NOVEL PROBES OF THE NUCLEON STRUCTURE

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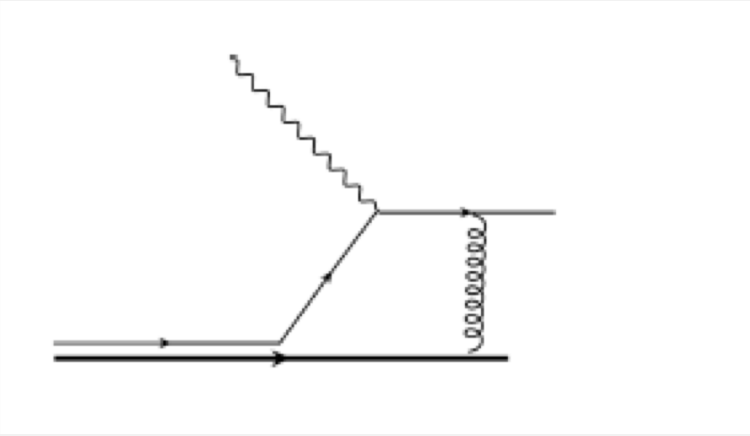
QUARK-GLUON INTERACTIONS

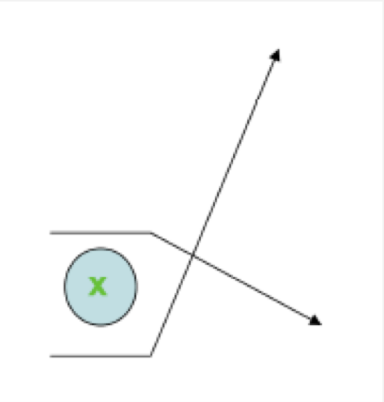
- Quarks probed in deep-inelastic scattering move in gluon background field
  - Gauge link Integrated effect of quark gluon interactions
- Some of the most interesting effects can be attributed to the dependence of these interactions on spatial deformations and polarization of PDFs
  - **Example: Sivers effect**

$$\langle \mathbf{k}_\perp \rangle \sim \left\langle P,S \left| \bar{q}(0)\gamma^+ \int_0^\infty d\eta^- G^{+\perp}(\eta) q(0) \right| P,S \right\rangle$$



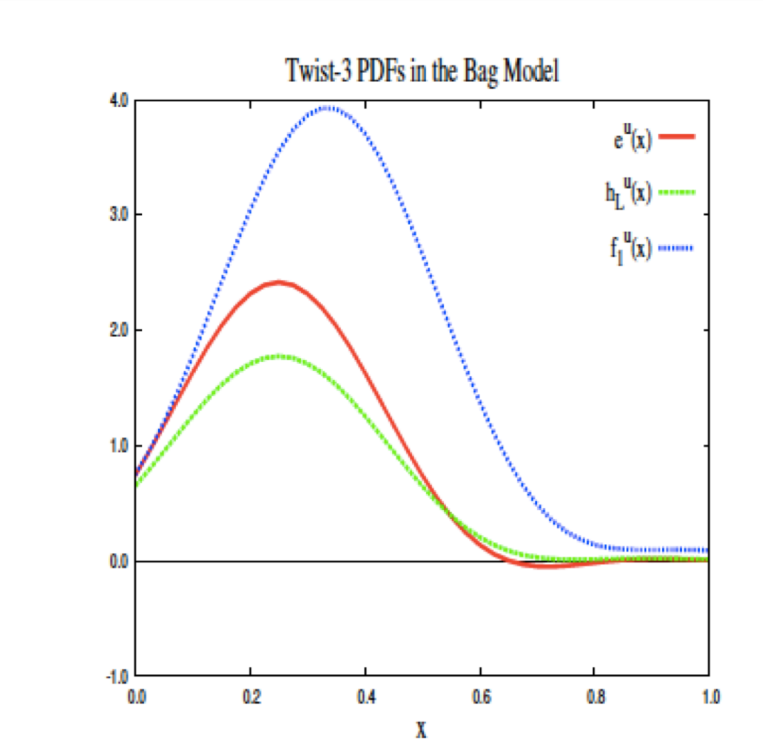
- The instant quark gluon interactions are described by Twist3 PDFs
- Projections of
-

$$\Phi^\mu_{Aij}(x) = \int \frac{\mathrm{d}\tau}{2\pi}\, \mathrm{e}^{\mathrm{i}\tau x} \langle PS|\bar{\phi}_j(0)\, gA^\mu(\tau n)\, \phi_i(\tau n)|PS\rangle\,.$$



EXAMPLE E(X)

- Transverse force on transversely polarized quarks (Burkhardt)
- Model calculations show significant magnitude:



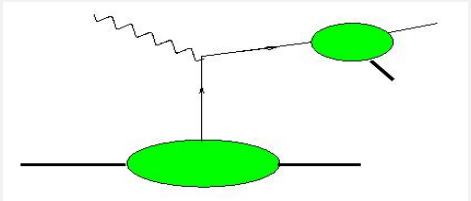
Jaffe, Ji, Nucl. Phys. **B**375, 527{560 (1992).

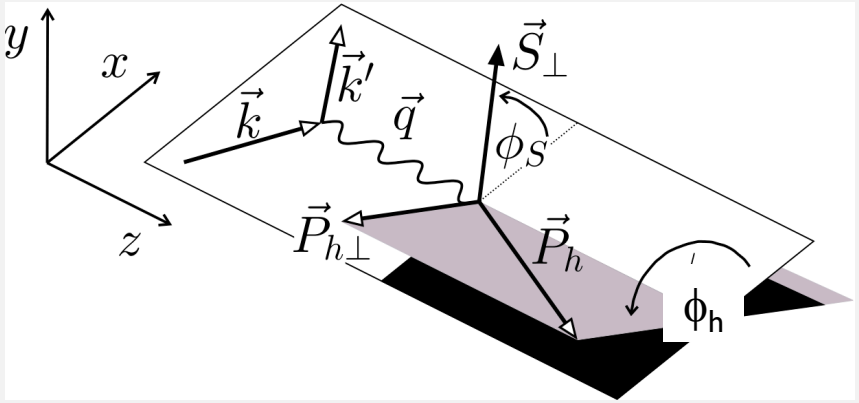
EXAMPLE, ACCESS OF e(x) in SIDIS X-SECTION

- Single hadron cross-section: mixes other contributions:

WW Approximation

$$F_{LU}^{\sin(\phi_h)} = \frac{2M}{Q}\mathcal{I}\left[-\frac{\boldsymbol{k}_T\hat{\boldsymbol{P}}_{h\perp}}{M_h}\left(xeH_1^\perp + \frac{M_h}{Mz}f_1\tilde{G}^\perp\right) + \frac{\boldsymbol{p}_T\hat{\boldsymbol{P}}_{h\perp}}{M}\left(xg^\perp D_1 + \frac{M_h}{Mz}h_1^\perp\tilde{E}\right)\right]$$

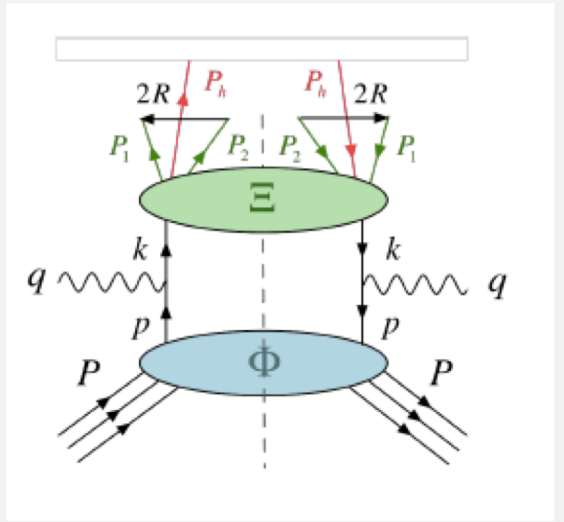




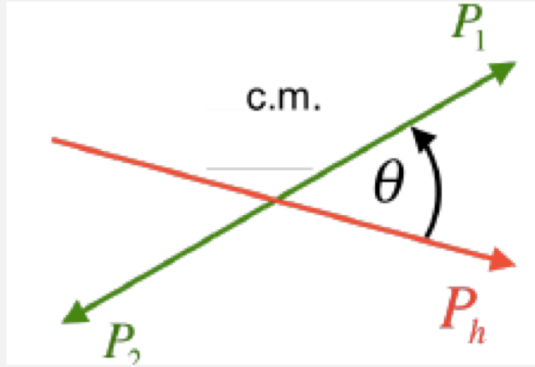
NEED NEW PROBES BEYOND 1H

- **Additional degrees of freedom to resolve ambiguities :**
- Di-hadron Correlations
- Polarized Λ production

DI-HADRON FRAGMENTATION FUNCTIONS



- Additional degree of freedom ($\vec{R} = \overrightarrow{P_1} - \overrightarrow{P_2}$)
  - Plus z, P_T
- Relative momentum of hadrons can carry away angular momentum
  - Partial wave decomposition in θ
  - Relative and total angular momentum →In principle endless tower of FFs
  - Analogue of 1h production with spin in final state
- Transverse polarization dependence in collinear framework $H^{\angle}$→ **Most precise extraction of transversity** → See M. Radici talk
- **Minimize systematics in pp**: No thrust axis, theoretically and experimentally cleaner
- **Makes 'new' FFs possible,** such as $G_1^{\perp}$:T-odd chiral even. In 1h case, this needs polarized hadron in the final state
- **→See Thursday talk for di-hadron measurements at Belle/BelleII**



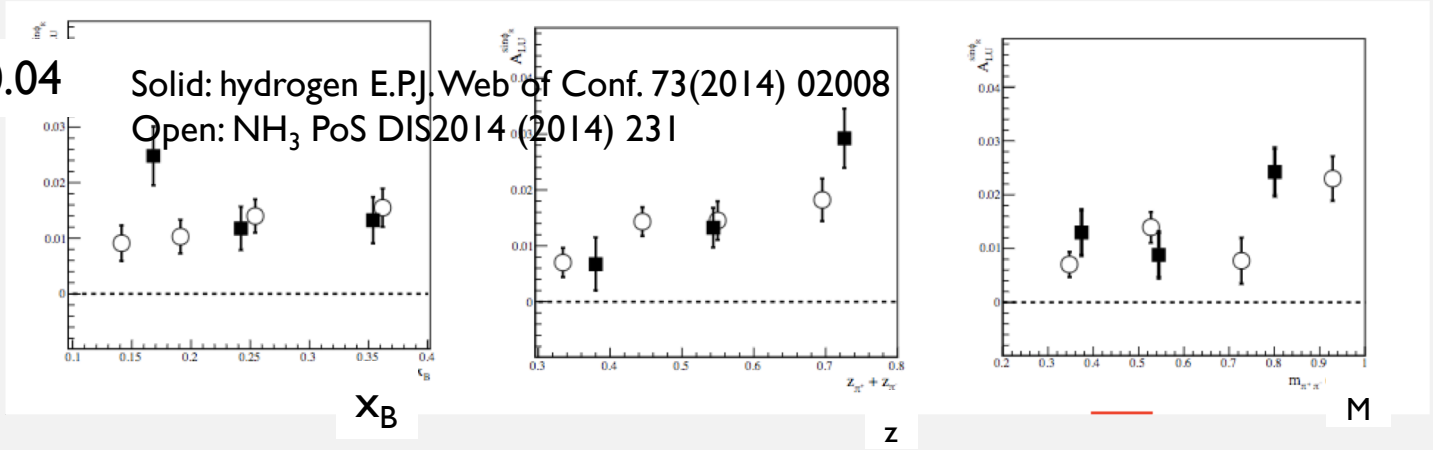
EXAMPLE, ACCESS OF e(x) in SIDIS X-SECTION

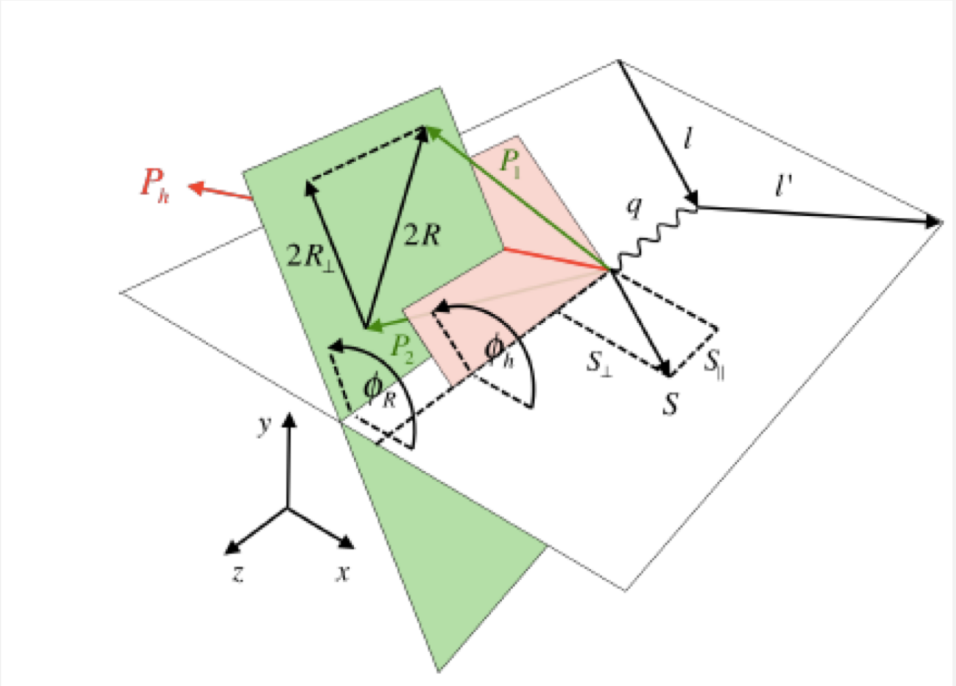
- Di-hadron cross section: Clean access to e(x)

WW Approximation

$$F_{LU}^{\sin\phi_R} = -x\frac{|\boldsymbol{R}|\sin\theta}{Q}\left[\frac{M}{m_{hh}}\,x\,e^q(x)\,H_1^{\sphericalangle q}(z,\cos\theta,m_{hh}) + \frac{1}{z}\,f_1^q(x)\,\tilde{G}^{\sphericalangle q}(z,\cos\theta,m_{hh})\right],$$

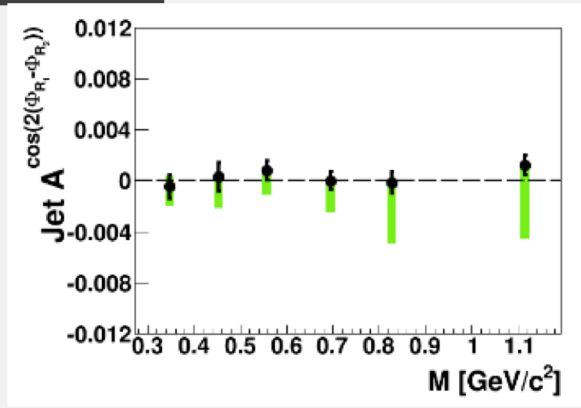
- Evidence from CLAS6:



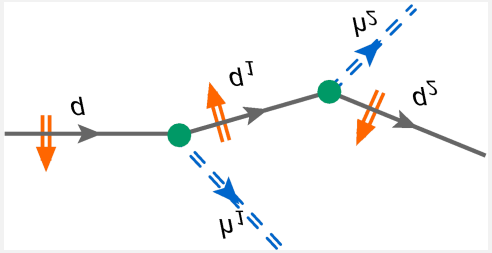


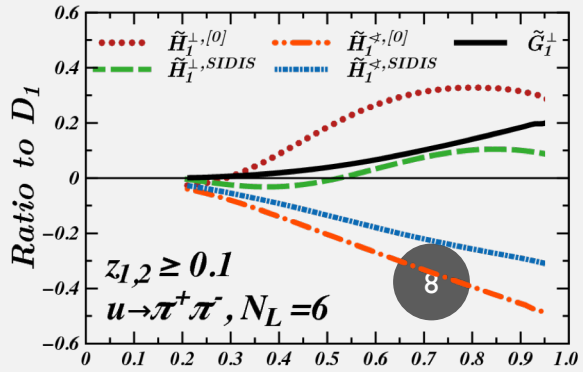
HISTORY OF $G_1^\perp$

- First suggestion to observe in e^+e^- by Boer, Jakob, Radici, PRD67 (2003) 094003
  - Postulate connection to jet handedness proposed by Efremov and Kharzeev Phys.Lett. **B**366 (1996) 311-315 (connection to chromomagnetic effects)
- Measurement by Belle→No signal
- New model calculations by Matevosyan et al connecting $G_1^\perp$ with single hadron Collins effect in string fragmentation (a bit like worm gear functions)→Interesting to learn about spin momentum correlations in hadronization: sizable asymmetries contradicted by Belle result??
- Mistake found in Boer et. al: Phys.Rev. D97 (2018) no.7, 074019 → Need weighted asymmetry including dependence on P_{hT}
- Accessible in SIDIS via weighted asymmetries



arXiv:1505.08020 [

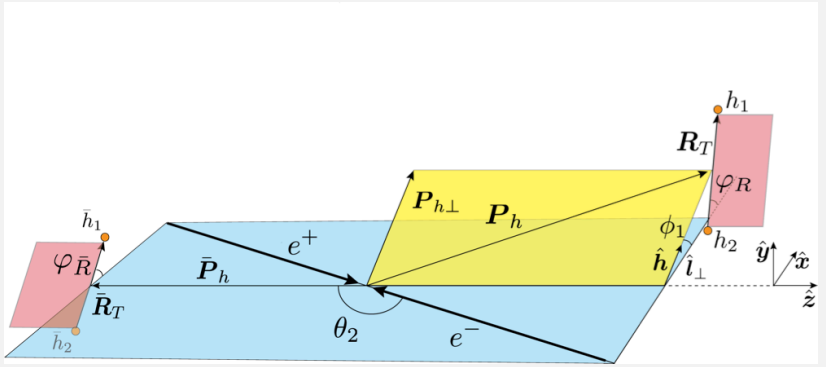




$G_1^{\perp}$ MEASUREMENT IN SIDIS AND e^+e^-

- New Observable in e^+e^-:

$$\left\langle \frac{q_T^2\left(3\sin(\varphi_q-\varphi_R)\sin(\varphi_q-\varphi_{\bar{R}})+\cos(\varphi_q-\varphi_R)\cos(\varphi_q-\varphi_{\bar{R}})\right)}{M_h\bar{M}_h}\right\rangle$$
$$=\frac{12\alpha^2A(y)}{\pi Q^2}\sum_{a,\bar{a}}e_a^2\left(G_1^{\perp a,[0]}-G_1^{\perp a,[2]}\right)\left(\bar{G}_1^{\perp\bar{a},[0]}-G_1^{\perp\bar{a},[2]}\right),$$



Matevosyan. , Bacchetta, Boer, Courtoy, Kotzinian, Radici, Thomas: Phys. Rev. **D** 97, 074019 (2018).

- New Observable in SIDIS with longitudinal target and beam spin asymmetries :

$$\left\langle \frac{P_{h\perp}\sin(\varphi_h-\varphi_R)}{M_h}\right\rangle_{UL}\sim S_L\sum_a e_a^2\; g_{1L}^a(x)\; z\; G_1^{\perp a}(z,M_h^2)$$

Matevosyan, Kotzinian ADP-17-42-T1048

$$\left\langle \frac{P_{h\perp}\sin(\varphi_h-\varphi_R)}{M_h}\right\rangle_{LU}\sim \lambda_e\sum_a e_a^2\; f_1^a(x)\; z\; G_1^{\perp a}(z,M_h^2)$$

N.B. Compass did not observe significant asymmetry for unweighted asymmetry

CLAS12

Forward Detector (FD)

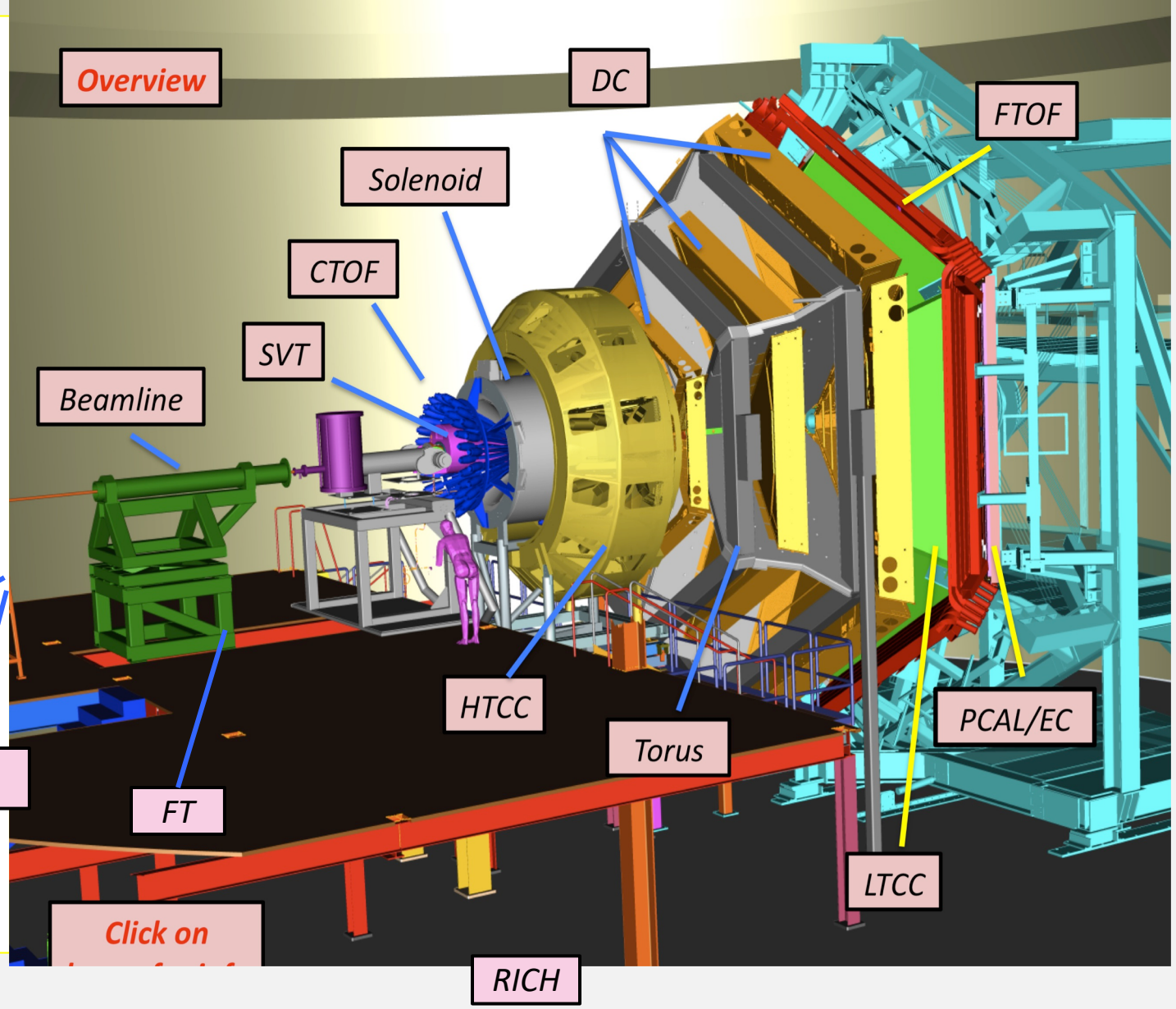
- TORUS magnet
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward ToF System
- Pre-shower calorimeter
- E.M. calorimeter
- Forward Tagger
- RICH detector

Central Detector (CD)

- Solenoid magnet
- Silicon Vertex Tracker
- Central Time-of-Flight
- Central Neutron Detector
- MicroMegas

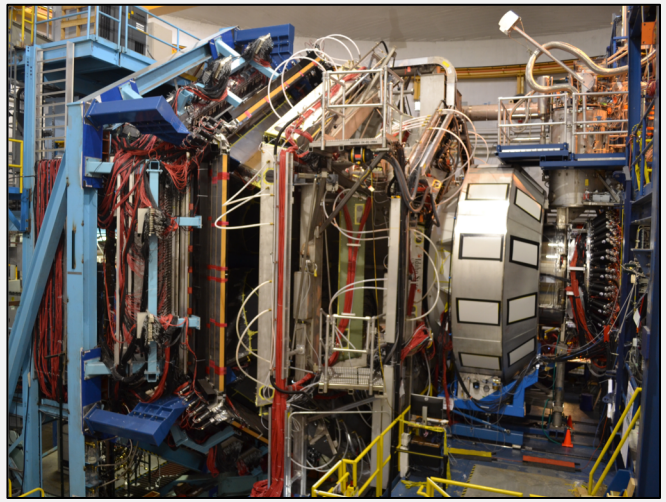
Beamline

- Photon Tagger Dump
- Shielding
- Targets
- Moller Polarimeter
- Faraday Cup

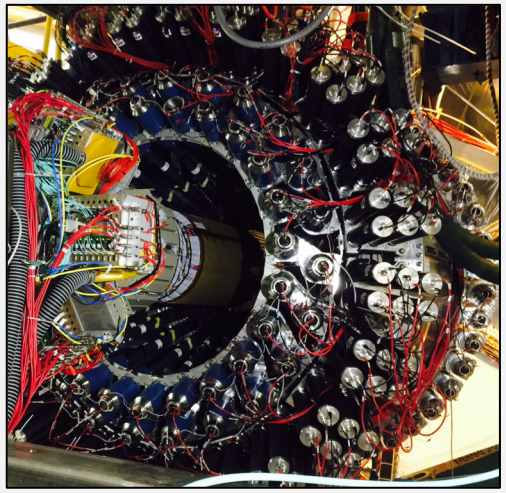


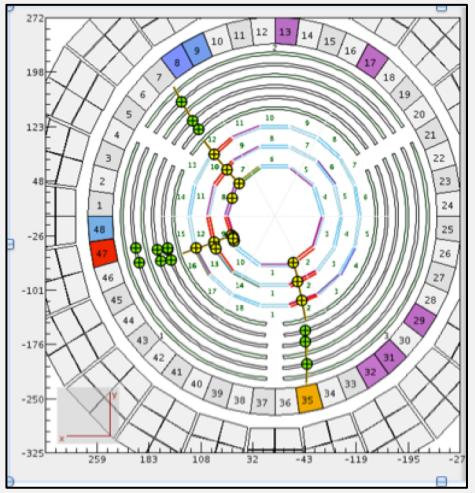
PHYSICS RUNNING STARTED

CLAS12 Forward Detector

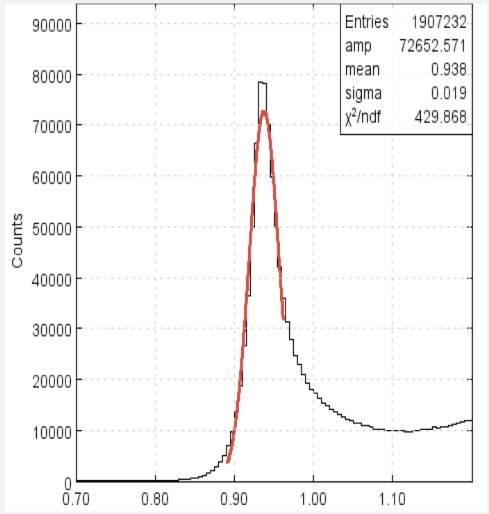


CLAS12 Central Detector with 3 charged particles

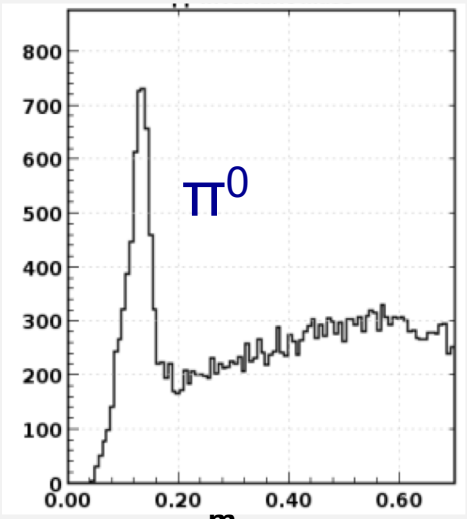




p(e,e')p @ 2.2 GeV



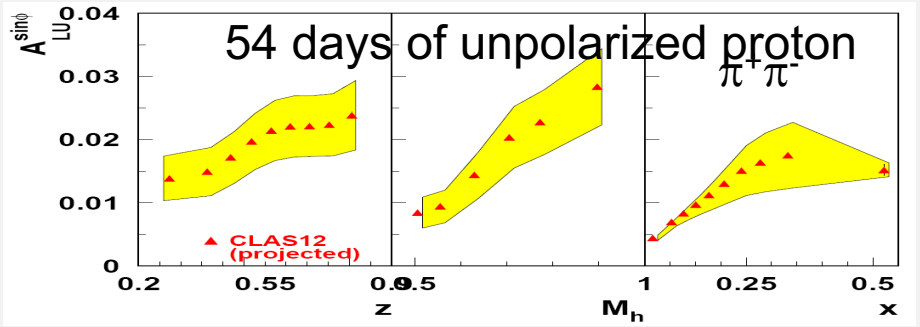
π^0 @ 10.6 GeV

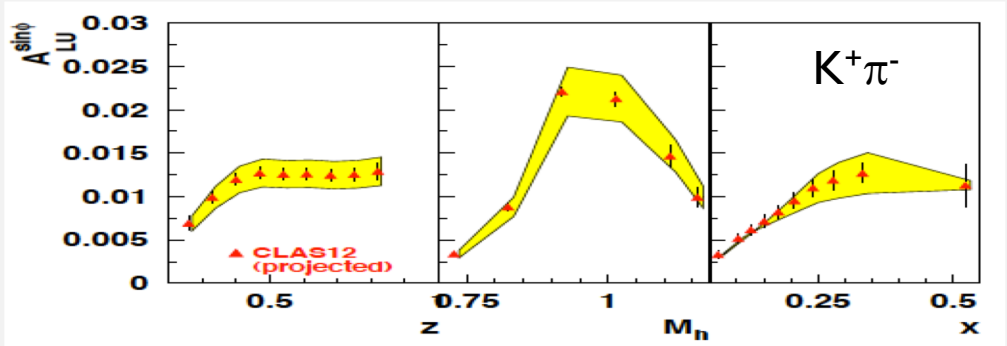


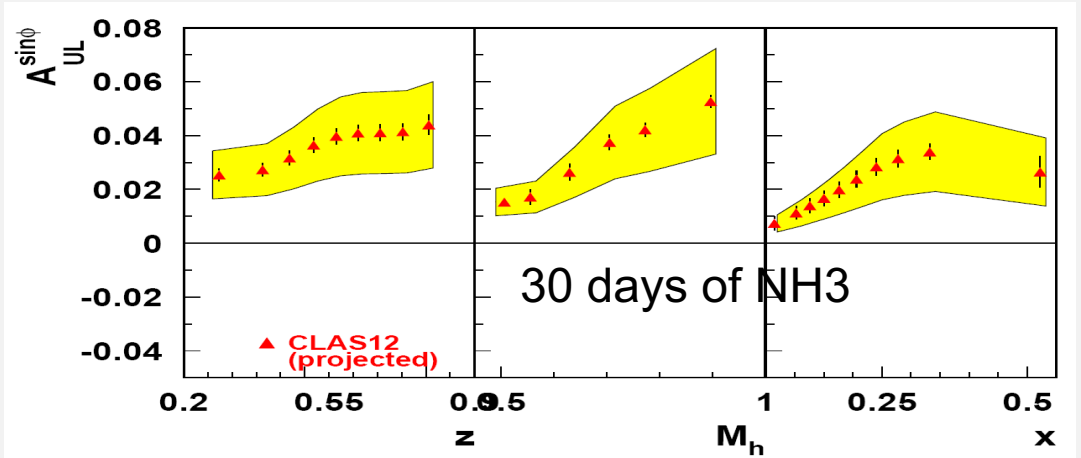
- Detectors were operated during engineering run at luminosities from 0.75 x 10^{34} to 1.75 x 10^{35}
- The latter is nearly twice the design luminosity!
- Physics production run started at a luminosity of 0.7 x 10^{35} – run group A (13 experiments)

PROJECTIONS FOR ASYMMETRIES SENSITIVE TO e(x)

- 120/30 days of running are approved with unpolarized liquid H2/liquid D2 targets **(underway!)**
- 120 + 50 days of running are approved with longitudinally polarized NH3/ND3 targets (targets ready ~2020)







Sensitive to h_L

LAMBDA PRODUCTION

- Inclusion of polarization leads to rich hadronization structure (see e.g. Kanazawa, Metz Pitonyak, Schlegel Phys.Lett. **B**744 (2015) 385-390 , Metz, Pitonyak Phys.Lett. **B**723 (2013) 365-370
- Longstanding question: Large Λ transverse polarization in unpolarized pp collision
- →Polarizing FF $D_{1T}^{\perp}(z, p_{\perp}^2)$?
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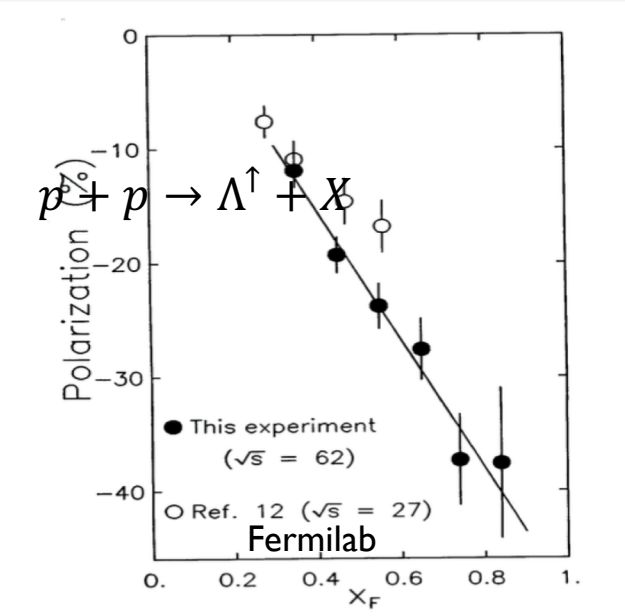
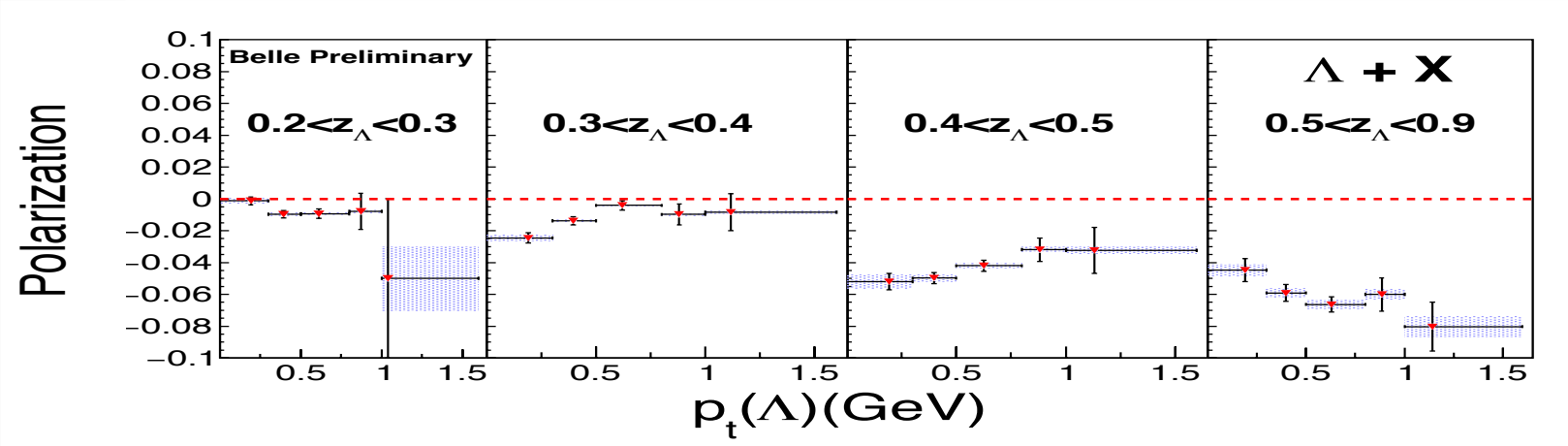


ISR data

(**Phys.Lett. B185 (1987) 209)**

$$x_F = p_L / \max p_L{\sim}_{LO} x_1 - x_2{\sim}_{forward} x_1$$

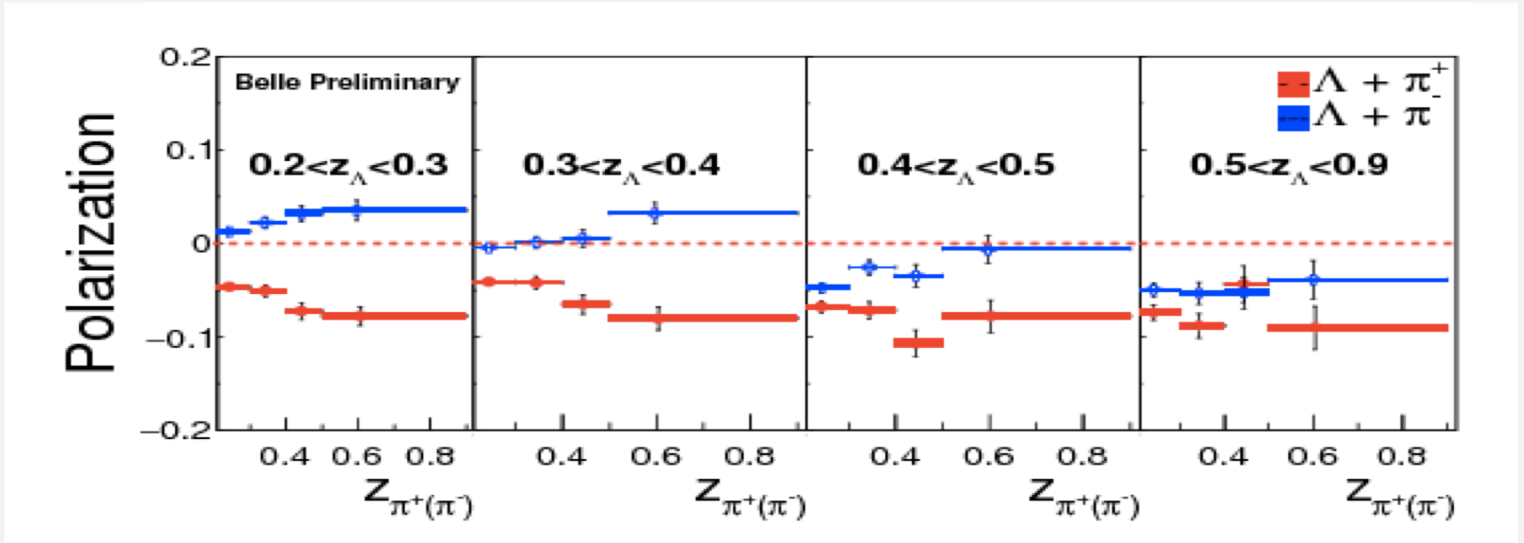
OBSERVATION BY BELLE

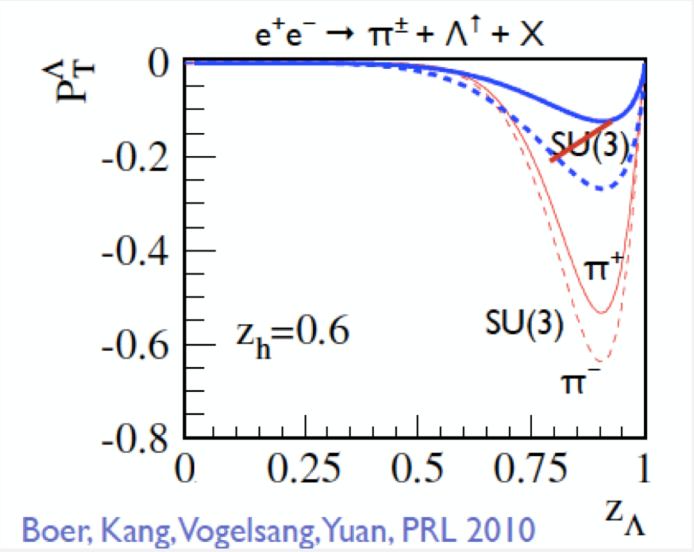


Y. Guan, arXiv:1611.0668

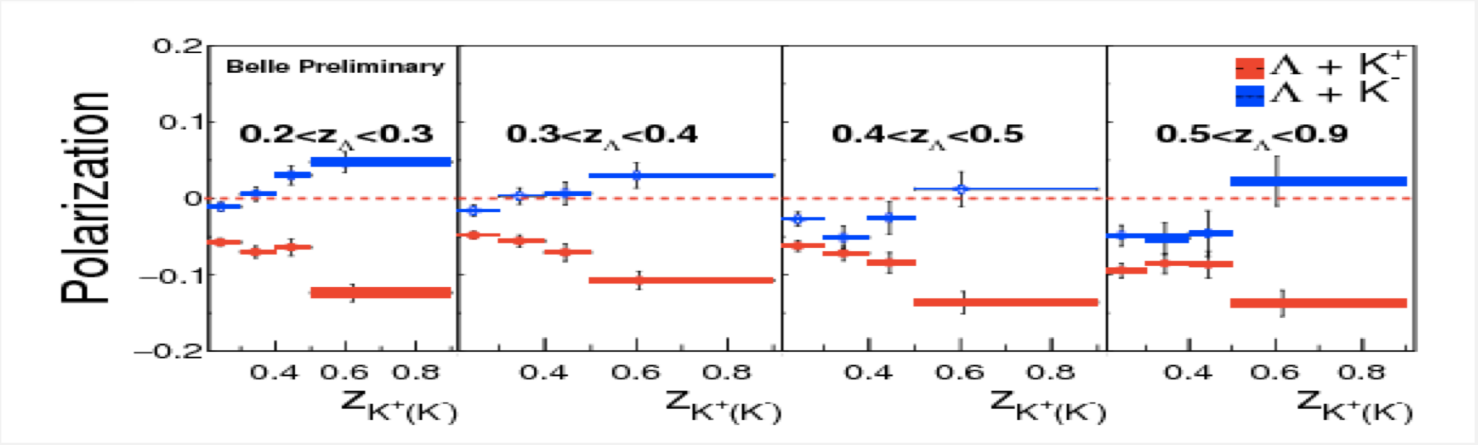
- More clarity
- Some questions remain
- SIDIS input will help with universality questions, modeling

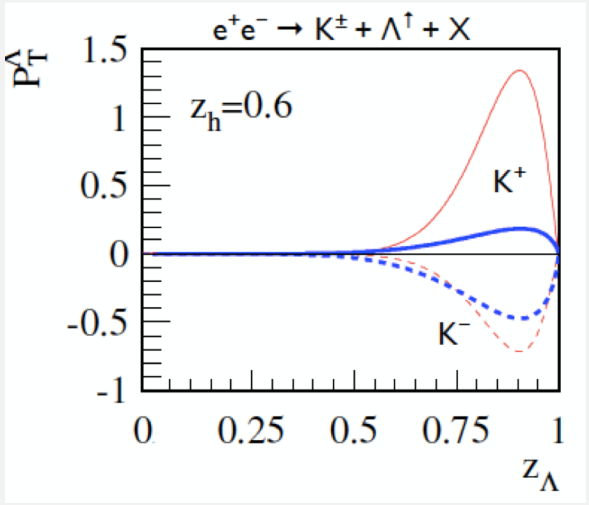
TENSION WITH THEORY: ASSOCIATED PRODUCTION



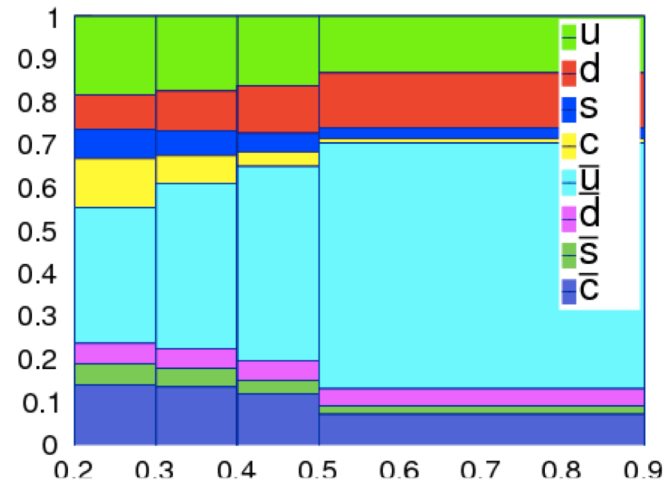
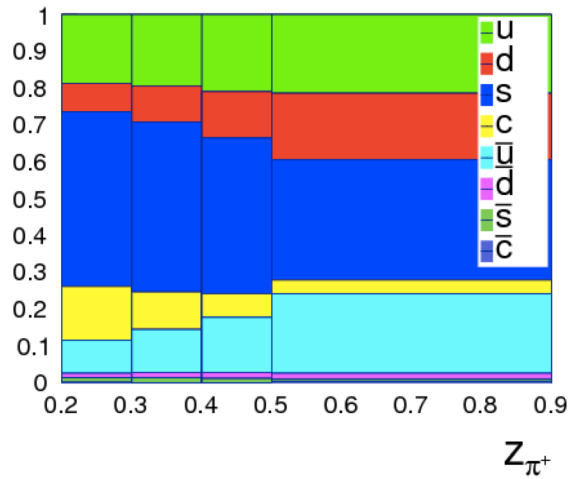
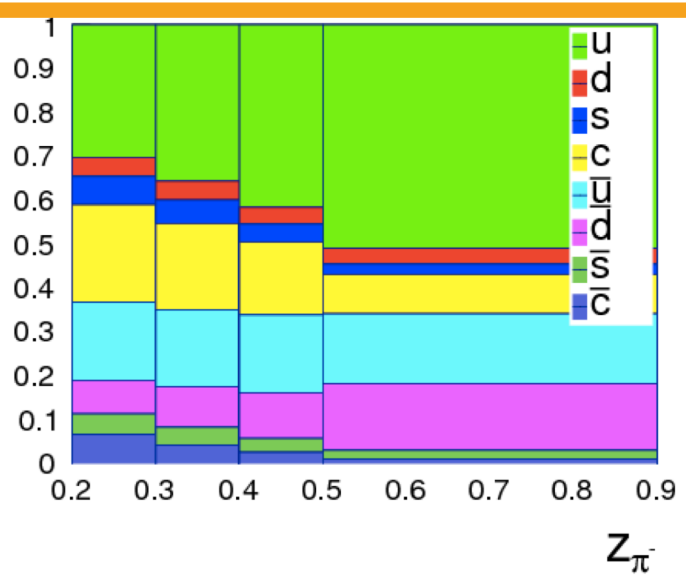
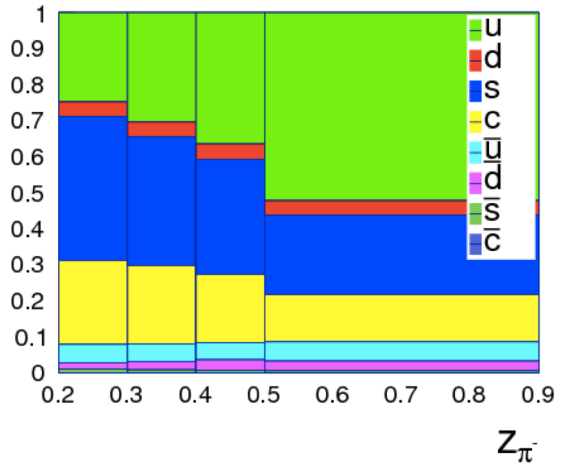


Boer, Kang, Vogelsang, Yuan, PRL 2010

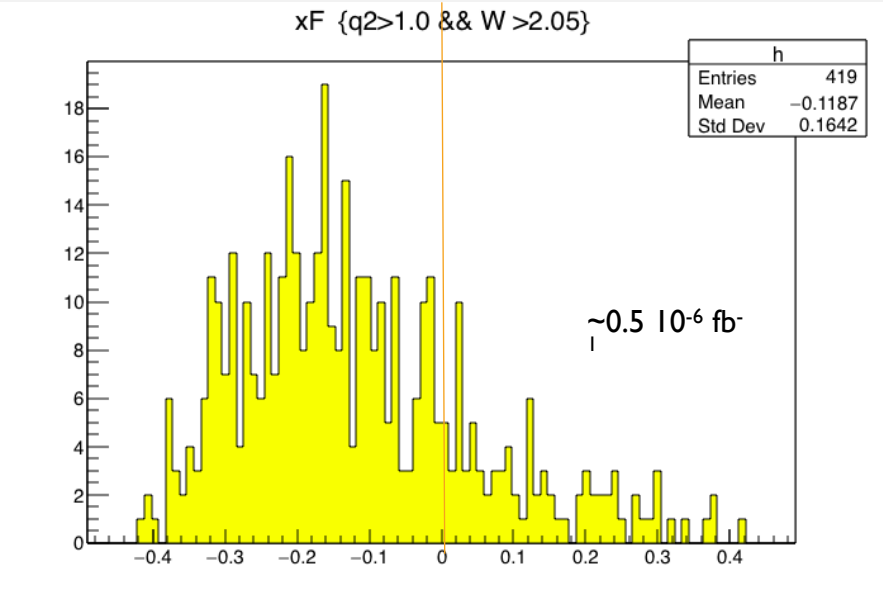




FLAVOR COMPOSITION

	$0.2<z_\Lambda<0.3$	$0.5< z_\Lambda <0.9$
π^+		
π^-		

CAN WE SEE CURRENT Λ AT CLAS12?



- Would open up many physics topics
- Example, compare with $\Lambda^{\uparrow}$ production in e+e- (Boer, Kang, Vogelsang, Yuan, PRL. 105 (2010) 202001, learn about TMD factorization
- **Optimistically** expect ~100M Λs is initial running with unpolarized target in acceptance

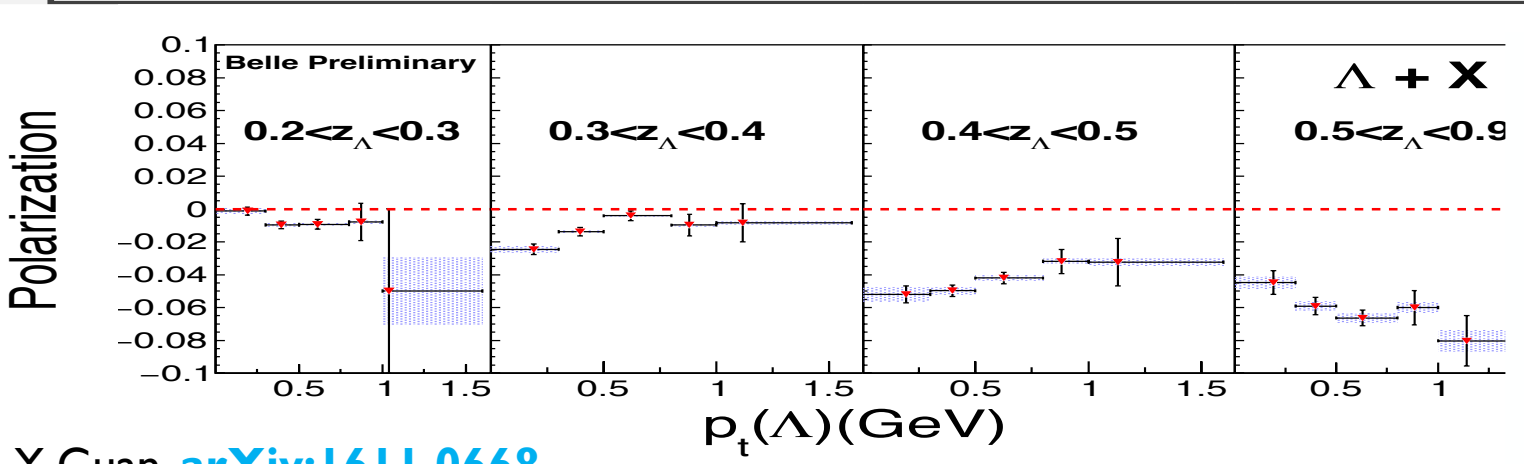
SUMMARY

- **Novel Probes Λ and IFF open up new physics opportunities**
- Need synergy between $\mathbf{e^+e^-}$ (Belle II)
  - $G_1^\perp$
  - Polarization dependent Di-hadron measurements with kaons in the final state

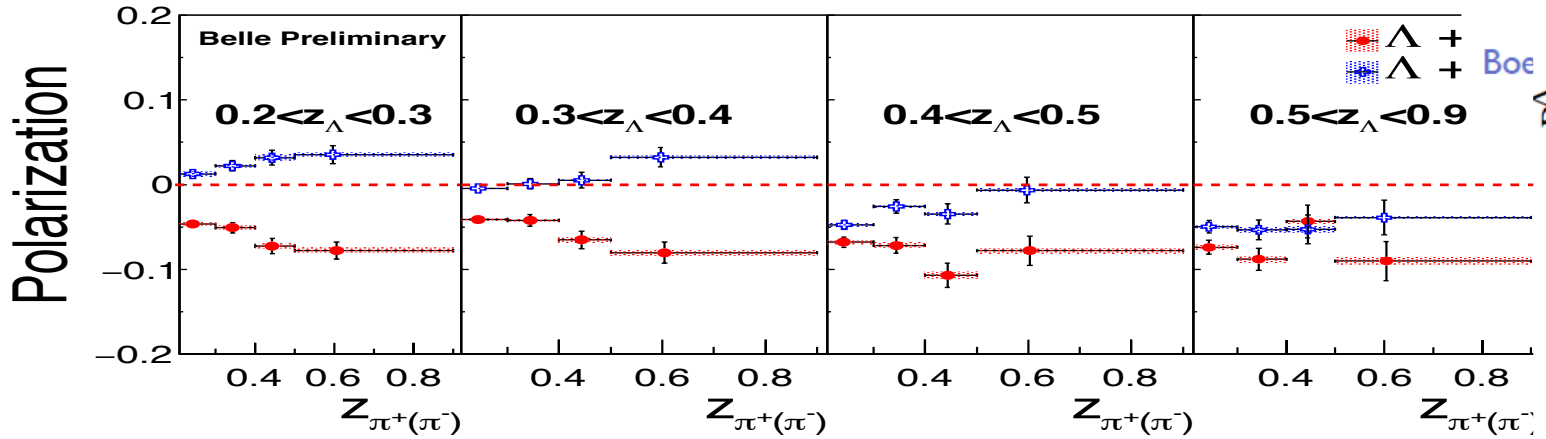
- and **SIDIS**
  - IFF and $G_1^\perp$ measurements at CLAS12 with polarized beam and polarized target
  - Λ at CLAS12

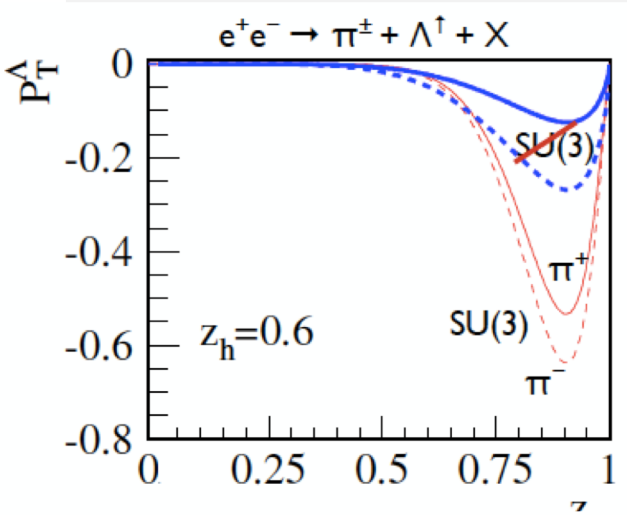
OUTLOOK TO BELLE II

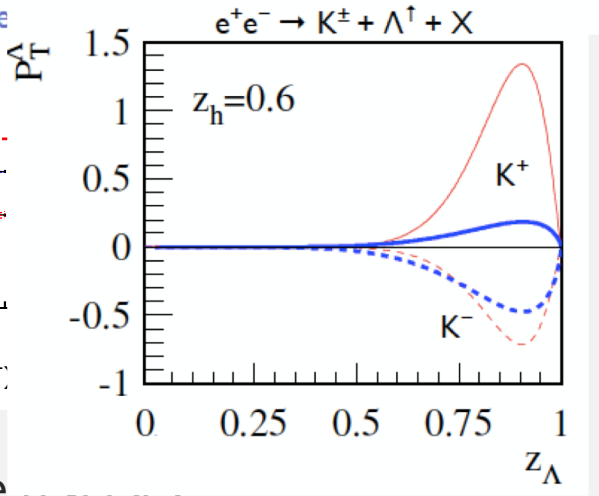
Z_Λ, P_T DEPENDENCE OF OBSERVED Λ POLARIZATION



Y. Guan, arXiv:1611.0668

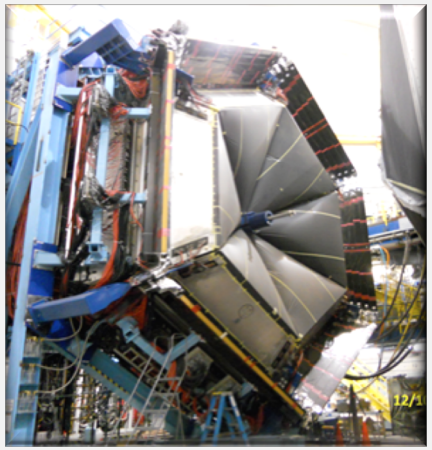




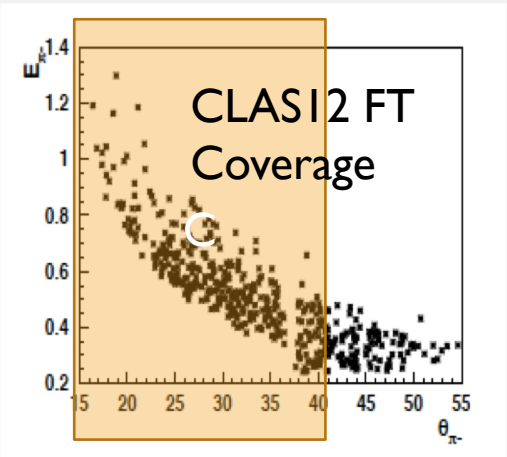


- Polarization rises with p_t in the lowest z_Λ and highest z_Λ bin. But the dependence reverses around 1 GeV in the intermediate z_Λ bins→**Unexpected!** (might be related to fragmenting quark flavor dependence on z_1,z_2)
- Correlation with opposite hemisphere light meson →quark flav/charge dependence

CONCLUSION



Hall B – understanding nucleon structure via generalized parton distributions and transverse momentum distributions



INITIATED FOUR HALL OPERATION!