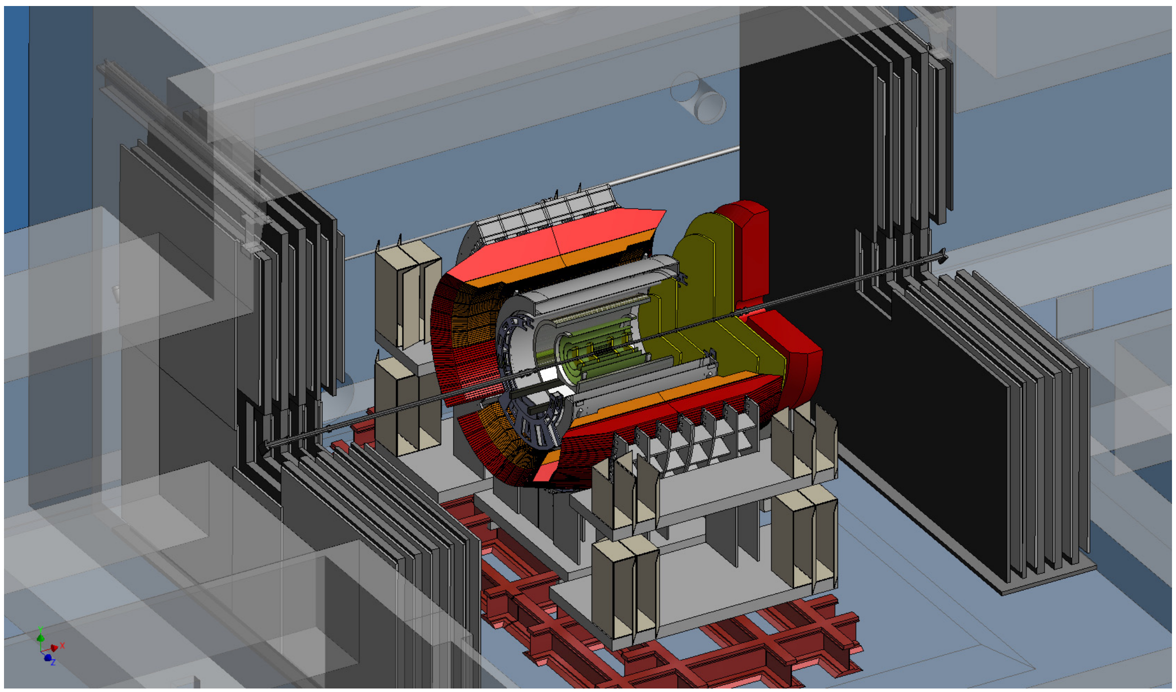
fsPHENIX

A Detector for the Study of Nucleon Spin Structure and Cold Nuclear Matter at RHIC



DIS2014

John Lajoie
Iowa State University

The RHIC Evolution to the EIC

- STAR/PHENIX charged by the BNL ALD to define a polarized p+p/p+A physics program in 2021-22 :

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 510 GeV pol p+p	• Sea quark and gluon polarization	• upgraded pol'd source • STAR HFT test
2014	• 200 GeV Au+Au • 15 GeV Au+Au	• Heavy flavor flow, energy loss, thermalization, etc. • Quarkonium studies • QCD critical point search	• Electron lenses • 56 MHz SRF • full STAR HFT • STAR MTD
2015-2016	• p+p at 200 GeV • p+Au, d+Au, ^{3}He+Au at 200 GeV • High statistics Au+Au	• Extract η/s(T) + constrain initial quantum fluctuations • More heavy flavor studies • Sphaleron tests	• PHENIX MPC-EX • Coherent electron cooling test
2017	• No Run		• Electron cooling upgrade
2018-2019	• 5-20 GeV Au+Au (BES-2)	Search for QCD critical point and deconfinement onset	• STAR ITPC upgrade
2020	• No Run		• sPHENIX installation
2021-2022	• Long 200 GeV Au+Au w/ upgraded detectors • p+p/d+Au at 200 GeV	• Jet, di-jet, γ-jet probes of parton transport and energy loss mechanism • Color screening for different QQ states	• sPHENIX
2023-24	• No Runs		Transition to eRHIC

Overlap with planned sPHENIX running.

10 weeks p+p @ 200 GeV
10 weeks p+Au @ 200 GeV

Physics

- **The fsPHENIX physics program seeks to address key issues in nucleon/nuclear structure:**
  – How is transverse spin carried by the partonic constituents of the nucleon?
    - Key tests of theoretical framework – can we relate what we know from SIDIS and polarized p+p?
    - Jet A_N, DY modified universality, Q^2 evolution,…
  – How are PDF’s modified in the nuclear environment at small-x?
    - Saturation (CGC) or parton energy loss?

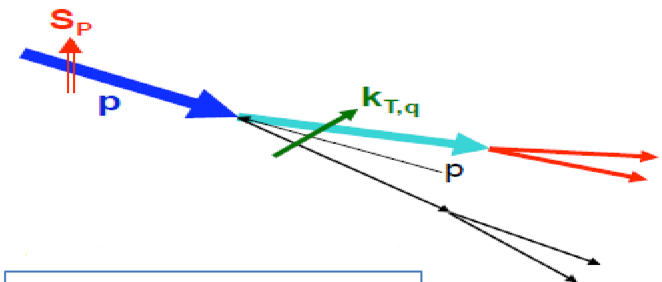
Sources of Transverse SSA's

"Sivers effect"

TMD: Correlation between nucleon spin and parton k_T.

Phys. Rev. D **41**, 83 (1990)
Phys. Rev. D **43**, 261, (1991)

$$d\sigma^{\uparrow} \propto \underbrace{\bar{f}_{1T}^{\perp q}(x,k_{\perp}^2)}_{\text{Sivers distribution}} \cdot D_q^h(z)$$



Twist-3: Quark-gluon correlations in polarized hadron
Phys. Rev. D **59**, 014004 (1998)

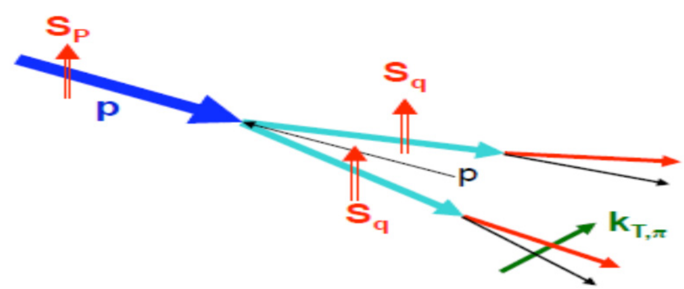
$$gT_{q,F}(x,x) = -\int d^2k_{\perp} \frac{|k_{\perp}|^2}{M} f_{1T}^{\perp q}(x,k_{\perp}^2)$$

Also evolution…

"Collins effect"

TMD: Transversity distributions + Spin dependent fragmentation functions
Nucl. Phys. B 396, 161 (1993)

$$d\sigma^{\uparrow} \propto \underbrace{\delta q(x)}_{\text{Transversity}} \cdot \underbrace{H_1^{\perp}(z_2,\bar{k}_{\perp}^2)}_{\text{Collins FF}}$$

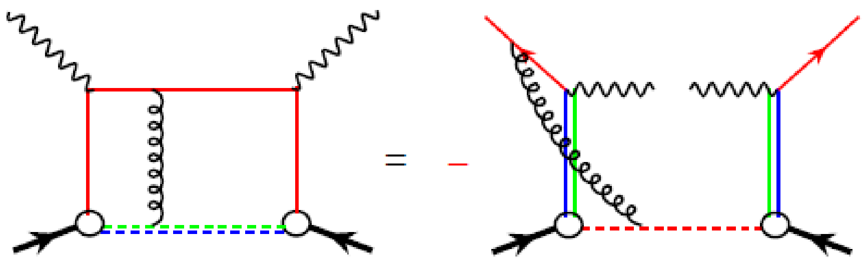


Twist-3: Transversity combined with twist-3 quark-gluon fragmentation function

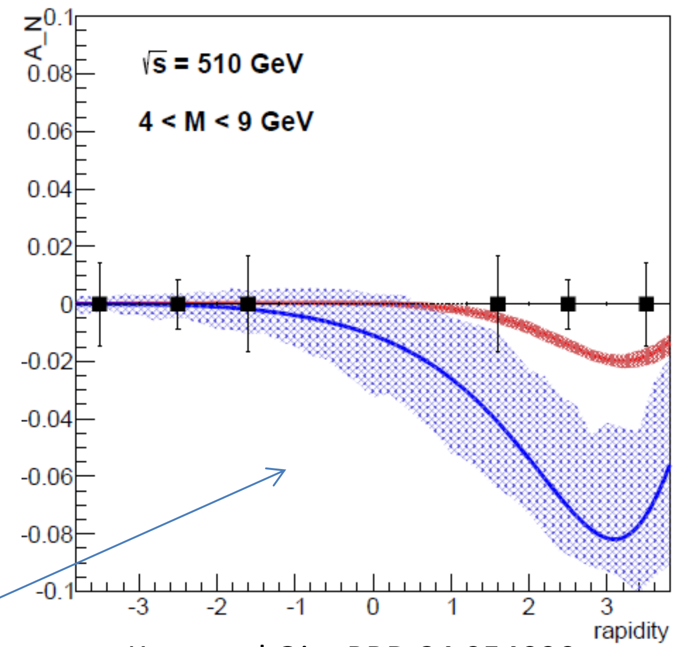
Drell-Yan in Polarized p+p

- A <u>theoretically clean</u>, fundamental study of the *Sivers effect*, *modified universality*, and *evolution of TMD's*:

$$\Delta^N f^{\rm SIDIS}_{q/h^\uparrow}(x,k_\perp) = -\Delta^N f^{\rm DY}_{q/h^\uparrow}(x,k_\perp)$$



SIDIS = – DY



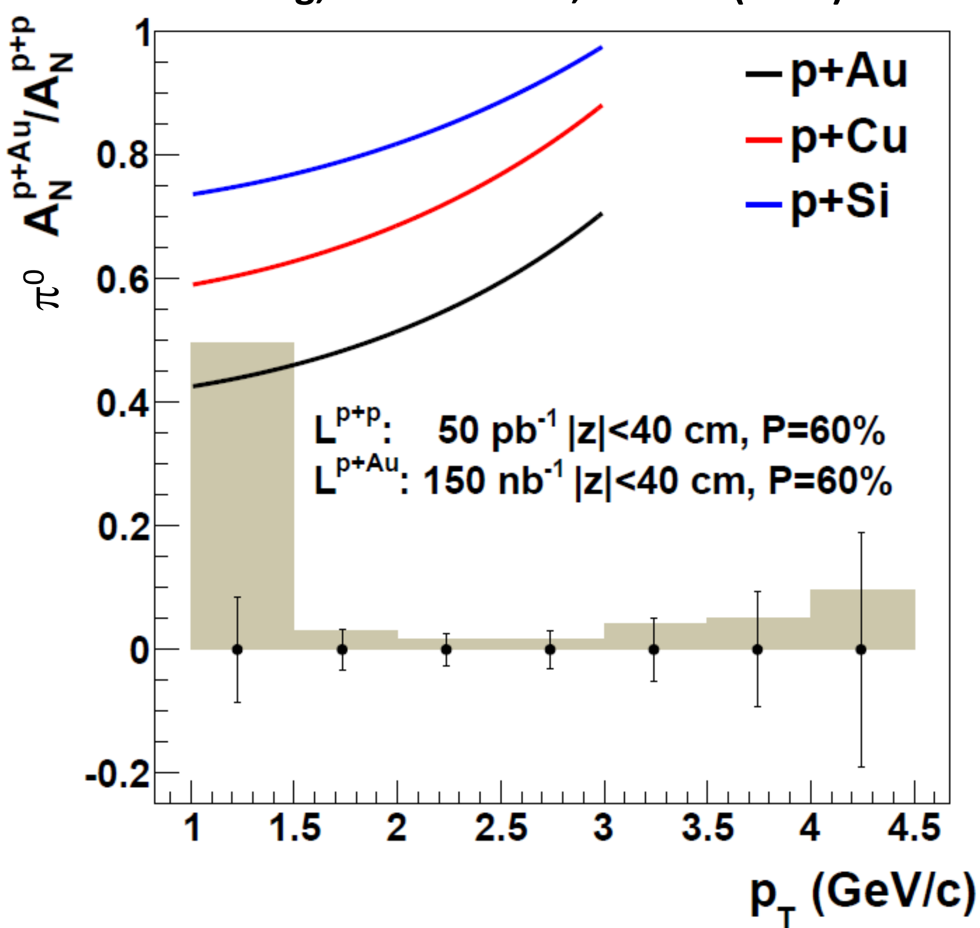
Kang and Qiu, PRD 84 054020
Exchevarria et. al., arXiv 1401.5078

How does evolution change the anticipated asymmetries? Theory predictions vary. Useful to look at <u>low mass</u> and <u>high mass</u> DY pairs.

Polarized p+A Collisions

- **The *fsPHENIX* physics program really depends on what we learn from Run-15/16:**
  - Are the single spin asymmetries suppressed in polarized p+A?
  - Does DY offer any advantages as a small-x probe?
  - Jet-Jet vs. Hadron-Hadron correlations
    - Take full advantage of *fsPHENIX+sPHENIX* jet coverage

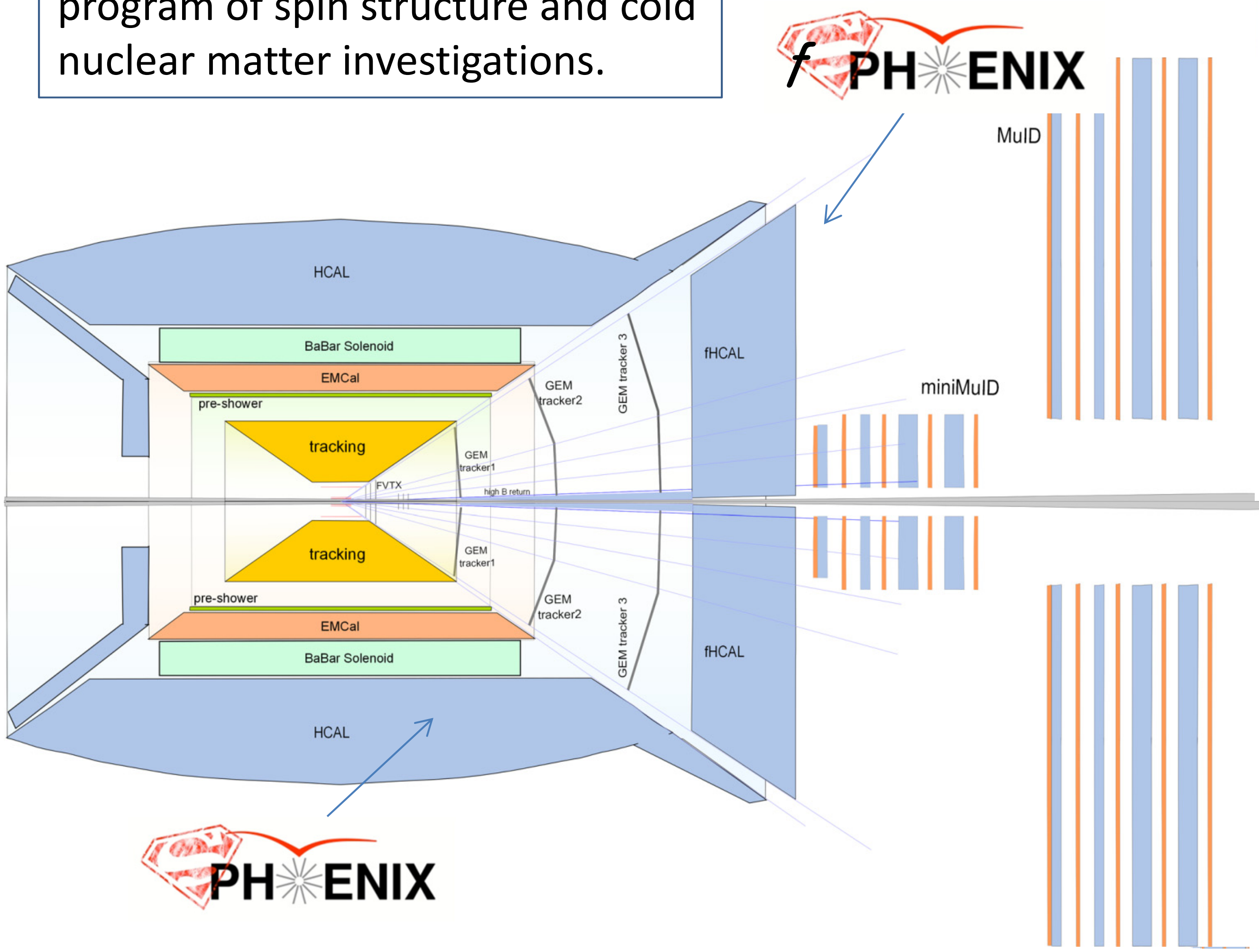
Kang, Yuan: PRD 84, 034019 (2011)



Polarized p+A a unique capability of RHIC!

fsPHENIX –"forward" sPHENIX!

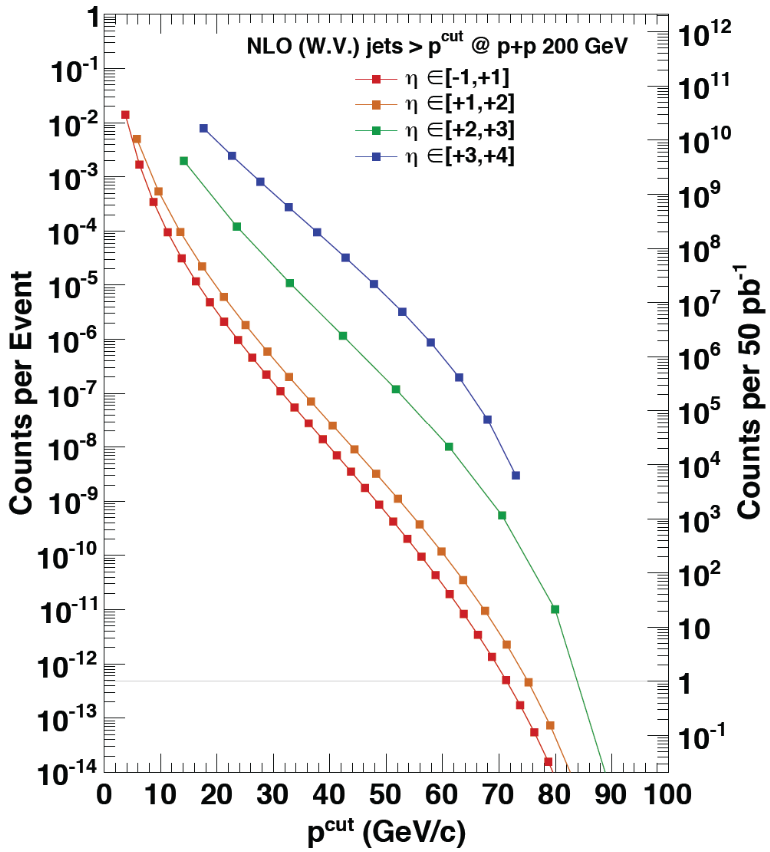
A detector for a *comprehensive* program of spin structure and cold nuclear matter investigations.



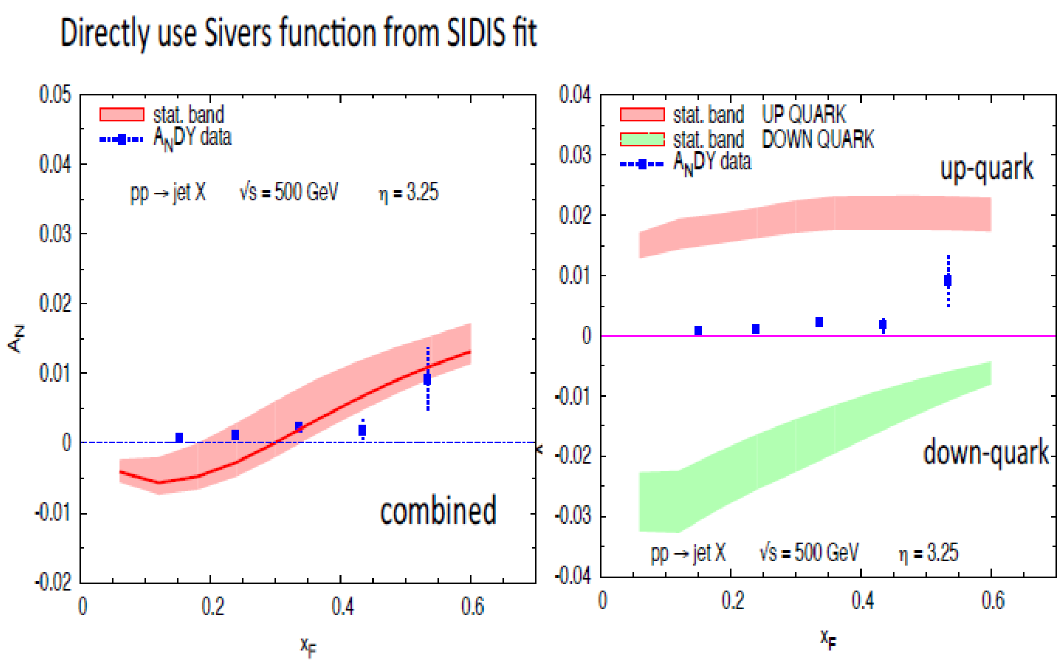
fsPHENIX HCAL, GEM trackers derived from EIC detector

- FVTX covering two regions
  - 3 planes covering $1.1 < \eta < 3$
  - 3 planes covering $3 < \eta < 4$
- field shaper piston made of 50% Co + 50%Fe
- 3 GEM tracker stations
- forward HCAL
- current MuID

fsPHENIX Jets @ 200GeV



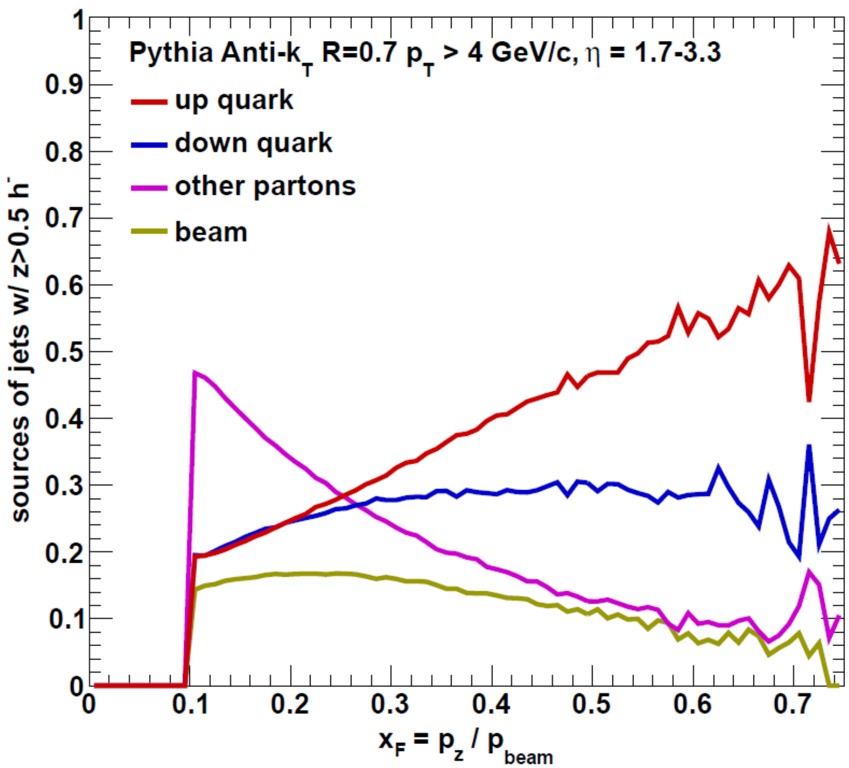
fsPHENIX Jet acceptance 1.7 < η < 3.3
with anti-k_T R=0.7



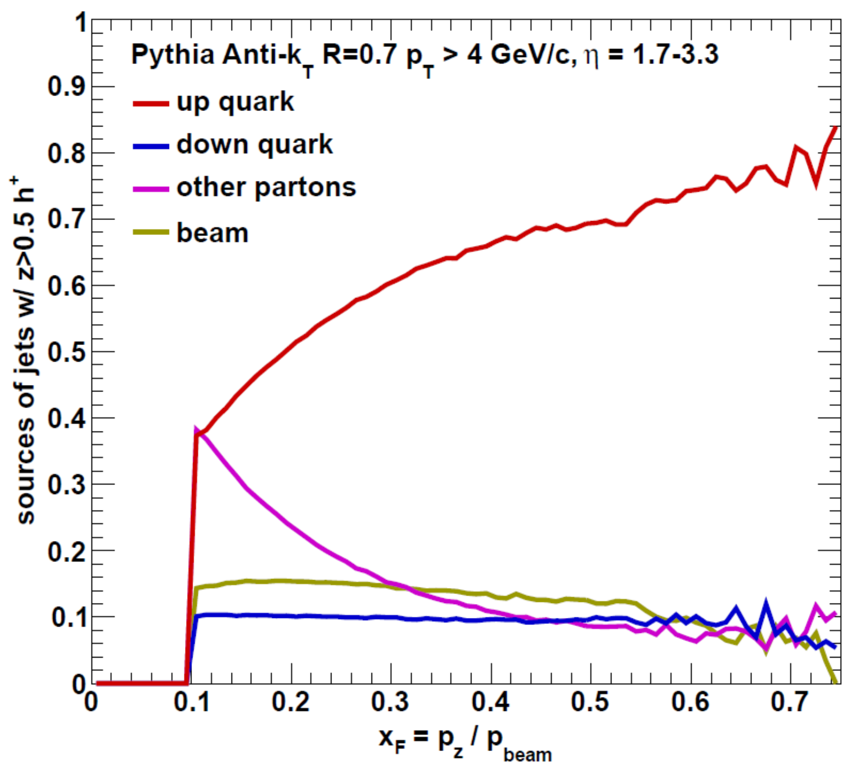
Is the small A_NDY asymmetry a cancellation between u and d quarks?

Jet Sources

Jets with negative hadron z>0.5



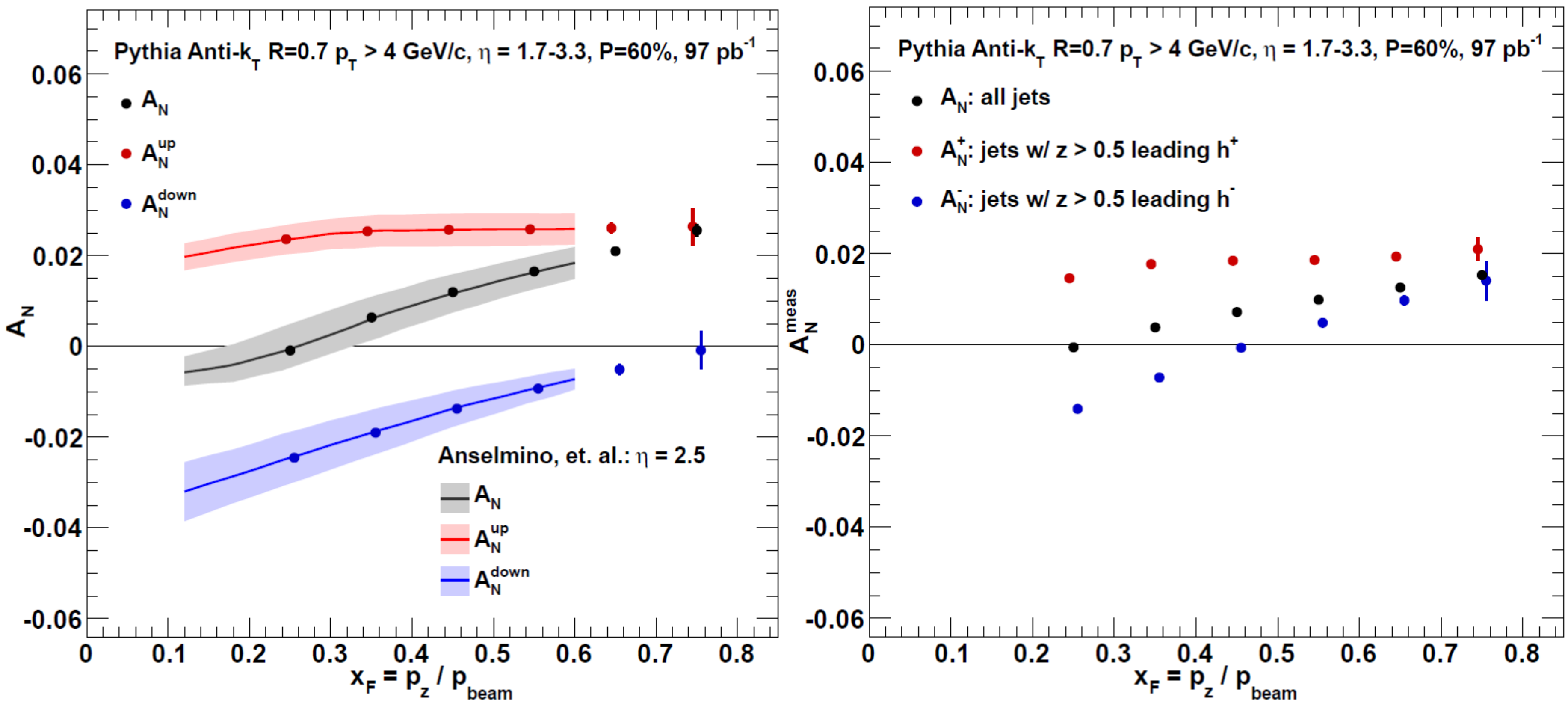
Jets with positive hadron z>0.5



Jets from standard PYTHIA Tune A, beam remnants from Tune A with k_T=0.36.

A cut on the charge of the leading hadron changes the composition of the jet sample.

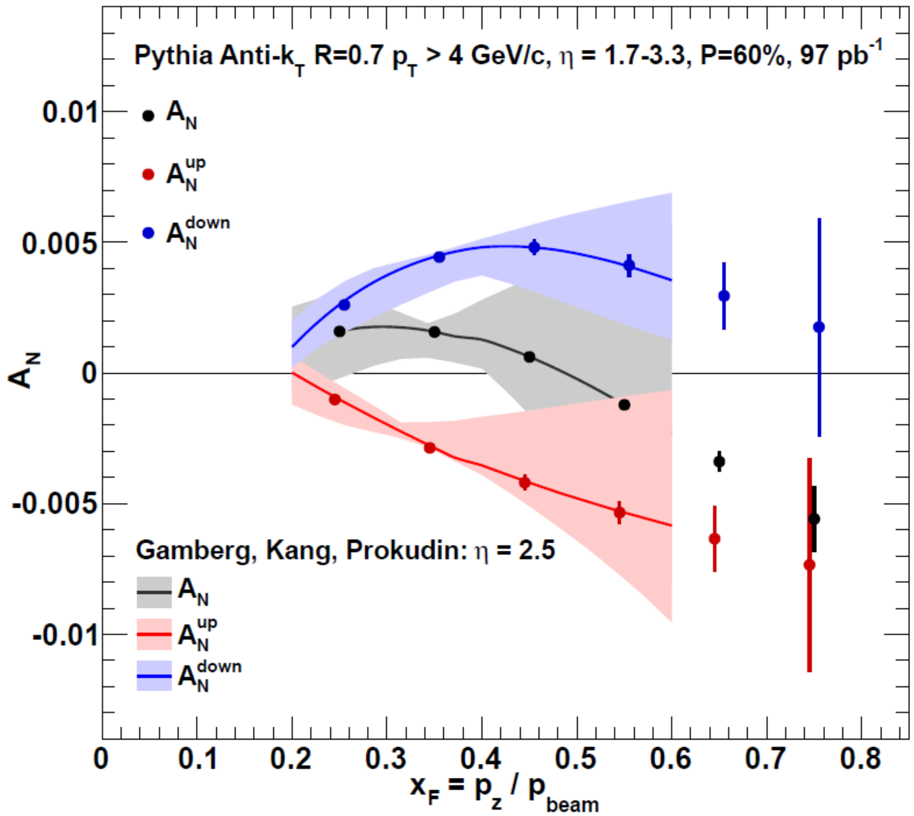
Jet Measurements in fsPHENIX

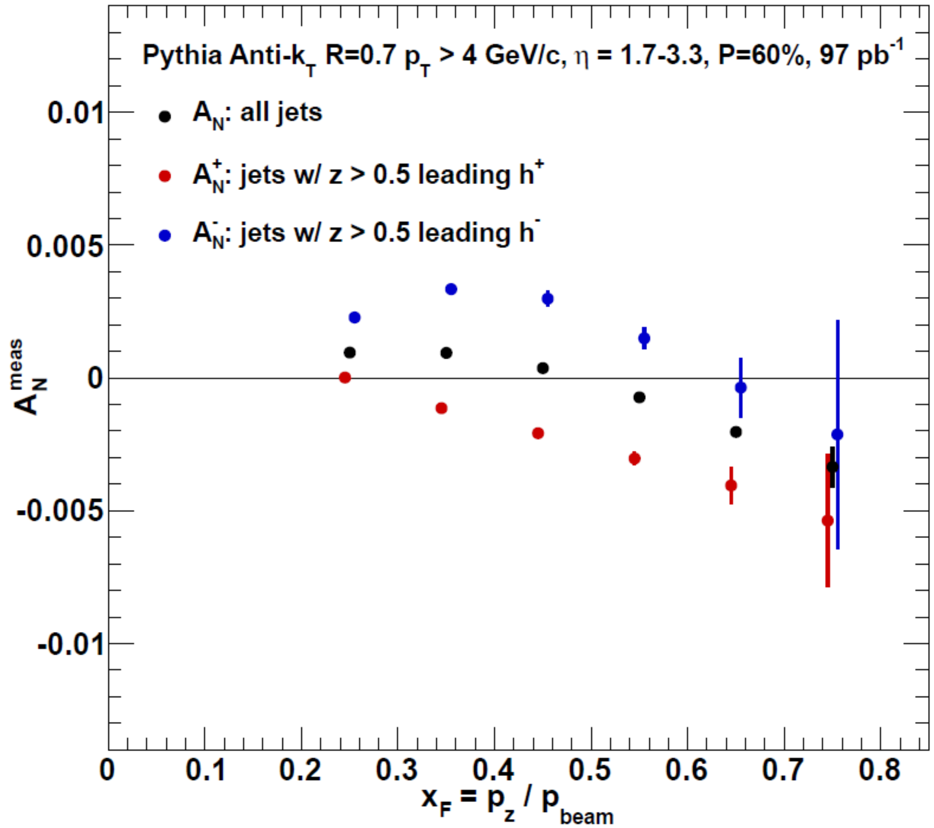


Anselmino et. al. : *Phys Rev. D* 88 054023 (2013)

Projected fsPHENIX data points (97pb^{-1}) compared to theoretical model.

Jet Measurements in fsPHENIX

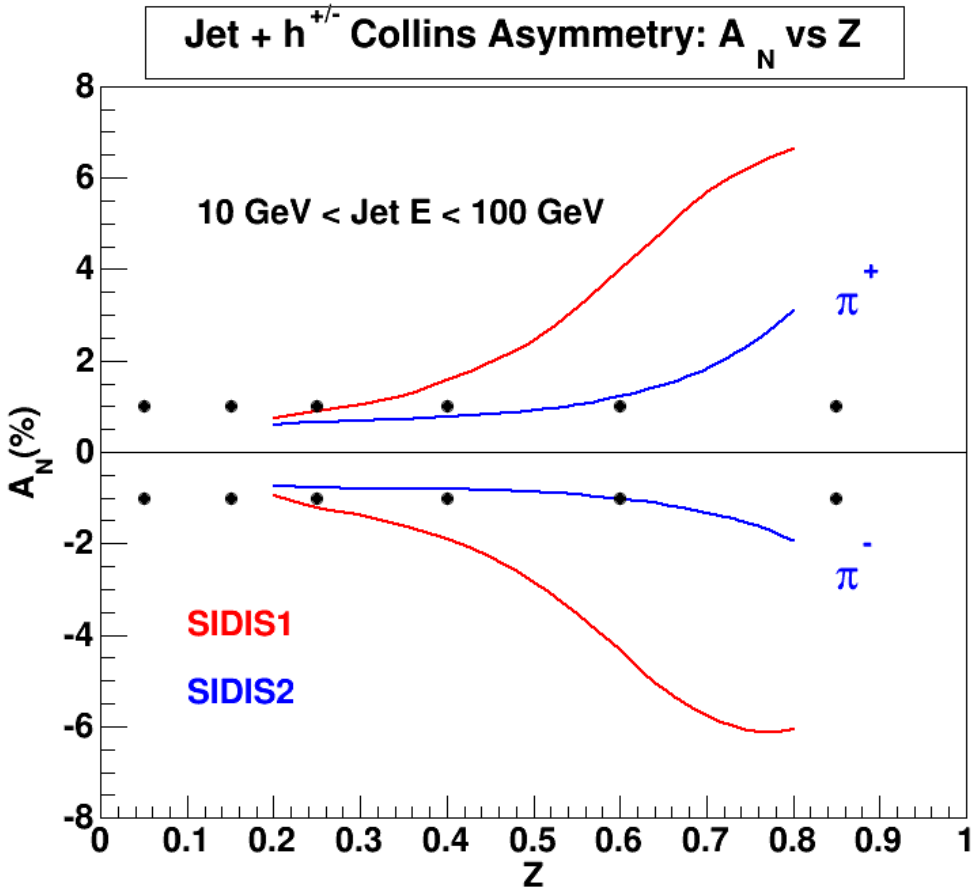




Gamberg, Kang and Prokudin: *Phys Rev. Lett*. 110:232301 (2013)

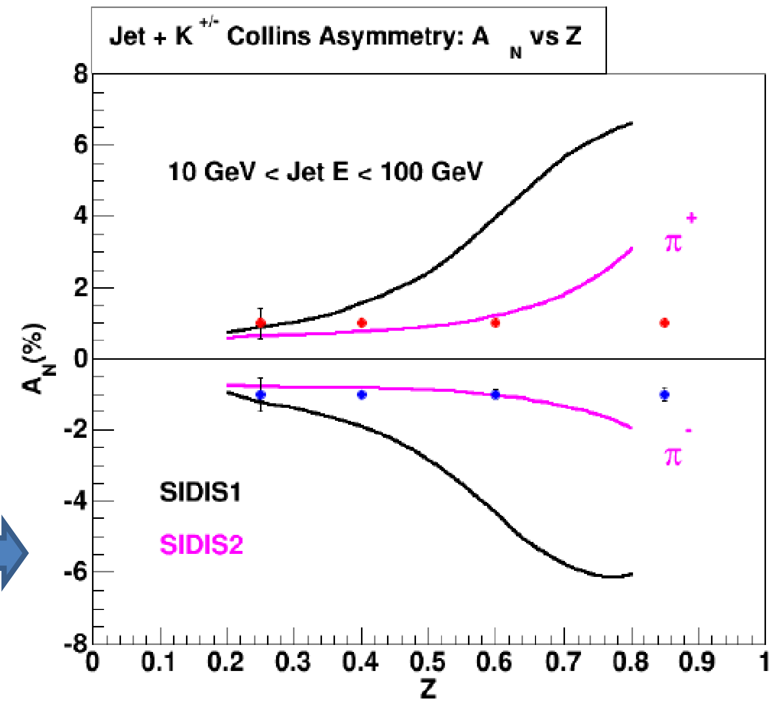
Projected fsPHENIX data points (97pb^{-1}) compared to theoretical model.

Collins in Jets



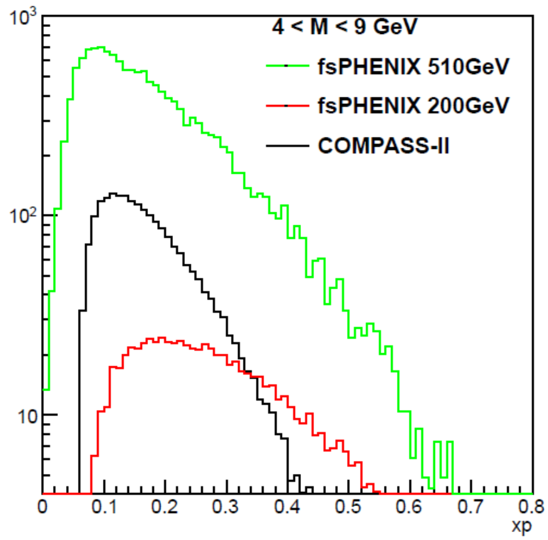
Lots of statistics for Collins in jets using charged hadrons. Issue is z-resolution as a function of jet energy.

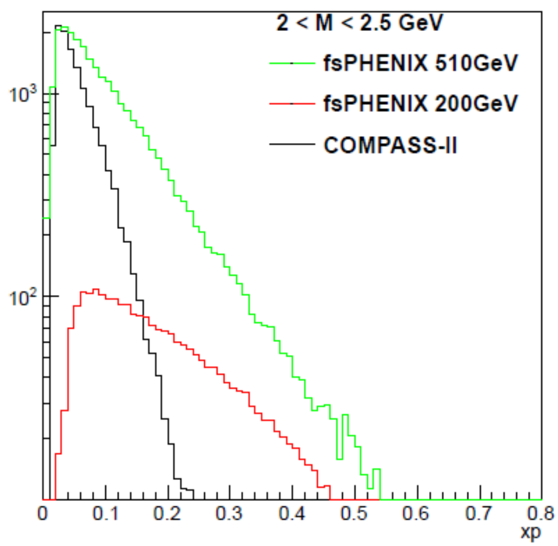
With addition of PID kaon measurements also have excellent statistics (not part of baseline).

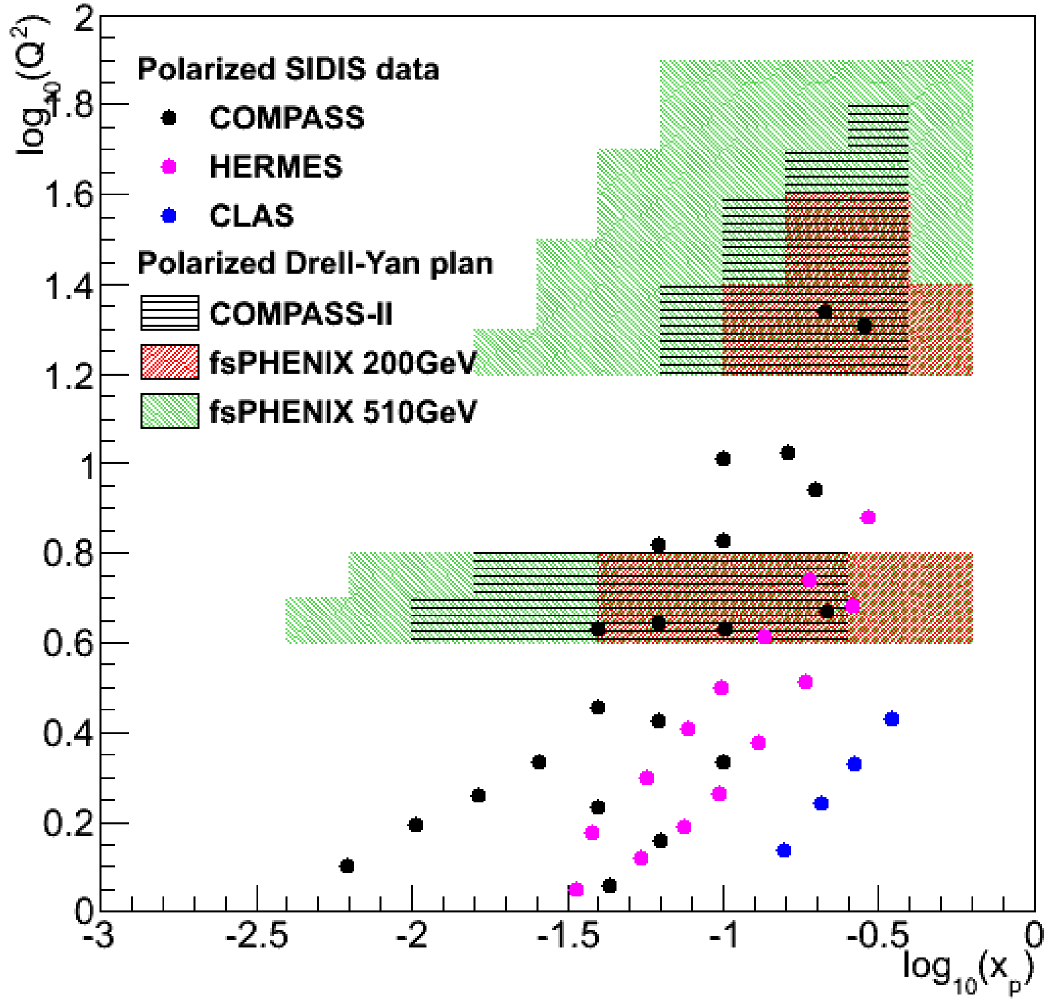


Drell-Yan : fsPHENIX and COMPASS-II

$$FoM = (1/\delta A_T^{\sin\phi_S})^2 = \frac{N}{2}P^2$$



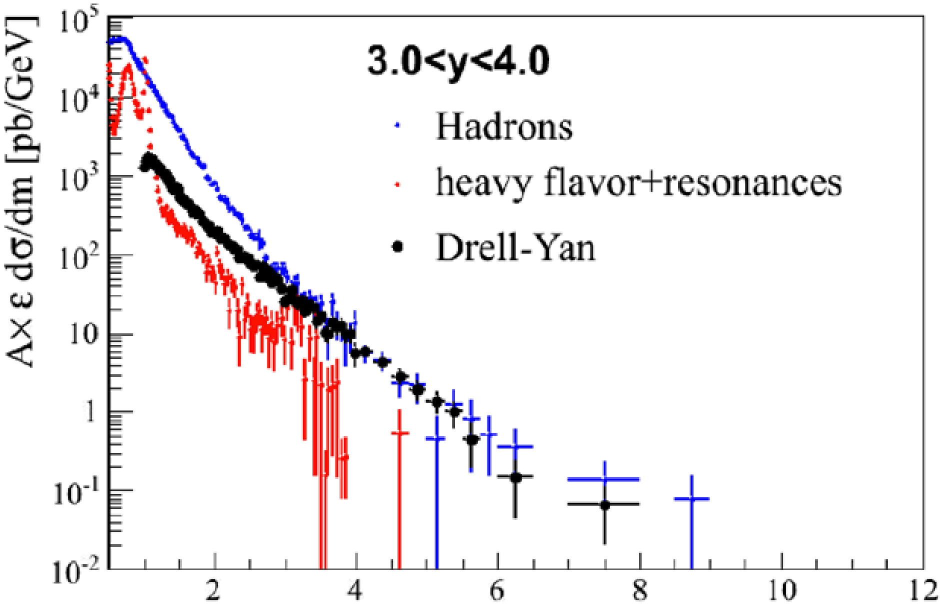




Shaded regions deliniate $\delta A_T^{\sin\phi_S} < 0.1$

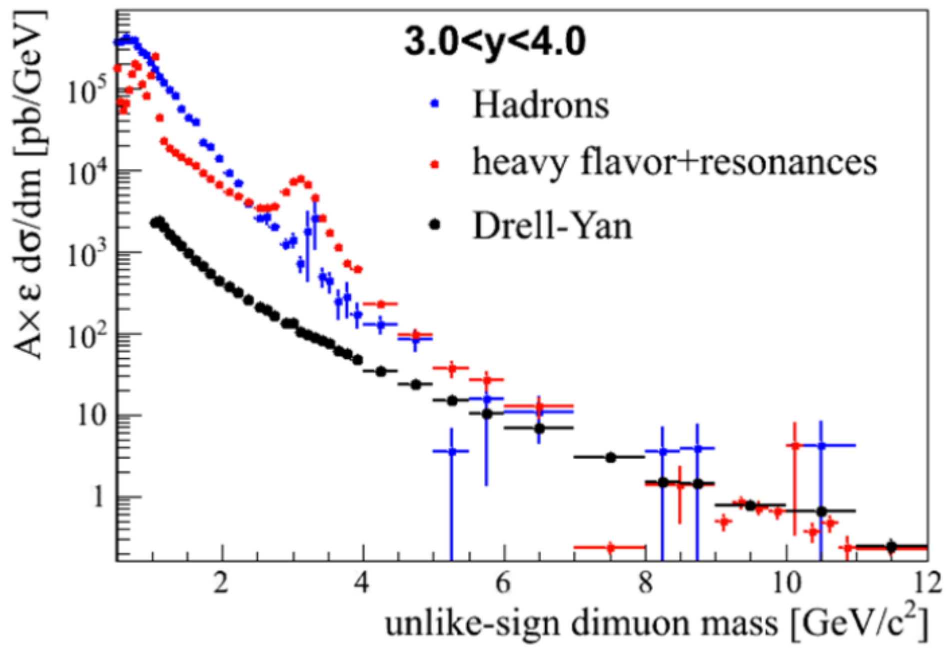
The Challenge of Drell-Yan

200 GeV



Plots reflect MC statistics, not fsPHENIX running.

510 GeV



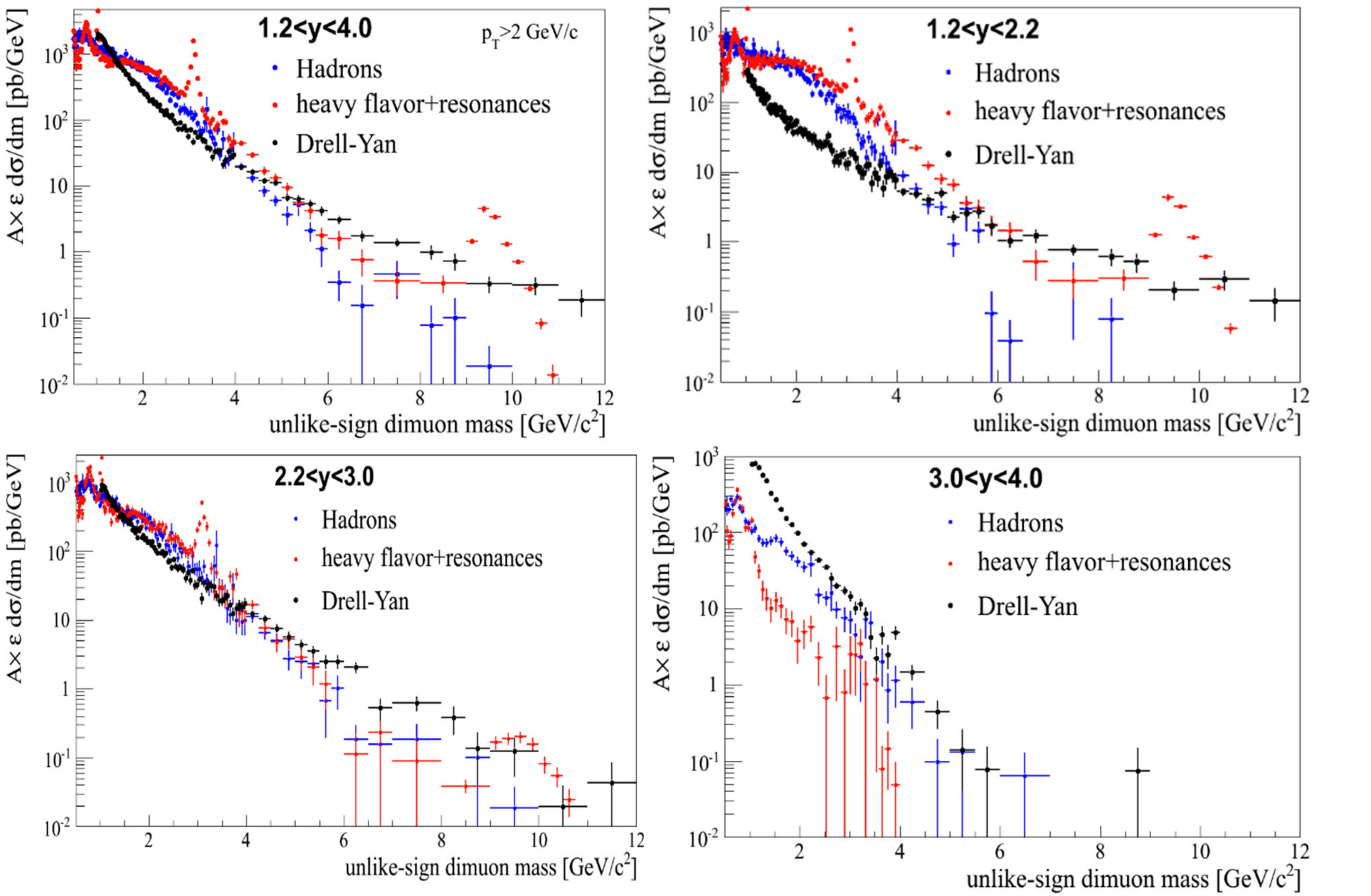
Very basic cuts <u>without</u> concerted effort to reduce backgrounds.

200 GeV offers better S/B (lower HF cross section), but reduced luminosity makes it difficult to get high statistics. 510 Gev offers much higher luminosity (higher statistics) but higher backgrounds as well.

Dramatically improve S/B at higher p_T, Drell-Yan at p_T>Q similar to direct photon.

Berger et. al., PRD 65 034006

Drell-Yan Performance (200 GeV, p_T>2GeV)

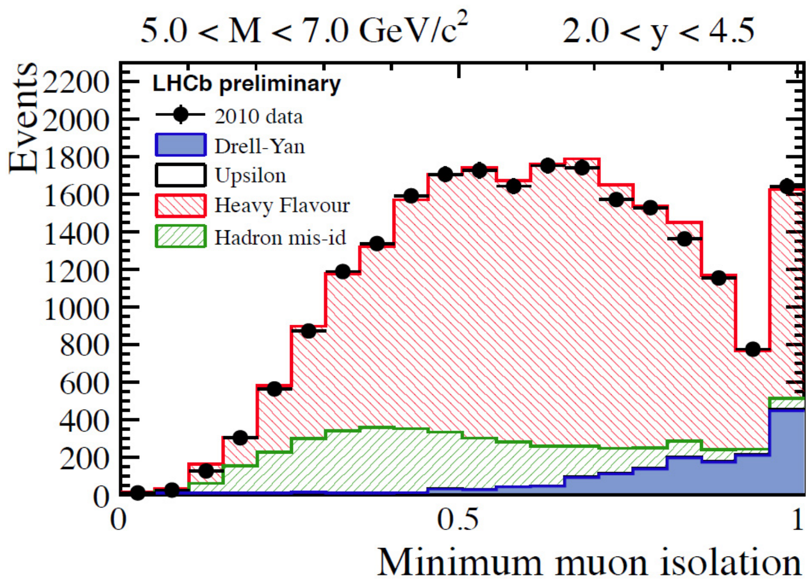


Plots reflect MC statistics, not fsPHENIX running.

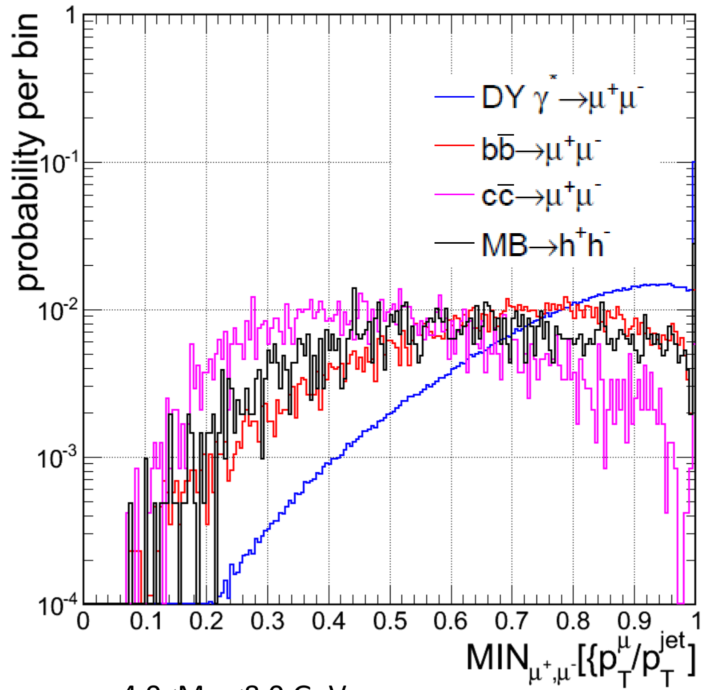
Reducing DY Backgrounds

Make use of the fact that most of the background is jet-associated, and DY is not (*fsPHENIX* is a jet detector!)

Example: LHCb motivated jet momentum cut.



√s = 510 GeV
1.2<y<4.0



4.0<$M_{\mu\mu}$<8.0 GeV

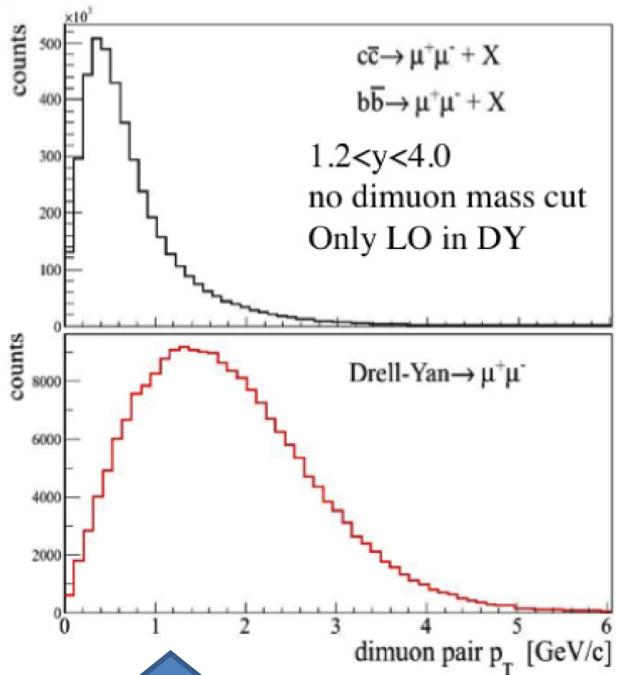
Possible to get large rejection factors at the expense of some DY pair efficiency.
A full characterization of *fsPHENIX* performance will require detailed simulations.

Conclusion

- **The *fsPHENIX* physics program covers a broad range of key scientific questions:**
  - The spin structure of the nucleon
  - The structure of nuclear matter at small-x
- **The ability to pursue these questions in p+p and p+A collisions may be lost in the transition to the EIC.**
- ***fsPHENIX* builds on the *sPHENIX* detector and integrates with a future EIC detector.**
  - 90% of the estimated cost of *fsPHENIX* is in common with the EIC detector

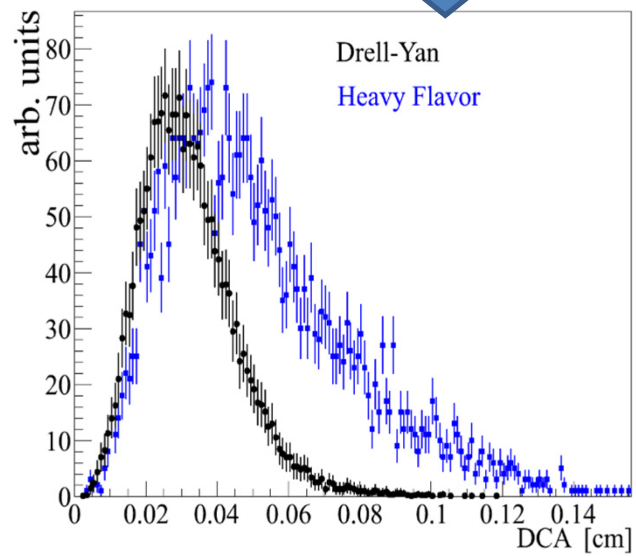
BACKUP

Reducing Drell-Yan Backgrounds

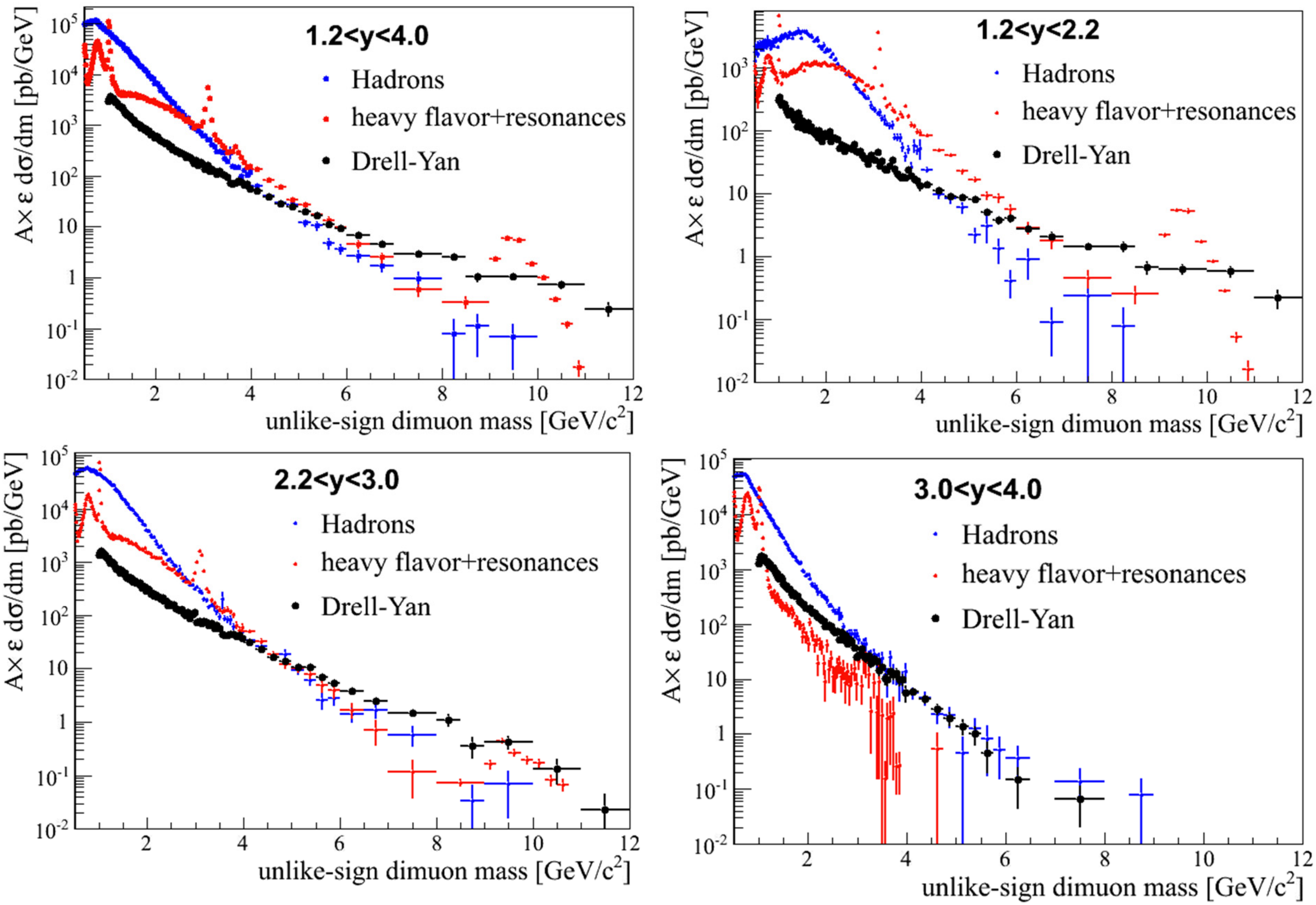


Cuts on q_T preserve DY and reduce background, but high q_T is difficult theoretically (especially for low mass)

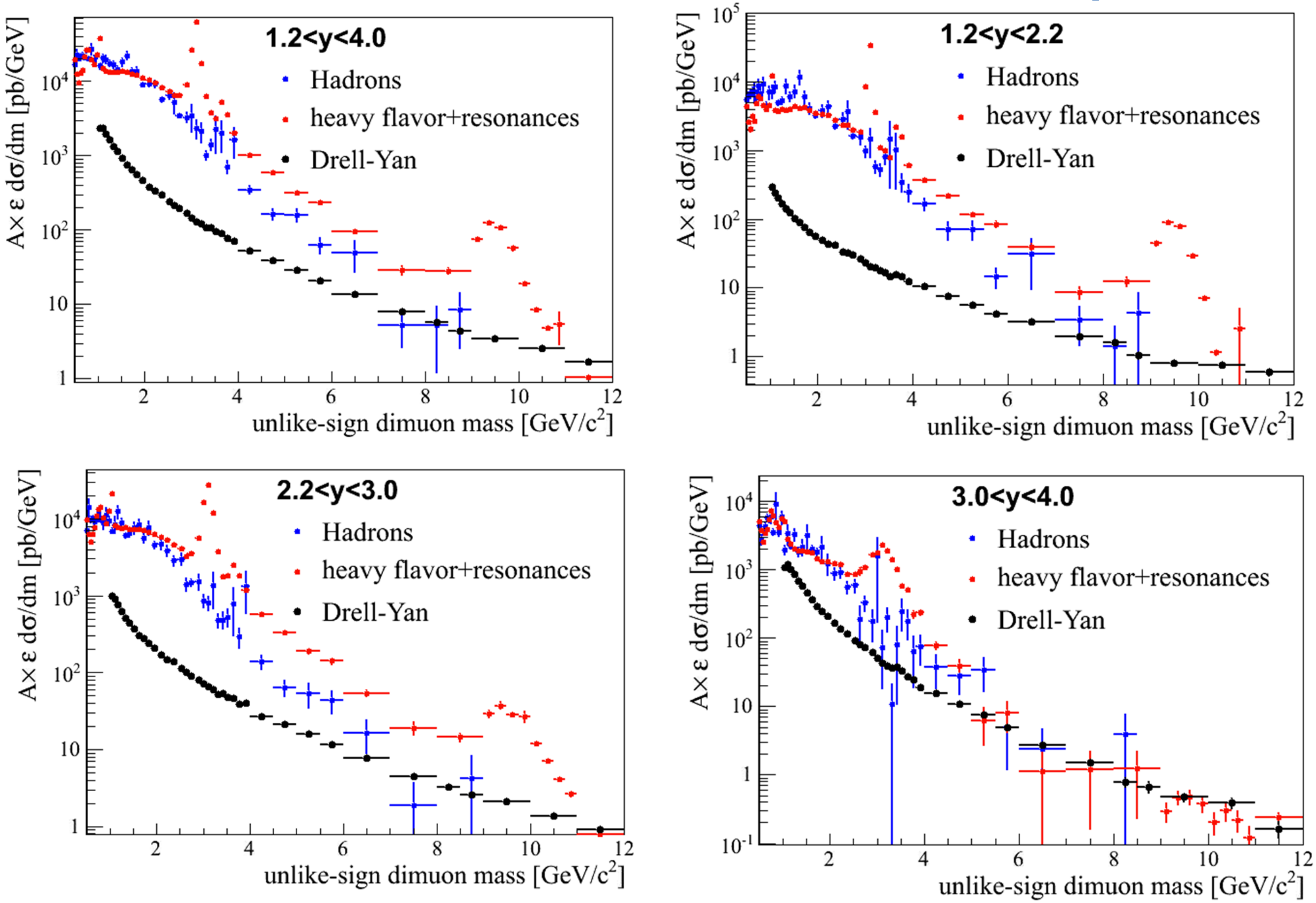
Tighter DCA cuts certainly possible, sacrifice some efficiency for $|z_{VTX}| > 10$cm?



Drell-Yan Performance (200 GeV, no p_T cut)

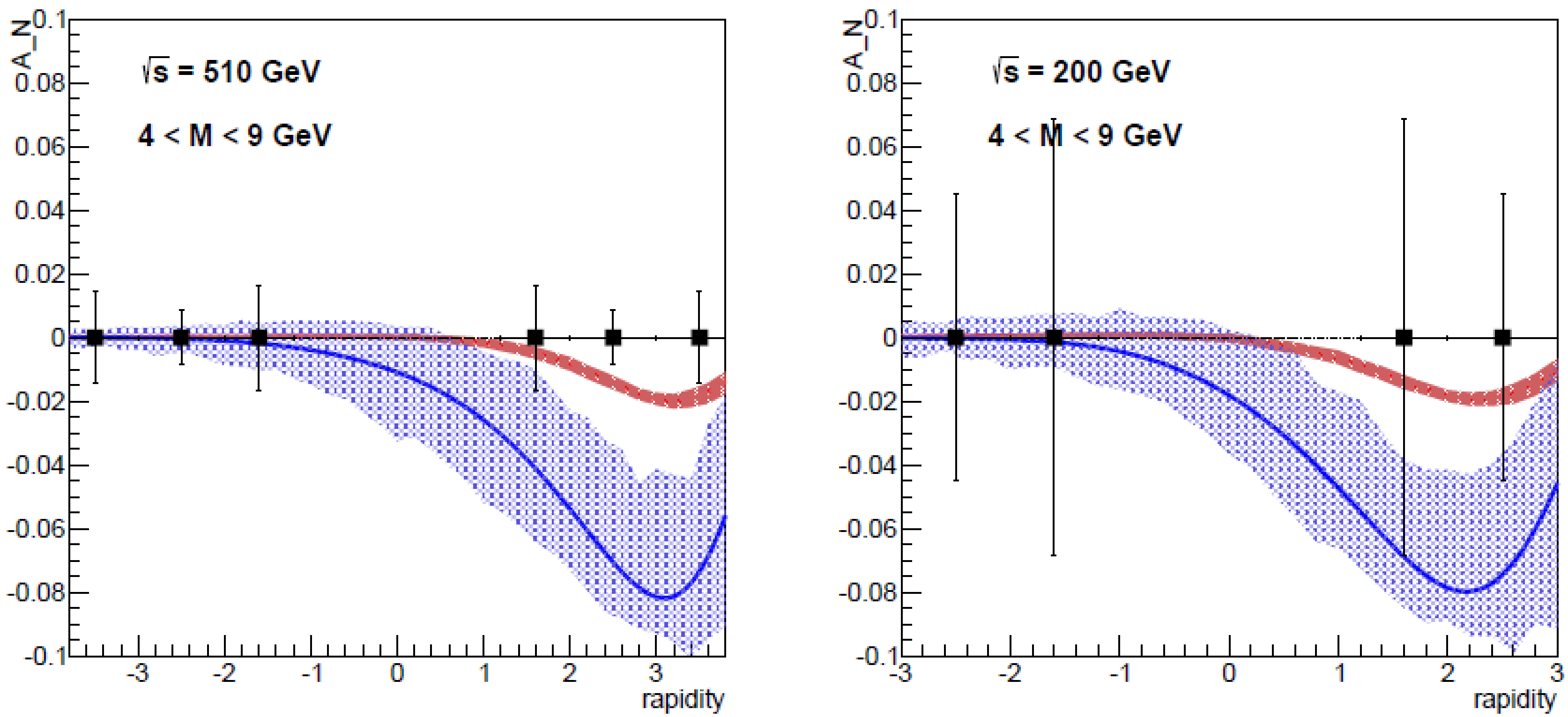


Drell-Yan Performance (510 GeV, p_T>2GeV)



Plots from Cesar

Drell-Yan Statistical Power



fsPHENIX Cost

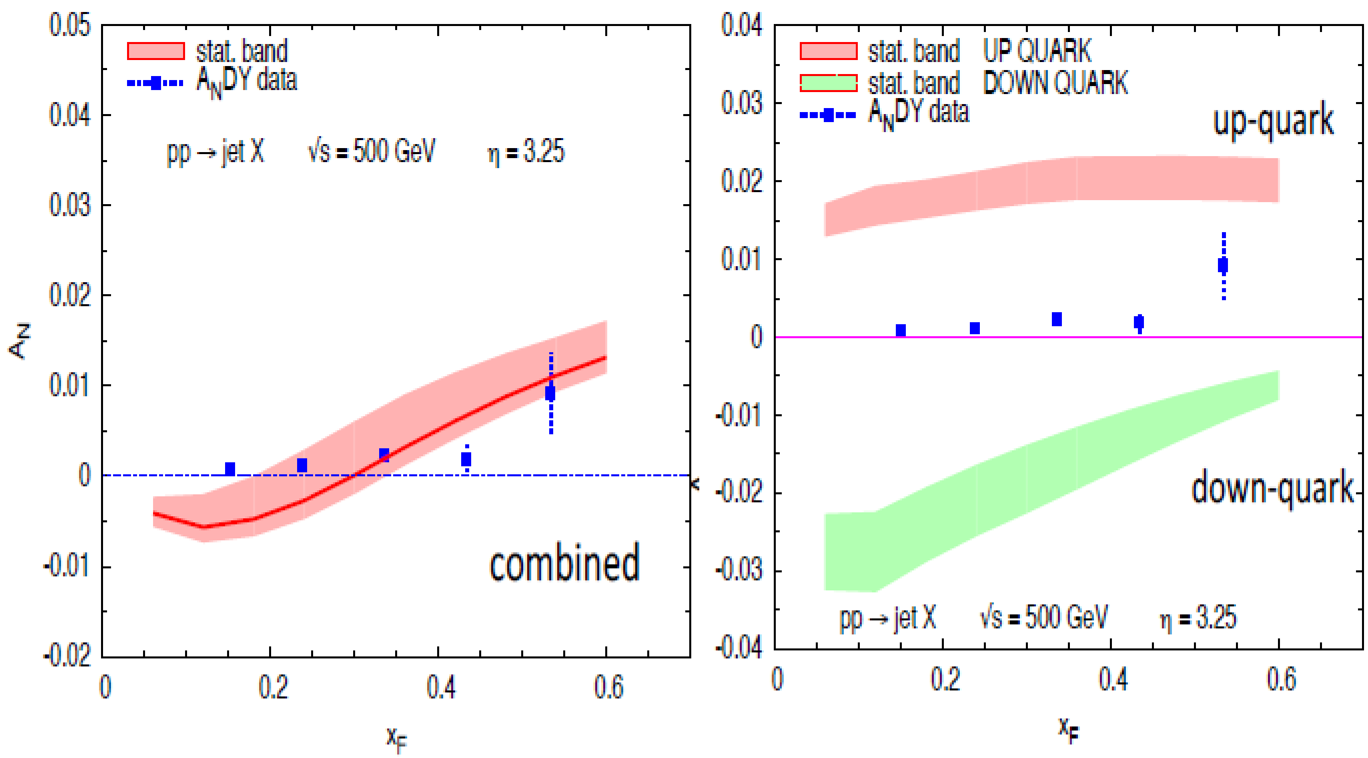
	Cost	Overhead	Contingency	Total
HCal	3.90	0.68	2.29	6.87
GEM Tracker	0.67	0.17	0.41	1.25
FVTX reconfiguration	0.53	0.11	0.31	0.95
Mini-MUID	0.13	0.03	0.08	0.24
Piston Field Shaper	0.06	0.02	0.04	0.12
HCal electronics/sensors	0.38	0.05	0.22	0.65
GEM electronics/sensors	0.63	0.16	0.39	1.18
Mini-MUID electronics/sensors	0.05	0.01	0.03	0.09
MUID trigger electronics	0.35	0.07	0.21	0.63
Total	6.7	1.3	3.98	11.98

$12M overall cost, about 90% common with ePHENIX.

Jet Physics in Polarized p+p

- **Measurements of Jet A_N sensitive to Sivers only (no Collins).**

Directly use Sivers function from SIDIS fit (Torino group)



Kang et. al. predict *opposite signs* for the u, d quark asymmetries!

fsPHENIX Luminosity Assumptions

- **Guidance from ALD (CAD Delivered):**
  - ALD guidance also cautions to assume lower estimates…
  - p+p@510GeV: 200pb^{-1}/week
    - Increase in bunch intensity by factor of 1.62 over achieved (electron cooling)
    - CAD 2014-2018 Projections (4 June 2013): 216pb^{-1} /week (max), 40pb^{-1} /week (min)
    - Max/Min Average = 128pb^{-1}/week average
  - p+Au@200GeV: 300nb^{-1}/week
    - Run-14 BUP guidance was 175nb^{-1}/week
    - Conservative: 225nb^{-1}/week (75% of maximum)
    - p+p equivalent: 44pb^{-1}/week
  - p+p@200GeV: no ALD guidance
    - CAD projection 28pb^{-1} (max), 9.3pb^{-1}/week (min)
    - Max/Min Average = 18.7pb^{-1}/week

Use these #'s for fsPHENIX

fsPHENIX Run Length

- **PHENIX Guidance:**
  - Assume 10 weeks running for p+p@200GeV
  - Assume 10 weeks running for p+Au@200GeV
- **What do we assume for Drell Yan p+p@510GeV?**
  - Make table assuming one 15-week run
- **Additional running time for different p+A species?**
- **Dell-Yan:**
  - **Assuming PHENIX Efficiency = 0.6 (uptime) x 0.62 ($-30<z_V<10$cm vertex)**
  - p+p@200GeV PHENIX Sampled = **69pb^{-1}**
  - p+A@200GeV PHENIX Sampled = 831nb^{-1} p+Au, **163pb^{-1} (pp equiv)**
  - p+p@510GeV PHENIX Sampled = **714pb^{-1}**
- **Jets:**
  - **Assuming PHENIX Efficiency = 0.6 (uptime) x 0.84 (+/-30cm vertex)**
  - p+p@200GeV PHENIX Sampled = **97pb^{-1}**
  - p+A@200GeV PHENIX Sampled = 1165nb^{-1} p+Au, **230pb^{-1} (pp equiv)**
  - p+p@510GeV PHENIX Sampled = **1002pb^{-1}**

Drell-Yan Statistics

fsPHENIX DY Statistics assuming all reconstruction efficiencies:

System and inv Mass		DY Pairs 1.2<eta<4	DY Pairs 1.2<eta<2	DY Pairs 2<eta<3	DY Pairs 3<eta<4
p+p 200 (1.5<M<2.5)		41634	4961	23685	11956
p+p 200 (2.0<M<2.5)		13469	1871	7997	3317
p+p 200 (4<M<9)		4153	1188	2743	209
p+Au 200 (1.5<M<2.5)		98225	11704	55879	28207
p+Au 200 (2.0<M<2.5)		30369	4415	18867	7825
p+Au 200 (4<M<9)		9798	2803	6472	492
p+p 510 (1.5<M<2.5)		579788	58575	307025	216419
p+p 510 (2.0<M<2.5)		207452	23280	113373	72469
p+p 510 (4<M<9)		116560	20280	75308	26573

200 GeV: Limited program for high-mass pairs, but a solid program for low mass pairs?
If DY in p+A is a CNM measurement, do we want to measure another species?

510 GeV: Lots of statistics but HF backgrounds higher, room to cut harder?