

HERMES and OLYMPUS experiments

***STUDY OF NUCLEON (HADRON) STRUCTURE USING ELECTRON
BEAMS AT DESY***

HERMES data taking period 1995-2007 , data analysis
OLYMPUS data taking 2012, data analysis

HERMES. Study of inclusive, semi inclusive and photo production reactions
 Using 27.6 GeV longitudinally polarized positron (electron) beam incident
 On polarized H or D target, or unpolarized nuclei target

Summary of HERMES data taking

<p><u>Ран I.</u> 1995-2000 годы, поляризация пучка</p> <p>$P_B=51\%$</p>	<p><u>Продольно-поляризованные мишени H,D,He3</u></p> <p>$P_T \approx 80\%$</p> <p><u>Неполяризованные мишени</u> H, D, ^3He, ^4He, ^{14}N, ^{20}Ne, ^{84}Kr</p>	<p><u>Интегральная светимость</u></p> <p>259 pb⁻¹</p> <p>619 pb⁻¹</p>	<p><u>Число неупруго-рассеянных электронов с $Q^2 > 1$ GeV² (DIS)</u></p> <p>11.8*10⁶</p> <p>27.9*10⁶</p>
<p>2001-2002 годы модернизация коллайдера ГЕРА</p>			
<p><u>Ран II.</u> 2002-2007 годы, поляризация пучка</p> <p>$P_B=36\%$</p> <p><u>Детектор отдачи</u> 2006-2007 годы</p>	<p><u>Поперечно-поляризованная мишень H</u></p> <p>$P_T \approx 80\%$</p> <p><u>Неполяризованные мишени</u> H, D, ^3He, ^4He, ^{14}N, ^{20}Ne, ^{84}Kr</p>	<p>150 pb⁻¹</p> <p>2180 pb⁻¹</p>	<p>7.44*10⁶</p> <p>98.2*10⁶</p>

Most important results

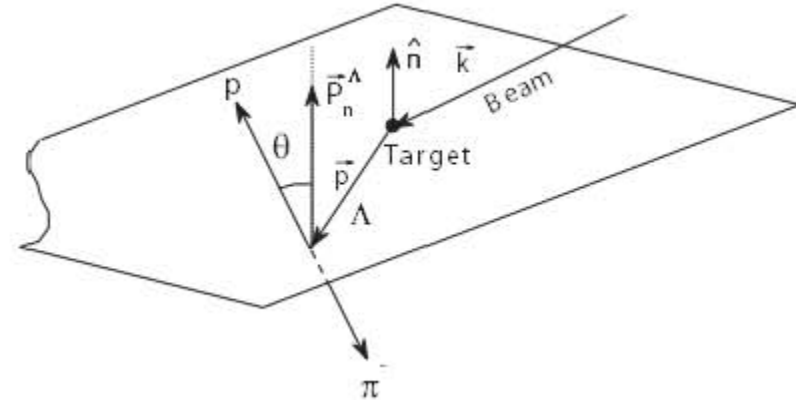
- ❑ Spin crisis DIS inclusive
 $\Delta\Sigma = 0.33 \pm 0.02_{\text{exp}} \pm 0.03_{\text{theo}}$
- ❑ Spin crisis DIS semi-inclusive
 $\Delta\Sigma = 0.359 \pm 0.026_{\text{exp}} \pm 0.018_{\text{theo}}$
- ❑ Estimation of gluon polarization
 $\frac{\Delta g(x)}{g(x)} = 0.049 \pm 0.034_{\text{stat}} \pm 0.010_{\text{sys}}$
- ❑ First measurement of Sivers DF and Collins FF
- ❑ Detailed study of GPDs

Transverse (spontaneous) polarization of Λ and anti Λ

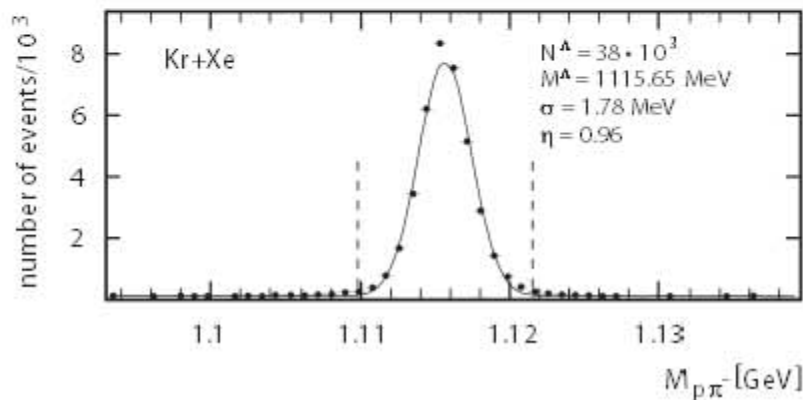
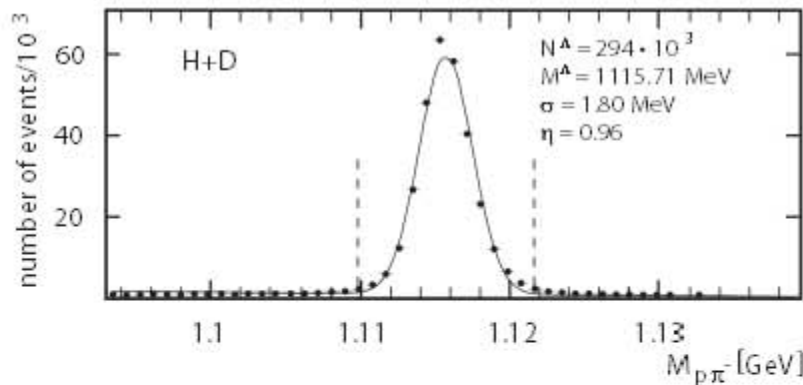
C.B.

$\tilde{\gamma} + A \rightarrow \Lambda(\bar{\Lambda}) + X$ at $Q^2 \approx 0$ **quasireal photoproduction**

$\Lambda \rightarrow p\pi^- \quad \bar{\Lambda} \rightarrow \bar{p}\pi^+$ **weak decay** $\frac{dN}{d\Omega_p} \sim 1 + \alpha P_\Lambda \cos \theta_p$



Event selection



Extraction of P_{Λ^-}

$$\frac{dN}{d\Omega_p} \sim (1 + \alpha P_\Lambda \cos \theta_p) \otimes \text{acceptance function}$$

moment method \Leftrightarrow

up/down detector mirror symmetry \Rightarrow

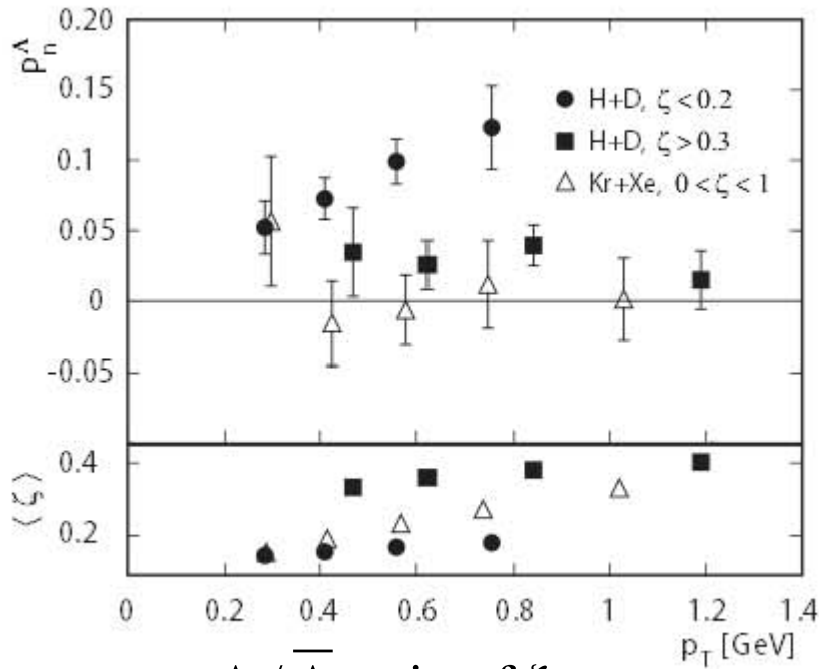
$$P_\Lambda = \frac{\langle \cos \theta_p \rangle}{\alpha \langle \cos^2 \theta_p \rangle}$$

$$\alpha_\Lambda = 0.62 \quad \alpha_{\bar{\Lambda}} = -0.62$$

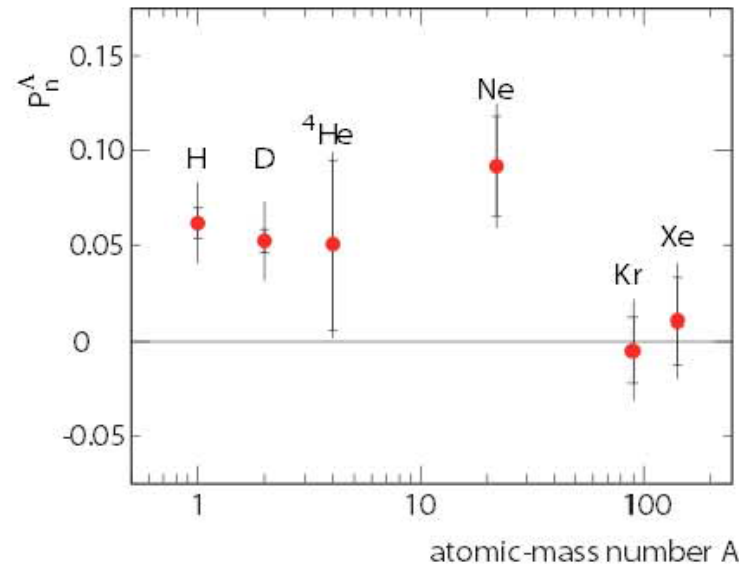
Results

Phys. Rev. D90 (2014) 7, 072007
 Phys. Rev. D76 (2007) 092008

Ю.Н. С.Б. К.Р.

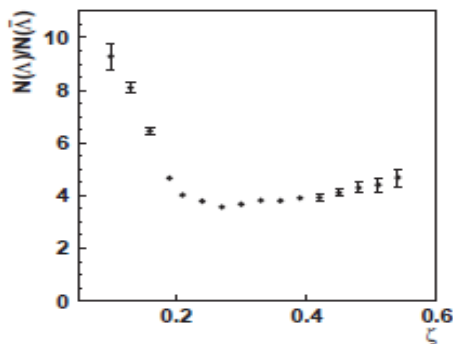


$\Lambda / \bar{\Lambda}$ ratio of ξ



$$P_{\Lambda}(\text{H} + \text{D}) = 0.056 \pm 0.005_{\text{stat}} \pm 0.02_{\text{sys}}$$

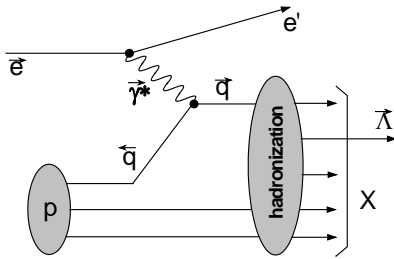
$$P_{\bar{\Lambda}} = 0.025 \pm 0.015_{\text{stat}} \pm 0.018_{\text{sys}}$$



- P_{Λ} positive like in $K^- \Sigma^-$ beam Λ production
- Polarization $P_{\bar{\Lambda}} \approx 0$
- Target and current fragmentation regimes
- P_{Λ} drops down for heavy nucleus targets

Spin transfer to Λ in polarized DIS

C.B.



$$\vec{e} + p \rightarrow e' + \vec{\Lambda} + X \quad P_{\Lambda} \sim D_{LL}^{\Lambda} \cdot P_{\text{beam}}$$

In LO QCD

$$D_{LL}^{\Lambda}(x, z) = \sum_{f=u,d,s,\dots} D_{LL,f}^{\Lambda}(z) \omega_f^{\Lambda}(x, z)$$

$$D_{LL,f}^{\Lambda}(z) = \frac{\Delta F_f^{\Lambda}}{F_f^{\Lambda}} \quad \text{access to spin-fragmentation } f\text{-n}$$

↳ partial spin transfer

$D_{LL,f}^{\Lambda}$ is strongly related to Λ spin structure
i.e., $D_{LL,f}^{\Lambda}$ is a measure of poorly known
u,d-quark polarization in Λ

Λ spin structure

Naïve CQM

$$\Delta\Sigma=1 \quad \Delta u=\Delta d=0 \quad \Delta s=1$$

SU(3)_f S.B. using HERMES $\Delta\Sigma=0.32$
 $\Delta u=\Delta d=-0.16 \quad \Delta s=0.64$

Lattice-QCD

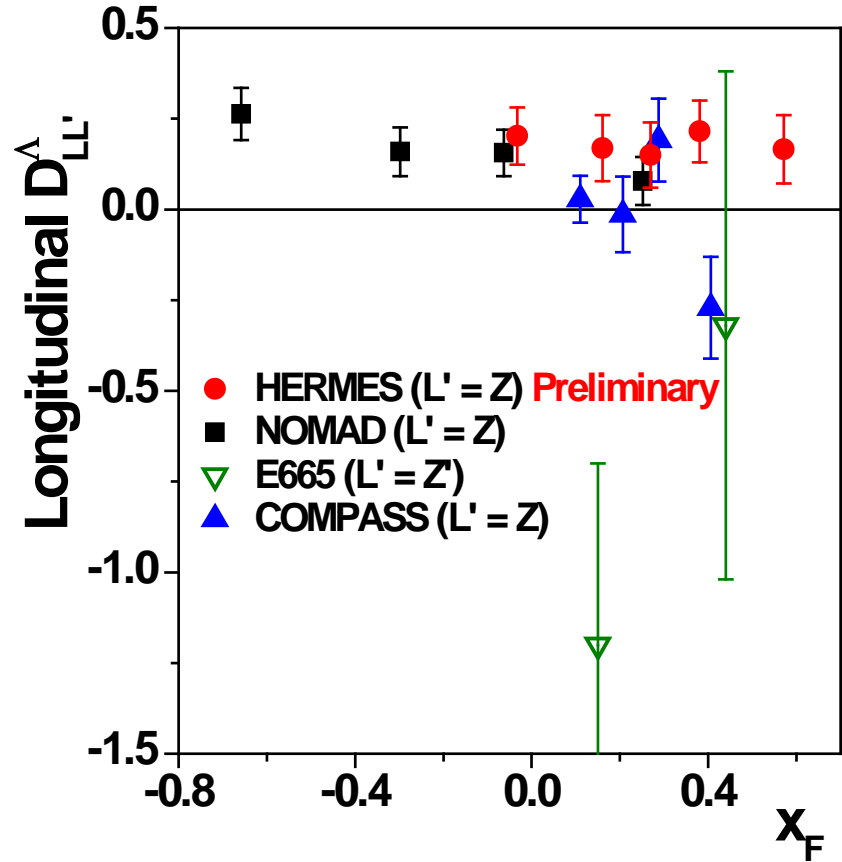
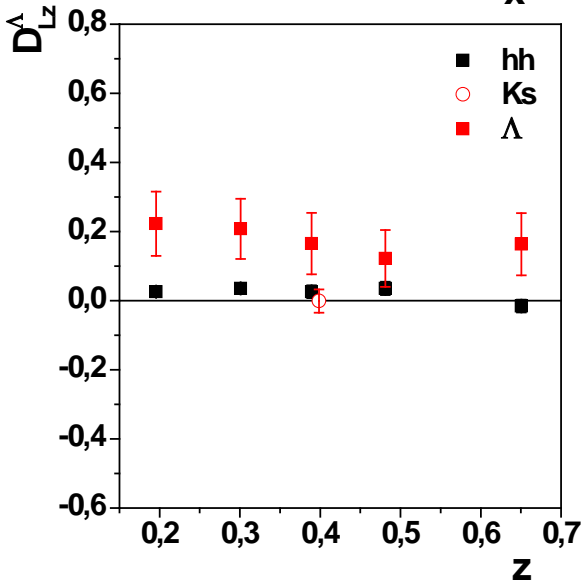
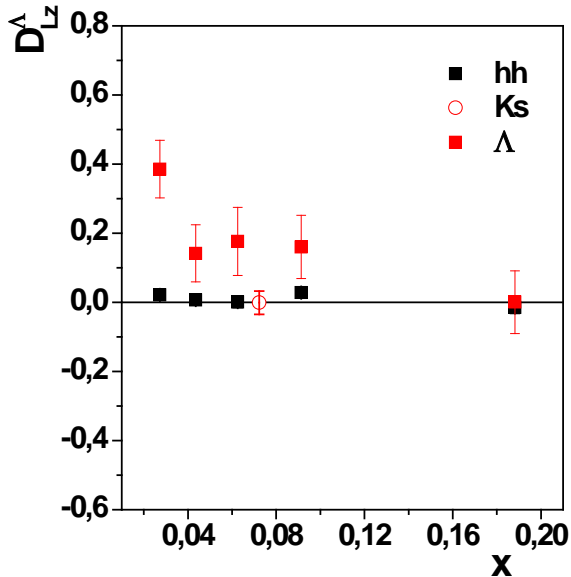
$$\Delta u=\Delta d=-0.02 \quad \Delta s=0.68 \quad (\pm 0.04)$$

$$\frac{\Delta F_u^{\Lambda}}{F_u^{\Lambda}} \sim \Delta_u \quad \frac{\Delta F_s^{\Lambda}}{F_s^{\Lambda}} \sim \Delta_s$$

Expectation

$$D_{LL}^{\Lambda} \approx D_{LL,u}^{\Lambda} \leq 0$$

HERMES spin transfer and world data



$$D_{LL}^{\Lambda} = 0.15 \pm 0.03_{stat} \pm 0.02_{syst}$$

Phys. Rev. D?? (2015)

Phys. Rev. D 74 (2006) 072004

Phys.Rev. D64 (2001) 112005

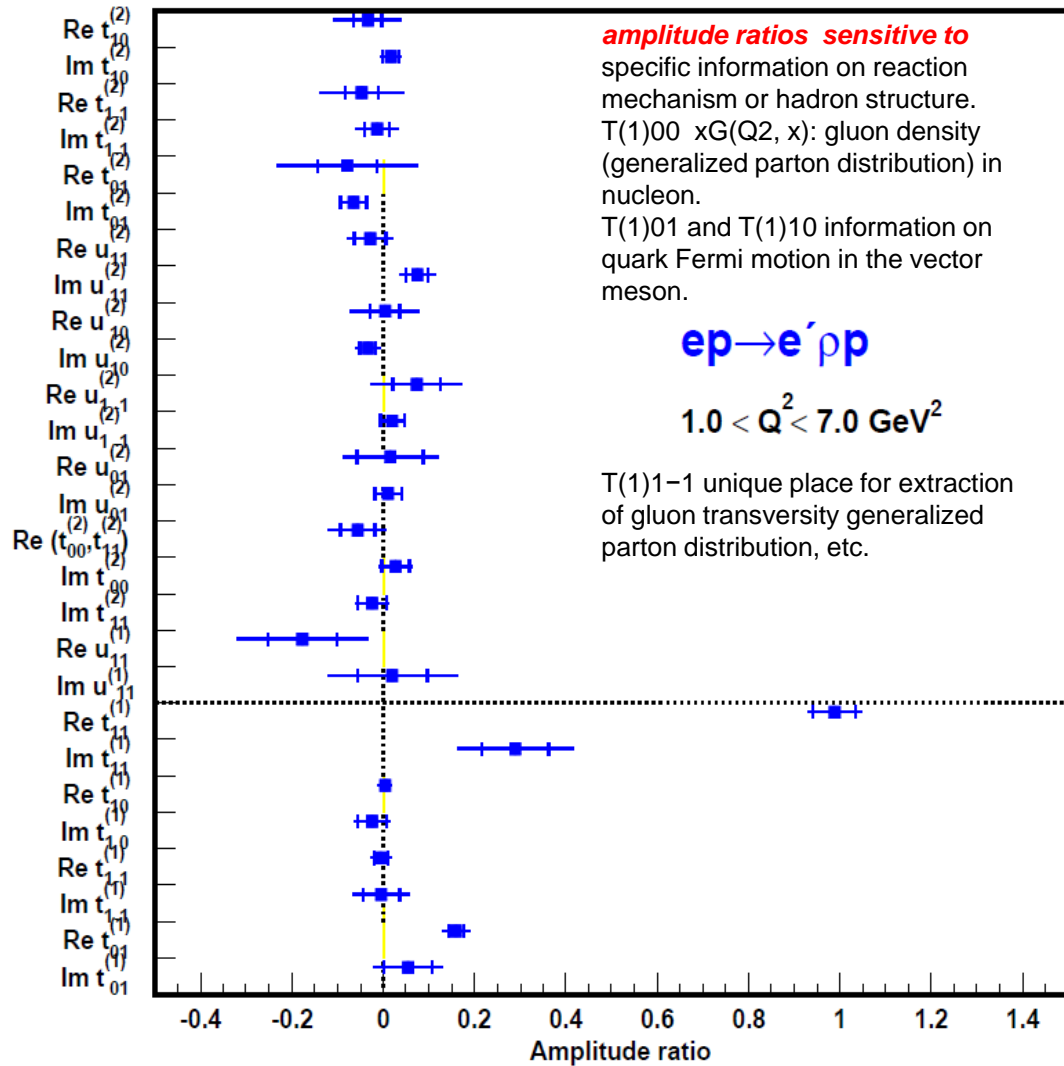
$$\vec{e} \rightarrow e' + \vec{\gamma}^*$$

$$\vec{\gamma}^* + \vec{N} \rightarrow \vec{V}(\rho, \varphi, \omega) + N'$$

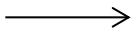
$$\{3 \times 3\}_{\gamma} \cdot \{2 \times 2\}_N \Rightarrow \{3 \times 3\}_V \cdot \{2 \times 2\}_{N'}$$

Virtual
Photon
SDM
известна
из К.Э.Д.

V-meson
SDM
измеряется



EPJ C 71 (2011) sdme
 EPJ 74 (2014)



**direct extraction amplitude
 new paper**

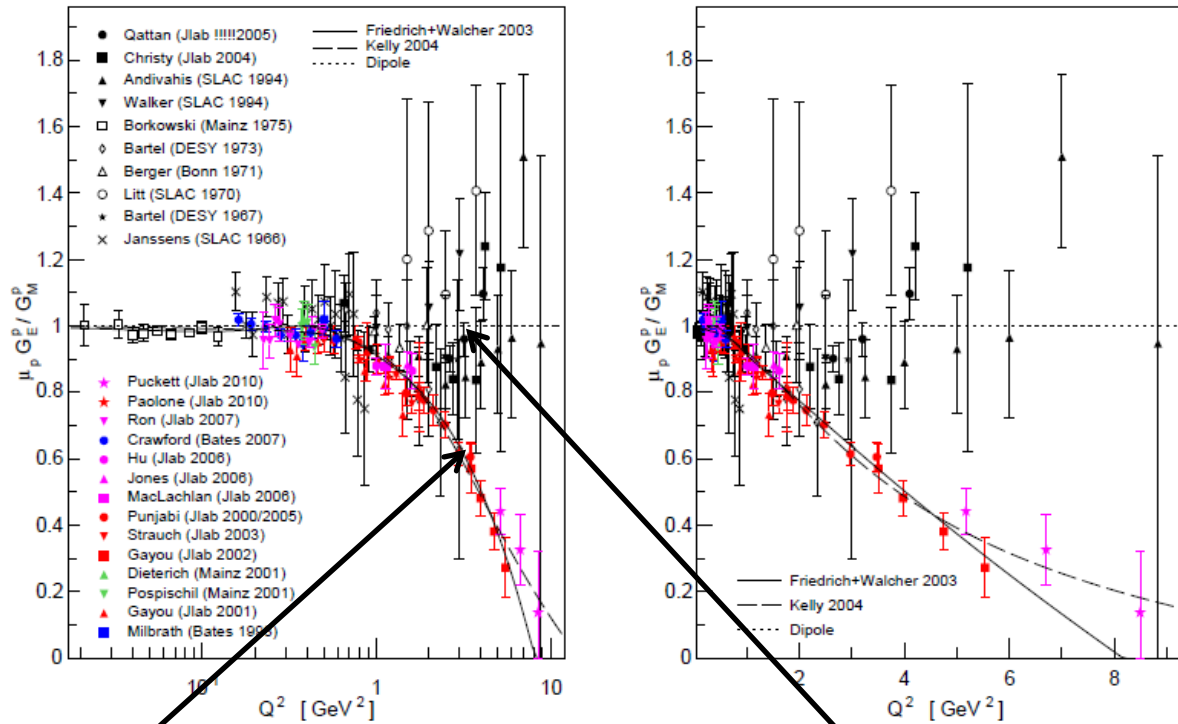
OLYMPUS motivation

Proton form factor problem

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_{\text{Mott}}} \frac{1}{\varepsilon(1+\tau)} \left[\varepsilon G_E^2(Q^2) + \tau G_M^2(Q^2) \right], \quad \tau = \frac{Q^2}{4M_p^2},$$

$$\text{photon polarization } \varepsilon = \frac{1}{1+2(1+\tau)\tan^2(\theta_e/2)}, \quad 0 < \varepsilon < 1.$$

$\mu_p G_E^p / G_M^p$ Discrepancy



M.Kohl - Hampton University

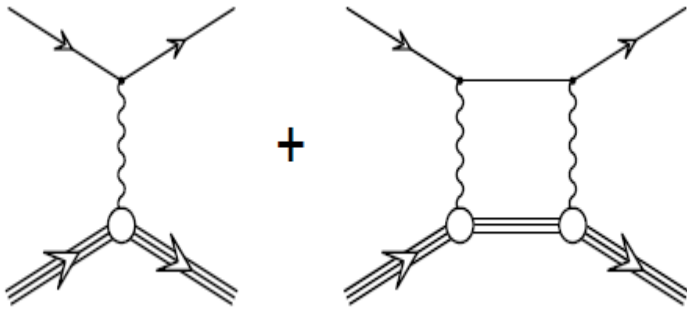


JLAB recoil proton polarization measurements

unpolarized Rosenbluth separation method

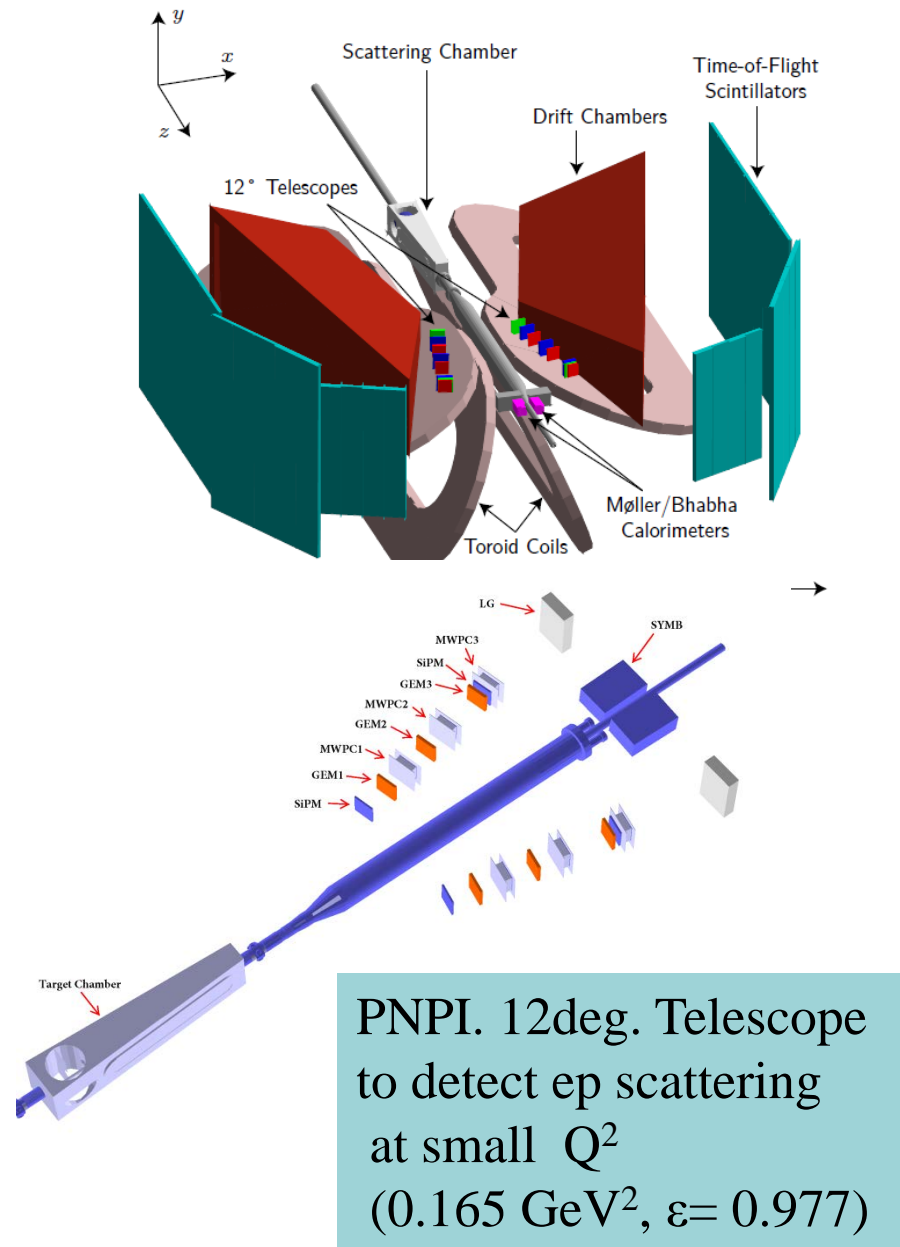
OLYMPUS experiment at DORIS 2 GeV e^+ / e^- beams

Proposed explanation
contribution **TPE**



$$\frac{\sigma^{e^+p}}{\sigma^{e^-p}} = 1 + \mathbf{TPE} + \dots$$

$$\mathbf{TPE} = 4 \frac{\text{Re} M_{2\gamma}^*(Q^2)}{M(Q^2)_{Born}}$$



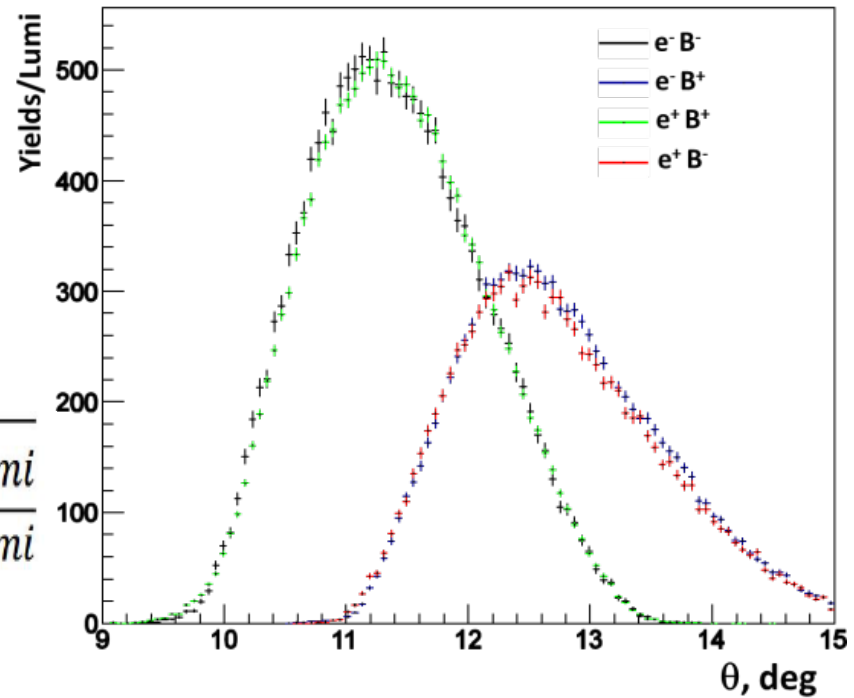
Data analysis. Double ratio

12 deg. telescope counts

Track topology and
detection efficiency
 $e^+B^+ = e^-B^-$ $e^+B^- = e^-B^+$



$$\frac{\sigma^+}{\sigma^-} = \sqrt{\frac{N_{tr}(e^+, B^+)/SCLumi}{N_{tr}(e^-, B^+)/SCLumi} * \frac{N_{tr}(e^+, B^-)/SCLumi}{N_{tr}(e^-, B^-)/SCLumi}}$$



	Lumi, fb ⁻¹	σ_{MC} , nB	σ_{MC} left, nB	σ_{MC} right, nB	Tot. stat.
e^-, B^-	0.24	18.42	8.98	9.44	~4.4 M
e^-, B^+	1.93	11.89	5.86	6.02	~23 M
e^+, B^-	0.32	12.07	5.94	6.13	~ 3.8 M
e^+, B^+	1.96	18.13	8.79	9.33	~ 35 M

BACKUP SLIDES

Поляризованные
позитроны
(электроны)
27.6 ГэВ

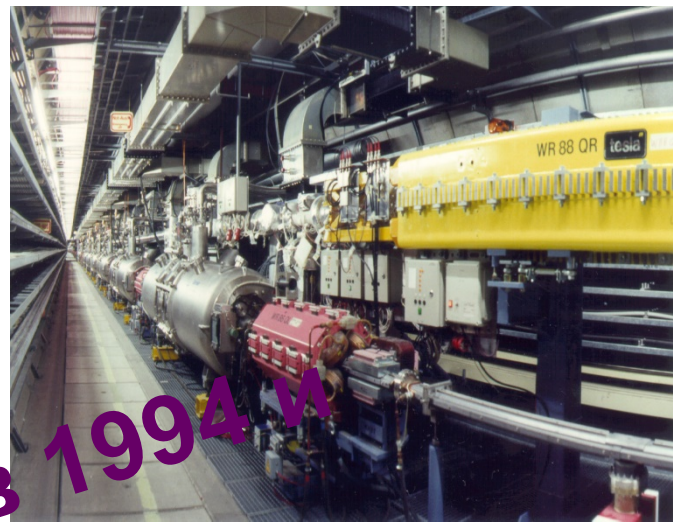
+

поляризованные
H или D мишени
поляризация 85%,
неполяризованные
ядерные мишени

Впервые реализована
идея само-поляризации
пучка электронов в
магнитном поле
ускорителя:

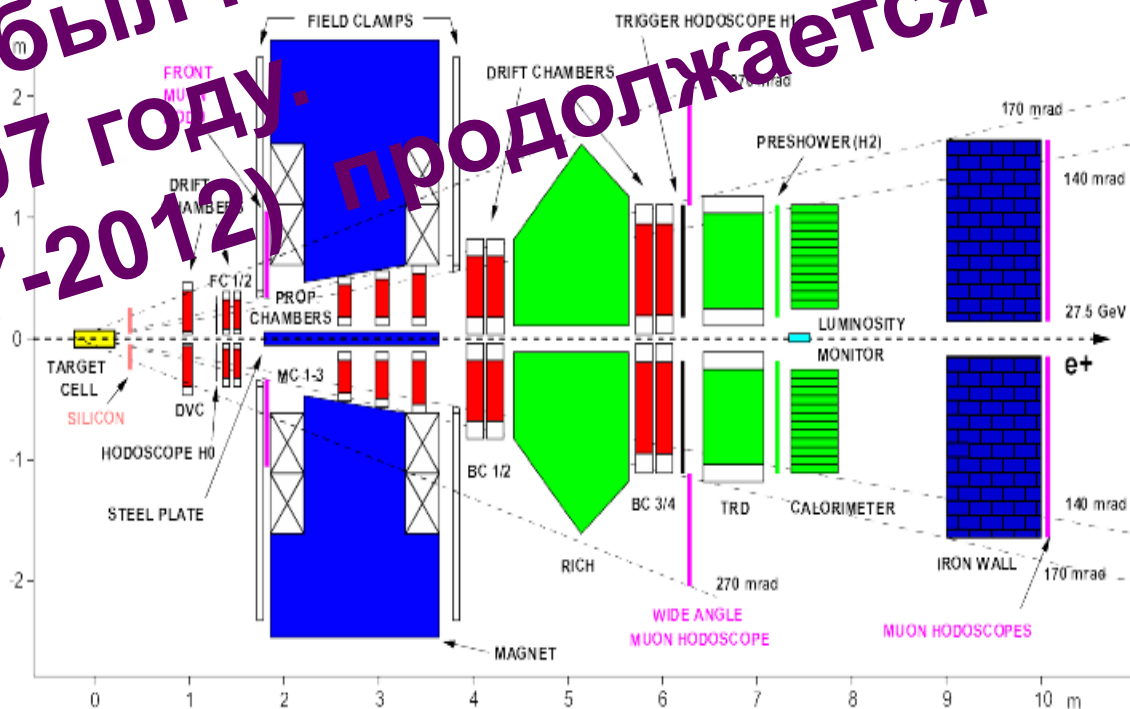
HERA RING

$P_{\text{beam}} \sim 50\%$



Hermes spectrometer

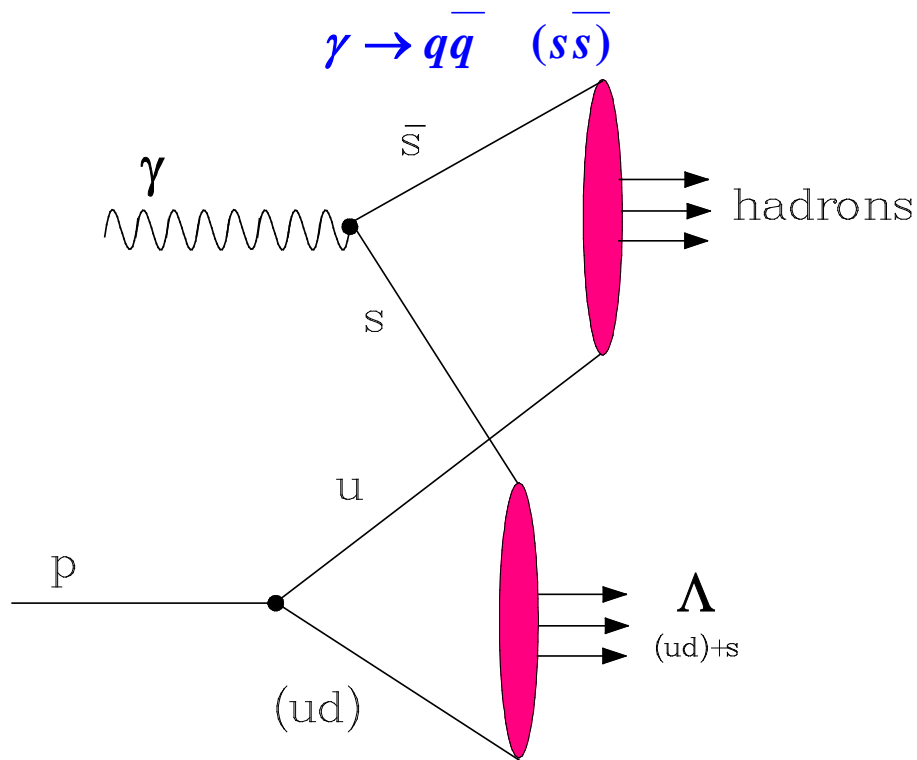
PID: 98% lepton
identification
Excellent
separation of
 π , K and p



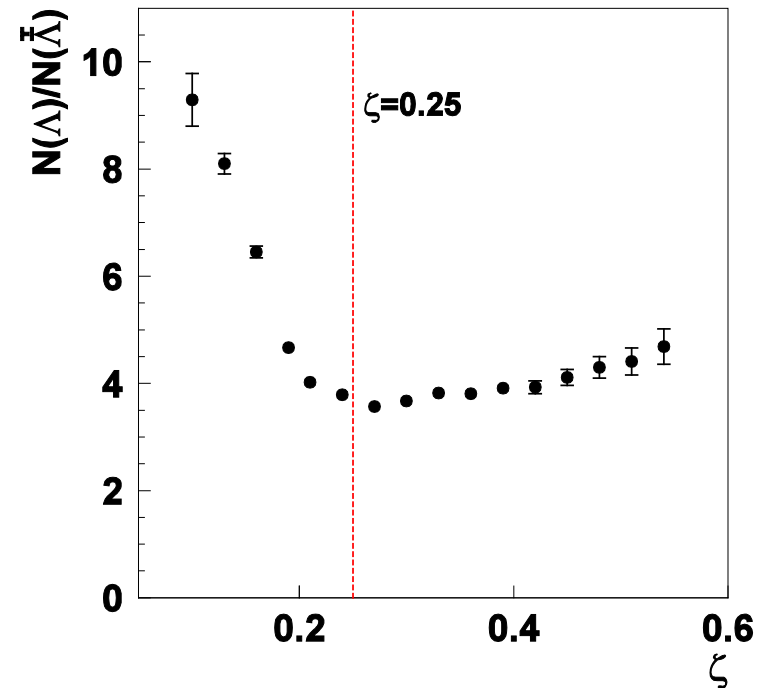
Набор данных был начат в 1994 и закончен в 2007 году. (2007-2012) анализ продолжается

Λ photoproduction mechanism by PYTHIA

$$\langle E_\gamma \rangle = \langle E_e - E_{e'} \rangle \approx 15.6 \text{ GeV}$$



Λ to $\bar{\Lambda}$ yield ratio

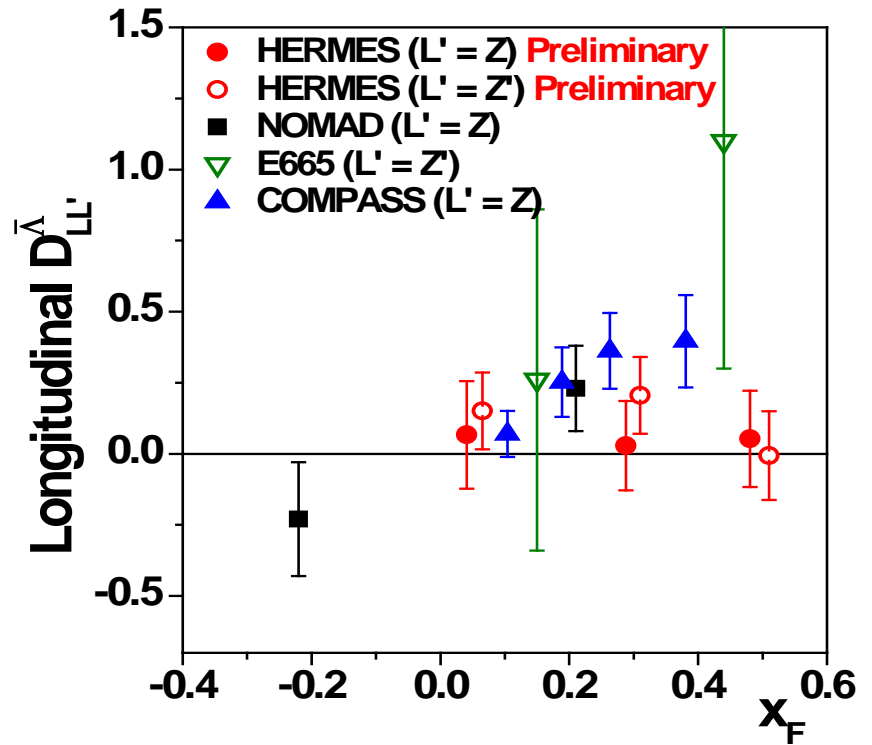
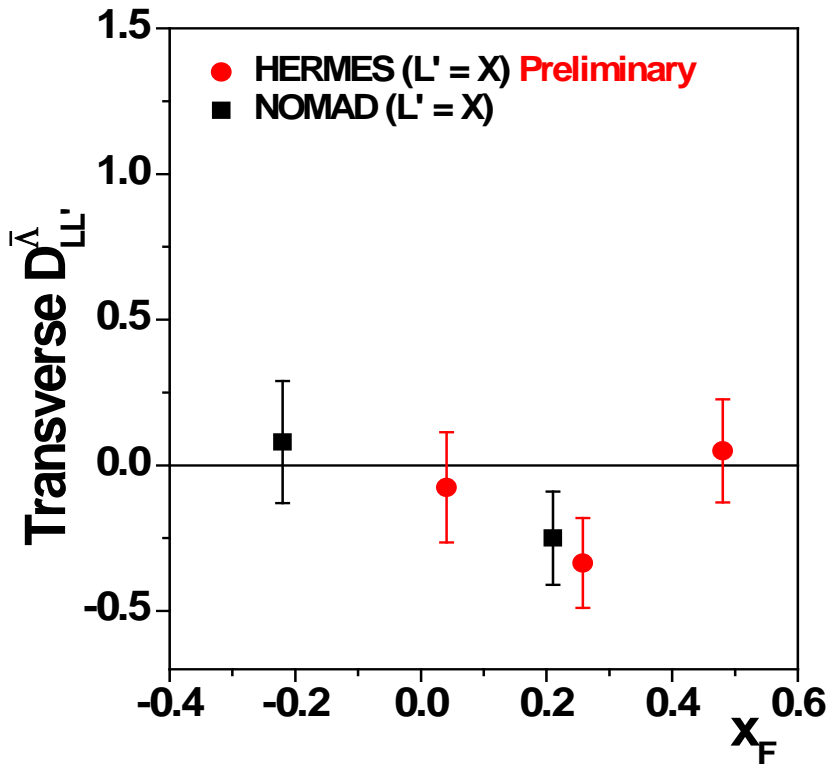


$$\zeta^\Lambda \approx \frac{E^\Lambda}{E_e} < 0.25 \quad \sqrt{t} = 3.31 \text{ GeV}$$



*target (ud)
mechanism*

Longitudinal and transverse spin transfer world data for $\bar{\Lambda}$



Λ and other hyperon spin structure still poorly established

SU(6) spin-1/2 hyperon octet

$\Delta\Sigma=0.32$ $F=0.47$ $D=0.81$

	Δu	Δd	Δs
p(uud)	0.84	-0.43	-0.09
n(udd)	-0.43	0.84	-0.09
Λ (uds)	-0.16	-0.16	0.64
Σ^+ (uus)	0.84	-0.09	-0.43
Σ^0 (uds)	0.375	0.375	-0.43
Σ^- (dds)	-0.09	0.84	-0.43
Ξ^0 (uss)	-0.43	-0.09	0.84
Ξ^- (dss)	-0.09	-0.43	0.84

Λ spin structure

Naïve CQM

$$\Delta\Sigma=1 \quad \Delta u=\Delta d=0 \quad \Delta s=1$$

Jaffe assumption ($\Delta s_{\text{proton}}=0$)

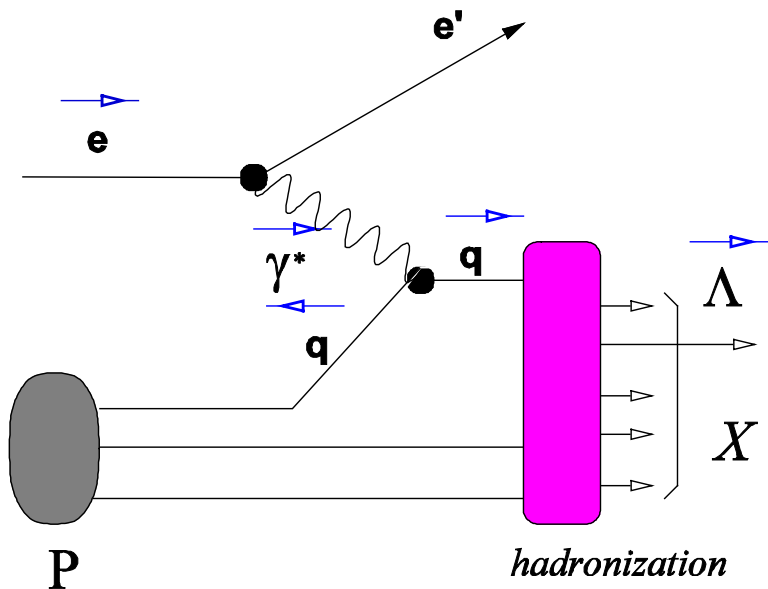
$$\Delta\Sigma=0.586 \quad \Delta u=\Delta d=-0.073 \quad \Delta s=0.732$$

Burkard & Jaffe from EMC result

$$\Delta\Sigma=0.12 \quad \Delta u=\Delta d=-0.23 \quad \Delta s=0.58 \quad (\pm 0.04)$$

Lattice-QCD

$$\Delta u=\Delta d=-0.02 \quad \Delta s=0.68 \quad (\pm 0.04)$$



$$P_{L'}^{\Lambda} = P_b D(y) D_{LL'}^{\Lambda}$$

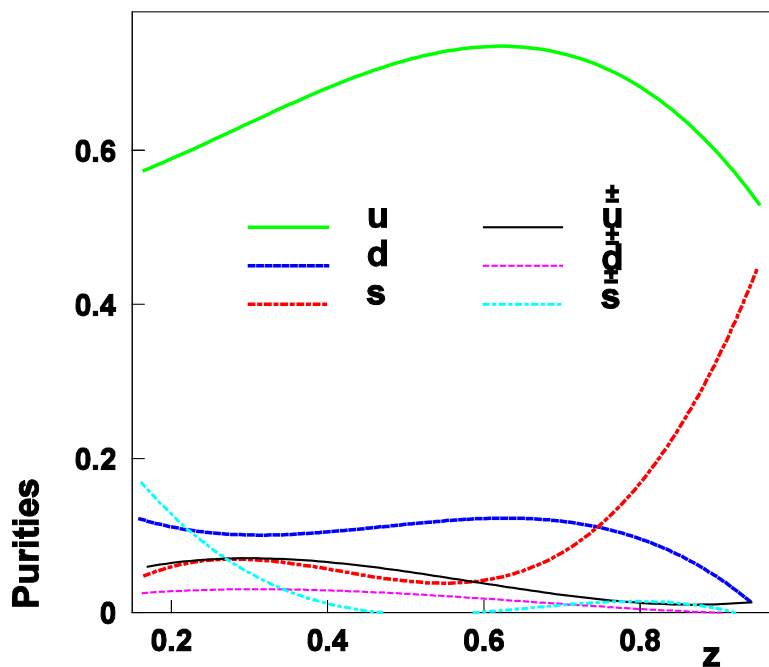
$$D_{LL'}^{\Lambda}(z) = \sum_q \tilde{P}_q(z) \cdot D_{LL'q}^{\Lambda}(z)$$

$$\tilde{P}_q(z) = \int \tilde{P}_q(x, z) dx$$

$$D_{LL'q}^{\Lambda}(z) = \frac{FF_q^{\Lambda\uparrow}(z) - FF_q^{\Lambda\downarrow}(z)}{FF_q^{\Lambda\uparrow}(z) + FF_q^{\Lambda\downarrow}(z)}$$

Partial spin - transfer

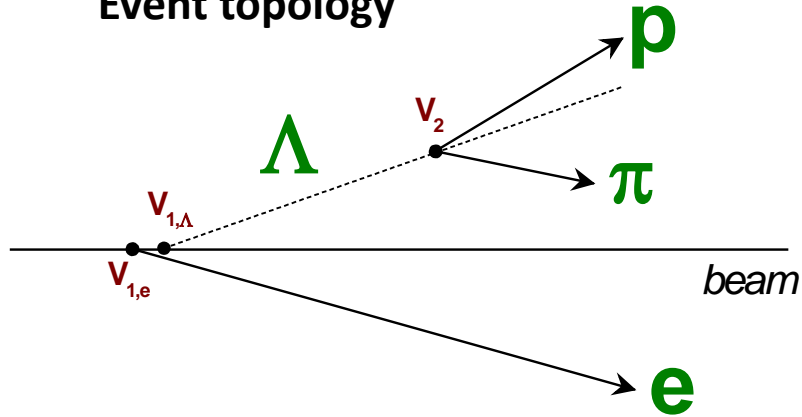
Due to strong u -dominance



$$D_{LL'}^{\Lambda} \approx \frac{\Delta u^{\Lambda}}{u^{\Lambda}}$$

Λ and $\bar{\Lambda}$ events selection

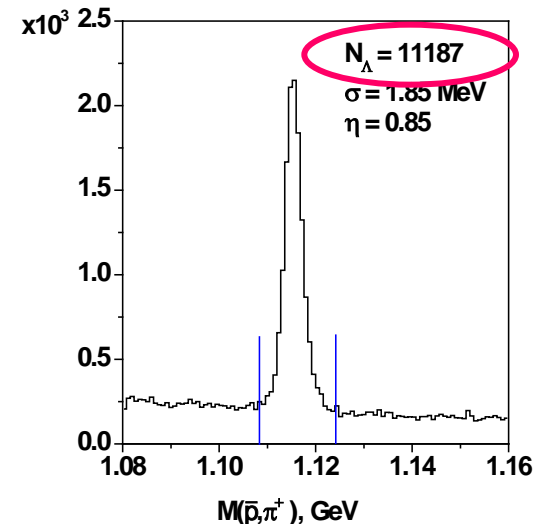
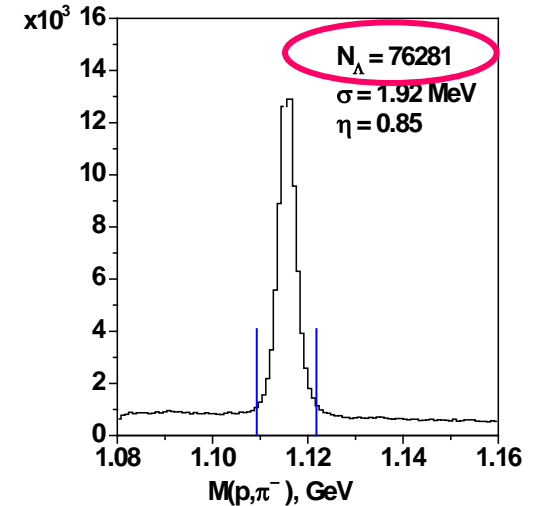
Event topology



h^+h^- pair background suppression

leading π or K rejection using threshold Cherenkov det. (1996-1997) or RICH (1998-2007)

vertex separation cut: distance between V_1 and V_2 vertices > 5 cm



Extraction of spin transfer components

$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p} (1 + \alpha \bar{P}^\Lambda \cdot \hat{k}_p) = \frac{dN_0}{d\Omega_p} (1 + \alpha_\Lambda P_B \sum_{i=x,y,z} D_{Li}^\Lambda \cos \theta_i)$$

$$\alpha_{\Lambda \rightarrow p+\pi^-} = 0.642 \pm 0.013 \quad \alpha_{\Lambda \rightarrow p+\pi^+} = -0.642 \pm 0.013$$

For beam helicity balance case $\left[\left[P_B^2 \right] \right] = \frac{\int P^2(t) L(t) dt}{\int L(t) dt} = 0$

MC simulation of spectrometer acceptance is not needed as in this case acceptance correction does not affect measured asymmetries. D_{Li} components are extracted using experimental data sample only without any MC inputs !!

$$\sum_{k=x,y,z} D_{Lk} A_{ik} = \frac{1}{\alpha} \frac{B_i}{\left[\left[P_B^2 \right] \right]} \quad i = x, y, z$$

$$A_{ik} = \frac{1}{N^\Lambda} \sum_{v=1}^{N^\Lambda} (D^2(y) \cos \theta_i \cos \theta_k)_v$$

$$B_i = \frac{1}{N^\Lambda} \sum_{v=1}^{N^\Lambda} (P_B D(y) \cos \theta_i)_v$$

average over experimental data sample

Вклад ПИЯФ в эксперимент

Hardware:

- **Магнит спектрометра** (разработка концепции, организация производства, частично инвестирование, магнитные измерения карты поля);
- **Пропорциональные камеры** (11тыс.каналов) в зазоре магнита;
- Инвестирование (частично) системы считывания PCOS-4;
- Автоматизированная **система охлаждения** для frontend PCOS-4 и TRD;
- **Система охлаждения** для силикон-стрип детектора Lambda Wheels;

Software

- Разработка программ кодирования события **HERMES Decoding**;
- Разработка программы улучшенного трекинга **HERMES TC**;
- Производство файлов данных **HERMES HRC /DST files**;
- Программа выстройки элементов детектора по трекам, и пр.
- Разработка программ **SLOW CONTROL**;

DATA TAKING

- Поддержание **MCs, TRD**;
- Поддержание силикон.-стрип дет. **LW**;
- Поддержание **DAQ**;
- Газообеспечение ;
- Поддержание **Slow Control**;
- Обработка **сырых данных**;
- Работа в качестве **период координатора**;

DATA ANALYSIS

Поляризация кварков в нуклоне (спиновый кризис ??)

$$\Delta\Sigma = 0.12 \pm 0.09 \pm 0.14 \neq 1 !!!$$

Inclusive polarized DIS

$$\Delta\Sigma = 0.33 \pm 0.02(\text{exp}) \pm 0.03(\text{theo})$$

Semi nclusive polarized DIS

evaluated at $0.021 < x < 0.6$

$$\Delta\Sigma = 0.359 \pm 0.026(\text{exp}) \pm 0.018(\text{theo})$$

$$(\alpha_s = 0.29 \pm 0.01 \quad Q_0^2 = 2.5 \text{ GeV}^2)$$

$$S_z = \frac{1}{2} = \frac{1}{2} \Delta\Sigma + \Delta G + L_q + L_g$$

quarks

Gluons high PT

$$\frac{\Delta g}{g} = 0.078 \pm 0.034 \pm 0.011$$

$$\text{at } \langle x \rangle = 0.204$$

