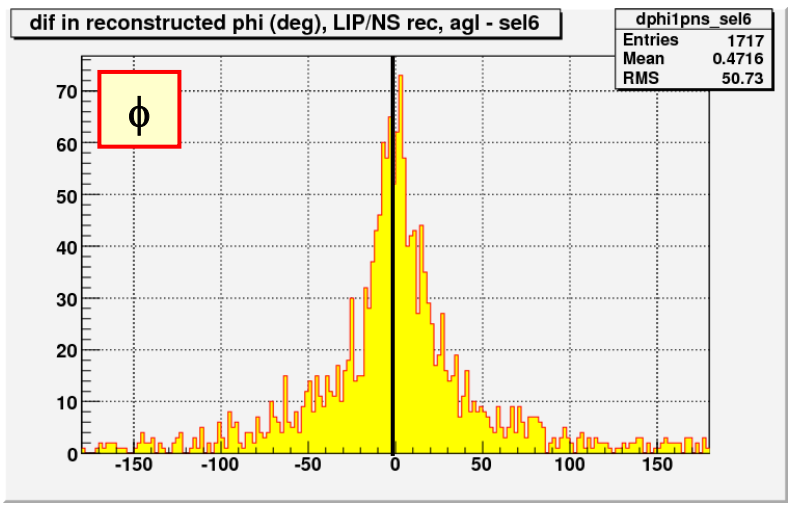
- Bias correction may improve quality of results (to be done)
- θ reconstruction still difficult for Z=1

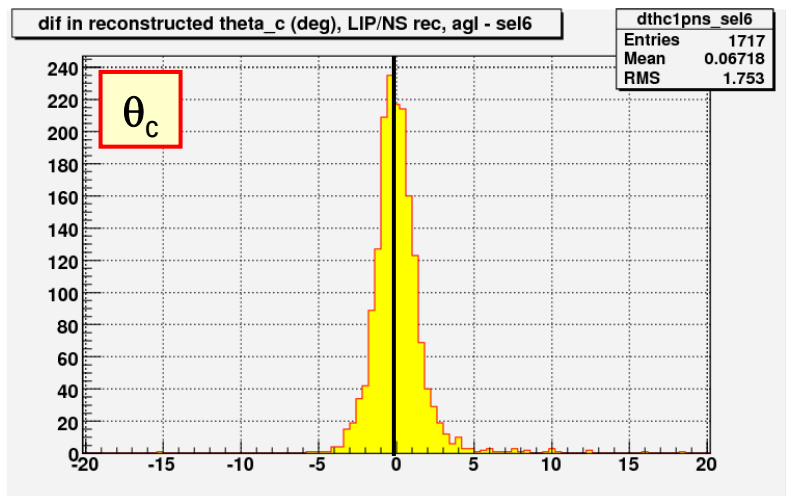
bars show RMS of distributions

Reconstruction quality: $\beta < 1$

- New method also tested for a sample with lower β:
  - Similar quality of reconstruction with $\beta \approx 1$ in all variables
  - No significant bias in θ_c
  - Cuts exclude larger fraction of events







bars show RMS of distributions

Track rec using ToF: update

- ToF clusters may provide the hint that is needed for a reconstruction method without using the Tracker
  - Work on these reconstructions is currently underway
- Two ways to choose ToF clusters to be used for track:
  - 1) LIP method (presented in May): scan cluster coordinates to find an aligned set
  - 2) take clusters used for ToF velocity reconstruction
- Two reconstruction possibilities were considered:
  - ToF clusters only
  - ToF clusters + RICH particle signal, with RICH acting as «5th ToF plane»

Track rec using ToF: update

- ToF, RICH clusters used as reference points for track reconstruction
  - Track assumed to be linear (linearity increases with particle energy)

- Two approaches to uncertaities in ToF coordinates:
  - a) uncertainties taken from AMS CERN files (σ_x, σ_y ~ 3 cm for most events)
  - b) only ToF paddle coordinates used for fit (x coordinate for planes 2 & 3, y coordinate for planes 1 & 4), each assumed to have σ = 6cm/$\sqrt{12}$ = 1.73 cm
    - requires 4 ToF planes if RICH is not used, 2 or 3 if RICH is used

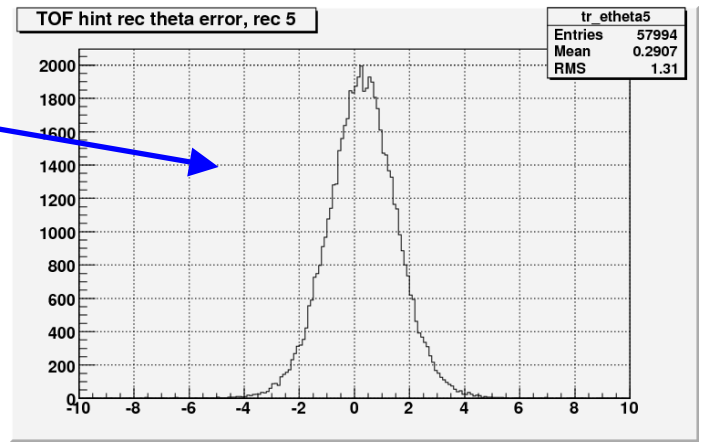
- Uncertainty on RICH coordinate taken from previous study on signal distribution:
  - $\sigma_{x,RICH}$ = 1.20 cm; $\sigma_{y,RICH}$ = 1.24 cm

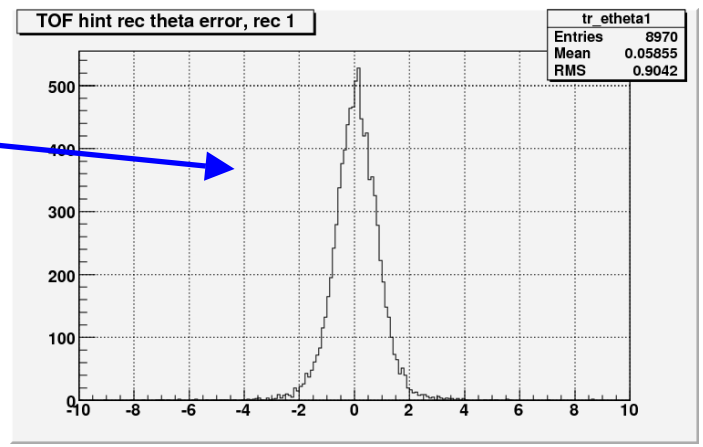
Track rec using ToF: acceptance

- At high E_{kin} (>9 GeV/nuc), events having RICH ring: 0.32 m^2.sr
- Using clusters from velocity reconstruction:
  - Full data:
    - ToF rec: 0.32 m^2.sr (all events), 0.28 m^2.sr (after cuts)
    - ToF-RICH: 0.26 m^2.sr (all events), 0.09 m^2.sr (after cuts)
  - Paddles only:
    - ToF rec: 0.19 m^2.sr (all events), 0.18 m^2.sr (after cuts)
    - ToF-RICH: 0.31 m^2.sr (all events), 0.09 m^2.sr (after cuts)
- Using LIP method for cluster selection:
  - Full data:
    - ToF rec: 0.18 m^2.sr (all events), 0.16 m^2.sr (after cuts)
    - ToF-RICH: 0.06 m^2.sr (all events), 0.04 m^2.sr (after cuts)
  - Paddles only:
    - ToF rec: 0.05 m^2.sr (all events), 0.04 m^2.sr (after cuts)
    - ToF-RICH: 0.06 m^2.sr (all events), 0.04 m^2.sr (after cuts)

Track rec using ToF: θ resolution

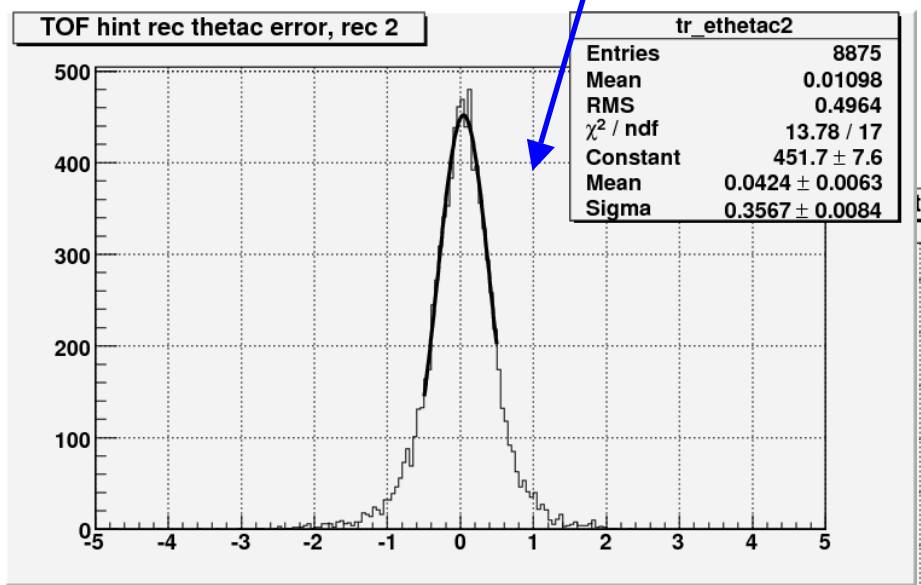
- Uncertainties for θ reconstruction at $\beta \approx 1$ (still to be fine tuned):
- Using clusters from velocity reconstruction:
  - Full data:
    - ToF rec: σ_θ = 1.31º
    - ToF-RICH: σ_θ = 1.52º
  - Paddles only:
    - ToF rec: σ_θ = 2.10º
    - ToF-RICH: σ_θ = 1.78º
- Using LIP method for cluster selection:
  - Full data:
    - ToF rec: σ_θ = 2.13º
    - ToF-RICH: σ_θ = 0.90º
  - Paddles only:
    - ToF rec: σ_θ = 1.67º
    - ToF-RICH: σ_θ = 1.62º

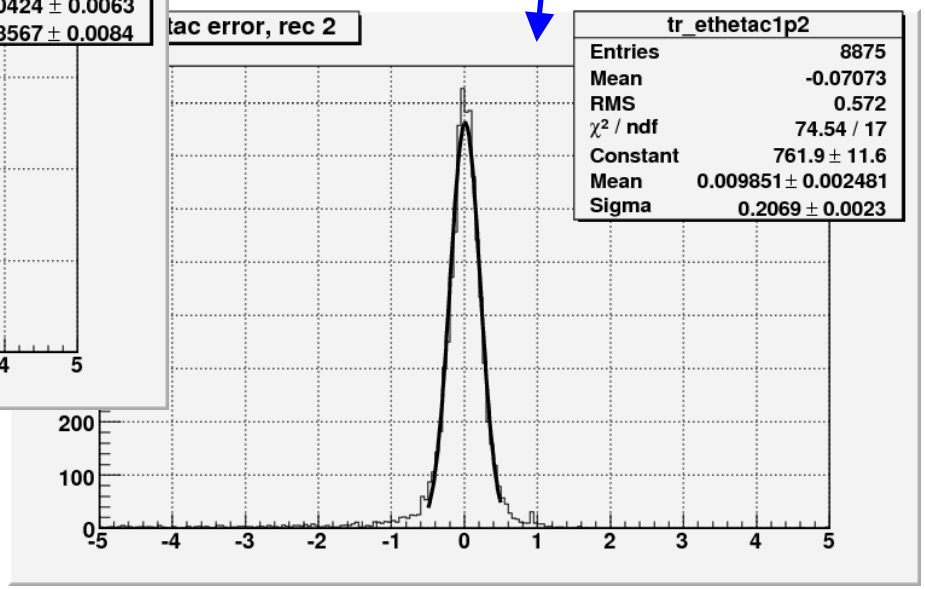




Track rec using ToF: θ_c resolution

- Error in θ_c (after cuts), from fit to peak using LIP method with full data: $\sigma_{\theta c}$ = 0.36º compared to $\sigma_{\theta c}$ = 0.21º for reconstruction using Tracker data





Conclusions

- New method for standalone reconstruction was developed
  - Advantages:
    - Sensitivity to particle direction (θ, ϕ), improving with number of hits, but significant tail of uncorrelated directions
    - Approximately unbiased estimator for Cerenkov angle (on average over all directions), $\sigma_{\theta c} \sim 1°$
    - Effective over a large range of θ_c, not only for $\beta \approx 1$
  - Disadvantages:
    - Very slow (~30× slower than standalone reconstruction with vertical hint), essentially due to repeated minimization procedures
    - No improvement in θ_c resolution with respect to previous standalone reconstruction
    - Significant bias in θ remains, but should be correctable
    - Reconstruction of events with Z = 1 still difficult
- Work on TOF-based reconstruction continues
  - Resolution: $\sigma_\theta \sim 1°\text{-}2°$, $\sigma_{\theta c} \sim 0.4°$ for $\beta \approx 1$