



Production of heavy quarks and quarkonia at LHC(b)

Vanya Belyaev (ITEP/Moscow)





Outline



- Heavy quark and quarkonia production
 - Why?
- LHCb experiment
- Open charm D^0 D^+ D_s Λ_c
- Hidden charm J/ψ ψ' χ_c
- Associative charm $2 \times J/\psi$ $J/\psi + C$ $2 \times C$ $Z^0 + C$
- Bottomonia Υ
- Next steps and conclusion



Heavy quarks & QCD



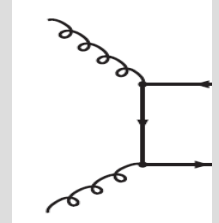
- HQ is likely the most powerful tool for quantitative study of QCD:
 $\alpha_s(m_Q)$, Λ_{QCD}/m_Q ,
 - Why one needs to know QCD ?
 - All mass of visible Universe is due to QCD
 - Higgs takes care only on $O(1\%)$ of proton mass
 - All fundamental quantities are affected by QCD corrections.
- The precise extraction is not possible without deep understanding of QCD
- Dominant source of systematic for Higgs properties
 - strong CP -problem
 - QCD effects could nicely mimic New Physics: DPS
 -



HQ and quarkonia production



- For high energy proton-proton collision (LHC)
 - Mainly gluon-gluon fusion
 - Contribution for other sources is small
 - Simple?
 - Long and rich history, experimental and theoretical
 - End of XX-century @ Tevatron:
 - DATA/theory $\gg 10$
 - Some improvements around mid 2000
 - Becomes clear that the pattern is not so simple....

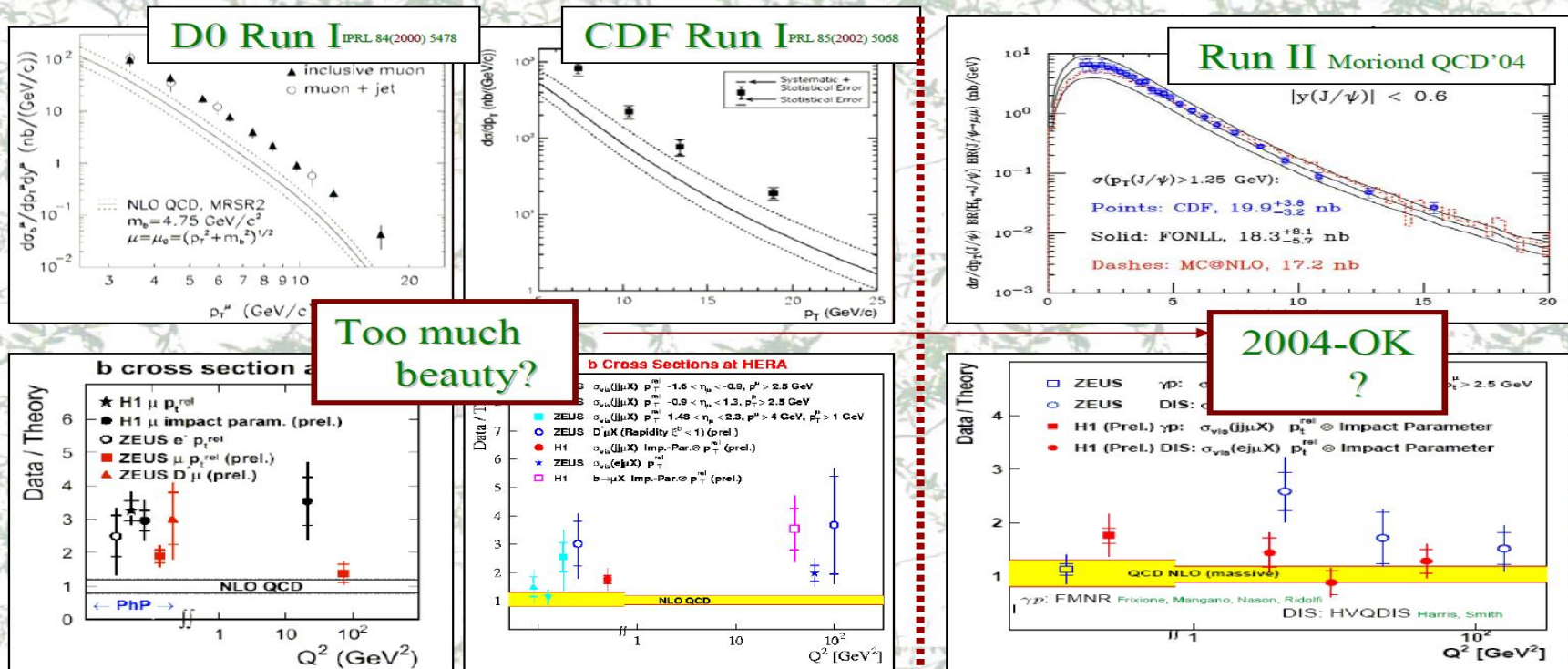




Some old slide: 2005



Beauty production at High Energy



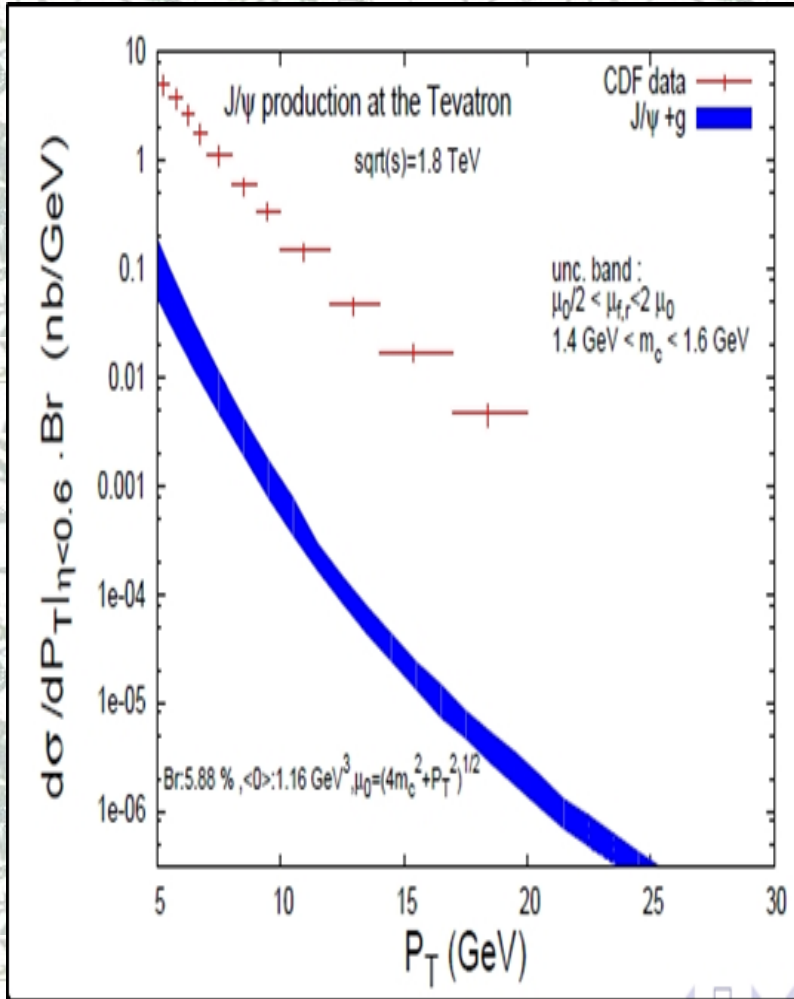
13 March'2k+5

"Heavy Flavours" Ivan Belyaev

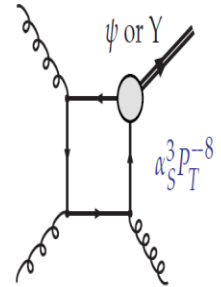
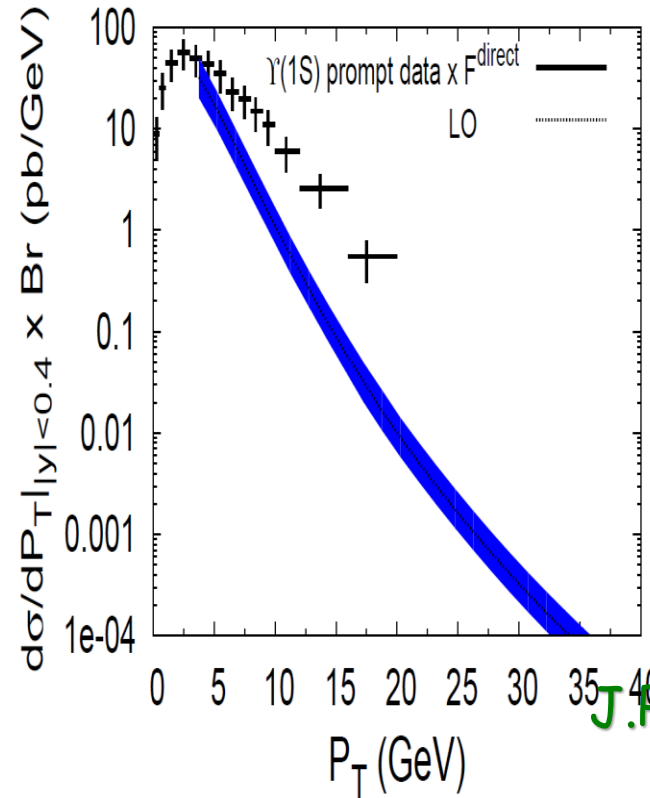
7



Another example J/ψ & Υ @Tevatron



J.Campbell, F. Maltoni, F. Tramontano, Phys.Rev.Lett. 98:252002,2007
P.Artoisenet, J.Campbell, JPL, F.Maltoni, F. Tramontano, Phys. Rev. Lett. 101, 152001 (2008)
CDF PRL 88 (2002) 161802; PRD 87, 052004 (2013)



J.P.Lansberg

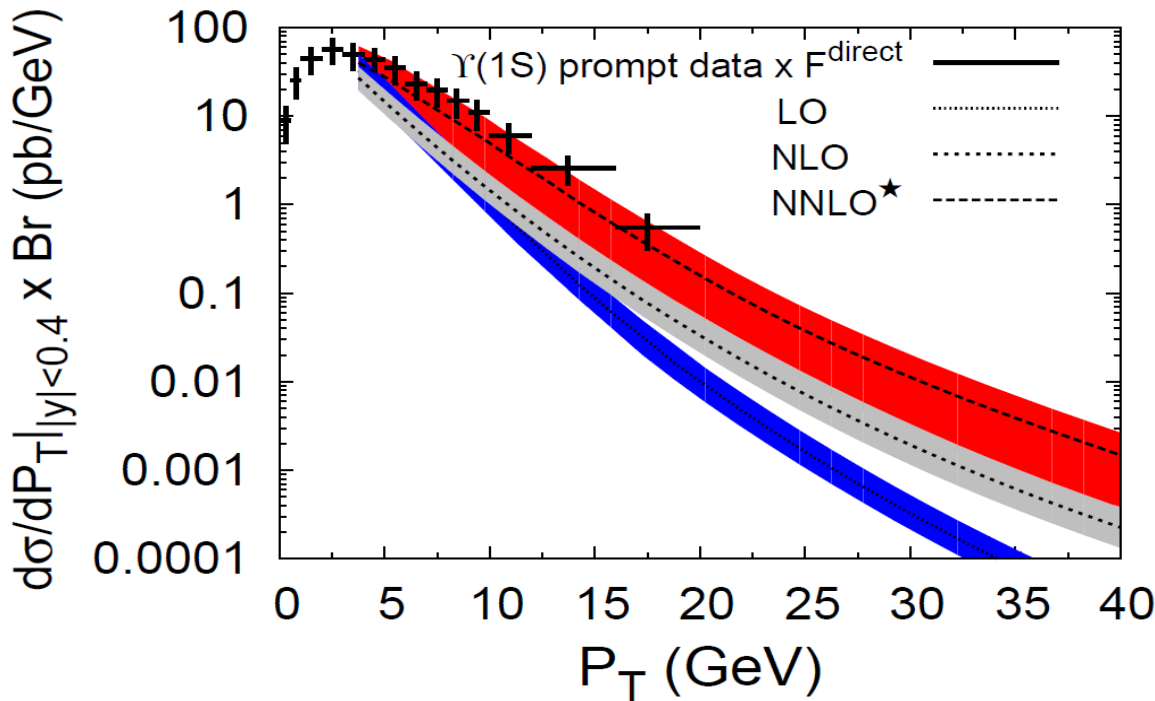


Progress with theory

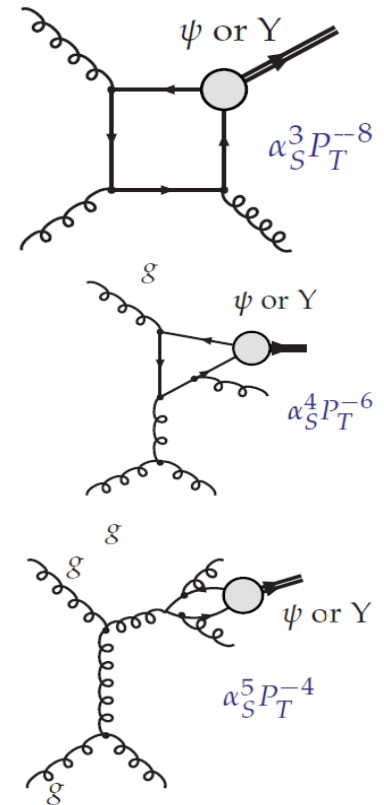


J.P.Lansberg

J.Campbell, F. Maltoni, F. Tramontano, Phys.Rev.Lett. 98:252002,2007
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CDF PRL 88 (2002) 161802;PRD 87, 052004 (2013)



+ double t -channel gluon exchange at α_S^5
Attention: the NNLO* is not a complete NNLO

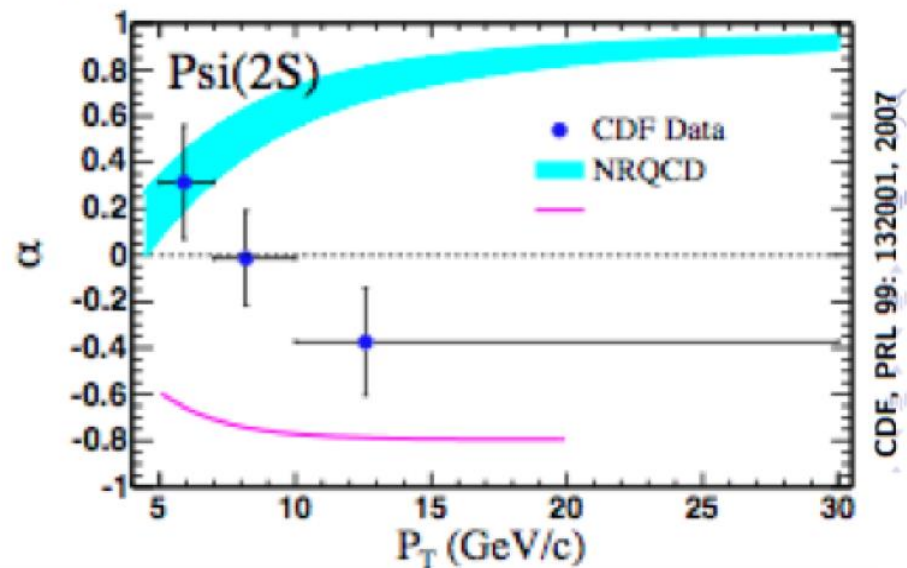
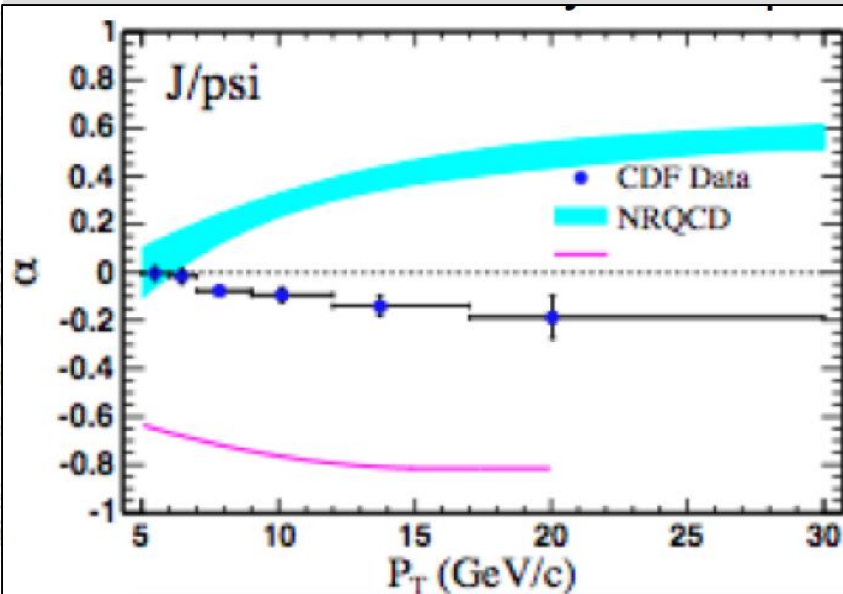




And what now?

- Almost 20 years of continuous progress
 - Great improvement between experiment and theory for cross-sections.
 - Everything understood?

Warning bell!



CDF, PRL 99: 132001, 2007



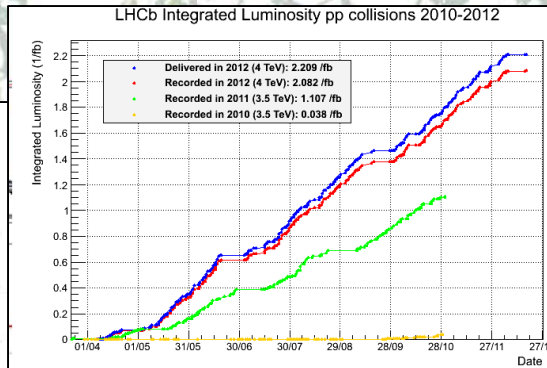
Polarization fiasco



- Reconsider the role of various mechanisms?
 - k_T -factorization?
- Importance of feed-down ?
 - Important to compare J/ψ and ψ'
 - Important to know production of P-wave states
- More data needed
- Other observables: $2 \times J/\psi$, quarkonia in pPb, $J/\psi + C$, $J/\psi + \Upsilon$, may shed light on the problem
LHCb is trying to attack all these targets..



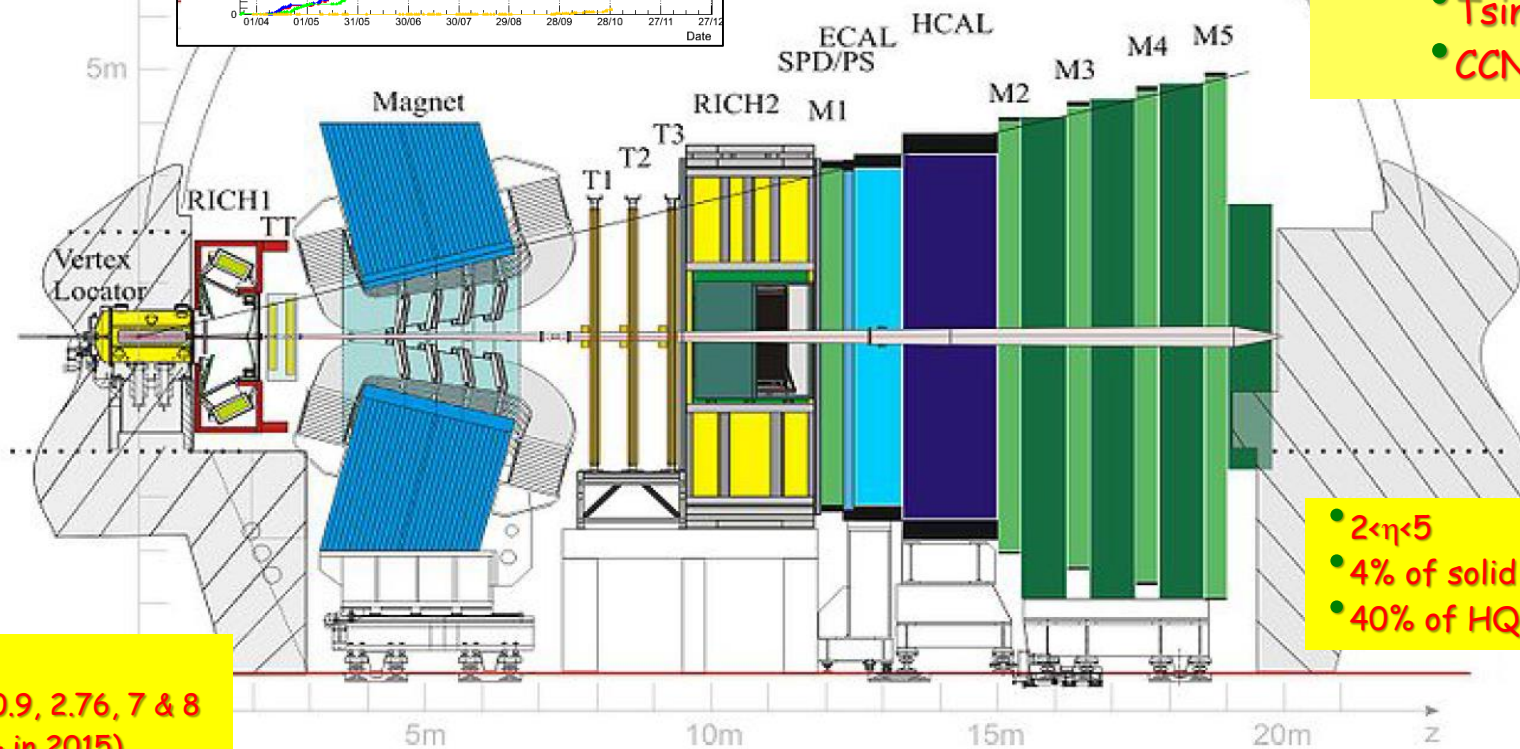
LHCb Experiment



- 1057 members
- 67 institutes
- 16 countries

2 groups from PRC

- Tsinghua
- CCNU



pp-collisions

$\sqrt{s} = 0.9, 2.76, 7 \text{ \& } 8$
(13++ in 2015)

pA and Ap

- $2 < \eta < 5$
- 4% of solid angle
- 40% of HQ



Trigger & Selection



- Very flexible trigger, down to low- p_T particles
 - Hardware: energetic (di)muon, hadron, $e^\pm$ or γ
 - Software: full reconstruction & particle ID
 - Typical efficiency for 2μ states $>70\%$, for hadronic states $\sim 30\%$
- Offline:
 - Refine reconstruction, track quality, particle ID, good common vertices,
 - For open charm and beauty exploit finite lifetime and require vertex separation

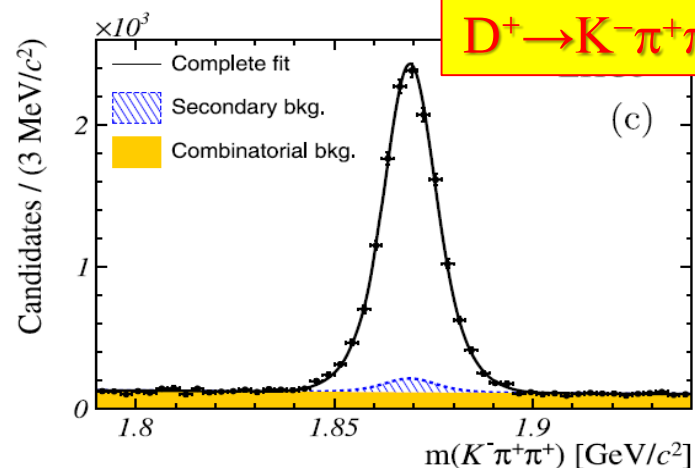
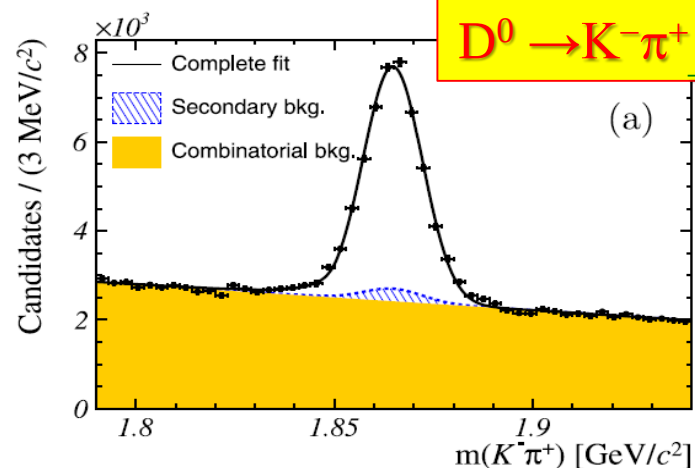
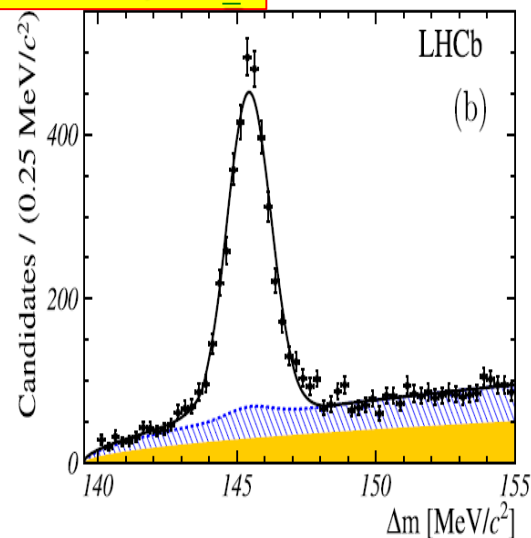
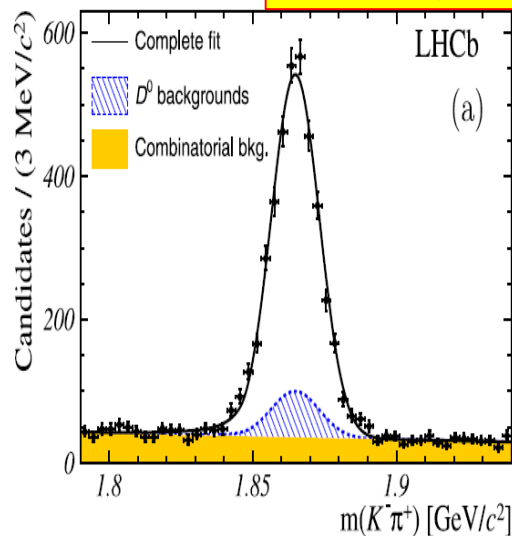


Prompt open charm D^0, D^{*+}, D^+

NPB 871(2013) 1

- “Early” measurement
 - only 15nb^{-1}
 - 5×10^{-6} from full dataset
- Contribution from $b \rightarrow c$ decays

$$D^{*+} \rightarrow (D^0 \rightarrow K^- \pi^+) \pi^+$$

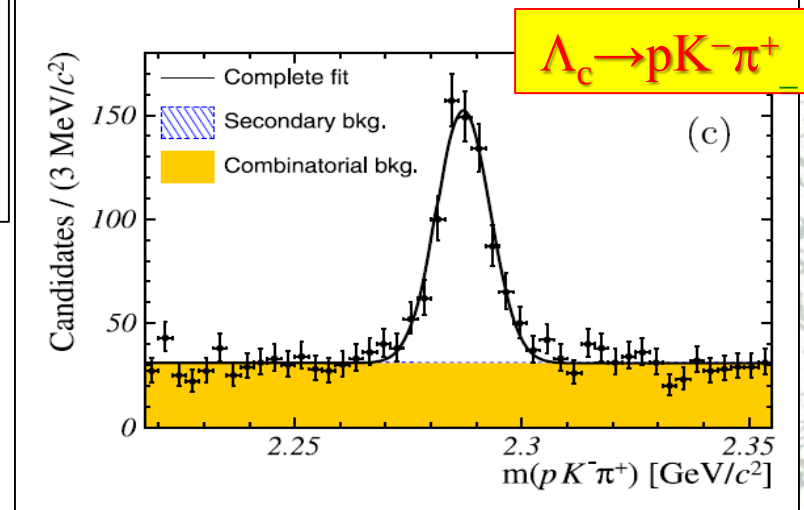
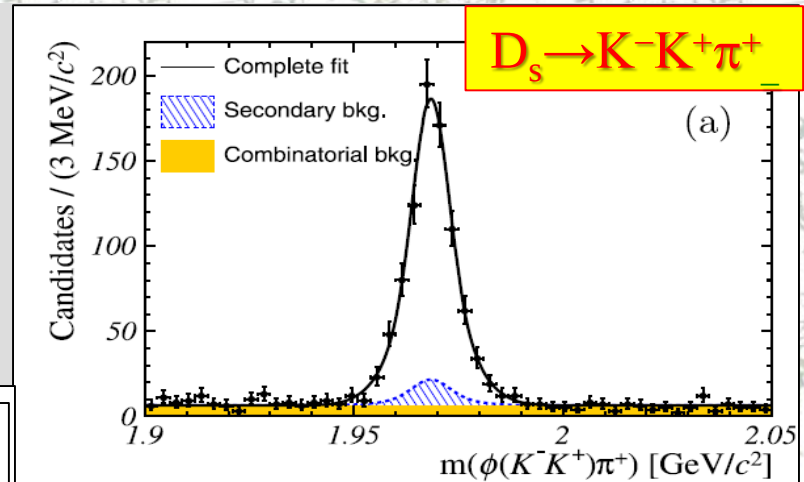
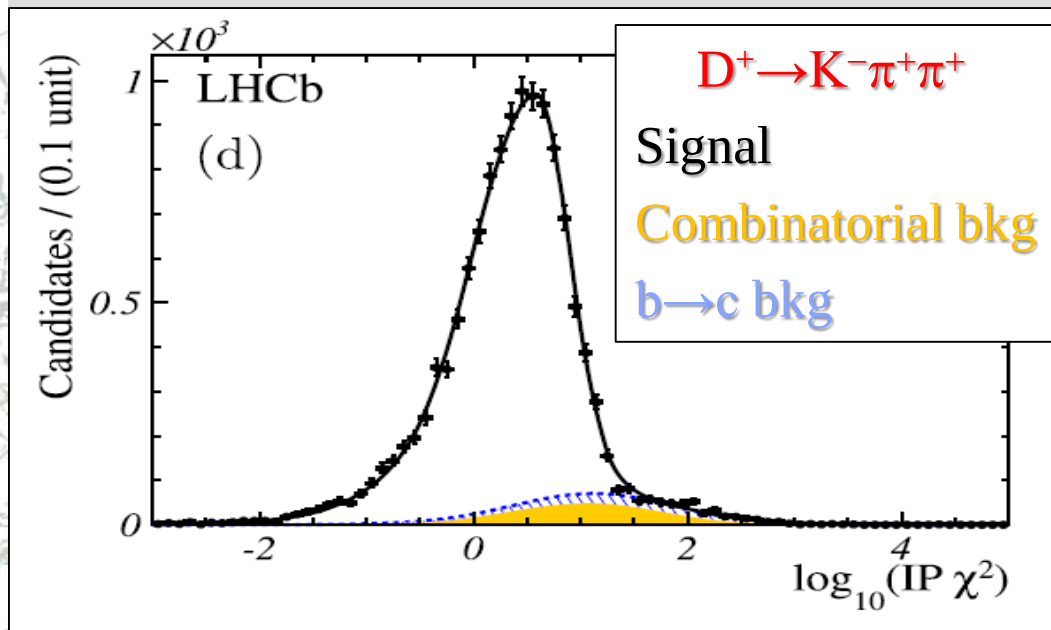




Prompt open charm D_s, Λ_c

NPB 871(2013) 1

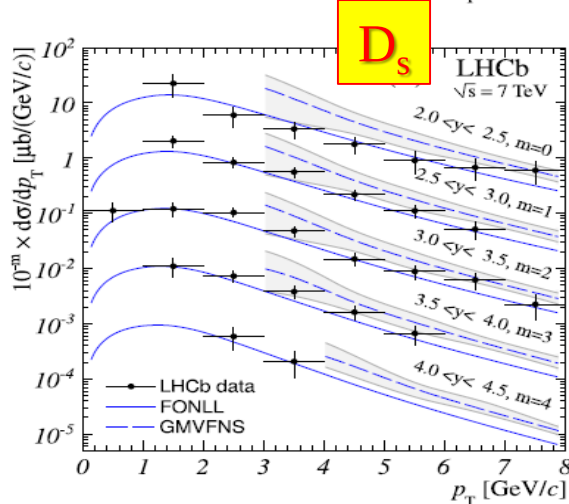
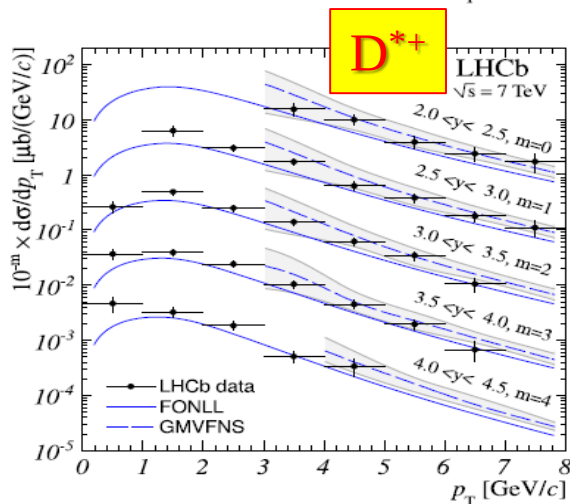
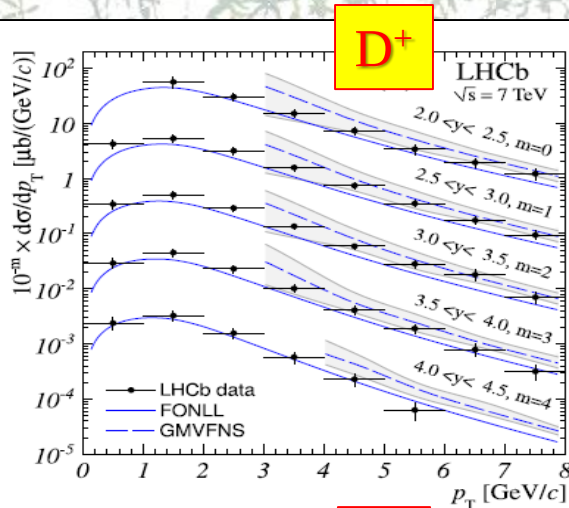
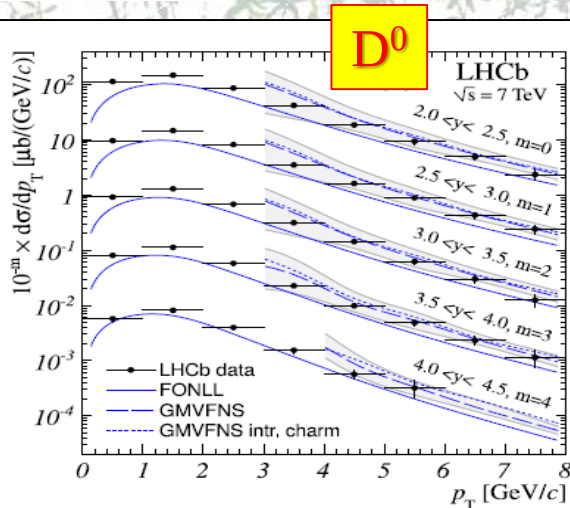
- All efficiencies were validated using data-driven techniques
- Major background has been extracted directly from data





Cross-sections vs theory

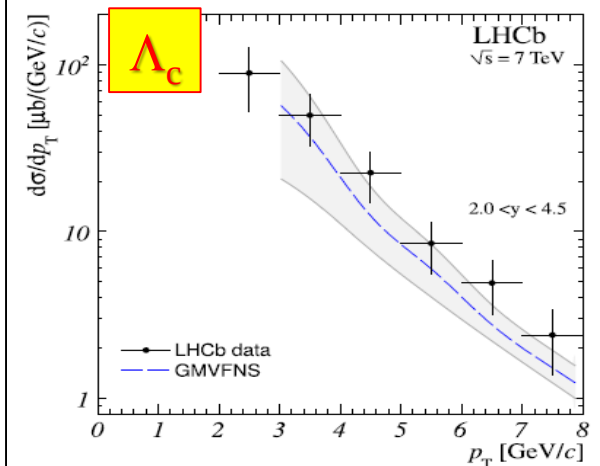
$$\sigma(c\bar{c})_{p_T < 8 \text{ GeV}/c, 2.0 < y < 4.5} = 1419 \pm 12 \text{ (stat)} \pm 116 \text{ (syst)} \pm 65 \text{ (frag)} \mu\text{b}.$$



$$\frac{d\sigma_i(H_c)}{dp_T} = \frac{1}{\Delta p_T} \cdot \frac{N_i(H_c \rightarrow f + \text{c.c.})}{\varepsilon_{i,\text{tot}}(H_c \rightarrow f) \cdot \mathcal{B}(H_c \rightarrow f) \cdot \mathcal{L}_{\text{int}}}$$

NPB 871(2013) 1

Good agreement with
GMVFNS Kniehl *et al.*
FONLL Cacciari *et al.*





Hidden charm J/ψ



EPJ C71 (2011) 1675

$J/\psi \rightarrow \mu^+\mu^-$ very nice signature, easy to trigger, low background

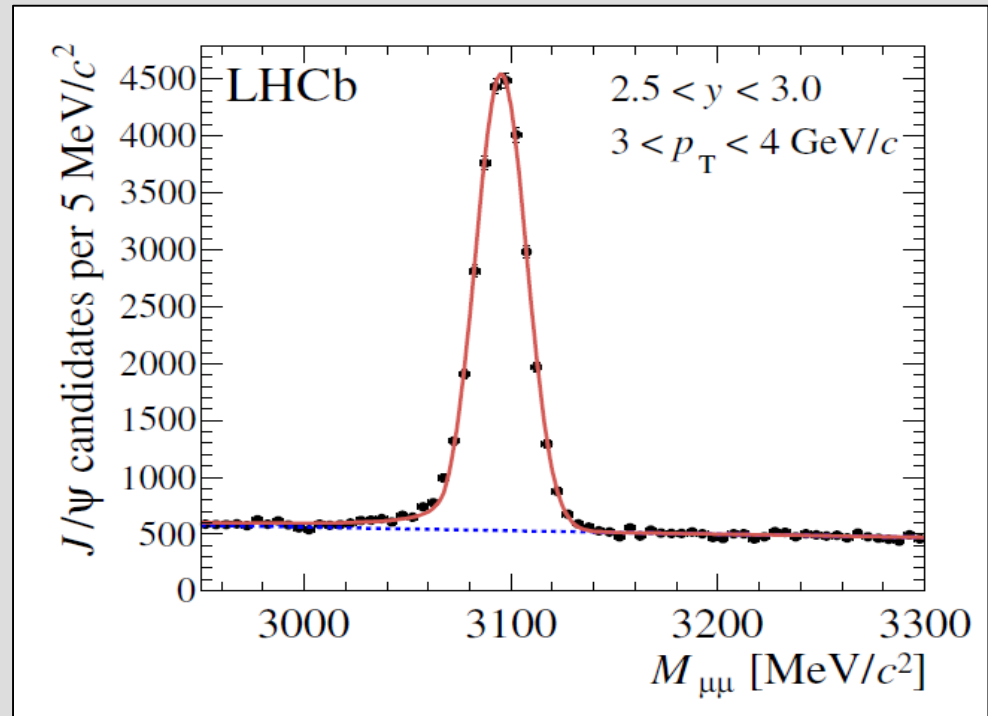
- Measure double differential cross-section

$$\frac{d^2\sigma}{dy dp_T} = \frac{N(J/\psi \rightarrow \mu^+\mu^-)}{\mathcal{L} \times \epsilon_{\text{tot}} \times \mathcal{B}(J/\psi \rightarrow \mu^+\mu^-) \times \Delta y \times \Delta p_T},$$

$$2 < y(J/\psi) < 4.5$$

$$p_T(J/\psi) < 14 \text{ GeV}/c$$

Efficiencies are
validated on data



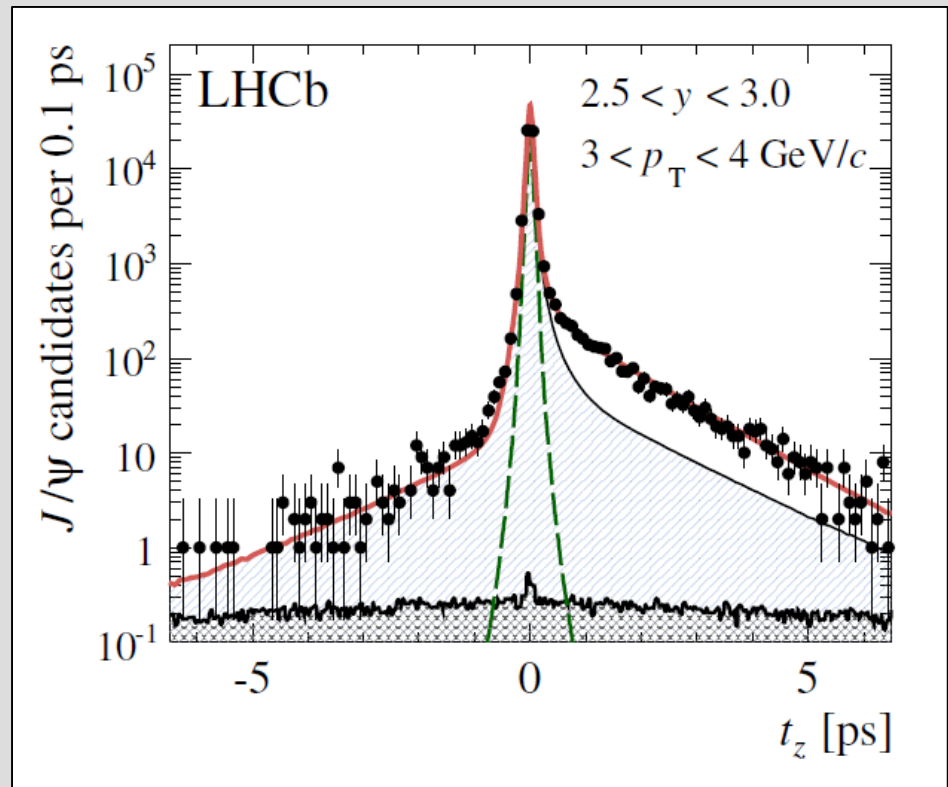


Contribution from B-decays

- There is large contribution from decays of long-lived B-hadrons, $\beta\gamma c\tau \sim O(1\text{cm})$
- Use "pseudo-lifetime"

$$t_z = \frac{(z_{J/\psi} - z_{PV}) \times M_{J/\psi}}{p_z},$$

- Simultaneous 2D-fit
 $m(\mu^+\mu^-)$
 t_z



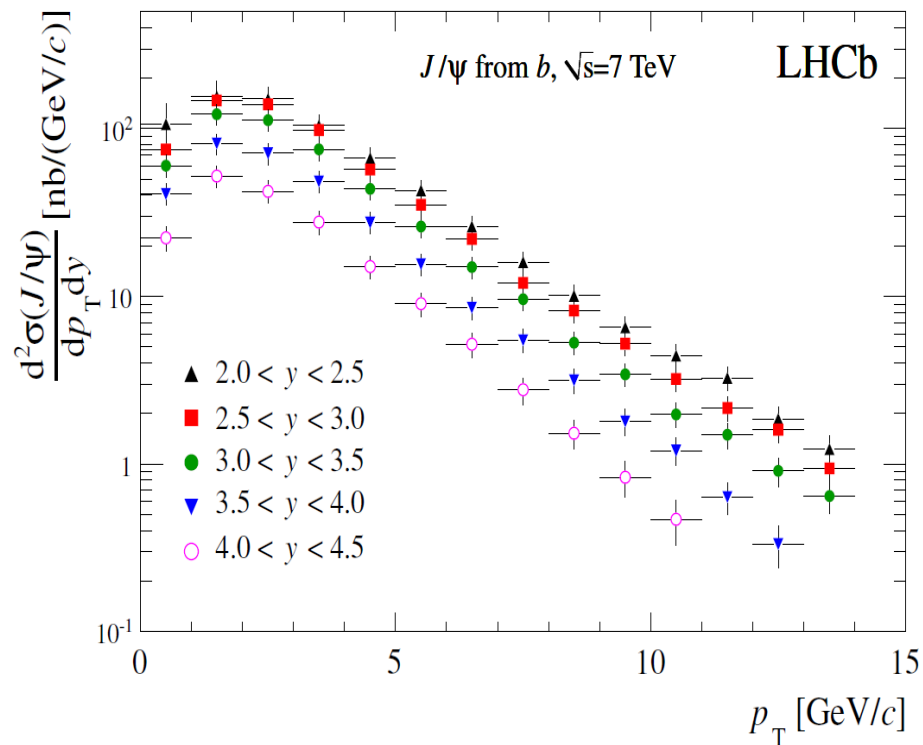
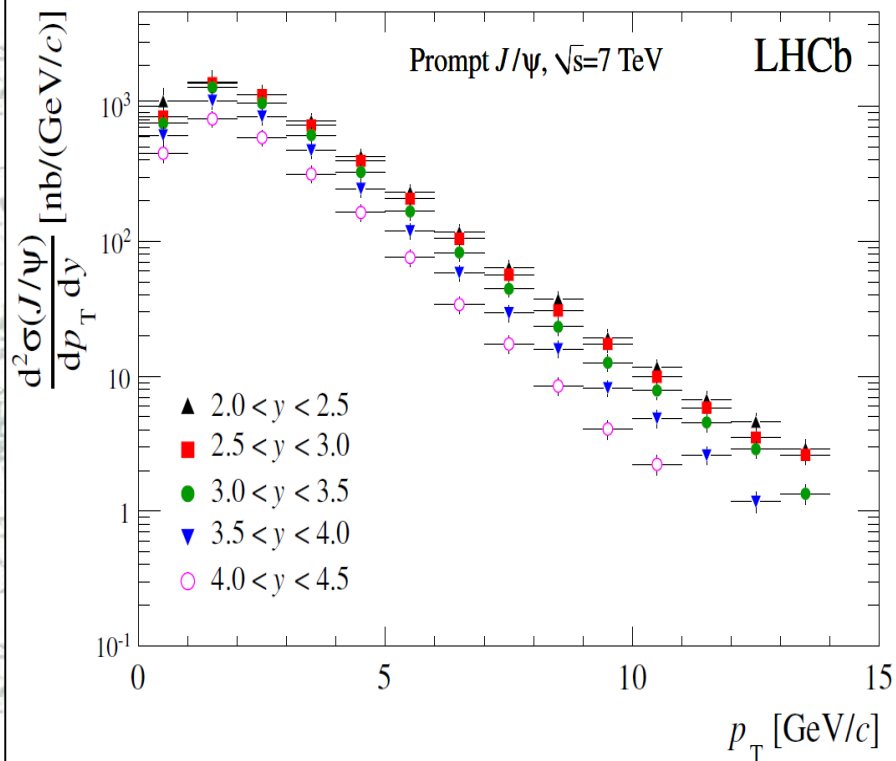


Differential cross-sections

EPJ C71 (2011) 1675

$$\frac{d^2\sigma}{dy dp_T} = \frac{N(J/\psi \rightarrow \mu^+\mu^-)}{\mathcal{L} \times \epsilon_{\text{tot}} \times \mathcal{B}(J/\psi \rightarrow \mu^+\mu^-) \times \Delta y \times \Delta p_T},$$

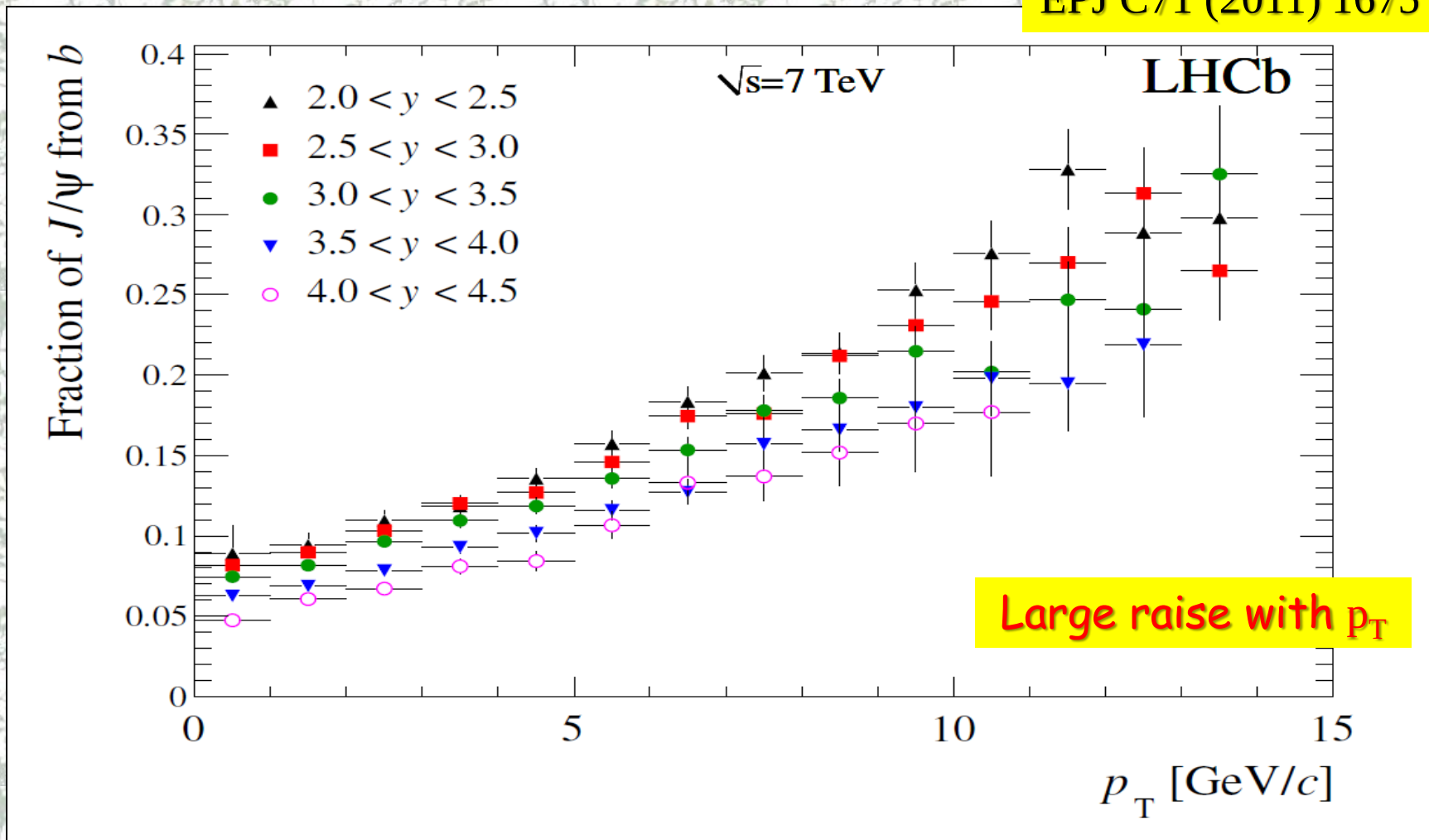
The slopes are different!





Fraction of J/ψ from B-decays

EPJ C71 (2011) 1675

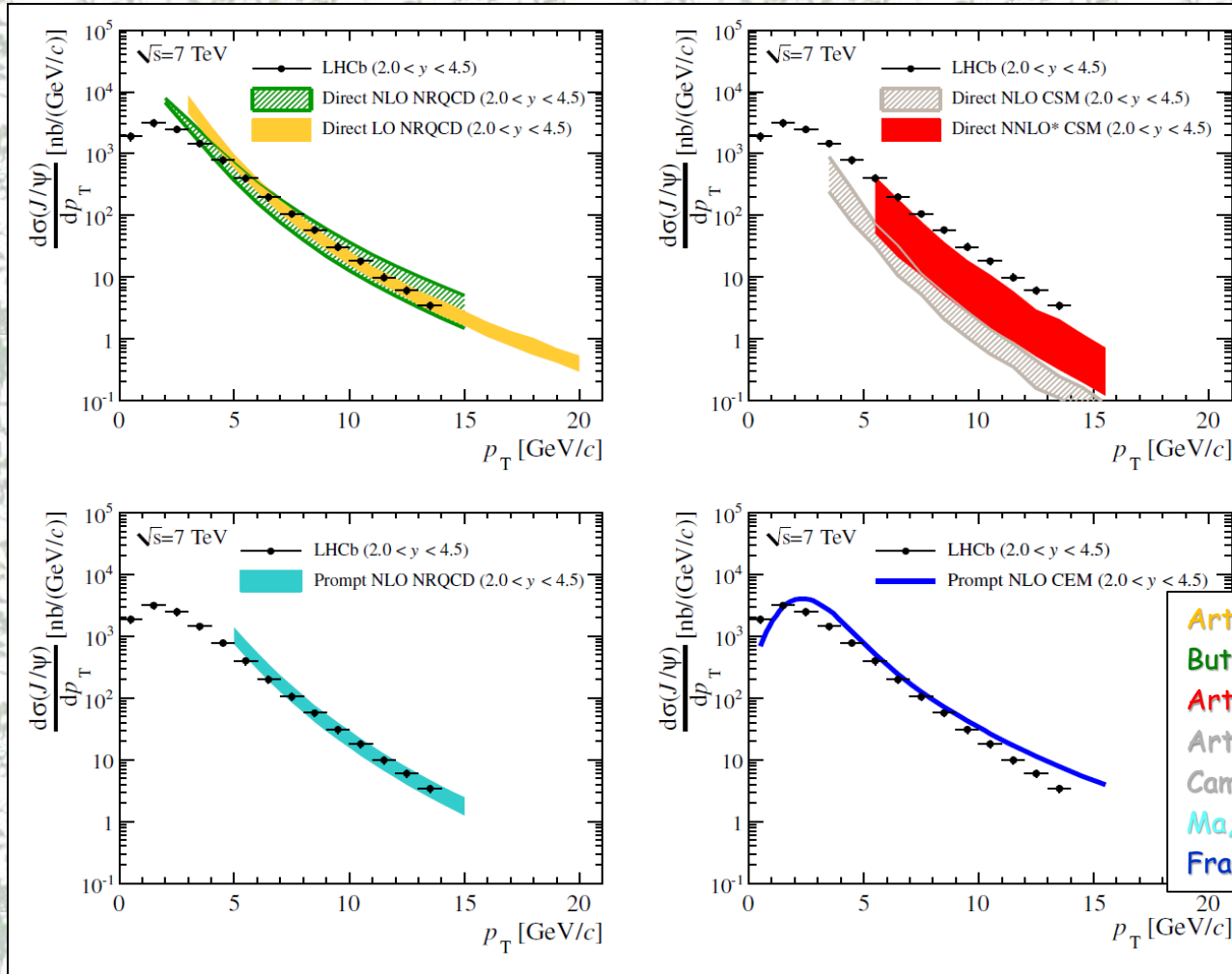




Prompt J/ψ DATA vs theory



EPJ C71 (2011) 1675



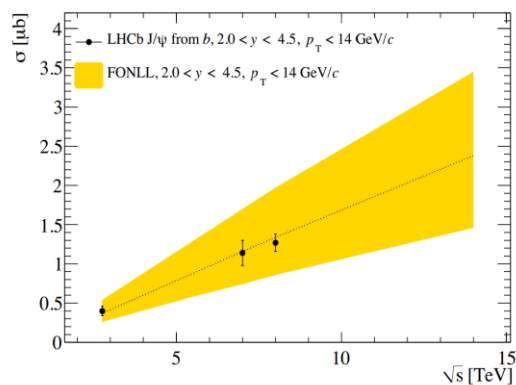
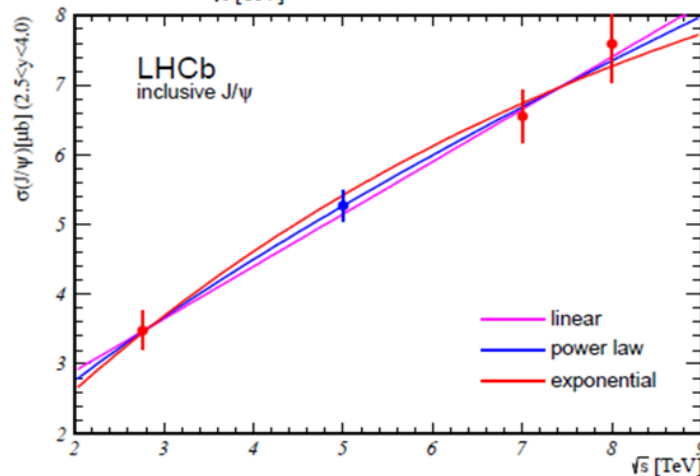
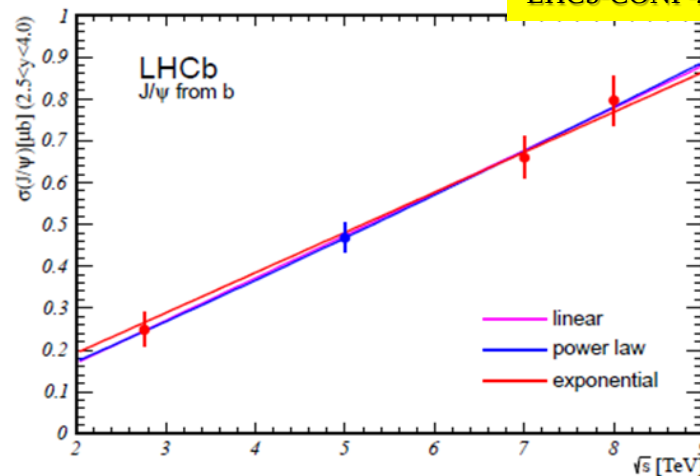
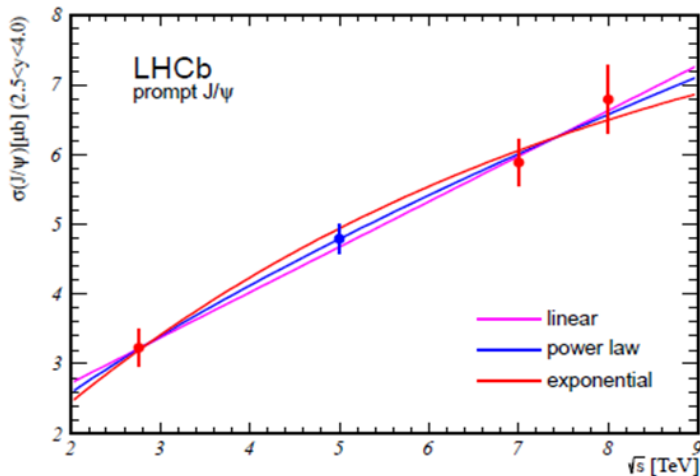
Artoisenet LO
 Butenshoen & Kniehl NLO
 Artoisenet et al, Lansberg, NNLO*
 Artoisenet, Lansberg, Maltoni;
 Campbell, Maltoni, Tramontano NLO CSM
 Ma, Wang, Chao NLO CS+CO
 Frawley, Ulrich, Vogt NLO CEM



J/ψ at $\sqrt{s}=2.76$ & 8 TeV



ALICE-PUBLIC-2013-002
LHCb-CONF-2013-013



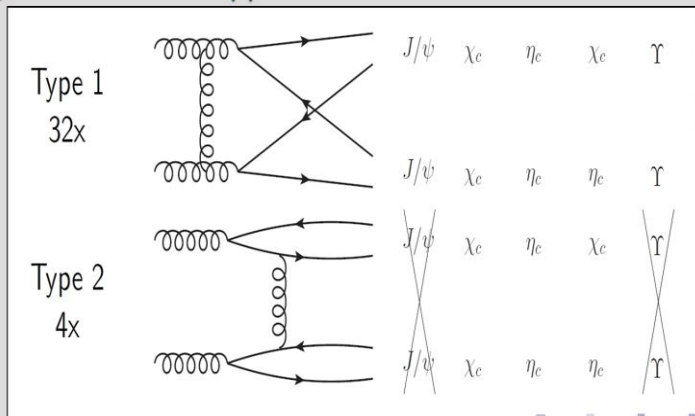
EPJ C71 (2011) 1675
JHEP 02 (2013) 041
JHEP 06 (2013) 064



Interesting case $2 \times J/\psi$

Valuable information for CS vs CO discrimination

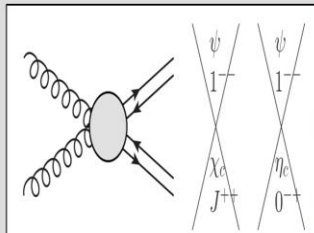
36 diagrams of two types



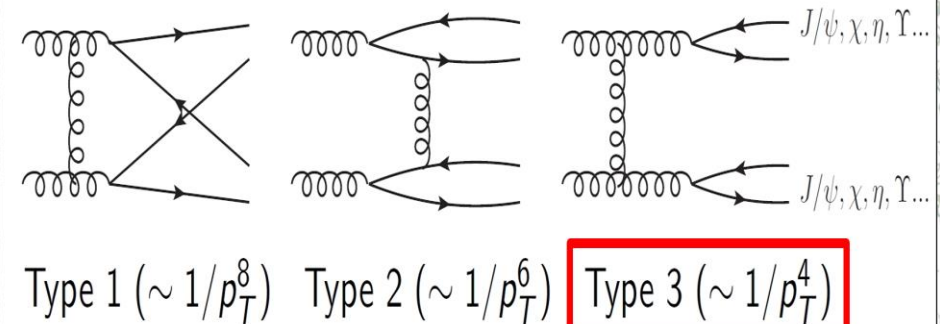
Intrinsically it can't be small!!

Selection rules:

(go off at (N)NLO)



No selection rules



"Small" $\sim 10^{-2 \dots -3}$ color-octet contribution to wave function of quarkonium

However could be dominating:

- For high p_T -region due to gluon fragmentation graph
- For final states, suppressed for CS scenario



2×J/ψ at (π,p)Pt collisions



NA3, 1982

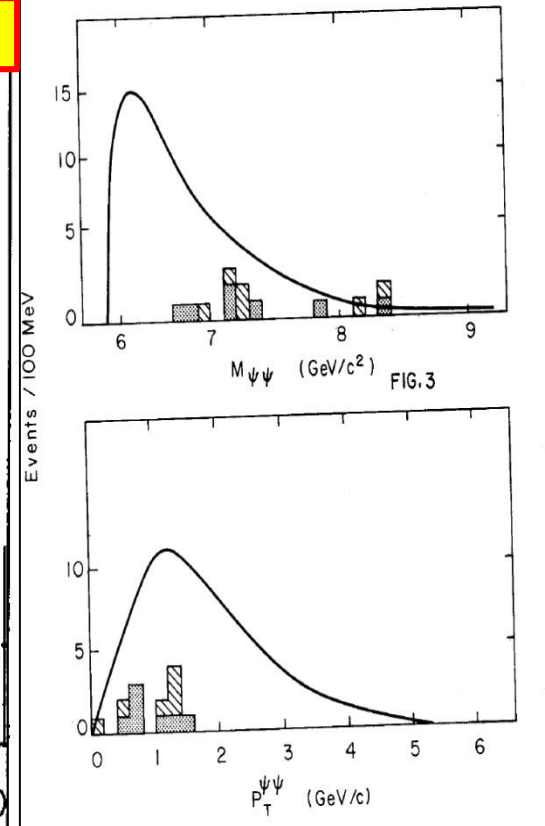
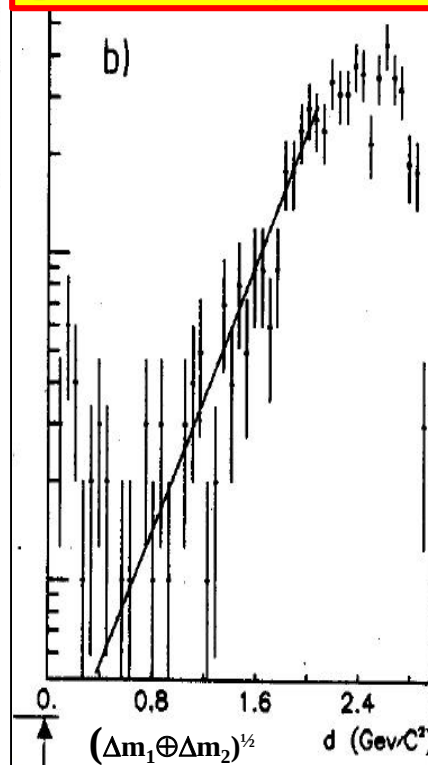
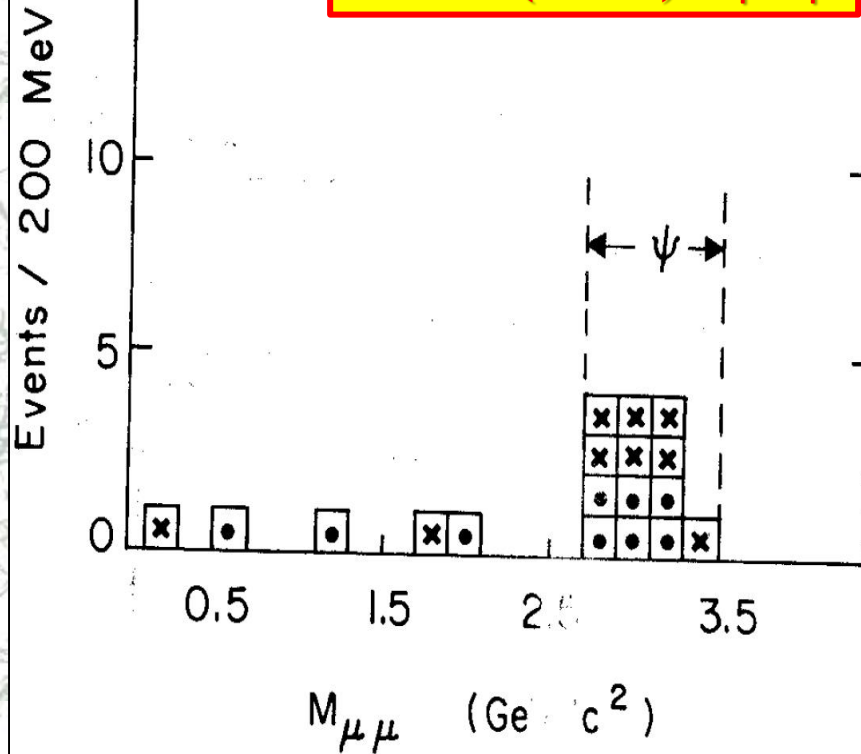
J. Badier *et al.*, "Evidence for $\psi\psi$ production in π^- interactions at 150 and 280 GeV/c", Phys. Lett. B 114, 457 (1982).

J. Badier *et al.*, " $\psi\psi$ production and limits on beauty meson production from 400 GeV/c protons", Phys Lett B 158, 85 (1985)

$$\sigma^{J/\psi J/\psi} / \sigma^{J/\psi} = (3 \pm 1) \times 10^{-4}$$

πPt: 13 (= 6+7) J/ψJ/ψ

pPt: 16±4 J/ψJ/ψ

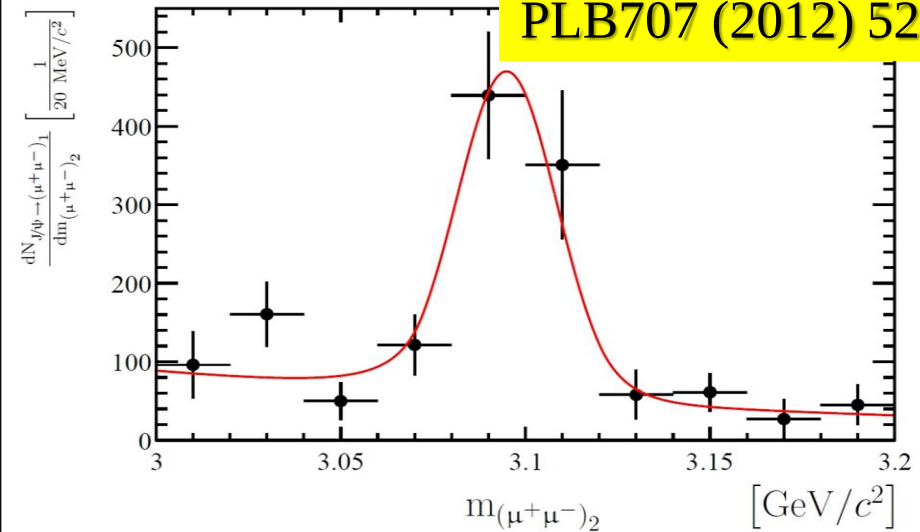
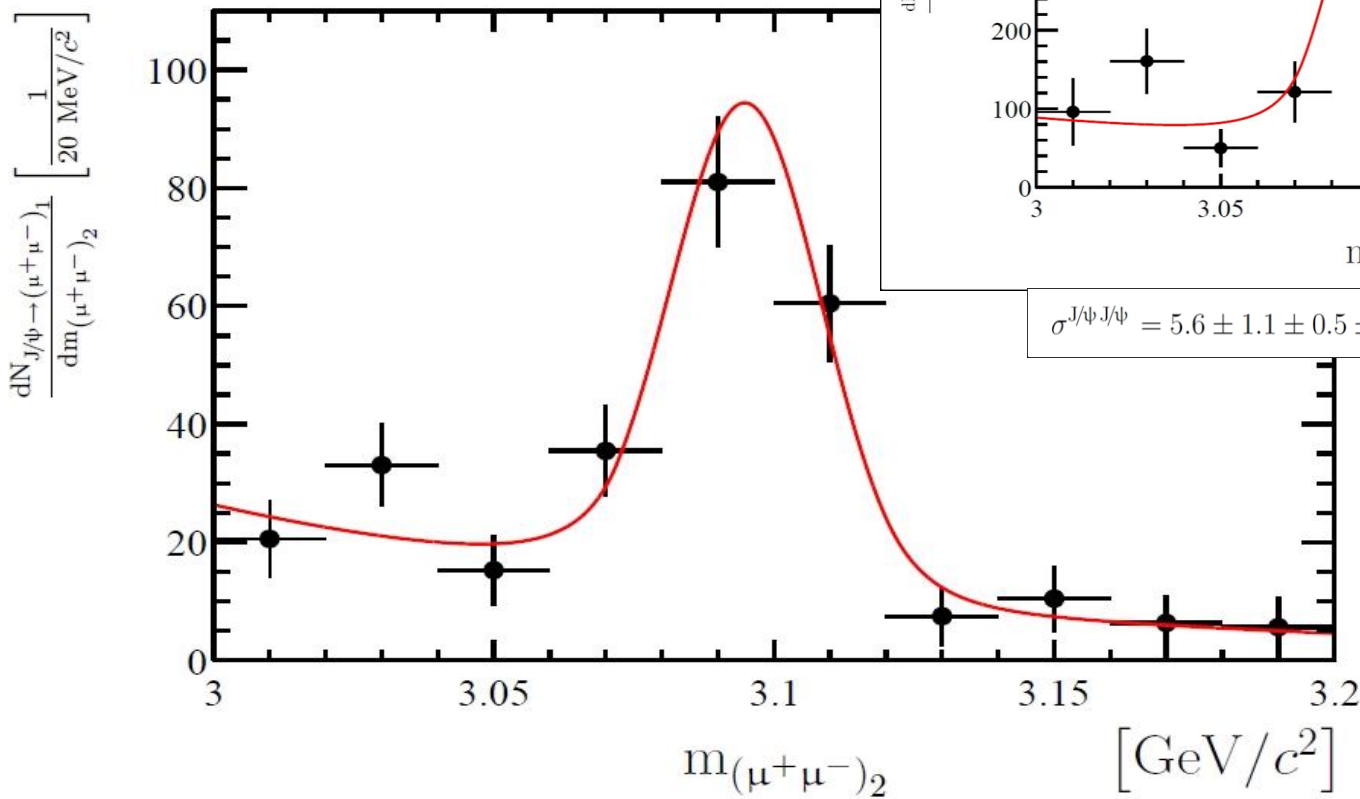




2×J/ψ at LHCb



#J/ψJ/ψ = 136.7 ± 17.5



$$\sigma^{J/\psi J/\psi} = 5.6 \pm 1.1 \pm 0.5 \pm 0.9|_{\text{tr}} \pm 0.6|_{\mathcal{L}} \text{ nb},$$

Theory: CS ~4nb

- Qiao, Sun, Sun
- Berezhnuy et al.



Double Parton Scattering

Google >300k documents



Double-Parton Scattering is Not Rare « Collider Blog

muon.wordpress.com/.../double-parton-scatt... - Перевести эту страницу

29 Dec 2009 – The thrust of the Berger, Jackson and Shaughnessy paper is a study showing that clear evidence for **double-parton scattering** can be obtained ...

[PDF] Double Parton Scattering at the LHC –

moriond.in2p3.fr/QCD/2011/.../Berger.pdf - Перевести эту страницу

Формат файлов: PDF/Adobe Acrobat - Быстрый просмотр

Double Parton Scattering at the LHC –. Dynamic and Kinematic Characteristics.

Example: $pp \rightarrow b\bar{b}$ jet jet X. Edmond L Berger. Argonne National Laboratory ...

Phys. Rev. D 56, 3811 (1997): Double parton scattering in $p[\overline{p}]p$...

link.aps.org/.../Volume 56/Issue 7 - Перевести эту страницу

The process-independent parameter of **double parton scattering**, σ_{eff} , is obtained without reference to theoretical calculations by comparing observed DP events ...

Fresh look at double parton scattering - APS Link Manager

link.aps.org/.../Volume 83/Issue 11 - Перевести эту страницу

24 Jun 2011 – A revised formula for the inclusive cross section of a **double parton scattering** process in a hadron collision is suggested basing on the modified ...

Double Parton Scattering

www-cdf.fnal.gov/.../double_parton_summ... - Перевести эту страницу

Double Parton Scattering in $p\bar{p}$ -p Collisions at $\sqrt{s} = 1.8$ TeV In a paper submitted to Physical Review Letters, the CDF collaboration announced the first ...

Signals for Double Parton Scattering at the Fermilab Tevatron

arxiv.org/hep-ph - Перевести эту страницу

29 May 1996 – Abstract: Four **double-parton scattering** processes are examined at the Fermilab Tevatron energy. With optimized kinematical cuts and realistic ...

Double parton scattering of hadron-hadron interaction and its ...

arxiv.org/hep-ph - Перевести эту страницу

25 Apr 1997 – Title: **Double parton scattering** of hadron-hadron interaction and its gluonic contribution. Authors: Hung Hsiang Liu (Inst. of Phys, Academia ...

[PDF] Signals for Double Parton

www.phys.psu.edu/~cteq/.../flaughner.pdf - Перевести эту страницу

Формат файлов: PDF/Adobe Acrobat - Быстрый просмотр

Double Parton Scattering (DPS). Two parton-parton hard scatters in one pp collision. Extend knowledge of proton structure. 0 spatial distribution of partons inside ...

High Energy Physics Group - Double Parton Scattering

www.hep.phy.cam.ac.uk/theory/.../dps.html - Перевести эту страницу

Cavendish High Energy Physics Group Research Theory **Double Parton Scattering**.

Is double parton scattering useful?

www.physicsforums.com/showthread.php?t... - Перевести эту страницу

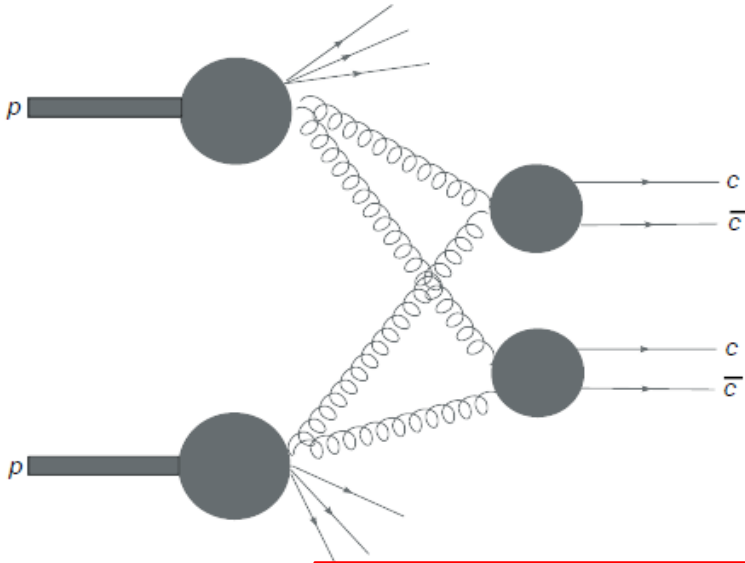
Заблокировать все результаты с www.physicsforums.com

Сообщений: 2 - Авторы: 2 - 19 июл 2011

Is **double parton scattering** useful? High Energy, Nuclear, Particle Physics discussion.



DPS: simple paradigm



Two independent scattering processes
Relations through (unknown) $_2$ PDFs

$$\Gamma_{ij}(x_1, x_2; b_1, b_2; Q_1^2, Q_2^2) = D_h^{ij}(x_1, x_2; Q_1^2, Q_2^2) f(b_1) f(b_2),$$

Assume factorization of $_2$ PDFs

$$D_h^{ij}(x_1, x_2; Q_1^2, Q_2^2) = D_h^i(x_1; Q_1^2) D_h^j(x_2; Q_2^2).$$

(Can't be true for all x, Q^2)

Easy to make predictions!
And the predictions are easy to test

$$\sigma_{\text{DPS}}^{AB} = \frac{m}{2} \frac{\sigma_{\text{SPS}}^A \sigma_{\text{SPS}}^B}{\sigma_{\text{eff}}}.$$

Universal (energy and process independent) factor)

$$1/\sigma_{\text{eff}} = \int d^2b F^2(b)$$

$$\sigma_{\text{eff}}^{\text{DPS}} = 14.5 \pm 1.7_{-2.3}^{+1.7} \text{ mb}$$

CDF, F.Abe *et al.*, PDR 56 3811 (1997)



How to test DPS ?

- For two species **A** and **B** one needs to measure associative production $\sigma(A+B)$ as well as their inclusive productions $\sigma(A)$, $\sigma(B)$
 - DPS contribution follows from identity:
 - Look for the correlations:
 p_T spectra, $\Delta\phi$ & Δy correlations, mass spectra, polarization effects, ?

$$\sigma_{\text{DPS}}^{AB} = \frac{m}{2} \frac{\sigma_{\text{SPS}}^A \sigma_{\text{SPS}}^B}{\sigma_{\text{eff}}}.$$

- Inclusive production is well measured at LHCb for many species

J/ψ

EJPC 71 (2011) 1645

Z^0

arXiv:1204.1620

Open charm: D^0 , D^+ , D_s , Λ_c

CERN-LHCb-PAPER-2012-041

jets

CERN-LHCb-CONF-2011-015

and many-many others: ψ' , $Y(nS)$, $W^\pm$, χ_c , χ_b , B-hadrons, ...

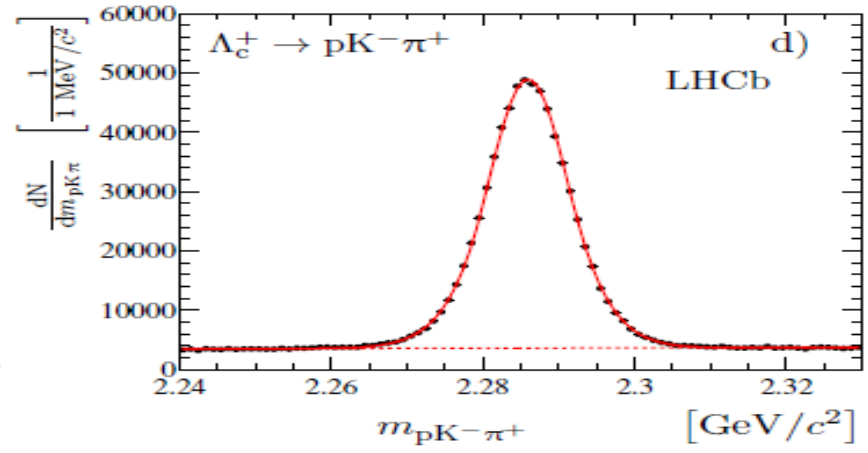
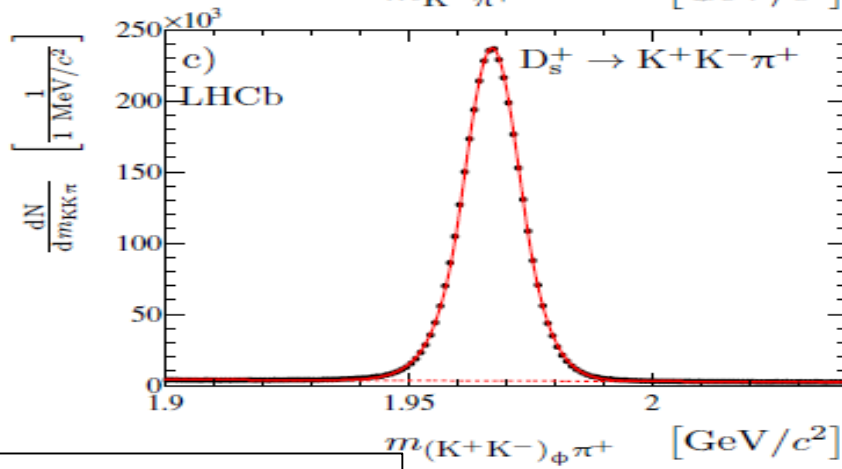
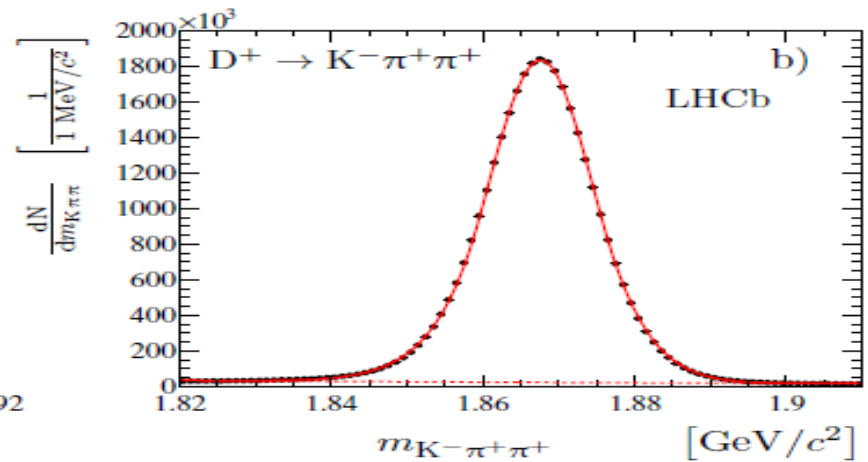
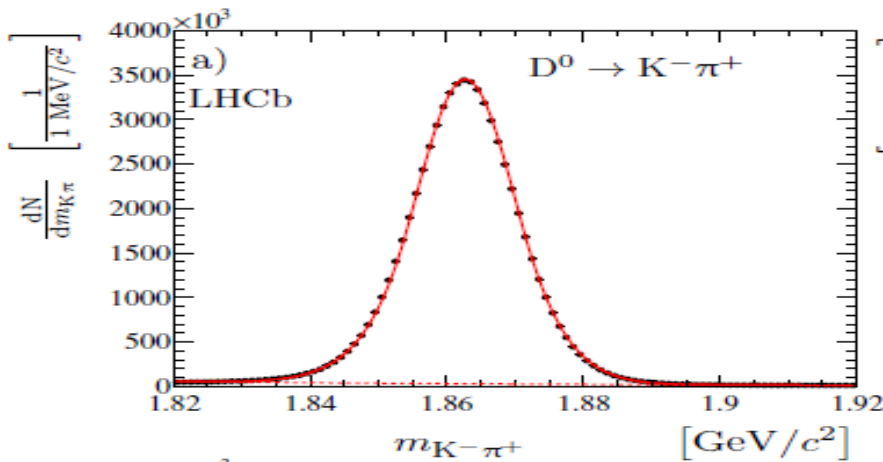
Today 26 pairs:

$2 \times J/\psi$ (1) J/ψ +open charm (4) $2 \times$ open charm (6+10) Z^0 +jets (1)



Open charm signals

$N(D^0) \approx 2 \times 10^8 / \text{fb}^{-1}$ $N(D^+) \approx 1 \times 10^8 / \text{fb}^{-1}$ $N(D_s) \approx 1 \times 10^7 / \text{fb}^{-1}$ $N(\Lambda_c) \approx 2 \times 10^6 / \text{fb}^{-1}$

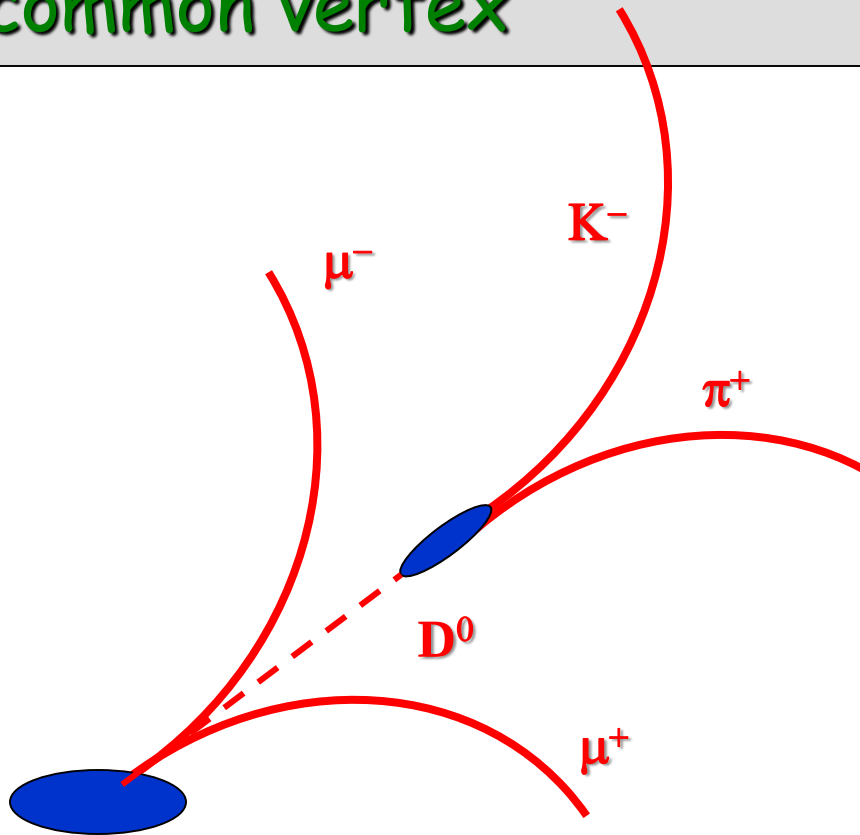


JHEP 06(2012) 141

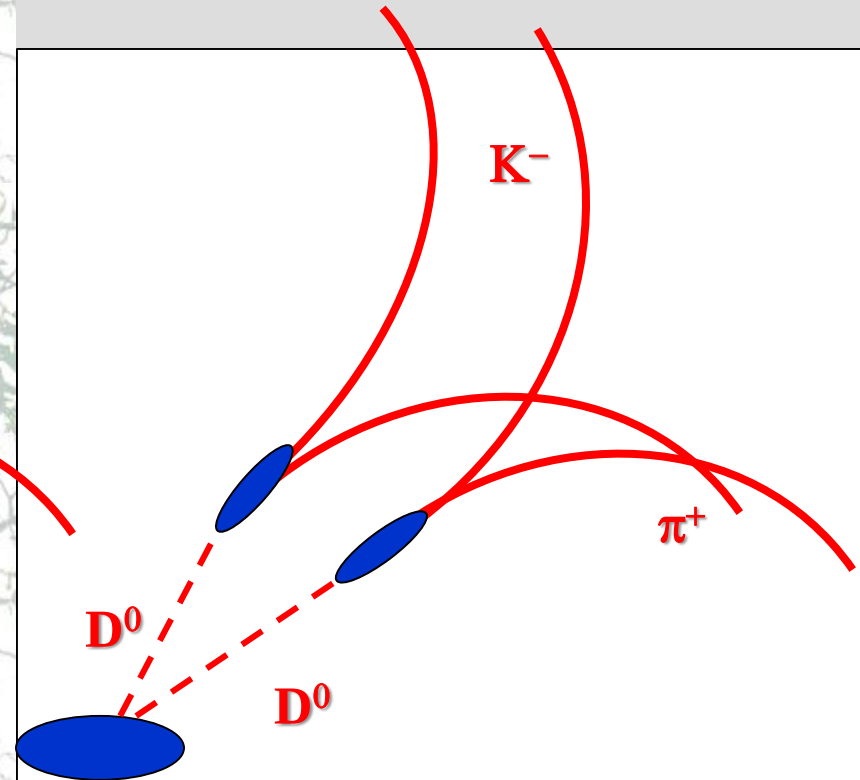


Event Selection

$J/\psi C$ two charm with
common vertex



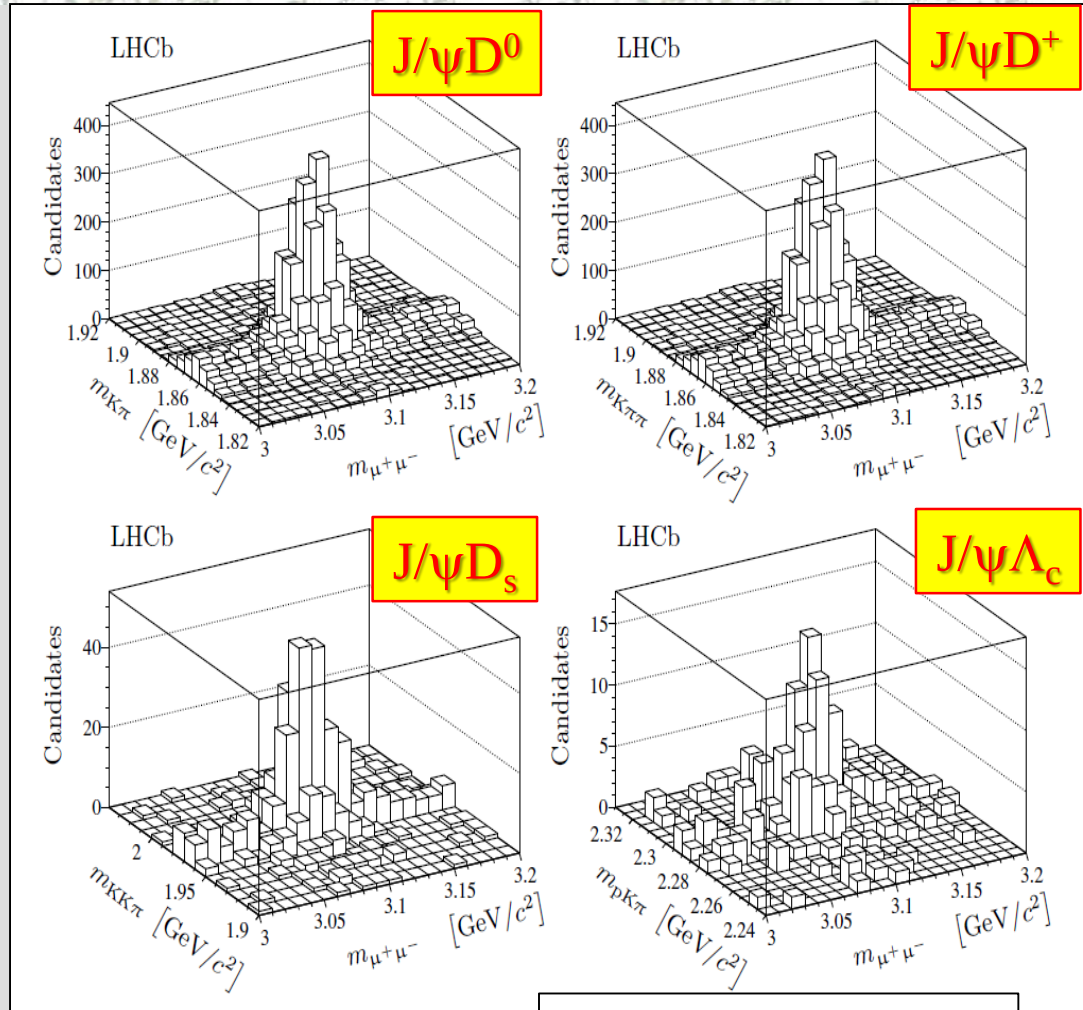
2×Open charm hadrons





Signal extraction

- J/ψ + open charm
- clear signals for all four modes
- Significances $> 7\sigma$



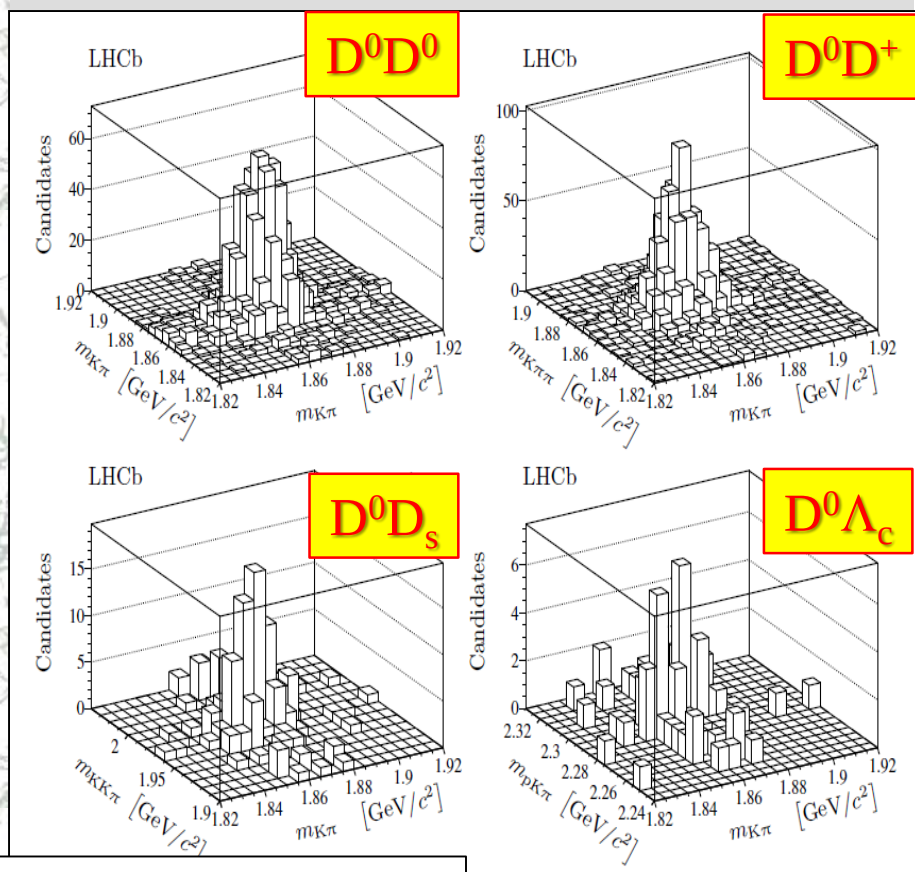
JHEP 06 (2012) 141



(open charm)²

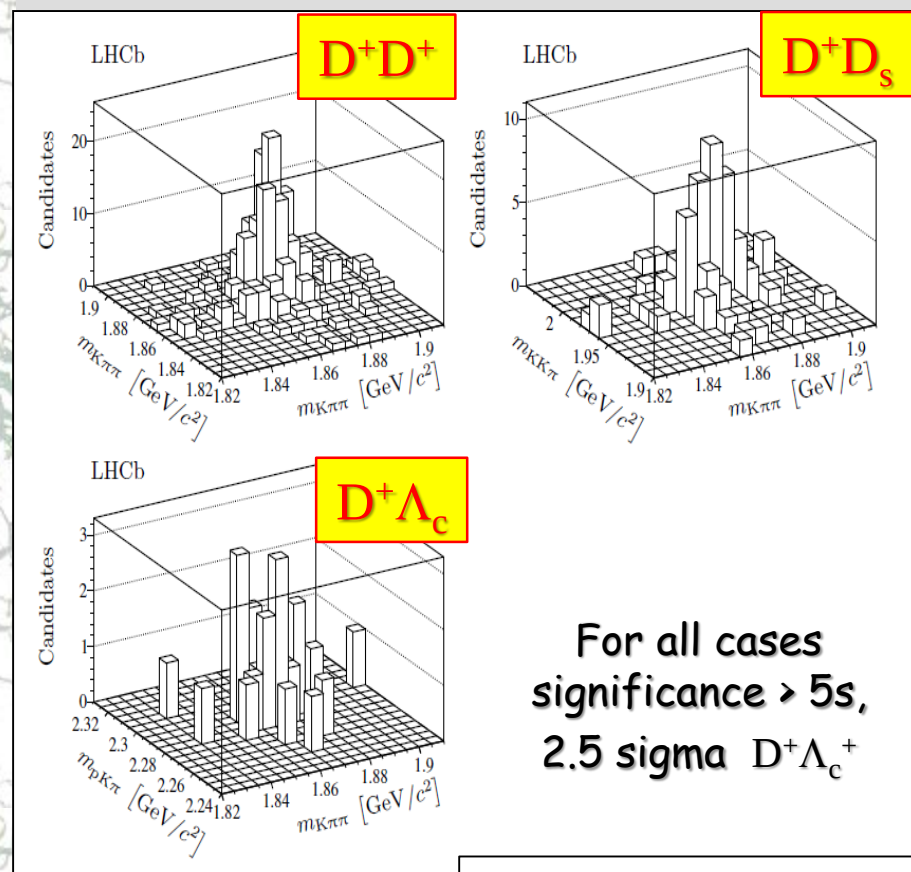


D⁰ & open charm



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D⁺ & open charm



For all cases
significance > 5s,
2.5 sigma D⁺Λ_c⁺

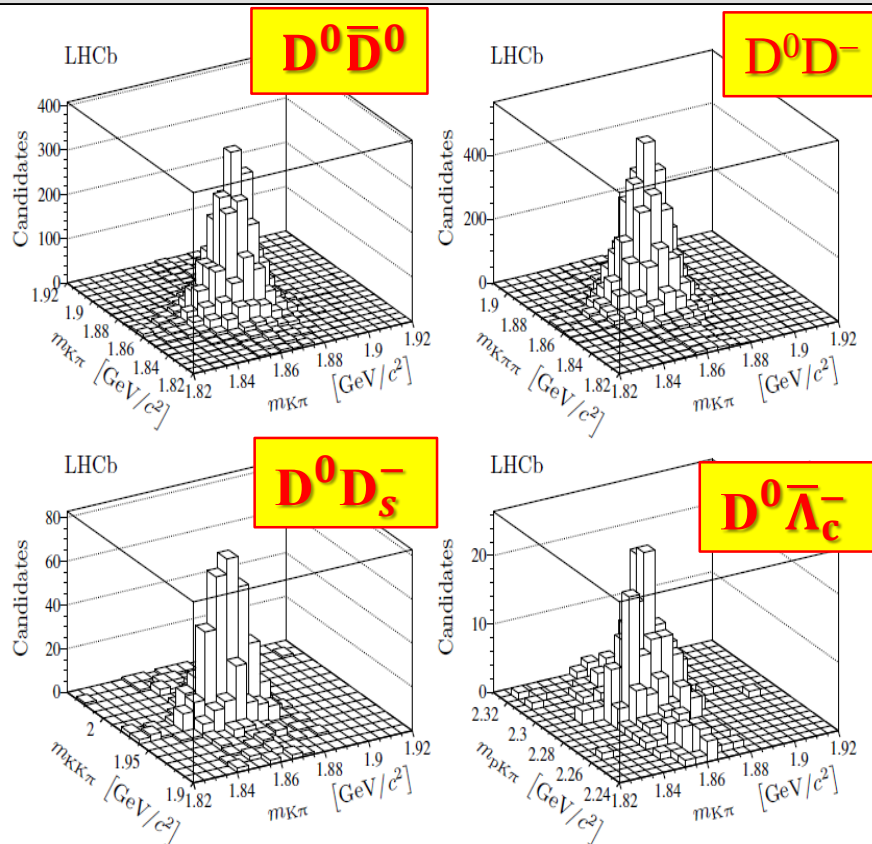
JHEP 06(2012) 141



Open charm + open anti-charm

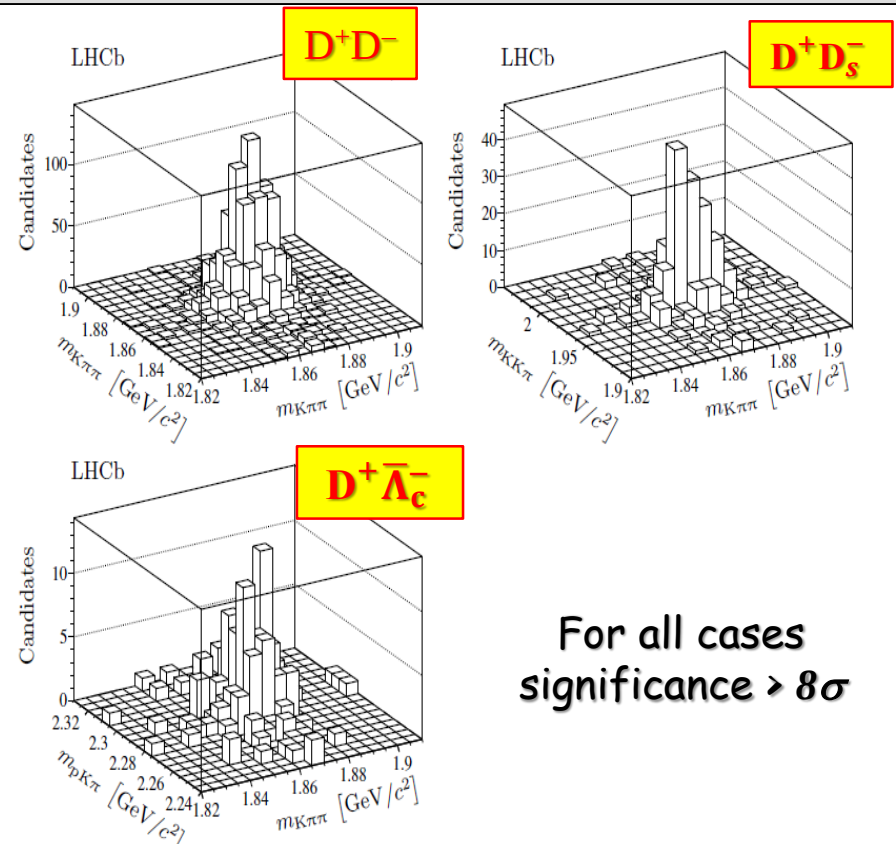


D^0 & open anti-charm



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D^+ & open anti-charm



For all cases
significance $> 8\sigma$

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Cross-sections



- Use per-event efficiency, mainly from DATA: trigger, particle ID, background etc.

$$\sigma^{J/\psi J/\psi} = 5.1 \pm 1.0 \pm 1.1 \text{ nb},$$

- Major systematic:
tracking (reducible)
 $Br(\Lambda_c), Br(D_s), \dots$

Mode	σ [nb]
$J/\psi D^0$	$161.0 \pm 3.7 \pm 12.2$
$J/\psi D^+$	$56.6 \pm 1.7 \pm 5.9$
$J/\psi D_s^+$	$30.5 \pm 2.6 \pm 3.4$
$J/\psi \Lambda_c^+$	$43.2 \pm 7.0 \pm 12.0$

Mode	$\sigma_{J/\psi C}/\sigma_{J/\psi} [10^{-3}]$	$\sigma_{J/\psi C}/\sigma_C [10^{-4}]$	$\sigma_{J/\psi} \sigma_C/\sigma_{J/\psi C} [\text{mb}]$
$J/\psi D^0$	$16.2 \pm 0.4 \pm 1.3^{+3.4}_{-2.5}$	$6.7 \pm 0.2 \pm 0.5$	$14.9 \pm 0.4 \pm 1.1^{+2.3}_{-3.1}$
$J/\psi D^+$	$5.7 \pm 0.2 \pm 0.6^{+1.2}_{-0.9}$	$5.7 \pm 0.2 \pm 0.4$	$17.6 \pm 0.6 \pm 1.3^{+2.8}_{-3.7}$
$J/\psi D_s^+$	$3.1 \pm 0.3 \pm 0.4^{+0.6}_{-0.5}$	$7.8 \pm 0.8 \pm 0.6$	$12.8 \pm 1.3 \pm 1.1^{+2.0}_{-2.7}$
$J/\psi \Lambda_c^+$	$4.3 \pm 0.7 \pm 1.2^{+0.9}_{-0.7}$	$5.5 \pm 1.0 \pm 0.6$	$18.0 \pm 3.3 \pm 2.1^{+2.8}_{-3.8}$



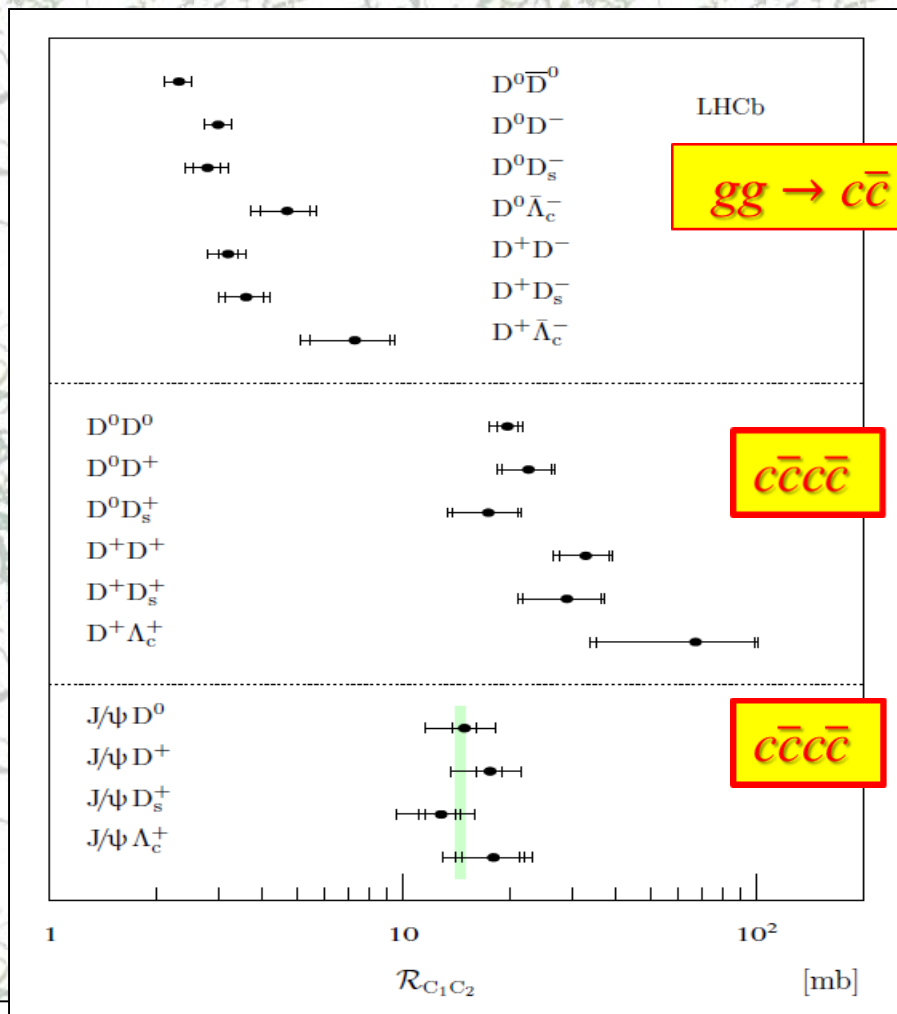
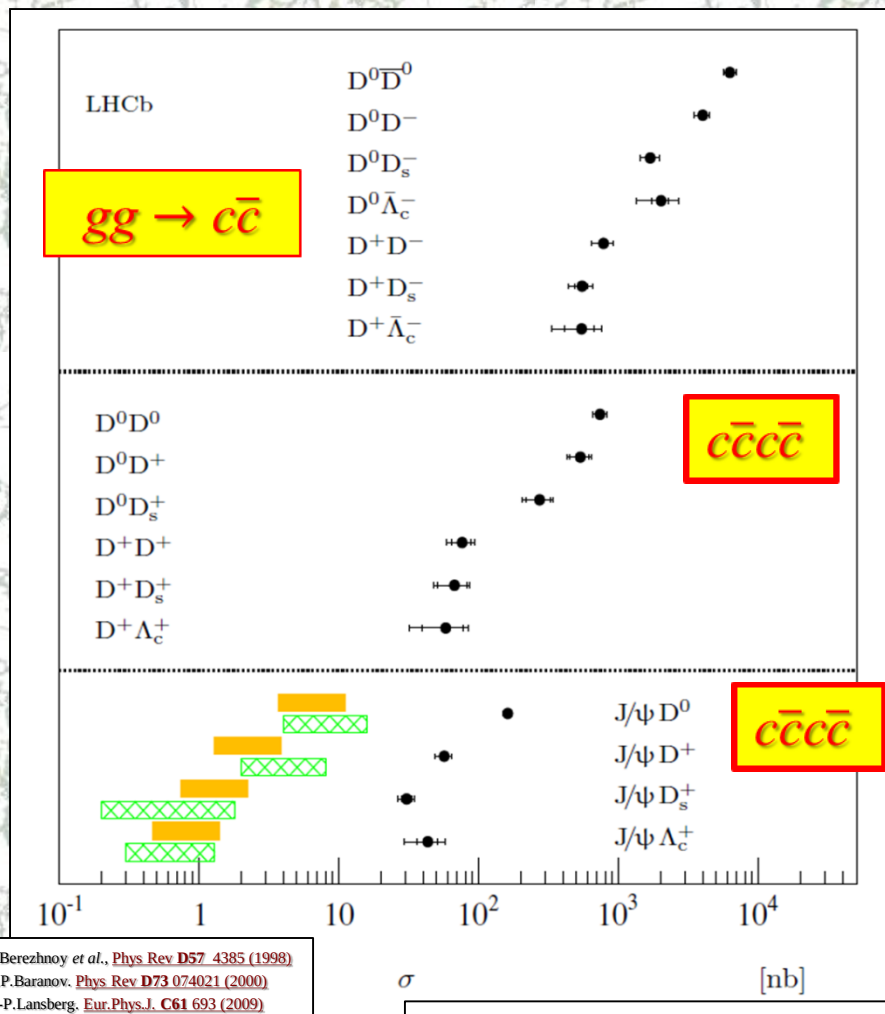
Cross-sections



Mode	σ [nb]	$\sigma_{CC}/\sigma_{C\bar{C}}$ [%]	$\sigma_{C_1}\sigma_{C_2}/\sigma_{C_1C_2}$ [mb]
D^0D^0	$690 \pm 40 \pm 70$	10.9 ± 0.8	$2 \times (42 \pm 3 \pm 4)$
$D^0\bar{D}^0$	$6230 \pm 120 \pm 630$		$2 \times (4.7 \pm 0.1 \pm 0.4)$
D^0D^+	$520 \pm 80 \pm 70$	12.8 ± 2.1	$47 \pm 7 \pm 4$
D^0D^-	$3990 \pm 90 \pm 500$		$6.0 \pm 0.2 \pm 0.5$
$D^0D_s^+$	$270 \pm 50 \pm 40$	15.7 ± 3.4	$36 \pm 8 \pm 4$
$D^0D_s^-$	$1680 \pm 110 \pm 240$		$5.6 \pm 0.5 \pm 0.6$
$D^0\bar{\Lambda}_c^-$	$2010 \pm 280 \pm 600$	—	$9 \pm 2 \pm 1$
D^+D^+	$80 \pm 10 \pm 10$	9.6 ± 1.6	$2 \times (66 \pm 11 \pm 7)$
D^+D^-	$780 \pm 40 \pm 130$		$2 \times (6.4 \pm 0.4 \pm 0.7)$
$D^+D_s^+$	$70 \pm 15 \pm 10$	12.1 ± 3.3	$59 \pm 15 \pm 6$
$D^+D_s^-$	$550 \pm 60 \pm 90$		$7 \pm 1 \pm 1$
$D^+\Lambda_c^+$	$60 \pm 30 \pm 20$	10.7 ± 5.9	$140 \pm 70 \pm 20$
$D^+\bar{\Lambda}_c^-$	$530 \pm 130 \pm 170$		$15 \pm 4 \pm 2$



Cross-sections

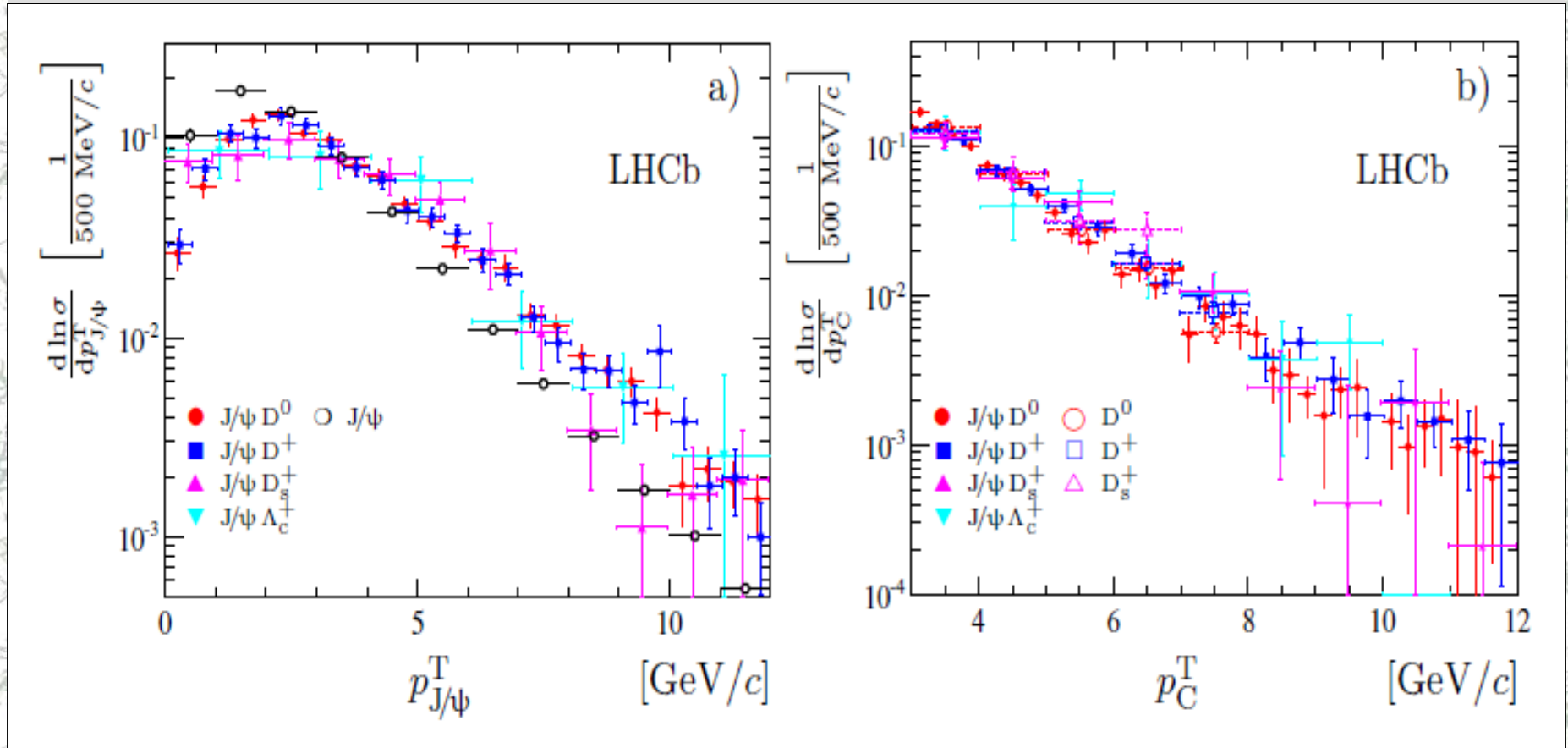


JHEP 06(2012) 141 **JHEP 03(2014) 108**



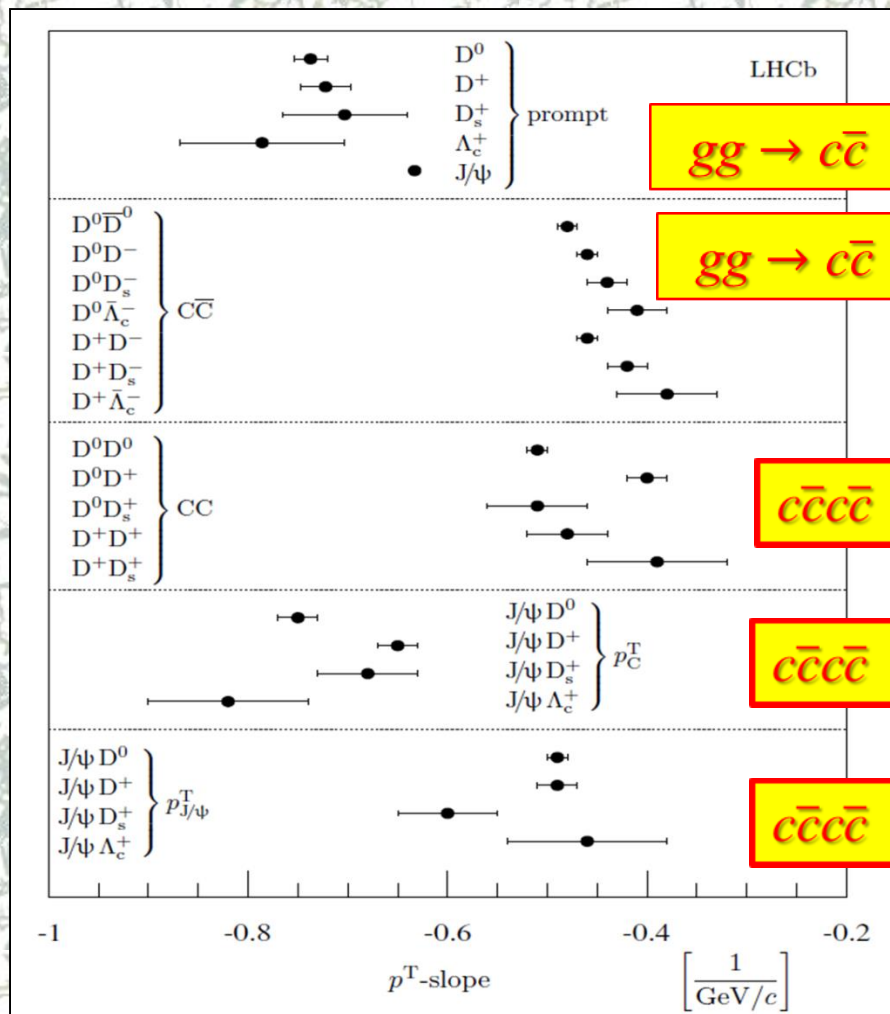
Event Properties: p_T

J/ψ + open charm:





Slope parameter for p_T -spectra

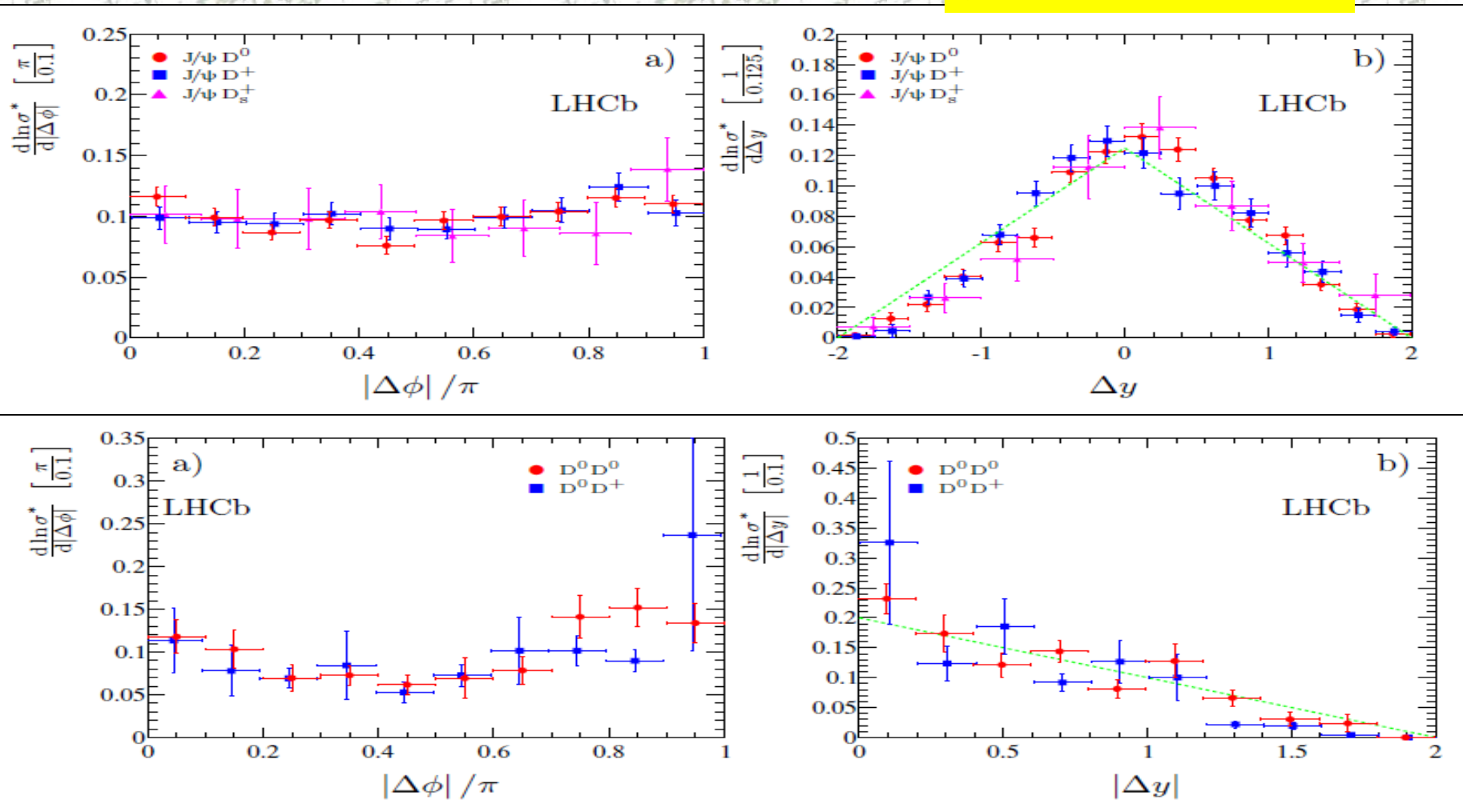


- Fit p_T -spectra with exponential function:
 $\sim \exp(\beta \times p_T)$
- DPS: expected similarity between *inclusive* and $c\bar{c}c\bar{c}$
- Expected to be similar between $J/\psi C$ and CC
- No reason to be the same for $J/\psi C$ and *inclusive*
- Expected to be similar between $c\bar{c}$ and *inclusive*



$\Delta\phi$ & Δy correlations

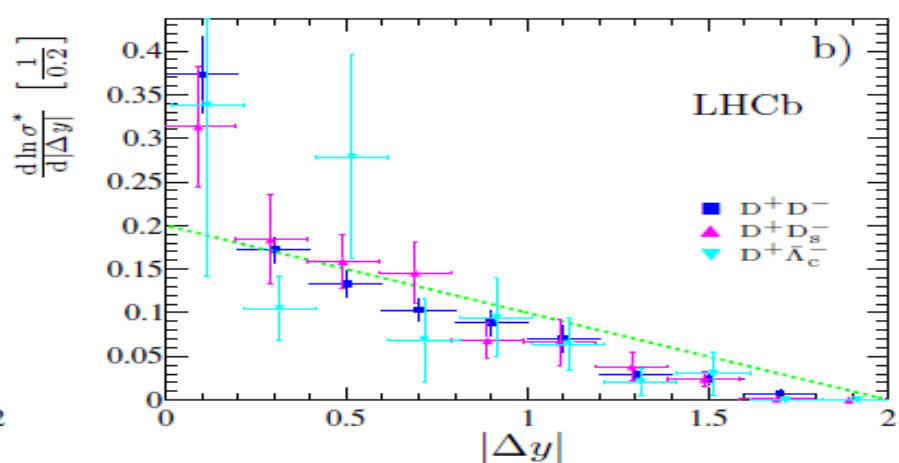
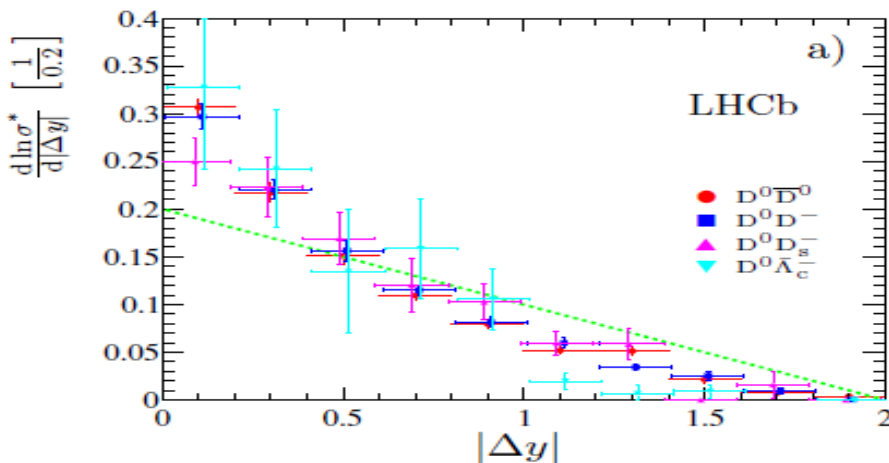
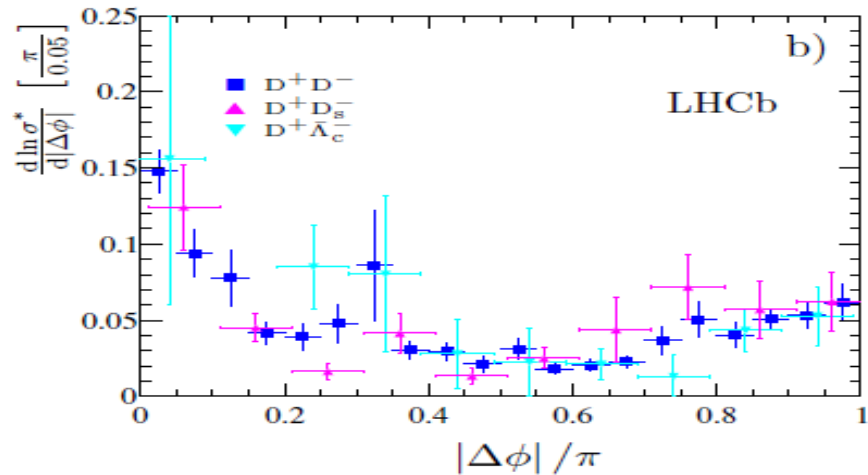
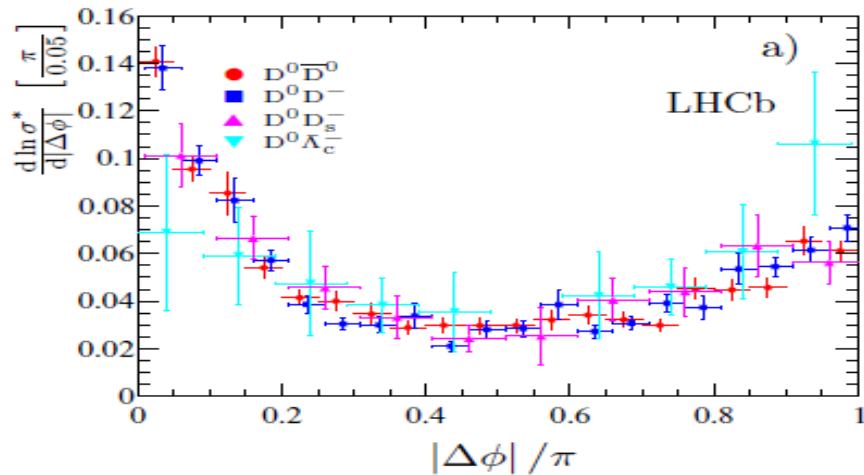
No evident correlations





$\Delta\phi$ & Δy correlations

Clear correlations!



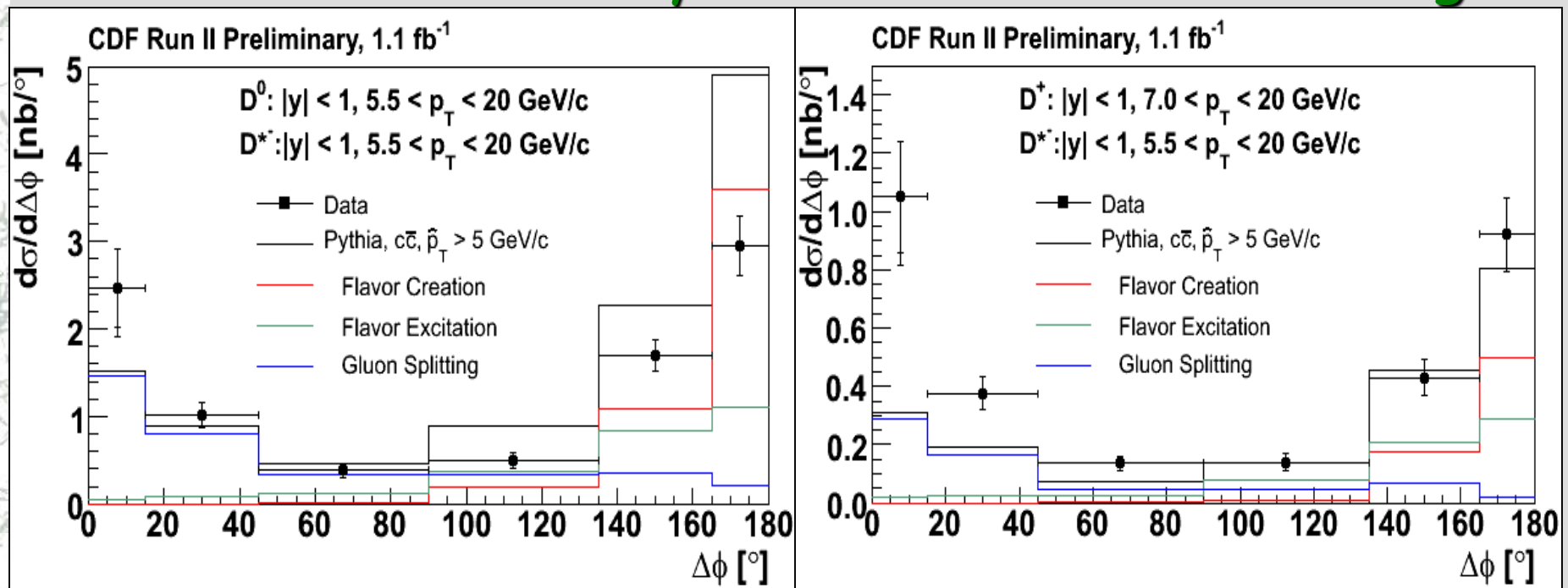


Compare with CDF'2k+6

<http://www-cdf.fnal.gov/physics/new/bottom/060921.blessed-double-charm-corr/>

- CDF: azimuthal correlations for $D^{(0,+)} D^{*-}$
- Large gluon splitting contribution

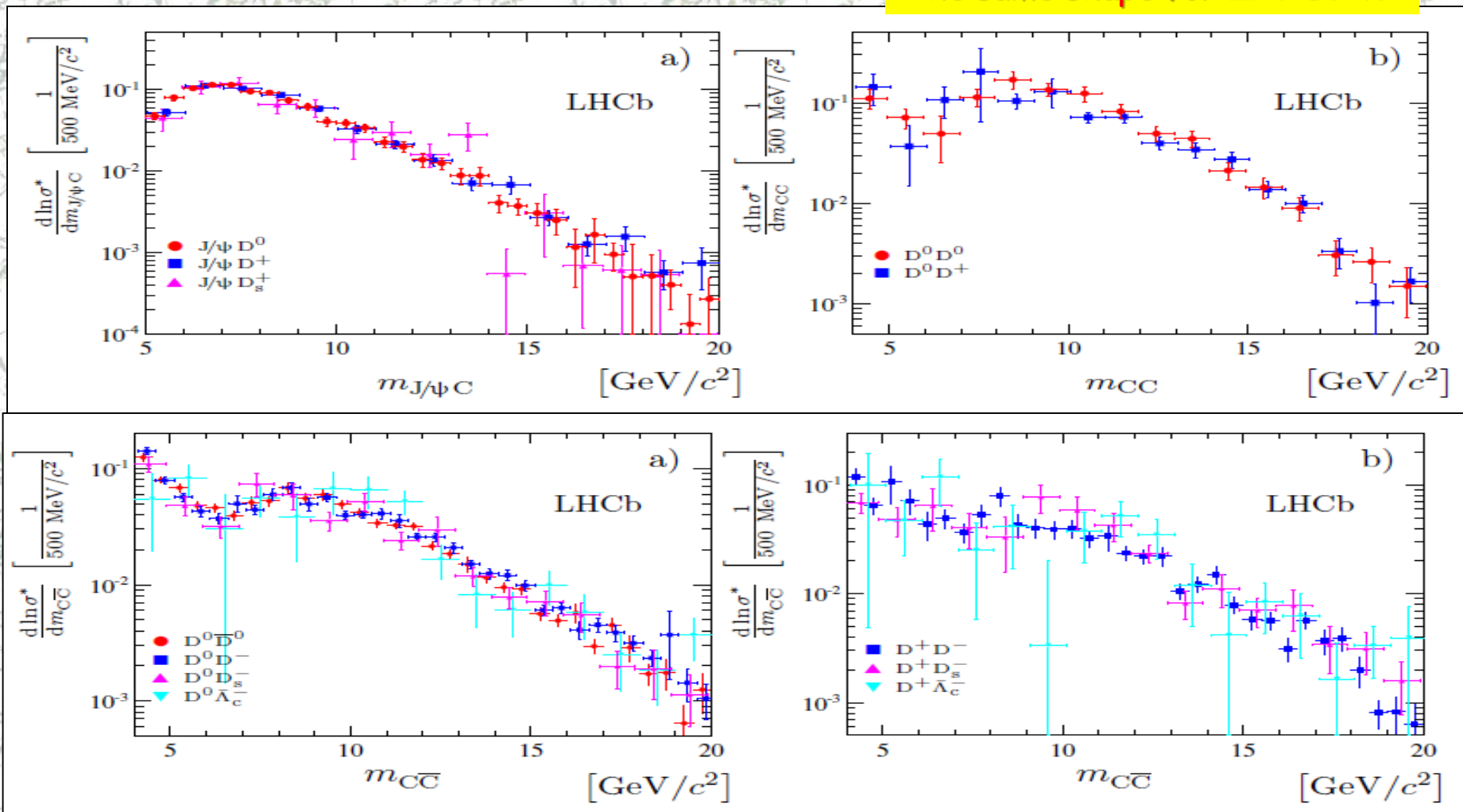
Very different kinematical region





Mass distributions

The same shape for $m > 7 \text{ GeV}/c^2$



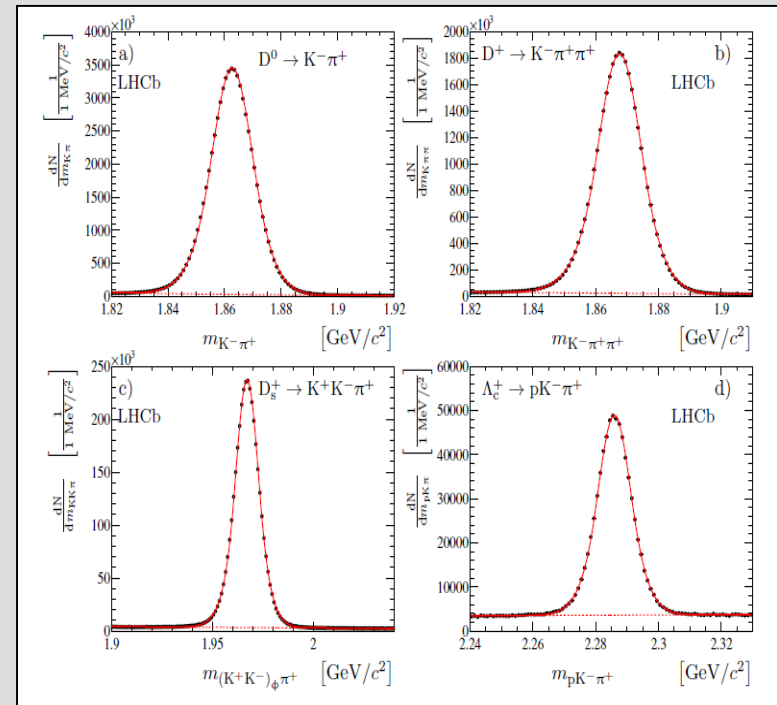
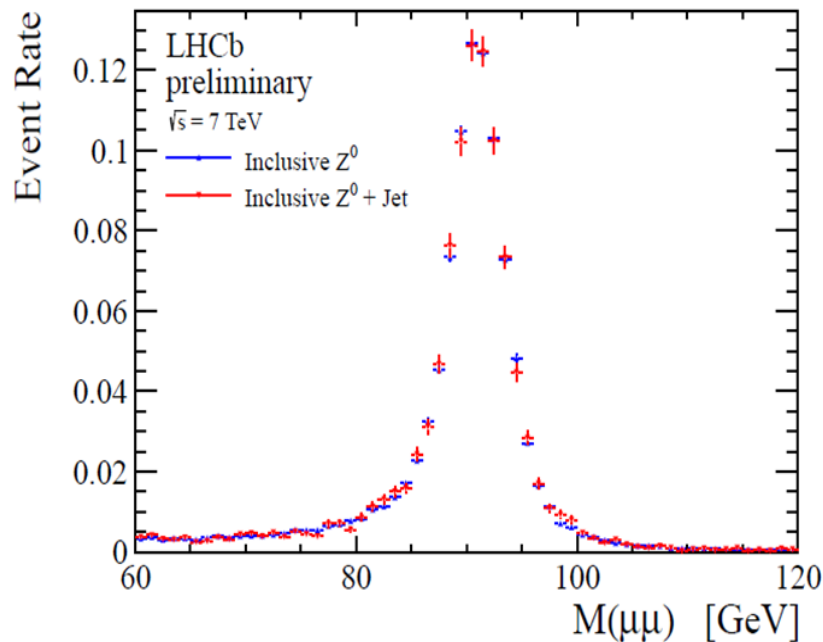


Z^0 + charm meson



- We have clear D-signals, we have clear $Z^0 \rightarrow \mu^+ \mu^-$ signals: try to merge them together

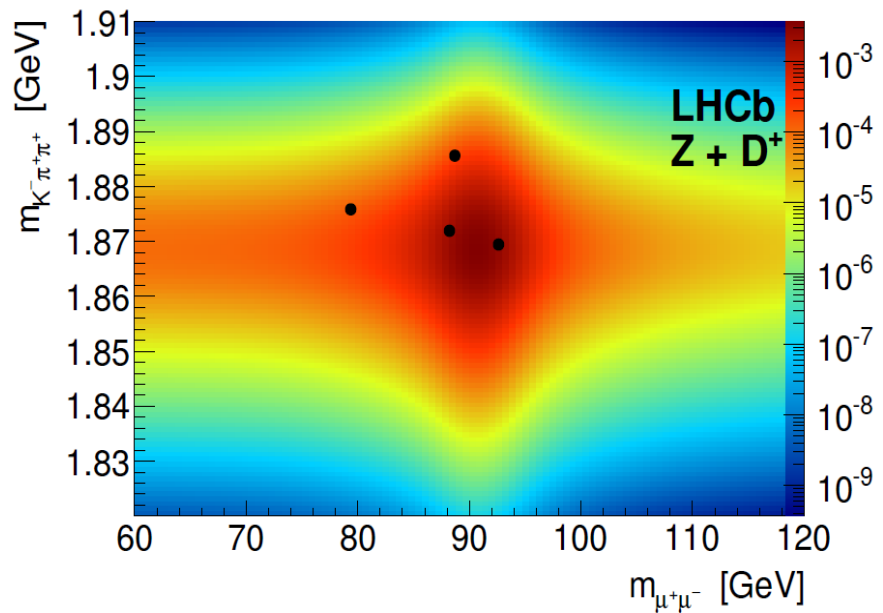
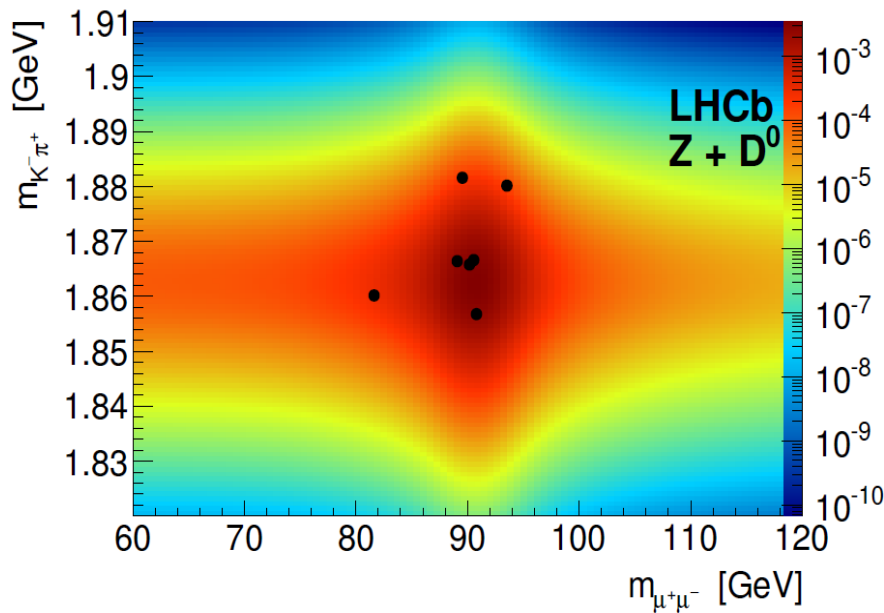
CERN-LHCb-CONF-2012-016





Z^0 + charm mesons

- 11 signal events: 7 $Z^0 D^0$ and 4 $Z^0 D^+$
- Statistical significance $>5\sigma$





Z^0 + charm meson



- Cross-section: sum of SPS and DPS

	Measured	MCFM massless [1]	MCFM massive [17]	DPS (Eq. (6.1))
$Z + D^0$	$2.50 \pm 1.12 \pm 0.22$	$0.85^{+0.12}_{-0.07} {}^{+0.11}_{-0.17} \pm 0.05$	$0.64^{+0.01}_{-0.01} {}^{+0.08}_{-0.13} \pm 0.04$	$3.28^{+0.68}_{-0.58}$
$Z + D^+$	$0.44 \pm 0.23 \pm 0.03$	$0.37^{+0.05}_{-0.03} {}^{+0.05}_{-0.07} \pm 0.03$	$0.28^{+0.01}_{-0.01} {}^{+0.04}_{-0.06} \pm 0.02$	$1.29^{+0.27}_{-0.23}$

- For Z^0+D^0 case: in agreement, for Z^0+D^+ case too small
- More data needed to make conclusions
 - Only $\sim 1/3$ of data is used in this analysis



P-wave charmonia: χ_c states

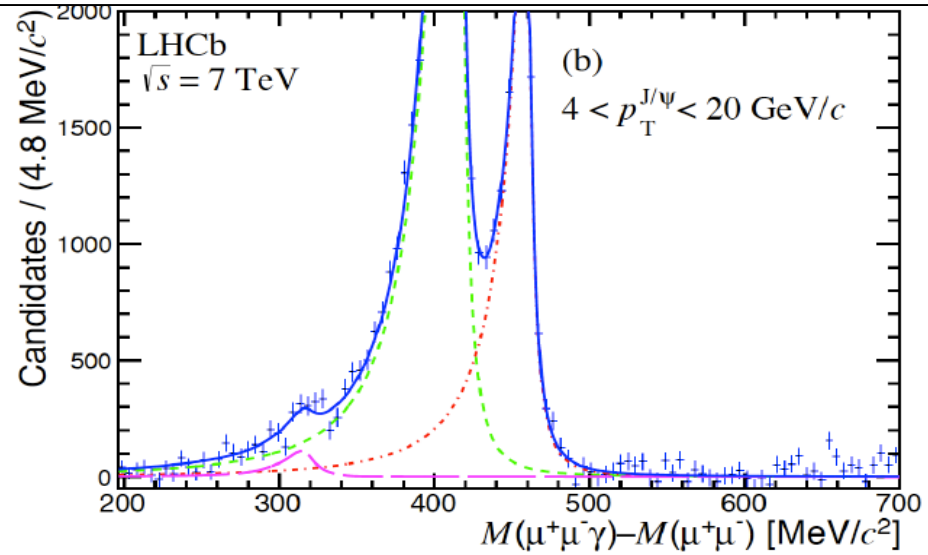
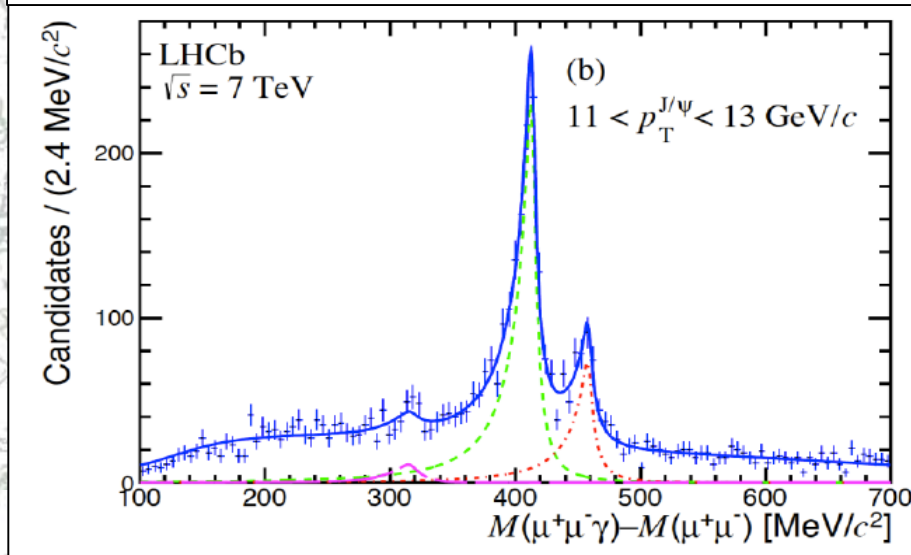
JHEP 10 (2013) 115

$\chi_c \rightarrow (J/\psi \rightarrow \mu^+ \mu^-) \gamma$ with γ -conversions

- Excellent mass resolution: resolve χ_{c1} and χ_{c2} !
- First evidence of χ_{c0} at hadron machines!

$$\sigma(\chi_{c0})/\sigma(\chi_{c2}) = 1.19 \pm 0.27(stat) \pm 0.29(sys) \pm 0.16(p_T model) \pm 0.09(B)$$

$$\sigma(\chi_{c2})/\sigma(\chi_{c1}) = 0.787 \pm 0.014(stat) \pm 0.034(sys) \pm 0.051(p_T model) \pm 0.047(B)$$

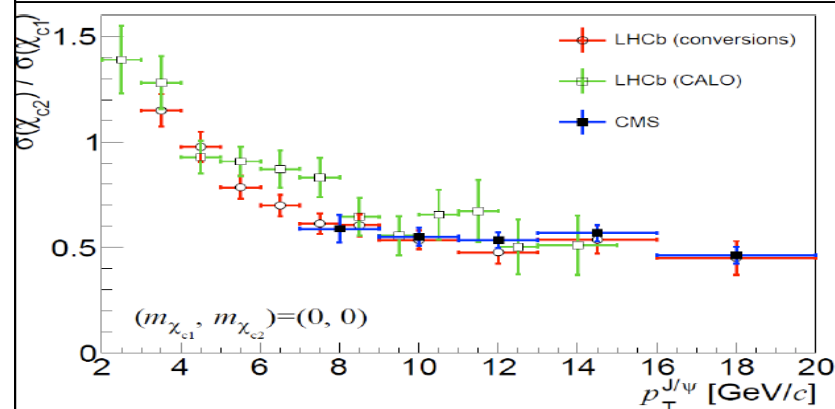
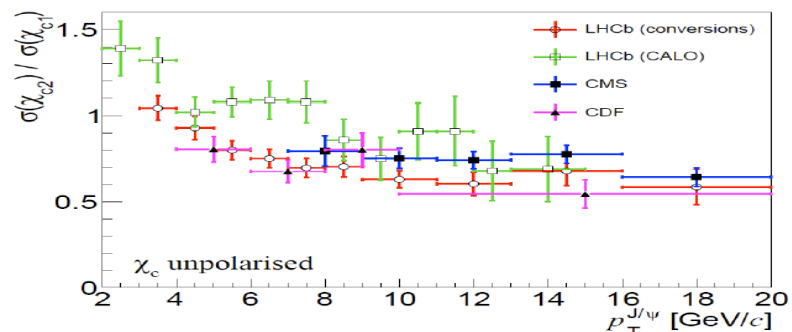
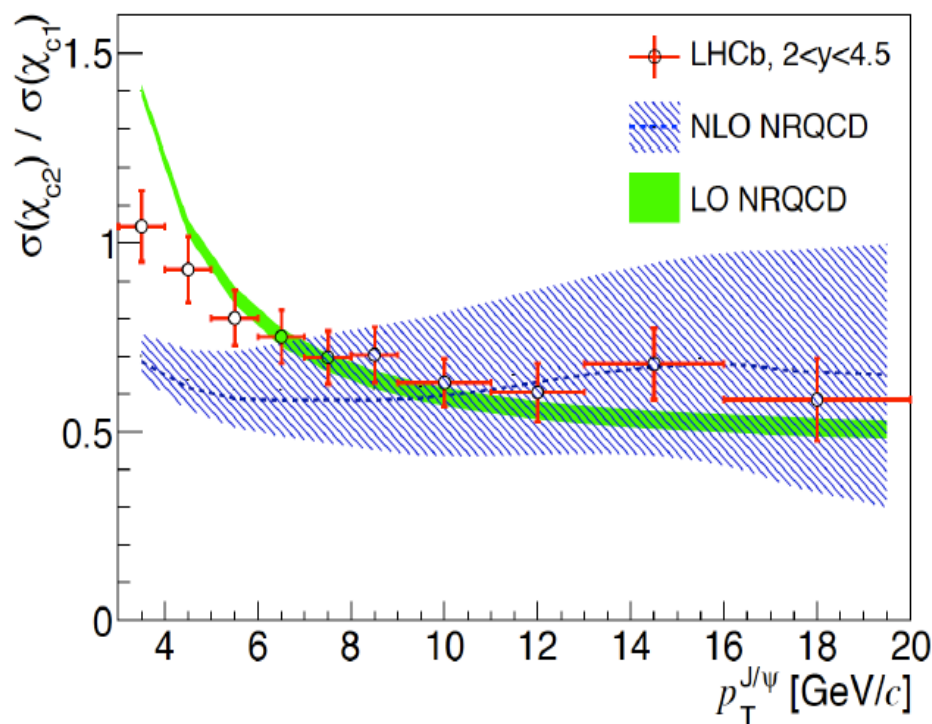




χ_{c2}/χ_{c1} ratio

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- for on-shell gluons $\sigma(gg \rightarrow \chi_{c1}) = 0$
- Important ingredient for S & P-wave CO



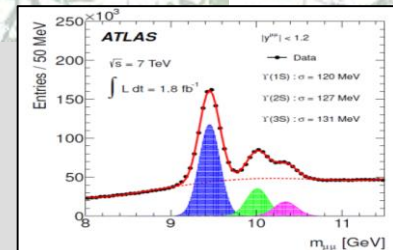


Υ production @2.76,7&8TeV

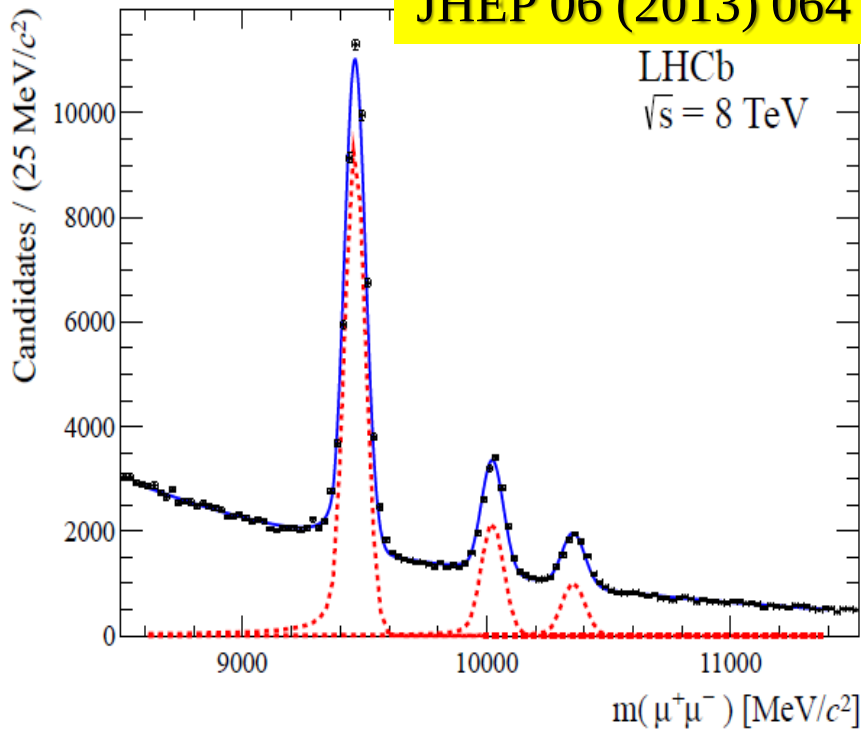


$\Upsilon \rightarrow \mu^+ \mu^-$ excellent mass resolution!

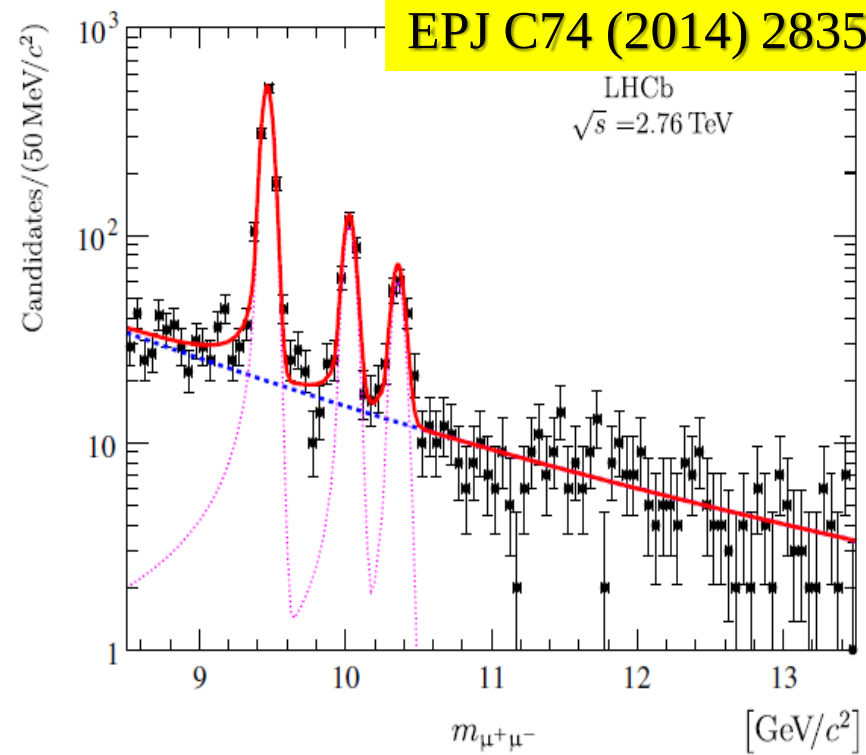
EPJ C72 (2012) 2025



JHEP 06 (2013) 064



EPJ C74 (2014) 2835

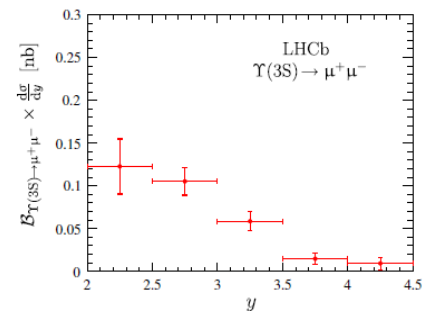
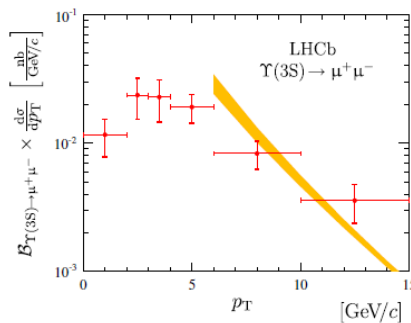
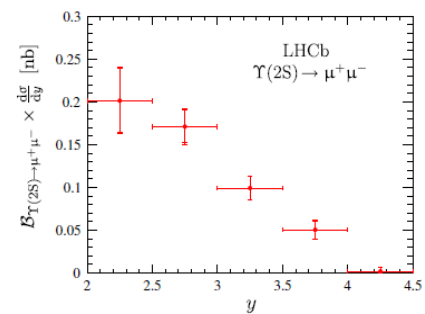
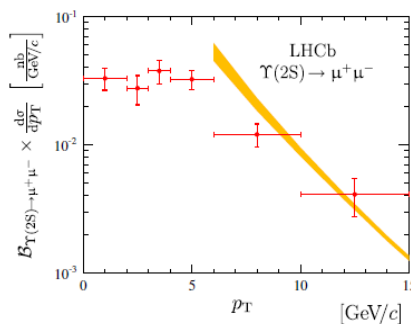
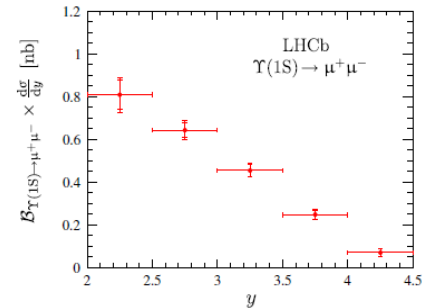
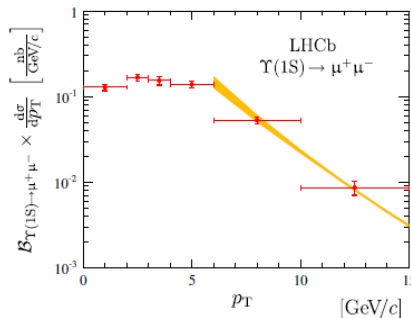
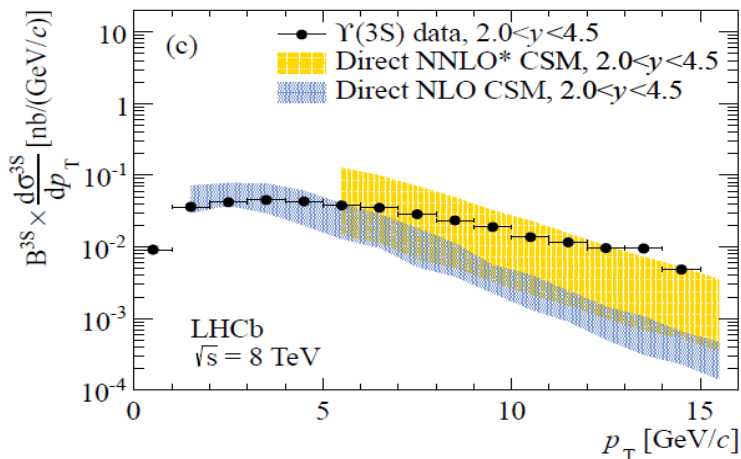
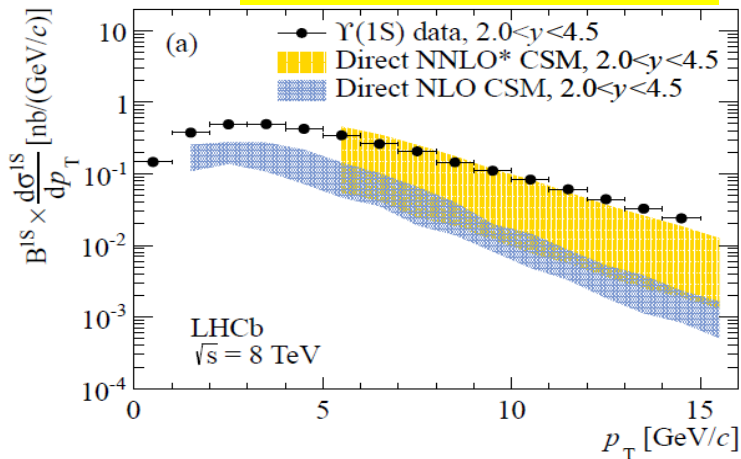




Υ production

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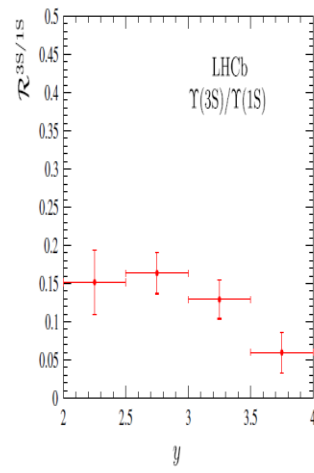
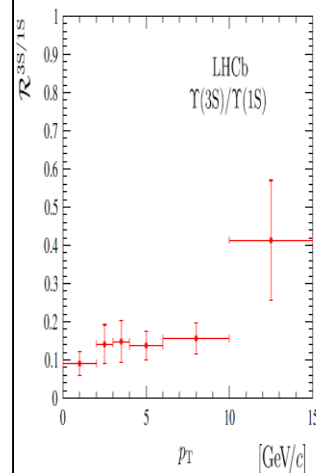
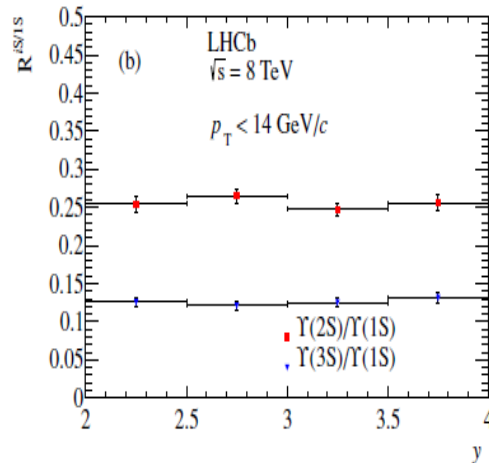
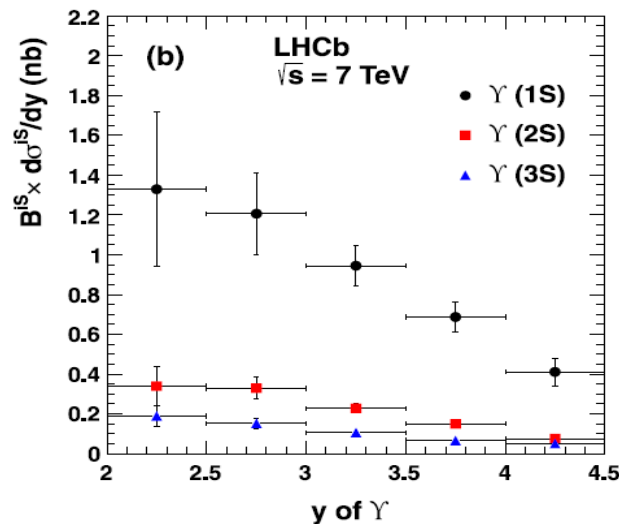
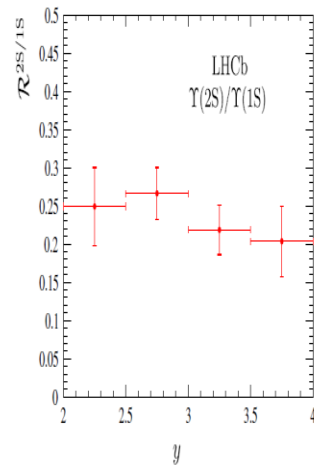
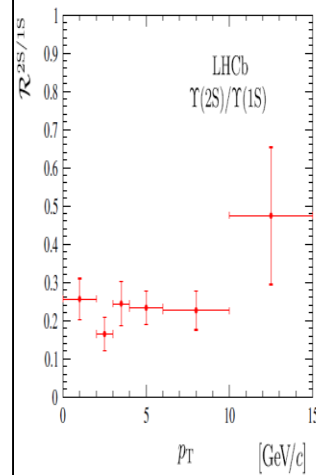
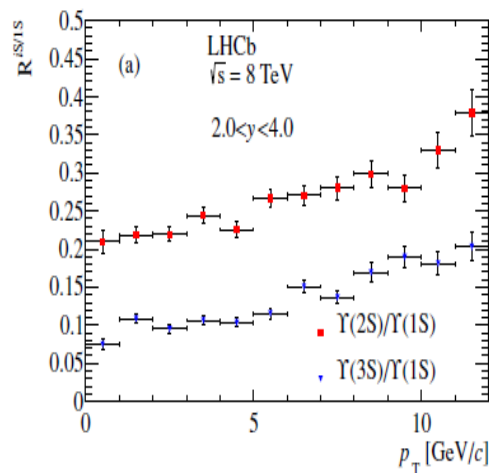
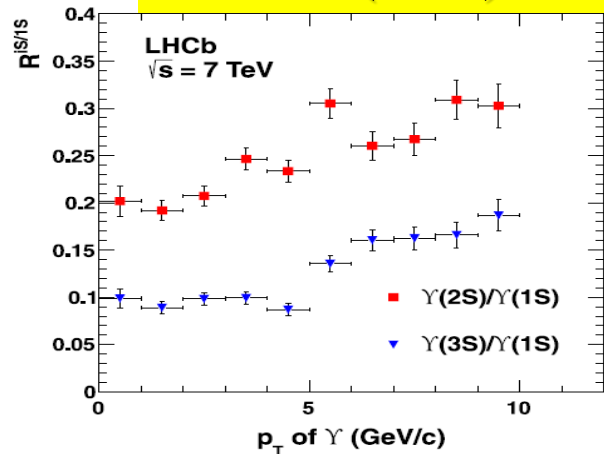
$\Upsilon(nS)/\Upsilon(1S)$ ratios



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Other interesting topics



- Production in pA & Ap collisions
 - JHEP 02 (2014) 074 LHCb-PAPER-2014-015, arXiv:1405.5151
- B-hadron production
 - JHEP 08 (2013) 117
- B_c production PRL 109 (2012) 231001
- Search for double charmed baryons
 - JHEP 12 (2013) 090

Leading role of Tsinghua group

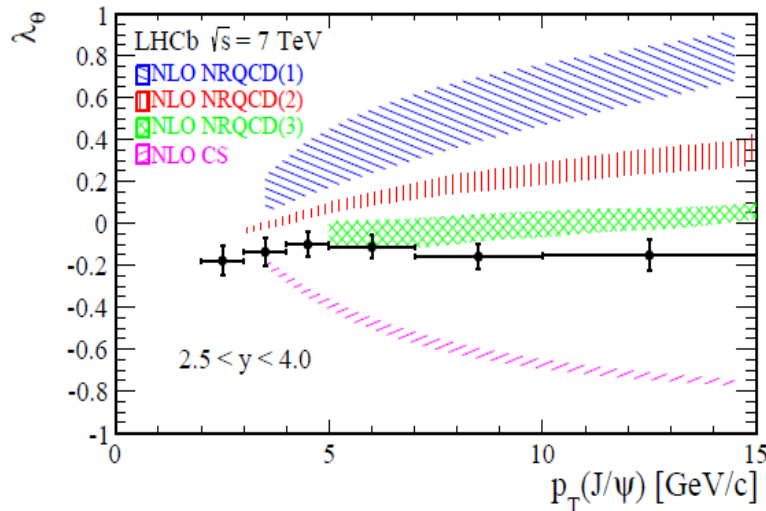




Polarisation fiasco (again)



EPJ C73 (2013) 2631



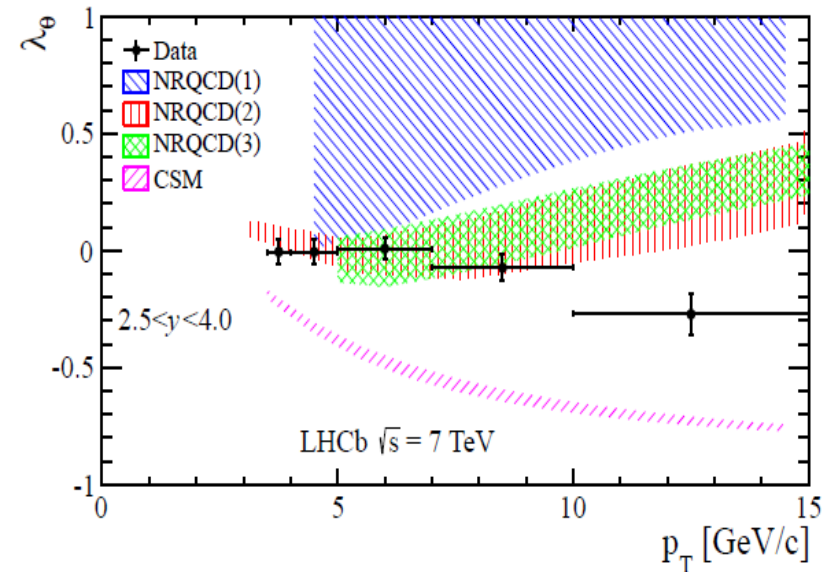
HX frame

- CSM no feed down: Nucl. Phys. Proc. Suppl. B222-224 (2012) 151
- NRQCD: no feed-down: Nucl. Phys. Proc. Suppl. B222-224 (2012) 151
- NRQCD: feed-down from $\chi_c(^3P_J^1, ^3S_J^8)$ and $\psi(2S)$ Phys. Rev. Lett. 110 (2013) 042002
- NRQCD: feed-down from $^3P^{[8]}$ Phys. Rev. Lett. 108 (2012) 242004

ψ' was expected to be easier:

- Free from feeddown

EPJ C74 (2014) 2871





Summary



- HQ production is interesting & hot topic
 - Many active players, including LHCb
- There is great theory progress
 - .. and nice collaboration
- Some "old" puzzles are still with us
 - Polarization, role of CO
- Interesting data appears from LHC that need to be explained: challenge for theory
 - At high collision energies/large gluon densities new effects appears, e.g. DPS