

Forward Physics: Theory

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HL/HE-LHC WG1 Meeting - QCD Physics

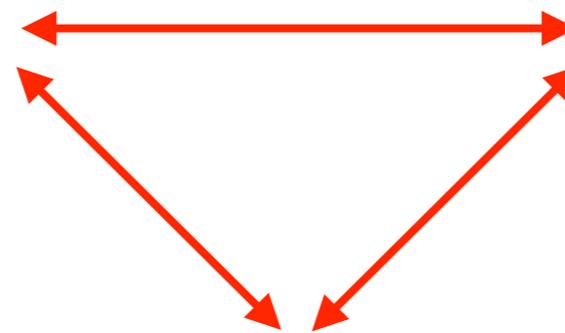
CERN, 2 May 2018

SM Physics (with tagged protons)

- The LHC offers a wide range of possibilities for exploring the Standard Model with tagged protons. Some examples:

Central Exclusive Production

- ★ Glueball searches.
- ★ Properties of gluon jets.
- ★ Dileptons - exclusive photon and proton structure.
- ★ Vector meson production and the gluon/saturation.
- ★ Wigner distribution.



Soft Physics

- ★ Testing the Odderon discovery.
- ★ A broad programme improving our understanding of pp interactions.

Inclusive Hard Diffraction

- ★ Single diffractive jet, Z, W and J/ψ production.
- ★ Double pomeron exchange - dijets and γ + jets.

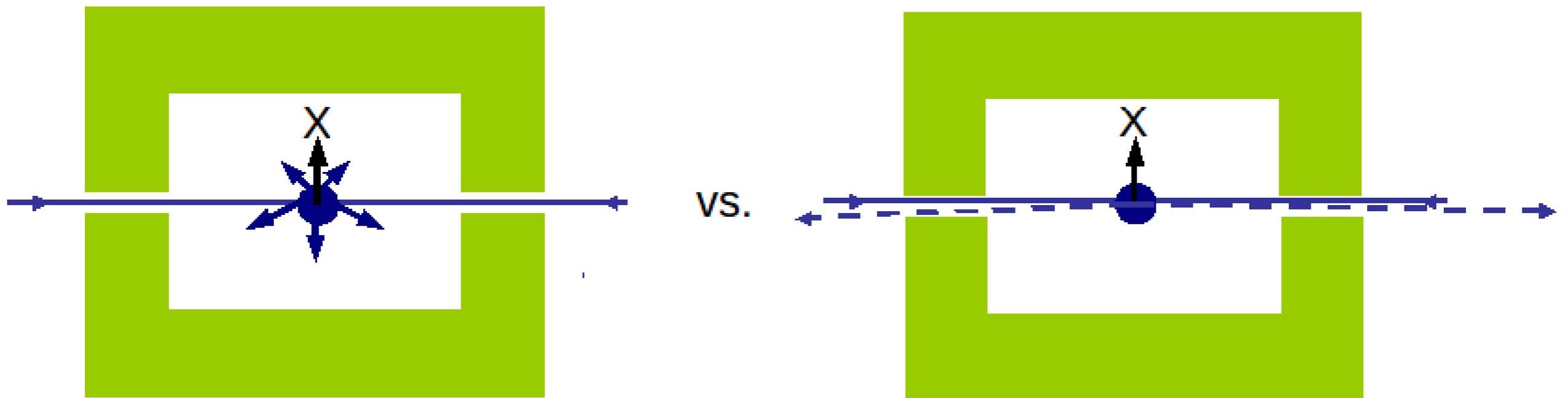
- Measure through special runs and/or tagged protons + high lumi
- Focus here on CEP (\rightarrow my work), but not to forget the others...

Central Exclusive Production

Central **E**xclusive **P**roduction (**CEP**) is the interaction:

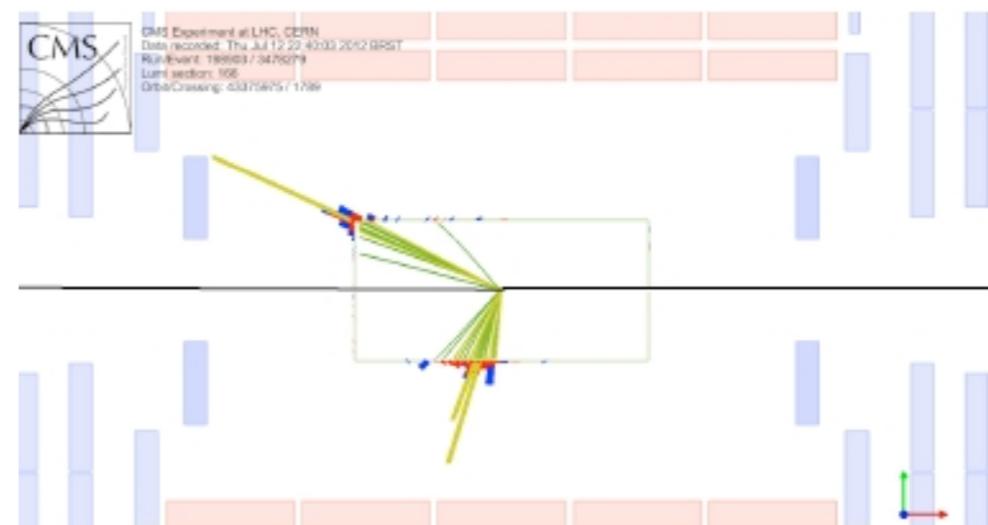
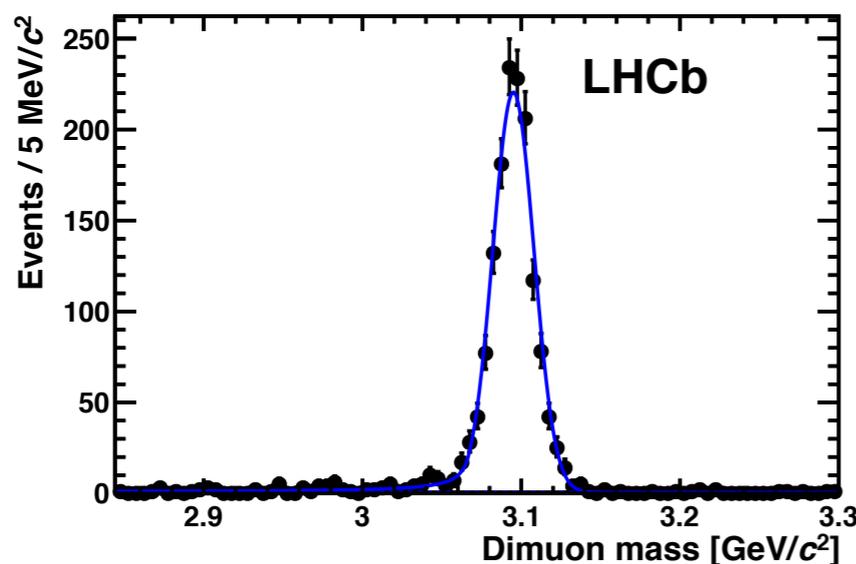
$$hh \rightarrow h + X + h$$

- **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 BSM/SM in comparison to inclusive production.



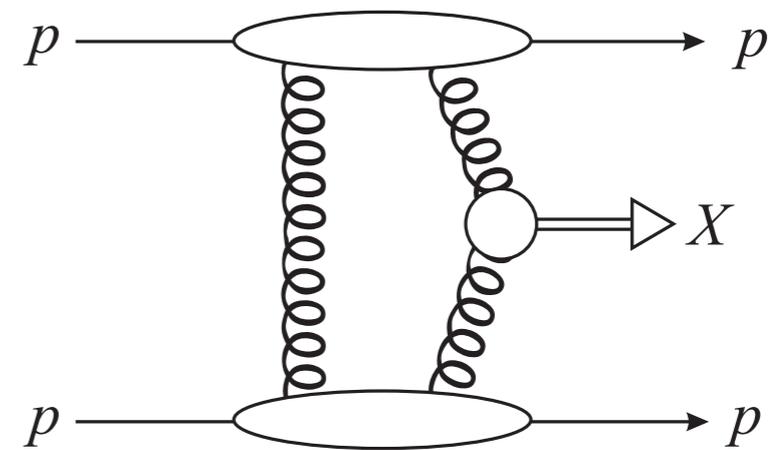
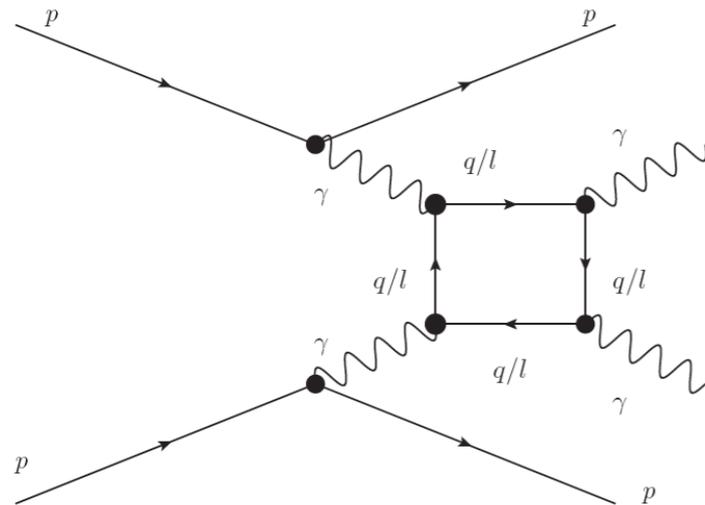
Production Mechanisms

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

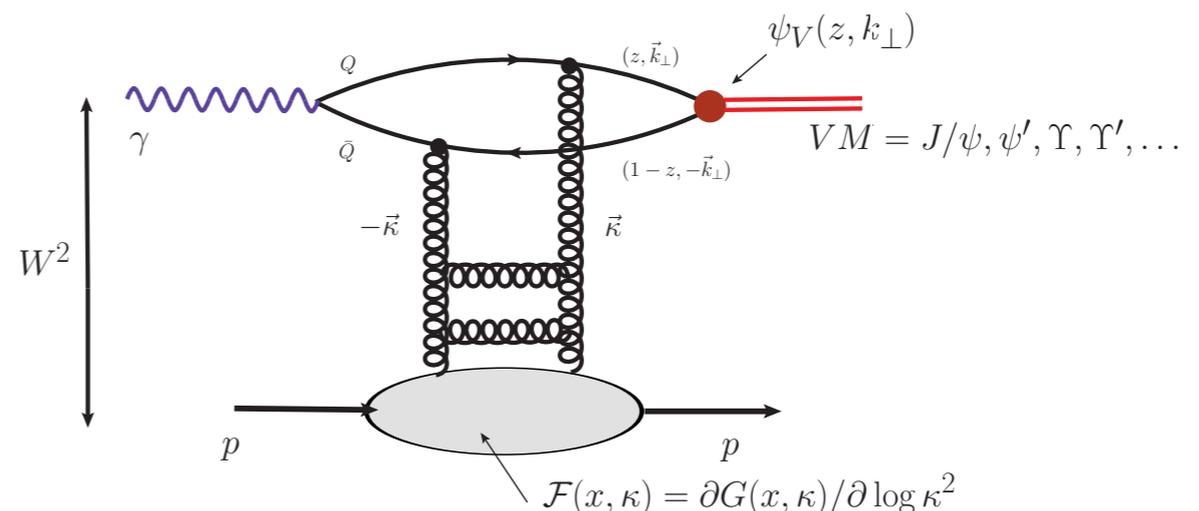
C-even, Couples to photons



Photon-induced

C-odd, couples to photons + gluons

Photoproduction



Each one offers different possibilities...

QCD-induced CEP

- Pure QCD production. Theory depends on scale of process:

- ★ Lower mass systems- tools of Regge theory.

- ★ **Double Pomeron Exchange**.

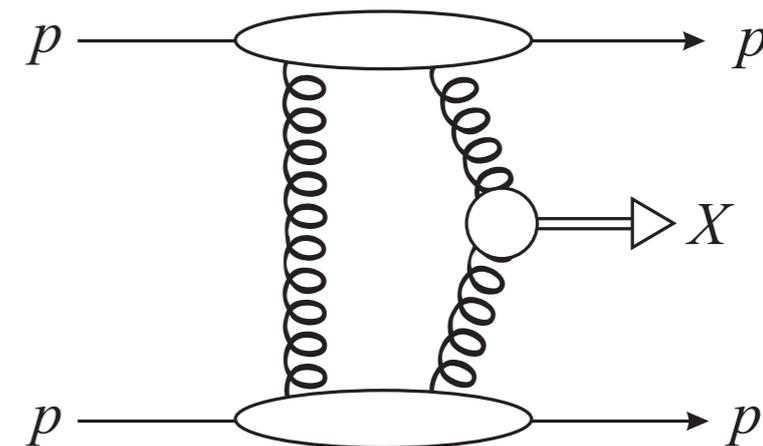
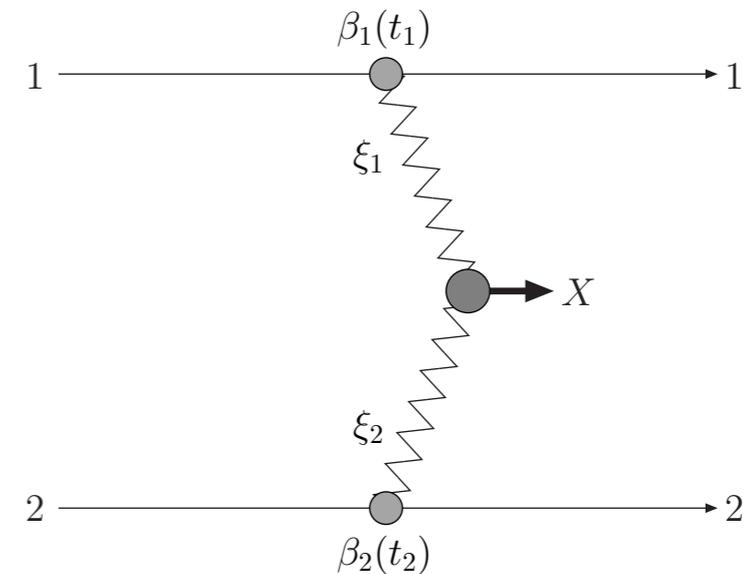
- ★ Hadron spectroscopy in unprecedented high energy 'gluon-rich' environment.

- ★ Particularly interesting: glueball (+ other exotic searches).

- ★ Higher mass systems- apply **pQCD**.

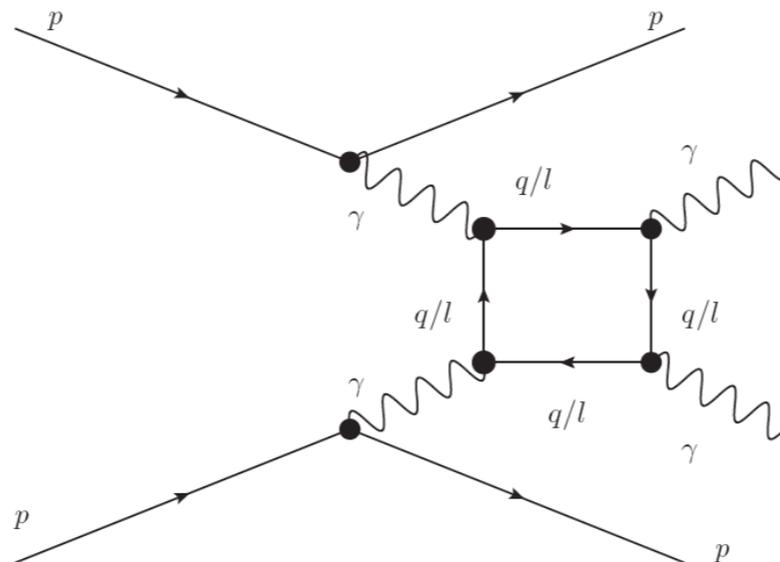
- ★ One example: **exclusive jet** production. CEP theory: dominantly gg colour singlet dijets. Novel features (radiation patterns/zeros) in trijets.

- ★ Others: exclusive Higgs... Lower mass: quarkonia (exotic/conventional), $\gamma\gamma$...



Photon-induced CEP and BSM

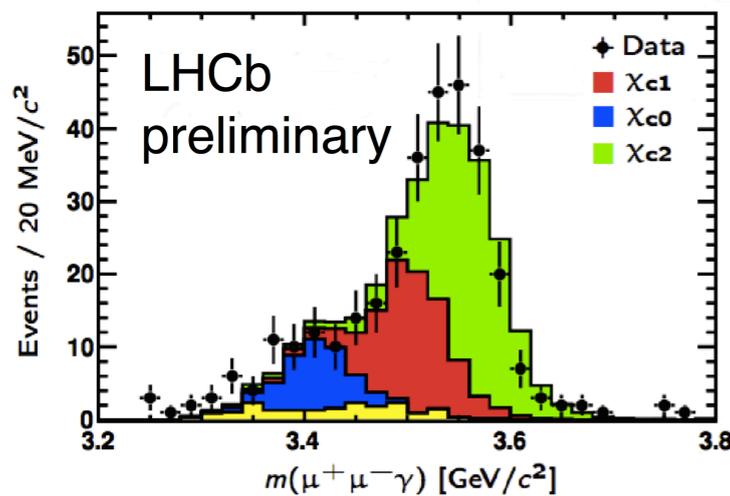
- Of particular interest for BSM is the photon-initiated channel:
 - ★ **Clean** and **well understood** $\gamma\gamma$ initial state.
 - ★ Impact of non-QED physics (e.g. MPI \rightarrow 'survival probability') low.
 - ★ Tagged protons: take data during nominal runs.
 - ★ Prospects for e.g. **anomalous coupling** (Christophe's talk) and **LbyL** in PbPb/pp.
 - ★ Other possibilities for EW-coupled **BSM** physics (Monopoles, SUSY...) Cross sections often low \rightarrow higher lumi. definitely helps.
 - ★ SM benchmark: high mass l^+l^- production. Sensitive to pp physics, photon PDF in non-inclusive environment...



Tools: SuperChic MC

- A MC event generator for CEP processes. **Common platform** for:
 - QCD-induced CEP.
 - Photoproduction.
 - Photon-photon induced CEP.
- Most complete generator of its kind. Code and manual available at:

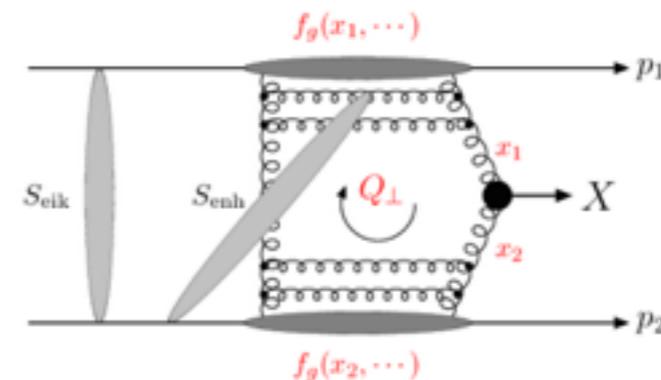
<https://superchic.hepforge.org>



SuperChic 2 - A Monte Carlo for Central Exclusive Production

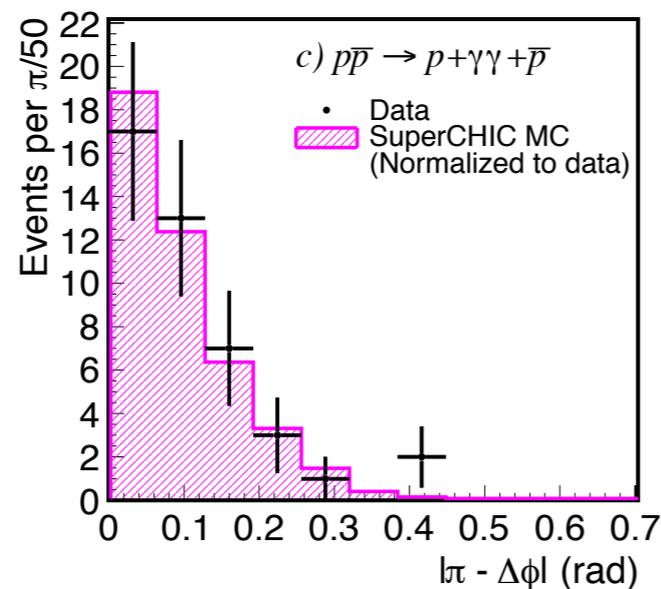
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SuperChic is a Fortran based Monte Carlo event generator for central exclusive production. A range of Standard Model final states are implemented, in most cases with spin correlations where relevant, and a fully differential treatment of the soft survival factor is given. Arbitrary user-defined histograms and cuts may be made, as well as unweighted events in the HEPEVT 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 <l.harland-lang (at) ucl.ac.uk >.



LHL, V. A. Khoze, M. G. Ryskin, Eur. Phys. J. C76 (2016) no.1, 9

What SuperChic does/doesn't do

- QCD-induced production:
 - ★ SM Higgs.
 - ★ Jets.
 - ★ Quarkonia
 - ★ Light meson pairs
 - ★ $\gamma\gamma$
- Photoproduction:
 - ★ Light mesons (ρ, ϕ).
 - ★ Quarkonia ($J/\psi, \Upsilon$)
- Photon-induced production:
 - ★ Lepton pair.
 - ★ W pair.
 - ★ $\gamma\gamma$ (LbyL in pp).
 - ★ SM Higgs
- All in official release. Not done, but **available unofficially**: heavy ion collisions, SUSY, Monopoles...
- Work currently **ongoing** to include **heavy ion** collisions (\rightarrow LbyL in PbPb), including full treatment of QCD-induced BG. Expect update in O(month).
- Other available generator: **FPMC** (Christophe's talk).

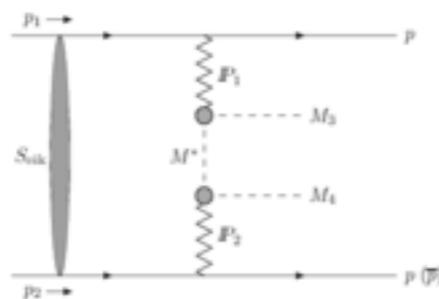
Low-mass spectroscopy: tools

- Key example - **glueball** searches (special runs).
- To my knowledge no public tool for low mass resonances via CEP.
- Dime MC: models continuum ($\pi\pi$, $KK\dots$).
- Possibility (*in principle*) to extend for resonance searches.

<https://dimemc.hepforge.org>

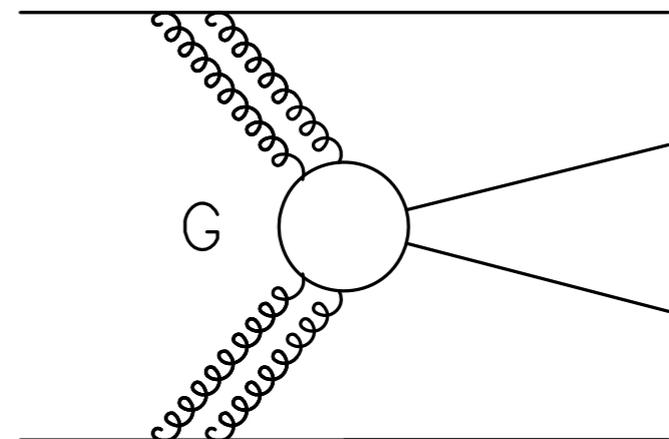
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Dime Monte Carlo: event generator for exclusive meson pair production via double Pomeron exchange



The enclosed standalone Fortran code provides public access to the Monte Carlo generator described in detail in:

L.A. Harland-Lang, V.A. Khoze, M.G. Ryskin
"Modeling exclusive meson pair production at hadron colliders"
arXiv:1312.4553



LHL, V. A. Khoze, M. G. Ryskin, Eur. Phys. J.
C74 (2014) 2848

YP Contributions

- **Experimental** contributions from:
 - ★ ALICE (E. Kryshen, C Mayer)
 - ★ ATLAS (J. Gramling, K. Schmeiden, M. Rijssenbeek).
 - ★ CMS (C. Royon).
- Focus on physics opportunities with tagged protons + high lumi, and special runs (special optics, heavy ions etc).
- **Theory**: provide contribution giving motivation/predictions (SuperChic) for CEP in the HL-LHC:
 - ★ Exclusive Jets.
 - ★ High mass lepton pair production.
 - ★ SM Higgs (?).
 - ★ Charm sector.
 - ★ BSM: anomalous coupling (C. Royon), monopoles, SUSY...
 - ★ Light-by-light scattering: predictions and BGs in pp and PbPb.
- Other topics: lower mass spectroscopy (glueballs, exotics...). Inclusive diffraction. Soft physics...
- Contact will continue with the LHC Forward Physics Working group.