SABRINA COTOGNO

CPHT, ÉCOLE POLYTECHNIQUE

In collaboration with Tomas Kasemets (Johannes Gutenberg University, Mainz)

and Miroslav Myska (Czech Technical University, Prague)

based on arXiv:1809.09024, SC's PhD thesis, and 1812.xxxxx.

A SPIN ON SAME-SIGN W BOSON PAIR PRODUCTION AT THE LHC

MPI@LHC - Perugia 10-14 December 2018

MAIN MESSAGE OF THIS TALK:

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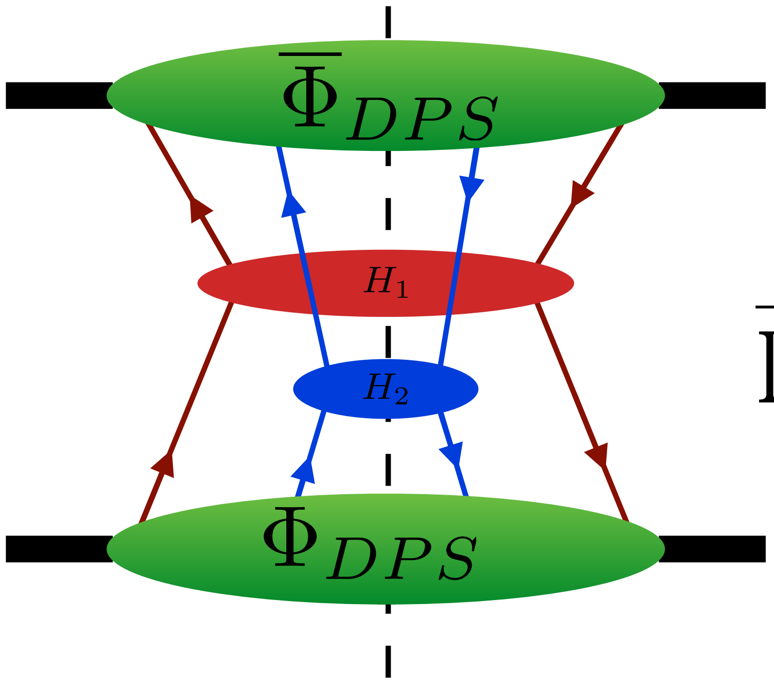
- Interparton correlations in the proton can be important
- Two-parton spin correlations can be measured at the LHC

PART I

INTERPARTON CORRELATIONS

THE PROTON STRUCTURE THROUGH A (PARTON-)PAIR OF GLASSES



Factorized cross section

$$\frac{d\sigma_{DPS}}{\prod_{i=1}^{2} dx_i d\bar{x}_i} \sim \prod_{i=1}^{2} \int d^2\boldsymbol{y} H_i(q_i^2) \boxed{\Phi_{DPS}(x_i, \boldsymbol{y}) \bar{\Phi}_{DPS}(\bar{x}_i, \boldsymbol{y})}$$

Paver, Treleani (1982); Mekhfi (1985)
Diehl, Ostermeier, Schäfer, (2011)

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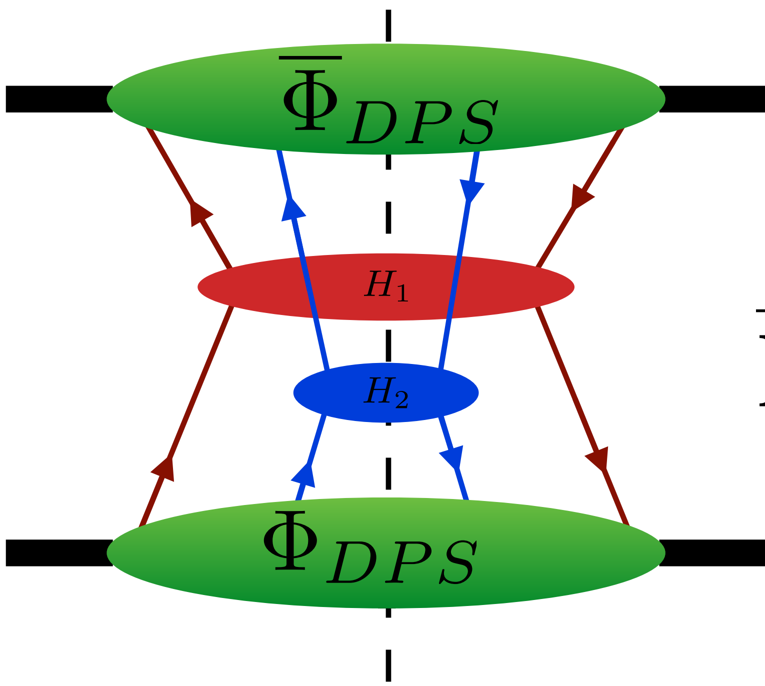

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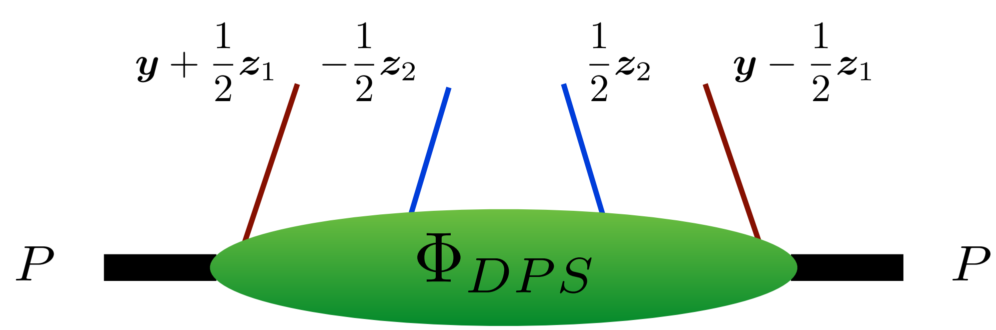
Diagrammatic approach

$$\Phi_{DPS} \sim \mathcal{FT} \langle P | [\bar{q}(-\frac{1}{2}z_2) U_{[0,z_2]} q(\frac{1}{2}z_2)][\bar{q}(y - \frac{1}{2}z_1) U_{[y,z_1]} q(y + \frac{1}{2}z_1)] | P \rangle$$



Double parton correlator -> It naturally includes all the two-patron information an correlations

TYPES OF CORRELATIONS BETWEEN PARTONS INSIDE THE PROTON

The correlator describes quantum correlations, kinematical or mixed ones:

Mehkfi, Artru (1985)

Diehl, Ostermeier, Schäfer, (2011)

Manohar, Waalewijn (2012)

Echevarria,Kasemets,Mulders,Pisano, (2014)

Rinaldi, Scopetta, Traini, Vento (2014)

Ceccopieri, Rinaldi, Scopetta (2017)

Kasemets, Scopetta (2017)

Blok, Strikman(2017)

TYPES OF CORRELATIONS BETWEEN PARTONS INSIDE THE PROTON

The correlator describes quantum correlations, kinematical or mixed ones:

- Color
- Spin (polarization)
  - longitudinal
- Flavor interference
- Fermion number interference

- Between $\boldsymbol{y}$ and x_i
- Parton type and $\boldsymbol{y}$
- Between x_i
- …

Mehkfi, Artru (1985)
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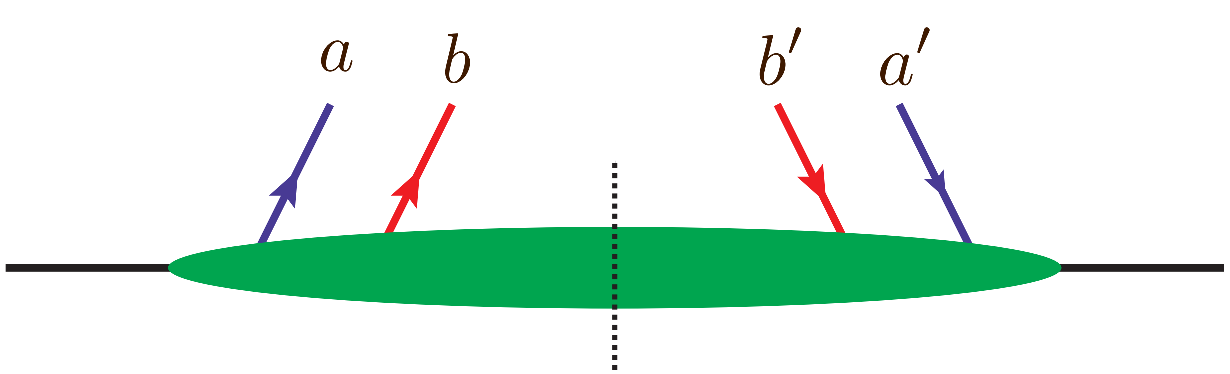

$$\Phi_{DPS}(x_1, x_2, \boldsymbol{y})$$

$$(a+b) = (a'+b') \not\Leftrightarrow \begin{cases} a = a' \\ b = b' \end{cases}$$

SPIN STRUCTURE

One can parametrize the Φ_{DPS} in terms of double parton distributions DPDs that contain parton polarization information.

$$f_{q_1,q_2} \sim \langle P|(\bar{q}_1\Gamma_{q_1}q_1)(\bar{q}_2\Gamma_{q_2}q_2)|P\rangle$$

The different Dirac matrices select quarks of different polarization:

$$\Gamma_q = \frac{1}{2}\gamma^+ \qquad \Gamma_{\Delta q} = \frac{1}{2}\gamma^+\gamma_5 \qquad \Gamma^j_{\delta q} = \frac{1}{2}i\sigma^{j+}\gamma_5 \quad (j=1,2)$$

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Unpolarized

$$f_{q_1 q_2}(x_1, x_2, \boldsymbol{y})$$

Transversely polarized

$$f_{\delta q_1 \delta q_2}(x_1, x_2, \boldsymbol{y})$$

Longitudinally polarized

$$f_{\Delta q_1 \Delta q_2}(x_1, x_2, \boldsymbol{y})$$

Mixed

$$f_{q_1 \delta q_2}(x_1, x_2, \boldsymbol{y})$$

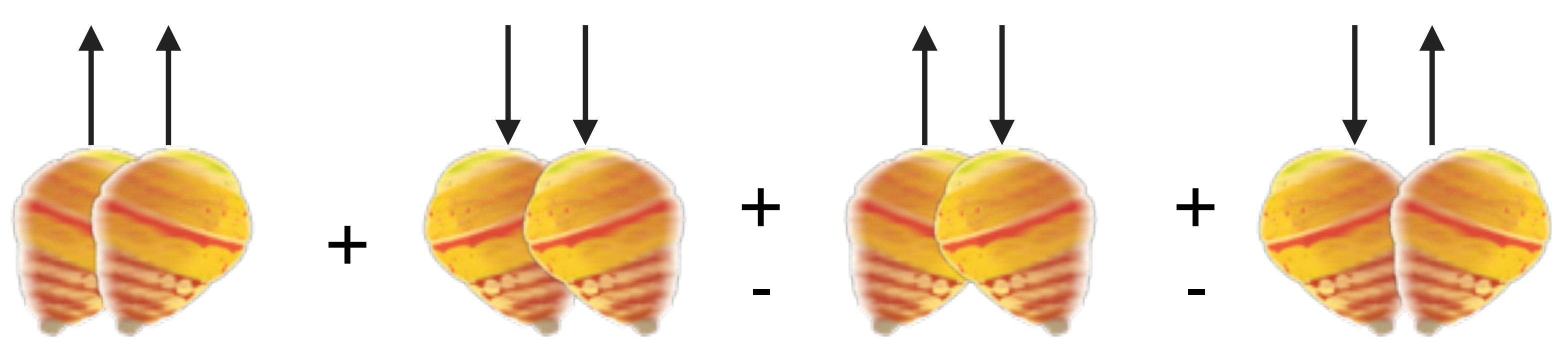
AMOUNT OF QUARK POLARIZATION

The collinear DPS correlator is a diagonal operator. Some combination of functions have a probability interpretation.

In absence of transverse polarization:

$$|f_{\Delta q \Delta q}| \leq f_{qq}$$

Partonic interpretation:



THE MODEL: MIX-TO-MAX POLARIZATION

$$f_{\Delta q \Delta q}(x_1, x_2, \boldsymbol{y}; Q_0) = (-1)^n f_{qq}(x_1, x_2, \boldsymbol{y}; Q_0)$$

$n = 1$ both quarks or antiquarks in the pair
$n = 2$ mixed quark-antiquark in the pair

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$n = 1$ both quarks or antiquarks in the pair
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- Bound saturated with mixed signs at the initial (low) scale + evolution with polarized dDGLAP
- Within what is allowed by the positivity bounds, we maximize the effects of polarization (mix-to-max scenario has the biggest impact on the final state distributions of all the other investigated correlations).
- Maximizing the correlation scenarios will help estimate if/when experiments can start detecting or constraining these correlation models.
- Other models are possible, e.g $n = 2$ for all quarks and antiquarks.

Diehl, Kasemets (2012)

SINGLE PDFS

All the DPDs are unknown, therefore we reduce them to single PDFs.

We assume that (unpolarized distribution):

$$f(x_1, x_2, \boldsymbol{y}; Q_0) = f(x_1; Q_0) f(x_2; Q_0) G(\boldsymbol{y})$$

$$\int d^2\boldsymbol{y} G^2(\boldsymbol{y}) = \sigma_{eff}^{-1} \qquad Q_0 = 1\,\mathrm{GeV}$$

Diehl, Kasemets (2012)

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KINEMATIC CORRELATIONS

- Evolution from the initial scale always creates (small) longitudinal correlations
- We investigated Additional phase-space factor $(1 - x_1 - x_2)^2 (1 - x_1)^{-2} (1 - x_2)^{-2}$
  These longitudinal correlations only minimally contribute wrt SPIN.
  Dedicated studies are necessary.

Plößl's talk

Gaunt, Stirling (2009)
Diehl,Kasemets,Keane (2014)
Ceccopieri, Rinaldi, Scopetta (2017)
Diehl, Plößl,Schafer (2018)
Ceccopieri, Rinaldi (2018)

THEORY VS REALITY

DPS theory in full glory

$$\sigma_{DPS} \sim \frac{\sigma_1 \sigma_2}{\sigma_{eff}}$$

THEORY VS REALITY

Full richness of quantum and kinematic two-patron correlations in the Φ_{DPS}

DPS theory in full glory

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Simplest possible approach is to assume that there are NO correlations of any types between the two partons inside the proton.

THEORY VS REALITY

Full richness of quantum and kinematic two-patron correlations in the Φ_{DPS}

DPS theory in full glory

We are here

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PART II

IMPACT OF CORRELATIONS IN SAME-SIGN W BOSON PAIR PRODUCTION (SSW)

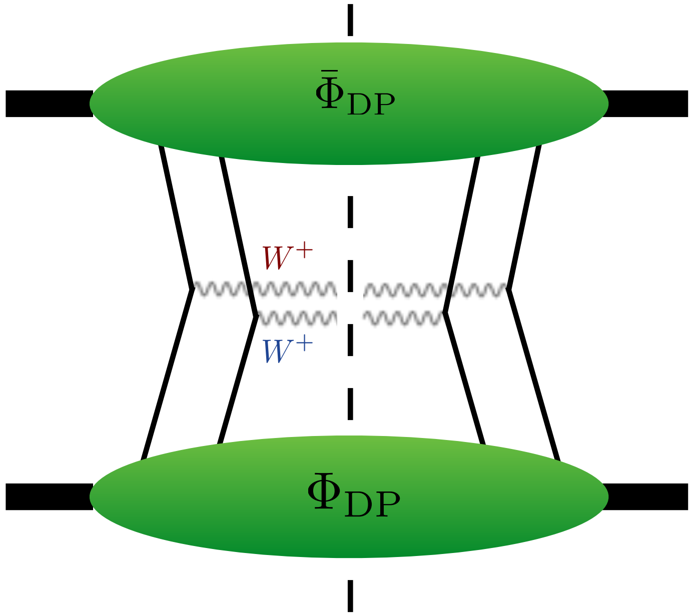
SAME SIGN W BOSON PAIR PRODUCTION (SSW)

Gaunt et al (2010)

CMS collaboration (2017)

Advantages

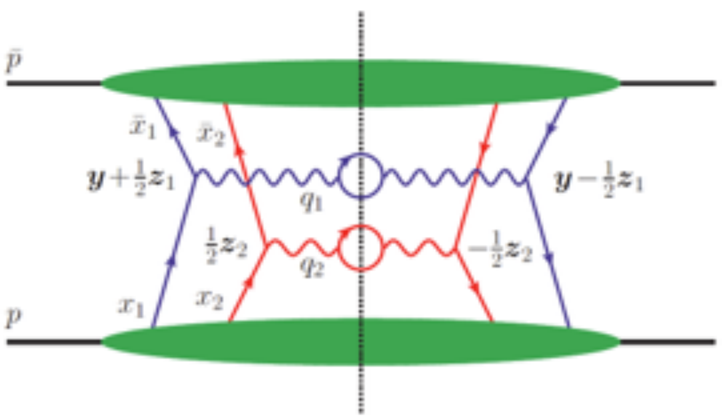
- It is initiated by quarks (we can study quark polarization)
- The W couples only with left-handed (right-handed) quarks (antiquarks) -> helicity flip is not allowed -> only longitudinal polarization of the quarks is directly accessed (no double transversity)
- The single parton equivalent is suppressed and it involves the production of two jets. This makes the signal clean.



IMPACT OF POLARIZATION IN THE CROSS SECTION

Considering quark polarization, the expression for the cross section reads:

Diehl, Kasemets (2012)
Cotogno (2018)



$$
\begin{aligned}
\sim\; & (1-\tanh\eta_{\mu_1})^2(1-\tanh\eta_{\mu_2})^2 \int d^2\boldsymbol{y}\,(f_{q_1q_2} + f_{\Delta q_1\Delta q_2})(\bar{f}_{\bar{q}_3\bar{q}_4} + \bar{f}_{\Delta\bar{q}_3\Delta\bar{q}_4}) \\
& (1-\tanh\eta_{\mu_1})^2(1+\tanh\eta_{\mu_2})^2 \int d^2\boldsymbol{y}\,(f_{q_1\bar{q}_4} - f_{\Delta q_1\Delta\bar{q}_4})(\bar{f}_{\bar{q}_3q_2} - \bar{f}_{\Delta\bar{q}_3\Delta q_2}) \\
& (1+\tanh\eta_{\mu_1})^2(1-\tanh\eta_{\mu_2})^2 \int d^2\boldsymbol{y}\,(f_{\bar{q}_3q_2} - f_{\Delta\bar{q}_3\Delta q_2})(\bar{f}_{q_1\bar{q}_4} - \bar{f}_{\Delta q_1\Delta\bar{q}_4}) \\
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\end{aligned}
$$

Longitudinal polarization

$\eta_\mu \rightarrow$ muon pseudorapidity

Longitudinal polarization changes both the **size** and the **shape** of the cross section.

OUR "GOLDEN" OBSERVABLE – ASYMMETRY

$$\sigma^-$$

Muons in opposite hemisphere of the detector

$$A = \frac{\sigma^- - \sigma^+}{\sigma^- + \sigma^+}$$

$$\sigma^+$$

Muons in the same hemisphere of the detector

OUR "GOLDEN" OBSERVABLE – ASYMMETRY

σ^-

Muons in opposite hemisphere of the detector

$$\boxed{A = \frac{\sigma^- - \sigma^+}{\sigma^- + \sigma^+}}$$

σ^+

Muons in the same hemisphere of the detector

Great observable from the theoretical point of view

$A = 0$

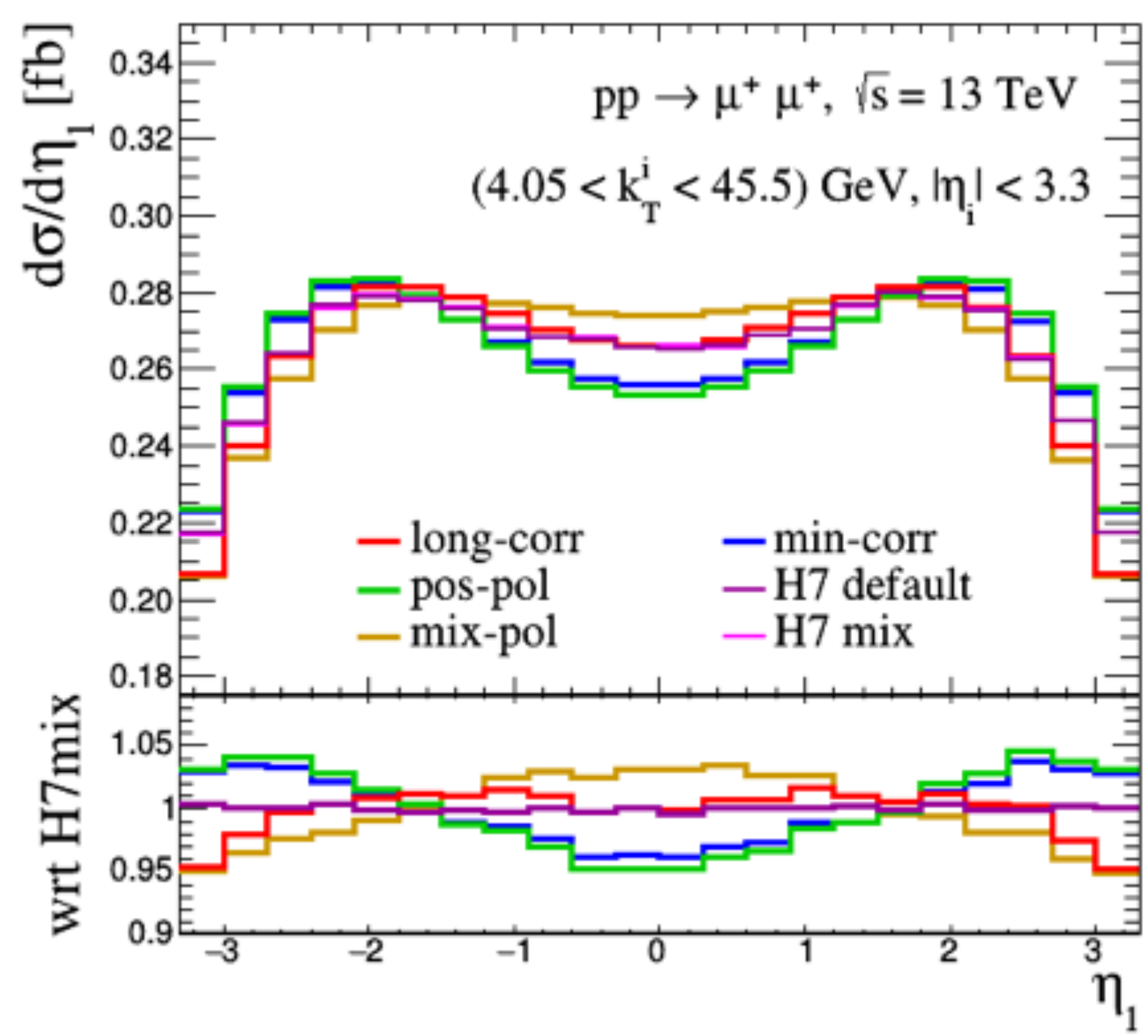
In the uncorrelated scenario the asymmetry must always be zero

$A \neq 0$

A value different from zero is a sign of parton correlation

MONTE CARLO EVENT GENERATORS FOR THE SIGNAL

- Herwig 7 is used to generate final-state distributions starting from our correlated parton level results.
- The default Herwig is re-weighted (more details in the upcoming paper by Cotogno, Kasemets, Myska 1812.xxx)



TAKING CARE OF THE BACKGROUND PROCESSES:

- $WW\,jj$: SPS equivalent to the DPS, the process is accompanied by two extra jets.
- WZ/ZZ production in which one muon from the Z decay is not detected.
- $t\bar{t}$ production: can produce a pair of positively charged muons.

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PHASE-SPACE CUTS

$$|\eta_i| < 2.4, \quad 25\mathrm{GeV} < k_T^{\mathrm{lead}} < 50\mathrm{GeV}, \quad 15\mathrm{GeV} < k_T^{\mathrm{subl}} < 40\mathrm{GeV}, \quad k_T^{\mu_3} < 5\mathrm{GeV},$$
$$\not{E}_T > 20\mathrm{GeV}, \quad dR(\mu_1, \mu_2) > 0.1\,, \quad k_T^{\mathrm{jet1}} < 50\mathrm{GeV}\,, \quad k_T^{\mathrm{jet2}} < 25\mathrm{GeV}$$

+ THEORETICAL SUBTRACTION

RAPIDITY OBSERVABLES SENSITIVE TO QUARK SPIN

- Product $\eta_1 \eta_2$, sum $\Sigma_\eta = |\eta_1 + \eta_2|$ and difference $\Delta_\eta = |\eta_1 - \eta_2|$ profiles and their slopes are sensitive to correlations.

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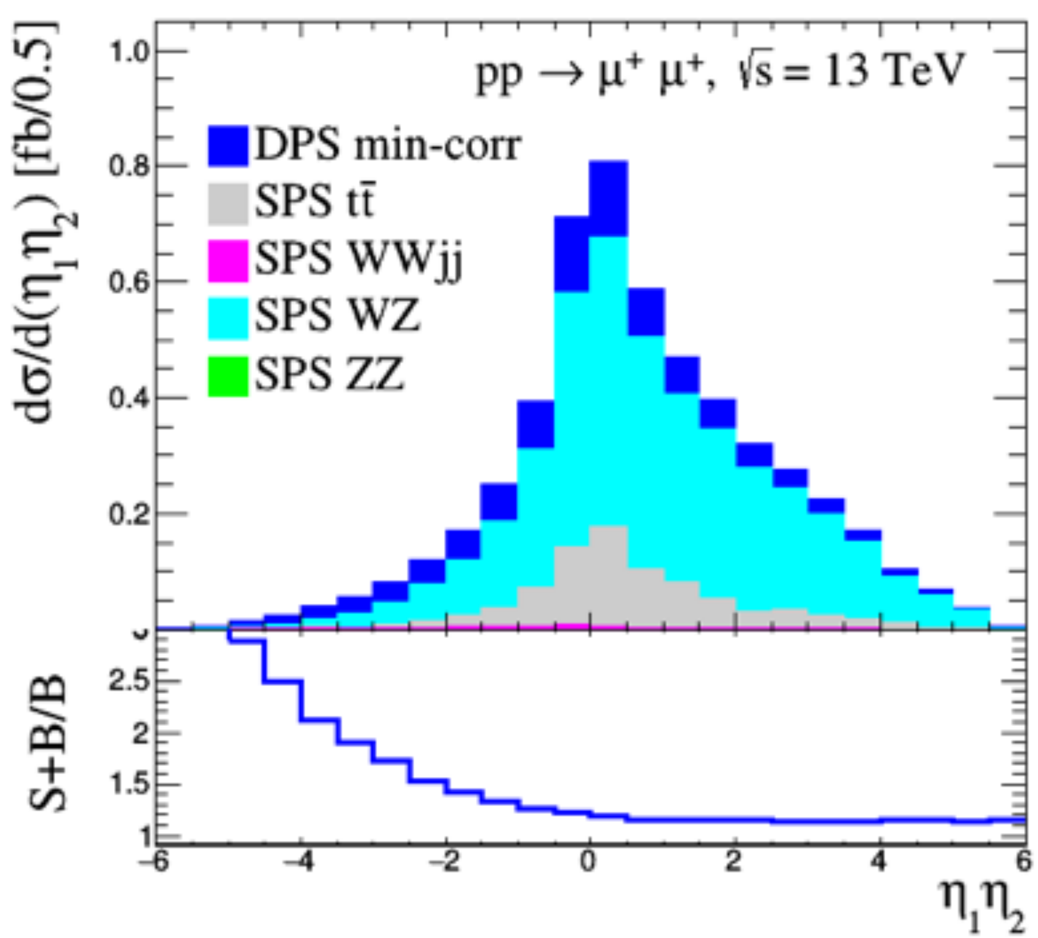
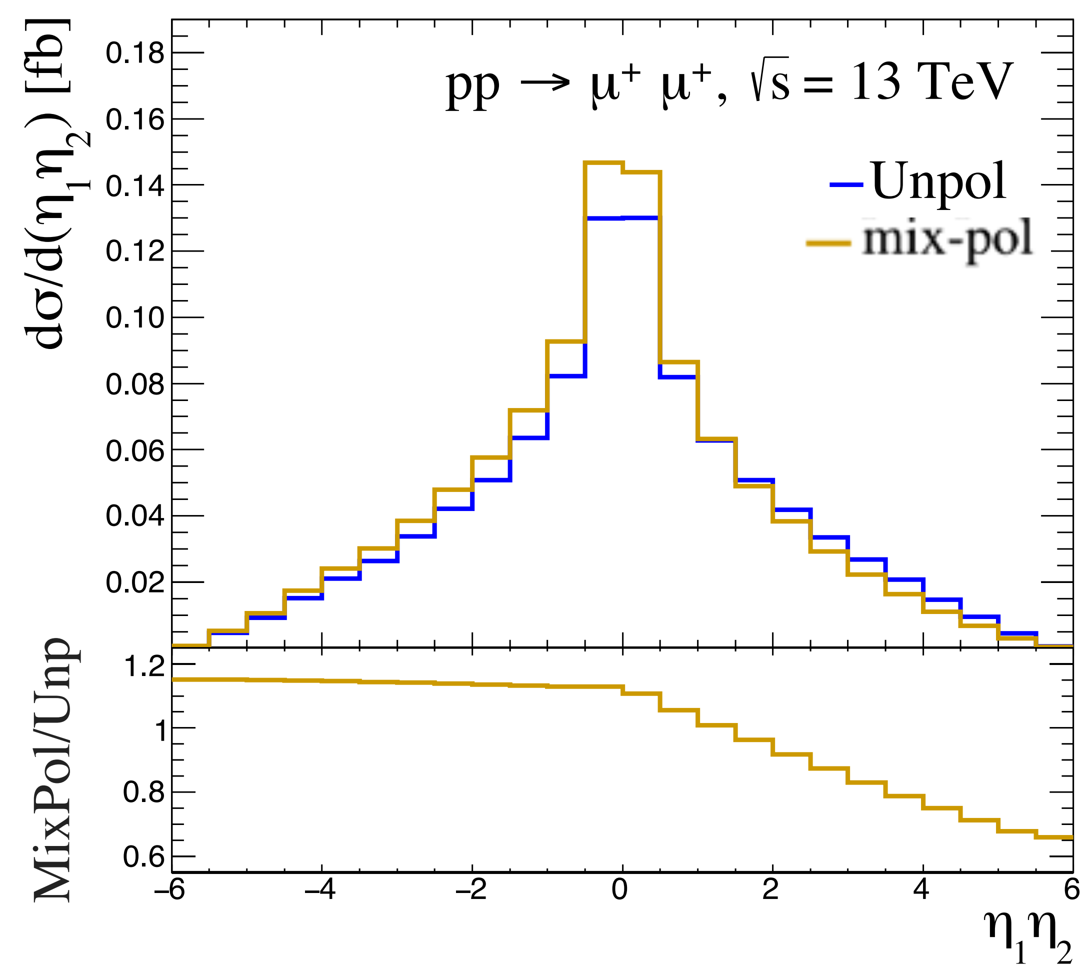
PHASE-SPACE CUTS + THEORETICAL SUBTRACTION

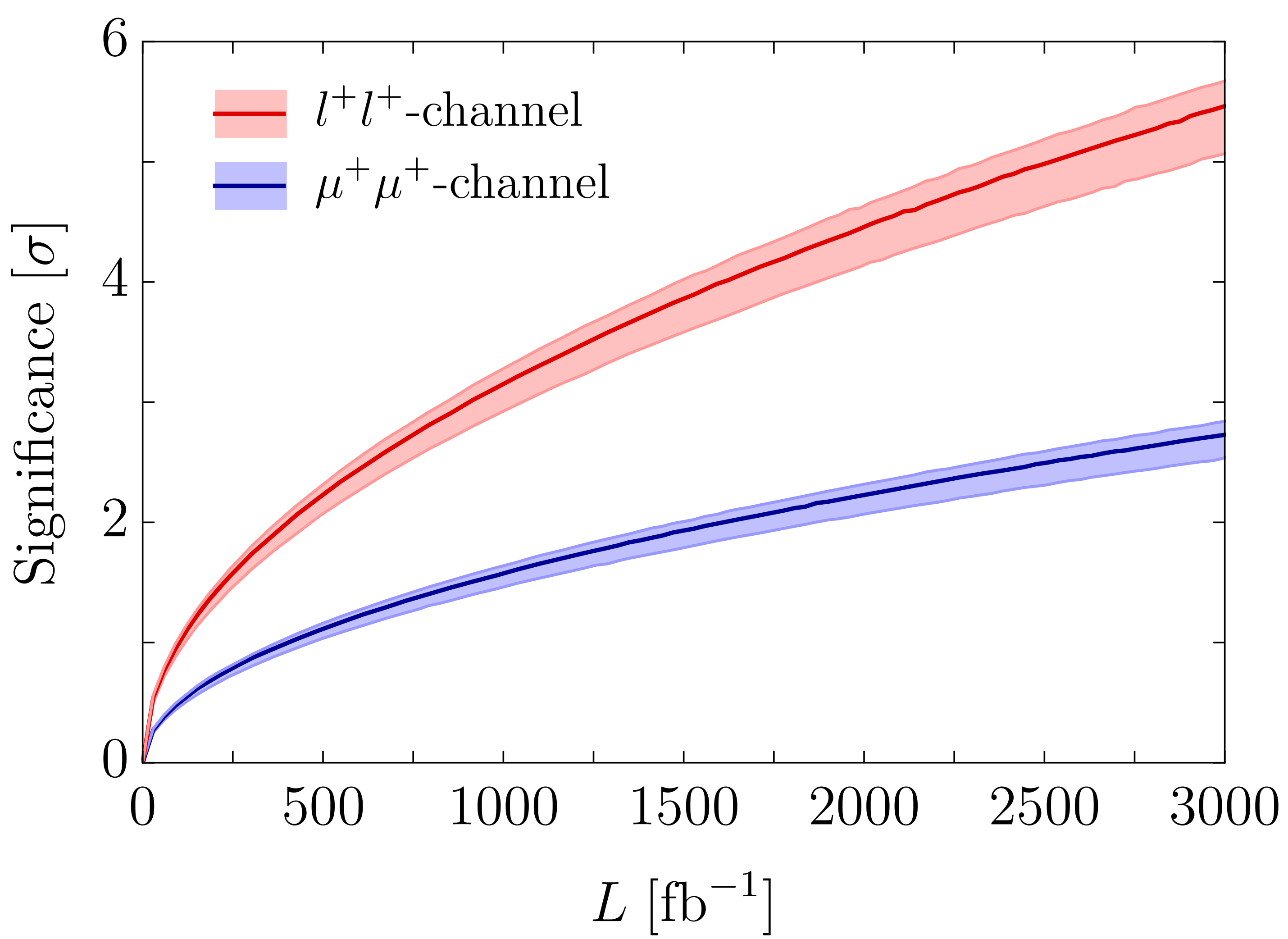




MEASURABLE AT THE LHC?

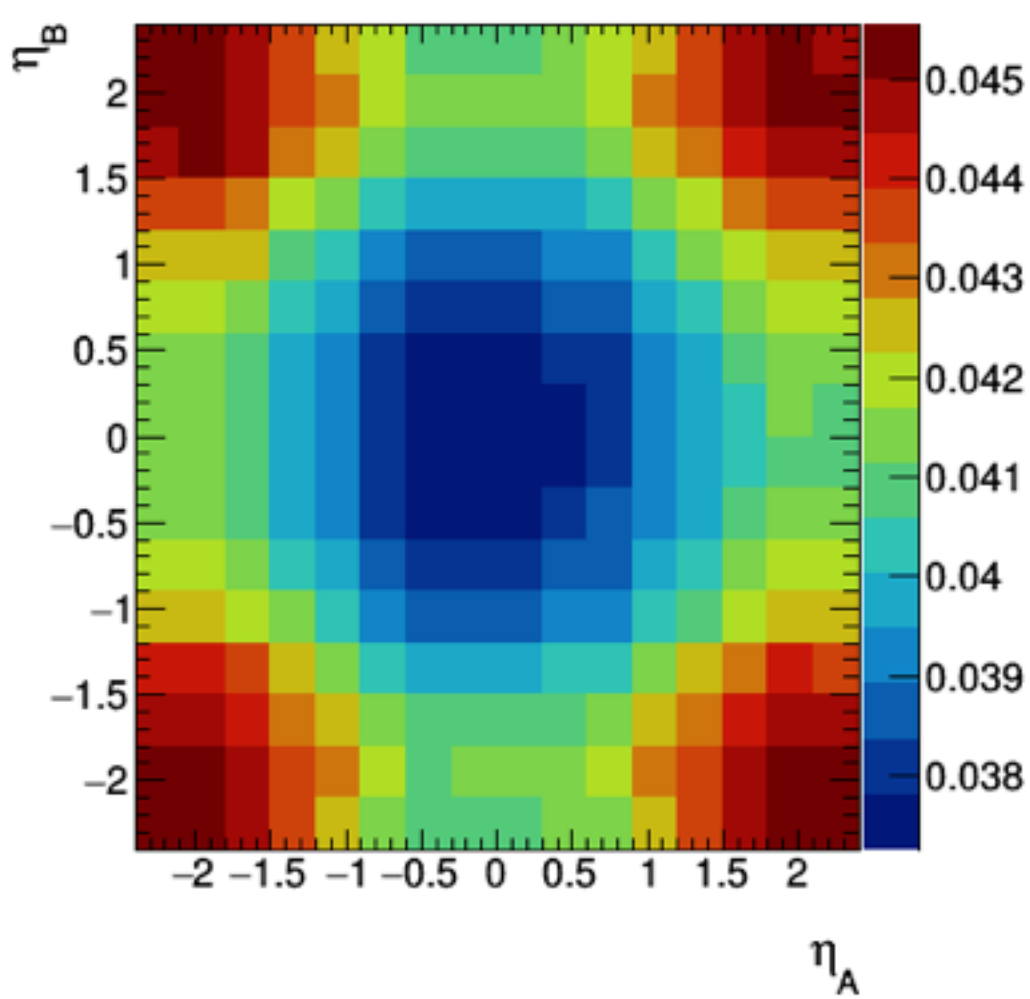
- Given that the background suppression is as effective as we assume, LHC can be sensitive to such values of the asymmetry in the near future.

$\lvert\eta_i\rvert$	> 0	> 0.6	> 1.2
σ [fb]	0.51	0.29	0.13
$A\rvert_{\text{Mix-Pol}}$	0.07	0.11	0.16

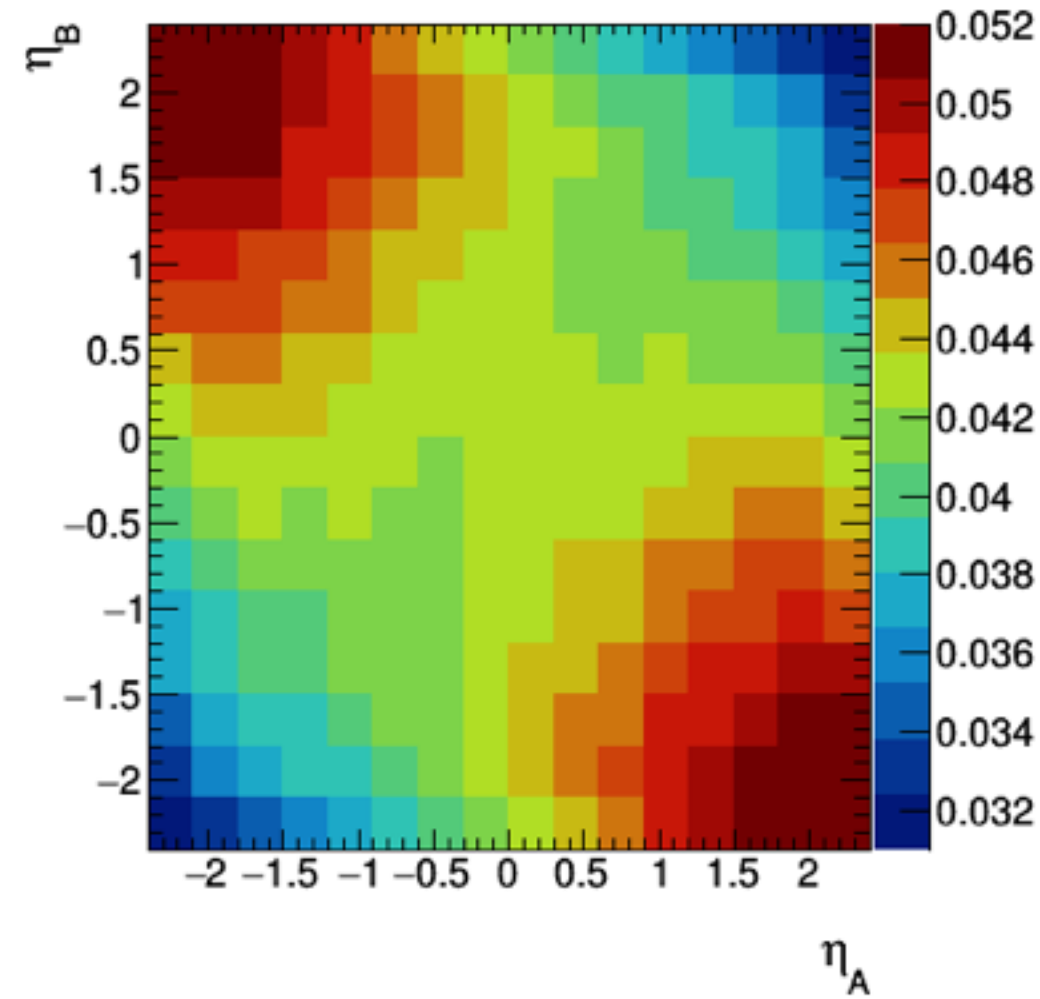


EFFECT ON THE RAPIDITY DISTRIBUTIONS: 2D PLOT

$$\frac{d\sigma_{WW}\big|_{\text{Unp}}}{d\eta_A d\eta_B}$$



$$\frac{d\sigma_{WW}\big|_{\text{Mix-Pol}}}{d\eta_A d\eta_B}$$



- Moreover, several different observables can be constructed from the rapidity distortion (more details can be provided…)

PART III

CONCLUSIONS

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- In double parton scattering the the final states produced in the two hard interactions are not independent of each other because parton correlations play a role.
- In particular, quark spin correlations play a role in creating distortions and asymmetries in the final state distributions.
- W boson pair production at the LHC is a very promising process for the study of polarized double parton distributions.
- We identify a promising observable to detect and measure such quark spin correlations.
- Within some assumption on the possibility of subtracting the background we predict that the measurement can be performed at the LHC in the near future.
- Even a zero value for the asymmetry would put severe constraints and provide important information on the interparton correlations in the proton.

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THANK YOU!

BACK-UP

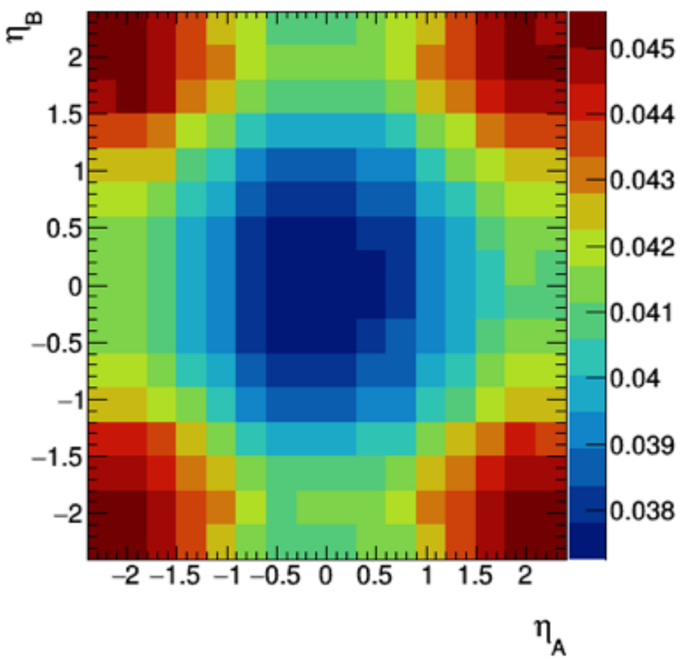
COMMENTS

- The size of the DPDs is unknown so we need to search for a relative change in specific observables.
- Including polarization in different models can change the cross section up to 30%
- Ranging between the several correlation scenarios (quantum and kinematic) the mix-to-max polarization scenario produces the largest asymmetry.

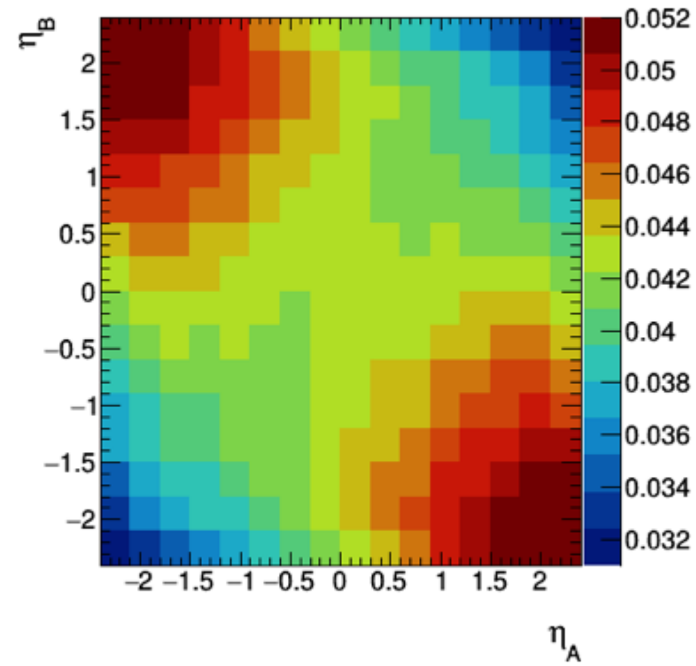
	Unp	Pos-Pol	Mix-Pol	Long-corr
A	0.00	-0.05	0.12	0.01
σ [fb]	1.74	1.90	1.21	1.37

OTHER OBSERVABLES IN SSW

$$\frac{d\sigma_{WW}\big|_{\rm Unp}}{d\eta_A d\eta_B}$$

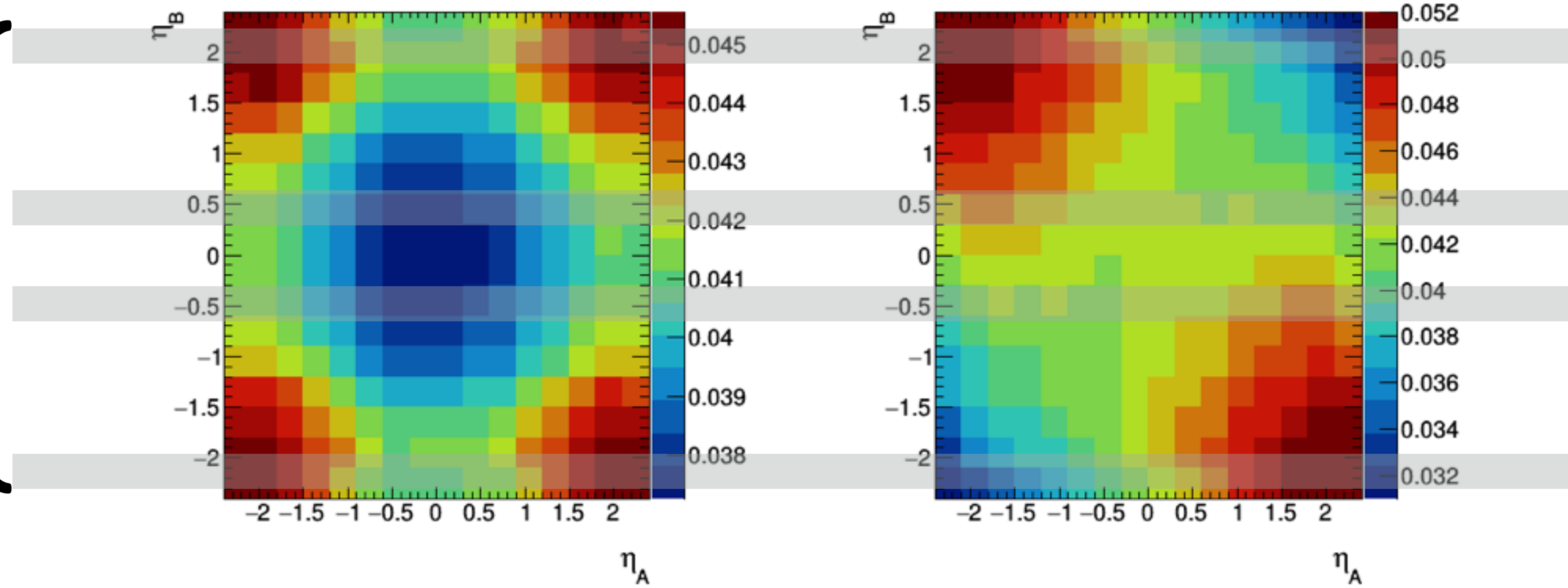


$$\frac{d\sigma_{WW}\big|_{\rm Mix\text{-}Pol}}{d\eta_A d\eta_B}$$



$$\frac{d\sigma_{WW}\big|_{\text{Unp}}}{d\eta_A d\eta_B} \qquad\qquad \frac{d\sigma_{WW}\big|_{\text{Mix-Pol}}}{d\eta_A d\eta_B}$$

η_B "Slices"



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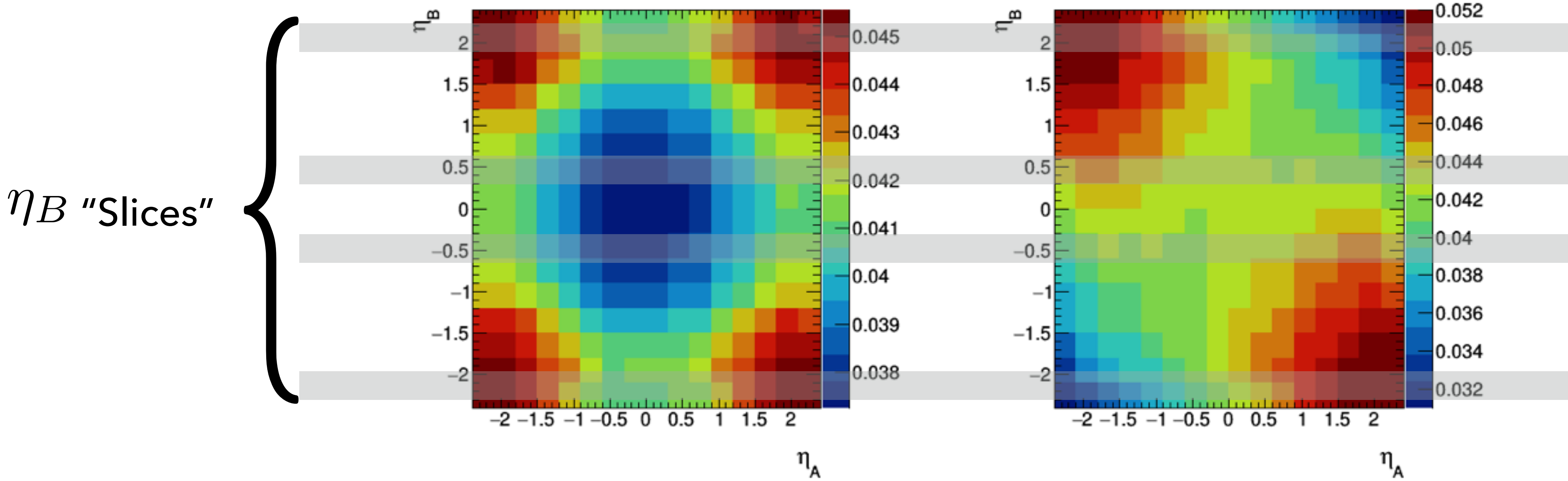
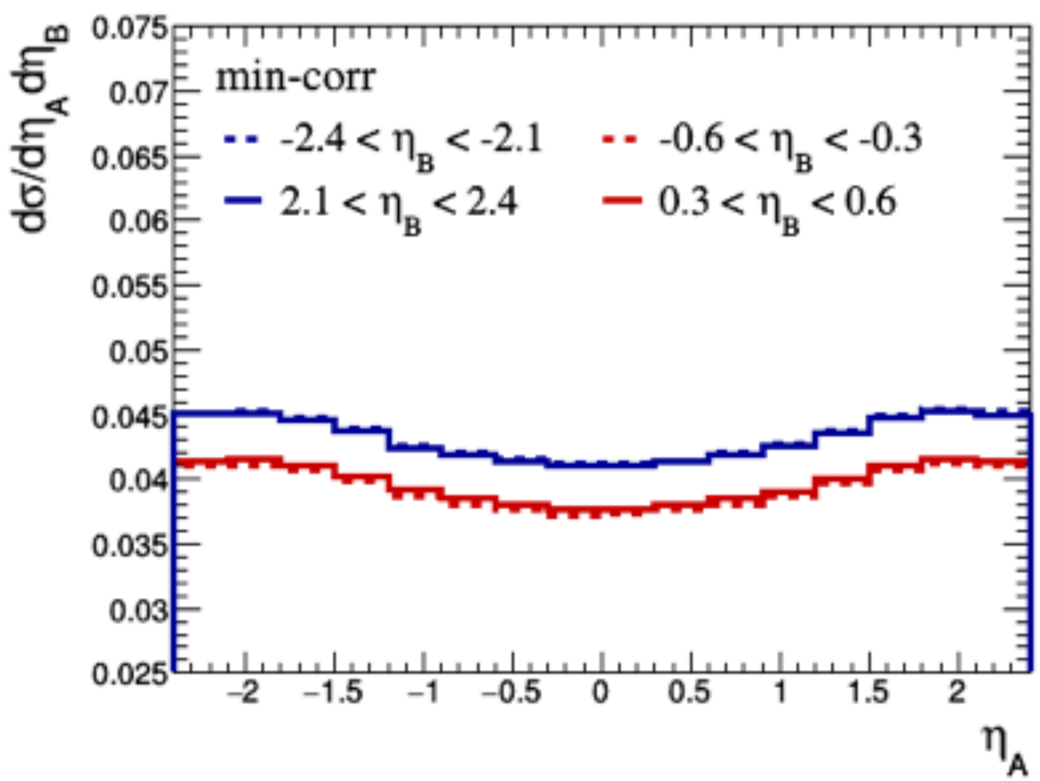
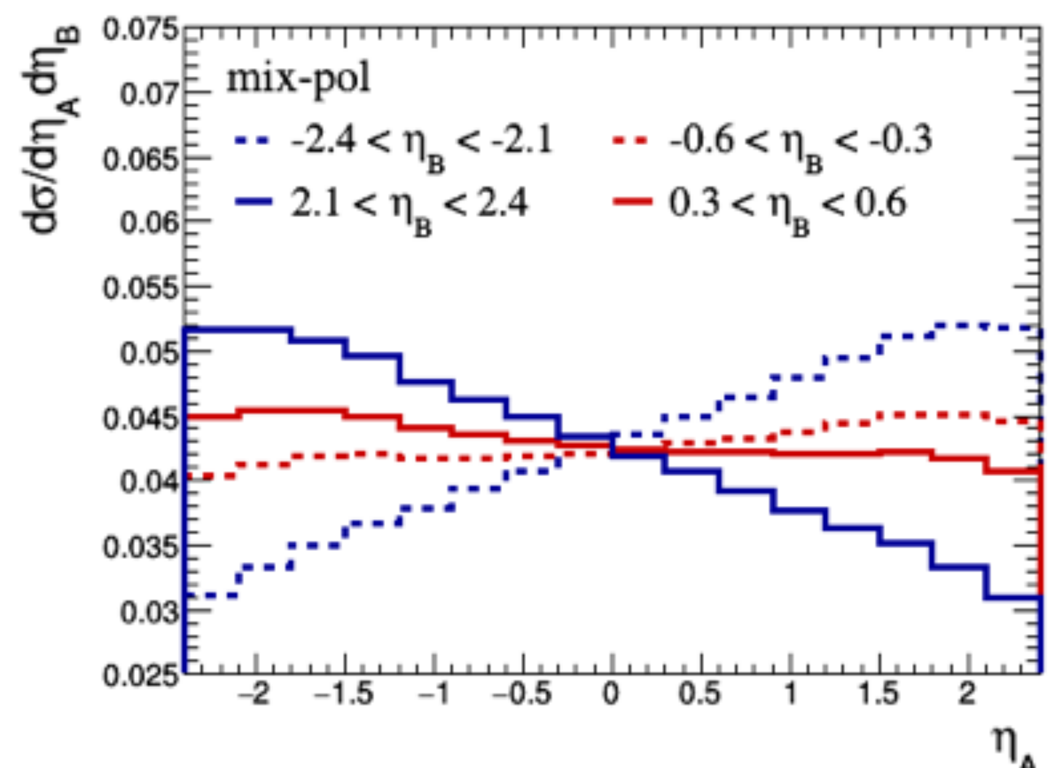
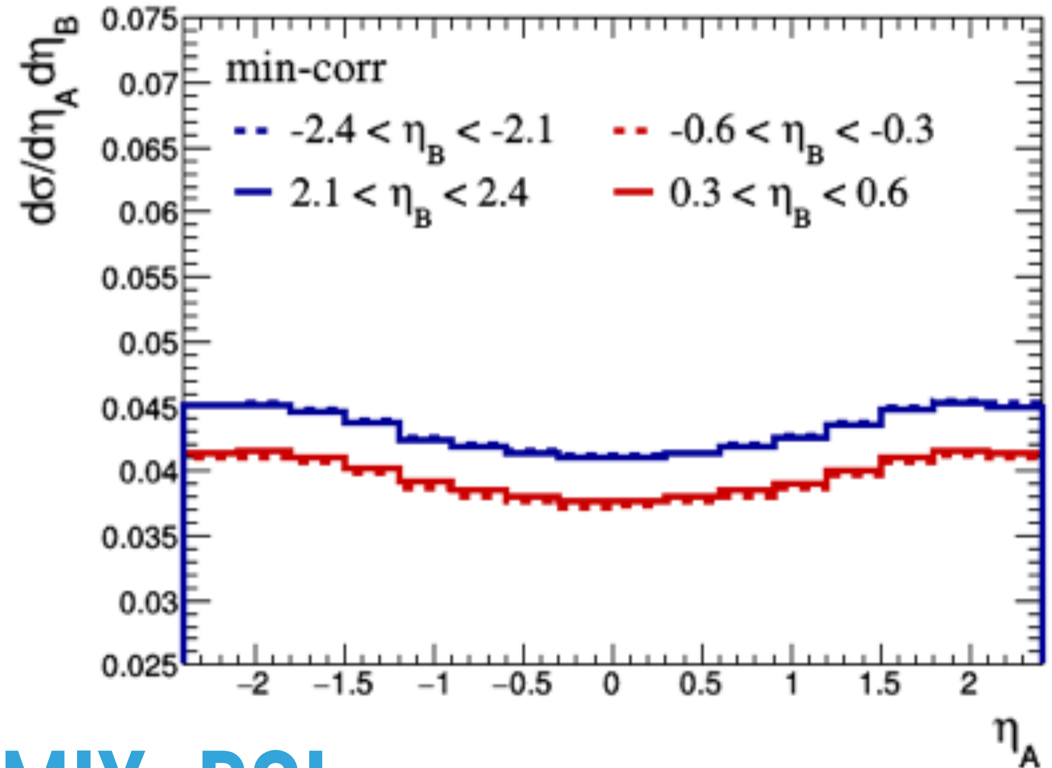


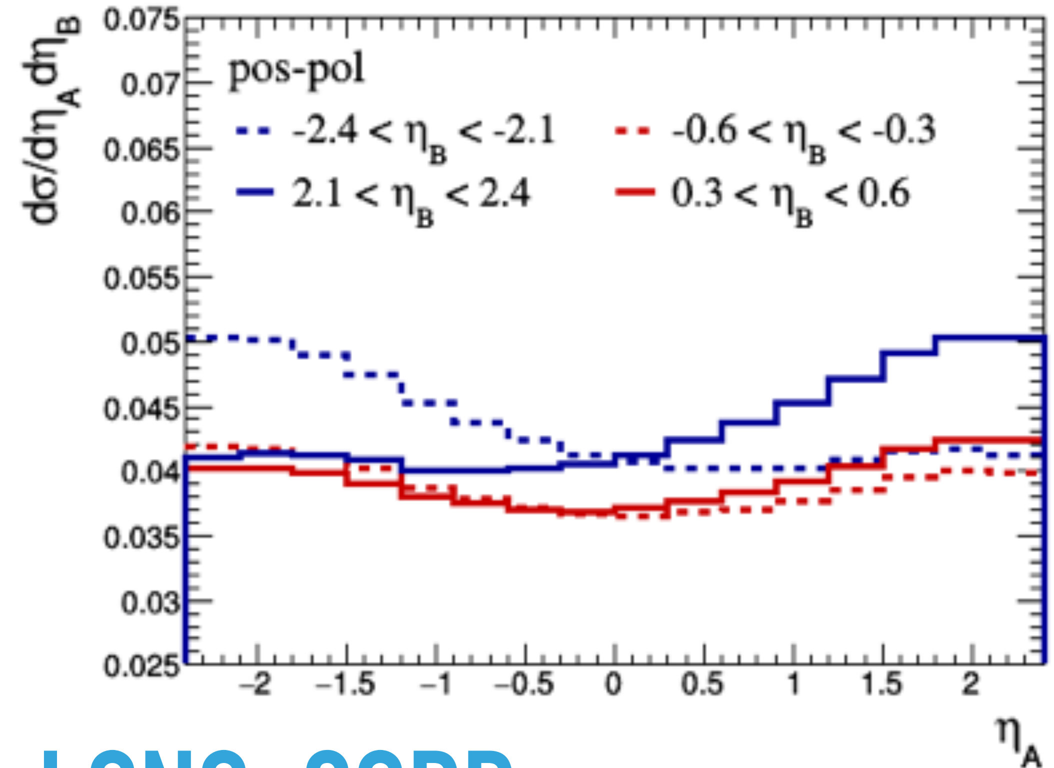




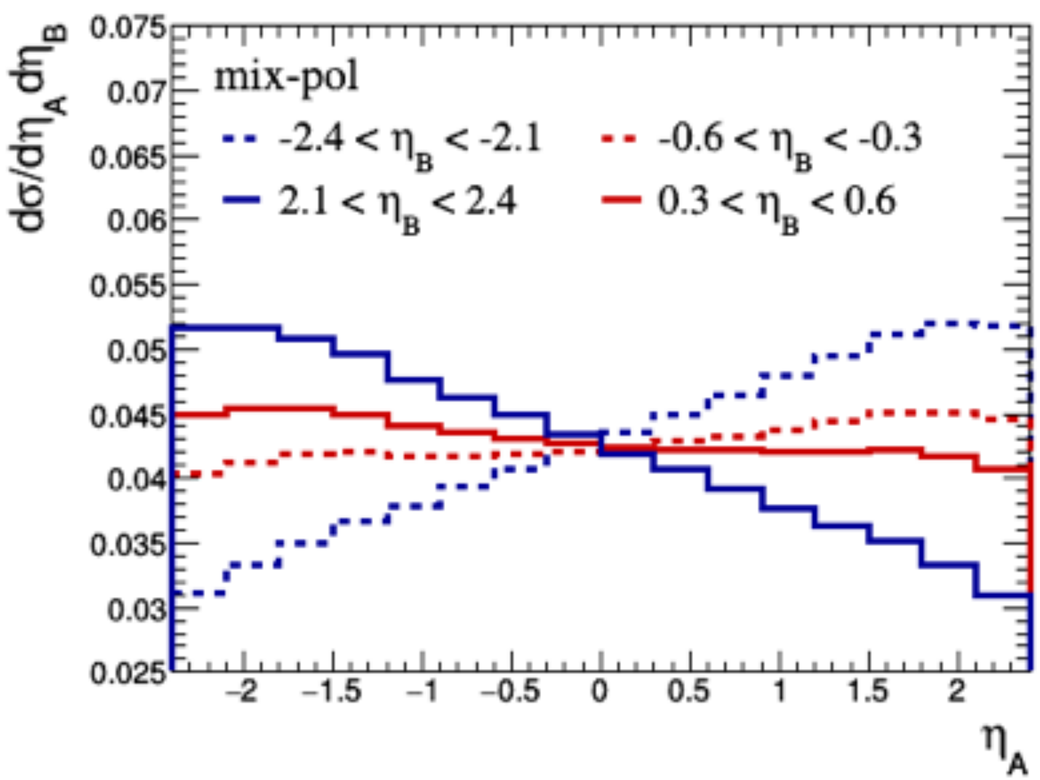
MIN-CORR



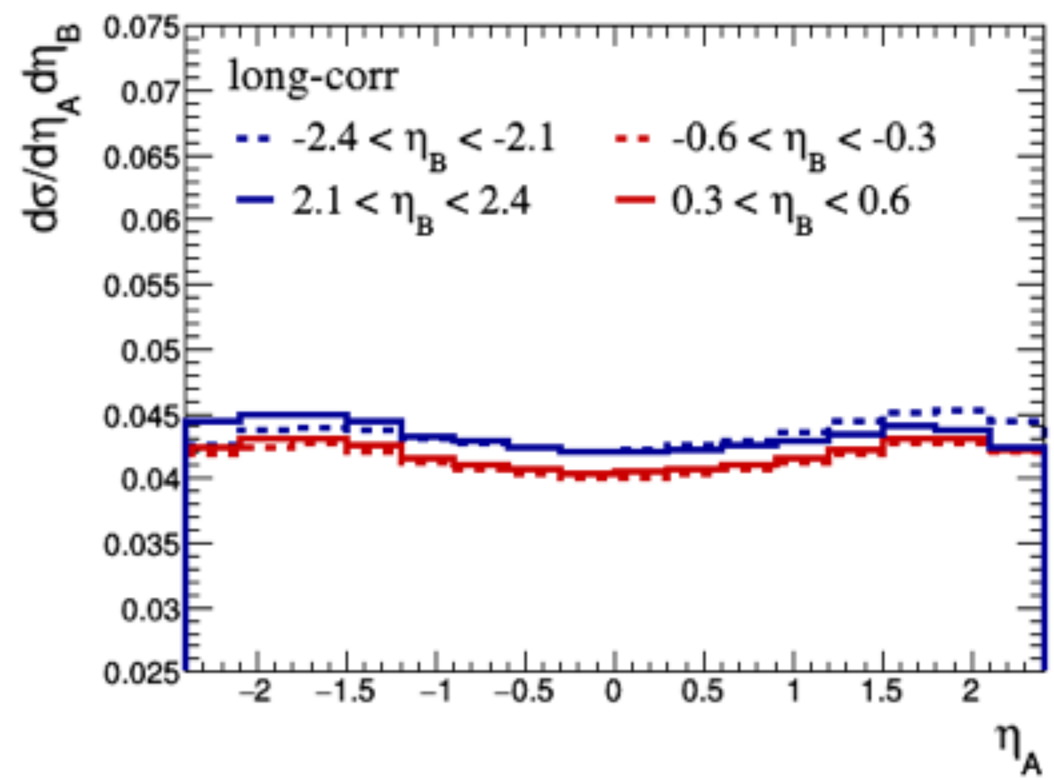
POS-POL



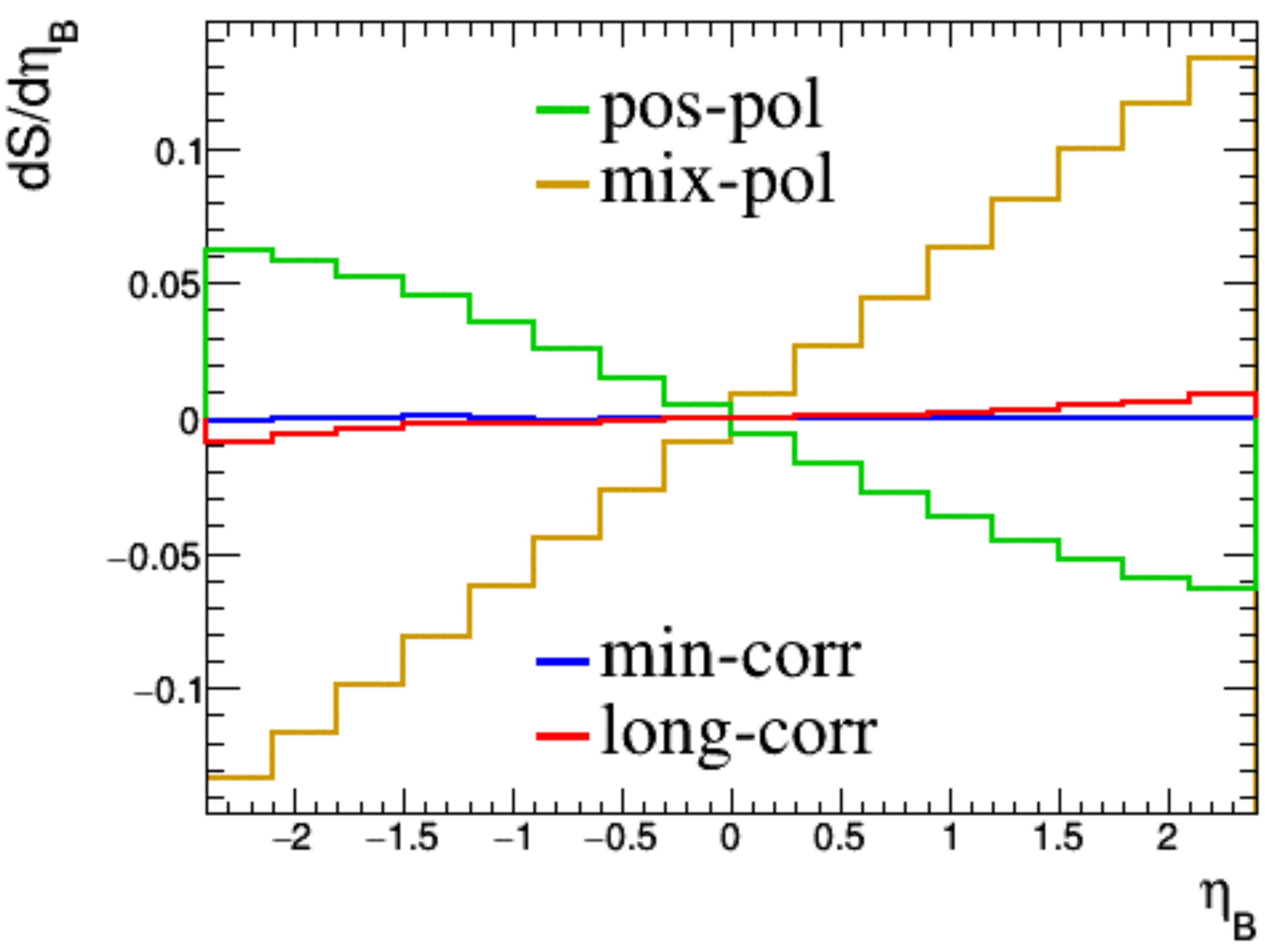
MIX-POL



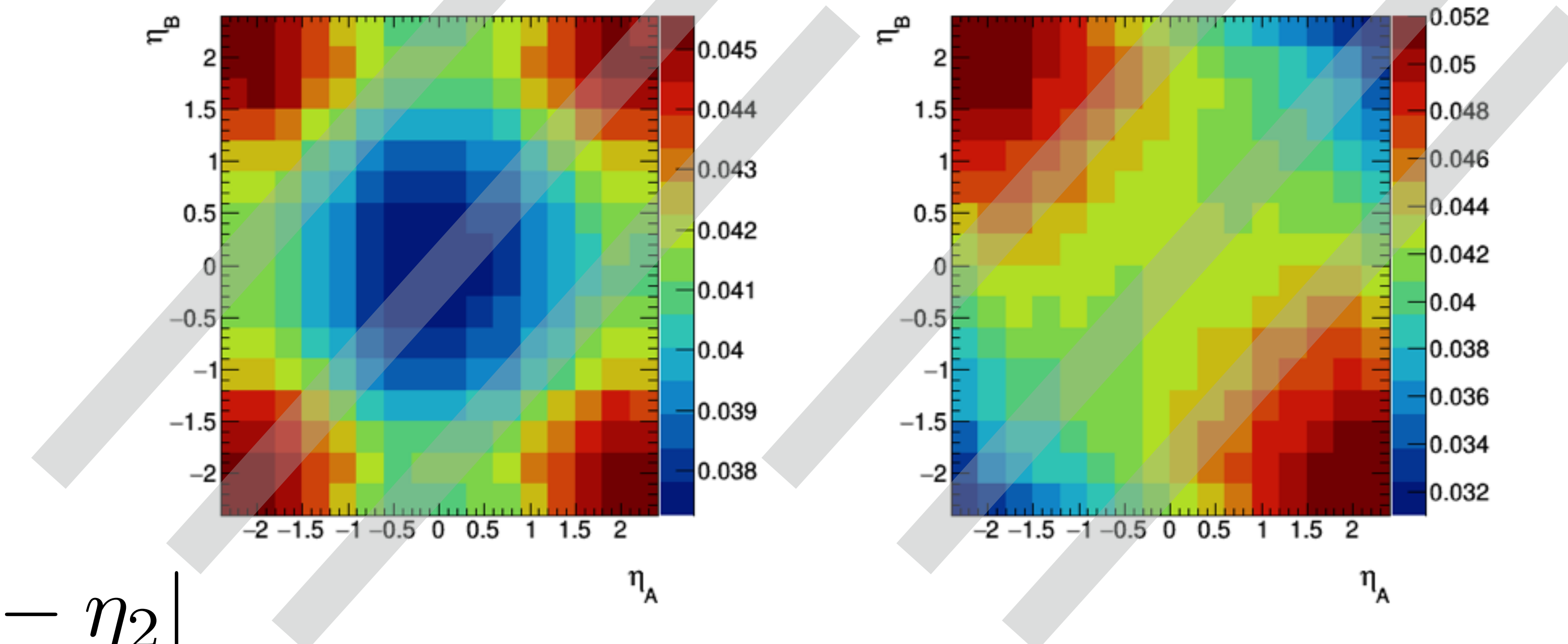
LONG-CORR



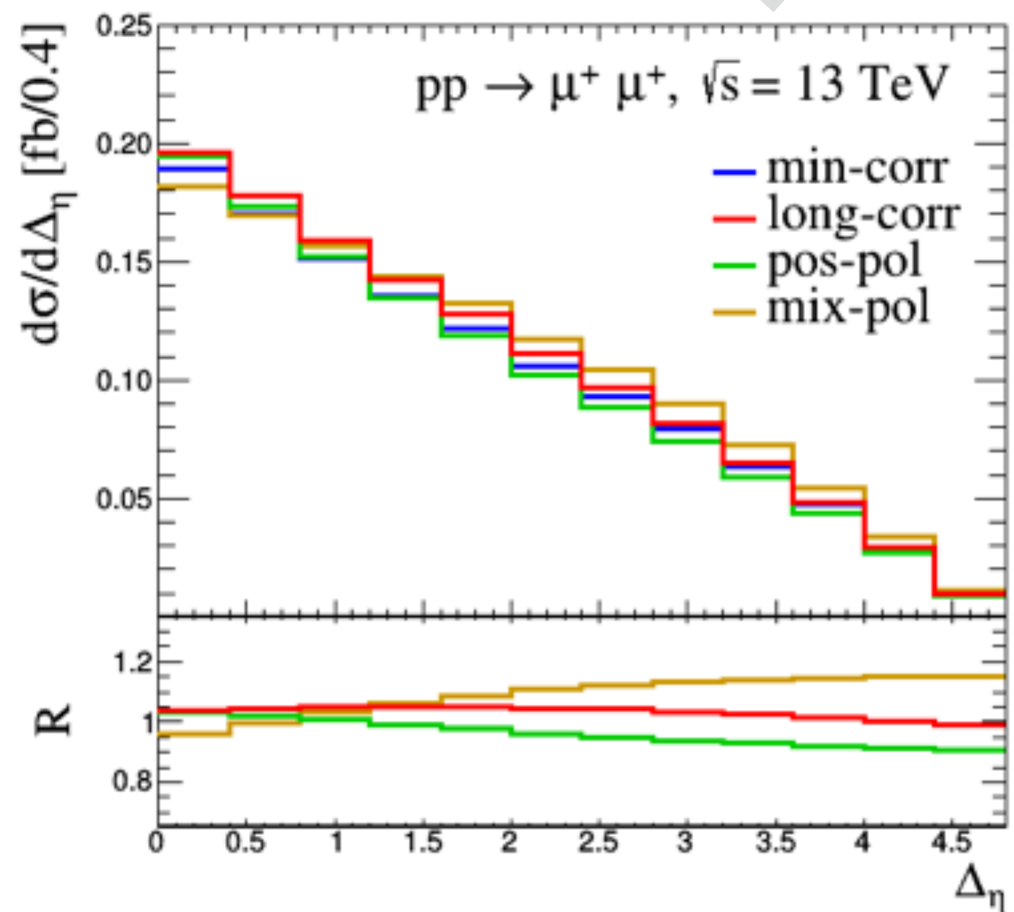
SLICE-ASYMMETRY



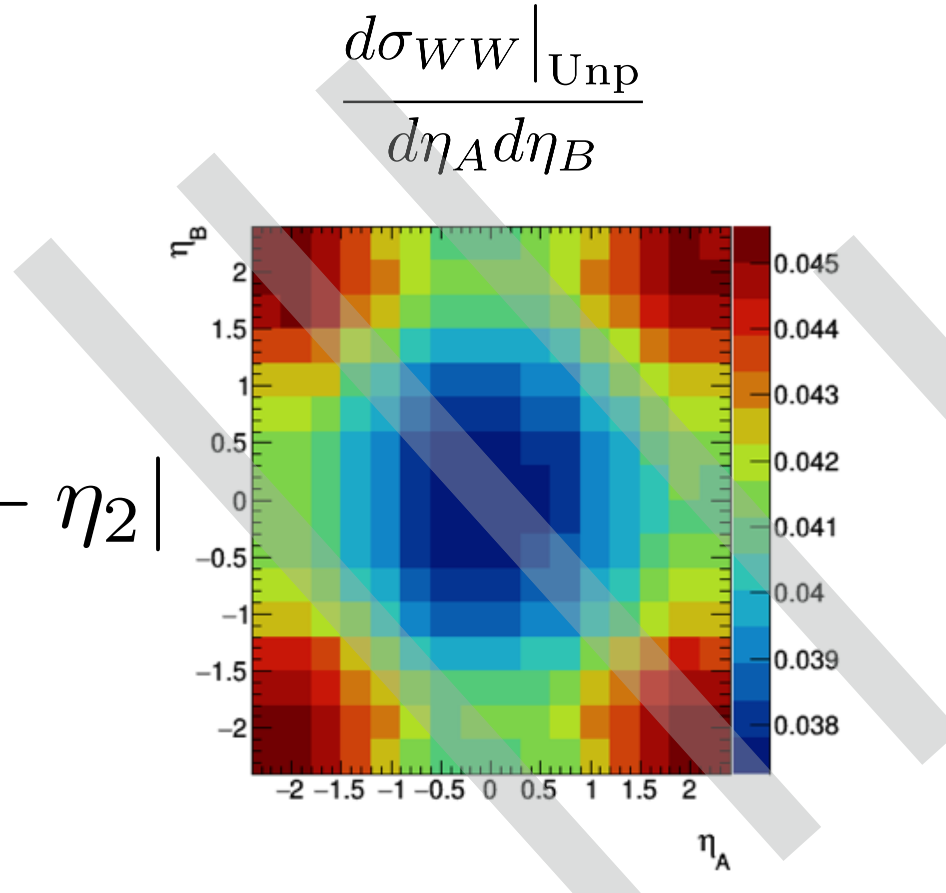
$$\frac{d\sigma_{WW}\big|_{\text{Unp}}}{d\eta_A d\eta_B} \qquad \frac{d\sigma_{WW}\big|_{\text{Mix-Pol}}}{d\eta_A d\eta_B}$$

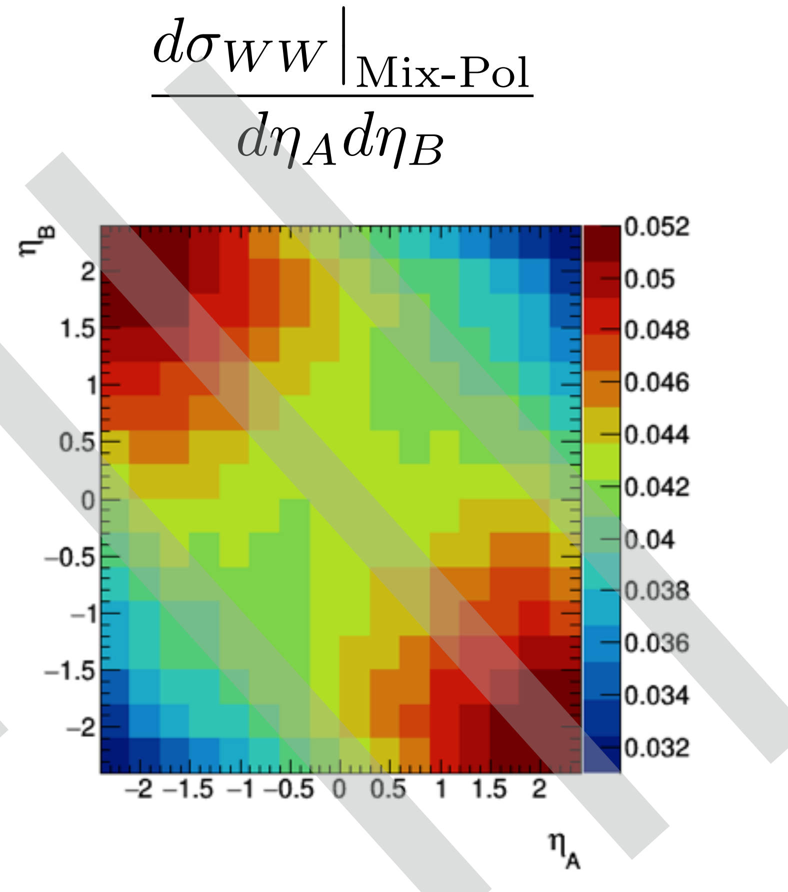


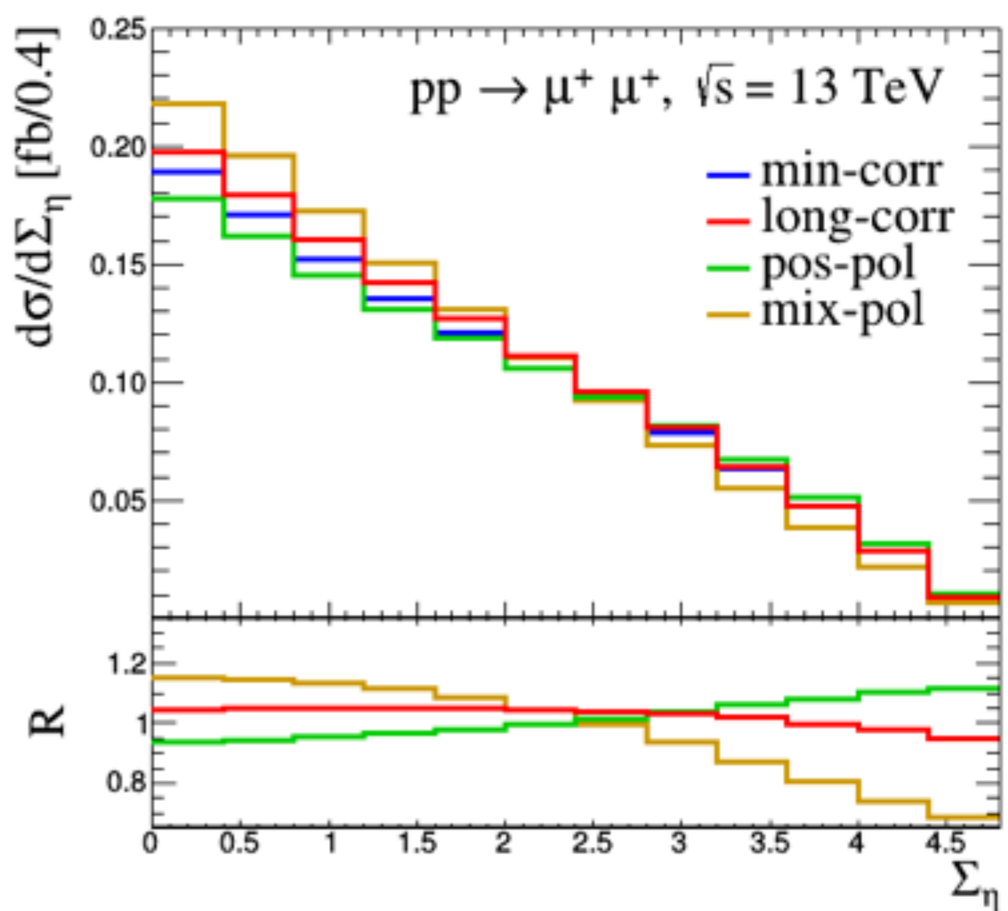
$$\Delta_\eta = |\eta_1 - \eta_2|$$



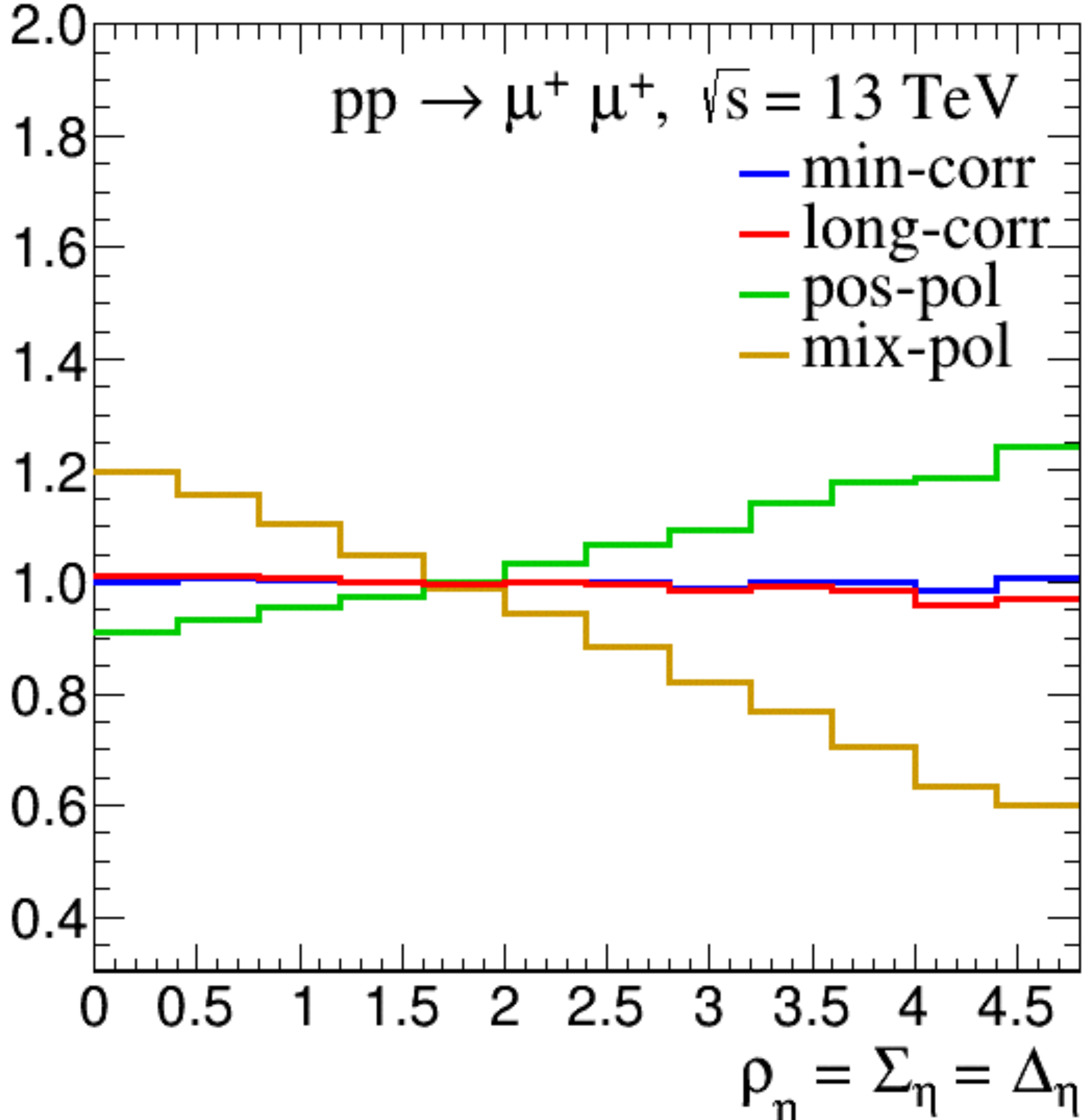
$$\Sigma_\eta = |\eta_1 + \eta_2|$$







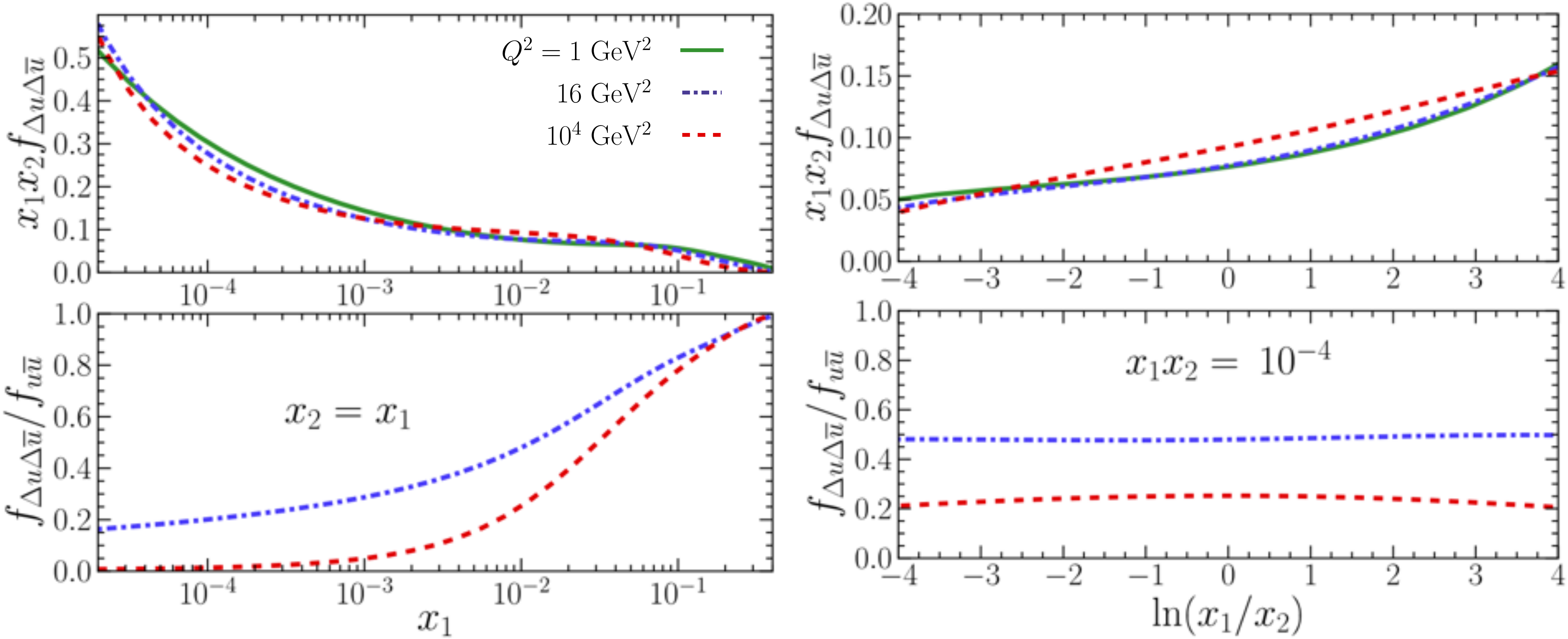
$$\frac{d\sigma}{d\Sigma_\eta} \Big/ \frac{d\sigma}{d\Delta_\eta}$$



IMPACT OF LONGITUNAL POLARIZATION

Diehl, Kasemets(2012)

$$f_{p_1 p_2}(x_1, x_2, \boldsymbol{y}; Q) = \tilde{f}_{p_1 p_2}(x_1, x_2; Q)\, G(\boldsymbol{y}) \,, \qquad G(\boldsymbol{y}) = 1$$



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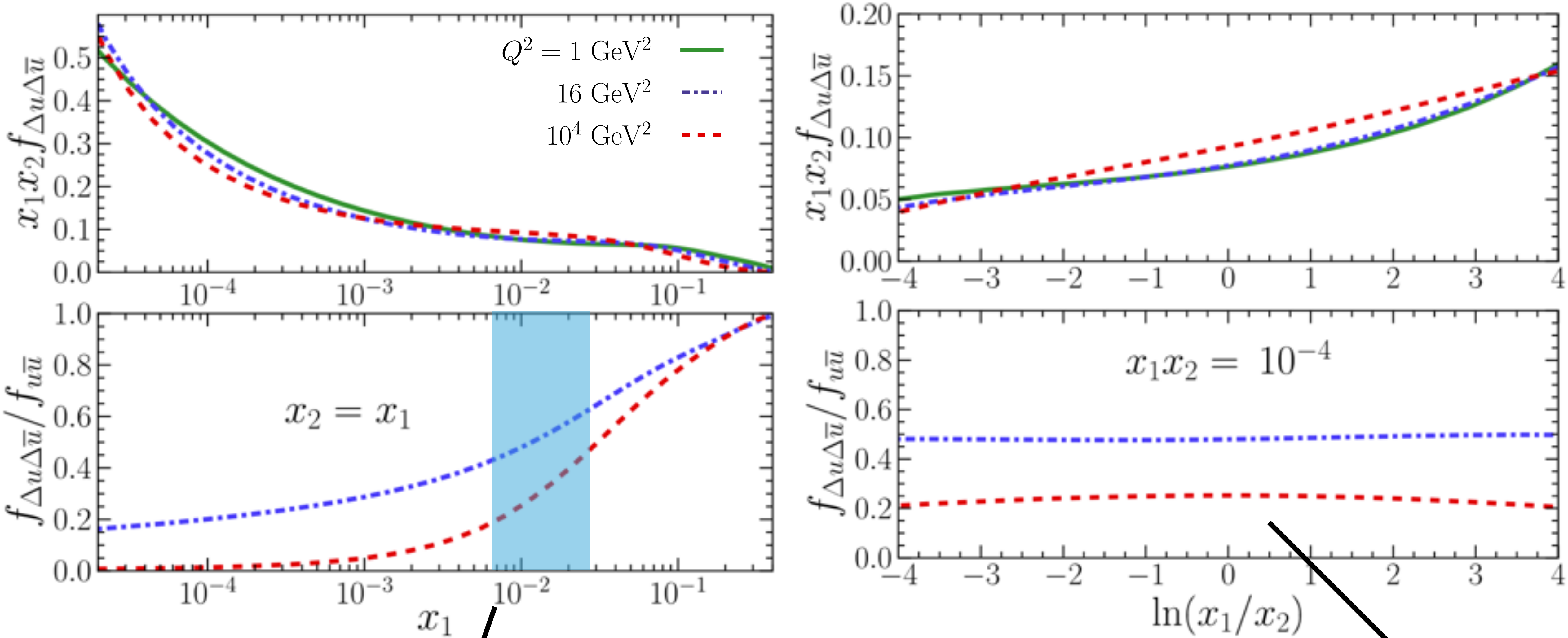

~20%

At values of Q and x typical of double W production the contribution of the longitudinal part can be relevant! Worth to be investigated deeper…