How to measure multiple parton interactions

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"Measuring Multiple Partonic Interactions at the LHC"
Tel Aviv, October 2012

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Disclaimer

- There's many things I will not do, like reviewing where we stand experimentally, talking about deep theoretical ideas, …
- What I'll try to do instead is to sketch an experimental program of possible measurements with some very rough numbers.
- I will try to put them into perspective, with a very simple (too simple) idea of the underlying physics.
- And I will try not to carry coal to Newcastle ….

.... of course I'll fail in most of these aspirations ....

Btw: Why are we actually interested?

- Pragmatists approach: Because MPI may spoil the fun in many discovery type measurements – take as example everything with a jet veto like WBF-Higgs production or $H \to WW$.
- Opportunists approach: Because they exist, can be easily calculated and even measured and because there are not many people right now who would like to embark on this, so a good, hassle-free project for myself and for my students.
- Idealists approach: Because this is some interesting corner of QCD we do not (yet?) understand and we owe it to ourselves.

Outline

- Introduction: A simple model
  - Ingredients to estimate the importance of MPI/check for their visibility
- Theory inputs: Some interesting processes
  - A quick listing of those inclusive cross-section I personally find most interesting and/or entertaining.
  - What cuts would we use?
- Flavouring it
  - Going for heavy quarks

Introduction: A simple model

A birds eye view

A simple model

- Cross section for the production of a composed system Y+Z

$$\mathrm{d}\sigma_{Y+Z} = \mathrm{d}\sigma^{\mathrm{dir}}_{Y+Z} + \frac{\mathrm{d}\sigma_Y \otimes \mathrm{d}\sigma_z}{\sigma_{\mathrm{eff}}}$$

- Direct components with textbook methods

$$\mathrm{d}\sigma^{\mathrm{dir}}_X = \mathrm{d}x_1 \mathrm{d}x_2\, f(x_1, \mu_F) f(x_2, \mu_F) \cdot \mathrm{d}\Phi_X \left|\mathcal{M}_{12\to X}(\Phi_x; \mu_F, \mu_R)\right|^2$$

- Use of factorisation-theorems (PDFs)

A simple model (cont'd)

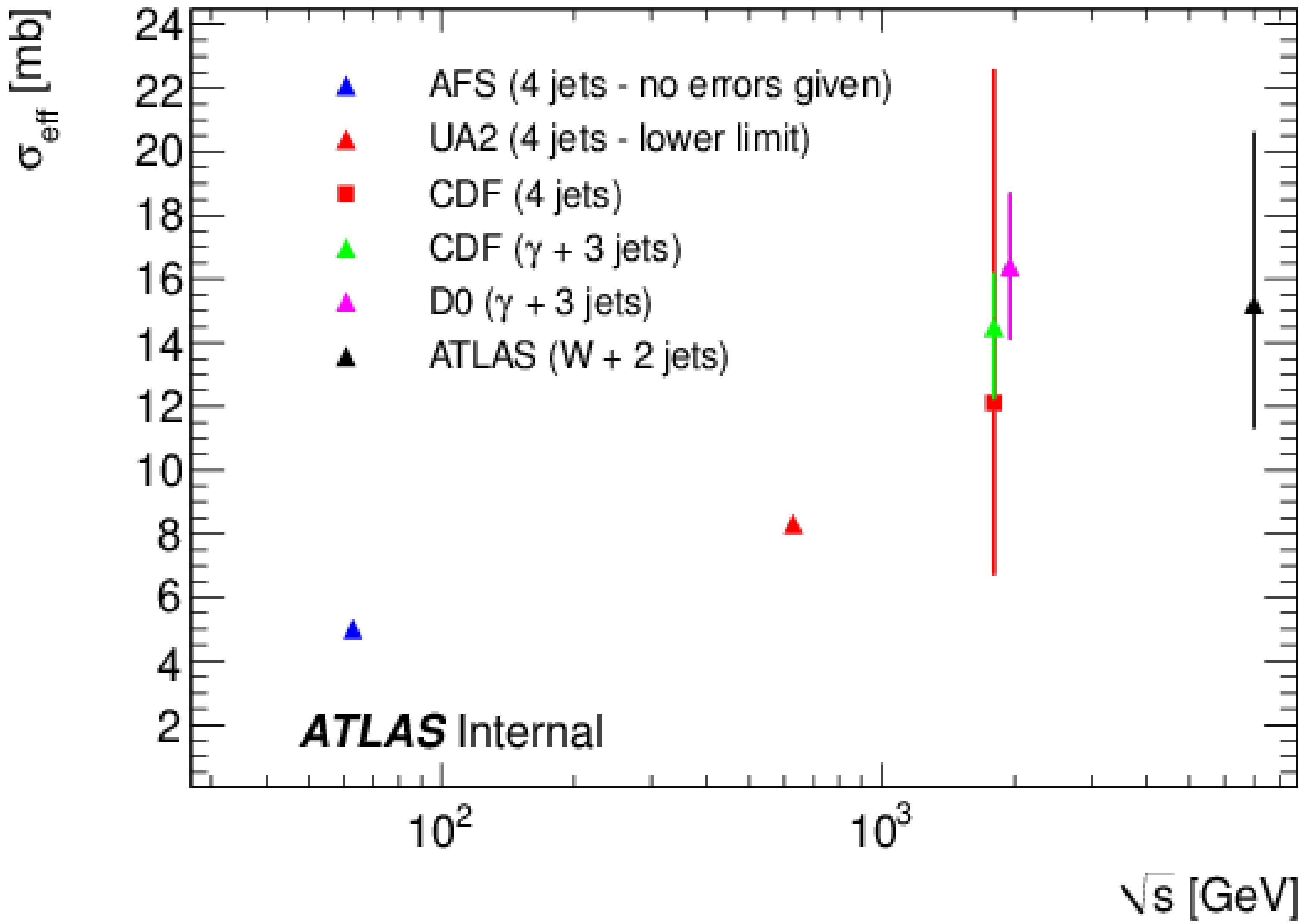
- Cross section for the production of a composed system Y+Z

$$\mathrm{d}\sigma_{Y+Z} = \mathrm{d}\sigma^{\mathrm{dir}}_{Y+Z} + \frac{\mathrm{d}\sigma_Y \otimes \mathrm{d}\sigma_z}{\sigma_{\mathrm{eff}}}$$

- DPS contribution parametrised by σ_{eff}, a process-independent quantity
- May have two-parton PDFs instead of $f(x_1,\mu_F)$
- This means: an idea of factorisation

(but there is no theorem here, or anything, it is just an ansatz!)

Energy dependence of σ_{eff}



So: What's the strategy?

- In a first step, establish whether indeed σ_{eff} is
  - Process- and cut-independent
- Then, try to extract properties of $f(y,z,\mu)$:
  - Naïve factorisation: $f(y,z,\mu) = (1-y-z)\, f(y,\mu) f(z,\mu)$
  - Is this true? More complicated form in y, z?
  - Or rather two scales?
  - Connection to other perturbative objects?

- **Measure DPS in a plethora of combinations**

Some fun processes to look at

(all at leading order, no loops)

Final state	Cut = 10 GeV	20 GeV	30 GeV
$W^- \rightarrow l\nu$		4.2 nb	
$W^+ \rightarrow l\nu$		6 nb	
$Z \rightarrow ll$		1 nb	
tt		94 pb	
bb	10 μb	1 μb	0.2 μb
jj	2.5 mb	0.2 mb	0.05 mb
jγ	650 nb	75 nb	20 nb
γγ	420 pb	60 pb	20 pb

Some fun combinations to look at

(all at leading order, no loops)

Final state	Direct contribution (2 → 4)	DPS contribution (4 → 4)
W-W-jj	1 fb (QCD) 2.5 fb (full)	1 fb
W+W+jj	2 fb (QCD) 5 fb (full)	2 fb
ttW+	10 fb	0.03 fb
ttW-	4 fb	0.02 fb
W+bb	1200 fb (QCD)	300 fb (really?)
W-bb	700 fb (QCD)	200 fb (really?)
Zbb	820 fb (QCD)	50 fb (really?)

- All bosons decay into one lepton species only, b-jets with pt = 20 GeV / D=0.4
- All numbers generated yesterday night – I was really puzzled by some.
- Needs checking! I did super simple scale choices etc..

→And of course, the “classical combinations” jjjj, jjjγ, jjbb, jγbb ….

Typical observables

- For b-jets it would be interesting to see, if we can push the pt to lower values, maybe by looking for b-hadrons only (they fragment fairly hard, with <x> = 0.8 or so)
- In general we will check for pt-balances, in the spirit of Yuri's talk or how it was done in Elli's analysis.
- It may be useful to also normalise the pt-imbalance on the scalar average of the two pt's – in some cases this may cancel nasty systematics.
- For W-bosons missing Et is a bit tricky – correlation of leptons instead (two leptons for WW, lepton-jet system for Wjj?)
- In case we can reconstruct two-imbalances the relative angle between both may be helpful to reduce contamination from $2 \rightarrow 4$ processes.
- We should also try to look for patterns in rapidity differences of the 4 objects or the two scatter systems.

Summary

- In my opinion, in the foreseeable future, the **physics of MPI will be driven by experiment** – there are still too many question marks in theory (factorisation? which PDFs? how to put things into numbers/simulations?)
- So, in a first step, I think we should go and check/falsify the simplistic picture outlined here – after all, this is the scientific principle (falsification, positivism, Ockham's razor or other posh words)
- We will most likely achieve a breakthrough through brute force only – many processes, many differing phase space configurations, scales, and x-values.
- Basically we need to **look for patterns of how the simplistic picture breaks down.**
- We will – hopefully – be able to do nifty after that.