Photon-Photon scattering in the resonance region at midrapidity at the LHC

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Motivation for this study

Elementary photon-photon scattering cross section

Photon-photon scattering in ultra-peripheral heavy-ion reactions

Signal resonance decays η, η'

Background from $\pi^0\pi^0$ decays

Conclusions, Outlook

Motivation for studying photon-photon scattering

- classical electrodynamics epitomised by Maxwell's equation:
  - $\partial_\alpha F^{\alpha\beta} = \frac{4\pi}{c} J^\beta, \qquad \partial_\alpha \mathcal{F}^{\alpha\beta} = 0$
- J.D. Jackson, Classical Electrodynamics, 3rd ed., Introduction and Survey, I.3: *Linear Superposition*

There *is* a *quantum-mechanical nonlinearity* of electromagnetic fields that arises because the uncertainty principle permits the momentary creation of an electron-positron pair by two photons and the subsequent disappearance of the pair with the emission of two different photons, as indicated schematically in Fig. I.3. This process is called the scattering of light by light.[‡]S The two incident plane waves $e^{i\mathbf{k}_1\cdot\mathbf{x}-i\omega_1 t}$ and $e^{i\mathbf{k}_2\cdot\mathbf{x}-i\omega_2 t}$ do not merely add coherently, as expected with linear superposition, but interact and (with small probability) transform into two different plane waves with wave vectors $\mathbf{k}_3$ and $\mathbf{k}_4$. This nonlinear feature of

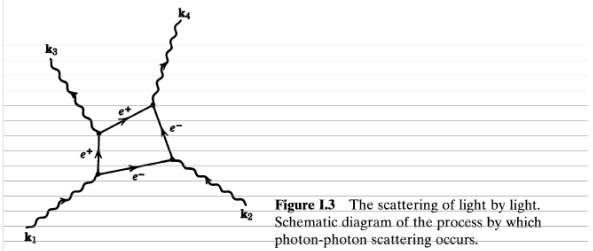


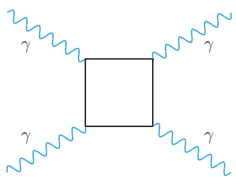
Figure I.3 The scattering of light by light. Schematic diagram of the process by which photon-photon scattering occurs.

quantum electrodynamics can be expressed, at least for slowly varying fields, in terms of electric and magnetic permeability tensors of the vacuum:

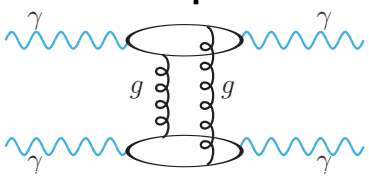
- Nonlinear modification of QED-Lagrangian by Born-Infeld (1934)
- Low-energy Photon-Photon cross section by the nonlinear Euler-Heisenberg QED Lagrangian (1936)
- QCD connection: role of meson exchange currents ?
- First measurements of light-by-light scattering at LHC by the ATLAS collaboration (arXiv:1702.01625)

Elementary photon-photon scattering cross section

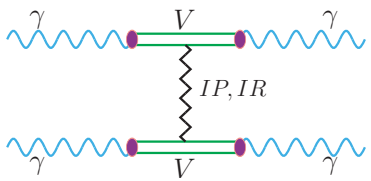
- M. Kłusek-Gawenda et al., Phys.Rev.C93 (2016) no.4, 044907, *"Light-by-Light scattering in ultraperipheral PbPb collisions at LHC"*
- different mechanisms of photon-photon scattering



lepton, quark loops

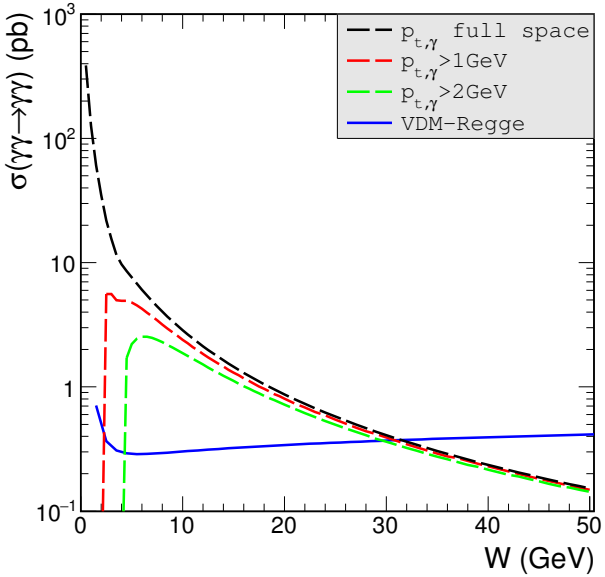


two gluon exchange



VDM-Regge mechanism

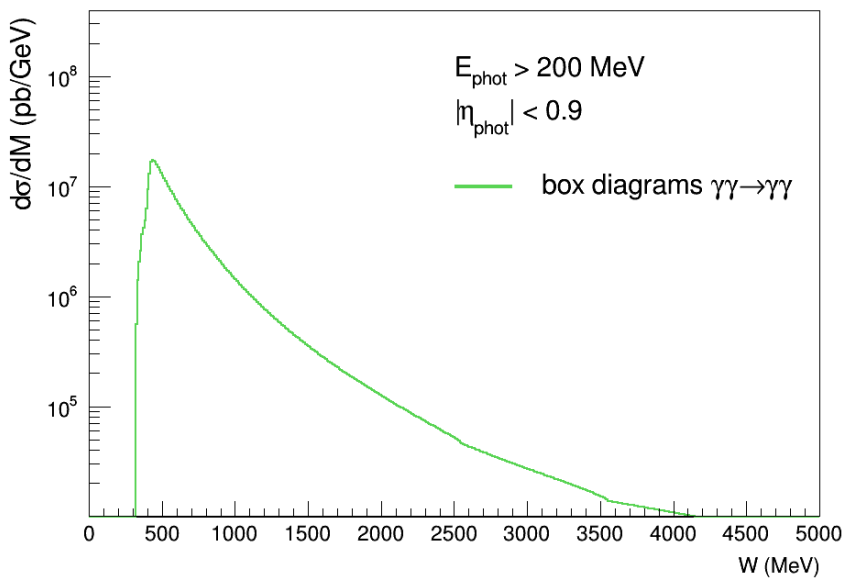
- angle-integrated cross section for box and VDM-Regge contribution



- box cross section: contribution of leptons five times larger than quark for 4<W<50 GeV (W = inv. mass of photon-pair)
- VDM-Regge contribution dominates cross section for W>30 GeV

Photon-photon scattering in ultra-peripheral heavy-ion reactions

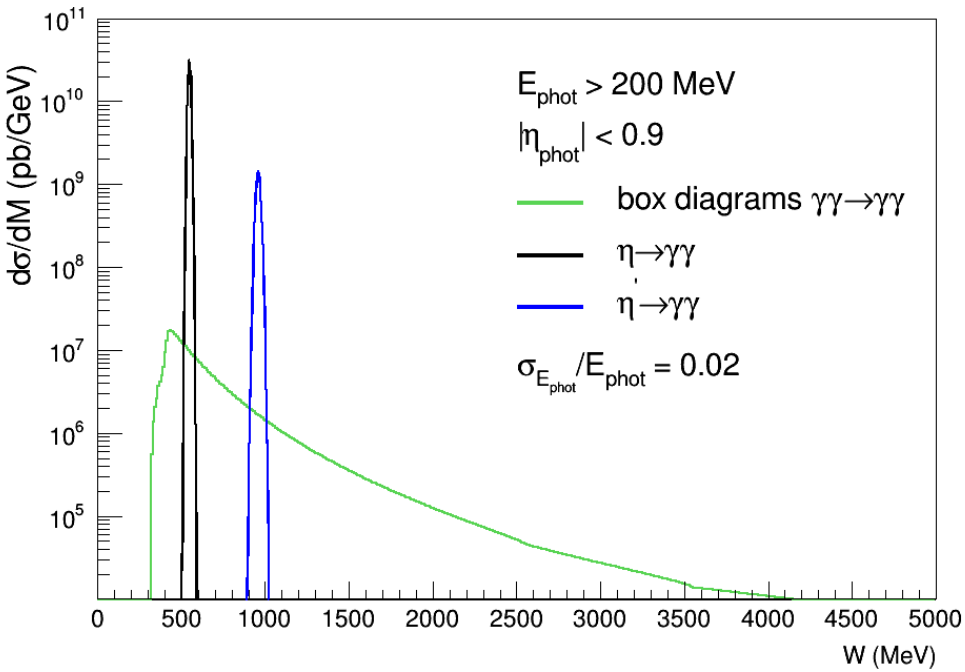
- Photon scattering in ultraperipheral heavy-ion reactions calculated by folding the elementary cross section with heavy-ion photon flux
- Equivalent photon approximation (EPA) by E. Fermi (1924), Weizsäcker-Williams (1934)
  $dn_\gamma(\omega, b) = \frac{Z_1^2 \alpha}{\pi^2} \frac{d\omega}{\omega} \frac{d^2 b}{b^2}$ (lead. log approx.)
- $\sigma^{EPA}_{PbPb \to PbPb\,X} = \iint dn^1_\gamma \; dn^2_\gamma \; \sigma_{\gamma\gamma \to x}(\omega_1\, \omega_2)$



- diff. cross section $d\sigma/dM$ in PbPb-collisions at LHC energy $\sqrt{s_{NN}} = 5.02$ TeV for scattering two photons with energy E>200 MeV into range -0.9$<\eta<$0.9

Resonance signal from η, η' decays

- Cross section for photoproduction of resonance
  $\sigma_{\gamma\gamma\to R} = 8\pi(2J+1)\frac{\Gamma_{\gamma\gamma}\Gamma_{tot}}{(W^2-M_R^2)^2+M_R^2\Gamma_{tot}^2}$
- $\sigma^{EPA}_{PbPb\to PbPb\,R} = \iint dn^1_\gamma\, dn^2_\gamma\, \sigma_{\gamma\gamma\to R}(\omega_1\,\omega_2)$

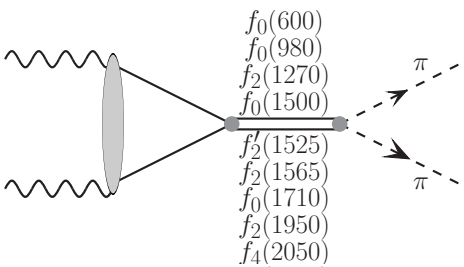


- Resonance mass width due to energy resolution of photon measurement $\sigma_E/E = 0.02$.

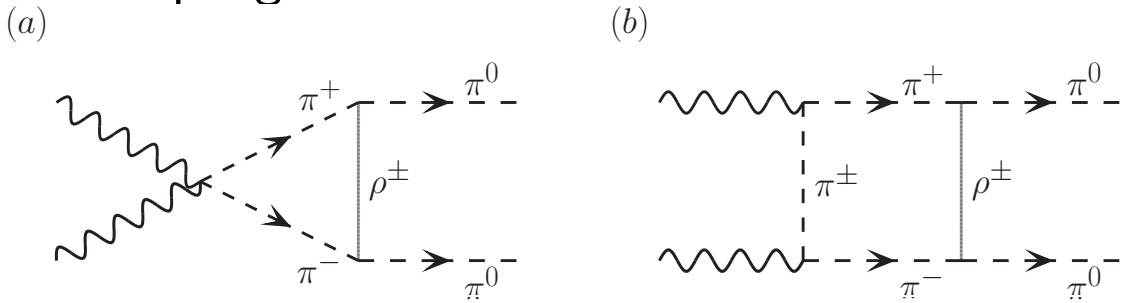
Photoproduction of $\pi^0\pi^0$-pairs

- M. Kłusek-Gawenda, A. Szczurek, Phys.Rev.C87(2013) no.5,054908
  "$\pi^+\pi^-$ and $\pi^0\pi^0$ pair production in photon-photon scattering and ultraperipheral ultrarelativistic heavy-ion collisions"

- resonant pion pair production



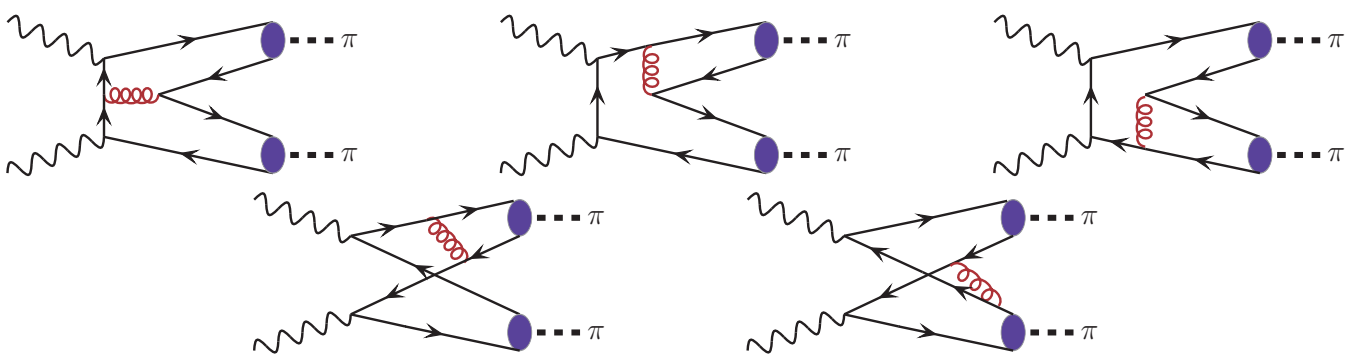
- coupling between $\pi^+\pi^-$ and $\pi^0\pi^0$ channels



s-channel contact amplitude

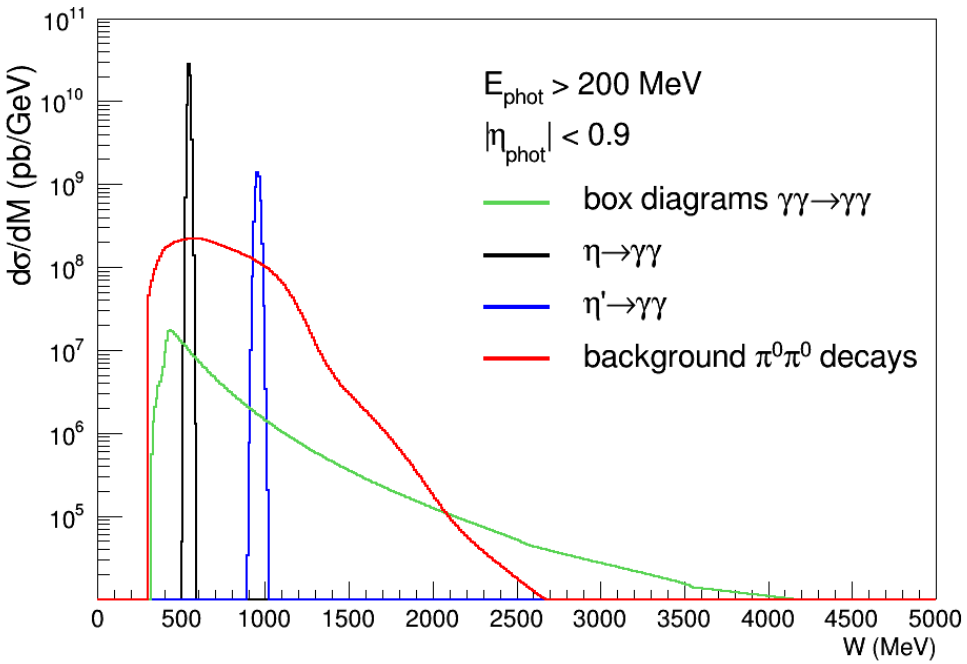
t-channel contact amplitude

- Perturbative mechanisms, leading order



Background from π^0, π^0 decays

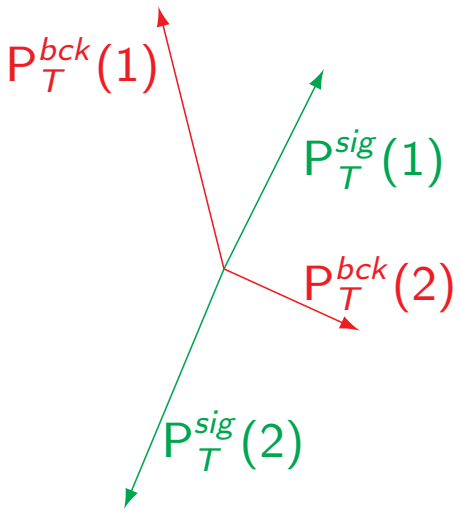
- Cross section $\pi^0\pi^0$-production in ultraperipheral heavy-ion reactions
  $\sigma^{EPA}_{PbPb\to PbPb\pi^0\pi^0} = \int\int dn^1_\gamma \; dn^2_\gamma \; \sigma_{\gamma\gamma\to\pi^0\pi^0}(\omega_1\,\omega_2)$
- The $\pi^0\pi^0$-channel contributes to background when only two of the four decay photons are in experimental acceptance, with the other two photons outside of acceptance

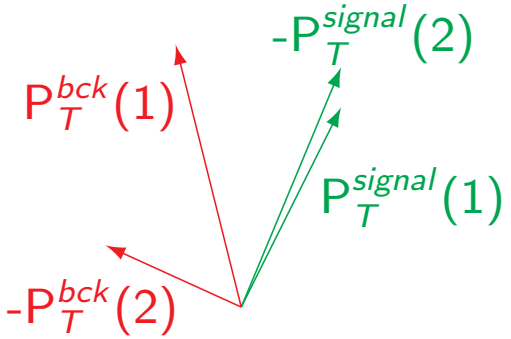


- Contributions to photon-photon invariant mass spectrum
- Resonance mass width due to energy resolution of photon measurement $\sigma_E/E = 0.02$.

Kinematics of background photon pairs

- transverse momenta photon pairs of signal and background
- photons opposite in $p_T(1)$,$p_T(2)$ are aligned in $p_T(1)$,-$p_T(2)$



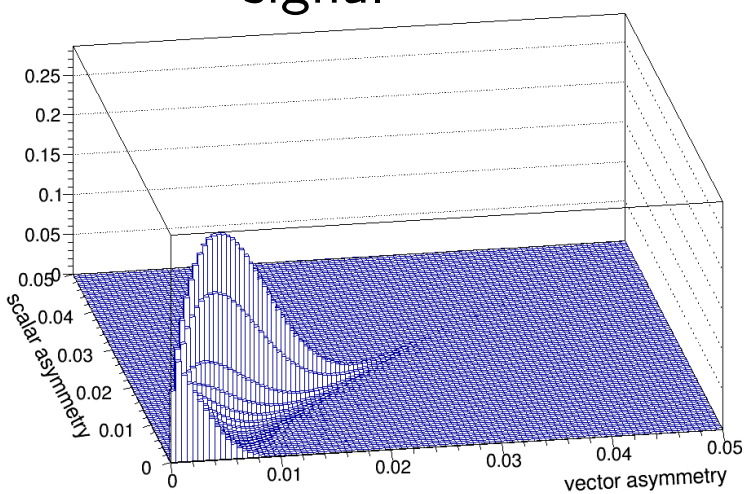


- scalar asym. $A_S = \left| \frac{|\vec{p}_T(1)| - |\vec{p}_T(2)|}{|\vec{p}_T(1)| + |\vec{p}_T(2)|} \right|$, $A_S^{signal} \neq 0$ due to energy res.
- vector asym. $A_V = \frac{|\vec{p}_T(1) - \vec{p}_T(2)|}{|\vec{p}_T(1) + \vec{p}_T(2)|}$, $A_V^{signal} \neq 0$, azim. angle res.
- $A_V > A_S$

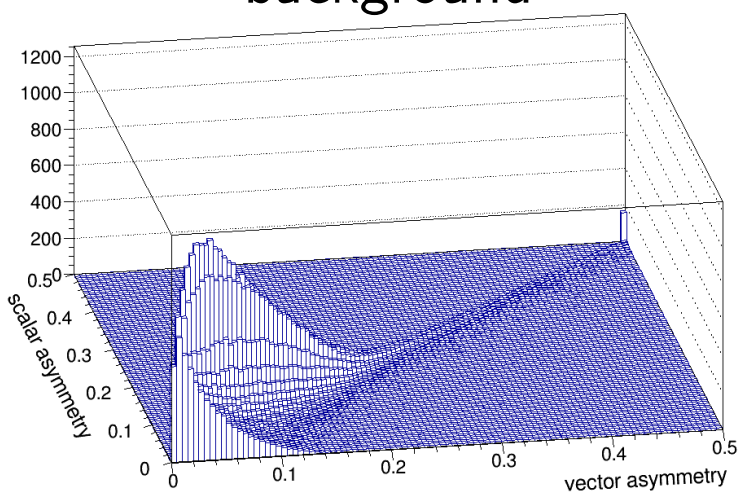
Asymmetries of signal and background

- 2-dim repr. vector vs scalar asym. of signal and background
- energy resol. $\sigma_E/E = 0.02$, azim. angle resol. $\sigma_\phi = 0.02$

signal



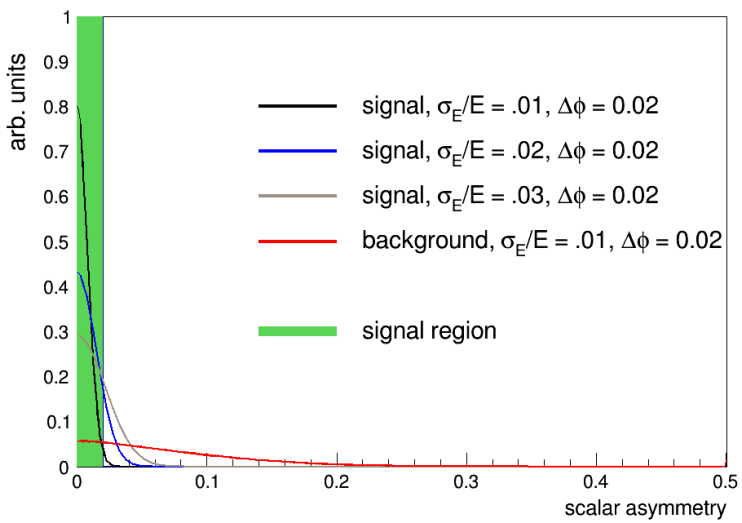
background

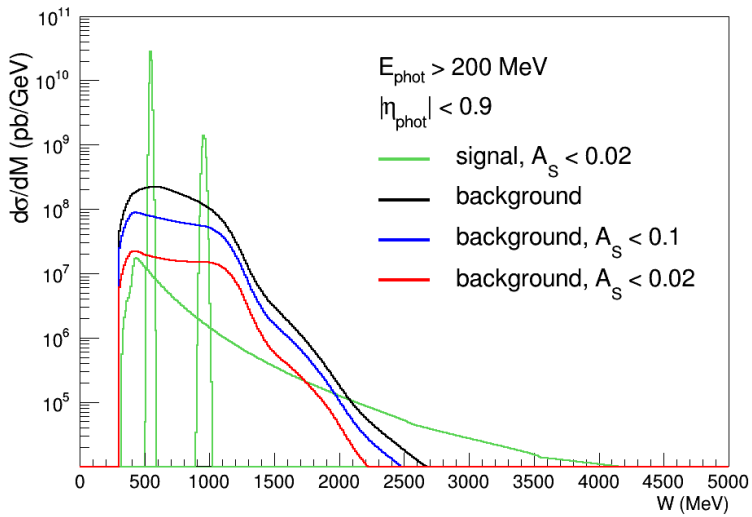


- if resolution dominated by energy resolution, then $A_V \sim A_S$
- consider only A_S in the rest of this analysis

Scalar asymmetry of signal and background

- scalar asym. signal and bck
- signal: region A_S <0.02, eff. ∼90% for σ_E/E=0.02
- inv. mass spectrum signal
- inv. mass spectra bck, for A_s <0.1 and A_s <0.02

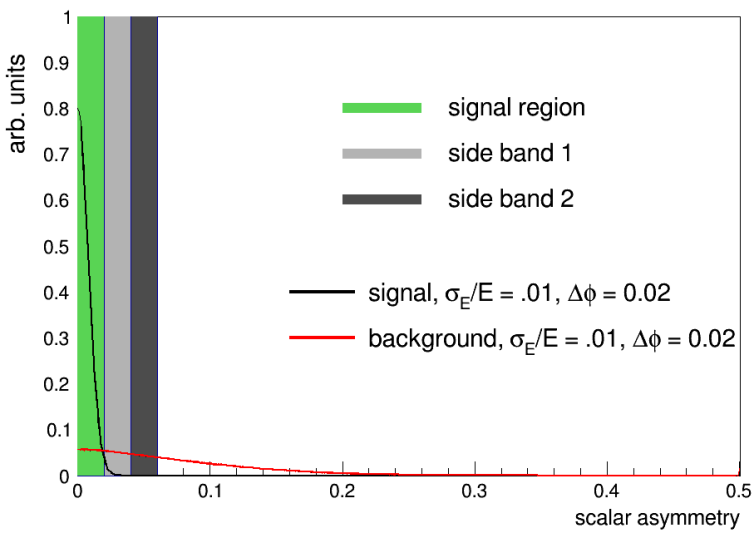


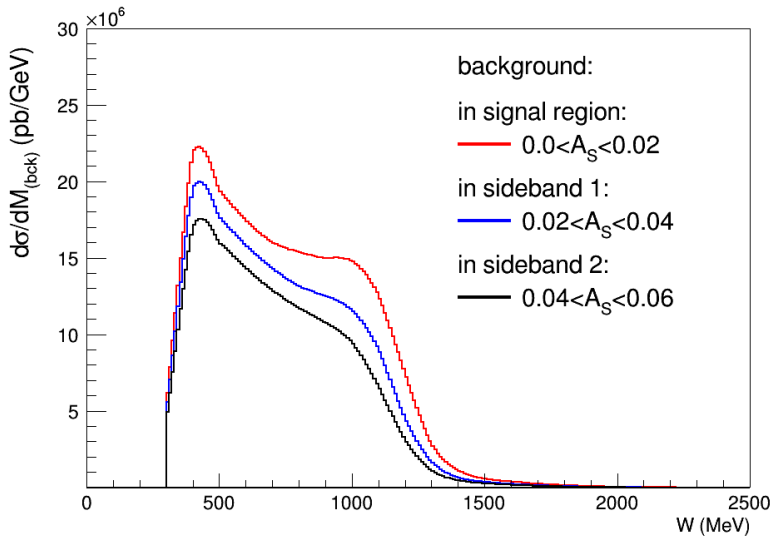


- background reduction by ∼10 when applying A_s <0.02 cut.

Background comparison to asymmetry sidebands

- define signal and sideband regions
  - signal region: $0.0 < A_S < 0.02$
  - sideband 1: $0.02 < A_S < 0.04$
  - sideband 2: $0.04 < A_S < 0.06$



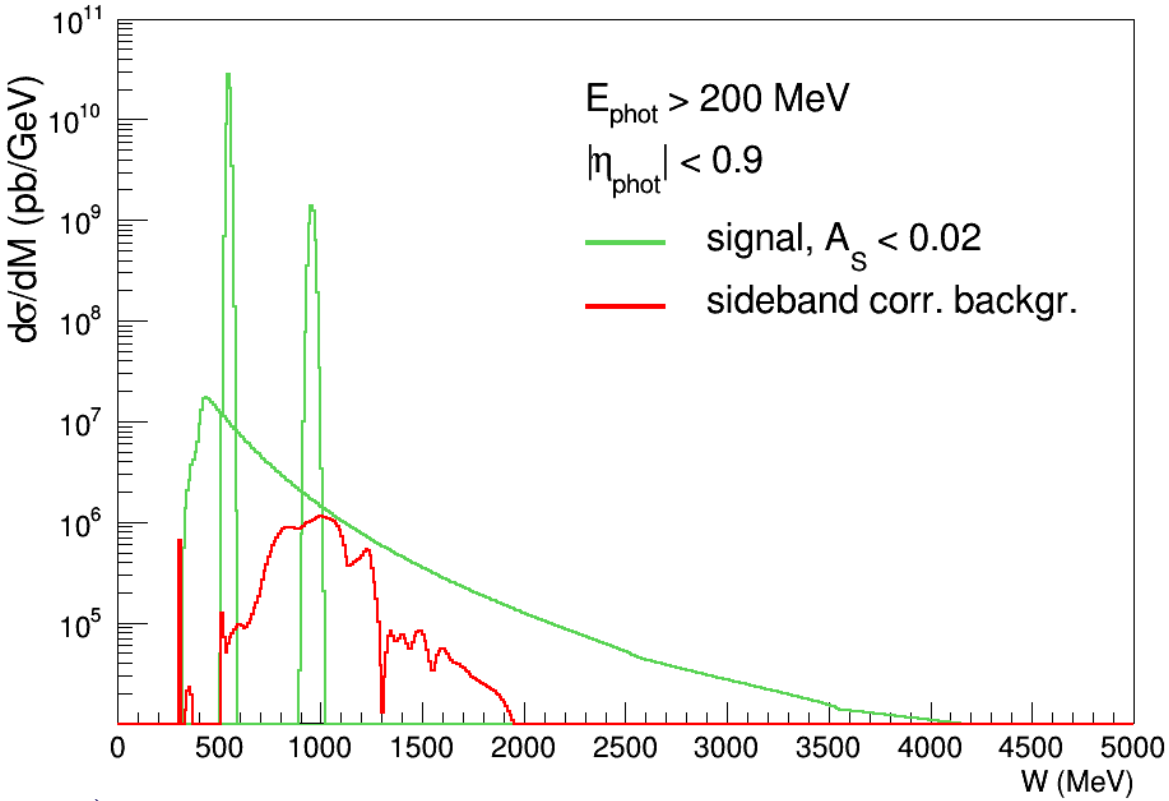


- asymmetry correlates with the background cross section and the maximum in background mass distribution
- additional background suppression possible

Background correction by sideband subtraction

- Estimate the background in signal region by linear extrapolation of sideband 1 and 2

  $d\sigma_{bck}^{signal}/dM = d\sigma_{bck}^{sideband1}/dM + \Delta(d\sigma_{bck}^{sideband1,sideband2}/dM) =$
  $d\sigma_{bck}^{signal}/dM = 2. * d\sigma_{bck}^{sideband1}/dM - d\sigma_{bck}^{sideband2}/dM)$
- Contributions to photon-photon invariant mass spectrum:



Conclusions, Outlook

- Elementary cross section for photon-photon scattering for energies W $>$ 400 MeV
- Photoproduction cross section for pseudoscalar resonances $\eta, \eta^{'}$
- Photon-photon scattering for energies W $>$ 400 MeV in ultraperipheral PbPb-collisions at LHC energies
- Photoproduction cross section for $\pi^0\pi^0$-pairs in ultraperipheral PbPb-collisions at LHC energies
- Background contribution of $\pi^0\pi^0$-decays
- Background reduction by asymmetry cuts and sideband correction
- to do:
  - Improve sideband correction of background by correlation analysis of asymmetry and maximum in mass distribution
  - Evaluate statistics of signal for realistic detector configurations in Run III at the LHC