MPI@LHC 2023

Probing factorization violation with vector angularities

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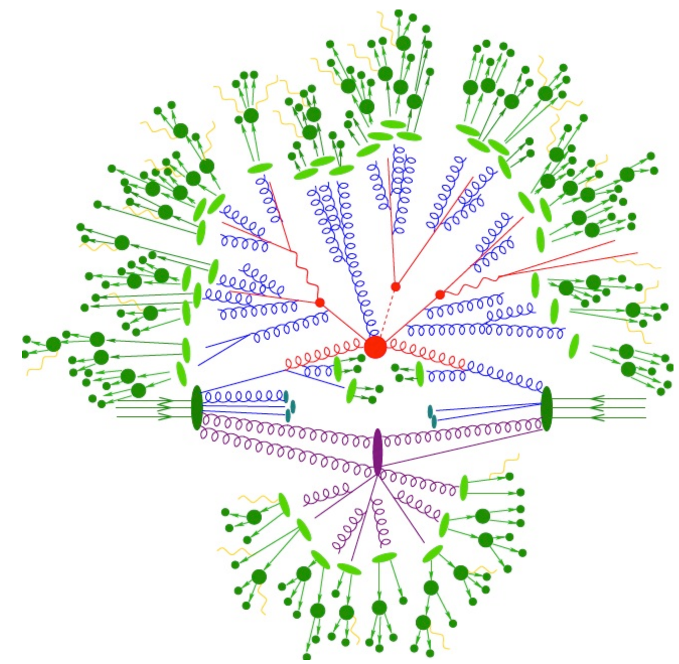
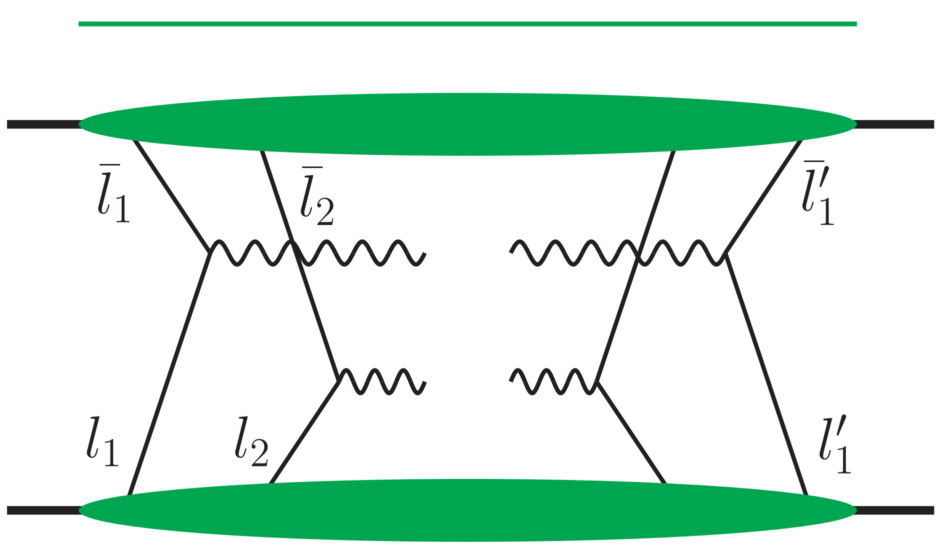
Motivation

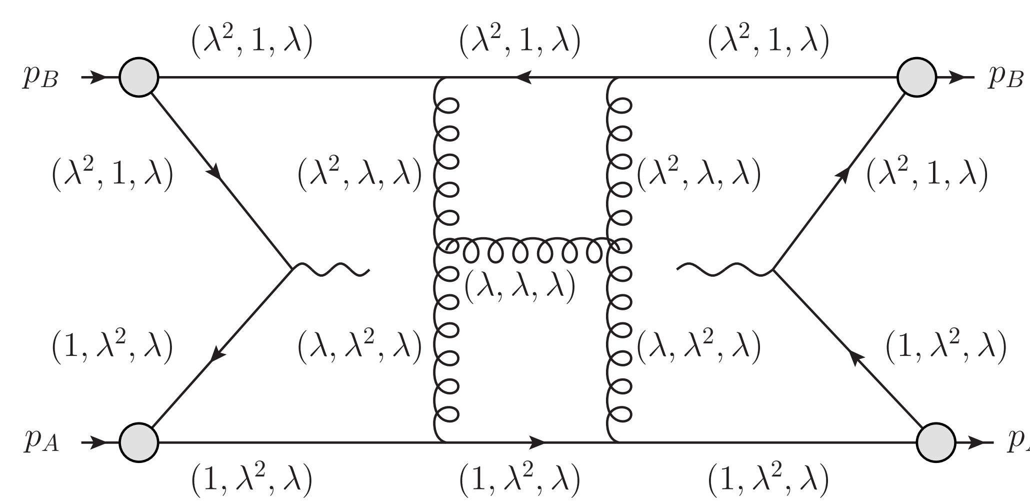
- What is the theoretical description of the underlying event?
  - MPI model in parton showers
  - Multi-parton scattering in factorization
  - Factorization violation*



Parton shower
[figure from Hoeche]



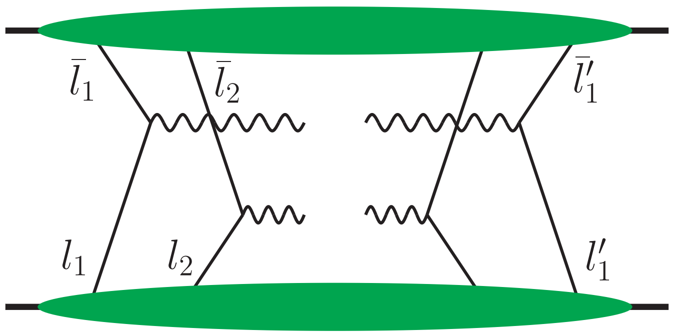
Double parton scattering
[figure from Diehl et al]



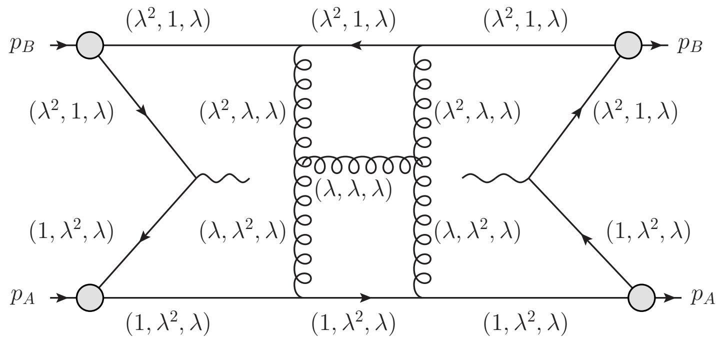
Factorization violation
[figure from Gaunt]

Double parton scattering vs. factorization violation

- Double parton scattering
  - Two hard collisions
  - Factorization proven for double Drell-Yan
    [Diehl, Gaunt, Ostermeier, Ploessl, Schafer]



- Factorization violation
  - Hard collision + Glauber exchanges
  - Observable dependent: no violation for Drell-Yan q_T
    [Collins, Soper, Sterman; Bodwin]
  - Glauber ladders don't violate fact., need soft emission (Lipatov vertex) [Schwartz, Yan, Zhu]



Vector angularities

$$\vec{\tau}_a = \sum_i \vec{p}_{T,i}\, e^{-a|y_i|},$$

- Motivation:
  - Smoothly connects to q_T (a=0), which factorizes with (approx.) N^{4}LL predictions [Neumann, Campbell; Camarda, Cieri, Ferrera; Moos, Scimemi, Vladimirov, Zurita]
  - Angularities well studied [Berger, Kucs, Sterman; Almeida, Lee, Perez, Sterman, Sung, Virzi; Ellis, Hornig, Lee, Vermilion, Walsh; Bell, Hornig, Lee, Talbert, ...]. Vector sum key difference

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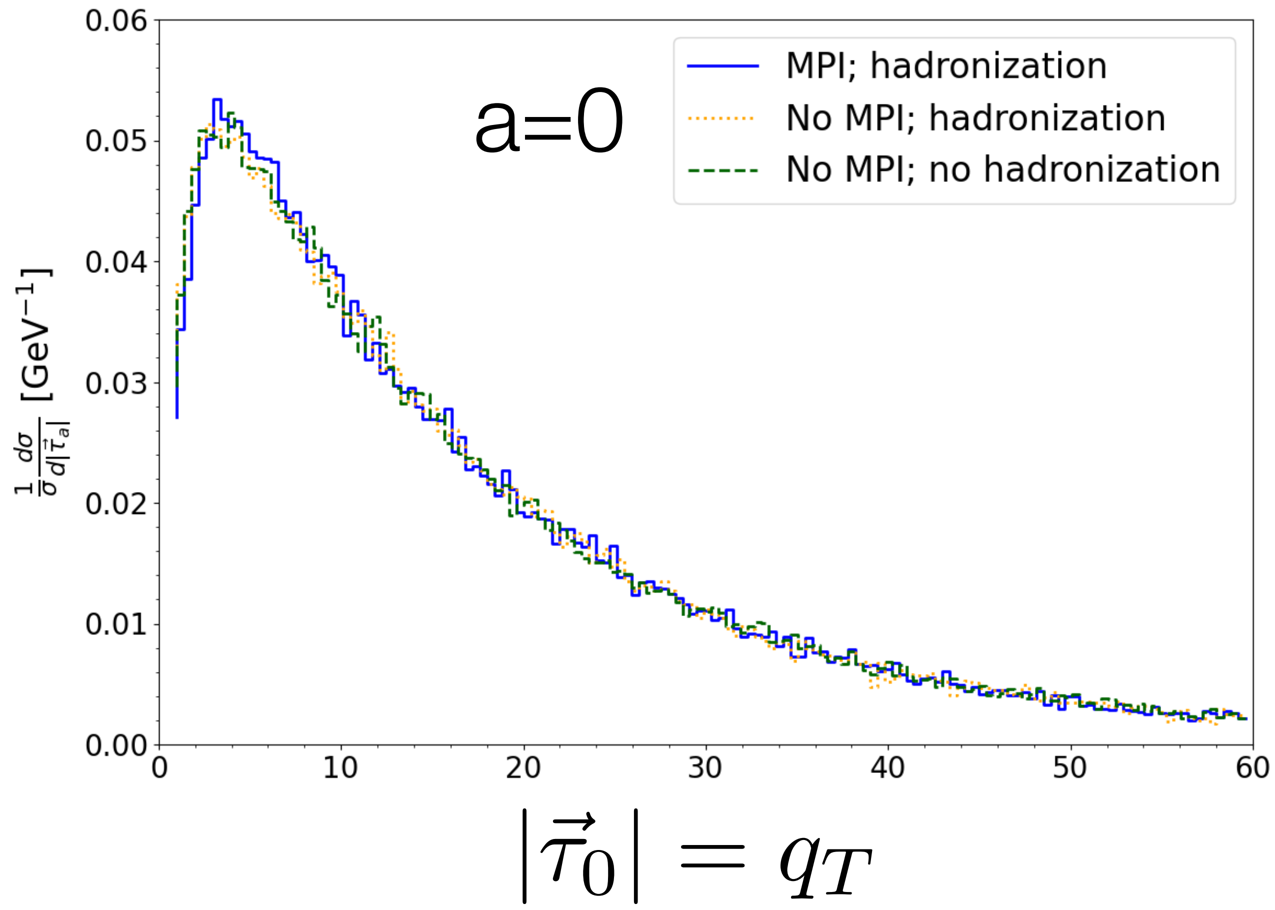
- This talk:
  - Study effect of MPI in Pythia as proxy of fact. violation [Gaunt]
  - Predictions without fact. violation → baseline for studying this

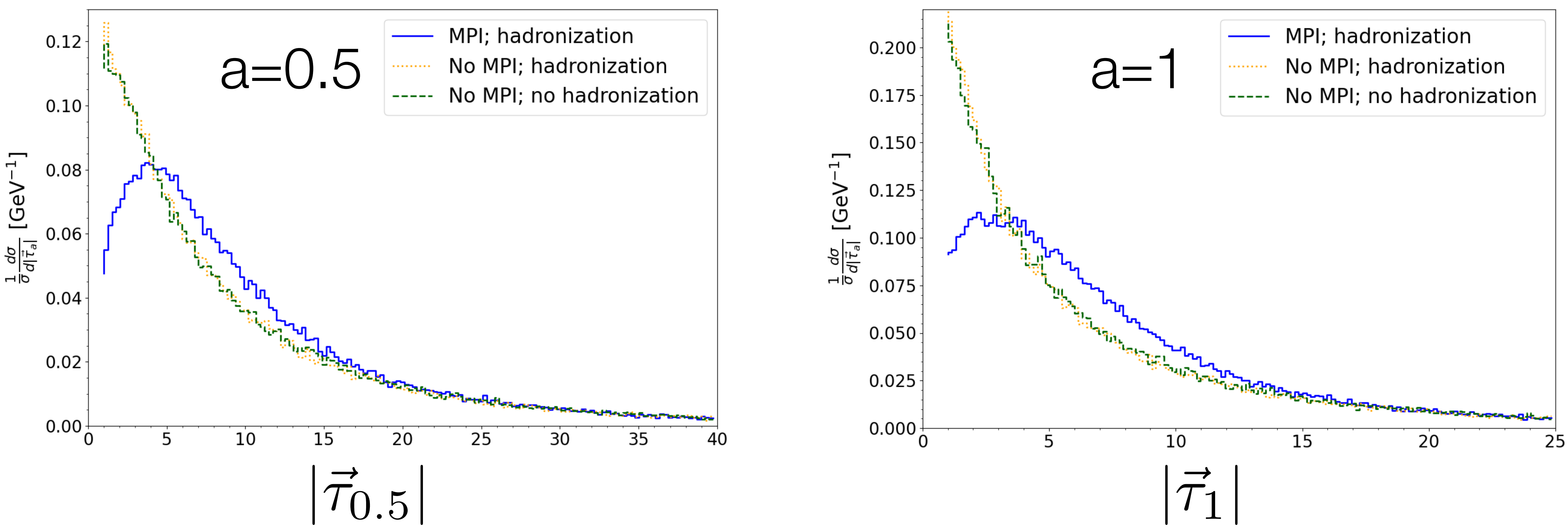
[Bijl, Niedenzu, WW - arXiv:2307.02521]

Effect of MPI in Pythia for a=0



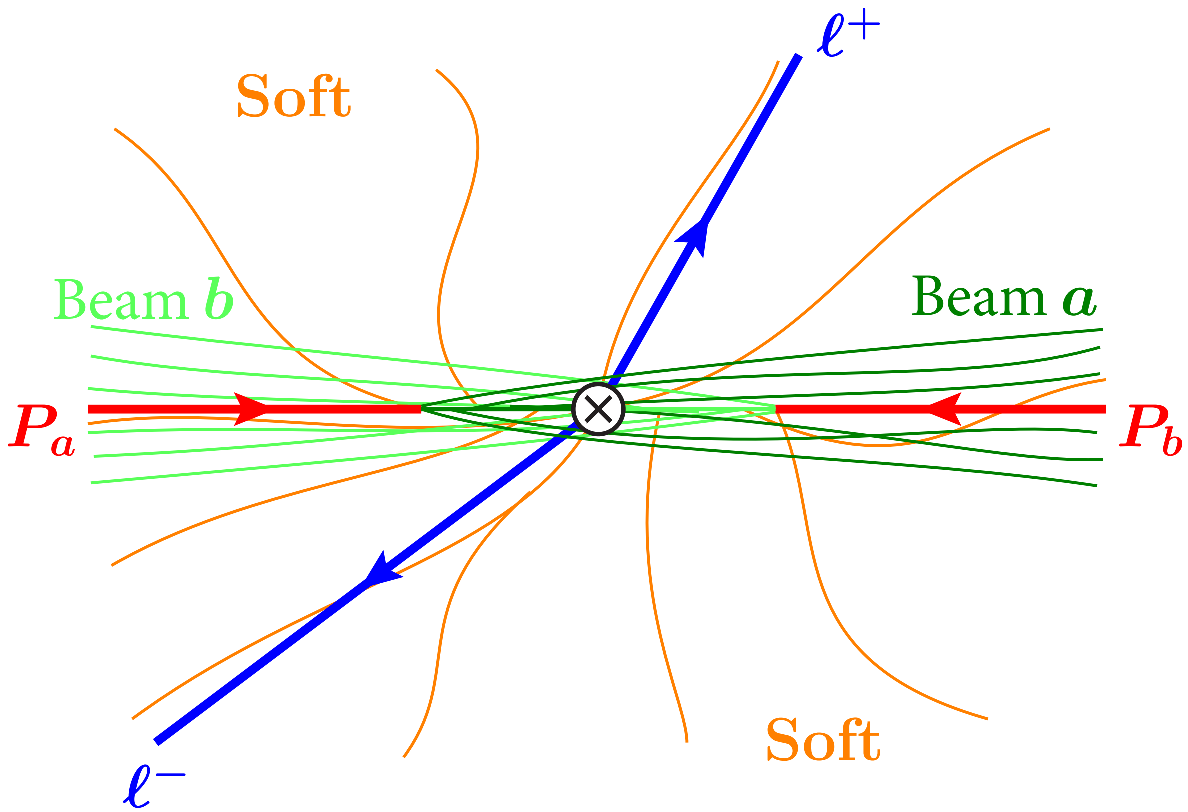
- No fact. violation for a=0, matches negligible effect of MPI
- This is **not** true for scalar sum of p_T (=H_T)
- Effect of hadronization is small

Effect of MPI in Pythia for a=0.5, 1



- For $a \neq 0$, substantial effect of MPI → suggest fact. violation
- Same seen for Herwig

Predictions without factorization violation



- Factorize cross section for small $|\vec{\tau}_a|$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}Q\,\mathrm{d}Y\,\mathrm{d}^2\vec{\tau}_a} = \sum_q \sigma_{0,q} H(Q^2,\mu) \int \mathrm{d}^2\vec{\tau}'_{a,1}\, B_q(\vec{\tau}'_{a,1}, x_1, \mu) \int \mathrm{d}^2\vec{\tau}'_{a,2}\, B_{\bar{q}}(\vec{\tau}'_{a,2}, x_2, \mu)$$

$$\times\, S\Big(\vec{\tau}_a - \frac{\vec{\tau}'_{a,1}}{(Qe^{Y})^a} - \frac{\vec{\tau}'_{a,2}}{(Qe^{-Y})^a}, \mu\Big)$$

into hard, collinear and soft functions. Ignore Glaubers

Factorization of scales

- Factorization separates the physics at different scales:

$$\int_{|\vec{\tau}_a|<\tau_a} \mathrm{d}\vec{\tau}_a \, \frac{\mathrm{d}\sigma}{\mathrm{d}^2\vec{\tau}_a} \sim \ln^2 \frac{\tau_a}{Q} = \underbrace{(1+a)\ln^2 \frac{Q}{\mu}}_{\text{hard}} - \underbrace{\frac{1}{a} \ln \frac{\tau_a Q^a}{\mu^{1+a}}}_{\text{collinear}} + \underbrace{\frac{1+a}{a} \ln^2 \frac{\tau_a}{\mu}}_{\text{soft}}$$

- From which we read off:

$$\mu_H \sim Q, \quad \mu_B \sim (|\vec{\tau}_a| Q^a)^{1/(1+a)}, \quad \mu_S \sim |\vec{\tau}_a|$$

- Vector or scalar sum doesn't matter for one emission → check on beam [Kang, Maji, Zhu] and soft function [Hornig, Lee, Ovanesyan]

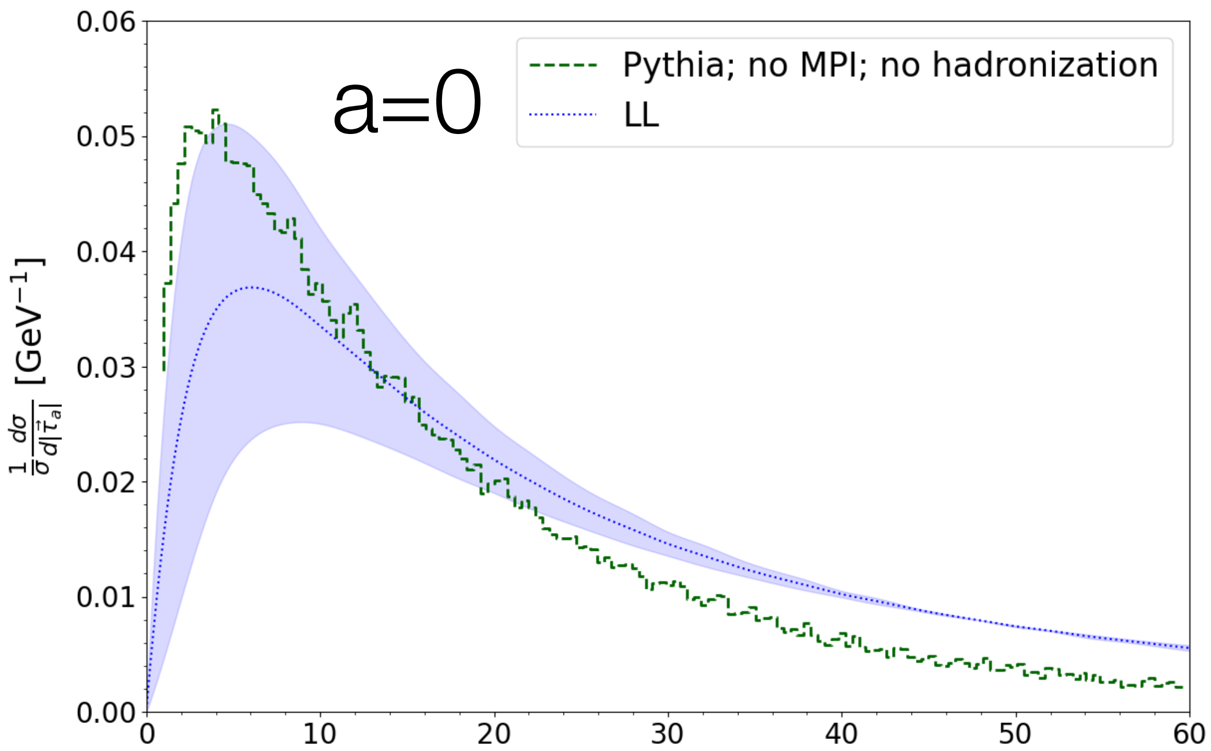
Resummation

- Resummation is different from scalar angularities, and must be performed in impact parameter space, as for TMDs:
[Frixione, Nason, Ridolfi; Ebert, Tackmann, …]

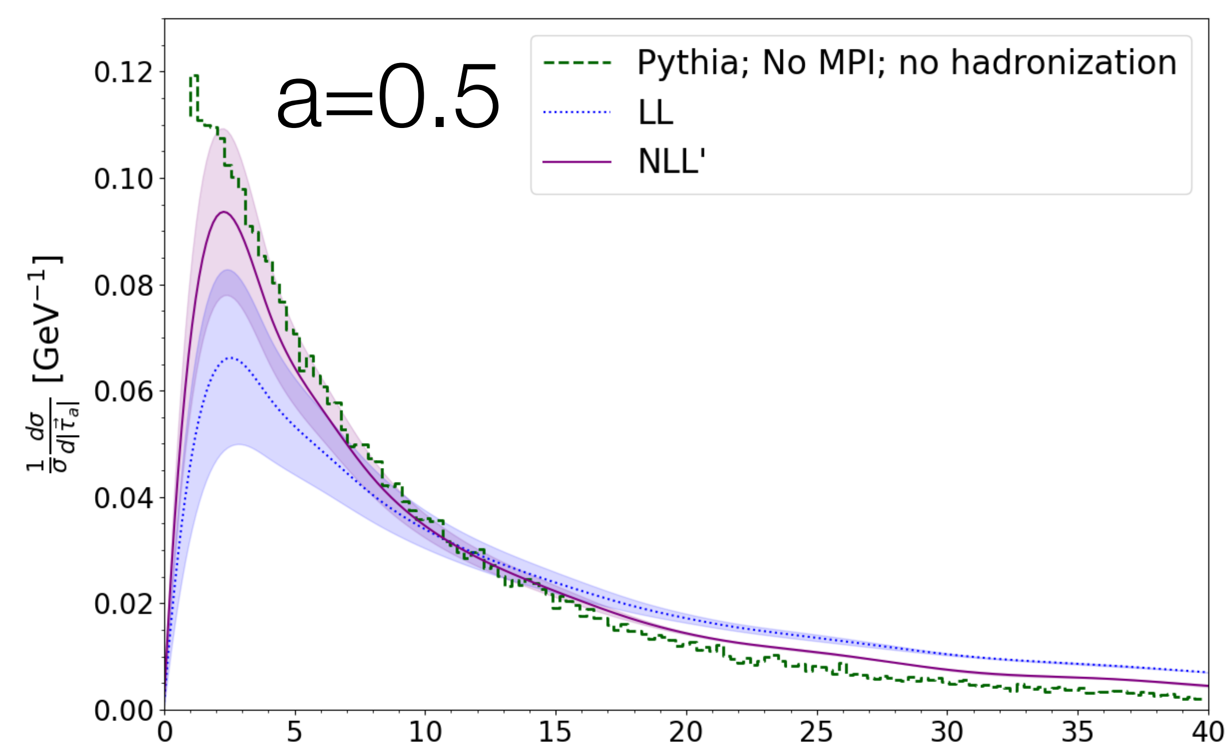
$$\frac{\mathrm{d}\sigma}{\mathrm{d}Q\,\mathrm{d}Y\,\mathrm{d}|\vec{\tau}_a|} = \sum_q \sigma_{0,q} H(Q^2,\mu_H) \int_0^\infty \mathrm{d}b_\perp\, b_\perp |\vec{\tau}_a|\, J_0\big(b_\perp|\vec{\tau}_a|\big)$$
$$\times\, \tilde{B}_q\Big(\frac{b_\perp^*}{(Qe^Y)^a}, x_1, \mu_B\Big)\, \tilde{B}_{\bar{q}}\Big(\frac{b_\perp^*}{(Qe^{-Y})^a}, x_2, \mu_B\Big)$$
$$\times\, \tilde{S}(b_\perp^*, \mu_S)\, U_H(Q^2, \mu_H, \mu_B)\, U_S(b_\perp^*, \mu_S, \mu_B, a)\,.$$

- Resum logarithms of $|\vec{\tau}_a|$ using renormalization group
- Treat Landau pole with b^* prescription

(N)LL' results compared to Pythia for a=0, 0.5



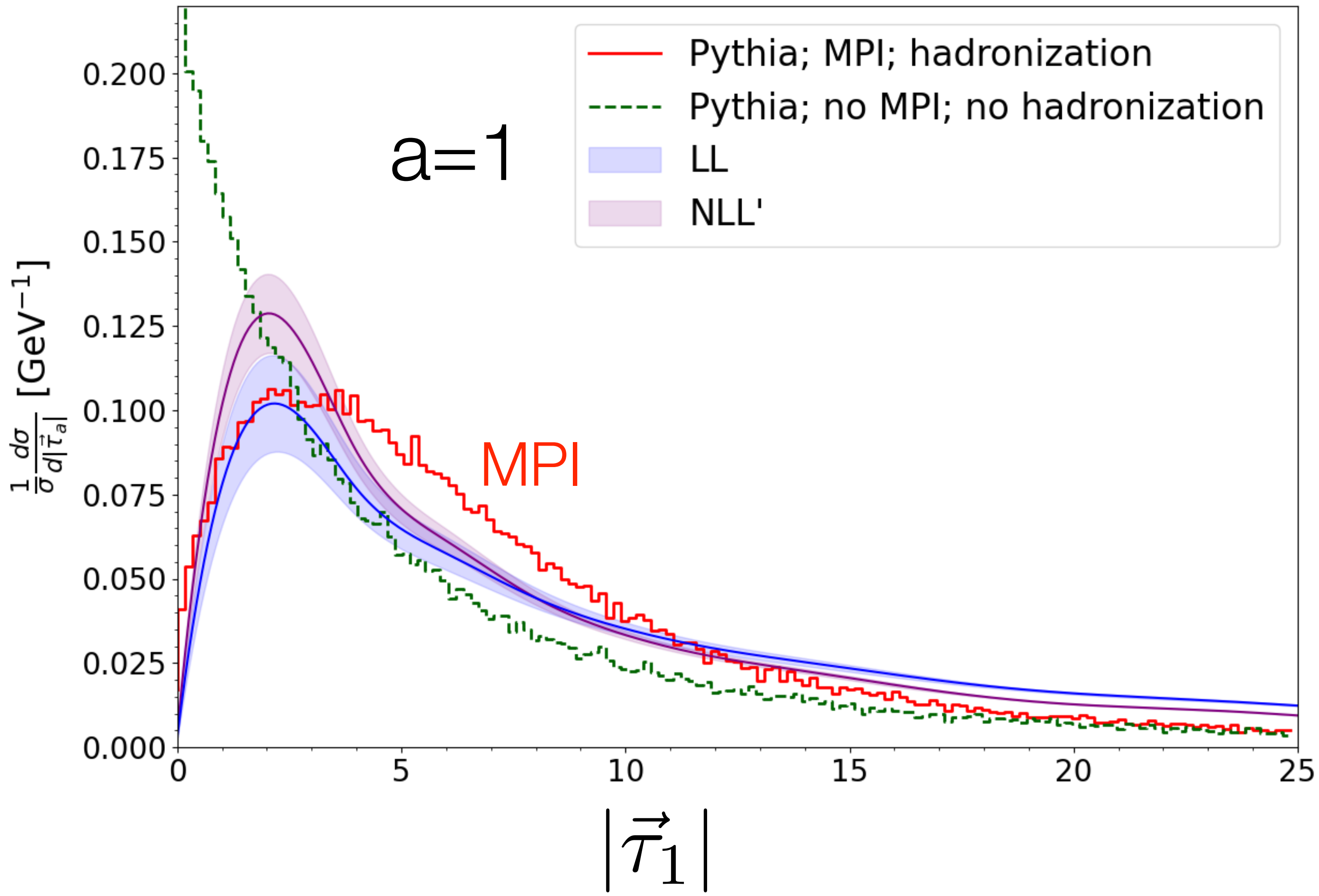
$|\vec{\tau}_0| = \vec{q}_T$



$|\vec{\tau}_{0.5}|$

- Resummed perturbation theory converges
- Agrees with Pythia in peak, difference in tail (no matching yet)
- For a=0, there are rapidity divergences. At LL this limit is smooth
  [Larkoski, Neill, Thaler]

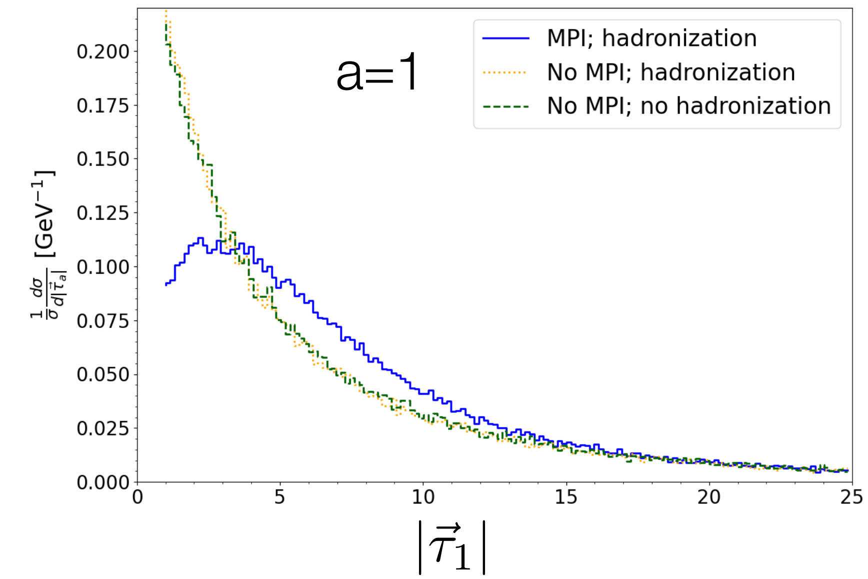
NLL' results compared to Pythia for a=1

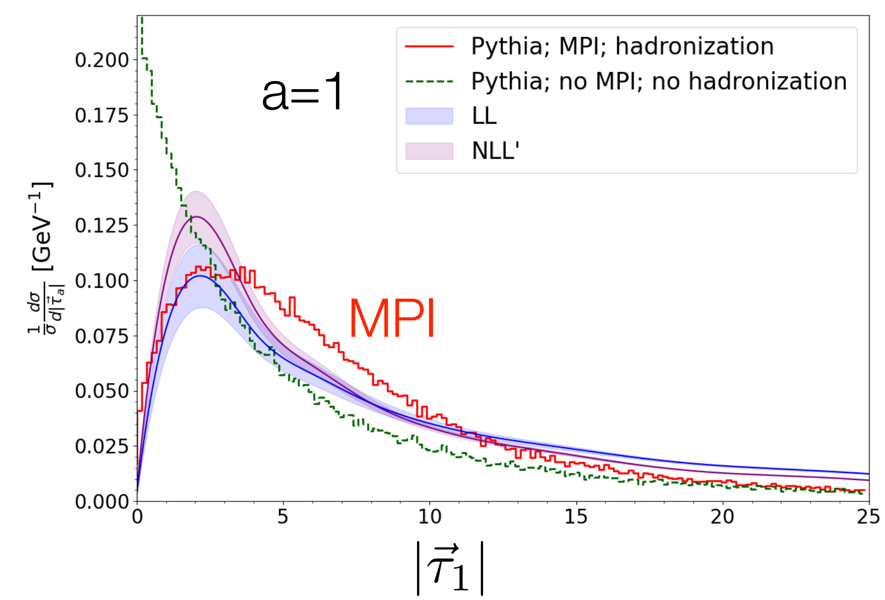


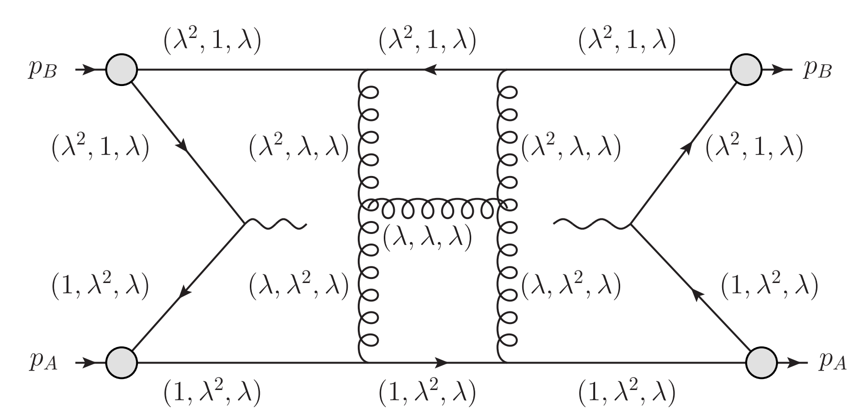
- Resummed perturbation theory converges
- Looks more like Pythia+MPI in peak
- Baseline **without Glaubers** important to study fact. violation

Conclusions

- Vector angularities smoothly connect to q_T, for which fact. is proven
- Fact. violated away from q_T case, using MPI models as proxy
- Baseline predictions without fact. violation needed. N^{4}LL available for q_T → High precision for vector ang.?
- Can we **calculate** effect of fact. violation using Soft-Collinear Effective Theory with Glaubers? [Rothstein, Stewart]







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Thanks!