Argonne's EIC Activities

José Repond
Argonne National Laboratory

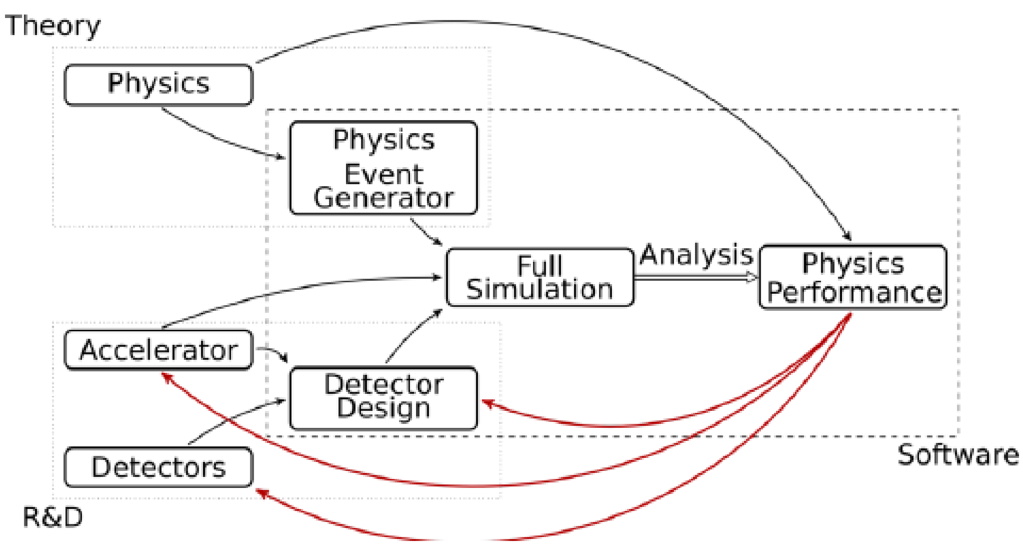
Spatial and Momentum Tomography of Hadrons and Nuclei
University of Washington
September 24 – 29, 2017

It all started

a year ago (October 2016)

With the support of an **LDRD Project**

1) Accelerator
2) Theory
3) Simulation
4) Detector R&D



Collaboration between Physics & HEP Divisions

Arrington, John	Simulation
Bodwin, Geoffrey	Theory
Chekanov, Sergei	Simulation
Cloet, Ian	Theory
Hafidi, Kawtar	Coordination
Hattawy, Mohammad	Simulation
Potterveld, David	Simulation
Metcalfe, Jessica Erin	Detector
Mezrag, Cedric	Theory
Mustapha, Brahim	Accelerator
Repond, José	Coordination, simulation, detector
Armstrong, Whitney	Simulation, detector
Xie, Junqi	Detector
Conway, Zachary	Accelerator
Ye, Zhihong	Simulation

New hires

Adam Freese	Theory
Sereres Johnston	Simulation
David Blyth	Simulation. detector
José Marin	Accelerator

ANL Accelerator R&D Related to the JLEIC

Injector Linac Design

Supported by DOE R&D funds for the EIC

Alternative Ion Accelerator Complex for the JLEIC

Supported by ANL LDRD for the EIC

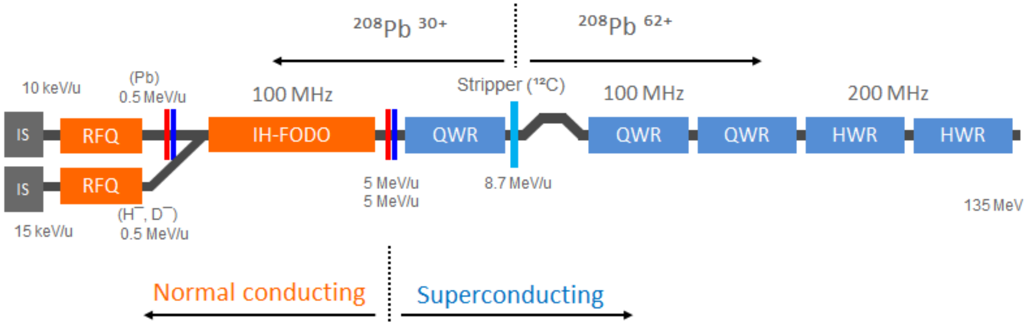
Characterization of pulsed Quarter-Wave Resonators (QWR)

Supported by ANL LDRD for the EIC

Effort

José Marin, Brahim Mustapha, and Zacharias Conway

Ion Injector Linac Design



Features

Initial section at room temperature, then superconducting

Two separate Radio-Frequency Quadrupoles (RFQs) for light and heavy ions

Heavy ions

Injector Linac design adequate: good beam dynamics and no beam loss

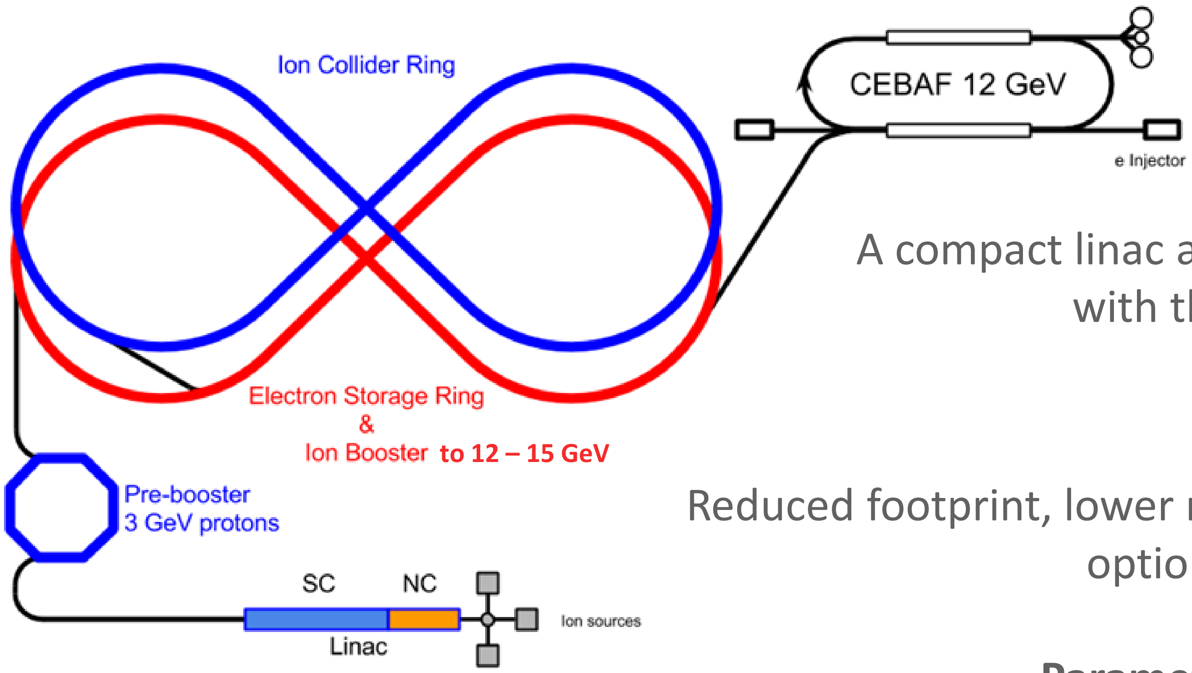
Light ions

Design revised to

- Reduce emittance growth in the RFQ -> Higher RFQ injection energy (15 keV/u -> 20 keV/u)
- Avoid beam loss in the DTL (Drift Tube Linac) -> Larger aperture (1.25 -> 1.50 cm)

Due to the large emittance of negatively charged polarized beams, the beam will be collimated at the source to produce smaller emittance

Alternative Ion Accelerator Complex



Proposal

A compact linac and pre-booster together with the e-ring as large booster

Advantages

Reduced footprint, lower risk (proven technology), options for staging (RT ⟶ SCR)

Parameter study was performed

Showed this is feasible

Recently

E-ring was adapted for ion acceleration
Beam optics studied for the proton beam

Characterization of pulsed Quarter-Wave Resonators (QWRs)

QWRs and HWRs

Needed for the ion accelerator complex for acceleration in the range of β from 0.1 to 0.5
Recently, ANL produced QWRs and HWRs which are operating in continuous wave mode

Operation in pulsed mode

Required for the EIC
(to be operated at record high voltages: 4 – 5 MV)

-> Reduces cryogenic refrigeration requirements
-> Increases resonator operating gradient

Disadvantage/risk: dynamic mechanical deformation leading to detuning

-> Needs to be tested/characterized

Theory: GPDs for Light Nuclei

Work by Adam Freese and Ian Cloët

Aim

Calculate Generalized Parton Distributions (GPDs) for light nuclei

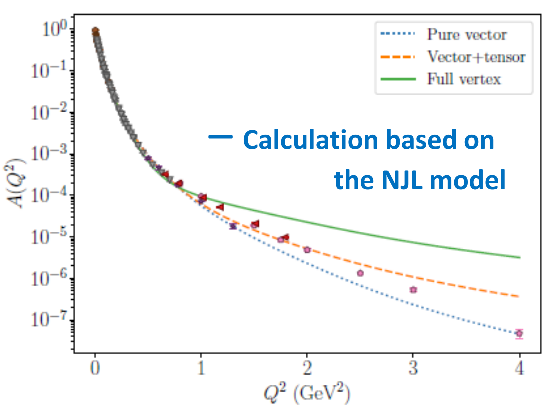
Use a simple theory to start

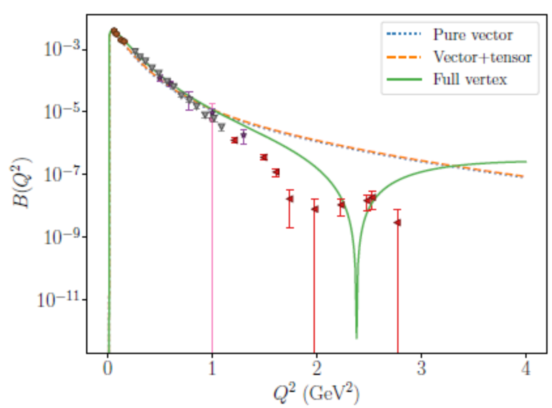
The Nambu-Jona-Lasinio (NJL) model
(Model of the nucleon which can provide form factors, structure functions…)
Build a manifestly covariant Bethe-Salpeter vertex to calculate deuteron structure

Fit of deuteron elastic form factors

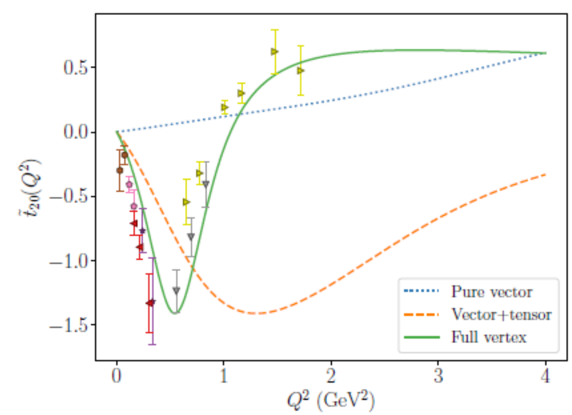
Fit quite reasonable, but fail at high Q^2 (necessity long-range pion-exchange?)

Elastic Structure Functions





Tensor polarization

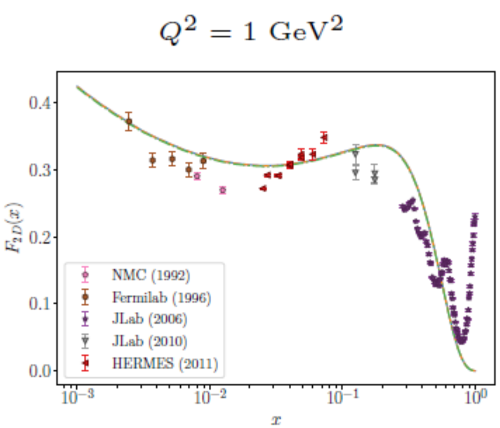


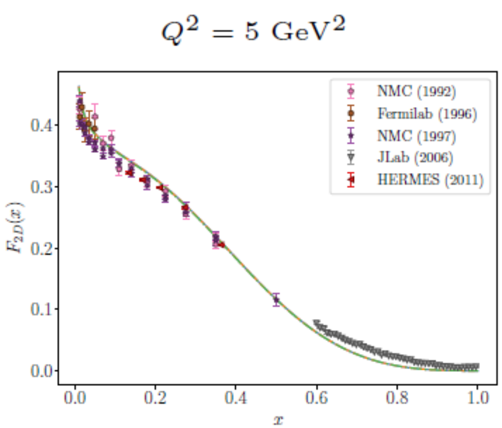
Calculation of Deuteron PDFs

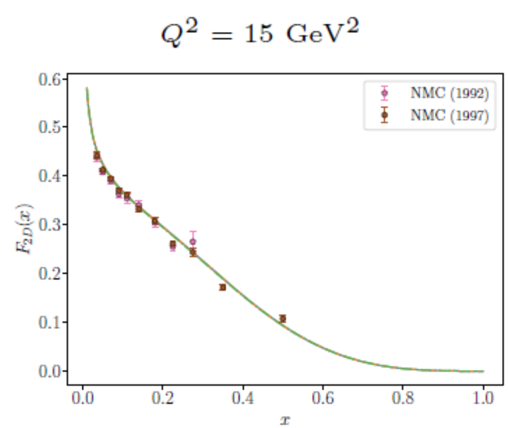
Deuteron PDFs related to nucleon PDFs through convolution formula

$$q_{i/d}^{(\lambda)}(x_A, Q^2) = \sum_{N=p,n} \int_{x_A}^{2} \frac{dy}{y} q_{i/N}\left(\frac{x_A}{y}, Q^2\right) f_{N/d}^{(\lambda)}(y)$$

Good agreement with DIS data for the deuteron







calculation

Next steps

The formalism for calculating **deuteron GPDs** is in place

-> Just technical matter to calculate some inverse Mellin transforms
-> These GPDs are also **ρ GPDs** in the NJL model

Calculate **GPDs for ^{3}H and ^{3}He**, and then more light nuclei

Implement into **event generator**

Stay tuned

For more details, see Adam Freese talk on September 26

Simulation Software

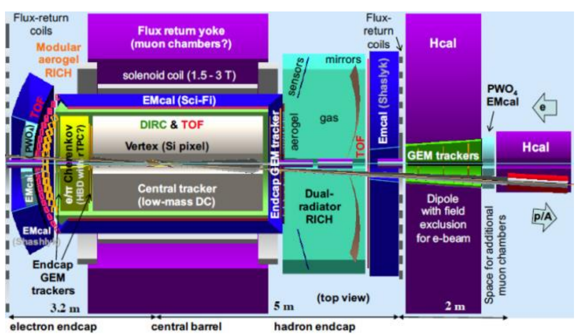
Work by W Armstrong, D Blyth, S Chekanov, A Freese, M Hattawy, S Johnston, J Repond

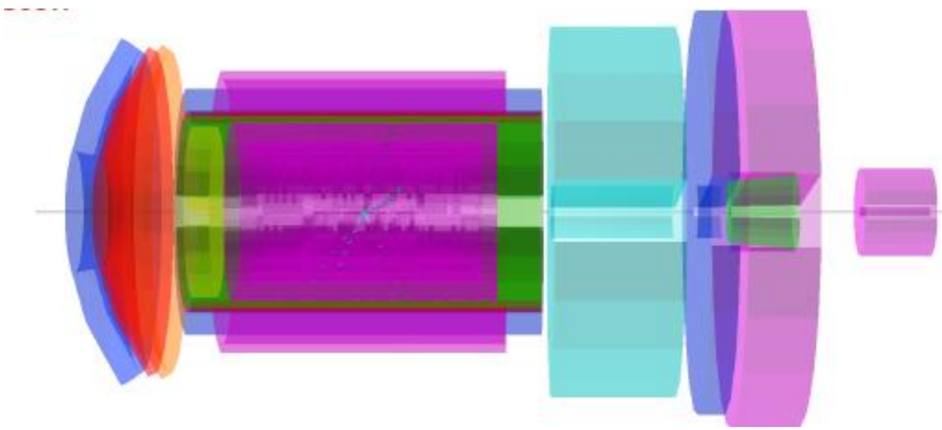
Goal

Build a maintainable, modular, flexible, consistent, user friendly simulation tool kit for EIC (and other) detectors

Tools

HepSim (Repository with Monte Carlo simulations for particle physics)
GEANT4 (A toolkit for the simulation of the passage of particles through matter)
ROOT (An object-oriented framework for large-scale data analysis)
LCIO (Data model)
DD4HEP (A detector description toolkit, including calibration, alignment…)
Marlin (Modular application framework for analysis and reconstruction code)
Collection of many Marlin processors)
ProIO (in the future: persistency tool)





Full simulation and reconstruction chain

Data Model

Event generation

Produce the simulation input events

HepSim

Detector simulation

Particle transport through detectors

GEANT4

DD4Hep

Digitization

Turn energy deposits in active media into detector hits

LCSim

Reconstruction of

Event vertex, charged tracks, Particle Flow Objects (PFO)

LCSim

Perform analysis

Collection of benchmark analyses

Root scripts

Tools

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

ProIO

- 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 (C++, Python, GO already done)
- Requires only lightweight dependencies
- Full ProIO -> Root conversion available

HepSim

A database and interface for detector simulations

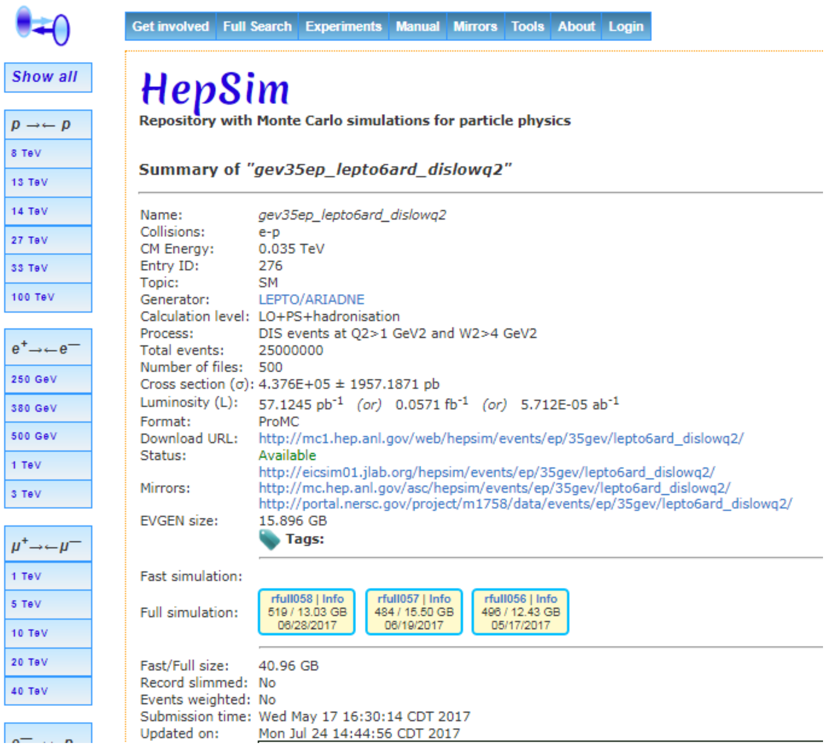
http://atlaswww.hep.anl.gov/hepsim/
Developed at Argonne by Sergei Chekanov
Used for various projects

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

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

List of colliders and their center of mass energies

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

Full documentation

HepSim

Repository with Monte Carlo simulations for particle physics

Summary of "*gev35ep_lepto6ard_dislowq2*"

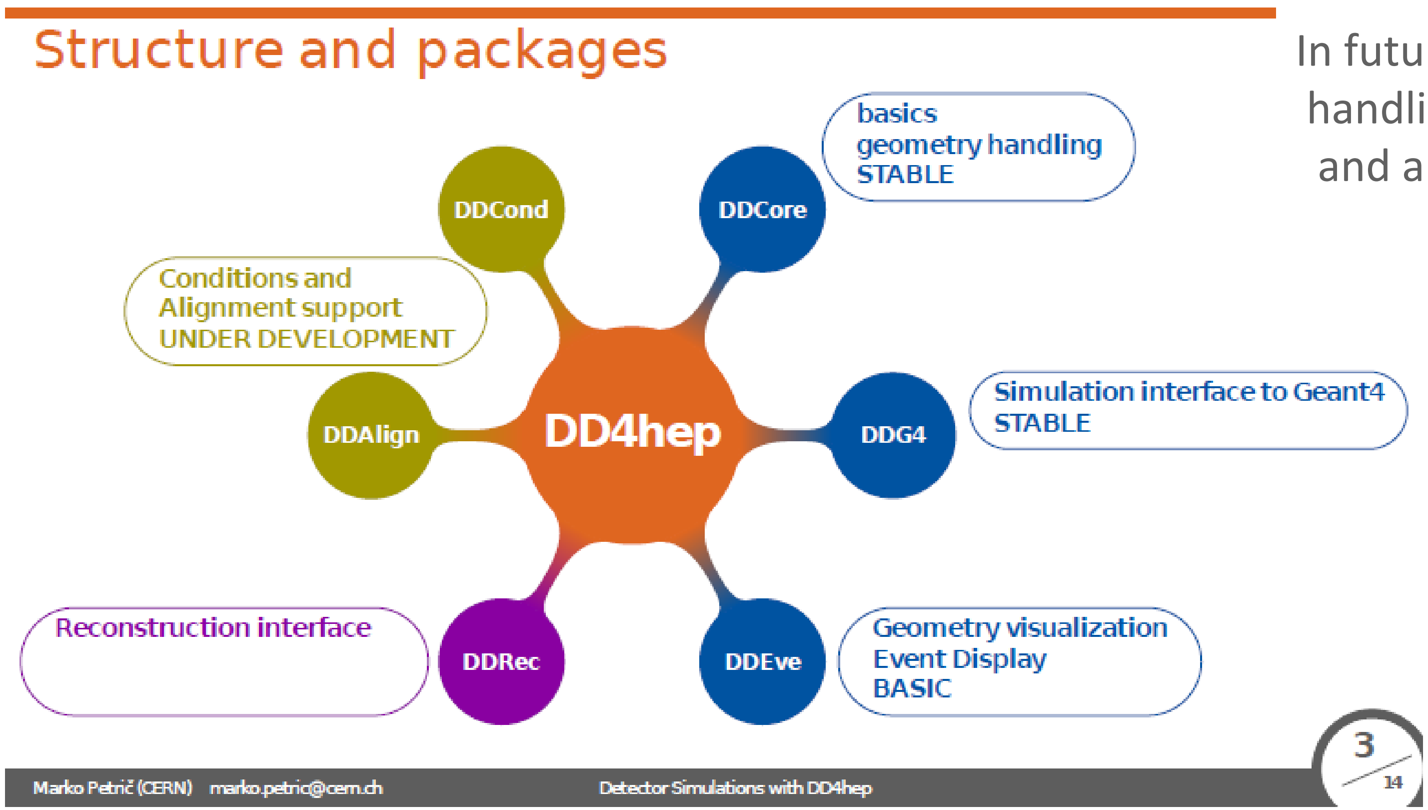
Name:	*gev35ep_lepto6ard_dislowq2*
Collisions:	e-p
CM Energy:	0.035 TeV
Entry ID:	276
Topic:	SM
Generator:	LEPTO/ARIADNE
Calculation level:	LO+PS+hadronisation
Process:	DIS events at Q2>1 GeV2 and W2>4 GeV2
Total events:	25000000
Number of files:	500
Cross section (σ):	4.376E+05 ± 1957.1871 pb
Luminosity (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:
Fast simulation:	
Full simulation:	rfull058 | Info 519 / 13.03 GB 06/28/2017 rfull057 | Info 484 / 15.50 GB 06/19/2017 rfull056 | Info 496 / 12.43 GB 05/17/2017
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

Information about event generator and sample size

Full detector simulations + reconstructions

DD4hep

The solution to the geometry problem



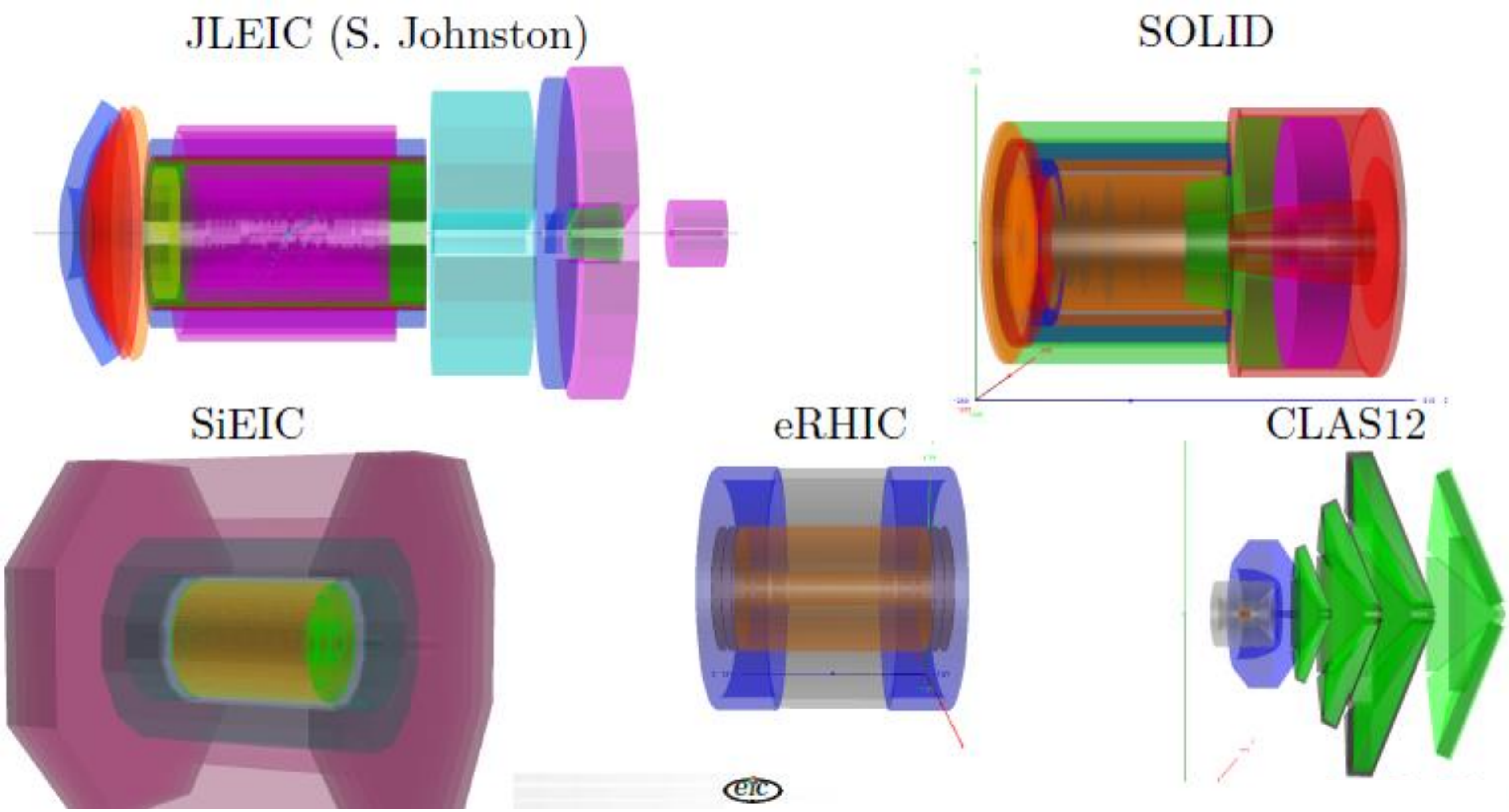
Single source of geometry

Full concept detector described in human readable text file

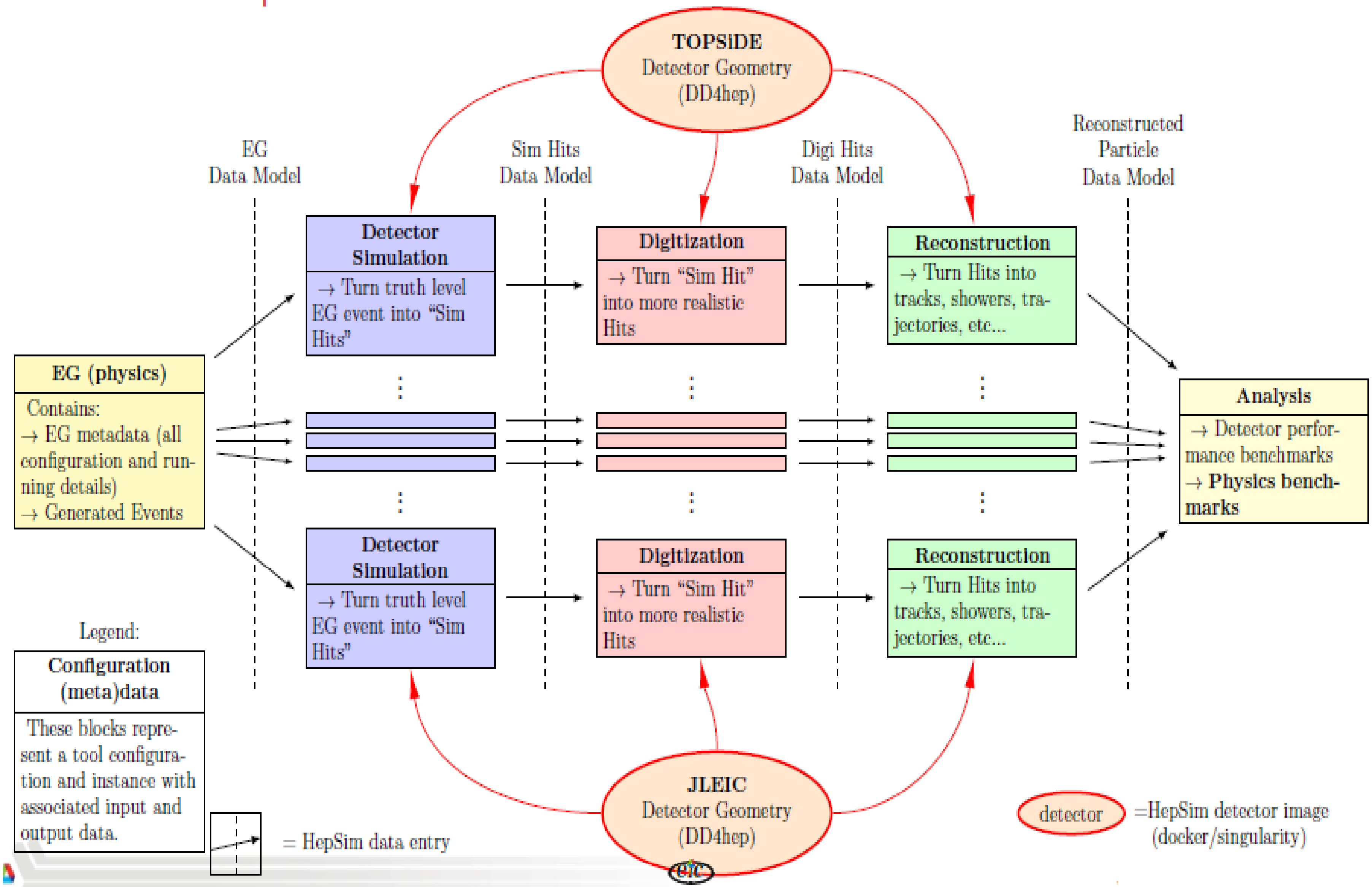
In future, will include handling of conditions and alignment

Nuclear Physics Detector Library (NPDet)

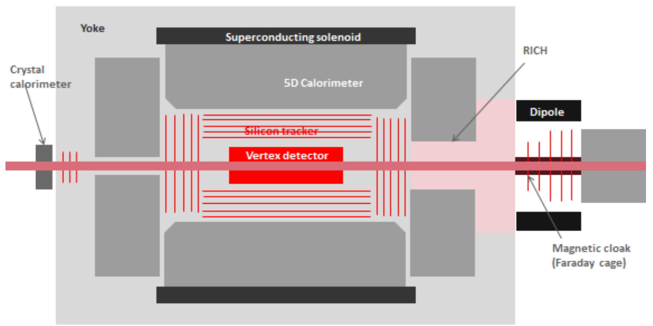
Collection of **parametrized** detectors which can be developed into full concepts



Data-flow Map



Detector philosophy…



Goal

All purpose, hermetic, high precision detector

All produced particles measured and ID'd individually

-> 5D detection (angle/position, energy, time)

Optimal detection means maximum use of luminosity

Implementation

Silicon inner and outer tracker

Silicon electro-magnetic calorimeter

-> Silicon with excellent timing resolution (for PID)

-> fine granularity for particle flow

Hadron calorimeter

-> Measure neutral hadrons (essential for charged currents, background rejection…)

Beam tracking/calorimeters

-> Measurement of forward particles (photons, charged leptons, hadrons, nuclei, neutrons)

Implementation: the SiEIC Concept

Definition: Particle Flow Algorithms (PFAs)

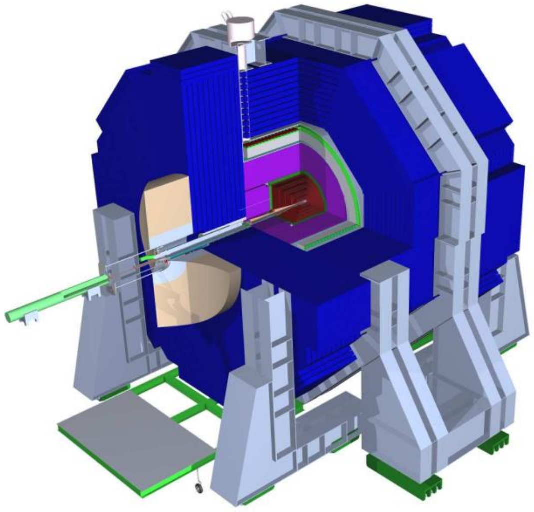
Measure each particle individually with the system providing the best E/p resolution

Based on the SiD concept: optimized for PFAs

High precision silicon tracker (5 vertex + 5 outer layers)
Calorimeters with extremely fine segmentation (Silicon, RPCs)

In general

Hermetic enclosure of interaction region
Concept not yet optimized for the EIC environment
Reduced magnetic field (5 – 2.5 T)
Reduced depths of calorimeters
Longer barrel (increased forward detection)



Data Analysis

Complete

Simulation, digitization, reconstruction, analysis chain

Generation of

Single particles (photons, pions, Kaons, protons…), DIS events

Study of single particle resolutions

Electrons, photons

Study of timing requirements for PID

Electrons, pions, kaons, protons

Validation of entire simulation/reconstruction/analysis chain

Reconstruction of F_2

In future

Dedicated physics analyses: DVCS, DVVM…

Single particle studies: photon energy resolution

Generation of

1 – 30 GeV photons
Covering uniformly the solid angle

Results

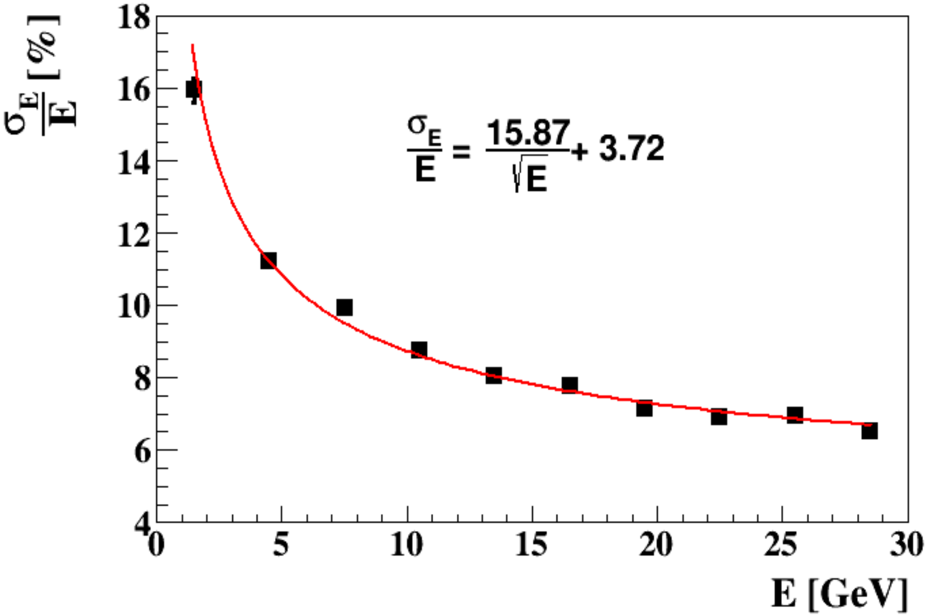
First iteration with 15 layer ECAL

-> Poor resolution

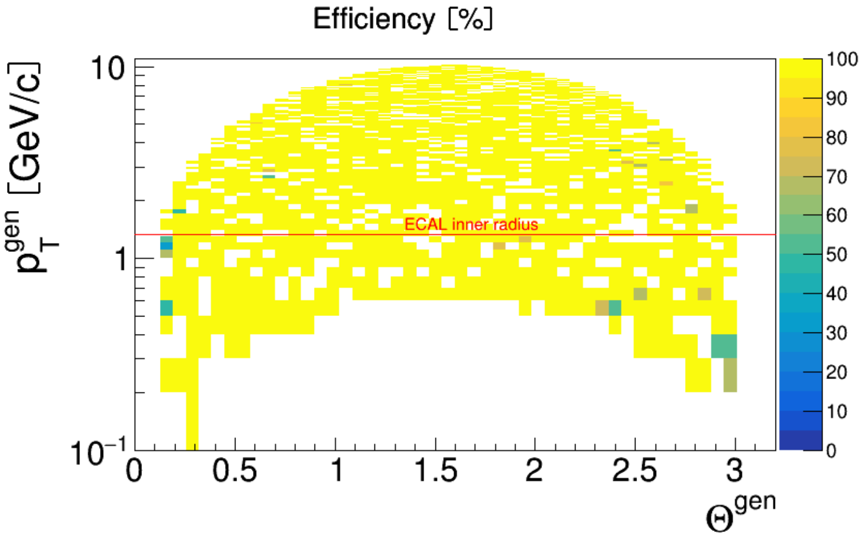
Increased thickness to 20 layers

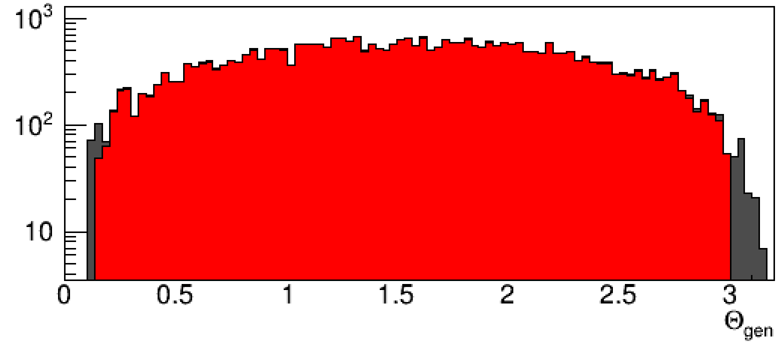
-> Acceptable results

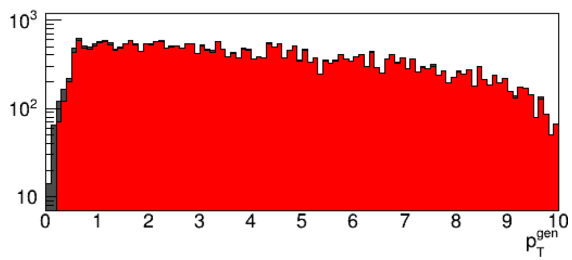
(DVCS studies forthcoming: requirement on resolution?)

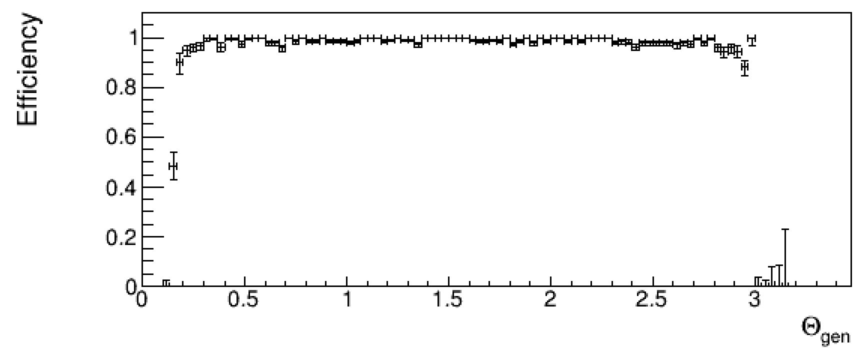


Single particle studies: pion tracking efficiency

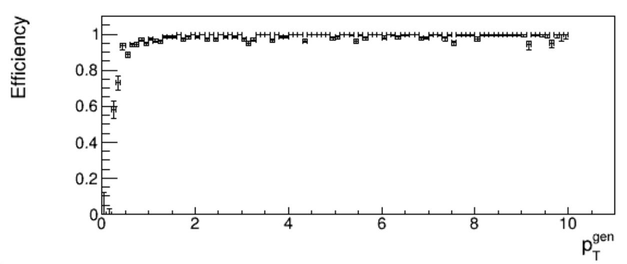








Results



Good efficiency in large solid angle

-> improved forward efficiency due to longer barrel

Good efficiency down to p_T ~ 0.5 GeV/c

-> more work on curlers needed

Study of Timing Requirements for PID

Generation of single particles into the barrel

Electrons, pions, kaons, protons with E < 10 GeV/c

Reconstruction of track parameters

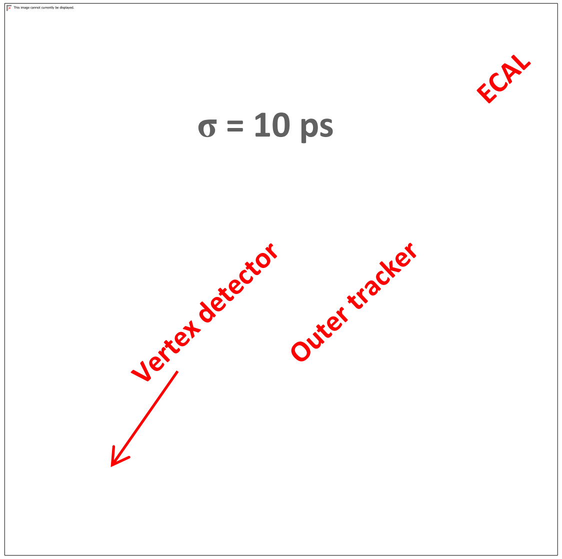
Calculation of track length up to a given sensor

Linear fit

Timing in sensor versus track length
Assumption track starts at (0,0)

Study of timing resolution

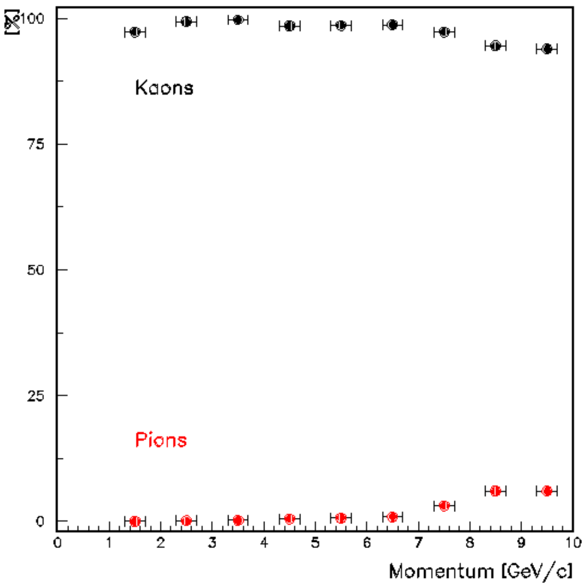
Smearing of times by Gaussian with a fixed width



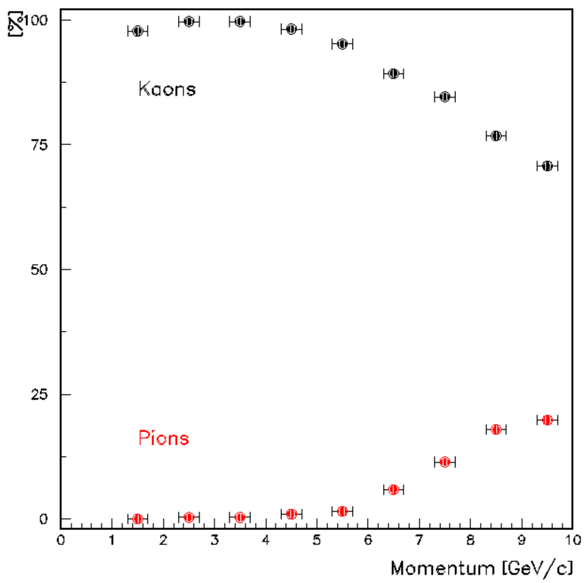
Performance as function of momentum

With the (0,0) constraint
(fit event vertex using all tracks: not entirely unrealistic)

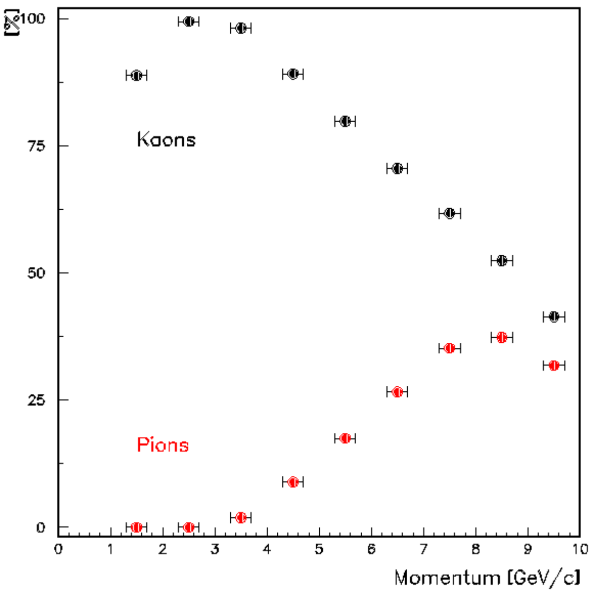
σ = 5.0 ps



10.0 ps



20.0 ps



Excellent pion/kaon separation for p < 7 GeV/c

10 ps timing resolution desirable

Identification of electrons and protons easy

Reconstruction of F_2

Goals

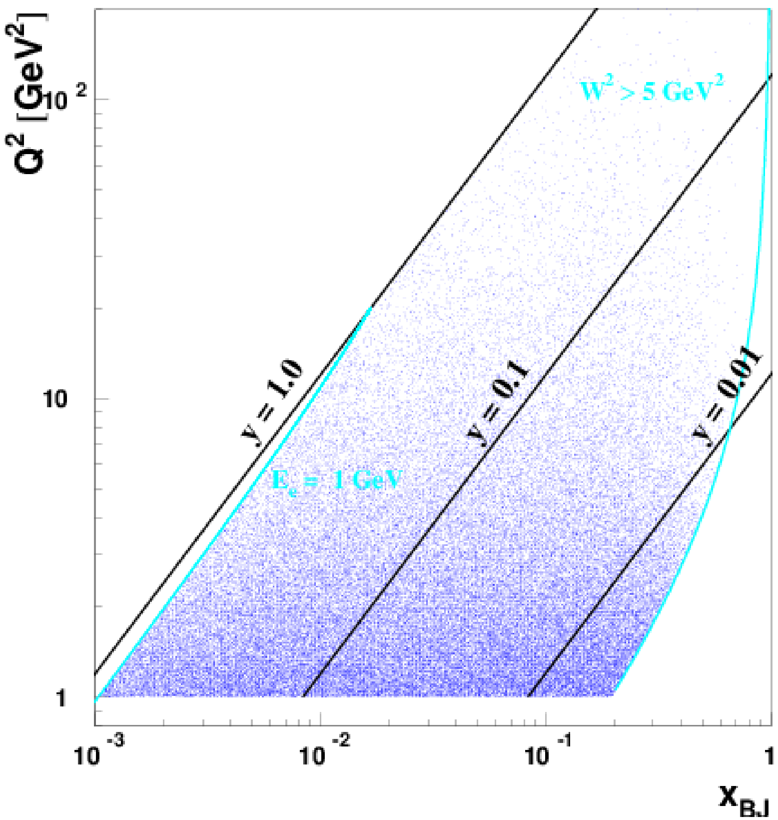
Exercise the whole simulation/digitization/reconstruction/analysis chain
Find bugs/bottle necks…
Identify areas where improvements are necessary

Starting point

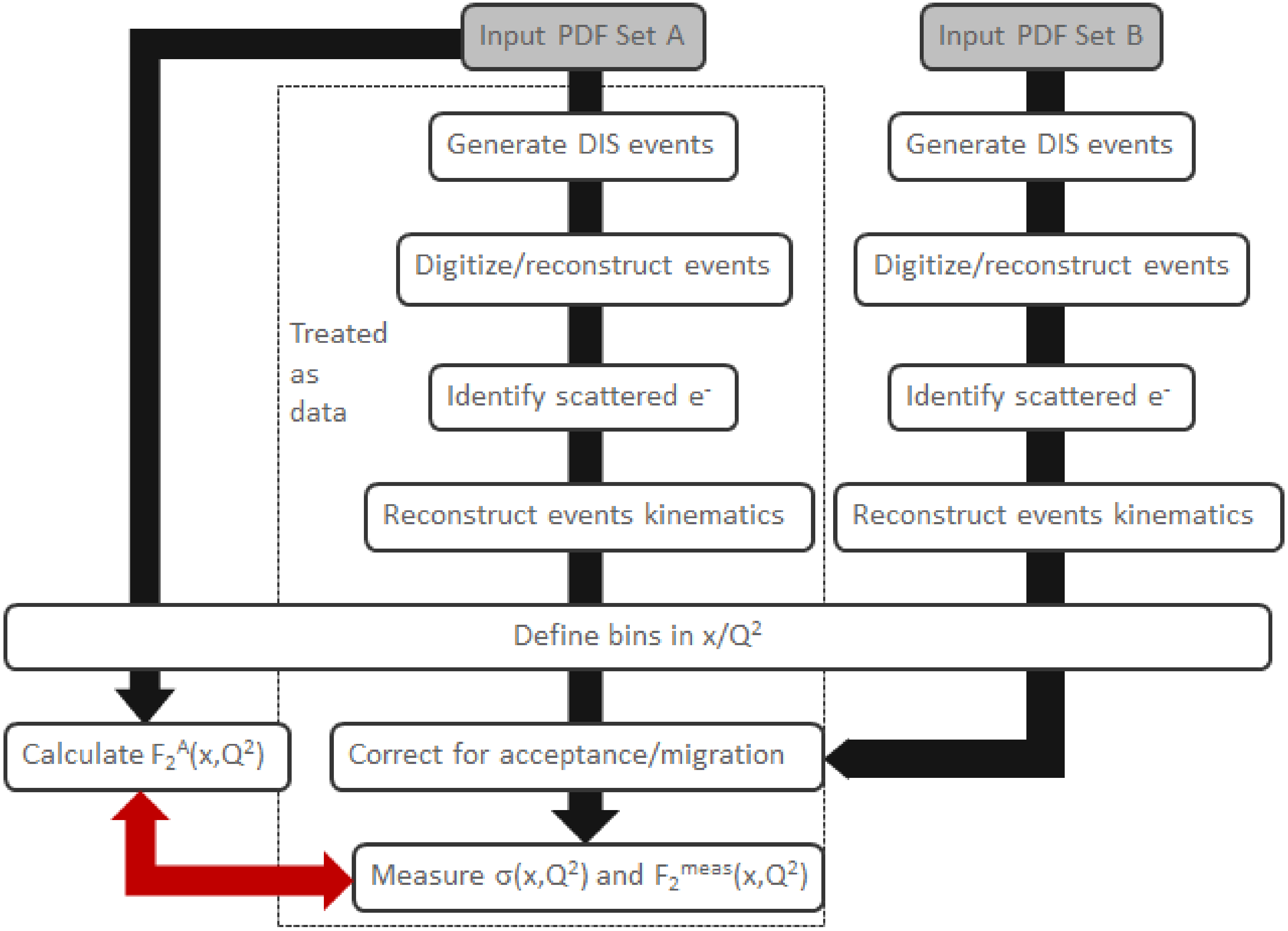
5 GeV electron beam
60 GeV proton beam
$\sqrt{s}$ = 34.64 GeV
SiEIC detector concept

Generator

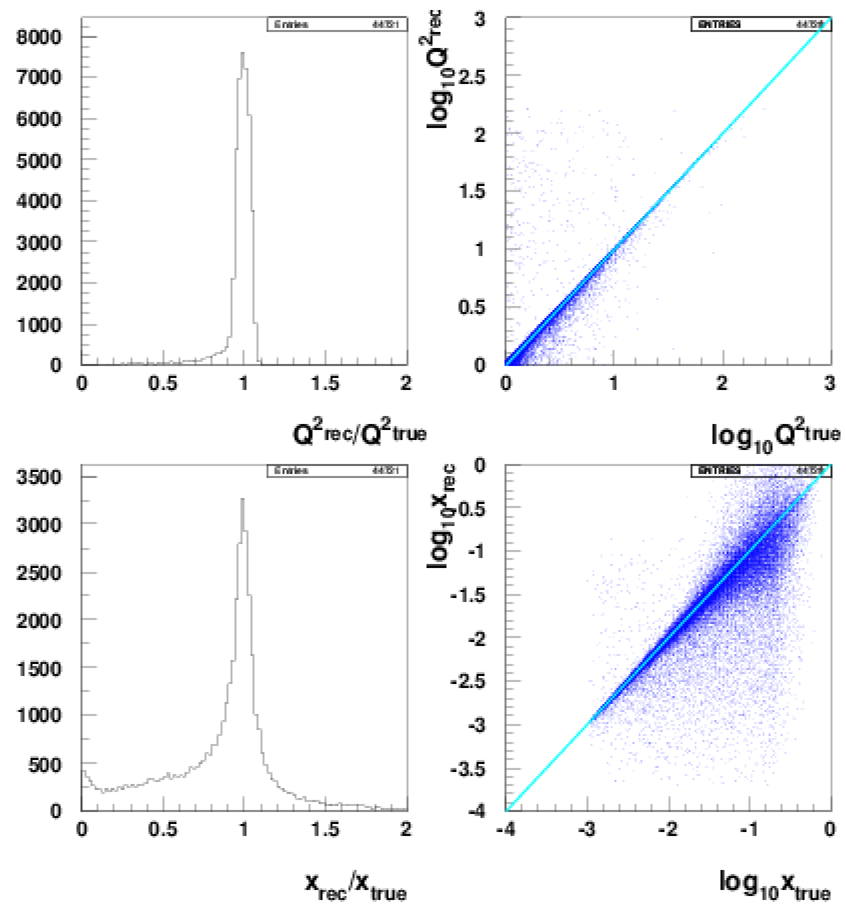
Lepto-Ariadne
250,000 events (fully simulated)
Cross section σ = 414,900 pb
Luminosity = $N/\sigma \sim 0.6\ pb^{-1}$

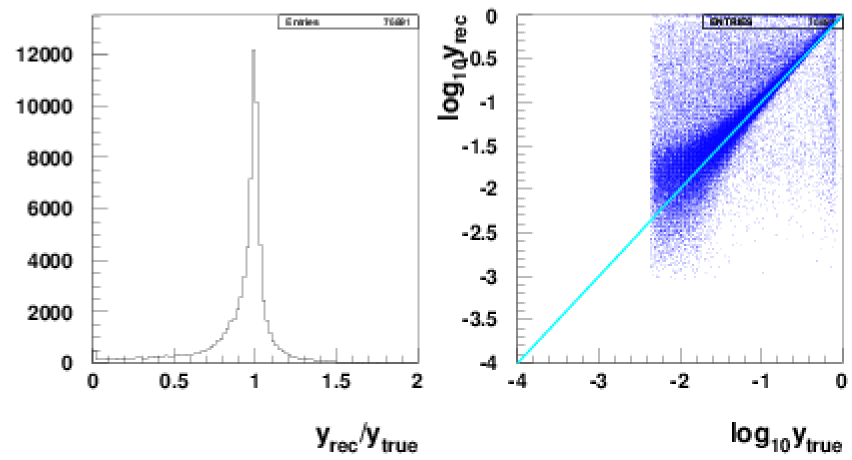


Analysis chain



Electron Method





Results

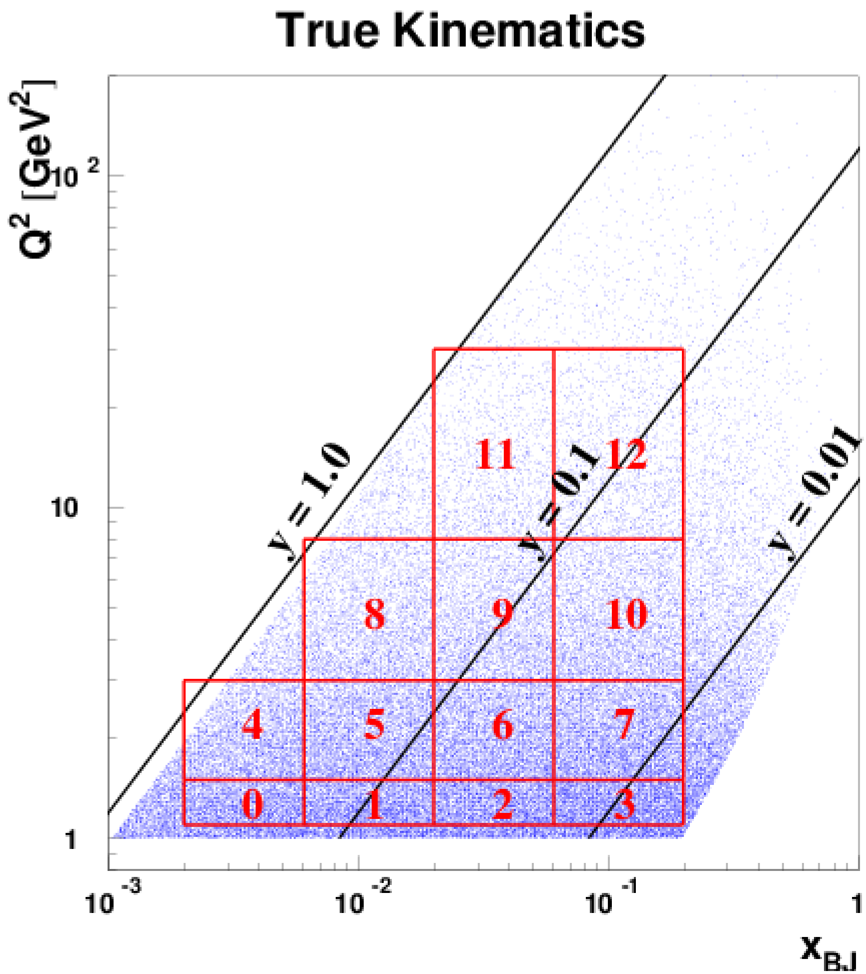
works quite well in general
-> In particular for Q^2 and at low-x

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	8.0	30.0	0.020	0.060
12			0.060	0.200



Correct for F_L

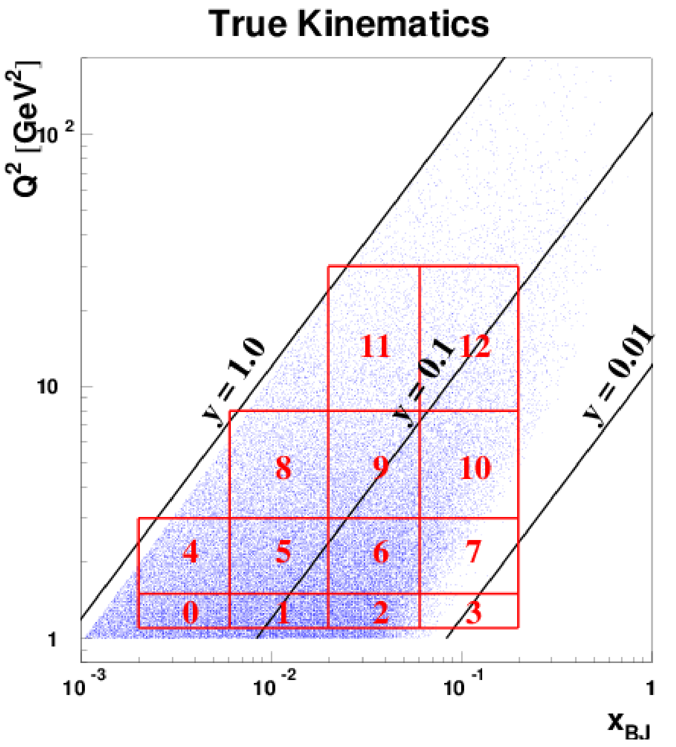
$$F_2(x,Q^2) = \frac{1}{2-2y+y^2}\frac{xQ^4}{2\pi\alpha^2}\frac{d^2\sigma}{dxdQ^2}\frac{1}{(\hbar c)^2} + \frac{y^2}{2-2y+y^2}F_L(x,Q^2)$$

-> Small correction < 1%

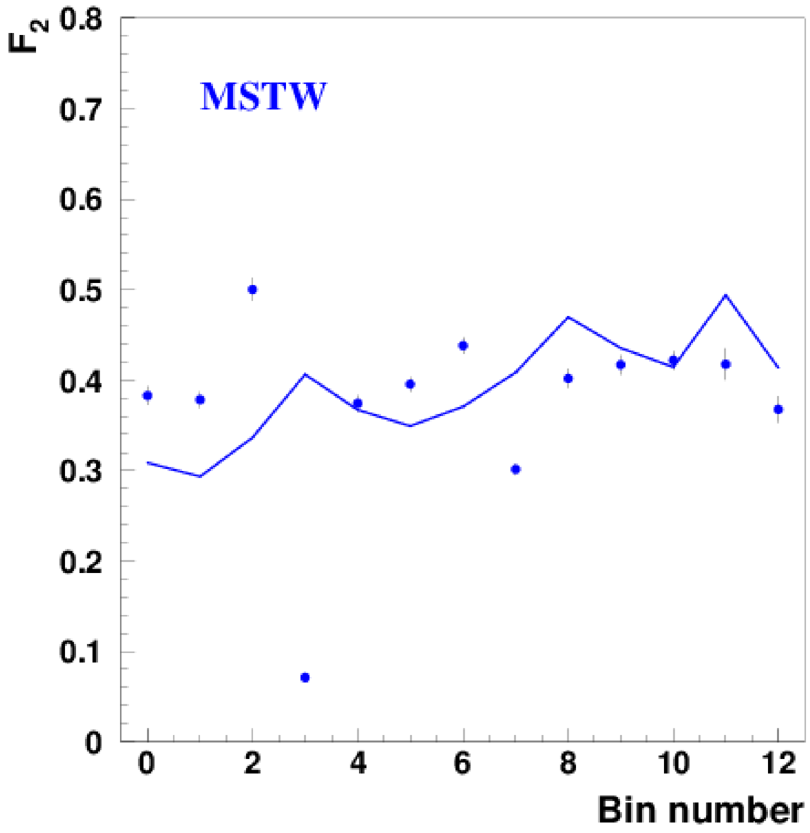
Repeat analysis with other PDF: CTEQ

Note: depletion of events at low y

-> Reason at the moment unknown
(CTEQ looking into this)



Correct MSTW results using CTEQ sample



Line

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

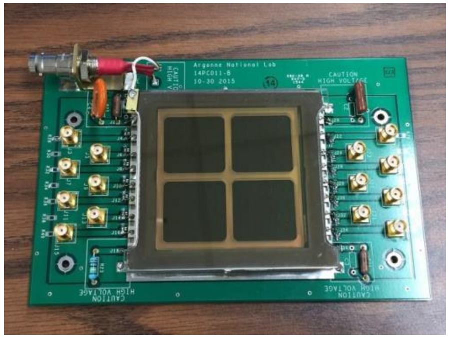
Statistical and due to correction

Low – y bins

Problems due to lack of events (CTEQ)

Detector R&D

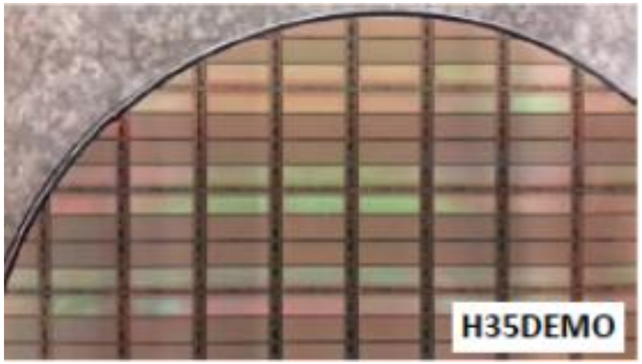
W Armstrong, D Blyth, J Metcalfe, J Repond, J Xie

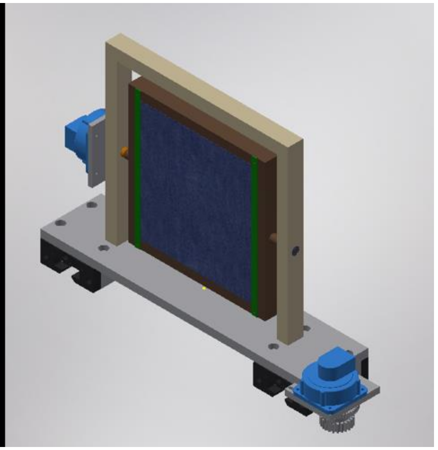


Development of photo sensors for TOF and Cerenkov detectors

Development of Ultra-fast Silicon sensors

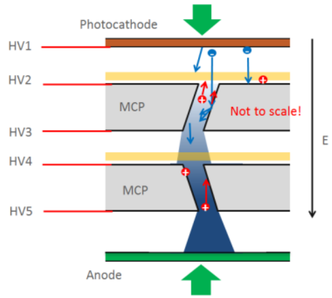
Development of a Time Distribution system





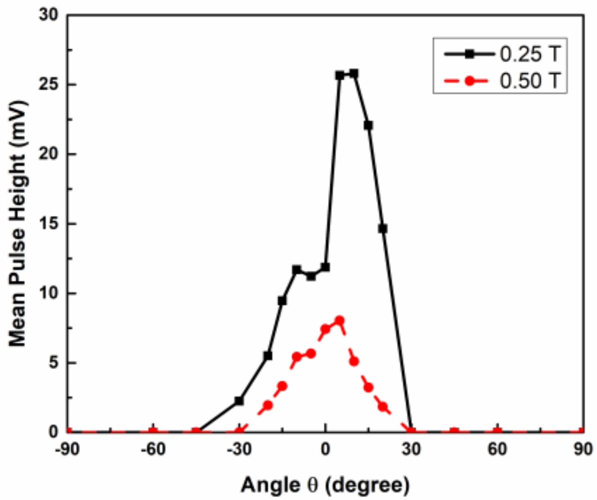
Development of photo sensors

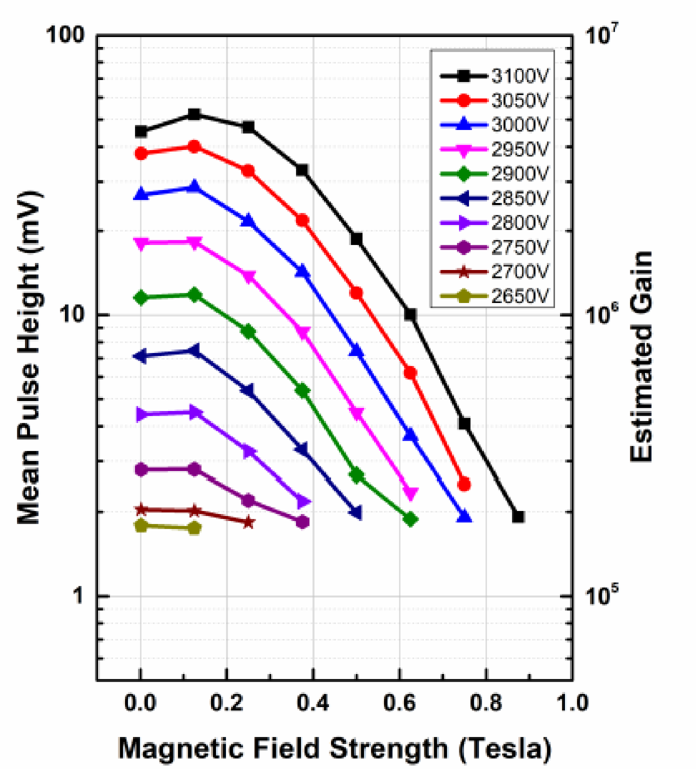
Based on the Argonne Large Area Picosecond Photo Detector (LAPPD)
Aim to adapt for operation in magnetic field
Reduction of a) MCP pore sizes and b) vertical dimensions
Tests in the **Argonne Magnetic Field Test Facility**



Status

Designed and fabricated fixture to hold and orient sensors in magnetic field
Developing software for data acquisition
First measurements on standard 6 x 6 cm^2 tiles





Ultra-fast Silicon Sensors

Application

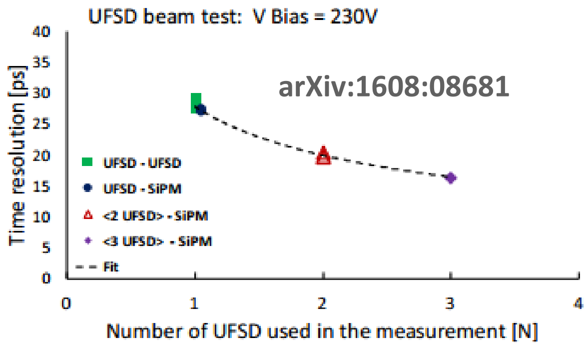
In a silicon tracker and a silicon-tungsten electromagnetic calorimeter

Ultra-fast timing sensors

With timing resolutions of the order of 10 picosecond: particle ID up to 7 GeV/c

Current state of the art

27 ps resolution has been obtained with LGAD sensors
Further optimization possible



Status

Argonne already involved in sensor testing at Fermilab (ATLAS experiment)
Plans to set-up a test station at Argonne
Effort in its infancy….still collecting ideas…Plans to ramp up effort in FY2018

Time Distribution System

Needed for synchronizing times across detector

Jitters smaller than 10 ps

Currently preferred solution

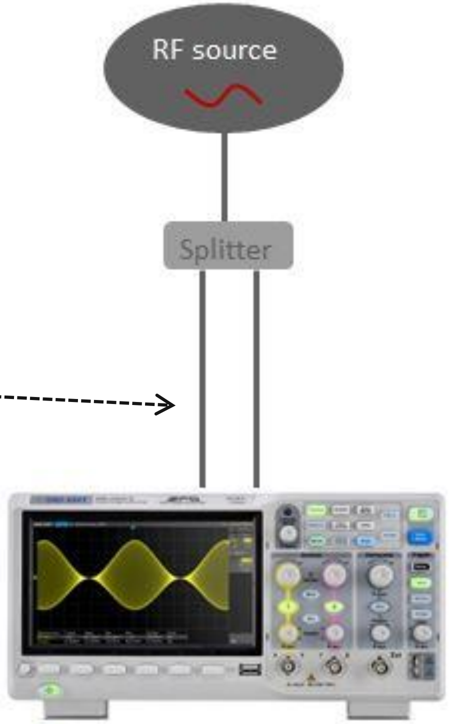
RF technology

First tests

Phase noise measurements on transmission lines

Acquisition of

RF source
Spectral analyzer
ps laser
Scope



Effort only just started…

Summary

Argonne EIC effort started in earnest in September 2016

Tackling **4 different areas**

Accelerator design, theory, simulation, detector R&D

Effort is still growing

Adding more detector R&D

Collaboration with other institutions

Very eager to do so