MEPS@NLO
Mulitjet merging at NLO

Frank Krauss

Institute for Particle Physics Phenomenology
Durham University

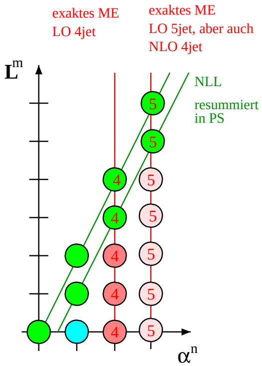
PDF4LHC, IPPP Durham, 26.9.2012

Multijet merging

Multijet merging: basic idea

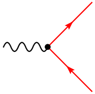
- parton shower resums logarithms
  fair description of collinear/soft emissions
  jet evolution (where the logs are large)
- matrix elements exact at given order
  fair description of hard/large-angle emissions
  jet production (where the logs are small)
- combine ("merge") both:
  - separate phase space with jet definition
  - correct multijet Born ME to log accuracy
  - veto hard emissions in PS

result: "towers" of MEs with increasing number of jets evolved with PS
But: cross section at Born accuracy

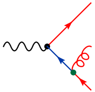


Why it works: jet rates with the parton shower

- Consider jet production in $e^+e^- \to$ hadrons
  Durham jet definition: relative transverse momentum $k_\perp > Q_J$
- fixed order: one factor α_S and up to $\log\frac{E_{\rm c.m.}}{Q_J}$ per jet
- use Sudakov form factor for resummation:



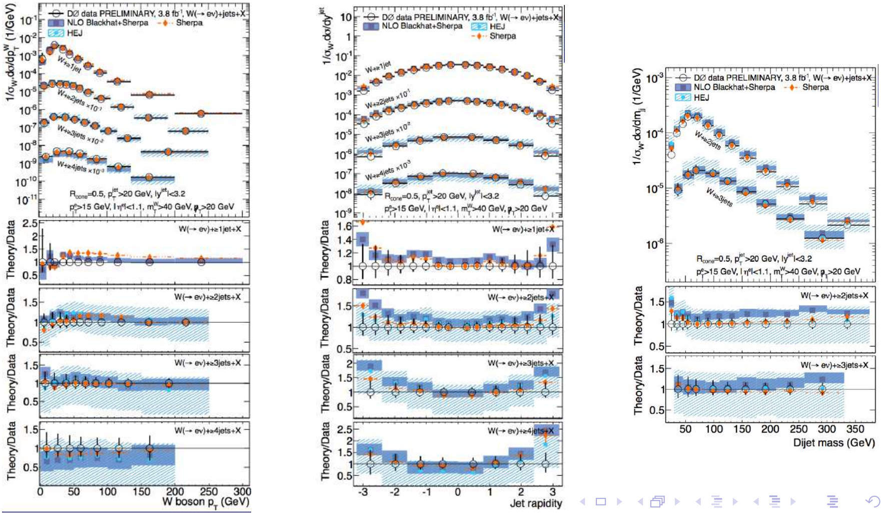
$$\mathcal{R}_2(Q_J) = \left[\Delta_q(E^2_{\rm c.m.},\, Q_J^2)\right]^2$$



$$\mathcal{R}_3(Q_J) = 2\Delta_q(E^2_{\rm c.m.},\, Q_J^2) \int\limits_{Q_J^2}^{E^2_{\rm c.m.}} {\rm d}k_\perp^2 \left[\frac{\alpha_S(k_\perp^2)}{2\pi}{\rm d}z\mathcal{K}_q(k_\perp^2, z) \times \frac{\Delta_q(E^2_{\rm c.m.},\, Q_J^2)}{\Delta_q(k_\perp^2,\, Q_J^2)}\Delta_q(k_\perp^2,\, Q_J^2)\Delta_g(k_\perp^2,\, Q_J^2)\right]$$

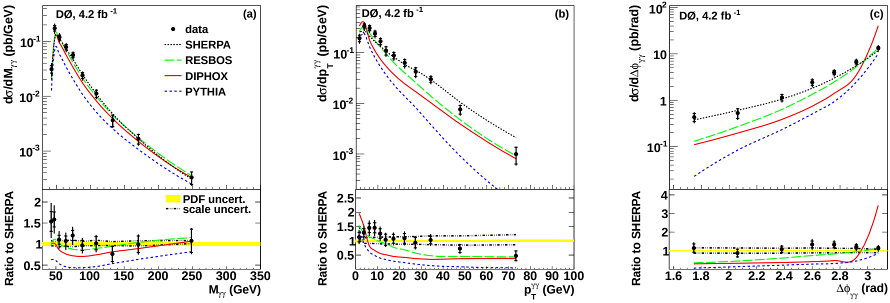
W+jets @ DØ: $p_{\perp,W}$ and y_{jet}

(From D.Price's talk at PLHC, Vancouver 2012)



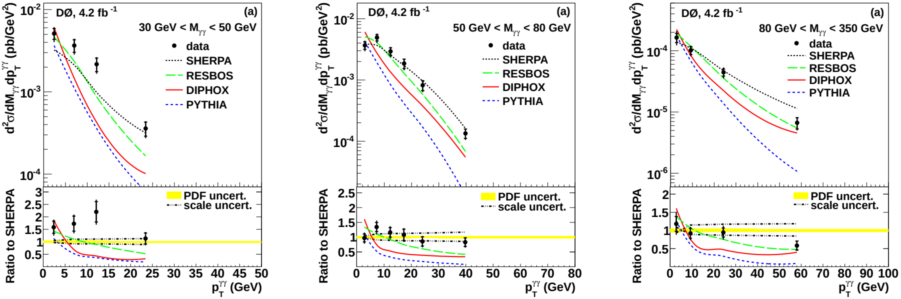
Di-photons @ DØ: $M_{\gamma\gamma}$, $p_{\perp,\gamma\gamma}$, & $\Delta\phi_{\gamma\gamma}$

(Update to Phys. Lett. B 690, 108 (2010), from analysis homepage)



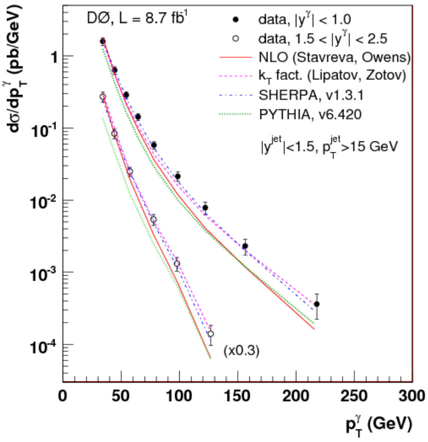
Di-photons @ DØ: $p_{\perp,\gamma\gamma}$ in different mass bins

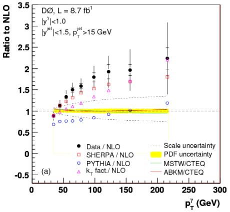
(Update to Phys. Lett. B 690, 108 (2010), from analysis homepage)

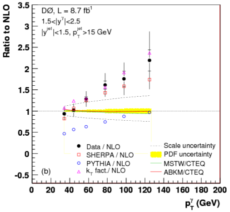


Photons+b @ DØ: $p_{\perp,\gamma}$ in different rapidities

(arXiv:1203.5865 [hep-ex])

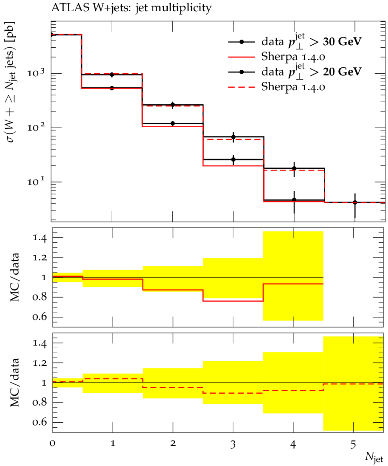


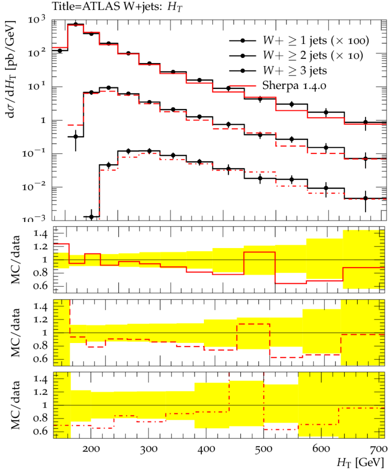




W+jets @ ATLAS: an update

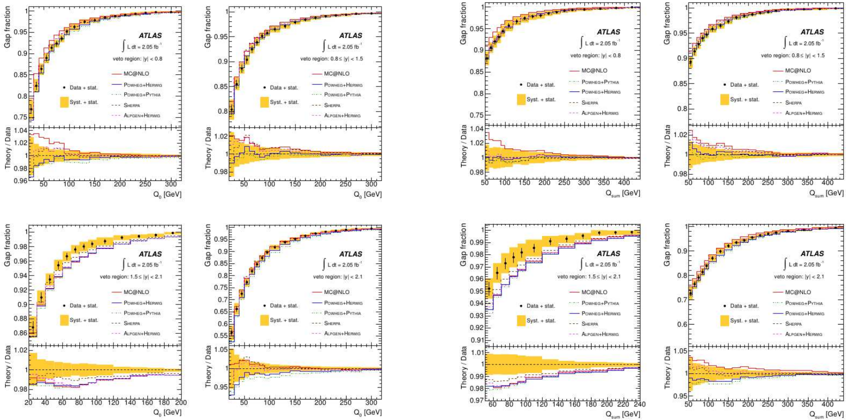
(arXiv:1201.1276 [hep-ex], SHERPA 1.3.1 was not very good . . .)





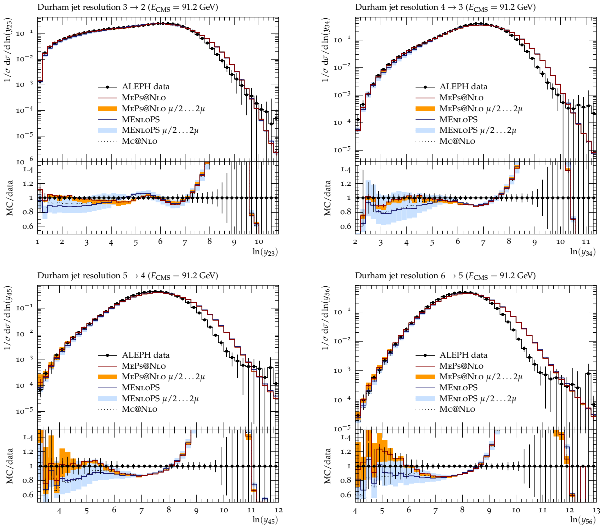
Rapidity gaps in $t\bar{t}$ @ ATLAS: gap probabilities

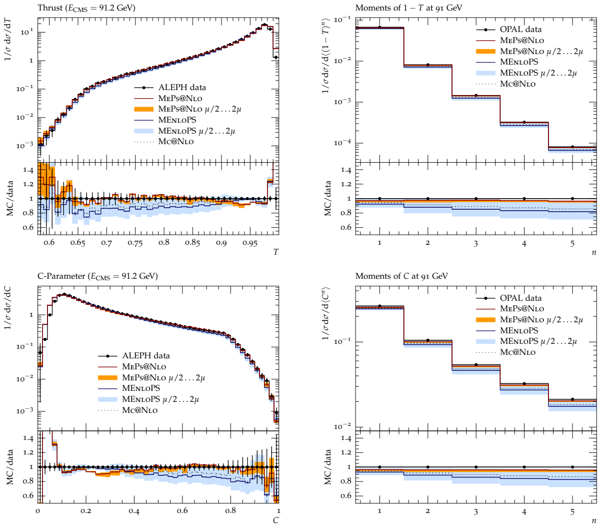
(arXiv:1203.5015 [hep-ex])

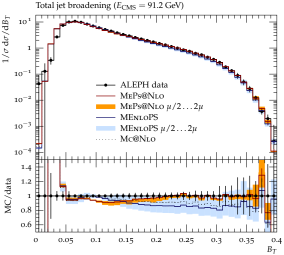


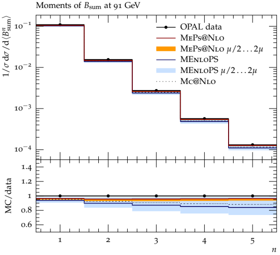
Multijet merging at NLO in SHERPA

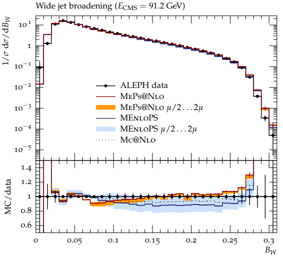
MEPS@NLO: example results for $e^-e^+ \to$ hadrons

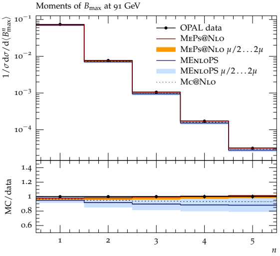



Thrust (E_{CMS} = 91.2 GeV)
1/σ dσ/dT
ALEPH data
MEPS@NLO
MEPS@NLO μ/2...2μ
MENLOPS
MENLOPS μ/2...2μ
MC@NLO
MC/data
T
Moments of 1 − T at 91 GeV
1/σ dσ/d⟨(1 − T)^n⟩
OPAL data
MEPS@NLO
MEPS@NLO μ/2...2μ
MENLOPS
MENLOPS μ/2...2μ
MC@NLO
MC/data
n
C-Parameter (E_{CMS} = 91.2 GeV)
1/σ dσ/dC
ALEPH data
MEPS@NLO
MEPS@NLO μ/2...2μ
MENLOPS
MENLOPS μ/2...2μ
MC@NLO
MC/data
C
Moments of C at 91 GeV
1/σ dσ/d⟨C^n⟩
OPAL data
MEPS@NLO
MEPS@NLO μ/2...2μ
MENLOPS
MENLOPS μ/2...2μ
MC@NLO
MC/data
n

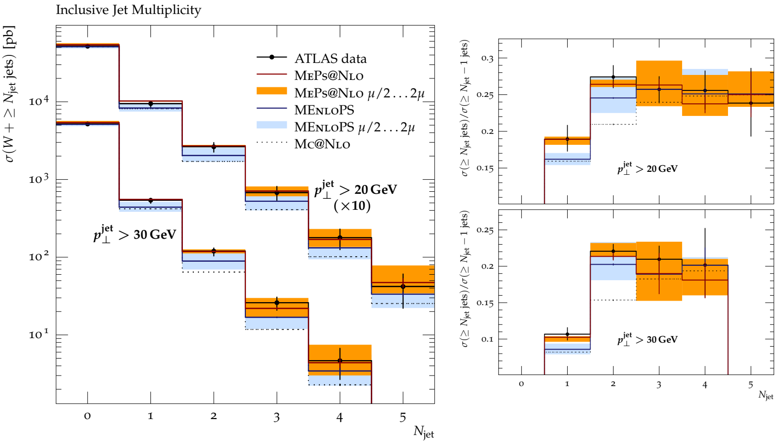

Total jet broadening (E_{CMS} = 91.2 GeV)
$1/\sigma\, d\sigma/dB_T$
ALEPH data
MEPS@NLO
MEPS@NLO $\mu/2\ldots2\mu$
MENLOPS
MENLOPS $\mu/2\ldots2\mu$
MC@NLO
MC/data
B_T

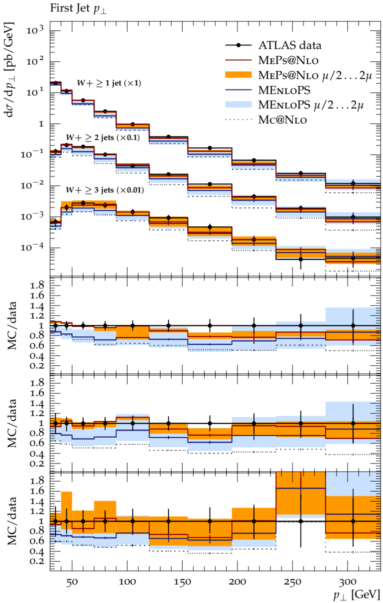

Moments of B_{sum} at 91 GeV
$1/\sigma\, d\sigma/d\langle B^n_{sum}\rangle$
OPAL data
MEPS@NLO
MEPS@NLO $\mu/2\ldots2\mu$
MENLOPS
MENLOPS $\mu/2\ldots2\mu$
MC@NLO
MC/data
n

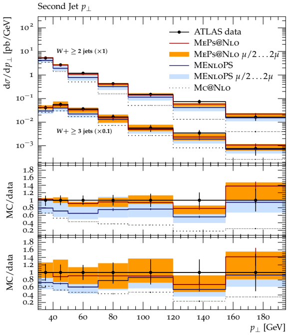

Wide jet broadening (E_{CMS} = 91.2 GeV)
$1/\sigma\, d\sigma/dB_W$
ALEPH data
MEPS@NLO
MEPS@NLO $\mu/2\ldots2\mu$
MENLOPS
MENLOPS $\mu/2\ldots2\mu$
MC@NLO
MC/data
B_W

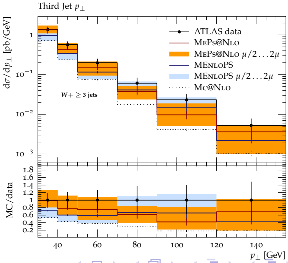

Moments of B_{max} at 91 GeV
$1/\sigma\, d\sigma/d\langle B^n_{max}\rangle$
OPAL data
MEPS@NLO
MEPS@NLO $\mu/2\ldots2\mu$
MENLOPS
MENLOPS $\mu/2\ldots2\mu$
MC@NLO
MC/data
n

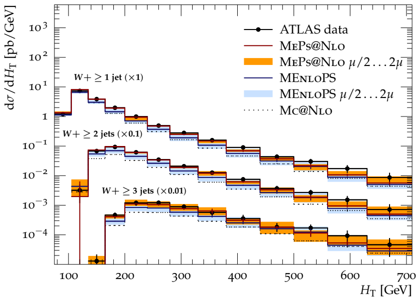
MEPS@NLO: example results for $W+$ jets

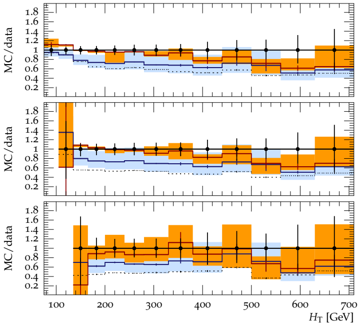


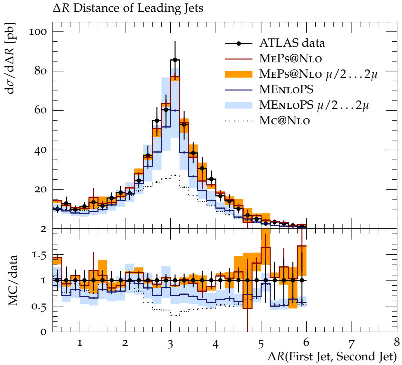

First Jet $p_\perp$
$d\sigma/dp_\perp$ [pb/GeV]
ATLAS data
MEPs@NLO
MEPs@NLO $\mu/2\ldots2\mu$
MENLOPS
MENLOPS $\mu/2\ldots2\mu$
MC@NLO
$W+\geq 1$ jet ($\times 1$)
$W+\geq 2$ jets ($\times 0.1$)
$W+\geq 3$ jets ($\times 0.01$)
MC/data
MC/data
MC/data
$p_\perp$ [GeV]

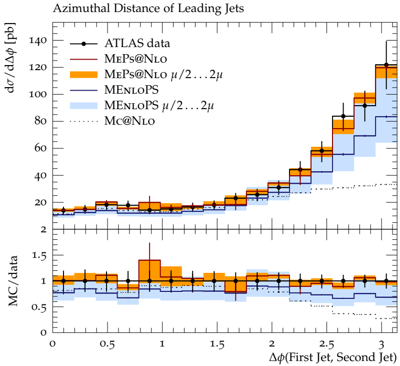

Second Jet $p_\perp$
$d\sigma/dp_\perp$ [pb/GeV]
ATLAS data
MEPs@NLO
MEPs@NLO $\mu/2\ldots2\mu$
MENLOPS
MENLOPS $\mu/2\ldots2\mu$
MC@NLO
$W+\geq 2$ jets ($\times 1$)
$W+\geq 3$ jets ($\times 0.1$)
MC/data
MC/data
$p_\perp$ [GeV]


Third Jet $p_\perp$
$d\sigma/dp_\perp$ [pb/GeV]
ATLAS data
MEPs@NLO
MEPs@NLO $\mu/2\ldots2\mu$
MENLOPS
MENLOPS $\mu/2\ldots2\mu$
MC@NLO
$W+\geq 3$ jets
MC/data
$p_\perp$ [GeV]


ATLAS data
MEPS@NLO
MEPS@NLO μ/2...2μ
MENLOPS
MENLOPS μ/2...2μ
MC@NLO
W+ ≥ 1 jet (×1)
W+ ≥ 2 jets (×0.1)
W+ ≥ 3 jets (×0.01)
dσ/dH_T [pb/GeV]
H_T [GeV]


MC/data
MC/data
MC/data
H_T [GeV]


ΔR Distance of Leading Jets
dσ/dΔR [pb]
ATLAS data
MEPs@NLO
MEPs@NLO μ/2...2μ
MENLOPS
MENLOPS μ/2...2μ
MC@NLO
MC/data
ΔR(First Jet, Second Jet)


Azimuthal Distance of Leading Jets
dσ/dΔφ [pb]
Δφ(First Jet, Second Jet)

Summary

- Systematic improvement of event generators by including higher orders has been at the core of QCD theory and developments in the past decade:
  - multijet merging ("CKKW", "MLM")
  - NLO matching ("MC@NLO", "POWHEG")

(methods are well understood and used in experiments)

- Multijet merging now also at NLO (MEPS@NLO) -

  need more tests before release.

- multijet merging an important tool for many relevant signals and backgrounds, will become **precision tool** now -

  LO and NLO algorithms have been pioneered by **SHERPA**