TMD evolution and intrinsic transverse momentum extraction

Laurent Favart, Aleksandra Lelek,
Francesco Hautmann, Louis Moureaux
... and the PB-TMD group

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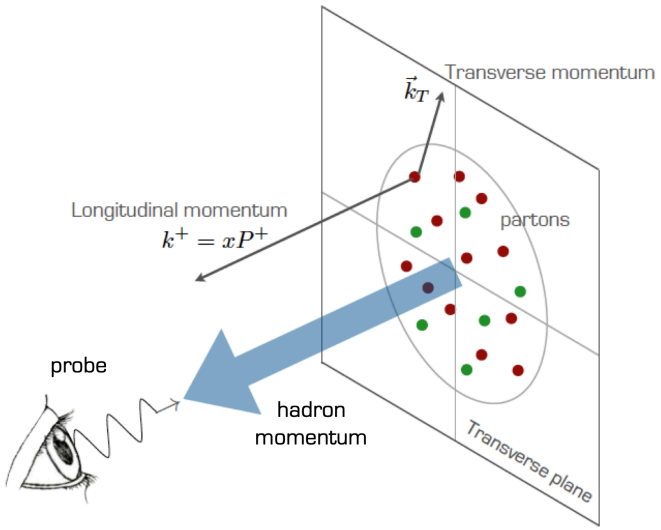
Transverse Momentum Distributions towards precision area

- Tremendous effort dedicated to precise PDF extraction during last decades
- More and more precise data available for TMD extraction



- This talk is about intrinsic kt extraction from Drell-Yan Pt measurements, using the TMD Parton Branching (PB-TMD) framework

⇨ See also talk of Andris Potrebko on Thursday

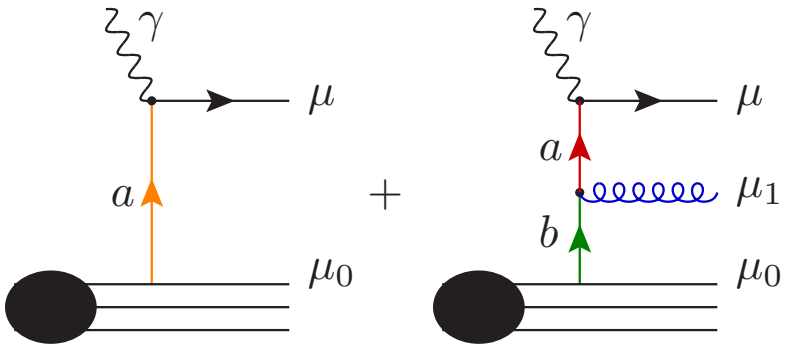
The PB-TMD approach

[JHEP 01 (2018), 070]

- Iterative method generating the recoil from the sum of each branching kt during the scale evolution

$$f_a(x,k_t^2,\mu^2) = f_a(x,k_{t0}^2,\mu_0^2)\Delta_a(z_M,\mu^2,\mu_0^2)$$
$$+\int_{\mu_0^2}^{\mu^2}\frac{d\mu_1^2}{\mu_1^2}\Delta_a(z_M,\mu^2,\mu_1^2)\sum_b\int_x^{z_M}\frac{dz}{z}\frac{\alpha_S}{2\pi}P_{ab}^R(z)\Delta_b(z_M,\mu_1^2,\mu_0^2)f_b\left(x/z,k_t^2,\mu_0^2\right)$$

$\Delta_a(z_M,\mu_1^2,\mu_2^2)$: Sudakov Form Factor $\mu_1^2 \to \mu_2^2$



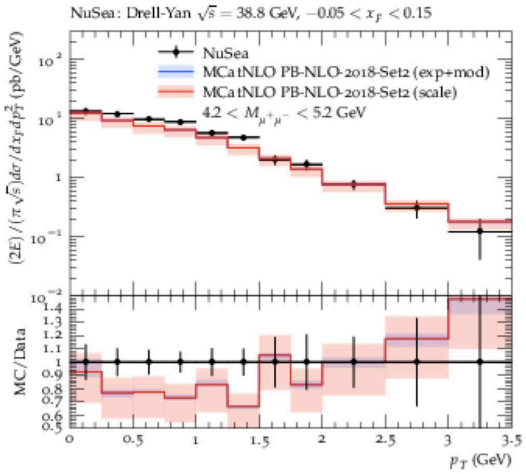
$k_{T,i} = (1-z)\mu_i$
angular ordering

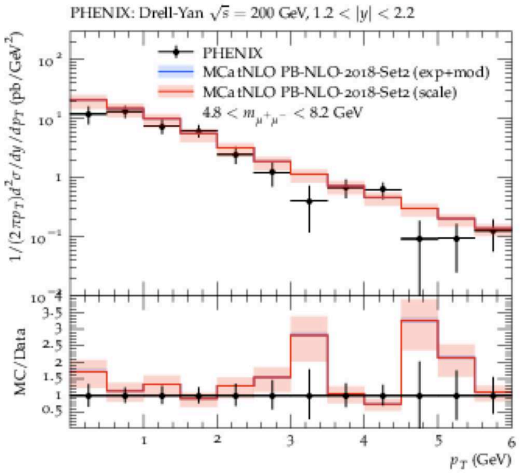
- Probabilistic interpretation and in kt space → easy to solve by Monte Carlo (CASCADE)
- Splitting functions at NLO

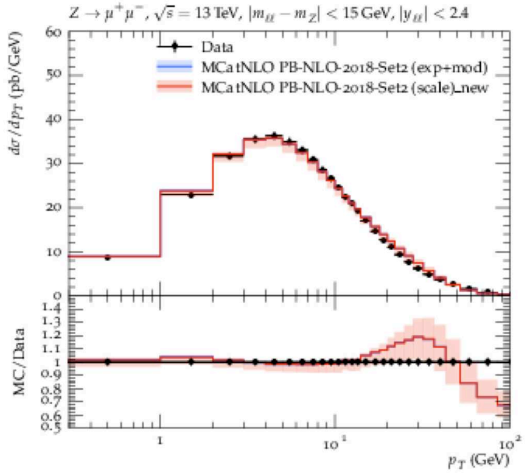
- $f_a(x, \mu_0^2)$ obtained from fit to HERA data (only)

PB Set 2	$k_{\perp,i} = (1-z)\mu_i$	$z_{Max} = 1-\epsilon$	$\alpha_S(\mu_i(1-z))$

- assuming Intrinsic kt $\quad f_a(x, k_{t0}^2, \mu_0^2) = f_a(x, \mu_0^2) \frac{1}{\pi q_s^2} e^{\frac{-k_{t0}^2}{q_s^2}} \quad q_s = 0.5$ GeV







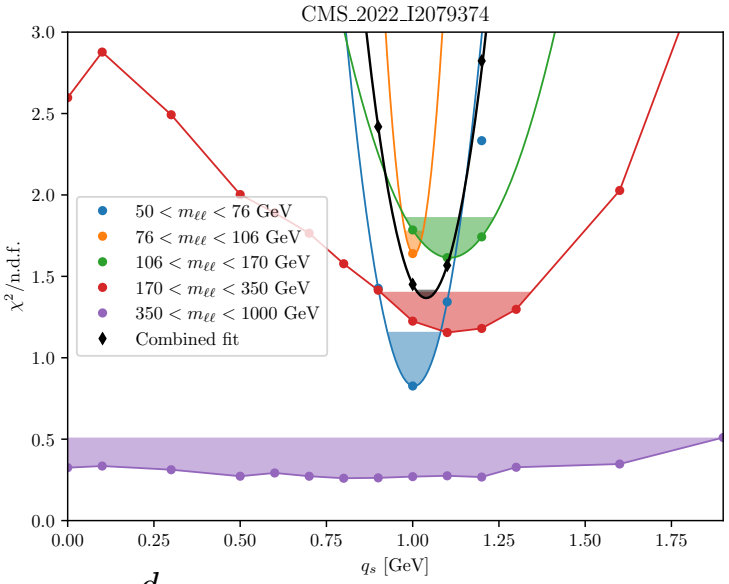
[Eur.Phys.J.C 80 (2020) 7, 598]

⇨ Good description of world Drell-Yan data
- with no parameter (except qs)

Good accuracy (NLO+NNLL) [Phys. Lett. B 868 (2025), 139762]
fast, robust and flexible

Tuning qs on CMS 13 TeV

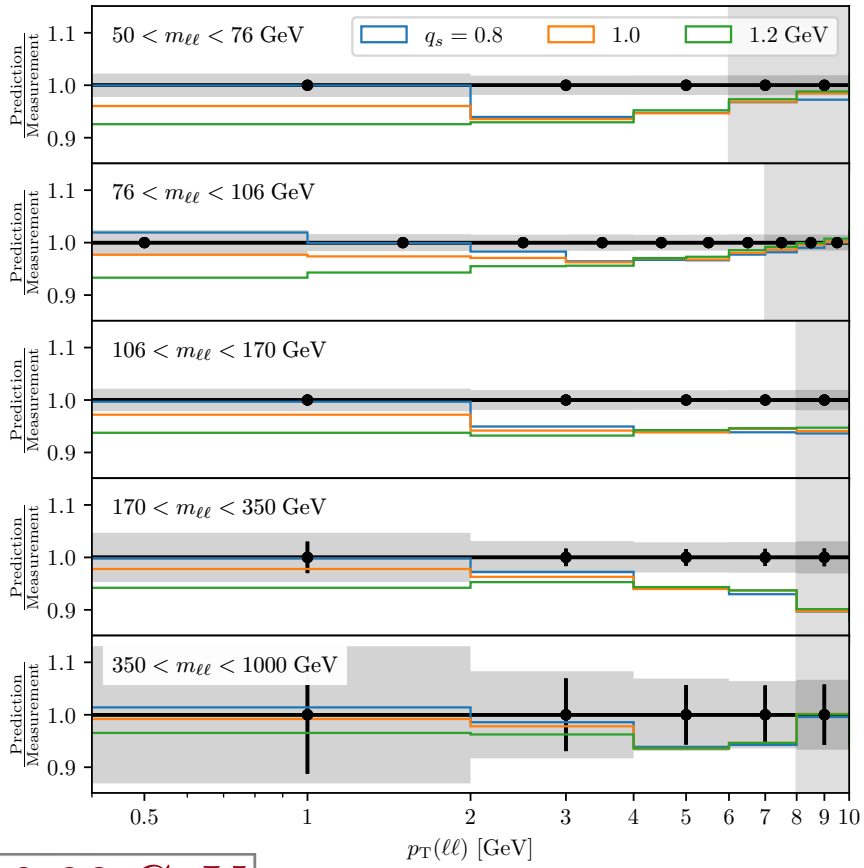
- Samples : aMC@NLO + CASCADE with PB-NLO-HERAI+II-2018-set2
- We vary qs and compare to data for low Pt bins
- We compute a χ^2 considering experimental uncertainty correlations (covariance matrix)



$$\chi^2 = \sum_{i,j=1}^{d} (x_i - p_i)(C^{-1})_{ij}(x_j - p_j)$$

data — prediction — Covariance matrix

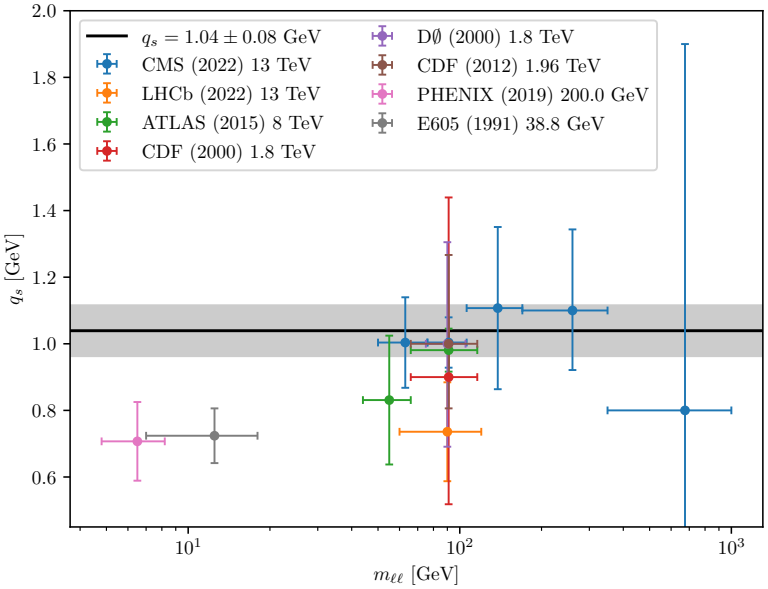
[Eur.Phys.J. C 84 (2024)154]

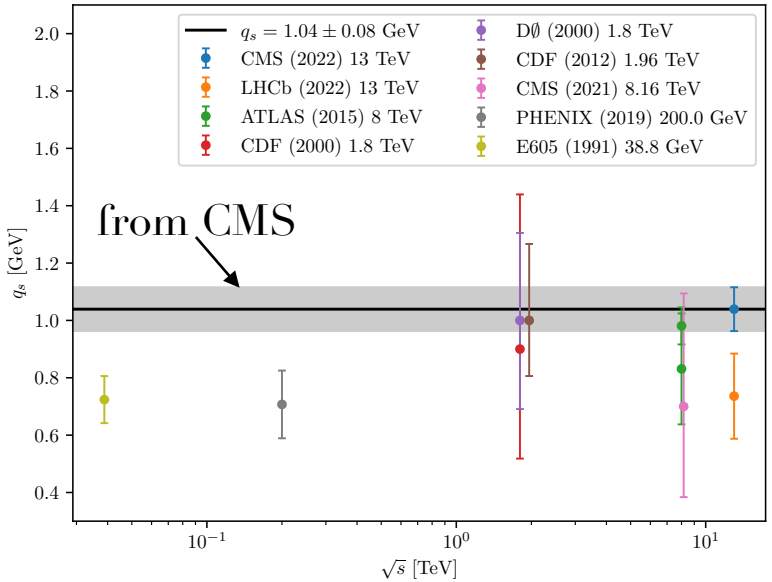


$$\Rightarrow \quad q_s = 1.04 \pm 0.08 \text{ GeV}$$

Comparing to world data

[Eur.Phys.J. C 84 (2024) no.2,154]

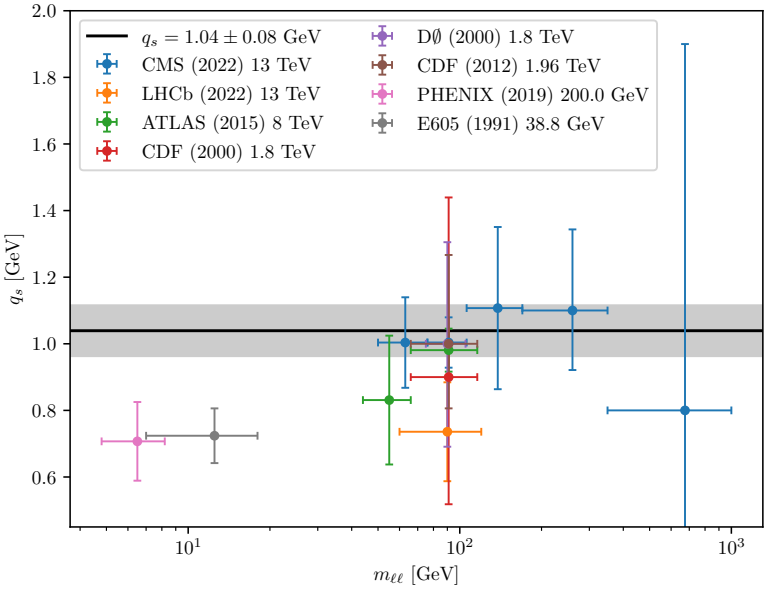


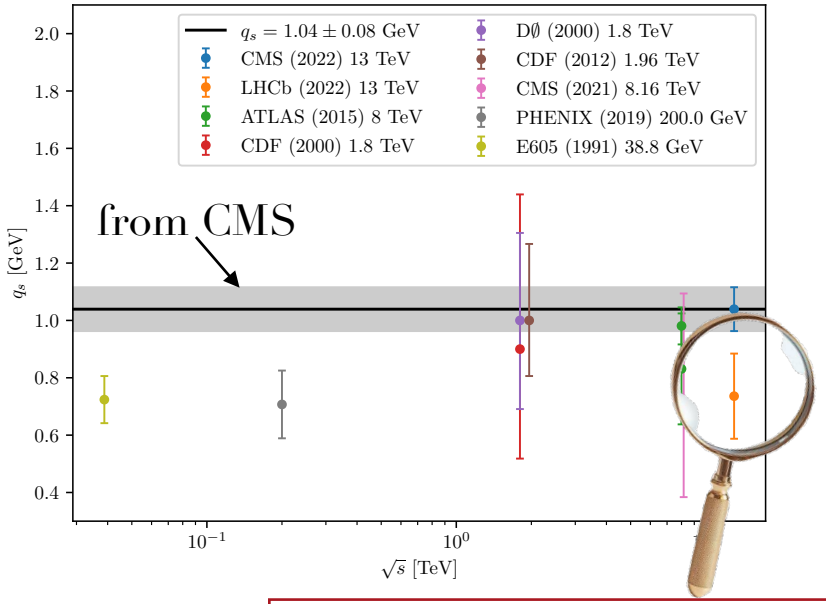


- No clear Mass dependence
- Maybe a √s dependence
- Note: for fit to other data (including LHCb) a simpler approach was used
- Tension CMS/ATLAS with LHCb → x dependence ?

Comparing to world data

[Eur.Phys.J. C 84 (2024) no.2,154]



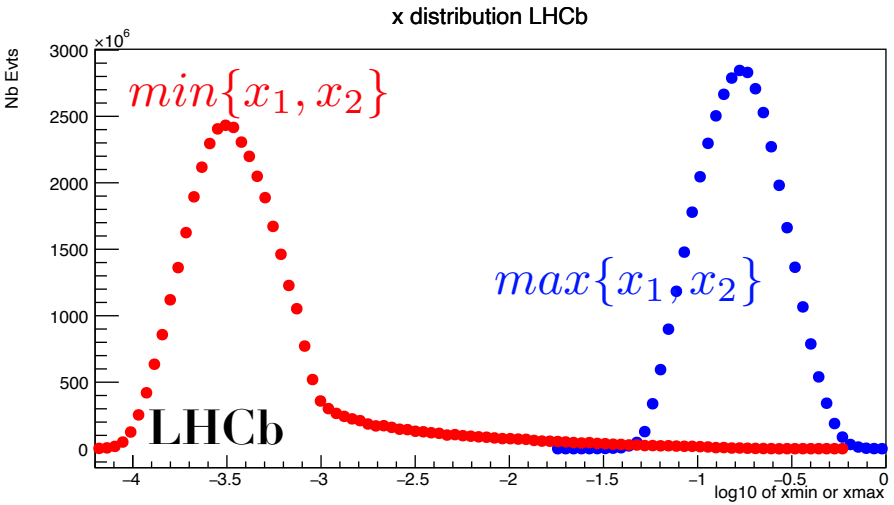


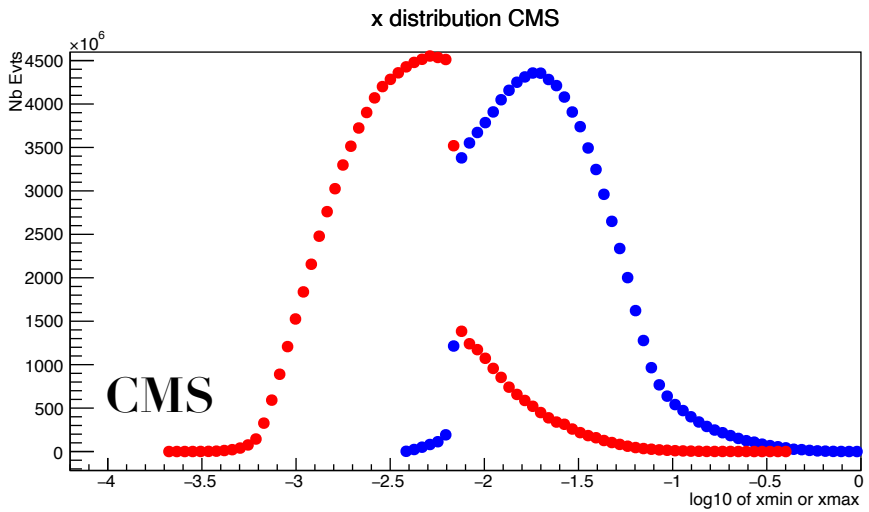
Closer look to LHCb

- No clear Mass dependence
- Maybe a $\sqrt{s}$ dependence
- Note: for fit to other data (including LHCb) a simpler approach was used
- Tension CMS/ATLAS with LHCb → x dependence ?

CMS/LHCb: probe different x regions

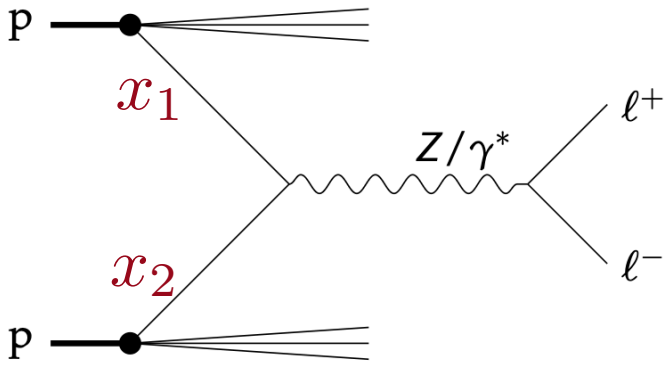
Could be due to different intrinsic kt in valence and sea





LHCb - 13 TeV

$2.0 < \eta_\mu < 4.5$



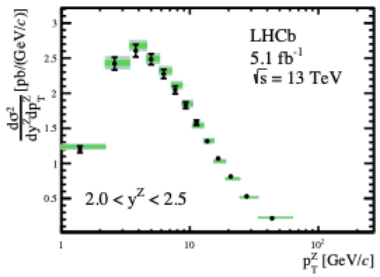
CMS - 13 TeV

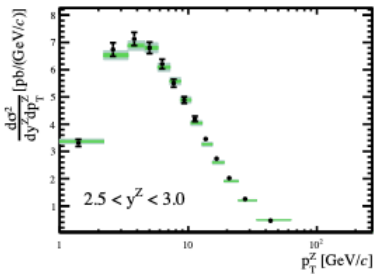
$|\eta_\mu| < 2.4$

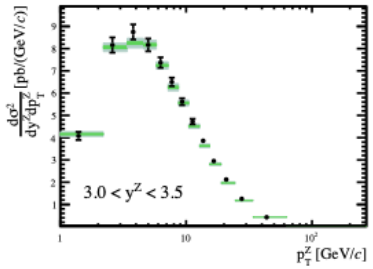
New LHCb data fit [arXiv:2609.25204]

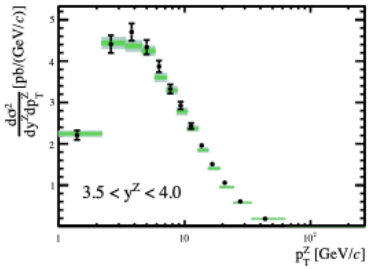
LHCb provides:

- Transverse momentum pT: TMD effects
- Rapidity y: PDF effects
- 2D pT—y: eventually we want to fit this
- Uncertainty breakdown
- Correlations for selected uncertainties



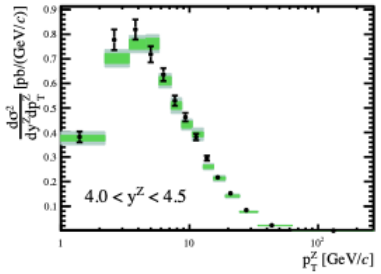






QED FSR correction:

- Published results at Born level leptons



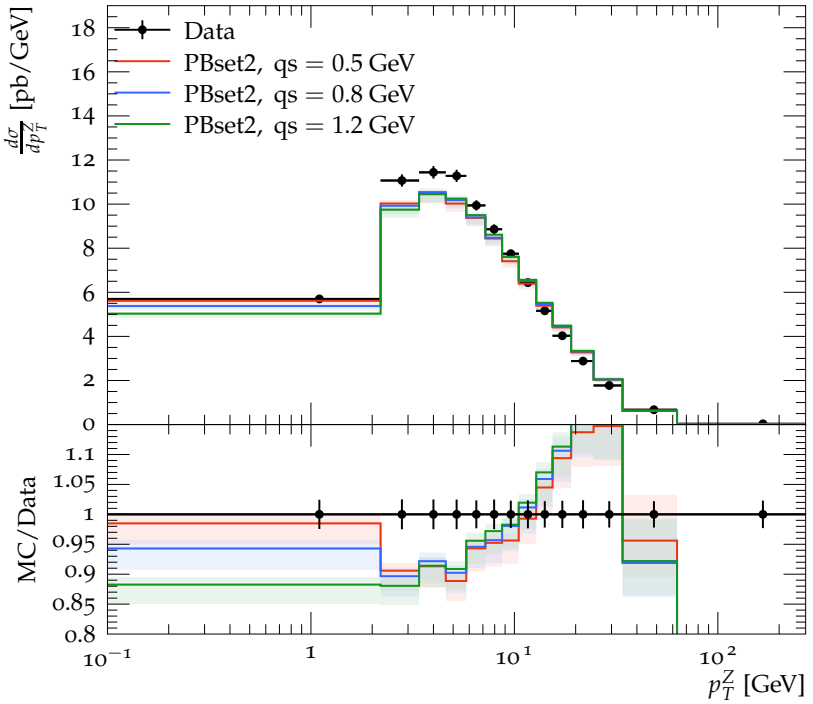
Fitting procedure

We build a covariance matrix

$$\chi^2 = \sum_{i,j=1}^{d} (x_i - p_i)(C^{-1})_{ij}(x_j - p_j)$$

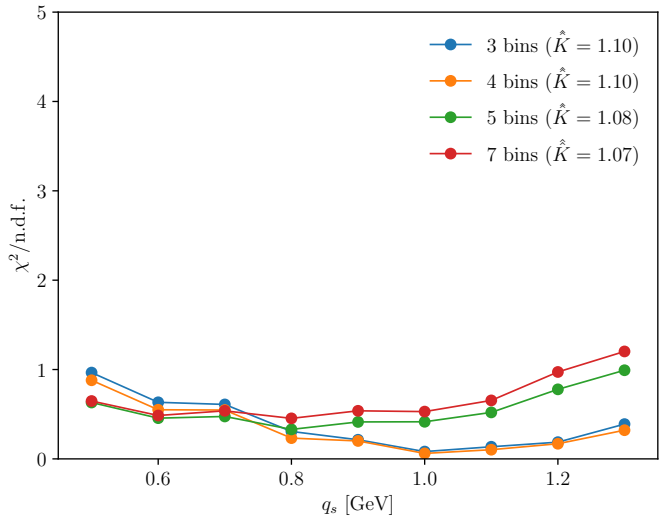
Uncertainty	Treatment
Statistical	Correlation matrix from HepData
Efficiency	Correlation matrix from HepData
Luminosity	Full correlation
Alignment	Full correlation
Closure	Full correlation
Background	Uncorrelated
Unfolding	Uncorrelated
FSR	Uncorrelated

⊕ MC statistics

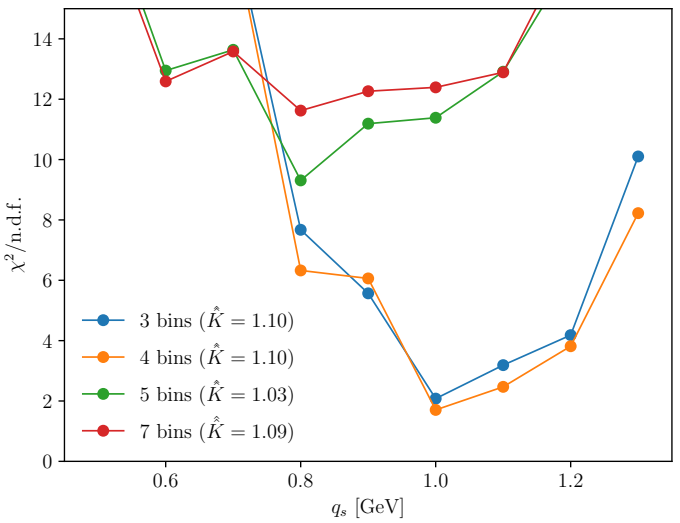


- Sensitivity to qs
- Normalisation off
- Missing higher ME orders (failure at large Pt)

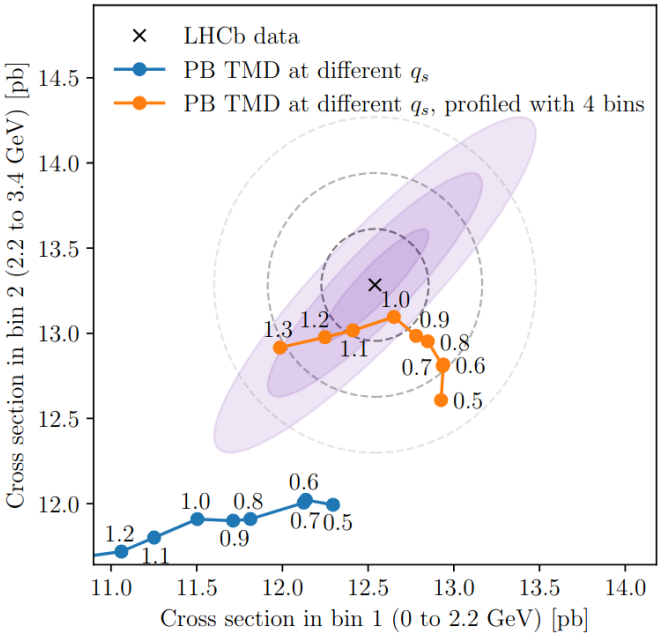
Important effect of bin-to-bin correlations



include correlations

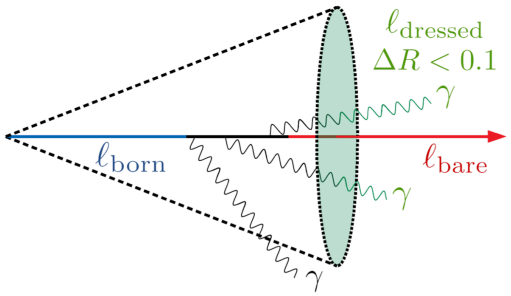


- As normalisation is off, we use a normalisation factor, which depends on the qs choice
- Correlation have a significant impact on qs extraction sensitivity
- We choose 4 bins in what follows

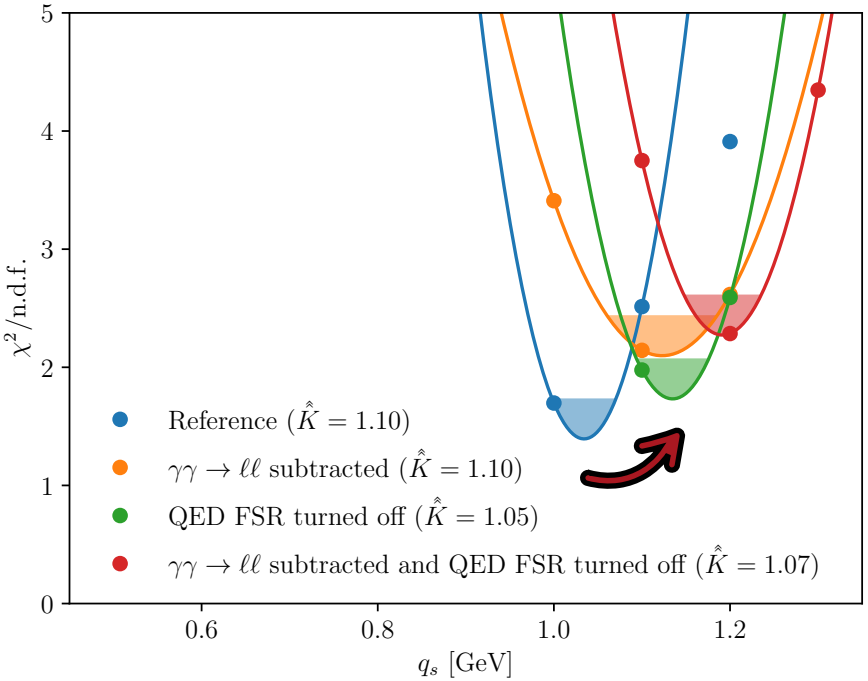


Other effects

- QED: correction factor from dressed → born leptons

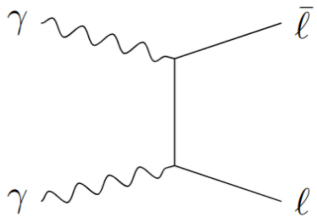


➡ moves qs by +0.1 GeV



- Subtract γ-γ background

✓ turns out to be probably negligible (recent private com)



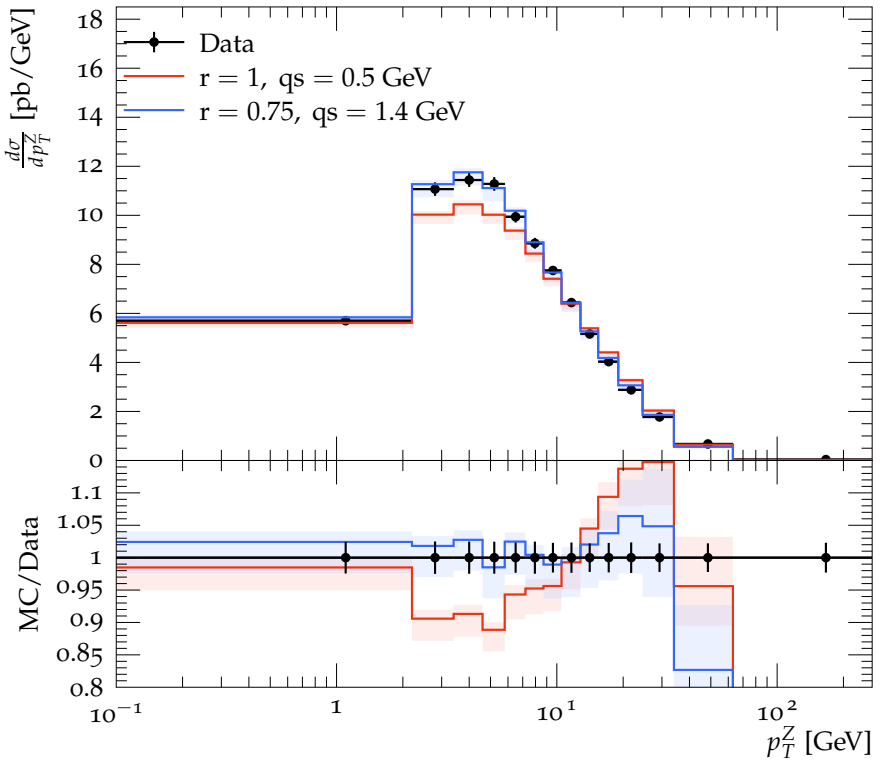
Effect of matching scale variation

- The bump at Pt ≃ 20 GeV can be much reduced by using a different Qcut for ME and for the TMD evolution/shower

$$r = \frac{Q^{cut}_{ME}}{Q^{cut}_{TMD}}$$

➡ best qs = 1.4 GeV

➡ significant effect



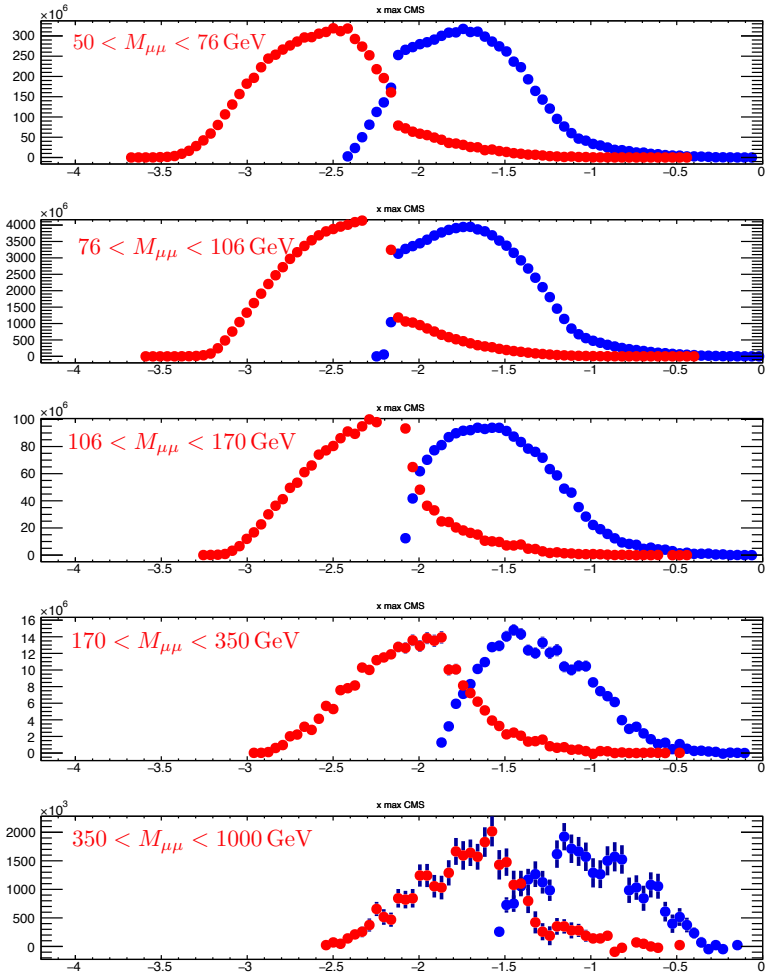
Conclusion

[arXiv:2609.25204]

- Fit of LHCb Drell-Yan at 13 TeV has been revisited
- Extracted intrinsic kt (qs) are in good agreement between CMS and LHCb (no strong valence/sea effect visible)
- More general lesson:
  - Intrinsic kt extraction are delicate
  - Important effect of:
    - QED correction
    - Bin-to bin correlations
- We call for:
  - Full clarity in the phase space description by experiments
  - Caution when fitting

Back-up slides

x-max and x-min distributions

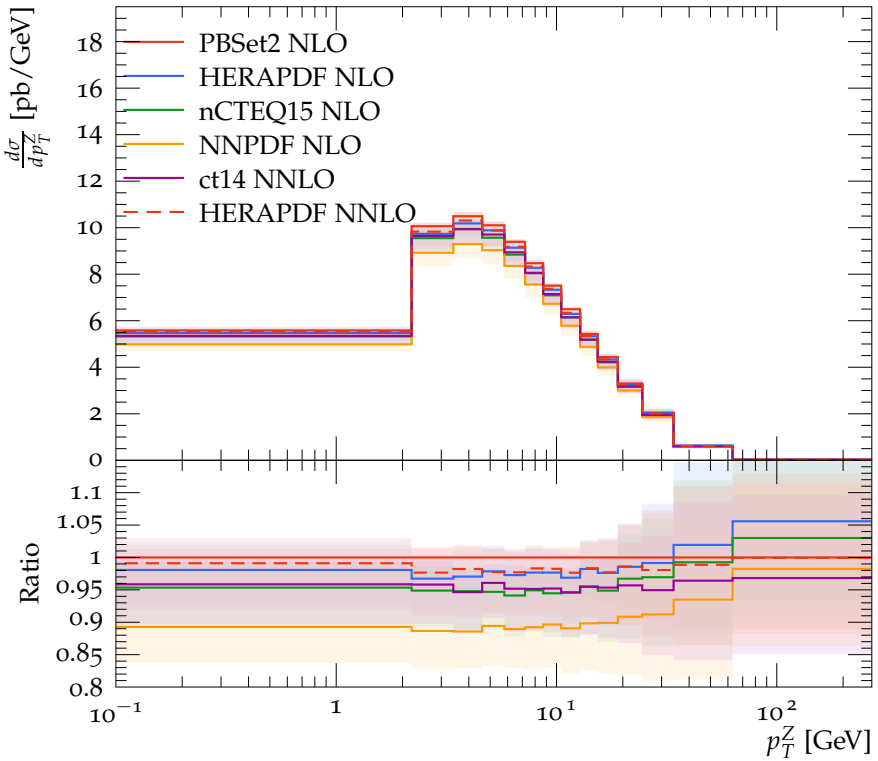


CMS - 13 TeV [arXiv:2205.04897]

$P_T > 20/15$ GeV && $|\eta_\mu| < 2.4$

5 mass bins

Sensitivity in the PDF set



Effect of QED correction

