η_b searches at hadron colliders

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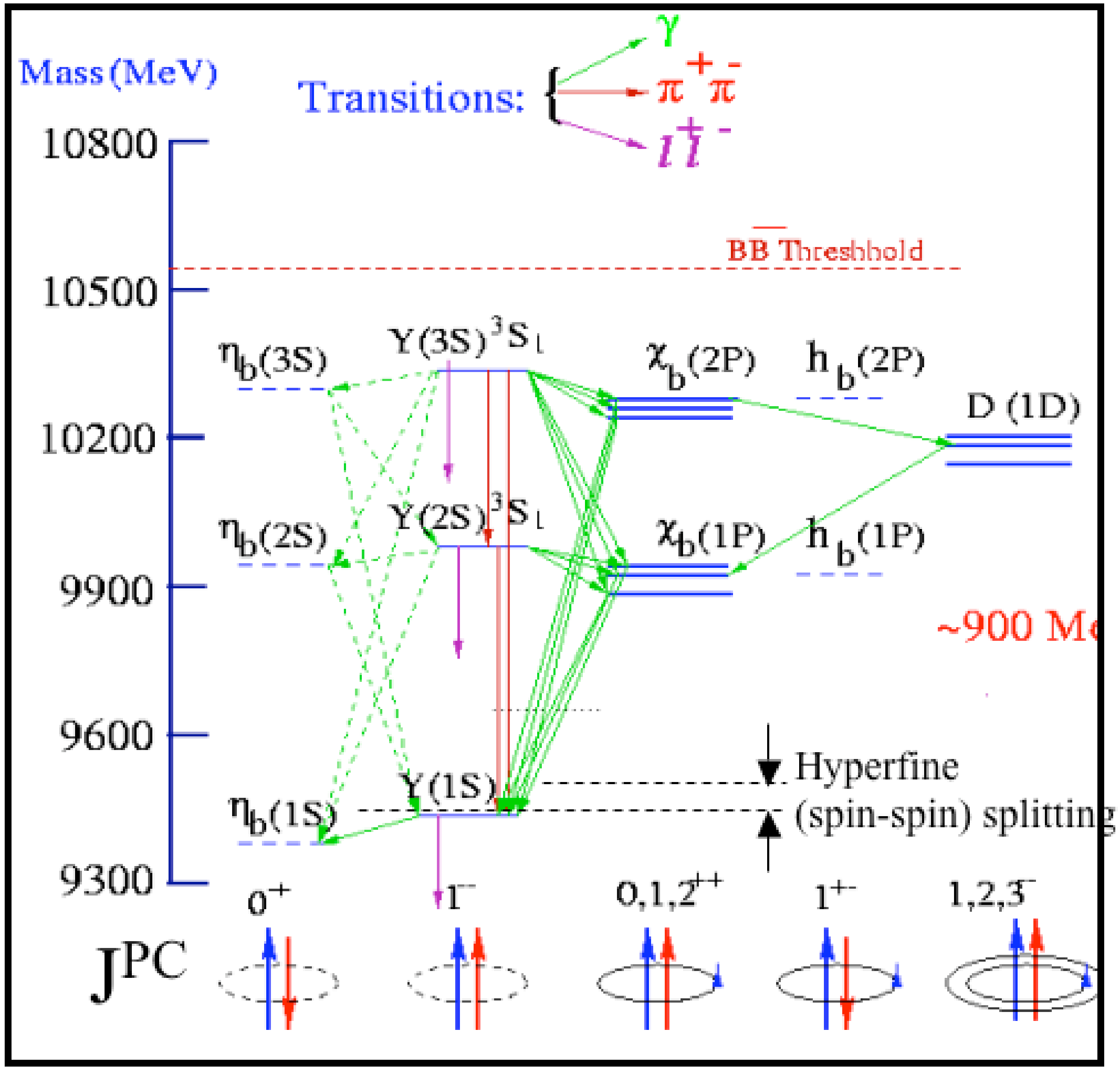
based on
F. M., A. Polosa, PRD70:054014,2004

Outline

- Motivations
- Production
- Decays
- Outlook

Bottomonium Spectrum



Unseen!

Lattice studies (unquenched) describe the spectrum pretty well.

Several EM transitions have been confirmed in experiments such as CLEO.

Hyperfine splitting

$$H_{q\bar{q}}^{cont} = \frac{32\pi}{9}\frac{\alpha_s(r)}{m_q m_{\bar{q}}}\vec{S}_q \cdot \vec{S}_{\bar{q}}\delta^3(\vec{r})$$

is responsible of the shift between the 3S1 and 1SO states.

CLEO has looked for the "hindered" M1 decays

$$\Gamma[\Upsilon(nS) \rightarrow \eta_b(n'S)\gamma] = \frac{4}{3}\alpha\frac{e_b^2}{m_b^2}I^2k^3$$

but found non-confirmed evidence for the 1S0 states

η_b hunter's rules

- The lowest bottomonium state has quantum numbers $J^{PC}=0^{-+}$ therefore it couples to two photons or gluons, and it does not to a lepton pair (through a photon).
- In ee colliders can be produced only in a decay chain from a higher n state or by photon photon interactions. Cross section is small, but possible to search in the inclusive decays (hadronic inclusive channels have br ~ 1).
- In hadron collisions, cross sections are large, but need a very clean signature (e.g a rare decay or associated production) to select it from the hadronic background

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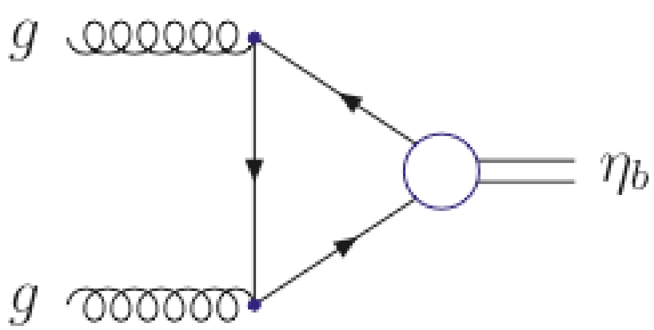
All searches have been so far inconclusive!

Inclusive η_b production



Born process is only at α_S^2 .

Compare with $^3S_1^{[1]}$ whose LO is at α_S^3.

This means that there cannot be any dynamical enhancement of the octet contributions, which remain suppressed by $v^4 \sim 0.01$.

We can neglect the octets. Singlet ME is the same as the Υ ⇒ prediction is absolute!!

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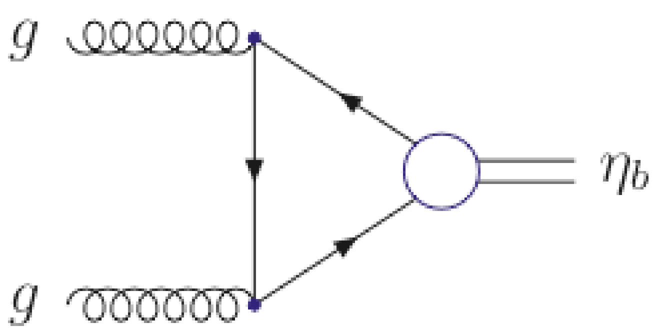

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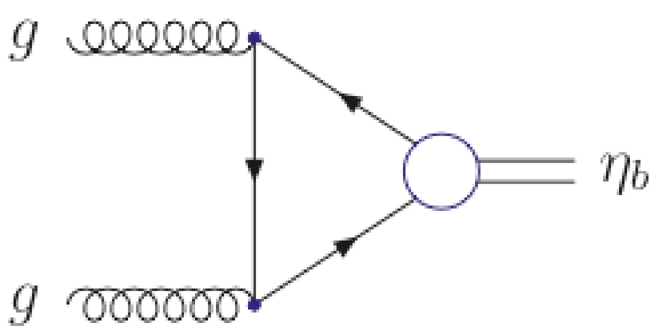
Up to corrections of order v^4, no free parameters enter in the theoretical prediction for η_b production

Inclusive η_b production at NLO

[Kuhn and Mirkes, 1993;Petrelli et al., 1998]



We can improve the theoretical prediction by calculating the short-distance coefficient at higher order.

$$\sigma(p\bar{p} \to \eta_b + X) = \sum_{i,j} \int dx_1 dx_2 f_{i/p} f_{j/\bar{p}} \hat{\sigma}(ij \to \eta_b),$$

$$\hat{\sigma}(gg \to \eta_b) = \frac{\pi^3 \alpha_S^2}{36 m_b^3 \hat{s}} \delta\left(1 - \frac{4m_b^2}{\hat{s}}\right) \langle 0 | \mathcal{O}_1^{\eta_b}({}^1S_0) | 0 \rangle$$

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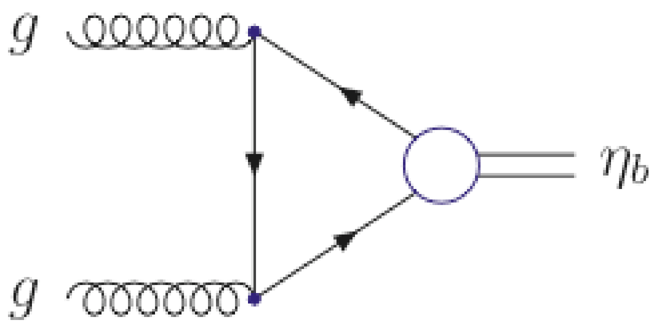

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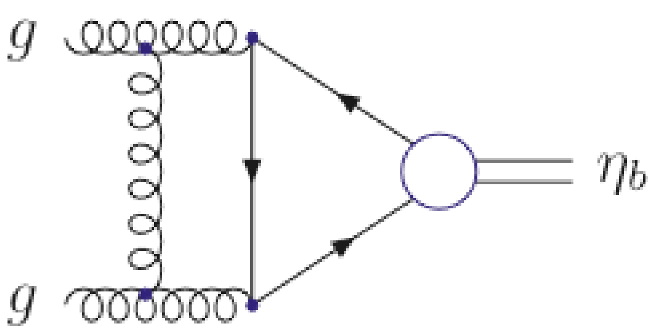
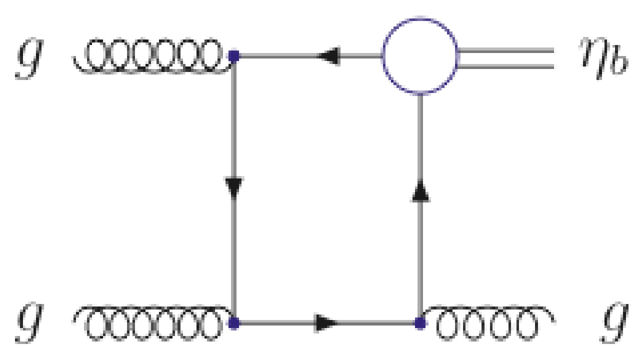
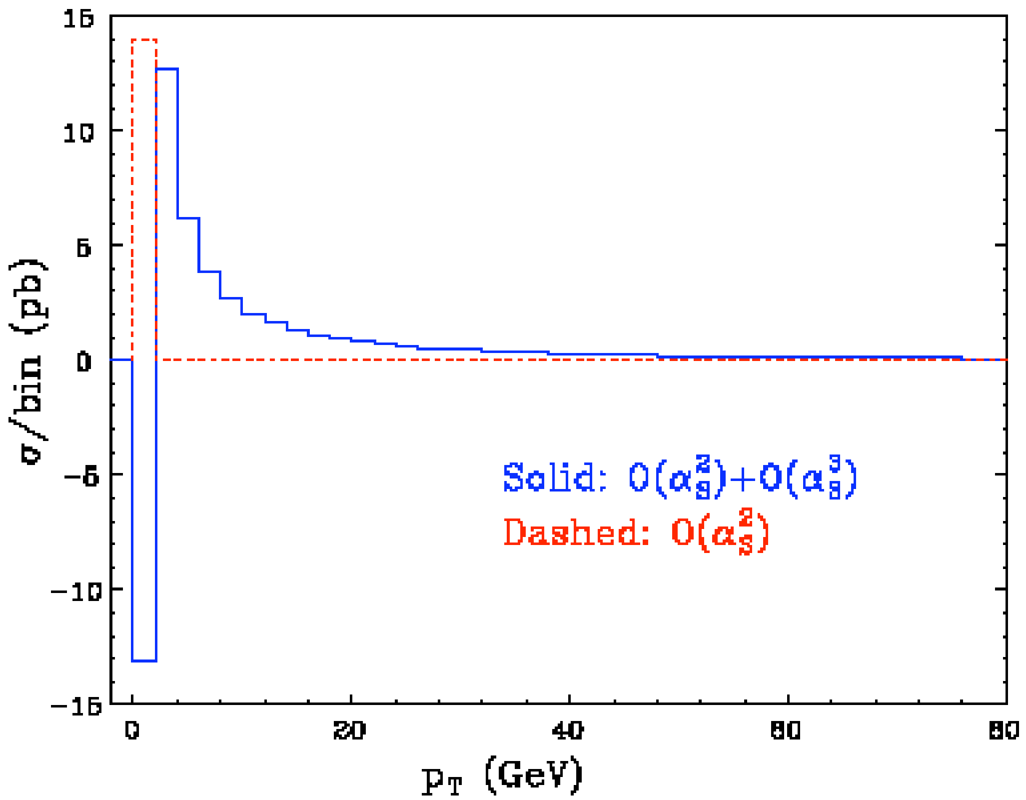




Virtual + Real = finite α_S corrections

$$\sigma(p\bar{p} \to \eta_b + X) = 2.5 \pm 0.3 \mu\text{b}$$

Problems with a NLO fixed-order calculation



$$\frac{d\sigma}{dp_T} = (A\alpha_S^2 + B\alpha_S^3)\,\delta(p_T) + C(p_T)\alpha_S^3$$

$$\int_{p_T^{min}}^{\infty} dp_T \frac{d\sigma}{dp_T} = \mathcal{C}_3\alpha_S^3, \qquad p_T^{min} > 0$$

$$= \mathcal{D}_2\alpha_S^2 + \mathcal{D}_3\alpha_S^3, \quad p_T^{min} = 0$$

$p_T^{min} > 0 \Rightarrow$ LO, $p_T^{min} = 0 \Rightarrow$ NLO

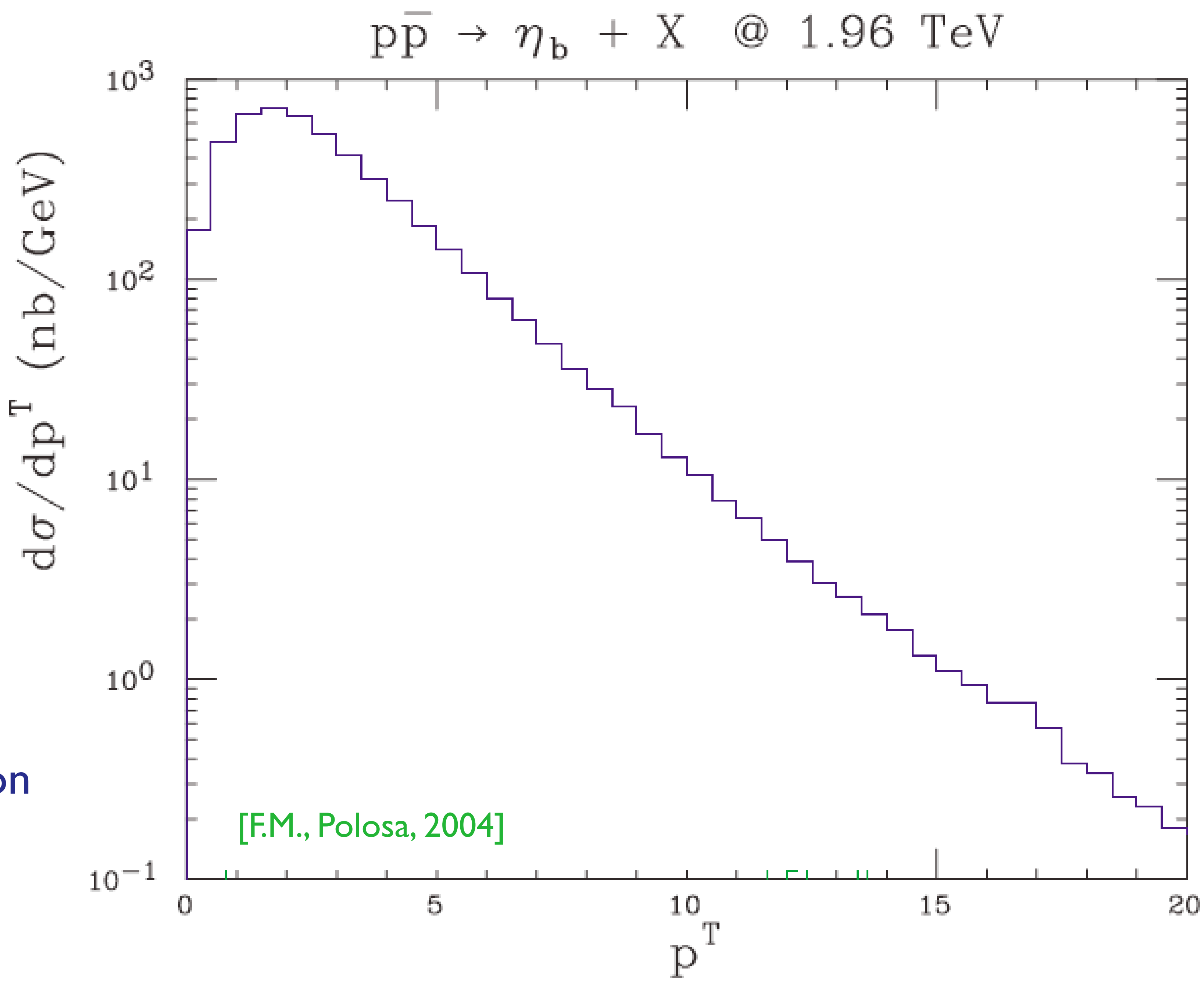
Small pt region is not well described by a FO calculation

Soft gluon resummation is needed

Elegant and efficient MC solution to the matching problem now known (e.g., MC@NLO by Frixione and Webber)

A solution: use PYTHIA+ ME corrections

Inclusive η_b production at the Tevatron



Normalization fixed by the total NLO calculation

Inclusive η_b production at the Tevatron

Soft-gluon resummation given by Pythia

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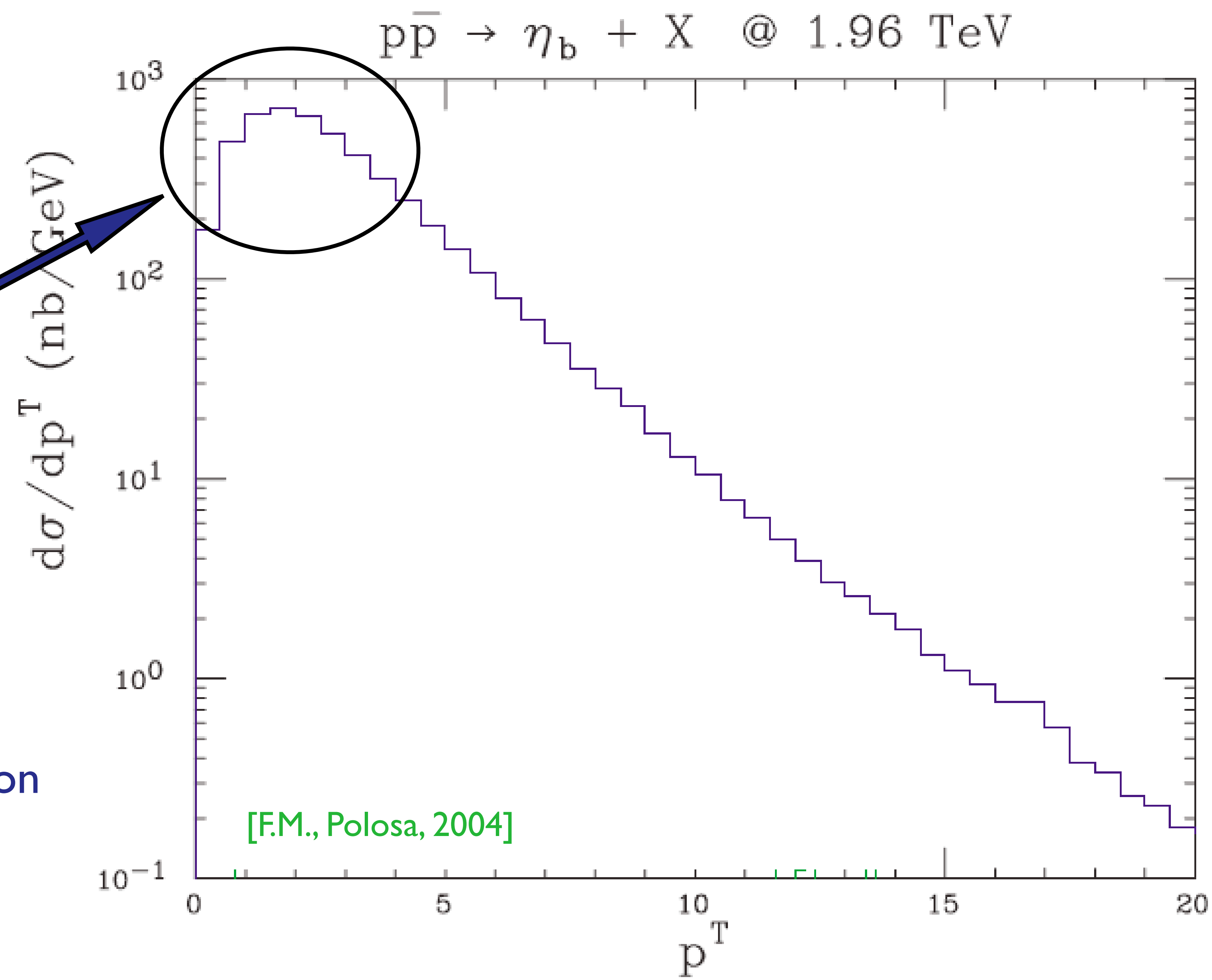

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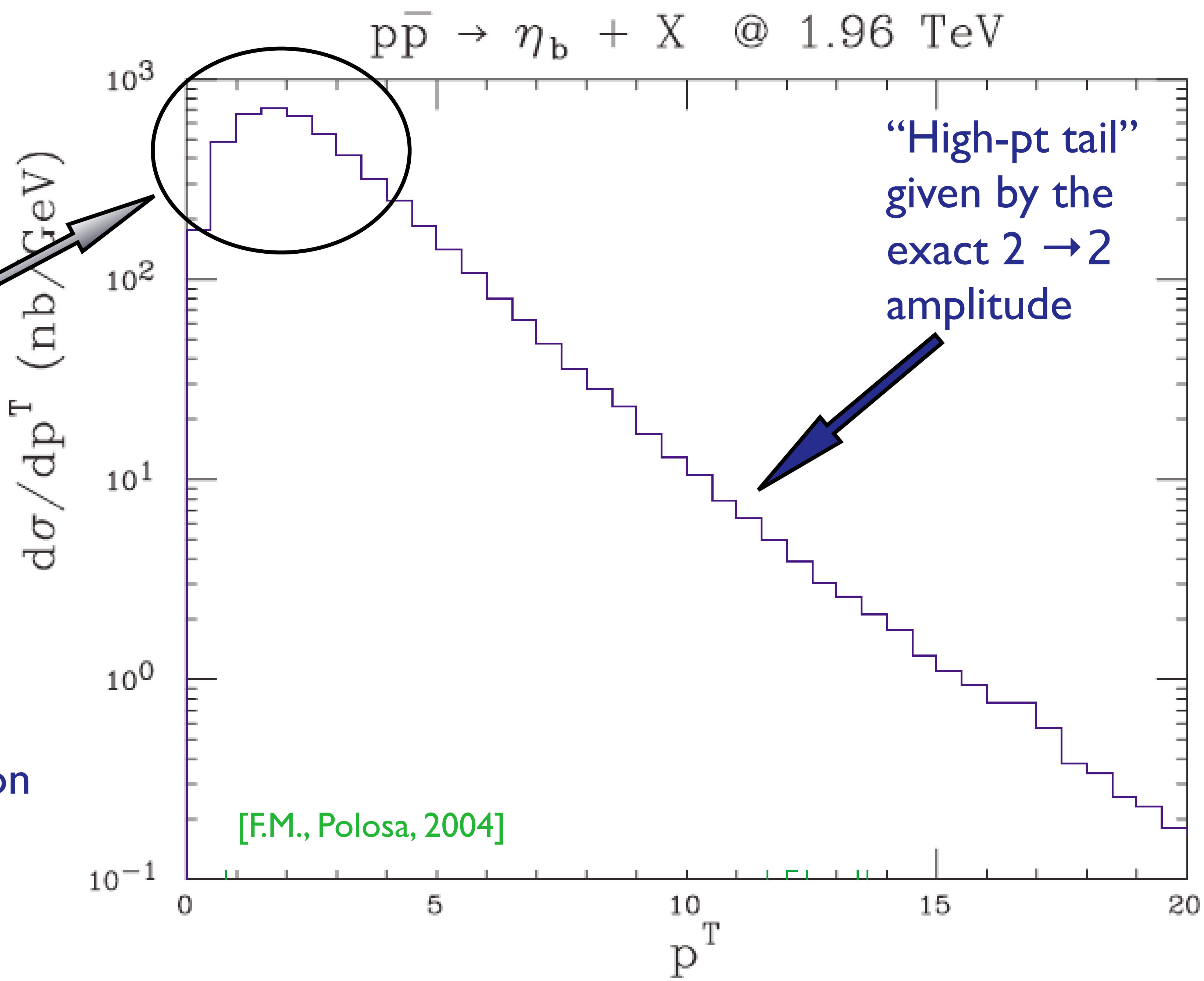

Inclusive η_b production

$$\sigma(p\bar{p} \to \eta_b + X) = 2.5 \pm 0.3 \mu\mathrm{b}$$ at TeV Run II

- Cross section is very large. It amounts to 2.5 millions of events per 1 inverse pb of integrated luminosity.
- Theoretical uncertaintes are under control: reduced scale dependence at NLO, relativistic corrections are small, mass uncertaintes mostly reabsorbed into the non-perturbative ME.
- Event generation obtained by matching the shower (collinear and soft resummation) and exact matrix elements. Satisfactory description of the events in all phase space: experimentalists are happy (hopefully).

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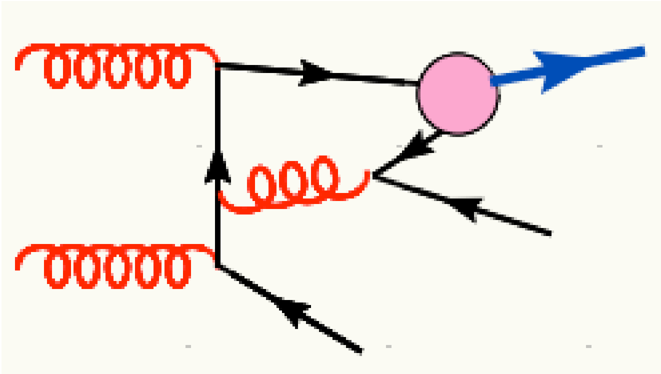
We need to find a clean signature for it!

Associated productions

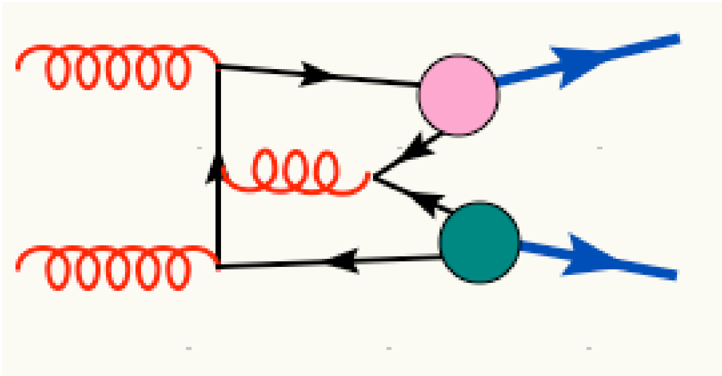


η_b - bb associated production

[P. Artoisenet, F.M., K. Pitts, H.K. Gerberich, in progress]

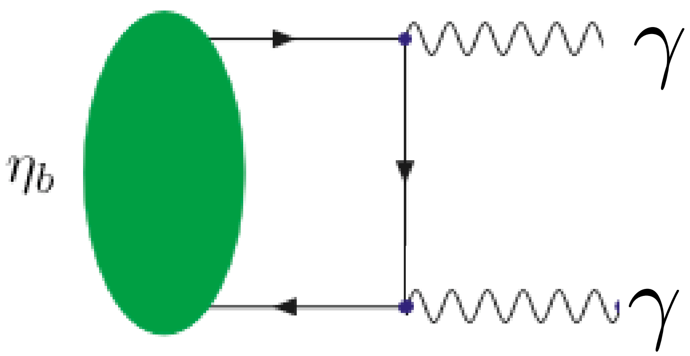
$\sigma \cong 300$ nb

[ppbar @1.96 TeV, CTEQ6M, dyn scale, <0>=3.094 GeV^3, no cuts, no Br's]

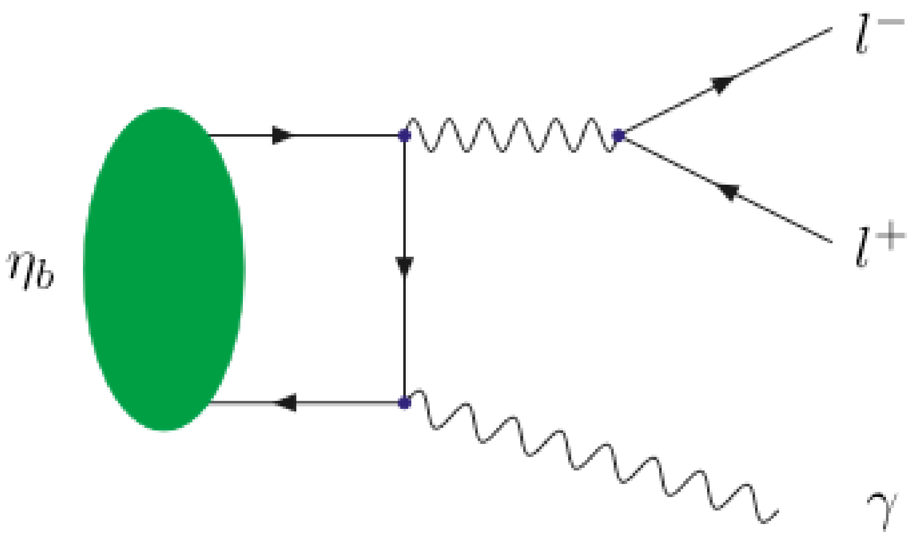


η_b - Υ associated production

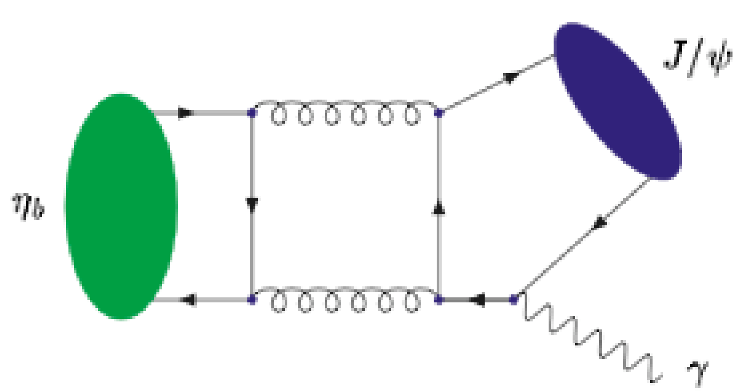
"Clean" decay channels: leptons and/or photons

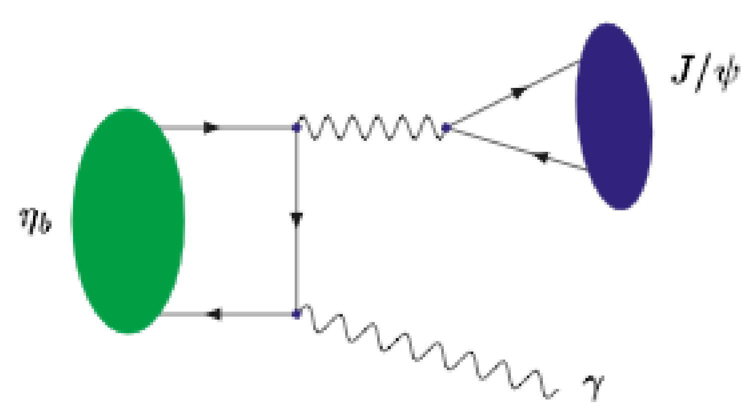


Higgs-like decay channel:
(Time conjugate of the LEP searches)
Br ~ 10^{-5} , difficult to trigger on <pt> ~ 5 GeV.



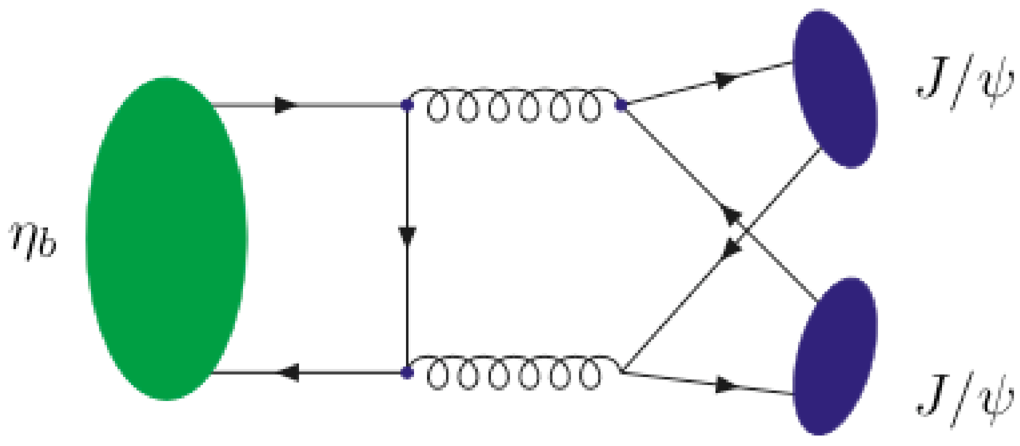
Lepton-photon channel.
interesting even when both photons are on shell and one converts in the detector.
Br < 10^{-7} , easier to trigger on the lepton.
Too small branching ratio.





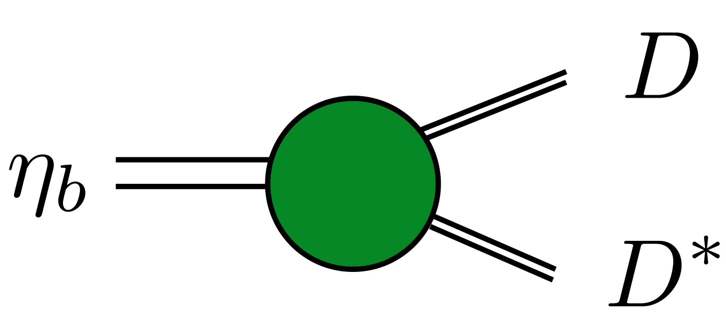
see Kong-Feng Qiao's talk

Hadronic decay channels



[Braaten, Fleming, Leibovich, 2001]

Very clean and inspired by the large analogue br for $\eta_c \to \phi\phi$.
Unfortunately, both direct calculation and inclusive estimates give a very small br.



[F.M., Polosa, 2004]

D mesons are detected on at CDF using a dedicated trigger. They have a huge data set, with also pairs of D mesons.

This decay is not calculable in PQCD but it reasonably estimated by the inclusive decay rate:

$$\Gamma(\eta_b \to D^* D^{(*)}) \lesssim \Gamma(\eta_b \to c\bar{c} + X),$$

More in Jia's and Santorelli's talks!!

Outlook

- η_b still elusive after all these years...
- NLO prediction for inclusive production + matching with the Pythia shower for p_T shapes available.
- Associated productions under study
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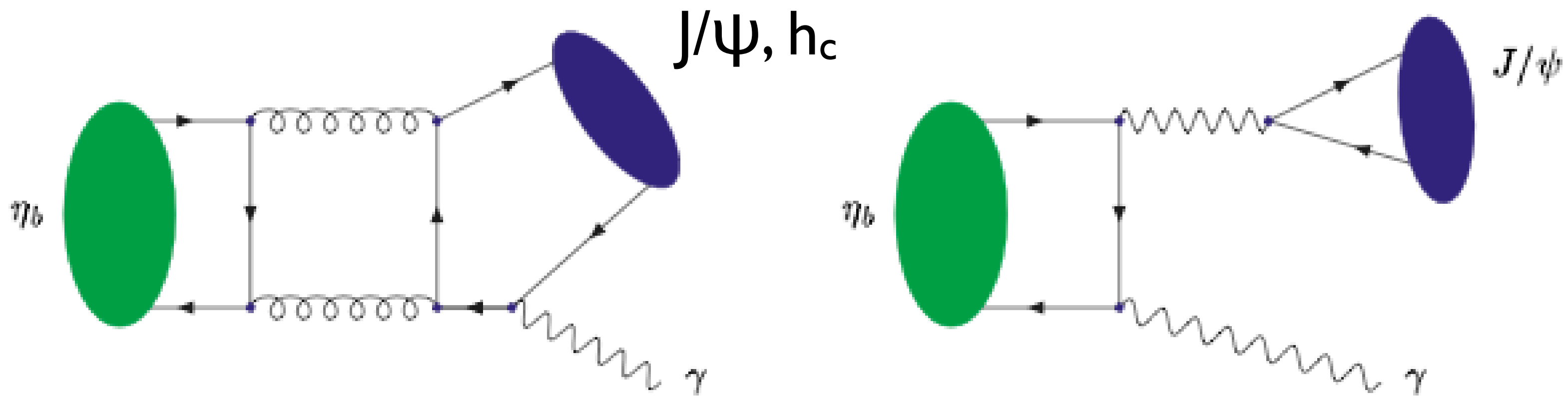
Room for new ideas, discussions and improvements!

"Clean" decay channels: radiative decays

see Kong-Feng Qiao's talk



$c\bar{c}$ state J^{PC}	η_c 0^{-+}	h_c 1^{-+}	J/ψ 1^{--}	χ_{cJ} J^{++}
η_b	–	$L=0$	$L=1$	–
h_b	$L=0$	–	–	$L=1$
Υ	$L=1$	–	–	$L=0$
χ_{bJ}	–	$L=1$	$L=0$	–