Muon Resolution Studies for the Higgs Mass Measurement

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ATLAS Canada Summer Student Presentations
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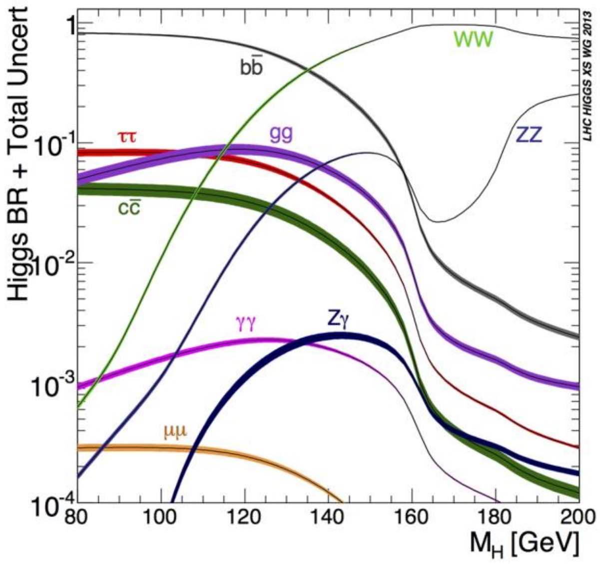
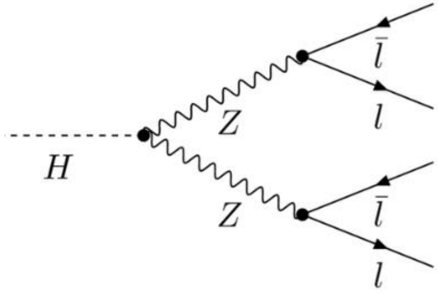
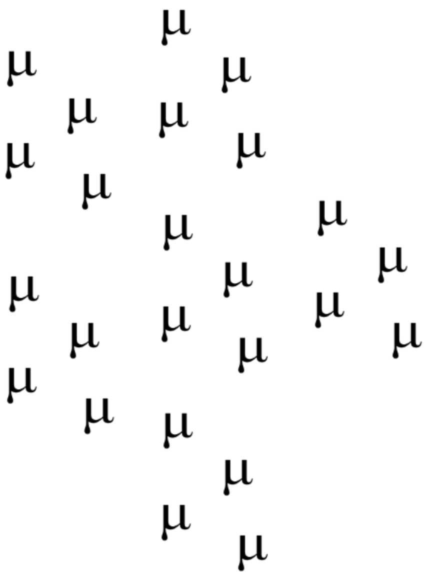
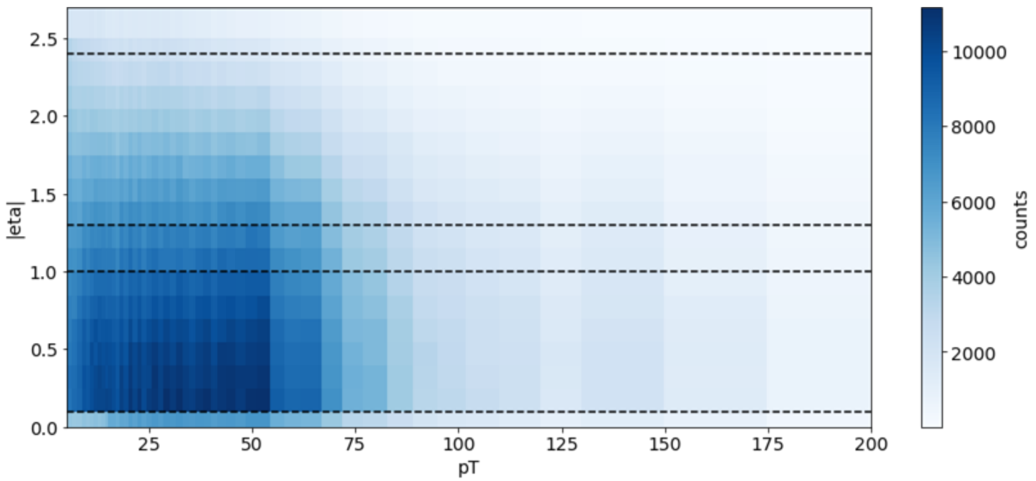




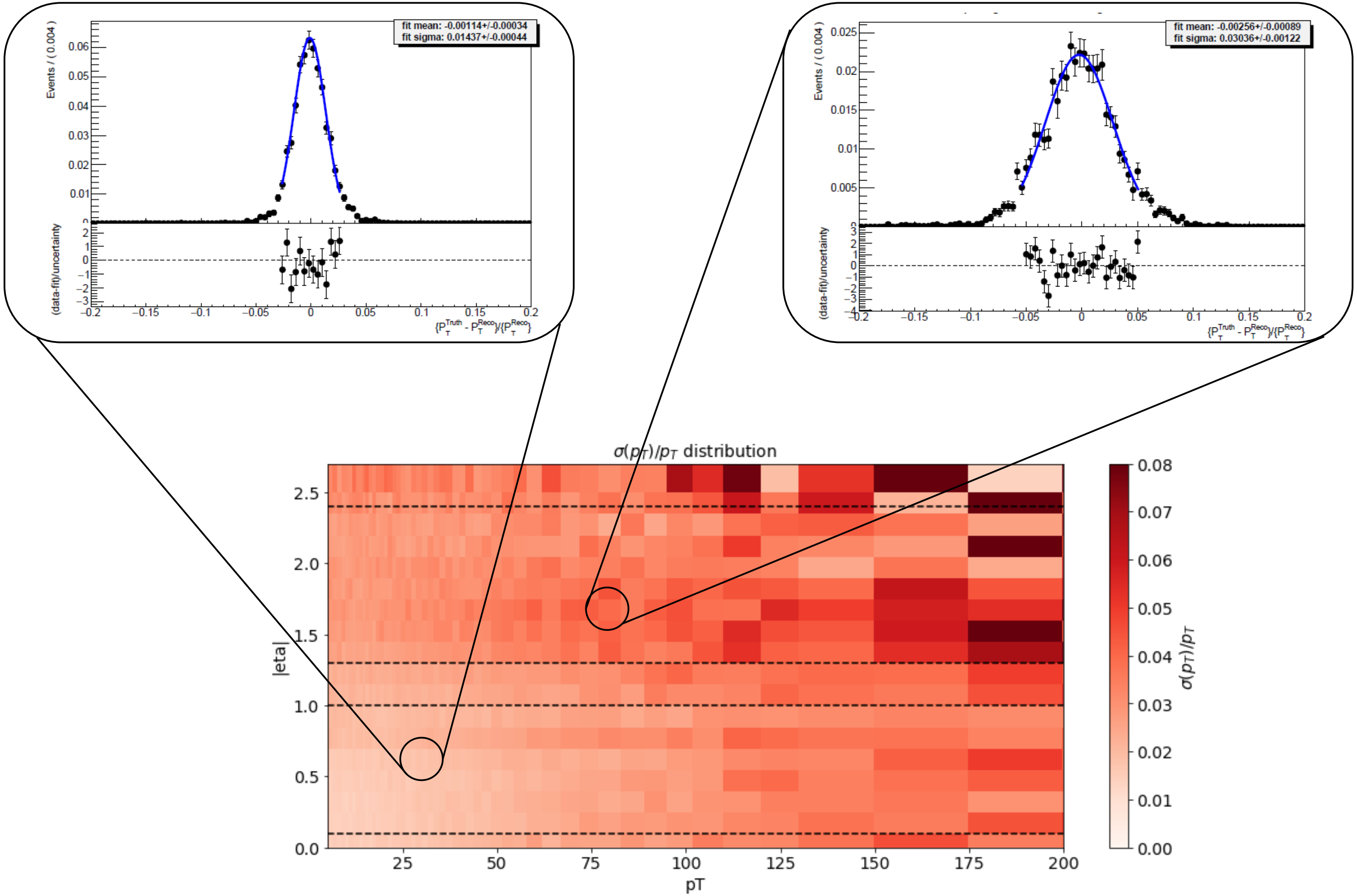
http://opendata.atlas.cern/books/current/get-started/_book/the-higgs-boson.html

Method





|eta|
pT
counts
0.0
0.5
1.0
1.5
2.0
2.5
25
50
75
100
125
150
175
200
2000
4000
6000
8000
10000


fit mean: -0.00114+/-0.00034
fit sigma: 0.01437+/-0.00044
Events / (0.004)
(data-fit)/uncertainty
{P_T^Truth - P_T^Reco}/{P_T^Reco}
fit mean: -0.00256+/-0.00089
fit sigma: 0.03036+/-0.00122
Events / (0.004)
(data-fit)/uncertainty
{P_T^Truth - P_T^Reco}/{P_T^Reco}
σ(p_T)/p_T distribution
|eta|
pT
σ(p_T)/p_T

$\mu_{\sigma(p_T)}$

$\mu_{\sigma(p_T)}$

$\mu_{\sigma(p_T)}$

$\mu_{\sigma(p_T)}$

Standard Error Propagation →

m_{4l}

$\sigma(m_{4l})$

Higgs Mass & Uncertainty

μ μ μ μ

$$m_{4l}^2 = \left(\sum_i E_i\right)^2 - \left|\sum_i \vec{p}_i\right|^2 \approx \left(\sum_i p_i\right)^2 - \left|\sum_i \vec{p}_i\right|^2$$

$$m_{4l}^2 = \sum_{i \neq j} (p_i p_j - \vec{p}_i \cdot \vec{p}_j)$$

μ μ μ μ

$$m_{4l}^2 = \left(\sum_i E_i\right)^2 - \left|\sum_i \vec{p}_i\right|^2 \approx \left(\sum_i p_i\right)^2 - \left|\sum_i \vec{p}_i\right|^2$$

$$m_{4l}^2 = \sum_{i \neq j} (p_i p_j - \vec{p}_i \cdot \vec{p}_j)$$

$$p_x = p_T \cos(\phi),\ p_y = p_T \sin(\phi),\ p_z = p_T \sinh(\eta)$$

$$|\vec{p}| = p_T \sqrt{\cos^2(\phi) + \sin^2(\phi) + \sinh^2(\eta)} = p_T \cosh(\eta)$$

μ μ μ μ

$$m_{4l}^2 = \left(\sum_i E_i\right)^2 - \left|\sum_i \vec{p}_i\right|^2 \approx \left(\sum_i p_i\right)^2 - \left|\sum_i \vec{p}_i\right|^2$$

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$$|\vec{p}| = p_T \sqrt{\cos^2(\phi) + \sin^2(\phi) + \sinh^2(\eta)} = p_T \cosh(\eta)$$

$$m_{4l}^2 = \sum_{i \neq j} p_{T,i} p_{T,j} \left(\cosh(\eta_i - \eta_j) - \cos(\phi_i - \phi_j)\right)$$

μ
μ
μ
μ

$$m_{4l}^2 = \left(\sum_i E_i\right)^2 - \left|\sum_i \vec{p}_i\right|^2 \approx \left(\sum_i p_i\right)^2 - \left|\sum_i \vec{p}_i\right|^2$$

$$m_{4l}^2 = \sum_{i \neq j} (p_i p_j - \vec{p}_i \cdot \vec{p}_j)$$

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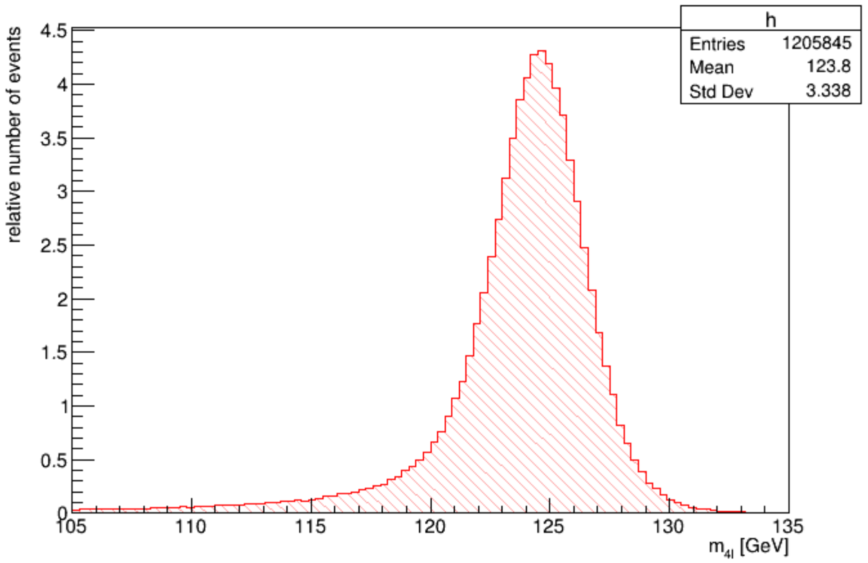
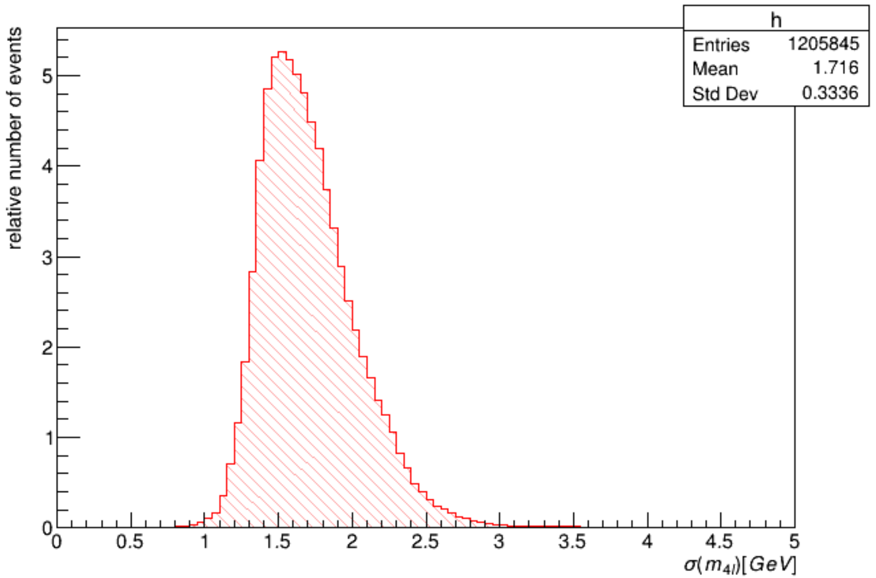
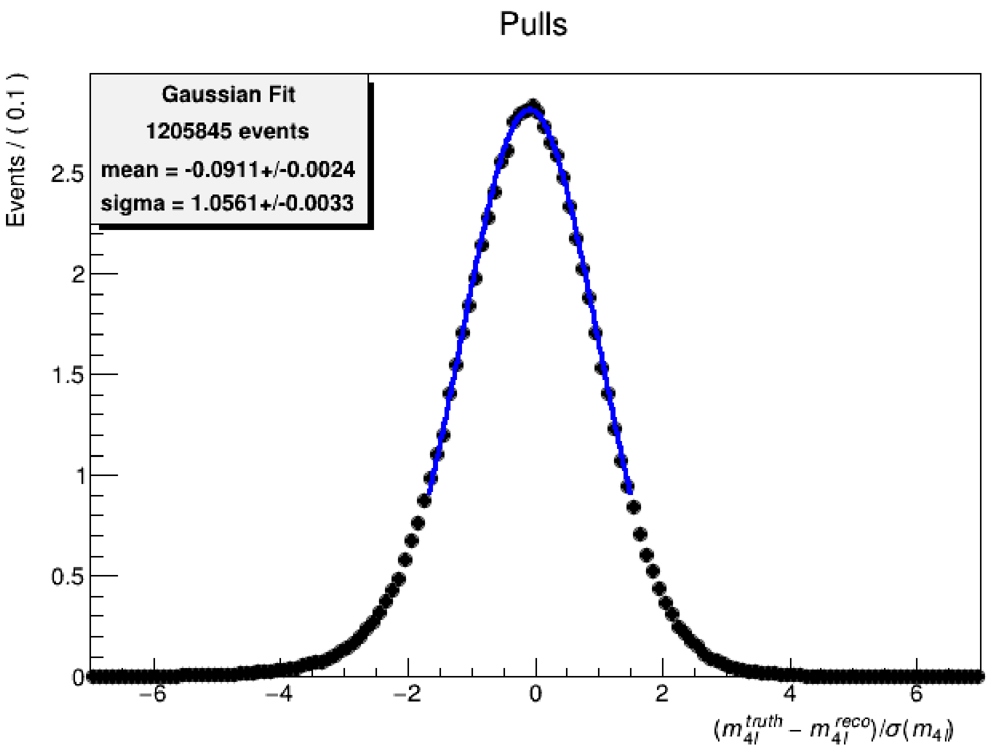
$$|\vec{p}| = p_T \sqrt{\cos^2(\phi) + \sin^2(\phi) + \sinh^2(\eta)} = p_T \cosh(\eta)$$

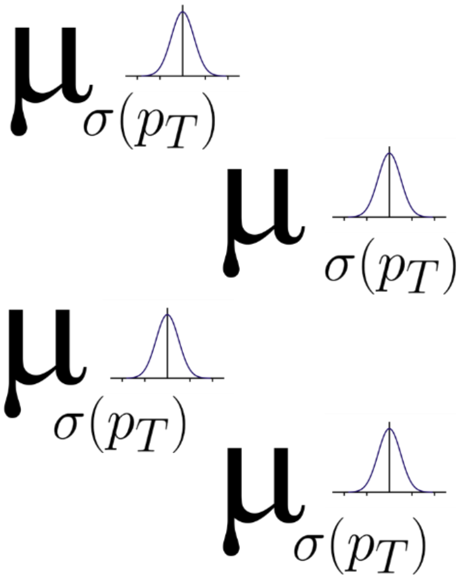
$$m_{4l}^2 = \sum_{i \neq j} p_{T,i} p_{T,j} \left(\cosh(\eta_i - \eta_j) - \cos(\phi_i - \phi_j)\right)$$

$$\sigma\left(m_{4l}^2\right) = \sqrt{\sum_i \left(\frac{\partial\left(m_{4l}^2\right)}{\partial p_{T,i}} \sigma(p_{T,i})\right)^2}$$


h
Entries 1205845
Mean 123.8
Std Dev 3.338
relative number of events
m_{4l} [GeV]

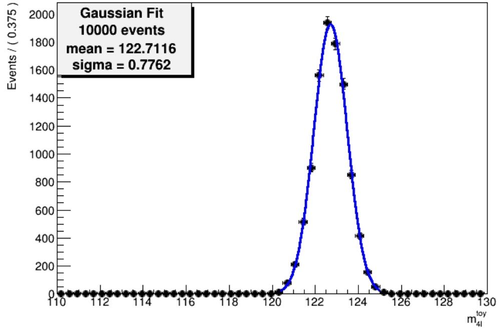

h
Entries 1205845
Mean 1.716
Std Dev 0.3336
relative number of events
$\sigma(m_{4l})[GeV]$


Pulls
Gaussian Fit
1205845 events
mean = -0.0911+/-0.0024
sigma = 1.0561+/-0.0033
Events / (0.1)
$(m_{4l}^{truth} - m_{4l}^{reco})/\sigma(m_{4l})$

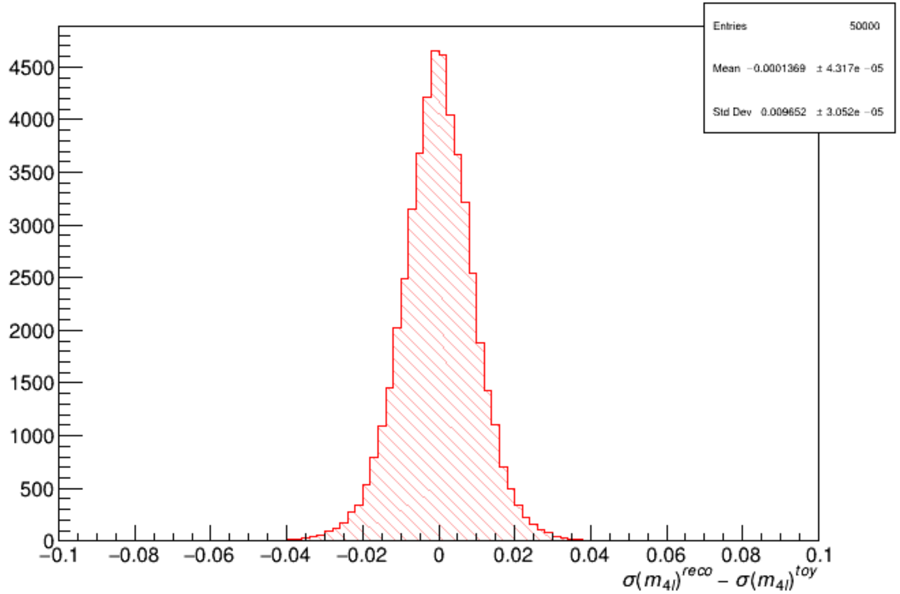


Sample many times

m_{4l} distribution

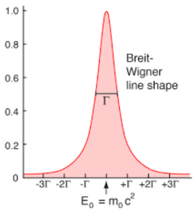


Higgs Mass & Uncertainty



Entries 50000
Mean −0.0001369 ± 4.317e −05
Std Dev 0.009652 ± 3.052e −05
4500
4000
3500
3000
2500
2000
1500
1000
500
0
−0.1
−0.08
−0.06
−0.04
−0.02
0
0.02
0.04
0.06
0.08
0.1
$\sigma(m_{4l})^{reco} - \sigma(m_{4l})^{toy}$

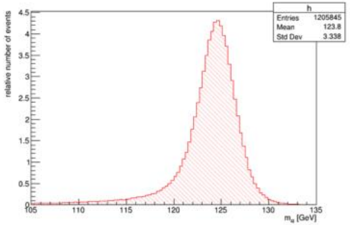
Mass Measurement



True mass value m_H

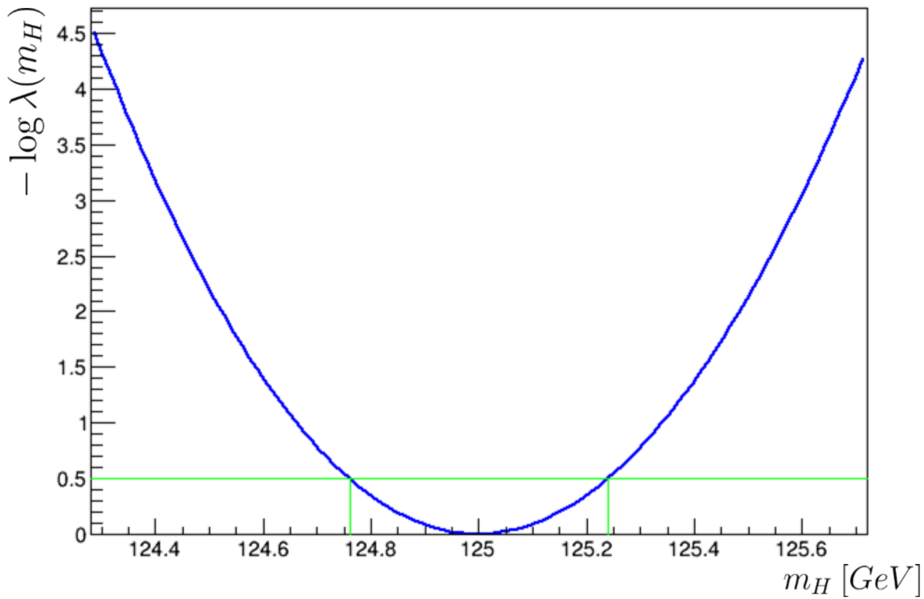
?

The mean of the resultant mass distribution (a double crystal ball)

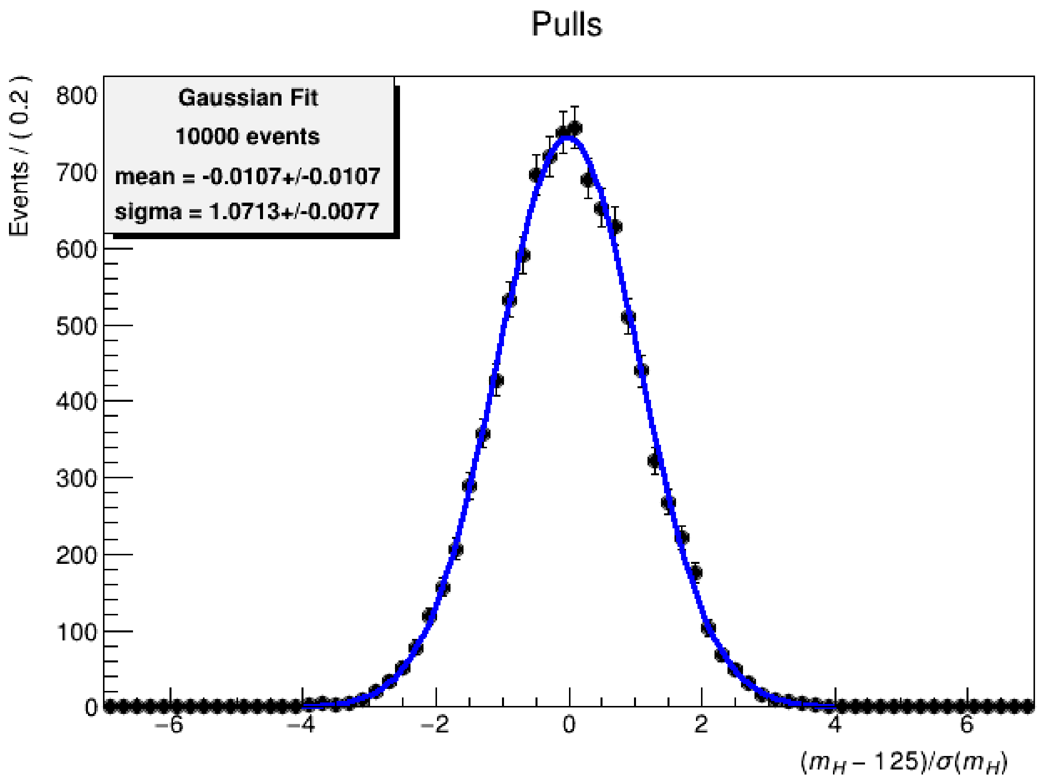


$$\text{mean} = a(m_H - 125) + b$$

Maximize the profile likelihood ratio λ with respect to m_H on, say, 125 GeV MC



$$125.00^{+0.24}_{-0.24} \quad GeV$$


Pulls
Gaussian Fit
10000 events
mean = -0.0107+/-0.0107
sigma = 1.0713+/-0.0077
Events / (0.2)
800
700
600
500
400
300
200
100
0
−6
−4
−2
0
2
4
6
$(m_H - 125)/\sigma(m_H)$

Summary:

- We have a simple, robust, and valid way of estimating per-event mass resolution
- We are still working on a model that improves the final mass resolution

$$125.00^{+0.24}_{-0.24} \quad GeV$$

Thanks!

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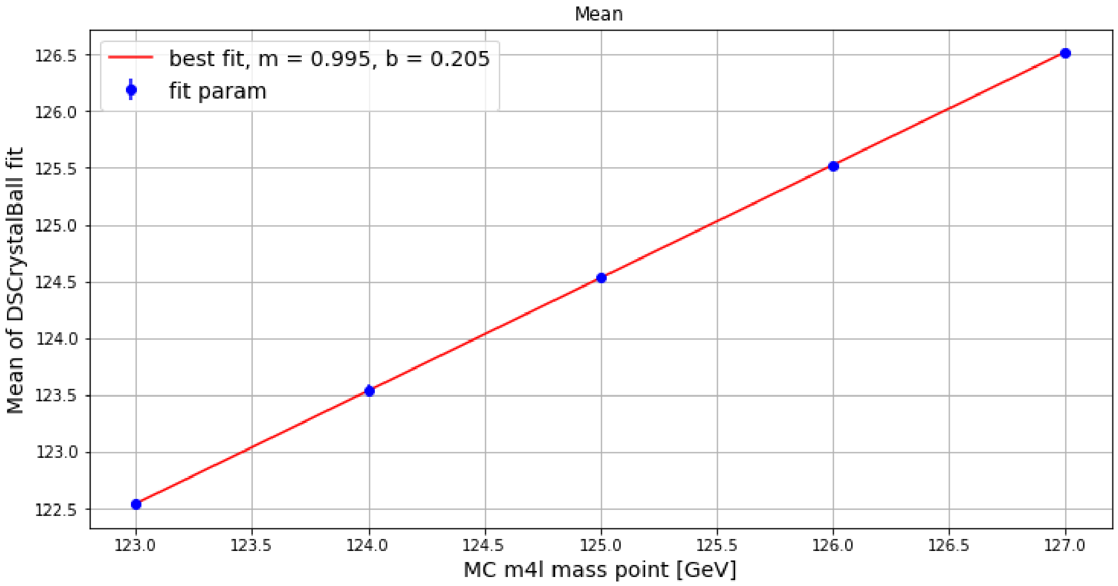
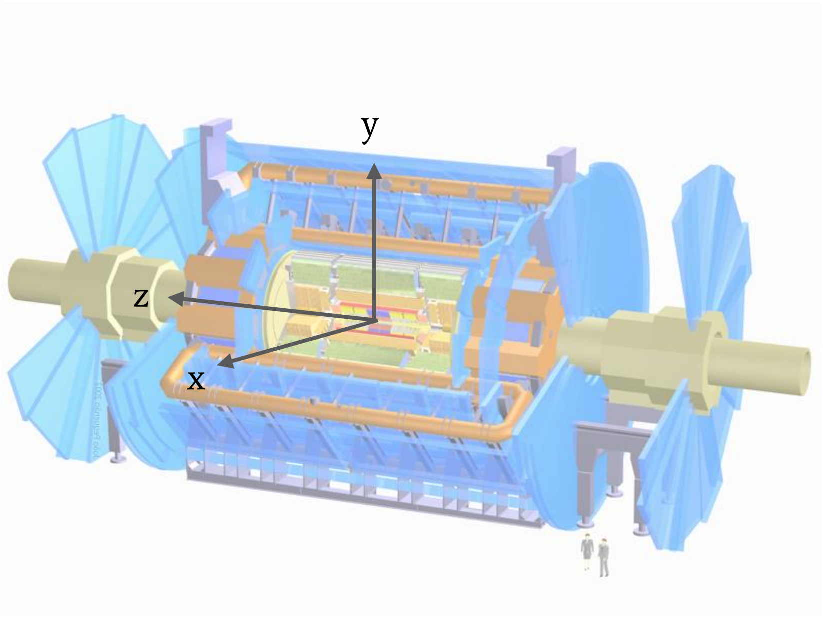
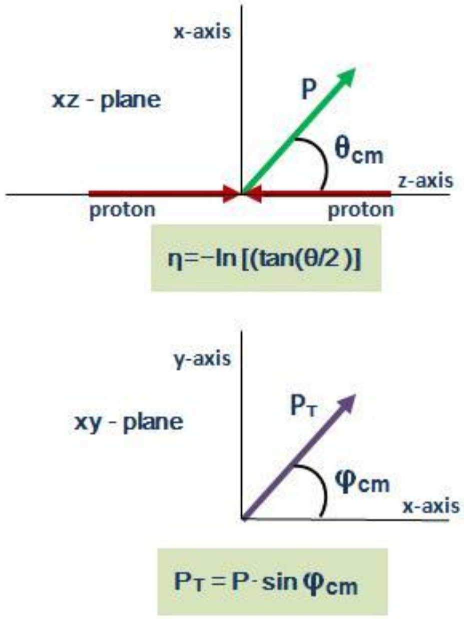
Backup


Mean
best fit, m = 0.995, b = 0.205
fit param
Mean of DSCrystalBall fit
MC m4l mass point [GeV]
126.5
126.0
125.5
125.0
124.5
124.0
123.5
123.0
122.5
123.0
123.5
124.0
124.5
125.0
125.5
126.0
126.5
127.0





https://www.lhc-closer.es/taking_a_closer_look_at_lhc/0.momentum
https://physicsmasterclasses.org/exercises/hands-on-cern/hoc_v21en/main_frame/de_atlas1.html#:~:text=An%20illustration%20of%20the%20Atlas%20detector.%20The%20two%20endcaps%20are

Current Approach

Assume we have muons 1, 2, 3, 4.

Assuming a negligible mass and therefore $E \approx p$,

$$m_{4l}^2 = (E_1 + E_2 + E_3 + E_4)^2 - (\vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \vec{p}_4)^2 \approx (p_1 + p_2 + p_3 + p_4)^2 - (\vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \vec{p}_4)^2$$

Expanding, cancelling terms, and rewriting the terms,

$$m_{4l}^2 = 2(p_1p_2 - \vec{p}_1 \cdot \vec{p}_1) + 2(p_1p_3 - \vec{p}_1 \cdot \vec{p}_3) + 2(p_1p_4 - \vec{p}_1 \cdot \vec{p}_4) + 2(p_2p_3 - \vec{p}_2 \cdot \vec{p}_3) + 2(p_2p_4 - \vec{p}_2 \cdot \vec{p}_4) + 2(p_3p_4 - \vec{p}_3 \cdot \vec{p}_4)$$

Defining $F(i,j) = (p_ip_j - \vec{p}_i \cdot \vec{p}_j)$ and using the idendities

- $p_x = p_T \cos(\phi)$
- $p_y = p_T \sin(\phi)$
- $p_z = p_T \sinh(\eta)$
- $p = p_T\sqrt{\cos^2(\phi) + \sin^2(\phi) + \sinh^2(\eta)} = p_T\sqrt{1 + \sinh^2(\eta)} = p_T \cosh(\eta)$

we obtain

$$F(i,j) = p_{T,i}p_{T,j}(\cosh(\eta_i)\cosh(\eta_j) - \cos(\phi_i)\cos(\phi_j) - \sin(\phi_i)\sin(\phi_j) - \sinh(\eta_i)\sinh(\eta_j))$$

which simplifies to

$$F(i,j) = p_{T,i}p_{T,j}(\cosh(\eta_i - \eta_j) - \cos(\phi_i - \phi_j))$$

Therefore, we can write

$$m_{4l}^2 = 2(F(1,2) + F(1,3) + F(1,4) + F(2,3) + F(2,4) + F(3,4))$$

Finally, it is a simple procedure to take the square root to get

$$m_{4l} = \sqrt{m_{4l}^2}$$

$$DCB\left(m_{4\ell};\mu,\sigma,\alpha_1,n_1,\alpha_2,n_2\right)=C\begin{cases}\left(\frac{n_1}{\alpha_1}\right)^{n_1}\cdot e^{-\frac{\alpha_1^2}{2}}\cdot\left(\frac{n_1}{\alpha_1}-\alpha_1-\frac{m_{4\ell}-\mu}{\sigma}\right)^{-n_1}, & \left(\frac{m_{4\ell}-\mu}{\sigma}\right)<-\alpha_1\\ e^{-0.5\frac{(m_{4\ell}-\mu)^2}{\sigma^2}}, & -\alpha_1\leq\left(\frac{m_{4\ell}-\mu}{\sigma}\right)\leq\alpha_2\\ \left(\frac{n_2}{\alpha_2}\right)^{n_2}\cdot e^{-\frac{\alpha_2^2}{2}}\cdot\left(\frac{n_2}{\alpha_2}-\alpha_2+\frac{m_{4\ell}-\mu}{\sigma}\right)^{-n_2}, & \alpha_2<\left(\frac{m_{4\ell}-\mu}{\sigma}\right)\end{cases}$$

$$\lambda(m_H)=\frac{L(m_H,\hat{\hat{\theta}}(m_H))}{L(\hat{m}_H,\hat{\theta})},$$