Radiative Corrections and Data Input for 3D pdf Analysis

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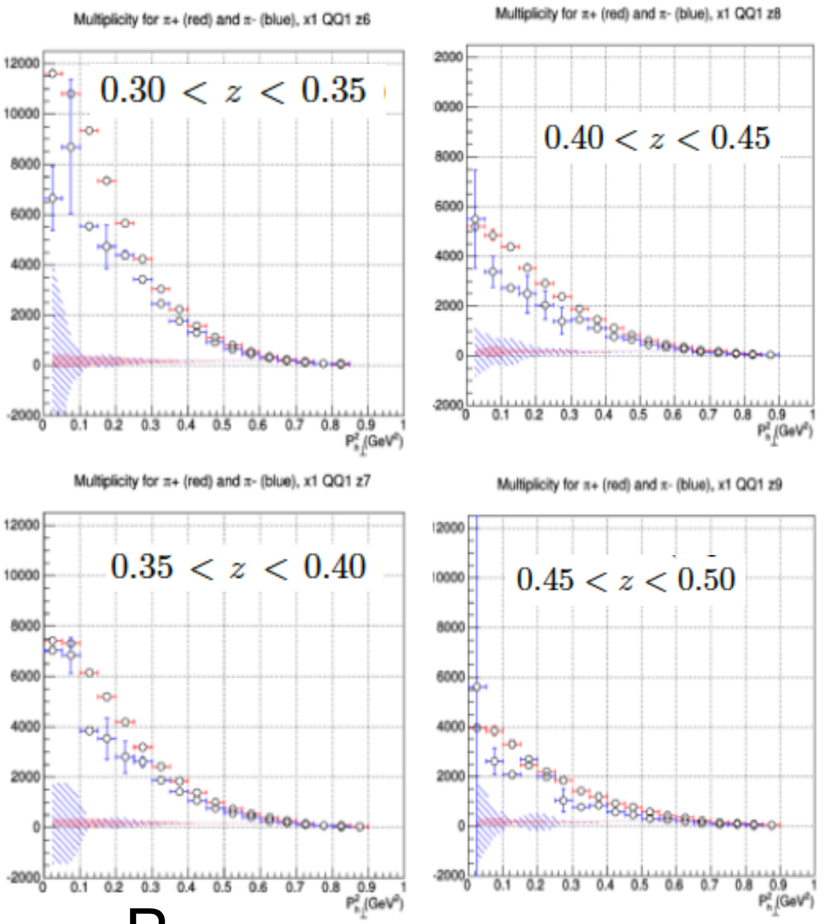
Deep processes working group meeting , JLab, June 17, 2016

- Structure Functions in Hard Scattering
- Separating the measurement from analysis
- 3D PDF extraction and validation chain
- Summary & Conclusions

LDRD-2016: Universal Analysis Framework for Nucleon Tomography:
Nucleon 3D PDF extraction (L. Elouadrhiri et al.)

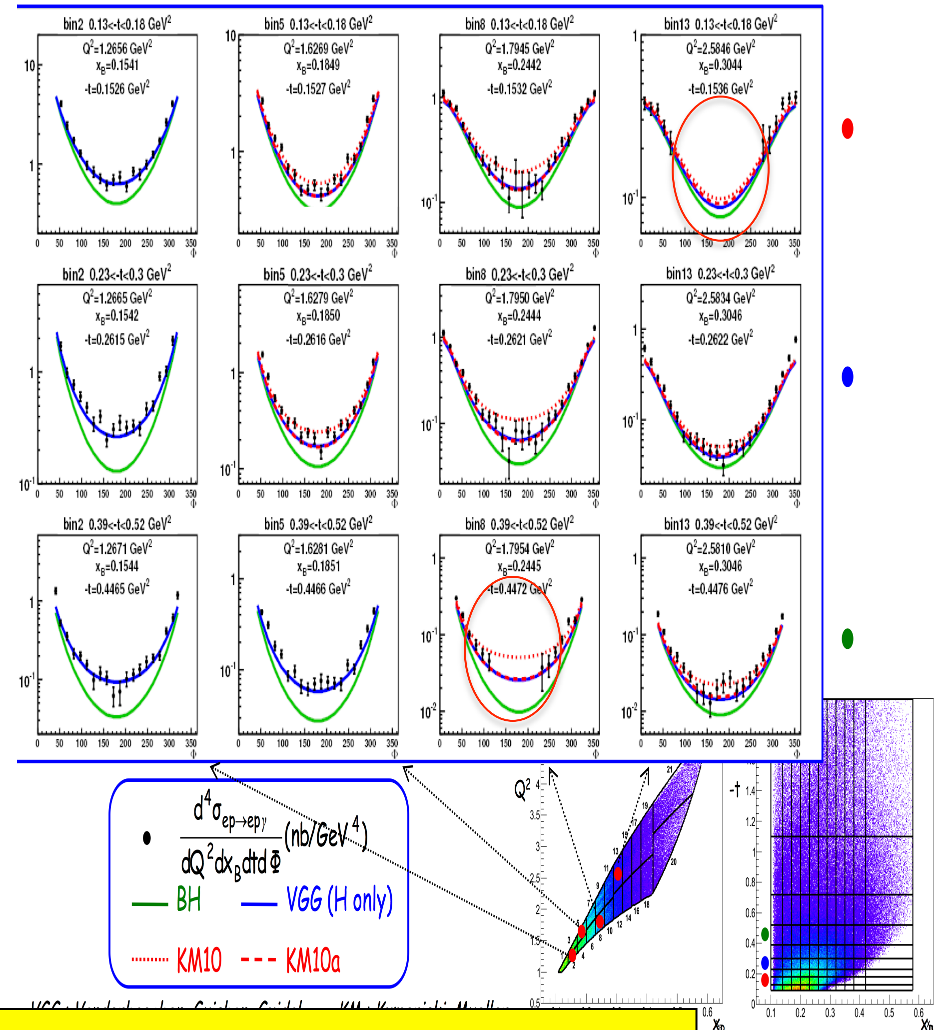
x-sections in hard scattering (SIDIS/DVCS)

SIDIS multiplicities (e1f: N.Harrison)



P_T

DVCS x-sections (e1dvcs)



x-sections change rapidly (cosφ most unknown!)

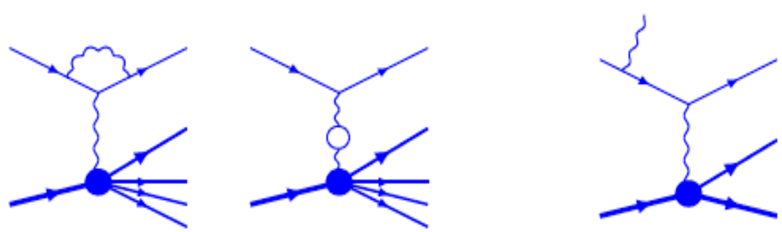
$$
\frac{d\sigma}{dx\,dy\,d\phi_S\,dz\,d\phi_h\,dP_{h\perp}^2}
$$

$F_{UU,T}(x, z, P_{h\perp}^2, Q^2)$

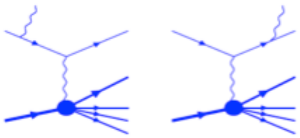
$$
\begin{aligned}
&= \frac{\alpha^2}{x\,y\,Q^2}\,\frac{y^2}{2\,(1-\varepsilon)} \Bigg\{ F_{UU,T} + \varepsilon\, F_{UU,L} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\, F_{UU}^{\cos\phi_h} + \varepsilon \cos(2\phi_h)\, F_{UU}^{\cos 2\phi_h} \\
&\quad + \lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\, F_{LU}^{\sin\phi_h} + S_L \Big[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\, F_{UL}^{\sin\phi_h} + \varepsilon \sin(2\phi_h)\, F_{UL}^{\sin 2\phi_h} \Big] \\
&\quad + S_L\,\lambda_e \Big[\sqrt{1-\varepsilon^2}\, F_{LL} + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\, F_{LL}^{\cos\phi_h} \Big] \\
&\quad + S_T \Big[\sin(\phi_h - \phi_S)\,\Big(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon\, F_{UT,L}^{\sin(\phi_h-\phi_S)} \Big) + \varepsilon\,\sin(\phi_h + \phi_S)\, F_{UT}^{\sin(\phi_h+\phi_S)} \\
&\qquad + \varepsilon\,\sin(3\phi_h - \phi_S)\, F_{UT}^{\sin(3\phi_h-\phi_S)} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\, F_{UT}^{\sin\phi_S} \\
&\qquad + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h - \phi_S)\, F_{UT}^{\sin(2\phi_h-\phi_S)} \Big] + S_T\lambda_e \Big[\sqrt{1-\varepsilon^2}\,\cos(\phi_h - \phi_S)\, F_{LT}^{\cos(\phi_h-\phi_S)} \\
&\qquad + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\, F_{LT}^{\cos\phi_S} + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h - \phi_S)\, F_{LT}^{\cos(2\phi_h-\phi_S)} \Big] \Bigg\}
\end{aligned}
$$

AB, Diehl, Goeke, Metz, Mulders, Schlegel, JHEP093 (07)

$$
F_{UU}^{\pi^+}(P_T) \propto \sum e_q^2 H \times f_1^q(x, k_T, ..) \otimes D_1^{q\to\pi^+}(z, p_T, ..) S
$$

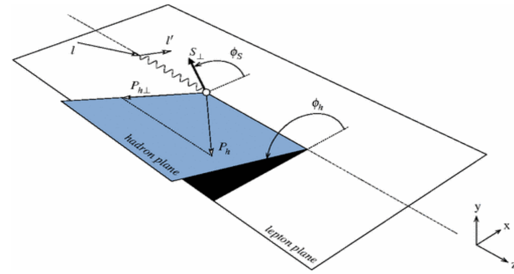


- x-sections have a number of azimuthal moments
- radiatiation may generate new moments and mix existing ones



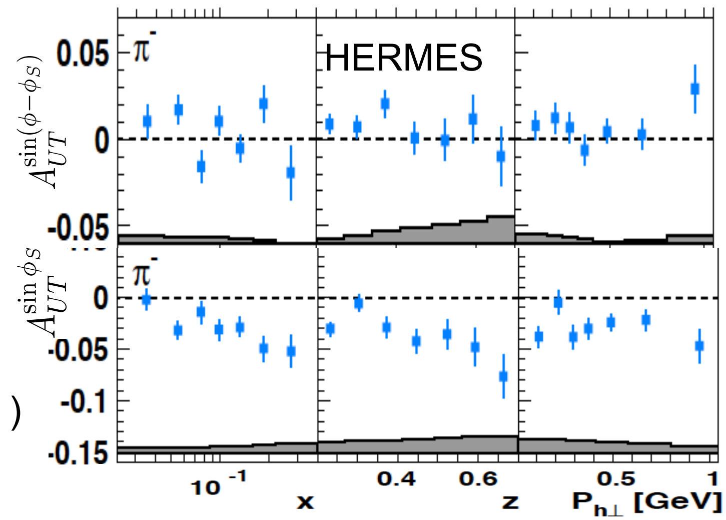
QED radiative corrections in SSA

$$\sigma = \sigma_{UU} + \sigma_{UU}^{\cos\phi} cos\phi + S_T \sigma_{UT}^{\sin\phi_S} \sin\phi_S + ...$$



Due to radiative corrections, ϕ-dependence of x-section will get more contributions

$$\sigma^h(x,z,P_T,\phi) \to \sigma^{B,h}(x,z,P_T,\phi) \times R(x,z,P_T,\phi) + \sigma^{R,h}(...)$$



using a simple approximation

$$R(x,z,P_T,\phi) = f_{XY}(x,z,P_T) * (1 + a_{XY} * cos\phi + ...)$$

we can get correction factors to moments (ex. for RC for $\sigma_{UT}^{\cos\phi}$)

$$\sigma_{UU} -> \sigma_{UU} + 1/2\sigma_{UU}^{\cos\phi} f_{UU} a_{UU}$$

we can get new moments

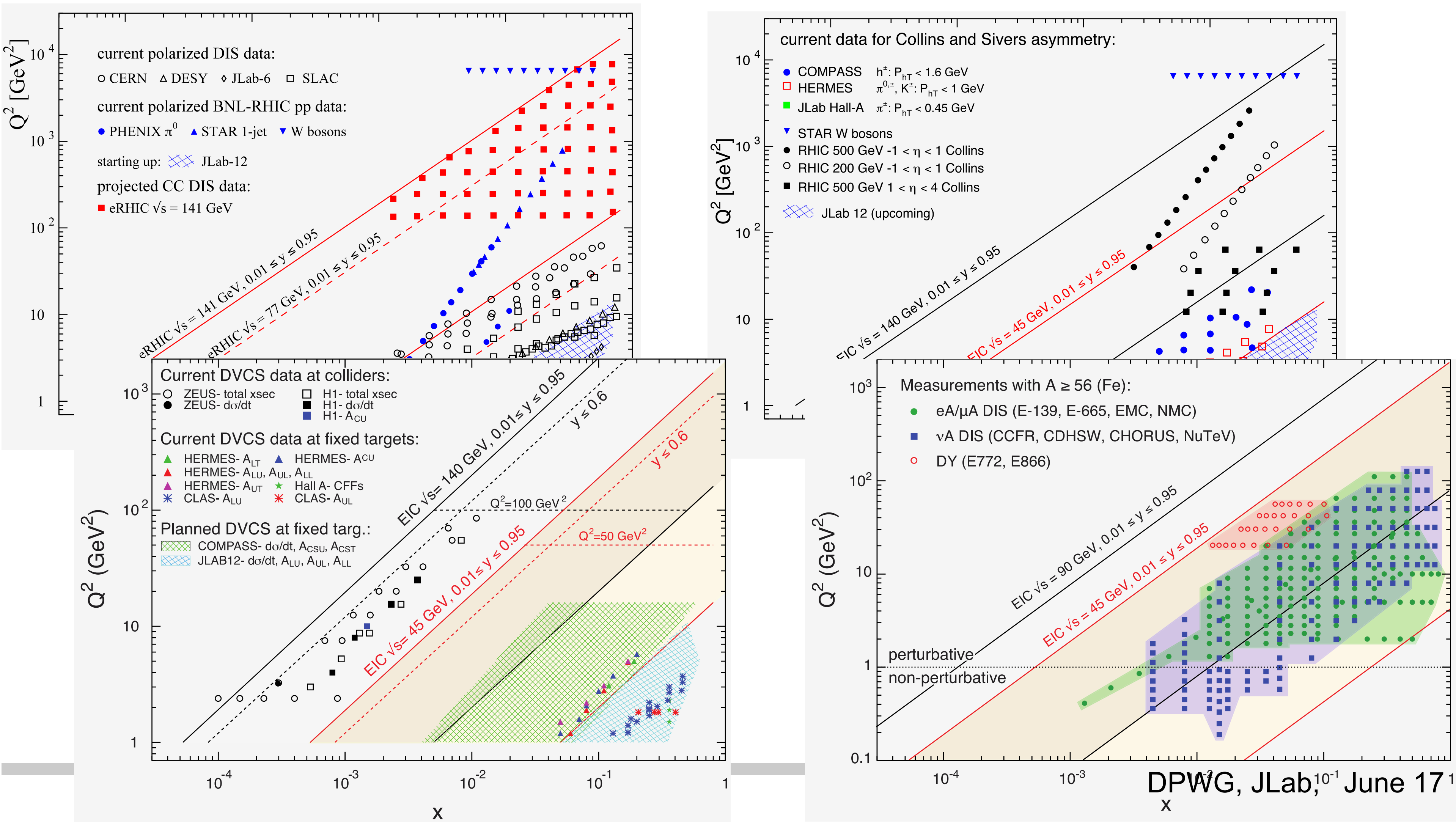
$$\sigma_{UT}^{\sin(\phi-\phi_S)} = 1/2\sigma_{UT}^{\sin\phi_S} f_{UT} a_{UT}$$

In reality contributions will me more complicated

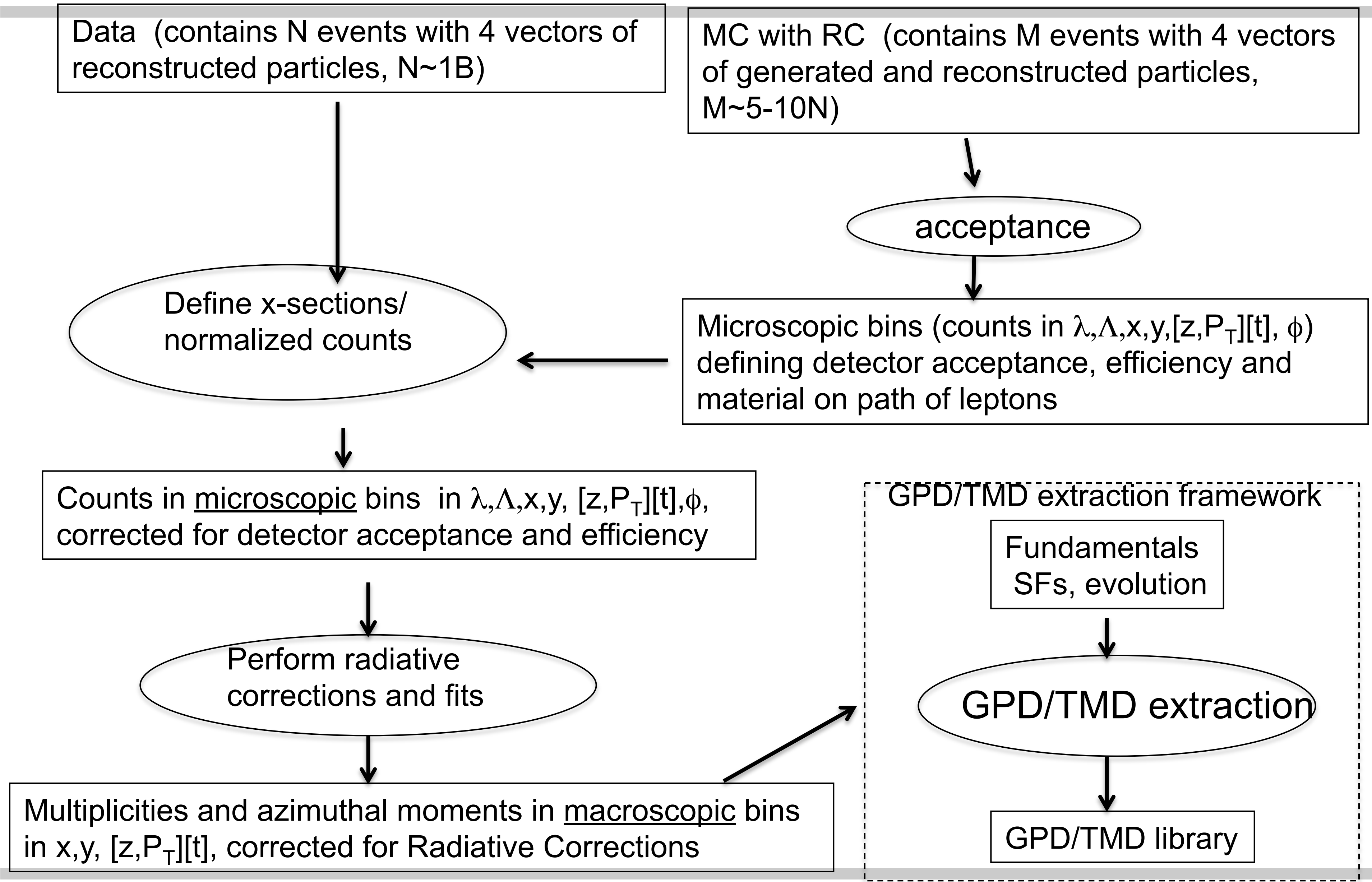
Due to radiative corrections, ϕ-dependence of x-section will get more contributions
- Some moments will modify
- New moments may appear, which were suppressed before in the x-section

EIC

- Need radiative corrections over a wide range in kinematics for a wide range of (un)polarised observables in ep / eA



Analysis of azimuthal moments in SIDIS/HEP



Analysis of azimuthal moments in SIDIS/HEP

Data (contains N events with 4 vectors of reconstructed particles, N~1B)

MC +RC (contains M events with 4 vectors of generated and reconstructed particles, M~10-100N)

acceptance

Elementary bins (counts in λ,Λ,x,y,[z,P_T][t], ϕ) defining detector acceptance, efficiency and material on path of leptons

Define x-sections/ normalized counts

Counts in elementary bins in λ,Λ,x,y, [z,P_T][t],ϕ,RC corrected for detector acceptance and efficiency

GPD/TMD extraction framework

Fundamentals
SFs, evolution,RC

GPD/TMD extraction

GPD/TMD library

Pros:
•Only pure (no theory based assumptions) experimental data will serve as input for extraction framework
•Elementary (limited by resolution) bins would allow also "event based" analysis (unbinned, Bessel,…)
Cons:
Require 10-100 times more computing power

Analysis framework

- Differential input (SIDIS):

bin#	x	Q^2	y	W	M_X	ϕ	z	P_T	λ	Λ	N(counts)	RC
1 ... N												

- Differential input (HEMP):

bin#	x	Q^2	y	W	M_X	ϕ	t		λ	Λ	N(counts)	RC
1 ... N												

•Need a TMD/GPD extraction framework to define the input data info needed
•Define all the data from other experiments which may be needed (data preservation)

Example of a table

N. Harrison (e1f)

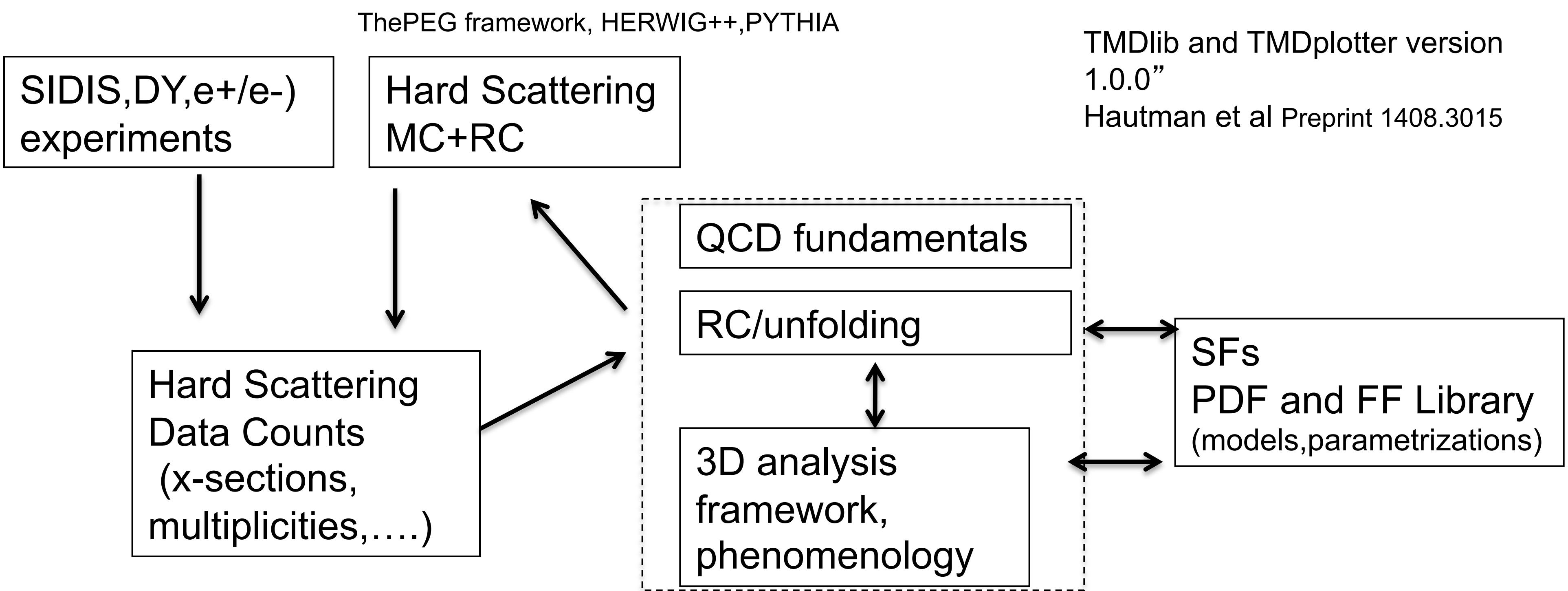
5D tables (counts in bins of x, Q^2, z, PT^2, \phi_h):

column 1: x bin number (0-4)
column 2: Q^2 bin number (0-1)
column 3: z bin number (0-17)
column 4: PT^2 bin number (0-19)
column 5: phi bin number (0-35)
column 6: <x>
column 7: <Q^2> (GeV^2)
column 8: <z>
column 9: <PT^2> (GeV^2)
column 10: <phi> (degrees)

column 11: <y>
column 12: number of counts, corrected for acceptance and radiative effects
column 13: statistical error on the the number of counts
column 14: the radiative correction factor

0	0	2	3	19	0.147459	1.16316	0.126884	0.171938	15	0.770322	20528	472.849	1.06035
0	0	2	3	20	0.147459	1.16316	0.126884	0.171938	25	0.770322	19958.1	619.905	1.06123
0	0	2	3	21	0.147459	1.16316	0.126884	0.171938	35	0.770322	20775.6	541.396	1.06257
0	0	2	3	22	0.147459	1.16316	0.126884	0.171938	45	0.770322	19948.5	434.023	1.06435
0	0	2	3	23	0.147459	1.16316	0.126884	0.171938	55	0.770322	21764.5	465.939	1.06671
0	0	2	3	24	0.147459	1.16316	0.126884	0.171938	65	0.770322	20436.3	445.162	1.06951
0	0	2	3	25	0.147459	1.16316	0.126884	0.171938	75	0.770322	20714.1	495.978	1.07289
0	0	2	3	26	0.147459	1.16316	0.126884	0.171938	85	0.770322	20714.4	634.193	1.07689
0	0	2	3	27	0.147459	1.16316	0.126884	0.171938	95	0.770322	21371.5	523.387	1.08116
0	0	2	3	28	0.147459	1.16316	0.126884	0.171938	105	0.770322	21770.1	460.747	1.08614
0	0	2	3	29	0.147459	1.16316	0.126884	0.171938	115	0.770322	21471.5	452.809	1.09134
0	0	2	3	30	0.147459	1.16316	0.126884	0.171938	125	0.770322	22028.4	467.693	1.09713
0	0	2	3	31	0.147459	1.16316	0.126884	0.171938	135	0.770322	24086.5	536.874	1.10245
0	0	2	3	32	0.147459	1.16316	0.126884	0.171938	145	0.770322	21488.1	616.541	1.10712
0	0	2	3	33	0.147459	1.16316	0.126884	0.171938	155	0.770322	23926.8	605.209	1.11166

Extraction and validation of 3D PDFs



Anselmino et al, arXiv:1510.05389
Observables which are constructed by taking ratios are not ideal grounds for the study of TMD evolution effects. More effort should be made towards measuring properly normalized SIDIS and e+e-, and Drell-Yan cross sections (both unpolarised and polarised)

Develop reliable and model independent techniques for the extraction of 3D PDFs and fragmentation functions from the multidimensional experimental observables.

SUMMARY

- Asymmetries complicated for complex analysis (may be combined with x-sections to provide spin dependent x-sections)
- Need to define the data input (x-sections, normalized counts)
- Electromagnetic corrections are crucial for interpretation of electroproduction data (SIDIS and DVEP).
- Need a self consistent procedure integrating radiative corrections in the extraction of 3D PDFs, GPDs and form factors in nucleons and nuclei.