

Full Simulation and Reconstruction of Concept Detectors



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LHeC Workshop
CERN
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This work being done in the context of the planned

Electron-Ion Collider EIC

mostly by the Argonne EIC group

Polarized ep, eA collider

$$\sqrt{s} = 35 - 180 \text{ GeV}$$

$$\text{Luminosity} = 10^{34} \text{ cm}^{-2}\text{s}^{-1}$$

Scientific goals

Study of perturbative & non-perturbative QCD

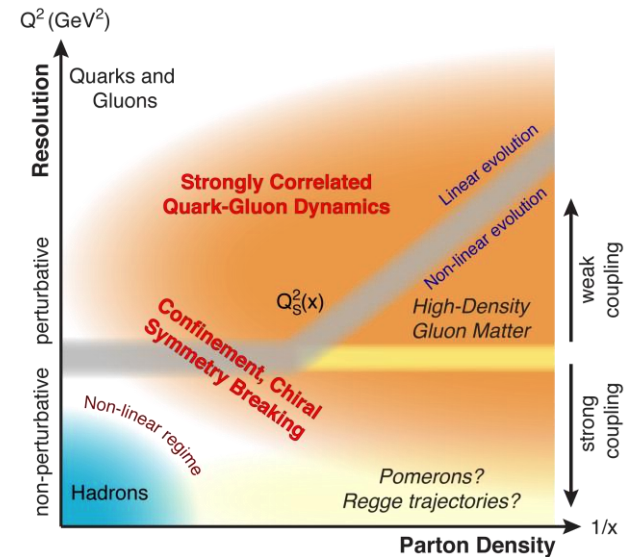
Tomography (including transverse dimension) of the nucleon, nuclei

Understanding the nucleon spin

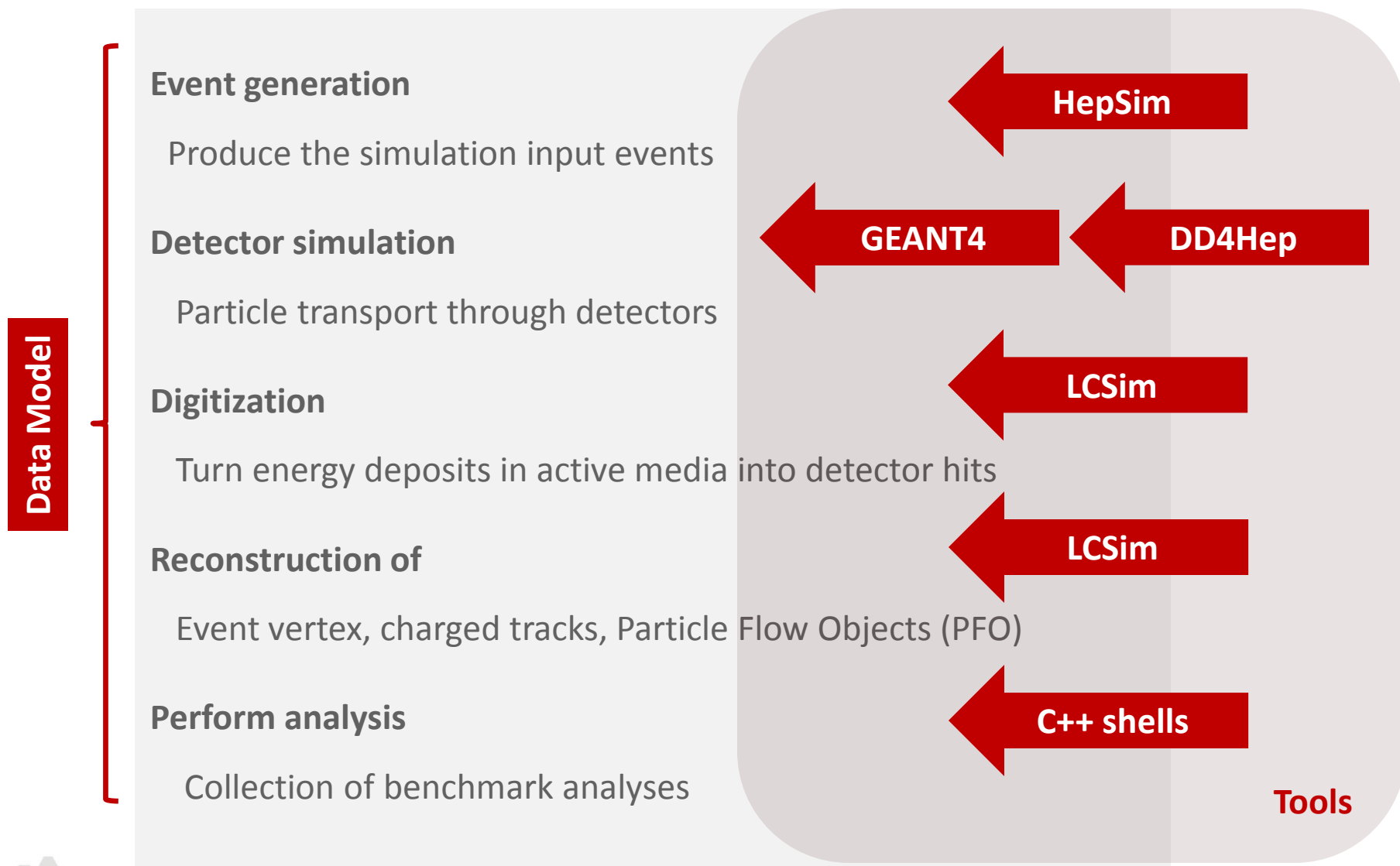
Discovery of gluon saturation...

Construction to start in 2025

Community optimistic about prospect of realization



Full simulation and reconstruction chain



Data Models

LCIO

Developed by the ILC community

Good start, but manually coded

Mostly linked to C++, other implementations (e.g. Java, GO) lagging behind

Not backwards compatible

**Almost ready
to
switch over**

EICIO

Developed at Argonne by David Blyth

Requires no manual coding to extend data model

Is fast and space efficient

Can be easily extended to almost any language

Requires only lightweight dependencies

Full EICIO -> Root conversion available

HepSim

A database and interface for detector simulations

<http://atlaswww.hep.anl.gov/hepsim/>
Developed at Argonne by Sergei Chekanov
Used for various projects

LHC, FCC, CLIC, ILC, and now EIC

A documentation and organizational tool

Stores and documents input MC data (from EG)
Stores input configurations

Geometry, digitization and reconstruction parameters

Stores and documents full detector simulation
Stores tagged containers of the full software tool-chain



The screenshot shows the HepSim website interface. At the top, there is a navigation bar with links: Get involved, Full Search, Experiments, Manual, Mirrors, Tools, About, Login. Below the navigation bar is the HepSim logo and the tagline "Repository with Monte Carlo simulations for particle physics". The main content area displays a "Summary of 'gev35ep_lepto6ard_dislowq2'". The summary includes the following information:

- Name: *gev35ep_lepto6ard_dislowq2*
- Collisions: e-p
- CM Energy: 0.035 TeV
- Entry ID: 276
- Topic: SM
- Generator: LEPTO/ARIADNE
- Calculation level: LO+PS+hadronisation
- Process: DIS events at Q2>1 GeV2 and W2>4 GeV2
- Total events: 25000000
- Number of files: 500
- Cross section (σ): 4.376E+05 ± 1957.1871 pb
- Luminosity (L): 57.1245 pb⁻¹ (or) 0.0571 fb⁻¹ (or) 5.712E-05 ab⁻¹
- Format: ProMC
- Download URL: http://mc1.hep.anl.gov/web/hepsim/events/ep/35gev/lepto6ard_dislowq2/
- Status: Available
- Mirrors: http://eicsim01.jlab.org/hepsim/events/ep/35gev/lepto6ard_dislowq2/, http://mc.hep.anl.gov/asc/hepsim/events/ep/35gev/lepto6ard_dislowq2/, http://portal.nersc.gov/project/m1758/data/events/ep/35gev/lepto6ard_dislowq2/
- EVGEN size: 15.896 GB
- Tags: (indicated by a tag icon)

Below the summary, there are sections for "Fast simulation:" and "Full simulation:". The "Full simulation:" section shows three tags with their respective sizes and dates:

- rfull058 | Info: 519 / 13.03 GB, 09/29/2017
- rfull057 | Info: 484 / 15.50 GB, 08/19/2017
- rfull056 | Info: 490 / 12.43 GB, 05/17/2017

At the bottom of the summary, the following information is provided:

- Fast/Full size: 40.96 GB
- Record slimmed: No
- Events weighted: No
- Submission time: Wed May 17 16:30:14 CDT 2017
- Updated on: Mon Jul 24 14:44:56 CDT 2017





Show all

$p \rightarrow \leftarrow p$

8 TeV

13 TeV

14 TeV

27 TeV

33 TeV

100 TeV

$e^+ \rightarrow \leftarrow e^-$

250 GeV

380 GeV

500 GeV

1 TeV

3 TeV

$\mu^+ \rightarrow \leftarrow \mu^-$

1 TeV

5 TeV

10 TeV

20 TeV

40 TeV

0 - 0

List of colliders and their center of mass energies

- Get involved
- Full Search
- Experiments
- Manual
- Mirrors
- Tools
- About
- Login

HepSim

Repository with Monte Carlo simulations for particle physics

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 Download URL: http://mc1.hep.anl.gov/web/hepsim/events/ep/35gev/lepto6ard_dislowq2/
 Status: Available
 Mirrors: http://eicsim01.jlab.org/hepsim/events/ep/35gev/lepto6ard_dislowq2/
http://mc.hep.anl.gov/asc/hepsim/events/ep/35gev/lepto6ard_dislowq2/
http://portal.nersc.gov/project/m1758/data/events/ep/35gev/lepto6ard_dislowq2/
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Fast simulation:

Full simulation:

rfull058 Info 519 / 13.03 GB 06/28/2017	rfull057 Info 484 / 15.50 GB 06/19/2017	rfull056 Info 498 / 12.43 GB 05/17/2017
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Full documentation

Information about event generator and sample size

Full detector simulations + reconstructions



Single source of geometry

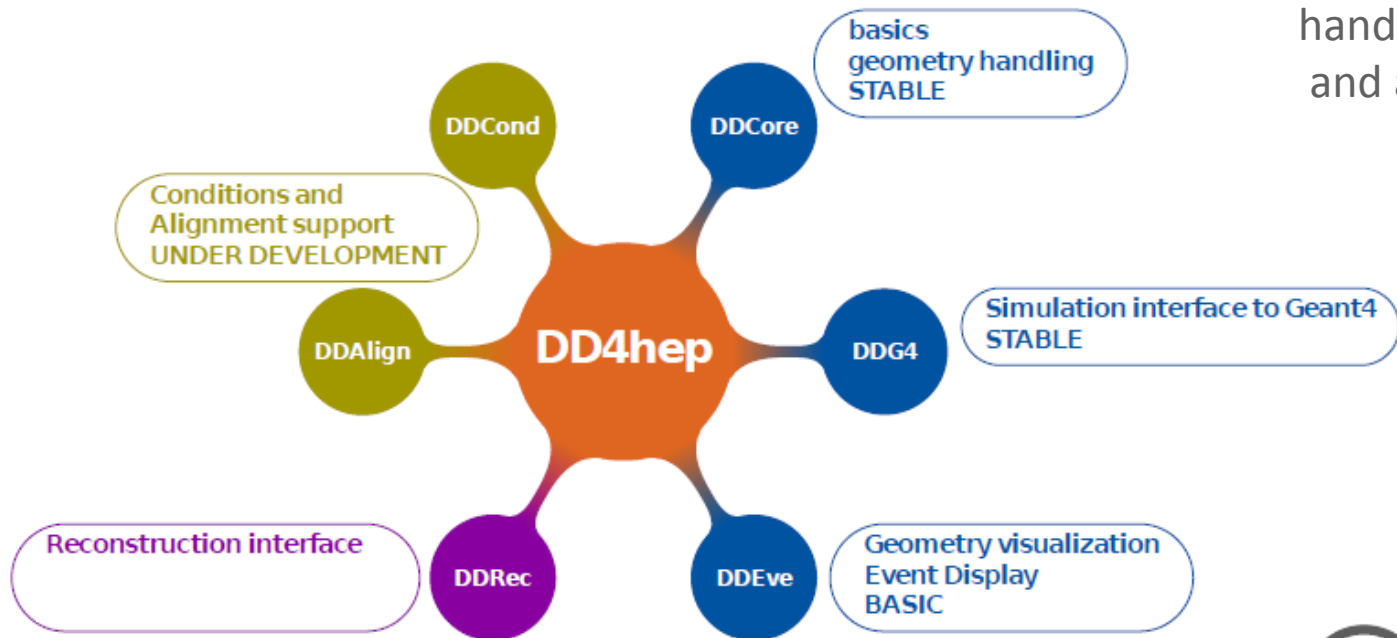
Full concept detector described in human readable text file

In future, will include handling of conditions and alignment

DD4hep

The solution to the geometry problem

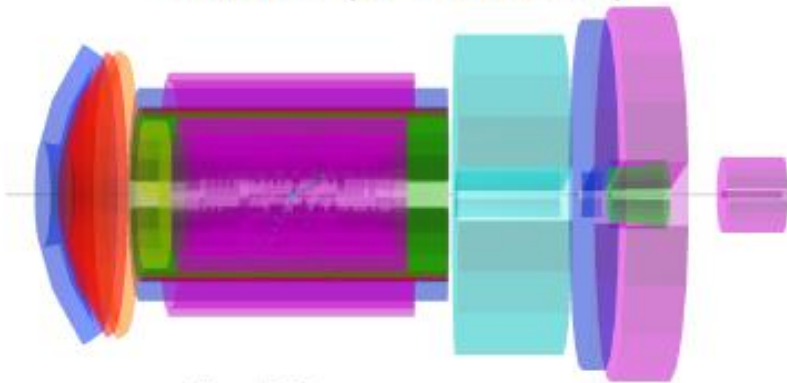
Structure and packages



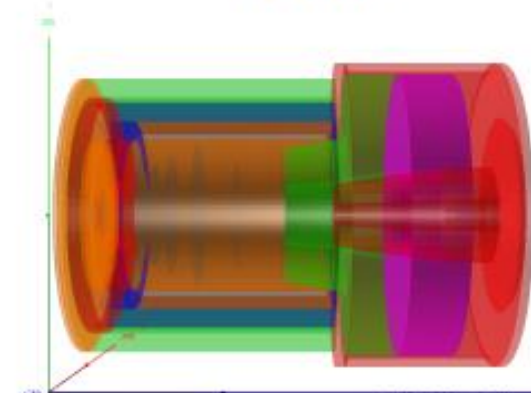
Nuclear Physics Detector Library (NPDet)

Collection of parametrized detectors which can be developed into full concepts

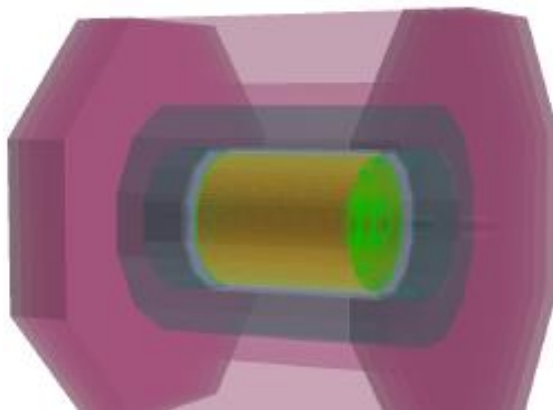
JLEIC (S. Johnston)



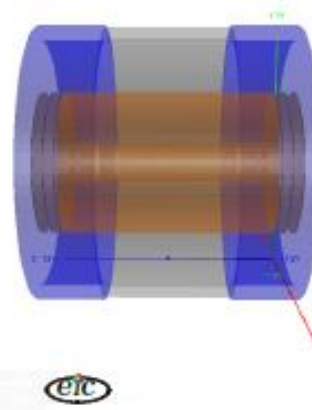
SOLID



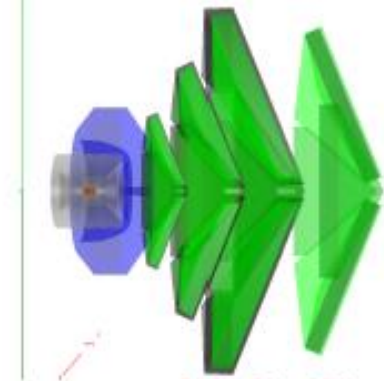
SiEIC



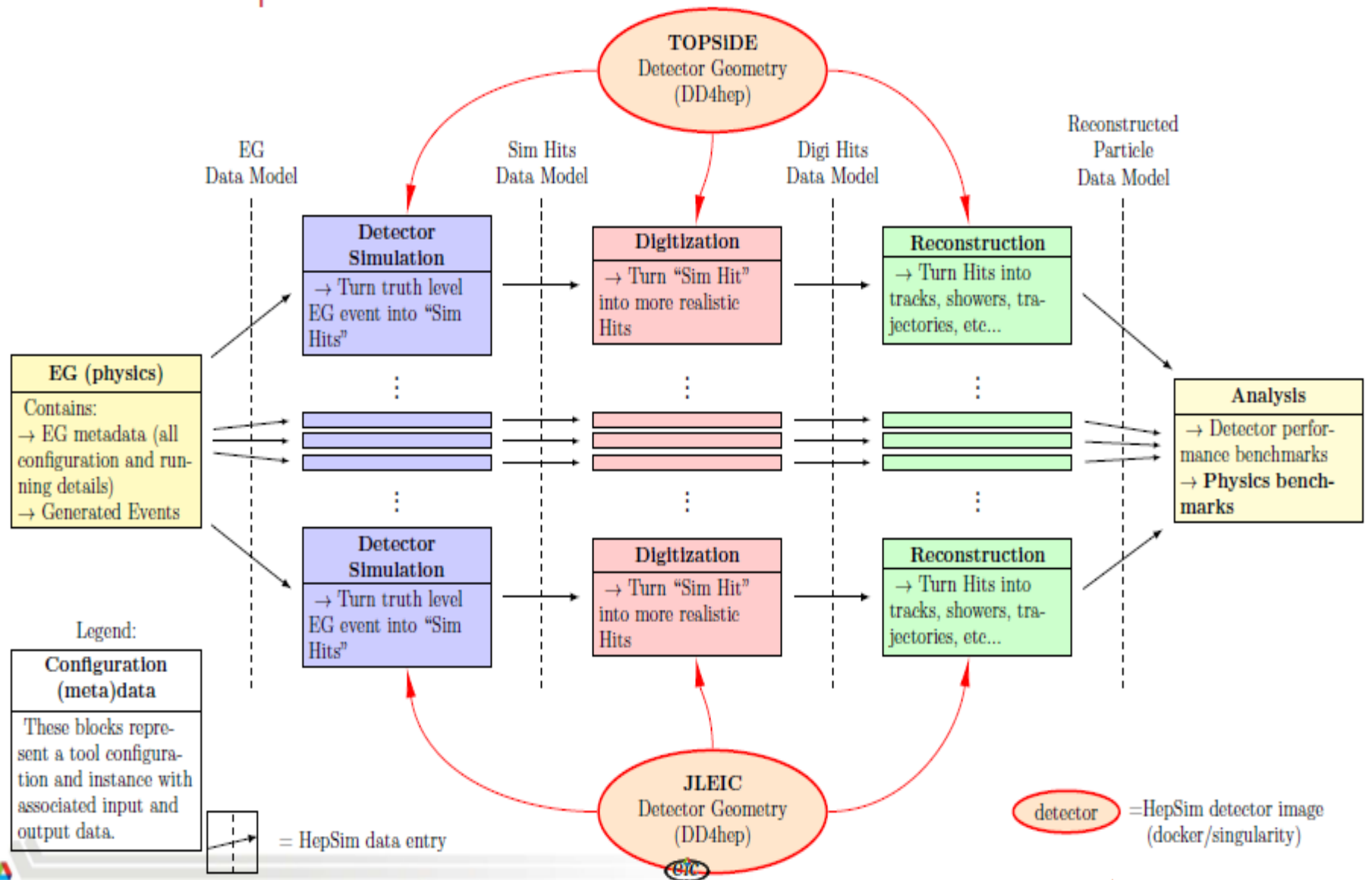
eRHIC



CLAS12



Data-flow Map



Example: Reconstruction of F_2

Goals

Exercise the whole simulation/digitization/reconstruction/analysis chain

Find bugs/bottle necks...

Identify areas where improvements are necessary

Starting point

5 GeV electron beam

60 GeV proton beam

$\sqrt{s} = 34.64$ GeV

SiEIC detector concept

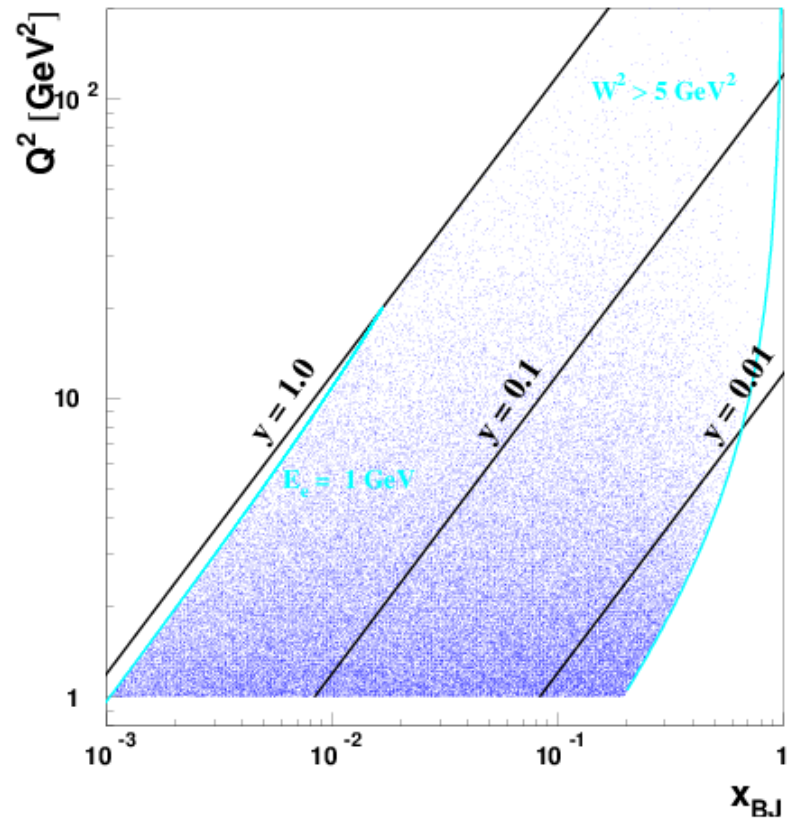
Generator

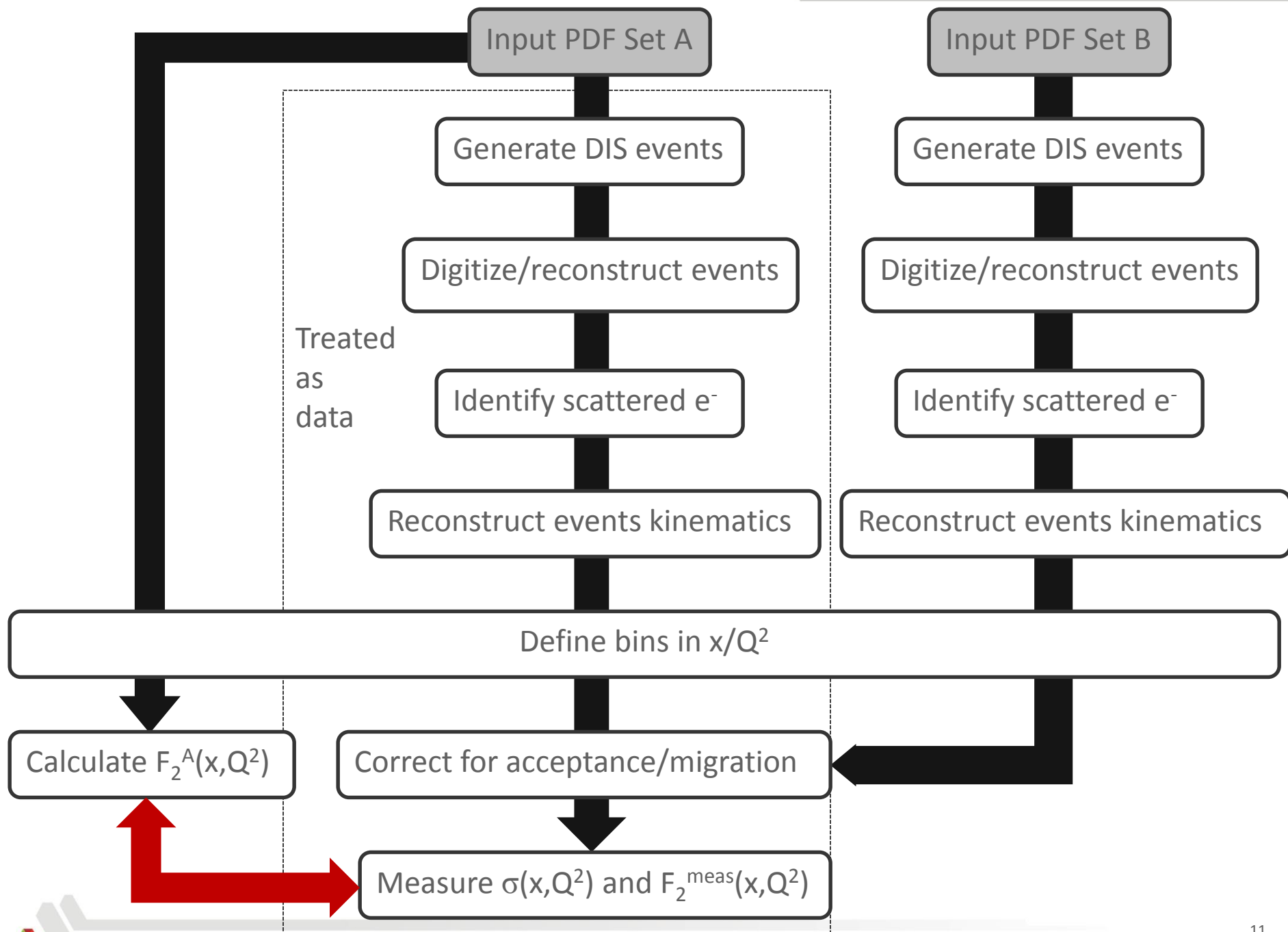
Lepto-Ariadne

250,000 events (fully simulated)

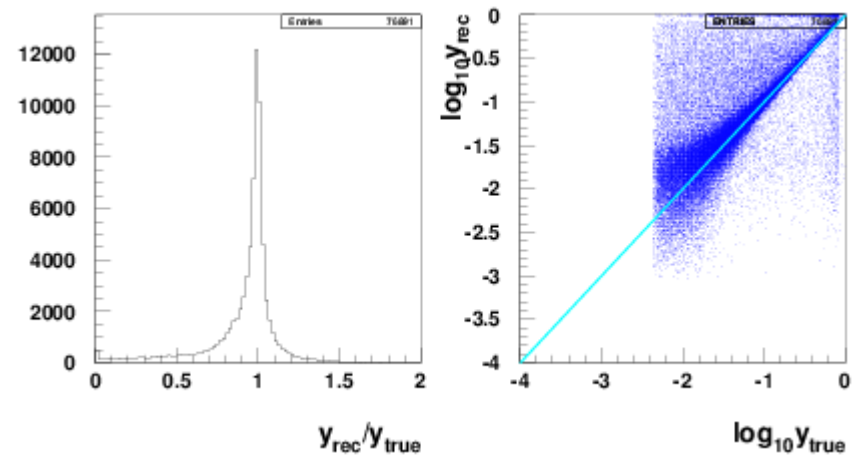
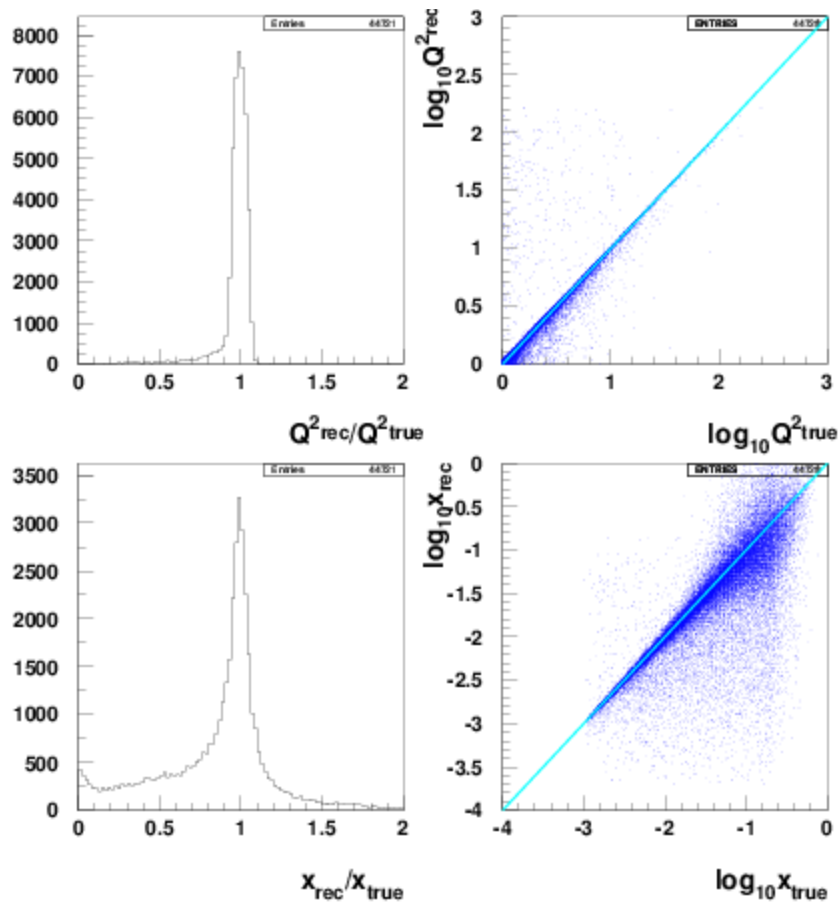
Cross section $\sigma = 414,900$ pb

Luminosity = $N/\sigma \sim 0.6$ pb⁻¹





Electron Method



Results

works quite well in general
-> In particular for Q^2 and at low- x

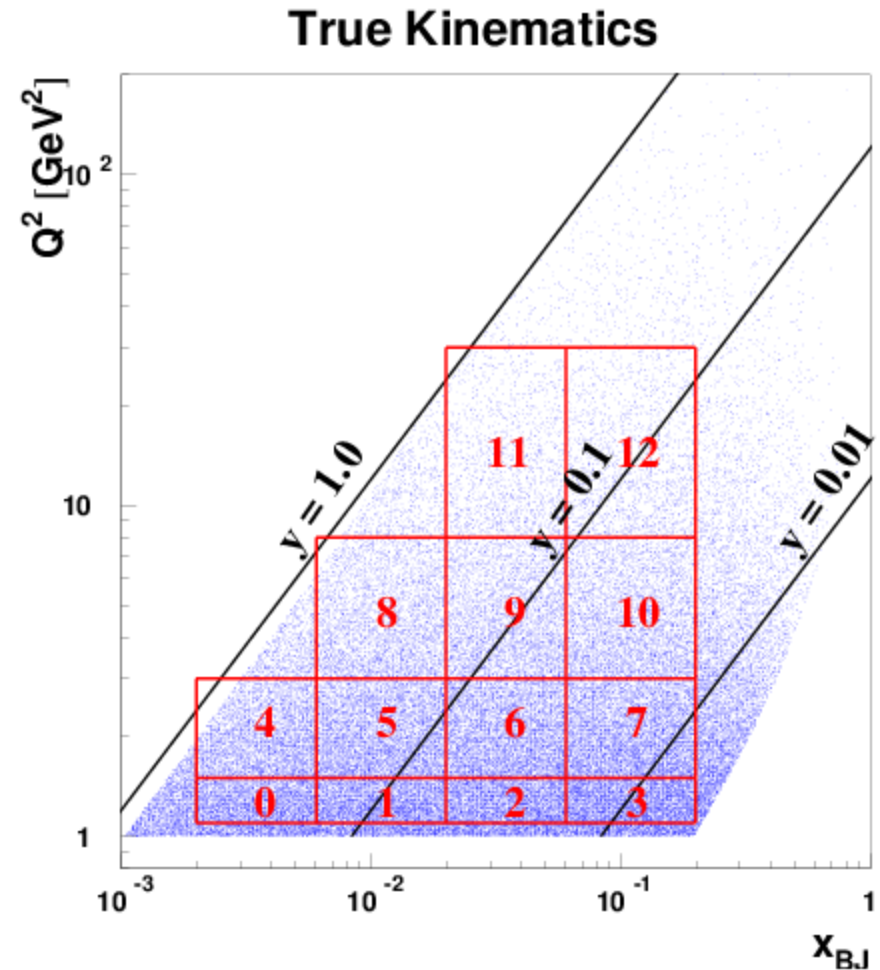
Poor resolution

at large- x or small- y

(here other methods are better)

Define bins in the (x, Q^2) – plane: MSTW PDF

Bin #	Q^2		x	
Bin #	Lower bound	Upper bound	Lower bound	Upper bound
0	1.0	1.5	0.002	0.006
1			0.006	0.020
2			0.020	0.060
3			0.060	0.200
4	1.5	3.0	0.002	0.006
5			0.006	0.020
6			0.020	0.060
7			0.060	0.200
8	3.0	8.0	0.006	0.020
9			0.020	0.060
10			0.060	0.200
11			0.020	0.060
12	8.0	30.0	0.020	0.060
			0.060	0.200



Correct for F_L

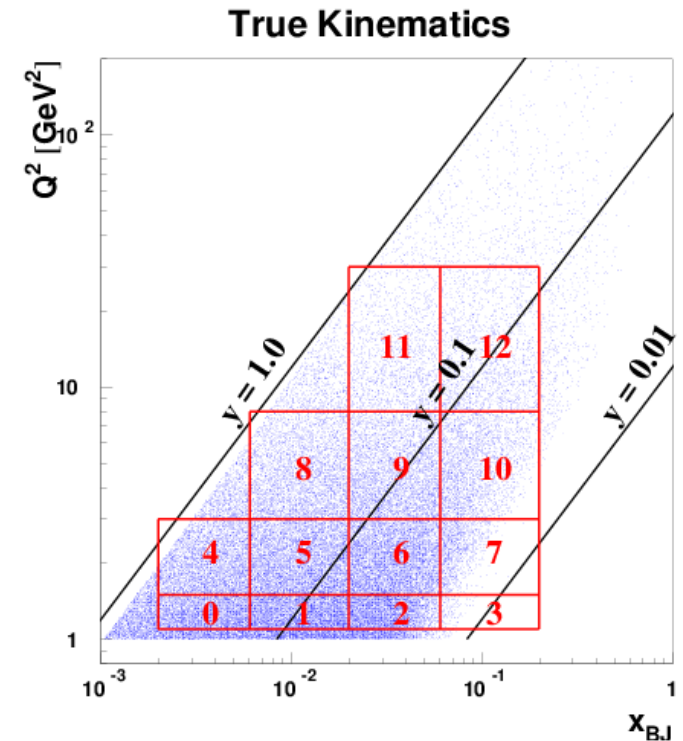
$$F_2(x, Q^2) = \frac{1}{2 - 2y + y^2} \frac{xQ^4}{2\pi\alpha^2} \frac{d^2\sigma}{dx dQ^2} \frac{1}{(\hbar c)^2} + \frac{y^2}{2 - 2y + y^2} F_L(x, Q^2)$$

-> Small correction < 1%

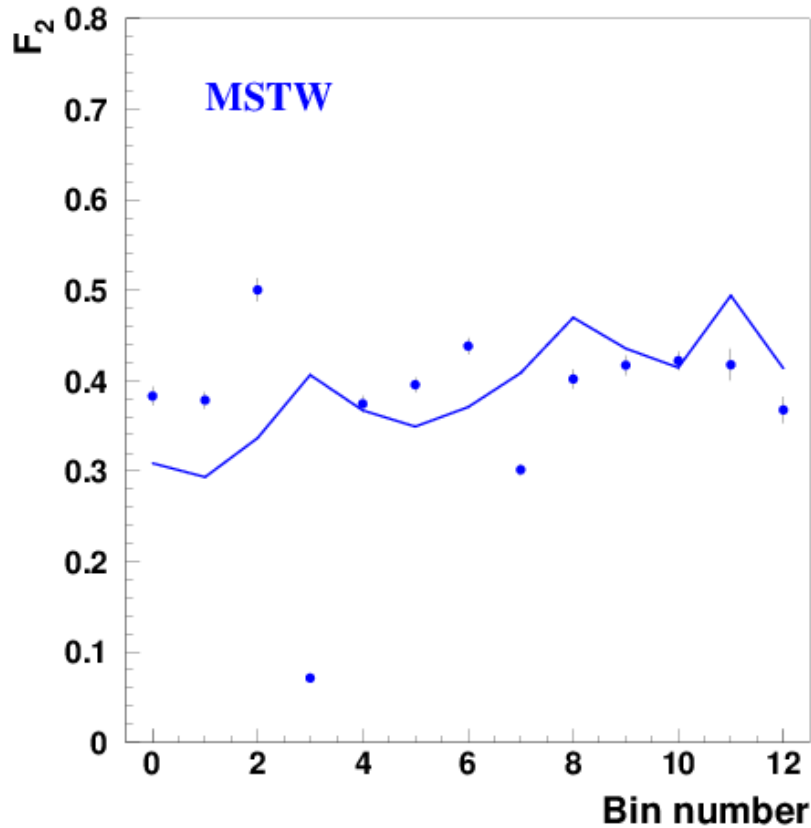
Repeat analysis with other PDF: CTEQ

Note: depletion of events at low y

-> Reason at the moment unknown



Correct MSTW results using CTEQ sample



Lines

Input $F_2(x, Q^2)$

Points

Reconstructed $F_2(x, Q^2)$

Simple bin-by-bin correction

$$N_i^{corr-MSTW}(rec) = N_i^{MSTW}(rec) \frac{N_i^{CTEQ}(gen)}{N_i^{CTEQ}(rec)}$$

Error bars

Statistical and due to correction

Low - y bins

Problems due to lack of events (CTEQ)

Conclusions

A flexible, full, and easy-to-use simulation, digitization, and reconstruction **toolchain** is available now

Work is still ongoing in

- Improving the tracking (general track finding tool)

- Integrating HepSim into containers

- Developing an event generator for deuteron scattering

- Completing the migration to the new data model (EICIO)

A collection of **parametrized detector models** have been created

Relative straightforward to **add new detector models**, like a detector for the LHeC

The **whole chain** has been exercised by reconstructing the an input F_2