

MENU 2026

The 17th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon

Beam-spin induced polarization of Λ and $\bar{\Lambda}$ hyperons in semi-inclusive DIS at hermes

G. Schnell

Single-hadron TMD*) fragmentation functions

*) TMD ... transverse-momentum dependent

hadron pol.	quark pol.		
	U	L	T
	U	D_1	$H_1^\perp$
	L		G_1
	T	$D_{1T}^\perp$	$G_{1T}^\perp$

Single-hadron TMD*) fragmentation functions

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	T	$D_{1T}^\perp$	$G_{1T}^\perp$	$H_1 H_{1T}^\perp$

➤ relevant for unpolarized final state

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relevant for unpolarized final state

Collins FF: $H_1^{\perp, q \rightarrow h}$

ordinary FF: $D_1^{q \rightarrow h}$

FF ... fragmentation function

Single-hadron TMD*) fragmentation functions

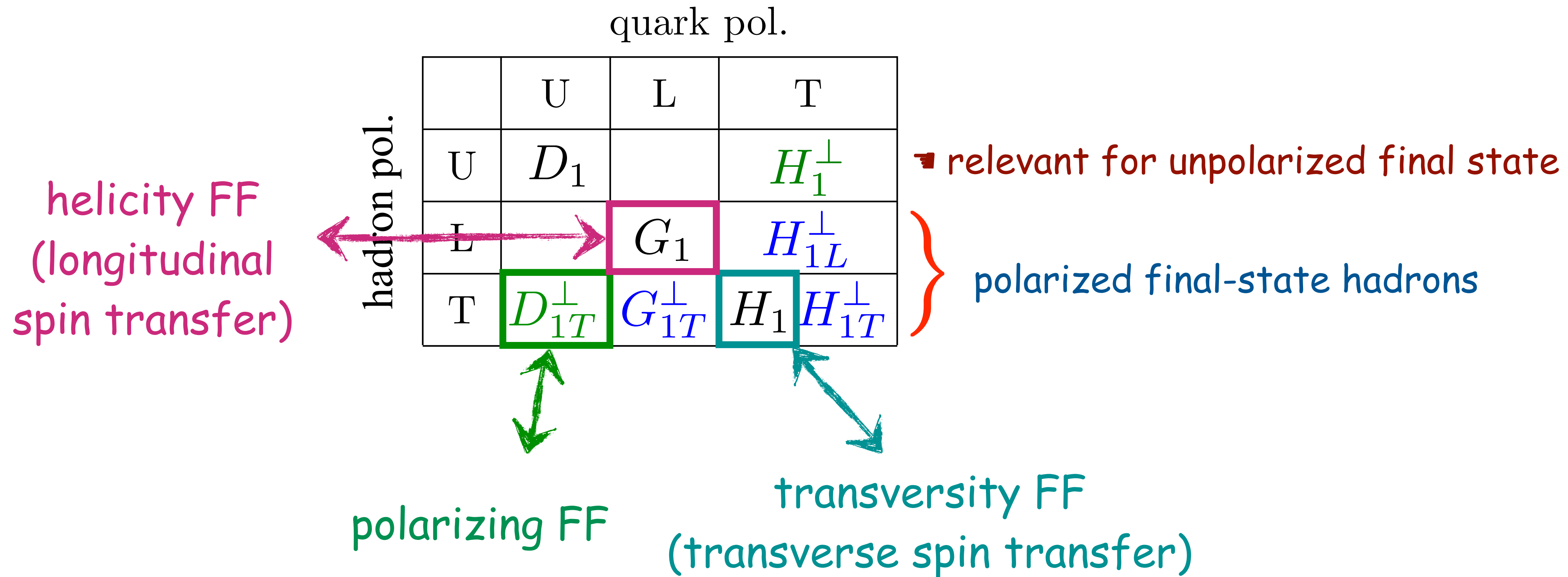
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hadron pol.	U	D_1		$H_1^\perp$	relevant for unpolarized final state
	L		G_1	$H_{1L}^\perp$	} polarized final-state hadrons
	T	$D_{1T}^\perp$	$G_{1T}^\perp$	$H_1 H_{1T}^\perp$	

FF ... fragmentation function

Single-hadron TMD*) fragmentation functions

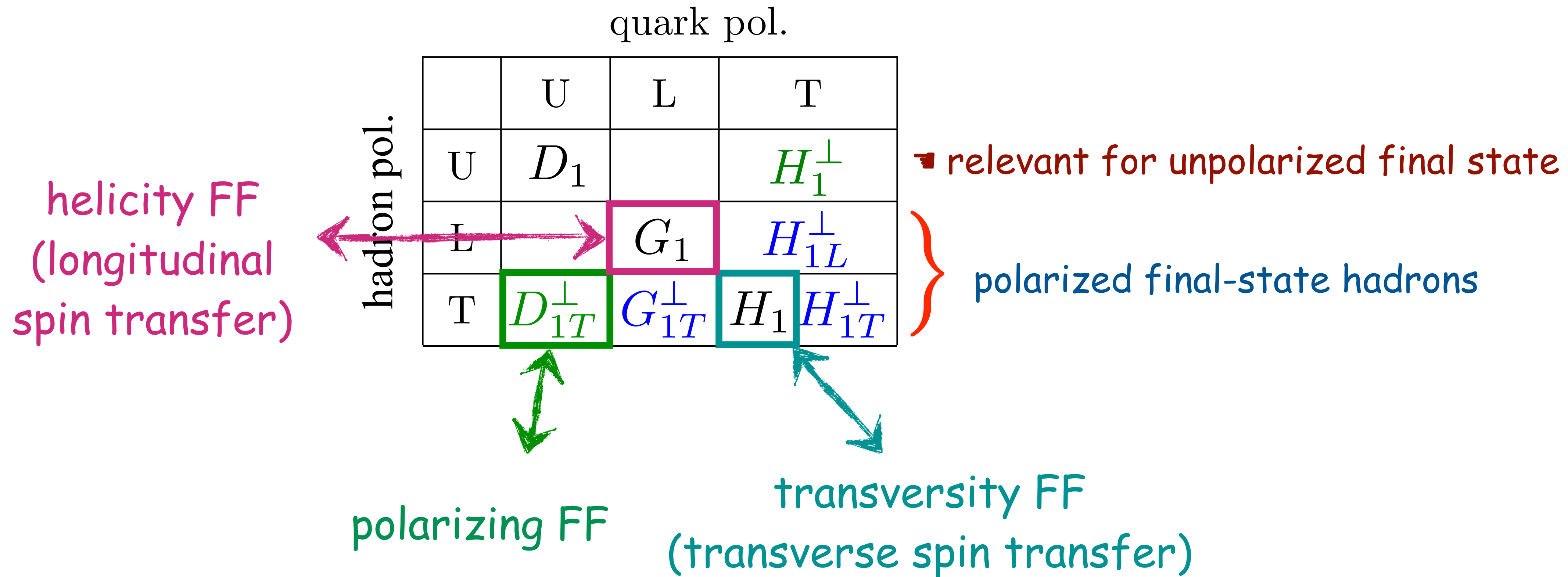
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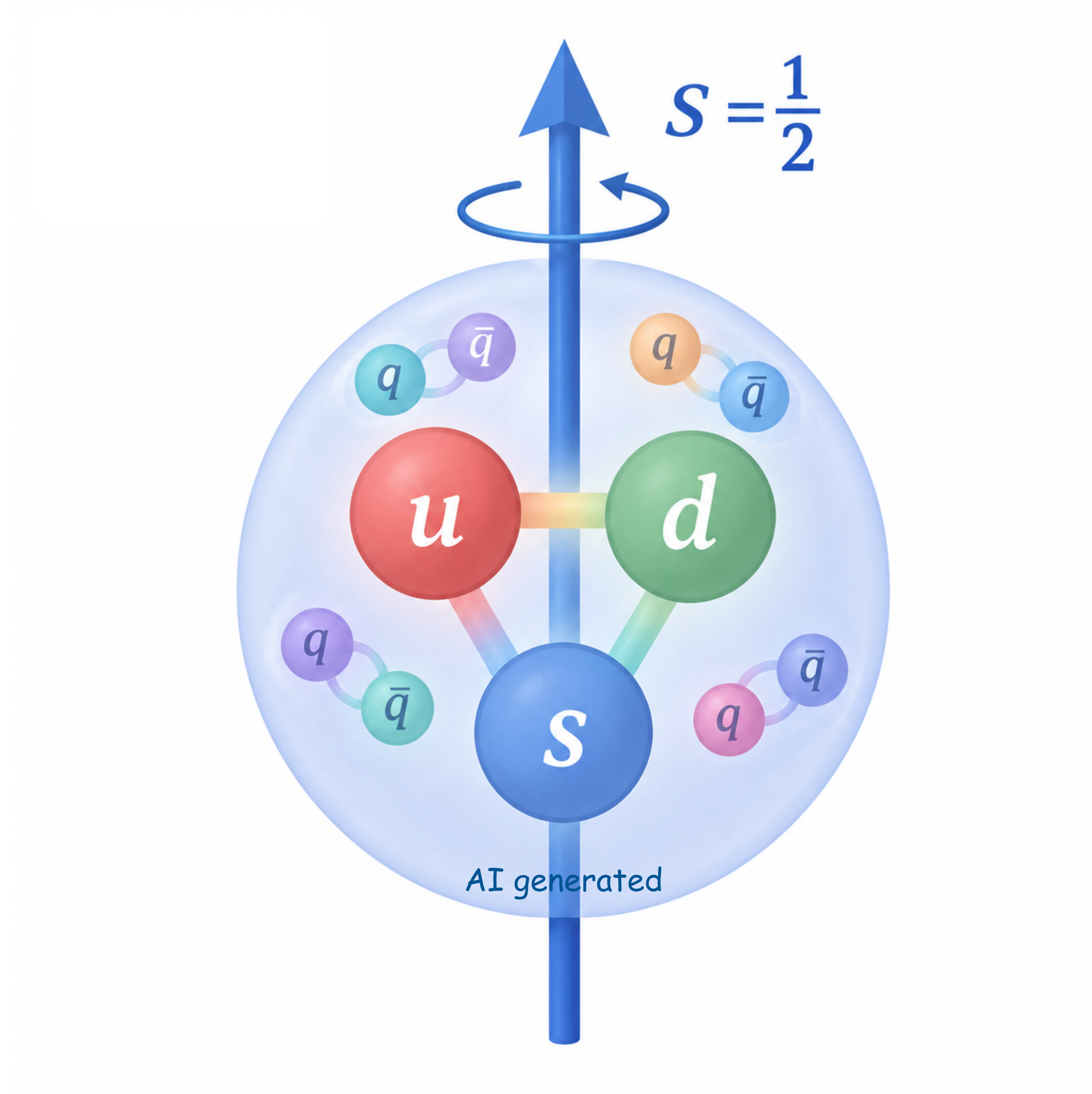
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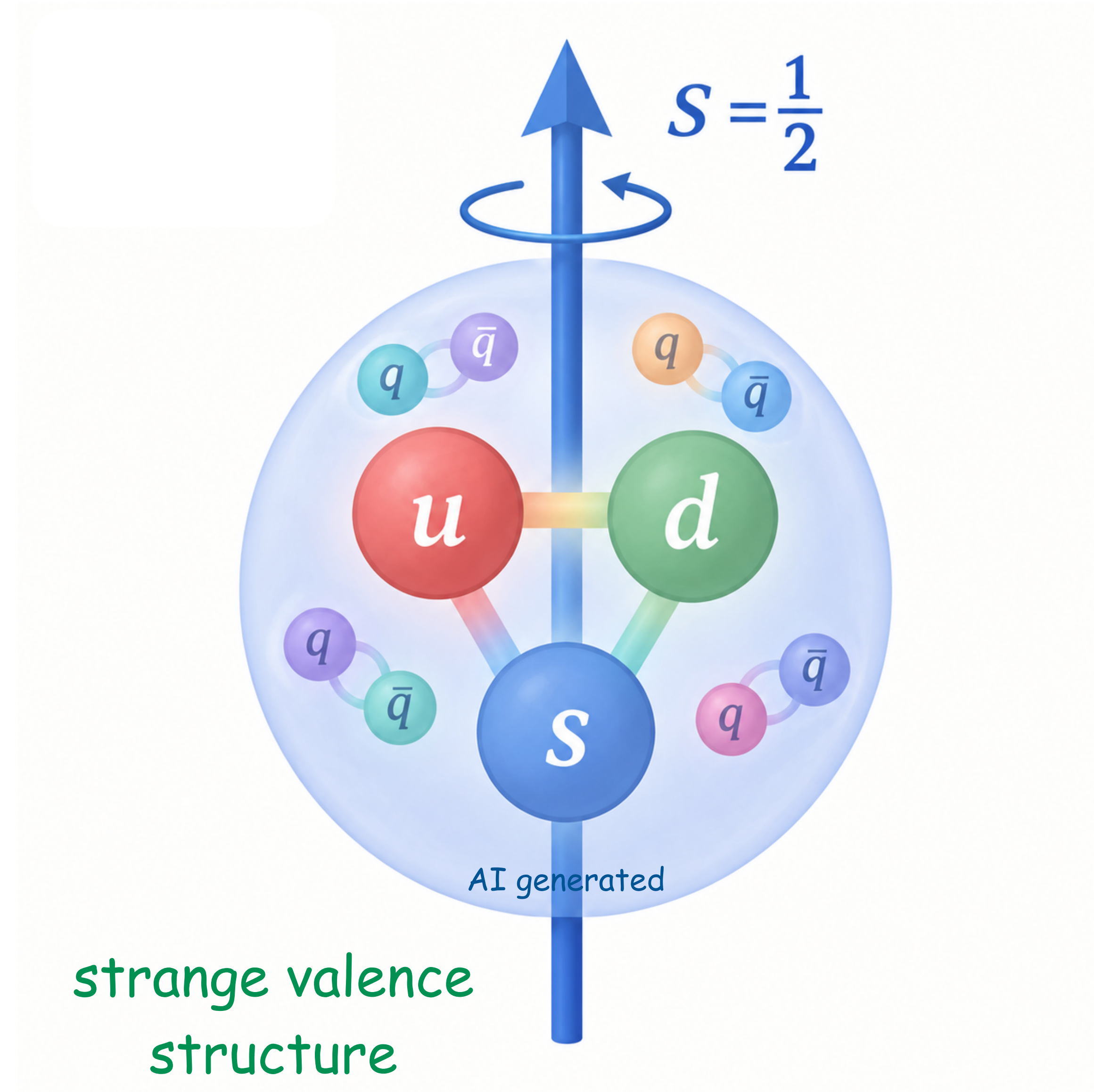
⇒ FFs act as quark flavor-tagger and polarimeter

FF ... fragmentation function

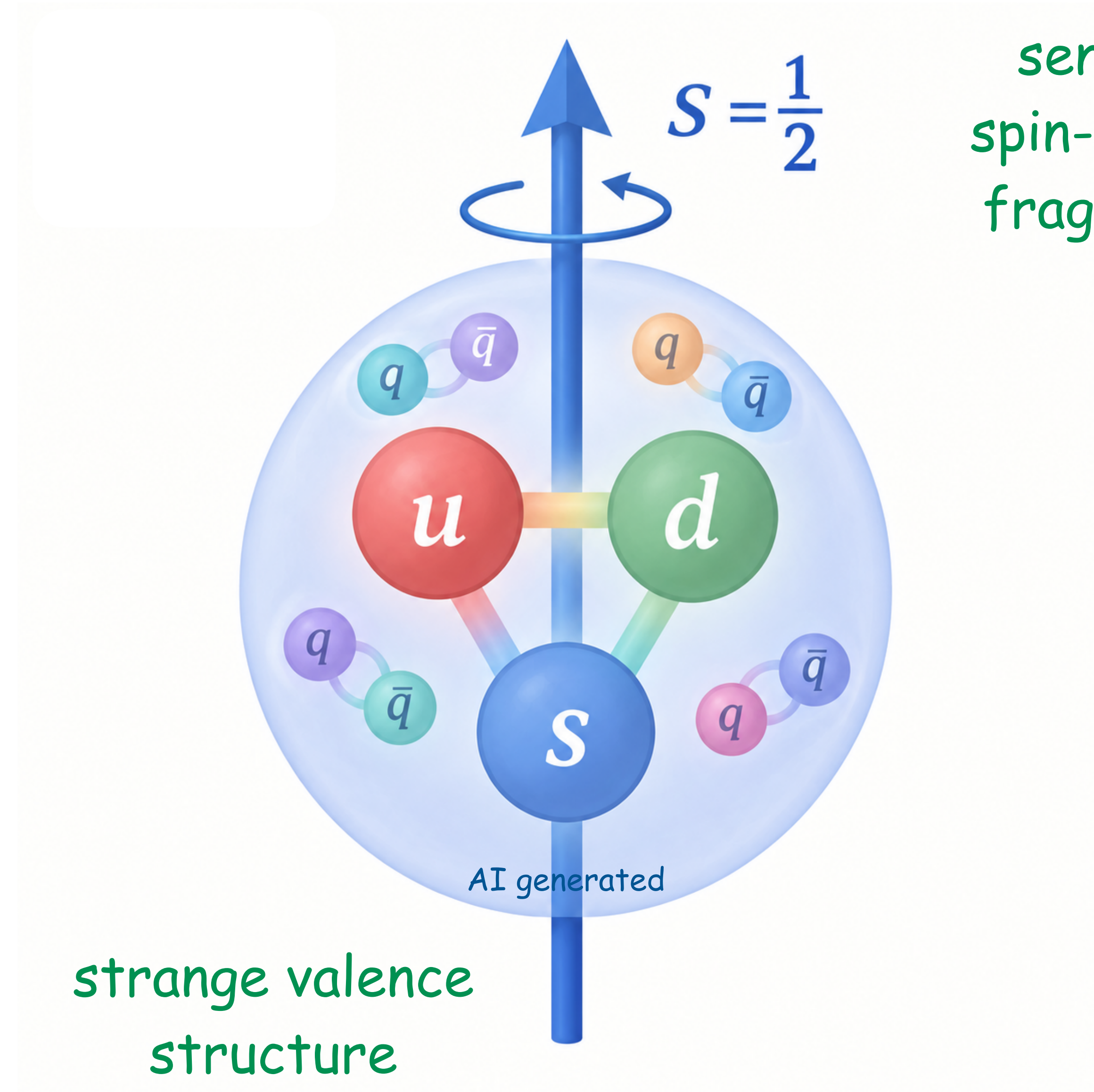
Why Lambda?



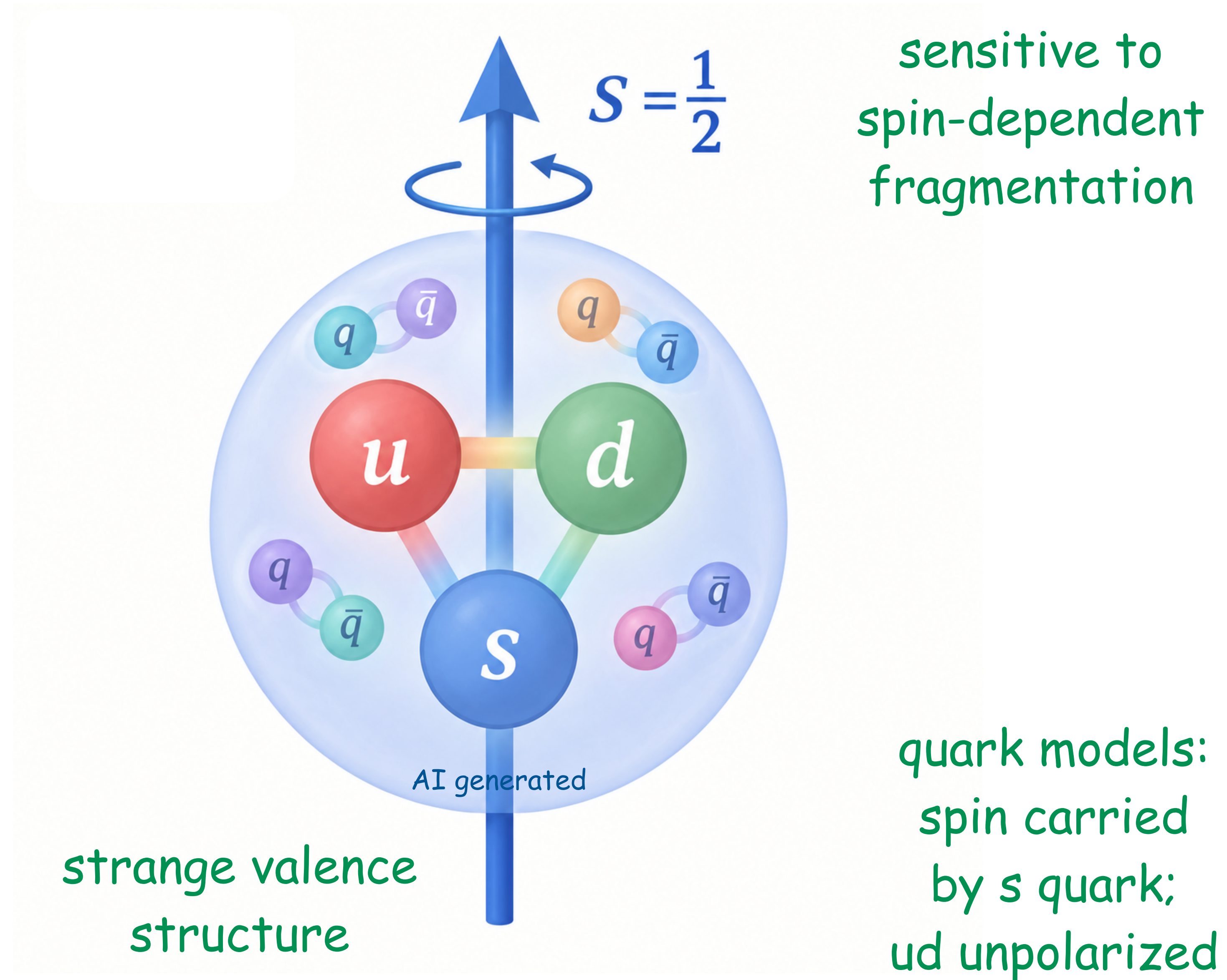
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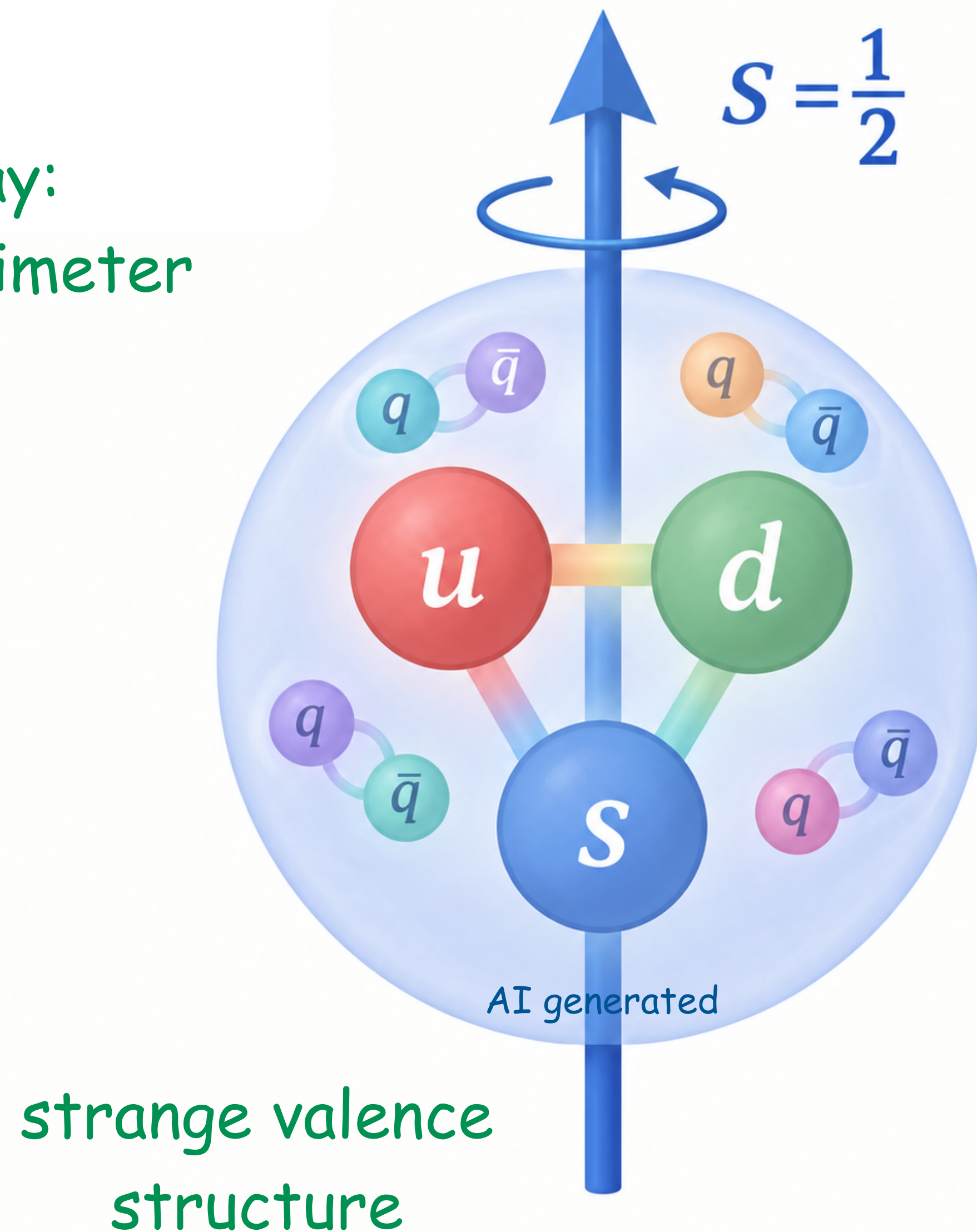
Why Lambda?



Why Lambda?

its weak decay:
easy-to-use polarimeter

sensitive to
spin-dependent
fragmentation



strange valence
structure

quark models:
spin carried
by s quark;
ud unpolarized

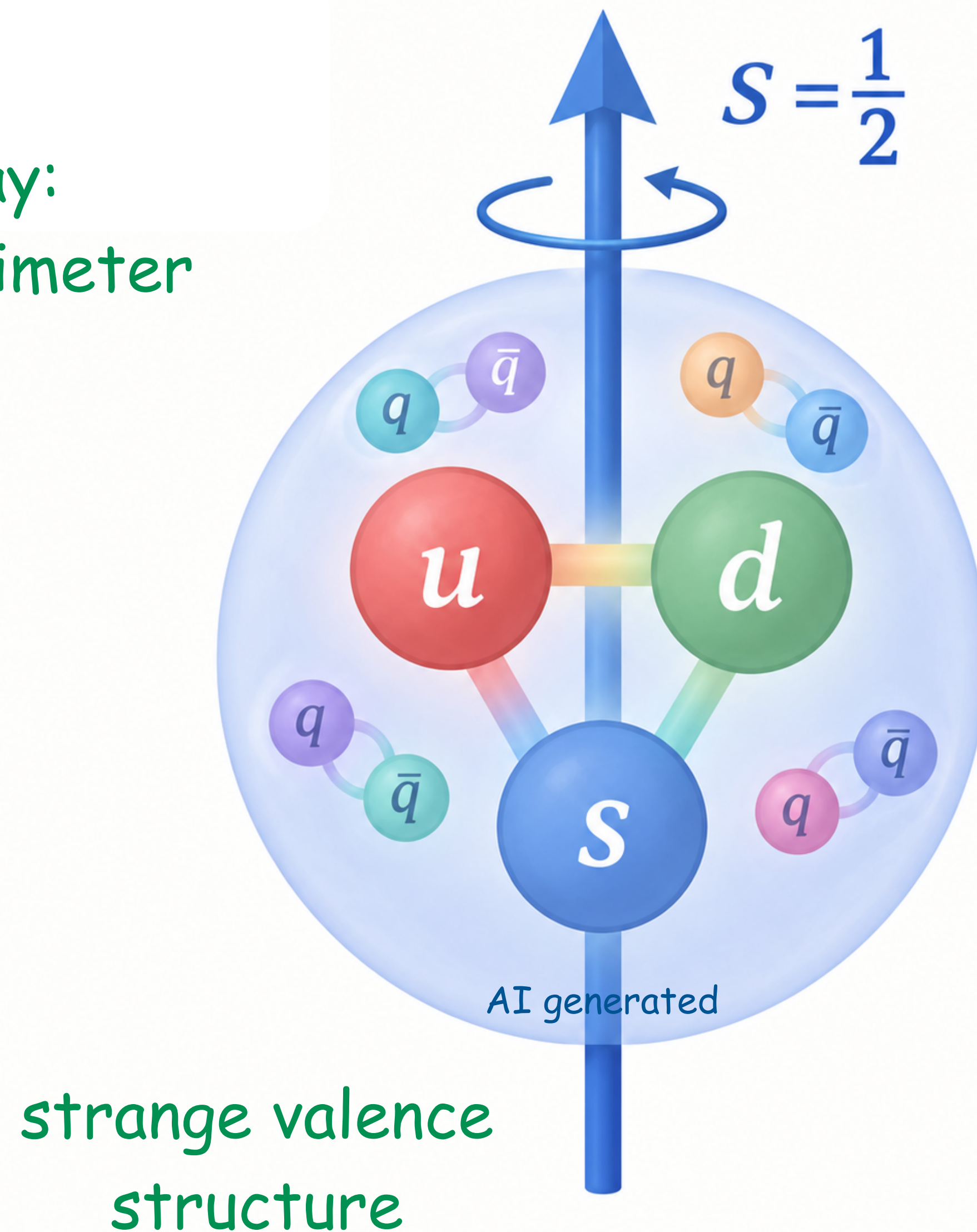
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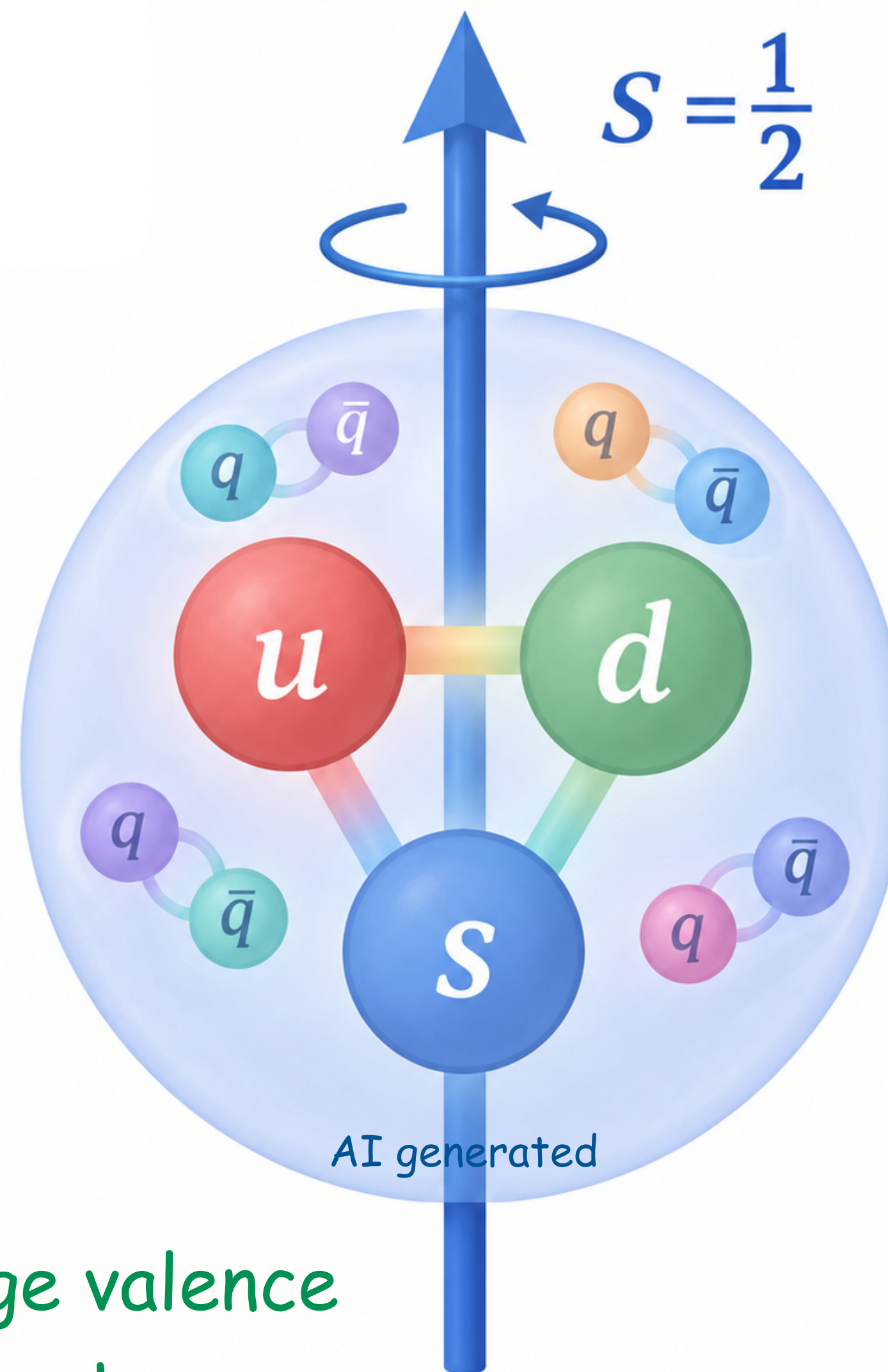
strange valence
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Why Lambda?

its weak decay:
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relatively low yield
compared to light
mesons

strange valence
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Lambda fragmentation – a window to strangeness



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First next-to-next-to-leading-order extraction of fragmentation functions for Λ hyperons

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ABSTRACT: We present MAPFF1.0_Lambda, the first global analysis at next-to-next-to-leading order in perturbative QCD of the collinear unpolarised fragmentation functions of Λ hyperons. The fit is based on data from single-inclusive electron-positron annihilation, and from both neutral-current and — for the first time — charged-current semi-inclusive deep-inelastic scattering. We have adopted a statistical framework based on Monte Carlo sampling and parametrised fragmentation functions in terms of a neural network. The fragmentation function set comprises a total of seven independent parton flavours, allowing for the first independent determination of valence-quark distributions. Our analysis offers new insights into the hadronisation mechanism of strange baryons and establishes a baseline for future phenomenological and experimental investigations.

JHEP10(2026)089

Lambda fragmentation - a window to strangeness

Motivation

Improving the determination of FFs by focusing on a less extensively explored hadron:
the Λ hyperon, the lightest among the strange baryons

State of the art of Λ collinear unpolarised fits

Collaboration	Data	Flavour separation	Accuracy	Extracted particle
DSV (1998) Phys. Rev. D 57, 5811	SIA	$u = d = s$		
AKK (2006) Nucl. Phys. B, 734	SIA	✓		$\Lambda + \bar{\Lambda}$
(2008) Nucl. Phys. B 803	SIA, pp collisions	✓	NLO	
NPC23 (2025) Phys. Rev. D 112, 054045	SIA, SIDIS, pp collisions	$u = d$		
MAPFF1.0_Λ (2026)	SIA, SIDIS (NC and CC)	✓	NNLO	$\Lambda, \bar{\Lambda}$

[JHEP10(2026)089]

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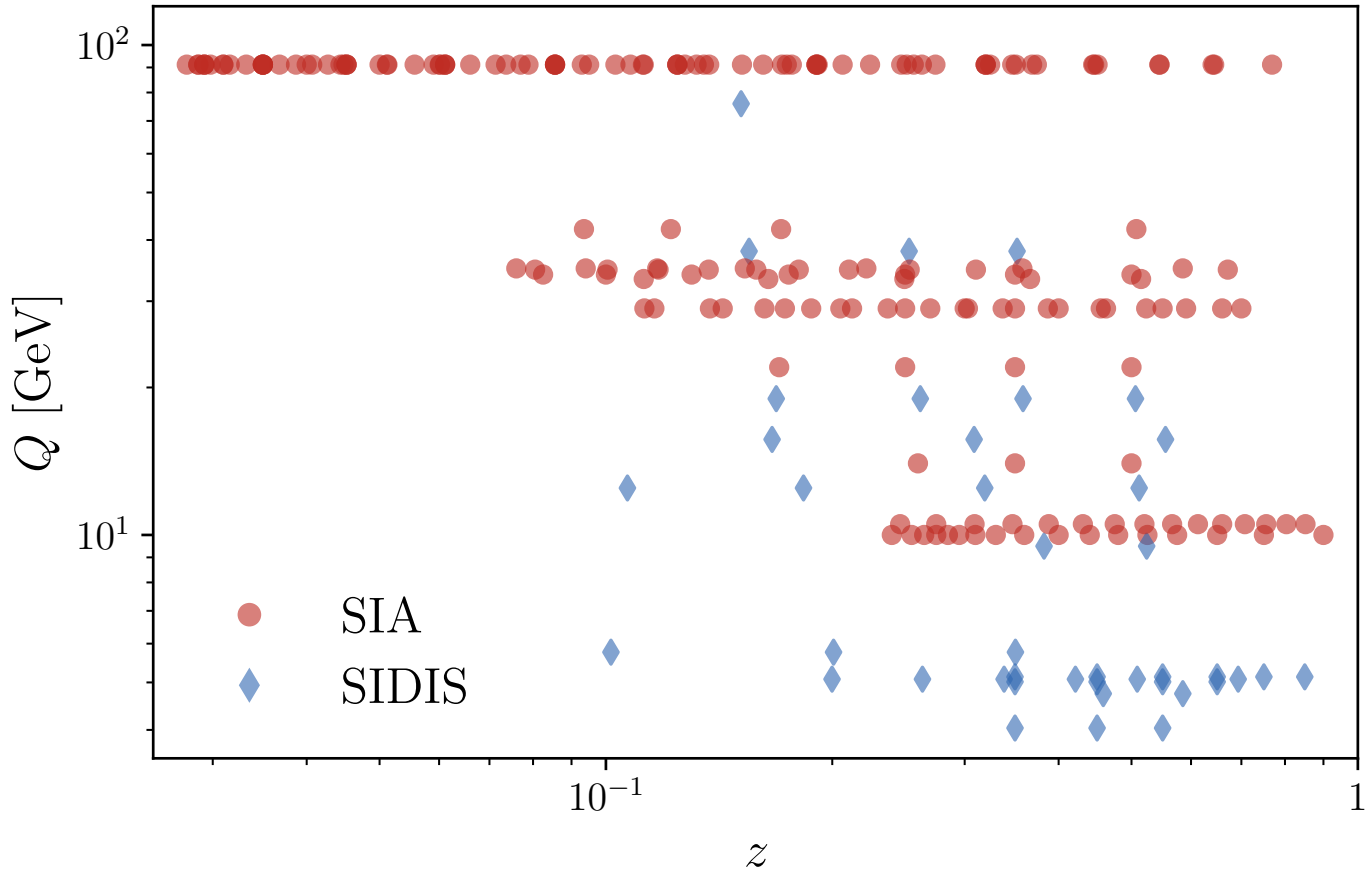
Collaboration	Data	Flavour separation	Accuracy	Extracted particle
DSV (1998) Phys. Rev. D 57, 5811	SIA	$u = d = s$		
Inclusion of all available SIDIS neutral- and – for the first time – charged-current data	First independent determination of valence-quark distribution for the Λ , i.e., for u, d, s	SIDIS data allow to reliably extract for the first time FFs for Λ and $\bar{\Lambda}$ separately		
NPC23 (2025) Phys. Rev. D 112, 054045	SIA, SIDIS, pp collisions	$u = d$		
MAPFF1.0_Λ (2026)	SIA, SIDIS (NC and CC)	✓	NNLO	$\Lambda, \bar{\Lambda}$

[JHEP10(2026)089]

Lambda fragmentation - a window to strangeness

Experimental data

Experiment	$\sqrt{s}$ [GeV]	$N_{\text{dat}}^{\Lambda+\bar{\Lambda}}$
SIA		
ARGUS	10.0	16
Belle	10.52	15
TASSO14	14.0	3
TASSO22	22.0	4
TASSO33.3	33.3	5
TASSO34	34.0	7
TASSO34.8	34.8	10
TASSO42.1	42.1	4
CELLO	35.0	7
MARK II	29.0	13
HRS	29.0	12
SLD	91.2	15
	91.2	8
	91.2	8
	91.2	8
ALEPH	91.2	25
DELPHI91	91.2	10
OPAL	91.2	15
Experiment	$\sqrt{s}$ [GeV]	$N_{\text{dat}}^{\Lambda} + N_{\text{dat}}^{\bar{\Lambda}}$
Neutral-Current SIDIS		
CHIO	20.6	3 + 4
EMC	23.5	4 + 3
E665	30.3	3 + 3
H1 1996	300	2
ZEUS 10–40	319	1
ZEUS 40–160	319	2
ZEUS 160–640	319	4
ZEUS 640–2560	319	3
ZEUS 2560–10240	319	1
Charged-Current SIDIS		
WA59	9.2	6 + 0
NOMAD	9.3	6 + 7
ABCMO	23.5	4 + 0
Total		241



SIA Range in $\sqrt{s}$ spans from 10 GeV to M_Z
Datasets delivered as the sum of Λ and $\bar{\Lambda}$

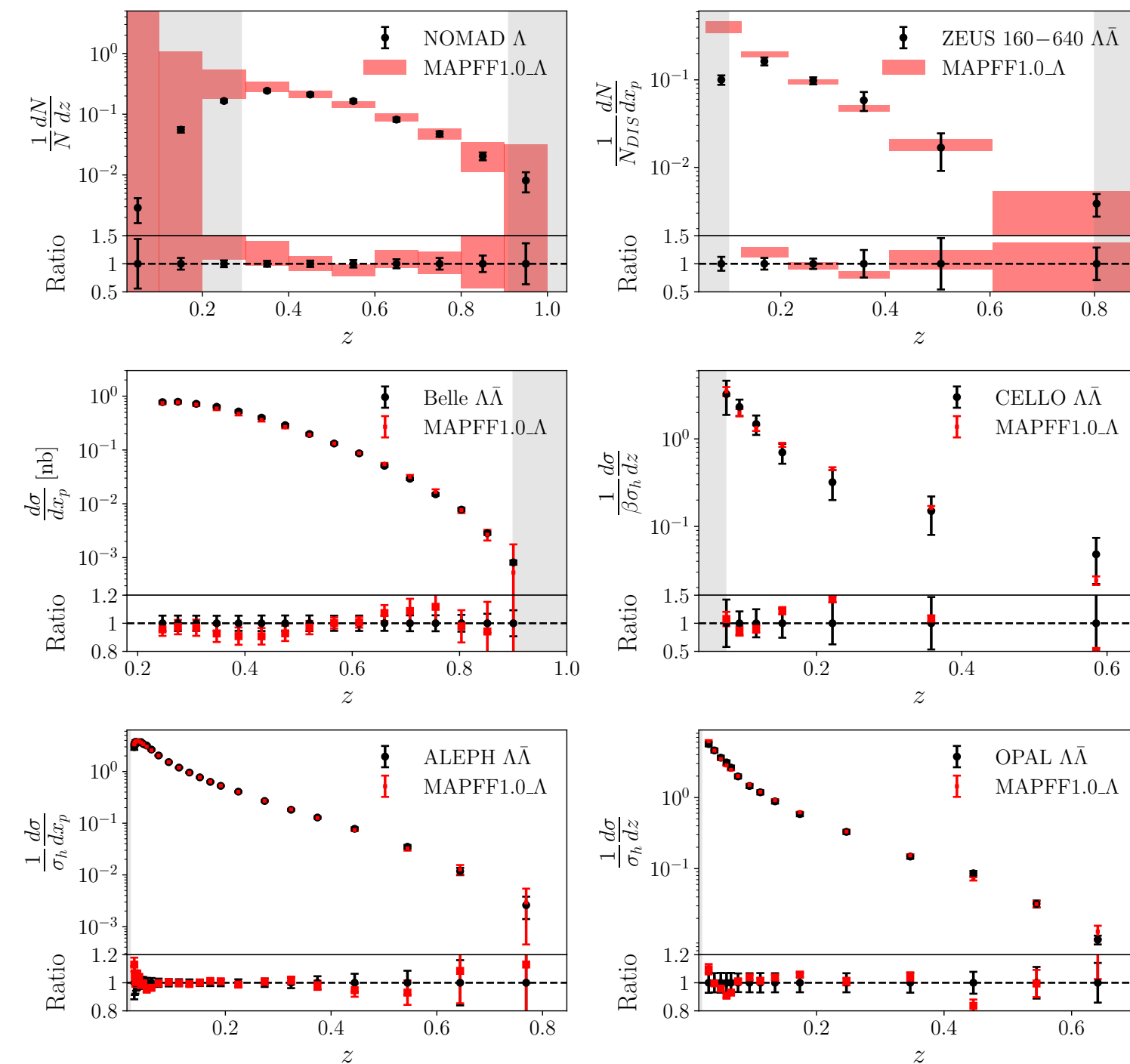
SIDIS Measurements for neutral- and charged-current
Data provided separately for Λ and $\bar{\Lambda}$

[JHEP10(2026)089]

Lambda fragmentation - a window to strangeness

Fit quality

Experiment	N_{dat}	χ^2/N_{dat} NLO	χ^2/N_{dat} NNLO
CHIO Λ	3	0.56	0.55
CHIO $\bar{\Lambda}$	4	1.11	1.03
EMC Λ	4	1.19	0.83
EMC $\bar{\Lambda}$	3	0.12	0.47
E665 Λ	3	0.50	0.48
E665 $\bar{\Lambda}$	3	1.00	1.27
H1 $\Lambda\bar{\Lambda}$	2	1.18	1.01
ZEUS $\Lambda\bar{\Lambda}$ 10-40	1	< 0.01	< 0.01
ZEUS $\Lambda\bar{\Lambda}$ 40-160	2	0.61	0.75
ZEUS $\Lambda\bar{\Lambda}$ 160-640	4	1.07	0.81
ZEUS $\Lambda\bar{\Lambda}$ 640-2560	3	0.46	0.37
ZEUS $\Lambda\bar{\Lambda}$ 2560-10240	1	0.03	0.03
WA59 Λ	6	0.34	0.33
NOMAD Λ	6	1.36	1.85
NOMAD $\bar{\Lambda}$	7	0.14	0.18
ABCMO Λ	4	4.05	3.05
ARGUS	16	1.49	1.55
Belle	15	1.13	1.26
TASSO 14	3	0.23	0.23
TASSO 22	4	0.48	0.49
TASSO 33	5	0.78	0.78
TASSO 34	7	0.57	0.56
TASSO 34.8	10	2.79	2.75
TASSO 42.1	4	1.13	1.12
HRS	12	0.82	0.82
MARK II	13	1.47	1.47
CELLO	7	0.52	0.51
ALEPH	25	0.48	0.44
DELPHI 91.2	10	2.62	2.58
OPAL	15	1.04	1.04
SLD	15	0.24	0.25
SLD UDS	8	2.30	2.02
SLD C	8	2.31	2.19
SLD B	8	0.50	0.80
Total	241	1.10	1.09



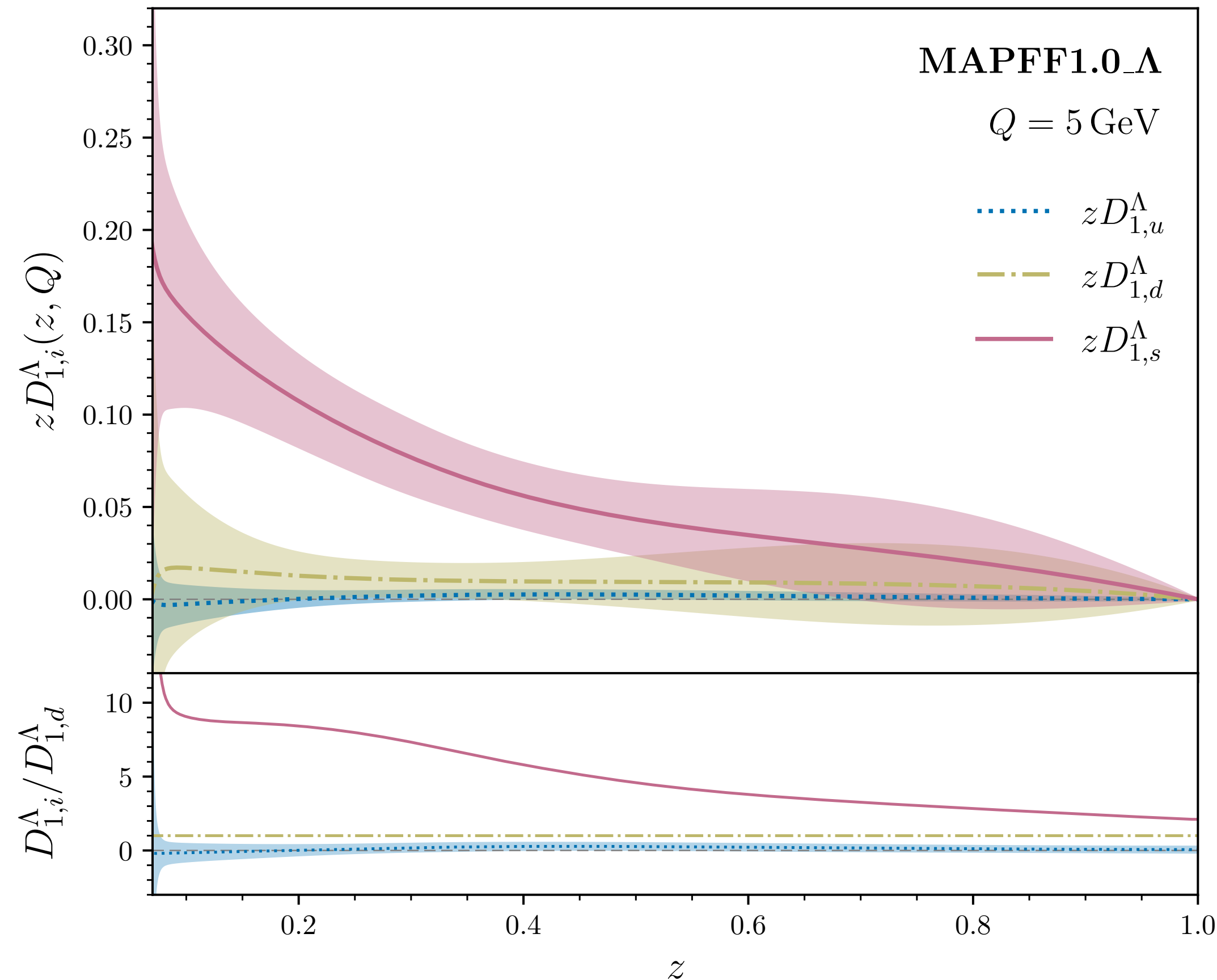
$$\chi^2 = 1.10 \text{ at NLO}, \quad \chi^2 = 1.09 \text{ at NNLO}$$

Quality of the fit stable when going at NNLO
Slight improvement for the majority of the datasets

[JHEP10(2026)089]

Lambda fragmentation - a window to strangeness

Valence quarks

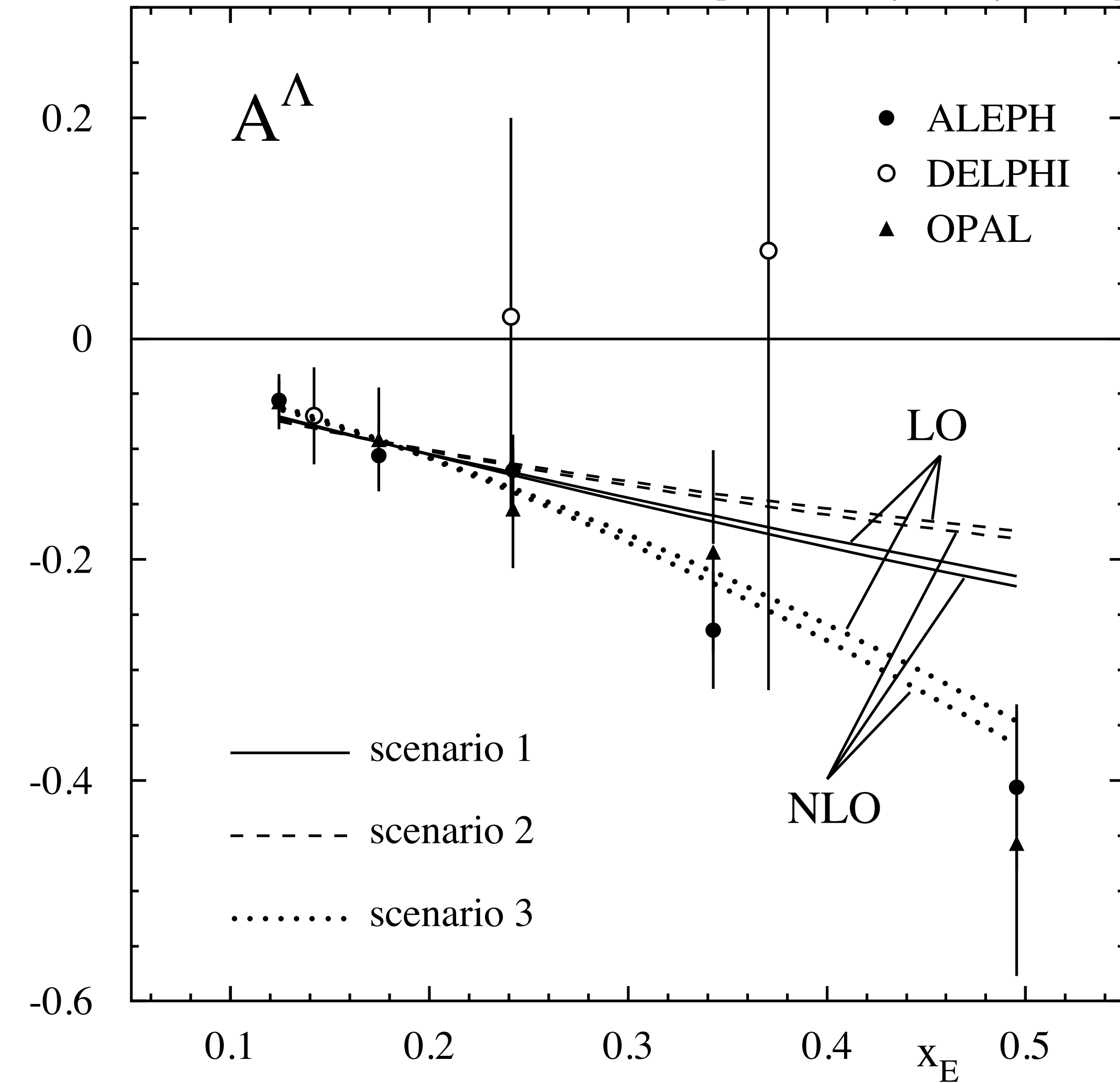


- **Dominance** of the strange quark over the entire z range: consistency with the quark composition of the Λ
- Fragmentation of u or d into Λ is less pronounced compared to s -quark fragmentation, the distributions show a similar shape

[JHEP10(2026)089]

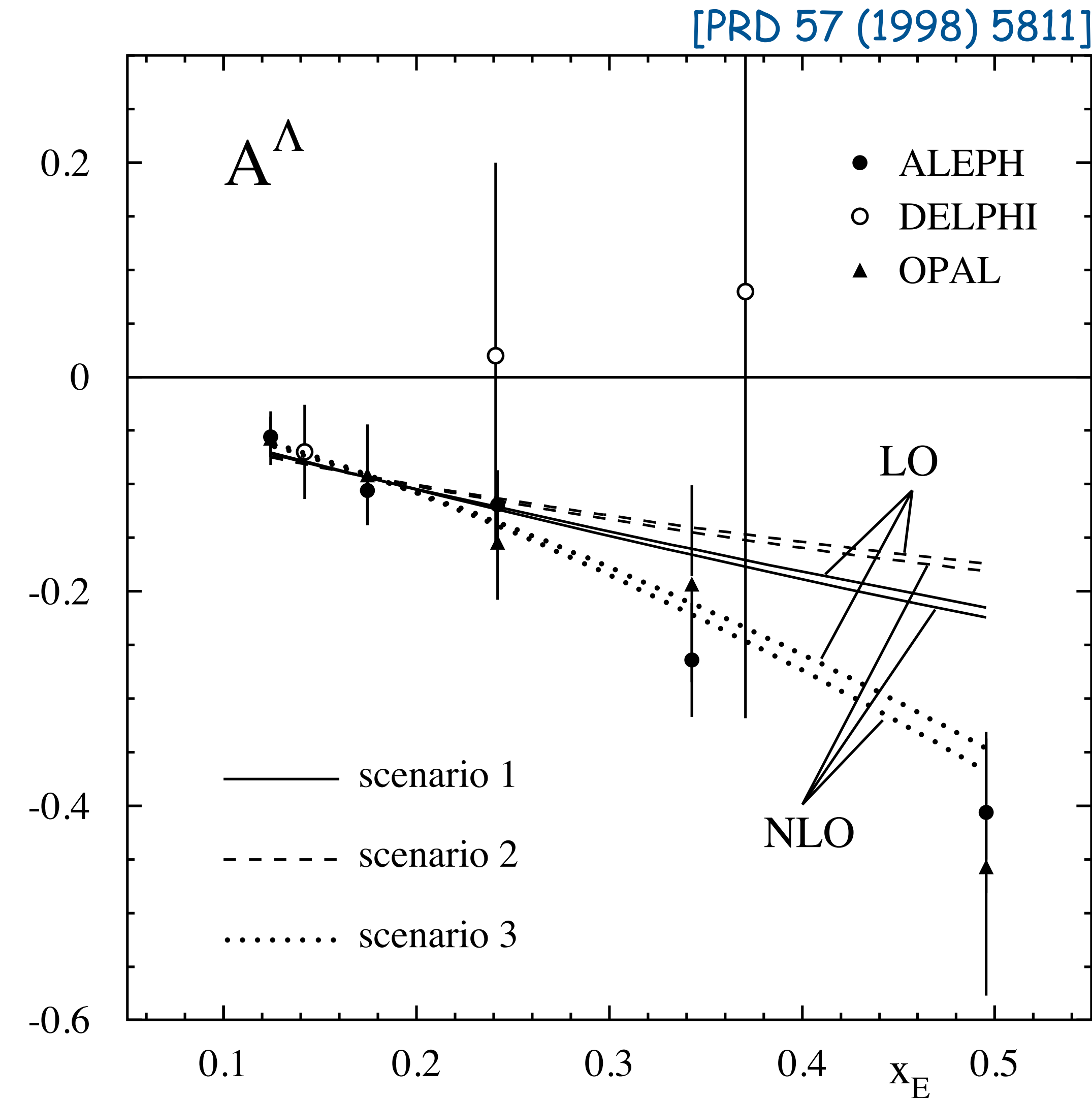
Longitudinal polarization in fragmentation?

[PRD 57 (1998) 5811]



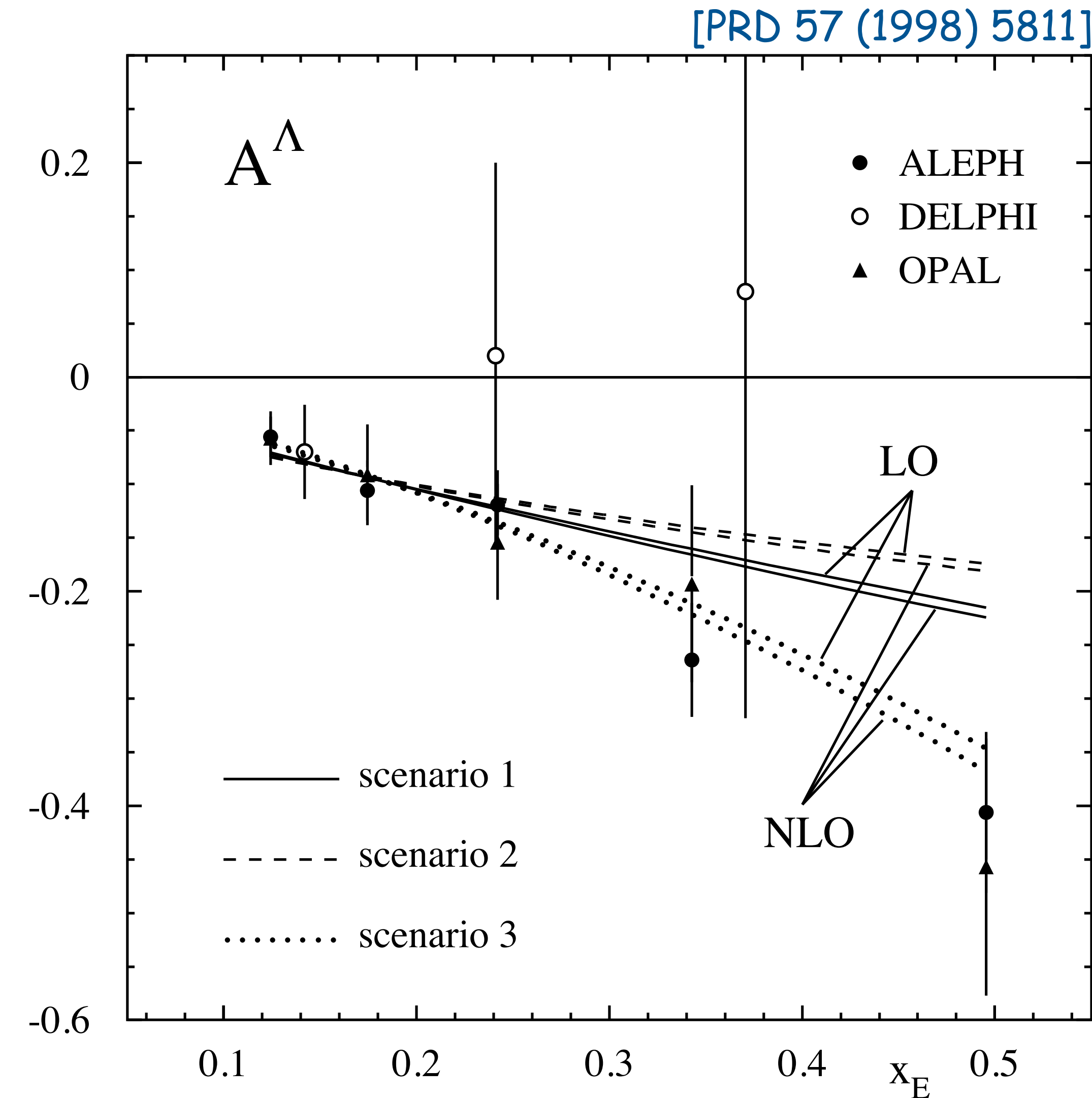
● large longitudinal polarization in e^+e^- at LEP
➡ $G_1 \neq 0$

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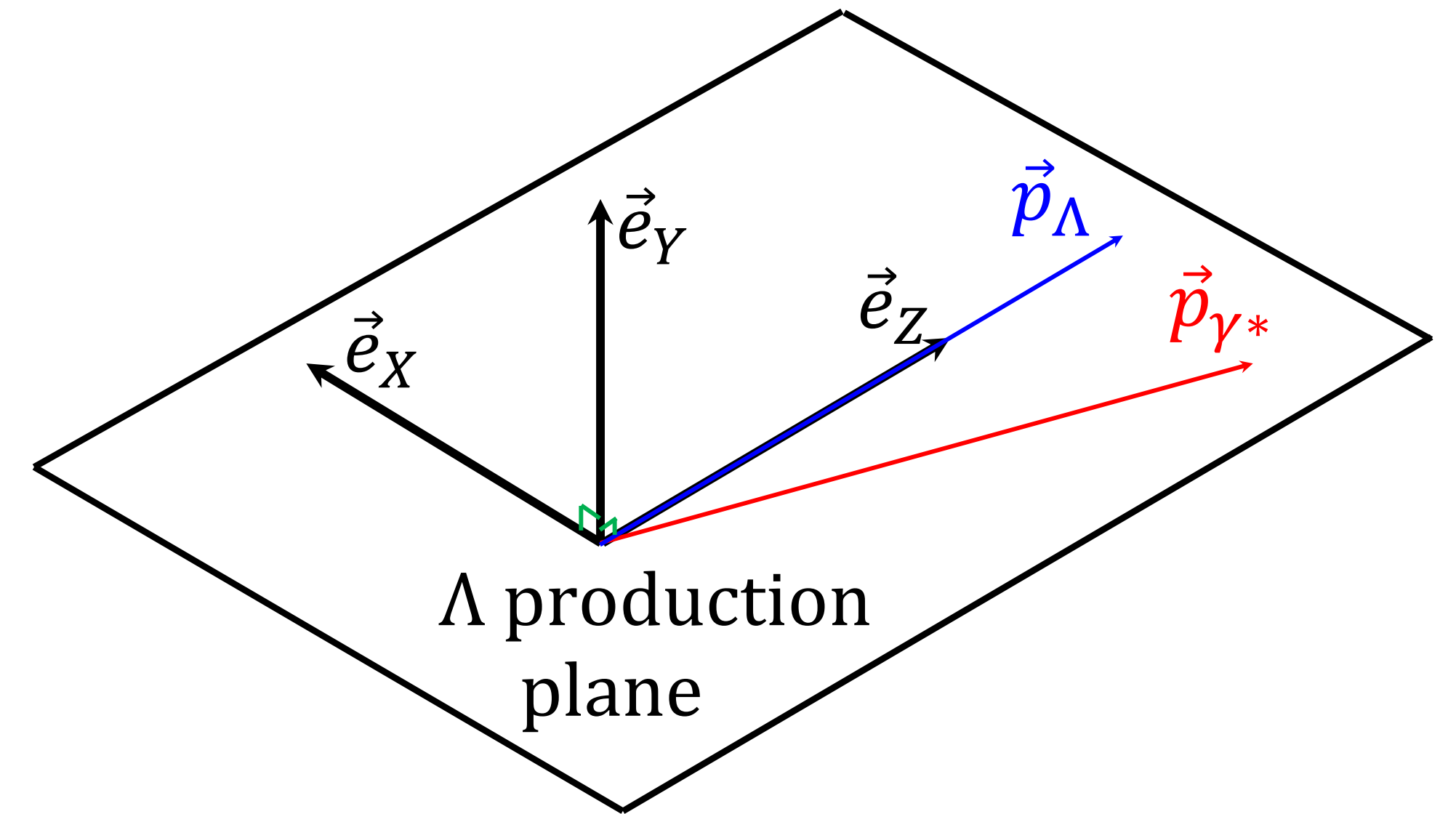
- large longitudinal polarization in e^+e^- at LEP
 ➔ $G_1 \neq 0$
- Z^0 decay produces pairs of highly polarized strange (anti)quarks
- in simple quark models, the Λ spin is carried by strange quarks; the ud pair has zero spin.
- suggests strong spin transfer from a polarized strange quark to Λ

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- in DIS, mainly scattering off u (and d) quarks

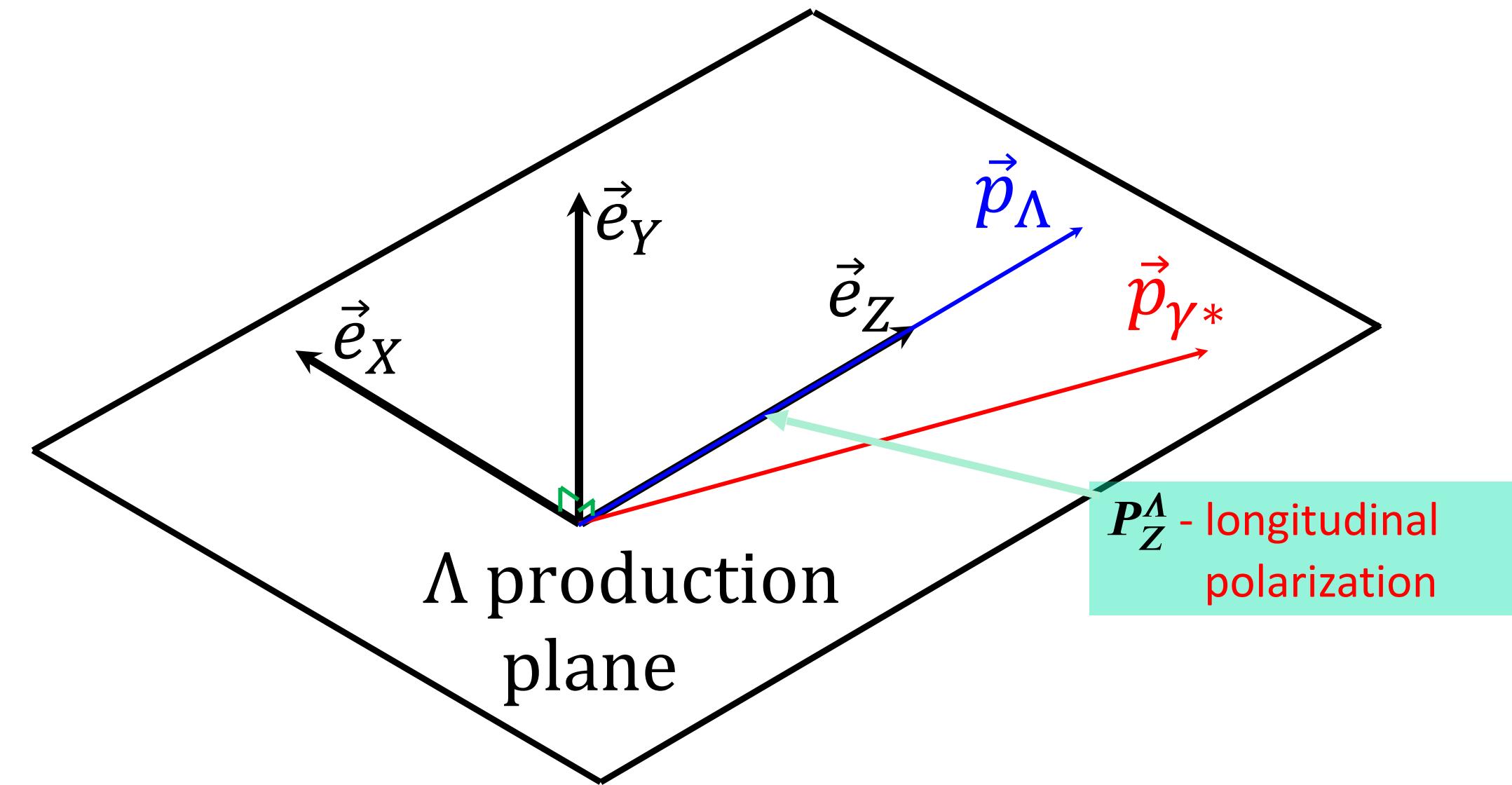
Lambda production in DIS



Lambda production in DIS

Mulders & Tangerman, Nucl. Phys. B 461 (1996) 197; unpolarized target:

$$P_Z^\Lambda = \textcolor{red}{P}_B D_Z(y) \frac{\sum_q e_q^2 x_B f_1^q(x_B) \textcolor{blue}{G}_1^q(z)}{\sum_q e_q^2 x_B f_1^q(x_B) D_1^q(z)}$$

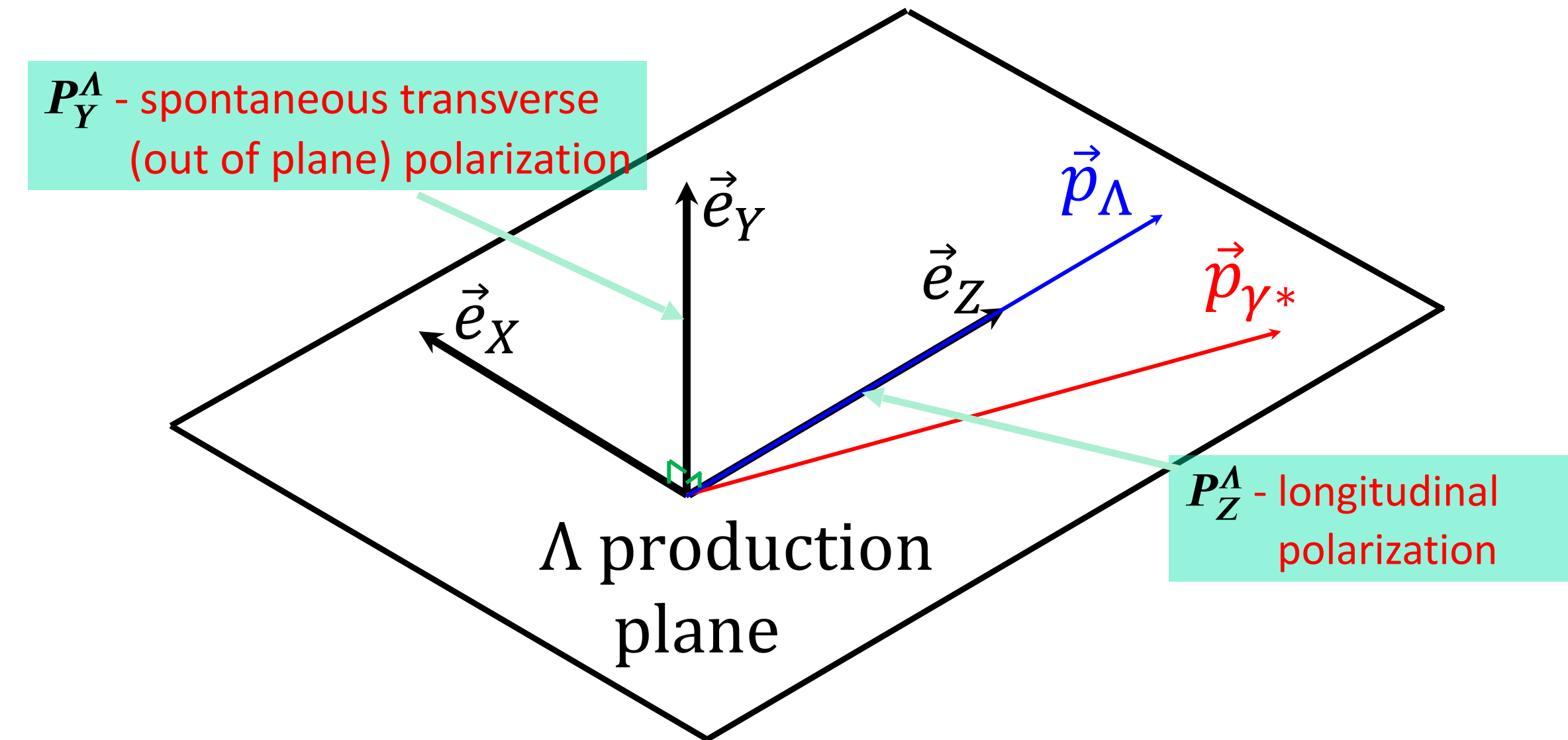


Lambda production in DIS

Mulders & Tangerman, Nucl. Phys. B 461 (1996) 197; unpolarized target:

$$P_Y^\Lambda = D_Y(y) \frac{M}{Q} \frac{\sum_q e_q^2 x_B f_1^q(x_B) D_{1T}^{\perp(1)q}(z)}{\sum_q e_q^2 x_B f_1^q(x_B) D_1^q(z)}$$

$$P_Z^\Lambda = P_B D_Z(y) \frac{\sum_q e_q^2 x_B f_1^q(x_B) G_1^q(z)}{\sum_q e_q^2 x_B f_1^q(x_B) D_1^q(z)}$$



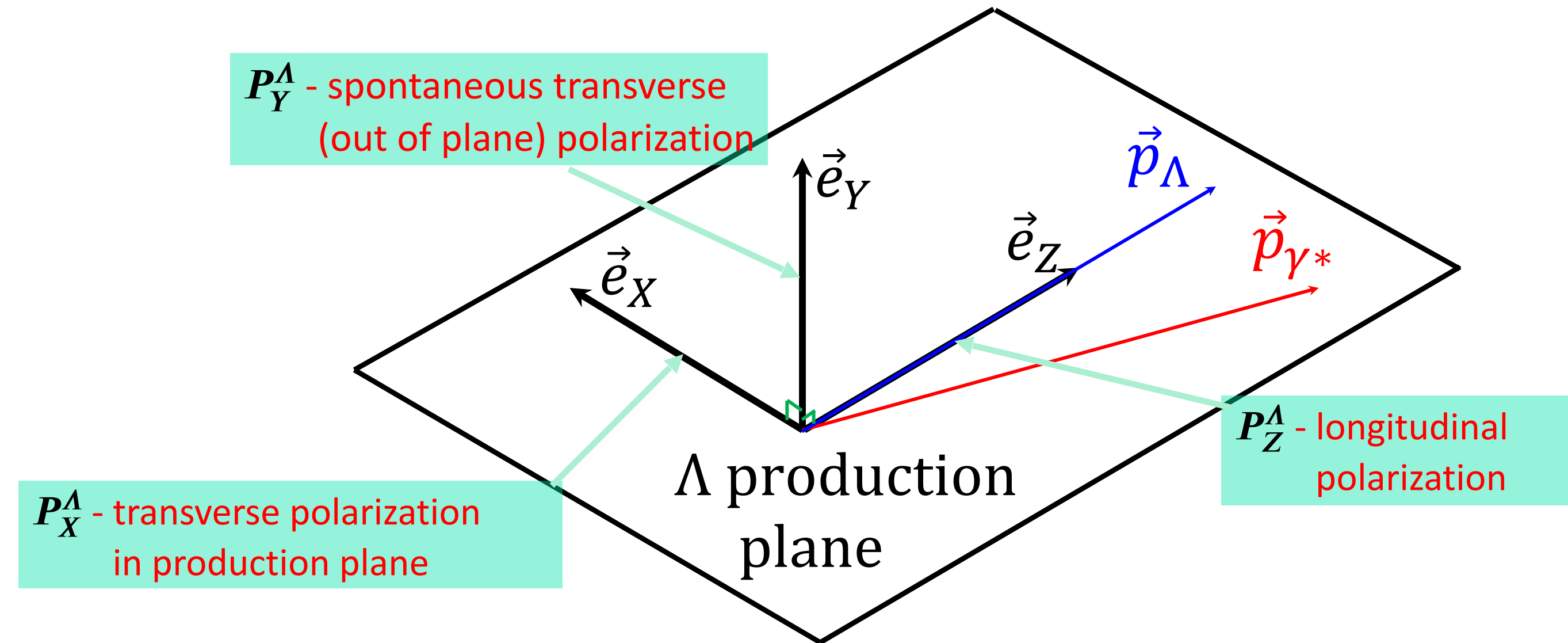
Lambda production in DIS

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$$P_X^\Lambda = -P_B D_X(y) \left\{ \frac{M \sum_q e_q^2 x_B e^q(x_B) H_1^q(z)}{Q \sum_q e_q^2 x_B f_1^q(x_B) D_1^q(z)} + \frac{M^\Lambda \sum_q e_q^2 x_B f_1^q(x_B) \tilde{G}_T^q(z)}{Q \sum_q e_q^2 x_B f_1^q(x_B) D_1^q(z)} \right\}$$

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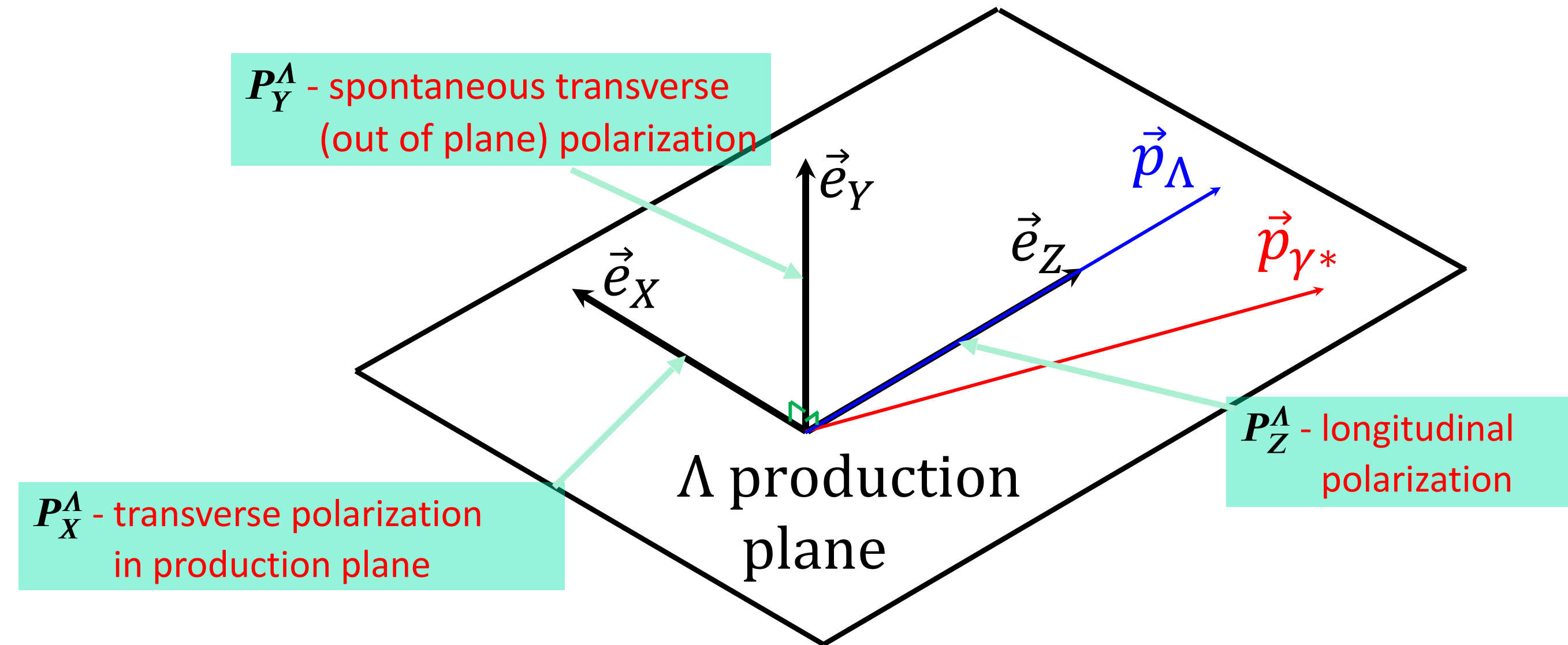
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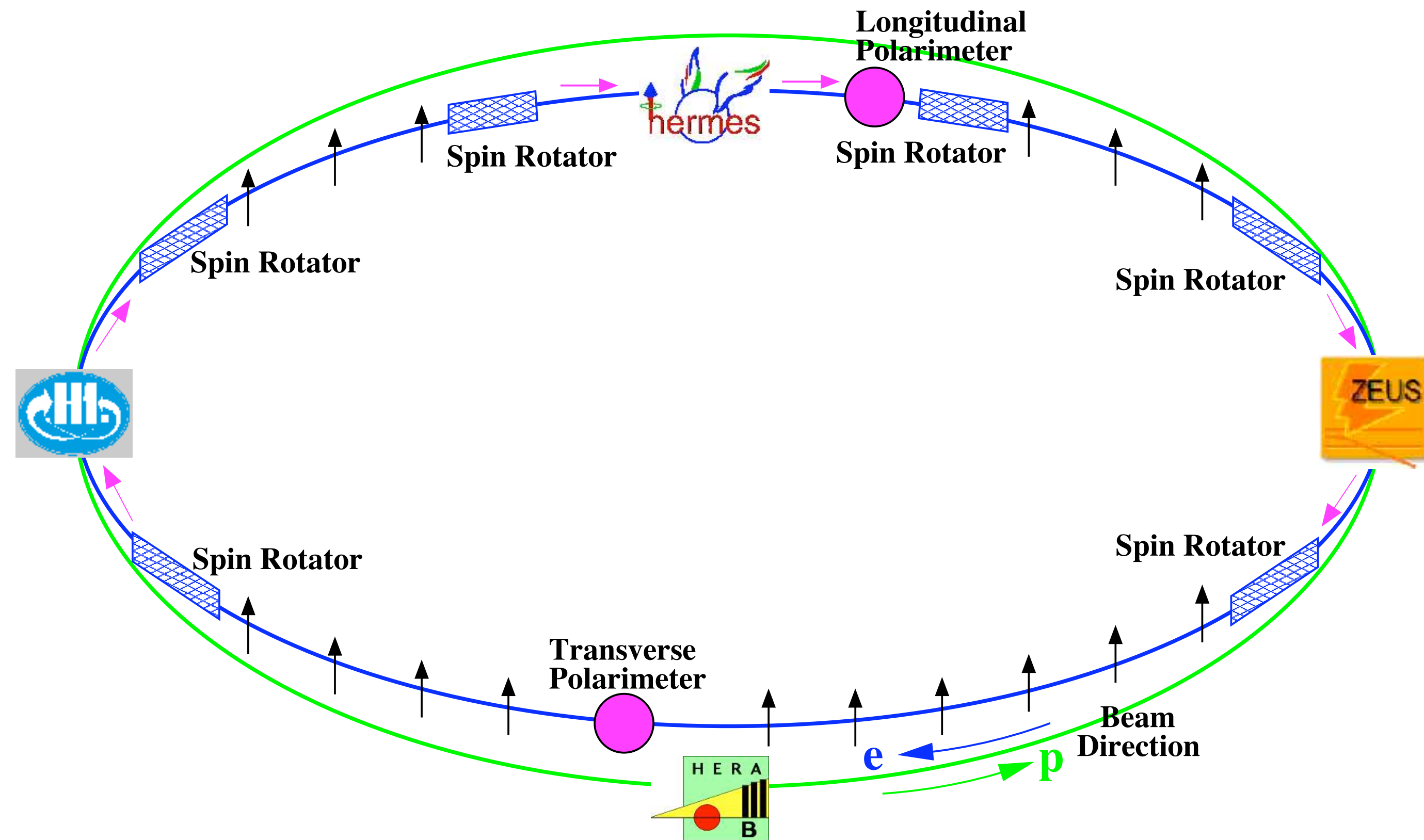
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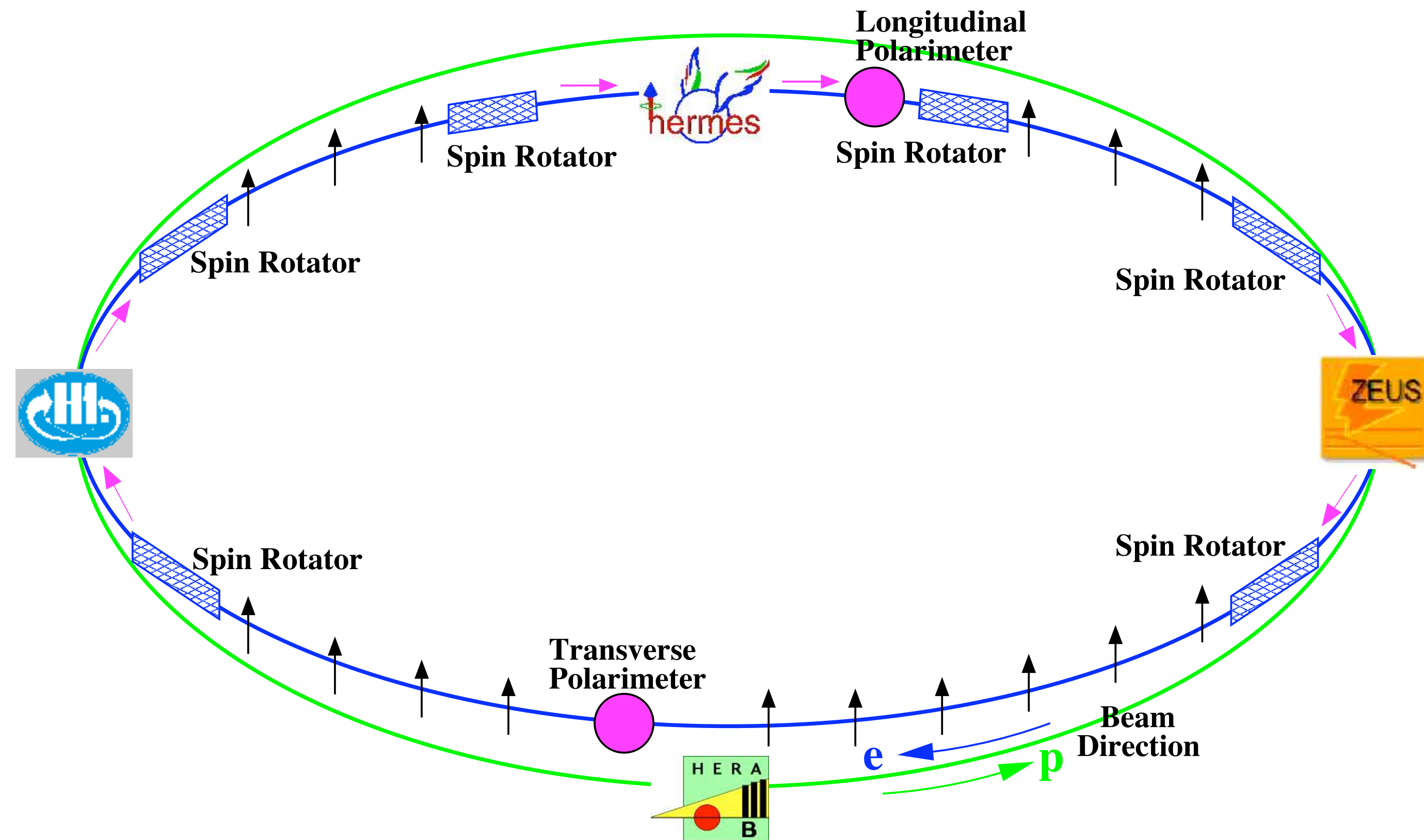


- access to several novel spin-dependent FFs
- Y-component of polarization ("self-polarization") not correlated with beam polarization P_B
 ➔ drops out in beam-spin asymmetries
- concentrate on longitudinal-to-longitudinal and longitudinal-to-transverse spin transfer

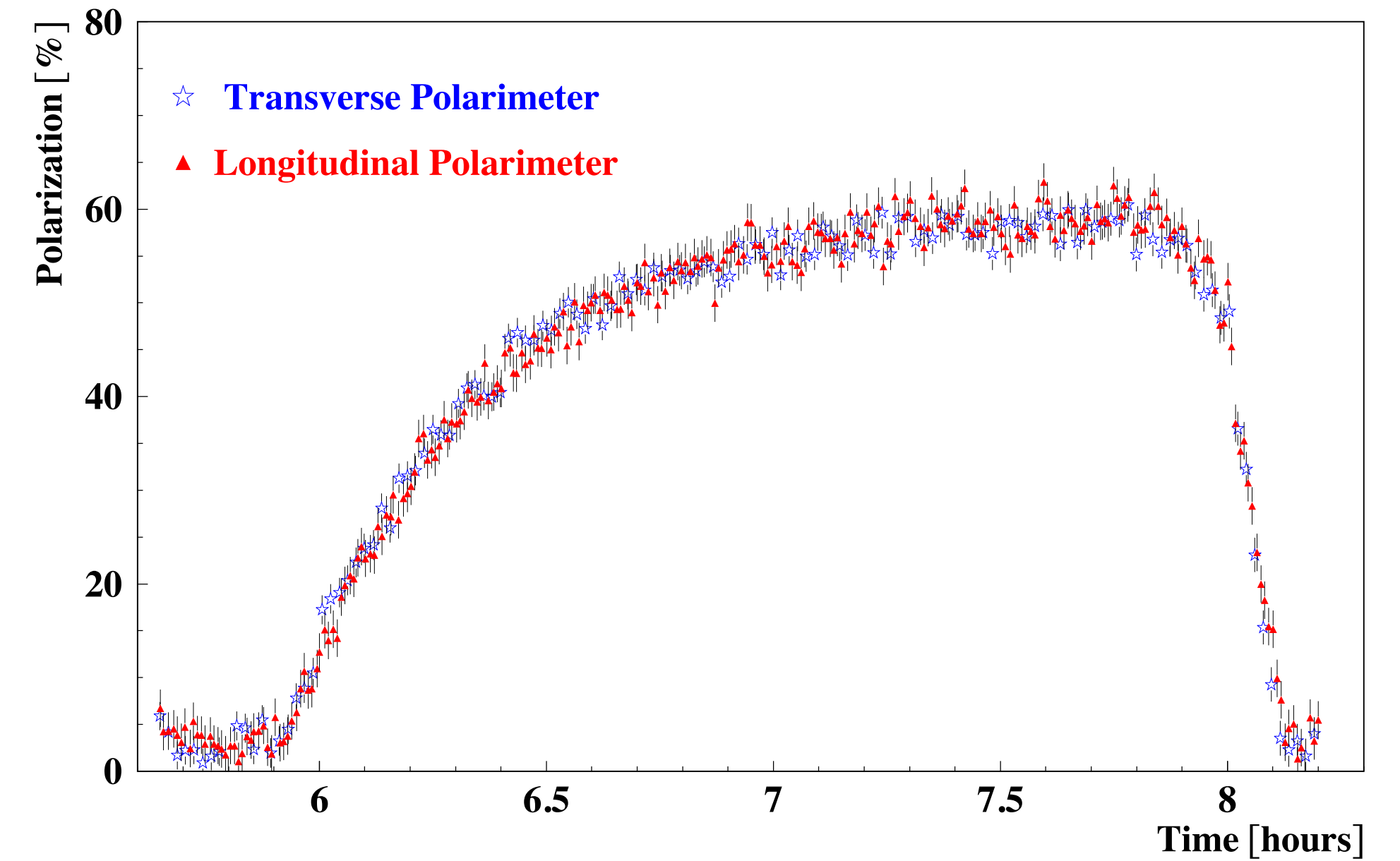
HERMES (1995-2007) @ HERA (DESY)



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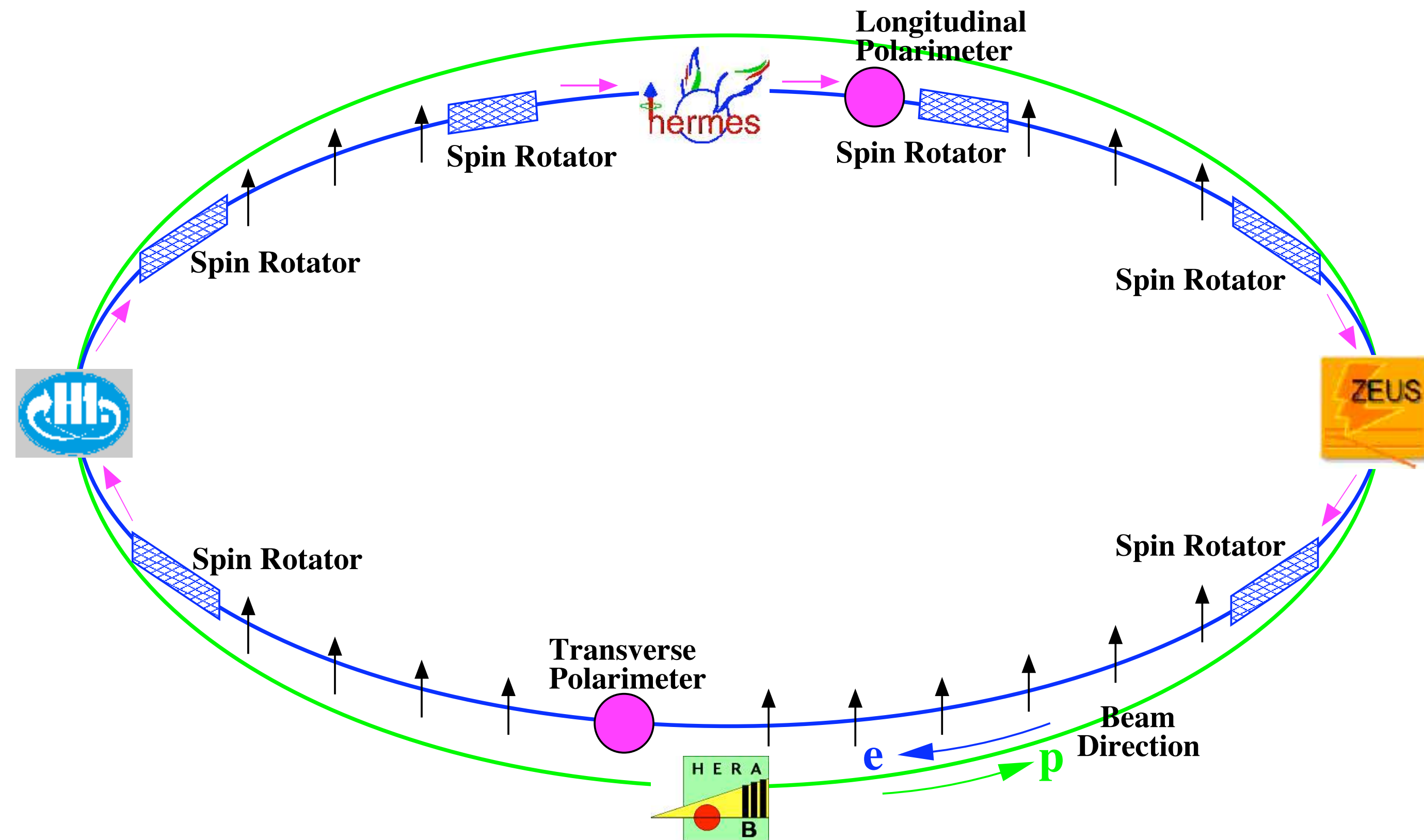


Comparison of rise time curves

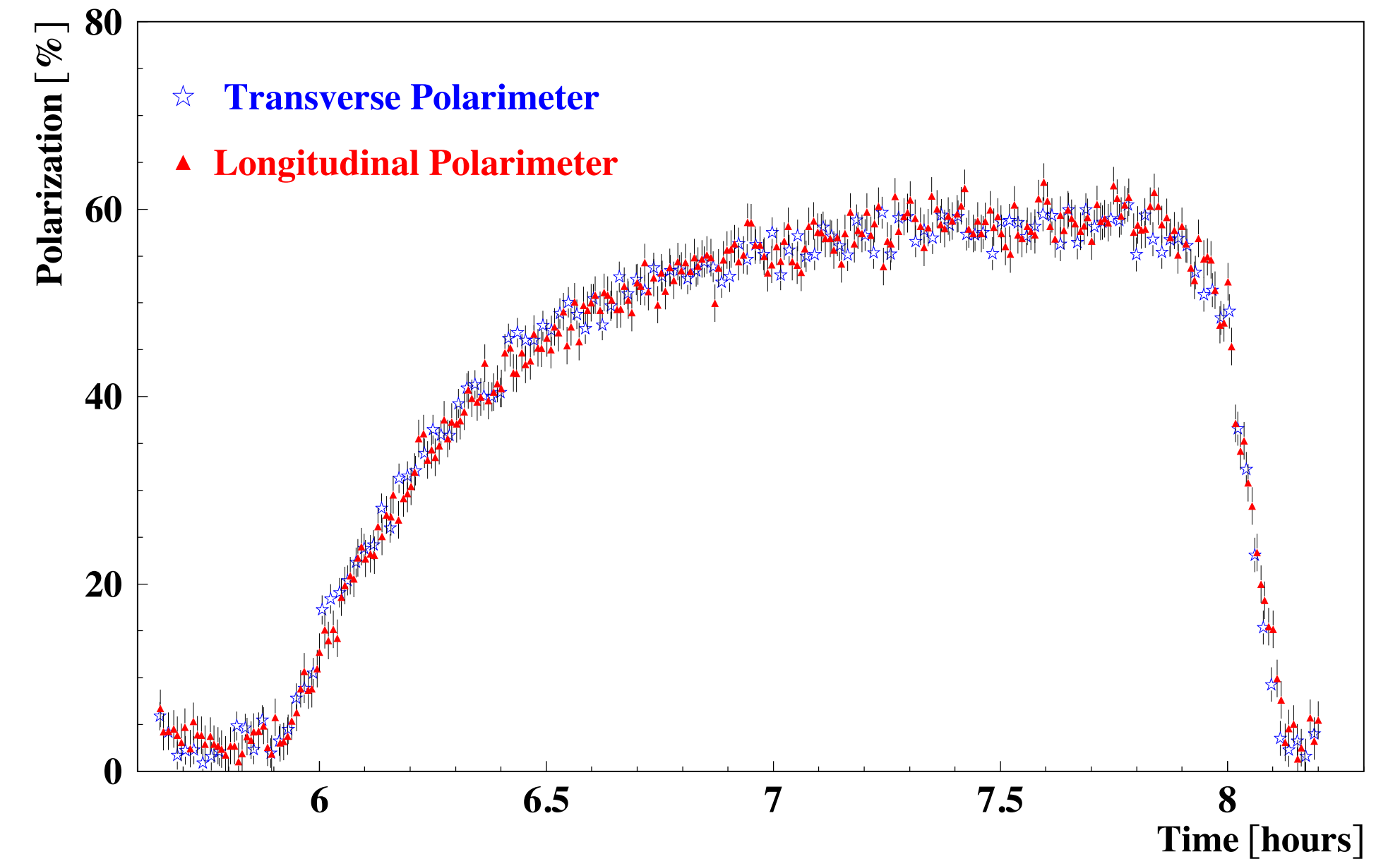


- ☑ beam polarization measured independently by two polarimeters
- ☑ excellent agreement

HERMES (1995-2007) @ HERA (DESY)



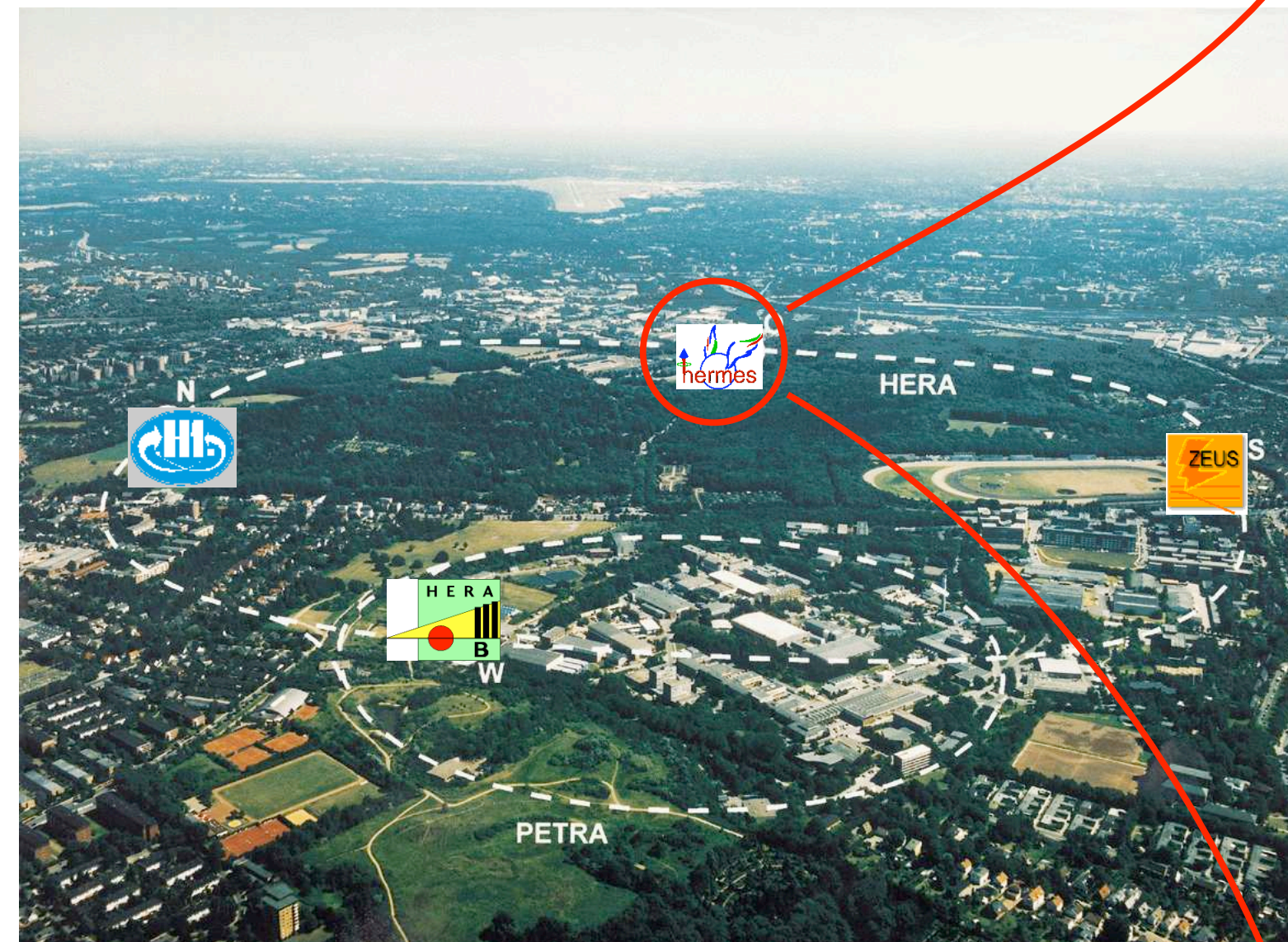
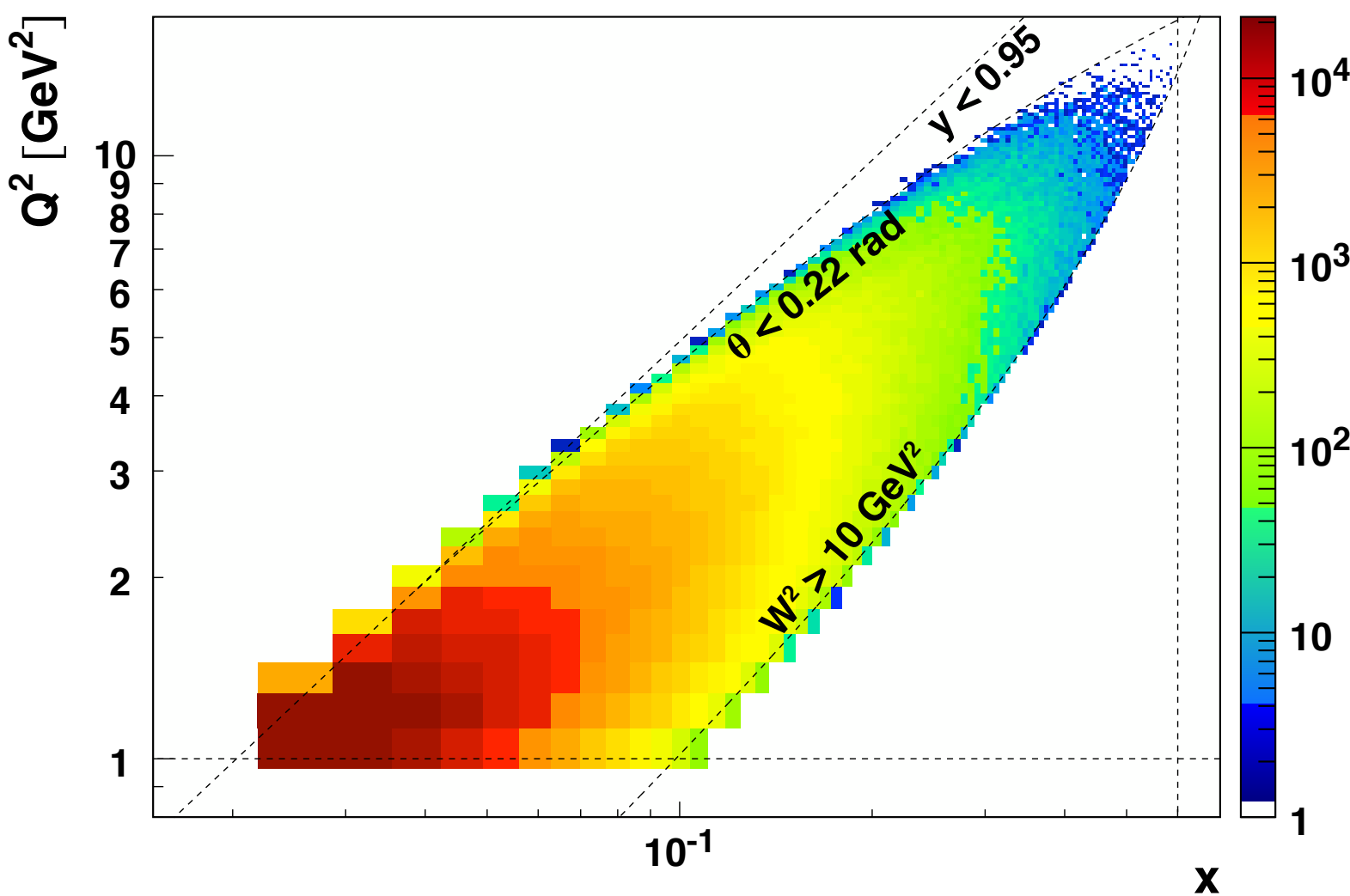
Comparison of rise time curves



- ☑ beam polarization measured independently by two polarimeters
- ☑ excellent agreement
- ☑ polarization up to 60% during HERA I

HERMES (1995-2007) @ HERA (DESY)

27.6 GeV polarized e^+/e^- beam scattered off ...



- ✓ unpolarized (H, D, He,..., Xe) as well as
- ✓ transversely (H) or longitudinally (H, D, He) polarized pure gas targets
- ✓ particle ID (incl. dual-radiator RICH) for efficient $e/\pi/K/p$ separation

Polarization measurement

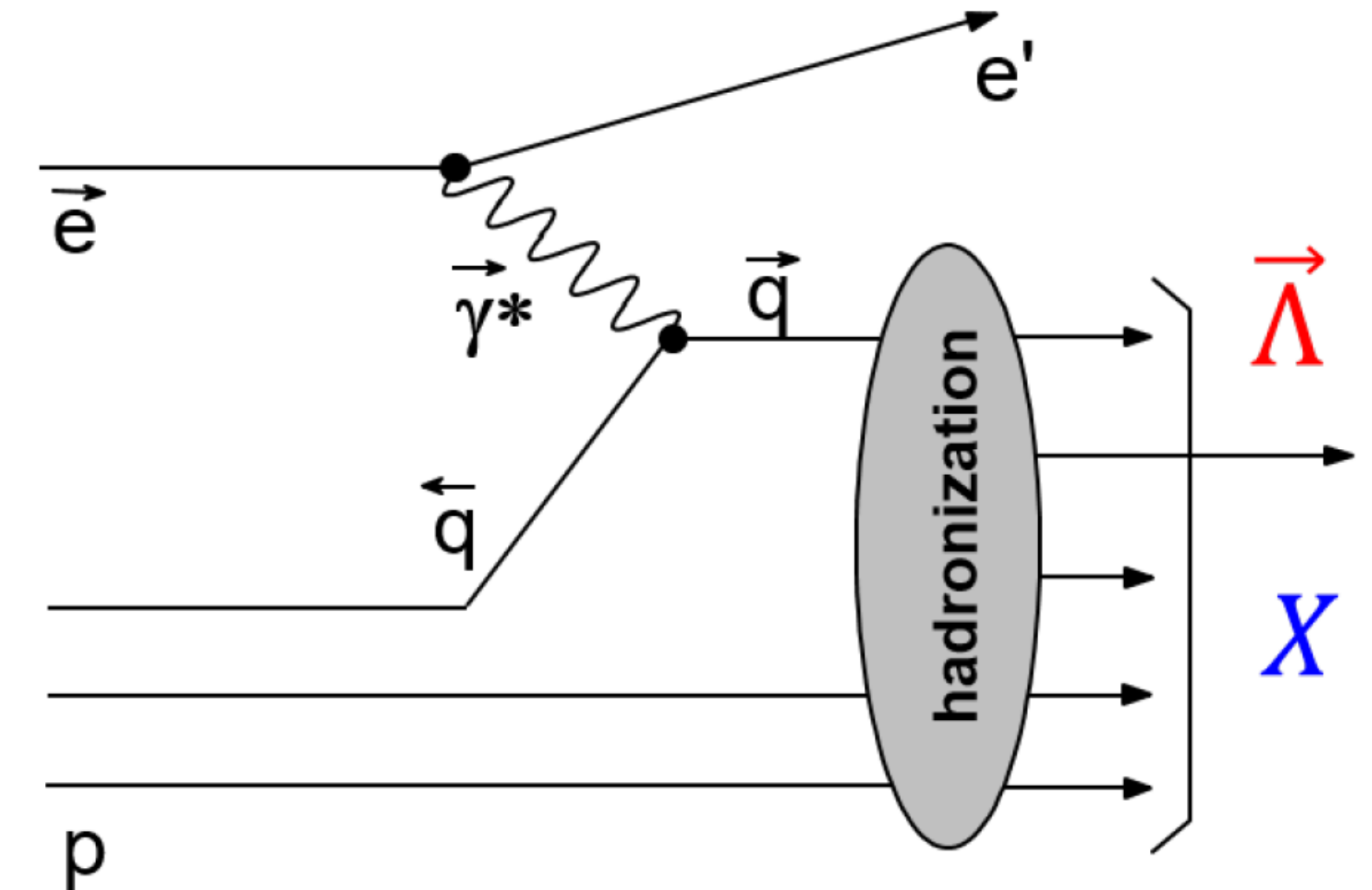
$$\vec{\gamma}^* + p \rightarrow \vec{\Lambda} + X$$

$$\quad \quad \quad \hookrightarrow p\pi^-$$

$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p} (1 + \alpha P_{L'}^{\Lambda} \cos\theta_{pL'})$$

unpolarised (uniform)
distribution

angle between proton
momentum and
 Λ spin in Λ rest frame



- "self-analyzing" particle due to its parity-violating decay
- polarization can be extracted by "simply" measuring angular distribution of decay protons
- in praxis distorted by instrumental effects

Polarization measurement

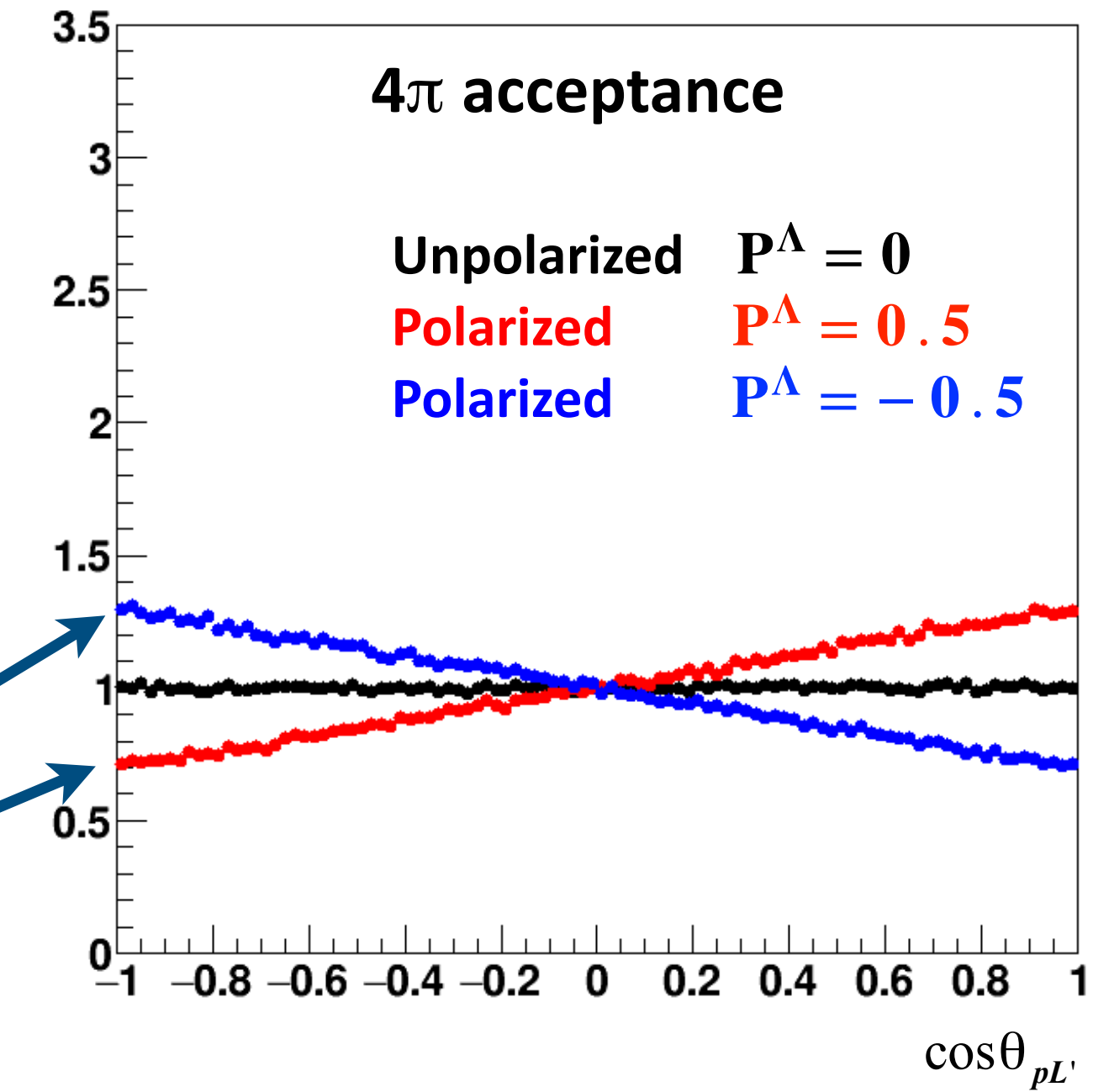
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unpolarised (uniform)
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tilts the uniform
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Polarization measurement

$$\vec{\gamma}^* + p \rightarrow \vec{\Lambda} + X$$

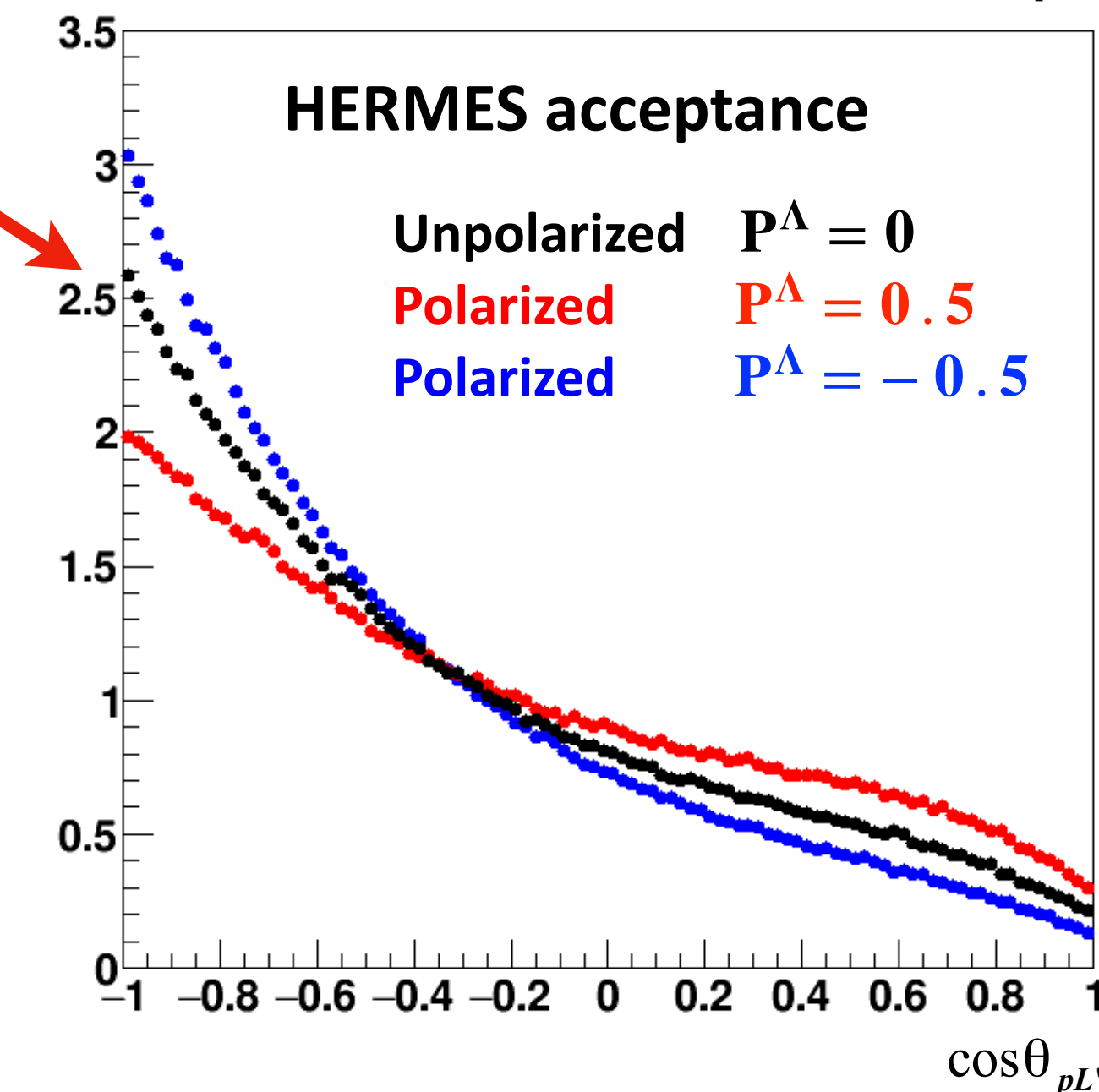
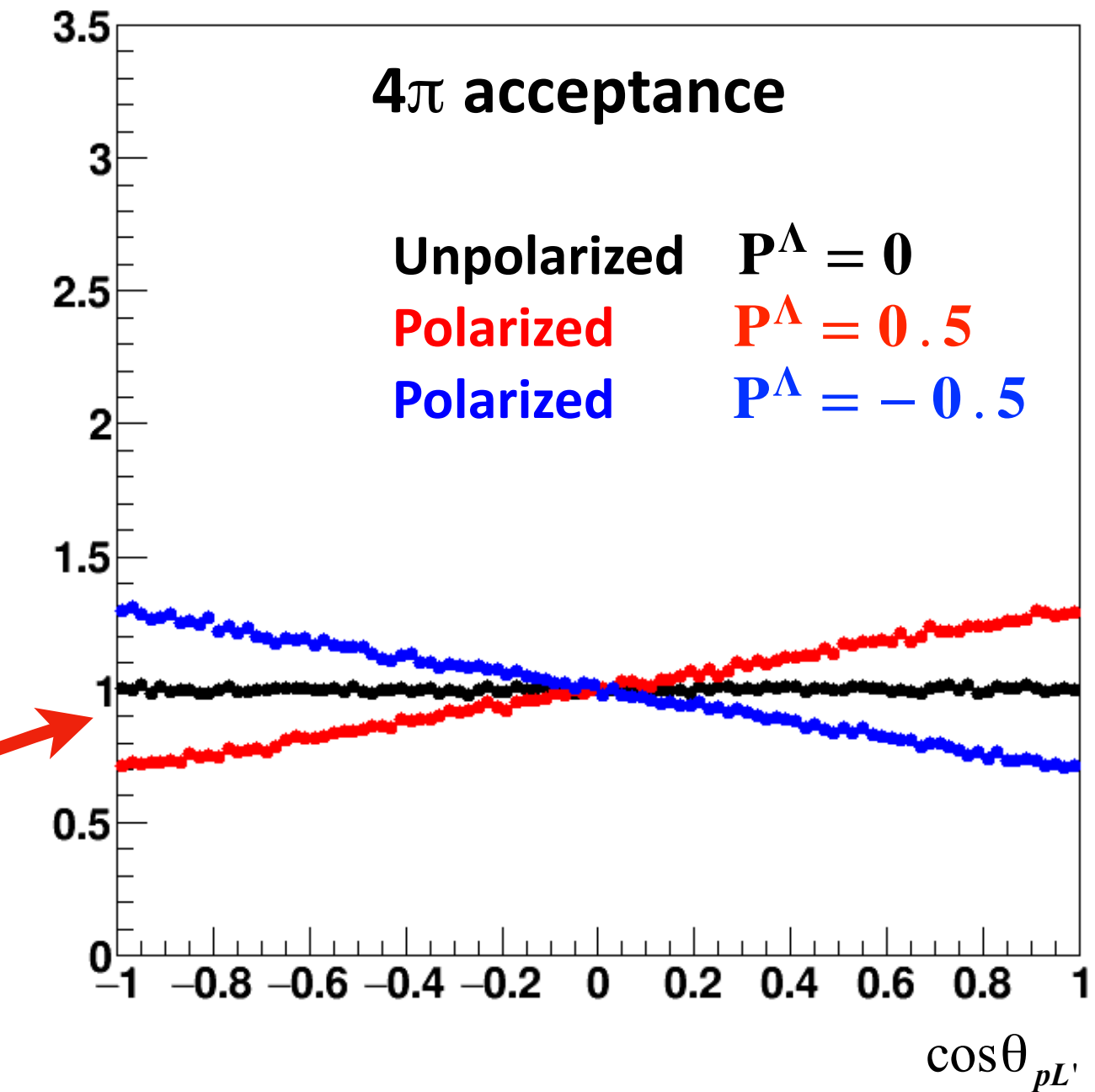
$\hookrightarrow p\pi^-$

$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p} (1 + \alpha P_{L'}^\Lambda \cos\theta_{pL'}) \otimes \varepsilon(\theta_{pL'})$$

unpolarised (uniform)
distribution

tilts the uniform
distribution

- acceptance ε distorts distribution
- heavy use of Monte Carlo to correct for acceptance
- major source of systematic uncertainty



$$\vec{\gamma}^* + p \rightarrow \vec{\Lambda} + X$$

$\hookrightarrow p\pi^-$

$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p} \left(1 + \alpha P_{L'}^A \cos\theta_{pL'} \right) \otimes \varepsilon(\theta_{pL'})$$

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- NOMAD: basically 4π acceptance

$$\vec{\gamma}^* + p \rightarrow \vec{\Lambda} + X$$

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$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p} \left(1 + \alpha P_{L'}^A \cos\theta_{pL'} \right) \otimes \varepsilon(\theta_{pL'})$$

unpolarised (uniform)
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tilts the uniform
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- NOMAD: basically 4π acceptance
- COMPASS: **MC** simulation of acceptance

Polarization measurement

$$\vec{\gamma}^* + p \rightarrow \vec{\Lambda} + X$$

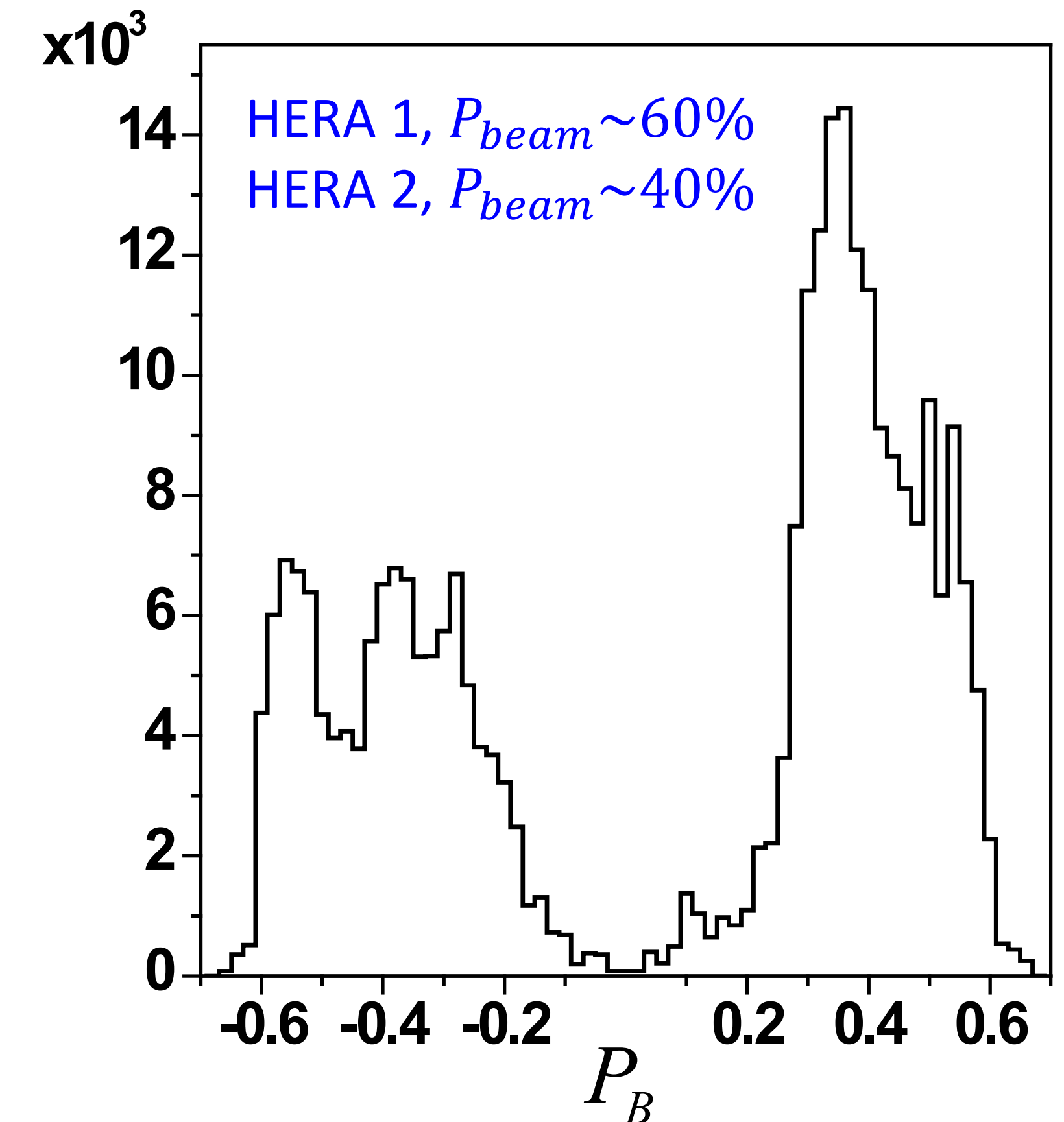
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$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p} \left(1 + \alpha P_{L'}^{\Lambda} \cos\theta_{pL'} \right) \otimes \varepsilon(\theta_{pL'})$$

unpolarised (uniform)
distribution

tilts the uniform
distribution

- NOMAD: basically 4π acceptance
- COMPASS: MC simulation of acceptance
- HERMES: **cancel** acceptance effect using two beam helicity states
(basically measures spin asymmetry)



Moment method [Phys. Rev. D64 (2001), 112005]:

Polarization measurement

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1. calculate $\langle P_B \cos \theta_{pL'} \rangle$ and $\langle \cos^2 \theta_{pL'} \rangle$ with $\frac{d\omega}{d\Omega_p} = \frac{d\omega_0}{d\Omega_p} \left(1 + \alpha \vec{P}^\Lambda \vec{k}_p \right)$

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- extended to 3D case

Extraction of spin transfer in 3D and unbalanced case:

$$\sum_{k=x,z} \mathbf{D}_{Lk} \left\langle \frac{D_k(y) D_i(y) \cos \theta_k \cos \theta_i}{1 + \alpha \llbracket P_B \rrbracket \sum_{j=x,z} D_j(y) \mathbf{D}_{Lj} \cos \theta_j} \right\rangle = \frac{1}{\alpha} \frac{\langle P_B D_i(y) \cos \theta_i \rangle - \llbracket P_B \rrbracket \langle D_i(y) \cos \theta_i \rangle}{\llbracket P_B^2 \rrbracket - \llbracket P_B \rrbracket^2}$$

- system of "linear" equations

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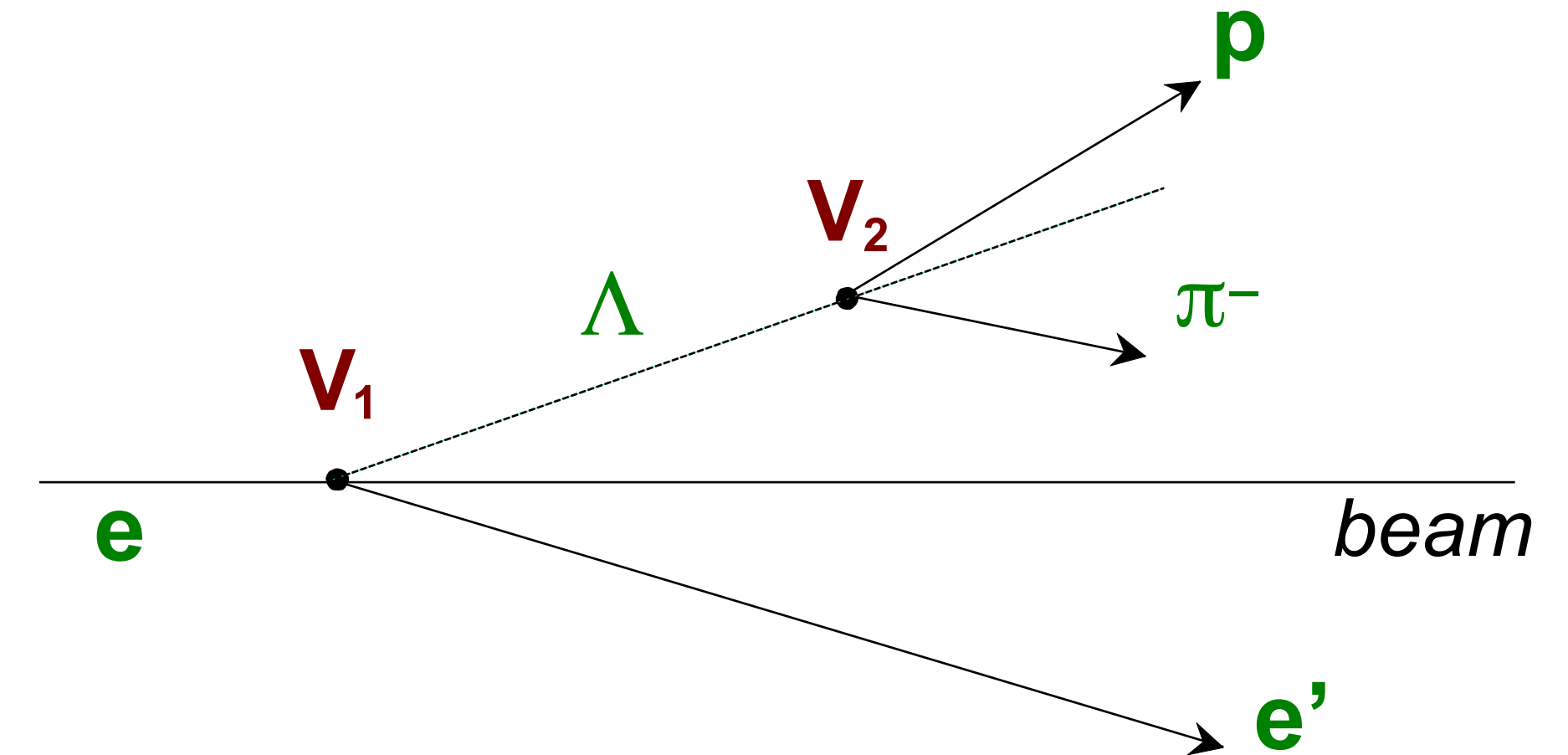
- 3 steps are sufficient to converge due to $\alpha \llbracket P_B \rrbracket \sum_{j=x,z} D_j(y) \mathbf{D}_{Lj} \cos \theta_j \sim 0$

(anti-)Lambda yields at HERMES

- HERA-I data of 1999-2000
- HERA-II data of 2003-2007
- DIS cuts
 - $W^2 > 10 \text{ GeV}^2$
 - $0.2 < y < 0.85$
 - $0.8 \text{ GeV}^2 < Q^2 < 24 \text{ GeV}^2$

$$x = \frac{Q^2}{2M\nu}, y = \frac{\nu}{E_e} = \frac{E_e - E'_e}{E_e}, z = \frac{E^\Lambda}{\nu} \quad [\text{fixed-target frame}]$$

$$x_F = \frac{p_{\parallel}^\Lambda}{p_{\max}^\Lambda} \quad [\text{photon-nucleon c.m. frame}]$$



Background suppression

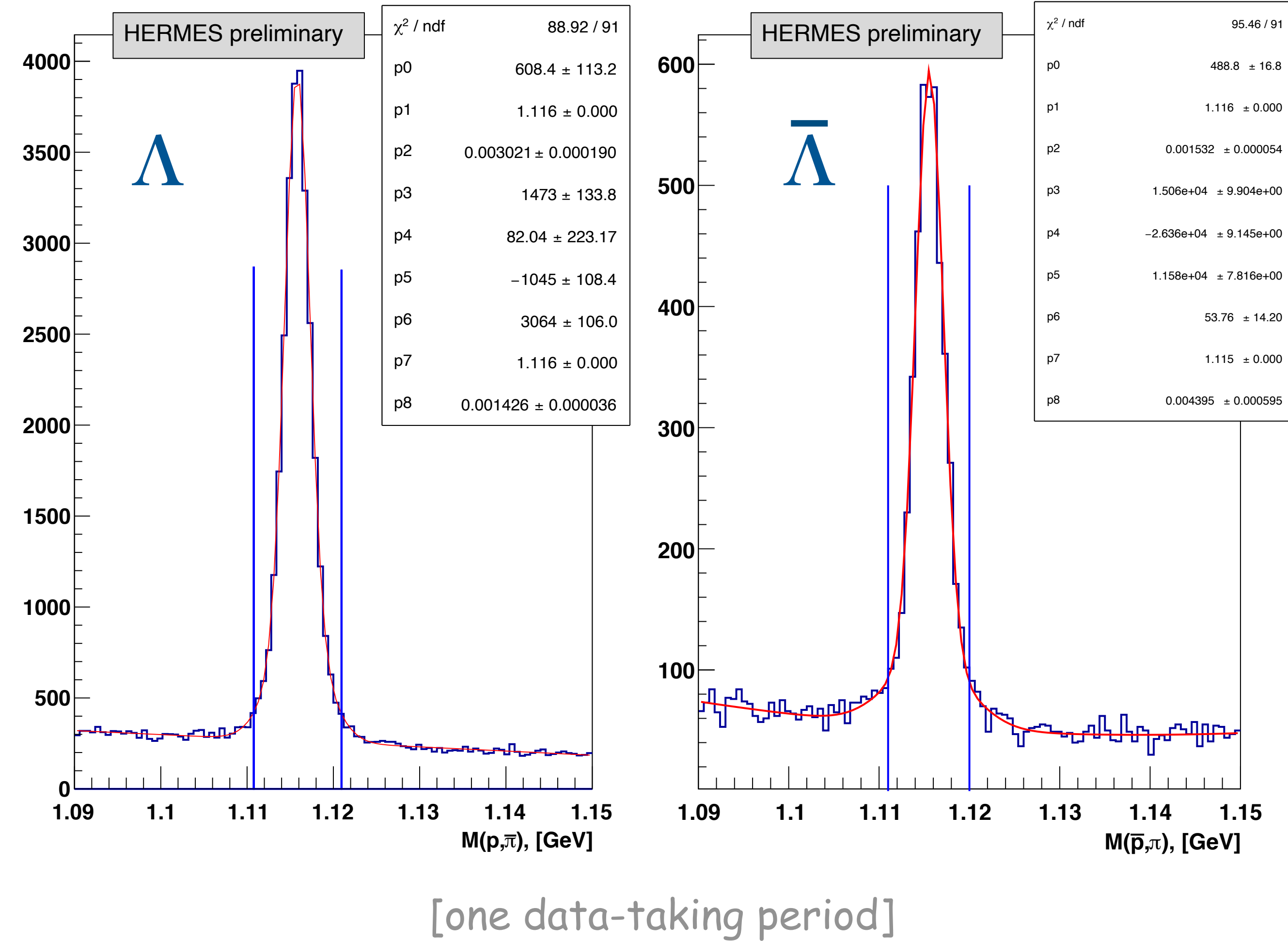
- leading π rejection
(in HERMES kinematics proton is always leading):
- h^+h^- pair background (coming from V_1) rejection, vertex separation:
 - $d(V_1, V_2) > 6 \text{ cm}$ for Λ
 - $d(V_1, V_2) > 10 \text{ cm}$ for $\bar{\Lambda}$

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- total number of (anti) Λ is about 40k (6k)

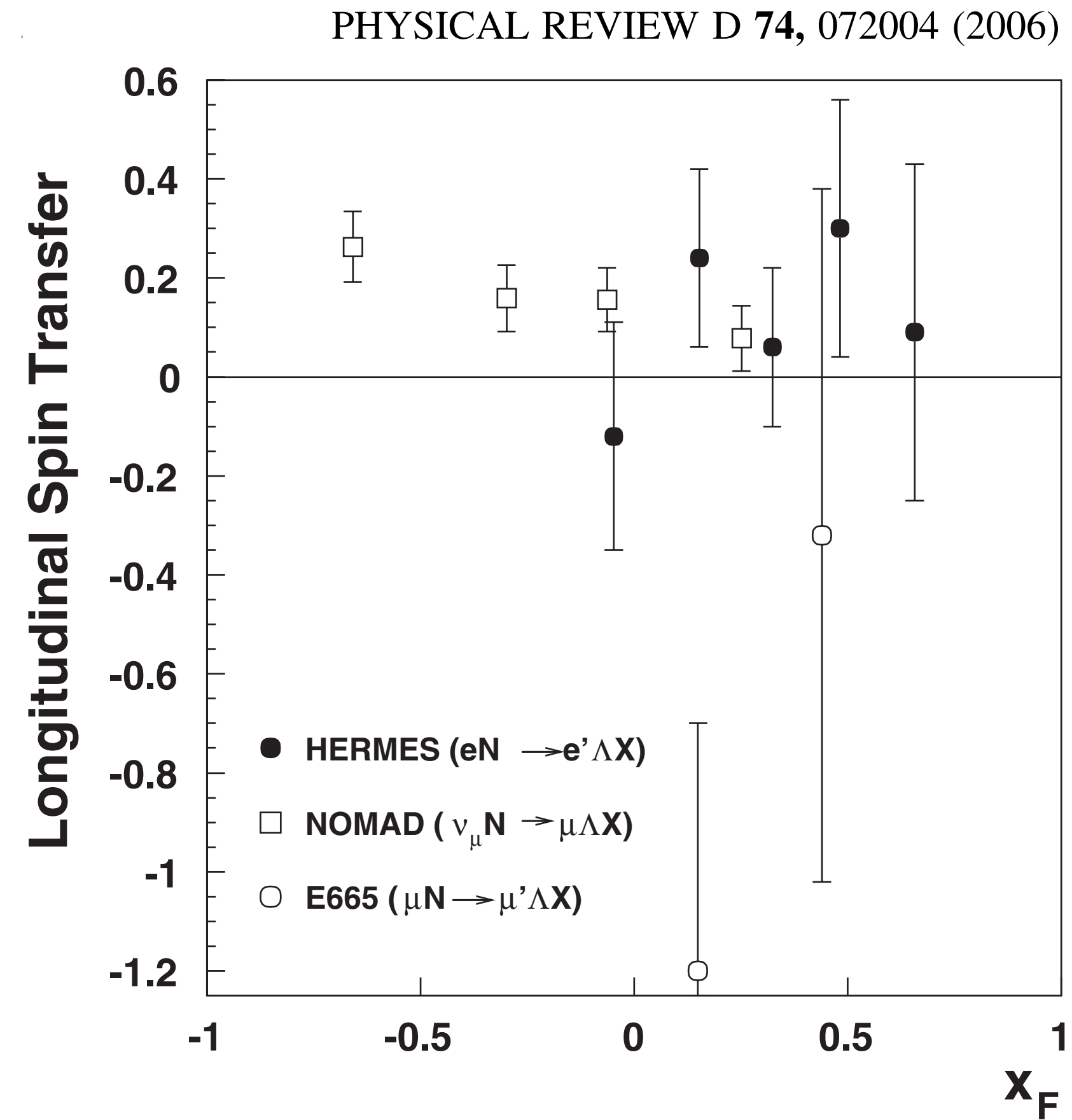
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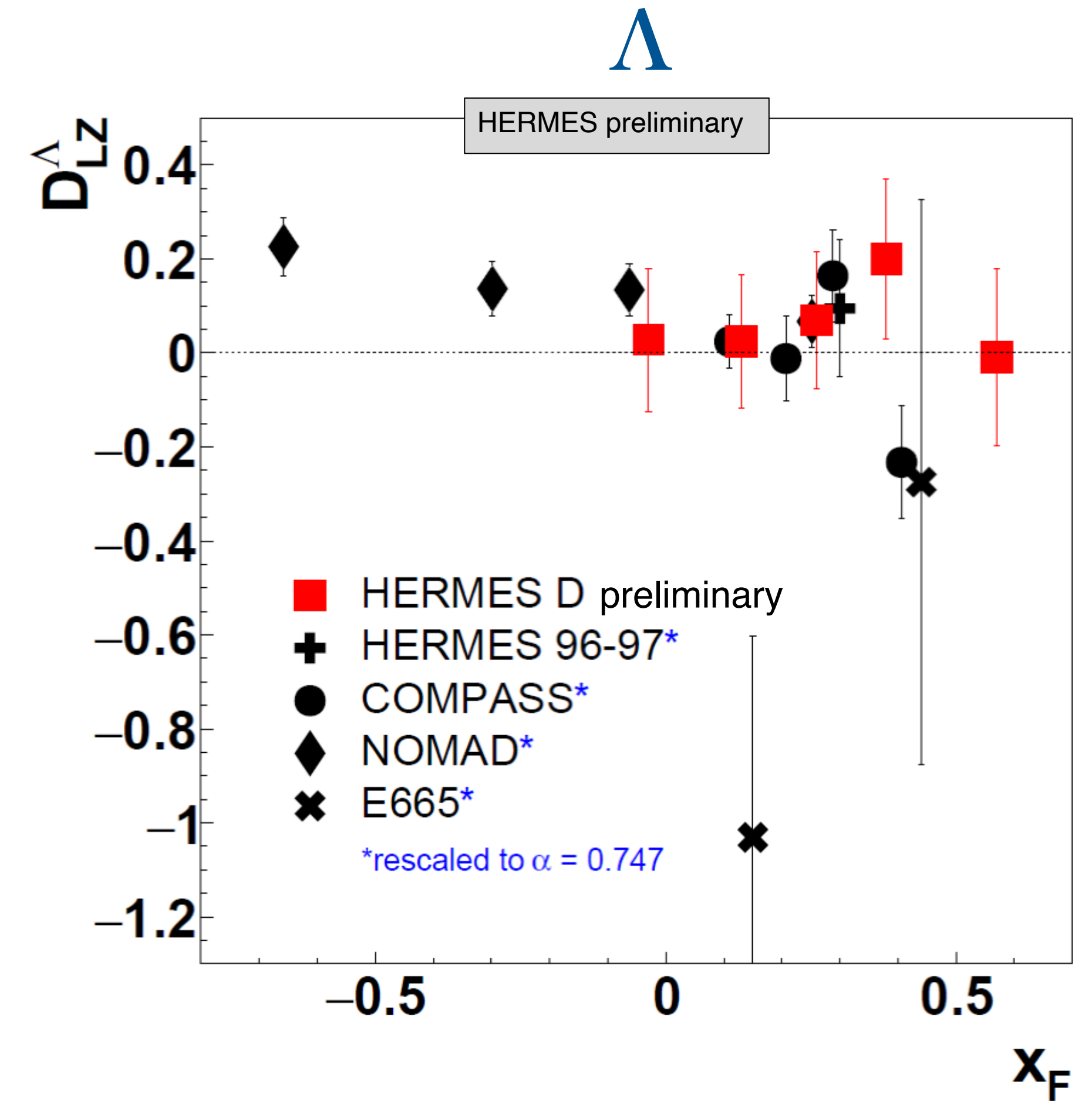
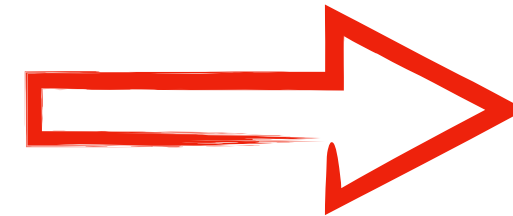
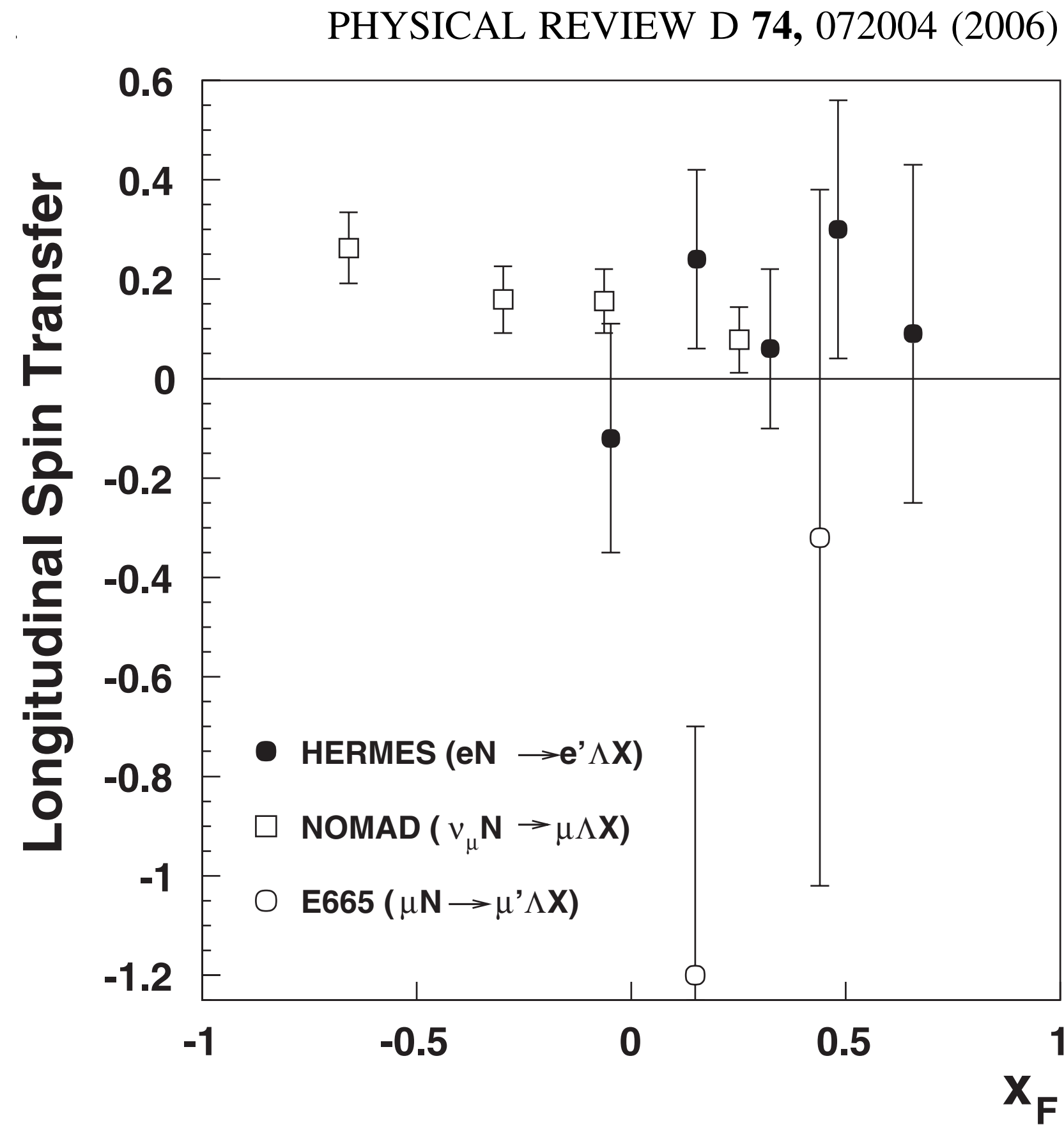
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Improvements from previous publication



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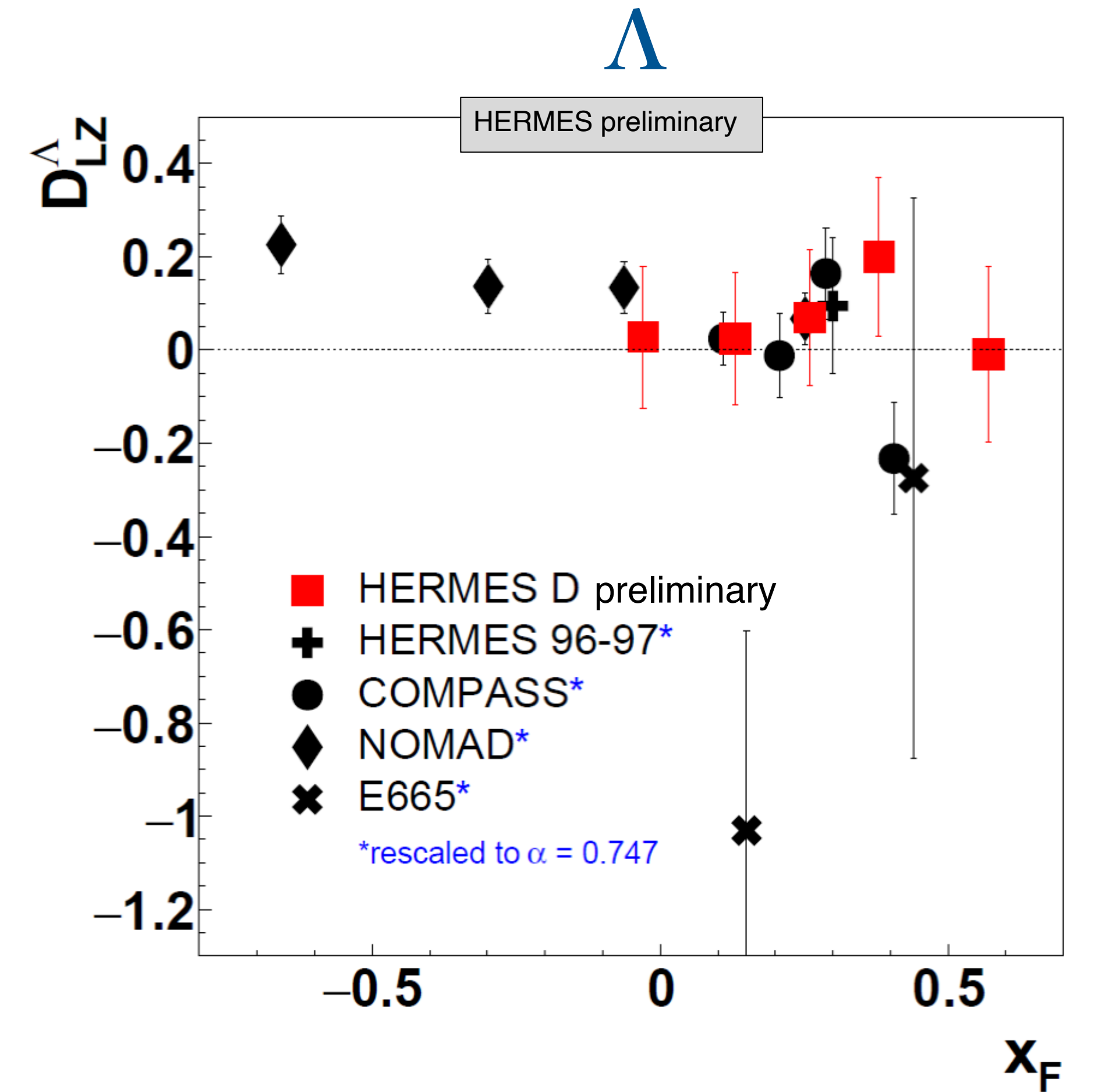
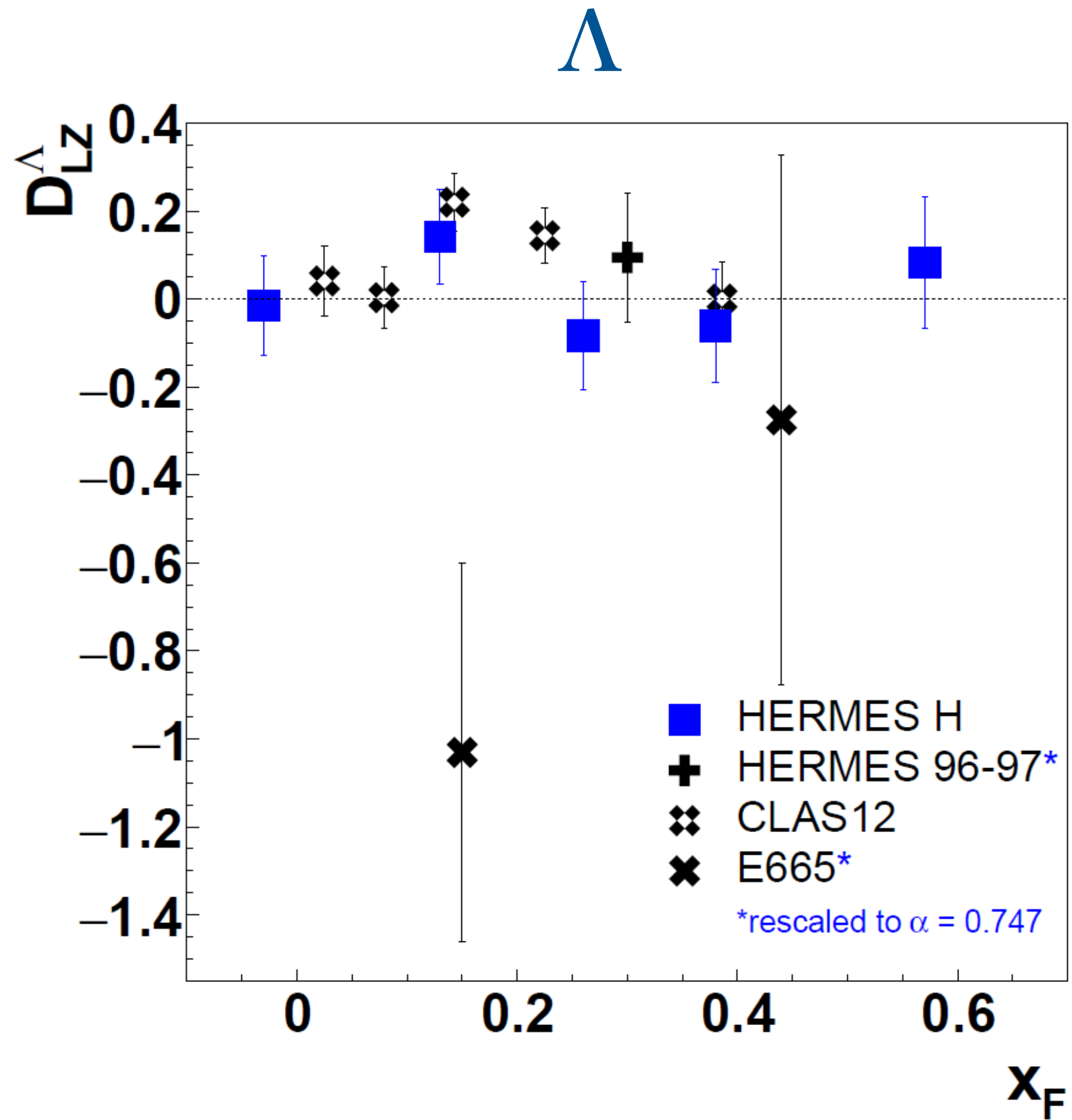
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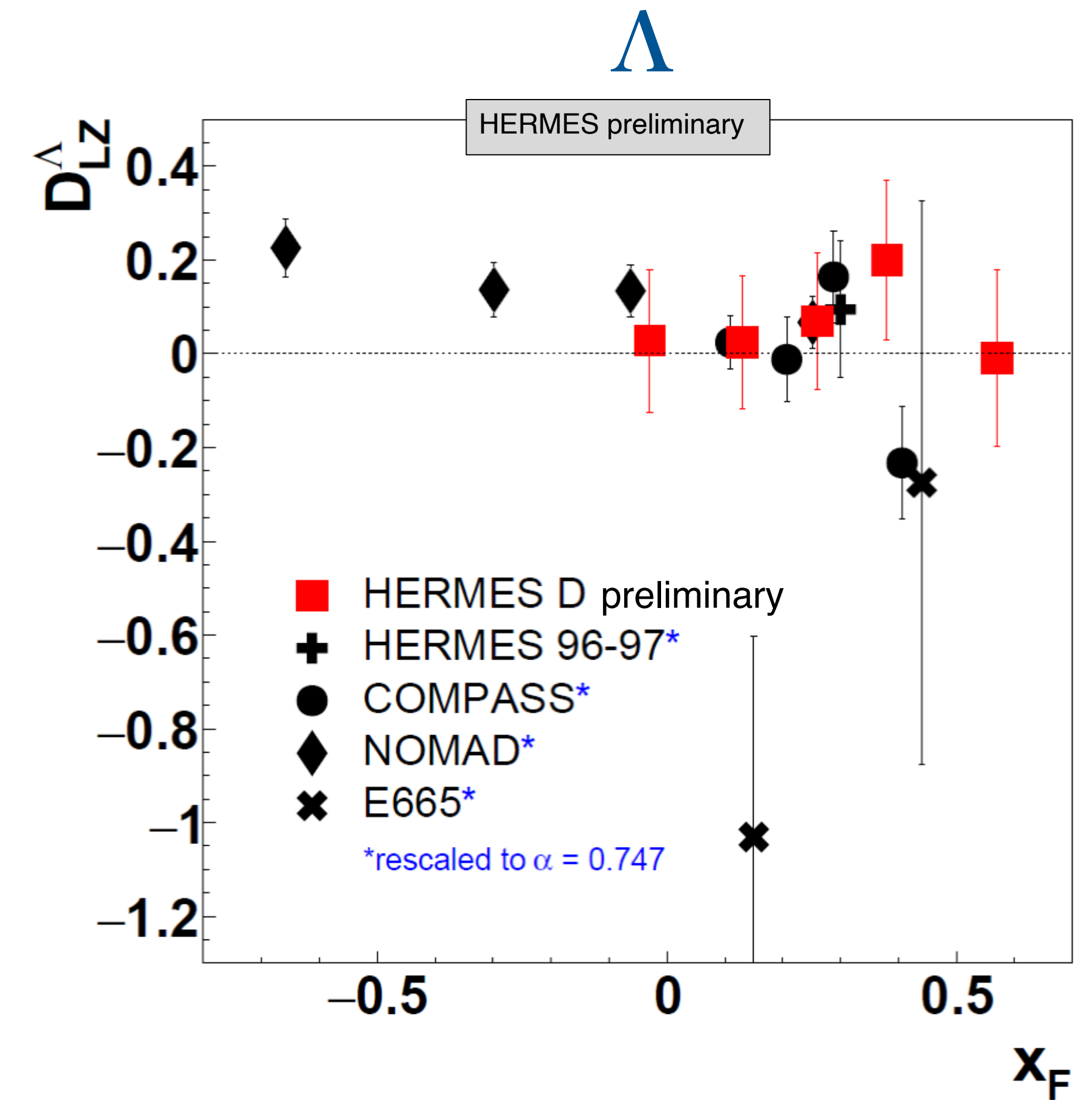
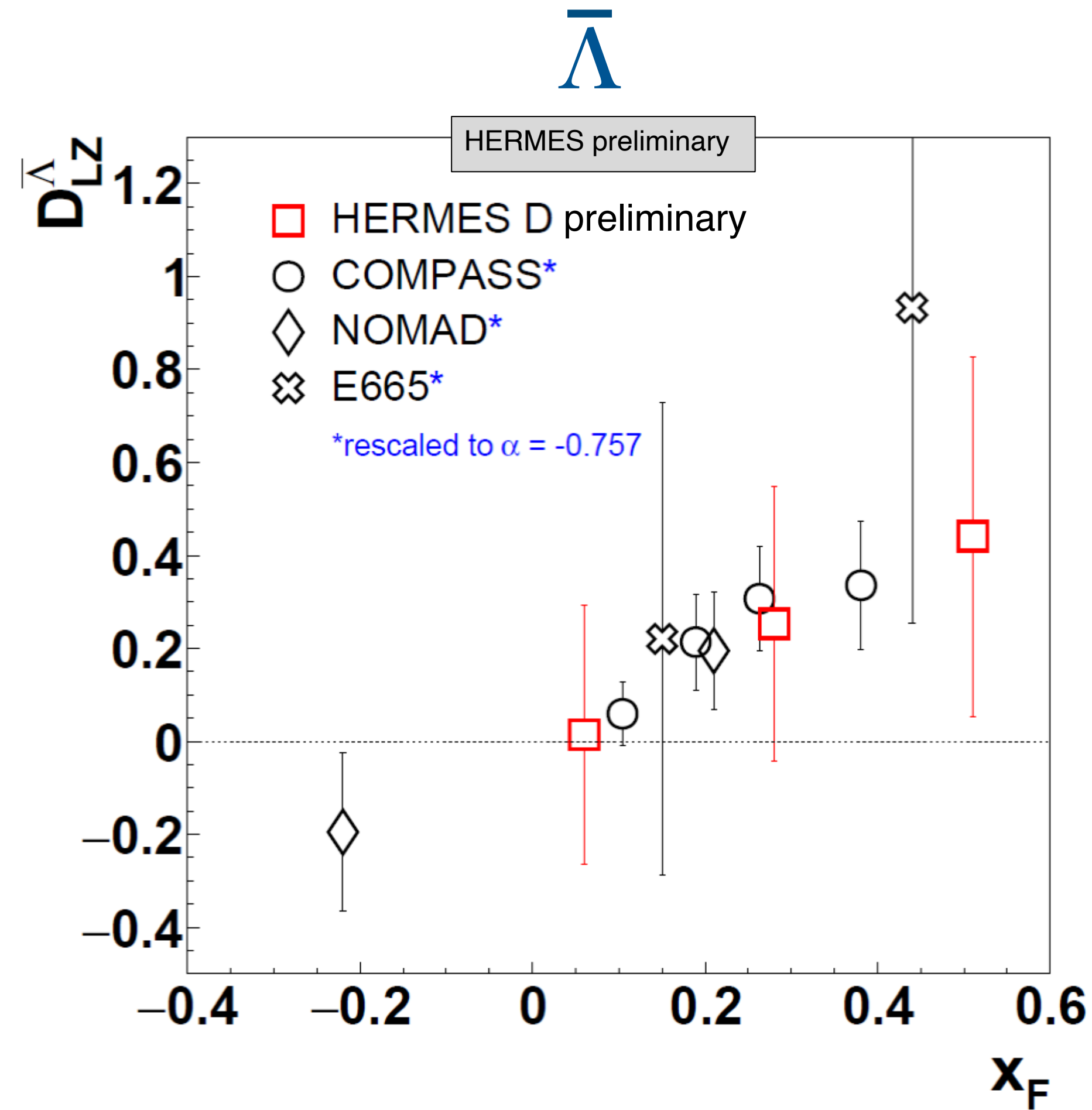
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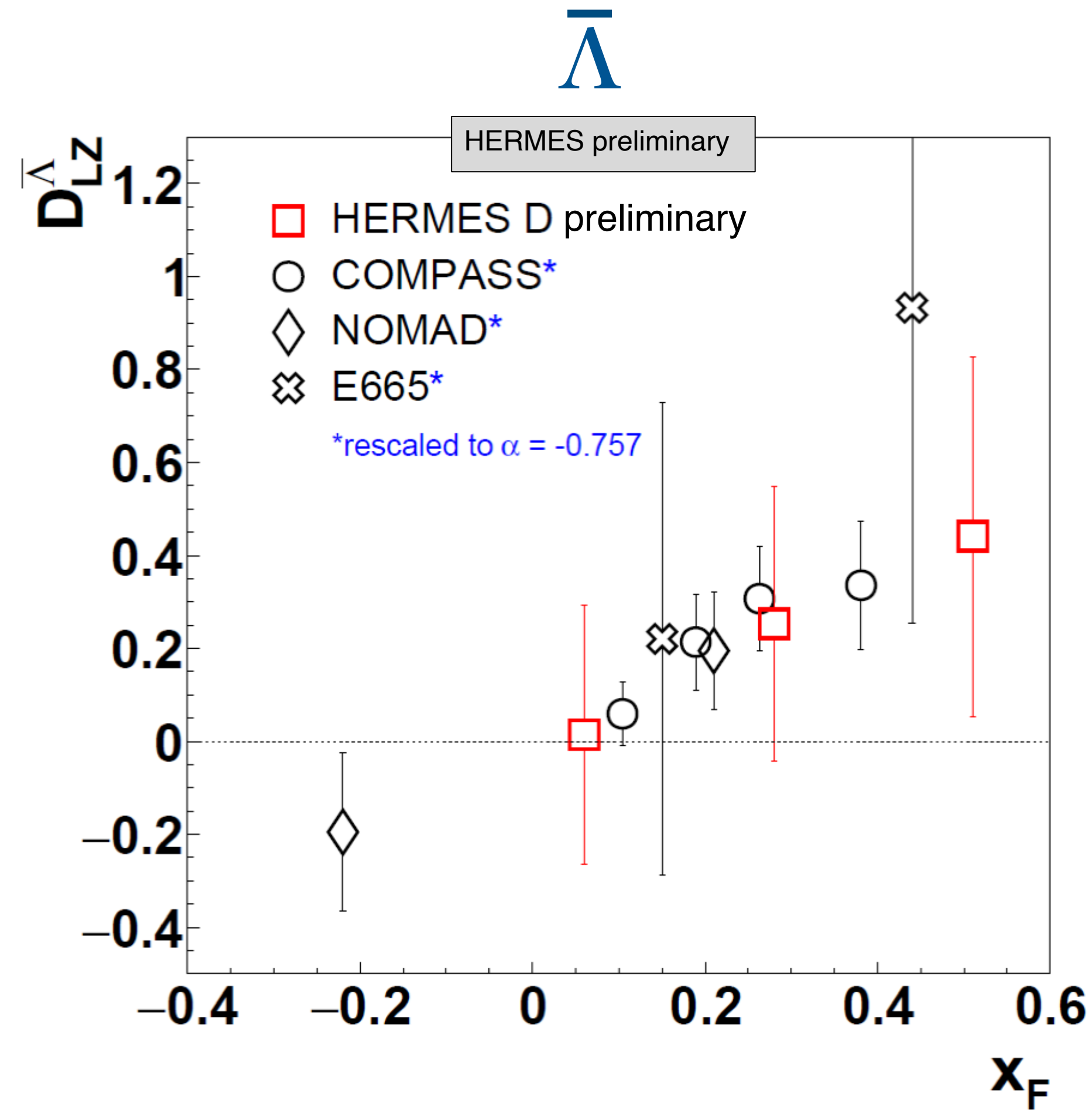
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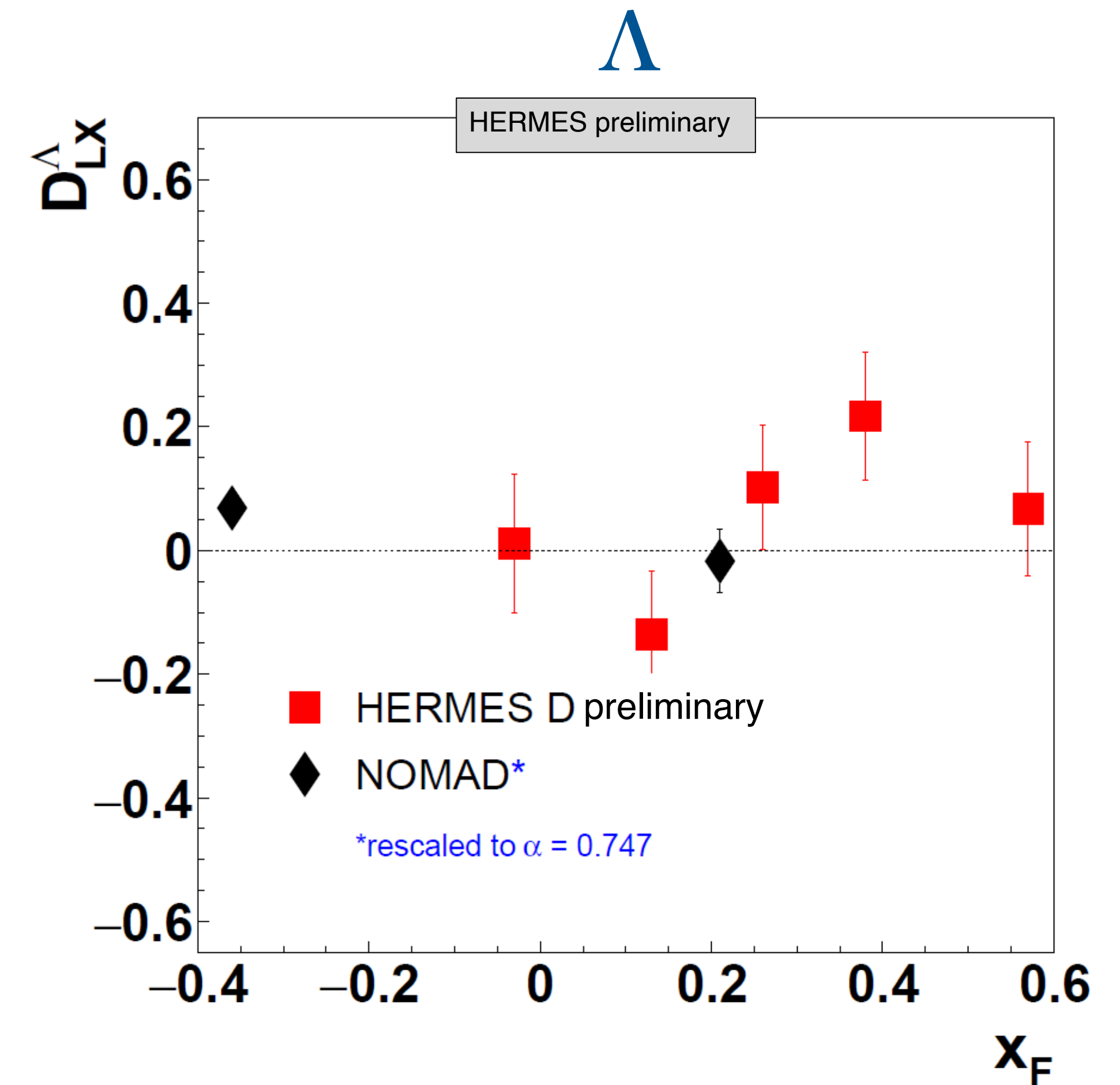
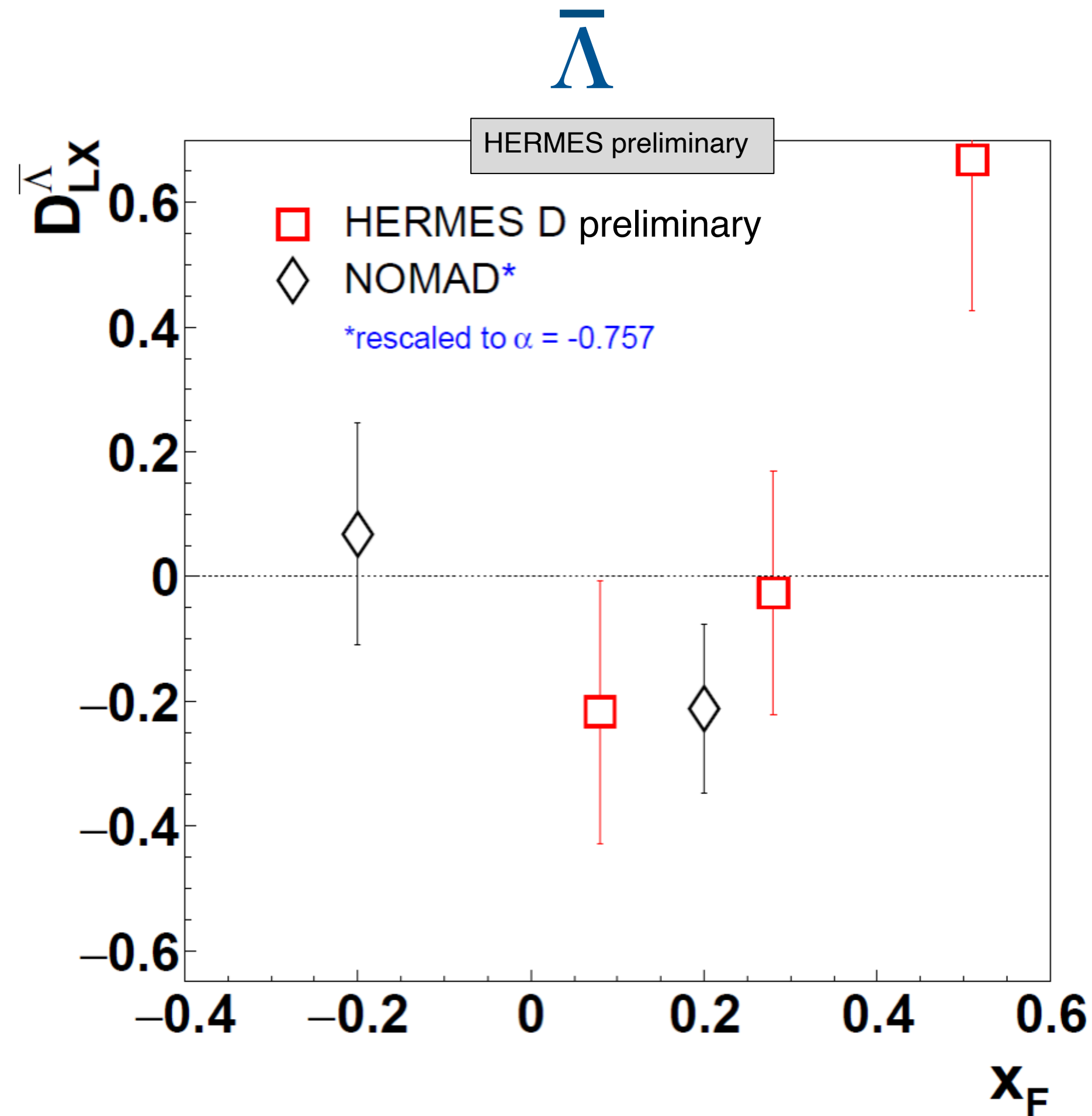


Clear rise of spin transfer:
result of less suppressed anti-s contribution
to anti-Lambda production in SIDIS?

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$$D_{LX} \propto \frac{e^q \otimes H_1^q}{f_1^q \otimes D_1^q} + \frac{f_1^q \otimes \tilde{G}_1^q}{f_1^q \otimes D_1^q}$$

Improvements from previous publication



first more detailed exploration of current fragmentation region for
longitudinal-to-transverse spin transfer
 e.g., sensitivity to twist-3 $e(x)$ and transversity FF $H_1(z)$

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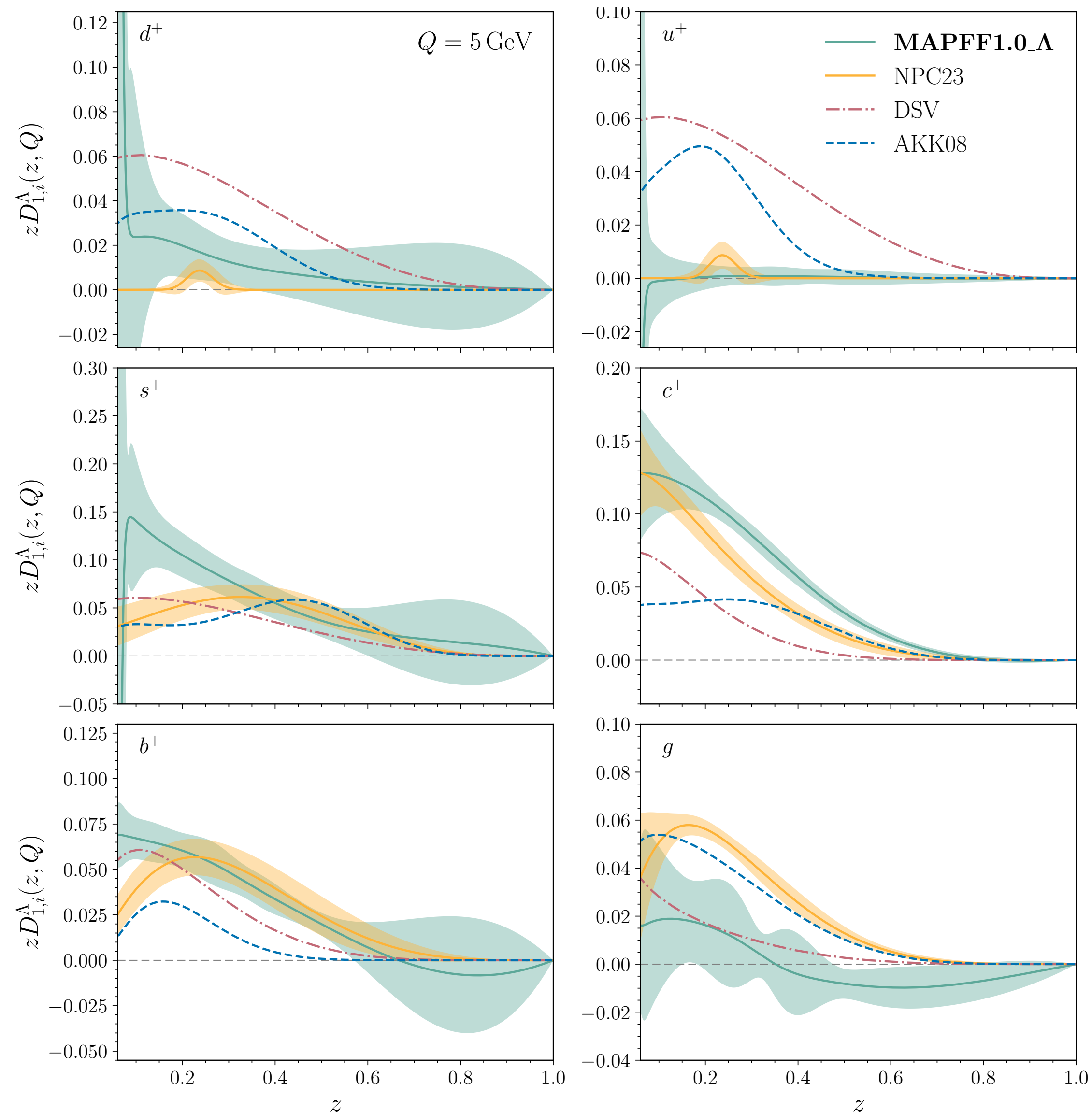
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- preliminary results from 1999-2007 data on longitudinal and longitudinal-to-transverse spin transfer to Lambda and anti-Lambda shows no significantly non-zero spin transfer coefficients
 - potentially consequence of up-quark dominance in contrast to strange-quark dominance at LEP (where large longitudinal polarization was observed)
 - global trend of rise with x_F for anti-Lambda suggestive for substantial strange G_1

Thank you!

back-up

Lambda fragmentation - a window to strangeness



[arXiv: 2605.05314]