UCLouvain
Institut de recherche en mathématique et physique
Centre de Cosmologie, Physique des Particules et Phénoménologie
Centre de Calcul Intensif et Stockage de Masse

The state of Event Generators for the HL-LHC

Olivier Mattelaer

Stean's question

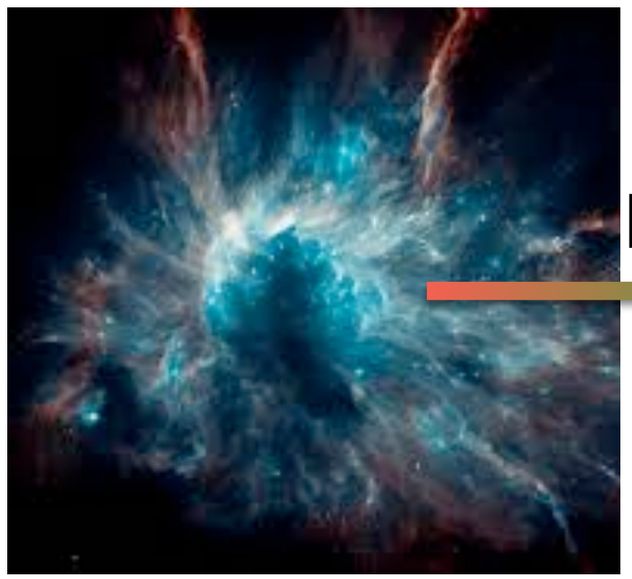
Do we need N(N)LO calculations?

Which event generators can be used?

How much is the complexity of computations going to increase?

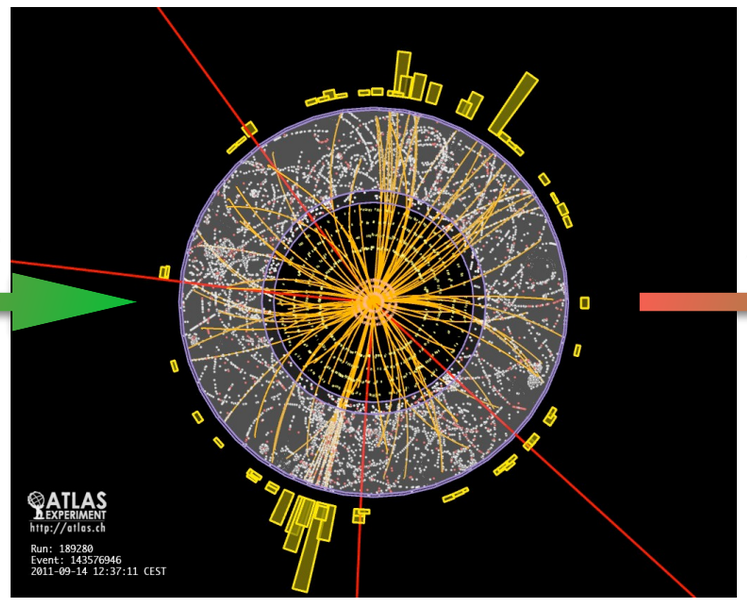
What is Event Generator ?

The World



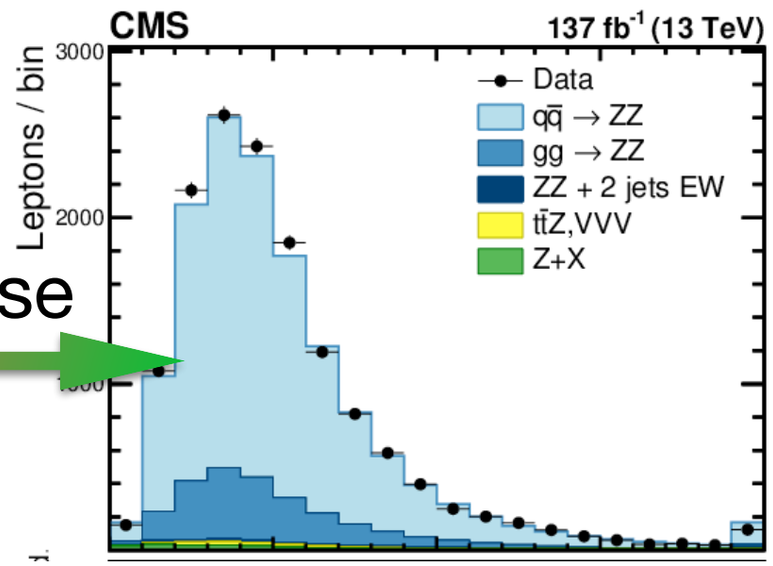
LHC

Experiment



Analyse

Measurement



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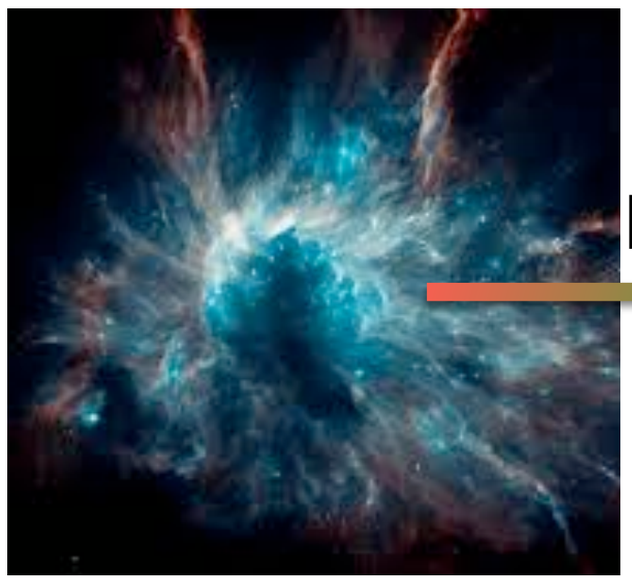

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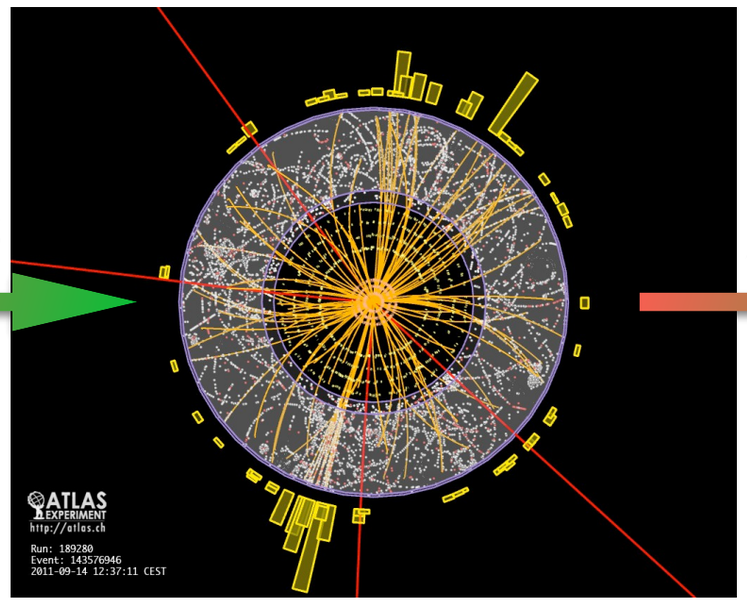

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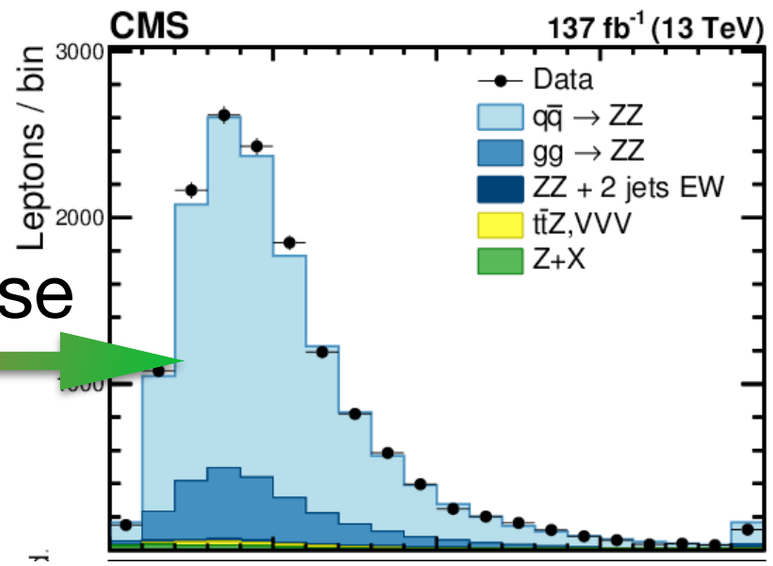

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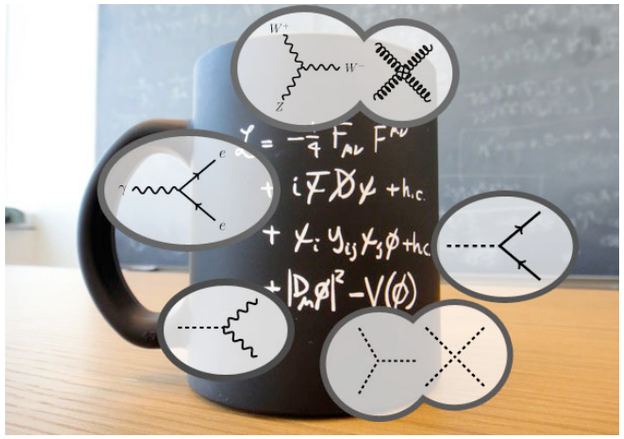

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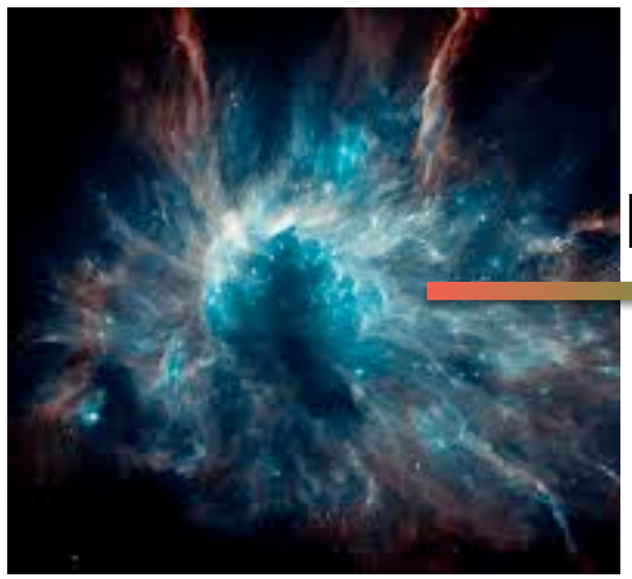

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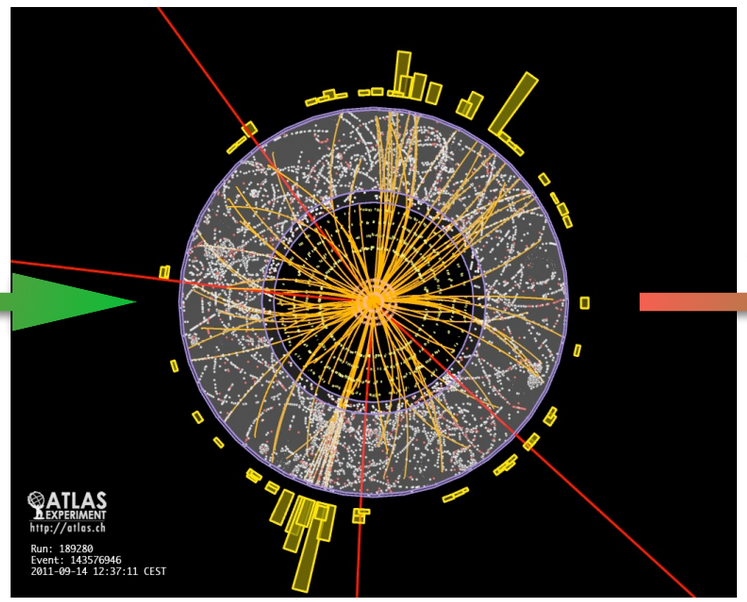

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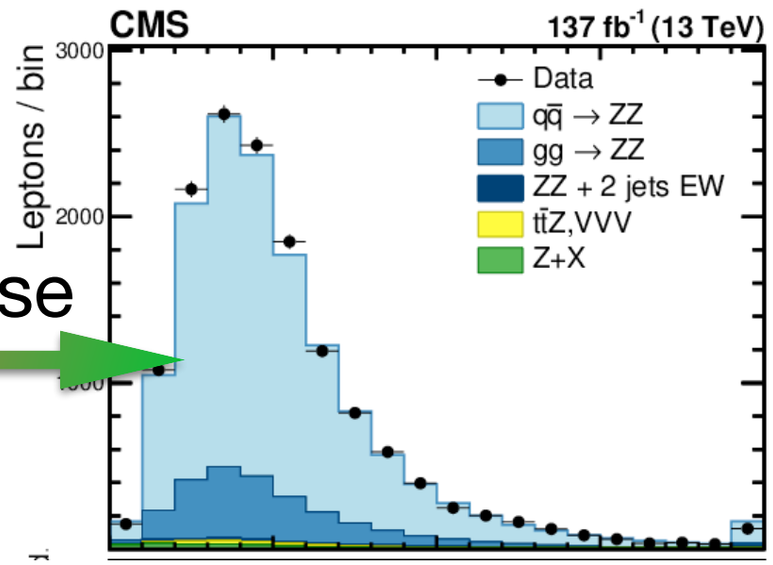

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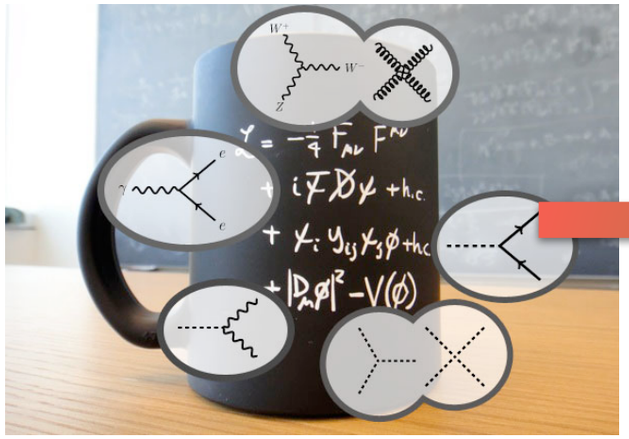

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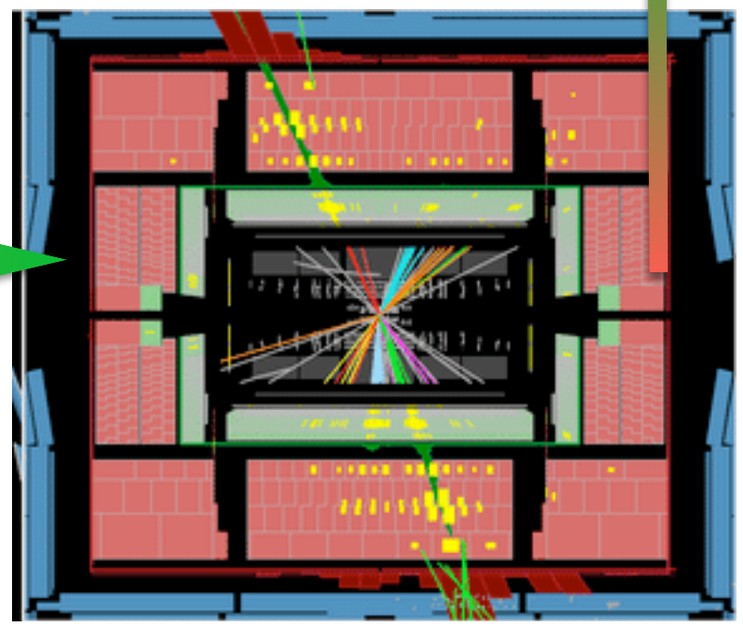

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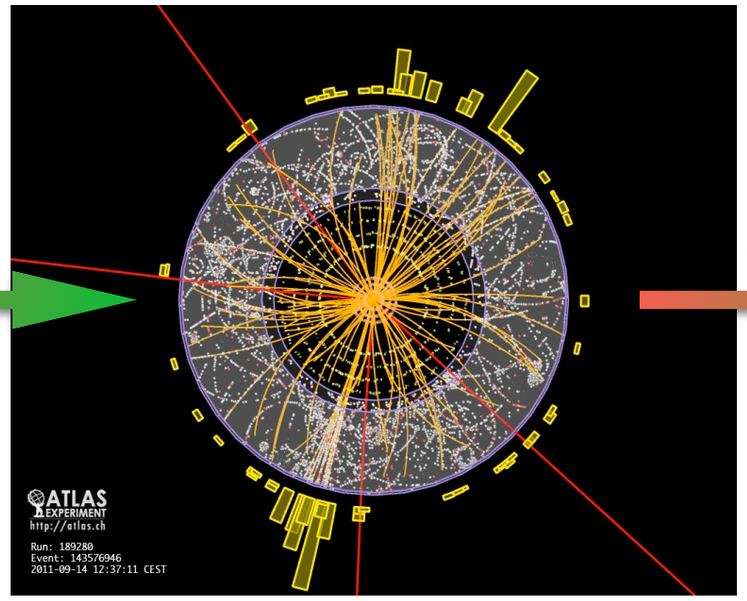

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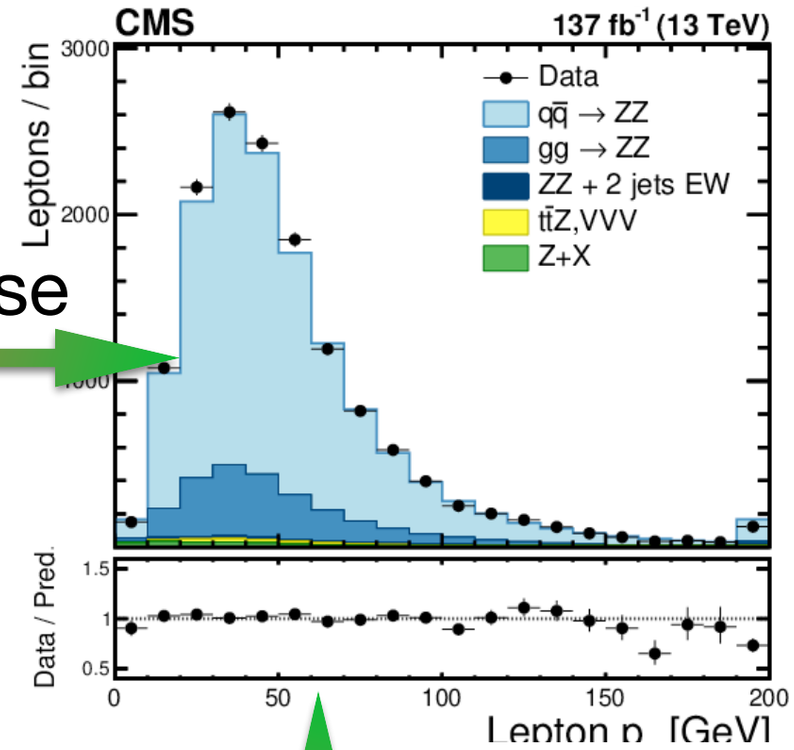

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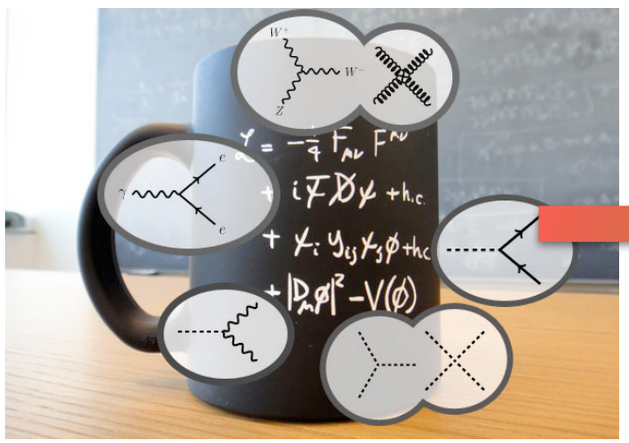

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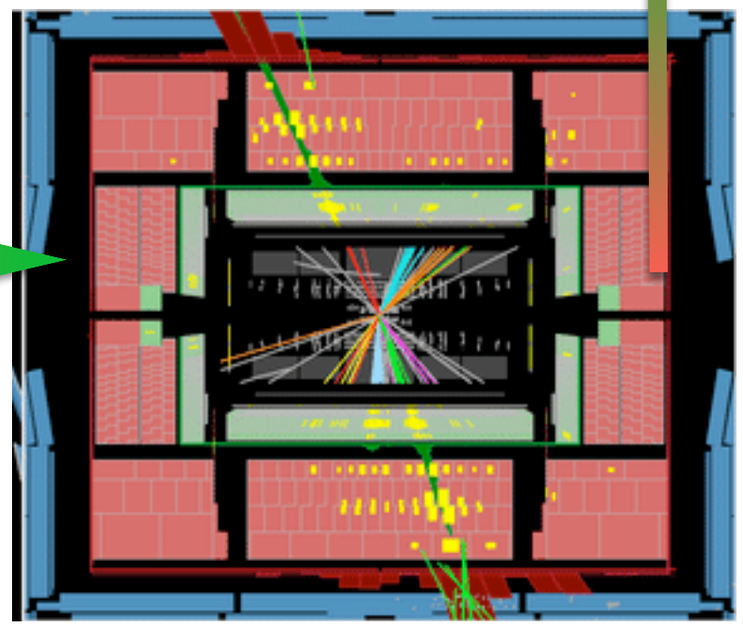
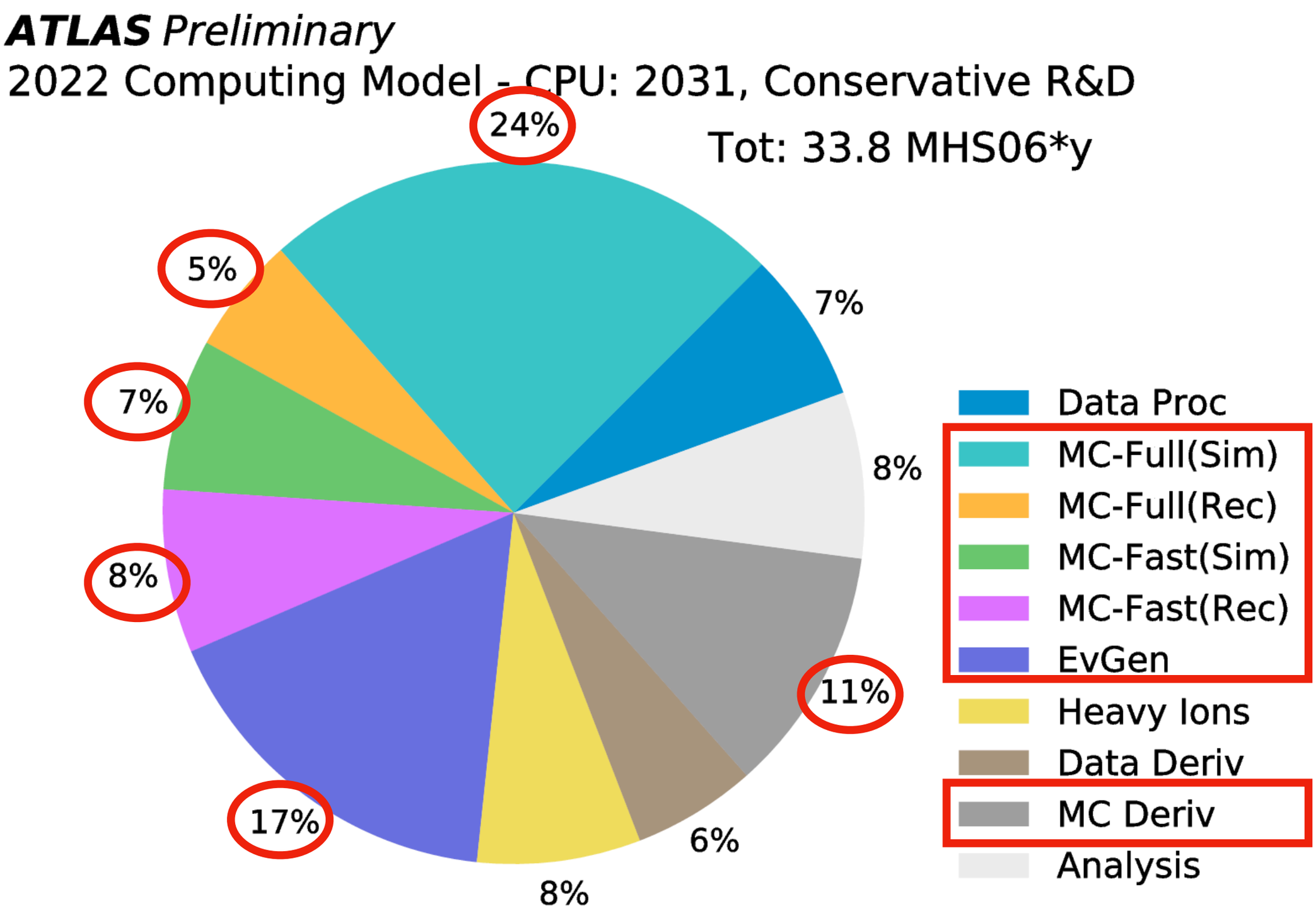


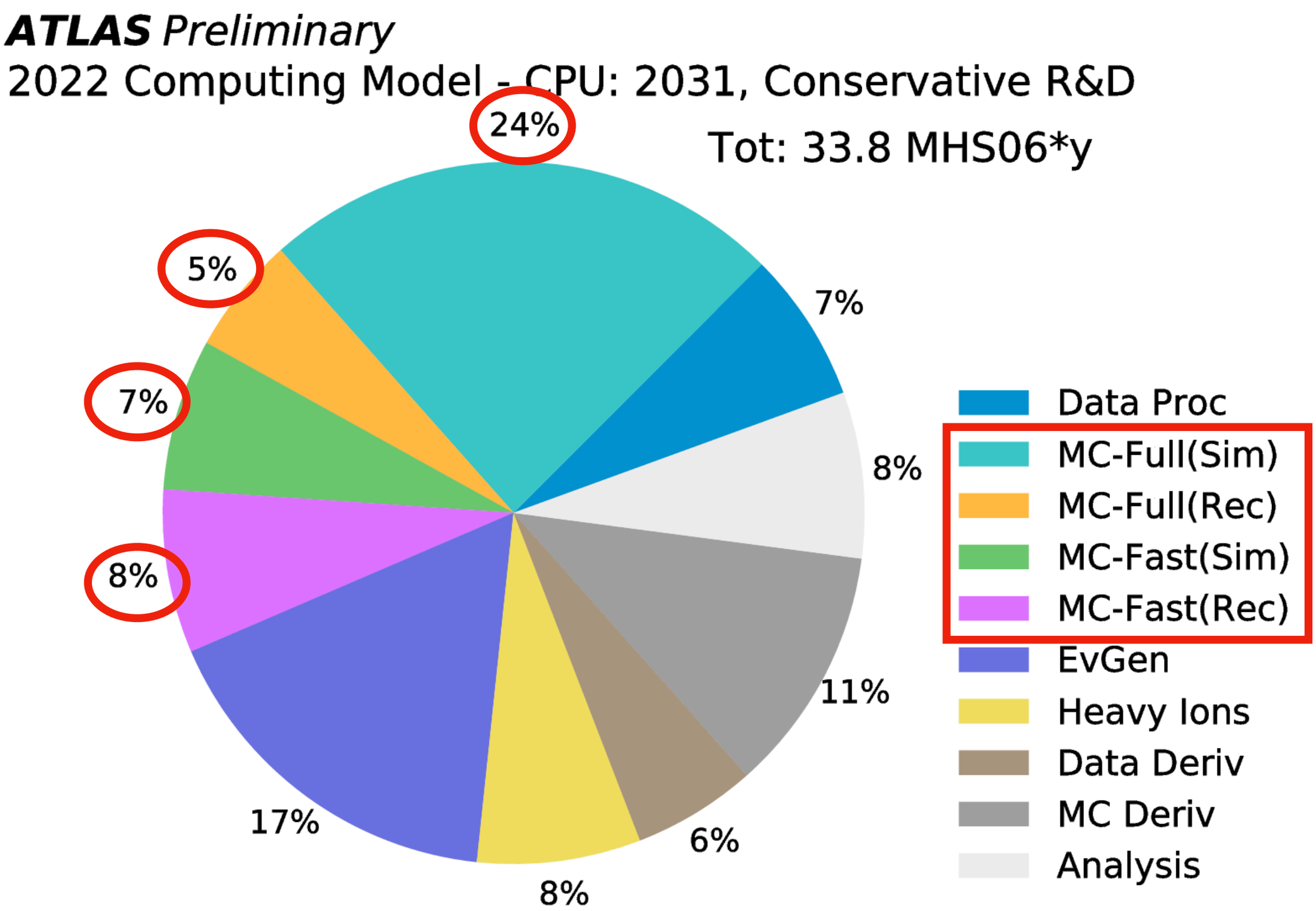
Analyse

Computing planning I



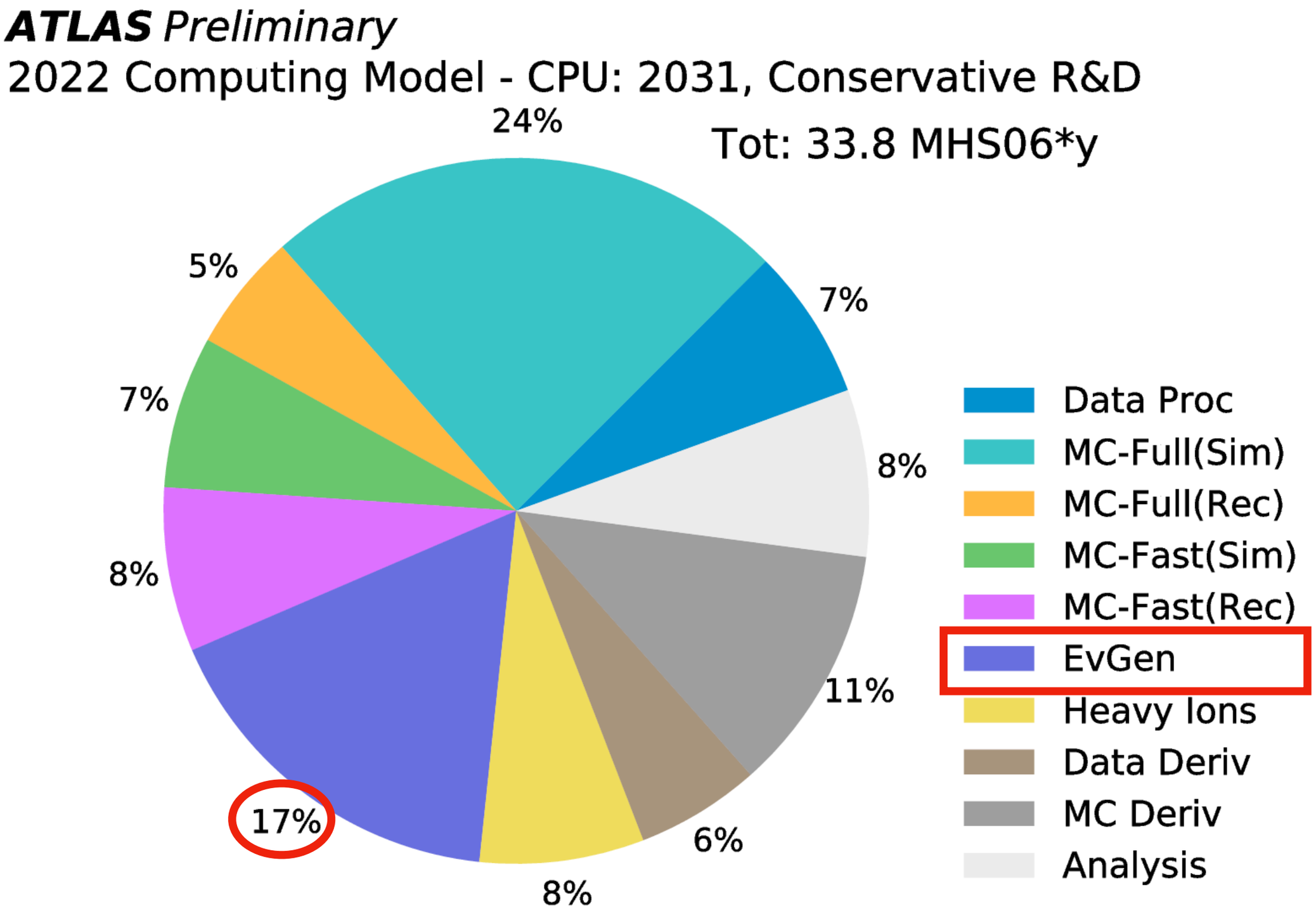
The full comparison to "theory" takes ~75%

Computing planning I



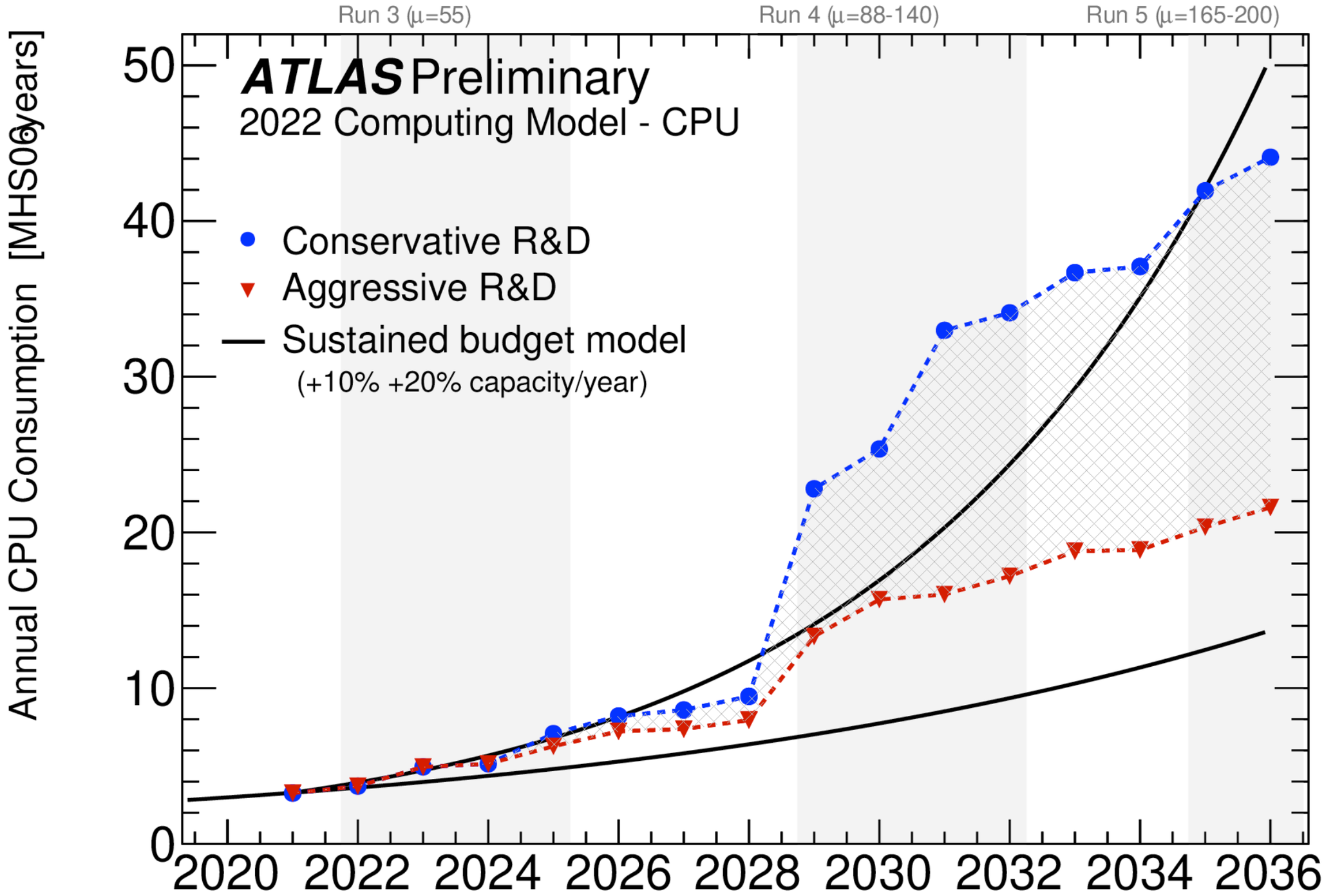
Detector Simulation of such events takes ~45%

Computing planning I



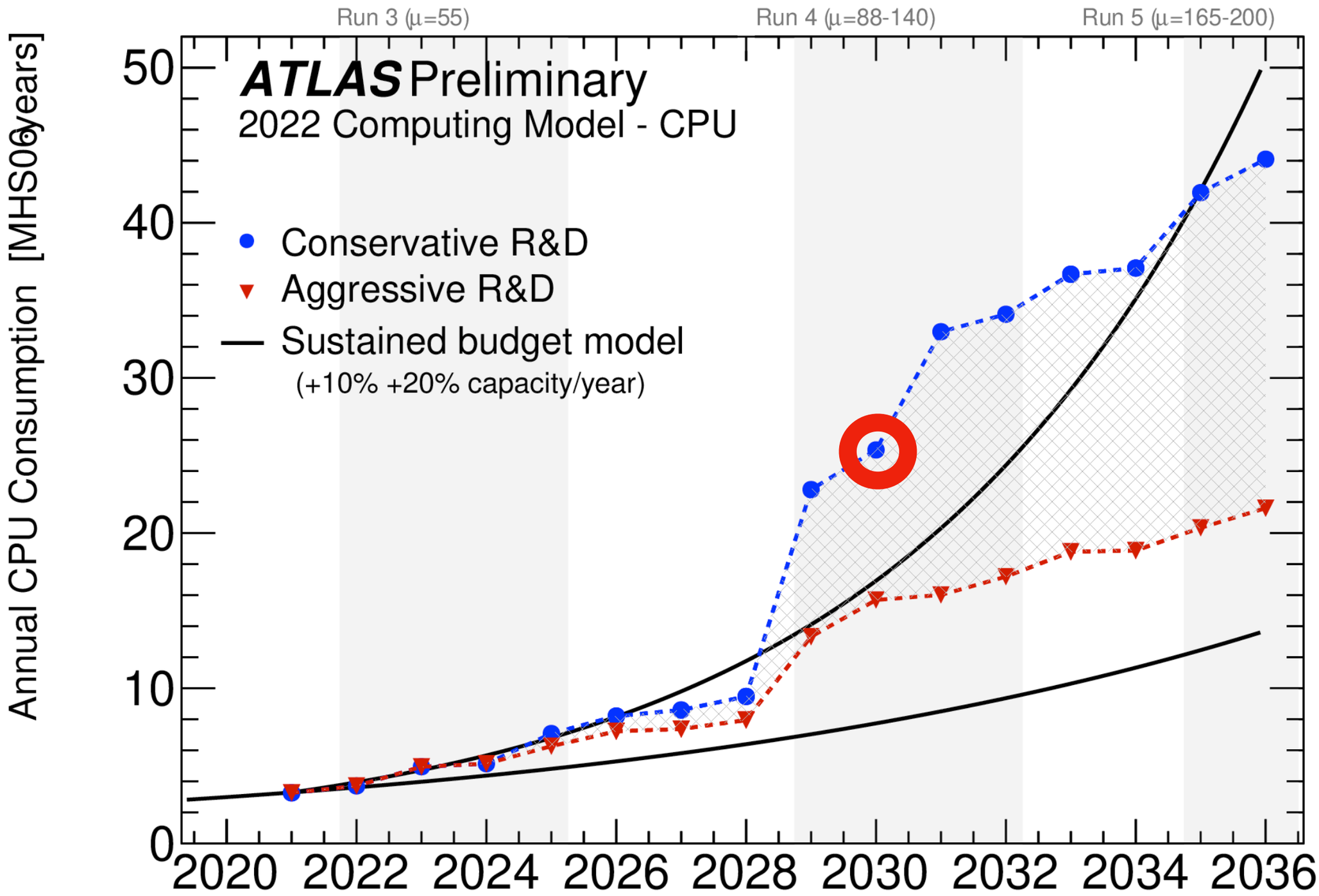
Pure simulation of events at 17%

Computing planning II



~ 2029 is the most critical period

Computing planning II



~ 2029 is the most critical period

Theory Need for HL

- We want **MORE, MORE and MORE**
  - **More** accurate (NLO/NNLO)
  - **More** event
  - **More** complex (less approximation)
- We need **cross-checking**
  - One tool is not enough

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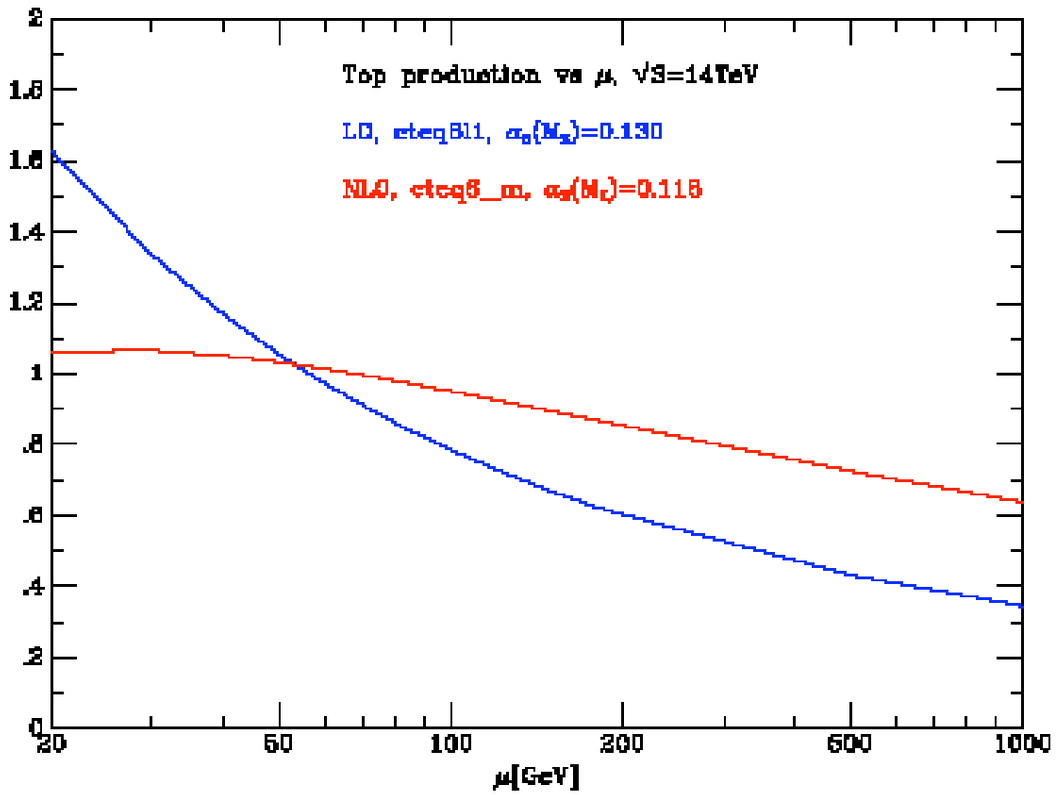
Improved predictions

$$\hat{\sigma} = \sigma^{\mathrm{Born}}\left(1 + \frac{\alpha_s}{2\pi}\sigma^{(1)} + \left(\frac{\alpha_s}{2\pi}\right)^2\sigma^{(2)} + \left(\frac{\alpha_s}{2\pi}\right)^3\sigma^{(3)} + \ldots\right)$$



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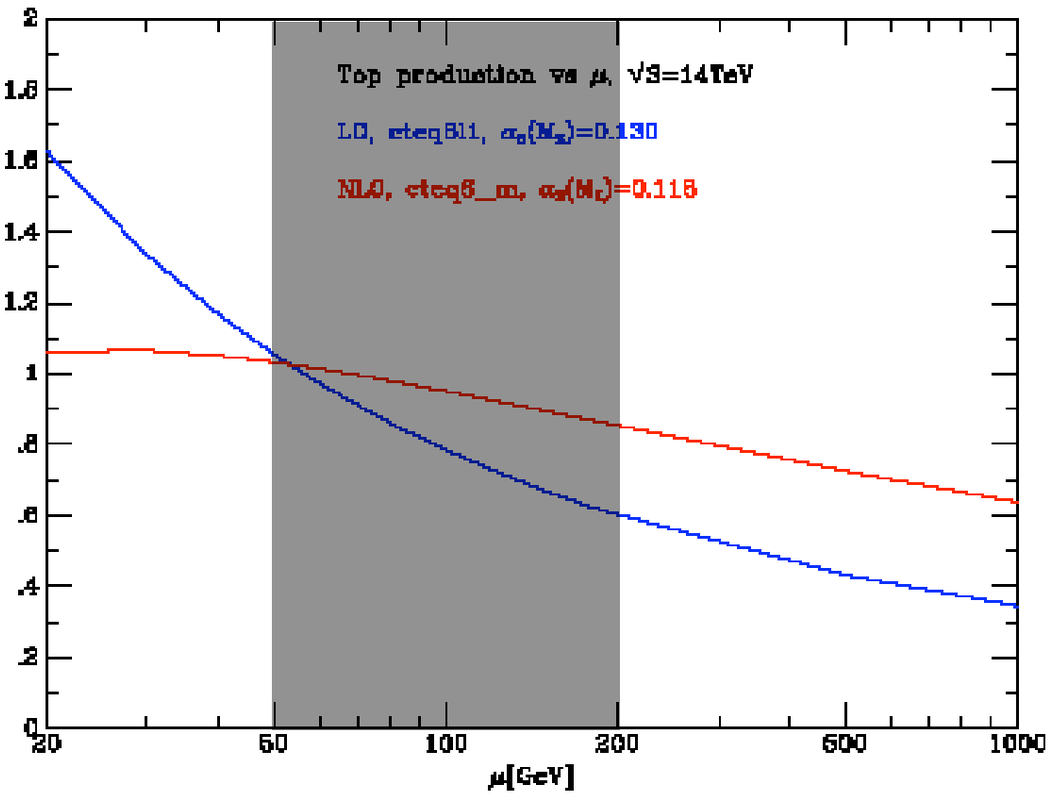

Improved predictions

LO

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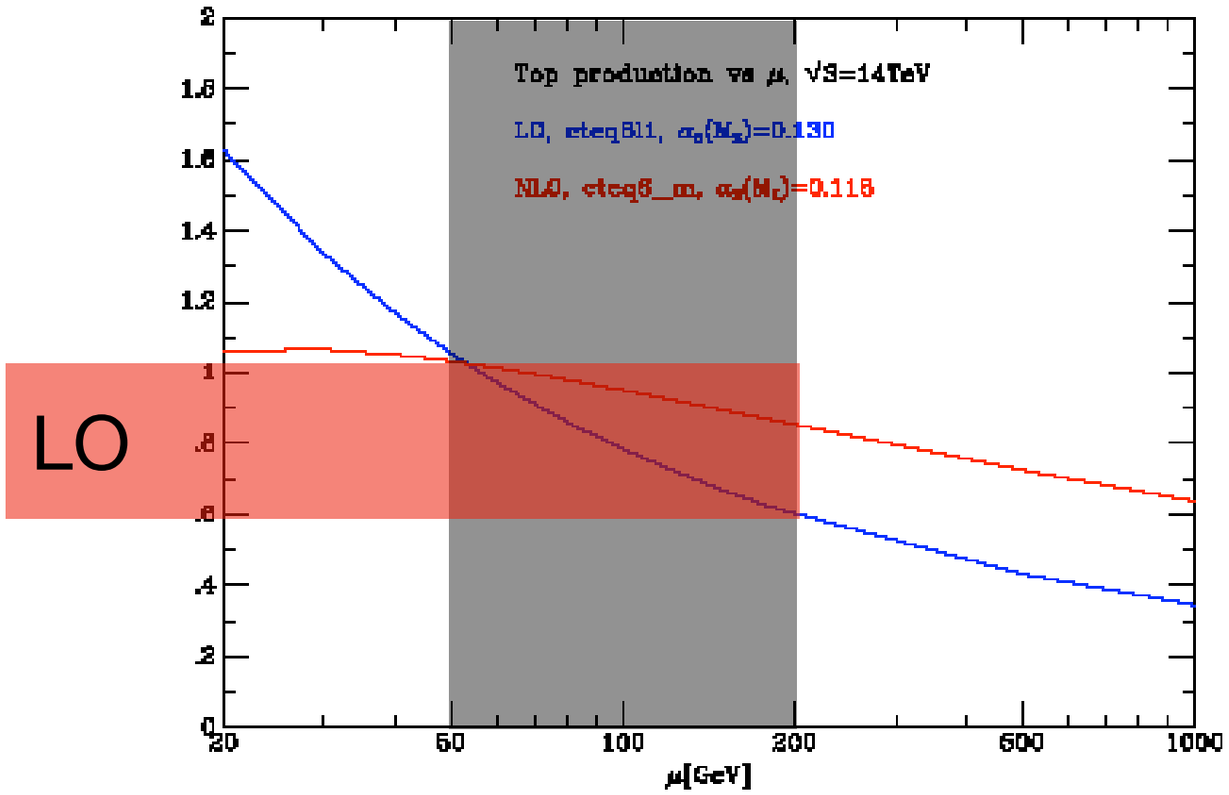

- Leading Order predictions depend strongly on arbitrary scales
  - Poor accuracy (error at ~40%)

Improved predictions

NLO

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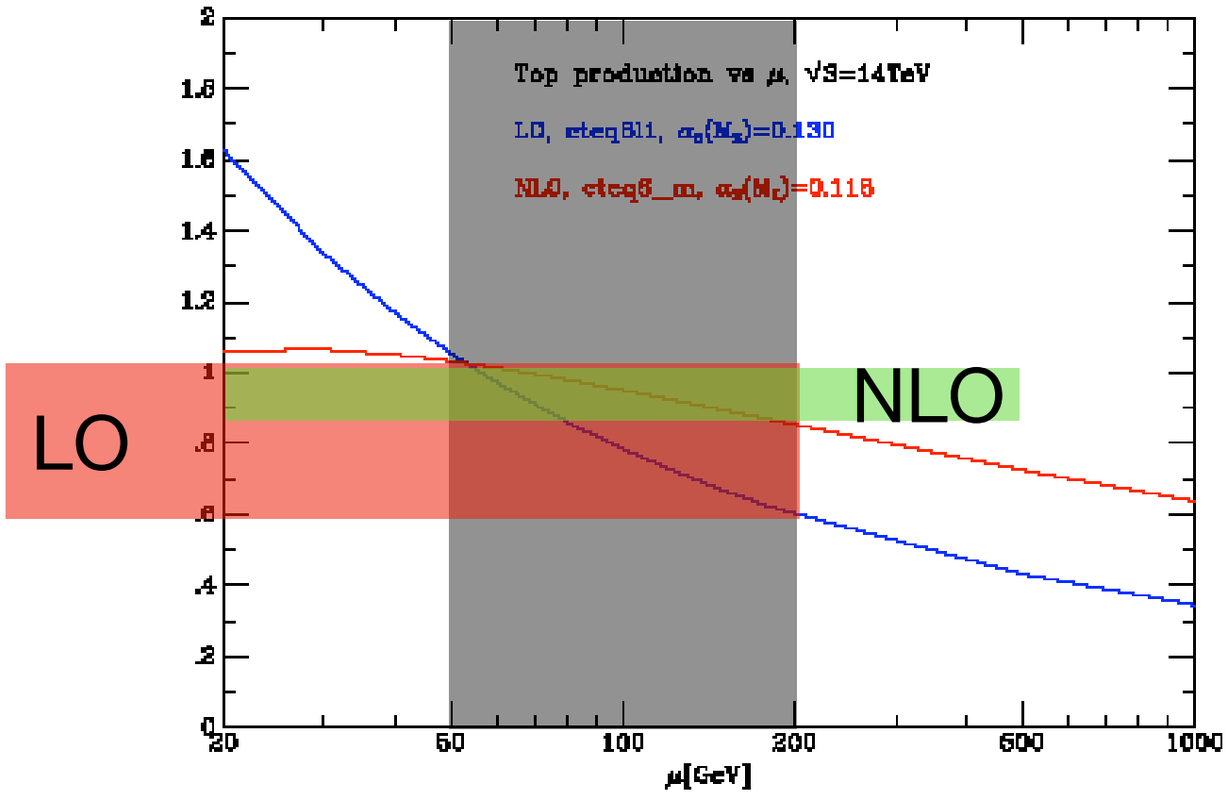

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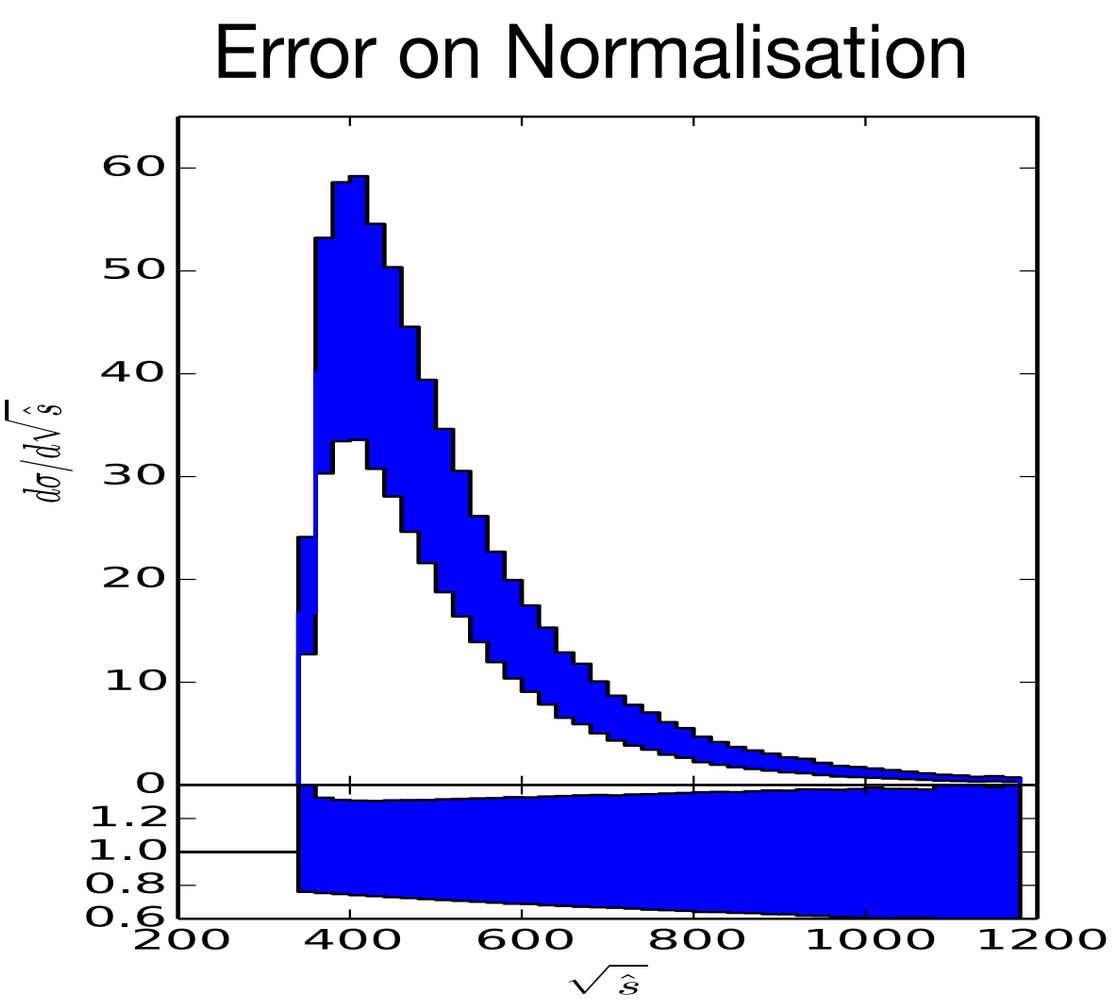
Is LO useful?

Error on LO prediction (top quark pair)



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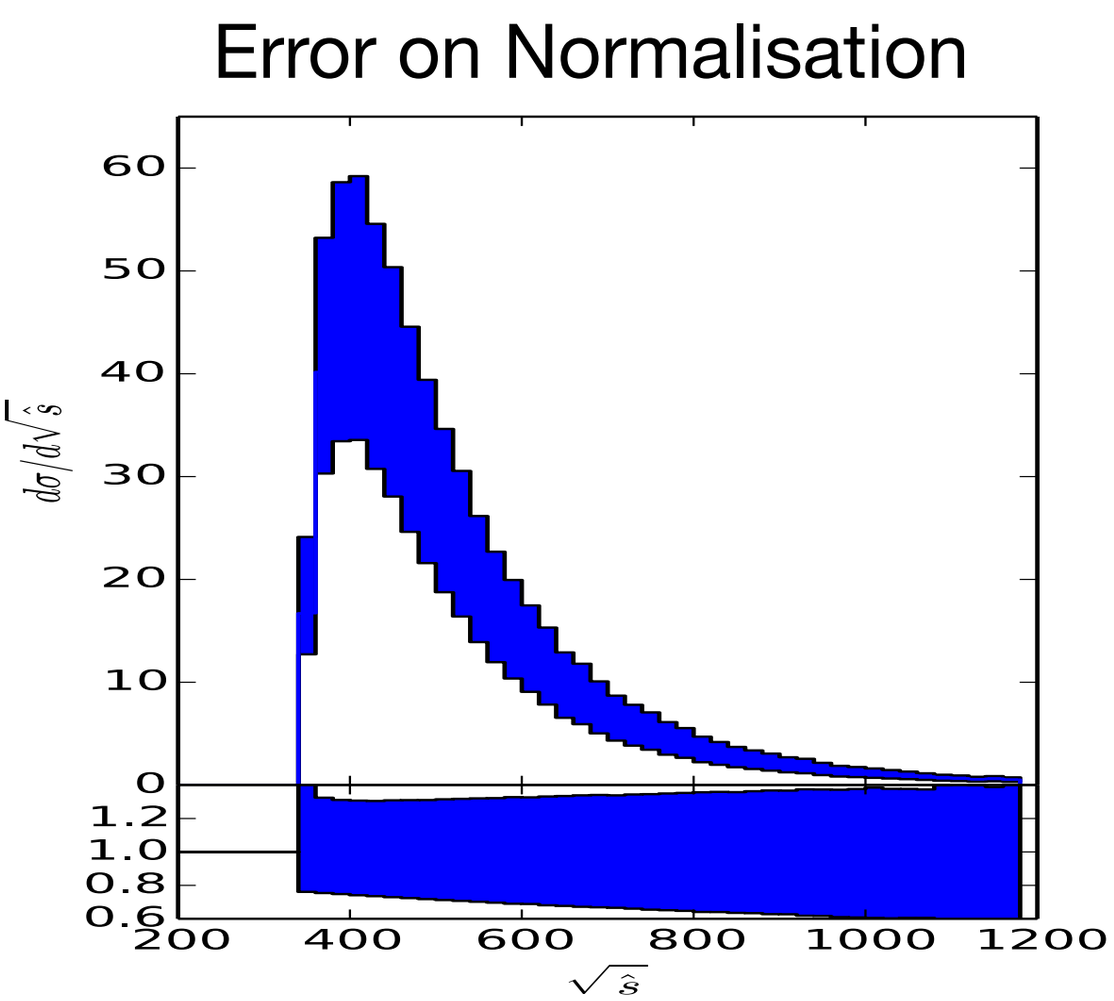

Too Large Error (30-50%)

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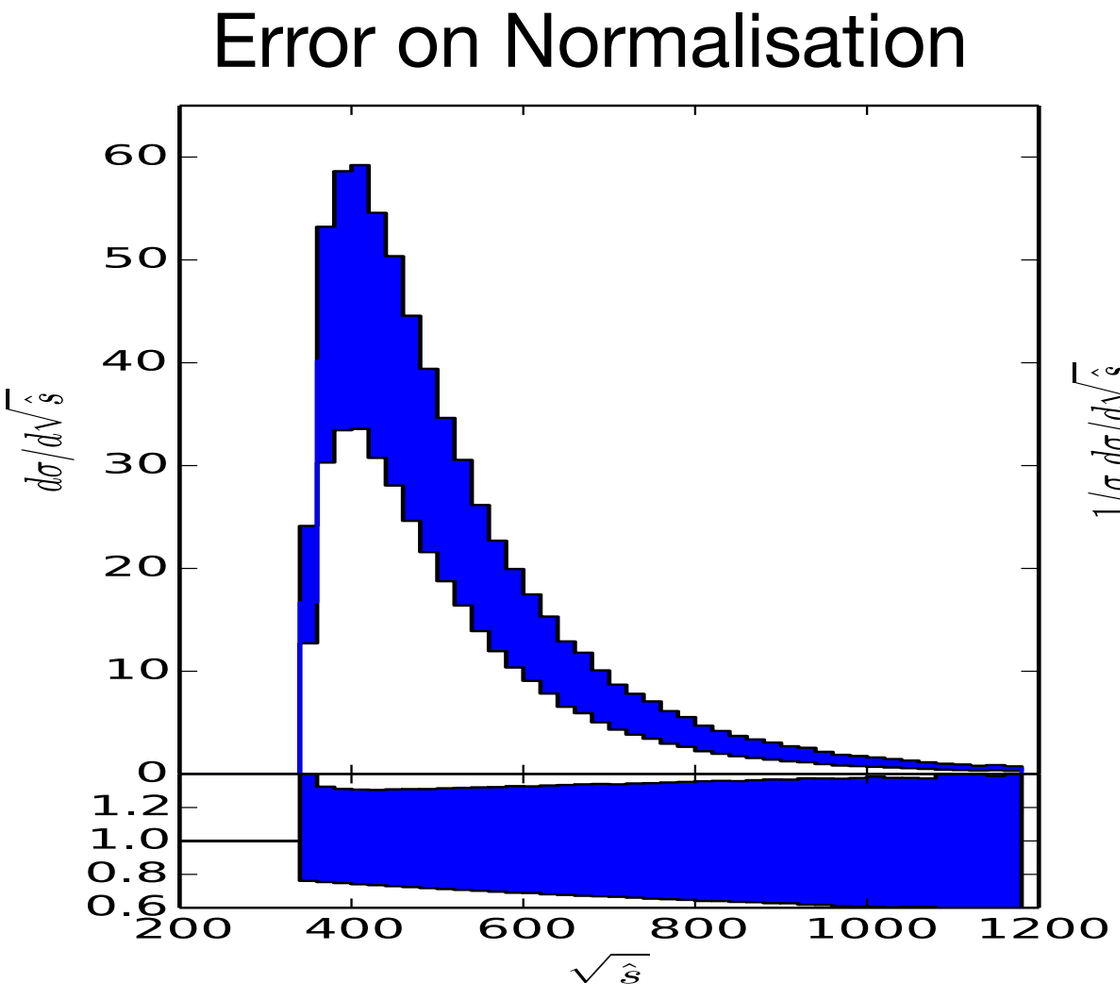

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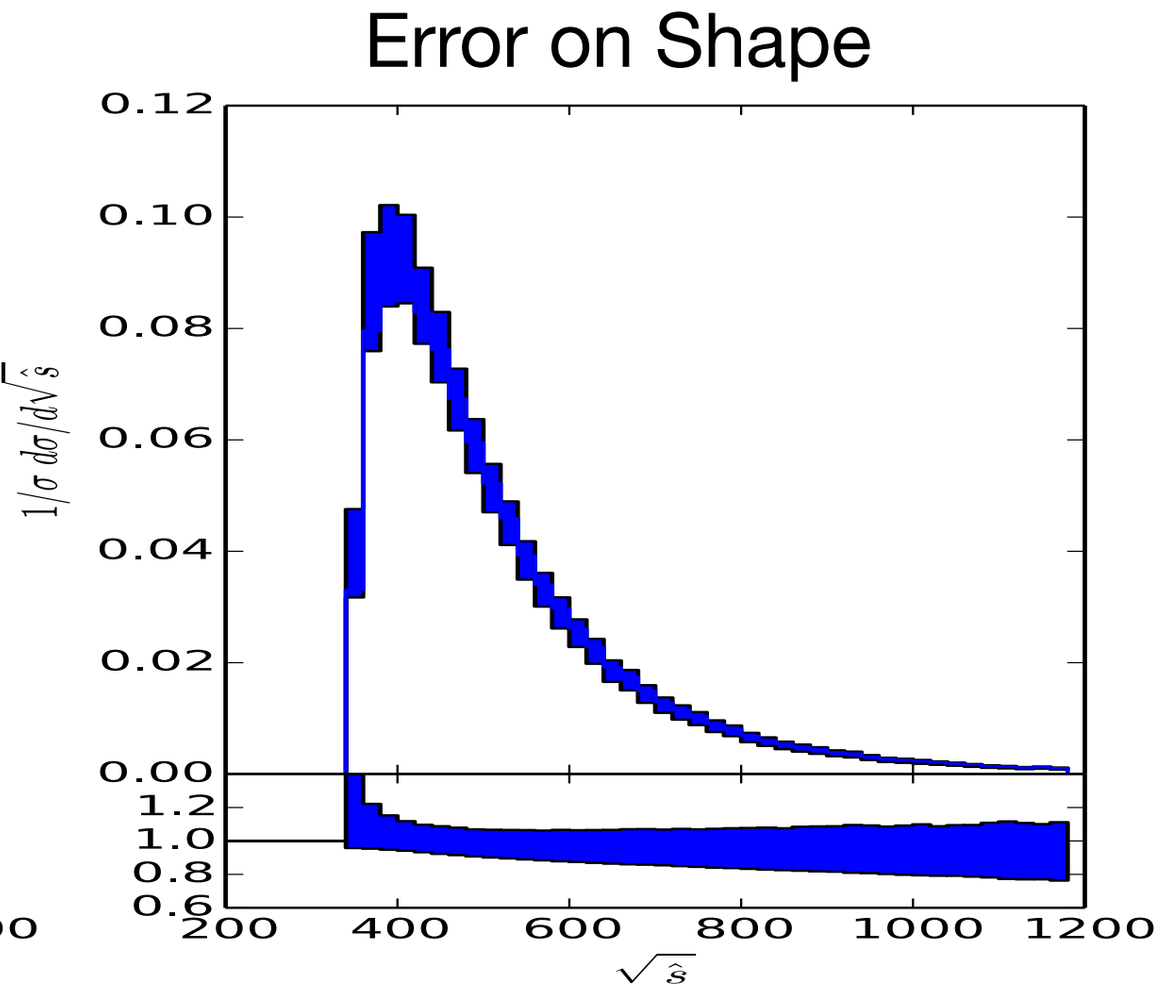
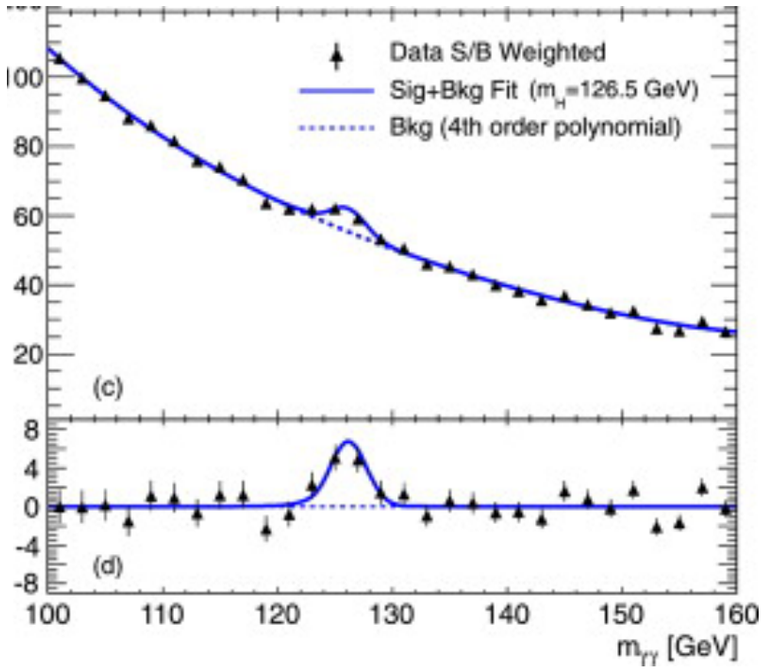


More reasonable (~10%)

Kind of measurement

Peak



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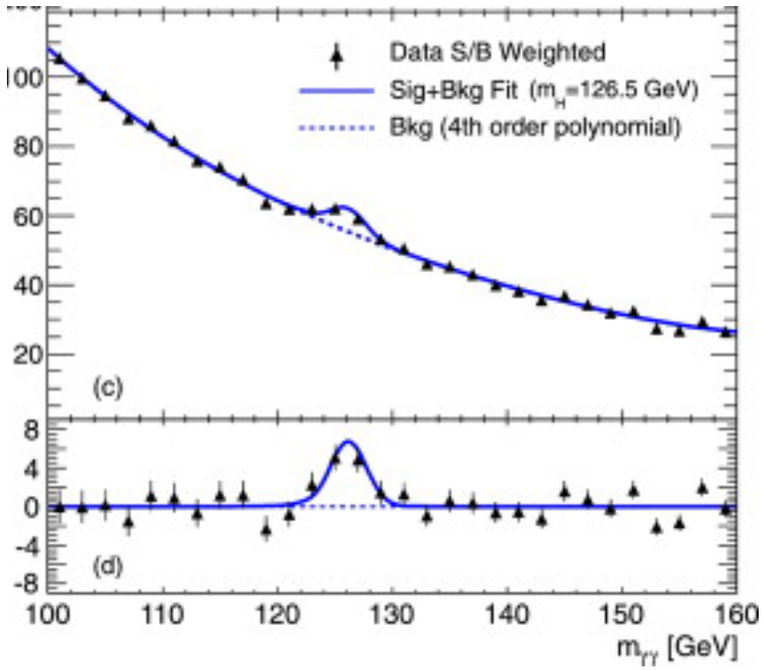

"EASY"

Background directly measured from **data**. Theory needed only for parameter extraction and validation

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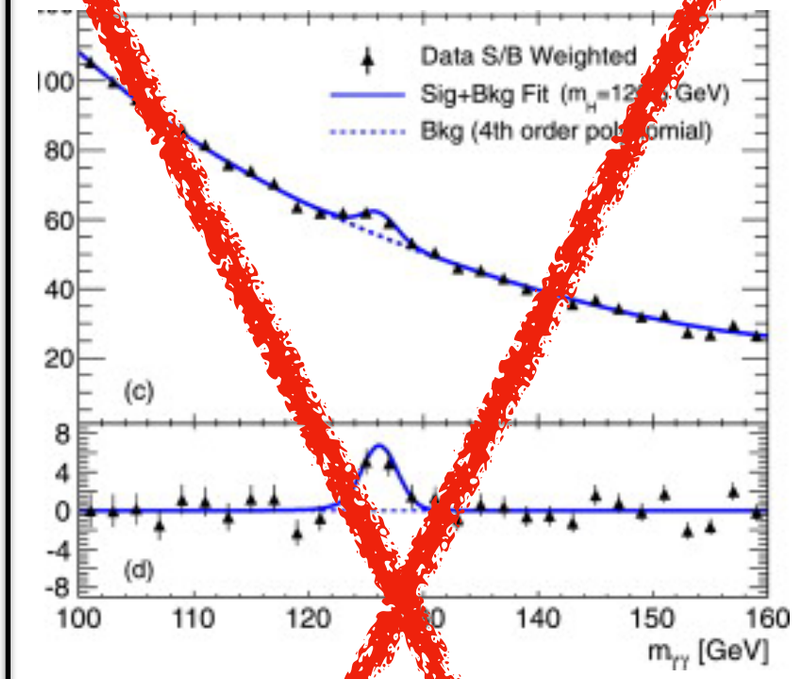

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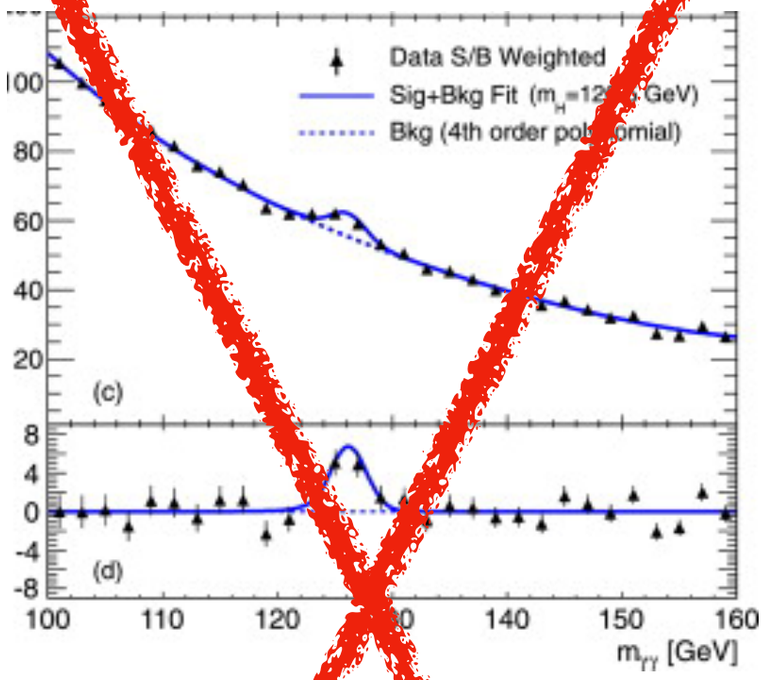

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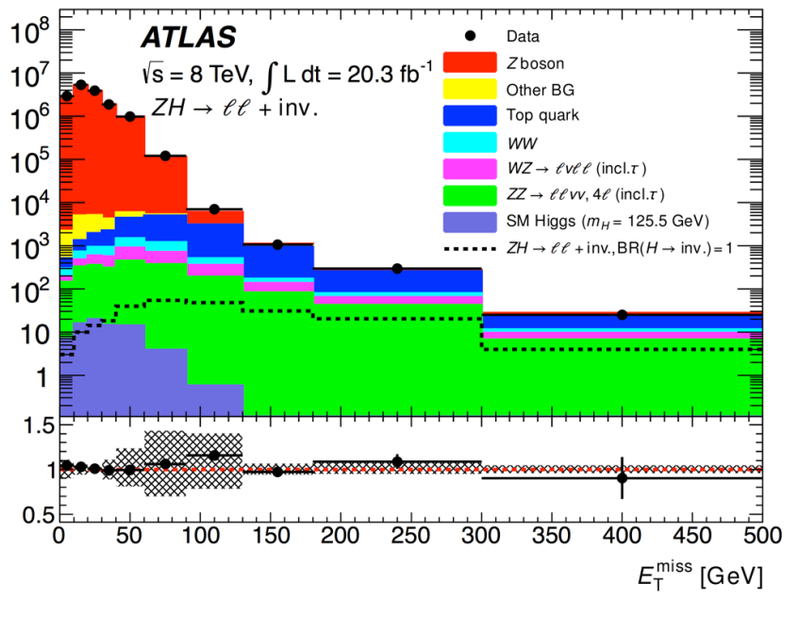

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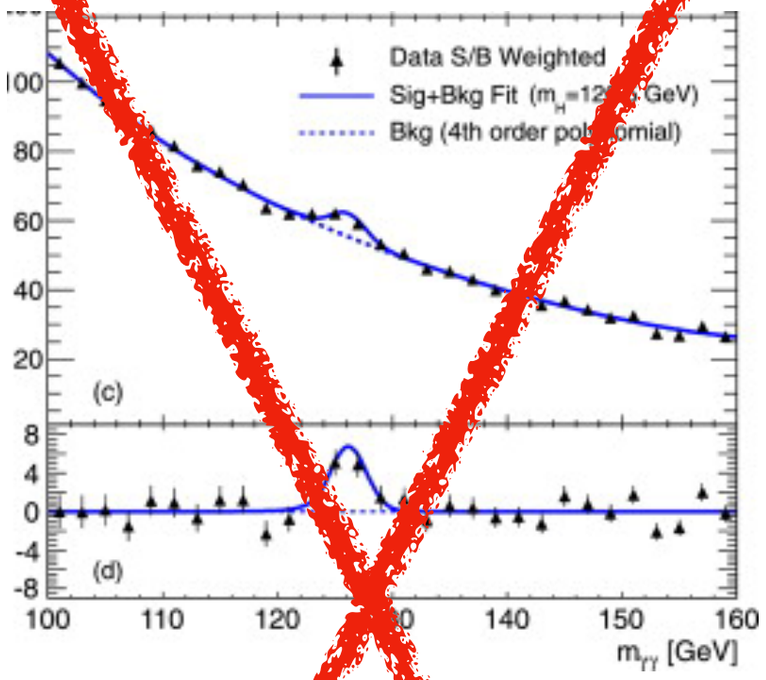

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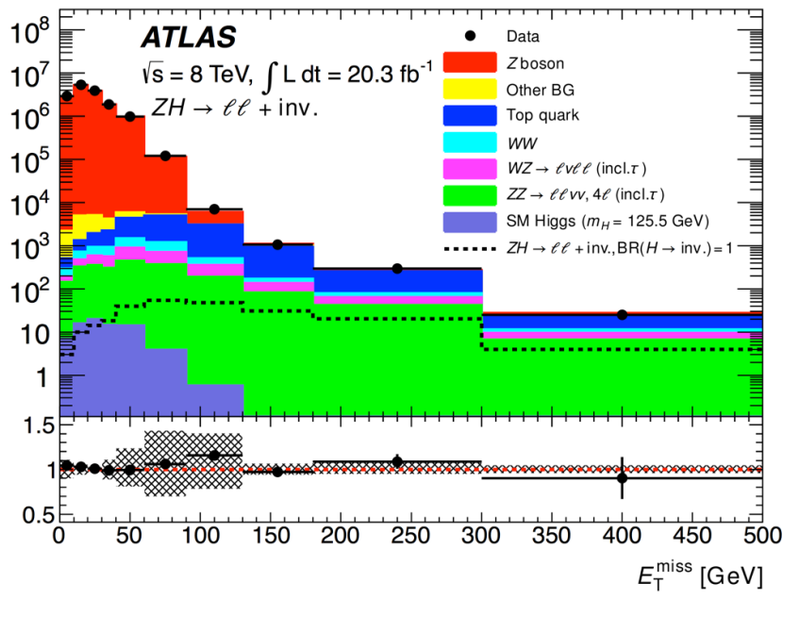

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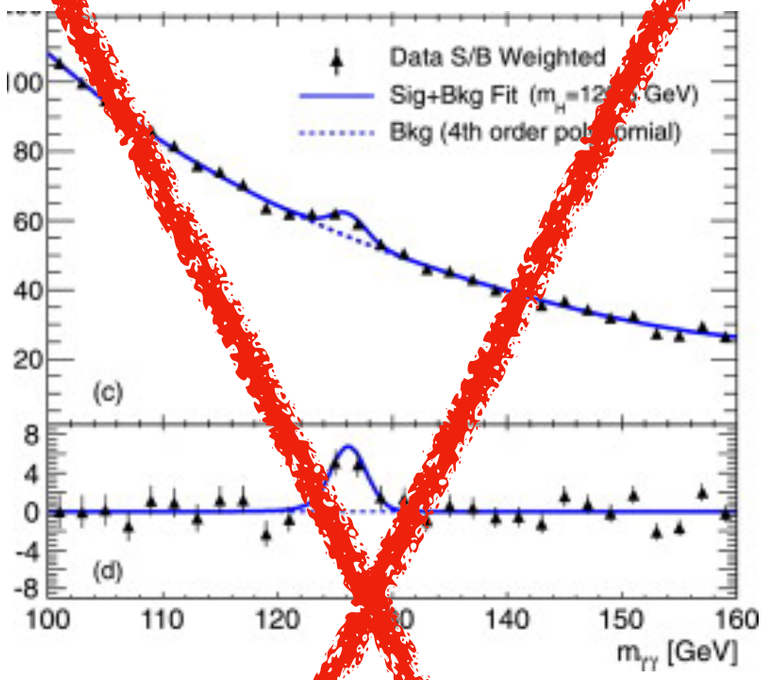

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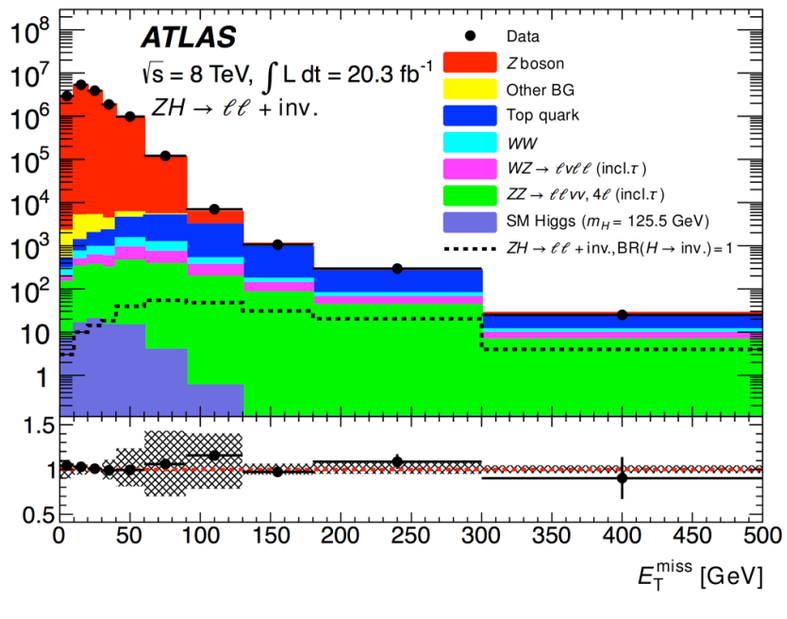

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NLO for HL

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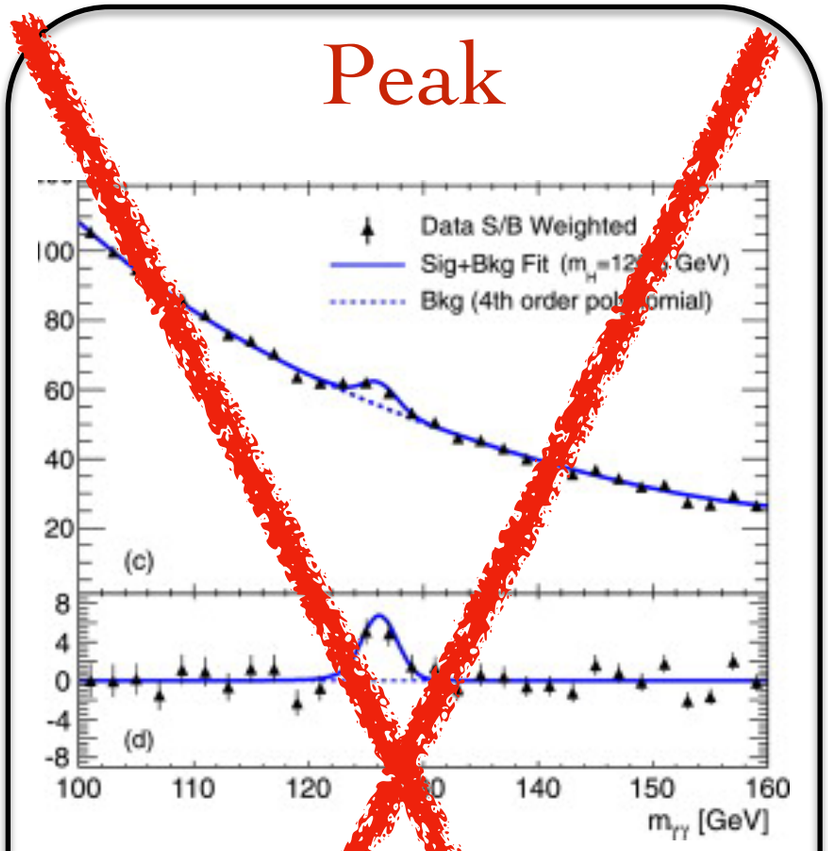

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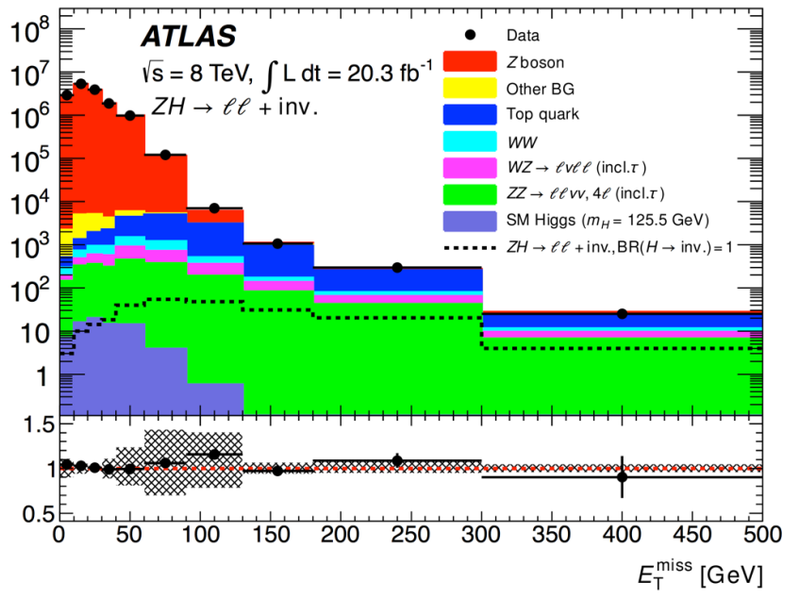

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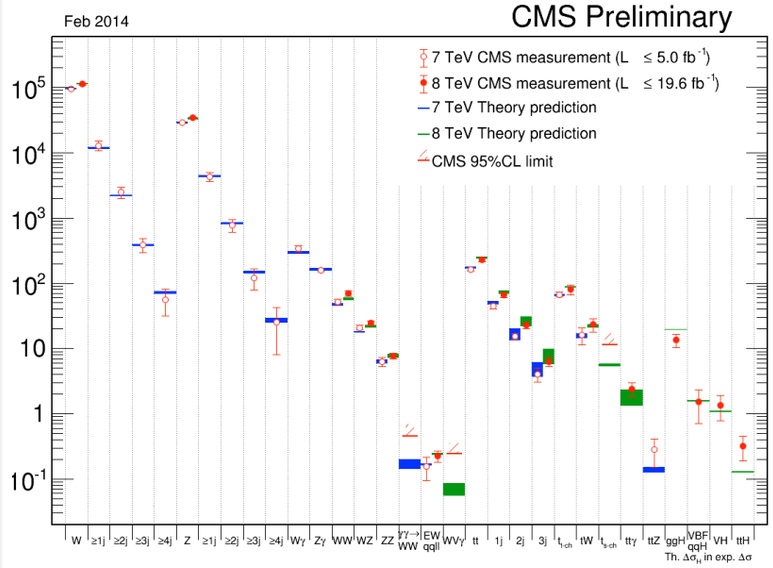

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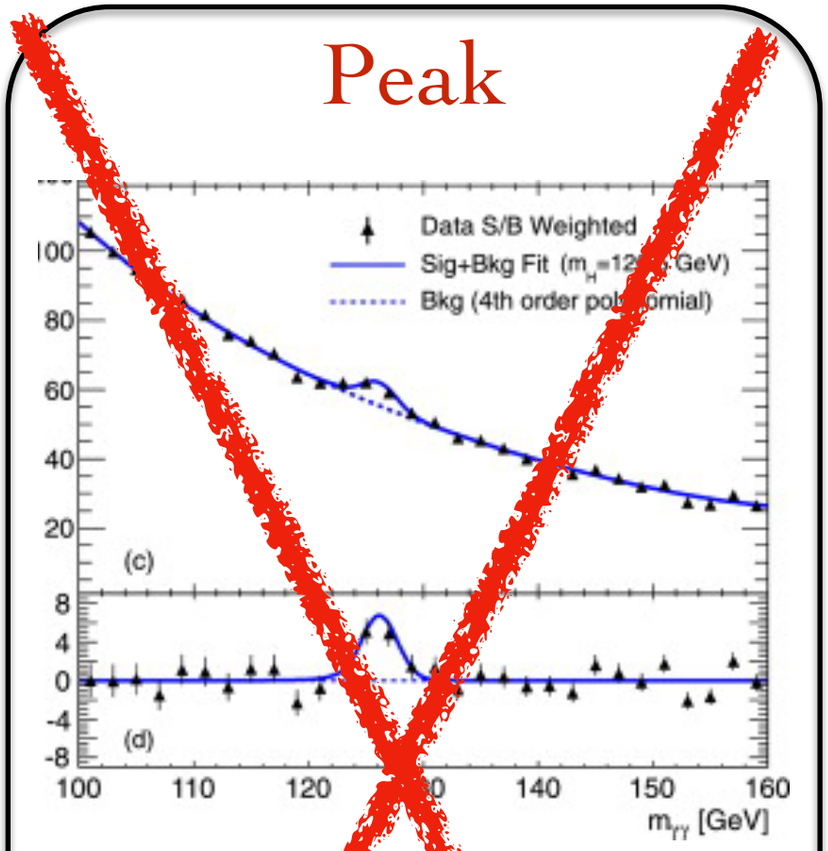

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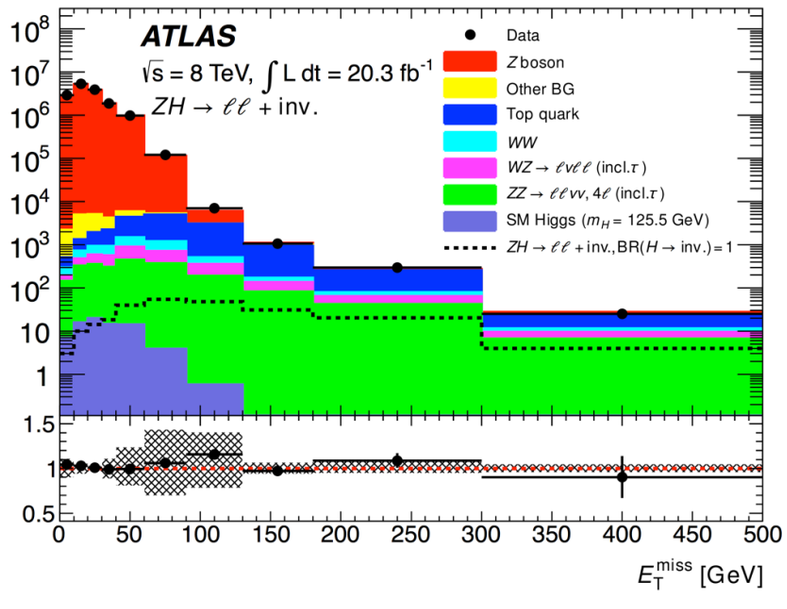

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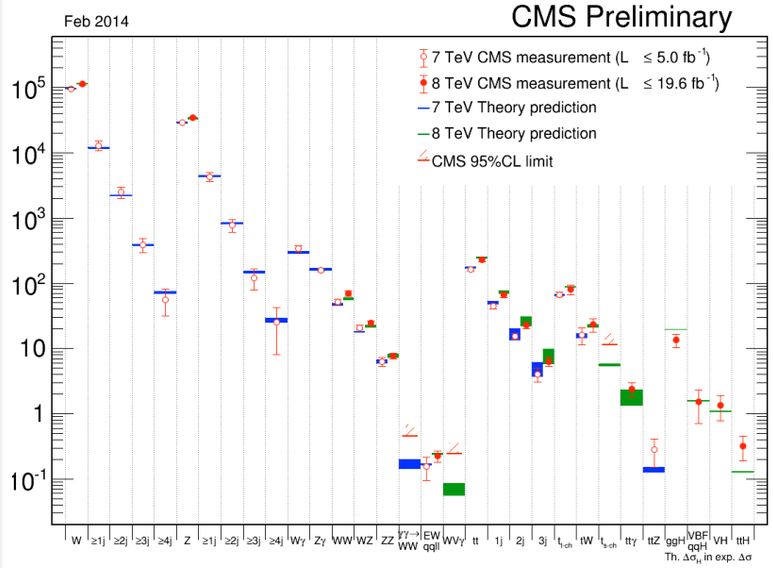

“VERY HARD”

Relies on prediction for both **shape** and **normalization**.
Complicated interplay of best simulations and data

Kind of measurement

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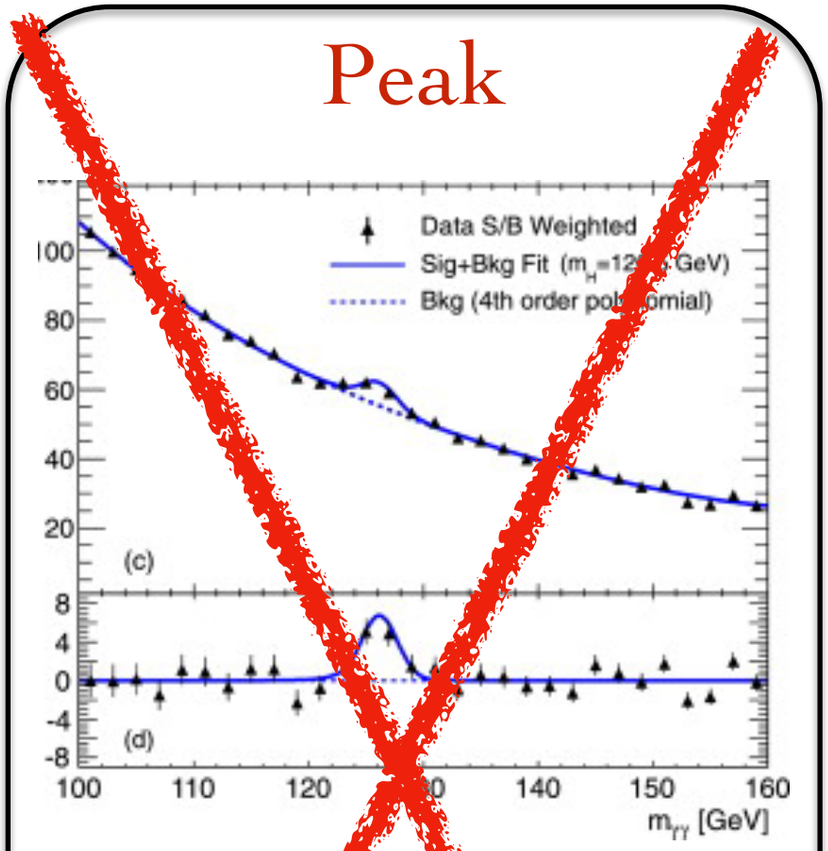

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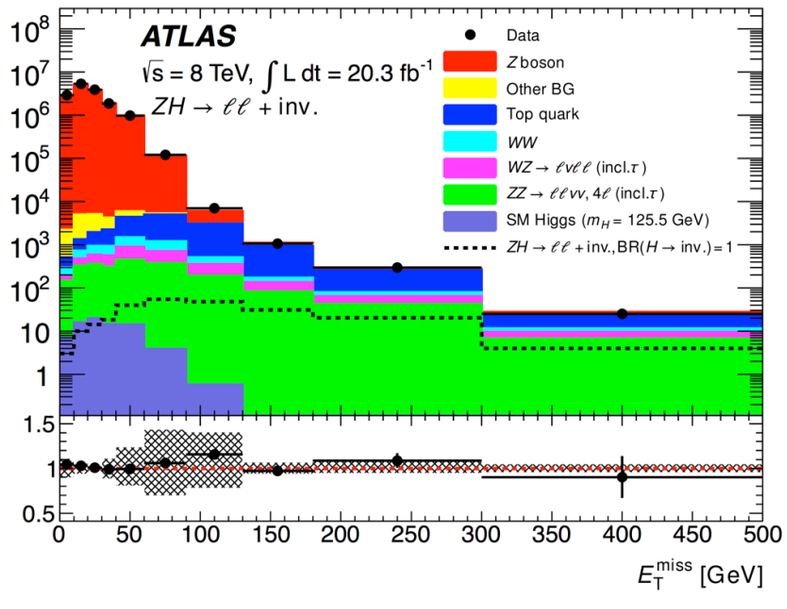

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NLO for HL

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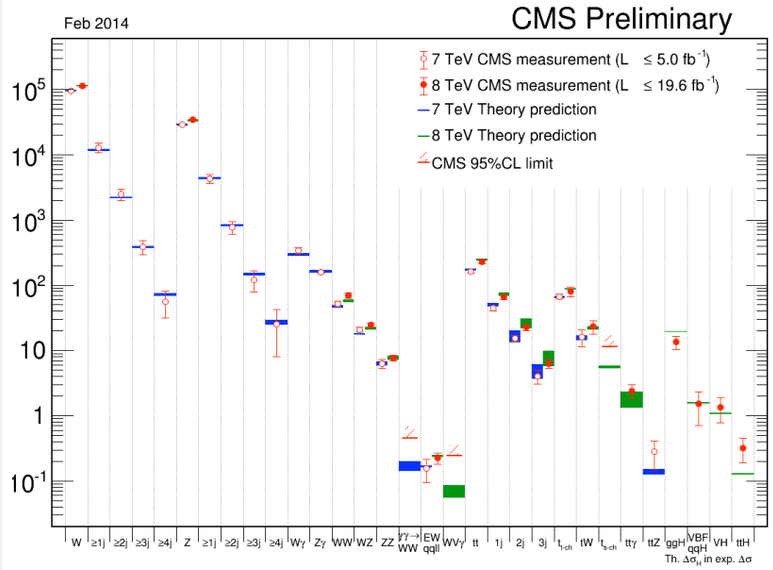

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Relies on prediction for both **shape** and **normalization**.
Complicated interplay of best simulations and data

NLO required
often NNLO for HL

Plan

- We want **MORE, MORE and MORE**
  - **More** accurate (NLO/NNLO)
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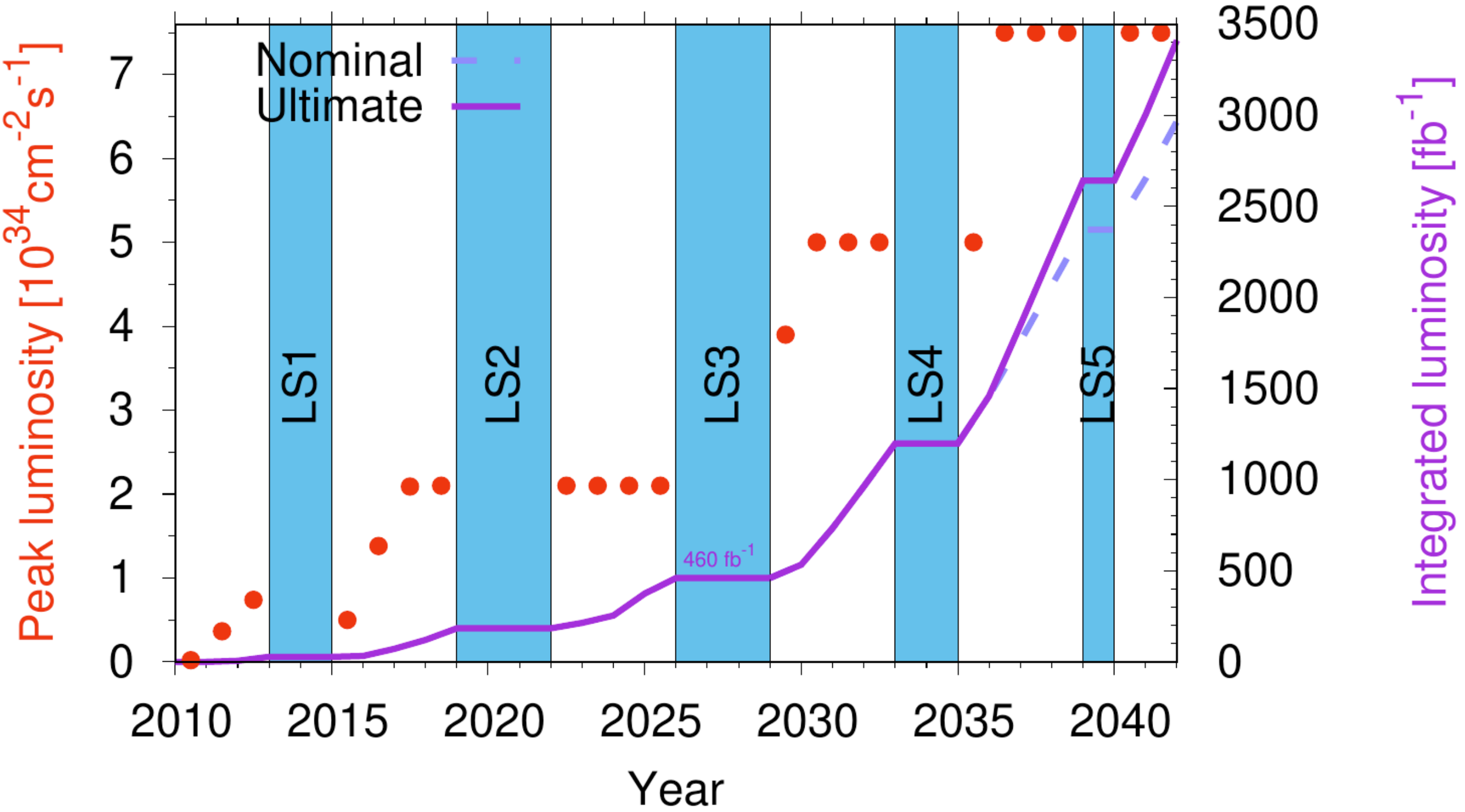
  - **More** complex (less approximation)

Do we really need more Events?

HL-LHC plan



We are at half time of the LHC, we will collect 6 times more data

Plan

- We want **MORE, MORE and MORE**
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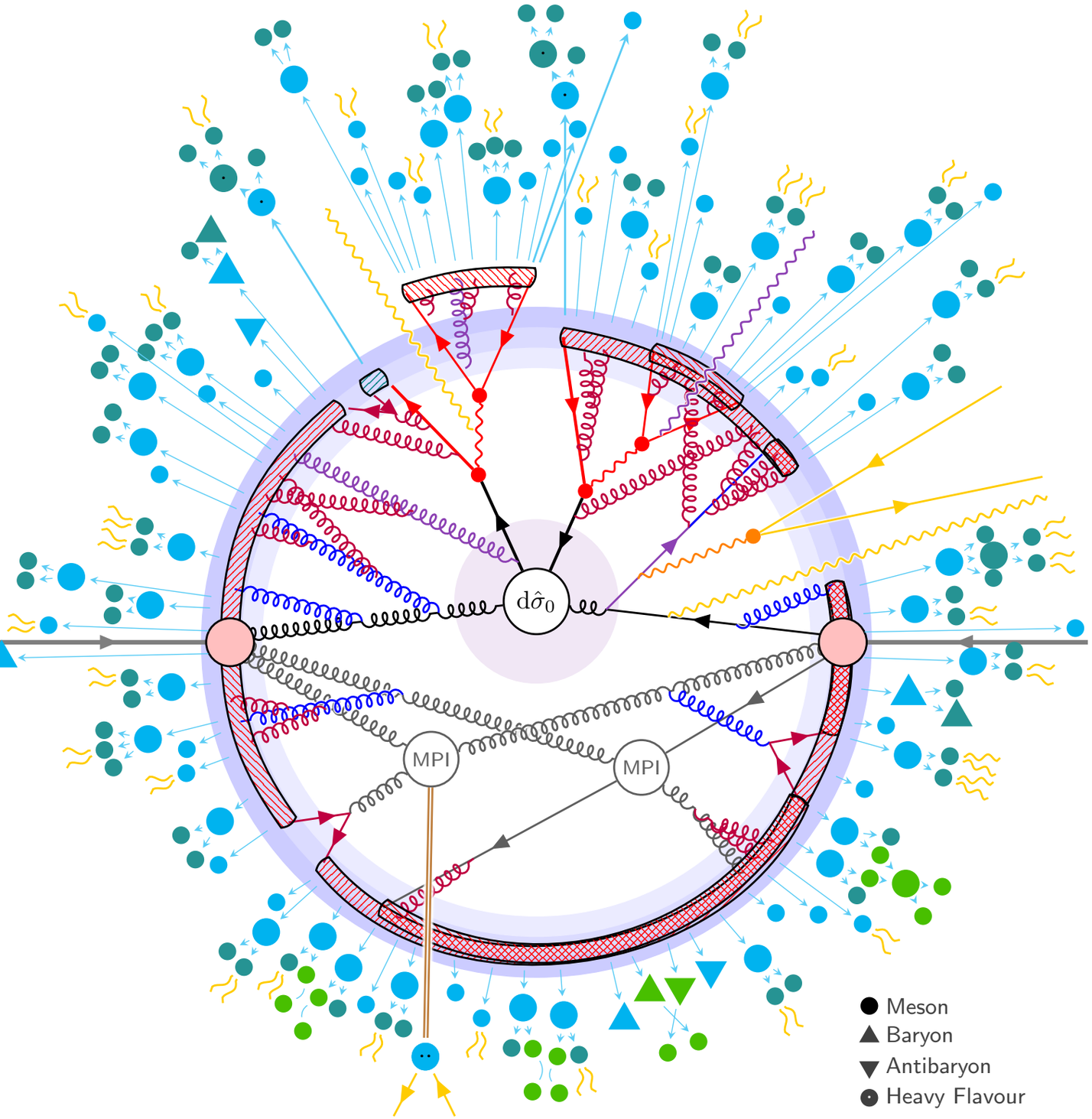
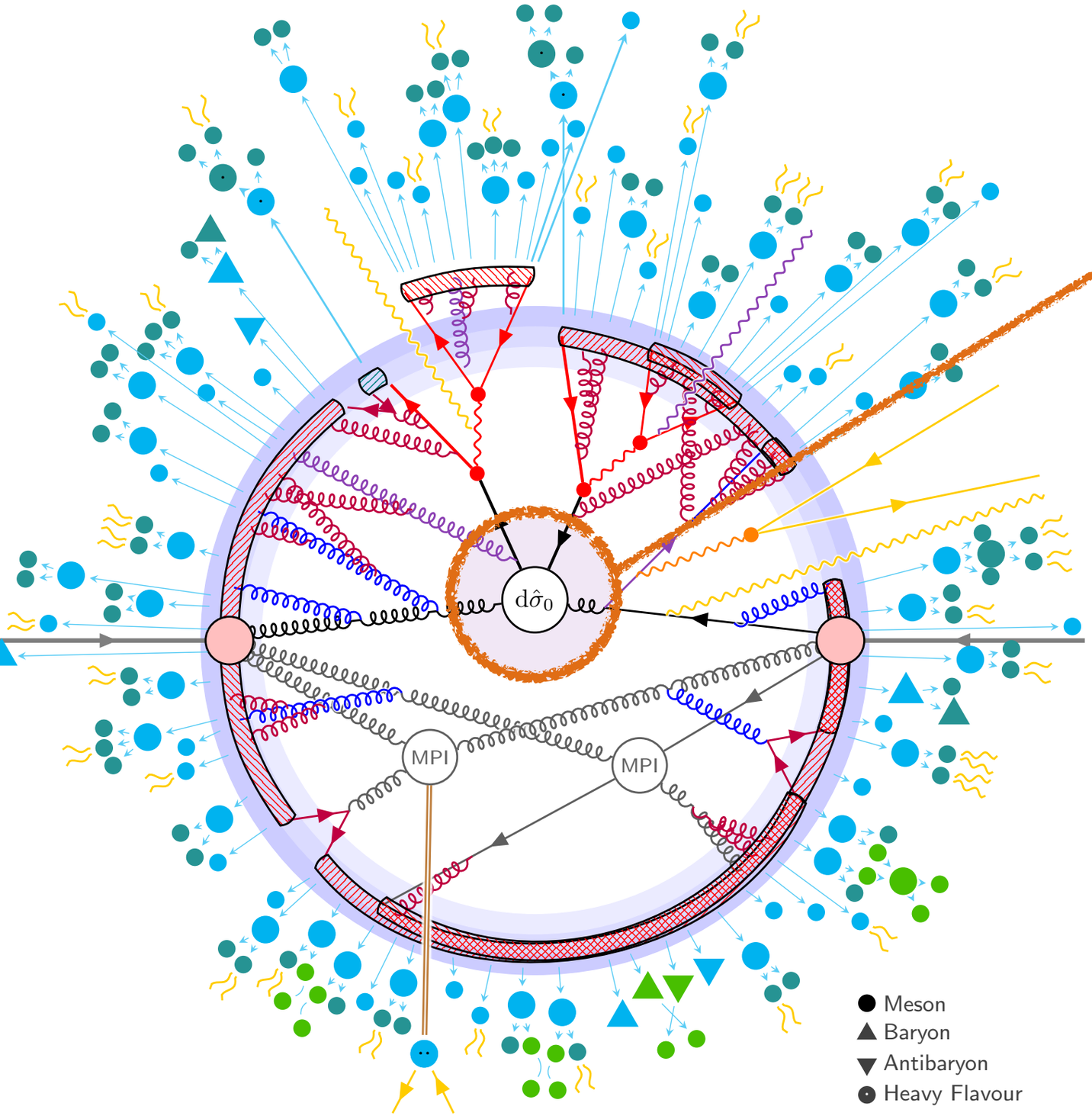
Do we really need more Complexity?

Where do we start PS?



From pythia8 manual

Where do we start PS?



Matrix Element

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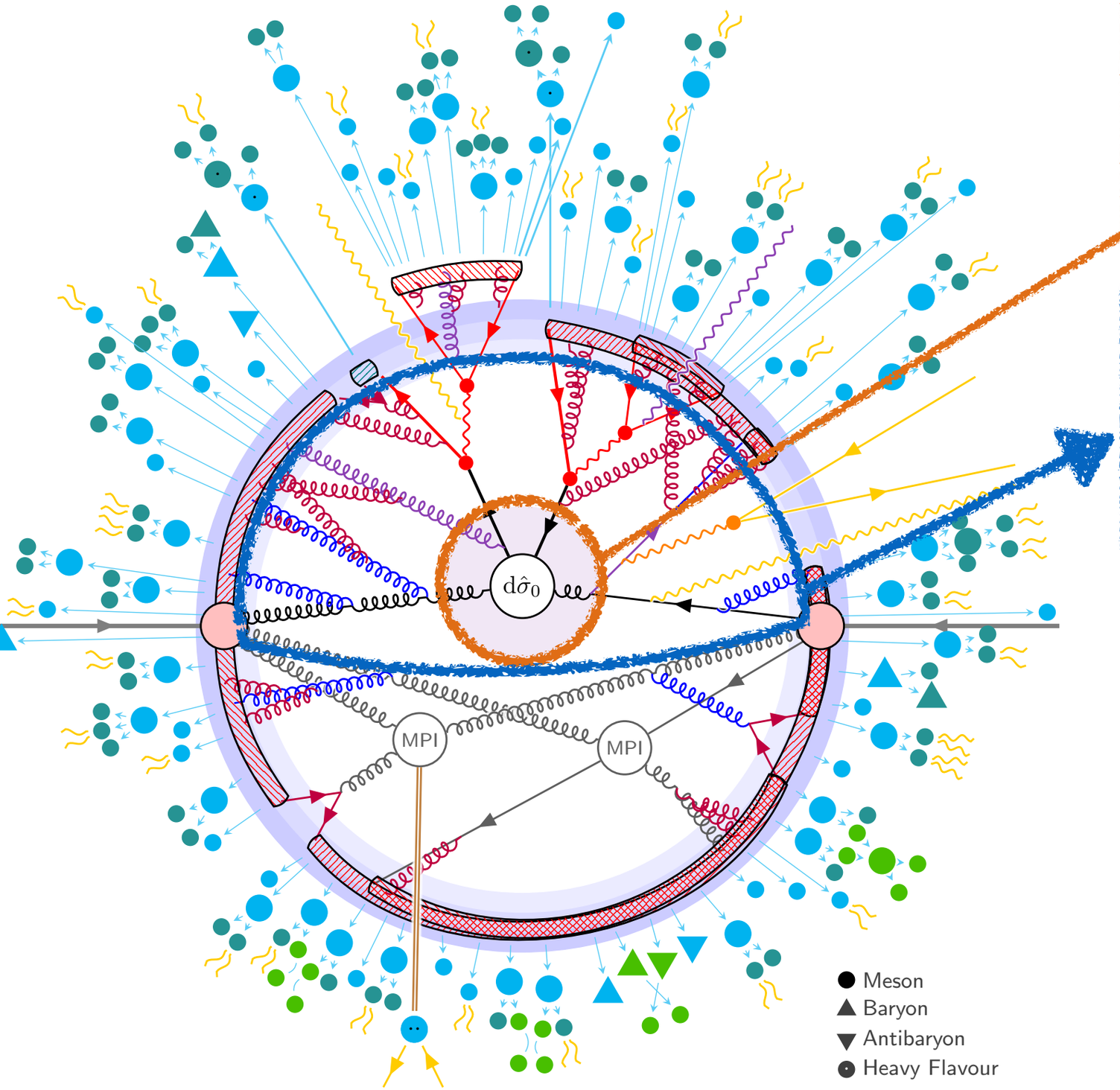

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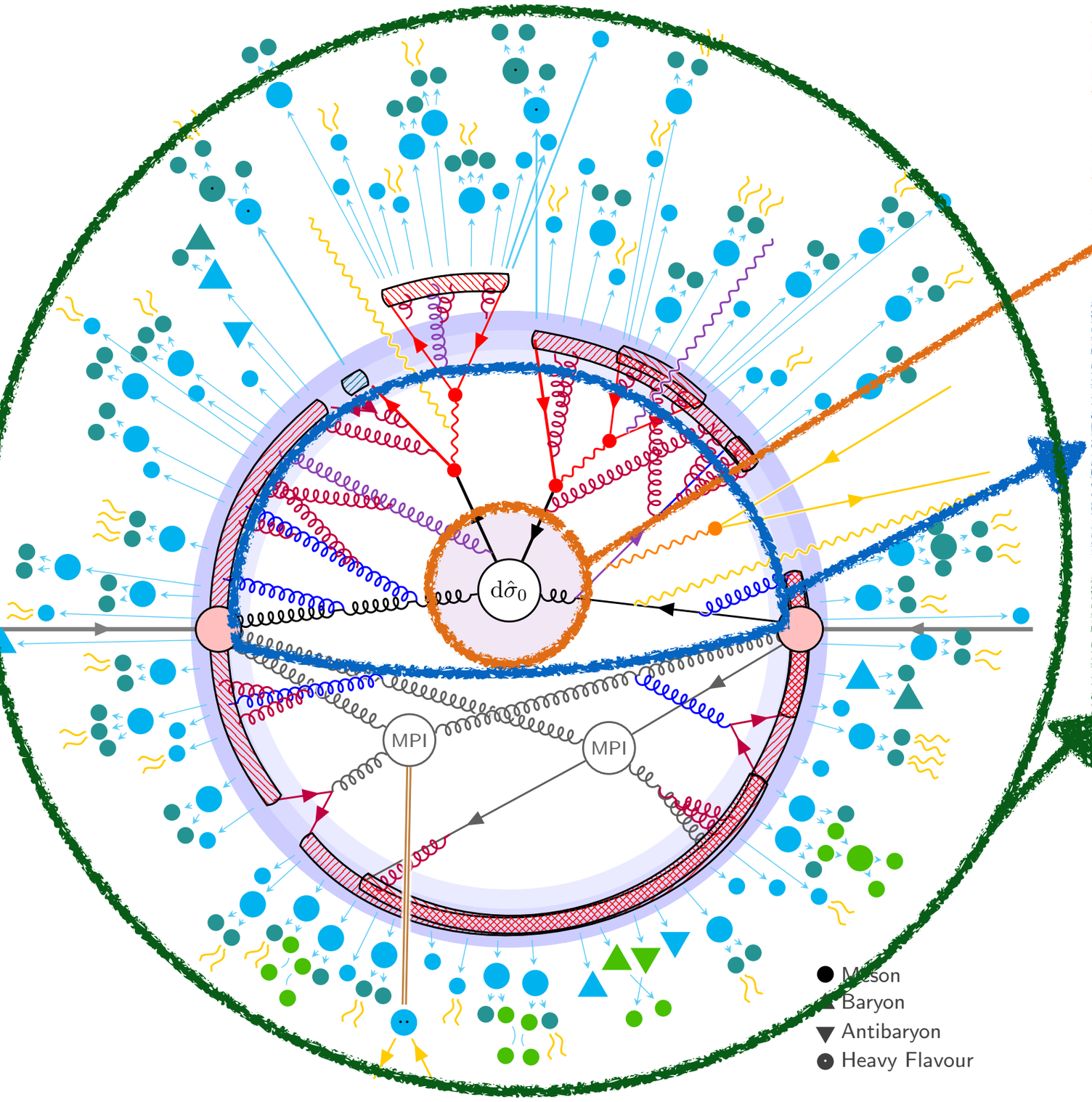

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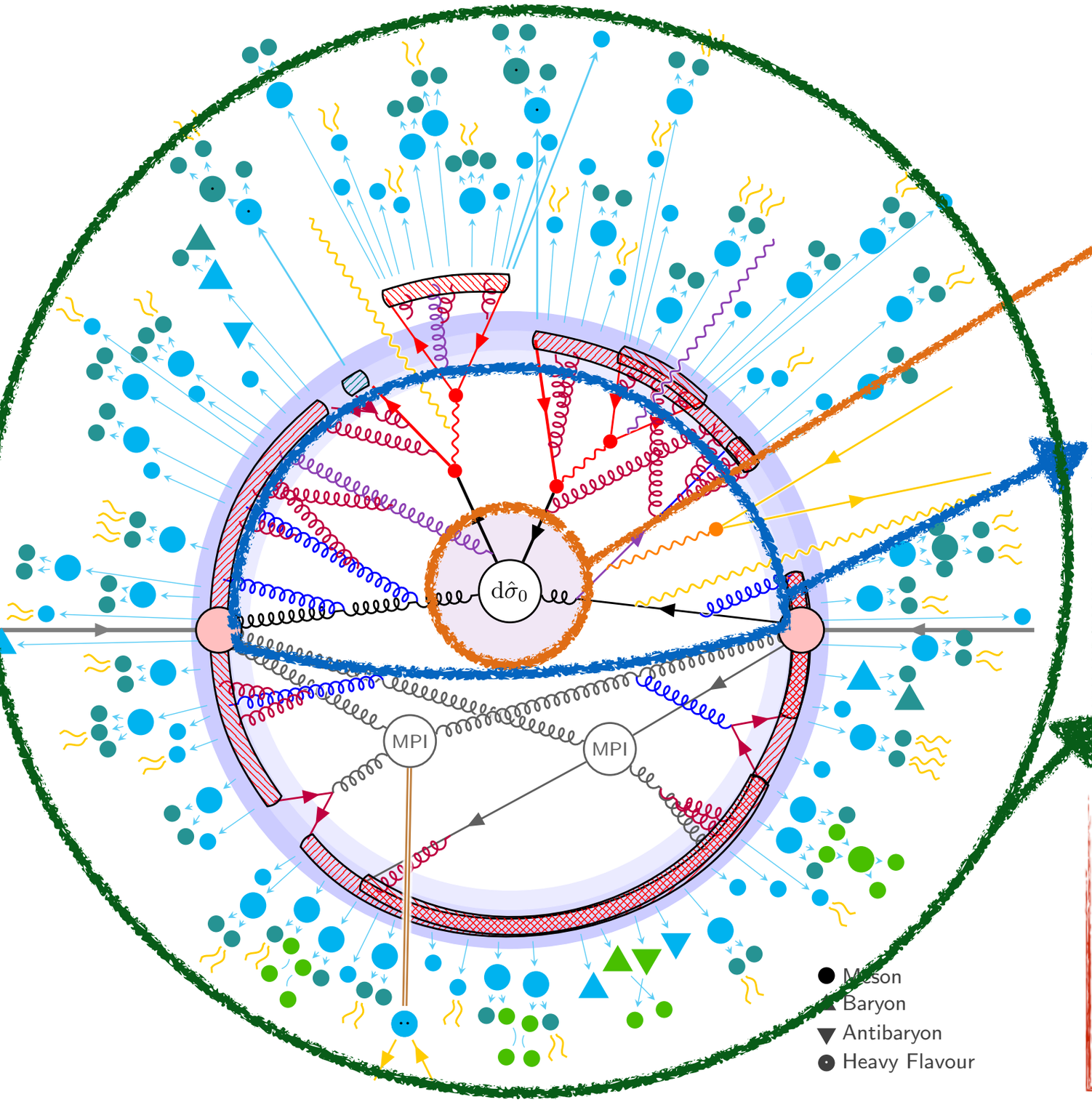

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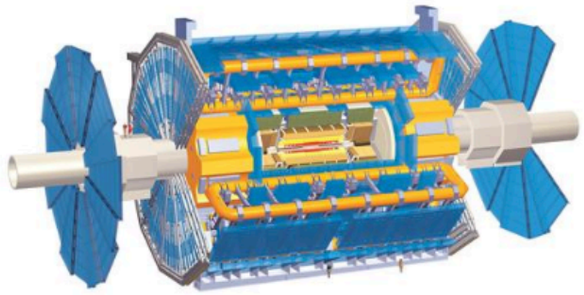
Soft Physics

- Model Based

Detector simulation



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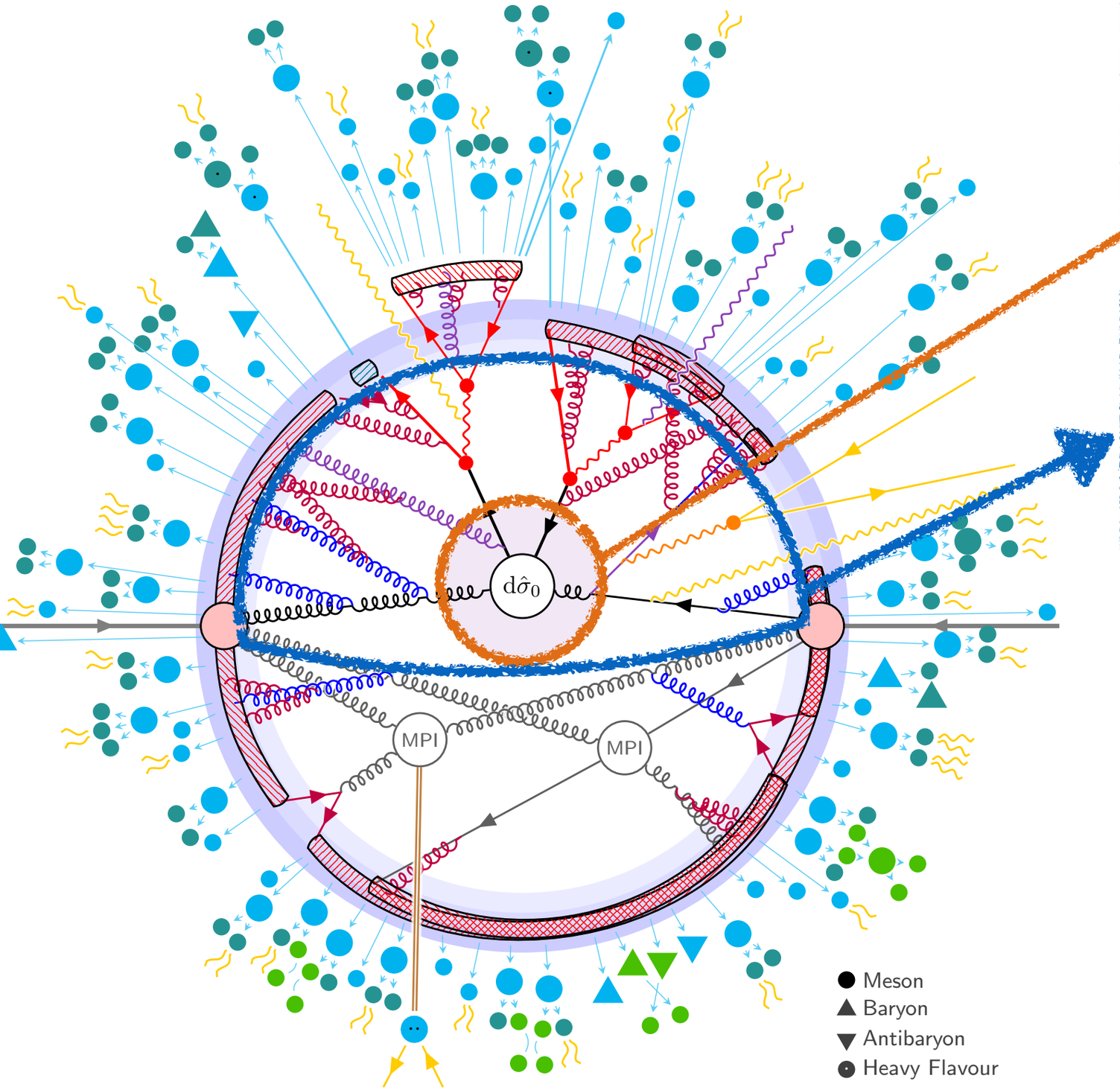

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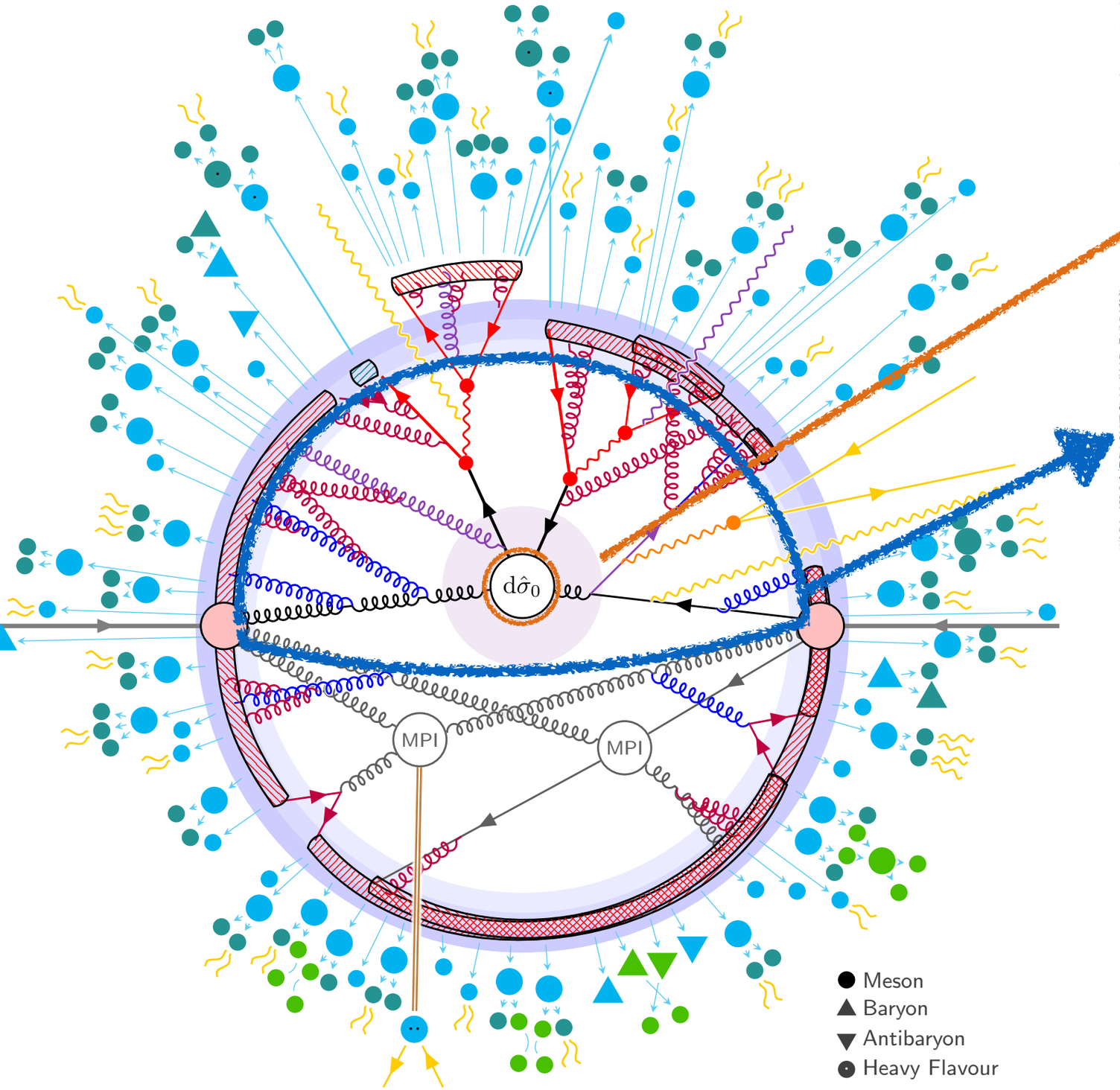

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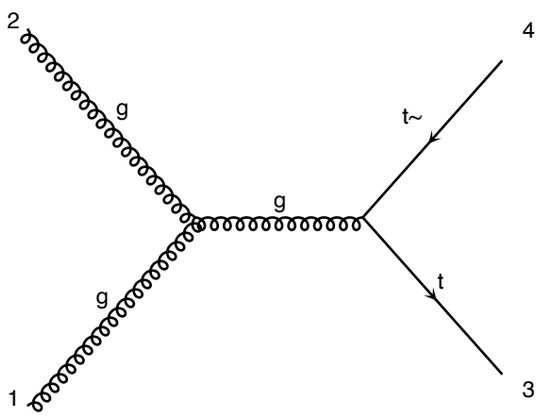
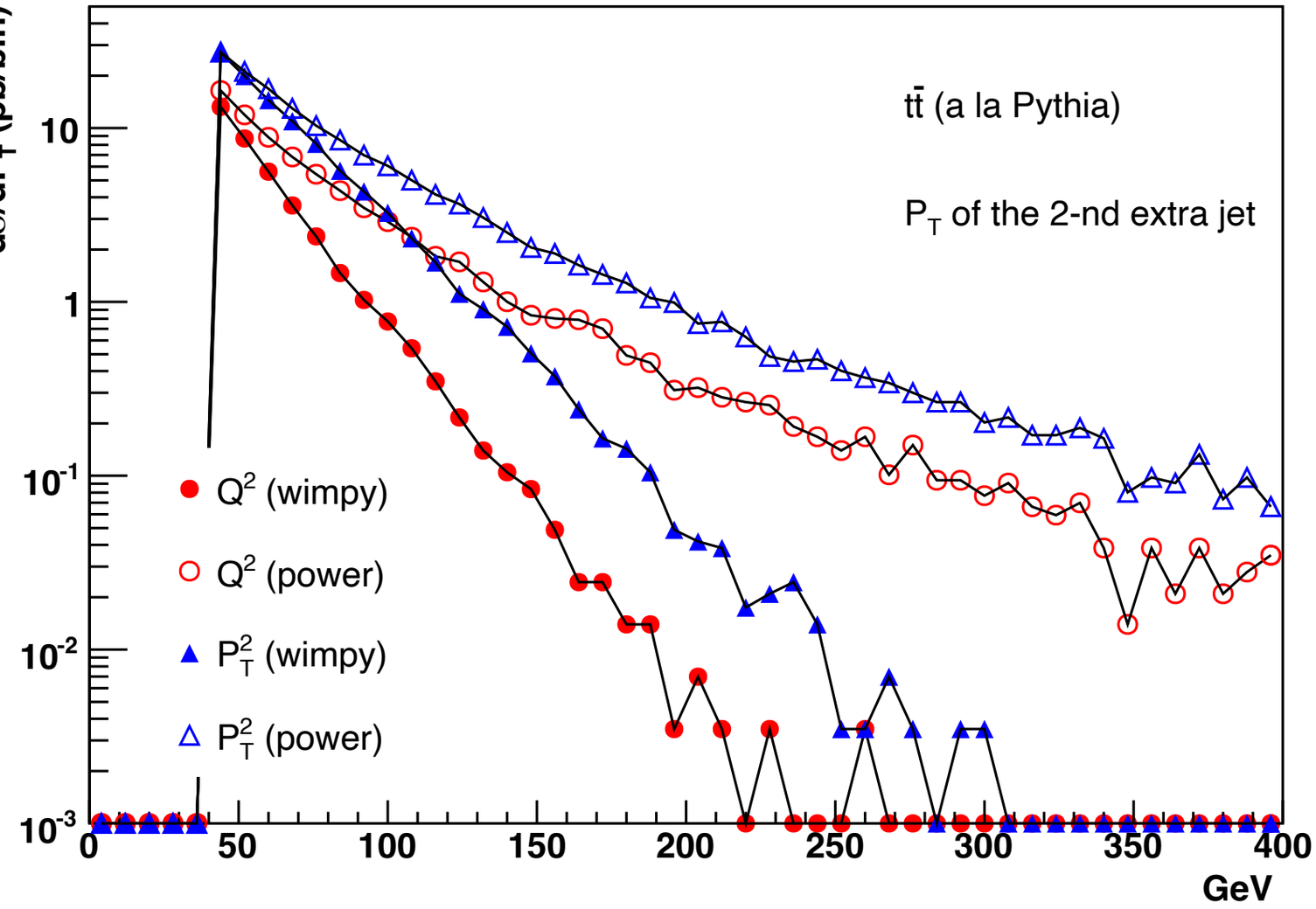
PS alone vs matched samples

If you stop too early: too large dependence in the Parton-Shower

Sample generated





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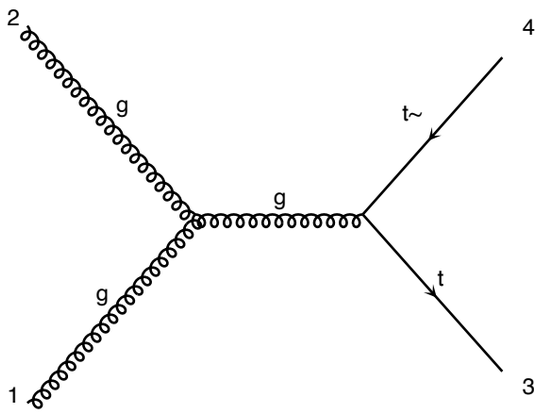
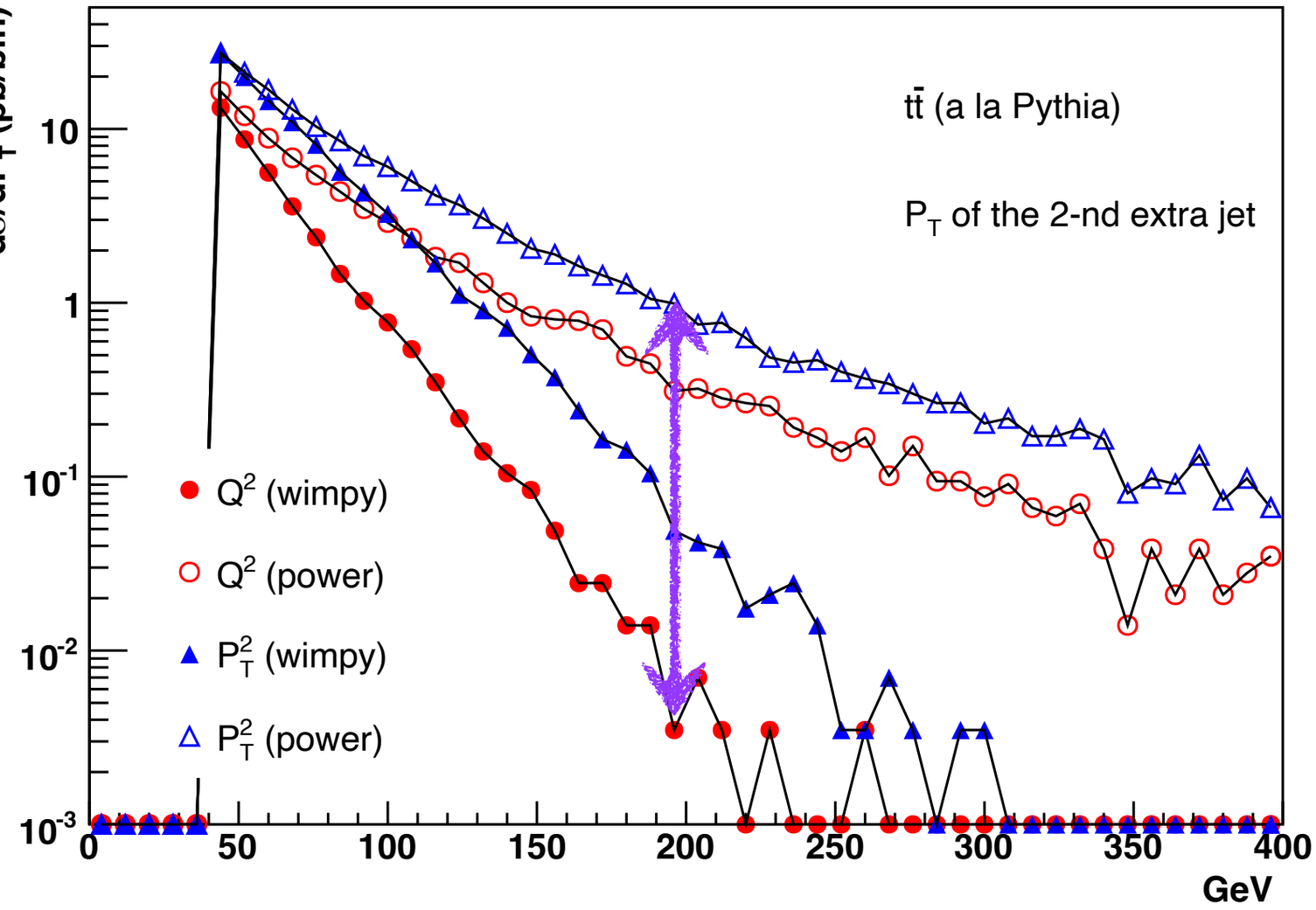


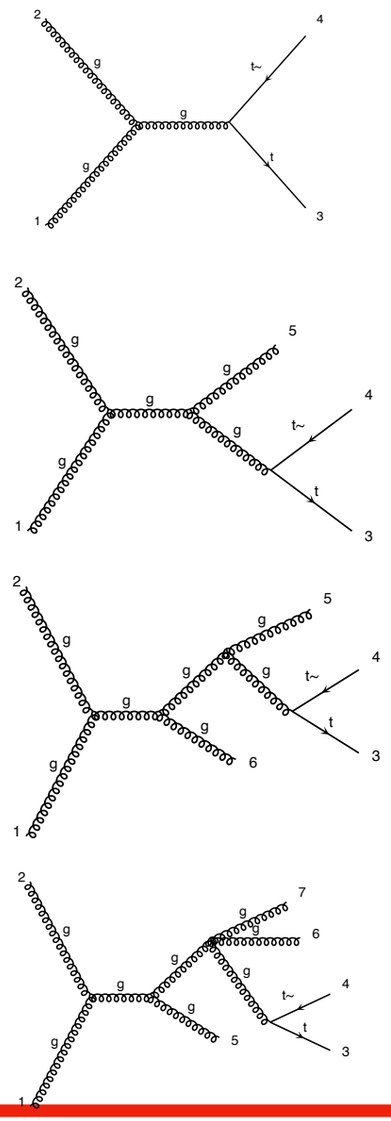


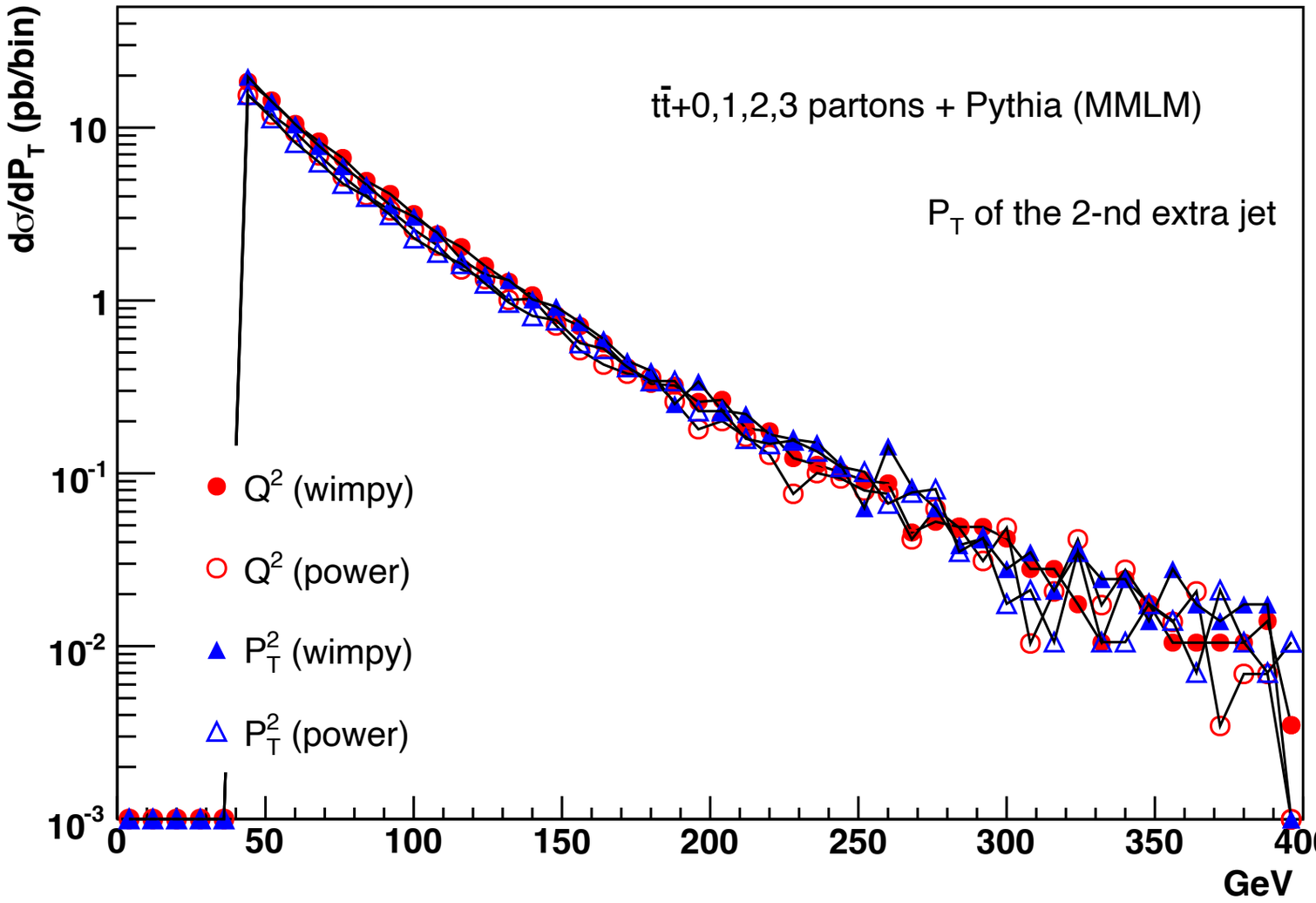
Two order of magnitude in the prediction

PS alone vs matched samples

If you stop too early: too large dependence in the Parton-Shower

Sample generated

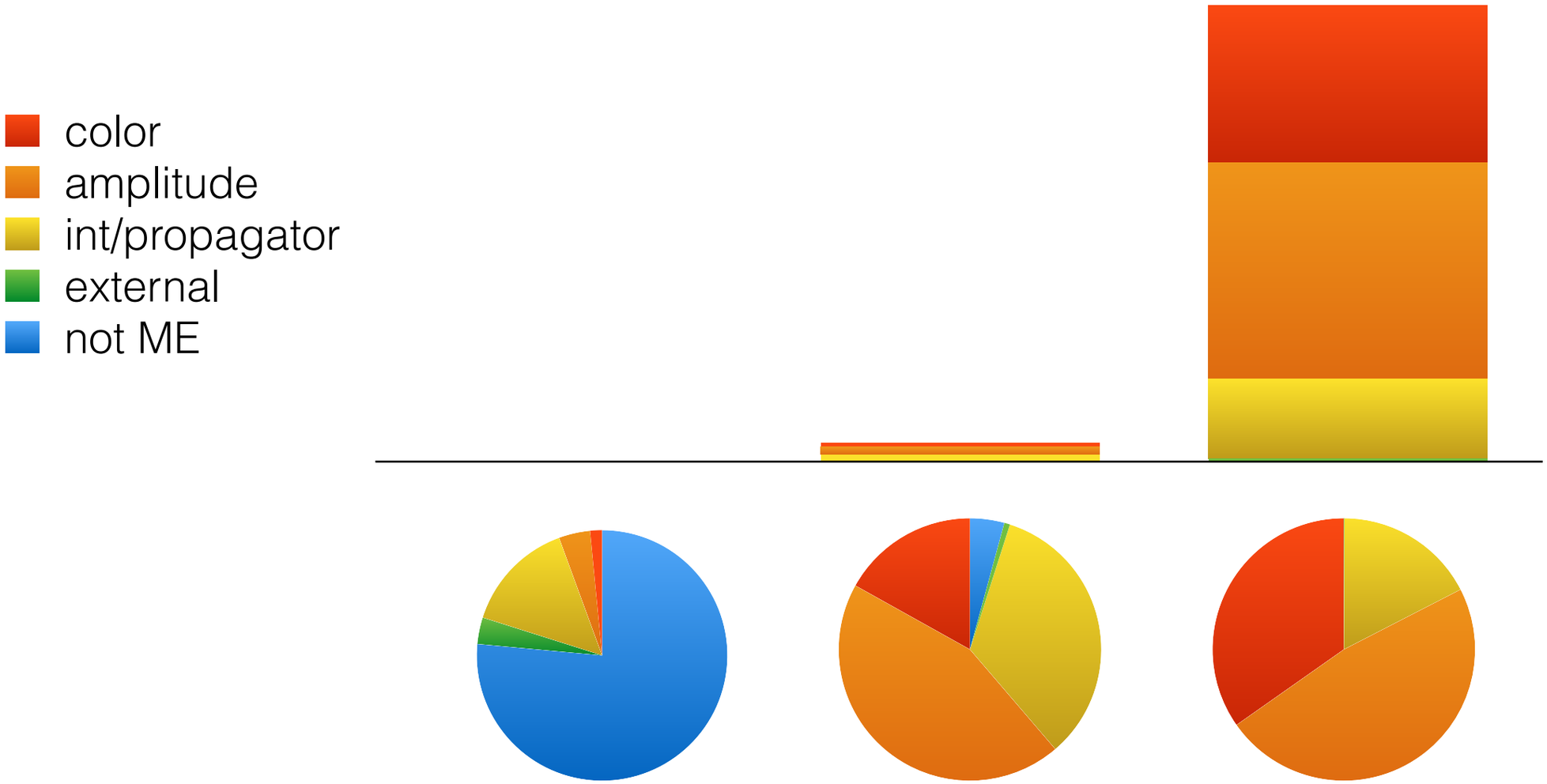




Error dominated by other factor !!

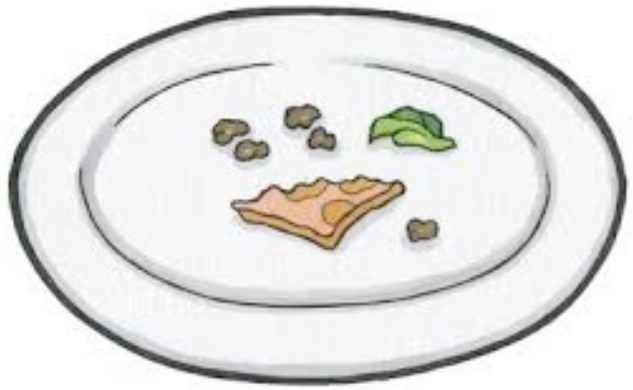
Code Complexity

	$gg \to t\bar{t}$	$gg \to t\bar{t}gg$	$gg \to t\bar{t}ggg$
`madevent`	13G	470G	11T
`matrix1`	3.1G (23%)	450G (96%)	11T (>99%)



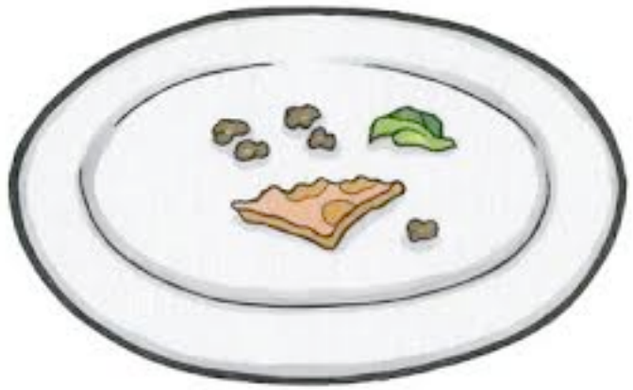
Complexity raise factorially square

Is it sustainable ?



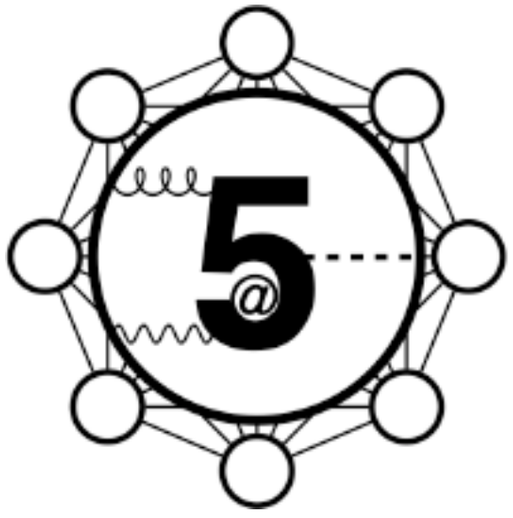
Can we do More with Less ?

Is it sustainable ?

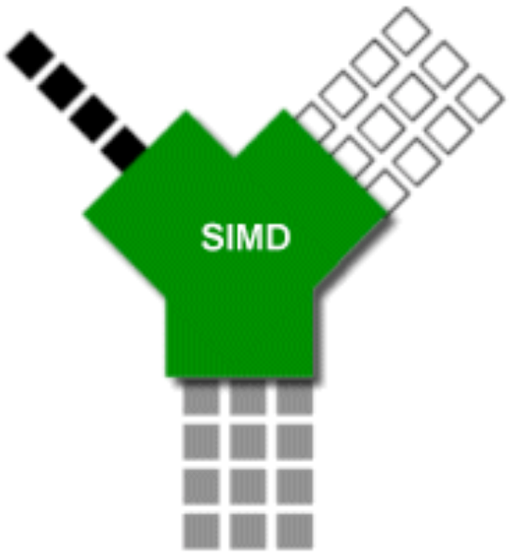


Can we do More with Less ?

Type of Solution

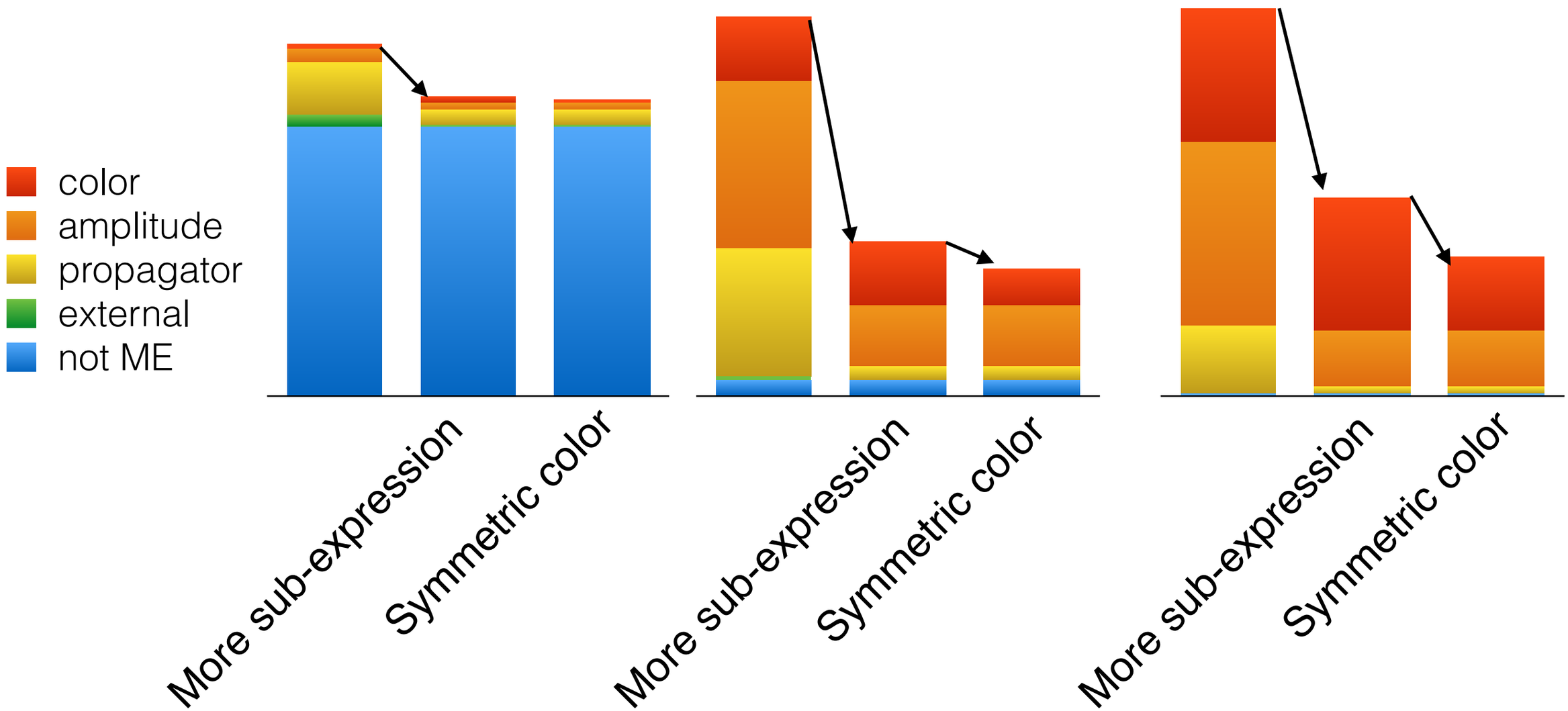


- We need better **code efficiency**
  - More efficient **algorithm**
  - More efficient use of **CPU/GPU**



Better evaluation Method

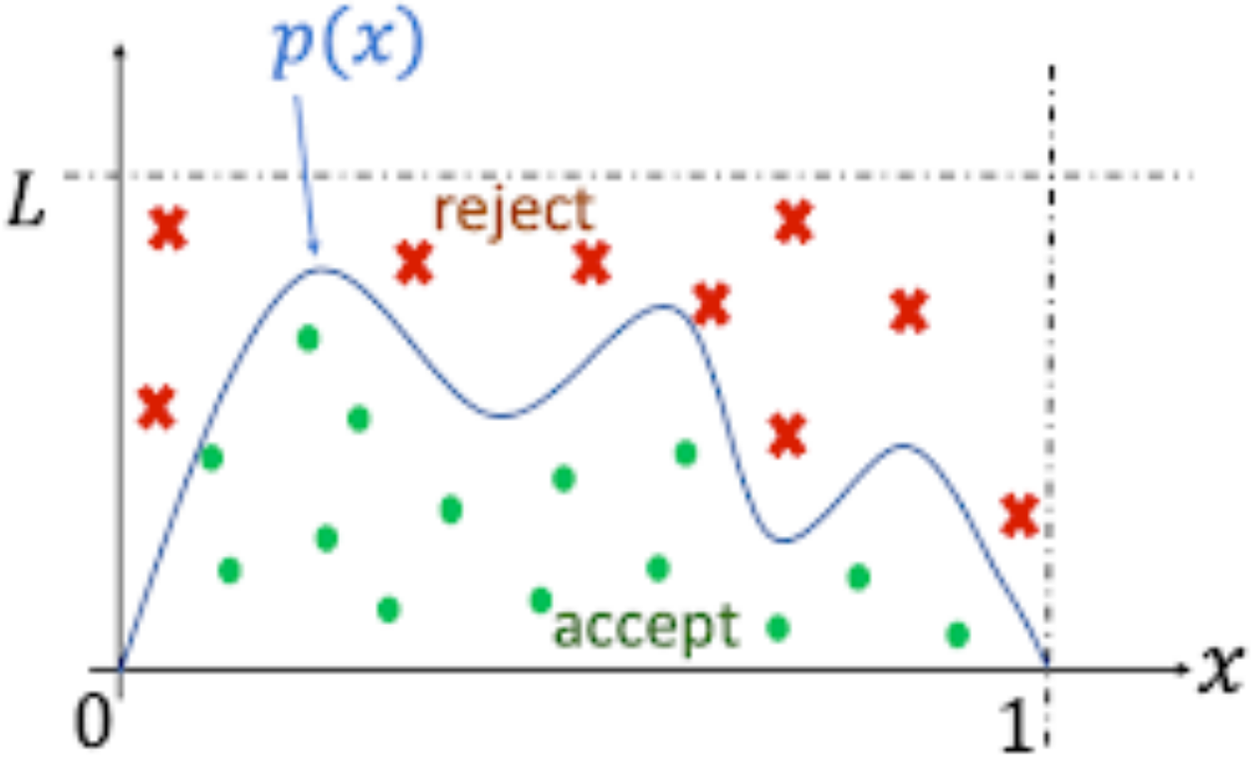
	$gg \to t\bar{t}$		$gg \to t\bar{t}gg$		$gg \to t\bar{t}ggg$	
	Instructions	Reduction	Instructions	Reduction	Instructions	Reduction
`madevent`	11G	15%	180G	62%	5T	55%
`matrix1`	1G (9.3%)	68%	160G (90%)	64%	4.9T (98%)	55%



In Collaboration with Kiran Ostrelenk (2102.00773)

Machine Learning

Monte-Carlo generation is based on accept/reject



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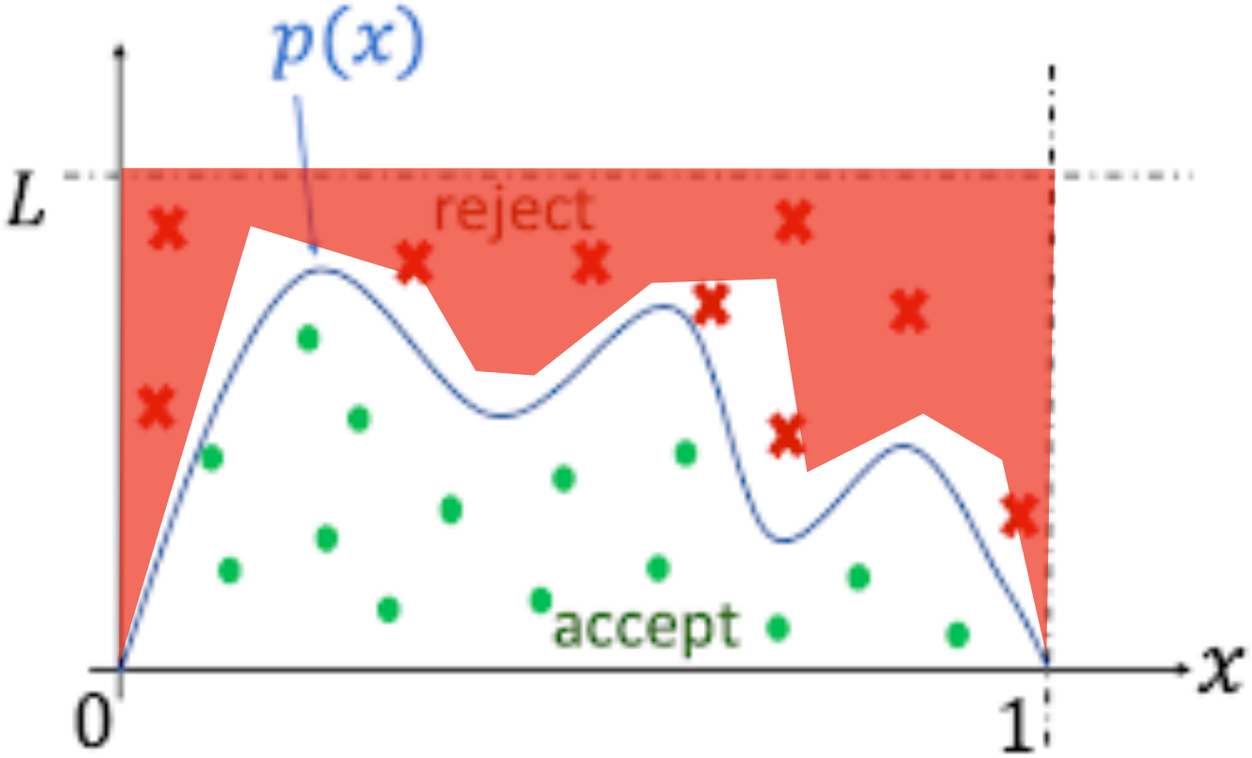

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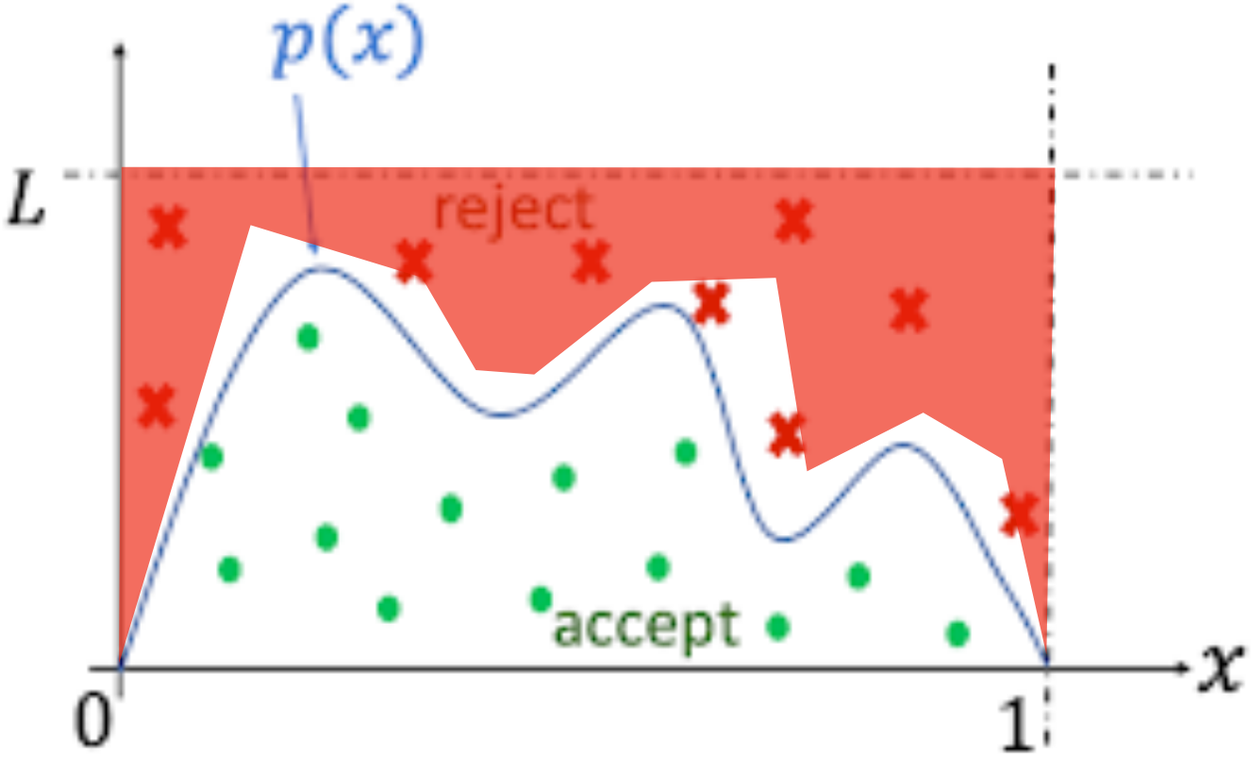

Machine Learning is key to improve our knowledge of the function

This is a perfect fit for modern AI

Machine Learning

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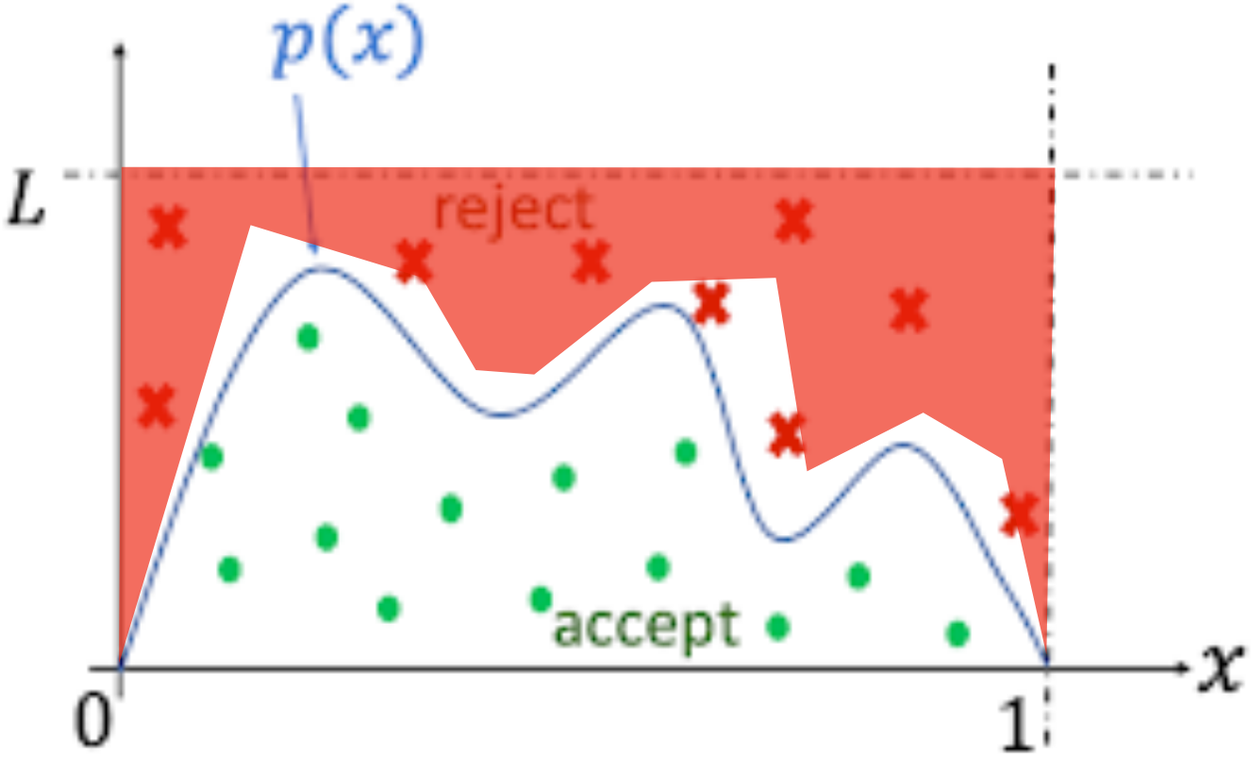

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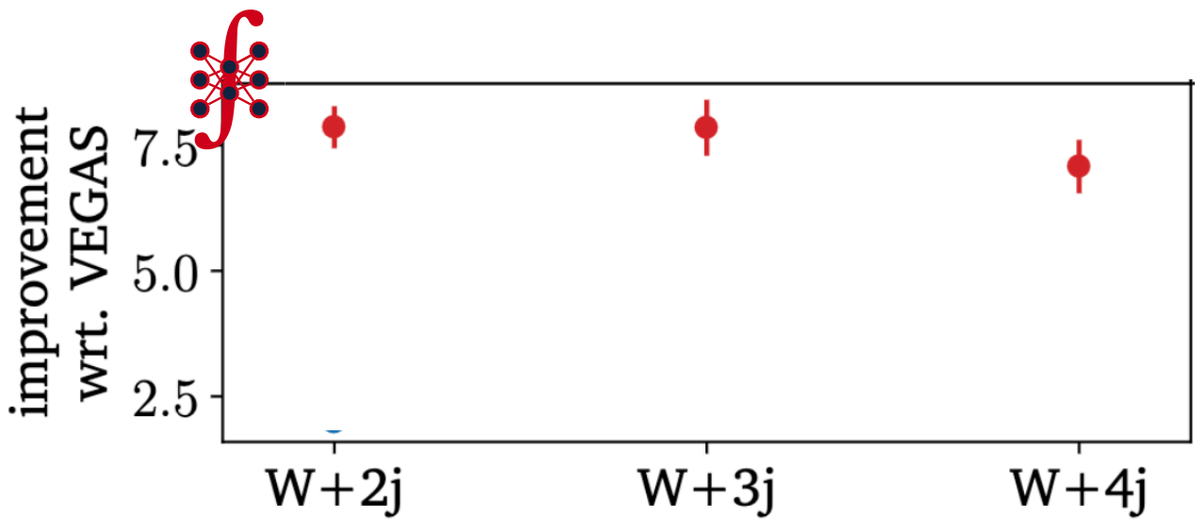
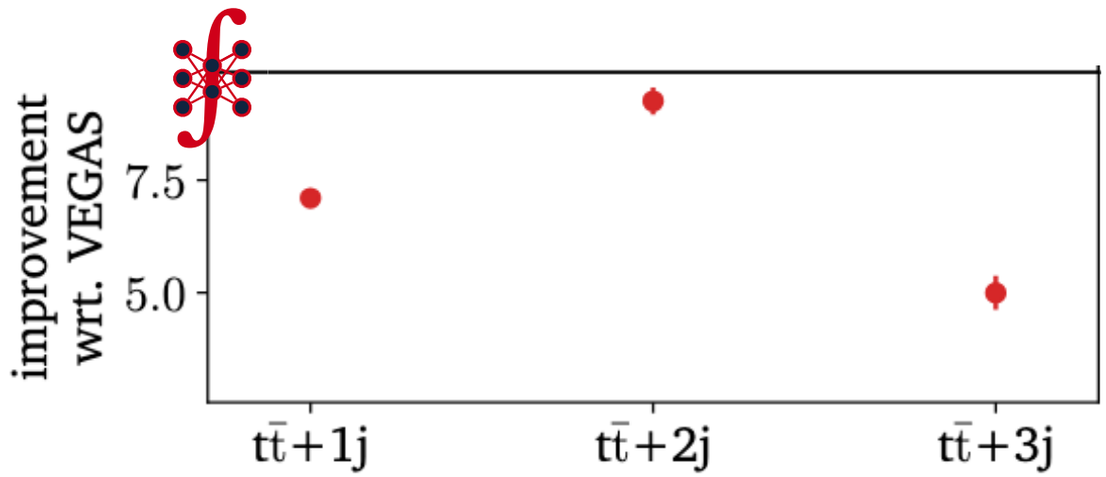
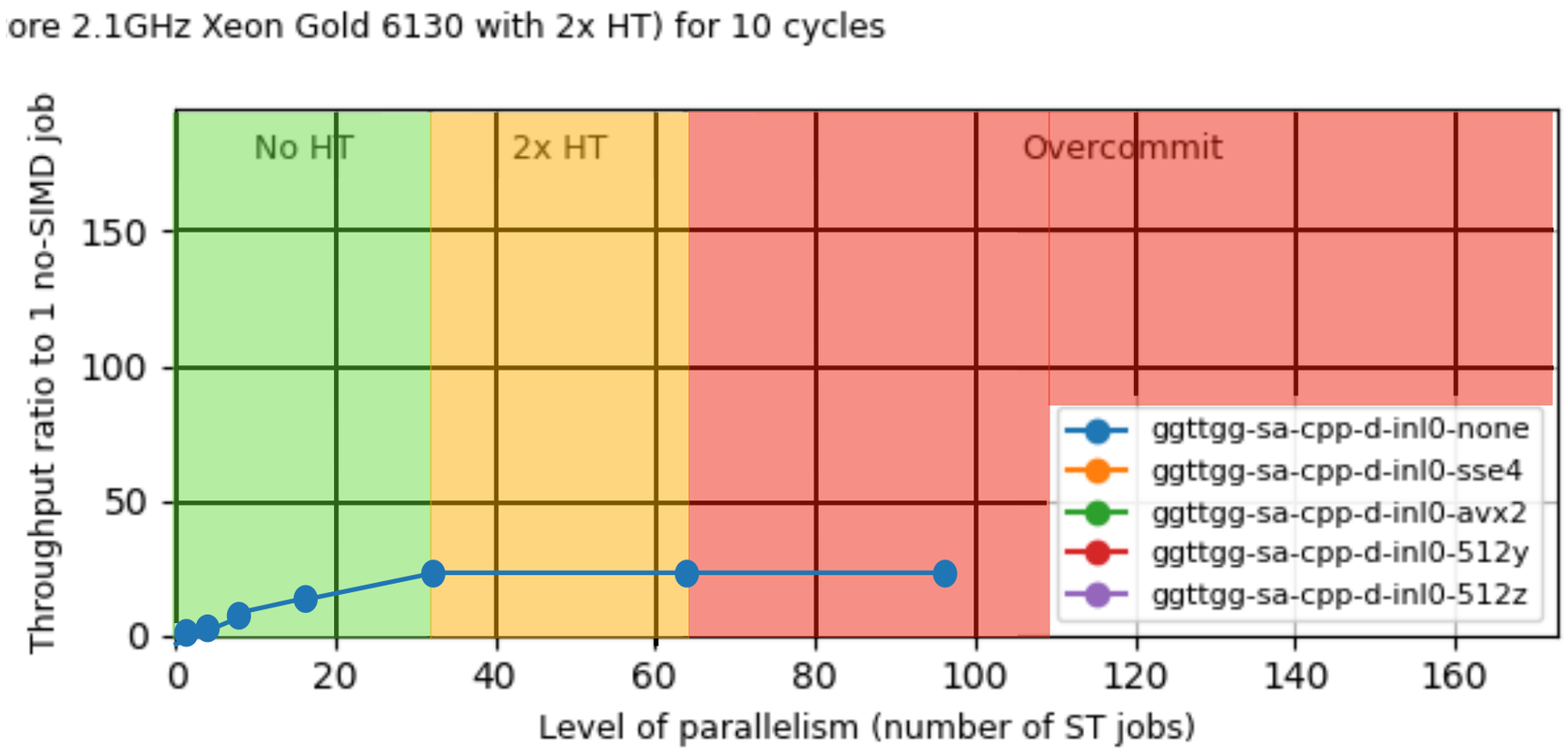
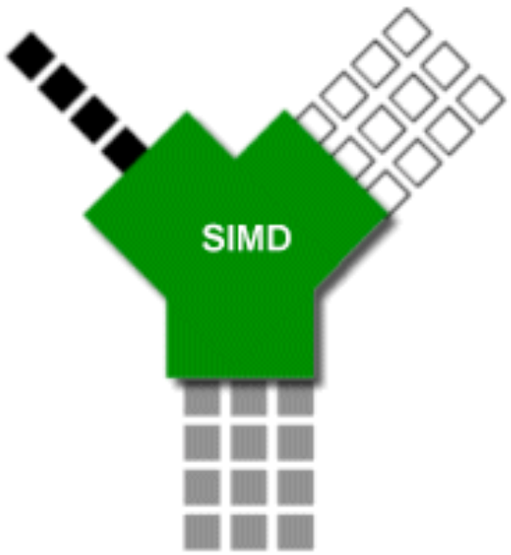




MadNIS collaboration: 2311.01548

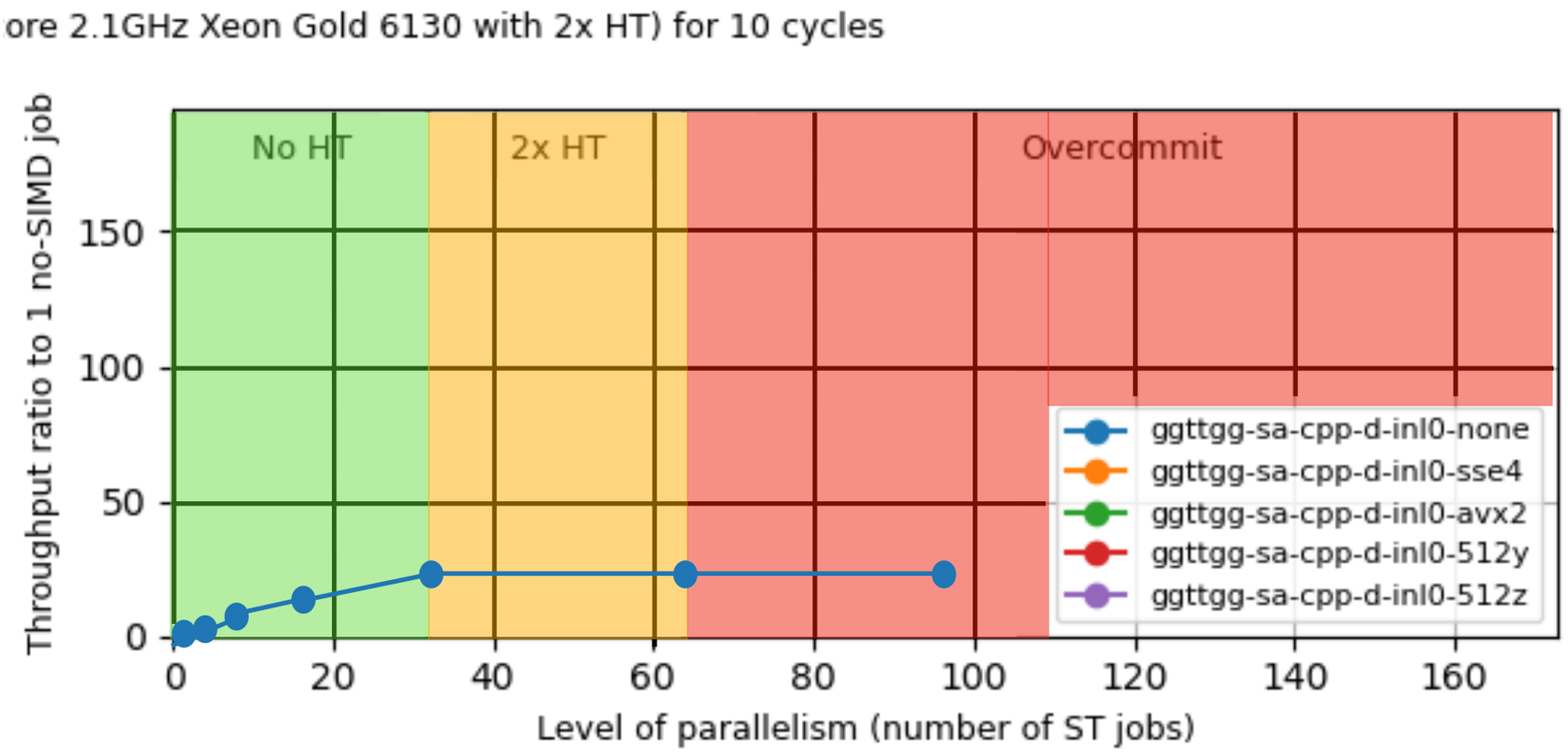
SIMD

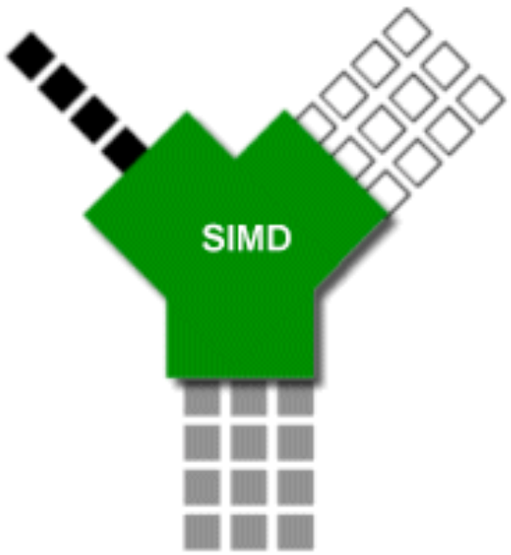




See Andrea Valassi talk for more details

SIMD





- Matrix-Element are naturally in lock step parralelism
- Perfect for SIMD (and GPU)

See Andrea Valassi talk for more details

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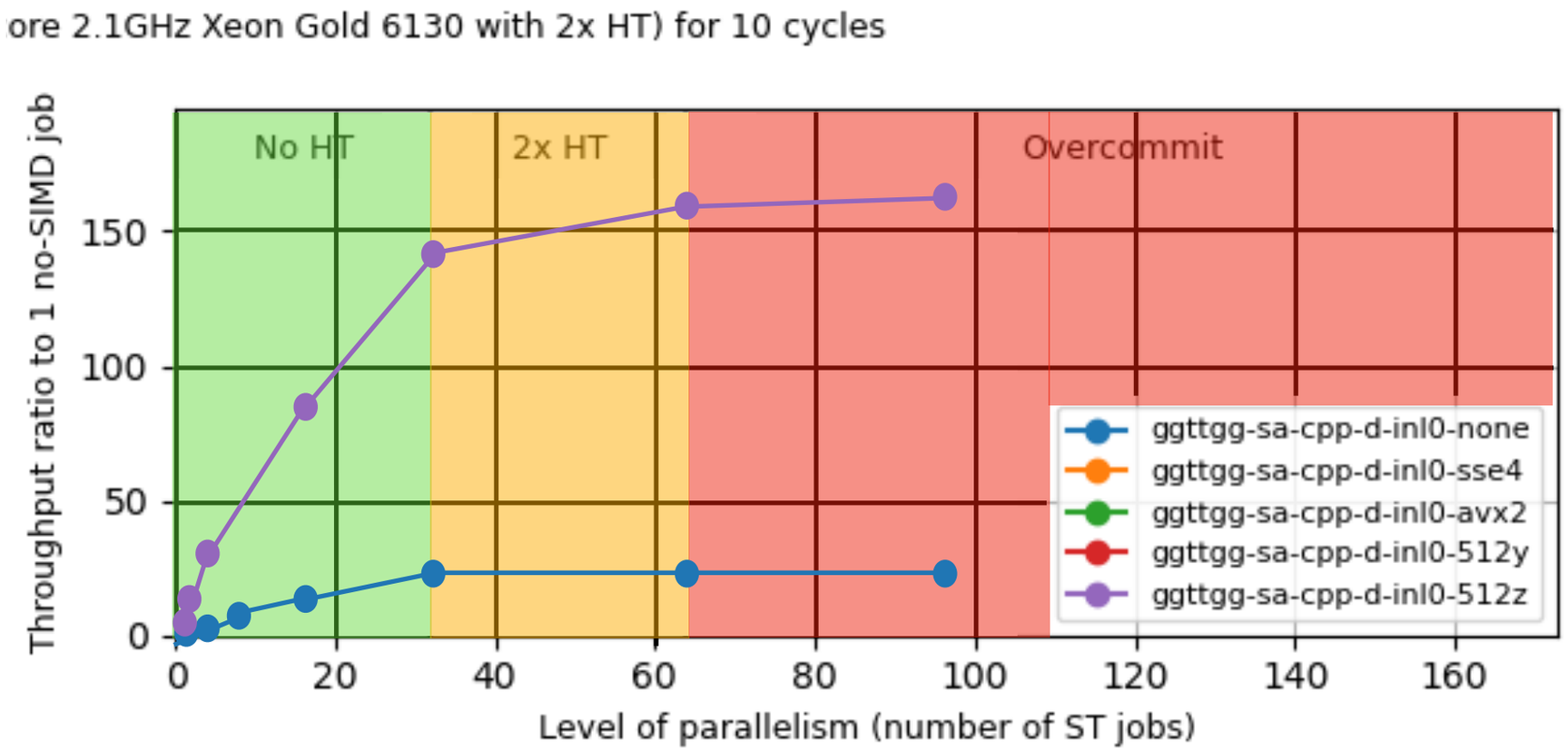

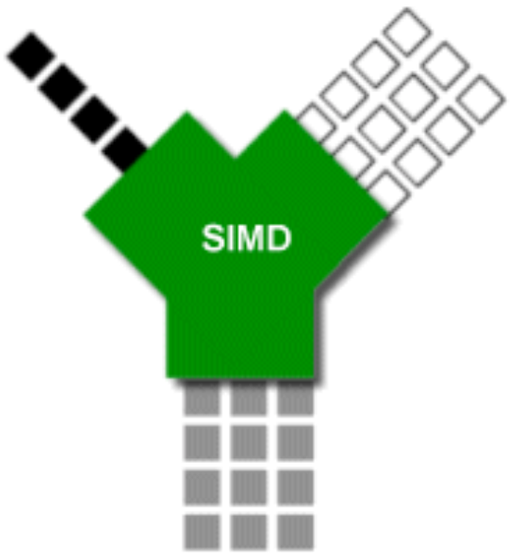

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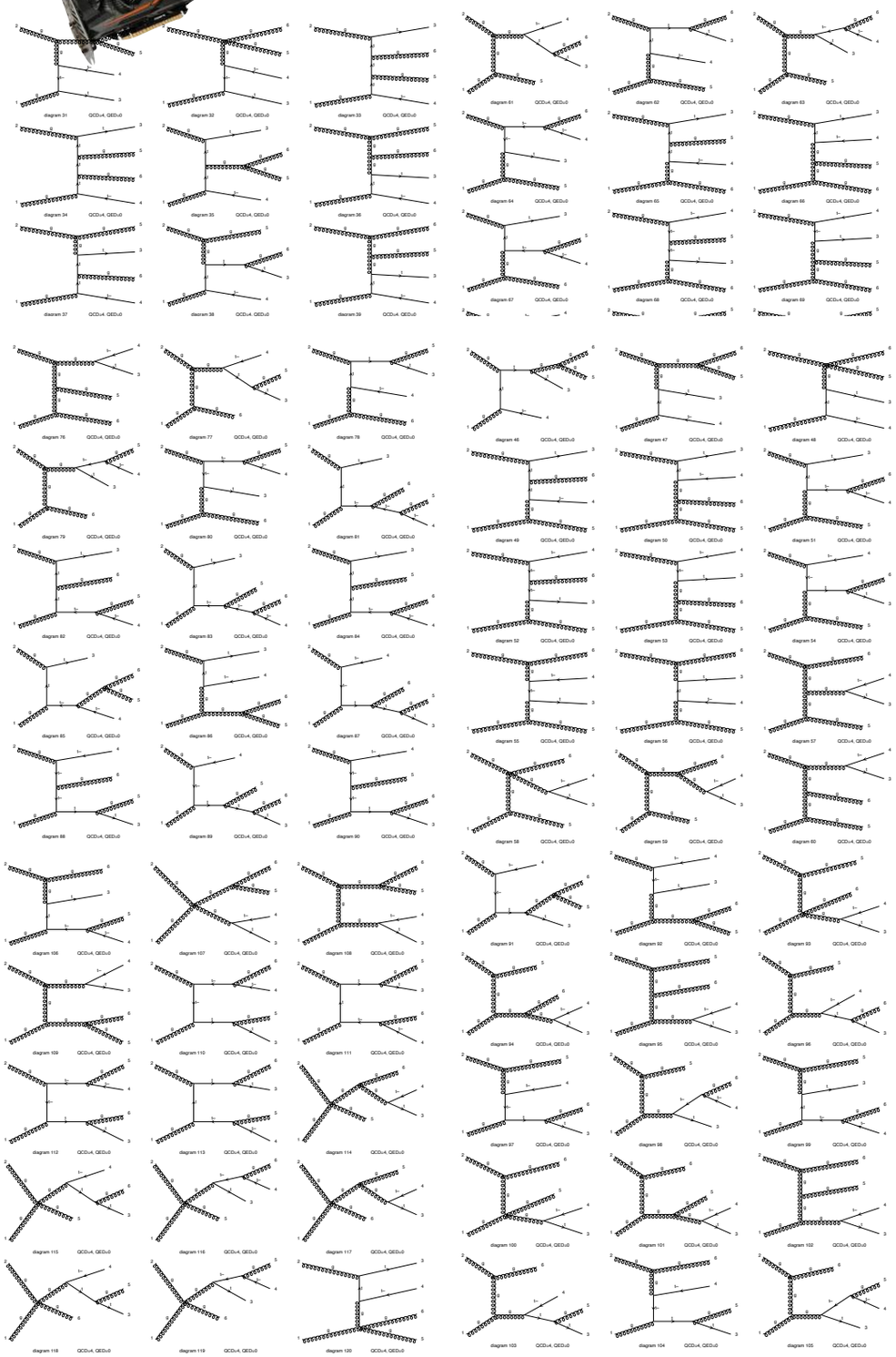
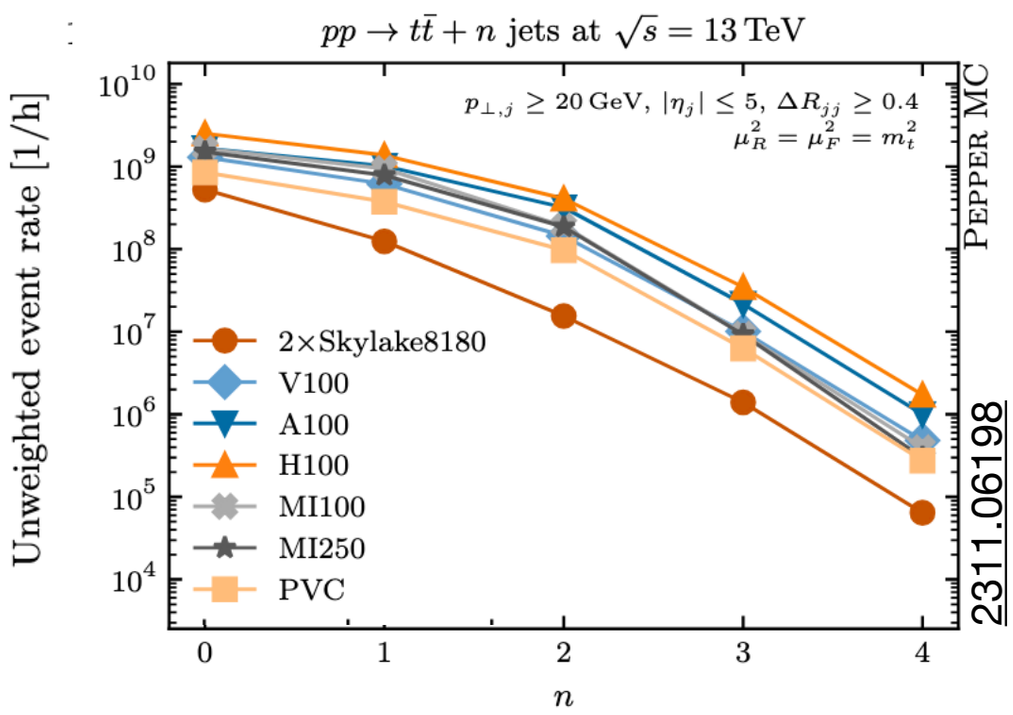
- Perfect for SIMD (and GPU)
- Near to perfect speed-up (7x instead)

See Andrea Valassi talk for more details

GPU



- Any LO code now capable to use GPU
  - MadGraph and Pepper
- Large Speed-up reported
  - 100 times faster
- NLO port in progress



See Andrea Valassi and Zenny Wettersten talk for more details

Conclusion

- Theoretician would like more and more FLOPS
- Experiments will need more events/accuracy/complexity
- FLOPS budget will be under tension in 3 years
- The IT community is helping towards more efficiency
- The theory community is starting to acknowledge effort for better hardware/software.

- Remember that we can not rely on a single tool.