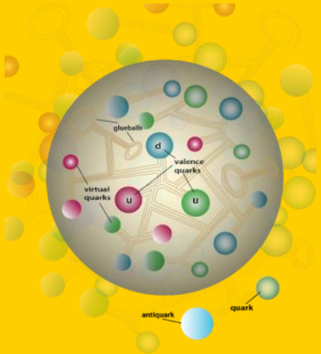
The transverse structure of the proton via Double Parton Scattering



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in collaboration with

Federico Alberto Ceccopieri
Marco Traini
Sergio Scopetta
Vicente Vento

STRONG 2020

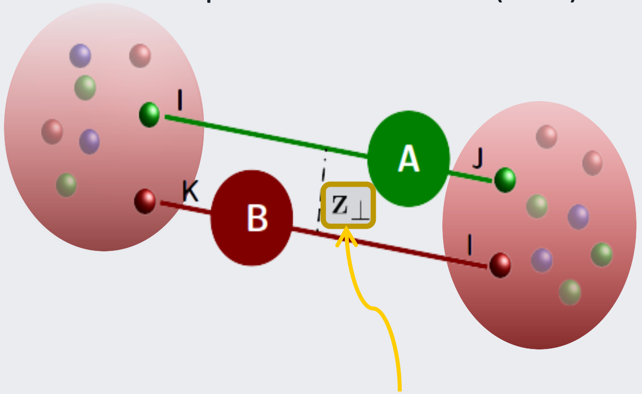
Istituto Nazionale di Fisica Nucleare

Roadmap

1. INTRODUCTION
2. 3D PROTON STRUCTURE VIA p-p DPS
3. INTERPRETATION OF LHC DATA
4. DPS VIA PHOTON-PROTON INTERACTIONS
5. PREDICTIONS AND OPPORTUNITIES
6. CONCLUSIONS

1 Double Parton Scattering @LHC

Multiparton interaction (MPI) can contribute to the, pp and pA, cross section @ the LHC:



Transverse distance between partons

The cross section for a double parton scattering (DPS) event can be written in the following way:

N. Paver, D. Treleani, Nuovo Cimento 70A, 215 (1982)

double PDF (dPDF)

$$d\sigma \propto \int d^2 z_\perp \, F_{ik}(x_1, x_2, \vec{z}_\perp; \mu_A, \mu_B) \cdot F_{jl}(x_3, x_4, \vec{z}_\perp; \mu_A, \mu_B)$$

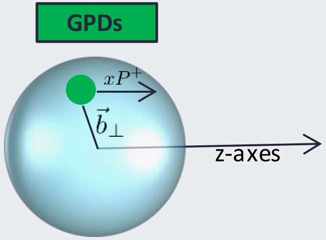
Momentum scales

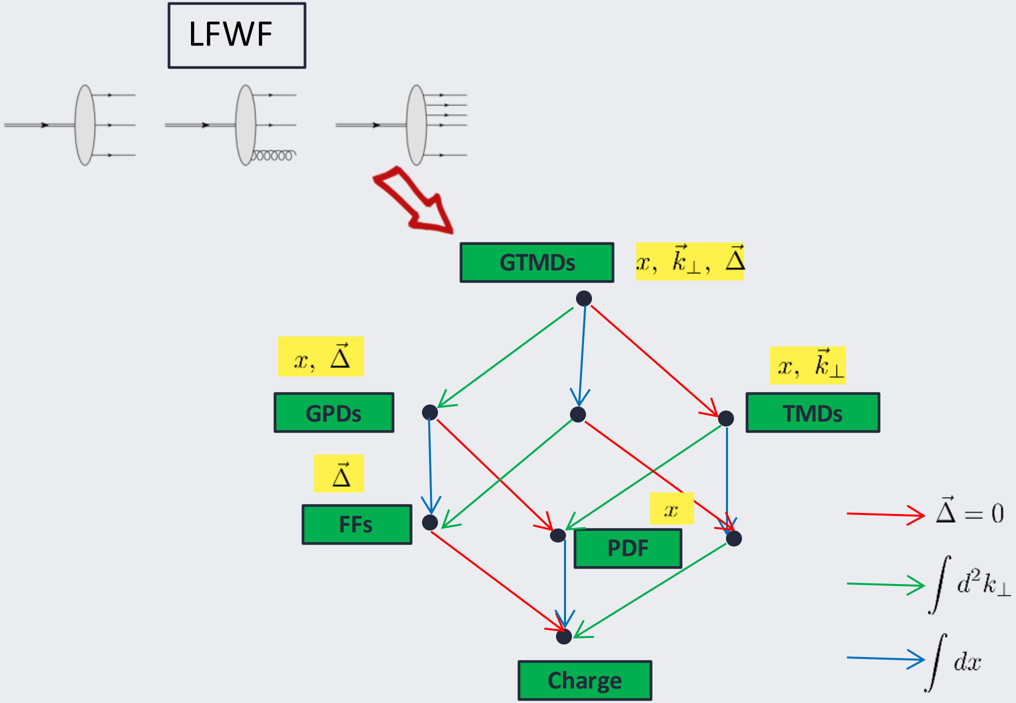
Momentum fractions carried by the parton inside the proton

DPS processes are important for fundamental studies, e.g. the background for the research of new physics and to grasp information on the **3D PARTONIC STRUCTURE OF THE PROTON**

1 Multidimensional Pictures of Hadron

1-body





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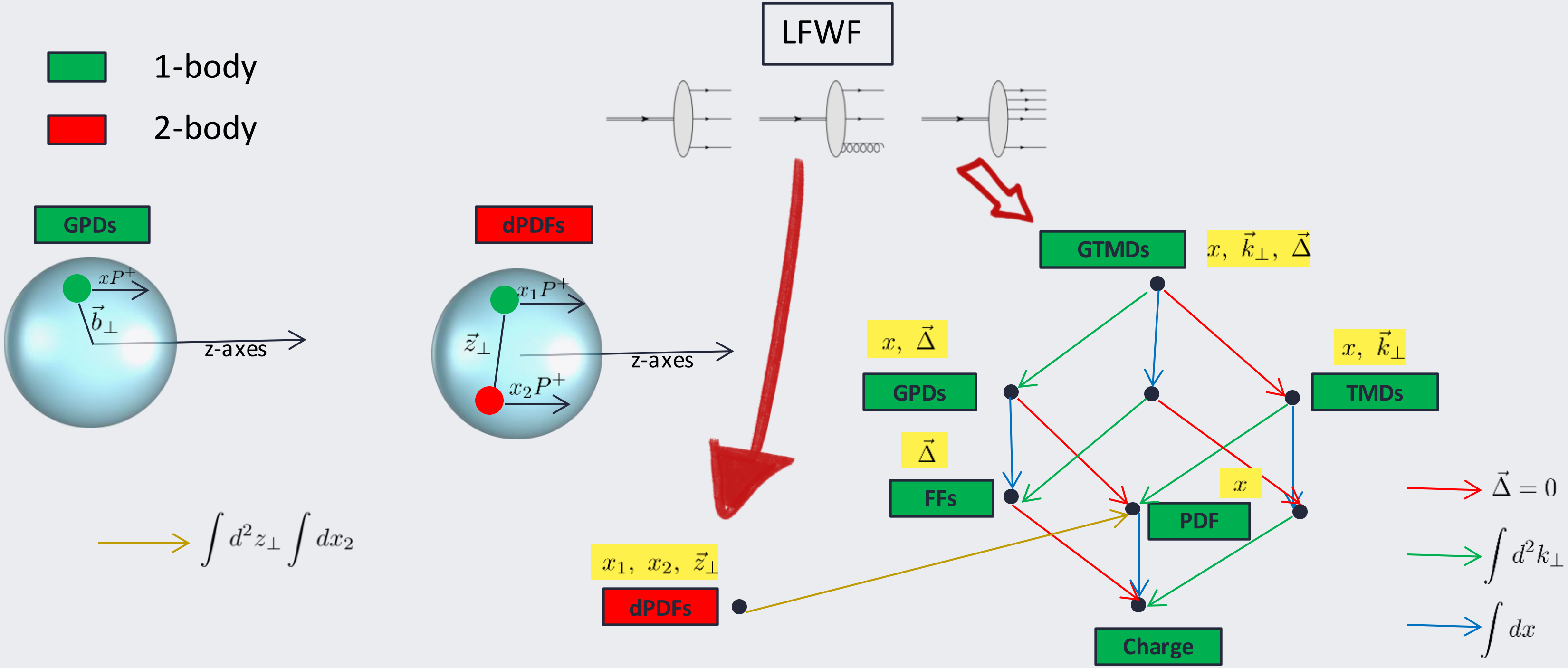

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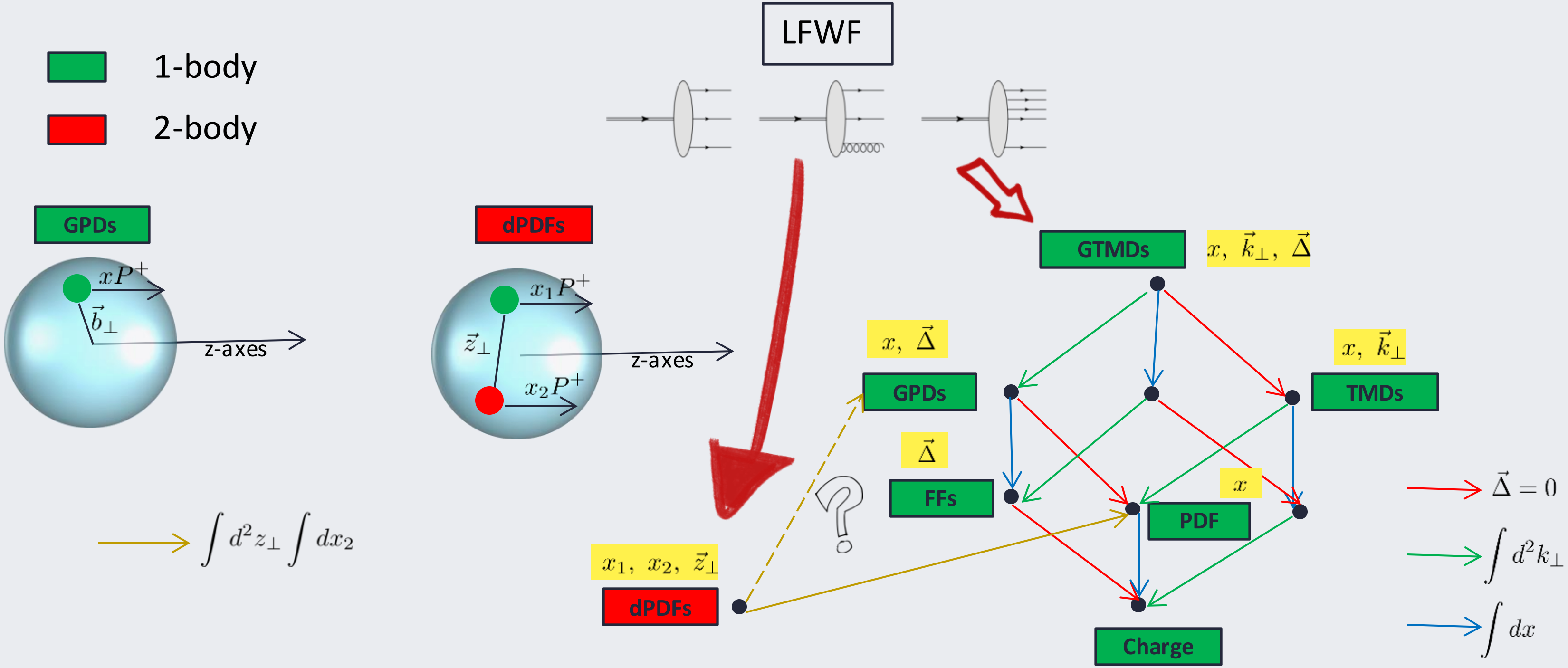

1 Double PDFs of the proton

$F_{ik}(x_1, x_2, \vec{z}_\perp)$ is unknown. However @LHC kinematics (small *x* and many partons produced)

$$F_{ik}(x_1, x_2, \vec{z}_\perp) \sim \overbrace{g(x_1, x_2)\tilde{T}(\vec{z}_\perp)}^{\text{1st uncorrelated scenario}}$$

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$g(x_1, x_2)$: DPD → SUM RULES AVAILABLE

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1st uncorrelated scenario

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DPD

- SUM RULES AVAILABLE
- MODELS BASED ON SUM RULES

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1st uncorrelated scenario

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- SUM RULES AVAILABLE
- MODELS BASED ON SUM RULES
- PDF(x_1)*PDF(x_2)
- [PDF(x_1)*PDF(x_2)] ⊗ pQCD EVOLUTION

2nd uncorrelated scenario (last two items)

J. R. Gaunt and W. J. Stirling, JHEP 03, 005 (2010)

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2nd uncorrelated scenario

PERTURBATIVE CORRELATIONS

1 Double PDFs of the proton

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PERTURBATIVE CORRELATIONS

Constituent quark models used to grasp basic NON PERTURBATIVE features

M.R., S. Scopetta et *al*, PRD 87 (2013) 114021
M.R., S, Scopetta et *al*, JHEP 12 (2014) 028

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$\tilde{T}(\vec{z}_\perp)$ → PROBABILITY DISTRIBUTION OF FINDING TWO PARTONS WITH GIVEN TRANSVERSE DISTANCE

F_{ik} → Constituent quark models used to grasp basic NON PERTURBATIVE features

M.R., S. Scopetta *et al*, PRD 87 (2013) 114021
M.R., S, Scopetta *et al*, JHEP 12 (2014) 028

$g(x_1, x_2)$ — DPD
- SUM RULES AVAILABLE
- MODELS BASED ON SUM RULES
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(last two: 2nd uncorrelated scenario)

PERTURBATIVE CORRELATIONS

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$$F_{ik}(x_1, x_2, \vec{z}_\perp) \sim g(x_1, x_2)\tilde{T}(\vec{z}_\perp)$$

$\tilde{T}(\vec{z}_\perp)$:
- PROBABILITY DISTRIBUTION OF FINDING TWO PARTONS WITH GIVEN TRANSVERSE DISTANCE
- UNKNOWN: ONLY MODELS

$g(x_1, x_2)$: DPD
- SUM RULES AVAILABLE
- MODELS BASED ON SUM RULES
- PDF(x_1)*PDF(x_2)
- [PDF(x_1)*PDF(x_2)] ⊗ pQCD EVOLUTION

The last two items: 2nd uncorrelated scenario

PERTURBATIVE CORRELATIONS

F_{ik}: Constituent quark models used to grasp basic non perturbative feature

M.R., S. Scopetta et *al*, PRD 87 (2013) 114021
M.R., S, Scopetta et *al*, JHEP 12 (2014) 028

1 Double PDFs of the proton

Some questions arose:

1) HOW CAN WE BE SURE OF THE ACCURACY OF SUCH APPROXIMATION?
dPDFs are non perturbative in QCD ➡ Cs cannot be accessed from QCD

2) WHICH INFORMATION ON THE PROTON STRUCTURE COULD BE ACCESSED FROM DPS?

PERTURBATIVE CORRELATIONS

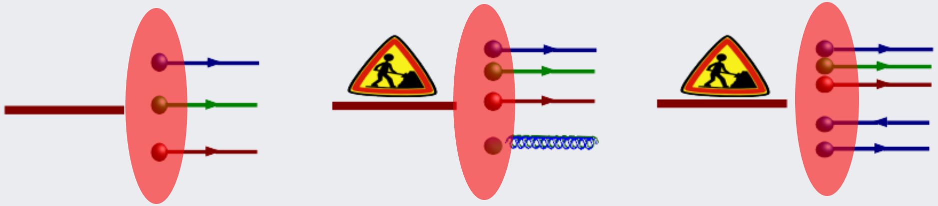
2 Double PDFs within the Light-Front

Extending the procedure developed in **S. Boffi, B. Pasquini and M. Traini, Nucl. Phys. B 649, 243 (2003)** for GPDs, we obtained the following expression of the dPDF in momentum space, often called $_2$GPDs:

$$F_{ij}(x_1,x_2,k_\perp) = 3(\sqrt{3})^3 \int \prod_{i=1}^{3} d\vec{k}_i \, \delta\left(\sum_{i=1}^{3} \vec{k}_i\right) \Phi^*(\{\vec{k}_i\},k_\perp)\Phi(\{\vec{k}_i\},-k_\perp) \times \delta\left(x_1 - \frac{k_1^+}{P_+}\right)\delta\left(x_2 - \frac{k_2^+}{P_+}\right)$$

Conjugate to $z_\perp$

LF wave-function



$$\Phi(\{\vec{k}_i\},\pm k_\perp) = \Phi\left(\vec{k}_1 \pm \frac{\vec{k}_\perp}{2}, \vec{k}_2 \mp \frac{\vec{k}_\perp}{2}, \vec{k}_3\right)$$

2 Double PDFs within the Light-Front:GPDxGPD

The dPDF is formally defined through the Light-cone correlator:

$$F_{12}(x_1, x_2, \vec{z}_\perp) \propto \sum_X \int dz^- \left[\prod_{i=1}^{2} dl_i^- e^{i x_i l_i^- p^+} \right] \langle p | O(z, l_1) | X \rangle \langle X | O(0, l_2) | p \rangle \Big|_{l_1^+ = l_2^+ = z^+ = 0}^{\vec{l}_{1\perp} = \vec{l}_{2\perp} = 0}$$

Approximated by the proton state!

$$\int \frac{dp'^+ d\vec{p}'_\perp}{p'^+} |p'\rangle\langle p'|$$

GPD

$$F_{12}(x_1, x_2, \vec{k}_\perp) \sim f(x_1, 0, \vec{k}_\perp) f(x_2, 0, \vec{k}_\perp)$$

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Approximated by th [illegible]

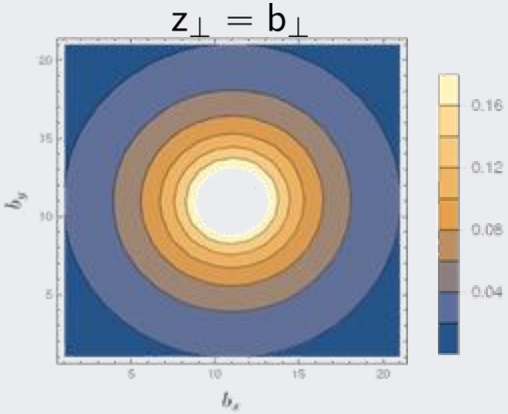
$$\int \frac{dp'^+ d \text{[illegible]}}{\text{[illegible]}}$$

TO BE TESTED WITH MODELS

GPD

$$F_{12}(x_1, \text{[illegible]}) \sim f(x_1, 0, \vec{k}_\perp) f(x_2, 0, \vec{k}_\perp)$$

2 Information from Quark Models

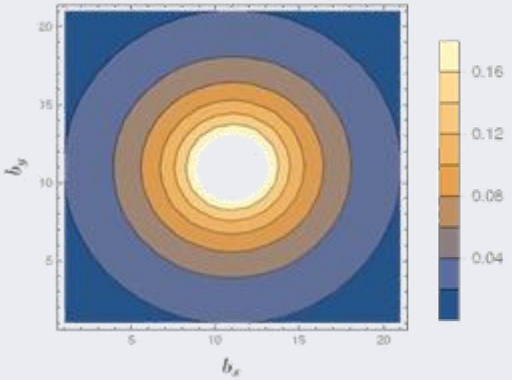


M.R. and F. A. Ceccopieri, JHEP 09 (2019) 097

1) e.g. the distance distribution of **two gluons** in the proton

$$\langle z_\perp^2 \rangle^{ij}_{x_1,x_2} = \frac{\int d^2 z_\perp \; z_\perp^2 F_{ij}(x_1, x_2, z_\perp)}{\int d^2 z_\perp \; F_{ij}(x_1, x_2, z_\perp)}$$

2 Information from Quark Models



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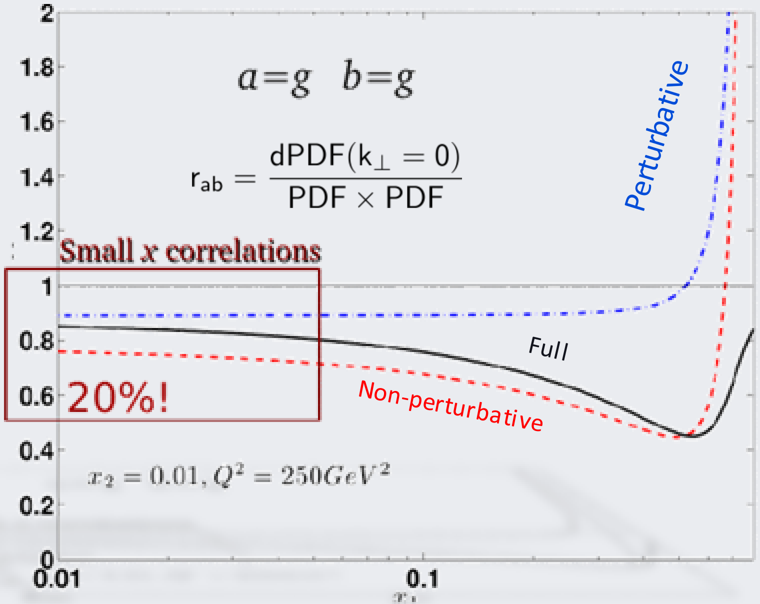


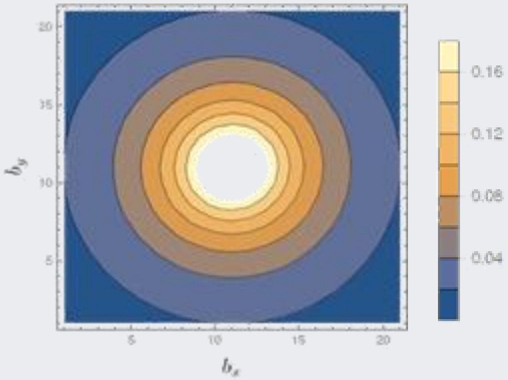
2) Correlations are important

M.R., S. Scopetta et al, JHEP 10 (2016) 063

M.R. and F. A. Ceccopieri PRD 95 (2017) 034040

…………….

2 Information from Quark Models



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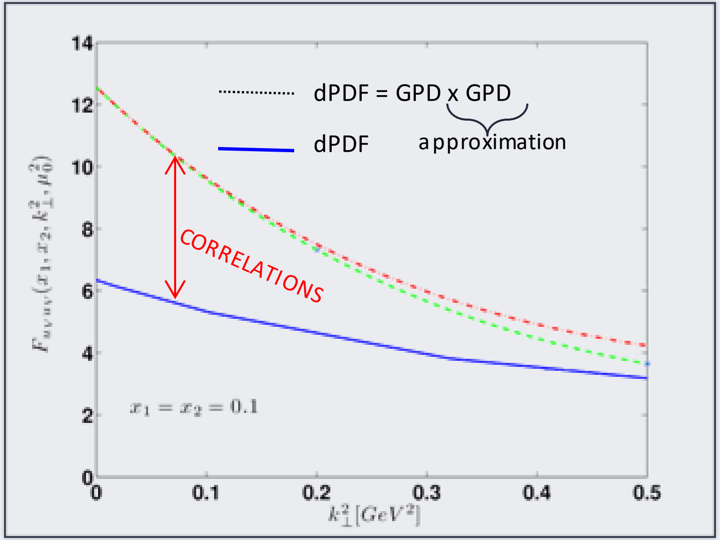

2) Correlations are important

M.R., S. Scopetta et al, JHEP 10 (2016) 063

M.R. and F. A. Ceccopieri PRD 95 (2017) 034040

3 Data and Effective Cross Section

A tool for the comprehension of the role of DPS in hadron-hadron collisions is the so called "effective X-section".

$$\sigma_{\text{eff}}^{\text{pp}} = \frac{m}{2} \frac{\sigma_A^{\text{pp}} \sigma_B^{\text{pp}}}{\sigma_{\text{DPS}}^{\text{pp}}}$$

POCKET FORMULA

Differential cross section for the process:
$pp \longrightarrow A(B) + X$

Differential cross section for a DPS event:
$pp \longrightarrow A + B + X$

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POCKET FORMULA

Differential cross section for the process:
$pp \longrightarrow A(B) + X$

Differential cross section for a DPS event:
$pp \longrightarrow A + B + X$

color factors — PDF

$$\sigma_{\text{eff}}(x_1,x_2,x_3,x_4) = \frac{\sum_{i,j,k,l} C_{ik}C_{jl}F_i(x_1)F_j(x_2)F_k(x_3)F_l(x_4)}{\sum_{i,j,k,l} C_{ik}C_{jl}\int d^2z_\perp\; F_{ij}(x_1,x_3,z_\perp)F_{kl}(x_3,x_4,z_\perp)}$$

M.R., S. Scopetta et al, PLB 752

M. Traini, M.R., S. Scopetta and V. Vento, PLB 768 (2017)

3 Data and Effective Cross Section

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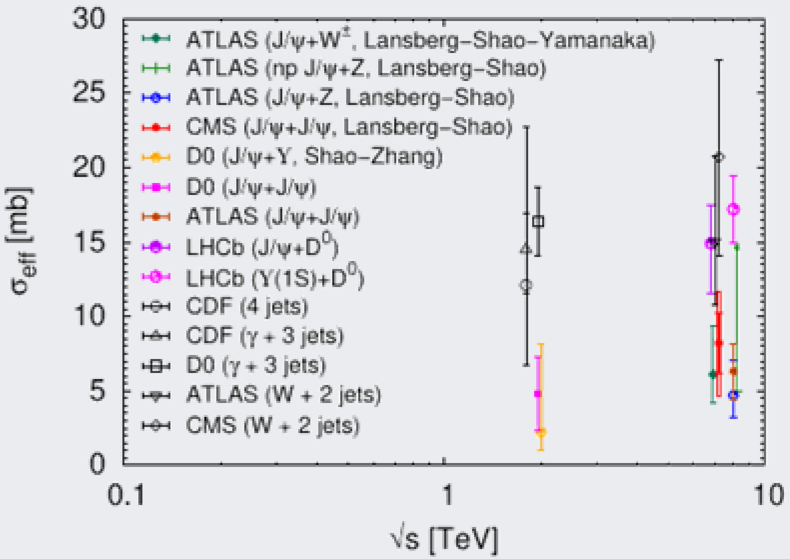

J.P. Lansberg's slide
MPI-2019 workshop

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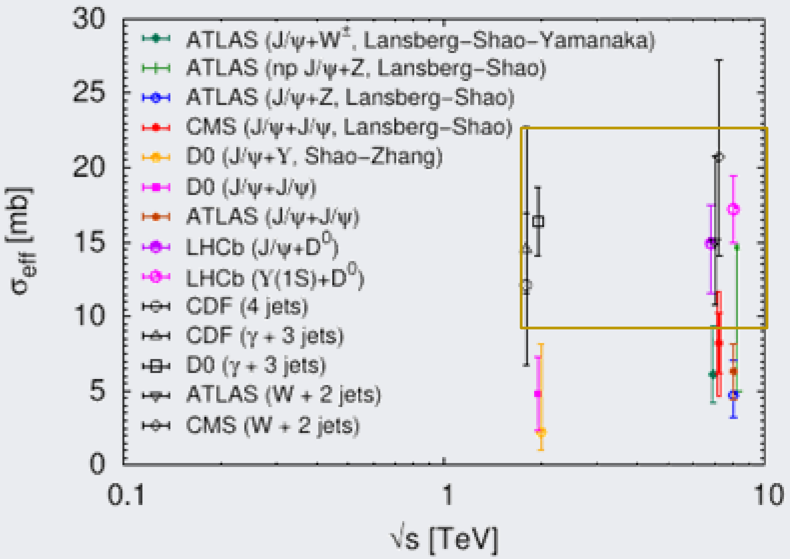


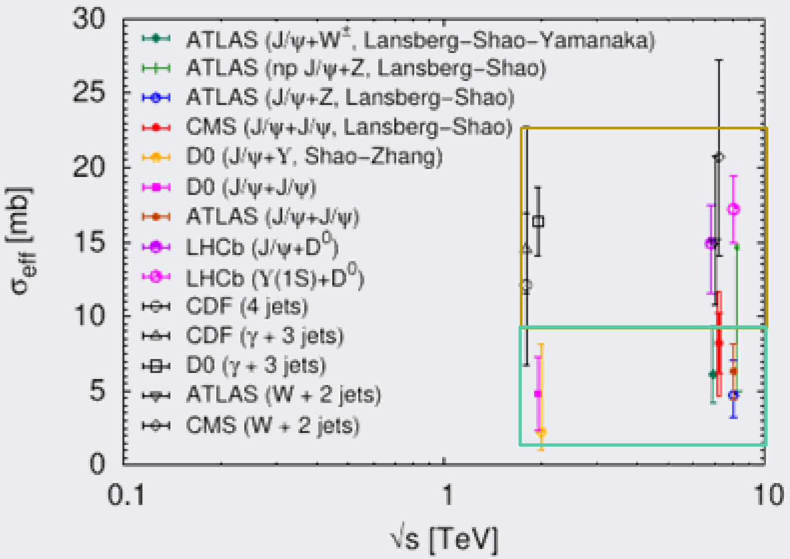
J.P. Lansberg's slide
MPI-2019 workshop

3 Data and Effective Cross Section

$$\sigma_{eff}^{pp} = \frac{m}{2} \frac{\sigma_A^{pp} \sigma_B^{pp}}{\sigma_{DPS}^{pp}}$$

- SENSITIVE TO CORRELATIONS
- PROCESS DEPENDENT?
- SENSITIVE TO INFORMATION ON THE PROTON STRUCTURE?
  As predicted by quark models

M.R. et al PLB 752,40 (2016)
M. Traini, M. R. et al, PLB 768, 270 (2017)
M. R. et al, Phys.Rev. D95 (2017) no.11, 114030



J.P. Lansberg's slide
MPI-2019 workshop

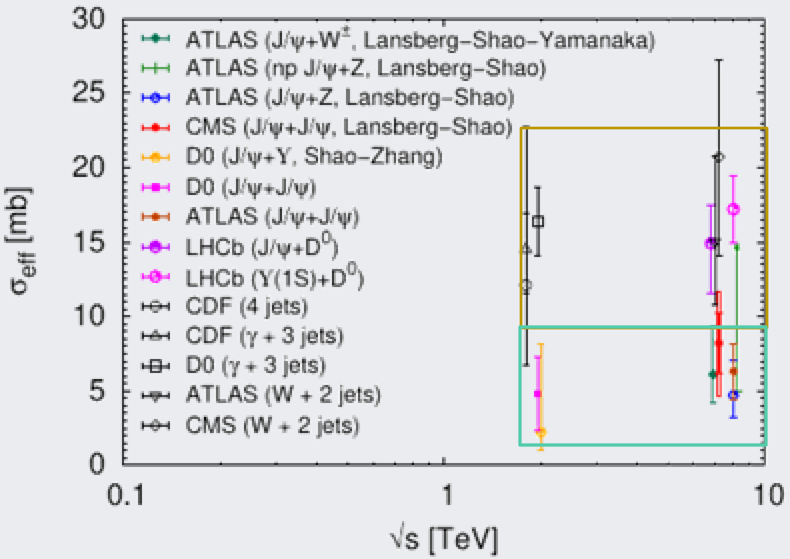
3 Data and Effective Cross Section

$$\sigma_{eff}^{pp} = \frac{m}{2}\frac{\sigma_A^{pp}\sigma_B^{pp}}{\sigma_{DPS}^{pp}}$$

- SENSITIVE TO CORRELATIONS
- PROCESS DEPENDENT?
- SENSITIVE TO INFORMATION ON THE PROTON STRUCTURE? and phenomenological analyses

T. Kasemets et al, JHEP 10 (2020) 214

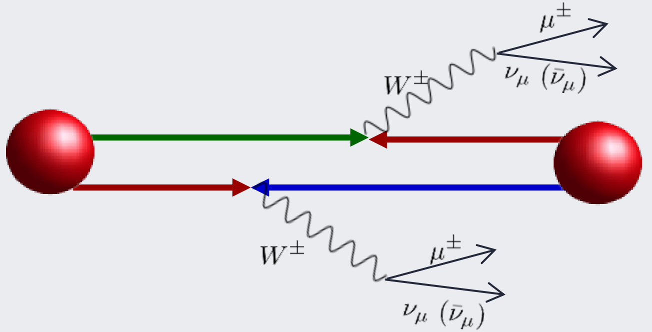
...



J.P. Lansberg's slide
MPI-2019 workshop

4 Same sign W's production at the LHC

M. R. et al, Phys.Rev. D95 (2017) no.11, 114030

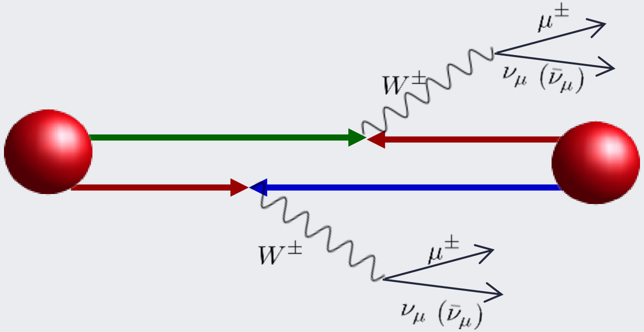


In this channel, the single parton scattering (usually dominant w.r.t to the double one) starts to contribute to higher order in strong coupling constant.

"Same-sign W boson pairs production is a promising channel to look for signature of double Parton interactions at the LHC."

4 Same sign W's production at the LHC

M. R. et al, Phys.Rev. D95 (2017) no.11, 114030



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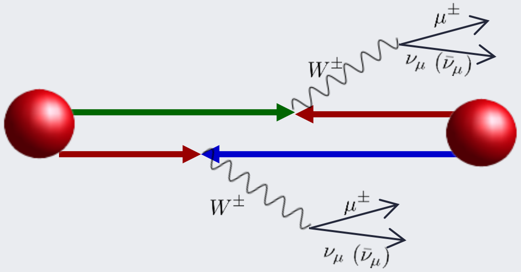
Can double parton correlations be observed for the first time in the next LHC run ?

4 Same sign W's production at the LHC

M. R. et al, Phys.Rev. D95 (2017) no.11, 114030



Kinematical cuts

$pp,\ \sqrt{s} = 13$ TeV
$p_{T,\mu}^{leading} > 20$ GeV, $\quad p_{T,\mu}^{subleading} > 10$ GeV
$\vert p_{T,\mu}^{leading}\vert + \vert p_{T,\mu}^{subleading}\vert > 45$ GeV
$\vert\eta_\mu\vert < 2.4$
20 GeV $< M_{inv} <$ 75 GeV or $M_{inv} >$ 105 GeV

DPS cross section:

$$\frac{d^4\sigma^{pp\to\mu^\pm\mu^\pm X}}{d\eta_1 dp_{T,1} d\eta_2 dp_{T,2}} = \sum_{i,k,j,l} \frac{1}{2} \int d^2\vec{b}_\perp F_{ij}(x_1, x_2, \vec{b}_\perp, M_W) F_{kl}(x_3, x_4, \vec{b}_\perp, M_W) \frac{d^2\sigma_{ik}^{pp\to\mu^\pm X}}{d\eta_1 dp_{T,1}} \frac{d^2\sigma_{jl}^{pp\to\mu^\pm X}}{d\eta_2 dp_{T,2}} \mathcal{I}(\eta_i, p_{T,i})$$

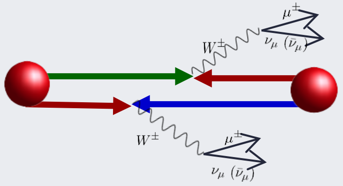
In order to estimate the role of double parton correlations we have used as input of dPDFs:

1) Longitudinal and transverse correlations arise from the relativistic CQM model describing three valence quarks

2) These correlations propagate to sea quarks and gluons through pQCD evolution

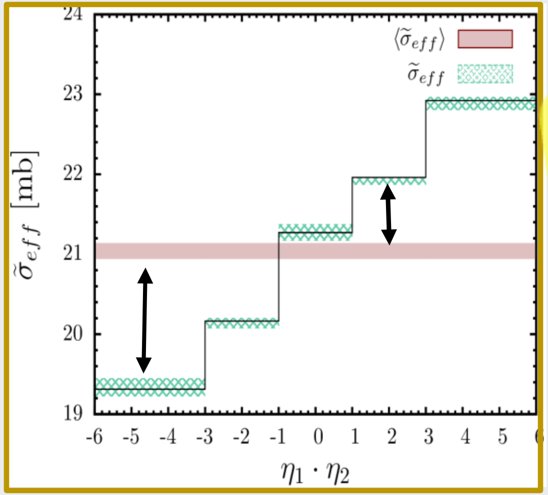
4 Same sign W's production at the LHC

M. R. et al, Phys.Rev. D95 (2017) no.11, 114030



$$\eta_1 \cdot \eta_2 \simeq \frac{1}{4} ln\frac{x_1}{x_3} ln\frac{x_2}{x_4}$$

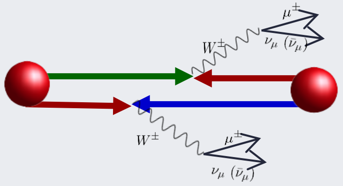
$$\langle\tilde{\sigma}_{eff}\rangle = 21.04 \,{}^{+0.07}_{-0.07}\,(\delta Q_0)\,{}^{+0.06}_{-0.07}(\delta\mu_F)\text{ mb}\,.$$



Difference [↕] between green and red line is due to correlations effects

4 Same sign W's production at the LHC

M. R. et al, Phys.Rev. D95 (2017) no.11, 114030



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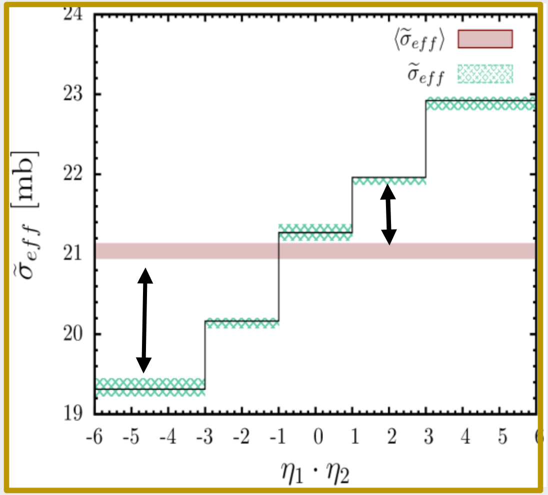


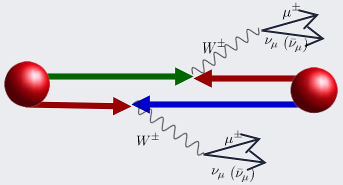
x- dependence of effective x-section
M.Rinaldi et al PLB 752,40 (2016)
M. Traini, M. R. et al, PLB 768, 270 (2017)

Assuming that the results of the first and the last bins can be distinguished if they differ by 1 sigma, we estimated that:

$$\mathcal{L} = 1000\ \mathrm{fb}^{-1}$$

is necessary to observe correlations
* to be updated to new CMS cuts

4 Same sign W's production at the LHC



In Ref. **S. Cotogno et al, JHEP 10 (2020) 214**, it has been shown that several experimental observable are sensitive to **double spin correlations**.

The LHC has the potential to access these new information!

IN THIS CHANNEL, WE ESTABLISHED THE POSSIBILITY TO OBSERVE, FOR THE FIRST TIME, TWO-PARTON CORRELATIONS IN THE NEXT LHC RUN!

M. R. and F. A. Ceccopieri, PRD 97, no. 7, 071501 (2018)

5 Clues from data?

If dPDFs factorize in terms of PDFs then

$$\sigma_{\text{eff}}^{-1} = \int \frac{d^2 k_\perp}{(2\pi)^2} T(k_\perp)^2$$

$T(k_\perp)$ → Effective form factor (EFF)

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M. R. and F. A. Ceccopieri, PRD 97, no. 7, 071501 (2018)

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$$\sigma_{\text{eff}}^{-1} = \int \frac{d^2k_\perp}{(2\pi)^2} T(k_\perp)^2$$

→ Effective form factor (EFF)

EFF can be formally defined as **FIRST MOMENT** of dPDF in momentum space

$$T(k_\perp) \propto \int dx_1 dx_2 \, \tilde{F}(x_1, x_2, k_\perp)$$

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M. R. and F. A. Ceccopieri, PRD 97, no. 7, 071501 (2018)

If dPDFs factorize in terms of PDFs then

$$\sigma_{\mathrm{eff}}^{-1} = \int \frac{d^2k_\perp}{(2\pi)^2} T(k_\perp)^2$$

→ Effective form factor (EFF)

EFF can be formally defined as **FIRST MOMENT** of dPDF in momentum space

$$T(k_\perp) \propto \int dx_1 dx_2 \, \tilde{F}(x_1, x_2, k_\perp)$$

$k_\perp$ is the conjugate variable to $z_\perp$. In analogy with the charge form factor:

$$\langle z_\perp^2 \rangle \propto \frac{d}{k_\perp dk_\perp} T(k_\perp) \Big|_{k_\perp = 0}$$

M. R. and F. A. Ceccopieri, PRD 97, no. 7, 071501 (2018)

5 Clues from data?

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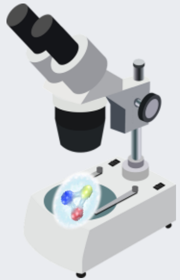
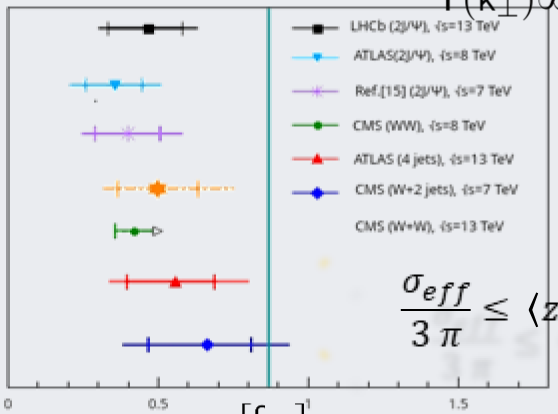


DPS processes:

The vertical line stands for the transverse proton radius



$$\frac{\sigma_{eff}}{3\pi} \leq \langle z^2 \rangle \leq \frac{\sigma_{eff}}{\pi}$$

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M. R. and F. A. Ceccopieri, PRD 97, no. 7, 071501 (2018)

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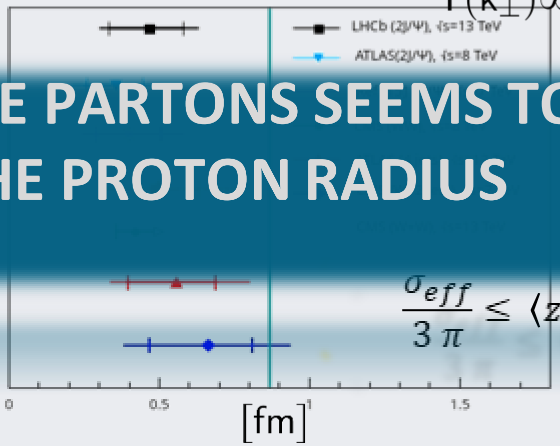
THE DISTANCE OF THESE PARTONS SEEMS TO BE SMALLER THEN THE PROTON RADIUS

transverse proton radius



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M. R. and F. A. Ceccopieri, PRD 97, no. 7, 071501 (2018)

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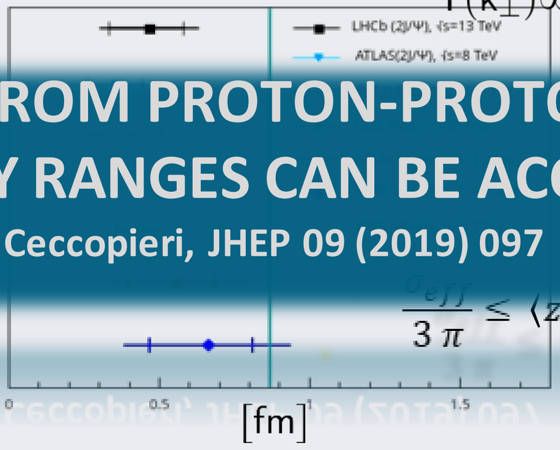


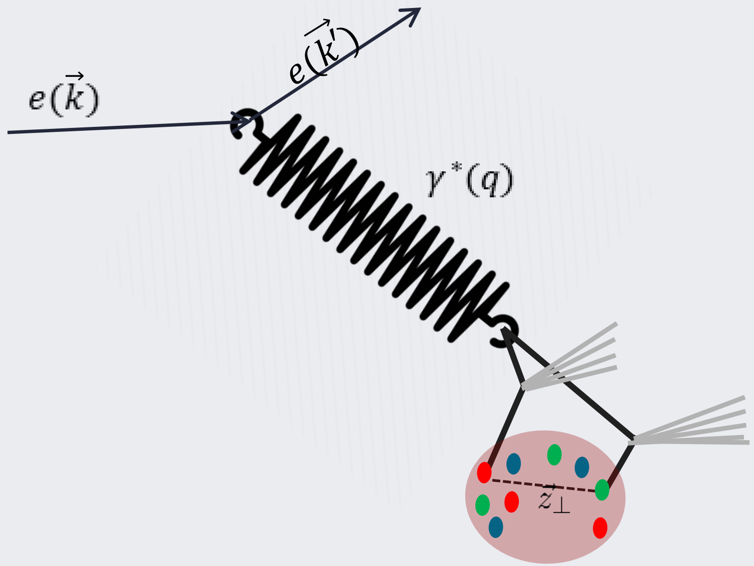
$$\frac{\sigma_{eff}}{3\pi} \le \langle z^2 \rangle \le \ldots$$

HOWEVER FROM PROTON-PROTON COLLISIONS ONLY RANGES CAN BE ACCESSED

M.R. and F. A. Ceccopieri, JHEP 09 (2019) 097

6 New Idea: DPS via γ-p interaction

We consider the possibility offered by a DPS process involving a photon FLACTUATING in a quark-antiquark pair interacting with a proton:



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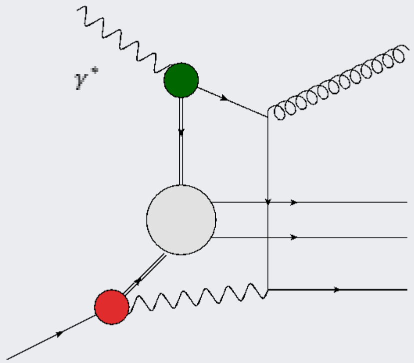
In order to study the impact of the DPS contribution to a process initiated via photon-proton interactions we evaluated the 4-JET photoproduction at HERA **(S. Checkanov et al. (ZEUS), Nucl. Phys B792, 1 (2008))**



In

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It has been shown that the agreement with data improves if MPI are included in the Monte Carlo

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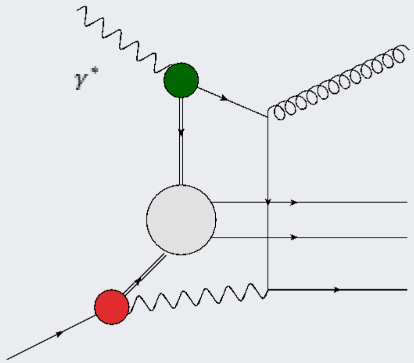

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WE EVALUATE THE DPS CONTRIBUTION TO THIS PROCESS

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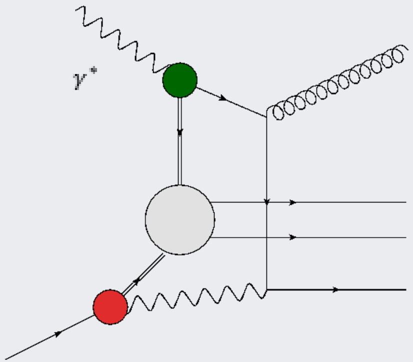

For this first investigation, we make use of the POCKET FORMULA:

$$d\sigma^{4j}_{DPS} = \frac{1}{2}\sum_{ab,cd}\int dy\, dQ^2 \frac{f_{\gamma/e}(y,Q^2)}{\sigma_{eff}^{\gamma p}(Q^2)} \times$$

$$\times \int dx_{p_a} dx_{\gamma_b} f_{a/p}(x_{p_a}) f_{b/\gamma}(x_{\gamma_b}) d\hat{\sigma}^{2j}_{ab}(x_{p_a}, x_{\gamma_b}) \quad \text{SPS*}$$

x

$$\times \int dx_{p_c} dx_{\gamma_d} \underbrace{f_{c/p}(x_{p_c})}_{\text{p-PDF}} \underbrace{f_{d/\gamma}(x_{\gamma_d})}_{\gamma\text{-PDF}} d\hat{\sigma}^{2j}_{cd}(x_{p_c}, x_{\gamma_d}) \quad \text{SPS}$$

Flux Factor: $f_{\gamma/e}(y,Q^2)$ — P. Nason et al, PLB319 339 (1993)

p-PDF (J. Pumplin et al. JHEP 07, 012 (2002))

γ-PDF **(M. Gluck et al. PRD46, 1973 (1992))**

*Single Parton Scattering (SPS)

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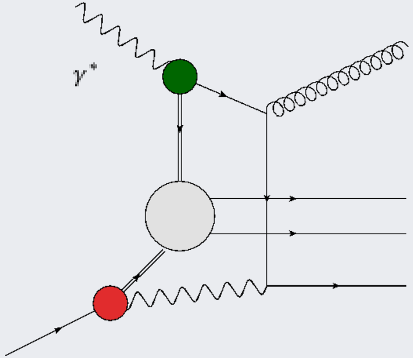

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$$\times \ldots)\, d\hat{\sigma}^{2j}_{ab}(x_{p_a}, x_{\gamma_b})$$ SPS*

x

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Flux Factor
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The main quantity we have to evaluate is:

$$\sigma_{eff}^{\gamma p}(Q^2)$$

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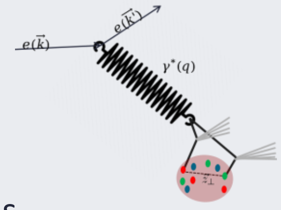
6 The γ-p effective cross section



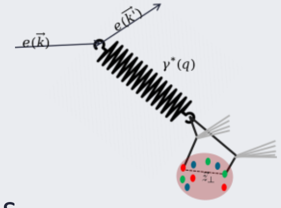
The expression of this quantity is very similar to the proton-proton collision case and can be formally derived by comparing the product of SPS cross sections and the DPS one obtained in **Gaunt, JHEP 01, 042 (2013)** and describing a DPS from a vector bosons splitting with given Q^2 virtuality

Proton EFF

$$\left[\sigma_{\rm eff}^{\gamma p}(Q^2)\right]^{-1} = \int \frac{d^2k_\perp}{(2\pi^2)} \boxed{T_p(k_\perp)} T_\gamma(k_\perp;Q^2)$$

M. R. and F. A. Ceccopieri, arXiv:2103.13480

6 The γ-p effective cross section



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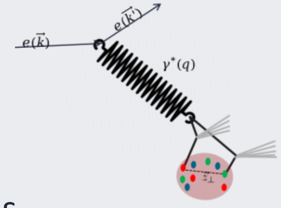

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Proton EFF

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The full DPS cross section depends on the amplitude of the splitting photon in a $q\,\bar{q}$ pair. The latter can be formally described within a Light-Front (LF) approach in terms of LF wave functions.

M. R. and F. A. Ceccopieri, arXiv:2103.13480

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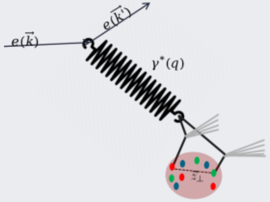

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$T_p(k_\perp)$ proton EFF

2

3 ψ_γ Photon WF

For the proton EFF use has been made of three choices:

M. R. and F. A. Ceccopieri, arXiv:2103.13480

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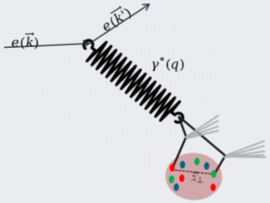

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M. R. and F. A. Ceccopieri, arXiv:2103.13480

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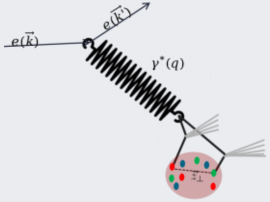

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M. R. and F. A. Ceccopieri, arXiv:2103.13480

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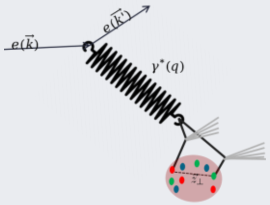

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3) S: $\left(1 + \frac{k_\perp^2}{m_g^2}\right)^{-4}$, $m_g^2 = 1.1 \text{ GeV}^2 \Longrightarrow \sigma_{\rm eff}^{pp} = 30 \text{ mb}$

B. Blok et al, EPJC74, 2926 (2014)

M. R. and F. A. Ceccopieri, arXiv:2103.13480

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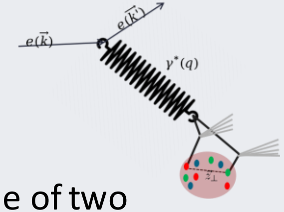

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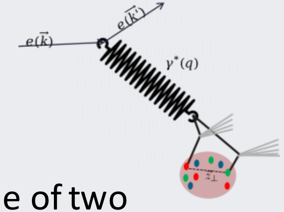
For the photon W.F. use has been made of two choices representing two extreme cases:

1) QED at LO (S.J. Brodsky et al. PRD50, 3134 (1994)):

$$\psi_{q,\bar{q}}^{\lambda=\pm}(x, k_{1\perp}; Q^2) = -e_f \frac{\bar{u}_q(k)\ \gamma \cdot \varepsilon^\lambda\ v_{\bar{q}}(q-k)}{\sqrt{x(1-x)}\left[Q^2 + \frac{k_{1\perp}^2 + m^2}{x(1-x)}\right]}$$

M. R. and F. A. Ceccopieri, arXiv:2103.13480

6 The γ-p effective cross section



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2) Non-Pertubative (NP) effects (E.R.Arriola et al, PRD74,054023 (2006))

$$\psi_A^\gamma(x, k_{\perp 1}; Q^2) = \frac{6(1 + Q^2/m_\rho^2)}{m_\rho^2\left(1 + 4\frac{k_{\perp 1}^2 + Q^2 x(1-x)}{m_\rho^2}\right)^{5/2}}$$

M. R. and F. A. Ceccopieri, arXiv:2103.13480

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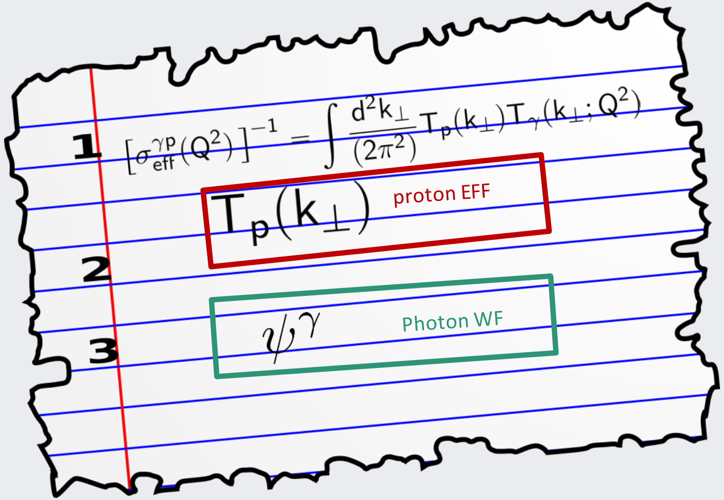

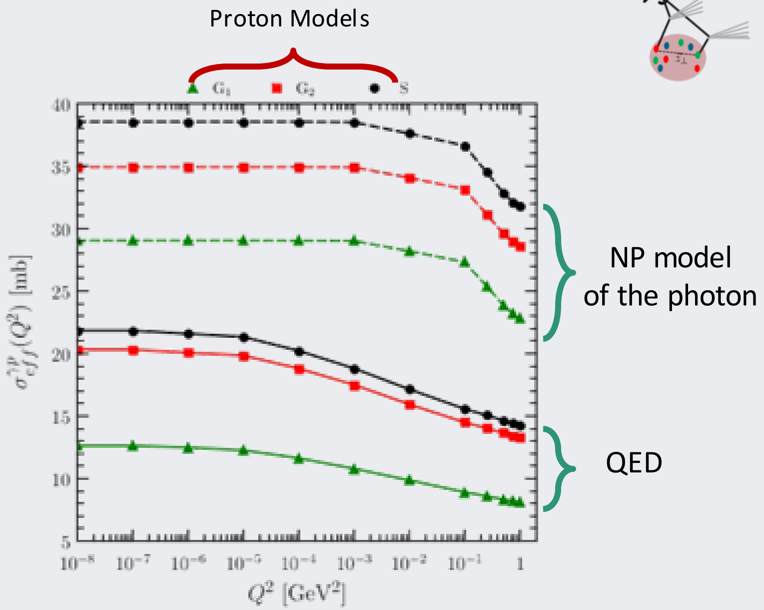

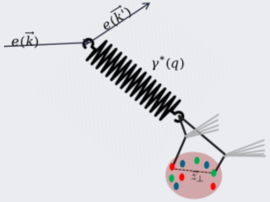

M. R. and F. A. Ceccopieri, arXiv:2103.13480

6 The 4 jet DPS cross section

The HERA KINEMATICS:

S. Checkanov et al. (ZEUS), Nucl. Phys B792, 1 (2008)

$E_T^{jet} > 6\ \mathrm{GeV}$	Transverse energy of the jets
$\lvert\eta_{jet}\rvert < 2.4$	Pseudorapidity
$Q^2 < 1\ \mathrm{GeV}^2$	Photon virtuality
$0.2 \leqslant y \leqslant 0.85$	Inelasticity

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The ZEUS collaboration quoted an integrated total 4-jet cross section of 136 pb
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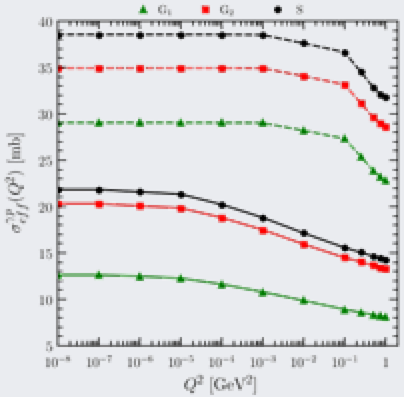

M. R. and F. A. Ceccopieri, arXiv:2103.13480

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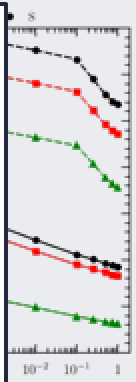
$Q^2 < 1$ GeV

$0.2 \leqslant y \leqslant 0.$

photon	proton	σ_{DPS} [pb] $Q^2 \leq 10^{-2}$ [GeV^2]	$10^{-2} \leq Q^2 \leq 1$ [GeV^2]	$Q^2 \leq 1$ [GeV^2]	$\frac{\sigma_{DPS}}{\sigma_{tot}}$ [%]
NP model	G_1	35.1	18.6	53.7	40
	G_2	29.1	15.2	44.3	33
	S	26.4	13.7	40.1	30
QED	G_1	87.8	54.3	142.1	101
	G_2	54.3	33.4	87.7	65
	S	50.5	31.1	81.6	60



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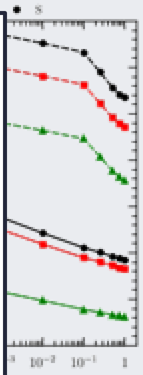

6 The 4 jet DPS cross section

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photon		σ_{DPS} [pb] $Q^2 \leq 1$ [GeV^2]	$\frac{\sigma_{DPS}}{\sigma_{tot}}$ [%]
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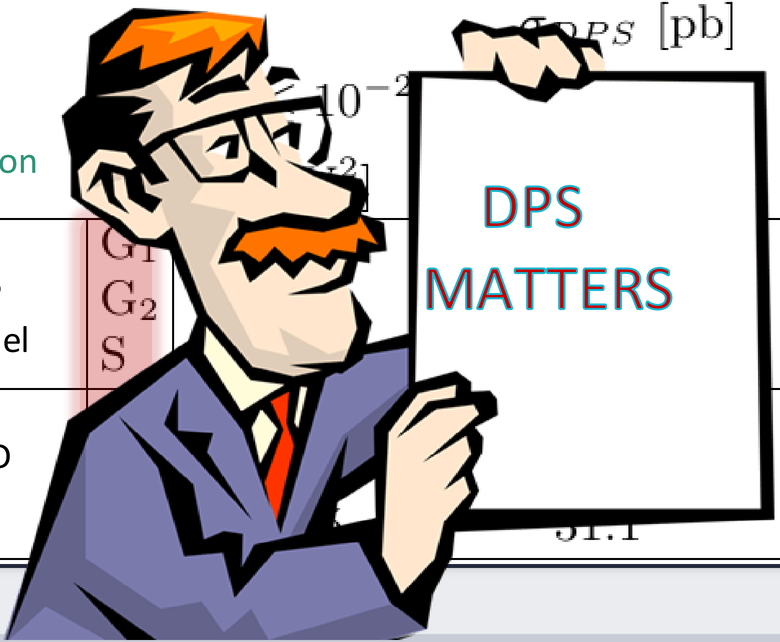
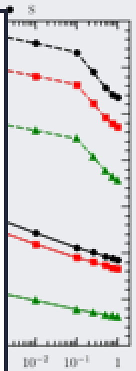
		87.7	65
		81.6	60





6 The 4 jet DPS cross section

KINEMATICS:

$E_T^{jet} > 6$ GeV

$|\eta_{jet}| < 2.4$

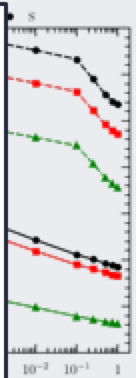
$Q^2 < 1$ GeV

$0.2 \leqslant y \leqslant 0.$

photon			σ_{DPS} [pb] $Q^2 \leq 1$ [GeV^2]	$\frac{\sigma_{DPS}}{\sigma_{tot}}$ [%]
NP model	G_1		…3.7	40
	G_2		44.3	33
	S		40.1	30
QED	G_1		142.1	101
	G_2		87.7	65
	S	50.5	81.6	60

proton

What can we learn about the proton structure?



6 The effective cross section: a key for the proton structure

The effective cross section can be also written in terms of Fourier Transform of the EFF:

$$\tilde{F}(z_\perp)$$

The probability of finding a parton pair at distance

$$z_\perp$$

M. R. and F. A. Ceccopieri, arXiv:2103.13480

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$$\left[\sigma_{eff}^{\gamma p}(Q^2)\right]^{-1} = \int d^2 z_\perp \ \tilde{F}_2^p(z_\perp)\tilde{F}_2^\gamma(z_\perp; Q^2)$$

M. R. and F. A. Ceccopieri, arXiv:2103.13480

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$$\tilde{F}_2^{\gamma}(z_\perp; Q^2) = \sum_n C_n(Q^2) z_\perp^n$$

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$$= \sum_n C_n(Q^2) \langle z_\perp^n \rangle_p$$

M. R. and F. A. Ceccopieri, arXiv:2103.13480

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$$= \sum_n C_n(Q^2) \langle z_\perp^n \rangle_p$$

Mean value on proton states

M. R. and F. A. Ceccopieri, arXiv:2103.13480

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If we can measure the dependence of the effective-cross section on the photon VIRTUALITY

M. R. and F. A. Ceccopieri, arXiv:2103.13480

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This coefficient can be determined from the structure of the photon described in a given approach

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We could access
for the first time
the mean transverse
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M. R. and F. A. Ceccopieri, arXiv:2103.13480

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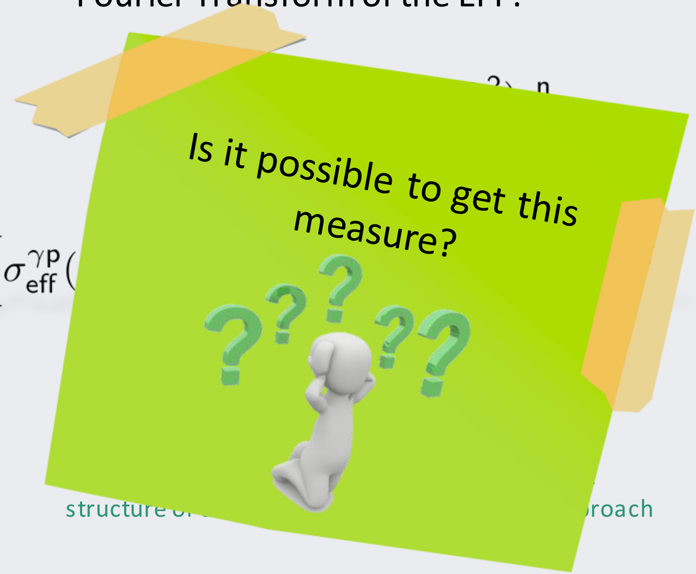

structure o... ...roach

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M. R. and F. A. Ceccopieri, arXiv:2103.13480

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To test if in future a dependence of the effective cross section on the photon virtuality could be observed, we considered again the 4 JET photoproduction:

M. R. and F. A. Ceccopieri, arXiv:2103.13480

6 The effective cross section: a key for the proton structure

To test if in future a dependence of the effective cross section on the photon virtuality could be observed, we considered again the 4 JET photoproduction:

1) We divided the integral of the cross section on Q^2 in two intervals:

$$Q^2 \leqslant 10^{-2} \quad \text{and} \quad 10^{-2} \leqslant Q^2 \leqslant 1 \quad \text{GeV}^2$$

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2) We have estimated for each photon and proton models a constant effective cross section $\bar{\sigma}_{\text{eff}}^{\gamma p}$ (with respect to Q^2) such that the total integral of the cross section on Q^2 reproduce the full calculation obtained by means of $\sigma_{\text{eff}}^{\gamma p}(Q^2)$

M. R. and F. A. Ceccopieri, arXiv:2103.13480

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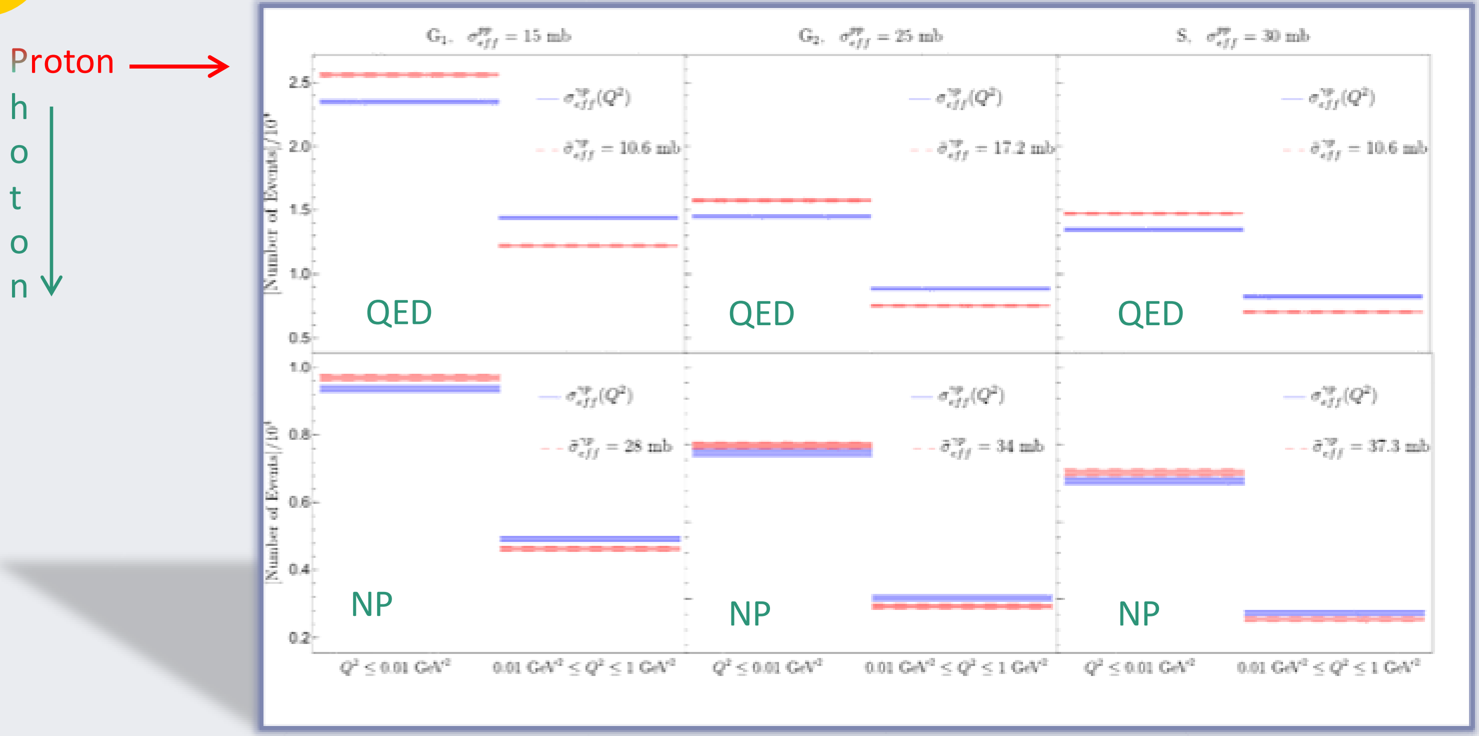
3) We estimate the minimum luminosity to distinguish the two cases

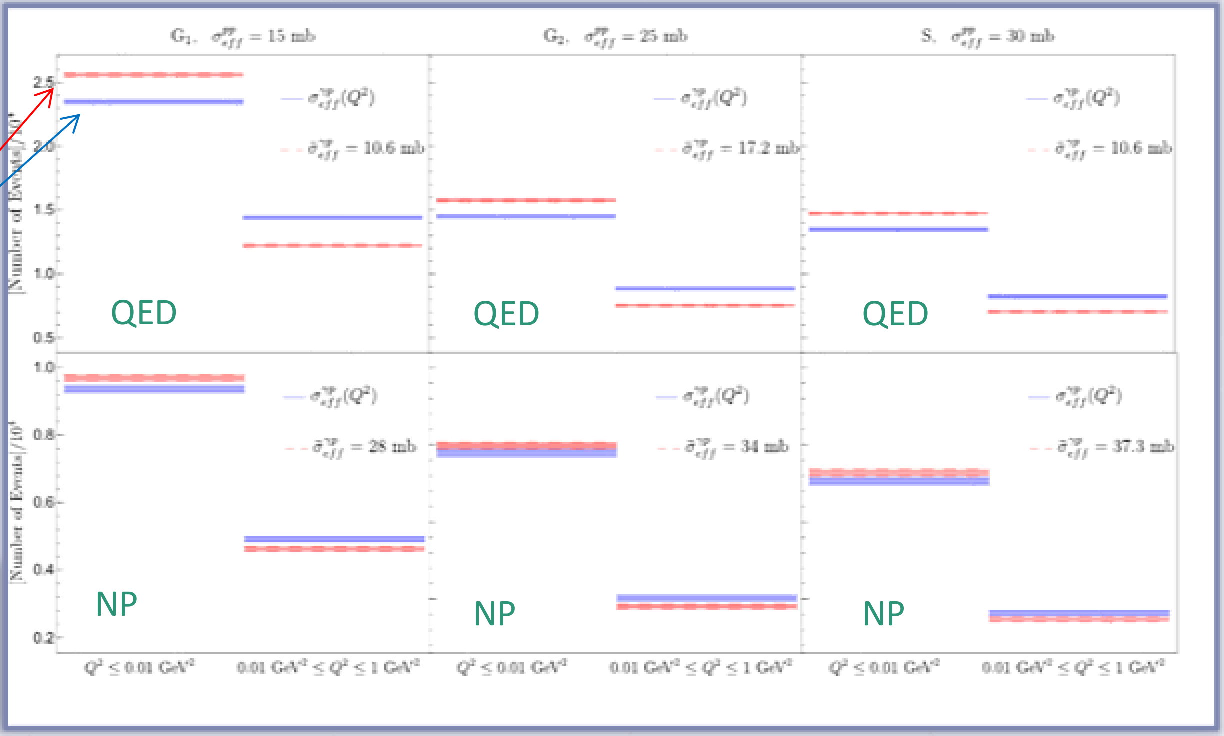
M. R. and F. A. Ceccopieri, arXiv:2103.13480

6 The effective cross section: a key for the proton structure

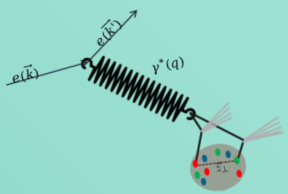


6 The effective cross section: a key for the proton structure

With an integrated luminosity of 200 pb^{-1} we can separate:



CONCLUSIONS



1) We investigated the impact of correlations in DPS proton-proton collisions to learn something new on the parton structure of the proton

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

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

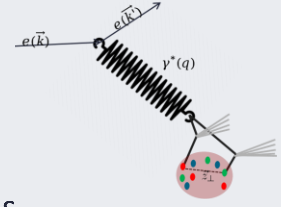
* DPS can contribute also in this case. Cross section of the 4 jet photo production strongly affected

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

* We show that by increasing the luminosity such a dependence can be exposed in future facilities such as the **Electron Ion Collider**

* In the future could be interesting to study other processes with different final states such as those associated to the **QUARKONIUM PRODUCTION**

6 The γ-p effective cross section



The expression of this quantity is very similar to the proton-proton collision case and can be formally derived by comparing the product of SPS cross sections and the DPS one obtained in **Gaunt, JHEP 01, 042 (2013)** and describing a DPS from a vector bosons splitting with given Q^2 virtuality

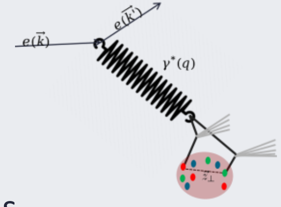
$$\left[\sigma_{\rm eff}^{\gamma p}(Q^2)\right]^{-1} = \int \frac{d^2k_\perp}{(2\pi^2)} T_p(k_\perp) T_\gamma(k_\perp; Q^2)$$

The full DPS cross section depends on the amplitude of the splitting photon in a $q\,\bar{q}$ pair. The latter can be formally described within a Light-Front (LF) approach in terms of LF wave functions (W.F.):

$$f^{\gamma}_{q,\bar{q}}(x, \tilde{k}_\perp; Q^2) = \int d^2k_{\perp,1}\, \psi^{\dagger\gamma}_{q\bar{q}}(x, \vec{k}_{\perp,1}; Q^2) \times \psi^{\gamma}_{q\bar{q}}(x, \vec{k}_{\perp,1} + \vec{k}_\perp; Q^2)$$

M. R. and F. A. Ceccopieri, arXiv:2103.13480

6 The γ-p effective cross section



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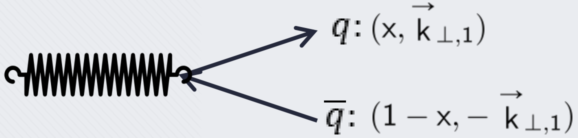
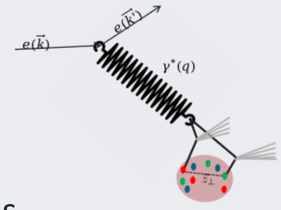


Similar definition of a meson dPDF

M. R. and F. A. Ceccopieri, arXiv:2103.13480

M. R. et al., EPJC78, 781 (2018)

6 The γ-p effective cross section



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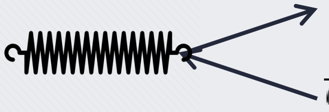
$$T_\gamma(k_\perp; Q^2) = \frac{\sum_q \int dx\, f^\gamma_{q,\bar q}(x, k_\perp; Q^2)}{\sum_q \int dx\, f^\gamma_{q,\bar q}(x, k_\perp = 0; Q^2)}$$

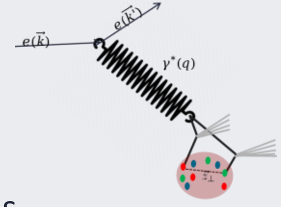


q: $(x, \vec{k}_{\perp,1})$

$\bar{q}$: $(1-x, -\vec{k}_{\perp,1})$

M. R. and F. A. Ceccopieri, arXiv:2103.13480

6 The γ-p effective cross section



The expression of this quantity is very similar to th... ollision case and can be forma... de... sections and the DPS... PS from a

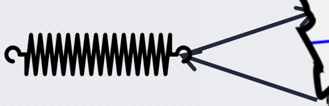
$$[\sigma_{eff}^{\gamma p}(Q^2)]^{-1} = \int \frac{d}{(2} \ldots \int dx\, f_{q,\bar{q}}^{\gamma}(x, k_\perp; Q^2)$$

$$\ldots dx\, f_{q,\bar{q}}^{\gamma}(x, k_\perp = 0; Q^2)$$

$$f_{q,\bar{q}}^{\gamma}(x, \tilde{k}_\perp; Q^2) = \int d^2 \ldots$$

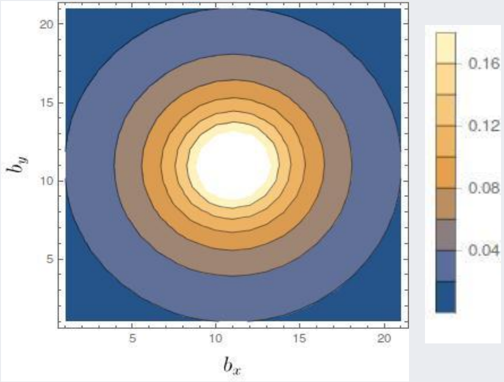
INGREDIENTS OF THE CALCULATION:

1. $T_p(k_\perp)$ proton EFF
2. ψ^γ Photon WF
3.



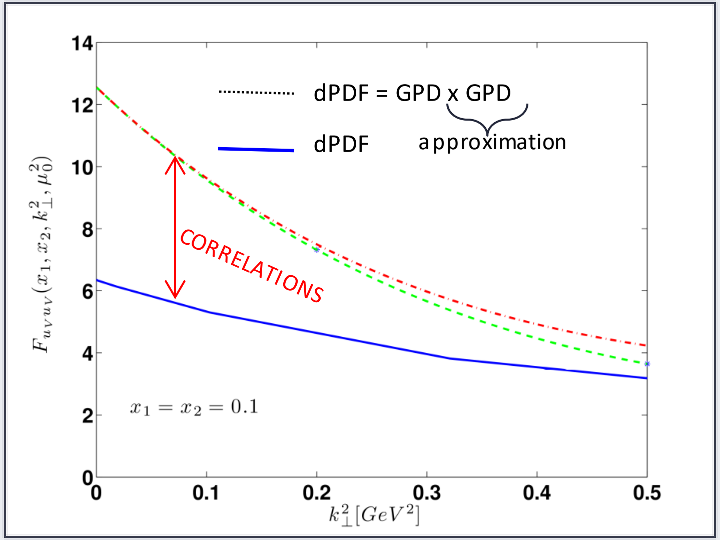
M. R. and F. A. Ceccopieri, arXiv:2103.13480

2 Information from Quark Models



M.R. and F. A. Ceccopieri, JHEP 09 (2019) 097

1) e.g. the distance distribution of two gluons in the proton



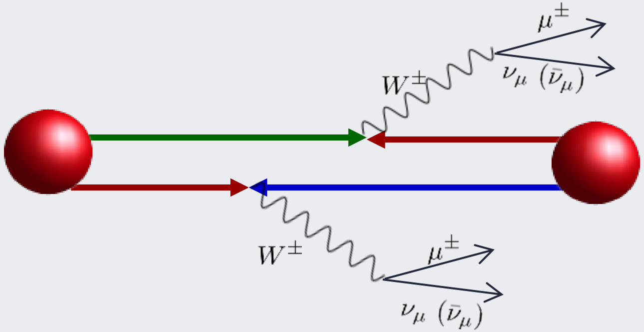
2) Correlations are important

M.R., S. Scopetta et al, JHEP 10 (2016) 063

M.R. and F. A. Ceccopieri PRD 95 (2017) 034040

4 Same sign W's production at the LHC

M. R. et al, Phys.Rev. D95 (2017) no.11, 114030



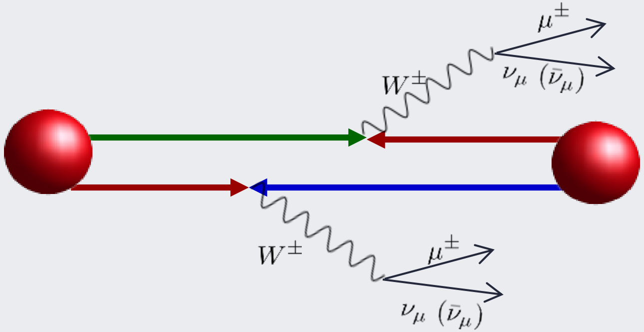
In this channel, the single parton scattering (usually dominant w.r.t to the double one) starts to contribute to higher order in strong coupling constant.

⬇

"Same-sign W boson pairs production is a promising channel to look for signature of double Parton interactions at the LHC."

4 Same sign W's production at the LHC

M. R. et al, Phys.Rev. D95 (2017) no.11, 114030



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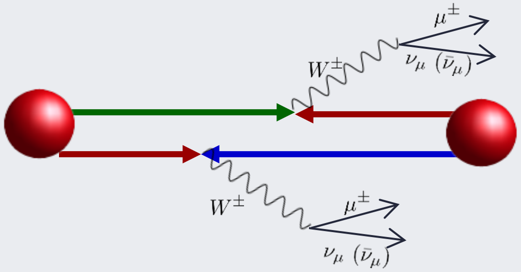
Can double parton correlations be observed for the first time in the next LHC run ?

4 Same sign W's production at the LHC

M. R. et al, Phys.Rev. D95 (2017) no.11, 114030



Kinematical cuts

$pp,\ \sqrt{s} = 13$ TeV
$p_{T,\mu}^{leading} > 20$ GeV, $\quad p_{T,\mu}^{subleading} > 10$ GeV
$\lvert p_{T,\mu}^{leading}\rvert + \lvert p_{T,\mu}^{subleading}\rvert > 45$ GeV
$\lvert\eta_\mu\rvert < 2.4$
20 GeV $< M_{inv} <$ 75 GeV or $M_{inv} >$ 105 GeV

DPS cross section:

$$\frac{d^4\sigma^{pp\to\mu^\pm\mu^\pm X}}{d\eta_1 dp_{T,1} d\eta_2 dp_{T,2}} = \sum_{i,k,j,l} \frac{1}{2} \int d^2\vec{b}_\perp F_{ij}(x_1, x_2, \vec{b}_\perp, M_W) F_{kl}(x_3, x_4, \vec{b}_\perp, M_W) \frac{d^2\sigma_{ik}^{pp\to\mu^\pm X}}{d\eta_1 dp_{T,1}} \frac{d^2\sigma_{jl}^{pp\to\mu^\pm X}}{d\eta_2 dp_{T,2}} \mathcal{I}(\eta_i, p_{T,i})$$

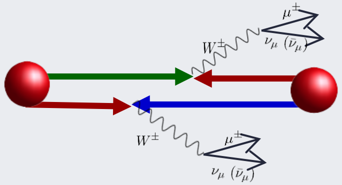
In order to estimate the role of double parton correlations we have used as input of dPDFs:

1) Longitudinal and transverse correlations arise from the relativistic CQM model describing three valence quarks

2) These correlations propagate to sea quarks and gluons through pQCD evolution

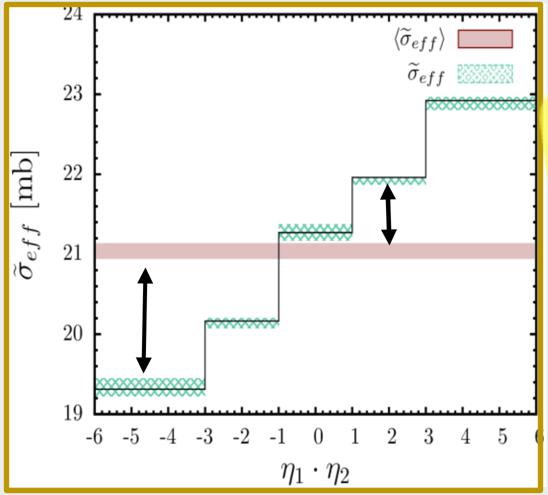
4 Same sign W's production at the LHC

M. R. et al, Phys.Rev. D95 (2017) no.11, 114030



$$\eta_1 \cdot \eta_2 \simeq \frac{1}{4} ln \frac{x_1}{x_3} ln \frac{x_2}{x_4}$$

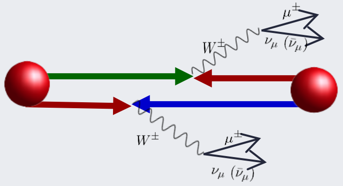
$$\langle \tilde{\sigma}_{eff} \rangle = 21.04 \ ^{+0.07}_{-0.07} (\delta Q_0) \ ^{+0.06}_{-0.07} (\delta \mu_F) \text{ mb} .$$



Difference [↕] between green and red line is due to correlations effects

4 Same sign W's production at the LHC

M. R. et al, Phys.Rev. D95 (2017) no.11, 114030



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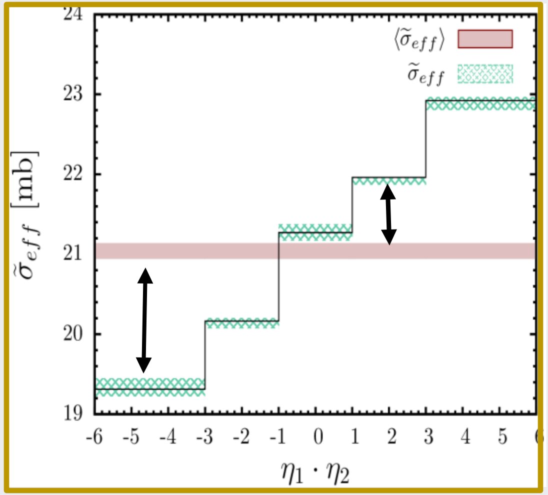


x- dependence of effective x-section

M.Rinaldi et al PLB 752,40 (2016)

M. Traini, M. R. et al, PLB 768, 270 (2017)

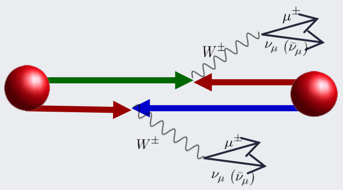
Assuming that the results of the first and the last bins can be distinguished if they differ by 1 sigma, we estimated that:

$$\mathcal{L} = 1000\ \text{fb}^{-1}$$

is necessary to observe correlations

* to be updated to new CMS cuts

4 Same sign W's production at the LHC

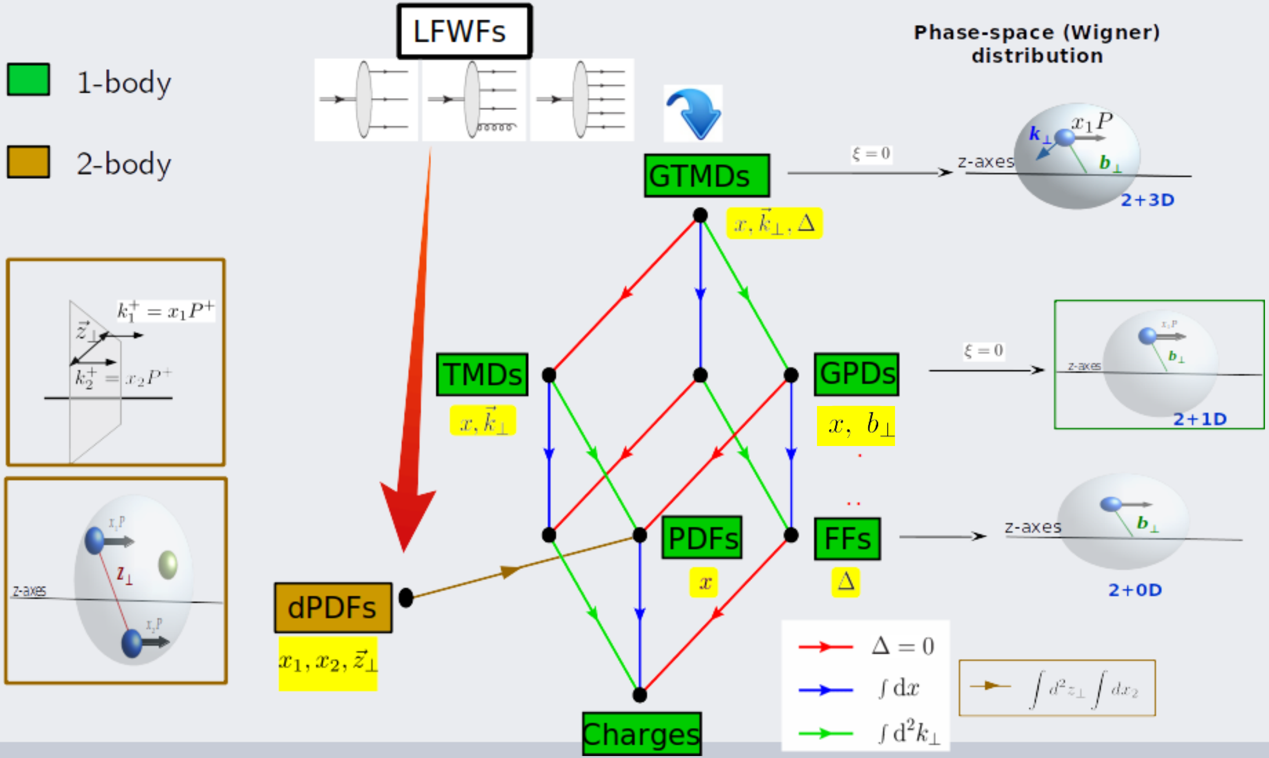


In Ref. **S. Cotogno et al, JHEP 10 (2020) 214**, it has been shown that several experimental observable are sensitive to **double spin correlations**.

The LHC has the potential to access these new information!

IN THIS CHANNEL, WE ESTABLISHED THE POSSIBILITY TO OBSERVE, FOR THE FIRST TIME, TWO-PARTON CORRELATIONS IN THE NEXT LHC RUN!

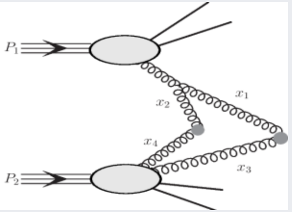
2 Multidimensional Pictures of Hadron



4 Further implementations

Relevant for processes involving heavy particles is the splitting term (1v2 mechanism) i.e.:

$^*D_{j_1,j_2}(x_1,x_2) = \int d^2b_\perp \tilde{F}_{j_1,j_2}(x_1,x_2,b_\perp)$

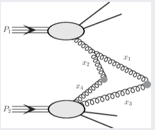


In pQCD evolution:
$$\frac{dD_{j_1j_2}(x_1,x_2;t)}{dt} = \begin{cases} \text{Homogeneous term (double DGLAP)} \\ + \\ \sum_{j'} F_{j'}(x_1+x_2;t) \underbrace{\frac{1}{x_1+x_2} P_{j'\to j_1j_2}}\left(\frac{x_1}{x_1+x_2}\right) \end{cases}$$

Gaunt J.R. and Stirling W. J., JHEP 03 (2010)

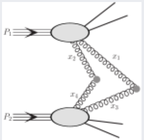
SPLITTING TERM

1v2



\+

2v2



$$\frac{\sigma_{eff}}{3\pi}\left(1+\frac{3}{2}r_v\right) \le \langle b^2\rangle \le \frac{\sigma_{eff}}{\pi}\left(1+2r_v\right)$$

$$r_v \sim \frac{F^{splitting}_{j_1j_2}(x_1,x_2,k_\perp=0;t)}{F_{j_1j_2}(x_1,x_2,k_\perp=0;t)}$$

with:
$0 \le r_v \le 1$

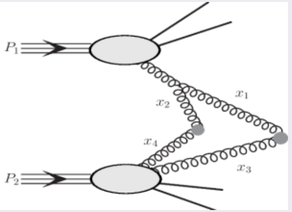
J.R. Gaunt, R. Maciula and A. Szczurek, PRD 90 (2014) 054017

Due to the difficulty in the estimate of the 2 contributions:

Absolute minimum $r_v = 0$ $$\frac{\sigma_{eff}}{3\pi} \le \langle b^2\rangle \le \frac{3\,\sigma_{eff}}{\pi}$$ Absolute maximum $r_v = 1$

4 Further implementations

Relevant for processes involving heavy particles is the splitting term (1v2 mechanism) i.e.:



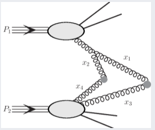
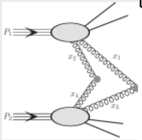
In p

Gaun

$) = \int d^2b_\perp \tilde{F}_{j_1,j_2}(x_1, x_2, b_\perp)$

DGLAP)

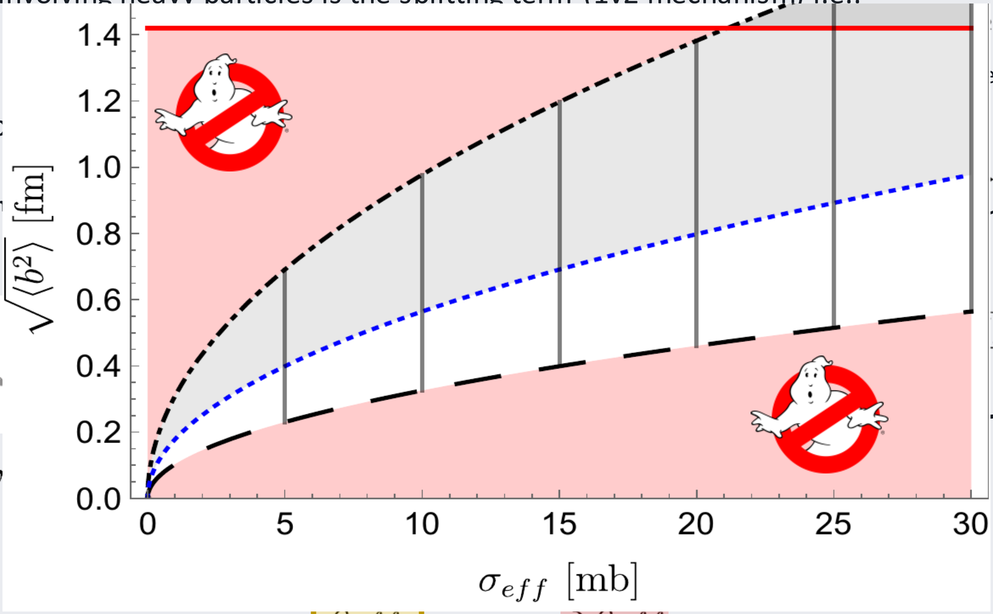
$_{j_1 j_2}\left(\frac{x_1}{x_1+x_2}\right)$

1v2  + 2v2 

$\frac{^{splitting}_{j_1 j_2}(x_1, x_2, k_\perp = 0; t)}{F_{j_1 j_2}(x_1, x_2, k_\perp = 0; t)}$

with:

$0 \le r_v \le 1$



1) Minimum as function of r_v

$$m(r_v)$$

2) Maximum as function of r_v

$$M(r_v)$$

Absolute minimum $r_v = 0$ $\frac{\sigma_{eff}}{3\pi} \le \langle b^2 \rangle \le \frac{3\,\sigma_{eff}}{\pi}$ Absolute maximum $r_v = 1$

4 Further implementations

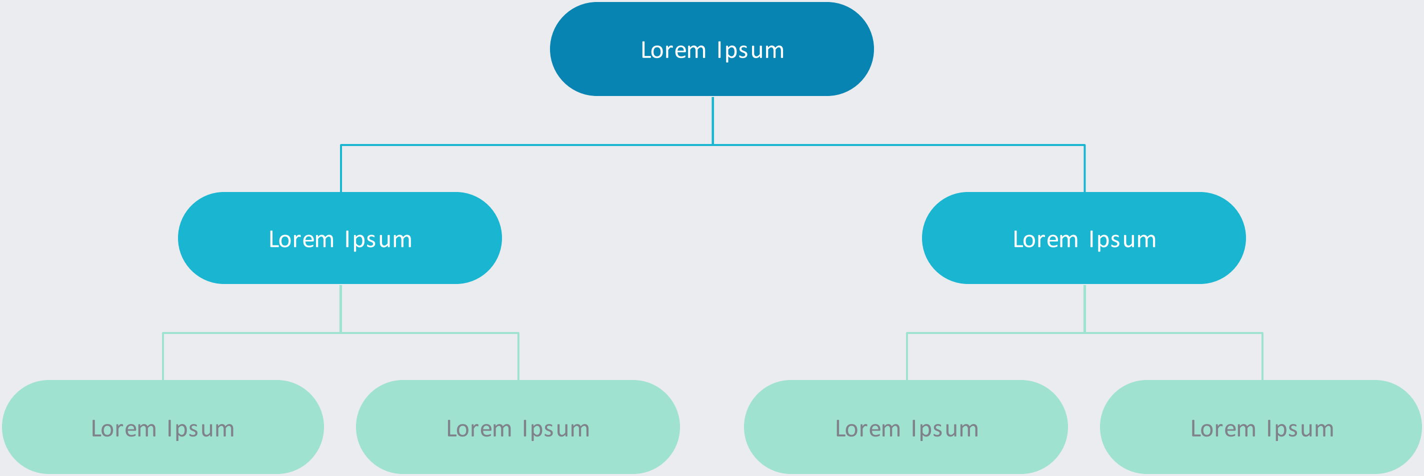
IF WE DO NOT CONSIDER ANY FACTORIZATION ANSATZ IN DOUBLE PDFs:

$$\frac{\sigma_{eff}(x_1,x_2)}{3\pi}\left[r^{2v2}(x_1,x_2)^2+\frac{3}{2}r^{2v1}(x_1,x_2)^2\ r_v\right]\leq \langle b^2\rangle_{x_1,x_2}\leq \frac{\sigma_{eff}(x_1,x_2)}{\pi}\left[r^{2v2}(x_1,x_2)^2+2r^{2v1}(x_1,x_2)^2\ r_v\right]$$

$$r^{2v2}(x_1,x_2)=\frac{F(x_1,x_2,k_\perp=0;t)}{F(x_1;t)F(x_2;t)}$$

$$r^{2v1}(x_1,x_2)=\frac{F^{splitting}(x_1,x_2,k_\perp=0;t)}{F(x_1;t)F(x_2;t)}$$

Use diagrams to explain your ideas



Our process is easy

Vestibulum congue tempus

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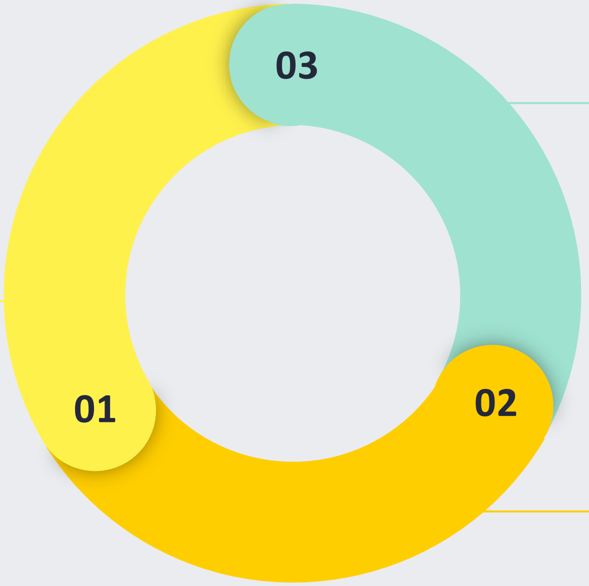

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Vestibulum congue tempus

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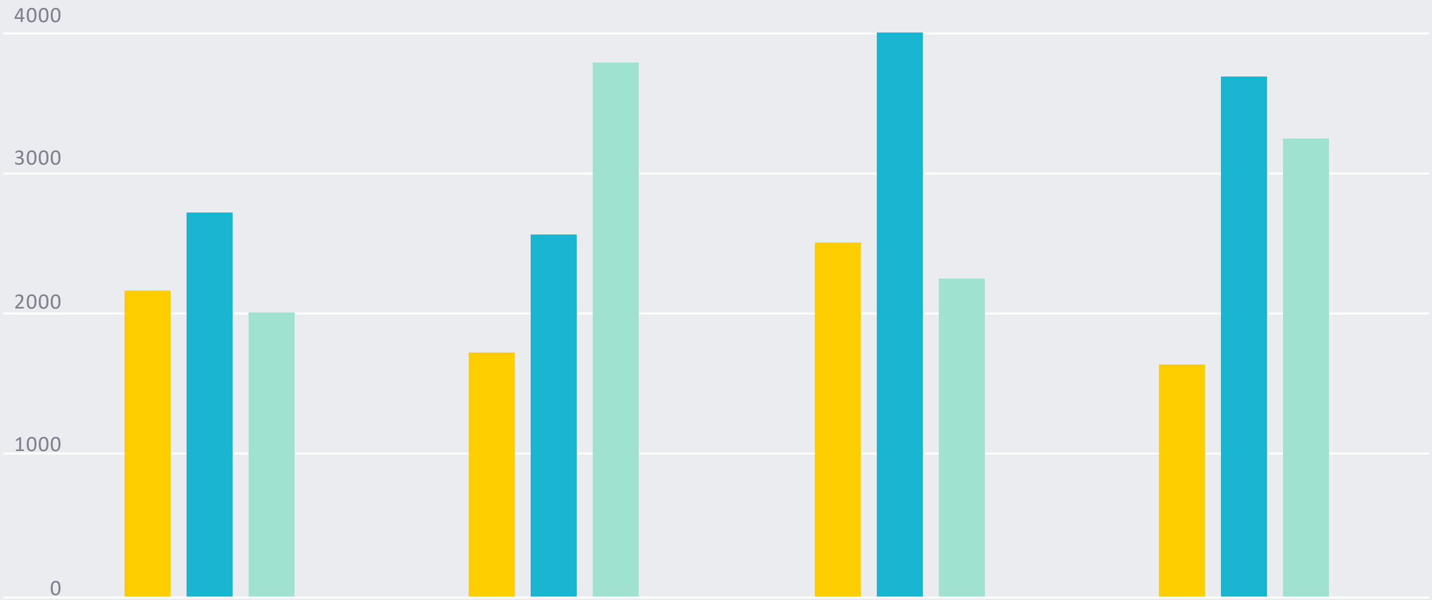

You can insert graphs from Excel or Google Sheets

Desktop project

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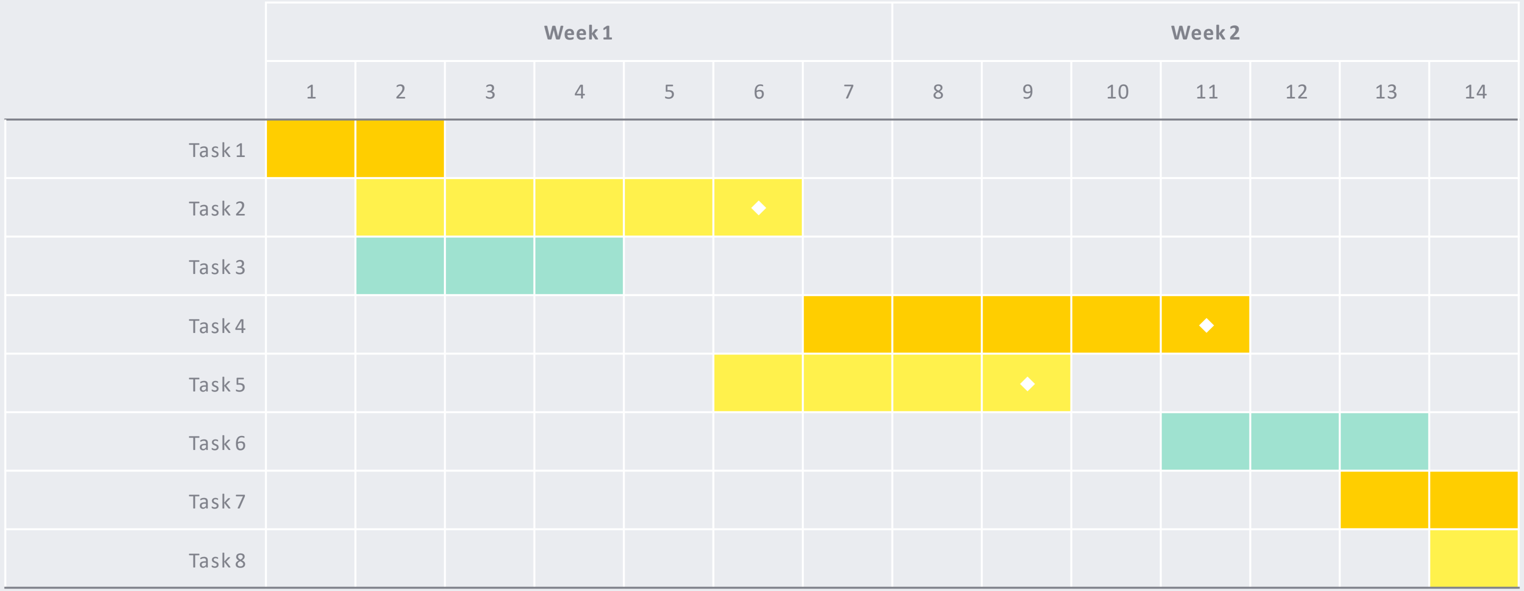
Timeline

- JAN: Blue is the colour of the clear sky and the deep sea
- FEB: Yellow is the color of gold, butter and ripe lemons
- MAR: Red is the colour of danger and courage
- APR: White is the color of milk and fresh snow
- MAY: Black is the color of ebony and of outer space
- JUN: Blue is the colour of the clear sky and the deep sea
- JUL: Yellow is the color of gold, butter and ripe lemons
- AUG: Red is the colour of danger and courage
- SEP: White is the color of milk and fresh snow
- OCT: Black is the color of ebony and of outer space
- NOV: Blue is the colour of the clear sky and the deep sea
- DEC: Yellow is the color of gold, butter and ripe lemons

Gantt chart



Week 1
Week 2
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Task 1
Task 2
Task 3
Task 4
Task 5
Task 6
Task 7
Task 8

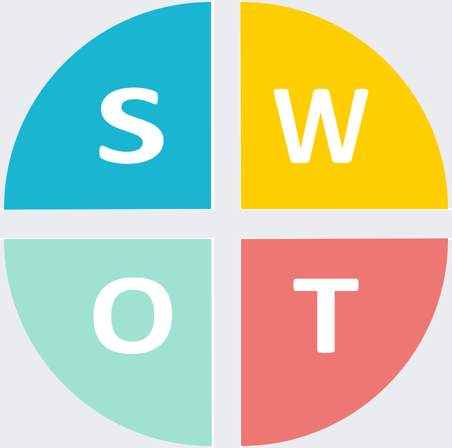
SWOT Analysis

STRENGTHS

Blue is the colour of the clear sky and the deep sea

WEAKNESSES

Yellow is the color of gold, butter and ripe lemons



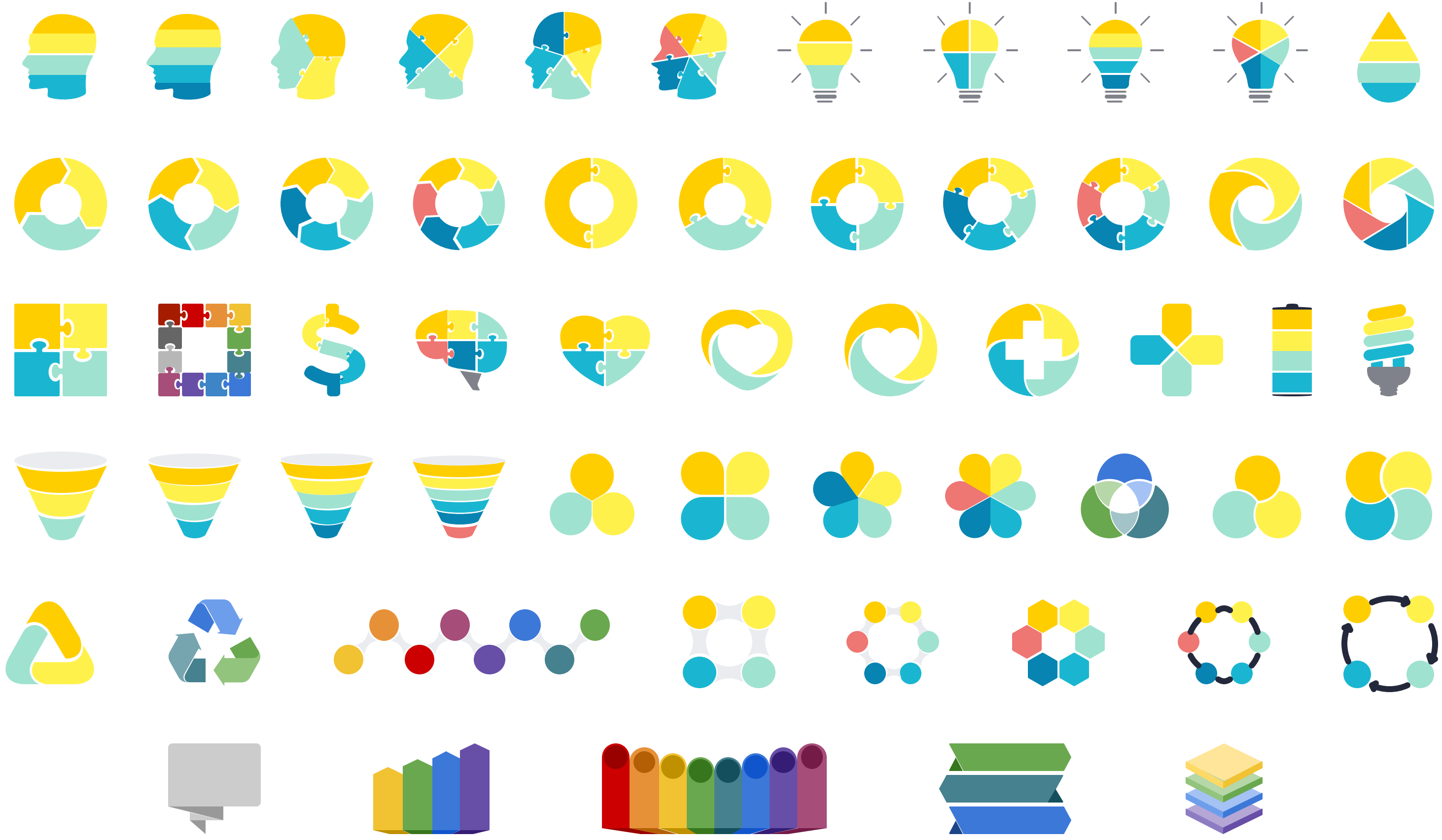
Black is the color of ebony and of outer space

OPPORTUNITIES

White is the color of milk and fresh snow

THREATS

Diagrams and infographics



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