Charmonium production at LHCb: search strategy with $p\bar{p}$ final state

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LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

cnrs IN2P3 Les deux infinis

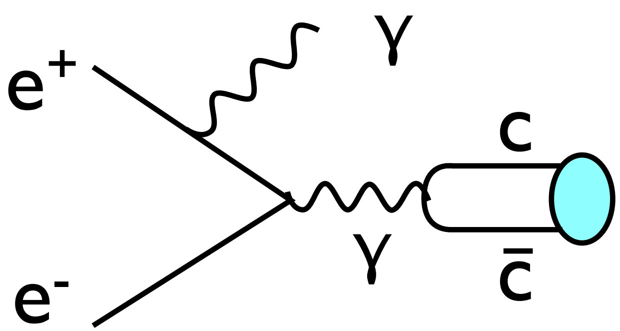
11-14 April 2011 @ Portoroz, Slovenia

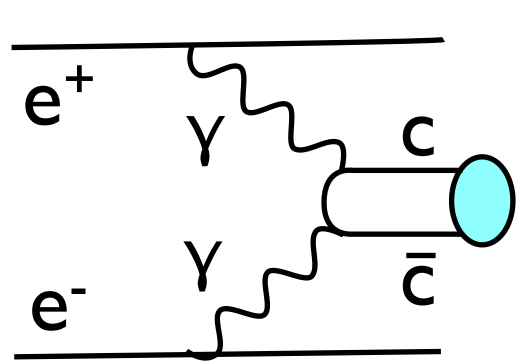
Introduction: charmonium spectroscopy

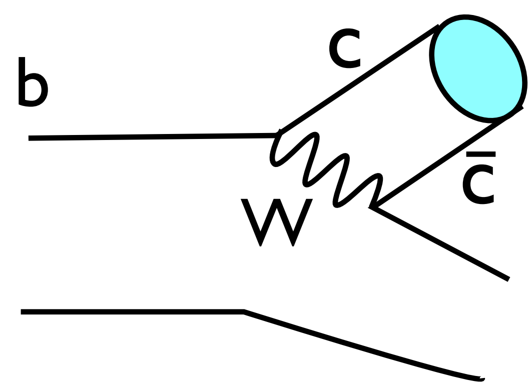
- Established charmonium below threshold (=2m$_D$)

		$n\ ^{2s+1}l_J$	J^{PC}	mass MeV	width MeV	discovery
η_c	pseudoscalar	$1\ ^1S_0$	0^{-+}	2980	25.5	1980
J/ψ	vector	$1\ ^3S_1$	1^{--}	3097	0.093	1974
h_c	axial vector	$1\ ^1P_1$	1^{+-}	3524		2005
χ_{c0}	scalar	$1\ ^3P_0$	0^{++}	3415	10.4	1975
χ_{c1}	axial vector	$1\ ^3P_1$	1^{++}	3511	0.89	1975
χ_{c2}	tensor	$1\ ^3P_2$	2^{++}	3556	2.06	1975
$\psi(3770)$	vector	$1\ ^3D_1$	1^{--}	3771	23.0	1977
$\eta_c(2S)$	pseudoscalar	$2\ ^1S_0$	0^{-+}	3637	< 55	2002
$\psi(2S)$	vector	$2\ ^3S_1$	1^{--}	3686	0.337	1974

Many new studies done at B factories above the threshold

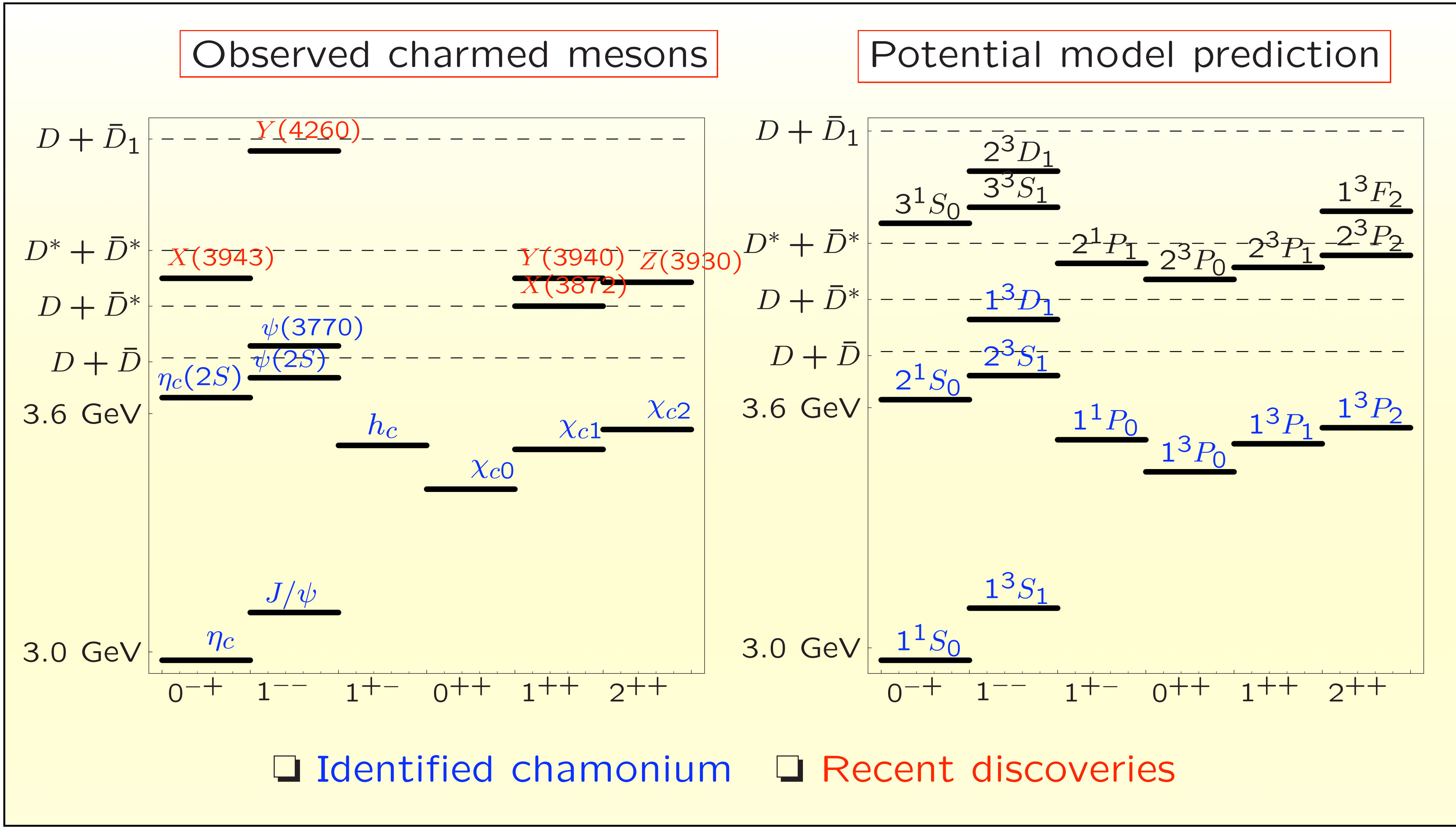






Introduction: charmonium spectroscopy

- Theoretical predictions and new states (XYZ):



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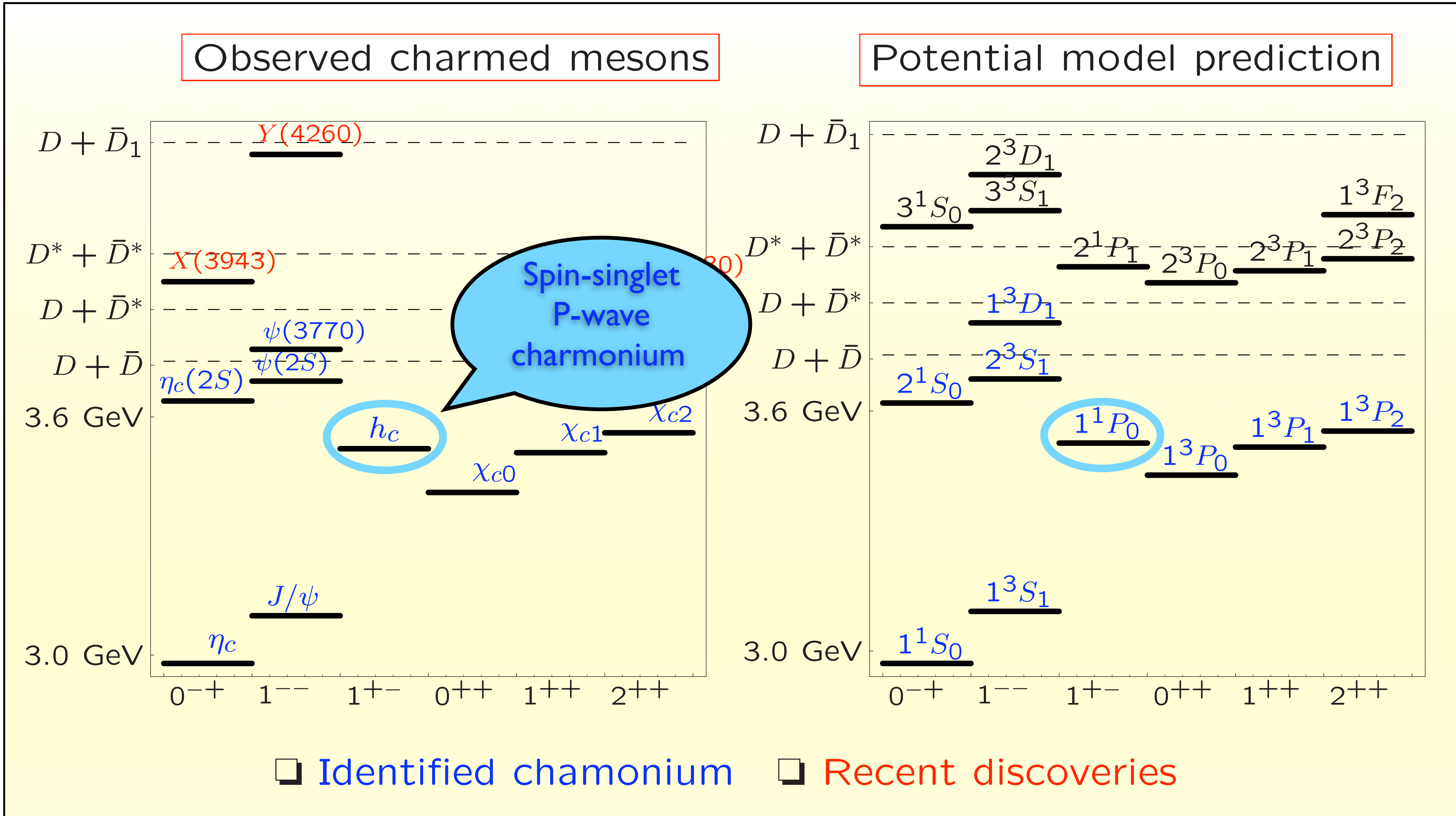

Recent discovery of the "missing" h_c

- h_c had been missing because...
  - e+e- machines can not produce it directly.
  - $B \to h_c K$ is a factorisation forbidden channel.

➡ E760 (Fermilab): ~50 events in '95

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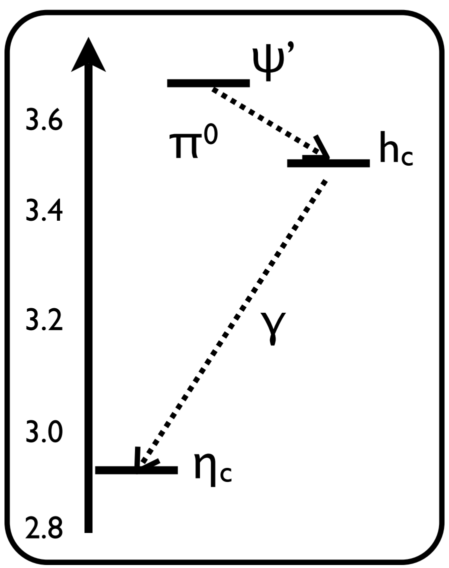
E835 PRD72 ('05)

➡ E760 (Fermilab): ~50 events in '95 confirmed by E835 in '05

CLEO PRL95 ('05)
CLEO PRL 101 ('08)

Strategy at e+e- machine

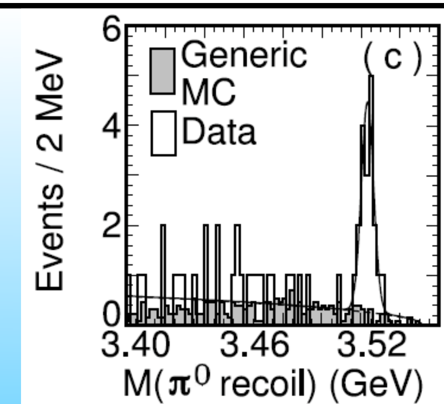


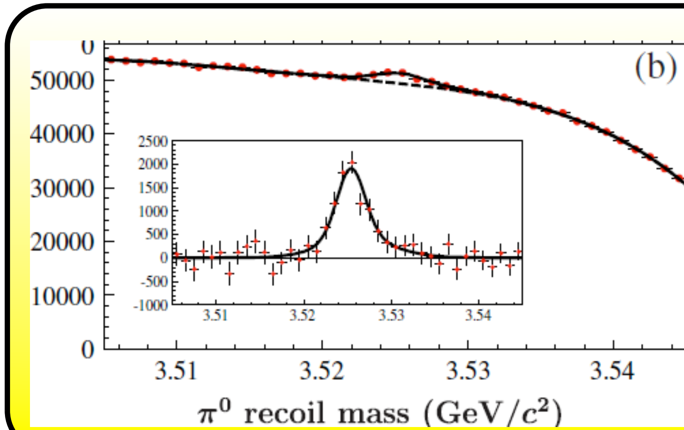
CLEO '05: ~10^2 events

CLEO '08: ~10^3 events

$Br(\psi' \to h_c \pi^0) \times Br(h_c \to \eta_c \gamma)$
$= (4.16 \pm 0.48) \times 10^{-4}$

$m(h_c) = 3525.4 \pm 0.22$ MeV





BESIII PRL104 ('10)

BESIII '10: 3×10^3 events

$Br(\psi' \to h_c \pi^0) = (8.4 \pm 1.3) \times 10^{-4}$

$Br(h_c \to \eta_c \gamma) = (54.3 \pm 6.7)\%$

$m(h_c) = 3525.4 \pm 0.22$ MeV

$\Gamma(h_c) = 0.73 \pm 0.53$ MeV

Theoretical issues on h_c

- Mass: Testing the hyper-fine splitting term in the potential model → The recent CLEO/BESIII measurements show an excellent agreement! *BESIII PRL104 ('10)*
- $B \to h_c$ K: Testing the non-factorisable contributions → Recent theoretical estimate $Br(B \to h_c K) \sim 2.5 \times 10^{-5}$; A search at SuperB/LHCb is important! *Beneke et al NP B811 ('09)* *Colangelo et al, PL B542 ('02)*
- Decay width: Testing the spin-symmetry of the non-relativistic QCD → The recent BESIII measurement shows an agreement. *BESIII PRL104 ('10)*
- Hadroproduction: Testing the color-octet mechanism → Search at LHCb is VERY important!

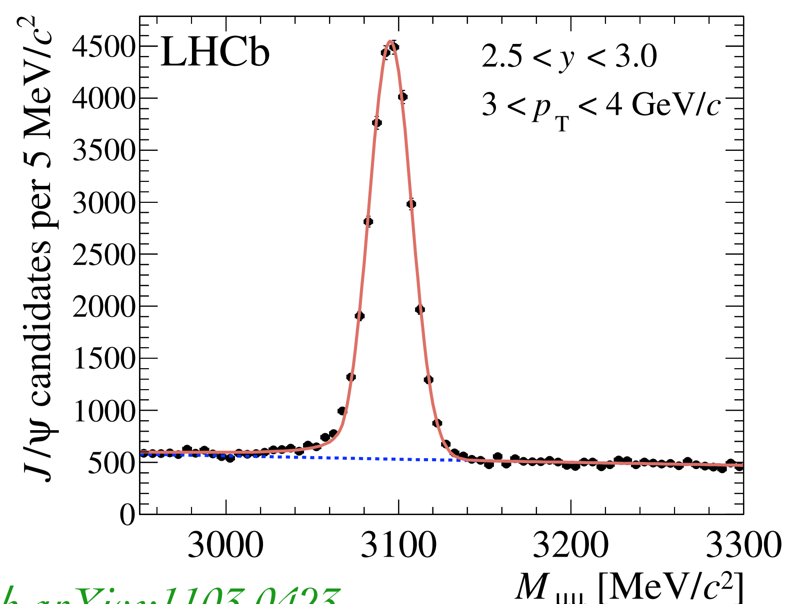
Charmonium hadroproduction at LHC

CDF, PRL79 ('97)

- The first measurement of direct J/ψ and ψ' production at CDF in '97: striking discrepancy from theoretical expectation
- NRQCD: double expansion in terms of α_s and v (velocity): an addition of "colour-octet" term is crucial to explain the cross section?! ➡ Still many questions remaining!!!

Bodwin, Braaten, Lepage, PRD51 ('95)

LHC early data: already a million of J/ψs been collected!



LHCb arXive:1103.0423

Detailed study will start!

- Polarisation measurement?
- How large is the feed-down?
- What is the p_T spectrum like?
- Observation of the other charmonium?

h_c hadroproduction at LHCb

- Importance of having a good search strategy:
  - At Tevatron, J/ψ production rate is measured by using the decay channel of $J/\psi \rightarrow \mu^+\mu$ (very clean!).
  - The χ_c production rates are measured using the decay channel of $\chi_c \rightarrow J/\psi\pi \rightarrow \mu^+\mu^-\pi$.
  - η_c and h_c do not decay to leptons, thus difficult to find.
  - Let us first go through the list of possible decay channels to find the best final state for LHCb.

Diagrams for h_c decays

M.Suzuki '02
S.Godfrey and J.L. Rosner '02

Surviving vs **Annihilating**

$$\Gamma \propto \langle \Psi_{h_c} | r | \Psi_{\eta_c} \rangle$$

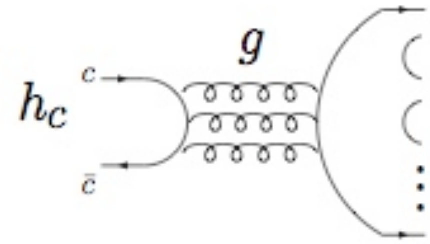
Assuming

$$\langle \Psi_{h_c} | r | \Psi_{\eta_c} \rangle \simeq \langle \chi_{c1} | r | \Psi_{J/\psi} \rangle$$

and using the observed width of

$$\Gamma(\chi_{c1} \to J/\psi\gamma) \simeq 0.3\text{MeV}$$

$$\begin{aligned} \Gamma(h_c \to \gamma\eta_c) &= \left(\frac{|\vec{P}|}{|\vec{P}'|}\right)^3 \Gamma(\chi_{c1} \to J/\psi\gamma) \\ &= 0.52 \pm 0.09 \text{ MeV} \end{aligned}$$



$$\Gamma \propto |\Psi_{h_c}(0)|^2$$

Assuming

$$|\Psi_{h_c}(0)| \simeq | \Psi_{\chi_{c1}}(0)|$$

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$$\Gamma(\chi_{c1} \to qqg) \simeq 0.6\text{MeV}$$

$$\begin{aligned} \Gamma(h_c \to ggg) &\simeq \frac{5}{6}\Gamma(\chi_{c1} \to qqg) \\ &\simeq 0.53 \pm 0.08 \text{ MeV} \end{aligned}$$

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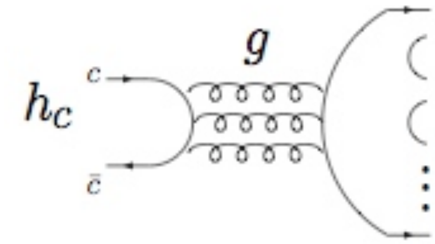

✓LHCb may see this channel through $\eta_c \to \Phi\Phi \to 2(K^+K^-)$ though our MC study shows it challenging...

$$\Gamma(h_c \to \gamma\eta_c) = \left(\frac{|\vec{P}|}{|\vec{P'}|}\right)^3 \Gamma(\chi_{c1} \to J/\psi\gamma)$$
$$= 0.52 \pm 0.09 \text{ MeV}$$

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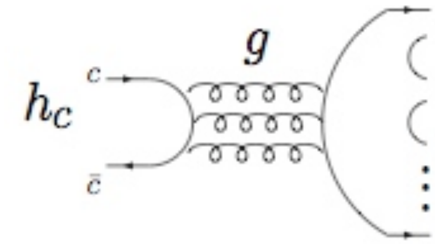

- ✓LHCb may see this channel through $\eta_c \to \Phi\Phi \to 2(K^+K^-)$ though our MC study shows it challenging...

- ✓There are over a hundred of possible final states.
- ✓We investigate what is the best channel for LHCb.

$$\Gamma(h_c \to \gamma\eta_c) = \left(\frac{|\vec{P}|}{|\vec{P}'|}\right)^3 \Gamma(\chi_{c1} \to J/\psi\gamma) = 0.52 \pm 0.09 \text{ MeV}$$

$$\Gamma(h_c \to ggg) \simeq \frac{5}{6}\Gamma(\chi_{c1} \to q\bar{q}g) \simeq 0.53 \pm 0.08 \text{ MeV}$$

Possible hadronic decay of h_c

✓ *C conservation: (1V+1P) or (1V+2P) or (3V) (V=vector mesons, P=pseudoscalar mesons)*

✓ π final state: *G-parity requires* odd number of π's, then always one π^0. So NG for LHCb. (cf CLEO arxiv:0906.4470)

✓ K final state: $\phi\phi$ is forbidden by C while ϕf_0, ϕf_2 (f's→KK or $\phi\phi$) are OK.

✓ π/K mixed final state: OZI forbidden except for special cases (e.g. $\pi\pi$-KK mixing).

✓ baryon final state: $p\bar{p}$, $\Lambda\bar{\Lambda}$ are possible.

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✓ baryon final state: $p\bar{p}$, $\Lambda\bar{\Lambda}$ are possible.

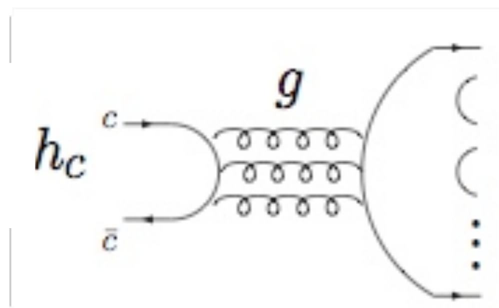
Thus, we consider the following channels...

$$h_c \rightarrow \phi K^+K^-,\ \phi\pi^+\pi^-,\ K^{*0}\overline{K}^{*0},\ p\bar{p},\ \Lambda\bar{\Lambda}$$

Estimating h_c branching ratios

- Simple extraction using the J/ψ hadronic decays

J/ψ
h_c



ϕK^+K^-,
$\phi\pi^+\pi^-$
$K^{*0}K^{*0}$,
pp, ΛΛ

$$\frac{Br(h_c \to final)}{Br(J/\quad \to final)} \simeq \frac{Br(h_c \to ggg)}{Br(J/\quad \to ggg)} \times \text{kinematical factor}$$

Our preliminary predictions....

$$\begin{aligned}
Br(h_c \to \phi K^+ K^-) &\simeq (0.52 \pm 0.12) \times 10^{-3} \\
Br(h_c \to \phi \pi^+ \pi^-) &\simeq (0.54 \pm 0.12) \times 10^{-3} \\
Br(h_c \to p\bar{p}) &\simeq (1.2 \pm 0.25) \times 10^{-3} \\
Br(h_c \to \Lambda\bar{\Lambda}) &\simeq (0.92 \pm 0.20) \times 10^{-3}
\end{aligned}$$

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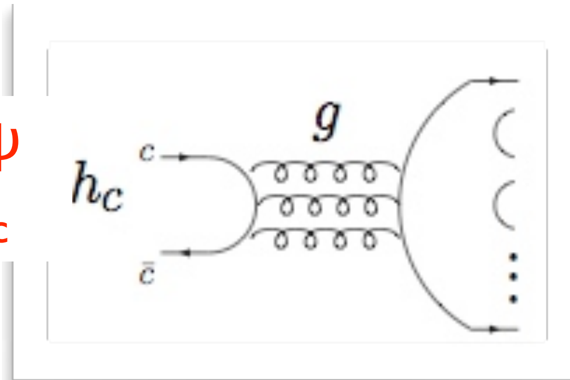

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Our preliminary predictions....

$$\begin{aligned} Br(h_c \to \phi K^+K^-) &\simeq \\ Br(h_c \to \phi\pi^+\pi^-) &\simeq (0.54 \pm 0.12) \times 10 \\ Br(h_c \to p\bar{p}) &\simeq (1.2 \pm 0.25) \times 10^{-3} \\ Br(h_c \to \Lambda\bar{\Lambda}) &\simeq (0.92 \pm 0.20) \times 10^{-3} \end{aligned}$$

From MC study,
we concluded the pp final state is
the best!!

Barsku, He, E.K. and Viaud '10

Simultaneous measurements of charmonium in the $p\bar{p}$ final states

Once we concentrate on the $p\bar{p}$ final state, we realise that most of the charmonium can decay to this channel.

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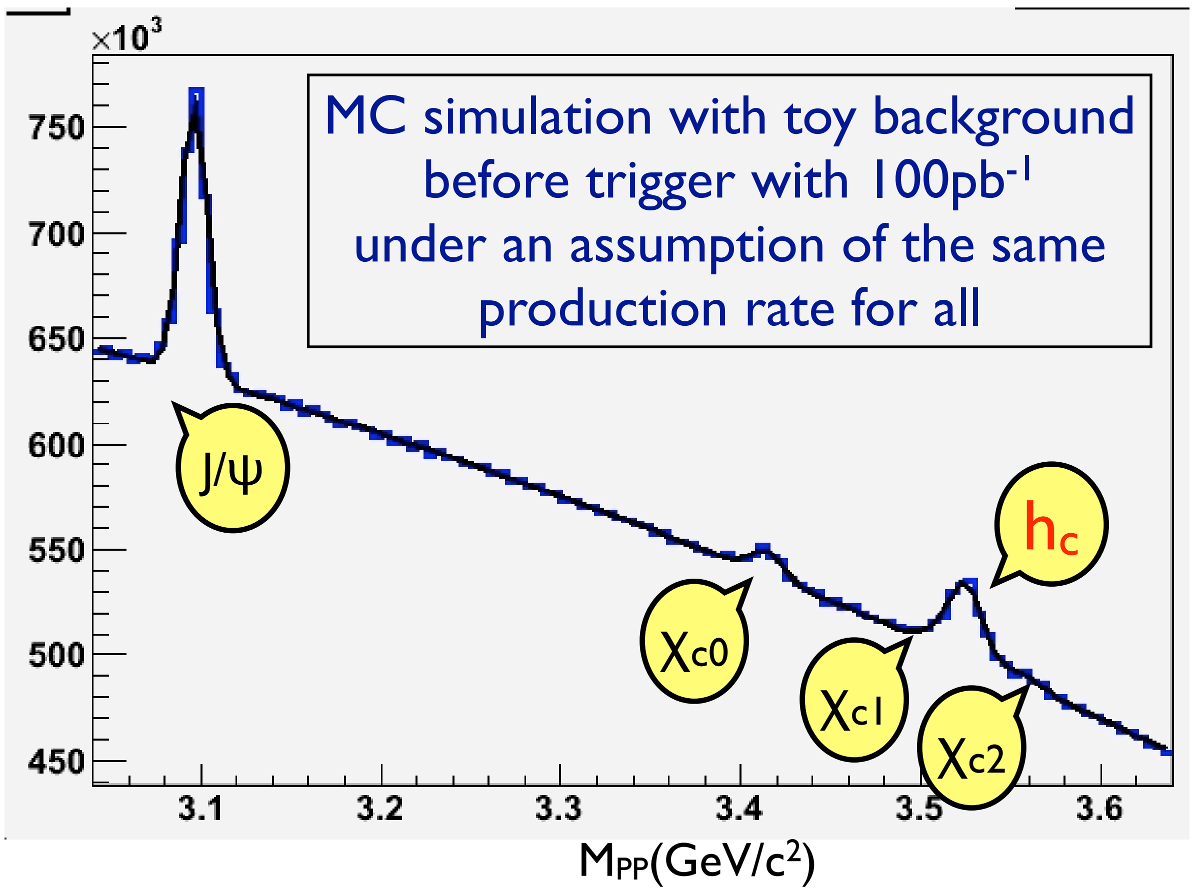
Experimental systematic errors can be reduce by measuring the ratio e.g.

$$\frac{Br(h_c \to pp)\sigma_{production}(h_c)}{Br(J/\psi \to pp)\sigma_{production}(J/\psi)}$$

Barsku, He, E.K. and Viaud '10



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✓First measurement of h_c (and η_c) hadroproduction

✓Re-determinations of the cross section of:

$$\sigma_{production}(J/\psi) \text{ and } \sigma_{production}(\chi_{cJ})$$

✓The puzzle of the χ_{cJ} cross section ratio:

$$\sigma_{production}(\chi_{c2})/\sigma_{production}(\chi_{c1})=(0.71+-0.04)_{exp} \text{ vs } (5/3)_{th}$$

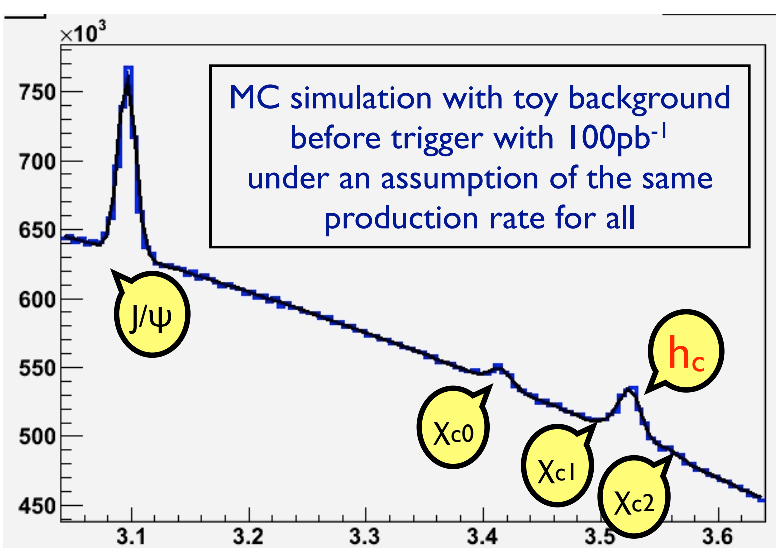
✓Searching for the factorization forbidden B decays:

$$B \to h_c Xs \text{ and } B \to \chi_{c2} Xs$$

etc etc...

Conclusions

- We proposed a LHCb search strategy of h_c with the pp final state.
- We investigated a possible simultaneous measurement of the different charmonium with this channel.
- Now the search at LHCb has started and...



$M_{PP}(GeV/c^2)$

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