

**RHIC Beam Use Request**

**For Runs 15 and 14**

**The STAR Collaboration**

**Version 1**

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# Executive Summary

# Highlights from STAR Science Programs:

## Polarized Proton+Proton Data:

### The Proton Helicity Structure:

The STAR spin physics program seeks to advance our understanding of the spin and flavor structure of the proton in terms of its constituent quarks and gluons, exploiting the unique capability of RHIC to provide access to polarized p+p collisions.  Using longitudinally polarized beams, one can probe the helicity preferences of the gluons and (flavor-separated) antiquarks, to determine the contribution of each to the total spin of the proton.  With spins transverse to their momentum direction, the p+p collisions exhibit kinematic and dynamical effects that are directly sensitive to quark transversity and partonic motion within the proton.  This program is complemented by studies of polarized p+p elastic scattering and central exclusive production, in which a far-forward proton is detected intact.

Since 2009 RHIC has just completed several very successful polarized p+p runs both at *√s* = 200 GeV and *√s* = 510 GeV. The STAR recorded luminosity and the average beam polarization as measured by the H-jet polarimeter are summarized in Table 2‑1.

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| **Year** | **√s (GeV)** | **Recorded Luminosity for Transverse p+p** | **Recorded Luminosity for Longitudinal p+p** | **<P>** |
| 2009 | 200  500 |  | 25 pb-1  10 pb-1 | 55  39 |
| 2011 | 500 | 25 pb-1 | 12 pb-1 | 48 |
| 2012 | 200  510 | 22 pb-1 | 82 pb-1 | 61/58  50/53 |
| 2013 | 510 |  | 300 pb-1 | 50/53 |

Table ‑: The STAR recorded luminosity and the average beam polarization as measured by the H-jet polarimeter.

These data sets formed the basis for papers and new preliminary results, which are highlighted in the following. Since the last PRC the STAR spin-working group published one paper in PRD [[[1]](#endnote-1)] and submitted two to PRL [[[2]](#endnote-2),[[3]](#endnote-3)]. The later two present milestones in our understanding of the proton helicity structure and such how the spin of the proton is decomposed by it constituents.

The inaugural run at √s = 500 GeV in 2009 yielded the first but still statistics challenged measurement of the longitudinal single-spin asymmetry *AL* in W± production [[[4]](#endnote-4)]. The rapid analysis of the 2011 (√s = 500 GeV ) and the high statistics 2012 (√s = 510 GeV) longitudinal polarized p+p data sets yielded the first results for *W±* providing impact on the light sea quark polarizations. Figure 2‑1 shows the final result of the longitudinal single-spin asymmetry, *AL*, for *W±* production as a function of lepton pseudorapidity *e*, in comparison to theory predictions. The STAR preliminary *AL* results based on the 2012 data set alone, have been included pQCD-fit by the DSSV group [[[5]](#endnote-5)]. A clear improvement on the determination of the polarization of the light sea quarks was observed. For a shift away from the current best mean value was observed, reflecting that the new STAR data lie above the central curve based on DSSV fits to semi-inclusive and inclusive data. Already, with only the preliminary 2012 STAR data, the new global analysis showed a preference for in the range x > 0.05. New pQCD fits based on the published STAR data are already underway by the DSSV and NNPDF groups.



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| Figure ‑: Longitudinal single-spin asymmetry, *AL*, for *W±* production as a function of lepton pseudorapidity *e*, in comparison to theory predictions. | Figure ‑: Midrapidity (|**| < 0.5, upper panel) and forward rapidity (0.5 < |**| < 1, lower panel) inclusive jet *ALL* vs. parton jet *pT*, compared to predictions from several NLO global analyses. The error bars are statistical. The gray boxes show the size of the systematic uncertainties. |

In 2009, with improved luminosity and polarization, as well as upgraded triggering and data acquisition systems at STAR, the uncertainties on the inclusive jet *ALL*measurements at √s = 200 GeV could be considerably improved. Figure 2‑2 shows the final inclusive jet *ALL* vs. parton jet *pT* at Midrapidity (|**| < 0.5, upper panel) and forward rapidity (0.5 < |**| < 1, lower panel), compared to predictions from several NLO global analyses. The error bars are statistical. The gray boxes show the size of the systematic uncertainties. The impact of the new inclusive jet data on the polarized gluon distribution and its integral was studied using the reweighting method developed by the NNPDF group [[[6]](#endnote-6)], which allows to include new experimental data into an existing PDF set without the need to repeat the entire fitting process. The obtained results are shown in Figure 2‑3. The integral of *g(x,Q2=10 GeV2)* over the range 0.05 < *x* < 0.5 is 0.06 ± 0.18 for the original NNPDF fit and 0.21 ± 0.10 when the fit is reweighted using the STAR jet data. The DSSV group has performed a new global analysis [[[7]](#endnote-7)] including the STAR jet *ALL* results. They find that the integral of *g(x,Q2=10 GeV2)* over the range *x* > 0.05 is at 90% C.L., consistent with the value STAR finds by reweighting the NNPDF fit.



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|  | Figure ‑: Gluon polarizations from NNPDF (blue dot-dashed curve, 135o hatched uncertainty band), and from modified versions of NNPDF that we obtain when including the 2006 (green dashed curve, 45o hatched uncertainty band) or 2006+2009 (red solid curve and uncertainty band) STAR inclusive jet *ALL* results through reweighting. |

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### The 2+1 Dimensional Structure of the Proton

A natural next step in the investigation of nucleon structure is an expansion of our current picture of the nucleon by imaging the proton in both momentum and impact parameter space. At the same time we need to further our understanding of color interactions and how they manifest in different processes. In the new theoretical framework of transverse momentum dependent parton distributions (TMDs) we can obtain an image in the transverse as well as longitudinal momentum space (2+1 dimensions). This has attracted renewed interest, both experimentally and theoretically in transverse single spin asymmetries (SSA) in hadronic processes at high energies, which have a more than 30 years history. First measurements at RHIC have extended the observations from the fixed-target energy range to the collider regime up to the highest center-of-mass energies to date at RHIC of √s = 500 GeV. Figure 2‑4 summarizes the measured asymmetries from different experiments as functions of Feynman-*x* (*xF ~ x1-x2*).

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| Figure ‑: Transverse single spin asymmetry measurements for charged and neutral pions at different center-of-mass energies as function of Feynman-*x.* |

The surprisingly large asymmetries seen are nearly independent of  over a very broad range. To understand the observed significant SSAs one has to go beyond the conventional collinear parton picture in the hard processes. Two theoretical formalisms have been proposed to generate sizable SSAs in the QCD framework: transverse momentum dependent parton distributions and fragmentation functions, which provide the full transverse momentum information and the collinear quark-gluon-quark correlation, which provides the average transverse information. STAR has made several important contributions to this program, primarily through study of forward neutral pion production in p+p collisions (see, for example, ref. [1,[[8]](#endnote-8)]). This effort has been extended to include the first measurements at *√s* = 200 GeV of the transverse spin asymmetry *AN* for the *η* meson [[[9]](#endnote-9)]. The Run-11 data taken with transverse polarization at *√s* = 500 GeV have revealed several surprising results. Figure 2‑5 shows the transverse single spin asymmetry *AN* for electromagnetic jets detected in the forward meson spectrometer (2.5 < ** < 4.0) as function of the jet *pT* and the photon multiplicity in the jet in bins of the jet energy. It can be clearly seen that with increasing number of photons in the electromagnetic jet (increasing jettiness of the event) the asymmetry becomes smaller and smaller. Jets with isolated *0*have the largest asymmetry consistent with the asymmetry in inclusive *0*events, see Figure 2‑4 most right panel. For all jet energies and photon multiplicities in the jet the asymmetries are basically flat as function of jet *pT* , a feature also already seen for inclusive *0* asymmetries.

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| Figure ‑: The transverse single spin asymmetry *AN* for electromagnetic jets detected in the forward meson spectrometer (2.5 < ** < 4.0) as function of the jet *pT* and the photon multiplicity in the jet in bins of the jet energy. |

To further study these effects the transverse single spin asymmetry *AN* of these electromagnetic jets was measured if in addition a correlated away side jet in the rapidity range -1 <  < 2 was required. Figure 2‑6 shows clearly that for requiring an additional correlated away-side jet the asymmetry for isolated forward 0s becomes smaller. For further details see reference [[[10]](#endnote-10)].

All these observations raise serious questions how much of the large forward *0*asymmetries are caused by 2🡪2 parton scattering processes.

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| Figure ‑: The transverse single spin asymmetry AN for electromagnetic jets detected in the forward meson spectrometer (2.5 < ** < 4.0) as function of the jet pT and the photon multiplicity in the jet in bins of the jet energy (red points). The blue points represent the transverse single spin asymmetry AN if further a correlated away side jet in the rapidity range -1 <  < 2 was required. The blue and red bands represent the systematic uncertainties. |

The Sivers function  is one of the transverse dependent parton distribution functions, which is of special interest. It describes the correlation of parton transverse momentum with the transverse spin of the nucleon. A non-vanishing means that the parton distribution will be azimuthally asymmetric in the transverse momentum space relative to the nucleon spin direction. There is evidence of a quark Sivers effect in semi-inclusive DIS (SIDIS) measurements of the HERMES, COMPASS, and JLab Hall-A experiments [[[11]](#endnote-11)]. An important aspect of the Sivers effect, which has emerged from theory lately, is its process dependence and the color gauge invariance. In SIDIS, the quark Sivers function is manifested in association with a final state effect from the exchange of (any number of) gluons between the struck quark and the remnants of the target nucleon. On the other hand, for the virtual photon production in the Drell-Yan process, the Sivers asymmetry appears as an initial state interaction effect. As a consequence, the quark Sivers functions are of opposite sign in these two processes and this non-universality is a fundamental prediction from the gauge invariance of QCD. The experimental test of this sign change is one of the open questions in hadronic physics and will provide a direct verification of QCD factorization.



While the required luminosities and background suppressions for a meaningful measurement of asymmetries in Drell-Yan production are challenging, other channels can be exploited in *p*+*p* collisions, which are similarly sensitive to the predicted sign change. These include prompt photons, W+/- and Z bosons, and inclusive jets. These are either already accessible with the existing STAR detector or need only modest upgrades and continued polarized beam operations.

The transverse polarized data taking in run-11 at *√s* = 500 GeV allowed to reconstruct the transverse single spin asymmetries for *AN*for W+/- and Z0 Bosons. Especially the measurement of the *AN*for *W+/-* Bosons is challenging as contrary to the longitudinal case it is required to completely reconstruct the W-Bosons as the kinematic dependences of *AN*can not easily be resolved through the high *pT* decay lepton, for details see [[[12]](#endnote-12),[[13]](#endnote-13)]. Due to the large STAR acceptance it was possible to reconstruct the W-Boson kinematics from the recoil jet, a technique used at D0, CDF and the LHC experiments to reconstruct the W-Boson kinematics. Figure 2‑7 shows the transverse single spin asymmetries for *AN*for *W+/-* as function of the W-Boson rapidity *y*. The asymmetries have also been reconstructed as function of the pT of the W-boson. For the *Z0*-Boson the asymmetry could only be reconstructed in one bin in *y* due to the limited statistics (25 pb-1) of the Run-11 transverse polarized data set. Details for this analysis can be found in [[[14]](#endnote-14)]. The analysis represents an important proof of principal equally as the run-09 *W+/- AL* measurement that a higher statistics run will allow to access the sign change and to constrain the till today unknown sea quark Sivers functions.

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| hd_Wp_AsymAmpSqrtVsRap.eps | hd_Wm_AsymAmpSqrtVsRap.eps |
| Figure ‑: The transverse single spin asymmetries for *AN*for W+/- as function of the W-Boson rapidity y. | |

**Paragraph on highlighting dA ridge result.**

# Run-14 Performance Report

# Run-15 BUR request on p+p and p+A collisions

In Run 13 STAR collected 3.5 times the Run 12 data set with longitudinal polarization at *√s* = 510 GeV. The beam polarizations attained at 510 GeV has stately increased from Run 9 and reached up to <P> ~ 54%. To build on these successes we request 12 weeks of polarized p+p operation at *√s* = 200 GeV in Run 15. The data would be split between longitudinally and transversely polarized data taking at STAR. As the polarization directions at IR-6 and IR-8 are completely independent from each other there is no interference between PHENIX and STAR choosing different polarization directions. Based on the guidance latest guidance from CAD we assume a delivered integrated luminosity of 45 pb-1 for the first 5 weeks and 15 pb-1/week for the later weeks, such a total delivered integrated luminosity of ~150 pb-1 with an average polarization of 60%. With an average data taking efficiency of 0.7 this would result in a integrated recorded luminosity of ~100 pb-1. The running time would be split equally between transverse and longitudinal running. Such a data set would significantly advance the STAR spin physics effort; in particular, our analyses would focus on:

* The impact of the increased precision in measurements of the double-spin asymmetry *ALL* in inclusive jet and coincident di-jet production is discussed in chapter 4.1
* The increased statistics in transverse polarized data together with the new equipment installed for run-15 (Roman Pot Phase-II\* and the FMS preshower) will allow us to address the underlying physics causing the large transverse single spin asymmetries AN at forward rapidities by measuring less inclusive observables, i.e. IFF, jets and direct photons. Details are discussed in chapter 4.2**.**

STAR assumes for 2015 a run with 22 cryo-weeks, which are split in 12 weeks polarized p+A collisions and 5 weeks of transversely polarized p+p collisions. To allow for new physics observables, discussed in section 4.1 and 4.2, in polarized p+p and p+A collisions several smaller detector upgrades need to be realized.

1. the Roman pot system of pp2pp is moved to a new location in the DX-D0 region (for details see section 6.1)
2. a pre-shower detector is installed in front of the STAR FMS (for details see section 6.2)

## Physics with 200 GeV longitudinally polarized p+p collisions

The final results, obtained in Run 9, on the double-spin asymmetry *ALL* in inclusive jet production at √s = 200 GeV from 20 pb-1 sampled with 58% average beam polarization are shown in Figure 2‑2. Both from the latest *g(x,Q2)* extractions from DSSV and STAR through the NNPDF reweighting technique it is obvious that the uncertainties on the polarized gluon distribution need to be further decreased in the x-range currently already covered by measurements and that measurements are need to extend to the till today unexplored lower x-range.

Run-15 is an integral part of a three-step plan to further advance our knowledge about the polarized gluon distribution and its integral. The plan follows these steps:  (1) reduce the statistical and systematic uncertainties of the workhorse of the STAR *Δg* program, inclusive jet *ALL*. (2) Make use of correlation measurements such as di-jets and di-hadrons, which give access to the partonic kinematics and thus the functional form of *Δg(x)* (Note: and, where η1,2 represent the pseudorapidities of the two outgoing partons). The functional form of *g(x)* also provides insight in the dynamical origin of gluons inside the proton. First results from di-jets from STAR have been released. (3) Access lower *x* by performing measurements at=500 GeV and at large forward rapidity.

A new data set of 50 pb-1 with 60% longitudinal polarization as anticipated for run-15 will provide a reduction by a factor of nearly 2 at high *pT* > 15 GeV/c while a smaller improvement by about √2 is still achievable at smaller *pT*. Doing so would provide significant further constraints on the polarized gluon distribution, especially for large momentum fractions *x*. The anticipated improvement in statistics on *ALL* and the complementarity in kinematics with √s = 510 GeV data is shown in Figure 4‑1. To quantify the impact of these inclusive jet *ALL* data sets on *g(x,Q2)* a pQCD fit in the DSSV framework based on pseudo data of the different data sets has been performed. Figure 4‑2 shows the improvement of the *χ2* profile for the integrated gluon contribution in the *x* region currently probed at RHIC. The current uncertainties for  will be reduced by a factor of 2. Of course the √s=500 GeV data will increase the x-range constrained by data down to x ~ 0.002.

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| Inclusive jets A_LL Runs 12+14 proj |  |
| Figure 4‑1: The expected precision for *ALL* vs. *pT* for inclusive jets at √s = 200 GeV p+p collisions after the proposed Run 15 data are combined with the existing Run 9 measurements (brown diamonds).  Also shown are the current Run 9 results (red diamonds) and the expected precision at √s = 510 GeV from Run 12 (blue squares), together with model predictions for both energies from GRSV-Std and DSSV 2008. | Figure 4‑2: The improvement of the χ2 profile for the integrated gluon contribution in the x region currently probed at RHIC for  = 200 GeV. The different curves represent including different data sets, red including the  = 510 GeV data from run 12 and 13 (red), blue including the expected data from run-15 (blue) and black represent a fit to all data at once. |

Figure 4‑3, Figure 4‑4 and Figure 4‑5 show the existing and projected uncertainties for the di-jet *ALL* as function of di-jet mass for different di-jet combinations. It is clearly visible that the new run-15 data set will also lead to significant improvement over the preliminary STAR measurements of the di-jet *ALL* at √s = 200 GeV from Run-09.

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|  | Figure ‑: Preliminary *ALL* di-jet as function of di-jets mass for from the run-09 √s = 200 GeV data taking. |

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|  | Figure ‑: Projected statistical uncertainties for *ALL*of di-jets at mid-forward rapidity at  = 500 GeV as function of di-jet mass. |

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|  | Figure ‑: Preliminary *ALL* for di-jet as function of di-jets mass for the upcoming run-15 √s = 200 GeV data taking. The assumed delivered luminosity is 75 pb-1 and a average polarization of 60% |

Combining the √s = 200 GeV di-jet *ALL* results from run-09 and run-15 with the results already taken and currently analyzed √s = 500 GeV di-jet *ALL* from run 12 and 13 will provide stringent constrains on the functional shape of the gluon distribution as well as on the overall value.

STAR can extend the physics reach of its gluon polarization measurement even further by tapping the low-*x* region accessible with both inclusive π0 and di-hadrons (π0s) and direct photon *ALL* in the Forward Meson Spectrometer (FMS) at 2.7<η<4.0. (Details about direct photon capabilities in the FMS are discussed in sections 4.2, 5.1 and 6.2). These important measurements will have a direct impact into any polarized NLO pQCD global analysis such as DSSV by supplying data in a previously unexplored kinematic zone.

**This paragraph will be expanded if I get reasonable projection for *ALL* π0 in the FMS.**

## Physics with 200 GeV transversely polarized p+p collisions

Determining the underlying physics process responsible for the large transverse single spin asymmetries at forward rapidities (see Figure 2‑4) is the new spin puzzle for the 21st century. As discussed earlier the processes deemed to be responsible go beyond the conventional collinear parton picture in the hard processes. The two theoretical formalisms, which can generate sizable SSAs in the QCD framework are: transverse momentum dependent parton distributions and fragmentation functions, which provide the full transverse momentum information and the collinear quark-gluon-quark correlation, which provides the average transverse information. The most prominent mechanisms in these frameworks possibly responsible for the large *AN* are transversity in combination with the Collins fragmentation function or the Sivers distribution function together with transverse momentum dependent fragmentation functions. To disentangle the different subprocesses it is important to measure less inclusive. Table 4‑1 identifies observables, which will help to separate the contributions from initial and final states, and will give insight to the transverse spin structure of hadrons. Depending the observable is a one-scale process, like most of the processes in p+p collisions we will probe the transverse spin structure of hadrons through the twist-3 formalism. Only 2-scale processes, like di-jets, W+/-, Z0 and DY, probe directly TMDs.

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| **Sivers** | **Transversity *h(x)* x Collins FF** |
| *AN* as function of rapidity, *ET, pT* and *xF* for inclusive jets, direct photons and charmed mesons  *AN*  as function of rapidity, *pT* for W+/-, Z0 and DY | *AN* as function *pT* and the invariant mass of the hadron pair (IFF)  Hadron correlations within a jet  *AUT* as function of the azimuthal dependence of the correlated hadron pair on the spin of the parent quark |

Table ‑: Observables to separate the contributions from initial and final states to the transverse single spin asymmetries. 2-scale processes are indicated in blue and 1-scale ones in black.

In the following the STAR capabilities to measure these different observables in run-15 will be discussed. With its broad acceptance for charged particles in the TPC, STAR is well positioned to carry out the study of di-hadron correlations within a jet, *i.e.*, at relatively small opening angle, where one works with the transverse momentum *pT* and the invariant mass of the pair, rather than with individual particle *pT*. These correlations can be described in terms of the product of the transversity *h(x)* and the so-called Interference Fragmentation Function, IFF, which is a chiral-odd quantity. Extracting the IFF in polarized *p+p* collisions at high energy is of particular interest as it will constrain *h(x)* at higher values of *x* than competing measurements in semi-inclusive DIS. Recent first results are shown in Figure 4‑6.

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|  | Figure ‑: (top)Preliminary measurements of the transverse single-spin asymmetry *AUT*, as defined in the text, as a function of the invariant mass of the unlike-sign di-pion. The choice of cone cut radius is strongly correlated with the average transverse momentum of the pair, as can be seen in the kinematic plot (bottom). |

The second observable is leading charged pions inside a reconstructed jet. In this case one is looking for correlations between the azimuthal distribution of the pion inside the jet and the spin orientation of the parent proton. Similarly to the IFF case, these correlations are sensitive to the product of transversity *h(x)* and the Collins Fragmentation Function *D(z),* also a chiral odd quantity. Measurements in semi-inclusive deep inelastic and electron-positron scattering have shown *D(z*) to be sizable and increasing with increasing pion momentum fraction *z*. Figure 4‑7 shows a recent measurement of this Collins asymmetry *AN* made using mid-rapidity jets reconstructed at STAR. It was calculated by forming the ratio of the of sum of the *sin(ϕh-ϕS)* weighted events and the sum of the polarization *P* weighted events. Systematic errors were conservatively estimated to be +/-0.023 for the π+ and π- results independently.

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| RESULTS.gif | Figure ‑: Preliminary results of the Collins moment for leading π+(red) and π-(blue) particles within mid-rapidity jets reconstructed by the STAR detector. Statistical errors are shown on data points and the grey shaded band indicates the systematic error bar for π+ and π- separately. |

Both the IFF and Collins analysis were exploratory measurements made using Run 6 transverse data. Indications of non-zero asymmetries motivated the extended 200 GeV running during Run 12 and for Run 15. Exceptional accelerator performance and high sampling rates at STAR during the 2012 run resulted in a sampled FOM of ~ 7.74 pb-1 in 5 weeks, compared to the ~2.2 pb-1 of transverse data taken in 2006 used in the STAR analysis, which indicate non-zero asymmetries. Data collected in Run 12 will allow these asymmetries to be measured with higher precision and increased kinematic coverage, see for quantitative projections. These data will also be used to tighten the constraints on the mid-rapidity inclusive jet *AN*, which will dominantly sensitive to the gluon Sivers contribution.

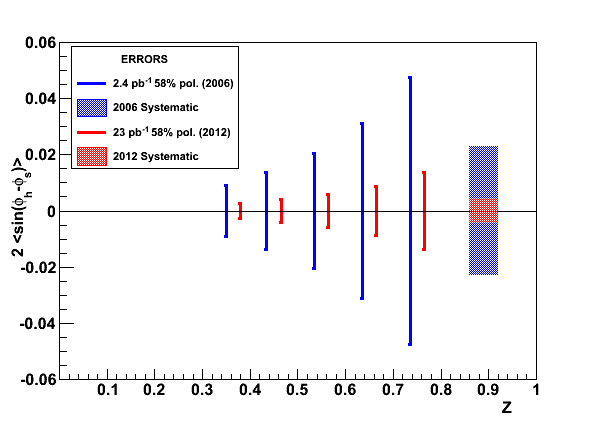
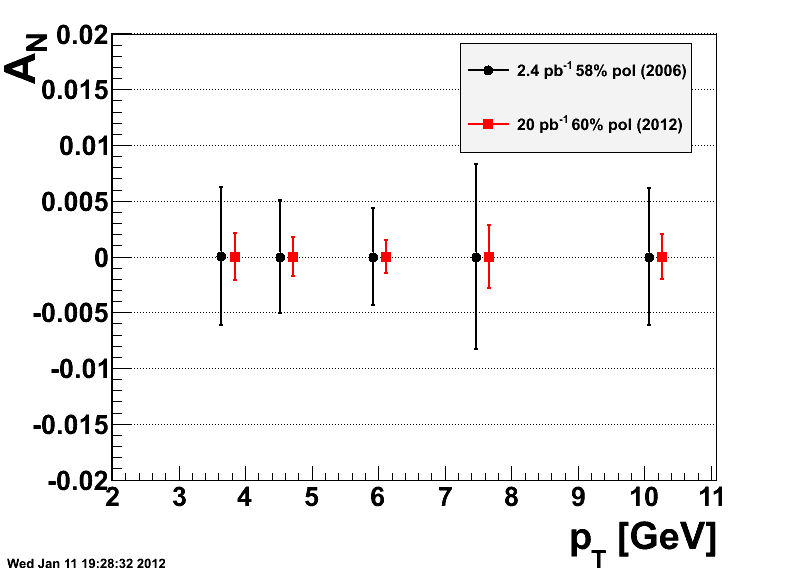
 

Figure ‑: Run 6 errors compared to Run 12 (√s= 200 GeV) projections for the ‘’Collins-jet asymmetry’’ (left) and for the mid-rapidity Interference Fragmentation Function (right).

Following the motivation for transverse polarized physics described in section 2.1.2, a transverse polarized p+p run with an integrated sampled luminosity of 50 pb-1 in run-15 will allow answering several open questions. Does the *pt*-dependence for the different asymmetries shown in Figure 2‑5 and Figure 2‑6 turn over from flat and follows the pQCD expected 1/pT behavior. Can the underlying sub-processes being responsible for the large forward *AN* cleanlt identified.

Figure 4‑9 shows the projected uncertainties for Run12+Run-15 for IFF for different pion combinations. The uncertainties for the Collins asymmetry as shown in Figure 4‑7 will be reduced by a factor of 1.4 for Run-15 compared to Run-12. These two Run 15 results together with the Run-12 data will provide a powerful data set for global fits to extract transversity and to further constrain the Collins and interference fragmentation functions. The STAR data will be extremely crucial to constrain transversity at high *x* where currently are absolutely no data available. Both data sets are very stringent tests to models trying to explain the transverse physics phenomena in p+p and especially the cause of the big forward pion *AN*.

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|  | Figure ‑: Runs 12 + 14 projections for the mid-rapidity Interference Fragmentation Function compared to the results based on Run 6. |

Having a first measurement of the direct photons *AN* with the FMS will be extremely crucial to understand the contribution of the Sivers-mechanism to the forward *AN*. For the measurement of the direct photons it will be important to have the pre-shower described in section 6.2 installed in front of the FMS. Direct photons are a rare process. Therefore it is important to suppress background from leptons, hadrons and 0 as much as possible. As shown by the first simulations the first 2 layers provide a lepton suppression of 98% by keeping 98% of photons, together with the third layer, which provides also 98% rejection of leptons and 85% rejection of hadrons, backgrounds can be suppressed enough allow a measurement of AN of direct photons. Figure 4‑9 shows on the left side theoretical prediction from Ref. [16] using different assumptions or the Sivers function. On the right hand side the projected uncertainty for the prompt photon ( = direct – fragmentation photon) *AN*. The uncertainty in the fragmentation photon AN was set to 5% The 40 pb-1 will allow for a measurement, which will be easily able to distinguish between the different model assumptions.

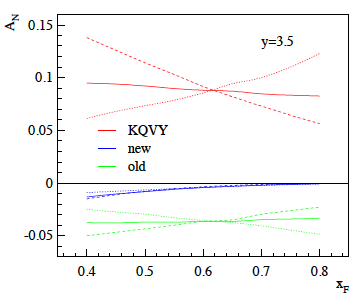
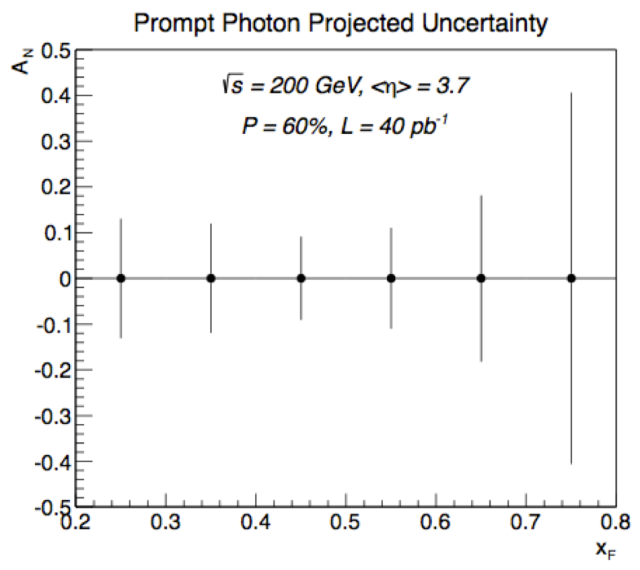
 

Figure 4‑10: (Left plot) Single transverse spin asymmetry for prompt photon production, p↑+p →  + X, plotted as a function of Feynman xF at rapidity y = 3.5 and √s = 200 GeV. For each colored curve, the dashed curve is the direct asymmetry ANdir, the dotted curve is the fragmentation asymmetry ANfrag, and the solid curve is the overall spin asymmetry. The different colors represent different assumptions about the magnitude of the Sivers asymmetry. (Right plot) The projected uncertainty for the prompt photon (=direct–fragmentation photon) *AN*. The uncertainty in the fragmentation photon AN was set to 5%.

This paragraph and plots will be changed with a new one based on the new preshower + FMS predictions.

The observation, see section 2.1.2, that the transverse single spin asymmetries drop with increased jettiness of the event, could indicate that the underlying subprocess causing the large transverse single spin asymmetries in the forward direction is of diffractive nature. The roman pot phase II\* upgrade (see section 6.1) will allow to make a measurement of *AN* 0 for single and double diffractive events by tagging one or both protons in the Roman Pots. A discovery of large transverse single spin asymmetries in diffractive processes would open a new avenue to study the nature of pomerons in p+p collisions.

## Physics with transversely polarised p+A collisions

# Run-16 Request

## Transverse polarized p+p running at √s=500 GeV

In addition to the physics motivations already discussed in section 2.1.2 and 4.2 there are two very basic questions in transverse spin physics, for which finding answers will be of fundamental interest for QCD. One is the question about the evolution of transverse dependent parton distribution functions and fragmentation functions, which is different to the well-known evolution following DGLAP. The other important aspect is the process dependence and the color gauge invariance of the Sivers function. In SIDIS, the quark Sivers function is manifested in association with a final state effect from the exchange of (any number of) gluons between the struck quark and the remnants of the target nucleon. On the other hand, for the virtual photon production in the Drell-Yan process, and the W+/-, Z0 Boson production, the Sivers asymmetry appears as an initial state interaction effect. As a consequence, the quark Sivers functions are of opposite sign in these two processes and this non-universality is a fundamental prediction from the gauge invariance of QCD. The experimental test of this sign change is one of the open questions in hadronic physics and will provide a direct verification of QCD factorization. The transverse single spin asymmetries for direct photon production provide also access to this sign change through the Twist-3 formalism. The importance of measuring this sign change is also reflected in the fact that it was made a HP performance milestone (HP13) during the last LRP.

As already discussed in section 2.1.2 STAR was able in a pilot run with transverse polarized p+p collisions at √s=500 GeV to measure the transverse single spin asymmetries *AN* for fully reconstructed W+/-, Z0 Bosons based on a recorded integrated luminosity of 25 pb-1. Figure 5‑1 shows the most up-to-date theoretical predictions for the transverse single spin asymmetries for W+/-, Z0 Bosons from reference [12] including TMD-evolution.

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| z0.eps | w_plus.eps | w_minus.eps |
| Figure ‑: Theoretical predictions from reference [12] for the transverse single spin asymmetries for W+/-, Z0 Bosons for 0 GeV <pt < 3 GeV. The yellow bands represent the uncertainties for the asymmetry due to the unknown sea quark Sivers function.  The production of W+/- bosons at √s=500 GeV provides an ideal tool to study the spin-flavor structure of sea quarks inside the proton. The left-handed W boson only couples to (anti)quarks of a certain helicity, giving rise to large parity-violating single spin asymmetries in polarized p+p collisions at RHIC. In addition, the coupling of the W’s to the weak charge correlates directly to quark flavor. Ignoring quark mixing, W+/- bosons are produced through  interactions. A measurement of the transverse single spin asymmetry will provide the world wide first constrain on the sea quark Sivers function in a *x*-range, where the measured asymmetry in the  and  unpolarized sea quark distribution functions, as measured by E866 [[[15]](#endnote-15)], can only be explained by strong non-pQCD contributions. Of course the same measurement is also able to access the sign change of the Sivers function. Figure 5‑2 shows the projected uncertainties for transverse single spin asymmetries of W+/-, Z0 Bosons as function of rapidity and *pT* for a delivered integrated luminosity of 900 pb-1 and an average beam polarization of 50%. The 900 pb-1 correspond to XX weeks running and a dynamic \* squeeze through the fill. The dynamic \* squeeze provides a factor 2 increase of the luminosity in a fill as the luminosity profile through the fill is kept flat. | | |

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| hd_WAsym2016ProjPt.eps | hd_WAsym2016ProjPt.eps | hd_WAsym2016ProjPt_zoom.eps |
| Figure ‑: The projected uncertainties for transverse single spin asymmetries of W+/-, Z0 Bosons as function of rapidity and pT for a delivered integrated luminosity of 900 pb-1 and an average beam polarization of 50%. | | |

Probing the TMD evolution formalism is possible through accessing the same observables at center-of-mass energies of 200 GeV and 500 GeV. A high statistics 500 GeV in combination with the earlier high statistics 200 GeV runs (2012 + 2015) gives the possibility to study the TMD evolution through the following processes

* Interference fragmentation
* AN for direct photons
* AN for jet observables sensitive to the Sivers fct or transversity times Collins FF

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| Figure ‑: Transverse single spin asymmetries for hadron–jets (left) sensitive to the Collins mechanism and inclusive jets (right) sensitive to the sivers mechanism at √s=500 GeV from Run-11 (25 pb-1). | |

Figure 5‑3 shows the transverse single spin asymmetries for hadron–jets (left) sensitive to the Collins mechanism and inclusive jets (right) sensitive to the Sivers mechanism for gluons at √s=500 GeV from Run-11 (25 pb-1). A high luminosity run will provide the possibility to have enough statistics to test the trends seen in the Collins-like jets at high z persist with higher luminosity as well as to make a high precision measurement of the gluon Sivers function in the Twist-3 formalism through *AN* for inclusive jets. The uncertainties shown in Figure 5‑3 will shrink by a factor XX after Run-16.

The ultimate test for the TMD evolution would be to measure *AN* for W+/-, Z0 Boson and DY production. To obtain a significant measurement of AN for DY production, the DY leptons need to be detected at rapidities 2 to 4 for a lepton pair mass of 4 GeV2 and bigger. This is a non-trivial measurement, as backgrounds mainly due to QCD2🡪2 processes need to be suppressed by a factor up to 106. Current preliminary studies indicate that this could be achieved by adding a postshower behind the current FMS. The design of such a postshower could be copied right from the FMS preshower (see section 6.2), but dropping the 3rd layer.

The capability to measure *AN* for DY, W+/-, Z0 Bosons and direct photons in one experiment would provide the world wide unique possibility to test TMD evolution, access the Sivers function for sea quarks and test the prediction of non-universality for the Sivers function through 3 different processes for 2 different theoretical approaches simultaneously.

# Detector and Upgrades relevant to BUR

## The Phase-II\* Upgrade of the Roman Pots around STAR

A short description of the project and status will be added

## A Preshower for the FMS

STAR is building a preshower detector in front of the FMS, which will help distinguish photons, electrons/positrons and charged hadrons. This detector will be comprised of two layers of perpendicularly arranged scintillator slats (PS1 and PS2), followed by a lead converter and a subsequent third layer of scintillator slats (PS3). PS1 and PS2 will be used to identify neutral particles (photons) from charged particles (hadrons and electrons), while PS3 after the converter will help separating electromagnetic showers (photons and electrons) from charged hadrons.

The preshower detector will be located in front of the FMS at a little less than 7 m downstream of the nominal interaction point in STAR and will cover a transverse area of about 2x2 m2 with a 40x40 cm2 cutout in the center for the beam pipe. The preshower layers will be divided into quadrants. The detector will be segmented to ~80 scintillator slats per layer, and the granularity of the array is going to match that of the FMS loosely as indicated in Figure 6‑1.

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| Figure ‑ Geometry of the layers of a preshower detector in front of the FMS electromagnetic calorimeter in STAR. Left: Layered setup of scintillators (grey) with a Pb converter (blue) and SiPM and FEE board (green). Right: Matching of granularity of preshower (layer 3, red) with the tower size of the FMS (black and blue). | |

Due to up to 400 gauss of magnetic field from the STAR solenoid magnet, SiPMs (MPPC) were chosen for the readout instead of conventional PMT. The scintillation light from a scintillator slat will be read out by two 3x3mm Hamamatsu S12572-050P (PS1 & PS2) and S12572-025P (PS3) MPPC (SiPM), which will be mounted on a FEE board and attached to light guides at the end of the scintillator slat as shown in Figure 6‑2. The initial tests of the SiPM and scintillator slats have been finished. The construction of the detector will take place summer 2014, followed by testing and installation to STAR before the 2015 RHIC run.

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| Figure ‑: To keep the taper angle small while making it compact, there will be one light guide with a “two mountain structure” glued at each end of a scintillator slat. A small board with two SiPM will be attached to the end of the light guides. The FEE board will be mounted along the light guide for compactness as well as to give mechanical stability. | |

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