QED contribution to the production of J/ψ+c$\bar{c}$+X at the Tevatron and LHC

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Outline

- Brief review of J/ψ associated production
- QED contribution to hadroproduction of J/ψ+X
- QED contribution to hadroproduction of J/ψ+$c\bar{c}$
- Summary and conclusion

- **Why the associated J/ψ +c$\bar{c}$ process ?**

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On the experimental side:

- A measurable process, by detecting J/ψ with a charmed hadron
- In some cases, a dominant contribution to J/ψ production

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On the theoretical side:

- A independent way to study J/ψ production mechanism
- A new process to determine NRQCD matrix elements
- Itself is non-factorizable at NNLO (Nayak, Qiu, Sterman PRL99,212001)

J/ψ +cc̄ production @ Belle

- In 2002, Belle measured (PRL 89,142001)

$$R_{c\bar{c}} = \frac{\sigma[e^+e^- \to J/\psi + c\bar{c} + X]}{\sigma[e^+e^- \to J/\psi + X]} = 0.59^{-0.13}_{+0.15} \pm 0.12$$

- The latest results given by Belle (PRD 79,071101)

$$\sigma[e^+e^- \to J/\psi + X] = 1.17 \pm 0.2 \pm 0.7\,\text{pb}$$

$$\sigma[e^+e^- \to J/\psi + c\bar{c} + X] = 0.74 \pm 0.08^{+0.09}_{-0.08}\,\text{pb}$$

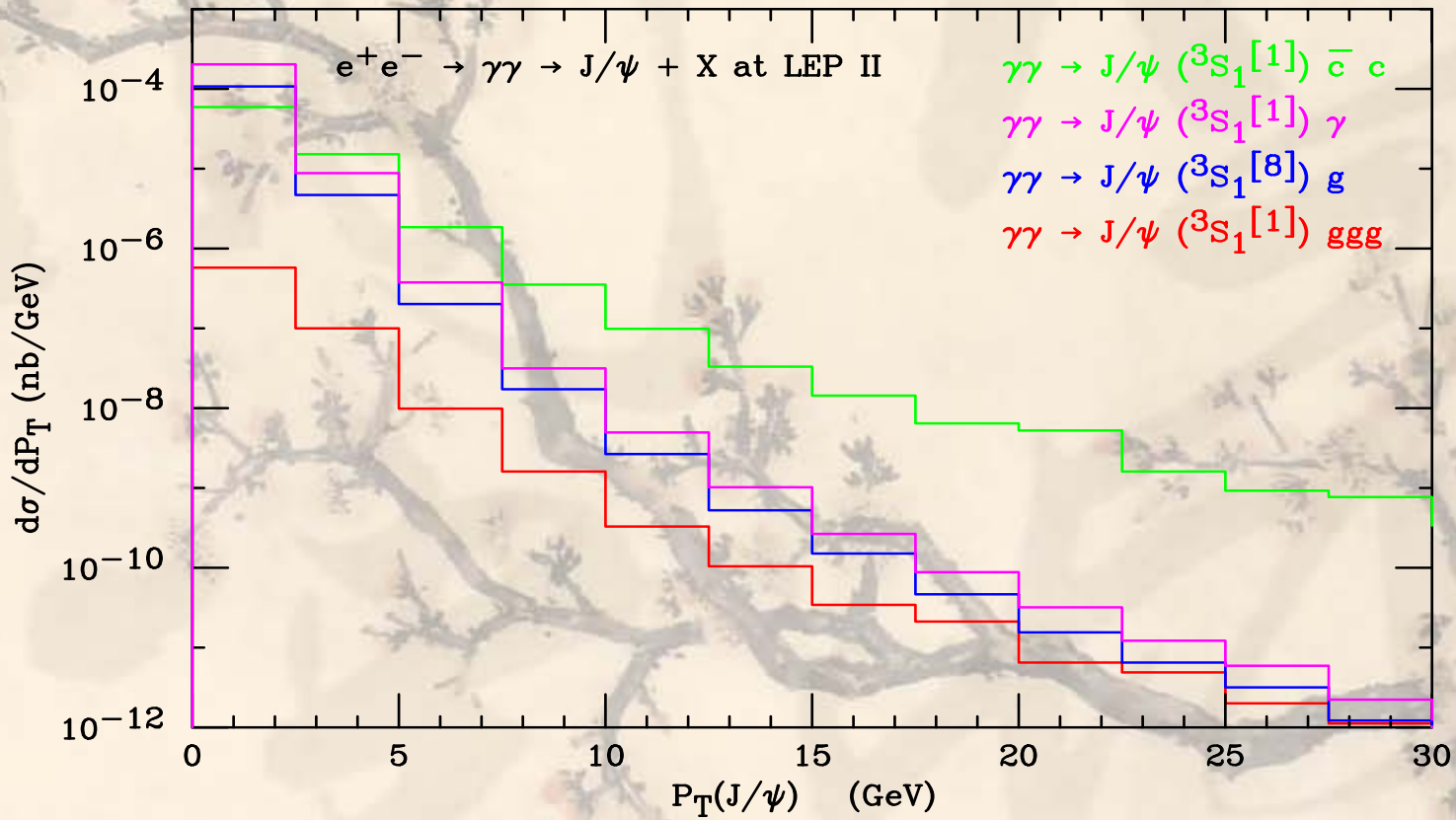
- NRQCD theoretical prediction at LO is ~0.1.

See Chao and Wang talks

- This puzzle is resolved by including NLO QCD corrections.

J/ψ +cc̄ production @ LEP II

- Theoretically, it is the most important color singlet process



P. Artoisenet, F.Maltoni, T.Stelzer JHEP 0802,102; C.F. Qiao, J.X.Wang PRD 69,014015

QED contribution to J/ψ production @ B-Factories Ⅰ

Double charmonium process

	J/ψ + η_c (fb)	J/ψ + χ_{c0} (fb)	J/ψ + $\eta_c(2S)$ (fb)
BABAR	17.6 ± 2.8 ± 2.1	10.3 ± 2.5 ± 1.8	16.4 ± 3.7 ± 3.0
Belle	25.6 ± 2.8 ± 3.4	6.4 ± 1.7 ± 1.0	16.5 ± 3.0 ± 2.4
Theory (NRQCD LO)	2.3～5.5	2.3～6.9	1.0～3.7

PRD 72, 031101(R)

PRD 70, 071102(R)

Liu et al, PLB 557,45
Bratten, Lee, PRD 67,054007

- **QED contribution, will enhance the cross sections by**

	η_c	χ_{c0}	χ_{c1}	χ_{c2}	$^1D_2$
J/ψ	20%	4%	-5%	8%	11%

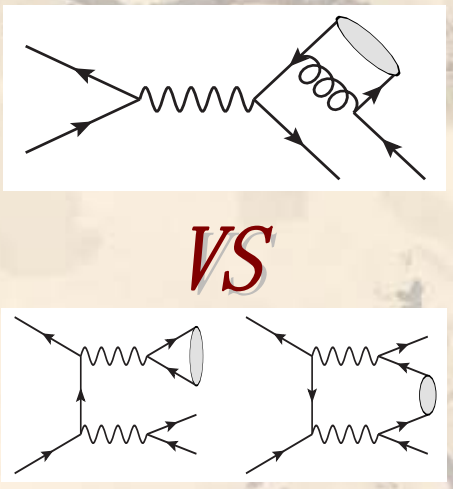
Liu,He,Chao PRD 77, 014002

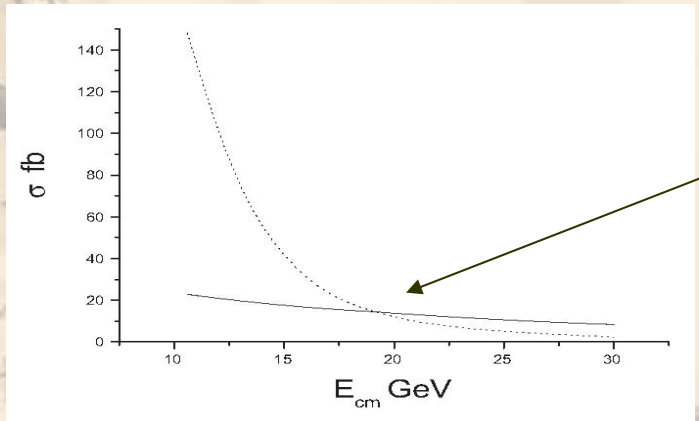
- **At NRQCD LO,** $\sigma[e^+e^- \to J/\psi + J/\psi] \simeq 1.8 \times \sigma[e^+e^- \to J/\psi + \eta_c]$

Bodwin, Brateen, Lee PRL 90,162001; PRL 95,239901(E)

QED contribution to J/ψ production @ B-Factories II

Inclusive J/ψ production





Liu,He,Chao PRD 68, 031501

When $S^{1/2}$>20GeV, the two photon process will prevail over to the one photon process even it is suppressed by a factor $(\alpha/\alpha_s)^2$.

QED contribution to J/ψ production @ B-Factories II

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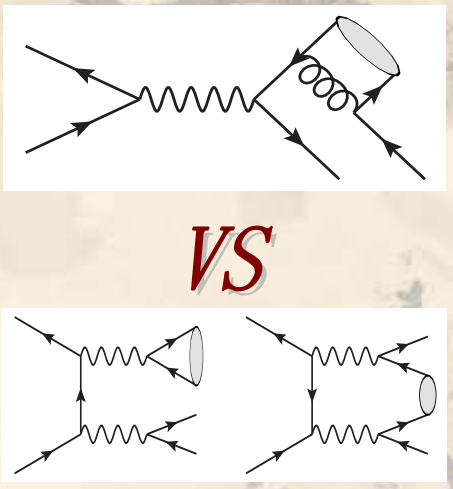

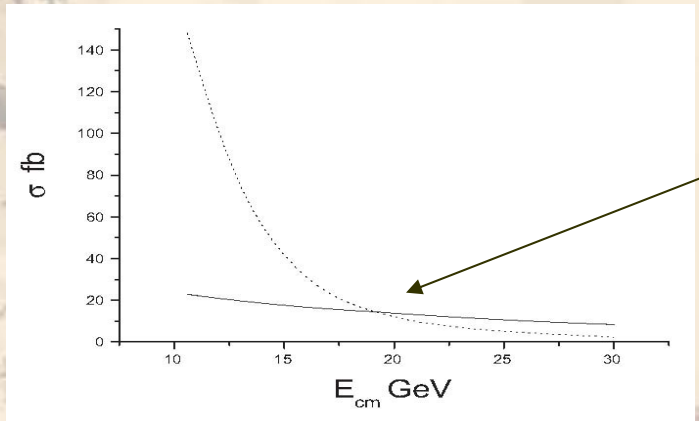

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When $S >> (m_{J/\psi})^2$, the QED contribution may be important!!!

QED contribution to J/ψ production @ B-Factories II

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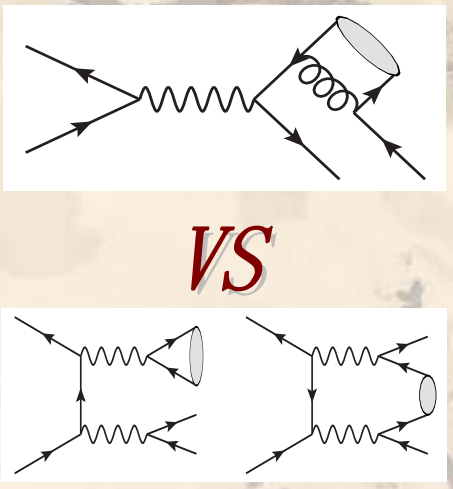

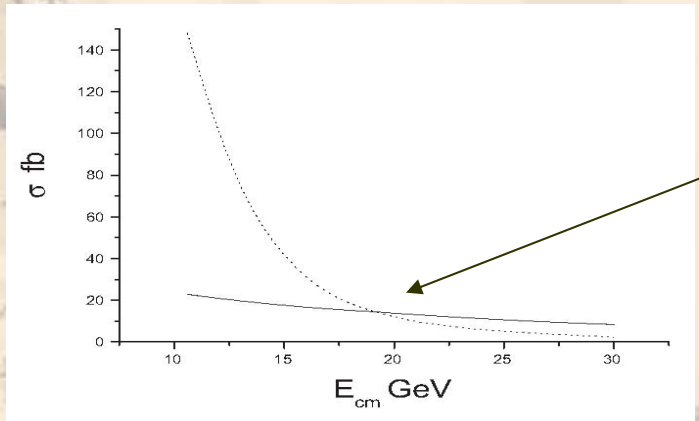

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Liu,He,Chao PRD 68, 031501

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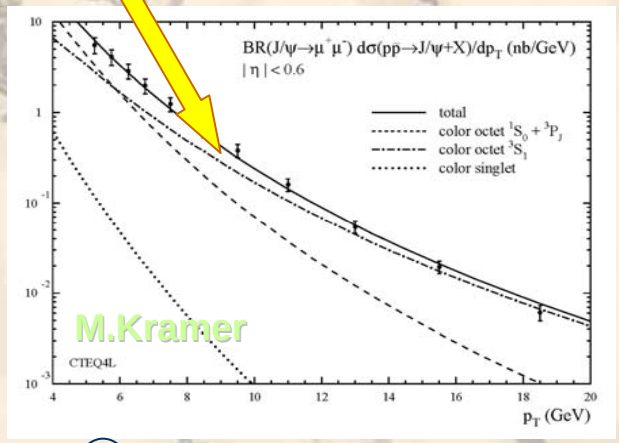
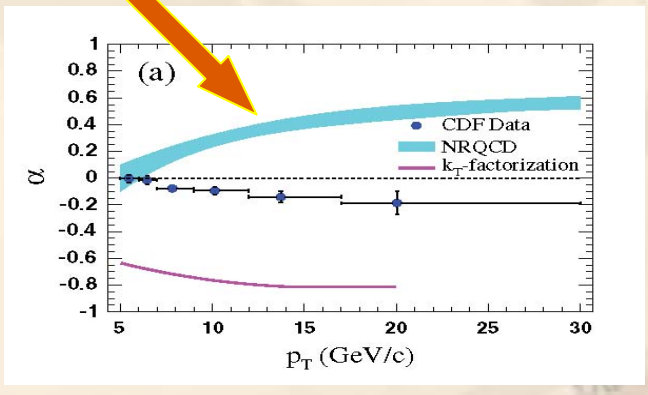
Next question: What will happen, when we consider the QED contribution to J/ψ hadroproduction???

J/ψ production @ Tevatron Ⅰ

The COM can explain the P_t distribution.

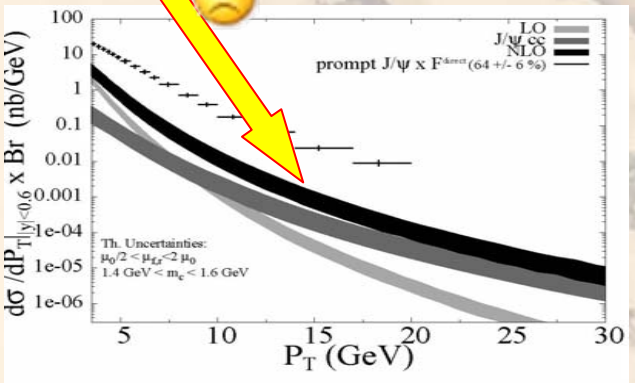


It can not explain the polarization.

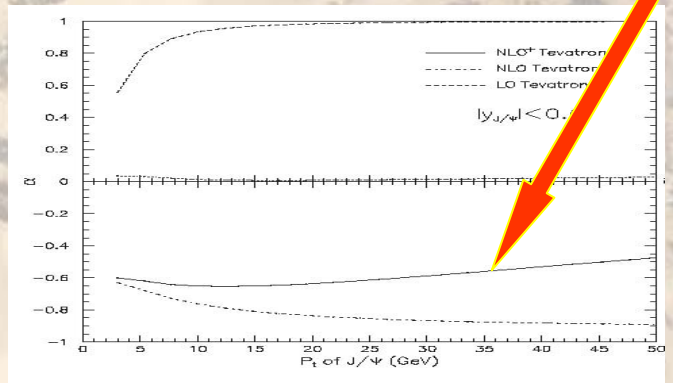


CDF PRL 99, 132001

In CS, P_t are largely changed when including NLO QCD corrections and so as the polarization .



Lansberg EPJC 60, 693

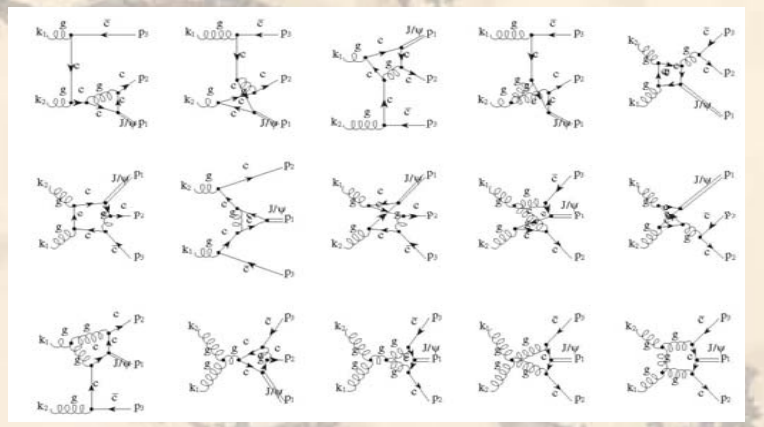


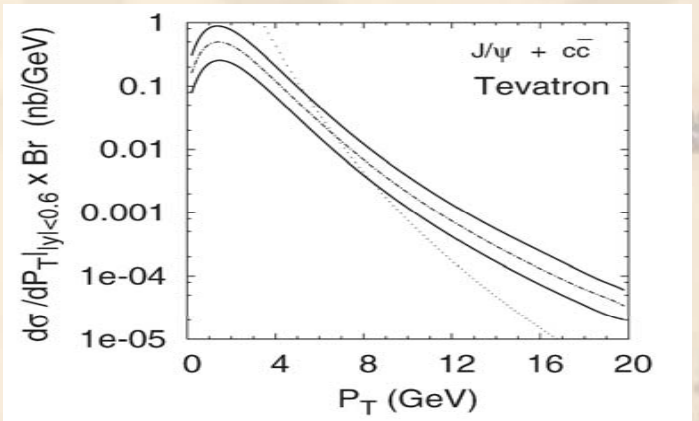
Gong, Wang, PRL 100, 232001

J/ψ production @ Tevatron II

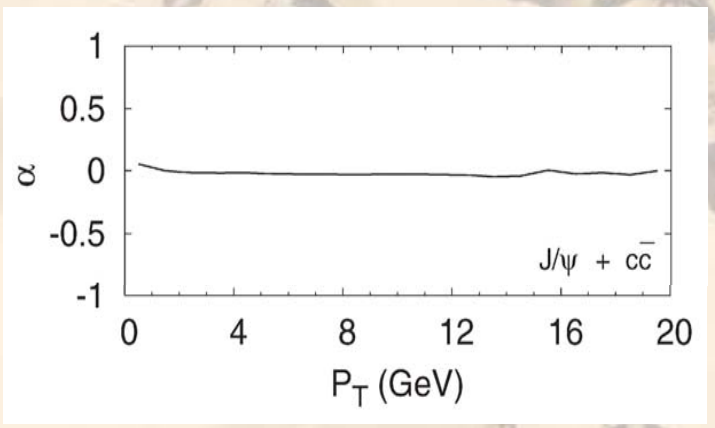
The J/ψ +$c\bar{c}$ process

- Part of α_s^4 corrections: gg →J/ψ +$c\bar{c}$





Artoisenet et al. PLB 653,60



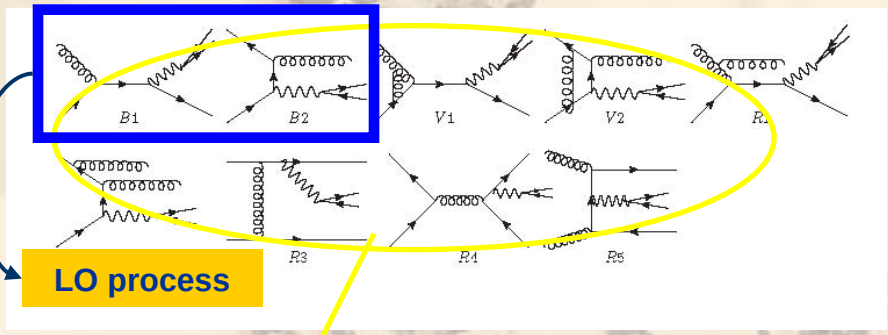
Artoisenet et al. PLB 653,60

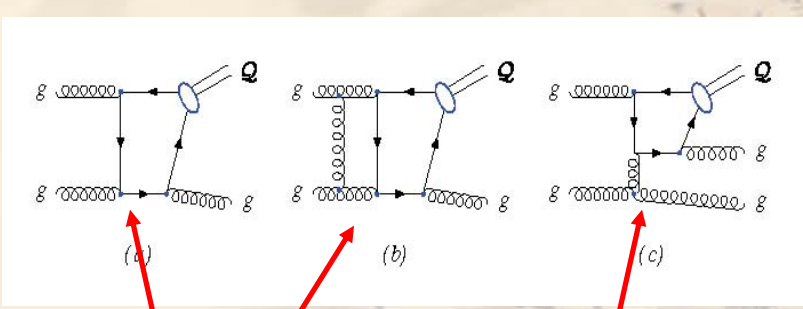
It's contribution to J/ψ production will be important at large p_t region.

The J/ψ is almost unpolarized in the whole region.

QED contribution to J/ψ +X production @ Tevatron and LHC Ⅰ

QED contribution up to $(\alpha\alpha_s)^2$ VS **QCD contribution up to α_s^4**

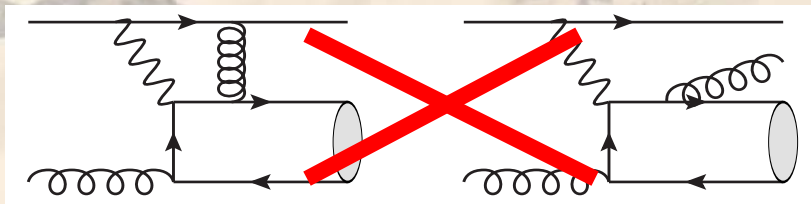




$d\sigma/dp_t \sim 1/p_t^4$ but $(\alpha/\alpha_s)^2$ suppressed

$d\sigma/dp_t \sim m_{J/\psi}{}^4/p_t^8$, $d\sigma/dp_t \sim m_{J/\psi}{}^2/p_t^6$

Note: The diagrams, in which J/ψ couples to three gauge bosons, are excluded.



QED contribution to J/ψ +X production @ Tevatron and LHC Ⅱ

LO results

Two partonic level sub-process:

$$g(p_1)+q(p_2)\to J/\psi(p_3)+q(p_4),$$
$$q(p_1)+\bar{q}(p_2)\to J/\psi(p_3)+g(p_4),$$

The analytical differential cross sections show explicit $1/p_t^4$ behaviors.

$$\frac{\mathrm{d}\hat{\sigma}_1}{\mathrm{d}t}=\frac{2\pi^2\alpha^2e_c^2e_q^2\alpha_s\langle\mathcal{O}_1^{J/\psi}\rangle}{3m_c^5s^2}\frac{((1-s)^2+(1-u)^2)}{su},$$
$$\frac{\mathrm{d}\hat{\sigma}_2}{\mathrm{d}t}=\frac{2\pi^2\alpha^2e_c^2e_q^2\alpha_s\langle\mathcal{O}_1^{J/\psi}\rangle}{3m_c^5s^2}\frac{((1-u)^2+(1-t)^2)}{ut}$$

where $s=\frac{(p_1+p_2)^2}{4m_c^2},\ t=\frac{(p_1-p_3)^2}{4m_c^2},\ u=\frac{(p_1-p_4)^2}{4m_c^2}$

Next NLO QCD corrections

Virtual corrections: 19 diagrams are left for each virtual processes.

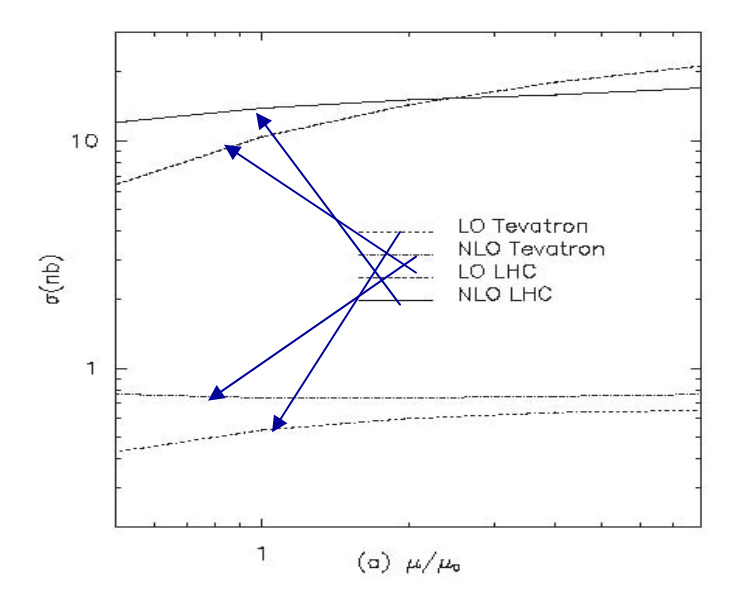
Real corrections: The real processes are divided into 7 categories.

$$gg\to J/\psi q\bar{q},\quad q\bar{q}\to J/\psi gg,$$
$$q\bar{q}\to J/\psi q\bar{q},\quad q\bar{q}\to J/\psi q'\bar{q}',$$
$$qq'\to J/\psi qq',\quad \bar{q}\bar{q}'\to J/\psi\bar{q}\bar{q}',$$
$$gq(\bar{q})\to J/\psi gq(\bar{q}),$$

After combining the real and virtual corrections, the UV and IR finite results are obtained!

QED contribution to J/ψ +X production @ Tevatron and LHC III

- The μ-dependence curves of the total cross sections



Parameters: $\alpha_s(M_Z)=0.130$ (LO), $\alpha_s(M_Z)=0.130$ (NLO), $m_c=M_{J/\psi}/2=1.5$ GeV, $\langle O_1^{J/\psi}\rangle=1.35\ \mathrm{GeV}^3$, and

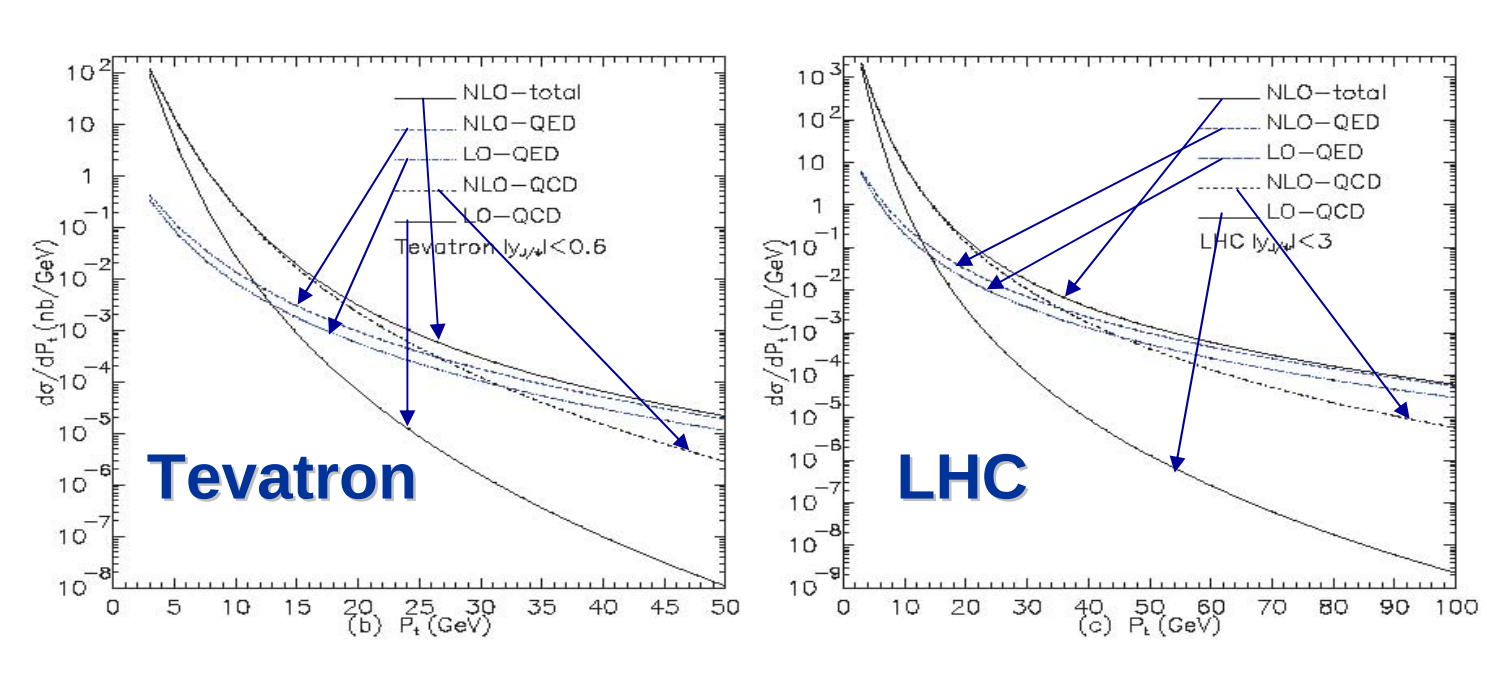
$$\mu_r = \mu_f = \mu_0 = \sqrt{4m_c^2 + p_t^2}\,.$$

Cut conditions: $P_t>3$GeV, $|y_{J/\psi}|<0.6$ (Tevatron), $|y_{J/\psi}|<3$ (LHC).

The NLO QCD corrections are positive, and they enhances the LO results by about 30%～40%, at $\mu_r=\mu_0$ for both Tevatron and LHC. And at NLO the μ-dependences are improved!

QED contribution to J/ψ +X production @ Tevatron and LHC Ⅳ

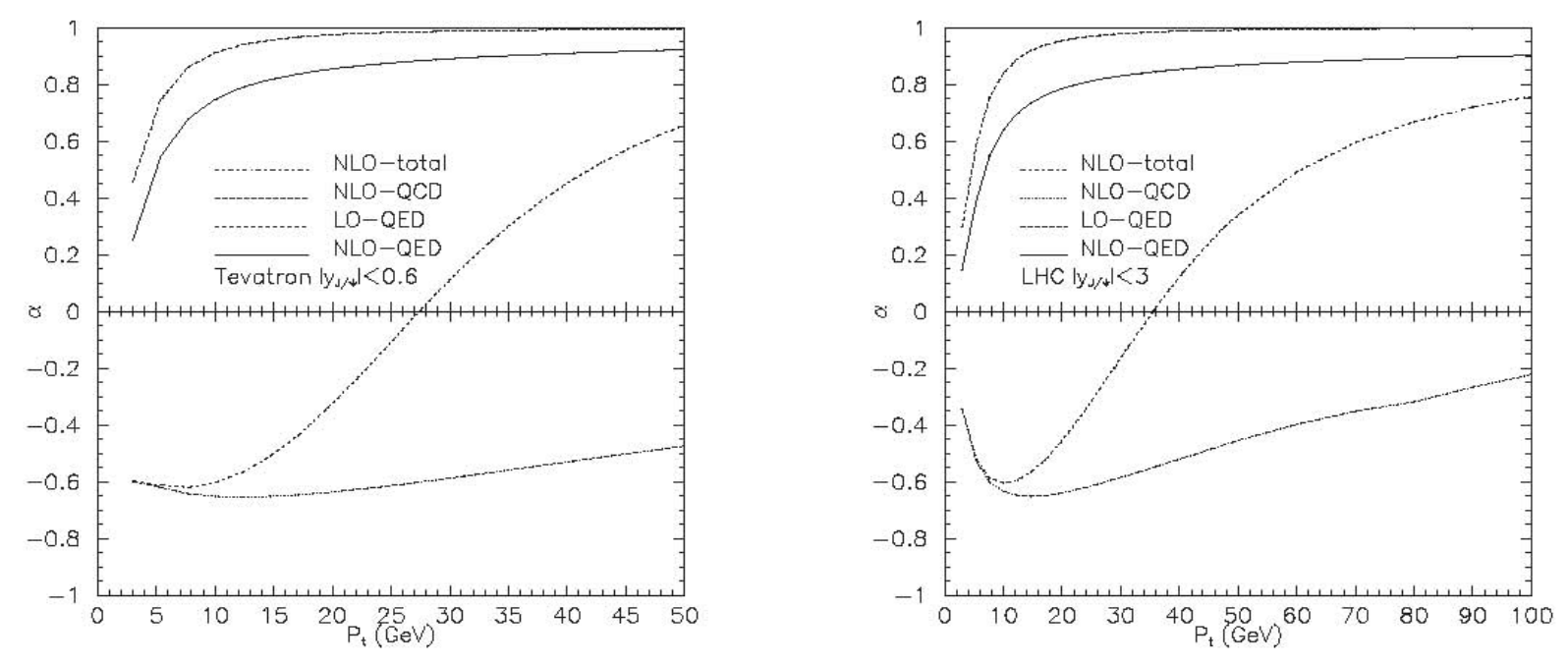
- The p_t distribution of the cross sections



At the Tevatron (LHC), the NLO QED contribution will be larger than that of the QCD contribution, when P_t >26 (35) GeV, and becomes 6 (10) times larger than that of the QCD contribution at P_t=50 (100) GeV.

QED contribution to J/ψ +X production @ Tevatron and LHC

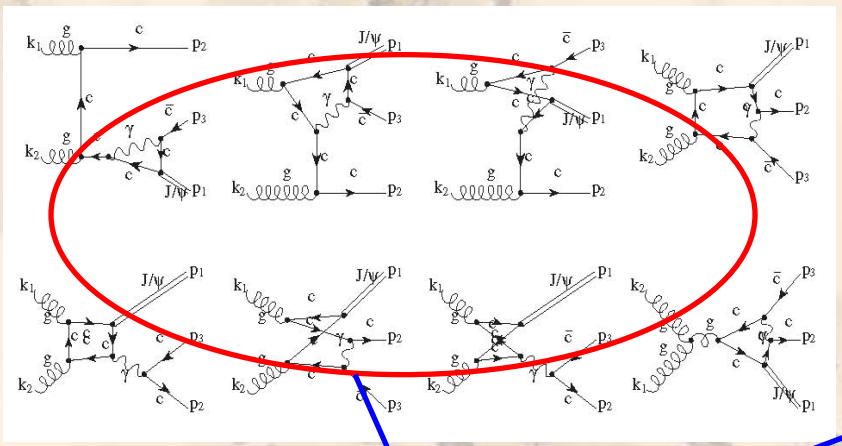
- The p_t distribution of the polarization of J/ψ :

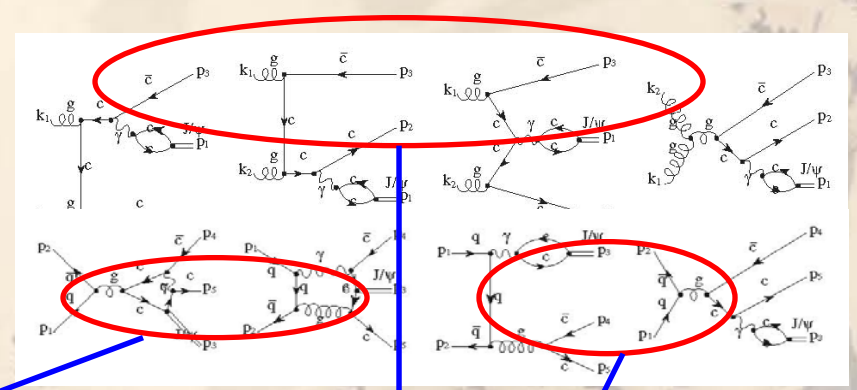


The J/ψ produced in the QED part mainly has transversal polarization. After combining both the QED and QCD parts, α changes from negative value to positive value rapidly.

QED contribution to J/ψ +c$\bar{c}$ production @ Tevatron and LHC Ⅰ

- gg(qq)→ J/ψ +c$\bar{c}$ process at O($\alpha^2 \alpha_s^2$)





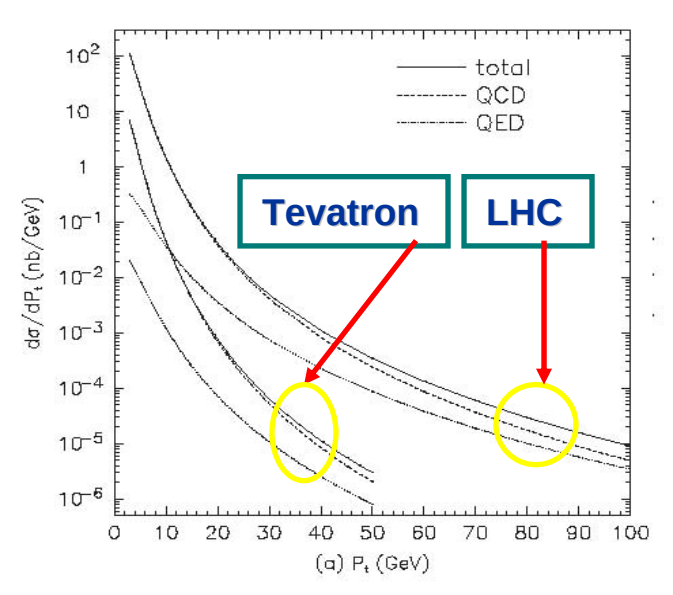
Non-fragmentation diagrams

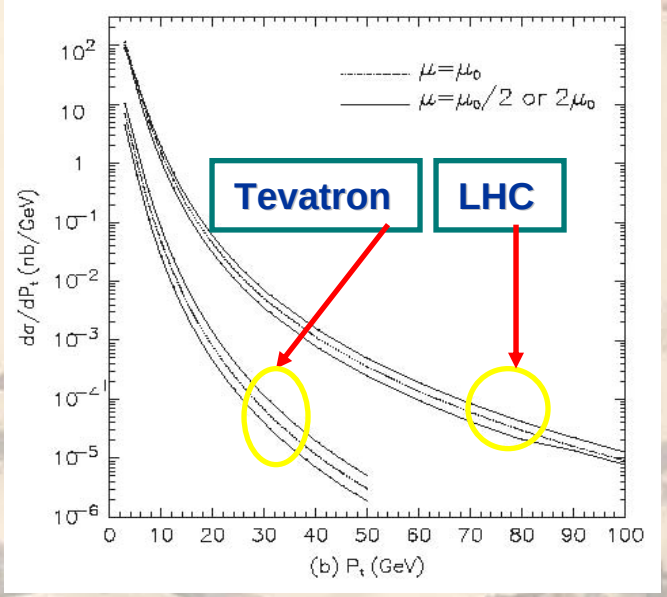
Fragmentation diagrams

The total cross sections of the QED part are about two orders of magnitude less than those of the QCD part in both Tevatron and LHC cases.

QED contribution to J/ψ +$c\bar{c}$ production @ Tevatron and LHC Ⅱ

- P_t distribution of the cross section

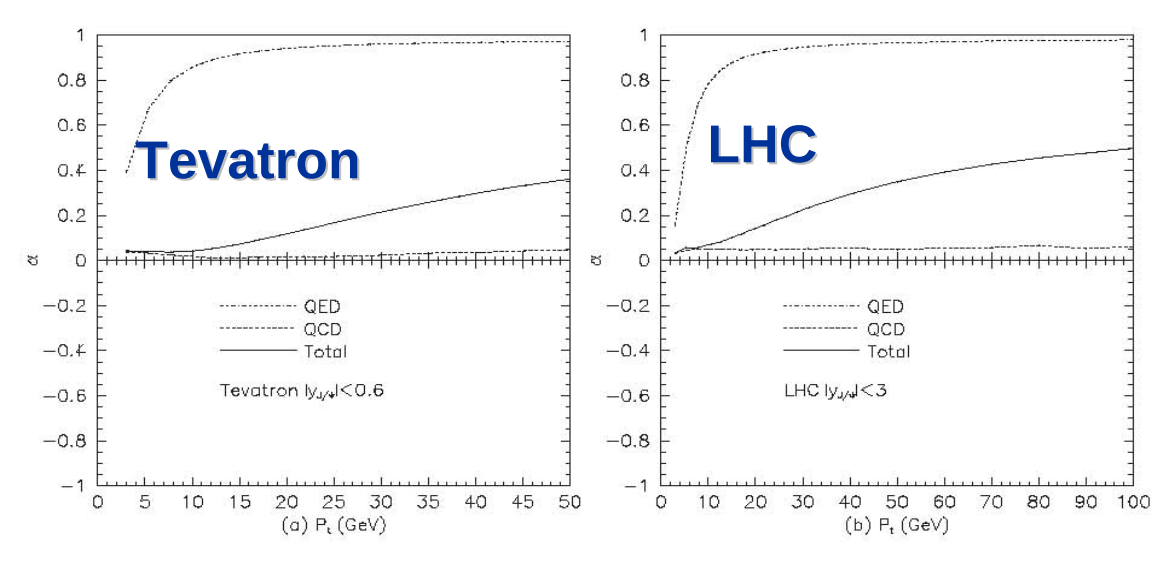




The p_t distribution of the QED part will be comparable to that of the QCD part in large p_t region.

QED contribution to J/ψ +$c\bar{c}$ production @ Tevatron and LHC III

- P_t distribution of J/ψ Polarization



The polarization of J/ψ will be changed largely, when the QED contribution is included in both Tevatron and LHC cases, even in the moderate p_t region.

Summary and conclusion

- The QED contribution to J/ψ production is important, when the typical energy scale is much larger $M_{J/\psi}$.
- For J/ψ prompt production at Tevatron (LHC), the P_t distribution of the QED part will be 6 (10) times larger than that of the CS QCD part at NLO, at P_t=50 (100) GeV.
- And the value of the polarization parameter α changes from negative to positive rapidly, when the QED contribution is taken into account.
- In the J/ψ +$c\bar{c}$ hadroproduction process, the QED contribution has a large impact on the P_t distribution in large P_t region and on the polarization distribution of J/ψ even in moderate P_t region.

Thank you !!