Double J/ψ production as a test of parton correlations in double parton scattering with the Gaunt-Stirling model

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Sergey Koshkarev and Stefan Groote

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“Pocket formula”

Double parton scattering results are usually interpreted in terms of the so-called “pocket formula” [D. d’Enterria and A. Snigirev, 2018]

$$\sigma_{DPS} = \frac{m}{2} \frac{\sigma^{A}_{SPS}\sigma^{B}_{SPS}}{\sigma_{eff}},$$

where the combinatorial factor is $m = 1$ for identical final states $A = B$ and $m = 2$ for $A \neq B$. This formula is derived under the assumption of independent parton scatterings

$$\sigma_{eff} = \left[\int d^2b\ T^2(\mathbf{b})\right]^{-1},$$

where $T(b)$ is the overlap function that characterizes the transverse area occupied by the interacting partons in the impact parameter space b.

“Pocket formula” phenomenology

Phenomenologically DPS process can be cast into the form

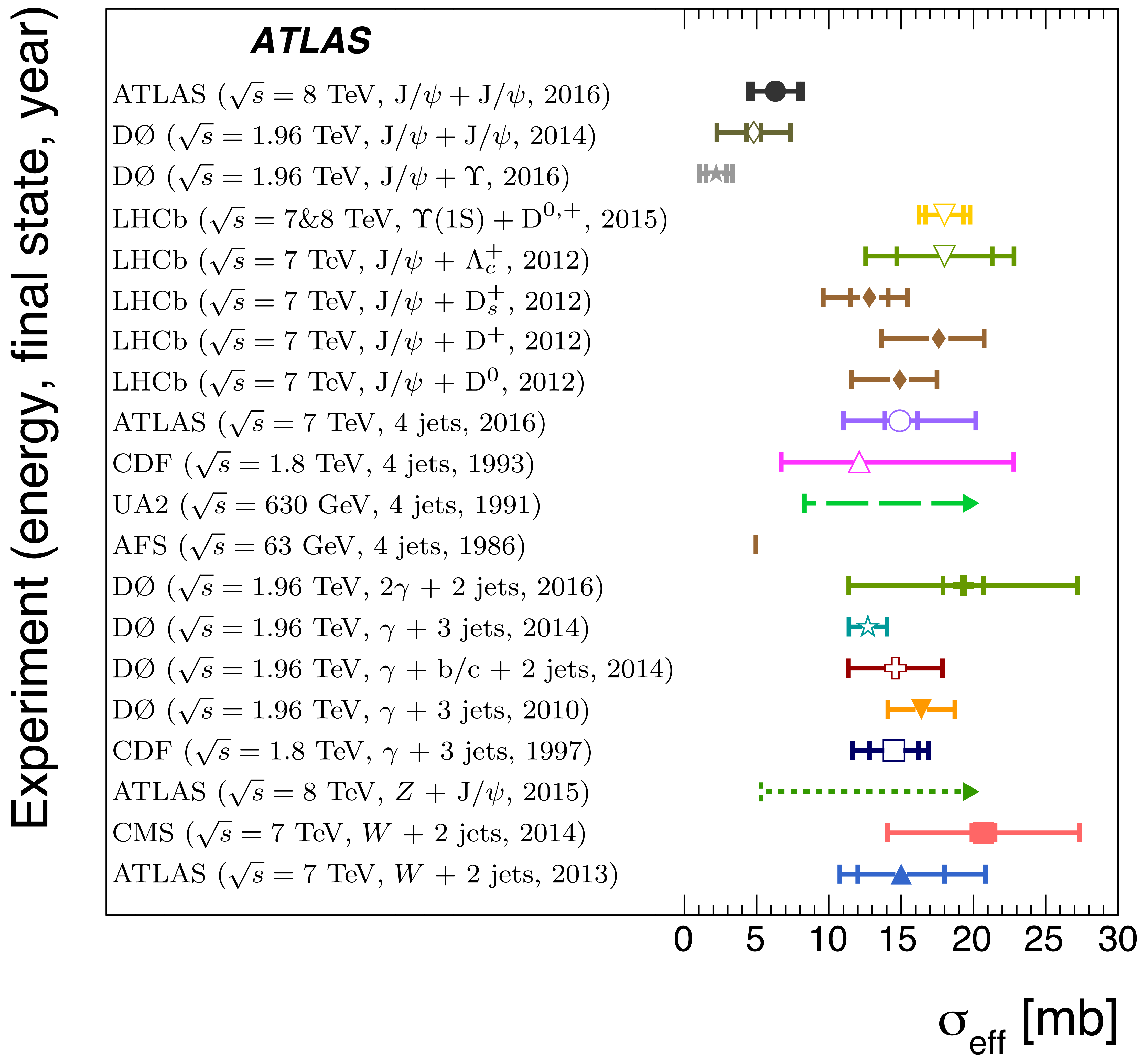
$$\sigma_{\mathrm{DPS}} = \frac{m}{2}\frac{1}{\sigma_{eff}}\int dx_1 \ldots dx_4 \; f(x_1, Q_A) f(x_2, Q_A) \hat{\sigma}_A(x_1, x_2) f(x_3, Q_B) \times$$

$$f(x_4, Q_B) \hat{\sigma}_B(x_3, x_4) \theta(1 - x_1 - x_3) \theta(1 - x_2 - x_4),$$

where $f(x, Q)$ denotes the parton distribution function, $\hat{\sigma}$ is the cross section at parton level, and θ is the Heaviside step function.

The effective cross section

Different energies and final states (ATLAS, 2017)

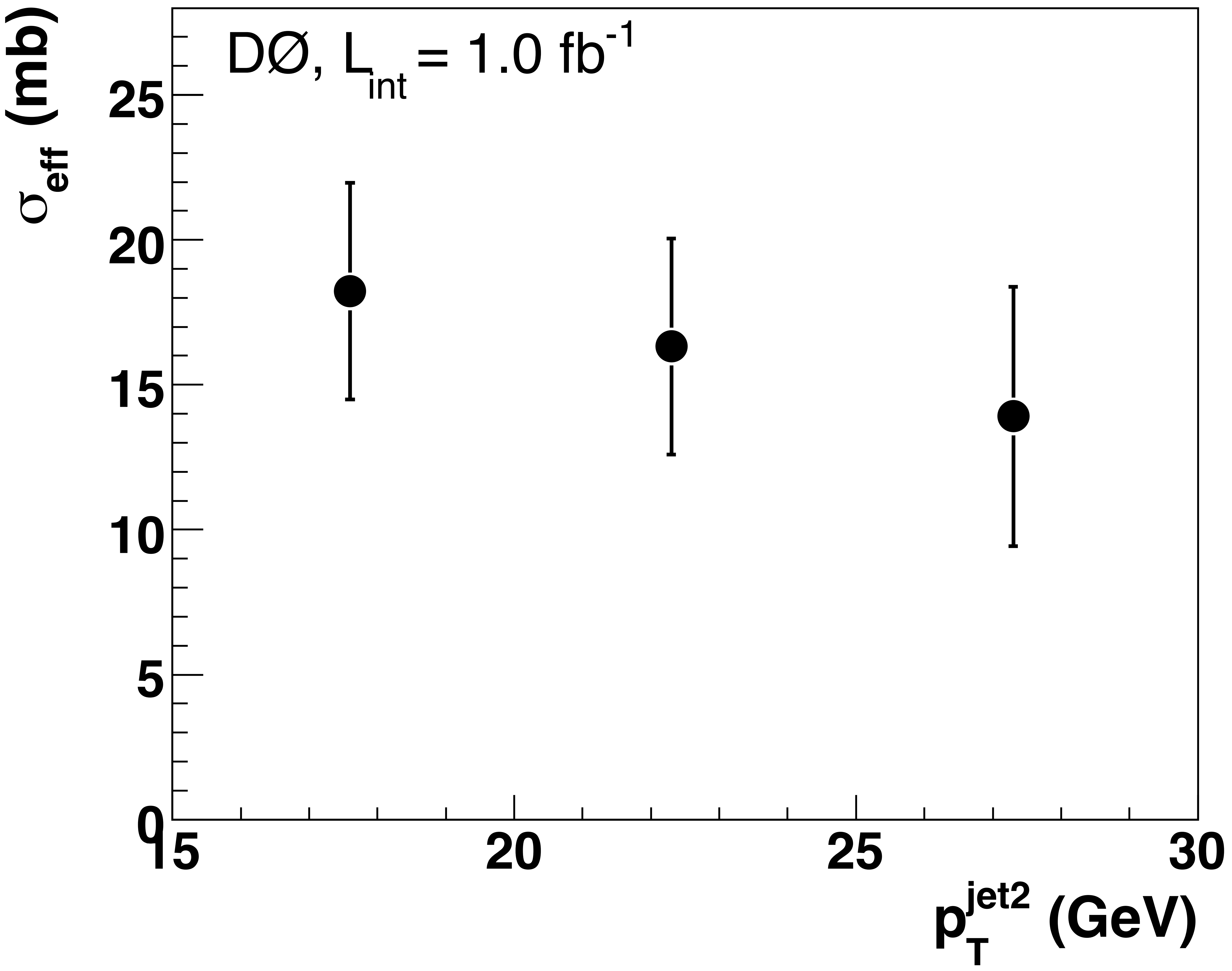


Effective cross section in $\gamma + 3$ jets process in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV at the DØ experiment

Year	$p_T^{\min}(GeV/c)$	y or η range	σ_{eff} (mb)
2010	$60 < p_T^{\gamma} < 80$ $p_T^{\text{jet 1}} > 25$ $p_T^{\text{jet 2,3}} > 15$	$\lvert y^{\gamma}\rvert < 1.0$ $1.5 < \lvert y^{\gamma}\rvert < 2.5$ $\lvert y^{\text{jet}}\rvert < 3.0$	$16 \pm 0.3 \pm 2.3$
2014	$p_T^{\gamma} > 26$ $p_T^{\text{jet 1}} > 15$ $15 < p_T^{\text{jet 2,3}} < 35$	$\lvert \eta^{\gamma}\rvert < 1.0$ $1.5 < \lvert \eta^{\gamma}\rvert < 2.5$ $\lvert \eta^{\text{jet}}\rvert < 2.5$	$12.7 \pm 0.2 \pm 1.3$

- The central values are different
- The errors bars do not overlap

Effective cross section in $\gamma + 3$ jets process in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV at the DØ experiment, 2010



Double Parton Distribution functions

Double parton distribution function phenomenology

$$D(x_1, x_3, Q_A, Q_B) \neq f(x_1, Q_A) f(x_3, Q_B) \theta(1 - x_1 - x_3)$$

$$\sigma_{\mathrm{DPS}} = \frac{m}{2} \frac{1}{\sigma_{eff}} \int dx_1 \ldots dx_4 \; D(x_1, x_3, Q_A, Q_B) D(x_2, x_4, Q_A, Q_B) \hat{\sigma}_A(x_1, x_2) \hat{\sigma}_B(x_3, x_4),$$

$J/\psi-$pair from DPS production

Feed-down effect

- Not all J/ψ's come from prompt production

State	Decay mode	Feed-down fraction (r)
J/ψ	-	0.62 ± 0.04
$\psi^{'}$	$J/\psi + X$	0.08 ± 0.02
χ_c	$J/\psi + \gamma$	0.30 ± 0.08

$$\sigma(J/\psi J/\psi) = \frac{\sigma(J/\psi)^2}{\sigma_{eff}}\left(\frac{r_{J/\psi}^2 + r_{\psi'}^2 + r_{\chi_c}^2}{2} + 2\cdot(r_{J/\psi}r_{\psi'} + r_{J/\psi}r_{\chi_c} + r_{\psi'}r_{\chi_c})\right)$$

$J/\psi-$pair from DPS production

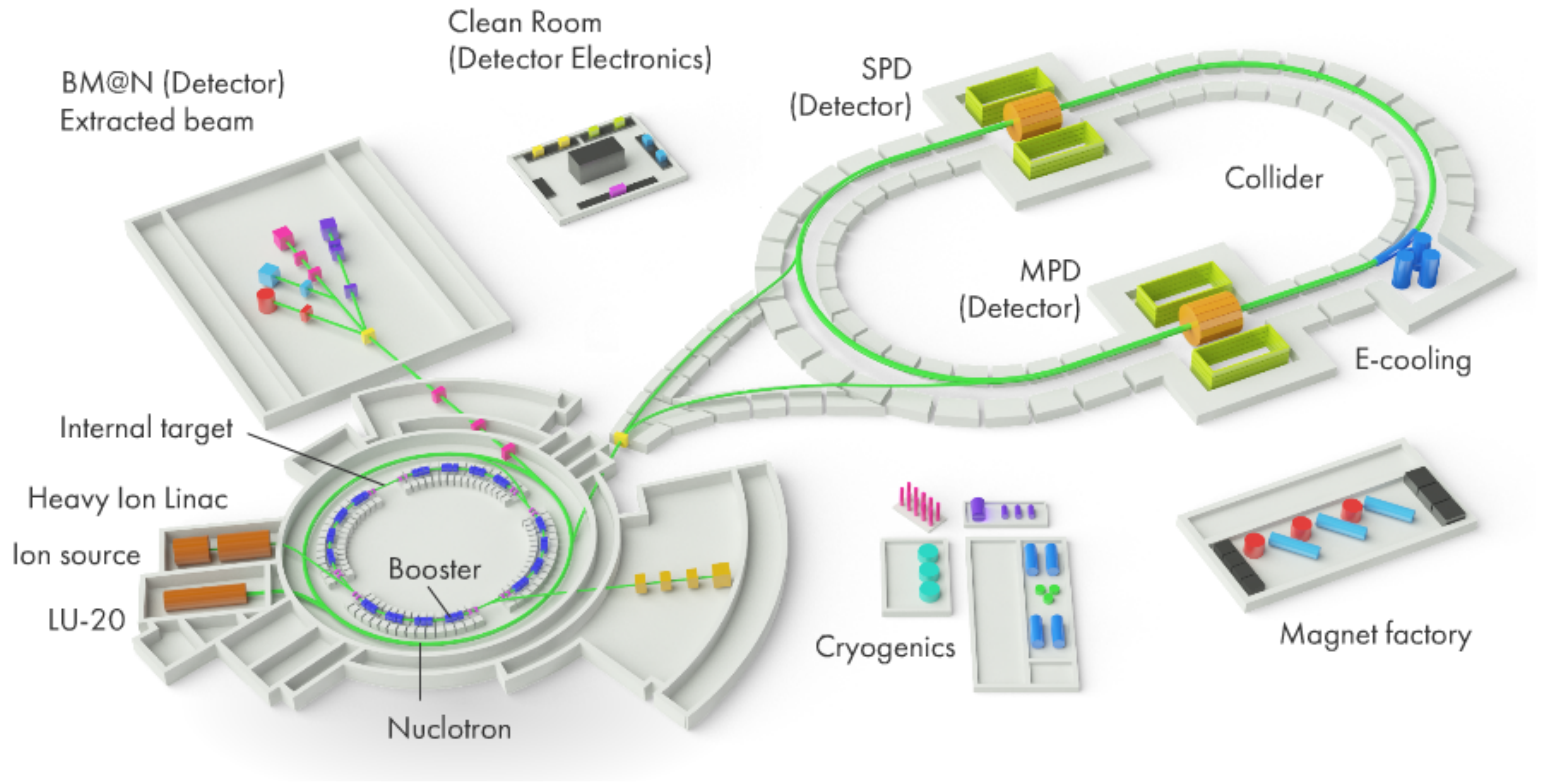
Effective cross section: reference value

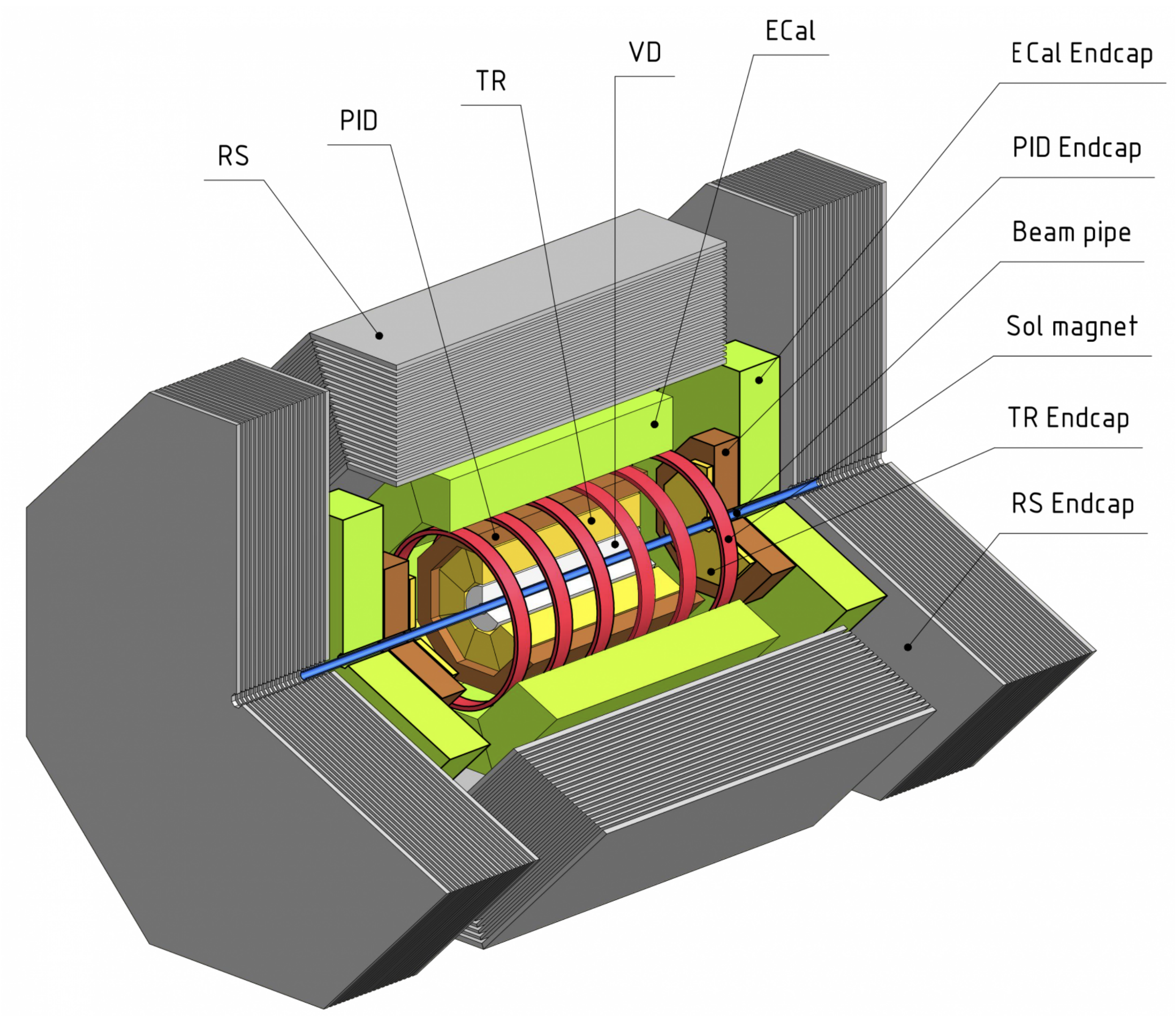
Experiment	$\sqrt{s}$, TeV	Colliding Mode	σ_{eff}, mb
DØ	1.96	$p\bar{p}$	$4.8 \pm 0.5(\text{stat}) \pm 2.5(\text{syst})$
ATLAS	8	pp	$6.3 \pm 1.6(\text{stat}) \pm 1.0(\text{syst})$
CMS	13	pp	$2.7^{+1.4}_{-1.0}(\text{exp})^{+1.5}_{-1.0}(\text{th})$

$$\langle \sigma_{eff} \rangle = 4.6 \text{ mb}$$

The Spin Physics Detector at the Nuclotron-based Ion Collider fAcility

- The Spin Physics Detector at the Nuclotron-based Ion Collider fAcility (NICA) collider is a universal facility to investigate the spin structure of the proton and deuteron and the other spin-related phenomena with polarized proton and deuteron beams at a collision energy up to 27 GeV and a luminosity up to $10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$.





$J/\psi-$pair from DPS production at NICA with the "pocket formula"

- Using the CERN proton beam at 400 GeV/c to produce charmonium with incident on different nuclear targets, the NA50 experiment measured single J/ψ production on on Be, Al, Cu, Ag, W, and Pb targets, $\langle\sigma(J/\psi)\rangle_{W,Pb} \approx 12.5\ \text{mb}$ per nucleon, the NA3 experiment provided data on the production of J/ψ pairs on a platinum target with the production cross sections of $27 \pm 10\ \text{pb}$ per nucleon.

$$\sigma_{DPS}(J/\psi J/\psi) \approx 2.6\ \text{pb}$$

$$f_{DP} \approx 9.6\,\%$$

$J/\psi-$pair from DPS production at NICA with the Gaunt—Stirling model

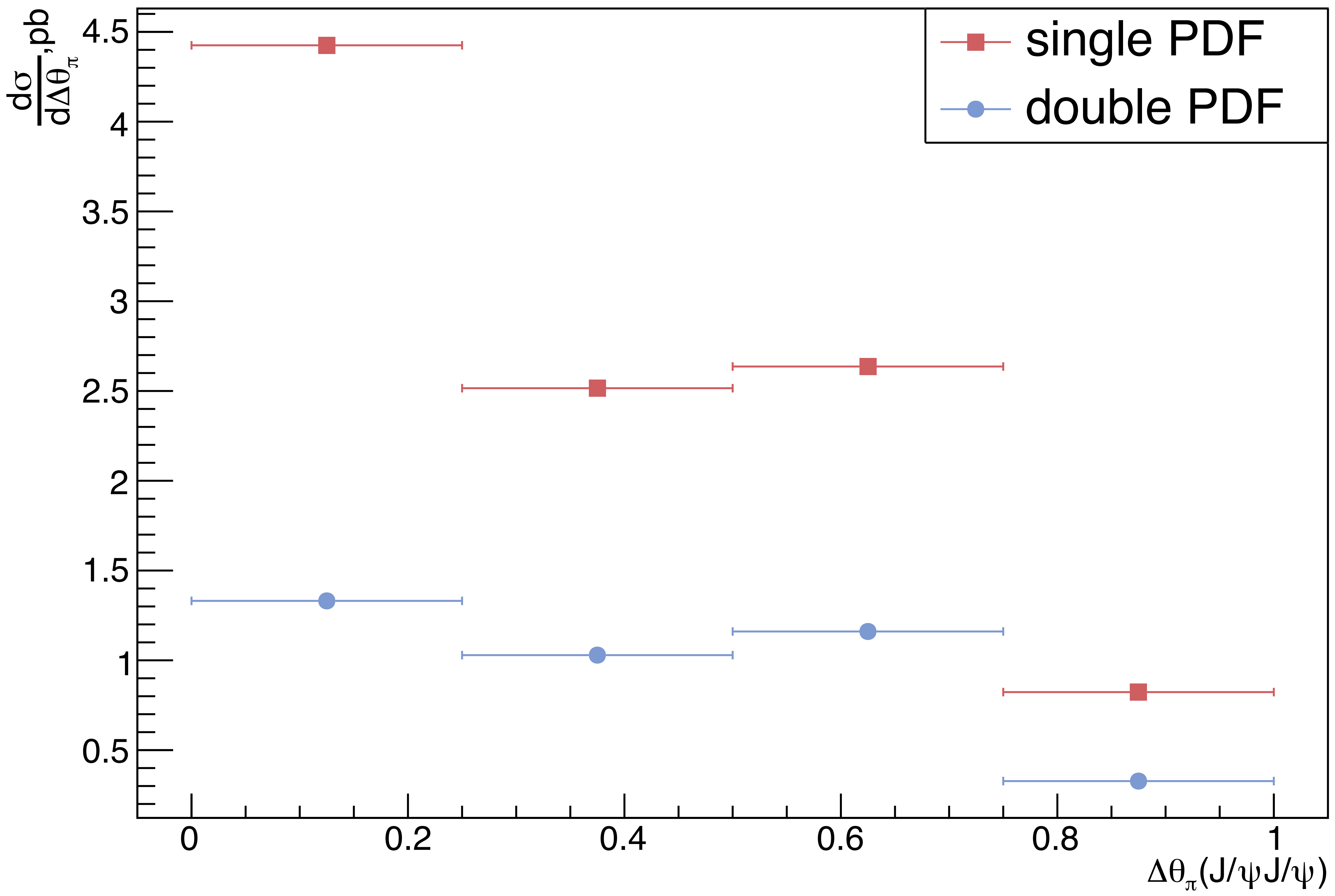
Monte-Carlo strategy

- In order to distinguish between single and double PDF predictions, we use a Pythia 8 Monte-Carlo simulation, where the single PDF are calculated with MSTW2008LO and the double PDF are calculated in the GS09 model employing the R_Δ, when the ration was calculated for every single event.

$$R_\Delta(x_1, x_2, x_3, x_4, Q_A, Q_B) = \frac{D(x_1, x_3, Q_A, Q_B)D(x_2, x_4, Q_A, Q_B)}{f(x_1, Q_A)f(x_2, Q_A)f(x_3, Q_B)f(x_4, Q_B)}$$

$J/\psi-$pair from DPS production at NICA with the Gaunt—Stirling model

Results



$$\langle R_\Delta \rangle \approx 0.37$$

$$\sigma_{eff} = \frac{\langle \sigma_{eff} \rangle}{\langle R_\Delta \rangle} \approx 12.4\ \text{mb}$$

$$f_{DP} \approx 3.6\ \%$$

Number of events

"Pocket formula" vs Gaunt—Stirling model

- According to estimations of SPD collaboration they expect up to 12M single J/ψ events per year.

- Using double and single J/ψ production cross sections measured by NA3 and NA50 experiments, we can calculation the following ratio

$$\frac{\sigma(J/\psi J/\psi)}{\sigma(J/\psi)} > 10^{-4}\,.$$

- Multiplying this ration with f_{DP}, we can estimate the number of DPS J/ψ—pairs per year: ~ 115 and ~ 43 in case of the "pocket formula" and GS09, respectively.

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 $\sim 1/3$.

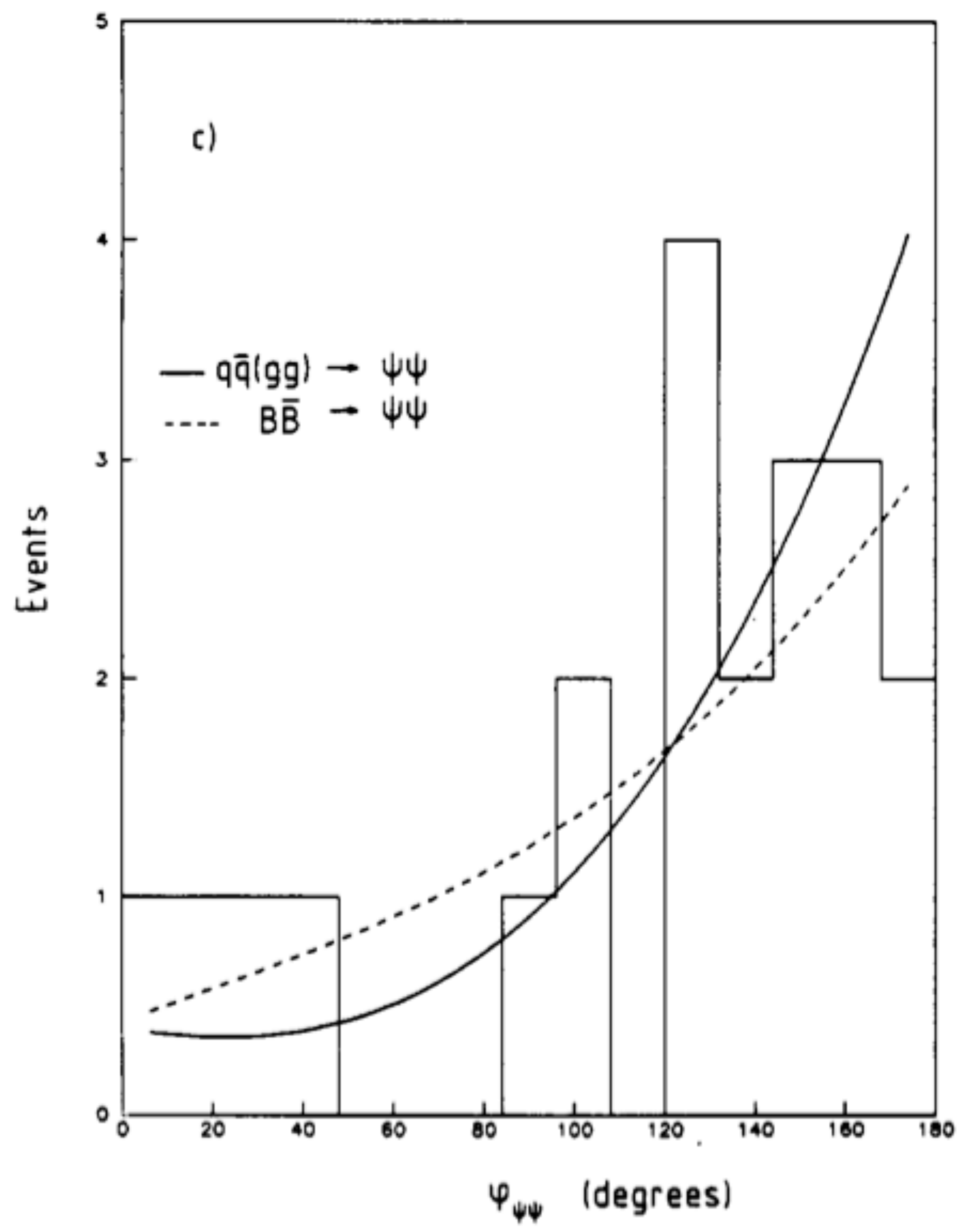
- Having taken into account the fact that $\Delta\phi_\pi = (\phi(J/\psi_1) - \phi(J/\psi_1))/\pi$ has a peak near 1 for SPS but a flat shape for DPS, we were able to exclude the region $\Delta\phi_\pi \sim 1$ in order to maximize the DPS/SPS ratio.

Thanks for your attention!

Back Up

Maximization DPS/SPS ratio

- 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.



NA3 experiment, 1985