QCD AND EVENT SIMULATION FOR THE LHC

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LECTURE I

Test: How much do I know about MC's?

	Statements	TRUE	FALSE	IT DEPENDS	I have no clue
0	MC's are black boxes, I don't need to know the details as long as there are no bugs.				
1	A MC generator produces "unweighted" events, i.e., events distributed as in Nature.				
2	MC's are based on a classical approximation (Markov Chain), QM effects are not included.				
3	The "Sudakov form factor" directly quantifies how likely it is for a parton to undergo branching.				
4	A calculation/code at NLO for a process provides NLO predictions for any IR safe observable.				
5	Tree-level based MC's are less accurate than those at NLO.				

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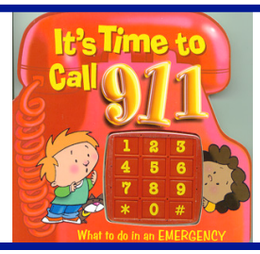
2	MC's are based on a classical approximation (Markov Chain), QM effects are not included.		✓		
3	The "Sudakov form factor" directly quantifies how likely it is for a parton to undergo branching.		✓		
4	A calculation/code at NLO for a process provides NLO predictions for any IR safe observable.		✓		
5	Tree-level based MC's are less accurate than those at NLO.			✓	

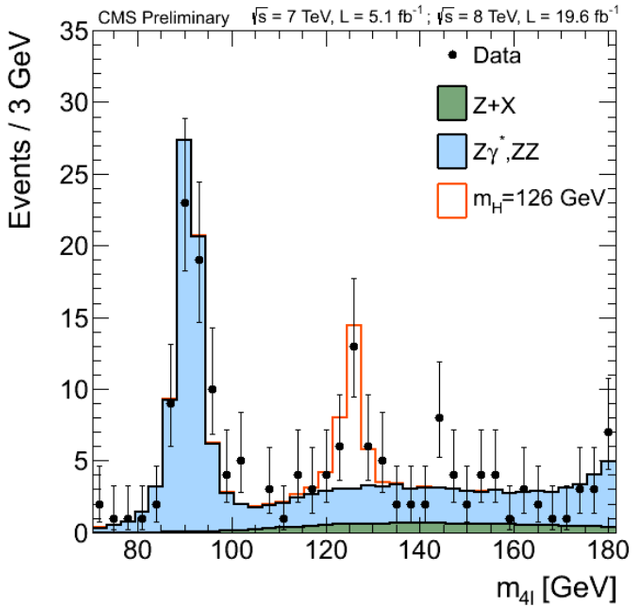
Test: How much do I know about MC's?

Score	Result	Comment
≥5	Addict	Always keep in mind that there are also other interesting activities in the field.
4	Excellent	No problem in following these lectures.
3	Fair	Check out carefully the missed topics.
≤2	Room for improvement	Enroll in a MC crash course at your home institution.
6 x no clue	No clue	

Discoveries at hadron colliders

peak

$pp \rightarrow H \rightarrow 4l$

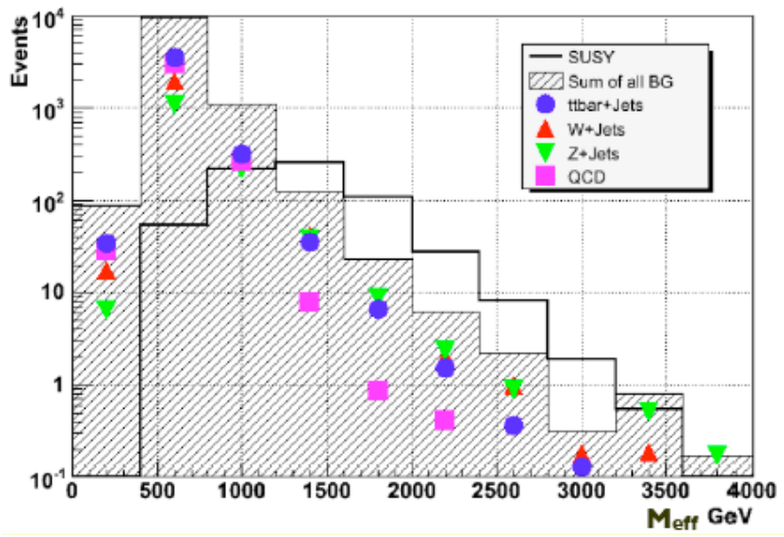


"easy"

Background directly measured from data. TH needed only for parameter extraction (Normalization, acceptance,...)

shape

$pp \rightarrow \tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{q}\tilde{q} \rightarrow \text{jets} + \not{E}_T$

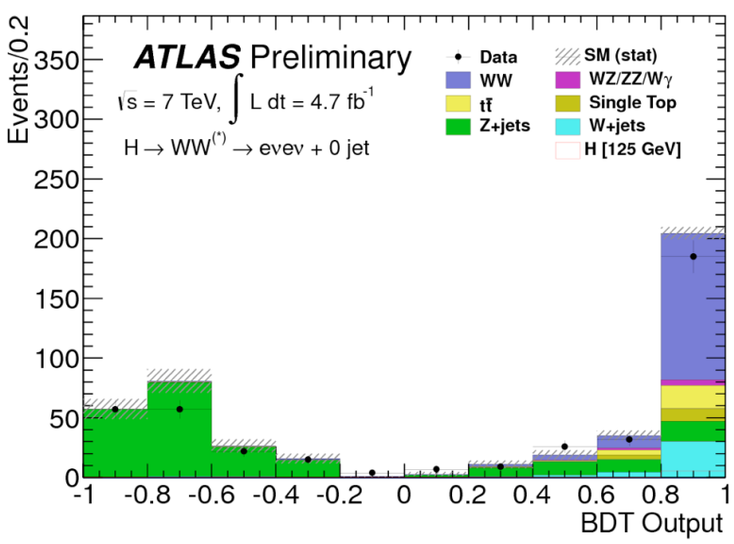


hard

Background shapes needed. Flexible MC for both signal and background tuned and validated with data.

discriminant

$pp \rightarrow H \rightarrow W^+W^-$



very hard

Background normalization and shapes known very well. Interplay with the best theoretical predictions (via MC) and data.

No sign of new physics (so far)!


MC developer

WHY HAPPY?

- Optimism: New Physics could be hiding there already, just need to dig it out.

- Democratization: No evidence of most beaten BSM proposals, means more and more room for diversification. Possibility for small teams to make a big discovery.

- Ingenuity/Creativity: From new signatures to smart and new analysis techniques (MVA), and combination with non-collider searches (DM, Flavor...).

- Massification (the practice of making luxury products available to the mass market) : MC's in the hands of every th/exp might turn out to be the best overall strategy for discovering the Unexpected.

- Flexibility: We need MC that are able to predict the pheno of the Unexpected.

- Accuracy: accurate simulations for both SM and BSM are a must.

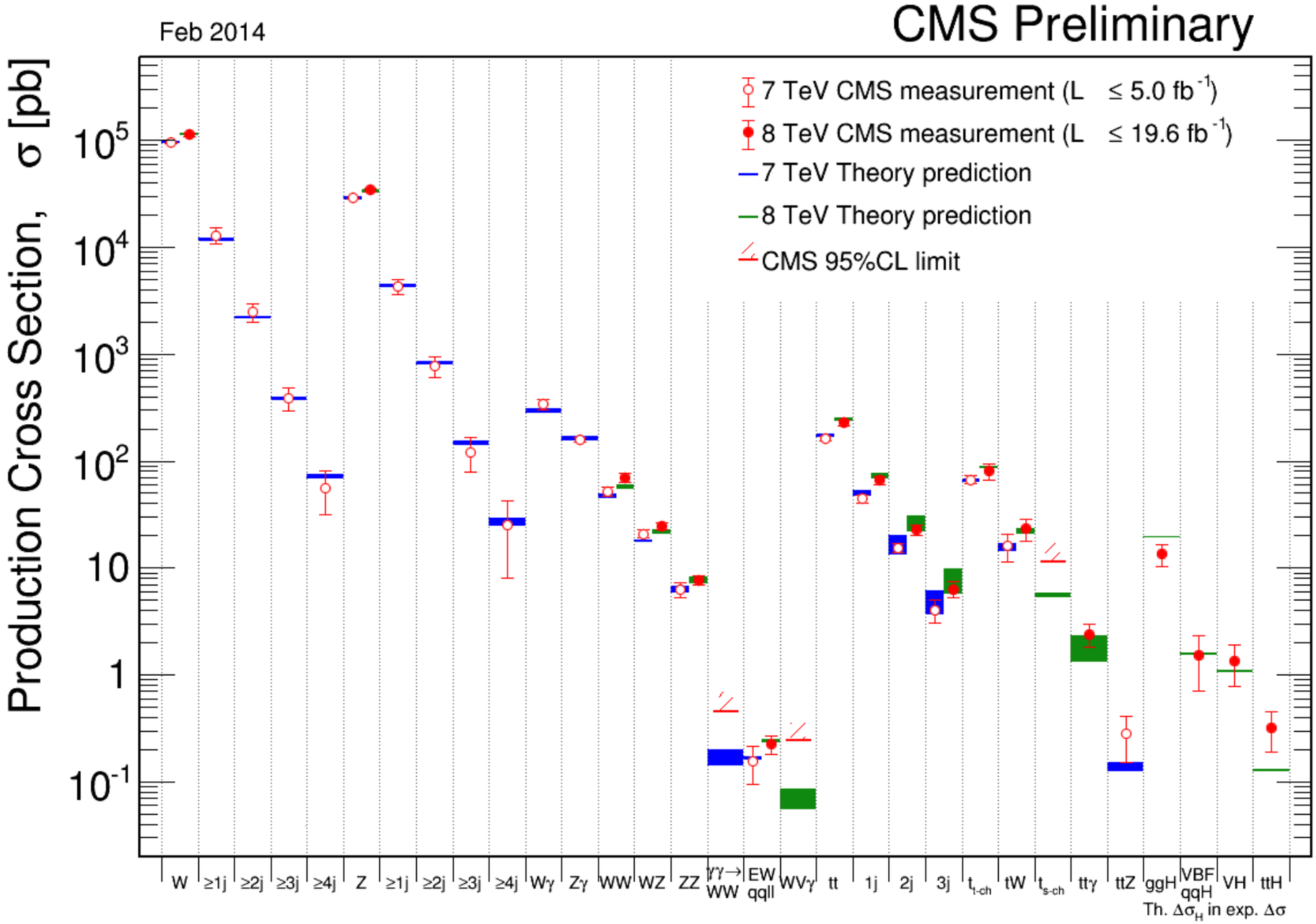
Challenges for LHC physicists

- Accurate and experimental friendly predictions for collider physics range from being very useful to strictly necessary.

- Confidence on possible excesses, evidences and eventually discoveries builds upon an intense (and often non-linear) process of description/ prediction of data via MC's.

- Both **measurements** and **exclusions** rely on accurate predictions.

Challenges for LHC physicists



Even this plot actually needs theory input (and the total quoted uncertainty in the measurements does have a contribution from theory)!!!

New generation (LHC) of MC tools

Theory

Lagrangian
Gauge invariance
QCD
Partons
NLO
Resummation
...

Detector simulation
Pions, Kaons, ...
Reconstruction
B-tagging efficiency
Boosted decision tree
Neural network
...

Experiment

Aims for these lectures

- Recall the basics of the necessary QCD concepts to understand what is going on in a pp event at the TeV scale.
- Critically revisit the "old" ways of making predictions for hadron colliders: either via fixed-order predictions or parton showers.
- Present the new ***predictive*** techniques which allow to:
  - Merge tree-level calculations with parton showers (CKKW/MLM).
  - Match NLO calculations with parton showers (MC@NLO and POWHEG) automatically.

PLAN

1. QCD basics
2. MC's