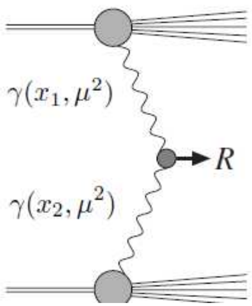
Low-x Meeting 2016

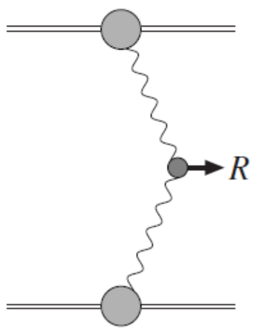
6-11 June 2016
Károly Róbert College, Gyöngyös, Hungary
CET timezone

$\gamma\gamma$ fusion and diphoton resonance production

V.A. Khoze (IPPP, Durham & PNPI, Spb)

(in collaboration with Lucian Harland-Lang and Misha Ryskin)





'Central Exclusive Production'

Outline

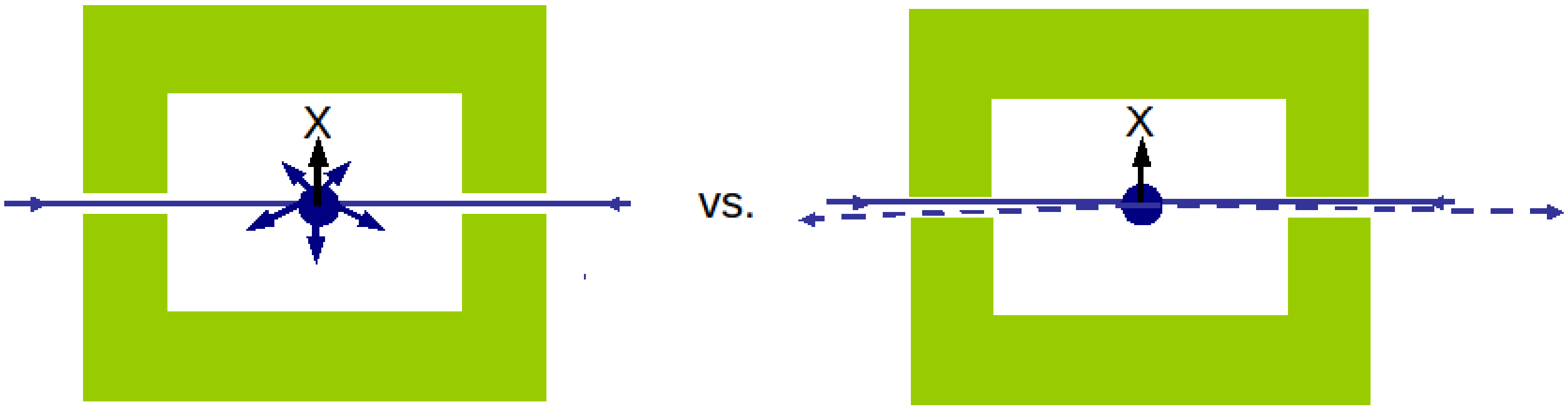
- **To refresh our memory**
- **LHC as a High Energy $\gamma\gamma$ Collider**
- **"The $\gamma\gamma$- Resonance that Stole Christmas"**
- **Summary and Outlook.**

What is it?

Central Exclusive Production (CEP) is the interaction:

$$pp \to p + X + p$$

- **CEP** 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.

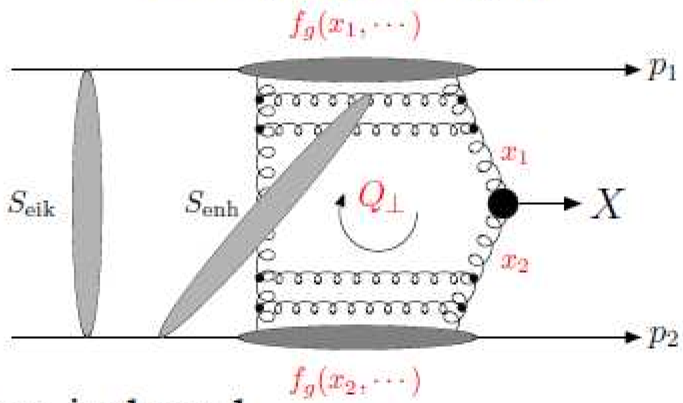


Production mechanisms

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

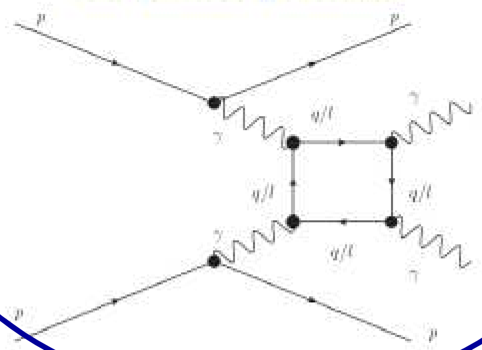
Gluon-induced (double pomeron exchange):

C-even, couples to gluons



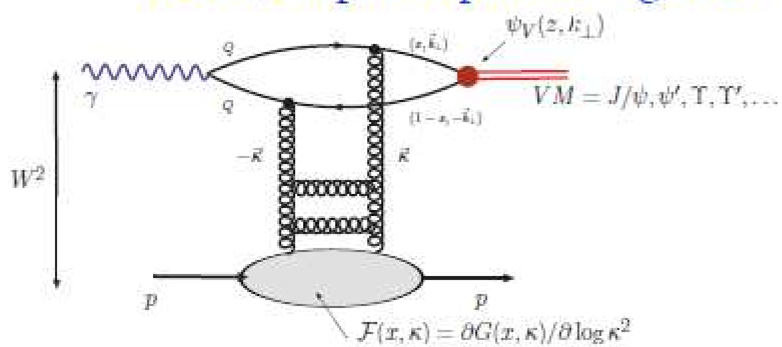
Photon-induced

Couples to photons



Photoproduction

C-odd, couples to photons + gluons



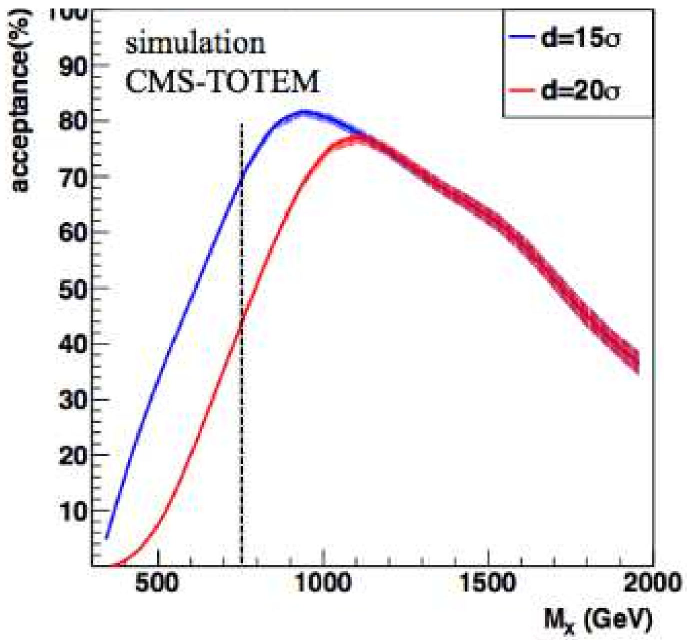
CT-PPS potential

- Expected LHC luminosity in 2016 is around 30 fb^{-1}

(Laurent's talk)

Acceptance depends on distance of approach to the beam

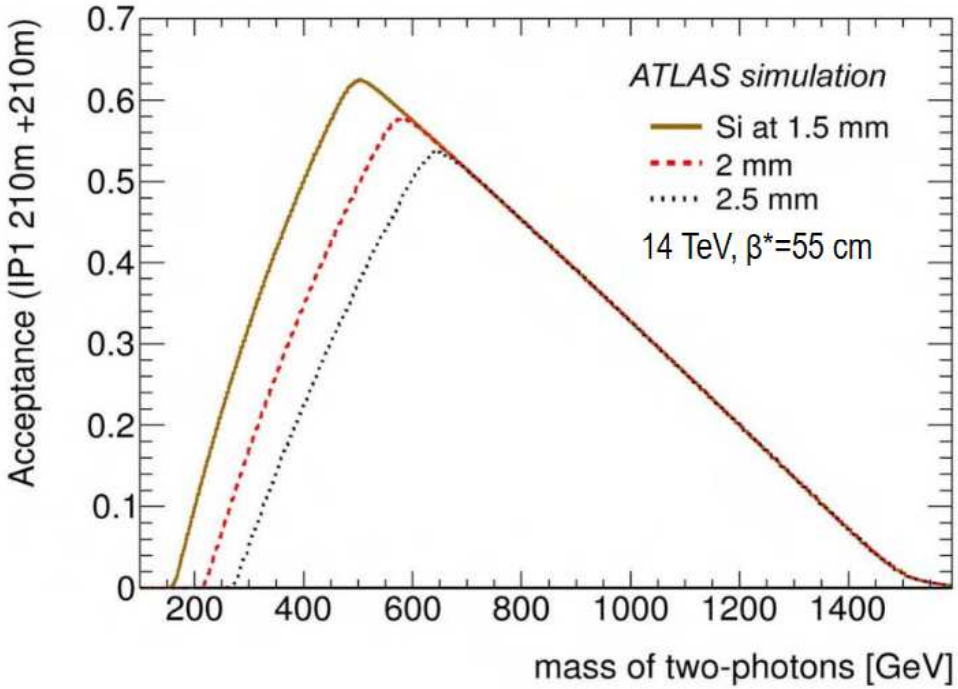
from CT-PPS TDR
LHC optics β^{*}=0.6m (2014)



(Rafal's talk)

Preparing for the 2nd AFP Arm

- AFP has excellent two-proton missing mass acceptance:
  - e.g. for an object produced by pp→p+X+p, X→γγ :



how close the RPs can safely approach the beam ?

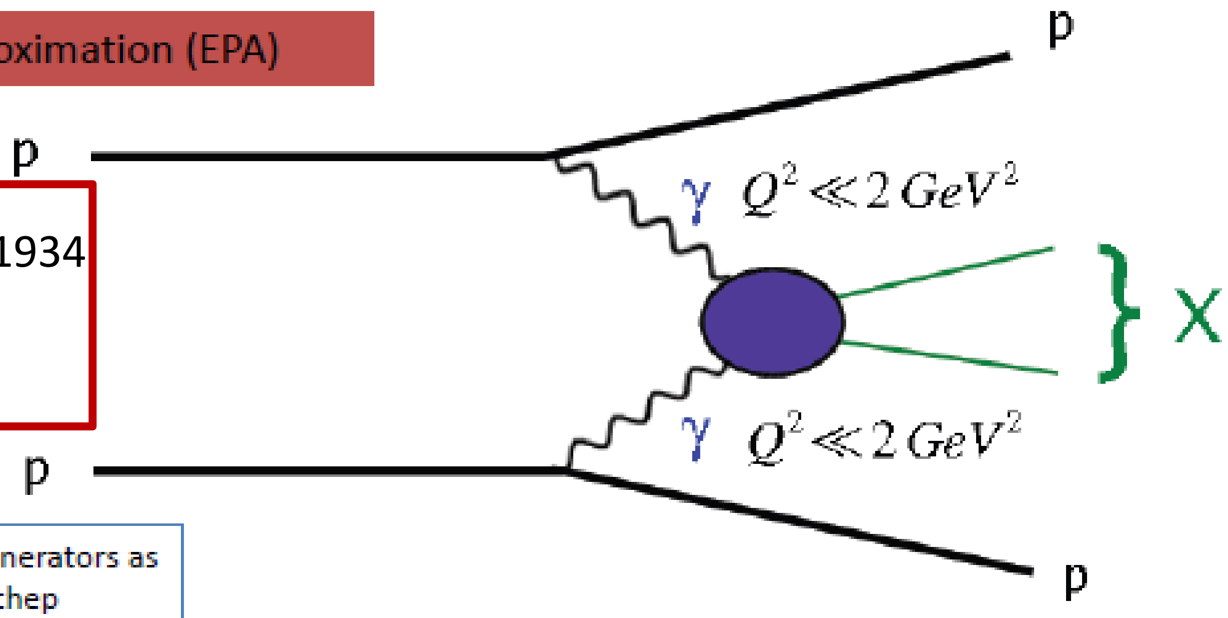
LHC as a $\gamma\gamma$ collider

Equivalent photon approximation (EPA)

C.F. von Weizsacker, 1934

E.J. Williams , 1934

E. Fermi, 1925



...introduced to major event generators as Madgraph, Pythia, Sherpa, Calchep

$$\sigma(\, pp \to (\gamma\gamma \to X)\, pp\,)$$

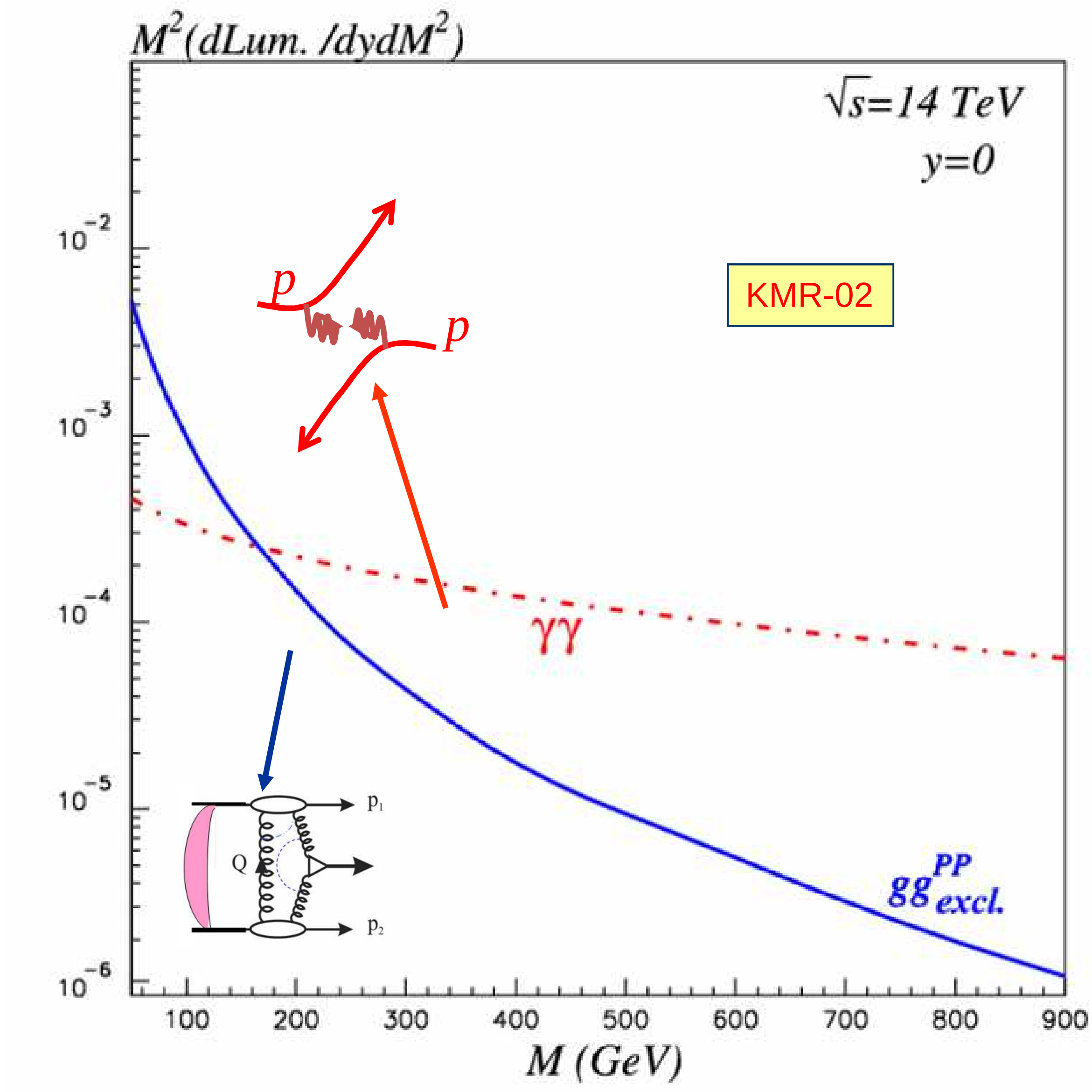
(Christophe, Lucian)

low γ virtuality WARNING (SuperChic 2 HKR-1508.02718)

- factorization to
  - long distance photon exchange
  - short distance $\gamma\gamma \to$ X interaction

$\alpha_S^2/8 \rightarrow \alpha^2$

QCD ‘radiation damage’ in action

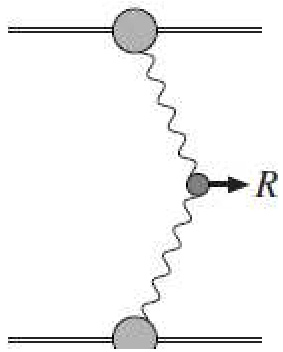


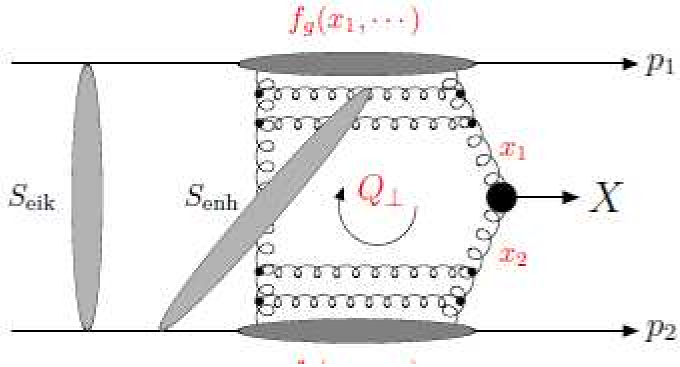
• Exclusive production via QCD-mediated process strongly suppressed at such higher masses. Gluons like to radiate!

$\longrightarrow$ Observing R production exclusively guarantees $\gamma\gamma$ coupling.

• Can measure protons! A $M_R = 750\,\mathrm{GeV}$ resonance is perfectly placed in terms of the mass acceptance of the AFP and CT-PPS detectors.

• Such a measurement would probe only the $\gamma\gamma$-initiated process, and measurements of the proton momenta provide additional insight…





Equivalent photon approximation

(Lucian's talk)

- Initial-state $p \to p\gamma$ emission can be to v. good approximation factorized from the $\gamma\gamma \to X$ process in terms of a flux:

$$n(x_i) = \frac{1}{x_i}\frac{\alpha}{\pi^2}\int \frac{\mathrm{d}^2 q_{i_\perp}}{q_{i_\perp}^2 + x_i^2 m_p^2}\left(\frac{q_{i_\perp}^2}{q_{i_\perp}^2 + x_i^2 m_p^2}(1-x_i)F_E(Q_i^2) + \frac{x_i^2}{2}F_M(Q_i^2)\right)$$

- Cross section the given in terms of $\gamma\gamma$ `luminosity':

$$\frac{\mathrm{d}\mathcal{L}_{\gamma\gamma}^{\mathrm{EPA}}}{\mathrm{d}M_X^2\,\mathrm{d}y_X} = \frac{1}{s}\, n(x_1)\, n(x_2)$$

THE TWO-PHOTON PARTICLE PRODUCTION MECHANISM.
PHYSICAL PROBLEMS. APPLICATIONS. EQUIVALENT PHOTON APPROXIMATION

V.M. BUDNEV, I.F. GINZBURG, G.V. MELEDIN and V.G. SERBO
USSR Academy of Science, Siberian Division, Institute for Mathematics, Novosibirsk, USSR

Received 25 April 1974
Revised version received 5 July 1974

$$\frac{\mathrm{d}\sigma^{pp\to pXp}}{\mathrm{d}M_X^2\mathrm{d}y_X} = \langle S_{\mathrm{eik}}^2\rangle \frac{\mathrm{d}\mathcal{L}_{\gamma\gamma}^{\mathrm{EPA}}}{\mathrm{d}M_X^2}\mathrm{d}y_X\, \hat{\sigma}(\gamma\gamma \to X)$$

$\langle S_{\mathrm{eik}}^2\rangle = 0.72 \quad : \quad J_P = 0^+$

$\langle S_{\mathrm{eik}}^2\rangle = 0.77 \quad : \quad J_P = 0^-$

In fact, the situation is more complicated due to the effects caused by the polarization structure of the production amplitude.

SURVIVAL GUIDE

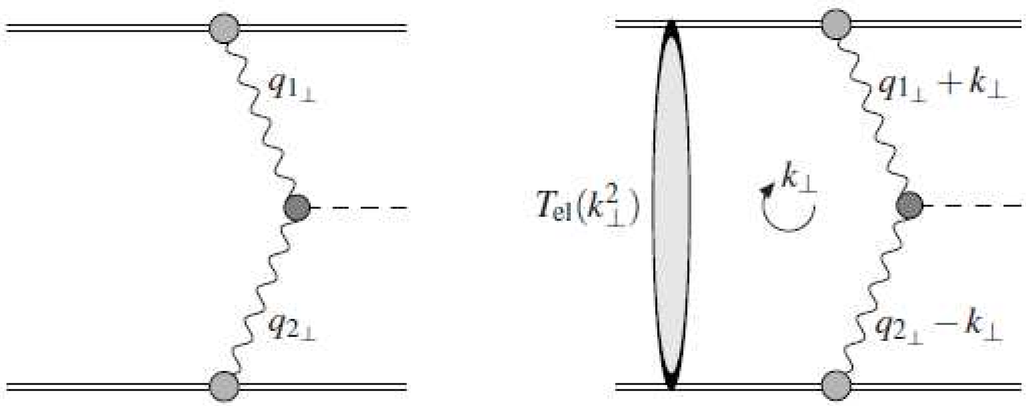
Soft survival factor

(Lucian's talk)

- In any pp collision event, there will in general be 'underlying event' activity, i.e. additional particle production due to pp interactions secondary to the hard process (a.k.a. 'multiparticle interactions', MPI).

- $\gamma\gamma$-initiated interaction is no different, but we are now requiring final state with no additional particle production (X + nothing else).

$\rightarrow$ Must multiply our cross section by probability of no underlying event activity, known as the soft 'survival factor'.



- Photon virtuality has kinematic minimum $Q^2_{1,\mathrm{min}} = \frac{\xi_1^2 m_p^2}{1-\xi_1}$

where $\xi_1 \approx \frac{M_\psi}{\sqrt{s}} e^{y_\psi}$ assuming photon emitted from proton 1 positive z-direction

$\longrightarrow$ Forward production $\Rightarrow$ higher photon Q^2 and less peripheral interaction

$\Rightarrow$ Smaller S^2_{eik}

- Not a constant: depends sensitively on the outgoing proton $\mathbf{p}_\perp$ vectors.

Physically- survival probability will depend on impact parameter of colliding protons. Further apart $\longrightarrow$ less interaction, and $S^2_{\mathrm{eik}} \to 1$.

b_t and $p_\perp$: Fourier conjugates.

Process dependence

$\longrightarrow$ Need to include survival factor differentially in MC.

First fully differential implementation of soft survival factor – **SuperChic 2** MC event generator- HKR, ArHiv:1508.02718

"The $\gamma\gamma$- Resonance that Stole Christmas"

ATLAS &CMS seminar on 15 Dec. 2015

750 GeV

The ATLAS announcement of a 3.6 σ local excess in diphotons with invariant mass ~750 GeV in first batch of LHC Run –II data, combined with CMS announcing 2.6 σ local excess.

EW Moriond, 17.03.2016

Theoretical community –frenzy of model building: >150 papers within a month.

Unprecedented explosion in the number of exploratory papers.

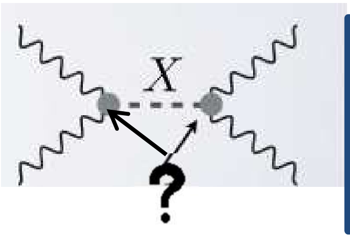
So far 'most statistically significant' deviation from SM at the LHC.

(About 400 papers currently)

If not a statistical fluctuation,

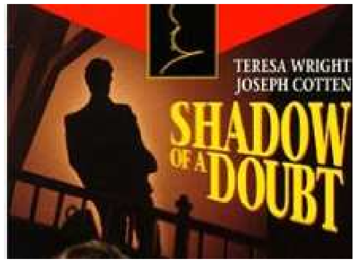
a natural minimal interpretation:

scalar/pseudoscalar resonance coupling dominantly to photons.



S. Fichet, G. von Gersdorff, and C. Royon, (2015), 1512.05751.

C. Csaki, J. Hubisz, and J. Terning, (2015), 1512.05776. + many more



What if this is due to a new state R which couples dominantly to photons ?

- The simplest model.
- Allows the most precise theoretical predictions.
- Provides strong motivations for the CT-PPS and AFP projects.
- 'Easier' scenario experimentally (BG, limit. jet activity or missing Et)
- and 'easier' to shoot down experimentally.

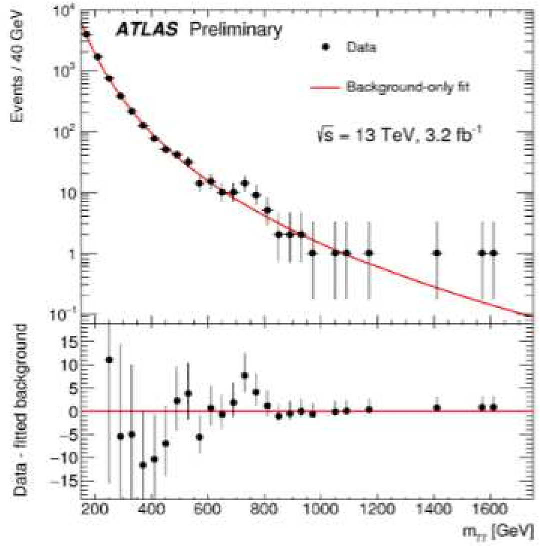
Digamma.

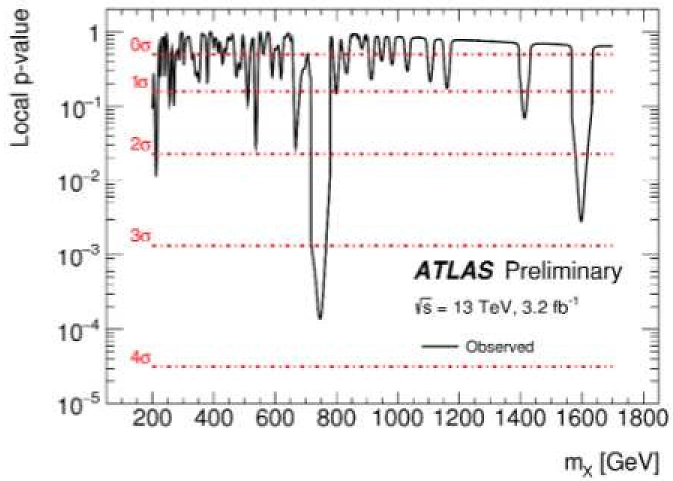
arXiv:1604.06446

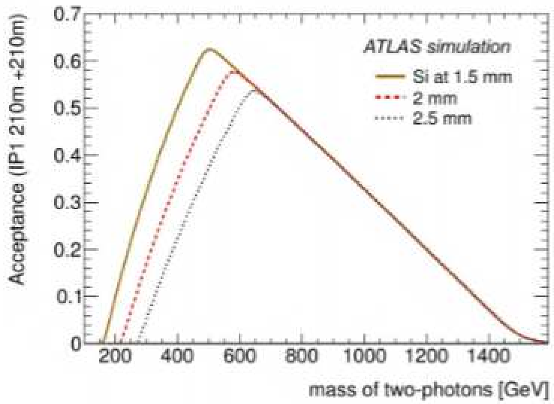
Preliminary LHC data at $\sqrt{s} = 13\,\text{TeV}$ show a hint for a new resonance in $pp \to \gamma\gamma$ (thereby denoted by the letter[1] *digamma*, $\digamma$) at invariant mass of 750 GeV [1], which stimulated intense experimental and theoretical interest. On the experimental side, dedicated analyses strengthen the statistical significance of the excess [2]. New measurements, which are underway, will tell us whether the excess is real and, if so, a thorough exploration of the new particle's properties will start.

Today, with the digamma, we are swimming in deep water. Many key issues related to the new resonance remain obscure. Does it have spin 0, 2, or more? Is it narrow or broad? Or, more generally, how large are its couplings? To which particles can it decay? Do its couplings violate CP? If not, is it CP-even or CP-odd? Is it a weak singlet or a weak doublet or something else? Is it produced through gg, $q\bar{q}$ or weak vector collisions? Is it elementary or composite? Is it a cousin of the Higgs boson? Is it related to the mechanism of electroweak breaking or to the naturalness problem? What is its role in the world of particle physics? Who ordered that?

Di-photon resonance at 750 GeV







- ATLAS and CMS observed an excess around 750 GeV in $\gamma\gamma$ events
- Decay to $\gamma\gamma$ means that exclusive two-photon production mechanism is possible:

$$pp \to p+\gamma\gamma+p \to p+R+p \to p+\gamma\gamma+p$$

- Within AFP2+2 acceptance!

ATLAS-CONF-2015-081; CMS-PAS-EXO-15-004

CERN-LHCC-2011-012

27 / **(Risto's talk)**

Brand new idea of combining BLM with LHC detectors for CEP physics searches.
Risto Orava et al 1604.05778

Main aim: to provide the most precise possible predictions for the $\gamma\gamma$ luminosity, needed to calculate the corresponding resonance production cross sections, in both the inclusive and exclusive cases.

The production of a diphoton resonance via photon–photon fusion

L. A. Harland–Lang[1], V. A. Khoze[2,3], M. G. Ryskin[3]

[1]Department of Physics and Astronomy, University College London, WC1E 6BT, UK
[2]Institute for Particle Physics Phenomenology, University of Durham, Durham, DH1 3LE
[3]Petersburg Nuclear Physics Institute, NRC Kurchatov Institute, Gatchina, St. Petersburg, 188300, Russia

Abstract

Motivated by the recent LHC observation of an excess of diphoton events around an invariant mass of 750 GeV, we discuss the possibility that this is due to the decay of a new scalar or pseudoscalar resonance dominantly produced via photon–photon fusion. We present a precise calculation of the corresponding photon–photon luminosity in the inclusive and exclusive scenarios, and demonstrate that the theoretical uncertainties associated with these are small. In the inclusive channel, we show how simple cuts on the final state may help to isolate the photon–photon induced cross section from any gluon–gluon or vector boson fusion induced contribution. In the exclusive case, that is where both protons remain intact after the collision, we present a precise cross section evaluation and show how this mode is sensitive to the parity of the object, as well as potential CP–violating effects. We also comment on the case of heavy–ion collisions and consider the production of new heavy colourless fermions, which may couple to such a resonance.

750 GeV resonance production

- Easiest to consider the $\gamma\gamma$ 'luminosity' of the colliding protons:

$$\frac{\mathrm{d}\mathcal{L}_{\gamma\gamma}^{\mathrm{inc}}}{\mathrm{d}M_X^2\,\mathrm{d}y_X} = \frac{1}{s}\gamma(x_1,\mu^2)\gamma(x_2,\mu^2) \qquad x_{1,2} = \frac{M_X}{\sqrt{s}}e^{\pm y_X}$$

where $\gamma(x,\mu^2)$ is given by DGLAP evolution from $\gamma(x,Q_0^2)$ given before.

- The resonance R production cross section given by

$$\frac{\mathrm{d}\sigma^{\mathrm{inc}}(pp\to R)}{\mathrm{d}y_R} = \frac{8\pi^2\Gamma(R\to\gamma\gamma)}{M_R}\,\frac{\mathrm{d}\mathcal{L}_{\gamma\gamma}^{\mathrm{inc}}}{\mathrm{d}y_R\,\mathrm{d}M_X^2}\bigg|_{M_X=M_R}$$

- If we are interested in, e.g., ratio of 13 to 8 TeV cross sections, simply consider ratio of corresponding luminosities.

$\longrightarrow$ Conservatively expect $\sim 15-20\,\%$ total uncertainty.

(Lucian's talk)

Enhancing the $\gamma\gamma$ contribution

- Even if R does not couple to colour, will still expect W, Z couplings

  $\Rightarrow$ Production via VBF.

- In addition, if it does couple to colour $\Rightarrow gg$ fusion.
- How can we suppress these/determine whether $\gamma\gamma$ fusion is indeed dominant?
- Answer: the $\gamma\gamma$ mechanism leads to unique and distinct predictions for the final state in inclusive events.

gg fusion

- Gluons: carry colour and like to radiate!
- Photons: colour-singlet and less likely to radiate ($\alpha \ll \alpha_S$).

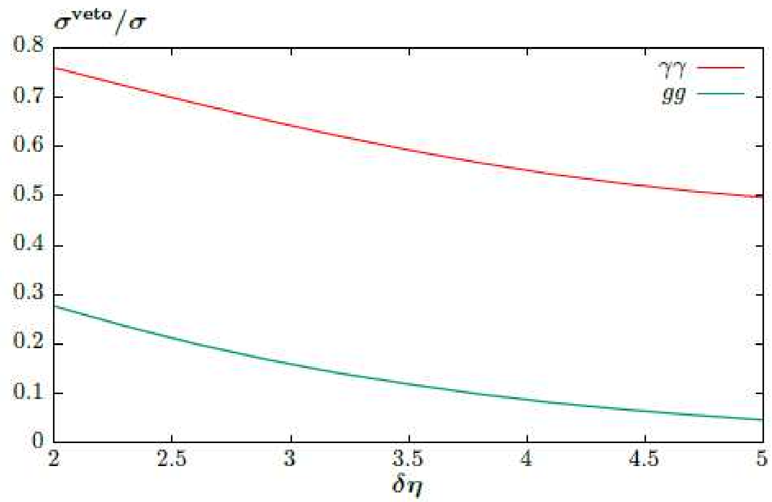
$\longrightarrow$ Natural to consider additional jet activity.

- What is cross section for R + no jets with $k_\perp > k_\perp^c$ and within $\delta\eta$ of R?
  - Gluons: requirement will strongly suppress cross section (double logarithmic 'Sudakov factor' for no parton emission in region).
  - Photons: can readily include veto in DGLAP evolution: suppression much less strong.

HKR 1601.03772

gg fusion

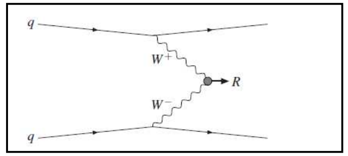
No jets with $k_\perp > 15\,\mathrm{GeV}$ in $\delta\eta$ either side of resonance

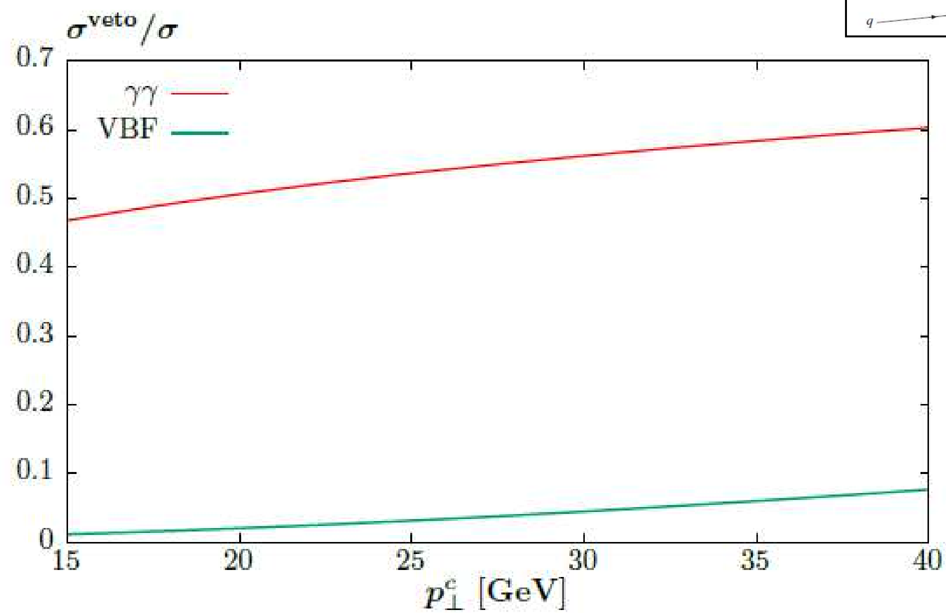


- For $\delta\eta \sim 2-3$ only $\sim 20\%$ of gg-initiated events have no additional jets, whereas for $\gamma\gamma$-initiated events $\sim 70\%$ do.
- For $k_\perp^c = 15(50)\,\mathrm{GeV}$ find $\sim 50(65)\,\%$ of $\gamma\gamma$-events with no jets, while for gg case this is below $\sim 10\%$. Expect continuum $\gamma\gamma$ BG to be similar to gg

$\longrightarrow$ Clear difference in event topology.

Vector boson fusion





- Fraction of VBF contribution with e.g. $p_\perp^R < 20$ GeV is $\sim$ % level, while for $\gamma\gamma$ -initiated production this is $\sim 50\%$.

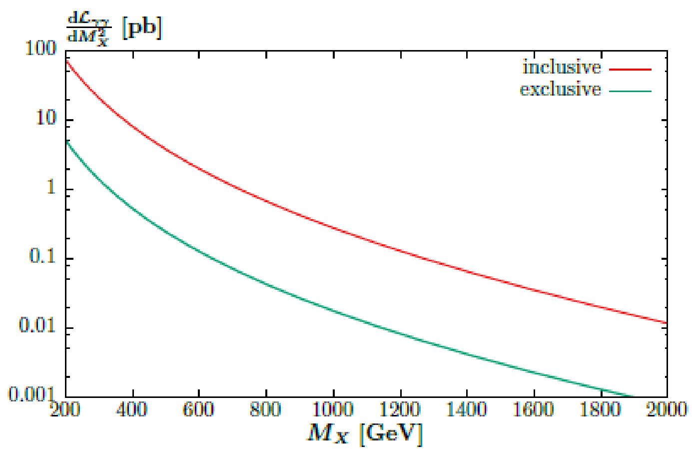
$\longrightarrow$ Extremely different behaviour under this simple cut.

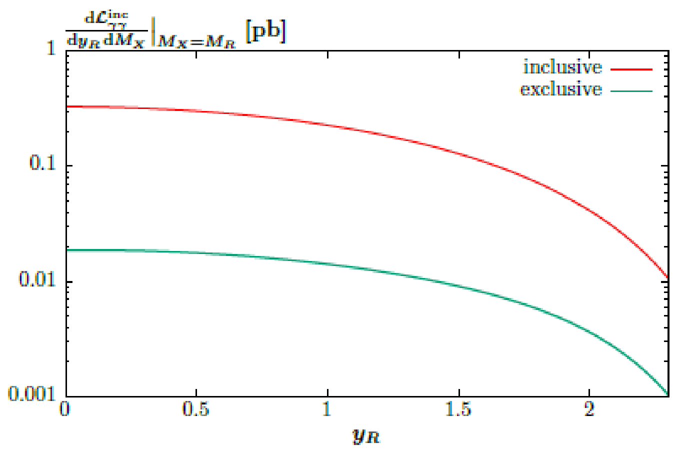
Exclusive resonance cross section

- As with inclusive case, we can consider the $\gamma\gamma$ luminosity, but for exclusive production.
- For R cross section, find:

assumes $\sigma^{\rm inc} = 4 - 8\,{\rm fb}$

$$\sigma^{\rm exc}(pp \to (R \to \gamma\gamma)) = 0.063 \cdot \sigma^{\rm inc}(pp \to (R \to \gamma\gamma)) = 0.25 - 0.50\,{\rm fb}$$





Assuming the 750 GeV- resonance survives and couples dominantly to photons :

HKR- arXiv:1601.07187

Main aim: to provide the most precise possible predictions for the $\gamma\gamma$ luminosity, needed to calculate the corresponding resonance production cross sections, in both the inclusive and exclusive cases.

- Simple cuts on the final state can efficiently reduce the relative contribution from gg and VBF resonance production, if such modes are present, relative to the $\gamma\gamma$–initiated case.
- A precise calculation of the exclusive $\gamma\gamma$ luminosity, relevant to the case where both protons remain intact after the interaction, has been presented, with an associated uncertainty that is very small, and does not exceed a few percent.

- Within this scenario if $\Gamma_{\rm tot} = 45$ GeV., then $\text{Br}(R \to \gamma\gamma) = 3.1 - 4.4\,\%$.
- $$\frac{\mathcal{L}^{inc}_{\gamma\gamma}(\sqrt{s} = 13\,\text{TeV})}{\mathcal{L}^{inc}_{\gamma\gamma}(\sqrt{s} = 8\,\text{TeV})} = 3.0$$

Exclusive case

- With good missing mass resolution: separation between resonance states.
- Resonance spin-parity, searches for CP-violating effects via the asymmetry in proton distributions...

- The exclusive channel leads naturally to a strong suppression of the gg and VBF initiated modes. The ratio of inclusive to exclusive $\gamma\gamma$ luminosities is found to be $\sim$ 16 with corresponding exclusive cross section $\sim 0.3 - 0.6$ fb via the $\gamma\gamma$ decay channel, for the current best estimate of the inclusive cross section corresponding to the apparent diphoton excess. Assuming favourable experimental efficiencies and resolution this could therefore be accessible with the hundreds of fb^{-1} of integrated luminosity which can be taken with the AFP [12, 13] and CT–PPS [14] forward proton taggers, associated with the ATLAS and CMS central detectors, respectively. It is in particular worth pointing out that the mass of the potential resonance is precisely in the region of maximum acceptance for these detectors [15].

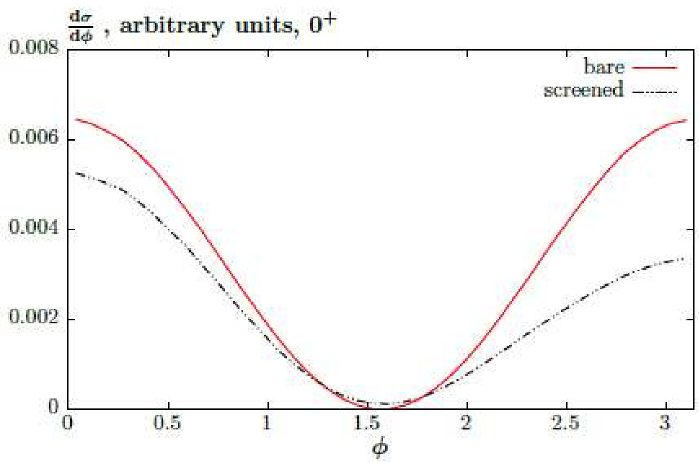
Important consequences of the $\gamma\gamma$ production:
depletion of multi-jet activity (due to the 'coherent' photon component);

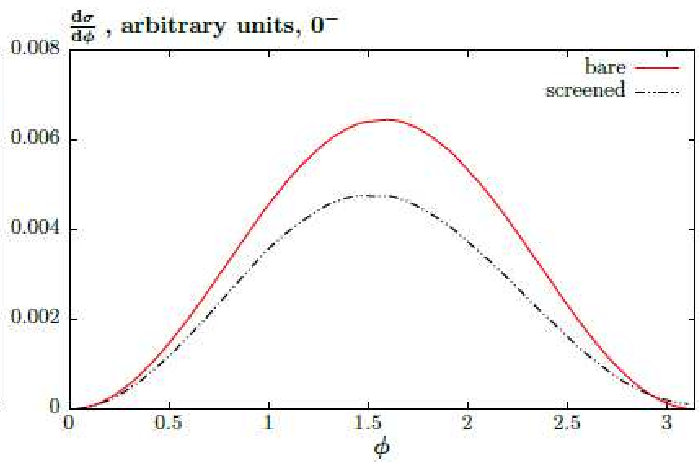
Asymmetric jet distribution;

Comparatively low transverse momentum of the resonance.

Proton correlations

- Consider distribution with respect to azimuthal angle ϕ between outgoing proton $p_\perp$ vectors.





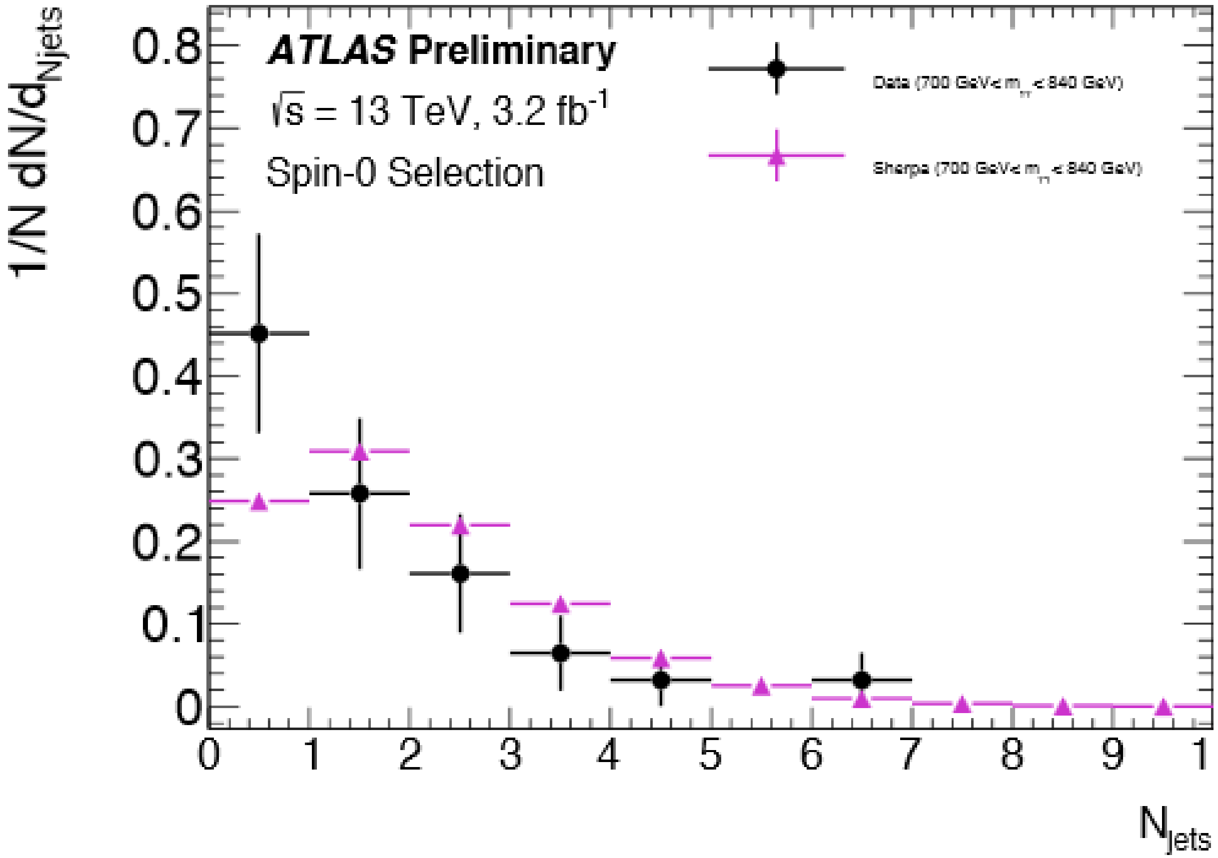
$\longrightarrow$ With just a handful of events, scalar/pseudoscalar hypotheses distinguishable.

- In addition (not discussed here) these distributions also sensitive to CP-violating effects in production mechanism.

Marco Delmastro
CNRS/IN2P3 LAPP
on behalf of the ATLAS Collaboration

Les Rencontres de Moriond EW 2016

$m_{\gamma\gamma}$ = [700-840] GeV



Summary

- presented the search for diphoton resonances with $m_{\gamma\gamma} > 500$ GeV at 8 and 13TeV

- simple and robust analysis strategy
- improved detector calibration @ 3.8 T
- analyzed dataset recorded @ 0T
- compared to previous results in Dec 15, 13TeV analysis improved sensitivity by more than 20%

- results interpreted in terms of scalar resonances & RS gravitons production for different widths
- modest excess of events observed at $m_{X=}$750(760)GeV for 8+13TeV(13TeV) dataset
- local significance is 3.4(2.9)σ, reduced to 1.6(<1)σ after accounting for look-elsewhere-effect

Summary

- Excess of events at $750\,\mathrm{GeV}$ seen so far only in $\gamma\gamma$ channel. Might be due to new resonance which couples dominantly to photons.
- Motivated by this, in arXiv:1601.03772 we present the **most** precise and up-to-date predictions for $\gamma\gamma$ initial-state.
- Photon PDF well determined: dominant contribution at Q_0 from 'coherent' emission from proton. $\sim 15-20\,\%$ uncertainty at $\mu = M_R$.
- VBF and gg production mechanisms can be separated by simple cuts on extra jet activity and $p_\perp$ of the final-state $\gamma\gamma$.
- $\gamma\gamma$-initated process naturally leads to 'exclusive' final state. Measurement of this probes only $\gamma\gamma$ initial state, and is sensitive to quantum numbers of R and CP-violating effects.

WARNING! Absorption effects in photon-induced 'CEP' processes at the LHC could be quite sizeable and should be accounted for, in particular for precise comparison

LOOKING FORWARD TO 2016 ARUN!
RICH PHYSICS PROGRAM ON THE WAY !


THANK YOU


QUESTIONS?

BACKUP

Why is it interesting?

- Clean:
  - Experimentally clean signal: low multiplicity ($\longrightarrow$ low background) process,* not typically seen in hadronic collisions.
  - Theoretically modeling such exclusive processes requires novel application of pQCD, quite different to inclusive case.
- Quantum number selection (gg-mechanism)
  - Demanding exclusivity strongly selects certain quantum numbers for produced object - the '$J_z^{PC} = 0^{++}$' selection rule for certain processes.
- Proton tagging:
  - Outgoing protons can be measured by tagging detectors installed at CMS (CT-PPS) and **Installed !** ATLAS (AFP). Handle to select events and provides additional event information (missing mass/proton correlations).

$\longrightarrow$ Clean production environment and selection rules provide potentially unique handle on QCD physics, but also BSM objects.

Resonance production with tagged protons

- Why might we be interested in exclusive resonance production? One major reason: protons remain intact and can therefore be measured.
- Detectors designed for precisely this currently installed/approved for installation:
  - ATLAS- AFP   CERN-LHCC-2011-012
  - CMS- CT-PPS   CERN-LHCC-2011-021
- A $M_R = 750\,\mathrm{GeV}$ resonance is perfectly placed in terms of the mass acceptance of these detectors.
- Such a measurement would probe only the $\gamma\gamma$-initiated process, and measurements of the proton momenta provide additional insight…

Luminosity predictions: uncertainties

(Lucian's talk)

- What are the sources of uncertainty?
- The photon PDF at the starting scale, $\gamma(x, Q_0^2)$:
  - Recall we know at least 75% of this (due to coherent emission) very precisely. In addition at $\mu = M_R$ large fraction also due to DGLAP splitting of quarks, washing out uncertainty.
  - Maximally conservative estimate: setting $\gamma^{\rm incoh}(x, Q_0^2) = 0$ gives $\sim 15\%$ smaller cross section than our upper bound. PDF fit can improve this.
- PDF uncertainty in quark/gluon PDFs in evolution: $\sim 2\%$
- Scale uncertainty: varying μ_F, μ_R independently between $(M_R/2, 2M_R)$ we find $\sim 10\%$ variation.

$\longrightarrow$ Conservatively expect $\sim 15-20\,\%$ total uncertainty.

Input photon PDF

- Photon PDF at Q_0 given as sum of coherent and incoherent terms:

$$\gamma(x, Q_0^2) = \gamma_{\rm coh}(x, Q_0^2) + \gamma_{\rm incoh}(x, Q_0^2)$$

  - Coherent: very precisely known.
  - Incoherent: some theoretical guidance, but known less precisely.

- However, consider momentum fraction of proton at Q_0 due to two contributions: $p_\gamma = \int {\rm d}x\, x\gamma(x, Q_0^2)$

- Find: $p_\gamma^{\rm incoh} \sim \frac{1}{3}\, p_\gamma^{\rm coh}$

- Recall our incoherent term is upper limit $\Rightarrow$ *at least* 75% of photon PDF is known very precisely! Entirely expected: at low Q^2 the dominant mechanism for γ emission from a proton is coherent.

Survival effects

- Consider amplitude for production of a $J = 0$ resonance

$q_{i\perp}$: photon transverse mom.

$$T(q_{1t}, q_{2t}) \sim -\frac{1}{2}(\mathbf{q}_{1t} \cdot \mathbf{q}_{2t})\,(T_{++} + T_{--}) - \frac{i}{2}(\mathbf{q}_{1t} \times \mathbf{q}_{2t}) \cdot \mathbf{n}_0\,(T_{++} - T_{--})$$

$T_{\lambda_1 \lambda_2}$: photon helicity λ_i

Scalar: $T_{++} = T_{--}$ Pseudoscalar: $T_{++} = -T_{--}$

$\longrightarrow$ Production amplitude and S^2 depends on quantum numbers of state (and on kinematics, e.g. M_X). Effect only included with proper treatment at amplitude level.

- Nonetheless for pheno. treatment can calculate average $\langle S^2 \rangle$.

$$\frac{\mathrm{d}\sigma^{pp\to pXp}}{\mathrm{d}M_X^2\,\mathrm{d}y_X} = \langle S^2_{\mathrm{eik}} \rangle \frac{\mathrm{d}\mathcal{L}^{\mathrm{EPA}}_{\gamma\gamma}}{\mathrm{d}M_X^2}\mathrm{d}y_X\,\hat{\sigma}(\gamma\gamma \to X)$$

- What sort of size for $\langle S^2_{\mathrm{eik}} \rangle$ do we expect?

Exclusive resonance cross section

- Predict: $\langle S^2_{\rm eik} \rangle = 0.72 \quad : \quad J_P = 0^+$

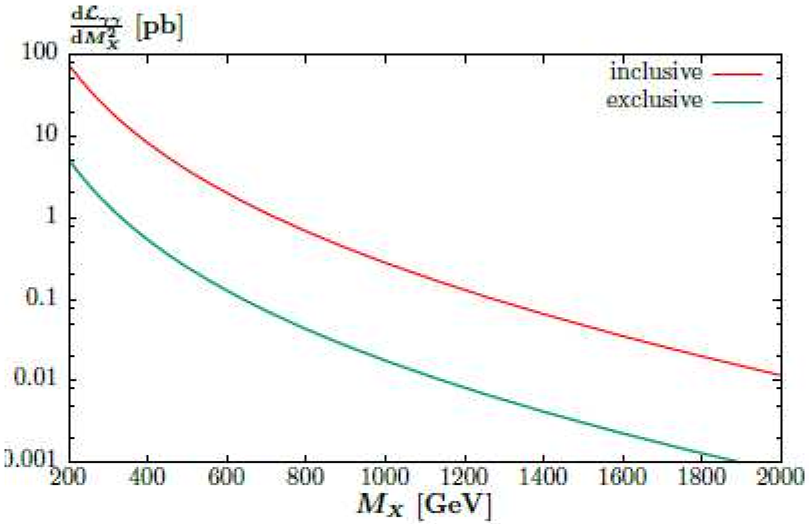
  $\langle S^2_{\rm eik} \rangle = 0.77 \quad : \quad J_P = 0^-$

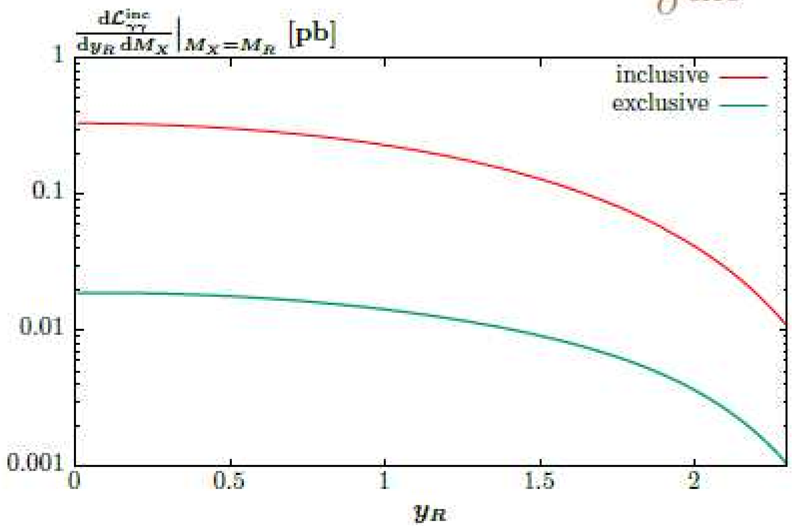
- For scalar R cross section, then find:

assumes $\sigma^{\rm inc} = 4 - 8\,{\rm fb}$

$$\sigma^{\rm exc}(pp \to (R \to \gamma\gamma)) = 0.063 \cdot \sigma^{\rm inc}(pp \to (R \to \gamma\gamma)) = 0.25 - 0.50\,{\rm fb}$$

$$\frac{\sigma^{\rm inc}}{\sigma^{\rm exc}} \sim 14$$





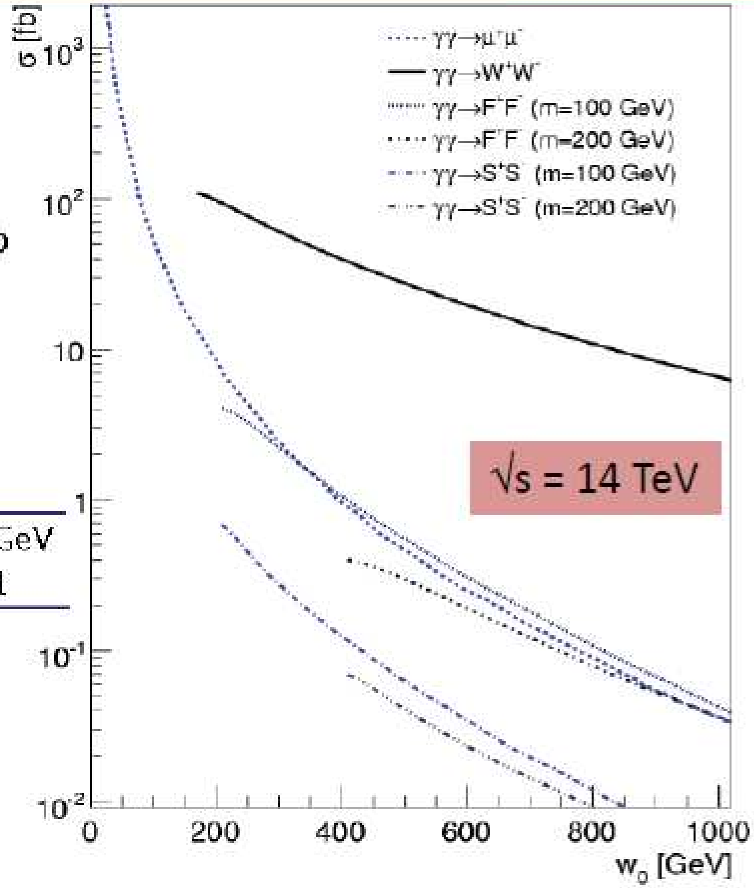
LHC as a $\gamma\gamma$ collider

arXiv:0908.2020

- $\gamma\gamma \to \mu\mu$ first $\gamma\gamma$ process to be seen
- $\gamma\gamma \to W^+W^-$ very interesting SM process 108fb
- New physics !

Processes		[fb]	Generator
$\gamma\gamma \to \mu\mu$		72 500	LPAIR pt > 2 GeV $\lvert\eta\rvert < 3.1$
$\gamma\gamma \to$ WW		108	
$\to$ FF	(m=100GeV)	4.06	MadGraph
$\to$ FF	(m=200GeV)	0.40	/
$\to$ SS	(m=100GeV)	0.68	MadEvent
$\to$ SS	(m=200GeV)	0.07	

moreover :
lepton final states
clear signature – background suppression



Cross sections for $\gamma\gamma$ processes as a function of the minimal $\gamma\gamma$ cms energy W_0

SURVIVAL GUIDE

- Averaged survival factor given by (in impact parameter space)

Opacity, relates to prob. of no inelastic scattering

$$\langle S^2_{\rm eik}\rangle = \frac{\int d^2 b_{1t}\, d^2 b_{2t}\, |T(s, b_{1t}, b_{2t})|^2 \exp(-\Omega(s, b_t))}{\int d^2 b_{1t} d^2 b_{2t}\, |T(s, b_{1t}, b_{2t})|^2}$$

One-channel for illustration

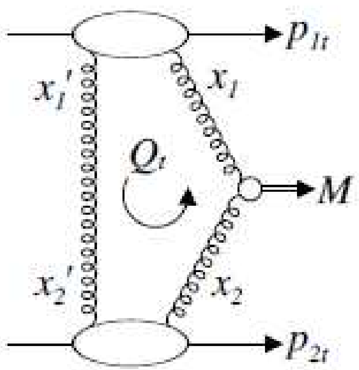
'Bare' amplitude

in $p_\perp$ space this is equivalent to

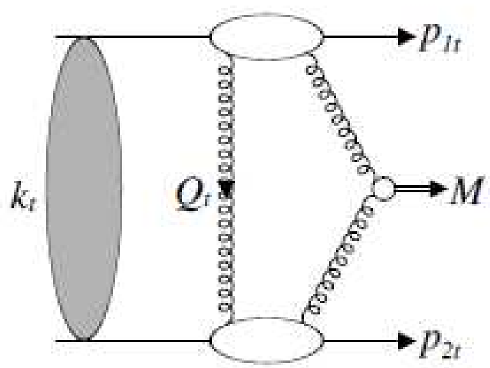
$$\langle S^2_{\rm eik}\rangle = \frac{\int d^2 p_{1_\perp}\, d^2 p_{2_\perp}\, |T(s, p_{1_\perp}, p_{2_\perp}) + T^{\rm res}(s, p_{1_\perp}, p_{2_\perp})|^2}{\int d^2 p_{1_\perp}\, d^2 p_{2_\perp}\, |T(s, p_{1_\perp}, p_{2_\perp})|^2}$$

where 'screened' amplitude is given by

$$T^{\rm res}(s, p_{1_\perp}, p_{2_\perp}) = \frac{i}{s}\int \frac{d^2 k_\perp}{8\pi^2}\, T_{\rm el}(s, k_\perp^2)\, T(s, p'_{1_\perp}, p'_{2_\perp})$$

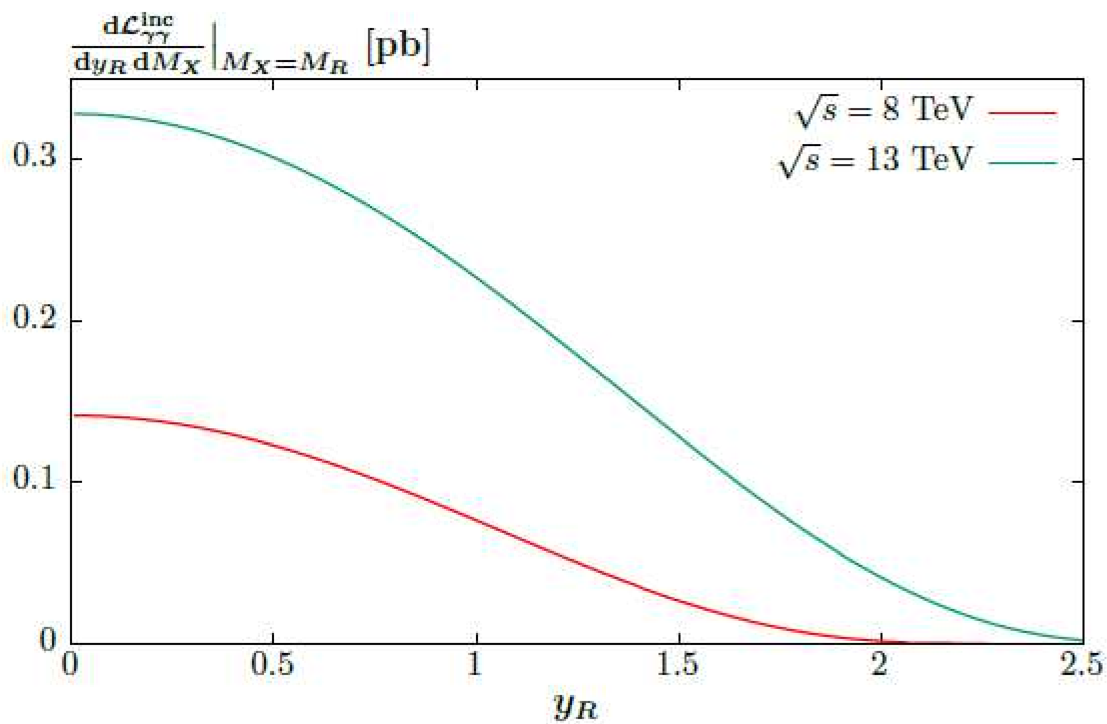


'Bare' amplitude



'Screened amplitude'

Luminosity predictions: c.m.s. energy ratios

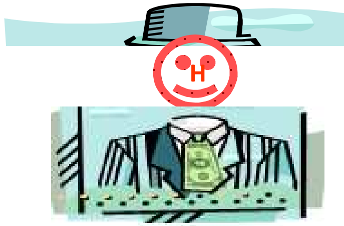


- For $M_R = 750\,\text{GeV}$ we find $\quad \dfrac{\mathcal{L}^{inc}_{\gamma\gamma}(\sqrt{s}=13\,\text{TeV})}{\mathcal{L}^{inc}_{\gamma\gamma}(\sqrt{s}=8\,\text{TeV})} = 2.9$

$\longrightarrow$ Consistent with lack of 8 TeV signal.

For high total width -sizeable branchings into other SM (or BSM) particles.

In principle: a possibility to search for invisible modes (dark matter particles etc), sharp peak in the missing mass spectrum



but **extremely** challenging if not impossible (in the large pile-up environment)

(BKMR , Eur.Phys.J. C36 (2004) 503-507)

New colourless heavy fermions: the $\gamma\gamma \to F\bar{F}$:

taking $m_F = 360$ GeV and $e_F = 1$, we get $\sigma_{F\bar{F}} = 0.12$ fb at $\sqrt{s} = 13$ TeV.

R production cross section, this will be strongly enhanced in a scenario where the new fermion carry higher electric charge $e_F > 1$. Note that the resonant $R \to F\overline{F}$ cross section may give a comparable contribution to the overall $F\overline{F}$ signal, provided the corresponding branching ratio is not too small.

(still relatively unconstrained, (1512.05327))

with my Durham hat on

Photo-production of a 750 GeV di-photon resonance mediated by Kaluza-Klein leptons in the loop

Steven Abel and Valentin V. Khoze

arXiv:1601.07167

Abstract

We consider the phenomenology of a 750 GeV resonance X which can be produced at the LHC by only photon fusion and subsequently decay into di-photons. We propose that the spin-zero state X is coupled to a heavy lepton that lives in the bulk of a higher-dimensional theory and interacts only with the photons of the Standard Model. We compute the di-photon rate in these models with two and more compact extra dimensions and demonstrate that they allow for a compelling explanation of the di-photon excess recently observed by the ATLAS and CMS collaborations. The central role in our approach is played by the summation over the Kaluza-Klein modes of the new leptons, thus providing a significant enhancement of the $X \to \gamma\gamma$ loops for the production and decay subprocesses.