DPS in pA collisions at LHC:how they can be observed?

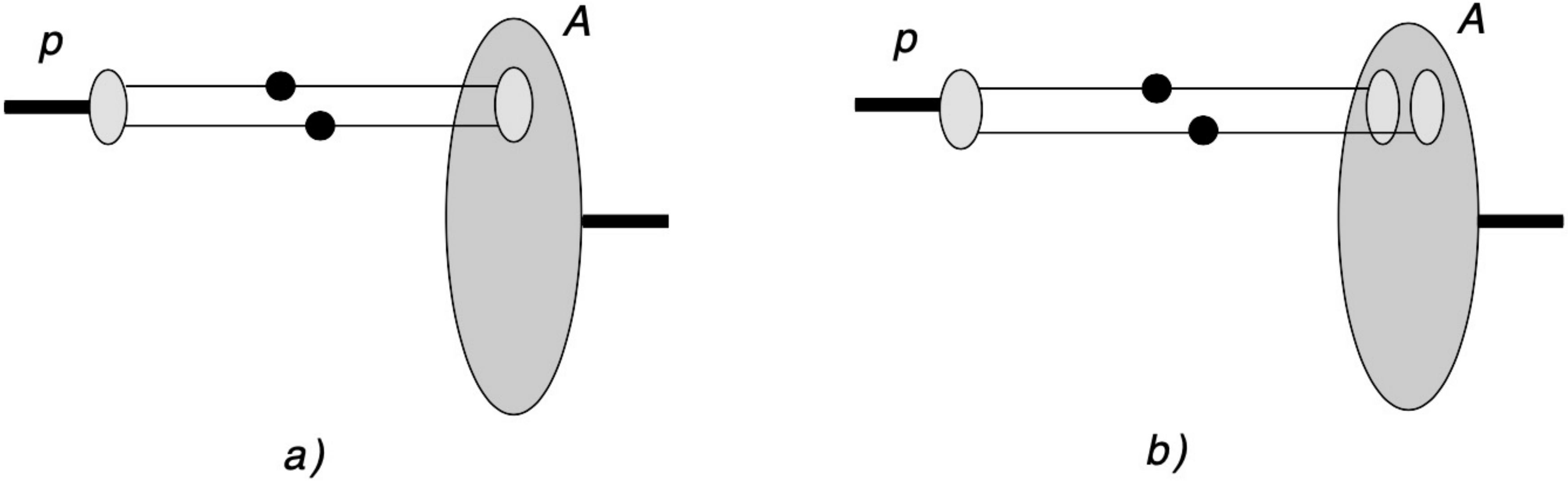
B.Blok (Technion)

Based on

B.Blok,, F.A. Ceccopieri *Eur.Phys.J.C* 80 (2020) 3, 278;

Eur.Phys.J.C 80 (2020) 8, 762; *Phys.Rev.D* 101 (2020) 9, 0940;

M.Alvioli,M.Azarkin.B. Blok,M.Strikman
Eur.Phys.J.C 79 (2019) 6, 482



DPS in pA where first studied in Strikman,Treleani 2002
Basic observation: there is DPS1-diagram a) like DPS in pp, but there is also diagram b) called DPS2 sometimes–two nucleons at the same impact parameter. The latter process is enhanced by factor $A^{1/3}$ *realistic estimate shows for A=200 the ratio of pA and pp DPS cross sections is approximately 3.*

QCD correctons were considered in Blok, Strikman,Wiedemann (2013)

$$R_{pA}^{4jet}(x_1,x_2,x_1',x_2') \equiv \frac{d\sigma_{4jet}^{pA}(x_1,x_2,x_1',x_2')}{d\hat{t}_1\, d\hat{t}_2} \Bigg/ \frac{A}{S}\frac{d\sigma_{2\,jet}(x_1',x_1)}{d\hat{t}_1}\frac{d\sigma_{2\,jet}(x_2',x_2)}{d\hat{t}_2}$$

$$= 1+\frac{S}{A}\frac{A-1}{A}\int T^2(b)d^2b\frac{G_p(x_1',x_2')}{f_p(x_1')f_p(x_2')},$$

$$R_{pA}^{4jet}(x_1,x_2,x_1',x_2') = 1 + S\,W(A)\,K(x_1',x_2') \qquad W(A) = \frac{A-1}{A^2}\int d^2bT^2(b)$$

$S\,W(A) \sim 2.1$ *S=15 mb,A=200*

$$K(x_1',x_2') = \frac{G_p(x_1',x_2',0)}{f_p(x_1')f_p(x_2')}$$

So the DPS in pA may measure longitudinal correlations of partons in the nucleon

Question: how to see DPS2?

Need to substract Leading twist contribution. Recently for the first time observed by LHCb in D system

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New method developed in Alvioli,Azarkin,Blok,Strikman (2019)

$$\sigma_{\mathrm{p}A} = A\,\frac{\sigma_1\,\sigma_2}{\sigma_{eff}} + \sigma_1\,\sigma_2 \int d^2b\,T^2(b)$$

In the b-space

$$\frac{d\sigma_{pA}^{\mathrm{DPS}}}{d^2b} = \sigma_{pN}\,T_A(b) + \sigma_1\,\sigma_2\,T^2(b)\,.$$

Such different dependences on impact parameter in pA collisions can be used for unambigious extraction of DPS2 from the data on pA scattering eliminating SPS and DPS1 backgrounds. So we can substract SPS background (Leading twist)

Question: can one indeed use this method to extract DPS2, what is the statistics needed for extraction and are there enough DPS2 events in pA collisions in 4 jet and dijet+Z,W processes to be measured in current and future runs?
Answer: all these processes can be studied at ATLAS and CMS with already the available data.

Basic formalism: mean field, corrections to mean field in pA are much smaller than in pp (Blok,Strikman, Wiedemann, 2013).

$$\frac{d\sigma^{CD}_{DPS}}{d\Omega_1 d\Omega_2} = \frac{m}{2}\sum_{i,j,k,l}\sum_{N=p,n} \sigma^{-1}_{\rm eff} f^i_p(x_1) f^j_p(x_2) f^k_N(x_3) f^l_N(x_4) \frac{d\hat{\sigma}^C_{ik}}{d\Omega_C}\frac{d\hat{\sigma}^D_{jl}}{d\Omega_D}\int d^2B T_N(B),$$

$$+\frac{m}{2}\sum_{i,j,k,l}\sum_{N_3,N_4=p,n} f^i_p(x_1) f^j_p(x_2) f^k_{N_3}(x_3) f^l_{N_4}(x_4) \frac{d\hat{\sigma}^C_{ik}}{d\Omega_C}\frac{d\hat{\sigma}^D_{jl}}{d\Omega_D}\int d^2B T_{N_3}(B) T_{N_4}(B)$$

$$\rho^{(p,n)}(r) = \frac{\rho^{(p,n)}_0}{1+e^{(r-R^{(p,n)}_0)/a_{(p,n)}}}. \qquad T_{p,n}(B) = \int dz \rho^{(p,n)}(B,z).$$

$$\sigma^{ATLAS}_{eff} = 15 \pm 3\,(\text{stat.})^{+5}_{-3}\,(\text{syst.})\,\text{mb}\,,$$

$$\sigma^{CMS}_{eff} = 20.7 \pm 0.8\,(\text{stat.}) \pm 6.6\,(\text{syst.})\,\text{mb}$$

$$\bar{\sigma}_{eff} = 18 \pm 6 \text{ mb}.$$

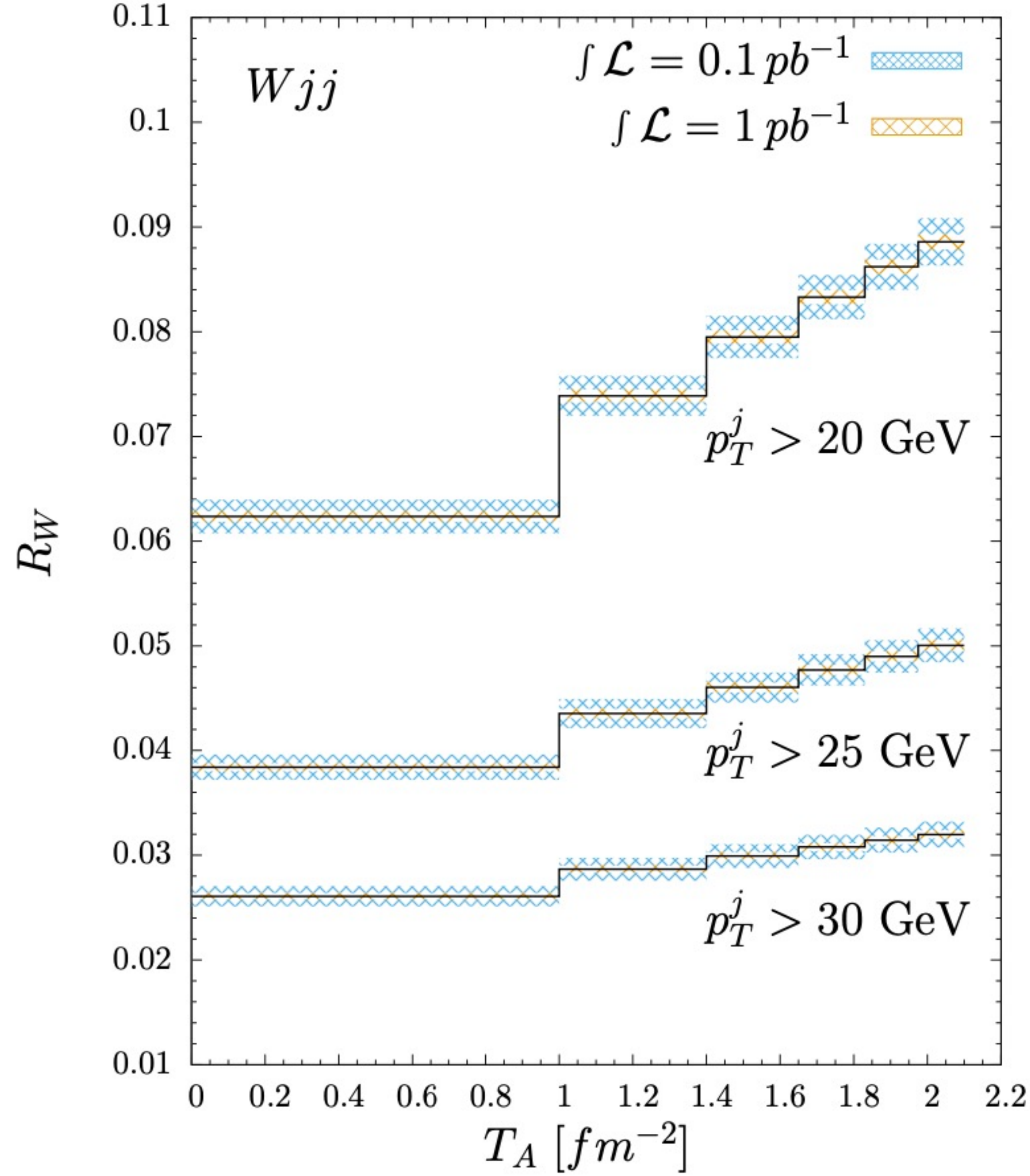
The nuclear pdfs include shadowing corrections

Example 1:Wjj process

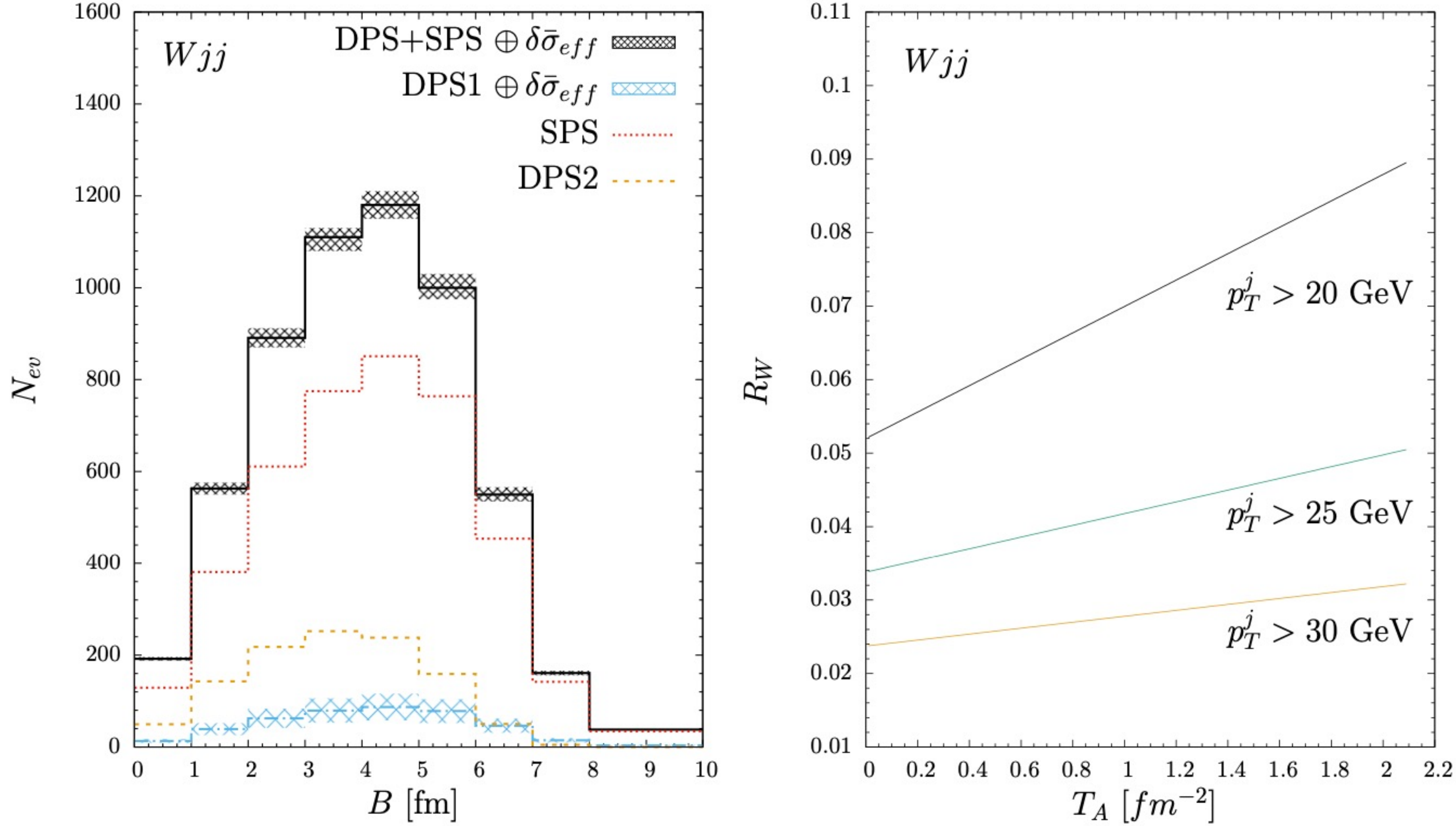
$$R_W(T) = N_{Wjj}(T)/N_W(T).$$

*Basic idea: to eliminate inaccuracies we take the ratio of the number of Wjj events and the number of W events, proportional to T(B)***.**

σ^{Wjj}	$p_T^j > 20$ GeV [nb]	$p_T^j > 25$ GeV [nb]	$p_T^j > 30$ GeV [nb]
DPS1	19 ± 6	8 ± 3	4 ± 2
DPS2	49	22	11
SPS	81	57	41
Tot	149 ± 6	87 ± 3	56 ± 2



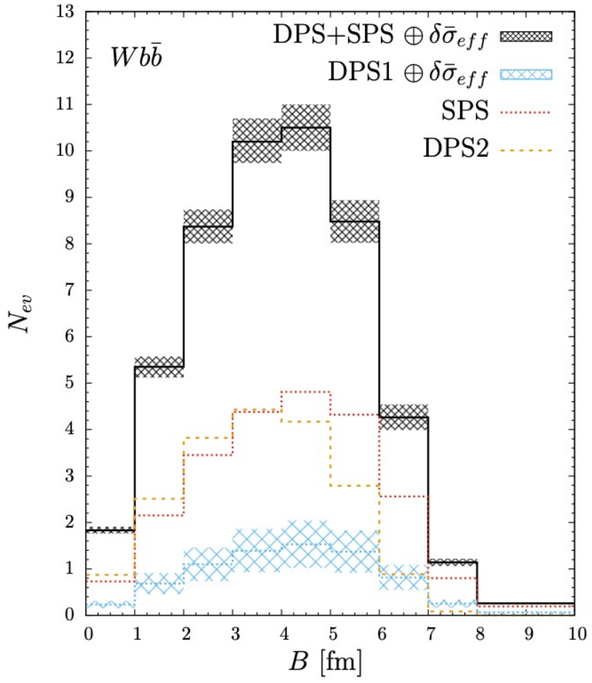
Wjj
$\int \mathcal{L} = 0.1\, pb^{-1}$
$\int \mathcal{L} = 1\, pb^{-1}$
$p_T^j > 20$ GeV
$p_T^j > 25$ GeV
$p_T^j > 30$ GeV
R_W
$T_A\ [fm^{-2}]$
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2

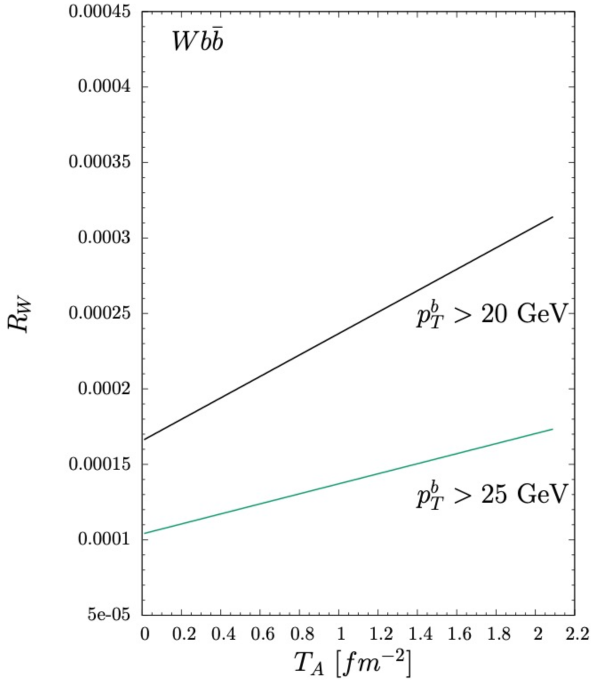


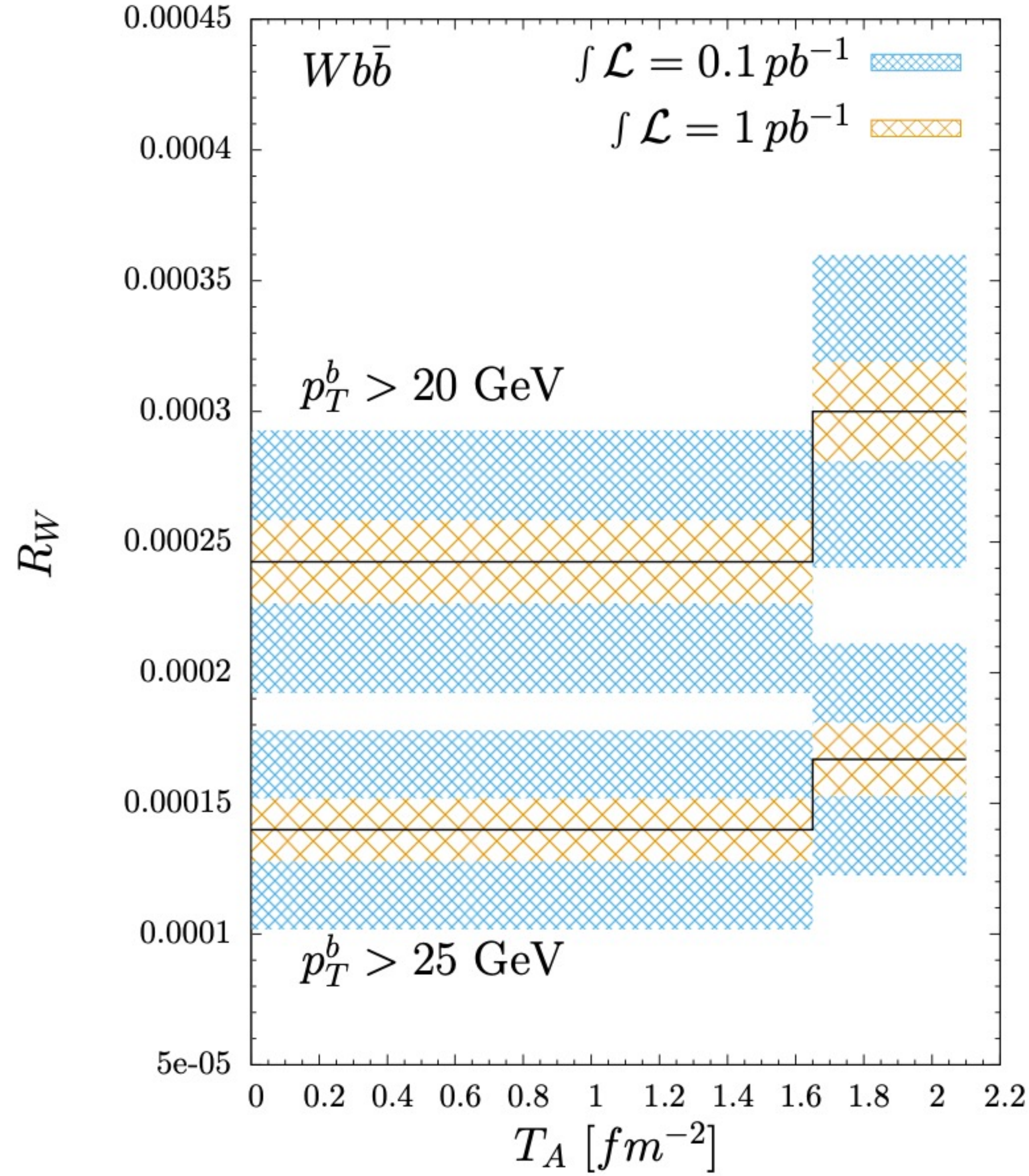
Wjj
DPS+SPS ⊕ δσ̄_eff
DPS1 ⊕ δσ̄_eff
SPS
DPS2
N_ev
B [fm]
0
200
400
600
800
1000
1200
1400
1600
0 1 2 3 4 5 6 7 8 9 10
Wjj
R_W
T_A [fm^-2]
p_T^j > 20 GeV
p_T^j > 25 GeV
p_T^j > 30 GeV
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.11
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2

Similar results for W+ two b-jets.

$\sigma^{Wb\bar{b}}$	$p_T^b > 20$ GeV [pb]	$p_T^b > 25$ GeV [pb]	$p_T^b > 30$ GeV [pb]
DPS1	74 ± 25	35 ± 12	18 ± 6
DPS2	196	92	48
SPS	234	158	114
Tot	504 ± 25	285 ± 12	180 ± 6



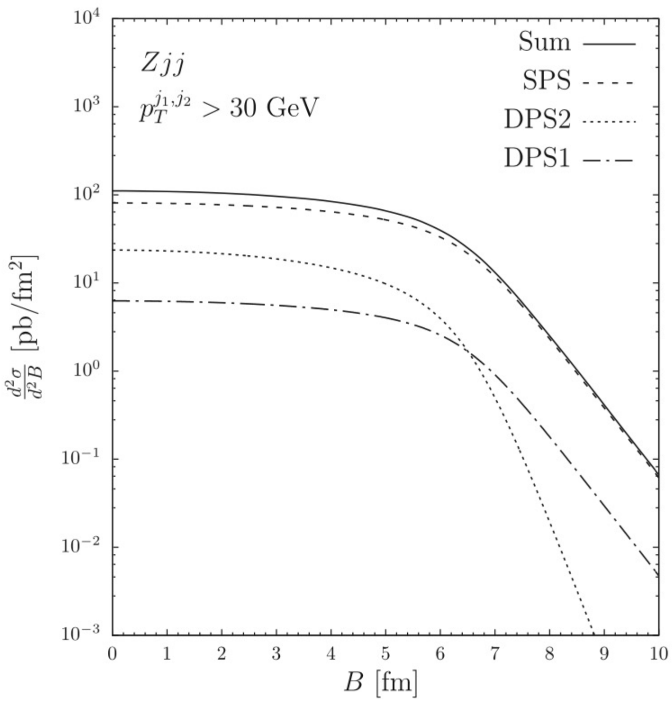


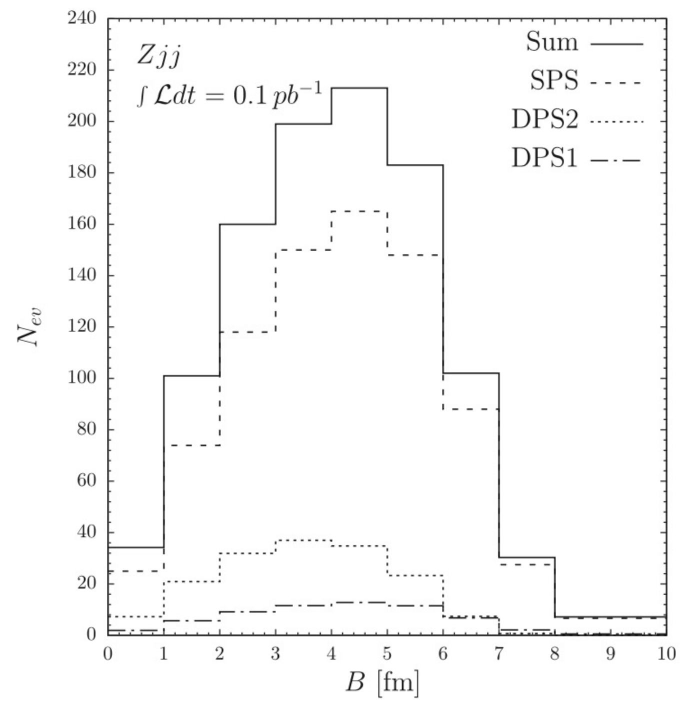


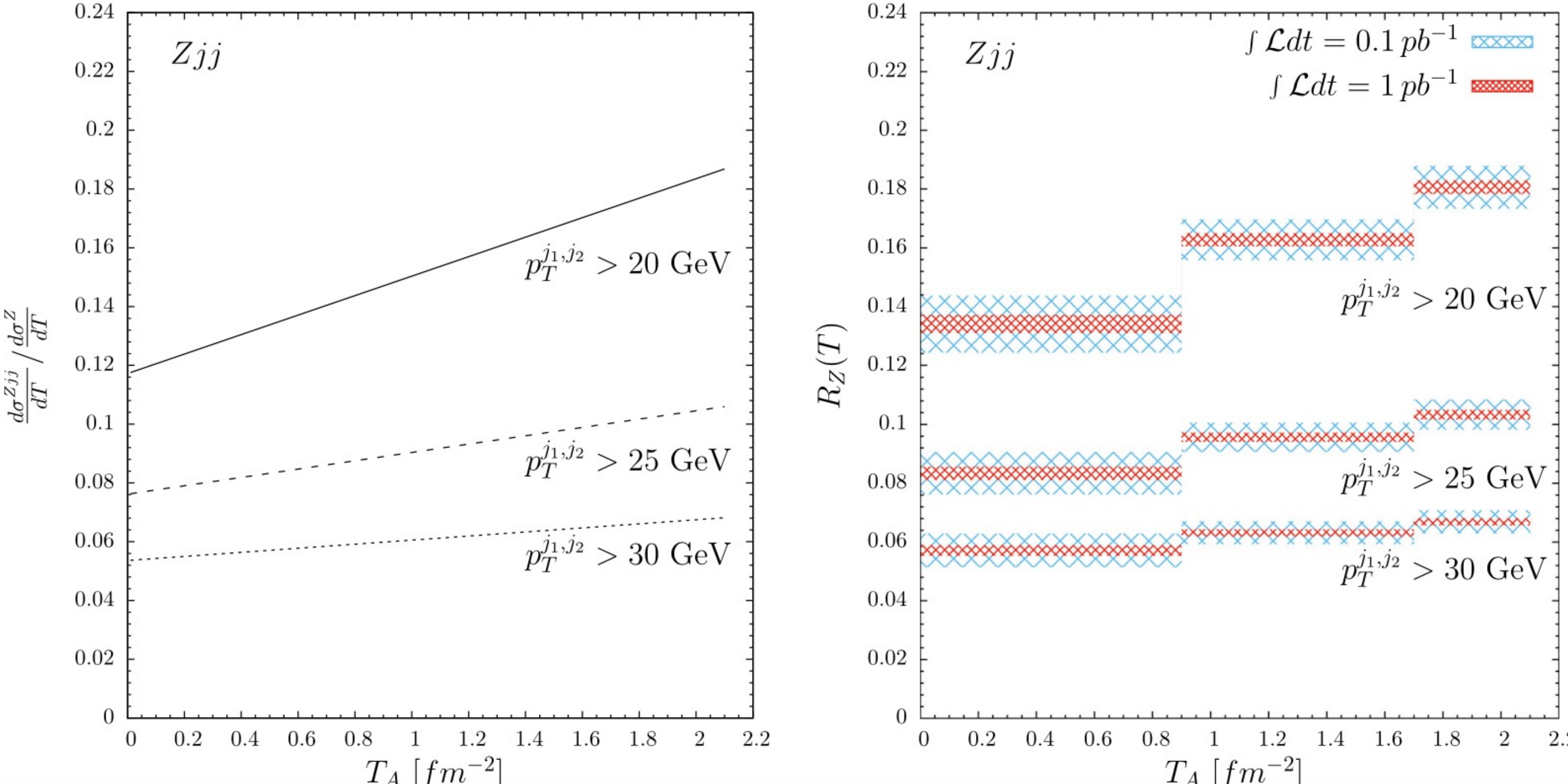
$Wb\bar{b}$
$\int \mathcal{L} = 0.1\,pb^{-1}$
$\int \mathcal{L} = 1\,pb^{-1}$
$p_T^b > 20$ GeV
$p_T^b > 25$ GeV
R_W
$T_A\ [fm^{-2}]$
0.00045
0.0004
0.00035
0.0003
0.00025
0.0002
0.00015
0.0001
5e-05
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2

Z+dijet

Zjj	DPS1 (pb)	DPS2 (pb)	SPS (pb)	Sum (pb)	$\sigma(Zjj)/\sigma(Z)$	f_{DPS1}	f_{DPS2}
$p_T^{j_1,j_2} > 20, 20$ GeV	2971	7814	15,940	26,725	0.166	0.111	0.292
$p_T^{j_1,j_2} > 25, 25$ GeV	1270	3341	11,024	15,636	0.097	0.081	0.213
$p_T^{j_1,j_2} > 30, 30$ GeV	621	1632	8030	10,283	0.064	0.060	0.158







Zjj
$p_T^{j_1,j_2} > 20$ GeV
$p_T^{j_1,j_2} > 25$ GeV
$p_T^{j_1,j_2} > 30$ GeV
$\frac{d\sigma^{Zjj}}{dT} / \frac{d\sigma^{Z}}{dT}$
$T_A\ [fm^{-2}]$
Zjj
$\int \mathcal{L}dt = 0.1\, pb^{-1}$
$\int \mathcal{L}dt = 1\, pb^{-1}$
$p_T^{j_1,j_2} > 20$ GeV
$p_T^{j_1,j_2} > 25$ GeV
$p_T^{j_1,j_2} > 30$ GeV
$R_Z(T)$
$T_A\ [fm^{-2}]$

Two dijets

$$N_{ev}(T_i, T_{i+1}) = \int d^2B \frac{d^2\sigma_{pA}}{d^2B} \Theta(T_A(B) - T_i)$$

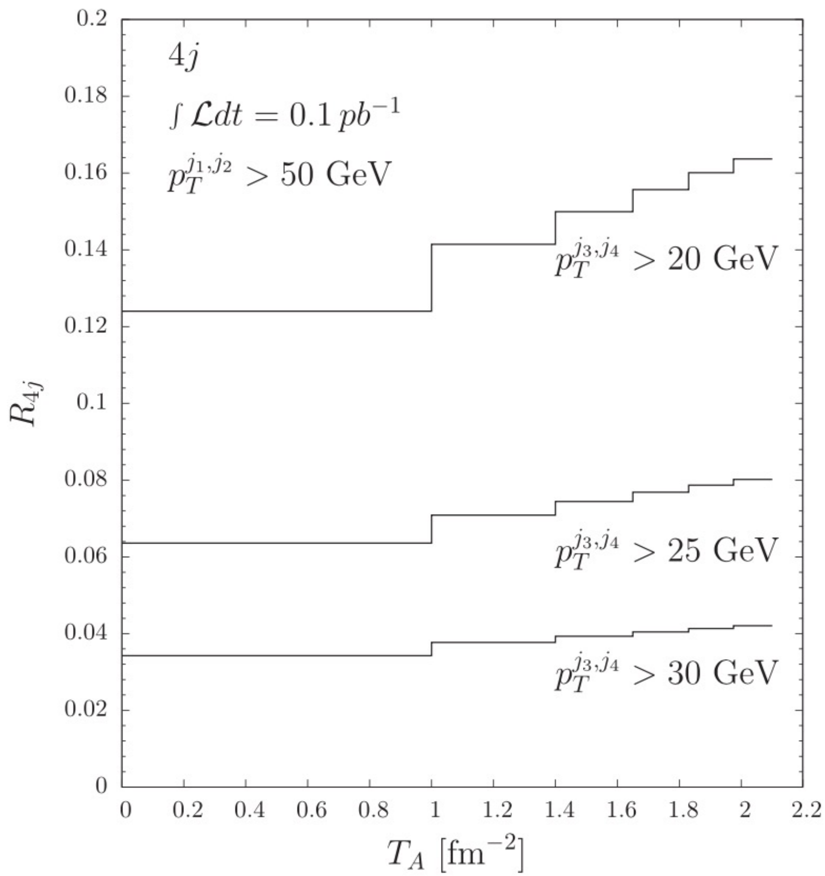
$$\times \Theta(T_{i+1} - T_A(B)), \quad R^0_{4j}(T_i, T_{i+1}) = \frac{N_{4j}(T_i, T_{i+1})}{N_{2j}(T_i, T_{i+1})} \left(\frac{N_{4j}(T_0, T_1)}{N_{2j}(T_0, T_1)}\right)^{-1};$$

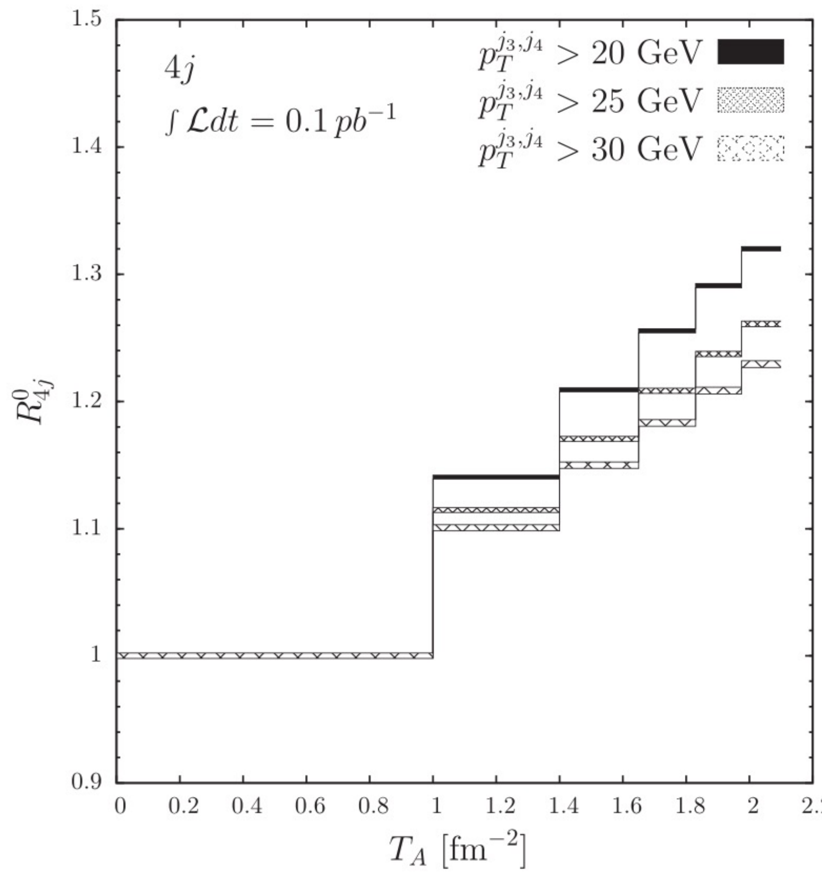
$$R_{4j}(T_i, T_{i+1}) = N_{4j}(T_i, T_{i+1})/N_{2j}(T_i, T_{i+1})$$

The double ratio to decrease sensitivity to higher order corrections

TABLE II. Predictions for $4j$ DPS and SPS cross sections in pA collisions in fiducial phase space, for different cuts on jets transverse momenta.

$4j$	DPS1 (μb)	DPS2 (μb)	SPS (μb)	Sum (μb)	$\sigma(4j)/\sigma(2j)$	f_{DPS1}	f_{DPS2}
$p_T^{j_3,j_4} > 20$ GeV	26.0	72.2	170.9	269.2	0.15	0.13	0.27
$p_T^{j_3,j_4} > 25$ GeV	10.8	30.2	92.9	133.9	0.07	0.10	0.22
$p_T^{j_3,j_4} > 30$ GeV	5.1	14.3	51.4	70.9	0.04	0.09	0.20

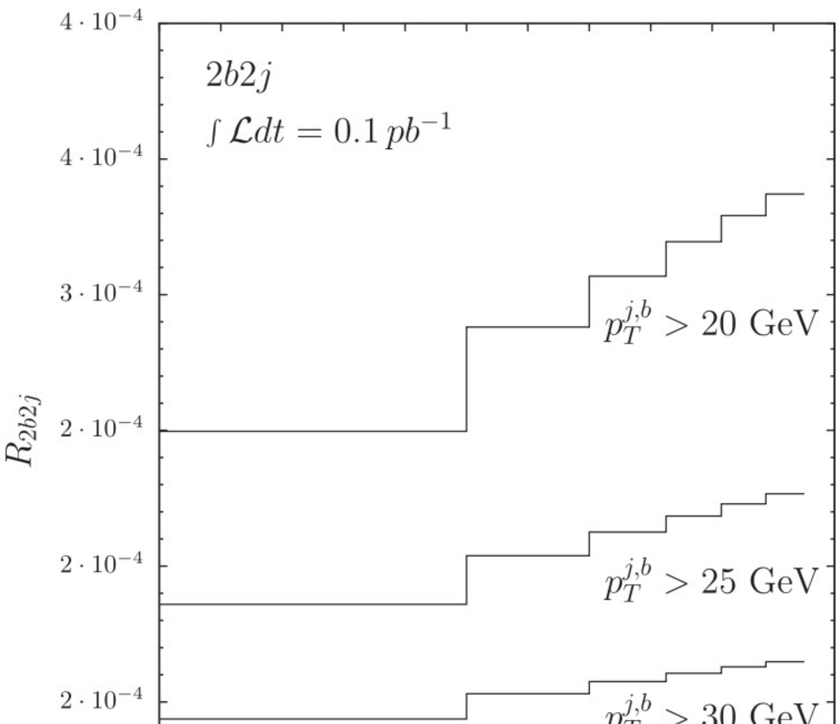


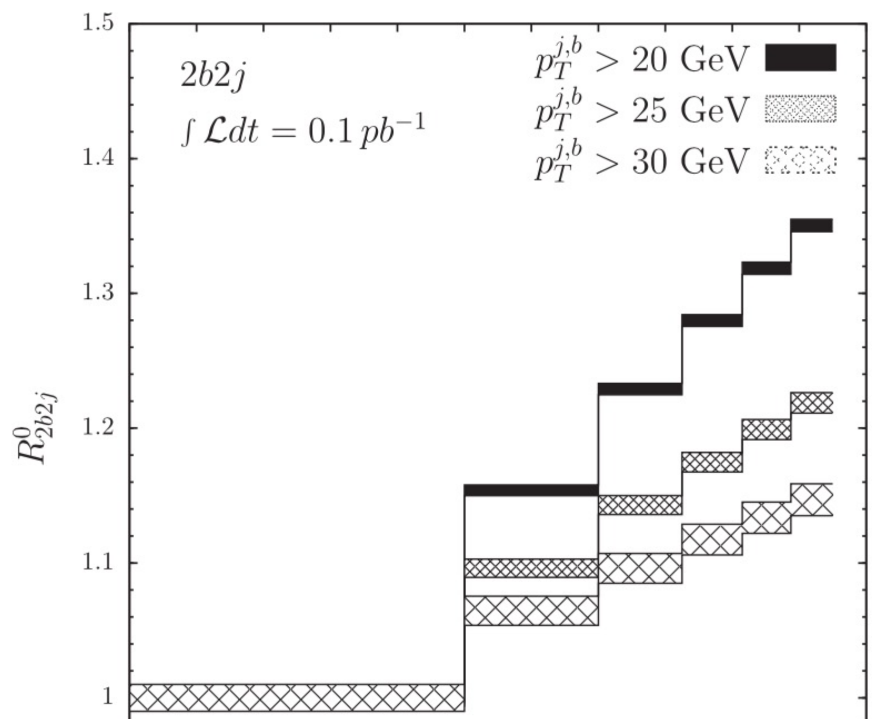


2j2b

TABLE III. Predictions for $2b2j$ DPS and SPS cross sections in pA collisions in fiducial phase space for different cuts on jets transverse momenta.

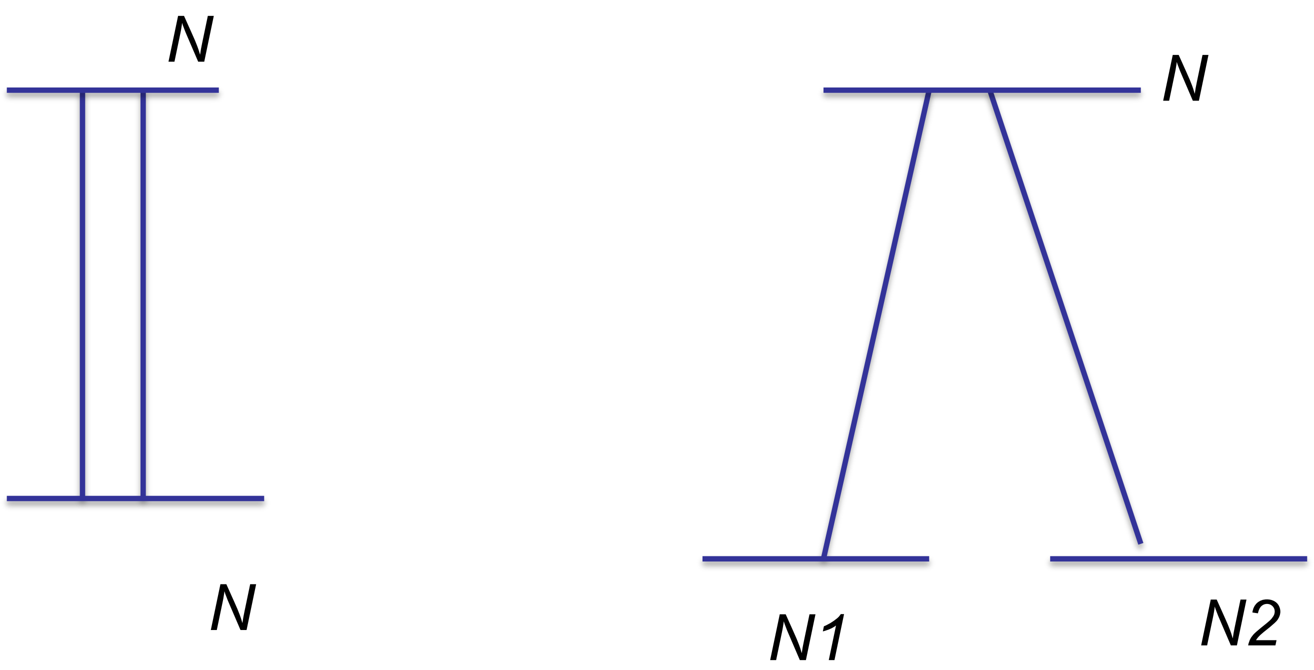
	DPS1	DPS2	SPS	Sum	$\sigma(2b2j)/\sigma(2j)$	f_{DPS1}	f_{DPS2}
$2b2j$	(μb)	(μb)	(μb)	(μb)	$\times 10^{-4}$		
$p_T^{b,j} > 20$ GeV	2.2	6.2	13.0	21.4	3.0	0.15	0.29
$p_T^{b,j} > 25$ GeV	0.4	1.2	4.7	6.4	2.1	0.09	0.19
$p_T^{b,j} > 30$ GeV	0.1	0.3	1.9	2.3	1.6	0.06	0.13





Conclusions

- There is enough statistics to see DPS2 in pA already with available data
- Additional work in particular calculation of NLO and NNLO corrections must be done to extract the longitudinal correlations due to large K factors in some channels.



N
N
N
N1
N2

MPI in pA scattering B.Blok, M. Strikman, U. Wiedemann)

Eur.Phys.J. C73 (2013) no.6, 2433

$$\frac{d\sigma^{AB}_{4jet}}{d\hat{t}_1 d\hat{t}_2} = \int \frac{d^2\vec{\Delta}}{(2\pi)^2} \frac{d\hat{\sigma}_1(x_1', x_1)}{d\hat{t}_1} \frac{d\hat{\sigma}_2(x_2', x_2)}{d\hat{t}_2} \; {}_2G_A(x_1', x_2', \vec{\Delta})\, {}_2G_B(x_1, x_2, \vec{\Delta})\,.$$

$${}_2G_A(x_1, x_2, \vec{\Delta}) = G_A^{\mathrm{single,1N}}(x_1, x_2, \vec{\Delta}) + G_A^{\mathrm{double,1N}}(x_1, x_2, \vec{\Delta}) + G_A^{2N}(x_1, x_2, \vec{\Delta})\,.$$

First two terms sum to expression increasing as A:

$$\frac{\sigma^{pA,1N}_{4jet}}{d\hat{t_1}\, d\hat{t_2}} \approx A \frac{d\sigma^{pp}_{4jet}}{d\hat{t_1}\, d\hat{t_2}} = \frac{A}{S} \frac{d\sigma^{pp}_{2jet}}{d\hat{t_1}} \frac{d\sigma^{pp}_{2jet}}{d\hat{t_2}}\,.$$

Third term: (3 to 4 from nucleon is suppressed

$$\frac{\sigma_4^{(III)}(x_1', x_2', x_1, x_2)}{d\hat{t}_1 d\hat{t}_2} = \frac{f_p(x_1', x_2')}{f_p(x_1') f_p(x_2')} \frac{d\sigma^{pp}_{\mathrm{2jet}}(x_1', x_1)}{d\hat{t}_1} \frac{d\sigma^{pp}_{\mathrm{2jet}}(x_2', x_2)}{d\hat{t}_2} \frac{(A-1)}{A} \underbrace{\int T^2(b) d^2 b}_{\propto A^{4/3}}\,.$$

-leading term A(A-1) (Strikman-Treleani)

$$R_{pA}^{4jet}(x_1,x_2,x_1',x_2') \equiv \frac{d\sigma_{4jet}^{pA}(x_1,x_2,x_1',x_2')}{d\hat{t}_1\, d\hat{t}_2} \Bigg/ \frac{A}{S} \frac{d\sigma_{2\,jet}(x_1',x_1)}{d\hat{t}_1} \frac{d\sigma_{2\,jet}(x_2',x_2)}{d\hat{t}_2}$$

$$= 1 + \frac{S}{A}\frac{A-1}{A}\int T^2(b) d^2b \frac{G_p(x_1',x_2')}{f_p(x_1')\, f_p(x_2')},$$

$$G_p(x_1',x_2') = f_p(x_1',x_2') + G_p^{\text{single}}(x_1',x_2',0)\,.$$

We measure:

$$K(x_1',x_2') = \frac{R_{pA}^{4jet}(x_1,x_2,x_1',x_2') - 1}{S\,W(A)} = \frac{G_p(x_1',x_2',0)}{f_p(x_1')f_p(x_2')}\,.$$

$$W(A) = \frac{A-1}{A^2}\int d^2b T^2(b)\,.$$

Distinction of K from 1 will mean longitudinal correlations

$$x \geq 0.005.$$

The corrections due to shadowing will be small in this kinematic region

(see also Treleani, Calucci 2012 for shadowing/interference for pd)