Physics opportunities with a polarised gas target

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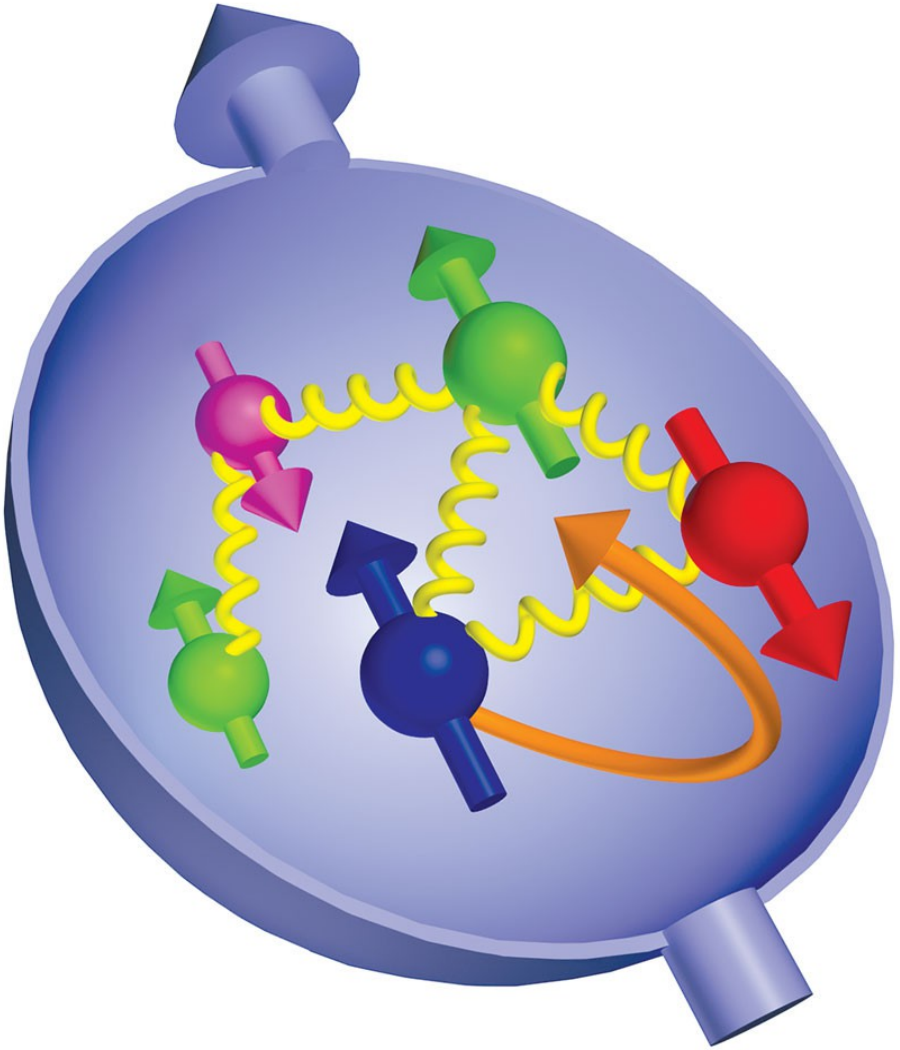
Opportunities with internal gas target at the LHC, CERN, 4-5 July 2016

Nucleon spin structure



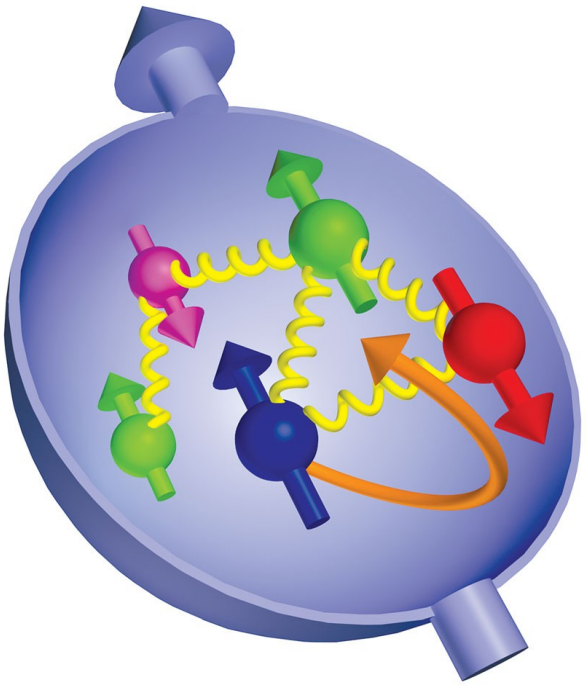
http://phys.org/news/2012-02-physicists-theoretical-framework-results-subatomic-particle.html,
Credit: 2011 Zhong-Bo Kang

Nucleon spin structure

Helicity Sum Rule

$$\frac{1}{2} = \frac{1}{2}\Sigma_q + \Sigma_g + L_q + L_g$$

quarks (~30%)



http://phys.org/news/2012-02-physicists-theoretical-framework-results-subatomic-particle.html

Credit: 2011 Zhong-Bo Kang

Nucleon spin structure

$$\frac{1}{2} = \frac{1}{2}\Sigma_q + \Sigma_g + L_q + L_g$$

gluons (~20%)

STAR, Phys. Rev. Lett. 115, 092002 (2015)

Nucleon spin structure

$$\frac{1}{2} = \frac{1}{2}\Sigma_q + \Sigma_g + L_q + L_g$$

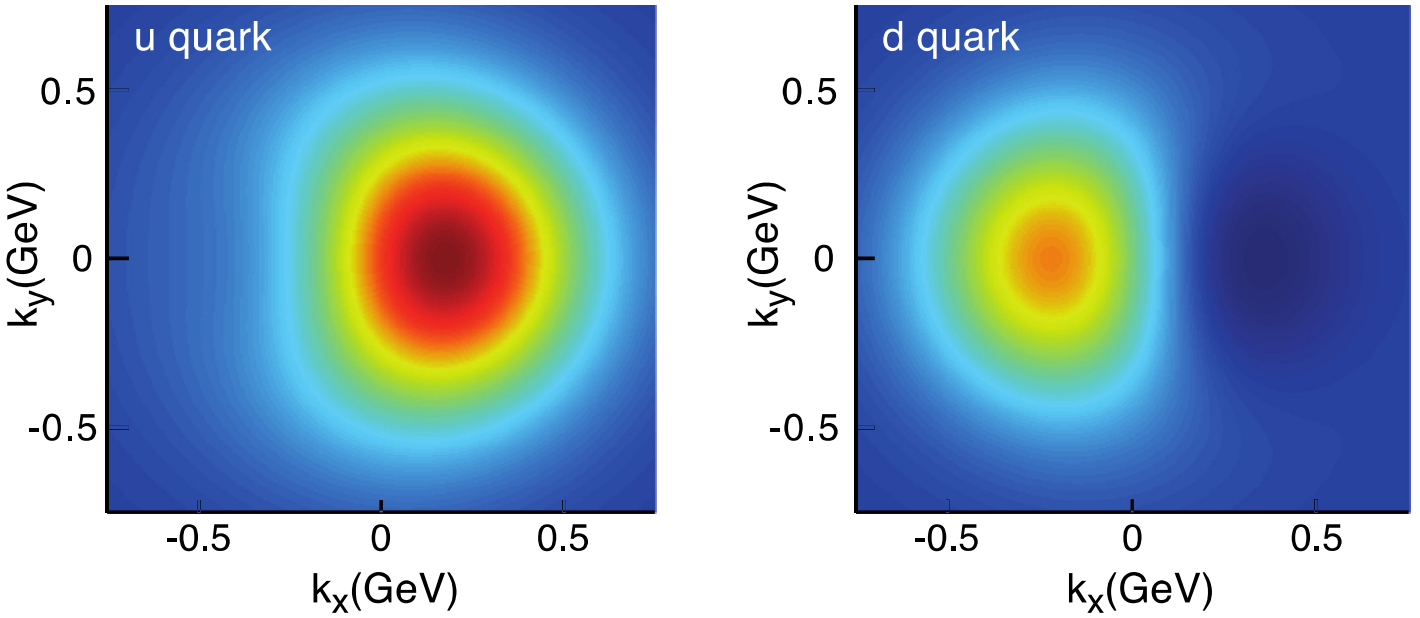
Angular momentum
→ **quark and gluon dynamics**

Transverse spin

Transverse Momentum Dependent parton distributions

→ proton “image” in transverse and longitudinal momentum space (2+1 dimensions).

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



Transverse spin

Experimentally: spin-dependent left-right asymmetry

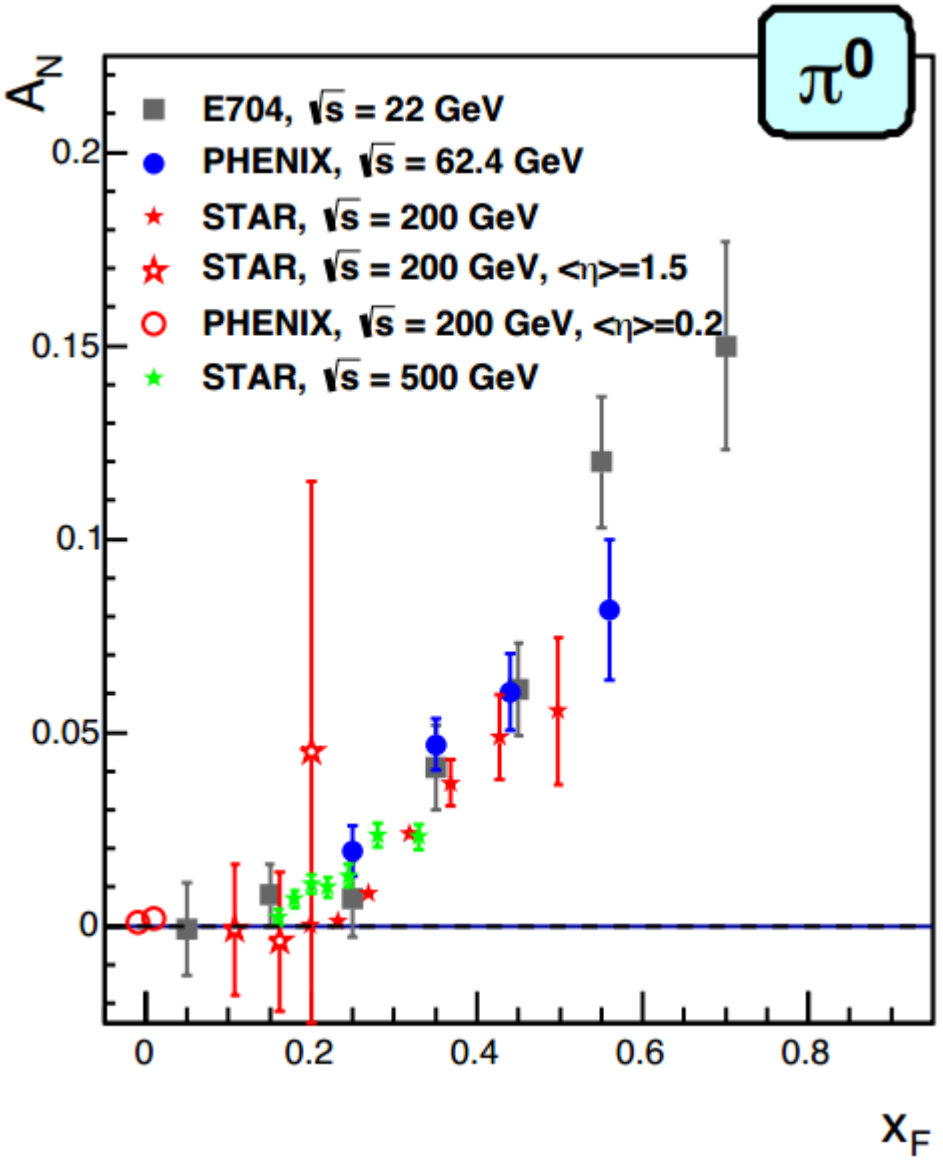
$$A_N = \frac{1}{P}\frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

$\sigma^{\uparrow(\downarrow)}$: production cross sections of particles produced with target spin polarized upward (downward).
P – average beam polarization

A_N - measurements

Expected small (~10^{-4})

Observed large (~10^{-1})

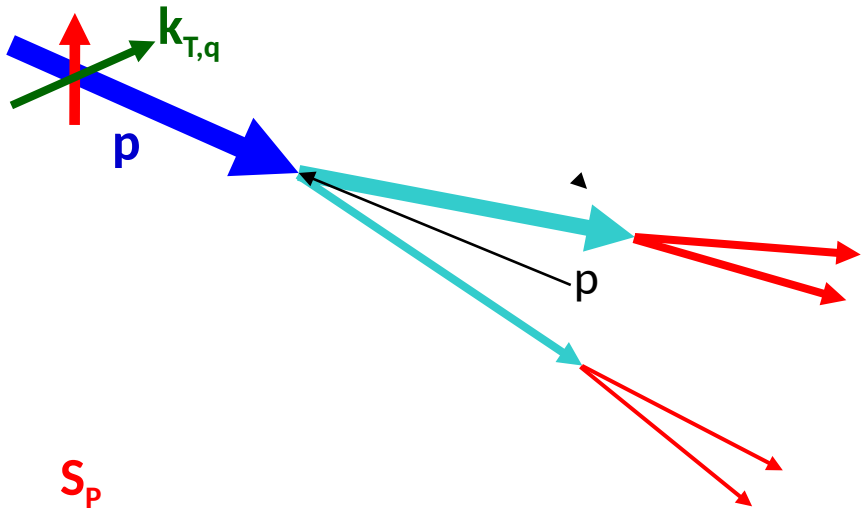


$x_F = x_1 - x_2$,

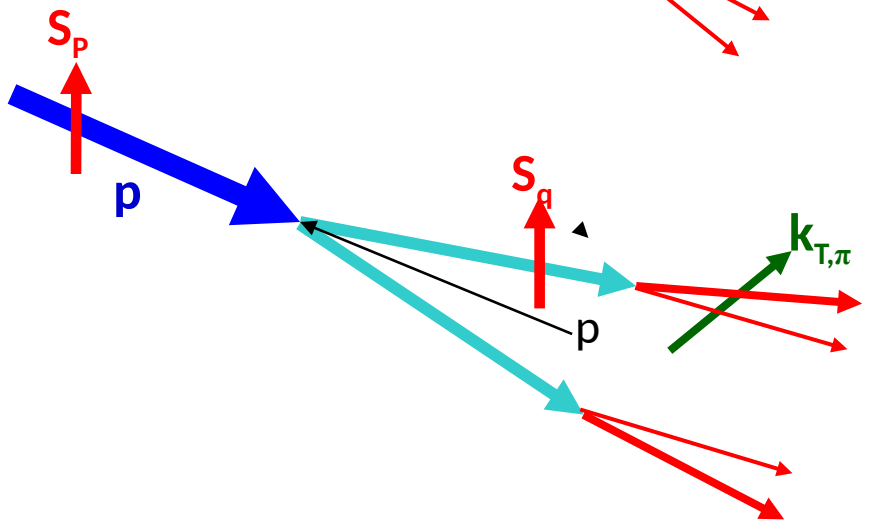
$x_1 = e^y m_T/\sqrt{s}$, $x_2 = e^{-y} m_T/\sqrt{s}$, $m_T^2 = m^2+p_T^2$

Possible sources of transverse spin asymmetry

- Sivers mechanism – correlation between spin and parton k_T



- Collins mechanism – spin and k_T dependent fragmentation function



- Collinear Twist-3 approach – quark-gluon/gluon-gluon correlation, tri-gluon correlations

Ilustrations: S. Fazio - RHIC & EGS Users' Meeting 2016

Sivers mechanism

- non-zero quark/gluon Sivers function → non-zero quark/gluon OAM

- Sivers f. sign change
  - Process dependence predicted:
  - $f_{1T}^{\perp q}(x, \vec{k}_\perp^2)_{Drell-Yan} = -f_{1T}^{\perp q}(x, \vec{k}_\perp^2)_{Semi-Inclusive\,DIS}$

Sivers mechanism

- non-zero quark/gluon Sivers function → non-zero quark/gluon OAM

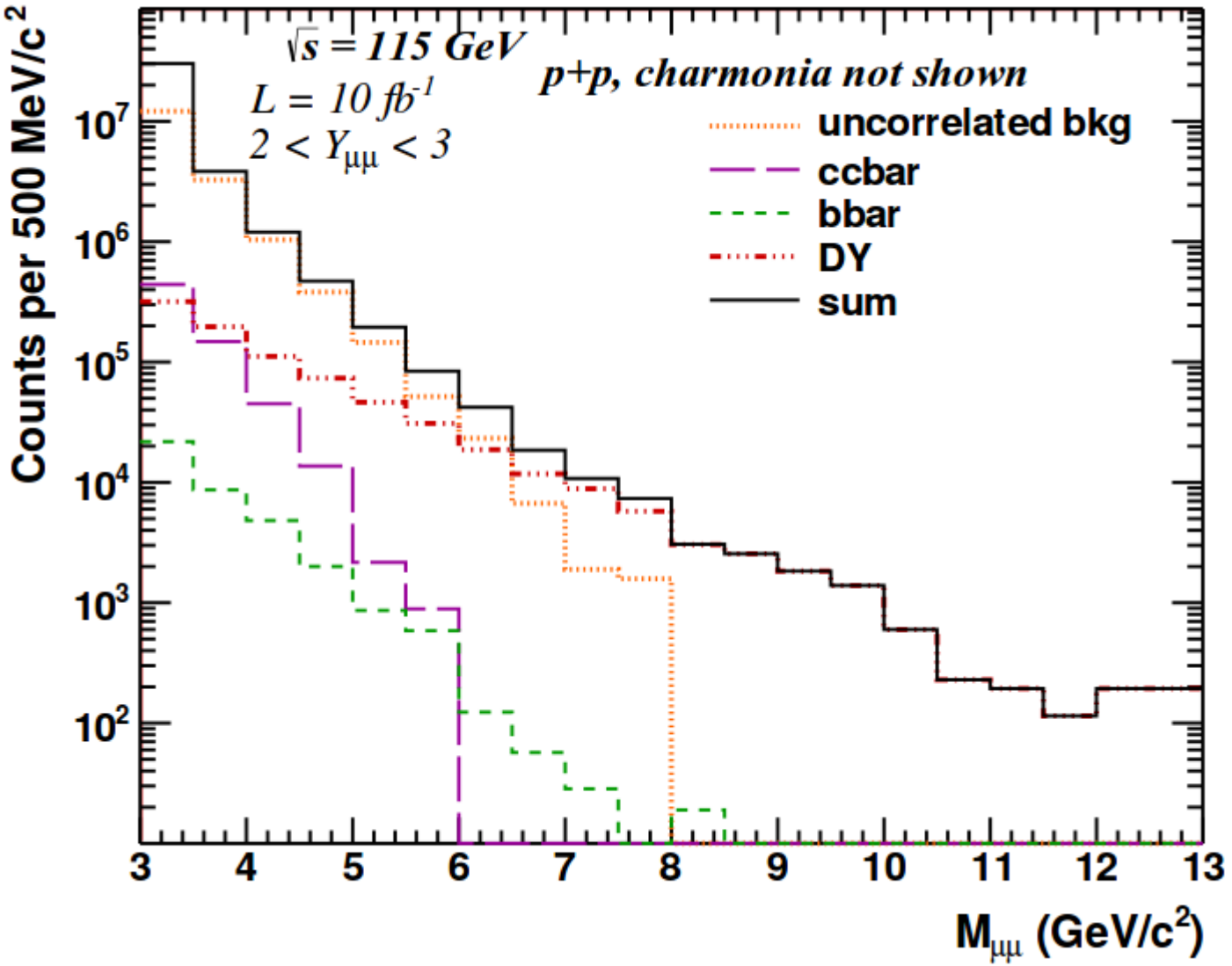
- Sivers function for gluons practically unconstrained
  - accessible with quarkonia or D,B-mesons
  - direct γ, γ-γ, γ-jet, J/psi – γ

Transverse single-spin asymmetry

Sensitivity studies for A_N

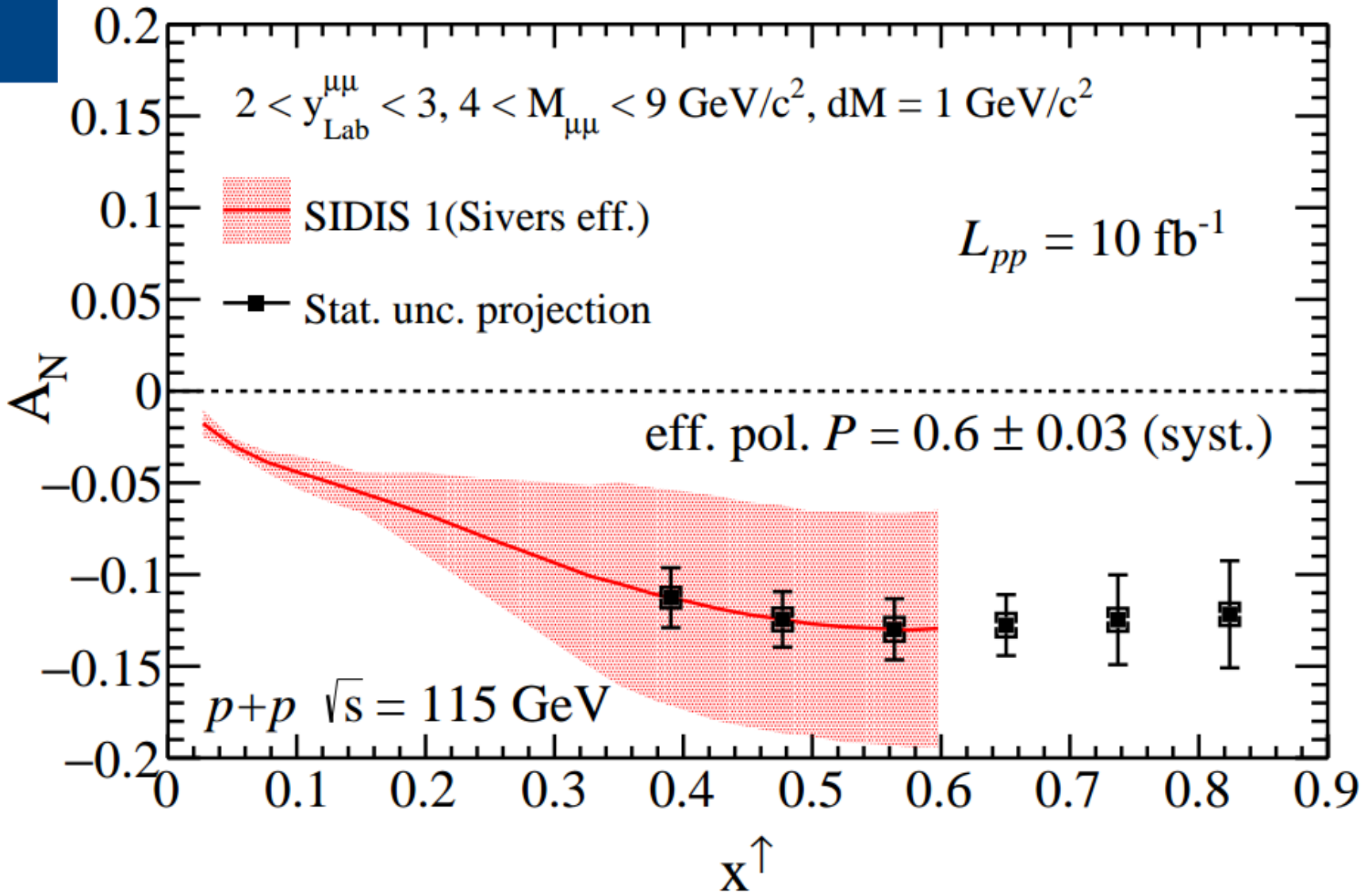
- Drell-Yan vs x_F
- J/ψ vs x_F
- $\Upsilon(1s)$,$\Upsilon(2s)$ and $\Upsilon(3s)$ vs x_F
- D^0 vs p_T and x_F

Drell Yan

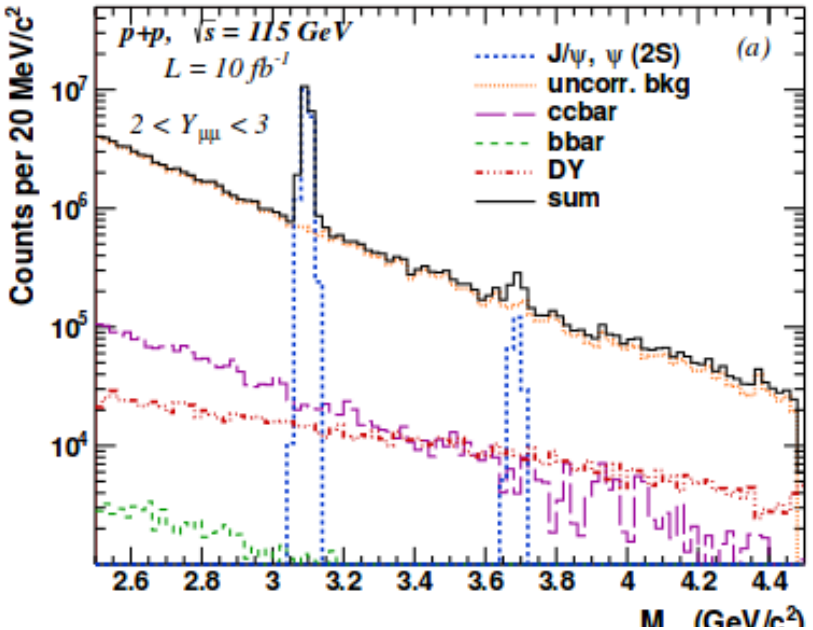

√s = 115 GeV
L = 10 fb-1
2 < Yμμ < 3
p+p, charmonia not shown
uncorrelated bkg
ccbar
bbar
DY
sum
Counts per 500 MeV/c2
Mμμ (GeV/c2)

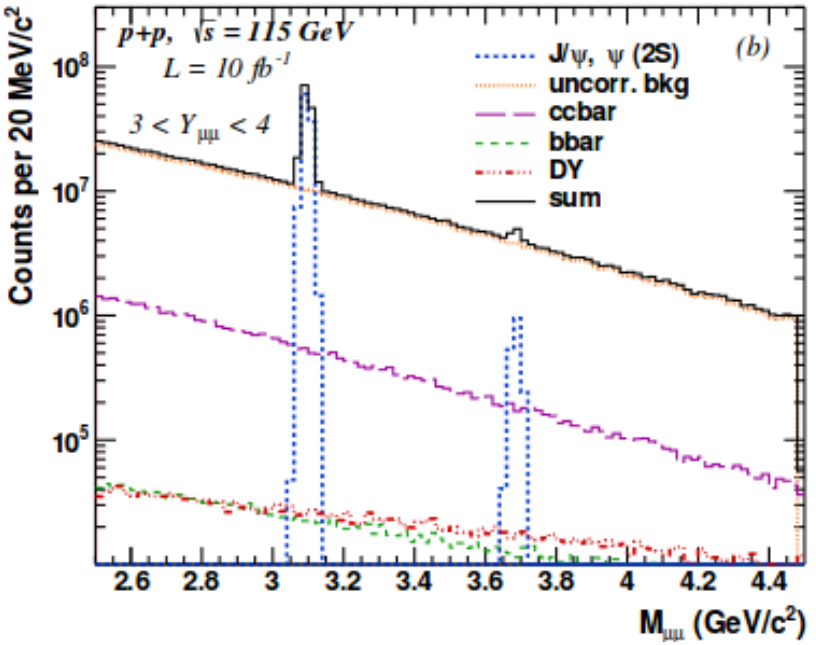
A_N sensitivity predictions

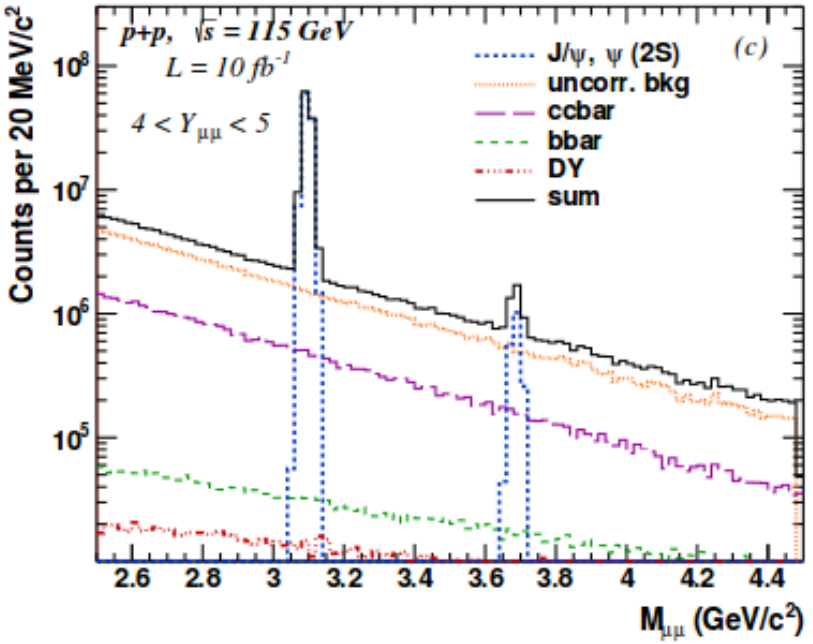
Drell Yan



J/ψ







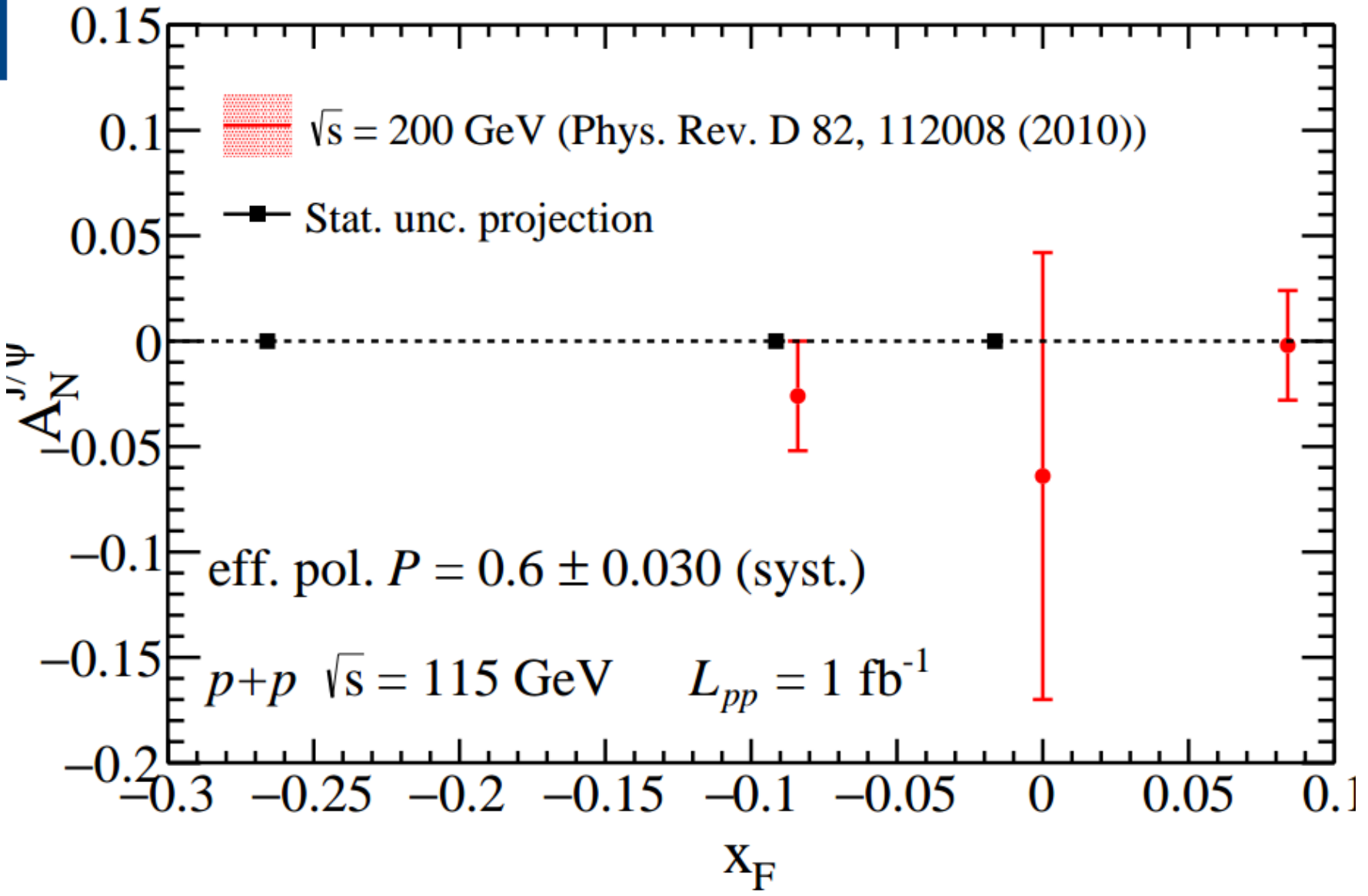
arXiv:1504.05145 [hep-ex], Fig. 8

Signal and background in

$3.06 < m < 3.12$ GeV/c^2

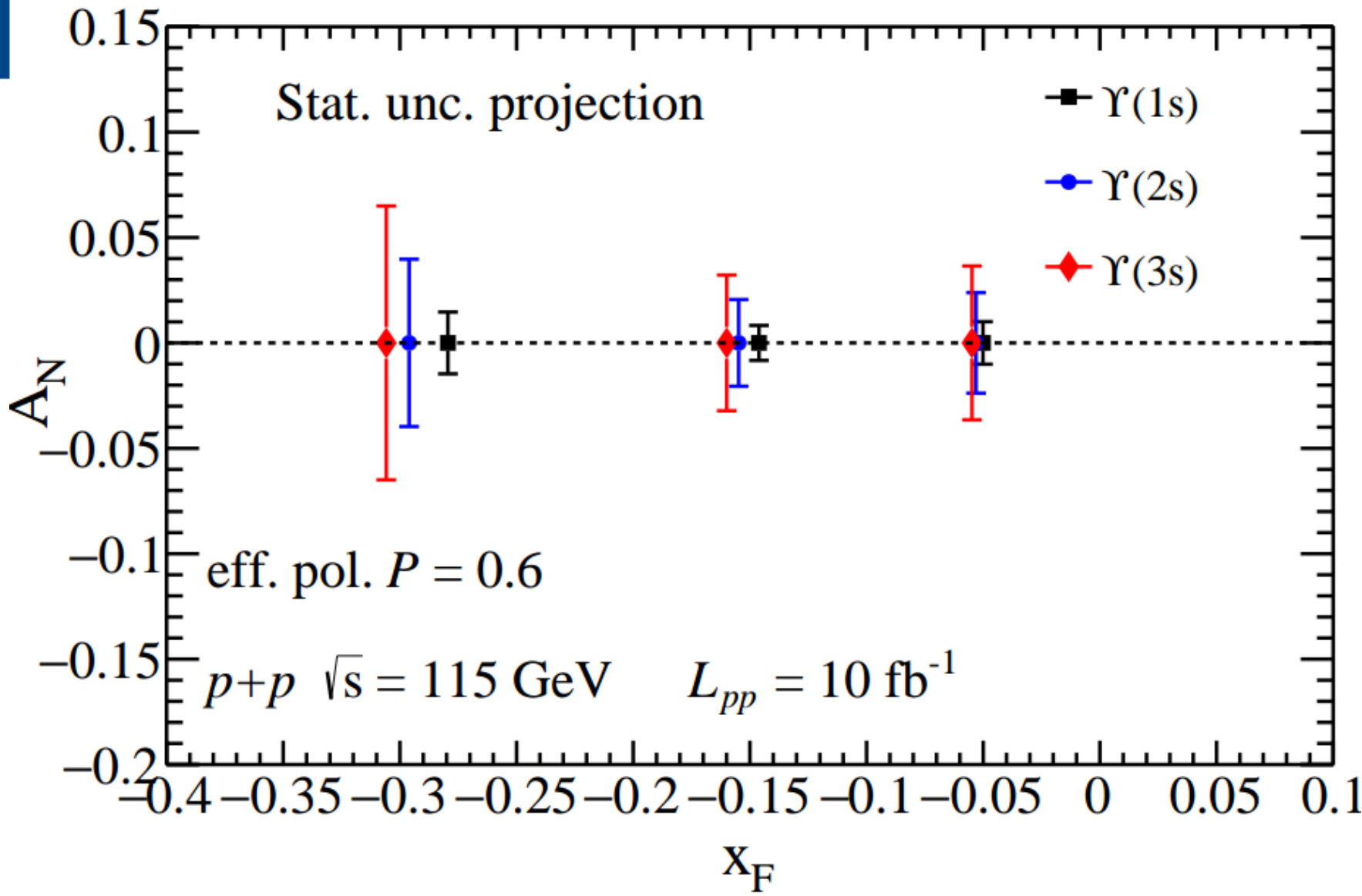
A_N sensitivity predictions

J/ψ



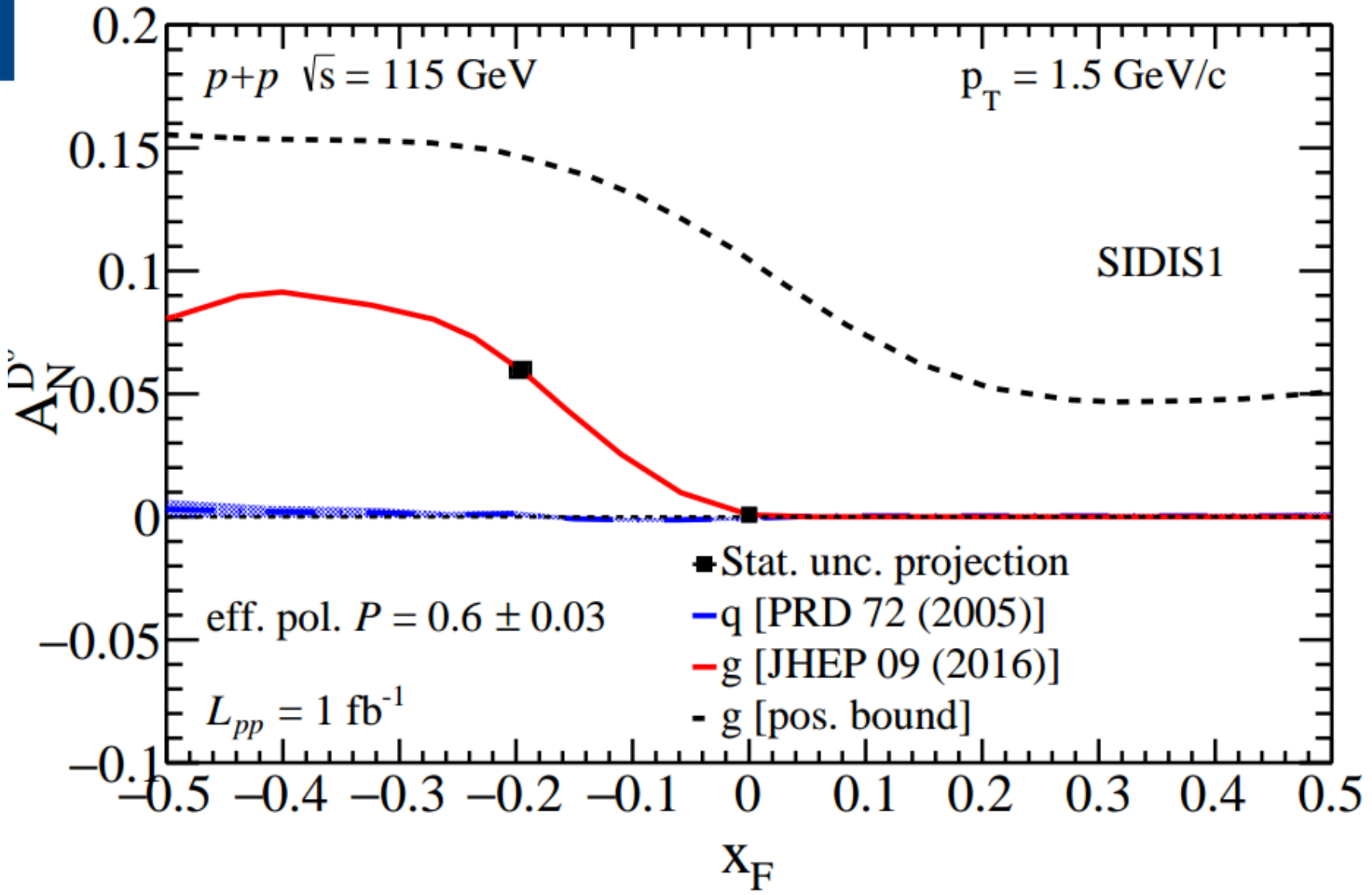
A_N sensitivity predictions

Upsilon



A_N sensitivity predictions

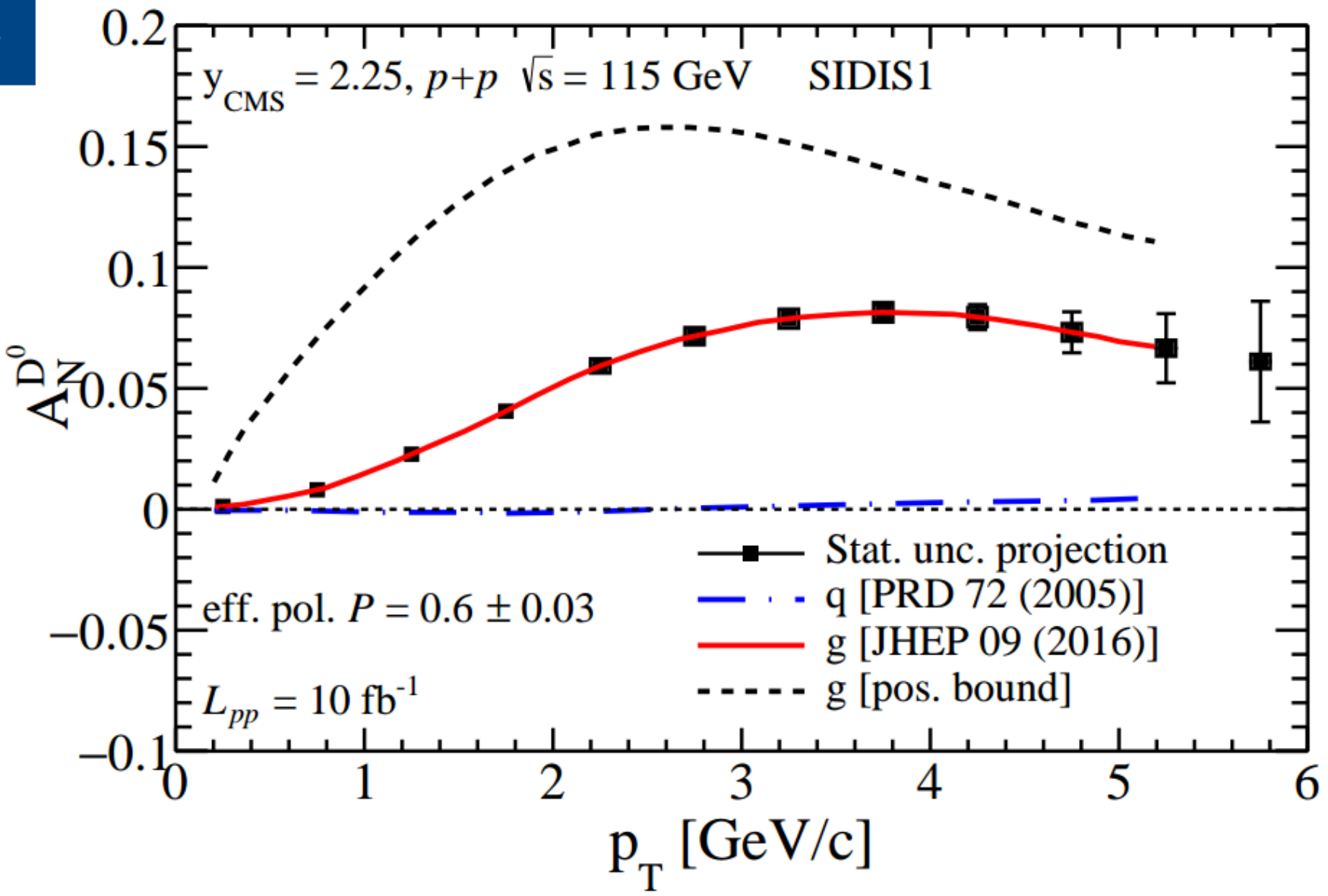
D^0 vs x_F



Source data: charm cross-section: FONLL, central value: http://www.lpthe.jussieu.fr/~cacciari/fonll/fonllform.html
D^0 efficiency: LHCb like detector, details in Daniel Kikoła, Advances in High Energy Physics, Volume 2015, Article ID 783134

A_N sensitivity predictions

D^0 vs p_T



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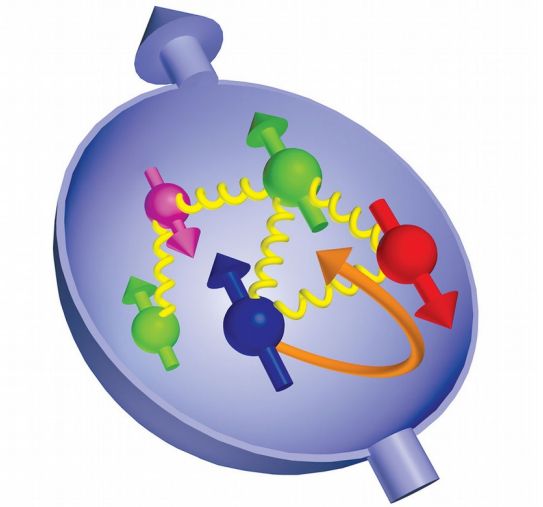
Summary

- Access to precise measurement of single-spin asymmetry for DY, heavy flavor and jets
- Verification of sing-change for Sivers function for Drell-Yan
- Heavy flavor A_N
  - constraining gluon orbital momentum by constraining Sivers effect for gluons (if any)
  - testing tri-gluon correlation



Backup

Uncertainty estimation

$$A_N = \frac{1}{P}\frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

$$\delta_{A_N} = \frac{2}{P(\sigma^{\downarrow}+\sigma^{\uparrow})^2}\sqrt{(\delta_{\sigma^{\uparrow}}\sigma^{\downarrow})^2 + (\delta_{\sigma^{\uparrow}}\sigma^{\downarrow})^2}$$

$$\delta_{\sigma} = \sqrt{\sigma + 2B},$$

σ - Signal cross section (yield) for a given spin configuration, B – uncorrelated background for a given configuration

Syst. uncertainty due to P: $\delta(A_N)^{syst} = A_N \frac{\delta P}{P}$

$$x_1 = \frac{m}{\sqrt{s}}e^{y}, \quad x_2 = x^{\uparrow} = \frac{m}{\sqrt{s}}e^{-y} \qquad x_F = x_1 - x_2$$