Top EFT

Sebastian Bruggisser
Based on work with:
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T. Plehn, E. Vryonidou, S. Westhoff, C. Zhan


LERY
MAN AT WORK

Why the Top-sector?

- Couples the strongest to the Higgs → Top-sector influences Higgs-sector and vice-versa.

- The LHC is a top-factory → wealth of data to be explored.

- Many BSM models modify the Top-sector: Light Top partners in SUSY/Composite Higgs, etc.

Why now?

- Existing top-fits:
  - TopFitter collaboration: 1512.03360, 1612.02294, 1901.03164
  - SMEFiT collaboration: 1901.05965

- What we can do:
  - Including ATLAS and CMS 13 TeV differential measurements
  - Studying the impact of NLO predictions
  - Detailed study of degeneracies
  - More honest treatment of theoretical uncertainties
  - Systematic study of the impact of correlated uncertainties (see Rhea's talk)

The Operators

$$\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i^{d=6} + \sum_j \frac{c_j}{\Lambda^4} \mathcal{O}_j^{d=8} + \dots$$

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- All relevant (including at least one Top) operators up to d=6

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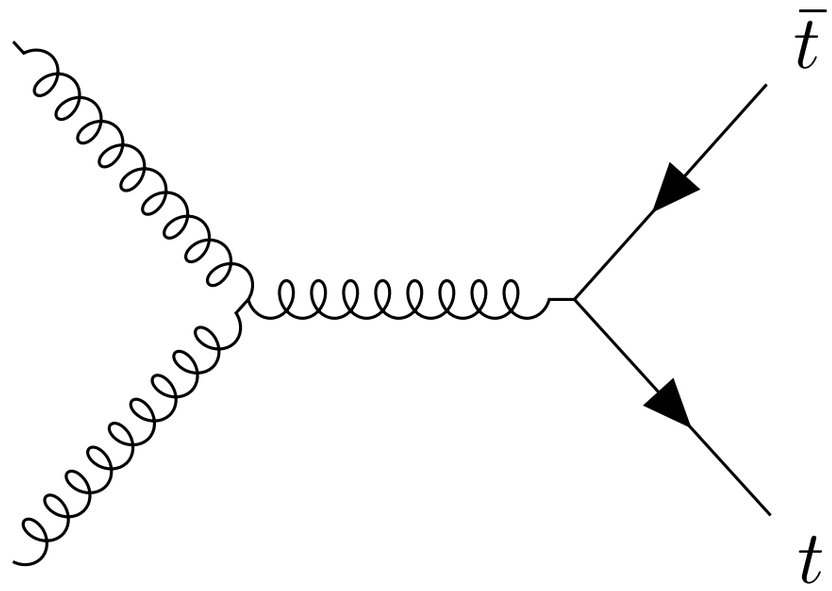

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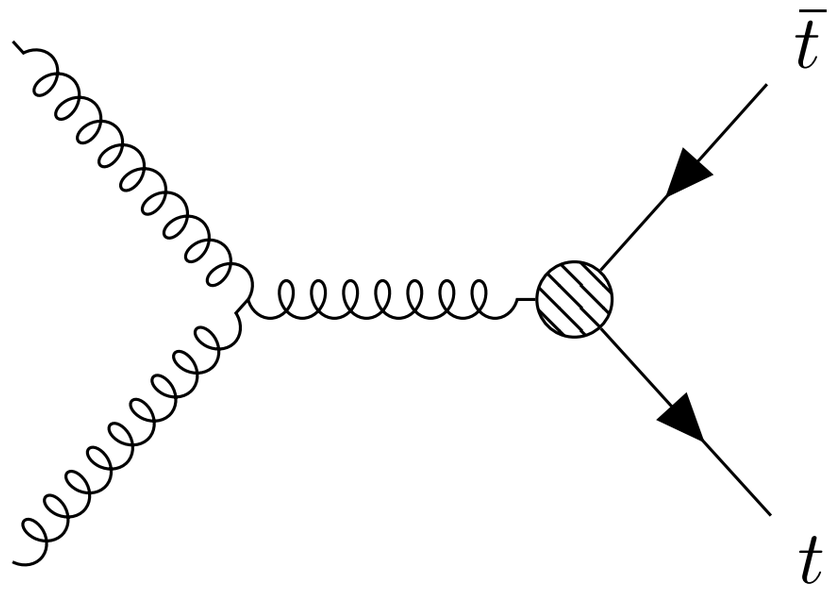

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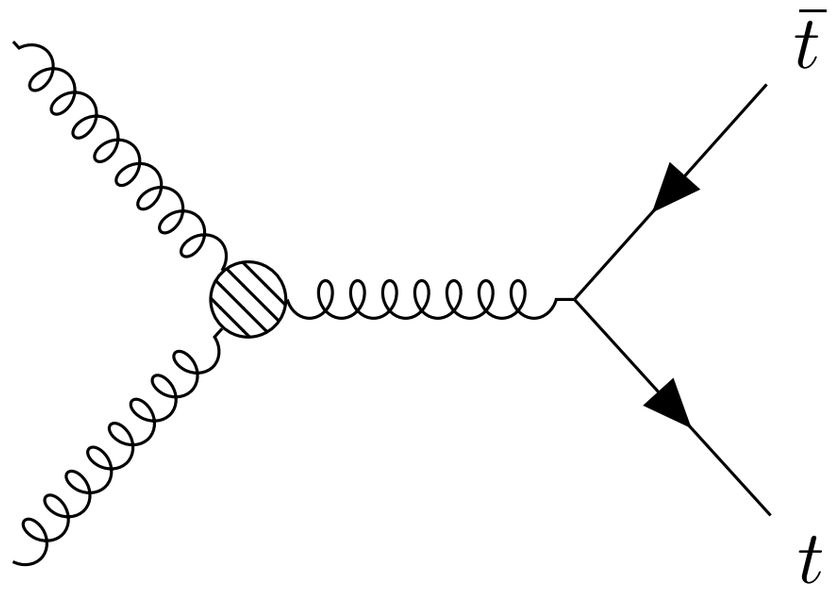

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- All relevant (including at least one Top) operators up to d=6

- Assumptions:
  - $U(2)_u \times U(2)_d \times U(2)_Q$ flavour symmetry
  - MFV
  - Light quarks considered massless (Yukawa=0)
  - Diagonal CKM
  - CP conserving

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- Warsaw-basis operators or linear combinations thereof

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- Warsaw-basis operators or linear combinations thereof

- Total of 34 operators considered

The Operators

Processes	Examples	4 heavy fermions	2 heavy - 2 light fermions	2 heavy fermions - boson

The Operators

For full list see 1802.07237

	4 heavy fermions	2 heavy - 2 light fermions	2 heavy fermions - boson
Processes			
Examples			

The Operators

For full list see 1802.07237

4 heavy fermions | **2 heavy - 2 light fermions** | **2 heavy fermions - boson**

Processes Examples

$C_{qu}^{8(3333)}(\bar{q}_3\gamma^\mu T^A q_3)(\bar{u}_3\gamma_\mu T^A u_3)$

The Operators

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4 heavy fermions | **2 heavy - 2 light fermions** | **2 heavy fermions - boson**

Processes Examples

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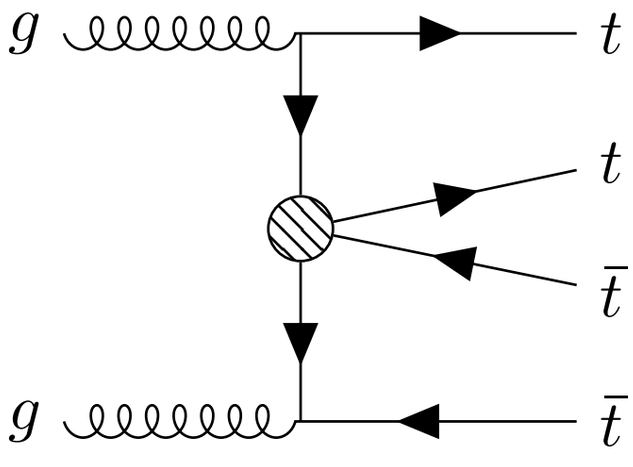

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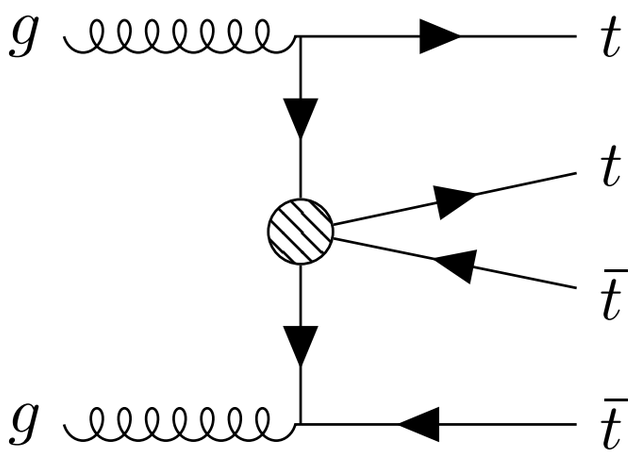

The Operators

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4 heavy fermions

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2 heavy fermions - boson

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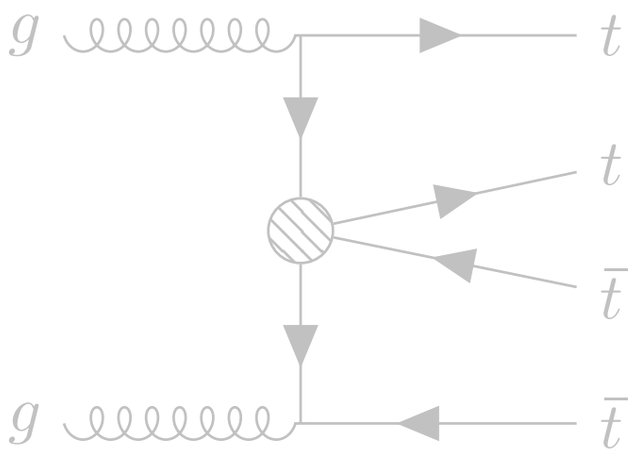

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2 heavy fermions - boson

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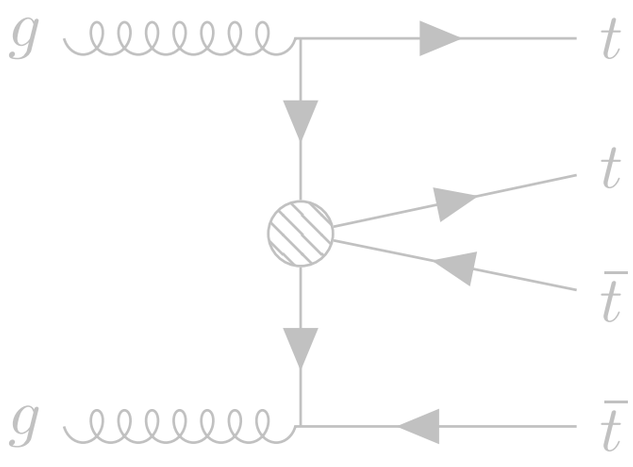

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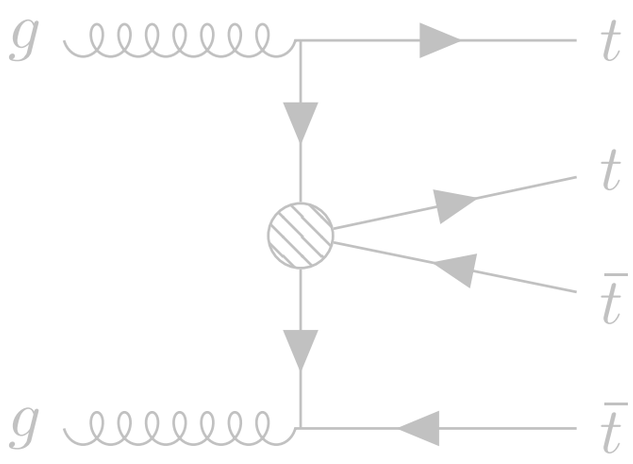
2 heavy fermions - boson

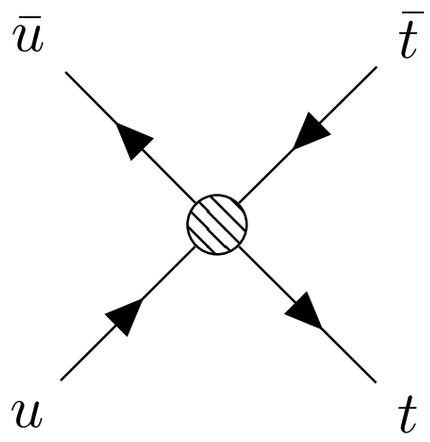
Processes

$t\bar{t}t\bar{t}$

$t\bar{t}b\bar{b}$

$t\bar{t}$ production





The Operators

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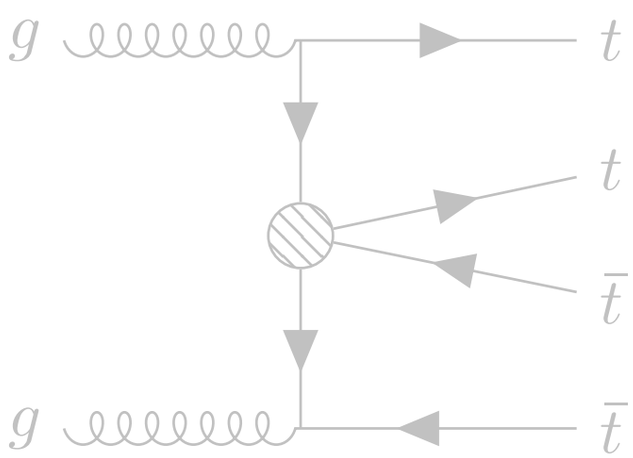
Processes

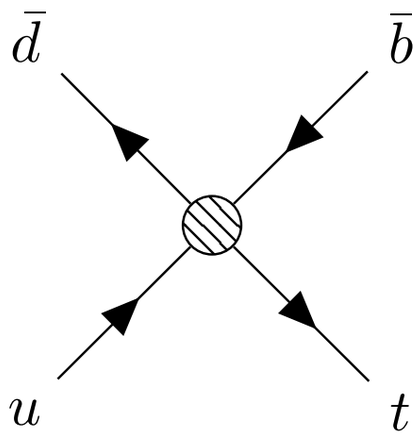
$t\bar{t}t\bar{t}$

tt production

$t\bar{t}b\bar{b}$

single t production





The Operators

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Examples

4 heavy fermions

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2 heavy fermions - boson

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$t\bar{t}t\bar{t}$

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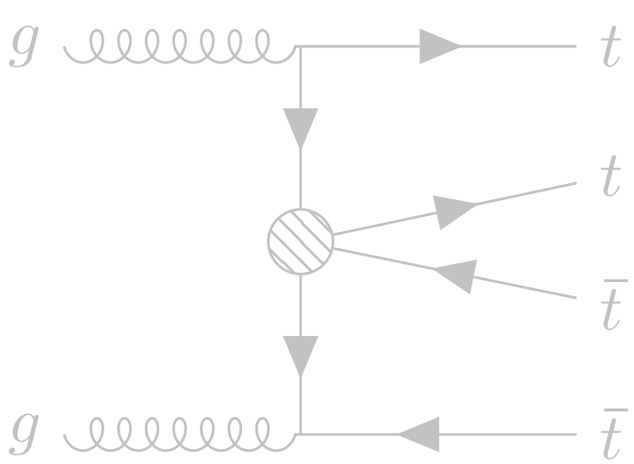

tt production

single t production

$t\bar{t}t\bar{t}$

$t\bar{t}b\bar{b}$

tZ

$t\bar{t}Z/W/H$

The Operators

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Examples

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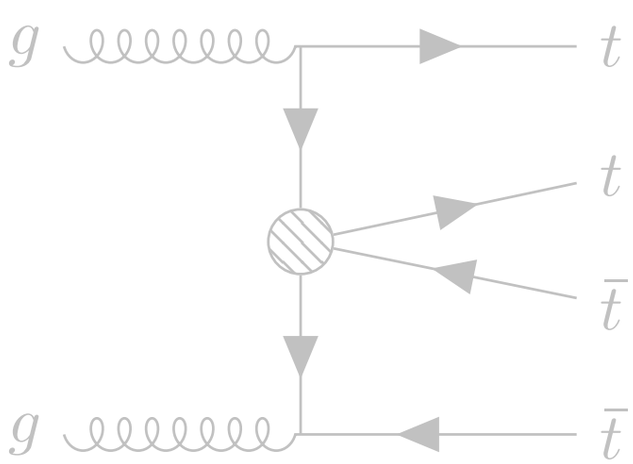
Processes

$t\bar{t}t\bar{t}$	tt production	$t\bar{t}t\bar{t}$
$t\bar{t}b\bar{b}$	single t production	$t\bar{t}b\bar{b}$
		tZ
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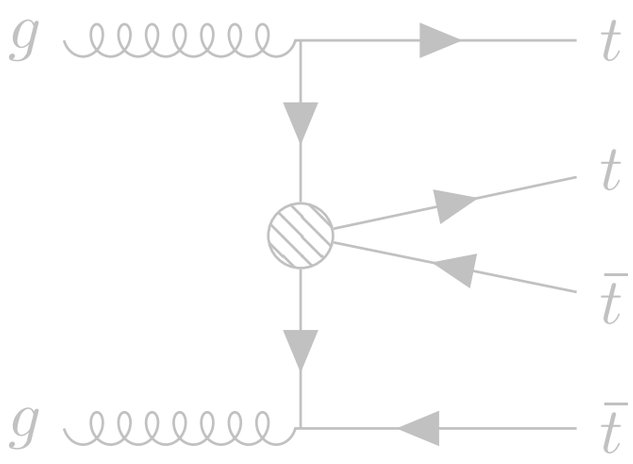
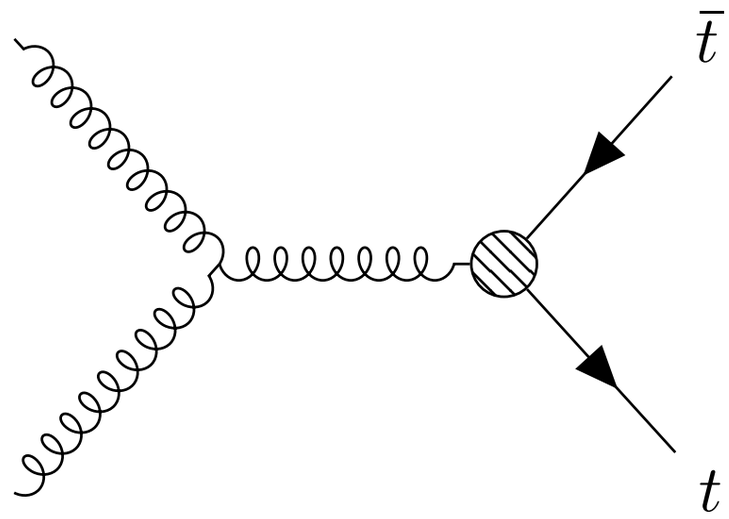
Processes	$t\bar{t}t\bar{t}$ $t\bar{t}b\bar{b}$	tt production single t production $t\bar{t}t\bar{t}$ $t\bar{t}b\bar{b}$ tZ $t\bar{t}Z/W/H$	tt production





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$t\bar{t}t\bar{t}$	tt production single t production	tt production single t production
$t\bar{t}b\bar{b}$	$t\bar{t}t\bar{t}$	
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	tZ	
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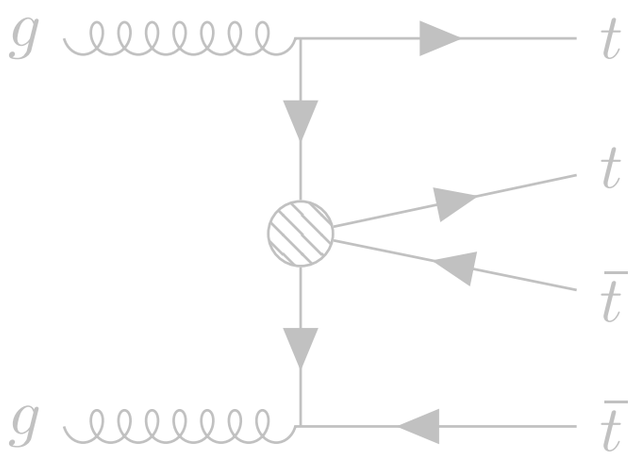

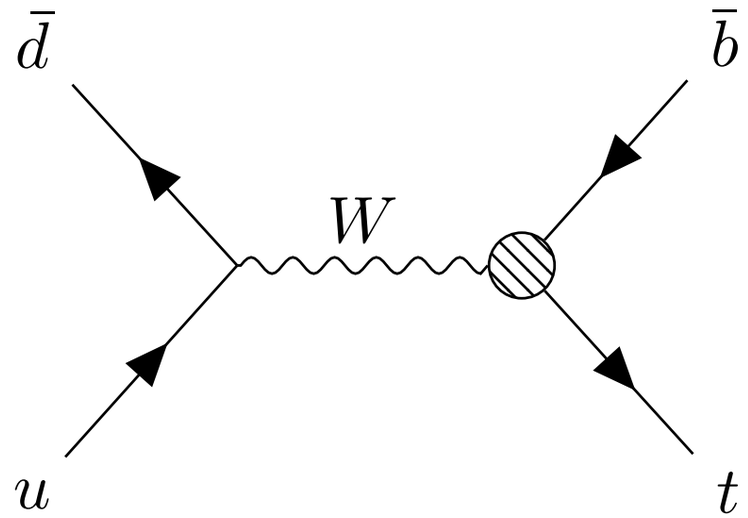

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Processes	$t\bar{t}t\bar{t}$ $t\bar{t}b\bar{b}$	$t\bar{t}$ production single t production	$t\bar{t}$ production single t production
		$t\bar{t}t\bar{t}$	$t\bar{t}t\bar{t}$
		$t\bar{t}b\bar{b}$	$t\bar{t}b\bar{b}$
		tZ	tZ/W
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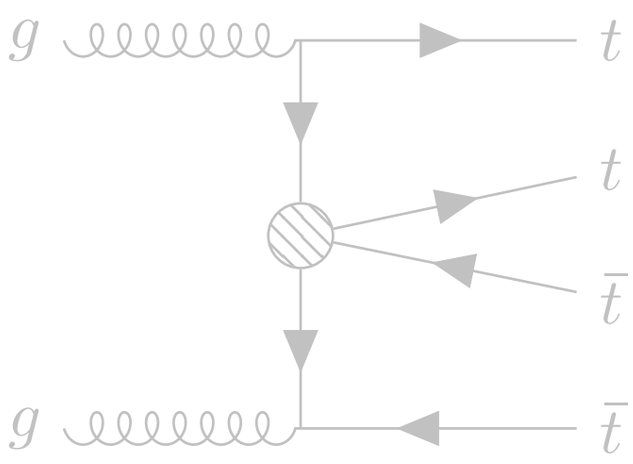

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Processes	$t\bar{t}t\bar{t}$	tt production single t production	tt production single t production
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		See Rhea's Talk	
		$t\bar{t}t\bar{t}$	$t\bar{t}t\bar{t}$
		$t\bar{t}b\bar{b}$	$t\bar{t}b\bar{b}$
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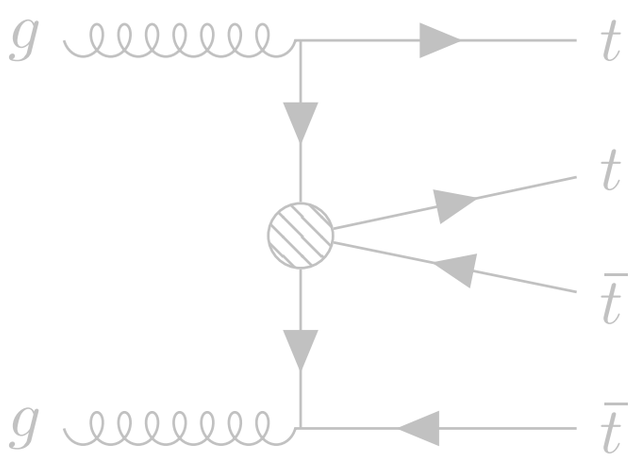

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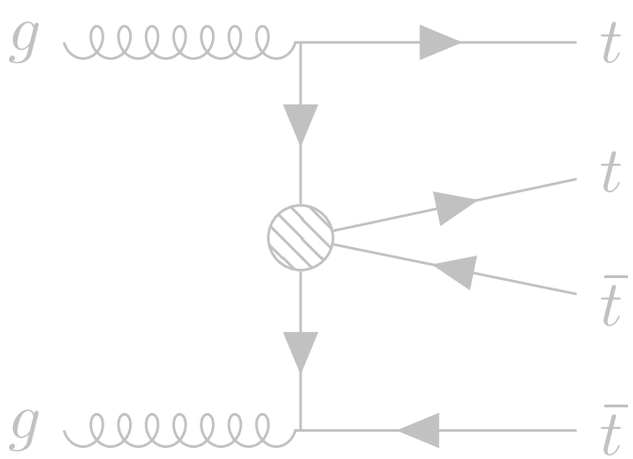
Processes

	$t\bar{t}$ production	$t\bar{t}$ production
$t\bar{t}t\bar{t}$	single t production	single t production
$t\bar{t}b\bar{b}$	$t\bar{t}t\bar{t}$	$t\bar{t}t\bar{t}$
	$t\bar{t}b\bar{b}$	$t\bar{t}b\bar{b}$
	tZ	tZ/W
	$t\bar{t}Z/W/H$	$t\bar{t}Z/W/H$

(Global-) Fitting strategy

Prediction $$\sigma_{EFT} = \sigma_{SM} + \sum_{d.o.f.} \sigma_i \frac{c_i}{\Lambda^2} + \sum_{d.o.f.} \sigma_{ij} \frac{c_i c_j}{\Lambda^4} \pm \delta_{th}$$

Measurements

(Global-) Fitting strategy

Prediction $\sigma_{EFT} = \sigma_{SM} + \sum_{d.o.f.} \sigma_i \frac{c_i}{\Lambda^2} + \sum_{d.o.f.} \sigma_{ij} \frac{c_i c_j}{\Lambda^4} \pm \delta_{th}$

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Measurements

(Global-) Fitting strategy

Prediction $$\sigma_{EFT} = \sigma_{SM} + \sum_{d.o.f.} \sigma_i \frac{c_i}{\Lambda^2} + \sum_{d.o.f.} \sigma_{ij} \frac{c_i c_j}{\Lambda^4} \pm \delta_{th}$$

Measurements

Total rates

8TeV, ATLAS and CMS
~5-7% precision

13TeV, ATLAS and CMS
~5-8% precision

See: 1603.02303
1712.06857
1701.06228
1812.10505
1606.02699

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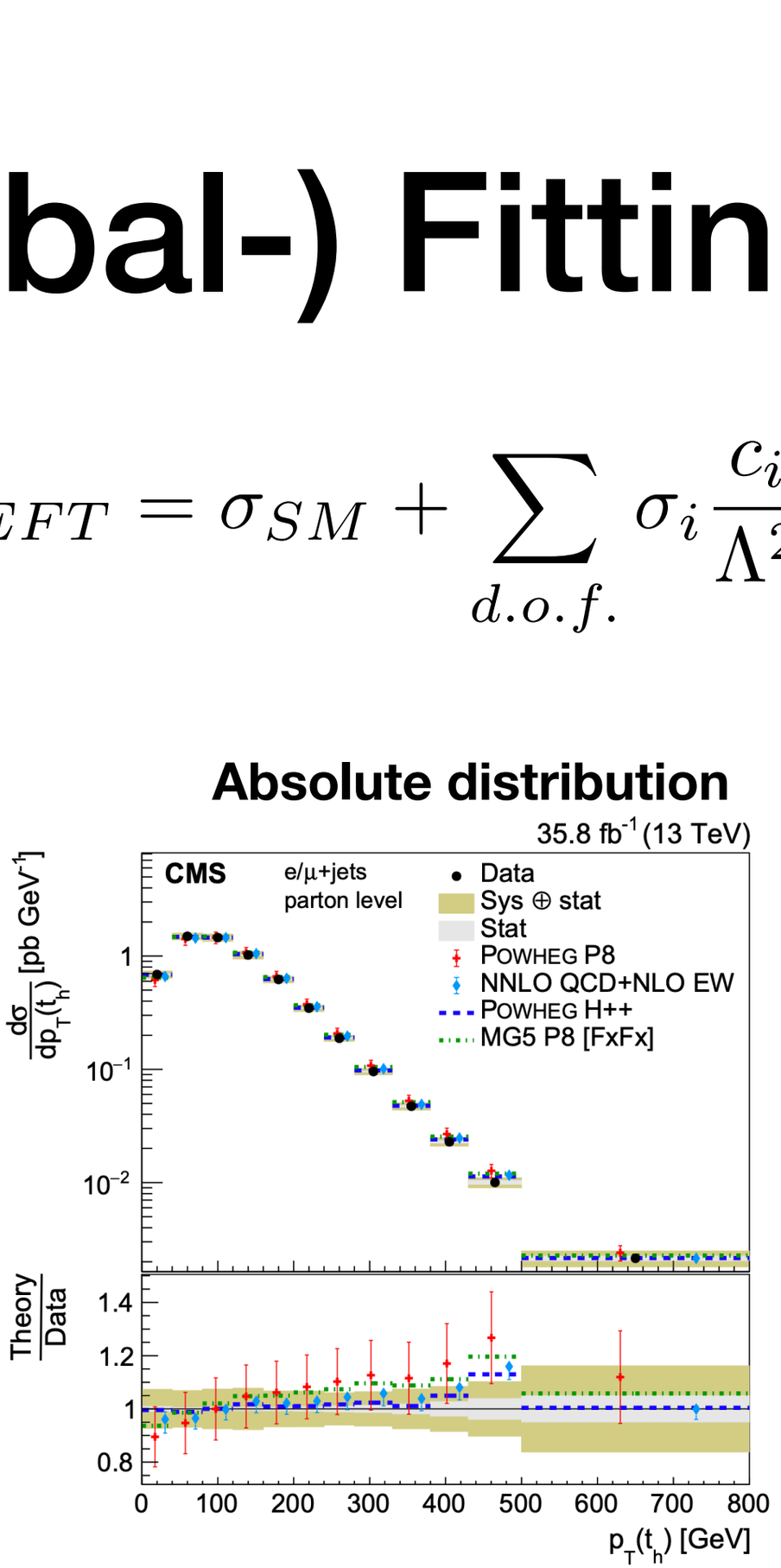
Measurements

Differenctial Measurements

Absolute distribution



Normalised distribution

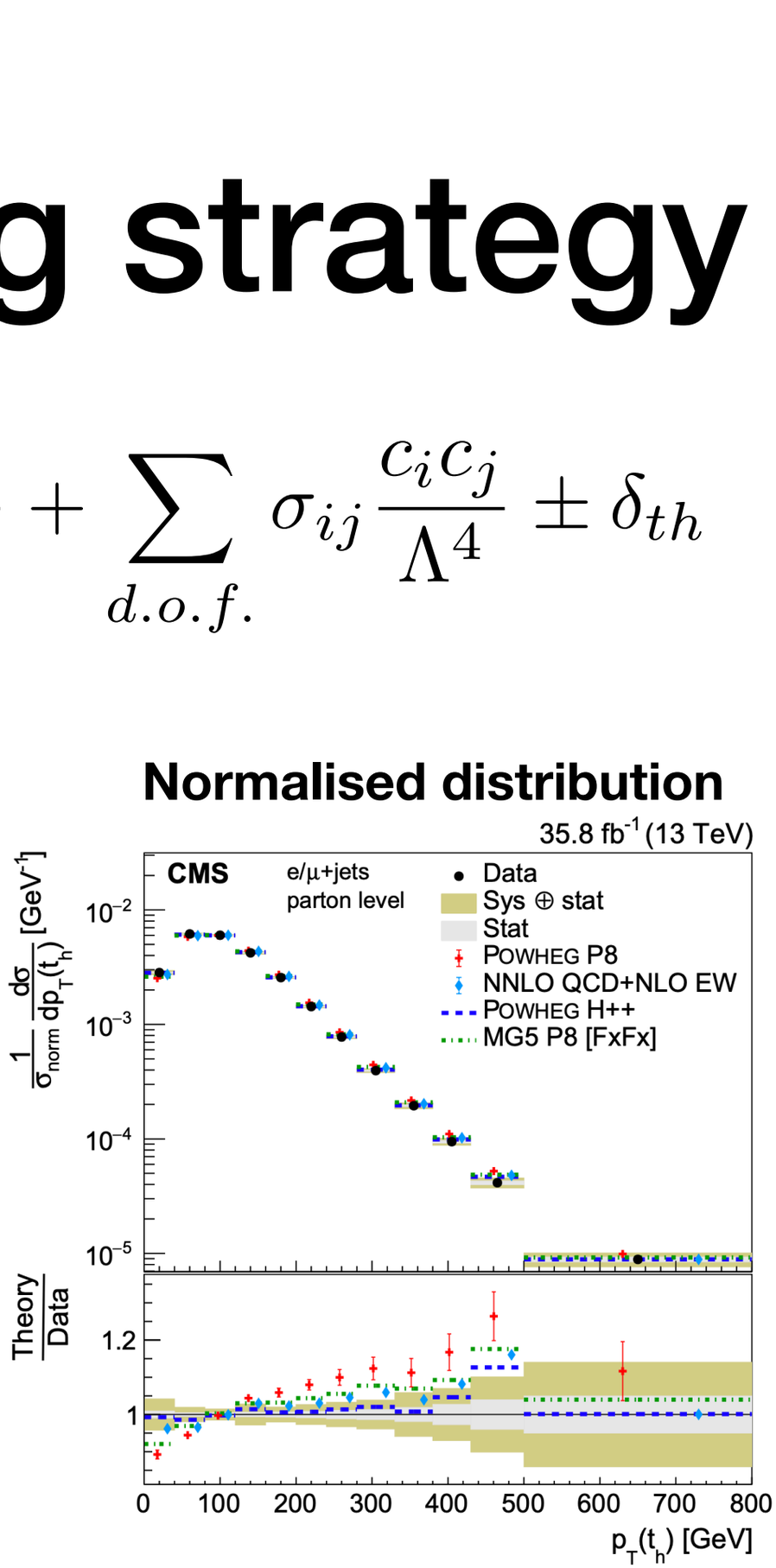


Figure from 1803.08856

SFitter

Toy MC method:

$$\sigma_{toy} = \sigma_{meas} \pm \delta_{th} \pm \delta_{exp}$$

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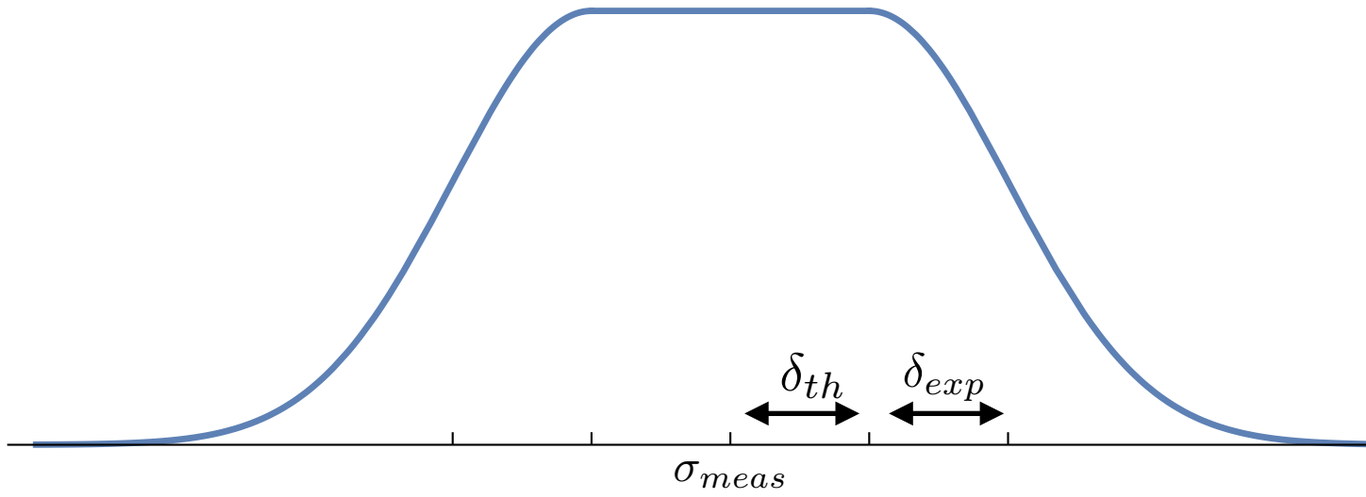

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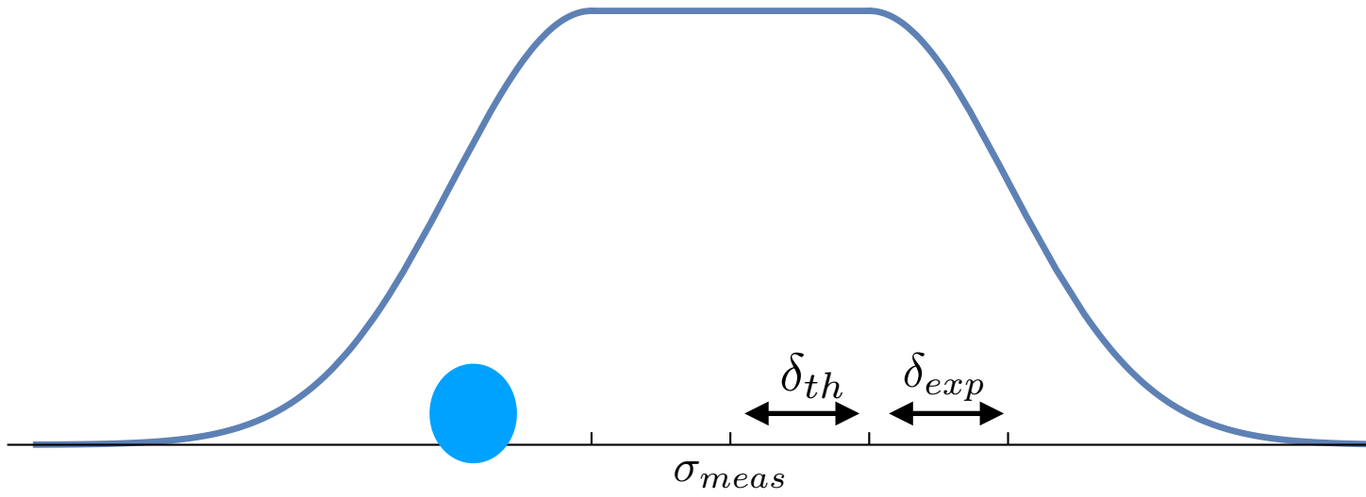

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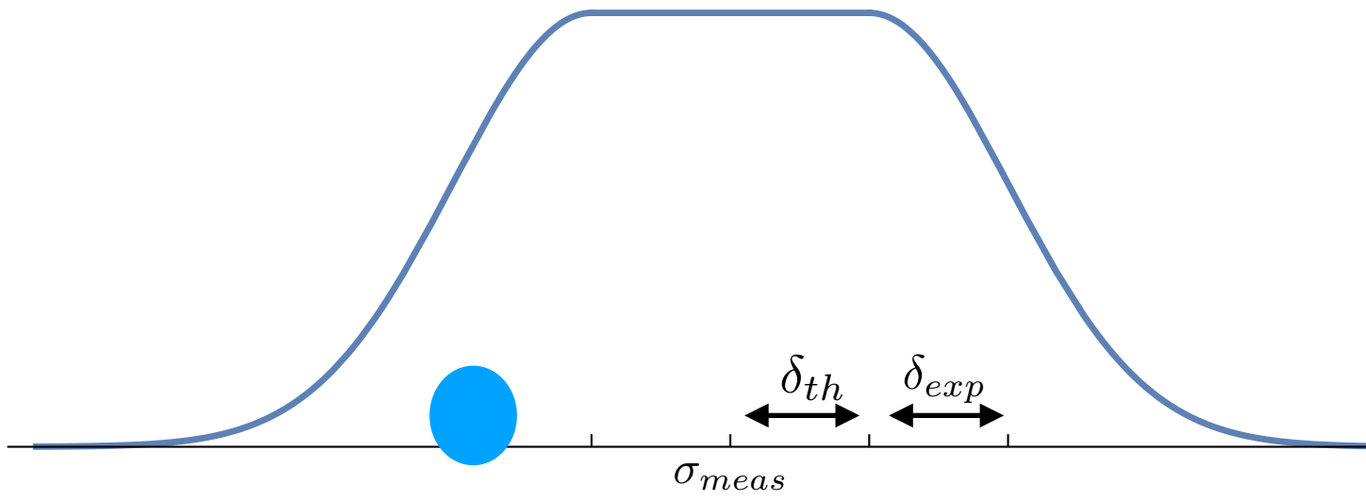

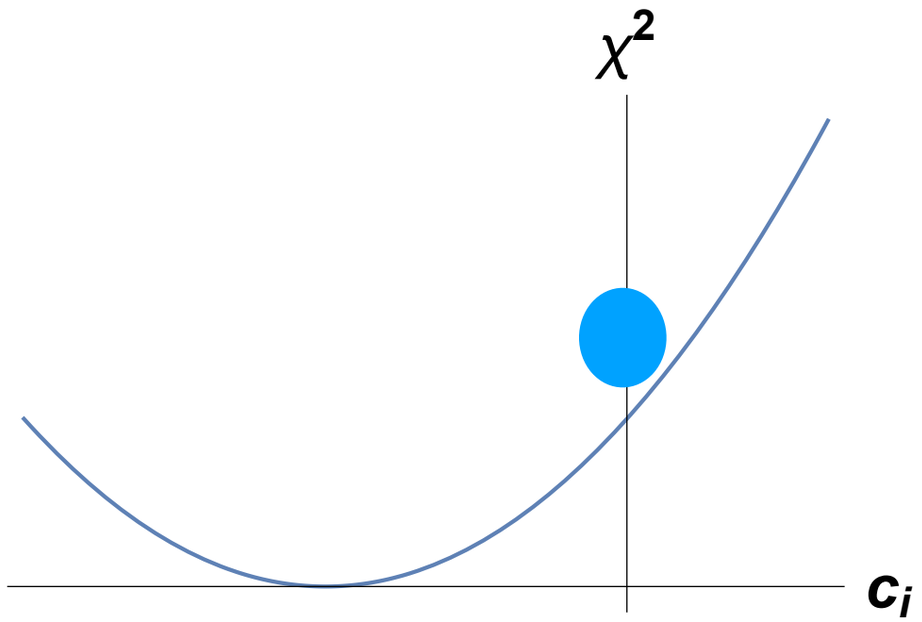

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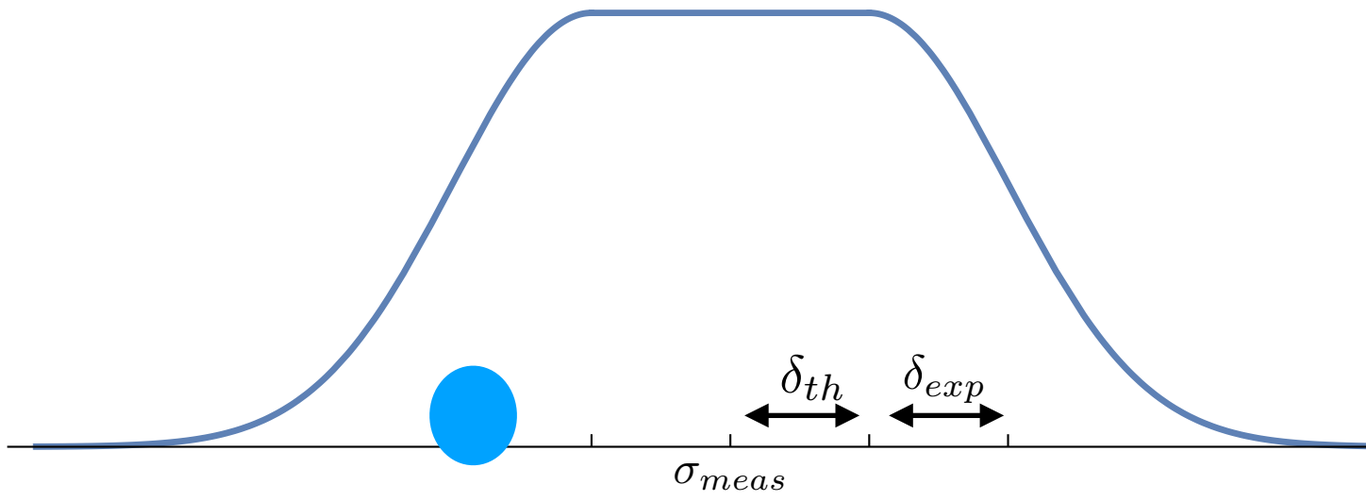

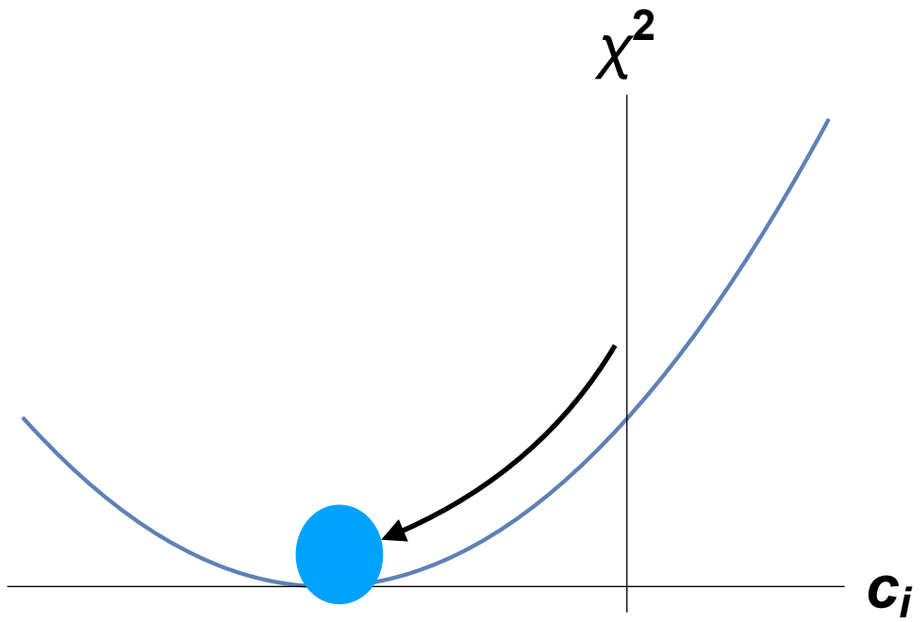

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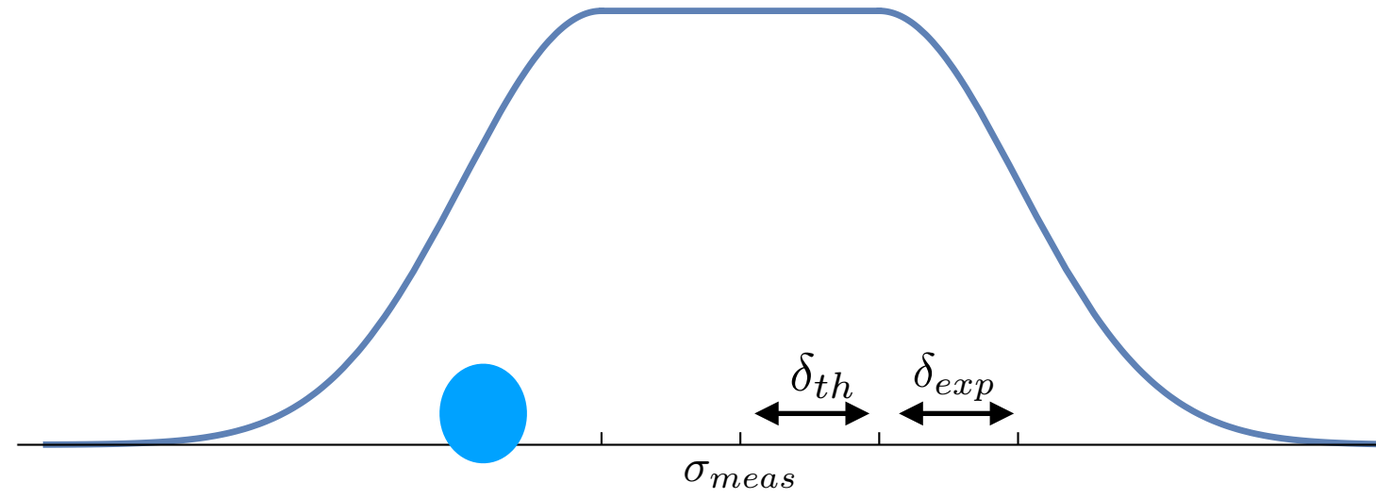

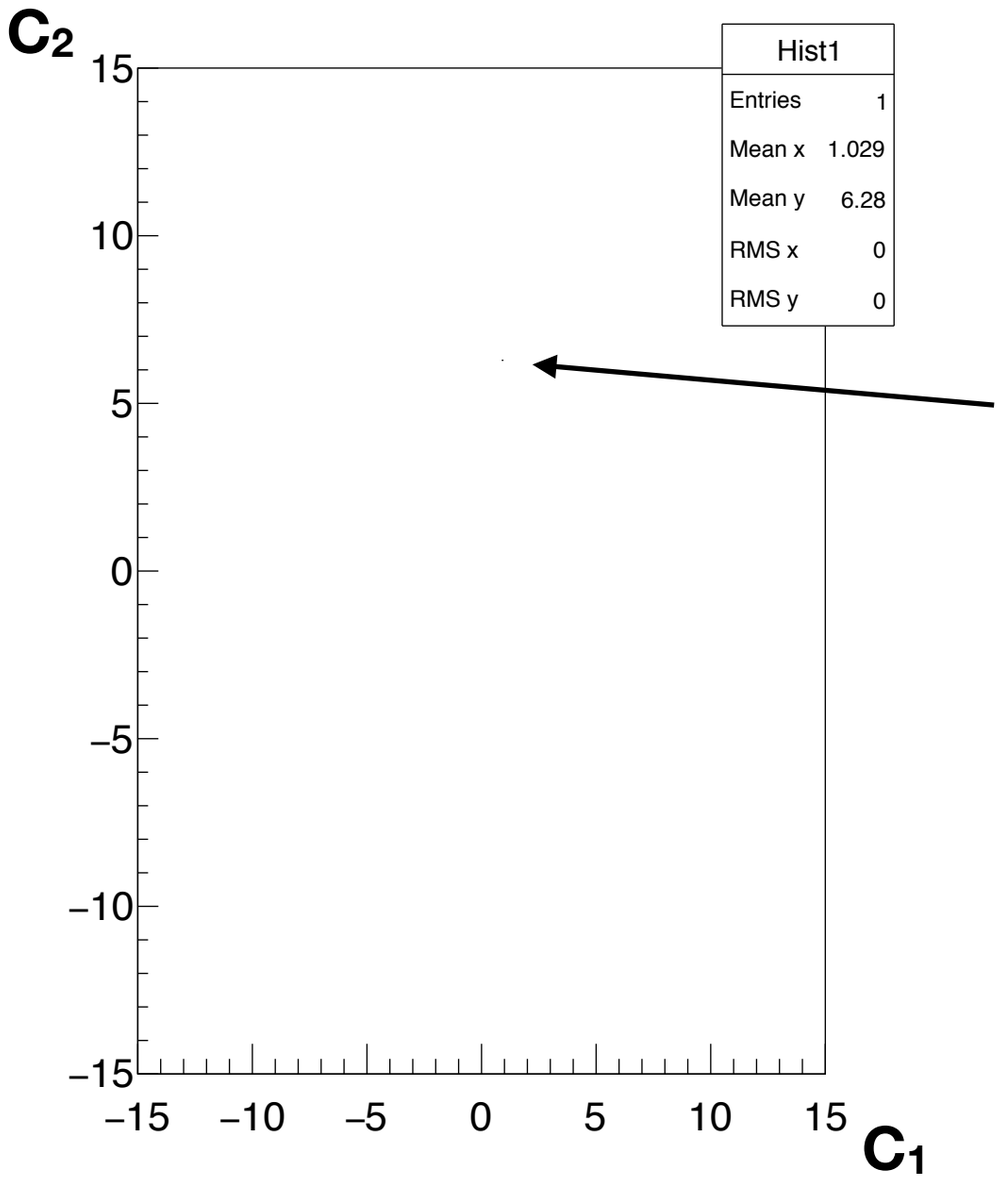

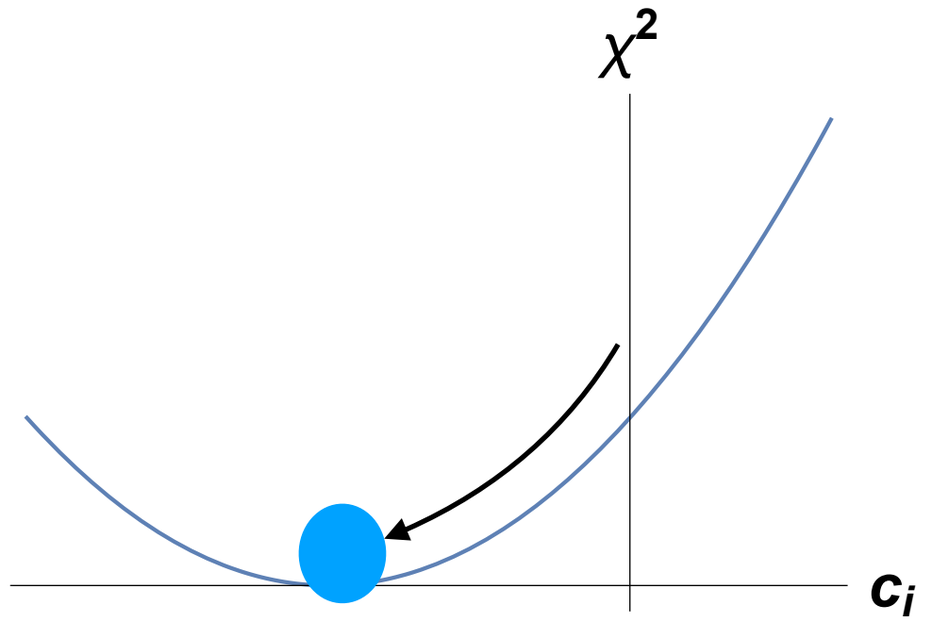

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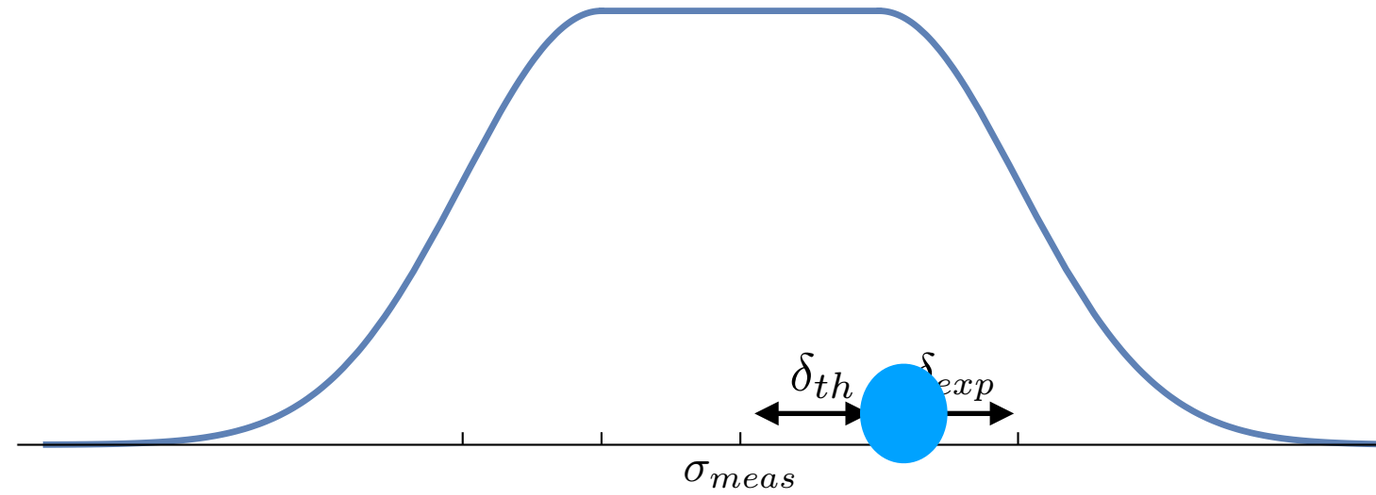

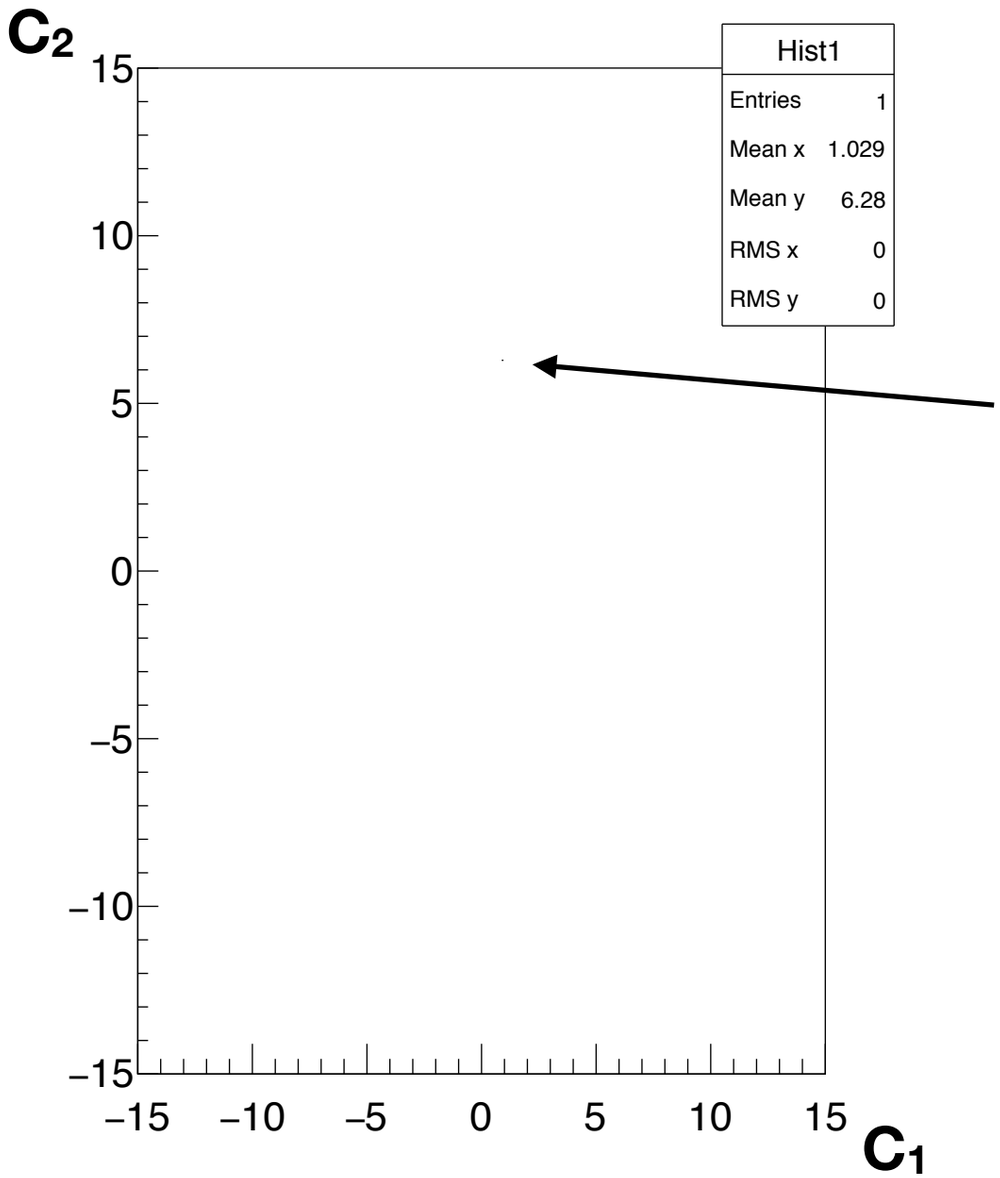

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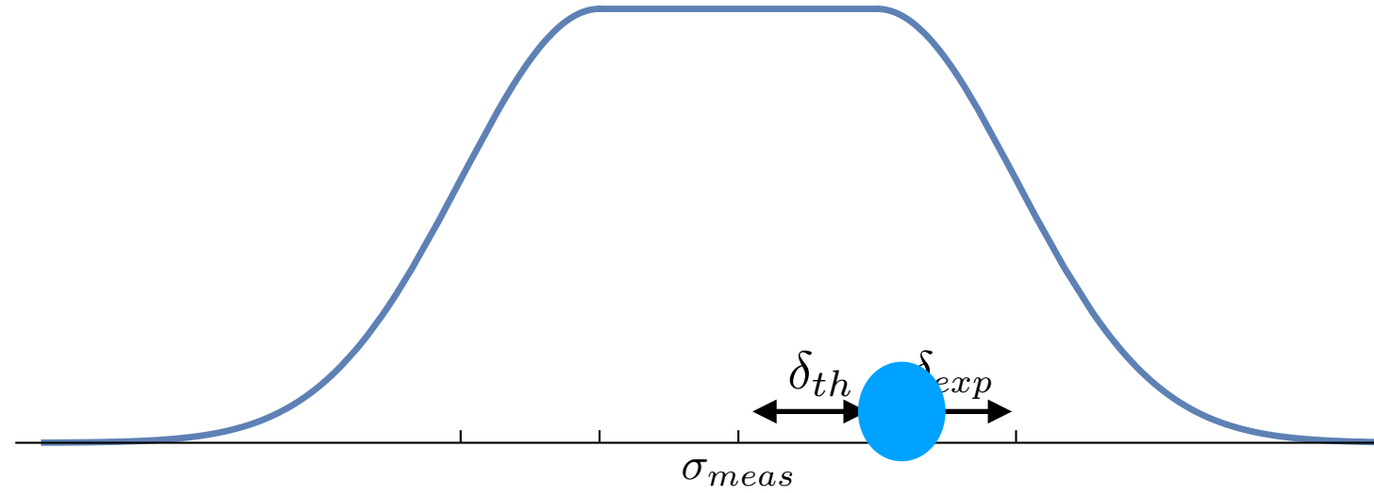

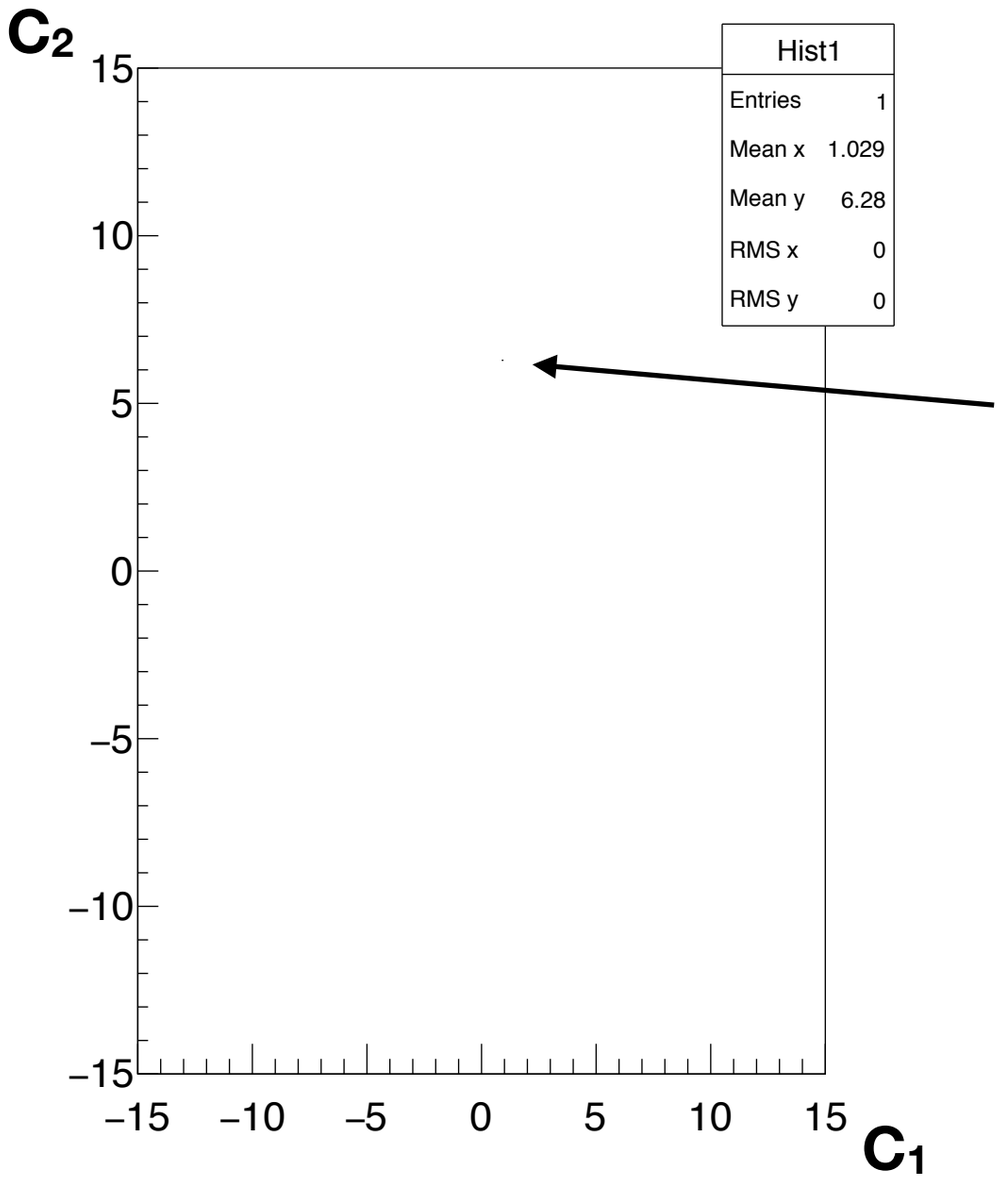

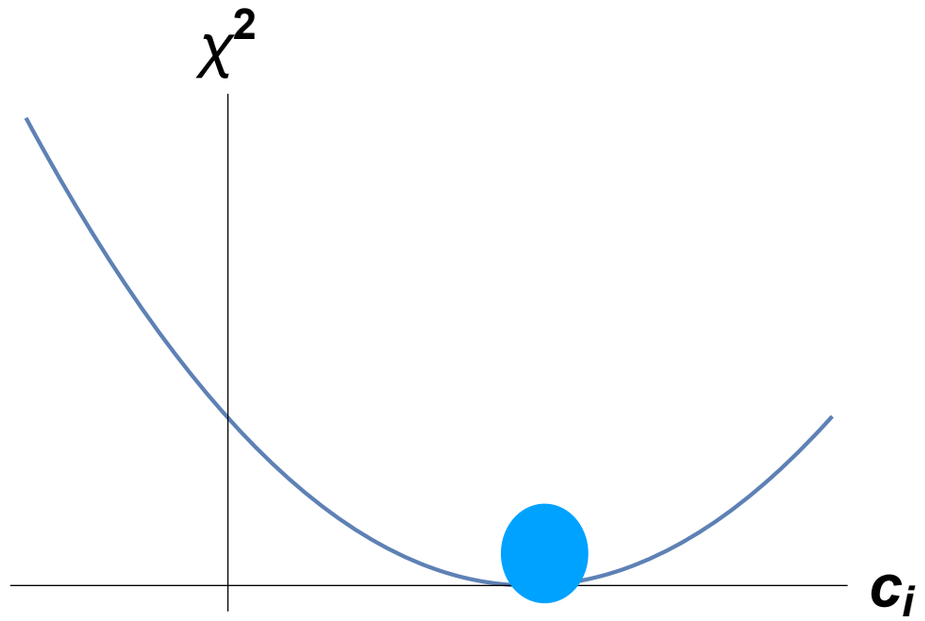

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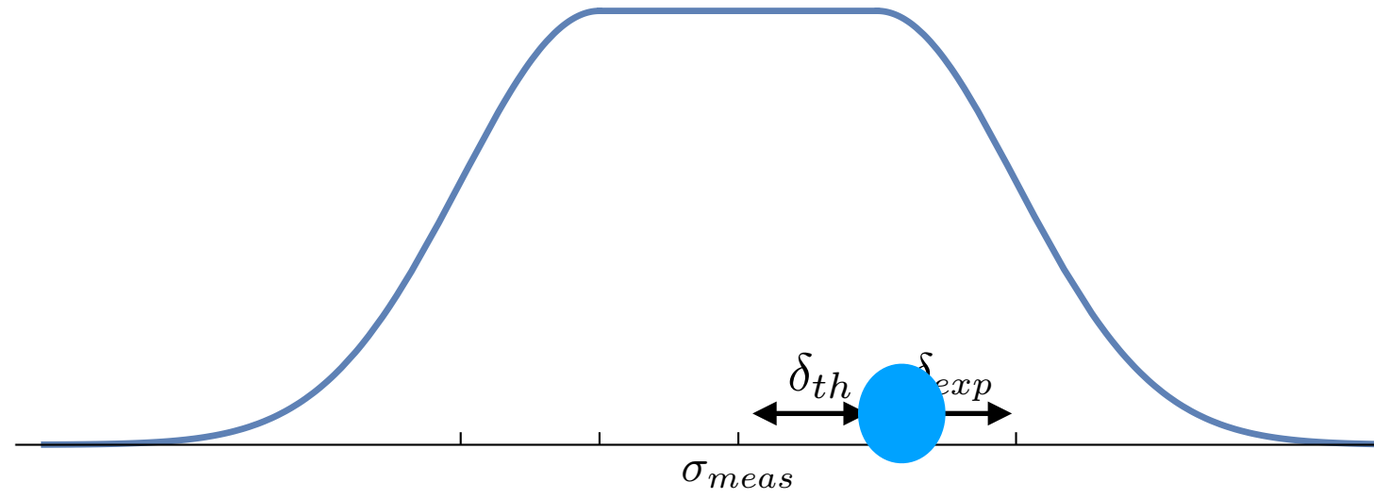

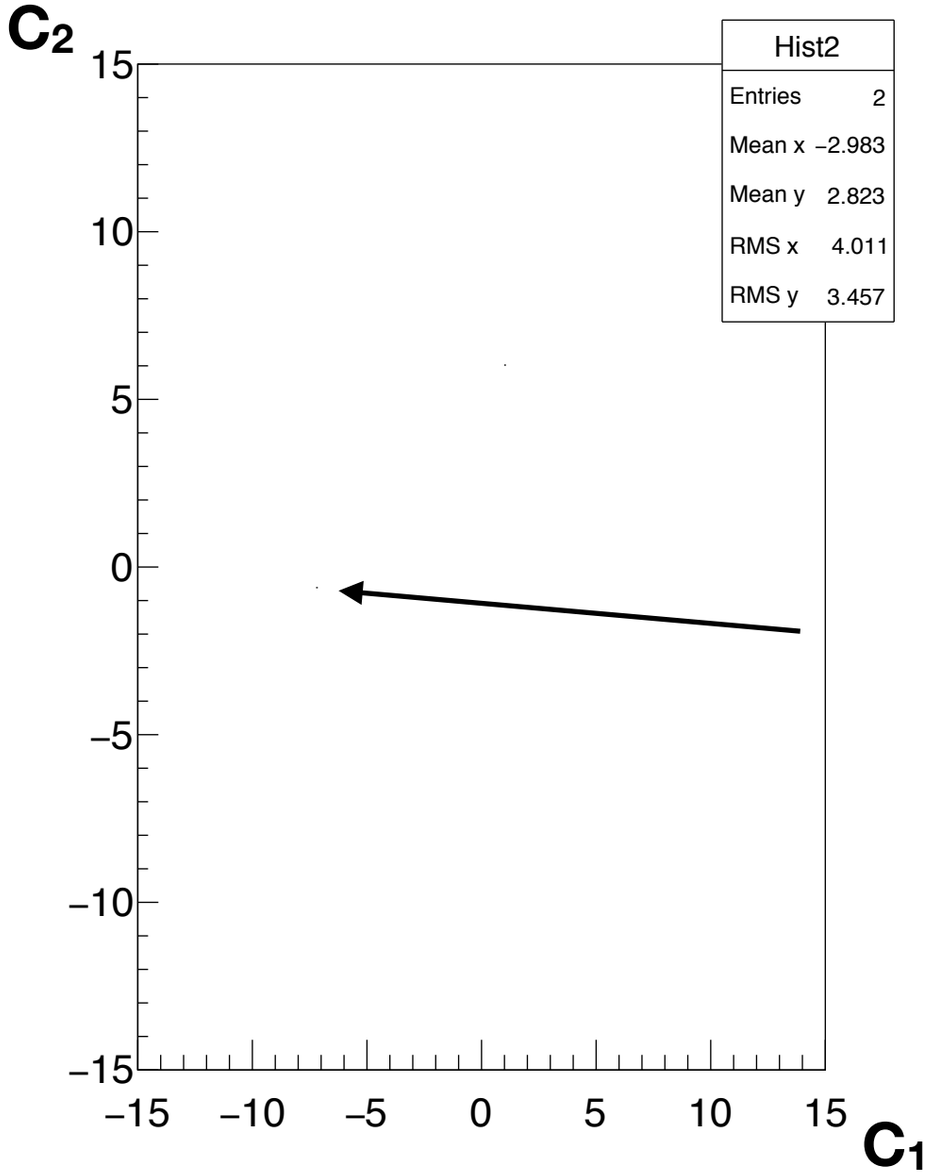

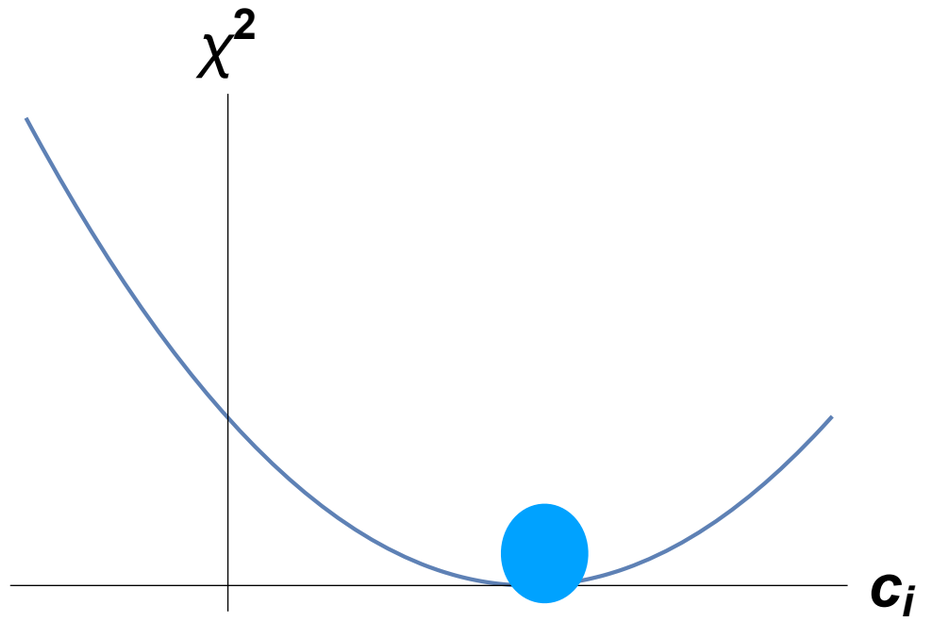

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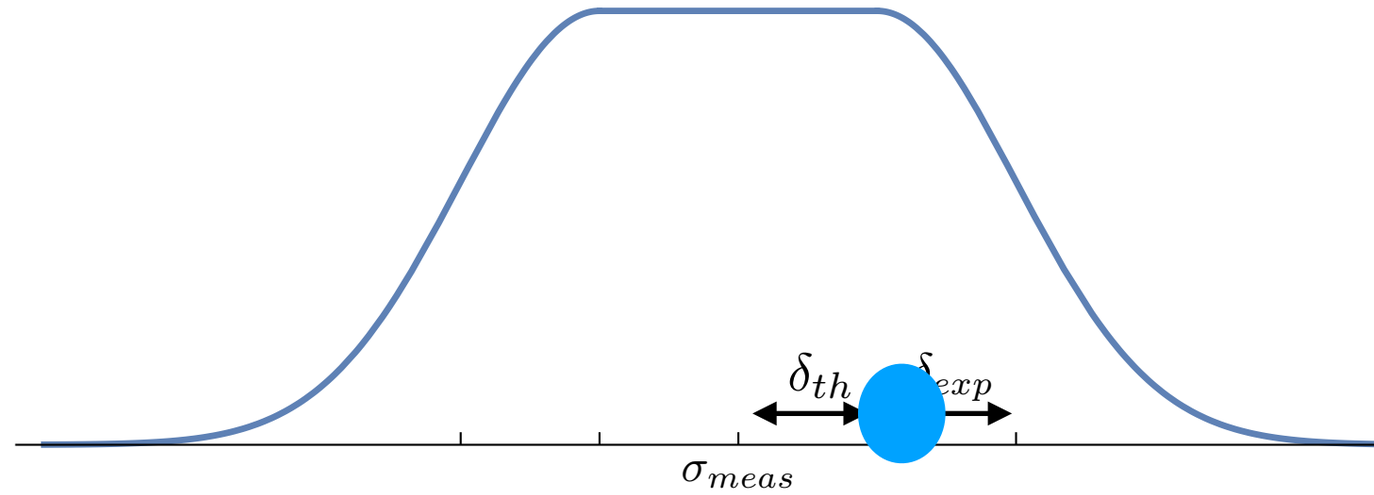

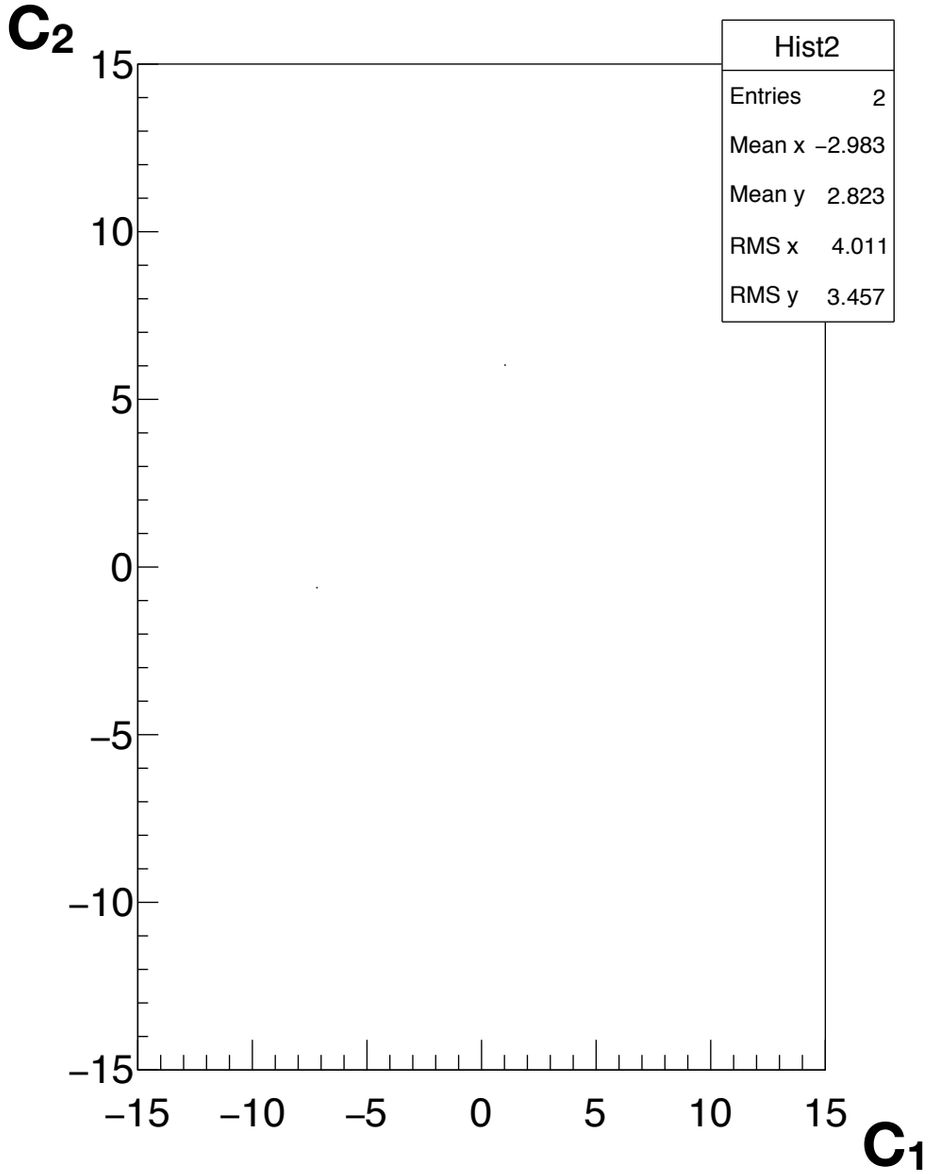

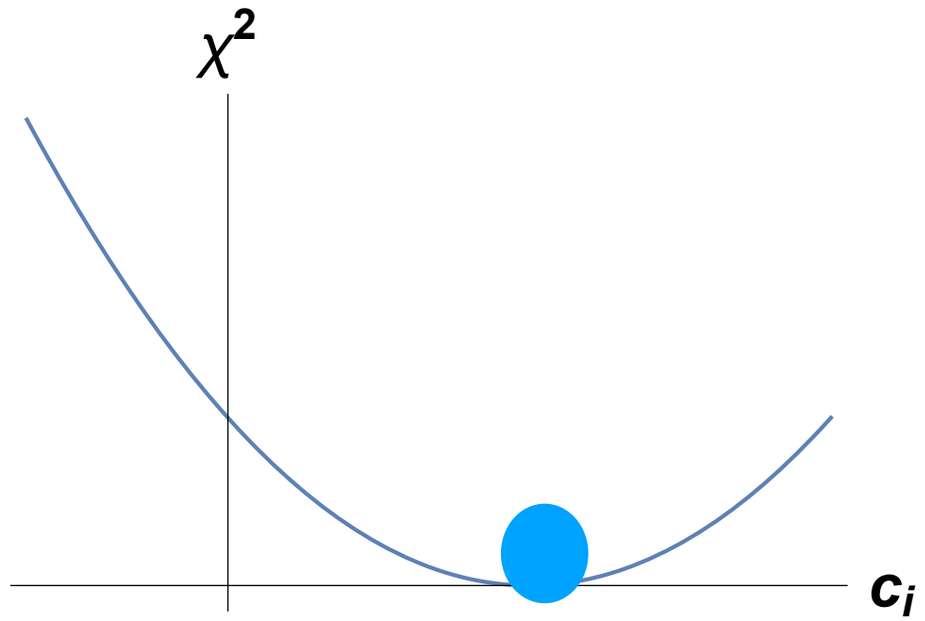

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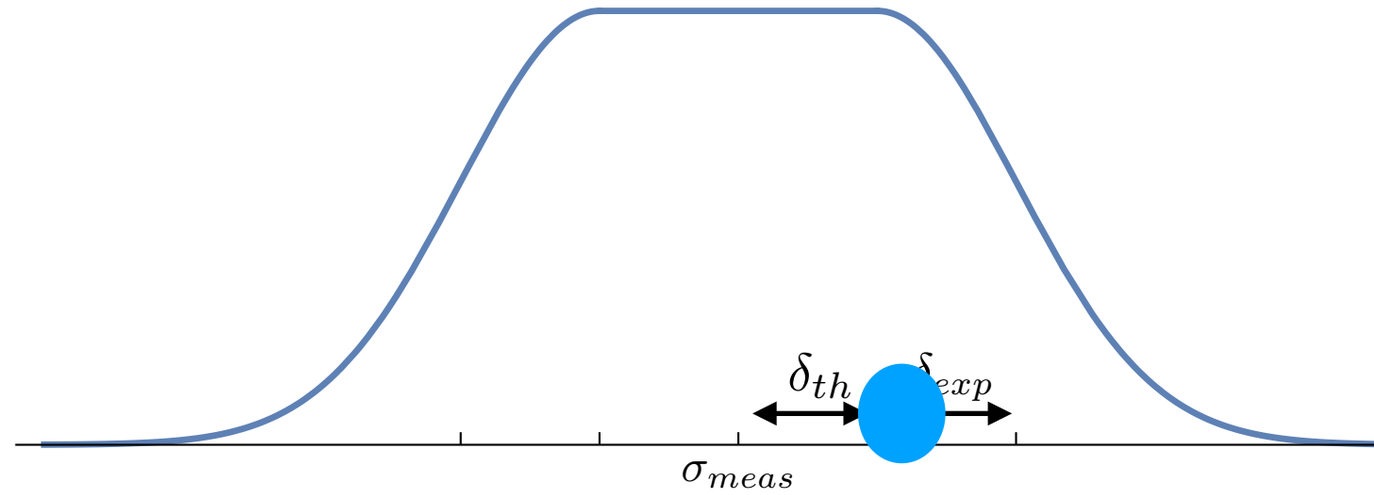

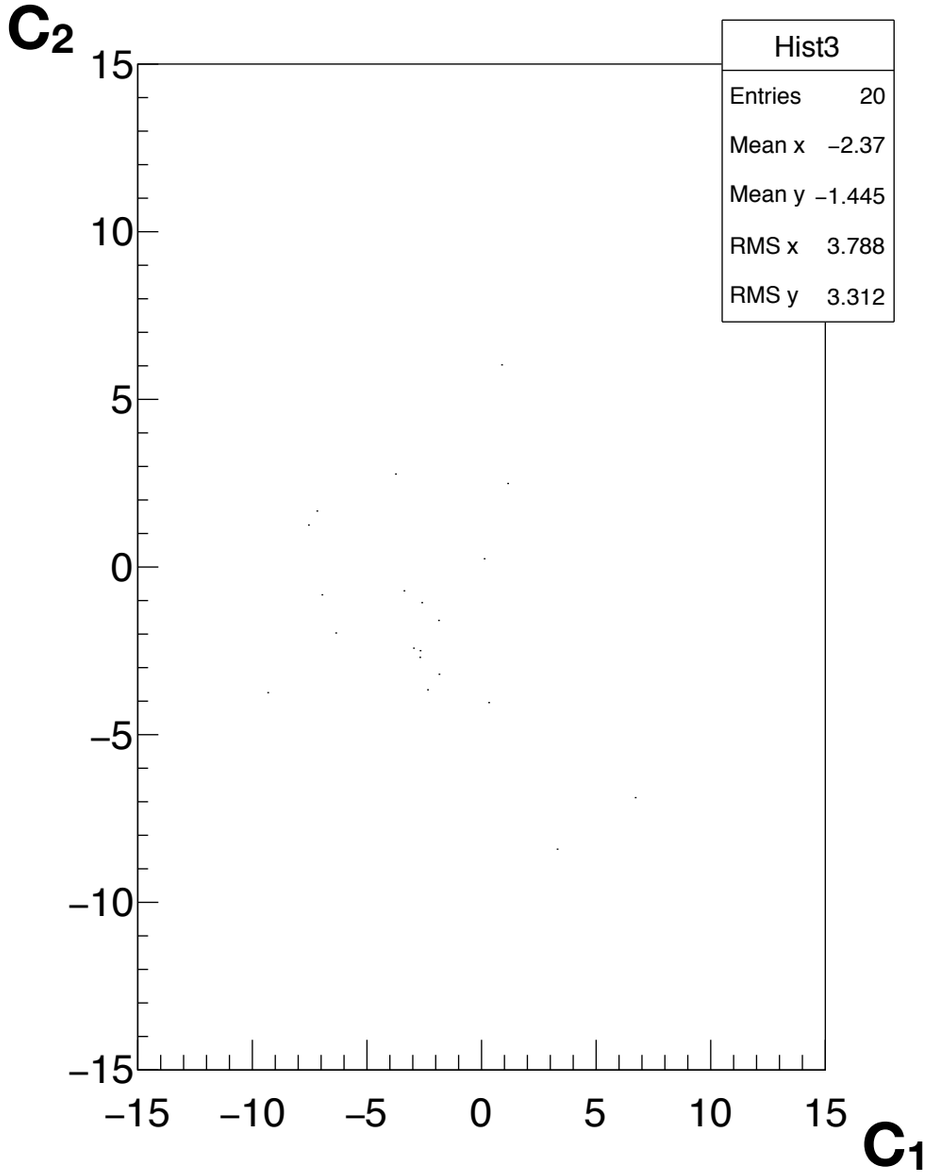

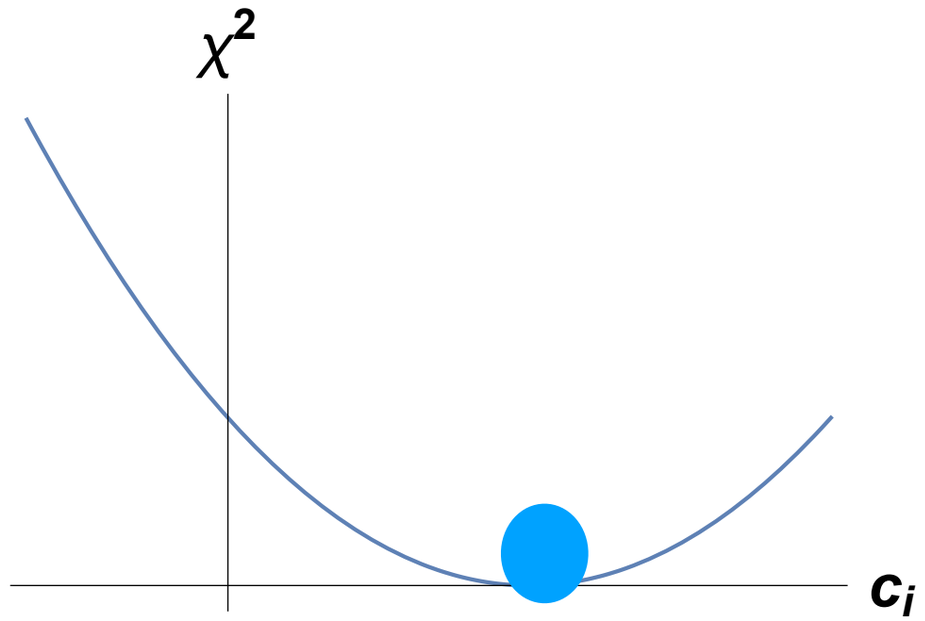

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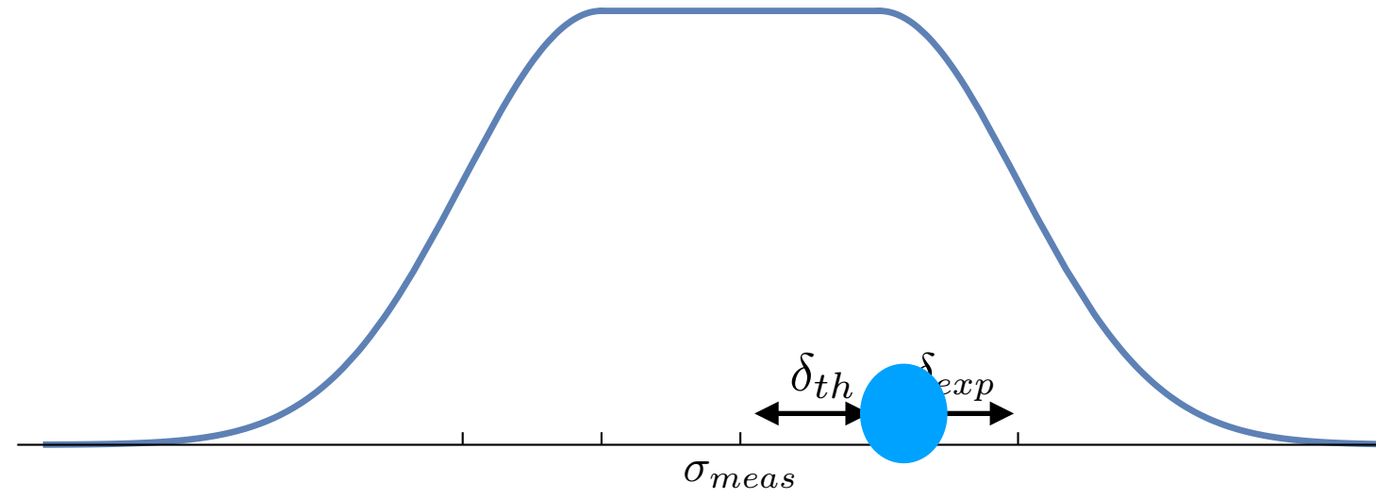

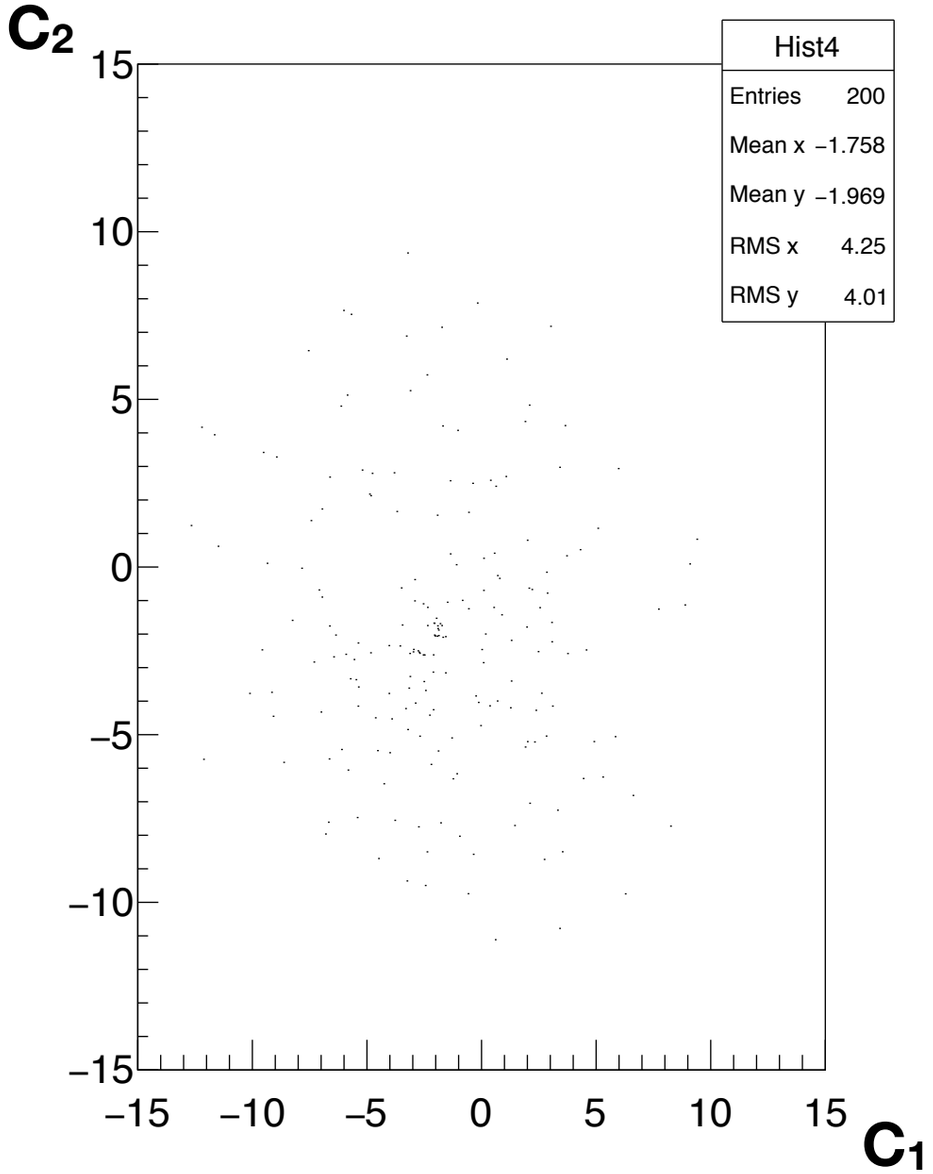

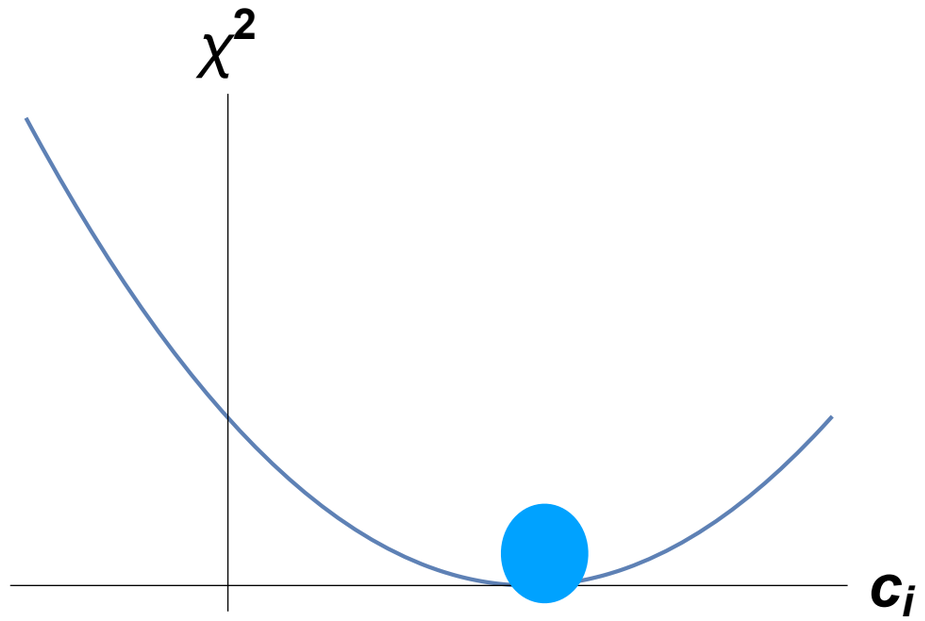

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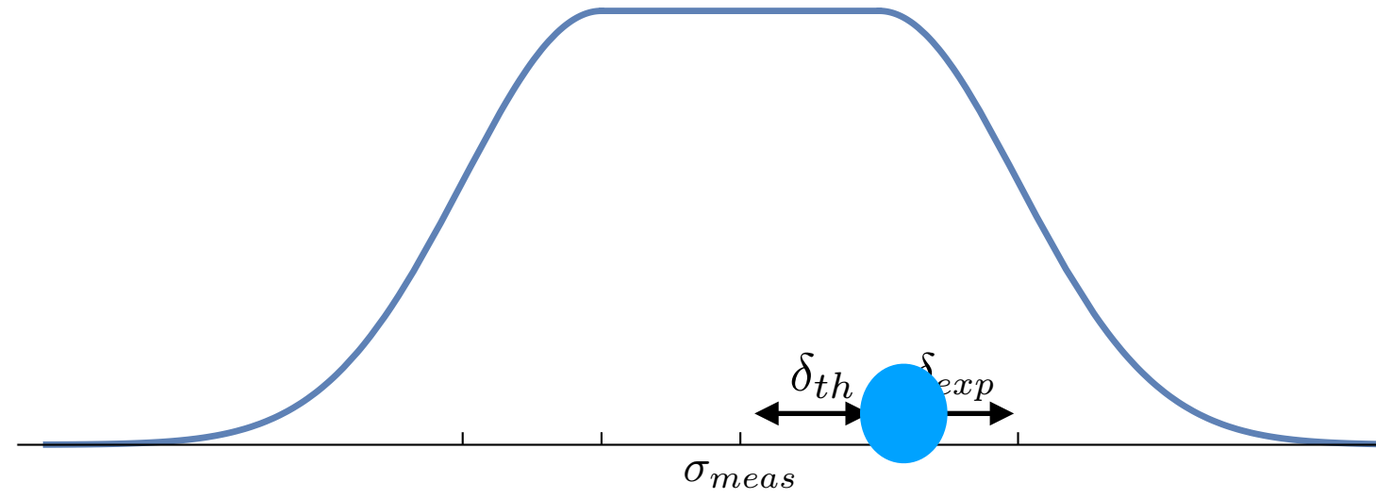

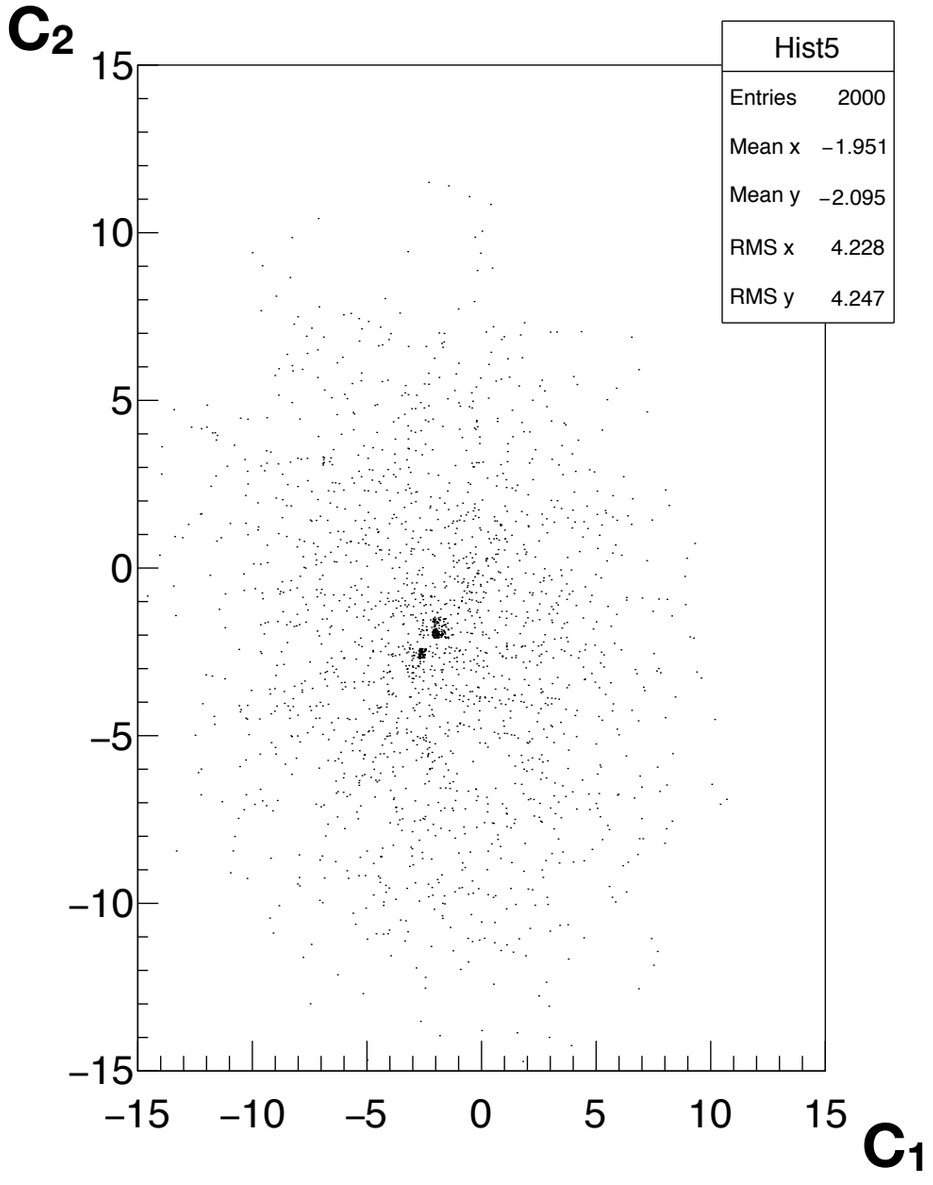

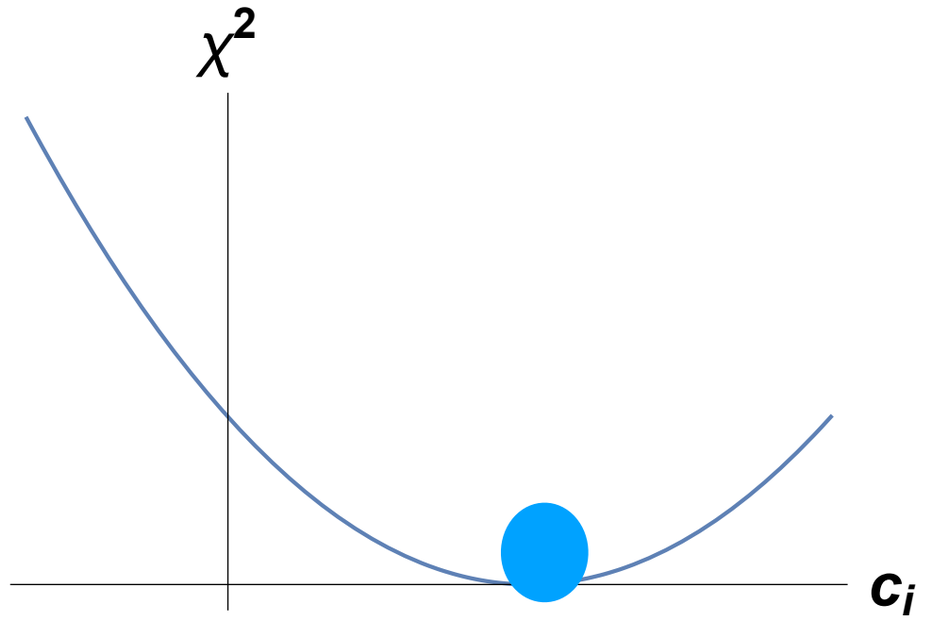

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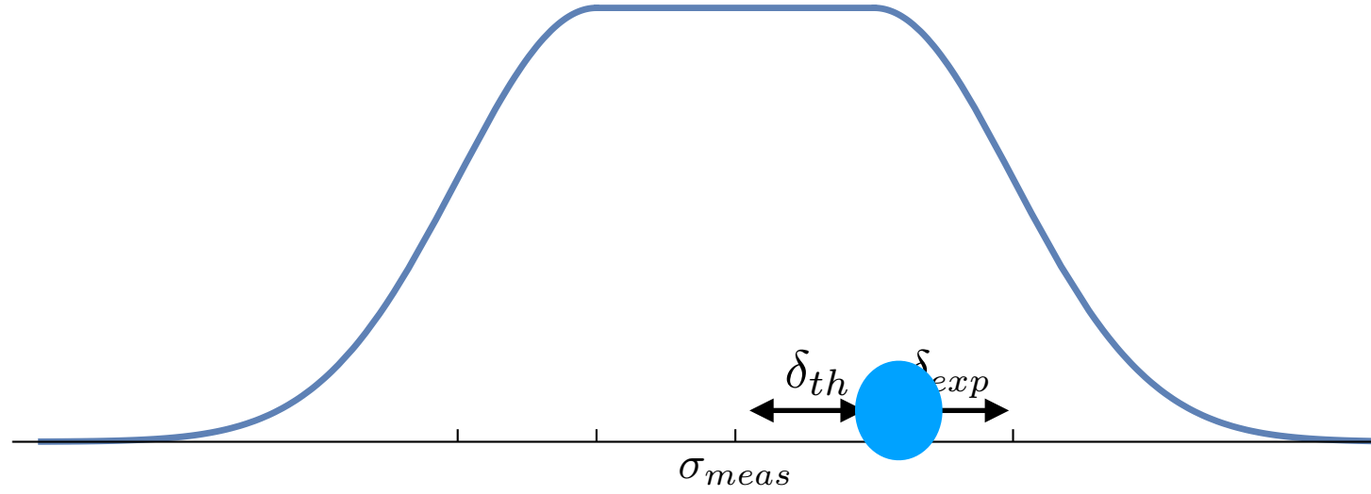

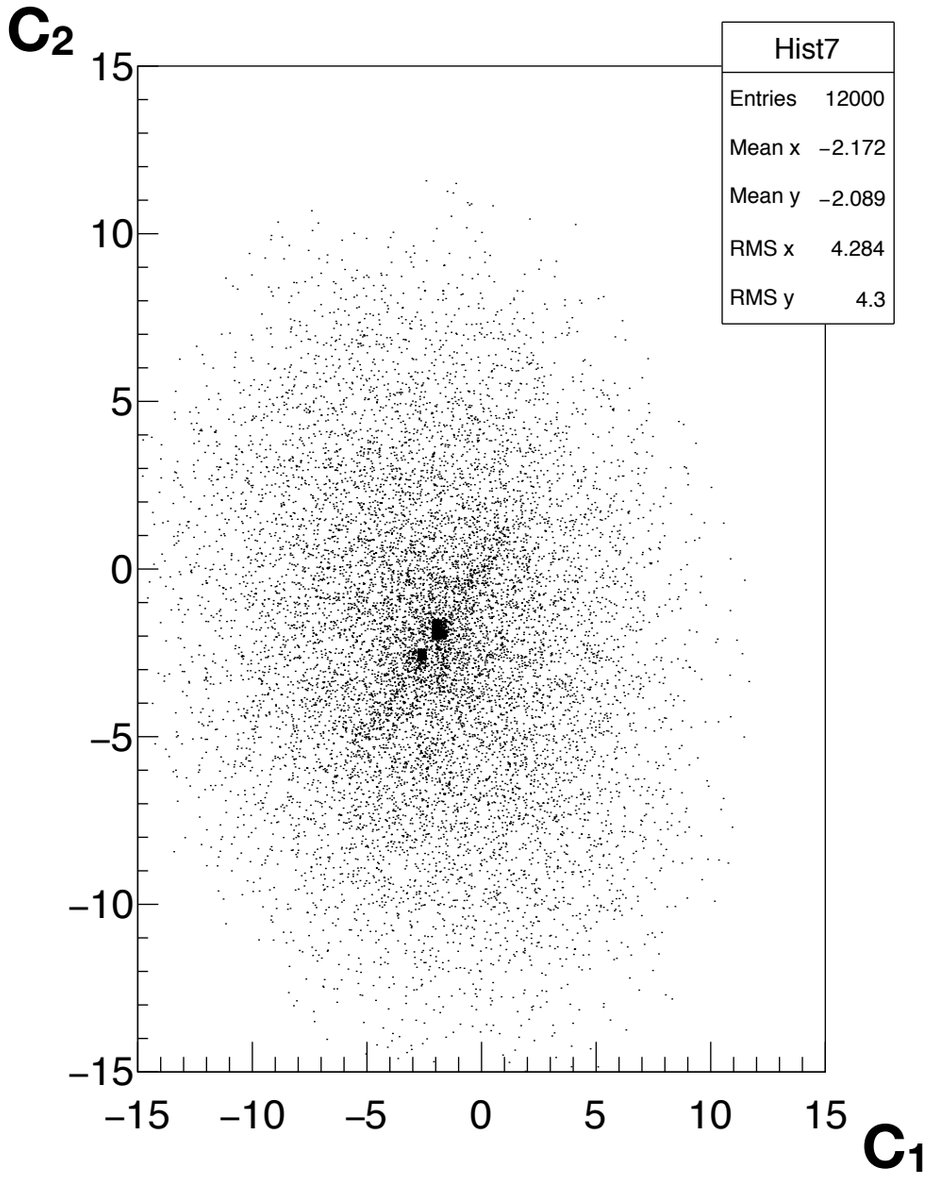

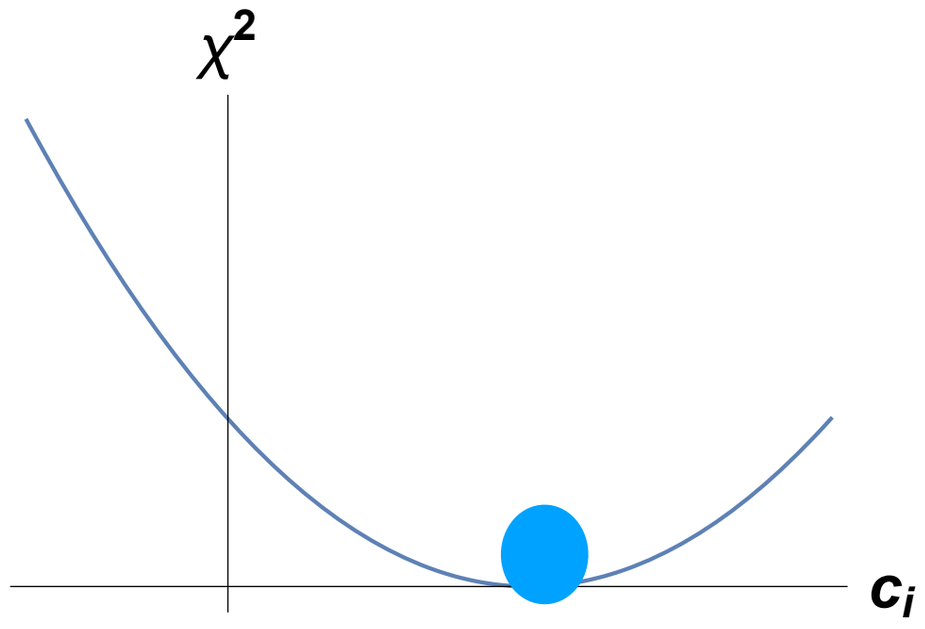

Some aspects of normalising

$$\hat{\sigma}_i = \frac{\sigma_i}{\sum_j \sigma_j \Delta_j} \rightarrow \sum_j \hat{\sigma}_j \Delta_j \equiv 1$$

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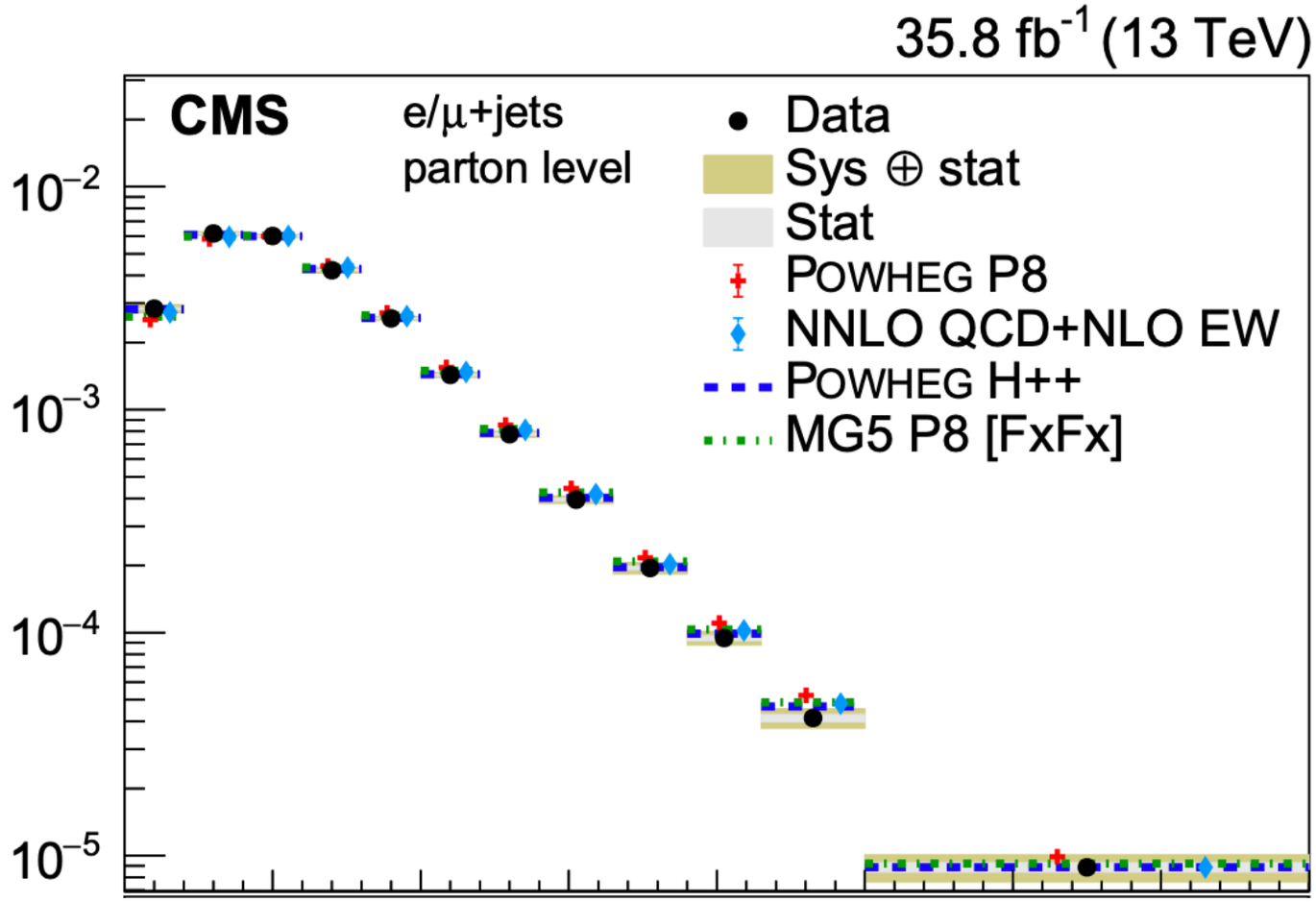

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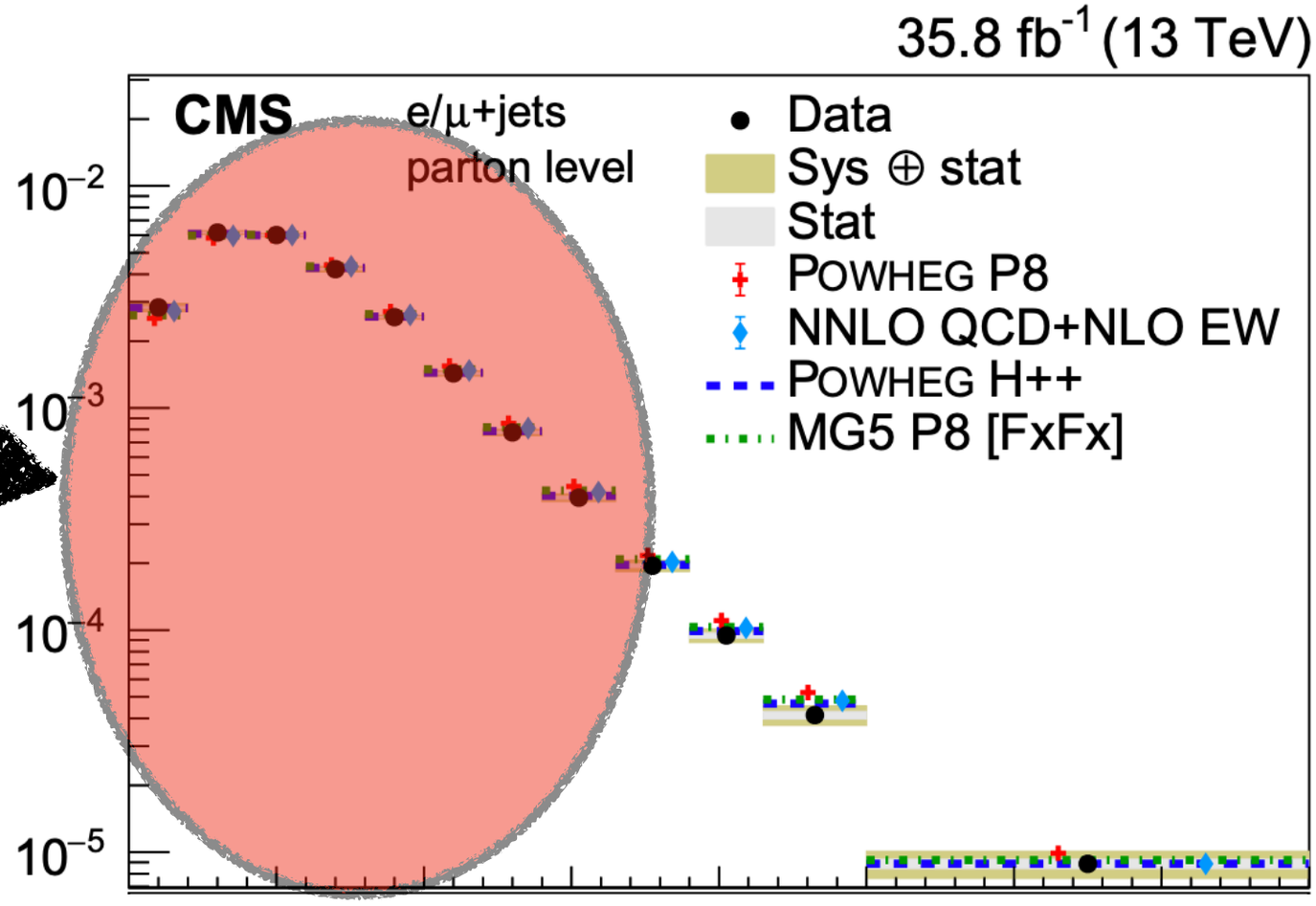

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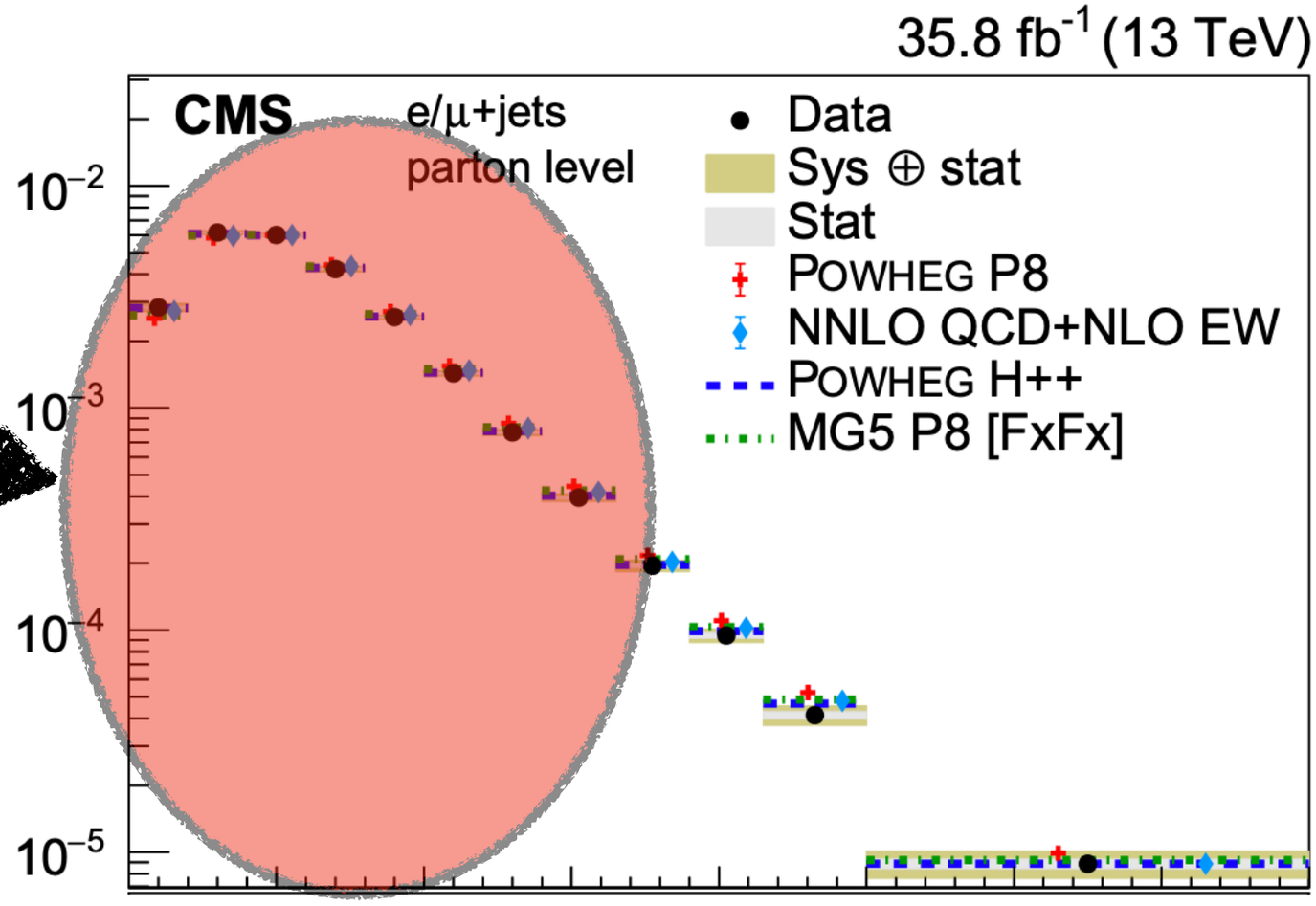

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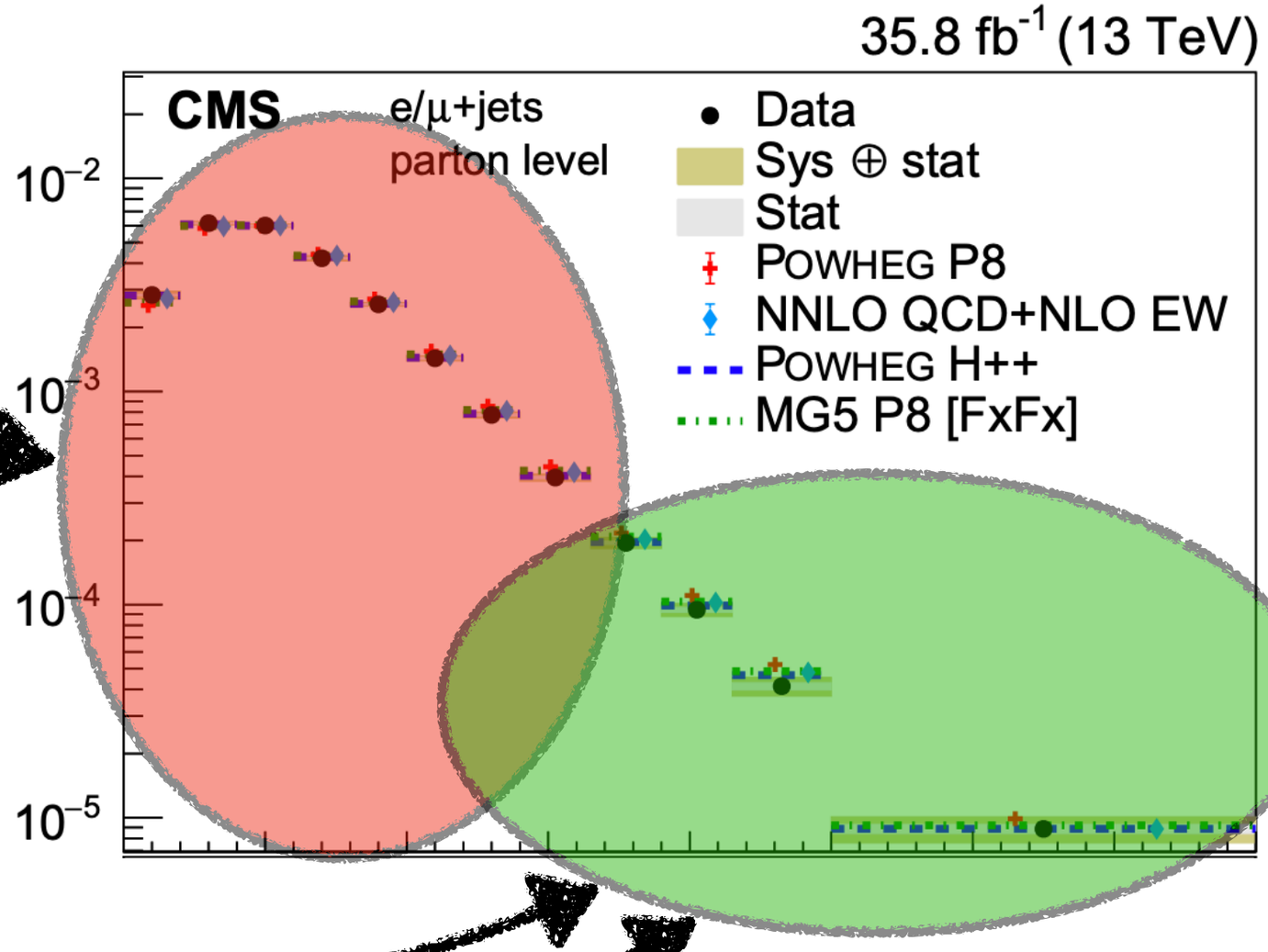

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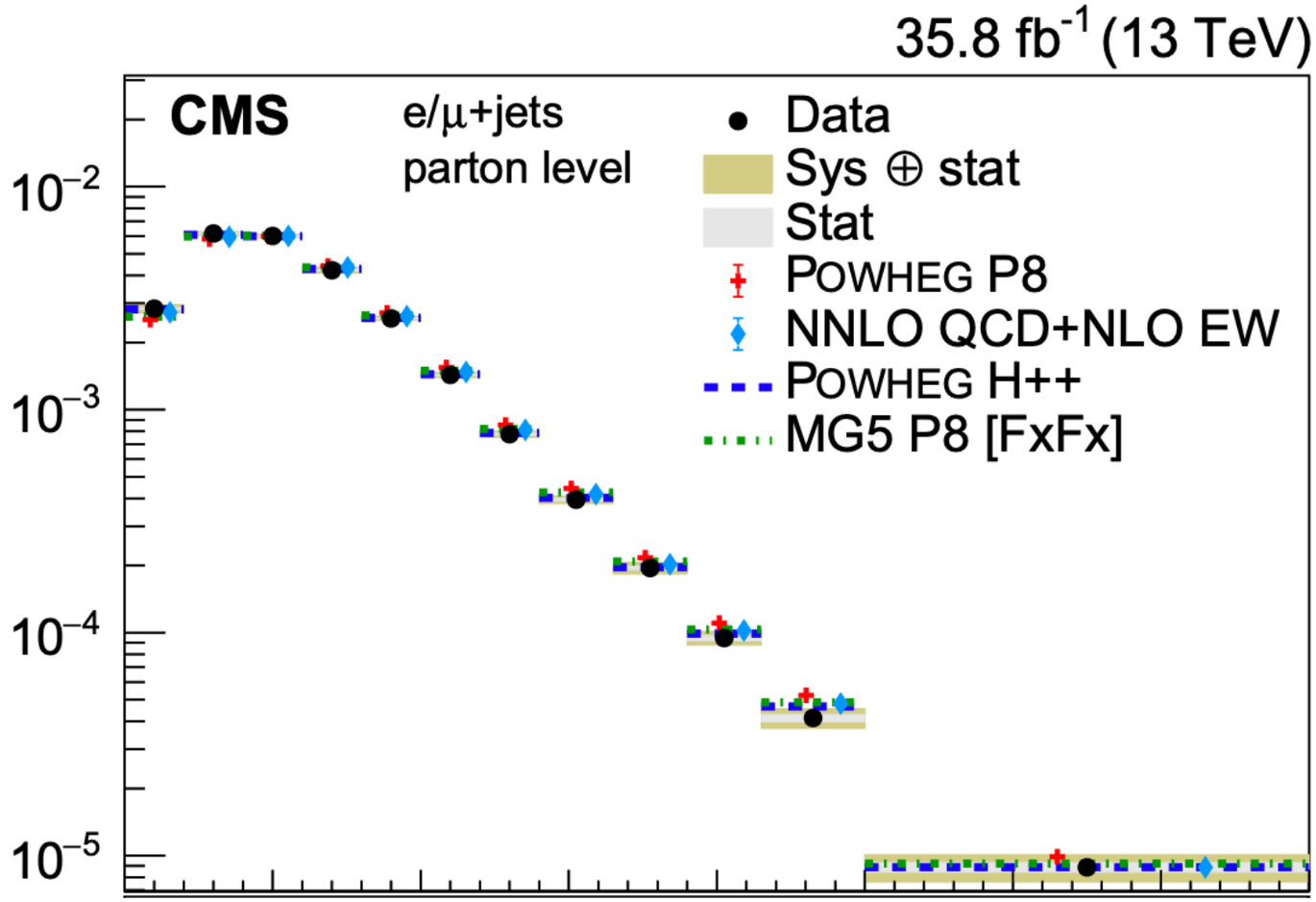

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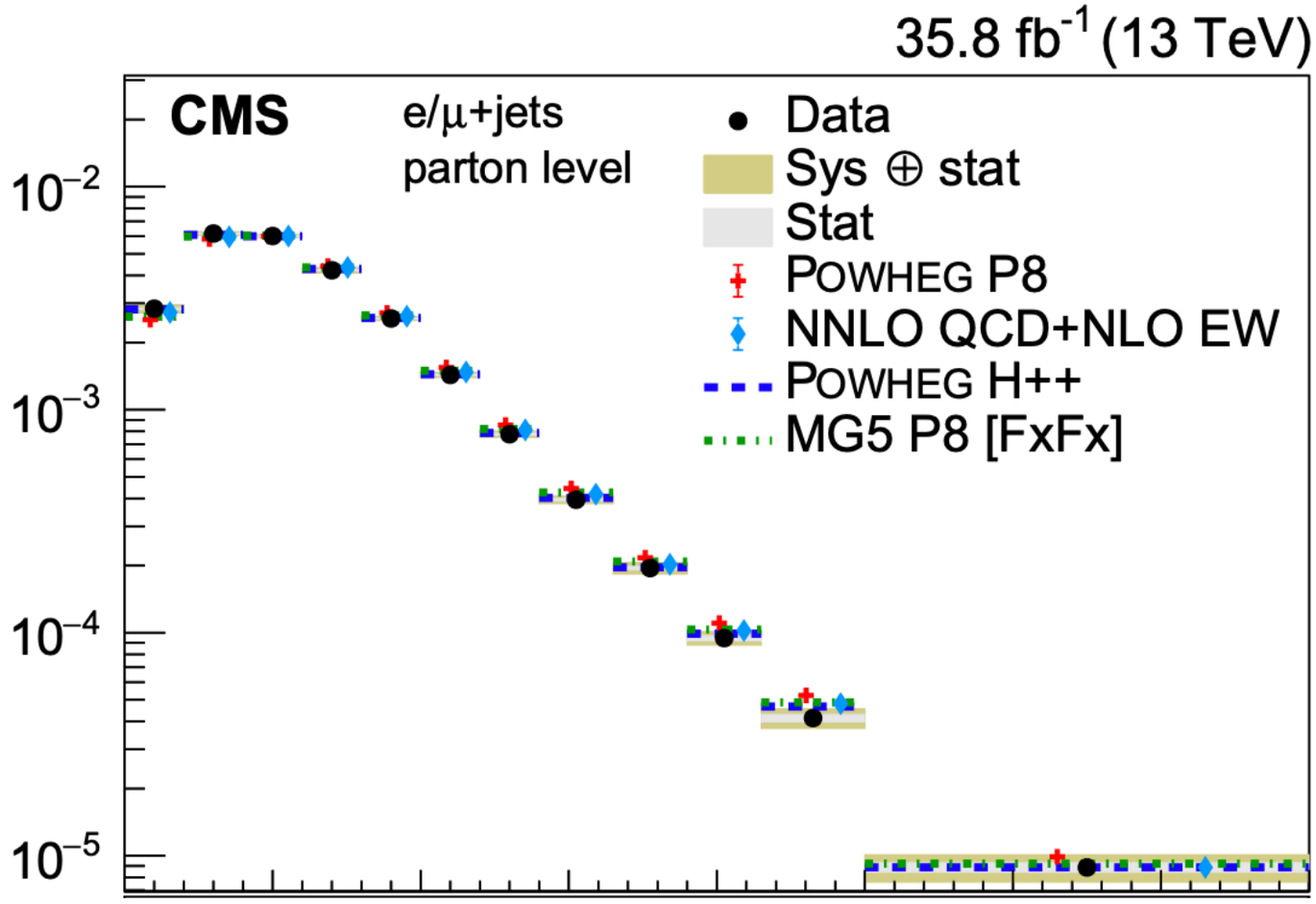

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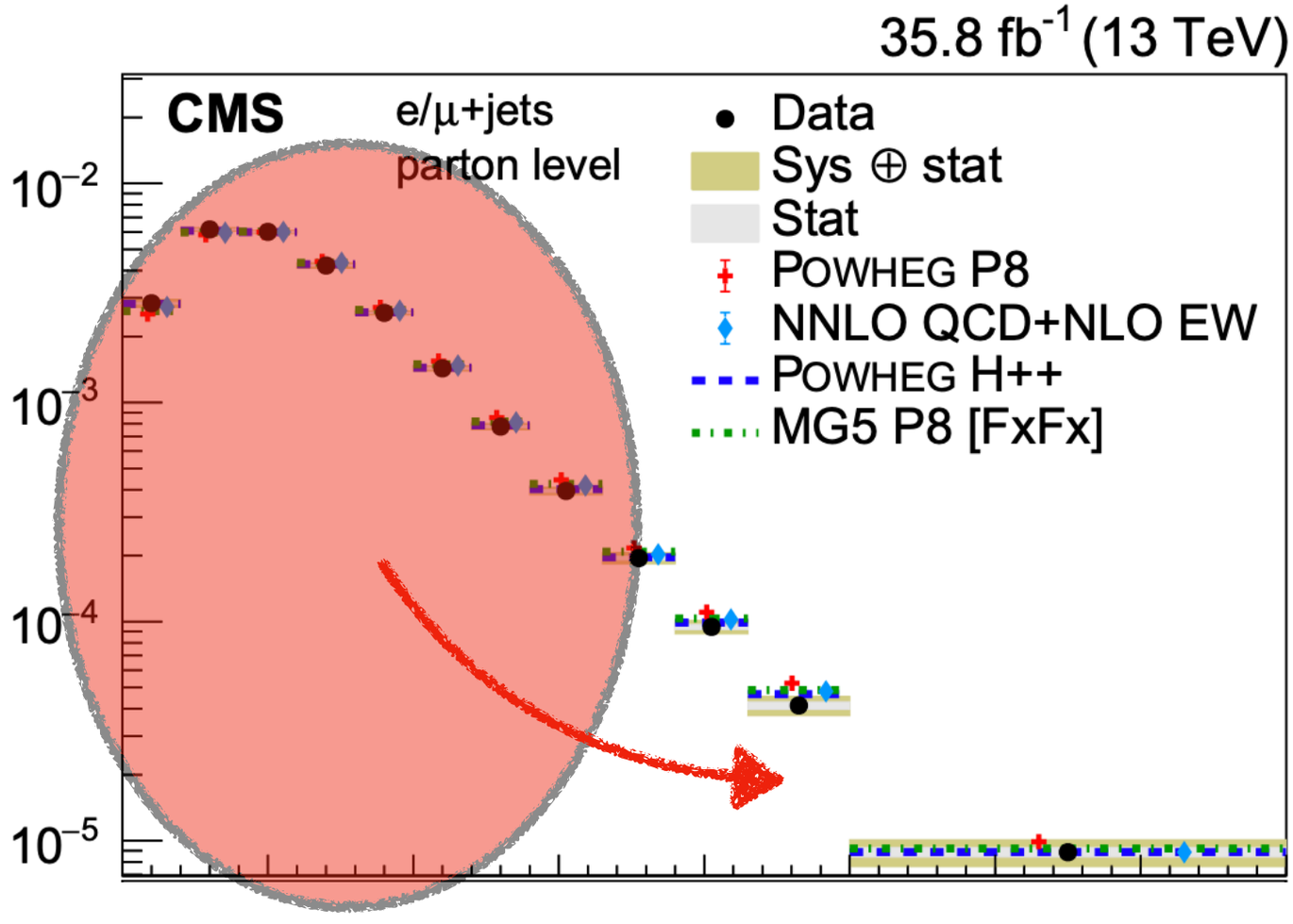

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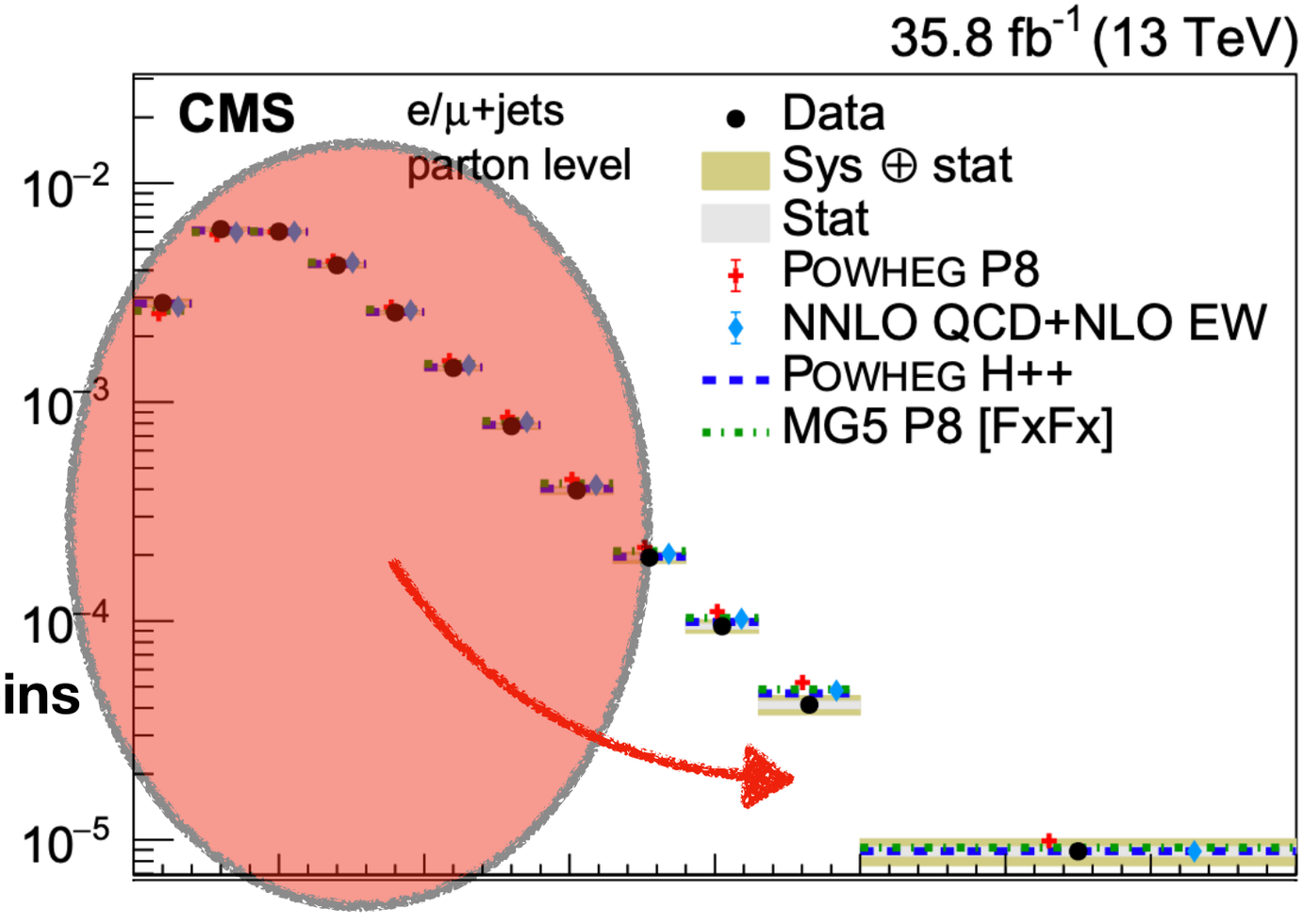

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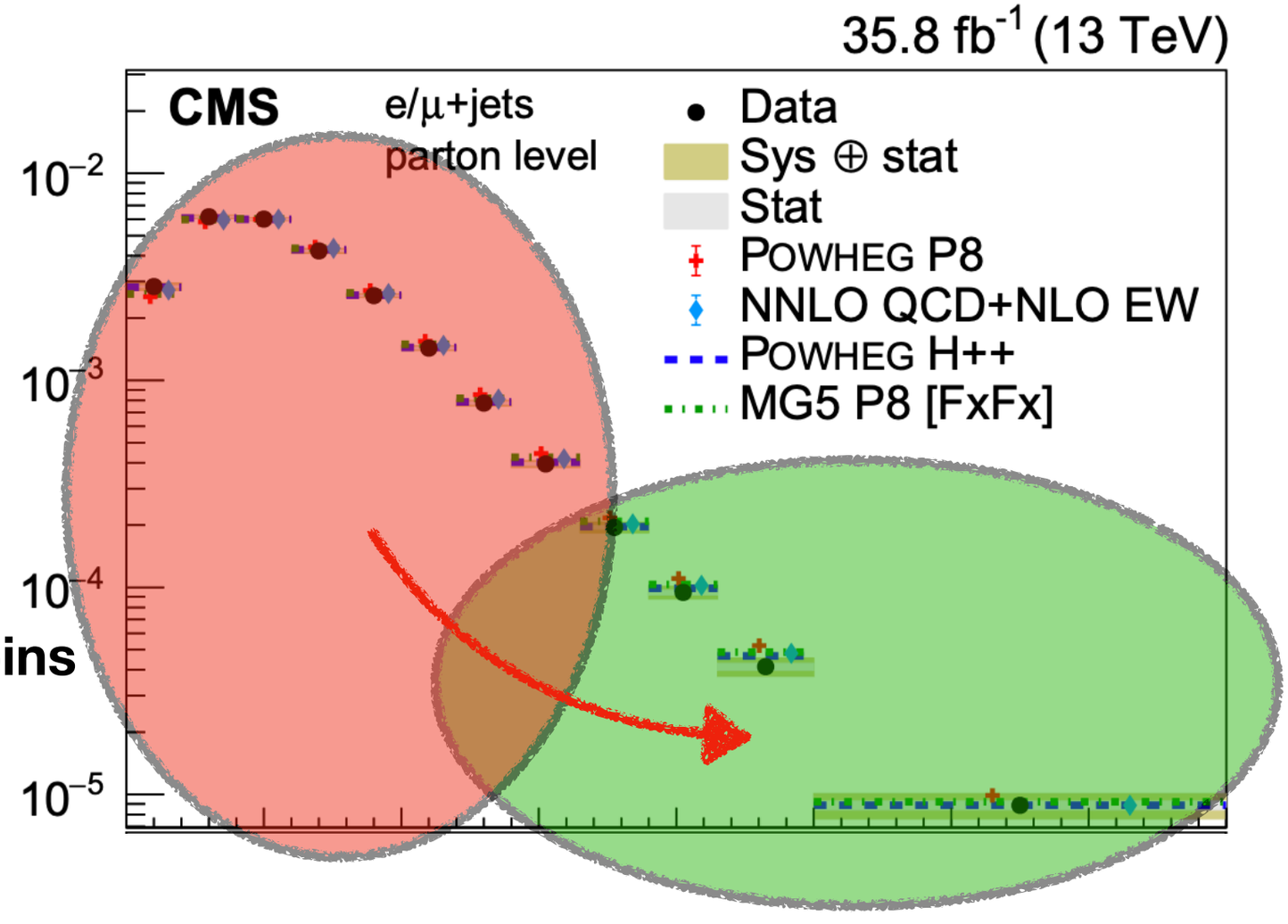

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Resolving Degeneracies

$$Out8 = 2C_{uu}^{8(i33i)}(\bar{u}_i\gamma^\mu T^A u_3)(\bar{u}_3\gamma_\mu T^A u_i)$$

$$u_R\bar{u}_R \to t_R\bar{t}_R$$

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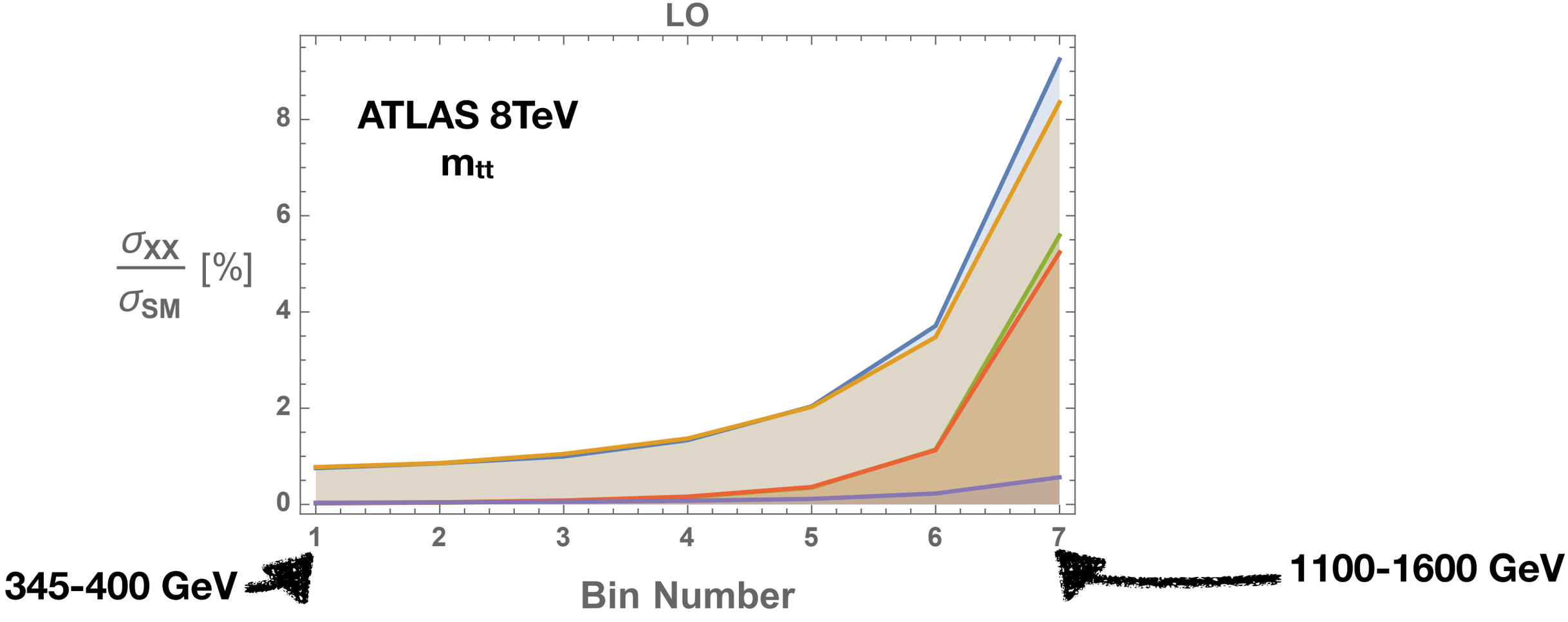

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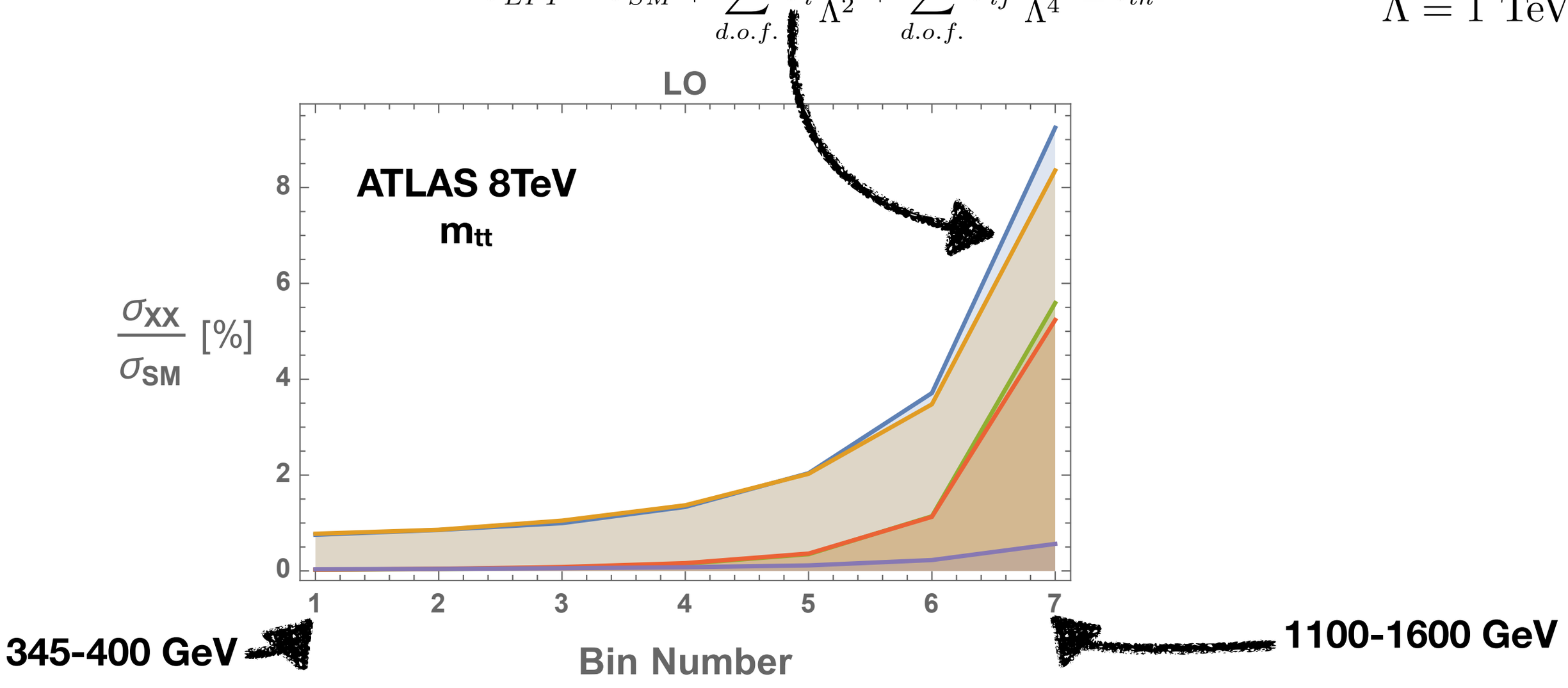

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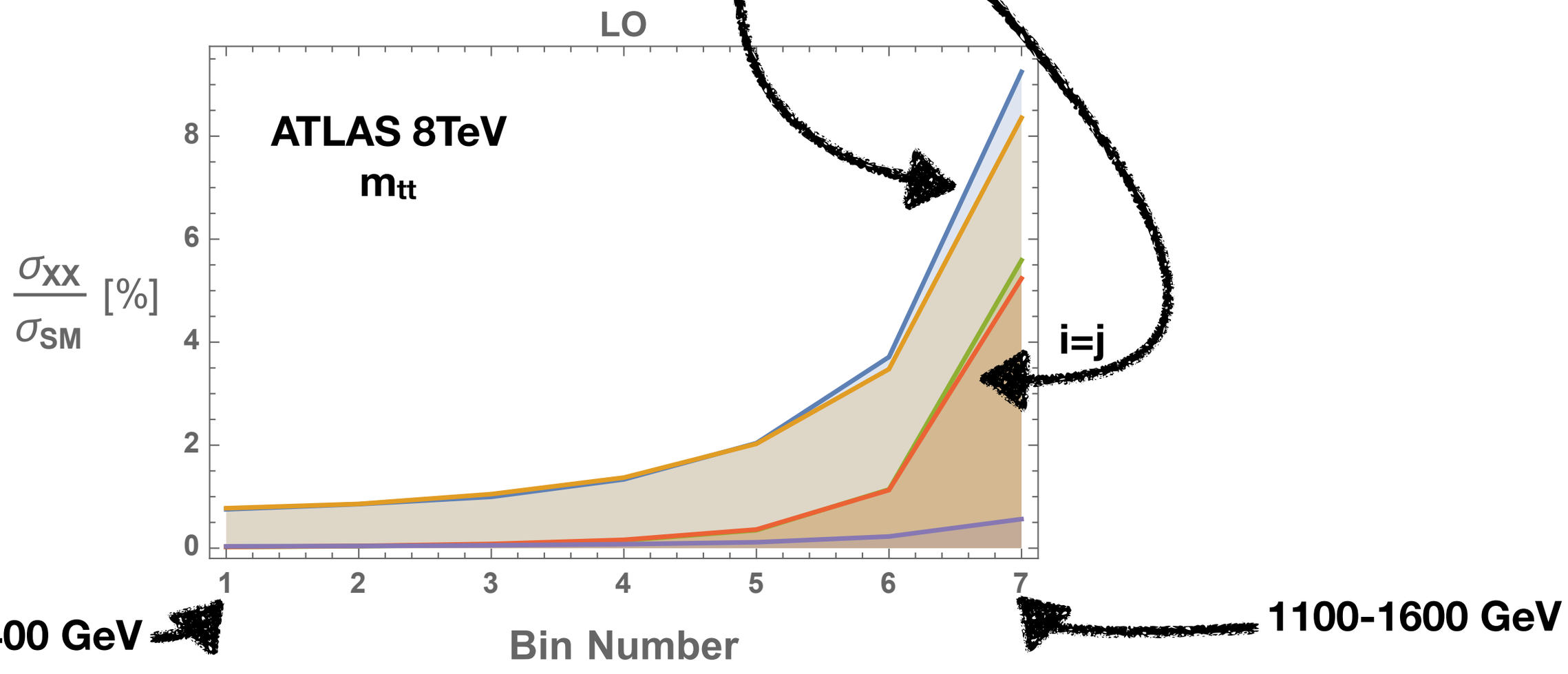

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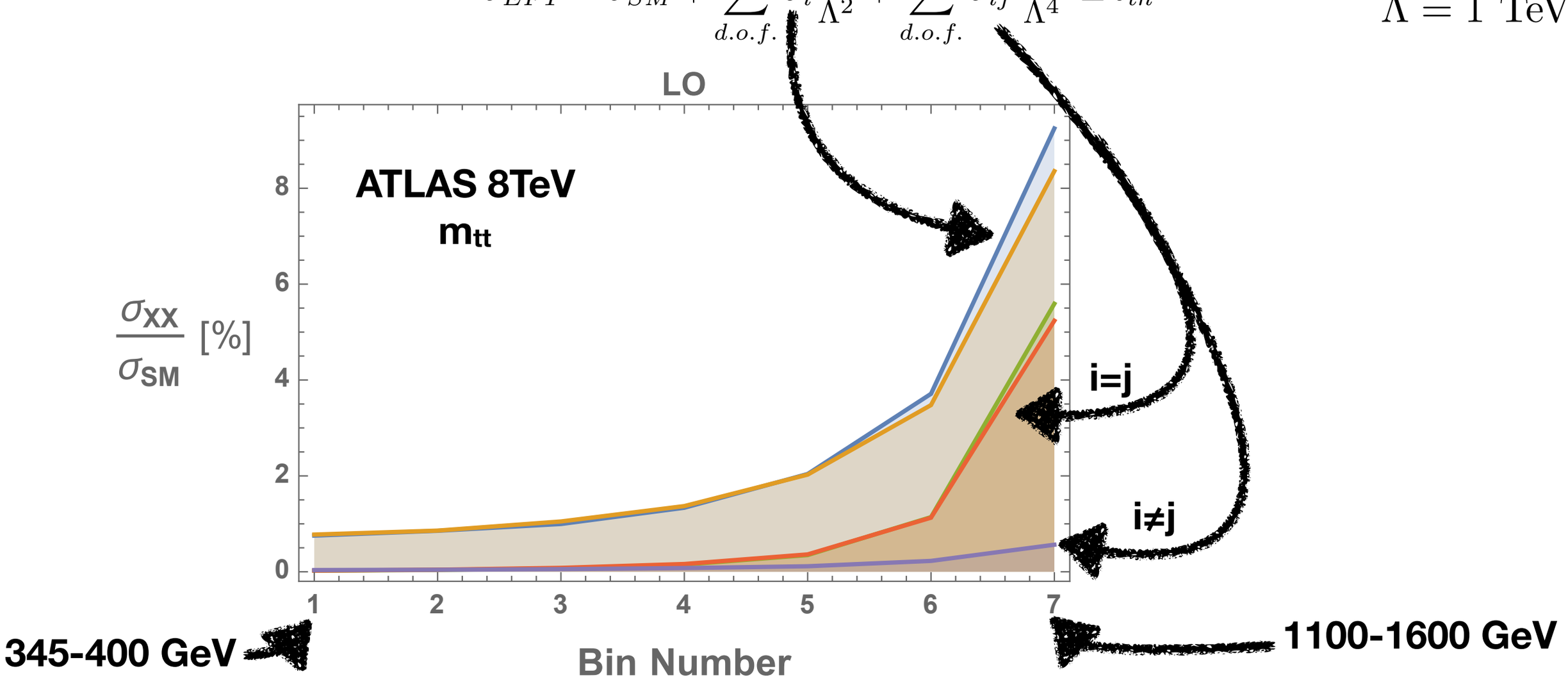

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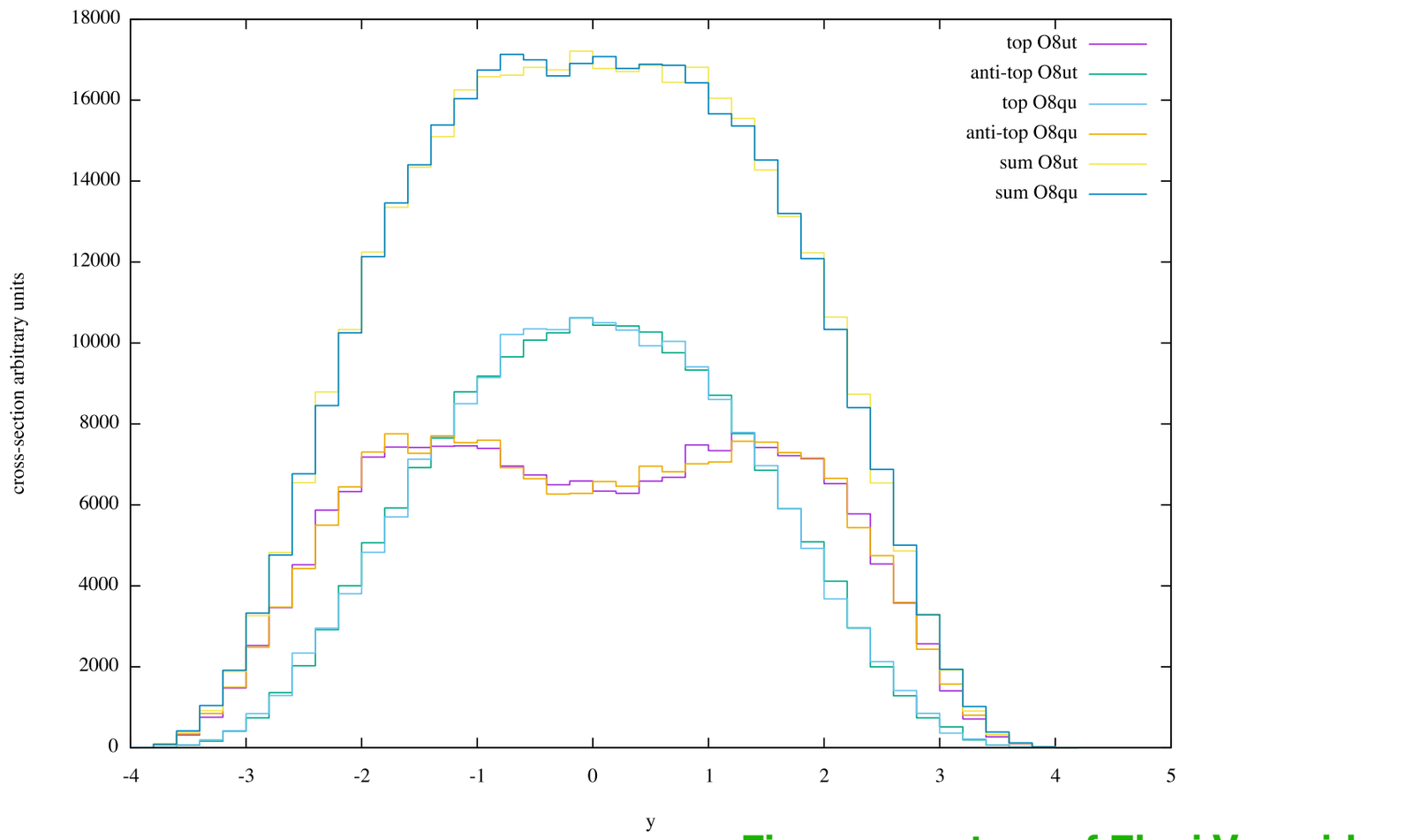

Figure: courtesy of Eleni Vryonidou

Resolving Degeneracies

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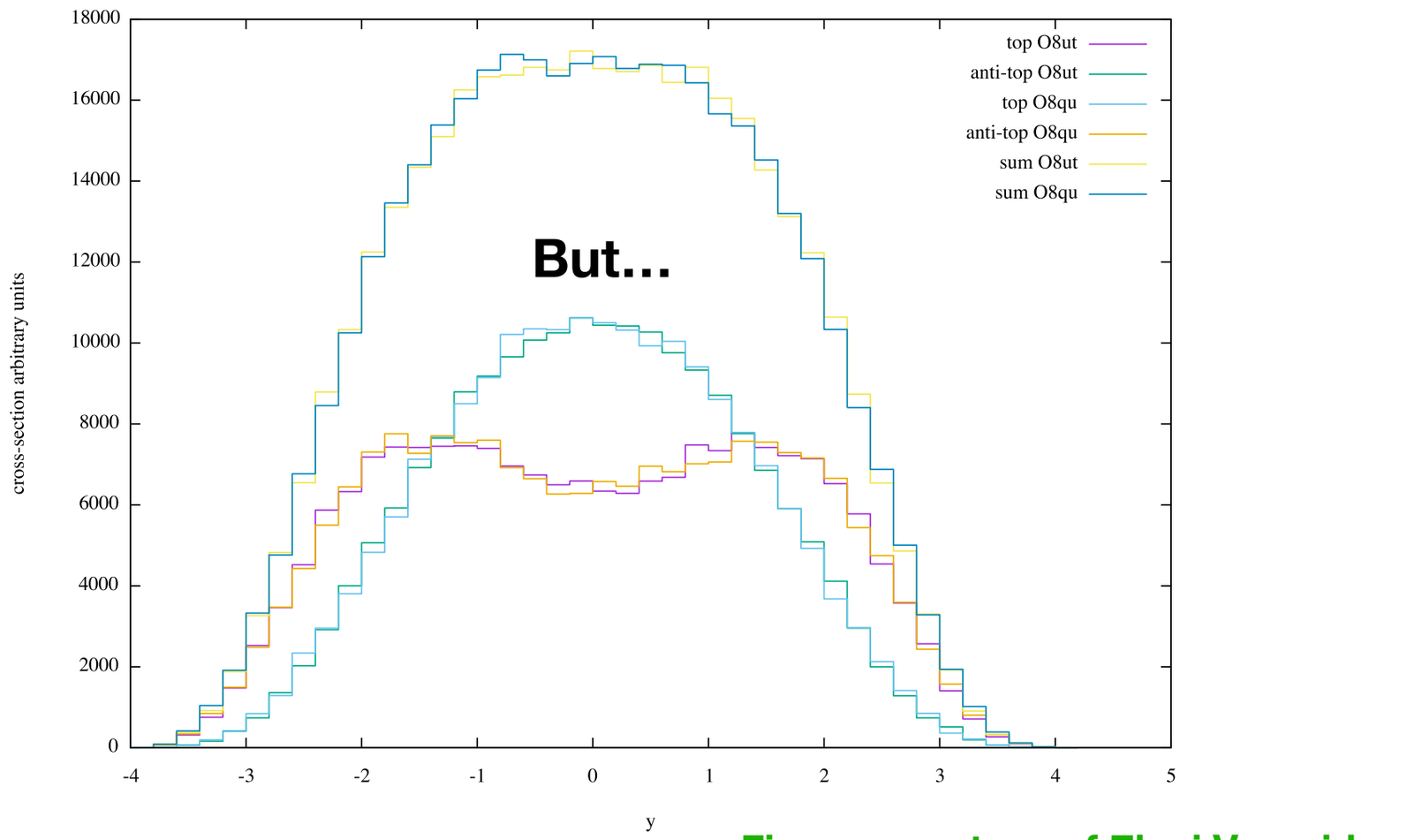

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Resolving Degeneracies

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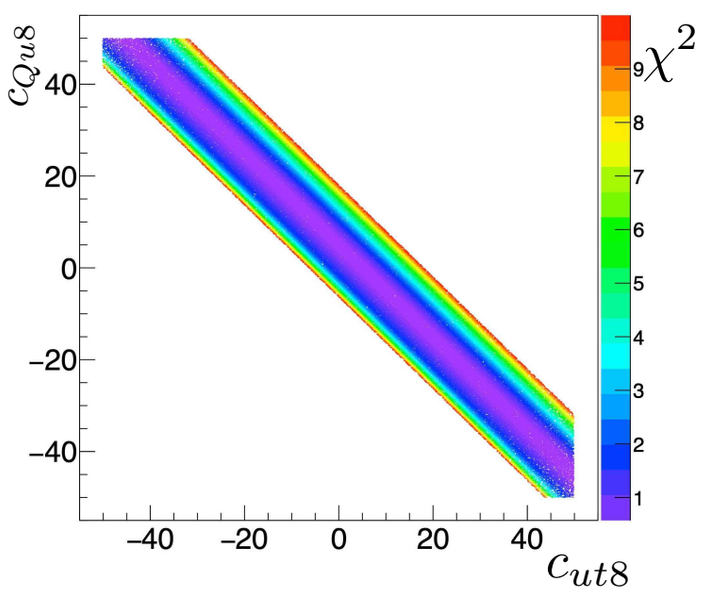

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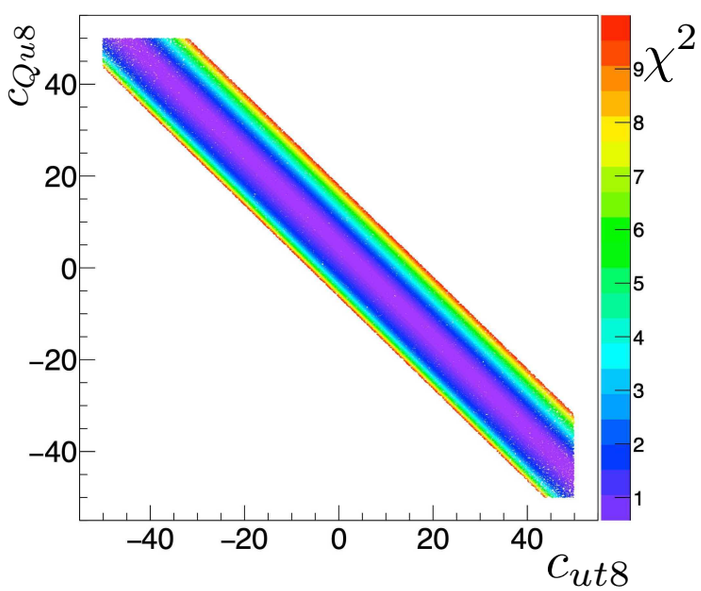

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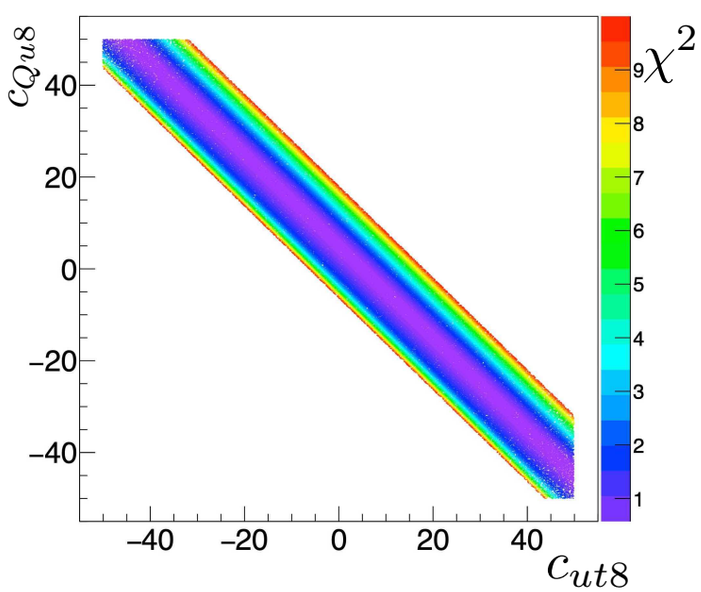

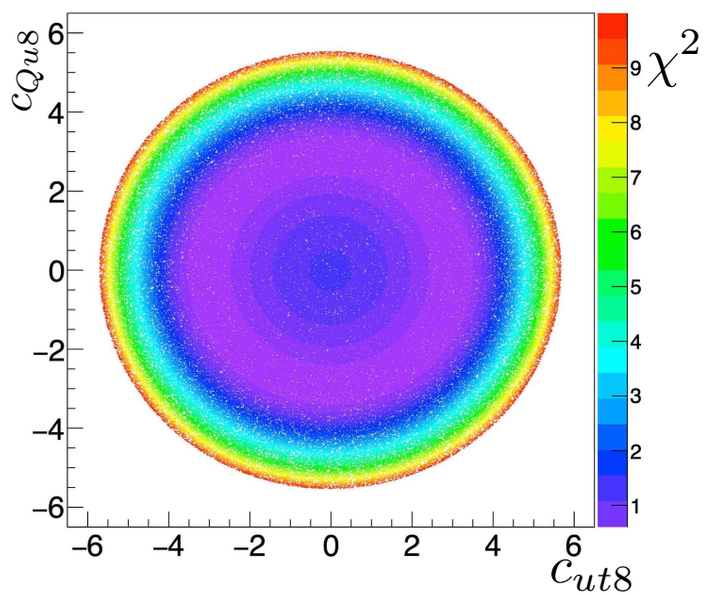

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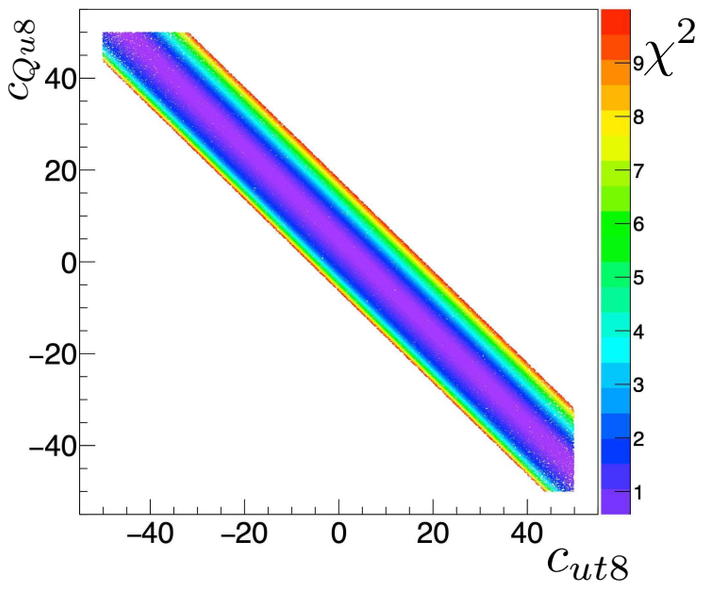
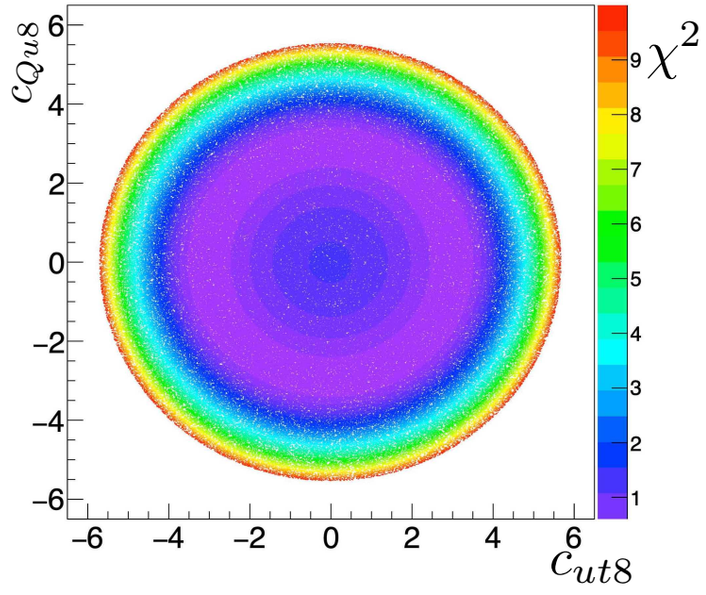
Blind hyperbola (negligible)





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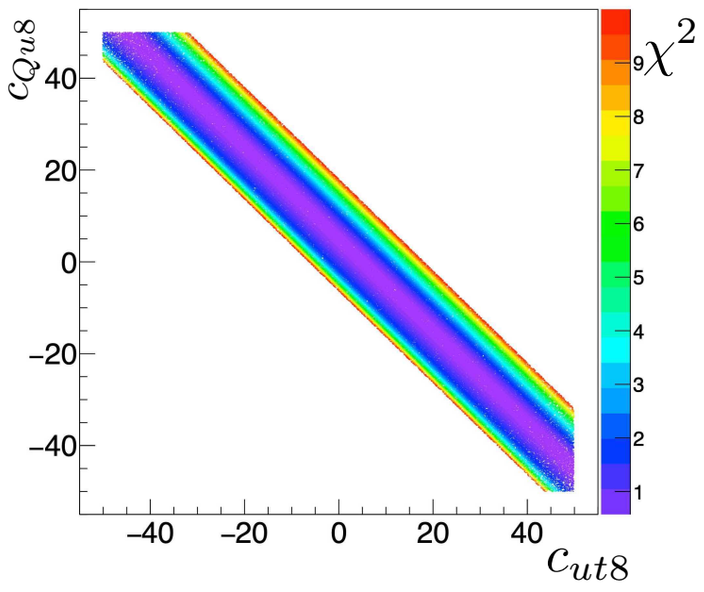

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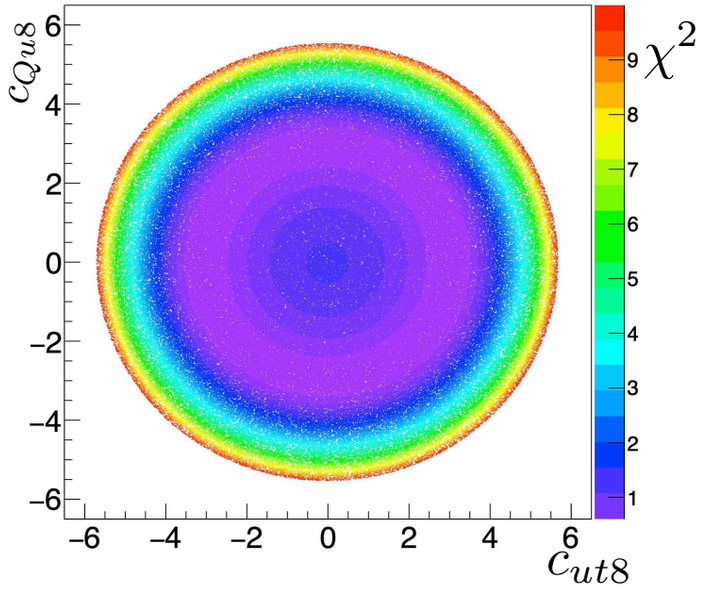

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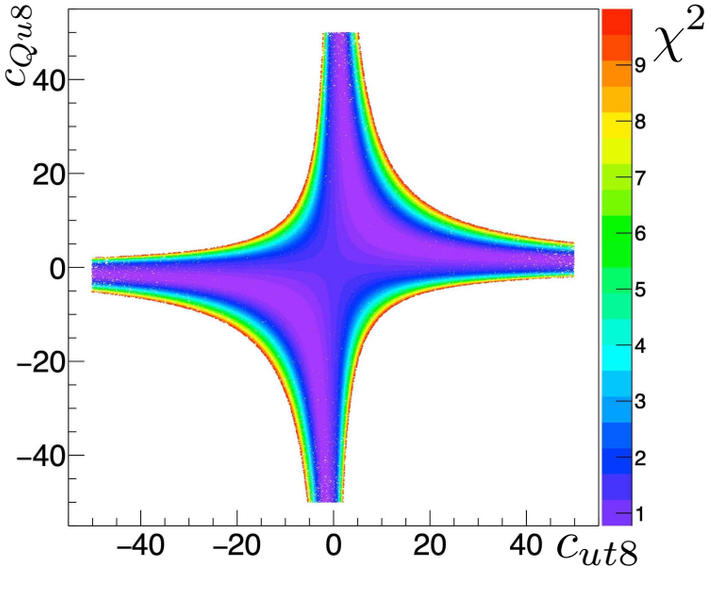

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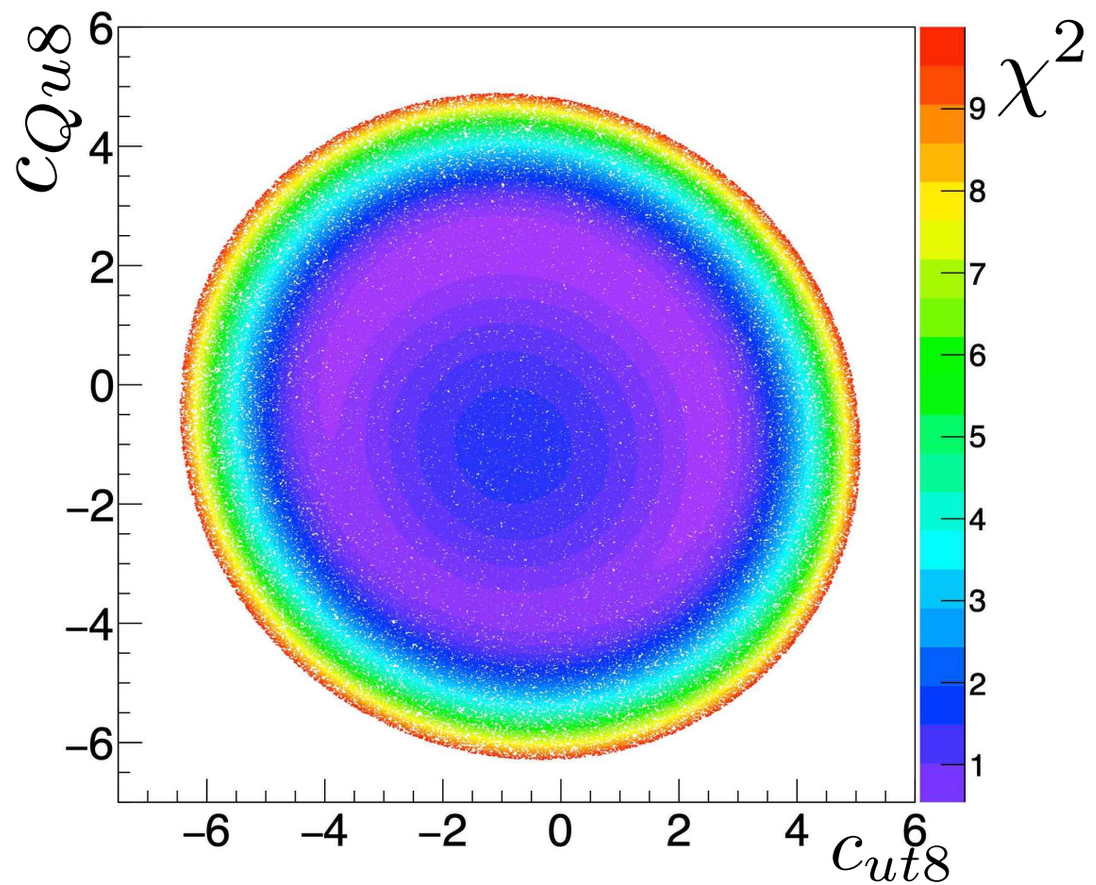

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- $\mathcal{O}(\Lambda^{-4})$ are important in resolving degeneracies due to their rapid growth with energy

Thank you

The Operators

25 four-fermion operators

$$OQq31 = C_{qq}^{3(ii33)} + \frac{1}{6}\left(C_{qq}^{1(i33i)} - C_{qq}^{3(i33i)}\right)$$
$$OQq38 = C_{qq}^{1(i33i)} - C_{qq}^{3(i33i)}$$
$$OQq18 = C_{qq}^{1(i33i)} + 3C_{qq}^{3(i33i)}$$
$$OQq11 = C_{qq}^{1(ii33)} + \frac{1}{6}C_{qq}^{1(i33i)} + \frac{1}{2}C_{qq}^{3(i33i)}$$
$$Oqt8 = C_{qu}^{8(ii33)}$$
$$Oqt1 = C_{qu}^{1(ii33)}$$
$$Out8 = 2C_{uu}^{(i33i)}$$
$$Out1 = C_{uu}^{(ii33)} + \frac{1}{3}C_{uu}^{(i33i)}$$
$$OQu8 = C_{qu}^{8(33ii)}$$
$$OQu1 = C_{qu}^{1(33ii)}$$
$$Odt8 = C_{ud}^{8(33ii)}$$
$$Odt1 = C_{ud}^{1(33ii)}$$
$$Oqd8 = C_{Qd}^{8(33ii)}$$
$$Oqd1 = C_{Qd}^{1(33ii)}$$

$$OQQ1 = 2C_{qq}^{1(3333)} - \frac{2}{3}C_{qq}^{3(3333)}$$
$$OQQ8 = 8C_{qq}^{3(3333)}$$
$$OQt1 = C_{qu}^{1(3333)}$$
$$OQt8 = C_{qu}^{8(3333)}$$
$$OQb1 = C_{qd}^{1(3333)}$$
$$OQb8 = C_{qd}^{8(3333)}$$
$$Ott1 = C_{uu}^{1(3333)}$$
$$Otb1 = C_{ud}^{1(3333)}$$
$$Otb8 = C_{ud}^{8(3333)}$$
$$OQtQb1 = C_{quqd}^{1(3333)}$$
$$OQtQb8 = C_{quqd}^{8(3333)}$$