SCUOLA
NORMALE
SUPERIORE

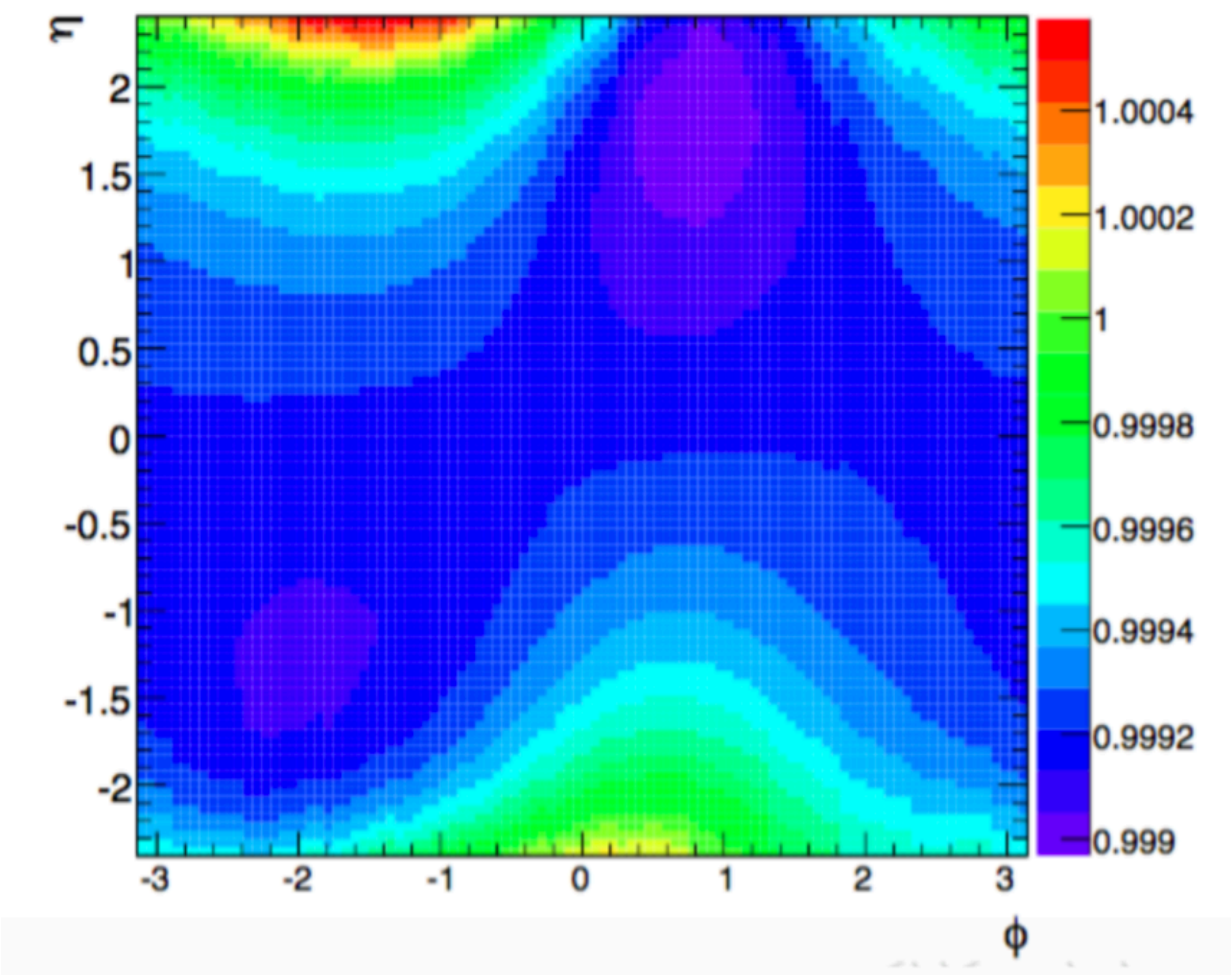
high precision muon momentum scale calibration in CMS

Elisabetta Manca, Gigi Rolandi (*Scuola Normale Superiore*)
Josh Bendavid (*CERN*)

PRIN meeting Milano
5th October 2021

correct k = 1/p_T using
a physics-driven model

magnetic field



multiplicative factor
and 3D/2D map correction

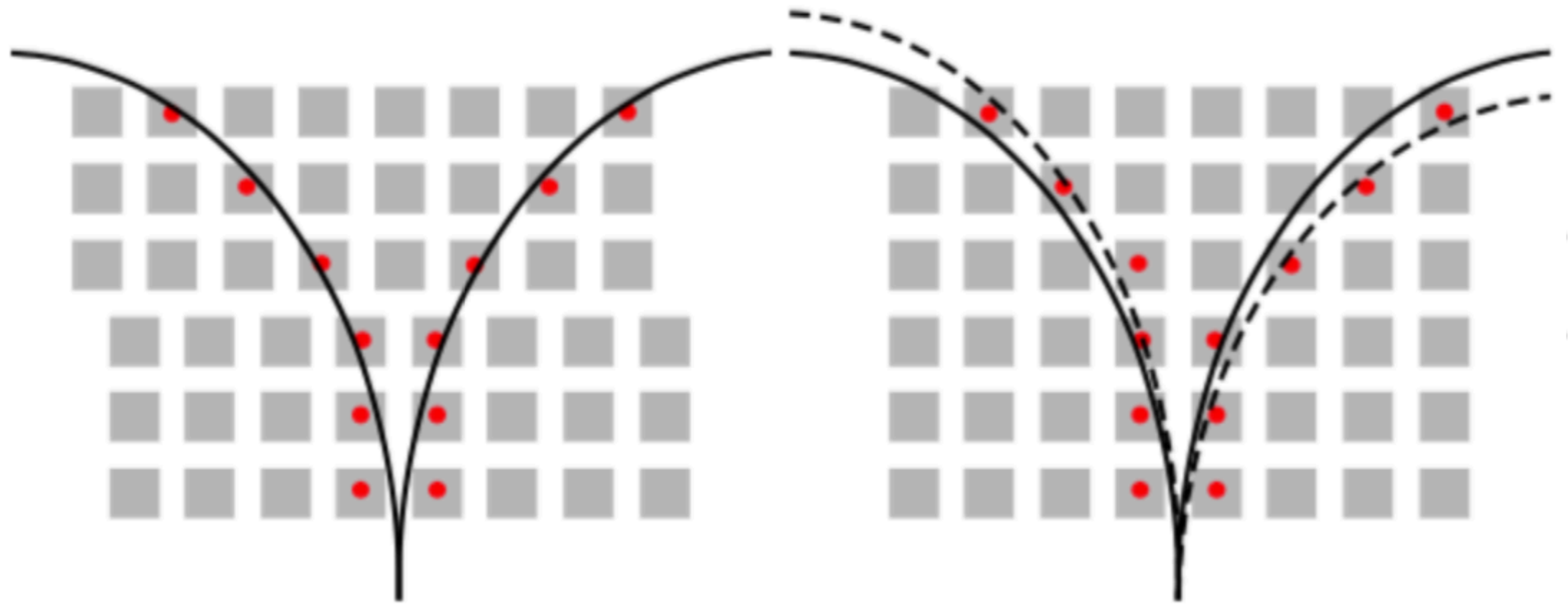
material mismodelling

corrected k

$$k^c = \frac{1}{E\sin\theta + \epsilon\sin\theta} = \frac{k}{1 + k\epsilon\sin\theta}$$

charge independent addictive factor

misalignment



charge dependent addictive factor

extract corrections from our model

$$\frac{k_{true}}{k} = A - \epsilon k + \frac{qM}{k}$$

material

B field

misalignment

make use of dimuon events

$$scale = \sqrt{\frac{k_{1,true}}{k_1}\frac{k_{2,true}}{k_2}}$$

previous effort in CMS

goal: calibrate muon momentum scale at 10^{-4} level (~10 MeV on m_W)

- in the context of “W-like” Z mass measurement at 7 TeV
- using J/ψ and ϒ dimuon mass
- muons in acceptance $|\eta|<1.4$
- using a Kalman Filter approach
- final precision reached: $2 \cdot 10^{-4}$ level

moving to run2 2016 data

goal: calibrate muon momentum scale at 10^{-4} level (~10 MeV on m_W)

- from to 5 fb^{-1} to 36 fb^{-1}
- extended η coverage to 2.4
- applying same approach: no satisfactory result
- …back to square one:
    - study and validate our model
    - find all approximations or mistakes in tracking code

a model for biases in fitted track parameters

fact: simple model only valid in case of uniform biases along the trajectory

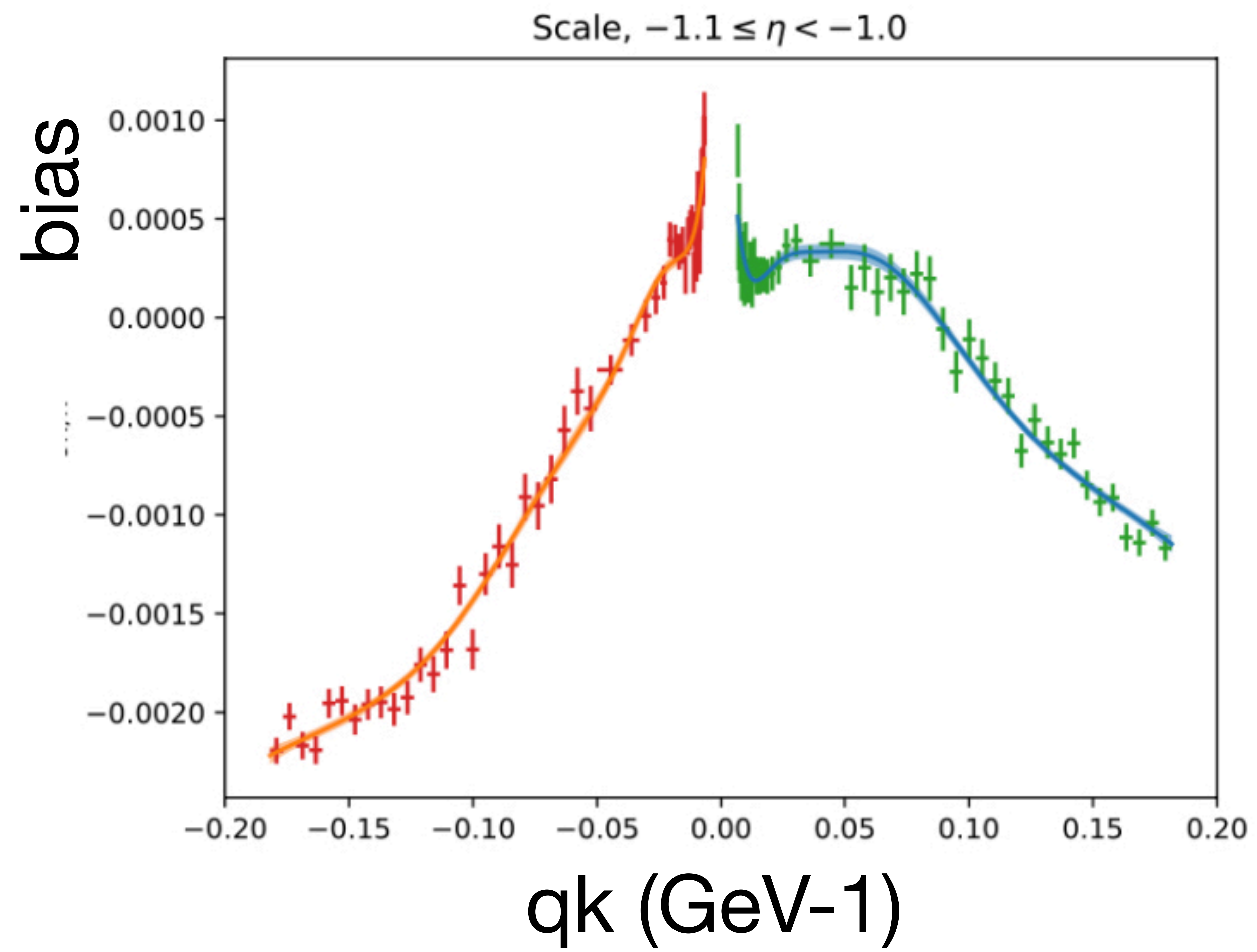
solution: introduce a more generic model:

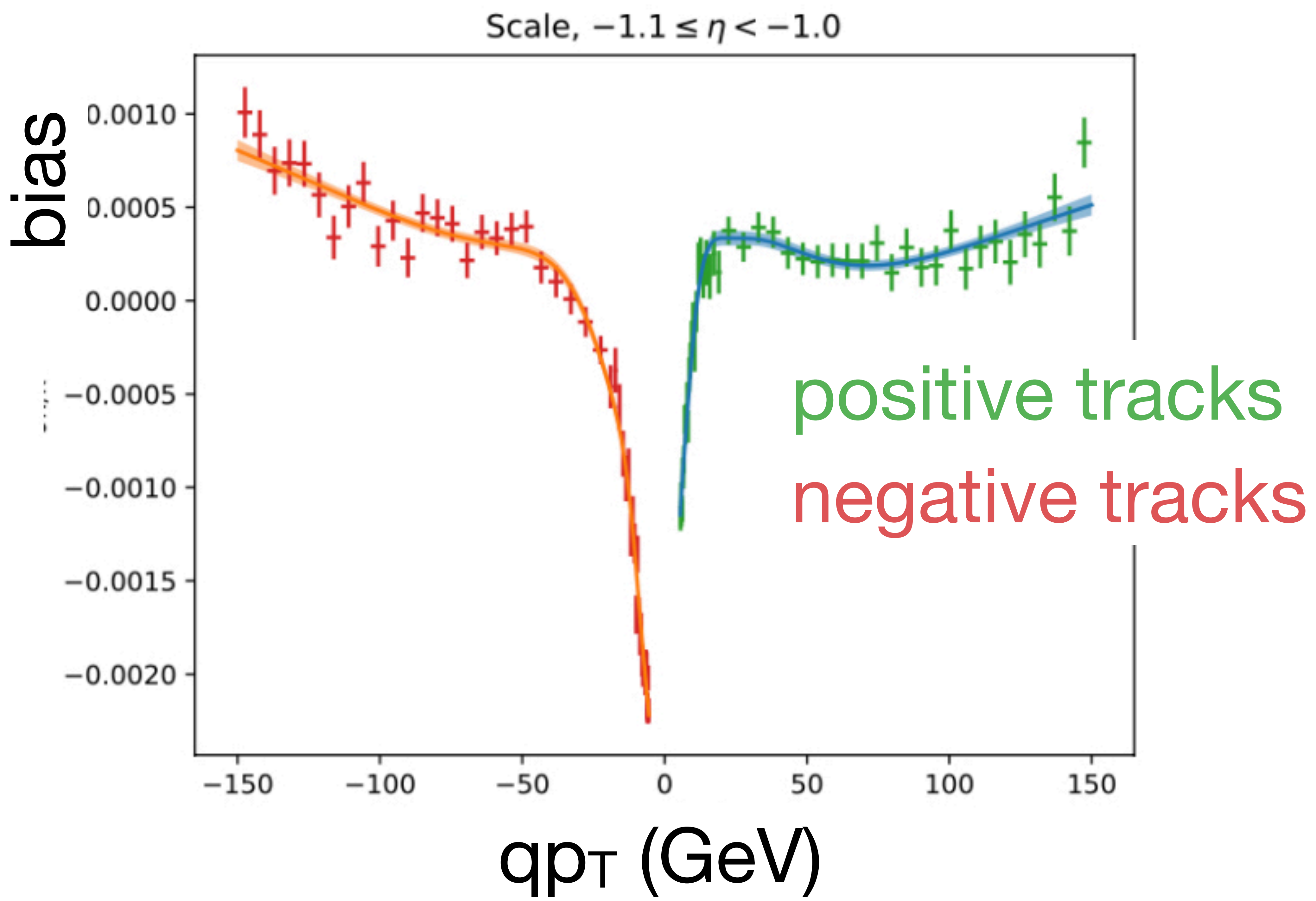
$$\frac{k^c}{k} = 1 + A - \epsilon k + qM/k + \sum_l \frac{A_l - \epsilon_l k + qM_l/k}{1 + d_l^2 k^2}$$

encodes biases *per layer*

validation of the model

- comparing generated and reconstructed curvature
- very good agreement between data points and model
- fitting procedure cumbersome and not applicable to dimuon events





improving CMS track fit

fact:

- CMS track fit delivers muons with ~10^{-3} precision
- this is enough for all analysis but high precision measurements
- we found approximations that led to non-uniform biases

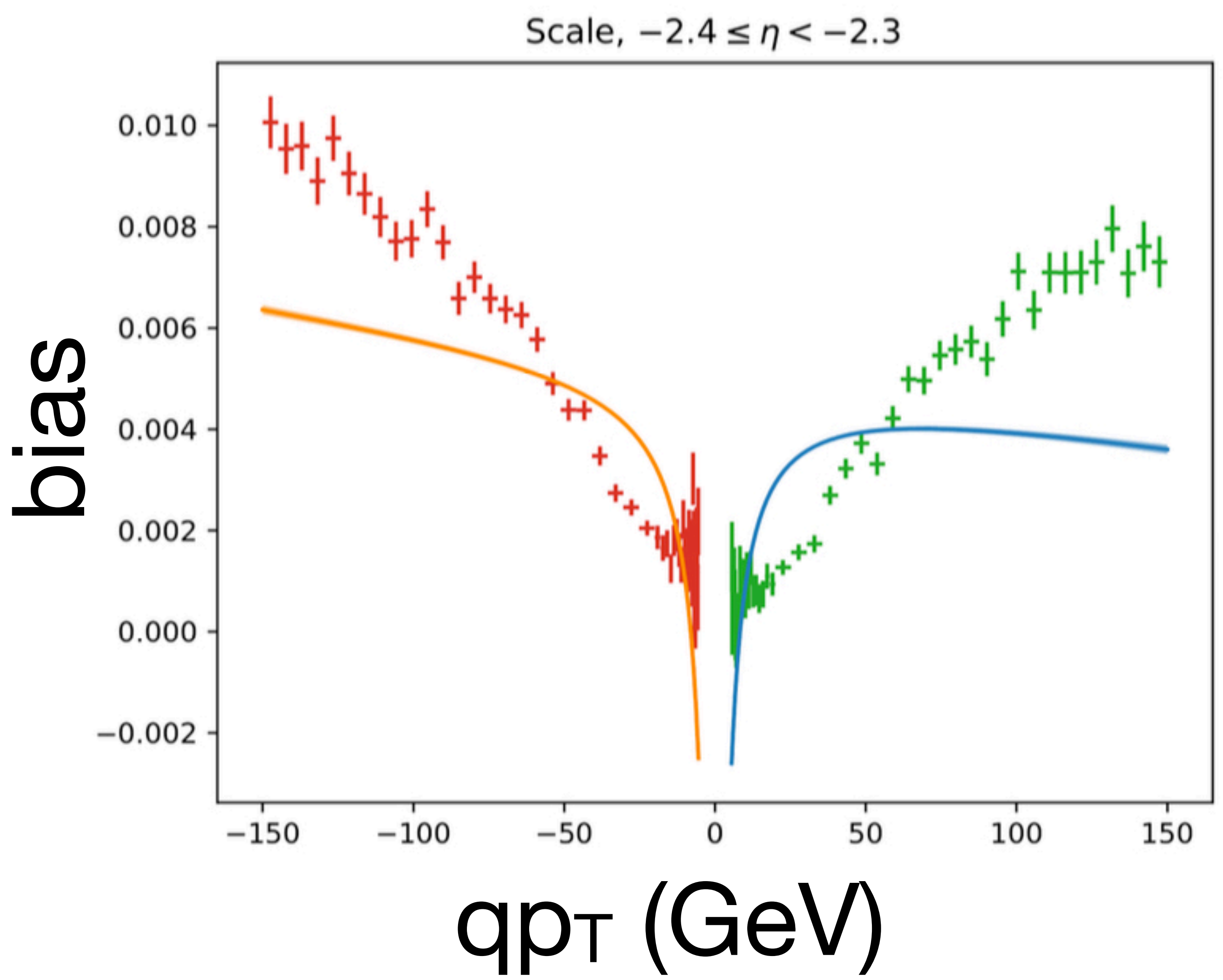
solution:

we have devised a new track fit:

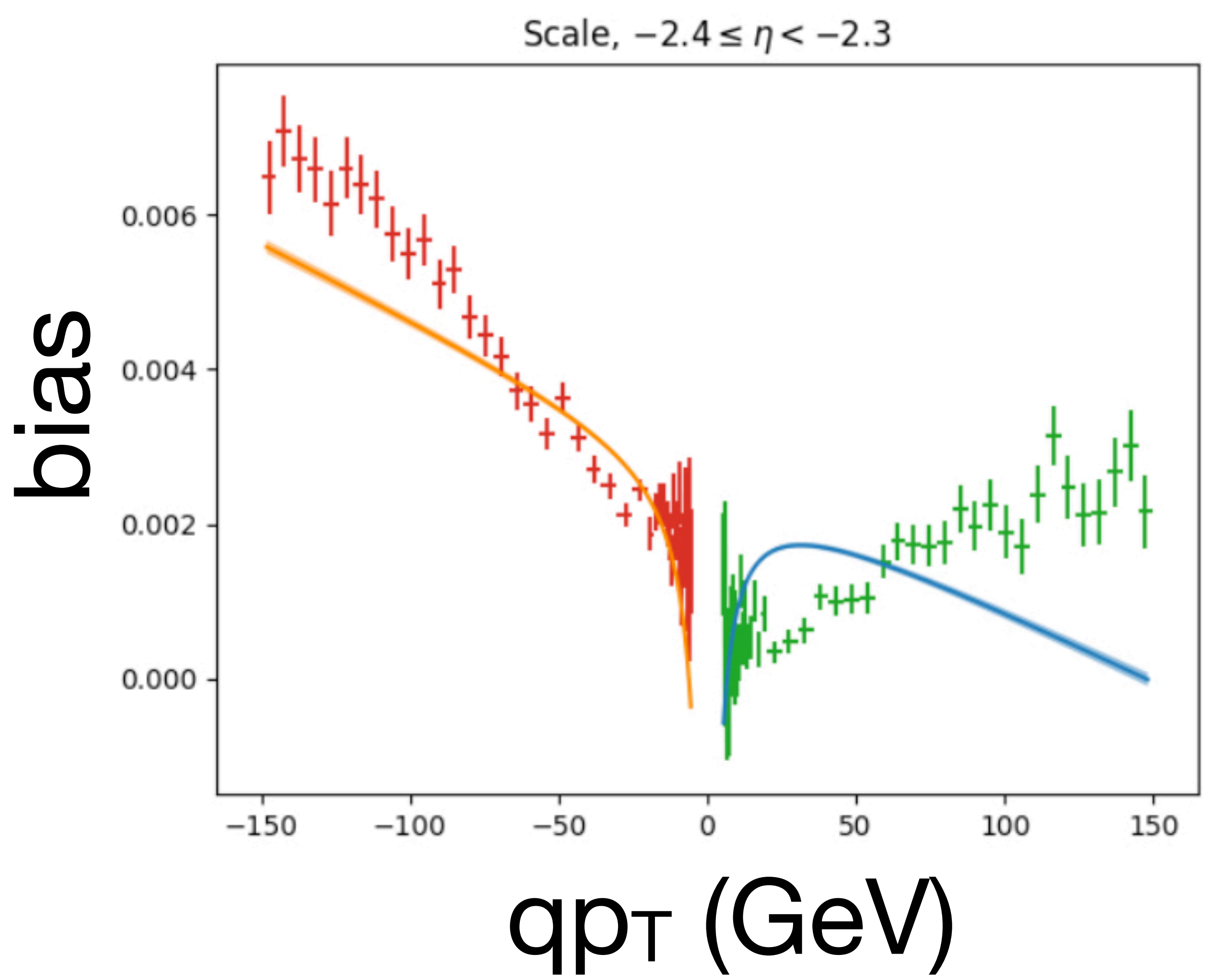
- removed approximations
- improved treatment of magnetic field and material

improving CMS track fit

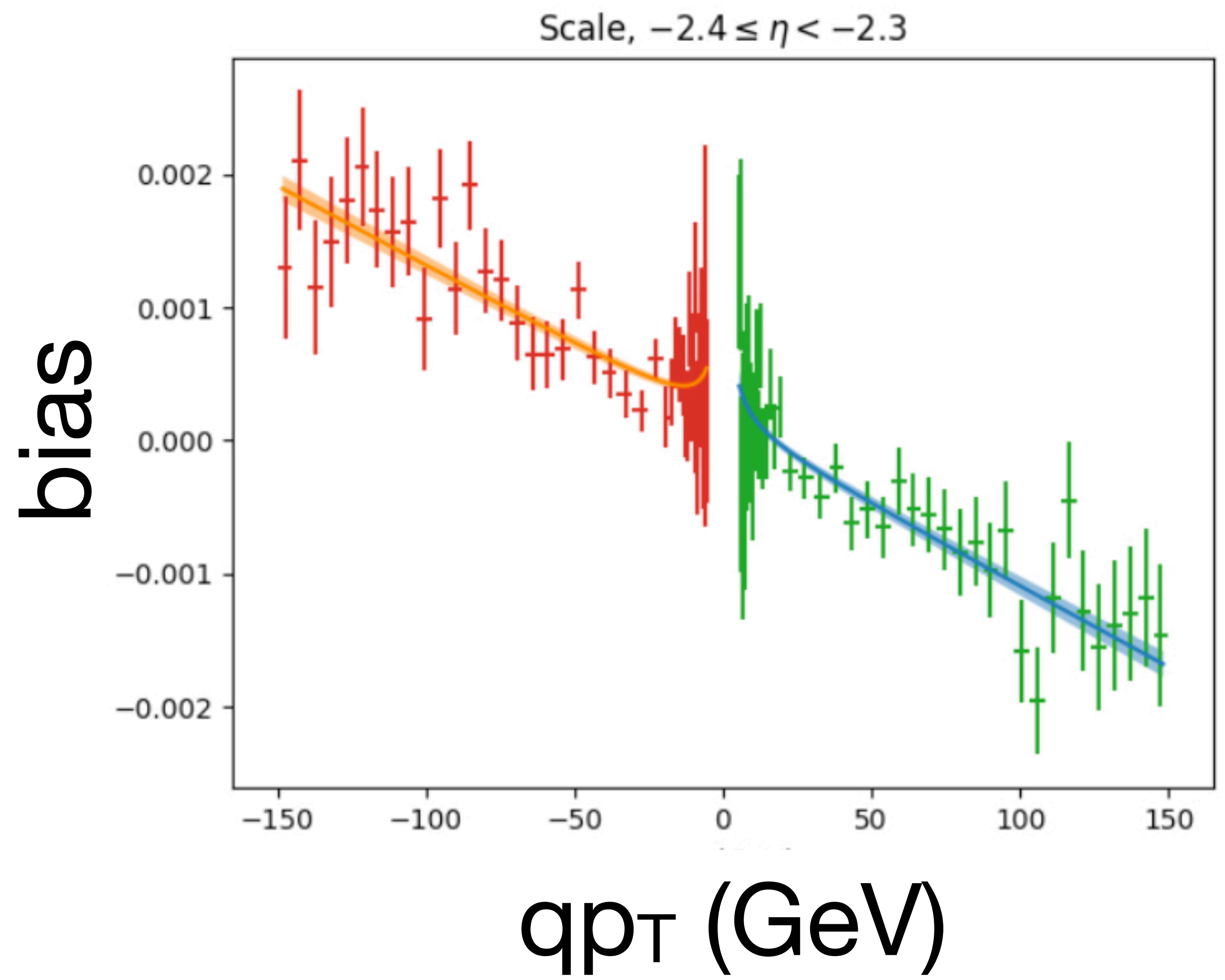
today we have a much better baseline:



standard
CMS track fit



standard
CMS track fit
+ fixing
approximations



improved
CMS track fit
+ fixing
approximations

extracting corrections

- start from new fit baseline
- use simplified model $$\frac{k_{true}}{k} = A - \epsilon k + \frac{qM}{k}$$
- use ~100M J/ψ collected by CMS
- divide phase space in bins of η_+,η_-,log(p_{T+}/p_{T-}),cosΔϕ
- in each bin, fit dimuon mass for scale and resolution

$$scale = \sqrt{\frac{k_{1,true}}{k_1}\frac{k_{2,true}}{k_2}}$$

a kernel model for scale and resolution

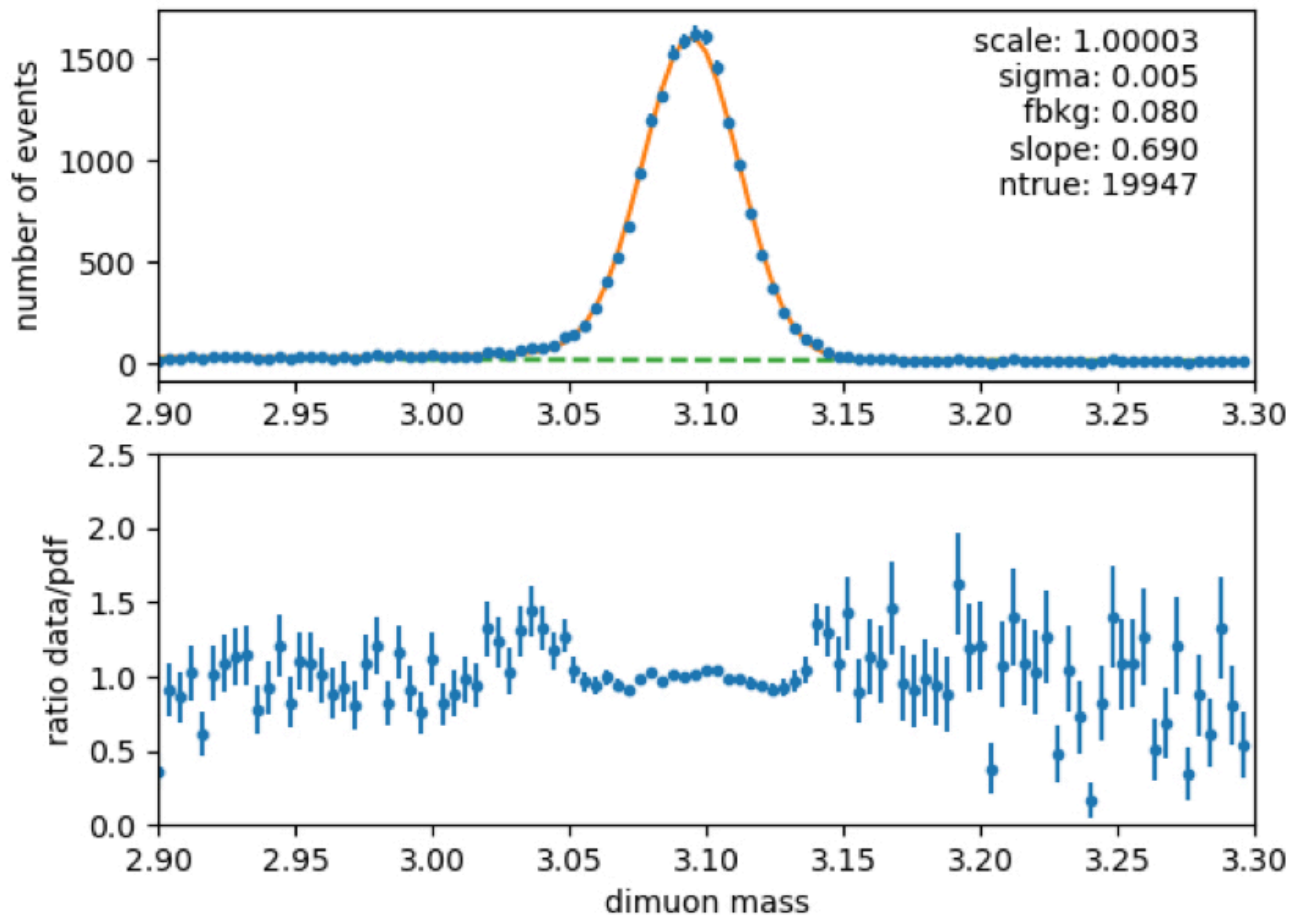
build lineshape pdf convoluting the generator-level mass spectrum with Gaussians

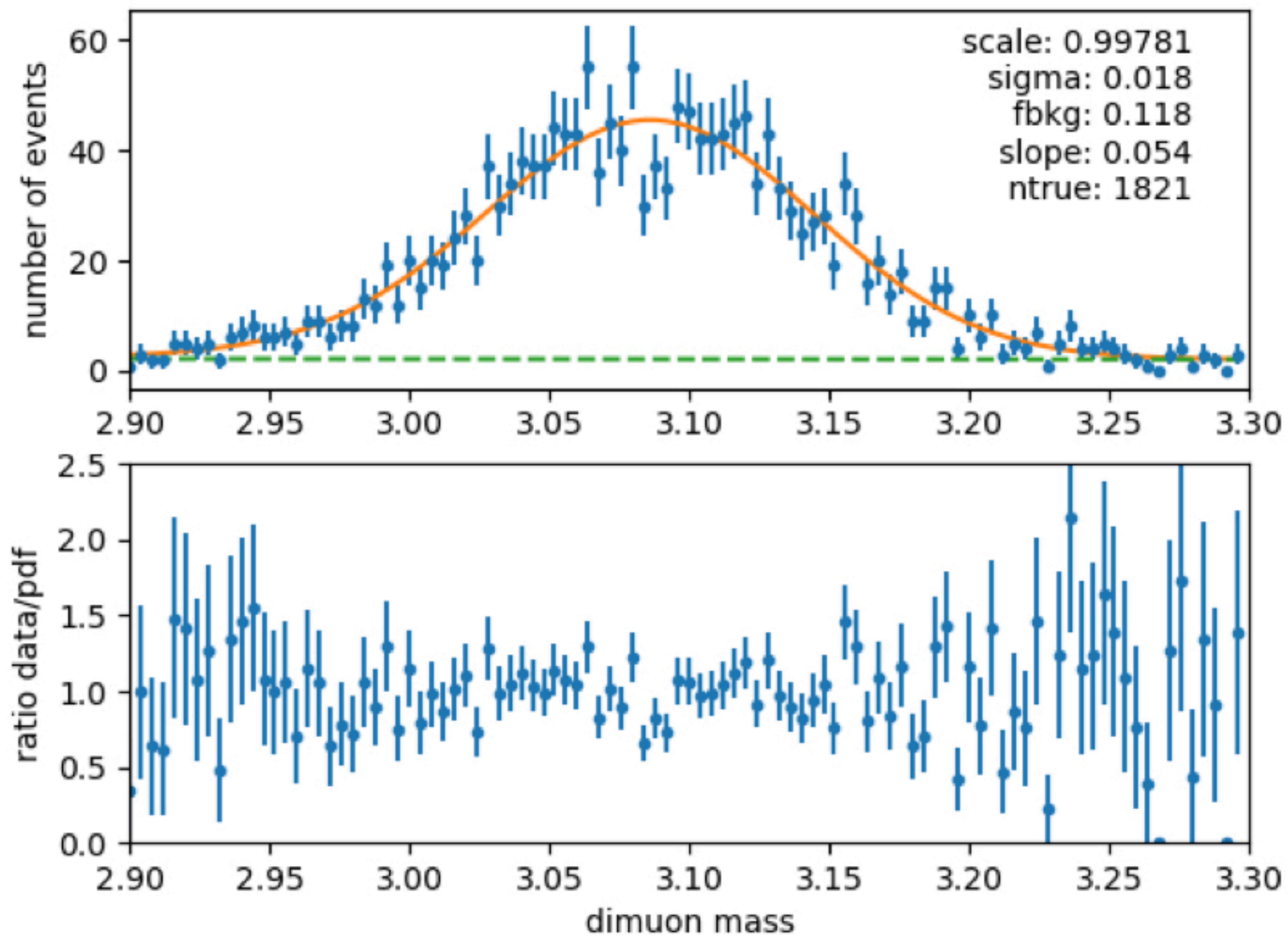
$$p(m_{reco}) = \int_{m_{gen}} p(m_{gen}) \frac{1}{\sigma m_{gen}\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{m_{rec} - \mu m_{gen}}{\sigma m_{gen}}\right)^2} dm_{gen}$$

this factorises out FSR and natural width and ɣ* in Z

fit μ and σ in each bin of η_{+},η_{-},log(p_{T+}/p_{T-}),cosΔϕ
→ O(12k) bins in J/ψ fit at full granularity!

some fits of scale and sigma with kernel model





extraction of the parameters

$$p(m_{reco}) = \int_{m_{\text{gen}}} p(m_{gen}) \frac{1}{\sigma\, m_{\text{gen}}\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{m_{rec} - \mu\, m_{gen}}{\sigma\, m_{\text{gen}}}\right)^2} dm_{gen}$$

with

$$\mu^2(\eta, p_T) = \left(1 + \delta A(\eta_+) - \frac{\epsilon(\eta_+)}{p_T^+} + M(\eta_+) p_T^+\right)\left(1 + \delta A(\eta_-) - \frac{\epsilon(\eta_-)}{p_T^-} - M(\eta_-) p_T^-\right)$$

$$\sigma^2(\eta, p_T) = a^2(\eta_+) + c^2(\eta_+) p_+^2 \frac{1 + \frac{g^2(\eta_+)}{p_+^2}}{1 + \frac{d^2(\eta_+)}{p_+^2}} + a^2(\eta_-) + c^2(\eta_-) p_-^2 \frac{1 + \frac{g^2(\eta_-)}{p_-^2}}{1 + \frac{d^2(\eta_-)}{p_-^2}}$$

how model is related to lineshape pdf

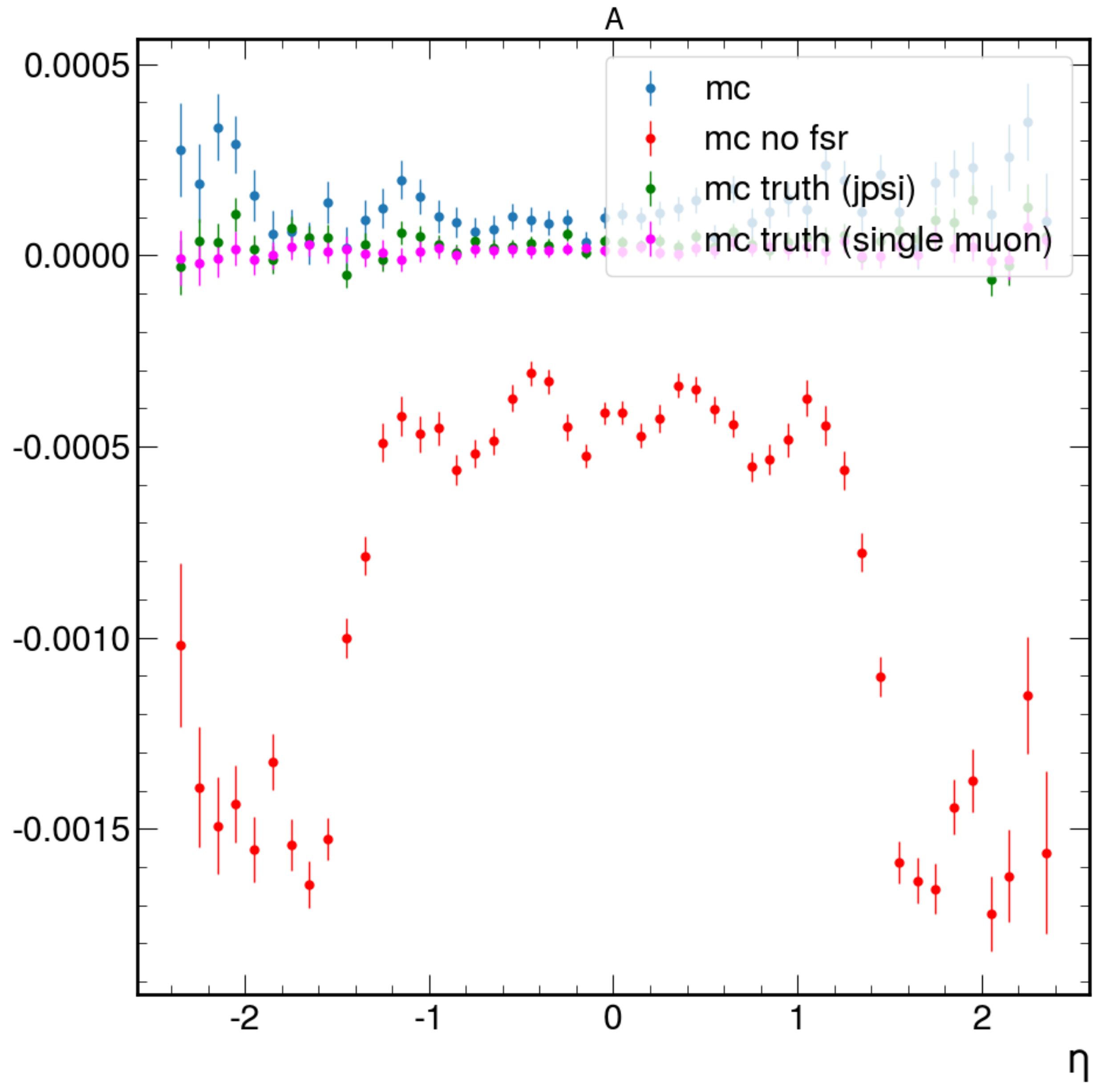
total likelihood (adding exponential bkg pdf for the J/ψ)

$$L = -\ln \sum \left(f_{bkg}\, p_{bkg}(m_{reco}) + (1 - f_{bkg}) p_{sig}(m_{reco})\right)$$

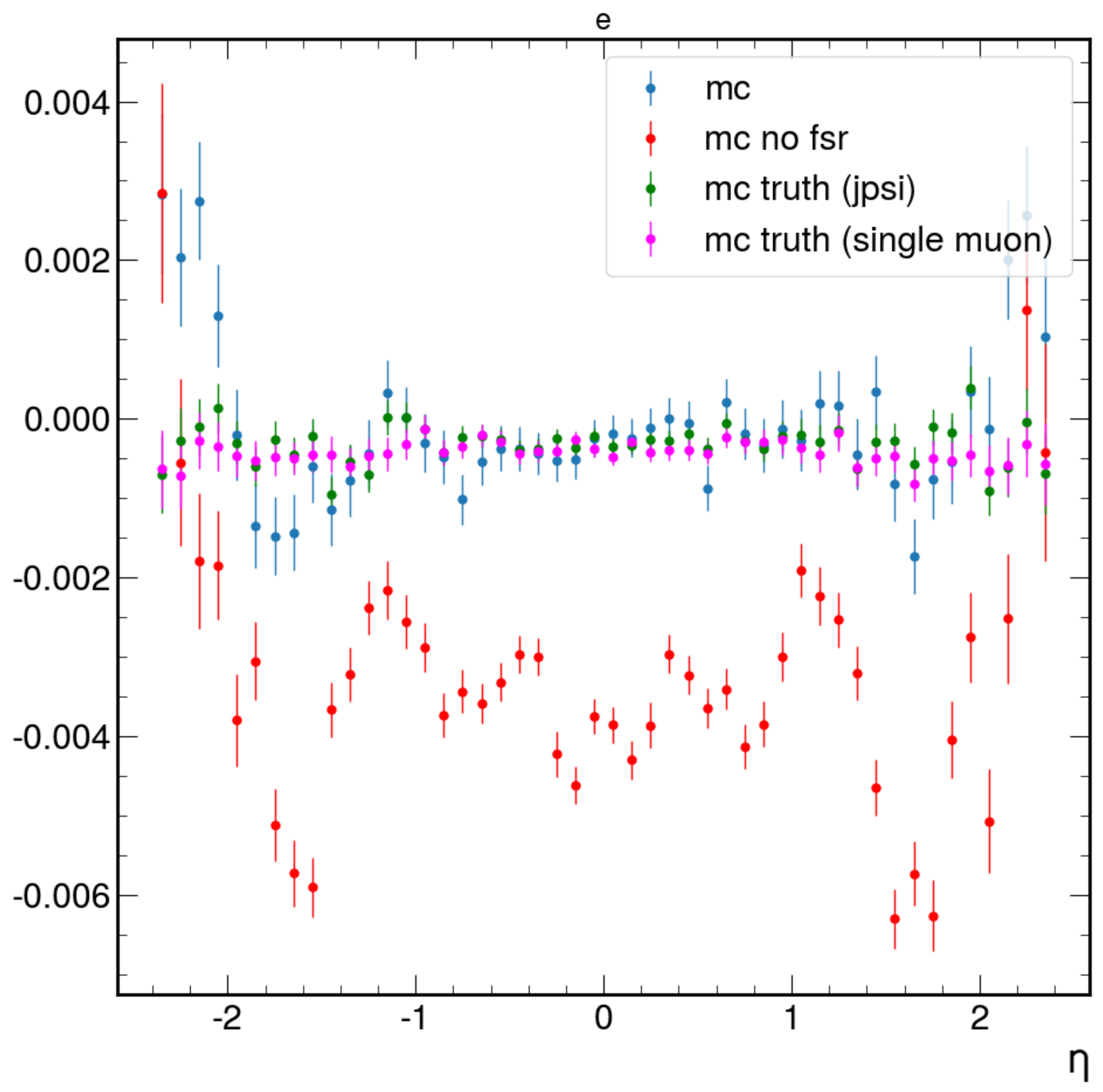
extraction of the parameters

extract corrections as a function of η from a χ^2 fit of the scale parameters in the phase space:

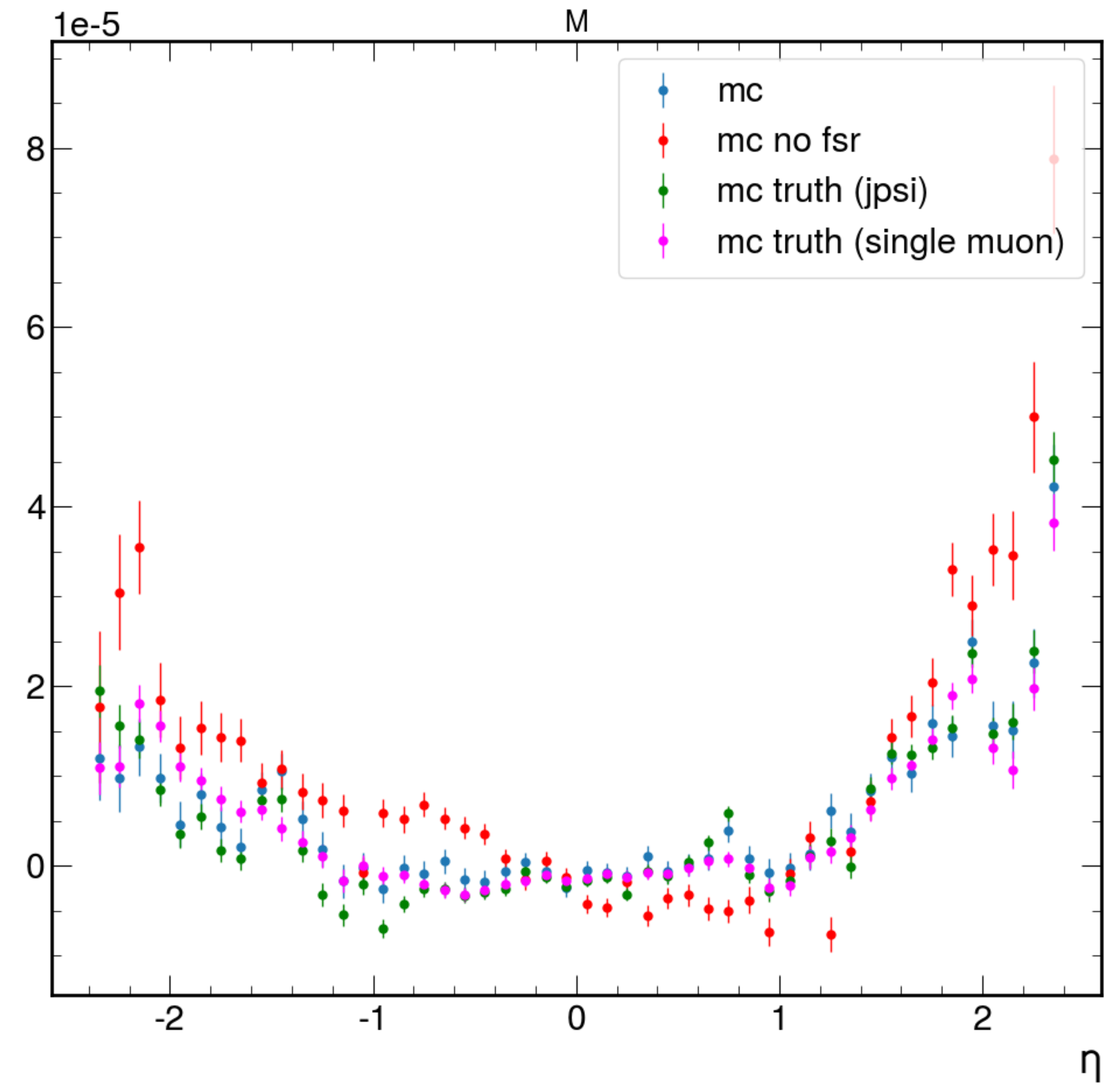
B field



material



misalignment



from J/ψ mass fits in MC

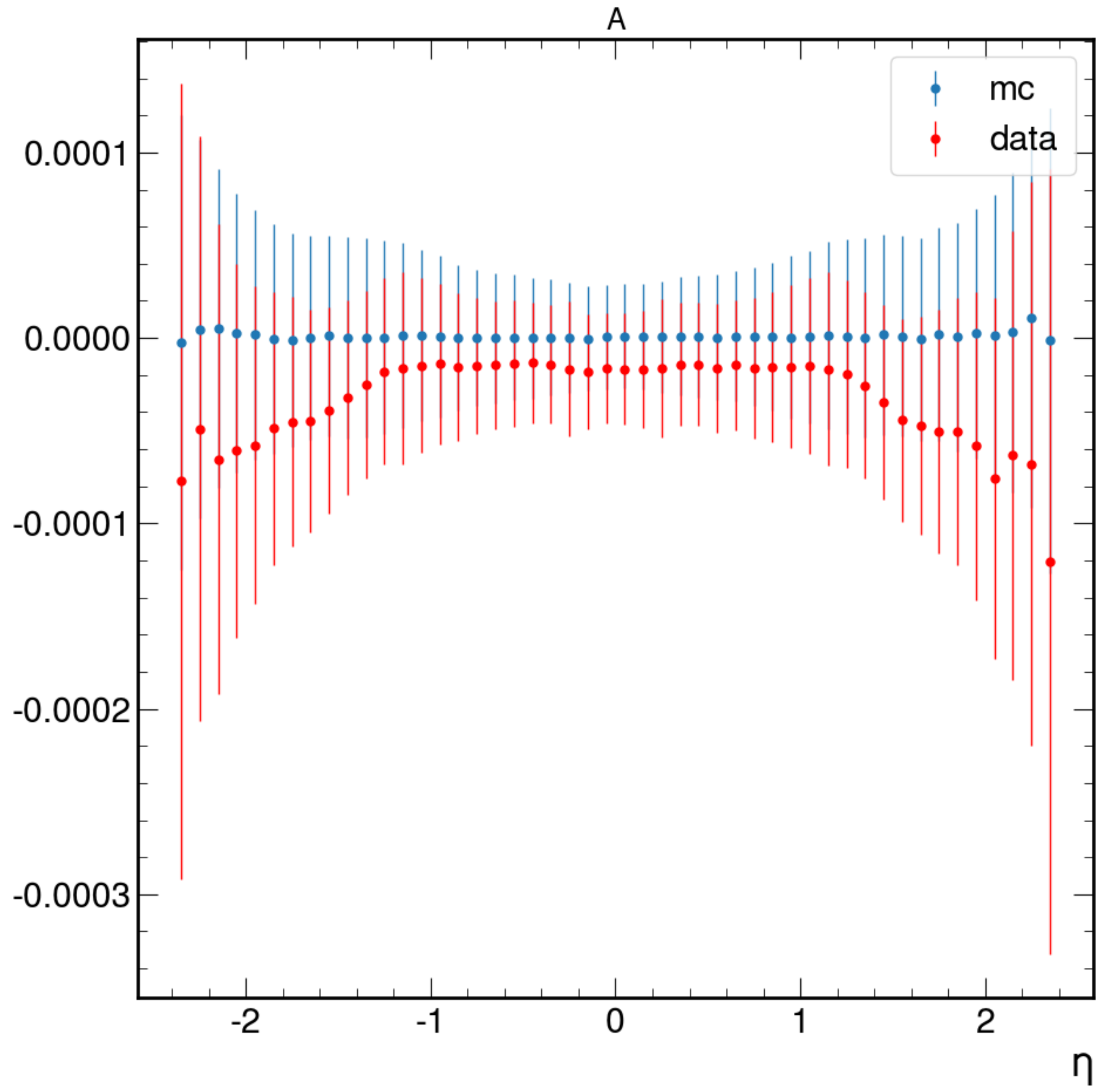
from J/ψ mass fits in data

from comparing gen and reco curvature

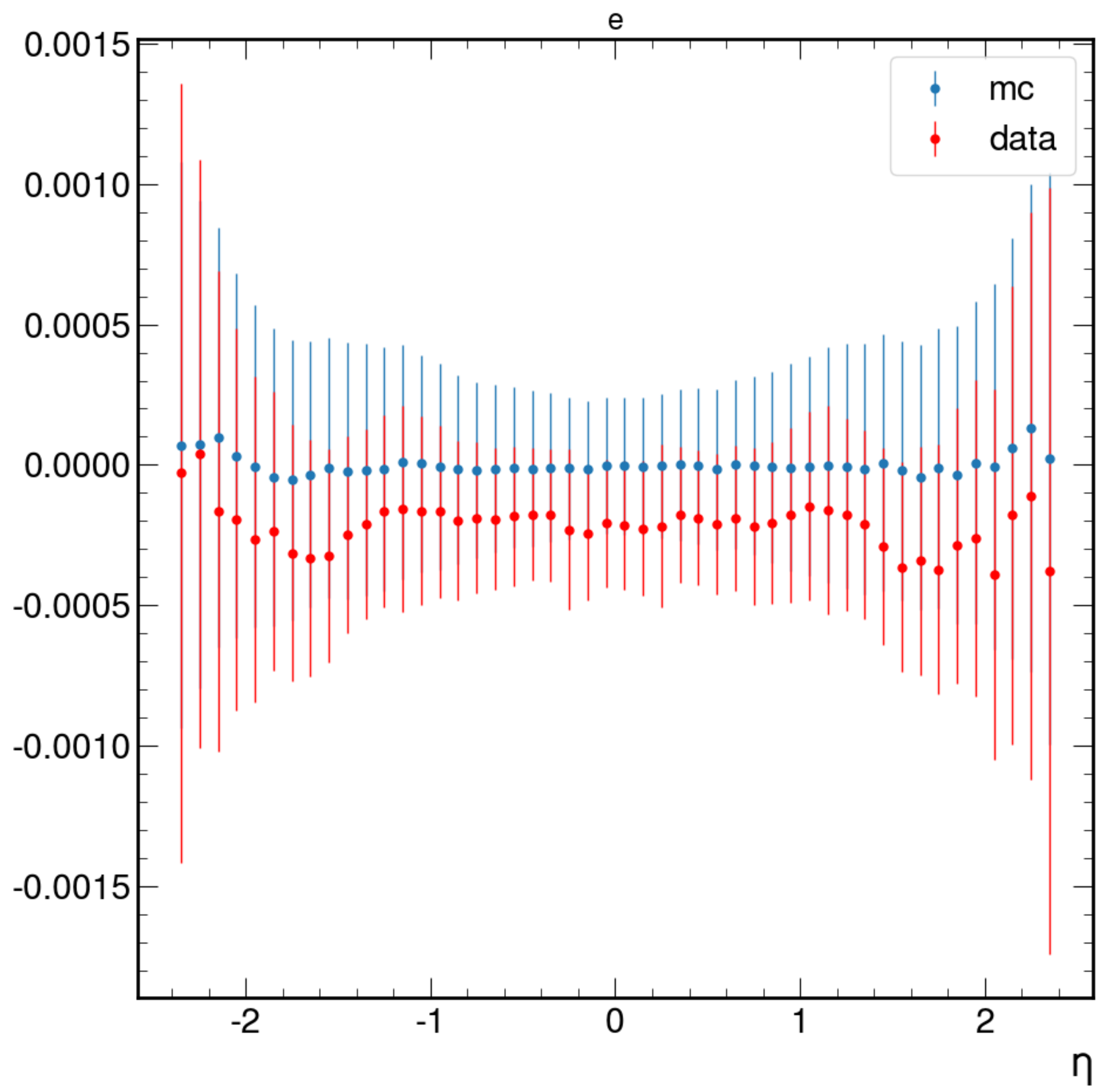
closure test

apply corrections and rerun fit
if parameters~0 calibration has worked

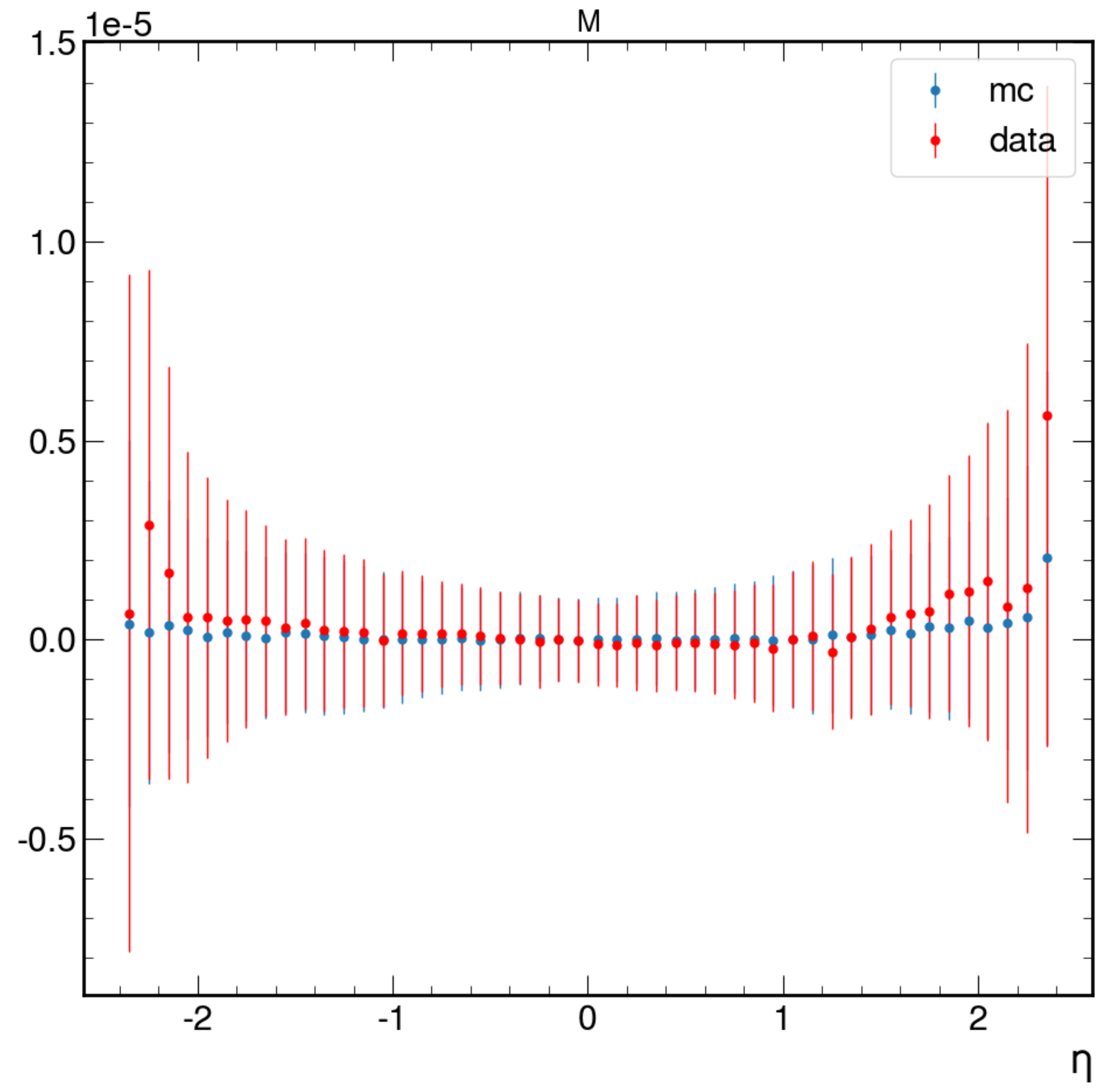
B field



material



misalignment



from J/ψ mass fits in MC
from J/ψ mass fits in data

conclusions

huge progress has been made to tackle high precision muon momentum scale calibration in the last 1.5 year

- we have studied a new model of track parameters bias
- we have improved the CMS track fit
- we have set up a new method to extract corrections from J/ψ mass

last step is validating the corrections on Z