Latest developments on particle identification with the RICH detector in the AMS-02 simulation

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Mass separation studies

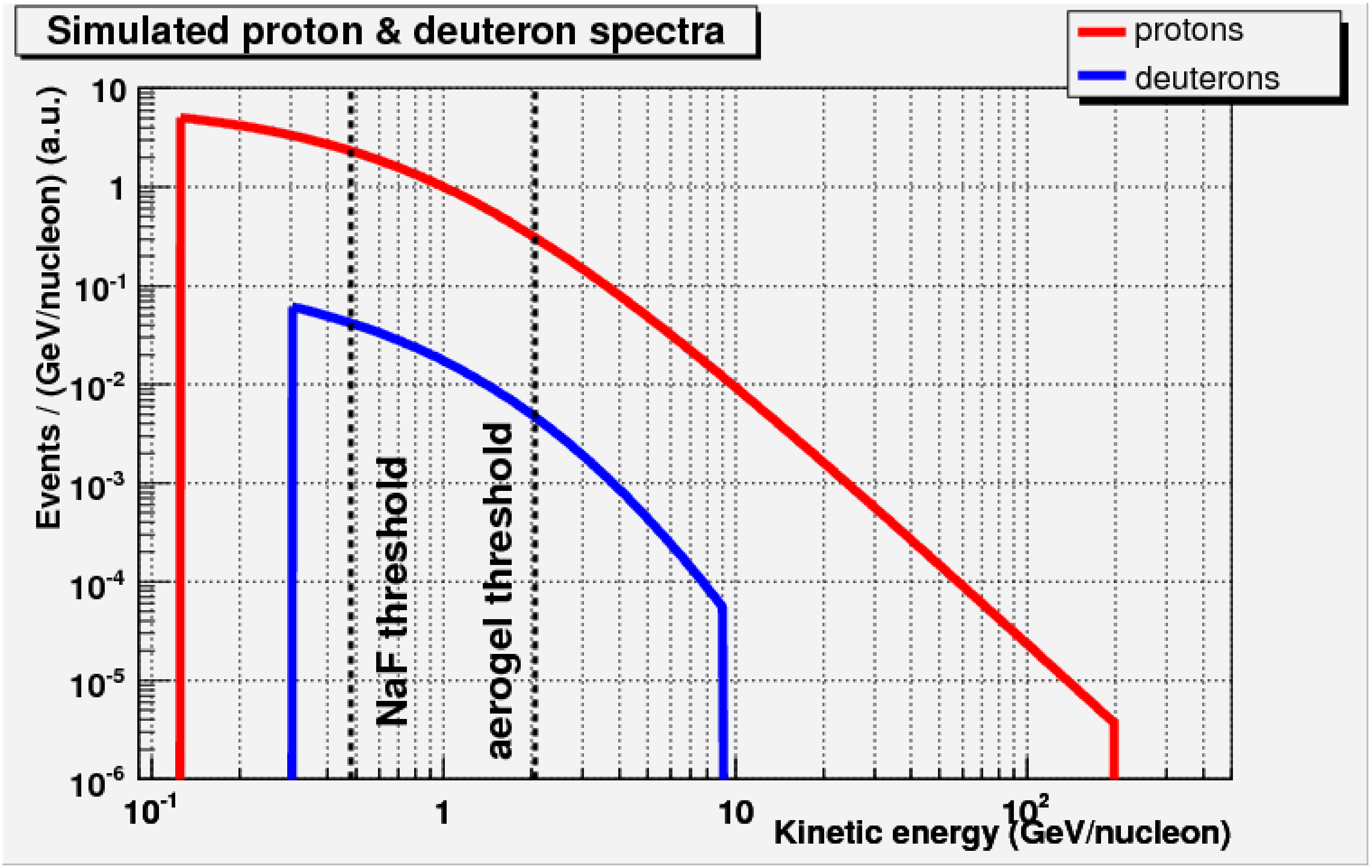
- Goal: realistic simulation of RICH performance on mass separation in the context of the AMS detector
- Full AMS-02 simulation used
- Procedure:
  - Establish a set of wide pre-selection cuts
  - Study and optimize RICH specific cuts
  - Evaluate mass separation capability
- Physics channels:
  - D/p case used, ongoing study
  - $^3He/^4He$ in future work

Data samples and event weights

- Data samples from AMS-02 simulated events:
  - Low momentum proton and deuteron samples
    - *protons: 3.1×10^8 events, 0.5-10 GeV/c/nucleon, log spectrum*
    - *deuterons: 5.6×10^7 events, 0.25-10 GeV/c/nucleon, log spectrum*
  - High momentum proton data samples
    - *protons: 1.3×10^8 events, 10-200 GeV/c/nucleon, log spectrum*
  - No deuteron files available for higher momenta
    - *Not really necessary if region of study is clearly under 10 GeV/c/nucleon*
- Event weights (for mass distributions only):
  - Events are weighted according to their spectra (weights are also function of simulated energy)
  - Theoretical spectra used:
    - *protons: $dN/dE_{tot} \propto E_{tot}^{-2.7}$, reference value for flux as given in Review of Particle Physics*
    - *deuterons: linear interpolation of D/p ratios according to Seo et al. (same model used in studies with the standalone RICH simulation)*

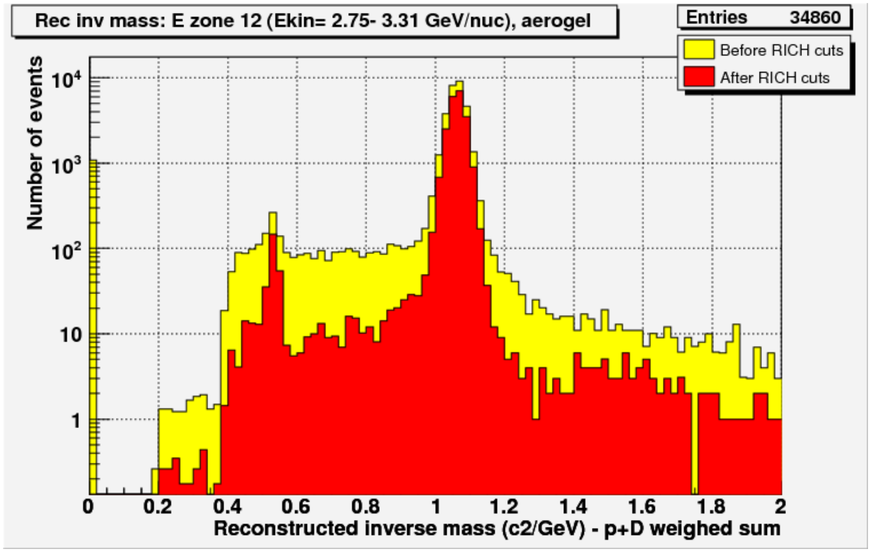
Simulated spectra

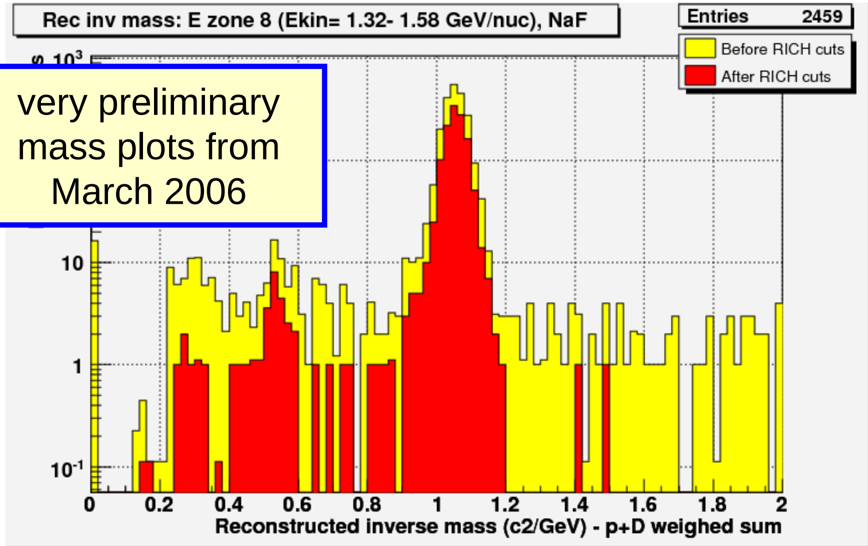
- Simulated proton and deuteron spectra:



LIP analysis: previous situation

- At the March 2006 meeting, a set of cuts was already in place
- Pre-selection cuts:
  - Number of particles
  - Tracker data (planes used, rigidity, Z, ...)
  - TOF data (planes used, β, Z, ...)
  - Additional data from ACC, TRD
- RICH cuts:
  - Geometrical acceptance
  - Number of hits
  - Ring probability
  - Ring signal
  - RICH-ToF β consistency
  - RICH β cross-check (CIEMAT & LIP reconstructions)
  - Z measurement
- Rejection factor ~10^2-10^3 (agl)





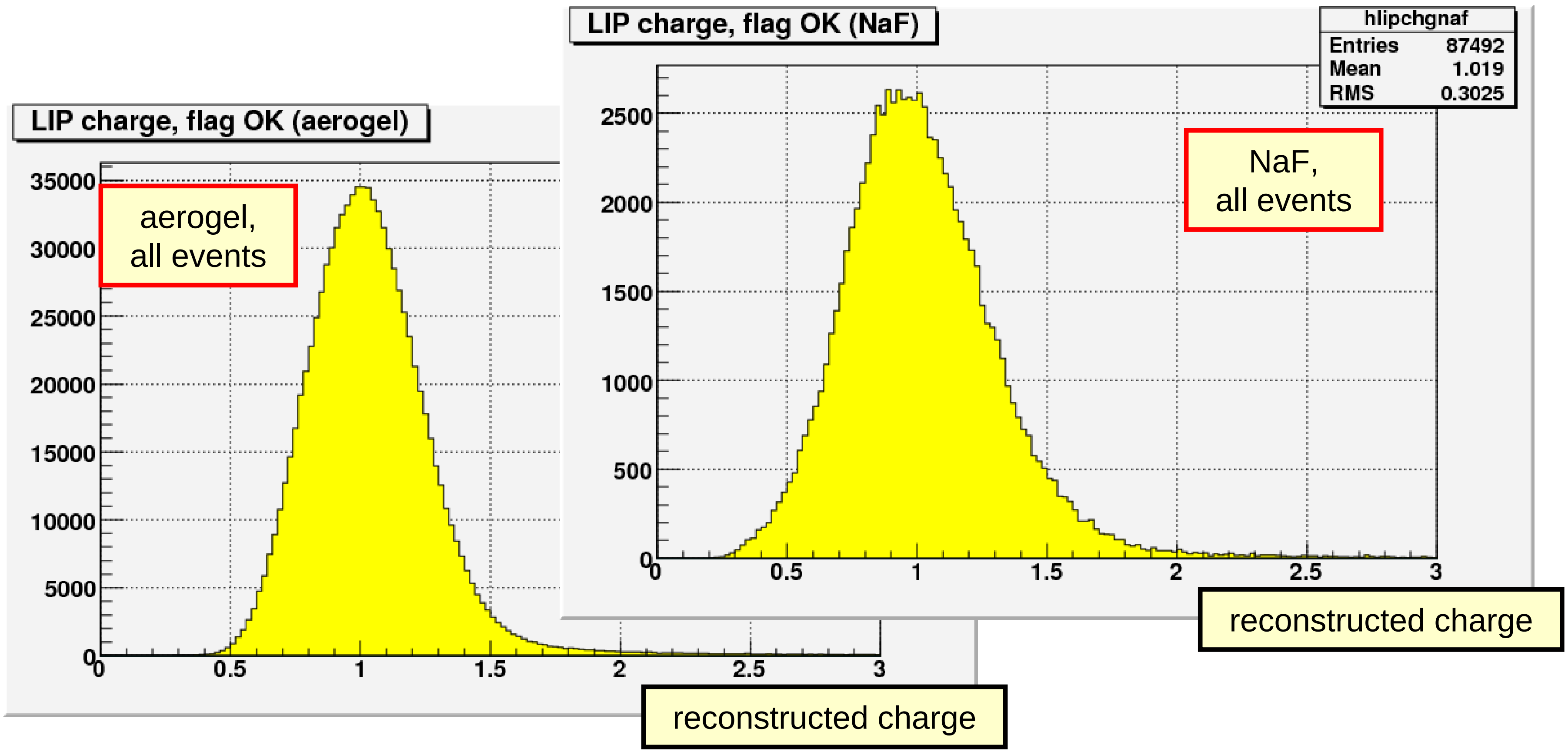
very preliminary mass plots from March 2006

LIP analysis: new features

- New tools from LIP analysis are currently being developed and applied to files of reconstructed events in AMS-02 simulation:
  - LIP charge reconstruction (also implemented in RICH standalone simulation)
  - 3-parameter β reconstruction
  - 5-parameter β reconstruction
  - Calculation of hit distances to reconstructed rings (1-, 3-, 5-parameter)
  - Studies on particle impact point in detection matrix
    - Comparison with particle signal
    - Optimization of effective impact matrix depth
  - Extension to the TOF mass reconstruction range

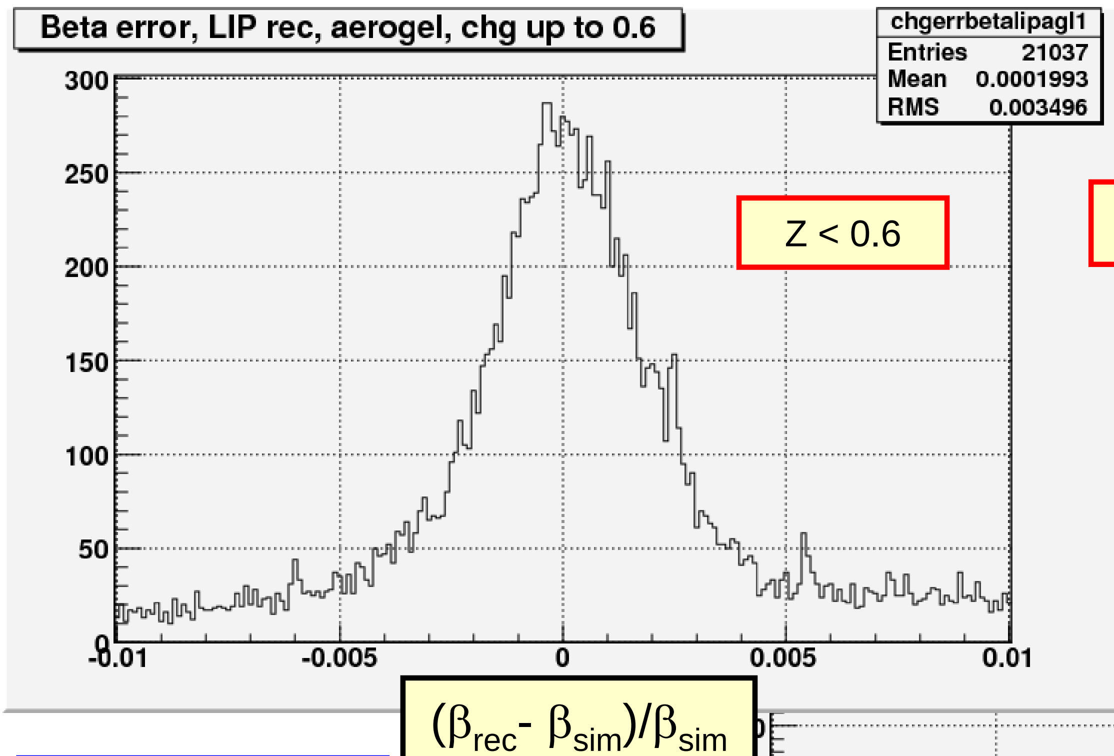
Charge reconstruction

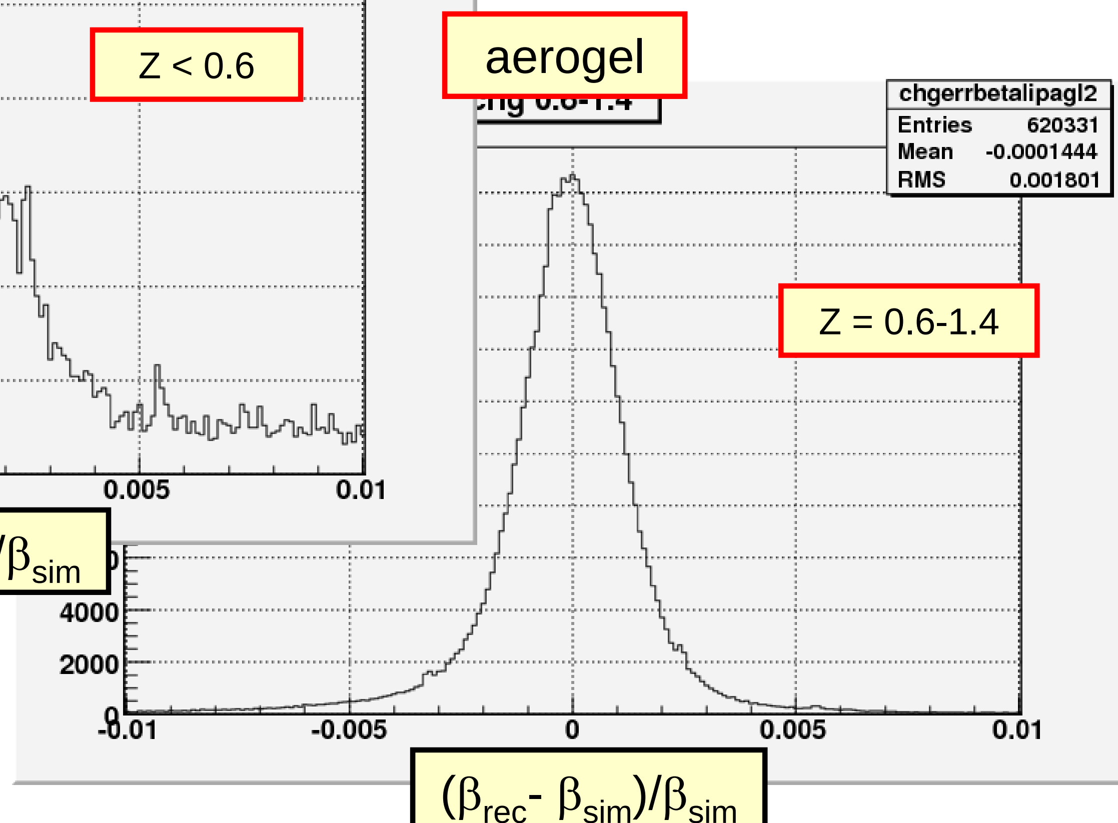
- LIP charge reconstruction applied to results of LIP velocity reconstruction data



Charge reconstruction

- Charge data help exclude events with bad reconstructions:





Fraction of events with error in β > 0.4%:

39.3% for **Z<0.6**

5.3% for **0.6<Z<1.4**

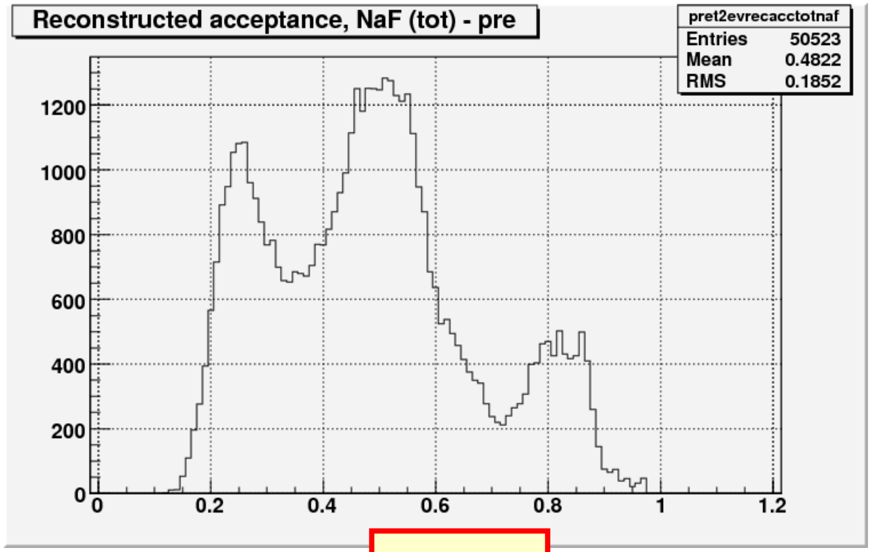
18.7% for **Z>1.4**

Charge reconstruction

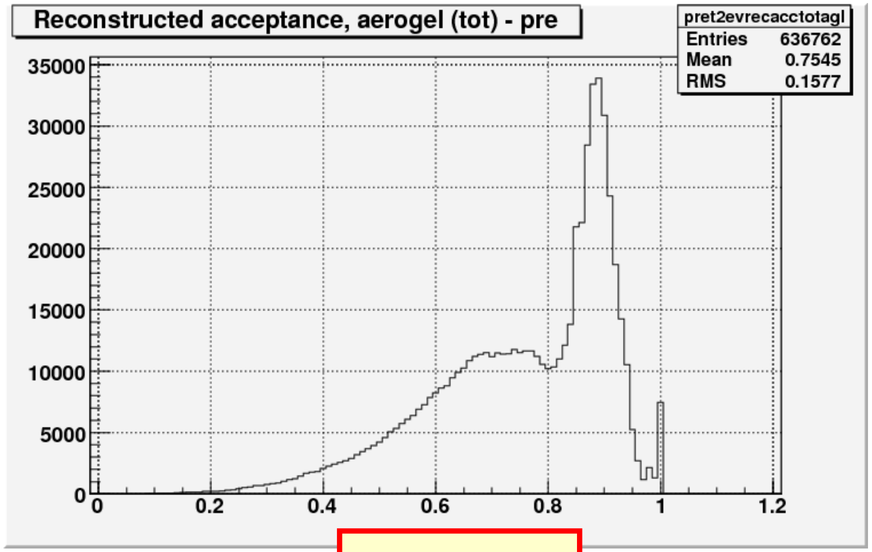
- Ring acceptances are calculated as part of the charge estimation
- Detailed calculation: ring width taken into account
- Total acceptance = direct + 0.85 × reflected

$$Z^2 \propto \frac{n_{pe}}{Acc_{tot}}$$

TOTAL ACCEPTANCE



NaF



aerogel

Charge reconstruction

- Ring acceptances are calculated as part of the charge estimation
- Detailed calculation: ring width taken into account
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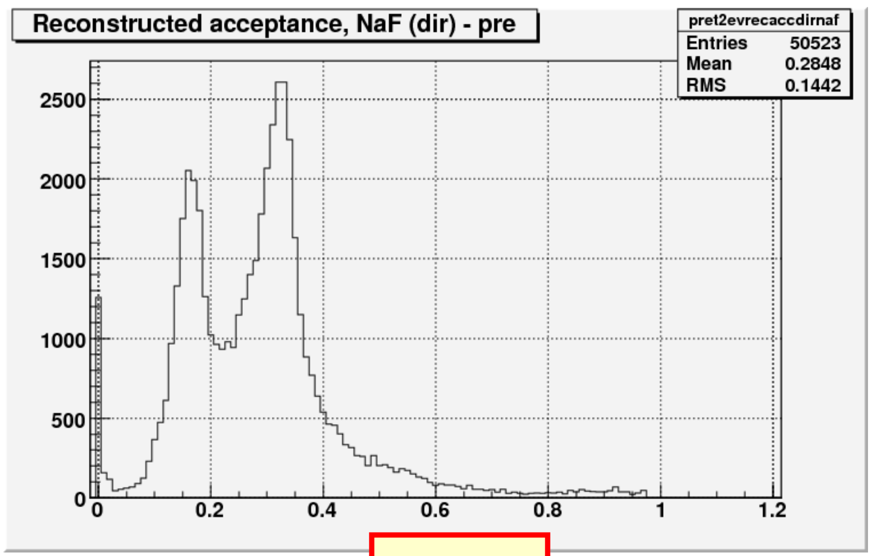
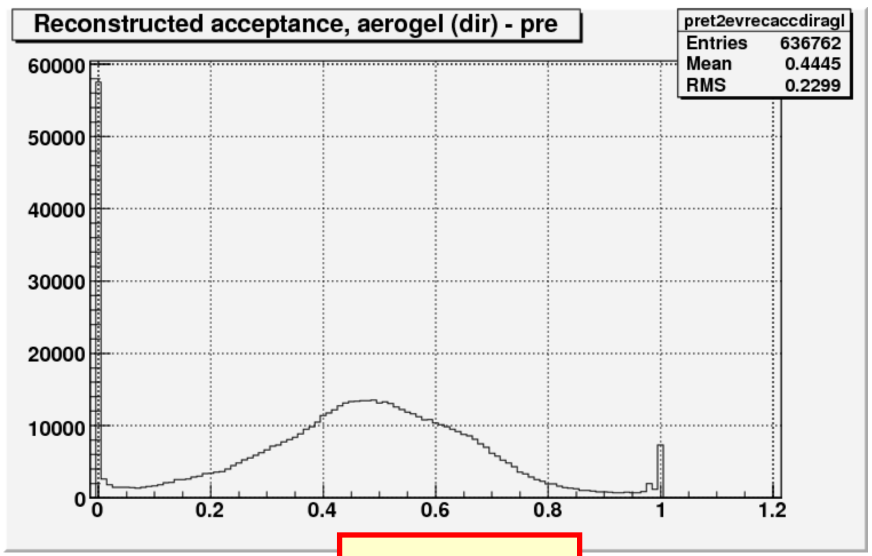
$$Z^2 \propto \frac{n_{pe}}{Acc_{tot}}$$

DIRECT ACCEPTANCE



NaF



aerogel

Charge reconstruction

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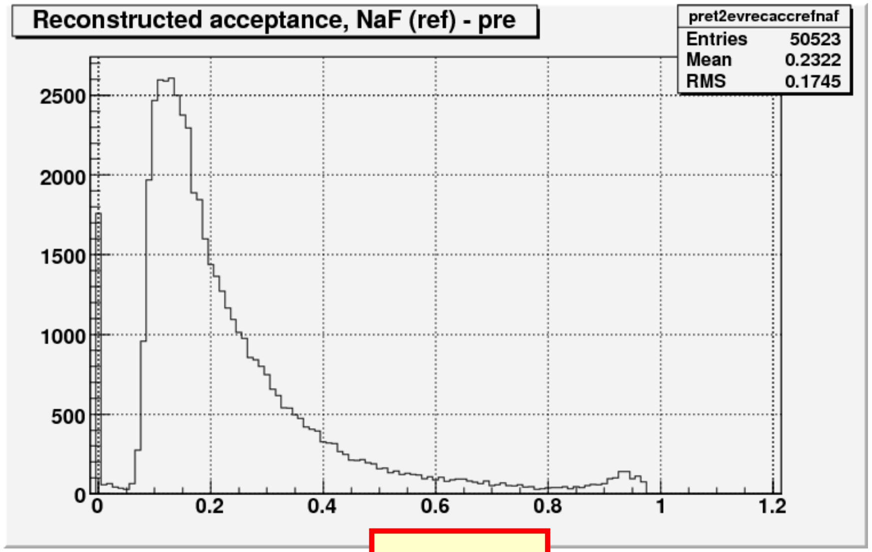
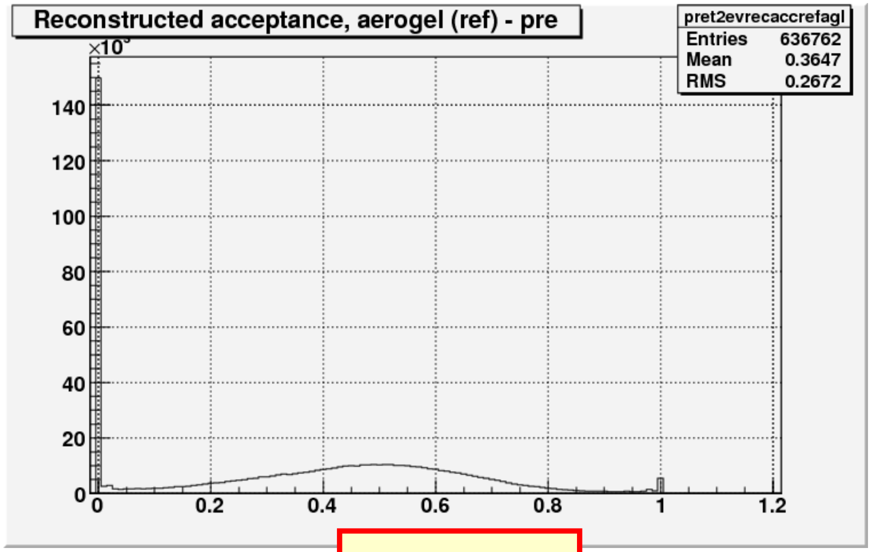
REFLECTED ACCEPTANCE



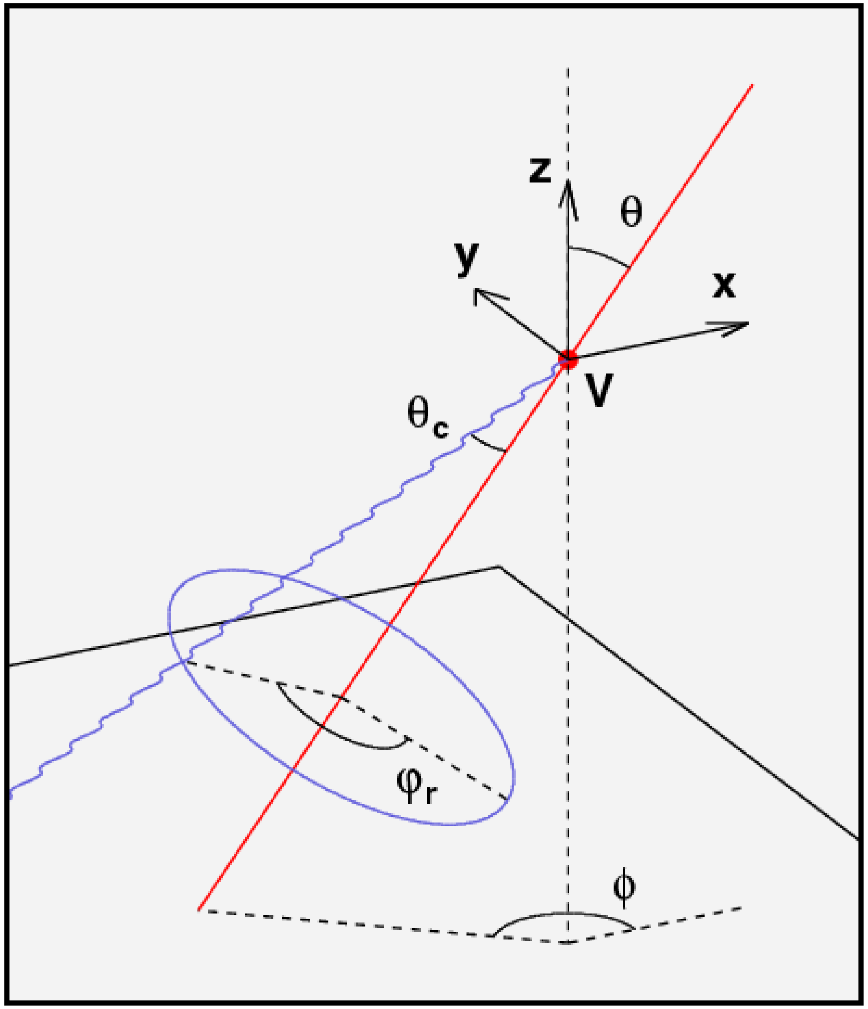
NaF



aerogel

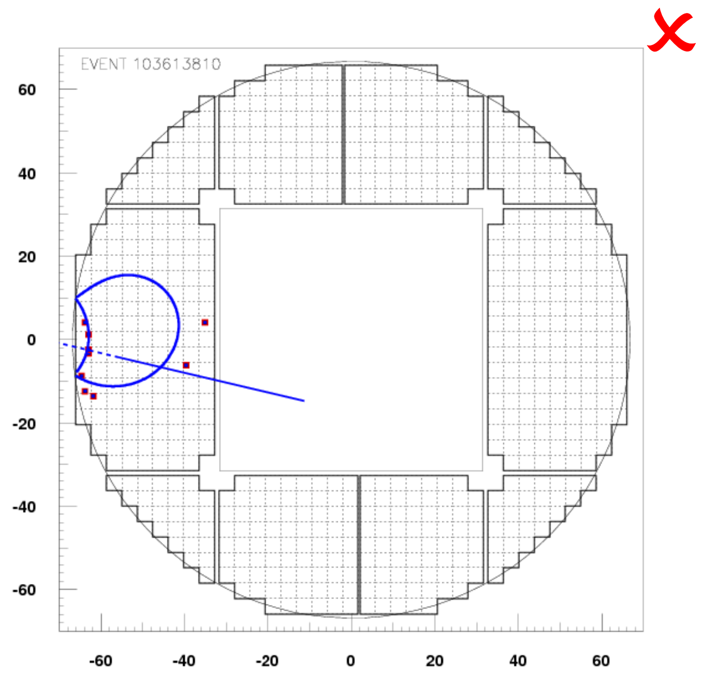
3- and 5-parameter β reconstructions

- Motivation: reconstruction of events with a bad track
- First approach, 3-parameter β reconstruction:
  - Track direction is still used, position is not
  - Free parameters: x_{matrix}, y_{matrix}, θ_c
  - Fixed parameters: θ, ϕ (from tracker)
- Second approach, 5-parameter β reconstruction:
  - Track data are abandoned
  - Free parameters: x_{matrix}, y_{matrix}, θ, ϕ, θ_c
- Result for 1-parameter β reconstruction given as initial hint
- Likelihood function used (similar to 1-parameter reconstruction)



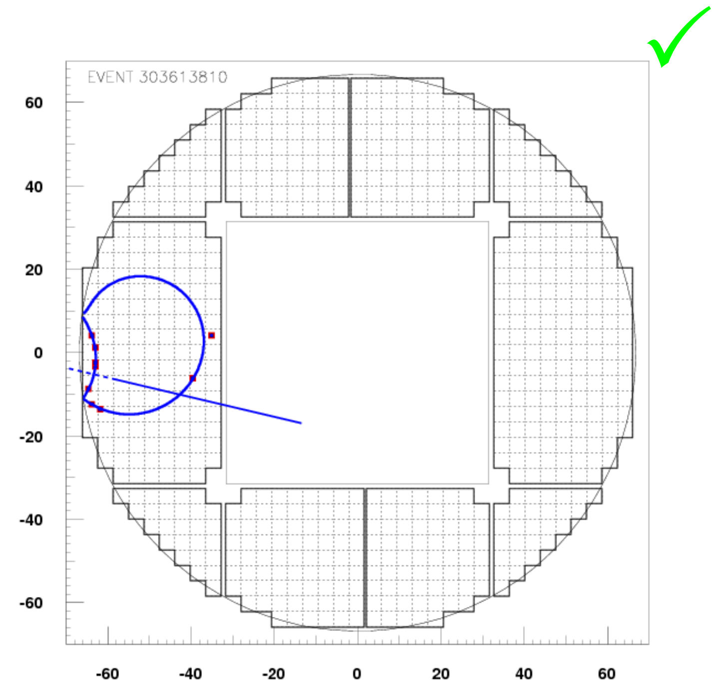
3- and 5-parameter β reconstructions

- Additional parameters improve reconstruction quality for some events:



1-parameter

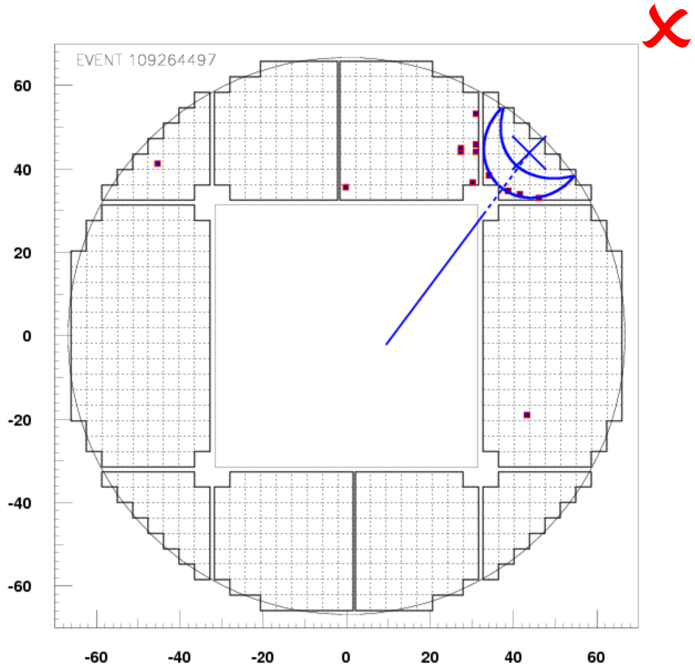
Ring hits: 9



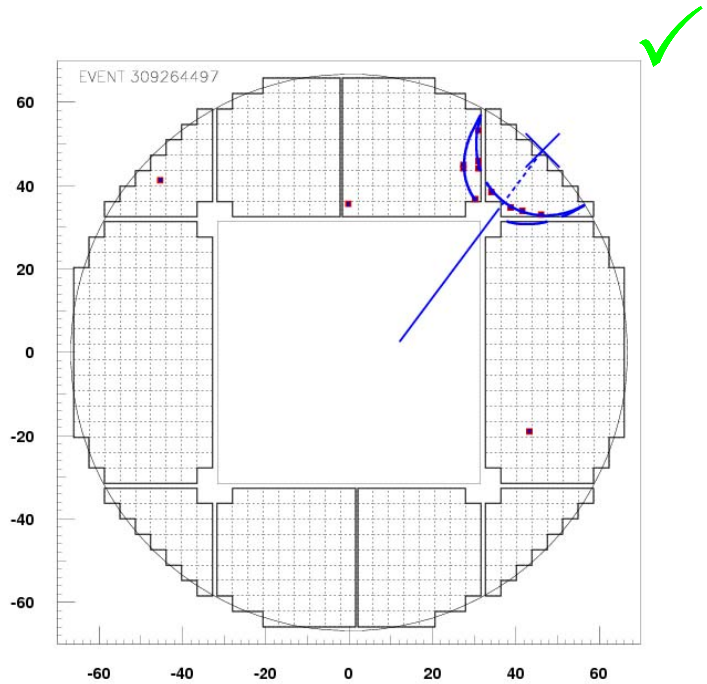
3-parameter

3- and 5-parameter β reconstructions

- Additional parameters improve reconstruction quality for some events:



1-parameter

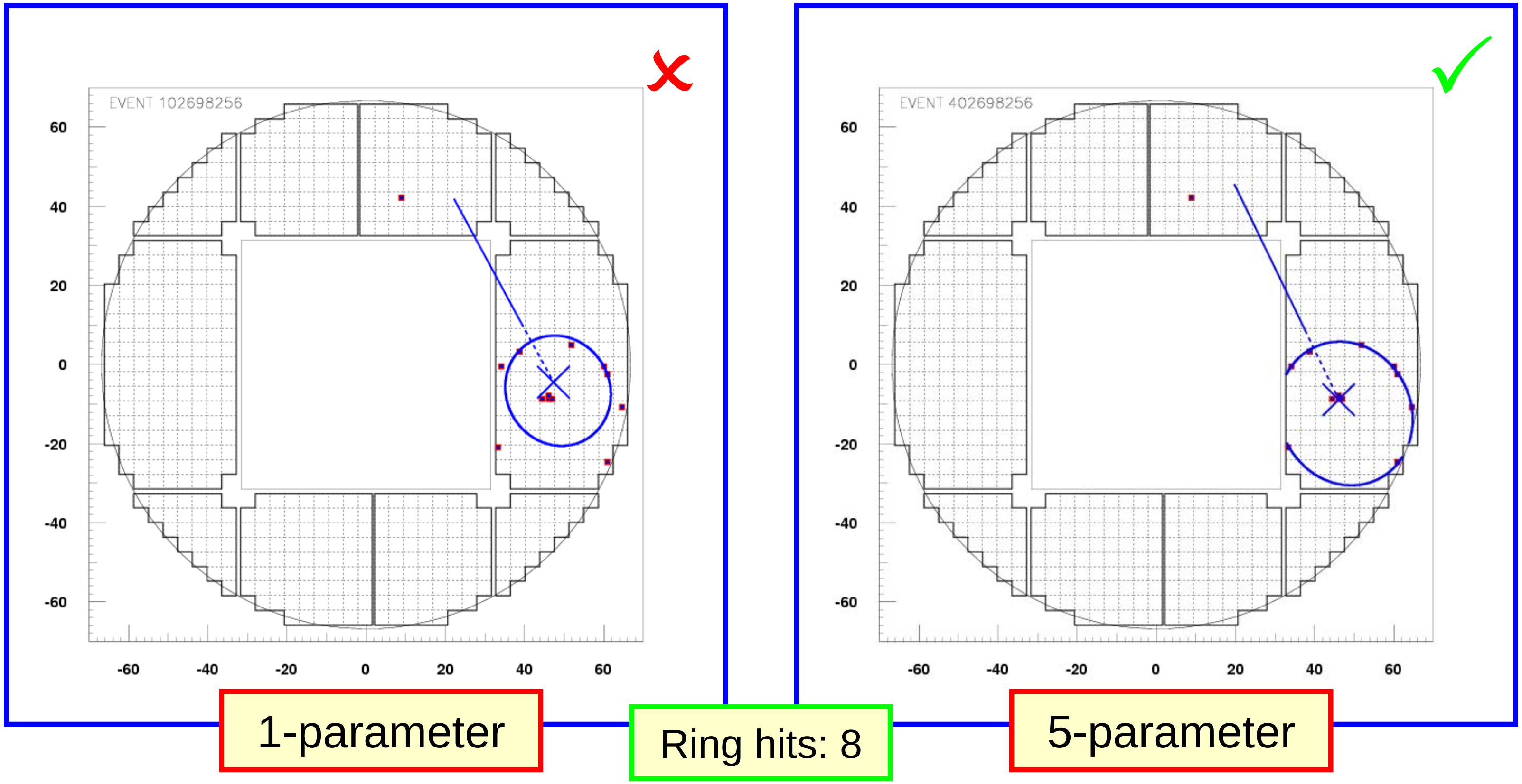


3-parameter

Ring hits: 10

3- and 5-parameter β reconstructions

- Additional parameters improve reconstruction quality for some events:



3- and 5-parameter β reconstructions

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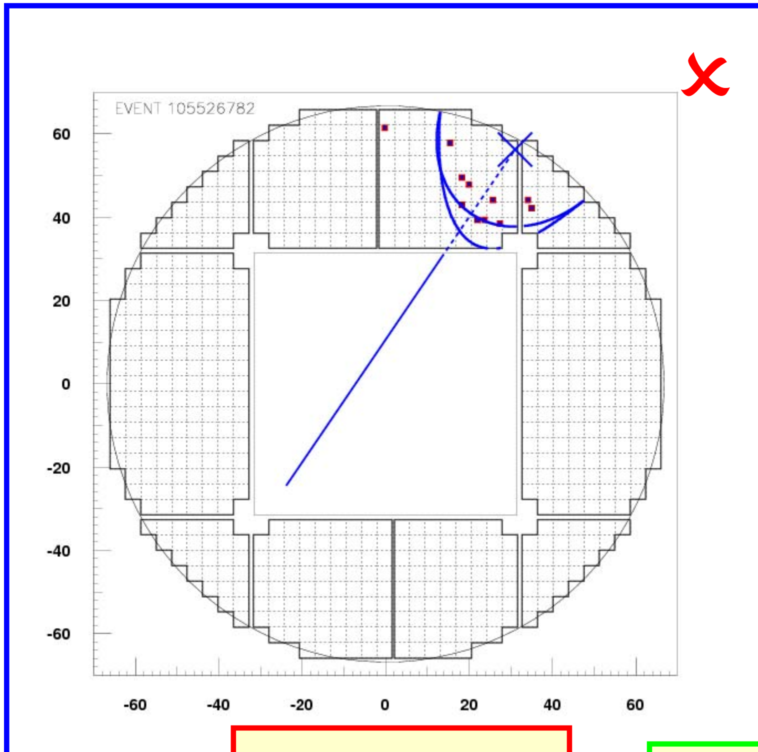
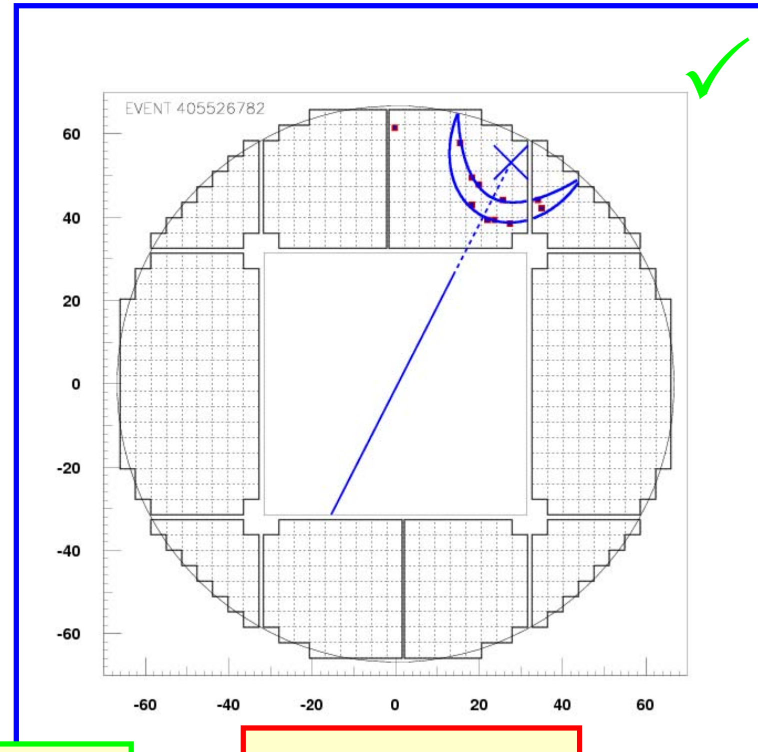




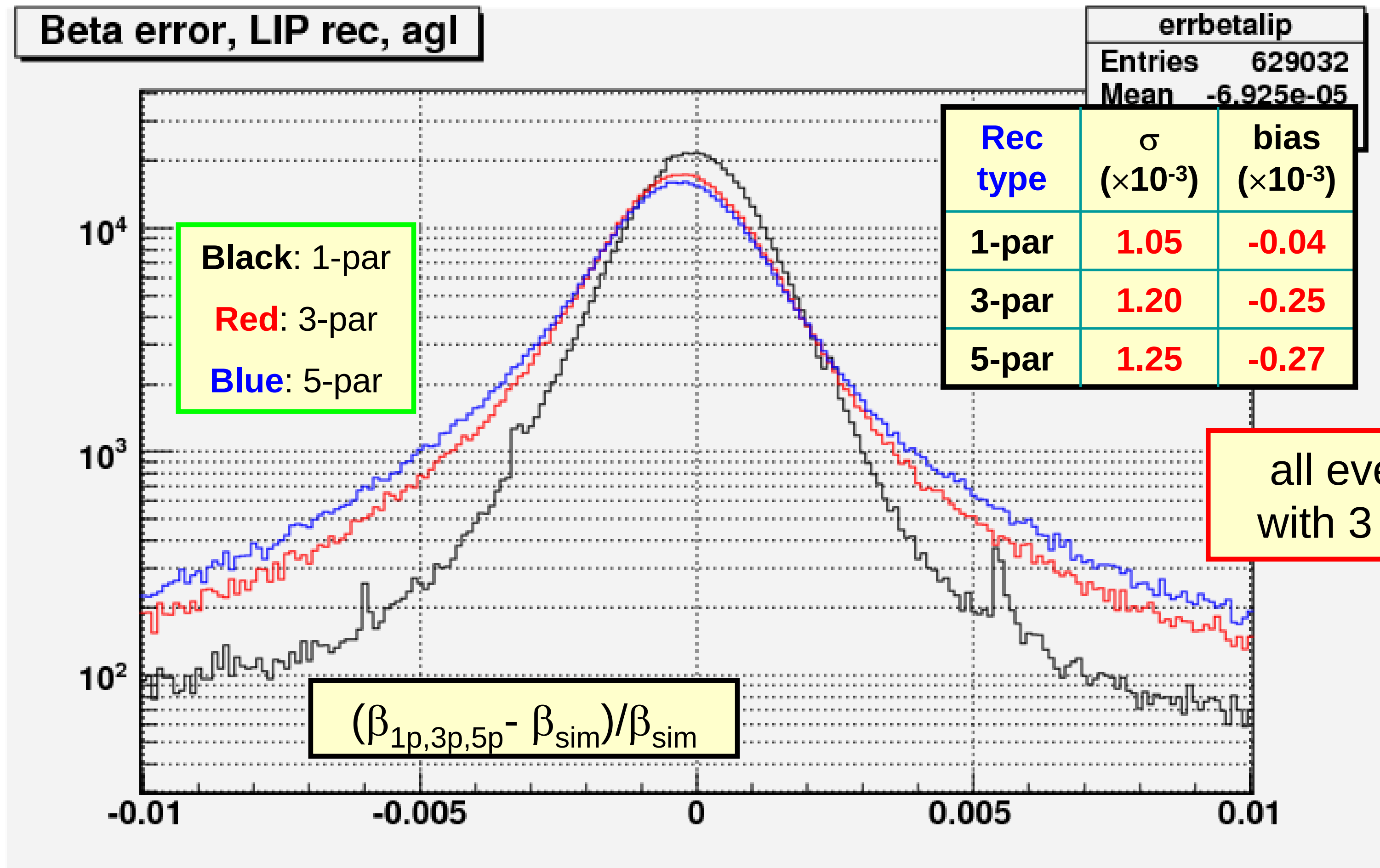
1-parameter

Ring hits: 10

5-parameter

3- and 5-parameter β reconstructions

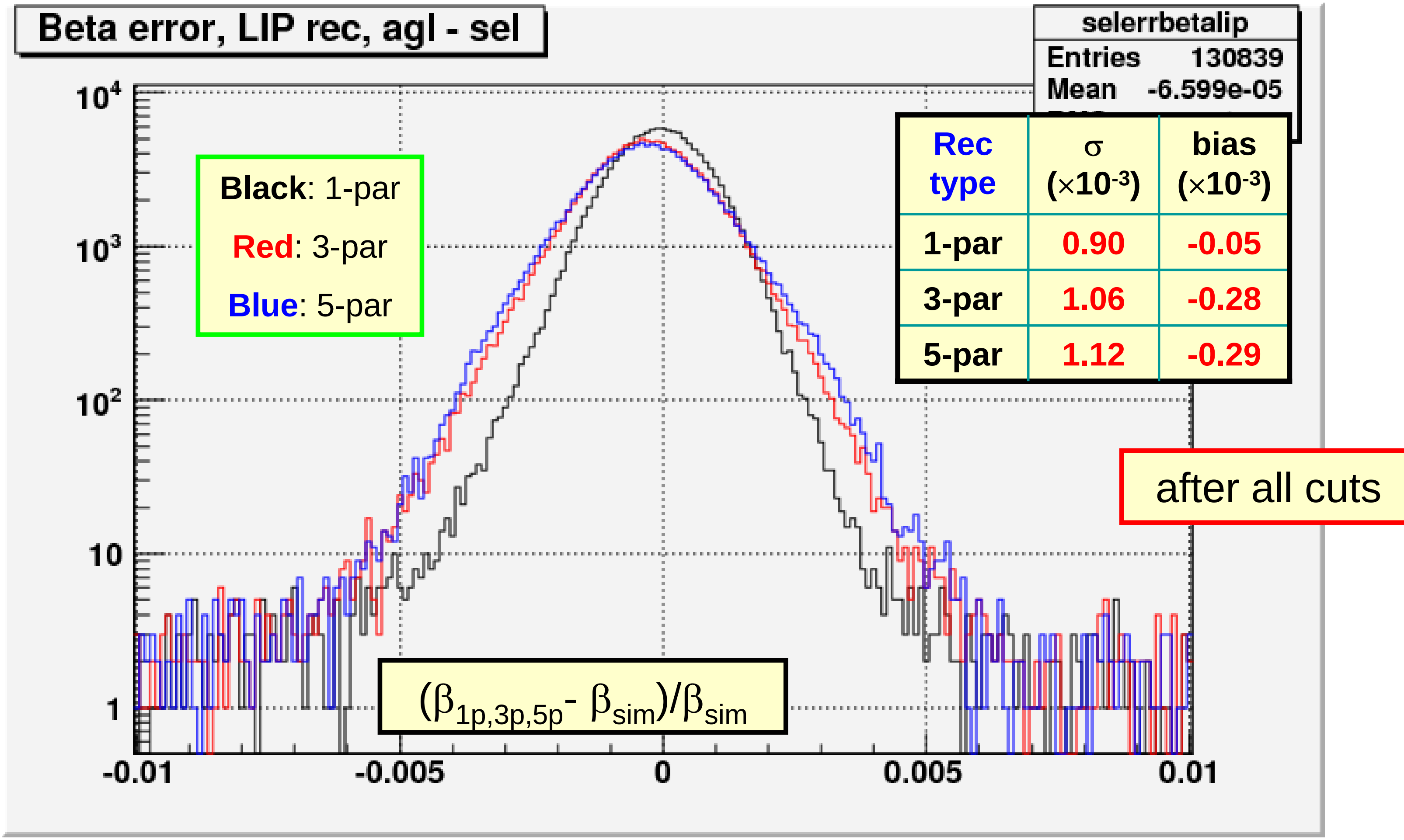
- Error in velocity measurements:
  - Error increase (esp. tails) as number of parameters increases
  - Slight bias ($<1 \times 10^{-4}$) for 1-par, increases to $\sim 3 \times 10^{-4}$ in 3,5-par cases



Rec type	σ ($\times 10^{-3}$)	bias ($\times 10^{-3}$)
1-par	1.05	-0.04
3-par	1.20	-0.25
5-par	1.25	-0.27

3- and 5-parameter β reconstructions

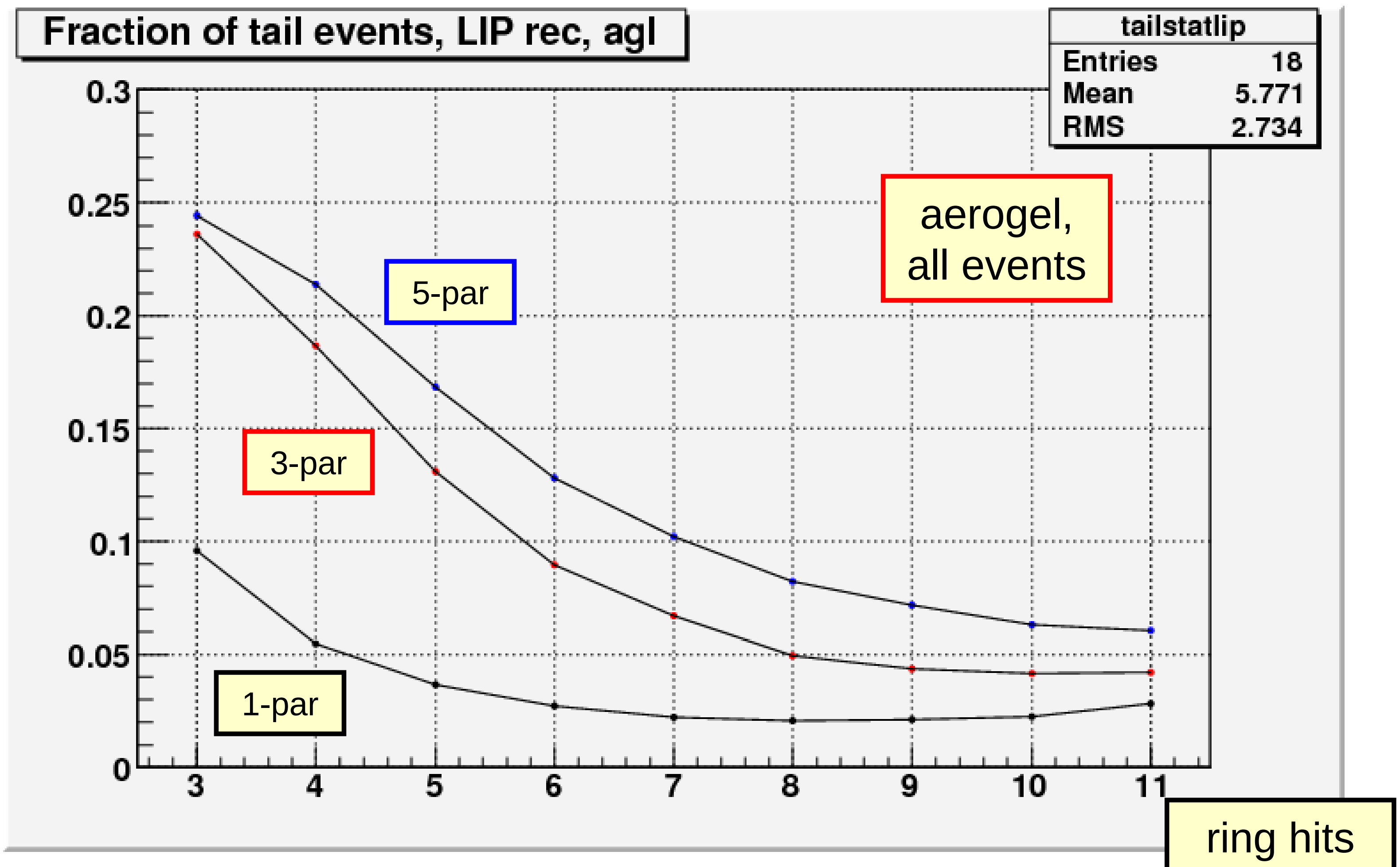
- Error in velocity measurements:
  - Smaller error in selected events (namely because 4 hits required)
  - No significant change in bias



Rec type	σ (×10⁻³)	bias (×10⁻³)
1-par	0.90	-0.05
3-par	1.06	-0.28
5-par	1.12	-0.29

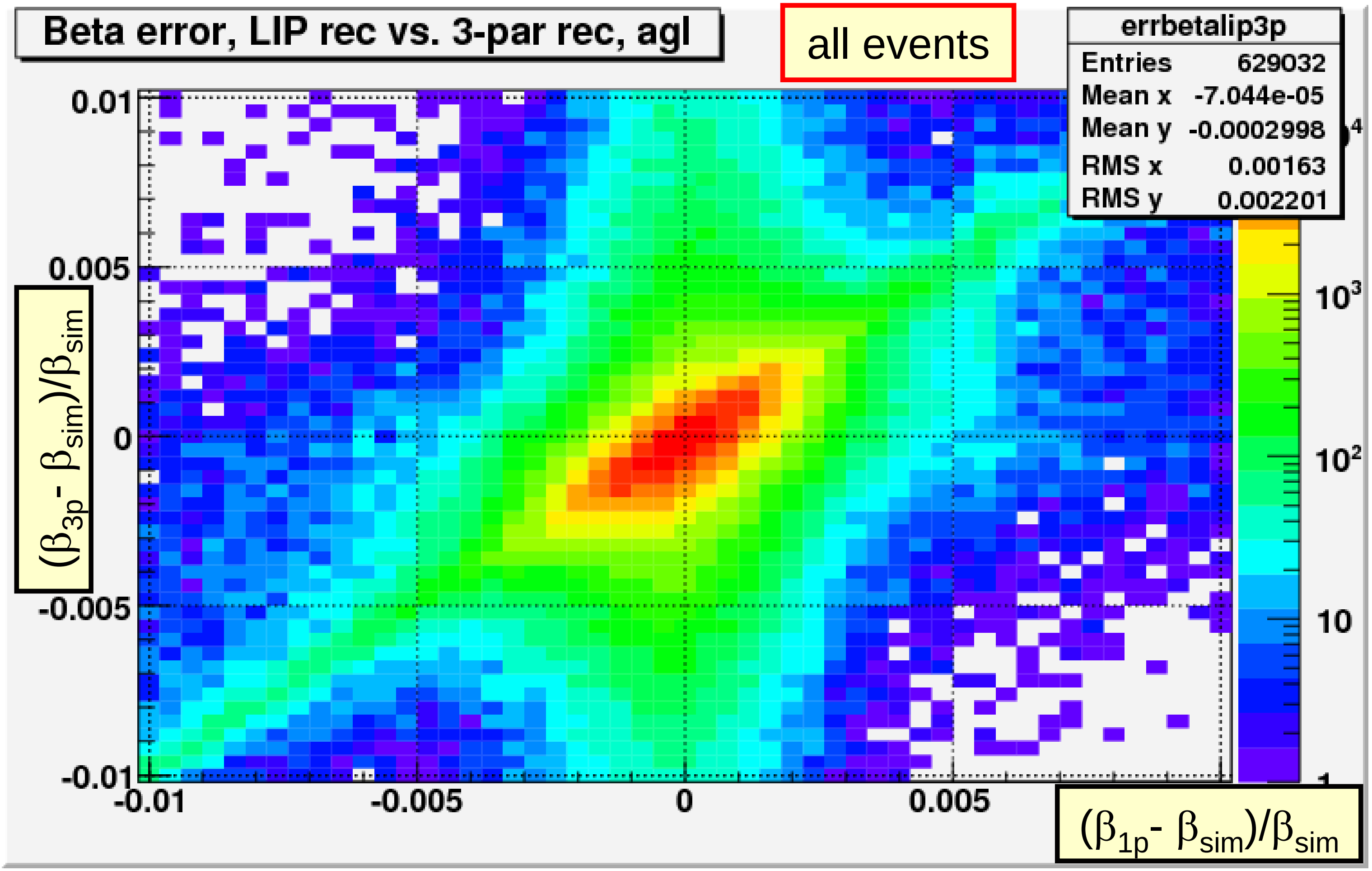
3- and 5-parameter β reconstructions

- Fraction of tail events:
  - Much higher in 3-, 5-parameter reconstructions when number of hits is low, difference decreases for higher number of hits



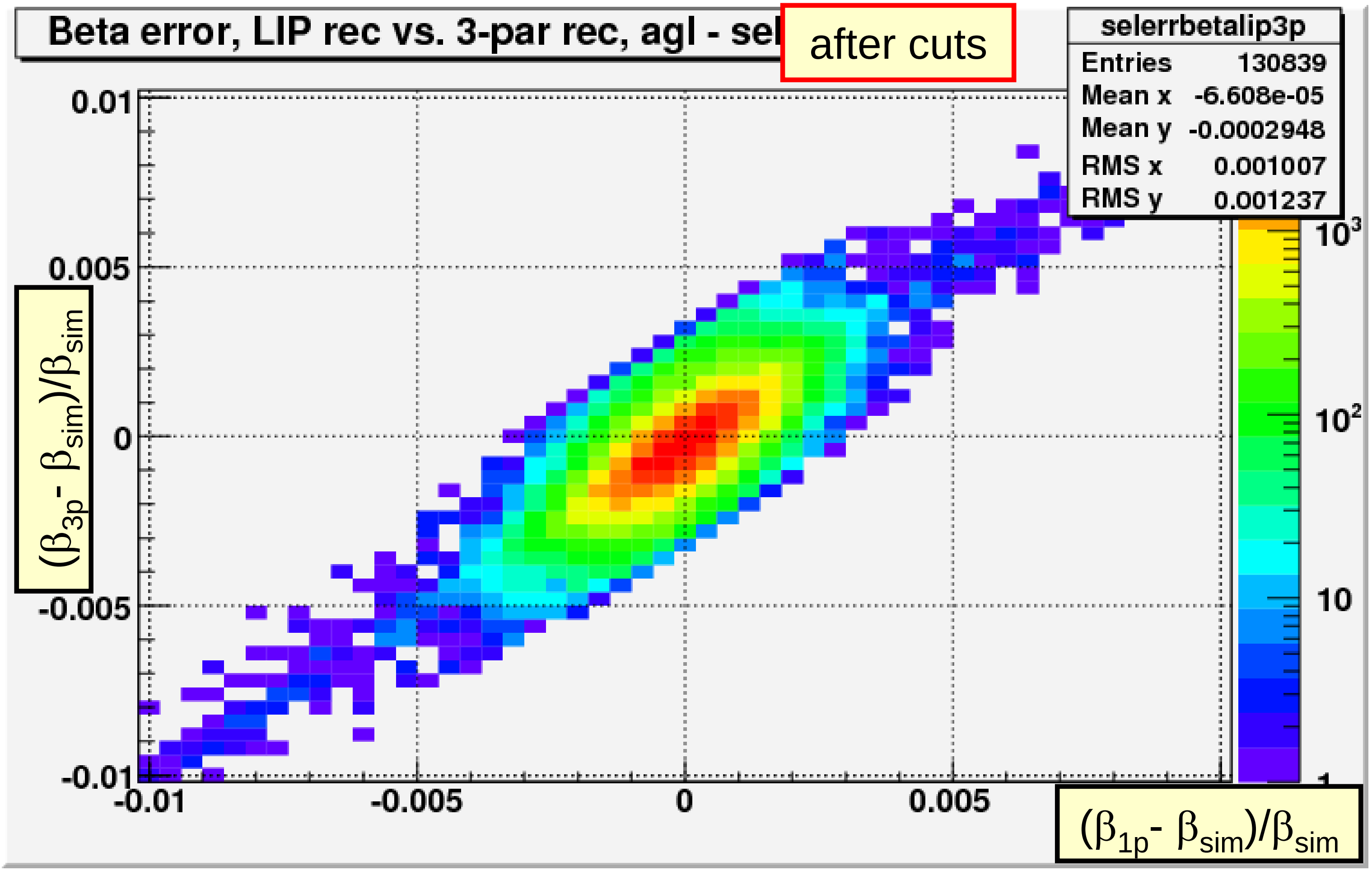
3- and 5-parameter β reconstructions

- Compatibility between velocity measurements:
  - 1-par vs. 3-par



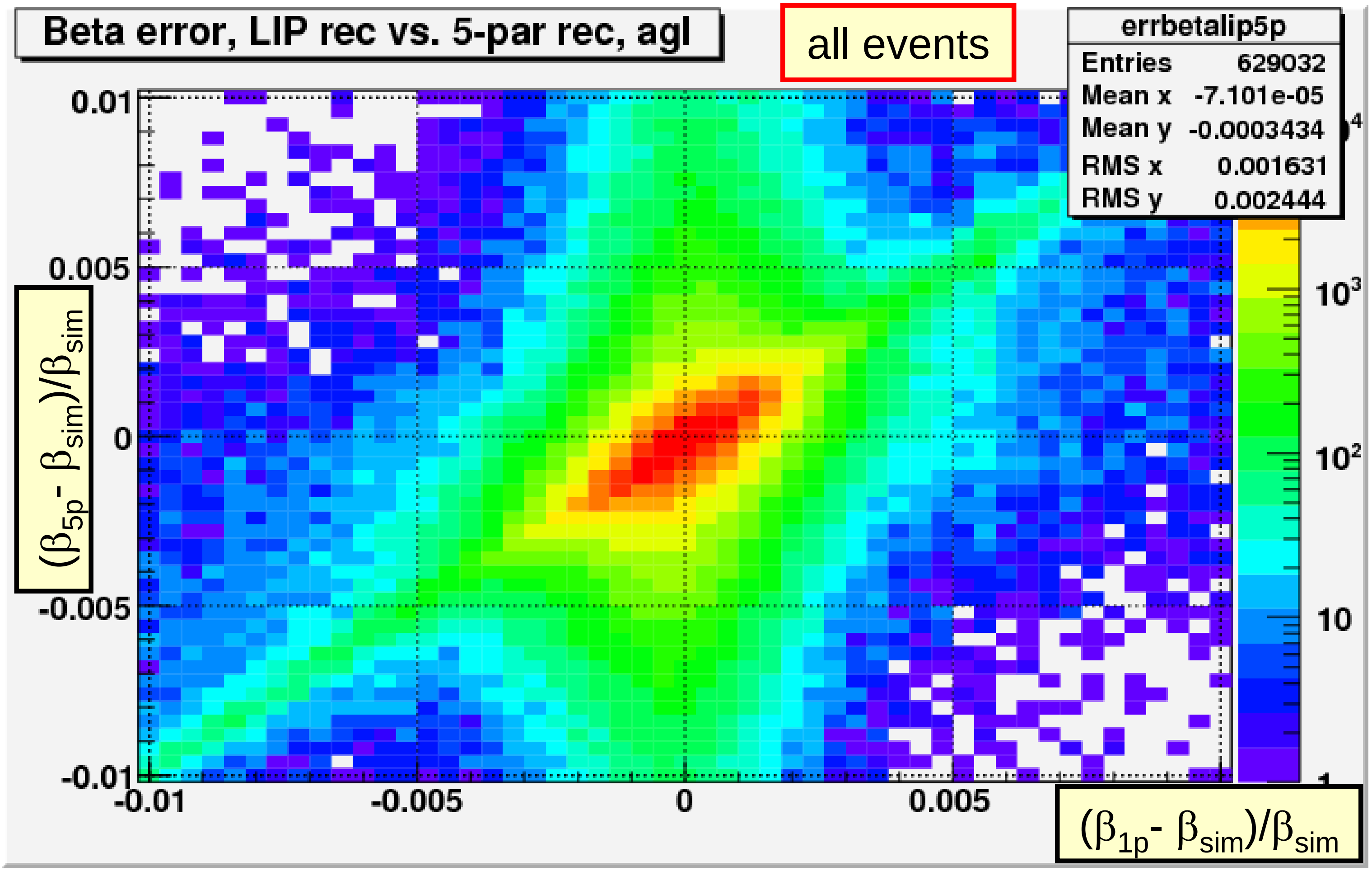
3- and 5-parameter β reconstructions

- Compatibility between velocity measurements:
  - 1-par vs. 3-par, after cuts (including agreement btw 1,3,5-par)



3- and 5-parameter β reconstructions

- Compatibility between velocity measurements:
  - 1-par vs. 5-par



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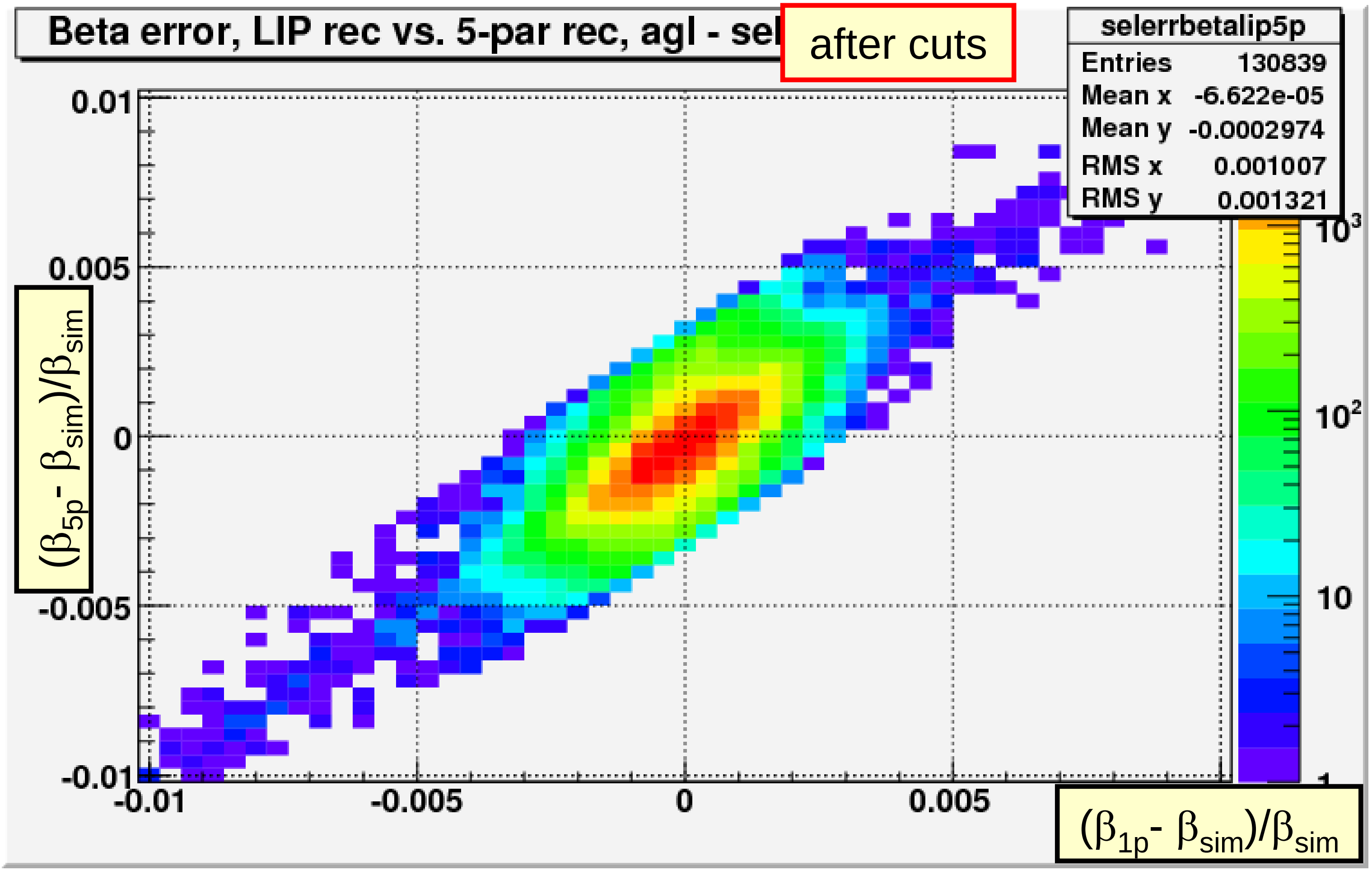
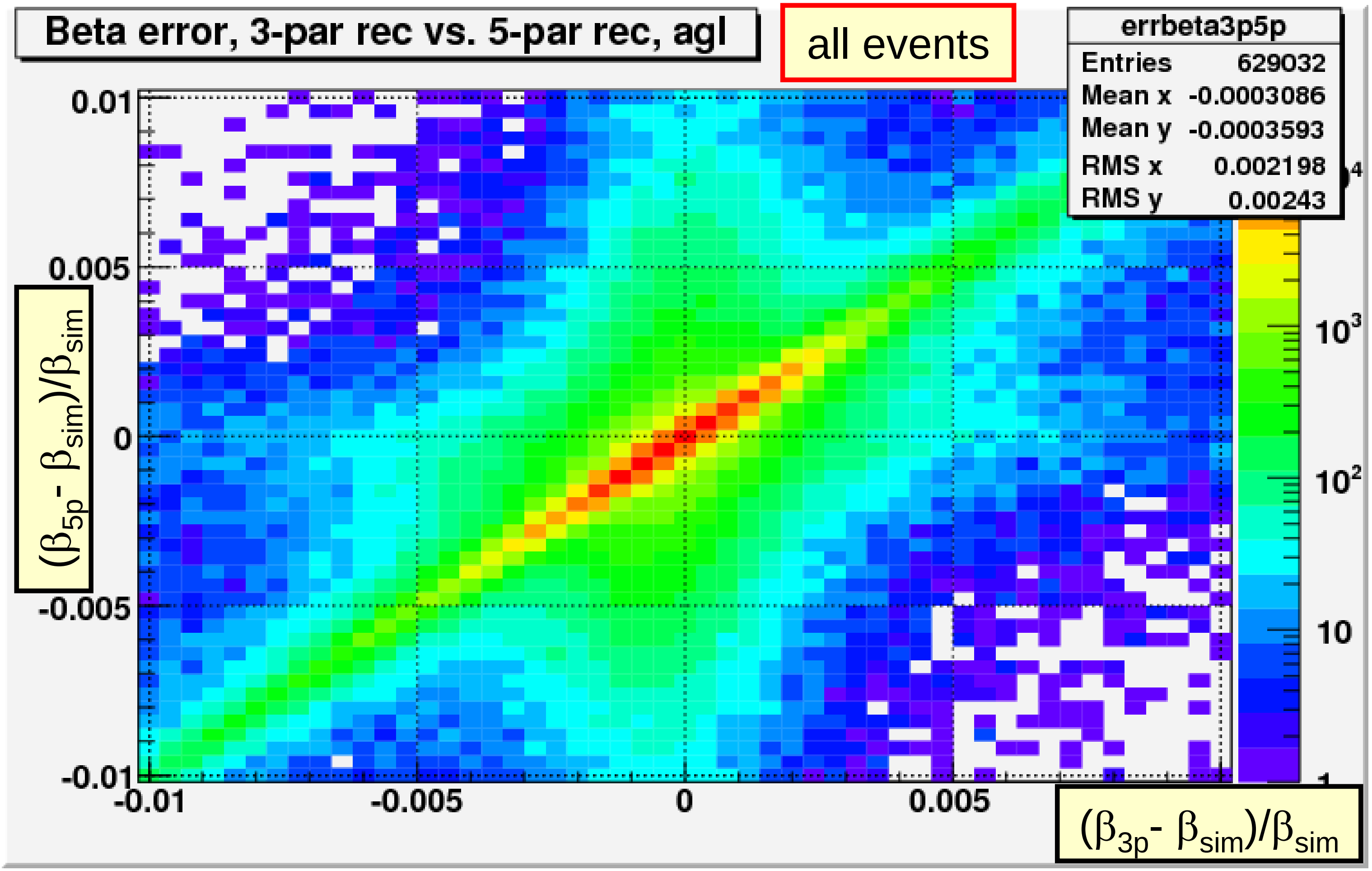


3- and 5-parameter β reconstructions

- Compatibility between velocity measurements:
  - 3-par vs. 5-par



3- and 5-parameter β reconstructions

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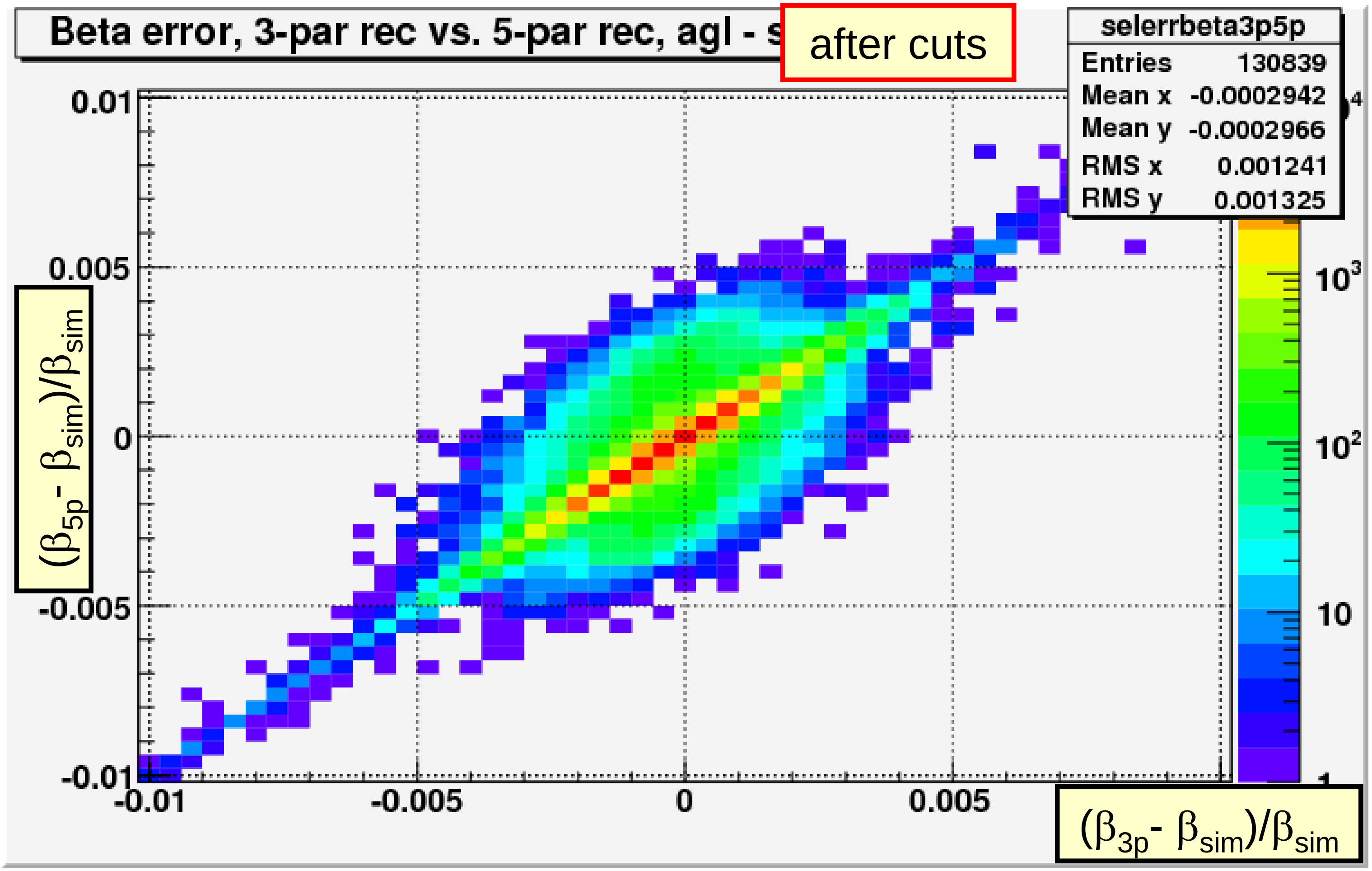
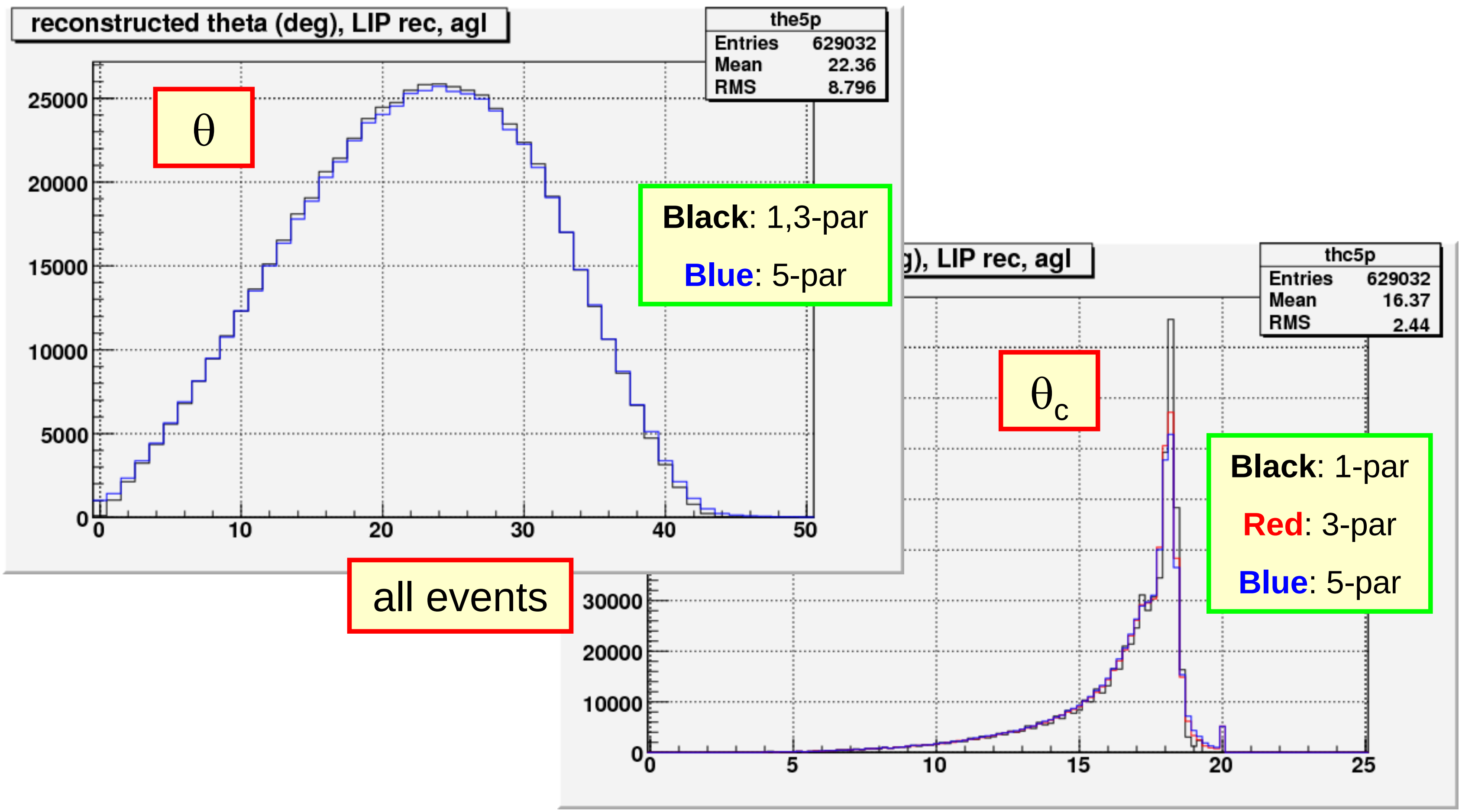


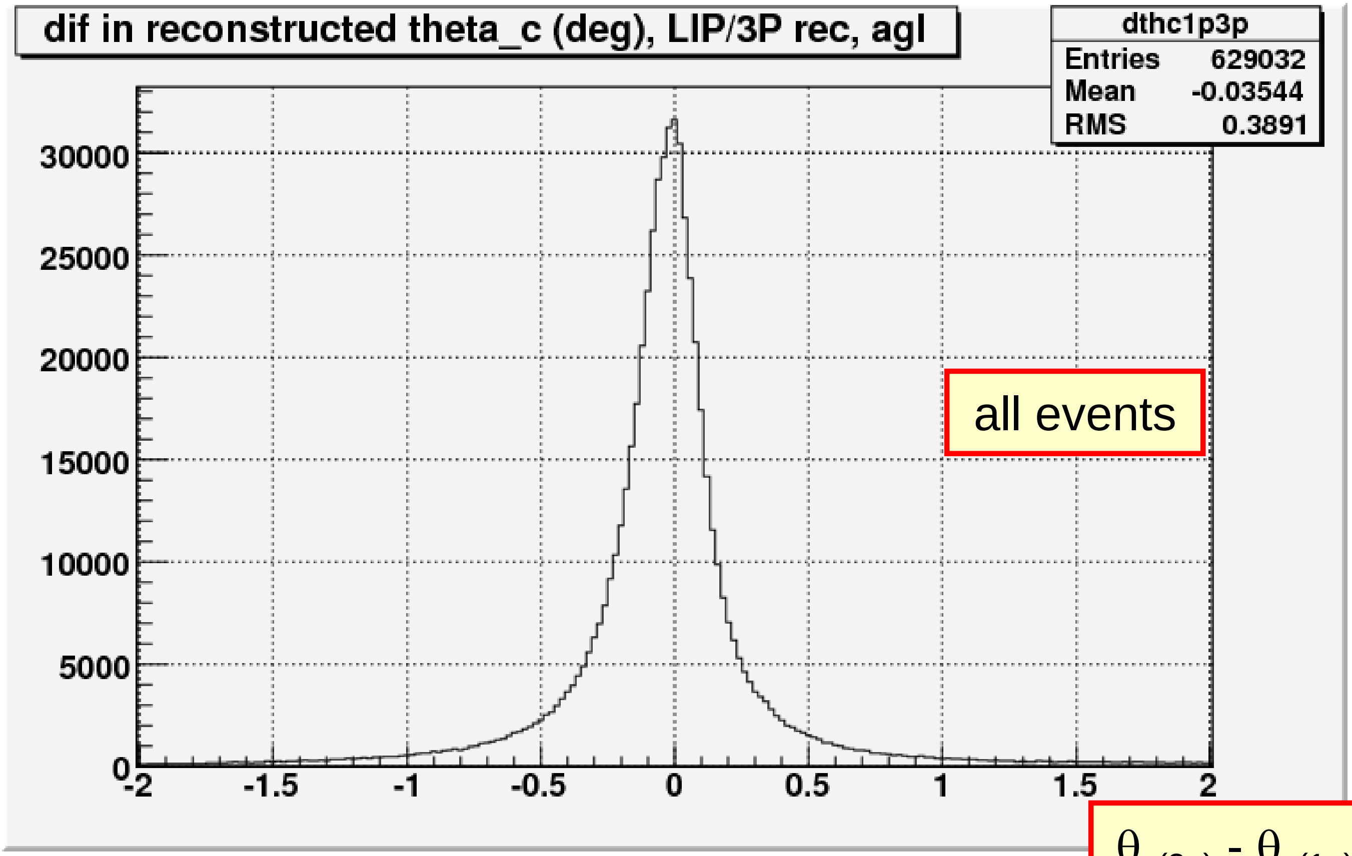
3- and 5-parameter β reconstructions

- Comparison of reconstructed angle distributions:



3- and 5-parameter β reconstructions

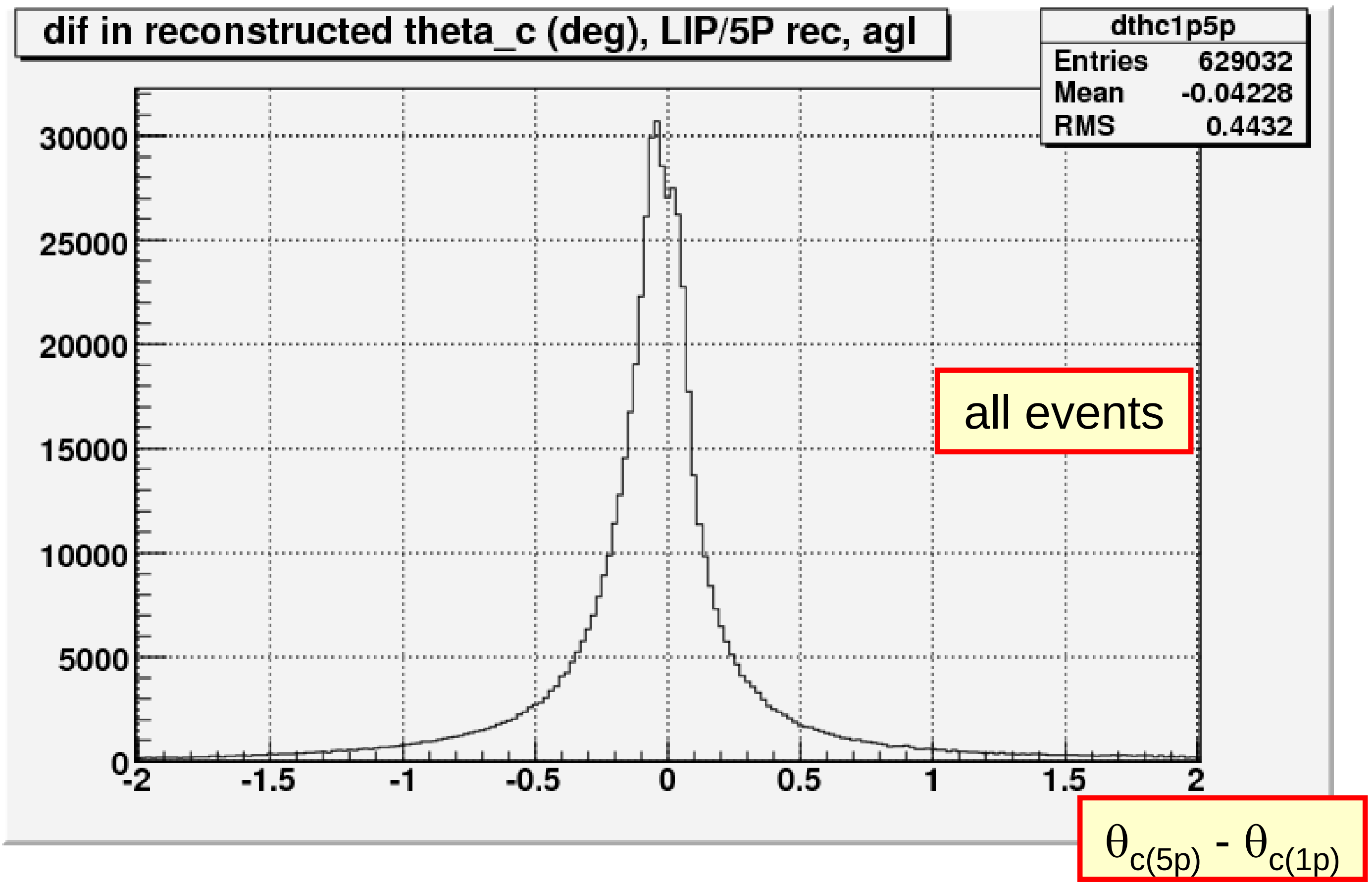
- Difference between reconstructed angles:
  - θ_c, 1-par versus 3-par



$\theta_{c(3p)} - \theta_{c(1p)}$

3- and 5-parameter β reconstructions

- Difference between reconstructed angles:
  - θ_c, 1-par versus 5-par



3- and 5-parameter β reconstructions

- Difference between reconstructed angles:
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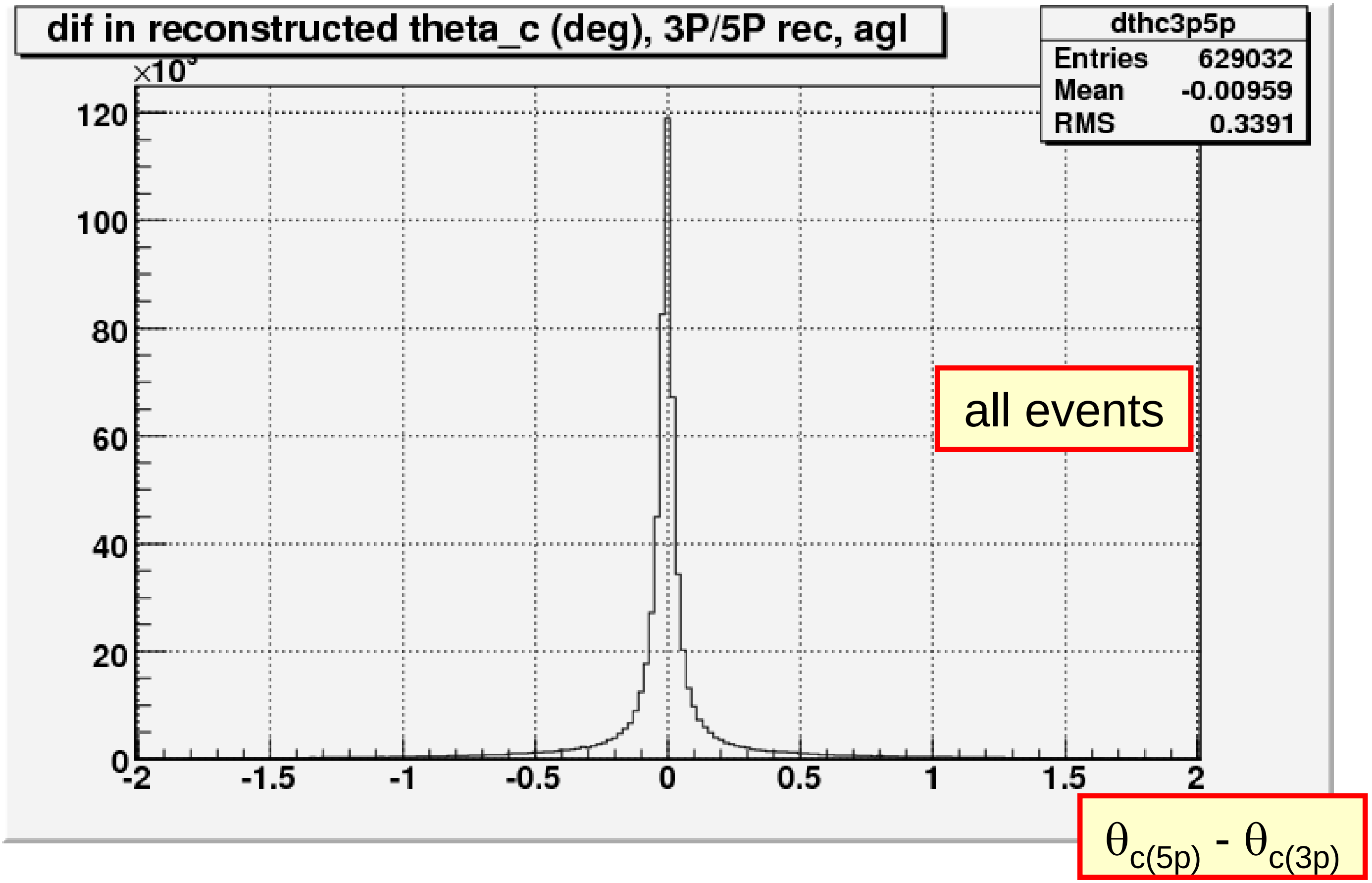
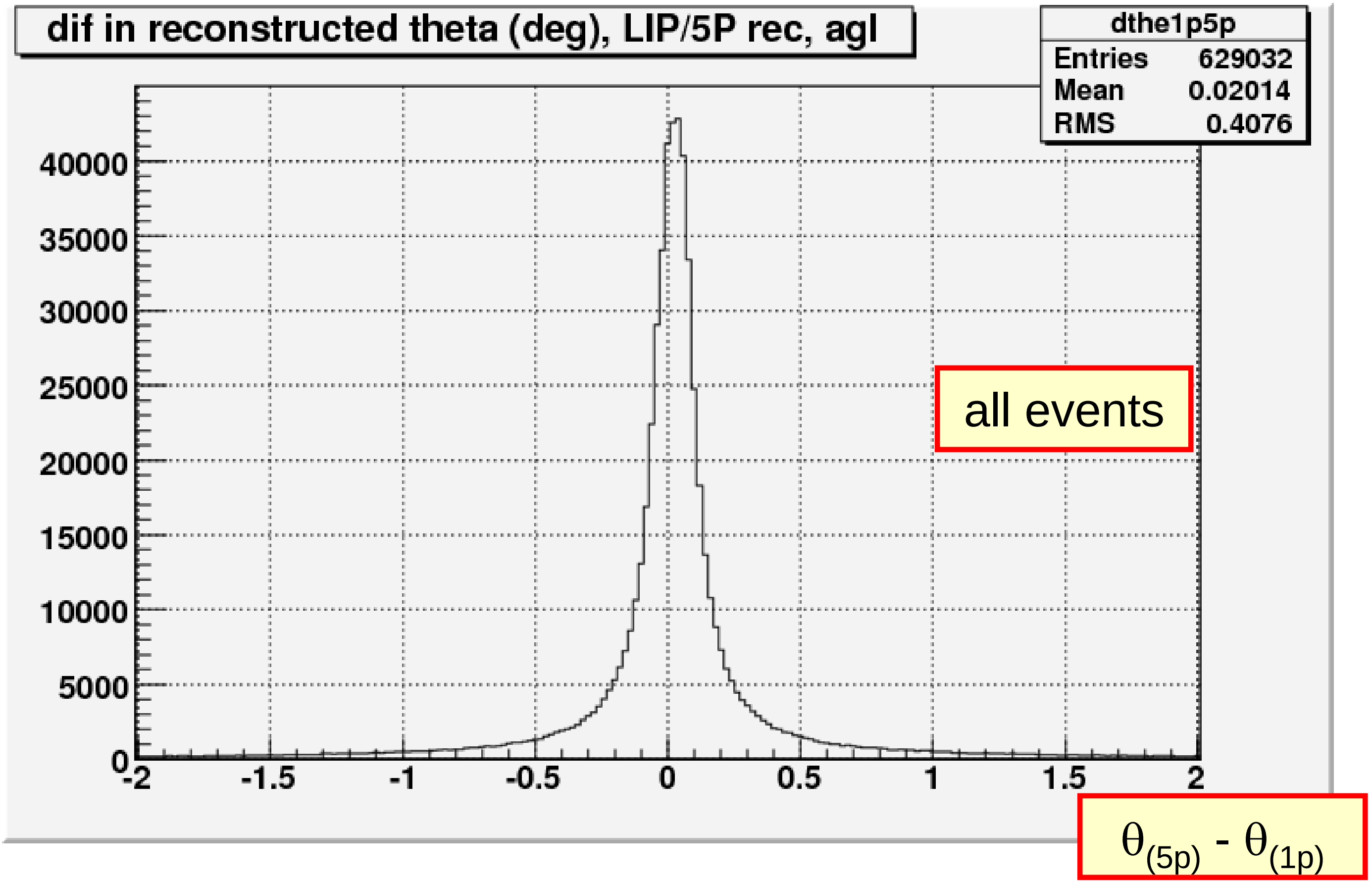


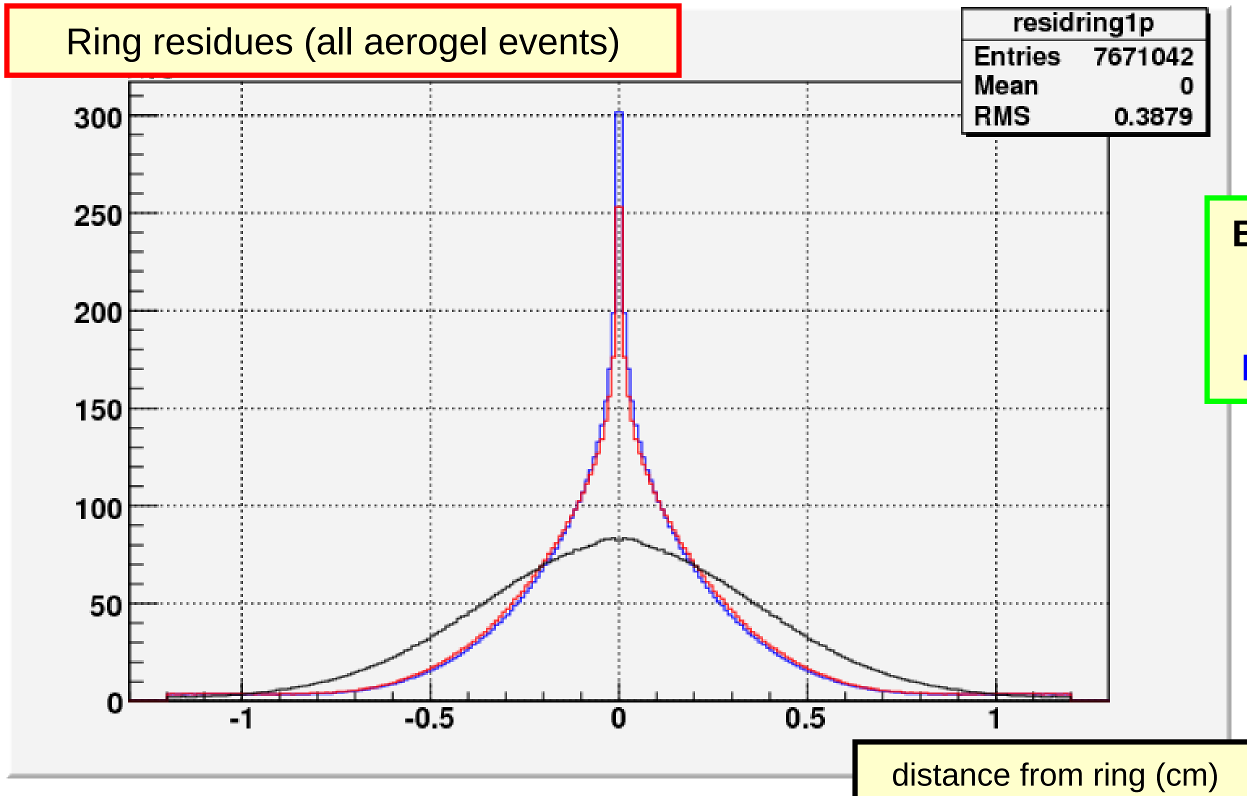
3- and 5-parameter β reconstructions

- Difference between reconstructed angles:
  - θ, 1-par versus 5-par



Hit distances to reconstructed rings

- Calculated for each of the three LIP β reconstructions (1-, 3-, 5-parameter)
- Hit distances become smaller as number of parameters increases
  - Behaviour was expected: larger number of parameters allows reconstruction to find rings that have a better agreement with hit data



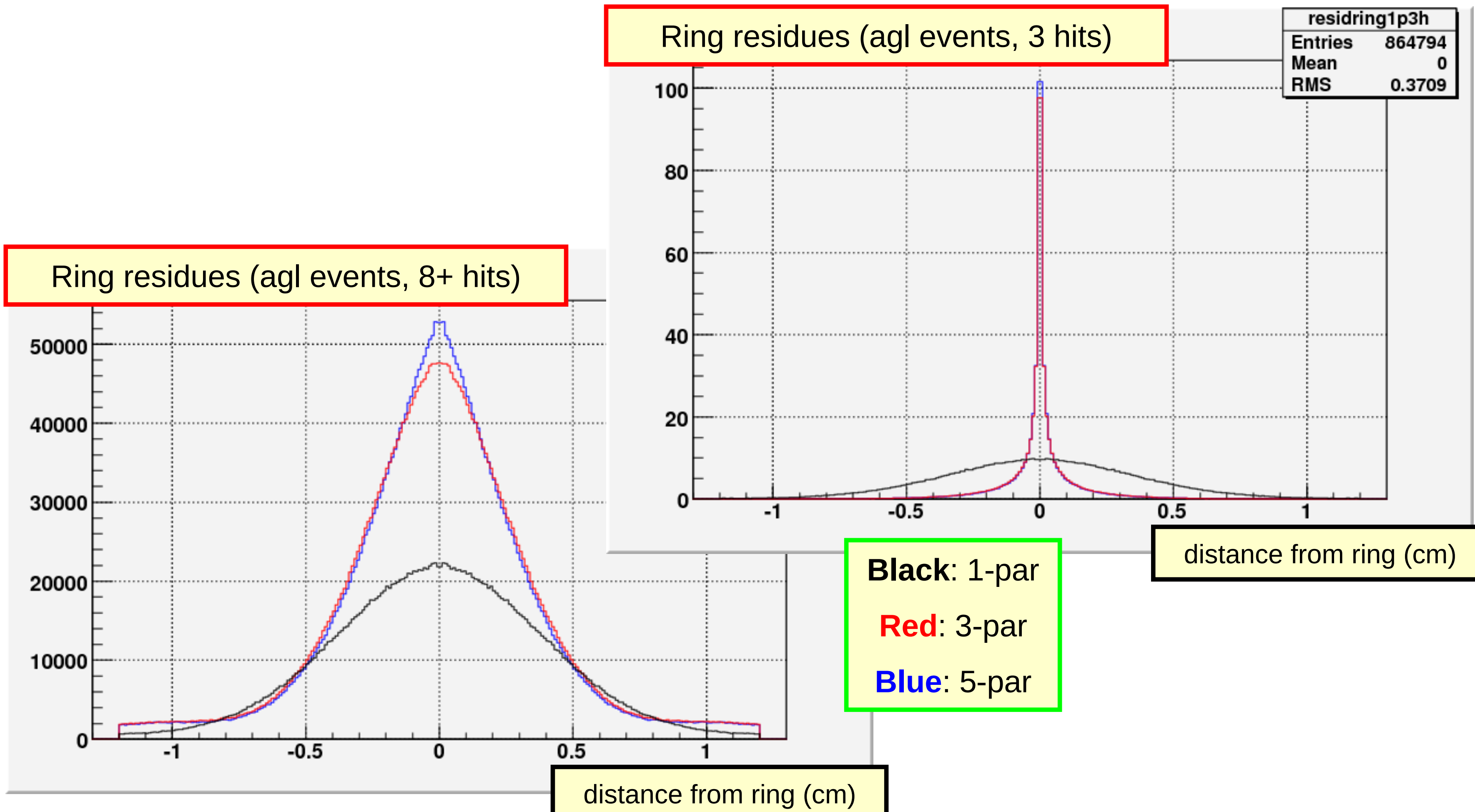
Black: 1-par

Red: 3-par

Blue: 5-par

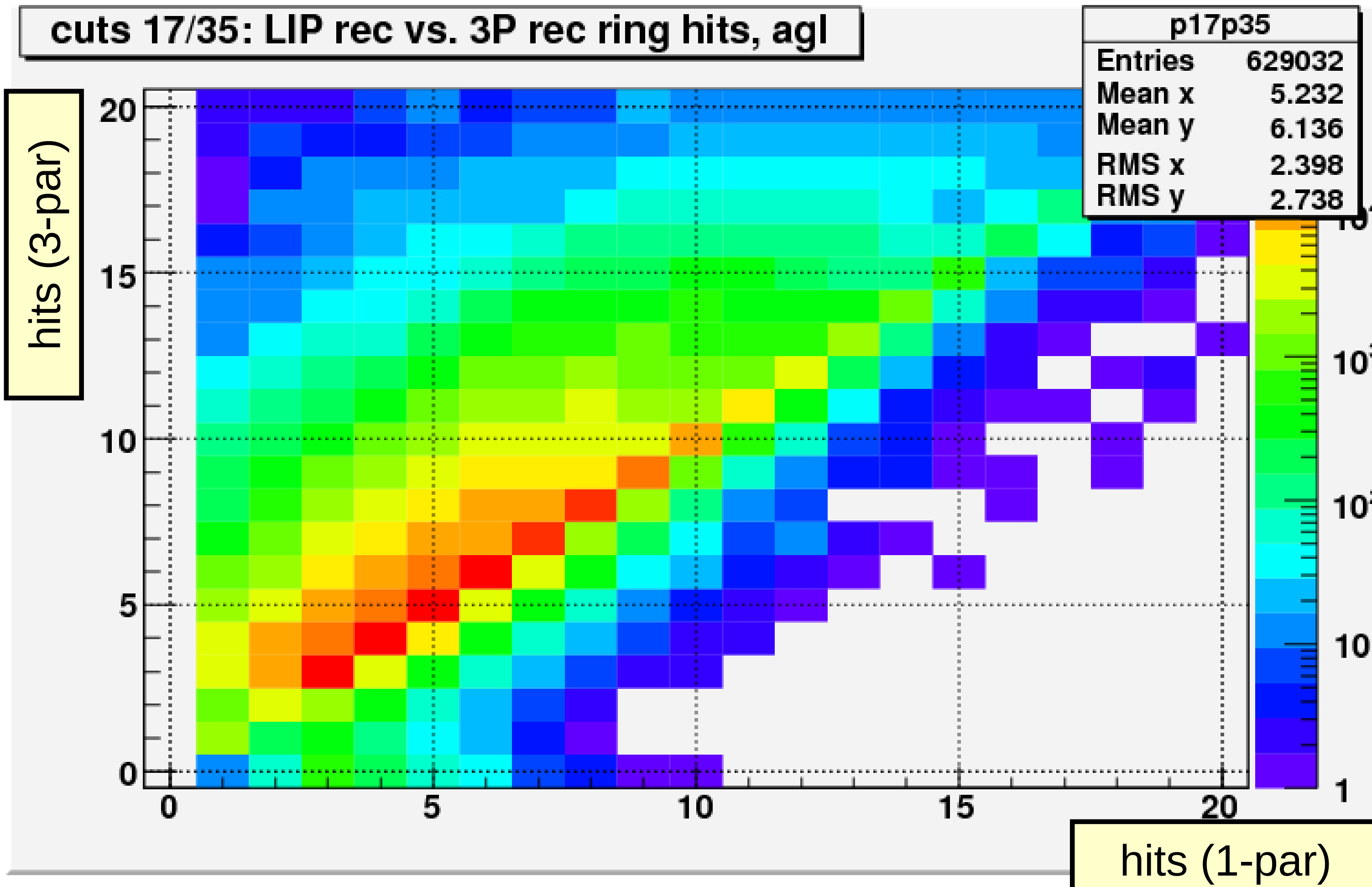
Hit distances to reconstructed rings

- Effect of free parameters is stronger in events with few hits:



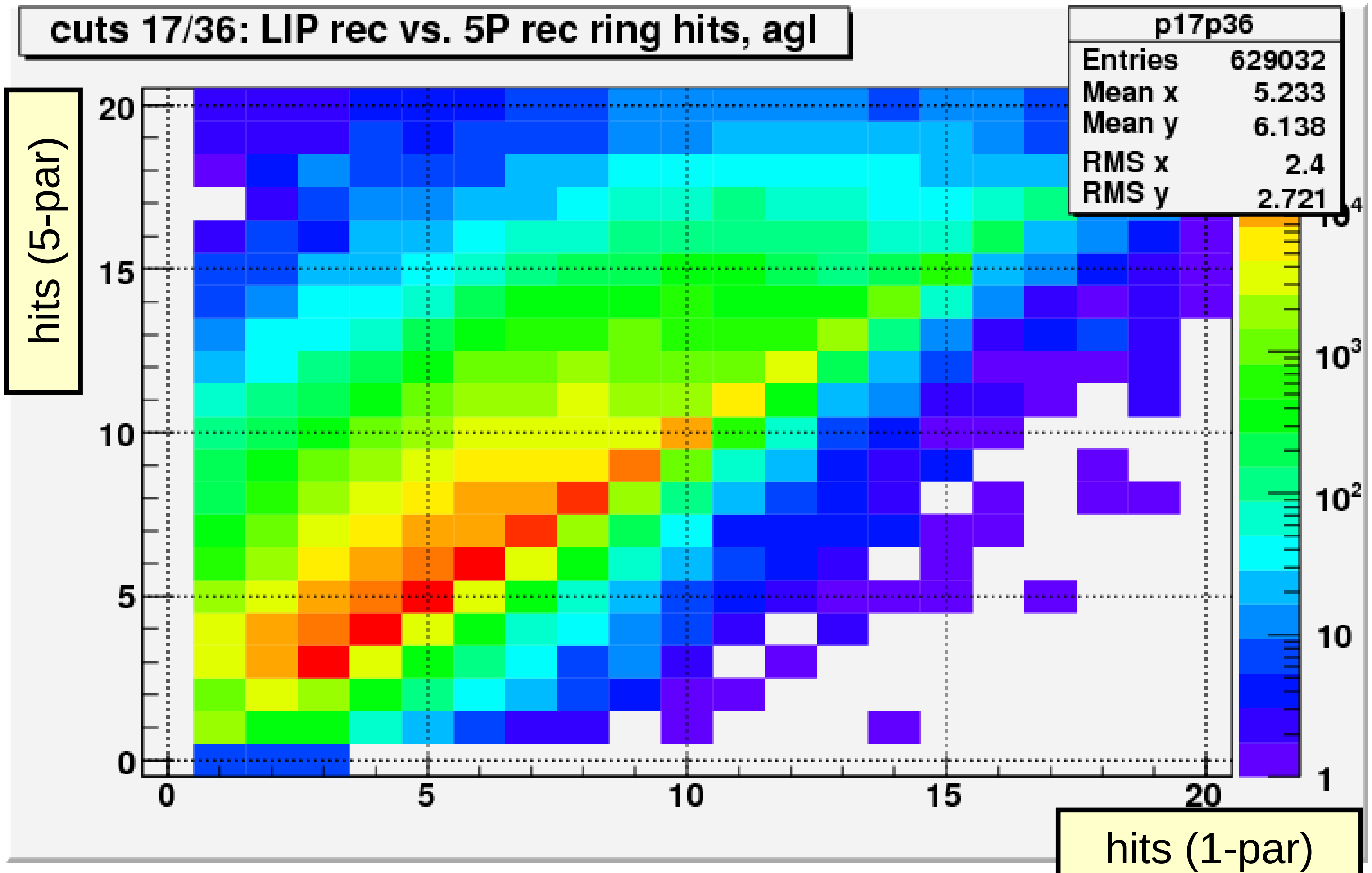
Number of ring hits

- Number of ring hits tends to increase in 3,5-par distribs.:
  - 1-par vs. 3-par



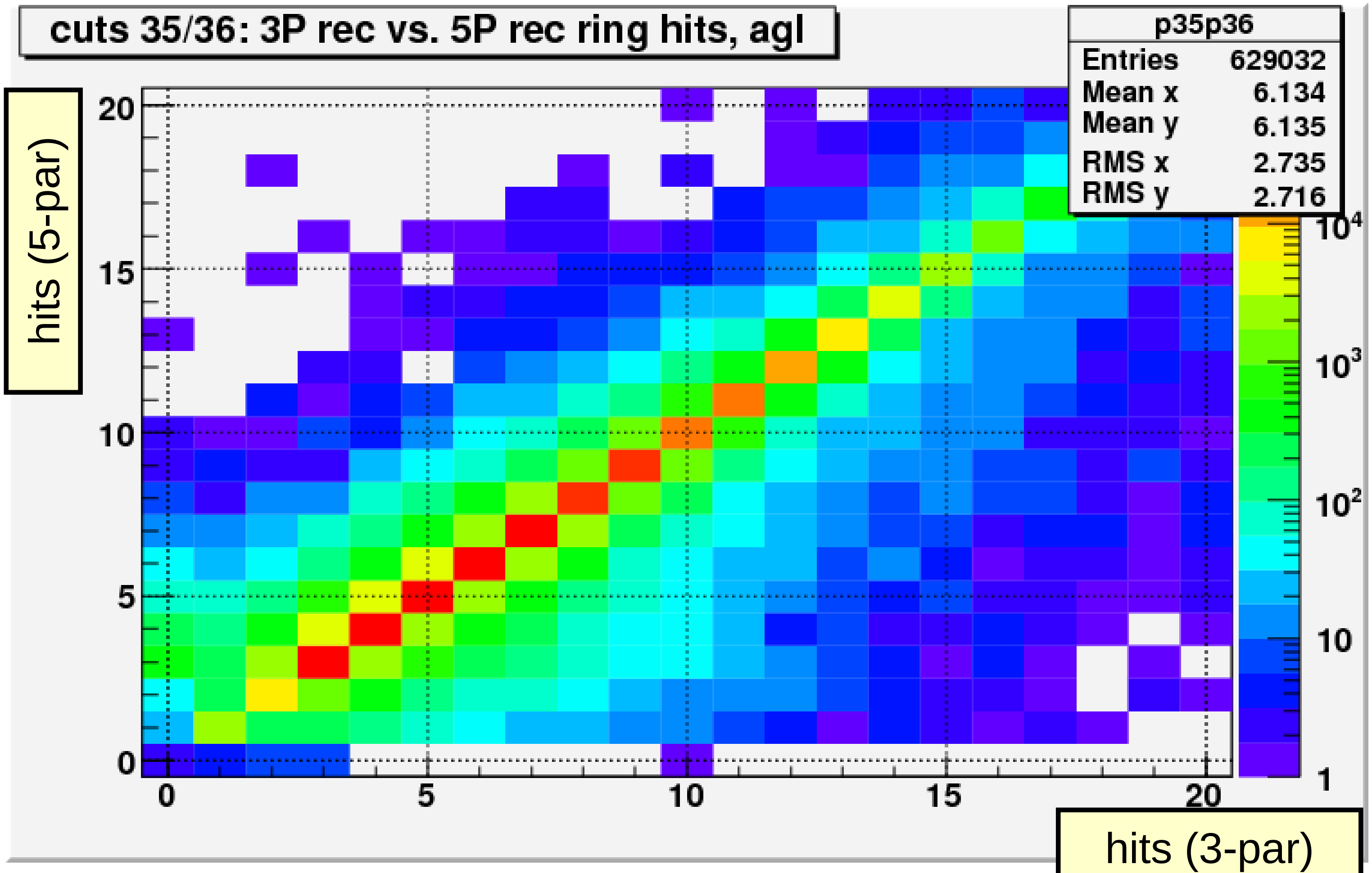
Number of ring hits

- Number of ring hits tends to increase in 3,5-par distribs.:
  - 1-par vs. 5-par



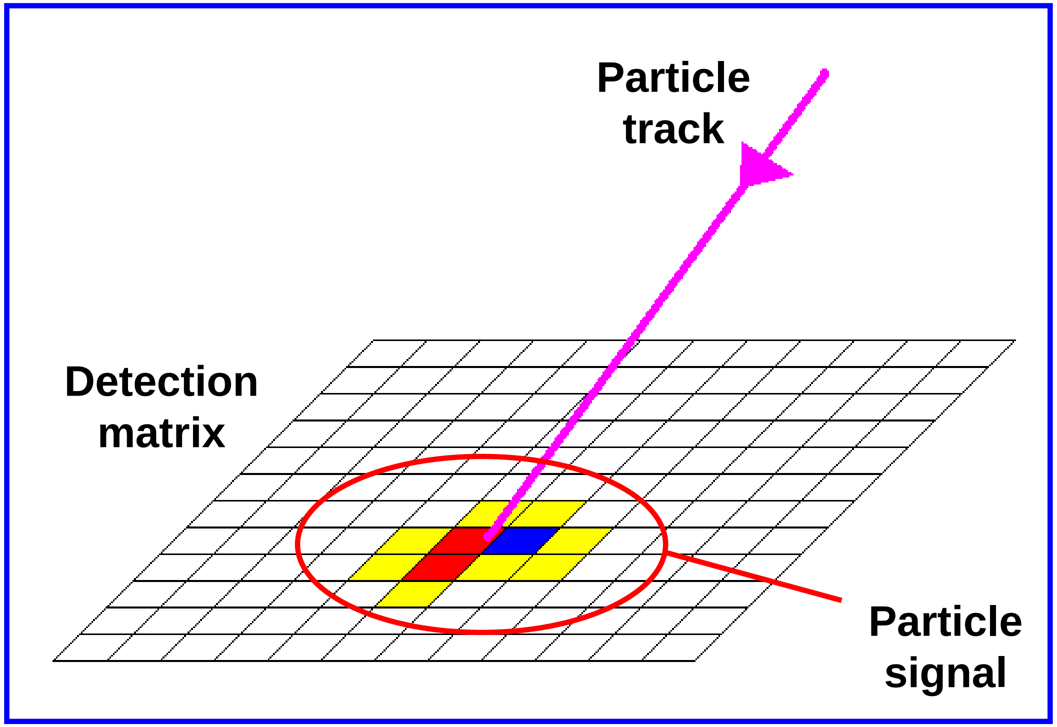
Number of ring hits

- Number of ring hits tends to increase in 3,5-par distribs.:
  - 3-par vs. 5-par



Light guide particle impact point

- Particle signal in PMT matrix provides independent information on its trajectory
- Comparison between reconstructed track and particle signal is useful to find events with bad Tracker data
- AMS-02 files have no data on the «real» (simulated) impact point

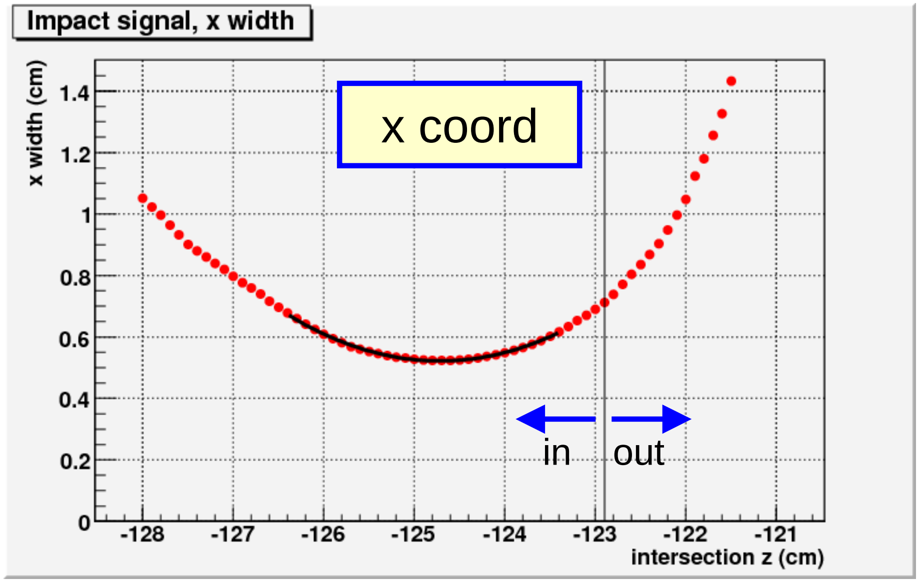


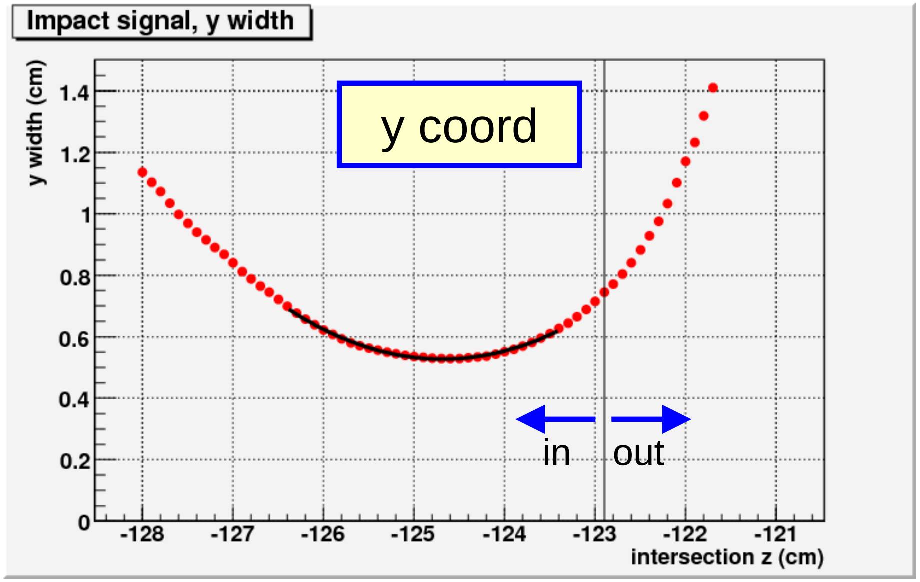
Effective matrix impact depth

- Optimization of effective impact point depth needed to make good comparison between Tracker data and particle signal in PMT matrix
  - Possible hint for standalone reconstruction
- Hits tagged as particle-associated if near (< 5 cm from) particle entry point at top of light guides
  - Entry point from Tracker data
  - 5 cm window >> expected shift in impact point due to optimization
- Scan in range of possible z_{impact} values:
  - Impact point coordinates (x_{impact}, y_{impact}) calculated from Tracker data
  - Combined distribution, for all particle-associated hits of all events (with associated n_{pe}), of differences between hit and impact coordinates:
    - $x_{hit}-x_{impact}$
    - $y_{hit}-y_{impact}$
  - Gaussian fit to distributions
  - Optimal effective impact point should have the lowest σ in both axes

Effective matrix impact depth

- Top of light guides is at z = -122.9 cm (in global AMS-02 coords)
- 71 points tested for z_{impact}: -128 to -121 cm with 0.1 cm step
- Quadratic fit used to find minimum
- Effective impact point is at z_{impact} = -124.7 cm, that is, at 1.8 cm depth
- Excellent agreement between x and y results
  - $z_{imp}(x)$ = -124.72 cm
  - $z_{imp}(y)$ = -124.69 cm
- Agreement also on optimal resolution in both coordinates:
  - σ_x = 0.524 cm
  - σ_y = 0.531 cm



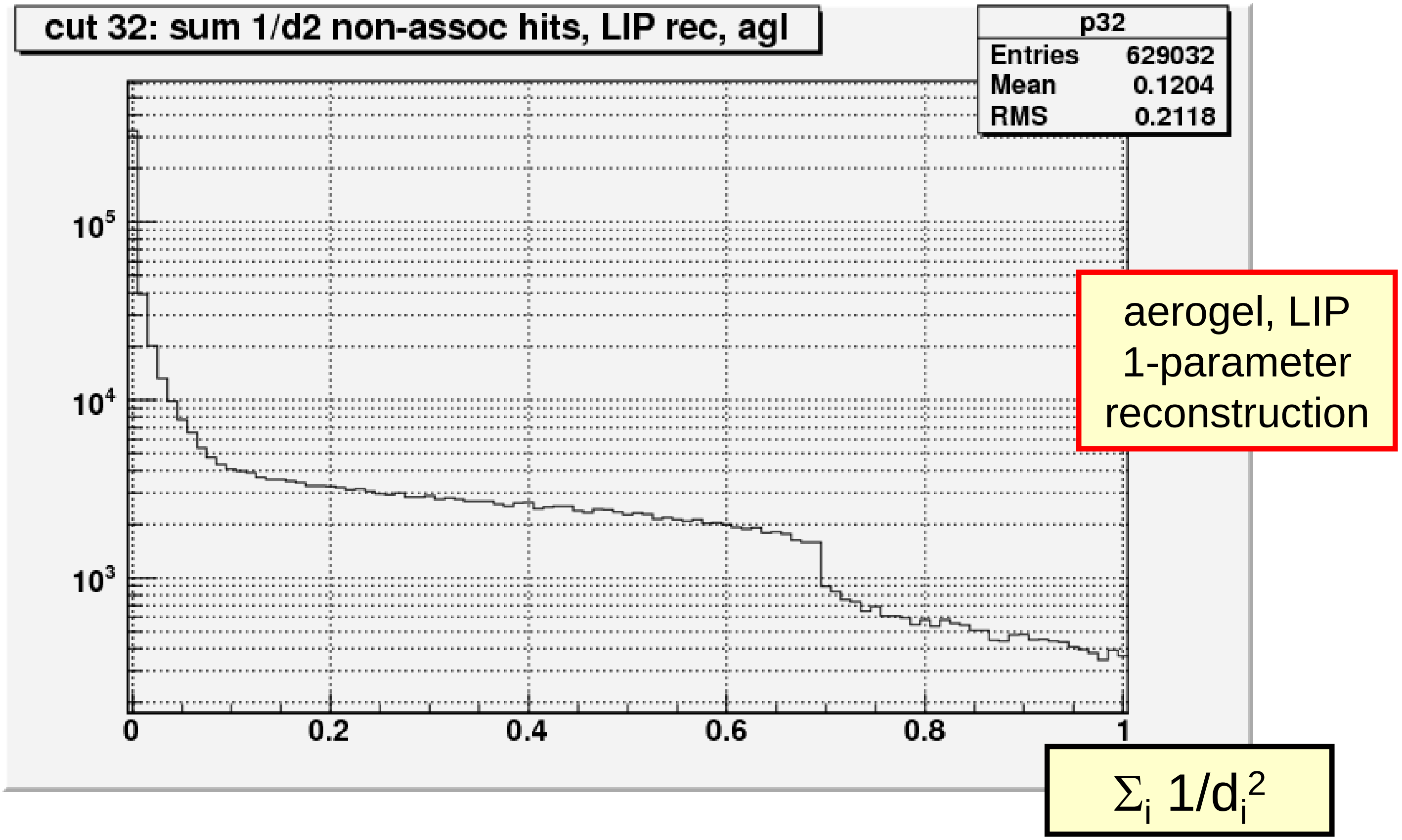


LIP analysis: new cuts

- New cuts included in event selection since March 2006
  - Pattern robustness confirmed by agreement between different algorithms:
    - All β reconstructions (CIEMAT, LIP-1,3,5-parameter) must find a ring
    - Reconstructed velocity: results of both 3-par & 5-par reconstructions should differ from 1-par by less than 0.3% (aerogel), 1% (NaF)
    - Minimum of 4 ring hits (instead of 3) in each reconstruction
  - Number of hits outside ring (excluding particle hits) is no greater that 2 (NaF), 4 (aerogel) in each of the LIP β reconstructions
    - Plays major role in excluding noisy events where random «false rings» become much more likely

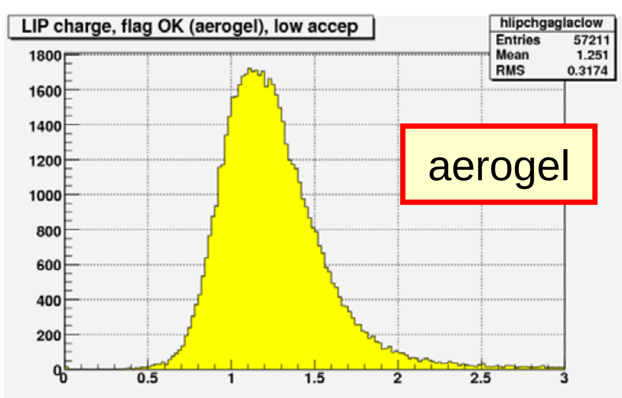
LIP analysis: new cuts

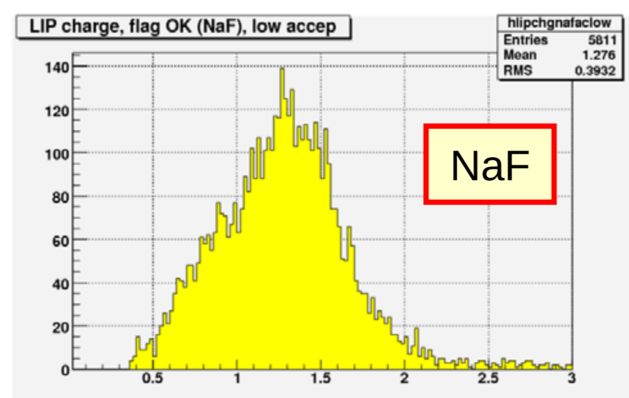
- New cuts included in event selection since March 2006
  - Additional cut on near non-associated hits: $\Sigma_i\ 1/d_i^2 < 0.1$, d_i is the hit distance to the reconstructed ring in cm



LIP analysis: new cuts

- New cuts included in event selection since March 2006
  - LIP charge reconstruction must give good result: Z_{rec} = 0.5-1.5 in NaF, Z_{rec} = 0.6-1.4 in aerogel
    - Excludes e.g. events where a strong signal from particle impact is mistakenly associated to a Cerenkov ring
    - Refinement of previous cuts on total ring signal
  - Ring acceptance > 20% (NaF), > 40% (aerogel)
    - Events with very small acceptance are prone to have bad velocity and charge reconstructions
- Cleaner sample, but lower acceptance
  - Increases need for using higher statistics in analysis
  - Development of a second set of (broader) cuts is under consideration

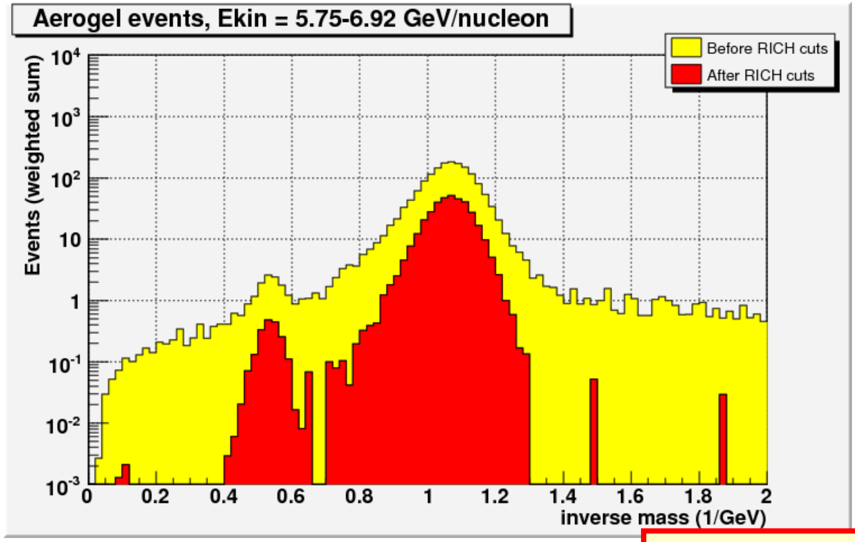




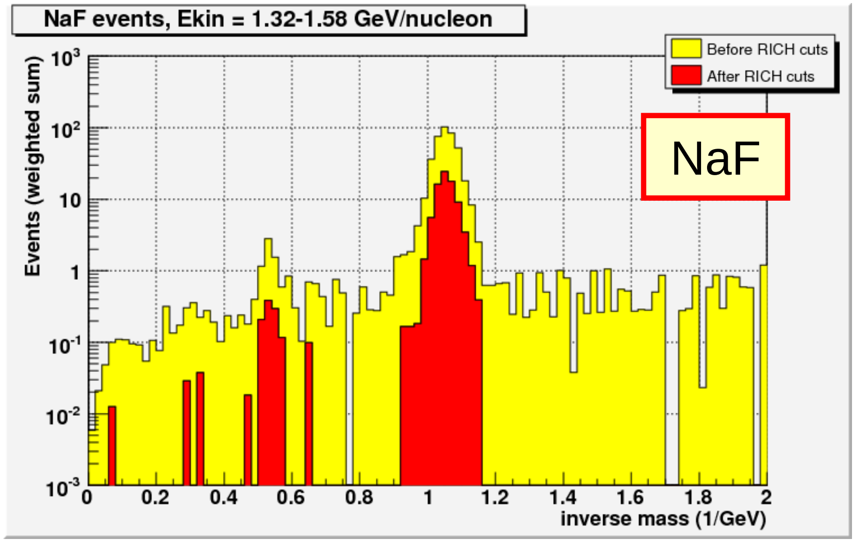
reconstructed charge for events with low acceptance

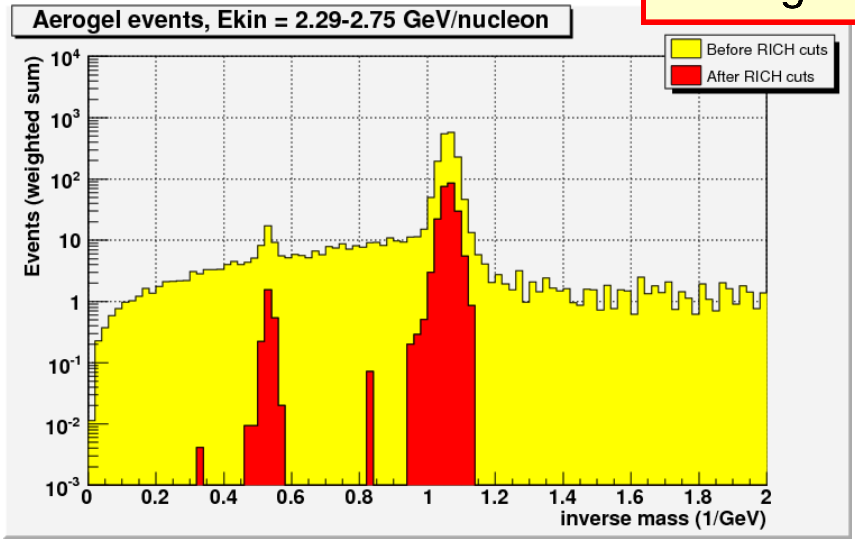
LIP analysis: D/p mass separation

- Results for mass separation
- Weighted inverse mass distributions
  - Total "=" $w_p N_p + w_d N_d + w_{hp} N_{hp}$ (each event has different weight)



aerogel

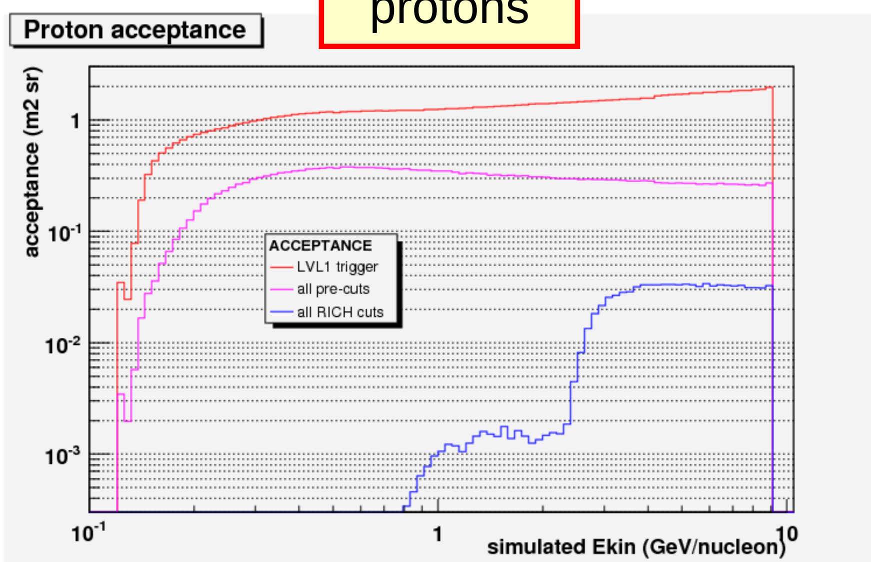




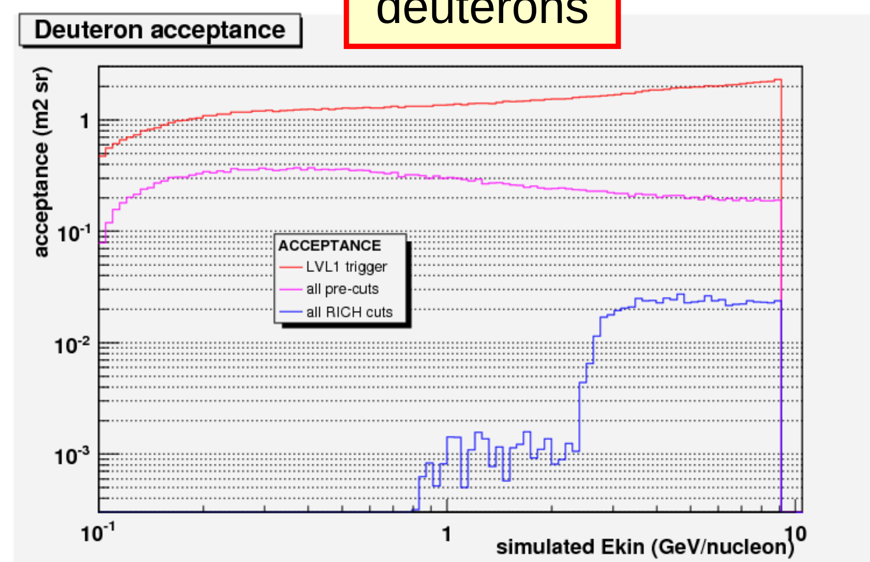
LIP analysis: acceptance

- Additional cuts have reduced the final acceptance
- Current figures for this analysis above aerogel threshold:
  - ~ 0.03 m^2sr for protons
  - ~ 0.02 m^2sr for deuterons

protons



deuterons



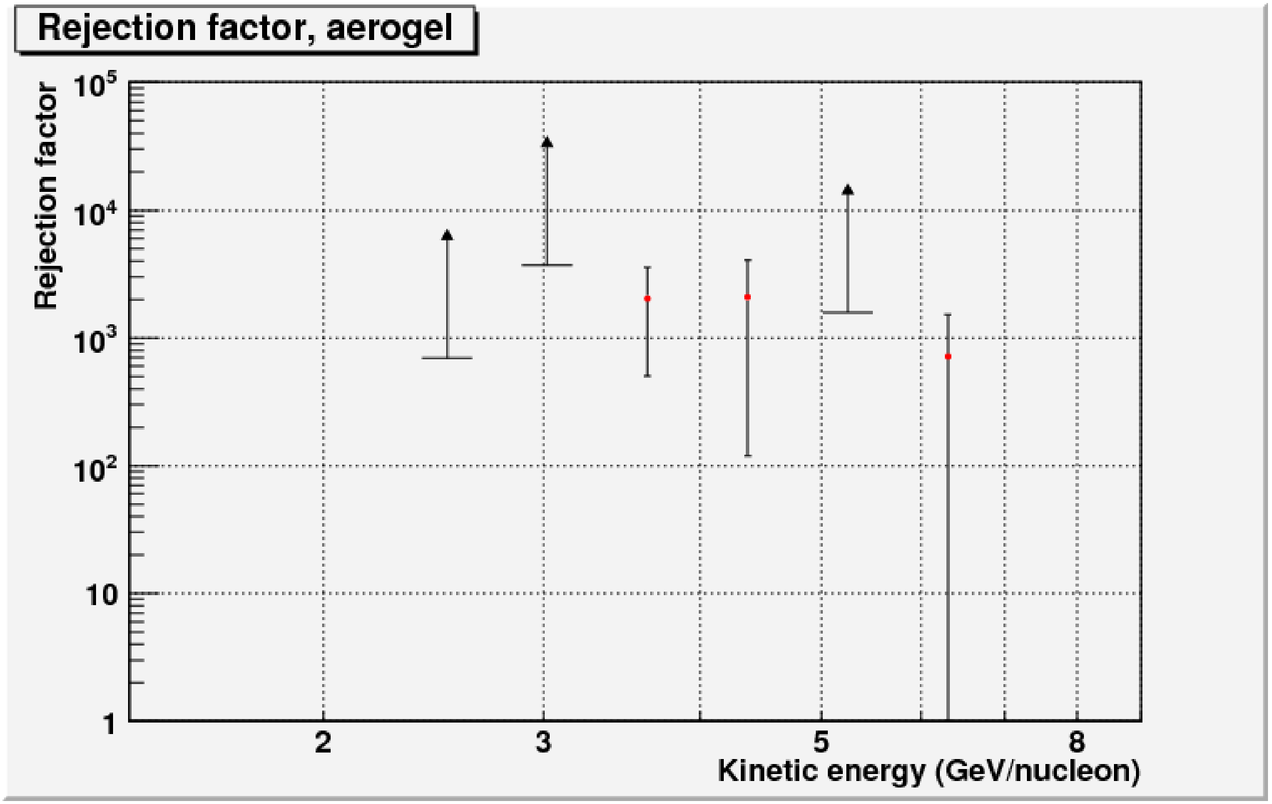
Red: Trigger LVL1

Magenta: after pre-cuts

Blue: after RICH cuts

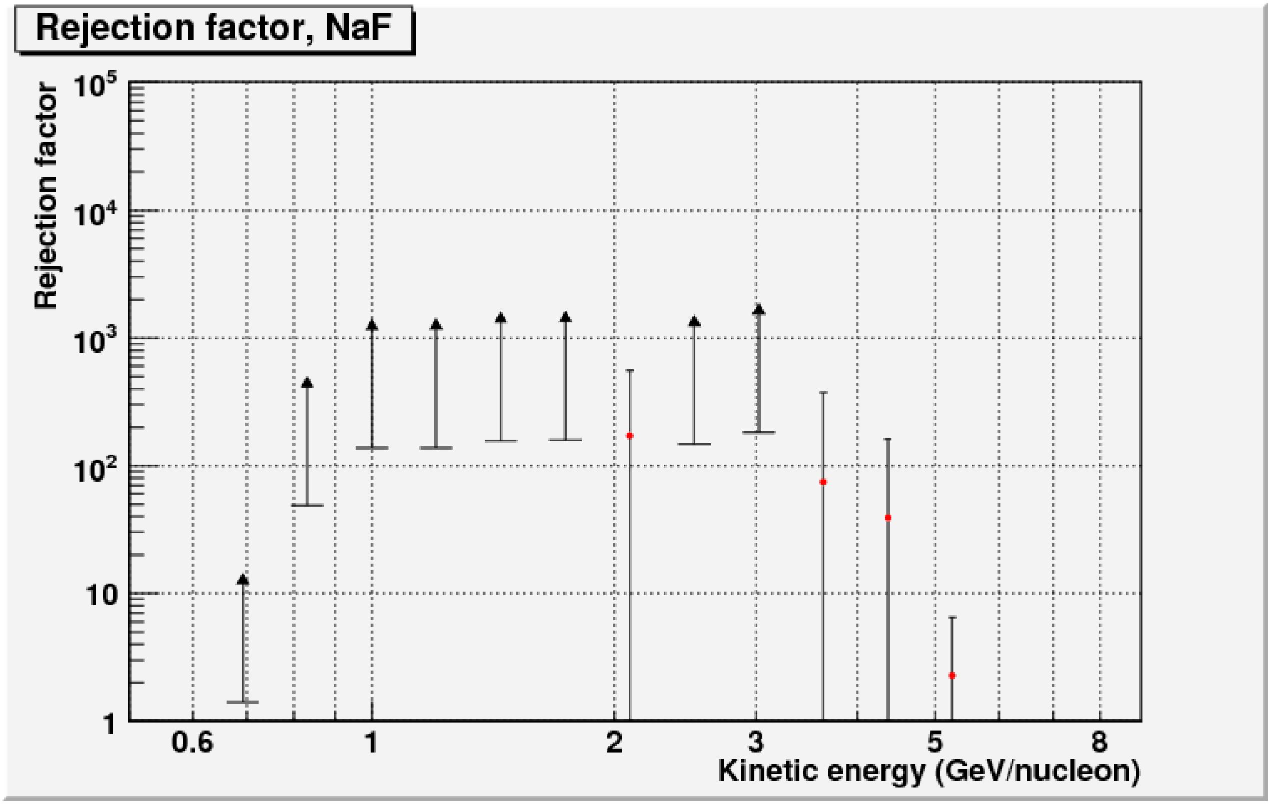
LIP analysis: rejection factor (aerogel)

- Rejection factor for D/p separation in aerogel > 10^3 for E_{kin} between 3 and 6 GeV
  - Should be at least ~10^4 around 3 GeV (no noise events fall in that region even with broader cuts)
- Additional statistics needed to give better estimates and evaluate further improvements



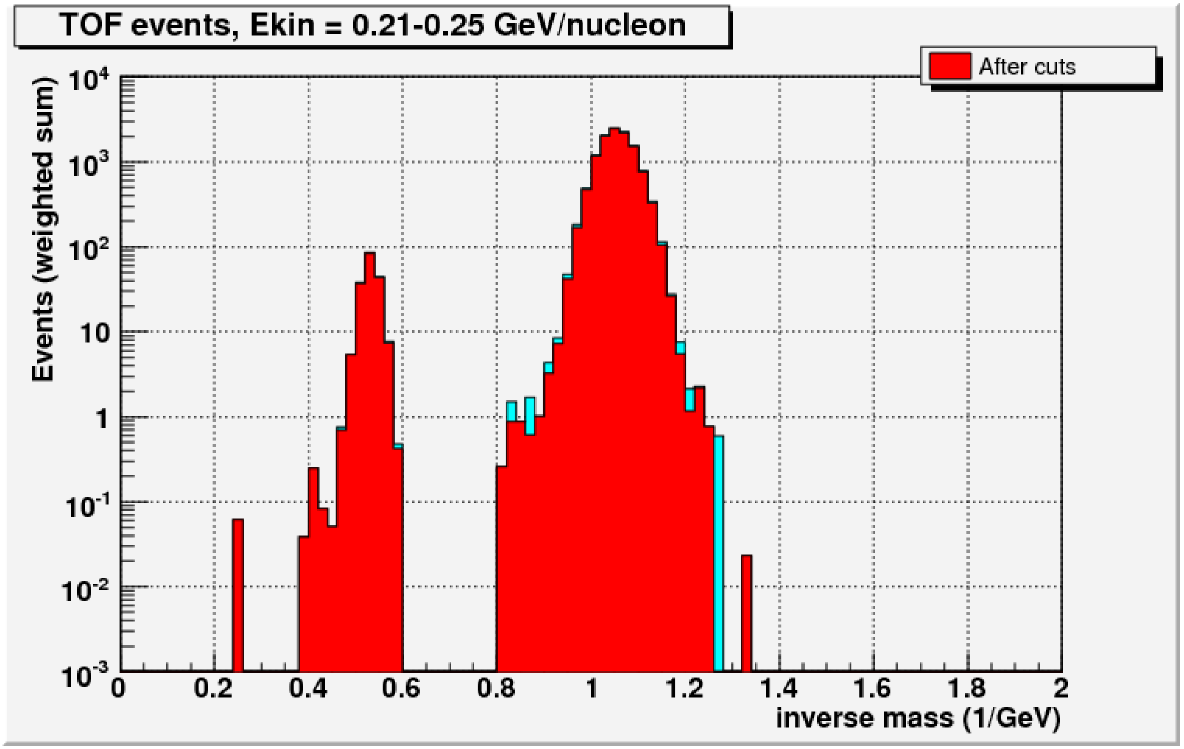
LIP analysis: rejection factor (NaF)

- Rejection factor for D/p in NaF > 10^2 for E_{kin} between 1 and 3 GeV
- Additional statistics also needed in this case



TOF mass reconstruction

- TOF data on velocity combined with rigidity data to find particle masses
- Extends mass reconstruction into the region of E_{kin} < 500 MeV (not accessible with RICH measurements)
- Mass distribution below is example only; analysis still to be done



Conclusions

- New analysis tools are available, still not fully explored
  - LIP charge reconstruction
  - 3-parameter β reconstruction
  - 5-parameter β reconstruction
  - Ring-hit distances
  - Impact point data
  - TOF mass reconstruction

- Quality of mass separation has improved
  - Evaluation of rejection factors limited by current statistics

Future work

- Future work will include:
  - Refinements on existing cuts to further improve mass separation
  - Possible second set of cuts
  - Further work on comparisons between particle signal and tracker data
  - Corrections to velocity bias in 3-, 5-parameter reconstructions
  - Study on feasibility of 5-parameter β reconstruction without Tracker hint
    - $\Rightarrow$ towards a true standalone reconstruction
  - TOF mass reconstruction
  - Higher statistics in analysis to get rid of rejection factor lower limits