Central Exclusive Production

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James Stirling Memorial Conference, 17th September 2019

My Work with James

★ Fortunate to spend over half a decade collaborating with and being supervised by James.

★ Published 9 papers + 1 review paper on topics relating to central exclusive production.

★ A few brief highlights follow.

Preprint typeset in JHEP style - PAPER VERSION

IPPP/09/70
DCPT/09/140
Cavendish-HEP-09/17

Central Exclusive χ_c Meson Production at the Tevatron Revisited

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Abstract: Motivated by the recent experimental observation of exclusive χ_c events at the Tevatron, we revisit earlier studies of central exclusive scalar χ_{c0} meson production, before generalising the existing formalism to include χ_{c1} and χ_{c2} mesons. Although χ_{c0} production was previously assumed to be dominant, we find that the χ_{c1} and χ_{c2} rates for the experimentally considered $\chi_c \to J/\psi\gamma \to \mu^+\mu^-\gamma$ decay process are in fact comparable to the χ_{c0} rate. We have developed a new Monte Carlo event generator, SuperCHIC, which models the central exclusive production of the three χ_c states via this decay chain, and have explored possible ways of distinguishing them, given that their mass differences are not resolvable within the current experimental set-up. Although we find that the severity of current experimental cuts appears to preclude this, the acceptance does not change crucially between the three states and so our conclusions regarding the overall rates remain unchanged. This therefore raises the interesting possibility that exclusive χ_{c1} and χ_{c2} production has already been observed at the Tevatron.

International Journal of Modern Physics A

CENTRAL EXCLUSIVE PRODUCTION WITHIN THE DURHAM MODEL: A REVIEW

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We review recent results within the Durham model of central exclusive production. We discuss the theoretical aspects of this approach and consider the phenomenological implications in a variety of processes, comparing to existing collider data and addressing the possibilities for the future.

Keywords: Central Exclusive Production; QCD; Diffraction.

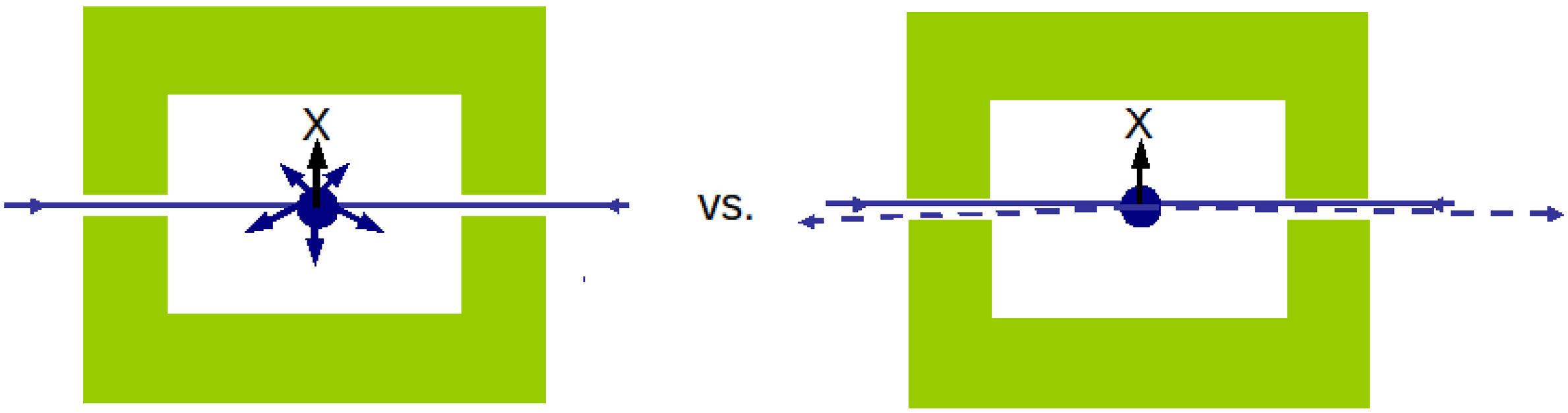
PACS numbers: 12.38.Aw, 12.38.Bx, 12.38.Qk.

Central Exclusive Production

Central Exclusive Production (CEP) is the interaction:

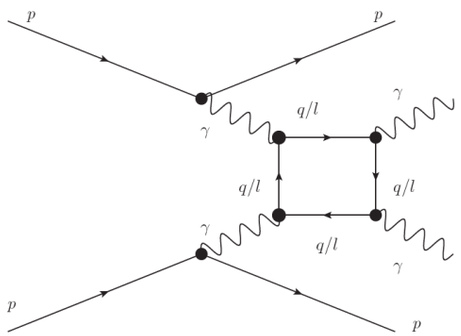
$$hh \to h + X + h$$

- Diffractive: 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.

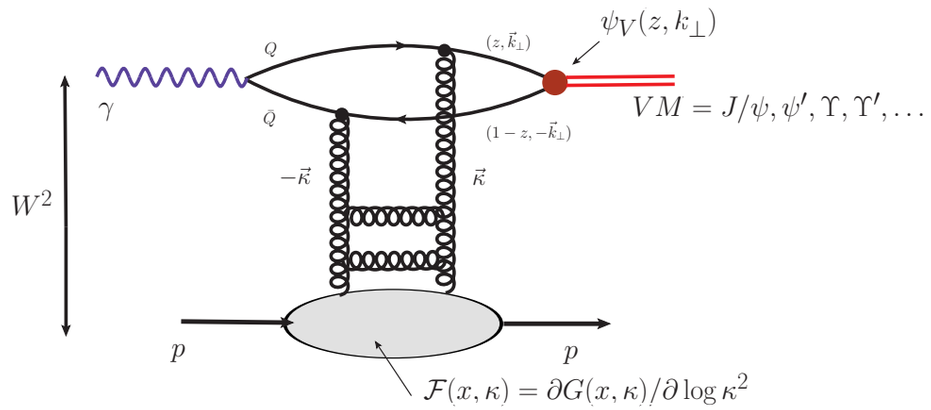


‘Durham’ Mechanism

- CEP can provide unique and clean environment to study the SM and physics beyond it. Many nice features (c.f. Valery’s talk).
- Different ways it can happen:

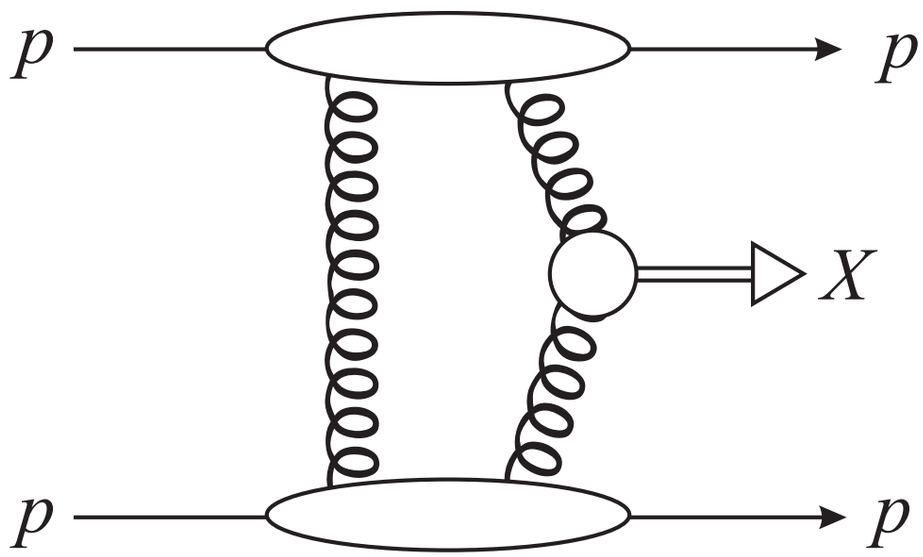


Photon-induced



Photoproduction

- Main focus with James was ‘Durham’ QCD mechanism.
- Unique QCD laboratory, possibility of exclusive Higgs.
- Do we understand the underlying QCD process?



Standard Candles

- Basic idea: test CEP theory by predicting (higher σ) production of lower mass states to compare with Tevatron and LHC data.

c.f. Valery's talk

LHL, V.A. Khoze, M.G. Ryskin, W.J. Stirling, arXiv:1005.0695

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Cavendish-HEP-10/08

Standard Candle Central Exclusive Processes at the Tevatron and LHC

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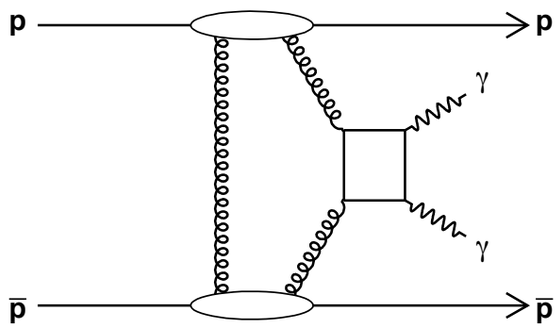
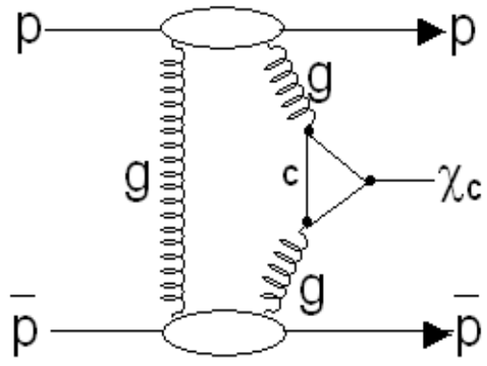




- How to facilitate such a comparison? $\rightarrow$ Need a Monte Carlo generator.

'SuperChic MC'

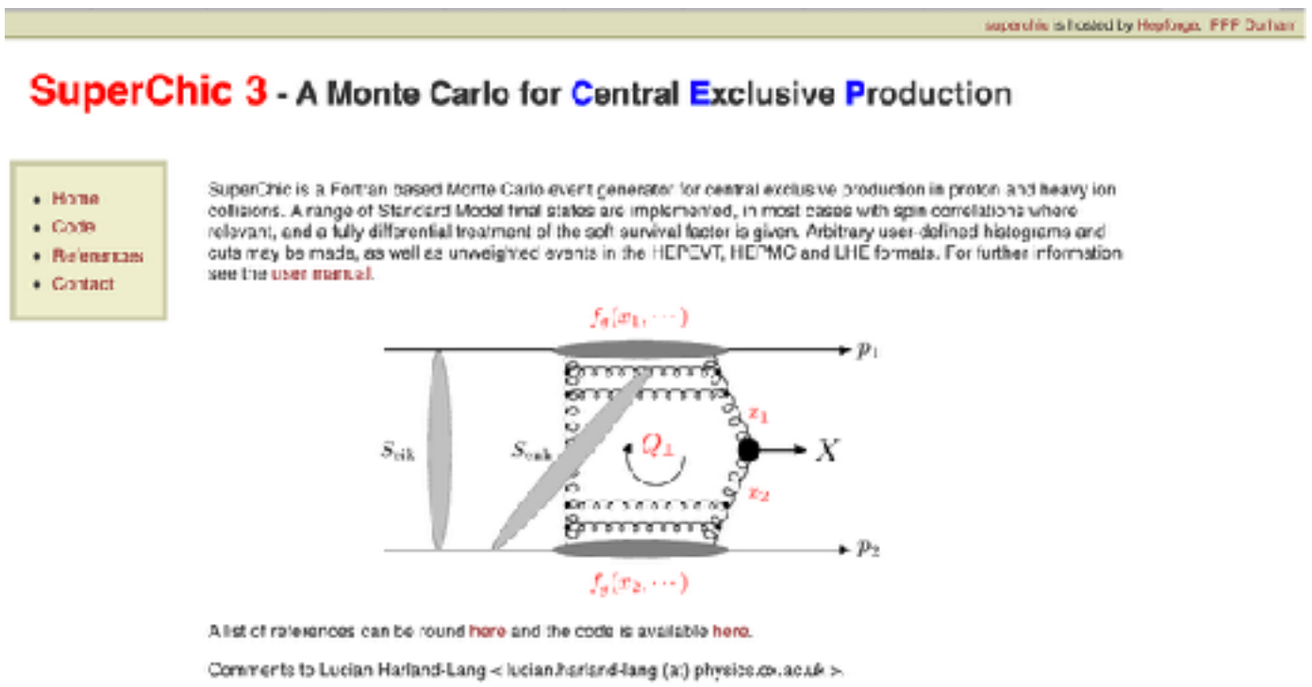
- First '`CHICMC`' due to James, for χ_c production in $pp(p\bar{p})$ collisions.

CDF Collab., arXiv:0902.1271

Observation of Exclusive Charmonium Production and $\gamma\gamma \to \mu^+\mu^-$ in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV

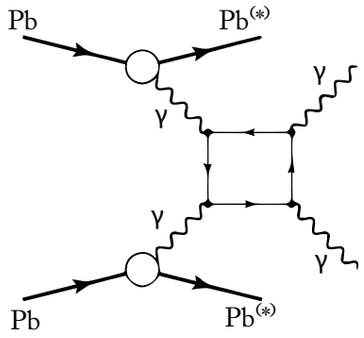
[20] W.J.Stirling, CHICMC, private communication.

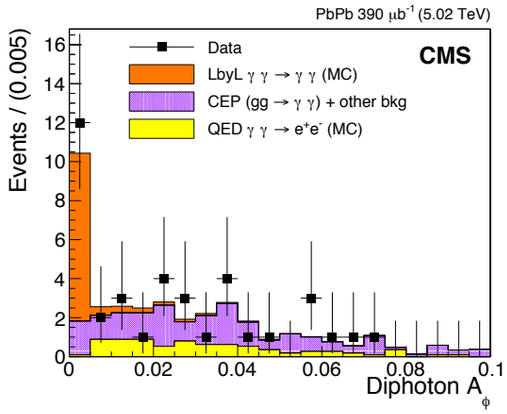
- Have since developed into MC for CEP in proton/ion collisions: '`SuperChic`'

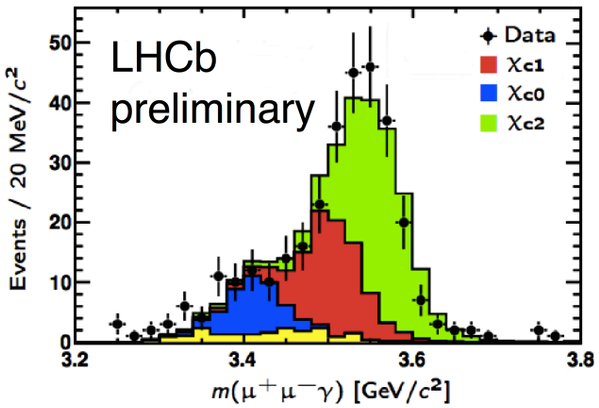


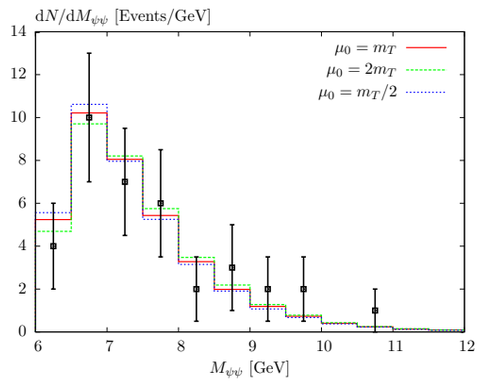
`https://superchic.hepforge.org`

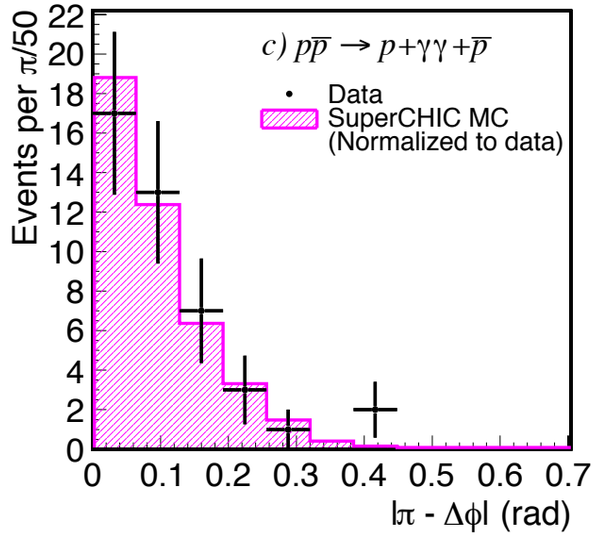
- Now widely used for LHC CEP analyses (and Tevatron before that): good agreement with data, supporting Durham approach.











- Seed of all of this in James' original MC.

'Stirling Plotter':

```
****************************************
mx
****************************************
inside,under,over : 396998     0     0
****************************************
                                  ----+----i----+----i----+----i
    177.604       0.161316E-05   i                        *    i
    211.541       0.190000E-05   i                         *i
    245.477       0.166169E-05   i                       *   i
    279.413       0.140452E-05   i                     *     i
    313.350       0.119599E-05   i                   *       i
    347.286       0.997086E-06   i                 *         i
    381.223       0.854394E-06   i               *           i
    415.159       0.716763E-06   i             *             i
    449.095       0.628261E-06   i           *               i
    483.032       0.548421E-06   i         *                 i
                                  ----+----i----+----i----+----i
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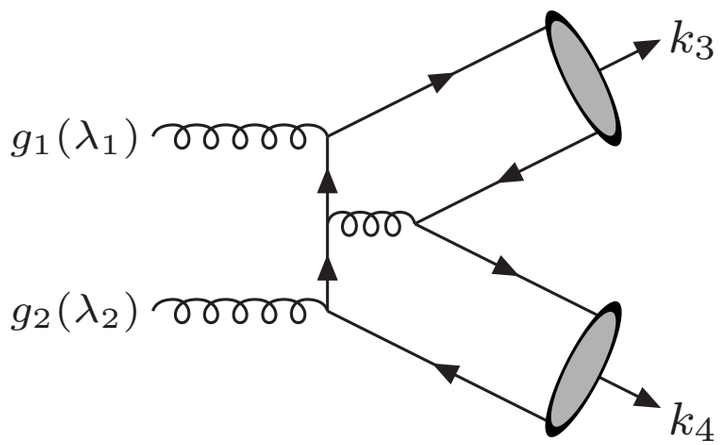
LHL, V.A. Khoze, M.G. Ryskin, W.J. Stirling, arXiv:1105.4133, 1302.2004, 1304.4262

CEP & MHV

- Work with James uncovered some interesting theoretical results.
- Original aim: $\pi^0\pi^0$ BG to $\gamma\gamma$ CEP.
- Study of underlying parton-level diagrams gave intriguing results.

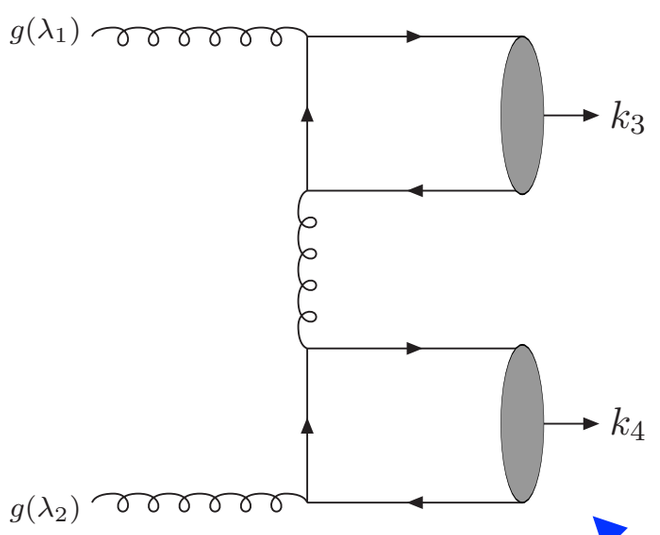


$$\sigma(gg \to \pi\pi) \sim \sigma(gg \to q\bar{q}q\bar{q}) \otimes \phi_\pi \otimes \phi_\pi$$

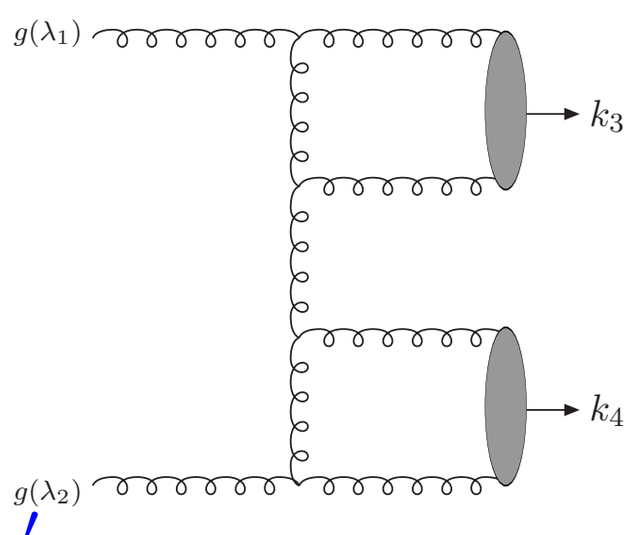
$J_z = 0$ dominant in CEP

★ $T(g(\pm)g(\pm) \to q\bar{q}q\bar{q}) = 0$

★ 'Ladder-type' $gg \to 4g$ amplitude simply proportional to $gg \to q\bar{q}q\bar{q}$ case.



$\propto$



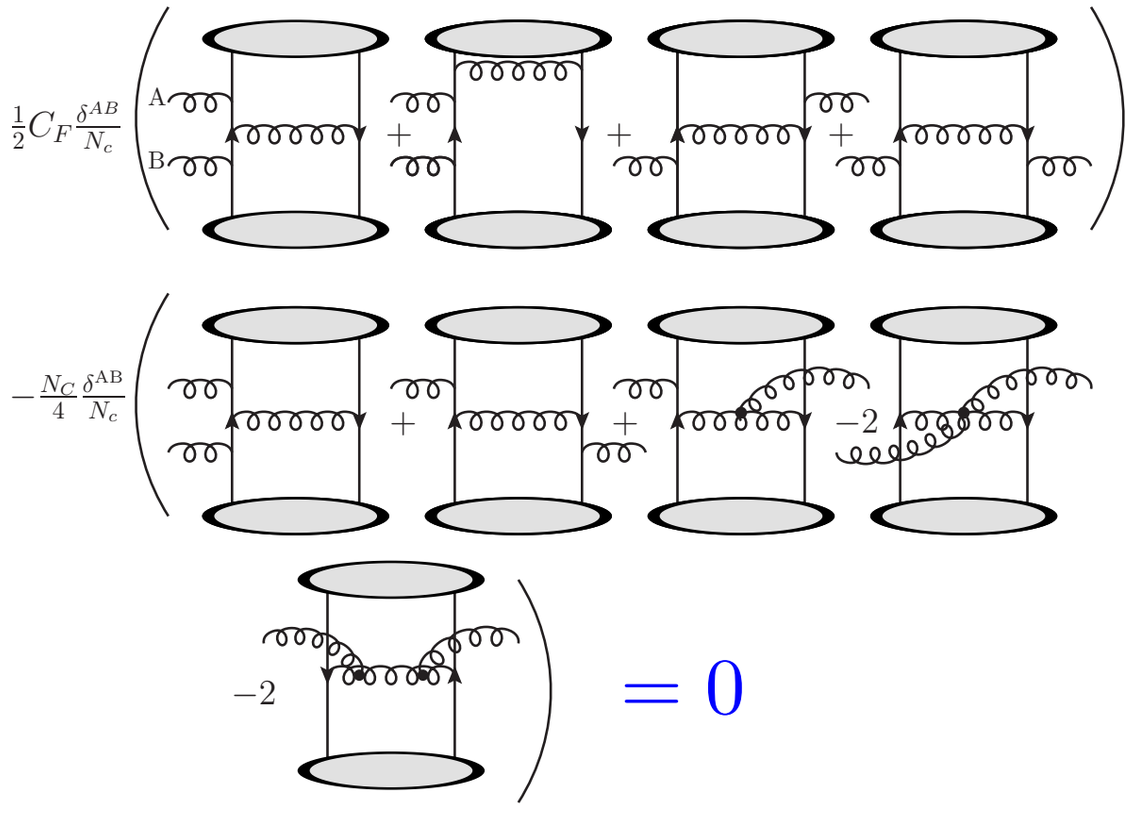
$\eta, \eta' \cdots$

- V. simple results from v. complex underlying Feynman diagrams: natural to think about within MHV formalism (James' suggestion).

• Plugging kinematics of underlying process into MHV 'dual expansion' these results naturally drop out in a number of lines

$$\mathcal{M}_n(\{p_i, h_i, c_i\}) = \sum_\sigma T_n(\{c_{\sigma(i)}\}) A_n(\{k_{\sigma(i)}, h_{\sigma(i)}\}) \ ,$$

$T(g(\pm)g(\pm) \to q\bar{q}q\bar{q}) = 0$:



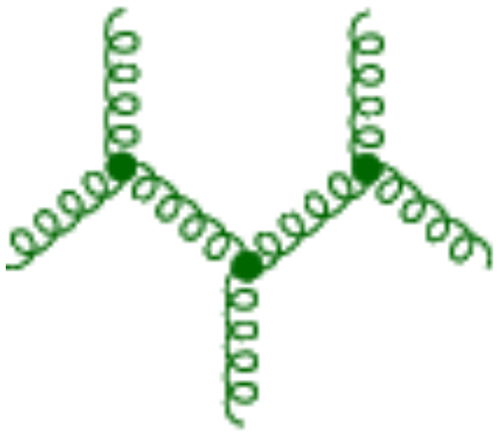
vs.

$$M \propto \frac{\langle k_3\, k_4\rangle}{\langle k_4\, k_1\rangle\langle k_1\, k_3\rangle\langle k_3\, k_2\rangle\langle k_2\, k_4\rangle} + \frac{1}{\langle k_3\, k_1\rangle\langle k_1\, k_2\rangle\langle k_2\, k_4\rangle} + \frac{1}{\langle k_3\, k_2\rangle\langle k_2\, k_1\rangle\langle k_1\, k_4\rangle}$$
$$\propto \langle k_3\, k_2\rangle\langle k_1\, k_4\rangle + \langle k_1\, k_3\rangle\langle k_2\, k_4\rangle - \langle k_3\, k_4\rangle\langle k_1\, k_2\rangle = 0 \ , \qquad (3.20)$$

LHL, arXiv:1503.06798

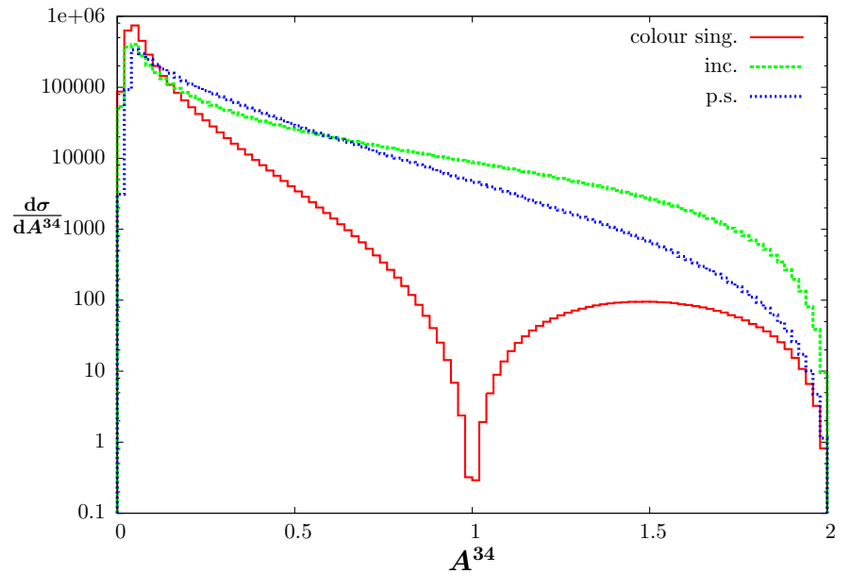
MHV & Radiation Zeros

- This original idea was seed of later work on 'radiation zeros' in 5 parton QCD amplitudes.



Gluons in plane

$\Rightarrow$



- Comes from same MHV simplicity. In principle observable in 3-jet CEP.

- These 'type-II' zeros: first noticed by James!

DTP/97/66
hep-ph/9707373
July 1997

Radiation Zeros at HERA — More About Nothing

M. Heyssler[a] and W.J. Stirling[a,b]

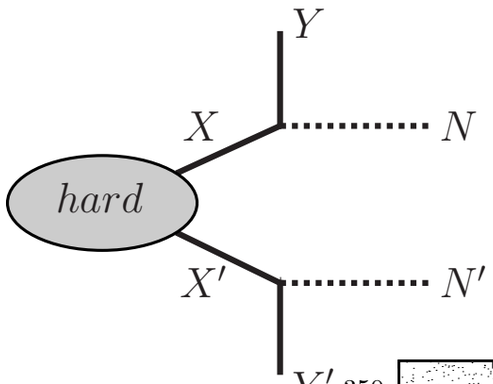
[a] *Department of Physics, University of Durham, Durham, DH1 3LE*
[b] *Department of Mathematical Sciences, University of Durham, Durham, DH1 3LE*

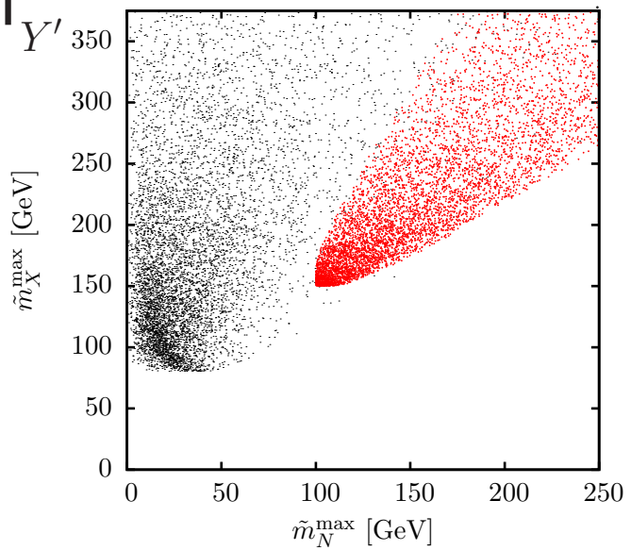
M. Heyssler, W.J. Stirling, hep-ph/9707373

LHL, V.A. Khoze, M.G. Ryskin, W.J. Stirling, arXiv:1110.4320,1202.0047

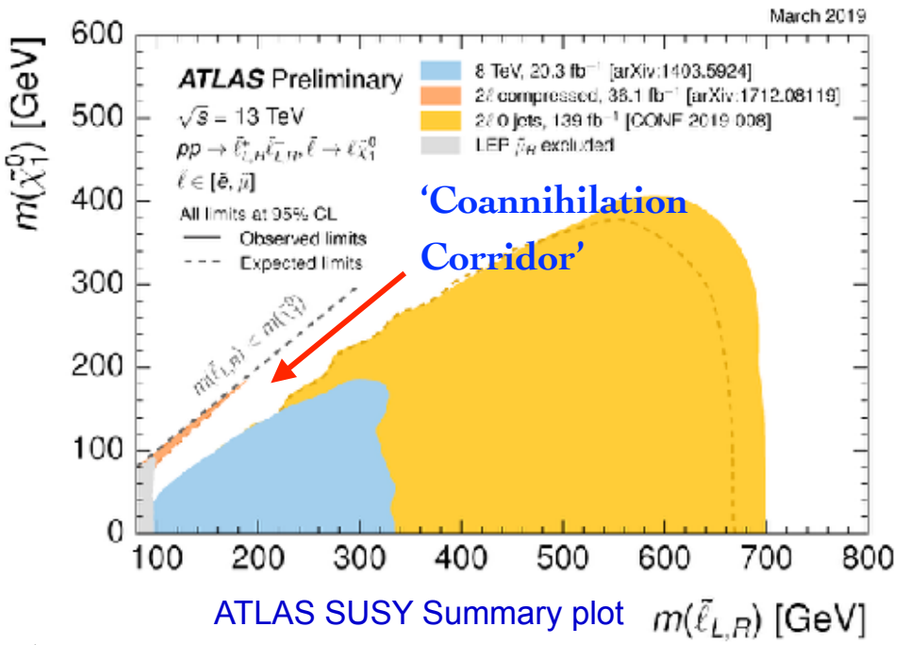
CEP & SUSY

- Work with James not relating to QCD.
- Use extra info. from tagged protons to pin down masses of new invisibly decaying particles (SUSY….).





- Best suited to clear large $\not{E}_\perp$ signals, but recently revived within context of compressed SUSY scenarios.



ATLAS SUSY Summary plot

LHL, V.A. Khoze, M.G. Ryskin, M. Tasevsky, arxiv:1812.04886

L. Beresford and J.Liu, arXiv:1811.06465

Thank you for listening!