Inclusive observables

High-p_T jets and hadrons

Werner Vogelsang

RBRC & BNL Nuclear Theory

RHIC/AGS Users' Meeting 05/10

Outline:

- A_{LL} for jets and inclusive hadrons

  Jäger, Kretzer, Stratmann, WV (PRL '04, PRD '04)

- asymmetric jet correlations in $p^{\uparrow}p$

  Boer, WV (PRD '04)

What carries the proton spin ?

- spin sum rule :

~ 0.1

$$\boxed{\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g}$$

where

$*$ $\Delta G(Q^2) = \int_0^1 dx\, \Delta g(x, Q^2)$

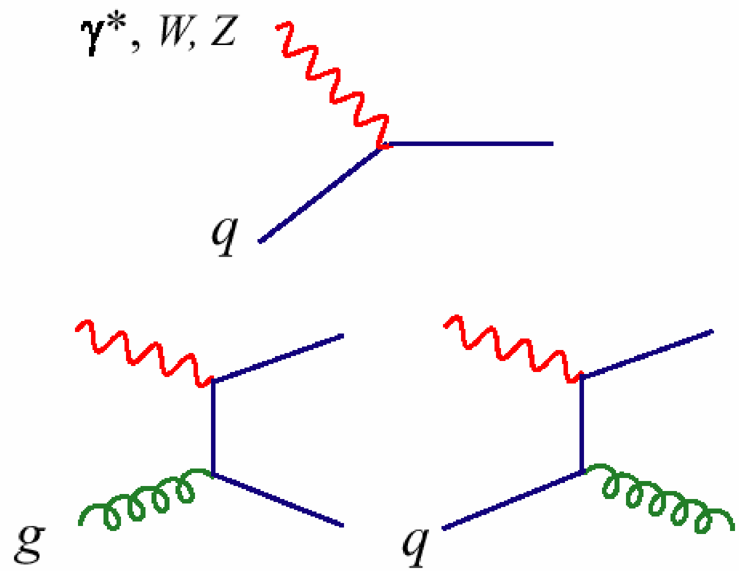
$$\Delta g(x) =$$

$*$ $L_{q,g}$ quark, gluon orbital angular momenta

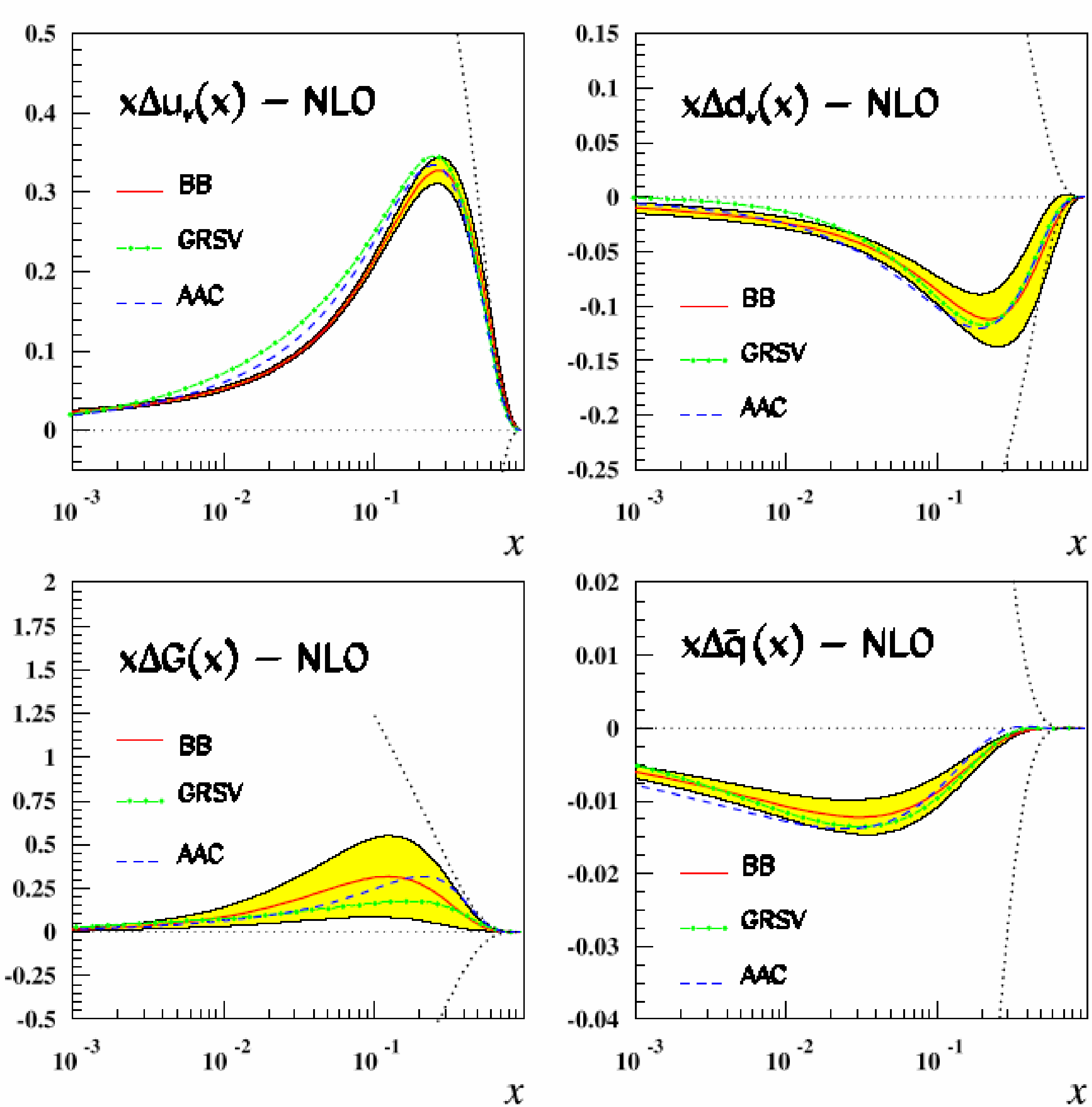
In inclusive DIS …

LO

NLO



… gluons are sub-dominant.



(Blümlein,Böttcher)

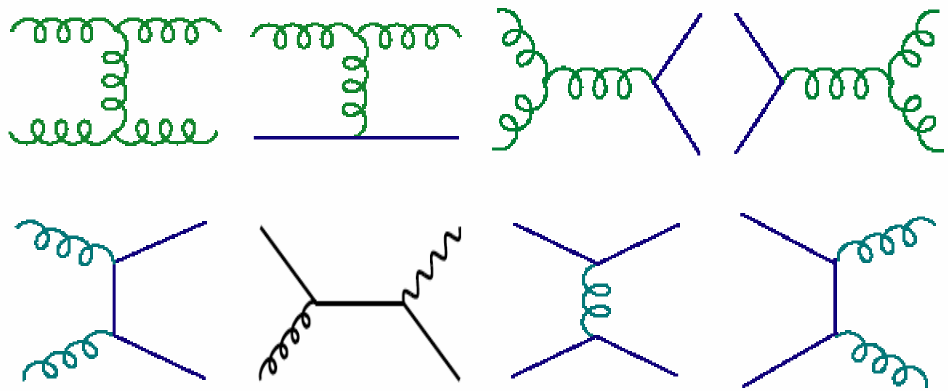
$\mu^2 = 4 \ \mathrm{GeV}^2$

$\leftarrow$ SU(3)$_\mathrm{f}$ symm. sea

$\Delta\bar{u} = \Delta\bar{d} = \Delta\bar{s}$

In hadronic collisions (RHIC) ...

LO



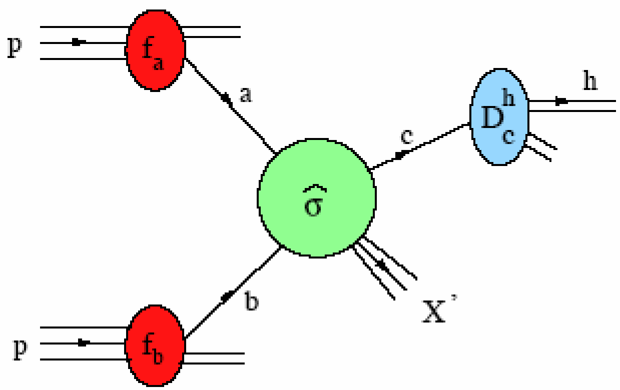
... gluons are "leaders".

$$A_{\rm LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \equiv \frac{\Delta\sigma}{\sigma}$$

Near-term prospects for measuring Δg

– High-$\mathrm{p_T}$ jets and hadrons –

$$p_T^3 \frac{d\Delta\sigma}{dp_T\, d\eta} = \Bigg|$$



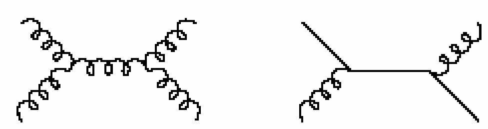
$$\Bigg|^2 + \mathcal{O}\left(\frac{\lambda}{p_T}\right)^n$$

$$\boxed{d\Delta\sigma^{pp\to hX} = \sum_{abc} \Delta f_a \otimes \Delta f_b \otimes d\Delta\hat{\sigma}^{ab\to cX'} \otimes D_c^h + \text{P.C.}}$$

$$\Delta\hat{\sigma}^{(0)} + \alpha_s \Delta\hat{\sigma}^{(1)} + \ldots \quad \text{pert.}$$

LO NLO

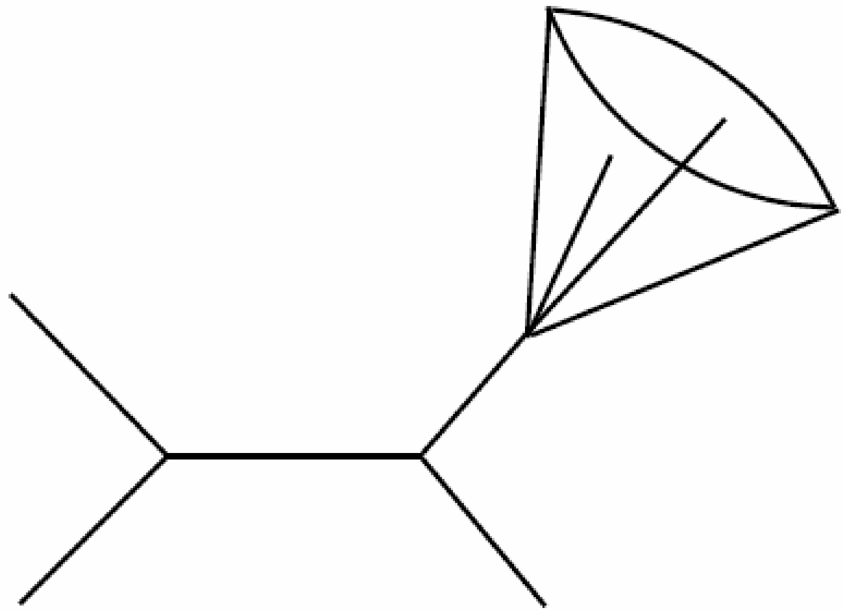
Jäger,Schäfer,Stratmann,WV
de Florian



- nucleon spin structure $\Delta f_{a,b}$
- for hadrons : fragmentation functions $D_c^h \quad \rightsquigarrow \quad e^+e^-$ annihilation

- jet and hadron caclulations share many features

- however :



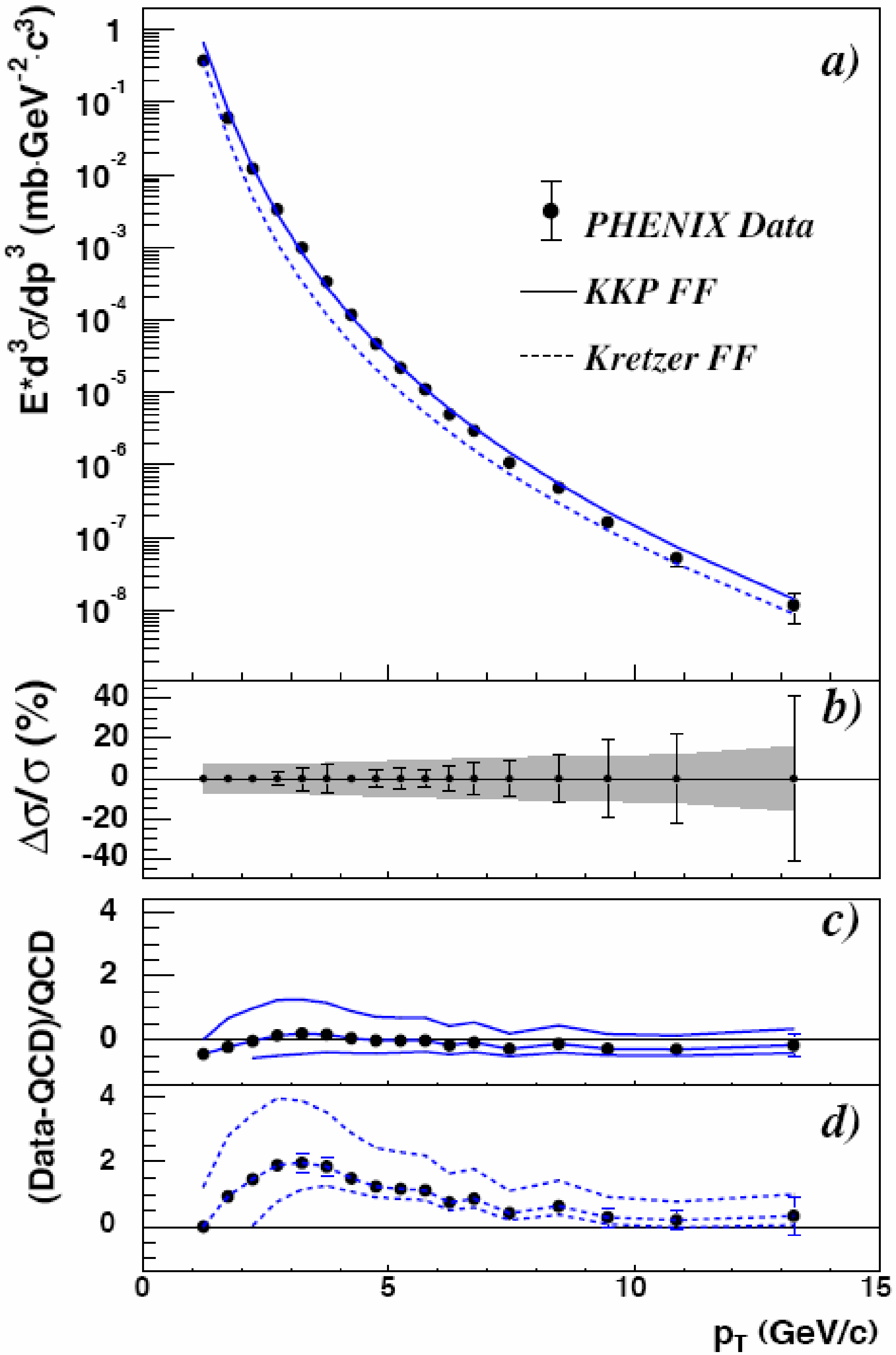
- final-state singularities . . .

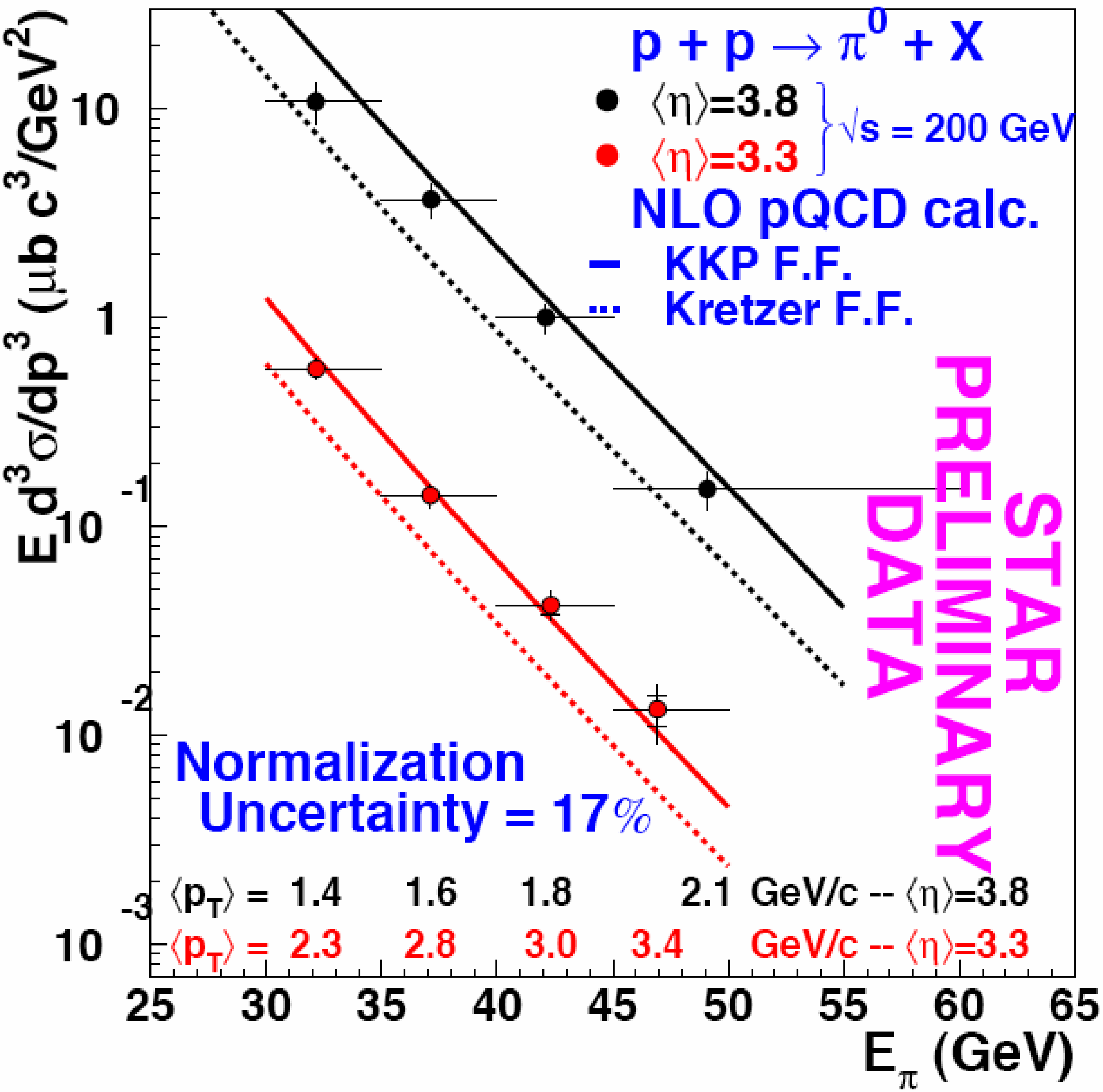
  . . . cancel for jets

  . . . imply additional non-perturbative input for incl. hadrons

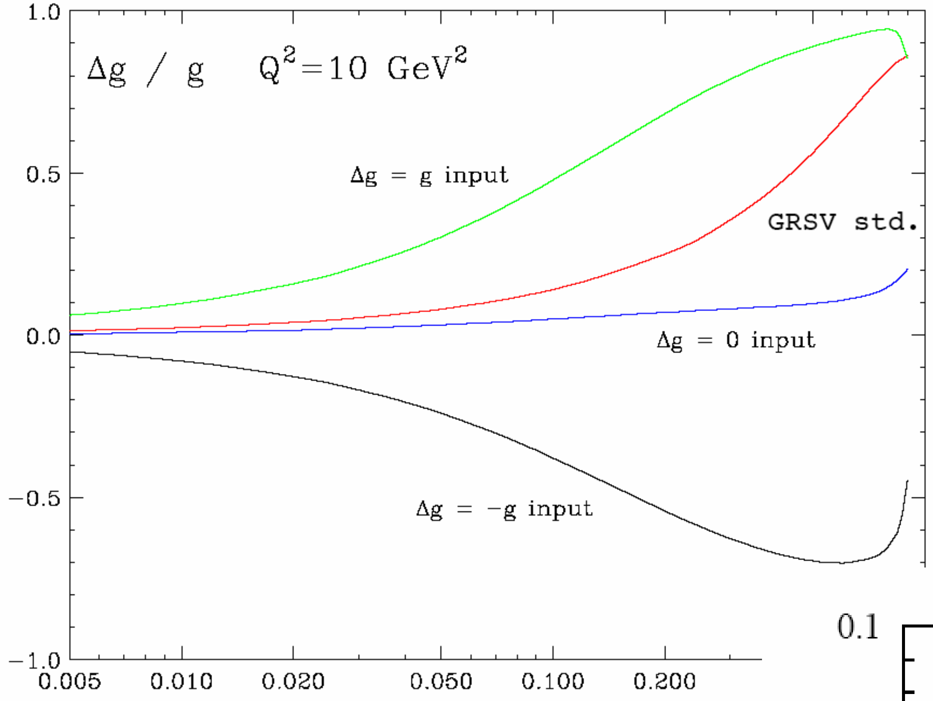
  $\longrightarrow$ fragmentation functions

$pp \to \pi^0 X$ **by PHENIX**

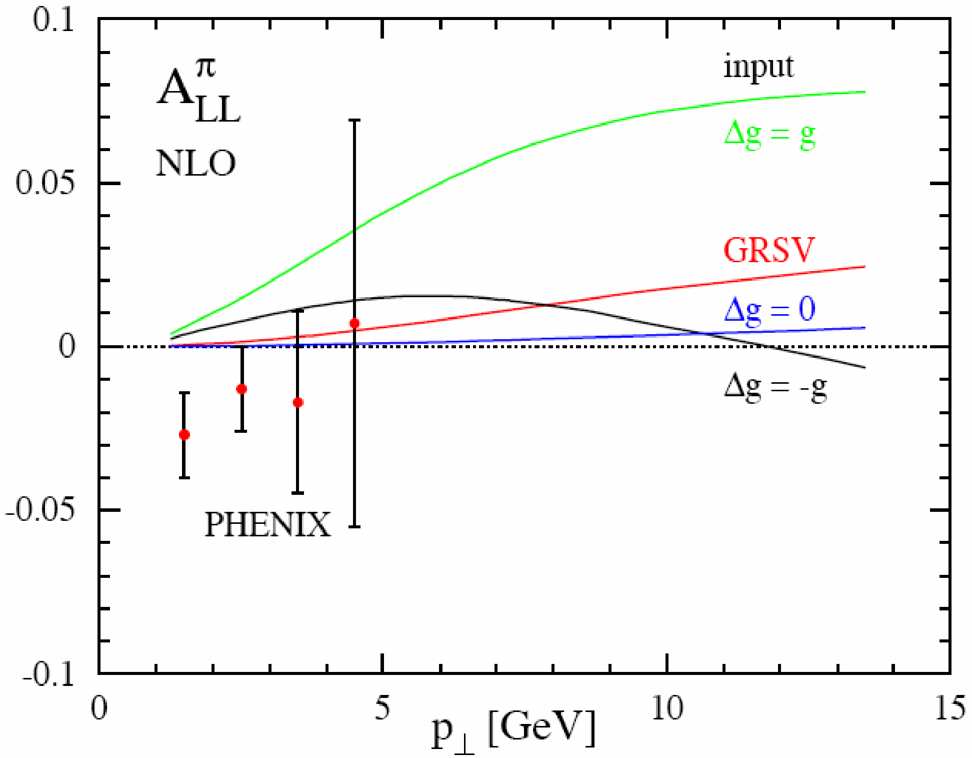




$p + p \to \pi^0 + X$
$\langle\eta\rangle$=3.8
$\langle\eta\rangle$=3.3
$\sqrt{s}$ = 200 GeV
NLO pQCD calc.
KKP F.F.
Kretzer F.F.
STAR PRELIMINARY DATA
Normalization Uncertainty = 17%
$\langle p_T \rangle$ = 1.4 1.6 1.8 2.1 GeV/c -- $\langle\eta\rangle$=3.8
$\langle p_T \rangle$ = 2.3 2.8 3.0 3.4 GeV/c -- $\langle\eta\rangle$=3.3
$E\, d^3\sigma/dp^3$ (μb c^3/GeV^2)
E_π (GeV)

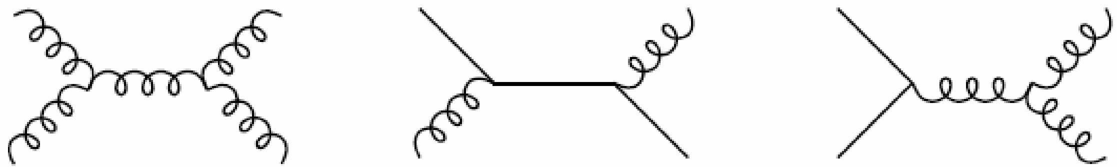


Glück, Reya, Stratmann, WV



Jäger, Stratmann, WV

recall : $gg,\ qg,\ qq$ scattering :



- therefore :

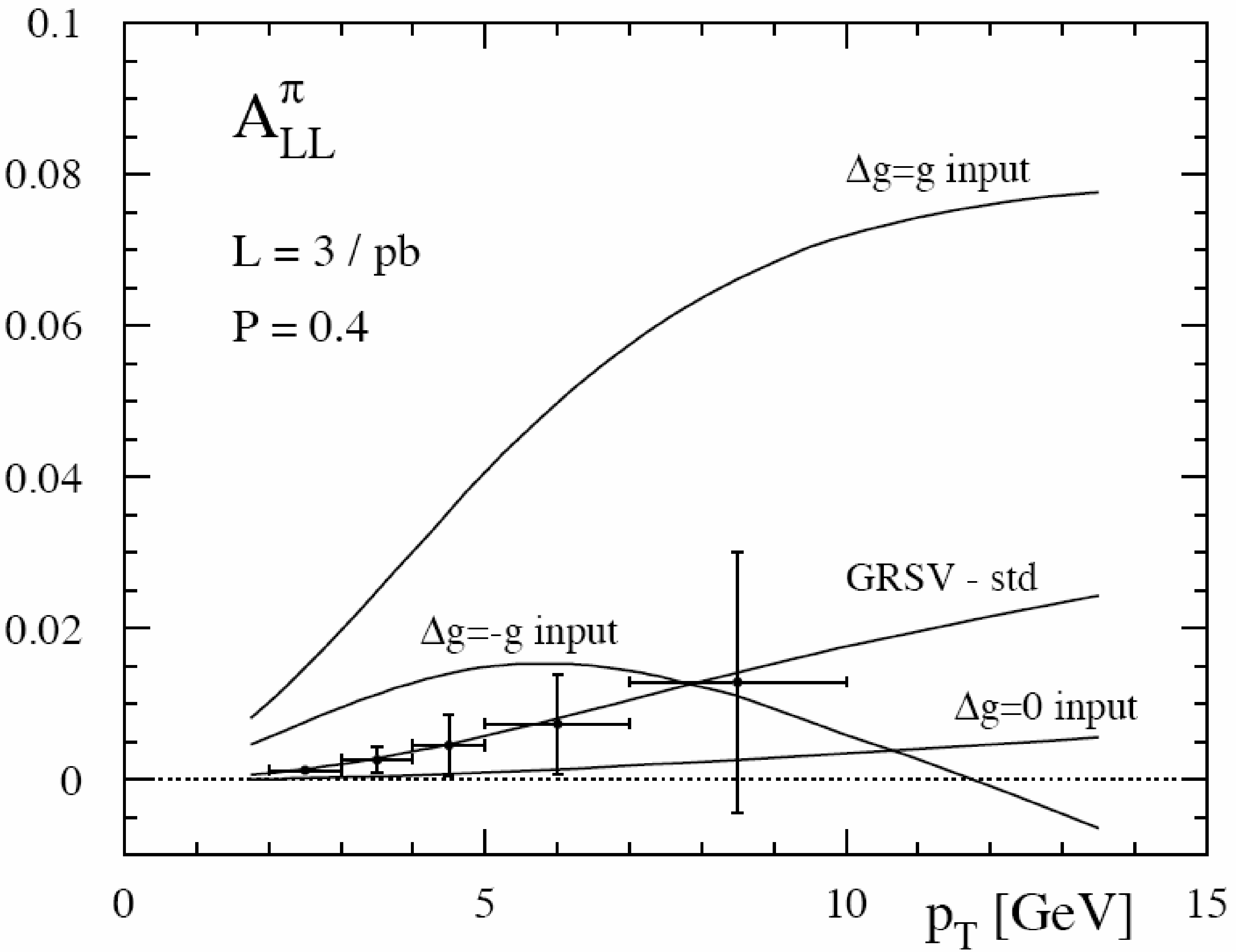
$$A_{LL} = (\Delta g(x))^2 \ \underset{>0}{\mathcal{A}} + \Delta g(x) \ \underset{>0}{\mathcal{B}} + \mathcal{C}$$

- a parabola – with a minimum that is negative, but tiny

$p_\perp = 1.5$ GeV : $\boxed{A_{\rm LL}^{\pi} \approx -10^{-4}}$

$p_\perp = 4.5$ GeV : $\boxed{A_{\rm LL}^{\pi} \approx -10^{-3}}$

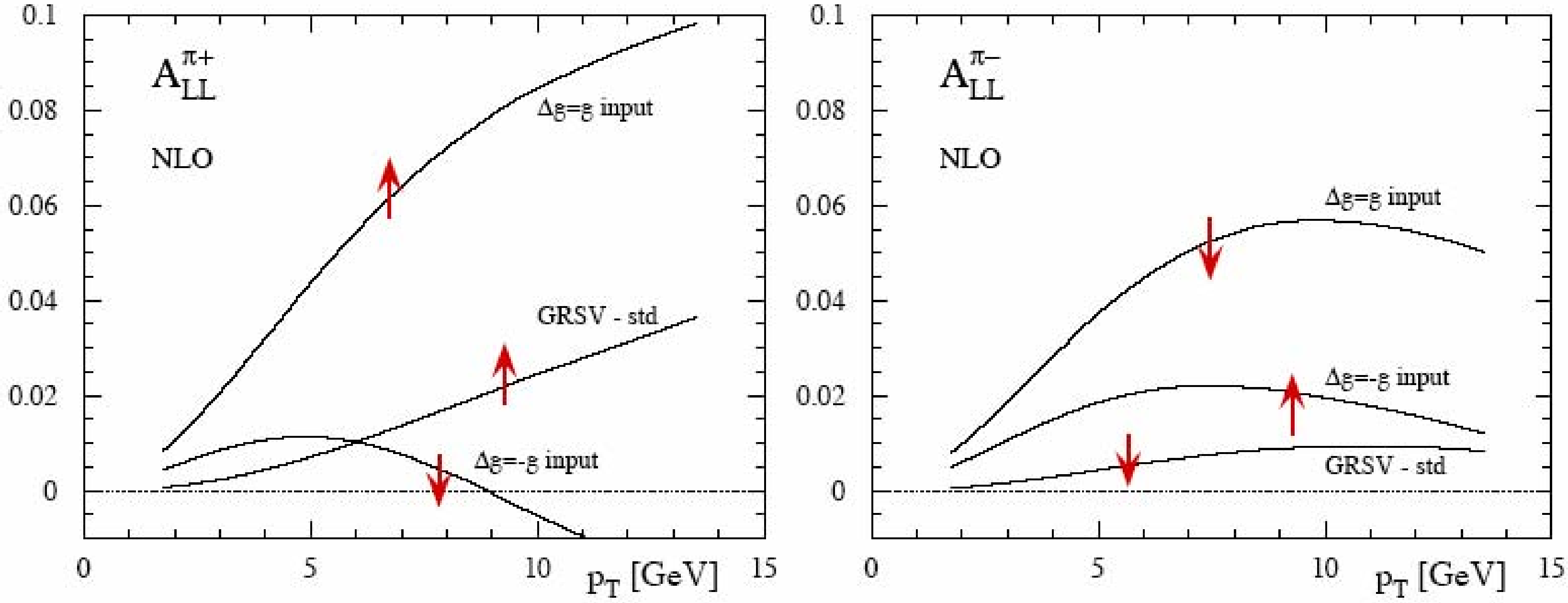
- can be shown with more rigor   Jäger,Kretzer,Stratmann,WV near-term future :



π^+ and π^-

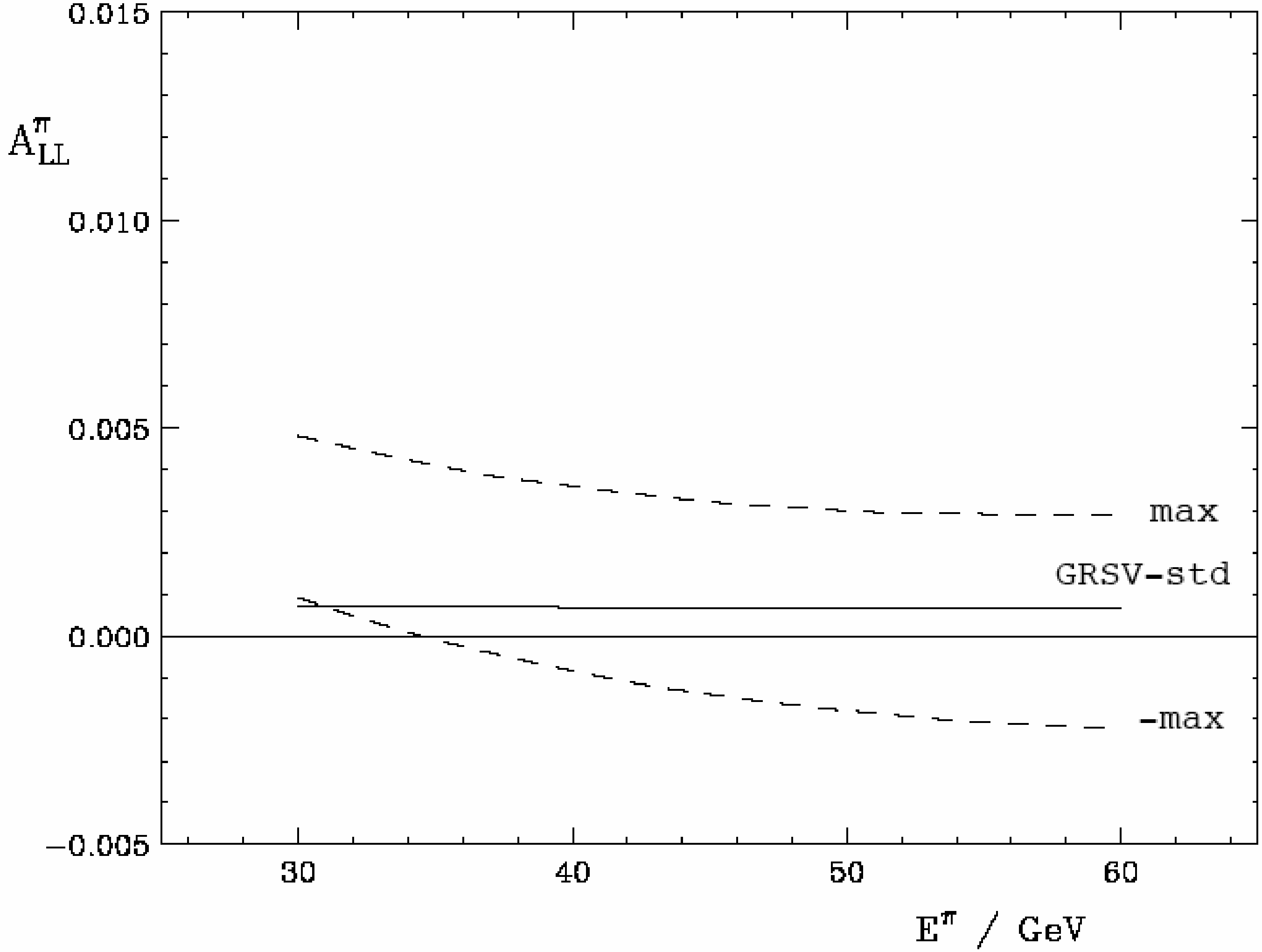
positive Δg: $A_{LL}^{\pi^+} > A_{LL}^{\pi^0}$
negative Δg: $A_{LL}^{\pi^+} < A_{LL}^{\pi^0}$

positive Δg: $A_{LL}^{\pi^-} < A_{LL}^{\pi^0}$
negative Δg: $A_{LL}^{\pi^-} > A_{LL}^{\pi^0}$



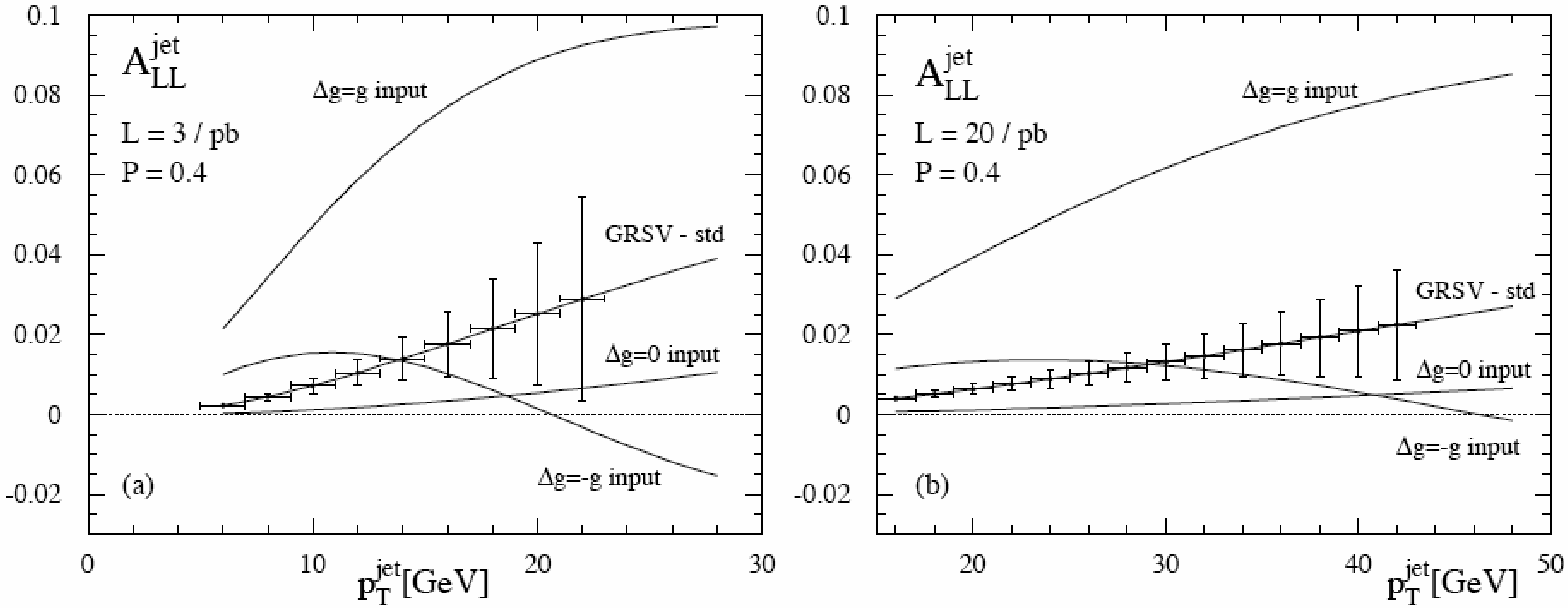
…only at $p_T > 5$ GeV, good statistics required

$pp \to \pi^0 X\,, \;\; \sqrt{S} = 200\,\mathrm{GeV}\,, \;\; \eta \, = \, 3.3$



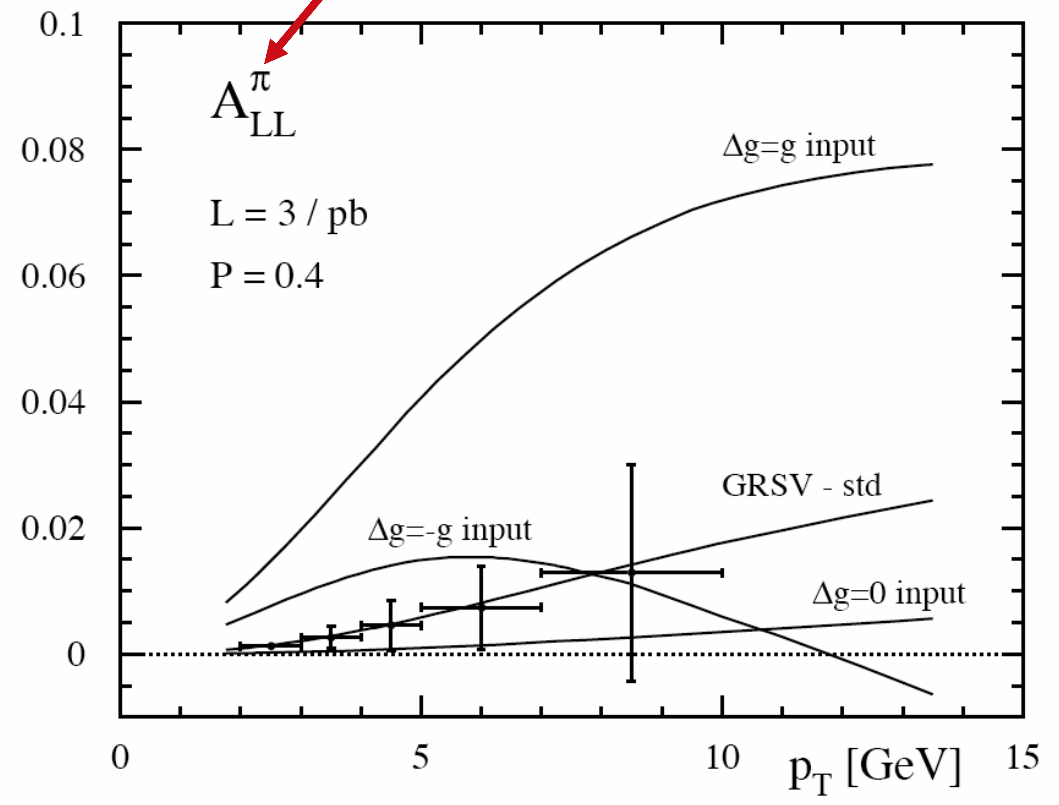
- dominance of $qg \to qg$ sets in

Spin asymmetry for jet production:

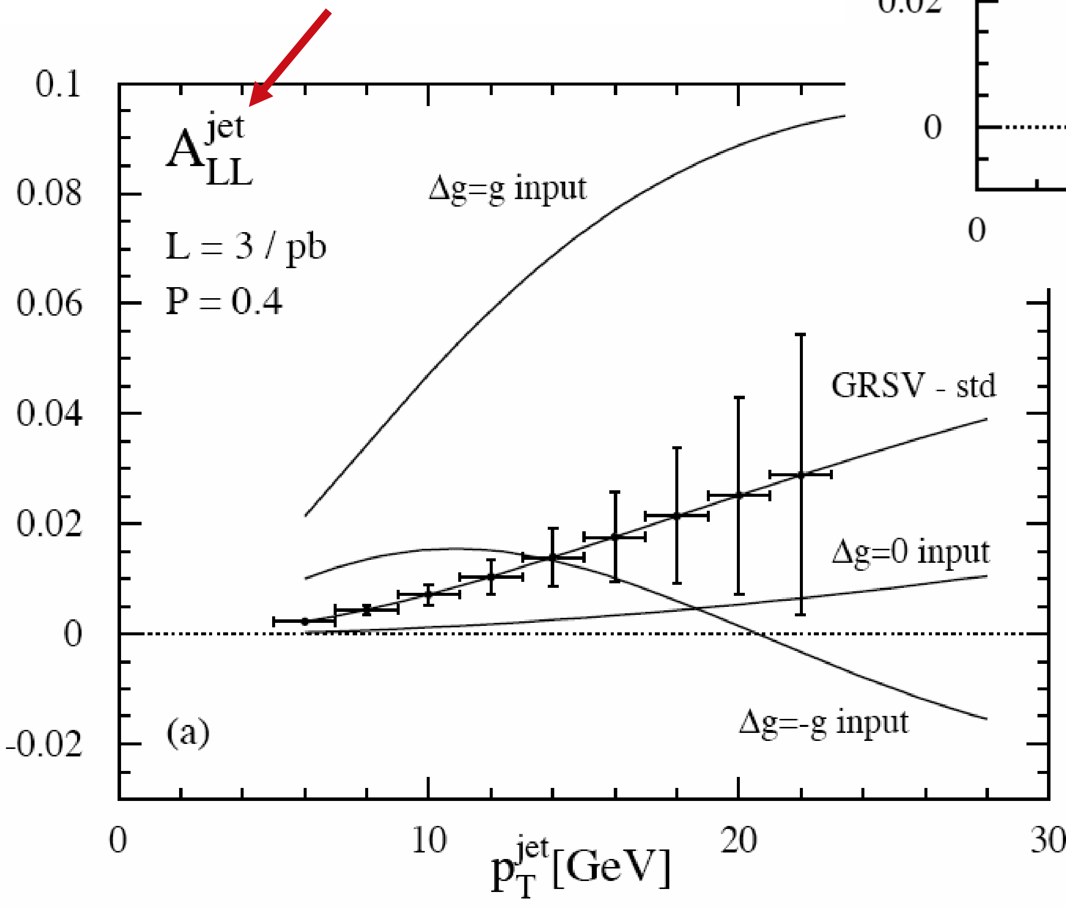


Jäger, Stratmann, WV

(de Florian, Frixione, Signer, WV)



0.1
0.08
0.06
0.04
0.02
0
A_{LL}^{π}
L = 3 / pb
P = 0.4
Δg=g input
GRSV - std
Δg=-g input
Δg=0 input
0
5
10
15
p_T [GeV]

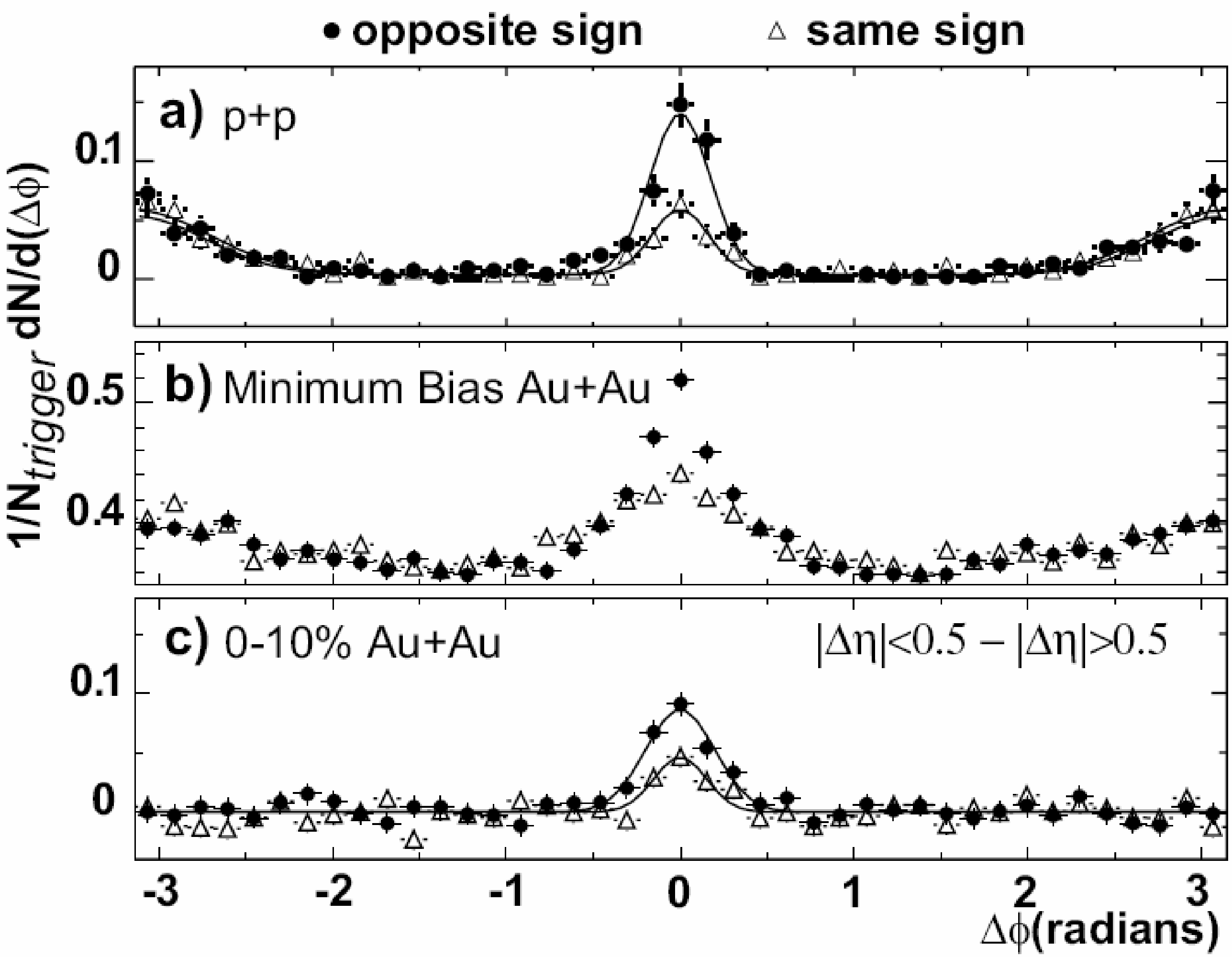


0.1
0.08
0.06
0.04
0.02
0
-0.02
A_{LL}^{jet}
Δg=g input
L = 3 / pb
P = 0.4
GRSV - std
Δg=0 input
Δg=-g input
(a)
0
10
20
30
p_T^{jet}[GeV]

Asymmetric jet correlations in $p^{\uparrow}p$

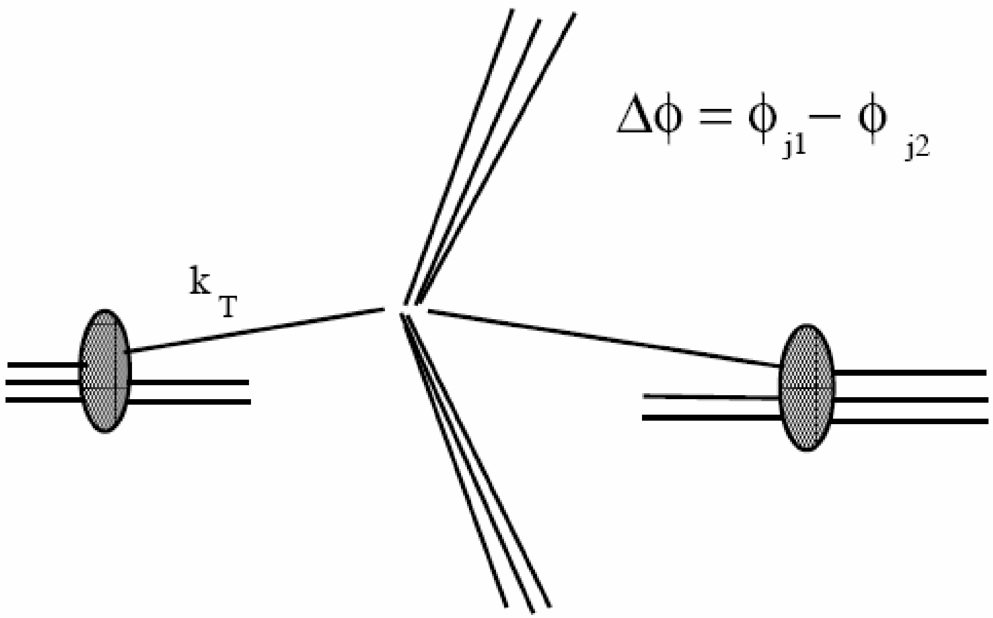
and the Sivers functions

* recent STAR for back-to-back hadrons :

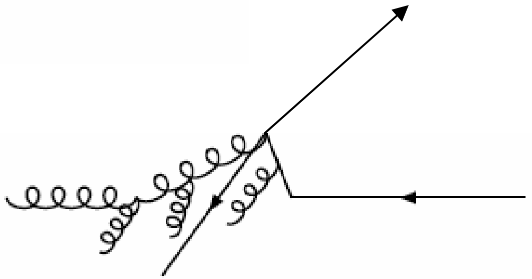


- 2 -> 2 scattering: exactly back-to-back

- intrinsic k_T of partons

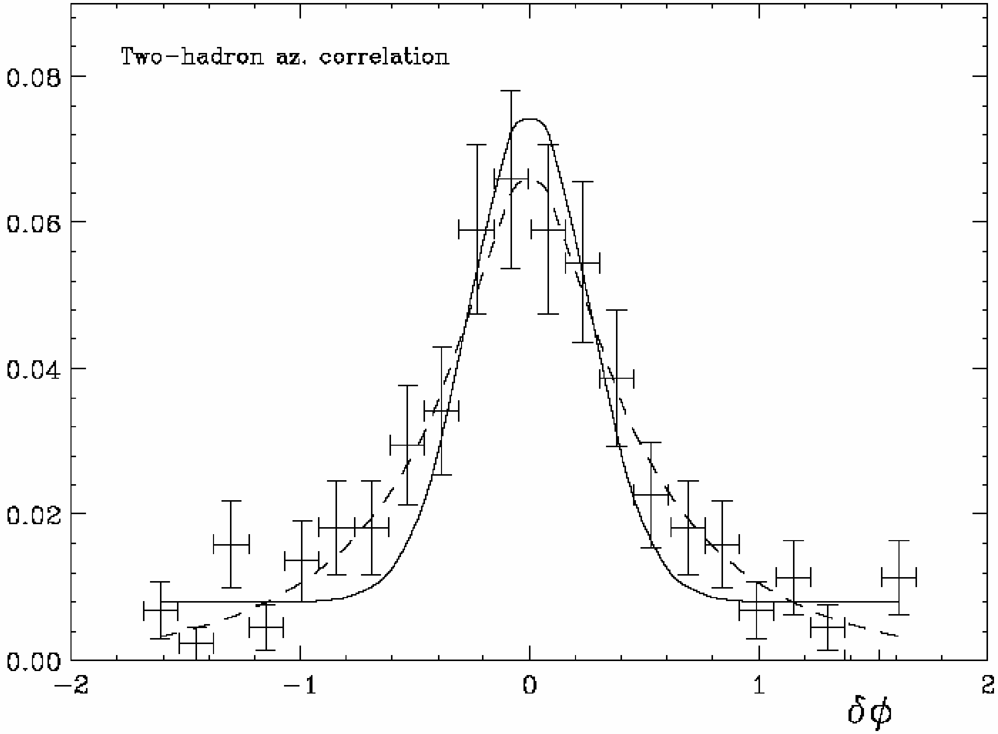


- gluon radiation: Sudakov effects



- Gaussian $k_\perp$ distribution for partons yields unpol. correlation :

$$\mathcal{U} \propto \; e^{a(1+\cos(\delta\phi))}$$



$\sqrt{\langle k_\perp^2 \rangle} \; \approx \; 2$ GeV

STAR

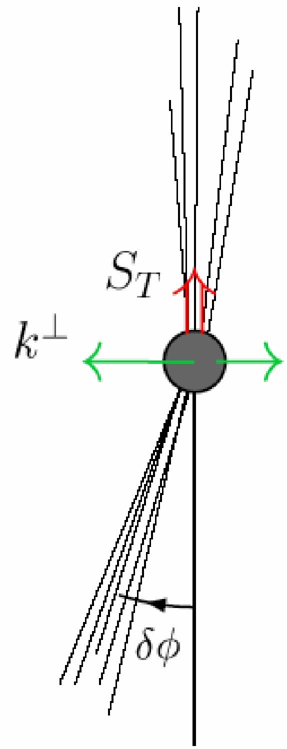
- dashed line: including Sudakov effects

  * markedly better agreement with data; $\sqrt{\langle k_\perp^2 \rangle} \; \approx \; 0.9$ GeV

What's in it for spin ?

- consider $p^{\uparrow}p \longrightarrow$ jet jet X

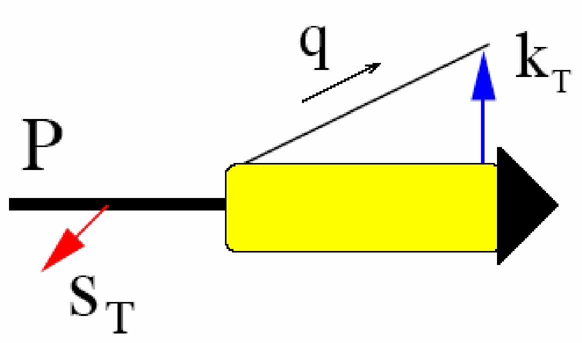
Boer, WV



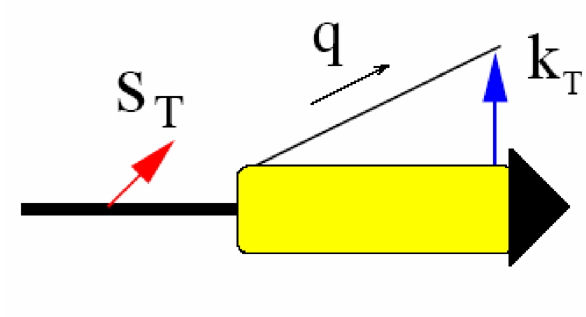
$$\delta\phi = \phi_2 - \phi_1 - \pi$$

- realized if

Sivers '90



$\neq$



- correlation $\sim \vec{S}_T \cdot \left(\vec{P} \times \vec{k}_T\right)$

- requires transverse momentum k_T for quark
- interference of $J_z = +\frac{1}{2}$ and $J_z = -\frac{1}{2}$ amplitudes
- involves quark orbital angular momentum

- rich phenomenology in single-spin asymmetries

- Sivers type correlation :

$$f_{1T}^{\perp}(k_{\perp}) \propto k_{\perp}^{x}\, \mathrm{e}^{-(k_{\perp})^2/\langle\kappa_{\perp}^2\rangle}$$

- leads to spin asymmetry

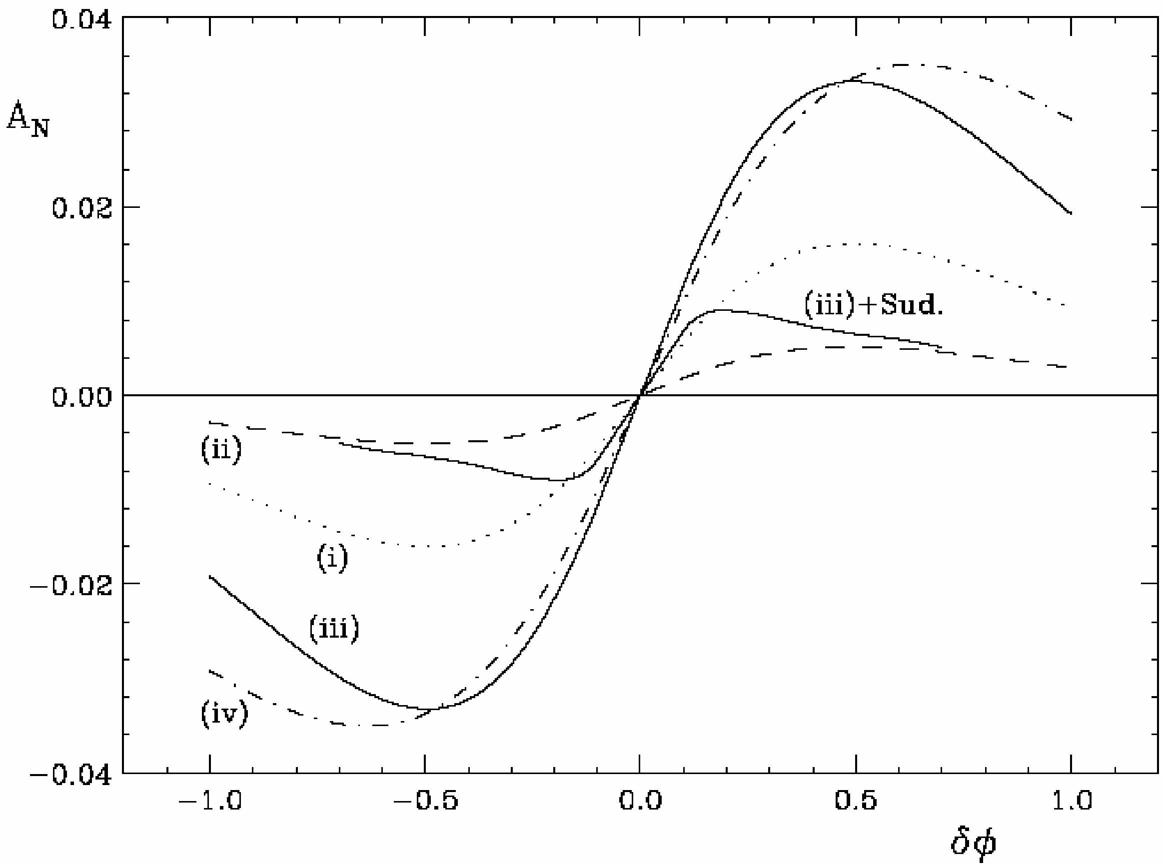
$$\propto \left(|\boldsymbol{P}_{j_1}^{\perp}|\sin\phi_{j_1} + |\boldsymbol{P}_{j_2}^{\perp}|\sin\phi_{j_2}\right)\, e^{-\left[P_{j_1}^{\perp\,2}+P_{j_2}^{\perp\,2}+2P_{j_1}^{\perp}P_{j_2}^{\perp}\cos(\Delta\phi)\right]/\left(\langle\kappa_1^{\perp\,2}\rangle+\langle k_2^{\perp\,2}\rangle\right)}$$

- for $\vec{P}_c^{\perp} \;\|\; \vec{S}_{\perp}$

$$\propto\; \sin(\delta\phi)\, \mathrm{e}^{a\,(1+\cos(\delta\phi))}$$

- use parameters of Anselmino,D'Alesio,Murgia
- very sensitive to gluon Sivers function (various models)

$\sqrt{S} = 200\,\mathrm{GeV},\ 8 \le p_{T_{1,2}} \le 12\ \mathrm{GeV},\ -1 \le \eta_{1,2} \le 1$ Boer,WV



- Sudakov effects
- factorization ?

Conclusions :

Δg

- a lot can be learned from jets and hadrons
- sign of Δg from forward region ?
- most theoretical tools in place – some challenges remain

A_{N}

- large potential for back-to-back observables