Measurement of J/ψ Double-Differential Cross Section in pp Collisions at $\sqrt{s}$=13.6 TeV with the CMS detector at the LHC

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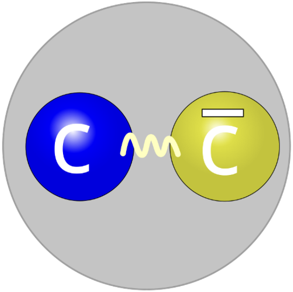
Content

J/ψ meson

- The observation of the J/ψ meson marked the discovery of the charm quark, confirming the existence of a fourth quark flavor
- Studying this system helps us understand non perturbative QCD



Motivation

- Quarkonium production in hadronic collisions has been the subject of many theoretical and experimental studies

$$\sigma(H) = \sum_n \hat{\sigma}(Q\bar{Q}[n]) \langle \mathcal{O}_n^H \rangle \tag{1}$$

- Measurement of long-distance matrix elements (LDME) present in non-perturbative hadronization processes from a theoretical framework to the description of quarkonium production using an effective NRQCD theory
- Additional data can help in improving the fits and determine more precisely the relative weights of the LDMEs

Quarkonia Production

$$\mathcal{L} \times \sigma(pp \to Q) \times \mathcal{B}(Q \to \mu^+\mu^-) \times \epsilon \times \mathcal{A} = N$$

The product of the branching fraction of quarkonia to muon pairs, $\mathcal{B}(Q \to \mu^+\mu^-)$, and the double-differential production cross section, $\frac{d^2\sigma}{dp_T\, dy}$, in bins of p_T and rapidity, y, is given by:

$$\frac{d^2\sigma(pp \to Q)}{dp_T\, dy} \times \mathcal{B}(Q \to \mu^+\mu^-) = \frac{N(p_T, y)}{\mathcal{L}\, \Delta p_T\, \Delta y\, \epsilon(p_T, y)\, \mathcal{A}(p_T, y)}$$

donde:

- N: Number of prompt signal events in the bin
- $\mathcal{L}$: Integrated luminosity
- Δp_T, Δy: Bin widths
- $\epsilon(p_T, y)$: Reconstruction efficiency of the bin
- $\mathcal{A}(p_T, y)$: Acceptance of the bin

Acceptances and efficiencies

The acceptance for dimuon events in a given (p_T, y) range is defined as:

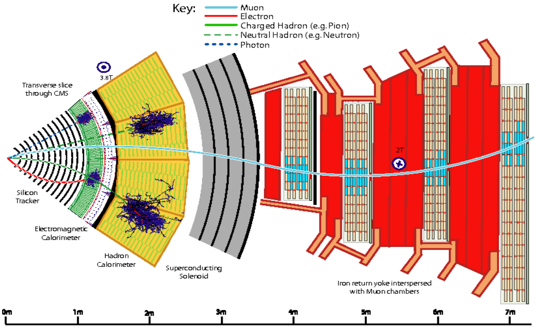
$$\mathcal{A}(p_T, y) = \frac{N^{gen}_{kin}(p_T, y)}{N^{gen}(p_T, y)}$$

where N^{gen}_{kin} is the number of event that pass the kinematic selection and N^{gen} is the total number of events generated.

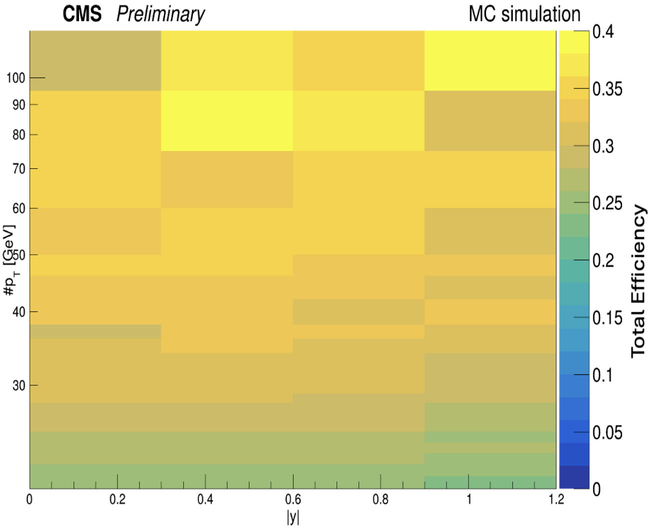
Efficiency is defined as:

$$\epsilon(p_T, y) = \frac{N^{full}(p_T, y)}{N^{Recogen}(p_T, y)}$$

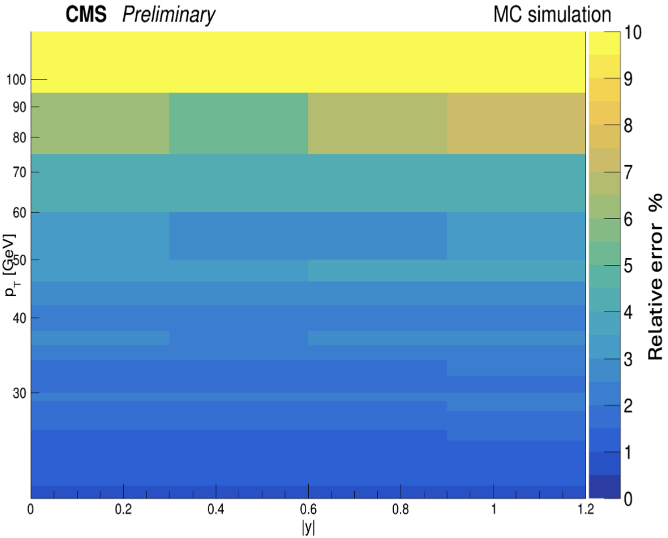
The ratio of events that were accepted, reconstructed and triggered to the events that were generated and accepted.



Total Efficiency



Relative error of the total efficiency



Determination of the yields

The prompt signal yields are obtained through an extended unbinned maximum-likelihood fit to the dimuon invariant mass and decay length distributions.

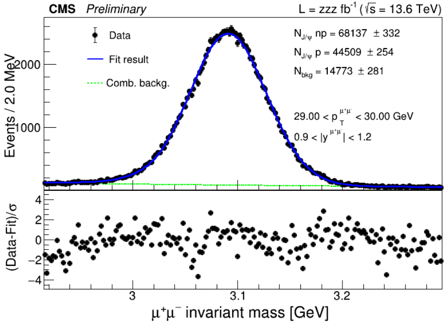
Mass Invariant Distribution

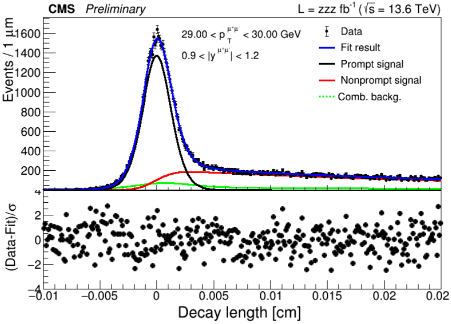
- Signal: a single sided Crystal Ball plus a Gaussian Function
- Background: Decreasing exponential function
- $\mathcal{F}(m_{\mu\mu}) = n_{NP} M_{Sig}(m_{\mu\mu}) + n_{PR} M_{Sig}(m_{\mu\mu}) + n_{Bkg} M_{Bkg}(m_{\mu\mu})$

Decay Length Distribution

- Prompt component (resolution): Two Gaussian Functions
- Non Prompt component: Exponential decay function convolved with the resolution
- Background: Two Gaussians plus an Exponential decay function convolved with the resolution
- $\mathcal{L}(ct, \sigma_i) = n_{NP} L_{NP}(ct, \sigma_{ct,i}) + n_{PR} L_{PR}(ct, \sigma_{ct,i}) + n_{Bkg} L_{Bkg}(ct, \sigma_{ct,i})$

Determination of the yields





Systematic Uncertainties

Uncertainties in the estimation of the yields are evaluated by changing the fixed/constrained parameters of the signal model and background models used in the maximum-likelihood fits.

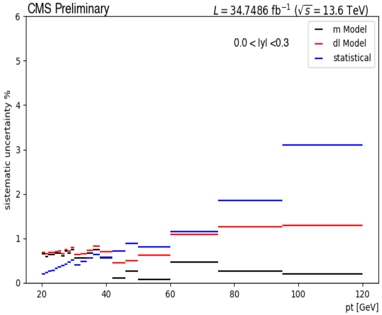
Mass Invariant Distribution

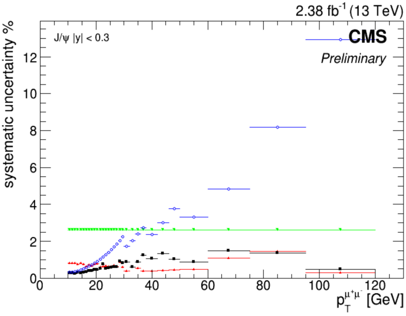
- μ which was fixed $\rightarrow$ free parameter
- CB is modified in its fixed parameter $n \rightarrow n \pm 5\sigma$
- Bkg $\rightarrow$ We changed to a linear shape

Decay Length Distribution

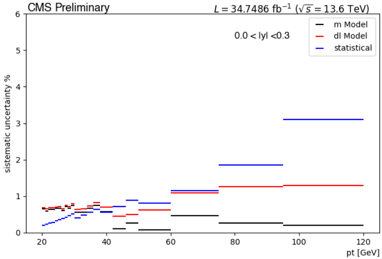
- The σ's variables of the resolution function (which were constraint) are varied by ± 1 standard deviation to study the impact of imperfect modeling of the resolution function
- The lifetime of the non prompt signal component, due to real b hadrons, should not depend on the pT or y. We tested this hypotesis fixing the λ parameter in the fit
- Bkg $\rightarrow$ A two side exponential plus a negative exponential tail and a positive exponential tail

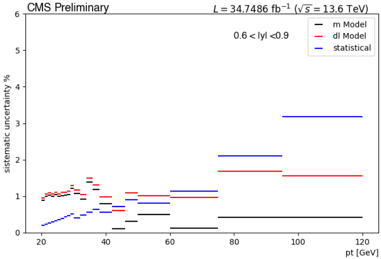
Systematic and Statistical Uncertainties

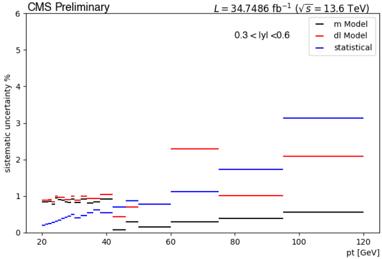


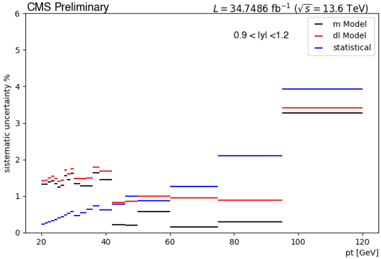


Systematic and Statistical Uncertainties



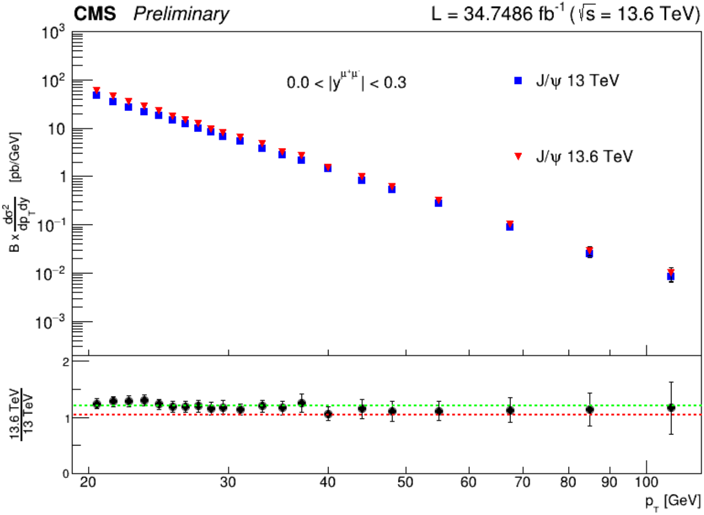




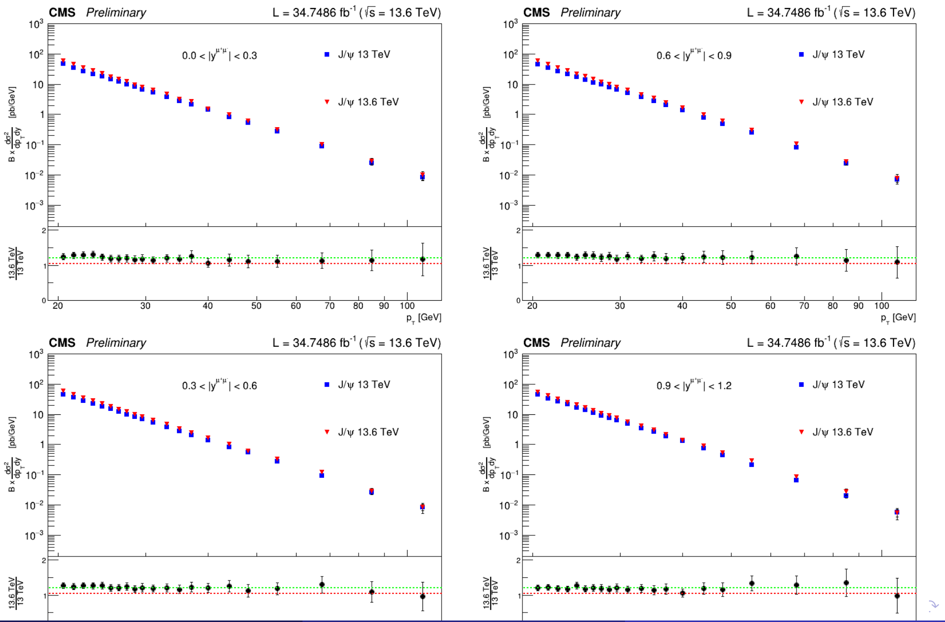


Preliminary results

Comparison between previous and current analysis



Preliminary results



Summary

- The double-differential production cross section of the J/ψ has been measured, using its dimuon decay mode,in pp collisions at $\sqrt{s} = 13.6$ TeV with the CMS detector at the LHC.
- The results obtained are in agreement with previous analyses at $\sqrt{s} = 13$ TeV
- The addition of new data has greatly reduced the statistical error

¡Thank you!

Backup

Current analysis

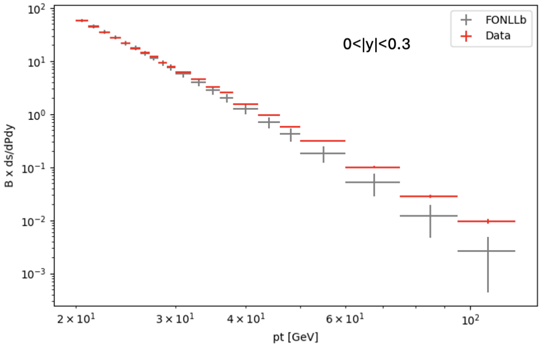
Table 1: J/ψ cross sections for $0.0 < |y| < 0.3$

pt	$\langle pt \rangle$	$\mathcal{B} \times d\sigma^2/dp_T dy$	*stat %*	*syst1 % N*	*syst2 % ϵ*	*$err_t ot$ %*
20	21	57.8527	0.207087	0.23	0.905264	0.956823
21	22	44.9363	0.233308	0.25	1.01221	1.06847
22	23	34.7954	0.259572	0.262	1.11393	1.17339
23	24	27.5653	0.288266	0.247	1.22753	1.28498
24	25	22.0451	0.320545	0.54	1.35352	1.49193
25	26	17.3019	0.354667	0.253	1.44465	1.50891
26	27	14.2626	0.390309	0.272	1.59133	1.66093
27	28	12.064	0.42811	0.59	1.78786	1.93066
28	29	9.36115	0.471223	0.291	1.85276	1.93374
29	30	7.87198	0.514438	0.483	2.03307	2.15195
30	32	6.19622	0.409722	0.311	1.61642	1.69621
32	34	4.57624	0.478909	0.628	1.94138	2.09593
34	36	3.23266	0.557686	0.486	2.16064	2.28368
36	38	2.60374	0.643615	0.333	2.64162	2.73924
38	42	1.54303	0.556957	0.4	2.07935	2.18949
42	46	0.958391	0.714886	0.486	2.72711	2.86077
46	50	0.587328	0.895771	0.695	3.36783	3.55358
50	60	0.309445	0.808506	0.617	3.0607	3.22525
60	75	0.100903	1.14852	1.374	4.073	4.44928
75	95	0.0286327	1.85437	1.328	6.04165	6.45784
95	120	0.00959245	3.0988	1.297	10.4756	11.0009

Previous analysis

p_T [GeV]	$\langle p_T \rangle$ [GeV]	$\mathcal{B}\, d\sigma^2/dp_T dy$ $\lvert y \rvert < 0.3$ [pb/GeV]	stat %	syst %
20–21	20.5	4.68E+01	1.7	5.3
21–22	21.5	3.52E+01	1.3	5.4
22–23	22.5	2.72E+01	1.4	5.2
23–24	23.5	2.14E+01	1.5	5.0
24–25	24.5	1.80E+01	1.6	5.0
25–26	25.5	1.46E+01	1.8	5.0
26–27	26.5	1.21E+01	1.9	5.1
27–28	27.5	1.00E+01	2.1	5.0
28–29	28.5	8.14E+00	2.3	5.1
29–30	29.5	6.68E+00	2.5	5.2
30–32	31.0	5.47E+00	1.9	5.2
32–34	33.0	3.84E+00	2.3	5.4
34–36	35.0	2.78E+00	2.7	5.7
36–38	37.0	2.12E+00	3.1	6.2
38–42	39.8	1.45E+00	2.6	6.4
42–46	43.8	8.33E-01	3.3	6.9
46–50	47.8	5.34E-01	4.2	7.0
50–60	54.2	2.79E-01	3.7	7.8
60–75	66.0	8.96E-02	5.4	8.0
75–95	82.7	2.54E-02	9.0	7.7
95–120	104.7	8.37E-03	15	8.3
120–150	131.1			

FONLL Aproximation



Prompt cross sections times branching ratios for the J/ψ

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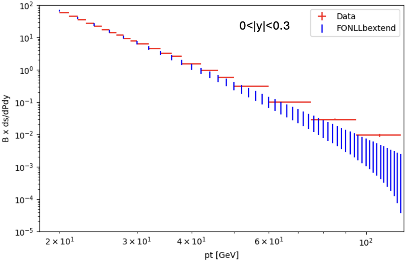

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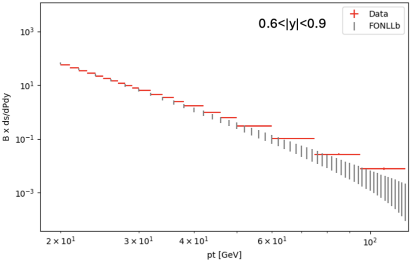

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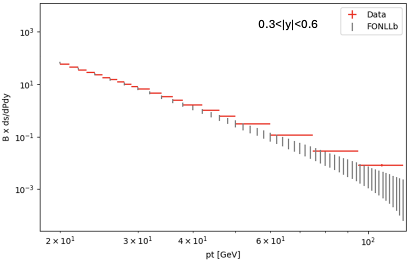
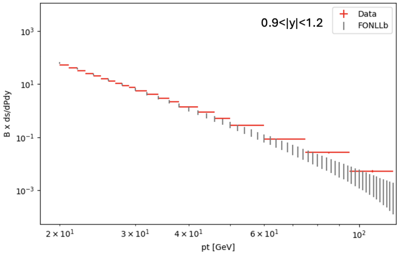


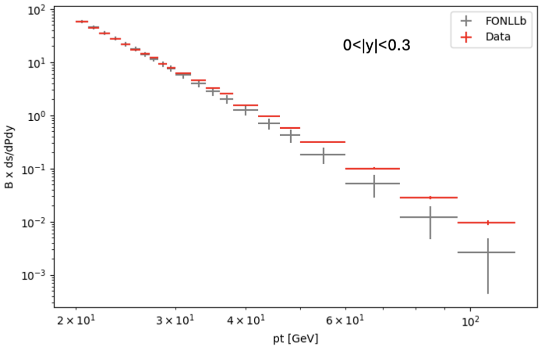


FONLL Aproximation

$$\frac{d^2\sigma(pp \to J/\psi)}{dp_T\, dy} \cdot \mathcal{B}(J/\psi \to \mu^+\mu^-) =$$

$$\left[\frac{d^2\sigma(pp \to c\bar{c})}{dp_T\, dy} \cdot f(c\bar{c} \to J/\psi)\right] \cdot \mathcal{B}(J/\psi \to \mu^+\mu^-) -$$

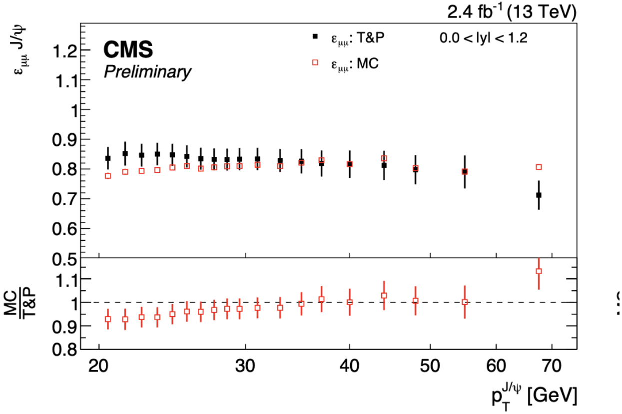
$$\frac{d^2\sigma(pp \to b\bar{b} \to B)}{dp_T\, dy} \cdot f(c\bar{c} \to J/\psi) \cdot \mathcal{B}(J/\psi \to \mu^+\mu^-)$$



Prompt cross sections times branching ratios for the J/ψ

Efficiencies with Tag Probe Aproach

Single-muon efficiencies are measured with a data-driven approach known as Tag and Probe (TnP). Total dimuon efficiencies are then obtained through the equation:
$\epsilon\mu\mu(pT, y) = \epsilon(p_{T1}, \eta_1)\epsilon(p_{T2}, \eta_2)\rho(pT, y)\epsilon_{tk}^2$



Caso Polarizado

$$\frac{d^2N}{d\cos\theta\, d\phi} \propto 1 + \lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos(2\phi) + \lambda_{\theta\phi} \sin(2\theta)\cos\phi$$

Where θ, ϕ are the angles of the muons in a reference frame (usual, HX)

Reconstruction and Selection

Acceptance cuts

- $p_T(\mu_{1,2}) > 4GeV, for|\eta(\mu_{1,2})| < 0{,}3$

Tracker or global muons satisfied

- Tracker track matched with at least one muon segment (in any station) in both X and Y coordinates ($< 3\sigma$) (TMOneStationTight) and arbitrated
- Number of tracker layer with hits > 5. This requirement guarantees a good p_T measurement, for which some minimal number of measurement points in the tracker is needed. Also suppresses muons from in-flight decays
- Number of pixel layers > 0, to further suppress muons from in-flight decays
- High-purity track flag. This requirement rejects tracks of bad quality
- Loose transverse and longitudinal impact parameter cuts: $dxy < 0{,}3cm, dz < 20cm$ w.r.t. the primary vertex. This requirement implies (loose) compatibility with the PV (or beam spot)

Analysis bins

Transverse momentum: 21 Bins

- 20-30 GeV, width = 1 GeV
- 30-38 GeV, width = 2 GeV
- 38-50 GeV, width = 4 GeV
- 50-60, 60-75, 75-95, 95-120 GeV

Rapidity: 4 Bins

- (0,0.3), (0.3,0.6), (0.6,0.9), (0.9,1.2)