E1039/SpinQuest Polarized Drell-Yan Experiment at Fermilab

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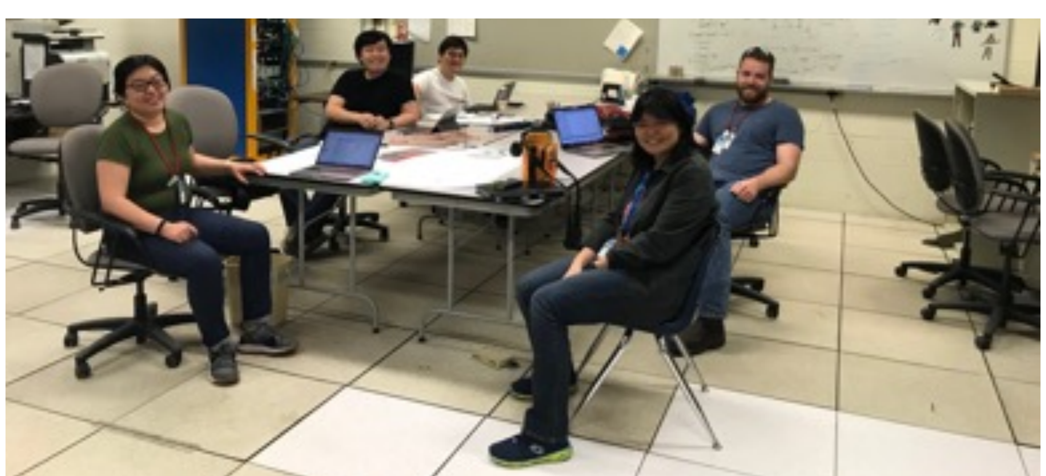
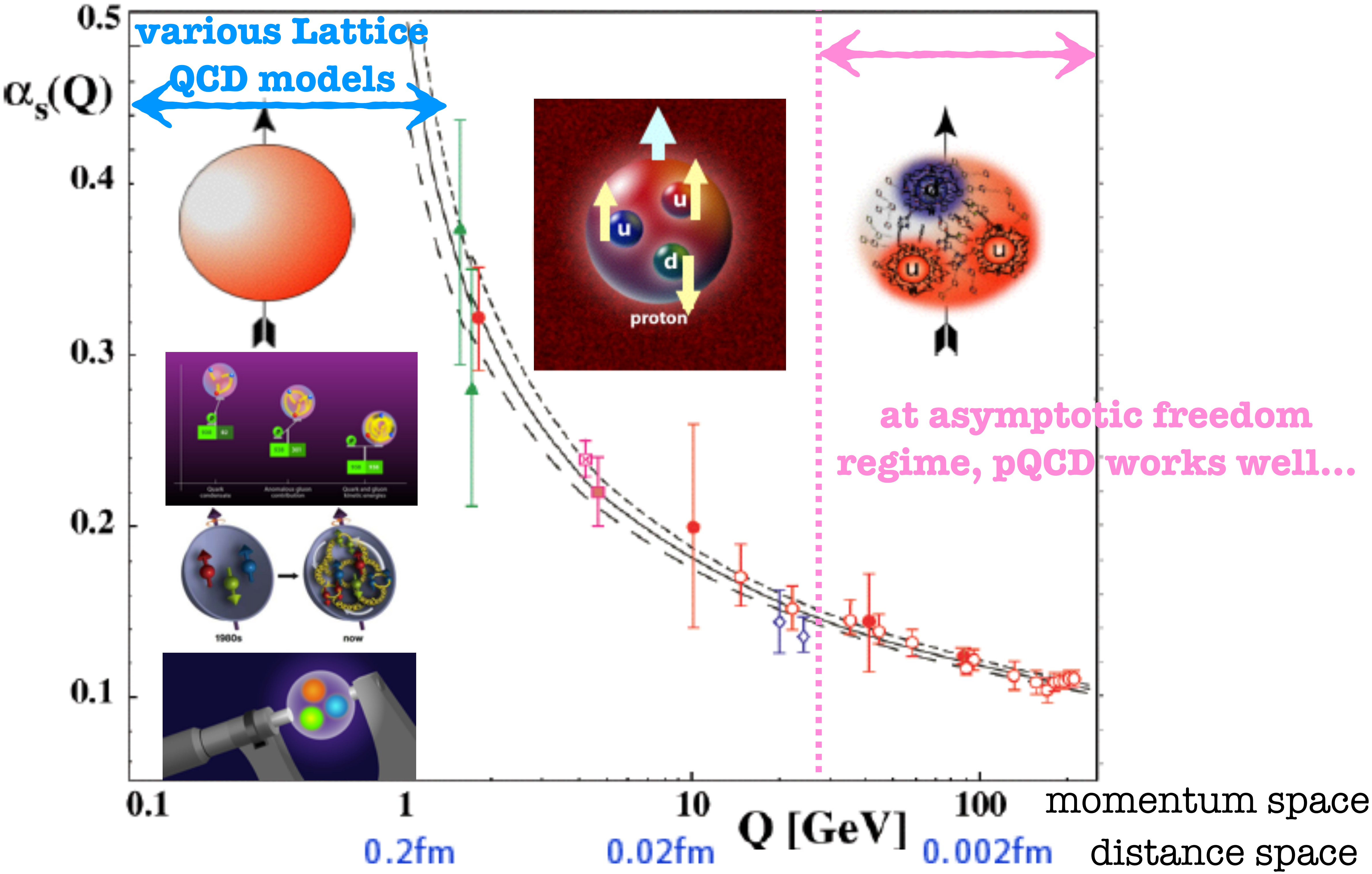
Fermilab New Perspective 2019

June 10th, 2019



Motivation

$$\alpha_s(Q^2) = \frac{1}{\frac{33-2N_f}{12\pi}\ln\left(\frac{Q^2}{\Lambda^2}\right)}$$

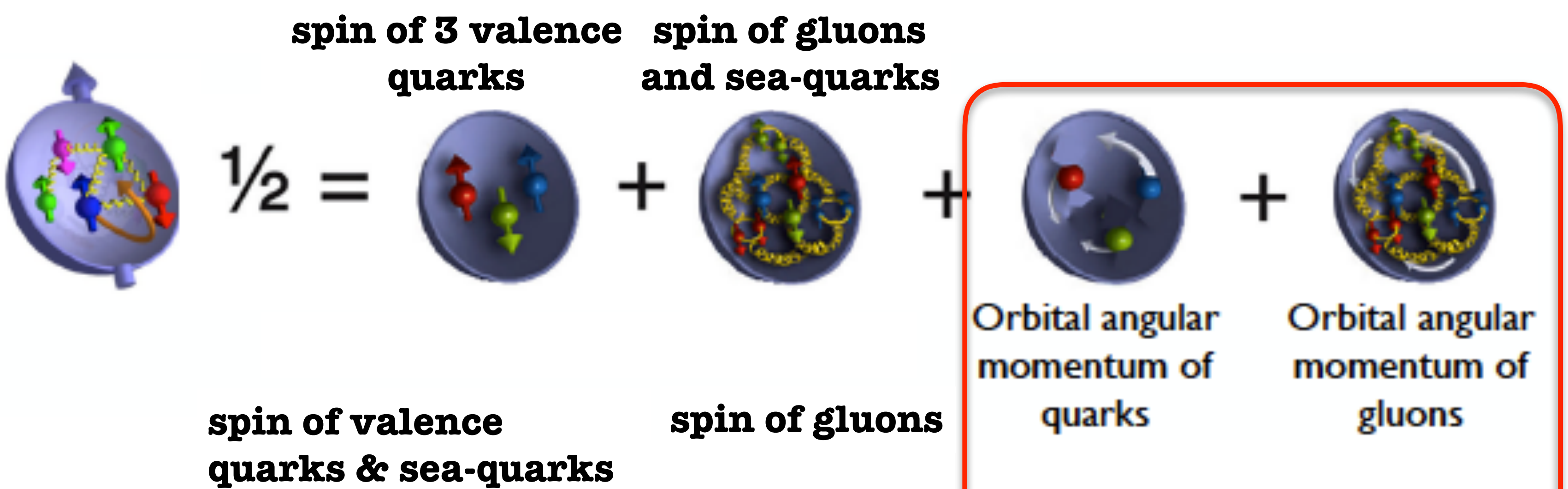


1. quarks & gluons contribute to single nucleon's mass, spin (this talk) and size

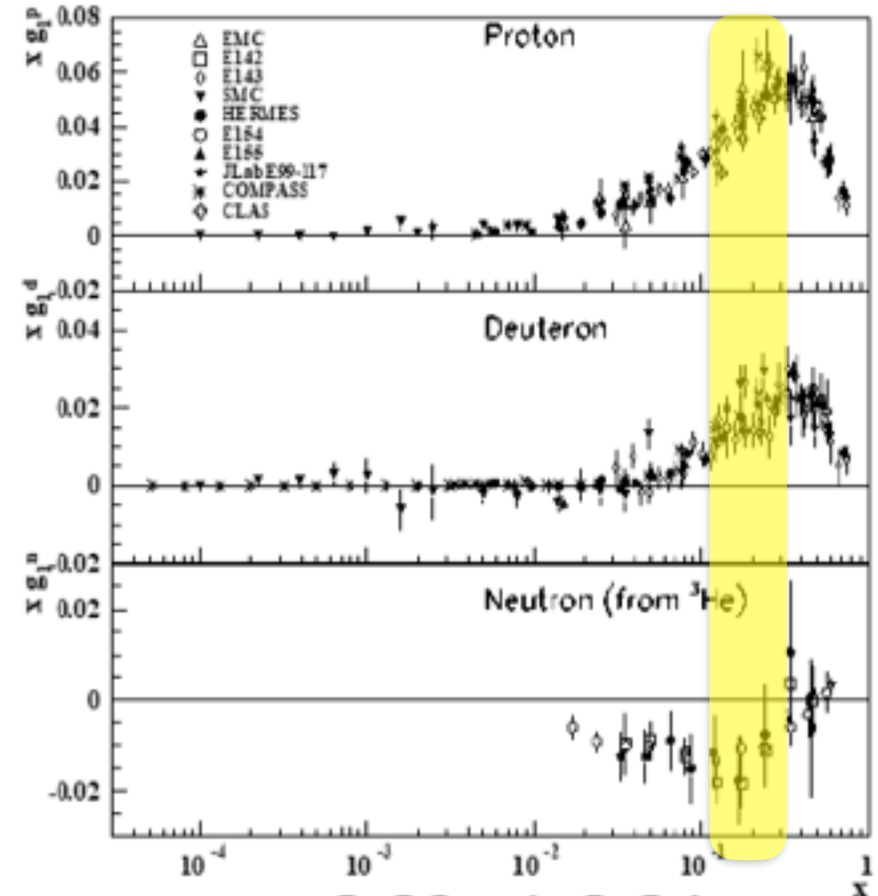
2. quarks & gluons contribute to nuclear binding energy

Measured contributions to the origin of proton spin

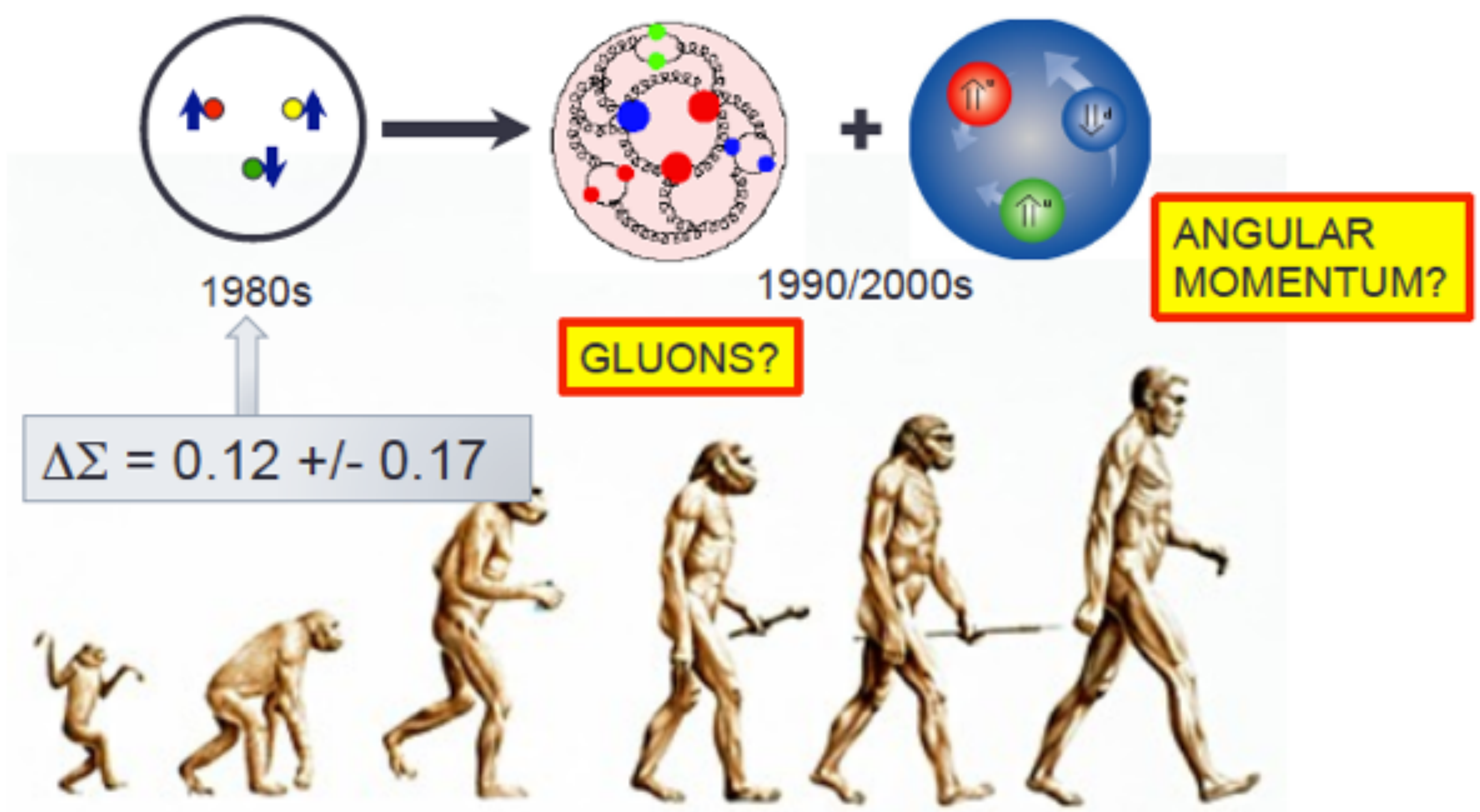
Nucleon spin puzzle has remained since 1988…

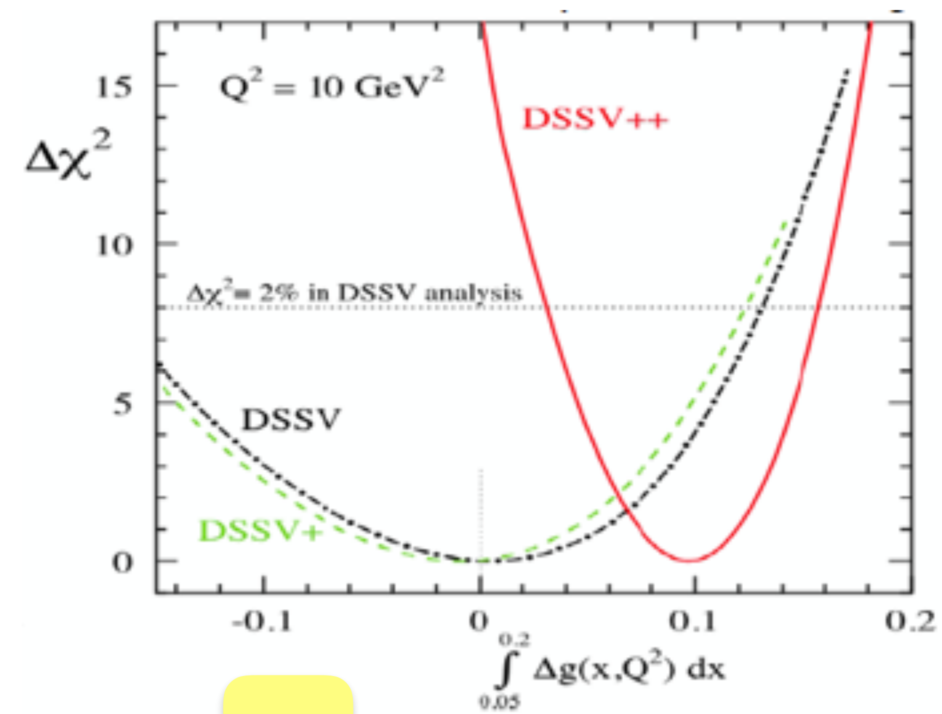


$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_Q + L_G$$



$\Delta\Sigma$ = 0.23 +/- 0.04





$$\int_{0.05}^{0.2} dx \Delta g(x) = 0.2 \pm 0.06$$

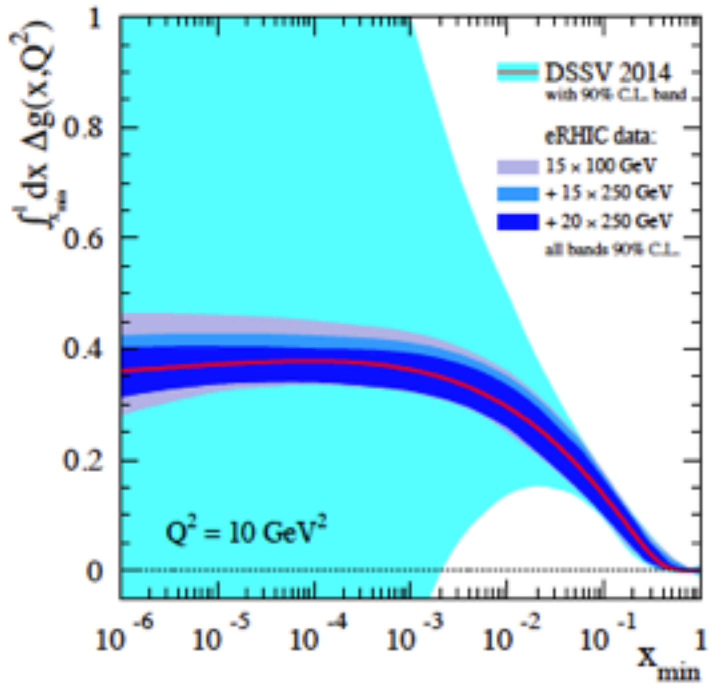
Predicted contributions to the origin of proton spin

Precision in $\Delta\Sigma$ and Δg → A clear idea
Of the magnitude of $L_Q + L_G$

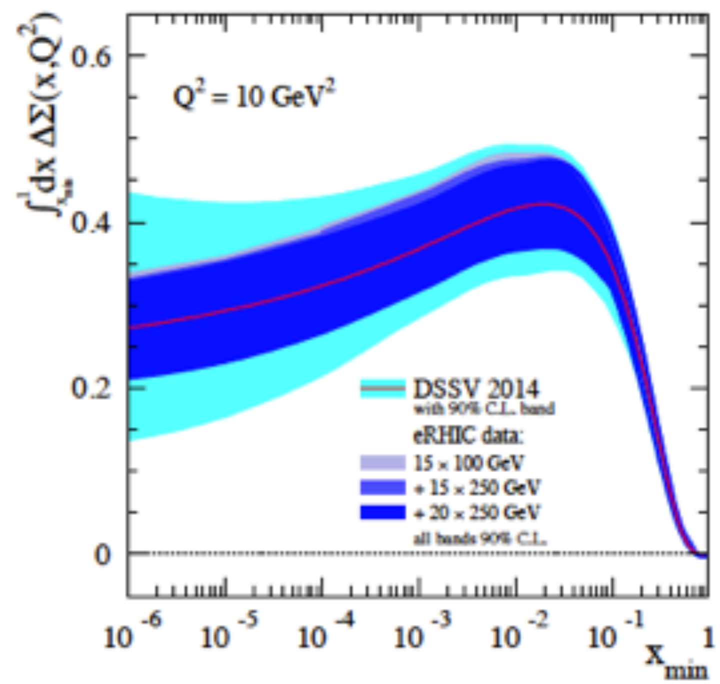
orbital motion of quarks & gluons (this talk)

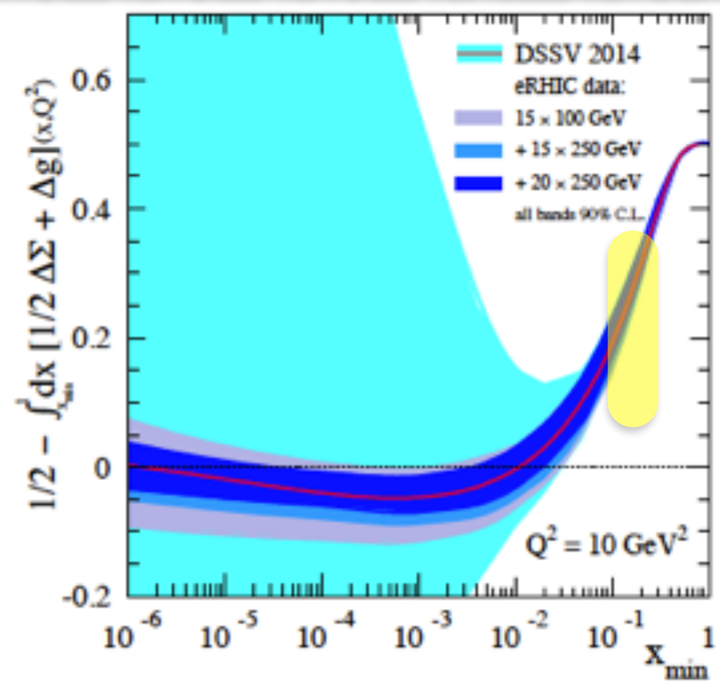
$$L_{Q,G} = ½ - (\Delta\Sigma + \Delta G)$$

ΔG

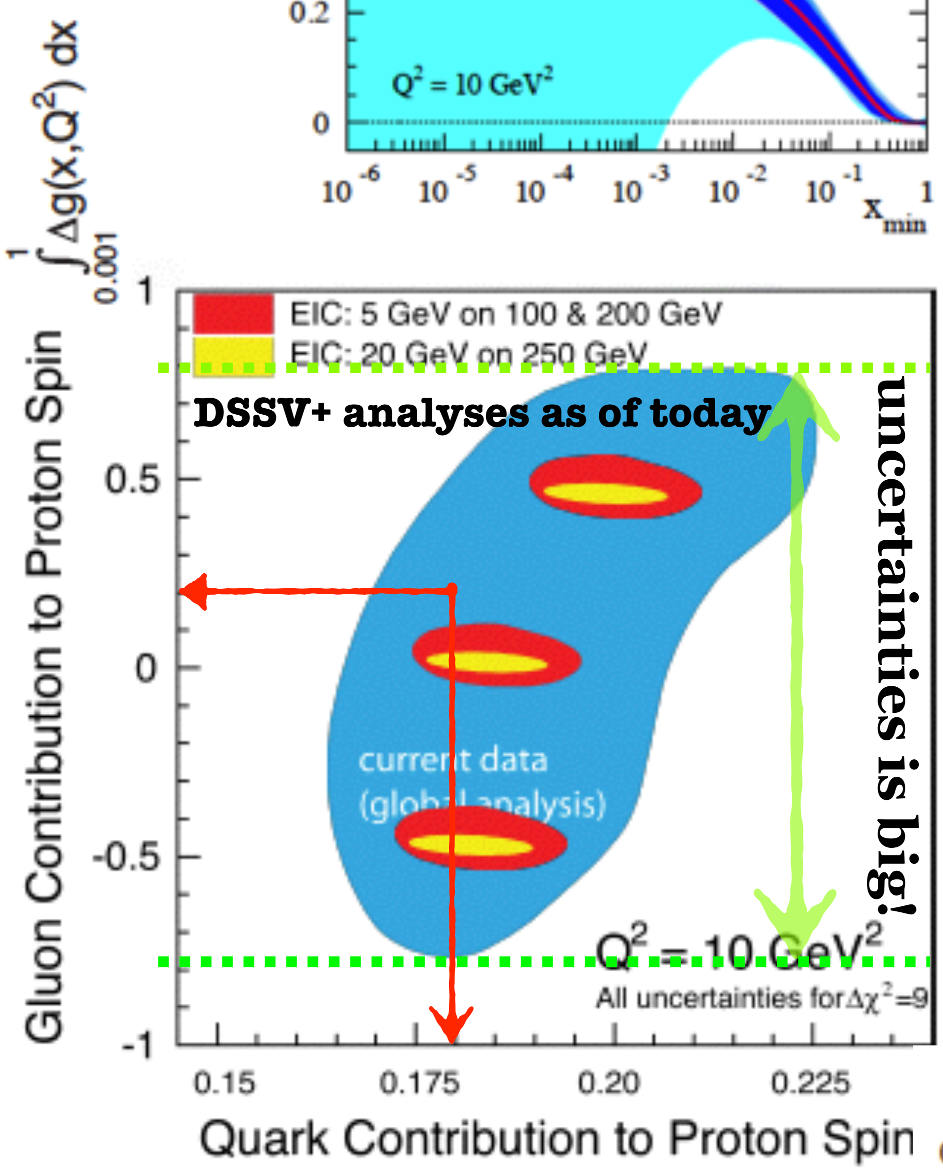


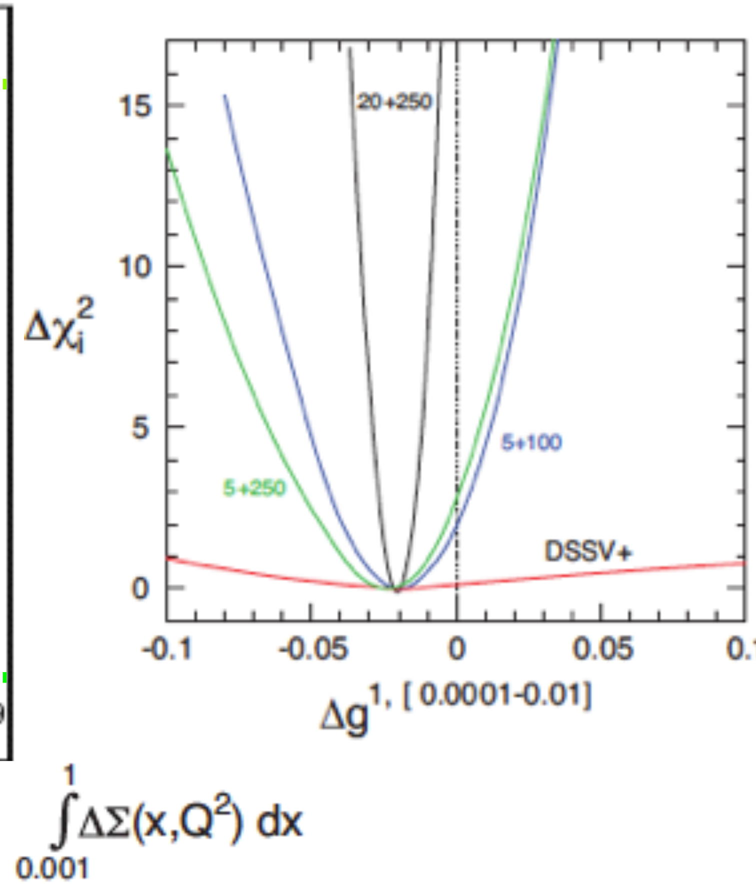
$\Delta\Sigma$

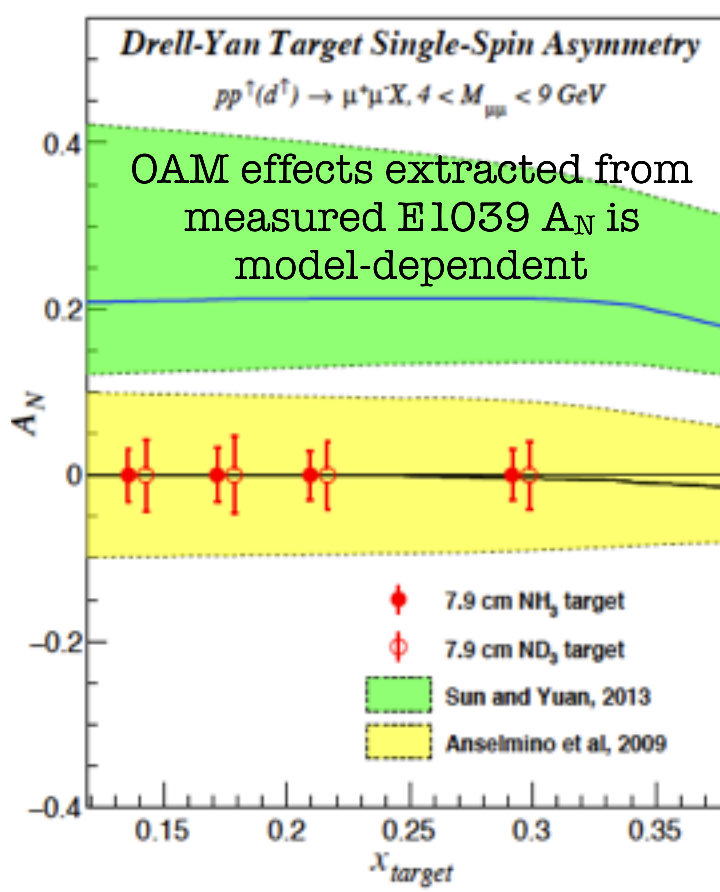




EIC prediction

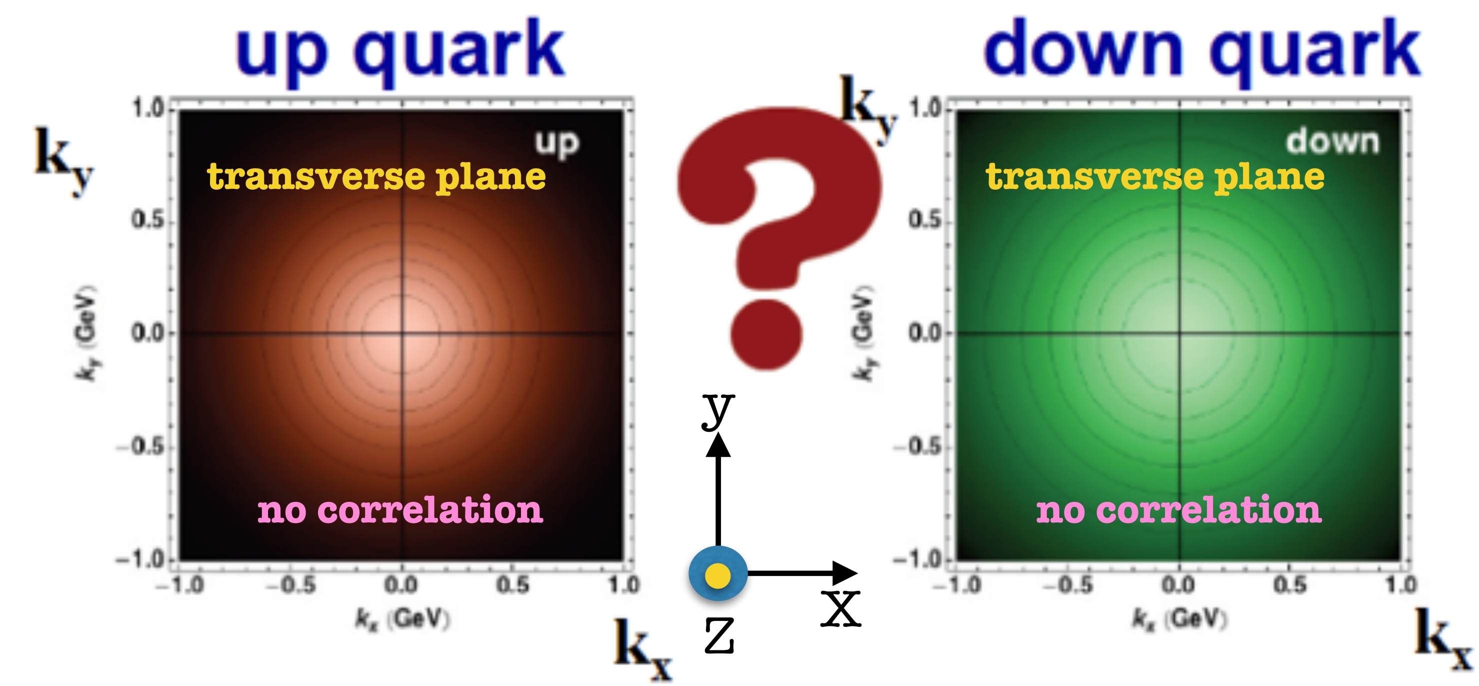






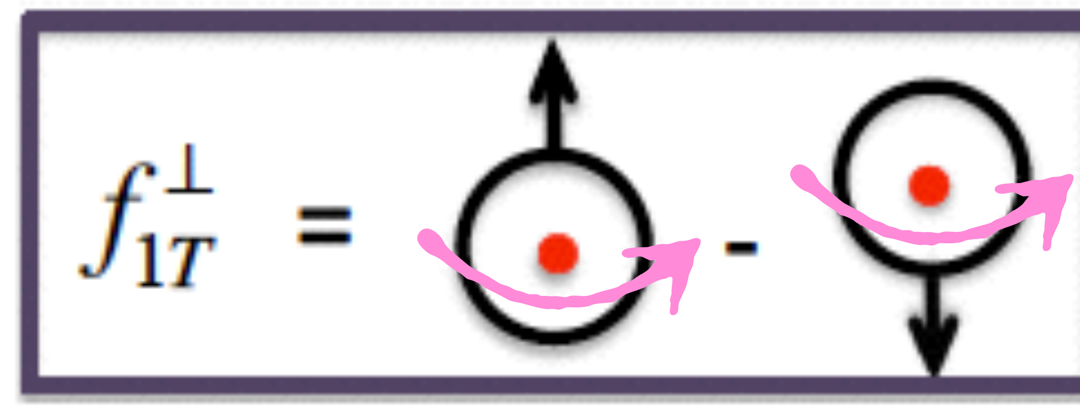
E1039 prediction

“Transverse” approaches of sea quarks’ orbital motions

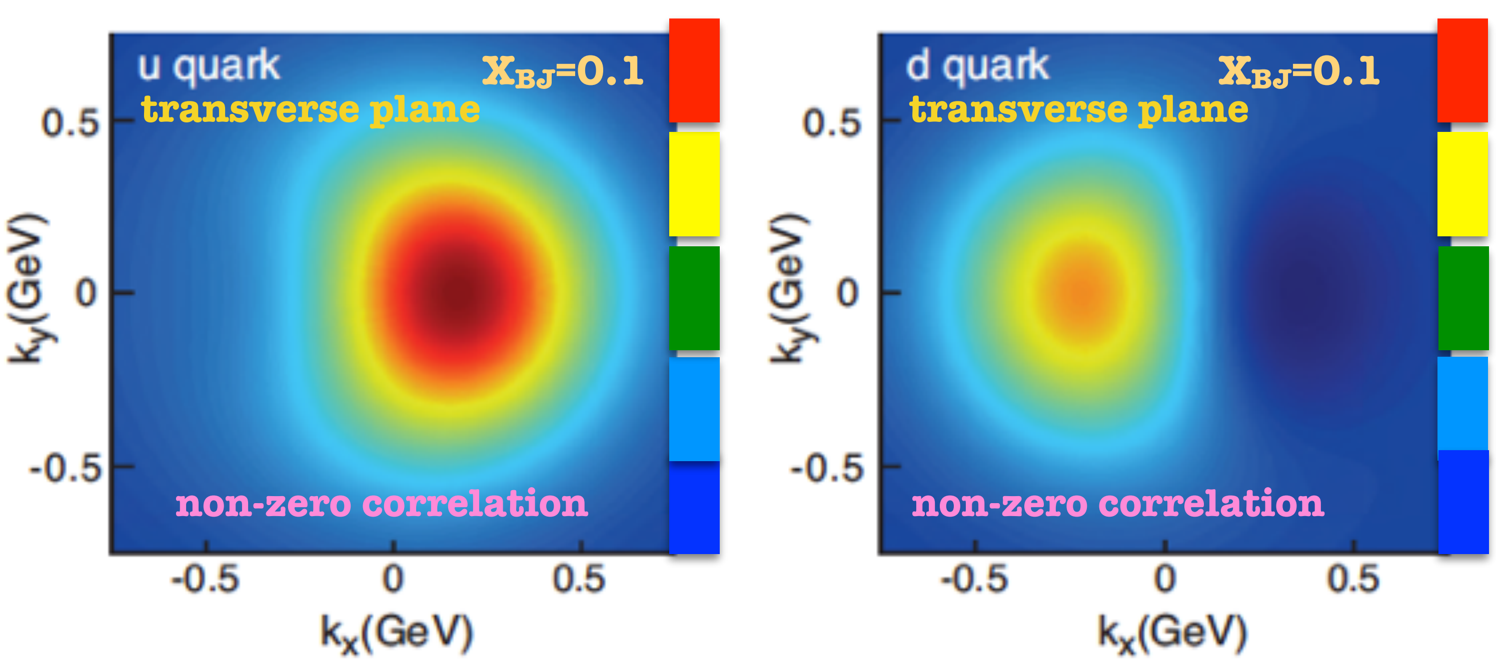


y-polarized nucleon moves along Z

$$\propto \vec{S}_1 \cdot (\vec{p}_1 \times \vec{k}_q)$$



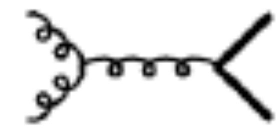
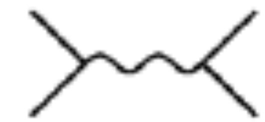
$x\, f_1(x, k_T, S_T)$



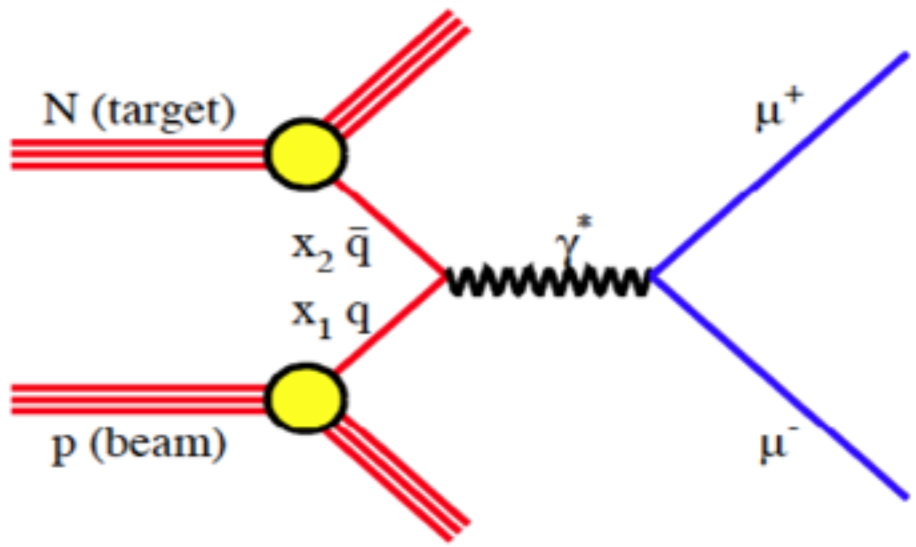
1. **intrinsic** orbital motion of sea quarks on transverse plane
2. **spin-orbital correlations** between polarized single nucleon’s spin, S^N and non-polarized sea quarks’, defined as $L_q = b^T_q \times K^L_q$ (non-zero b^T_q implies non-zero L_q and K^T_q. besides, $K^L_q = x_{BJ} * P^N_Z$) orbital angular momentum, aka: OAM
3. transverse motion (L_q and K^T_q) of quarks is **flavor-dependent** (both in valence and sea quarks?)
4. accessible in Drell-Yan

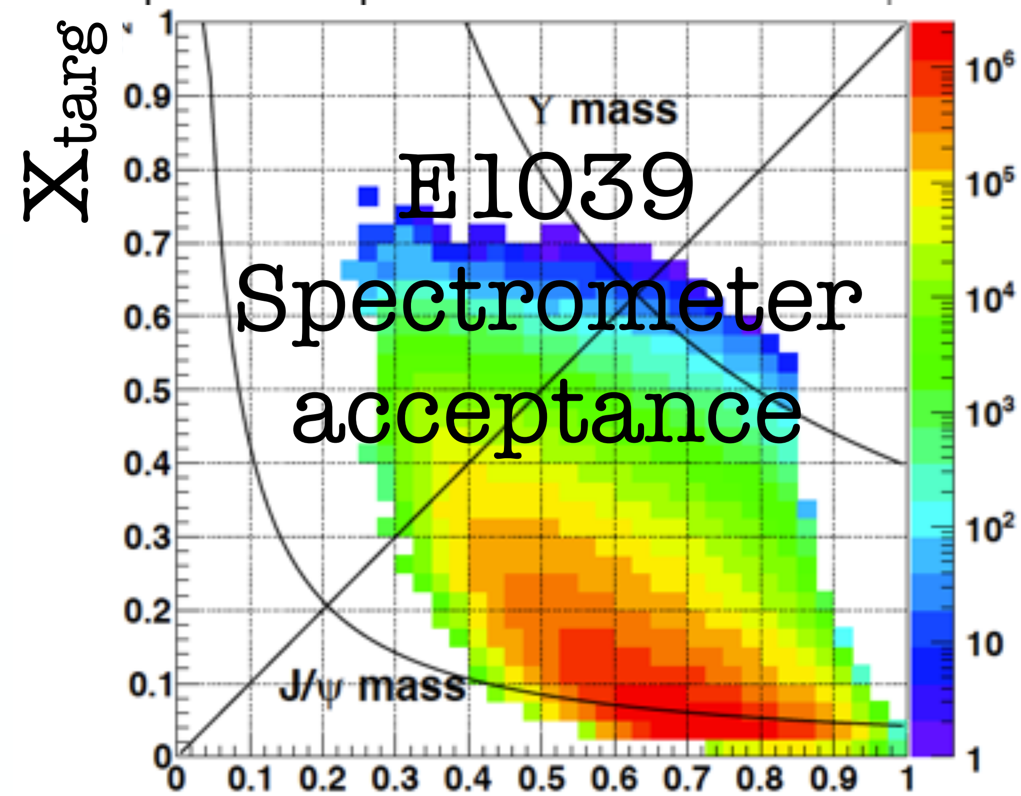
OAM of sea quarks & gluons (this talk)

Sivers asymmetry measurements in Drell-Yan

Reaction	Dom. partonic process	probes	LO Feynman diagram
$\vec{p}\vec{p} \to DX, BX$ unpolarized proton beam transversally polarized NH3 target	$\vec{g}\vec{g} \to c\bar{c}, b\bar{b}$	Δg	
$\vec{p}\vec{p} \to \mu^+\mu^- X$ (Drell-Yan) unpolarized proton beam transversally polarized NH3 target	$\vec{q}\vec{\bar{q}} \to \gamma^* \to \mu^+\mu^-$	$\Delta q, \Delta\bar{q}$	

The Drell-Yan process:

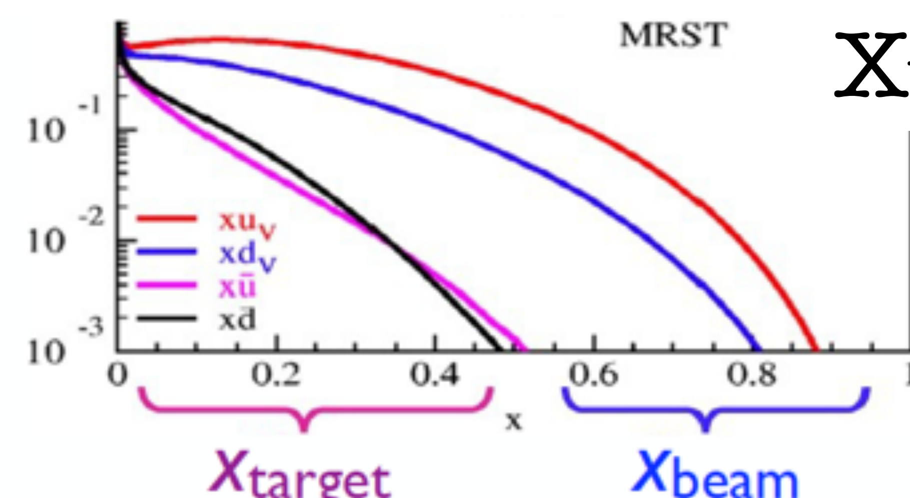




$$\frac{d^2\sigma}{dx_b\,dx_t} = \frac{4\pi\alpha^2}{9x_b\,x_t}\frac{1}{s}\sum_q e_q^2\left[\bar{q}_t(x_t)q_b(x_b) + q_t(x_t)\bar{q}_b(x_b)\right]$$

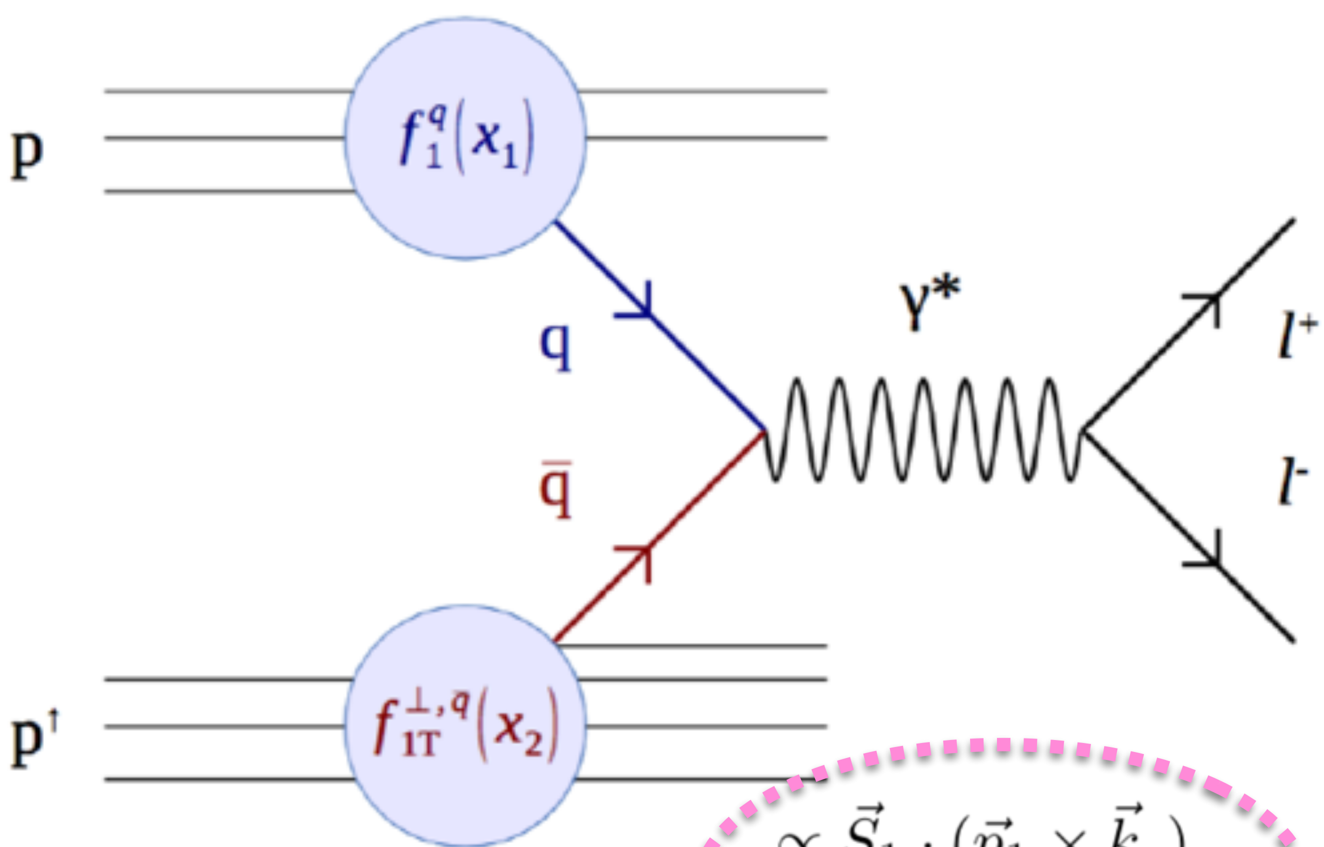
small

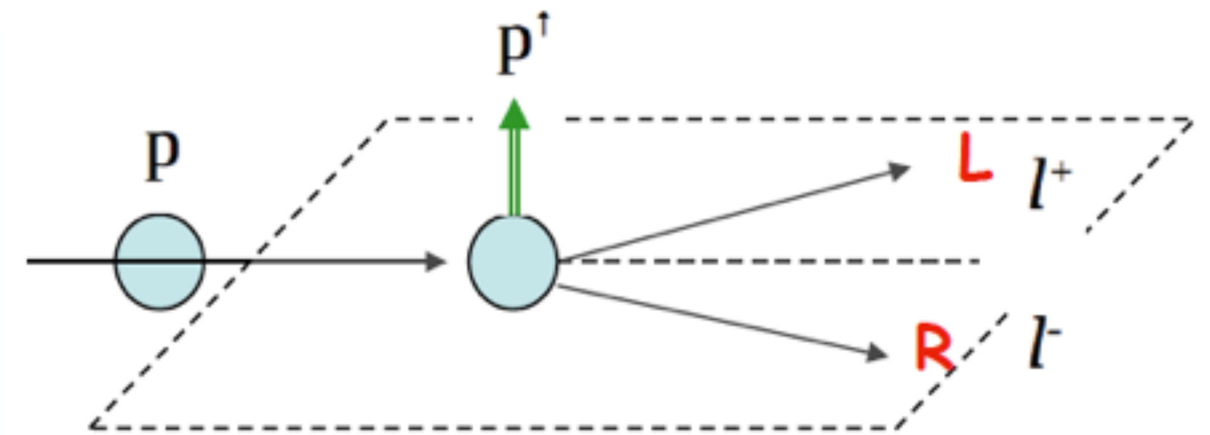
$\bar{q}_t(x_t)$: target sea quark at low/intermediate x
$q_b(x_b)$: beam valence quark at high x



Sivers asymmetry measurements in Drell-Yan

Polarized Drell-Yan





$$A_N = \frac{\sigma_L^\uparrow - \sigma_R^\uparrow}{\sigma_L^\uparrow + \sigma_R^\uparrow} = \frac{N_L - N_R}{N_L + N_R}$$

$$\propto \vec{S}_1 \cdot (\vec{p}_1 \times \vec{k}_q)$$

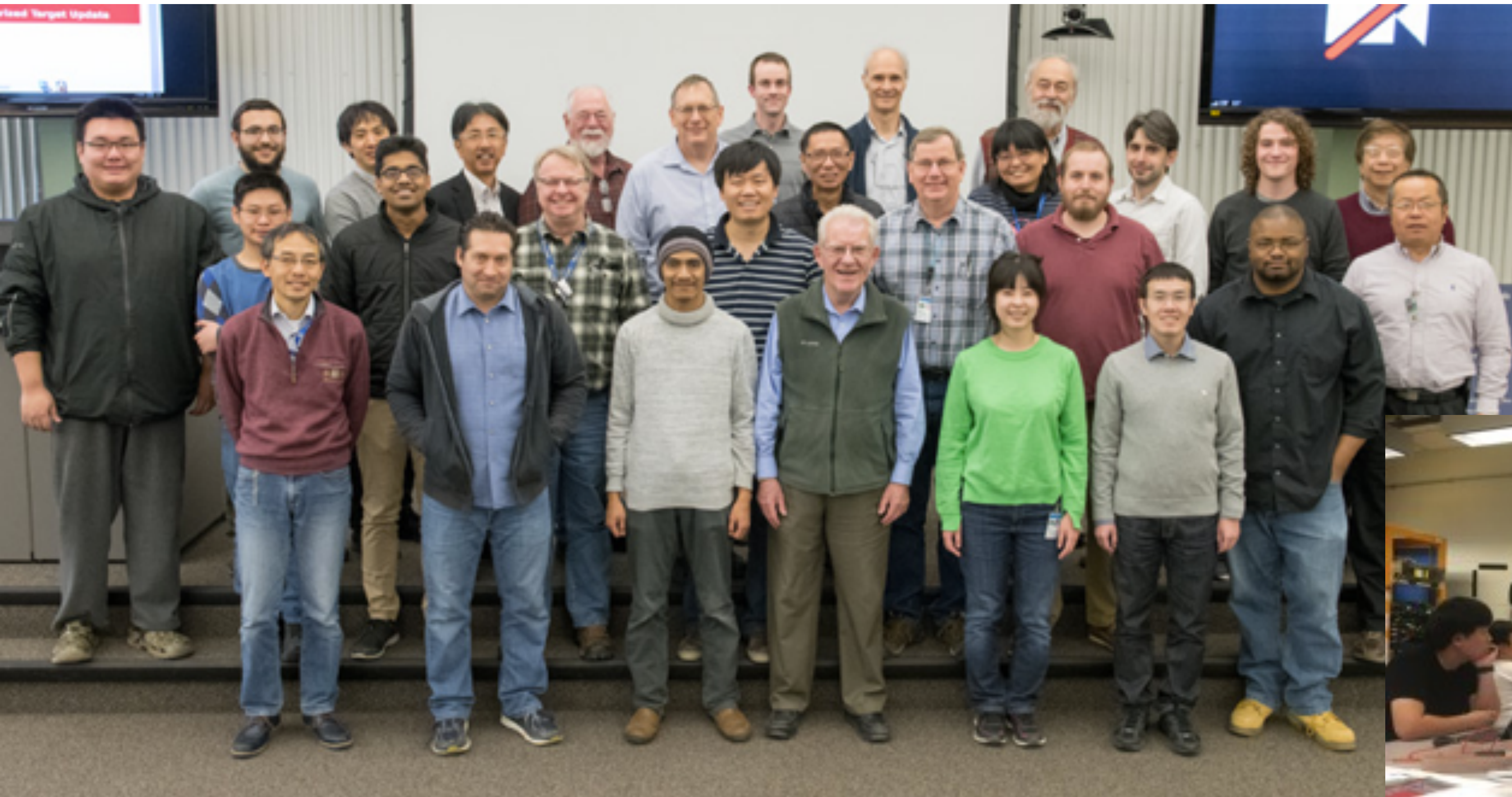
$$A_N^{DY} \propto \frac{\sum_q e_q^2 \left[f_1^q(x_1) \cdot f_{1T}^{\perp,\bar{q}}(x_2) + 1 \leftrightarrow 2 \right]}{\sum_q e_q^2 \left[f_1^q(x_1) \cdot f_1^{\bar{q}}(x_2) + 1 \leftrightarrow 2 \right]}$$

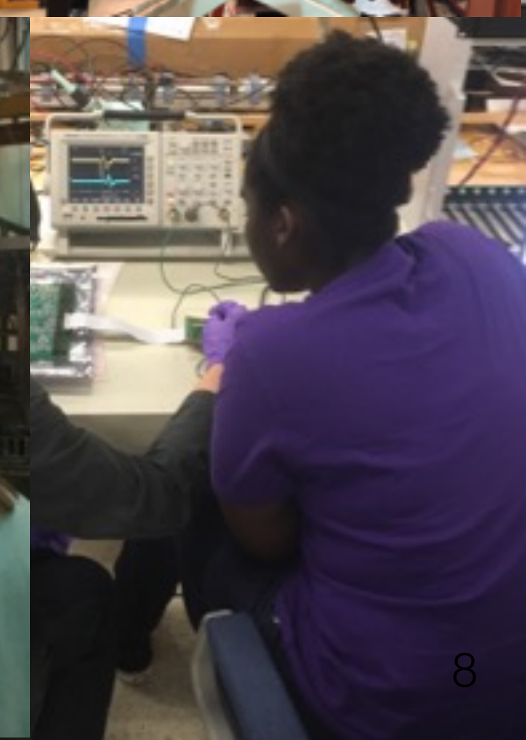
non-zero asymmetry measurements imply non-zero Sivers, leading to non-zero OAM contribution of sea quarks to the origin of proton's spin

E1039/SpinQuest (fixed-target experiment) is designed to get A_N in order to shed light on OAM contribution from sea quarks to the origin of proton's spin!

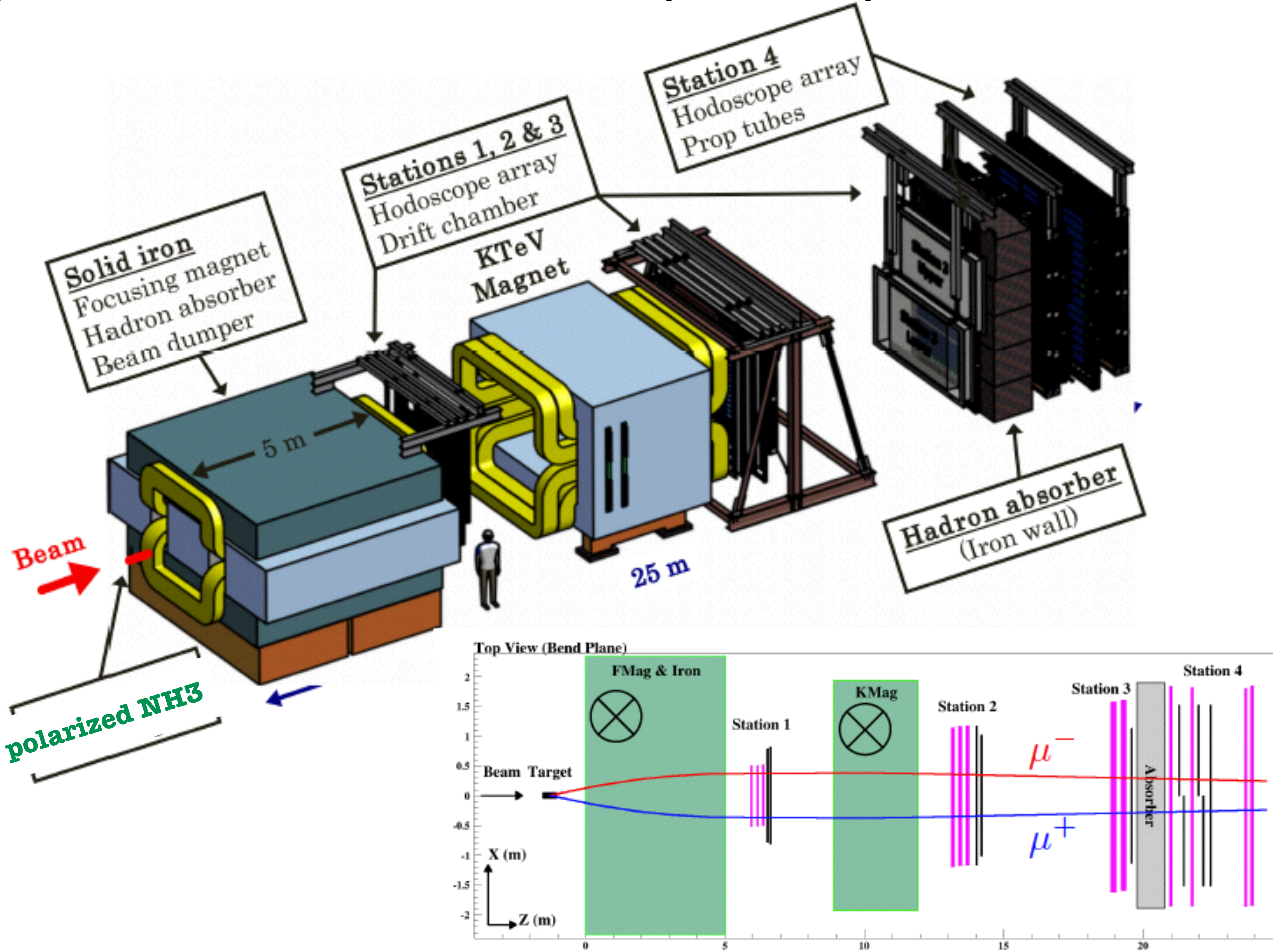
E1039/SpinQuest Collaboration

Sivers Asymmetries in Drell-Yan

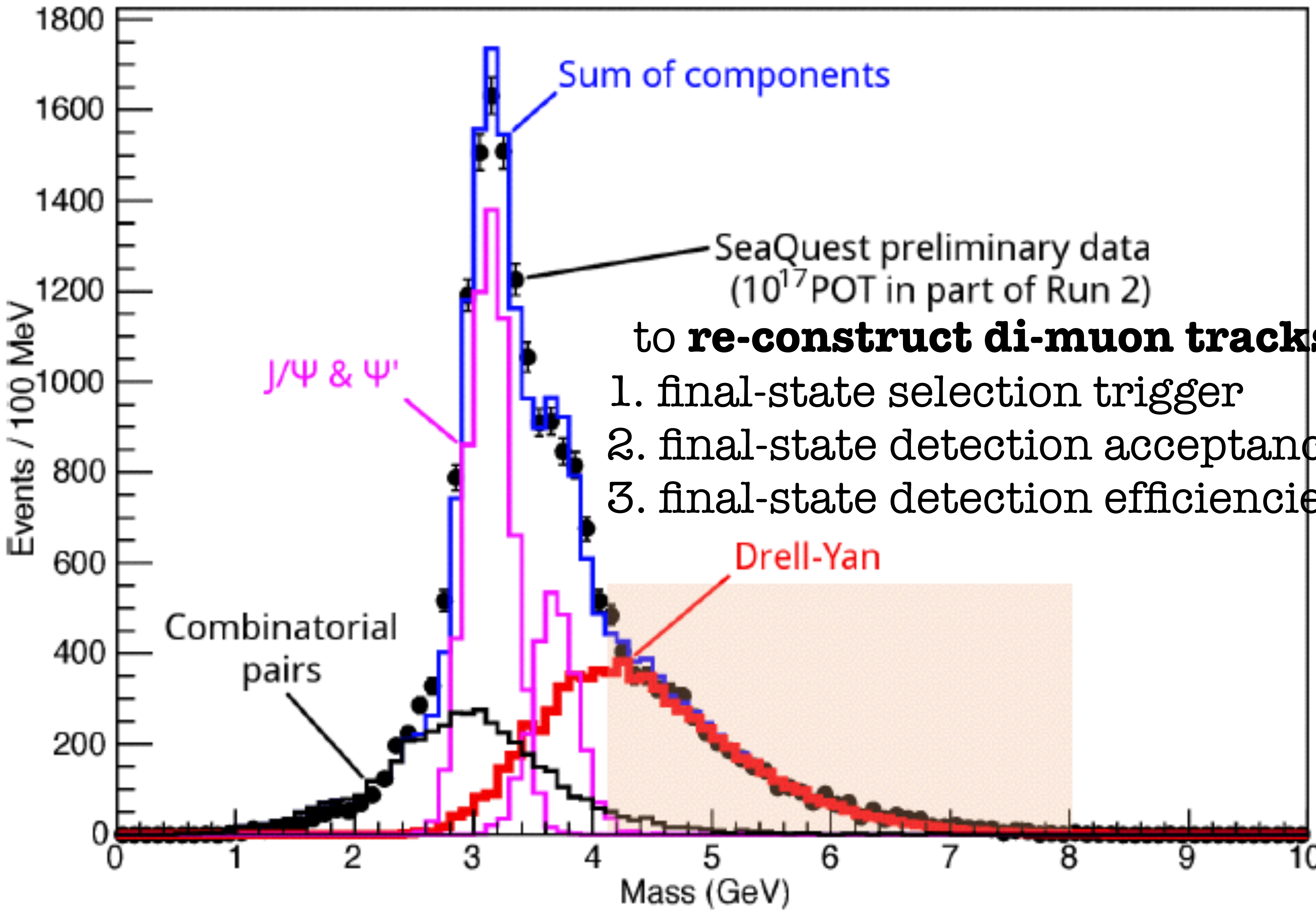




Spectrometer for Sivers asymmetry measurements



Reconstructed final-states through multi-wire proportional/drift chambers (simulation vs. E906 data)



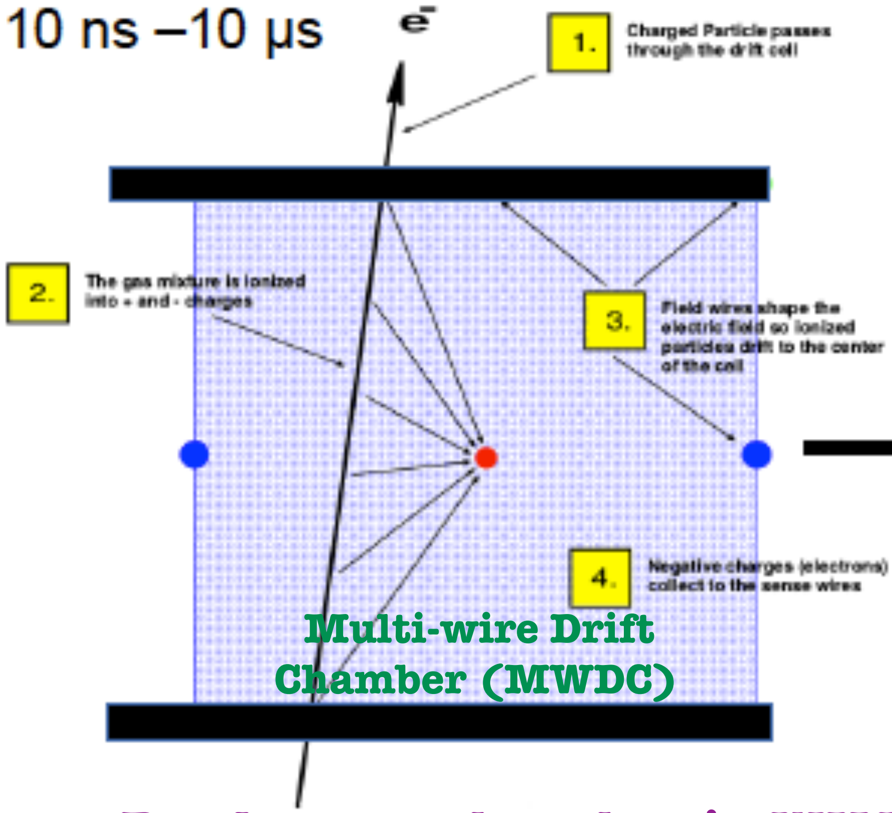
to **re-construct di-muon tracks**:

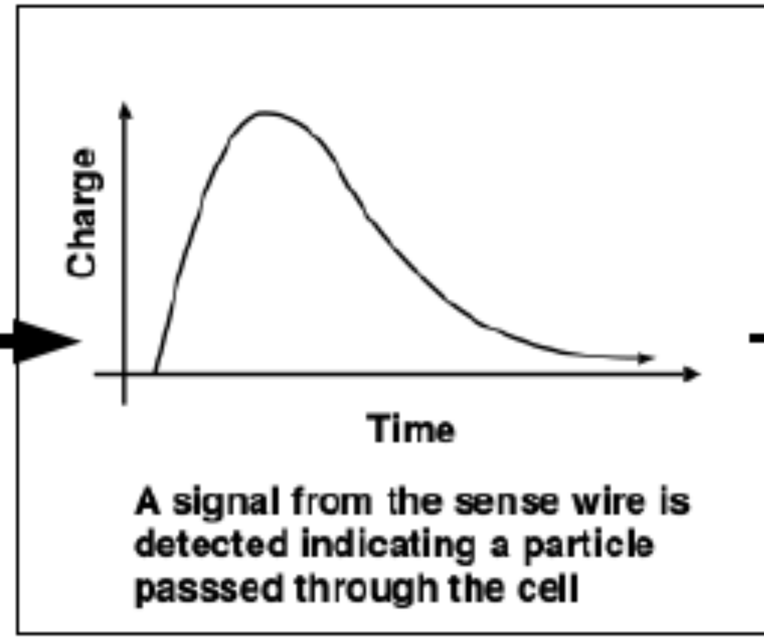
1. final-state selection trigger
2. final-state detection acceptance
3. final-state detection efficiencies

Chamber readout principle

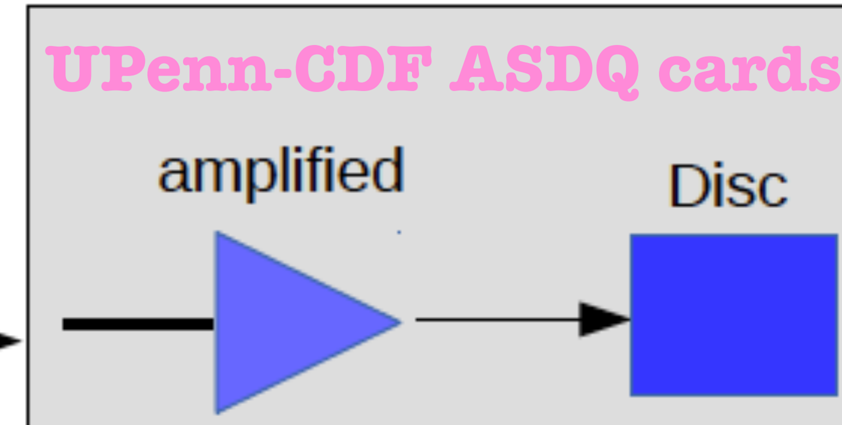
signal response time

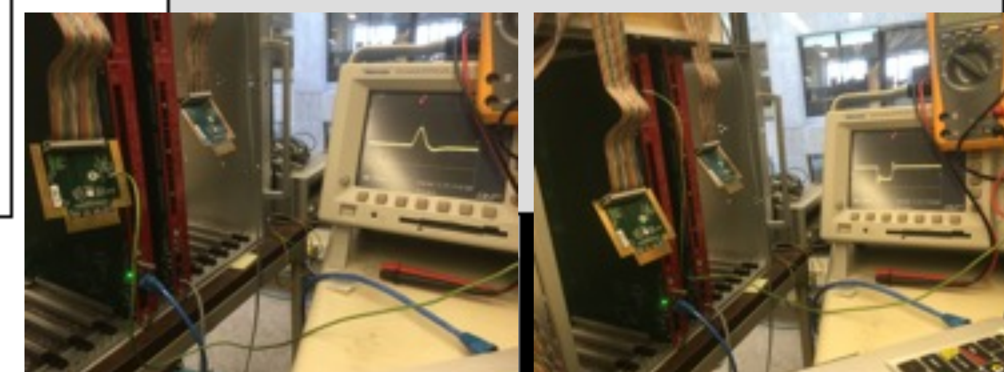
10 ns –10 μs





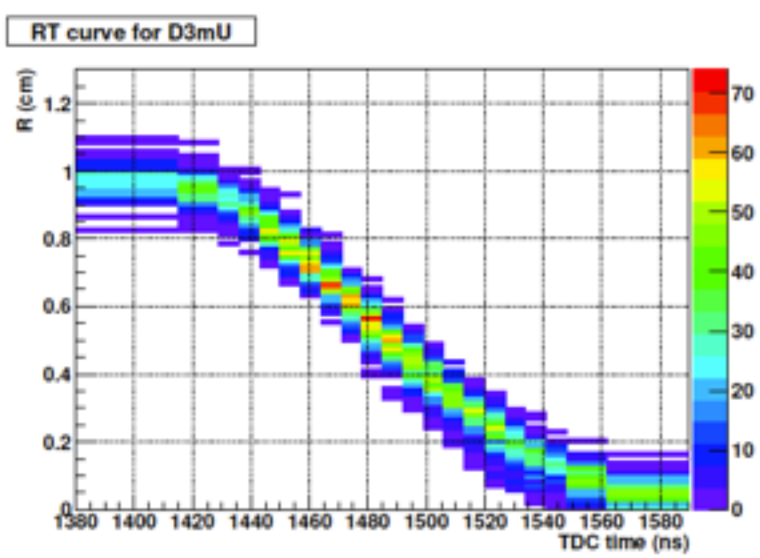
card attached directly to DC





Readout test benches in WH14E/NM4@Fermilab

Single drift cell



Read out

1010011

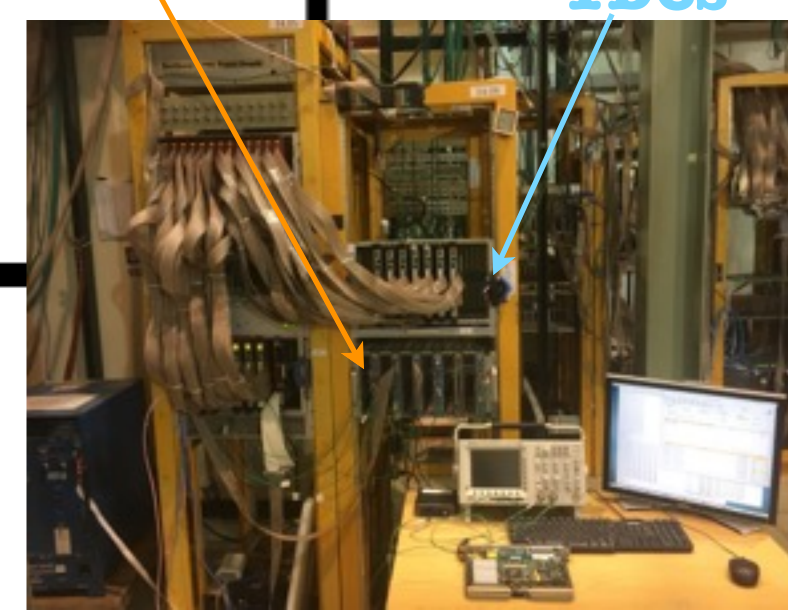
Taiwan TDCs

TDC

time-to-digital converter

DAQ Set-up

Taiwan TDCs



convert drift time to drift distance in use for hit recognition and track reconstruction as well

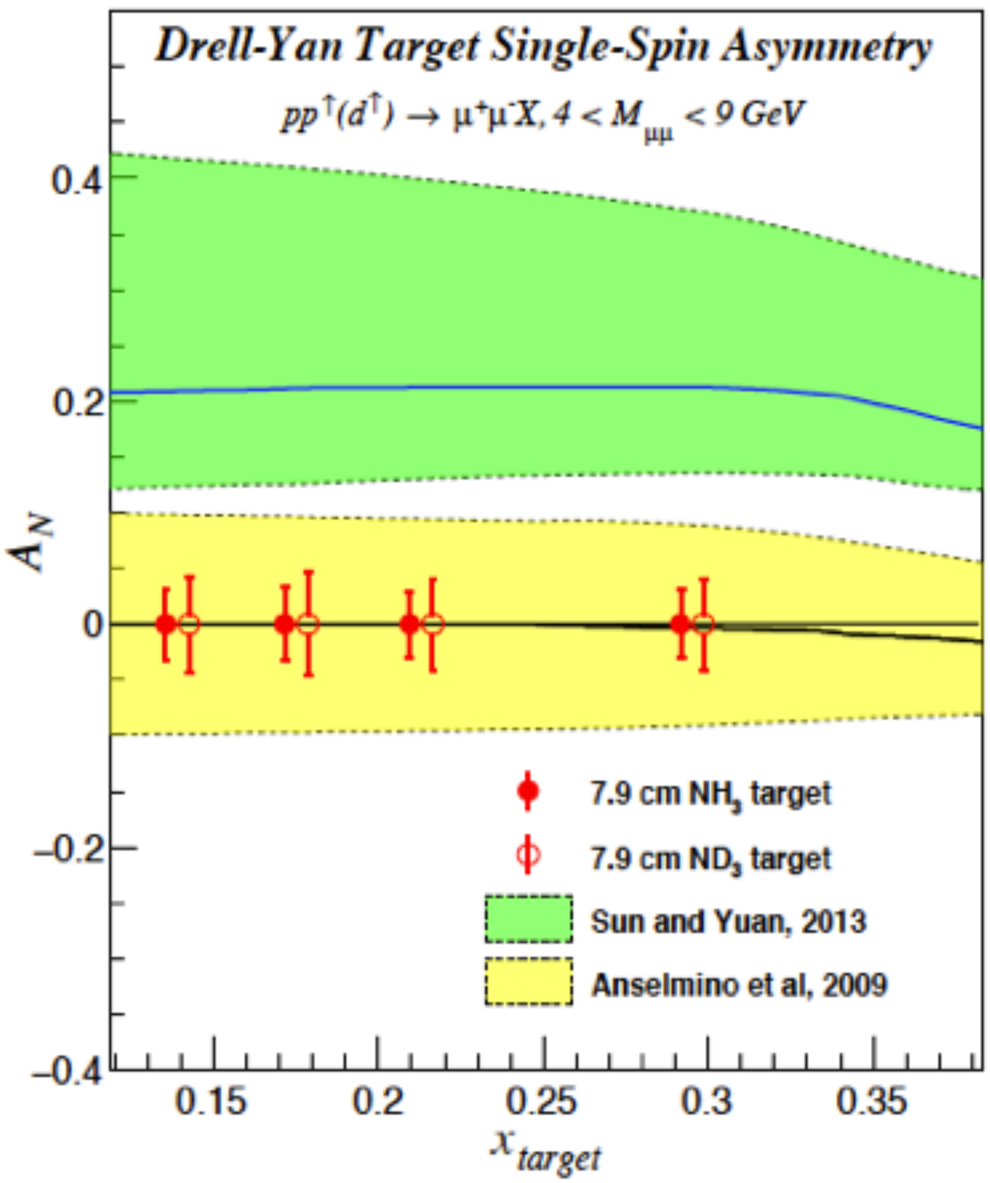
Projected Drell-Yan Transverse Single Spin Asymmetry

$$A_N^{DY} \propto \frac{u(x_b) \cdot f_{1T}^{\perp,\bar{u}}(x_t)}{u(x_b) \cdot \bar{u}(x_t)}$$

dilution factor, target polarization

$$A_{\text{meas}} = f \cdot P_{\text{T}} \cdot A_{\text{phy}}$$

$$\Delta A = \frac{1}{f}\frac{1}{P}\frac{1}{\sqrt{N^+ + N^-}}$$



X_{targ}	<X_{targ}>	NH$_3$ ($p^{\uparrow}$)		ND$_3$ ($d^{\uparrow}$)		$n^{\uparrow}$
		N	ΔA (%)	N	ΔA (%)	ΔA(%)
0.10 - 0.16	0.139	5.0×10^4	3.2	5.8×10^4	4.3	5.4
0.16 - 0.19	0.175	4.5×10^4	3.3	5.2×10^4	4.6	5.7
0.19 - 0.24	0.213	5.7×10^4	2.9	6.6×10^4	4.1	5.0
0.24 - 0.60	0.295	5.5×10^4	3.0	6.4×10^4	4.1	5.1

Current & Future Exp.

E1039 Status & Plan

- DOE approval, March 2018
- E906 decommissioned 6/2018
- E1039 target shielding in progress
- Beam collimatorin progress
- Polarized target to be installed by fall of 2019

- Fermilab Stage-2 approval, May 2018
- Target installation in progress 2019
- E1039 commissioning starts in late 2019
- Run for 2+ years, 2019-2021+