Drell-Yan studies with SPD. Status and Plans.

on behalf of DY team

1. Introduction

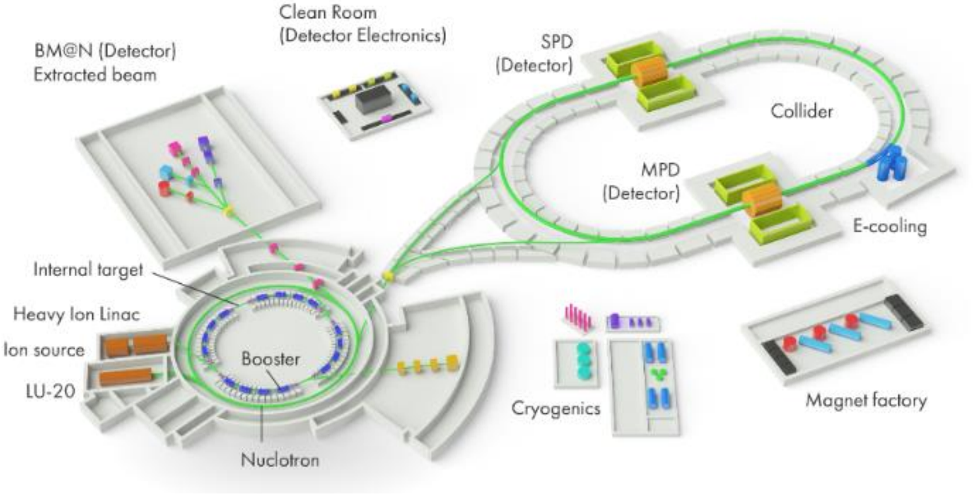
2. Cross sections and statistics

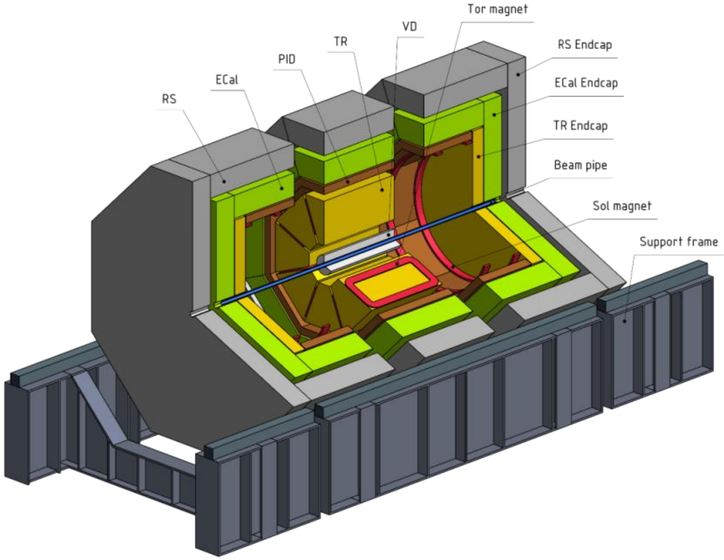
3. Background studies

4. MC weighted asymmetries

5. Some estimations and proposals

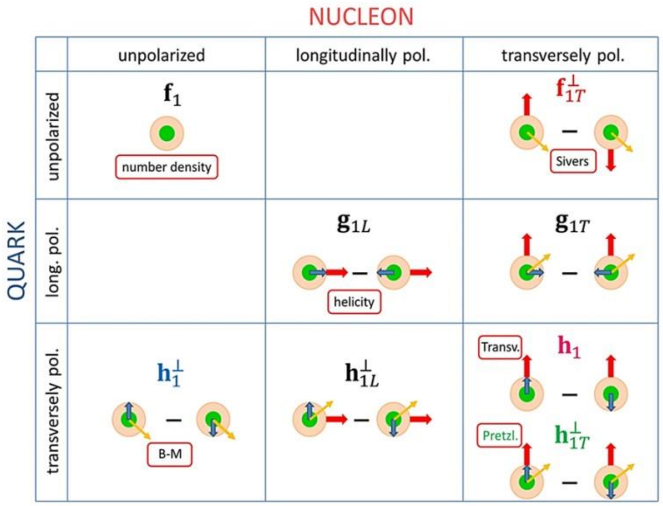
6. Plans



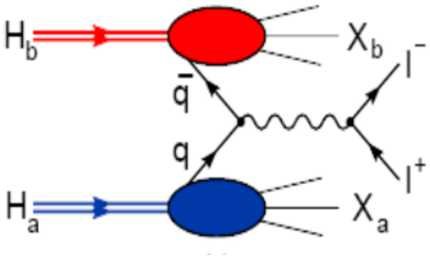


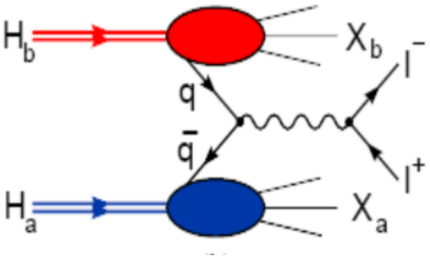
Drell-Yan studies with SPD. Status and Plans.

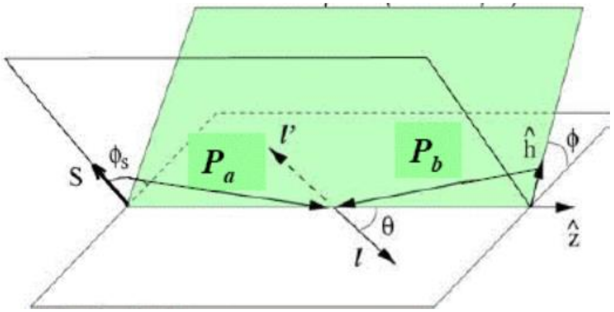
Introduction.



1. Transversity: $A_{UT}^{\sin(\phi+\phi_S)}$, represents the number distribution of transversely polarized quarks in a transversely polarized nucleon;
2. Sivers: $A_{UT}^{\sin(\phi-\phi_S)}$, represents the distribution over the transverse momentum of non-polarized quarks in a transversely polarized nucleon;
3. Pretzelosity: $A_{UT}^{\sin(3\phi-\phi_S)}$, represents the distribution over the transverse momentum of transversely polarized quarks in a transversely polarized nucleon;
4. Boer-Mulders: $A_{UU}^{\cos(2\phi_h)}$, represents the distribution over the transverse momentum of transversely polarized quarks in a non-polarized nucleon;
5. Worm-Gears: $A_{UL}^{\cos(2\phi_h)}$, represents the distribution over the transverse momentum of longitudinally polarized quarks in a longitudinally polarized nucleon.







Drell-Yan studies with SPD. Status and Plans.

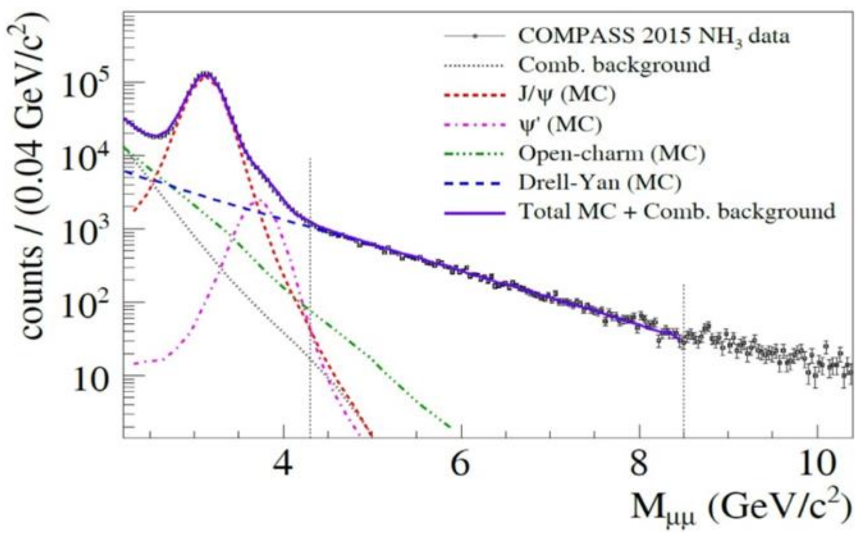
Cross sections and statistics.

Estimation of DY pairs production rates in Pythia6.4

DY via μ-μ+, $\sqrt{s}$= 26 GeV
Some settings:

MSEL=0	! turn OFF global process selection
MSUB(1)=1	! turn ON q+qb -> gamma*/Z0 -> mu+mu- (Drell-Yan process)
MSTP(43)=1	! only gamma* included (Drell-Yan)
MDME(184,1)=1	! Z0 -> mu+mu- turned ON

$M_{\mu\mu}$ GeV	σ tot, nb
>2	1.23
>3	0.27
>4	0.07



Drell-Yan studies with SPD. Status and Plans.

Cross sections and statistics.

For various invariant mass ranges with P_{μ} >1 GeV

$$\sigma_{range} = \sigma_{tot} \times N_{evt\ range} / N_{evt}$$

	$M_{\mu\mu}$ 2 - 11 GeV	$M_{\mu\mu}$ 2 - 4 GeV	$M_{\mu\mu}$ 4 - 9 GeV	$M_{\mu\mu}$ 9 - 11 GeV
√s GeV	σ_{tot}, nb	σ_{tot}, nb	σ_{tot}, nb	σ_{tot}, nb
26	0.9	0.82	0.07	<0.01
20	0.6	0.56	0.03	<0.01
15	0.3	0.29	0.009	<0.01

Drell-Yan studies with SPD. Status and Plans.

Cross sections and statistics.

DY pairs production rate vs. Luminosity ($\sqrt{s}$= 26 GeV) per month

$$R = L \times \sigma \times Time \times Eff$$

L, $cm^{-2} s^{-1}$	$M_{\mu\mu}$ = 2-9, GeV			$M_{\mu\mu}$ = 2-4, GeV			$M_{\mu\mu}$ = 4-9, GeV		
	Eff 100%	Eff 80%	Eff 60%	Eff 100%	Eff 80%	Eff 60%	Eff 100%	Eff 80%	Eff 60%
	R $\times 10^3$			R $\times 10^3$			R $\times 10^3$		
$1x10^{31}$	23	19	14	21	17	13	1,8	1.4	1
$5x10^{31}$	162	93	70	103	82	61	9	7,2	1.4
$1x10^{32}$	233	169	139	207	165	124	18	14	10
$2x10^{32}$	466	338	278	415	332	250	36	29	21

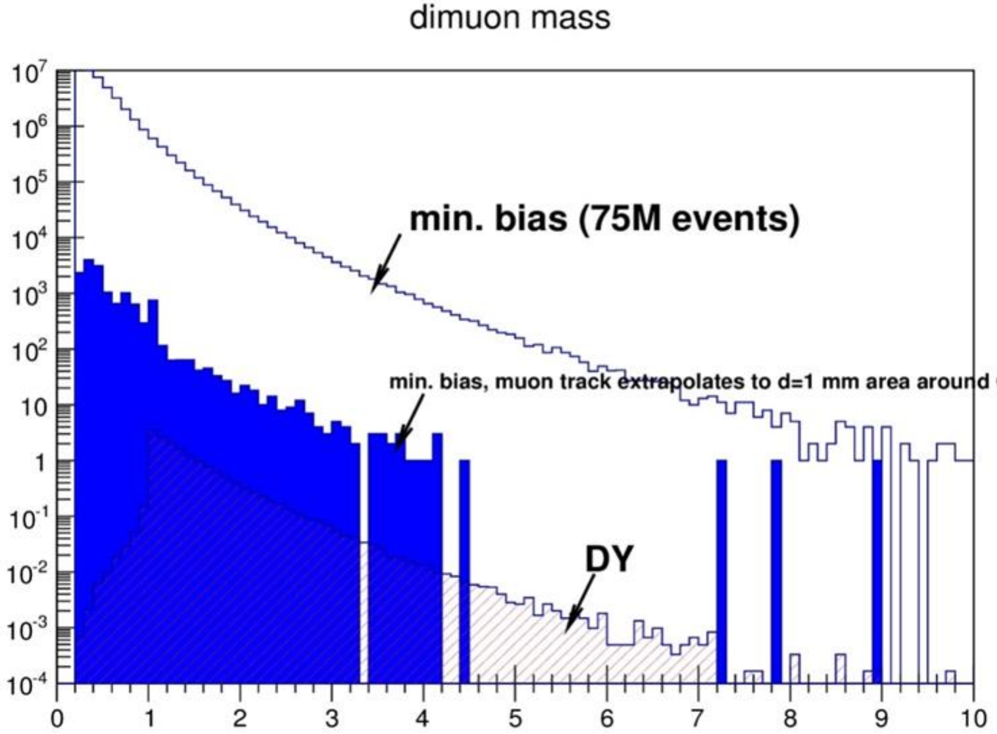
COMPASS-II proposal

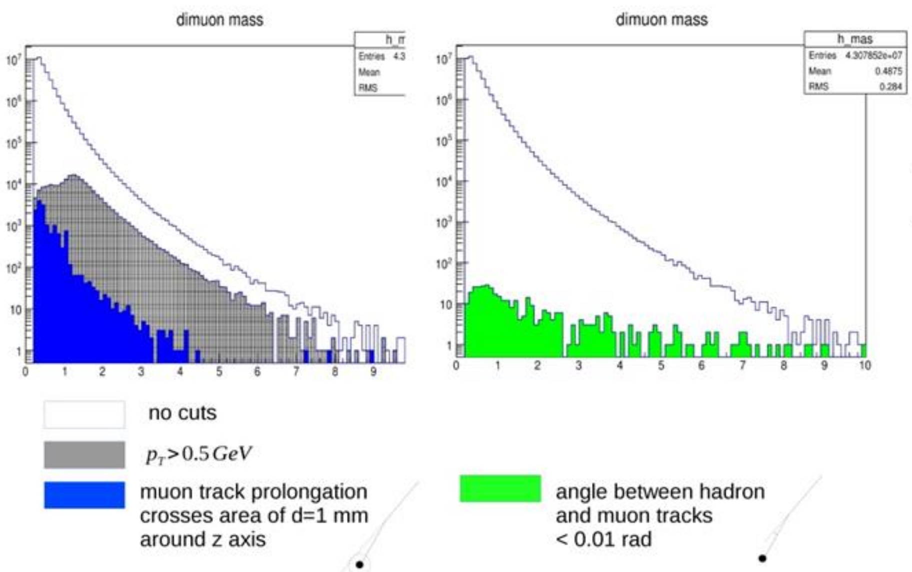
π^- beam, GeV	R (day)		R (month) $\times 10^3$	
	Mμμ=2-2.5	Mμμ=4-9	Mμμ=2-2.5	Mμμ=4-9
106	4013	440	120	13
160	4617	695	139	21
190	4858	809	146	24

Drell-Yan studies with SPD. Status and Plans.

Background studies (old results).

- 2 proton beams with E=12 GeV
- Only process $q\bar{q}\to\gamma^*\to\mu^+\mu^-$
- $m_{\mu\mu}>1\,GeV$
- Decays of $\pi^{\pm}, K^{\pm}, K^0_L$ turned on
- 10^5 events
- $\sigma_{tot}=8.7\,nb$ (ratio $\sigma_{tot}(MB)/\sigma_{tot}(DY)\approx 4.5\cdot 10^6$)
- Only muons produced in volume with L=8 m and D=7 m were taken into account.
- (For $m_{\mu\mu}>3\,GeV$ $\sigma_{tot}=0.23\,nb$)





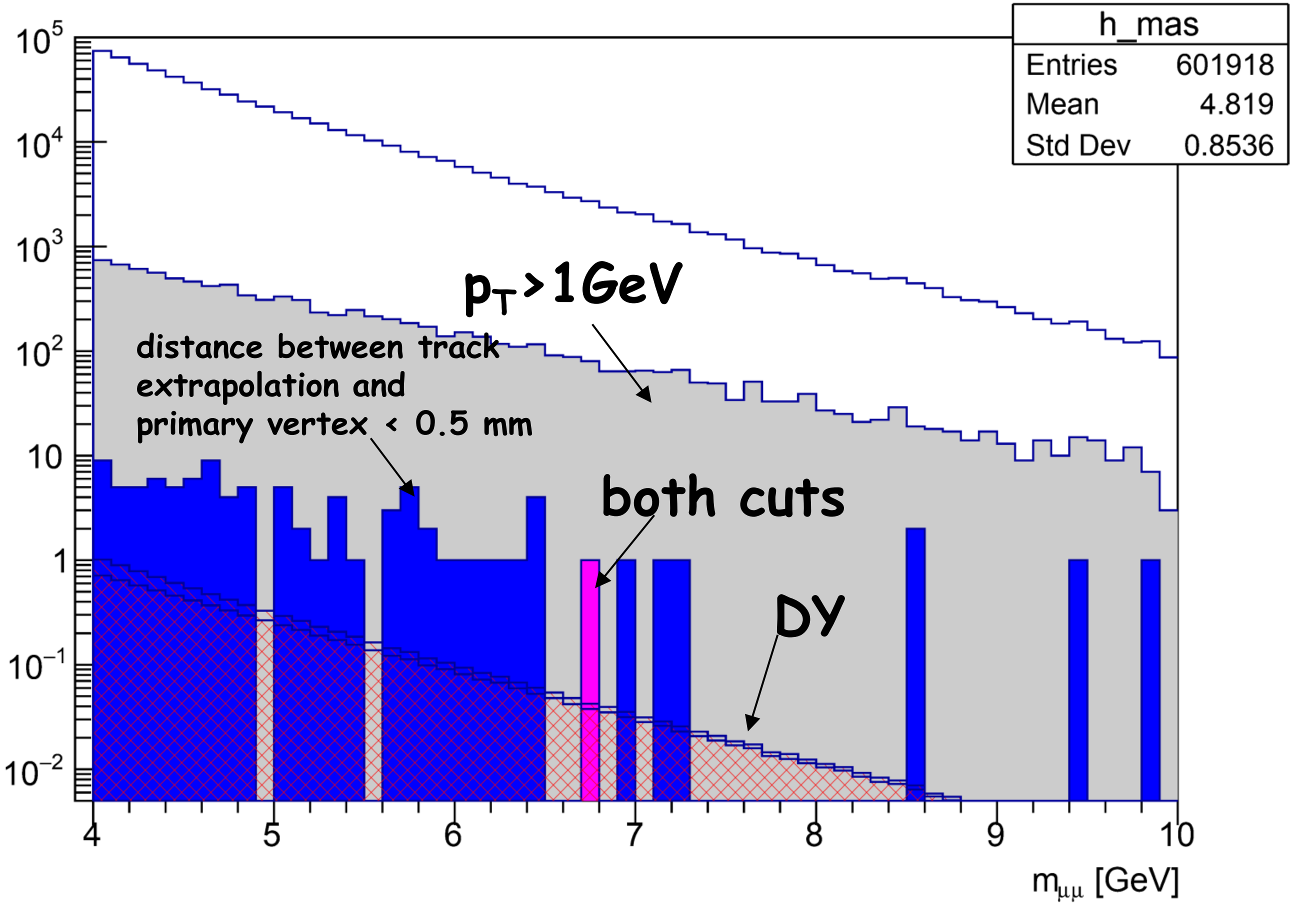
~1:60 signal/background - *07.2018*

Drell-Yan studies with SPD. Status and Plans.

Background studies (new results).

10^6 DY events in range $m_{\mu\mu} > 4$ GeV. $\sigma_{tot,DY} = 0.074$ nb

4,9·10^9 min. bias events in Pythia 6. $\sigma_{tot,MB} = 39$ mb. ~ 10^{-4} of these events contribute to background in our invariant mass range.

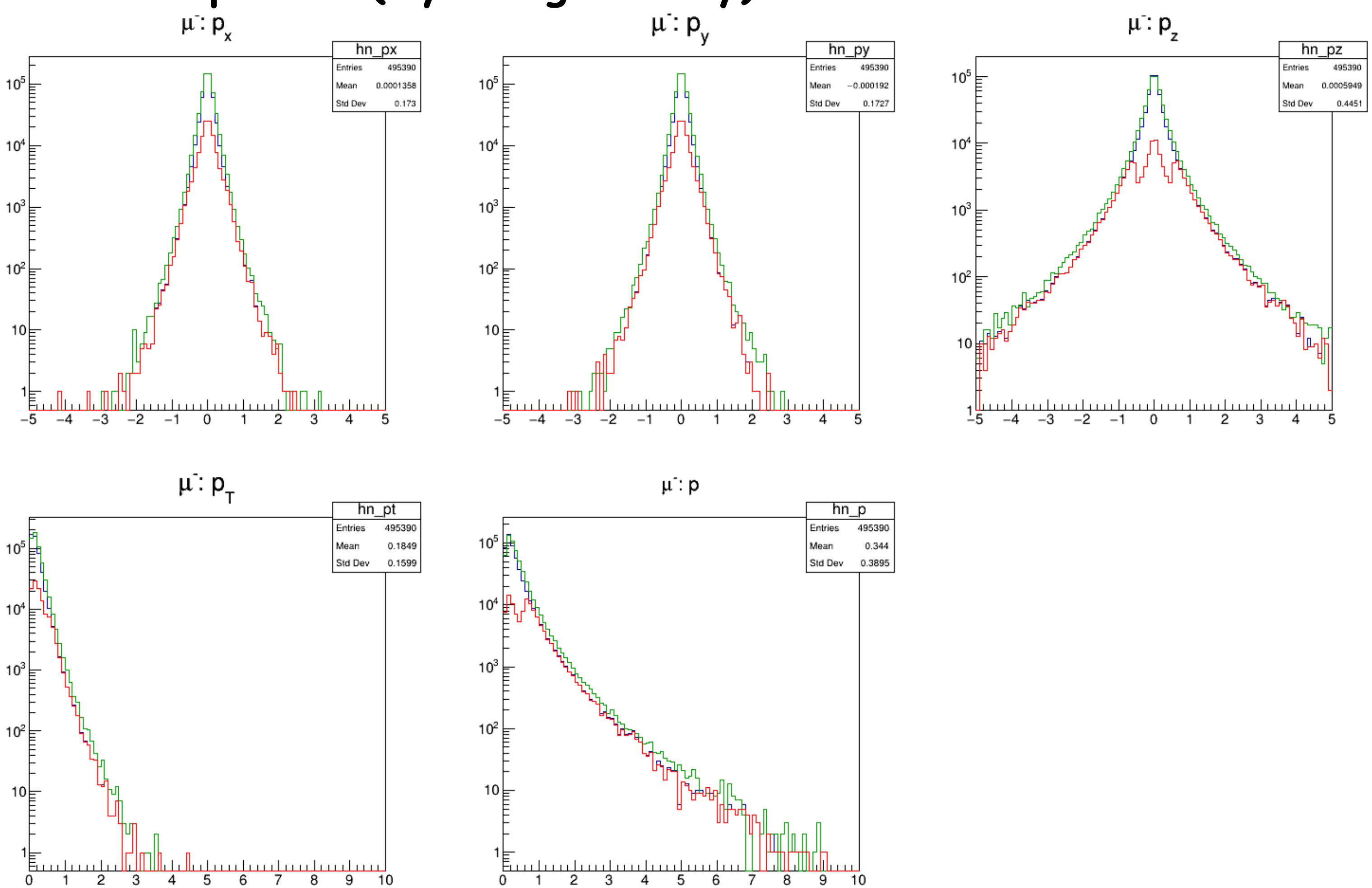


Drell-Yan studies with SPD. Status and Plans.

Background studies.

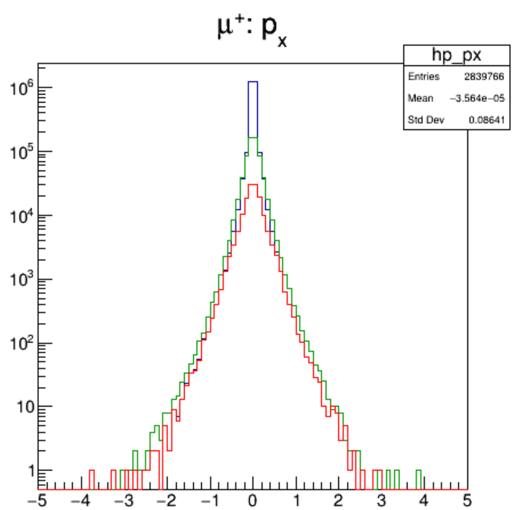
1M min. bias events with Pythia6

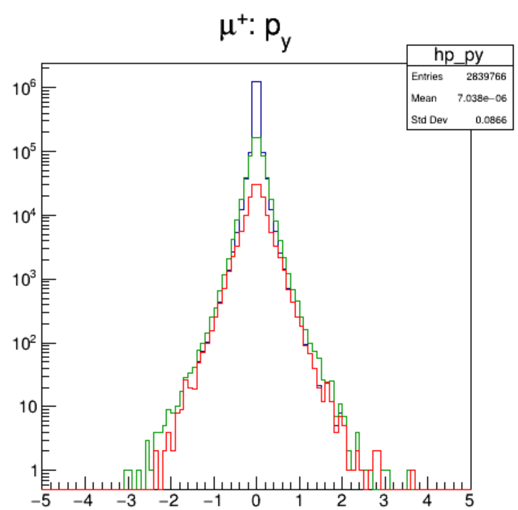
- green - “Pure” Pythia6
- blue - SpdRoot (Hybrid geometry) all muons
- red - SpdRoot (Hybrid geometry) reached RS

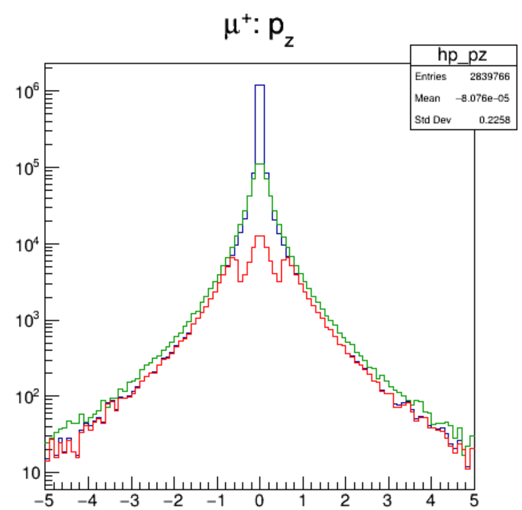


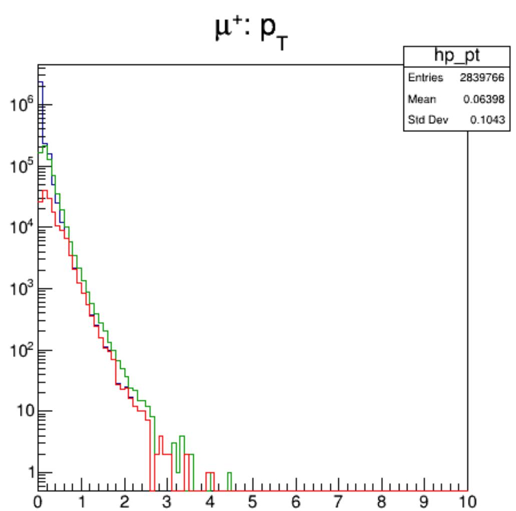
Drell-Yan studies with SPD. Status and Plans.

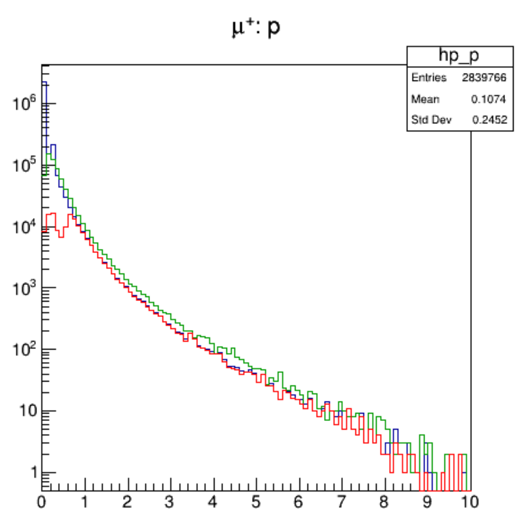
Background studies.





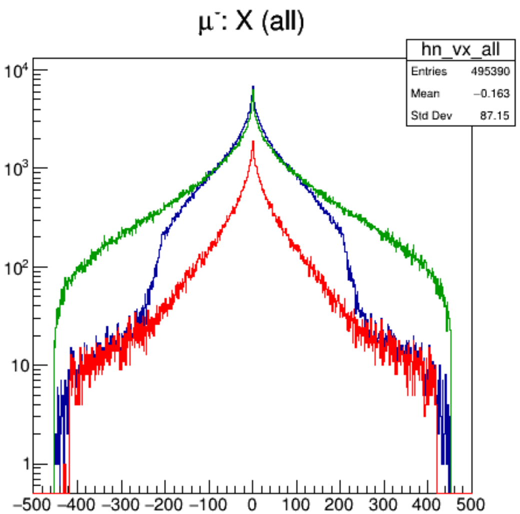


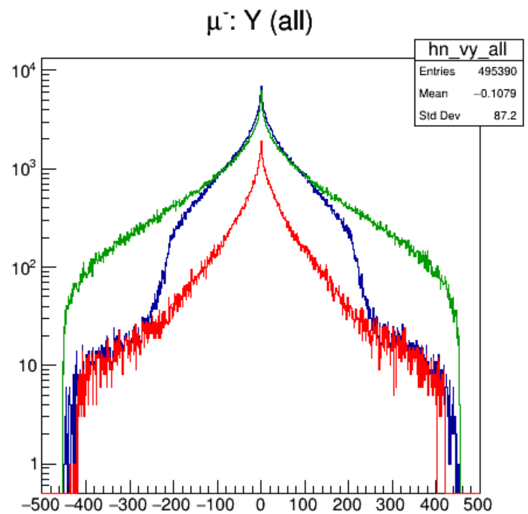


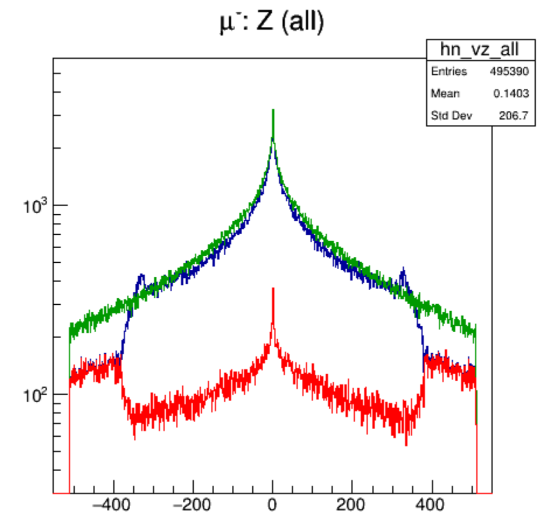


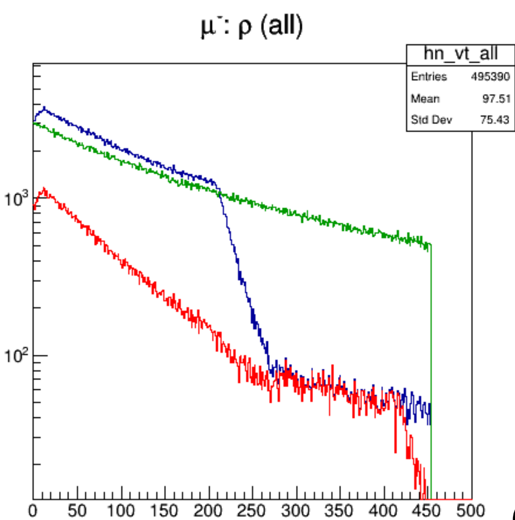
Drell-Yan studies with SPD. Status and Plans.

Background studies.





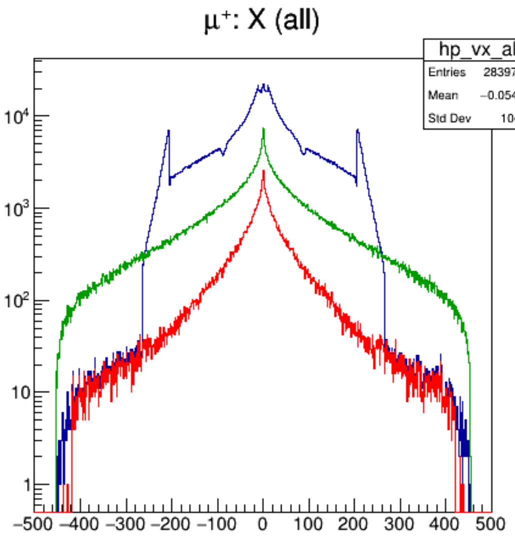


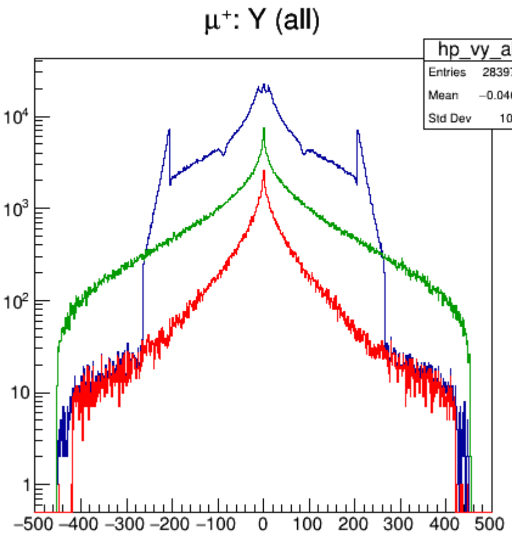


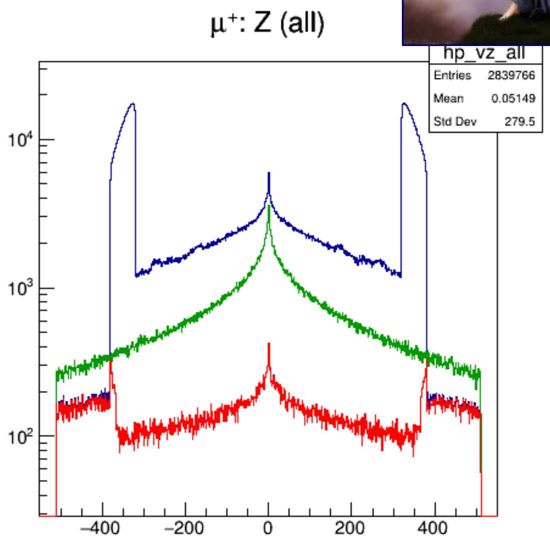
$$\rho=\sqrt{(x^2+y^2)}$$

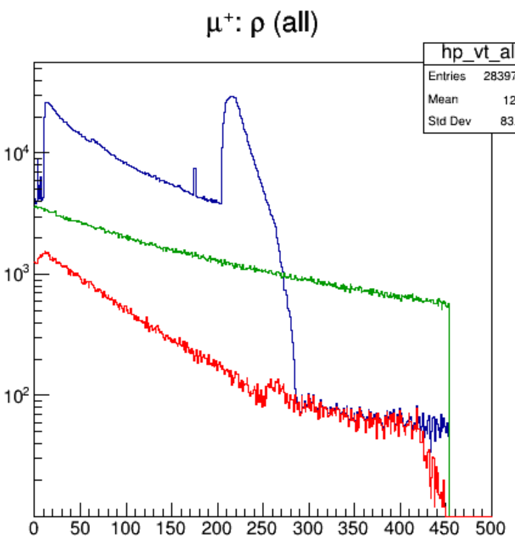
Drell-Yan studies with SPD. Status and Plans.

Background studies.







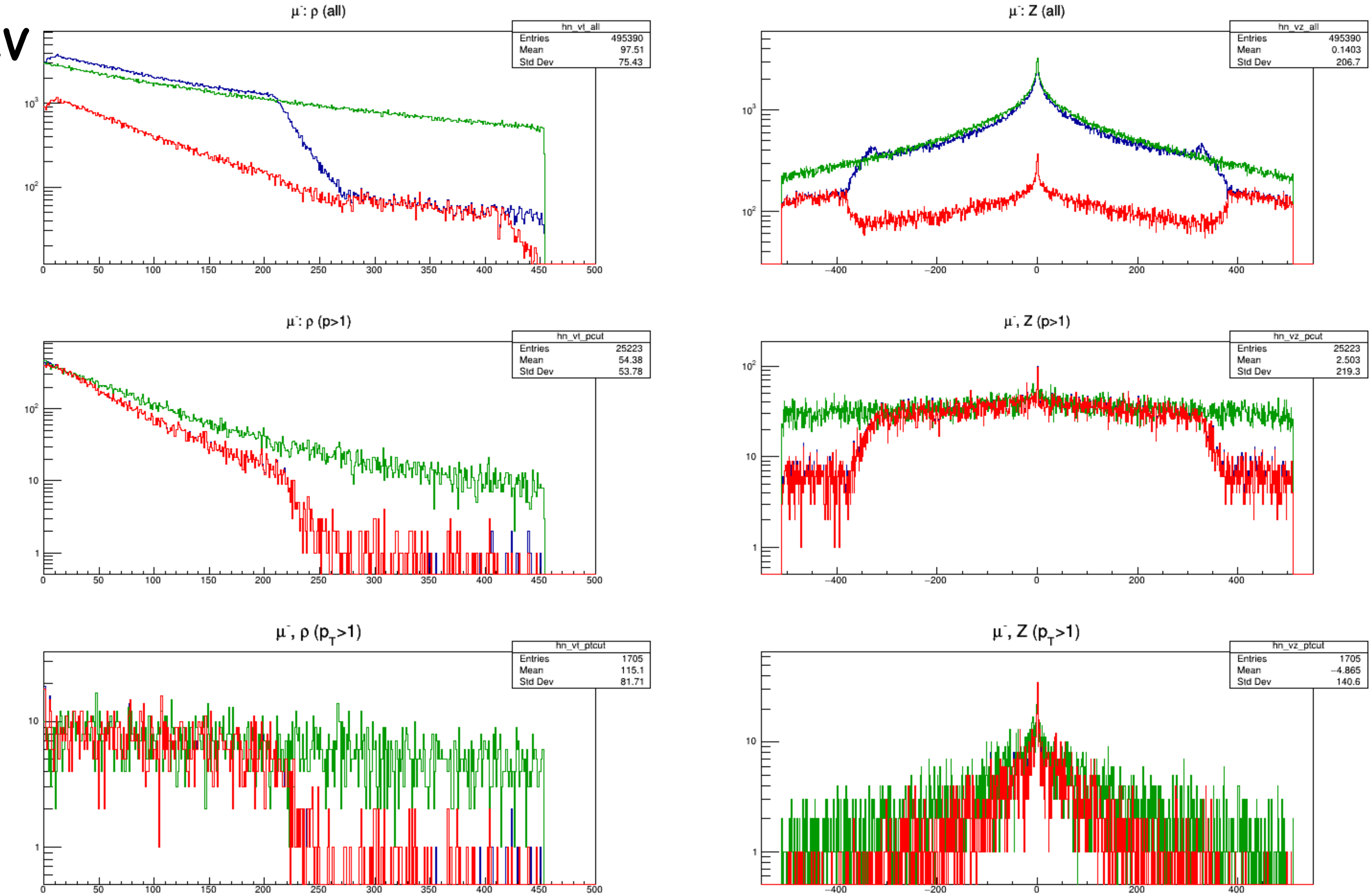


Drell-Yan studies with SPD. Status and Plans.

Background studies.

Cuts:

- p > 1GeV
- p_T > 1 GeV

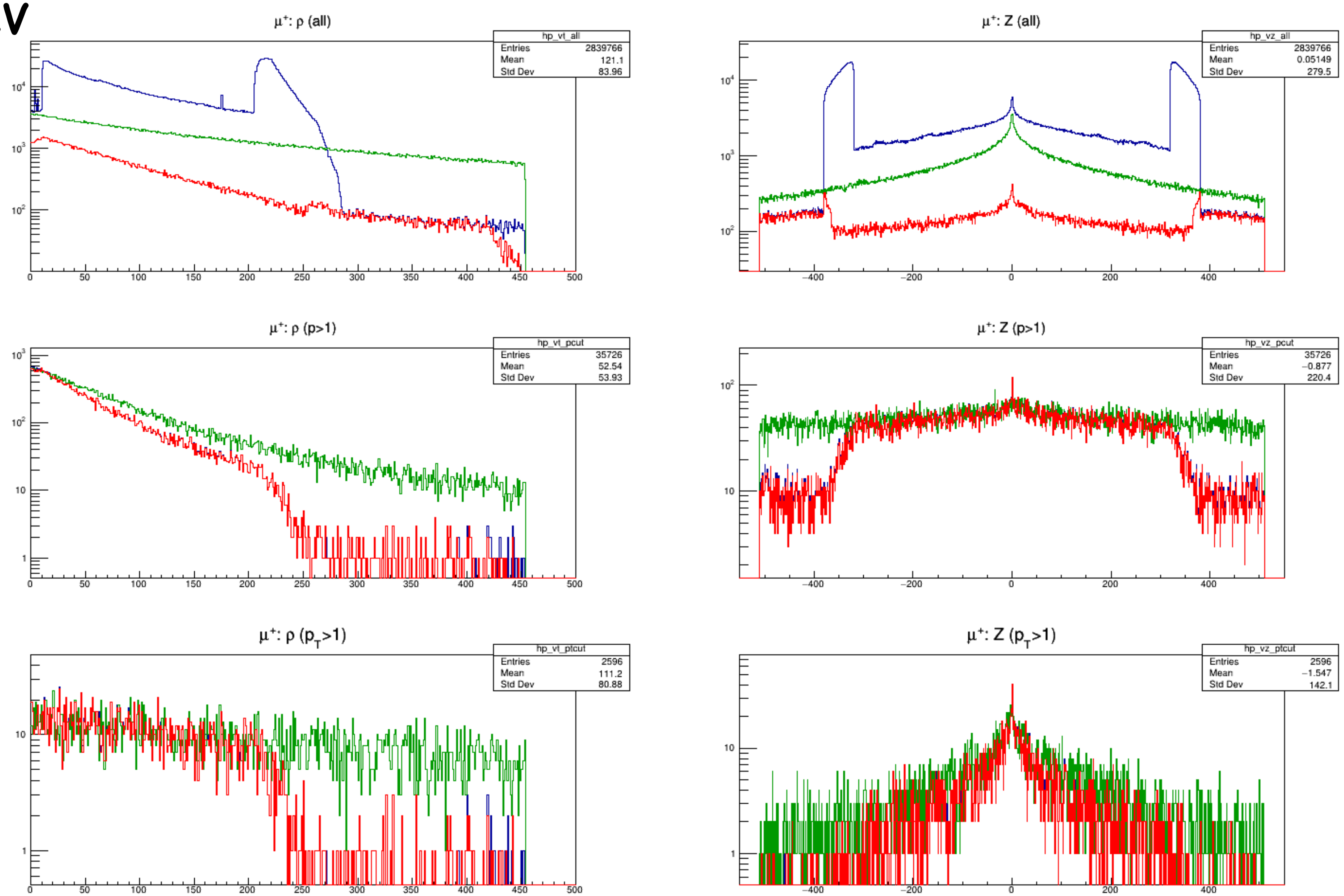


Drell-Yan studies with SPD. Status and Plans.

Background studies.

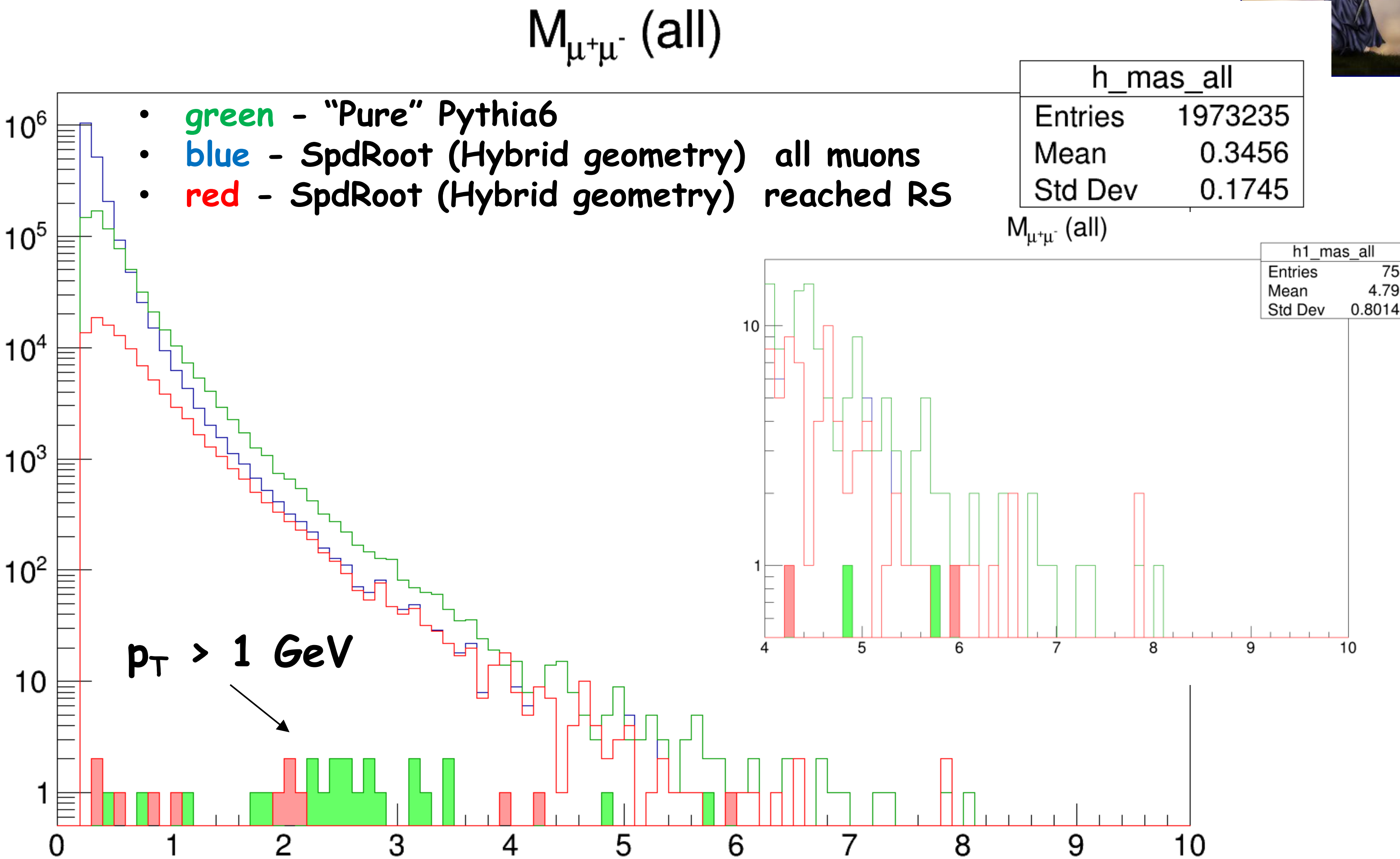
Cuts:

- $p > 1 GeV$
- $p_T > 1 GeV$



Drell-Yan studies with SPD. Status and Plans.

Background studies.



Drell-Yan studies with SPD. Status and Plans.

MC weighted asymmetries (like B-M).

SETS	%
PV	100
RS	96.7
RS-BB	27.3
RS-EE	16.2
RS-BEEB	53.2

N_{DY} generated events = 1×10^6 [4.0 ->]

- **N muon pairs [4-9] = (PV) - 100%**
- **N muon pairs [4-9] = (RS) - 96 %**

Hybrid set-up

- $4.0\ GeV/c^2 < M_{\mu\mu} < 9.0\ GeV/c^2$
- $\langle P_b \rangle = 1.0$

Boer-Mulders

$$weight = \sigma_0 + kP\cos 2\varphi_{CS}$$

$$\sigma_0 = 1.0$$
$$k = 0.5$$
$$P = \pm 1$$

$$A = \frac{N_{w,2} - N_{w,1}}{N_{w,2} + N_{w,1}}$$

$$N_{w,1} = \sum_{1}^{N1} (\sigma_0 - k\cos 2\varphi_{CS})$$

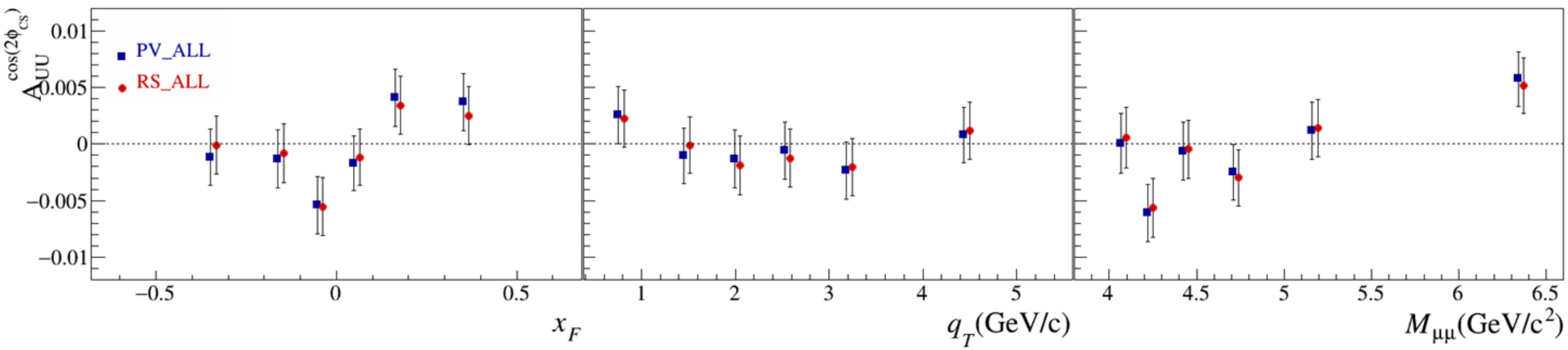
$$N_{w,2} = \sum_{1}^{N2} (\sigma_0 + k\cos 2\varphi_{CS})$$

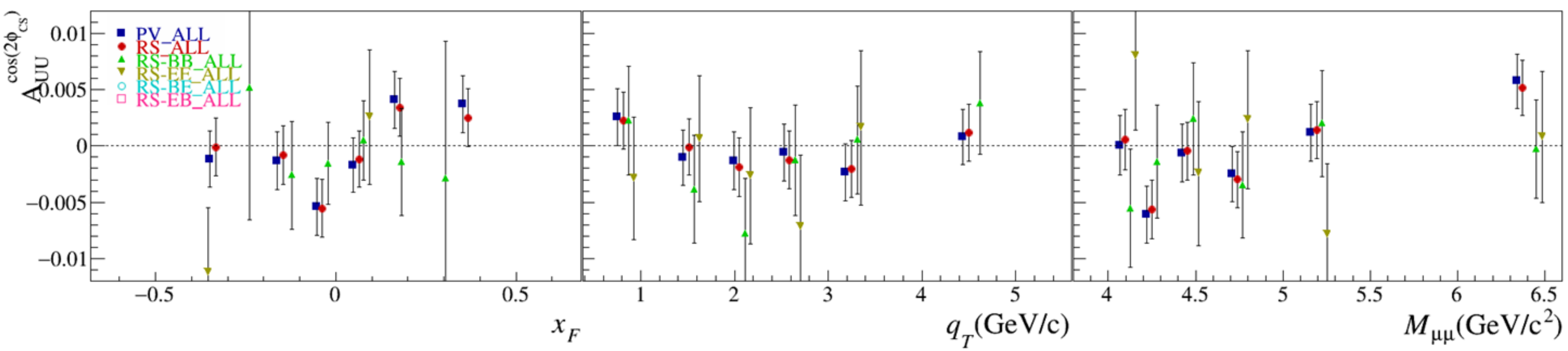
$$dA = \frac{1}{\sqrt{N_1 + N_2}}$$

Drell-Yan studies with SPD. Status and Plans.

MC weighted asymmetries(like B-M).

Standart Magnetic field map in SPDRoot

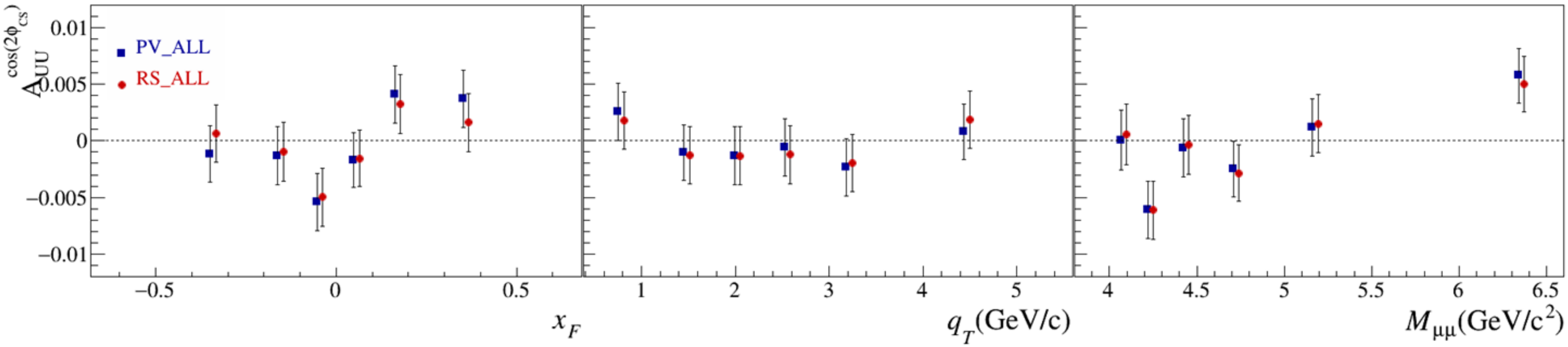


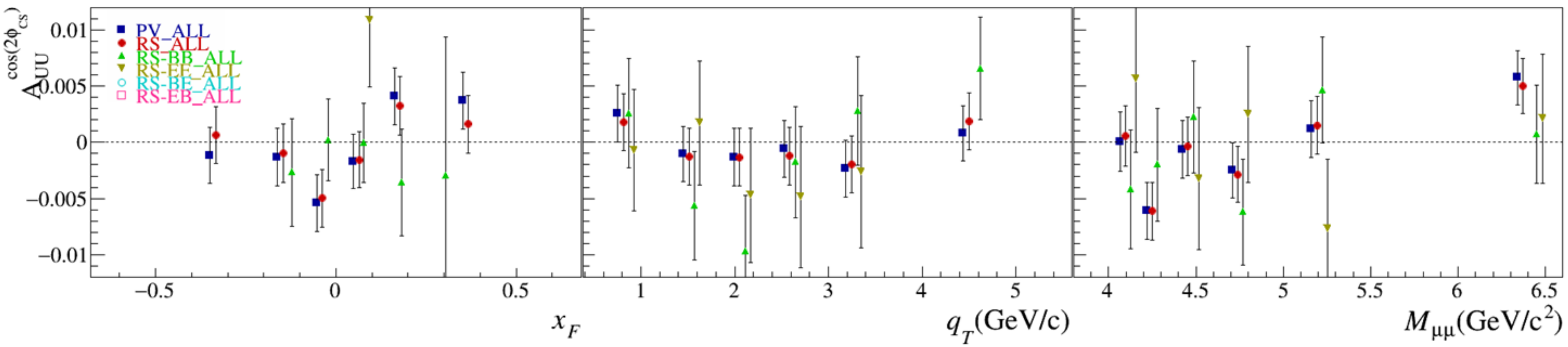


Drell-Yan studies with SPD. Status and Plans.

MC weighted asymmetries(like B-M).

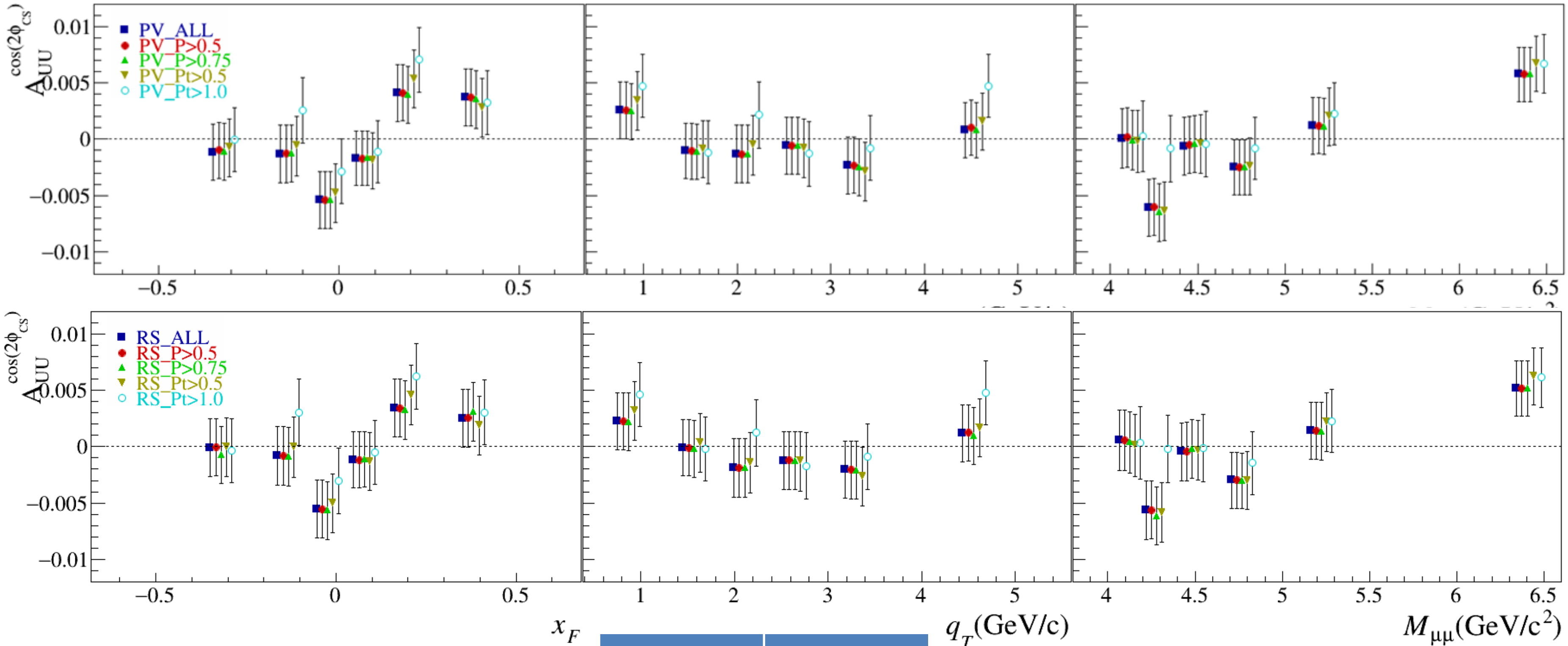
Magnetic field map in SPDRoot x2





Drell-Yan studies with SPD. Status and Plans.
MC weighted asymmetries(like B-M).

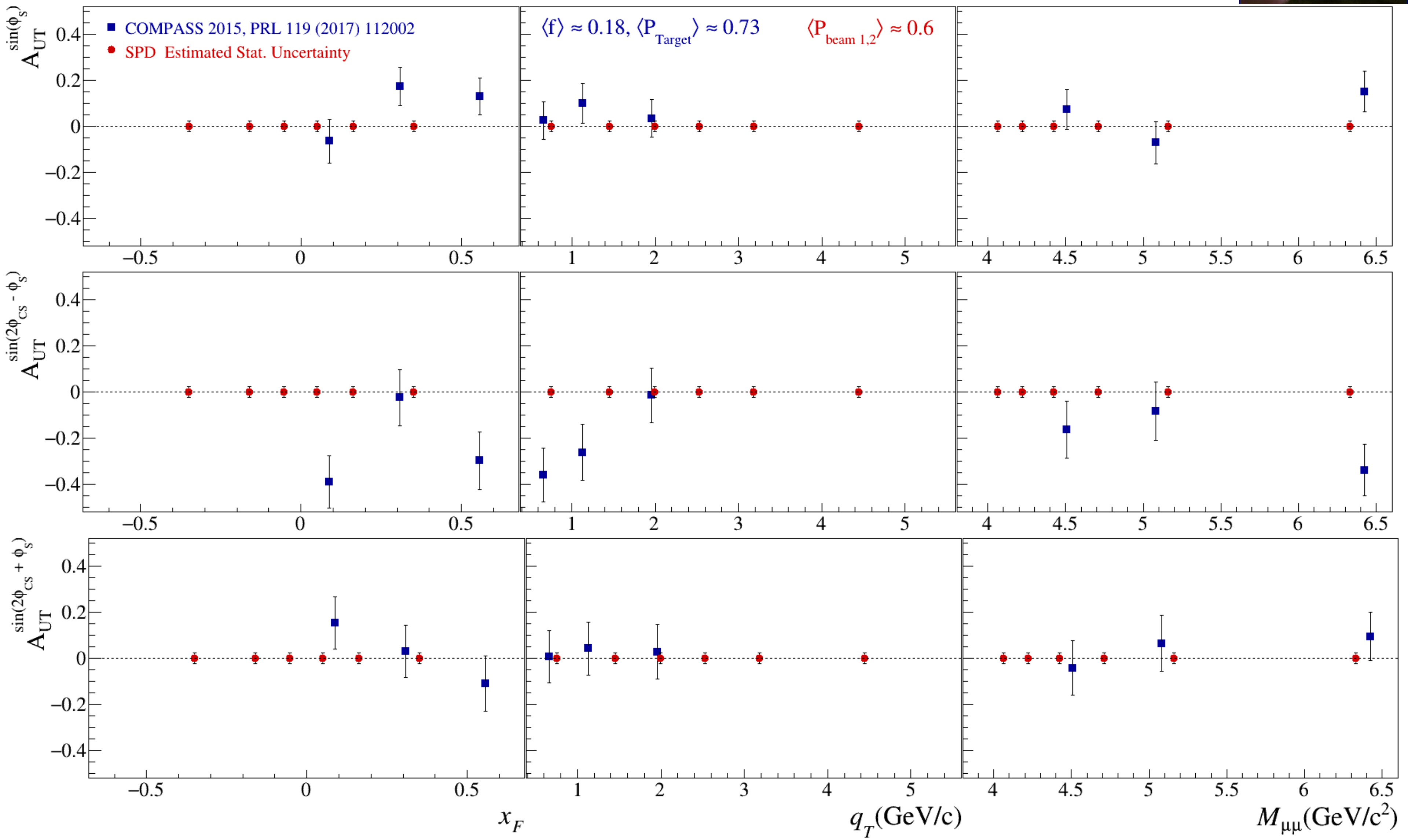
Standart Magnetic field map in SPDRoot



SETS	%
ALL	100
P>0.5	99.95
P>0.75	99.3
Pt>0.5	94.6
Pt>1.0	77.9

Drell-Yan studies with SPD. Status and Plans.

MC weighted asymmetries (comparison with COMPASS).



Drell-Yan studies with SPD. Status and Plans.

Some estimations and proposals.

For BG studies:

- one needs to add materials as possible;
- responses in ECAL and RS;
- tracking;
- vertex;
- PID for DY via e+e- (aerogel blocks or other)

For ASYM studies:

- one needs to have preliminary tracking;
- magnet field maps (toroid vs solenoid);
- theoretical predictions on asyms for NICA;

From NICA:

- one needs to have solid parameters of NICA (lumi, Nbanches etc);
- Beam structure (IP sizes etc);
- Estimations on polarization's values;
- Run time (statistics).

Drell-Yan studies with SPD. Status and Plans.

Plans.

To do:

- Background studies
  cuts, vertex, tracking dets,
  PID dets, beam params etc
- MC asymmetries studies
- Estimation of feasibility of exclusive DY
- Deuteron tensor structure via DY

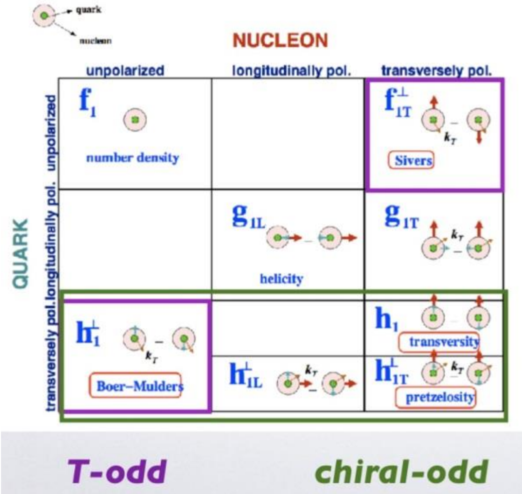
Results on all tasks have to be done for the end of September 2019

DY Team:
Akhunzyanov Ruslan
Gribowsky Alexandr
Ivanov Artem
Mescheryakov Gleb
Nagaytsev Alexander

welcome to join

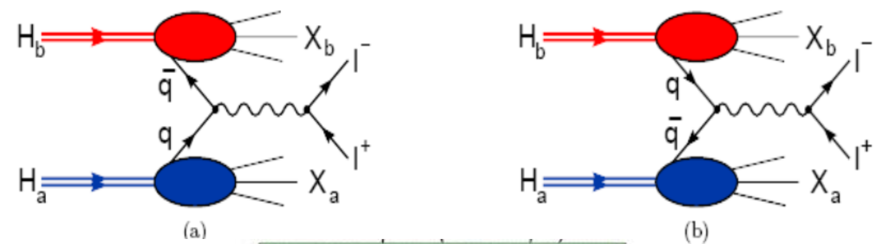
Backup slides

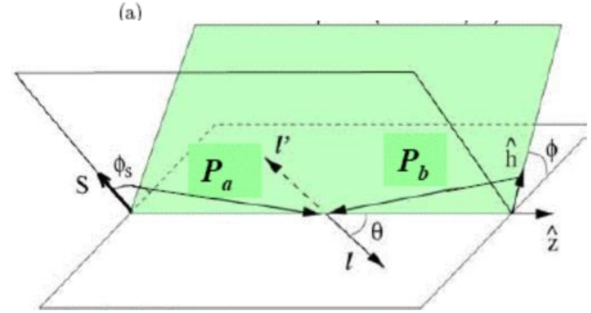
Drell-Yan studies with SPD.



3 PDFs are needed to describe nucleon structure in collinear approximation

8 PDFs are needed if we want to take into account intrinsic transverse momentum k_T of quarks





$$\frac{d\sigma}{dx_a dx_b d^2q_T d\Omega} = \frac{\alpha^2}{4Q^2} \times$$

$$\Big\{\Big((1+\cos^2\theta)F^1_{UU} + \sin^2\theta\cos 2\phi F^{\cos 2\phi}_{UU}\Big) + S_{aL}\sin^2\theta\sin 2\phi F^{\sin 2\phi}_{LU} + S_{bL}\sin^2\theta\sin 2\phi F^{\sin 2\phi}_{UL}$$

$$+\left|\vec{S}_{aT}\right|\Big[\sin(\phi-\phi_{S_a})(1+\cos^2\theta)F^{\sin(\phi-\phi_{S_a})}_{TU} + \sin^2\theta\Big(\sin(3\phi-\phi_{S_a})F^{\sin(3\phi-\phi_{S_a})}_{TU} + \sin(\phi+\phi_{S_a})F^{\sin(\phi+\phi_{S_a})}_{TU}\Big)\Big]$$

$$+\left|\vec{S}_{bT}\right|\Big[\sin(\phi-\phi_{S_b})(1+\cos^2\theta)F^{\sin(\phi-\phi_{S_b})}_{UT} + \sin^2\theta\Big(\sin(3\phi-\phi_{S_b})F^{\sin(3\phi-\phi_{S_b})}_{UT} + \sin(\phi+\phi_{S_b})F^{\sin(\phi+\phi_{S_b})}_{UT}\Big)\Big]$$

$$+S_{aL}S_{bL}\Big[(1+\cos^2\theta)F^1_{LL} + \sin^2\theta\cos 2\phi F^{\cos 2\phi}_{LL}\Big] \qquad (2.1.2)$$

$$+S_{aL}\left|\vec{S}_{bT}\right|\Big[\cos(\phi-\phi_{S_b})(1+\cos^2\theta)F^{\cos(\phi-\phi_{S_b})}_{LT} + \sin^2\theta\Big(\cos(3\phi-\phi_{S_b})F^{\cos(3\phi-\phi_{S_b})}_{LT} + \cos(\phi+\phi_{S_b})F^{\cos(\phi+\phi_{S_b})}_{LT}\Big)\Big]$$

$$+\left|\vec{S}_{aT}\right|S_{bL}\Big[\cos(\phi-\phi_{S_a})(1+\cos^2\theta)F^{\cos(\phi-\phi_{S_a})}_{TL} + \sin^2\theta\Big(\cos(3\phi-\phi_{S_a})F^{\cos(3\phi-\phi_{S_a})}_{TL} + \cos(\phi+\phi_{S_a})F^{\cos(\phi+\phi_{S_a})}_{TL}\Big)\Big]$$

$$+\left|\vec{S}_{aT}\right|\left|\vec{S}_{bT}\right|\Big[(1+\cos^2\theta)\Big(\cos(2\phi-\phi_{S_a}-\phi_{S_b})F^{\cos(2\phi-\phi_{S_a}-\phi_{S_b})}_{TT} + \cos(\phi_{S_b}-\phi_{S_a})F^{\cos(\phi_{S_b}-\phi_{S_a})}_{TT}\Big)\Big]$$

$$+\left|\vec{S}_{aT}\right|\left|\vec{S}_{bT}\right|\Big[\sin^2\theta\Big(\cos(\phi_{S_a}+\phi_{S_b})F^{\cos(\phi_{S_a}+\phi_{S_b})}_{TT} + \cos(4\phi-\phi_{S_a}-\phi_{S_b})F^{\cos(4\phi-\phi_{S_a}-\phi_{S_b})}_{TT}\Big)\Big]$$

$$+\left|\vec{S}_{aT}\right|\left|\vec{S}_{bT}\right|\Big[\sin^2\theta\Big(\cos(2\phi-\phi_{S_a}+\phi_{S_b})F^{\cos(2\phi-\phi_{S_a}+\phi_{S_b})}_{TT} + \cos(2\phi+\phi_{S_a}-\phi_{S_b})F^{\cos(2\phi+\phi_{S_a}-\phi_{S_b})}_{TT}\Big)\Big]\Big\}$$

where F^i_{jk} are the Structure Functions (SFs) connected to the corresponding PDFs. The SFs depend on four variables $P_a \cdot q$, $P_b \cdot q$, $\mathbf{q_T}$ and q^2 or on $\mathbf{q_T}$, q^2 and the Bjorken variables of colliding hadrons, x_a, x_b,

$$x_a = \frac{q^2}{2P_a\cdot q} = \sqrt{\frac{q^2}{s}}e^{y},\quad x_b = \frac{q^2}{2P_b\cdot q} = \sqrt{\frac{q^2}{s}}e^{-y},$$ y is the CM rapidity and

The cross section cannot be measured directly because there is no single beam containing particles with the U, L and T polarization. To measure SFs entering this equation one can use the following procedure: first, to integrate cross section over the azimuthal angle Φs, second, following the SIDIS practice, to measure azimuthal asymmetries of the DY pair's production cross sections. The integration over the azimuthal angle Φ gives:

$$\sigma_{int} \equiv \frac{d\sigma}{dx_a dx_b d^2q_T d\cos\theta} = \frac{\pi\alpha^2}{2q^2}\times(1+\cos^2\theta)\Big[F^1_{UU} + S_{aL}S_{bL}F^1_{LL}$$

$$+\left|\vec{S}_{aT}\right|\left|\vec{S}_{bT}\right|\Big(\cos(\phi_{S_b}-\phi_{S_a})F^{\cos(\phi_{S_b}-\phi_{S_a})}_{TT} + D\cos(\phi_{S_a}+\phi_{S_b})F^{\cos(\phi_{S_a}+\phi_{S_b})}_{TT}\Big)\Big]$$

Drell-Yan studies with SPD.

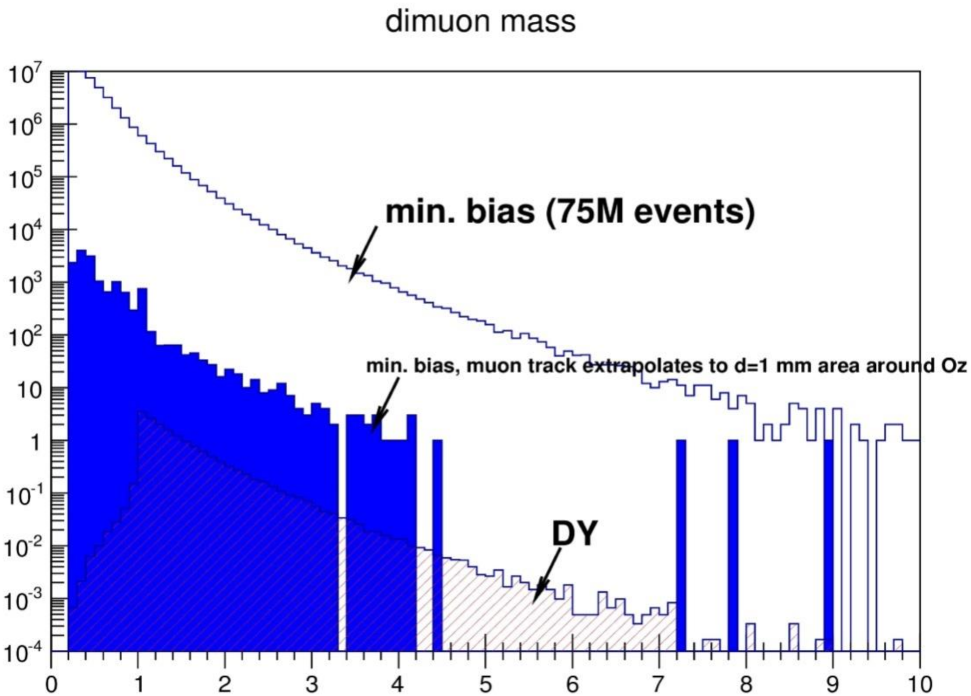
DY background studies

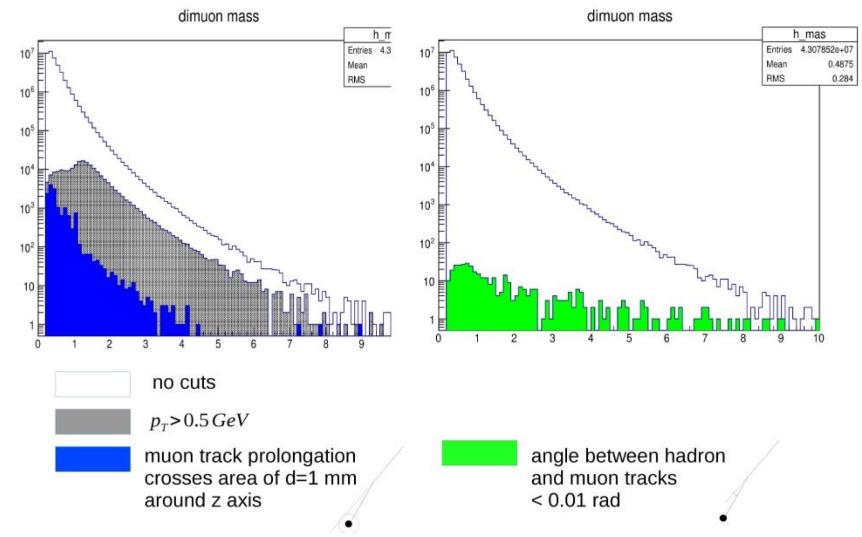
DY and min bias events were generated with PYTHIA 6

- 2 proton beams with E=12 GeV
- Only process $q\bar{q} \to \gamma^* \to \mu^+\mu^-$
- $m_{\mu\mu} > 1\,GeV$
- Decays of $\pi^\pm, K^\pm, K^0_L$ turned on
- 10^5 events
- $\sigma_{tot} = 8.7\,nb$ (ratio $\sigma_{tot}(MB)/\sigma_{tot}(DY) \approx 4.5 \cdot 10^6$)
- Only muons produced in volume with L=8 m and D=7 m were taken into account.

- (For $m_{\mu\mu} > 3\,GeV$ $\sigma_{tot} = 0.23\,nb$)

- PYTHIA 6
- MSEL=2
- 2 proton beams with E=12 GeV
- Decays of $\pi^\pm, K^\pm, K^0_L$ turned on
- $75 \cdot 10^6$ events
- $\sigma_{tot} = 39.4\,mb$





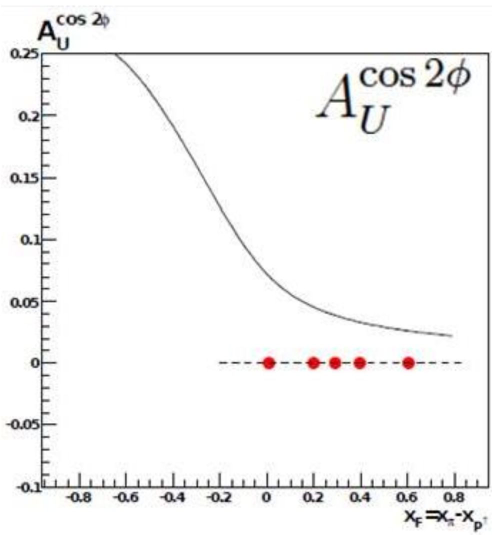
Tracking system has to be done with very high efficiency to reduce DY background.
~1:60 signal/background

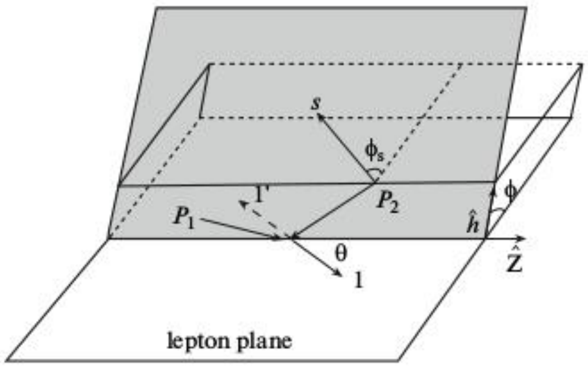
Drell-Yan studies with SPD.

At LO the general expression of the DY cross-section simplifies to (S. Arnold, et al, Phys.Rev. D79 (2009) 034004) :

$$\frac{d\sigma^{LO}}{d^4q\,d\Omega} = \frac{\alpha_{em}^2}{Fq^2}\hat{\sigma}_U^{LO}\Big\{\Big(1 + D_{[\sin^2\theta]}^{LO} A_U^{\cos 2\varphi}\cos 2\varphi\Big) + |\vec{S}_T|\Big[A_T^{\sin\varphi_S}\sin\varphi_S + D_{[\sin^2\theta]}^{LO}\Big(A_T^{\sin(2\varphi+\varphi_S)}\sin(2\varphi+\varphi_S) + A_T^{\sin(2\varphi-\varphi_S)}\sin(2\varphi-\varphi_S)\Big)\Big]\Big\}$$

$A_U^{\cos 2\varphi}$ - gives access to the Boer-Mulders function





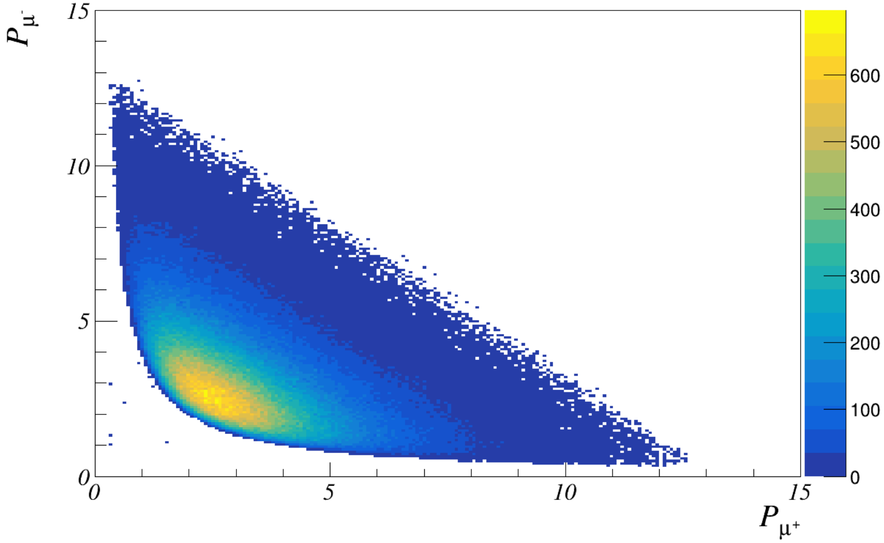
Definition of angles in Collins–Soper reference frame.

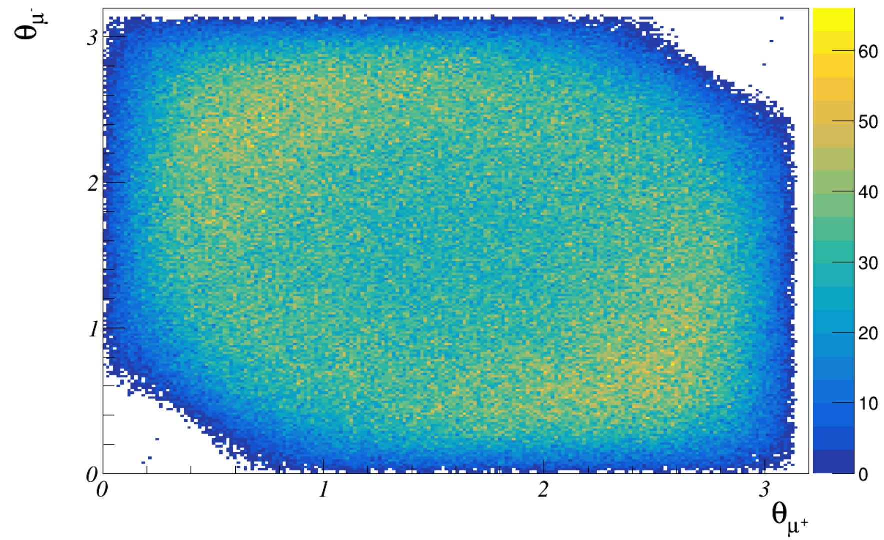
For MC studies we can take Boer-Mulders asymmetry as reference function via weights, and extract this asymmetry from simulated MC data after simplified SPD set-up with two magnet systems. The toroidal system must be checked most thoroughly since it is a new one.

Future DY experiments

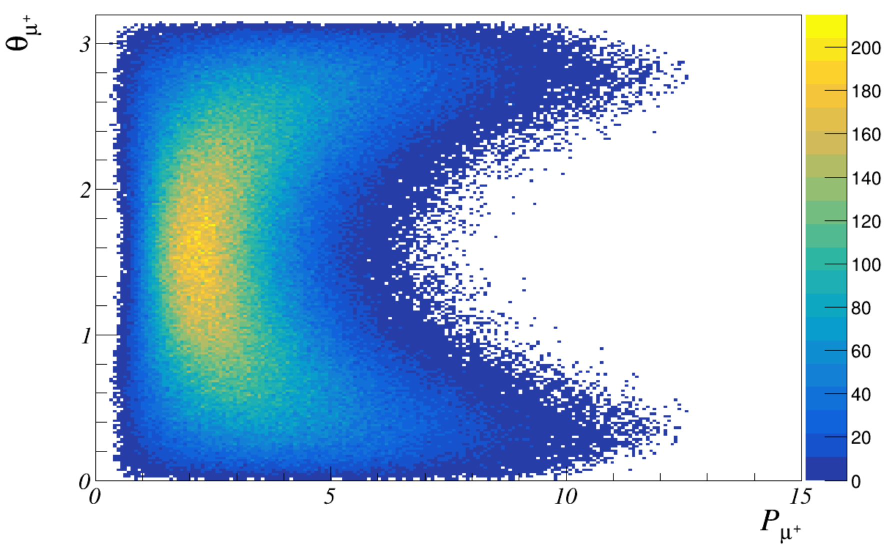
The SPD experimentswill have a number of advantages for DY measurements related to nucleon structure studies. These advantages include:
- operations with pp, pd and dd beams,
- scan of effects on beam energies,
- measurement of effects via muon and electron-positron pairs simultaneously,
- operations with non-polarized, transverse and longitudinally polarized beams or their combinations.
Such possibilities permit for the first time to perform comprehensive studies of all leading twist PDFs of nucleons in a single experiment with minimum systematic errors.

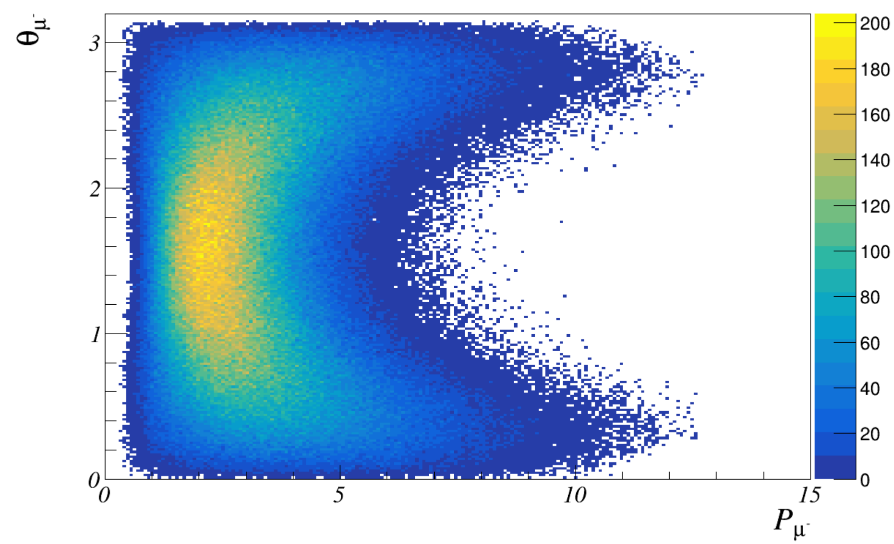
Experiment	CERN, COMPASS-II	FAIR, PANDA	FNAL, E-906	RHIC, STAR	RHIC-PHENIX	NICA, SPD
mode	fixed target	fixed target	fixed target	collider	collider	collider
Beam/target	π- , p	anti-p,p	π- , p	pp	pp	pp, pD,DD
Polarization: beam, target	0; ~ 0.8	0; 0	0; 0;	0.5 ; 0.5	0.5 ; 0.5	0.5 ; 0.5
Luminosity, $cm^{-2}s^{-1}$	10^{32}	10^{32}	10^{42}	10^{32}	10^{32}	10^{32}
$\sqrt{s}$, *GeV*	17	6	16	200	200	10-26
$x_{1(beam)}$ $x_{2(targ)}$ ranges	0.1-1.0 ; 0.5-0.9	0.1-1.0 ; 0.3-0.8	0.1-1.0 ; 0.3-0.8	0.1-0.9 ; 0.1-0.9	0.1-0.9 ; 0.1-0.9	0.1-0.8 ; 0.1-0.8
q_T, GeV	0.5 -4.0	0.5 -1.5	0.5 -3.0	1.0 -10.0	1.0 -10.0	0.5 -6.0
Lepton pairs,	μ-μ+	μ-μ+	μ-μ+	μ-μ+	μ-μ+	μ-μ+, e+e-
Data taking	2014	>2018	2013	>2016	>2016	>2017
Transversity PDF	YES	NO	NO	YES	YES	YES
Boer-Mulders PDF	YES, valence, $h_{1(\pi)}^{\perp} \otimes h_{1(p)}^{\perp}$	YES	YES	YES	YES	YES
Sivers PDF	YES, π PDF	YES	YES	YES	YES	YES
Pretzelosity PDF	YES	NO	NO	NO	YES	YES
Worm Gear PDFs	YES	NO	NO	NO	NO	YES
Duality, J/Ψ	YES	YES	NO	NO	NO	YES
Flavour decomposition	NO	NO	YES	NO	NO	YES
Lam-Tung relation	NO	NO	NO	NO	NO	YES

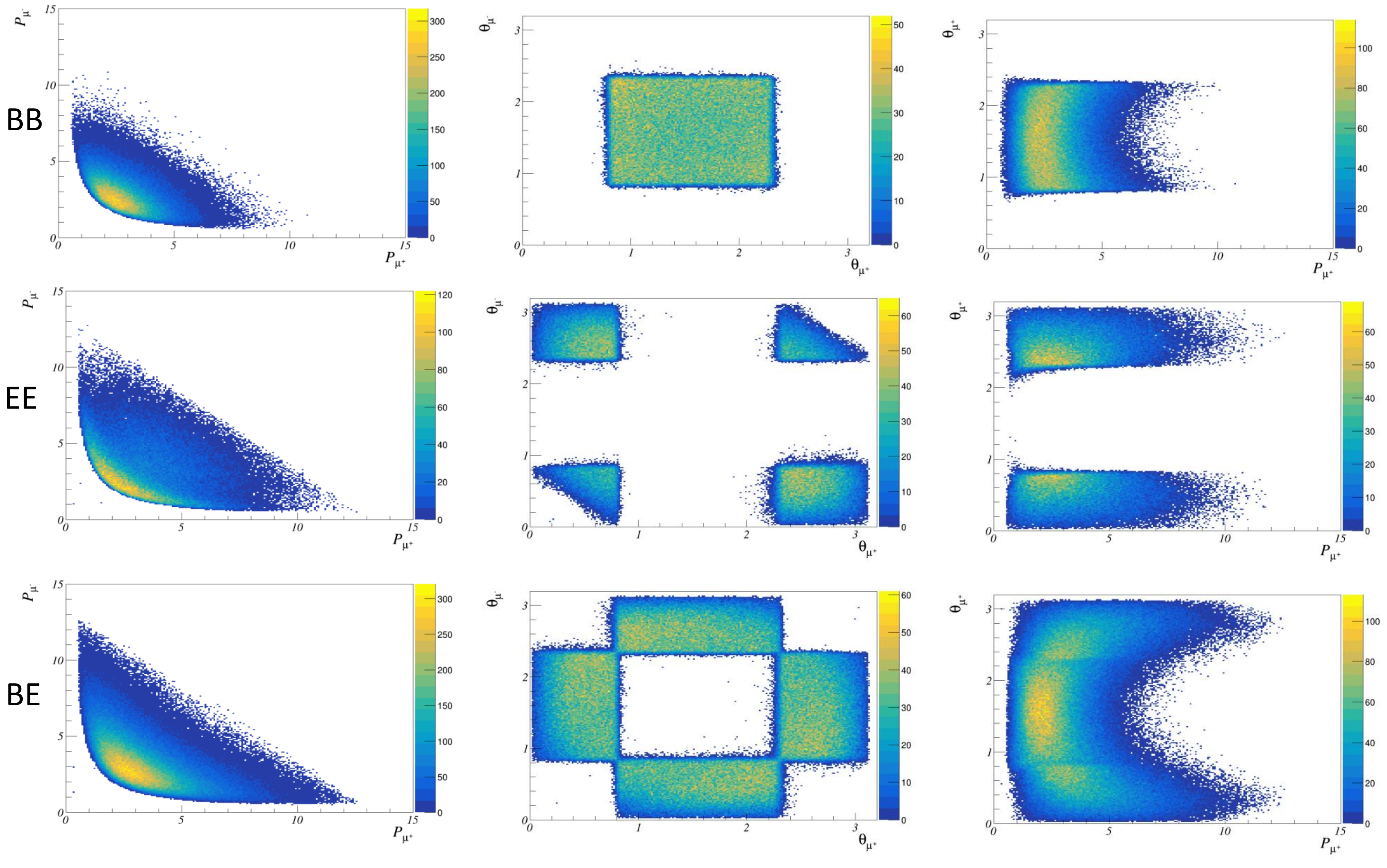




RS







BB
EE
BE
P_{μ^-}
P_{μ^+}
θ_{μ^-}
θ_{μ^+}