Spin Physics results from

PHENIX

International conference on New Frontiers in Physics 2015, Kolymbari, Greece
August 25, 2015

Ralf Seidl
(RIKEN)
For the PHENIX collaboration
Spin and Nucleon structure: Test-bed to theories

- Spin is extremely relevant to the understanding of matter, many surprises when studying spin quantities.
- Naïve spin composition by otherwise successful quark model not valid → Spin crisis.
- Traditional pQCD did not care about transverse momenta and expected small transverse spin effects → Large asymmetries seen, resulting in boost of our theoretical understanding of the nucleon AND QCD, connection to LHC.
• Polarized proton beams from $\sqrt{s}$ of 62-510 GeV
• pA, AA collisions up to 200 GeV
• Spin rotators around PHENIX and STAR to select long. or transversely polarized beams
• Global and local polarimetry
Polarized proton beams from $\sqrt{s}$ of 62-510 GeV
- pA, AA collisions up to 200 GeV
- Spin rotators around PHENIX and STAR to select long. or transversely polarized beams
- Global and local polarimetry
Longitudinal Spin: Main Questions

• The momentum of the proton is made up to 50% by gluons and 50% by quarks, is it similar for the spin?
• What happens to quark spins when approaching x=1, helicity retention?
• The un-polarized sea is not symmetric, is the polarized sea symmetric?
• Are the strange (and other sea) quark helicities really negative at unmeasured low x?
• Not just spins but also Orbital angular momentum can contribute – does it? If so, how much?
Gluon polarization

- Barely access via DIS data through DGLAP evolution (no large $Q^2$ lever arm)
- Some access in SIDIS through high $P_t$ hadrons and charmed mesons
Gluon polarization

- Barely access via DIS data through DGLAP evolution (no large $Q^2$ lever arm)
- Some access in SIDIS through high Pt hadrons and charmed mesons
- Polarized $pp$ collisions at LO in $\alpha_s$ sensitive to gluons
  - long. double spin asymmetries $A_{LL}$ access $\Delta g$
Current highlights: gluon helicities

- 200 GeV up to 2009 did not show any large $A_{LL}$
- First indications of nonzero gluons in 2009 data, especially Star's jet $A_{LL}$s
First nonzero gluon spin indication


- Low $x$, not covered so far $\rightarrow$ more forward pp, EIC

- $x$ region covered by current RHIC and DIS results
Other 200 GeV results not yet used in global fit

- Charged pions as potential direct indicator for sign of $\Delta g$ via pion $A_{LL}$ ordering
- 500 GeV analysis ongoing
- Reduced statistics compared to $\pi^0$ due to triggering
- Also central $\eta$

Single electrons at central rapidity from heavy flavor production directly sensitive to gluon helicity

Large scale given by the HF quark masses
Next steps: extend gluon x range

- **Higher beam energies** at 510 GeV in 2011-2013 increase sensitivity towards lower x for workhorse measurements (central pions and Jets)
- **Forward measurements** will access more asymmetric collisions and even lower x to below \( x = 10^{-2} \) in forward pion and jet measurements
- Improved precision in central jet and pion measurements
- Later: Forward jet and Di-jets to scan x range

Even lower x accessible eventually at EIC
Forward J/Psi asymmetries @ 510 GeV

- J/Psi predominantly produced via gluon-gluon scattering
- Access to $x_g \sim 2-3 \times 10^{-3}$
- Production mechanism still not entirely clear
- Feed down with similar gluon dependence
510 GeV $\pi^0$ results

- Large 2013 data set provides very sizeable, nonzero asymmetry
- Consistent with latest DSSV14 results
- Effect of DGLAP evolution visible between 200 and 510 GeV data
- Systematics due to luminosity normalization between same and opposite helicity collisions reduced to be smaller than low $P_T$ statistical uncertainties
Expected impact of existing RHIC data

Forward $\pi^0$ in $3.1<\eta<3.9$, $p_T>1$GeV

• 2013 data analysis of forward $\pi^0$/clusters sensitive to lower $x$
• Analysis ongoing

• Running integral of the total gluon helicity

RHIC Spin LRP white paper:

Forward $p_0$ in $3.1<\eta<3.9$, $p_T>1$GeV
Expected impact of existing RHIC data

Forward $\pi^0$ in $3.1 < \eta < 3.9$, $p_T > 1\text{GeV}$

- 2013 data analysis of forward $p^0$/clusters sensitive to lower $x$
- Analysis ongoing

- Running integral of the total gluon helicity

Expected impact of existing RHIC data

- 2013 data analysis of forward $\pi^0$ in $3.1 < \eta < 3.9$, $p_T > 1$ GeV
- Analysis ongoing


- Running integral of the total gluon helicity
Real W production as access to quark helicities

- Maximally parity violating V-A interaction selects only lefthanded quarks and righthanded antiquarks:
  - Having different helicities for the incoming proton then selects spin parallel or antiparallel of the quarks
  - Difference of the cross sections gives quark helicities $\Delta q(x)$

- No Fragmentation function required
- Very high scale defined by W mass

Sea quark polarization via $W$ production

- Single spin asymmetry proportional to quark polarizations
- Large asymmetries
- Forward/backward separation smeared by $W$ decay kinematics

\[
A_L^{W^+} \approx \frac{-\Delta u(x_1)\bar{d}(x_2)(1 - \cos \theta)^2 + \Delta \bar{d}(x_1)u(x_2)(1 + \cos \theta)^2}{u(x_1)\bar{d}(x_2)(1 - \cos \theta)^2 + \bar{d}(x_1)u(x_2)(1 + \cos \theta)^2}
\]

\[
A_L^{W^-} \approx \frac{-\Delta d(x_1)\bar{u}(x_2)(1 + \cos \theta)^2 + \Delta \bar{u}(x_1)d(x_2)(1 - \cos \theta)^2}{d(x_1)\bar{u}(x_2)(1 + \cos \theta)^2 + \bar{u}(x_1)d(x_2)(1 - \cos \theta)^2}
\]
Central $W^+Z^0 \rightarrow e$ asymmetries

arXiv:1504.07451

- Leptonic $W$ decays very clearly visible via Jacobian peak
- Large asymmetries found, consistent with STAR 2012 data
- $e^-$ significantly above latest global fit
Forward $W+Z \rightarrow \mu$ asymmetries

- At forward rapidities no Gaussian peak to identify $W$ decay muons
- Lower $P_T$ hadrons as fake high $P_T$ "muons"
- Successfully performed unbinned max likelihood analysis to identify signal
- Asymmetries as expected
- Still working on improving the uncertainties
Forward $W+Z \to \mu$ asymmetries

- At forward rapidities no Gaussian peak to identify $W$ decay muons
- Lower $P_T$ hadrons as fake high $P_T$ “muons”
- Successfully performed unbinned max likelihood analysis to identify signal

- Asymmetries as expected
- Still working on improving the uncertainties
Expected impact on sea quark helicities

- Already from existing data indication of asymmetric polarized light sea
- Opposite sign to unpolarized light sea asymmetry disfavors pion cloud based models
Transverse single spin asymmetries

- Large left-right asymmetries $A_N$ seen in polarized pp collisions from low energies up to RHIC energies
- Both initial state and final state effects contribute
- Some indications for potentially other origins
- Near term: concentrate on disentangling initial state (direct $\gamma$, jets) from final state (Collins in jet), coincidence with Roman pots and forward neutrons
- Drell Yan as test for our understanding in sign change compared to SIDIS Sivers asymmetries

Polarized pA collisions taken in 2015 of interest for low $x$ behavior of cold nuclear matter $\rightarrow$ A dependence of single spin asymmetries?

Phys.Rev. D90 (2014) 1, 012006
Outlook:

a new detector + Babar magnet

- Open questions in spin accessible in pp before EIC:
  - Lower x gluon access via more forward jets and di-jets
  - Remaining open questions about large single transverse spin asymmetries in pp (unique to RHIC): jet $A_N$, direct $\gamma A_N$, Drell Yan

  ➔ For spin forward rapidities 2-4 are most interesting

- PHENIX will finish data-taking in 2016 ➔ construction of new detector around Babar solenoid

  ➔ More in Talk by Mike McCumber tomorrow