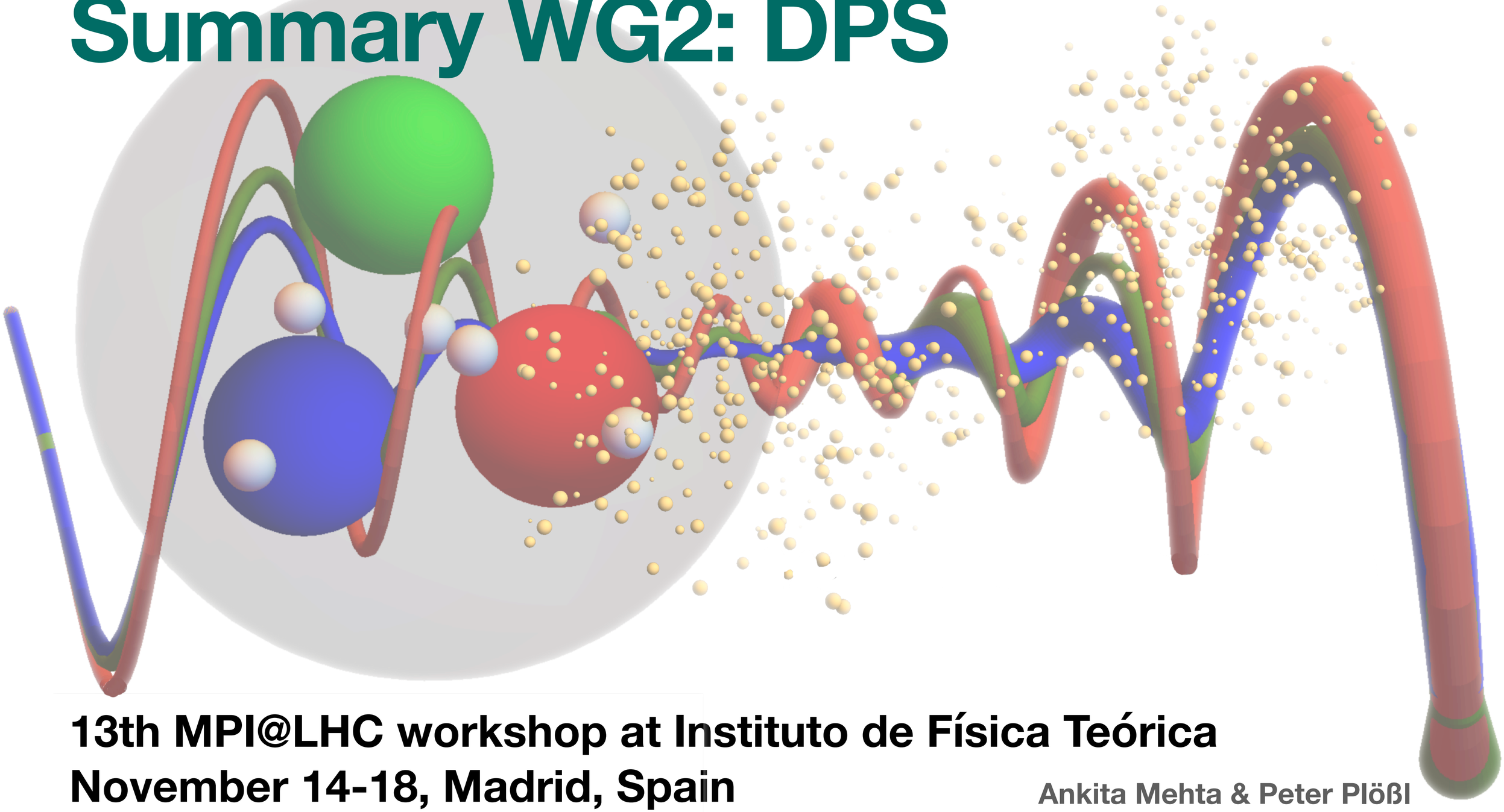
Summary WG2: DPS



13th MPI@LHC workshop at Instituto de Física Teórica
November 14-18, Madrid, Spain

Ankita Mehta & Peter Plößl

Double parton scattering

Monday session (4 in person & 4 remote talks)

- Max Jaarsma
- Daniel Reitinger
- Sergey Koshkarev
- Andrei Gridin for COMPASS
- Ankita Mehta for CMS
- Jonathan Gaunt
- Peter Plößl
- Matteo Rinaldi

6 theory talks & 2 experimental talks

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Double parton scattering

Thursday session (1 in person & 4 remote talks)

- Tom Hadavizadeh
- David d’Enterria
- Yonathan Mehl
- Florian Fabry
- Antoni Szczurek

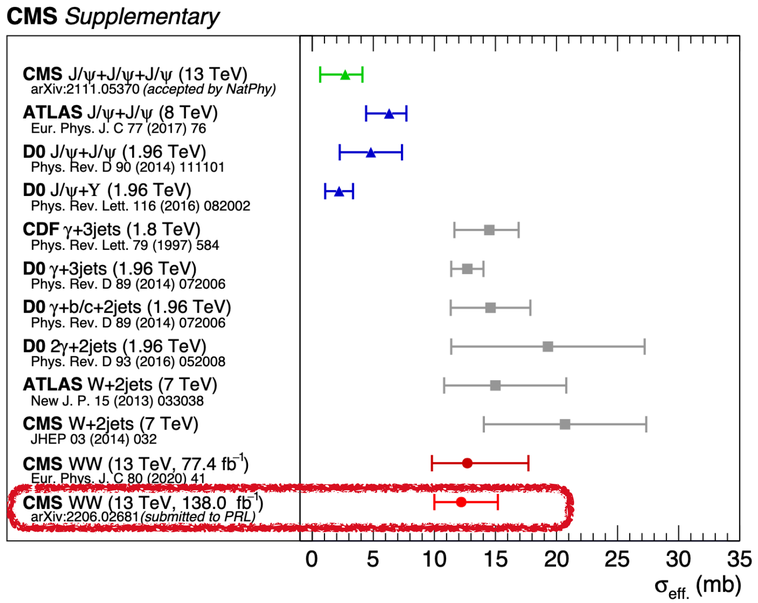
5 theory talks

DPS: Experiment

CMS WW measurement

- First measurement of like-sign WW production!
- ATLAS also working on this!

Summary



- Consistent with previous measurement from the same channel & other measurements involving W bosons from ATLAS & CMS
  - Improved precision
  - Tensions with most gluon induced processes

DPS: Experiment

J/ψ + J/ψ at COMPASS

- Data consistent with SPS production only.
- DPS contribution estimated at ~8%, but not taken into account in fit.

Summary and conclusions

1. The COMPASS $2J/\psi$ data are consistent with SPS production mechanism.
   - the SPS contribution can be the dominant one at NA3 and SELEX.
2. The COMPASS collaboration has estimated $\sigma_{2J/\psi}$ for each nuclear target.
3. An upper limit on double IC production mechanism is established.
4. No statistically significant resonant structures related to T_{4c} states in $M_{2J/\psi}$ spectrum.

DPS: Theory

Studying DPS in J/ψ + J/ψ

- Suggestion to study DPS in J/ψ + J/ψ in low energy collisions.
- Exploratory study for the kinematics of the NICA collider.

Conclusion

- First of all, GS09 model predicts much higher value of σ_{eff} than the value previously measured by DØ, ATLAS and CMS at low Bjorken-x.
- We can investigate the following ratio $N(\Delta_\theta < 0.25)/N(\Delta_\theta > 0.25)$. For the "pocket formula" this ratio is equal to $\sim 2/5$ and for GS09 $\sim 1/3$.
- Having taken into account the fact that $\Delta\phi_\pi = (\phi(J/\psi_1) - \phi(J/\psi_1))/\pi$ has a peak near 1 for SPS but a flat shape for DPS, we were able to exclude the region $\Delta\phi_\pi \sim 1$ in order to maximize the DPS/SPS ratio.

DPS: Theory

DPDs from lattice QCD

Conclusion

Achievement unlocked: formulating DPDs on the lattice

We are paving the way for lattice calculations of double parton distributions

- Lattice calculations of PDFs possible using quasi-PDF approach
- Conjectured a matching relation for the double parton case
  - quasi-DPD = perturbative kernel $\otimes$ rapidity evolution $\otimes$ physical-DPD
- Passed the one-loop consistency check: no infrared logs
- Some interesting findings:
  - No mixing between color- and spin structures
  - Relation to single-PDF matching kernel
  - Relation between color-summed/correlated kernels

Max Jaarsma

- Extension of the quasi PDF approach to DPDs

  ➡ x-dependent DPDs from the lattice!

- Calculation of the matching kernels onto nigh-cone DPDs.

Summary and Outlook

Achieved/Observed:

- Calculated two-current matrix elements on the lattice and extracted Lorentz invariant functions with clear signals
- Clear signals for polarization and flavor dependence:
  - Polarization effects clearly visible for *ud* and *duud*, suppressed for *uu*
  - Flavor dependence evident
- Size of interference effects comparable to *dd*, sign change possible
- Model predictions and tests:
  - $SU(6)$ prediction: fails completely for polarized quarks. Interference effects cannot be described.
  - Factorization test: yields correct order of magnitude, deviations visible

Future work / currently in progress:

- Repeat analysis for further ensembles to both study artifacts and to extrapolate towards the physical masses and continuum limit. **This can then be used as basis for experimental data analysis. Precise lattice input is available, even for interference cases.**

Questions?

Daniel Reitinger

- Moments of flavour interference DPDs.
- Calculation of the matching kernels onto nigh-cone DPDs.

DPS: Theory

Mass effects in splitting DPDs

- Small inter-carton distance DPDs can be matched onto PDFs.
- Consistent treatment of quark mass effects in this matching.

Summmary.

At small interparton distances y DPDs can be matched onto PDFs with perturbative $1 \to 2$ splitting kernels:

- Splitting evaluated at $\mu_{\text{split}} \sim 1/y$.
- For $\mu_{\text{split}} \sim m_Q$ quark mass effects have to be taken into account!

Consistent treatment of quark mass effects:

- Heavy quark decouples for $\mu_{\text{split}} \ll m_Q$.
- Heavy quark treated as massive for $\mu_{\text{split}} \sim m_Q$.
- Heavy quark treated as massless for $\mu_{\text{split}} \gg m_Q$.

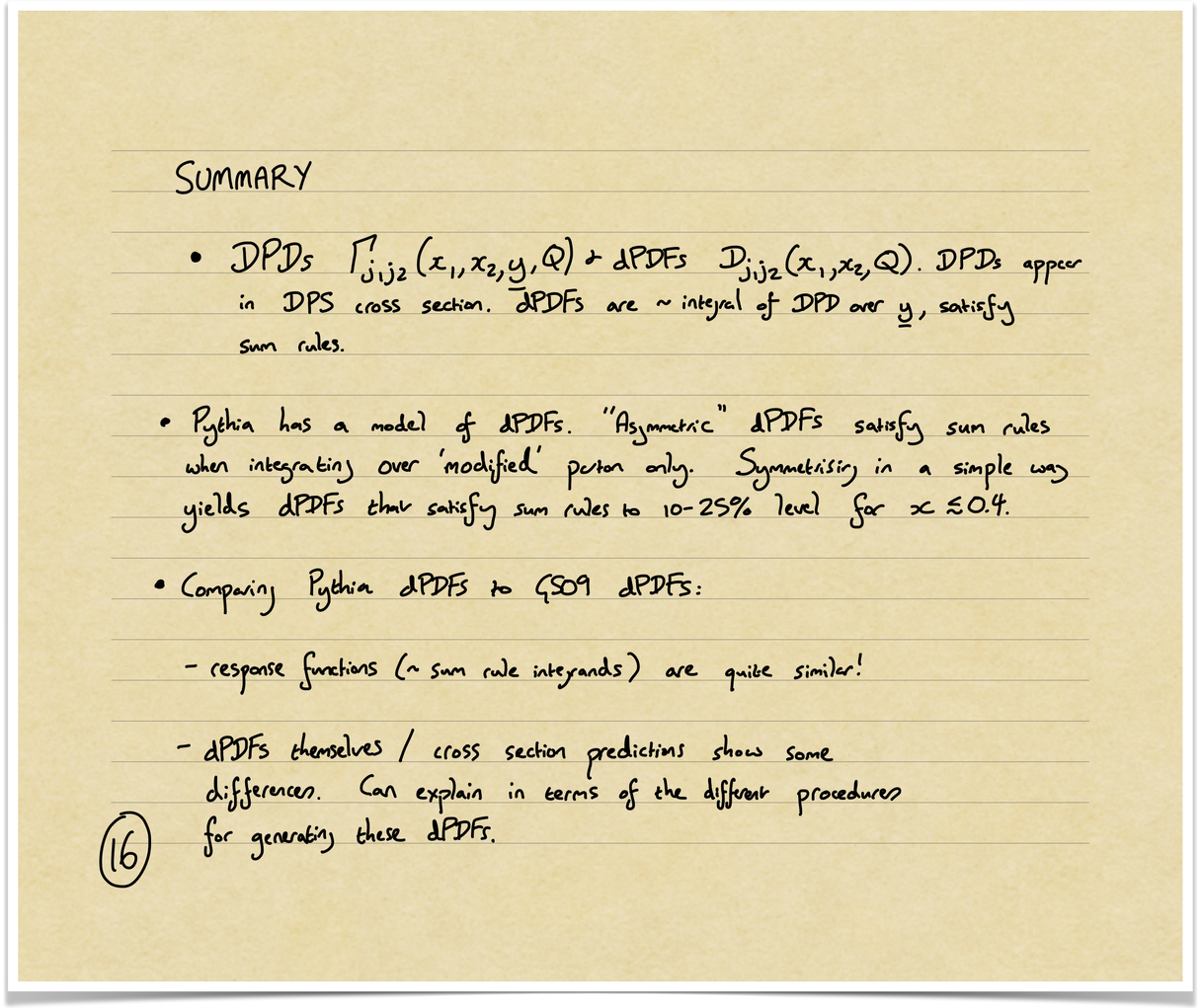
Including quark mass effects leads to DPDs with smaller discontinuities and stabilizes DPD luminosities compared to the purely massless case!

Thank you for your attention!

DPS: Theory

Comparing GS09 & Pythia DPDs

- dPDFs obtained from Pythia are remarkably similar to the GS09 dPDFs.
- Both are obtained in rather different ways.
- Are they a good approximation to the real distributions?



DPS: Theory

Colour non-singlet DPDs

Conclusion

- The total contribution of color correlation account only to 5% of the total cross section. This contribution is, however, approximately constant in hard scale Q (relative to the total DPS cross section)
- We did not account for non-diagonal ladders (i.e soft gluons connecting different partons [Gaunt, 2013]) that can contribute to the direct diagram
- Although the contributions are small they might be observed experimentally when comparing different kinematics (e.g as function of $\frac{x_1}{x_2}$ and $\frac{x_3}{x_4}$), we will leave this for future research

Yonathan Mehl

- Smaller Sudakov suppression of colour non-singlet DPDs in certain kinematics!

Summary

- For the first time, obtained all colored NLO DGLAP kernels, for unpolarized, longitudinal and transversity distributions
- All non-*δ(1-x)* terms are cross-checked with two completely independent methods
- Also obtained the NLO anomalous dimension of the CS-kernel for higher-than-octet representations

Stay tuned for numerical results!

Florian Fabry

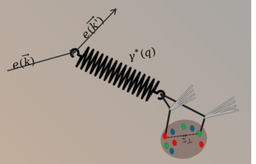
- Extend evolution of colour non-singlet DPDs to NLO.
- Calculate NLO colour non-singlet DGLAP kernels.

DPS: Theory

Photon initiated DPS

- Suggestion to study DPS in photon-proton collisions.
- Access to mean distance of partons in the proton.
- DPS at the EIC?

CONCLUSIONS



1) We demonstrated that in p-p collisions only some limited information on the proton can be obtained

2) We proposed to consider DPS initiated via photon-proton interactions by showing that:

* DPS can contribute also in this case. Cross section of the 4 jet photo production strongly affected

* The dependence of $\sigma_{eff}^{\gamma p}(Q^2)$ on the Q^2 can unveil the mean distance of partons in the proton

* We started the **QUARKONIUM Photo-PRODUCTION analysis:**

  - Quarkonium production is a rich channel to probe the parton correlations through DPS
  - We have estimated SPS and DPS cross sections for quarkonium-pair photoproduction at the EIC using the NRQCD framework
  - DPS total cross section is small compared to the SPS but could be measured if σ_{eff} small
  - Quarkonium-pair photoproduction is a promising channel to probe the gluonic content of the photon structure

MATTEO RINALDI MPI 2022 42

DPS: Theory

Triple parton scattering (TPS)

- Extension of pocket formula to TPS for p-p and p-A.
- Study TPS contributions to triple charm and triple-J/ψ (measured at CMS.
- Investigate TPS in p-A collisions!

Summary: Triple parton scatterings

- What's the parton transverse density of a proton? Its energy evolution? How do partons correlate (kinemat., quantum numbers) transversely?
- Triple hard parton scatterings in p-p collisions:

$$\sigma^{\mathrm{TPS}}_{hh'\to a_1 a_2 a_3} = \left(\frac{m}{3!}\right) \frac{\sigma^{\mathrm{SPS}}_{hh'\to a_1} \cdot \sigma^{\mathrm{SPS}}_{hh'\to a_2} \cdot \sigma^{\mathrm{SPS}}_{hh'\to a_3}}{\sigma^{2}_{\mathrm{eff,TPS}}}$$

(closely related to DPS in the absence of parton correlations):

$\sigma_{\mathrm{eff,TPS}} = (0.82 \pm 0.11)\ \sigma_{\mathrm{eff,DPS}}$

- Triple charm amounts to ~15% of inclusive charm x-sections in p-p collisions at the LHC. Triple-J/Ψ fully dominated by DPS/TPS: "golden channel" to extract $\sigma_{\mathrm{eff,pp}}$: 1st-ever observation by CMS.
- Derived TPS x-sections "pocket formula" for p-A:

$$\sigma^{\mathrm{TPS}}_{\mathrm{pA}\to abc} = \left(\frac{m}{6}\right) \frac{\sigma^{\mathrm{SPS}}_{\mathrm{pN}\to a} \cdot \sigma^{\mathrm{SPS}}_{\mathrm{pN}\to b} \cdot \sigma^{\mathrm{SPS}}_{\mathrm{pN}\to c}}{\sigma^{2}_{\mathrm{eff,TPS,pA}}}$$

$$\sigma_{\mathrm{eff,TPS,pA}} = \left[\frac{A}{\sigma^{2}_{\mathrm{eff,TPS}}} + \frac{3\,F_{\mathrm{pA}}[\mathrm{mb}^{-1}]}{\sigma_{\mathrm{eff,DPS}}} + C_{\mathrm{pA}}[\mathrm{mb}^{-2}]\right]^{-1/2}$$

- Large TPS yields in p-Pb, e.g. σ_{TPS}(triple-ccbar)=200 mb (~20% of incl. ccbar x-section): provide useful independent extractions of $\sigma_{\mathrm{eff,pp}}$. [Don't be shy to attempt a 1st-ever measurement in p-Pb...].

MPI@LHC, Madrid, Nov'22 13/13 David d'Enterria (CERN)

DPS: Theory

DPS to doubly-heavy hadrons

- Significant DPS contributions to doubly-heavy hadron production found in Pythia.
- Hadronization despite large distance between the two hard scatterings?

Outlook

- Recent studies with Pythia suggest DPS may significantly contribute to doubly-heavy hadron production
- Measurements of doubly-heavy hadron production as a function of event multiplicity can differentiate SPS vs. DPS production
- If DPS contribution is observed it can provide further insight into colour reconnection modelling

DPS: Theory

Structure of X(3872)

Conclusions

- The structure of famous $X(3872)$ is not known.
- Can the production of $X(3872)$ in proton-proton scattering be a new source of information ?
- We have calculated production of $X(3872)$ as the $c\bar{c}$ in the k_t-factorization approach within nonrelativistic approach for the $g^*g^* \to X(3872)$ vertex with modern unintegrated distributions.
  A reasonable results have been obtained.
- We have done similar calculation for the DD^* fusion. $c\bar{c}$ is calculated in the k_t-factorization approach. D and D^* mesons calculated in infinitly heavy quark approximation.
  A reasonable results have been obtained.
- Having in mind the finite lifetime of D^* mesons we have shown results for both directly produced D^0 and for all D^0, including the feeddown contribution.

Conclusions

- In addition, a hybrid model (mixture of $c\bar{c}$ and molecular component).
  A reasonable results have been obtained.
- All three (naive) approaches describe the LHC data for $pp \to X(3872)$.
- The lifetime argument discussed here for the first time suggests that in reality one should rather include rather only directly produced D^0 (or $\bar{D}^0$). This strongly reduces the cross section and causes that the purely molecular scenario is disfavoured.
- Therefore in the hybrid scenario the probability of the molecular component should not be too big.

- Structure and production mechanism of X(3872) are unknown.
- Can the inclusion of DPS solve this puzzle?

We’re looking forward to many new and exciting developments!

See you next year!