The SoLID program in JLab

Yuxiang Zhao (INFN Trieste)

On behalf of the SoLID collaboration

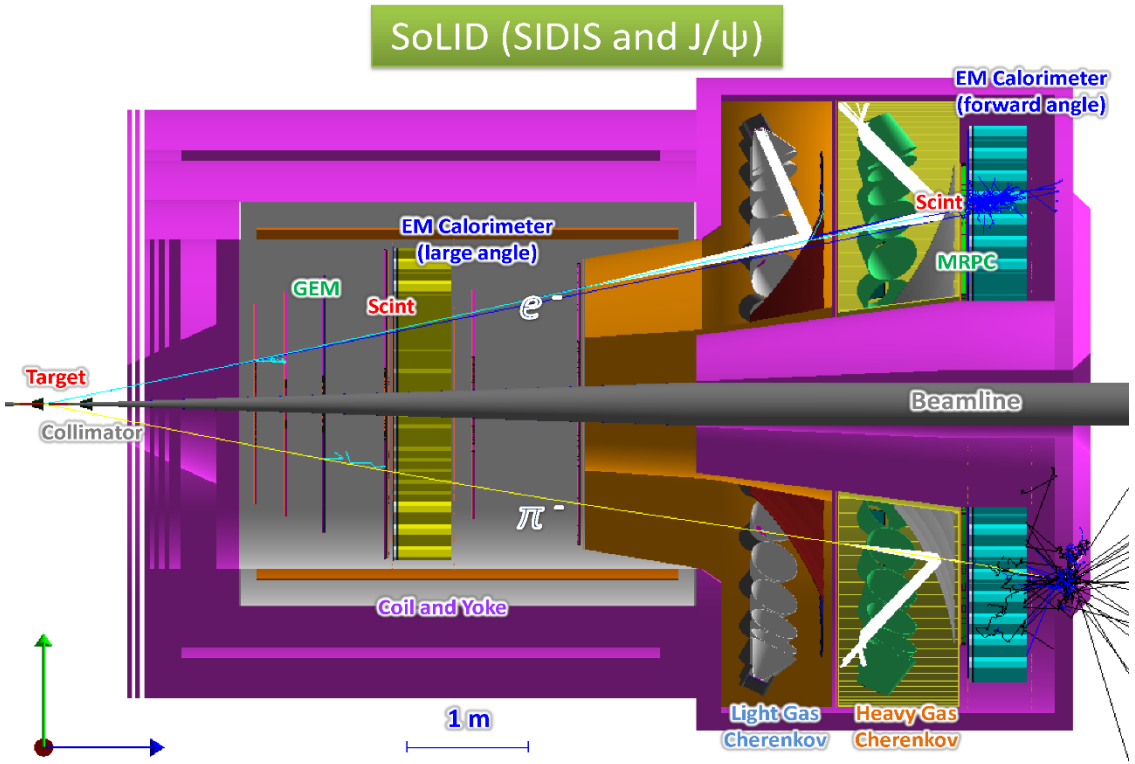
Outline

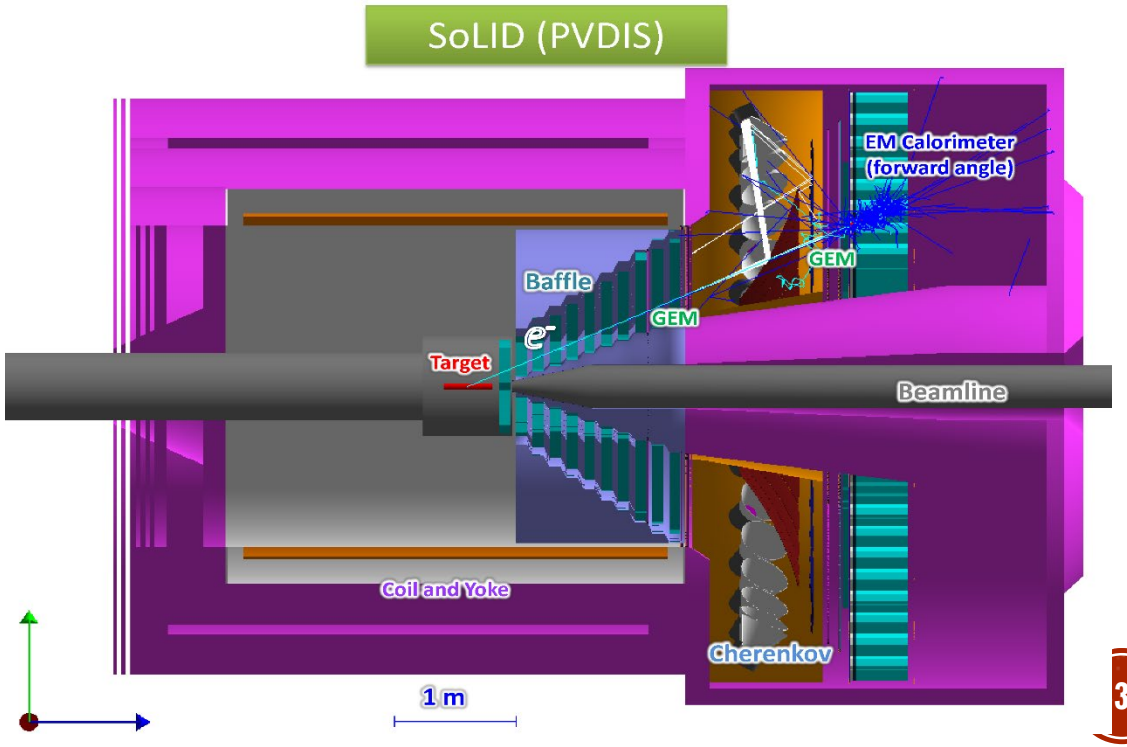
- SoLID overview
- Physics programs
  - ✓Semi-Inclusive Deep Inelastic scattering (SIDIS) program
  - ✓Parity-Violating Deep Inelastic scattering (PVDIS) program
  - ✓J/ψ near threshold production
- Project status and summary

SoLID overview

SoLID: Solenoidal Large Intensity Device

- High Luminosity: 10^{37} (SIDIS and J/ψ) ~ 10^{39} $cm^{-2}s^{-1}$ (PVDIS with baffles), electron beam at 11 GeV (max)
- Large Acceptance with a full azimuthal coverage based on CLEO-II magnet (3m diameter, 3.5m long, field ~1.5T)
- Take advantage of latest development in detectors and data acquisitions





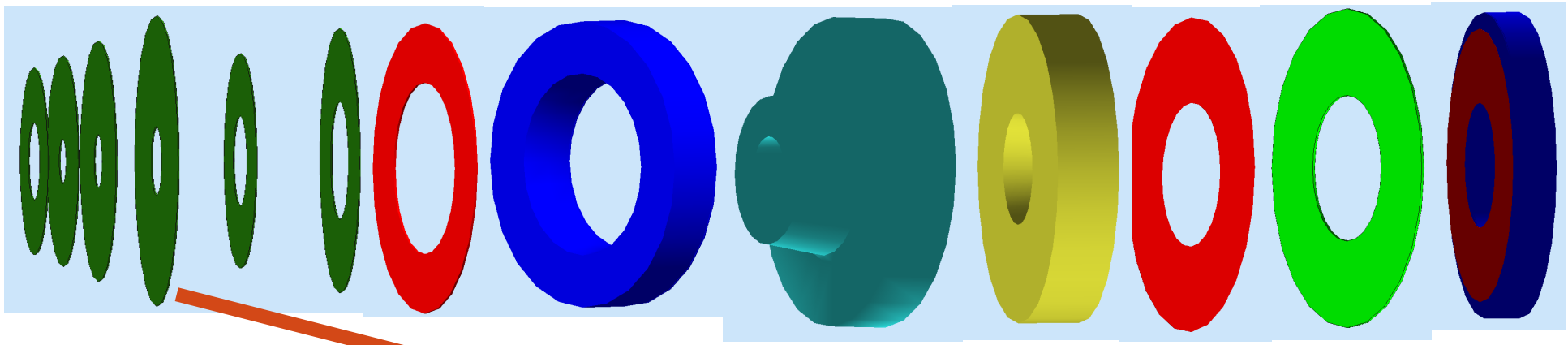
Detector system, SIDIS as an example

SIDIS & J/Psi:

LA: large angle

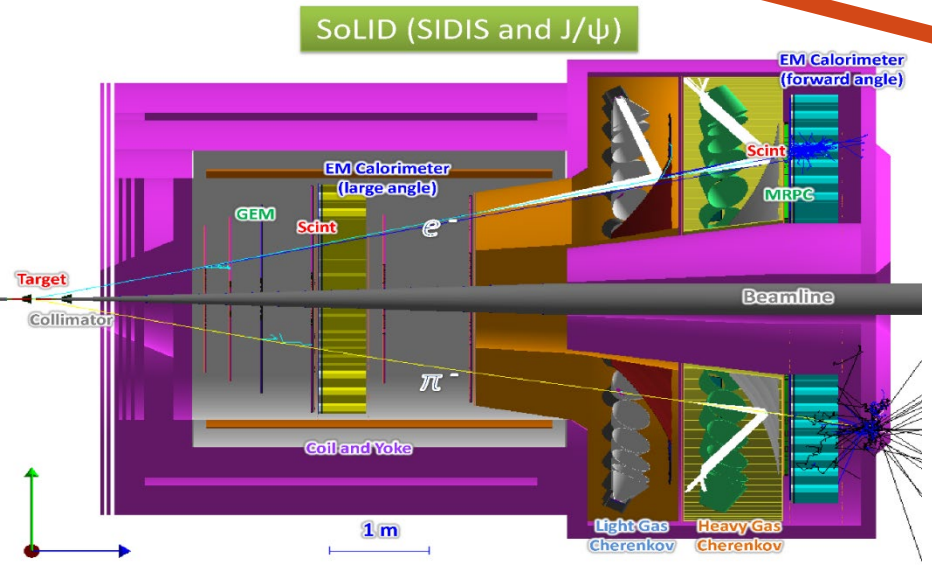
FA: Forward angle

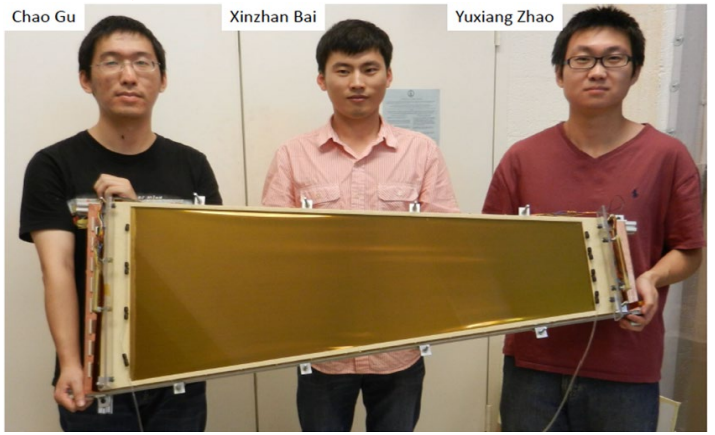
6xGEMs LASPD LAEC LGC HGC FASPD MRPC FAEC

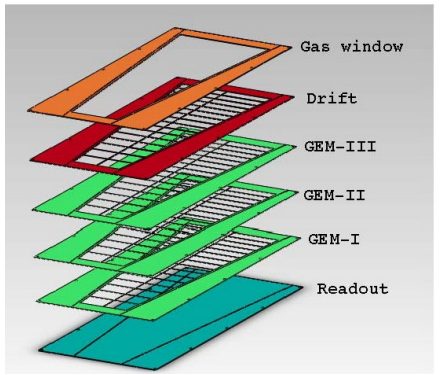


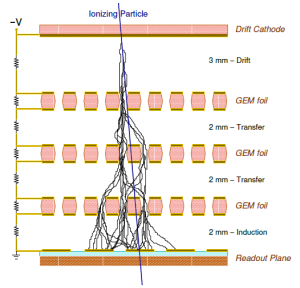
GEM trackers in total: > 35m^2 and > 160 k channels of readout

One GEM module, U/V strip 2D readout, resolution<200μm









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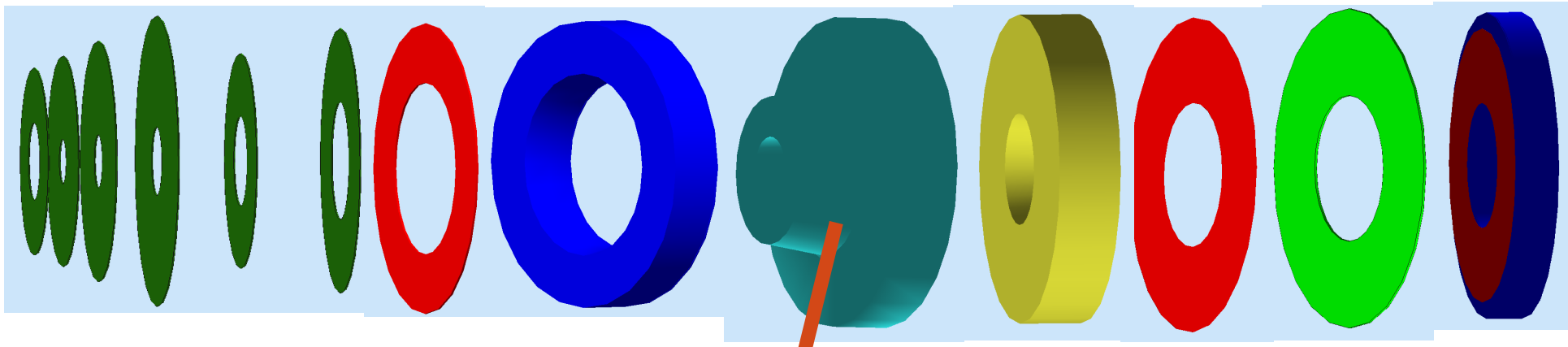

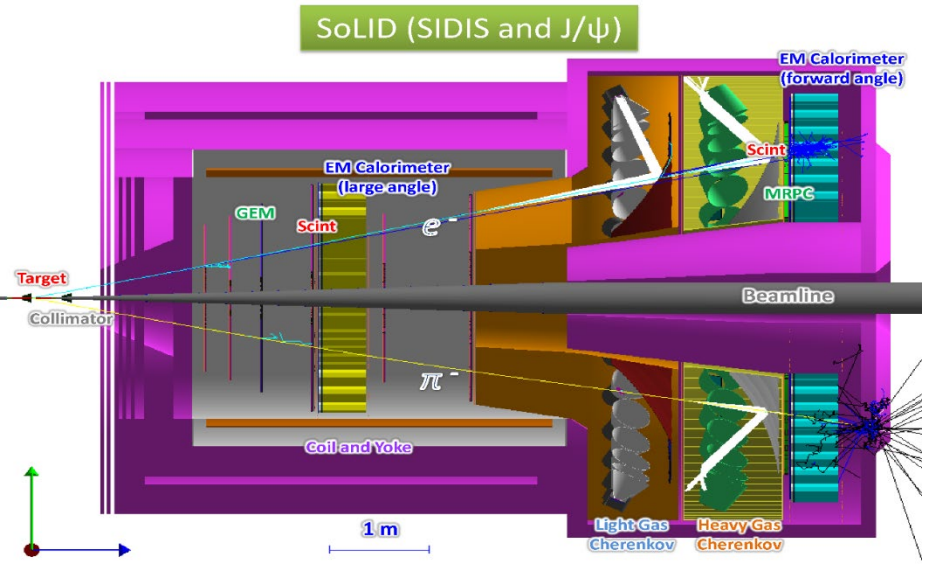

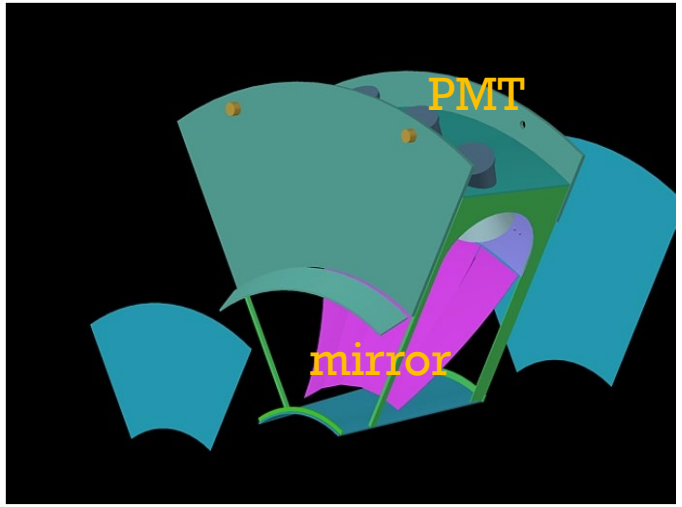

Threshold Cherenkov detector

Light gas (CO_2), n=1.0004

identify electrons, threshold~1.8 GeV

suppress pions, threshold~4.9 GeV

Detector system, SIDIS as an example

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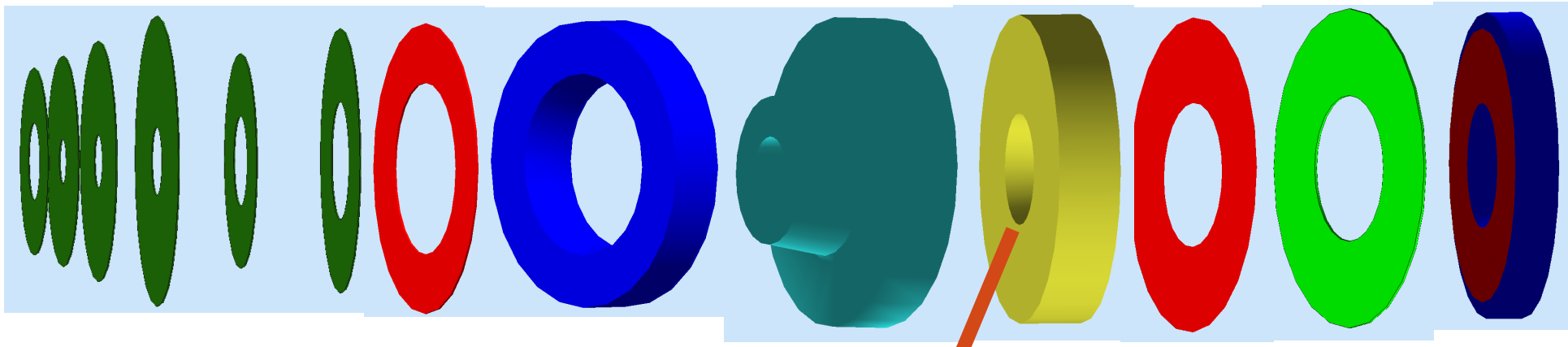
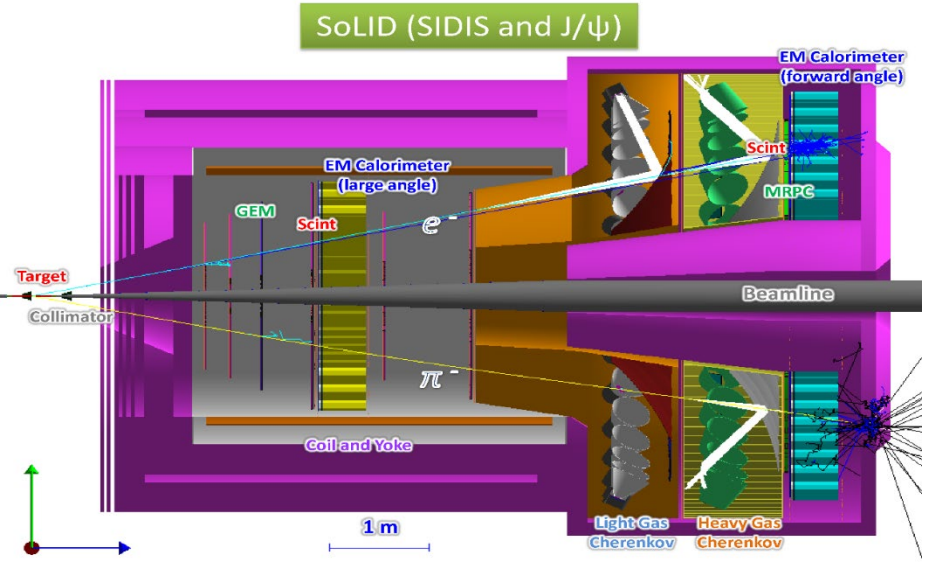
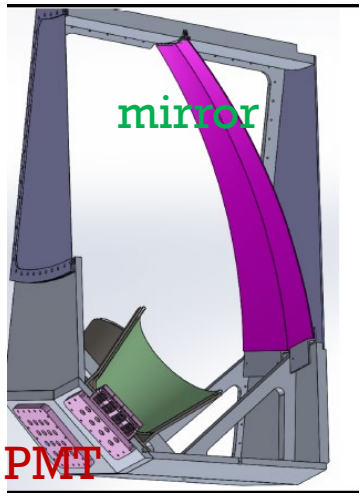




A sector



Threshold Cherenkov detector

Heavy gas (C_4F_{10}), n~1.00129

identify pions, threshold~2.7 GeV

suppress kaons, threshold~9.7 GeV

Detector system, SIDIS as an example

SIDIS & J/Psi:

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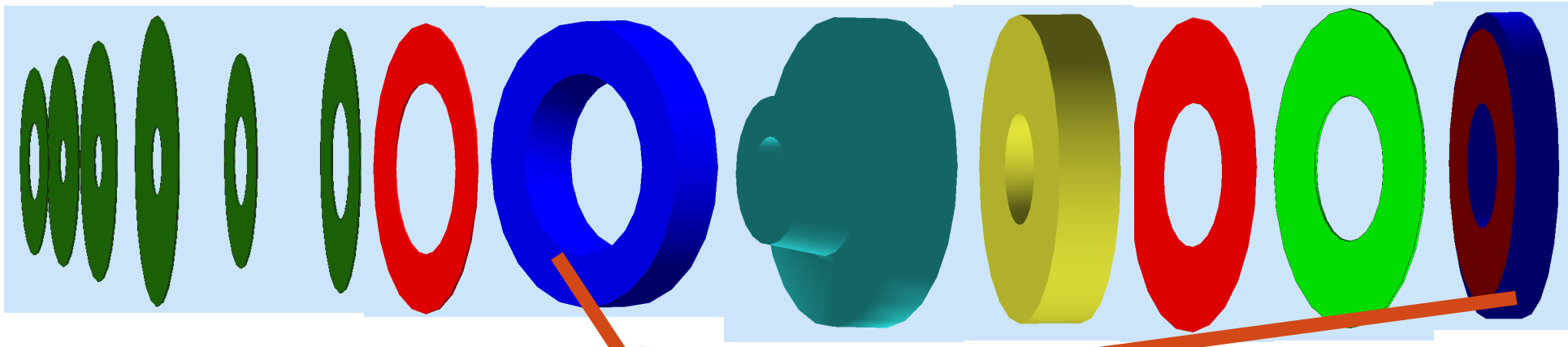
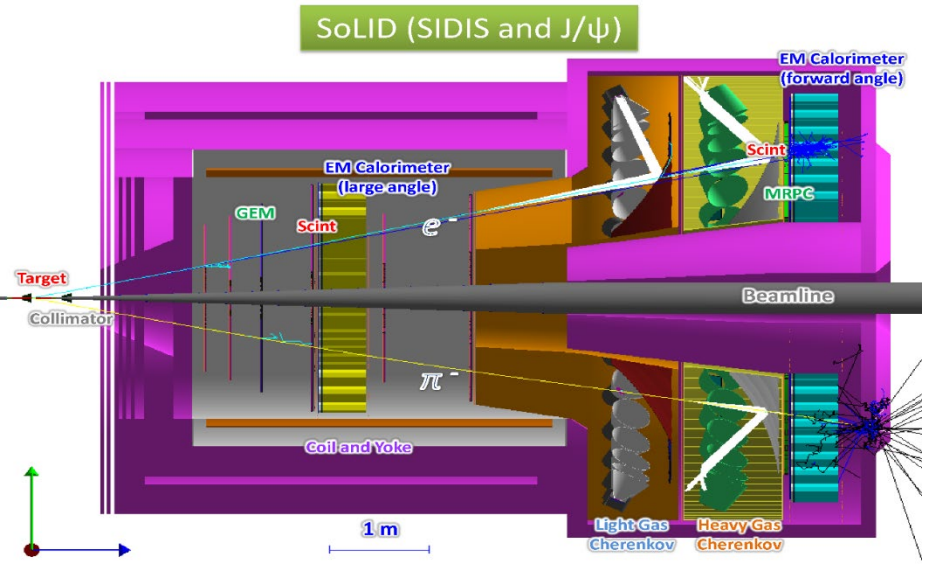
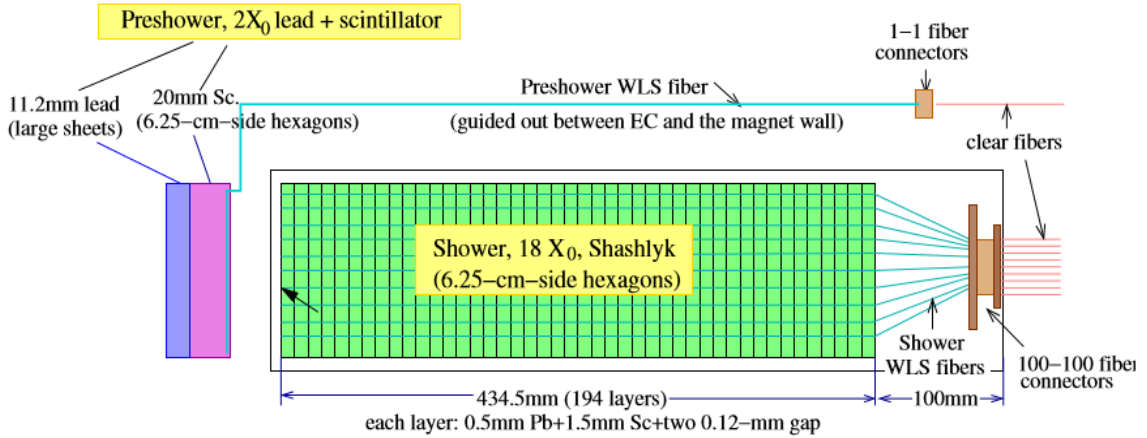




shashlik calorimeter, segmented to pre-shower/shower



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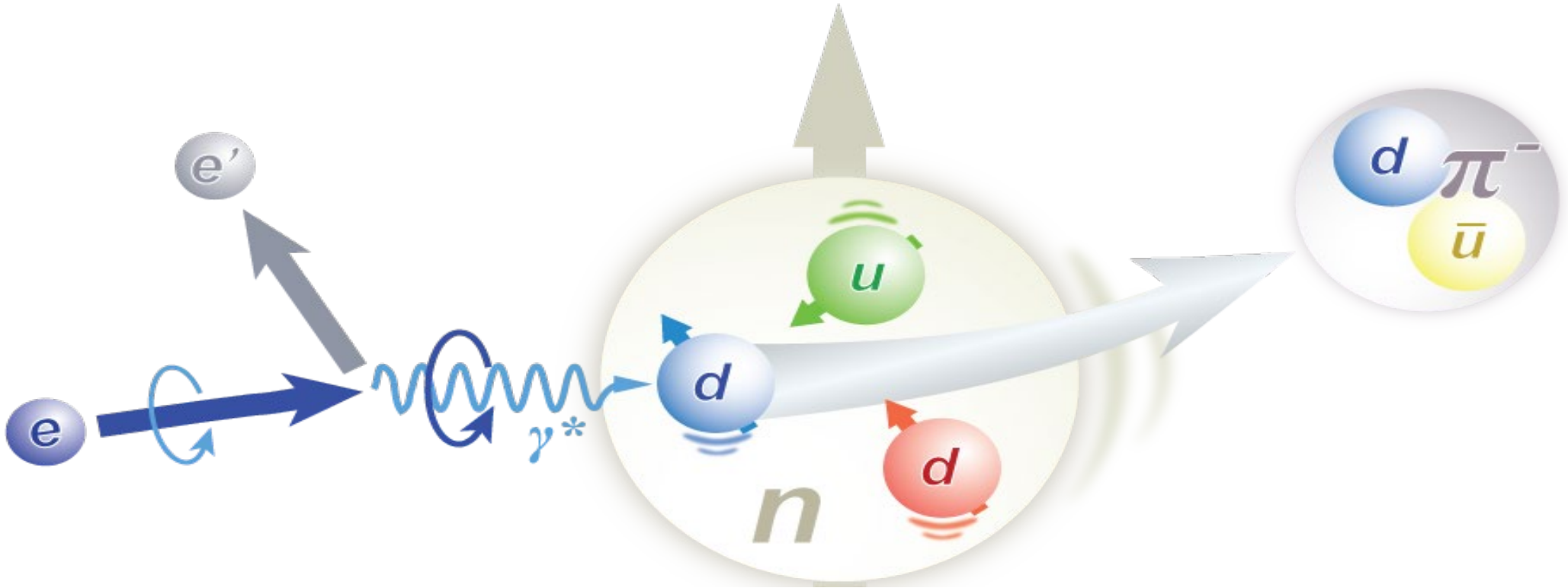
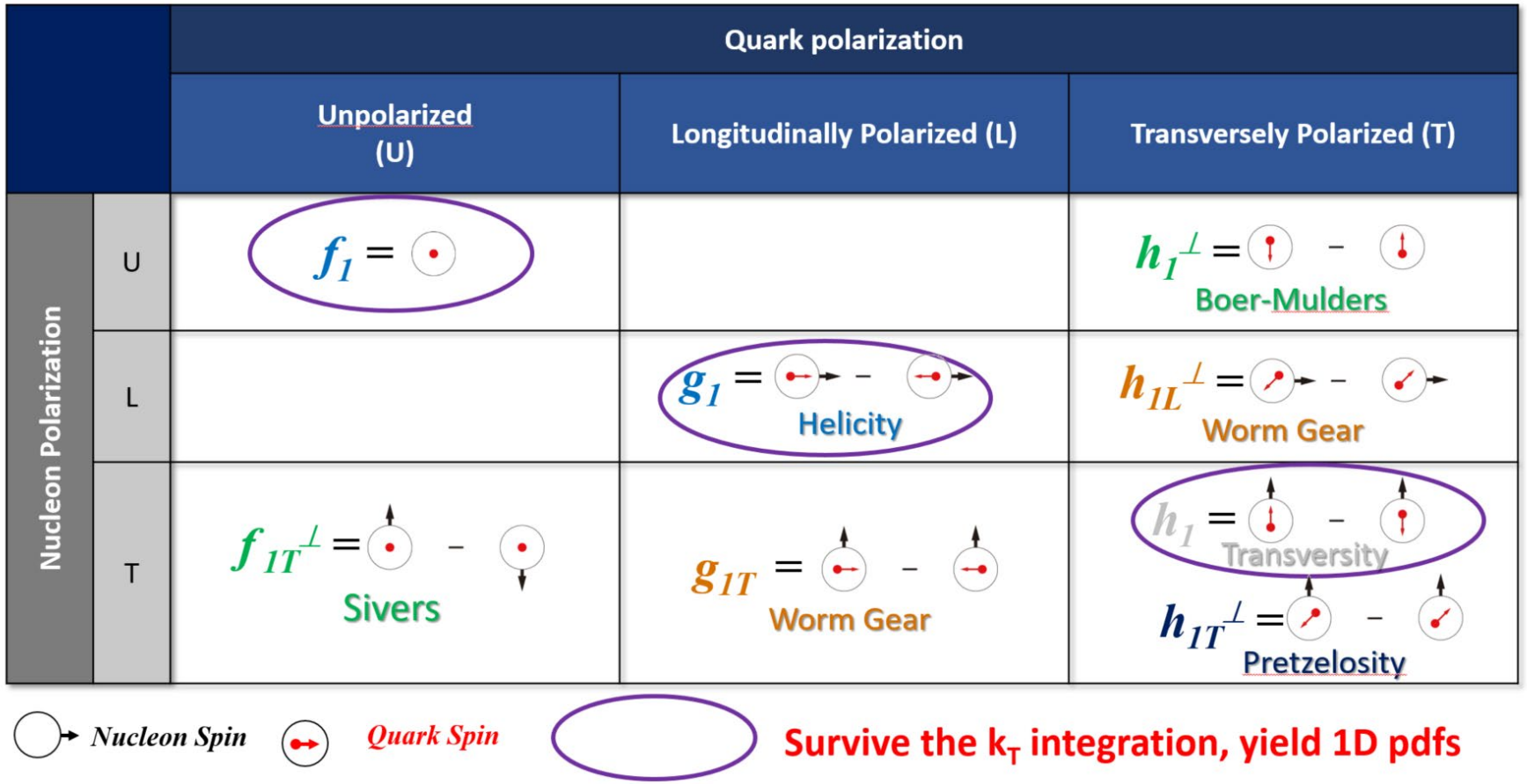
SIDIS program



SIDIS program to study TMDs precisely in the valence region

- E12-10-006(A), Single Spin Asymmetry on Transversely Polarized ^{3}He, 90 days
- E12-11-007(A), Single and Double Spin Asymmetry on Longitudinally Polarized ^{3}He, 35 days
- E12-11-108(A), Single Spin Asymmetry on Transversely Polarized Proton , 120 days



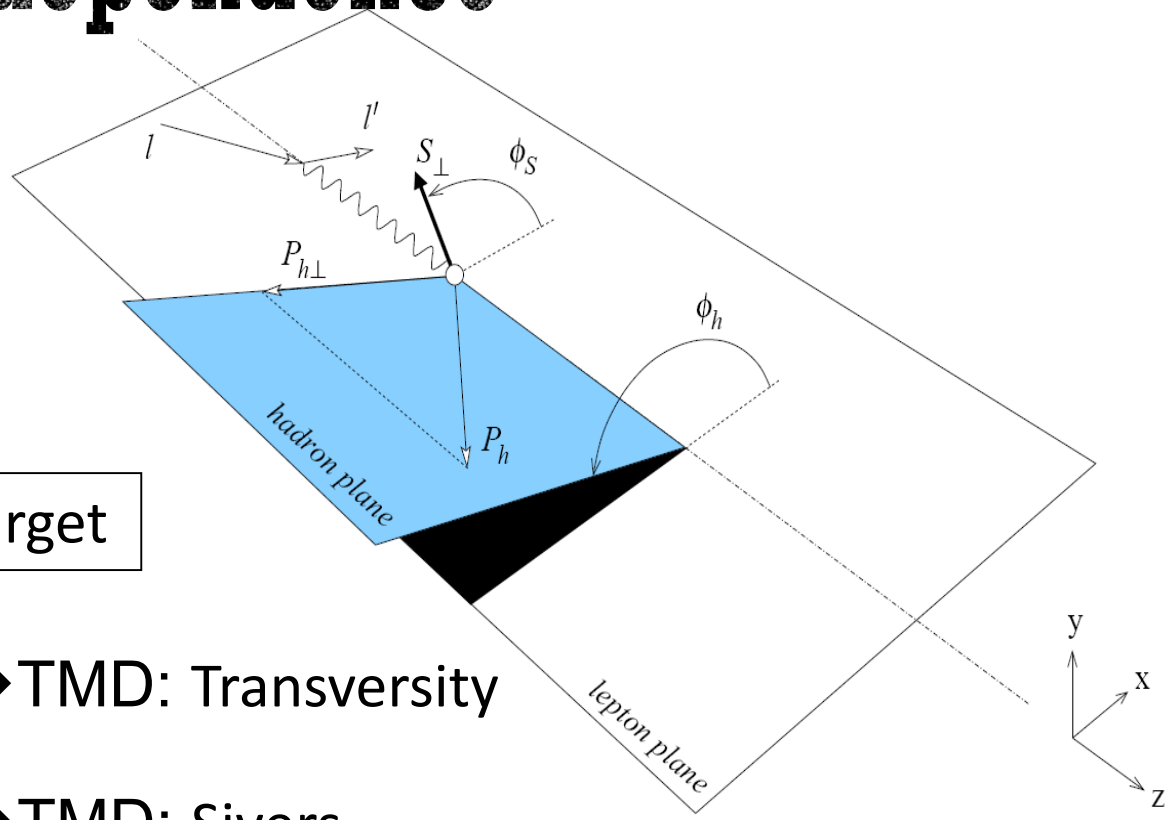
Separation of Collins, Sivers and Pretzelosity through azimuthal angular dependence

$$A_{UT}(\varphi_h^l, \varphi_S^l) = \frac{1}{P}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

$$= A_{UT}^{Collins} \sin(\phi_h + \phi_S) + A_{UT}^{Sivers} \sin(\phi_h - \phi_S)$$

$$+ A_{UT}^{Pretzelosity} \sin(3\phi_h - \phi_S)$$

UT: **U**npolarized beam + **T**ransversely polarized target

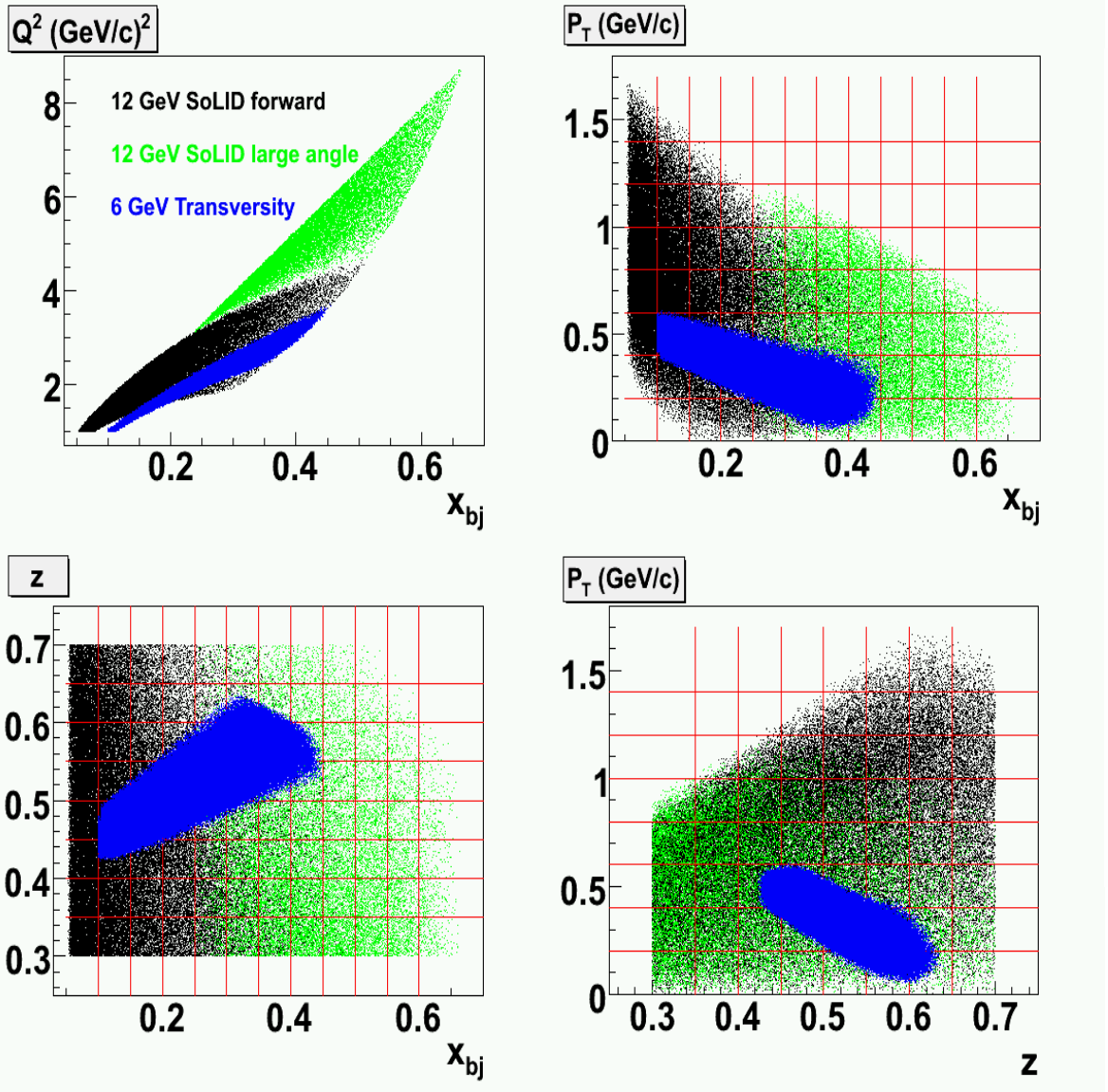


$$A_{UT}^{Collins} \propto \left\langle \sin(\phi_h + \phi_S) \right\rangle_{UT} \propto h_1 \otimes H_1^{\perp}$$ →TMD: Transversity

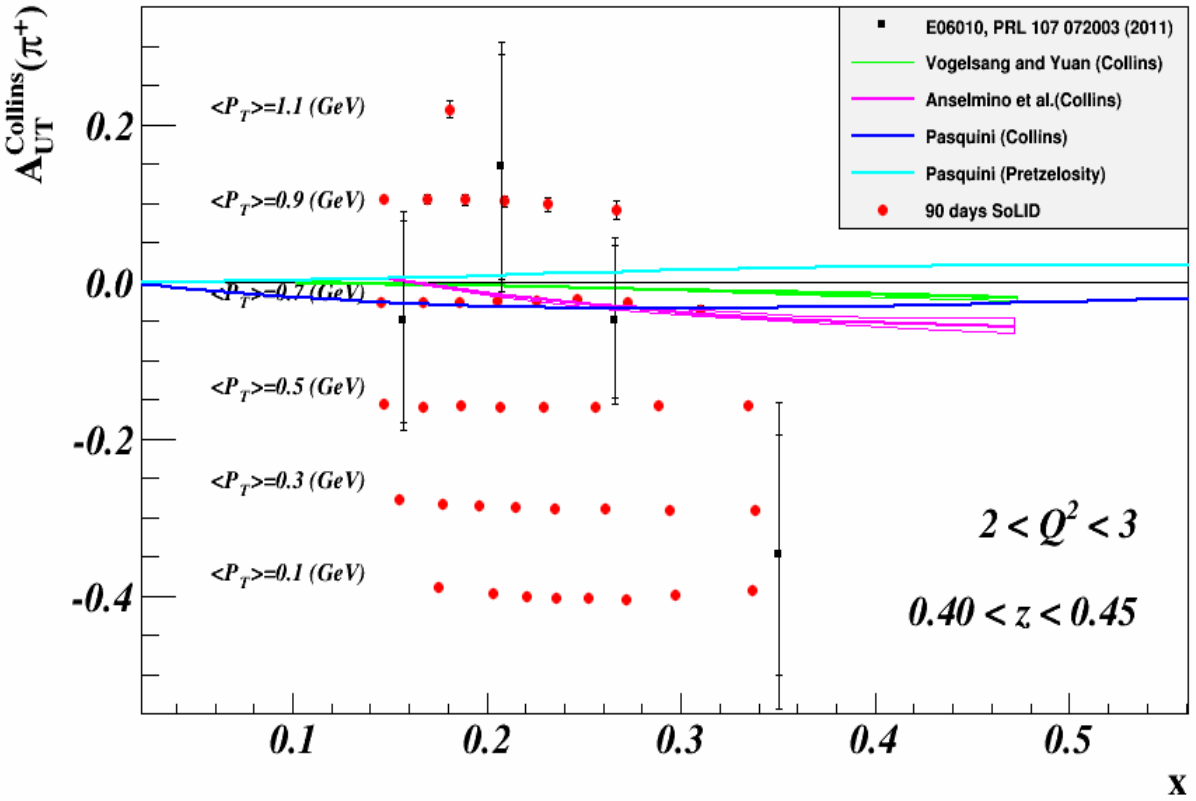
$$A_{UT}^{Sivers} \propto \left\langle \sin(\phi_h - \phi_S) \right\rangle_{UT} \propto f_{1T}^{\perp} \otimes D_1$$ →TMD: Sivers

$$A_{UT}^{Pretzelosity} \propto \left\langle \sin(3\phi_h - \phi_S) \right\rangle_{UT} \propto h_{1T}^{\perp} \otimes H_1^{\perp}$$ →TMD: Pretzelosity

Phase space coverage



One example on Collins asymmetry

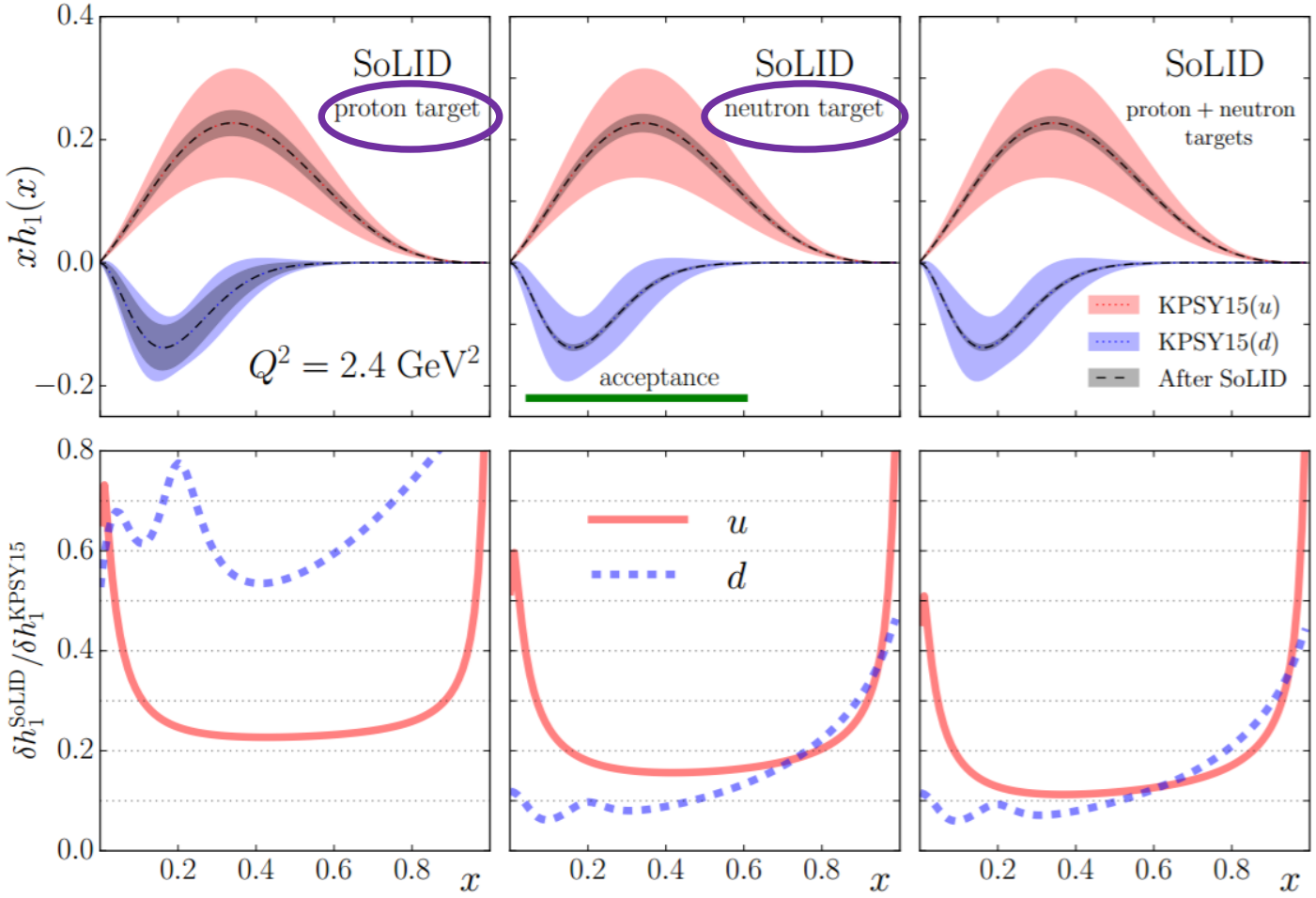


P_T vs. x for one (Q^2, z) bin
Total > 1400 data points

4 D mapping at SoLID with high precision

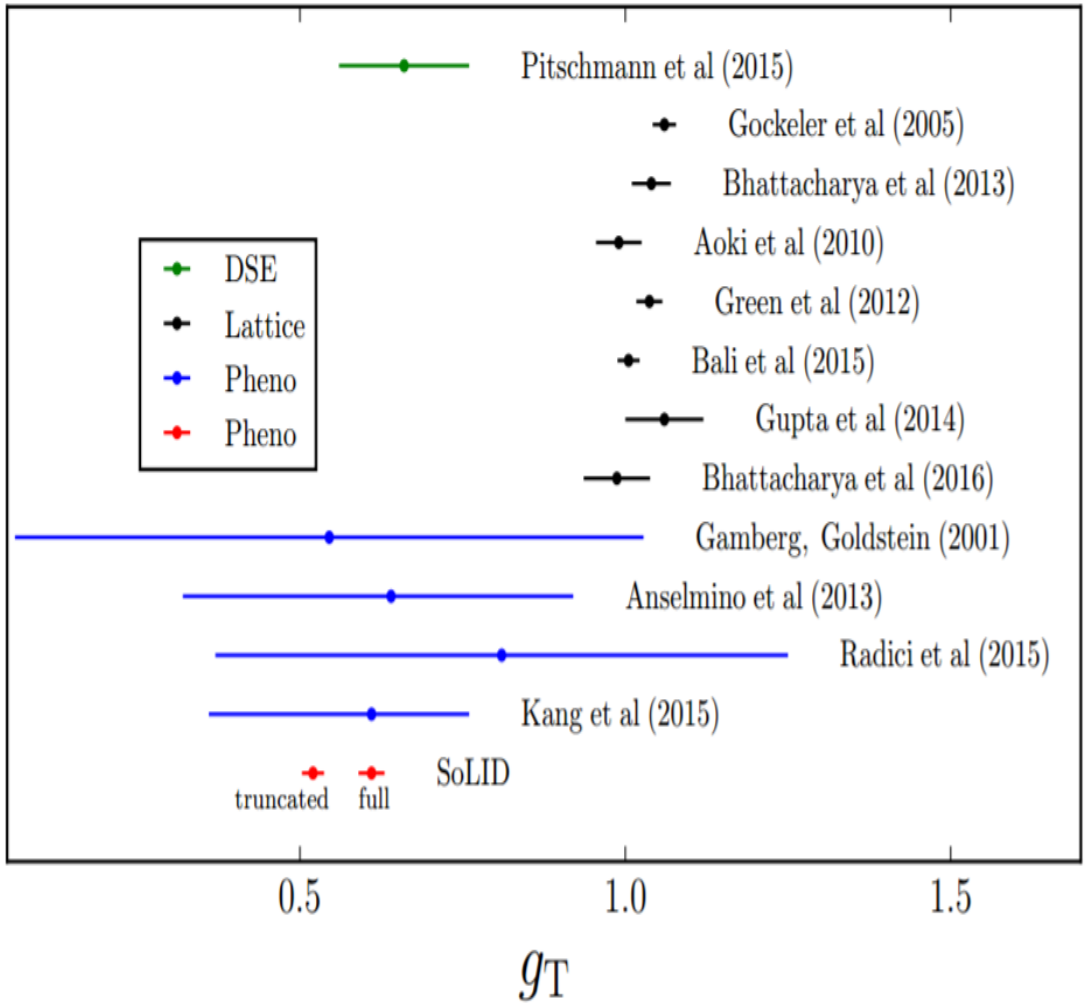
Transversity and Tensor charge from SoLID

$$g_T^{(\text{truncated})} = +0.55^{+0.018}_{-0.018}, \qquad g_T^{(\text{full})} = +0.64^{+0.021}_{-0.021}$$

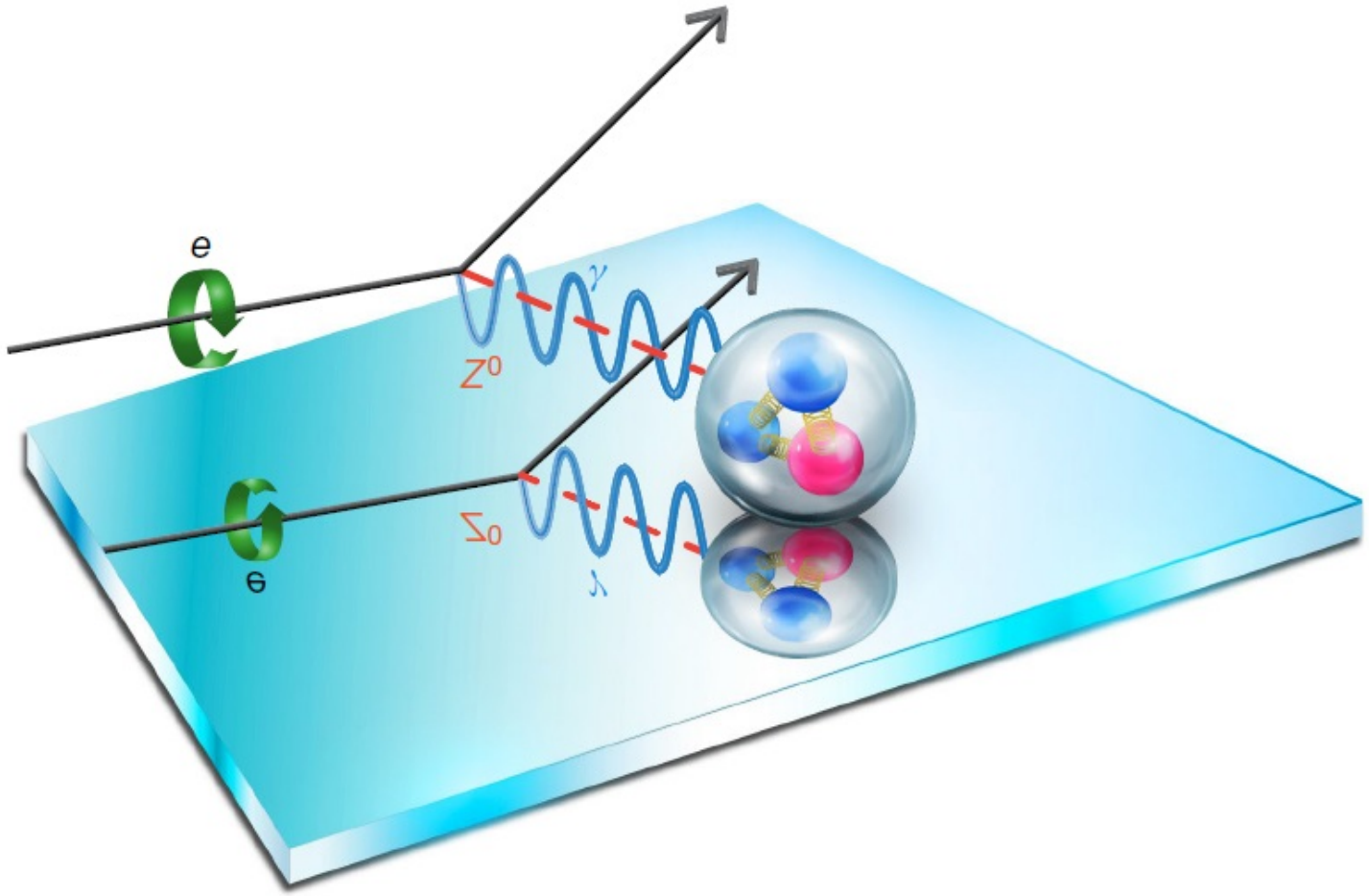


$$g_T = \delta u - \delta d \qquad \delta q(Q^2) = \int_0^1 dx[h_1^q(x,Q^2) - h_1^{\bar{q}}(x,Q^2)]$$

Z. Ye et al., PLB 767, 91 (2017)

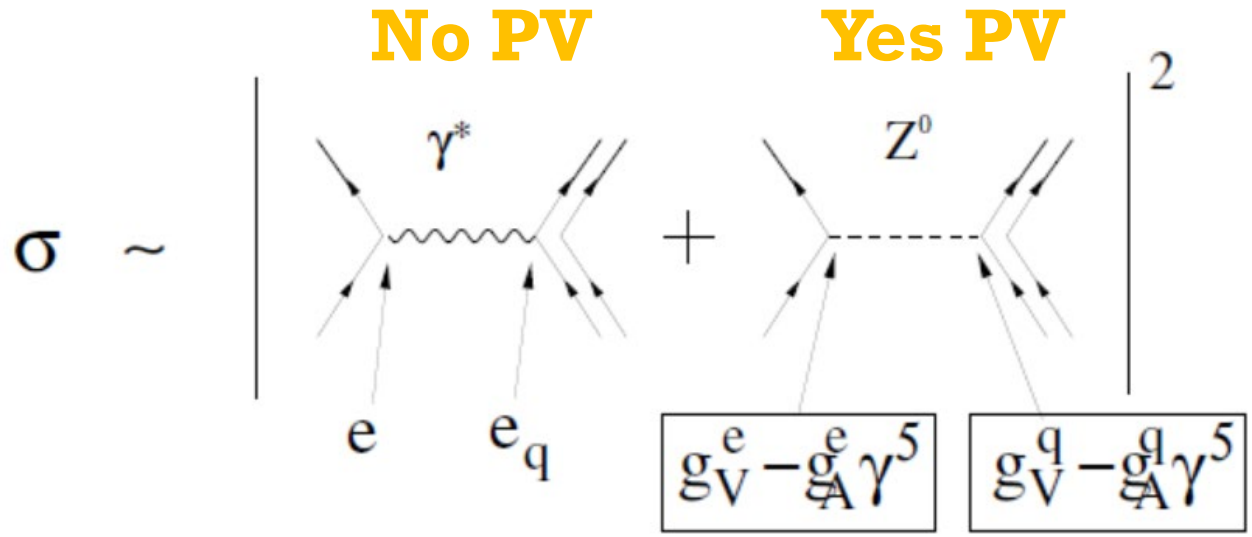


PVDIS program



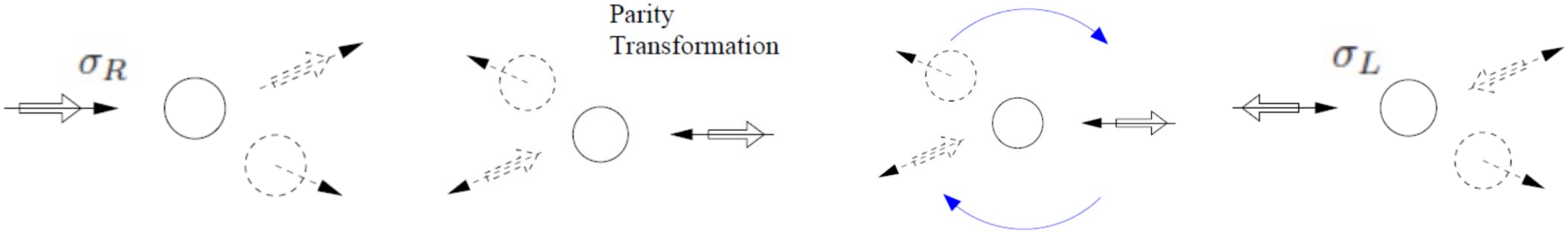
E12-10-007 (A), Parity Violating Asymmetry in DIS with LH_2 and LD_2 , 169 days

Parity Violating electron scatterings

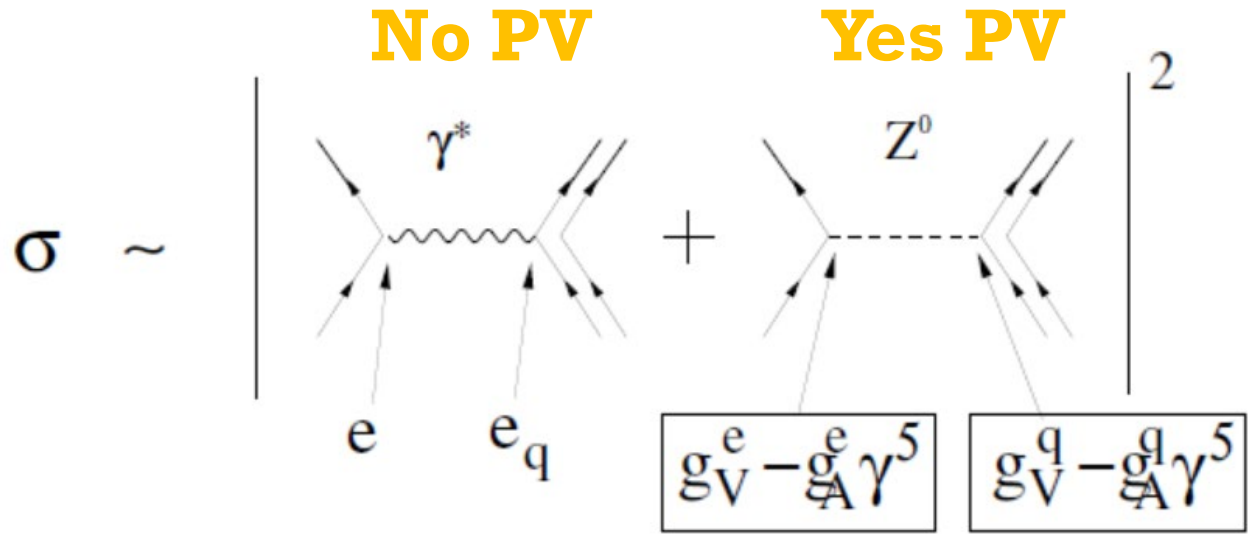


Tree level…

To detect PV : **long. pol. Electron + unpol. Nucl.**



Parity Violating electron scatterings



Tree level…

To detect PV : **long. pol. Electron + unpol. Nucl.**

$$A_{PV} \equiv \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

Parity Violating electron scatterings

$$A_{PV} \sim \frac{\left| \gamma^* \right| \left| Z^0 \right|^*}{\left| \gamma^* \right|^2} \sim 100 - 1000 \text{ ppm}$$

$$\approx -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left[a_1(x) + \frac{1-(1-y)^2}{1+(1-y)^2} a_3(x)\right], y = 1 - \frac{E'}{E}$$

New structure functions

$$a_1(x) = 2g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}} \qquad F_1^{\gamma Z} = \sum_f e_{q_f} (g_V)_{q_f} (q_f + \bar{q}_f)$$

$$a_3(x) = g_V^e \frac{F_3^{\gamma Z}}{F_1^{\gamma}} \qquad F_3^{\gamma Z} = 2\sum_f e_{q_f} (g_A)_{q_f} (q_f - \bar{q}_f)$$

New effective weak couplings

$$C_{1u} = 2g_A^e g_V^u = 2\left(-\frac{1}{2}\right)\left(\frac{1}{2} - \frac{4}{3}\sin^2\theta_W\right) = -\frac{1}{2} + \frac{4}{3}\sin^2\theta_W$$

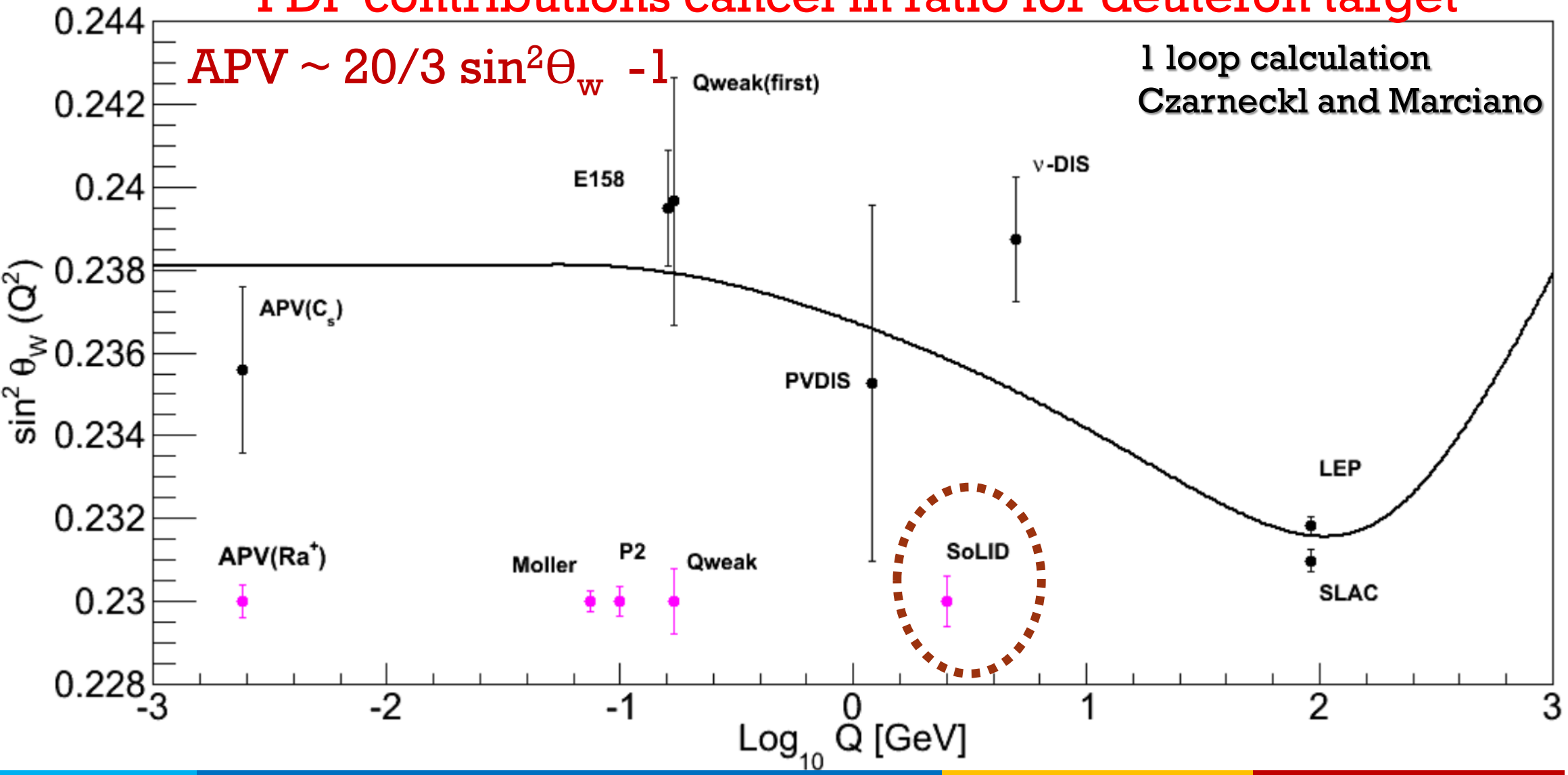
$$C_{2u} = 2g_V^e g_A^u = 2\left(-\frac{1}{2} + 2\sin^2\theta_W\right)\left(\frac{1}{2}\right) = -\frac{1}{2} + 2\sin^2\theta_W$$

$$C_{1d} = 2g_A^e g_V^d = 2\left(-\frac{1}{2}\right)\left(-\frac{1}{2} + \frac{2}{3}\sin^2\theta_W\right) = \frac{1}{2} - \frac{2}{3}\sin^2\theta_W$$

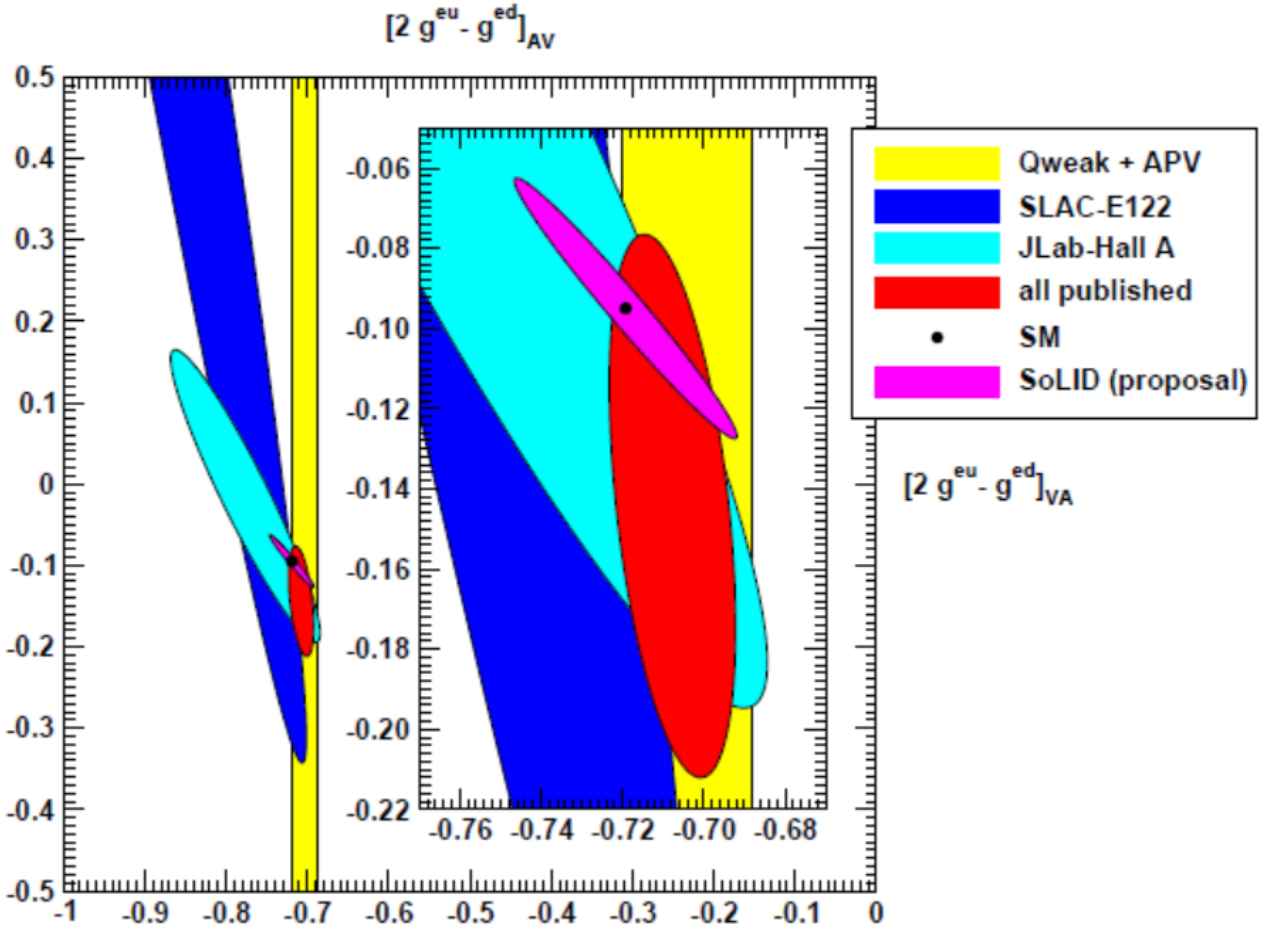
$$C_{2d} = 2g_V^e g_A^d = 2\left(-\frac{1}{2} + 2\sin^2\theta_W\right)\left(-\frac{1}{2}\right) = \frac{1}{2} - 2\sin^2\theta_W$$

Weak mixing angle

PDF contributions cancel in ratio for deuteron target



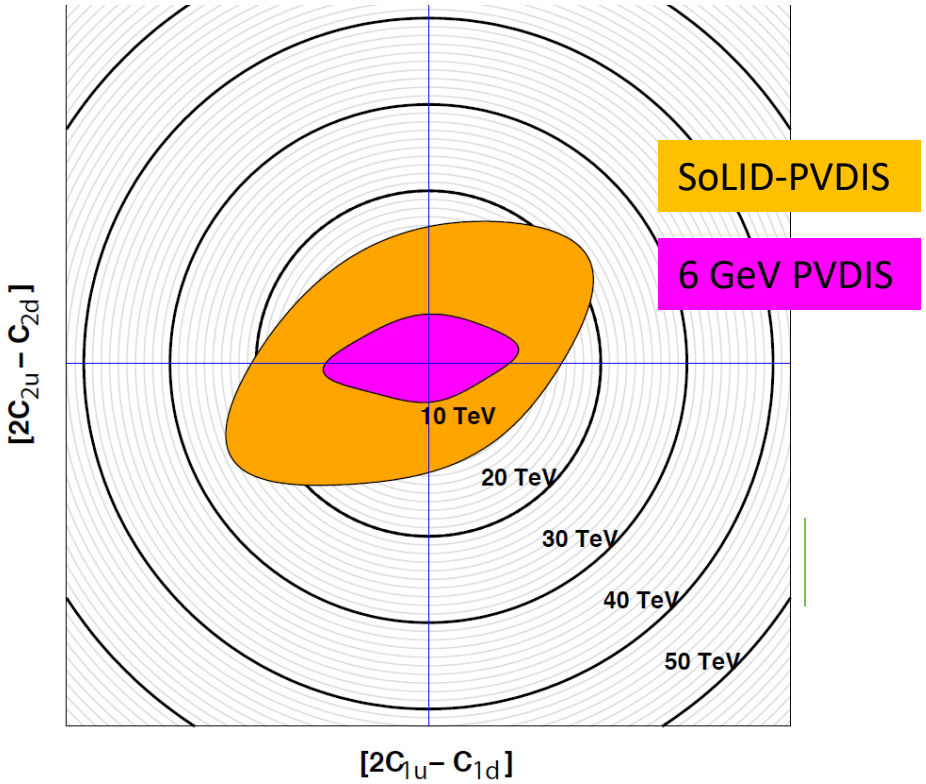
New effective weak couplings: big impact on C_{2q}



PVDIS asymmetry has two terms (C_{1q} , C_{2q}):

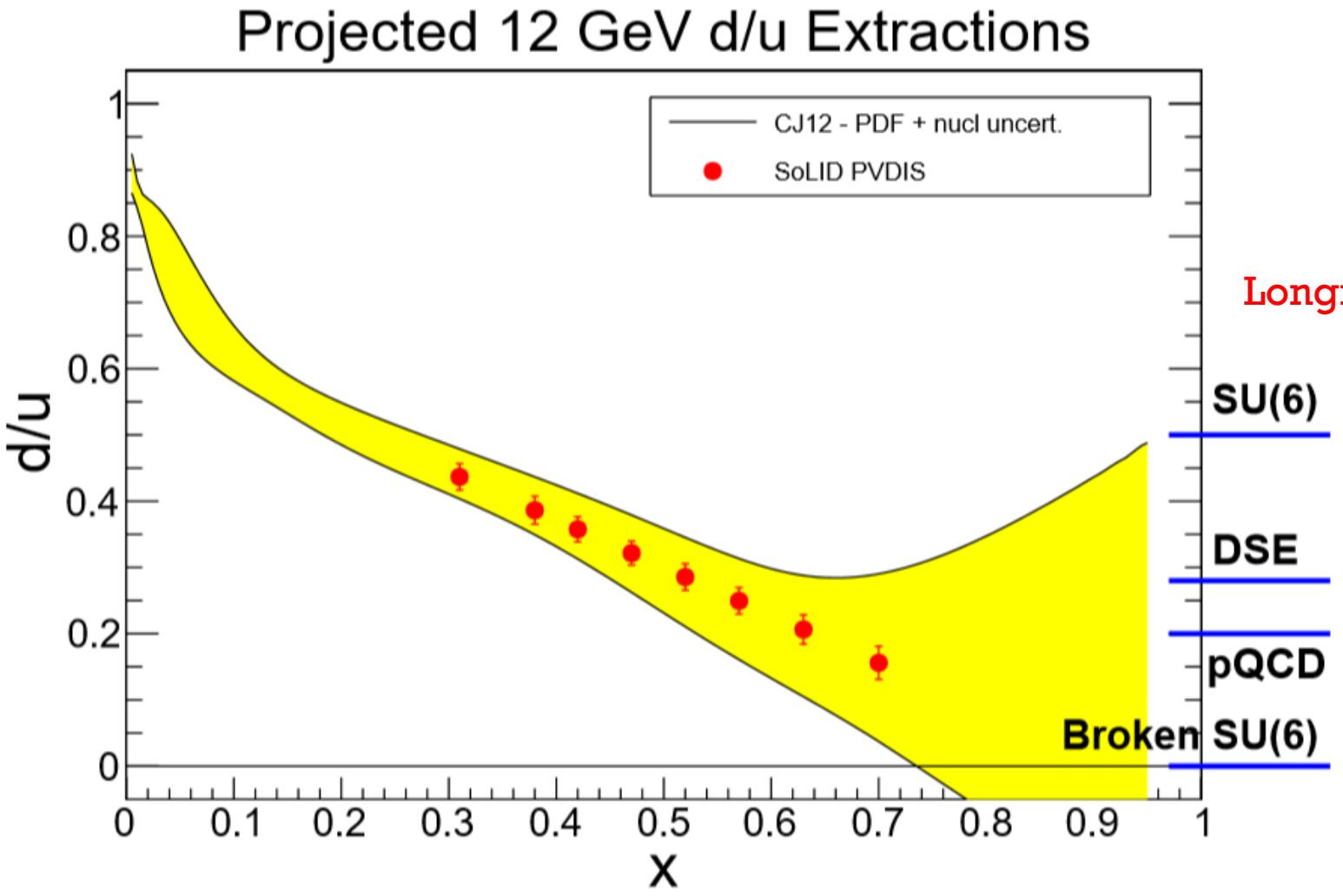
1) Unique opportunity on C_{2q} through **electron-quark** interaction in DIS

2) C_{2q} weak couplings, test of Standard Model, constrain on **leptophobic Z'**



Mass reach in a composite model, SoLID-PVDIS ~ 20 TeV, sensitivity match LHC reach with complementary Chiral and flavor combinations

Precise d/u measurement with PVDIS on a proton target



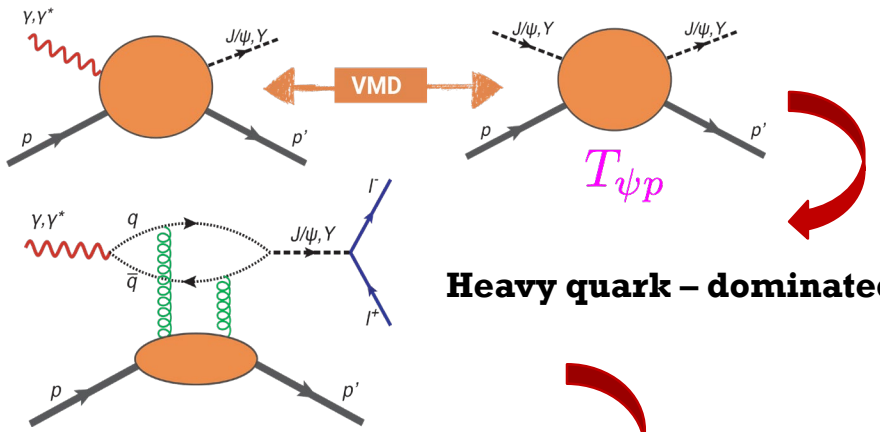
Longitudinally polarized electron + unpol. proton

$$A_{PV} \approx -\frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\frac{1+d/u}{4+d/u}$$

J/ψ near threshold production at SoLID

E12-12-006 (A-), Near Threshold Electroproduction of J/ψ at 11 GeV, 60 days

$$\gamma^* + N \rightarrow N + J/\psi$$



Heavy quark – dominated by two gluons

Proton Mass:

$$\langle P|T^\alpha_\alpha|P\rangle = 2P^\alpha P_\alpha = 2M_p^2$$

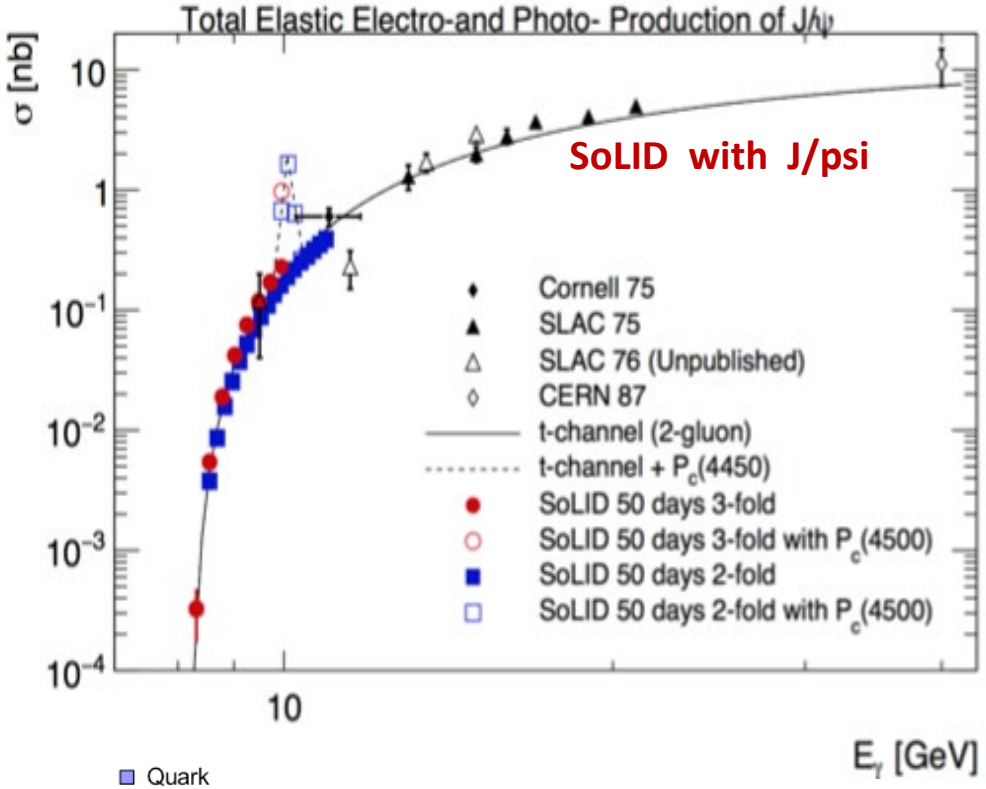
Covariant Decomposition of the Energy Momentum Tensor (EMT)

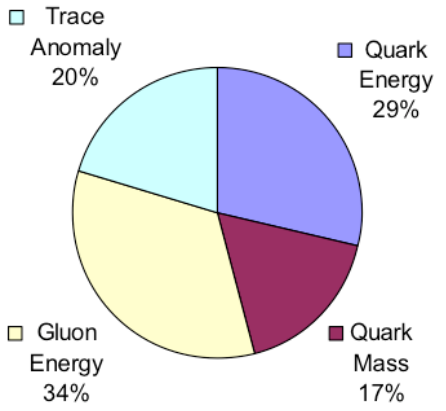
$$T^\alpha_\alpha = \frac{\tilde{\beta}(g)}{2g} F^{\mu\nu,a} F^a_{\mu\nu} + \sum_{q=u,d,s} m_q(1+\gamma_m)\bar{\psi}_q\psi_q$$

QCD trace anomaly — Light quark mass

Trace of EMT proportional to Quarkonium-proton scattering amplitude

$T_{\psi p}$ to be measured at JLab with J/psi at SoLID or Upsilon at EIC





Open question:
How does QCD generate the mass of the proton?

X.Ji PRL741071(1995)

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Project status

- pCDR submitted in July 2014
- Director's review in Feb. 2015
  - ✓Recommendations received
- Revised pCDR submitted in May 2017, followed by a second review in Oct. 2017
  - ✓Very positive feedback
- Meeting with DOE to discuss the plan and progress in July 2018
  - ✓Homework: re-estimate the cost for all subsystem. pCDR updated and submitted in Dec. 2018
- The 2019 Director's review will be held soon. After that the Science Review will be requested.

- Hope that the project will start in **FY21** and it takes around 5 years to have experiment running in the Hall

Summary

- SIDIS program at SoLID will do excellent job in x>0.1 region for TMDs study
- PVDIS program at SoLID will do precision test of the SM and precise d/u measurement
- J/Ψ production at threshold allows us to study the proton mass structure experimentally
- More physics topics and details are not mentioned here …

SoLID core working groups:

- **ECal:**
- **GEM:**
- **MRPC:**
- **Light Gas Cherenkov:**
- **Heavy Gas Cherenkov:**
- **Magnet:**
- **Simulations:**