Probing the theoretical description of central exclusive production

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Central exclusive production

- Central exclusive production is the process

$$h_1(p_1) + h_2(p_2) \to h_1(p_1') \oplus X \oplus h_2(p_2')$$

- Hadrons remain intact, but lose energy to produce the central system, X, which is observed in the central detector.

- Scattered hadrons bent out of the beam pipe by magnets (like a spectrometer). At the LHC, adding detectors at ~ 220 m, ~ 420 m down the beam pipe enables one to measure their four-momenta.

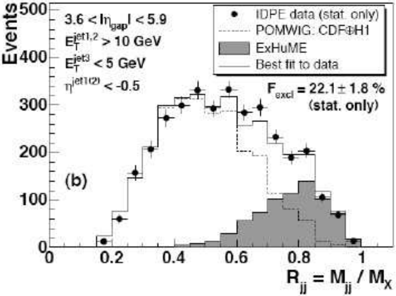
- The $\oplus$ denote rapidity gaps; the central system is produced, but nothing else i.e. exclusive.

Why is it interesting?

- Can provide, potentially unique, information on the central system:
  - Gives quantum numbers of central system (non $J^{PC} = 0^{++}$ production heavily suppressed).
  - Reconstructed proton momenta give central system invariant mass, $\sqrt{\hat{s}}$, with a resolution ~ 2-3 GeV (*per event*), via a missing mass method (Albrow and Rostovtsev - arXiv:hep-ph/0009336).
- Central exclusive $b\bar{b}$ production is suppressed (due to a $J_z = 0$ selection rule): Offers a chance to study the Higgs coupling to bottom quarks (probably not in the Standard Model).
- Feasibility at the LHC studied by the FP420 R&D collaboration (arXiv:0806.0302). Groups in ATLAS and CMS working to install additional detectors.

Observations at the Tevatron

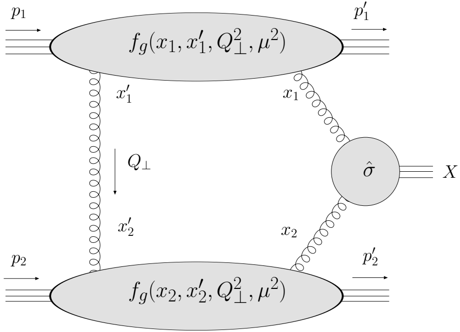
- CDF has observed an excess of dijet events consistent with central exclusive production (*Phys. Rev. D 77*).



- Also observed:
  - Quark jet suppression in the dijet events (result of $J_z = 0$ selection rule).
  - Exclusive $\gamma\gamma$ (*Phys. Rev. Lett. 99*) and χ_c (*Phys. Rev. Lett. 102*) production.

Theoretical predictions - the Durham model

- Central exclusive production calculated in perturbative QCD by Khoze, Martin and Ryskin (see for example *Eur. Phys. J. C23*).
- Schematically:



The Durham model - cross-section

- The cross-section is assumed to factorise as

$$\frac{\partial\sigma}{\partial\hat{s}\partial y\partial\boldsymbol{p}'^2_{1\perp}\partial\boldsymbol{p}'^2_{2\perp}} = S^2 e^{-b(\boldsymbol{p}'^2_{1\perp}+\boldsymbol{p}'^2_{2\perp})}\frac{\partial\mathcal{L}}{\partial\hat{s}\partial y}d\hat{\sigma}(gg\to X)\ .$$

- Sub-process cross-section:

$$d\hat{\sigma}(gg\to X) = \frac{1}{2\hat{s}}\left|\bar{\mathcal{M}}(gg\to X)\right|^2 d\mathrm{PS}_X$$

where,

$$\bar{\mathcal{M}}(gg\to X) = \frac{1}{2}\frac{1}{N^2-1}\sum_{a_1 a_2}\sum_{\lambda_1\lambda_2}\delta_{a_1 a_2}\delta_{\lambda_1\lambda_2}\mathcal{M}^{a_1 a_2}_{\lambda_1\lambda_2}(gg\to X)\ .$$

The sum over equal helicities here gives the $J_z = 0$ selection rule.

The Durham model - effective luminosity

- Effective luminosity, $\frac{\partial \mathcal{L}}{\partial \hat{s} \partial y}$, given by

$$\frac{\partial \mathcal{L}}{\partial \hat{s} \partial y} = \frac{1}{\hat{s}} \left(\frac{\pi}{N^2 - 1} \int \frac{d\boldsymbol{Q}_\perp^2}{\boldsymbol{Q}_\perp^4} f_g(x_1, x_1', \boldsymbol{Q}_\perp^2, \mu^2) f_g(x_2, x_2', \boldsymbol{Q}_\perp^2, \mu^2) \right)^2 \ .$$

- The kinematics are such that $x_i' \ll x_i$. In this limit:

$$f_g(x, x', \boldsymbol{Q}_\perp^2, \mu^2) \approx R_g \frac{\partial}{\partial \ln \boldsymbol{Q}_\perp^2} \left(\sqrt{T(\boldsymbol{Q}_\perp, \mu)} x g(x, \boldsymbol{Q}_\perp^2) \right) \ .$$

- $T(\boldsymbol{Q}_\perp, \mu)$ is a Sudakov factor and R_g accounts for the off-forward kinematics ($x_i' \neq x_i$).

The Sudakov factor - a new result

- Sudakov factor previously found to be given by (Kaidalov, Khoze, Martin and Ryskin *Eur. Phys. J.* C33)

$$T(\boldsymbol{Q}_\perp, \mu) = \exp\left(- \int_{\boldsymbol{Q}_\perp^2}^{\hat{s}/4} \frac{dk_\perp^2}{k_\perp^2} \frac{\alpha_s(k_\perp^2)}{2\pi} \int_0^{1-\Delta} dz \left[zP_{gg}(z) + \sum_q P_{qg}(z) \right] \right)$$

where

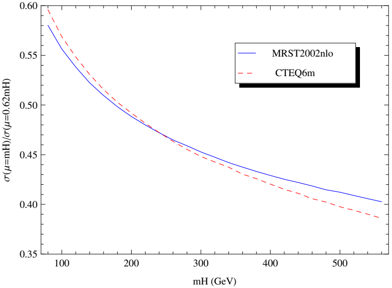
$$\Delta = \frac{k_\perp}{k_\perp + \mu} , \qquad \mu = 0.62\sqrt{\hat{s}} .$$

- Collects all terms of order $\alpha_s^n \ln^m(\boldsymbol{Q}_\perp^2/\hat{s})$, where $m = 2n, 2n-1$.

- After performing an independent calculation of the next-to-leading order corrections to the Sudakov factor, we find instead $\mu = \sqrt{\hat{s}}$ (TC, J. Forshaw - *JHEP 1001*).

Implications

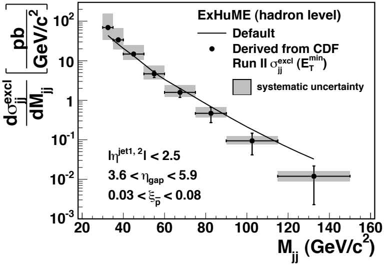
- New scale suppresses the cross-section relative to the original Durham predictions.
- The suppression increases with central system mass.
- To understand the size of the effect, consider the full (i.e. no cuts) central exclusive Higgs cross-section at the LHC (14 TeV).



- Approximately a factor two difference.

Comments on predictions at the Tevatron

- Would be interesting to see the effect on predictions for observed processes at the Tevatron ($\gamma\gamma$, di-jets, χ_c).
- However, typical theoretical uncertainties (unintegrated pdfs, soft-survival factor, etc.) of a similar size, so unlikely to find disagreement.
- Di-jet production is especially interesting. The fit is worst at high mass - where the change in Sudakov factor has the largest effect. Could lead to a better shape.



Summary and outlook

- Have computed the subset of next-to-leading order corrections sensitive to the central exclusive production Sudakov factor.
- Find that the Durham result must be modified, by the replacement $\mu = 0.62\sqrt{\hat{s}} \to \sqrt{\hat{s}}$.
- Decreases the cross-section by a factor ~ 2 for $\sqrt{\hat{s}}$ in the range 80-560 GeV.
- May improve the shape of the di-jet invariant mass distribution at the Tevatron.
- Corrections computed so far form part of the full next-to-leading order corrections. Currently in the process of extending our result to give the full contribution.