High Energy Resummation of Transverse Momentum Distributions

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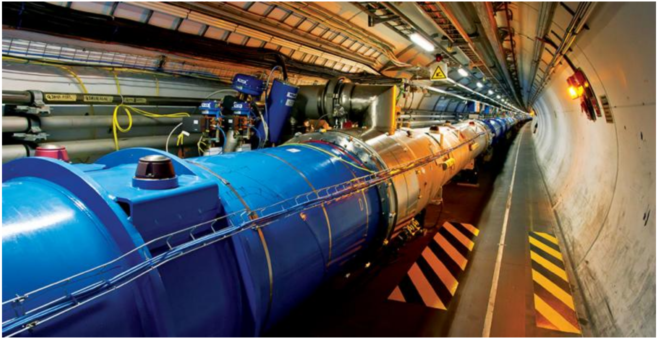
LHC Phenomenology



I will present a new method to increase the precision of the theoretical predictions at LHC.

LHC Phenomenology

- **Particle Physics Phenomenology** is a part of the Theoretical Physics, with a crucial role in collider physics experiments.
- Its task is to calculate detailed prediction for the collider experiments, with high precision.
- These predictions, built in the Standard Model, are fundamental in discovering any trace of New Physics.

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Discovering New Physics

- New Physics at LHC appears as a *significant discrepancy* between the theoretical prediction and the experimental data.
- "significant" means a discrepancy greater than the uncertainties, both theoretical and experimental.

High sensitivity is obtained also by *lowering* the *theoretical error*.

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  Example in Particle Physics:
  Number of Higgs in unit time and area

$$\sigma = 100 \cdot 10^{-36} cm^{-2} \tag{1}$$

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In order to find traces of New Physics, we measure at LHC:

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  Example in **real** life:
  Number of Marios today in Milan

$$\sigma_{\mathrm{MARIO}} = 274 \tag{1}$$

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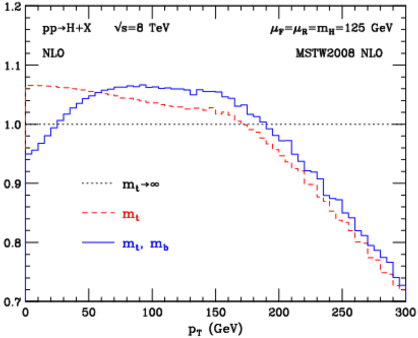
  Example in Particle Physics:

  Number of Higgs in unit time and area with a certain angle

$$\frac{d\sigma}{dp_{\mathrm{T}}^2}$$



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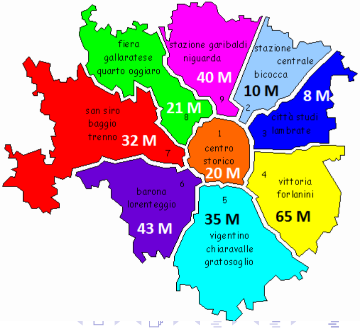
  Example in **real** life:

  Number of Marios today in Milan in a certain neighbourhood

$$\frac{d\sigma_{MARIO}}{dp^2_{NEIGHBOURHOOD}}$$



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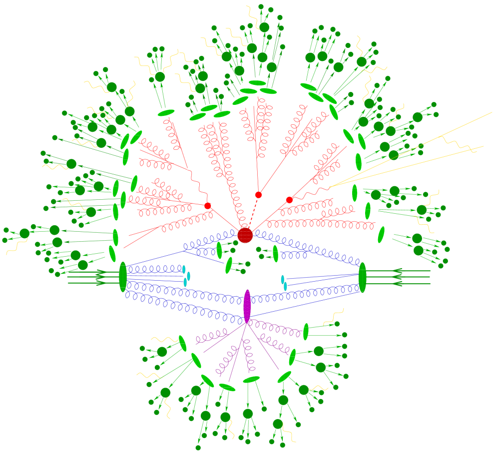
Exclusive $\rightarrow$ More Information $\rightarrow$ More complexity

What do we see at LHC??



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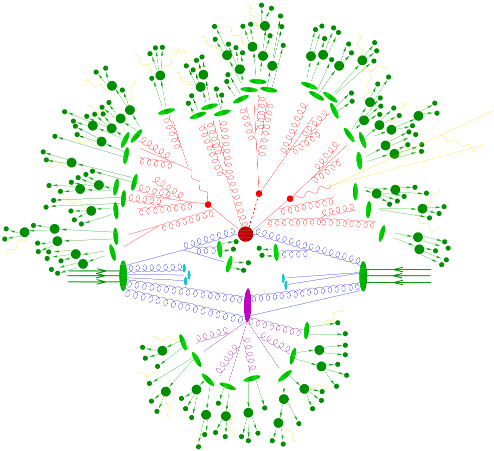

What we want to predict is this mess!!!

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Let's inspect more carefully...

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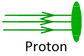

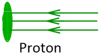

We start with **proton**

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PDF, Parton Distribution Function

What do we see at LHC??

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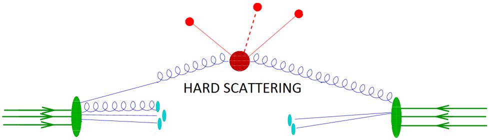

Parton Process (New Physics is Here!!)

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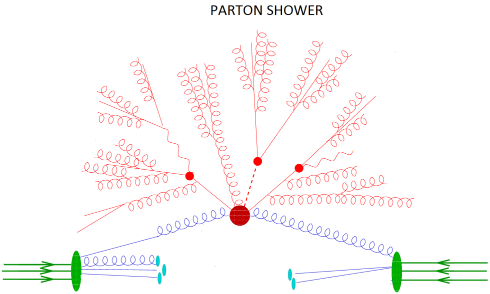

Parton Shower Tools (PYTHIA or POWEG)

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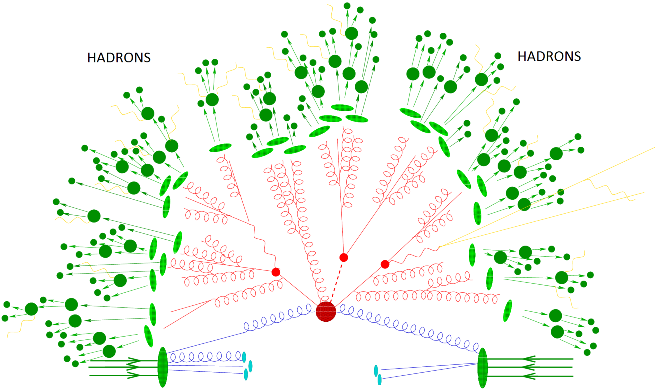

Hadronization Models

What do we see at LHC??

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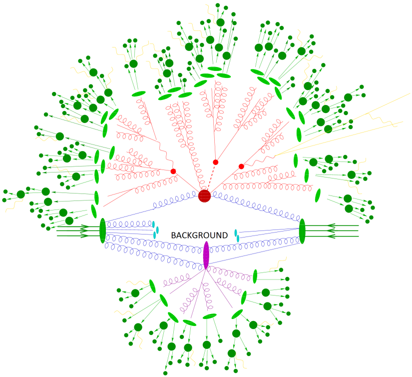
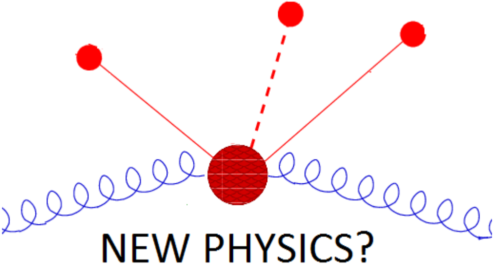


Then there are Experimental Problems (BACKGROUND)!

Parton Process Calculation

We study this process in **Perturbative QCD**:



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We study this process in **Perturbative QCD**:

$$\frac{d\sigma}{dp_{\mathrm{T}}^2} = C_0 \left(1 + C_1\alpha_s + C_2\alpha_s^2 + ...\right) \tag{1}$$

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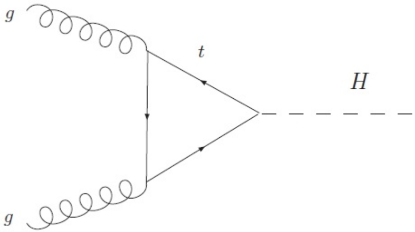

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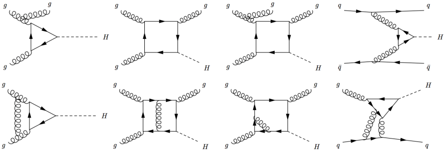

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Feynman Diagram Evaluation is not enough!!

There are cases where the usual Fixed Order Evaluation does not permit us to reach the desired accuracy!

A Simple Example: Higgs Boson Production

At LHC, the Higgs Boson is produced mainly by gluon fusion:

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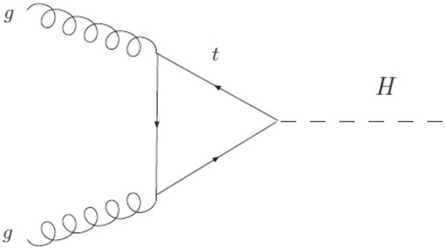

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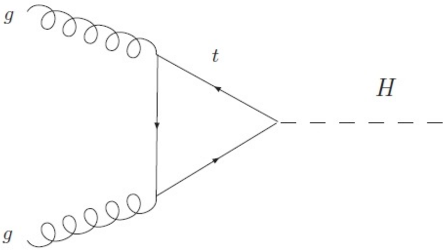

Too difficult!

The presence of a loop and the huge number of diagrams in the next orders prevent us from reaching the desired accuracy.

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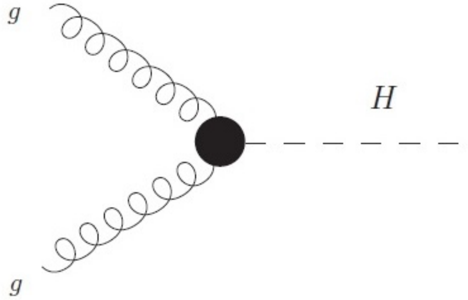

So...

...normally we use a approximation called *heavy top approximation*

How good is this approximation?

Correct answer: We don't know!!

This is now our biggest uncertainty in the final result

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Correct answer: We don't know!! [Langenegger *et al* '15]

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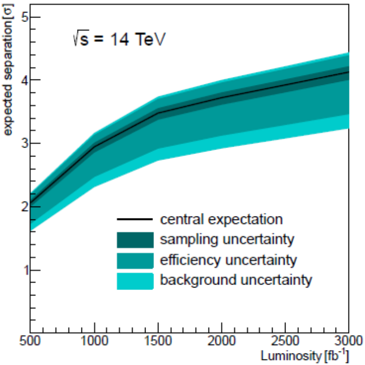
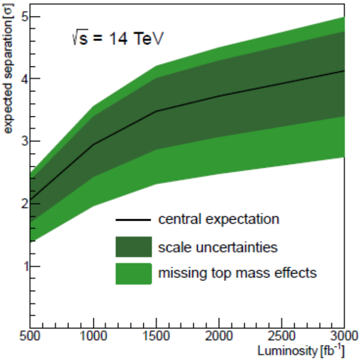
Experimental



Theoretical



How good is this approximation?

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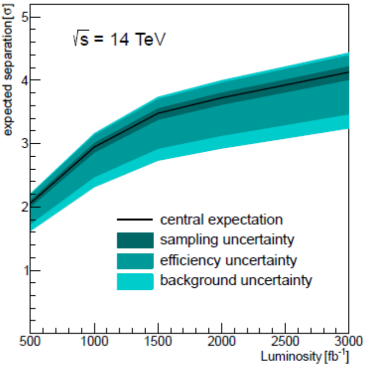

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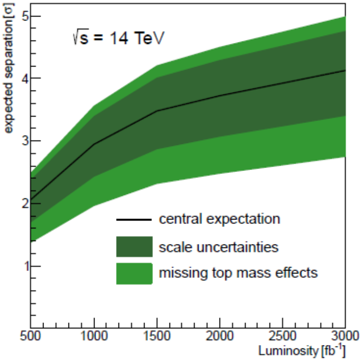

The inclusion of the mass quark effects is of primary importance in this context

Changing point of view

Since technical difficulties does not allow us to evaluate higher orders in the full theory, we follow a new road

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Resummation

Resummation in QCD

$$x = \frac{m_{\rm H}^2}{s}$$

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...	...	...	...	...

Resummation in QCD

Fixed Order Evaluation

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Fixed Order+Resummation

$\frac{d\sigma}{dp_T^2}\,(x, p_T^2)$	Threshold $x \to 1$	Collinear $p_T^2 \to 0$	H. E. $x \to 0$	Other
LO α_s	$\bar{c}_0 \left(\frac{\ln(1-x)}{1-x}\right)_+$	$\tilde{c}_0 \frac{1}{p_T^2}$	$c_0 \frac{1}{x}$	$C_0^{\mathrm{reg}}\,(x, p_T^2)$
NLO α_s^2	$\bar{c}_1 \left(\frac{\ln^2(1-x)}{1-x}\right)_+$	$\tilde{c}_1 \frac{\ln p_T^2}{p_T^2}$	$c_1 \frac{\ln x}{x}$	$C_1^{\mathrm{reg}}\,(x, p_T^2)$
NNLO α_s^3	$\bar{c}_2 \left(\frac{\ln^3(1-x)}{1-x}\right)_+$	$\tilde{c}_2 \frac{\ln^2 p_T^2}{p_T^2}$	$c_2 \frac{\ln^2 x}{x}$	$C_2^{\mathrm{reg}}\,(x, p_T^2)$
...	...	...	...	...

History of High Energy Resummation

Periodo	Risultati	Autori
Fine '70	P_{gg} - BFKL equation	Balitsky, Fadin, Kuraev, Lipatov
'80	Amplitude Factorization	Catani, Ciafaloni e collab.
'90-'00	DIS,Heavy flavour production	Catani, Ciafaloni, Hartmann - Ellis, Ball
'00	Parton Evolution at small-x	Ciafaloni, Colferai, Salam, Stasto (CCSS) Altarelli, Ball, Forte (ABS)
2008	Higgs in gluon fusion	Marzani, Ball, Forte, Vicini, Del Duca
2007-2010	Rapidity Distribution	Caola, Forte, Marzani
2014-2015	Transverse Momentum Distribution	Forte, Muselli

Building a Resummation Theory

1. Select the limit and the observable
   High Energy $x \to 0$ Transverse momentum distribution $\frac{d\sigma}{dp_T^2}$
2. **Factorization** In the limit, a generic dominant diagram is wirtten as $\longrightarrow D_n = F\left(E_1, \ldots, E_m\right)$ with E_i some simple ingredients or subdiagrams

$$D_n = \frac{1}{n!} K^n H$$

3. Sum all the D_n $\longrightarrow$ Exponentiation $R = \sum_n D_n = H \exp K$

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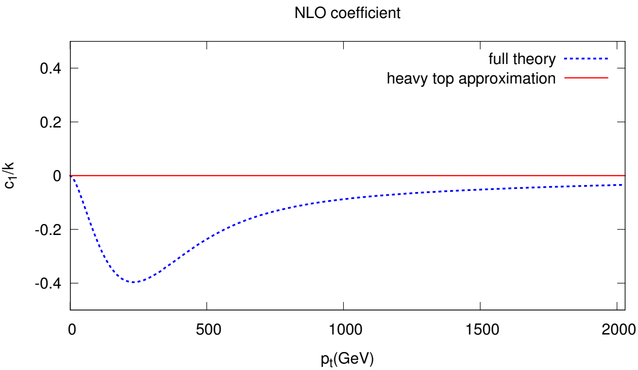

- Sizeable difference also at relative small value of p_T.
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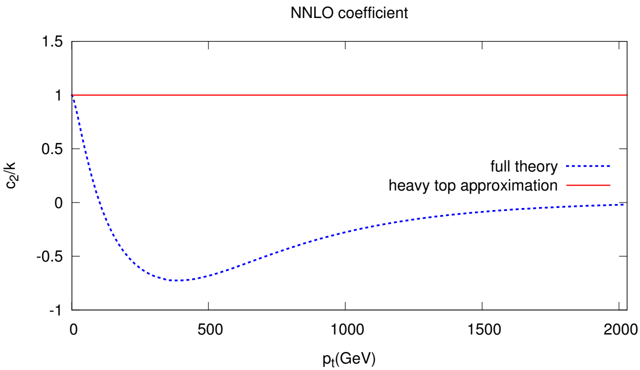

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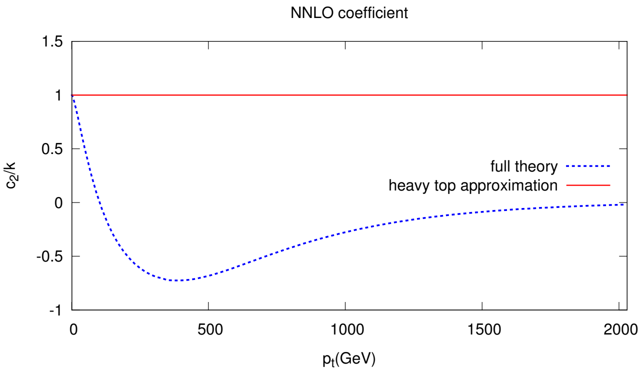

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In conclusion:

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That's all Folks!