a Monte Carlo generator for TMDs

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based on the work by: hermes

A. Bachetta, U. Elschenbroich, **S. Gliske, N.Makins, G. Schnell**, R. Seidl

[see also: G. Schnell @PKU-RBRC workshop on Transverse Spin Physics, July 2008]

4th meeting of the JLab12 INFN collaboration, Roma, La Sapienza, June 10/11, 2010

portrait

- physics generator for sidis hadron production
- includes transverse momentum dependence of distribution and/or fragmentation fcts. :

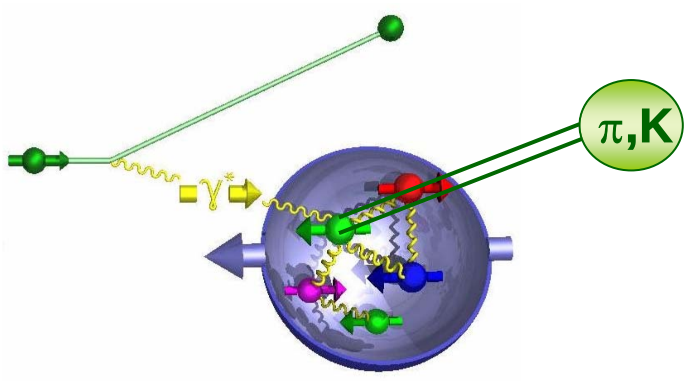
  Collins & Sivers effects ++

- allow comparison of input model and reconstructed amplitudes
- modular (extendable) & fast
- originally built within 'HERMES environment'

  → new, independent C^{++} version by Steve Gliske

TMDs: nucleon tomography & OAM

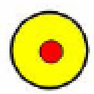
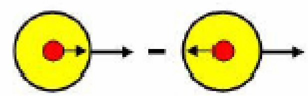
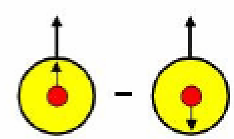
SIDIS cross section



$$\sigma^{\mathrm{h}}_{\mathrm{XY}} \propto \sum_f \hat{\sigma}_{part} \otimes pdf(x, k_T) \otimes frag^{\mathrm{q,g}\to\mathrm{h}}(z, p_T)$$

TMDs: nucleon tomography & OAM

@leading twist, integrated over P_{hT}:

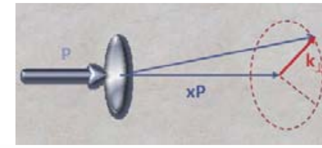
		quark		
		U	**L**	**T**
nucleon	**U**	f_1 		
	L		g_1 	
	T			h_1 

'transversity'

TMDs: nucleon tomography & OAM

@leading twist, no P_{hT} integration:

→ **spin-orbit correlations**



		quark		
		U	**L**	**T**
nucleon	**U**	f_1		$h_1^{\perp}$
	L		g_1	$h_{1L}^{\perp}$
	T	$f_{1T}^{\perp}$	$g_{1T}^{\perp}$	h_1 $h_{1T}^{\perp}$

‘Boer-Mulders’ ($h_1^{\perp}$)

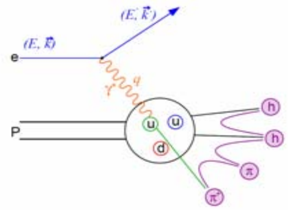
‘worm-gear’ ($h_{1L}^{\perp}$)

‘transversity’ (h_1)

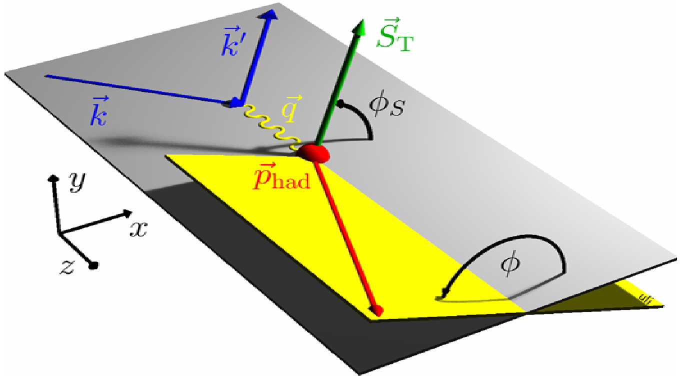
‘pretzelosity’ ($h_{1T}^{\perp}$)

‘Sivers’ ($f_{1T}^{\perp}$)

‘worm-gear’ ($g_{1T}^{\perp}$)



TMDs from SIDIS



σ_{XY}

beam: λ target: S_L, S_T

8 leading-twist terms

$$d\sigma = d\sigma^0_{UU} + \cos 2\phi\, d\sigma^1_{UU} + \frac{1}{Q}\cos\phi\, d\sigma^2_{UU} + \lambda_e \frac{1}{Q}\sin\phi\, d\sigma^3_{LU}$$

$$+ S_L\left\{\sin 2\phi\, d\sigma^4_{UL} + \frac{1}{Q}\sin\phi\, d\sigma^5_{UL} + \lambda_e\left[d\sigma^6_{LL} + \frac{1}{Q}\cos\phi\, d\sigma^7_{LL}\right]\right\}$$

$$+ S_T\left\{\sin(\phi-\phi_S)\; d\sigma^8_{UT} + \sin(\phi+\phi_S)\; d\sigma^9_{UT} + \sin(3\phi-\phi_S)\; d\sigma^{10}_{UT}\right.$$

$$+ \frac{1}{Q}\sin(2\phi-\phi_S)\; d\sigma^{11}_{UT} + \frac{1}{Q}\sin\phi_S\, d\sigma^{12}_{UT}$$

$$\left. + \lambda_e\left[\cos(\phi-\phi_S)\; d\sigma^{13}_{LT} + \frac{1}{Q}\cos\phi_S\, d\sigma^{14}_{LT} + \frac{1}{Q}\cos(2\phi-\phi_S)\, d\sigma^{15}_{LT}\right]\right\}$$

extracting TMDs

e.g. Sivers effect: $e\, p^{\uparrow} \rightarrow e\, h\, X$

$$\sigma_{\mathrm{UT}}(\phi,\phi_S) \sim \sin(\phi-\phi_S) \sum e_q^2 \; f_{1T}^{\perp}(x,k_T) \otimes D_1(z,p_T) + \ldots$$

convolution integral over initial and final quark transverse momenta

extracting TMDs

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$$\sigma_{\mathrm{UT}}(\phi,\phi_S) \sim \sin(\phi-\phi_S) \sum \mathrm{e}_{\mathrm{q}}^2 \; f_{1T}^{\perp}(x,k_T) \otimes D_1(z,p_T) + \ldots$$

convolution integral over initial and final quark transverse momenta

→ **deconvolution:**

- ‘easy’ ansatz: *gaussian* dependencies of DFs and FFs on intrinsic quark transverse momentum ← model dependent !

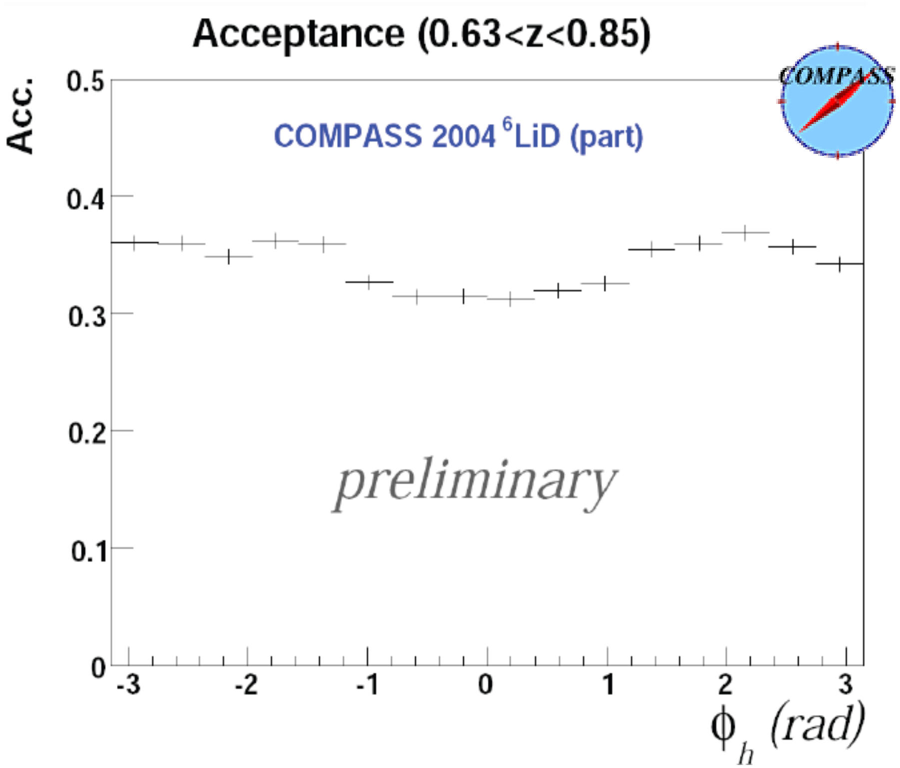
- evaluate P_{hT} weighted moments ← model *in*dependent !

$$\left\langle \frac{P_{hT}}{zM} \sin(\phi-\phi_S) \right\rangle_{\mathrm{UT}}^{\mathrm{h}} \propto \sum e_q^2 \; f_{1T}^{\perp}(x) \cdot D_1(z)$$

why a new generator ?

why a new generator ?

“No particle physics experiment has a perfect acceptance ! “

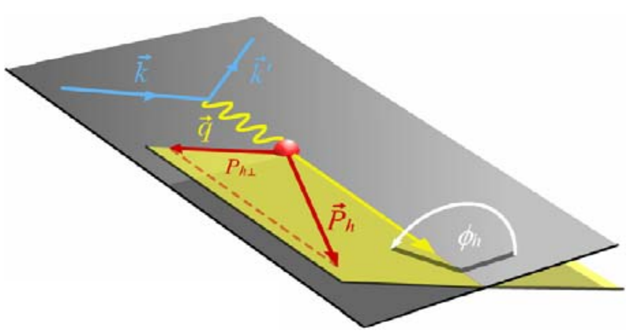


[W. Kaefer, Transversity 2008, Ferrara]

maybe “4π” around beam axis but

NOT around virtual-photon axis

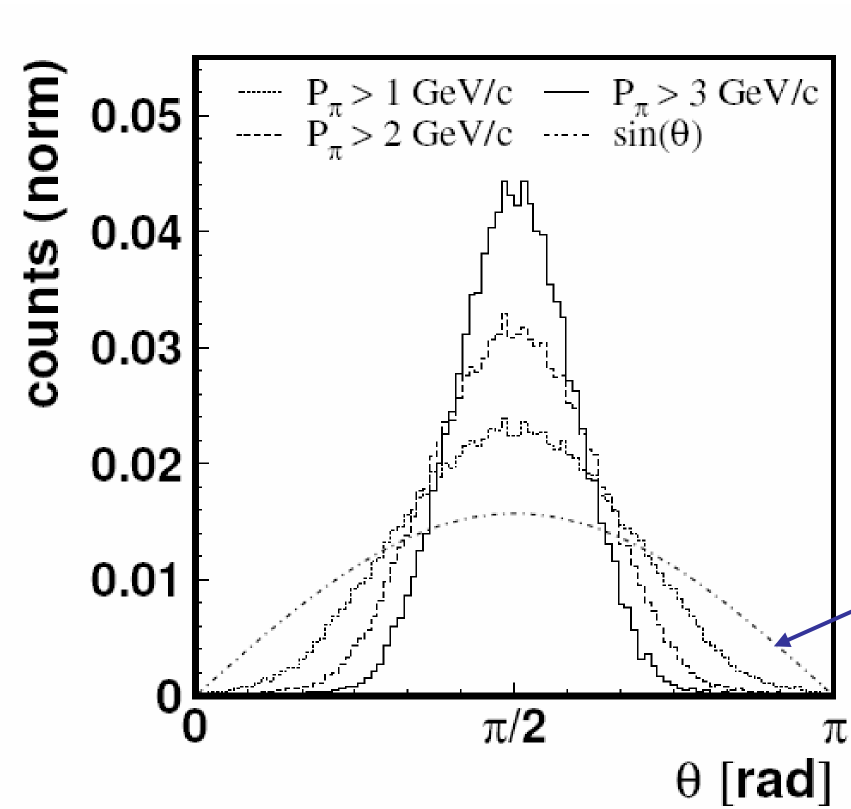
because of lower limit on θ

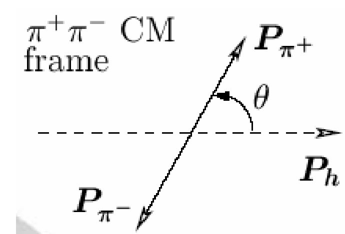


why a new generator ?

“No particle physics experiment has full kinematic coverage ! “

$$e\,p^{\uparrow} \rightarrow e\,h_1 h_2\,X \quad \Rightarrow \quad \sigma_{UT} \sim \sin(\phi_{R\perp} + \phi_S)\sin\theta \sum e_q^2\, \delta q \cdot H_1^{\triangleleft q}$$





unavoidable momentum cuts strongly distort kinematic distributions even for “4π” acceptance

[P. van der Nat, Ph.D. thesis (2007)]

why a new generator ?

e.g. Sivers effect: $\mathrm{e\,p^{\uparrow} \rightarrow e\,}h\,\mathrm{X}$

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convolution integral over initial and final quark transverse momenta

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- extraction requires *full* integration over P_{hT} $[0,\infty]$
- experimentally: partial coverage in P_{hT}

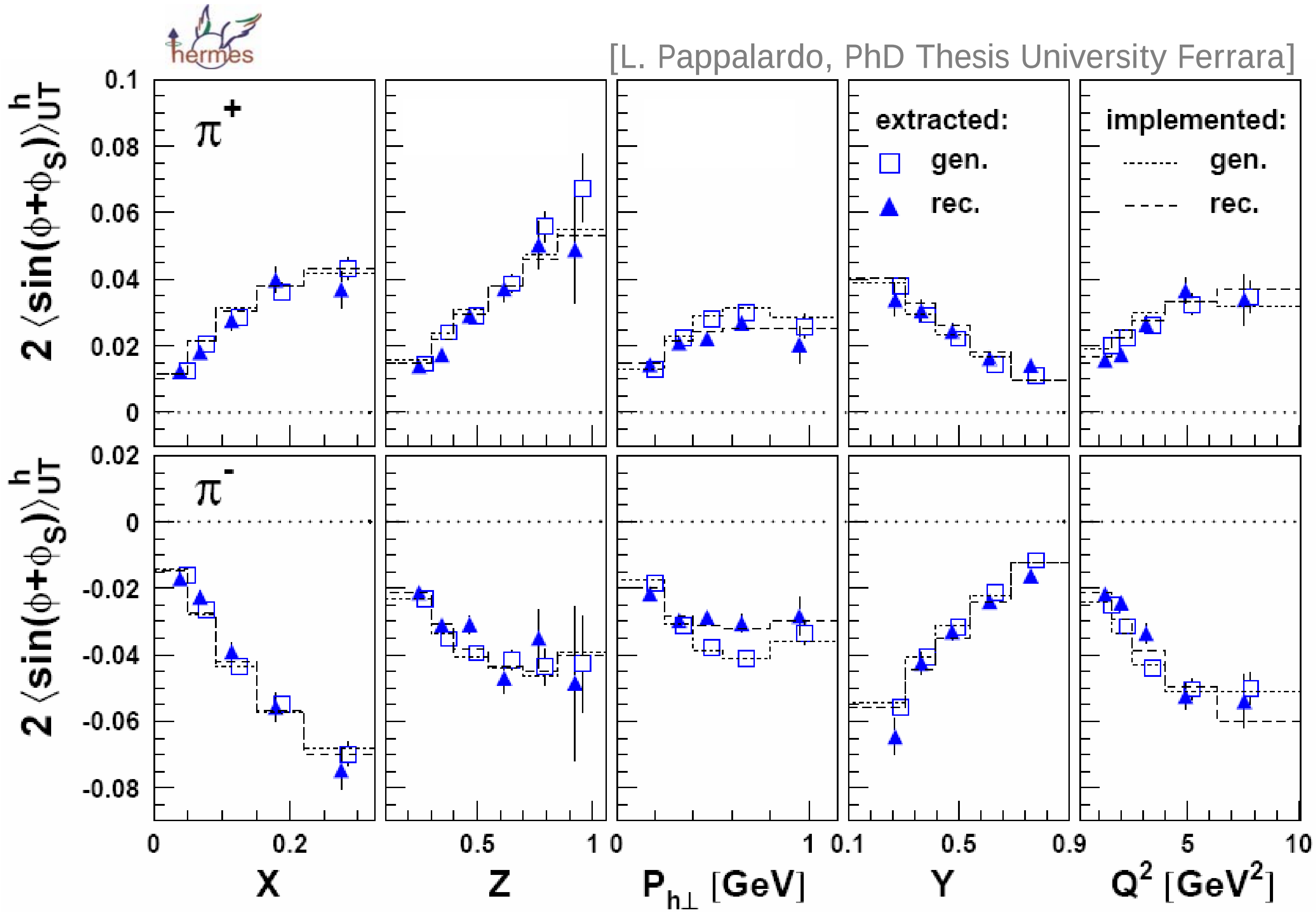
→ evaluation of acceptance effects crucial !

acceptance studies I

Monte Carlo: gmc_trans: generator for transversity + TMDs

simulates full kinematic dependences of observables

[L. Pappalardo, PhD Thesis University Ferrara]



Collins moments **unweighted**

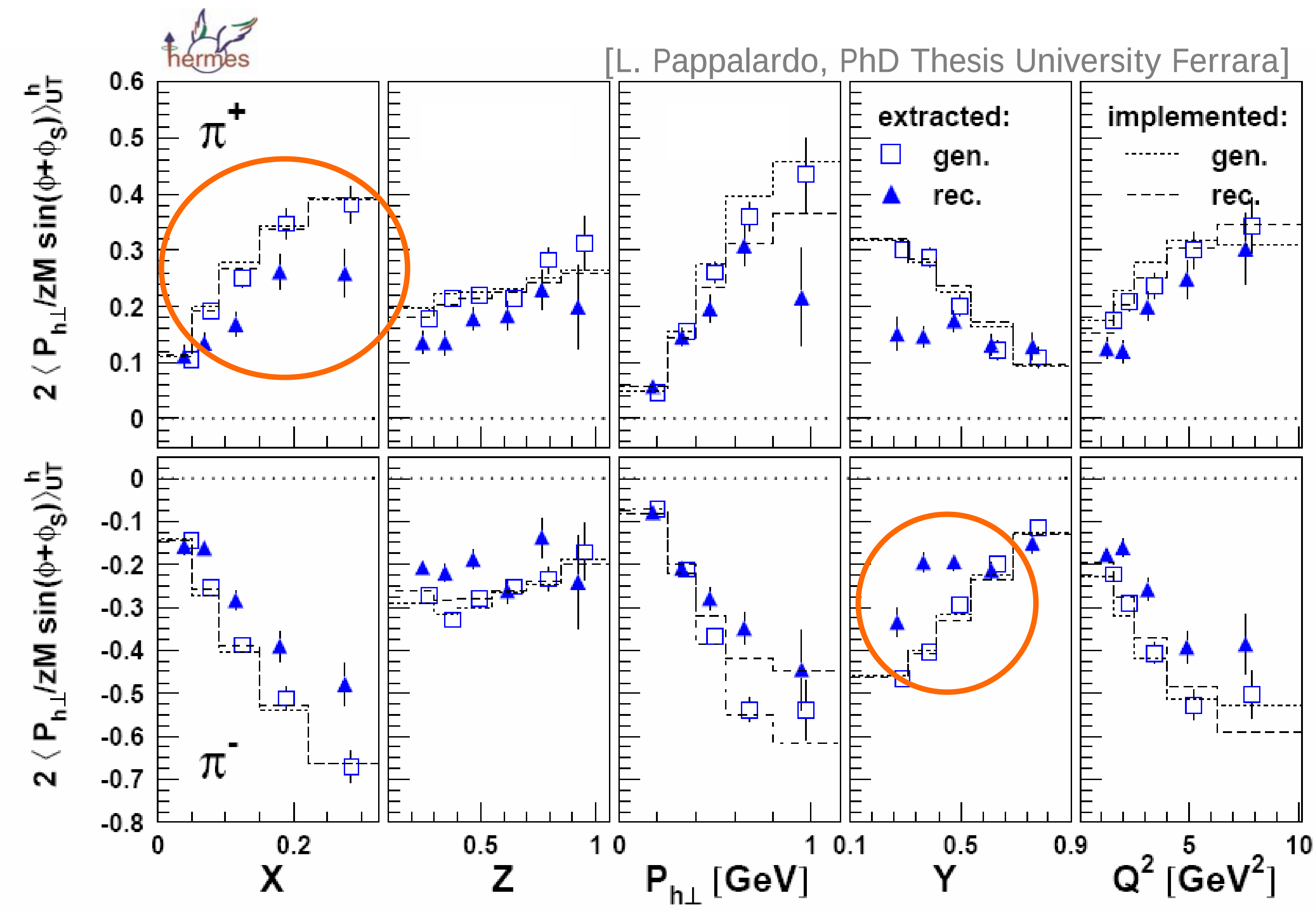
→ no significant acceptance effects

acceptance studies II

Monte Carlo: gmc_trans: generator for transversity + TMDs

simulates full kinematic dependences of observables

[L. Pappalardo, PhD Thesis University Ferrara]

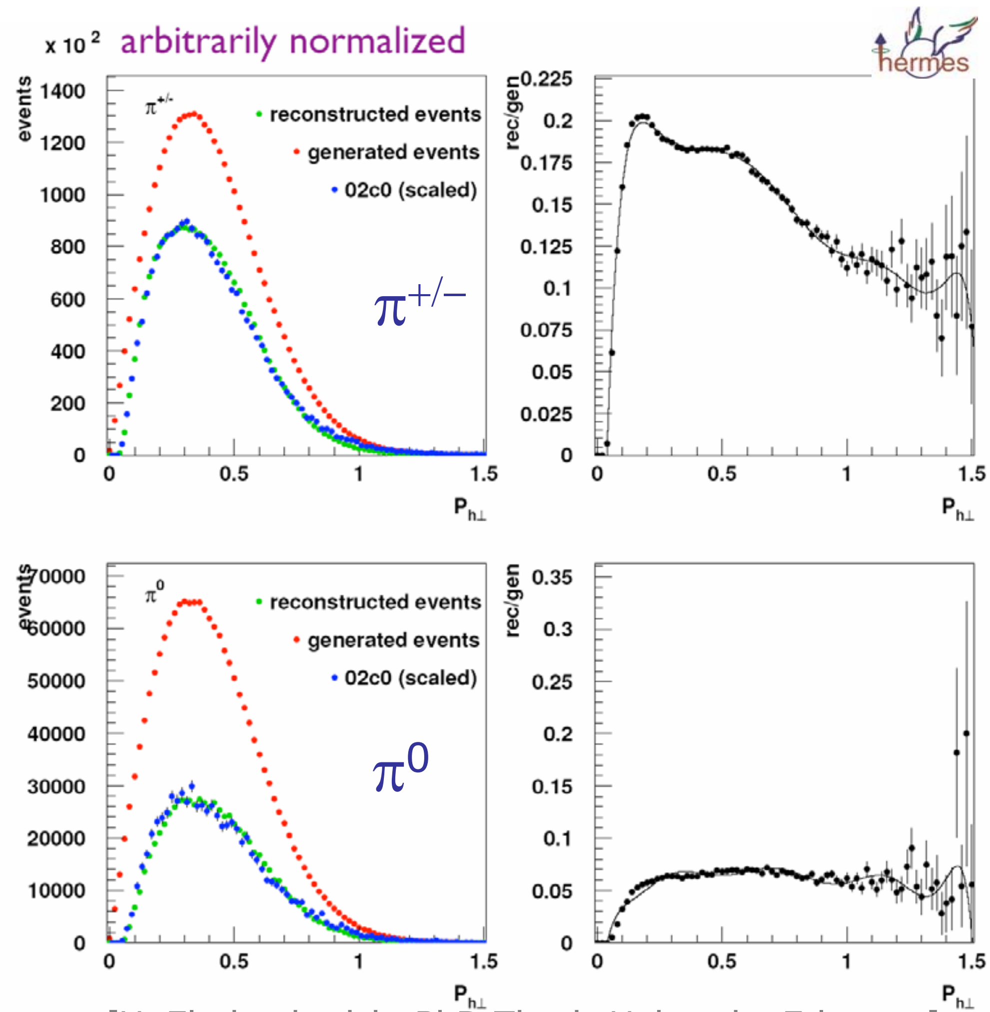


Collins moments P_{hT} **weighted**

→ large acceptance effects

P_{hT} weighted asymmetries:

acceptance depends strongly on P_{hT}:



[U. Elschenbroich, PhD Thesis University Erlangen]

MC P_{hT} distributions:

$\langle p_T \rangle$ = 0.38 and

$\langle K_T \rangle$ = 0.38 constant

gmc_trans: basic workings

- uses cross section that can (almost) be calculated analytically
- starting point: 1-hadron SIDIS expression of Mulders & Tangermann [NPB461 (1996) 197]
- uses gaussian ansatz for all transverse-momentum dependencies of DFs & FFs
- unpolarized DFs, helicity distributions and FFs from fits / parametrisations (e.g. CETQ, Kretzer, DSS)
- **TMDs** either related to the unpolarised ones (e.g. saturation of Soffer bound for transversity) or parametrisations used

summary & ToDo

- modular MC generator for TMDs in SIDIS 1&2 hadron production

  based on gaussian ansatz for transverse-momentum dependencies

- allows to study possible kinematic and flavour dependence of gaussian widths

- inevitable tool for extraction of pT weighted TMD observables

summary & ToDo

- modular MC generator for TMDs in SIDIS 1&2 hadron production

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ToDo:

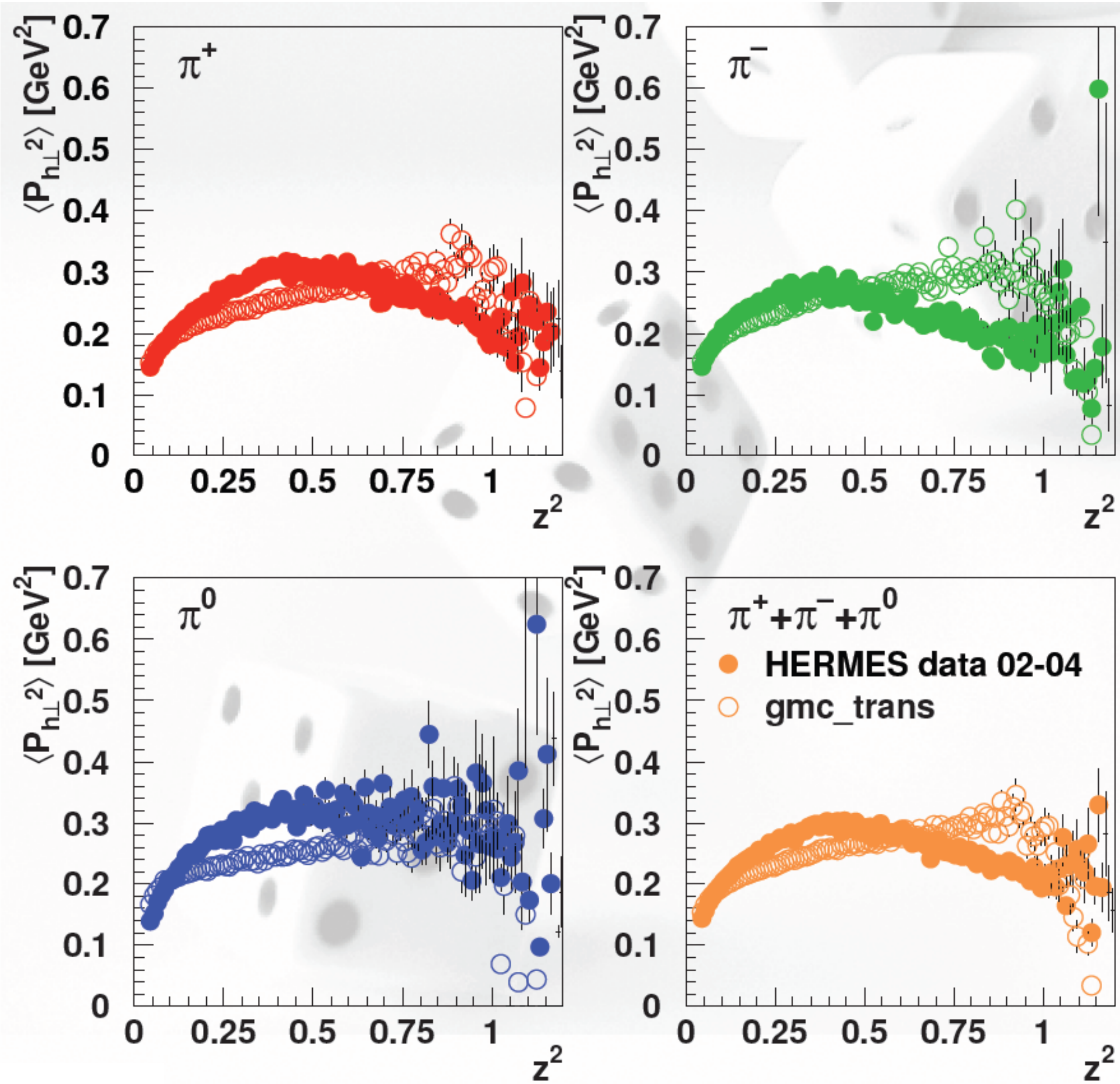
→ learn C^{++} ☺

→ implementation in CLAS environment

→ implementation of radiative effects

BACKUP SLIDES

tuning the gaussians in gmc_trans

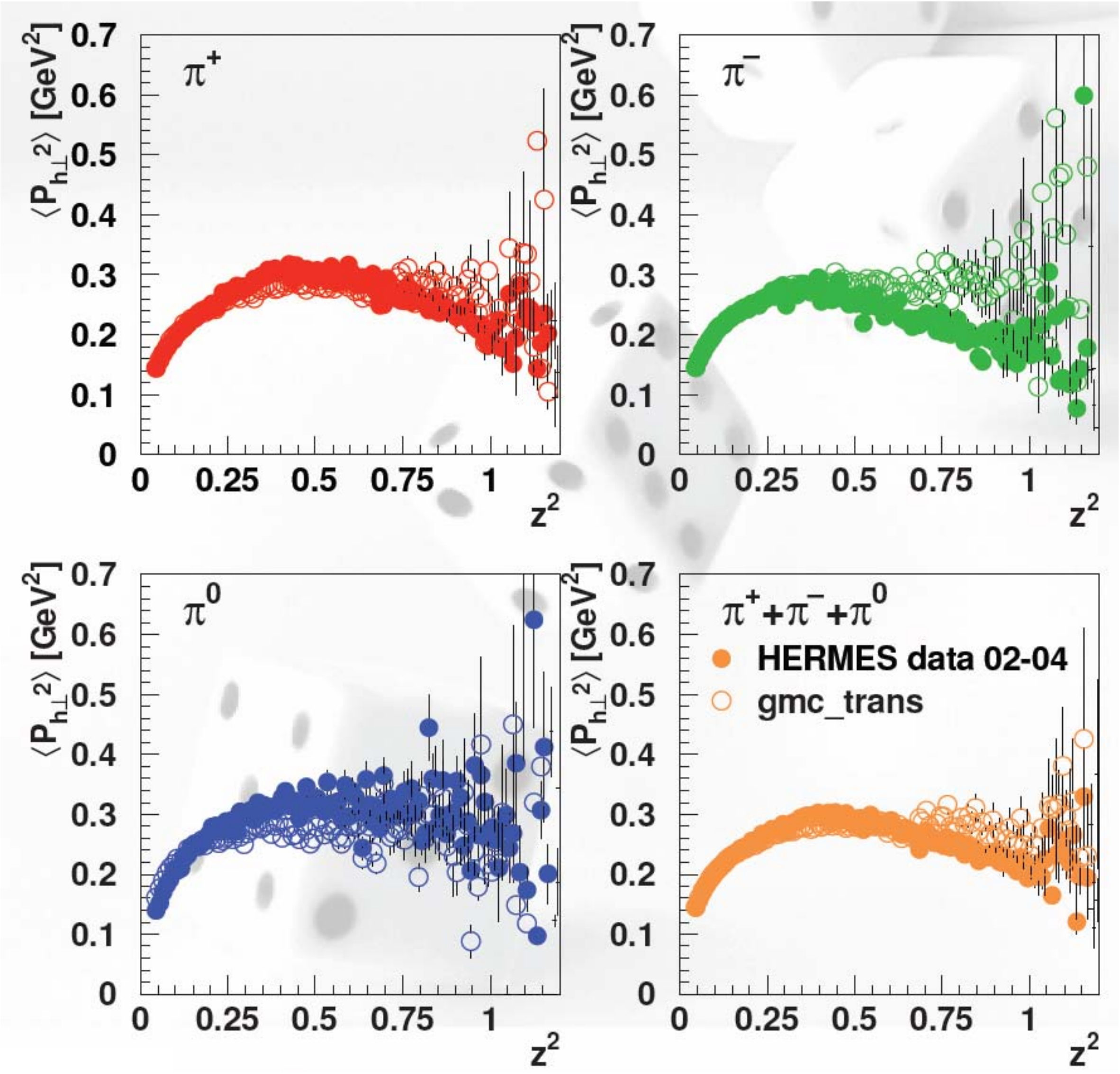


$$\left\langle P_{hT}^2(z) \right\rangle = z^2 \left\langle k_T^2 \right\rangle + \left\langle p_T^2(z) \right\rangle$$

const: $\left\langle k_T \right\rangle = 0.38$ GeV

$\left\langle p_T \right\rangle = 0.38$ GeV

tuning the gaussians in gmc_trans



$$\left\langle P_{hT}^2(z) \right\rangle = z^2 \left\langle k_T^2 \right\rangle + \left\langle p_T^2(z) \right\rangle$$

now z dependent !

leading-tw distribution functions

$$\sigma^{h}_{XY} \propto \sum_f \hat{\sigma}_{part} \otimes pdf(x, k_T) \otimes frag^{q,g\rightarrow h}(z, p_T)$$

XY		pdf		frag
UU	1	$f_1 =$	$\otimes$	$D_1 =$
	$\cos(2\phi_h^l)$	$h_1^{\perp} =$	$\otimes$	$H_1^{\perp} =$
UL	$\sin(2\phi_h^l)$	$h_{1L}^{\perp} =$	$\otimes$	$H_1^{\perp} =$
UT	$\sin(\phi_h^l + \phi_S^l)$	$h_1 =$	$\otimes$	$H_1^{\perp} =$
	$\sin(\phi_h^l - \phi_S^l)$	$f_{1T}^{\perp} =$	$\otimes$	$D_1 =$
	$\sin(3\phi_h^l - \phi_S^l)$	$h_{1T}^{\perp} =$	$\otimes$	$H_1^{\perp} =$
LL	1	$g_1 =$	$\otimes$	$D_1 =$
LT	$\cos(\phi_h^l - \phi_S^l)$	$g_{1T} =$	$\otimes$	$D_1 =$

chiral-odd pdf & Collins FF

'Amsterdam notation'