Fisica Adronica: i tomografi del protone

The 3DSPIN group:
Alessandro, Barbara, Marco,
Giuseppe, Miguel, Pieter,
Chiara, Filippo, Fulvio, Simone, Stefano

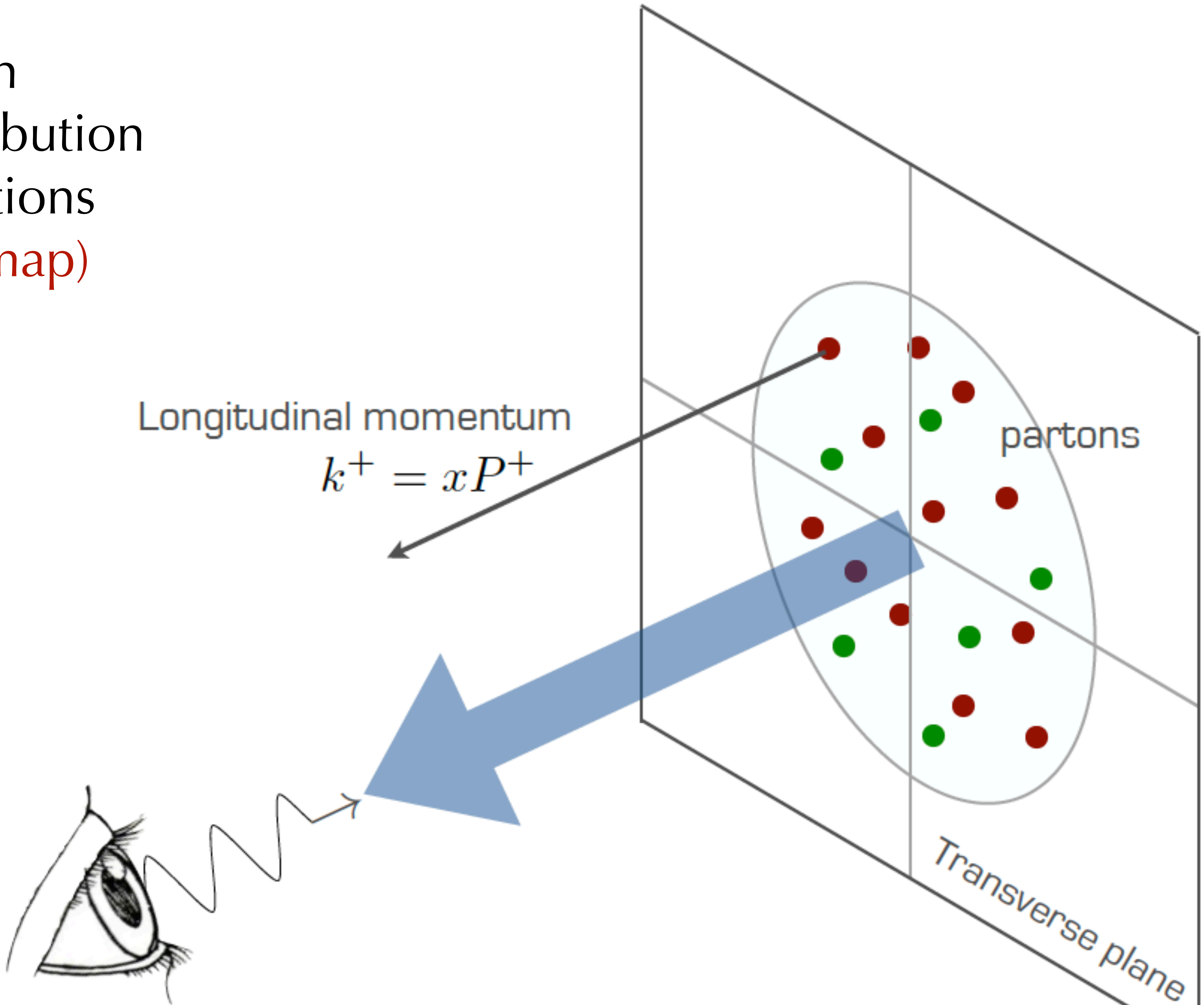
Istituto Nazionale di Fisica Nucleare

3DSPIN MAPPING THE PROTON IN 3D

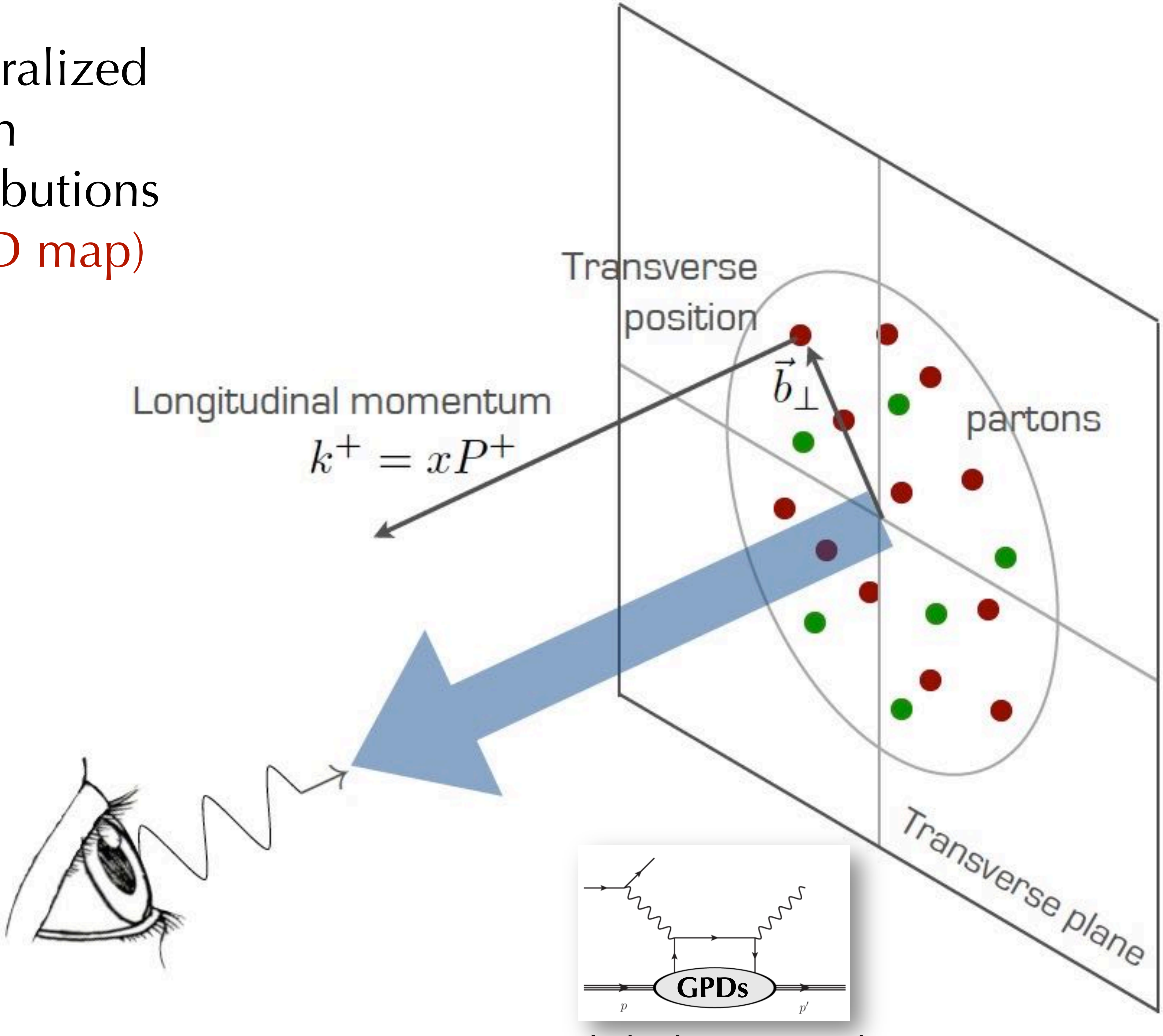
European Research Council

UNIVERSITÀ DI PAVIA

Parton
Distribution
Functions
(1D map)

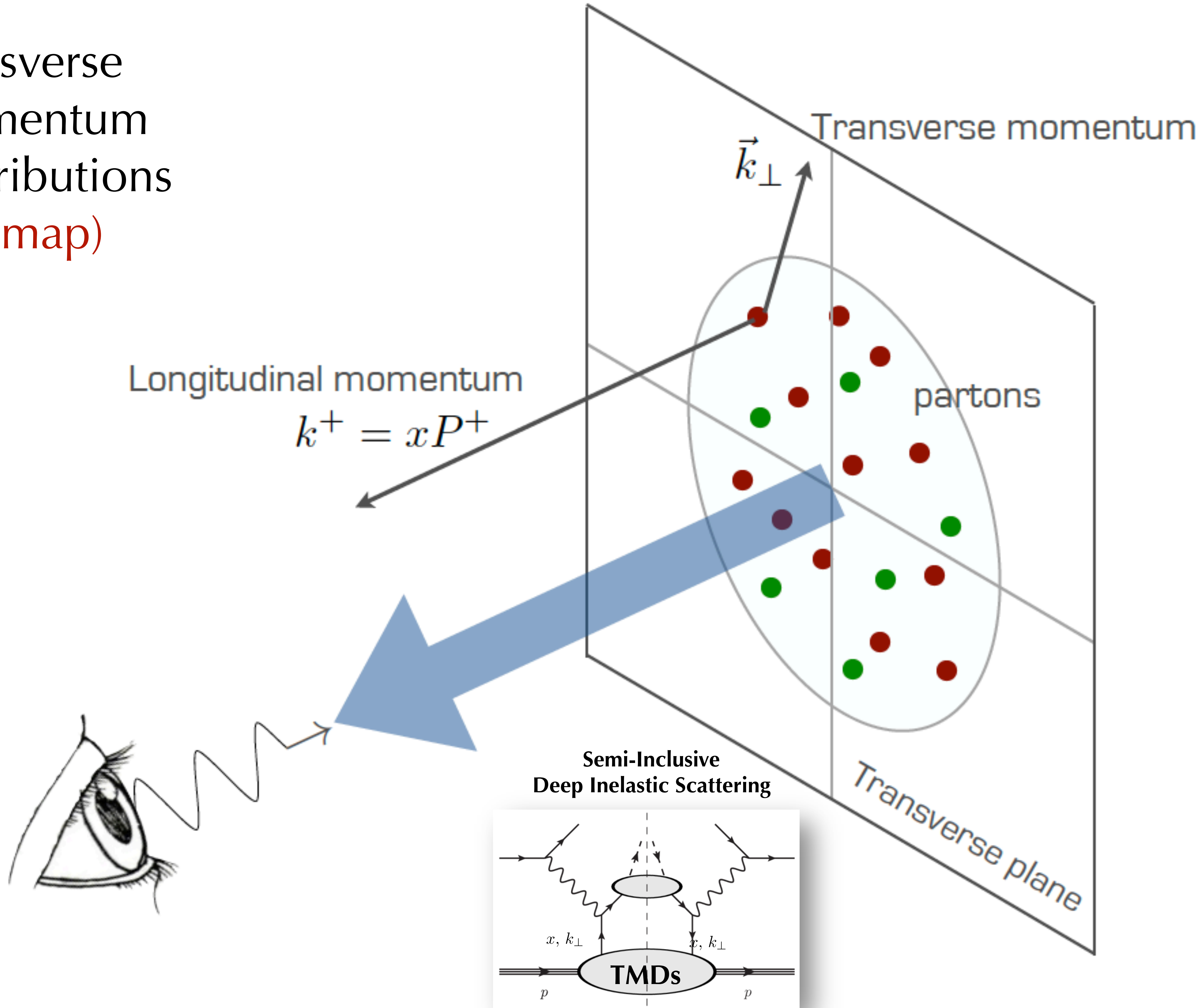


Generalized Parton Distributions (1+2D map)

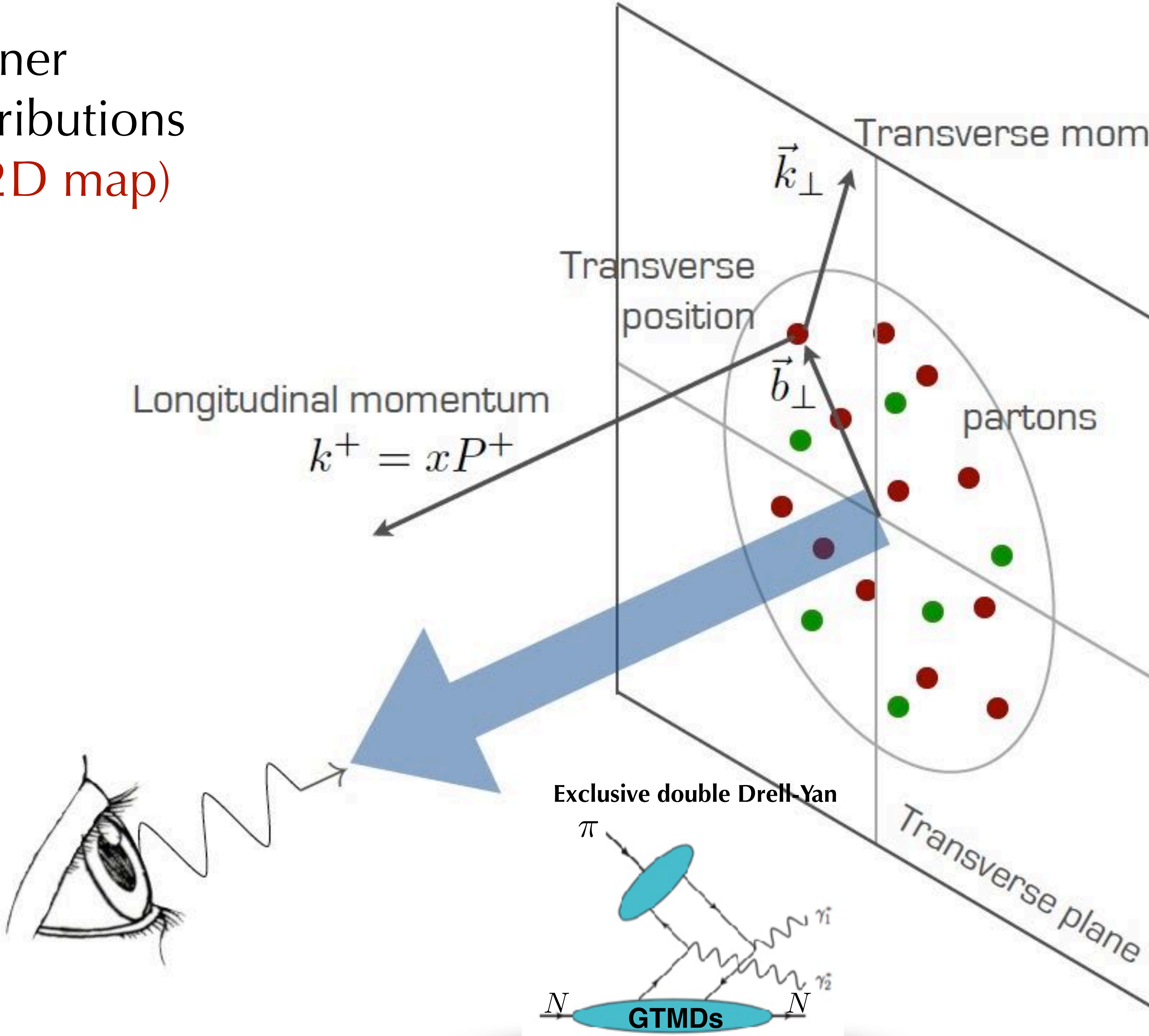


Deeply Virtual Compton Scattering

Transverse
Momentum
Distributions
(3D map)



Wigner Distributions
(3+2D map)

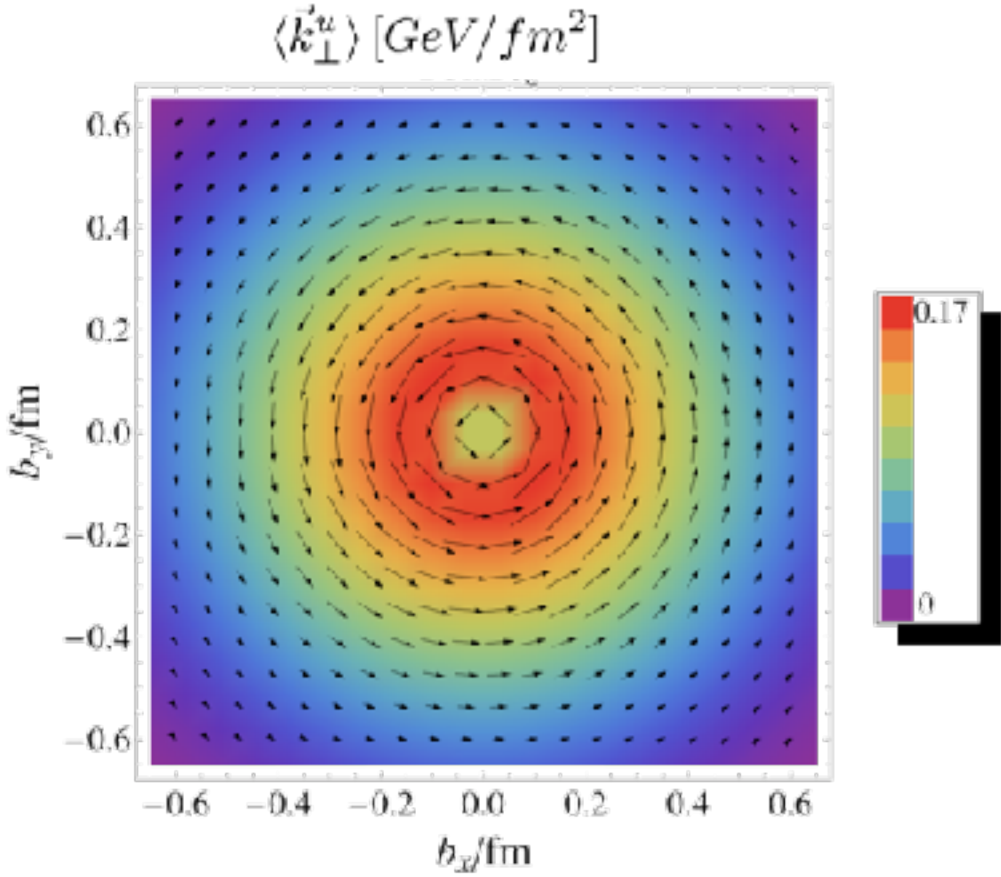


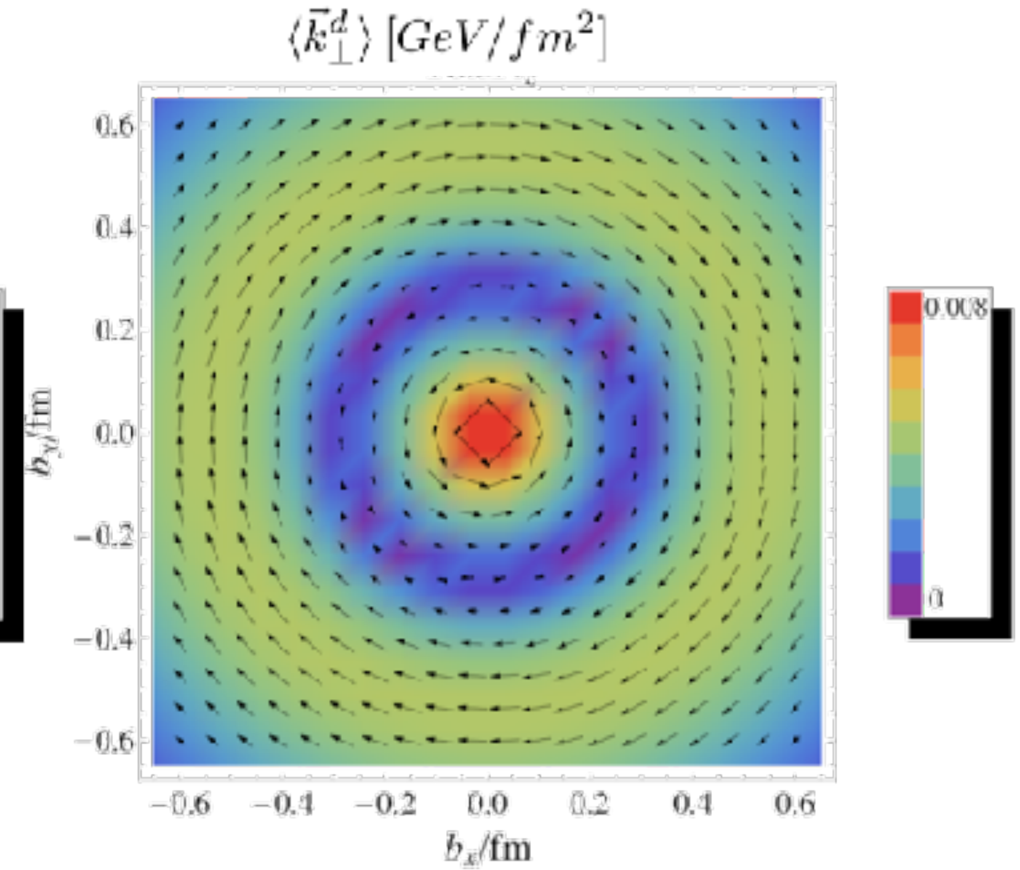
Wigner: Quark Orbital Angular Momentum

Lorcé, Pasquini, PRD 84 (2011) 014015

Lorcé, Pasquini, Xiong, Yuan, PRD 85 (2012) 114006

Wigner: Quark Orbital Angular Momentum





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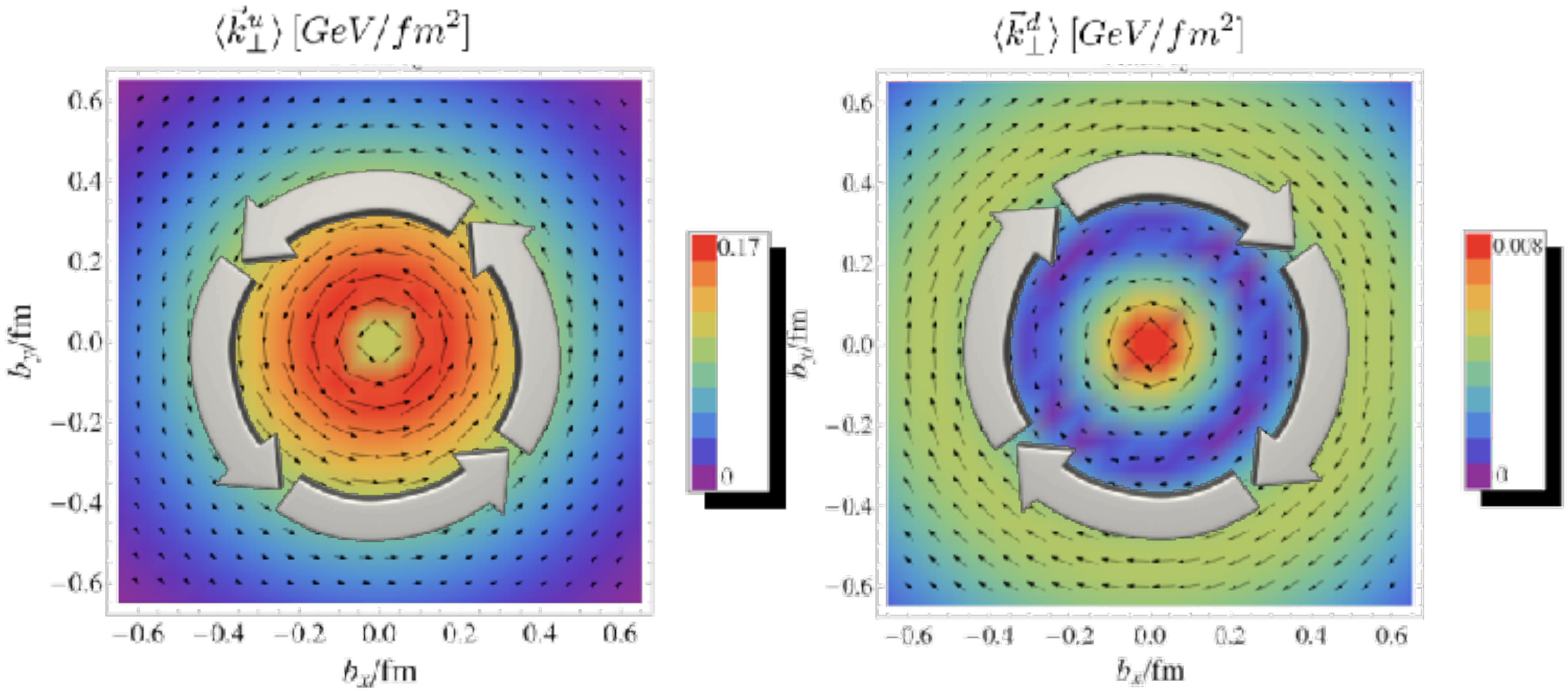


Proton spin

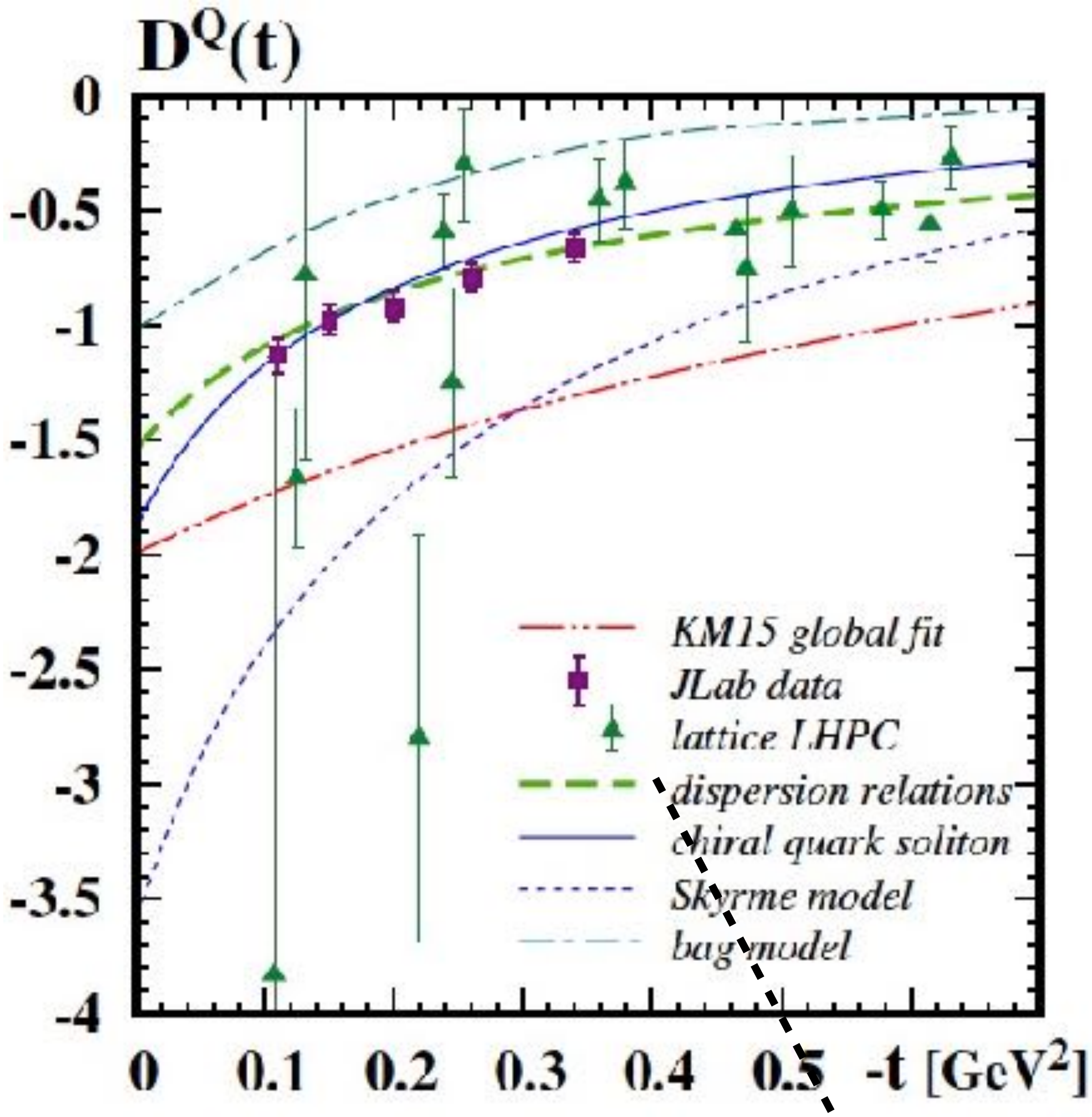
u-quark OAM

d-quark OAM

Lorcé, Pasquini, PRD 84 (2011) 014015

Lorcé, Pasquini, Xiong, Yuan, PRD 85 (2012) 114006

GPD: E-M tensor form factors from DVCS data



Polyakov and Schweitzer, arXiv:1805:06596

Girod, Elouadrhiri,Burkert, Nature 557 (2018) 7705

Dispersion Relations: Pasquini, Polyakov, Vanderhaeghen, PLB739(2014)133

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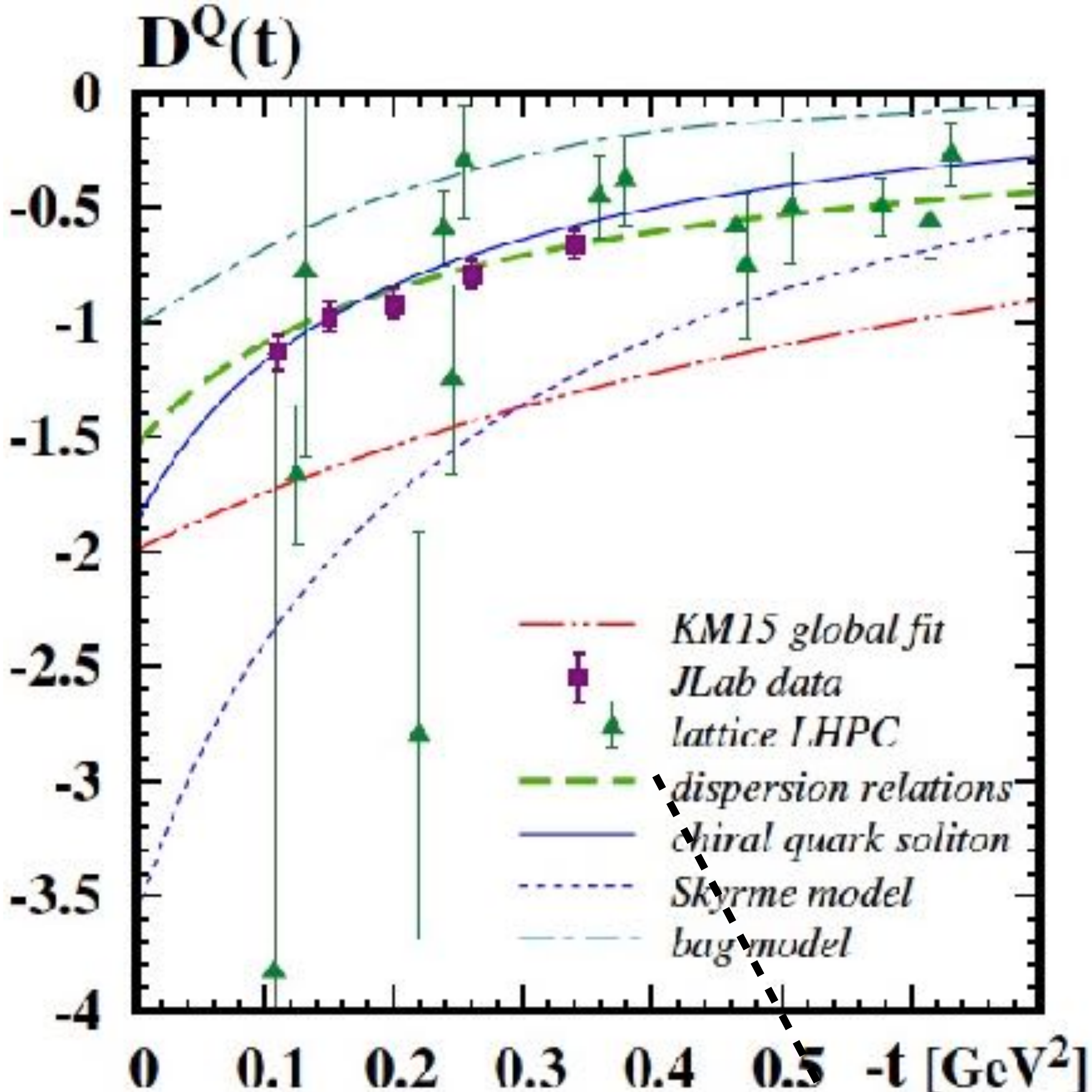
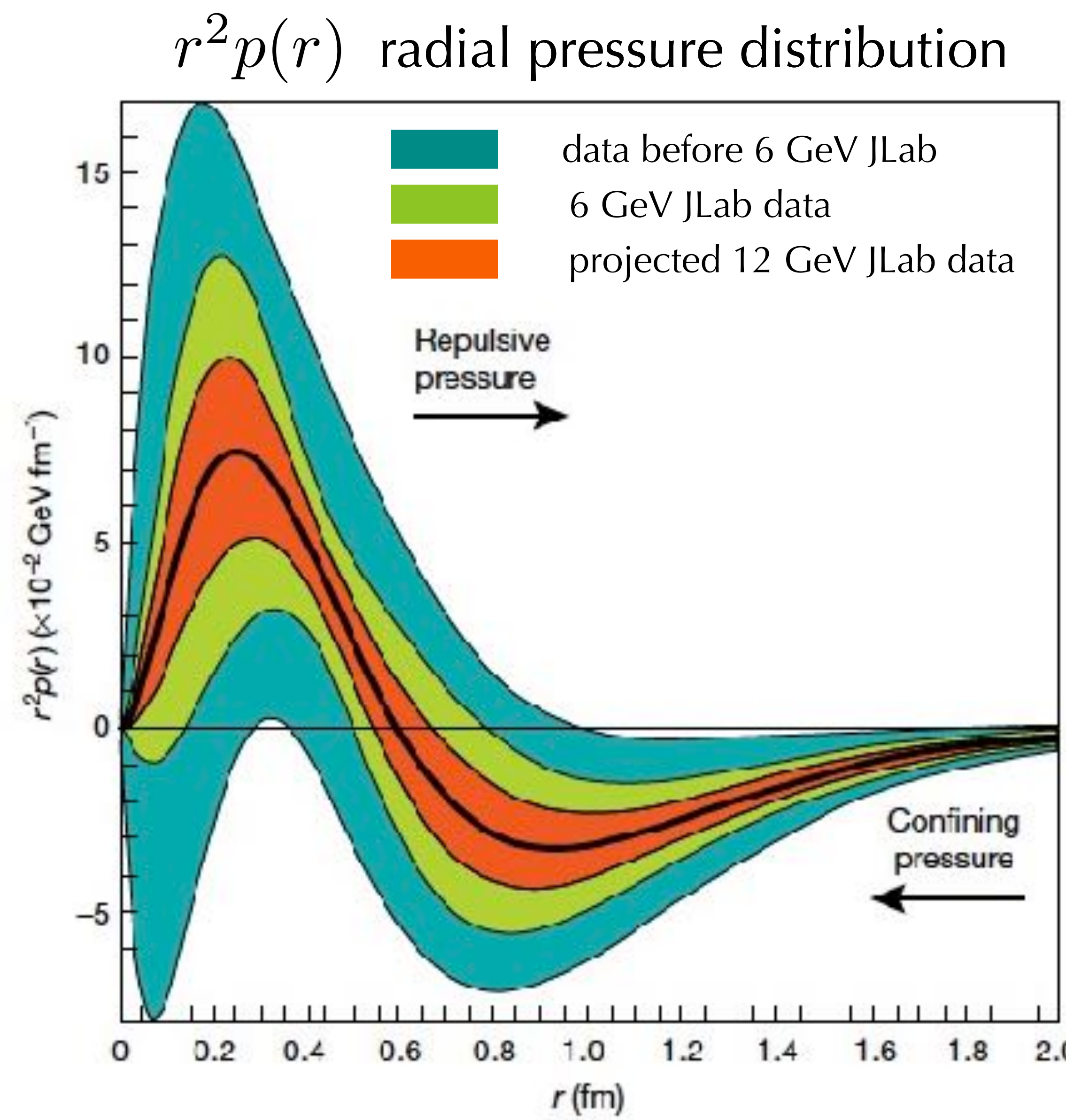


Polyakov and Schweitzer, arXiv:1805:06596

FT



Girod, Elouadrhiri,Burkert, Nature 557 (2018) 7705

Dispersion Relations: Pasquini, Polyakov, Vanderhaeghen, PLB739(2014)133

Deriving the unpolarised TMD (Pasquini, Rodini 1806.10932)

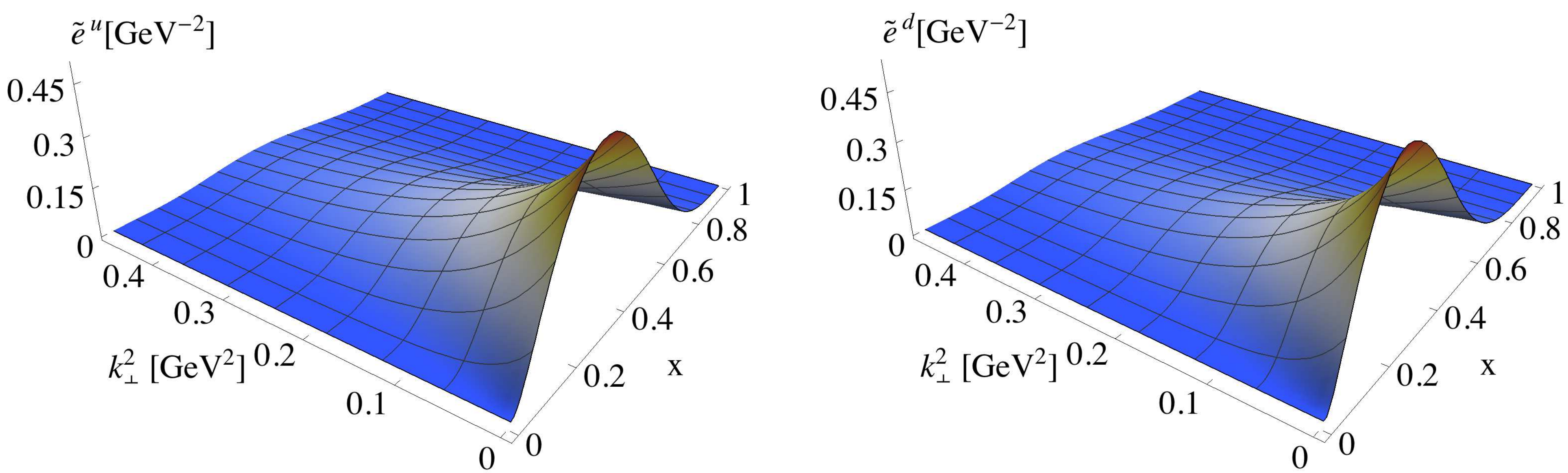
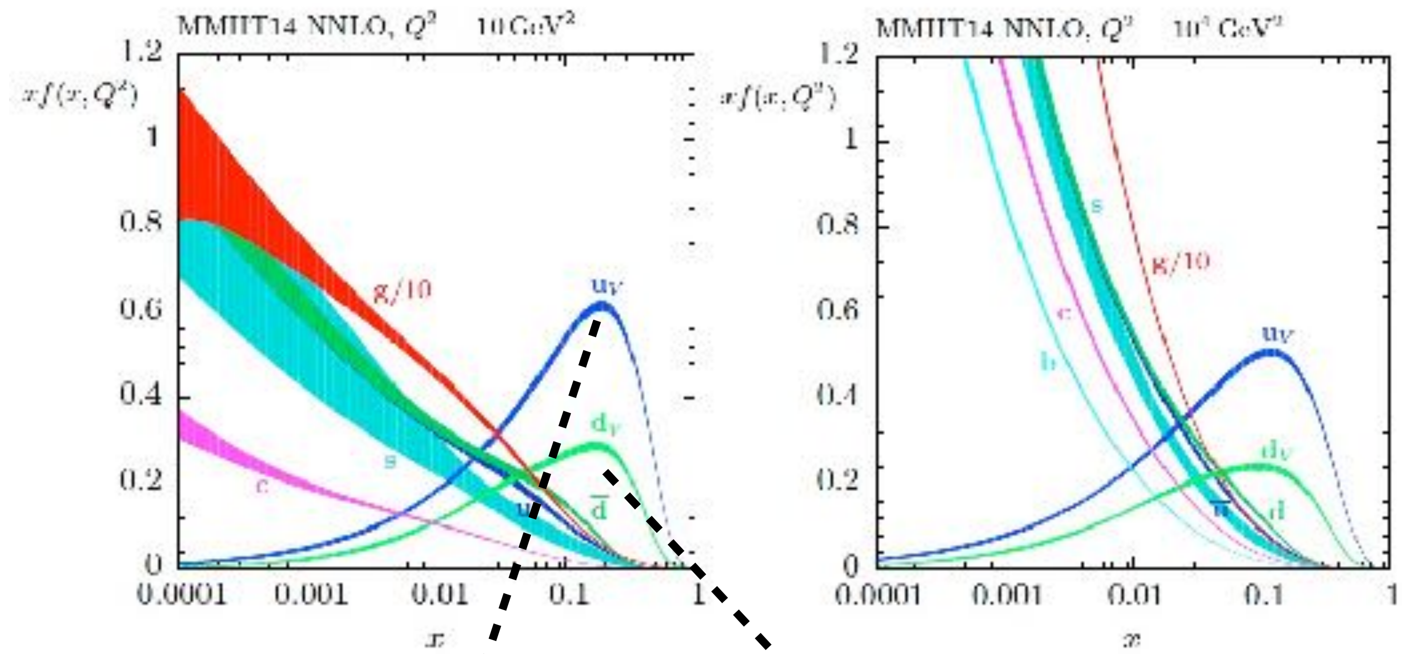


FIG. 5: $\tilde{e}$ for the up (left panel) and down (right panel) quark as a function of x and $k_\perp^2$.

Deriving the unpolarised TMD (Pasquini, Rodini 1806.10932)



MMHT2014 Eur. Phys. J. C75

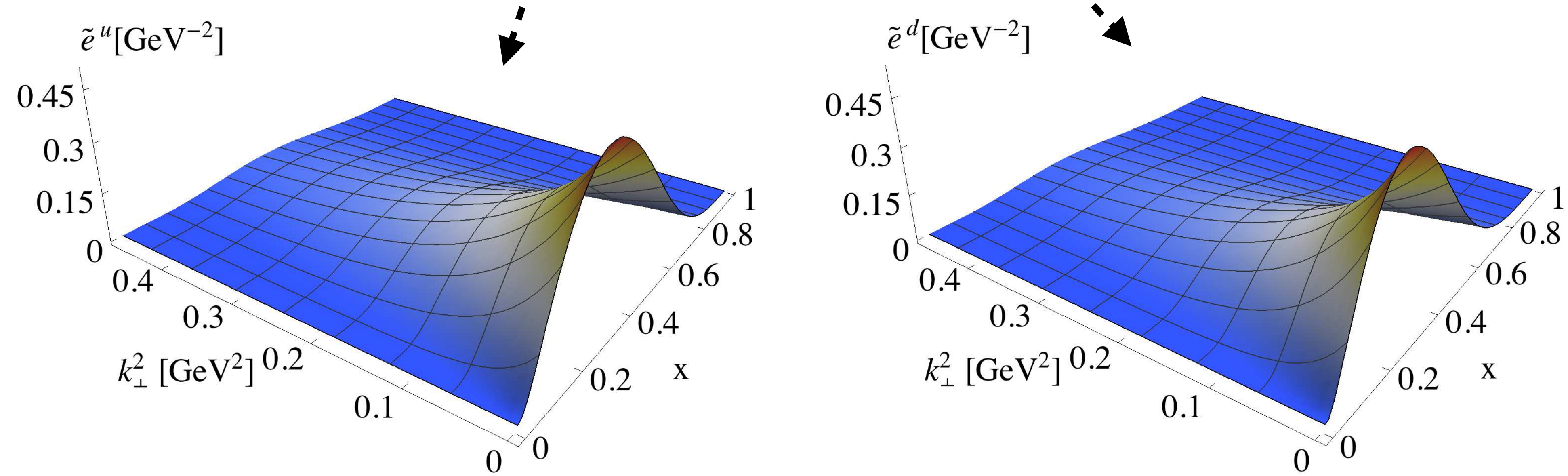


FIG. 5: $\tilde{e}$ for the up (left panel) and down (right panel) quark as a function of x and $k_\perp^2$.

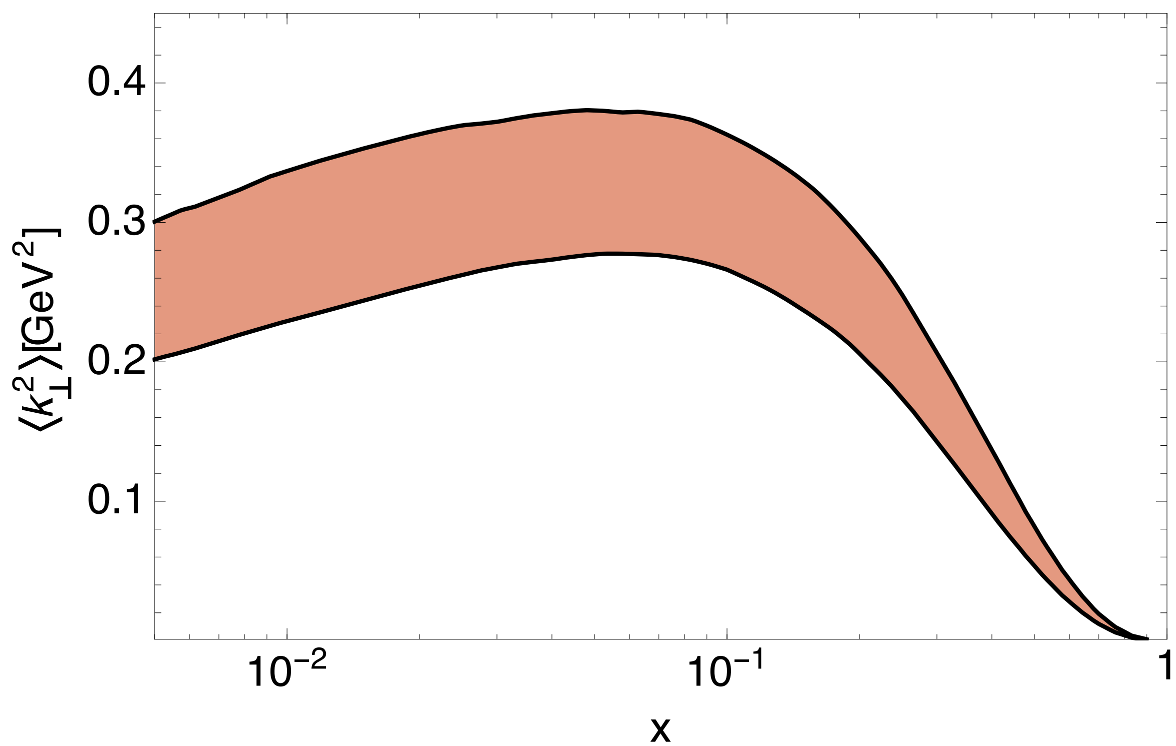
Quark unpolarized TMD extractions

	Framework	HERMES	COMPASS	DY	Z production	N of points
KN 2006 hep-ph/0506225	NLL/NLO	✘	✘	✔	✔	98
Pavia 2013 arXiv:1309.3507	No evo	✔	✘	✘	✘	1538
Torino 2014 arXiv:1312.6261	No evo	✔ (separately)	✔ (separately)	✘	✘	576 (H) 6284 (C)
DEMS 2014 arXiv:1407.3311	NNLL/NLO	✘	✘	✔	✔	223
EIKV 2014 arXiv:1401.5078	NLL/LO	1 (x,Q^2) bin	1 (x,Q^2) bin	✔	✔	500 (?)
Pavia 2016 arXiv:1703.10157	NLL/LO	✔	✔	✔	✔	8059
SV 2017 arXiv:1706.01473	NNLL/ NNLO	✘	✘	✔	✔	309

Global extraction from SIDIS, DY and Z boson

- ☑ Definition of a parametrization of TMDs from 8000 data points
- ☑ Test of the universality and evolution formalism of TMDs

$Q^2 = 1\ \mathrm{GeV}^2$

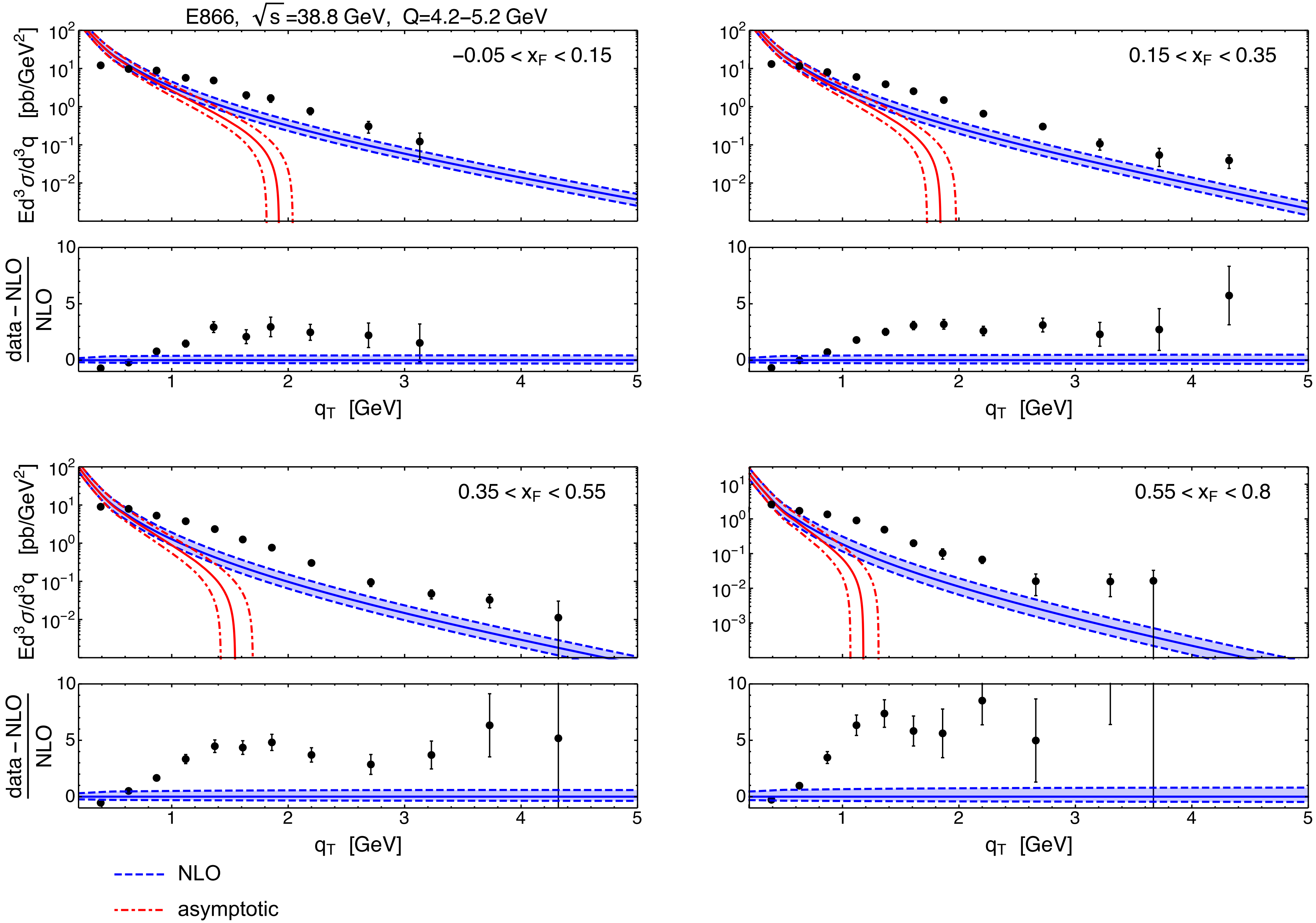


Pavia 2017, JHEP 1706 (2017) 081

Open issues:

- ☐ Flavour dependence
- ☐ Different choices in implementation of TMD formalism
- ☐ More data needed
- ☐ Improvements on the knowledge of fragmentation functions
- ☐ NLL+LO —> NLL+NLO ***Pavia 2018, arXiv:1812.xxxx***

Problems with DY at low Q and high qT

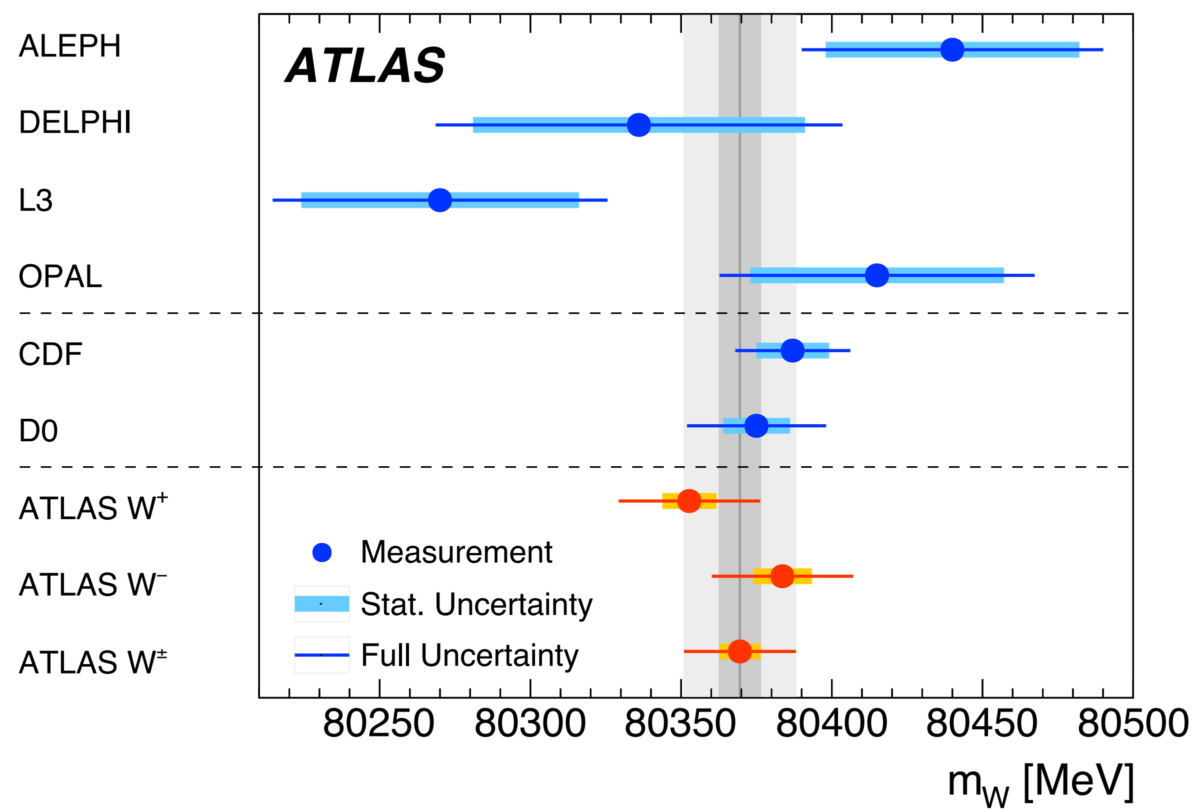


Similar plots for E605 & E288 (Tevatron), R209 (CERN)

Bacchetta, Bozzi, Piacenza, Vogelsang arXiv:1809.xxxx

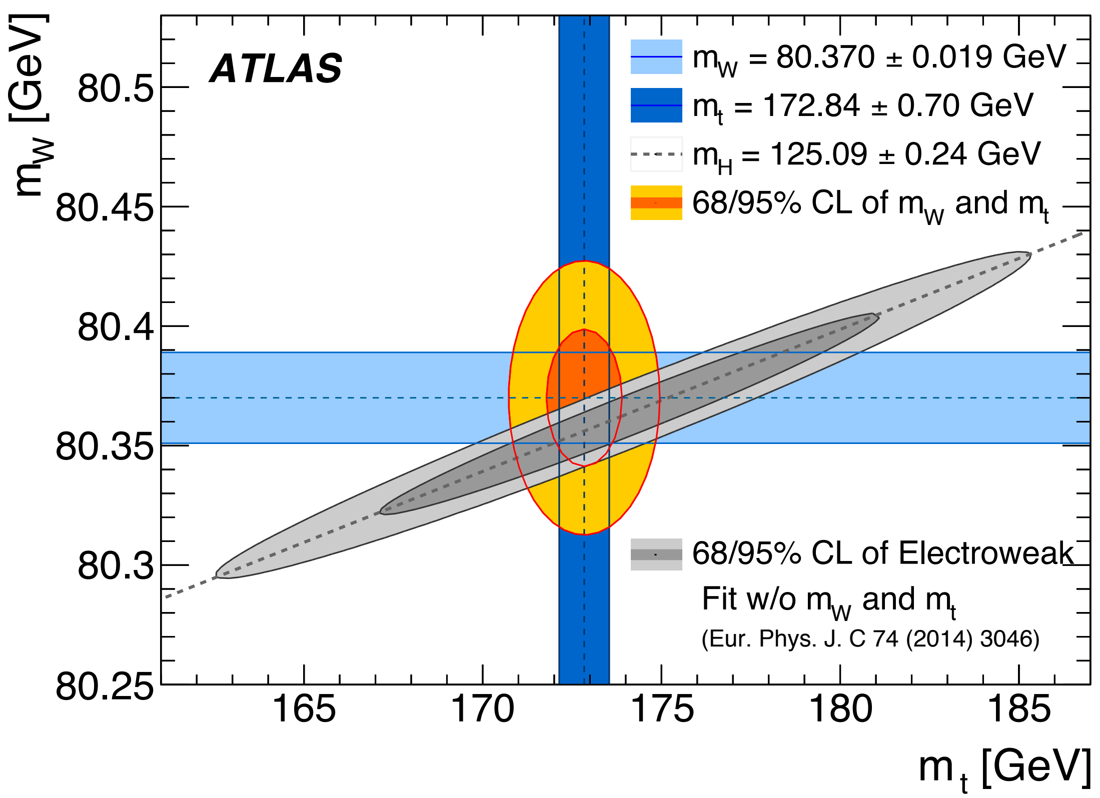
The *W* mass

ATLAS, EPJC 78, 110 (2018)



Experimental measurements

$$M_W = 80.379 \pm 12\ \mathrm{MeV}$$



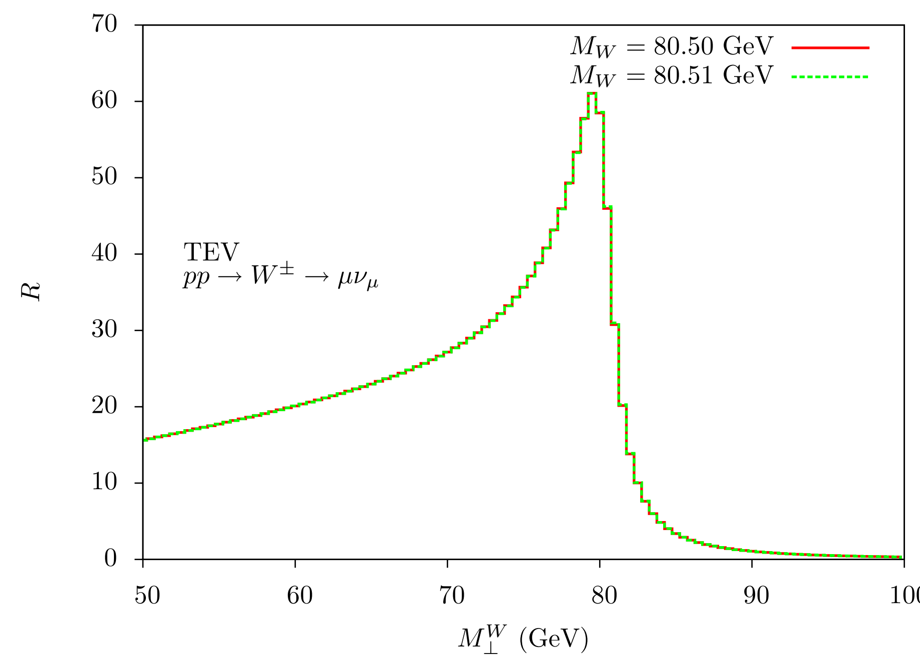
Global EW fit

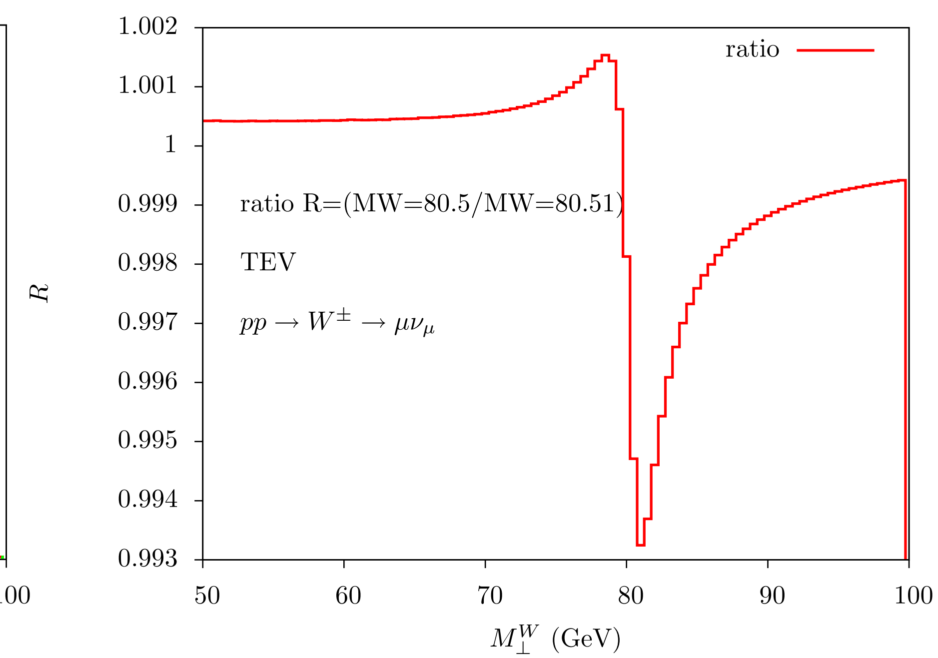
$$M_W = 80.356 \pm 8\ \mathrm{MeV}$$

Observables and techniques

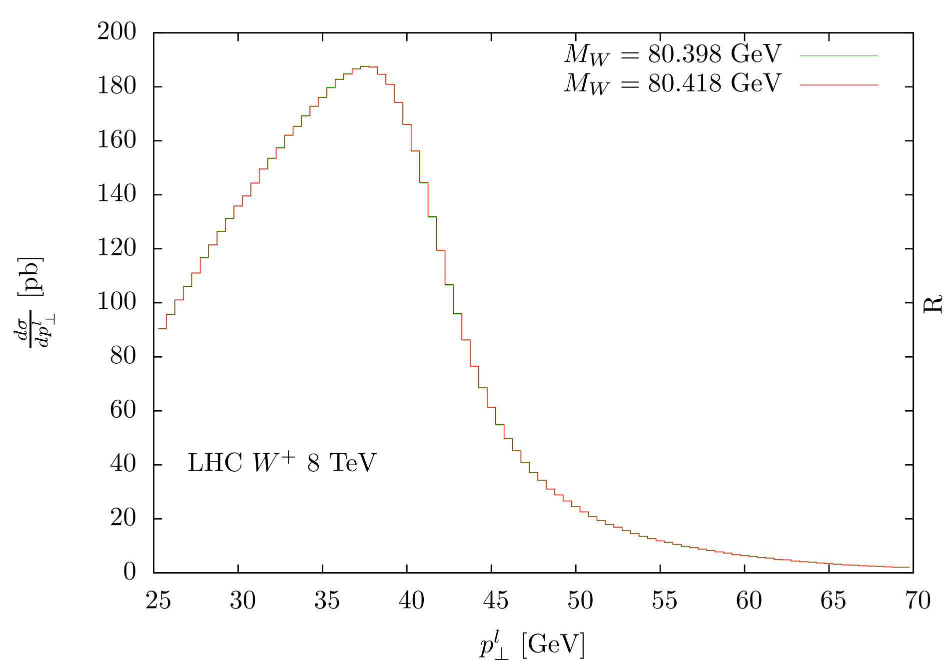
Challenging shape measurement: a distortion at the few per mille level of the distributions yields a shift of O(10 MeV) of the M_W value

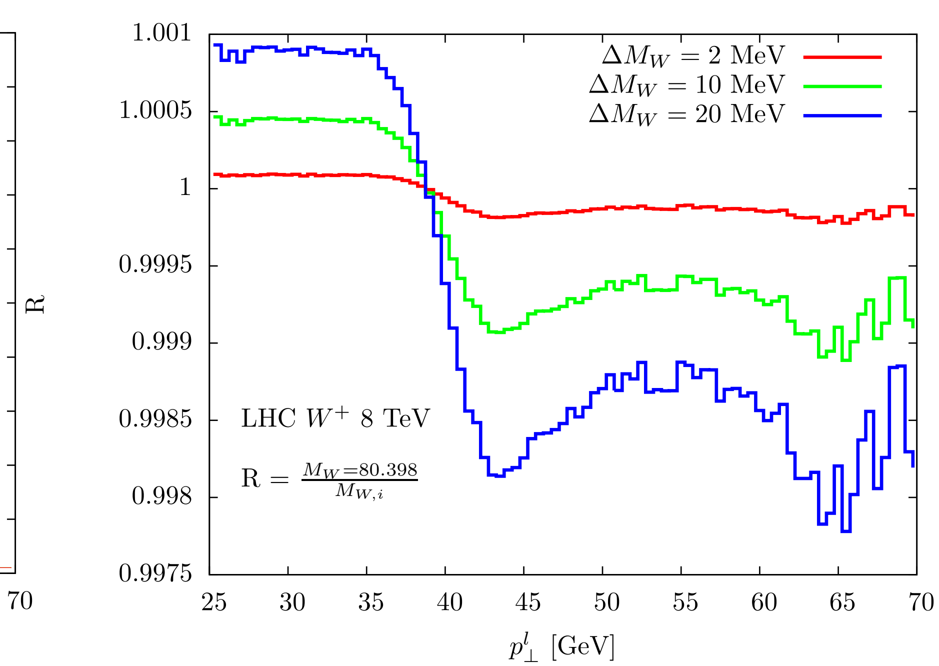
m_T





p_{Tl}





p_{TW} and the modelling of intrinsic k_T

- $p_{Tl} \Leftarrow p_{TW} \Leftarrow$ QCD initial state radiation + intrinsic k_T (usually, a Gaussian in k_T)
- Intrinsic k_T effects measured on Z data and used to predict W distributions, *assuming universality*

but

different flavour structure

different phase space available

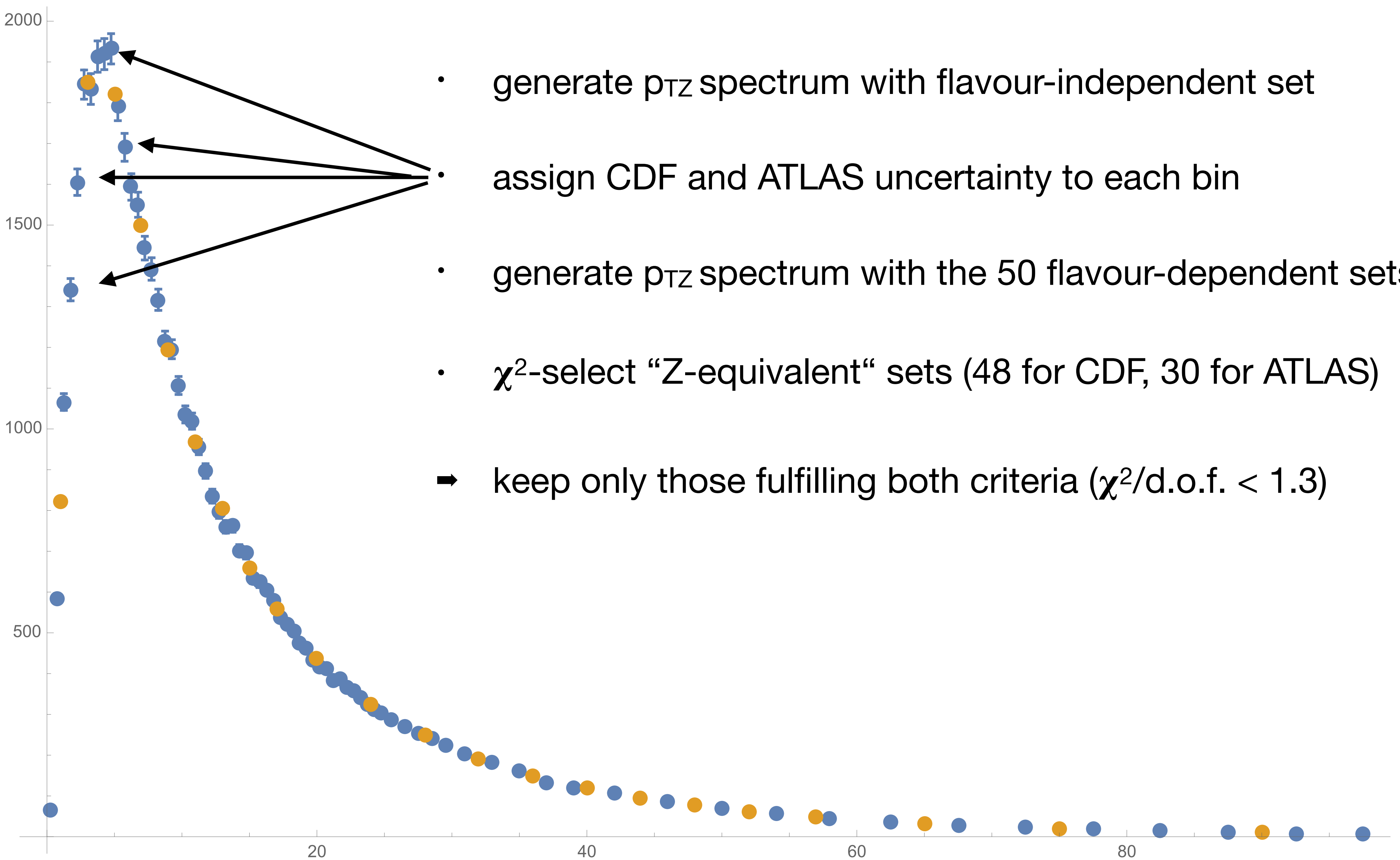
—> *different Gaussian factors for different flavours*

$$f_1^{aNP}(x, k_\perp^2; Q^2) = \frac{f_1^a(x, Q^2)}{\pi \langle k_\perp^2 \rangle_a} e^{-k_\perp^2/\langle k_\perp^2 \rangle_a}$$

$$\langle k_{\perp,u_v}^2 \rangle \neq \langle k_{\perp,d_v}^2 \rangle \neq \langle k_{\perp,u_s}^2 \rangle \neq \langle k_{\perp,d_s}^2 \rangle \neq \langle k_{\perp,sea}^2 \rangle$$

Flavor and ~~kinematic~~ dependent widths

“Z-equivalent” sets



- generate p_{TZ} spectrum with flavour-independent set
- assign CDF and ATLAS uncertainty to each bin
- generate p_{TZ} spectrum with the 50 flavour-dependent sets
- χ^2-select “Z-equivalent“ sets (48 for CDF, 30 for ATLAS)

➡ keep only those fulfilling both criteria (χ^2/d.o.f. < 1.3)

NLL+LO QCD curves obtained through a modified version of the **DYqT** code [Bozzi, Catani, deFlorian, Ferrera, Grazzini (2009,2011)] (Tevatron 1.96 TeV & LHC 7 TeV)

Impact on the determination of M_W

- Take the "Z-equivalent" *flavour-dependent* parameter sets and compute *low-statistics* (135M) m_T and p_{Tl} distributions

  ➡ these are our **pseudodata**

Set	u_v	d_v	u_s	d_s	s
1	0.34	0.26	0.46	0.59	0.32
2	0.34	0.46	0.56	0.32	0.51
3	0.55	0.34	0.33	0.55	0.30
4	0.53	0.49	0.37	0.22	0.52
5	0.42	0.38	0.29	0.57	0.27

- Take the *flavour-independent* parameter set and compute *high-statistics* (750M) m_T and p_{Tl} distributions for 30 different values of M_W

  ➡ these are our **templates**

	ΔM_{W^+}		ΔM_{W^-}	
Set	m_T	$p_{T\ell}$	m_T	$p_{T\ell}$
1	0	-1	-2	3
2	0	-6	-2	0
3	-1	9	-2	-4
4	0	0	-2	-4
5	0	4	-1	-3

- **perform the template fit procedure and compute the shifts induced by flavour effects**

- transverse mass: zero or few MeV shifts, generally favouring lower values for W^- (preferred by EW fit)

- lepton pt: quite important shifts (W^+ set 3: **9 MeV**, envelope: **up to 15 MeV**)

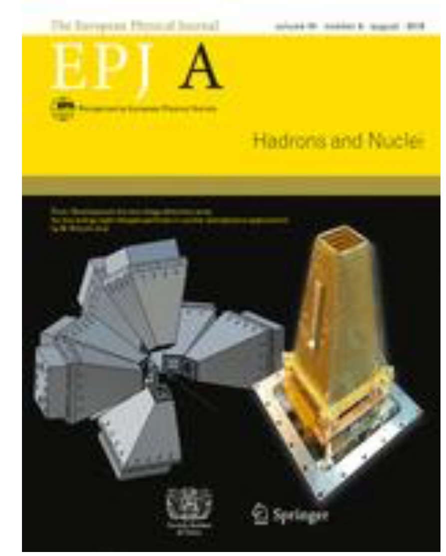
NLL+LO QCD analysis obtained through a modified version of the **DYRes** code [Catani, deFlorian, Ferrera, Grazzini (2015)] (LHC 7 TeV, ATLAS acceptance cuts)

Statistical uncertainty: 2.5 MeV

Bacchetta, Bozzi, Radici, Ritzmann, Signori (arXiv:1807.02101)

Conclusions

•TMDs and GPDs extend the concept of standard PDFs and provide a 3D description (tomography) of the nucleon



The 3-D Structure of the Nucleon

•TMDs and GPDs provide complementary information and allow us to investigate aspects of nucleon structure that are not accessible to standard collinear PDFs

•Uninterrupted progress in the field of multidimensional ``imaging" in the last decade, but we are a long way from anything similar to PDF global fits: busy and exciting times ahead!

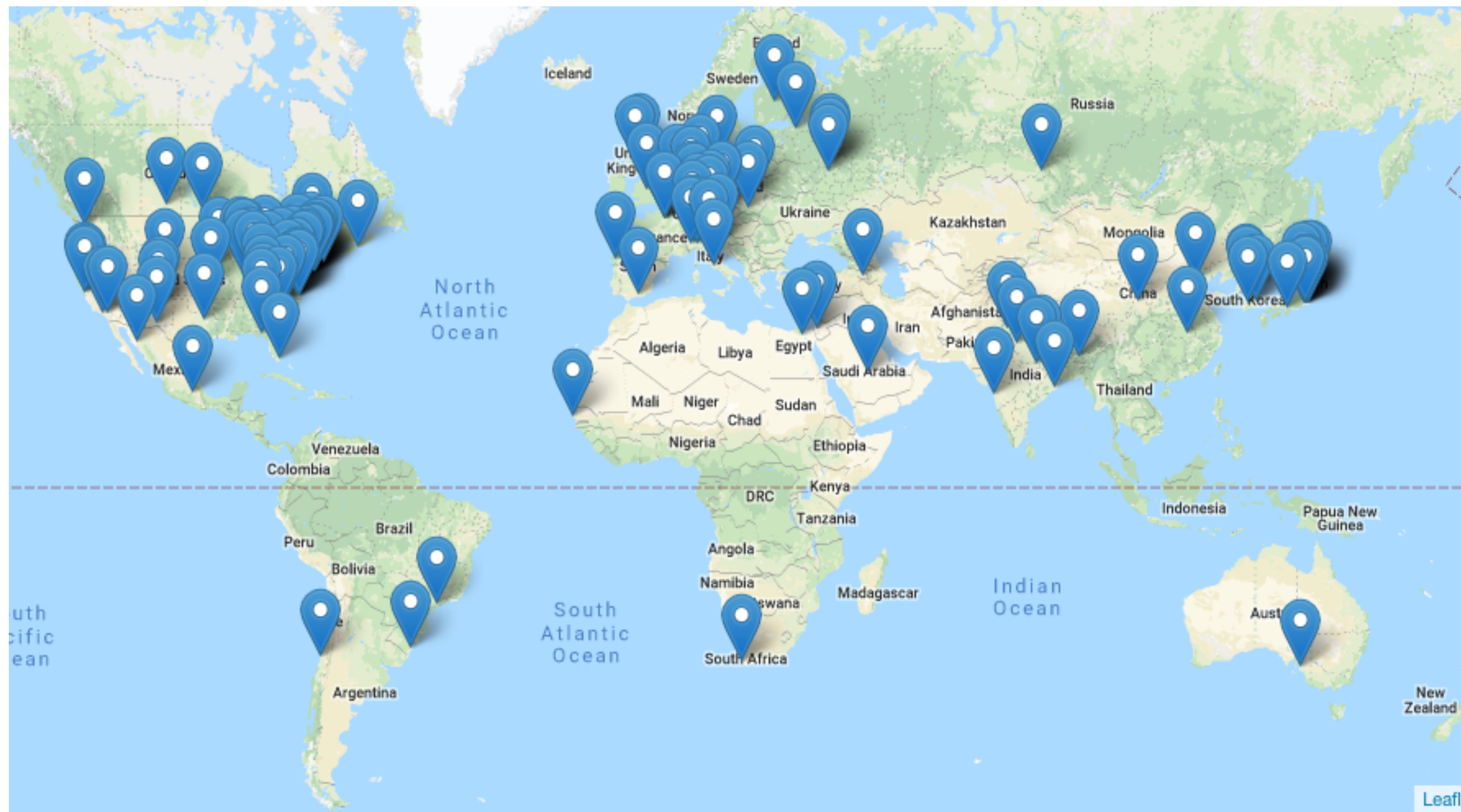
•A lot of data is already available, but we expect more from e+e−, SIDIS, Drell-Yan from:

- JLab 12 GeV (just started)
- COMPASS transverse run (approved in 2021)
- Polarized SeaQuest at FermiLab (approved)
- STAR@RHIC (upgrade)
- SMOG2, i.e., LHCb fixed target (CERN, under examination)
- …and, of course, the **EIC**

Electron Ion Collider User Group - August 2018

- Size and demographics (2)
  - EICUG organization established in summer 2016
  - In numbers….: 809 members (Experimental scientists: 465 / Theory scientists: 160 / Accelerator scientists: 142 / Support: 3 / Other: 39), 173 institutions, 30 countries, 7 world regions
  - World map:

EIC Users' Group Meeting - CUA
Washington, DC, July 30 - August 2, 2018



Marco in the Steering Committee

Barbara in the Conference and Talks Committee

"The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely." (NAS report - 24/07/18)