Luminosity analysis for KLOE HVP

Niels Vestergaard 12/01/2026 - Muon group meeting

Motivation and background

Measure luminosity using the KLOE detector with very large angle Bhabha events (VLAB) and calculate the relevant systematics associated with luminosity. This is especially important for the cross check of the $\mu^+\mu^-\gamma$ cross section

The total integrated luminosity can be found by:

$$\int \mathscr{L} dt = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\sigma_{\text{eff}}}$$

where N_{obs} is the number of events, N_{bkg} is the number of background events and σ_{eff} is obtained with the MC generator Babayaga interfaced with GEANFI for the detector response

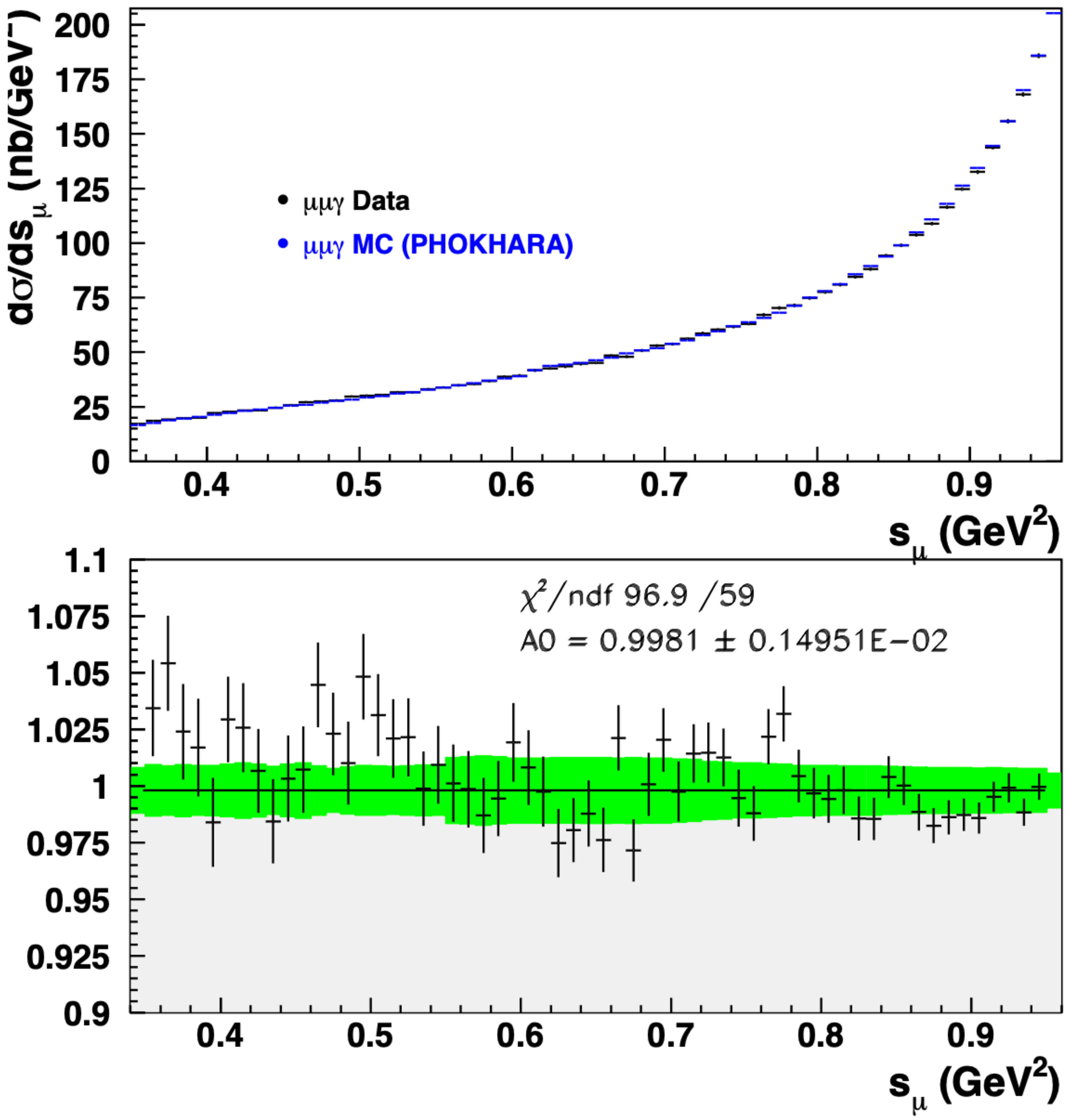
Motivation and background

The main advantages of this method are:

- The high theoretical accuracy by which the process is known
- The clean event topology of the signal
- The high statistics available due the the very large cross section, even at large polar angles ($\sigma \approx 430$ nb at $45^\circ < \theta_e < 125^\circ$)

Motivation and background

Compare total cross section of $\mu^+\mu^-\gamma$ with the QED MC prediction using the Monte Carlo generator Phokara, as seen by this plot from the KLOE12 analysis



Previous KLOE Luminosity study

In 2006, a note (KLOE Note 202 by A. Denig and F. Nguyen) and a paper (Measurement of the DAΦNE luminosity with the KLOE detector using large angle Bhabha scattering) was released using 2001 data

As a starting point, everything is done following the methods of KN202 closely with regards to the relevant systematics as well as cuts used for selecting VLAB events. The major difference is the use of 2002 data as well as the MC sample using Babayaga NLO whereas KN202 used Babayaga 3.5

Relevant systematics studied in KN202

	correction (%)	systematic error (%)
acceptance	$\delta_{accept} = +0.25$	$\Delta_{accept} = 0.25$
tracking	–	$\Delta_{track} = 0.06$
clustering	$\delta_{split} = +0.14$	$\Delta_{cluster} = 0.11$
background	$\delta_{bkg} = -0.55$	$\Delta_{bkg} = 0.08$
cosmic veto	$\delta_{cosmic} = +0.40$	–
dependence on $\sqrt{s}$	$\delta_{\sqrt{s}} = +0.10$	$\Delta_{\sqrt{s}} = 0.10$
E_{clu} drifts	–	$\Delta_{E_{clu}} = 0.10$
Total experimental	$\boldsymbol{\delta_{tot} = +0.34}$	$\boldsymbol{\Delta_{tot} = 0.32}$

Table 1: *Summary of the different corrections and systematic errors in the measurement of the luminosity by* `VLAB` *events. In the case of the acceptance correction we decided to quote a systematic error equal to the correction, to be conservative. The correction and the uncertainties related to the dependence on $\sqrt{s}$ and to the drifts in the cluster energy should be regarded as average values.*

Dataset and initial selection of Bhabha events

DATA: Selected using the offline background filter "FILFO" using only calorimeter information

MC: Produced using the MC generator Babayaga NLO

At least two clusters in the event with the following conditions:

1) Energy of 240 MeV $< E_{clu} < 800$ MeV

2) $r_{xy} > 65$ cm, where $r_{xy} = \sqrt{x^2_{\text{clu1}} + y^2_{\text{clu2}}}$

3) $|t_{\text{clu1}} - t_{\text{clu2}}| < 4$ ns

4) $d > 200$ cm, where

$$d = \sqrt{(x_{\text{clu1}} - x_{\text{clu2}})^2 + (y_{\text{clu1}} - y_{\text{clu2}})^2 + (z_{\text{clu1}} - z_{\text{clu2}})^2}$$

Produces $e^+e^- \to e^+e^-(\gamma)$ with $35 < \theta_e < 145$ taking input from the database about $\sqrt(s)$ and other machine parameters to match a given run

LAB-selection

Initial large angle selection is done using only calorimeter information:

1) At least two calorimeter clusters with an energy 300 MeV $< E_{clu} < 800$ MeV

2) For all pairs of clusters fulfilling the energy requirement, the polar angle acollinearity $\zeta = |\theta_{\text{clu1}} + \theta_{\text{clu2}} - 180^\circ|$ is calculated. The pair of clusters minimising ζ is chosen, and $\zeta_{\text{min}} < 10^\circ$ is required

3) These two clusters must satisfy the time cut $|t_{\text{clu1}} - t_{\text{clu2}}| < 4$ ns

4) Both clusters have to be located at large polar angles $45^\circ < \theta_{\text{clu}} < 135^\circ$

5) An additional cut on the three-dimensional angle between the two clusters is applied: $\cos(\alpha) > -0.975$, where $\cos(\alpha) = \dfrac{\vec{r}_{\text{clu1}} \cdot \vec{r}_{\text{clu2}}}{|\vec{r}_{\text{clu1}}||\vec{r}_{\text{clu2}}|}$. This cut has been introduced to reject $e^+e^- \rightarrow \gamma\gamma$ events, which are completely back-to-back

6) At least 50 hits in the DC have to be present: $N_{\text{hits}} \geq 50$

VLAB-selection

Further selection includes information from the DC and further tightens the EmC cuts

1) For the two tracks tr1 and tr2, with the largest number of associated hits to the tracks we require the track's point-of-closest approach to the origin (PCA) to be close to the interaction point: $\sqrt{x_{\text{pca}}^2 + y_{\text{pca}}^2} < 7.5$ cm and $|z_{\text{pca}}| < 15$cm

2) If d is the spatial distance between the first hits of tr1 and tr2 we require $d > 50$ cm. This cut rejects a contamination from the process $e^+e^- \to \gamma\gamma \to \gamma e^+e^-$, where the e^+e^- pair in the final state results from photon conversion.

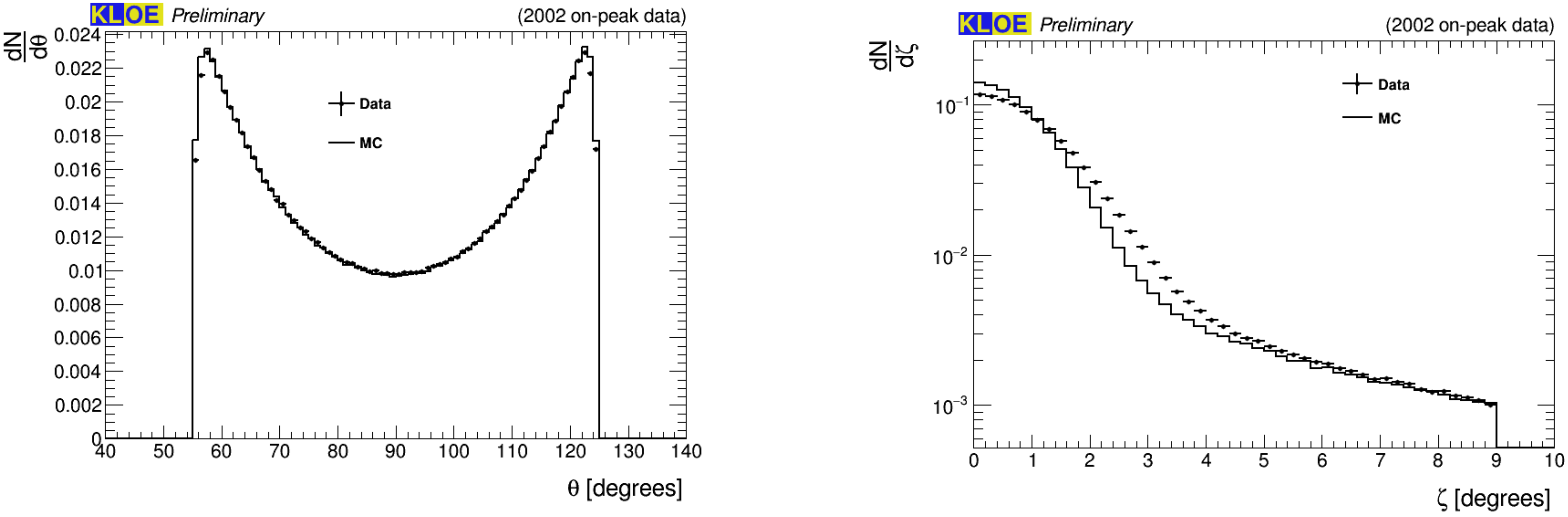
3) The two selected tracks tr1 and tr2 are required to have opposite signs of curvature.

4) For both tracks the momentum cut $p \equiv |p| \geq 400$ MeV is applied.

5) For the two clusters preselected by the LAB filter a tighter cut on the polar angle is applied: $55^\circ < \theta < 125^\circ$

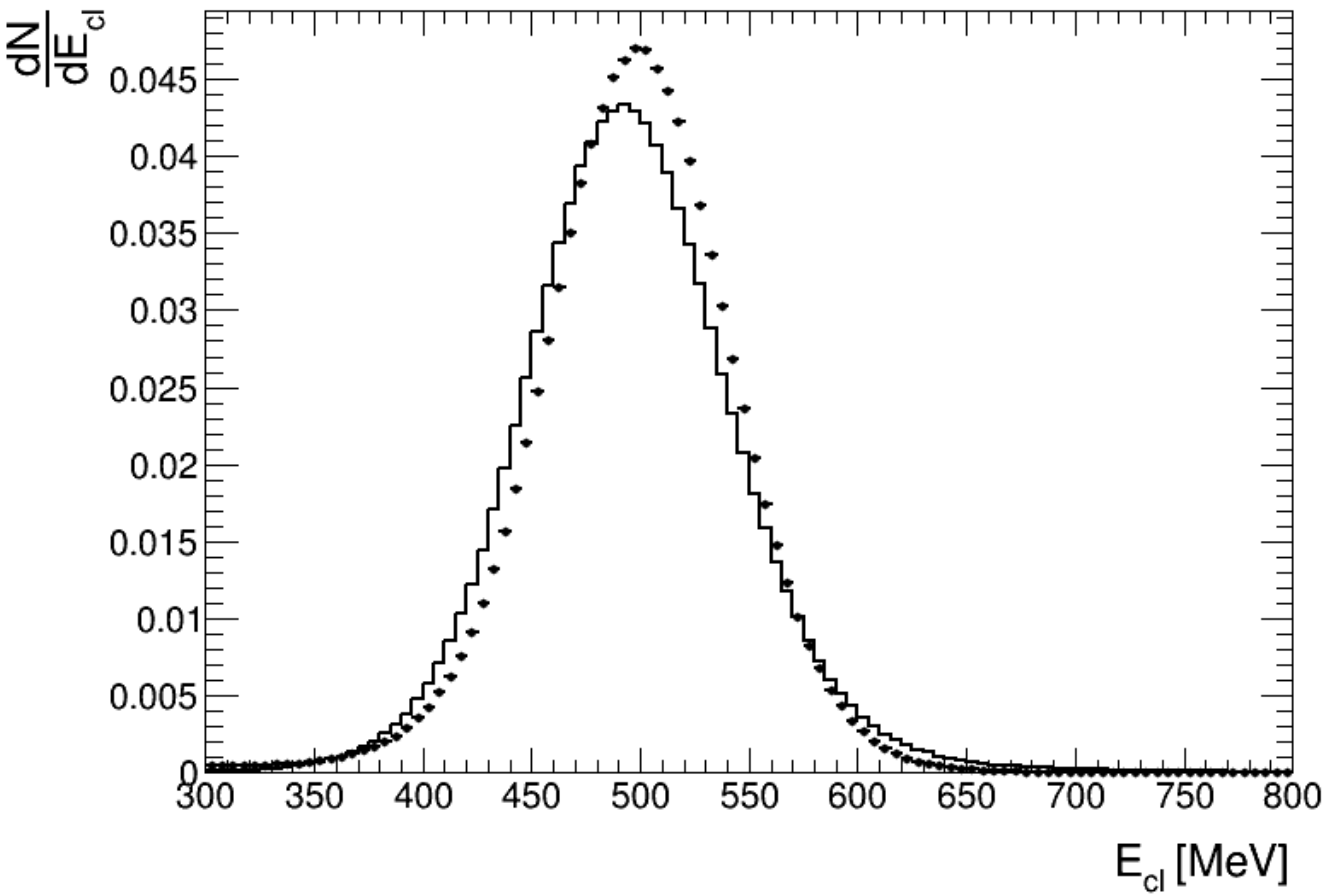
6) Also the cut on the polar angle acollinearity for the two LAB cluster is further tightened: $\zeta < 9^\circ$

Calorimeter plots

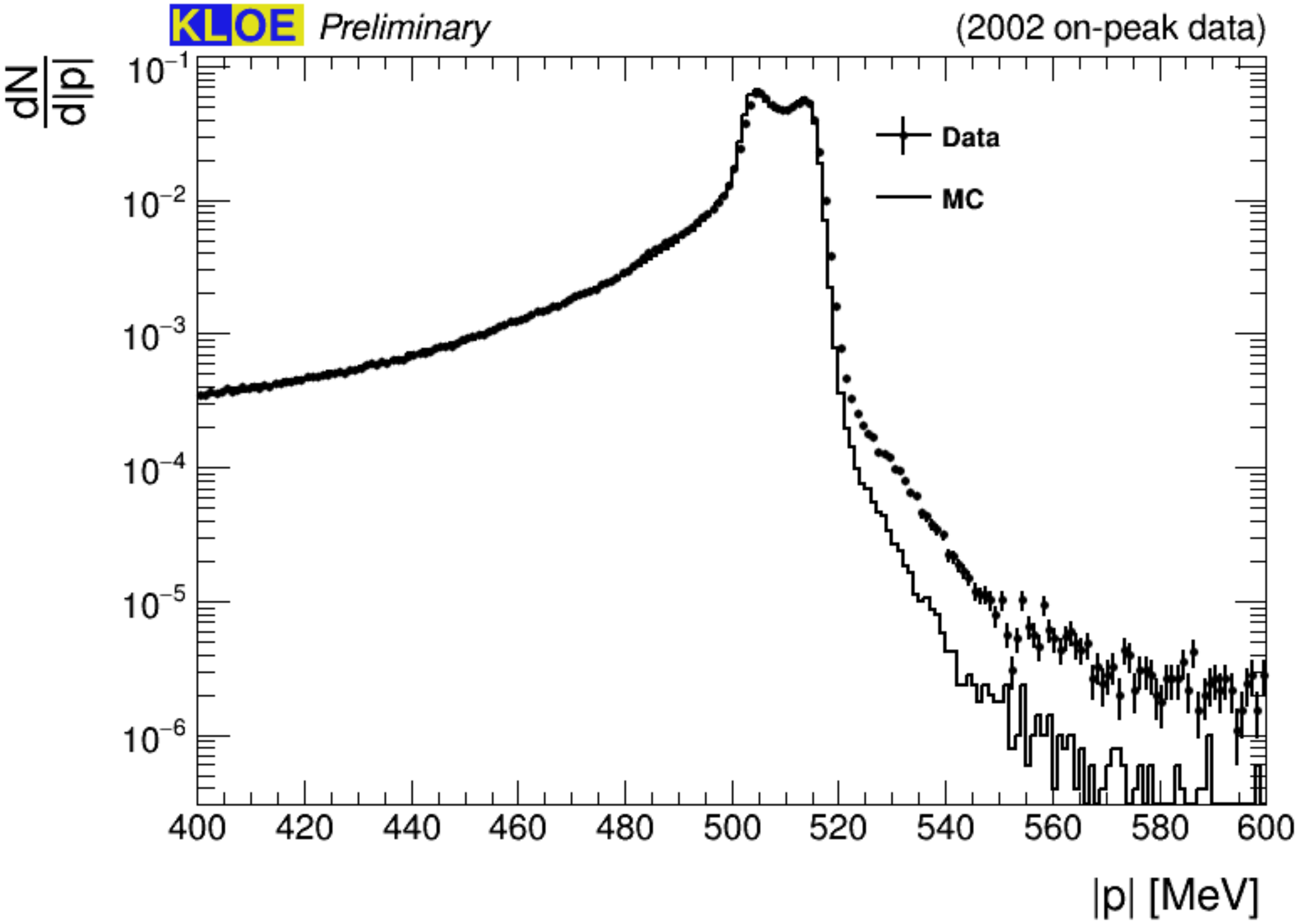


Work currently in progress to smear MC to match resolution of data

Difference in energy of clusters



Tracks



KLOE Preliminary
(2002 on-peak data)
$\frac{dN}{d|p|}$
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
Data
MC
400
420
440
460
480
500
520
540
560
580
600
|p| [MeV]

Background subtraction

Two separate methods are used to subtract background from signal:

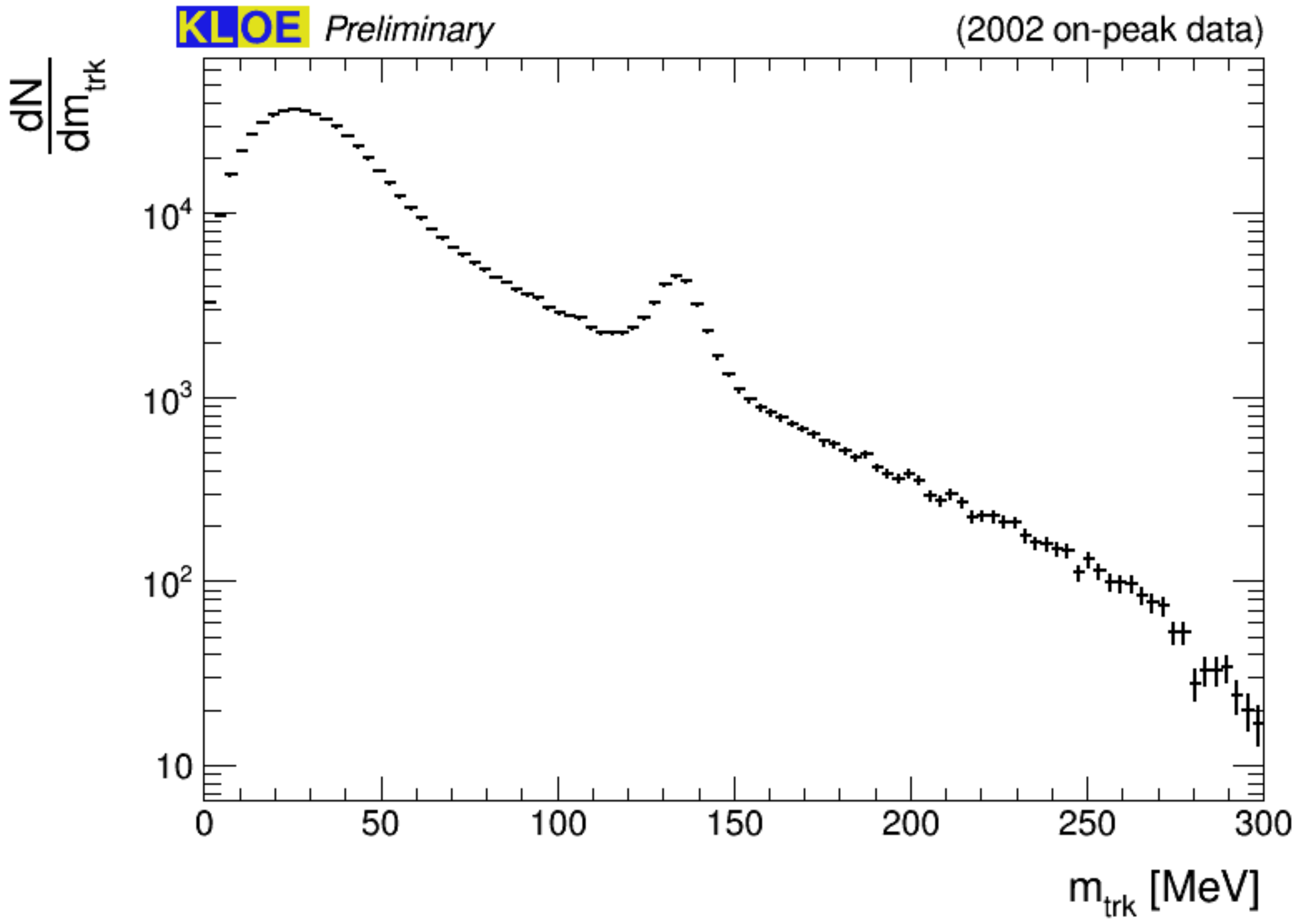
Approach 1: Fit the trackmass (m_{trk}) spectrum in the range [100,170] MeV with a function consisting of a Gaussian (background) plus and exponential function (signal), assuming the background gives rise to a Gaussian background.

$$\left(\sqrt{s} - \sqrt{|\mathbf{p}_+|^2 + \mathbf{M}^2_{\text{trk}}} - \sqrt{|\mathbf{p}_-|^2 + \mathbf{M}^2_{\text{trk}}}\right)^2 - (\mathbf{p}_+ + \mathbf{p}_-)^2 = 0$$

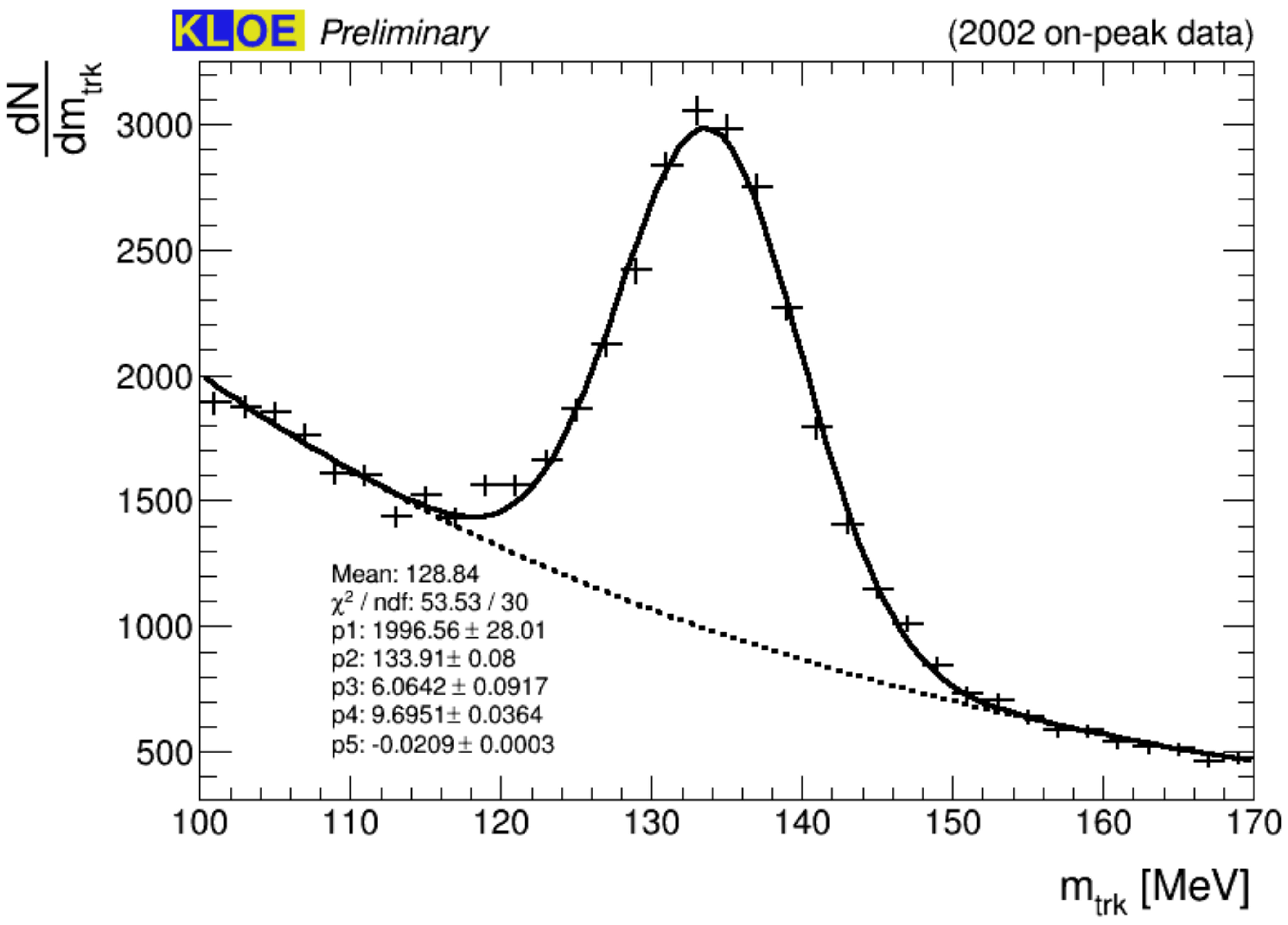
Approach 2: Use the likelihood PID variable in KLOE to discriminate pions from electrons on an event-by-event basis. Pion events are defined as events where at least one track has been identified as a pion (logrl > 0)

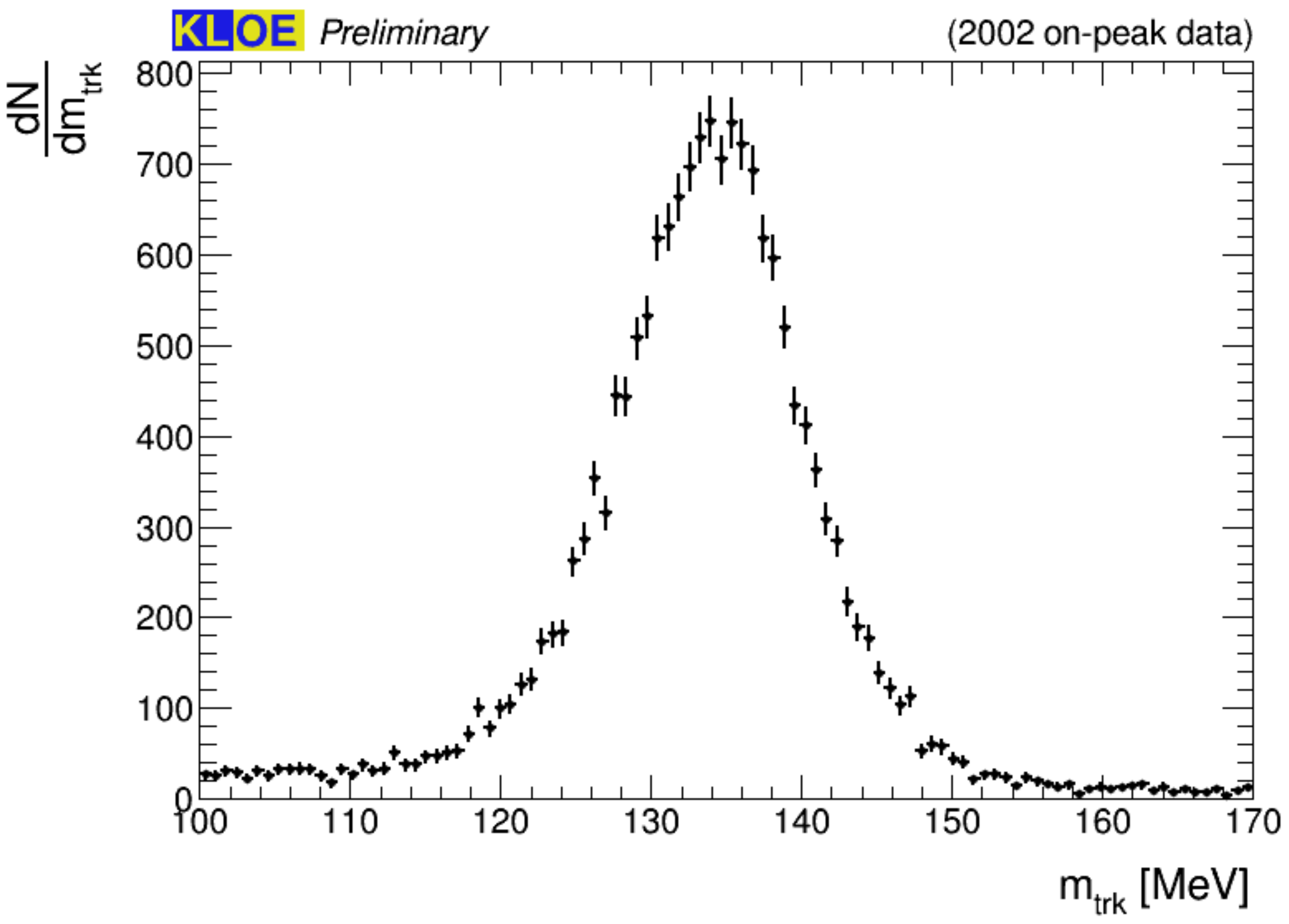
Background subtraction

Peak at $m_{\text{trk}} \approx 135$ MeV associated with collinear $\pi^+\pi^-$



Background subtraction





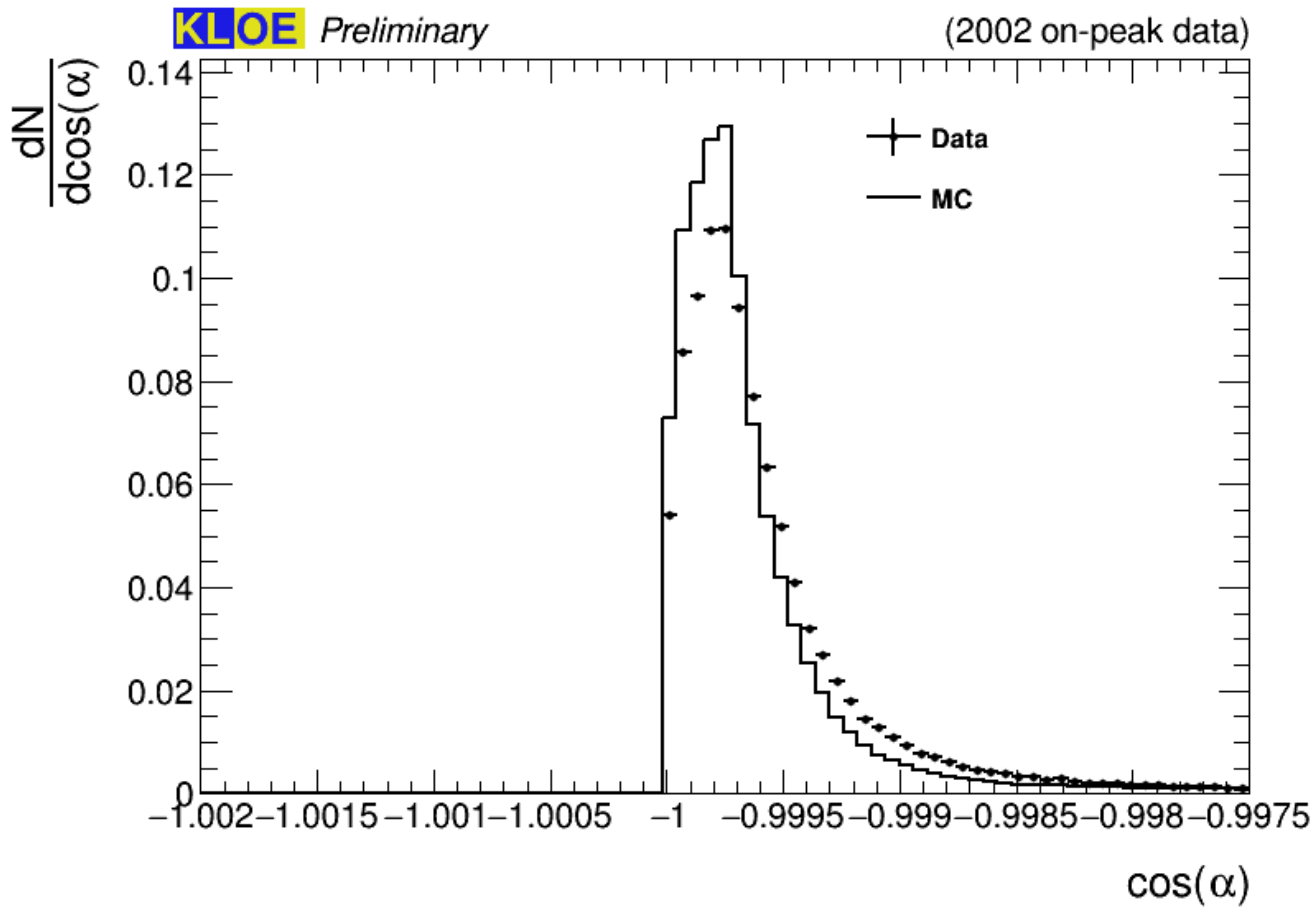
$$N_{bkg} = (0.665 \pm 0.005)\,\%$$

$$N_{bkg} = (0.763 \pm 0.006)\,\%$$

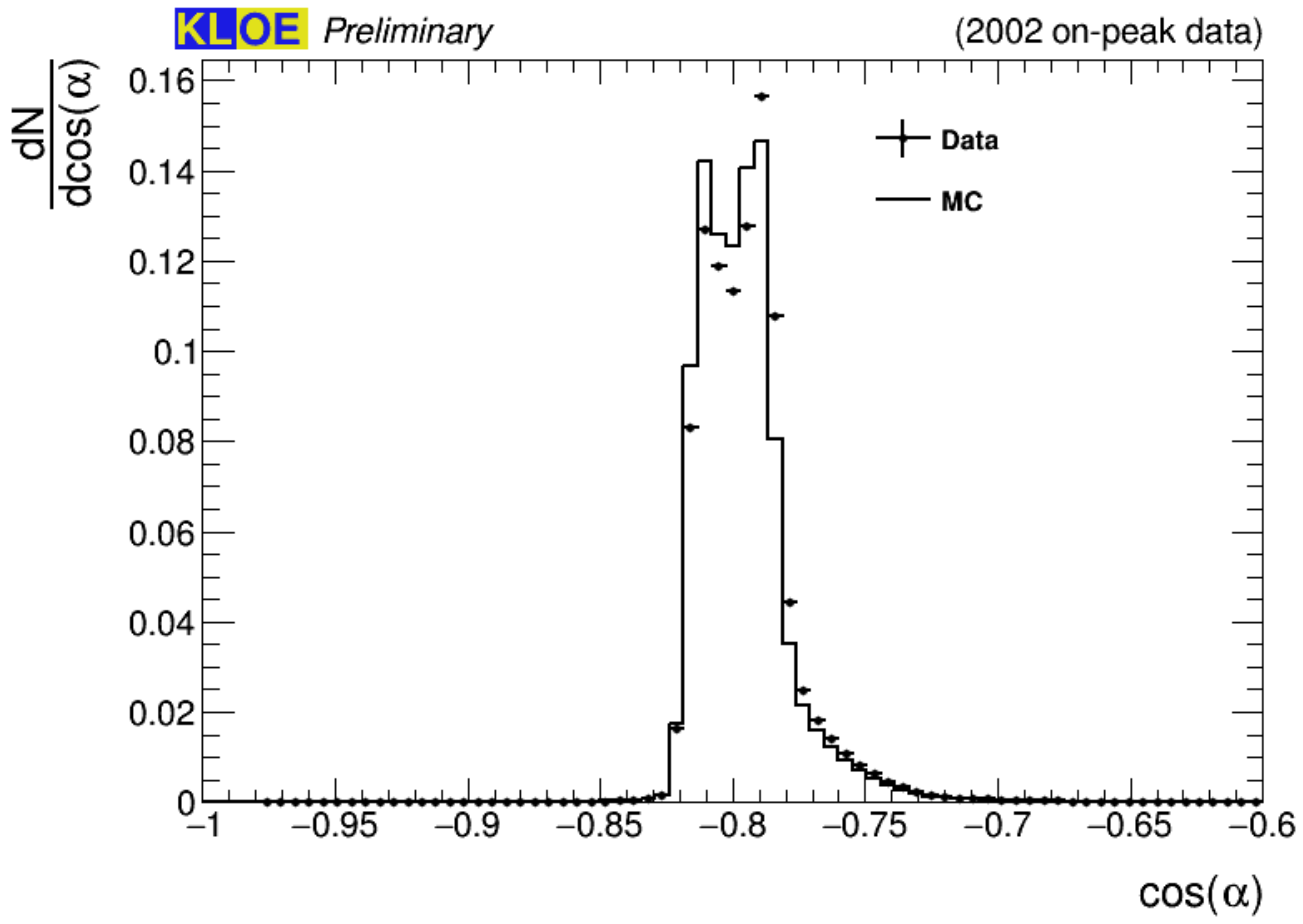
Cross check using $e^+e^- \to \gamma\gamma$

Well separated in $\cos(\alpha)$ and number of tracks

$\gamma\gamma$

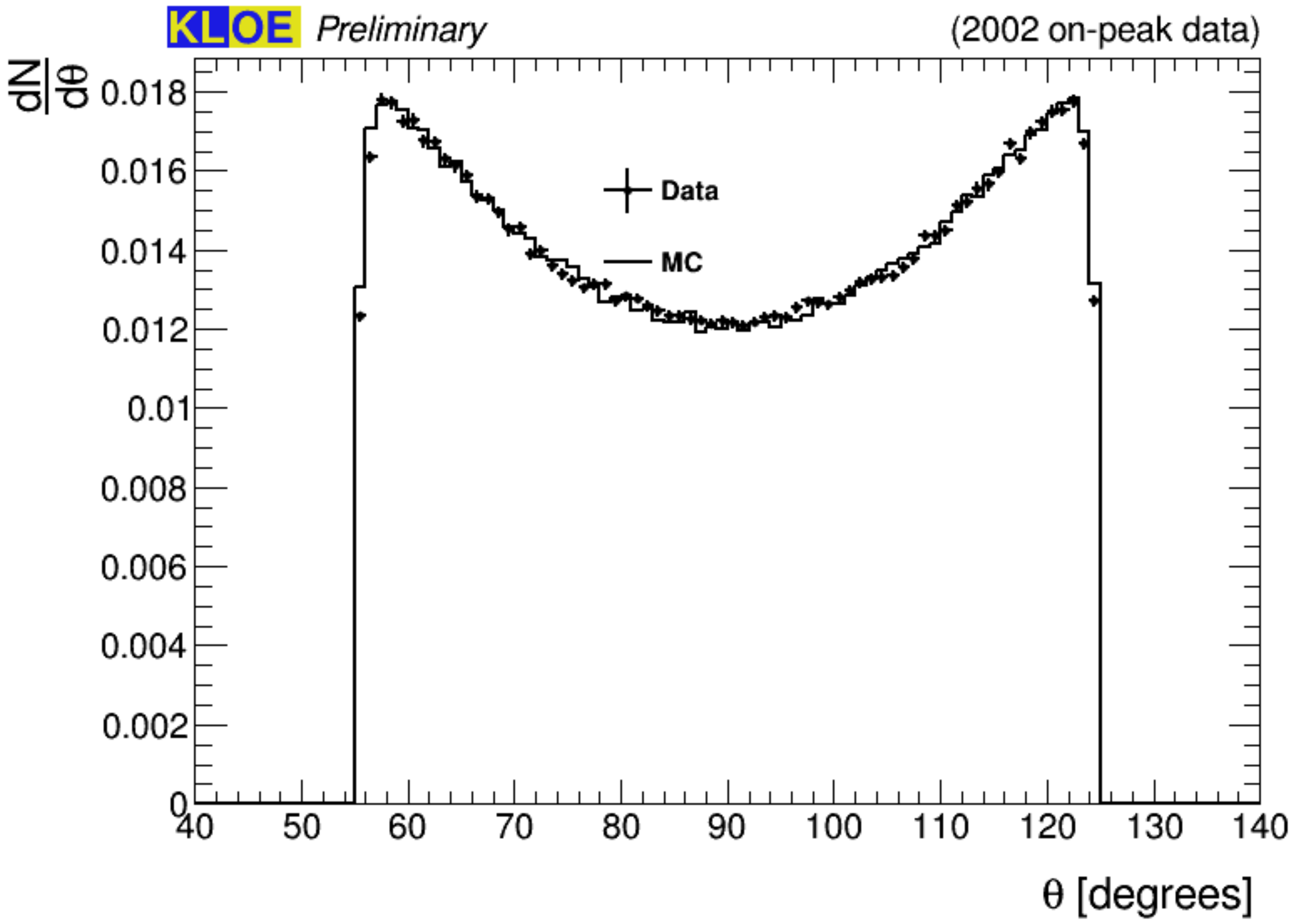


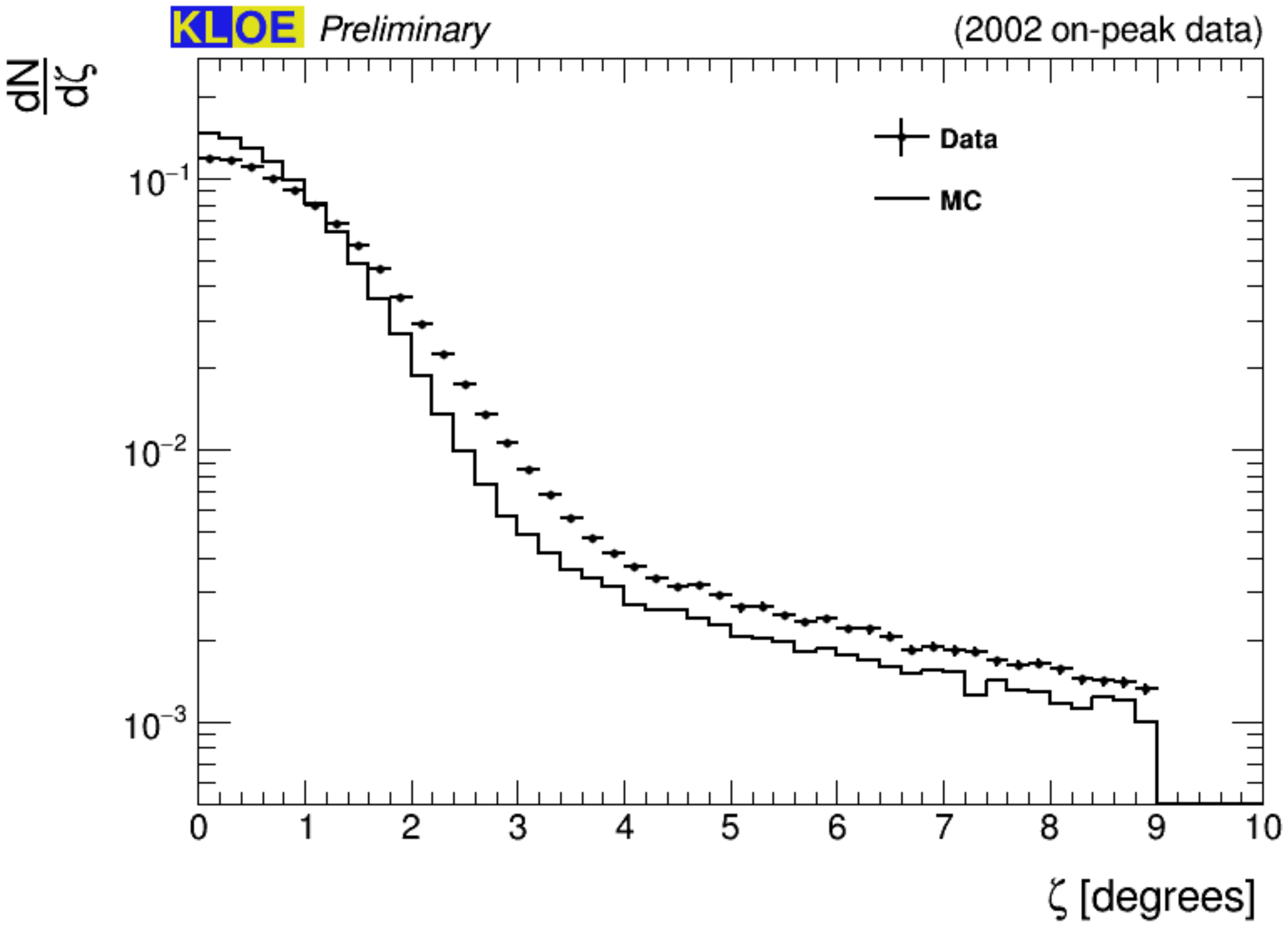
e^+e^-



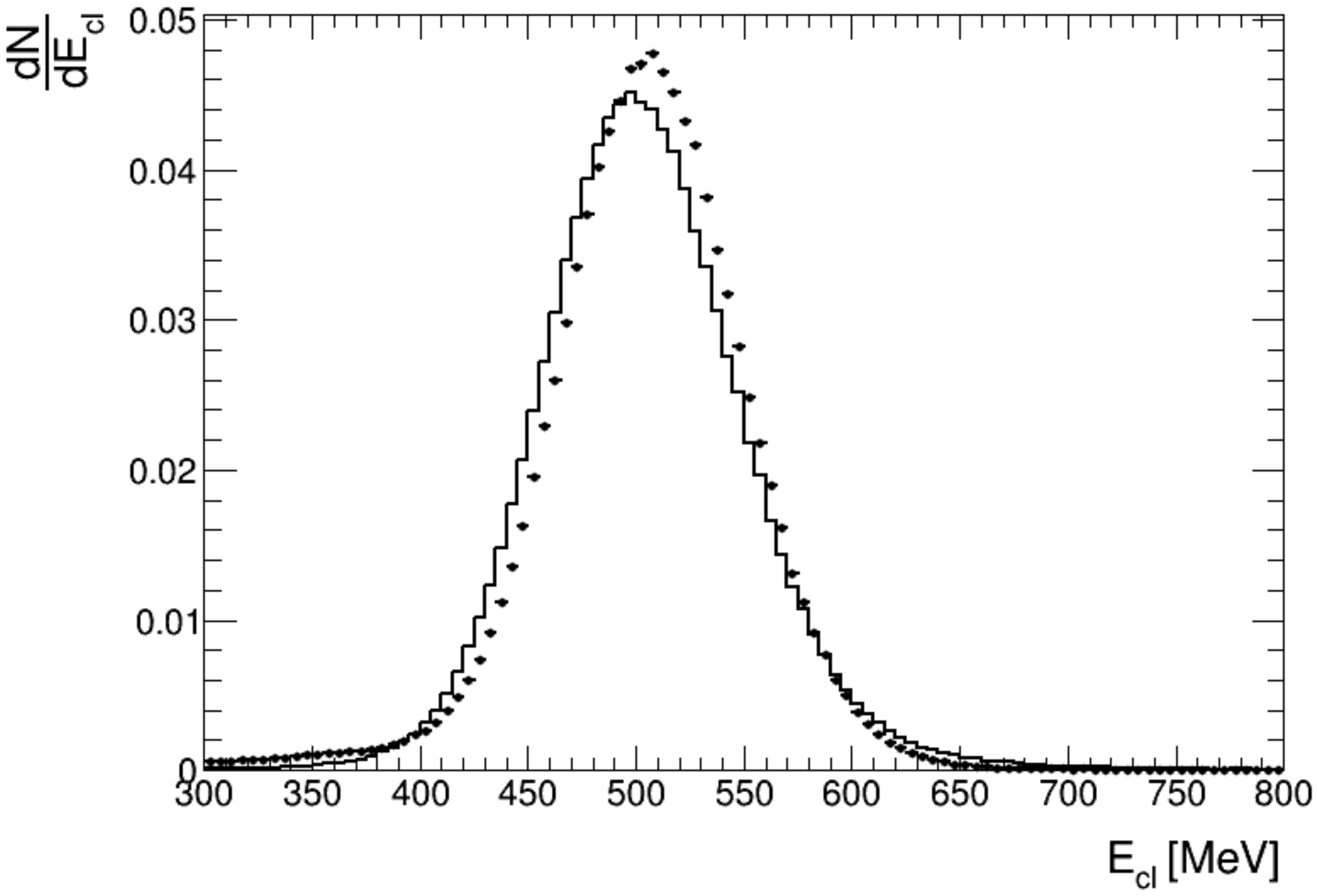
Cross check using $e^+e^- \to \gamma\gamma$

Only calorimeter information due to absence of tracks





Cross check using $e^+e^- \to \gamma\gamma$



Conclusion and next steps:

- New luminosity study in progress to calculate systematic errors
- Disagreements in quantities from calorimeter
- Correct MC events to match data
- Calculate total luminosity and relevant systematic errors
- Scrutinise cuts and investigate whether tightening cuts even further can decrease systematics due to being at less steep areas
- Additional analysis on $e^+e^- \to \gamma\gamma$ made possible with better precision from Babayaga NLO