W+dijet production in pA collisions via DPS revisited

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Outline

- DPS in pA collisions : new DPS mechanism at work never confirmed experimentally
- However pA runs deliver rather low integrated luminosity: 0.2 pb^{-1} in 2016
- Need for large DPS cross section: $W + jj$
- Study the dependence on impact parmater B of DPS the cross section
- Observe and desentangle the two DPS components
- Attempt a characterization of DPS cross section

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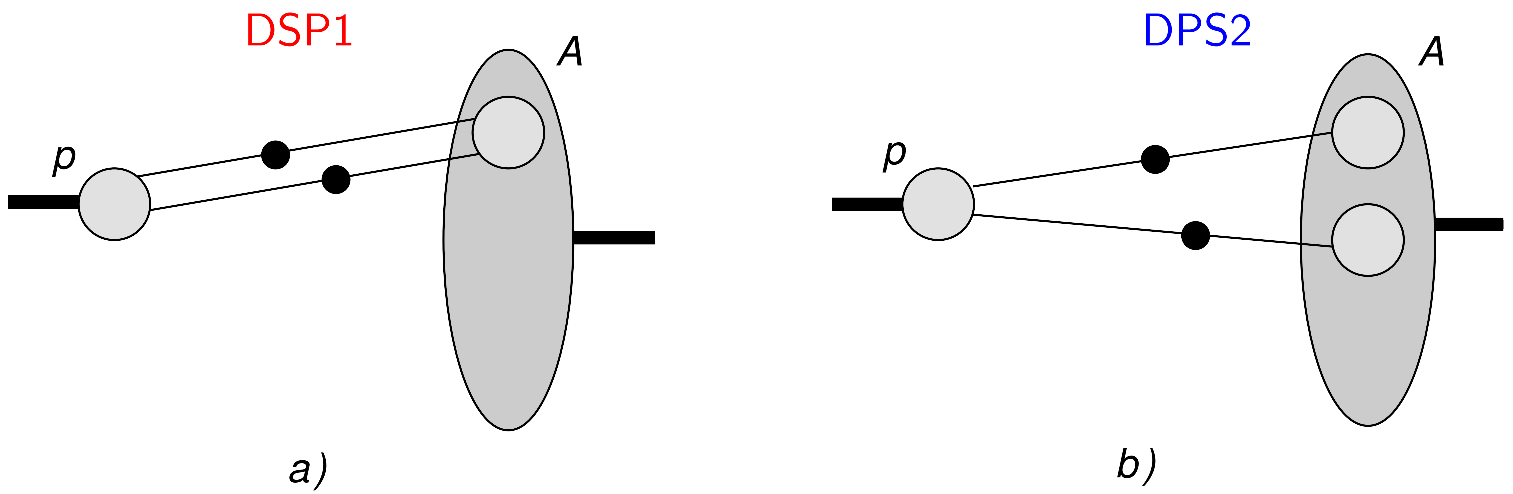
DPS in pA collisions

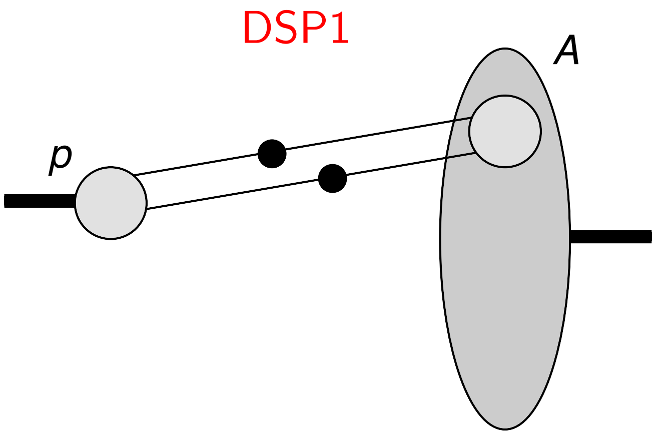


$$d\sigma^{CD}_{DPS} = \frac{m}{2}\sum_{i,j,k,l}\;\sum_{N=p,n}\int d\vec{b}_\perp \int d^2B\; D_p^{ij}(x_1,x_2;\vec{b}_\perp)\,D_N^{kl}(x_3,x_4;\vec{b}_\perp)\,T_N(B)\,d\hat{\sigma}^C_{ik}\,d\hat{\sigma}^D_{jl} +$$

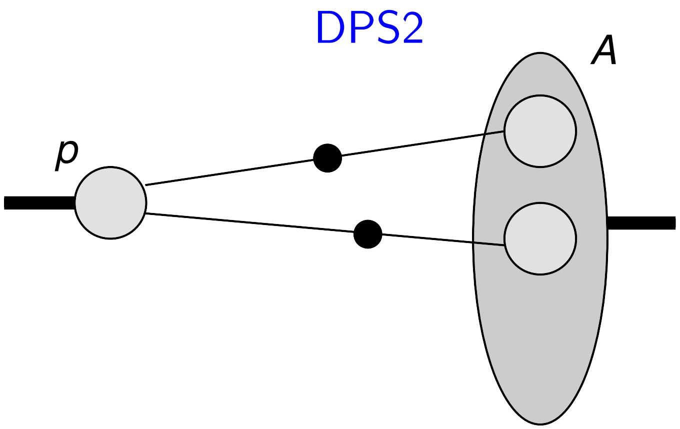
$$+\frac{m}{2}\sum_{i,j,k,l}\;\sum_{N_3,N_4=p,n}\int d\vec{b}_\perp\, D_p^{ij}(x_1,x_2;\vec{b}_\perp)\int d^2B\; f^k_{N_3}(x_3)\,f^l_{N_4}(x_4)\,T_{N_3}(B)\,T_{N_4}(B)\,d\hat{\sigma}^C_{ik}\,d\hat{\sigma}^D_{jl}$$

- First discussed in M. Strikman and D. Treleani, PRL **88** (2002) 031801
- B is the impact parameter of the proton-nucleus collision, $T(B)$ nuclear thickness function

DPS in pA collisions



a)



b)

$$d\sigma^{CD}_{DPS} = \frac{m}{2}\sum_{i,j,k,l}\sum_{N=p,n}\int d\vec{b}_\perp \int d^2B\, D_p^{ij}(x_1,x_2;\vec{b}_\perp)D_N^{kl}(x_3,x_4;\vec{b}_\perp)T_N(B)d\hat{\sigma}^C_{ik}d\hat{\sigma}^D_{jl} +$$

$$+\frac{m}{2}\sum_{i,j,k,l}\sum_{N_3,N_4=p,n}\int d\vec{b}_\perp D_p^{ij}(x_1,x_2;\vec{b}_\perp)\int d^2B\, f^k_{N_3}(x_3)f^l_{N_4}(x_4)T_{N_3}(B)T_{N_4}(B)d\hat{\sigma}^C_{ik}d\hat{\sigma}^D_{jl}$$

- DPS1 $\propto T$, DPS2 $\propto T^2$
- For large A, $R_p \ll R_A$, $T(b+B) \sim T(B)$, $b_\perp$ and B integrals decouple

The nuclear target

- ${}^{208}P_b$ nucleus : proton and neutron densities described by a Wood-Saxon distribution

$$\rho_{(p,n)}(r) = \frac{\rho_0^{(p,n)}}{1 + e^{(r - R_0^{(p,n)})/a_{(p,n)}}}$$

- r indicates the distance of a given nucleon from nucleus center.

○ neutron: $R_0^n = 6.7$ fm and $a_n = 0.55$ fm C. M. Tarbert *et al.*, PRL **112** (2014) no.24, 242502

○ proton: $R_0^p = 6.68$ fm and $a_p = 0.447$ fm M. Warda *et al.*, PRC **81** (2010) 054309

- normalizations $\rho_0^{(p,n)}$ fixed by: $\int d^3 r \rho_{(p)}(r) = Z, \quad \int d^3 r \rho_{(n)}(r) = A - Z$
- The nuclear thickness function $T(B)$, as a function of the impact parameter between the colliding proton and nucleus, B, is given by ($r = \sqrt{B^2 + z^2}$)

$$T_{(p,n)}(B) = \int dz \rho_{(p,n)}(B, z)$$

- Additional details in M. Alvioli and M. Strikman, PRC **100** (2019) no.2, 024912

DPS Wjj cross sections

- Proton (and nuclear) double PDFs are treated in mean field approximation
- $D_p^{ij}(x_1, x_2, \mu_A, \mu_B, \vec{b}_\perp) \simeq f_p^i(x_1, \mu_A) f_p^j(x_2, \mu_B)\, \mathcal{T}(\vec{b}_\perp)$,
- $\sigma_{eff}^{-1} = \int d\vec{b}_\perp [\mathcal{T}(\vec{b}_\perp)]^2$
- $pA \to W^\pm +$ dijets +X DPS cross section:

$$\frac{d\sigma^{Wjj}_{DPS}}{d^2B} = \sum_{i,j,k,l} \left\{ \sigma_{eff}^{-1} \sum_{N=p,n} f_p^i(x_1, M_W) f_p^j(x_2, p_T^j) f_N^k(x_3, M_W) f_N^l(x_4, p_T^j) T_N(B) + \sum_{N_3,N_4=p,n} f_p^i(x_1, M_W) f_p^j(x_2, p_T^j) f^k_{N_3/A}(x_3, M_W) f^l_{N_4/A}(x_4, p_T^j) T_{N_3}(B) T_{N_4}(B) \right\} d\hat{\sigma}^W_{ik}\, d\hat{\sigma}^{jj}_{jl} \, .$$

- see also S. Salvini, D. Treleani and G. Calucci, PRD **89** (2014) no.1, 016020

Kinematics and fiducial cross sections

Kinematics:

- Beam energies : E_p=6.5 TeV, E_N=2.56 TeV, $\sqrt{S_{pN}} = 8.16$ TeV
- Boost : $y_{CM} = y_{lab} - \Delta y$ with $\Delta y_{CM} = 0.465$
- Future pA run : $\mathcal{L} = 10^{29}$ cm^{-2} s^{-1}, $\Delta t = 10^6$ s $\rightarrow \mathcal{L}\Delta t = 0.1$ pb^{-1}

PDFs & perturbative settings:

- LO CTEQ6L1 free proton + nuclear EPS09 + 1 loop $\alpha_s(M_Z)$=0.130, $n_f = 5$.
- LO ME, $W^\pm$ and dijet cross section differential in muon/jet rapidities y_{CM} and transverse momenta p_T

Fiducial phase space:

- W assumed to decay leptonically into muon: $|\eta^\mu_{lab}| < 2.4$, $p^\mu_T > 25$ GeV
- Dijet identified with final state partons: $|\eta^{jet}_{lab}| < 2.4$, $p^{jet}_T > 20$ GeV

Choice for σ_{eff}

- Within these approximation, DPS1 rate controlled by one single parameter : σ_{eff}
- From the DPS analysis in $pp \to W(\to l\nu)jjX$:
  - ATLAS New J. Phys. **15** (2013) 033038:

    $\sigma_{eff}^{WJJ}(\sqrt{s} = 7\text{ TeV}) = 15 \pm 3(\text{stat.})^{+5}_{-3}(\text{syst.})$ mb
  - CMS JHEP **1403** (2014) 032:

    $\sigma_{eff}^{WJJ}(\sqrt{s} = 7\text{ TeV}) = 20.7 \pm 0.8(\text{stat.}) \pm 6.6(\text{syst.})$ mb
- We use the averaged value: $\bar{\sigma}_{eff} = 18 \pm 6$ mb
- Constant in fiducial phase space and the same for all partonic channels

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Fiducial DPS cross sections and uncertainties

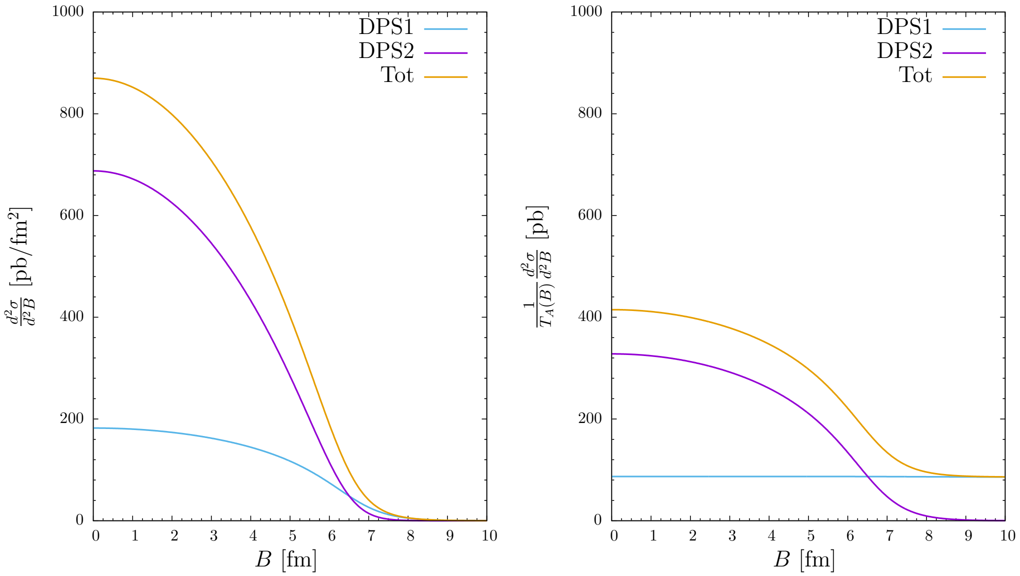
- DPS cross sections in fiducial phase space in the Wbb and Wjj channels:

	σ^{Wbb} [pb]	σ^{Wjj} [nb]
pA DPS1	102 ± 34	18 ± 6
pA DPS2	269	47
pA DPS	372 ± 34	65 ± 6

- Charged summed W cross sections with W boson decaying into muons or electrons.
- The quoted error is entirely due to σ_{eff} uncertainty.
- σ(DPS2) cross section is more than twice σ(DPS1)
- Wjj has large cross section, differential measurement possible

Disentangle DPS1 from DPS2 : strategy

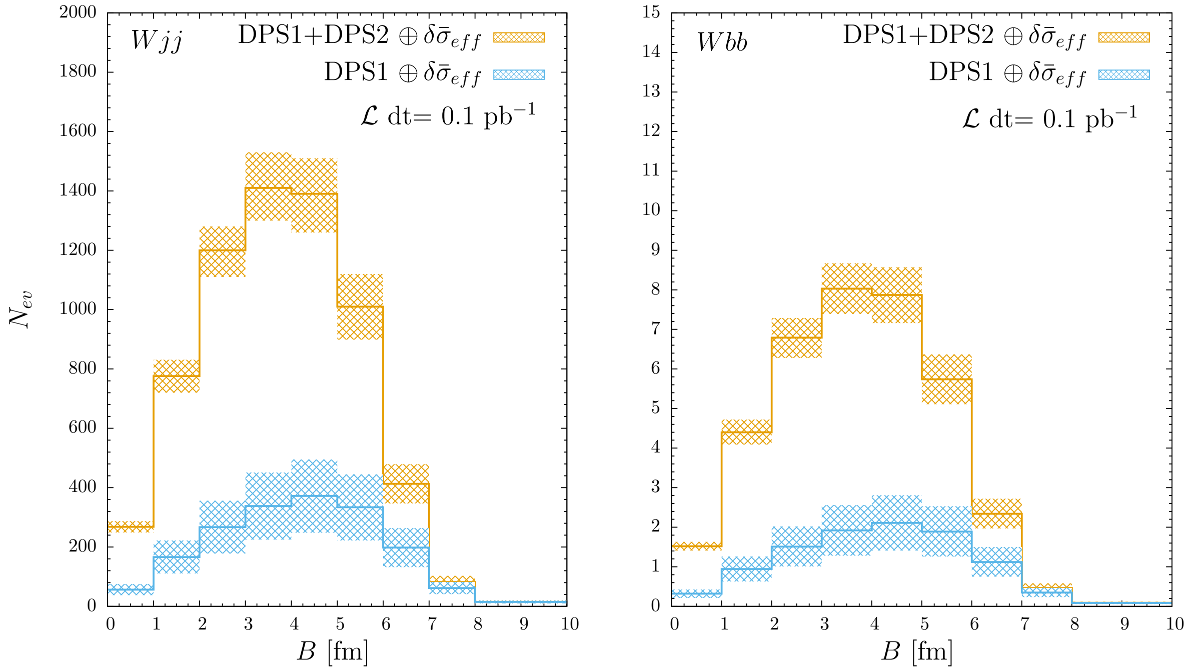
- Disentangle DPS1 from DPS2 via different B dependence
  M. Alvioli, M. Azarkin, B. Blok and M. Strikman, EPJC **79** (2019) 482



- Two contributions have different T dependence: DPS1 $\sim T$ and DPS2 $\sim T^2$
- Normalize the cross section to the nuclear thickness function $T_A(B)$
- Then DPS1 (and SPS) is constant vs B while DPS2 inherits shape from $T_A(B)$

Number of Signal events for DPS1 and DPS2

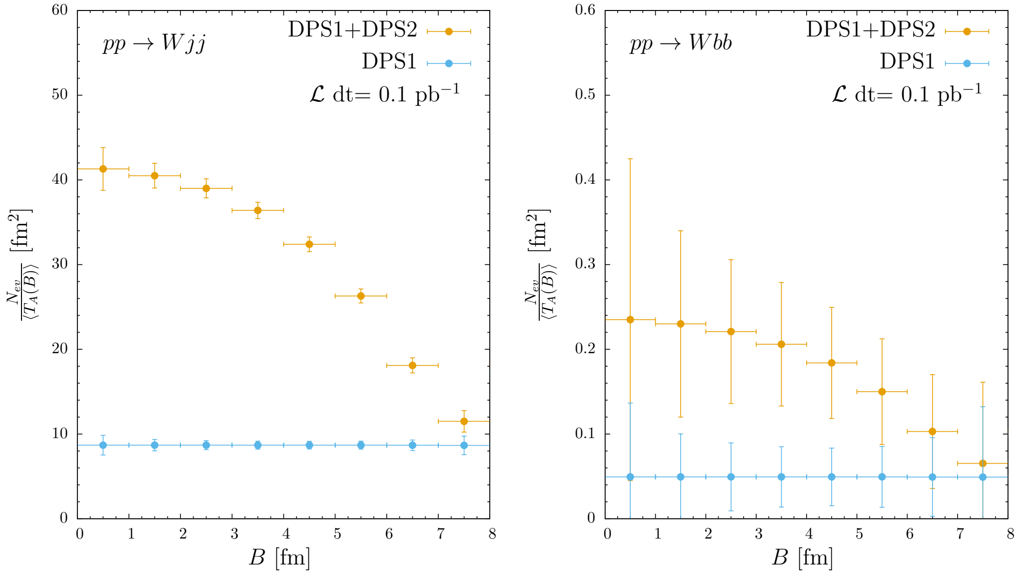
- $\mathcal{L}\Delta t = 0.1$ pb^{-1}
- distribution has a kinematic zero for $B = 0$
- Error due to $\delta\sigma_{eff}$



- For Wjj, $N_{ev} > 50$ in all bins for $B < 8$ fm:
- Differential distribution for Wjj (but unlikely for Wbb)

Single out DPS2 vs DPS1 and SPS

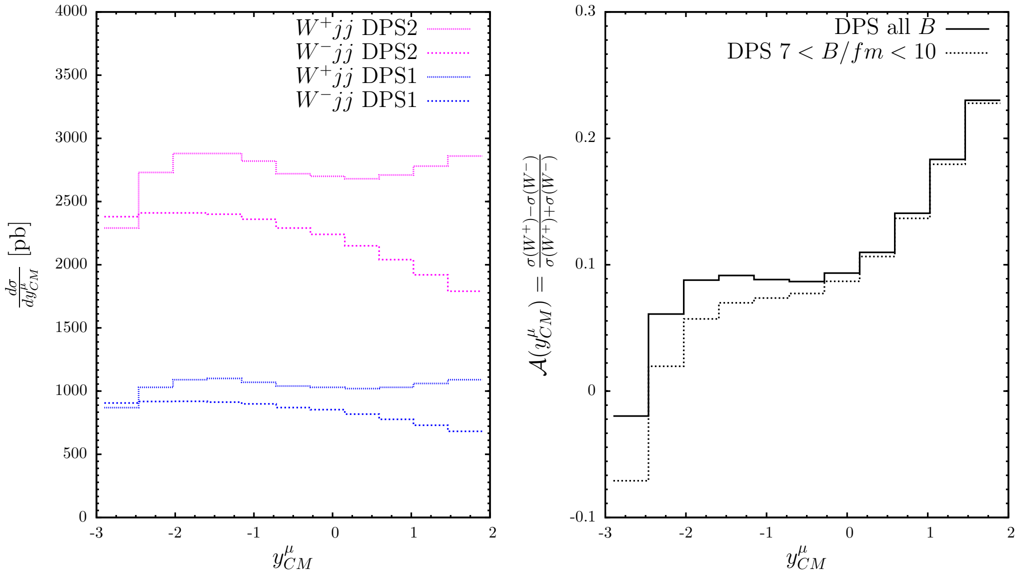
- Normalize N_{ev} by average thickness function $\langle T_A(B)\rangle$ in a given B bin.
- Assume errors scale as $\sim \sqrt{N_{ev}^{theo}}$,



- Non constant behaviour vs B: ok for Wjj, ambigous in Wbb
- Method is efficient if accompained with standard SPS subtraction techniques.
- NB: SPS is constant vs B → Additional discriminating power

DPS characterization in Wjj

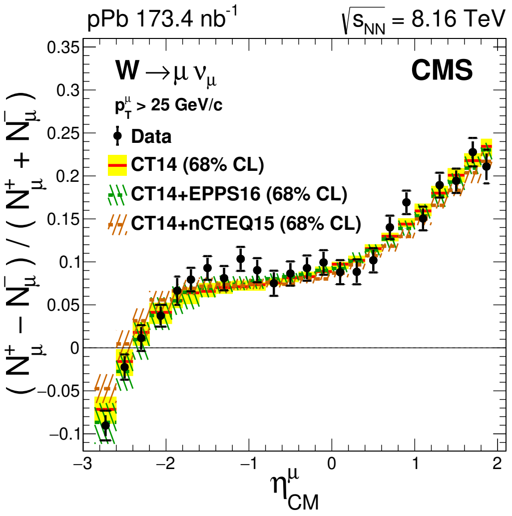
- distributions in charged muon rapidity, dijet system integrated over

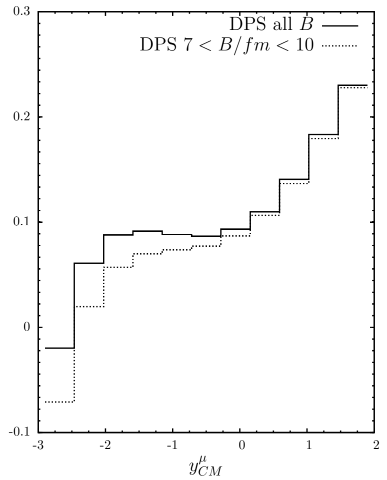


- DPS1 and DPS2 show similar shape vs y^μ_{CM}: observable not suitable to disentangle
- BUT these results follows from mean field approximation on double PDFs
- IF correlations are present → distortion of the spectra might be visible

DPS characterization in Wjj: lepton charge asymmetry

- Consider the charged asymmetry : $\mathcal{A}(y^{\mu}_{CM}) = \frac{d\sigma_{DPS}(W^{+}jj) - d\sigma_{DPS}(W^{-}jj)}{d\sigma_{DPS}(W^{+}jj) + d\sigma_{DPS}(W^{-}jj)}$
- Already measured
  in pA collision
  at $\sqrt{s}$=8.16 TeV
  for single W production
  CMS arXiv:1905.01486





- IF strong correlations are present (*e.g.* valence effects in $W^{\pm}$ production)
  $\rightarrow$ distortion of the asymmetry might be visible
- Asymmetry changes in peripheral collision ($7 < B < 10$) given the change in relative abundance of neutrons over protons at large B (neutron skin effect)

Summary

- We have analyzed Wjj (and Wbb) production via DPS in pA
- DPS2 mechanism in pA never searched for/confirmed experimentally
- DPS2 is more than twice larger than DPS1 (at work in pp)
- We proposed and discussed a new strategy to single out DPS2 contribution via centrality dependence of the cross section
- DPS2 gives access in a rather clean way to $\int d\vec{b}_\perp D_p^{ij}(x_1, x_2; \vec{b}_\perp)$, free of uncertainty related to σ_{eff}
- Depending on the SPS subtraction and centrality determiantion efficiency, such an analysis could be performed already with the 2016 LHC pA data
  - in Wbb at the inclusive level
  - in Wjj at the differential level
- Repeated in future pA high luminosity run at LHC

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