CS kernel determination from MC (PB-TMDs)

04.05.2022

A. Bermúdez Martínez, A. Vladimirov

See yesterday talks (WG4), and Safura's talk earlier today

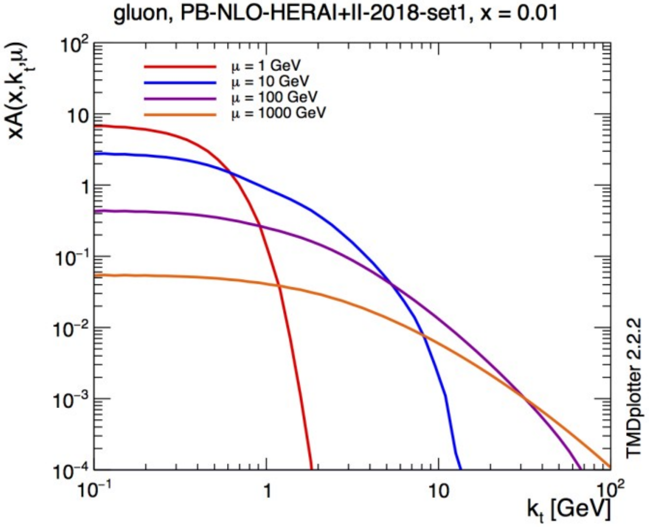
Parton Branching (PB) method

FH et al. [PLB 772 (2017) 446–451]
FH et al. [JHEP 2018, 70 (2018)]
ABM et al. [PRD 99, 074008 (2019)]

- Evolution of TMDs (and collinear PDFs)
- Resummation of soft gluons at LL and NLL
- Solution valid at LO, NLO and NNLO
- Determination of TMDs from the fully exclusive solution
- **Backward evolution fully determines the TMD shower**

nation of TMDs from

→ consistently treats perturbative and non-perturbative transverse momentum effects



Implemented in the CASCADE generator

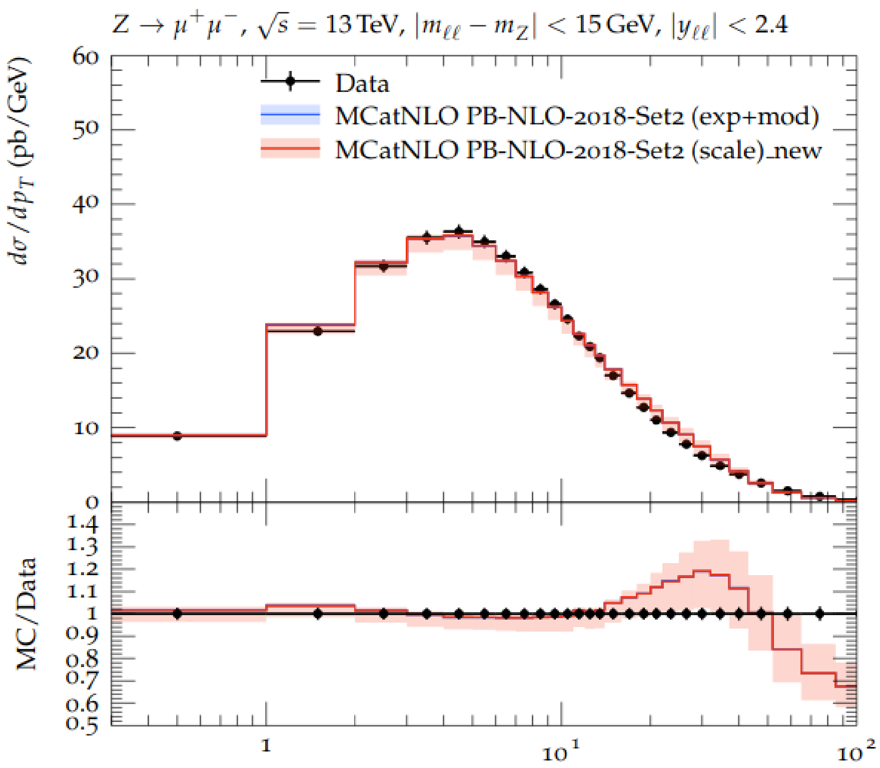
Eur. Phys. J. C 81 (2021) 425

PB-TMDs in high mass DY production

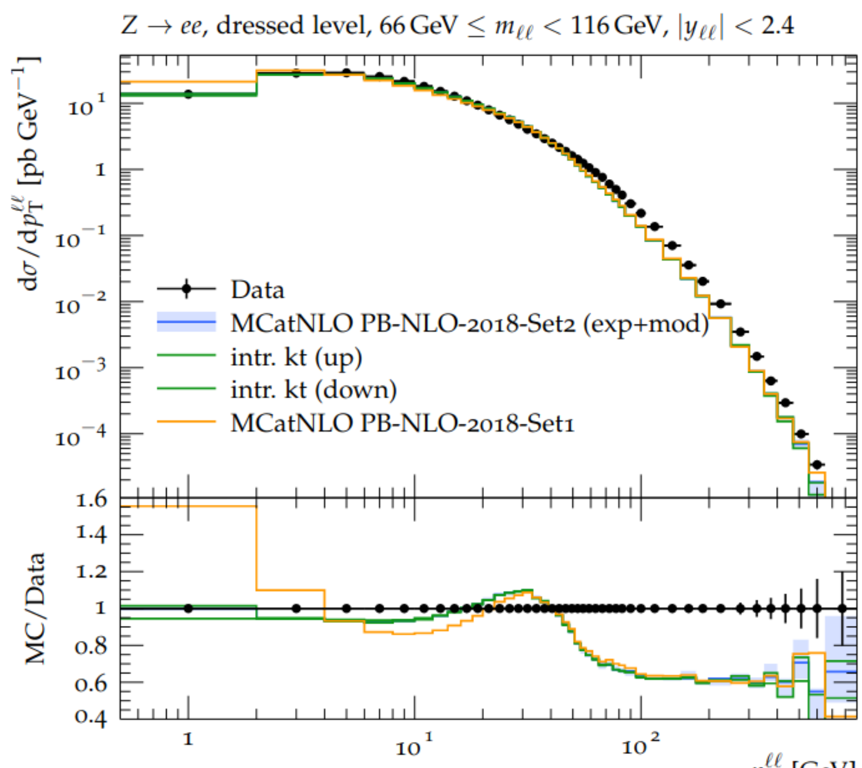
DY pt spectrum

- Combined with MC@NLO
- **Excellent description of DY pT spectrum**
- **Non-perturbative TMD effects not significant at high pT**
- **Missing contributions at high pT**

ABM et al. [PRD 100, 074027 (2019)]
ABM et al. [EPJC 80, 598 (2020)]



CMS at 13 TeV



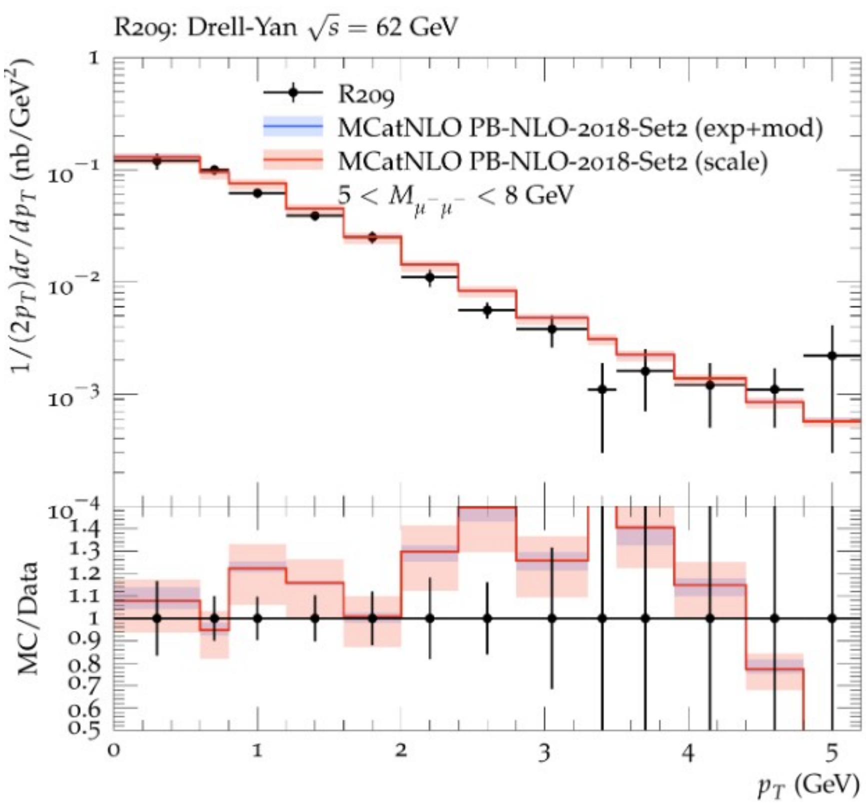
ATLAS at 8 TeV

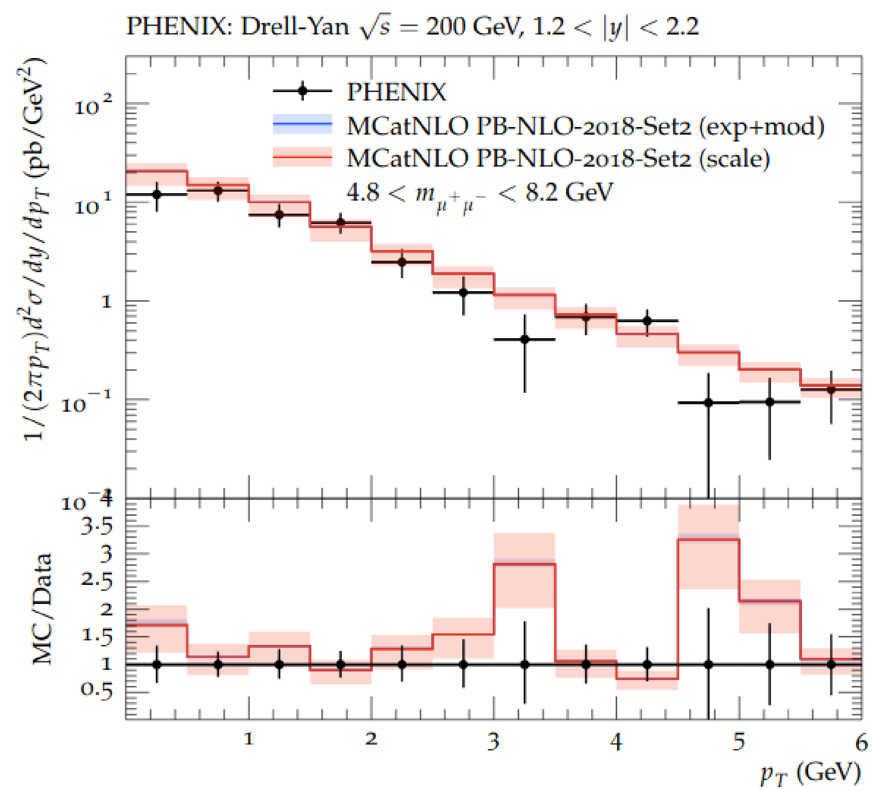
PB-TMDs to low mass DY production

DY pt spectrum

ABM et al. [PRD 100, 074027 (2019)]
ABM et al. [EPJC 80, 598 (2020)]

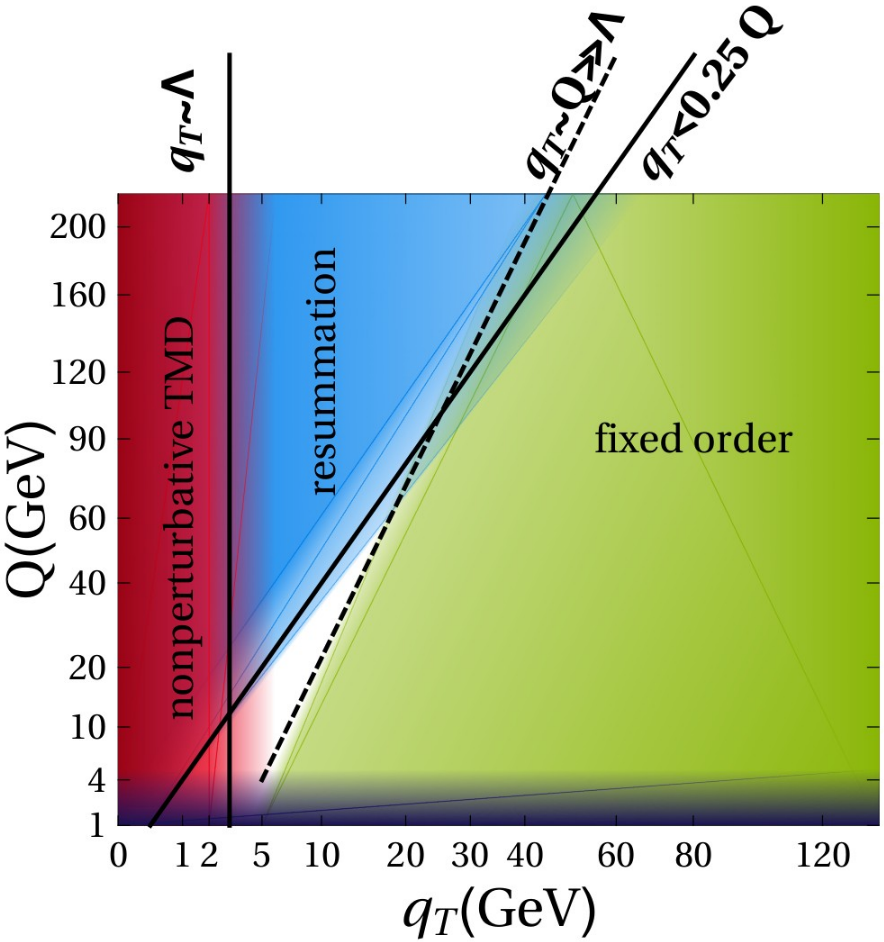
- Combined with MC@NLO
- Excellent description of DY pT spectrum
- **First simultaneous description of both low and high-mass DY pT spectrum**
- **No more low pT crisis** **Bacchetta et al. [PRD 100 (2019) 014018]; ABM et al. [EPJC 80, 598 (2020)]**

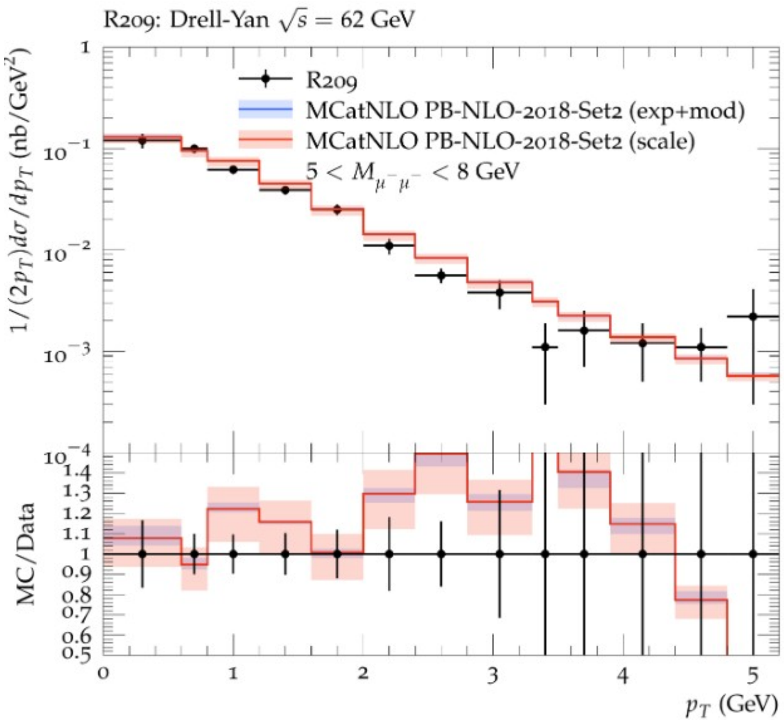




PB-TMDs to DY production

- Description of the pT spectrum over a wide DY mass range
- **Valuable non-perturbative information**





Glance at TMD factorization

At small kt:

$$\frac{d\sigma}{dQ^2 dy dq_T^2} = \frac{2\pi}{9}\frac{\alpha_{\rm em}^2(Q)}{sQ^2} W_{f_1 f_2}(x_1, x_2, Q, q_T),$$

$$W_{f_1 f_2} = |C_V(Q)|^2 \int_0^\infty db b J_0(b q_T) \sum_q e_q^2 f_{q_1}(x_1, b; Q, Q^2) f_{q_2}(x_2, b; Q, Q^2).$$

Notice the dependence on two scales of the parton distributions

---

Taking the Hankel (Fourier) transform of the xsec:

$$\boxed{\Sigma(y, Q; b) = \frac{2\pi}{9}\frac{\alpha_{\rm em}^2(Q)}{sQ^2} |C_V(Q)|^2 \sum_q e_q^2 f_{q_1}(x_1, b; Q, Q^2) f_{q_2}(x_2, b; Q, Q^2).}$$

Glance at TMD factorization

Evolving the parton densities to fixed scales:

$$\Sigma(y,Q;b) = \frac{2\pi}{9}\frac{\alpha_{\rm em}^2(Q)}{sQ^2}|C_V(Q)|^2 \boxed{e^{2\Delta(b;Q\to(\mu_0,\zeta_0))}} \sum_q e_q^2 f_{q_1}(x_1,b;\mu_0,\zeta_0) f_{q_2}(x_2,b;\mu_0,\zeta_0),$$

Notice the following points:

- The Q dependence of the parton densities transferred to a **residual exponential factor**
- Ratios of the xsec for different Qs do not depend on the collinear parton densities
- **Non-perturbative component** of those ratios would then live only in the exponential

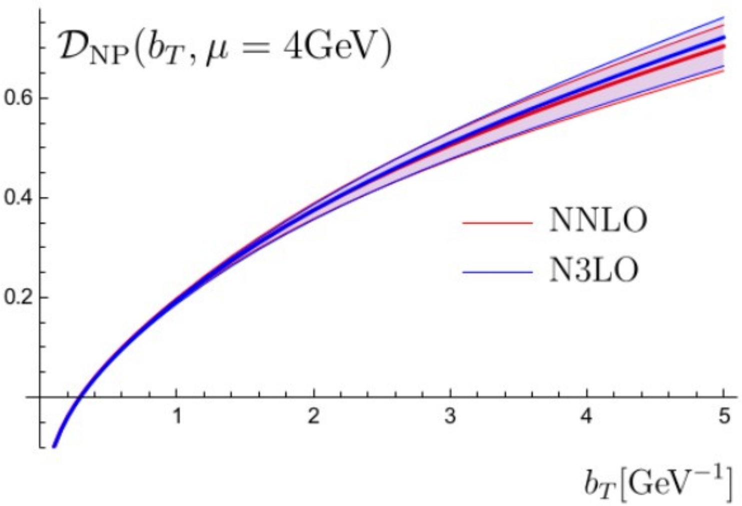
$$\Delta(b;Q\to(\mu_0,\zeta_0)) = \int_P \left(\gamma_F(\mu,\zeta)\frac{d\mu}{\mu} - \boxed{\mathcal{D}(b,\mu)}\frac{d\zeta}{\zeta}\right),$$

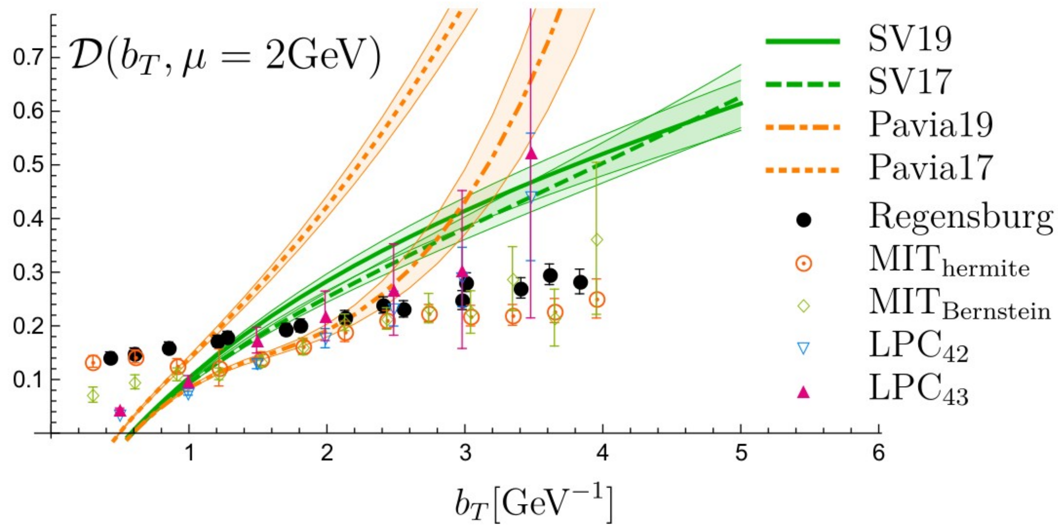
Collins-Soper kernel

CS kernel

- **Self-contained object**
- Perturbative sensitivity at small b
- **Non-perturbative sensitivity at small b**
- Existing lattice calculations

A. Vladimirov, [Phys. Rev. Lett. 125, 192002]





Let’s dive into the new method, applied in MC (PB-TMDs) and extendable to real data!!

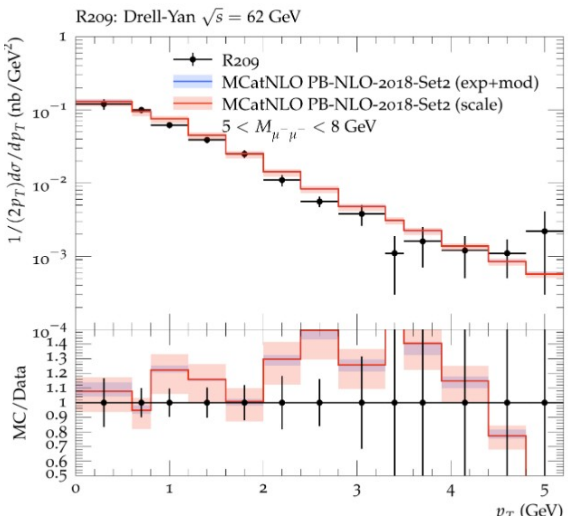
ABM and A. Vladimirov [in preparation]

CS kernel from Parton Branching

Main formula

$$\boxed{\frac{\Sigma_1}{\Sigma_2}} = \frac{s_2}{s_1}\frac{Q_2^2}{Q_1^2} Z(Q_1, Q_2) e^{\boxed{2\Delta(b;Q_1 \to Q_2)}}$$

Simulation/ Measurement



But in b space!

Analytically

Get CS kernel from here

CS determination process

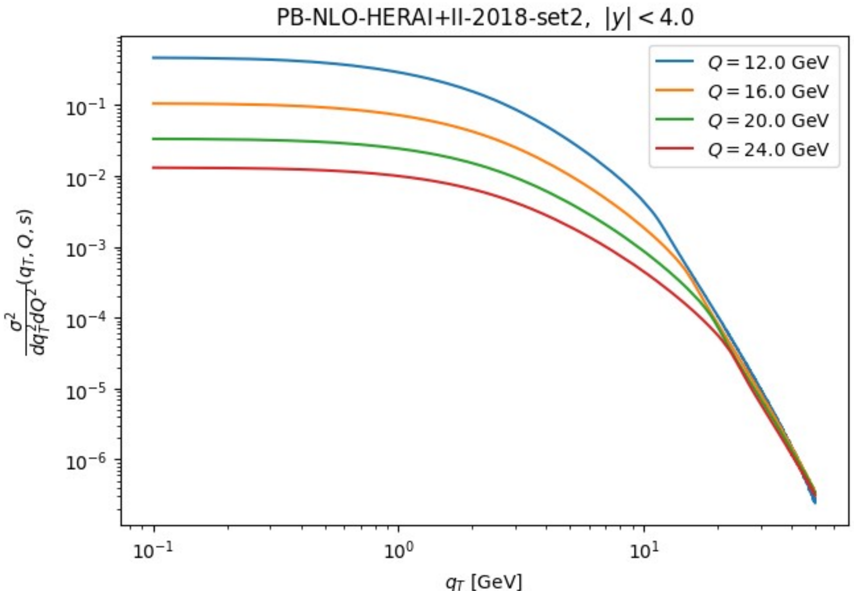
- DY pT in narrow bins of Q={Q1, Q2}
- Choose {s, y} such that x's coincide
- Very fine binning in pT

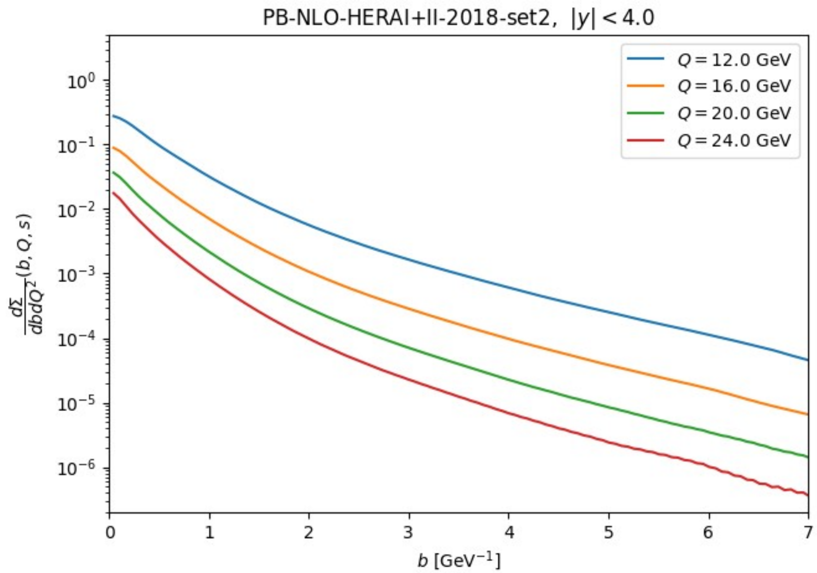
Get the Fourier transform

CS kernel from Parton Branching

Hankel/Fourier transform of the xsec

$$\Sigma(b, Q, y, s) = \int_0^\infty dq_T\, q_T\, J_0(bq_T)\, \frac{d\sigma}{dQ^2 dy d^2\mathbf{q}_T^2}$$



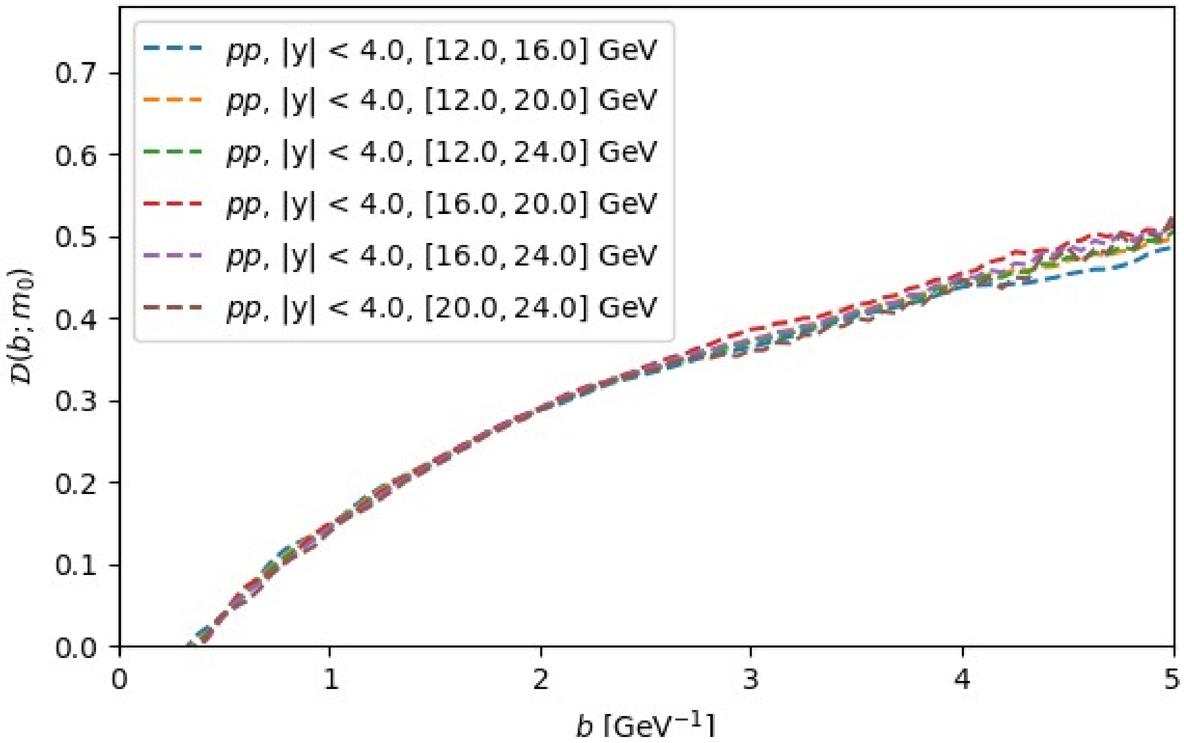


CS determination process

- DY pT in narrow bins of Q={Q1, Q2}
- Choose {s, y} such that x's coincide
- Very fine binning in pT

CS kernel from Parton Branching

Determine CS kernel



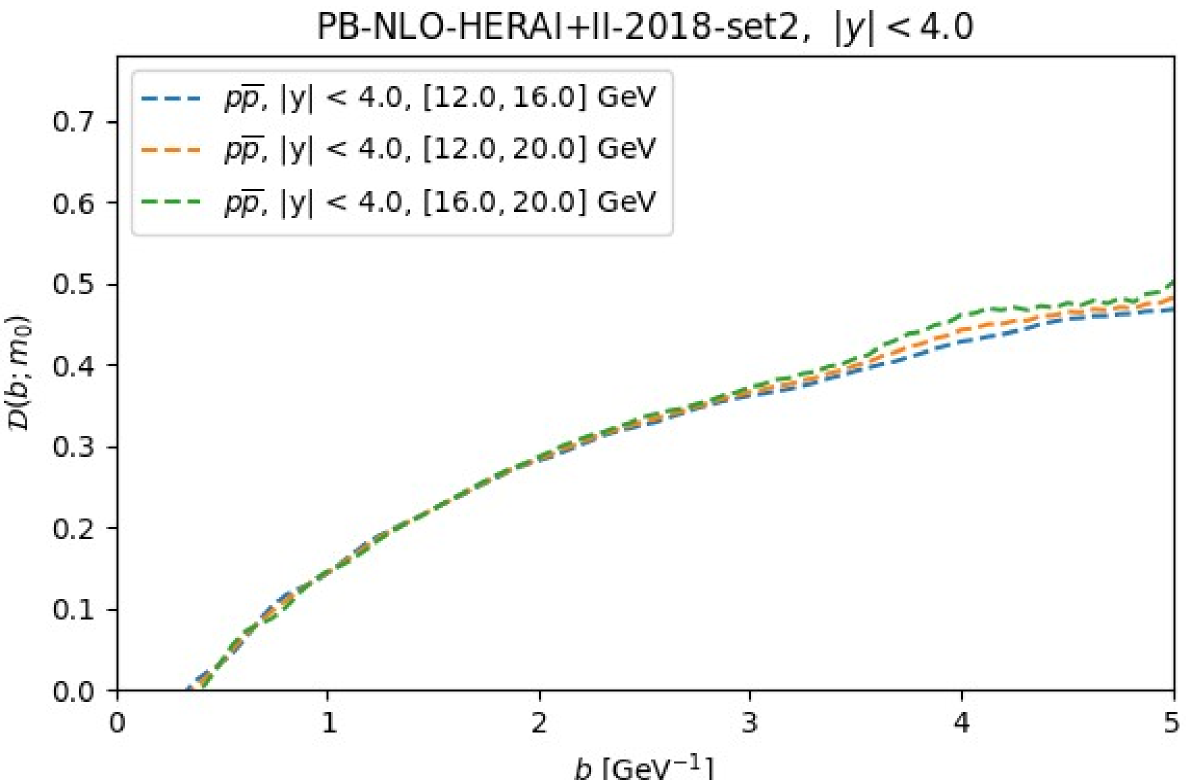
Ideally

- **Different Q's must coincide**
- Different processes must coincide
- Should not depend on y range
- Should not depend on collinear PDF input

ABM and A. Vladimirov [in preparation]

CS kernel from Parton Branching

Determine CS kernel

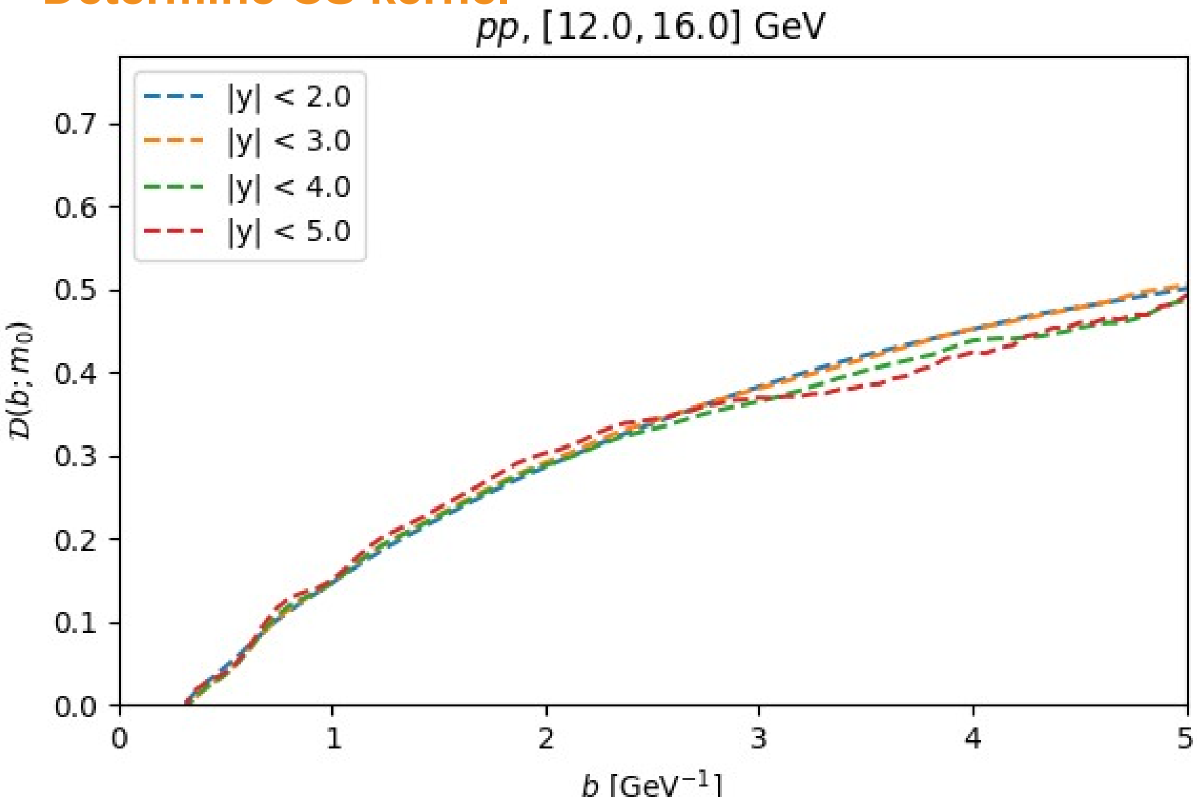


Ideally

- Different Q's must coincide
- **Different processes must coincide**
- Should not depend on y range
- Should not depend on collinear PDF input

CS kernel from Parton Branching

Determine CS kernel

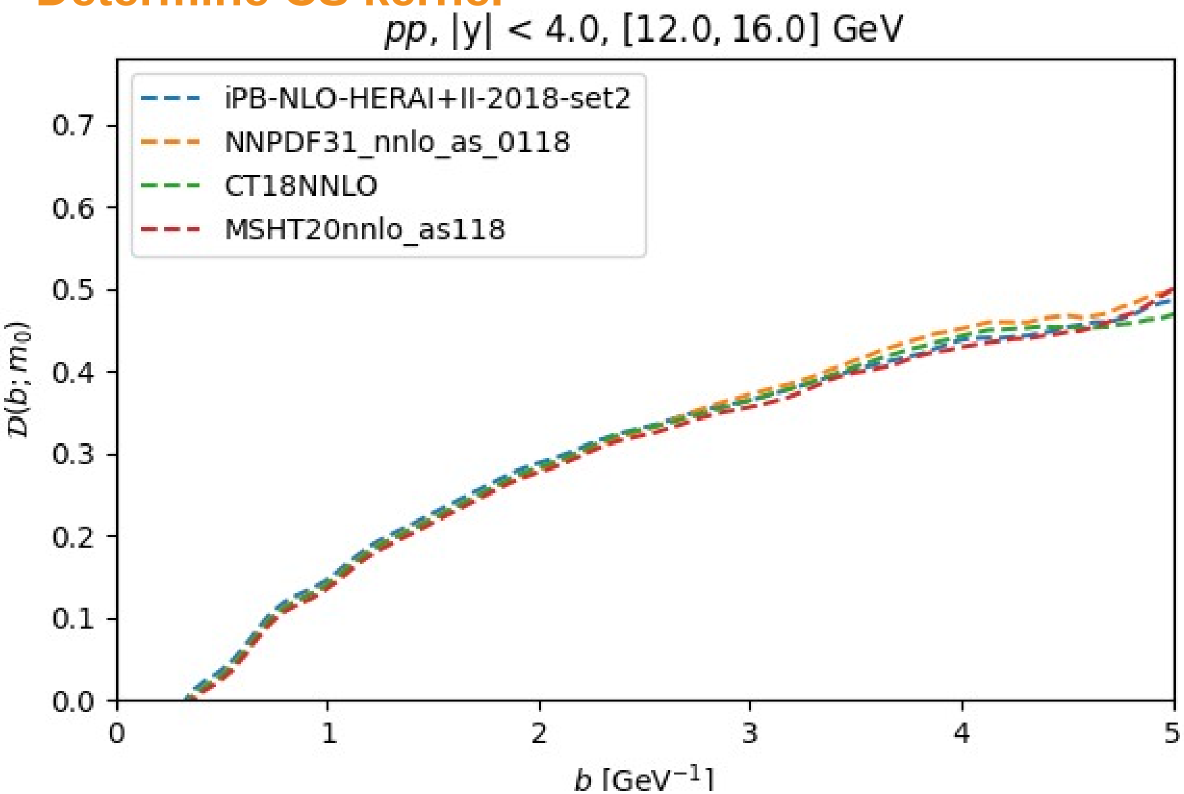


Ideally

- Different Q's must coincide
- Different processes must coincide
- **Should not depend on y range**
- Should not depend on collinear PDF input

CS kernel from Parton Branching

Determine CS kernel



Ideally

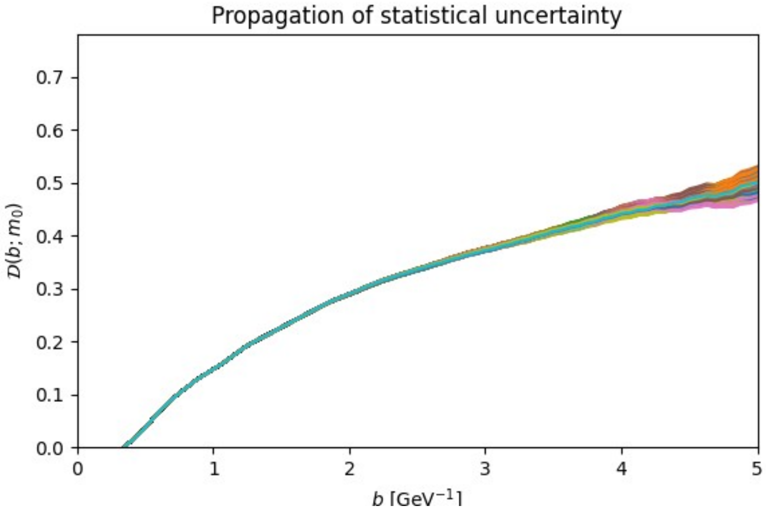
- Different Q's must coincide
- Different processes must coincide
- Should not depend on y range
- **Should not depend on collinear PDF input**

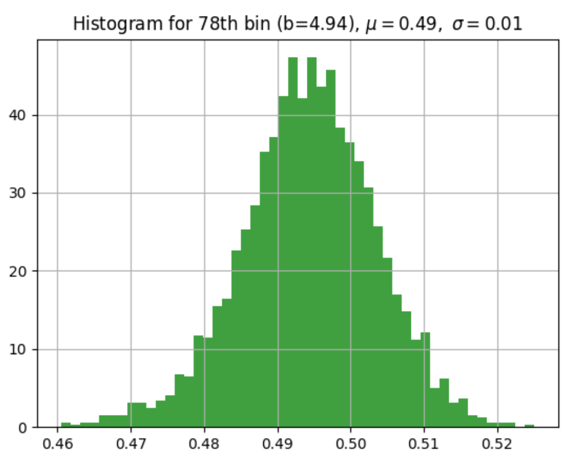
PB passed!!

CS kernel from Parton Branching

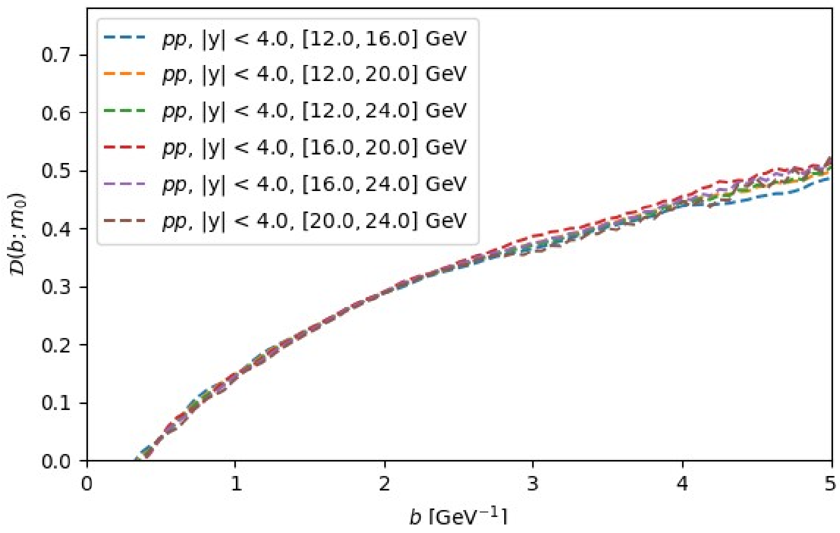
Uncertainty sources

Statistical propagation



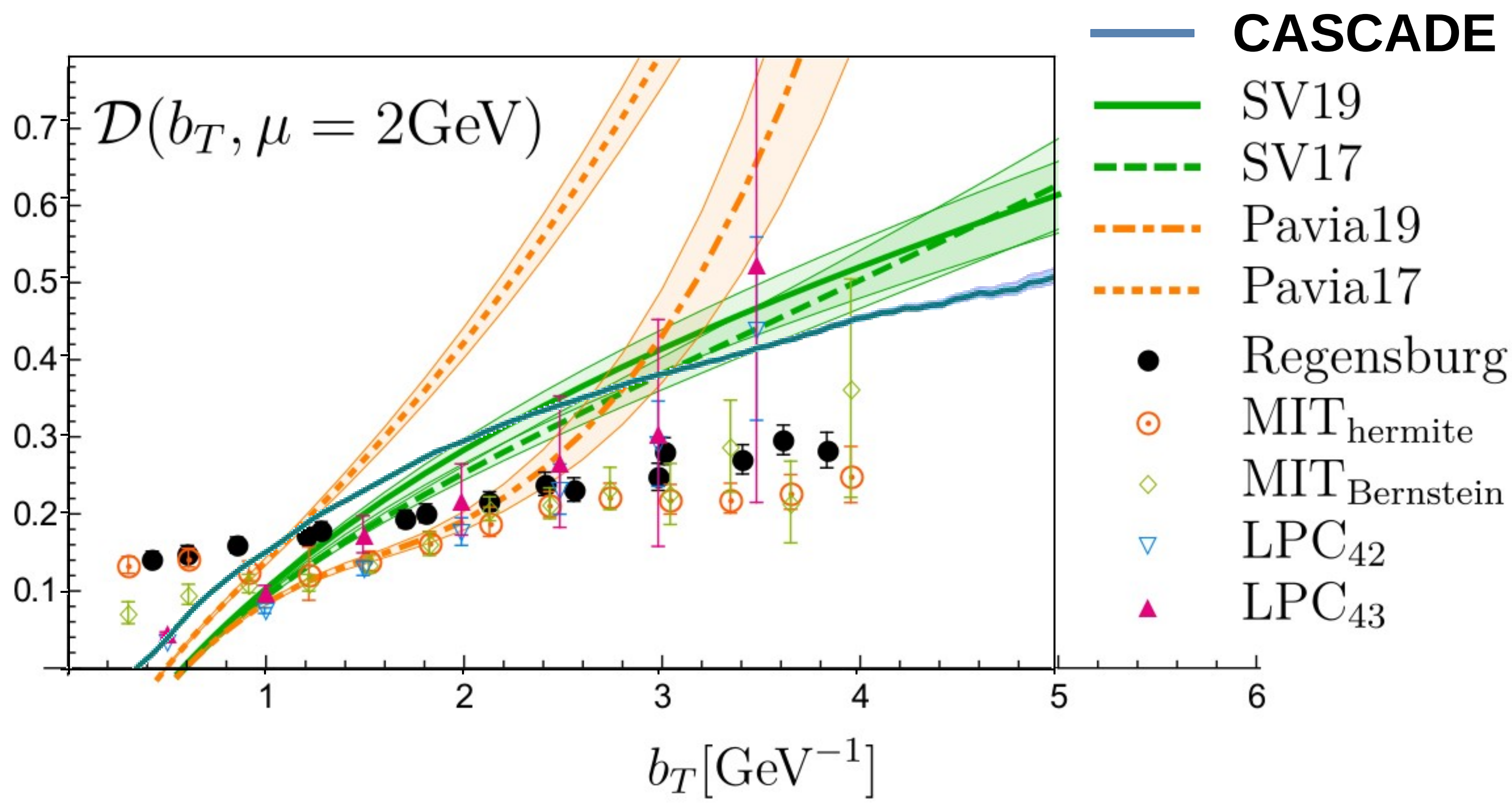


Scale variations



CS kernel from Parton Branching

Determine CS kernel



- There is a general agreement in shape between MC, Lattice, SV19 at large b
- MC shape consistent with perturbative calculation at low b

Conclusions

- CASCADE generator (PB-TMDs) consistent with TMD factorization
- Method to determine CS kernel from MC
- First determination of CS kernel from MC
- MC shape consistent with perturbative calculations at small b
- MC shape consistent with lattice calculations at large b
- Prove of concept → **to be used with real measurements**