Multiple parton interactions

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Why care?

Why care about multiple parton interactions

- impact on jets: fragmentation makes jets loose energy, MPI put "oompfh" back
- impact on jet vetoes, rapidty gaps, and similar observables
- there is no "proper" theory yet, but still QCD is "solved"

(I know, this sounds odd . . .)

- this presents an interesting challenge to better understanding of a complex theory when exposed to reality
- they are there and can be measured

How?

Multiple parton interactions in Monte Carlos

- origin of MPI:

$$\hat{\sigma}_{ik,\mathrm{tot}}(p_{\perp,\mathrm{min}}) = \int_{p^2_{\perp,\mathrm{min}}}^{s/4} \mathrm{d}p^2_\perp \, \frac{\mathrm{d}\hat{\sigma}_{ik}(p^2_\perp)}{\mathrm{d}p^2_\perp}$$

- for low $p_{\perp,\mathrm{min}}$: $\langle \hat{\sigma}_{ik,\mathrm{tot}}(p_{\perp,\mathrm{min}})/\sigma_{pp,\mathrm{total}} \rangle \geq 1$
  $\longrightarrow$ more than one parton scatter per hadron interaction
- simple model: given scale of last scatter Q^2,
  select next parton scatter at $p^2_\perp$ with probability

$$\Delta(Q^2, p^2_\perp) = \exp\left[-\frac{1}{\sigma_{\mathrm{nd}}} \int_{p^2_\perp}^{Q^2} \mathrm{d}k^2_\perp \, \frac{\mathrm{d}\hat{\sigma}_{ik}(k^2_\perp)}{\mathrm{d}k^2_\perp} \right]$$

Simplest model for double parton scattering

- production of combined system $Y + Z$:

(like, for example, $W + jj$)

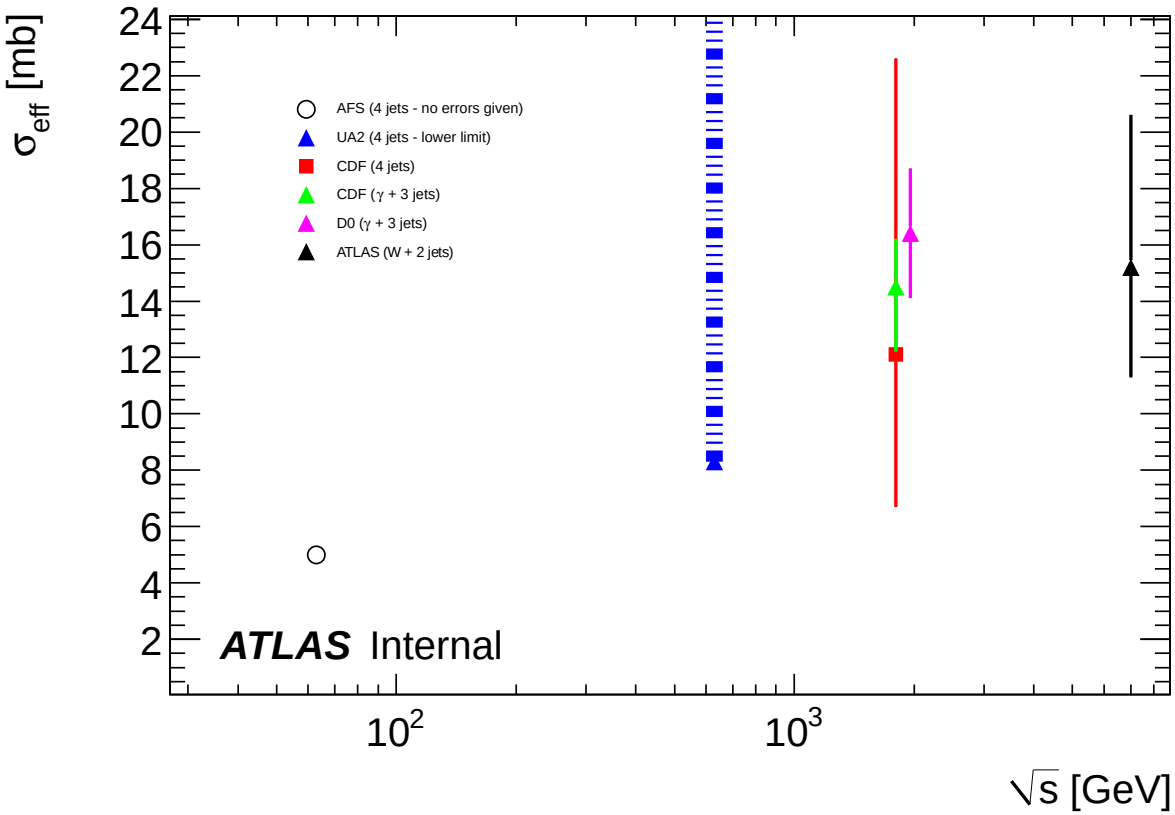
$$\mathrm{d}\sigma_{Y+Z} = \mathrm{d}\sigma^{\mathrm{dir}}_{Y+Z} + \frac{\mathrm{d}\sigma_Y \otimes \mathrm{d}\sigma_Z}{\sigma_{\mathrm{eff}}}$$

- introduce parameter σ_{eff}, of the order of hadronic cross sections

(a few to tens of mb's: $\pi r^2_{\mathrm{proton}}$)

- σ_{eff} will scale with hadronic c.m.-energy (like σ_{tot}?)

Energy dependence of σ_{eff}



Strengths and weaknesses of simple models

- ✓ straightforward to produce numbers
- ✓ easily testable experimentally

(passed all tests until now, if $\sigma_{\rm eff}$ scales with energy)

- ✓ no better & simpler one around

(strength if you believe in Ockham's razor)

- ✗ no factorisation theorem for DPS/MPI

(hard to do meaningful calculations)

- ✗ does not include correlations in flavour/spin/colour space

(although I'm sure they exist!)

- ✗ $\sigma_{\rm eff}$ hard to extract experimentally, heavily relying on MCs
- ✗ not enough tested until now

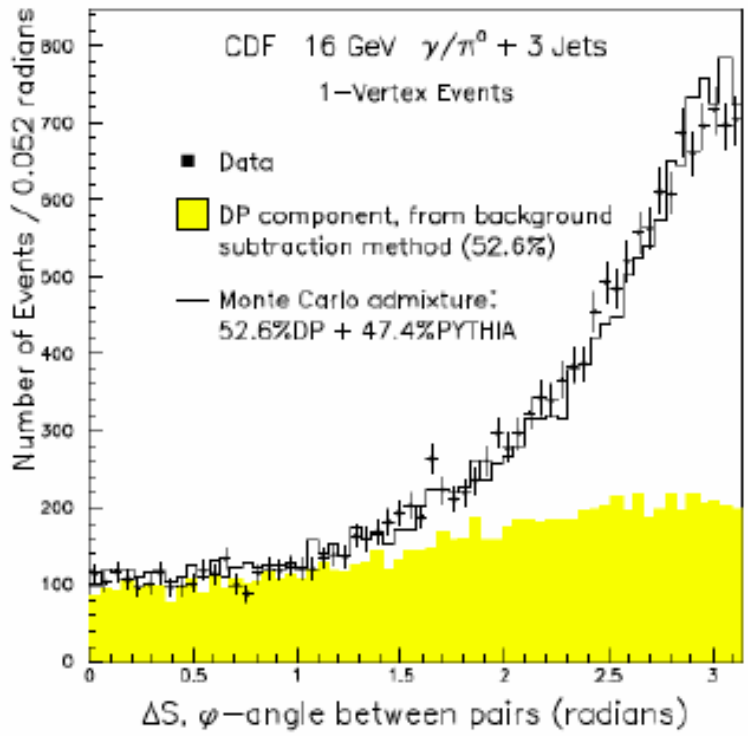
(a challenge/charge for the experimental colleagues)

What?

Evidence for multiple parton scattering: Tevatron

CDF collaboration, Phys. Rev. **D56** (1997) 3811.

- events with $\gamma + 3$ jets:
  - cone jets, $R = 0.7$, $E_T > 5$ GeV; $|\eta_j| < 1.3$;
  - "clean sample": two softest jets with $E_T < 7$ GeV;
- pair jj and $j\gamma$ to be "back-to-back"
- measure angle between planes spanned by pairs
- result: $\sigma_{\rm eff} \approx 14 \pm 4$ mb.



Disecting a LHC analysis: DPS in $W + jj$ at ATLAS

ATLAS collaboration, New J. Phys. 15 (2013) 033038

- consider Wjj production at 7 TeV, low lumi run in 2010
- typical W-signature: isolated lepton, $p_\perp \geq p_{\perp\min} = 20$ GeV, $\not{E}_T \geq 25$ GeV, $m_T \geq 40$ GeV
- exactly two anti-k_T jets with $R = 0.4$, $p_\perp \geq 20$ GeV
- consider two observables

$$\Delta_{jj} = p_{jj,\perp} = |\vec{p}_{1,\perp} + \vec{p}_{2,\perp}|$$

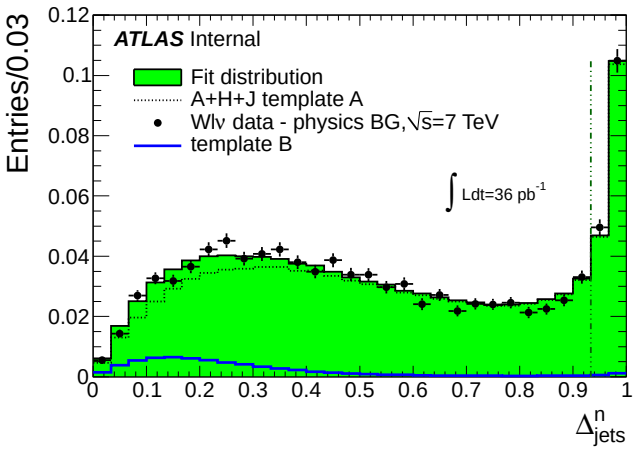
$$\Delta^n_{jj} = \frac{p_{jj,\perp}}{p_{1,\perp} + p_{2,\perp}} = \frac{|\vec{p}_{1,\perp} + \vec{p}_{2,\perp}|}{|\vec{p}_{1,\perp}| + |\vec{p}_{2,\perp}|}$$

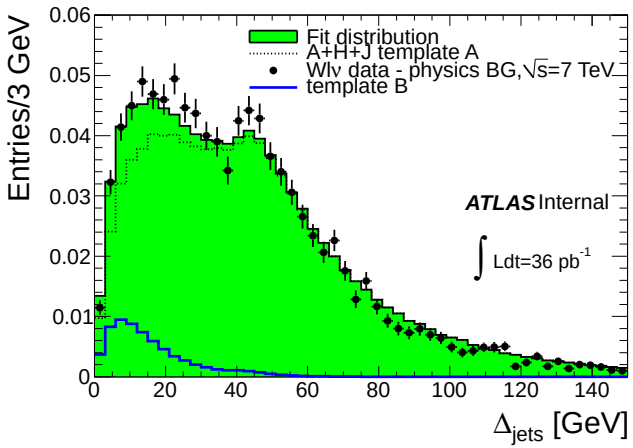
- DPS region at low $\Delta_{jj} \leq 20$ GeV and $\Delta^n_{jj} \leq 0.2$

- produce a "direct-only" sample with MC ("template A")
  $\longrightarrow$ no jets from MPI in MC $\longrightarrow$ constrain $p_\perp$ in MPI model

(we found $p_{\perp\mathrm{MPI}} < p_{\perp\mathrm{min}} - 5$ GeV)

- add dijets from data with floating normalisation ("template B")





- deduce DPS fraction and σ_{eff} from fit to normlisation:

$$f_{\mathrm{DP}} = 0.08 \pm 0.01\,(\mathrm{stat}) \pm 0.02\,(\mathrm{syst})$$
$$\sigma_{\mathrm{eff}} = 15 \pm 3(\mathrm{stat}) \,{}^{+5}_{-3}\,(\mathrm{sys.})\ \mathrm{mb}.$$

And now?

How to test simple models: toolkit

disclaimer: all LO numbers @ 8 TeV, enough to have some ideas

	inclusive xsec per lepton flavour
$W^+ \to \ell\nu$	6 nb
$W^- \to \ell\nu$	4.2 nb
$Z \to \ell\bar{\ell}$	1 nb

	inclusive xsec
$t\bar{t}$	0.1 nb

	$p_\perp > 10$ GeV	$p_\perp > 20$ GeV	$p_\perp > 30$ GeV
jj	2.5 mb	0.2 mb	0.05 mb
$b\bar{b}$	10 μb	1 μb	0.2 μb
$j\gamma$	650 nb	75 nb	20 nb

- in order to turn numbers above into something useful: must consider ratio of combination with direct process
- name of the game: check process & kinematics-independence watch simple model fail in describing it & learn
- some indicative numbers below with $p_\perp > 20$ GeV

	$\sigma^{\rm dir}_{X+Y}$	$\sigma^{\rm DPS}_{X+Y}$
W^+W^+jj	2 fb (QCD), 5 fb (full)	2 fb
W^-W^-jj	1 fb (QCD), 2.5 fb (full)	1 fb
$W^+b\bar{b}$	1.2 pb (QCD)	0.3 pb
$W^-b\bar{b}$	0.7 pb (QCD)	0.2 pb

Conclusion

- in foreseeable future, physics of MPI/DPS will be driven by experiment
- many theory obstacles: lack of factorisation theorems, properly defined calculational setup, ...
  only simplistic models and very specific calculations available
- in my opinion needs a brute-force approach:
  many processes & kinematical situations to falsify simplistic ideas
- a playground for tough measurements