Standard Candle Central Exclusive Processes at the Tevatron and LHC

Lucian Harland-Lang

Cavendish Laboratory, University of Cambridge

IOP 2010, 29-31 March, University College London

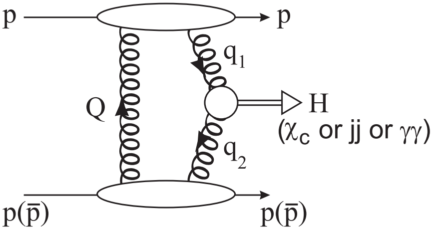
In collaboration with M.G. Ryskin, V.A. Khoze and W.J. Stirling.
For more details see arXiv:0909.4748

What is central exclusive diffraction?

- Diffraction: colour singlet exchange between colliding protons, with large rapidity gaps in the final state.
- Exclusive: protons remain intact after collision and can in principal be measured by forward proton detectors down the beam line.
- Central: A system of mass M_X is produced at the collision point, and *only* its decay products are present in the central detector region.
- Experimentally very favorable: potential for measuring central object properties (spin, parity, mass...) by forward proton tagging (e.g. light Higgs production).
- Theoretically challenging: carries significant uncertainties (requires model of soft interactions, also higher order effects, PDF uncertainties etc...).

Durham Model of central exclusive diffraction

- The generic process $pp \to p + X + p$ is modeled perturbatively by the exchange of two t-channel gluons.
- The use of pQCD is justified by the presence of a hard scale $\sim M_X/2$, which ensures an infrared stable result.



- The possibility of additional soft rescatterings filling the rapidity gaps is encoded in the 'eikonal' and 'enhanced' survival factors, $S^2_{\rm eik}$ and $S^2_{\rm enh}$.

'Standard Candle' processes

- Central exclusive production (CEP) is a promising way to study the physics of new particles at the LHC.
- However, we can also consider the CEP of lighter, better understood objects, e.g. χ_c, χ_b, $\gamma\gamma$ and *jj* production.
- These are driven by the same mechanism as Higgs (or other new object) CEP at the LHC, but will have larger cross sections.
- χ_c, *jj* and $\gamma\gamma$ CEP has been observed by CDF.

$\rightarrow$ Can serve as 'Standard Candle' processes, which allow us to check the theoretical predictions for central exclusive new physics signals at the LHC.

CDF χ_c data

(CDF Collaboration, arXiv:0902.1271)

- 65 ± 10 signal χ_c events observed, but with a limited $M(J/\psi\gamma)$ resolution.
- Possible contribution from higher spin χ_{c1} and χ_{c2} states assumed, rather than observed, to be negligible.
- Assuming χ_{c0} dominance, CDF found:

$$\left.\frac{\mathrm{d}\sigma(\chi_{c0})}{\mathrm{d}y_\chi}\right|_{y=0} = (76 \pm 14)\,\mathrm{nb}\;,$$

  in good agreement with the previous Durham value of 90 nb (arXiv:0403218).
- But can we be sure that χ_{c1} and χ_{c2} events to do not contribute?

χ_{c1} and χ_{c2}: general considerations

- General considerations tell us that χ_{c1} and χ_{c2} CEP rates are strongly suppressed, giving vanishing contributions in the limit that the outgoing proton $p_\perp \to 0$ (approximately true).
- However the experimentally observed decay chain $\chi_c \to J/\psi\gamma \to \mu^+\mu^-\gamma$ strongly favours $\chi_{c(1,2)}$ production, with:

$$\begin{aligned} \mathrm{Br}(\chi_{c0} \to J/\psi\gamma) &= 1.1\% \,, \\ \mathrm{Br}(\chi_{c1} \to J/\psi\gamma) &= 34\% \,, \\ \mathrm{Br}(\chi_{c2} \to J/\psi\gamma) &= 19\% \,. \end{aligned}$$

- We should therefore seriously consider the possibility of $\chi_{c(1,2)}$ CEP.[1]
- While the $\chi_{c(1,2)}$ CEP amplitudes vanish in the limit of forward outgoing protons, we expect some violation of this from the effect of non-zero proton $p_\perp$.

[1] See also R.S. Pasechnik et al., arXiv:hep-ph/0912.4251 and references therein

Results

- An explicit calculation gives ($\sqrt{s} = 1.96$ TeV):

$$\frac{\Gamma^{\chi_0}_{J/\psi+\gamma}}{\Gamma^{\chi_0}_{\rm tot}} \frac{{\rm d}\sigma^{\rm pert}_{\chi_{c0}}}{{\rm d}y} : \frac{\Gamma^{\chi_1}_{J/\psi+\gamma}}{\Gamma^{\chi_1}_{\rm tot}} \frac{{\rm d}\sigma^{\rm pert}_{\chi_{c1}}}{{\rm d}y} : \frac{\Gamma^{\chi_2}_{J/\psi+\gamma}}{\Gamma^{\chi_2}_{\rm tot}} \frac{{\rm d}\sigma^{\rm pert}_{\chi_{c2}}}{{\rm d}y} \approx 1 : 0.6 : 0.2 \, .$$

- Note: these approximate values carry a factor of $\sim\stackrel{\times}{\div} 2$ uncertainty.
- Using these values we can predict the total χ_c cross sections (i.e. including all spin states) at the Tevatron and LHC.[2]
- The updated Tevatron prediction is still in good agreement with the data (within the quite large theoretical uncertainties), but spin discrimination not possible by mass resolution or angular measurement of $\mu^+\mu^-$ pair.[3]
- Using the same formalism, we can make predictions for the pseudoscalar η_c CEP cross section as well.

---

[2] L.A.Harland-Lang,M.G. Ryskin, V.A. Khoze and W.J. Stirling, future publication

[3] L.A.Harland-Lang,M.G. Ryskin, V.A. Khoze and W.J. Stirling, Eur.Phys.J.C65:433-448,2010.

χ_b CEP

- Calculation exactly analogous to χ_c case. However we have a stronger suppression in the χ_{b1} and χ_{b2} rates than for the χ_c.
- Significant uncertainties in input parameters:
  - Only have $\mathrm{Br}(\chi_{b0} \to \Upsilon\gamma) < 6\%$ from experiment (PDG 2009).
  - $\Gamma_{\mathrm{tot}}(\chi_{b0})$ experimentally undetermined.
  - $\to$ Must use, e.g., potential model estimates.
- Performing the same explicit calculation as for the χ_c case, we find the following results:

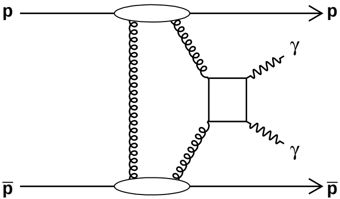
$$\frac{\Gamma^{\chi_0}_{\Upsilon+\gamma}}{\Gamma^{\chi_0}_{\mathrm{tot}}}\frac{\mathrm{d}\sigma^{\mathrm{pert}}_{\chi_{b0}}}{\mathrm{d}y} : \frac{\Gamma^{\chi_1}_{\Upsilon+\gamma}}{\Gamma^{\chi_1}_{\mathrm{tot}}}\frac{\mathrm{d}\sigma^{\mathrm{pert}}_{\chi_{b1}}}{\mathrm{d}y} : \frac{\Gamma^{\chi_2}_{\Upsilon+\gamma}}{\Gamma^{\chi_2}_{\mathrm{tot}}}\frac{\mathrm{d}\sigma^{\mathrm{pert}}_{\chi_{b2}}}{\mathrm{d}y} \approx 1 : 0.03 : 0.1$$

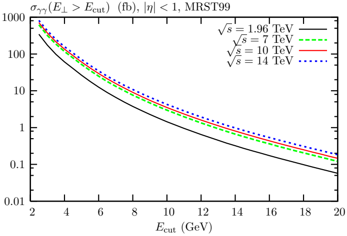
- Predictions for the Tevatron and LHC (including η_b CEP) to be published soon.

$\gamma\gamma$ CEP

(KMRS, arXiv:0409037)

- 3 candidate events observed by CDF (arXiv:0707.237), with more to come very soon.
- More events would allow us to probe scaling of σ with cut on photon $E_\perp$ ($\sim 2M_{\gamma\gamma}$).
- Similar uncertainties to χ_c case for low E_{cut} scale, but this decreases for higher scales.
- Results for the Tevatron and LHC to be published soon.





SuperCHIC MC

- A new MC (available on HepForge) including:
  - Non-forward $p_\perp \neq 0$ protons.
  - Full simulation of $\chi_{c(0,1,2)}$ CEP via the $\chi_c \to J/\psi\gamma \to \mu^+\mu^-\gamma$ decay chain.
  - $\chi_{b(0,1,2)}$ CEP via the equivalent $\chi_b \to \Upsilon\gamma \to \mu^+\mu^-\gamma$ decay chain.
  - $\chi_{(c,b)0}$ CEP via two-body decay (e.g. $\chi_c \to \pi\pi$, $\chi_c \to K\overline{K}$).
  - $\gamma\gamma$ CEP.
  - More to come...

Conclusion

- CEP processes observed at the Tevatron and early LHC can serve as 'standard candles' for new physics CEP at the LHC.
- Possibility that χ_{c1} and χ_{c2} CEP may contribute to CDF χ_c events.
- Cannot currently distinguish different J states, but may be possible with:
  - More detailed analysis and/or higher statistics.
  - Forward proton detection.
  - Different decay modes, e.g. $\chi_c \to \pi\pi$, $\chi_c \to K\overline{K}$.
- $\gamma\gamma$ CEP of interest- variable $M_{\gamma\gamma}$ of central system allows a wider range of studies.
- χ_b CEP a potential observable at the LHC (ongoing study).
- CEP of higher excitation χ_{nP} states?