PacificSPIN 2026

The Circum-Pan-Pacific Symposium on High Energy Spin Physics

27–30 Oct 2026

Institute of Physics, Academia Sinica

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

G. Schnell

ikerbasque Basque Foundation for Science

EUSKO JAURLARITZA GOBIERNO VASCO

MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

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Plan de Recuperación, Transformación y Resiliencia

AGENCIA ESTATAL DE INVESTIGACIÓN

DESY.

eman ta zabal zazu

Universidad del País Vasco

Euskal Herriko Unibertsitatea

EHU QC

EHU Quantum Center

Single-hadron TMD*) fragmentation functions

*) TMD … transverse-momentum dependent

quark pol.

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

Single-hadron TMD*) fragmentation functions

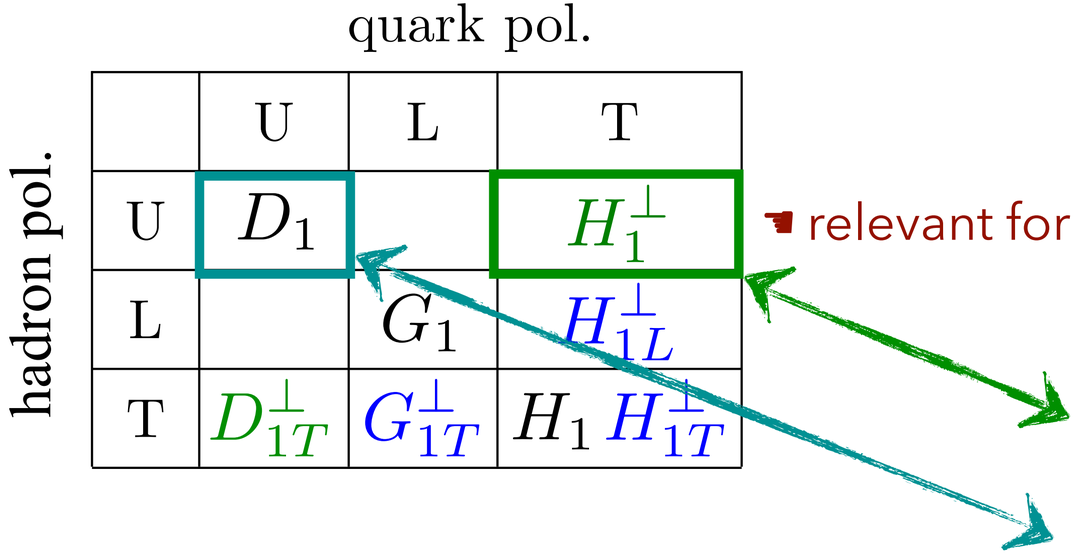
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☚ relevant for unpolarized final state

Single-hadron TMD*) fragmentation functions

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relevant for unpolarized final state

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

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

FF … fragmentation function

Single-hadron TMD*) fragmentation functions

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U	D_1		$H_1^\perp$
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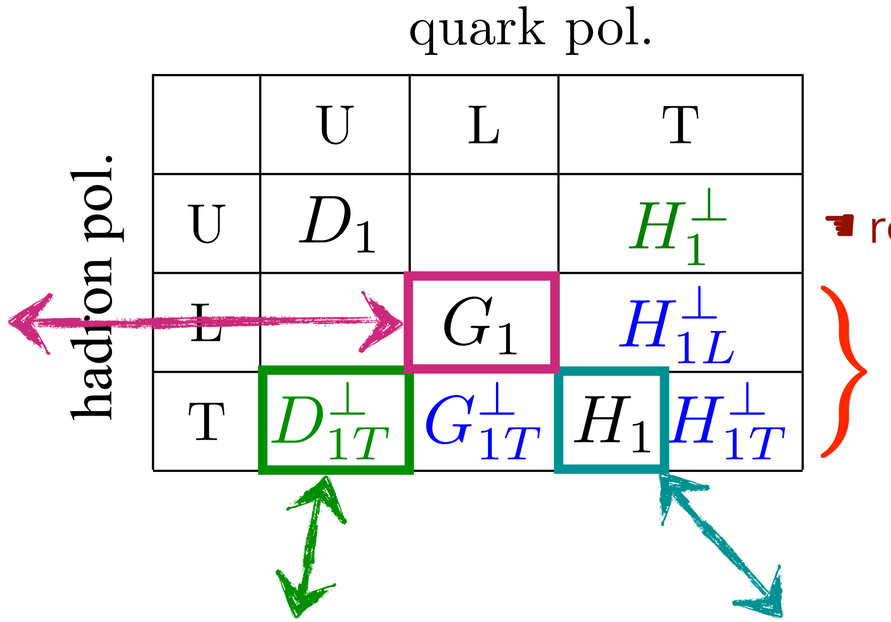
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FF … fragmentation function

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helicity FF (longitudinal spin transfer)

relevant for unpolarized final state

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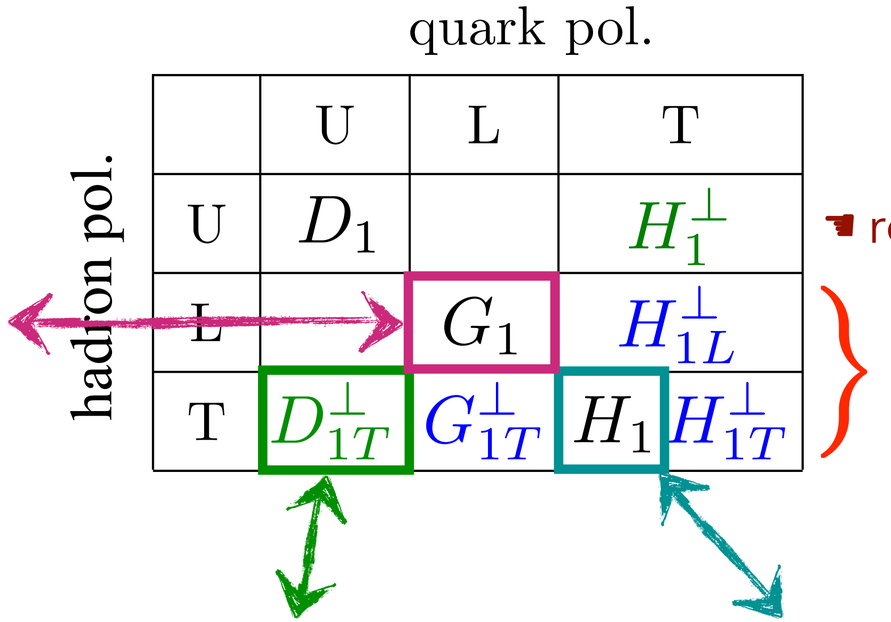
polarizing FF

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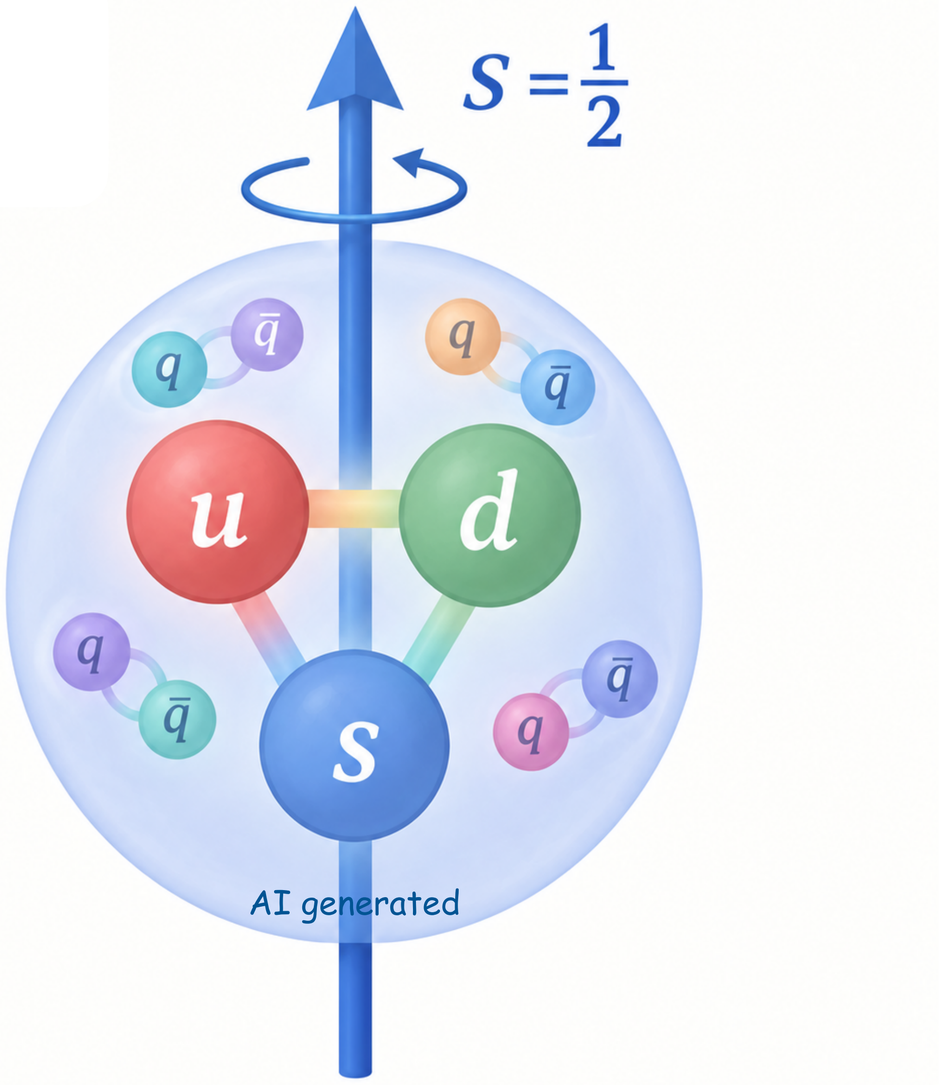
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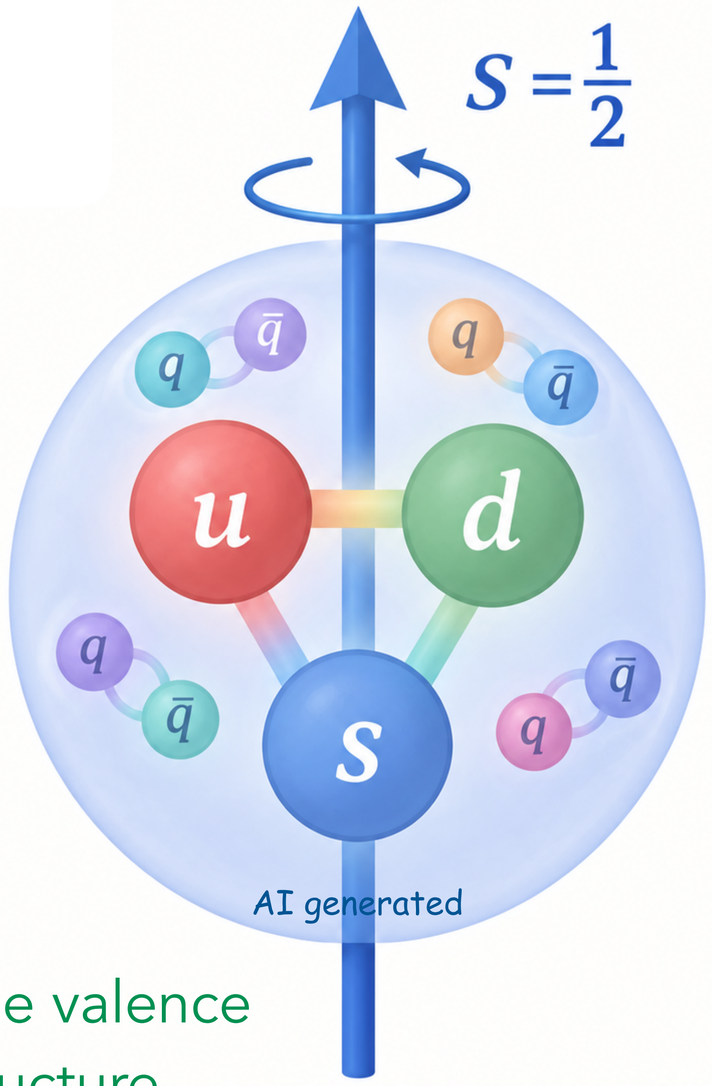
➠ **FFs act as quark flavor-tagger and polarimeter**

FF … fragmentation function

Why Lambda?

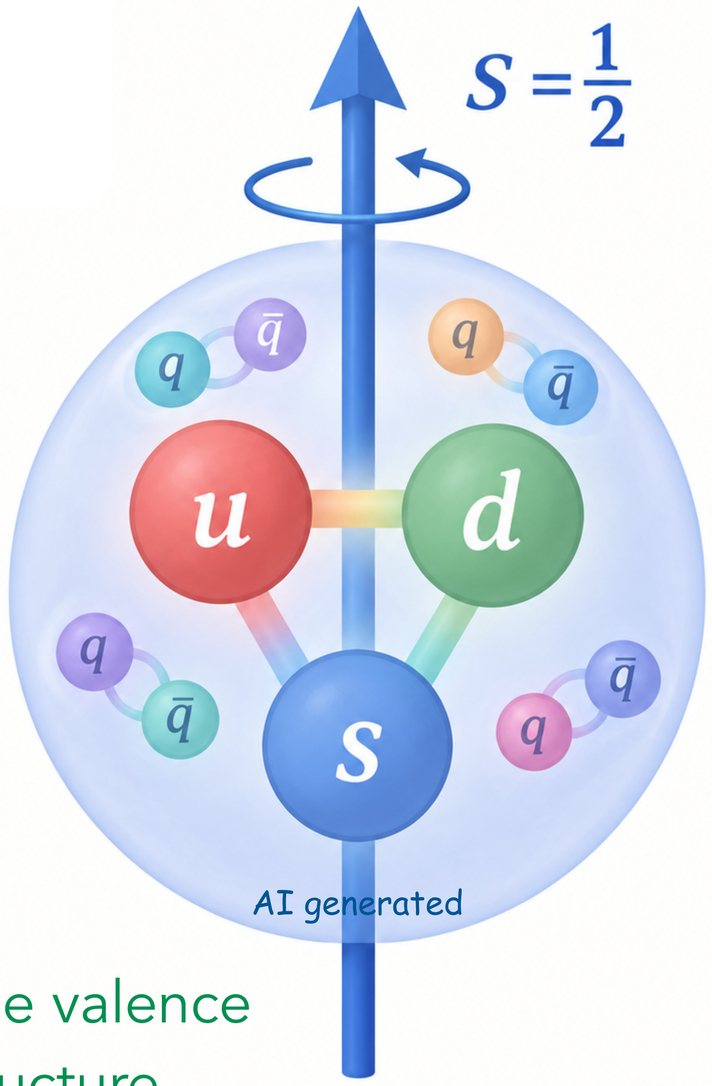


Why Lambda?



strange valence structure

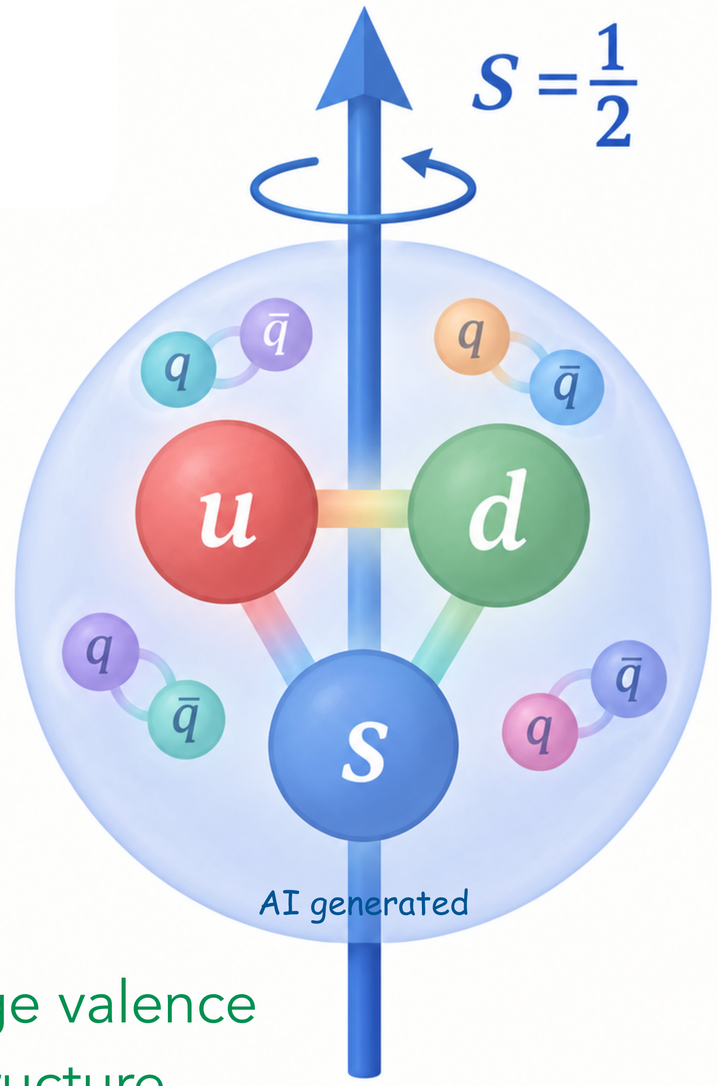
Why Lambda?



sensitive to spin-dependent fragmentation

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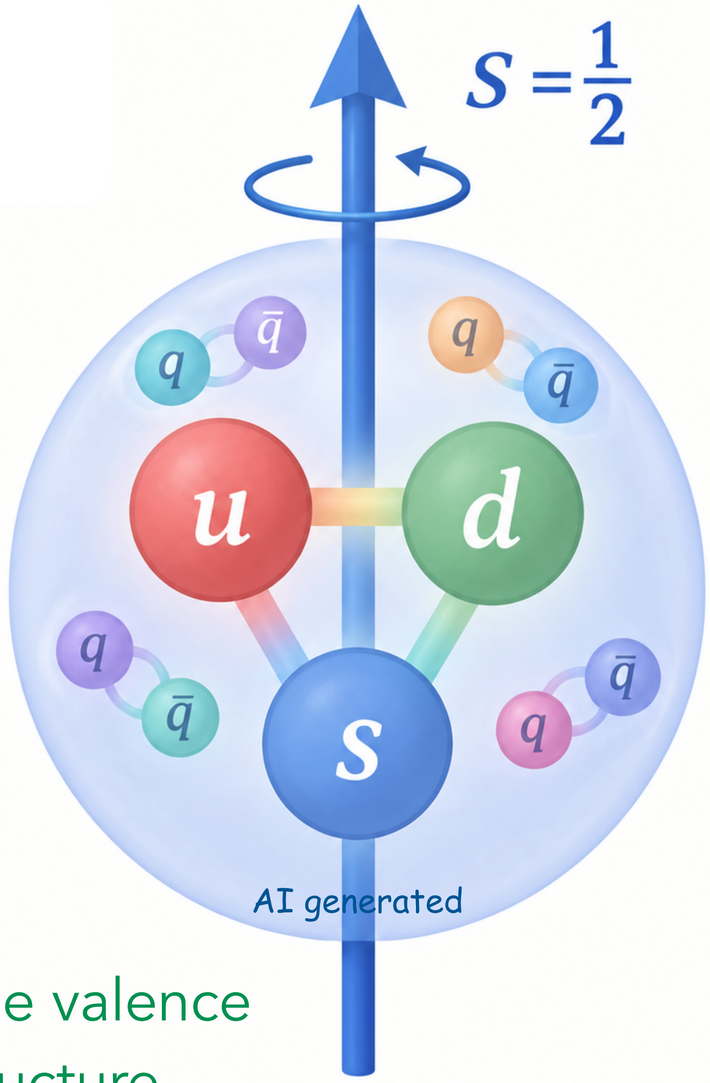
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strange valence structure

quark models: spin carried by s quark; ud unpolarized

Why Lambda?

its weak decay:
easy-to-use polarimeter



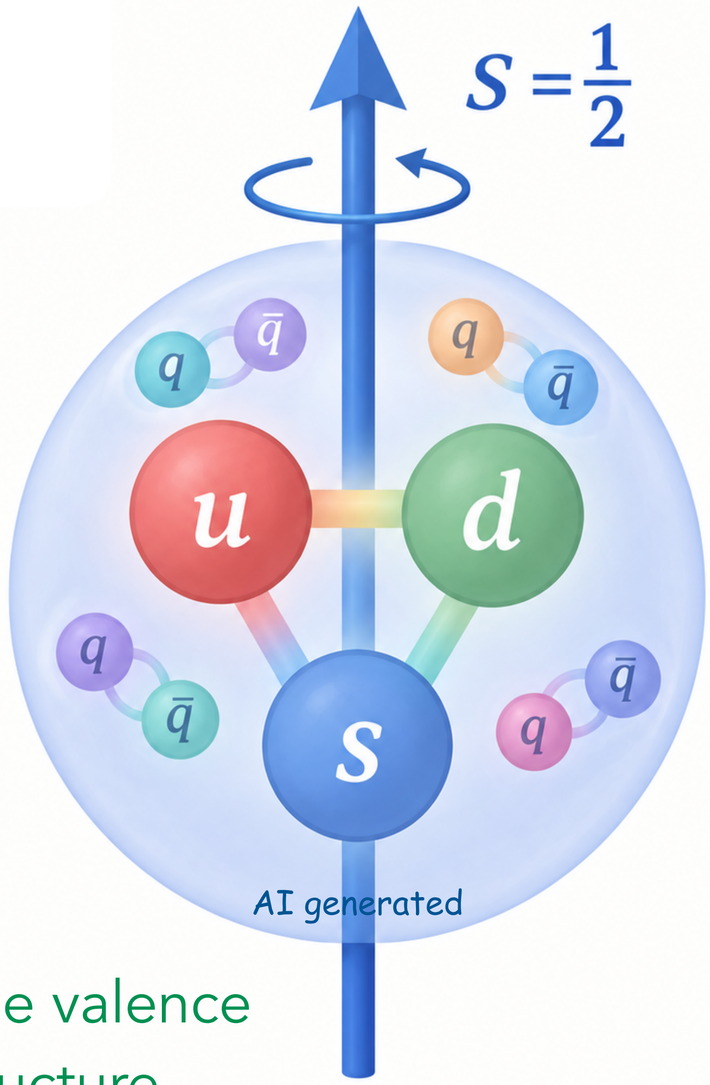
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lowest-mass hyperon:
largest production rate

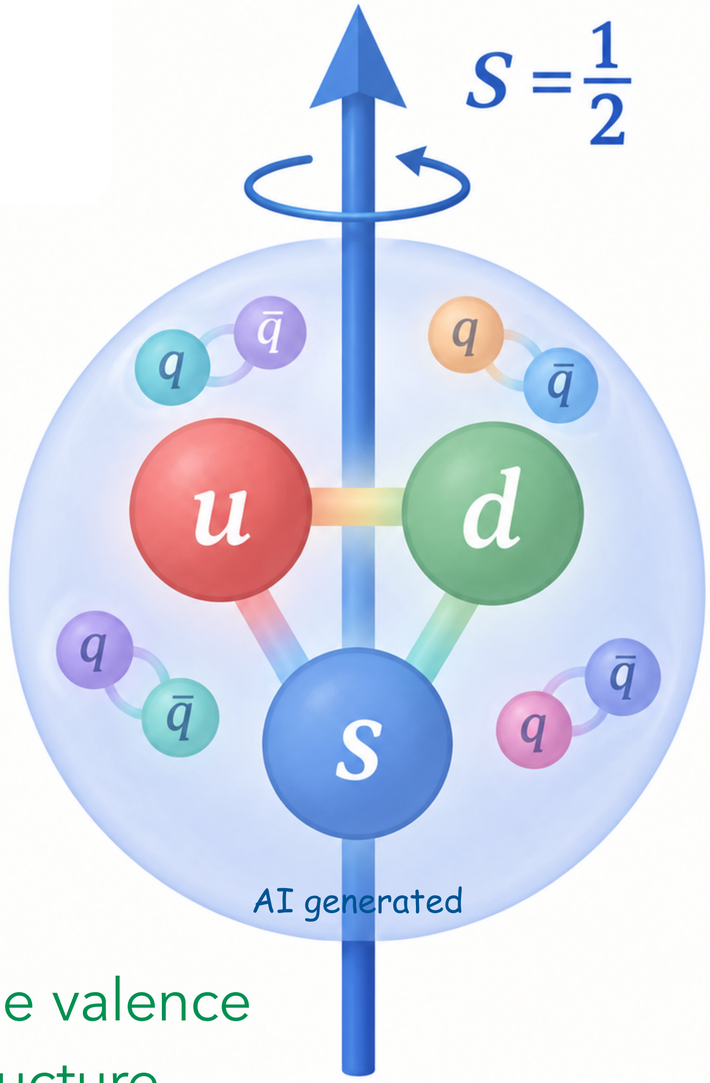
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ud unpolarized

Why Lambda?

its weak decay:
easy-to-use polarimeter

relatively low yield
compared to light
mesons



strange valence
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Lambda fragmentation – a window to strangeness

JHEP

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

Valerio Bertone,[a] **Alessia Bongallino**,[b] **Amedeo Chiefa**,[c] **Miguel G. Echevarría**[b] **and Gunar Schnell**[b,d]

[a] *Université Paris-Saclay, CEA, IRFU, 91191 Gif-sur-Yvette, France*
[b] *Department of Physics & EHU Quantum Center, University of the Basque Country (EHU), P.O. Box 644, 48080 Bilbao, Spain*
[c] *The Higgs Centre for Theoretical Physics, University of Edinburgh, JCMB, KB, Mayfield Rd, Edinburgh EH9 3JZ, Scotland*
[d] *IKERBASQUE, Basque Foundation for Science, Plaza Euskadi 5, 48009 Bilbao, Spain*

E-mail: valerio.bertone@cea.fr, alessia.bongallino@ehu.eus, amedeo.chiefa@ed.ac.uk, miguel.garciae@ehu.eus, gunar.schnell@desy.de

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	$u = d = s$	NLO	$\Lambda + \bar{\Lambda}$
AKK (2006) Nucl. Phys. B, 734	SIA	✓		
(2008) Nucl. Phys. B 803	SIA, pp collisions	✓		
NPC23 (2025) Phys. Rev. D 112, 054045	SIA, SIDIS, pp collisions	$u = d$		
MAPFF1.0_Λ (2026)	SIA, SIDIS (NC and CC)	✓	NNLO	$\Lambda, \bar{\Lambda}$

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MAPFF1.0_Λ (2026)	SIA, SIDIS (NC and CC)	✓	NNLO	$\Lambda, \bar{\Lambda}$

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

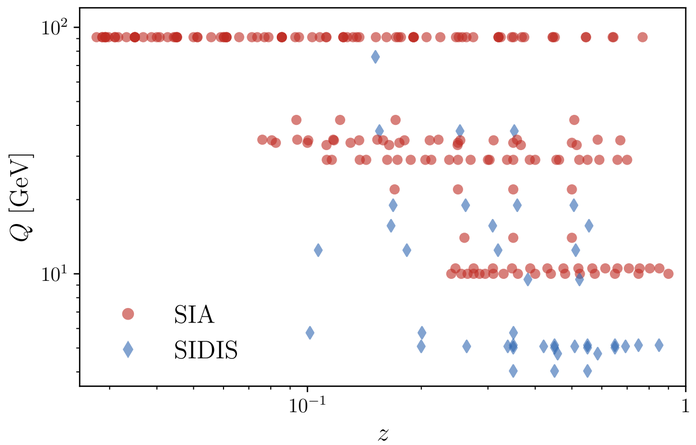
SIDIS data allow to reliably extract for the first time FFs for Λ and $\bar{\Lambda}$ **separately**

[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 $10\,\text{GeV}$ to M_Z

Datasets delivered as the sum of Λ and $\bar{\Lambda}$

SIDIS Measurements for neutral- and charged-current

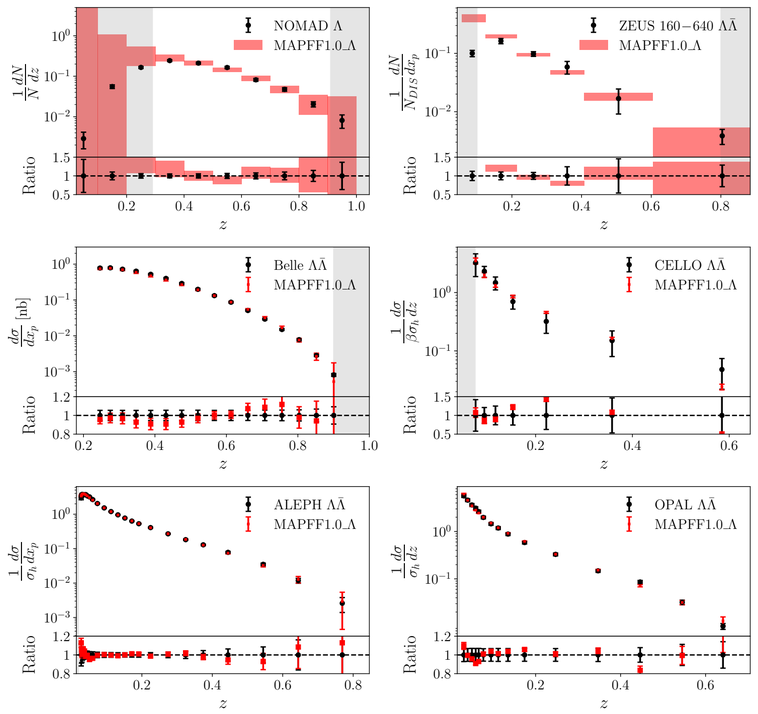
Data provided separately for Λ and $\bar{\Lambda}$

[JHEP10(2026)089]

Lambda fragmentation – a window to strangeness

Fit quality

Experiment	$N_{\rm dat}$	$\chi^2/N_{\rm dat}$ NLO	$\chi^2/N_{\rm dat}$ 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



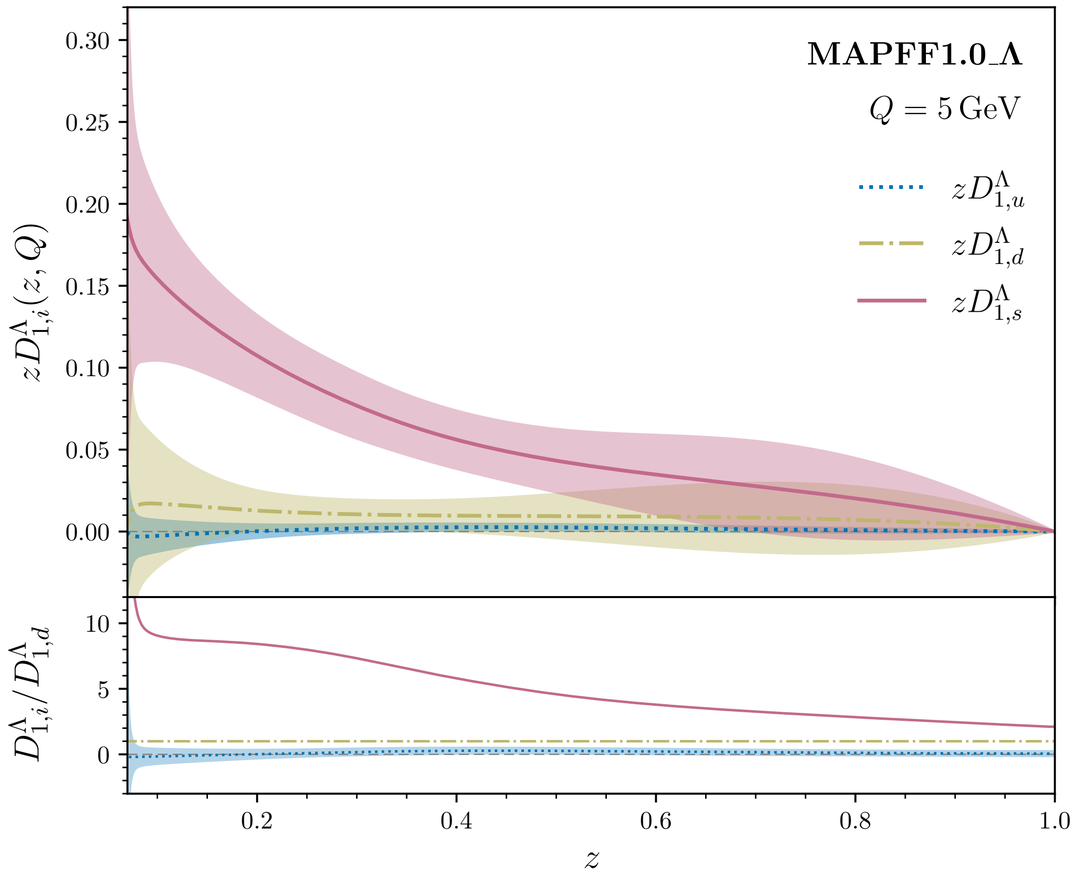
$\chi^2 = 1.10$ at NLO, $\chi^2 = 1.09$ at NNLO

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



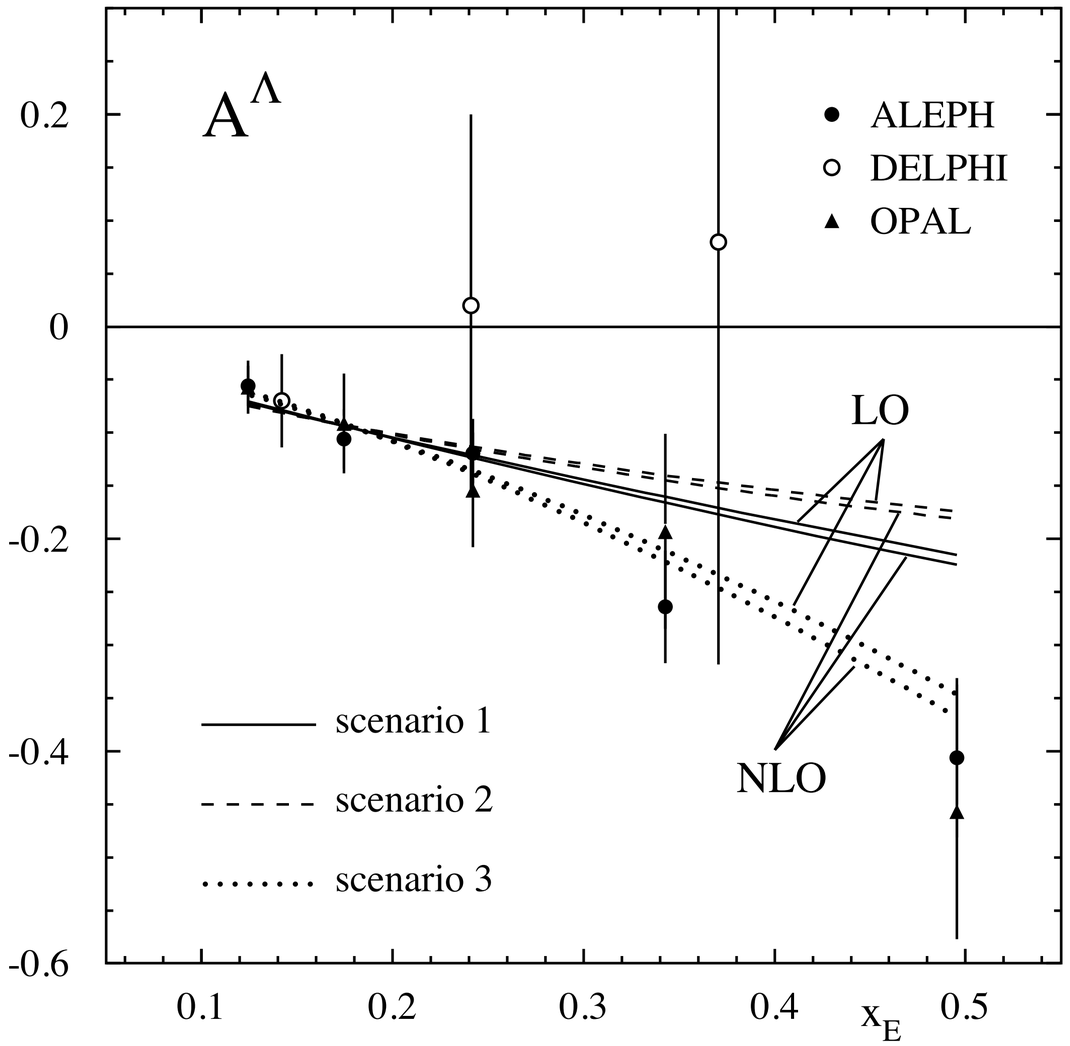
- **Dominance** of the strange quark over the entire z range: consistency with the quark composition of the Λ
- Fragmentation of u or d into Λ is less pronounced compared to s-quark fragmentation, the distributions show a similar shape

[JHEP10(2026)089]

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Longitudinal polarization in fragmentation?

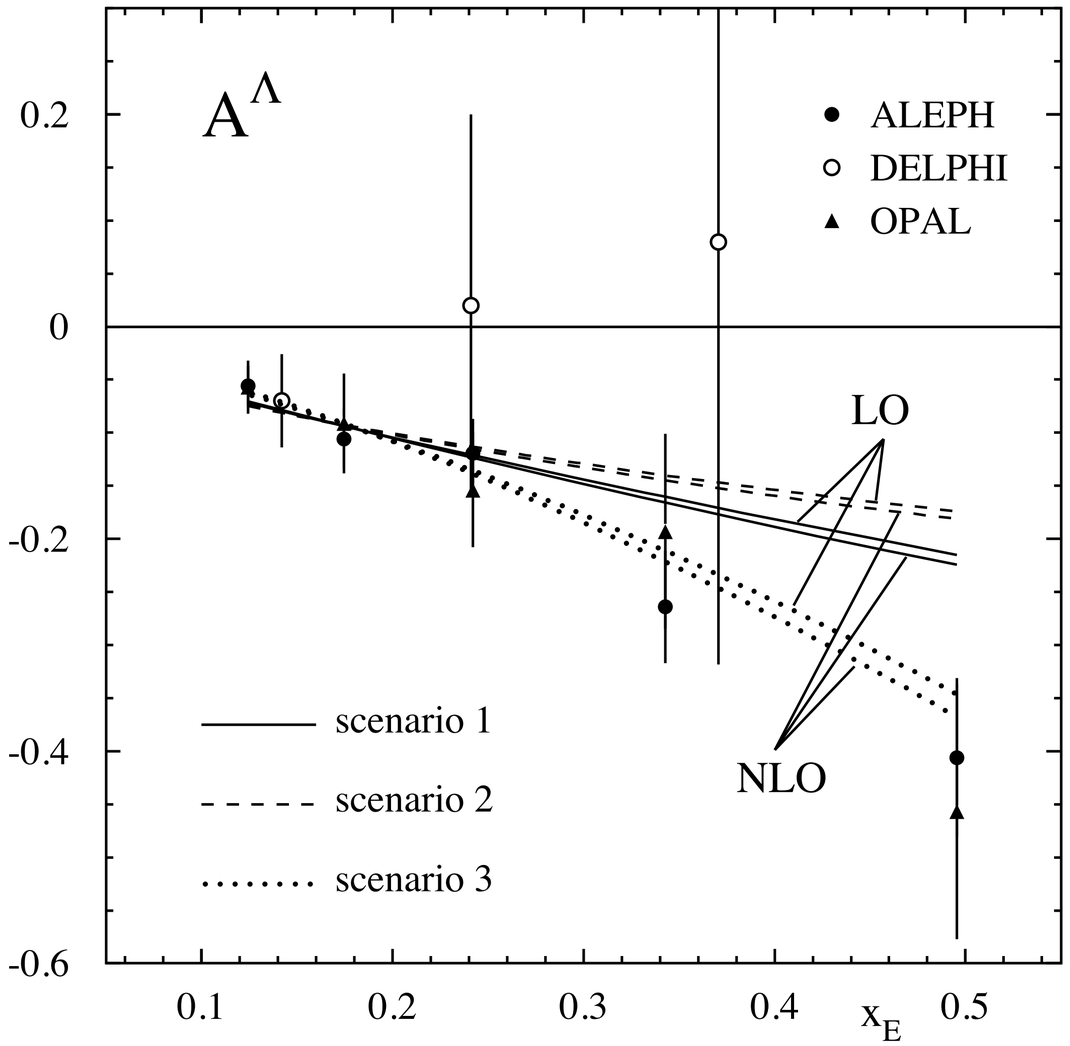
[PRD 57 (1998) 5811]



- large longitudinal polarization in e^+e^- at LEP
  ➥ **$G_1 \neq 0$**

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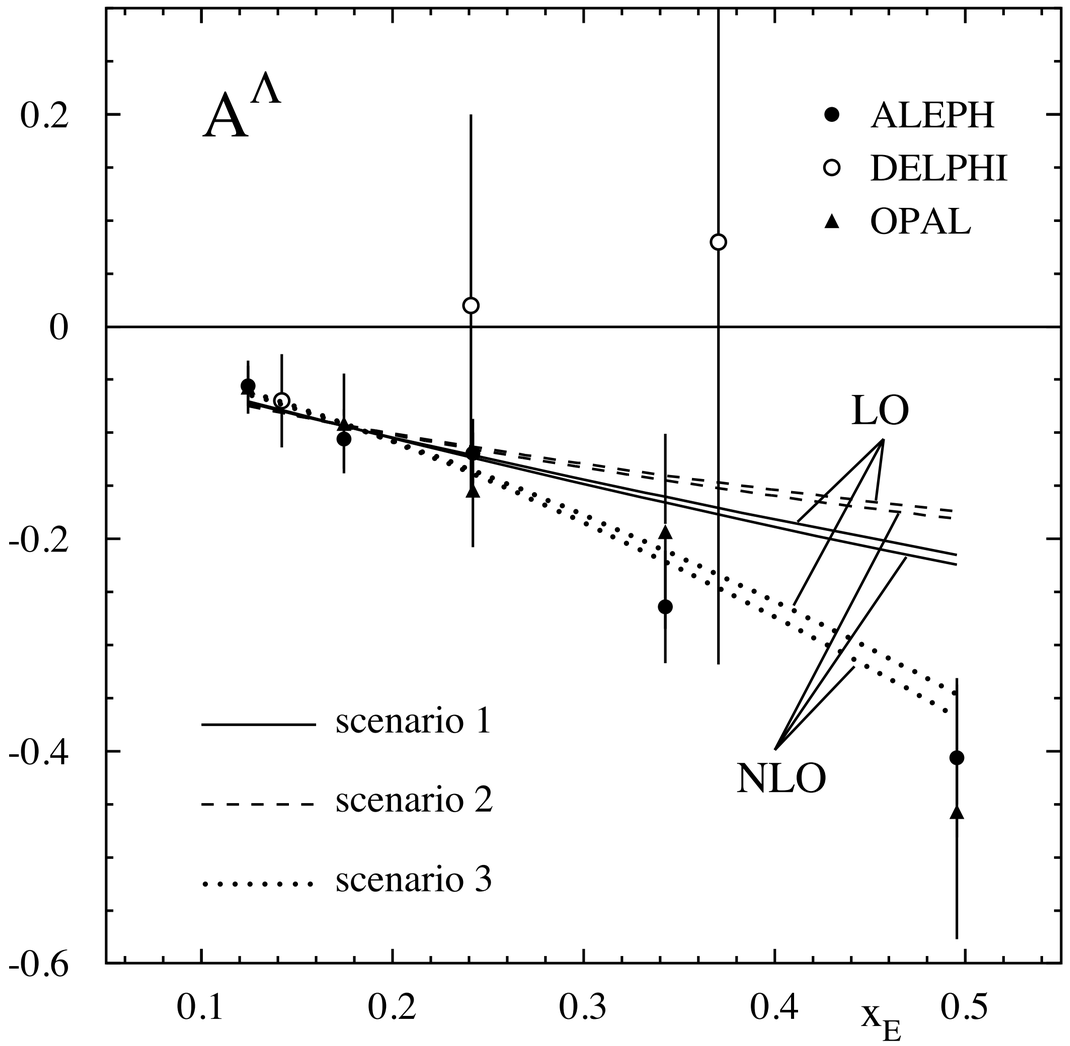
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- Z^0 decay produces pairs of highly polarized strange (anti)quarks
- in simple quark models, the Λ spin is carried by strange quarks; the ud pair has zero spin.
  - suggests strong spin transfer from a polarized strange quark to Λ

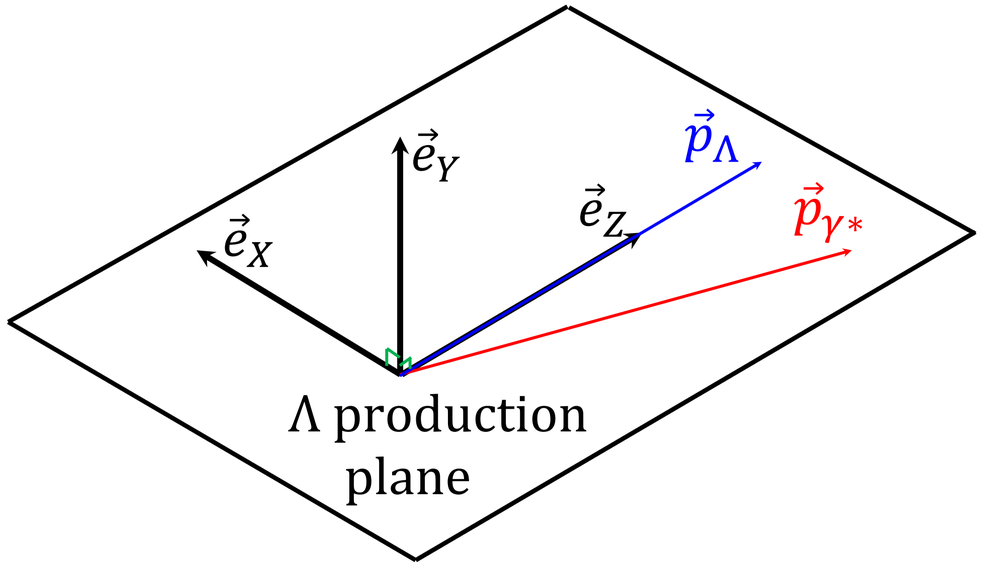
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  - suggests strong spin transfer from a polarized strange quark to Λ
- in DIS, mainly scattering off u (and d) quarks

Lambda production in DIS

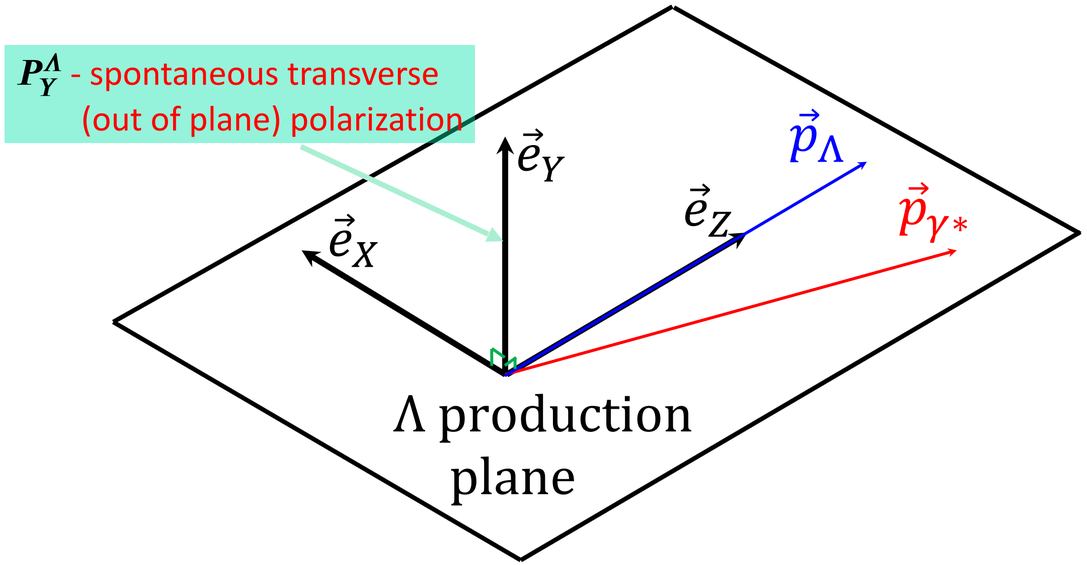


Lambda production in DIS

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

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

$$D_Y(y) \approx \frac{2(2-y)\sqrt{1-y}}{1-y+y^2/2}$$

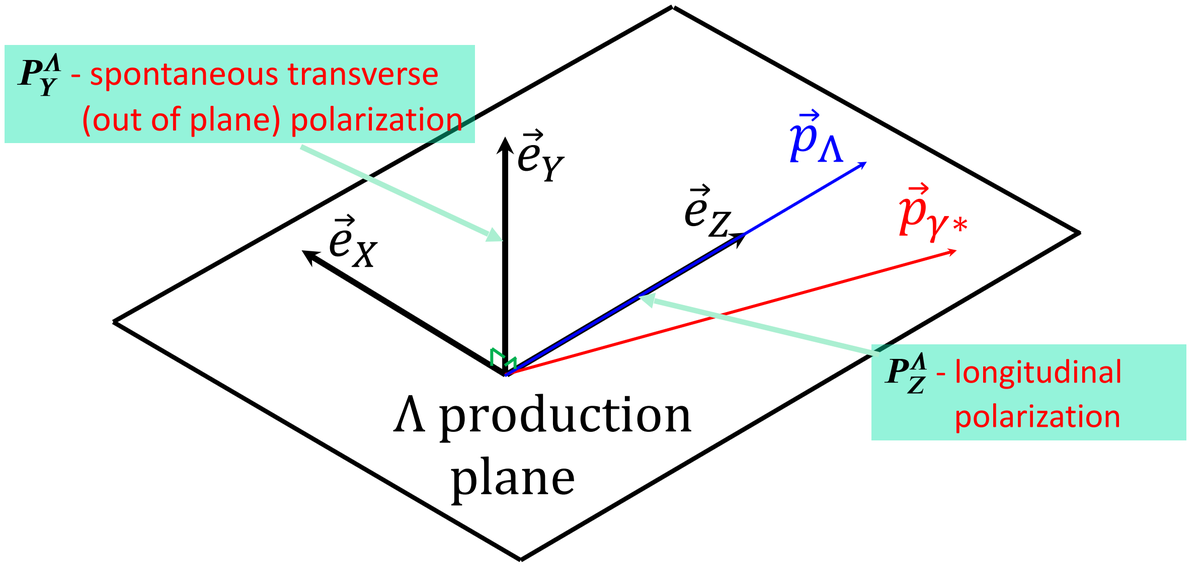


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$$P_Z^\Lambda = P_B D_Z(y)\frac{\sum_q e_q^2 x f_1^q(x) G_1^{q\to\Lambda}(z)}{\sum_q e_q^2 x f_1^q(x) D_1^{q\to\Lambda}(z)} \equiv P_B D_Z(y) D_{LZ}^\Lambda(x,z)$$



$$D_Y(y) \approx \frac{2(2-y)\sqrt{1-y}}{1-y+y^2/2}$$

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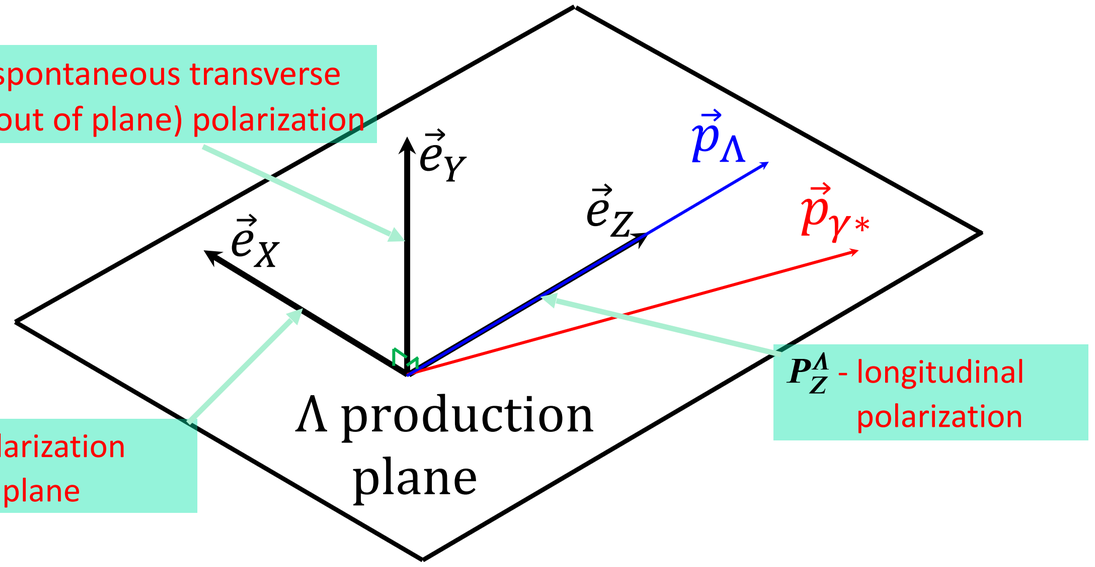
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$$D_X(y) \approx \frac{2y\sqrt{1-y}}{1-y+y^2/2}$$

$$D_Y(y) \approx \frac{2(2-y)\sqrt{1-y}}{1-y+y^2/2}$$

$$D_Z(y) \approx \frac{y-y^2/2}{1-y+y^2/2}$$

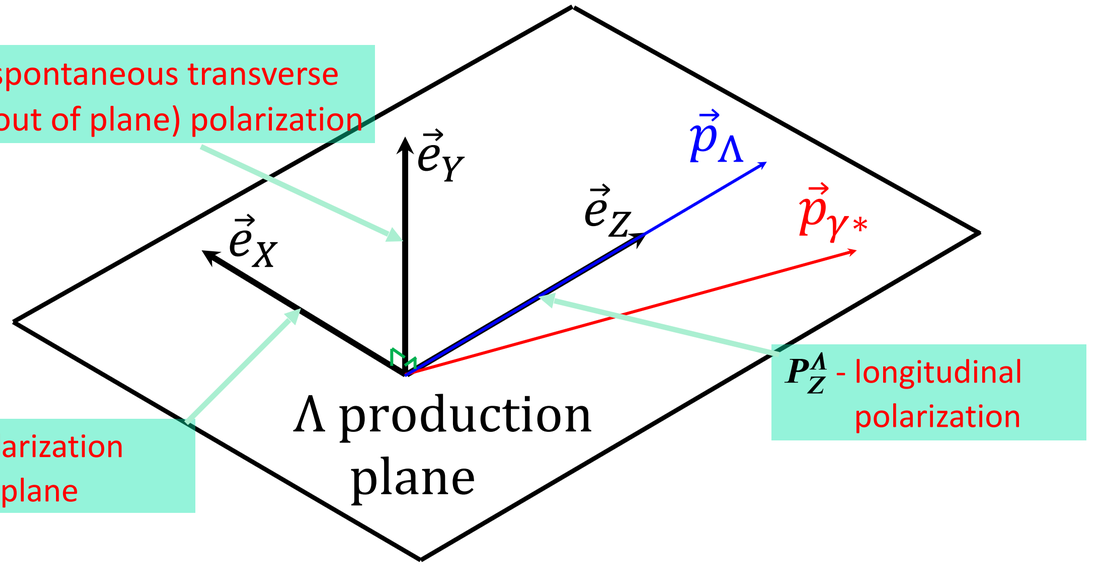
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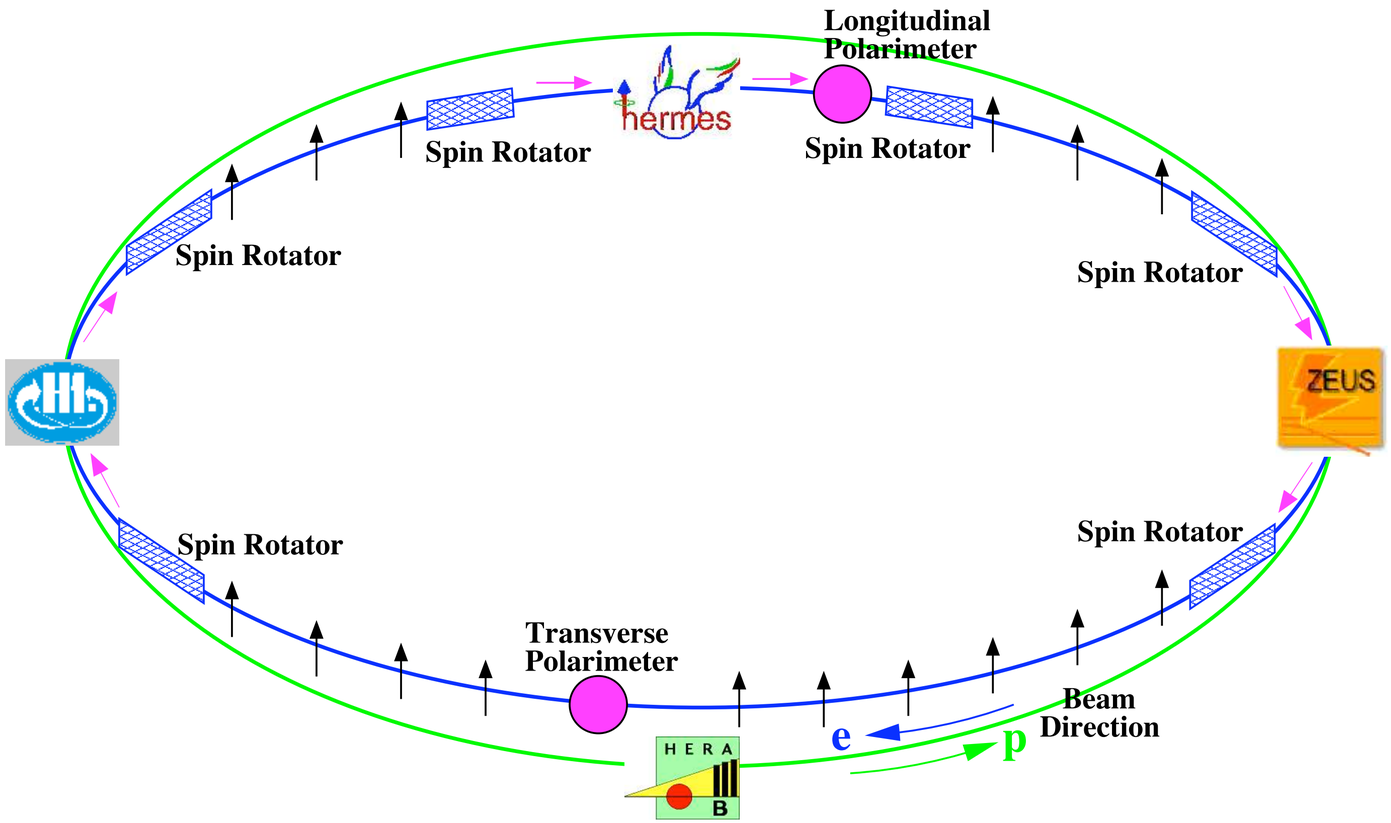
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$$P_Z^\Lambda = P_B D_Z(y)\frac{\sum_q e_q^2 x f_1^q(x) G_1^{q\to\Lambda}(z)}{\sum_q e_q^2 x f_1^q(x) D_1^{q\to\Lambda}(z)} \equiv P_B D_Z(y) D_{LZ}^\Lambda(x,z)$$

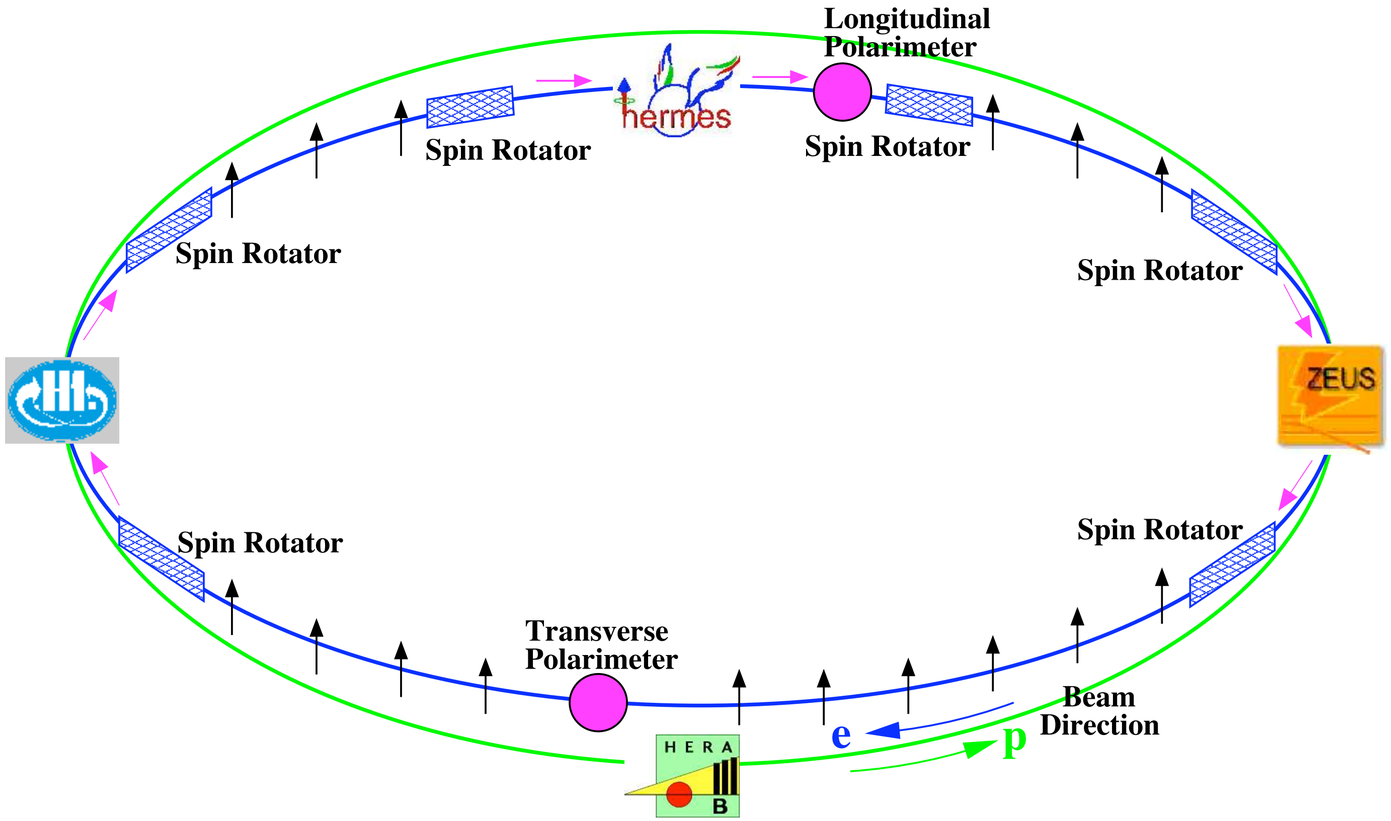


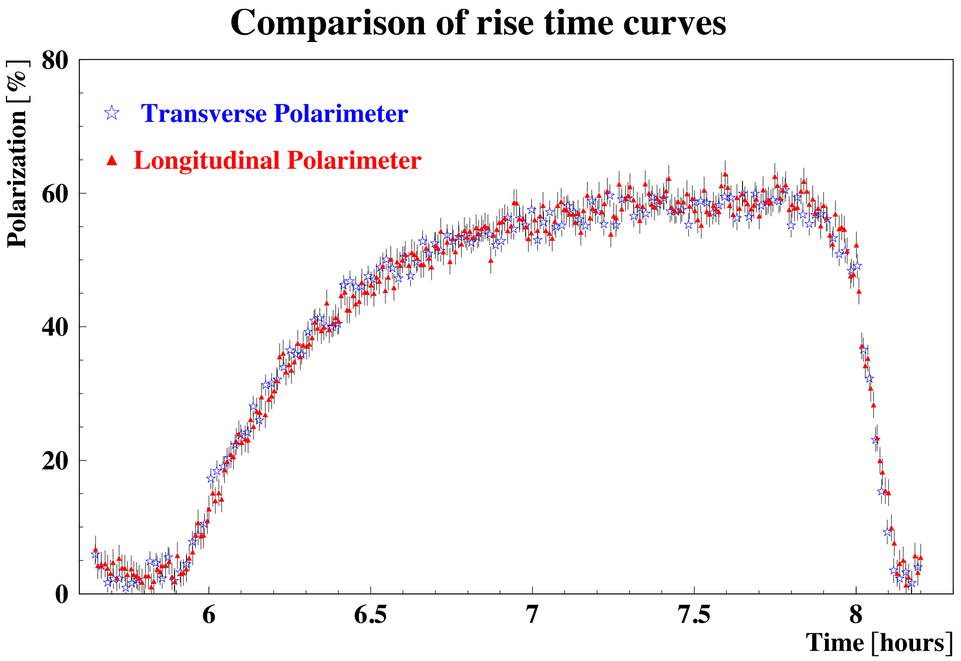
- $D_{L[X,Z]}^\Lambda$: spin-transfer coefficients
  - access to several novel spin-dependent FFs
- Y-component of polarization ("self-polarization") not correlated with beam polarization P_B
  ➥ drops out in beam-spin asymmetries
  - concentrate on longitudinal-to-longitudinal and longitudinal-to-transverse spin transfer

HERMES (1995-2007) @ HERA (DESY)



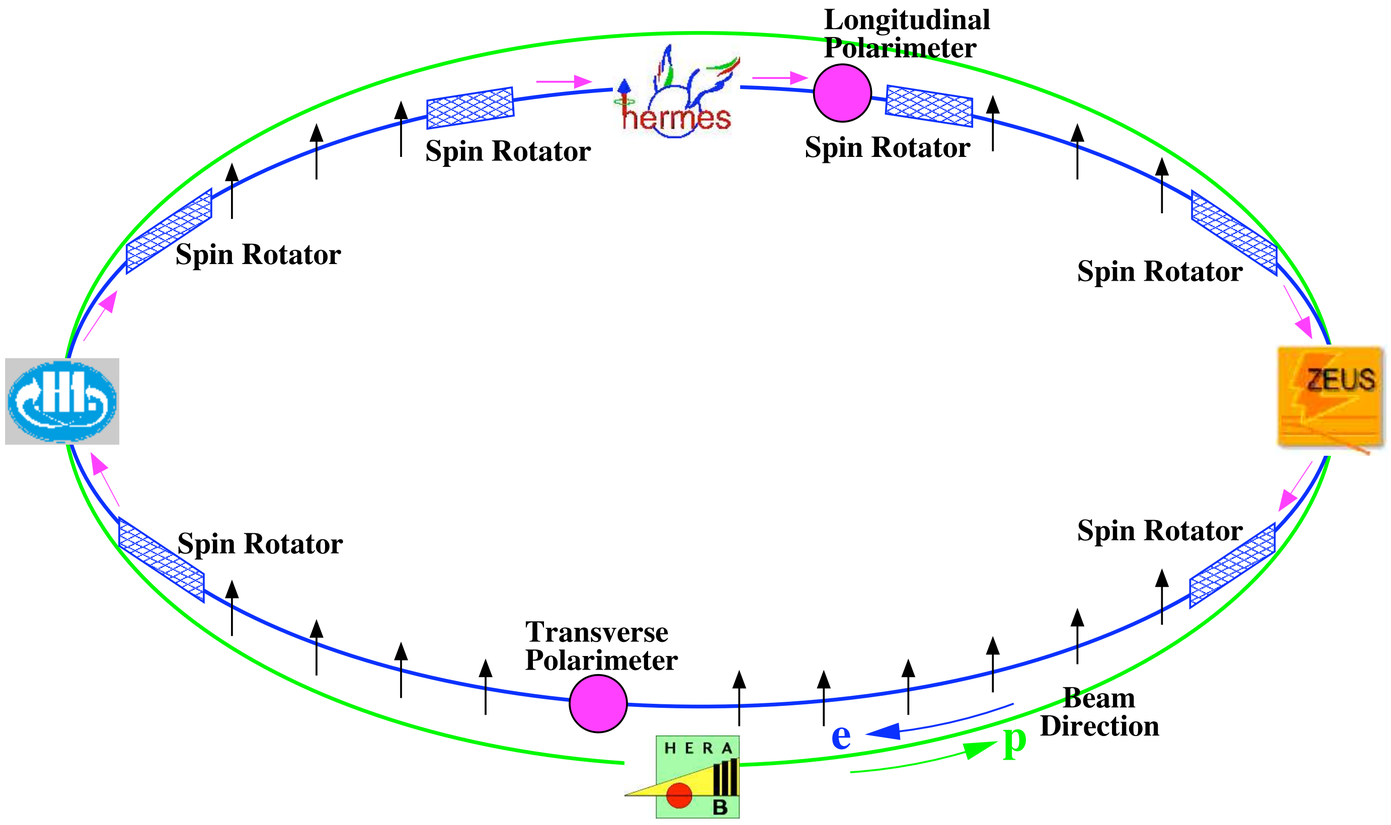
HERMES (1995-2007) @ HERA (DESY)

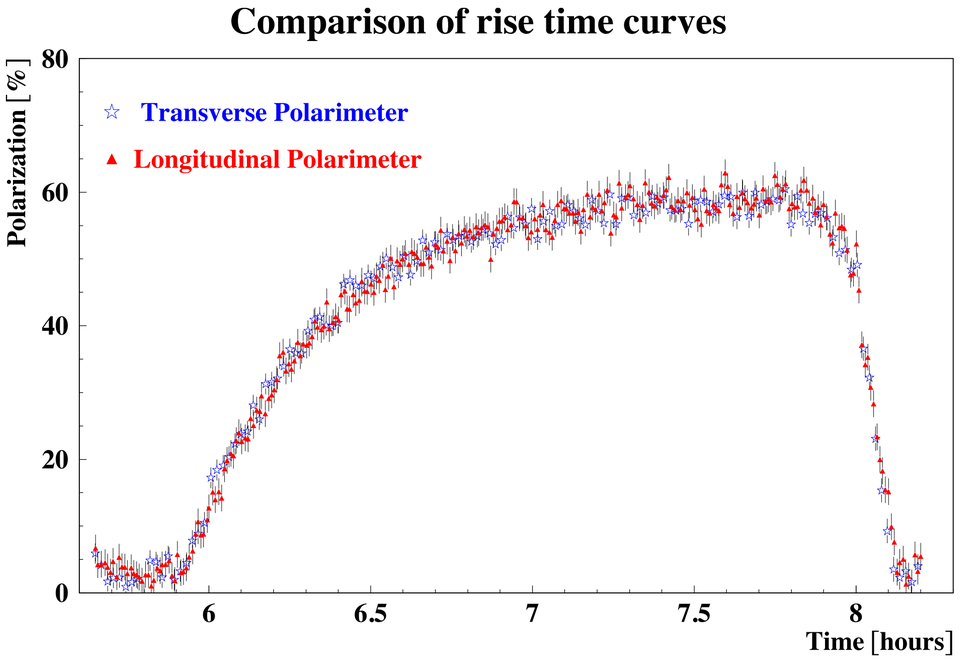




- ☑ beam polarization measured independently by two polarimeters
  - ☑ excellent agreement

HERMES (1995-2007) @ HERA (DESY)

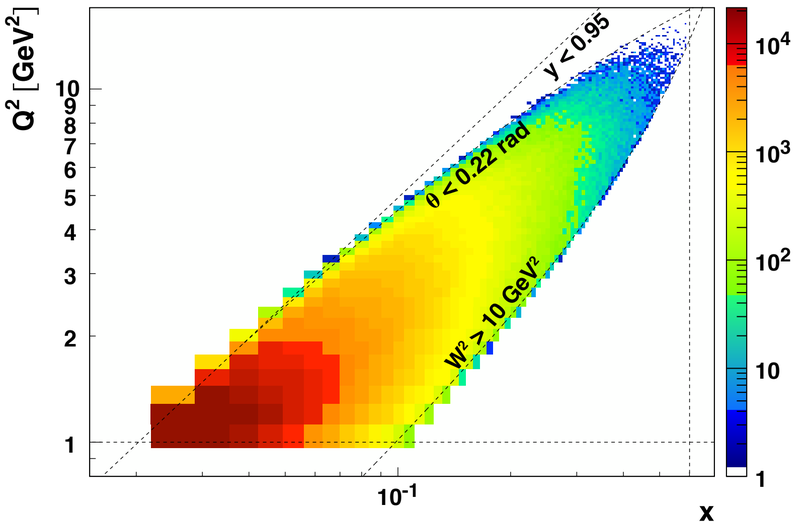


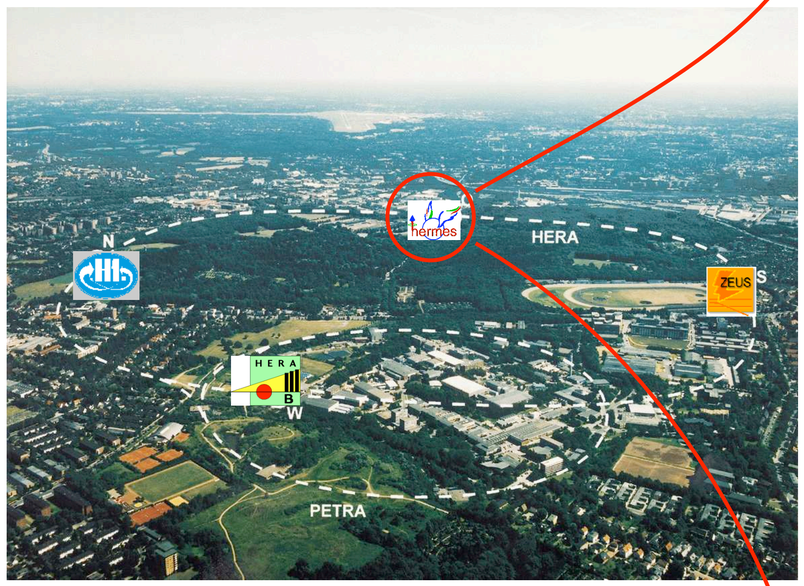


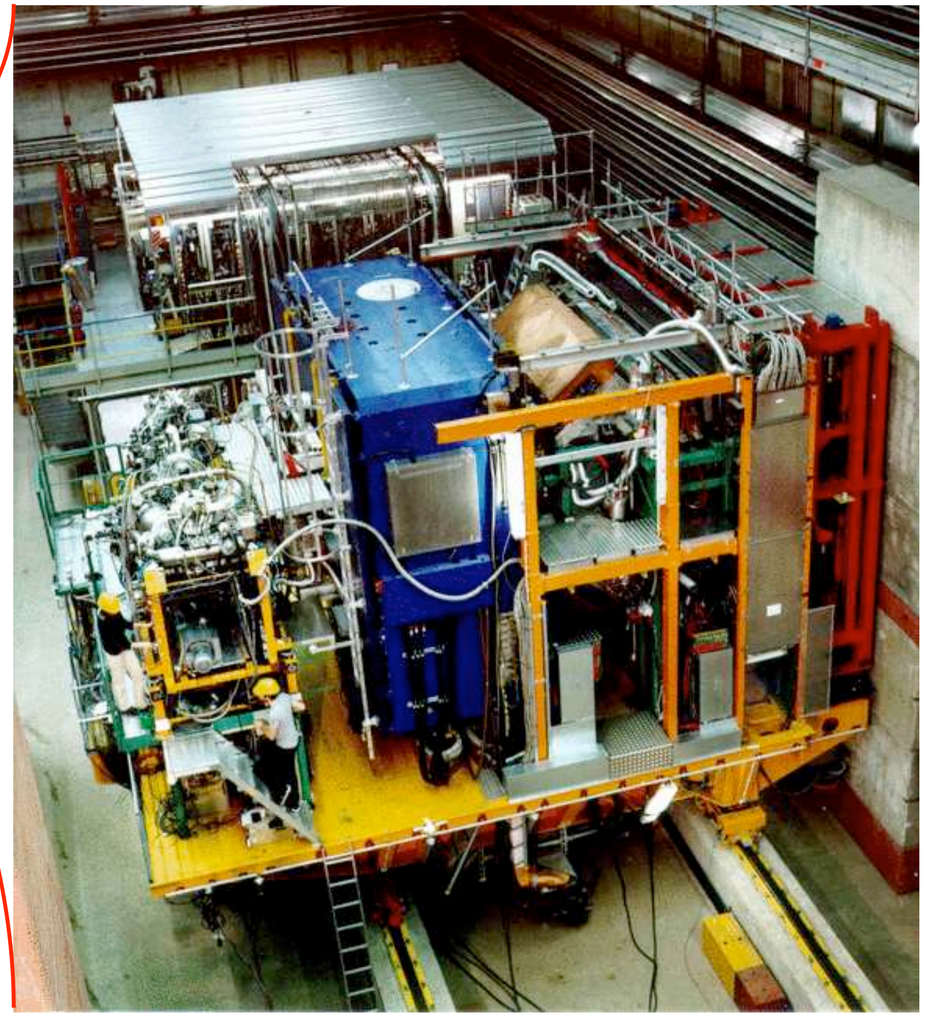
- ☑ beam polarization measured independently by two polarimeters
  - ☑ excellent agreement
- ☑ polarization up to 60% during HERA I

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**, ^{3}He) polarized **pure gas targets**
- ☑ particle ID (incl. dual-radiator RICH) for efficient **e/π/K/p separation**

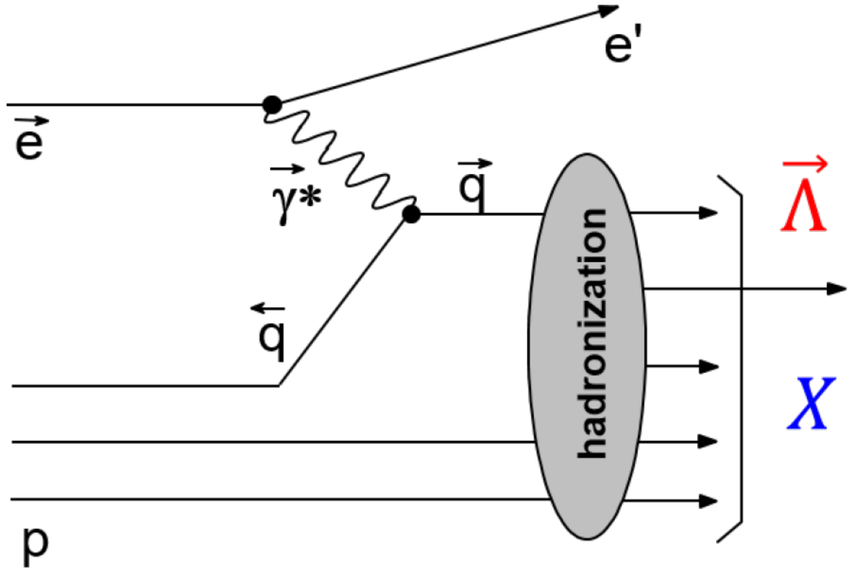
Polarization measurement

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

$$\frac{\mathrm{d}N}{\mathrm{d}\Omega_p} \propto \frac{\mathrm{d}N_0}{\mathrm{d}\Omega_p}\left(1 + \alpha P_{L'}^{\Lambda} \cos\theta_{pL'}\right)$$

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

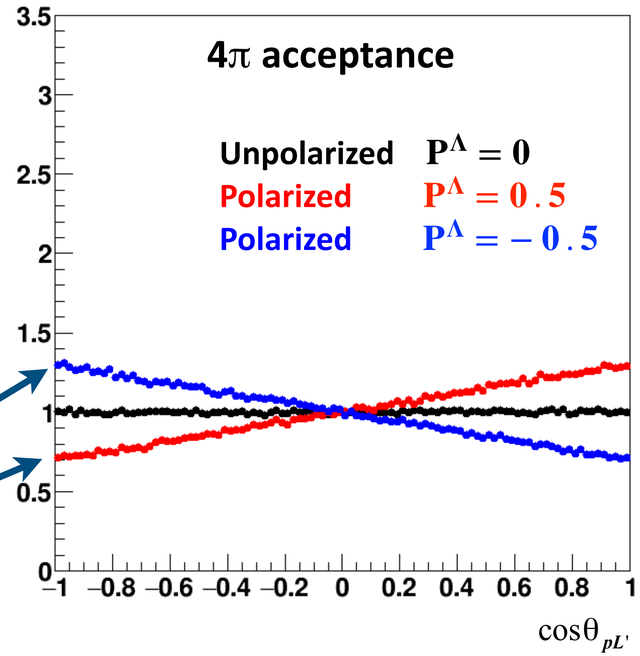
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unpolarised (uniform) distribution

tilts the uniform distribution



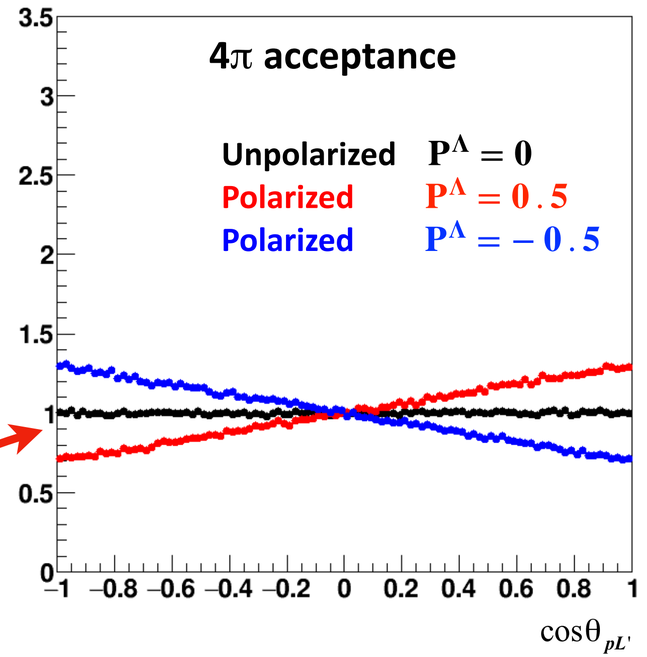
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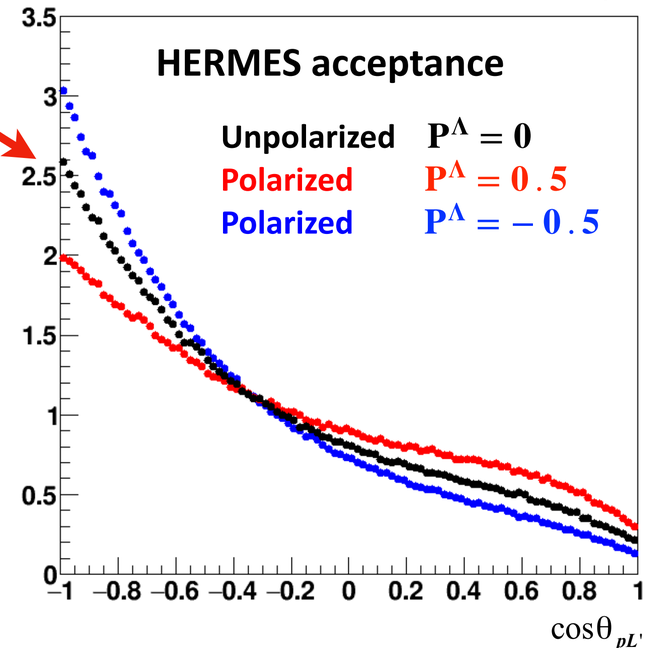
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$$\frac{\mathrm{d}N}{\mathrm{d}\Omega_p} \propto \frac{\mathrm{d}N_0}{\mathrm{d}\Omega_p}\left(1 + \alpha P^{\Lambda}_{L'} \cos\theta_{pL'}\right) \otimes \varepsilon(\theta_{pL'})$$

- acceptance **ε** distorts distribution
- NOMAD: basically **4π** acceptance
- COMPASS: MC simulation of acceptance
  - major source of systematic uncertainty
- HERMES: cancel acceptance effect using two beam helicity states (basically measures spin asymmetry)





Polarization measurement

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

Polarization measurement

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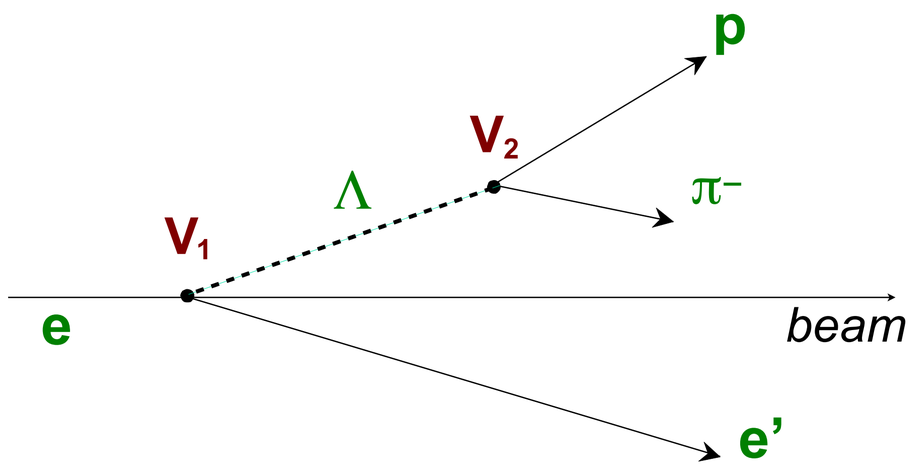
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- slightly more complicated iteration procedure used in case of unbalanced P_B
- extended to 3D case [cf. backup]

Λ & $\bar{\Lambda}$ yields at HERMES

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



Background suppression

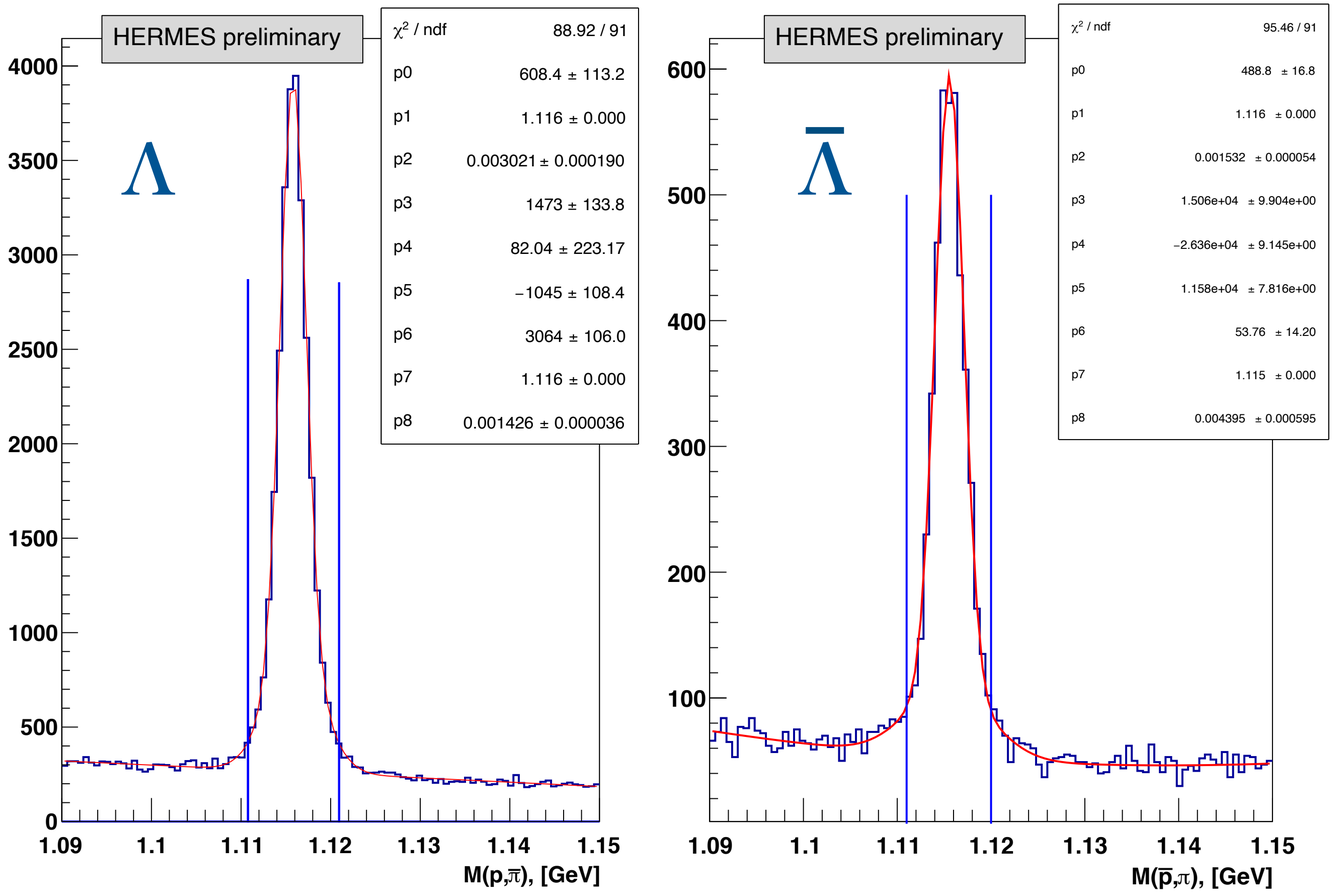
- leading π rejection
  (in HERMES kinematics proton is always leading):
- h^+h^- pair background (coming from V_1) rejection,
  vertex separation:
  - d(V_1,V_2) > 6 cm for Λ
  - d(V_1,V_2) > 10 cm for $\bar{\Lambda}$

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

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

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  - $W^2 > 10$ GeV^2
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  - 0.8 GeV$^2 < Q^2 < 24$ GeV^2
- total number of $\Lambda(\bar{\Lambda})$ is about **40k (6k)**



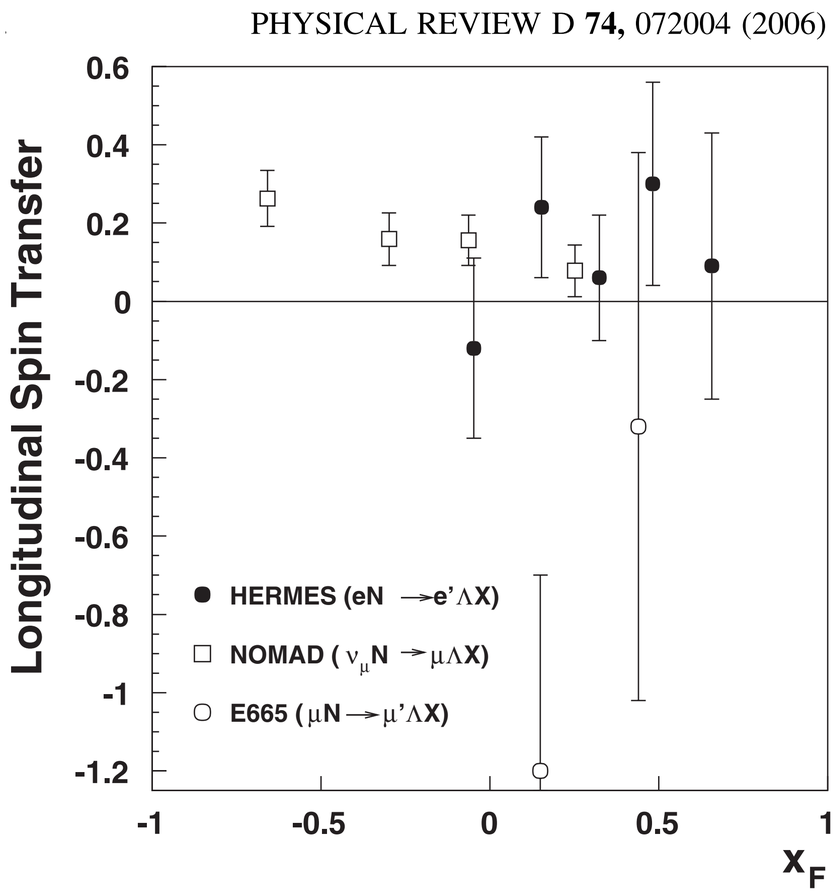
[one data-taking period]

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$$D_{LZ} \propto \frac{f_1^q \otimes G_1^q}{f_1^q \otimes D_1^q}$$

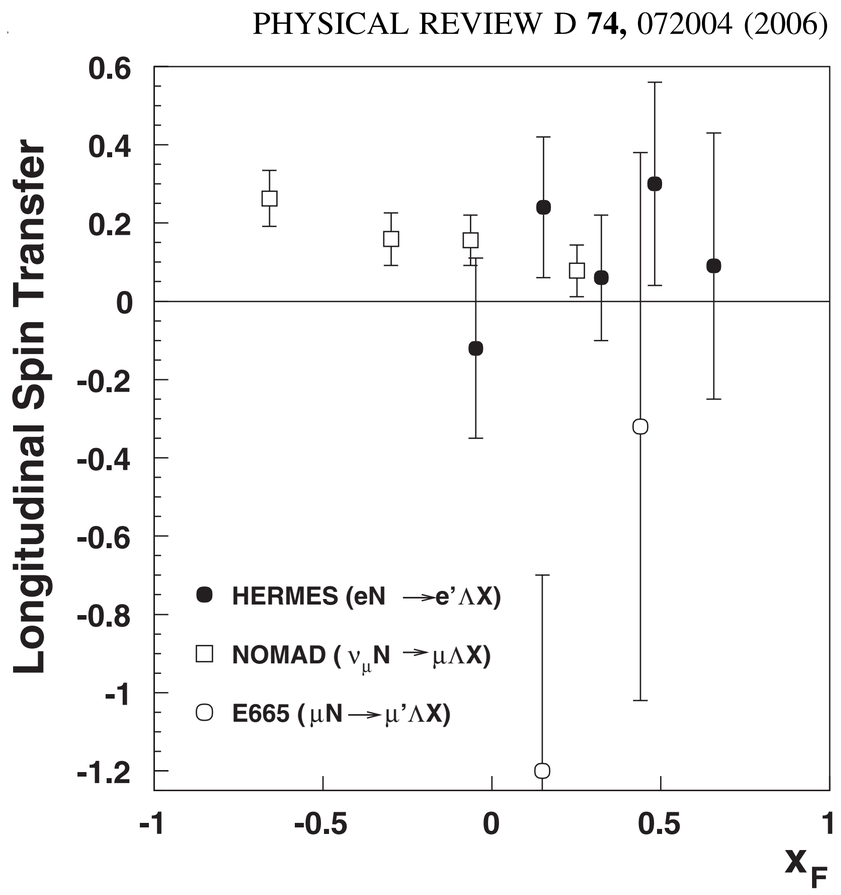
Improvements from previous publication

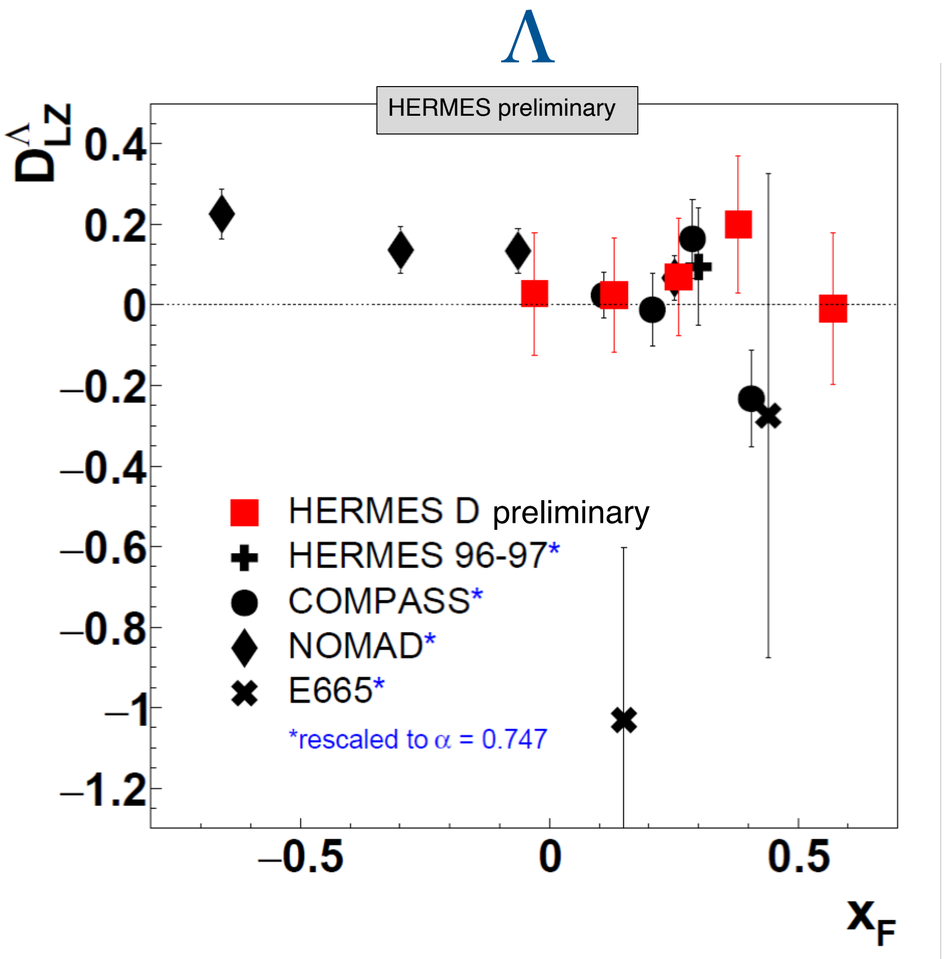


- PDG updated values of asymmetry parameter ➠ rescaled older results that used previous ±0.642

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Improvements from previous publication

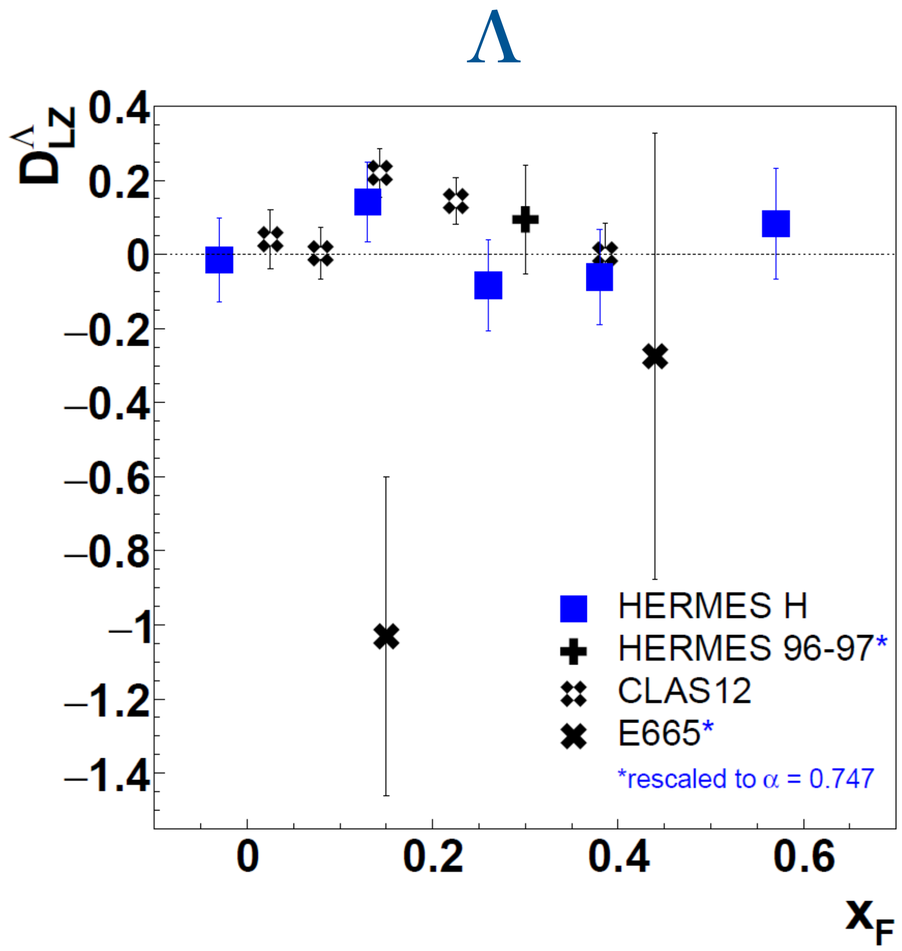


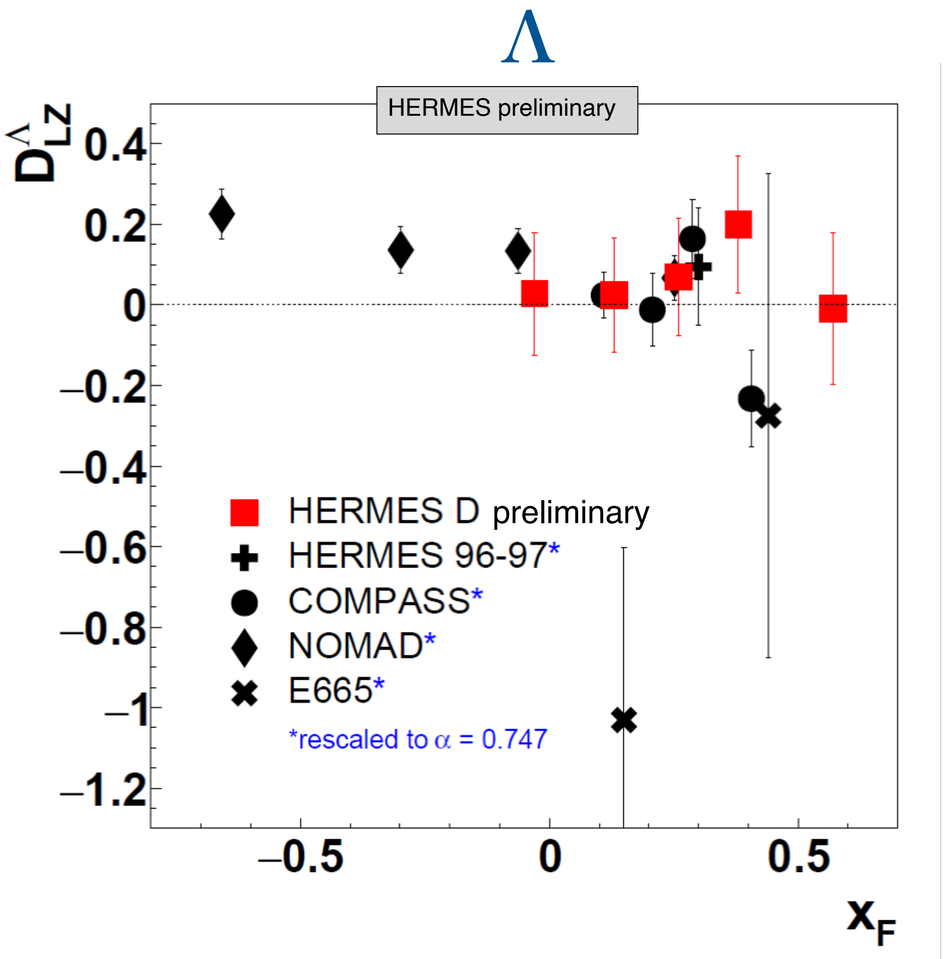


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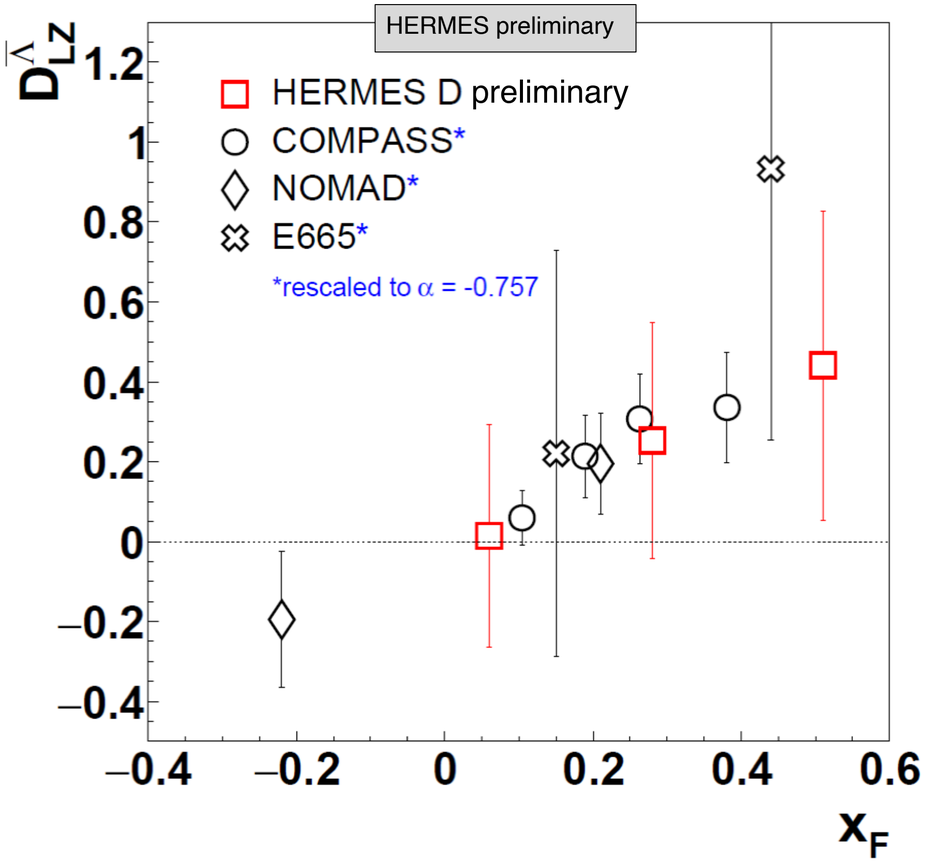


- PDG updated values of asymmetry parameter ➠ rescaled older results that used previous ±0.642
- separate results for **H** and **D** targets

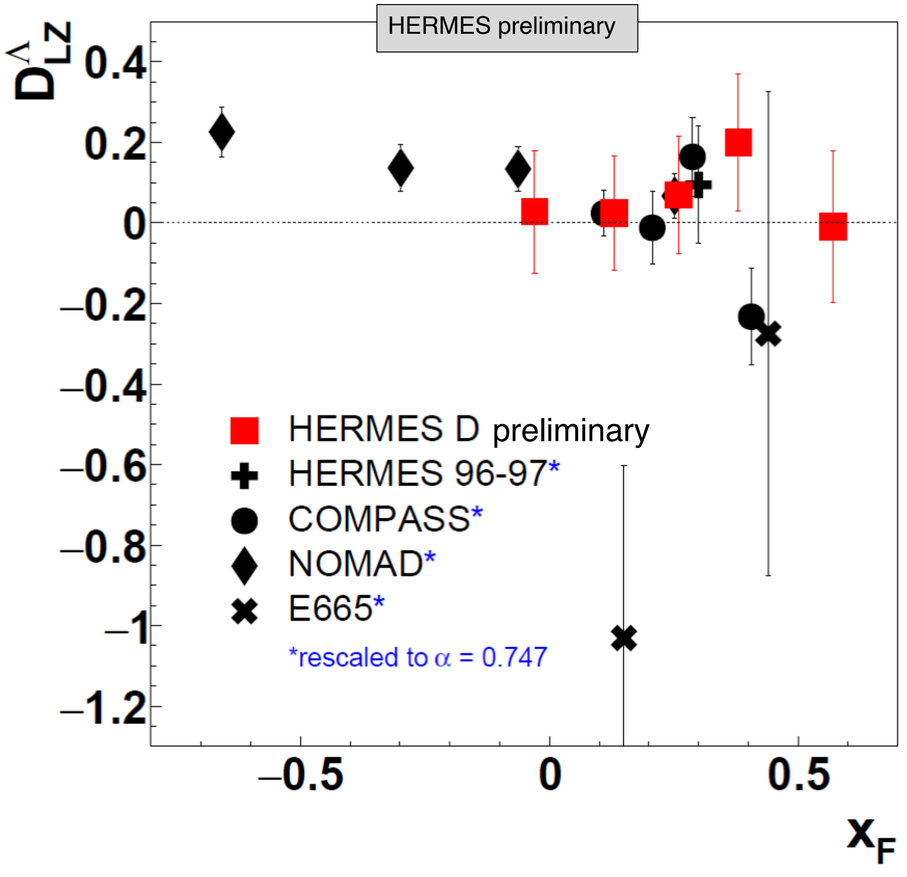
$$D_{LZ} \propto \frac{f_1^q \otimes G_1^q}{f_1^q \otimes D_1^q}$$

Improvements from previous publication

$\bar{\Lambda}$



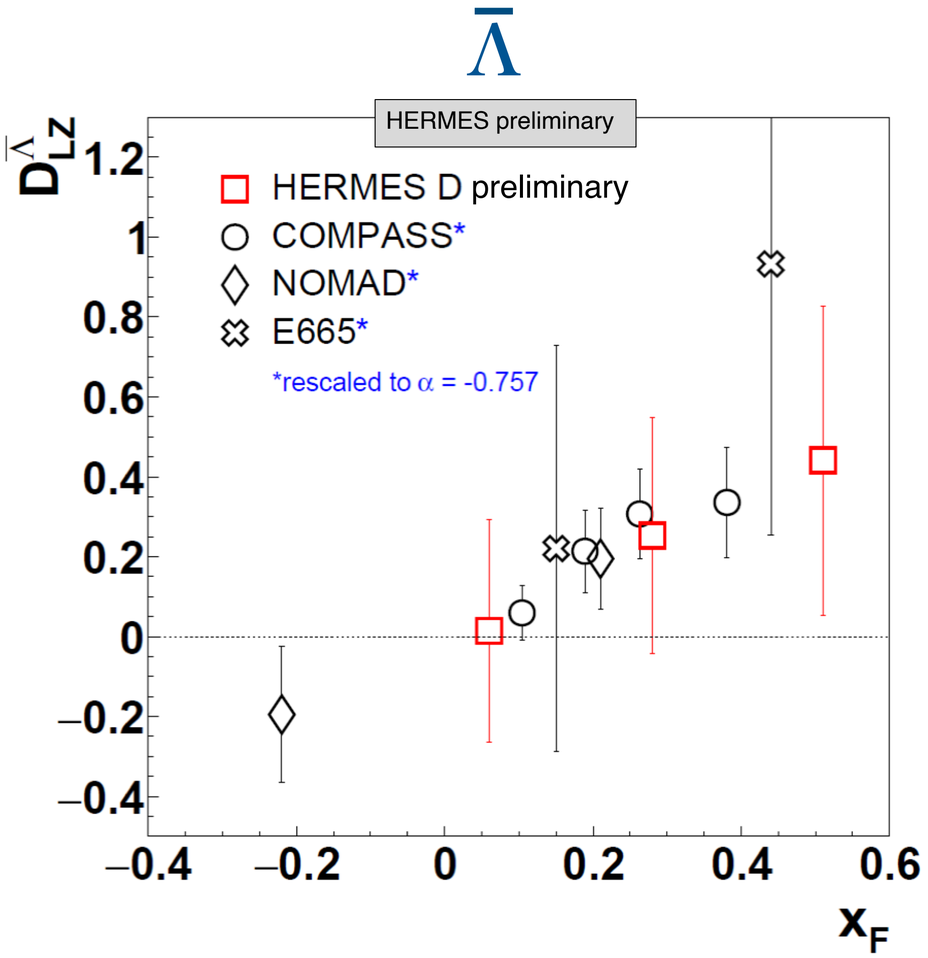
Λ



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$$D_{LZ} \propto \frac{f_1^q \otimes G_1^q}{f_1^q \otimes D_1^q}$$

Improvements from previous publication



Clear rise of spin transfer:

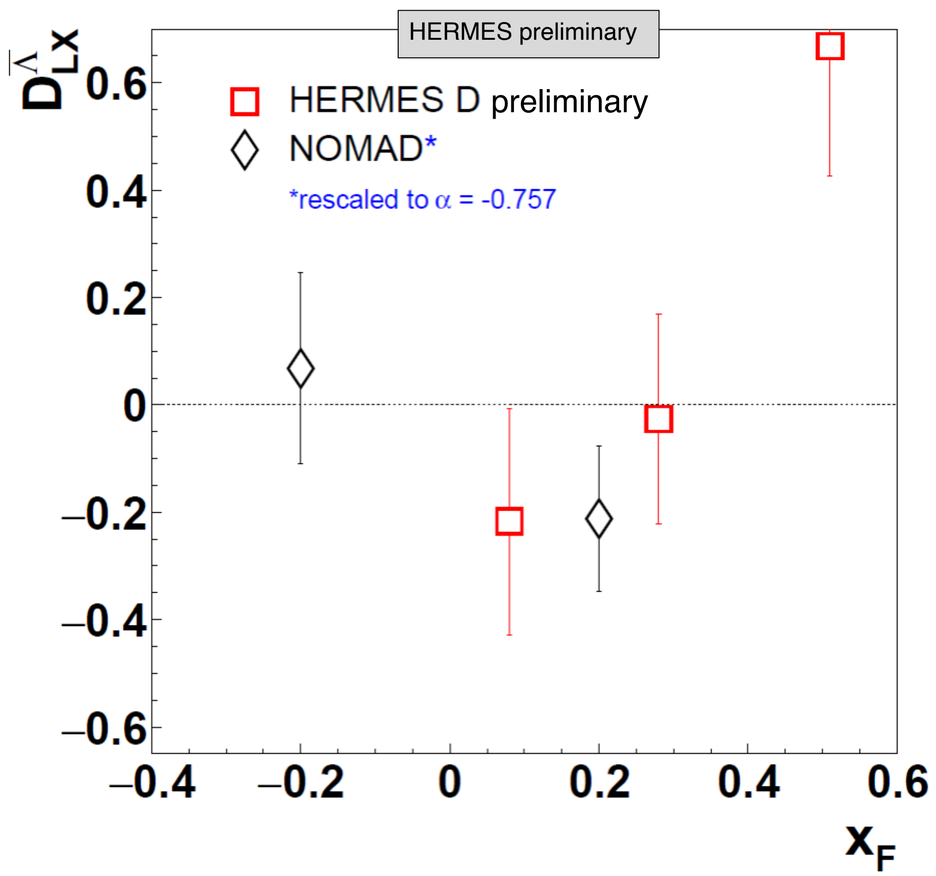
result of less suppressed $\bar{s}$ contribution to $\bar{\Lambda}$ production in SIDIS?

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- results for $\bar{\Lambda}$

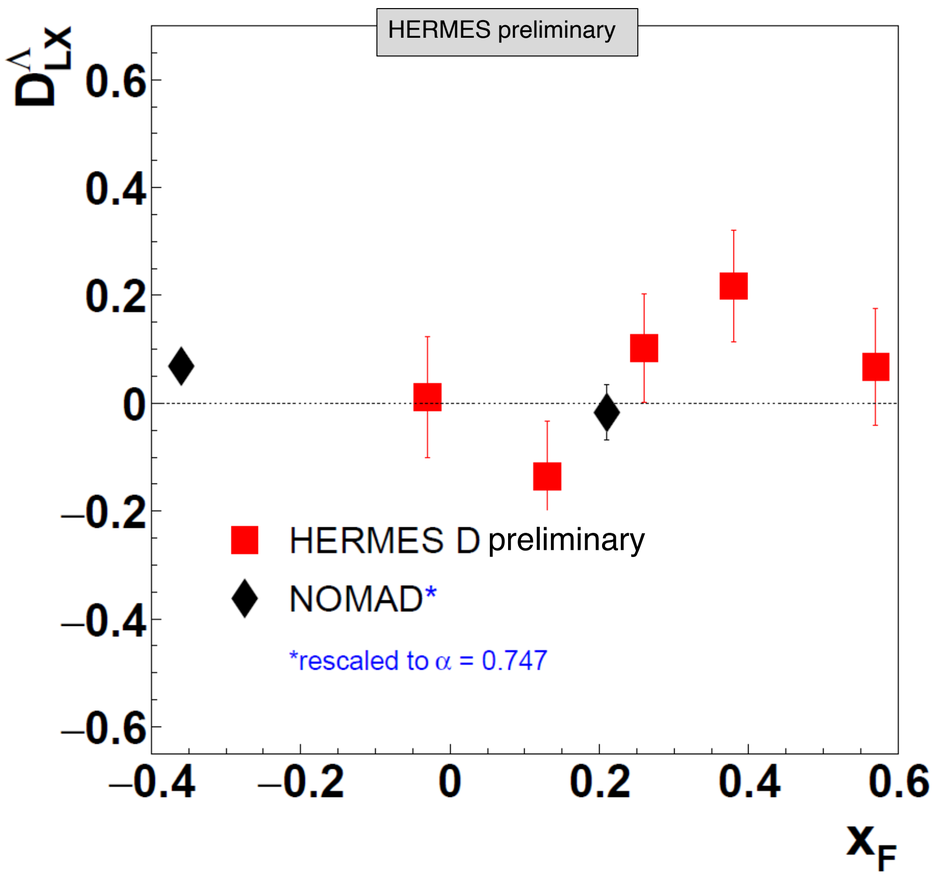
$$D_{LX} \propto \frac{e^q \otimes H_1^q}{f_1^q \otimes D_1^q} + \frac{f_1^q \otimes \tilde{G}_1^q}{f_1^q \otimes D_1^q}$$

Improvements from previous publication

$\bar{\Lambda}$



Λ



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 $H_1(z)$

conclusions

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- HERMES in good position to measure beam-spin dependent Λ polarization due to frequent reversal of beam helicity
  - reduction of systematic uncertainties from detector acceptance
- preliminary results from 1999-2007 data on longitudinal and longitudinal-to-transverse spin transfer to Λ and $\bar{\Lambda}$ exhibit 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 $\bar{\Lambda}$ suggestive for substantial strange G_1

Thank you!

back-up

Polarization measurement

Extraction of spin transfer in 3D and unbalanced case:

$$\sum_{k=x,z} D_{Lk} \left\langle \frac{D_k(y) D_i(y) \cos\theta_k \cos\theta_i}{1 + \alpha [\![P_B]\!] \sum_{j=x,z} D_j(y) D_{Lj} \cos\theta_j} \right\rangle = \frac{1}{\alpha} \frac{\left\langle P_B D_i(y) \cos\theta_i \right\rangle - [\![P_B]\!] \left\langle D_i(y) \cos\theta_i \right\rangle}{[\![P_B^2]\!] - [\![P_B]\!]^2}$$

- system of "linear" equations

$$\sum_k D_{Lk} a_{ik} = c_i$$

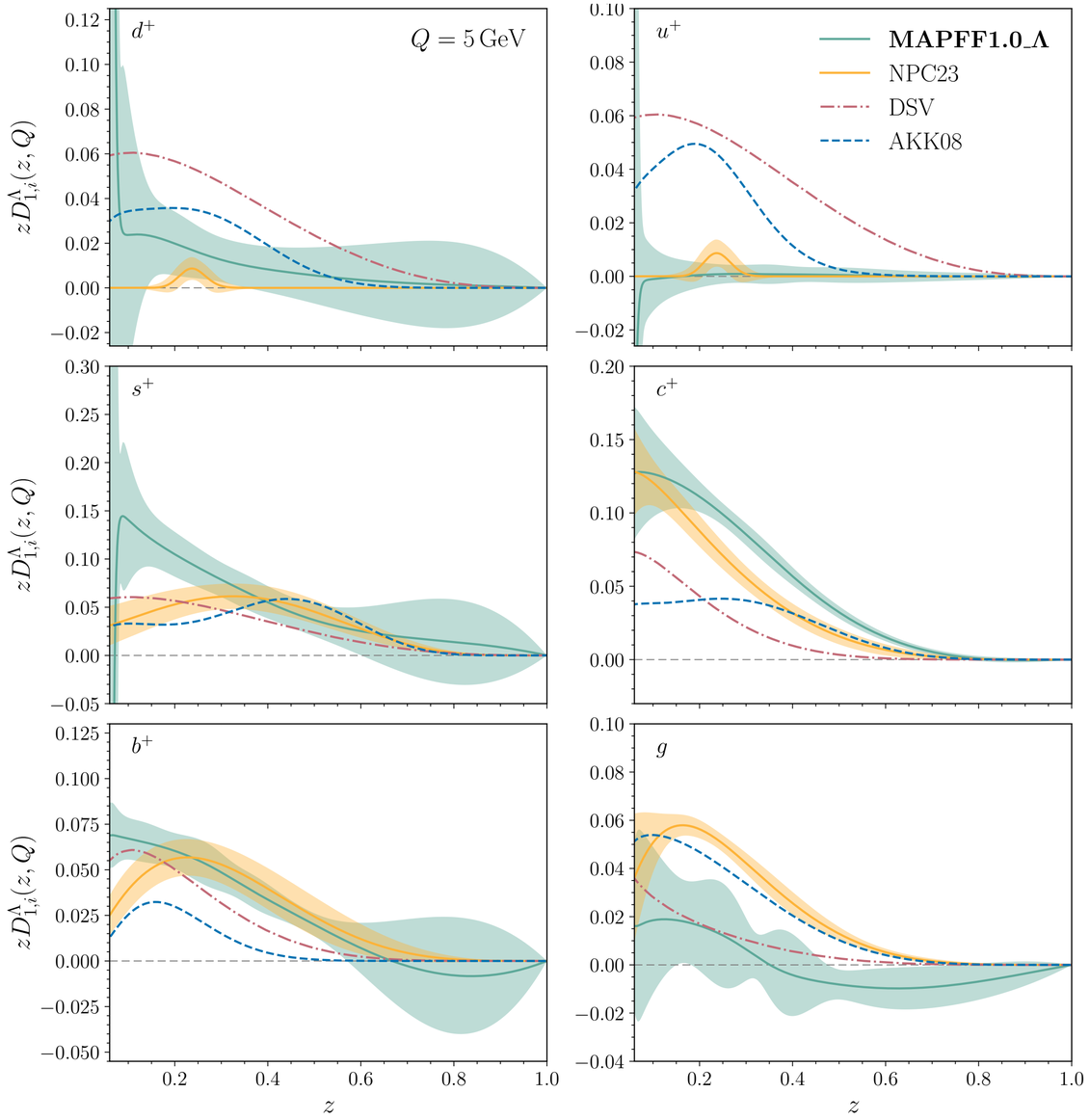
$$\begin{bmatrix} a_{xx} & a_{xz} \\ a_{zx} & a_{zz} \end{bmatrix} \begin{bmatrix} D_{Lx} \\ D_{Lz} \end{bmatrix} = \begin{bmatrix} c_x \\ c_z \end{bmatrix}$$

- coefficients a_{ik} are **dependent** from D_{Li} (unless helicity balance $[\![P_B]\!] = 0$)
- denominator in matrix elements are close to unity
- to solve given system, an iteration procedure is used

$$D_{Lk}^{(0)} \xrightarrow{\text{calculate } a_i^k} a_i^{k(0)} \xrightarrow{\text{solve } a_i^k D_{Lk} = c_i} D_{Lk}^{(1)} \rightarrow \dots$$

- 3 steps are sufficient to converge due to $\alpha [\![P_B]\!] \sum_{j=x,z} D_j(y) D_{Lj} \cos\theta_j \sim 0$

Lambda fragmentation – a window to strangeness



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