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VIRTUAL CONFERENCE

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Precision Jet/Event Substructure using Collinear Drop

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In collaboration with Iain Stewart and Yen-Jie Lee

JHEP 06 (2020) 064

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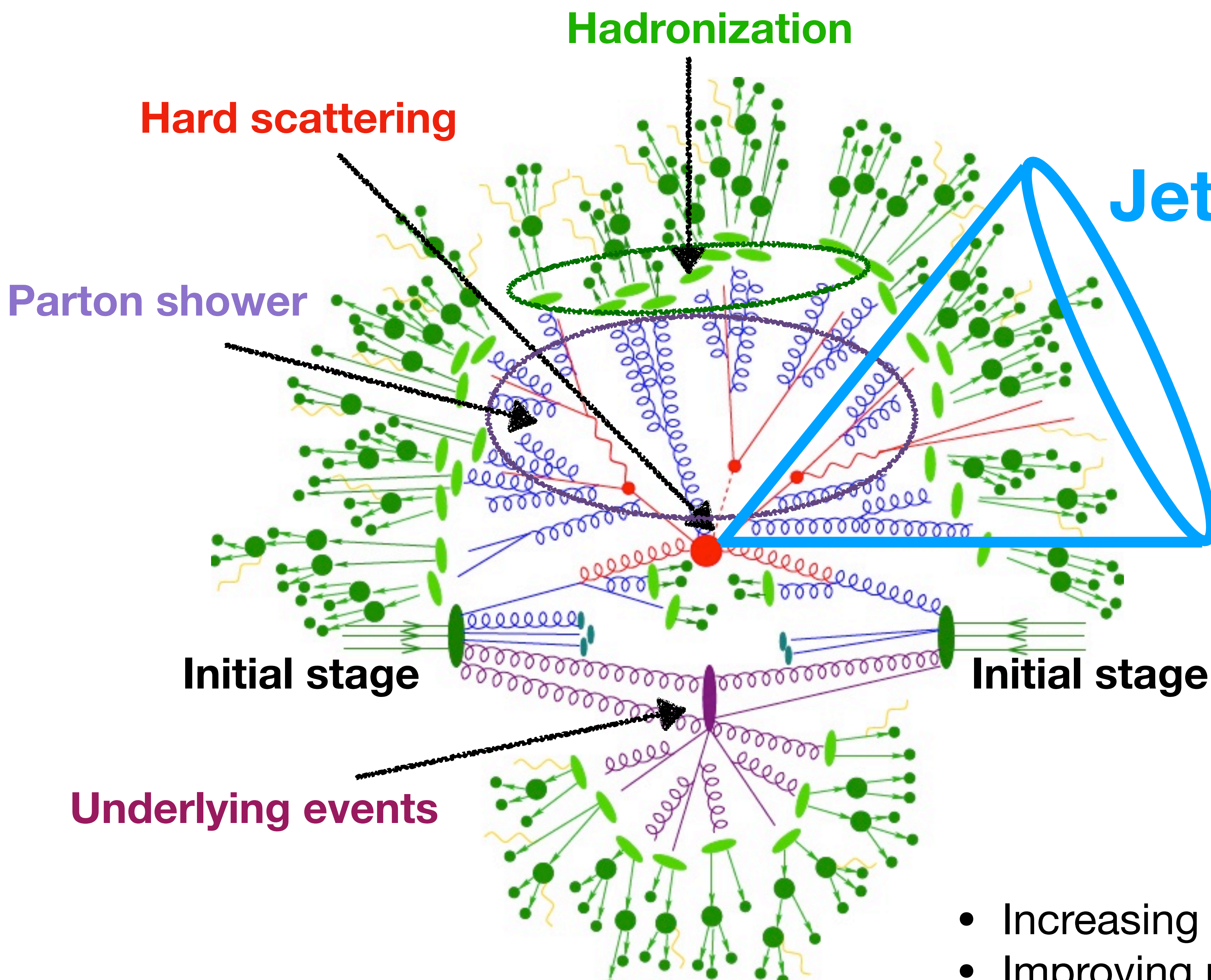
Outline

- **Jet and event substructure as multi-scale probes**
- **Collinear drop: taming soft radiation**
  - **Soft-collinear effective theory with Glauber interaction ($SCET_G$)**
- **Applications to pp, AA, e^+e^- and EIC** (work in progress)
  - **Parton shower**
  - **Hadronization and underlying event**
  - **Medium-induced bremsstrahlung**
- **Conclusion**

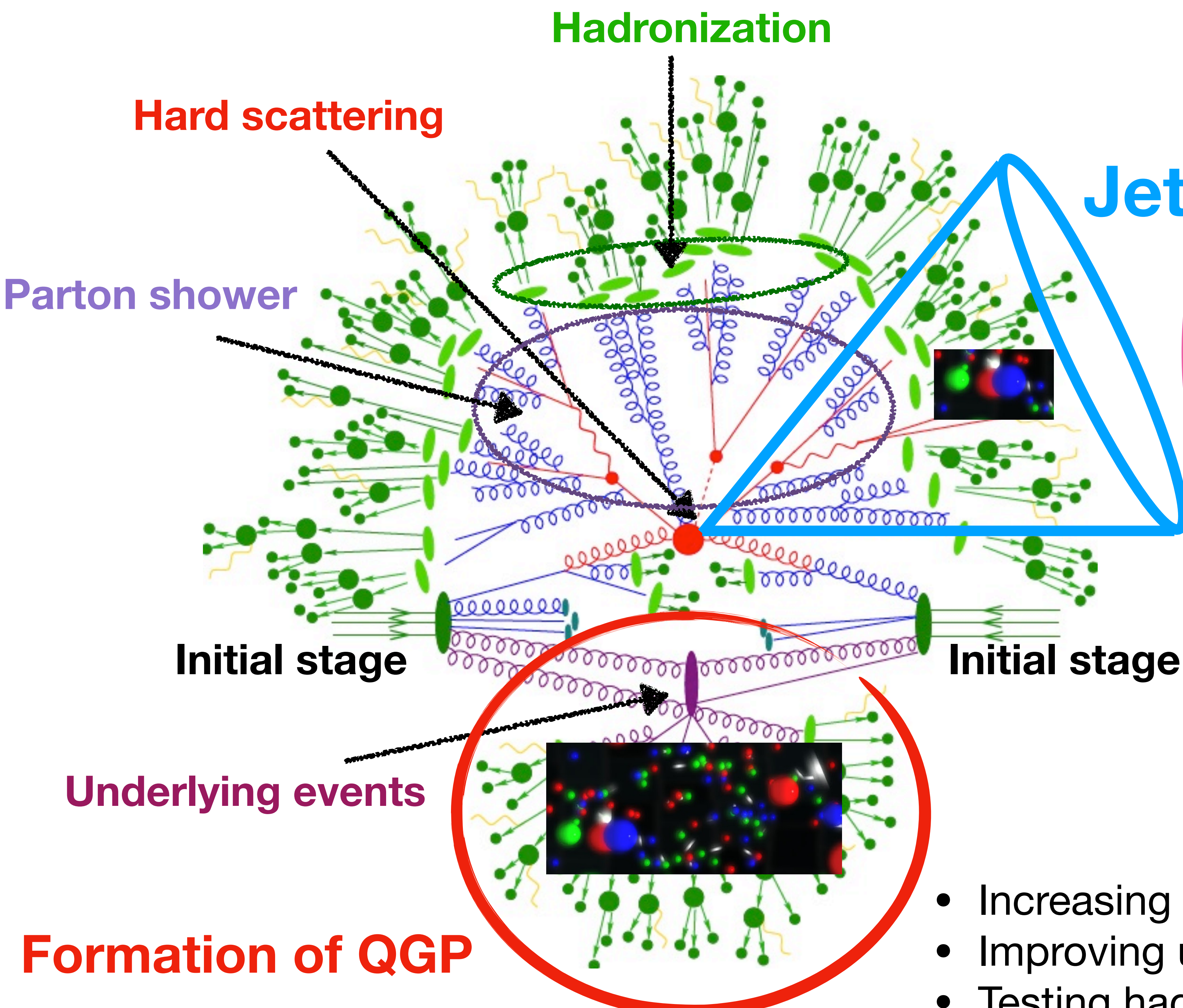
Distinct physics happening at all scales



Systematic

- Increasing parton shower precision
- Improving underlying event description
- Testing hadronization modeling

Distinct physics happening at all scales



- Jet quenching: how is the lost energy distributed?
- How is parton shower and hadronization modified?
- How is QGP formed through underlying events?
- What is the structure of initial stages?

Systematic

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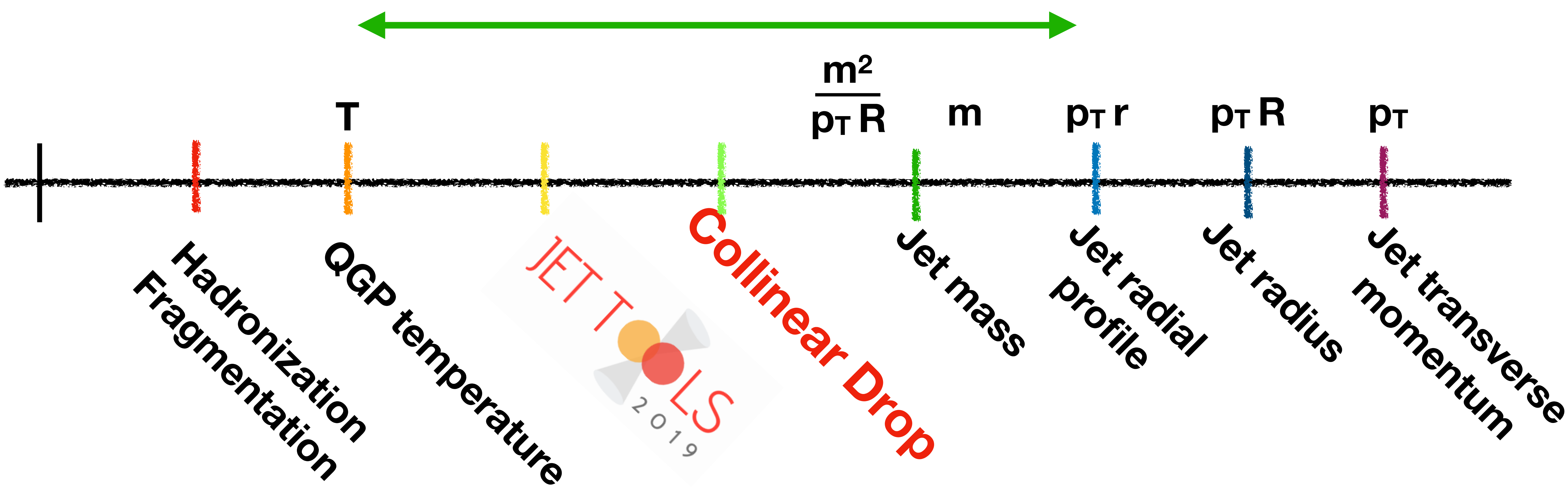
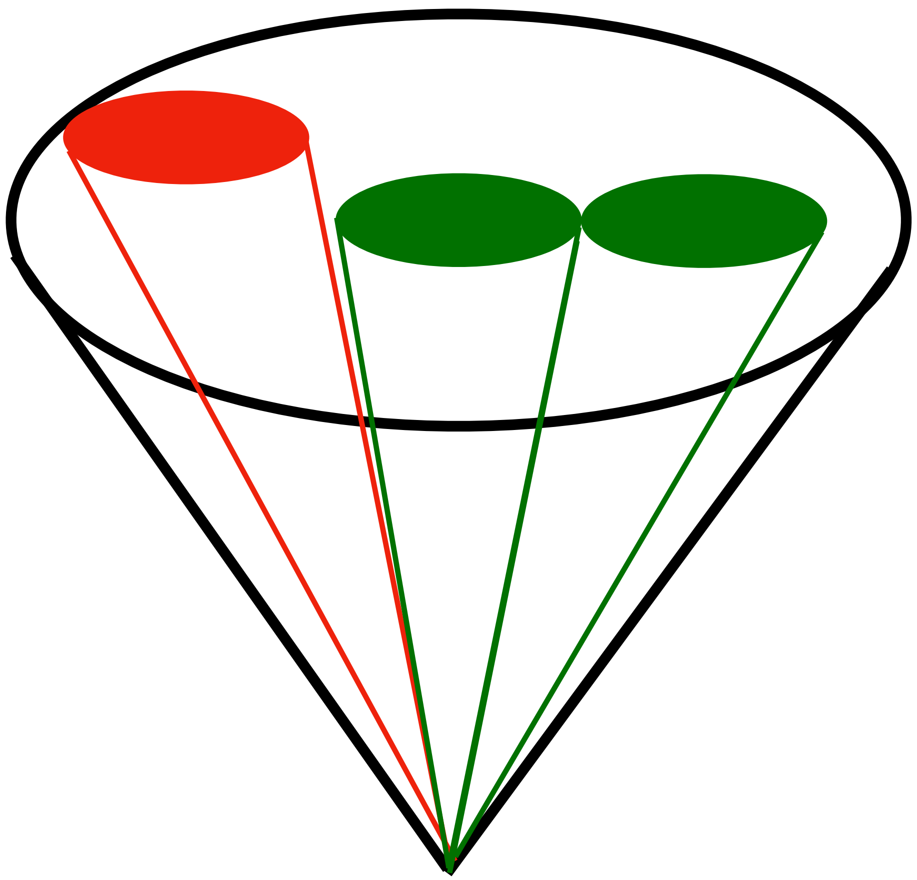
Jet and event substructure as multi-scale probes

- We need qualitatively different observables sensitive to specific energy scales
- Sensitivity and precision are the key
  - The effect is **large** and can be measured **precisely**
- This requires an optimization in the design of substructure observables
  - Flexibility with tunable parameters

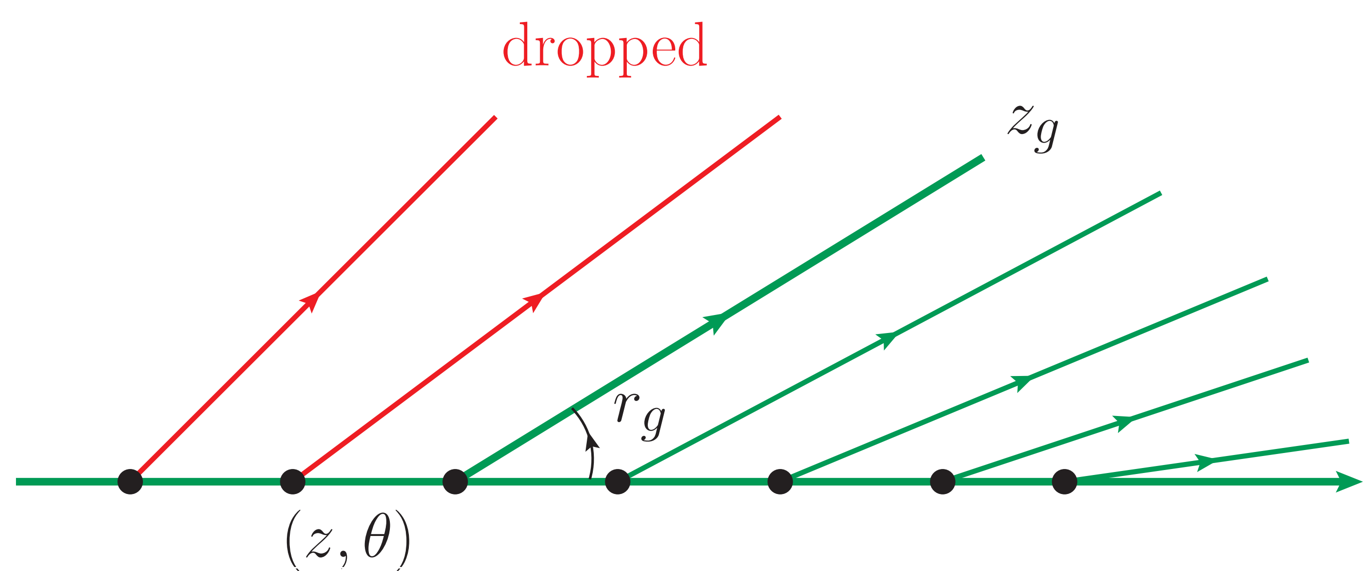


J.Phys.G 47 (2020) 6, 065102

Soft drop



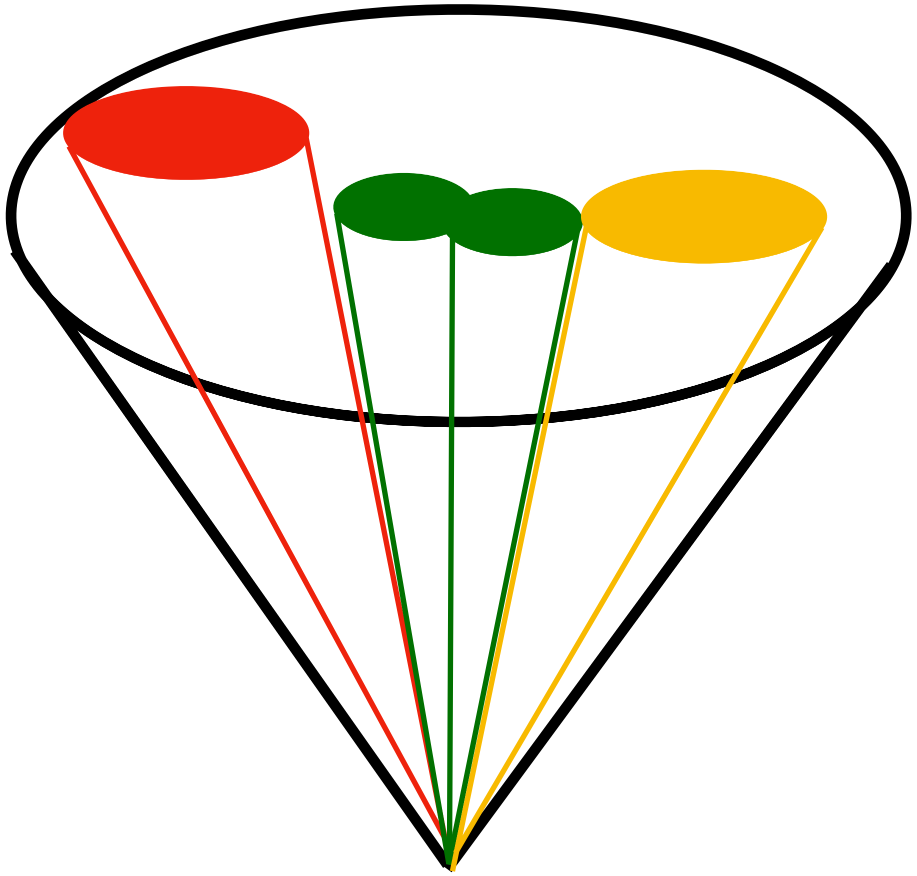
Larkoski et al, JHEP 1405 (2014) 146



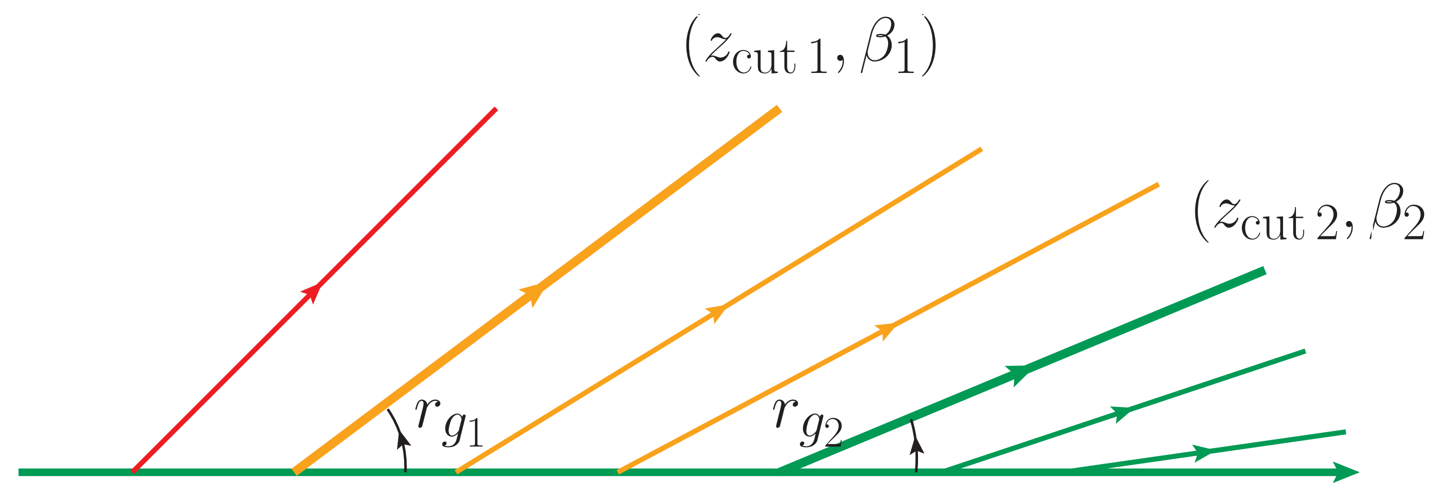
- Recluster the jet using C/A algorithm: angular-ordered tree
- For each branching, consider the **momentum fraction z** and **angle θ**
- Soft-drop condition:
  - $z < z_{cut} (\theta / R)^{\beta}$
- z_{cut} and β are the soft-drop parameters
  - z_{cut} : setting the energy scale
  - β: setting the angular scale

Thanks James for the nice introduction

Collinear drop

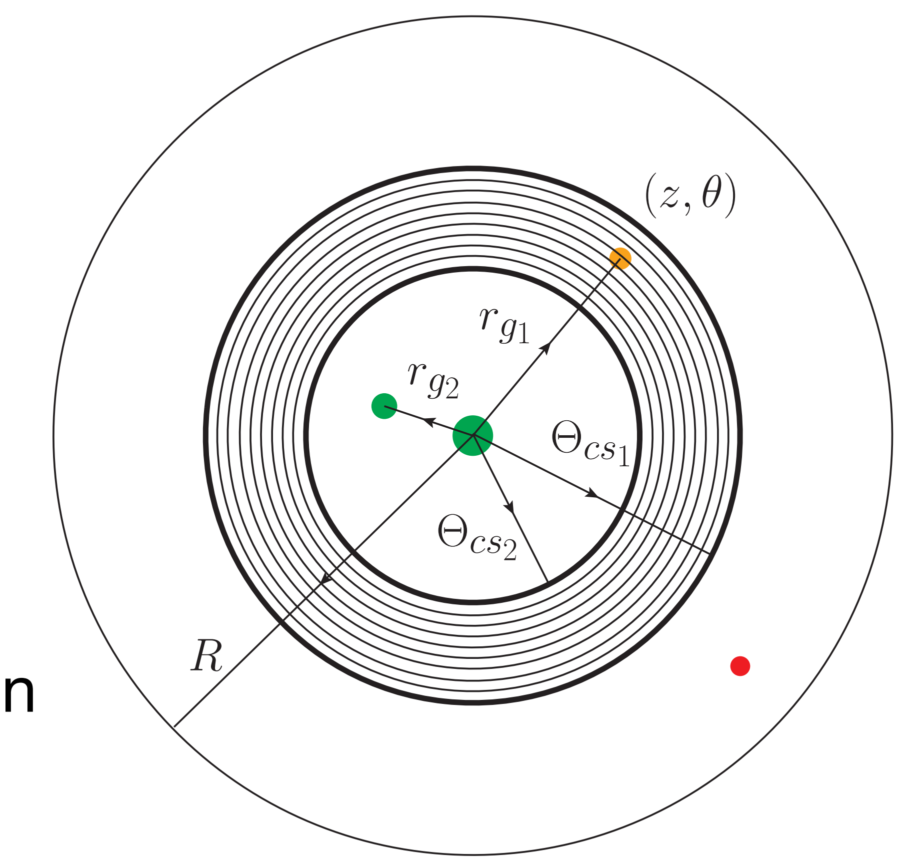


Chien et al, JHEP 06 (2020) 064



As one concrete example,

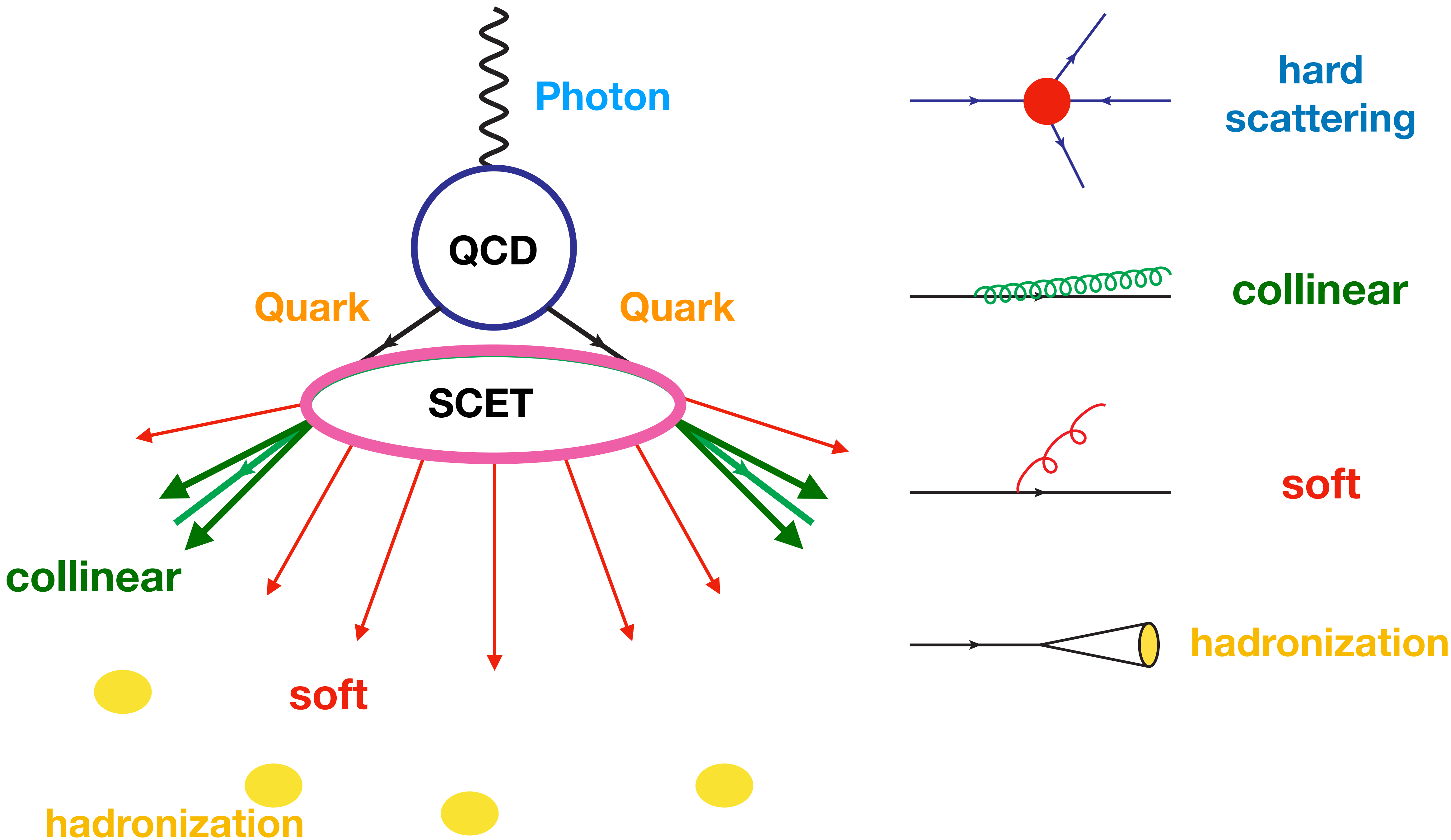
- Consider the observable $\Delta m^2 = m^2_{\mathrm{SD}_1} - m^2_{\mathrm{SD}_2}$
- Collinear-drop condition:
  - $z_{cut1}\ (\theta / R)^{\beta 1} < z < z_{cut2}\ (\theta / R)^{\beta 2}$
- Enhance the sensitivity to the soft and intermediate radiation



(See also Cal et al, Jet energy drop 2007.12187)

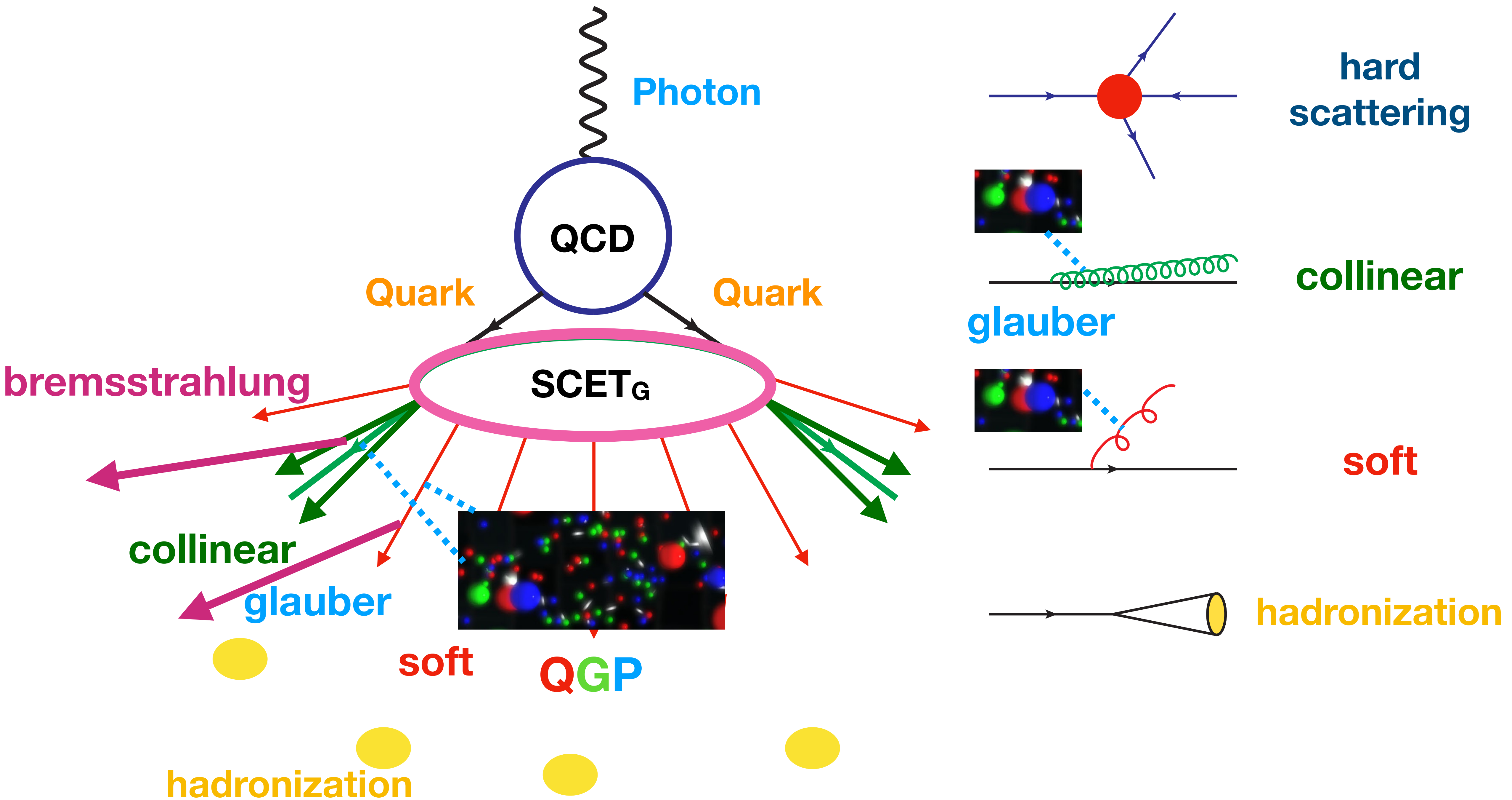
Soft Collinear Effective Theory

Bauer et al, PRD 63, 114020 (2001)

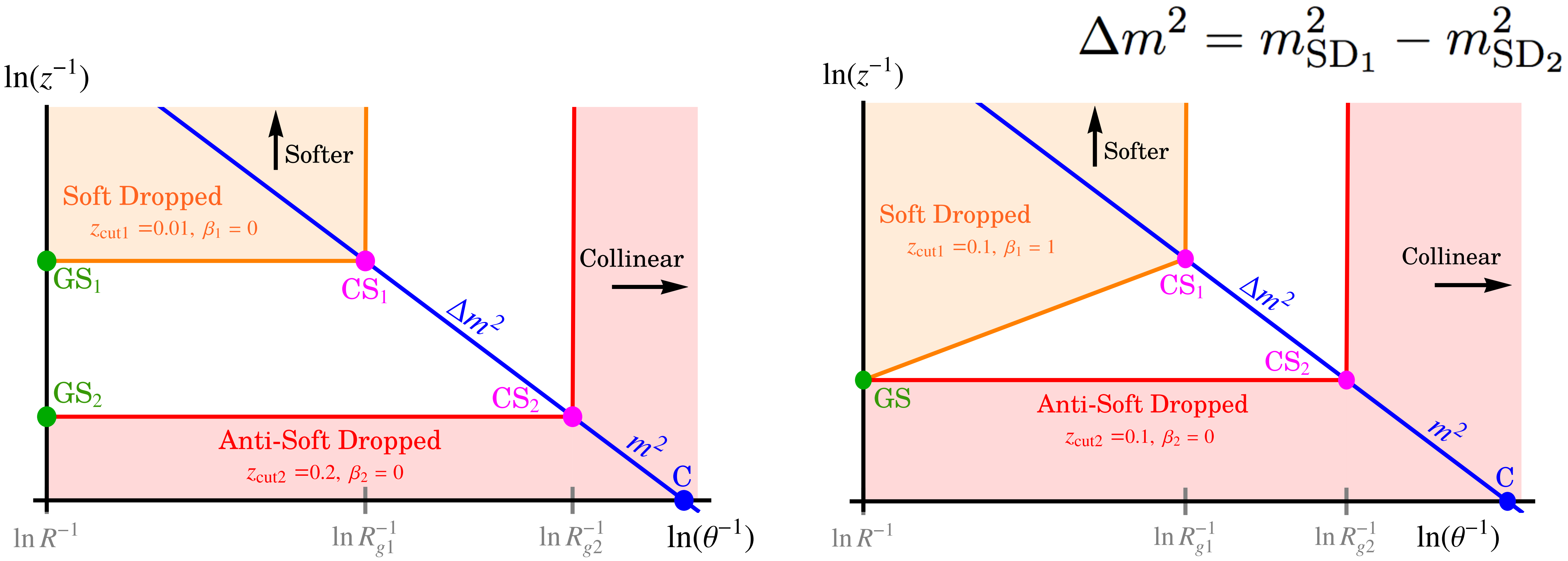


Soft Collinear Effective Theory with Glauber interaction ($SCET_G$)

Bauer et al, PRD 63, 114020 (2001)
Ovanesyan et al, JHEP06(2011)080



Factorization and resummation



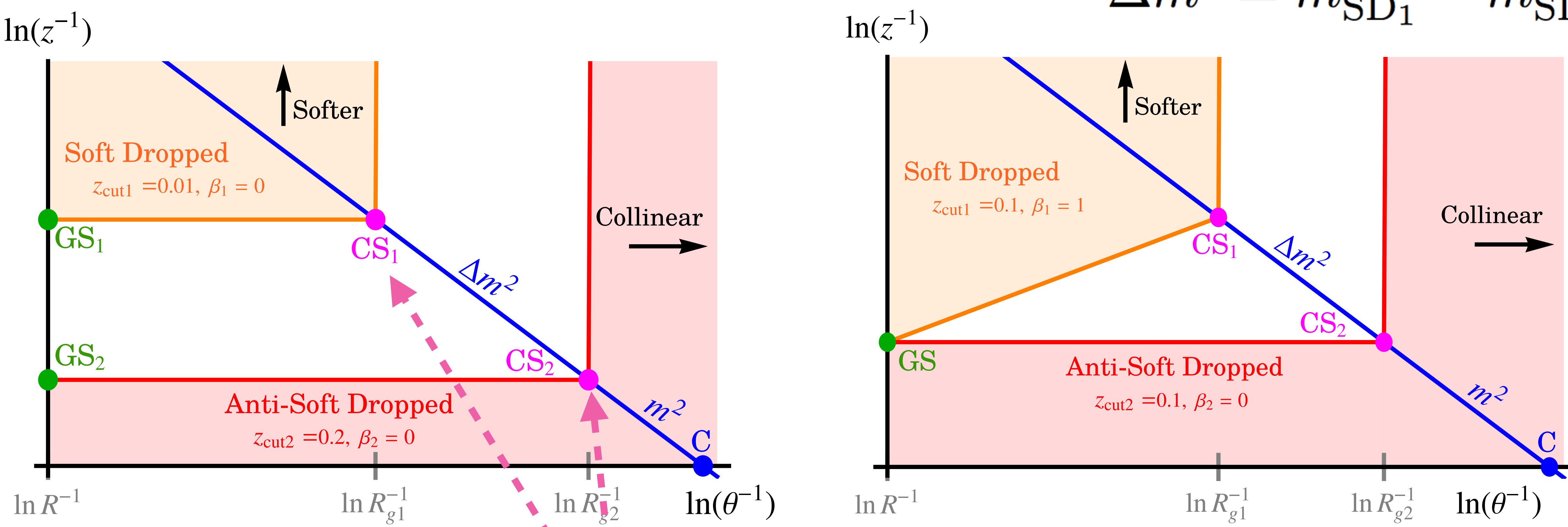
- Hierarchical soft-drop conditions $\mathrm{SD}_1 < \mathrm{SD}_2$ with
  - Fixed β and varying z_{cut}
  - Fixed z_{cut} and varying β
- Identify relevant SCET degrees of freedom with corners of phase space boundaries
- Factorization and resummation with renormalization group evolution

$$\frac{d\sigma}{d\Delta m^2} = \sum_{i=q,g} N_i(z_{\mathrm{cut}\,i}, \beta_i, \mu) P_i^{\mathrm{CD}}(\Delta m^2, z_{\mathrm{cut}\,i}, \beta_i, \mu)$$

$$P_i^{\mathrm{CD}}(\Delta m^2, \mu) = \int dk_i D_{C_2,i}(k_2, \mu) S_{C_1,i}(k_1, \mu) \delta(\Delta m^2 - 2E_J(k_1 + k_2))$$

Factorization and resummation

$$\Delta m^2 = m^2_{\mathrm{SD}_1} - m^2_{\mathrm{SD}_2}$$



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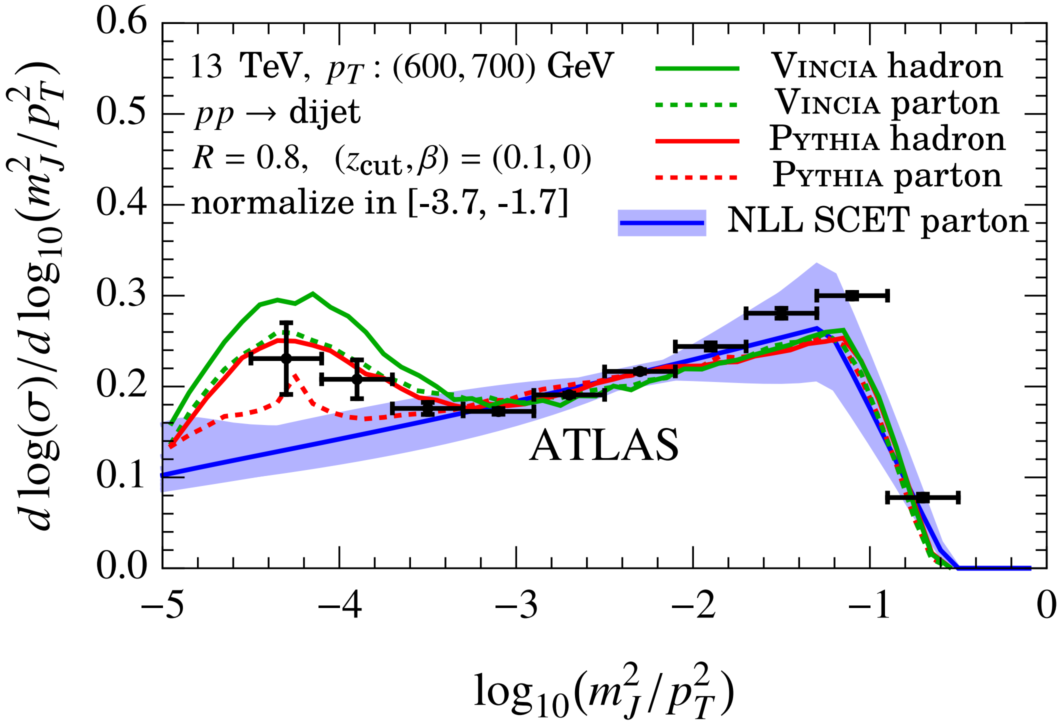
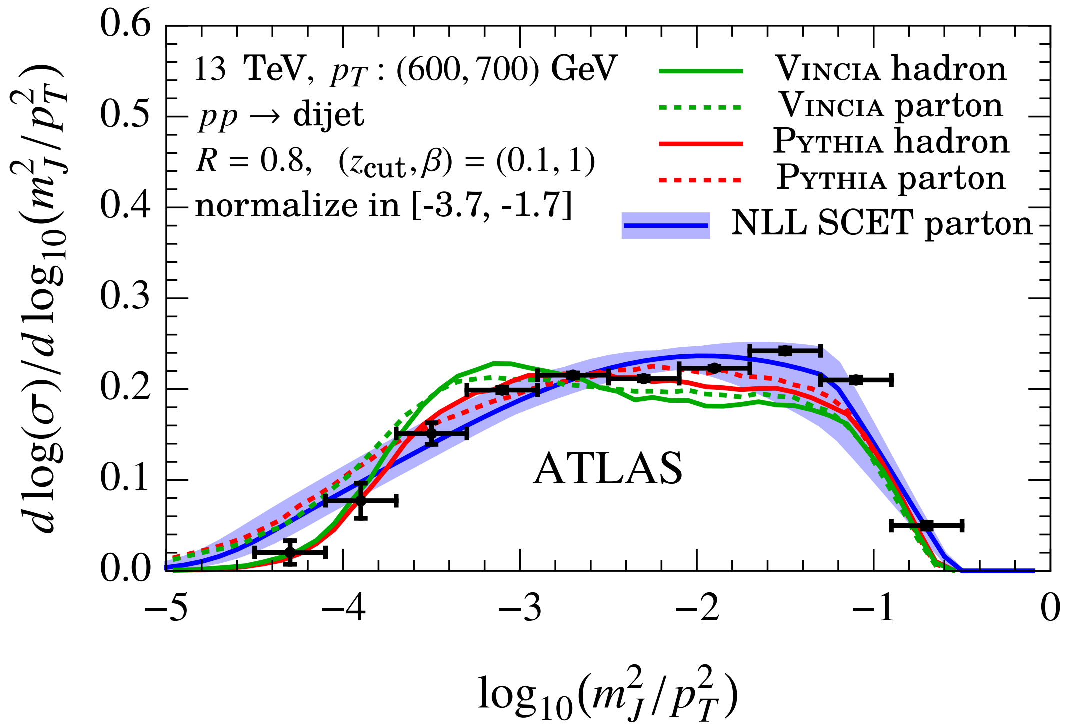
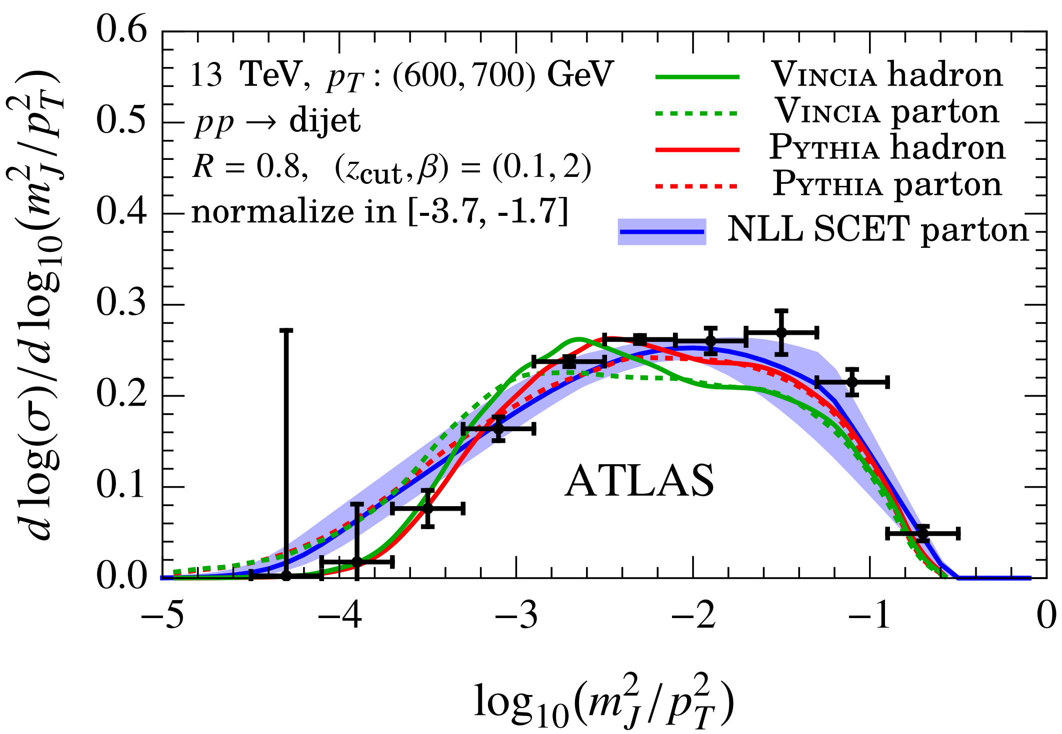
Turning off collinear drop: soft drop

Larkoski et al ’16, Marzani et al ’17, Kang et al ‘18
ATLAS: PRL 121.092001, CMS: JHEP11(2018)113

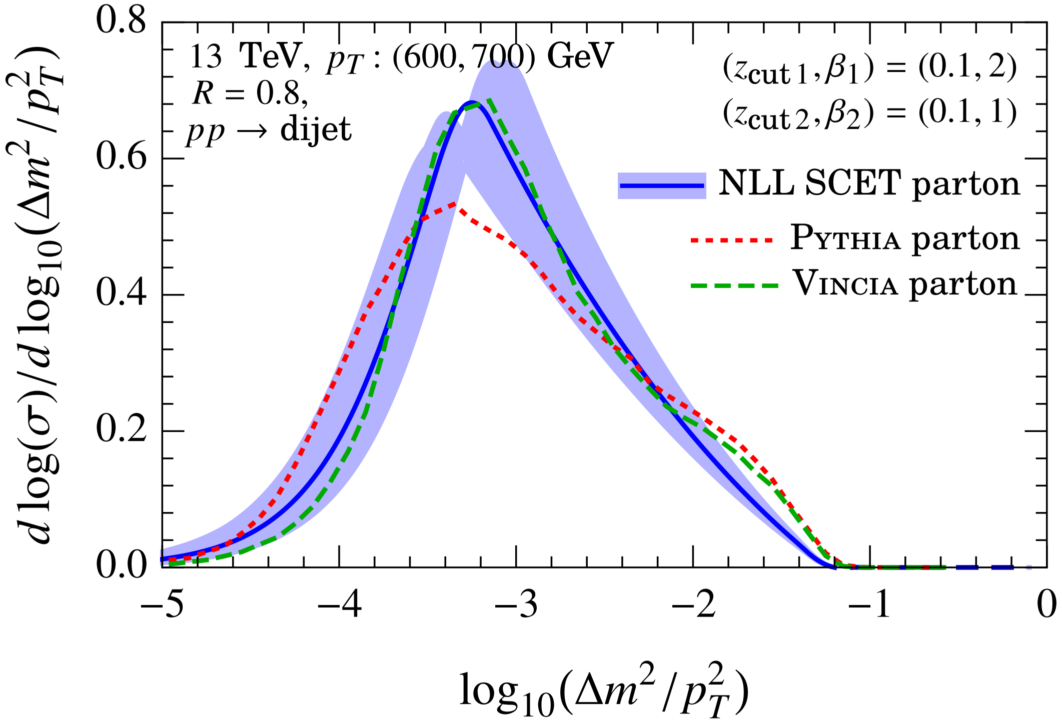




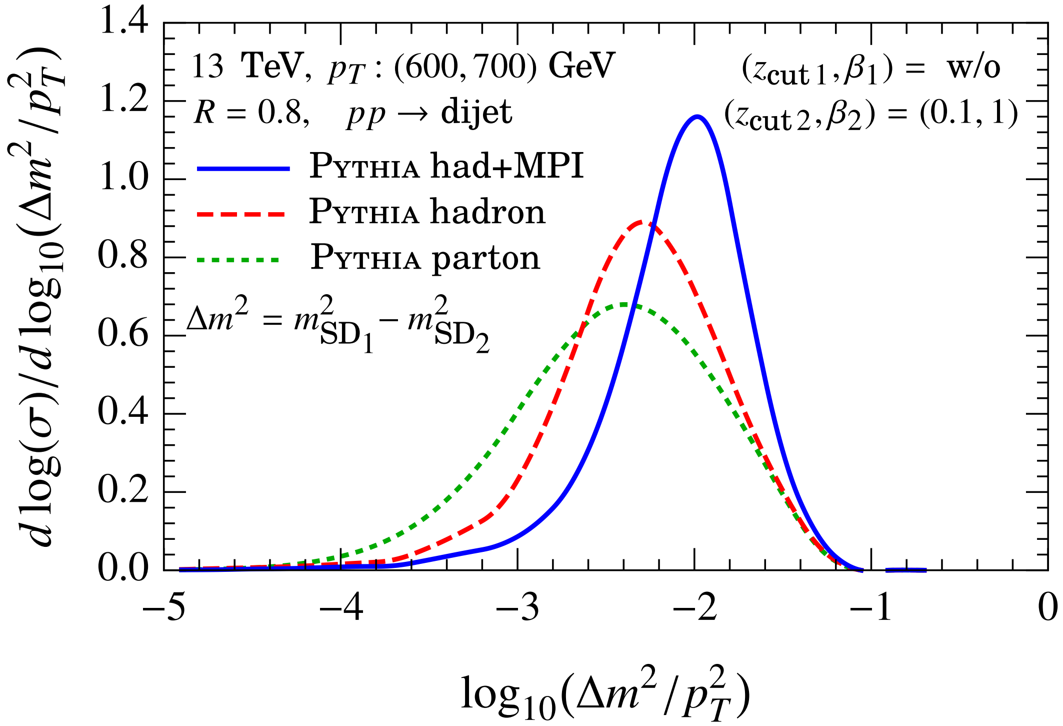


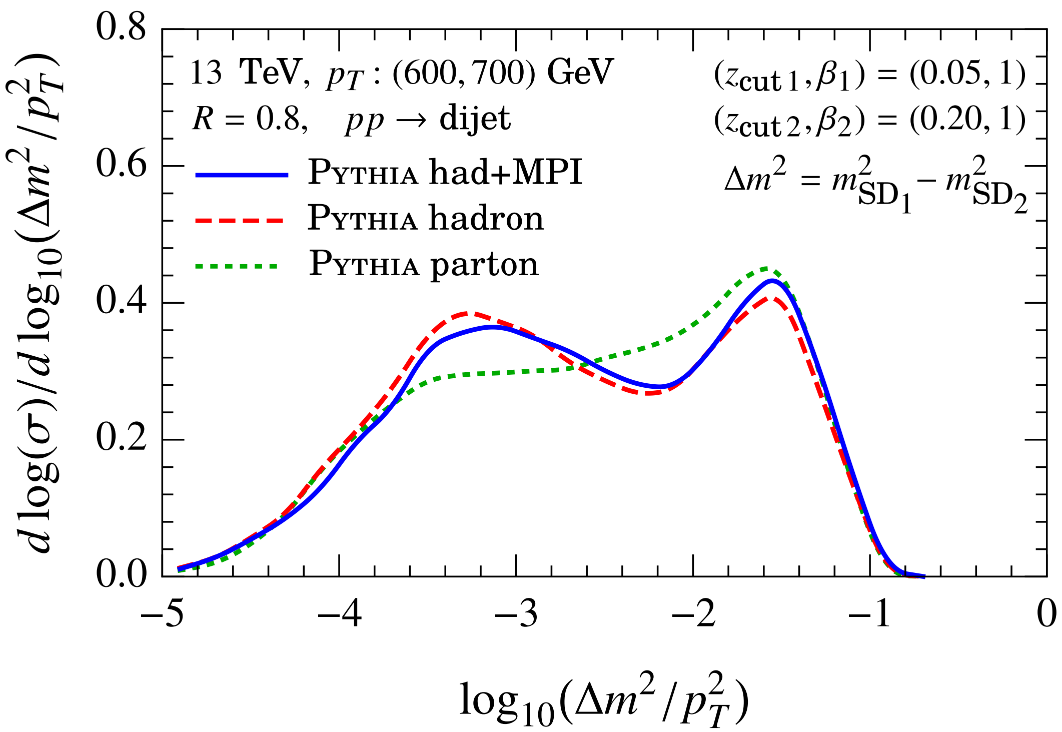
- Soft drop reduces sensitivity to soft physics
- Bands correspond to next-to-leading log (NLL) calculation with uncertainty estimated by scale variations
- Good agreement with ATLAS measurements

Probing soft components of jets



- Significant difference between PYTHIA and VINCIA is observed
- Impressive agreement between VINCIA and analytic calculation





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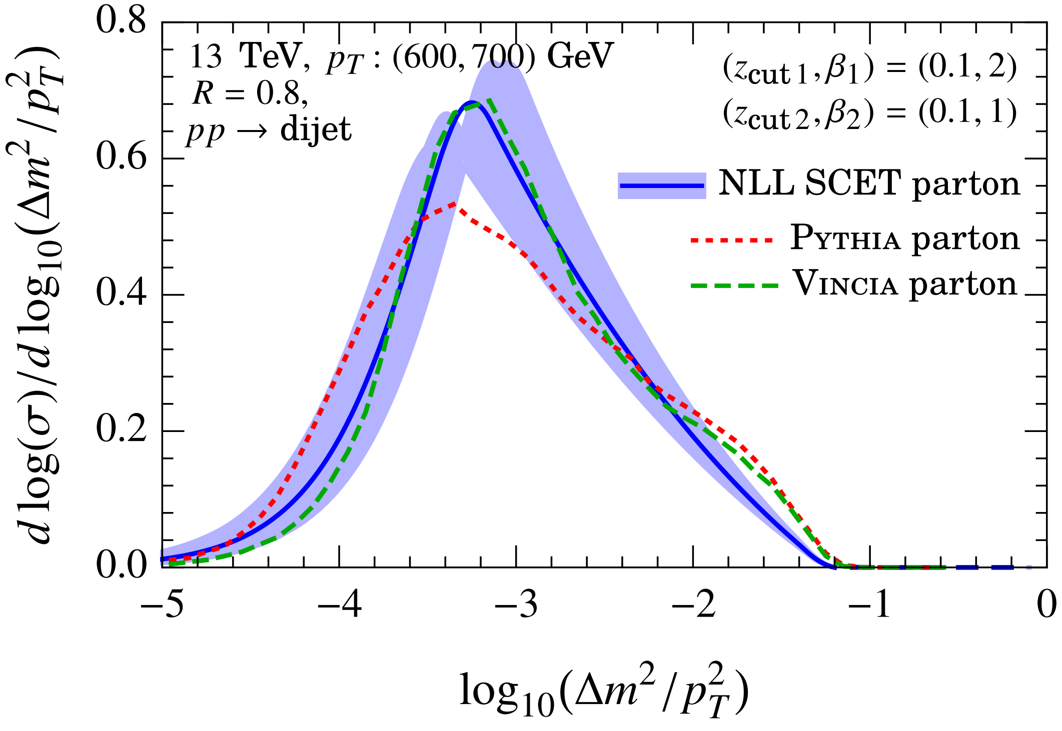

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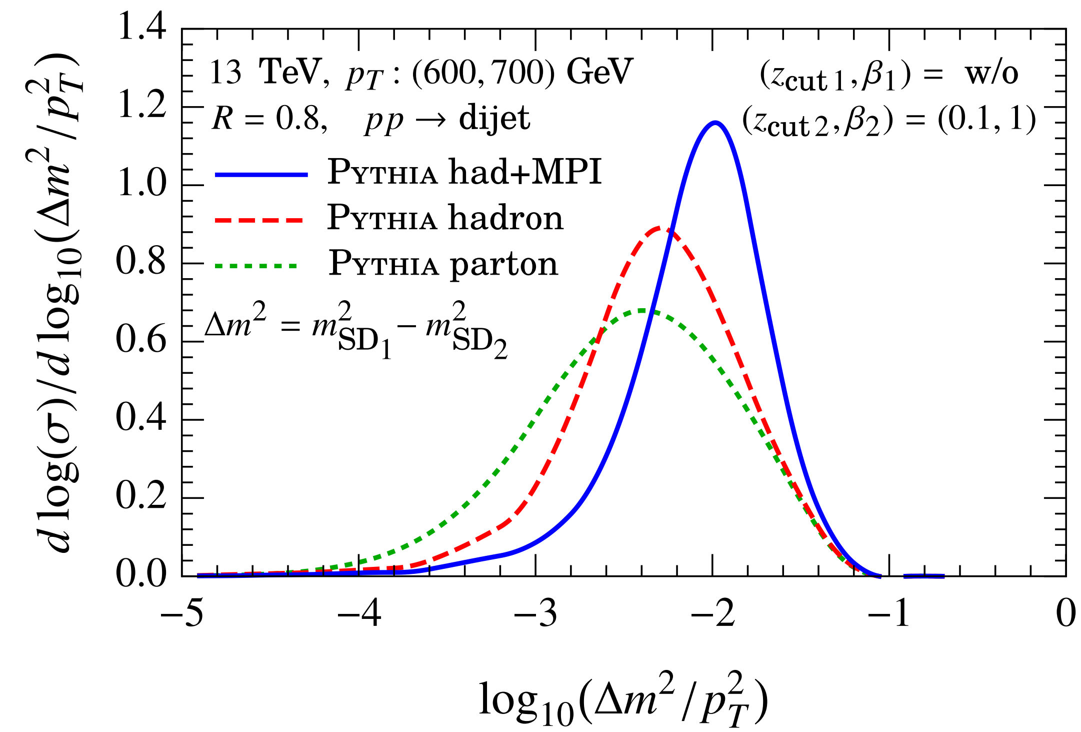

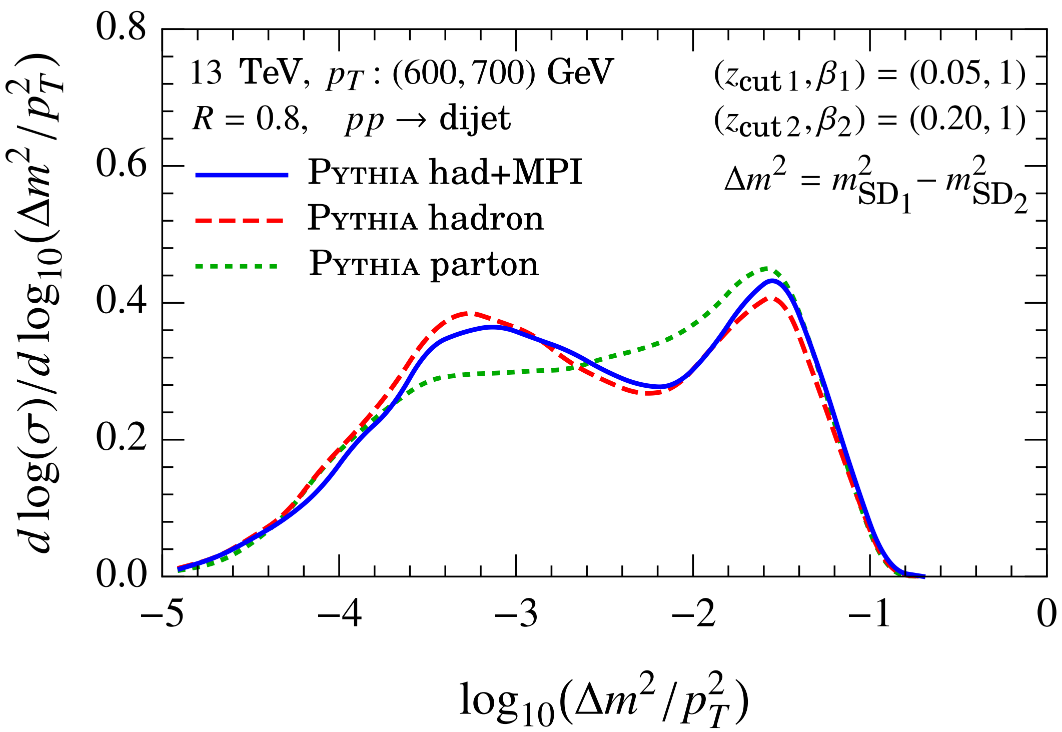

Underlying event can be suppressed while keeping sensitivity to hadronization

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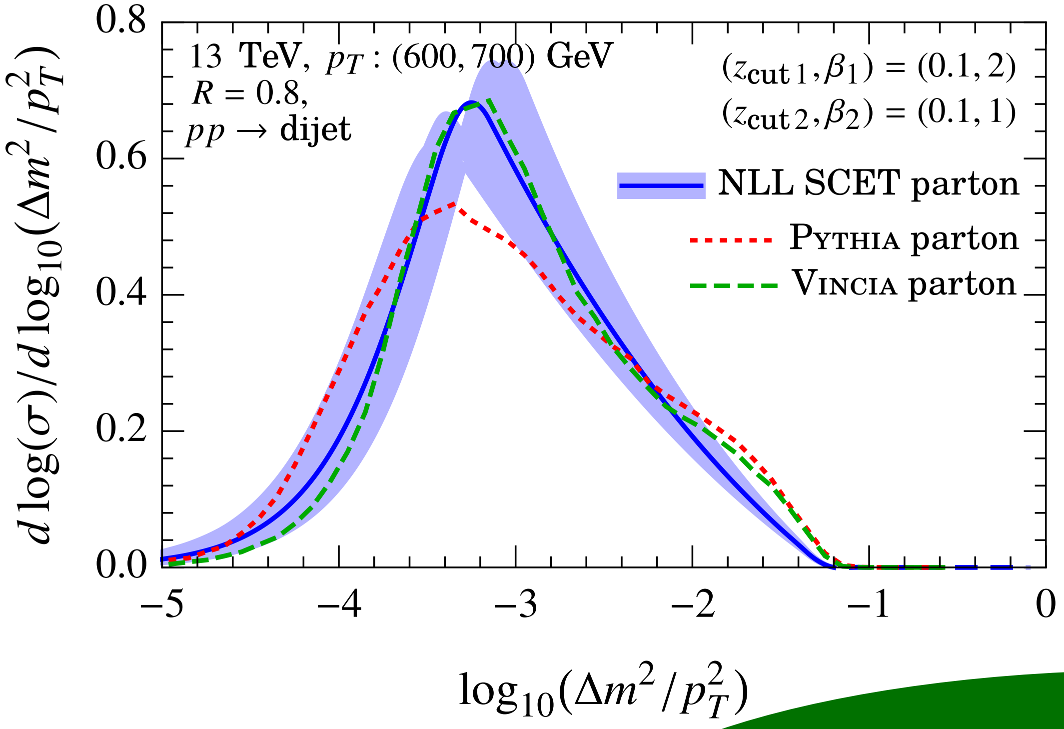

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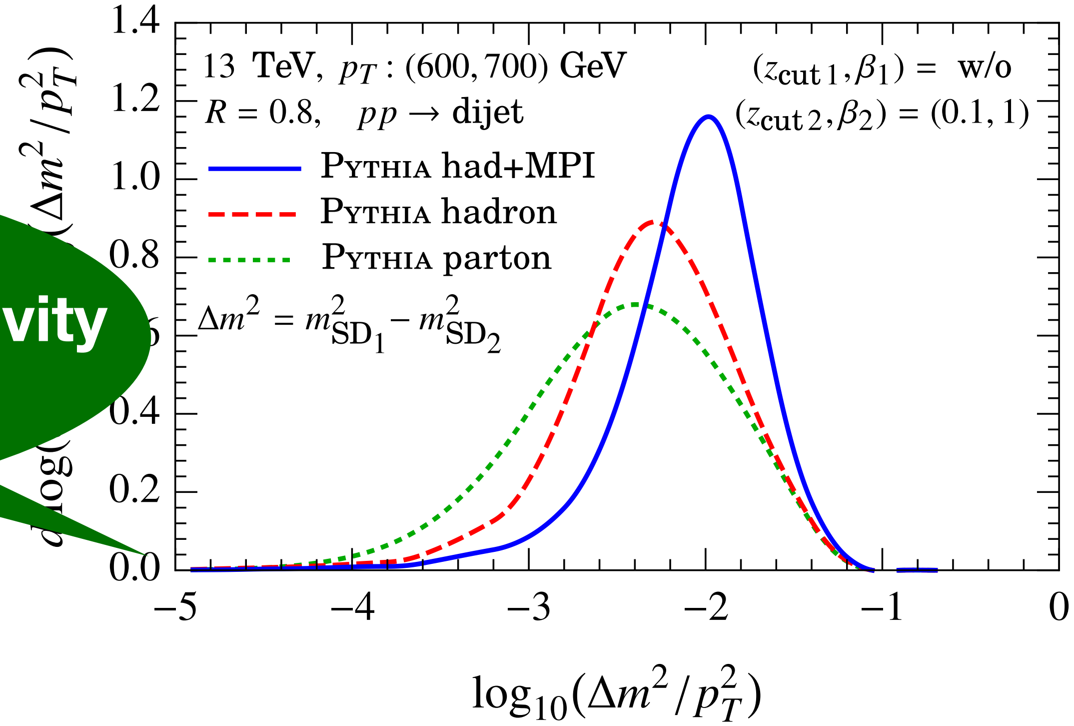
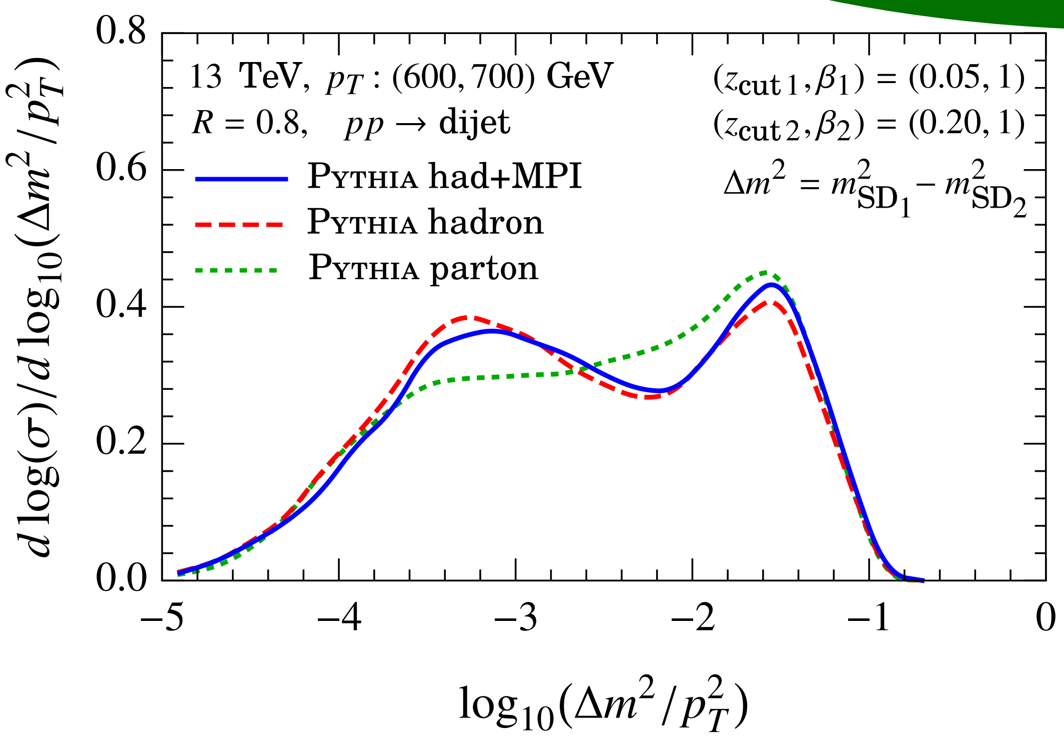
One can also increase the sensitivity to underlying events



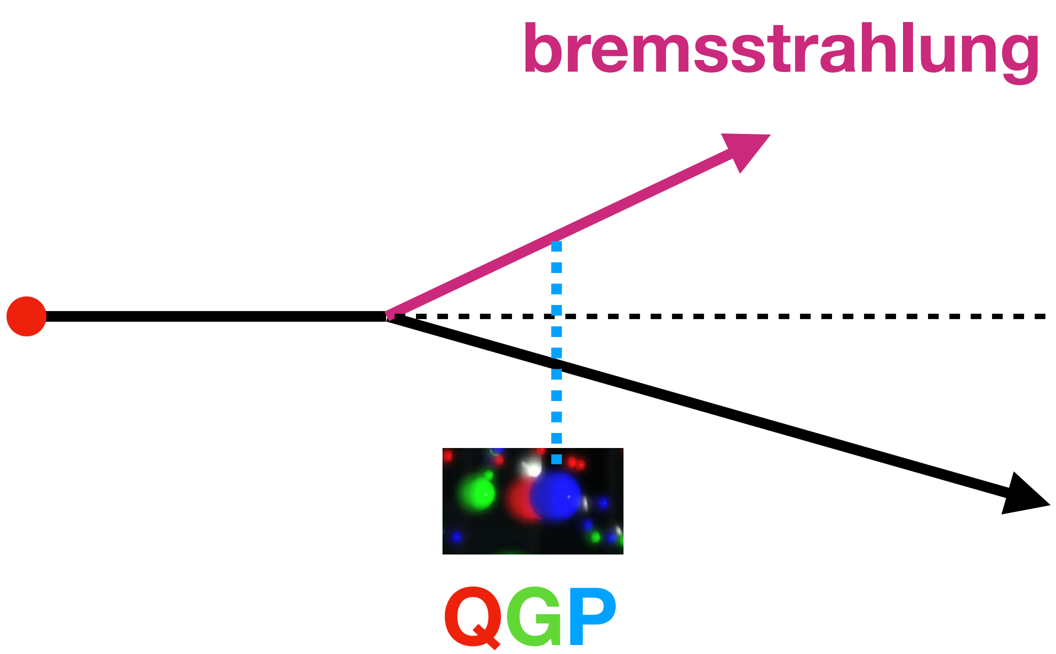


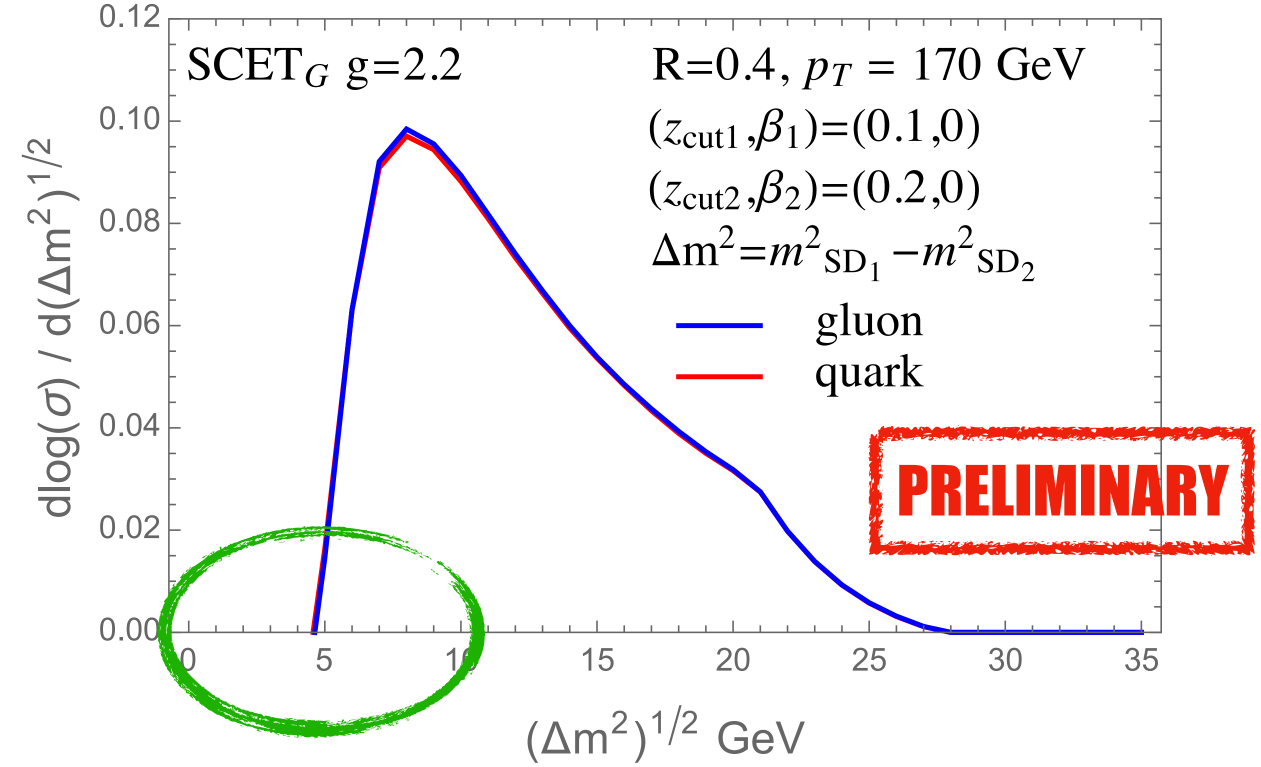
Underlying event can be suppressed while keeping sensitivity to hadronization

Medium-induced radiation

$$\Delta m^2 = m^2_{\mathrm{SD}_1} - m^2_{\mathrm{SD}_2}$$

Ovanesyan et al, JHEP06(2011)080





- Distribution of medium-induced radiation affects jet substructure
- Medium contribution to collinear drop is physically cutoff
  - The shapes are the same for quark and gluon jets
  - Normalizations are different
- Examine the Sudakov peak modification in jet substructure distribution (work in progress)

Previous CMS measurement cut off the Sudakov peak region

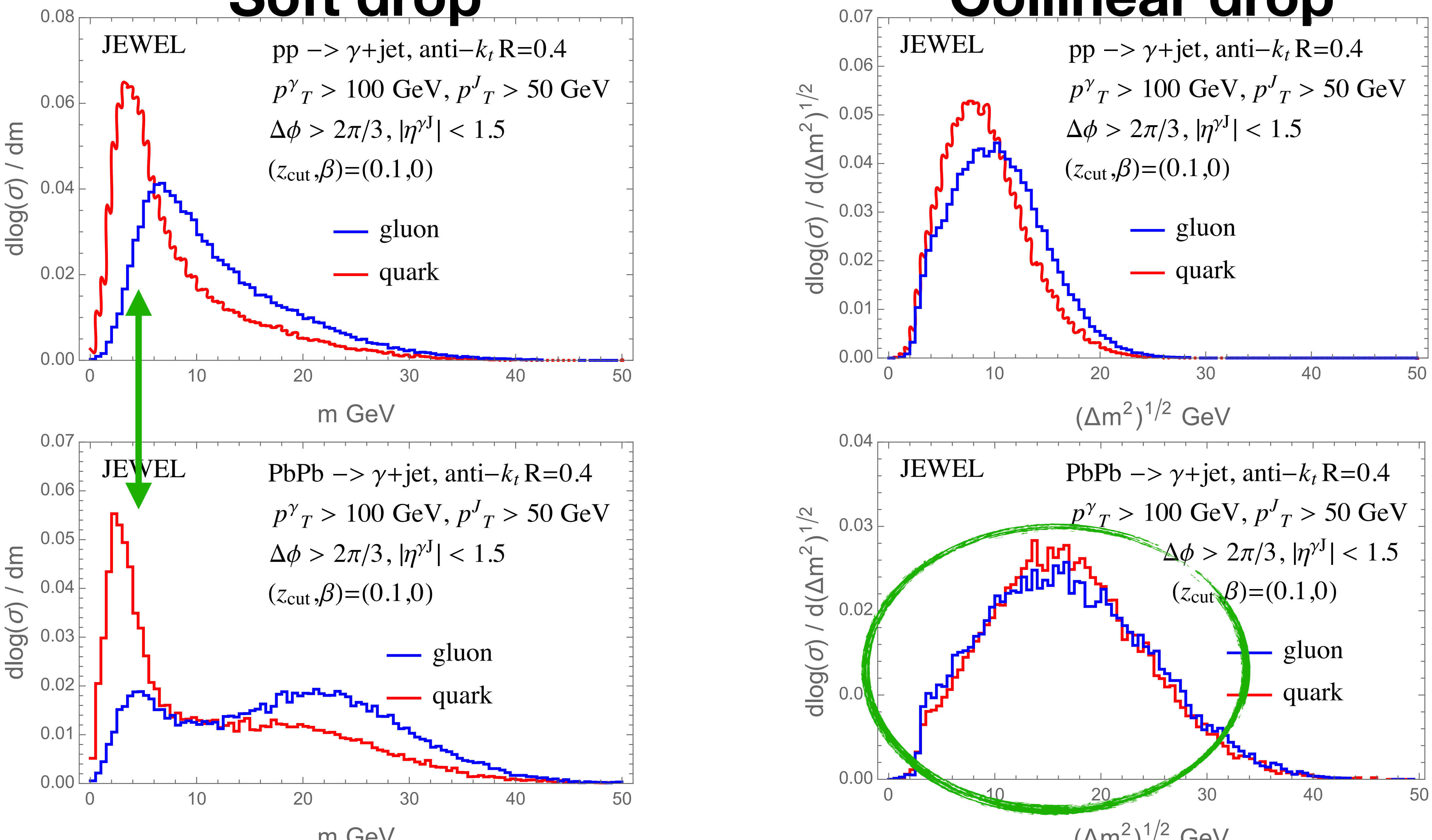
Heavy ion quark gluon jet

$$\Delta m^2 = m^2 - m^2_{\mathrm{SD}}$$

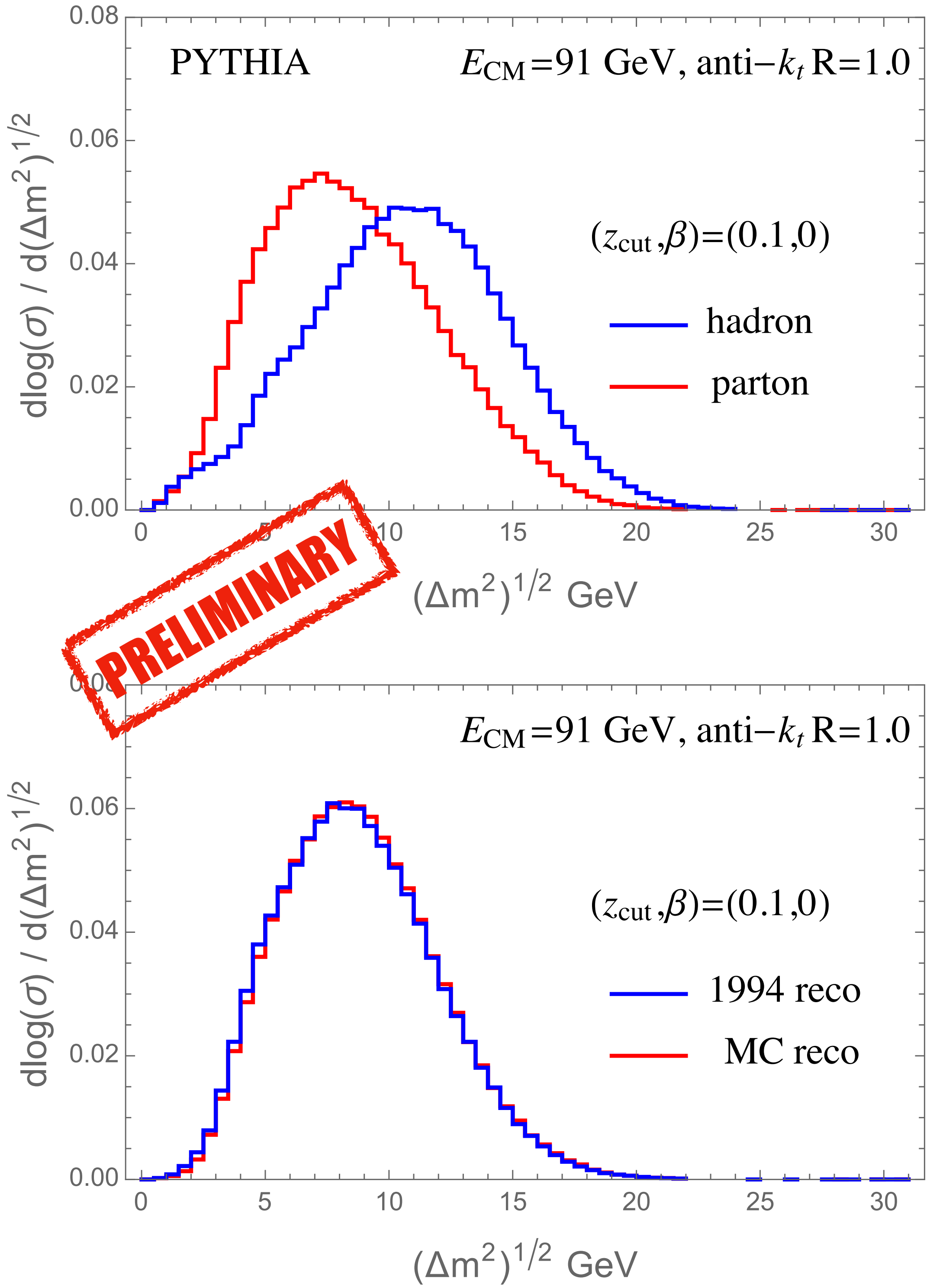
- Soft drop helps remove soft particles and expose collinear components
- Collinear drop isolates the soft particles and shows its universal structure in JEWEL quark and gluon jets

Soft drop

Collinear drop



Application to LEP and EIC



- Significant hadronization correction to collinear drop observables at LEP
  - Ideal for testing hadronization modeling
- Data and Monte Carlo agree at reco level
- Work in progress:
  - Unfolding
  - Heavy quark hadronization
  - Hunting for QGP in high multiplicity events
  - Struck quarks at EIC hadronize without much parton shower evolution: the emergence of jets and extension to event-level substructure studies

Conclusion

- **Collinear drop is a new class of observables**
- **Collinear drop can be used to directly examine soft physics in jets for**
  - **Probing soft radiation contributions**
  - **Testing Monte Carlo simulations**
  - **Determining hadronization corrections**
  - **Studying perturbative-nonperturbative transition**
  - **Probing QCD medium in heavy ion collision**
- **Factorization of collinear drop observables is derived in SCET which allows us to resume logarithmically enhanced contributions**

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Thank you!