Pion TMDPDFs from phenomenology

a soon to be published extraction

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Charged pion TMDPDFs from fixed target Drell-Yan measurements

Taiwan Nuclear Physics Retreat 2026 in Jiaoxi

What do I do (in case i forget myself..)

- **WHAT** do I study: TMDPDFs :
  (naively) an extension of (collinear) **P**arton**D**istribution**F**unction that captures the total momentum distribution of the hadron among its constituents (partons).
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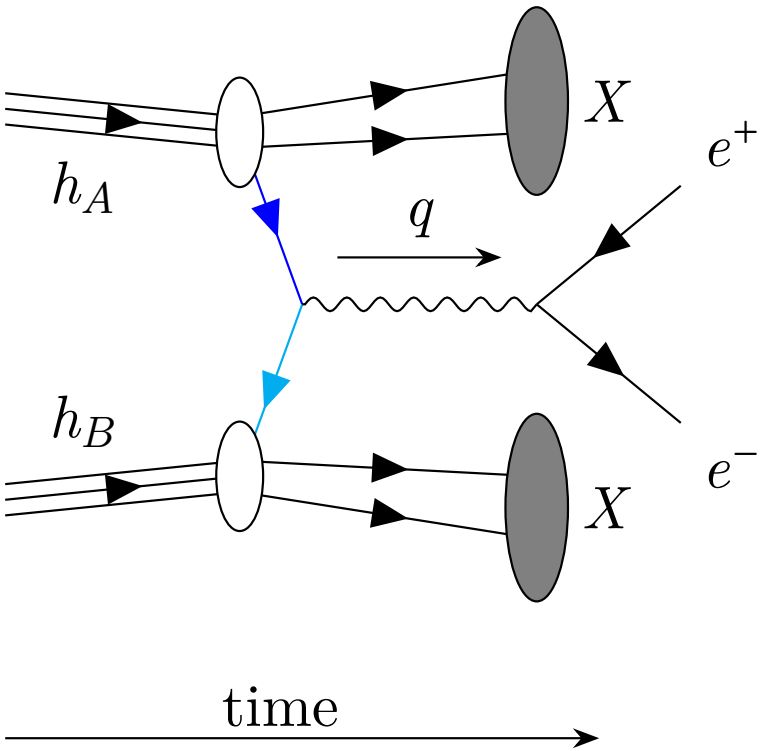
- **HOW** do I get them:
  TMDs can describe the cross section of hadronic scattering events
  $\longrightarrow$ Method = parametrise and fit.

Example: III The Drell Yan process

A *clean* process:

$$h_A + h_B \longrightarrow l + \bar{l} + X$$

Two colliding hadrons → two parton distribution functions necessary.



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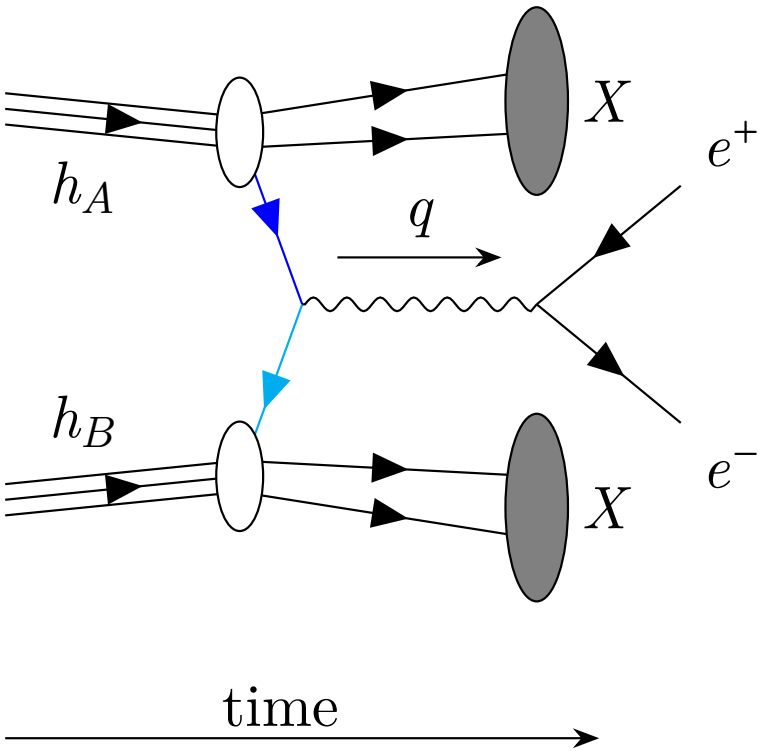

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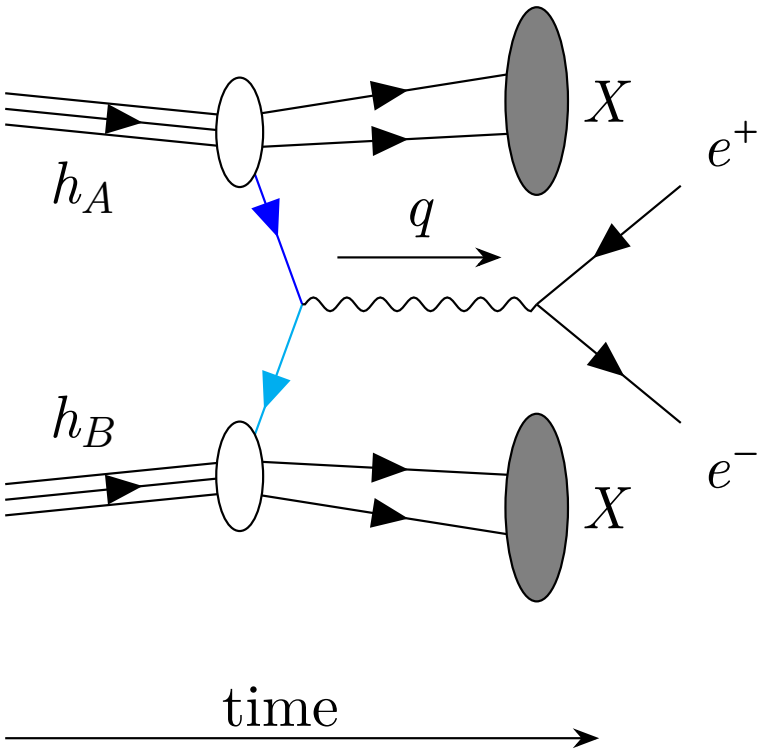

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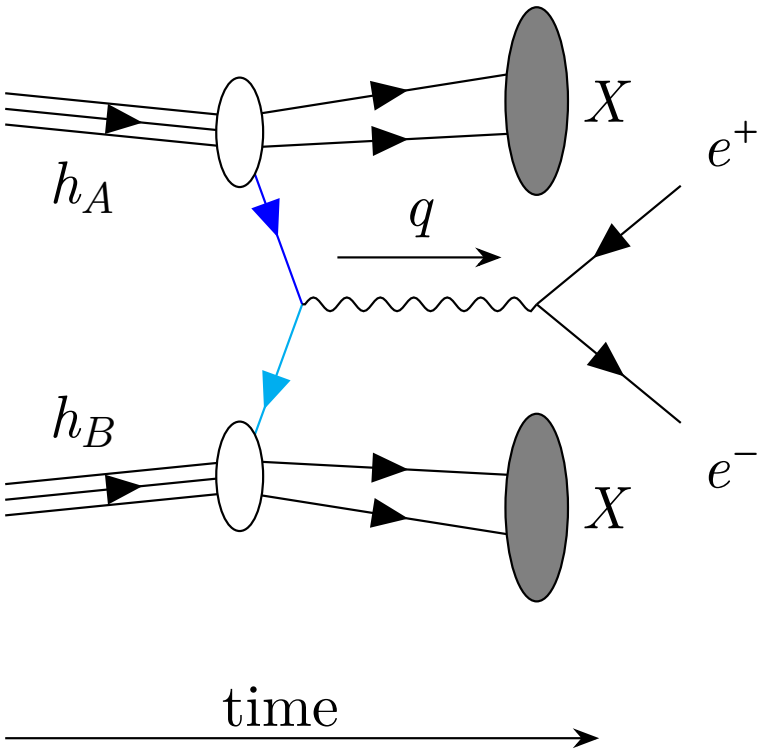

- only PDFs involved
- momentum of lepton pair q = momentum of virtual boson = momentum of colliding quarks
- small transverse momentum q_T of photon ~ notion of small transverse motion of quarks

PDFs and TMDs: operators

- TMD distributions and operators

$$\Phi^{[\Gamma]}_{q\leftarrow h}(x,b) = \int \frac{dz}{2\pi} e^{-ixzp_+} \langle P,S|\,\overline{q}\Gamma\left[zn+b,\cdots\mp\infty,0\right]q|P,S\rangle$$

  - n (light-cone vector) ~ hadrons large momentum P
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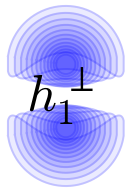
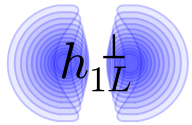
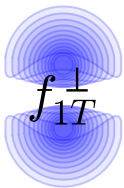
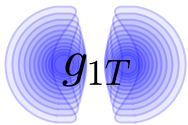
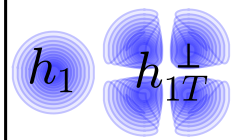
$$\Psi^{[\Gamma]}(x) \sim \lim_{b\to 0} \Phi^{[\Gamma]}(x,b)$$

8 TMD distributions

quark polarization

Nulceon polarization

N \ q	U	L	T
U	 f_1		 $h_1^\perp$
L		 g_1	 $h_{1L}^\perp$
T	 $f_{1T}^\perp$	 g_{1T}	 h_1 $h_{1T}^\perp$

Parametrised forms of TMDs include 8 functions.

Polarisation of quark
~ spinor operator (Γ)

Posalisation of hadron
~ exterior state

PDFs and TMDs: independent yet related

How do we "construct" the TMDPDFs:

$$f_{1,f}(x,b) = \left(C_{f\to f'} \otimes q_{f'}\right)(x,b) \cdot f^{f}_{\mathrm{NP}}(x,b)$$

$\longrightarrow$ use perturbative expantision in collinear PDFs multiplied by NP parametrisation for large distance decay

TMD cross section

. . . on the example of γ^* production in DY

$$\frac{d\sigma}{dQ^2\,dy dq_T^2} = \frac{2\pi\alpha_{\text{em}}^2(Q)}{3N_c s Q^2}\left(1+\frac{q_T^2}{2Q^2}\right)\sum_f C_{\text{DY}}(Q)$$
$$\times \int_0^\infty db\, b\, J_0(bq_T)\left(\frac{Q^2}{\zeta_Q(b)}\right)^{-2\mathcal{D}(b,Q)} f_{1,f}(x_1,b) f_{1,\bar{f}}(x_2,b)$$

Schematic:

$$\sigma = H_{\text{pert.}} \otimes F_{\text{NP}}$$

Scale dependence of TMDs – both pert. and NP.

Scale dependence of TMDs:

PDF $f(x;\mu) \longrightarrow$ TMDPDF $f(x,b;\mu,\zeta)$

Evolution equations

$$\mu^2 \frac{d}{d\mu^2} f(x,b;\mu,\zeta) = \frac{\gamma_F(\mu,\zeta)}{2} f(x,b;\mu,\zeta)$$

$$\zeta \frac{d}{d\zeta} f(x,b;\mu,\zeta) = -\mathcal{D}(b,\mu) f(x,b;\mu,\zeta)$$

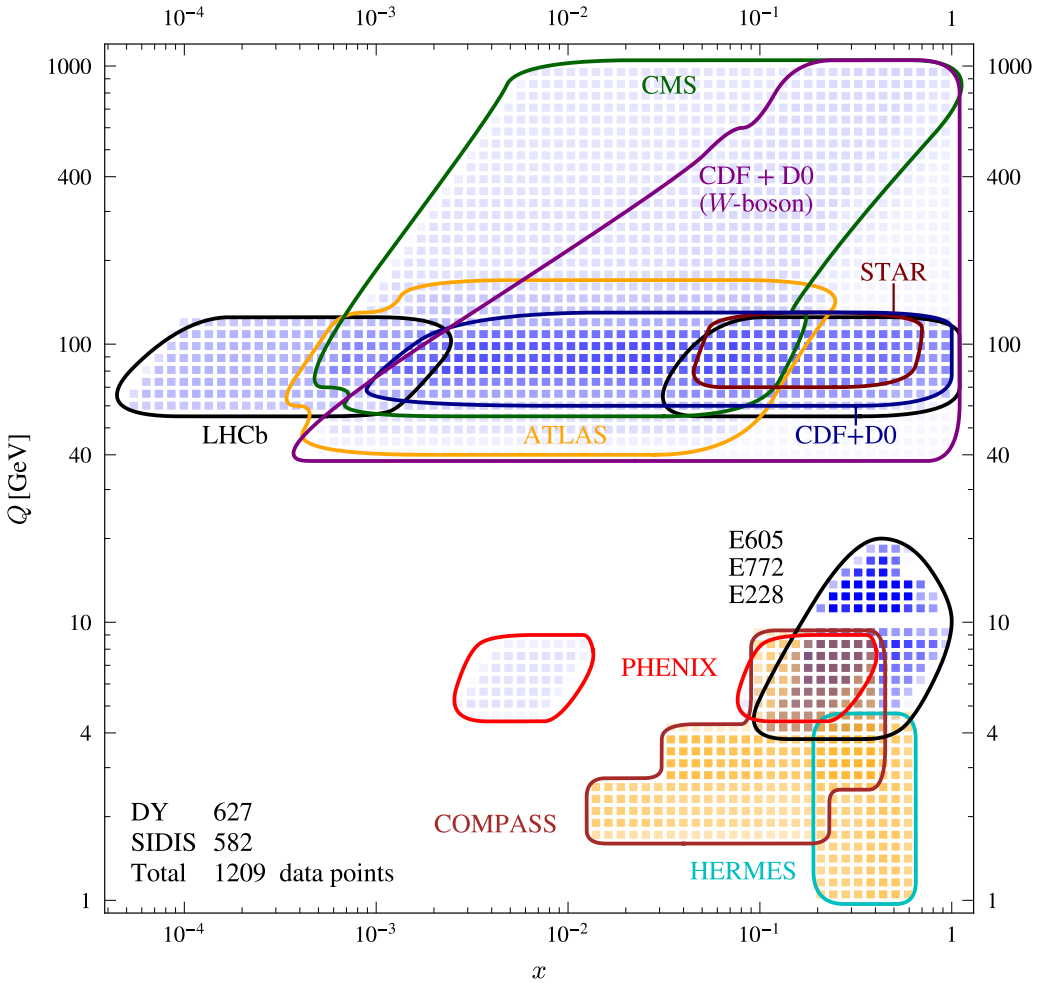
μ evolution is perturbative ✓

ζ evolution is not:

Parametrisation of TMD Evolution: (Collins-Soper kernel $\mathcal{D}$)

$$\begin{aligned}\mathcal{D}(b,\mu) &= \mathcal{D}_{\text{small-b}}(b^*,\mu) && + \mathcal{D}_{\text{NP}}(b) \\ &= \mathcal{D}_{\text{small-b}}(b^*,\mu^*) + \int_{\mu^*}^{\mu} \frac{d\mu'}{\mu'} \Gamma_{\text{cusp}}(\mu') && + \mathcal{D}_{\text{NP}}(b)\end{aligned}$$

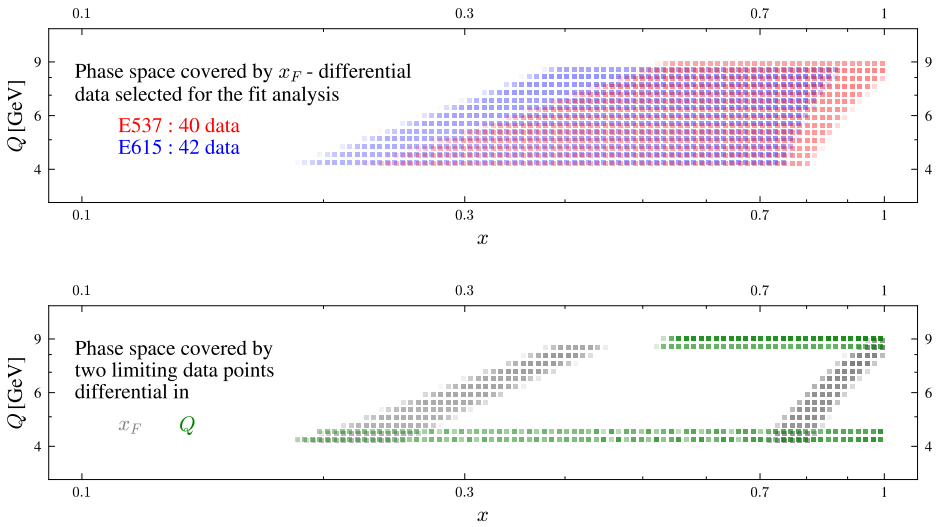
Kinematic range of included data that constrains the nucleon...



Features:

- large range of resolution scale: 1 GeV $\rightarrow$ 1 TeV
- W production in DY
- $\frac{q_T}{Q} < 0.25$ (TMD region!)

... and the pion

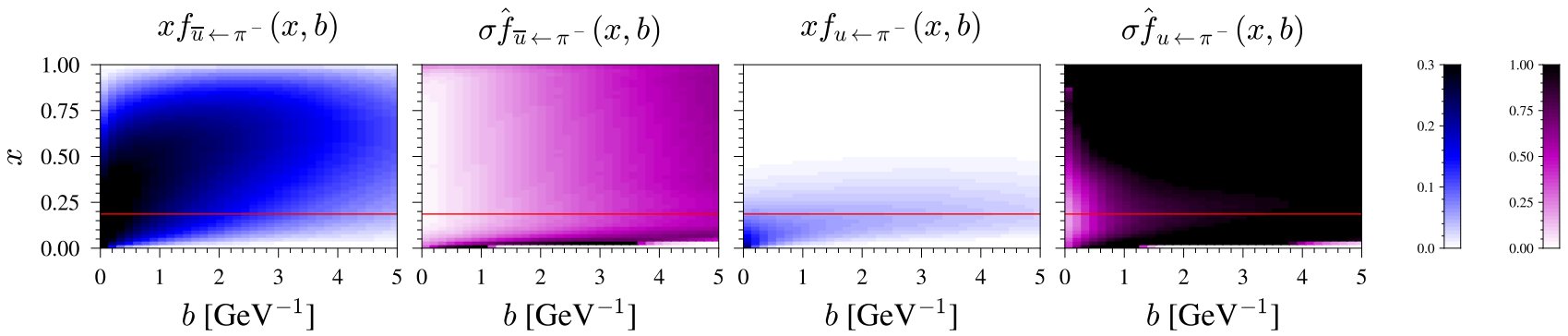


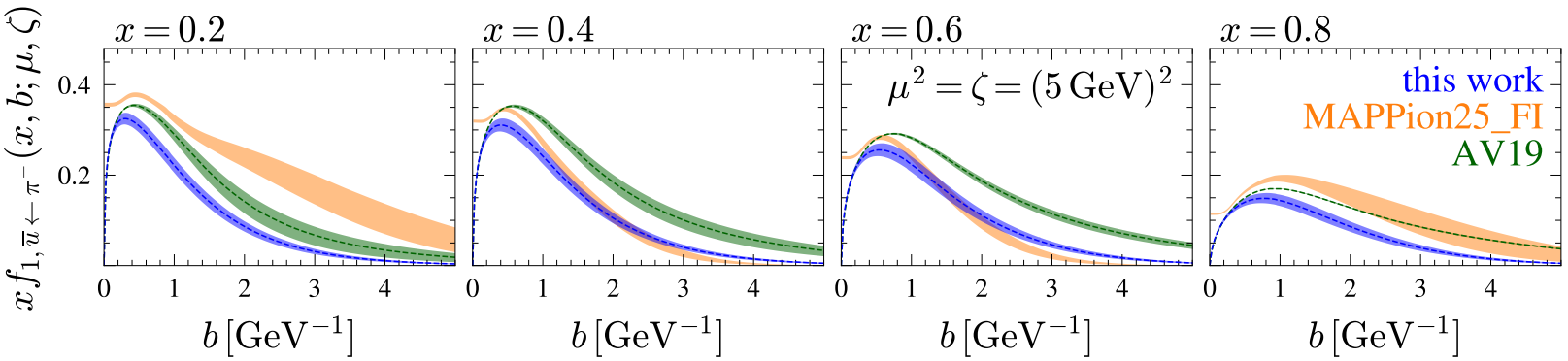
Features:

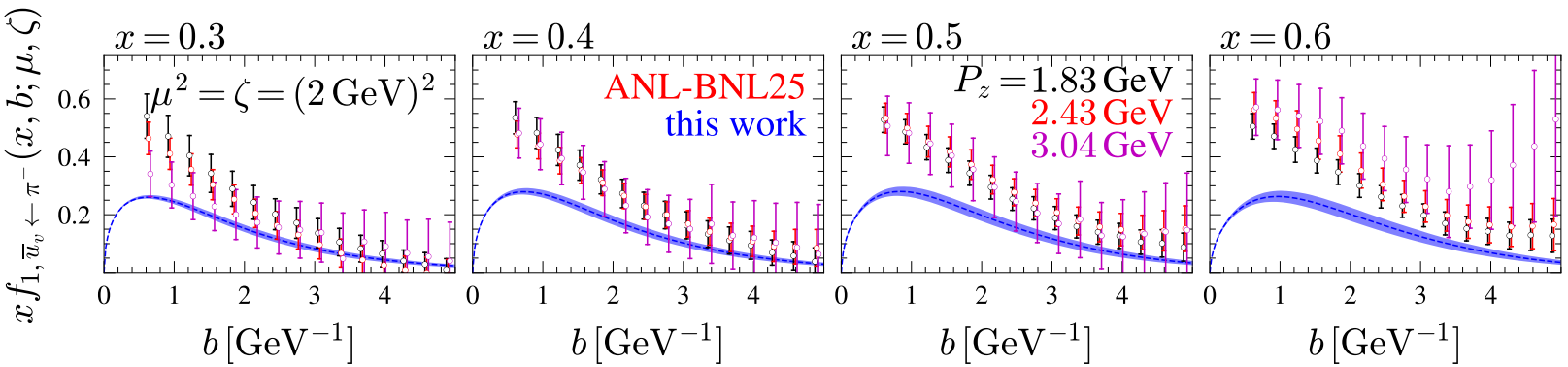
- small range of resolution scale: 4 GeV $\rightarrow$ 8 GeV
- small range of momentum fraction x: 0.2 - 1.0
- basically only valence quark ($\overline{u}$ contribution dominates $\pi^- + p/n$)
- $\frac{q_T}{Q} < 0.25$ (TMD region!)

Let me flash a few results...

Let me flash a few results... the extracted distributions







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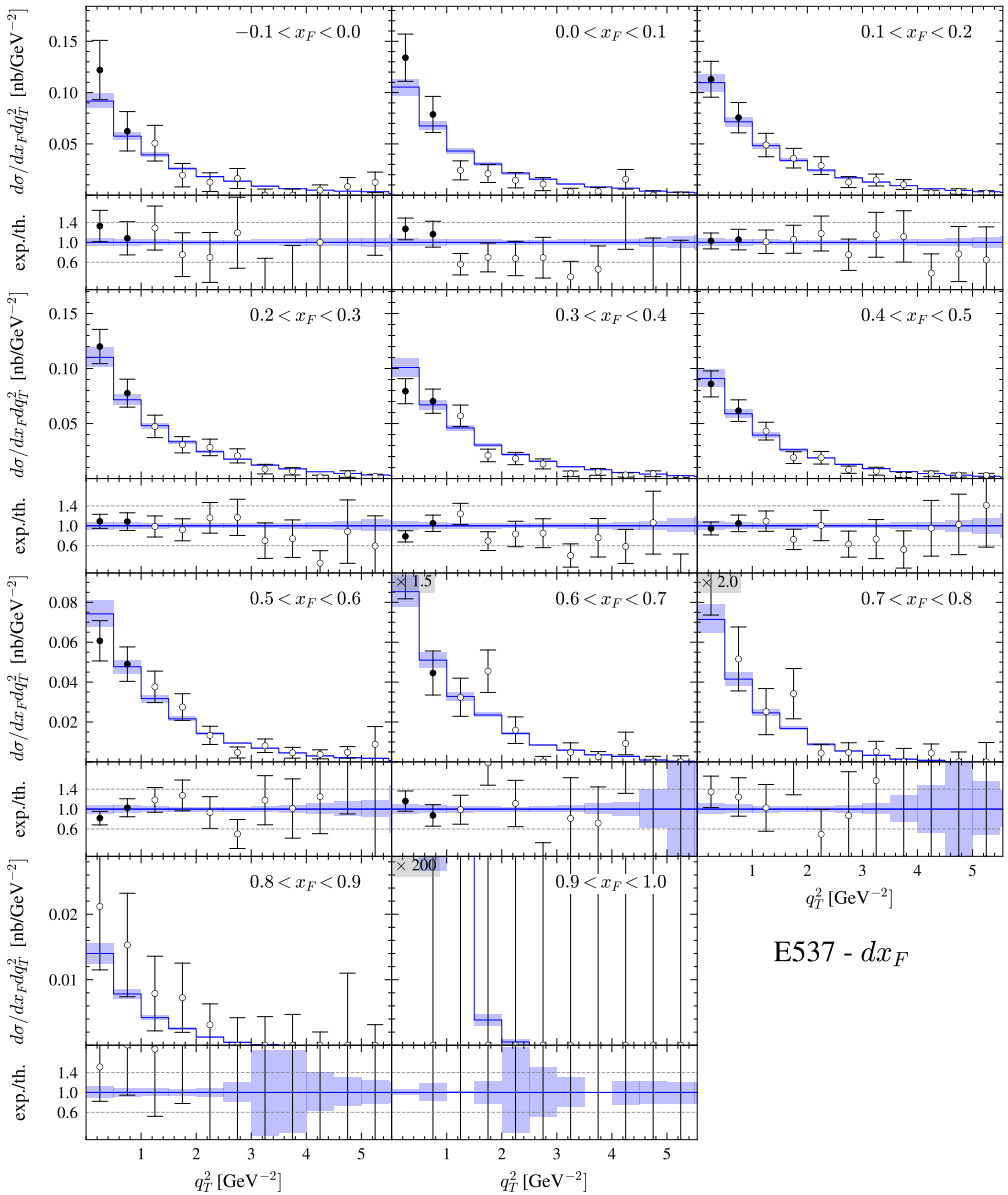

E537 - dx_F

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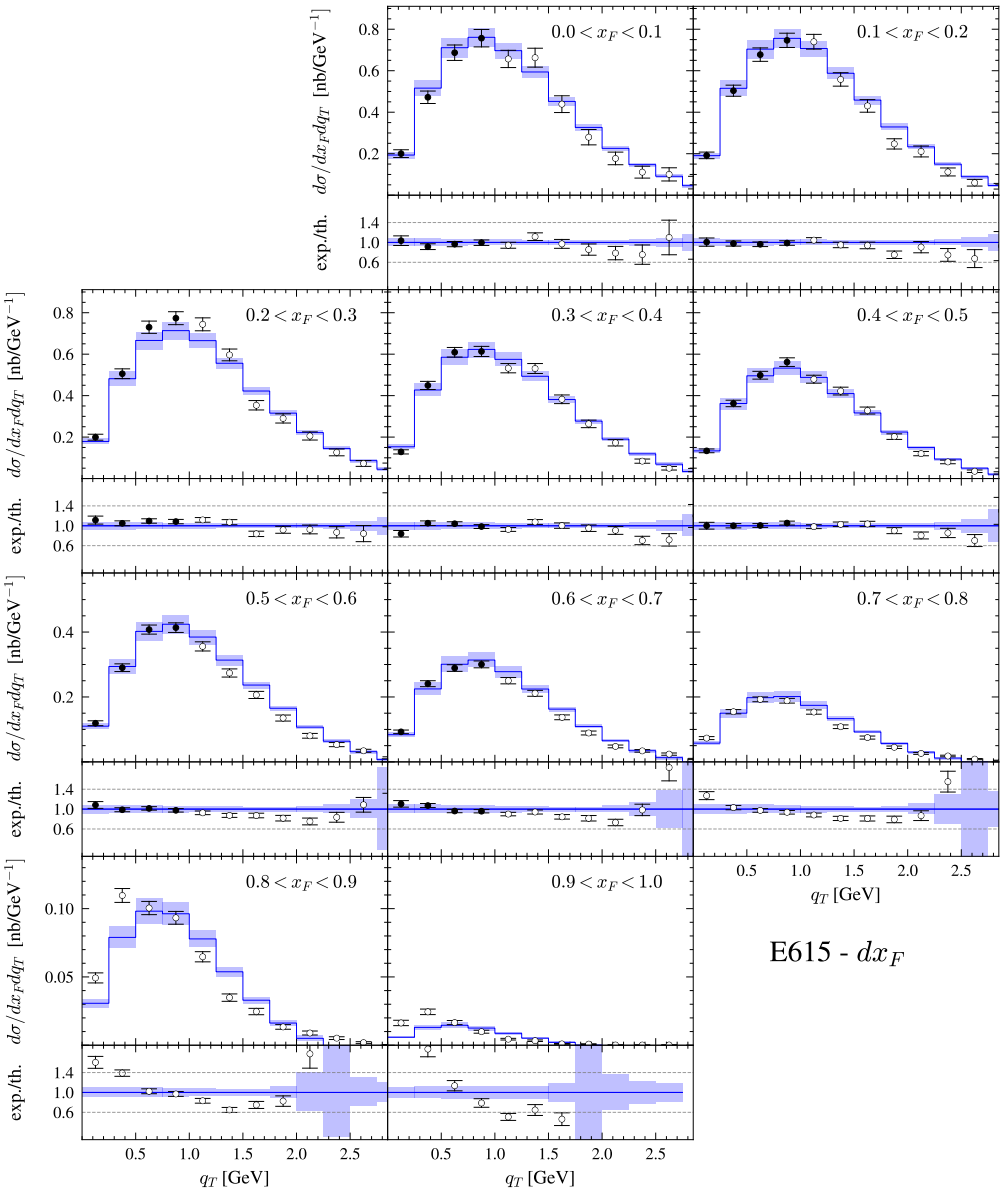

E615 - dx_F

I showed you

WHAT physical function we extract (unpol. pion TMDPDFs)

and **HOW** we do it (DY data + parametrisation (intuition) + fit)

and showed a few details and a few results.
A paper should appear soon on the arXive.