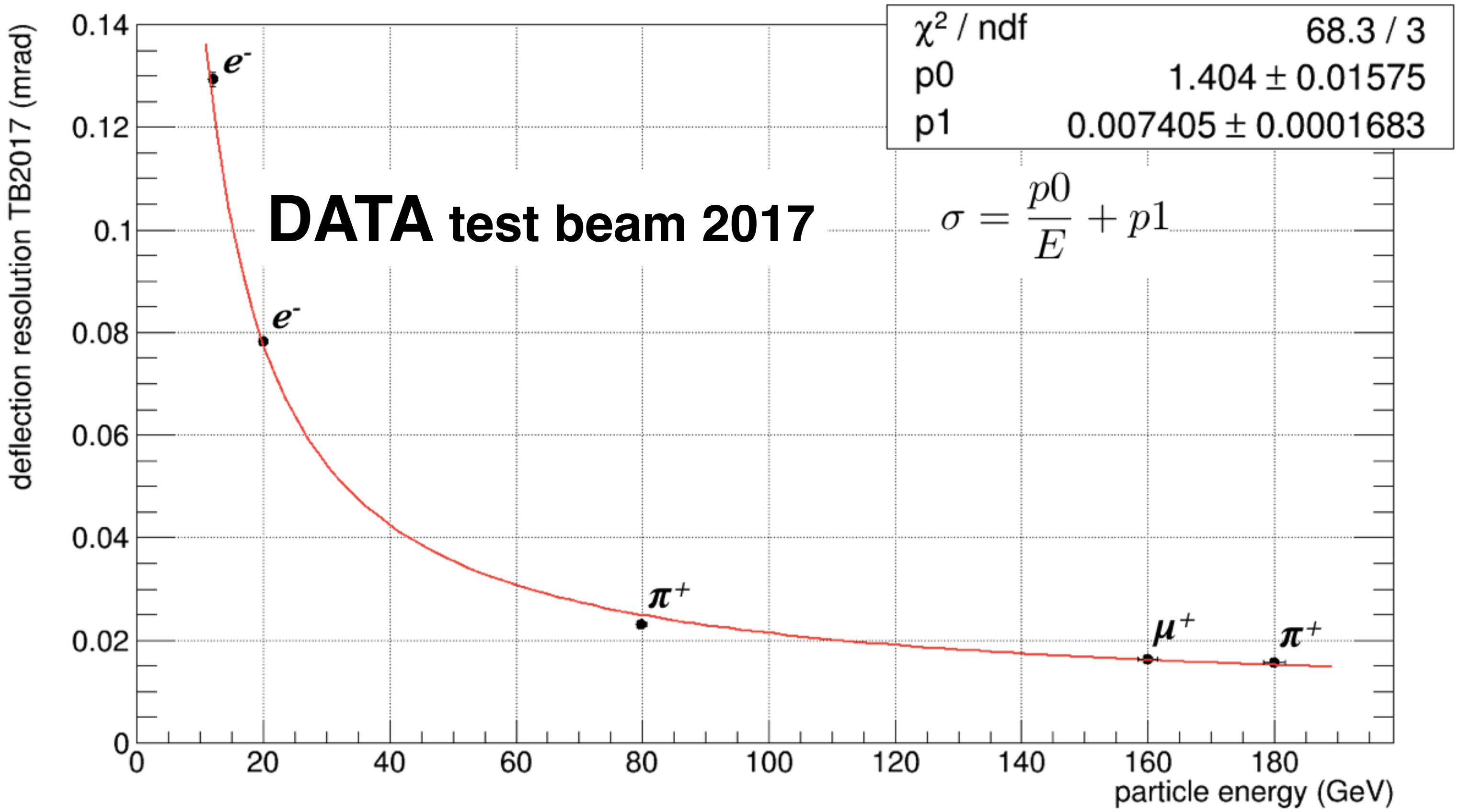
Fast MC and cross section fit

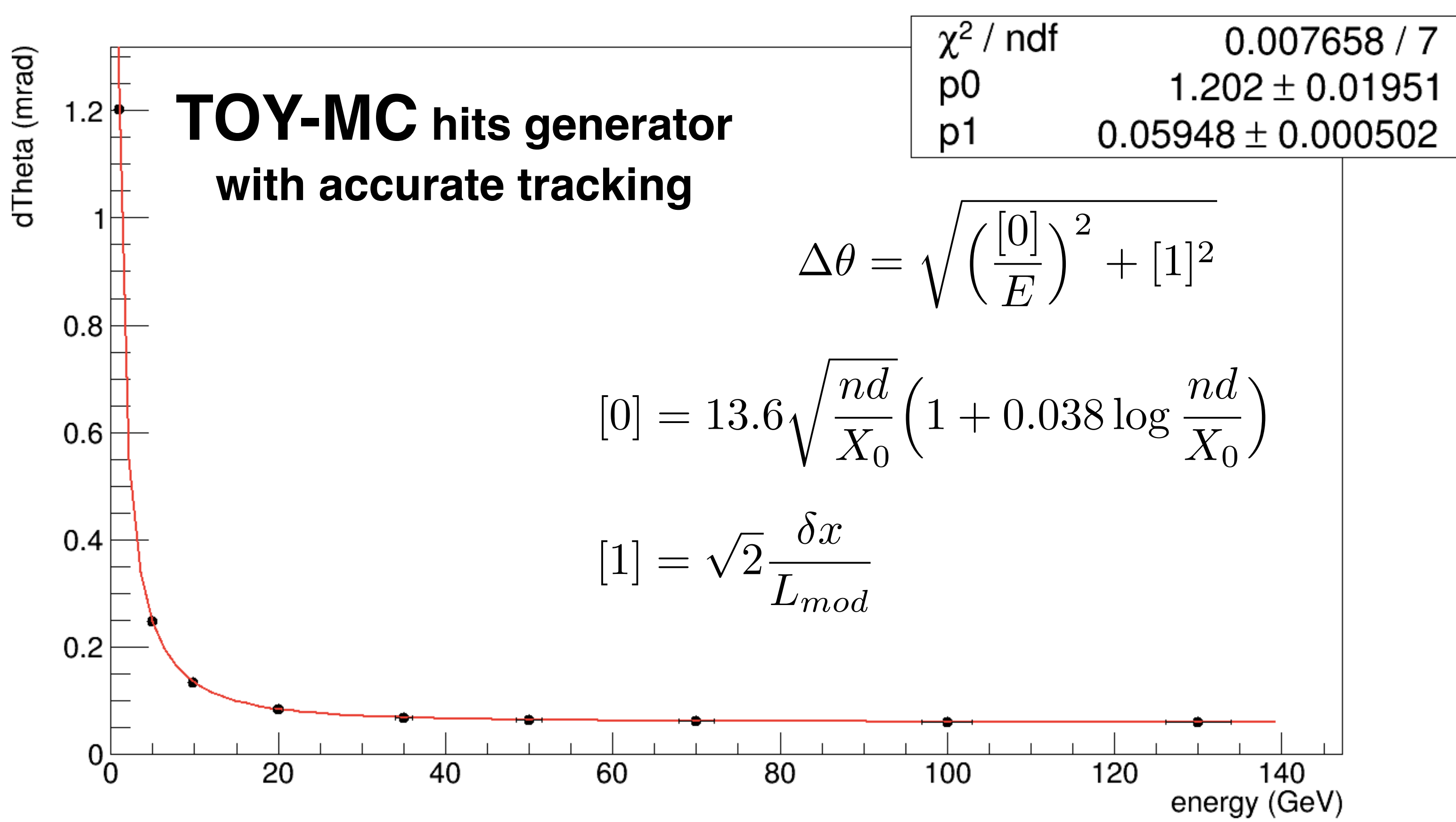
MUonE weekly meeting
23/10/2018

A. Principe

Fast simulation:
motivation and preliminary checks

Fast simulation of apparatus: idea





- **Observation**: gaussian convolution of PDG mcs model with intrinsic resolution fits very well our data (without target) between a large range of energy [12, 180] GeV.
- **Confirm**: toy-MC generator / tracker, with a more accurate fit, gives us confidence on physical sense of parametric coefficients and how they can change with different apparatus setup: in this case CBC doublet solution (see previous weekly meeting).

Fast simulation apparatus+target: proposal

- LO cross section:

$$f(\theta_e) = [0] \cdot \left(\frac{d\sigma}{d\theta_e}\right)^{LO} = [0] \cdot \frac{4\pi\alpha^2(t)}{\lambda(s, m_\mu^2, m_e^2)} \left(\frac{(s - m_\mu^2 - m_e^2)^2}{t^2} + \frac{s}{t} + \frac{1}{2}\right) \left|\frac{dt}{d\theta_e}\right|$$

- Apparatus:

$$A(E(\theta_e)) = \mathcal{G}\left(0, \sqrt{\left(\frac{[0]}{E}\right)^2 + [1]^2}\right)$$

- Target:

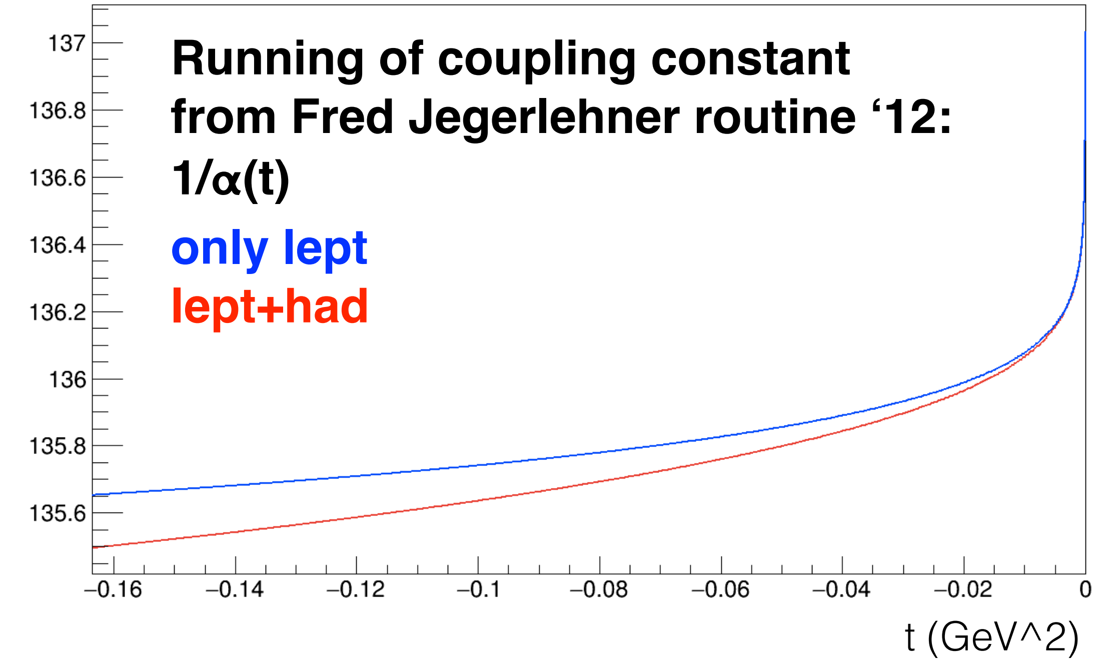
$$T(E(\theta_e)) = \mathcal{G}\left(0, \frac{[2]}{E}\right)$$

- Convolution of cross section with parametric apparatus + target:

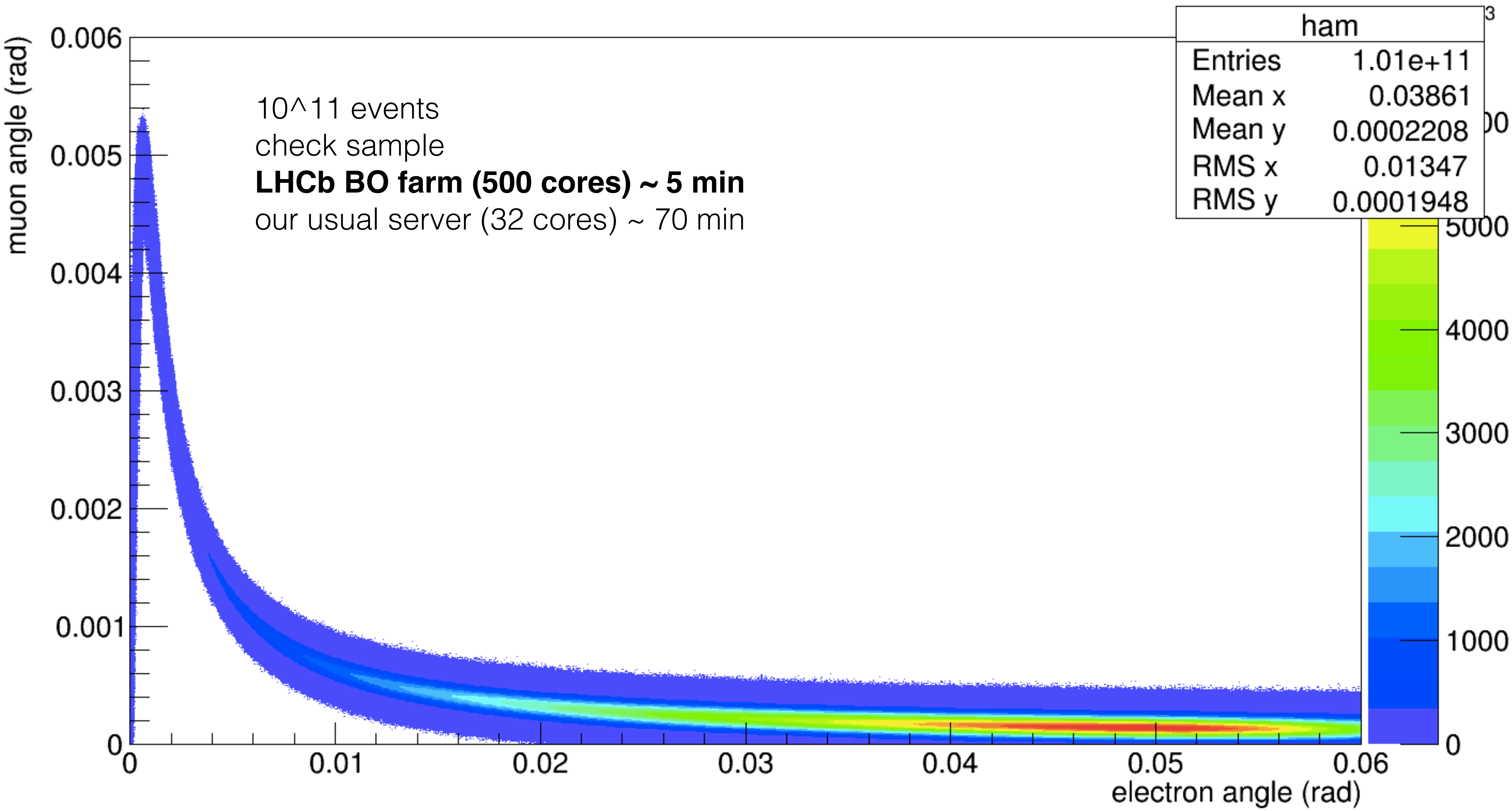
$$\left(\frac{d\sigma}{d\theta_e}\right)^{LOsmear} = \left(\frac{d\sigma}{d\theta_e}\right)^{LO} \otimes \left(T \oplus A\right)$$

Hypothesis:

- Only three coefficient to describe experimental response.
- **Gaussian** model of resolution: mcs tails (~5-10% of distributions) contain particles which loss a lot of energy: we will add bremsstrahlung contribution to simulate tails.
- So no energy loss in this model: restrictive for electron, but maybe a possible control of energy / momentum will make it less restrictive.



Computing resources

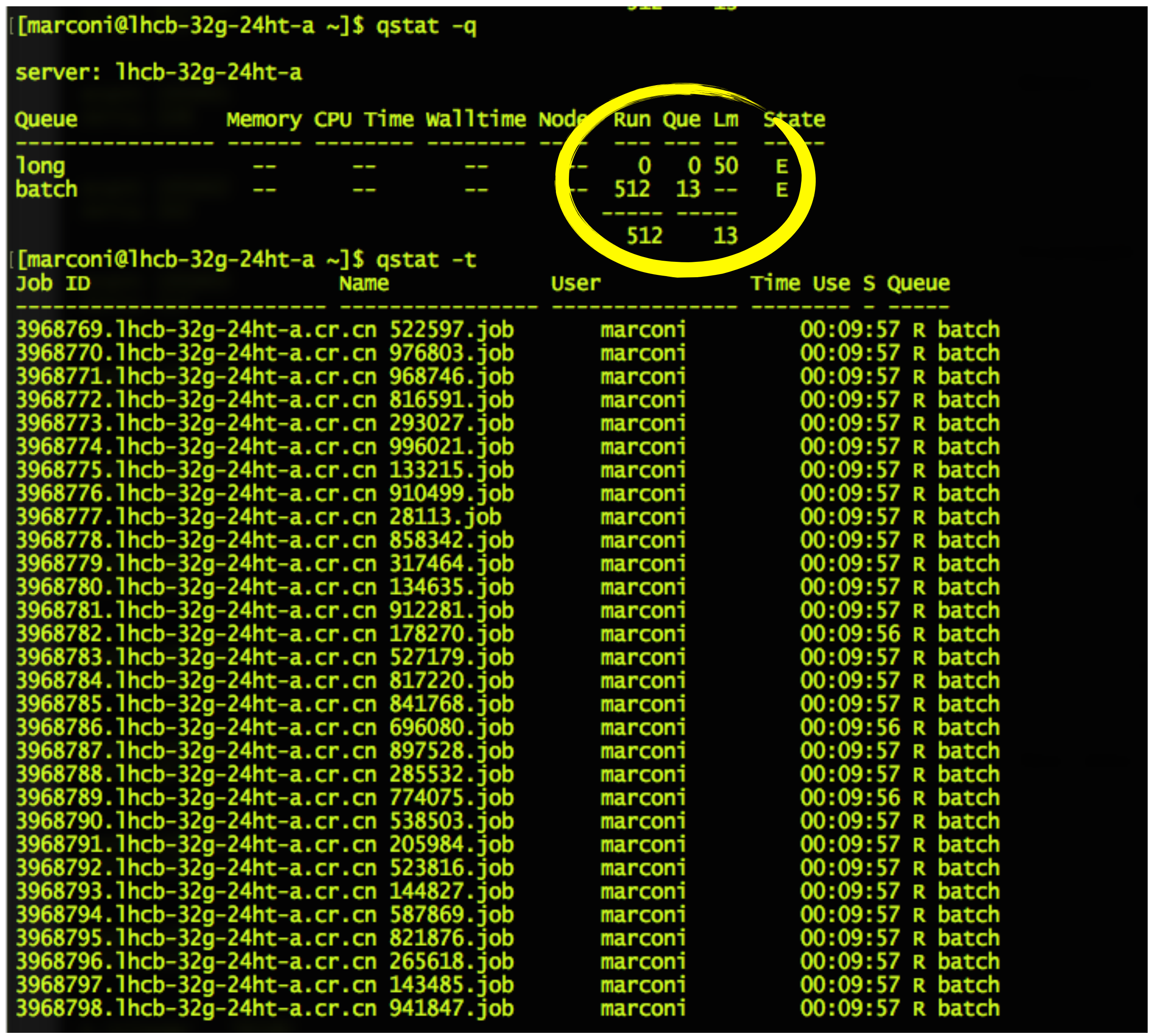


- For comparison, usual Geant full simulation of singole module (10^7 events) ~ 10-15 min.
- In this MC, 2.5e+10 within 30 mrad: 1/160 = 0.625% requested statistics, so total events in the histo within 60 mrad has to be **~1.6e+13.**
- With LHCb BO farm: ~ 13.3 hour.
- Hypothetical full simulation of a singole module: ~ 2 years!! (if I'm not wrong…)

Computing resources

So….

- impossibile to use ntuple (unbinned data) and “normal” server, but anyway we need high statistics simulation in more “realistic” conditions in a reasonable time.
- **Solution**: parametric response of detector = fast MC. We will complicate it step by step.
- For the moment: thanks for **LHCb BO** people! (in particular Dr. Fabio Ferrari)



```
[marconi@lhcb-32g-24ht-a ~]$ qstat -q

server: lhcb-32g-24ht-a

Queue            Memory CPU Time Walltime Node  Run Que Lm  State
---------------- ------ -------- -------- ----  --- --- --  -----
long               --      --       --      --    0   0 50   E
batch              --      --       --      --  512  13 --   E
                                               ----- -----
                                                 512    13

[marconi@lhcb-32g-24ht-a ~]$ qstat -t
Job ID                    Name             User            Time Use S Queue
------------------------- ---------------- --------------- -------- - -----
3968769.lhcb-32g-24ht-a.cr.cn 522597.job       marconi         00:09:57 R batch
3968770.lhcb-32g-24ht-a.cr.cn 976803.job       marconi         00:09:57 R batch
3968771.lhcb-32g-24ht-a.cr.cn 968746.job       marconi         00:09:57 R batch
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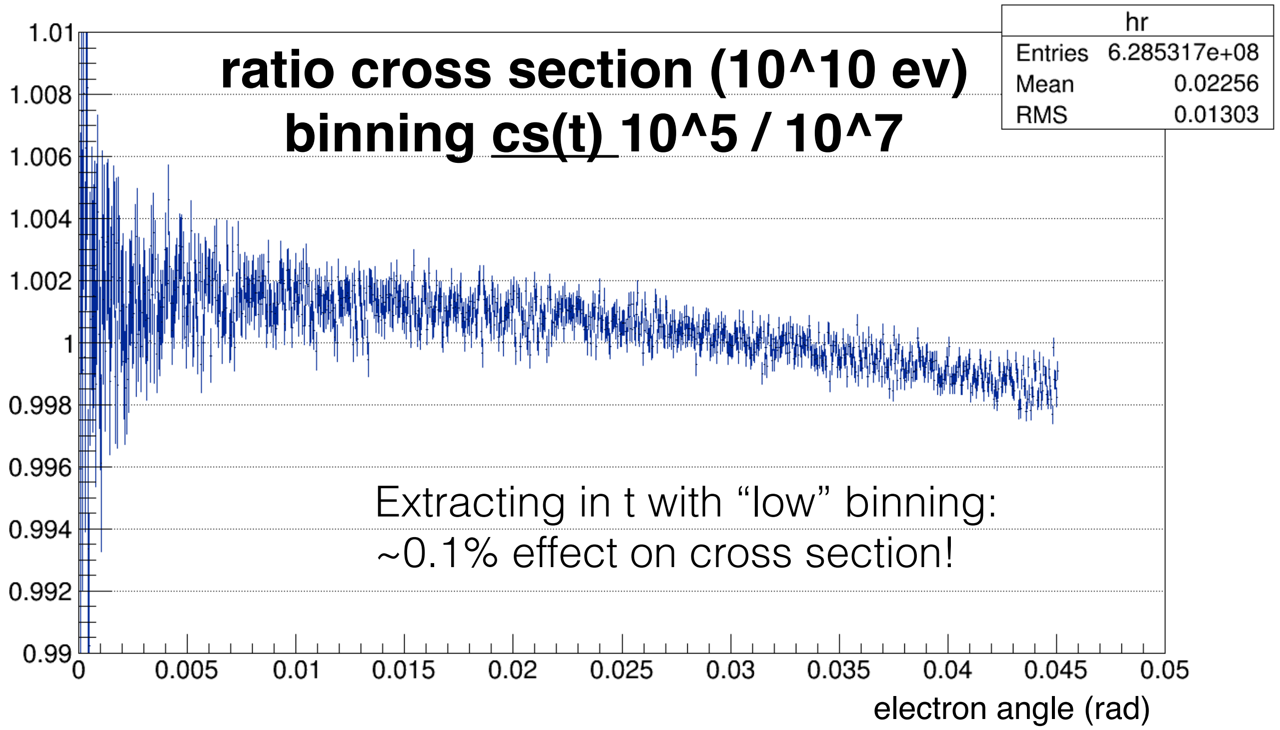
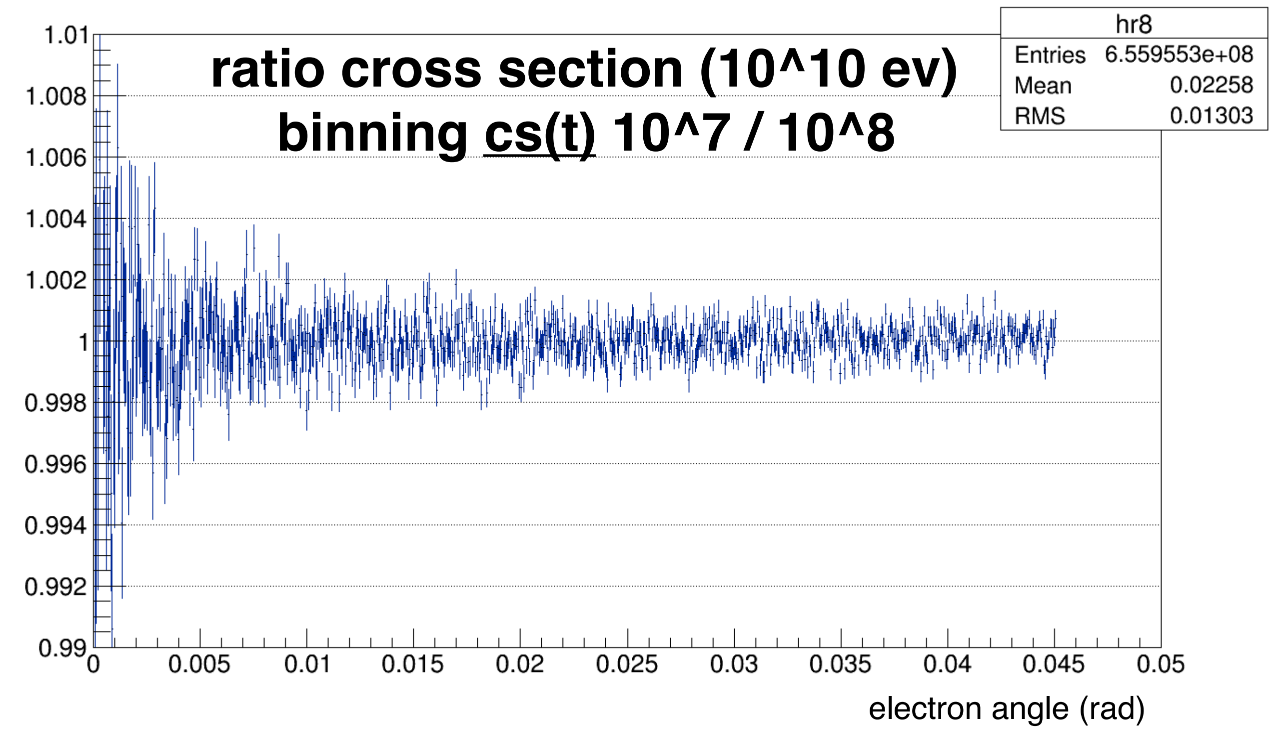
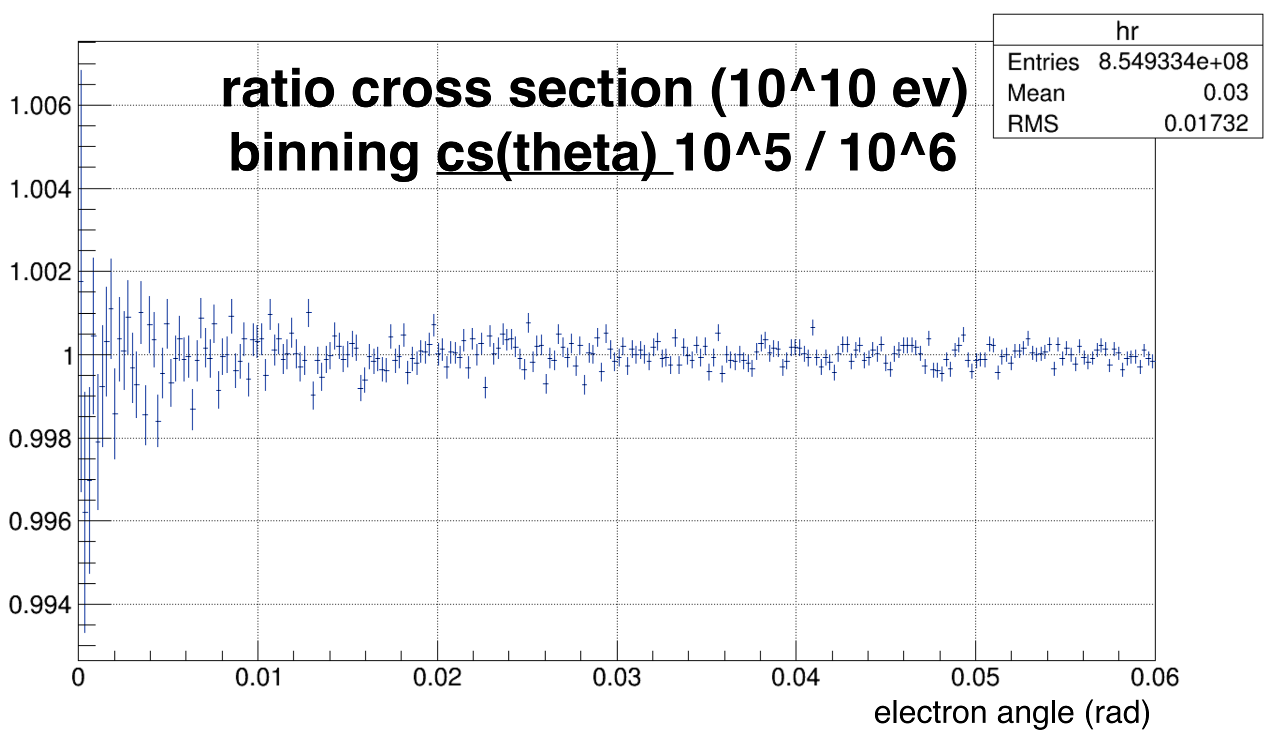
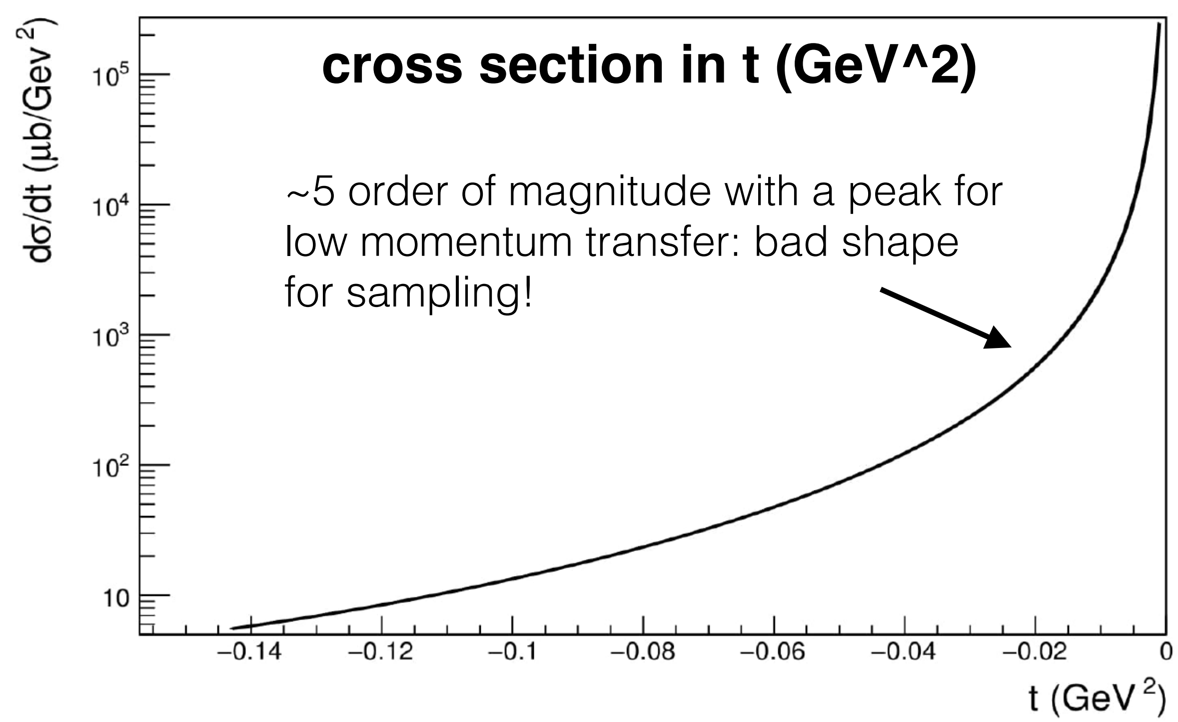
Sampling of differential cross sections



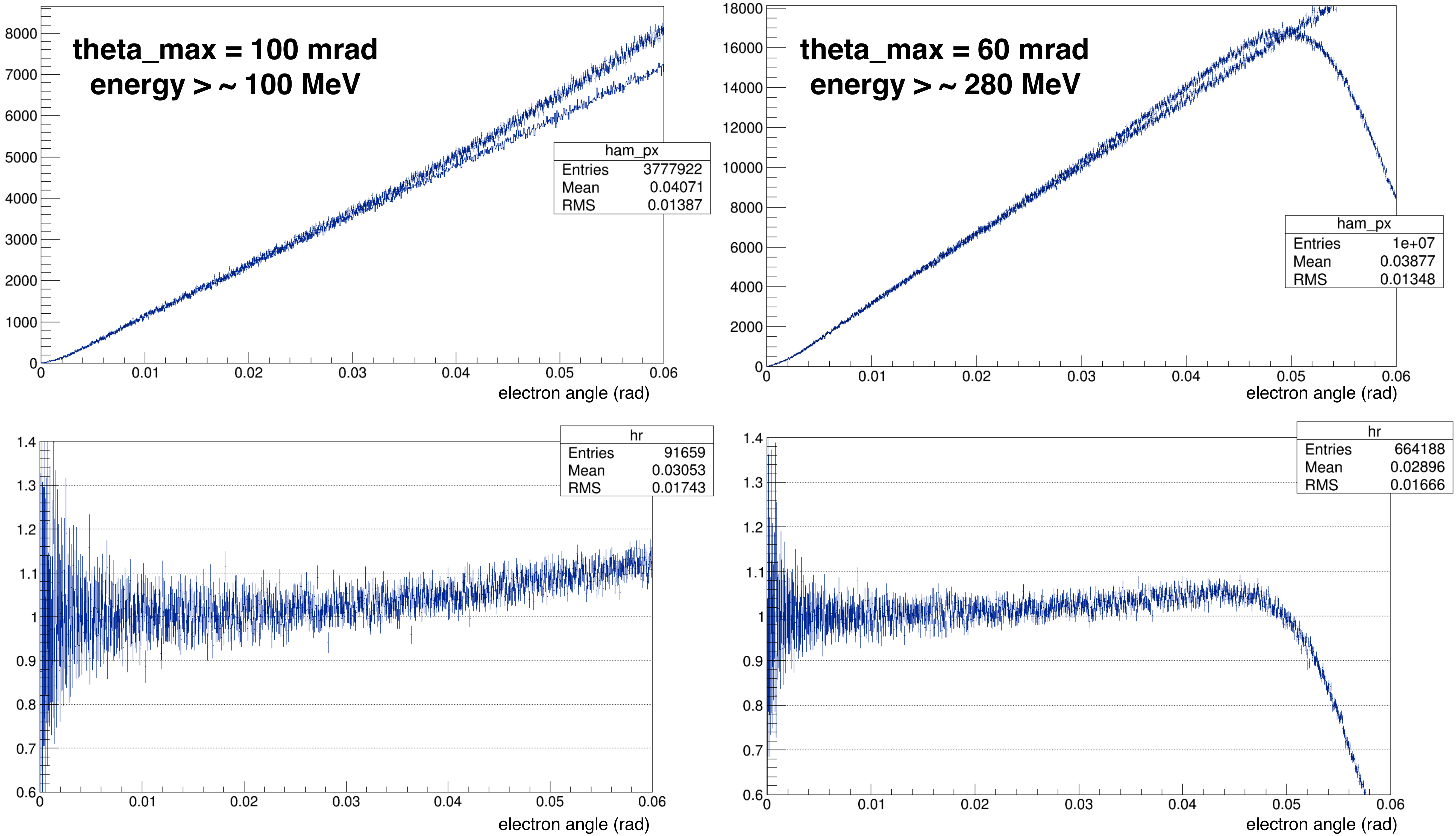






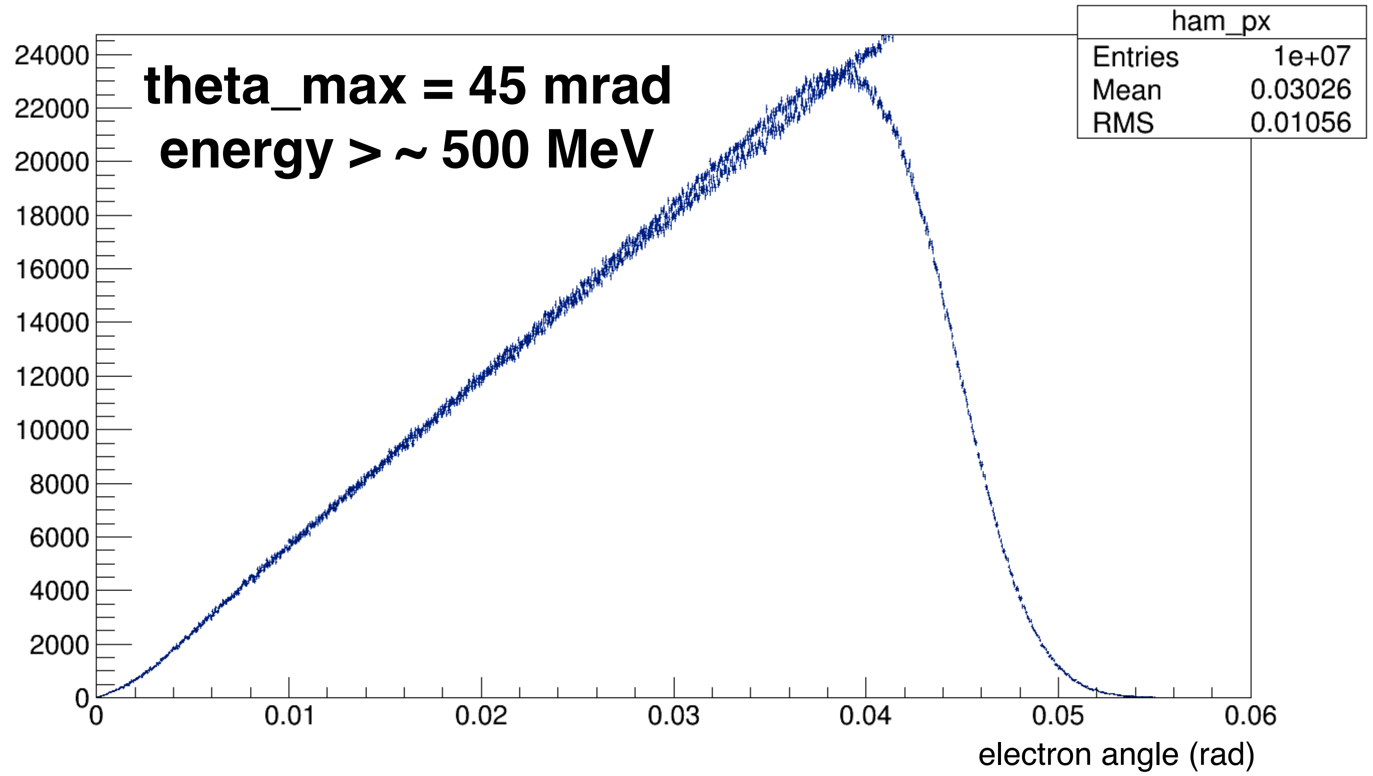
- Best and natural choice: extract in electron angle (not in t) and choice max angle (next slide).

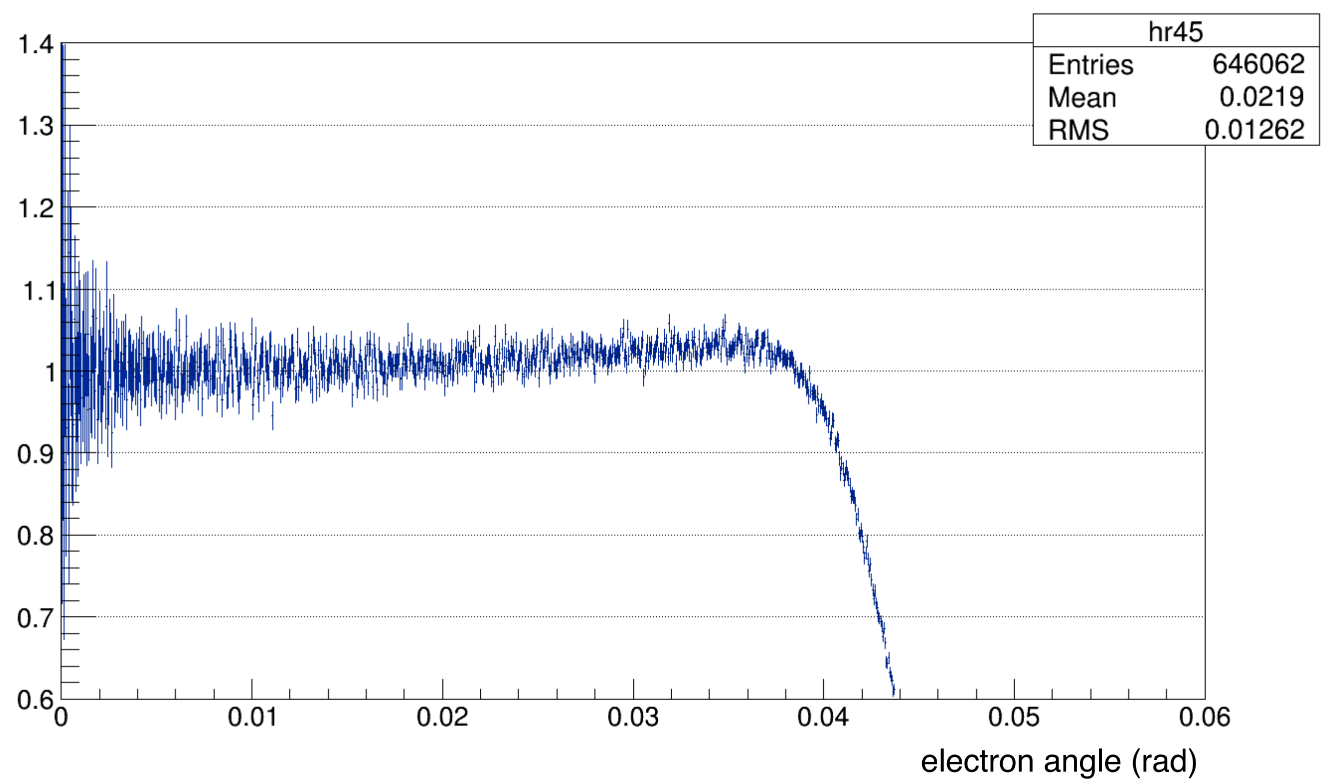
Max angle for smeared LO cross section



- **Question**: how to preserve the high angle region, but do not waste computing time? Max angle cut in generation distorts the spectrum.

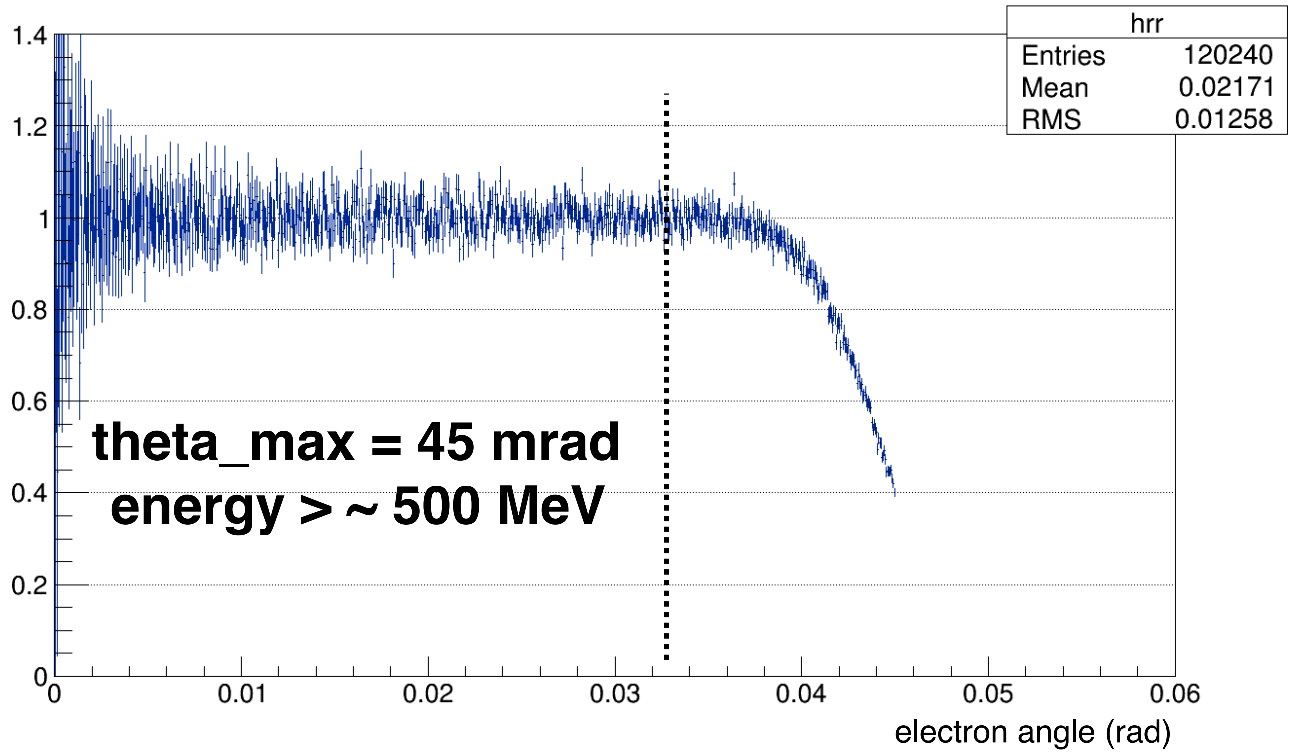
Max angle for smeared LO cross section

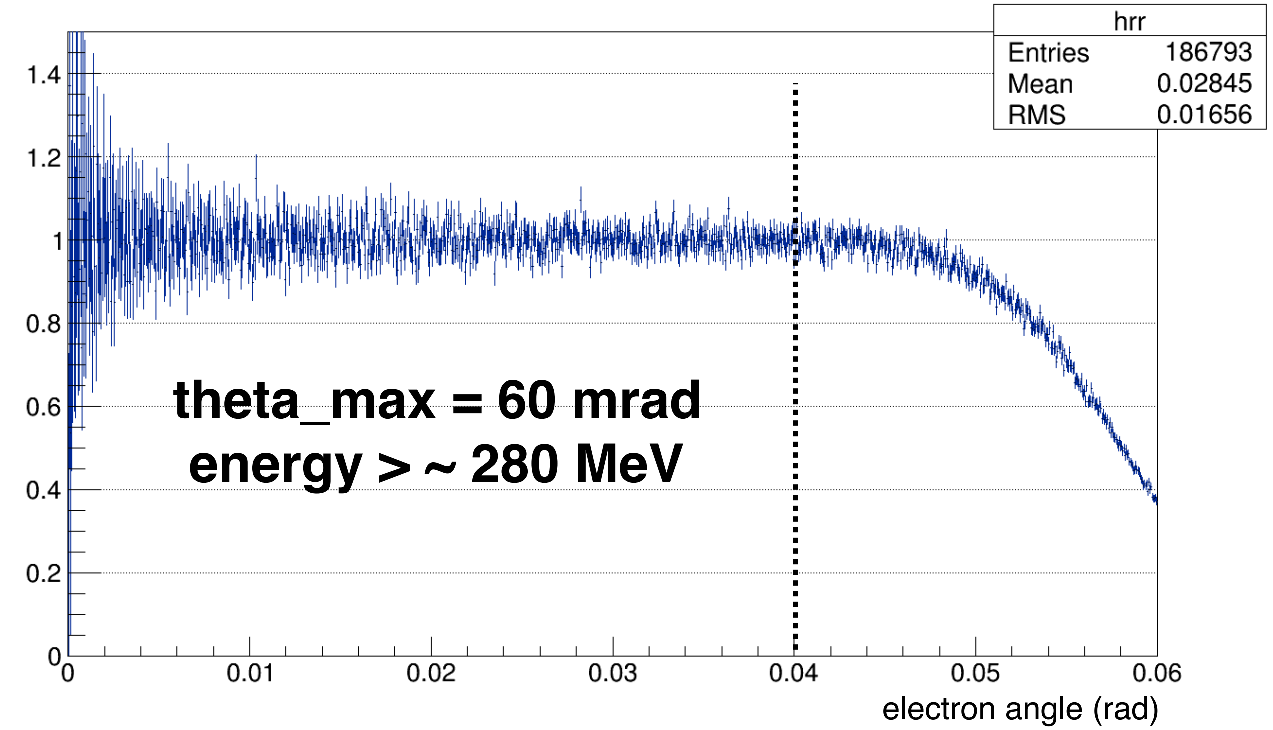




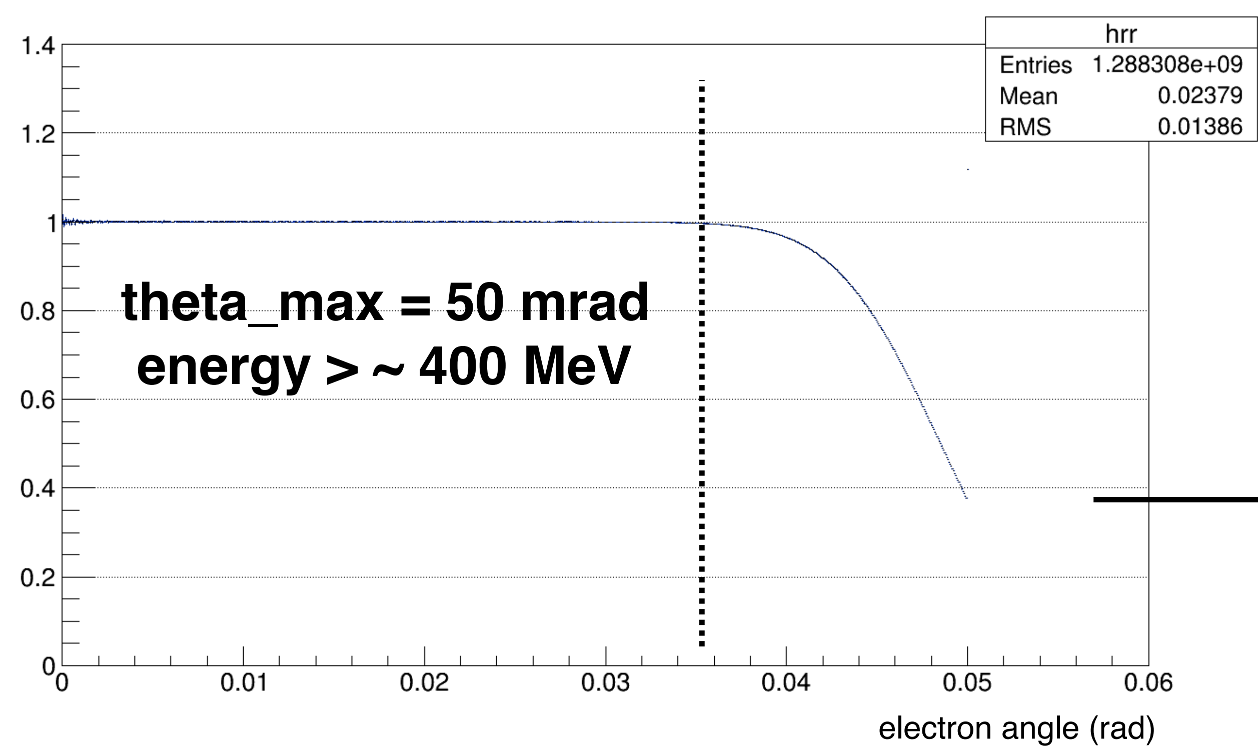
- Although low statistics samples, a 45 mrad cut affects the angular spectrum too much: next slide.
- **n.b. Angle cut = energy cut on "true" value (at interaction).**

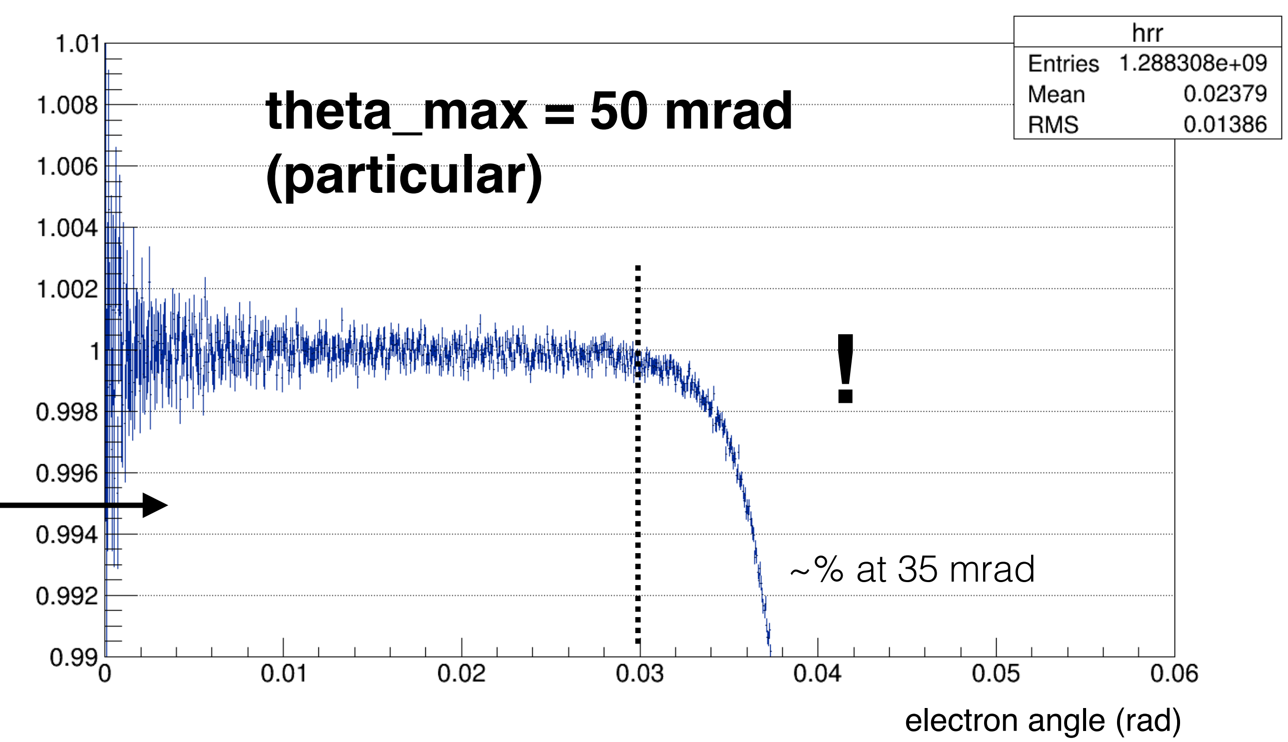
Angle distortion respect of 100 mrad cut





high statistics sample, cut 50 mrad

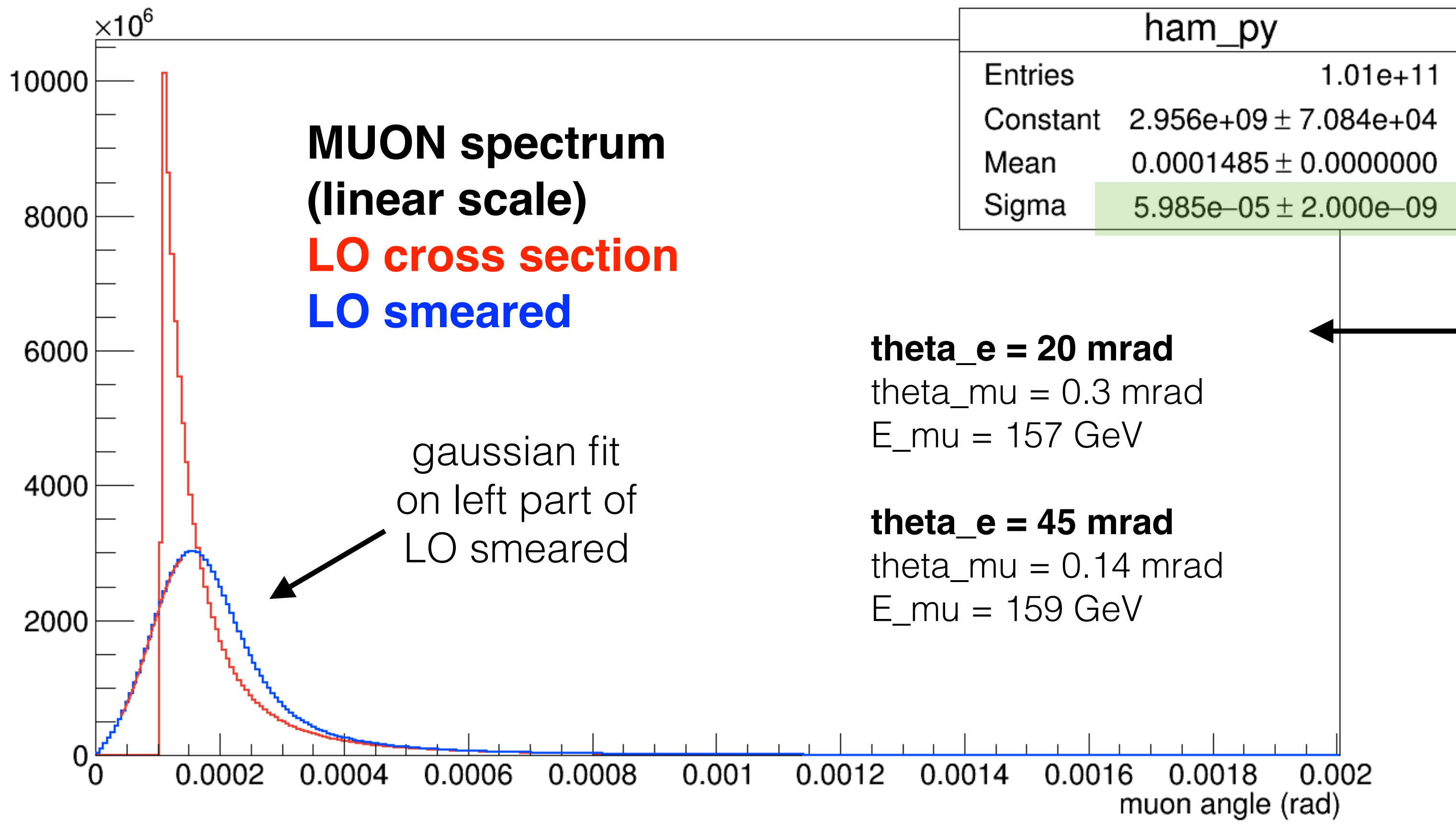




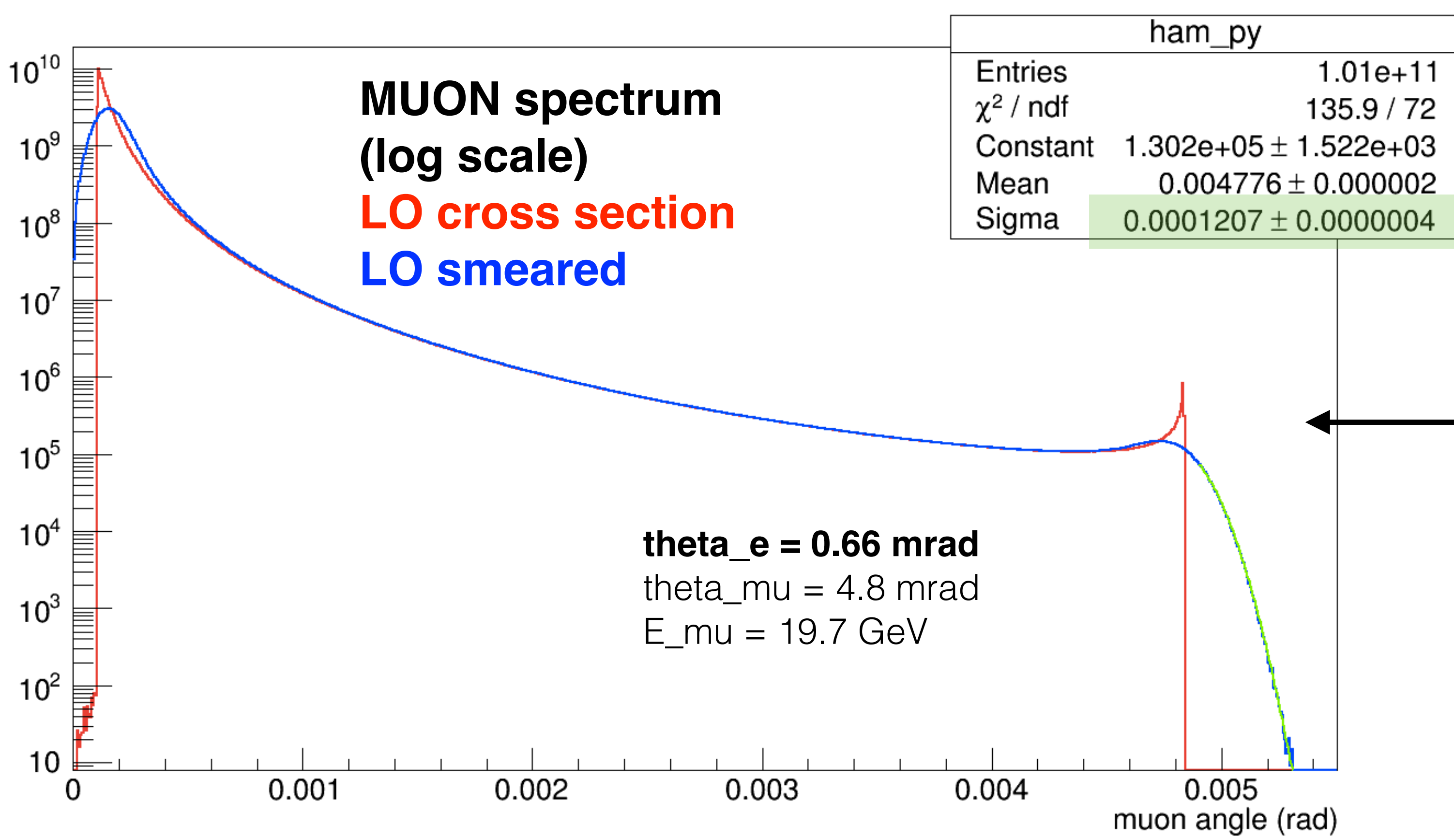
- **Conclusion**: Looking for a trade-off between CPU time and accuracy, ~60 mrad looks better to preserve the region until 35 mrad.

Fast simulation:
examples of possible studies

Muon smeared cross section: first view



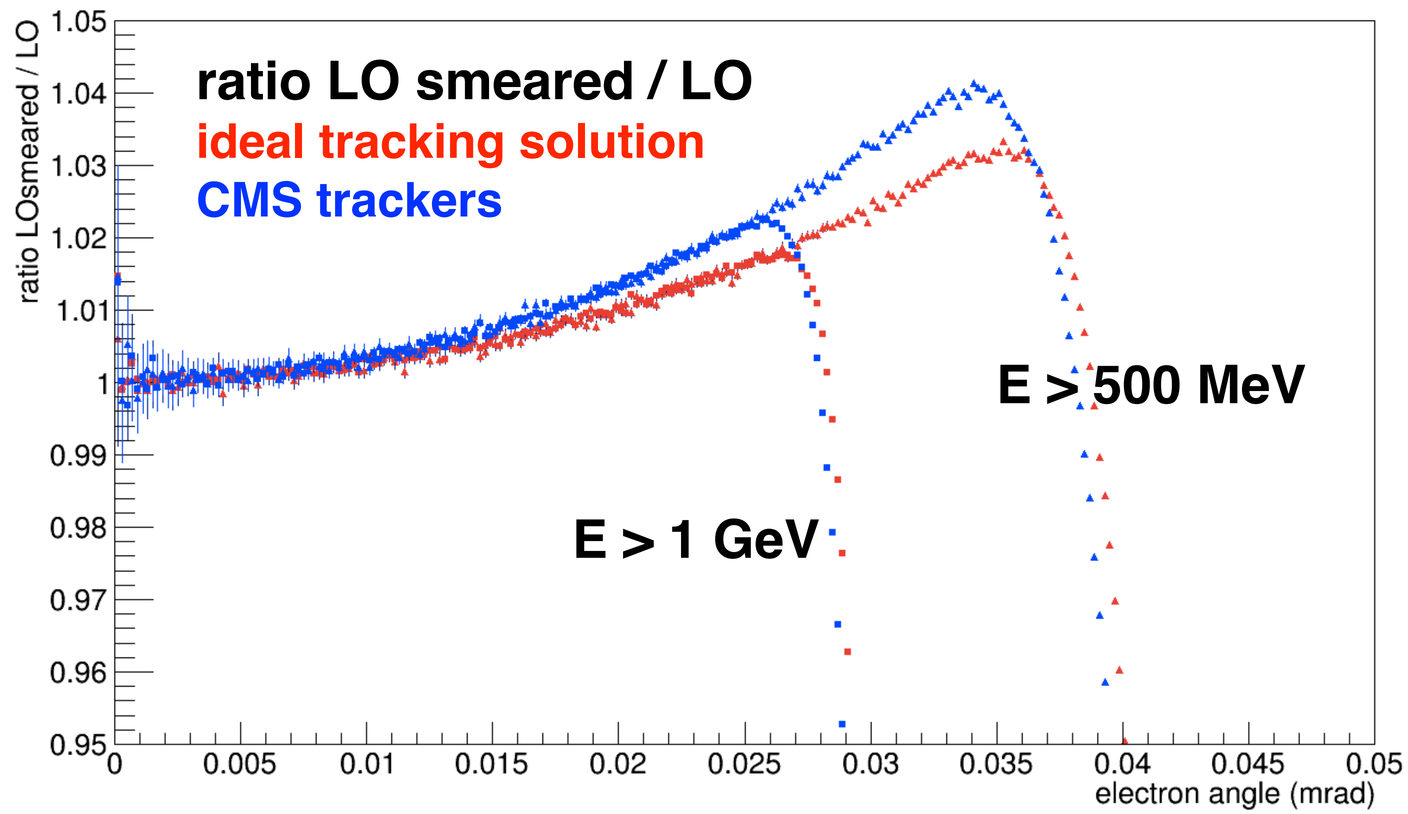
- **Low angle peak**: high energy muons, E > ~150 GeV, smeared because of intrinsic resolution.
- Here CBC doublet solution: **0.059 mrad point resolution** inserted as a par[1] in parametrization.
- An adventurous fit of left part of gaussian-like shape gets us this value!

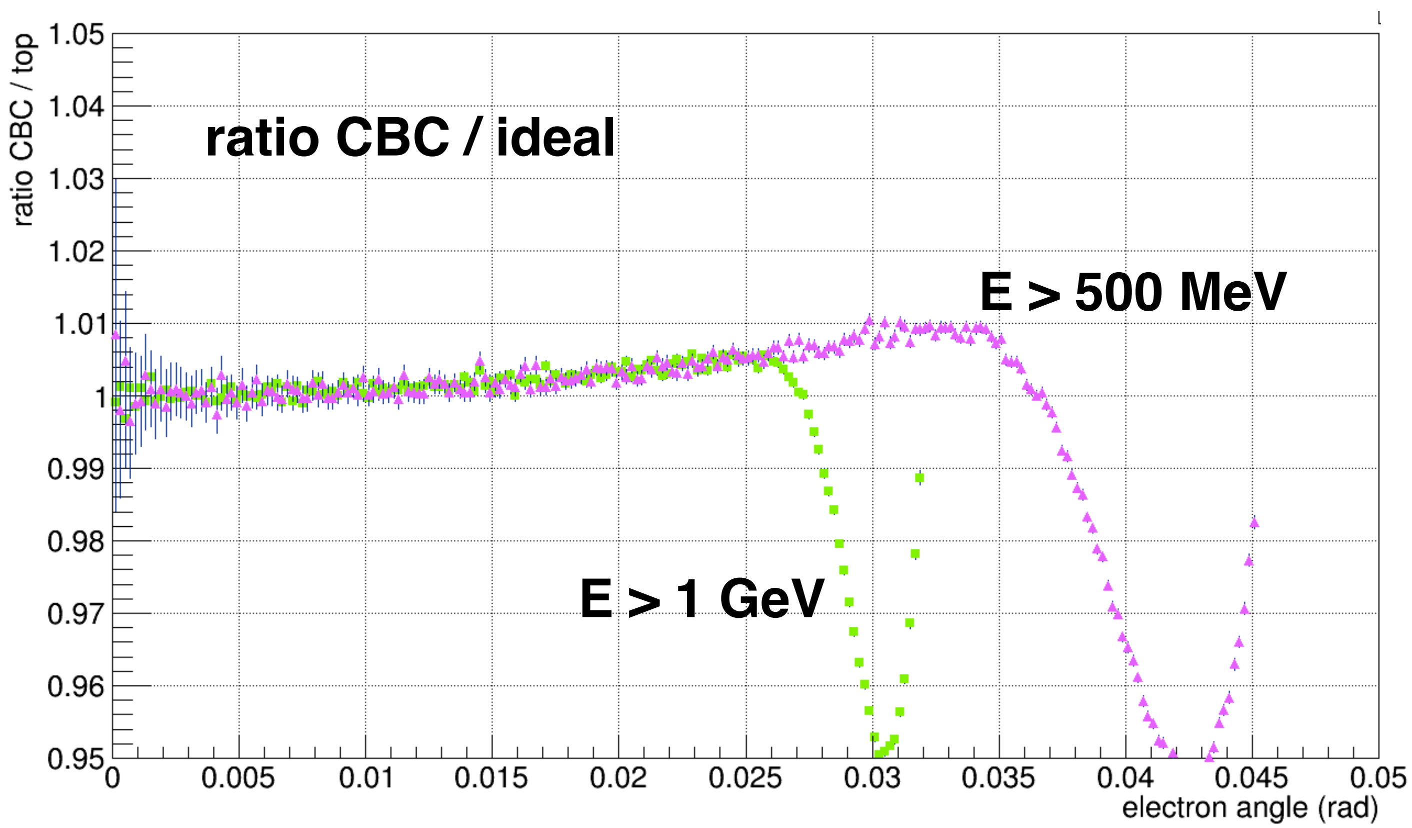


- **High angle peak**: low energy muons, E < ~20 GeV, smeared because of multiple scattering.
- Here CBC: **1.2 mrad sigma mcs at 1 GeV** inserted as a par[0] in parametrization.
- A fit of right part of shape gives exactly 0.12 mrad, expected for 10 GeV muons, so twice for ~20 GeV muons (at peak).

- Anyway muon cross section carry very useful information about apparatus, because of its shape.

Comparison ideal / CBC: spectrum smearing

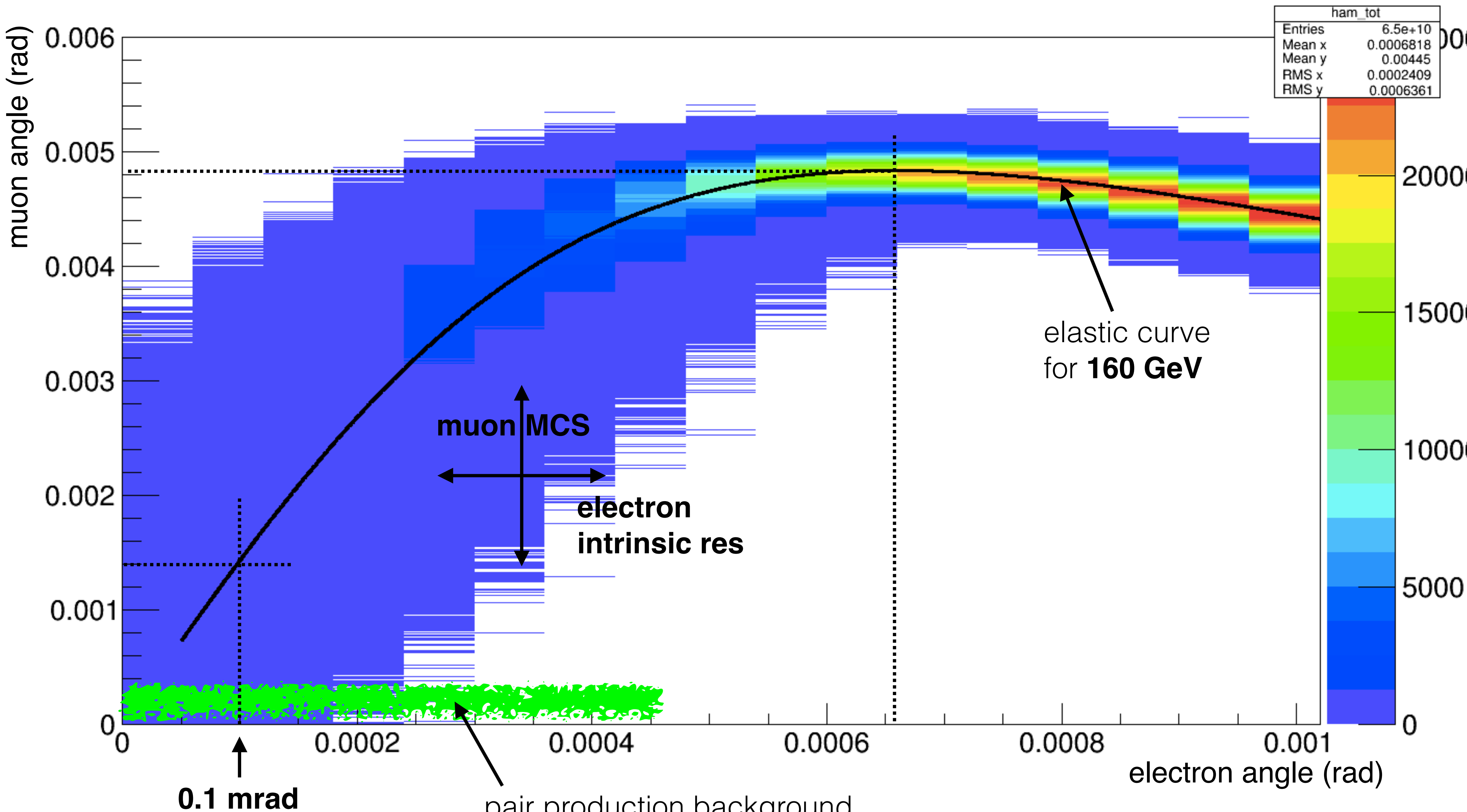




- **Tracking solution:** fast MC allows us to study different solutions and their impact on final measure.
- Here: red curve shows the "best solution" from the point of view of material budget, 300 um silicon for x/y single sided against blue (CBC), 600 um doublet.

- **Measure strategy**: if we want to use the normalization region up to 30-35 mrad, we <u>cannot cut to 1 GeV</u>: have to measure from 500-600 MeV. But this region is very problematic because it is the most affected by experimental smearing.

Correlation plot at low angle: [0, 1] mrad, 160 GeV



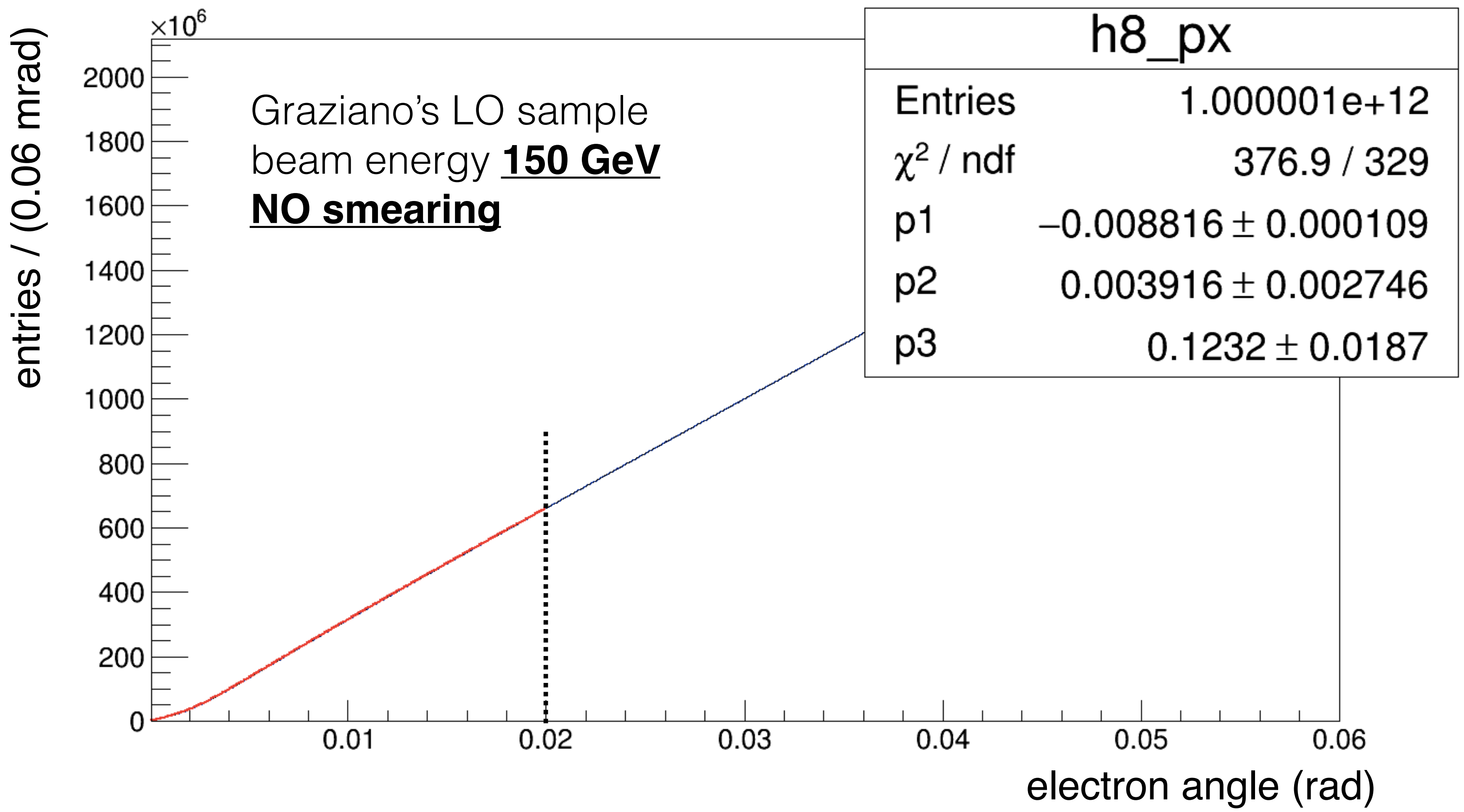
For theta_e = 0.1 mrad:
muon energy ~10.4 GeV
electron energy ~149.6 GeV
x(t) = 0.9360, t = -0.1528 GeV^2
Dalpha_had ~ 0.00109

For theta_e = 0.66 mrad:
muon energy ~19.2 GeV
electron energy ~140.8 GeV
x(t) = 0.9325, t = -0.1439 GeV^2
Dalpha_had ~ 0.00104

Fitting attempts:

Graziano’s and our smeared data (low statistics)

LO cross section fit: extracting final measure



Statistics: ~1/13.3 of requested at L = 1.5e+7 nb.

For theta_e = 20 mrad (150 GeV):
muon energy ~147.5 GeV
electron energy **~2.5 GeV**
x(t) = 0.378, t = -0.00256 GeV^2
Dalpha_had ~ 2.33e-05

- **Strategy**: shape fit of cross section within [0,20] mrad, using least squares / maximum likelihood, <u>without using of "normalization region" (theta > 20-25 mrad)</u>

$$f(\theta_e) = [0] \cdot \left(\frac{d\sigma}{d\theta_e}\right)^{LO} = [0] \cdot \frac{4\pi\alpha^2(t)}{\lambda(s, m_\mu^2, m_e^2)} \left(\frac{(s - m_\mu^2 - m_e^2)^2}{t^2} + \frac{s}{t} + \frac{1}{2}\right) \left|\frac{dt}{d\theta_e}\right|$$

← **model**: first loop to fix pdf normalization [0].

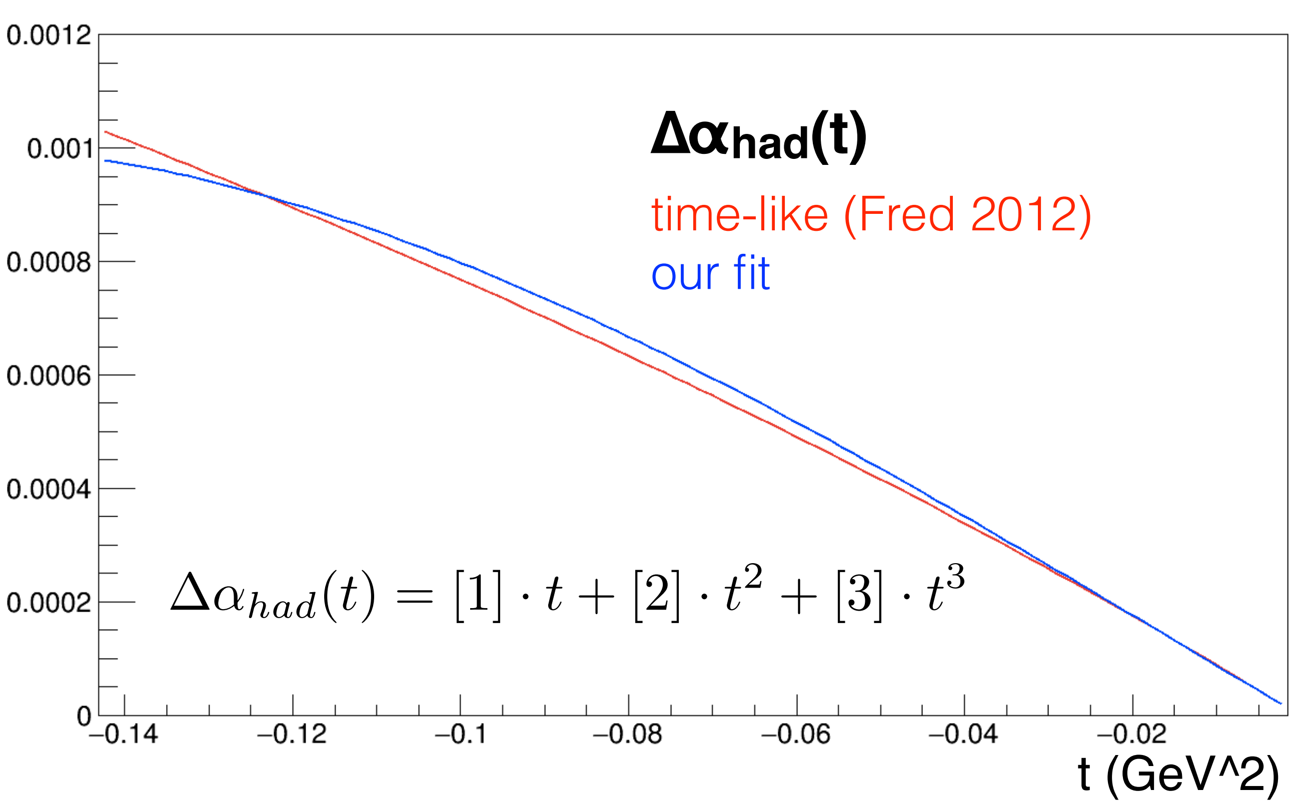
$$\alpha(t) = \frac{\alpha_0}{1 - \Delta\alpha(t)} = \frac{\alpha_0}{1 - \Delta\alpha_{lep}(t) - \Delta\alpha_{had}(t)}$$

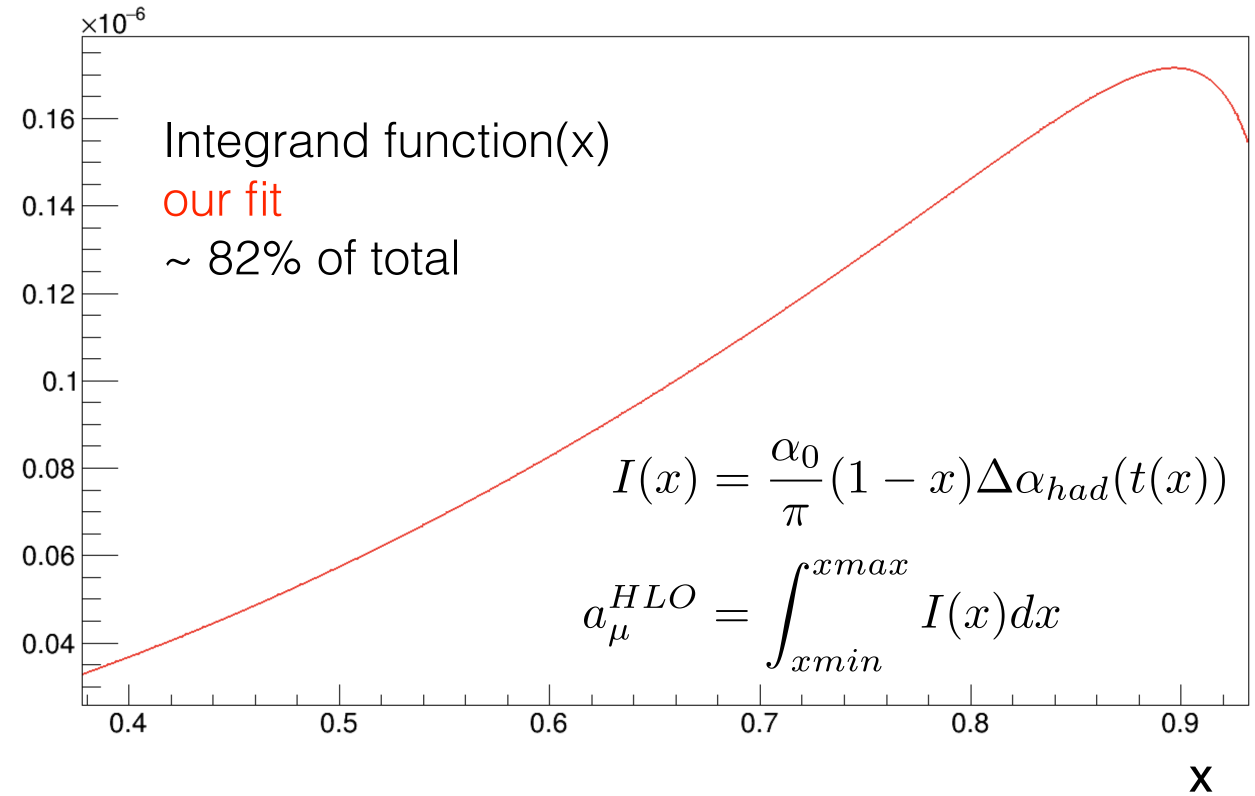
← **running**: leptonic part from Carlo's routine

$$\Delta\alpha_{had}(t) = [1] \cdot t + [2] \cdot t^2 + [3] \cdot t^3$$

← **had part**: pol3 from literature (also Padé function with 3 parameter)

LO not smeared fit: our exercise at 1/13 of full stat





Integration interval in x: 0.377952 0.932039
Angle MIN: 0.0001 rad, angle MAX: 0.02 rad
tmin: -0.142698 GeV^2 tmax: -0.00256365 GeV^2
electron energy
MIN: 2.50898 GeV, MAX: 139.627 GeV

**** amu^HLO *****

integral in x time-like (from Fred '12):	**5.58042e-08**
integral with gaussian integrator:	**5.64466e-08**
integral error in x (analytical):	**1.03782e-09**

a_μ^{HLO} = (564 ± 10) · 10^{-10}
precision: 1.77%

~% difference in time-like value: different parametrization?

X= 0.377952 - 0.931984

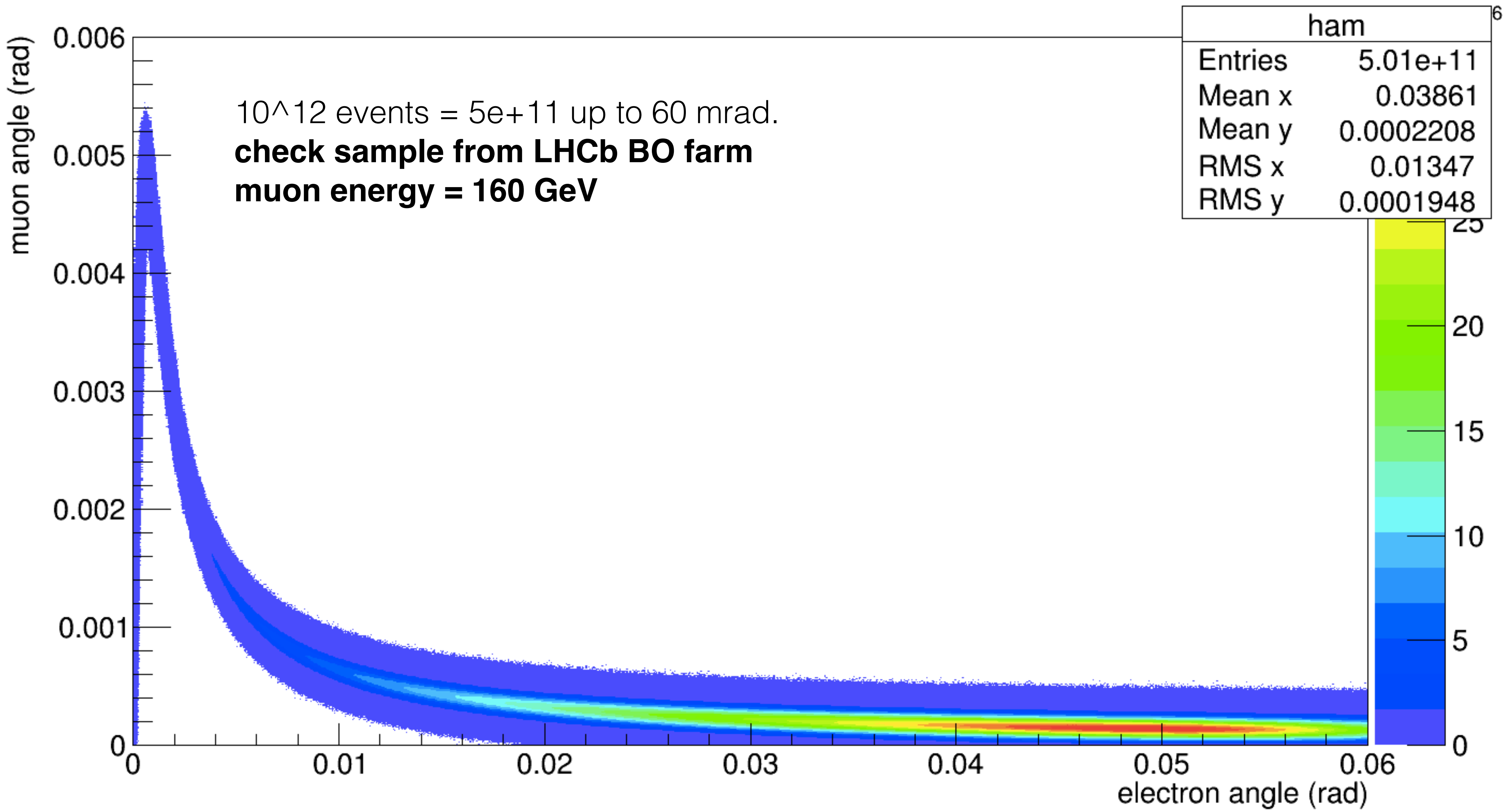
From timelike data:
Δa_μ^{LO} = 563.4 +- 2.8 x 10^{-10}

Integral After last iteration:
565.5 +- 7.8 x 10^{-10}

Precision 1.37%
Compatible with 0.4%

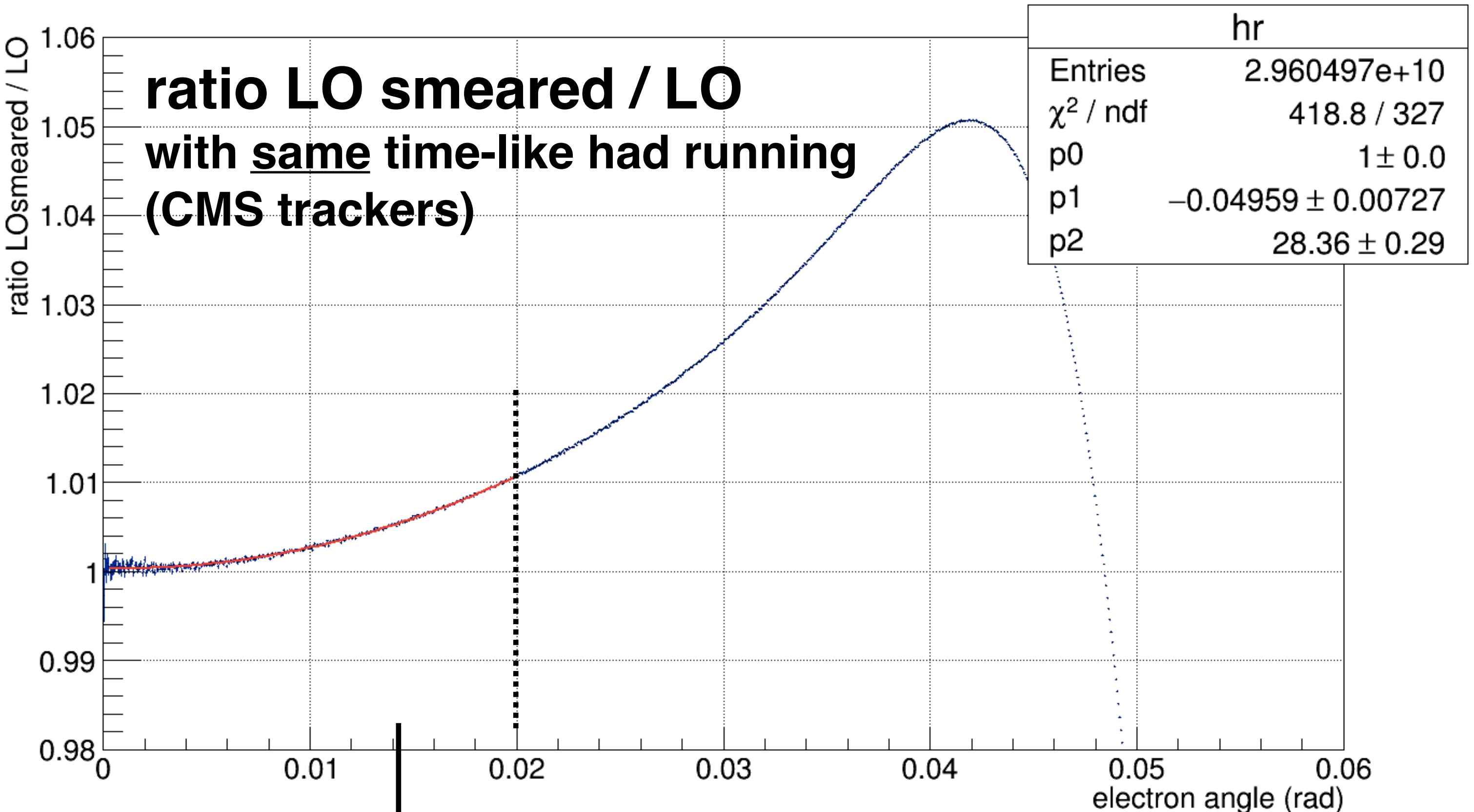
Fedor

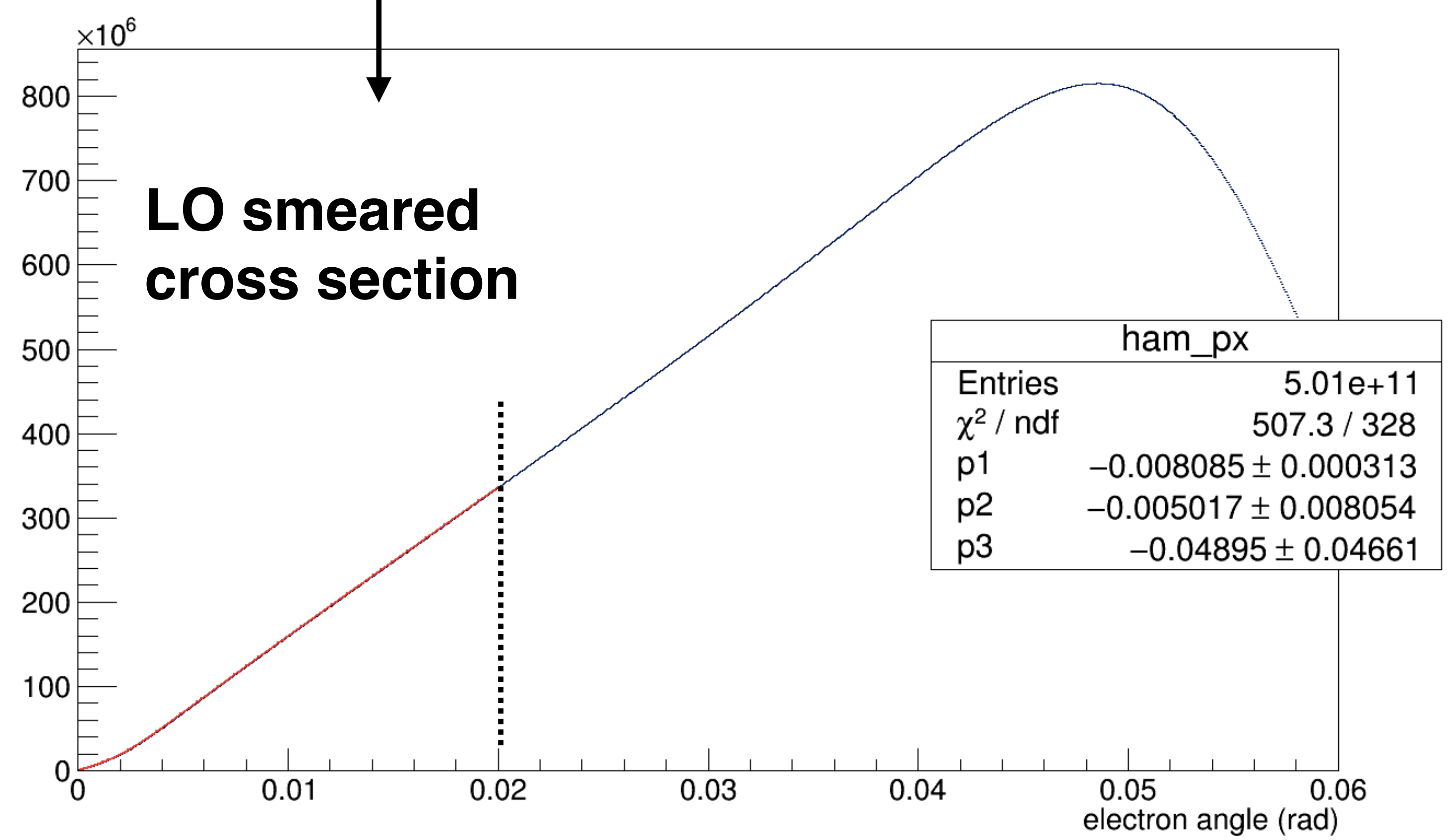
Cross section smeared fit: first view at low stat (~1/33)



- **Statistics: 1/32.8** of requested one at L = 1.5e+7 nb.
- **First fitting strategy** for smeared sample: extract a correction function in θ_e to apply at LO cross section (model), from ratio between LO smeared and LO with same running and statistics. All in "signal region" (θ_e < 20 mrad), without using "normalization" one.
- **Strong hypothesis:** ratio LO smeared / LO (all MC) with same running should be dependent only from apparatus, i.e. the correction function (or maybe a correction histo) has to be universal and independent from running. Obviously we're checking this… (impossible to say something at low statistics).

Cross section **smeared** fit: first results at **low stat (~1/33)**





- Correction function: pol2 but looks better pol3.

- Beam energy: **160 GeV.**
- Time-like, x [0.378126 0.936009]: **564.4e-10**

- LO fit (**NOT smeared**) results, θ_e [0,20] mrad:

$a_\mu^{HLO} = (539 \pm 23) \cdot 10^{-10}$
precision: 4.3%

- LO fit (**smeared**) results, θ_e [0,20] mrad:

$a_\mu^{HLO} = (533 \pm 31) \cdot 10^{-10}$
precision: 5.8%

- These preliminary results was obtained with a statistics of less than one month of data taking!
- With less events, we obtained higher values respect of time-like, so we're seeing statistical oscillations.

- **This is an exercise yet**, because I applied correction function at the same LO smeared sample! (with the same had running).

Conclusions

- We're completing cross checks of generated samples: with LHCb BO farm we should be able to produce full statistics (~1.6e+13 within 60 mrad) in a reasonable time.
- This fast MC is a starting point, but for the first time we can work with this statistics on smeared samples: it's showing us interesting results on measurement constraints and it will be a tool for future studies to answer to this question: <u>how different setups / sensors propagate their effects on final measure?</u>
- Fitting attempts was developed firstly to check our samples, but anyway preliminary results are interesting.