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Electron Ion Collider と ILC-N

宮地義之　山形大学

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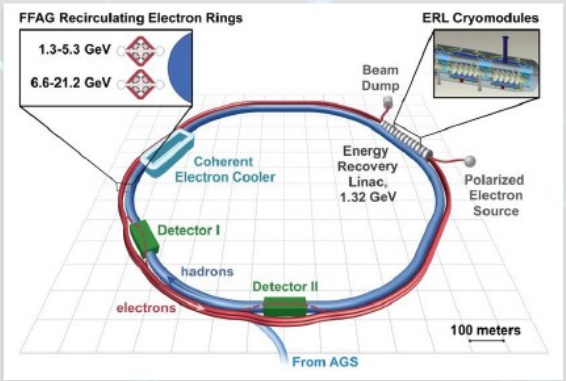
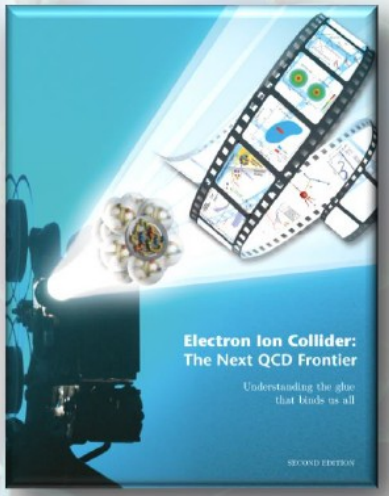
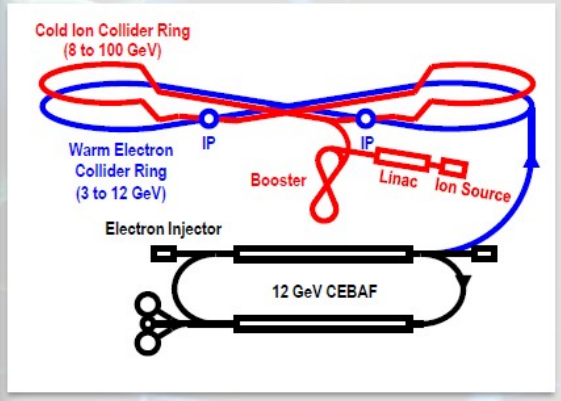
U.S. DEPARTMENT OF ENERGY | Office of Science | JSA

The US-based Electron-Ion Collider: Imaging the Gluons and Quark Sea of Nucleons and Nuclei







Rolf Ent
Jefferson Lab

Non-Perturbative Phenomena in Hadron and Particle Physics, Brazil, 1-7 May 2016

Jefferson Lab
Thomas Jefferson National Accelerator Facility

The Electron Ion Collider

For e-N collisions at the EIC:

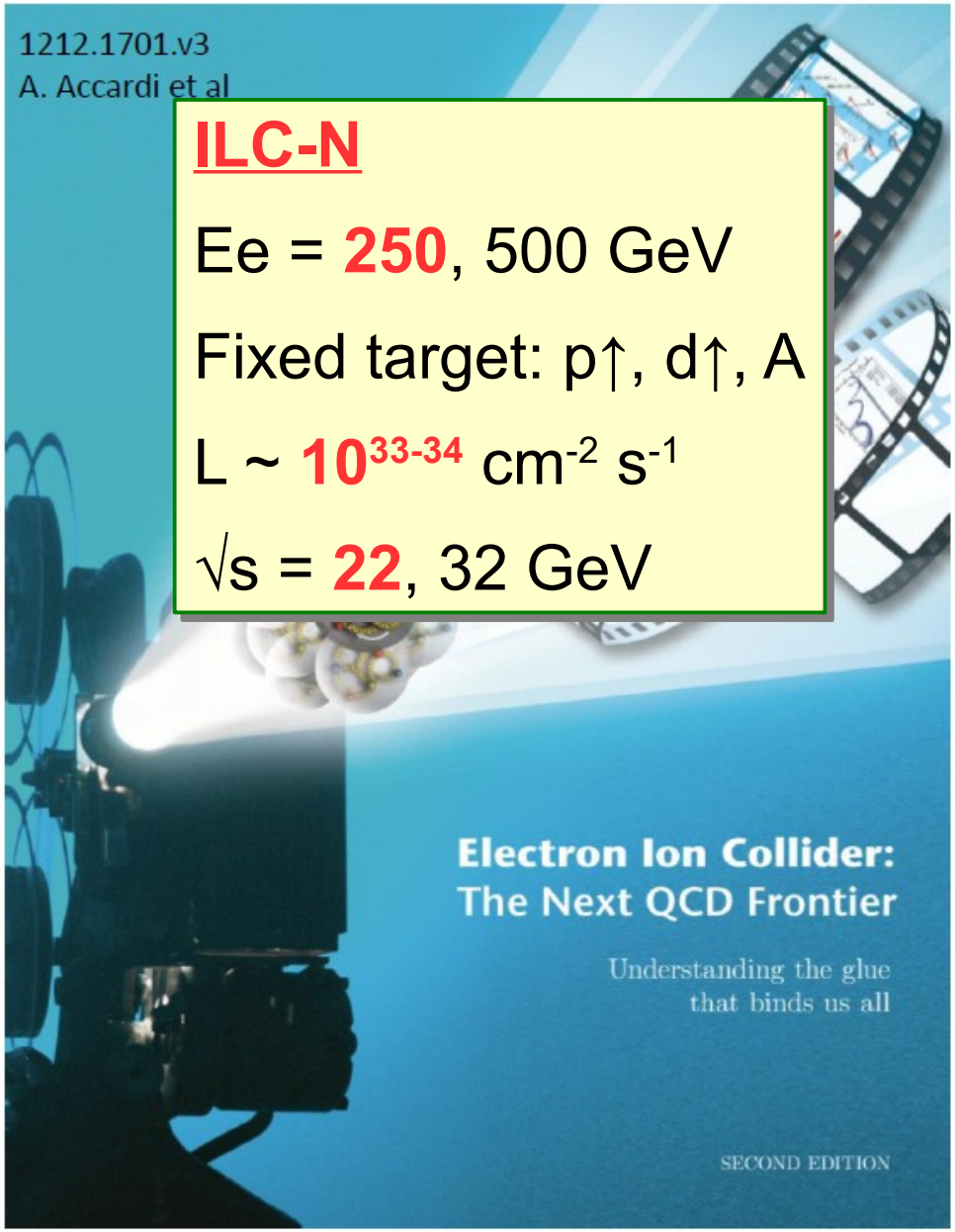
- ✓ Polarized beams: e, p, d/^{3}He
- ✓ e beam 3-10(20) GeV
- ✓ Luminosity $L_{ep} \sim 10^{33\text{-}34}$ cm^{-2}sec^{-1}
  100-1000 times HERA
- ✓ 20-~100 (140) GeV Variable CoM

For e-A collisions at the EIC:

- ✓ Wide range in nuclei
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy

World's first
Polarized electron-proton/light ion
and electron-Nucleus collider

Two proposals for realization of the science case -
both designs use DOE's significant investments in infrastructure



Electron Ion Collider

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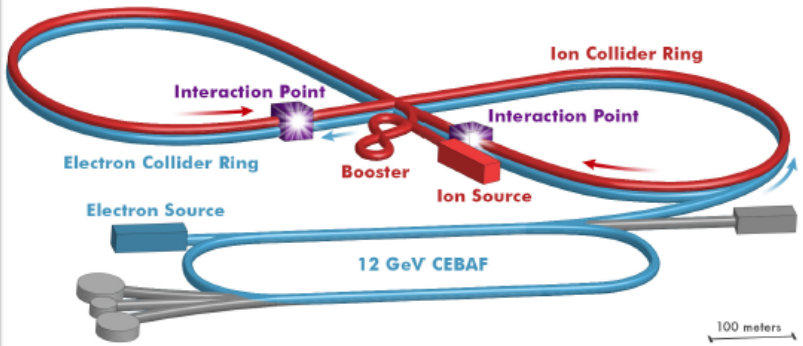
Accelerator designs….



@JLab

Ring-Ring Design

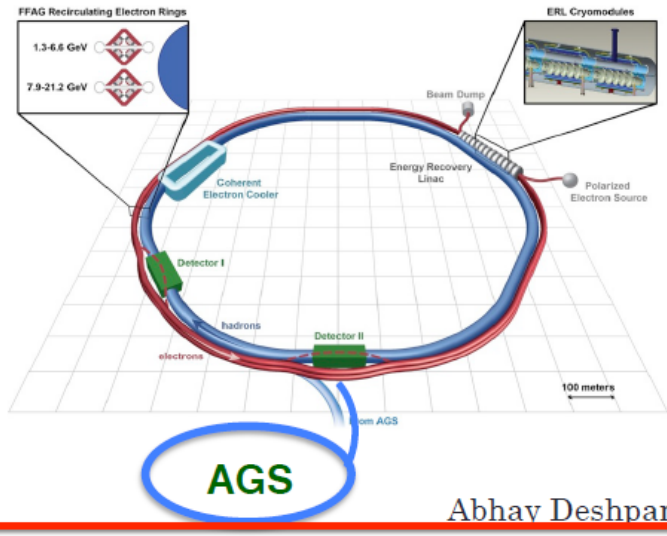
Bow-Tie shaped ring to address the polarization preservation without Siberian snakes

V. Ptitsyn, eRHIC

Linac-Ring design
(also developing a Ring-Ring design)

Uses existing Blue Ring from RHIC
And a multi-pass 1.3 GeV ERL

@BNL



Stony Brook University

Abhay Deshpande

EIC

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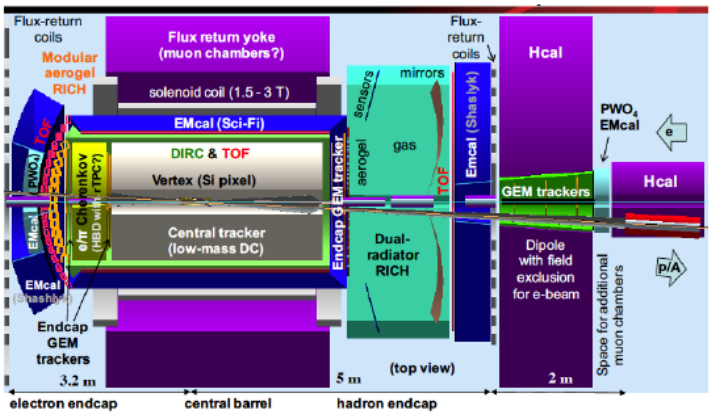
Wednesday, July 7, 16 State of EIC @ EICUG ANL 17

The Detector Ideas... (not to scale!)

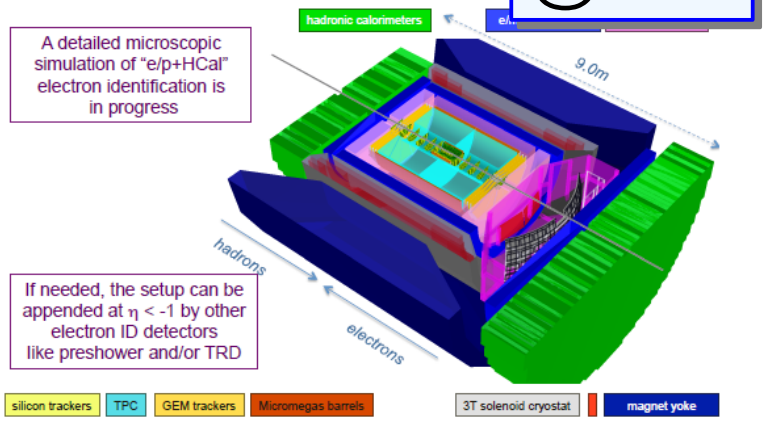
R. Yoshida, JLEIC WG



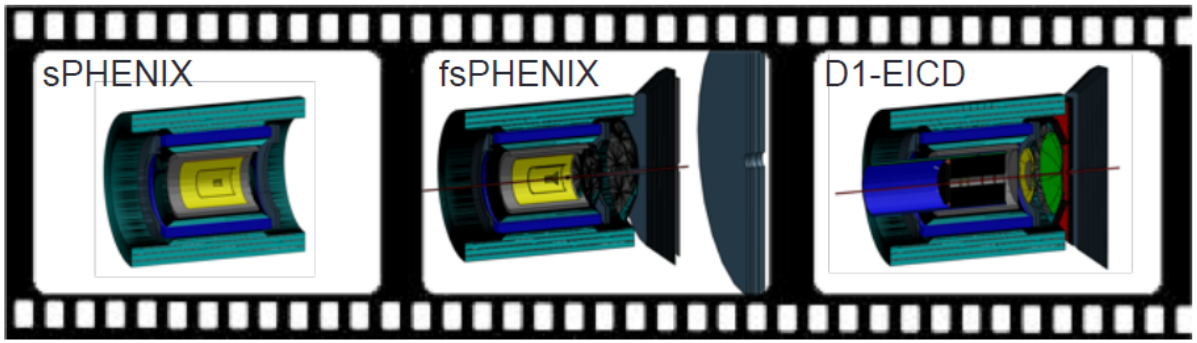
A. Kise @JLab

A detailed microscopic simulation of "e/p+HCal" electron identification is in progress

If needed, the setup can be appended at $\eta < -1$ by other electron ID detectors like preshower and/or TRD



K. Barish @BNL

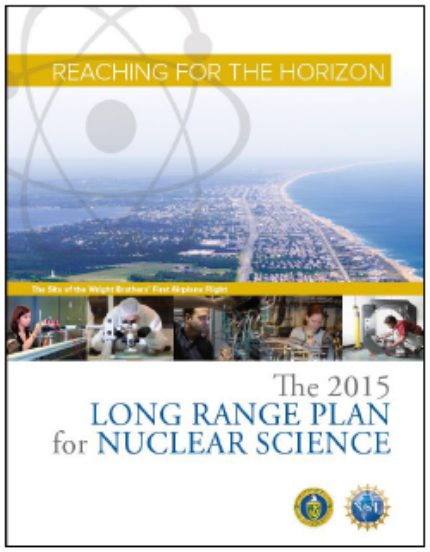


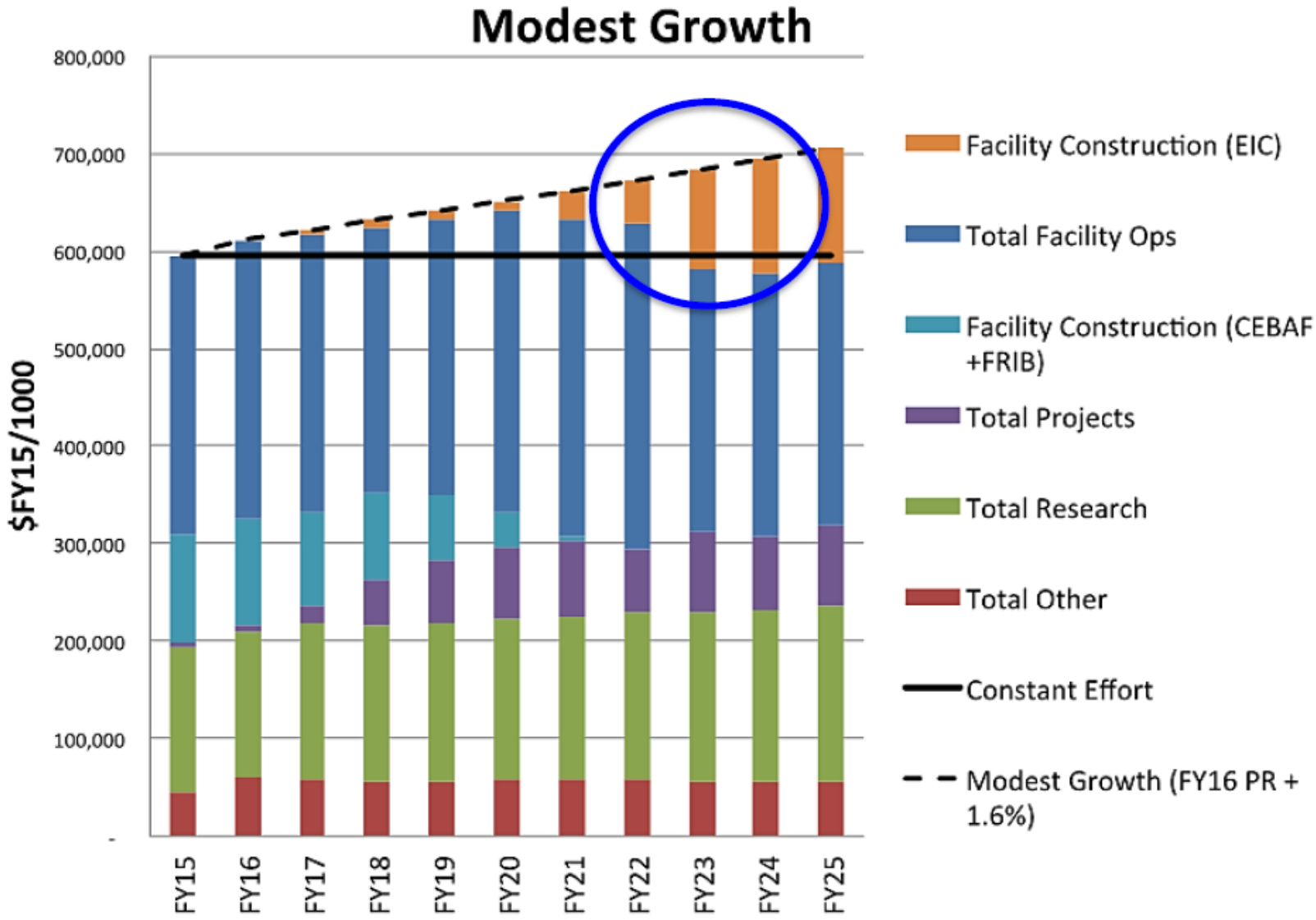
Stony Brook University

Abhay Deshpande

段階的にアップグレード

DOE budget in FY 2015 dollars for Modest Growth scenario





EIC と ILC: スケジュールの比較

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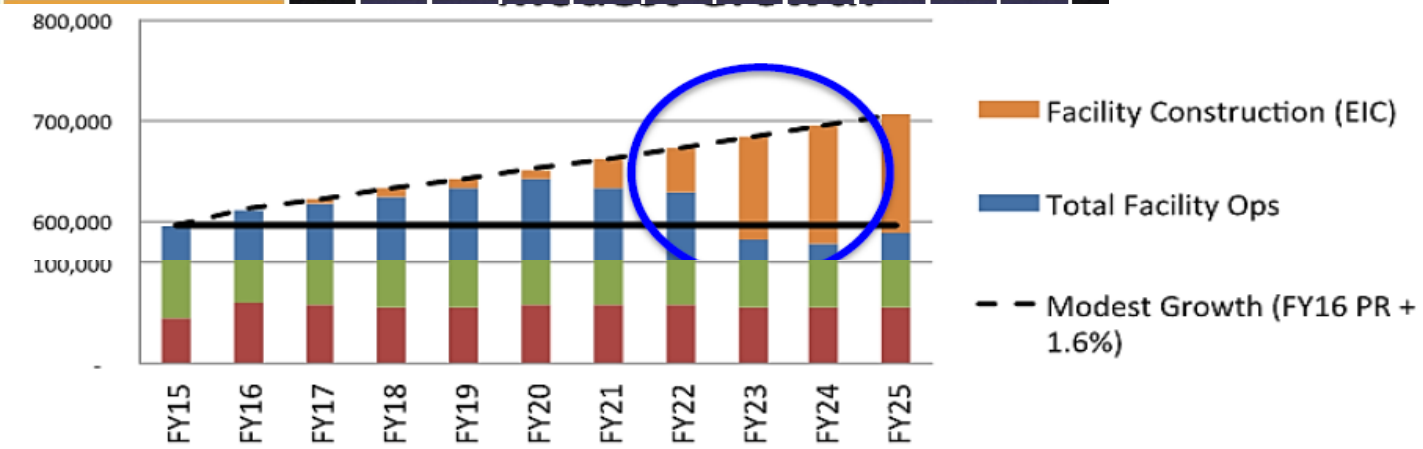
ILC の実現へ向けて

研究者が提案したスケジュール（2013）

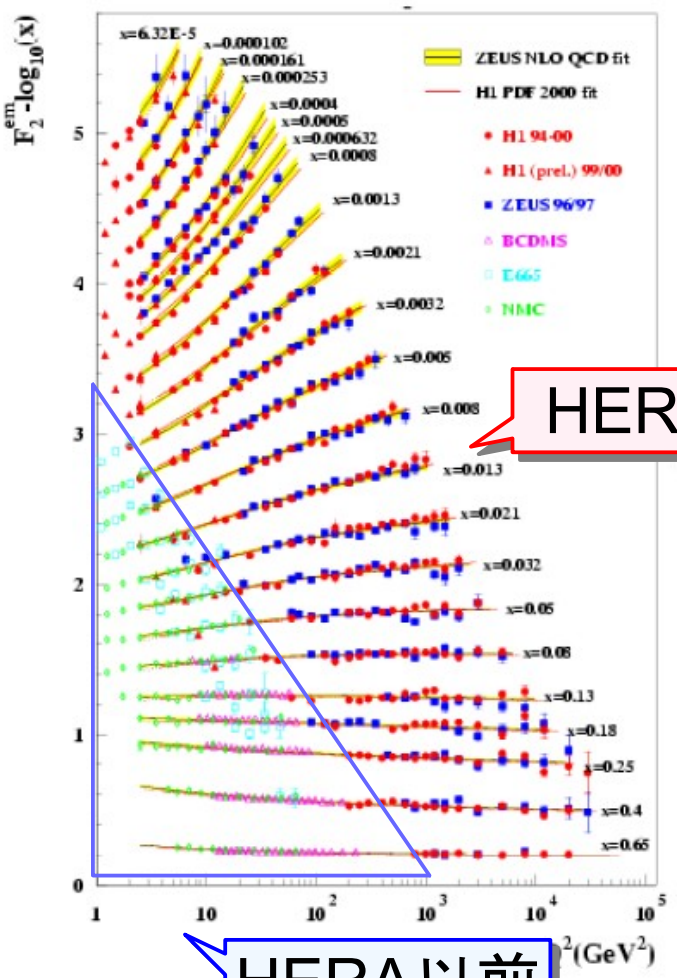
	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
政府間交渉															
機器・施設詳細設計															
国際研究所の準備															
"青信号"															
国際合意の形成															
国際研究所の設立															
調達の準備															
建設															
竣工															

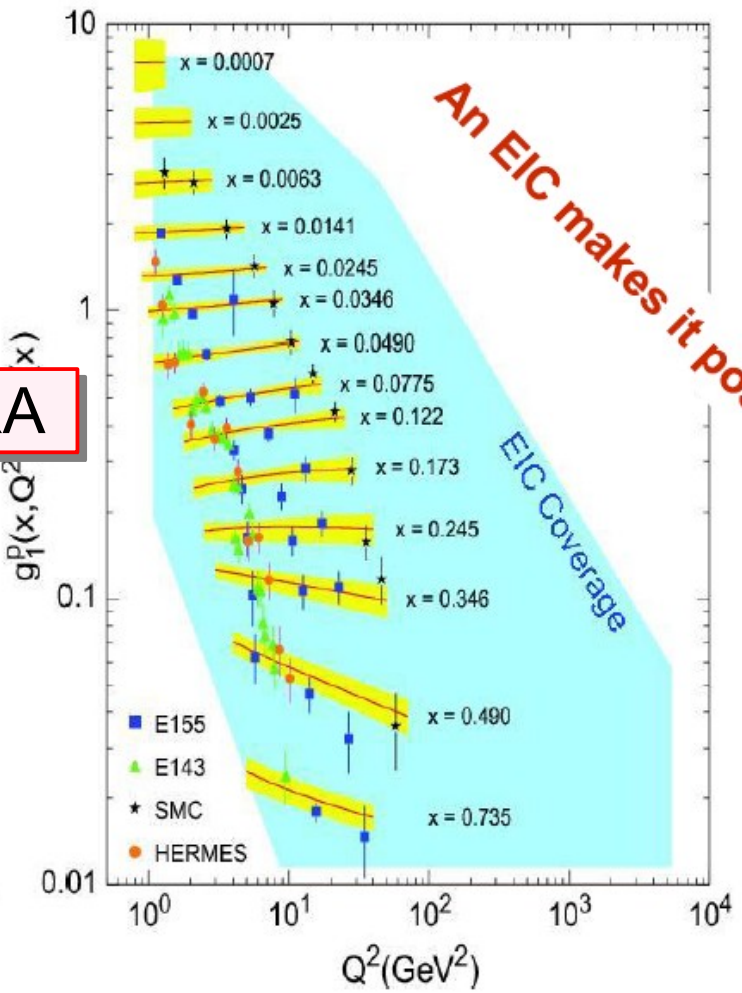


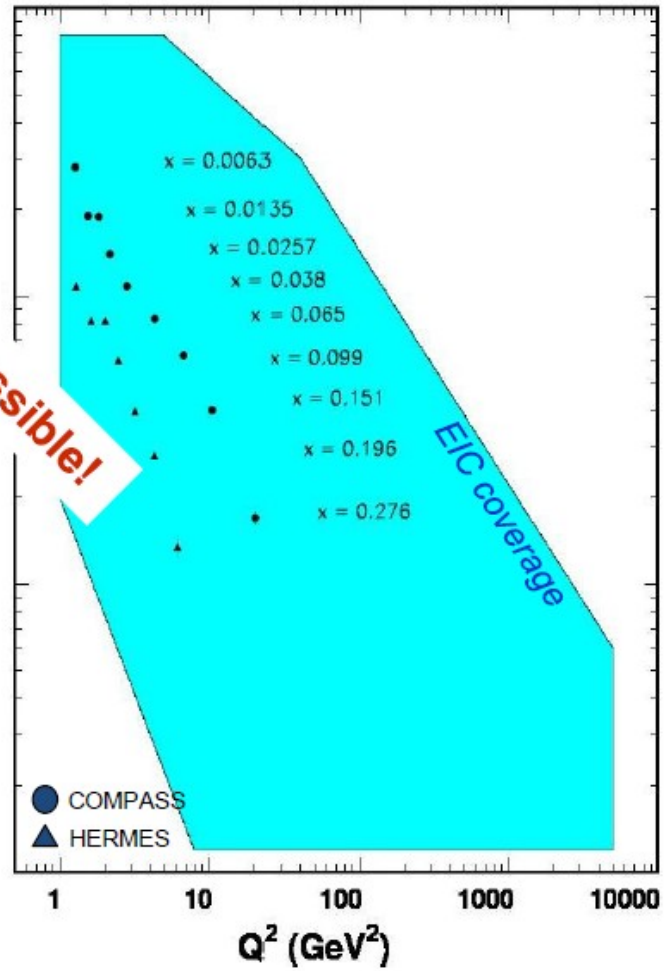
TOKYO 2020

World Data on F_2^p World Data on g_1^p World Data on h_1^p

$$F_{UT}^{\sin(\phi_h+\phi_s)}(x,Q^2) + C(x) \propto h_1$$

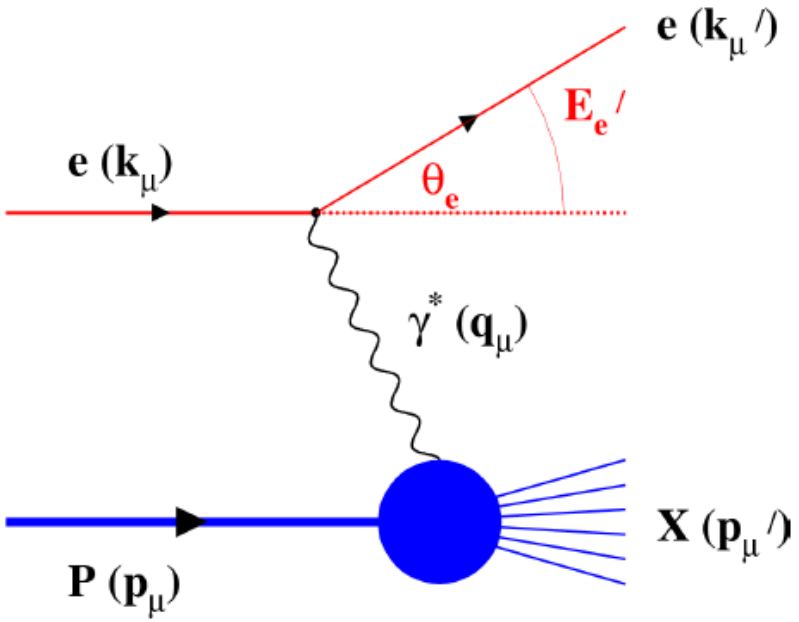






Deep Inelastic Scattering

➔ Precision microscope with superfine control



Q^2 → Measure of resolution

y → Measure of inelasticity

x → Measure of momentum fraction of the struck quark in a proton

$Q^2 = S\ x\ y$

Inclusive events: e+p/A → e'+X

Detect only the scattered lepton in the detector

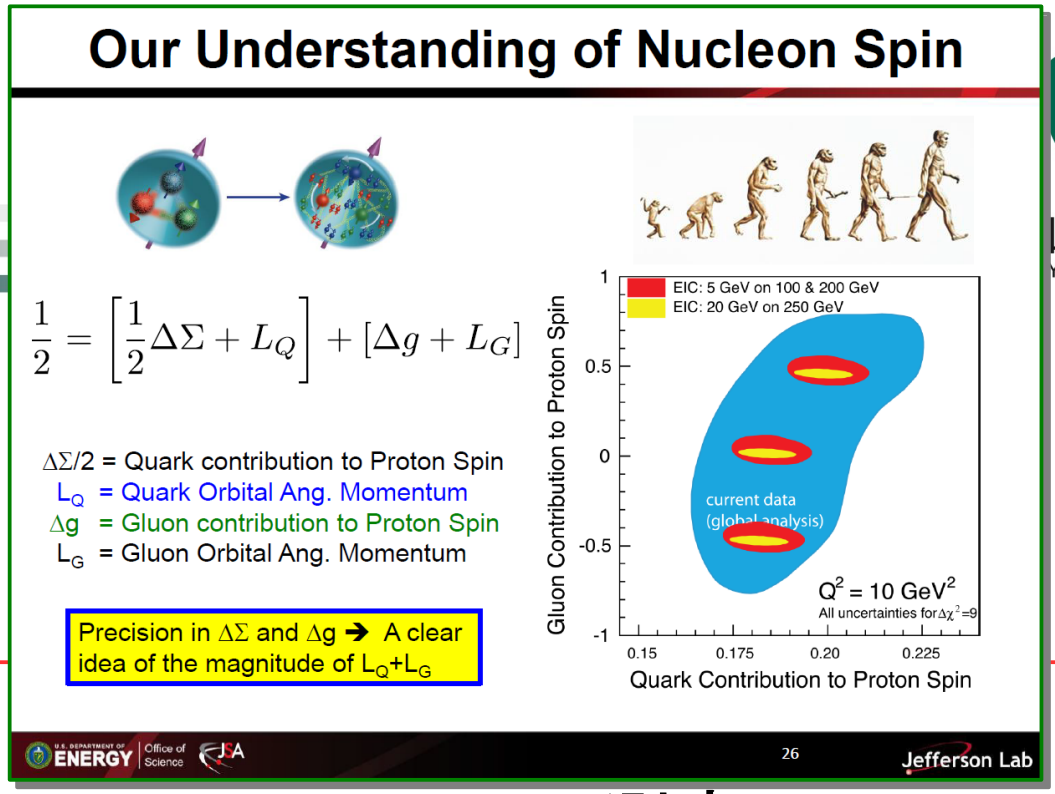
Semi-Inclusive events: e+p/A → e'+h(π,K,p,jet)+X

Detect the scattered lepton in coincidence with identified hadrons/jets in the detector

Exclusive events: e+p/A → e'+ p'/A'+ h(π,K,p,jet)

Detect every things including scattered proton/nucleus (or its fragments)

EICの物理



- **グルーオンの物理**
  - 『核子』
  - 『原子核』
- **核子『スピン』構造**
  - 『縦』偏極　(Semi-) Inclusive DIS 測定
  - 『横』偏極　Semi-Inclusive DIS 測定
  - 三次元構造　**Hard Exclusive** Production

Inclusive-DIS 測定

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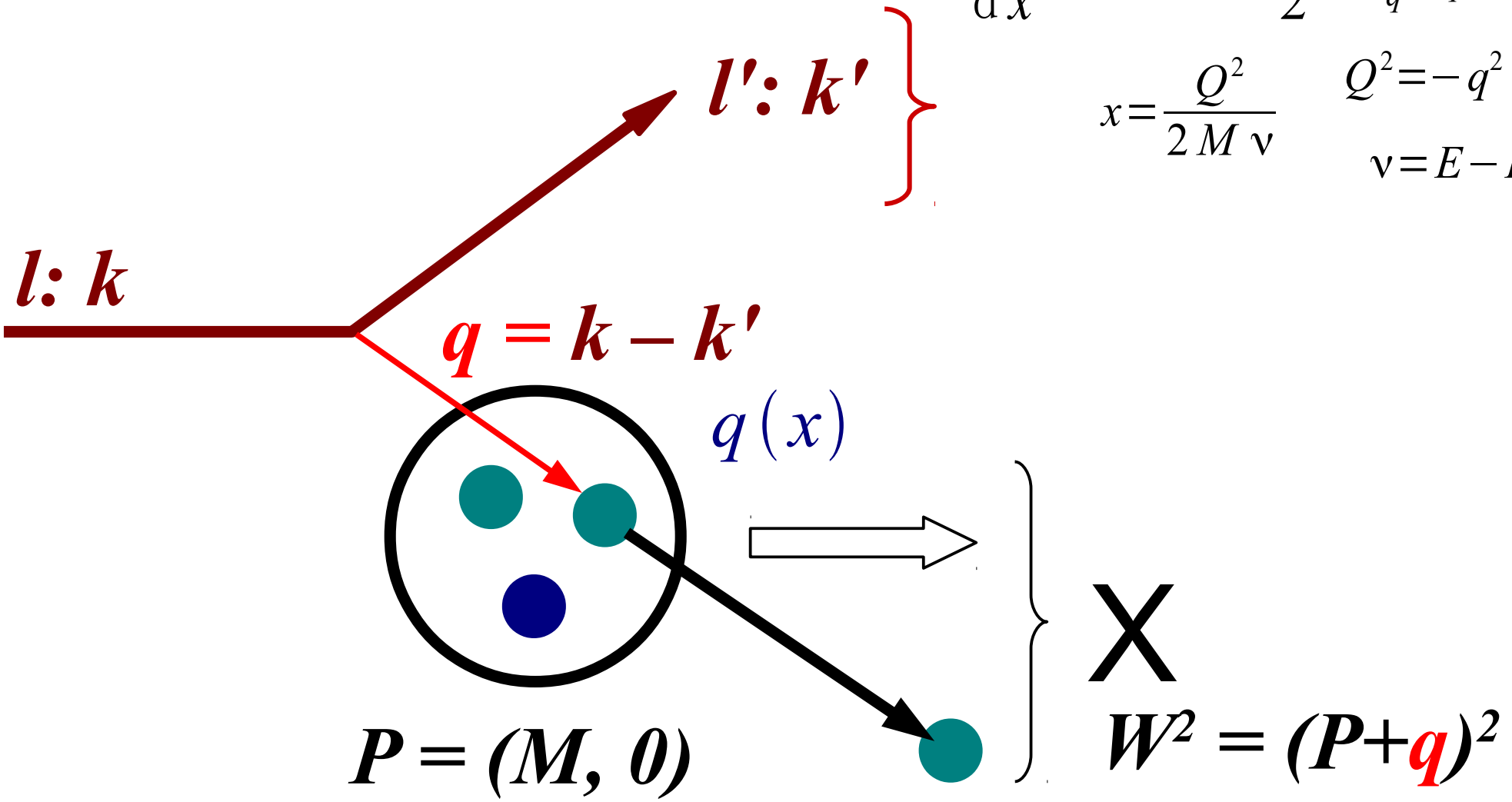
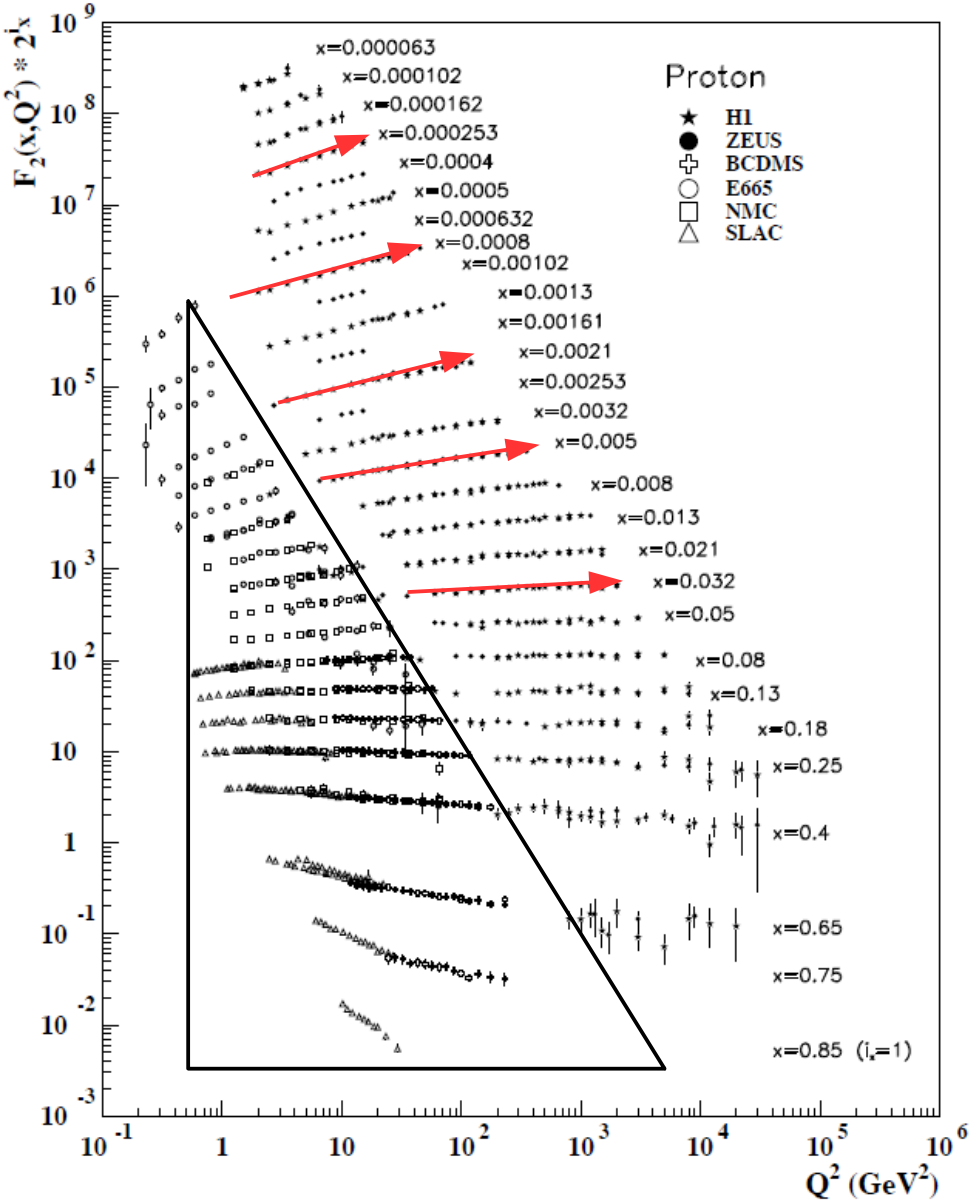
$$l + N \rightarrow l' + X$$

$$\frac{d\sigma}{dx} \propto F_1(x) = \frac{1}{2}\sum_q e_q^2 q(x)$$

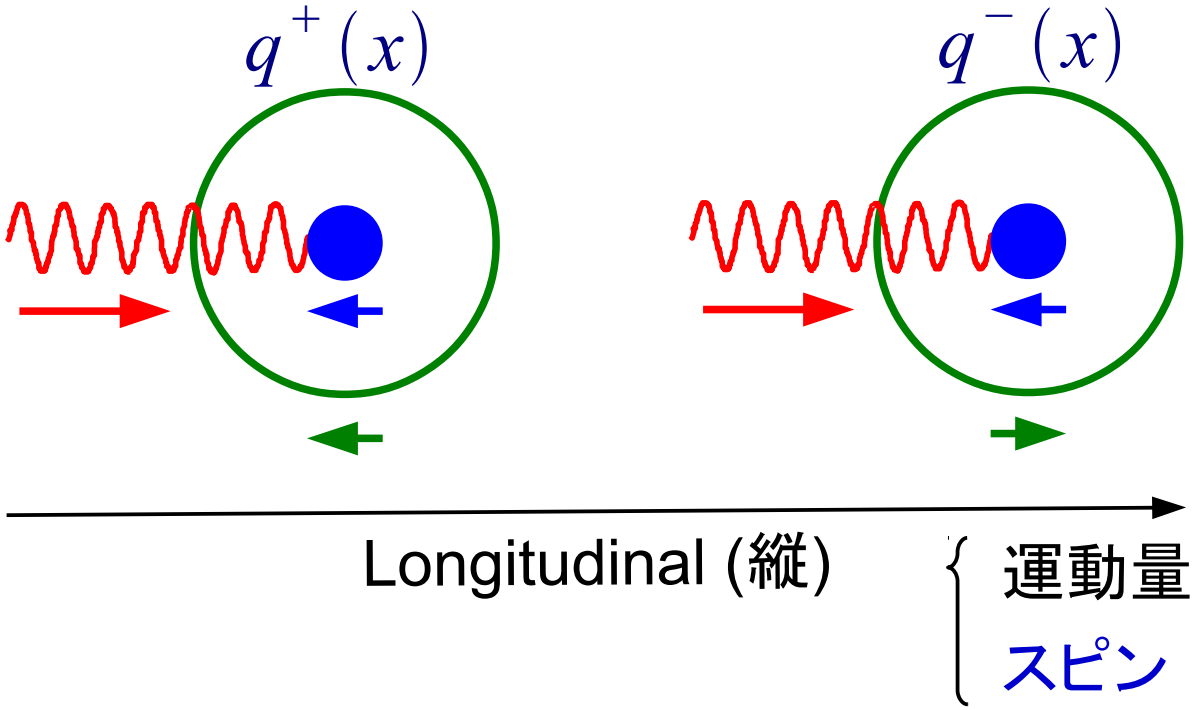
$$x = \frac{Q^2}{2M\nu} \qquad Q^2 = -q^2 \qquad \nu = E - E'$$



Glue in DIS


$F_2(x,Q^2) * 2^{i_x}$
Q^2 (GeV^2)
Proton
H1
ZEUS
BCDMS
E665
NMC
SLAC
x=0.000063
x=0.000102
x=0.000162
x=0.000253
x=0.0004
x=0.0005
x=0.000632
x=0.0008
x=0.00102
x=0.0013
x=0.00161
x=0.0021
x=0.00253
x=0.0032
x=0.005
x=0.008
x=0.013
x=0.021
x=0.032
x=0.05
x=0.08
x=0.13
x=0.18
x=0.25
x=0.4
x=0.65
x=0.75
x=0.85 (i_x=1)

Spin dependent PDF



	Structure function	PDF
Unpol.	$F_1(x)=\frac{1}{2}\sum_q e_q^2 q(x)$	$q(x)=q^+(x)+q^-(x)$
Pol.	$g_1(x)=\frac{1}{2}\sum_q e_q^2 \Delta q(x)$	$\Delta q(x)=q^+(x)-q^-(x)$

CERN-COMPASS

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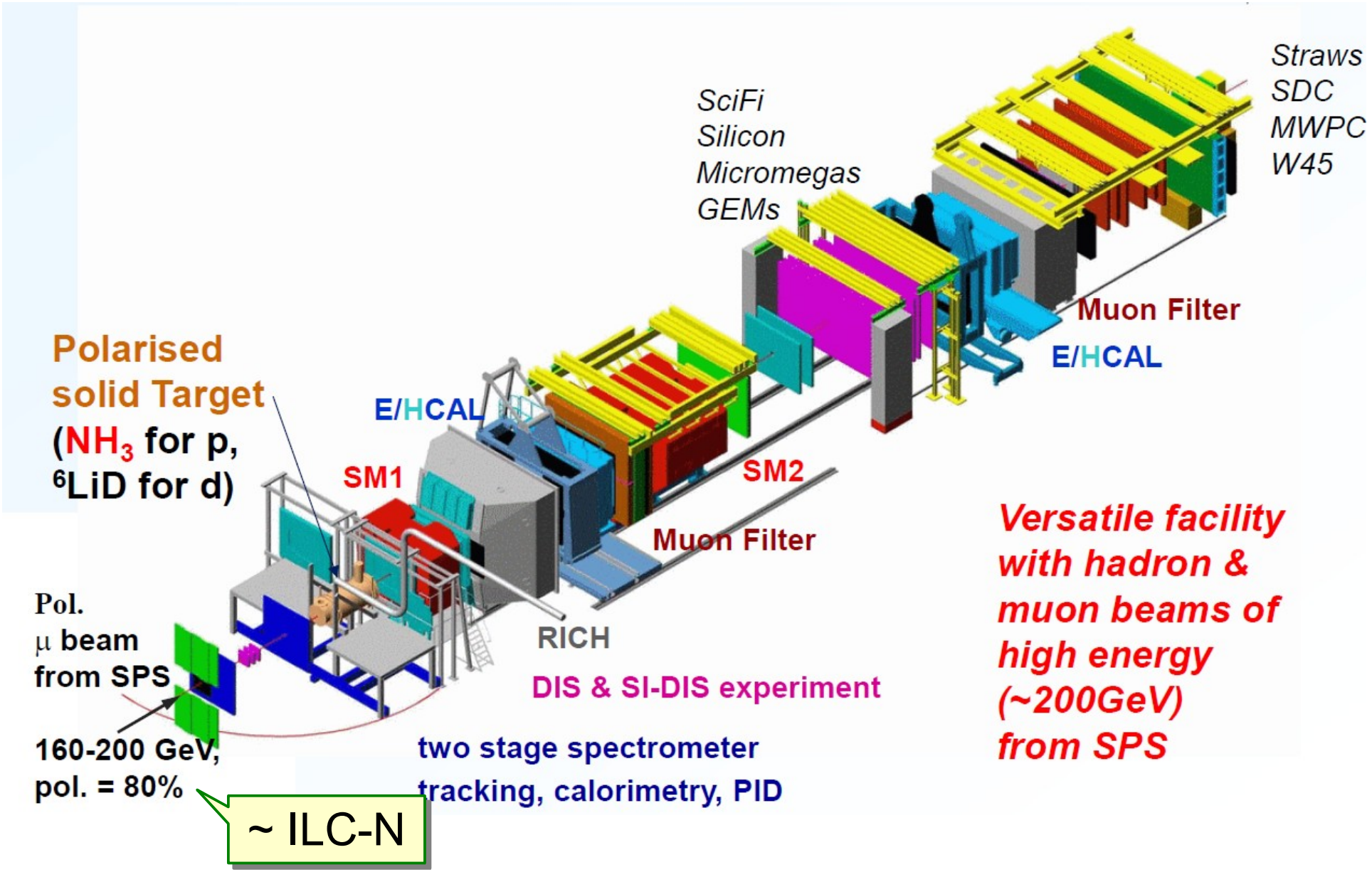
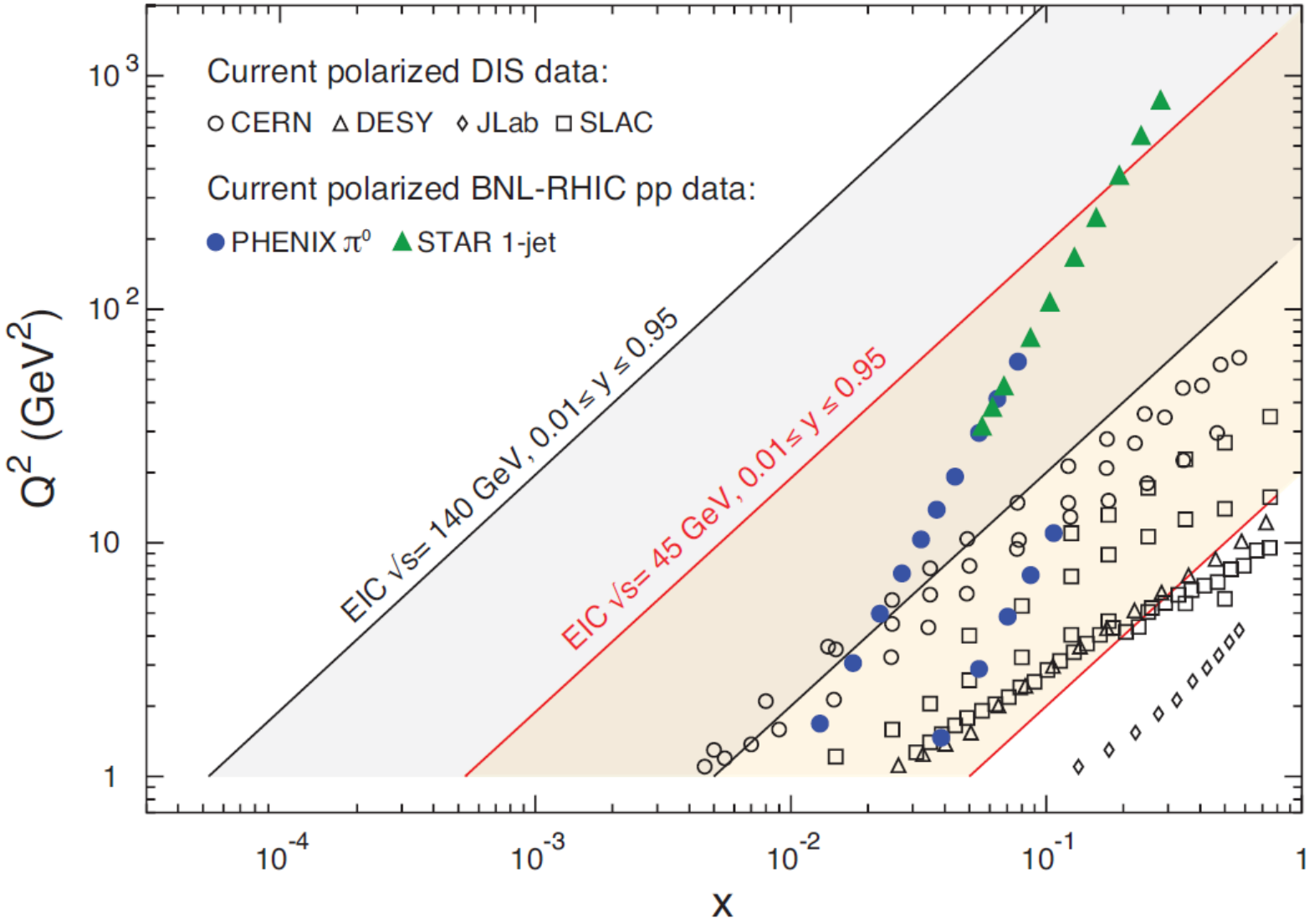
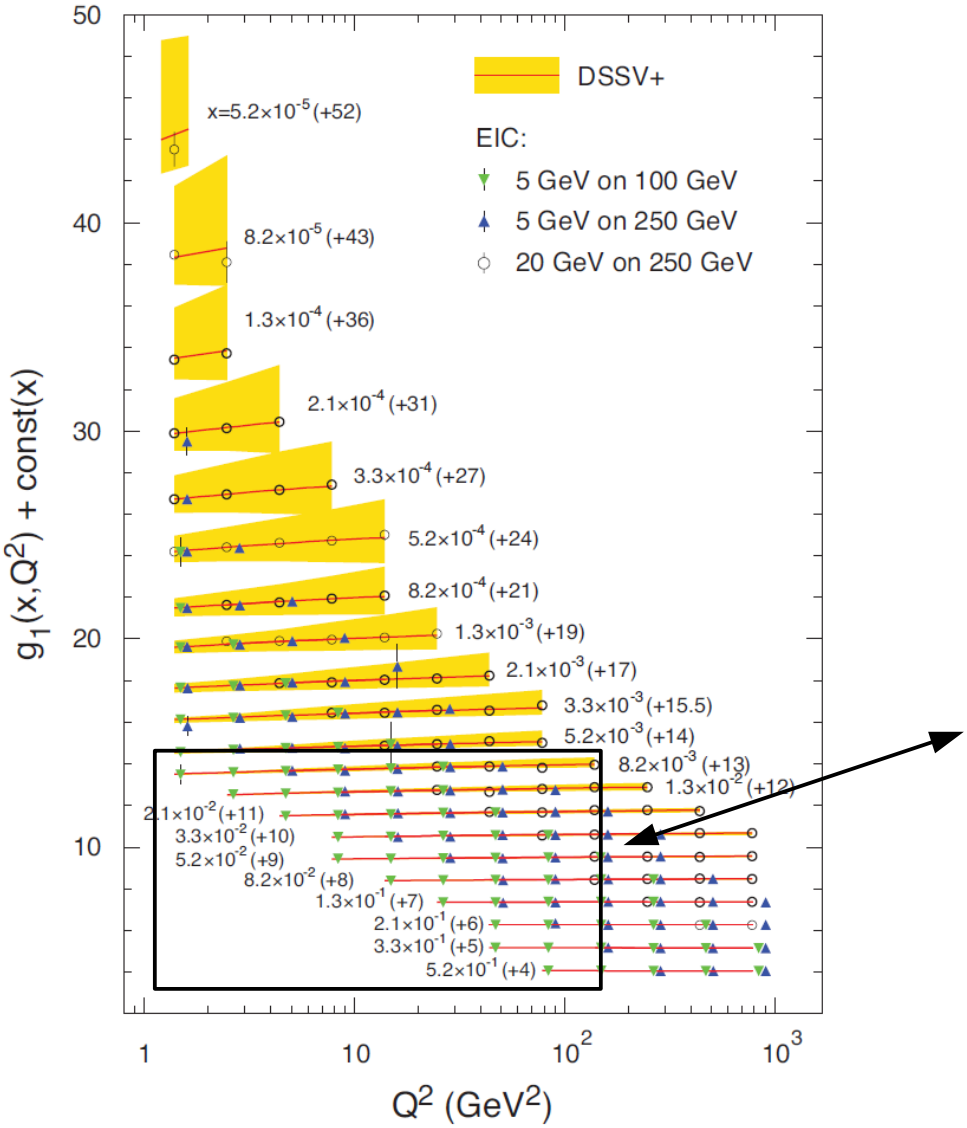
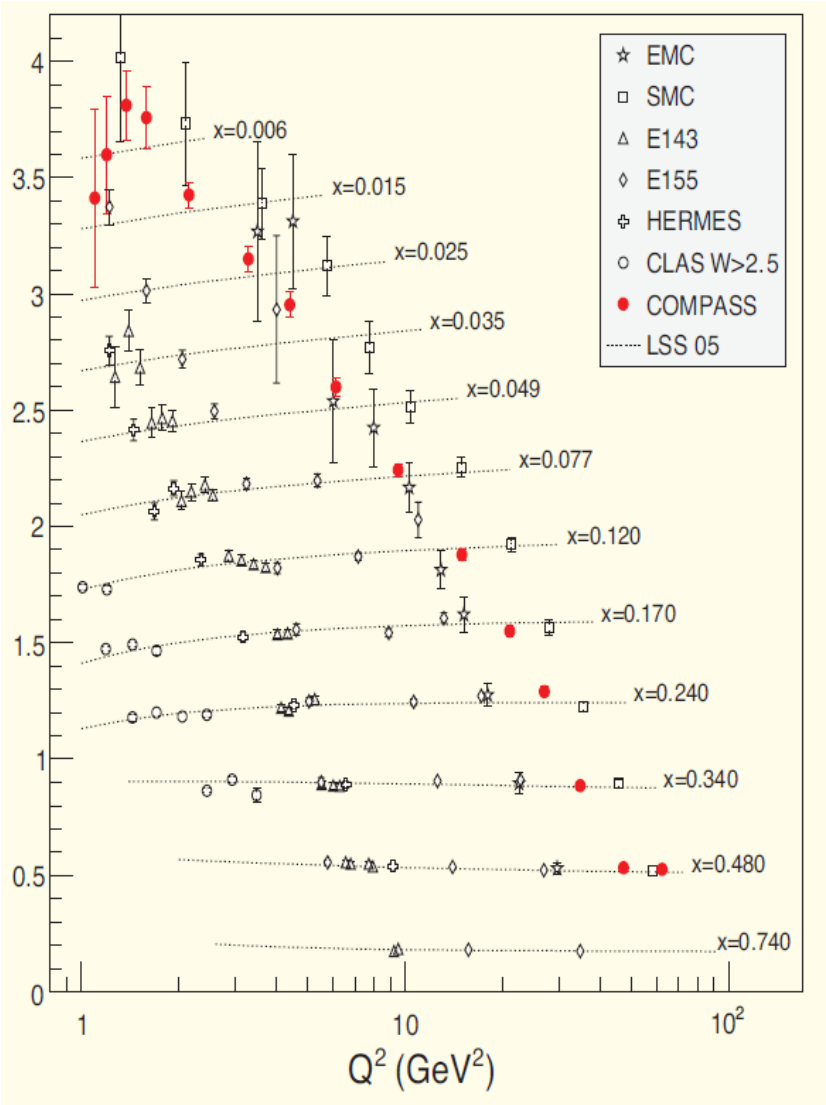


EIC kinematics: Inclusive

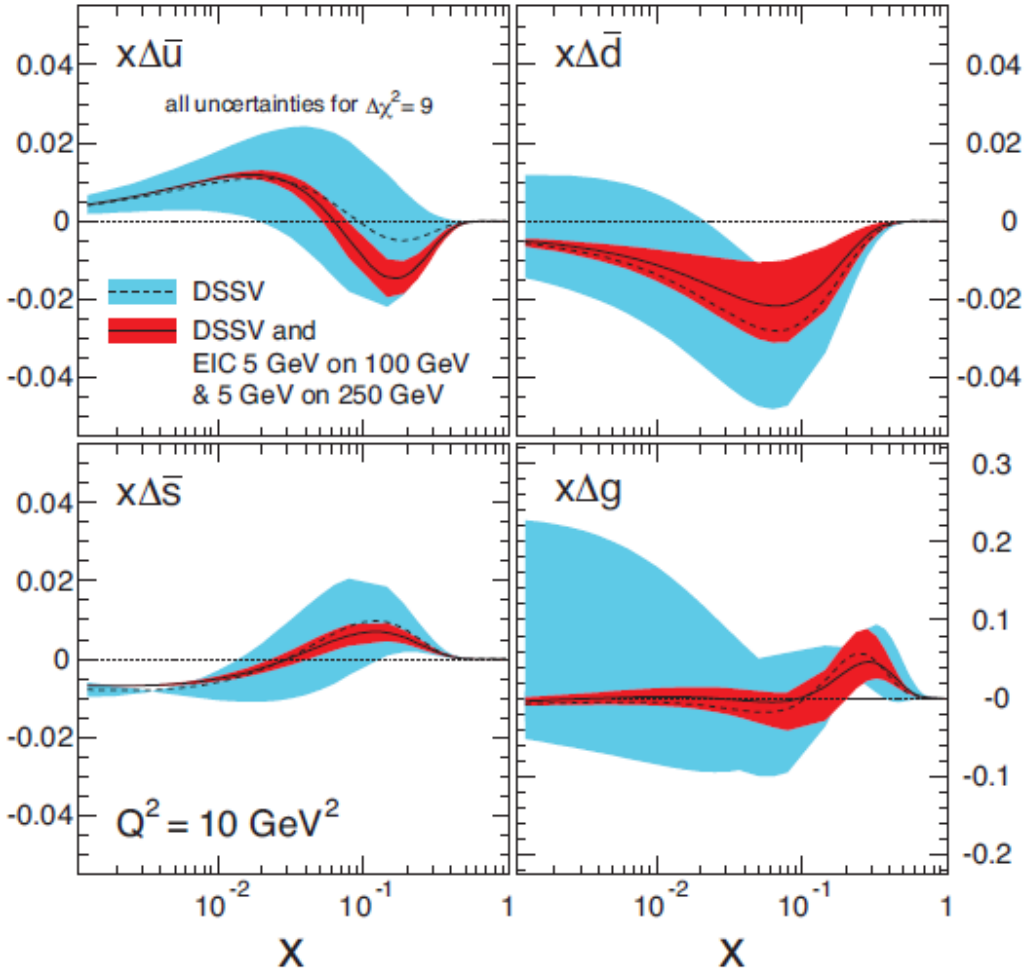


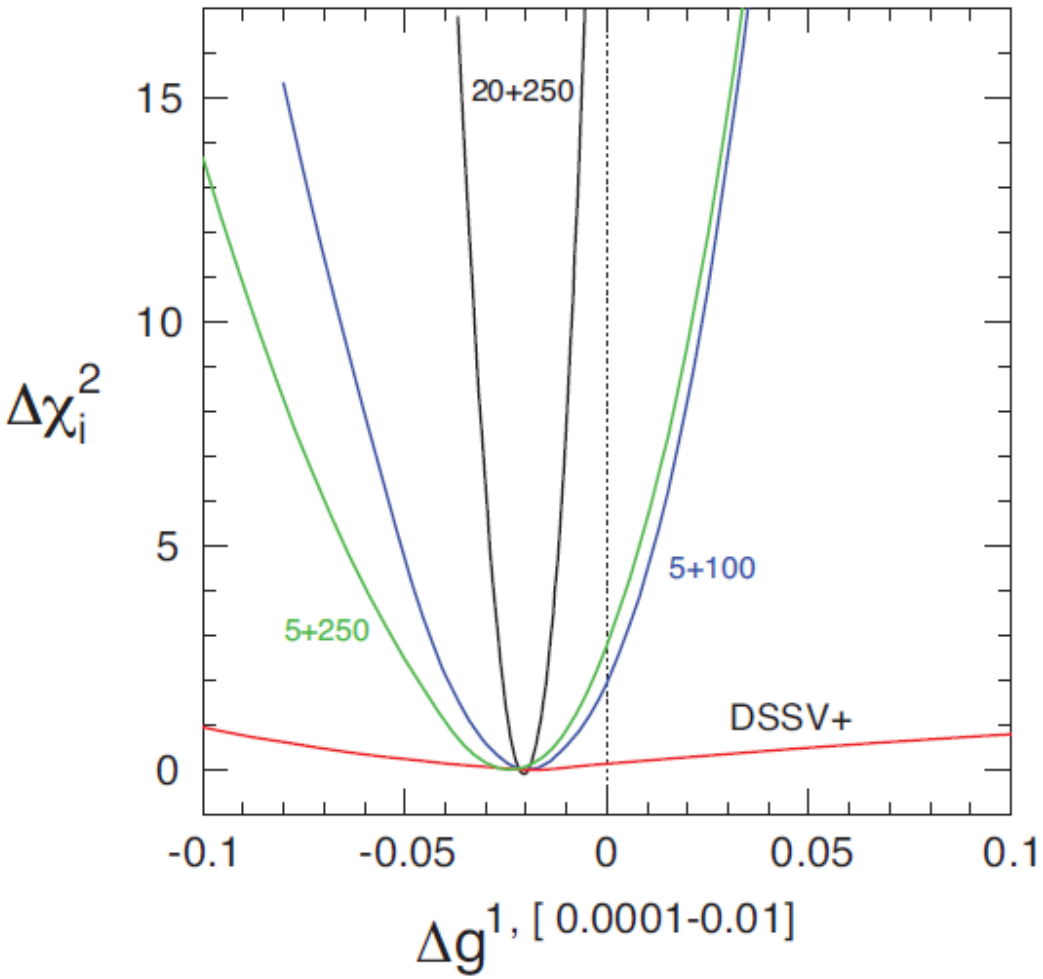
EIC expectation: g_1^p





Gluon polarization





Semi-inclusive DIS測定

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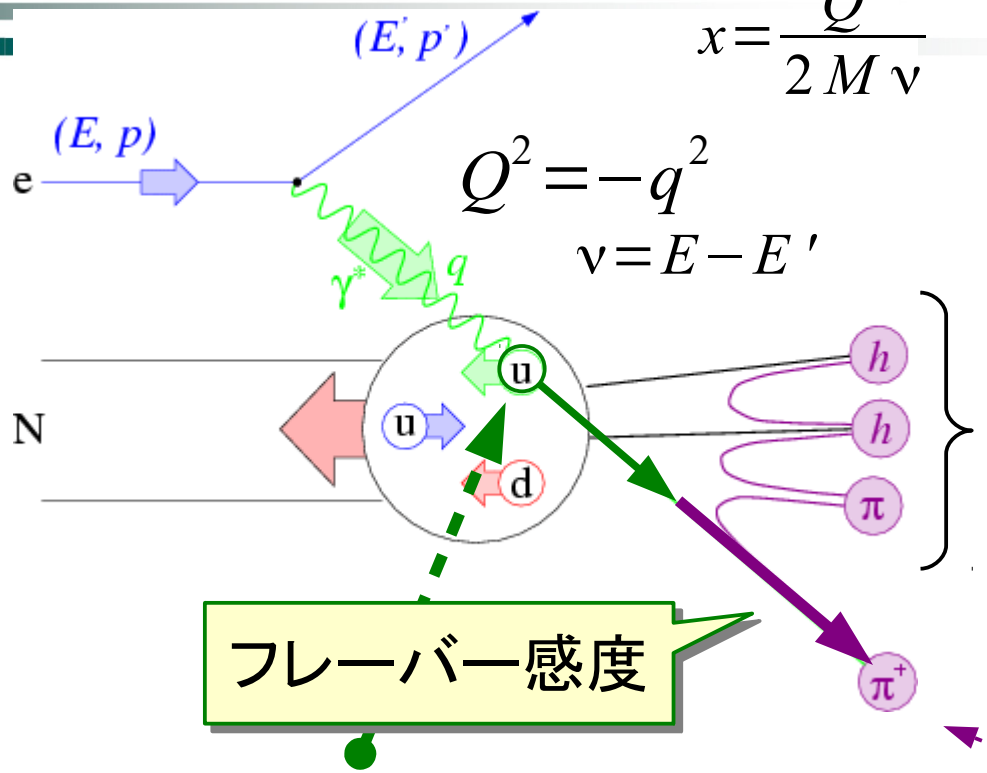
$$e\,N \rightarrow e'\,h\,X$$



$$x = \frac{Q^2}{2\,M\,\nu}$$

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

$$\nu = E - E'$$

$$z = \frac{E_h}{\nu}$$

$$\sigma^{eN \rightarrow e'hX} = \sum_q f^{N \rightarrow q} \otimes \hat{\sigma}^{eq \rightarrow e'q} \otimes D^{q \rightarrow h}$$

Parton **D**istribution **F**unction

$$f\left(x, Q^2\right)$$

Fragmentation **F**unction

$$D\left(z, Q^2\right)$$

Transverse structure of the nucleon

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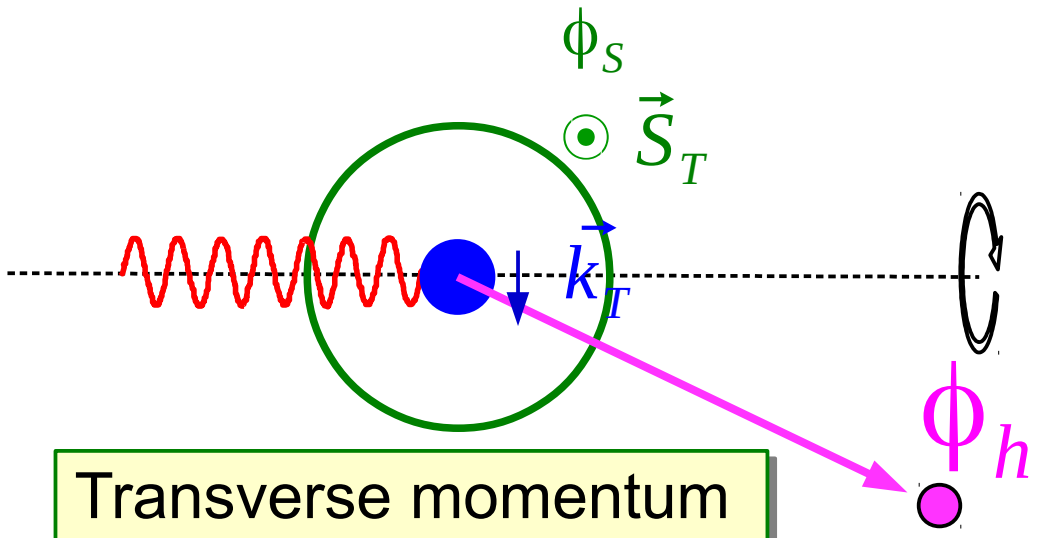
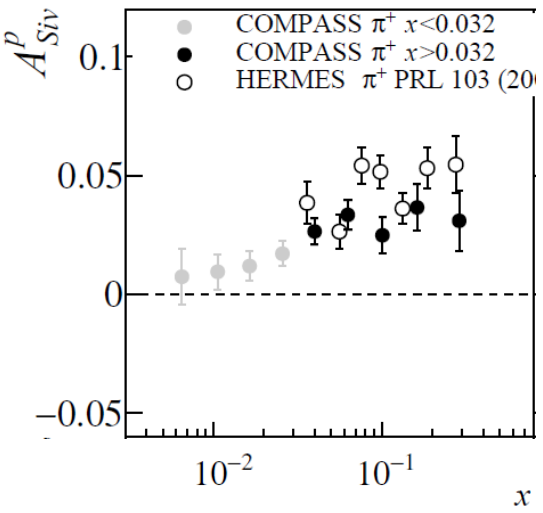
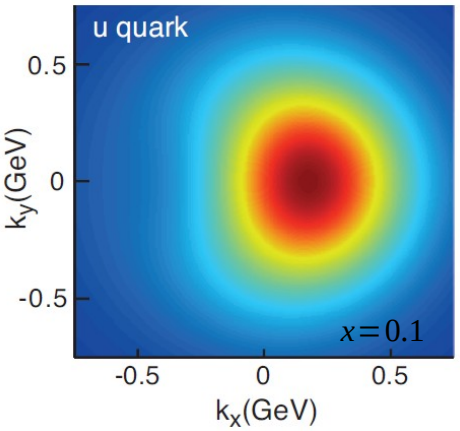


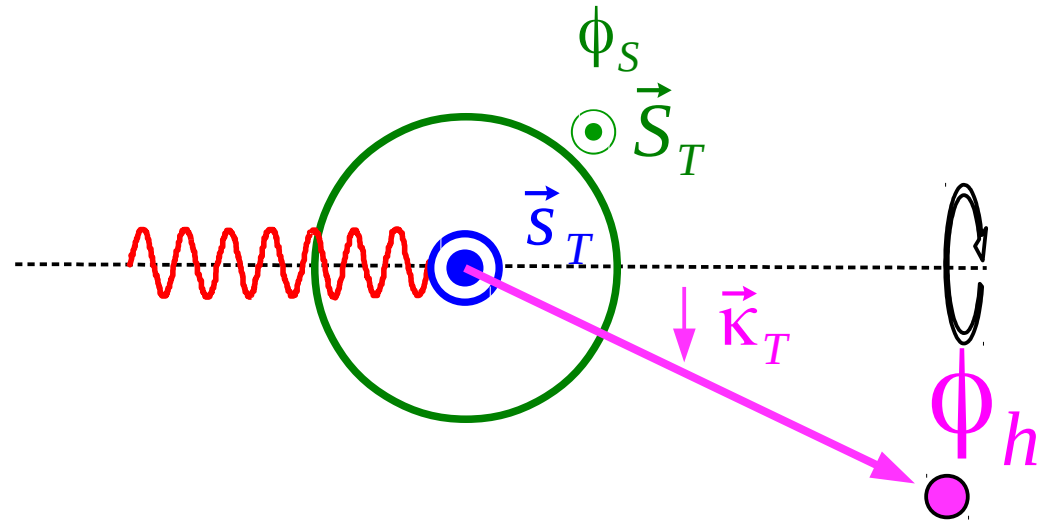
Transverse momentum dependent, **TMD**, PDF

$A^{\sin(\phi_h - \phi_S)}$

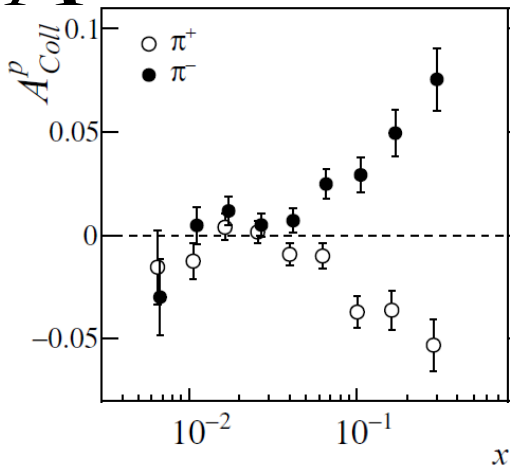


『横』運動量





$A^{\sin(\phi_h + \phi_S)}$



『横』スピン

Transverse Observables in SIDIS

1.) Sivers asymmetry:

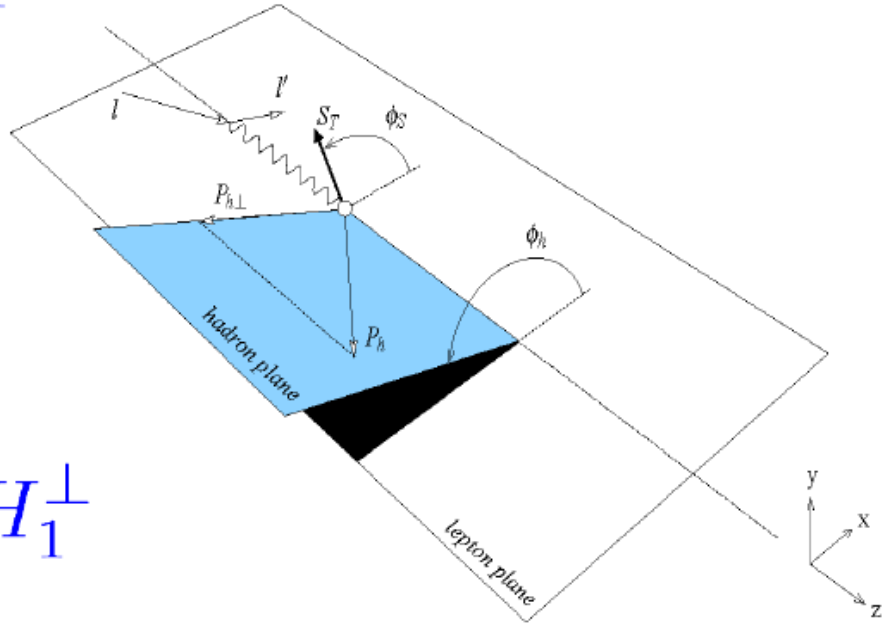
$$\sigma_{UT}^{\text{SIDIS}} \propto \sin(\phi_h - \phi_S) f_{1T}^{\perp} \otimes D_1$$

2.) Collins asymmetry:

$$\sigma_{UT}^{\text{SIDIS}} \propto \sin(\phi_h + \phi_S) h_1 \otimes H_1^{\perp}$$

3.) "pretzelosity":

$$\sigma_{UT}^{\text{SIDIS}} \propto \sin(3\phi_h - \phi_S) h_{1T}^{\perp} \otimes H_1^{\perp}$$



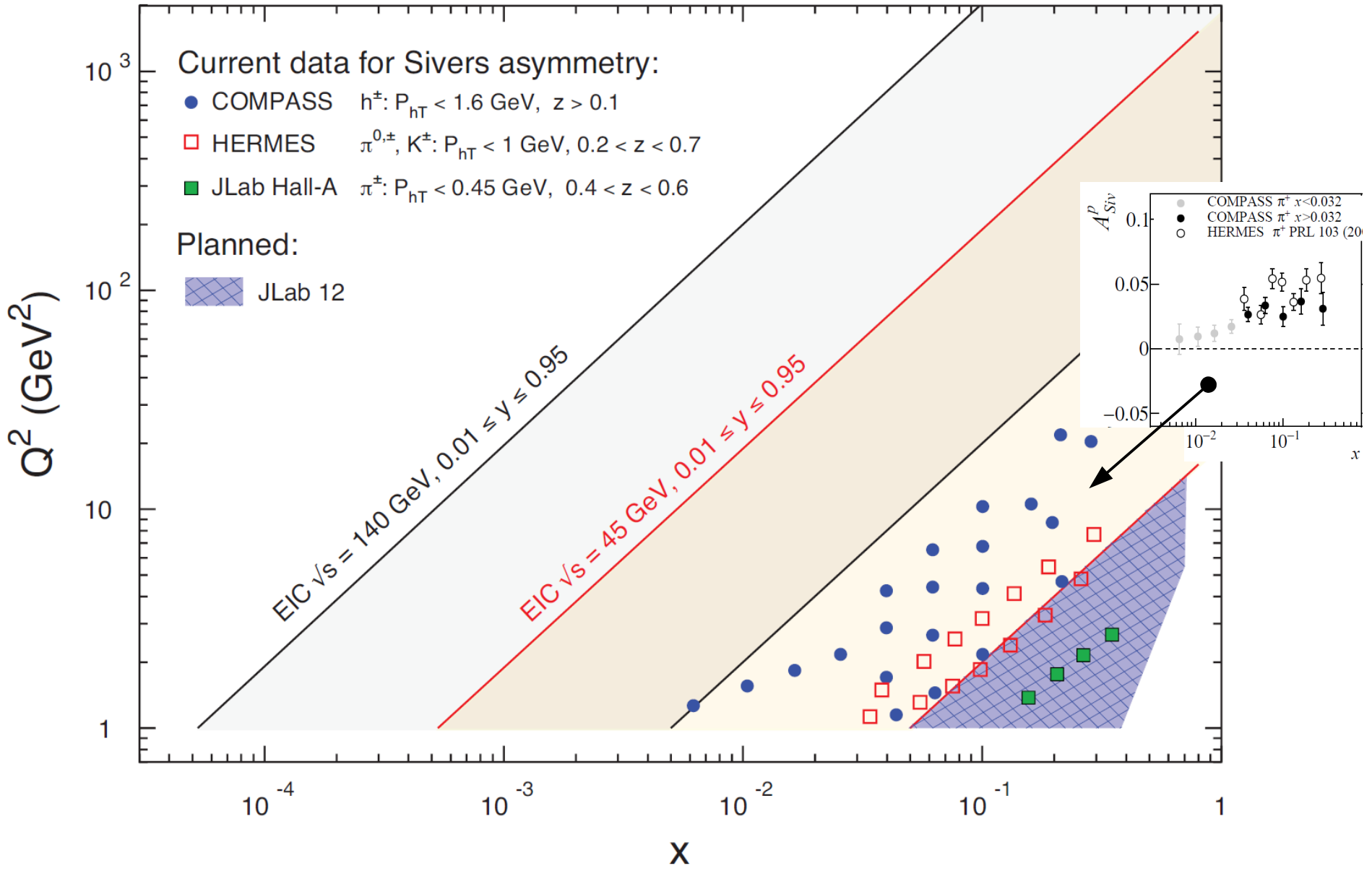
4.) double spin asymmetry:

$$\sigma_{LT}^{\text{SIDIS}} \propto \sin(\phi_h - \phi_S) g_{1T} \otimes D_1$$

also: $\cos(2\phi) \propto h_1^{\perp} \otimes H_1^{\perp}$, beam-SSA $\sin(2\phi_h)\, h_{1L}^{\perp} \otimes H_1^{\perp}$

double spin (LL): $\cos(\phi_h)\, g_{1L} \otimes D_1$

EIC kinematics: Semi-inclusive



Transverse structure of the nucleon

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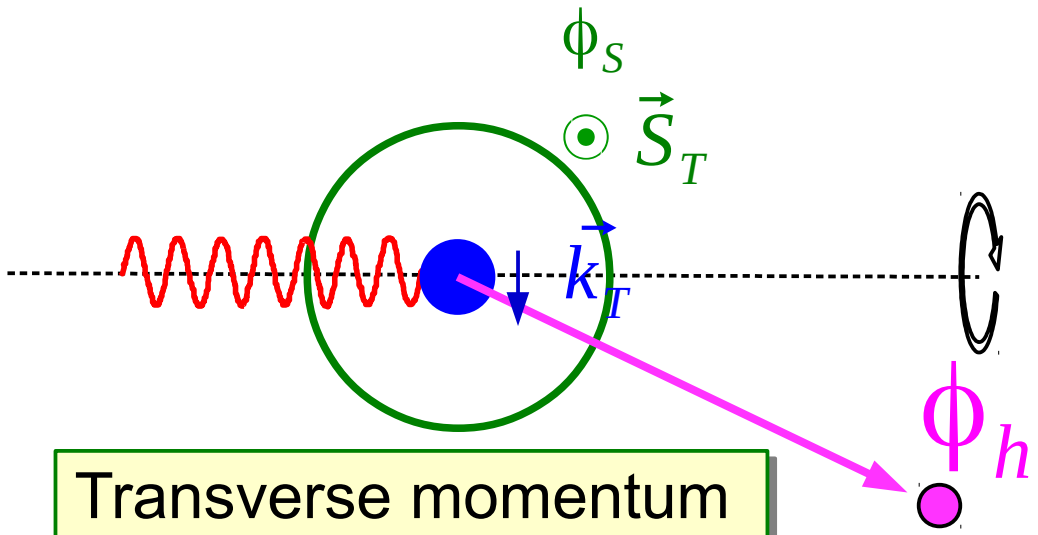
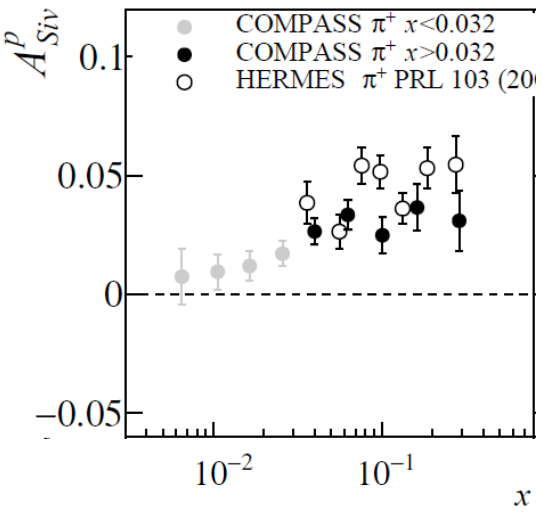
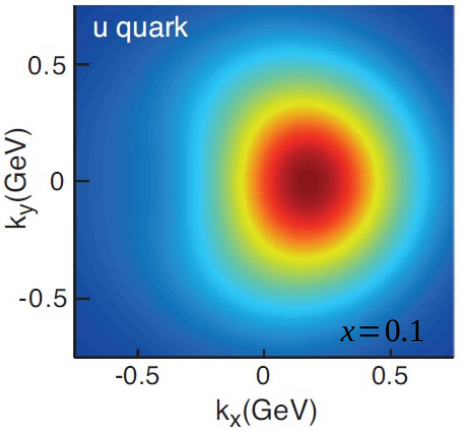


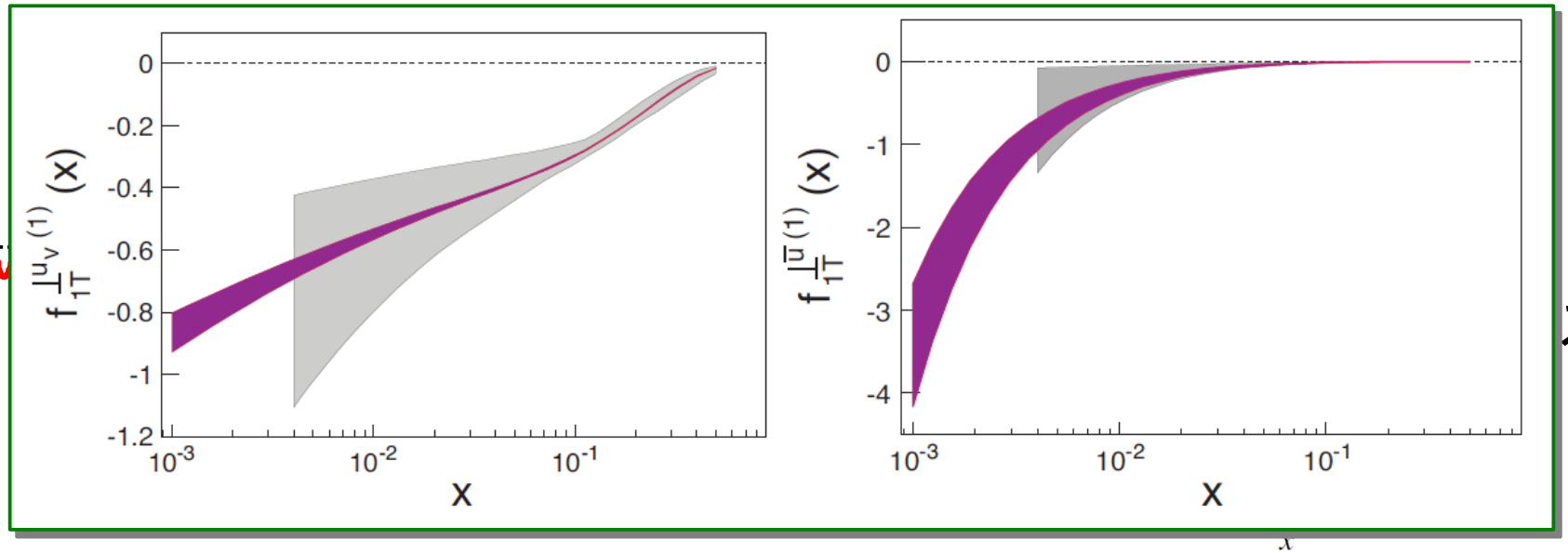
Transverse momentum dependent, **TMD**, PDF

$A^{\sin(\phi_h - \phi_S)}$



『横』運動量





スピン

Hard exclusive production

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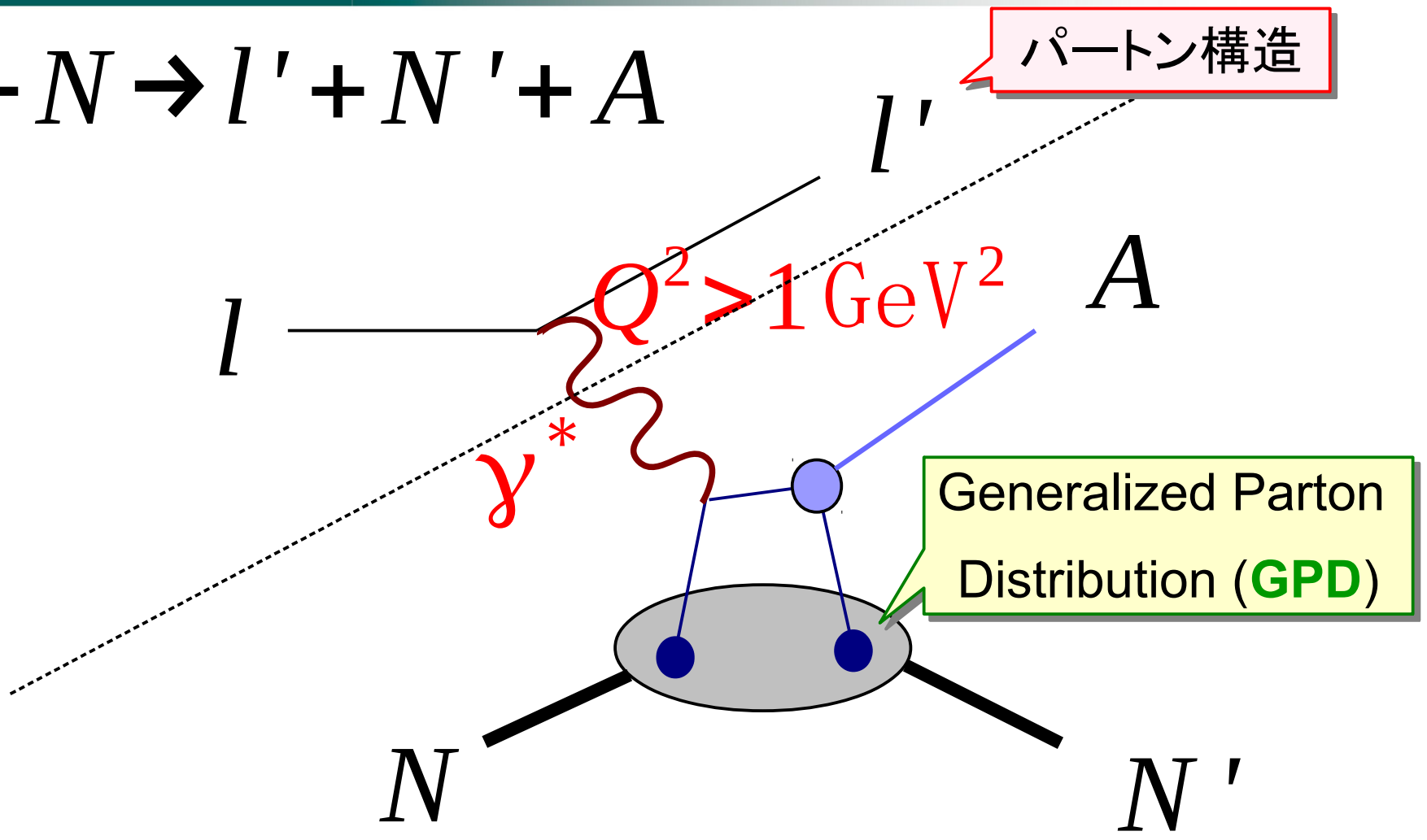
$$l + N \rightarrow l' + N' + A$$



運動量比 x 毎に形状因子を測る

弾性散乱 ⇒ 形状因子

Hard Exclusive Production

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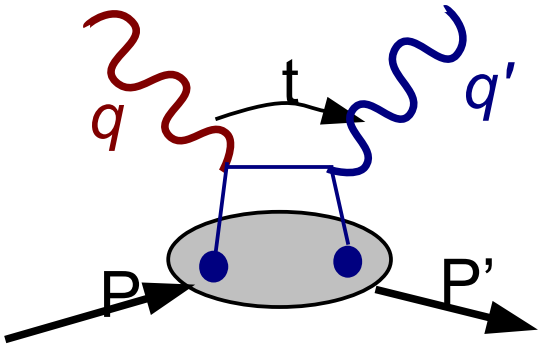
Deeply Virtual Compton Scattering (DVCS):

$e + N \rightarrow e' + N' + \gamma$

Involved GPDs: $H,\ E,\ \tilde{H},\ \tilde{E}$

clean reaction



vs Bethe-Heitler process

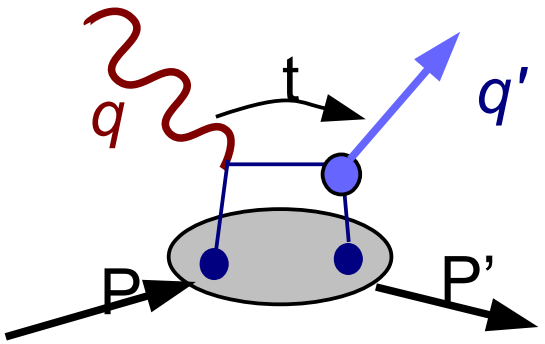
Deeply Virtual Meson Production (DVMP):

$e + N \rightarrow e' + N' + \{\rho,\ \pi, ...\}$

vector meson: $H,\ E$

pseudo-scalar meson: $\tilde{H},\ \tilde{E}$

Meson amplitude involved



DVCS@HERMES, with pol. target

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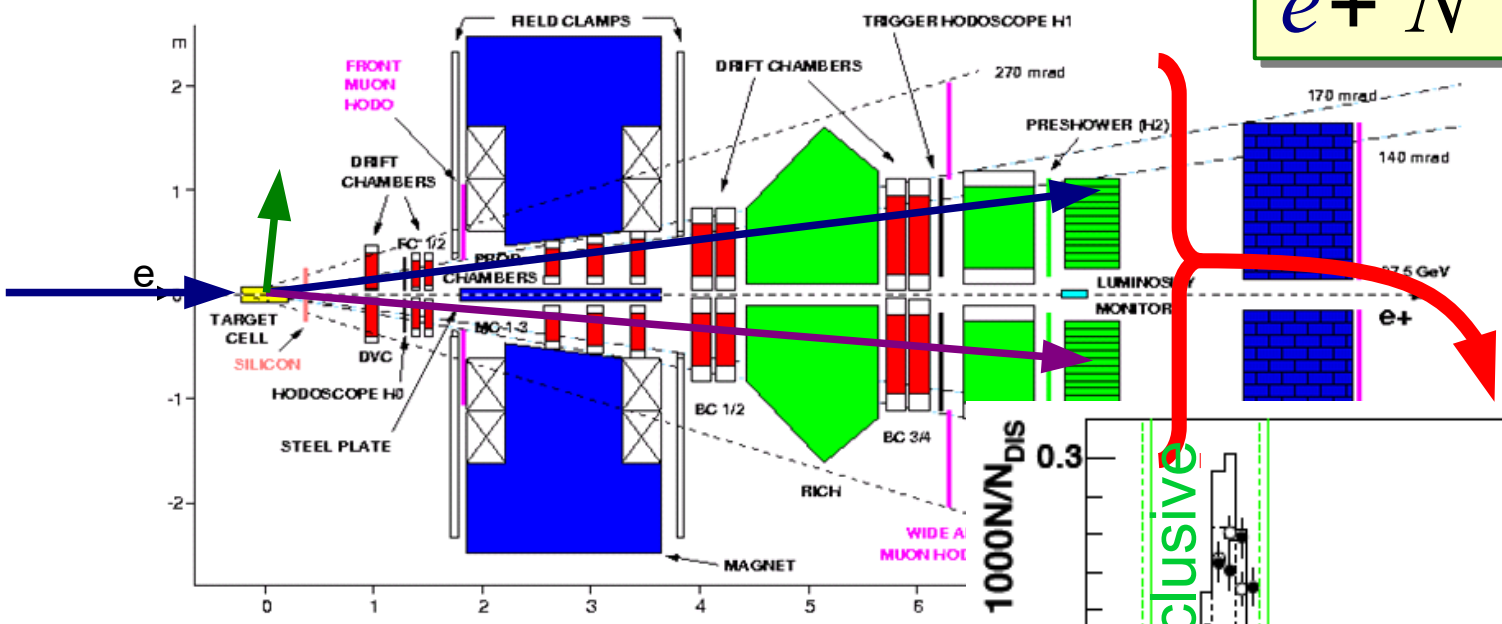
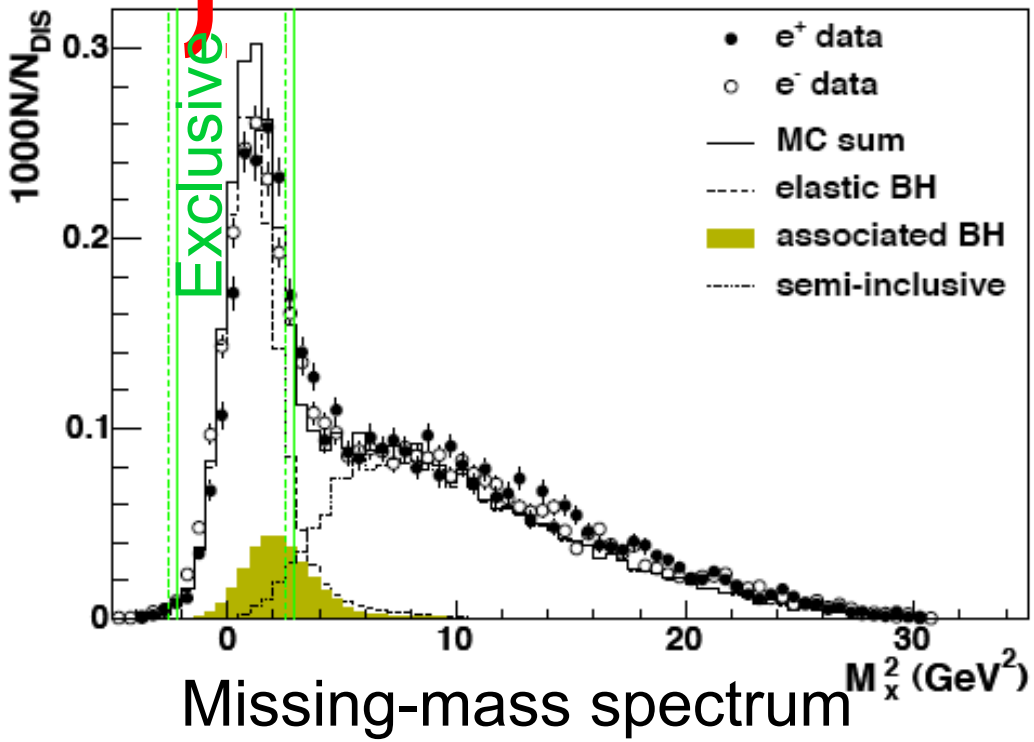
$$e + N \rightarrow e' + N + \gamma$$





1996 ~ 2005:

w/ Polarized H/D target

No detector for the recoil proton

Cut on missing-mass spectrum

Missing-mass spectrum

DVCS @ HERMES: unpol. Target + recoil

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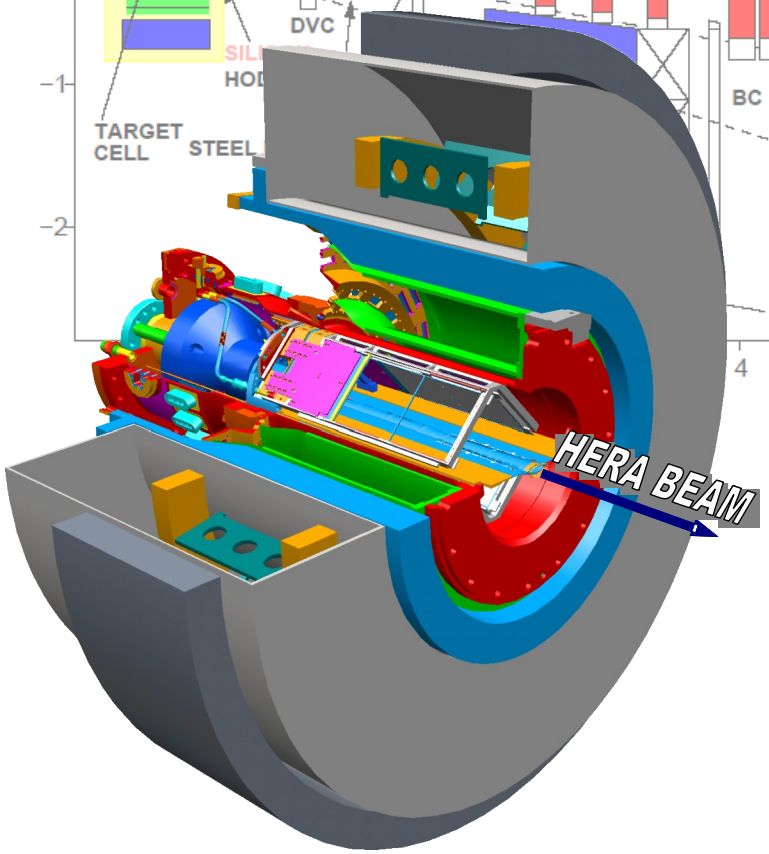

- **Sub-detectors in 1 T Solenoid**
  - Photon Detector (**PD**)
    - 3 Tungsten/Scintillator layers, π^0, π/p
  - Scintillation Fiber Tracker (**SFT**)
    - 2 x (2 Parallel and 2 Stereo layers), momentum reconstruction and π/p
  - Silicon Strip Detector (**SSD**)
    - 2 layers of 16 double sided sensor, momentum reconstruction and π/p
- **Unpol. H&D targets: (2006, 2007)**

DVCS @ COMPASS

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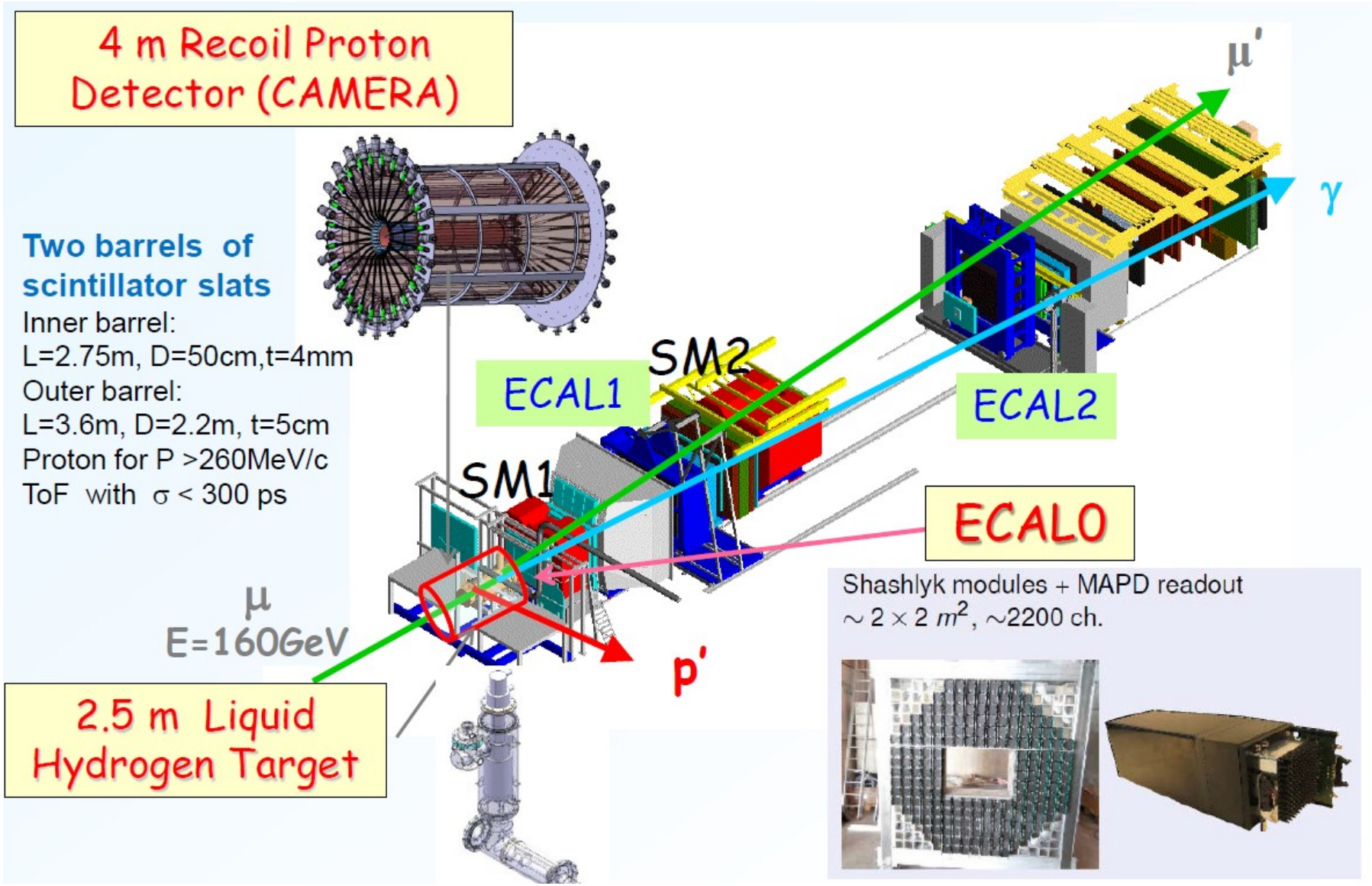

HERMES & COMPASS

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	HERMES@DESY	COMPASS@CERN
Beam	Pol. e+/e- in HERA e-ring E = 27.6 GeV $e^{-/\leftarrow}, e^{-/\rightarrow}, e^{+/\leftarrow}, e^{+/\rightarrow}$	Pol. μ+/μ- E = 160~200 GeV $\mu^{+/\leftarrow}, \mu^{-/\rightarrow}$ @ 160 GeV
Target	1996~2000: L-pol. H/D 2002~2005: T-pol. H	2006, 2007: Unpol. H/D 2002~2011: Pol. ^{6}LiD 2012, 2016, 2017: Pol. NH_3, Unpol. H
	w/o recoil detector	w/ recoil detector

w/ ECAL upgrade

DVCS @ HERMES

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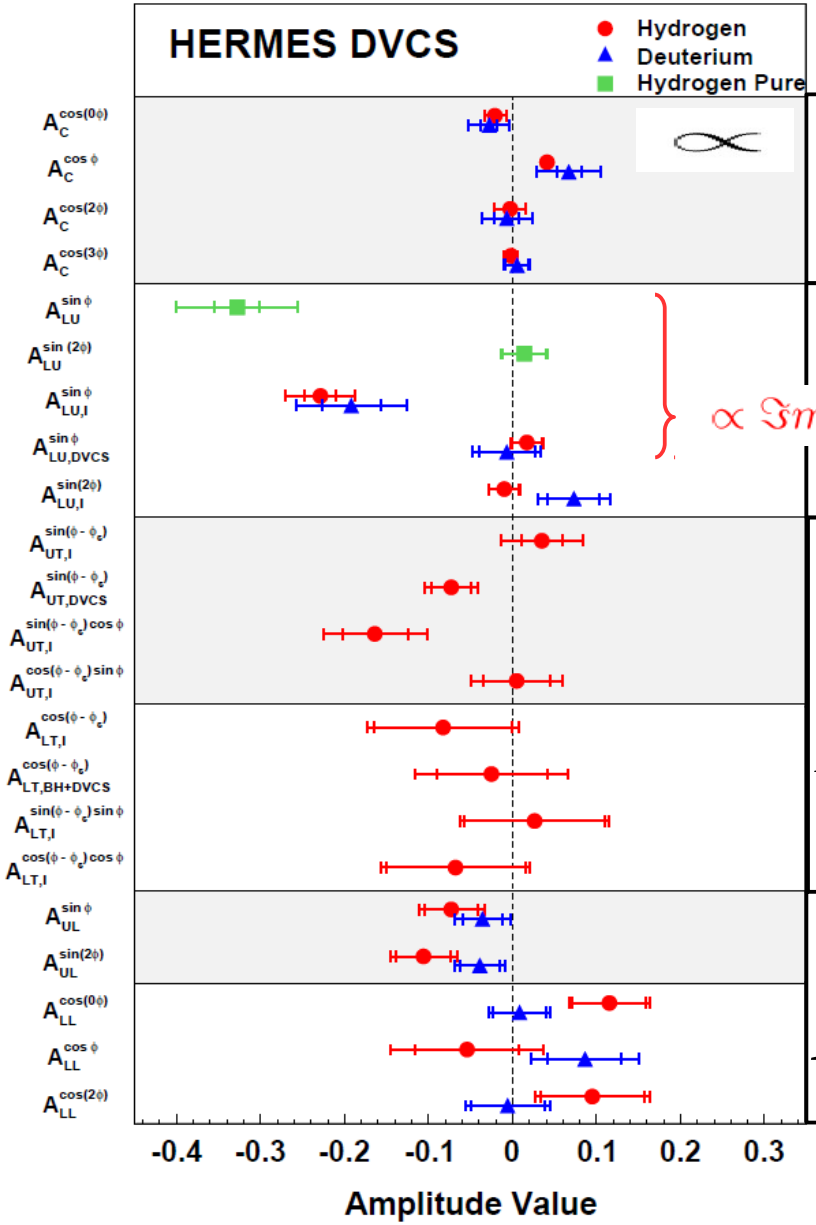

GPD

Beam Charge Asymmetries

Beam Spin Asymmetries

PRL 87 (2001) 182001
PRD 75 (2007) 011103
JHEP 11 (2009) 083
JHEP 07 (2012)032
JHEP 10 (2012) 042
NPB 829 (2010) 1

H

$p^{\uparrow\downarrow}$

Target Spin Asymmetries

Double Spin Asymmetries

JHEP 06 (2008) 066
PLB 704 (2011) 15

E

クォーク全角運動量⇔

$p^{\leftrightarrow}$

Target Spin Asymmetries

Double Spin Asymmetries

JHEP 06 (2010) 019
NPB 842 (2011) 265

$\tilde{H}$

EIC kinematics: DVCS

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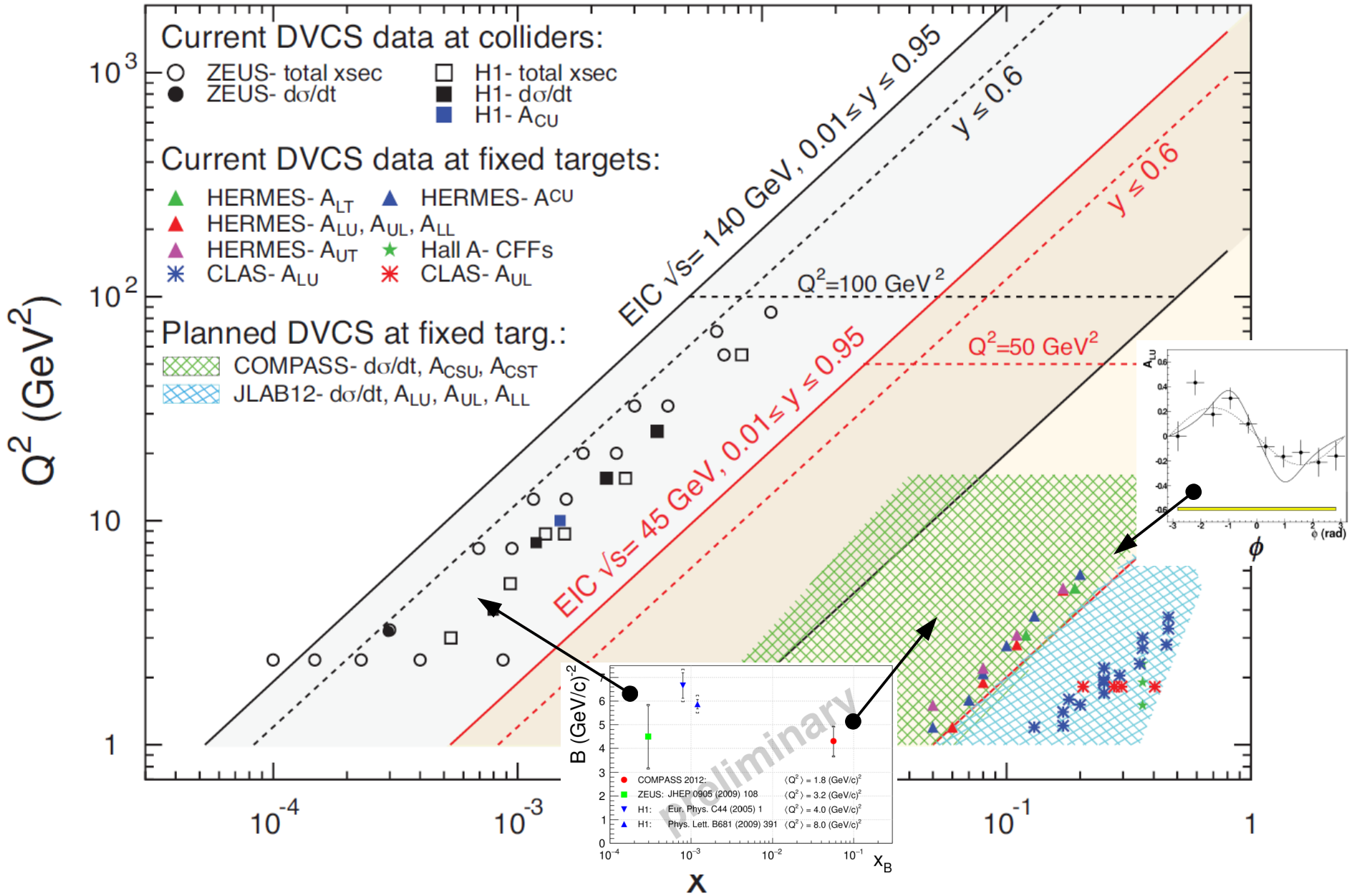
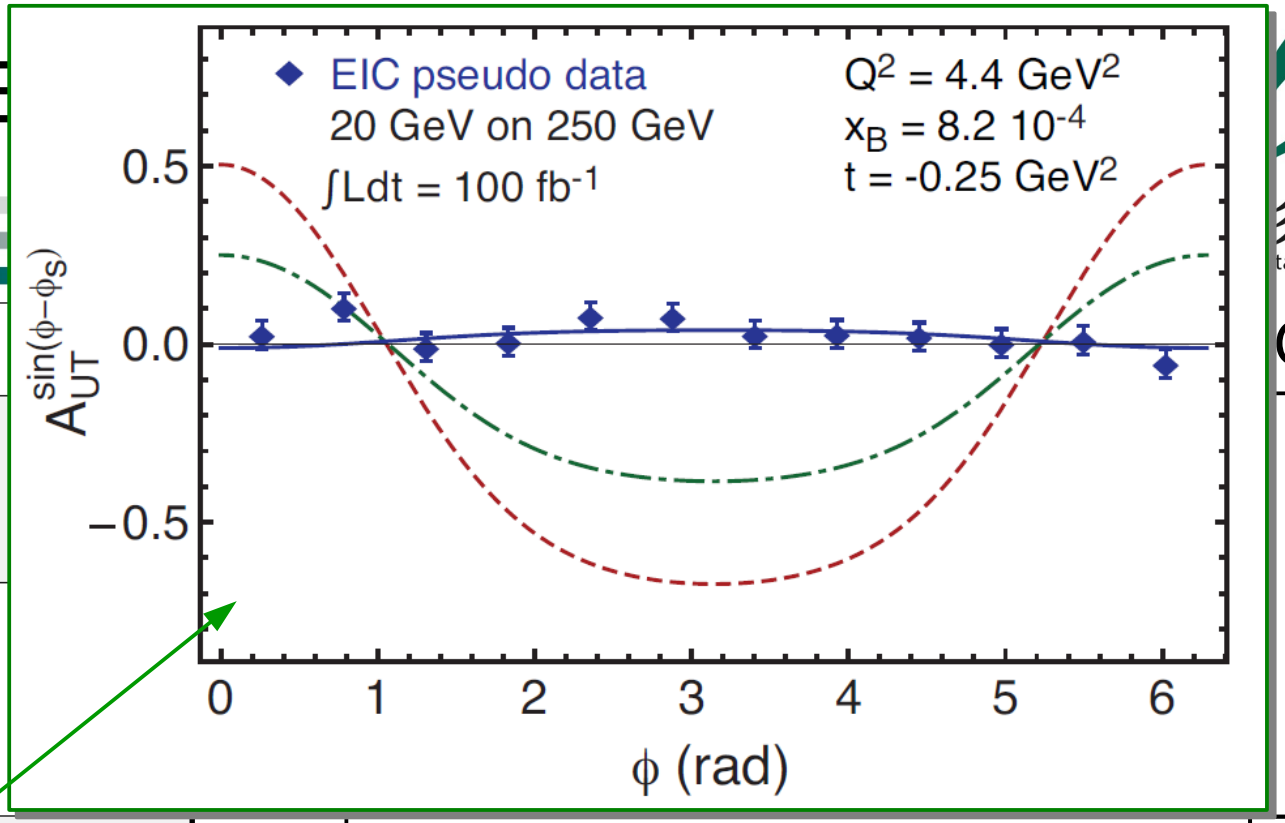
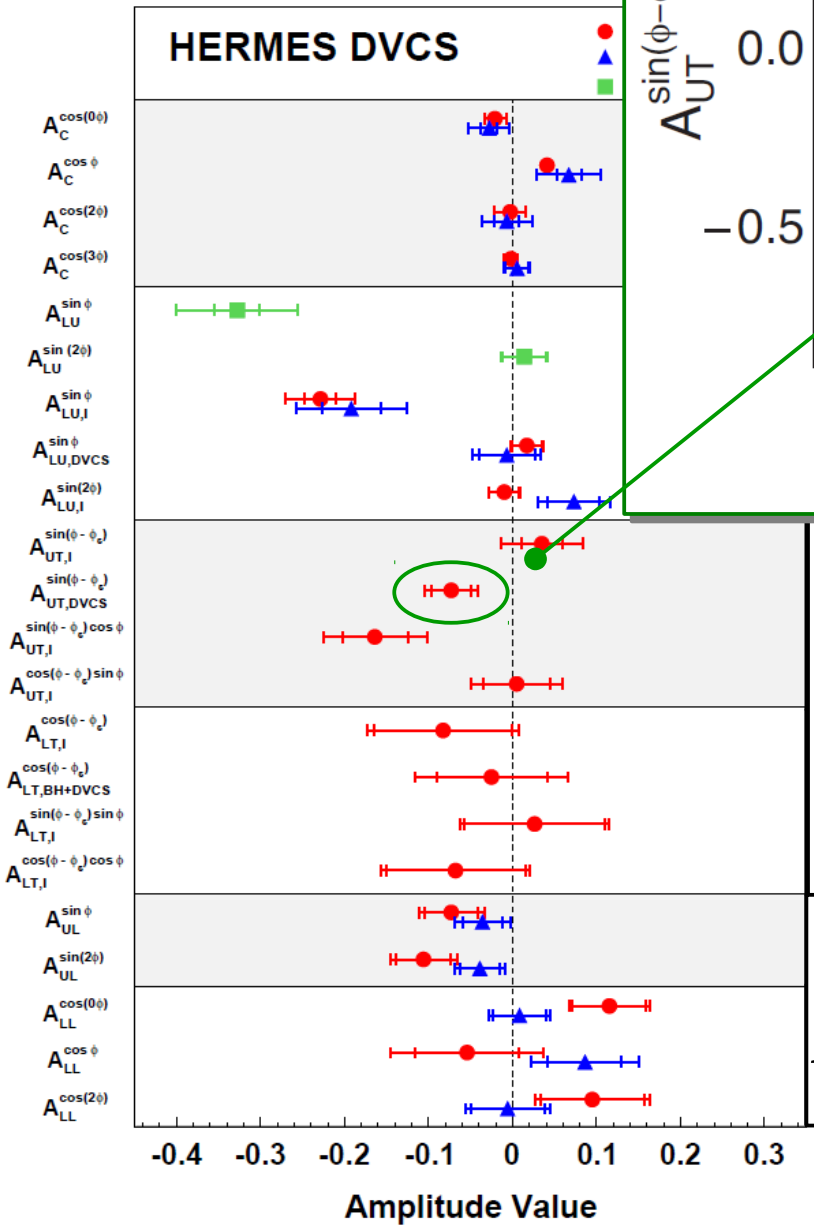


DVCS @ HERME





GPD

			H
$p^{\uparrow\downarrow}$	Target Spin Asymmetries	JHEP 06 (2008) 066 PLB 704 (2011) 15	E
	Double Spin Asymmetries		
$p^{\leftrightarrow}$	Target Spin Asymmetries	JHEP 06 (2010) 019 NPB 842 (2011) 265	$\tilde{H}$
	Double Spin Asymmetries		

クォーク全角運動量⇔

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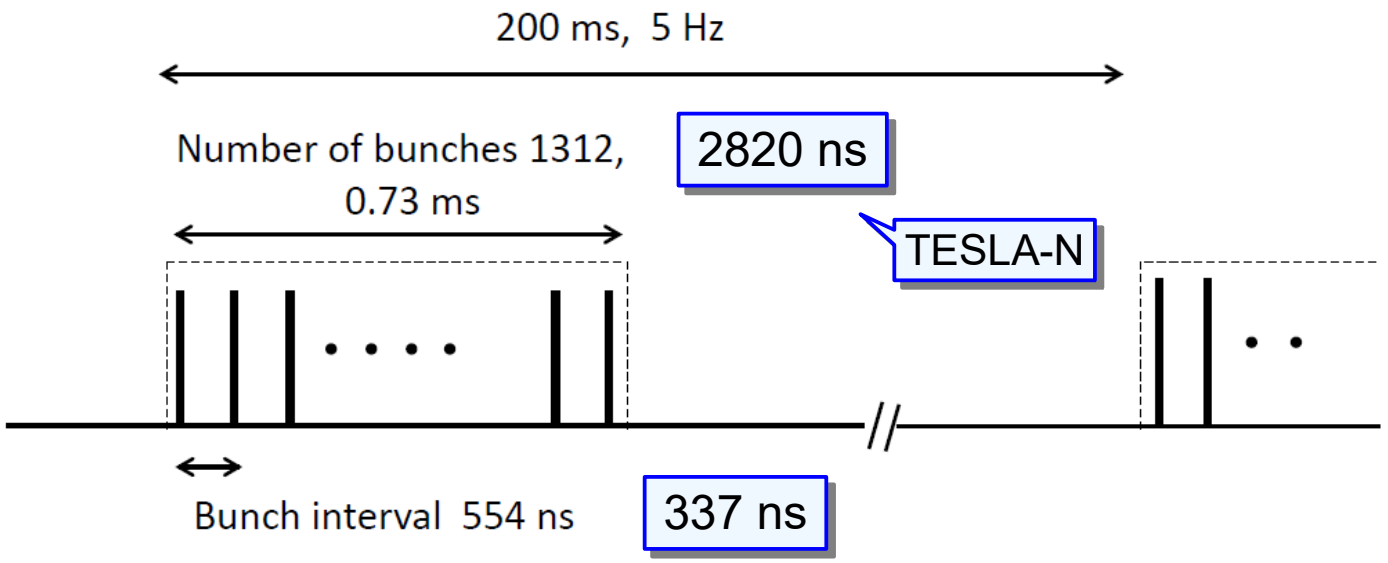
ILC-N

2016.7.10

Time Structure of Electron Beam for ILC-N

E = 125 - 250 GeV

2×10^{10} Electrons per bunch



TESLA-N setup

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~ COMPASS setup

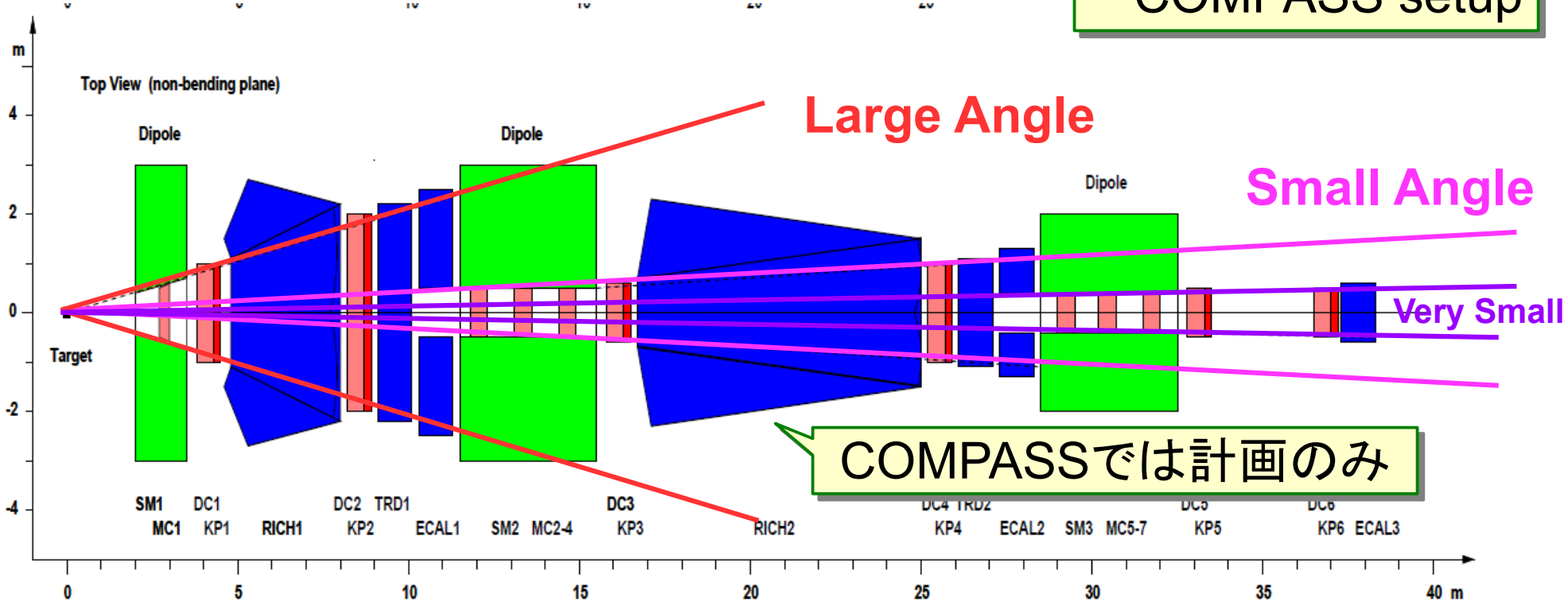

Figure 3.3.2: *Schematic side view and top view of the envisaged TESLA-N apparatus. For an explanation of the acronyms see the text.*

※ TESLA-N検討時

DVCS測定は想定外

and more sophisticated hadron wave functions. A great potential to achieve an even deeper understanding of the nucleon structure may arise from a comprehensive, generalized analysis of many different processes based on the new tool of skewed parton distributions (SPDs).

ILC-N kinematics: Inclusive

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Experiment	c.m. Energy [GeV]	Luminosity [$cm^{-2}\ s^{-1}$]
TESLA-N	22	$7.5 \cdot 10^{34}$
TESLA-N (10 Hz)	22	$1.5 \cdot 10^{35}$
COMPASS	20	$5.0 \cdot 10^{32}$
SLAC (incl.)	$5 \div 10$	$5.0 \cdot 10^{34}$
HERMES (unpol.)	7.2	$4.0 \cdot 10^{33}$
HERMES (pol.)	7.2	$2.0 \cdot 10^{31}$
ELFE@CERN (unpol.)	7	$1.0 \cdot 10^{38}$
ELFE@CERN (pol.)	7	$5.0 \cdot 10^{35}$
HERA $\vec{e}\vec{p}$	318	$1.0 \cdot 10^{31}$
HERA eA	150	$1.0 \cdot 10^{30}$
eRHIC	100	$2.0 \cdot 10^{32}$
EPIC	31	$1.0 \cdot 10^{33}$

$W^2 > 4\ \mathrm{GeV}^2$

$0.01 < y < 0.9$

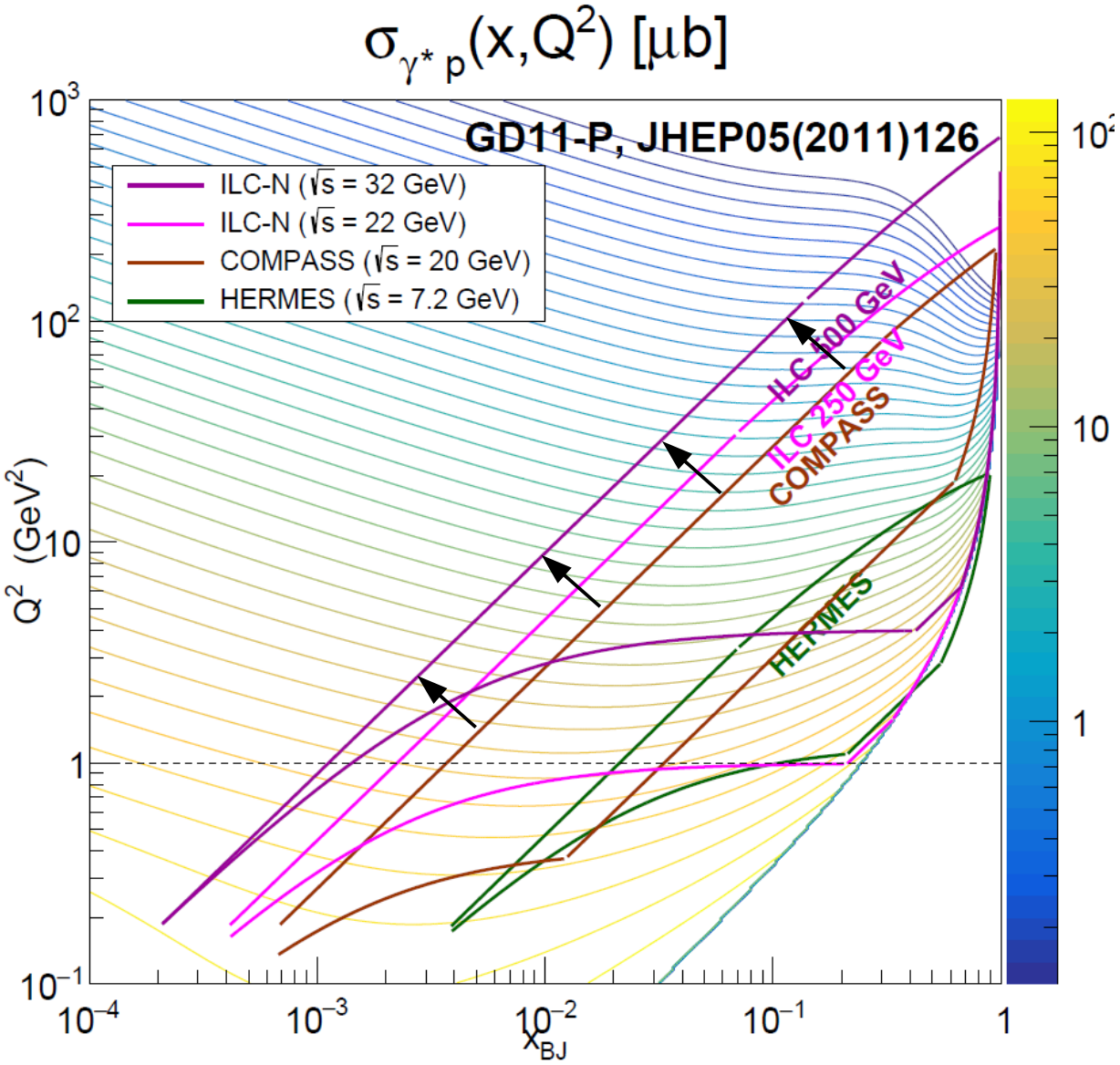
$4 < \theta < 100\ \mathrm{mrad}$

COMPASS

$W^2 > 12\ \mathrm{GeV}^2$

$0.1 < y < 0.9$

$4 < \theta < 180\ \mathrm{mrad}$



HERMES, COMPASS condition

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	HERMES@DESY			COMPASS@CERN
Beam	Pol. e+/e- in HERA e-ring E = 27.6 GeV $e^{-/\leftarrow}, e^{-/\rightarrow}, e^{+/\leftarrow}, e^{+/\rightarrow}$			Pol. μ+/μ- E = 160~200 GeV $\mu^{+/\leftarrow}, \mu^{-/\rightarrow}$ @ 160 GeV
Target	L-pol. H/D		Δq, ΔG	L-pol. H/D
	T-pol. H	GPD-E	TMD	T-pol. H/D
	U-pol. H/D	GPD-H		
	U-pol. H/D + recoil		GPD-H	U-pol. H + recoil

EIC: $\sqrt{s}$ = 45 GeV, 0.01 < y < 0.95

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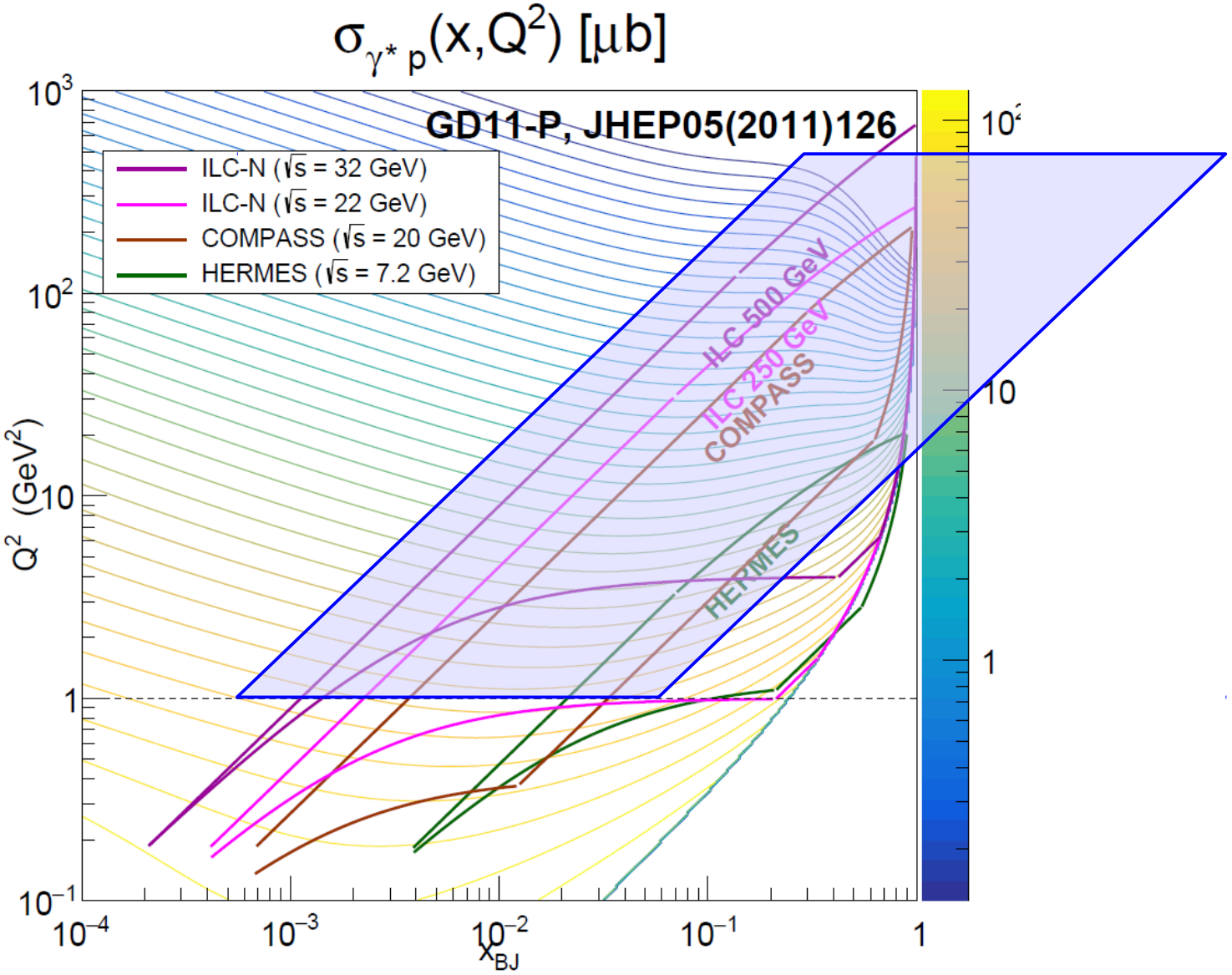

EIC: $\sqrt{s}$ = 140 GeV, 0.01 < y < 0.95

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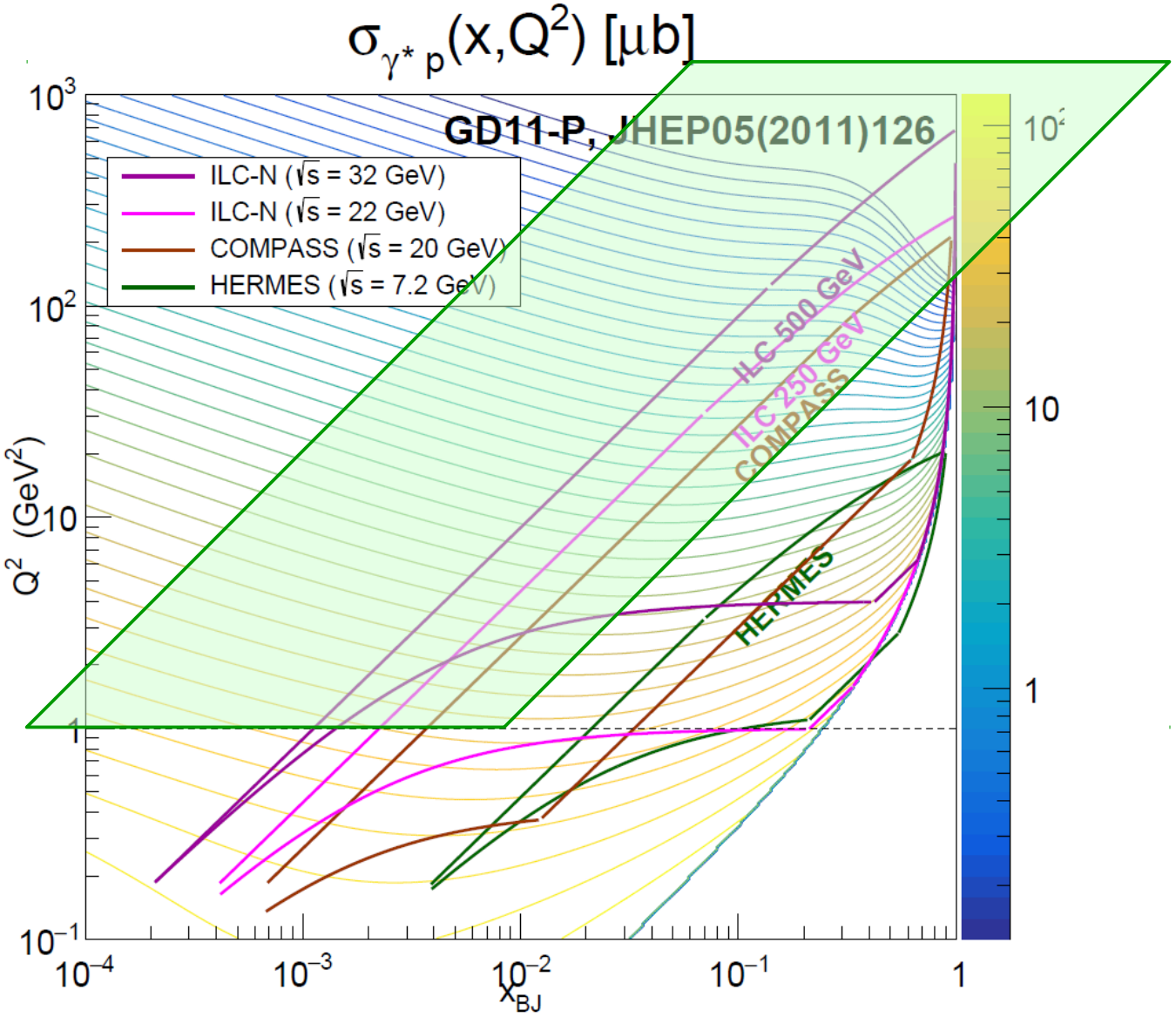

ILC-Nで目指すべきもの

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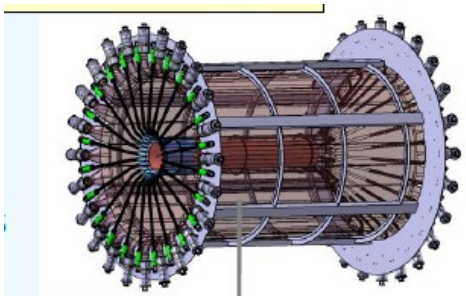
- **運動学的領域**
  - CERN-COMPASSより low-x, high-Q^2
    - E = 250 GeV ではあまりかわらない。(500 GeVならば・・・)
  - EIC ($\sqrt{s}$ = 20 ~ 100 (140) GeV)
    - 小さな$\sqrt{s}$ でオーバーラップ
- **横偏極標的＋反跳陽子検出：DVCS**
  - HERMES: without the recoil detector
  - **COMPASS将来計画(2019年以降)**
- **重陽子テンソル構造**
  - HERMES($\sqrt{s}$ = 7 GeV)の測定
  - Jlab ($\sqrt{s}$ = 5 GeV)での計画

COMPASSで未測定

3.2.6 Specific Deuteron Structure Functions

熊野@KEKと具体的議論

Possible ILC-N setup



+ T-pol. p

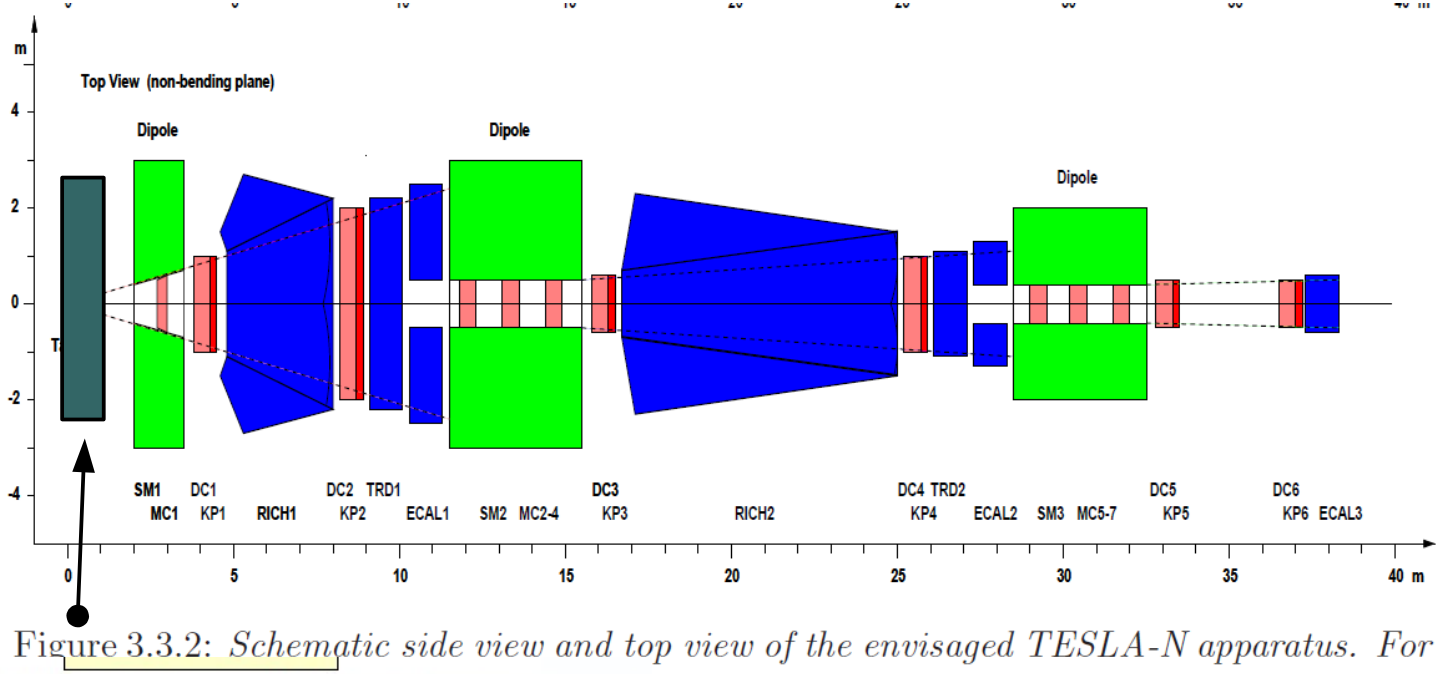


Figure 3.3.2: *Schematic side view and top view of the envisaged TESLA-N apparatus. For text.*

Shashlyk modules + MAPD readout
$\sim 2 \times 2\ m^2$, ~2200 ch.