

Quarkonia production in SuperChic: a brief overview

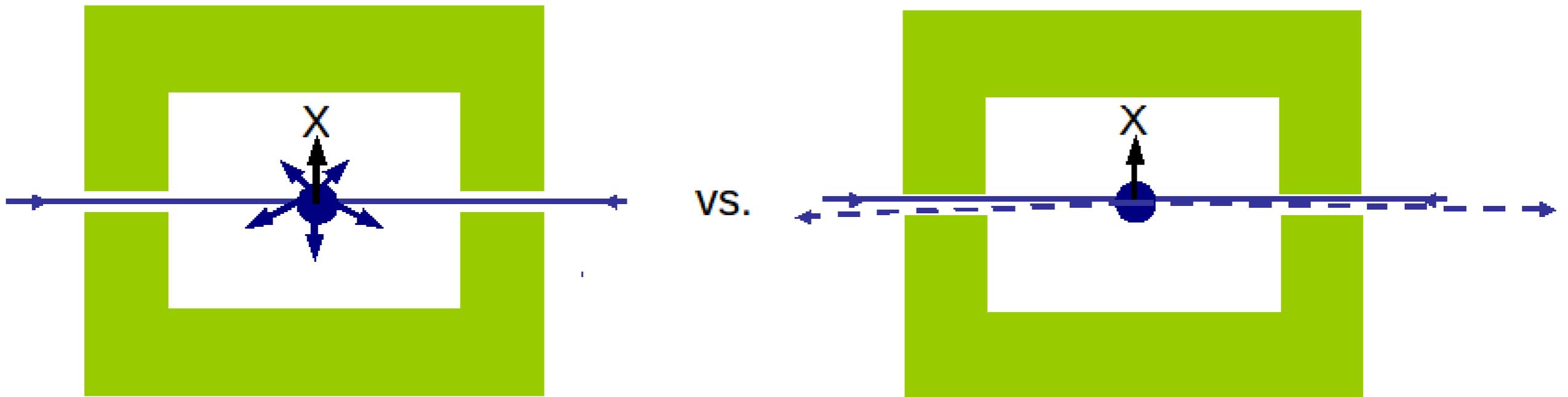
Lucian Harland-Lang, University of Oxford

Quarkonia as Tools 22, 11 Jan 2022



Outline

- In this talk I will provide a brief outline of the **SuperChic MC** generator relevant to quarkonium production.
- Caveat: no substantial updates to SC with respect quarkonia for ~ 5 years. However hopefully this talk can initiate some new ideas for future!

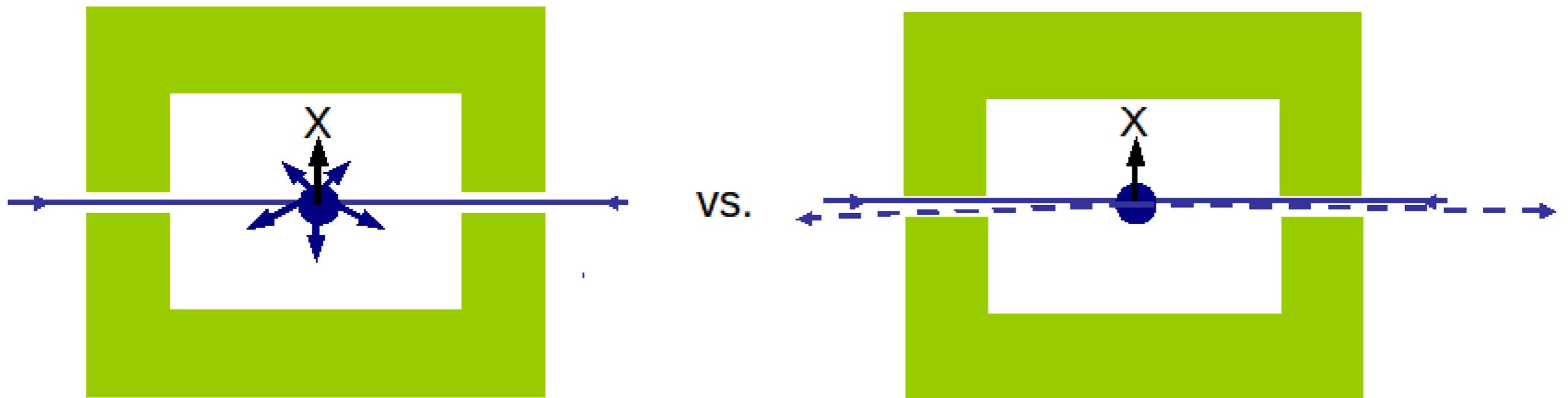


Central Exclusive Production

Central Exclusive Production (CEP) is the interaction:

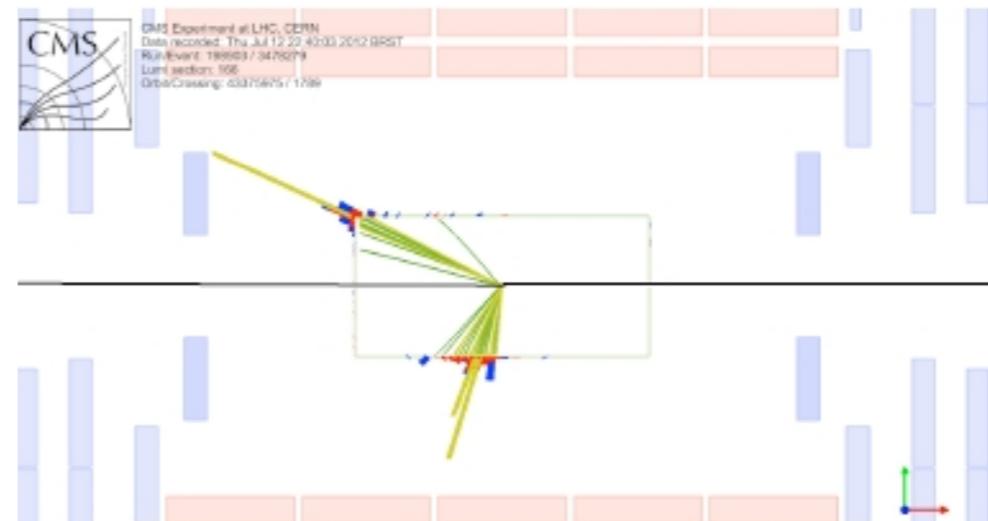
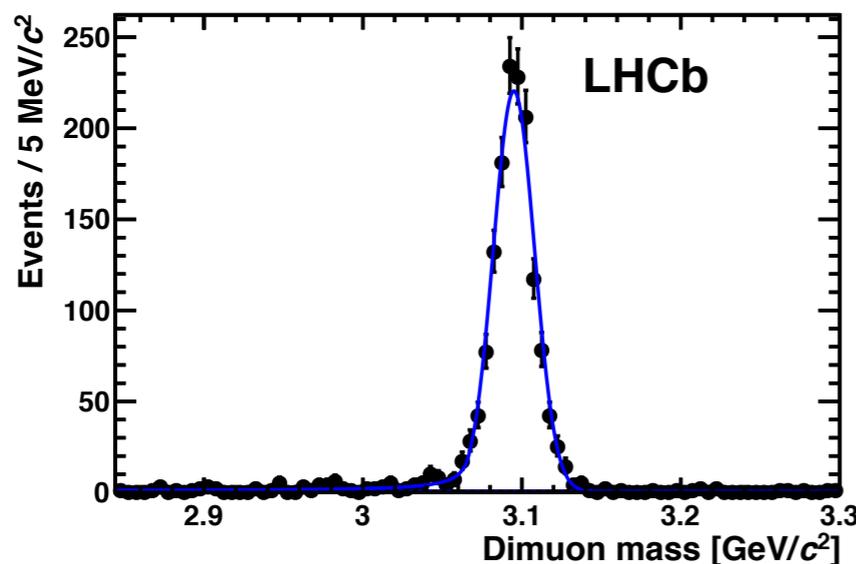
$$hh \rightarrow h + X + h$$

- **Diffraction**: colour singlet exchange between colliding protons, with large rapidity gaps ('+') in the final state.
- **Exclusive**: hadron lose energy, but remain intact after the collision.
- **Central**: a system of mass M_X is produced at the collision point and only its decay products are present in the central detector.



Advantages of CEP

- Clean, definite final state: object X + **nothing else** from interaction.
 - **Protons** intact and can be **tagged** \Rightarrow provides additional information about central state, as well as selection of CEP events.
 - Exclusive nature of the final state and kinematics of this provide important constraints on the final state (**spin-parity-colour selection**).
- \rightarrow Naturally provides **complementary handle** to study the SM in comparison to inclusive production.



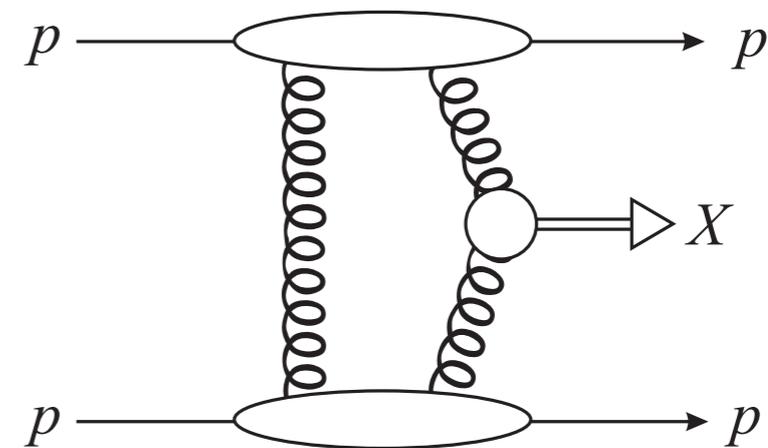
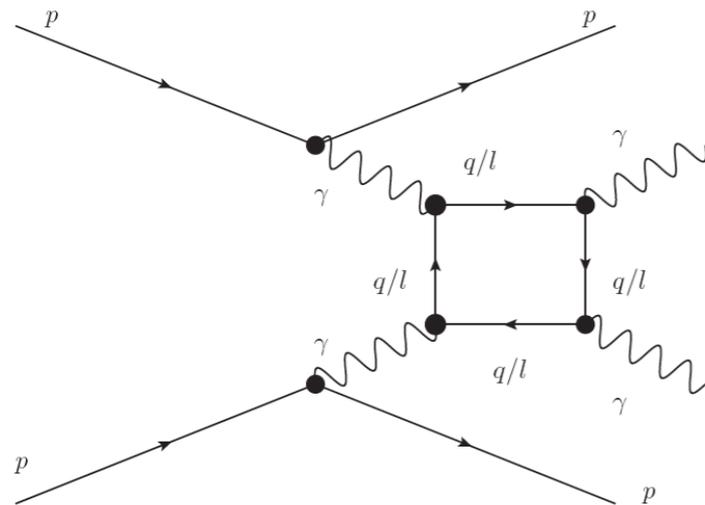
Production Mechanisms

Exclusive final state can be produced via three different mechanisms, depending on kinematics and quantum numbers of state:

QCD-induced

C-even, couples to gluons

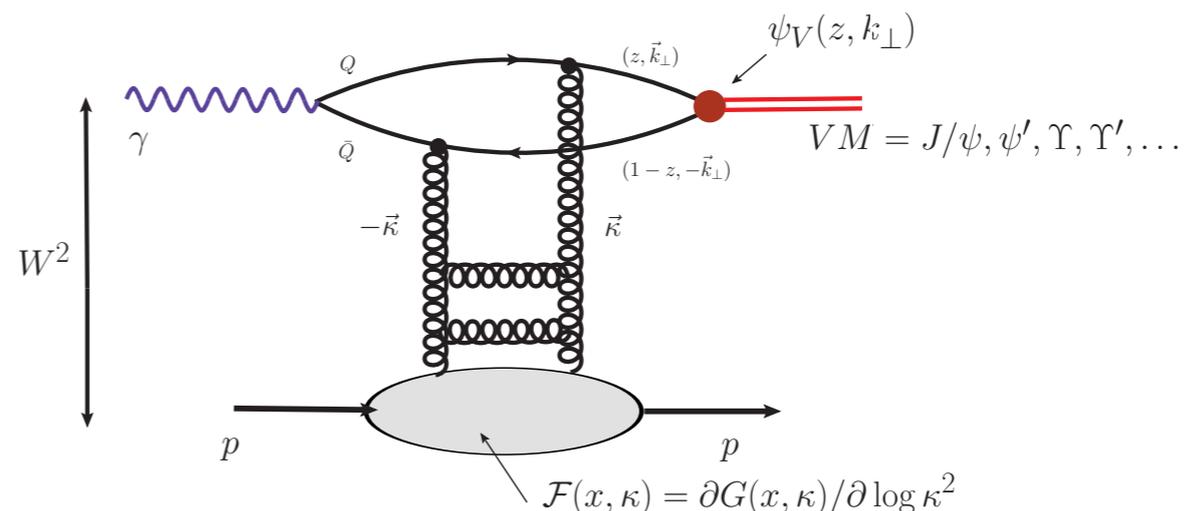
C-even, Couples to photons



Photon-induced

C-odd, couples to photons + gluons

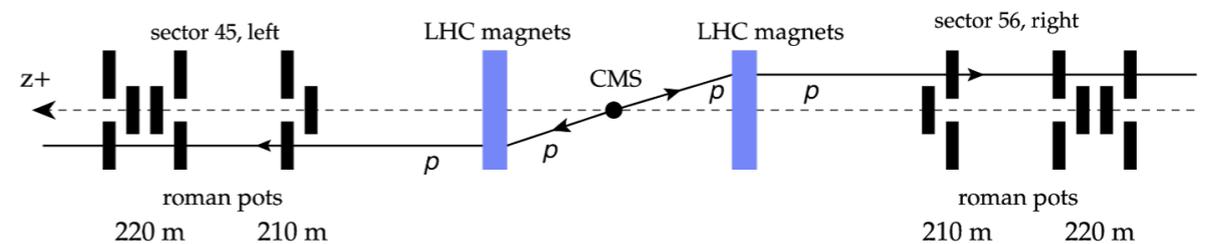
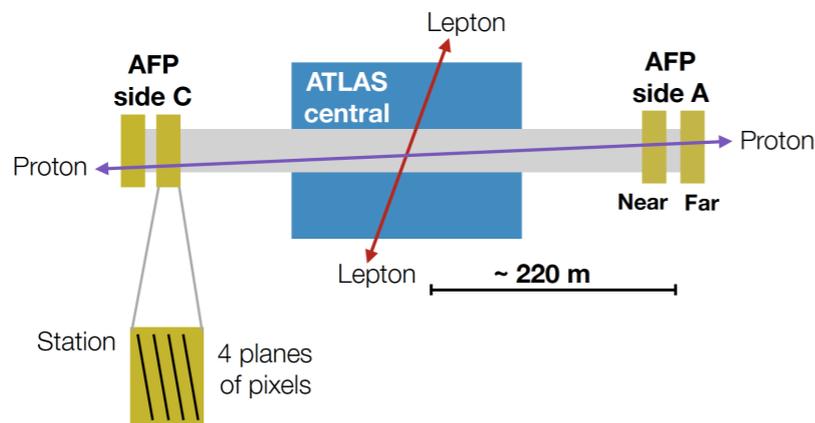
Photoproduction



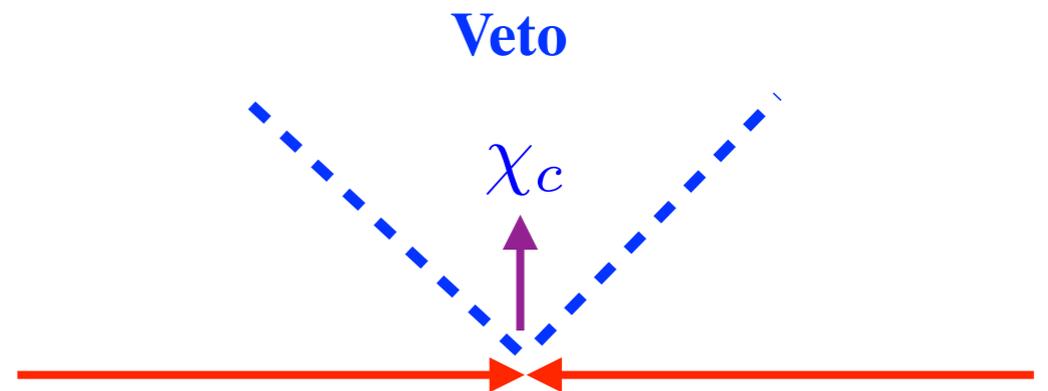
Each one offers different possibilities...

Selecting CEP events

- CEP events can be selected either by:
 - ★ **Tagging** outgoing protons with dedicated AFP (ATLAS) and CT-PPS detectors (CMS). Here mass acceptance is well above quarkonium region (except special runs).



- ★ **Vetoing** on additional tracks in detector region. Selects dominantly CEP, though still have proton dissociation.



SuperChic 4

- A MC event generator for CEP processes. **Common platform** for:

- QCD-induced CEP.
- Photoproduction.
- Photon-photon induced CEP.

- For **pp**, **pA** and **AA** collisions. Weighted/unweighted events (LHE, HEPMC) available- can interface to Pythia/HERWIG etc as required.

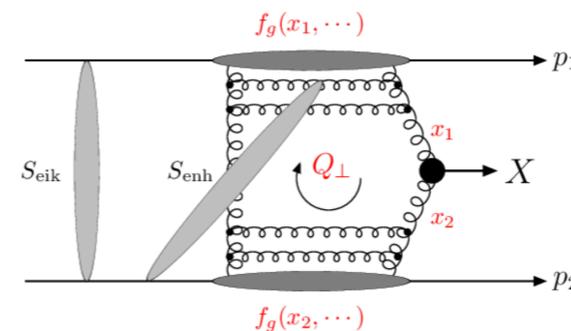
- Full treatment of proton dissociation for photon-initiated production in pp collisions currently available for lepton pair production.

superchic is hosted by Hepforge, IPPP Durham

SuperChic 4 - A Monte Carlo for Central Exclusive and Photon-Initiated Production

- [Home](#)
- [Code](#)
- [References](#)
- [Contact](#)

SuperChic is a Fortran based Monte Carlo event generator for exclusive and photon-initiated production in proton and heavy ion collisions. A range of Standard Model final states are implemented, in most cases with spin correlations where relevant, and a fully differential treatment of the soft survival factor is given. Arbitrary user-defined histograms and cuts may be made, as well as unweighted events in the HEPEVT, HEPMC and LHE formats. For further information see the [user manual](#).



A list of references can be found [here](#) and the code is available [here](#).

Comments to Lucian Harland-Lang < lucian.harland-lang (at) physics.ox.ac.uk >.

<https://superchic.hepforge.org>

Quarkonium Production in SC

- Two relevant production mechanisms: **QCD-induced** and **photoproduction**.

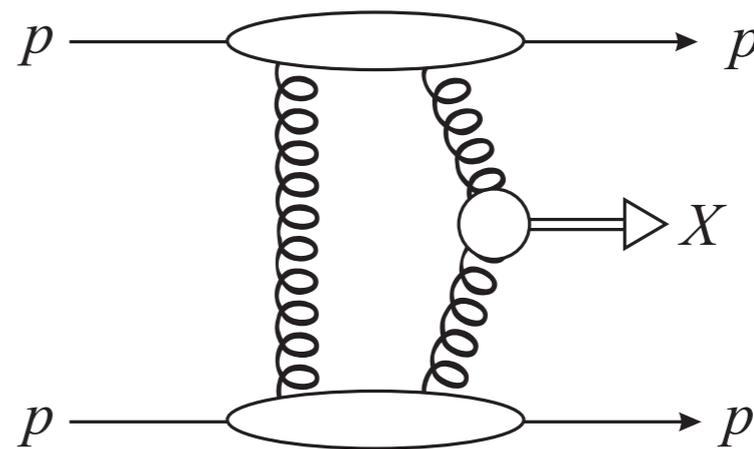
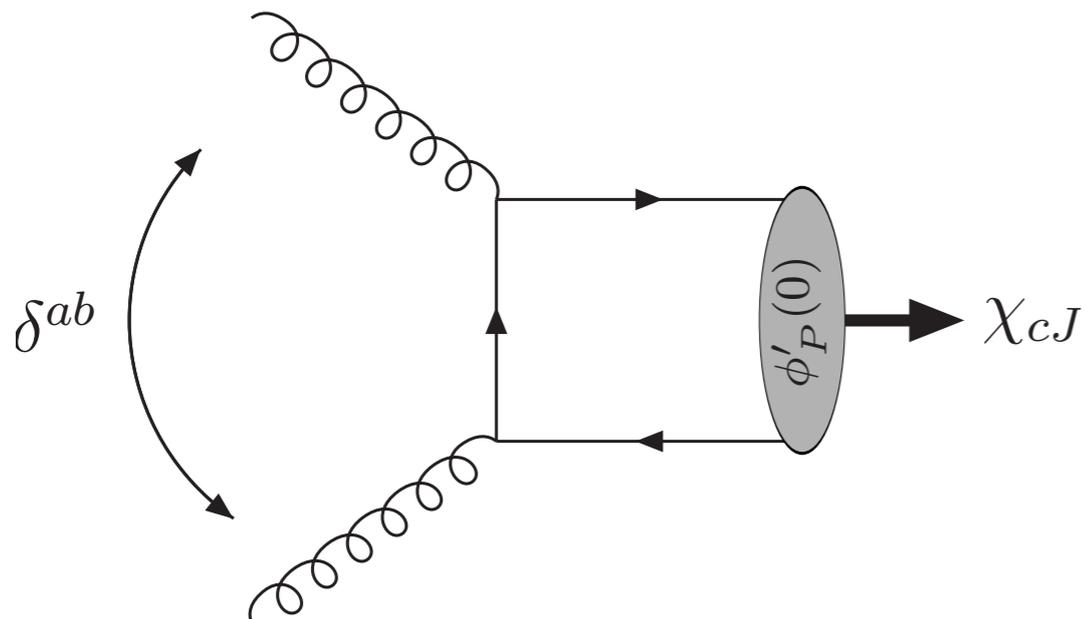
- QCD induced:

$$\chi_{c0}, \chi_{c1}, \chi_{c2}, \eta_c$$

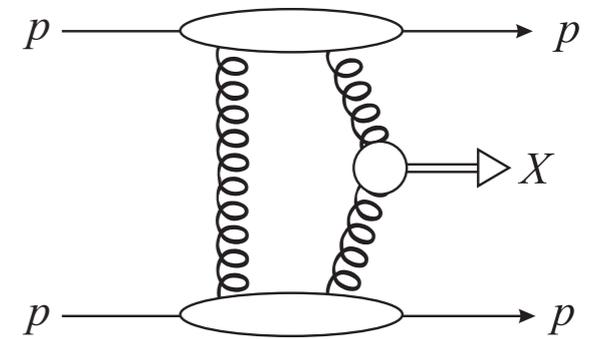
$$\chi_{b0}, \chi_{b1}, \chi_{b2}, \eta_b$$

via range of 2, 4 body decays.

- How is this modelled?



QCD-induced CEP



- In a nutshell:

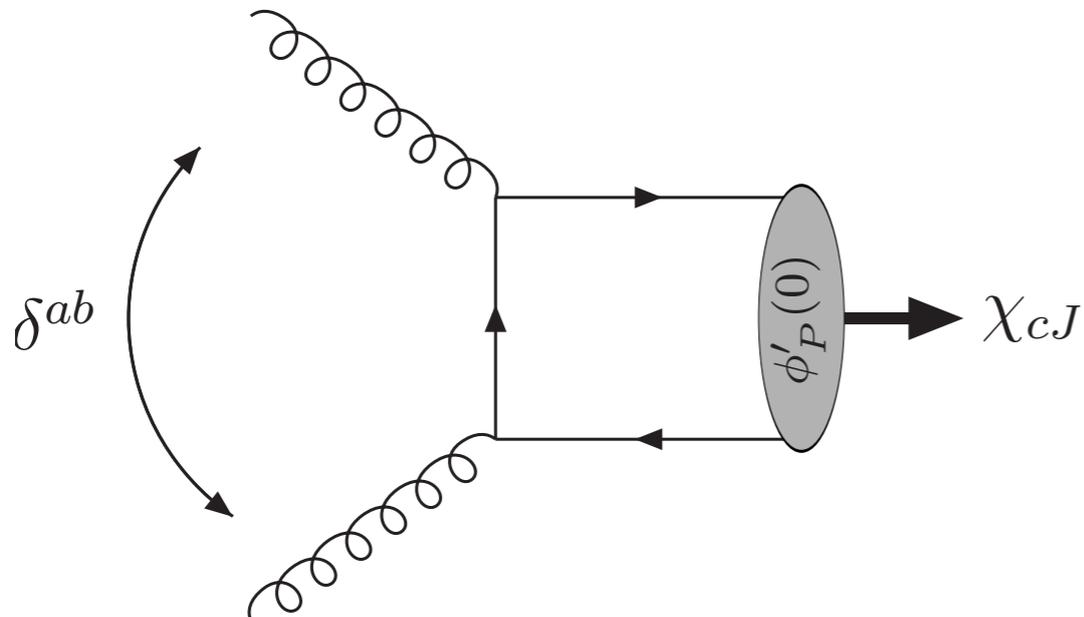
Related to standard gluon PDFs + Sudakov factor of no gluon emission

$$T = \pi^2 \int \frac{d^2 \mathbf{Q}_\perp \overline{\mathcal{M}}}{\mathbf{Q}_\perp^2 (\mathbf{Q}_\perp - \mathbf{p}_{1\perp})^2 (\mathbf{Q}_\perp + \mathbf{p}_{2\perp})^2} f_g(x_1, x'_1, Q_1^2, \mu_F^2; t_1) f_g(x_2, x'_2, Q_2^2, \mu_F^2; t_2) ,$$

Integral over gluon loop

- With

$$\overline{\mathcal{M}} \equiv \frac{2}{M_X^2} \frac{1}{N_C^2 - 1} \sum_{a,b} \delta^{ab} q_{1\perp}^\mu q_{2\perp}^\nu V_{\mu\nu}^{ab} .$$

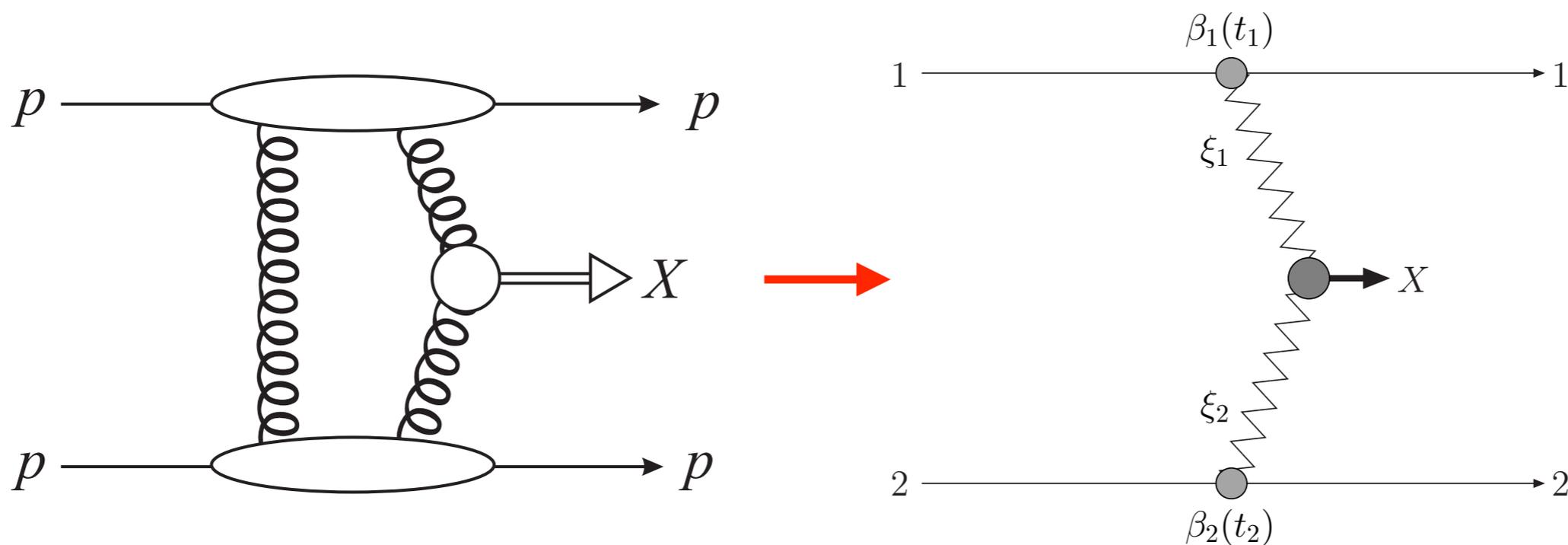


i.e. colour singlet $gg \rightarrow X$
amplitude, for particular
helicity configuration.

- In addition include 'survival factor' probability of no MPI (will not discuss in detail here).

Caveat

- Use of pQCD picture justified by high scale of process $\sim M_{q\bar{q}}$.
- For e.g. χ_c this might be at limit of region of validity \Rightarrow non perturbative picture?

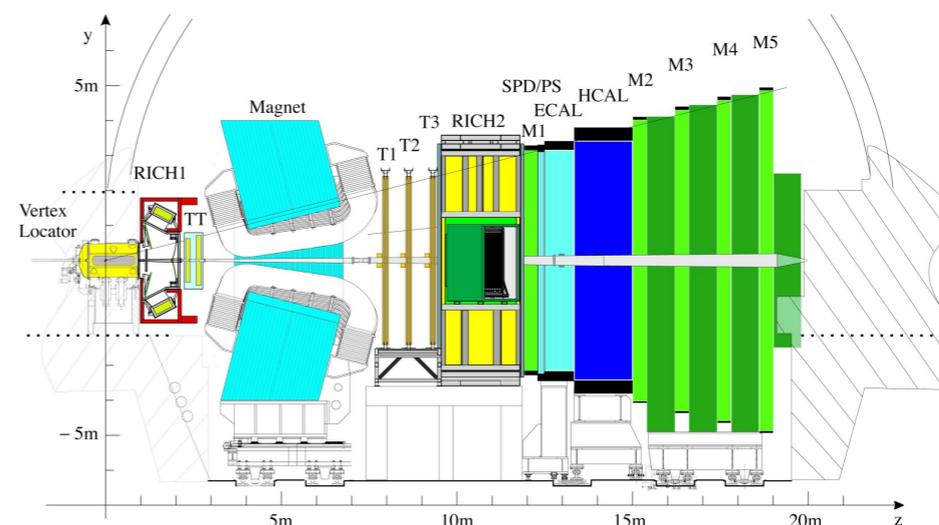
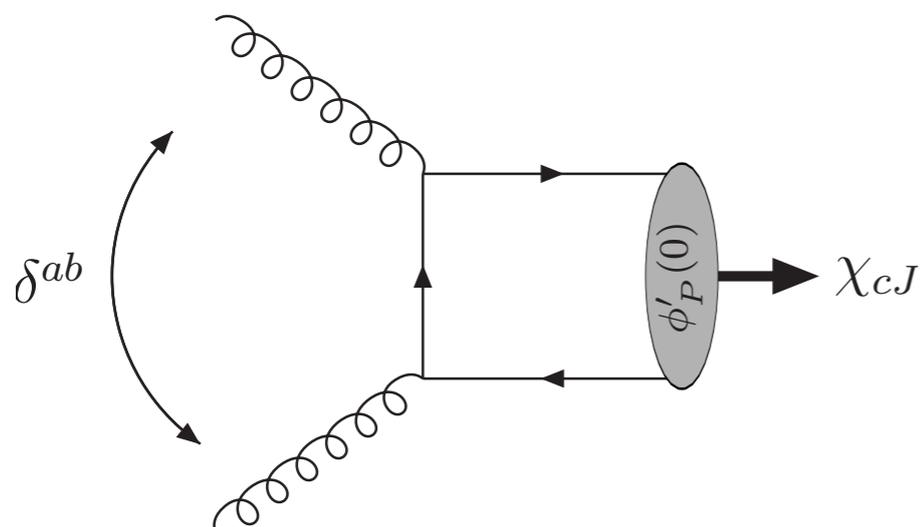


- pQCD approach only included in SC.

χ_c Production

$\chi_{cJ} : L = 1, S = 1, J^{PC} = (0, 1, 2)^{++} c\bar{c}$ meson states, $M_{\chi_c} \approx 3.5$ GeV.

- Production cross sections determined by unique CEP kinematics:
 - ▶ χ_{c2} : in the non-relativistic quarkonium approximation coupling to gg in a $J_z = 0$ state vanishes (dominant configuration for CEP).
 - ▶ χ_{c1} : Landau-Yang theorem forbids coupling of a $J = 1$ particle to on-shell gluons (true to good approximation in CEP). Additionally suppressed by specific form of vertex.
- No suppression in $\chi_{c0} \Rightarrow$ expect strong hierarchy in rates. Completely different to inclusive case.
- Colour singlet $gg \rightarrow \chi_c$: no room for NRQCD...



- Measurements made by CDF and LHCb, by vetoing on additional activity in given η range in the $\chi_c \rightarrow J/\psi\gamma$ channel (favours $\chi_{c(1,2)}$).

- CDF show good agreement with Durham predictions, while LHCb see:

CERN-LHCb-CONF-2011-022

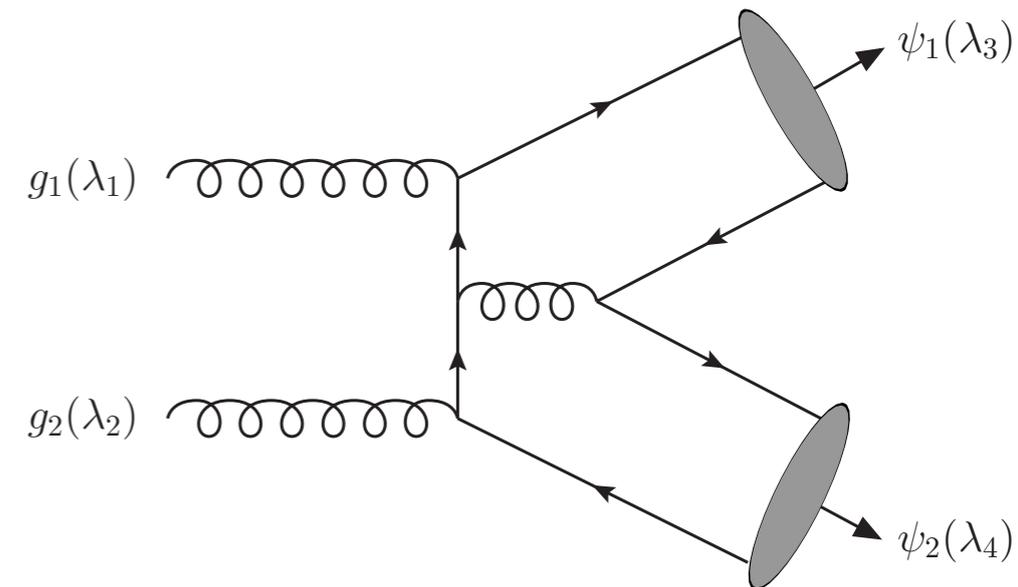
	$\frac{\sigma(pp \rightarrow pp(\mu^+ \mu^- + \gamma))}{\text{Br}(J/\psi \rightarrow \mu^+ \mu^-) \text{Br}(\chi_{cJ} \rightarrow J/\psi\gamma)}$	LHCb (nb)	SuperCHIC (nb)
χ_{c0}	13 ± 6.5		20
χ_{c1}	0.80 ± 0.35		0.49
χ_{c2}	2.4 ± 1.1		0.26

- See clear suppression in $\chi_{c(1,2)}$ states. **Do not** expect to see (and do not see) in inclusive production. [LHCb, arXiv:1307.4285](#) : **first inclusive χ_{c0}**
- Good data/theory agreement for $\chi_{c(0,1)}$ states (within quite large theory uncertainty), but significant χ_{c2} excess. Could be due to proton dissociation (**forward shower counters...?**), or further theory input could be needed (**relativistic/non-perturbative corrections...**).

Quarkonium pair production

- Quarkonium pair production also generated:

$J/\psi J/\psi$ $J/\psi\psi(2S)$ $\psi(2S)\psi(2S)$

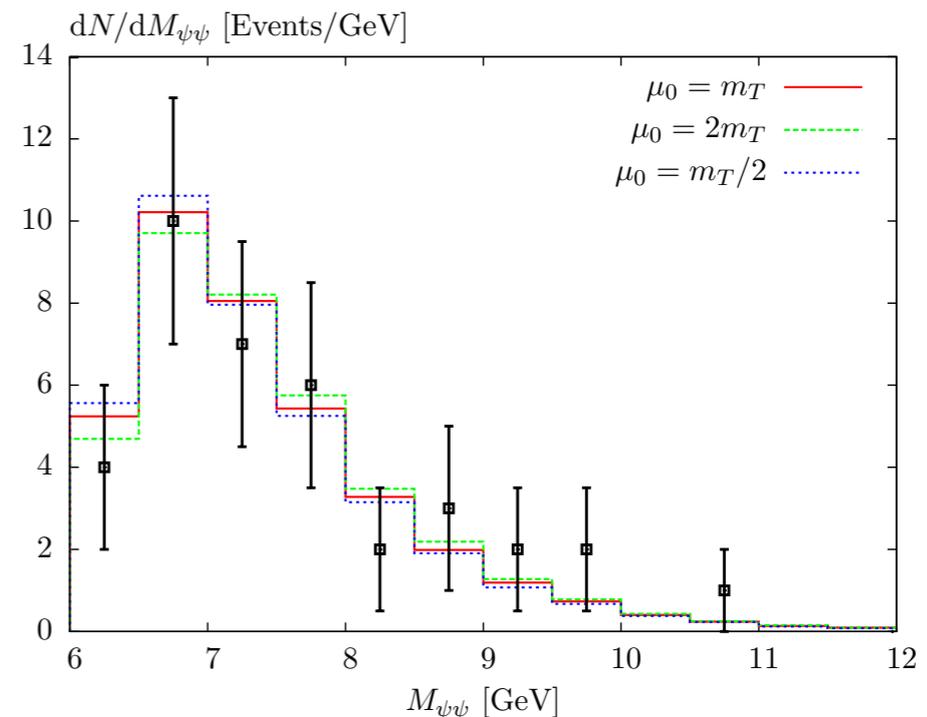


$$T_{+-,00} = T_{-+,00} = -\delta^{ab} \frac{8|R_0(0)|^2}{\pi M_\psi} \frac{16\pi^2\alpha_s^2}{\hat{s}} \left(\cos^2\theta - \frac{C_F}{N_c} \right).$$

- Various interesting features observed, including radiation zeros.

- Agreement good with LHCb data.

R. Aaij et al. [LHCb], *J. Phys. G: Nucl. Part. Phys.* 41 (2014) 115002.



Photoproduction

- Modelled in SC:

$$J/\psi, \psi_{2S} \quad \Upsilon_{1S}$$

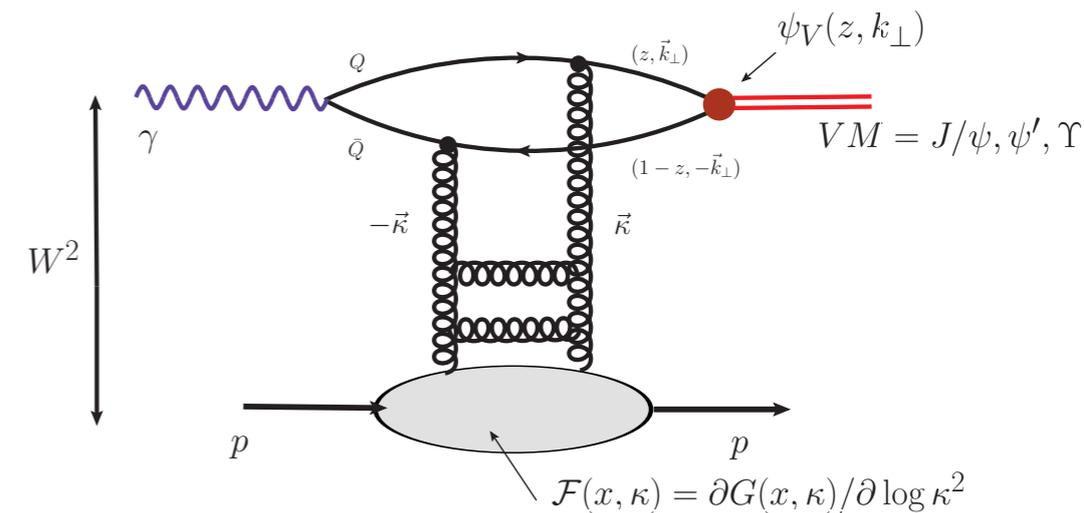
via leptonic decays.

- Cross section taken from simple power law fit:

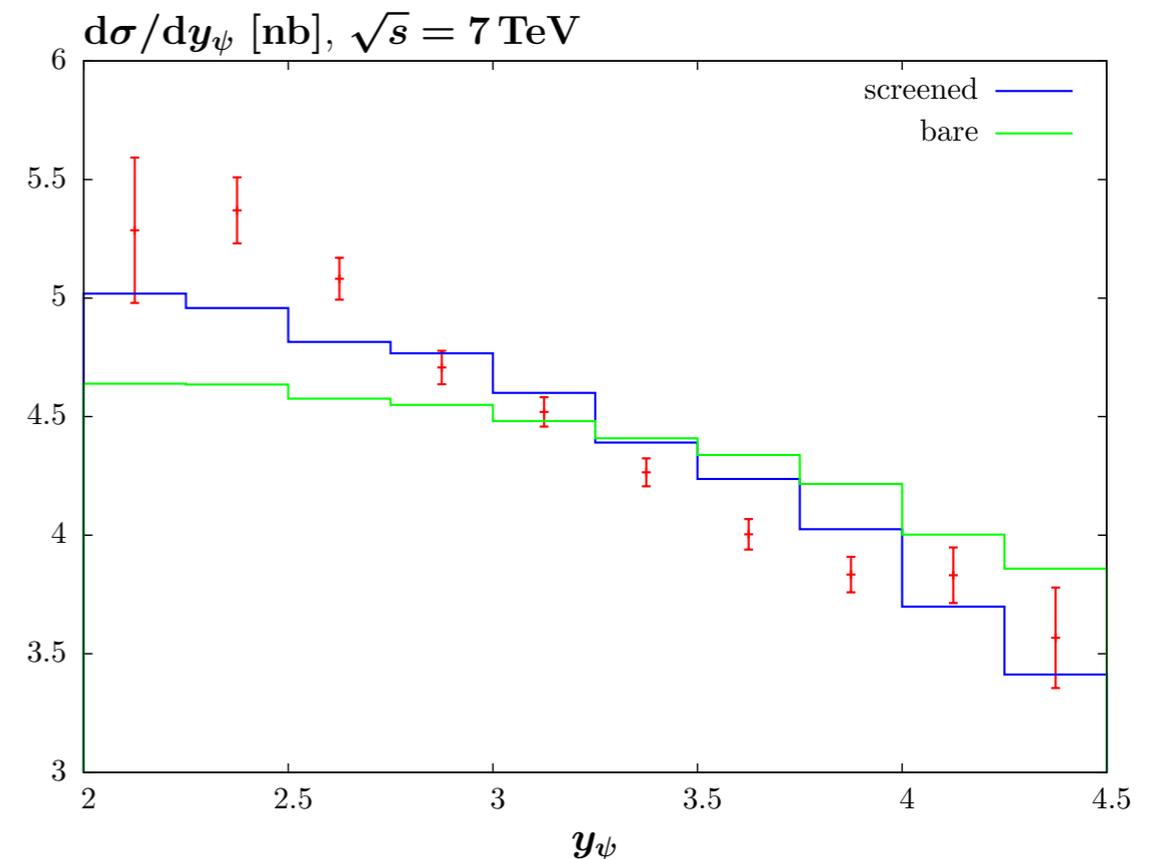
$$\frac{d\sigma^{\gamma p \rightarrow V p}}{dq_{2\perp}^2} = N_V \left(\frac{W_{\gamma p}}{1 \text{ GeV}} \right)^{\delta_V} b_V e^{-b_V q_{2\perp}^2} .$$

i.e. suitable for testing validity of this fit/
basic MC studies, but no complete
theoretical treatment in SC for now.

- Survival effects included fully, and
found to modify rapidity distributions



LHL, V.A. Khoze, M.G. Ryskin,
Eur.Phys.J.C 76 (2016) 1, 9



Summary/What is not included

- SuperChic MC: general purpose tool for CEP production, including quarkonia.
- Range of QCD-induced and photoproduction processes implemented. Not included currently:
 - ★ Exotic quarkonia: $X(3872)$...possibilities to shed light on their nature via CEP?
 - ★ QCD modelling of underlying photoproduction process.
 - ★ Proton dissociation: only purely exclusive case include (intact protons). Recently implemented for photon-initiated production. QCD case more complex.
- Production mechanism(s) generic & all key elements in SC: reasonably straightforward to add in new processes. Open to future collaboration on this/new ideas.