Simulating hard photon production with WHIZARD

LCWS2021
International Workshop on Future Linear Colliders

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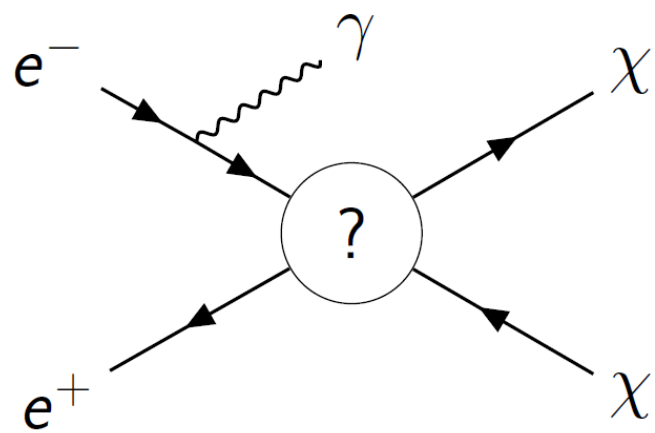
based on Eur. Phys. J. C 80 (2020) 7, 634 [arXiv:2004.14486]

Motivation

- The mono-photon signature is considered to be the most generic ways to look for DM particle production in future e^+e^- colliders



- In renormalizable theory DM can be pair produced in the e+ e− collisions via exchange of a new mediator particle, which couples to both electrons (SM) and DM states
- This process can be detected if additional hard photon radiation from the initial state is observed in the detector analogues to a monojet signature at the LHC
- Extracting useful information about BSM physics from such events will require reliable simulation of BSM signal and SM background

Simulating mono-photons at e^+e^- collider

- Whizard is the workhorse for future e+e- experiments – especially when it comes to simulating BSM processes (handling of BMS models through an UFO interface)
- To avoid systematic bias it would advantageous to treat the SM processes in the same way
- While the precision of simulating such processes in Whizard (currently only tree level, work on automatizing one-loop calculation is ongoing) is lower compared with dedicated codes like for example KKMC nevertheless for feasibility studies at future e+e- colliders
  - it might be more important to compare apples with apples than to compute only the background with highest possible precision
  - the overall QED and EW corrections are usually small (although local K-factors might be substantial)
  - we want to look at configuration which are dominated by photon emissions where the precision of even state-of-the-art codes is lower than in the case of core process with 0γ

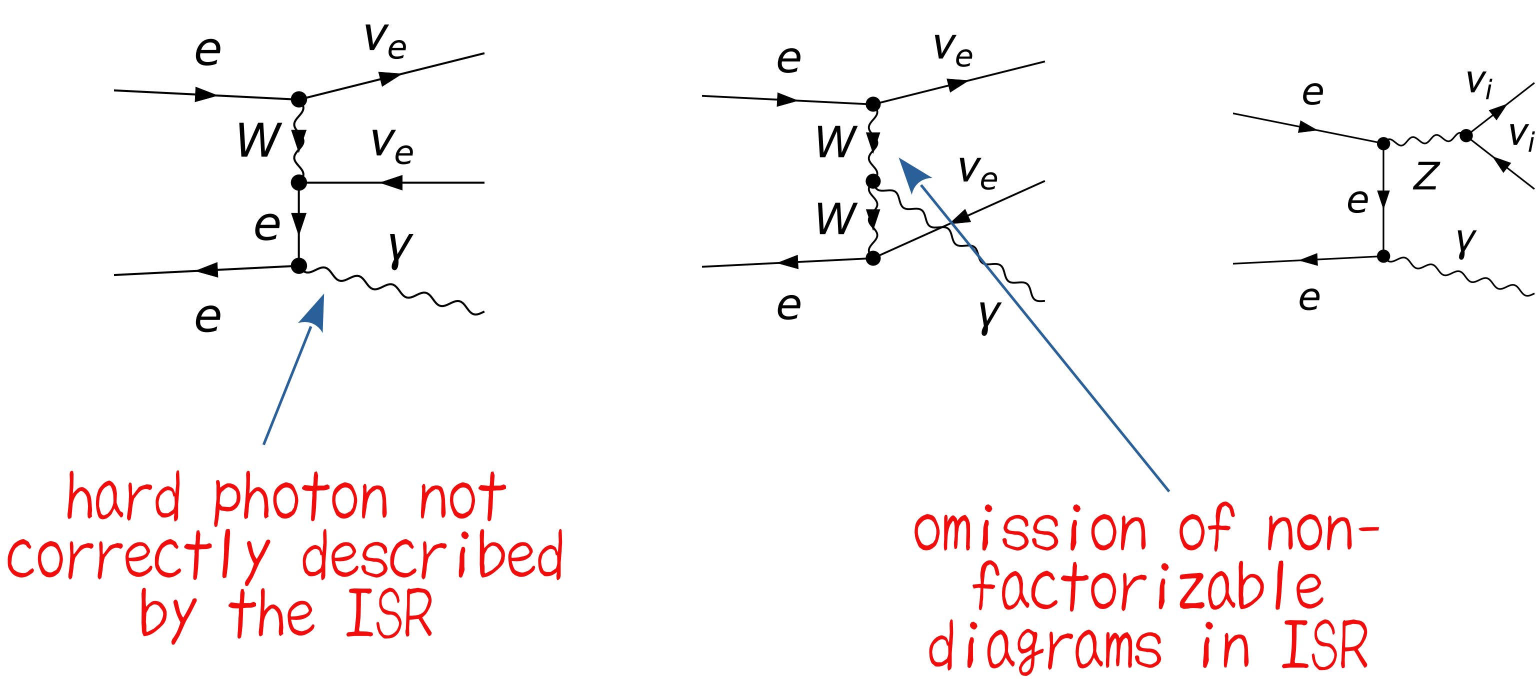
  => Whizard might be therefore a useful in simulating SM backgrounds too
- I discuss here background, for physics application check Today's Filip talk which was at 7:20 (Dark matter production via light mediator exchange at future e+e− colliders)

ISR in WHIZARD

- The standard procedure to take ISR effects into account when generating events with WHIZARD is to use the built-in lepton ISR structure function which includes all orders of soft and soft-collinear photons as well as up to the third order in high-energy collinear photons.
- This approach allows only for a proper modelling of the kinematics of the hard scattering
  - is not suitable when we expect photons to be detected in the experiment
  - ISR photons generated by WHIZARD should not be considered as ordinary final state particles. Their energy and transverse momenta correspond to the sum over all photons radiated in the event from a given lepton line.
- For proper description of the photon measurement, the hard non-collinear photon emission should be included in the generation of the considered background process on the matrix element level.

SM backgrounds to mono-photon searches

- irreducible background of $e^+e^- \longrightarrow \nu\nu + (n)\gamma$
  - same experimental signature (though possible different dependence on the polarization)
- Bhabha scattering
  - with electron and positron scattered close to the collision axis
  - the *t*-channel singularity is removed by requirement of at least one hard photon



Idea of the procedure

- Generator-level cuts can be applied, corresponding to the detector acceptance, on the final state photon(s), which should also allow to remove divergences in the cross section calculations.
- Pure-ME calculation also inadequate: strong dependence on the regulator of IR divergences => the solution is to combine ME calculation with build in ISR
- To avoid double-counting, a dedicated merging procedure is then used to remove events with photons from ISR structure function emitted in the same kinematic region.
- This is similar in spirit (though much less sophisticated) to the merging/matching techniques know from pp colliders

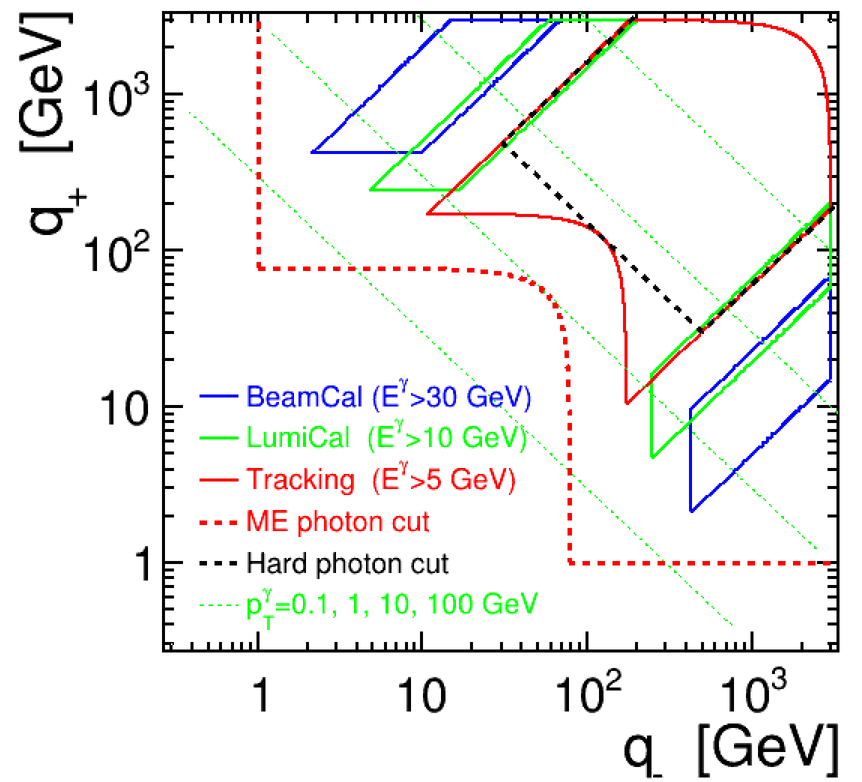
Technical details

- Introduce variable

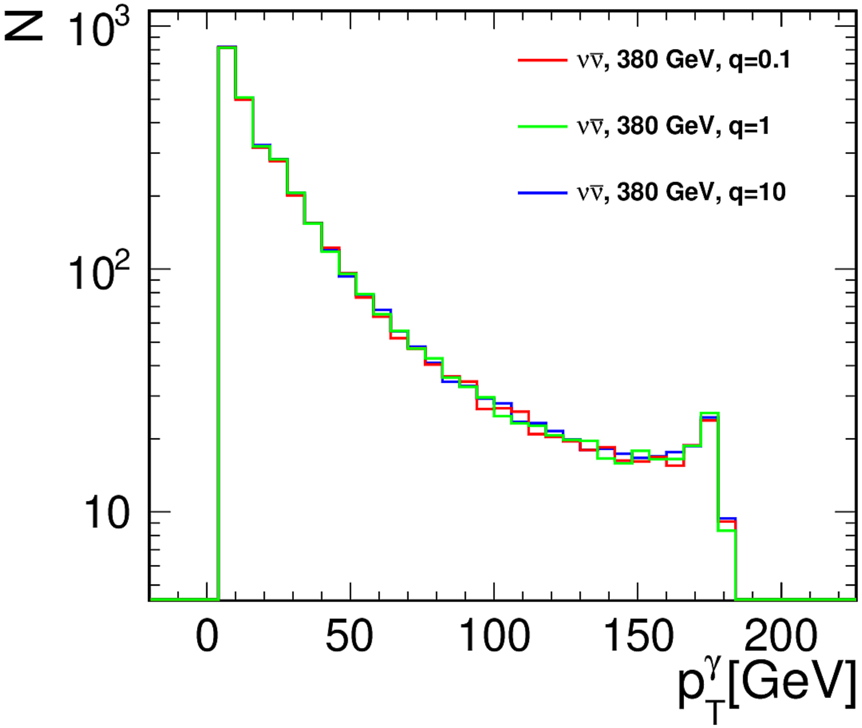
$$q_- = \sqrt{4E_0E_\gamma} \sin\frac{\theta_\gamma}{2}$$
$$q_+ = \sqrt{4E_0E_\gamma} \cos\frac{\theta_\gamma}{2}$$

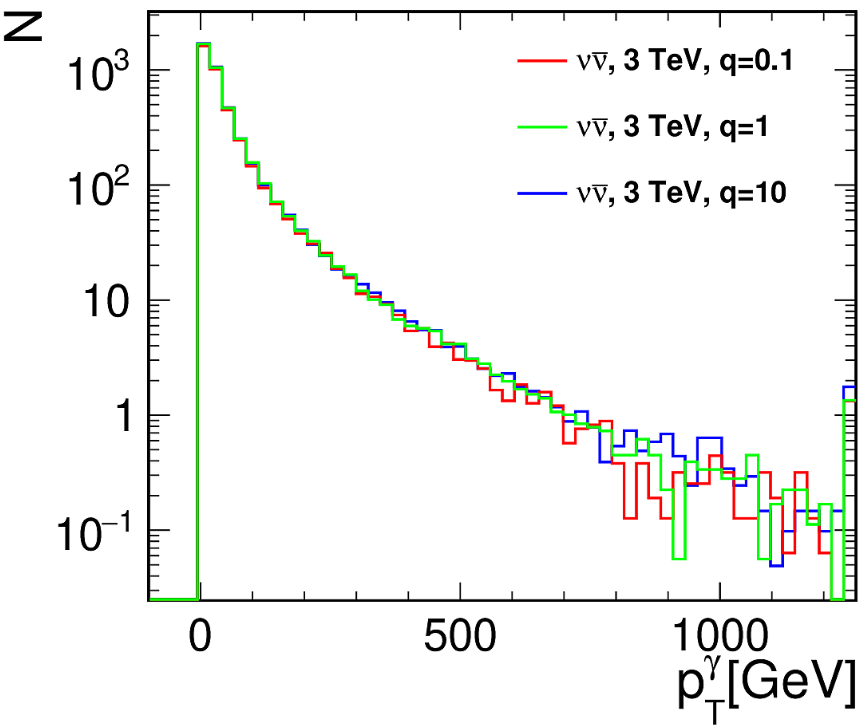
  equivalent to description via (E_γ, θ_γ)
- Used do separate soft and/or collinear region for the region described by matrix element
- Generation: 1, 2 or 3 ME photons nonradiative events for signal only (for normalisation)
- all ME photons with $q_\pm$ > 1 GeV & E_γ > 1 GeV
- rejected are events with $q_\pm$ > 1 GeV & E_γ > 1 GeV for any of the ISR photons

detectro acceptance in $q_\pm$ variable at sqrt(s)=3 TeV

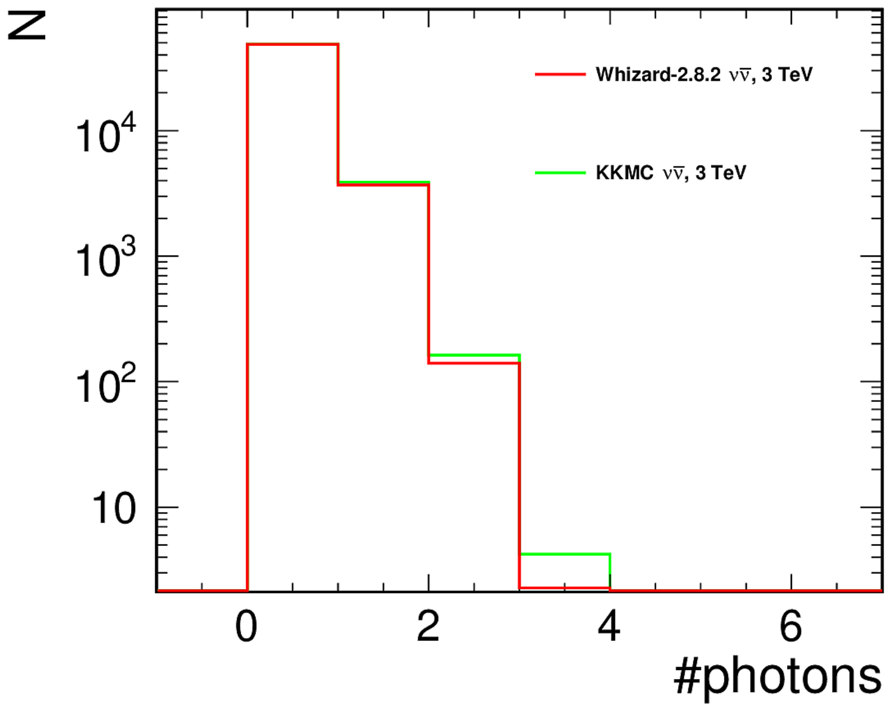


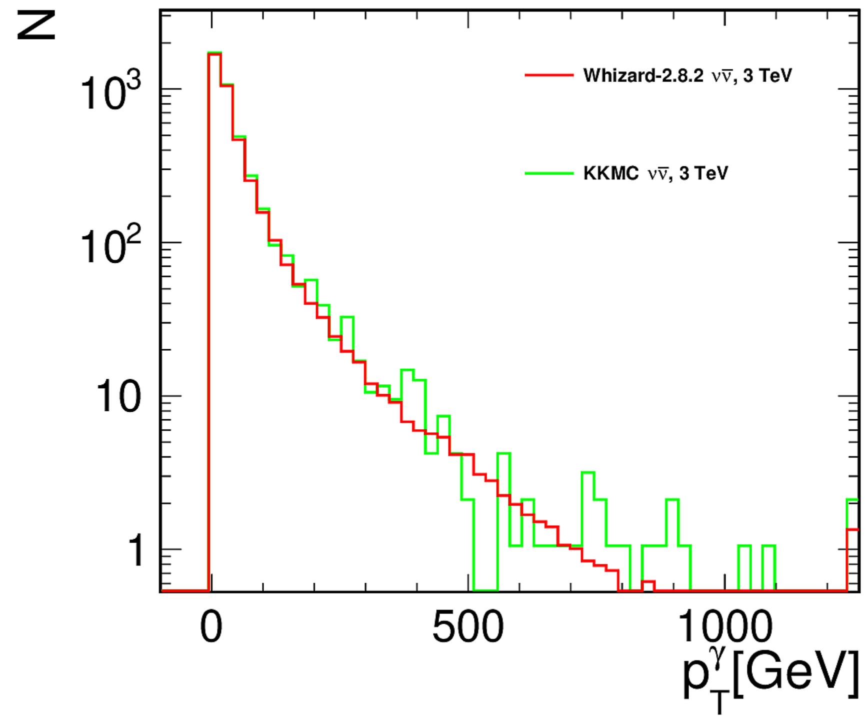
Consistency check for $e^+e^- \rightarrow \nu\nu+(n)\gamma$



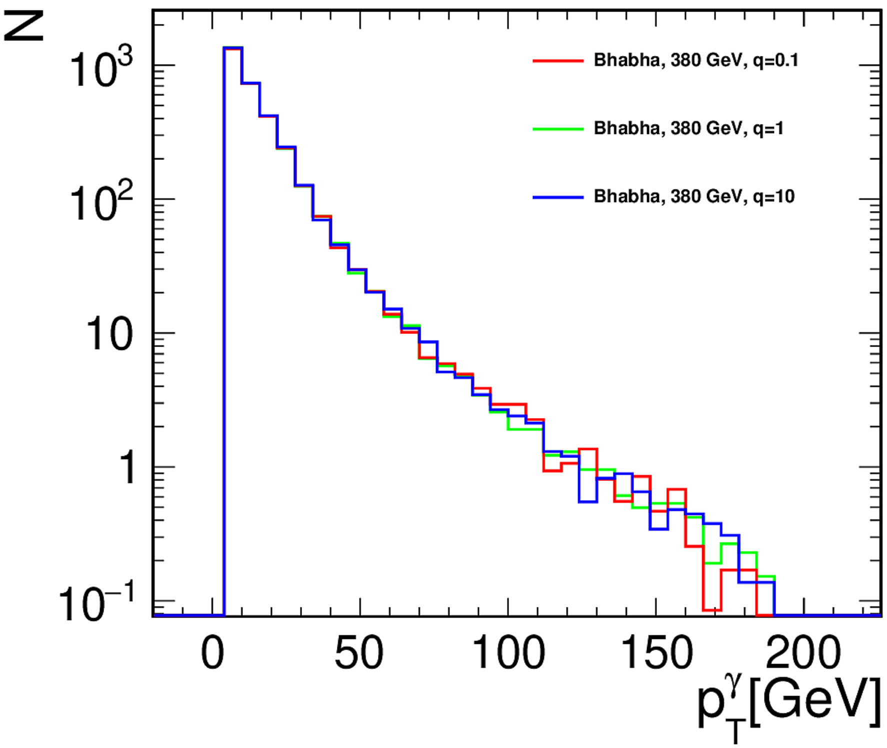


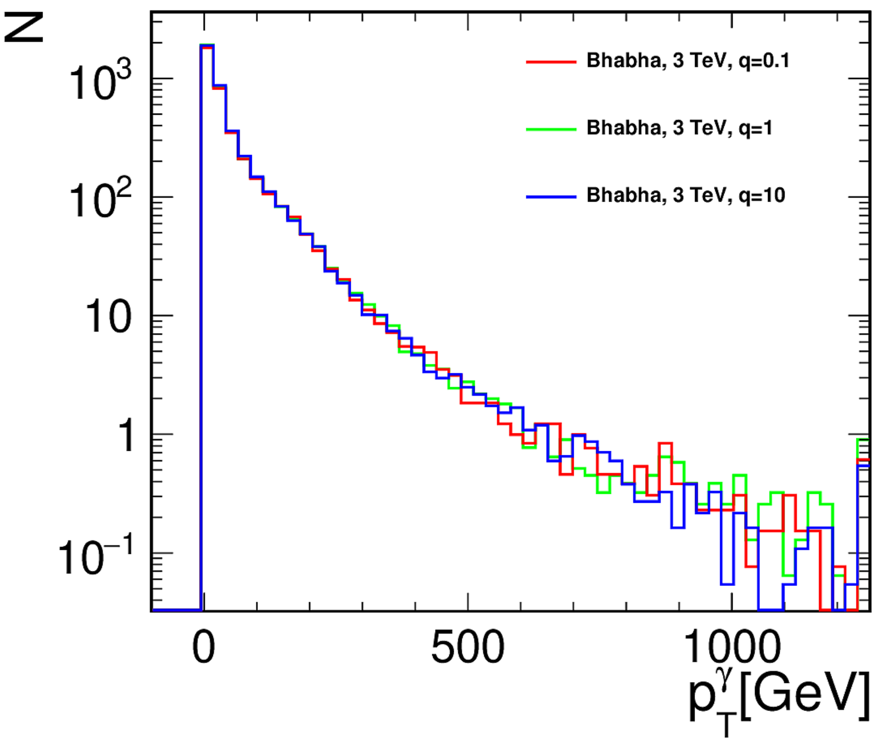
Comparison with KKMC





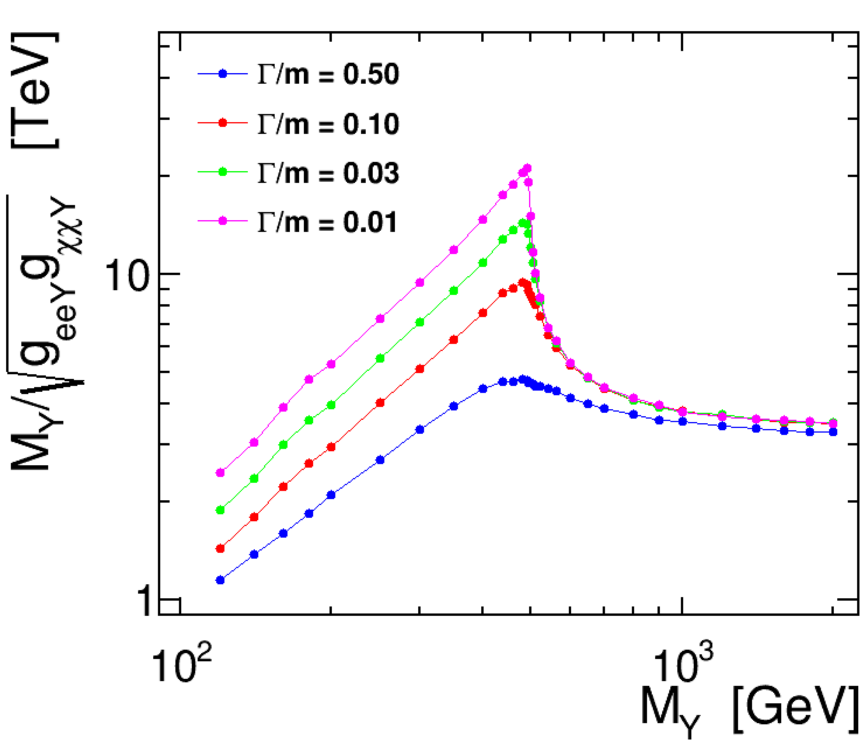
Consistency check for Bhabha scattering

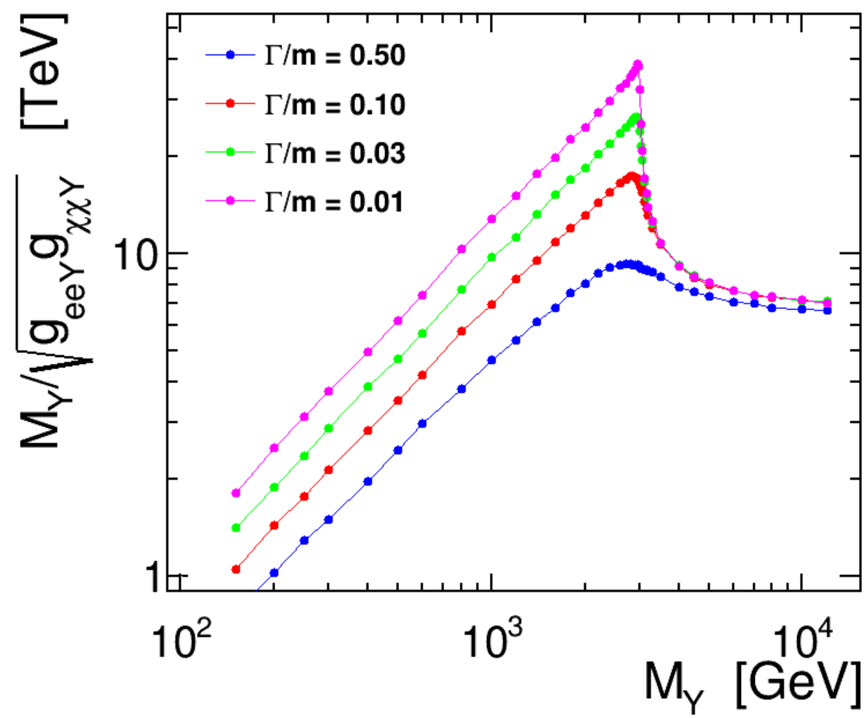




Application

- Described procedure is an essential tool in estimating discovery reach of ILC and CLIC for various DM models
- Example from Filip's talk from the morning session: ILC and CLIC reaches for the case of fermion DM χ with a scalar mediator Y





for M_Y>>sqrt(s) this corresponds to a limit on EFT scale Λ

Conclusions

- Proposed merging procedure allows to treat two main SM backgrounds for mono-photon events on equal footing with the signal
- Reliable simulation of the mono-photons in Whizard was demonstrated
- The same procedure can be applied for polarised beams
- Results checked against KKMC generator for neutrino pairs
- Our procedure is already being used by others (arxiv:2103.06006)

Thanks!