double parton scattering

12^{th} MPI at LHC

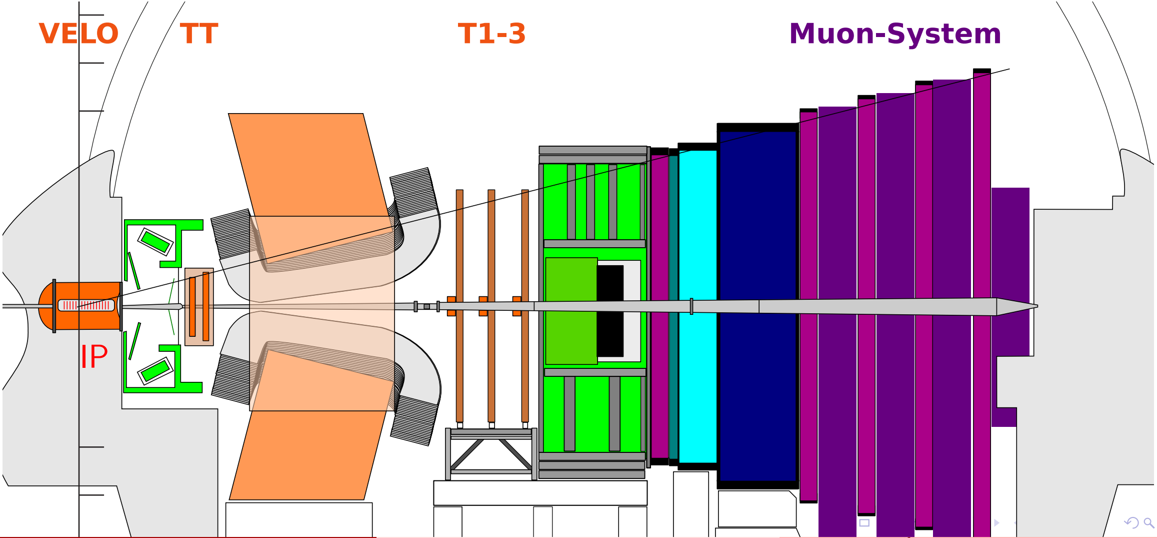
LIP Lisbon, Portugal

Albert Frithjof Bursche
South China Normal University
on behalf of the LHCb Collaboration

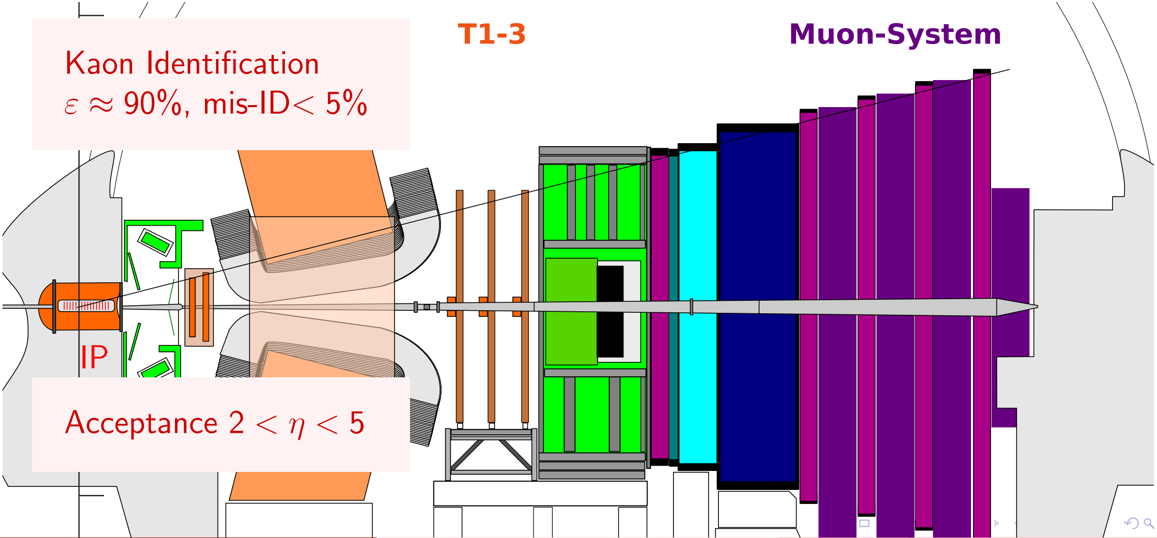
10^{th} October 2021

Experimental Setup

LHCb Experiment



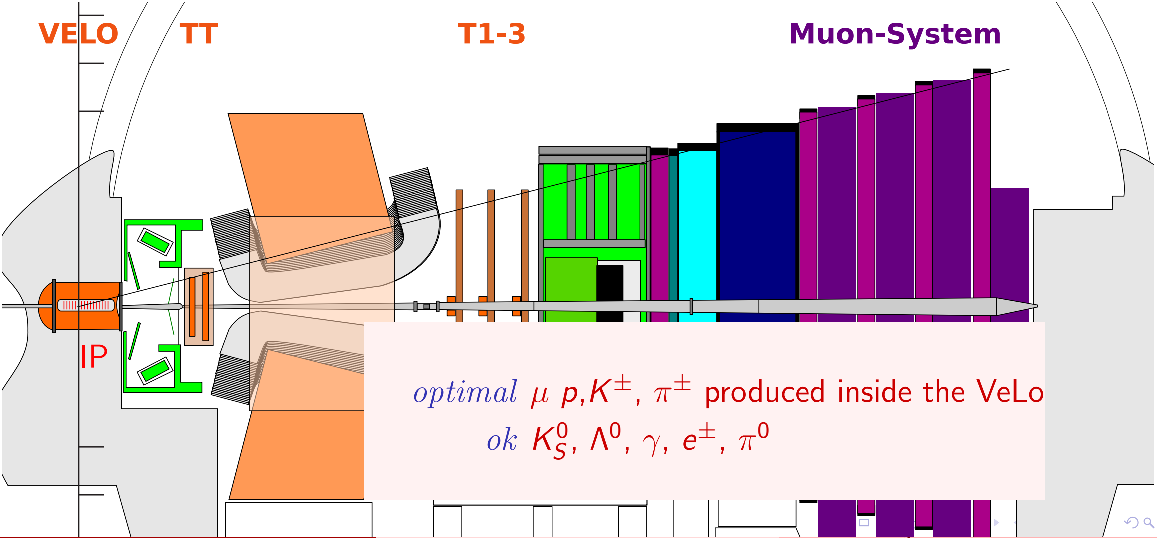
LHCb Experiment



Kaon Identification
$\varepsilon \approx 90\%$, mis-ID$< 5\%$

Acceptance $2 < \eta < 5$

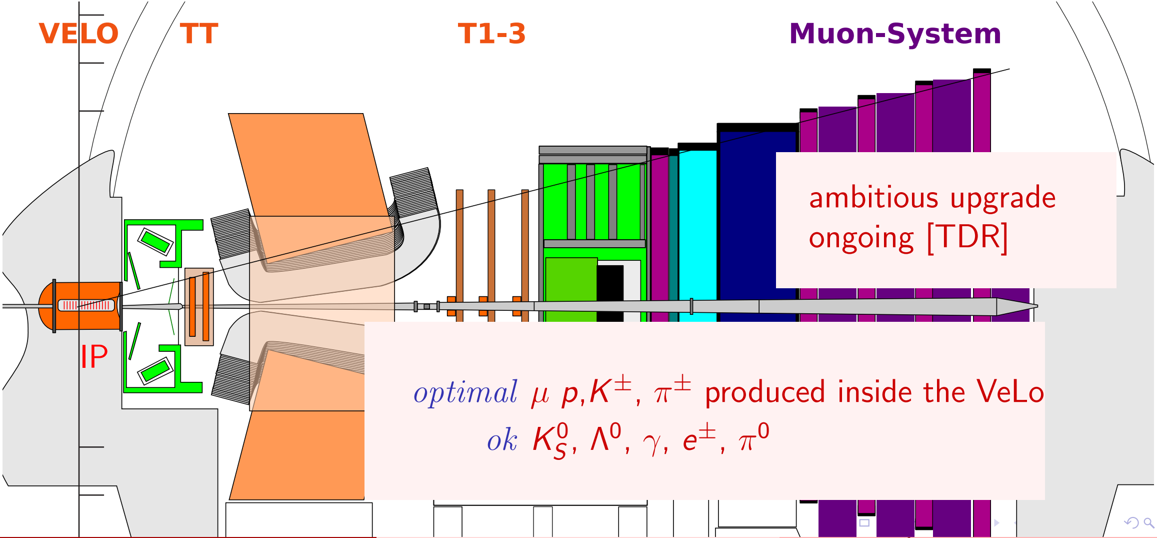
LHCb Experiment



optimal μ p, $K^{\pm}$, $\pi^{\pm}$ produced inside the VeLo

ok K_S^0, Λ^0, γ, $e^{\pm}$, π^0

LHCb Experiment



ambitious upgrade ongoing [TDR]

optimal μ $p, K^{\pm}$, $\pi^{\pm}$ produced inside the VeLo

ok K_S^0, Λ^0, γ, $e^{\pm}$, π^0

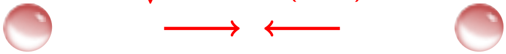
Analysis

double parton scattering in proton proton collisions

protons

protons

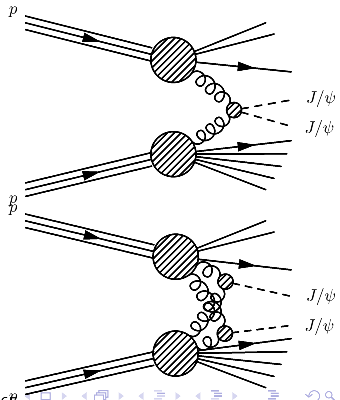
$$\sqrt{s_{NN}} = \mathcal{O}(\mathrm{TeV})$$



experimentalists view on theory

$$\sigma_{AB} = \frac{m}{2} \sum_{i,j,k,l} \int \mathrm{d}\, t \,\mathrm{d}\, x_1 \,\mathrm{d}\, x_2 \,\mathrm{d}\, x_1' \,\mathrm{d}\, x_2' \,\mathrm{d}^2\, b\; \Gamma_{i,j}(x_1, x_2, b, t_1, t_2) \Gamma_{k,l}(x_1', x_2', b, t_1, t_2) \hat{\sigma}_{ik}(x_1, x_1') \hat{\sigma}_{jl}(x_2, x_2')$$

assumptions and approximations



Formulas from J.R. Gaunt, C-H. Kom, A. Kulesza, W. J. Stirling arχiv:1003.3953, Eur.Phys.J.C 69 (2010) 53-65

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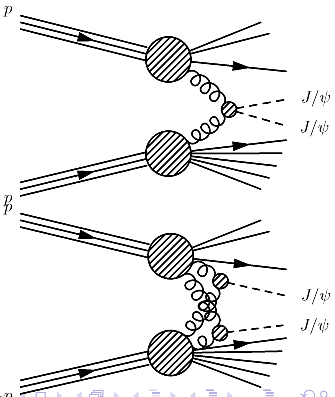
assumptions and approximations

- double pdf dependency on impact parameter factorizes $\Gamma_{i,j}(x_1,x_2,b,t_1,t_2) = D_p^{ij}(x_1,x_2,t_1,t_2)F_i^j(b)$ allows to define $\sigma_{\text{eff}}^{-1} = \int \mathrm{d}^2\,bF_i^j(b)$



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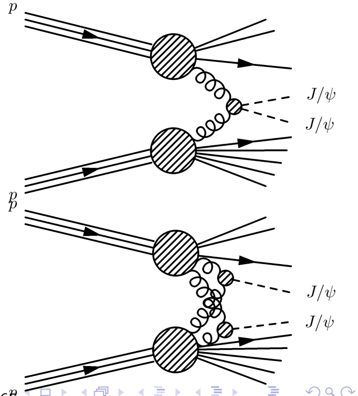
- factorisation of the parton properties $t_1 = t_2 = t$ and $D_h^{i,j} = D^i D^j$ allows the integral to be calculated and yields full factorisation
  $\sigma_{AB} = \frac{m}{2} \frac{\sigma_A \sigma_B}{\sigma_{\text{eff}}} \quad \Rightarrow \sigma_{\text{eff}} = \frac{m}{2} \frac{\sigma_A \sigma_B}{\sigma_{AB}}$



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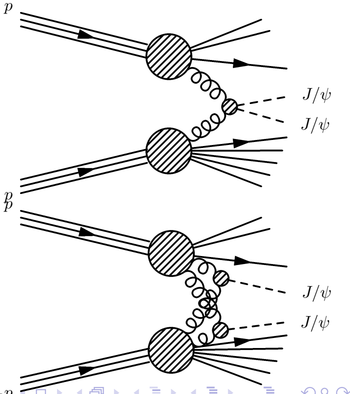

assumptions and approximations

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$$\sigma_{AB} = \frac{m}{2\sigma_{\text{eff}}} \sum_{i,k} \int \mathrm{d}\,t\,\mathrm{d}\,x_1\,\mathrm{d}\,x_1'\; D_p^i(x_1,t) D_p^k(x_1',t)\hat{\sigma}_{ik}(x_1,x_1') \sum_{j,l} \int \mathrm{d}\,x_2\,\mathrm{d}\,x_2' D_p^j(x_2,t) D_p^l(x_2',t)\hat{\sigma}_{jl}(x_2,x_2')$$

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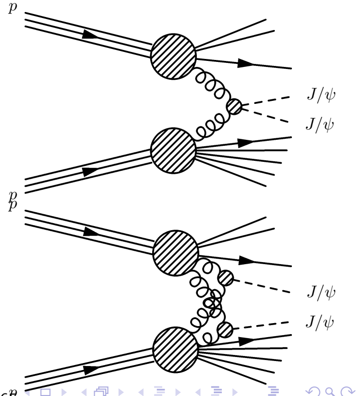
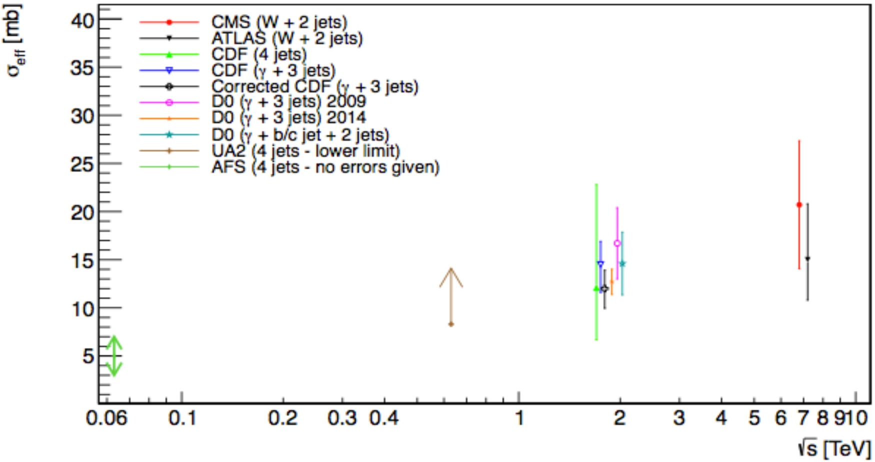


Formulas from J.R. Gaunt, C-H. Kom, A. Kulesza, W. J. Stirling arχiv:1003.3953, Eur.Phys.J.C 69 (2010) 53-65

effective cross section

a surprisingly simple model approximately holds over a large variety of processes and energies



effective cross section - cont.

[1] Morad Aaboud et al. "Measurement of the prompt J/ ψ pair production cross-section in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector". In: *Eur. Phys. J. C* 77.2 (2017), p. 76. DOI: 10.1140/epjc/s10052-017-4644-9. arXiv: 1612.02950 [hep-ex].

[2] Roel Aaij et al. "Measurement of the J/ψ pair production cross-section in pp collisions at $\sqrt{s} = 13$ TeV". In: *JHEP* 06 (2017). [Erratum: JHEP 10, 068 (2017)], p. 047. DOI: 10.1007/JHEP06(2017)047. arXiv: 1612.07451 [hep-ex].

[3] Roel Aaij et al. "Observation of double charm production involving open charm in pp collisions at $\sqrt{s} = 7$ TeV". In: *JHEP* 06 (2012). [Addendum: JHEP 03, 108 (2014)], p. 141. DOI: 10.1007/JHEP06(2012)141. arXiv: 1205.0975 [hep-ex].

[4] Roel Aaij et al. "Production of associated Y and open charm hadrons in pp collisions at $\sqrt{s} = 7$ and 8 TeV via double parton scattering". In: *JHEP* 07 (2016), p. 052. DOI: 10.1007/JHEP07(2016)052. arXiv: 1510.05949 [hep-ex].

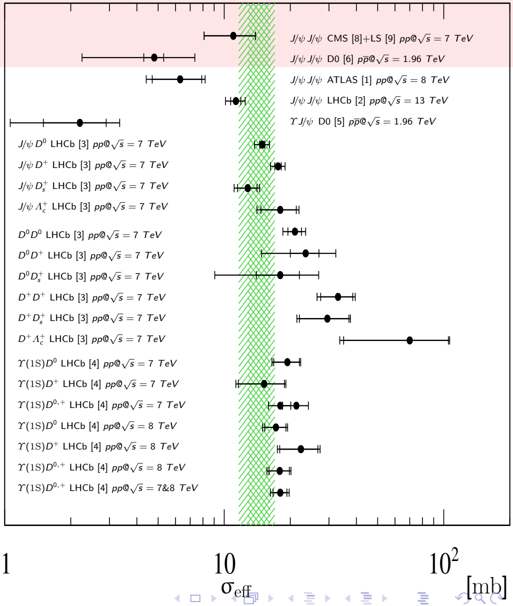
[5] Victor Mukhamedovich Abazov et al. "Evidence for simultaneous production of J/ψ and Υ mesons". In: *Phys. Rev. Lett.* 116.8 (2016), p. 082002. DOI: 10.1103/PhysRevLett.116.082002. arXiv: 1511.02428 [hep-ex].

[6] Victor Mukhamedovich Abazov et al. "Observation and Studies of Double J/ψ Production at the Tevatron". In: *Phys. Rev. D* 90.11 (2014), p. 111101. DOI: 10.1103/PhysRevD.90.111101. arXiv: 1406.2380 [hep-ex].

[7] F. Abe et al. "Double parton scattering in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$TeV". In: *Phys. Rev. D* 56 (1997), pp. 3811–3832. DOI: 10.1103/PhysRevD.56.3811.

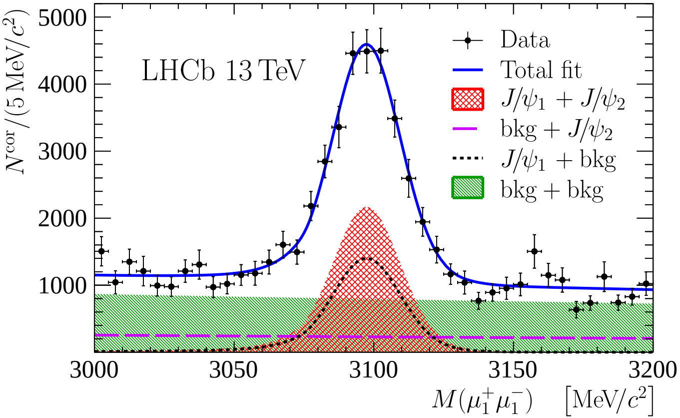
[8] Vardan Khachatryan et al. "Measurement of Prompt J/ψ Pair Production in pp Collisions at $\sqrt{s} = 7$ Tev". In: *JHEP* 09 (2014), p. 094. DOI: 10.1007/JHEP09(2014)094. arXiv: 1406.0484 [hep-ex].

[9] Jean-Philippe Lansberg and Hua-Sheng Shao. "J/ψ -pair production at large momenta: Indications for double parton scatterings and large α_s^5 contributions". In: *Phys. Lett. B* 751 (2015), pp. 479–486. DOI: 10.1016/j.physletb.2015.10.083. arXiv: 1410.8822 [hep-ph].



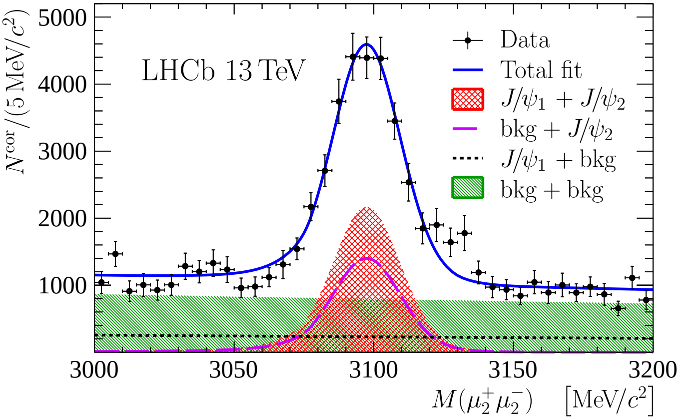
The hatched area shows the reference value [7] of $\sigma_{\text{eff}} = 14.5 \pm 1.7^{+1.7}_{-2.3}$ mb measured in multi-jet events at the Tevatron.

double J/ψ production - mass



JHEP 1706 (2017) 047

double J/ψ production - mass



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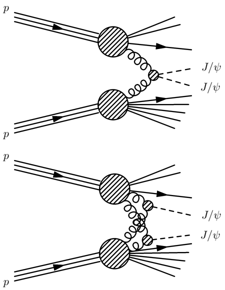
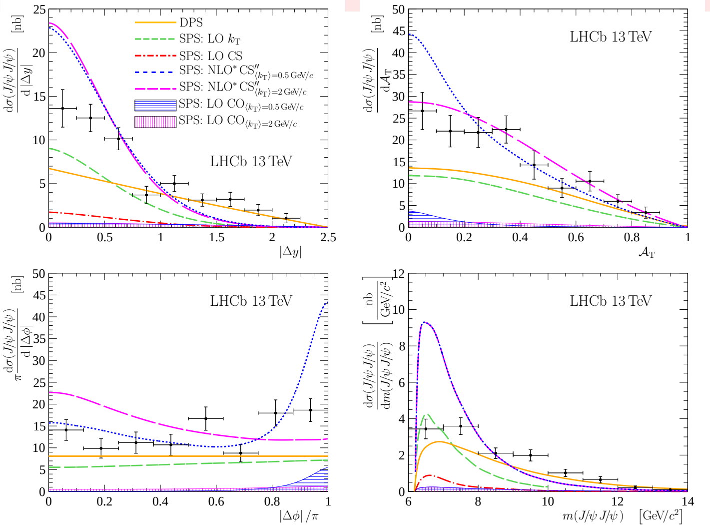
double J/ψ production - results





- doth SPS and DPS contribute to measured double J/ψ cross section
- fit DPS fraction

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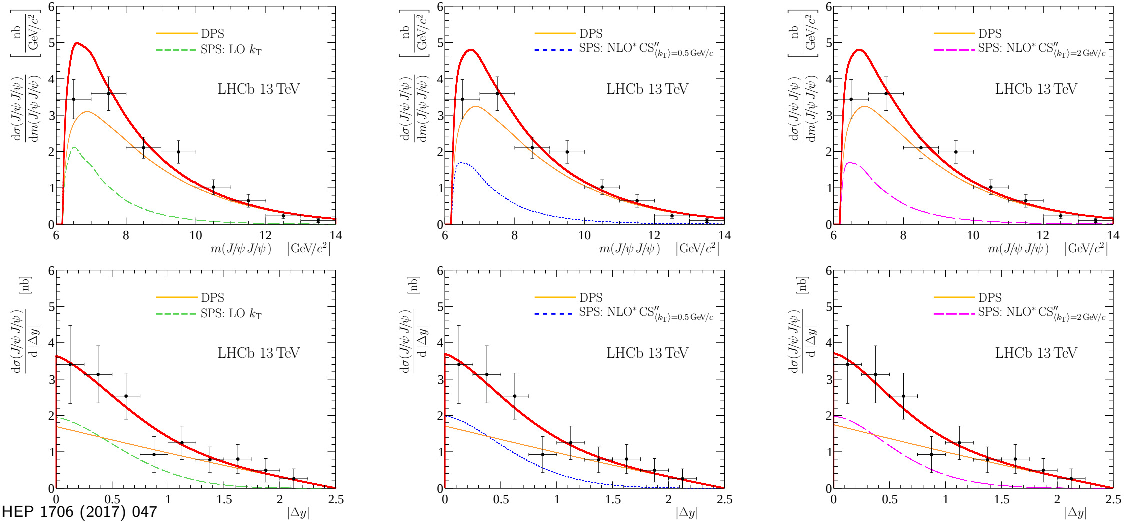
double parton scattering fraction - fits



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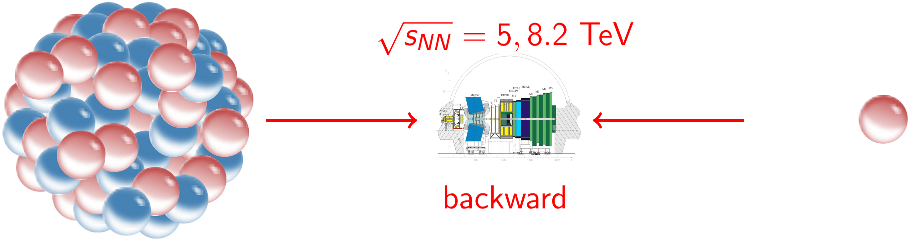
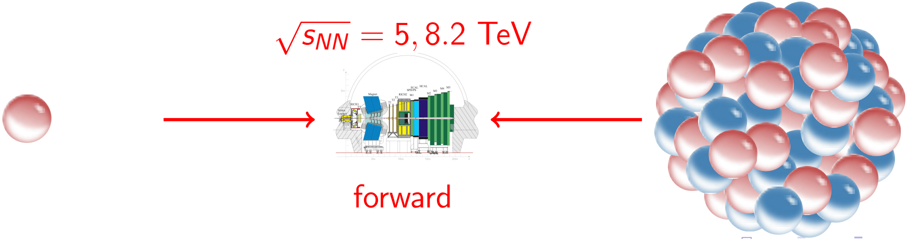
double parton scattering fraction - fit results

Variable	LO CS	LO k_T	NLO* CS′	NLO* CS″ $\langle k_T \rangle = 2\,\text{GeV}/c$	NLO* CS″ $\langle k_T \rangle = 0.5\,\text{GeV}/c$	NLO CS
no $p_T(J/\psi\, J/\psi)$ cut						
$p_T(J/\psi\, J/\psi)$	—	78 ± 2	—	86 ± 55	81 ± 7	—
$y(J/\psi\, J/\psi)$	83 ± 39	—	—	75 ± 37	68 ± 34	—
$m(J/\psi\, J/\psi)$	76 ± 7	74 ± 7	—	78 ± 7		77 ± 7
$\lvert\Delta y\rvert$	59 ± 21	61 ± 18	—	63 ± 18	61 ± 18	69 ± 16
$p_T(J/\psi\, J/\psi) > 1\,\text{GeV}/c$						
$y(J/\psi\, J/\psi)$	—	—	75 ± 24	71 ± 38	68 ± 34	—
$m(J/\psi\, J/\psi)$	—	73 ± 8	76 ± 7	88 ± 1		—
$\lvert\Delta y\rvert$	—	57 ± 20	59 ± 19	60 ± 18	60 ± 19	—
$p_T(J/\psi\, J/\psi) > 3\,\text{GeV}/c$						
$y(J/\psi\, J/\psi)$	—	—	77 ± 18	64 ± 38	64 ± 35	—
$m(J/\psi\, J/\psi)$	—	76 ± 10	84 ± 7	87 ± 2		—
$\lvert\Delta y\rvert$	—	42 ± 25	53 ± 21	53 ± 21	53 ± 21	—

- $\sigma_{J/\psi\, J/\psi} = 15.2 \pm 1.0 \pm 0.9$ nb
- $\frac{1}{2}\frac{\sigma^2_{J/\psi}}{\sigma_{J/\psi\, J/\psi}} = 7.3 \pm 0.5 \pm 1.0$ mb
- Determination of the DPS fraction introduces large model dependence
- Assumptions on the J/ψ polarisation affect the acceptance ($\lambda_\theta \pm 20 \Rightarrow a \pm 7\%$)

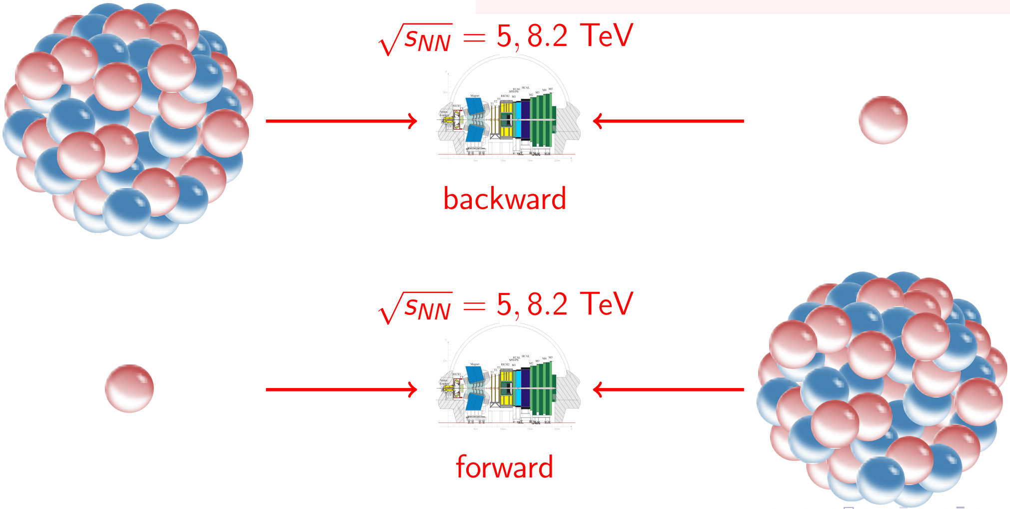
LHCb Results from Proton Lead Collisions



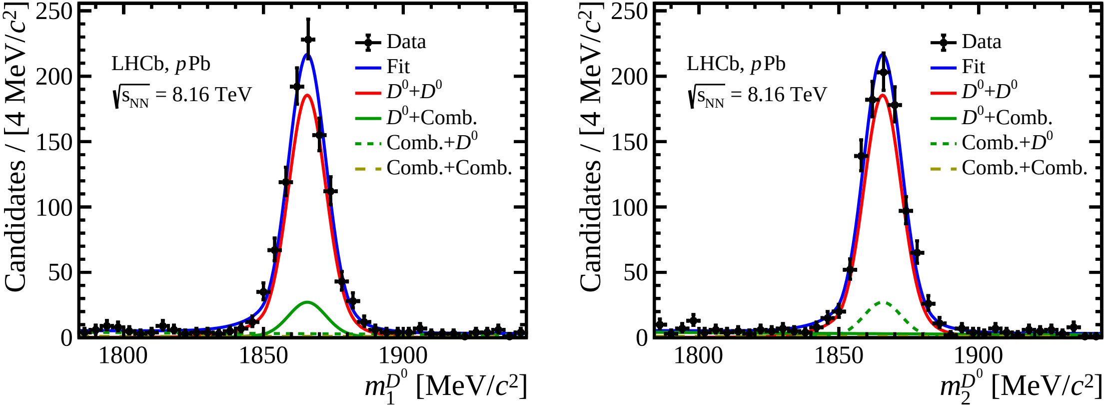


LHCb Results from Proton

- CM frame Rapidity ±0.465 in Lab Frame



double open charm in proton ion collisions

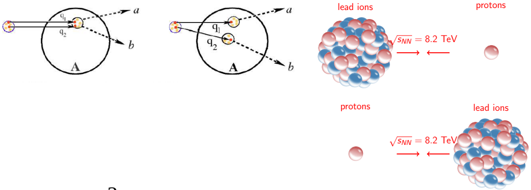


$\sqrt{s_{NN}} = 8.2$ TeV *Phys. Rev. Lett. 125 (2020) 212001*

double charm production in proton lead collisions

- select pairs of D^0, $\bar{D}^0$, D^+, D^-, D_s^+, D_s^- and J/ψ
- sort them into pair production and “DPS” categories

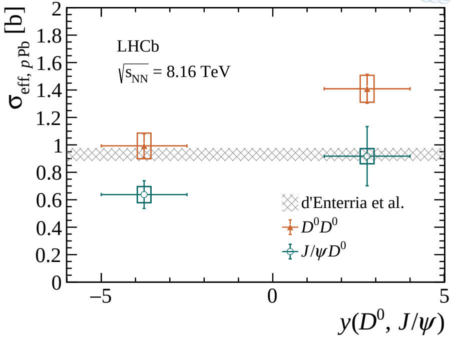
$$\sigma_{C_1,C_2} = \alpha \frac{\sigma_{C_1}\sigma_{C_2}}{\sigma_{\text{eff}}}$$



$$R^{D_1D_2}_{forward} = \frac{\sigma_{D_1D_2}}{\sigma_{D_1\bar{D}_2}} = 0.308 \pm 0.015 \pm 0.010$$

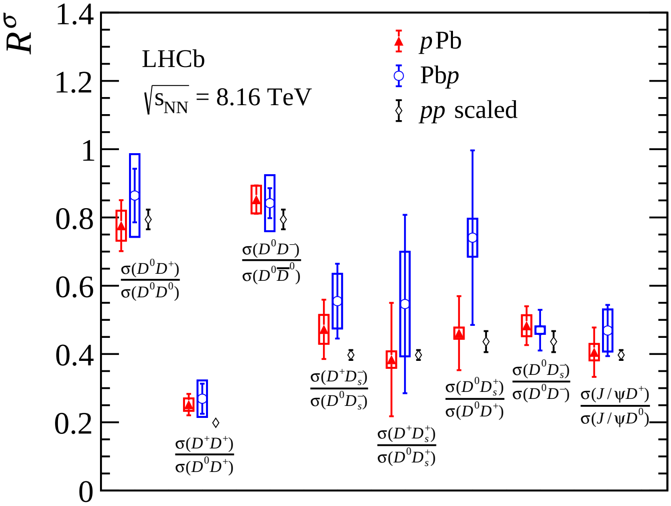
$$R^{D_1D_2}_{backward} = 0.391 \pm 0.019 \pm 0.025$$

$$R^{D^0D^0}_{pp} = 0.109 \pm 0.008$$



Like sign charm fraction tripled!

$\sqrt{s_{NN}} = 8.2$ TeV *Phys. Rev. Lett. 125 (2020) 212001*



- build the double production cross section ratios
- keep one state identical in nominator and denominator
- fragmentation similar to proton collisions

$\sqrt{s_{NN}} = 8.2$ TeV *Phys. Rev. Lett. 125 (2020) 212001*

conclusion

- LHCb keeps producing double production results
- Theory uncertainties affect the precision of the measurements
- Large enhancement of like sign open charm in proton lead collisions