Discussion session
03/10 Monday afternoon

RECEIVED QUESTIONS (THANKS !)

- How well is quarkonium production understood in exclusive production?
- ptQ>>M as criterion to define fragmentation regime: no other limits from “hadronic environment”?

Other inputs

QUARKONIA: STILL NO SINGLE CONSISTING PICTURE OF PRODUCTION MECHANISMS

Maxim Nefedov, morning talk

WANTED, BIASED LIST

LDMEs	J/ψ hadropr.	J/ψ photopr.	J/ψ polar.	η_c hadropr.
Butenschön et al.	✓	✓	✗	✗
Chao et al. + η_c	✓	✗	✓	✓
Zhang et al.	✓	✗	✓	✓
Gong et al.	✓	✗	✓	✗
Chao et al.	✓	✗	✓	✗
Bodwin et al.	✓	✗	✓	✗

- Cover largest possible **pT and rapidity ranges**, or at least match TH (simultaneous or, at least, matching description over the entire range; x-checks using c-cbar, b-bbar and Bc ?) vs. EXP (overlap between experiments; access to low-pT ?) coverages
- **More data** from (HL-)LHC, more efficient data collection, however, higher trigger thresholds + competition for a bandwidth … dedicated triggers ?
- Measure **linked observables**: charmonia with linked LDMEs; charmonia from different sources; …
- Further development of **combined or global fits**
- **Test factorisation, universality and HQSS** … which data wanted ?
- How to reduce **scale uncertainties** limiting the precision ?
- (Too) much experience that LO is not sufficient. How to cope with **NLO, NNLO calculation challenges**, where they are needed … what are perspectives ?
- How to interpret **negative x-sections at large pT** ?

HADRONISATION: OPEN POINTS AND NEXT STEPS

- Can the expected validity range of factorisation approach in pQCD-based calculation be well defined?
- D_s^+/D^0 does not change much from e^+e^- to pp, contrary to $\Xi_c^{0,+}/D^0$ and $\Sigma_c^{0,+,++}/D^0$, both increasing more than Λ_c^+/D^0, with $\Sigma_c^{0,+,++}/\Xi_c^{0,+}$ staying not far from e^+e^-
  - Higher-mass states
  - Diquark-formation suppression in e^+e^- or easier diquark-formation in hadronic collisions?
    - diquark role in Pb-Pb for EoS?
  - how much the production rate of a given hadronic state can depend on its internal structure?
- Relativistic Quark Model: several baryon states not yet observed
  - which collision system better suited for searching them? why not seen in e^+e^-?
  - expected rates? (e.g. SHM expectation as a baseline?)
  - which decays? (mostly strong decays to lower-mass states + pions)
- Low-mult pp vs. e^+e^-
  - Modification of hadronisation mechanisms
  - Yields vs. mult, MPI vs. edge effects
- Different models may describe differently similar effects, adopting different point of views
  - PYTHIA with CR beyond LC, Coalescence, SHM all imply departure from “standard” fragmentation and universality assumption
  - Can we connect them?
- Models including both fragmentation and coalescence often assume that fragmentation kicks in when coalescence probability results small (“leftover” c-quarks are fragmented): is there a foundation behind this?
- p_T-integrated vs. p_T-differential multiplicity evolution of Λ_c^+/D^0
  - Flow? Unnecessary coincidence of getting p_T-int =1… or not?
  - Hadronic part expected small, theory + femto studies

QUARKONIUM PRODUCTION - DISCUSSION/BRAINSTORMING
SELECTED QUESTIONS ON STATUS, PROBLEMS AND PROSPECTS

CORE MEASUREMENTS:

- differential x-sections: pT, rapidity, event topology/multiplicity, … ?
- x-section ratios (states with the linked LDMEs, e.g. J/ψ/ηc, χ_ci/χ_cj, ratios at different sqrt(s), experimentally useful ratios – directly measured, x-check ratios e.g. ψ(2S)/J/ψ, J/ψ/Y(1S), …), double ratios (e.g. J/ψ/ηc / ψ(2S)/ηc(2S), J/ψ/ηc / Y(1S)/ηb), … are the ratios useful (TH vs EXP) ?

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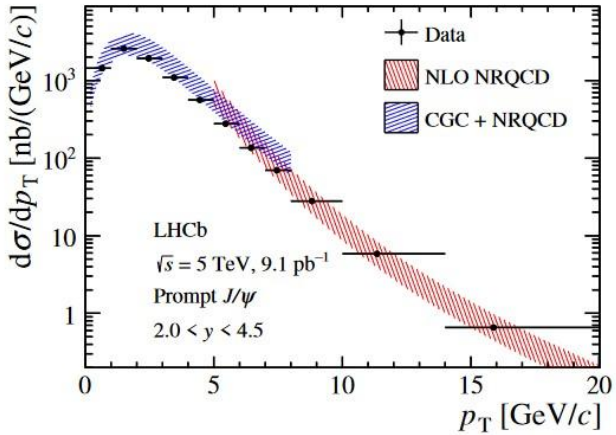
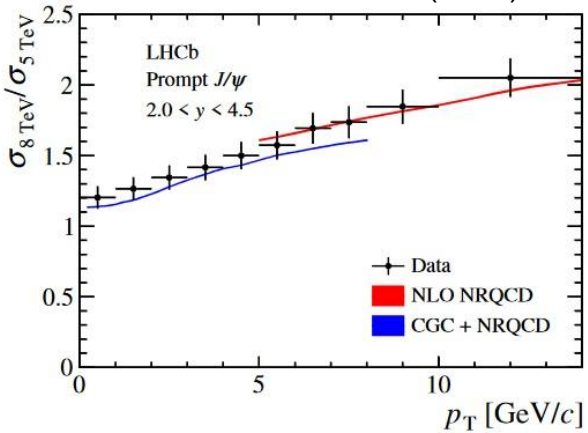




- vector-state polarizations … how many *independent* observables ?
- ???

QUARKONIUM PRODUCTION - DISCUSSION/BRAINSTORMING
SELECTED QUESTIONS ON STATUS, PROBLEMS AND PROSPECTS

Whom to measure:

- charmonia, JPC = 1 - -, but also other using decays to hadronic final states
- charmonium-like states, X(3872), but also others … what is the added value ?
- bottomonia, Y(iS), ηb and χ_bi, … sufficient x-section @ LHC ? significant BRs and EXP-friendly decays ?
- ???

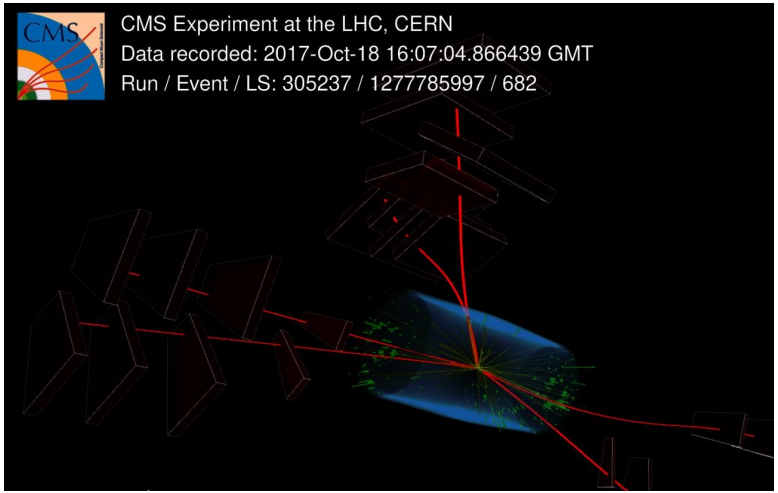
Where to measure:

- e+e-, ep, hadronic collisions, heavy ions, …
- hadroproduction, b-decay production, photoproduction, diffractive processes and CEP
    - CEP: only CS present; link between the quantum number of final state and virtually exchanged states (gamma, odderon, pomeron) -> study nature of exchanged states; quantum numbers of final state particles, parton distributions of colliding objects; ?
    - (Natural) Link between CEP and photoproduction. How straightforward is the contribution to understanding of other production mechanisms ?
    - EXP friendly signature: rapidity gap and pT spectrum. However, becomes difficult at higher mu values
- multiple and associated production, … -> x-checks and/or complementary information ?

QUARKONIUM PRODUCTION - DISCUSSION/BRAINSTORMING
SELECTED QUESTIONS ON STATUS, PROBLEMS AND PROSPECTS

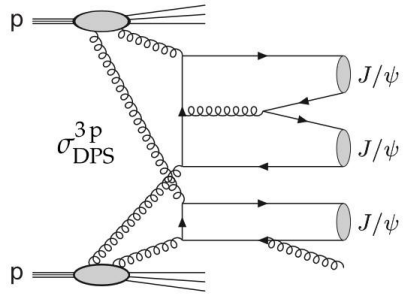
Associated production, links to single hadroproduction

- Double- or triple- charmonia (SPS vs DPS vs TPS)

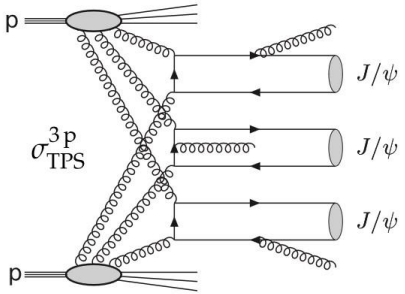


arXiv:2111.05370

- **DPS** triple J/ψ production
  - a mixture of $(J/\psi+J/\psi)_{sps} + J/\psi_{sps}$



- **TPS** triple J/ψ production
  - a mixture of $J/\psi_{sps} + J/\psi_{sps} + J/\psi_{sps}$



- How to interpret the effective x-section from triple charmonia ?
- Should we study associated production as a function of pT/M(Q-Q) ?

SERVICE MEASUREMENTS / CALCULATIONS

Input BRs:

- Charmonia decays to lower charmonium states (for feeddown accounting)
- b-decays to charmonia (production in b-decays, also EXP x-feed)
- 1 - - charmonia to di-muons (already sufficient accuracy ?); charmonia to hadronic channels (ideally significant BRs for several charmonia, however, at LHC largely limited to LHCb)
- x-checks or independent valuable measurements:
  e.g. ratio of ηc -> 2φ / ηc -> ppbar
- ???

ψ(2S) decay BR

$\gamma\chi_{c0}(1P)$	$(9.79 \pm 0.20)\%$
$\gamma\chi_{c1}(1P)$	$(9.75 \pm 0.24)\%$
$\gamma\chi_{c2}(1P)$	$(9.52 \pm 0.20)\%$
$\gamma\eta_c(1S)$	$(3.4 \pm 0.5) \times 10^{-3}$
$\gamma\eta_c(2S)$	$(7 \pm 5) \times 10^{-4}$

hc decay BR

$\gamma\eta_c(1S)$	$(50 \pm 9)\%$

PDG live

Feeddowns, production of higher states:

- ψ(2S), χ_ci, hc + X(3872)
- Also b-production affecting via EXP x-feed between hadroproduction and b-decays
- ???

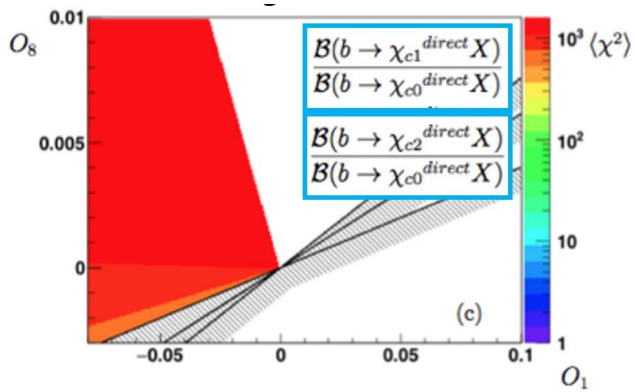
COMBINED MODEL TESTS

Linked measurements, improve precision and/or test assumptions:

- Linked LDMEs, e.g. J/ψ and ηc (1 CS and 3 CO LDMEs), χ_ci (1 CS and 1 CO LDMEs)

Branching fractions calculation
Beneke, Maltoni, Rothstein, PRD 59 (1999) 054003

LAL-17-051



- Hadroproduction vs. b-decays
- e+e- vs. ep vs. pp(pbar) vs. … ; pp vs heavy ions
- Global fits
- ???

- Simultaneous measurement of charmonia with linked LDMEs from different sources constrains theory under **assumptions of factorization, universality and HQSS.**
- Once the complete set of measurements is available, can the above **assumptions be tested quantitatively** ?

HADRONISATION: OPEN POINTS AND NEXT STEPS

- What can we learn from
  - correlation measurements (production yields, angular and momentum correlations)
    - of HF-signal pairs
    - HF - light flavour (e.g. Λ_c^+-p vs. Λ_c^+ - p)
  - HF jets, in particular: momentum fraction and radial profile of D-tagged, Λ_c^+-tagged jets?

- Exotic states (X(3872), pentaquarks):
  - how can we further understand their nature?
  - which additional information can the measurement of their production yields in different collision systems add?
  - could femtoscopy measurements help? (= could femtoscopy measurements of D-pion, D-p, Λ_c-pion, Σ_c-pion constrain the hadronic potential in such a way to provide information useful also for the molecular picture of these states?)

questions during 1st talk

ptQ>>M as criterion to define fragmentation regime: no other limits from “environment”?