TMD evolution and intrinsic k_T in Monte Carlo generators

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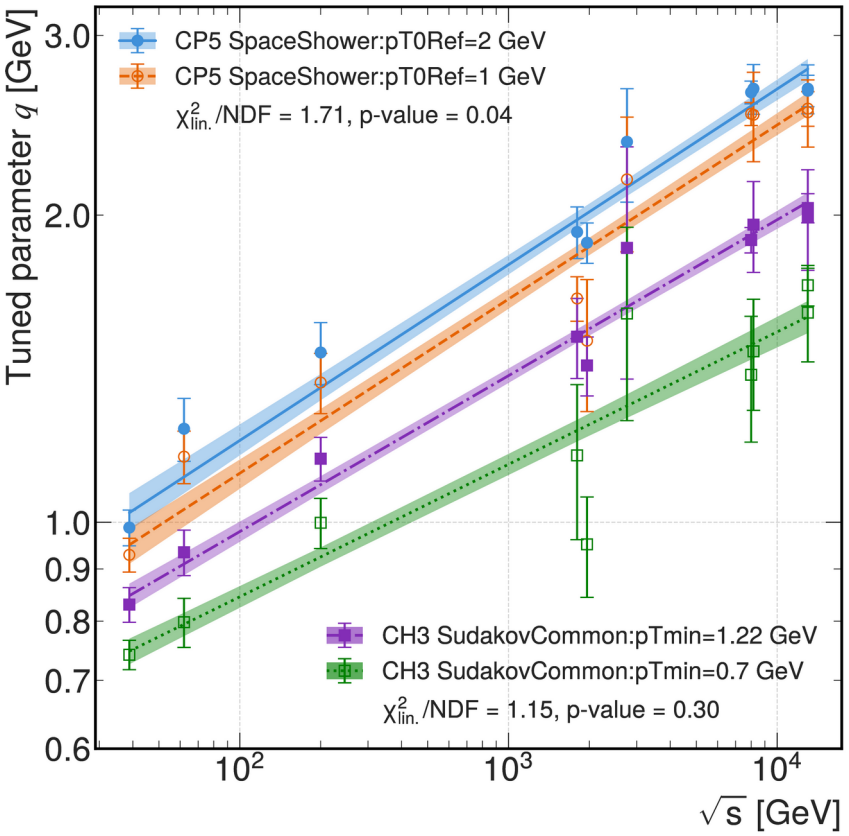
Intrinsic k_T in parton showers

- Most predictions for LHC experiments done with Pythia/Herwig
- They have an “initial” k_T parameter
- Inconsistent values depending on $\sqrt{s}$

- **Do TMDs modify this picture?**

CMS-GEN-22-001



Intrinsic k_T with PB TMD

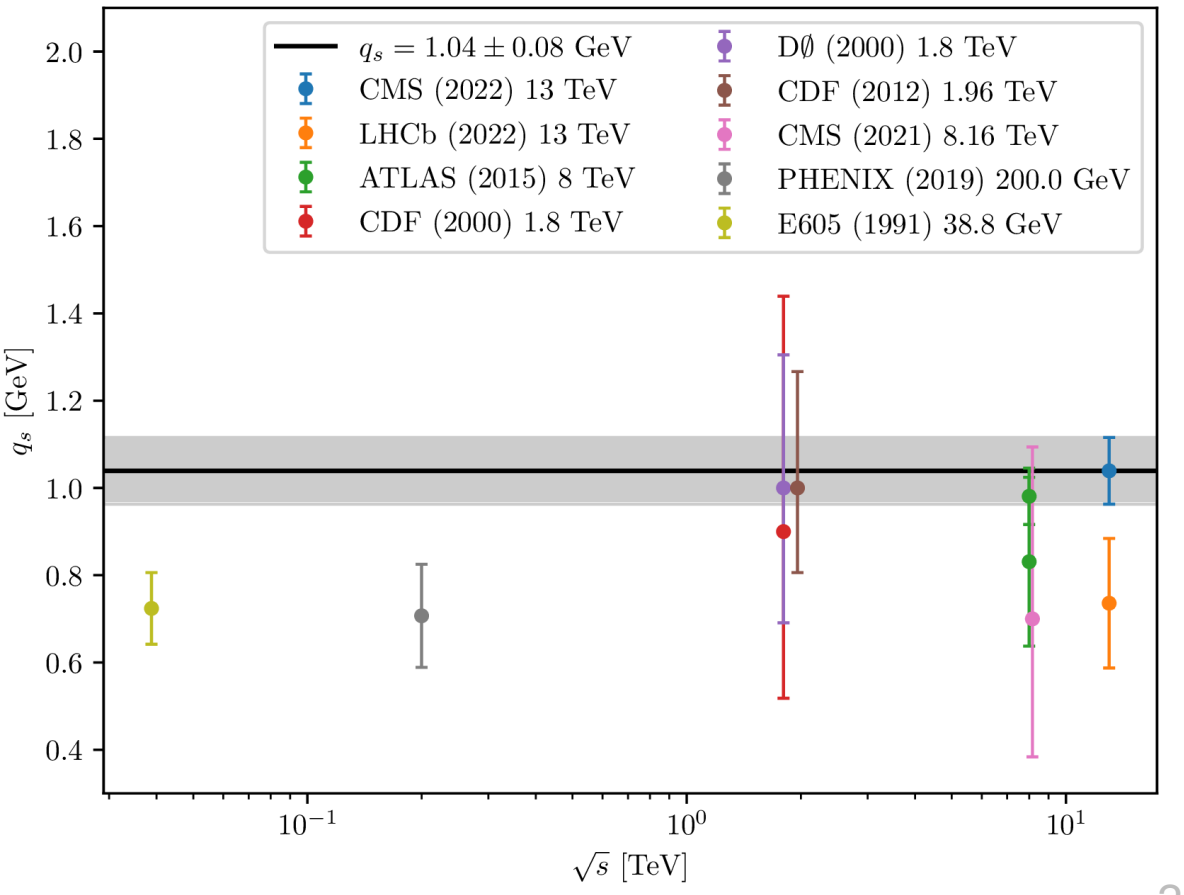
We use the parton branching approach:

- Intrinsic k_T has a Gaussian distribution at low scale
- Only parameter: q_s = width of the distribution
- We obtained that:

  q_s = (1.04 ± 0.08) GeV

  from PB TMD fit to CMS 13 TeV data

EPJ C 84 (2024) 154 (I. Bubanja, …, LM, …)



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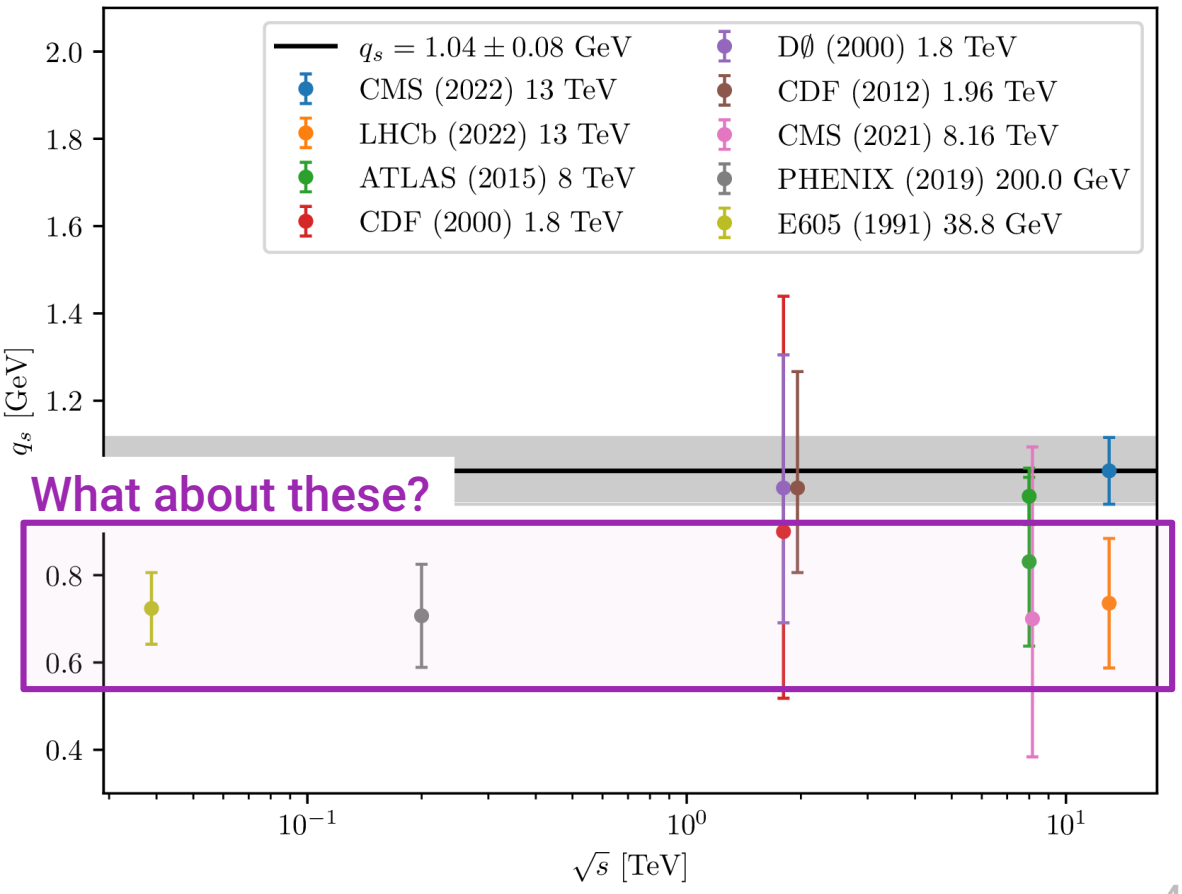

Points favoring lower q_s

Three points favor lower q_s:

- **E609** at Fermilab
- **PHENIX** at the RHIC
- **LHCb** at the LHC

Two low(er)-energy experiments, a forward detector...

- High- or low-*x* behavior?
- Valence vs sea effects?

This talk: revisit the LHCb point

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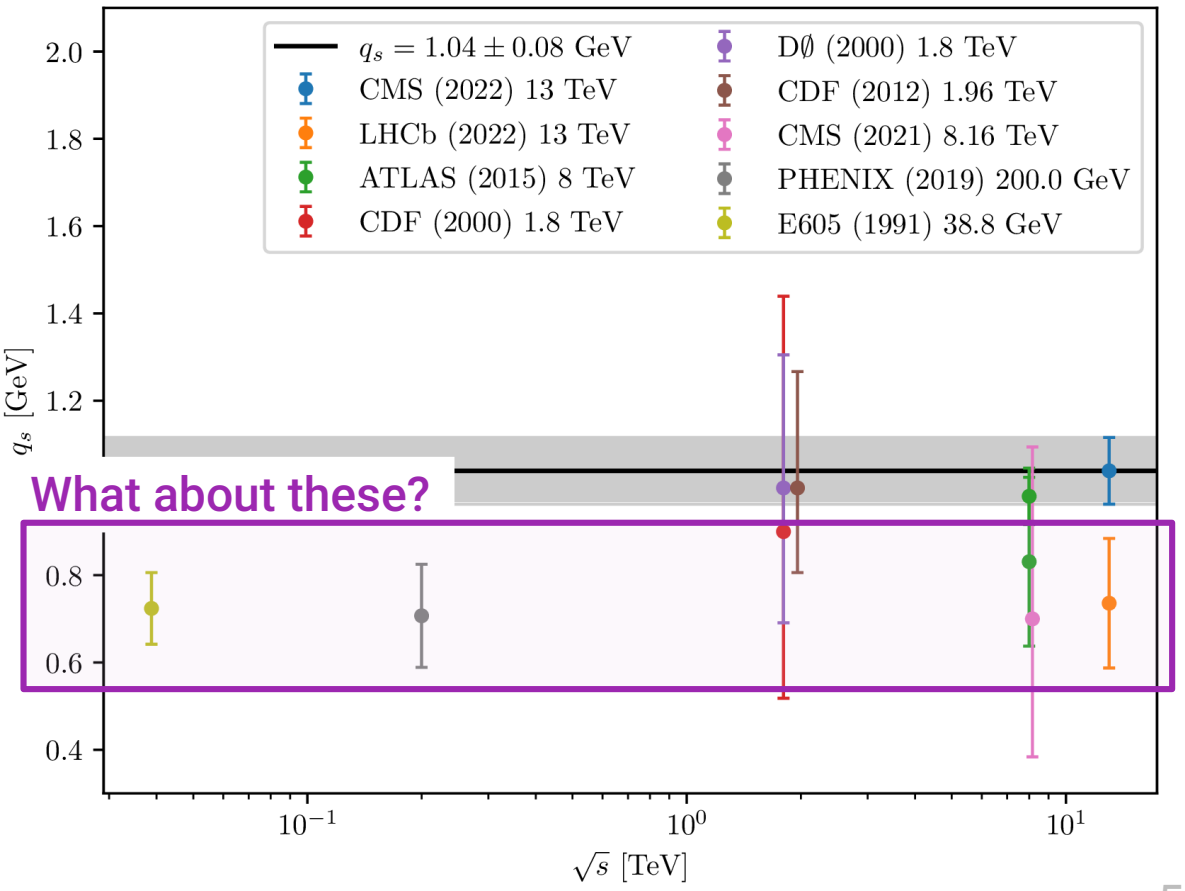
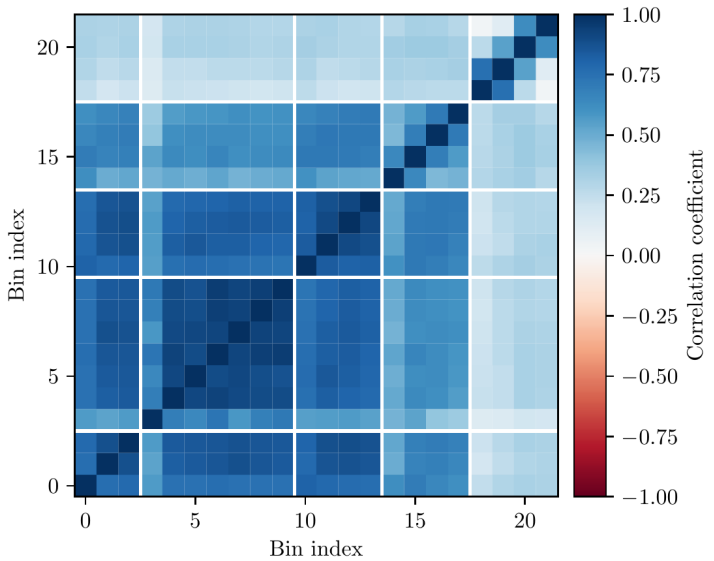


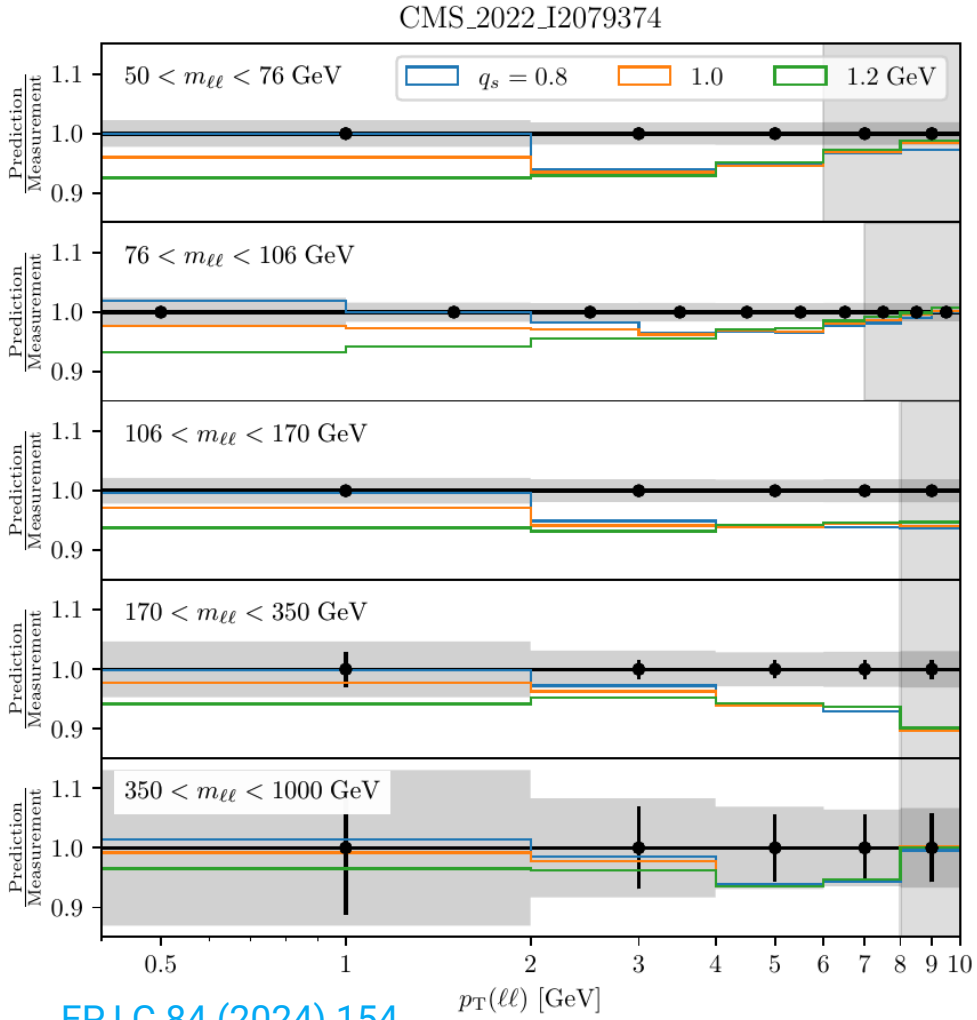
Recap of fit to CMS data

We used low-p_T Drell-Yan

Detailed fit taking the complete correlation matrix into account:



Simpler approach used for the LHCb point



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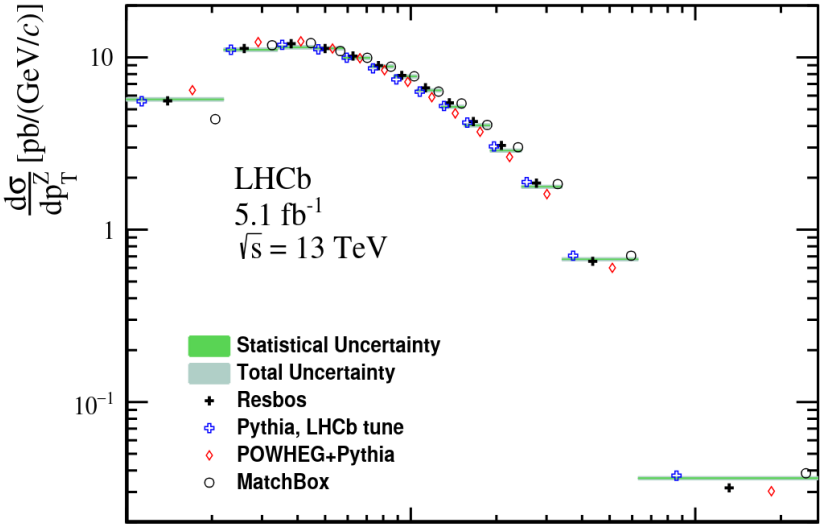
What LHCb provides

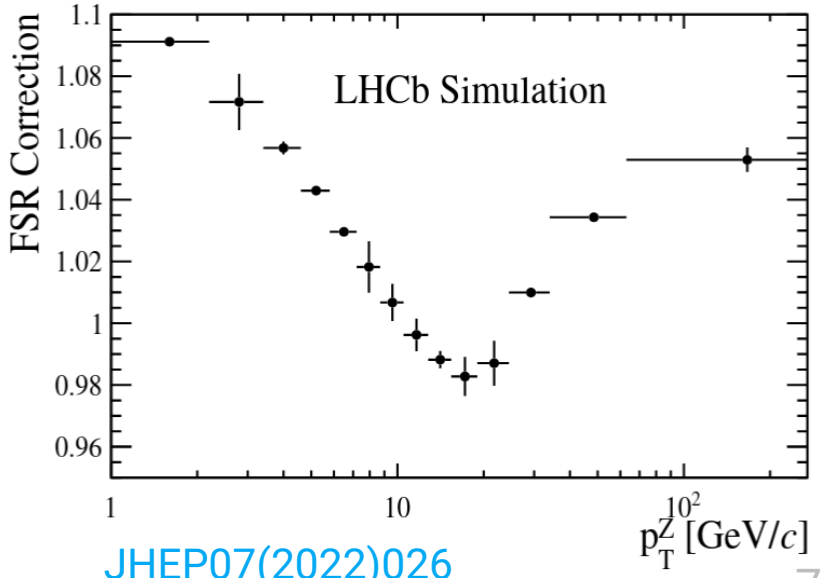
HepData record

- Total cross section
- Transverse momentum p_T: TMD effects
- Rapidity y: PDF effects
- 2D p_T—y: ideally we want to fit this!
- Correlation breakdown

FSR correction:

- Published results are at Born level
- The Rivet routine dresses leptons
- Small inconsistency, for now we ignore





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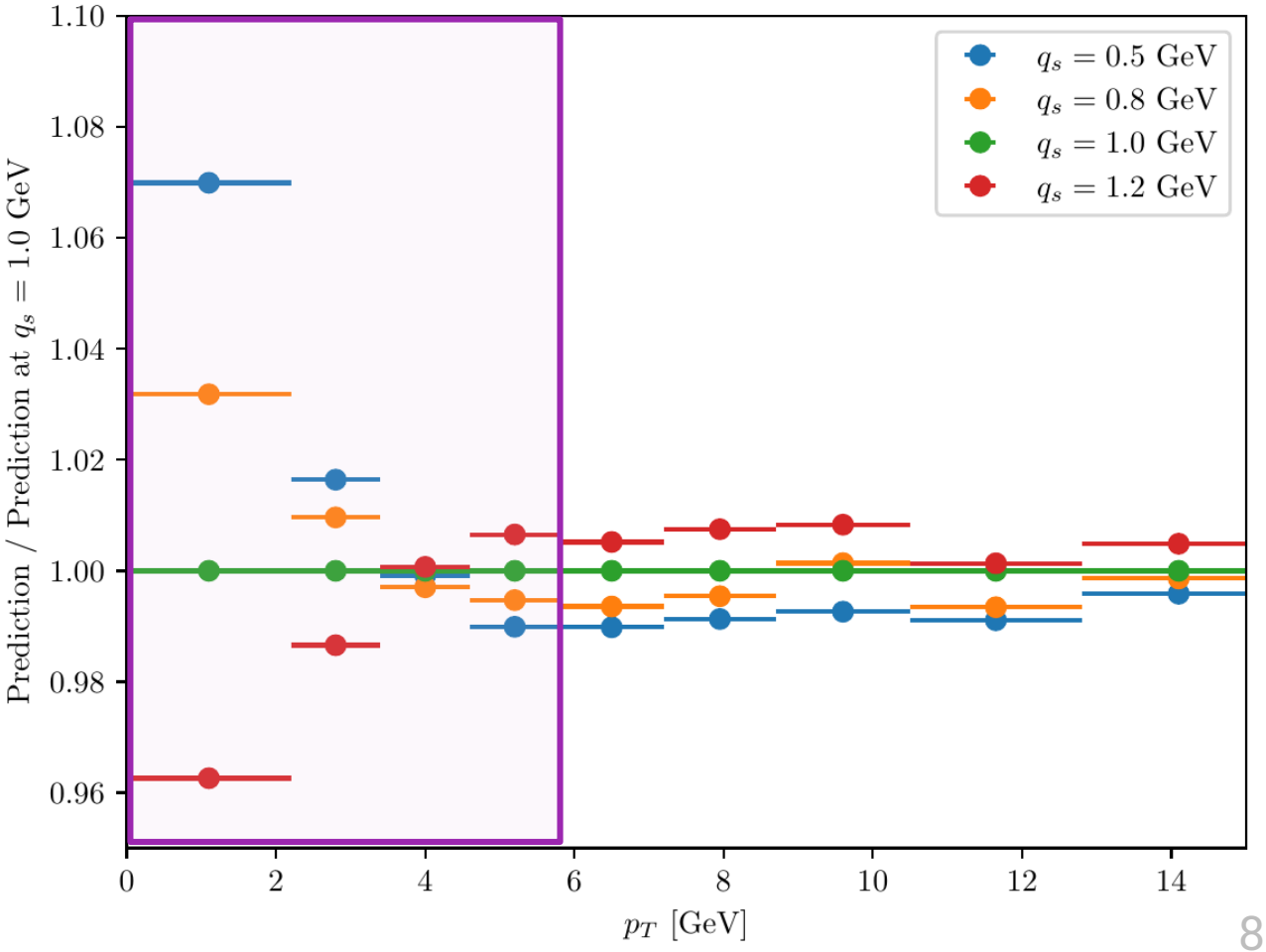
Sensitive bins

Before we fit, check which bins are sensitive:

➔ 3 to 4 bins

➔ Stop at 4.6 or 5.8 GeV

Our NLO prediction is insufficient at medium p_T, so we need to stop early

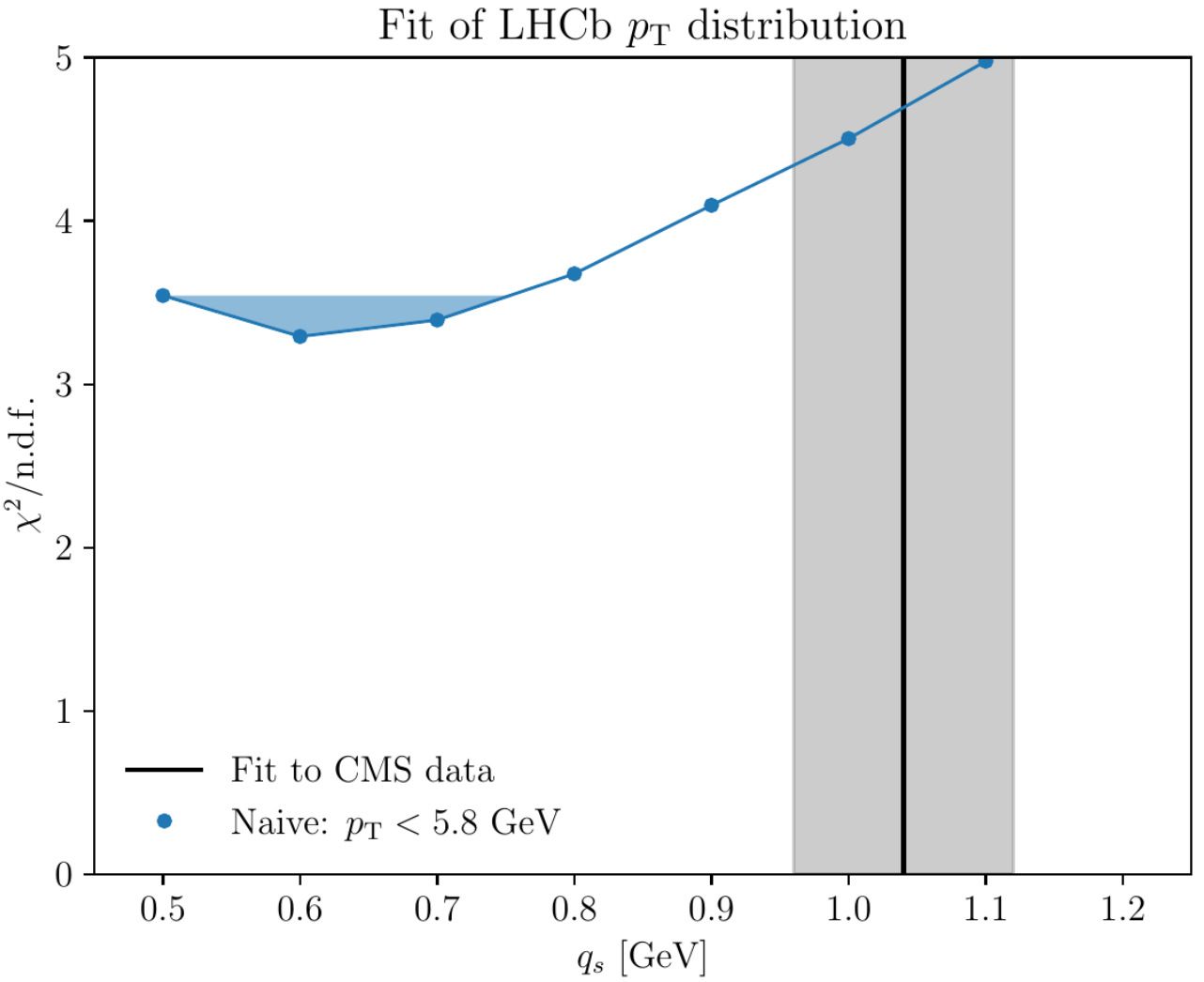


First fit

Check results **without correlations**

We recover $q_s \sim 0.7$ as in the published results

Bad χ^2:
Overall normalization is off by ~10%



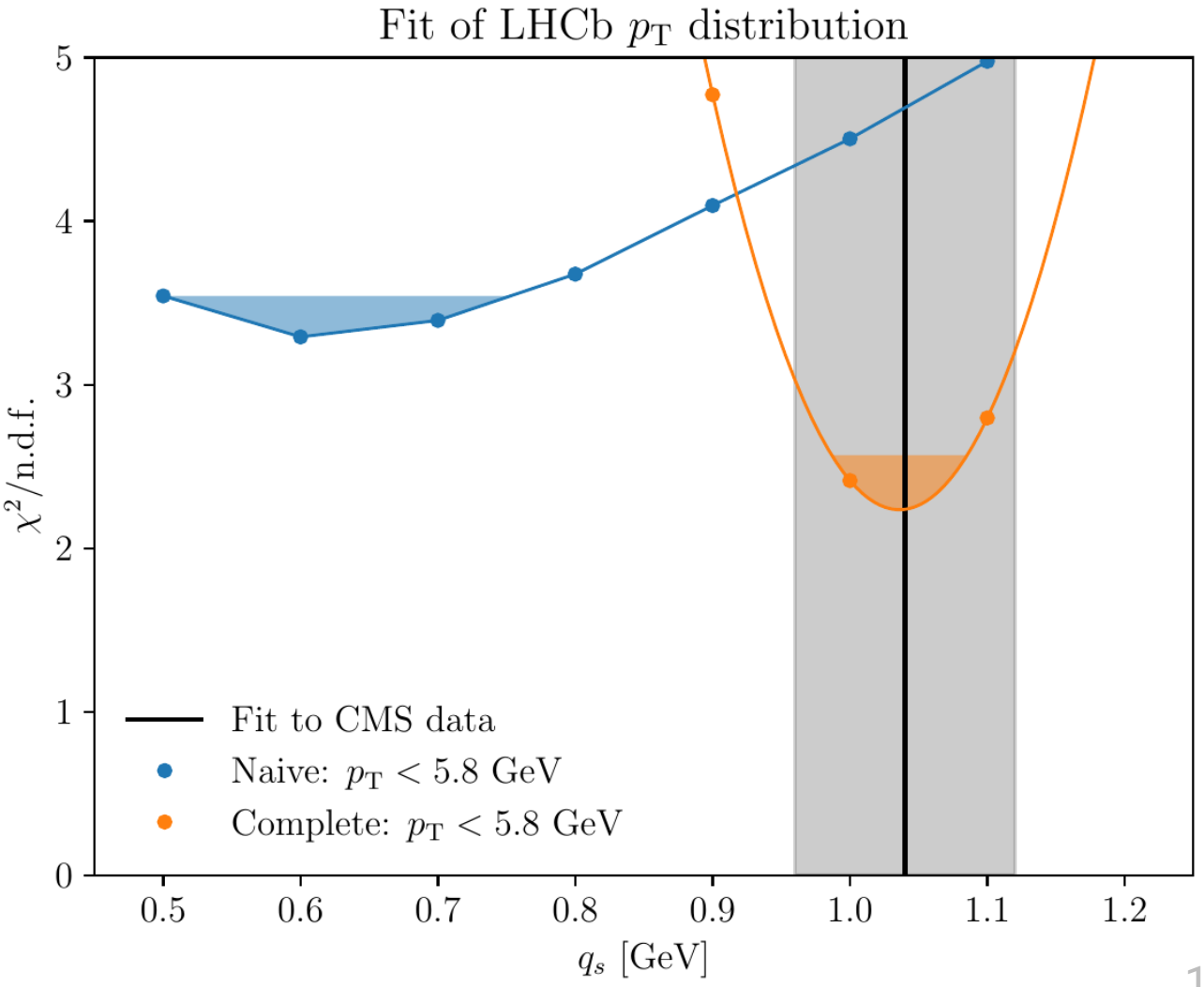
Better fit

Changes:

- Let normalization float (−1 d.o.f.)
- Take correlations into account

Outcome:

- Reduced uncertainty
- Compatible with CMS!



Stability

How stable is this?

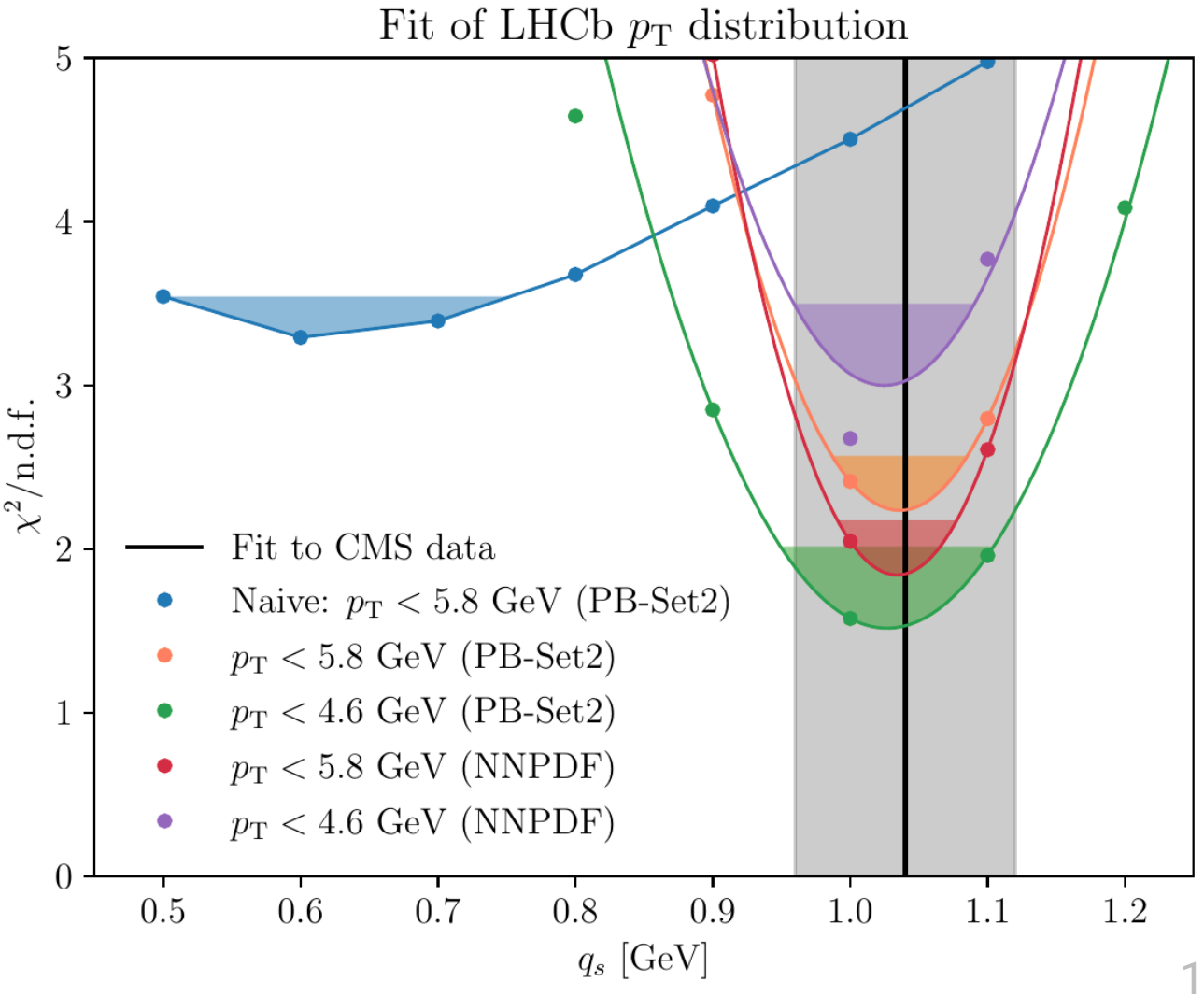
➔ Vary fit conditions

All fits agree:

q_s = (1.03 ± TBD) GeV

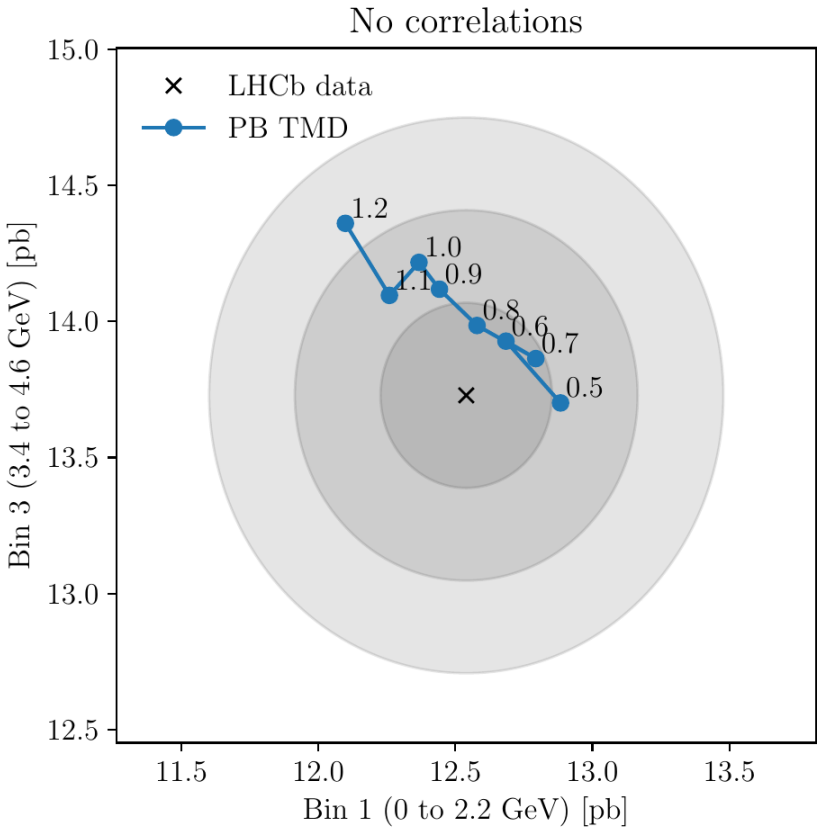
Compare to CMS data:

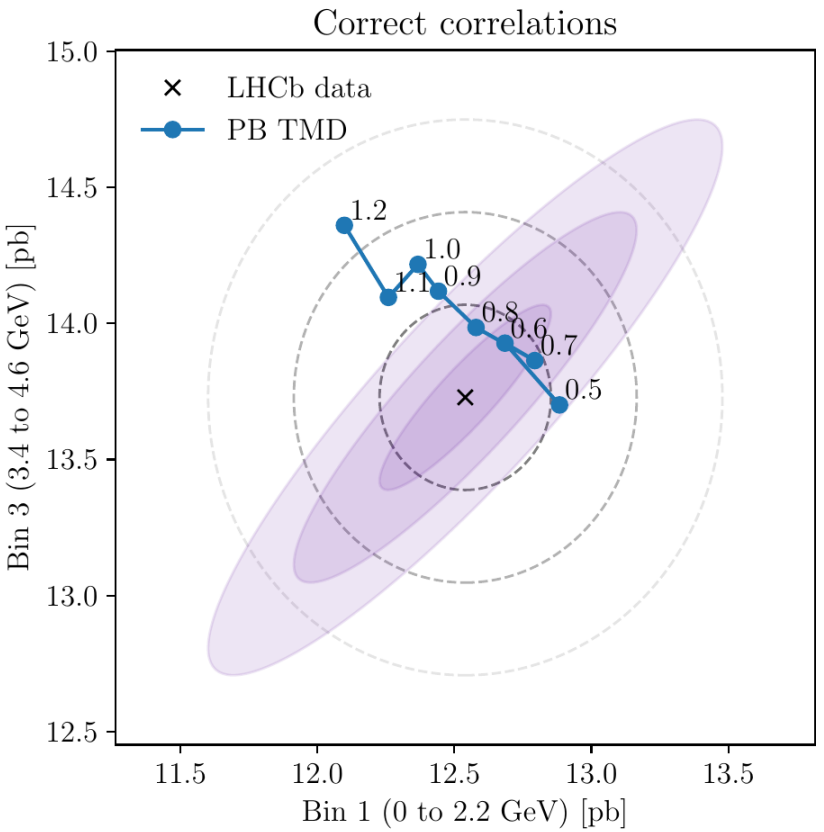
q_s = (1.04 ± 0.08) GeV



Intermezzo – Why do correlations matter so much?

With multiple bins, we need to look at uncertainties in a multidimensional space





An optimistic 2D fit in $|y|-p_T$

We are interested in a potential $|y|$ dependence of q_s

- High- and low-x
- Valence vs sea

Let's use our best fit setup on the 2D measurement

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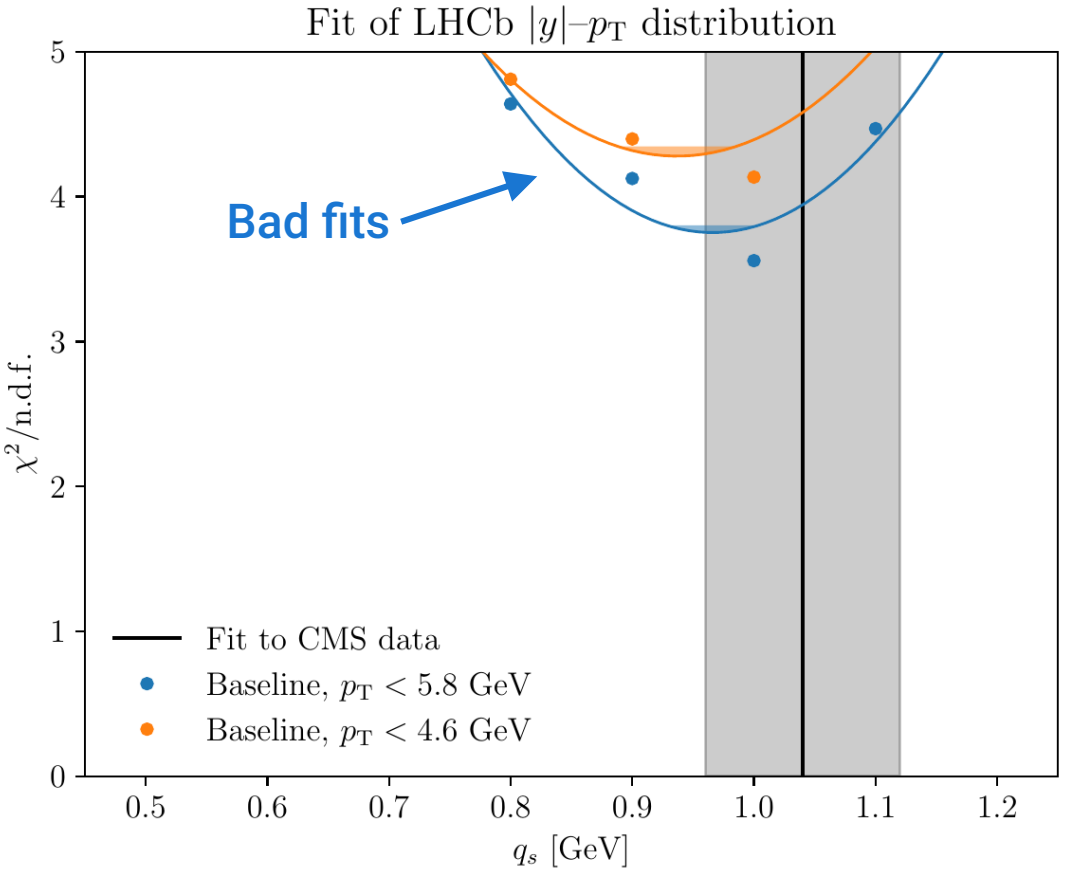
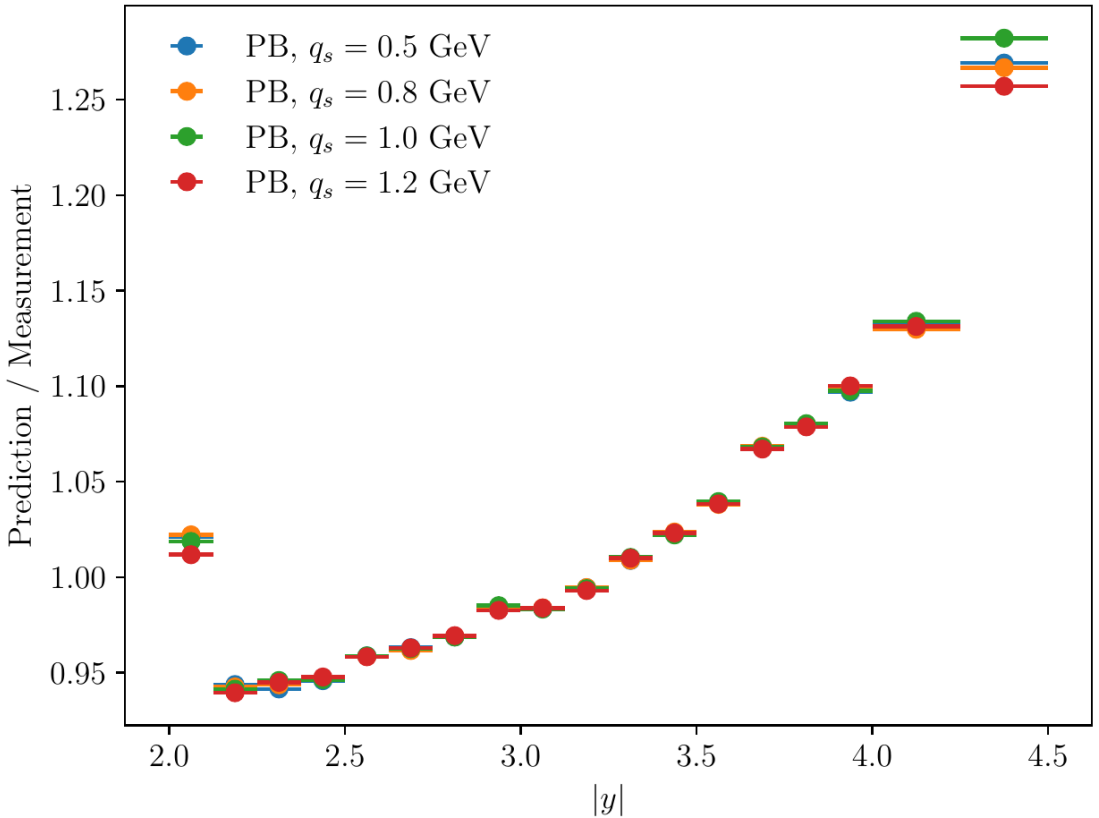


Rapidity



Adding |y| kills fit quality:

- The integrated TMD already predicts |y| incorrectly
- Independent of q_s
- Expected at high/low x because the PB fit uses HERA data only

➔ A correction is needed

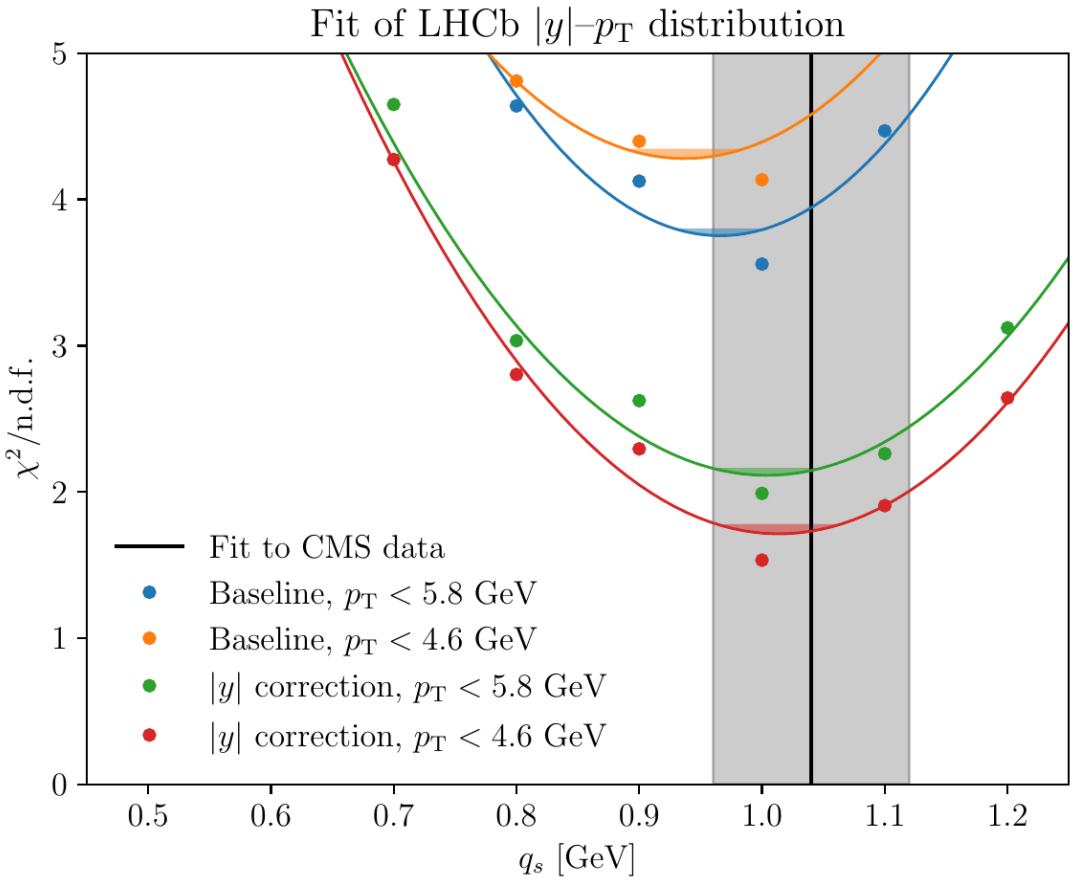
Fit with |y| correction

Ad hoc correction method:

- Take each |y| bin
- Derive ratio from data / PB TMD
- Rescale PB 2D prediction
  (all p_T bins by the same factor)

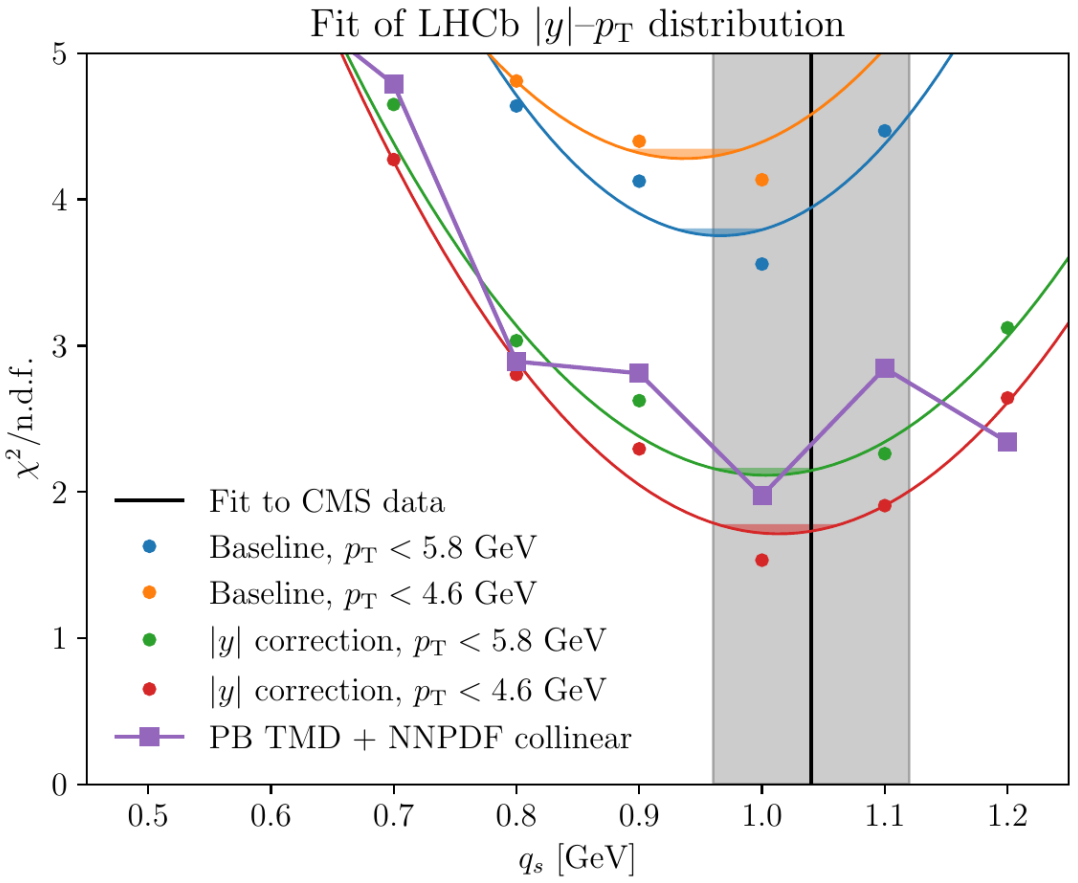
Significantly improves fit quality

- Still some tension
- Is the correction valid?



Correction with NNPDF

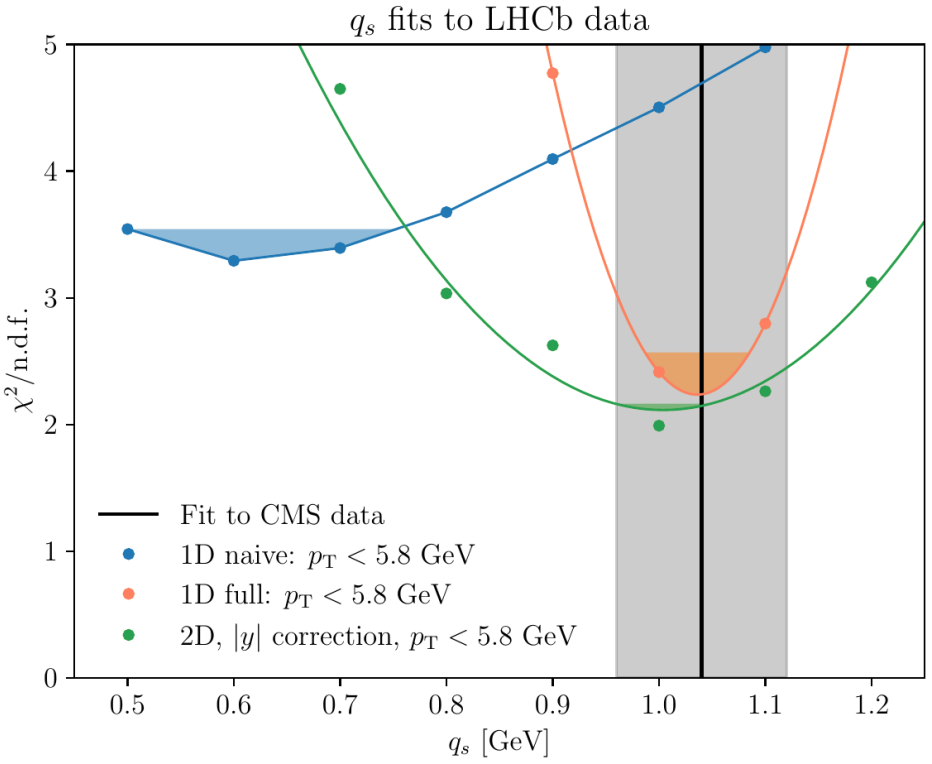
- Low/high-x behavior of PB TMD questionned
- Use a modern PDF set?
- NNPDF 3.1 in matrix element + PB TMD evolution
- Confirms validity of ad-hoc correction
- Calls for fitting the collinear part of the PB TMD with more than just HERA data



Summary

- Revisited LHCb data with PB TMD
- Fit of 1D and 2D with full correlations
- Beautiful agreement with CMS
- Correlations are important!

- Next: check for *x* dependence
- Some remaining tension in the fits
- PB TMD fit with high-*x* data?



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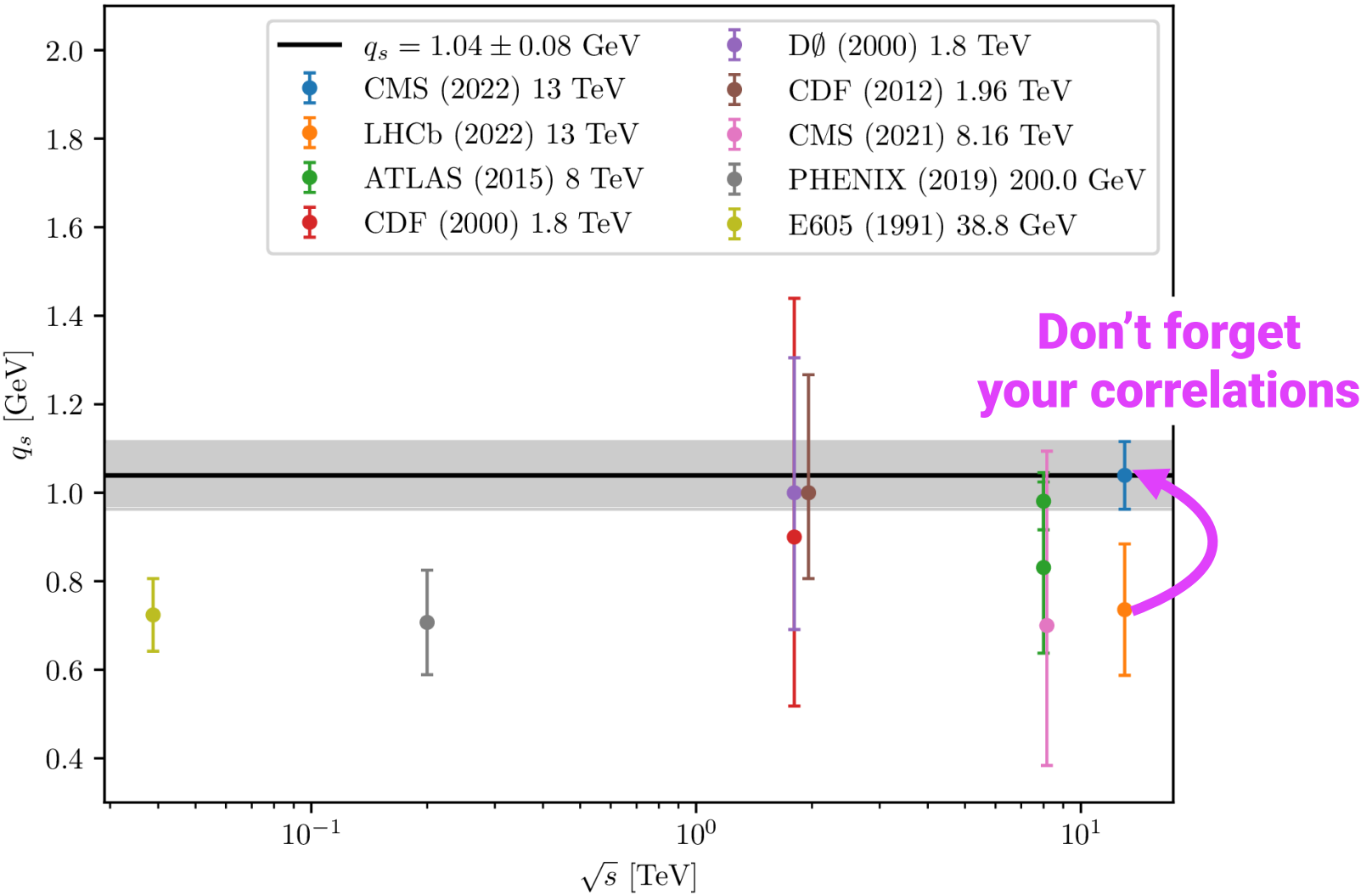
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