Jet physics at HL and HE (ATLAS + CMS)

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based on contributions from
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Why jet physics at high luminosity?

- Jets $x$-sections at highest transverse momenta $p_T$
  - access to scales in the multi-TeV range
  - never tested before
  - access to highest $x$:
    - small parton densities

![LHC parton kinematics graph](image)
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LHC parton kinematics

$$x_{1,2} = (M/14 \text{ TeV}) \exp(\pm y)$$

- $Q = M$
- $M = 10 \text{ TeV}$
- $M = 1 \text{ TeV}$
- $M = 100 \text{ GeV}$
- $M = 10 \text{ GeV}$

HERA, fixed target
Why jet physics at high luminosity?

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  - access to highest x:
    - small parton densities
  - "soft gluon" resummation
  - "soft" == jets of measurable $p_T$
  - flavor blindness of QCD
    - all known parton flavors are "light"
    - x-sections behave similarly
  - vector-bosons appear as jets
    - boosted W/Z with hadronic decay

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LHC parton kinematics

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\[ Q = M \]

M = 10 TeV

M = 1 TeV

M = 100 GeV

M = 10 GeV

HERA

fixed target

\[ x \quad 10^{-7} \quad 10^{-6} \quad 10^{-5} \quad 10^{-4} \quad 10^{-3} \quad 10^{-2} \quad 10^{-1} \quad 10^0 \]

\[ Q^2 \quad (\text{GeV}^2) \quad 10^1 \quad 10^2 \quad 10^3 \quad 10^4 \quad 10^5 \quad 10^6 \quad 10^7 \quad 10^8 \quad 10^9 \]
Cross sections at high pt

- at 14 TeV

- at 27 TeV

- all flavors have same hard scattering x-section
  - boosted V-boson have similar x-section as flavor jets:
    - at 14 TeV: $p_T$'s up to 3 TeV
    - at 27 TeV: $p_T$'s up to 7 TeV

Inclusive jet cross sections at HE

- Rate estimates for inclusive jets at NLO
  - with 100 fb\(^{-1}\) can reach \(p_t \sim 7\) TeV
  - with 1000 fb\(^{-1}\) can reach \(p_t \sim 9\) TeV
Inclusive jets at $\sqrt{s} = 27$ TeV: theory uncertainties

from P. Starovoitov
PDF comparisons at 14 TeV (central)

- even with NLO calculation, PDF uncertainties dominant at high $p_T$
  - with NNLO calculations scale uncertainties smaller!
- inclusive jets can constrain PDFs at large $x$ (especially gluon)
PDF comparisons at 14 TeV (forward)

from P. Starovoitov
PDF comparisons at 27 TeV (central)

- PDF uncertainties are large (> 10%) at highest $p_T$!
PDF comparisons at 27 TeV (forward)

from P. Starovoitov

Inclusive b-jet cross - sections

- b-jet x-sections:
  - tag with b-hadron inside jet

- In central region pt up to 3-4 TeV can be reached
  - main challenge is experimentally b-tagging at high $p_t$
    - tagging efficiencies decrease from ~ 50 % to ~ 15 % at $p_t$ ~ 1 TeV
    - critical is mis-tagging rate (background)!
b-jet cross-section

- B-jet not only from hard process, but also from $g \rightarrow b\bar{b}$ during initial/final state shower
- at $p_t \sim 1$ TeV gluon splitting makes $\sim 80\%$
Why jet physics at high transverse momenta?

- at high $p_T$, jets are pencil-like at $p_T > 1$ TeV
  - core radius $R_{core} < 0.05$

- angular resolution improves at high $p_T$
  - $\delta(\Delta \phi) \sim 1^\circ (0.02)$ at $p_T = 200$ GeV
  - $\delta(\Delta \phi) \sim 0.5^\circ (0.009)$ at $p_T = 1$ TeV

from A. Bermudez Martinez
High $p_T$ di-jet production: resummation effects

Dijet production at highest $p_T$:

- study of resummation effects in truly perturbative region:
  - for jet $p_T$ of 300 GeV, *soft gluons* with 1% of transverse momentum: 3 GeV
  - for jet $p_T$ of 3 TeV, *soft gluons* with 1% of transverse momentum: 30 GeV:
    - truly perturbative jets, measurable
High $p_T$ di-jet production: resummation effects

Dijet production at highest $p_T$:
- $\sigma$-section for $p_T > 4$ TeV: $\sim 10$ fb
- jets are pencil-like (very narrow, like single particles)

Challenge:
- best $\Delta \phi$ resolution (at present $\sim 0.5$ deg)
Which pt can be reached in di-jet production?

from A. Bermudez Martinez

at 14 TeV:
- for $\mathcal{L}_{\text{int}} = 30 fb^{-1}$ reaching $p_t \sim 3$ TeV
- for $\mathcal{L}_{\text{int}} = 300 fb^{-1}$ reaching $p_t \sim 4$ TeV
- for $\mathcal{L}_{\text{int}} = 3000 fb^{-1}$ reaching $p_t \sim 5$ TeV

at 27 TeV:
- jet $p_t > 6$ TeV reachable
High $p_T$ di-jet production - resummation effects: $\Delta \phi$

- Di-jet production at moderate $p_T$: sensitive to production mechanism
- Di-jet production at highest $p_T$: similar shape, similar resummation at back-to-back

from R. Zlebcik
“Soft gluon” resummation in analogy to DY

- “soft gluon” resummation at small $q_T$ of DY limited by momentum resolution
  - angular variables much better: define $\phi^*$ (arXiv:1009.1580)
  - high pt jets (pencil-like) have similarities to leptons from DY :)
Resummation in Jet Mass

- parton shower generates mass of jets
  - investigation of jet mass for heavy objects: top-jets

- measure evolution of top-mass from hadronic top jets
  - compare with light flavor mass evolution: soft gluon radiation flavor blind
Top-Jet Mass at large $p_T$

- Top-Jet mass with realistic Top-tagger:
  - $\text{ak8 Jet, 2 sub-jets, B-tag, } \tau_3/\tau_2 < 0.54$

- measurement possible at high lumi, extend to large $p_T$
  - depends on kinematic selection, realistic scenario now to be studied
  - challenge: disentangle jet broadening (mass) coming from initial state!
Summary

• Jet physics at largest pt requires high luminosity
  • extend the range in scales up to ~ 3 (5) TeV for heavy (all) flavor jets at 14 TeV with 3000 fb\(^{-1}\)
  • extend the range in scales up to ~ 6 (9) TeV for heavy (all) flavor jets at 27 TeV with 15000 fb\(^{-1}\)
  • NNLO calculations for inclusive jets, PDF gives largest uncertainty
    • constrain PDFs (gluon) at large x

  “soft gluon” resummation studies (“soft gluon” == jet with \(p_t > 30 \text{ GeV}\))
  • possible at largest \(p_t\) (and scales)
  • “soft gluon” resummation dependent on flavor: flavor blindness

• Prospects:
  • with Delphes simulation available perform detailed acceptance, efficiency studies for realistic scenarios
Appendix
Di-jet correlations in $\Delta y$

- differences in flavor-x-sections at moderate and large $p_T$:
  - different subprocesses contribute!


from R. Zlebcik
“Soft gluon” resummation in analogy to DY

- resolution in $\phi^*$

**distribution**

- typical resolution between 0.005 and 0.01 allows measurements in small $\phi^*$ region
- “soft gluon” resummation can be studied at highest $p_t$