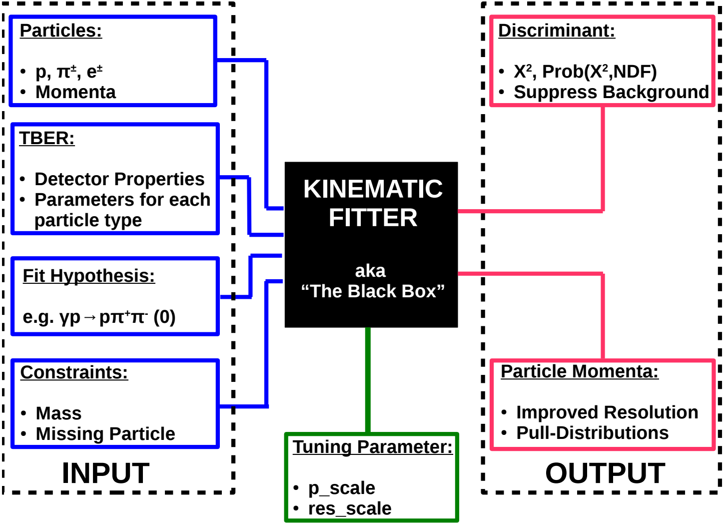
Investigation of the CLAS g12 Kinematic Fitter

Daniel Lersch

17.06.2016

Kinematic Fit: Basics



⇒ For much more detailed information please read (and understand) CLAS-NOTE on kinematic fitting, written by Dustin Kellner

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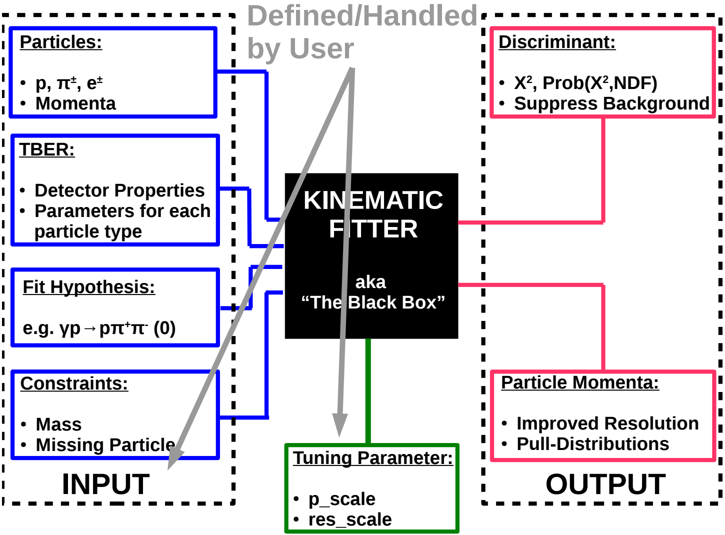

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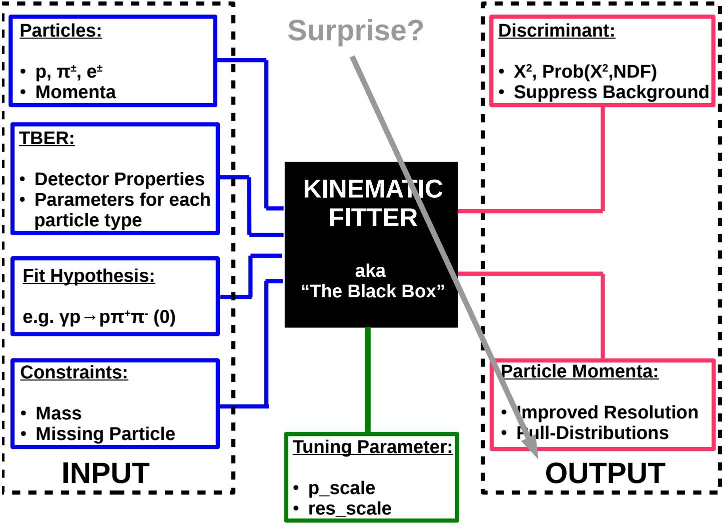

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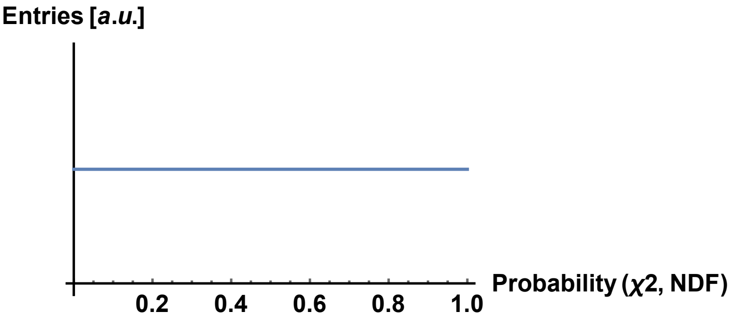
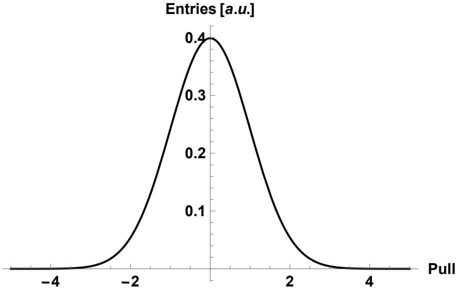
Performance of the Kinematic Fit: The Fit probability



- Least squares fit: $\chi^2 = \sum_{i=1}^{N_p} \sum_{j=1}^{N_v} \left(\frac{v_{ij}^{\mathbf{fit}} - v_{ij}^{\mathbf{meas}}}{\sigma_{ij}^{\mathbf{meas}}} \right)^2 + 2 \sum_{\mu} \lambda_\mu F_\mu (v_{11}^{\mathbf{fit}}, ..., v_{N_p N_v}^{\mathbf{fit}})$
- With:
  - v_{ij} measured/fitted variable j (e.g. angle) of particle i (e.g. proton)
  - $\sigma_{ij}^{\mathbf{meas}} \equiv$ TBER of variable j for particle i
  - F_μ: Constraints (e.g. energy and momentum conservation)
- $P(\chi^2, N) = \frac{1}{\sqrt{2^N \cdot \Gamma(\frac{1}{2} N)}} \int_{\chi^2}^{\infty} e^{-\frac{t}{2}} \cdot t^{\frac{1}{2} N - 1} dt$
- $P(\chi^2, N)$ should ideally (non-correlated variables, gaussian residuals) be flat

Performance of the Kinematic Fit: The Pull-Distribution



- $\mathrm{Pull}(v_{ij}) = \frac{v_{ij}^{\mathbf{meas}} - v_{ij}^{\mathbf{fit}}}{\sqrt{(\sigma_{ij}^{\mathbf{meas}})^2 - (\sigma_{ij}^{\mathbf{fit}})^2}}$
- Pull-Distribution should be gaussian with mean value μ and width σ

Scenario	Meaning
$\sigma = 1,\ \mu = 0$	Everything is fine

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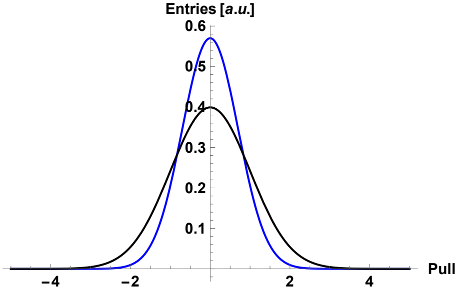

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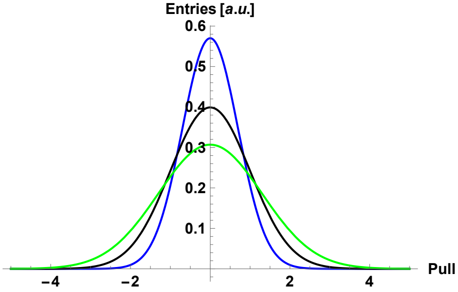

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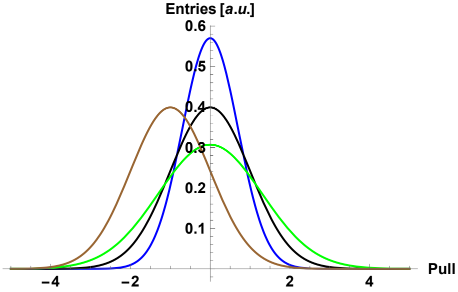

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$\mu \neq 0$	Systematic bias

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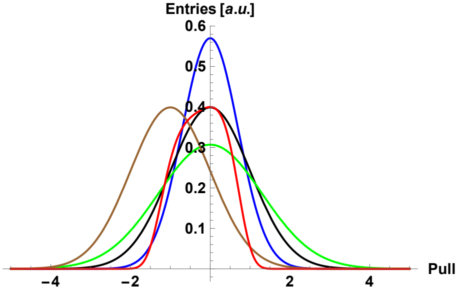

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$\mu \neq 0$	Systematic bias
Pull-Distr. has non gaussian shape	You might be in trouble

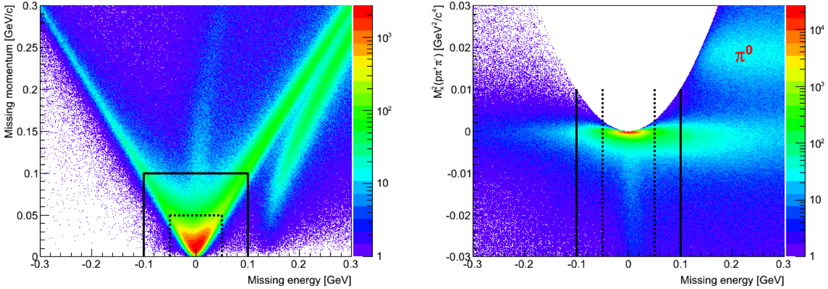
Performance and Tuning of the Kinematic Fit

Homework

- Tasks:
  - i) Investigate performance of the g12 kinematic fitter
  - ii) Tune fitter, if necessary (spoiler: it will be!), via adjusting p_scale and res_scale
- Questions related to task ii):
  - a) Will an adjustment/change of p_scale and res_scale affect the pull-distributions?
  - b) Are run-wise or global corrections necessary?
  - c) Does each reaction hypothesis require a different tuning?

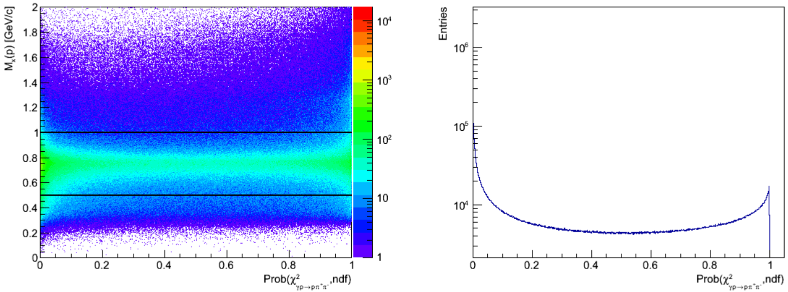
- For task i): Look at an exclusive (and abundant) reaction: $\gamma p \to p\pi^+\pi^-$
- Advantages:
  - All particles are reconstructed (take all information into account)
  - Maximum sensitivity with respect to changes (i.e. no constraints on missing particles/masses)
- Prerequisites:
  - Use g12 data set in Jülich (skimmed by M.C. Kunkel)
  - Applied g12 corrections
  - Default: p_scale = 1.94 and res_scale = 2.83

Reconstruction of $\gamma p \rightarrow p\pi^+\pi^-$: Check Energy and Momentum Balance



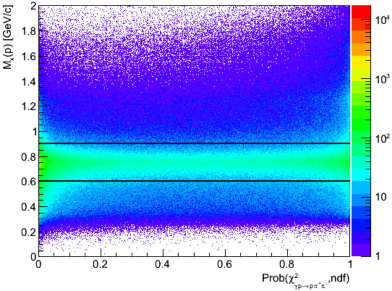
- Missing energy and missing momentum:
  - Missing momentum: $P_{miss} = |\vec{P}_{in} - \vec{P}_{out}|$
  - Missing energy: $E_{miss} = E_{in} - E_{out}$
  - Shape might be parameterised by: $P_{miss} = \sqrt{(E_{miss} + \delta)^2 + M}$
- Use tight box cut to select events only with charged particles in the final state
- Remark: This cut should used with caution in a "regular" analysis

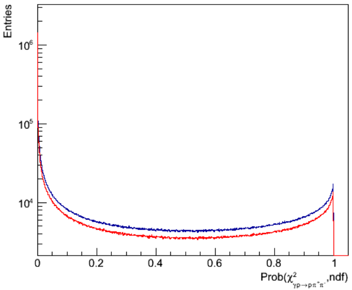
Reconstruction of $\gamma p \to p\pi^+\pi^-$: The Kinematic Fit Probability



- Look at $M_x(p)$ vs. the kinematic fit probability
- Do a projection onto the X-axis for different missing mass windows:
  - Inspect shape of probability distribution $\to$ not flat
  - Recheck event selection $\to$ Is there a contamination from other reaction channels?

Reconstruction of $\gamma p \rightarrow p\pi^+\pi^-$: The Kinematic Fit Probability





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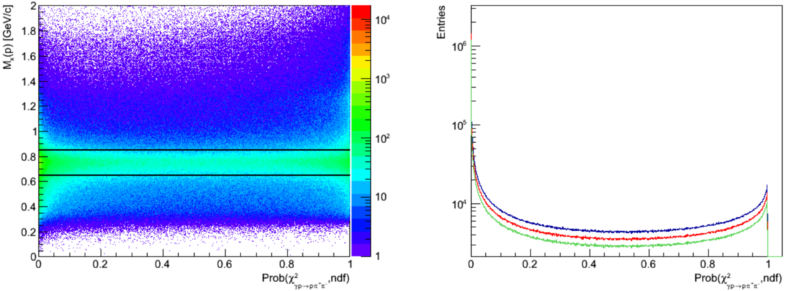

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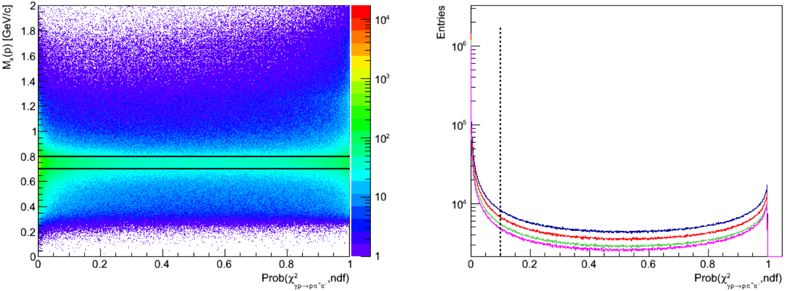

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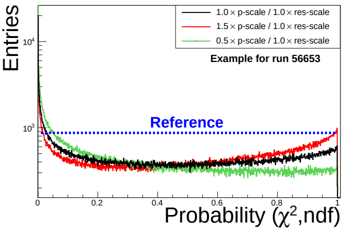
⇒ Probability distributions have same (non-flat) shape for values > 0.1

Tuning the Kinematic Fit to $\gamma p \rightarrow p\pi^+\pi^-$: Idea

I) Sensitivity



Tuning performed via: p_scale $\mapsto$ p_scale $\times f_p$ and res_scale $\mapsto$ res_scale $\times f_{res}$

1.) Set $f_{res} = 1$ and $f_p = 1 \pm 0.5$ (red/green curve in left figure)

2.) Calculate deviation from flat prob. dist.:

$$\delta(f_p) \equiv \frac{\int_{0.01}^{1.0} [\text{Prob. dist}(f_p) - \text{Reference}]dx}{\int \text{Prob. dist}(f_p)dx}$$

3.) Determine impact imp_p of f_p with respect to δ: $imp_p \equiv \delta(f_p = 1.5) - \delta(f_p = 0.5)$

4.) Repeat steps 1.) - 3.) for res_scale respectively

II) Adjustment of p_scale and res_scale

5.) Change f_p and f_{res} after each iteration i:

- $f_p(i+1) = \left[1 + \frac{\delta(f_p(i))}{imp_p}\right] \cdot f_p(i)$ with: $f_p(0) = 1$
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- It turned out that 9 iterations are sufficient
- Apply this method of each run within the g12 Jülich data set
  → Analyse several runs in parallel
  → Obtain run dependent correction

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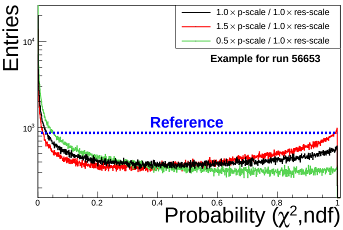

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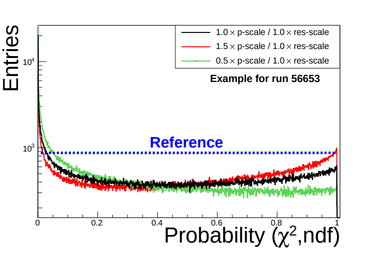

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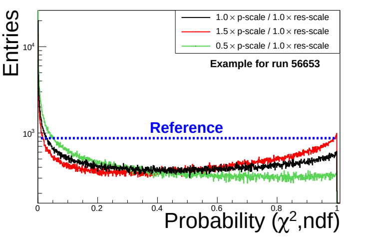

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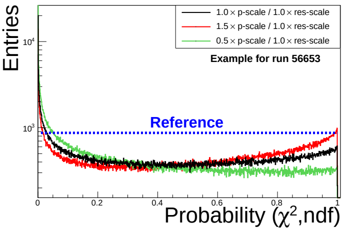

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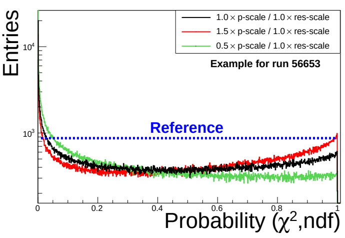

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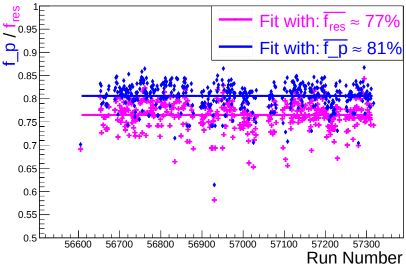
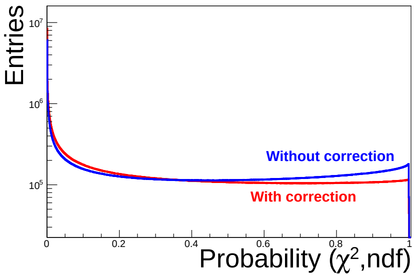
Tuning of the Kinematic Fit to $\gamma p \rightarrow p\pi^+\pi^-$: Results

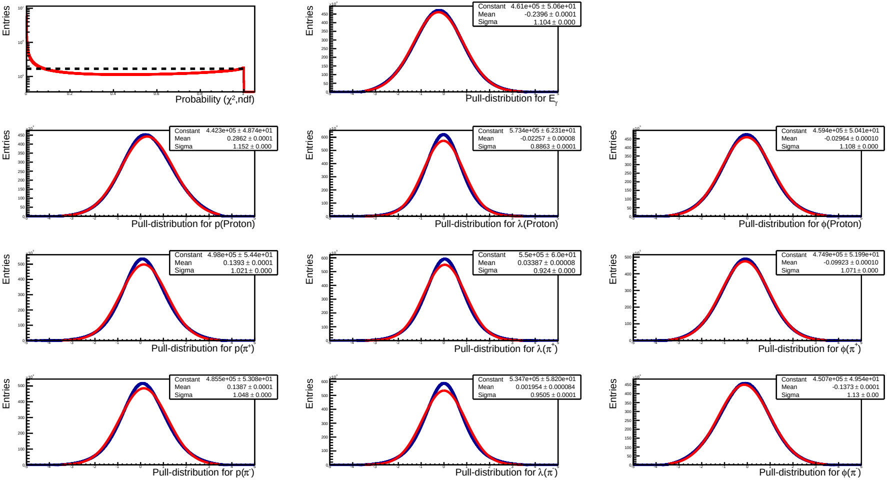




- Applied run-wise correction (see left figure)
  - Effect on the probability distribution is shown in the right figure
  - Calculated global correction factors (discussed in 5 slides)
- Next step: Pull-Distributions for Prob ≥ 0.01

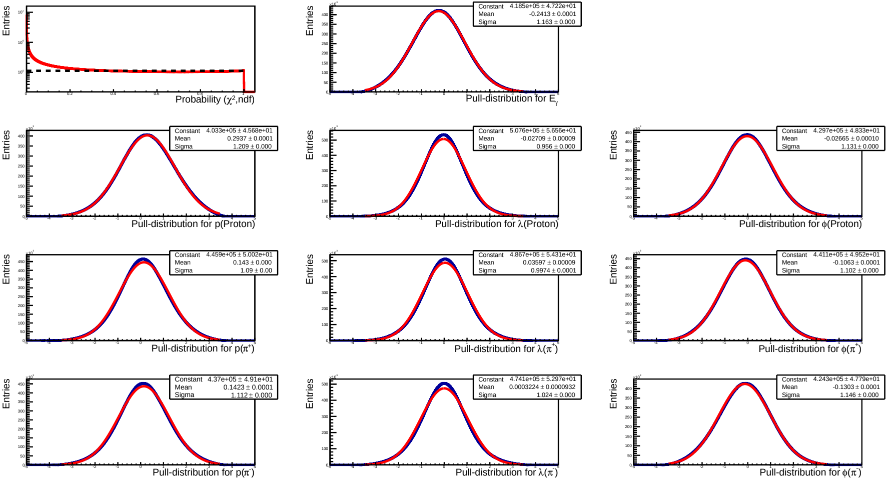
Tuning of the Kinematic Fit to $\gamma p \rightarrow p\pi^+\pi^-$: Pull-Distributions

No run-wise correction applied



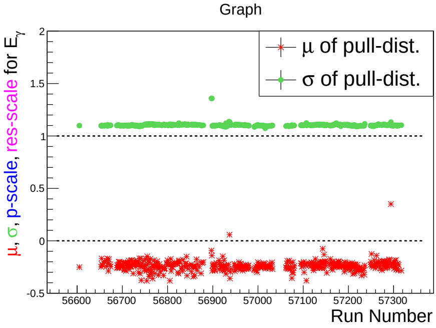
Tuning of the Kinematic Fit to $\gamma p \to p\pi^+\pi^-$: Pull-Distributions

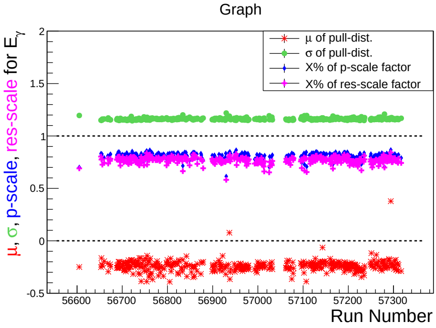
Run-wise correction applied



Tuning of the Kinematic Fit to $\gamma p \rightarrow p\pi^+\pi^-$

Detailed Example: Pull-Distributions for E_γ

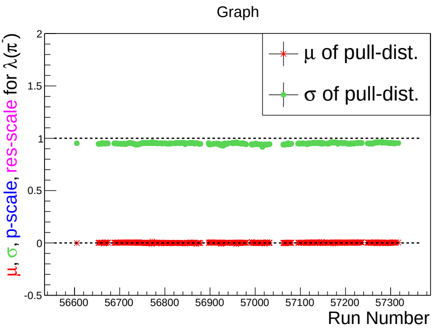


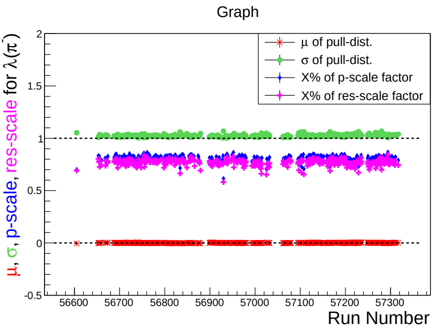


- Left: without run-wise correction
- Right: with run-wise correction (excluding low statistic runs)
- Low statistics runs are grouped into clusters

Tuning of the Kinematic Fit to $\gamma p \rightarrow p\pi^+\pi^-$

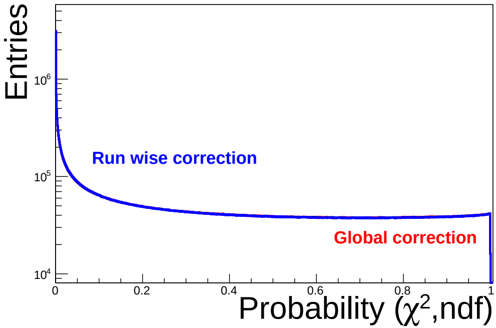
Detailed Example: Pull-Distributions for $\lambda(\pi^-)$





- Left: without run-wise correction
- Right: with run-wise correction
  (excluding low statistic runs)
- More fun with pull-distributions: see backup slides!

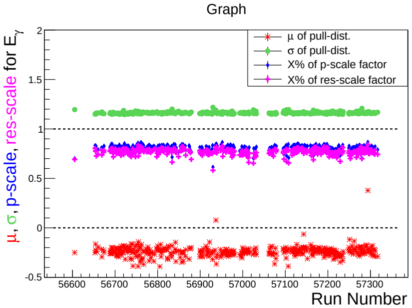
Tuning of the Kinematic Fit to $\gamma p \rightarrow p\pi^+\pi^-$: Global Corrections - The Probability Distribution

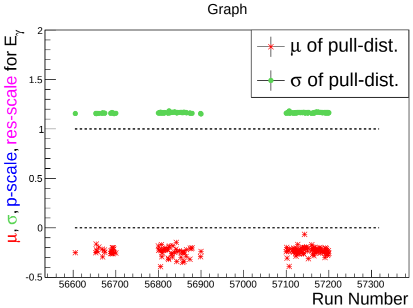


- **Average correction factor(s) for p_scale:** 0.81 **and for res_scale:** 0.77
- Blue curve: Run/Cluster wise correction
  (only 36% of the total data shown here)
- Red curve: (under blue curve) Average correction factors
  (only 36% of the total data shown here

Tuning of the Kinematic Fit to $\gamma p \rightarrow p\pi^+\pi^-$: Global Corrections - Pull-Distributions

For E_γ

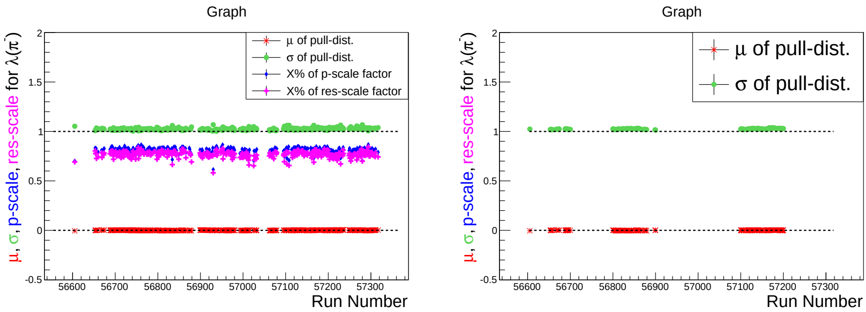




- **Average correction factor(s) for p_scale:** 0.81 **and for res_scale:** 0.77
- Left: Run/Cluster wise correction
- Right: Average correction factors (only 36% of the total data shown here)

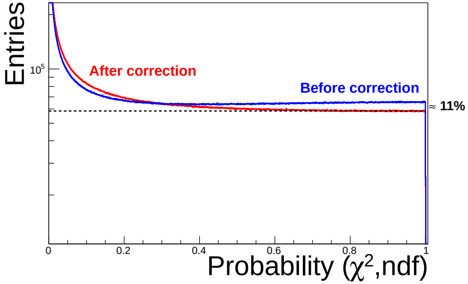
Tuning of the Kinematic Fit to $\gamma p \to p\pi^+\pi^-$: Global Corrections - Pull-Distributions

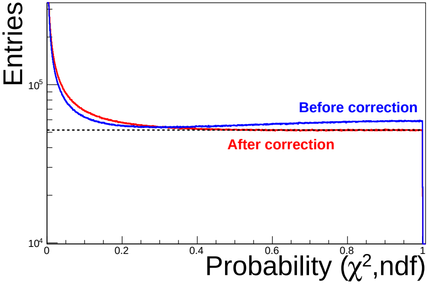
For $\lambda(\pi^-)$



- **Average correction factor(s) for p_scale:** 0.81 **and for res_scale:** 0.77
- Left: Run/Cluster wise correction
- Right: Average correction factors (only 36% of the total data shown here)

Other Channels before/after Tuning





- Left: probability distribution for $\gamma p \to p\pi^+(\pi^-)$ with / without global correction
- Right: probability distribution for $\gamma p \to \pi^+\pi^-(p)$ with / without global correction
- Corresponding pull-distributions (see backup slides) show no significant change (i.e. comparing σ/μ before/after tuning)
- Checked tuning (i.e. pull- and prob.- distributions) also for the reaction hypotheses:
  - i) $\gamma p \to p\pi^-(\pi^+)$ (see backup slides)
  - ii) $\gamma p \to p\pi^+\pi^-(\gamma)$
  - iii) $\gamma p \to p\pi^+\pi^-(\pi^0)$ (see backup slides)

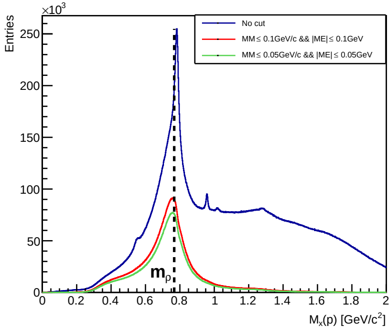
Summary and Outlook

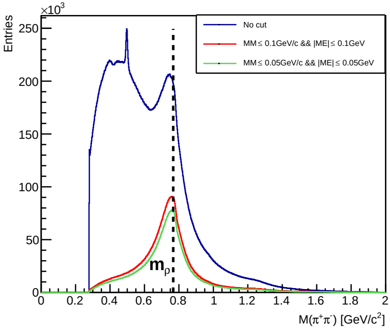
☑ Homework

- Tasks:
  - i) Investigate performance of the g12 kinematic fitter
    ⇒ Done via exclusive $\gamma p \rightarrow p\pi^+\pi^-$
  - ii) Tune fitter, if necessary, via adjusting p_scale and res_scale
    ⇒ Tuning was necessary and done via method presented on slide 8
- Questions related to task ii):
  - a) Will an adjustment/change of p_scale and res_scale affect the pull-distributions?
    ⇒ Yes, in the order of: $\Delta\sigma \lesssim 10\%$ and $\Delta\mu \lesssim 5\%$
  - b) Are run-wise or global corrections necessary?
    ⇒ Global corrections are sufficient
  - c) Does each reaction hypothesis require a different tuning?
    ⇒ Well, the new p_scale and res_scale values are suitable for all channels including protons and pions

- Extracted (global) correction factors for p_scale and res_scale from run-wise correction:
  - **Old p_scale value:** 1.94 → **New p_scale value:** 1.5714
  - **Old res_scale value:** 2.83 → **New res_scale value:** 2.1791
- Next/Ongoing steps:
  - i) Qualitative judgement of Pull-Distributions: Include skewness and kurtosis
  - ii) Check g12 Kinematic Fitter for leptons
  - iii) Check/Tune g12 Kinematic Fitter for Simulations

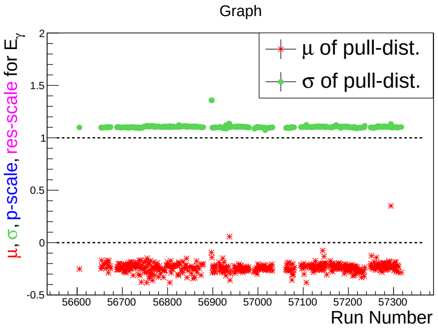
Backup: Reconstruction of $\gamma p \to p\pi^+\pi^-$: Missing Mass and Invariant Mass

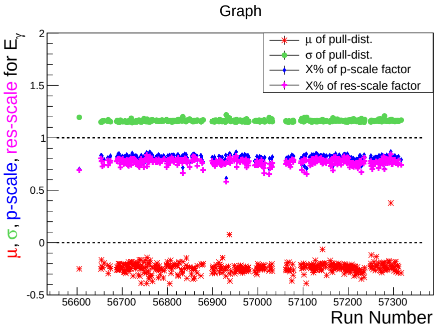




- Invariant mass of final state pions and proton missing mass have same shape
  $\Rightarrow$ Indication of proper event selection
- Next step: Look at probability distribution

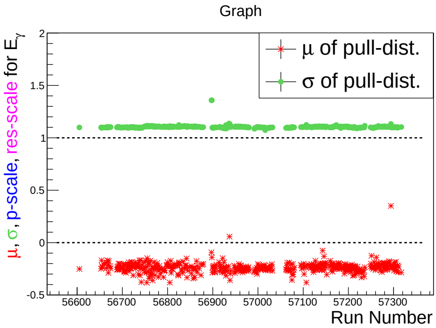
Backup: Pull-distributions for E_γ

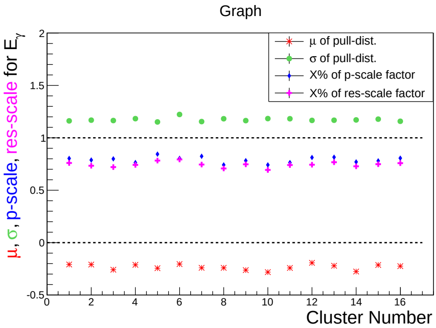




- Left: without run-wise correction
- Right: with run-wise correction (excluding low statistic runs)

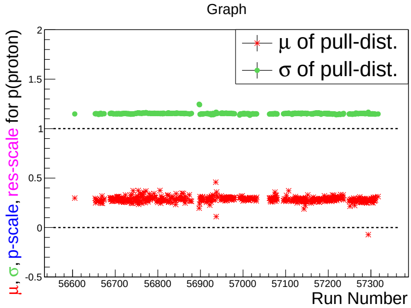
Backup: Pull-distributions for E_γ

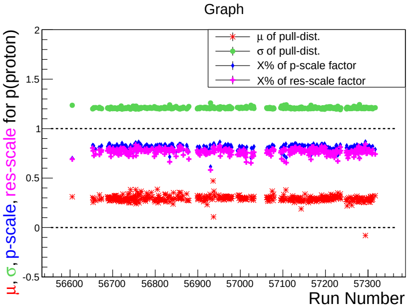




- Left: without run-wise correction
- Right: with run-wise correction
  (Grouping low statistic runs into clusters)

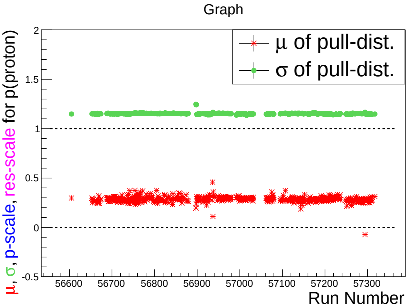
Backup: Pull-distributions for $p(p)$

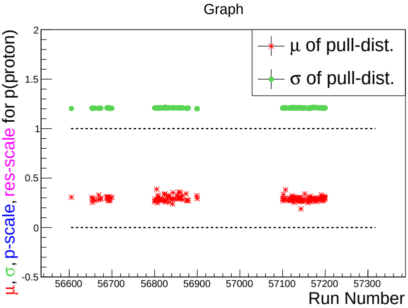




- Left: Without corrections
- Right: With run wise corrections and clustering

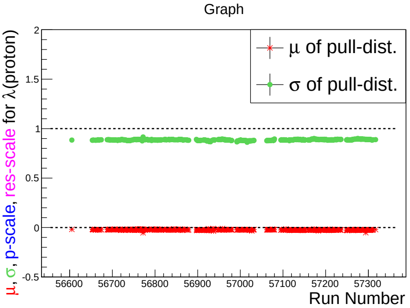
Backup: Pull-distributions for $p(p)$

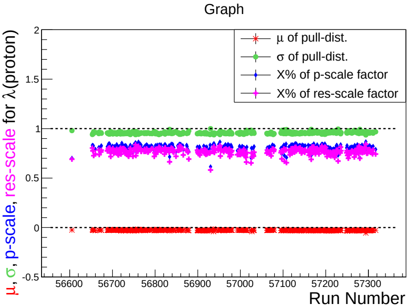




- Left: Without corrections
- Right: With global corrections

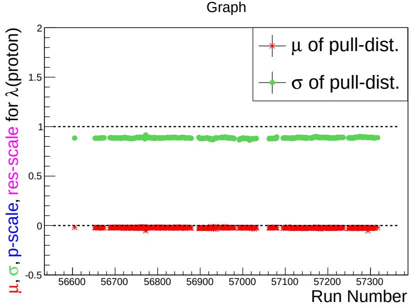
Backup: Pull-distributions for $\lambda(p)$

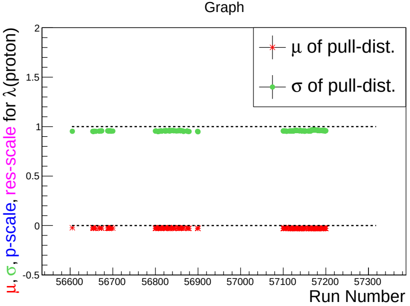




- Left: Without corrections
- Right: With run wise corrections and clustering

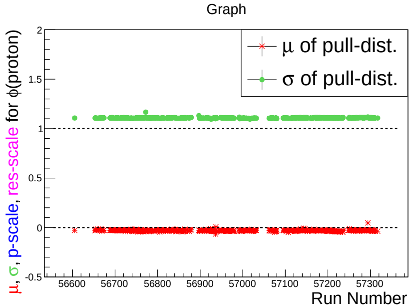
Backup: Pull-distributions for $\lambda(p)$

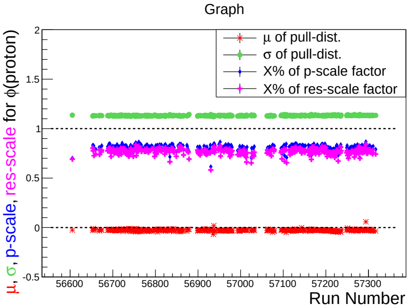




- Left: Without corrections
- Right: With global corrections

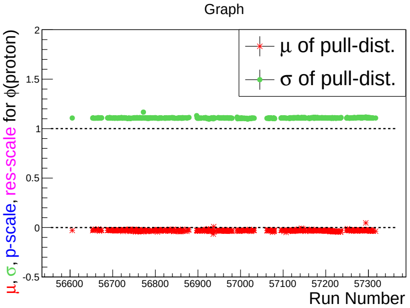
Backup: Pull-distributions for $\phi(p)$

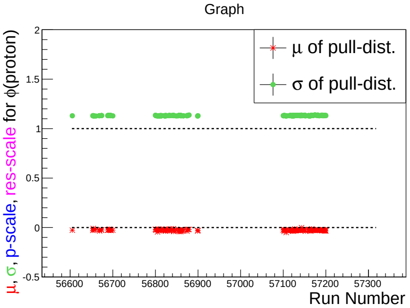




- Left: Without corrections
- Right: With run wise corrections and clustering

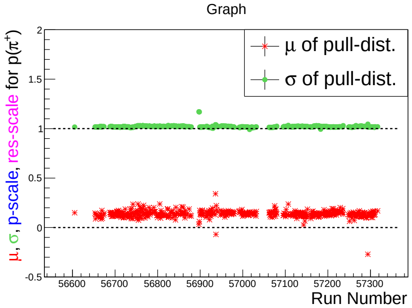
Backup: Pull-distributions for $\phi(p)$

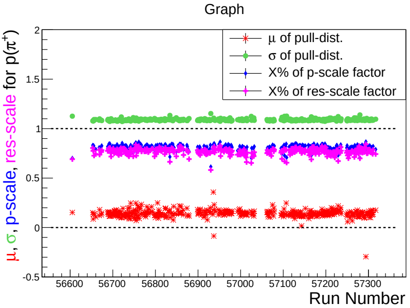




- Left: Without corrections
- Right: With global corrections

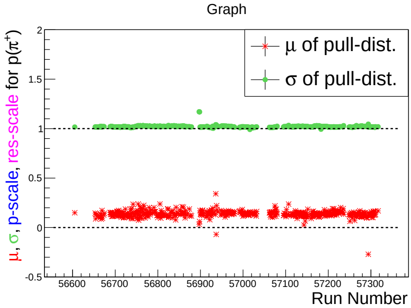
Backup: Pull-distributions for $p(\pi^+)$

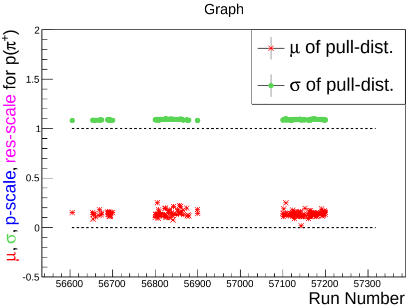




- Left: Without corrections
- Right: With run wise corrections and clustering

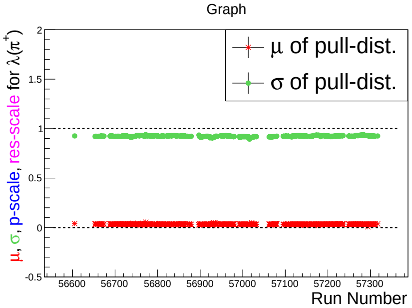
Backup: Pull-distributions for $p(\pi^+)$

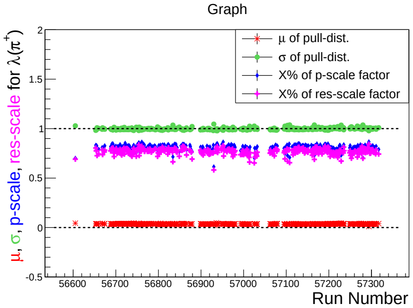




- Left: Without corrections
- Right: With global corrections

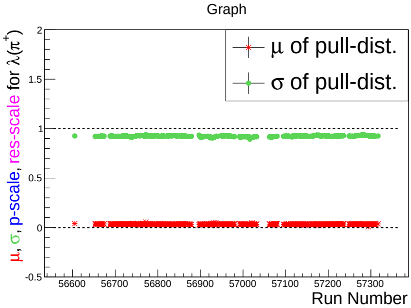
Backup: Pull-distributions for $\lambda(\pi^+)$

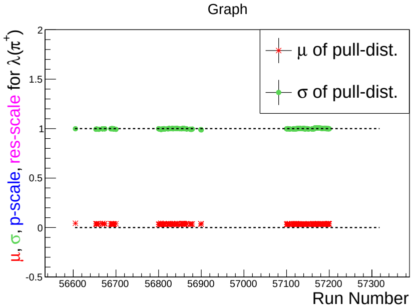




- Left: Without corrections
- Right: With run wise corrections and clustering

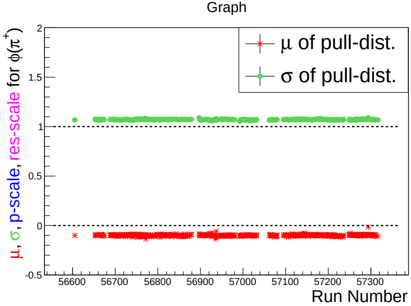
Backup: Pull-distributions for $\lambda(\pi^+)$

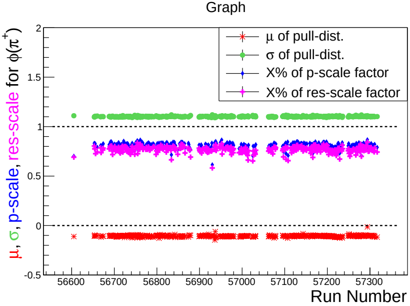




- Left: Without corrections
- Right: With global corrections

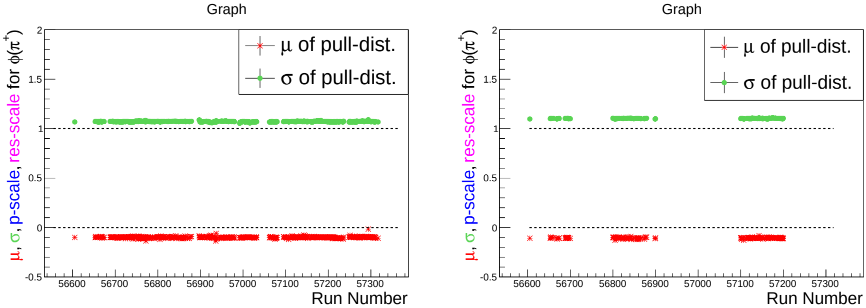
Backup: Pull-distributions for $\phi(\pi^+)$





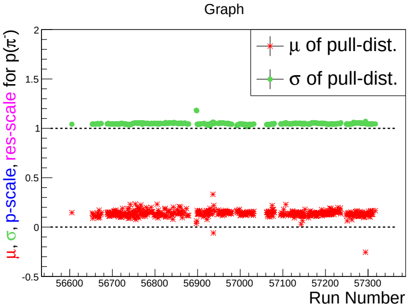
- Left: Without corrections
- Right: With run wise corrections and clustering

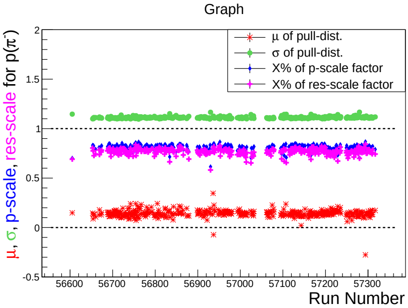
Backup: Pull-distributions for $\phi(\pi^+)$



- Left: Without corrections
- Right: With global corrections

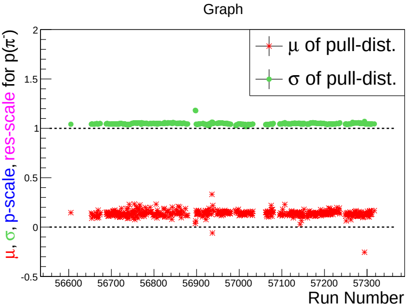
Backup: Pull-distributions for $p(\pi^-)$

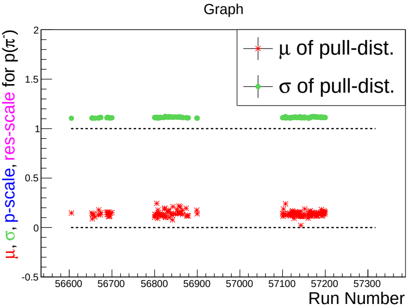




- Left: Without corrections
- Right: With run wise corrections and clustering

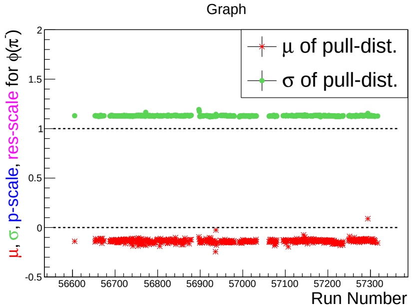
Backup: Pull-distributions for $p(\pi^-)$

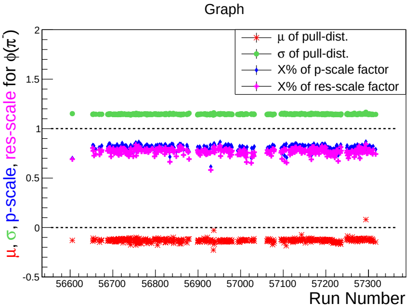




- Left: Without corrections
- Right: With global corrections

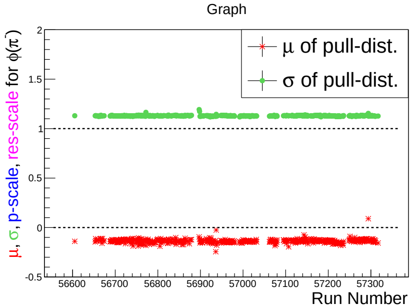
Backup: Pull-distributions for $\phi(\pi^-)$

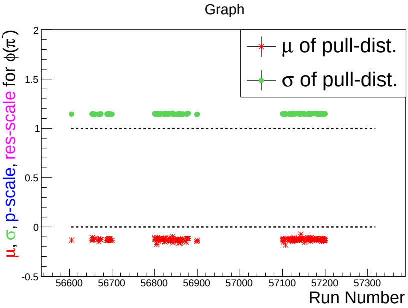




- Left: Without corrections
- Right: With run wise corrections and clustering

Backup: Pull-distributions for $\phi(\pi^-)$

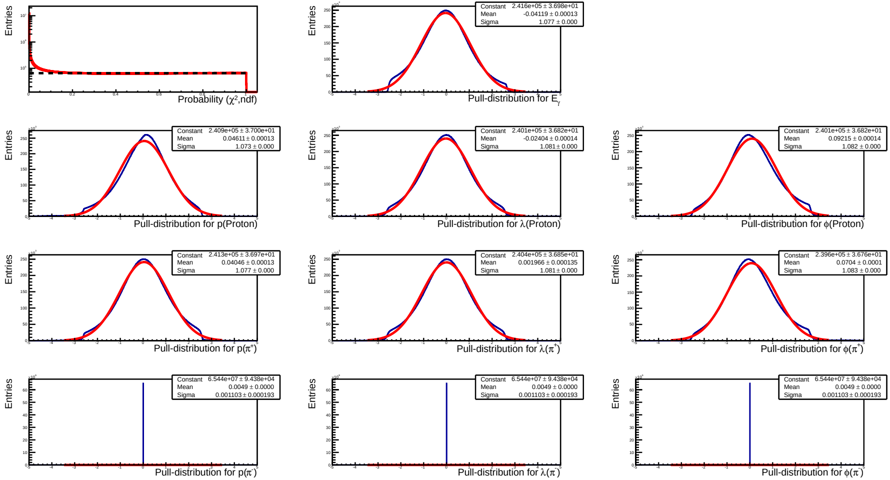




- Left: Without corrections
- Right: With global corrections

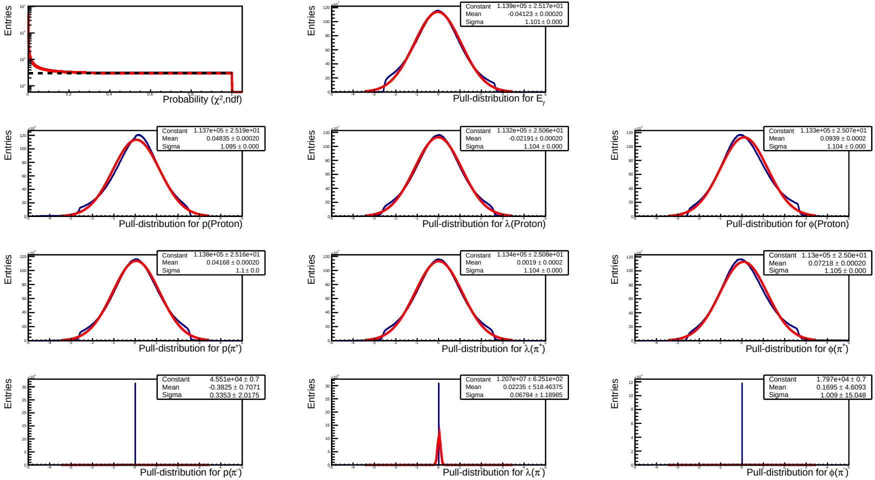
Backup: $\gamma p \rightarrow p\pi^+(\pi^-)$: with/without correction

No correction



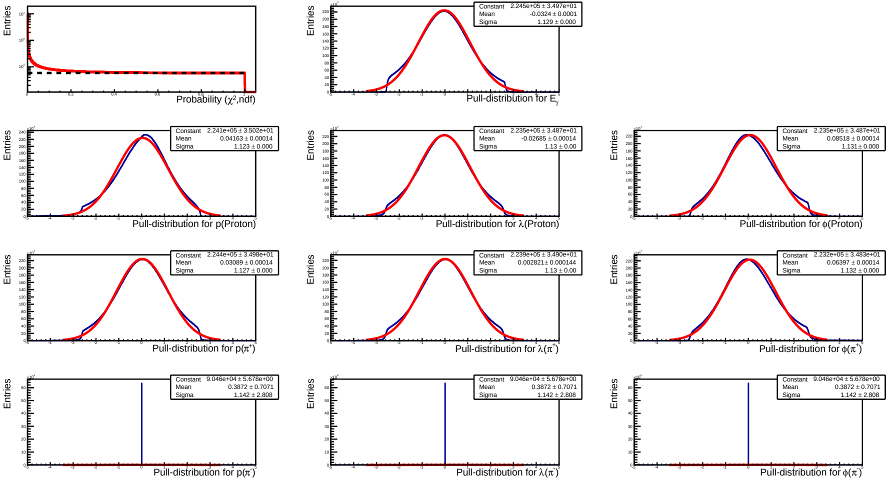
Backup: $\gamma p \rightarrow p\pi^+(\pi^-)$: with/without correction

Run wise correction



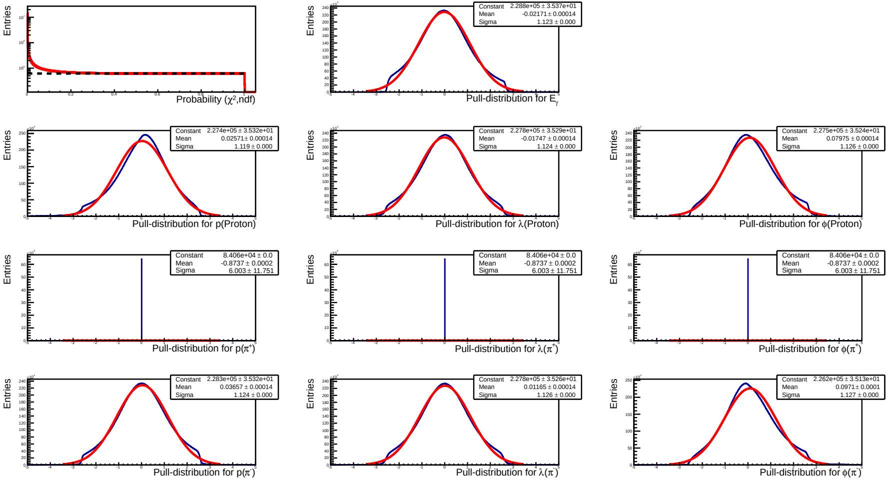
Backup: $\gamma p \rightarrow p\pi^+(\pi^-)$: with/without correction

Global correction



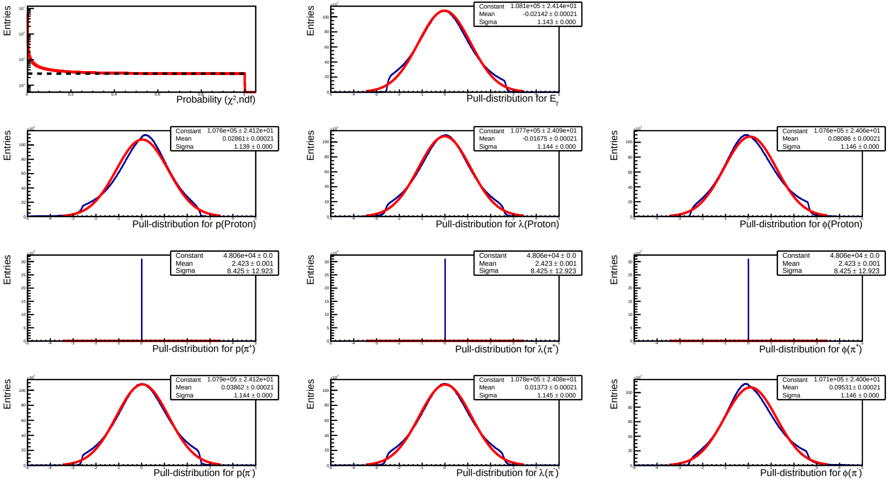
Backup: $\gamma p \rightarrow p\pi^-(\pi^+)$: with/without correction

No correction



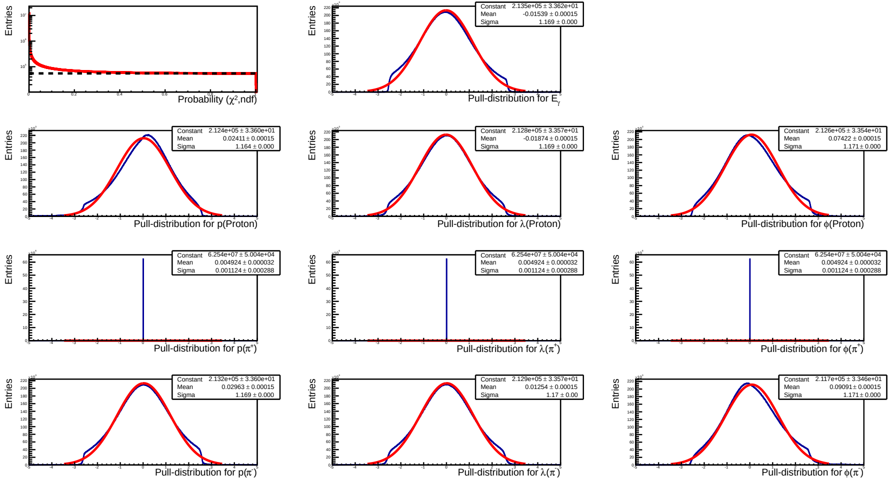
Backup: $\gamma p \to p\pi^-(\pi^+)$: with/without correction

Run wise correction



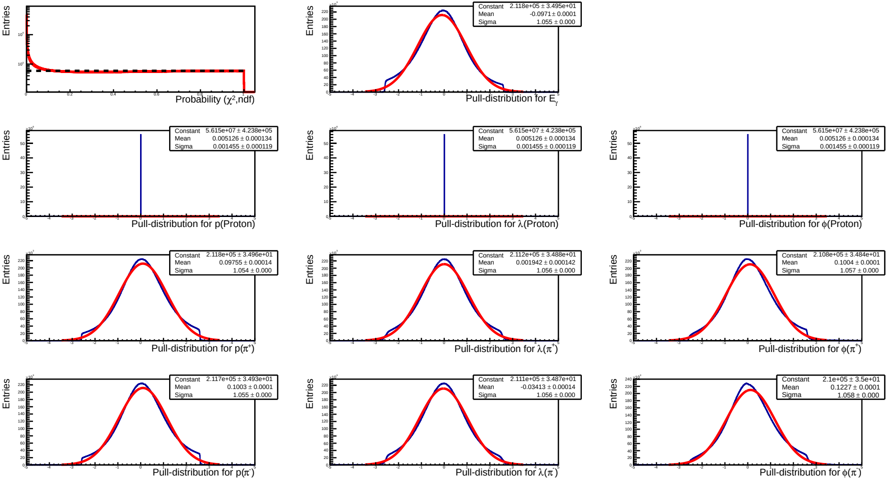
Backup: $\gamma p \to p\pi^-(\pi^+)$: with/without correction

Global correction



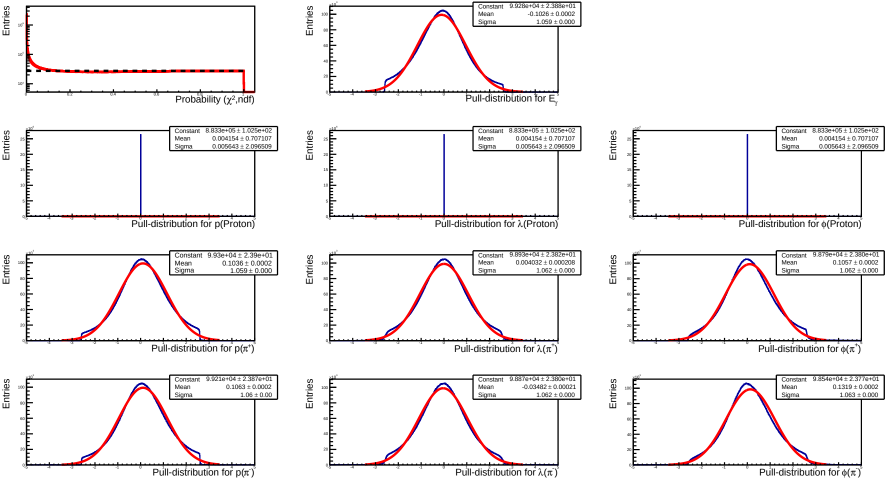
Backup: $\gamma p \to \pi^+\pi^-(p)$: with/without correction

No correction



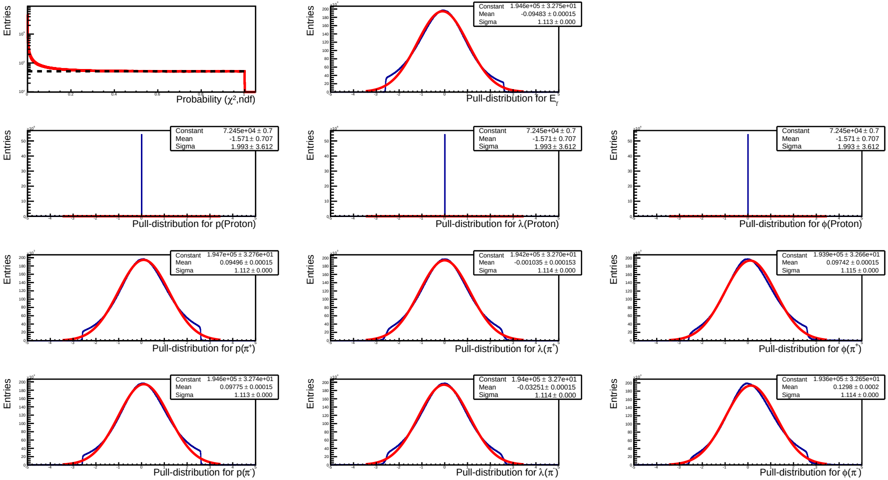
Backup: $\gamma p \rightarrow \pi^+\pi^-(p)$: with/without correction

Run wise correction



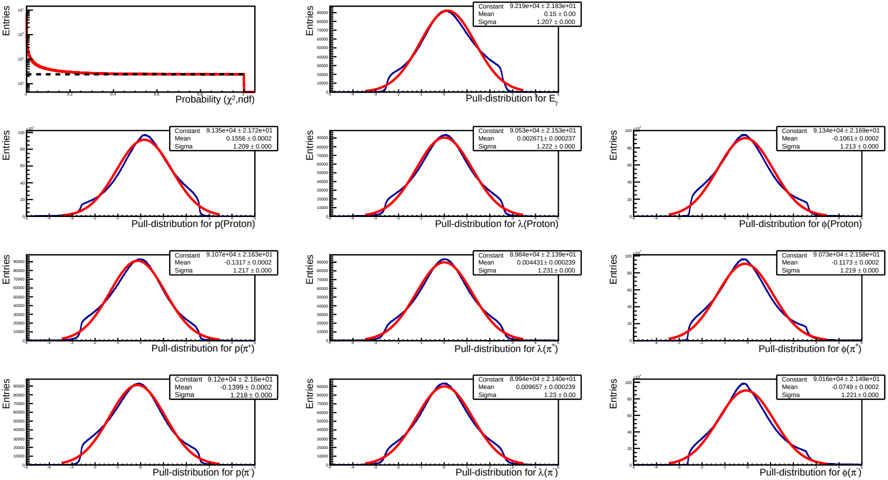
Backup: $\gamma p \rightarrow \pi^+\pi^-(p)$: with/without correction

Global correction



Backup: $\gamma p \rightarrow p\pi^+\pi^-(\pi^0)$: with/without correction

No correction



Backup: $\gamma p \rightarrow p\pi^+\pi^-(\pi^0)$: with/without correction

Run wise correction