From HIAF to EicC

The path ahead is a natural intersection of heavy ion physics and hadron physics

Yuxiang Zhao (yxzhao@impcas.ac.cn)

Institute of Modern Physics, Chinese Academy of Sciences

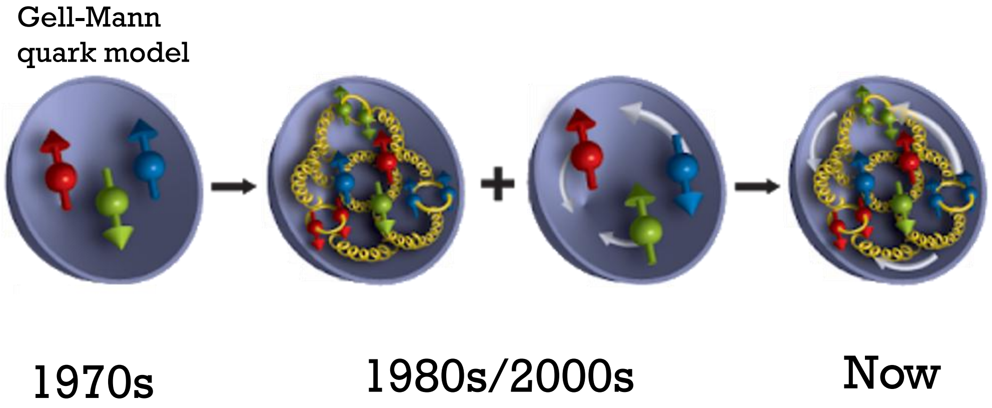
Outline

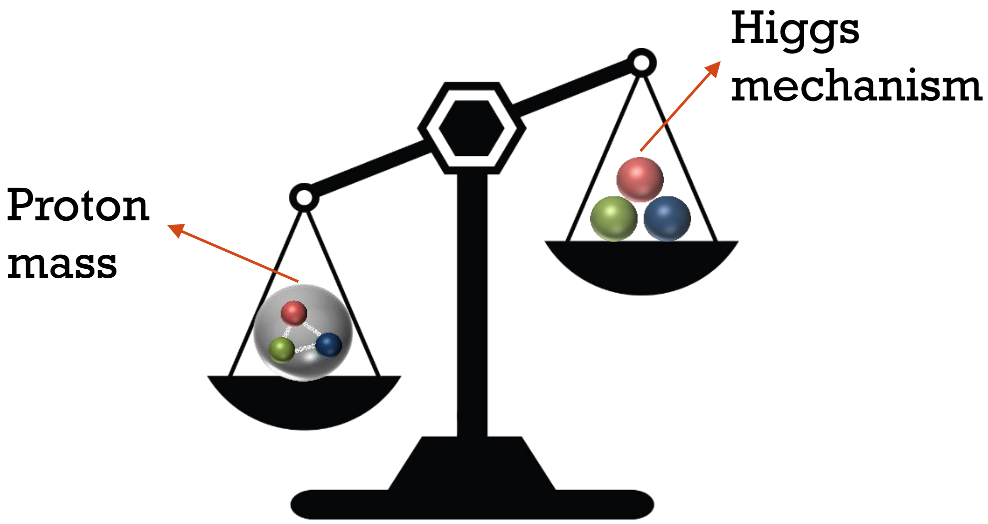
Physics

Detector

Accelerator

Physics of EicC:
Origin of nucleon spin and mass





Spin decomposition:

$$S_{tot} = \frac{1}{2} = \underbrace{\frac{1}{2}\Delta\boldsymbol{\Sigma}}_{\textbf{Quark spin}} + \underbrace{\Delta \boldsymbol{G}}_{\textbf{Gluon Spin}} + \underbrace{\boldsymbol{\mathcal{L}}_{q}}_{\textbf{Quark OAM}} + \underbrace{\boldsymbol{\mathcal{L}}_{g}}_{\textbf{Gluon OAM}}$$

Mass decomposition:

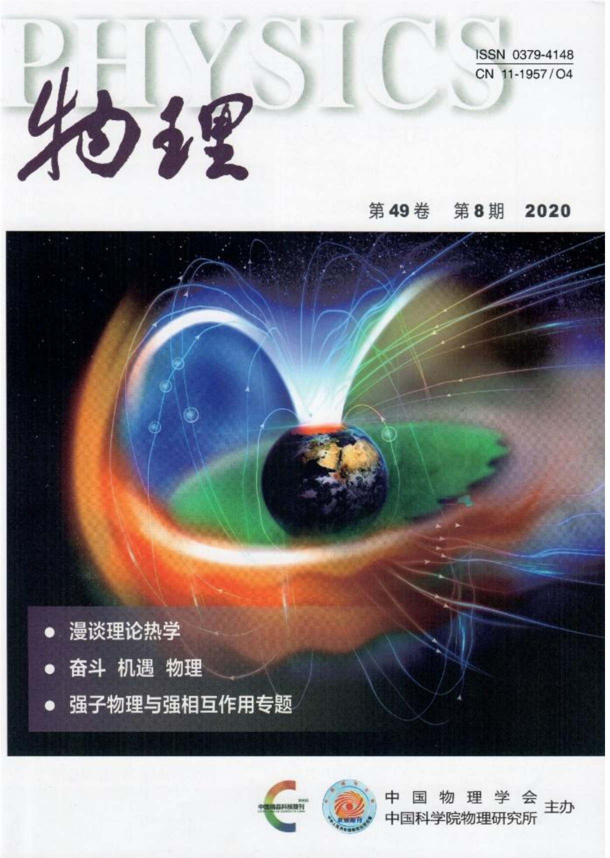
$$M = \underbrace{M_q}_{\textbf{Quark energy}} + \underbrace{M_m}_{\textbf{Quark mass}} + \underbrace{M_g}_{\textbf{Gluon energy}} + \underbrace{M_a}_{\textbf{Trace anomaly}}$$

we need to determine each of the above contributions

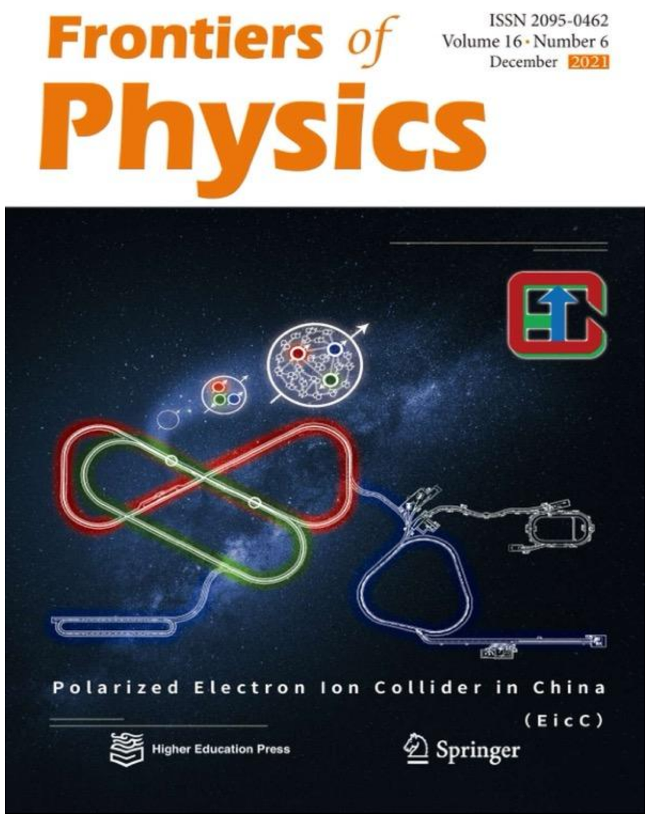
EicC milestones after the idea been proposed in 2012

EicC Chinese WP (2020)

Physics (2020)



EicC English WP (2021)



EicC CDR (2024)

EicC

Conceptual Design Report

Volume I: Accelerator

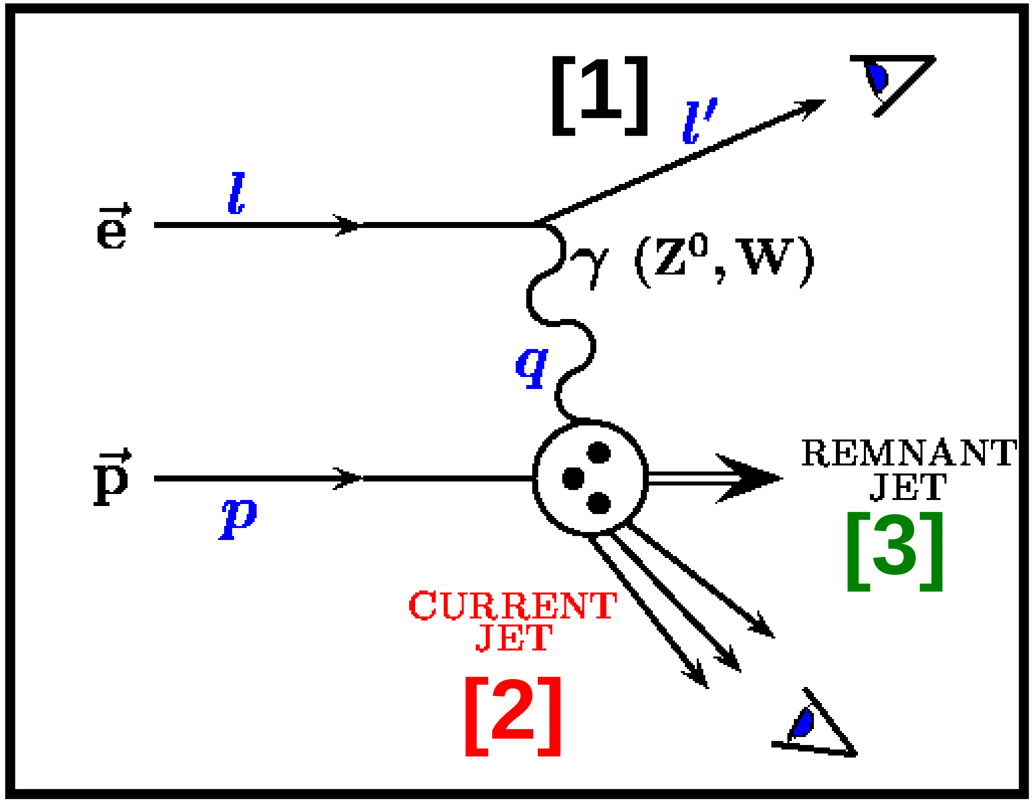
EicC

Conceptual Design Report

Volume II - Physics & Detector

Efforts of around 45 institutes and more than 200 physicists

Lepton-Nucleon Scatterings



QED tool to study QCD nature of the nucleon

$$Q^2 = -q^2 = sxy$$

$$x = \frac{Q^2}{2p\cdot q}$$

$$y = \frac{p\cdot q}{p\cdot l}$$

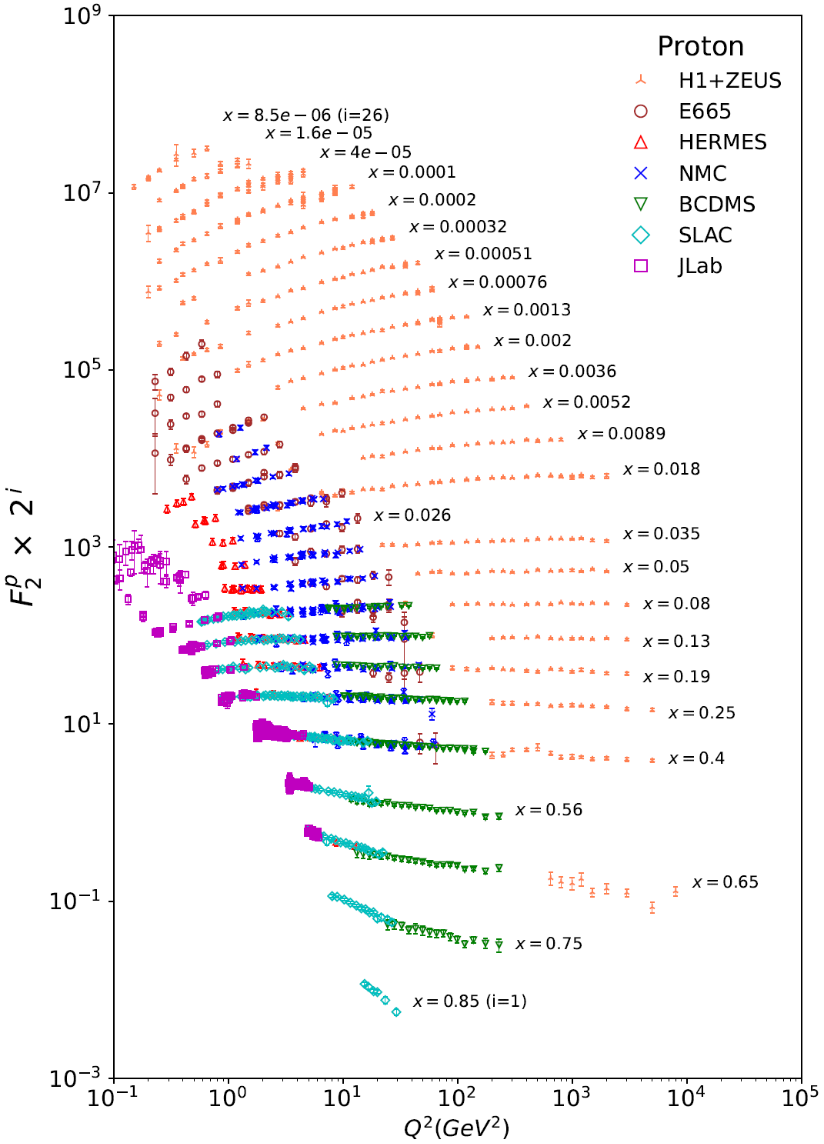
$$s = 4E_eE_p$$

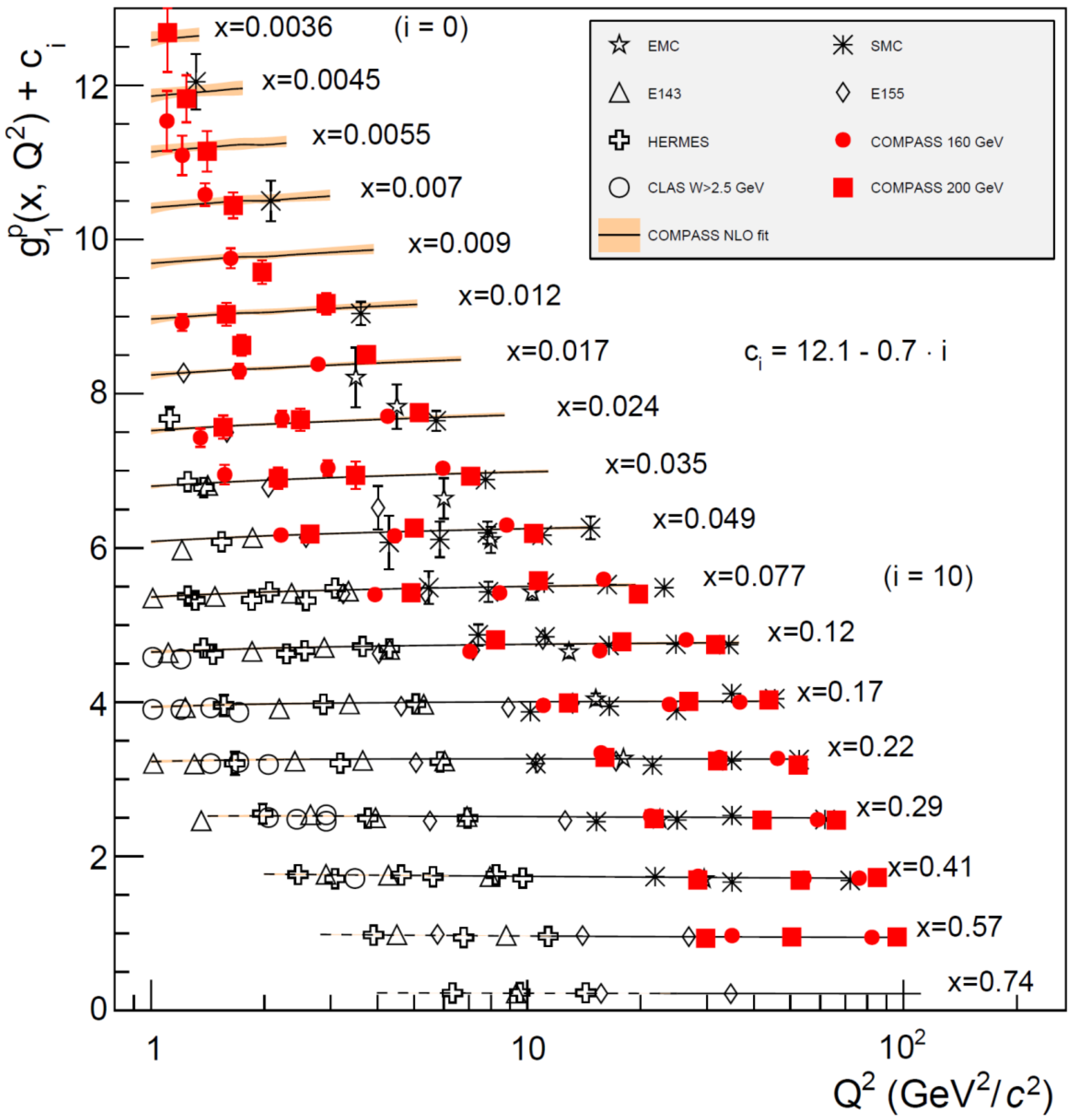
$$W = (q+p)^2$$

- QED probe is clean
- α_{EM} ~1/137 with broad Q coverage
- One-photon exchange approximation: ~1% accuracy
- Detection scale is determined by Q: 200MeV ~ nucleon size

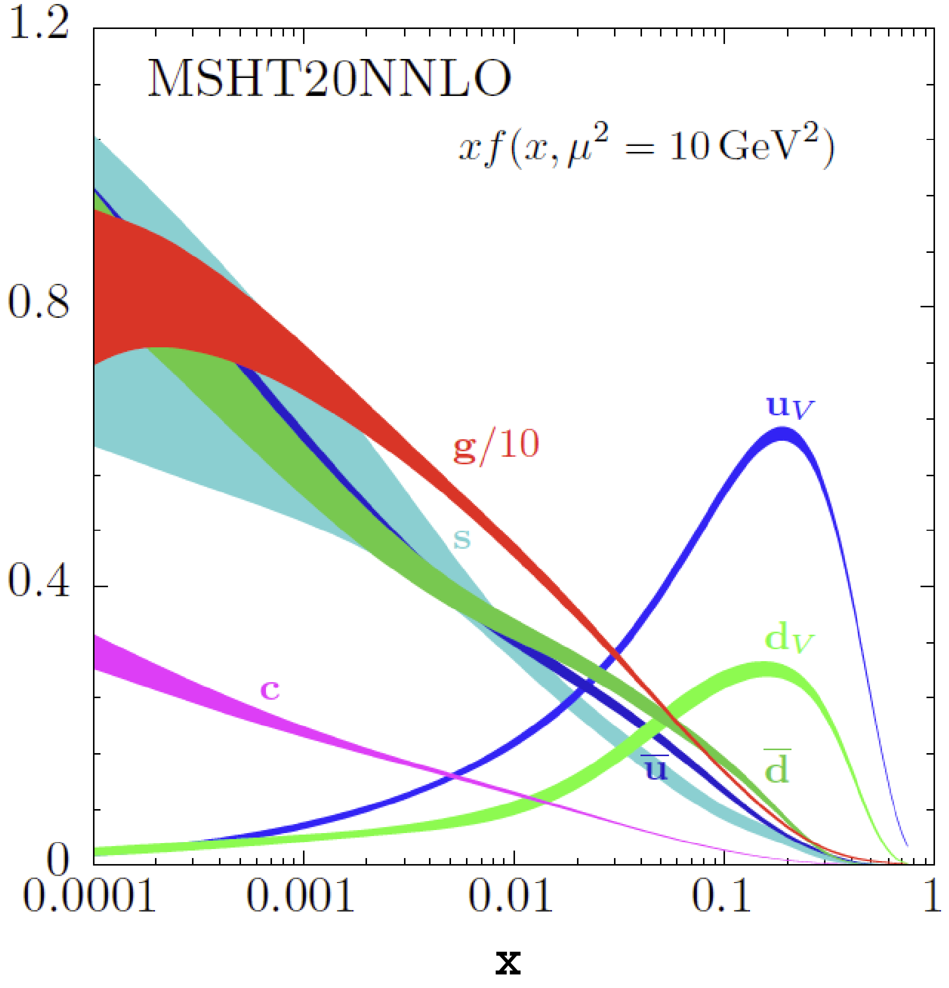
Observe scattered electron/muon	[1]	→ **inclusive**
Observe current jet/hadron	[1]+[2]	→ **semi-inclusive**
Observe remnant jet/hadron as well	[1]+[2]+[3]	→ **exclusive**

Inclusive process

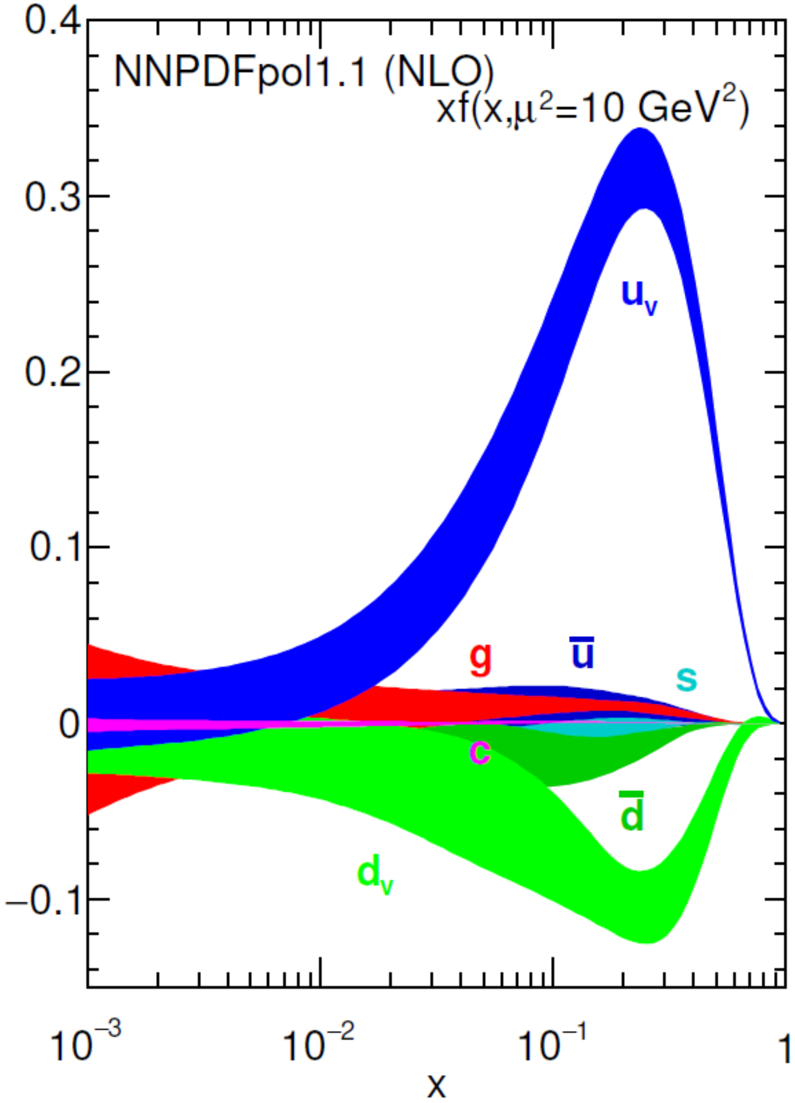




Inclusive process



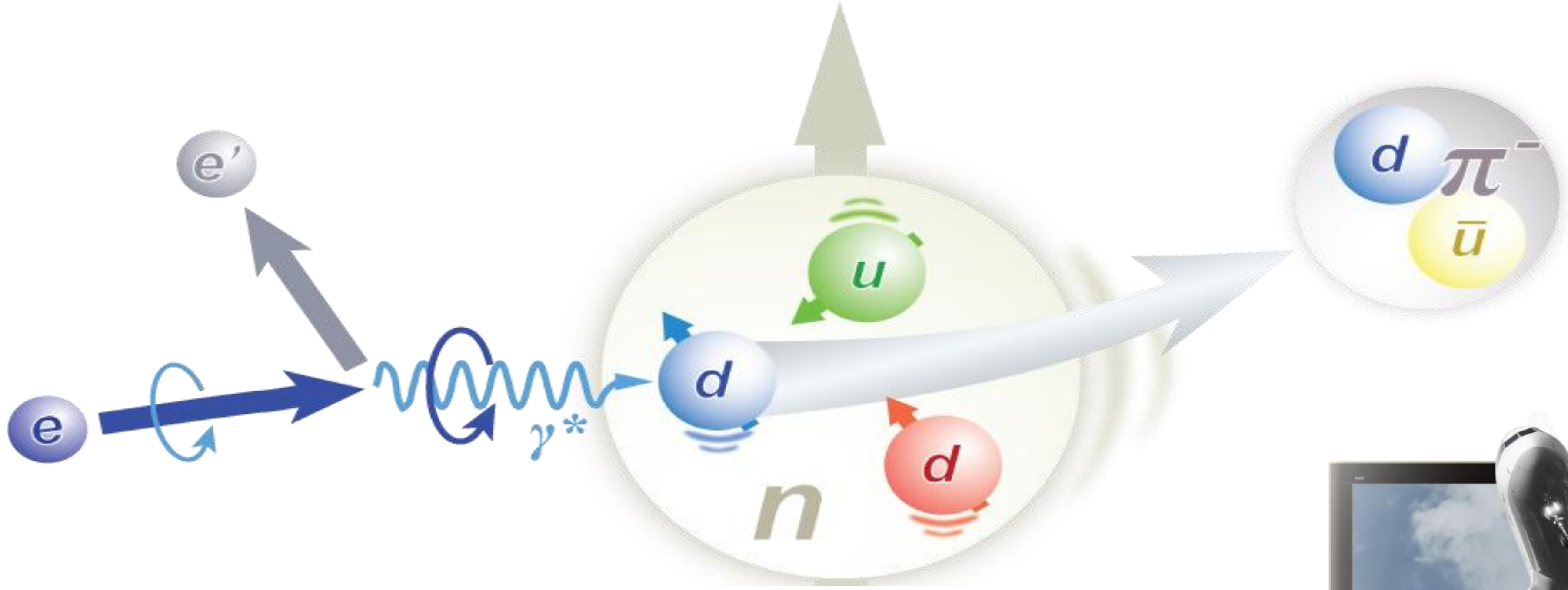
Unpolarized PDFs



Polarized PDFs: helicity distribution

Quark/gluon spin contribution to proton spin

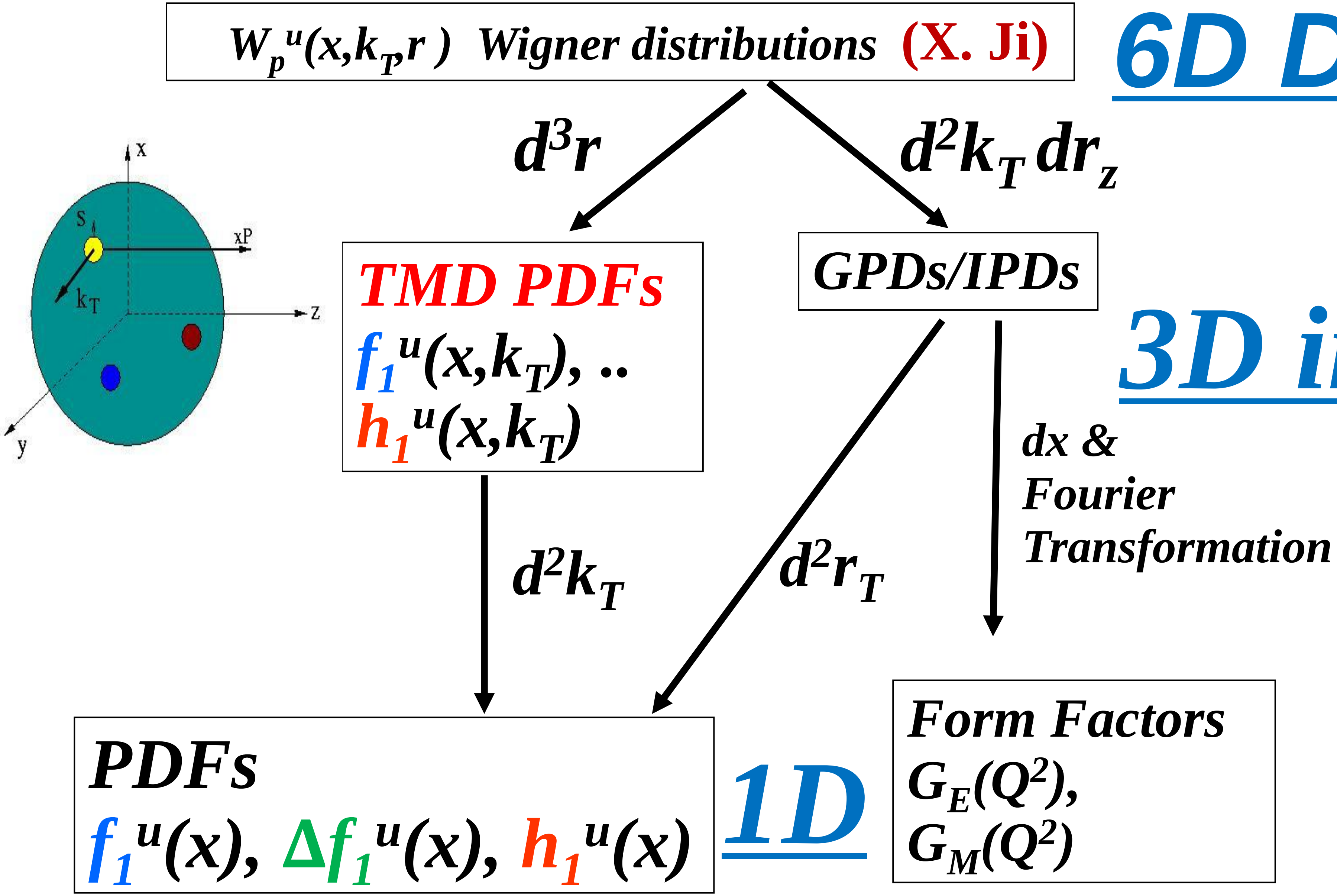
Semi-inclusive process



From 1D to 3D for nucleon structure study

Need polarized target and polarized electron beam

Unified view of nucleon structure



$W_p^u(x,k_T,r)$ Wigner distributions **(X. Ji)**

6D Dist.

d^3r

$d^2k_T\, dr_z$

TMD PDFs

$f_1^u(x,k_T)$, ..

$h_1^u(x,k_T)$

GPDs/IPDs

3D imaging

d^2k_T

d^2r_T

dx &
Fourier
Transformation

PDFs

$f_1^u(x)$, $\Delta f_1^u(x)$, $h_1^u(x)$

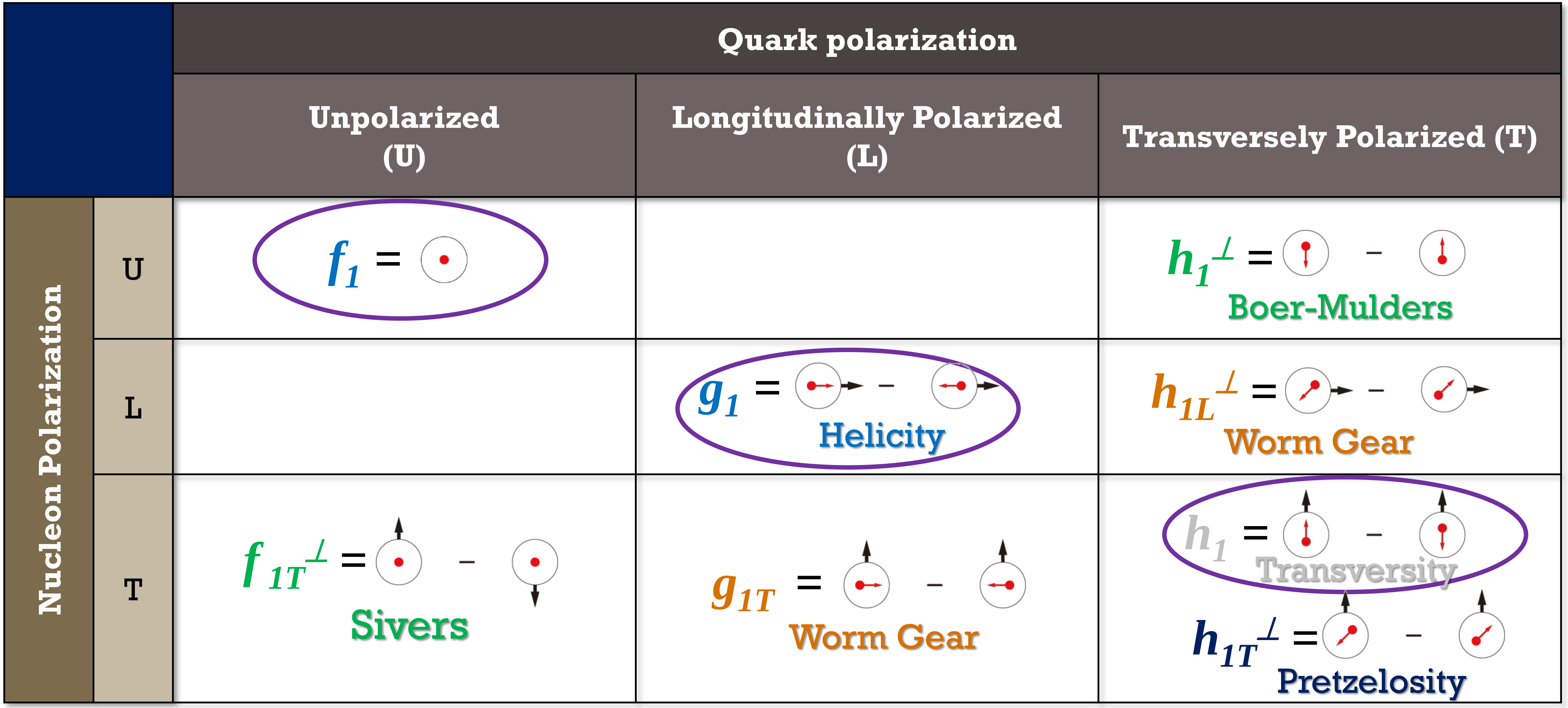
1D

Form Factors

$G_E(Q^2)$,

$G_M(Q^2)$

Leading-Twist TMDs



		Quark polarization		
		Unpolarized (U)	**Longitudinally Polarized (L)**	**Transversely Polarized (T)**
Nucleon Polarization	**U**	$f_1 =$		$h_1^\perp =$ − Boer-Mulders
	L		$g_1 =$ − Helicity	$h_{1L}^\perp =$ − Worm Gear
	T	$f_{1T}^\perp =$ − Sivers	$g_{1T} =$ − Worm Gear	$h_1 =$ − Transversity $h_{1T}^\perp =$ − Pretzelosity

Nucleon Spin *Quark Spin*

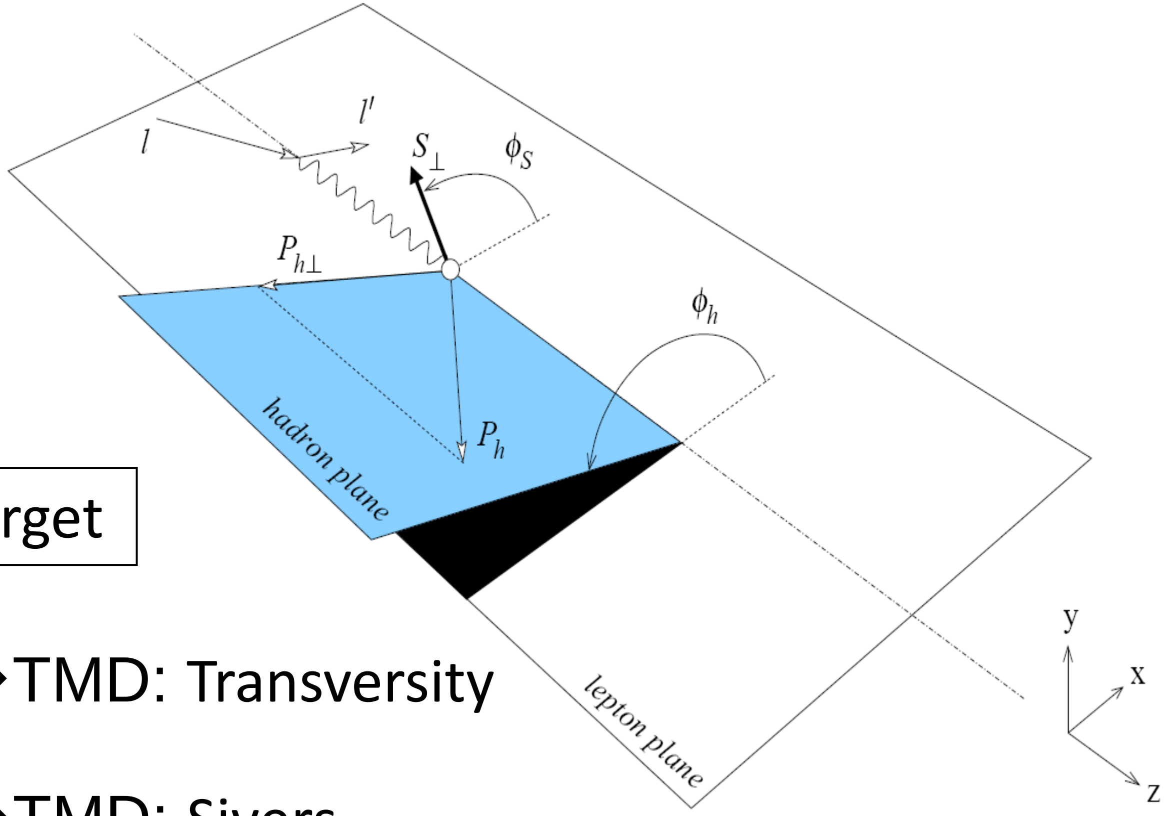
Survive the k_T integration, yield 1D pdfs

Separation of Collins, Sivers and Pretzelosity through azimuthal angular dependence

$$A_{UT}(\varphi_h^l, \varphi_S^l) = \frac{1}{P}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

$$= A_{UT}^{Collins}\sin(\phi_h + \phi_S) + A_{UT}^{Sivers}\sin(\phi_h - \phi_S)$$

$$+ A_{UT}^{Pretzelosity}\sin(3\phi_h - \phi_S)$$



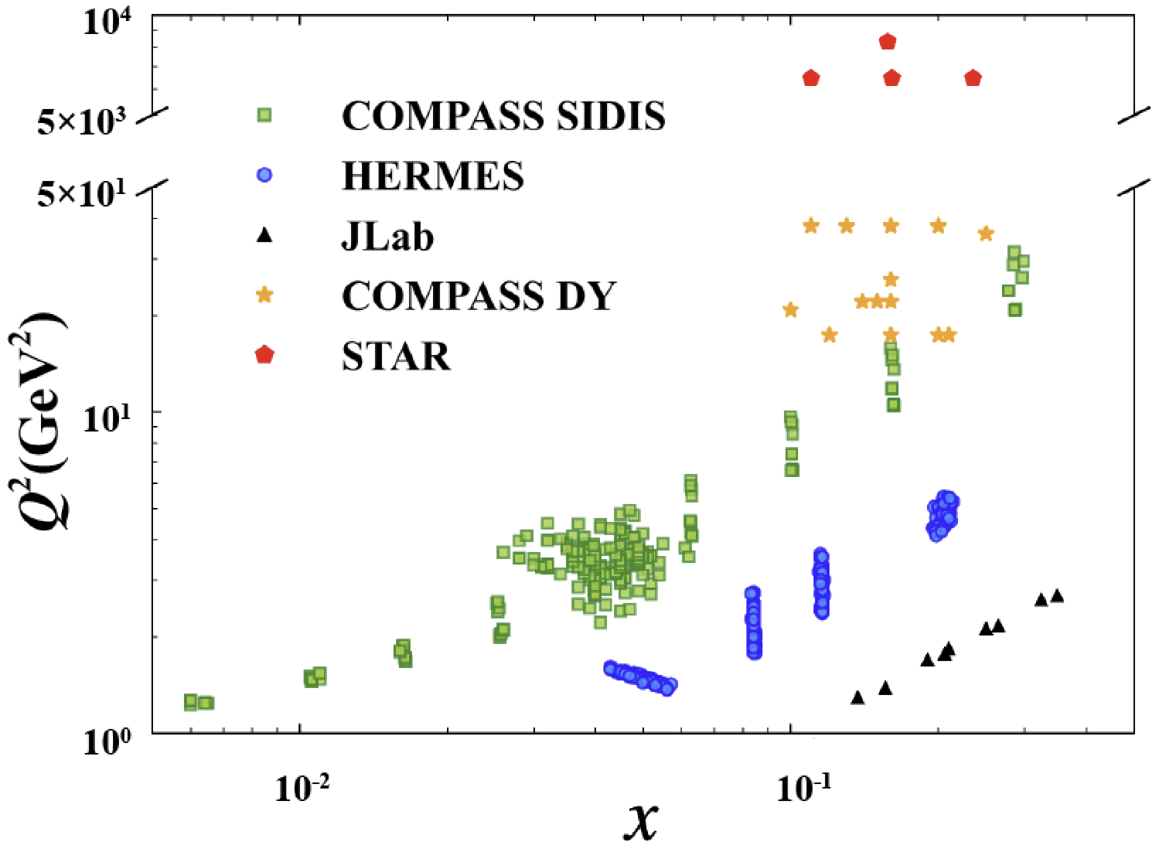
UT: **U**npolarized beam + **T**ransversely polarized target

$$A_{UT}^{Collins} \propto \langle \sin(\phi_h + \phi_S) \rangle_{UT} \propto h_1 \otimes H_1^{\perp}$$ →TMD: Transversity

$$A_{UT}^{Sivers} \propto \langle \sin(\phi_h - \phi_S) \rangle_{UT} \propto f_{1T}^{\perp} \otimes D_1$$ →TMD: Sivers

$$A_{UT}^{Pretzelosity} \propto \langle \sin(3\phi_h - \phi_S) \rangle_{UT} \propto h_{1T}^{\perp} \otimes H_1^{\perp}$$ →TMD: Pretzelosity

World data



Data set	Target	Beam	Reaction
HERMES [39]	H_2	27.6 GeV $e^{\pm}$	$e^{\pm}p \to e^{\pm}\pi^{\pm}(K^{\pm})X$
COMPASS [40]	^{6}LiD	160 GeV μ^+	$\mu^+d \to \mu^+\pi^{\pm}(K^{\pm})X$
x bin			
z bin			
$P_{h\perp}$ bin			
COMPASS [41]	NH_3	160 GeV μ^+	$\mu^+p \to \mu^+\pi^{\pm}(K^{\pm})X$
x bin			
z bin			
$P_{h\perp}$ bin			
COMPASS [45]	^{6}LiD	160 GeV μ^+	$\mu^+d \to \mu^+h^{\pm}X$
x bin			
z bin			
$P_{h\perp}$ bin			
JLab2011 [42]	^{3}He	5.9 GeV e^-	$e^-n \to e^-\pi^{\pm}X$
JLab2014 [43]	^{3}He	5.9 GeV e^-	$e^-{}^3\text{He} \to e^-K^{\pm}X$

Recent knowledge of TMDs via global data fit

- by Transverse Nucleon Tomography Collaboration

Sivers distribution functions:

Chunhua Zeng, Tianbo Liu, Peng Sun, Yuxiang Zhao, Phys. Rev. D 106 (2022) 094039.

Transversity distribution functions and Collins fragmentation functions:

Chunhua Zeng, Hongxin Dong, Tianbo Liu, Peng Sun, Yuxiang Zhao, Phys. Rev. D 109 (2024) 056002.

Trans-helicity worm-gear distribution functions:

Ke Yang, Tianbo Liu, Peng Sun, Yuxiang Zhao, Bo-Qiang Ma, Phys. Rev. D 110 (2024) 034036.

Transverse momentum dependent helicity distribution functions:

Ke Yang, Tianbo Liu, Peng Sun, Yuxiang Zhao, Bo-Qiang Ma, Phys. Rev. Lett. 134 (2025) 121902.

Sivers, transversity, and Collins functions including DY and new COMPASS data:

Chunhua Zeng, Hongxin Dong, Tianbo Liu, Peng Sun, Yuxiang Zhao, Phys. Lett. B (2025).

Helicity distributions and azimuthal modulations in longitudinal DSA:

Ke Yang, Tianbo Liu, Peng Sun, Yuxiang Zhao, Bo-Qiang Ma, in preparation.

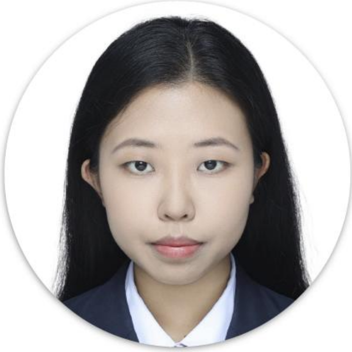
Transverse Nucleon Tomography Collaboration

Tianbo Liu
SDU

Bo-Qiang Ma
PKU/ZZU

Peng Sun
IMP

Yuxiang Zhao
IMP



Weiwei Chen
SDU

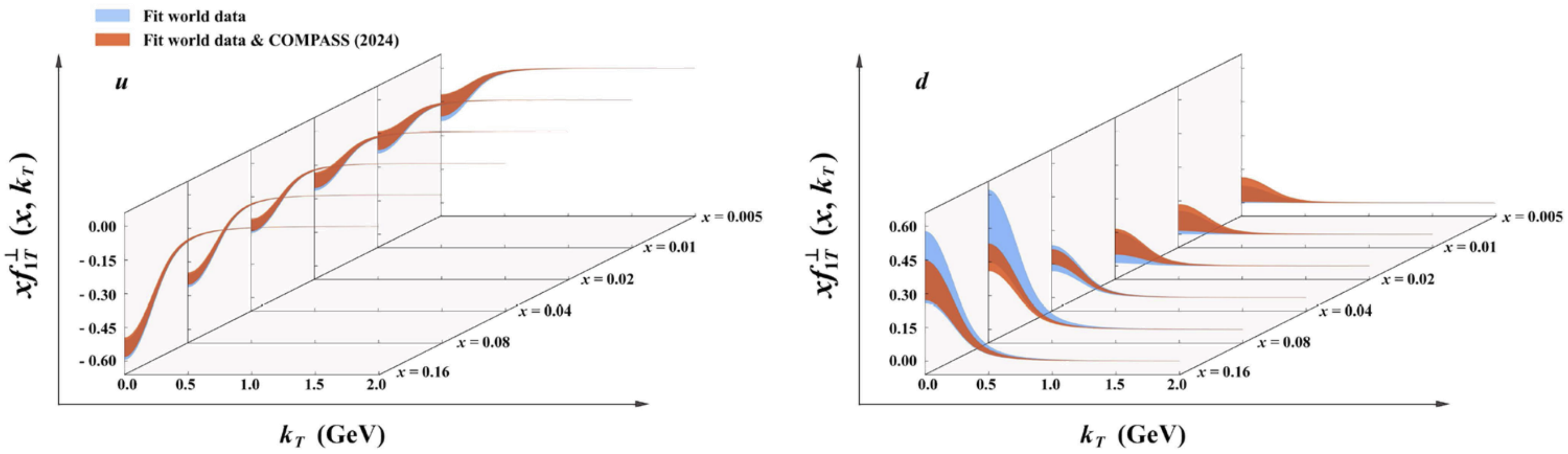
Hongxin Dong
NJNU

Ke Yang
SDU

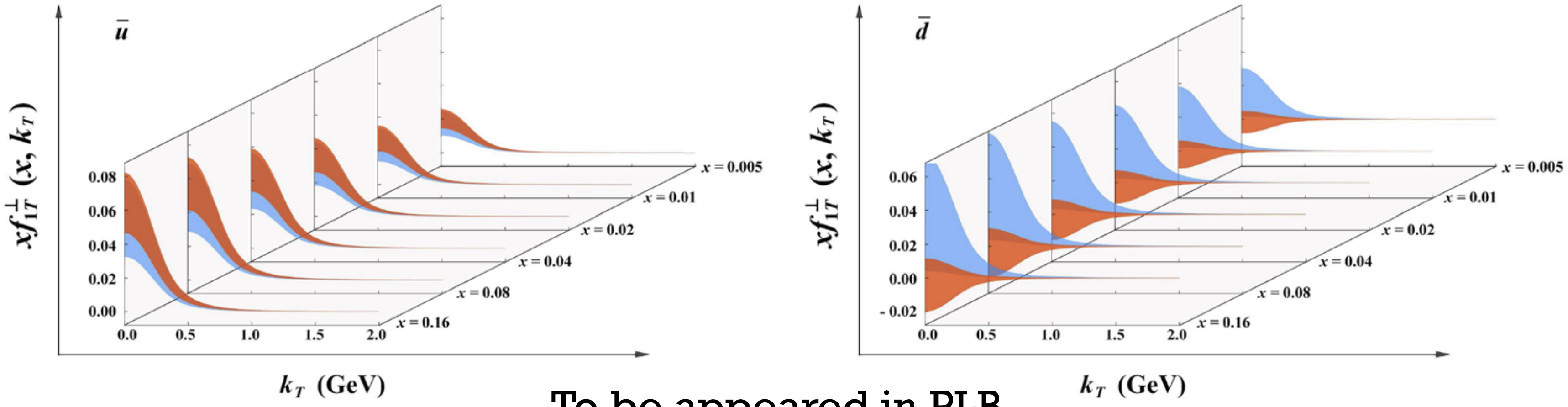
Chunhua Zeng
IMP

Recent knowledge of TMDs

- by Transverse Nucleon Tomography Collaboration



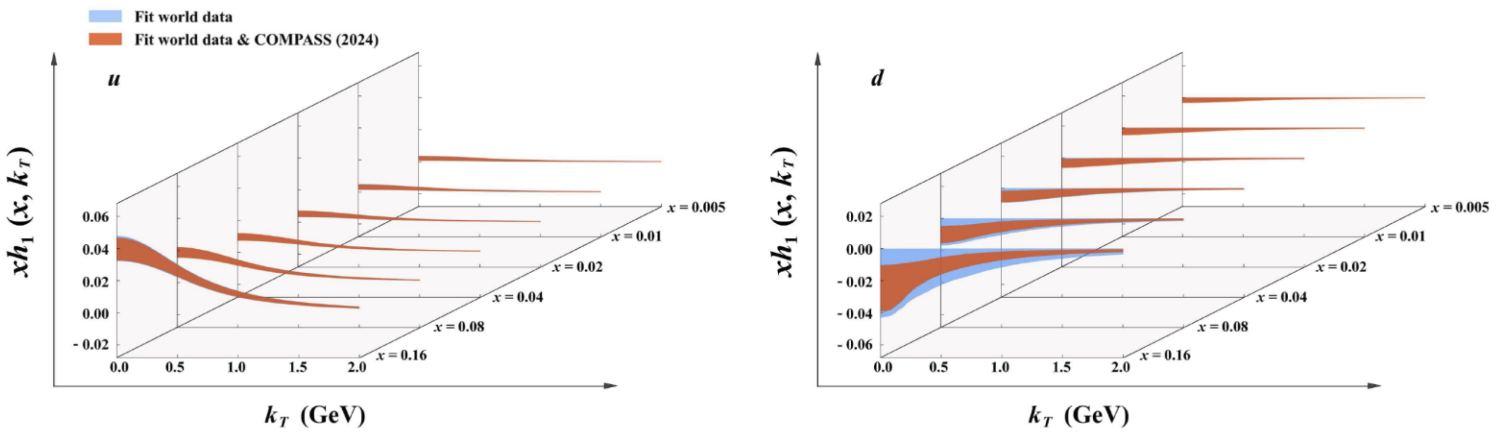
Sivers function



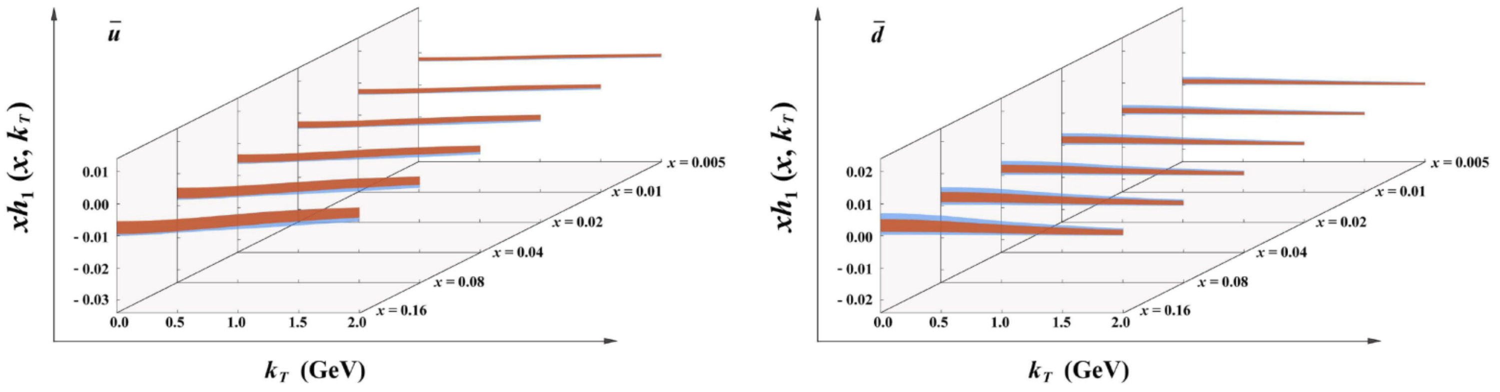
To be appeared in PLB

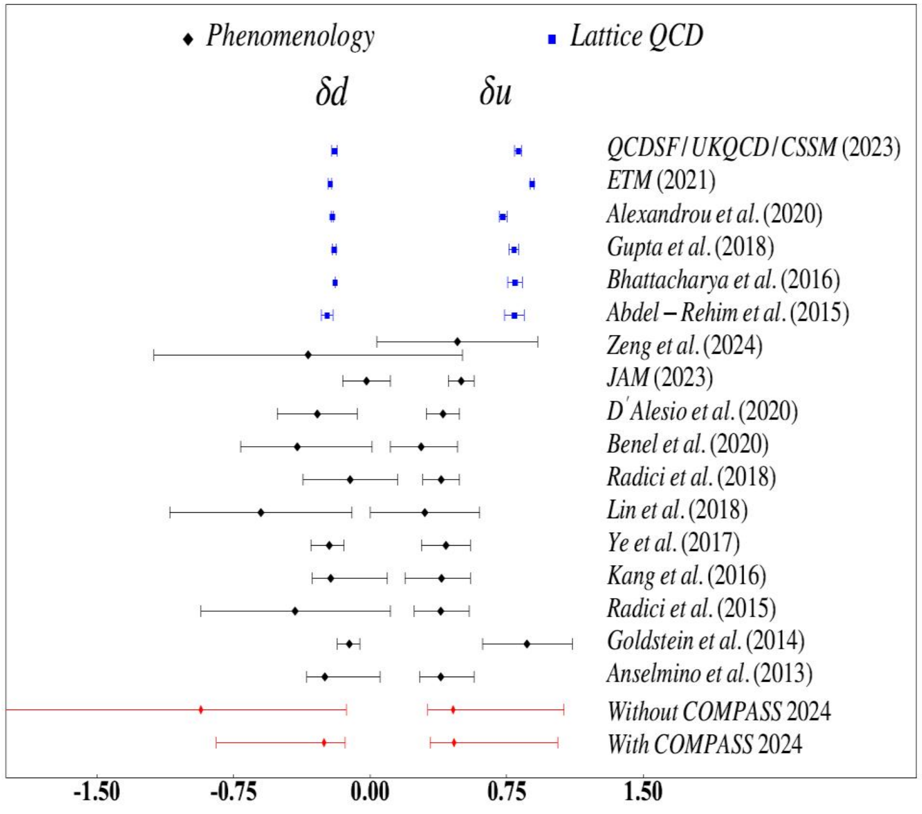
Recent knowledge of TMDs

- by Transverse Nucleon Tomography Collaboration



Transversity function



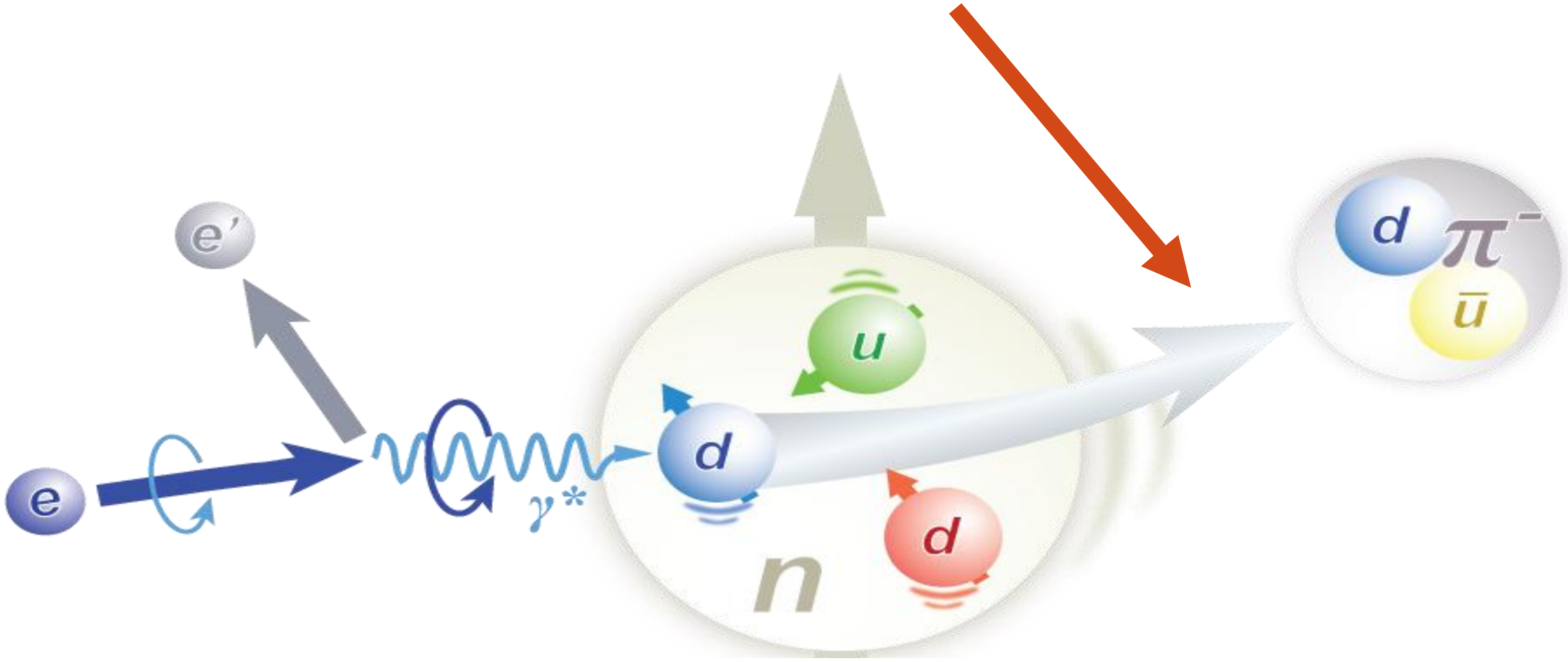


Tensor charge of proton

To be appeared in PLB

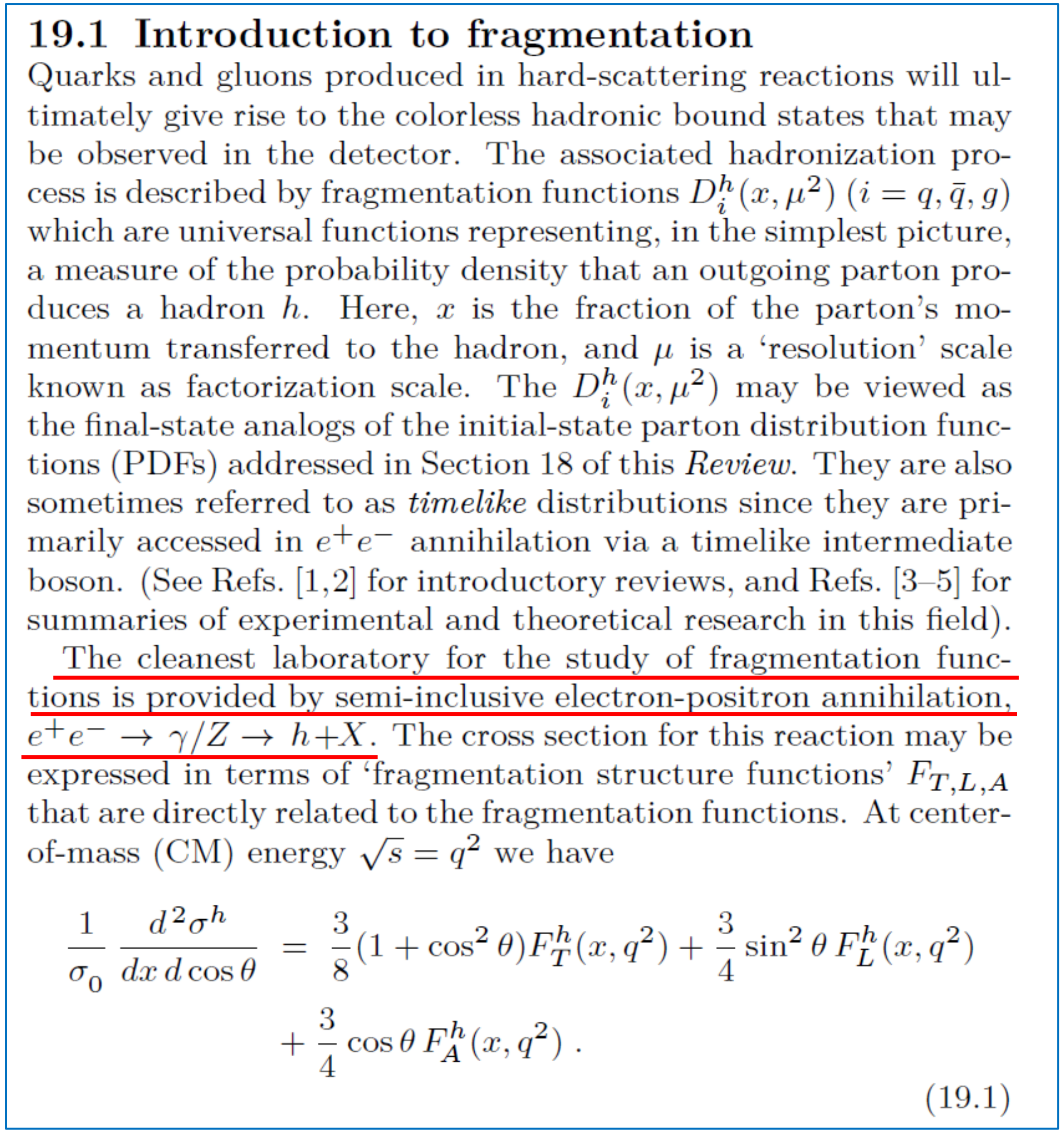
Fragmentation Functions are critical for TMDs

Fragmentation Functions: Parton → final state identified hadron



$$\mathrm{d}\sigma^{\mathrm{SIDIS}} = \sum_i H_{ij}^{\mathrm{SIDIS}} \otimes f_i \otimes D_j$$

Fragmentation Functions study at BESIII



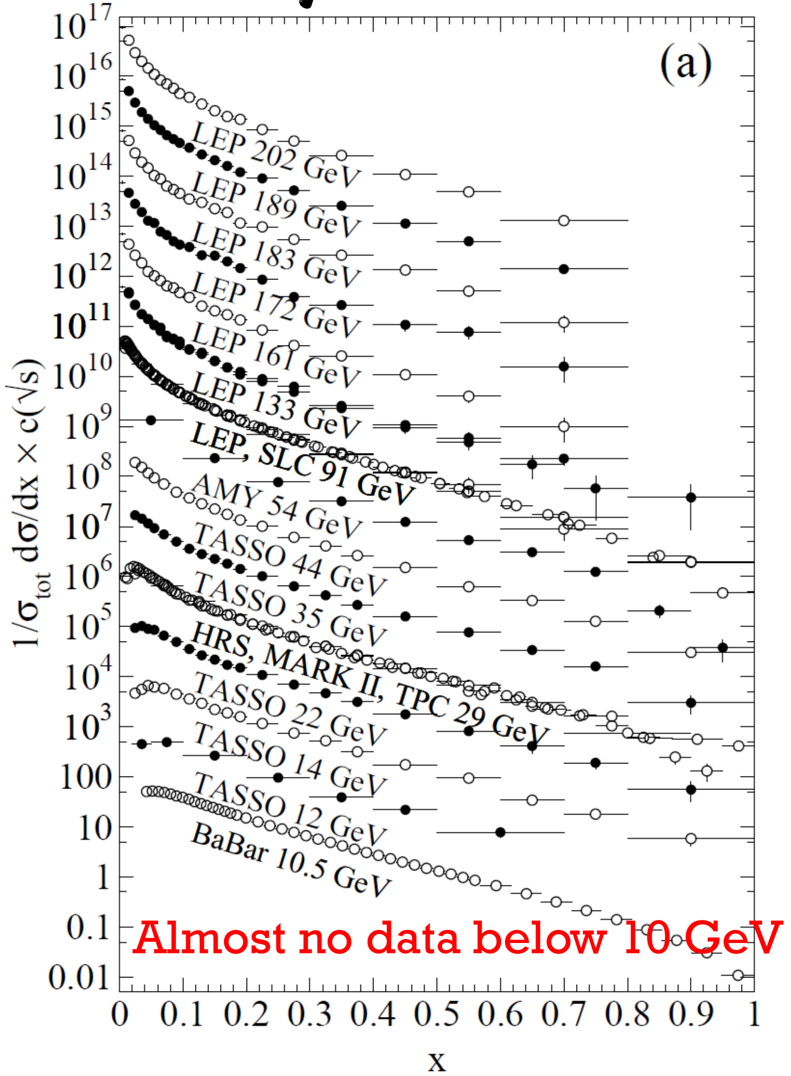
19.1 Introduction to fragmentation

Quarks and gluons produced in hard-scattering reactions will ultimately give rise to the colorless hadronic bound states that may be observed in the detector. The associated hadronization process is described by fragmentation functions $D_i^h(x,\mu^2)$ $(i = q, \bar{q}, g)$ which are universal functions representing, in the simplest picture, a measure of the probability density that an outgoing parton produces a hadron h. Here, x is the fraction of the parton's momentum transferred to the hadron, and μ is a 'resolution' scale known as factorization scale. The $D_i^h(x,\mu^2)$ may be viewed as the final-state analogs of the initial-state parton distribution functions (PDFs) addressed in Section 18 of this *Review*. They are also sometimes referred to as *timelike* distributions since they are primarily accessed in e^+e^- annihilation via a timelike intermediate boson. (See Refs. [1,2] for introductory reviews, and Refs. [3–5] for summaries of experimental and theoretical research in this field).

The cleanest laboratory for the study of fragmentation functions is provided by semi-inclusive electron-positron annihilation, $e^+e^- \to \gamma/Z \to h + X$. The cross section for this reaction may be expressed in terms of 'fragmentation structure functions' $F_{T,L,A}$ that are directly related to the fragmentation functions. At center-of-mass (CM) energy $\sqrt{s} = q^2$ we have

$$\frac{1}{\sigma_0}\frac{d^2\sigma^h}{dx\,d\cos\theta} = \frac{3}{8}(1+\cos^2\theta)F_T^h(x,q^2) + \frac{3}{4}\sin^2\theta\,F_L^h(x,q^2) + \frac{3}{4}\cos\theta\,F_A^h(x,q^2)\,. \qquad (19.1)$$

Quotation from PDG2024

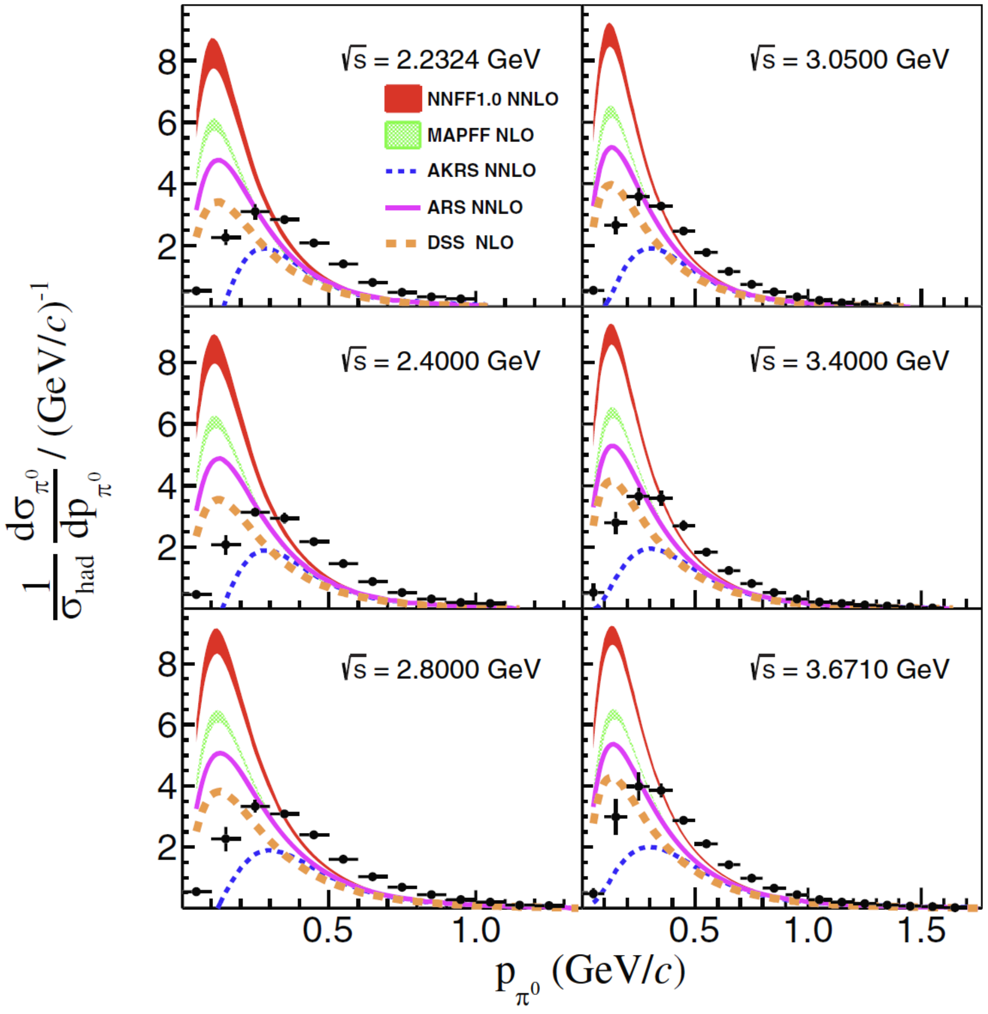


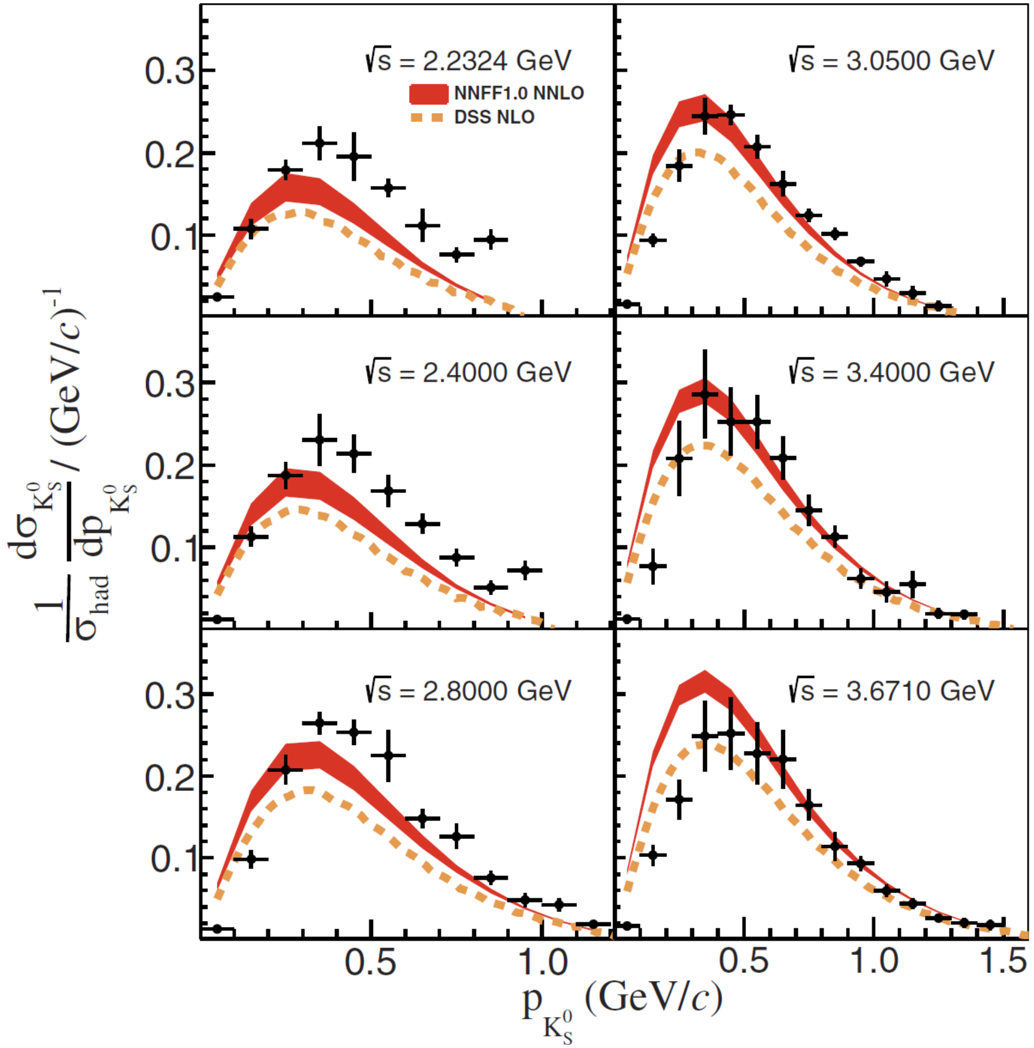
Almost no data below 10 GeV

Great potential at BESIII !

Center-of-mass coverage: 2-5(.6)GeV

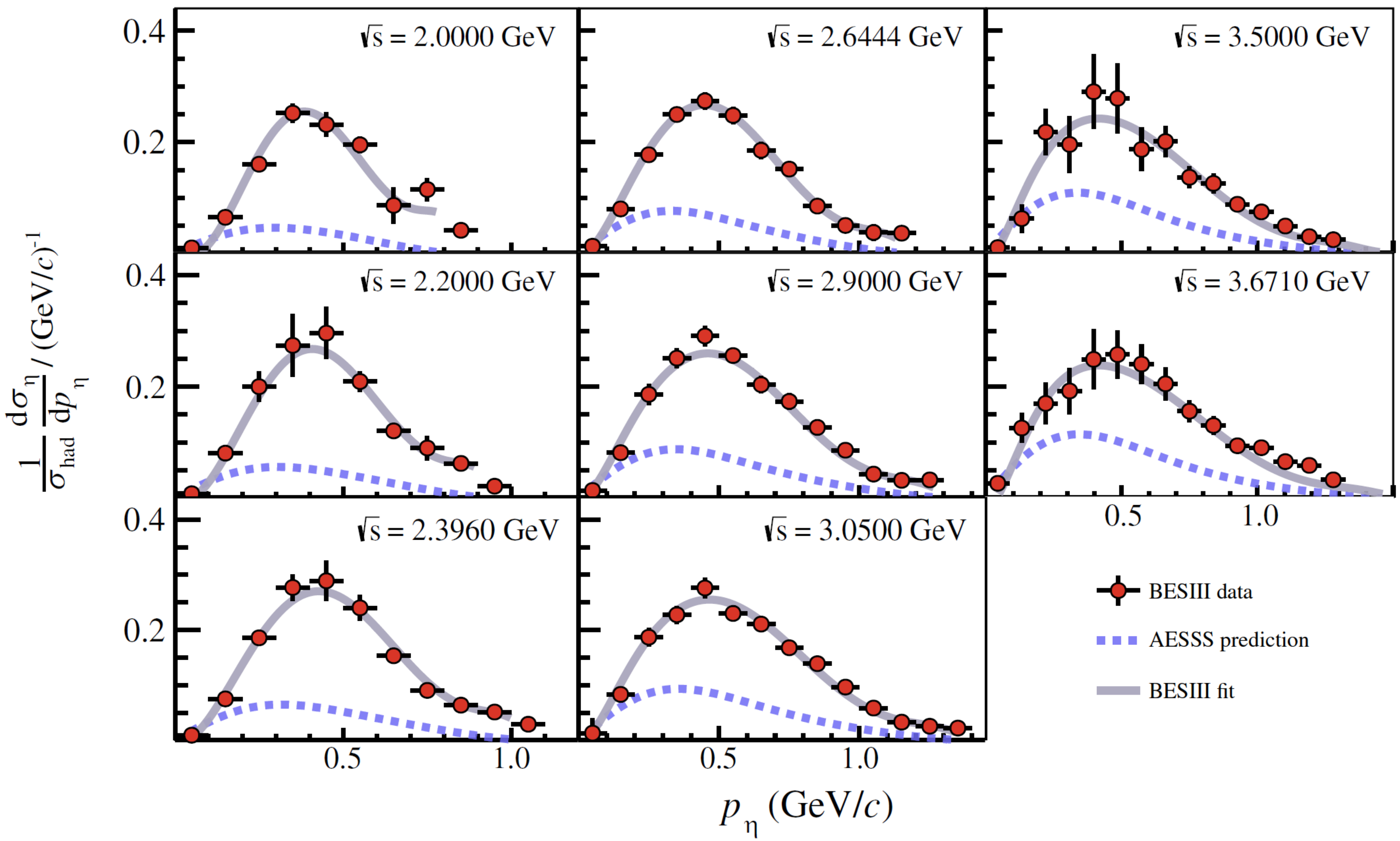
Fragmentation Functions study at BESIII





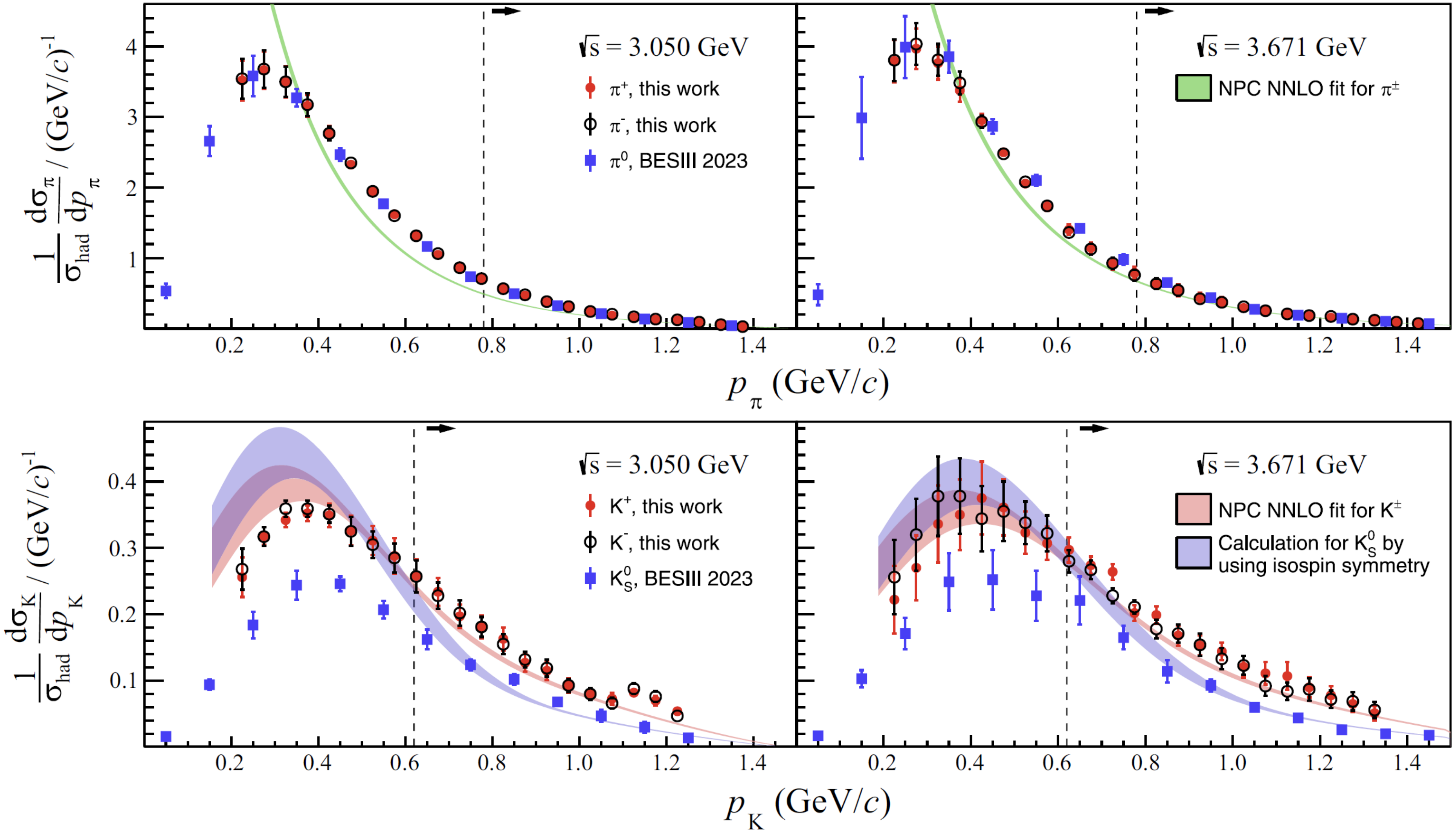
Phys. Rev. Lett. 130, 231901 (2023), by IMP, USTC, ZZU

Fragmentation Functions study at BESIII



Phys. Rev. Lett. 133, 021901 (2024), by IMP, SCNU, USTC, ZZU

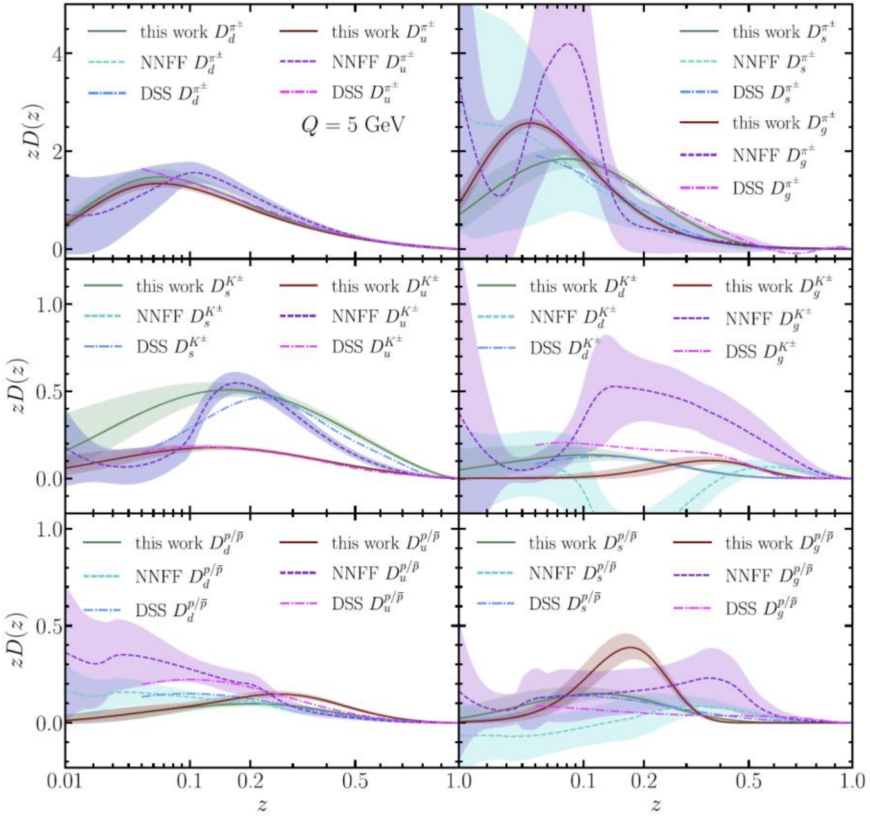
Fragmentation Functions study at BESIII



Phys. Rev. Lett. 135, 151901 (2025), by IMP, USTC, ZZU

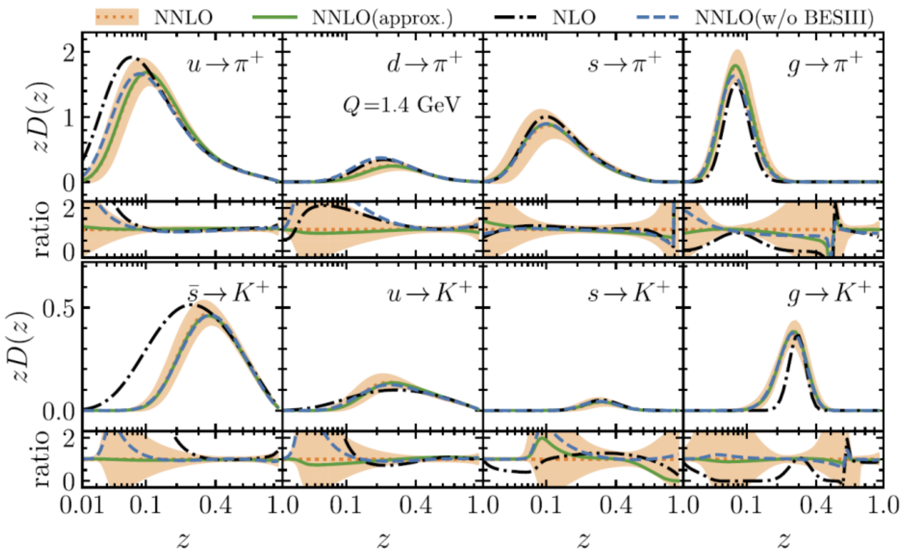
Global data fit for FFs

-by Non-perturbative Physics Collaboration



NLO FFs

Phys. Rev. Lett. 132, 261903 (2024)



	$r_a(x=0.2, Q=2\ \mathrm{GeV})$
NNPDF4.0	0.408 ± 0.107
NNPDF4.0(reweighting)	0.281 ± 0.086
MSHT20	0.213 ± 0.126
MSHT20(profiling)	0.167 ± 0.136

$$r_a \equiv \frac{s - \bar{s}}{s + \bar{s}}$$

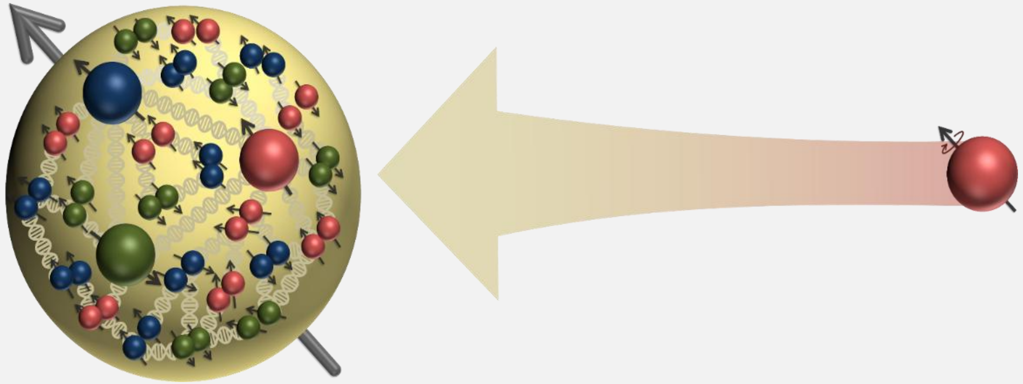
NNLO FFs

Phys. Rev. Lett. 135, 041902 (2025)

Refer to Xiaomin Shen's talk for more details

From Nucleon spin to hyperon polarization

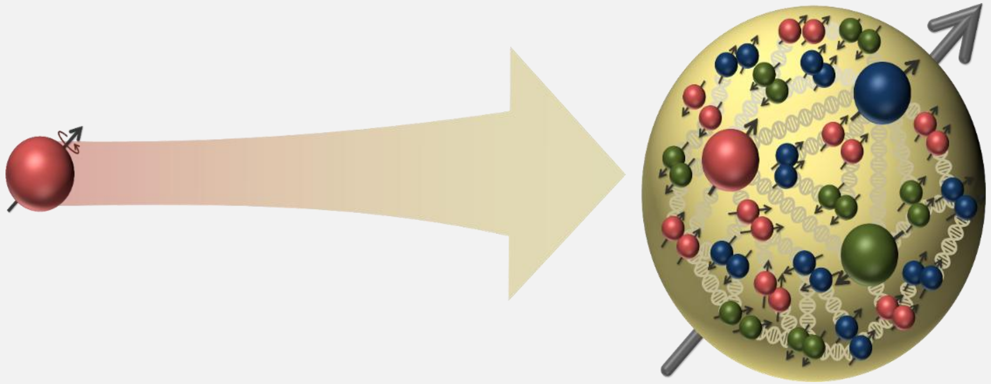
EIC: **Initial state** is polarized
-How do partons form up a polarized nucleon?



Initial state

Polarized by device

Λ polarization: **Final state** is polarized
-How do partons form up a polarized Λ?



Final state

Λ serves as its own spin analyzer through the decay $\Lambda^0 \rightarrow p + \pi^-$

origin of nucleon spin VS origin of Λ polarization

Aiqiang Guo's talk will cover our plan for Λ polarization at HIAF

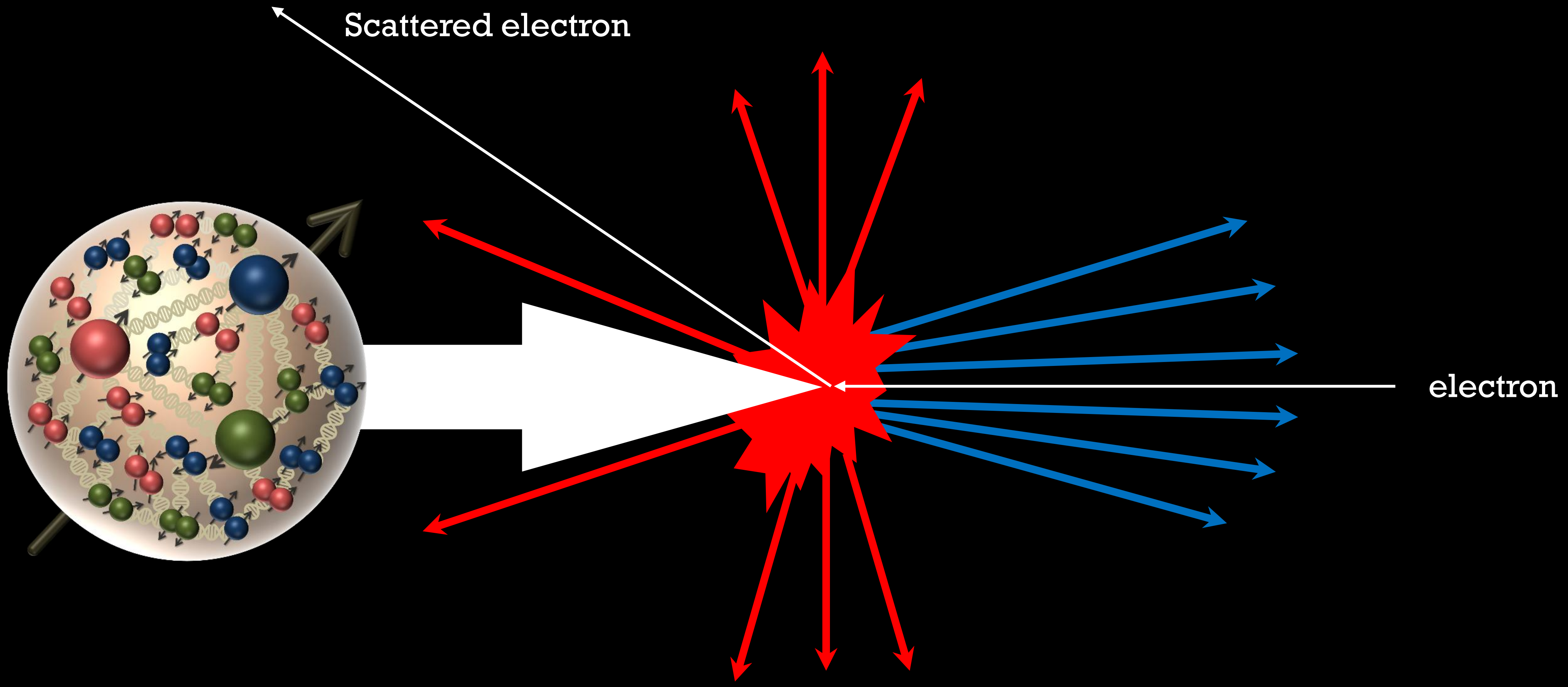
Outline

Physics

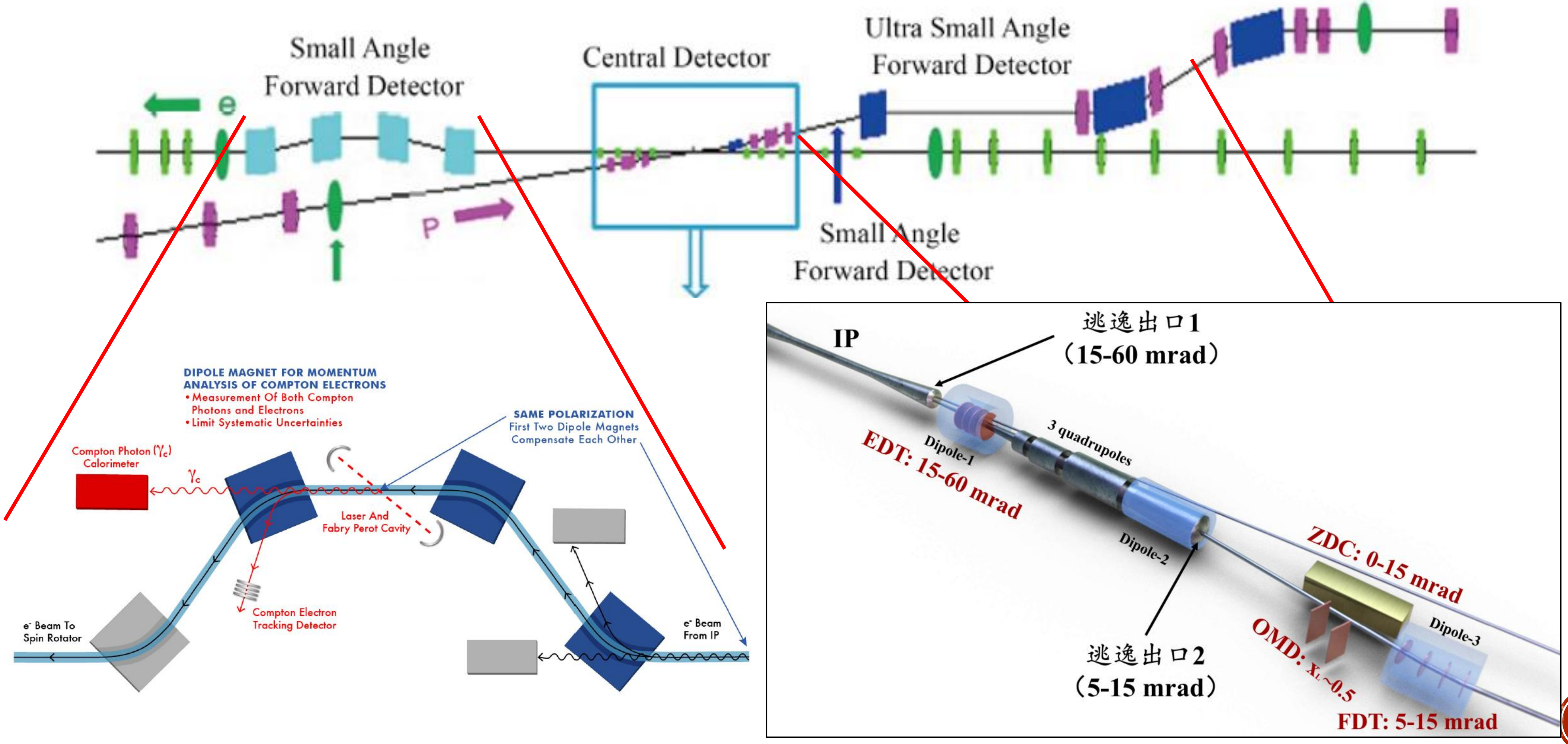
Detector

Accelerator

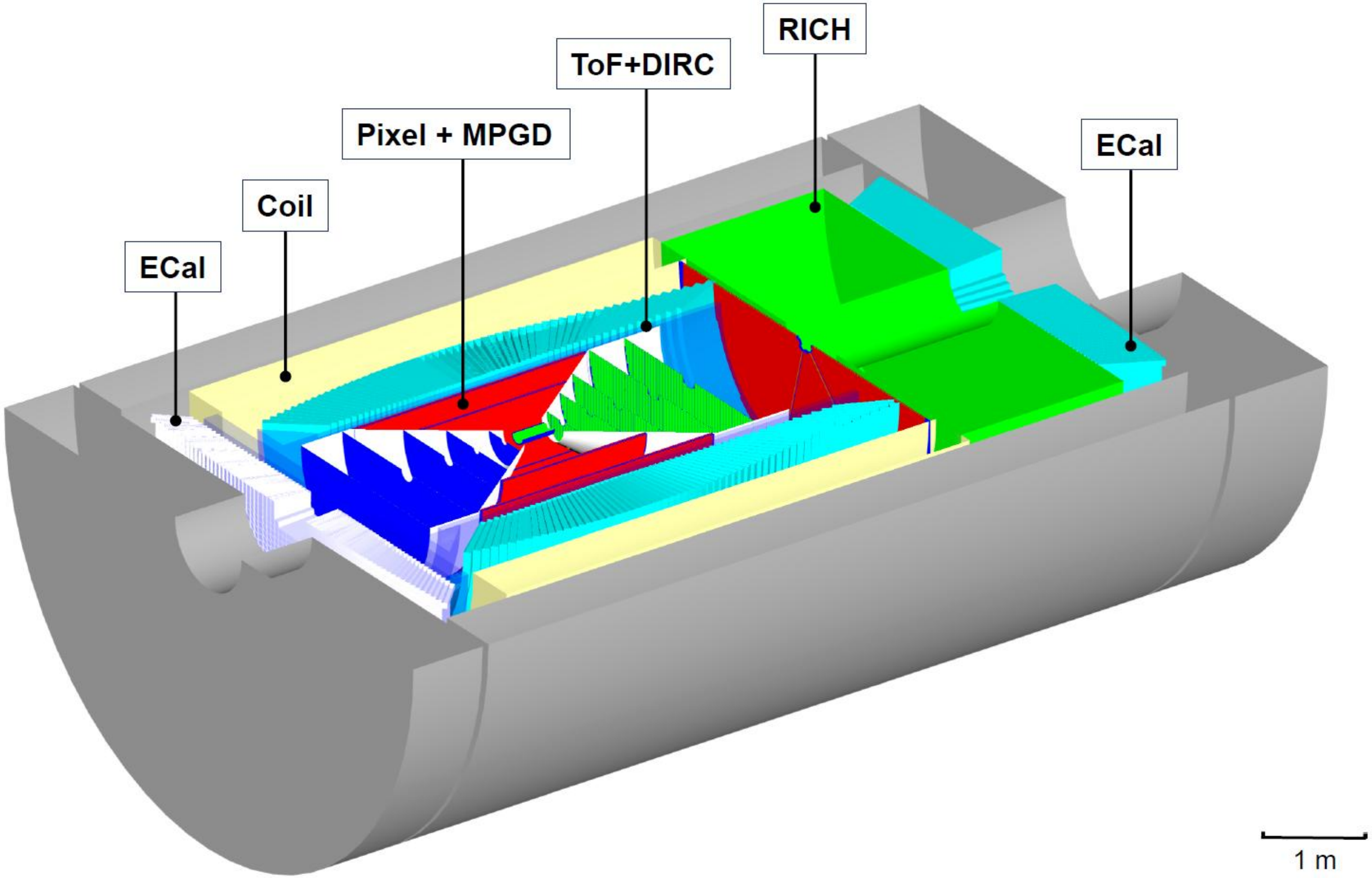
Detection of Electron-Ion Collision



EicC interaction region



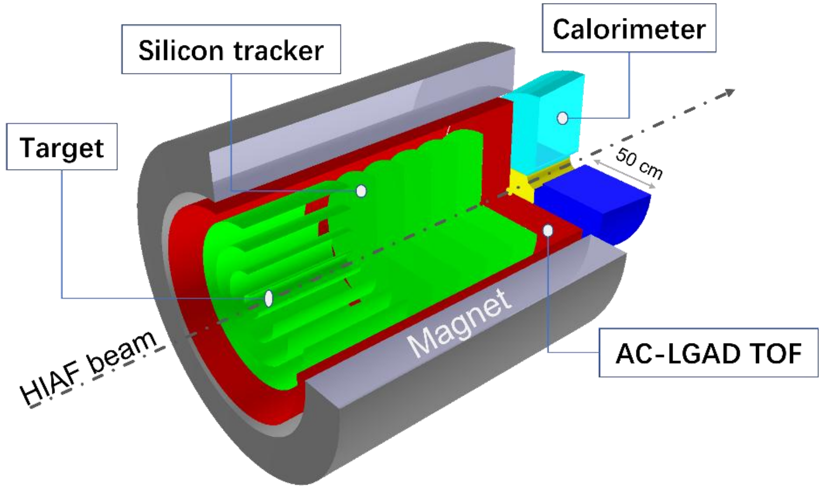
EicC Central detector design



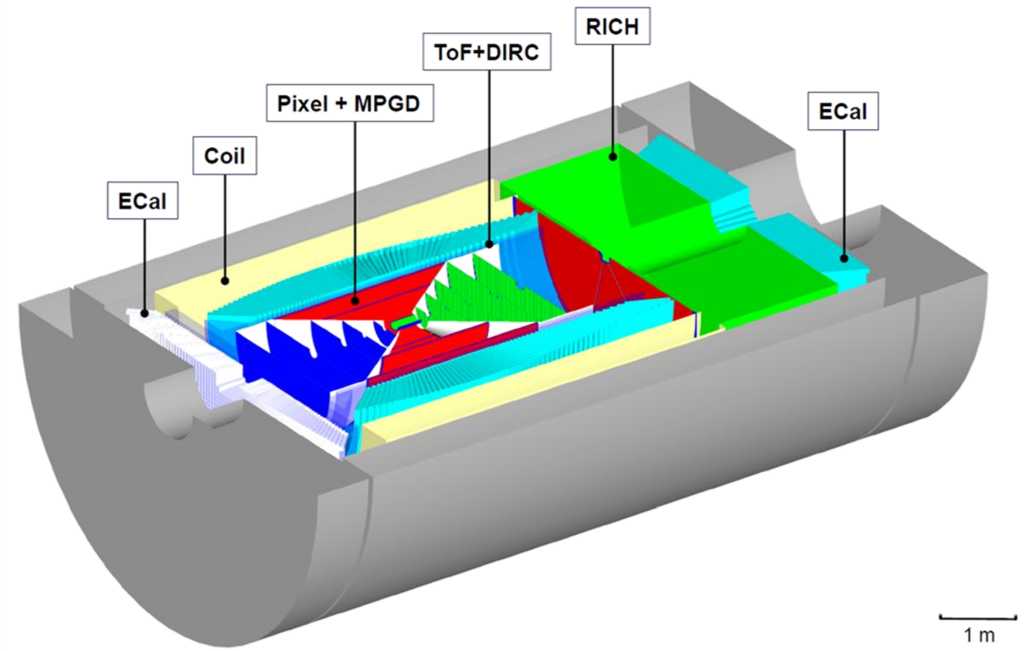
A smooth transition: H-NS detector to EicC detector

Large area Tracker: MPGD + dedicated electronics
PID: DIRC (up to 7 GeV) + RICH (up to 15 GeV)

Potential upgrade:
DIRC→ high momentum PID



Hyperon-Nucleon Spectrometer



EicC detector

Outline

Physics

Detector

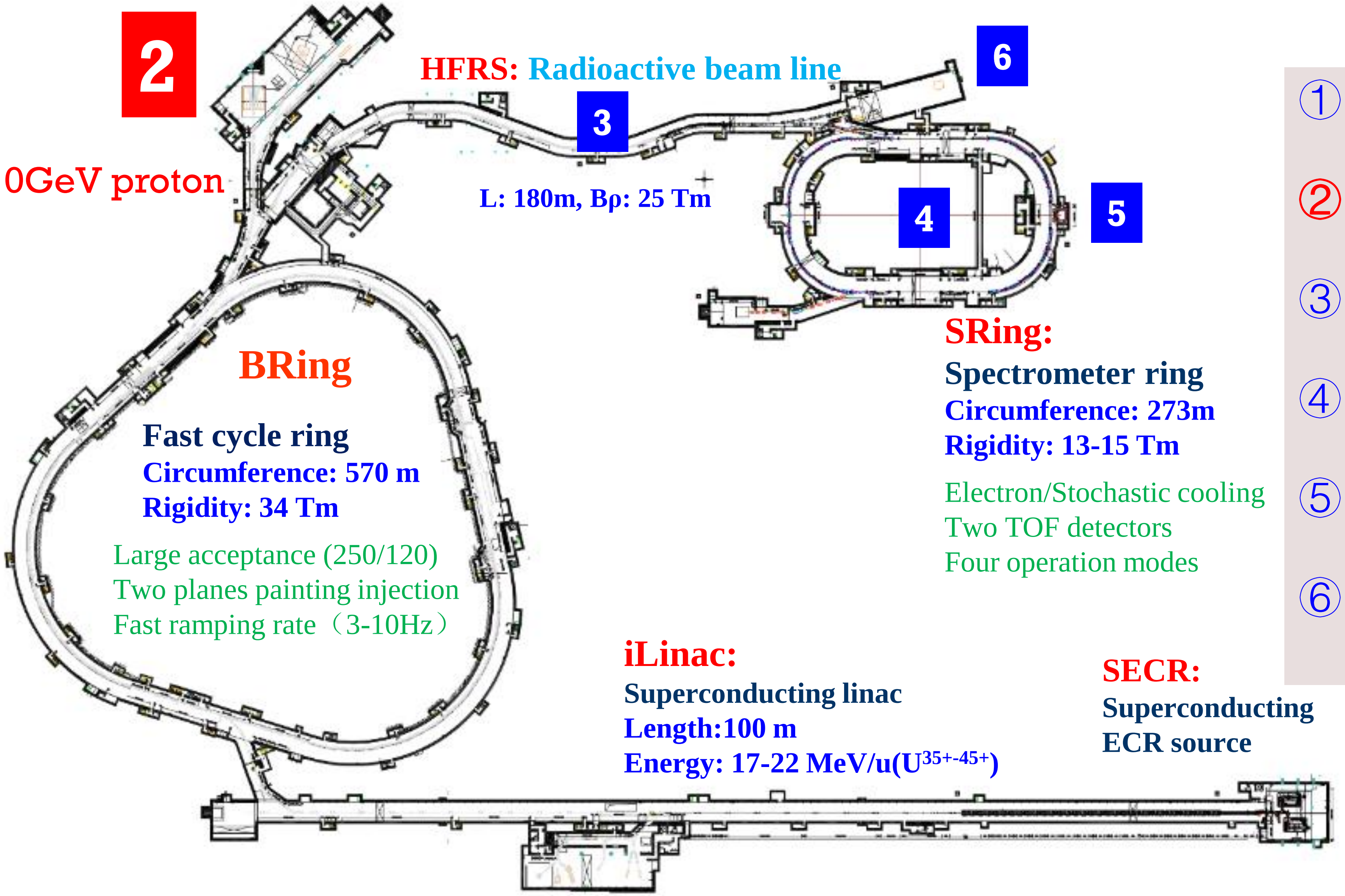
Accelerator

HIAF: High Intensity heavy-ion Accelerator Facility

Budget ~3 billion CNY (including civil construction), start from Dec. 2018, installation finished in Sept. 2025, located in Huizhou.

December 2018 **September 2025**

HIAF layout



HFRS: Radioactive beam line

BRing

Fast cycle ring

Circumference: 570 m

Rigidity: 34 Tm

Large acceptance (250/120)
Two planes painting injection
Fast ramping rate（3-10Hz）

SRing:

Spectrometer ring

Circumference: 273m

Rigidity: 13-15 Tm

Electron/Stochastic cooling
Two TOF detectors
Four operation modes

iLinac:

Superconducting linac

Length:100 m

Energy: 17-22 MeV/u($U^{35+\text{-}45+}$)

SECR:

Superconducting ECR source

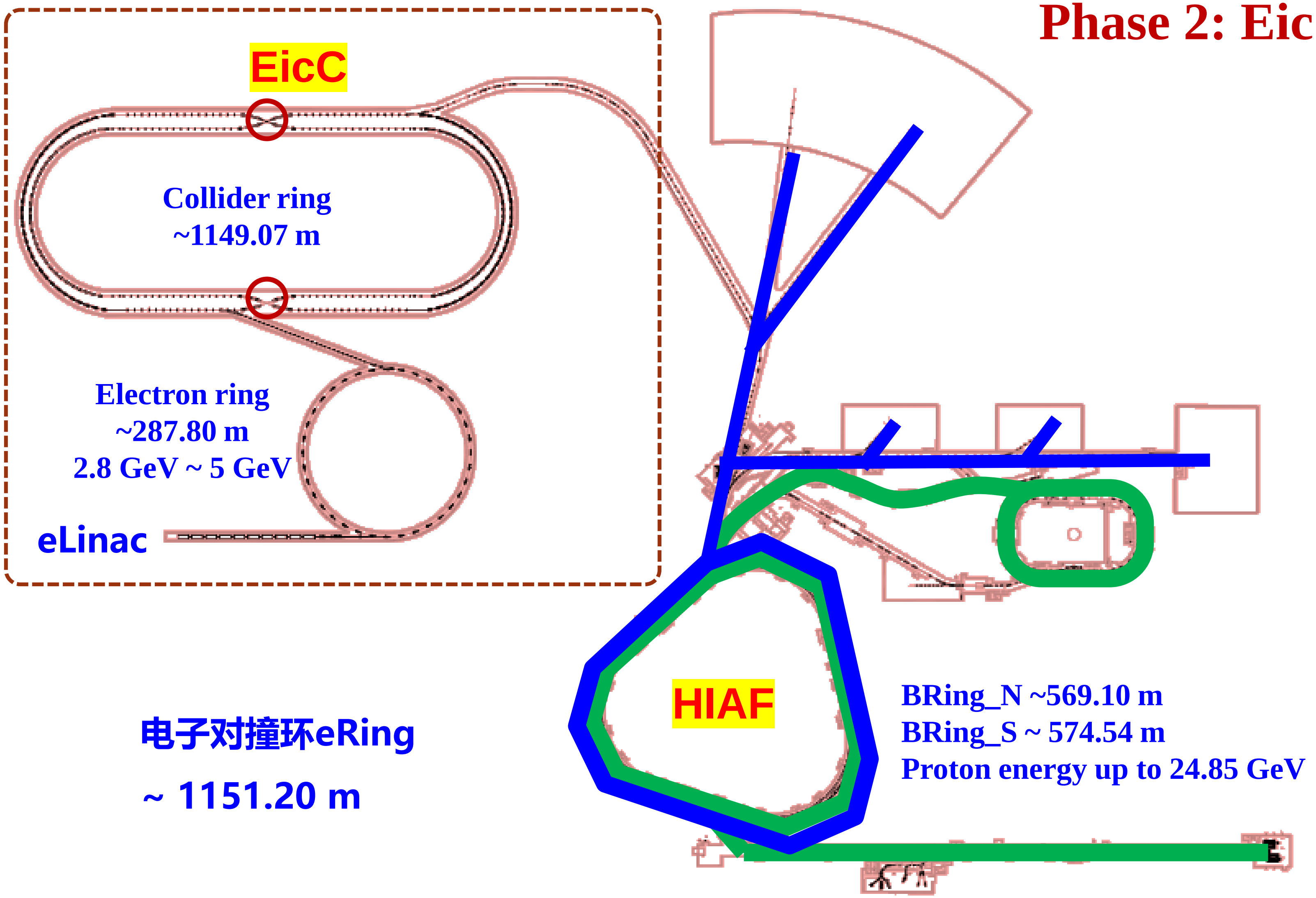
① Low energy nuclear structure terminal
② **High energy experimental terminal**
③ High energy fragment separator HFRS
④ High precision spectrometer ring SRing
⑤ Electron ion recombination terminal
⑥ Radioactive ion beam physics terminal

HIAF upgrade

Phase 0-ongoing: HIAF for nuclear physics

Phase 1: HIAF upgrade for applied science

Phase 2: EicC



EicC

Collider ring
~1149.07 m

Electron ring
~287.80 m
2.8 GeV ~ 5 GeV

eLinac

HIAF

BRing_N ~569.10 m
BRing_S ~ 574.54 m
Proton energy up to 24.85 GeV

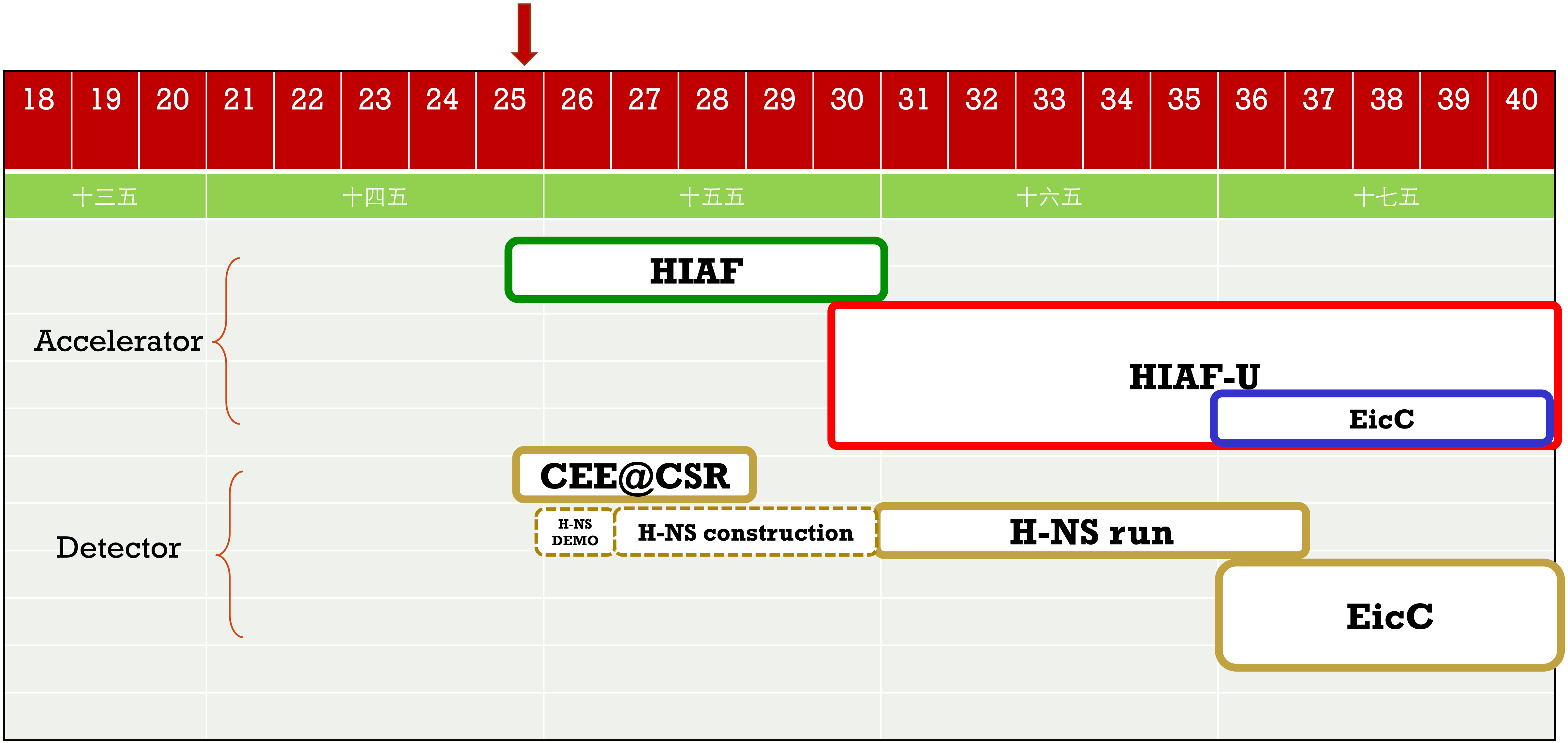
电子对撞环eRing

~ 1151.20 m

Parameter	electron	proton
Circumference (m)	1151.20	1149.81
Kinetic energy (GeV)	3.5	19.08
CM energy (GeV)	16.76	
$f_{collision}$ (MHz)	100	
Polarization	80%	70%
Bunch intensity (x10^{11})	1.7	1.05
$\varepsilon_x, \varepsilon_y$ (nm·rad, rms)	50/15	**100/50**
β_x^*/β_y^* (cm)	10/4	5/1.2
RMS divergence (mrad)	-	**1.4/2.0**
Bunch length (cm, rms)	0.75	8
Average current (A)	2.7	1.68
Crossing angle (mrad)	50	
Luminosity(cm^{-2}s^{-1})	**4.25×10^{33}**	

Proposed in the next “5-year-plan”

Timeline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39
40
十三五
十四五
十五五
十六五
十七五
Accelerator
HIAF
HIAF-U
EicC
Detector
CEE@CSR
H-NS DEMO
H-NS construction
H-NS run
EicC

Summary and outlook

➢EicC physics study is NOT far away

1. Summarize world data: know where we are and guide us where to go

   → supporting our domestic efforts of "QCD global data analysis" is critical !

2. Take advantage of existing facilities for EIC/EicC physics

➢HIAF installation is finished and under commissioning

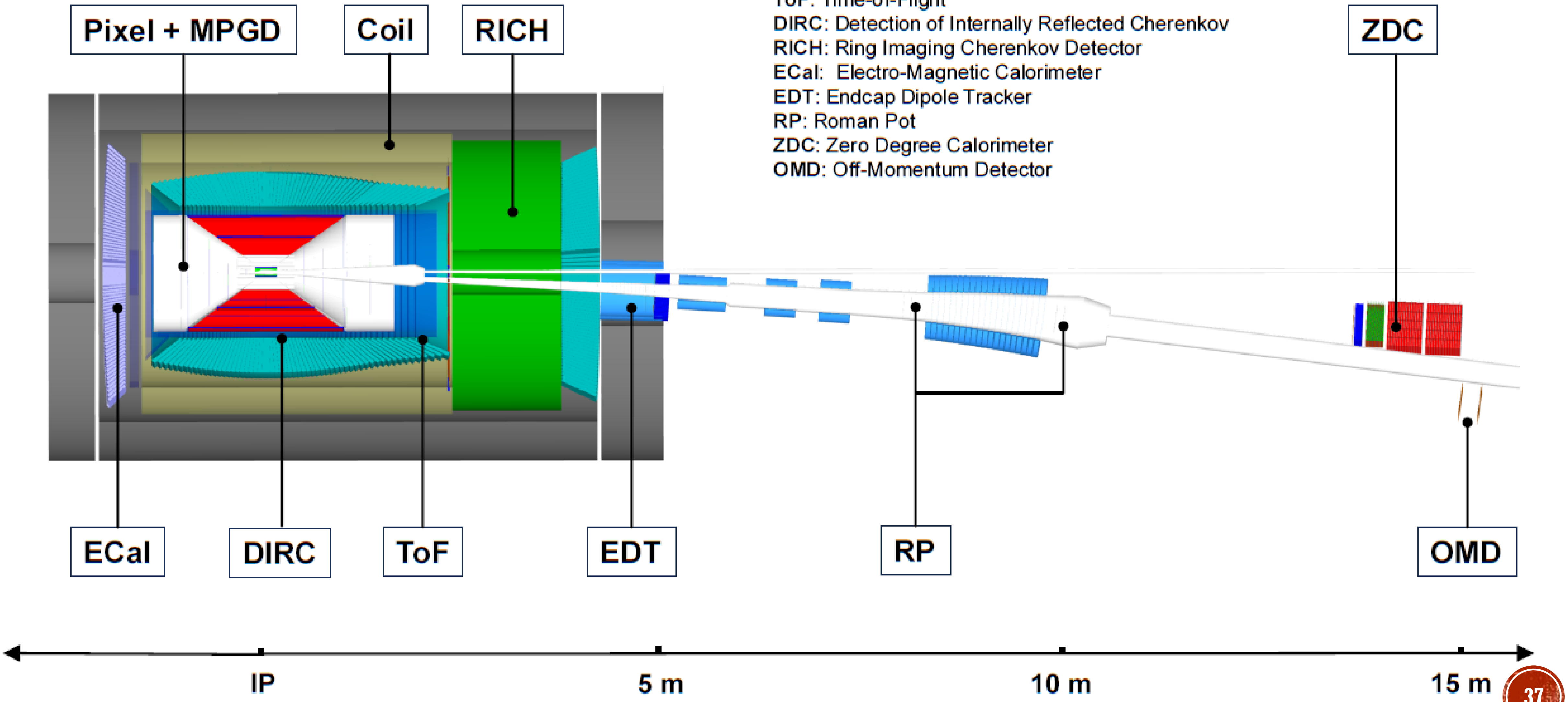
1. Hyperon-Nucleon Spectrometer at HIAF for Λ polarization study
2. H-NS to EicC: a smooth transition for both physics and detectors

Thank you！

Backups

Detector conceptual design

MPGD: Micro Pattern Gaseous Detector
ToF: Time-of-Flight
DIRC: Detection of Internally Reflected Cherenkov
RICH: Ring Imaging Cherenkov Detector
ECal: Electro-Magnetic Calorimeter
EDT: Endcap Dipole Tracker
RP: Roman Pot
ZDC: Zero Degree Calorimeter
OMD: Off-Momentum Detector



Process	Subprocess	Partons	x range
$\ell^{\pm}\,\{p,n\} \to \ell^{\pm}\,X$	$\gamma^{*} q \to q$	$q, \bar{q}, g$	$x \gtrsim 0.01$
$\ell^{\pm}\,n/p \to \ell^{\pm}\,X$	$\gamma^{*}\,d/u \to d/u$	d/u	$x \gtrsim 0.01$
$pp \to \mu^{+}\mu^{-}\,X$	$u\bar{u}, d\bar{d} \to \gamma^{*}$	$\bar{q}$	$0.015 \lesssim x \lesssim 0.35$
$pn/pp \to \mu^{+}\mu^{-}\,X$	$(u\bar{d})/(u\bar{u}) \to \gamma^{*}$	$\bar{d}/\bar{u}$	$0.015 \lesssim x \lesssim 0.35$
$\nu(\bar{\nu})\,N \to \mu^{-}\,(\mu^{+})\,X$	$W^{*} q \to q'$	$q, \bar{q}$	$0.01 \lesssim x \lesssim 0.5$
$\nu\,N \to \mu^{-}\mu^{+}\,X$	$W^{*} s \to c$	s	$0.01 \lesssim x \lesssim 0.2$
$\bar{\nu}\,N \to \mu^{+}\mu^{-}\,X$	$W^{*} \bar{s} \to \bar{c}$	$\bar{s}$	$0.01 \lesssim x \lesssim 0.2$
$e^{\pm}\,p \to e^{\pm}\,X$	$\gamma^{*} q \to q$	$g, q, \bar{q}$	$10^{-4} \lesssim x \lesssim 0.1$
$e^{+}\,p \to \bar{\nu}\,X$	$W^{+}\,\{d,s\} \to \{u,c\}$	d, s	$x \gtrsim 0.01$
$e^{\pm} p \to e^{\pm}\,c\bar{c}X, e^{\pm}\,b\bar{b}X$	$\gamma^{*} c \to c,\ \gamma^{*} g \to c\bar{c}$	c, b, g	$10^{-4} \lesssim x \lesssim 0.01$
$e^{\pm} p \to$ jet$+X$	$\gamma^{*} g \to q\bar{q}$	g	$0.01 \lesssim x \lesssim 0.1$
$p\bar{p}, pp \to$ jet(dijet)$+X$	$gg, qg, qq \to 2j$	g, q	$0.00005 \lesssim x \lesssim 0.5$
$p\bar{p} \to (W^{\pm} \to \ell^{\pm}\nu)\,X$	$ud \to W^{+}, \bar{u}\bar{d} \to W^{-}$	$u, d, s, \bar{u}, \bar{d}, \bar{s}$	$x \gtrsim 0.05$
$pp \to (W^{\pm} \to \ell^{\pm}\nu)\,X$	$u\bar{d} \to W^{+}, d\bar{u} \to W^{-}$	$u, d, s, \bar{u}, \bar{d}, \bar{s}, g$	$x \gtrsim 0.001$
$p\bar{p}(pp) \to (Z \to \ell^{+}\ell^{-})X$	$uu, dd, ..(u\bar{u}, ..) \to Z$	$u, d, s, ..(g)$	$x \gtrsim 0.001$
$pp \to W^{-}c,\ W^{+}\bar{c}$	$gs \to W^{-}c$	$s, \bar{s}$	$x \sim 0.01$
$pp \to (\gamma^{*} \to \ell^{+}\ell^{-})X$	$u\bar{u}, d\bar{d}, .. \to \gamma^{*}$	$\bar{q}, g$	$x \gtrsim 10^{-5}$
$pp \to (\gamma^{*} \to \ell^{+}\ell^{-})X$	$u\gamma, d\gamma, .. \to \gamma^{*}$	γ	$x \gtrsim 10^{-2}$
$pp \to b\bar{b}\,X,\quad t\bar{t}X$	$gg \to b\bar{b},\quad t\bar{t}$	g	$x \gtrsim 10^{-5}, 10^{-2}$
$pp \to t(\bar{t})\,X,$	$bu(\bar{b}d) \to td(\bar{t}u)$	$b, d/u$	$x \gtrsim 10^{-2}$
$pp \to$ exclusive $J/\psi,\ \Upsilon$	$\gamma^{*}(gg) \to J/\psi,\ \Upsilon$	g	$x \gtrsim 10^{-5}, 10^{-4}$
$pp \to \gamma\,X$	$gq \to \gamma q,\ g\bar{q} \to \gamma\bar{q}$	g	$x \gtrsim 0.005$