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Simulating hard photon production with WHIZARD

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Outline

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- Motivation
- Simulating mono-photon events with WHIZARD

  More details in: Eur. Phys. J. C (2020) 80: 634

- Prospects on future use

Motivation

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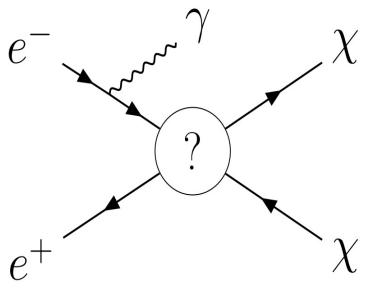
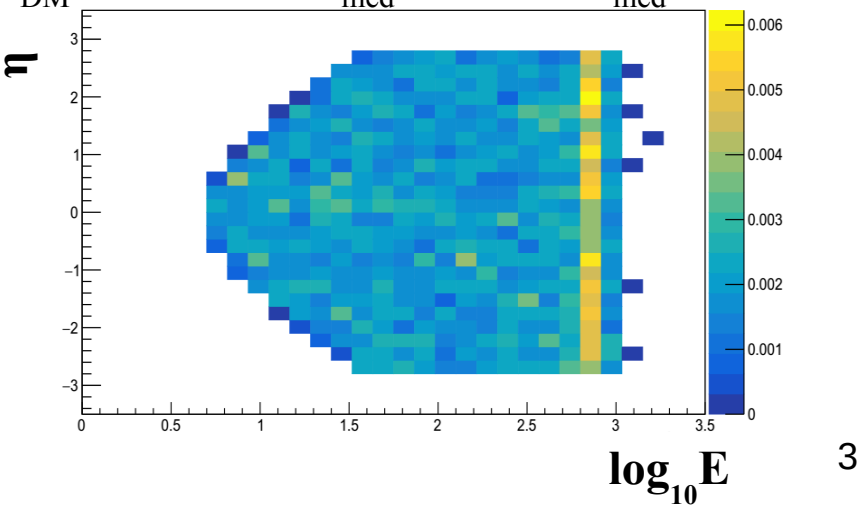
- Many models consider direct DM production in e^+e^-
- Experimental-like approch
  - Set limits on cross section as a function of mediator mass&width
- Realistic background description needed
  - The same procedure for handling the signal and background



M_{DM}=50GeV M_{med}=2TeV Γ_{med}=50GeV



Motivation

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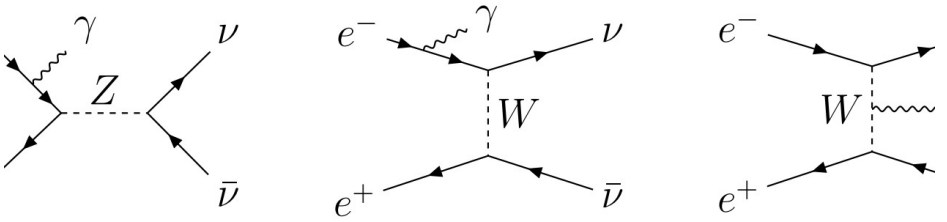
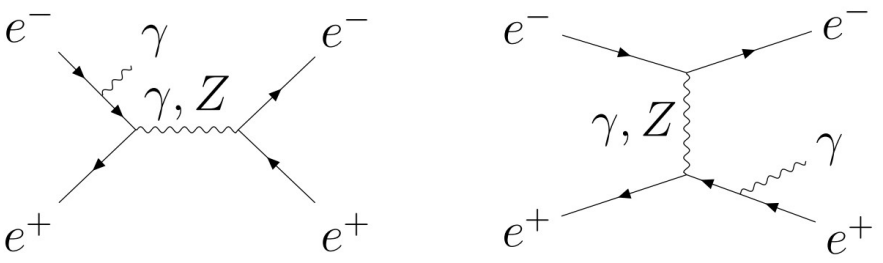
- Main backgrounds of mono-photon type of analysis: **neutrino production** and **Bhabha**
- One would like to measure **matrix elements photons (γ^{ME})** and keep soft photon emission parametrization **(ISR photons, γ^{ISR})**
  - **Issue to be solved: how to avoid double counting of γ^{ISR} and γ^{ME}**

$e^+e^- \to \nu\bar{\nu}$



- **Outcome: procedure general enough for any BSM searches with neutrino and Bhabha mono-photon events**
  - **NOTE: WHIZARD ISR structure functions do not describe t-channel W radiation events**

$e^+e^- \to e^+e^-$



Simulating mono-photon events with WHIZARD

WHIZARD mono-photons

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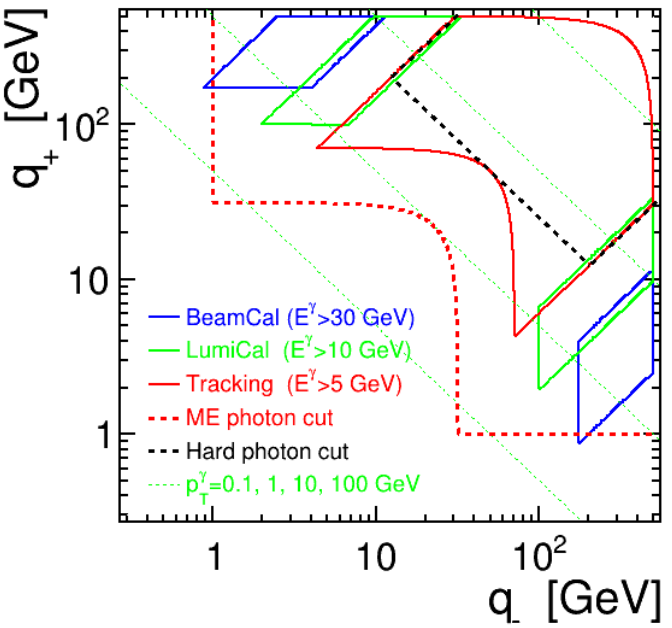
- **Lets define variables q^+ and q^- calculated for each photon in the event. e^-/e^+ fixed as beam energies:**

$$q_- = 2\sqrt{(E_{e_-} E_\gamma)}\sin(\frac{\theta_\gamma}{2})$$

$$q_+ = 2\sqrt{(E_{e_+} E_\gamma)}\cos(\frac{\theta_\gamma}{2})$$

- **Merging would be done for energy E^{min} and q^{min} : generated γ^{ME} should have q^+ and q^- above q^{min} and energy above E^{min}**
- **ISR photons accepted only below given E^{min} and q^{min} values**
- **Additional 'hard photon' selection: events with at least one γ having pT > 5 GeV and 7° < θ < 173°**



q^+/q^- phase space for √s of 500 GeV
(more cases in backup)

Merging ISR and γ^{ME}

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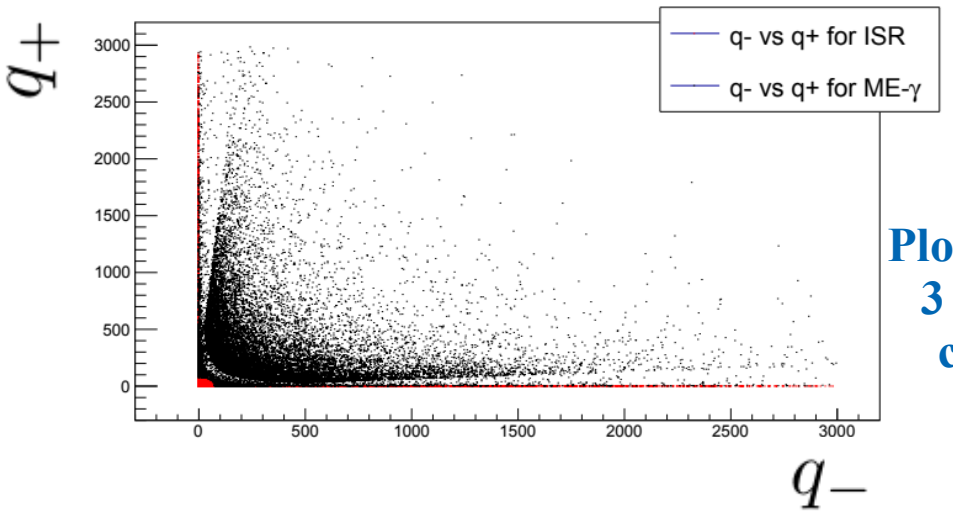
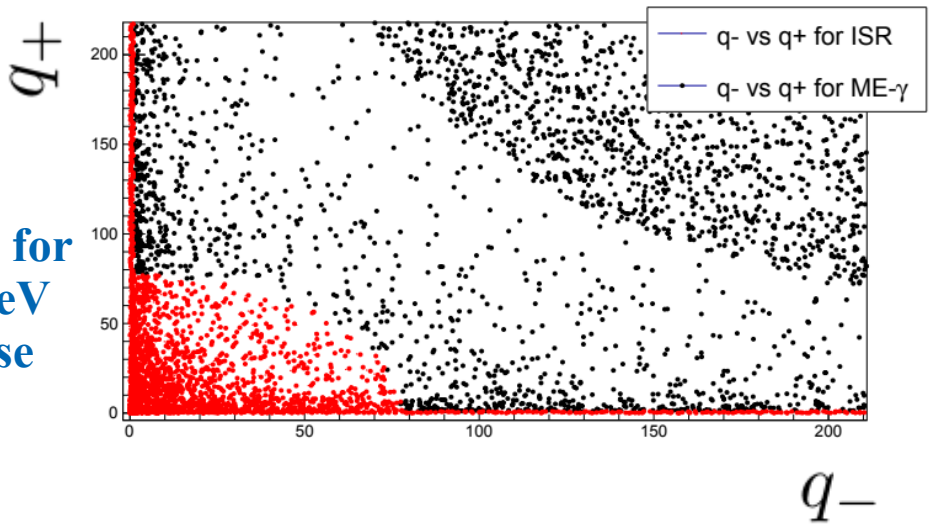
Neutrino sample



Zoom



Plots for 3 TeV case

Selection: 'hard photons'

Red – γ ISR
Black - γ^{ME}

$q^{merge} = 1$ GeV

Neutrino sample

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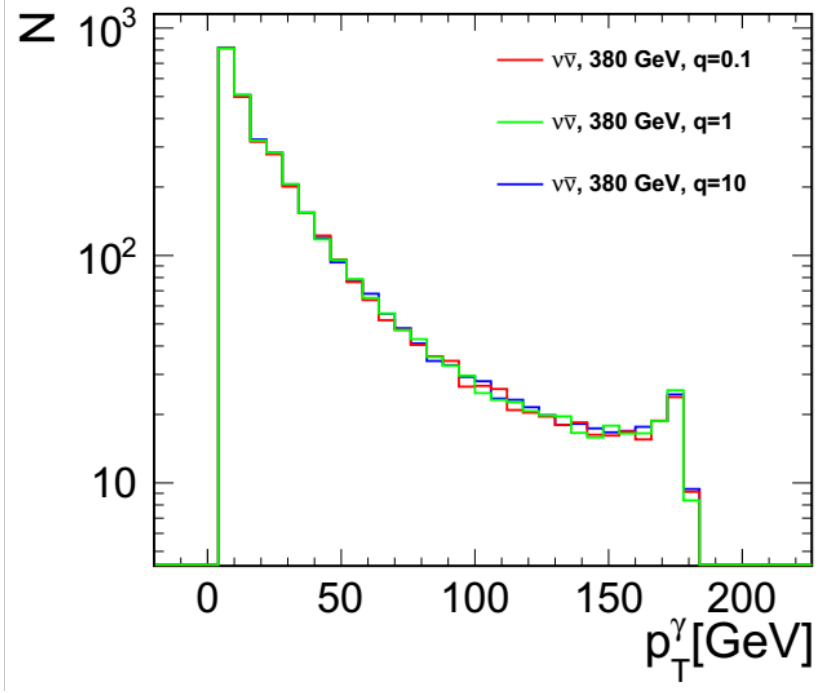
$e^+e^- \rightarrow \nu\bar{\nu} + N\gamma$



Impact of q_{min} cut on cross section calculation: stable

$\sqrt{s}$[GeV]	q_{min}[GeV]	Whizard-2.8 $\sigma(e^+e^- \rightarrow \nu\bar{\nu})$ [fb]				$\sigma(e^+e^- \rightarrow \nu\bar{\nu})$ [fb] after ISR rejection
		$\nu\bar{\nu}$	$\nu\bar{\nu}+\gamma_{ME}$	$\nu\bar{\nu}+2\gamma_{ME}$	$\nu\bar{\nu}+3\gamma_{ME}$	
380	q_{min}=0.1	50900	16500	2600	220	50000
	q_{min}=0.5		12600	1600	110	50400
	q_{min}=1		10900	1200	55	50600
	q_{min}=5		7000	480	15	50700
	q_{min}=10		5300	270	7	50800

With 'hard photon' selection:

$\sqrt{s}$[GeV]	q_{min}[GeV]	Whizard-2.8 $\sigma(e^+e^- \rightarrow \nu\bar{\nu})$ [fb]			$\sigma(e^+e^- \rightarrow \nu\bar{\nu})$ [fb] after ISR rejection
		$\nu\bar{\nu}+\gamma_{ME}$	$\nu\bar{\nu}+2\gamma_{ME}$	$\nu\bar{\nu}+3\gamma_{ME}$	
380	q_{min}=0.1	3200	910	120	3000
	q_{min}=0.5	3200	670	55	3000
	q_{min}=1	3200	570	43	3100
	q_{min}=5	3200	340	10	3100
	q_{min}=10	3200	230	6	3100

Bhabha sample and ISR/γ^{ME} merging

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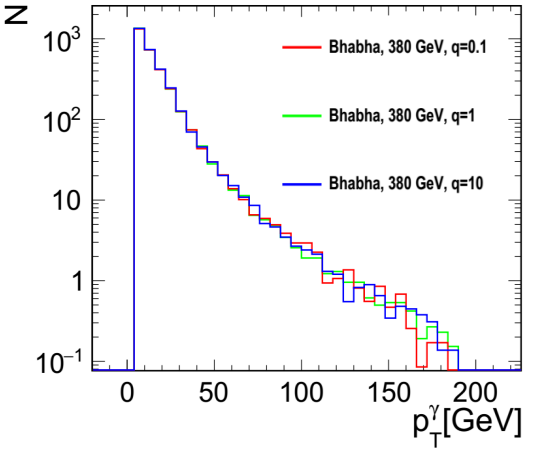
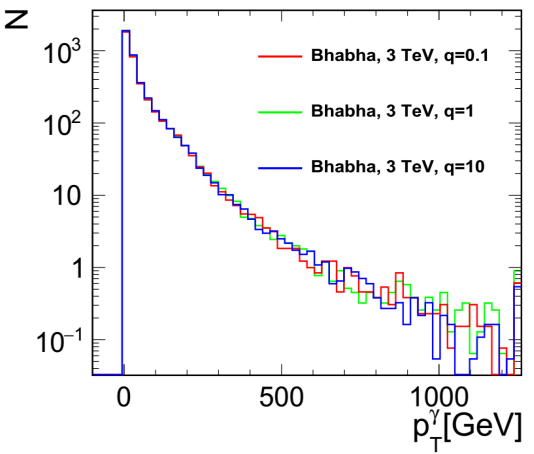
- **Comparison of pT spectra for energies of 380 GeV and 3 TeV for Bhabha background as a function of different merging parameters q^{min}**
- **Distributions show small impact on the shapes of the given spectra**
- **For further studies q^{min} value set to 1 GeV**





$\nu\bar{\nu}$ sample: WHIZARD vs KKMC

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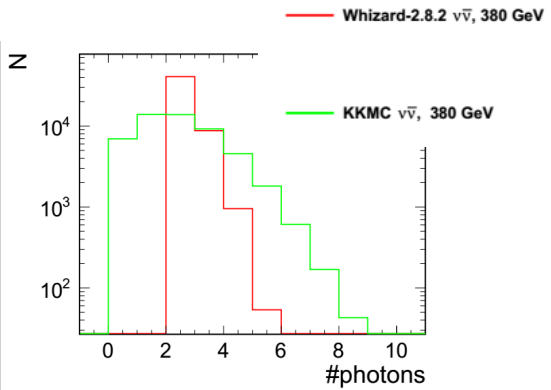
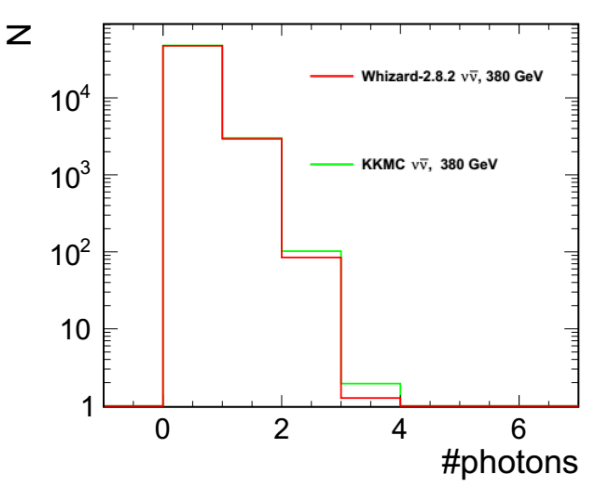
Comparison of WHIZARD and KKMC generators for neutrino sample at √s = 380 GeV

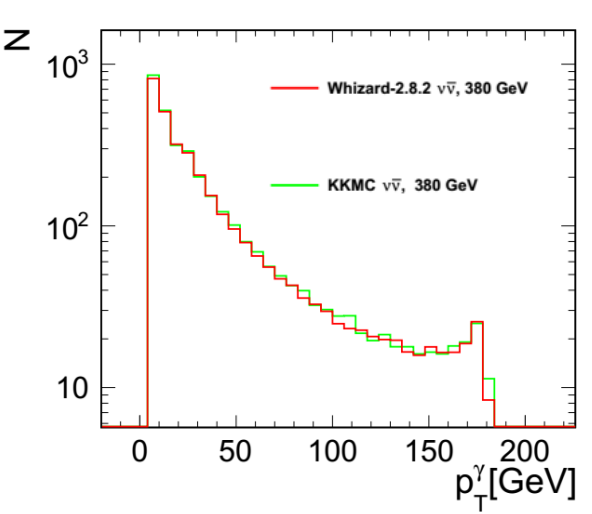
KKMC generator:
S. Jadach, B.F.L. Ward, Z. Wąs
Computer Physics Communications 130 (2000) 260–325

- Using generators with different ISR/FSR descriptions
- no photon cuts



The same 'hard photon' selection imposed:





q^{min} set to 1 GeV

Prospects on DM searches

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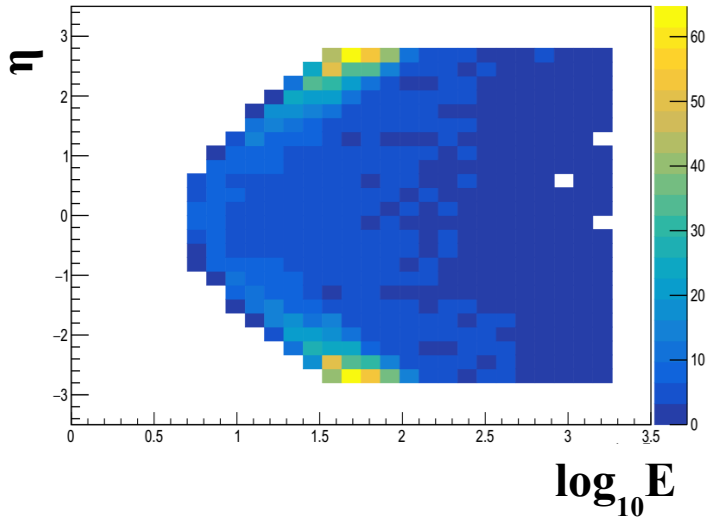
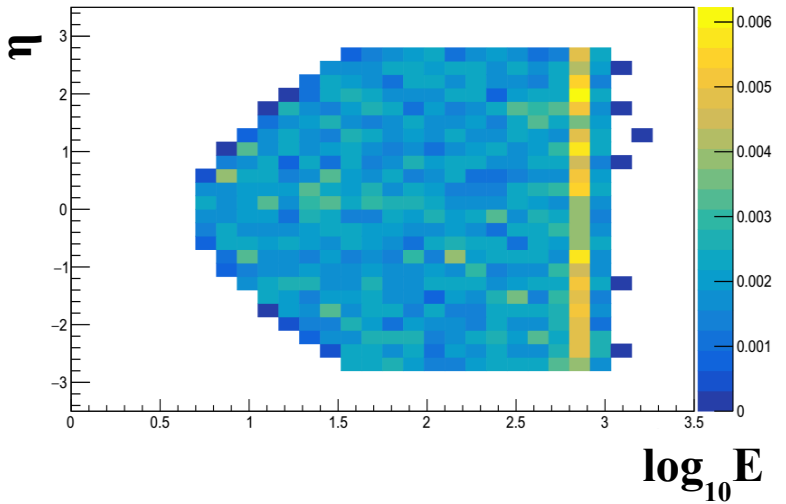
- Experimental-like approach:
  consider 2-D distribution of mono-photon event to set limits on σ

- Main backgrounds vs signal @ 3TeV CLIC
  $e^+e^- \rightarrow \nu\bar{\nu}$ + $e^+e^- \rightarrow e^+e^-$ M_{DM}=50GeV M_{med}=2TeV Γ_{med}=50GeV





Conclusions

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- **Presented merging procedure allows to treat two main backgrounds of mono-photon analysis with the same approach and obtain stable cross section calculations also for the Bhabha background. This procedure is general enough to be used for arbitrary BSM scenarios with mono-photon signature**

- **Working merging procedure allows to obtain model independent limits on Dark Matter production cross sections for different experimental setups**
  - **Only coupling structure needed**
  - **Impact of the mediator width on signal-to-background separation**

Backup

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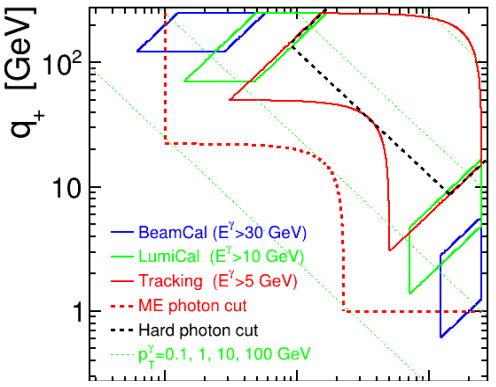
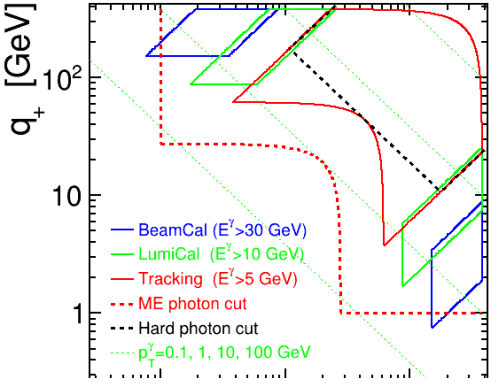
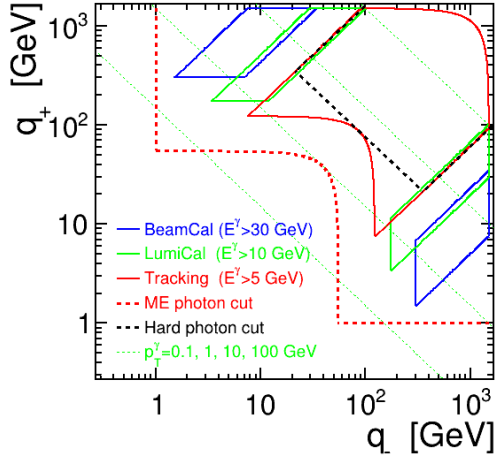
$\sqrt{s} = 250$ GeV



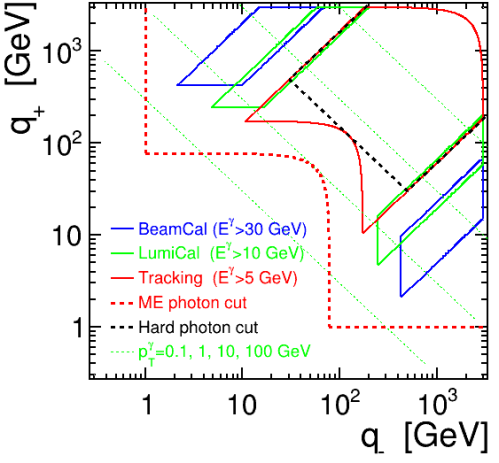
$\sqrt{s} = 380$ GeV



$\sqrt{s} = 1.5$ TeV



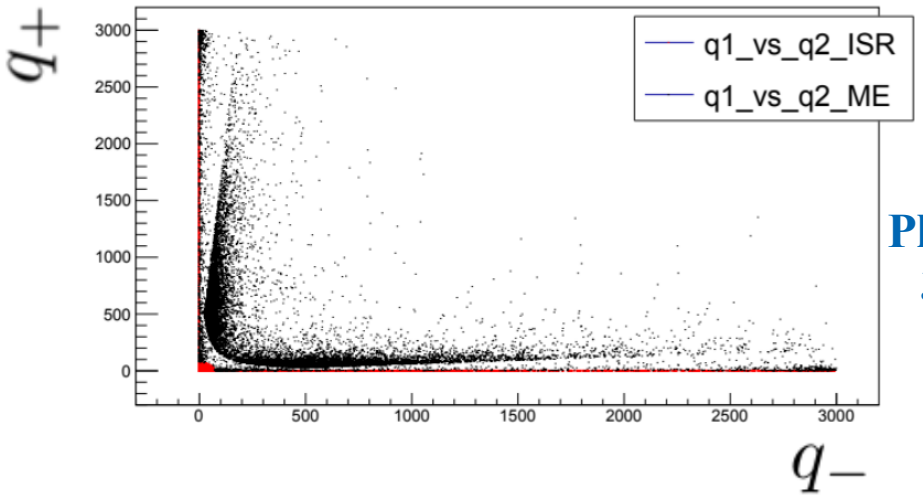
$\sqrt{s} = 3$ TeV



Merging ISR and γ^{ME} for sample with Pt > 5 GeV cut

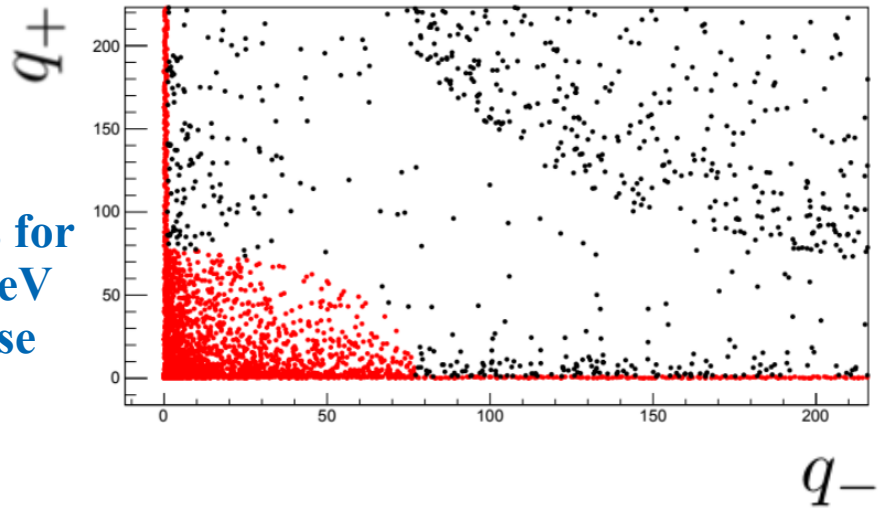
$q^{merge} = 1$ GeV

Bhabha sample



Plots for 3 TeV case

Zoom



Red – γ ISR

Black - γ^{ME}

$q^{merge} = 1$ GeV

WIHZARD mono-photons: Bhabha

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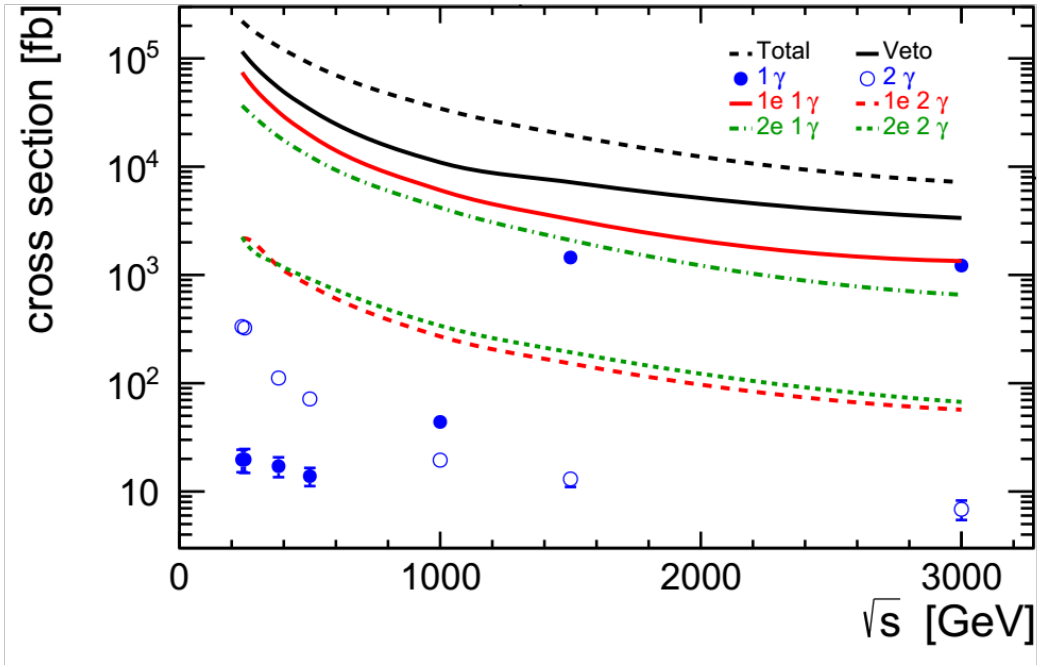

Prospects on DM searches with mono-photon signature

New approach to DM searches

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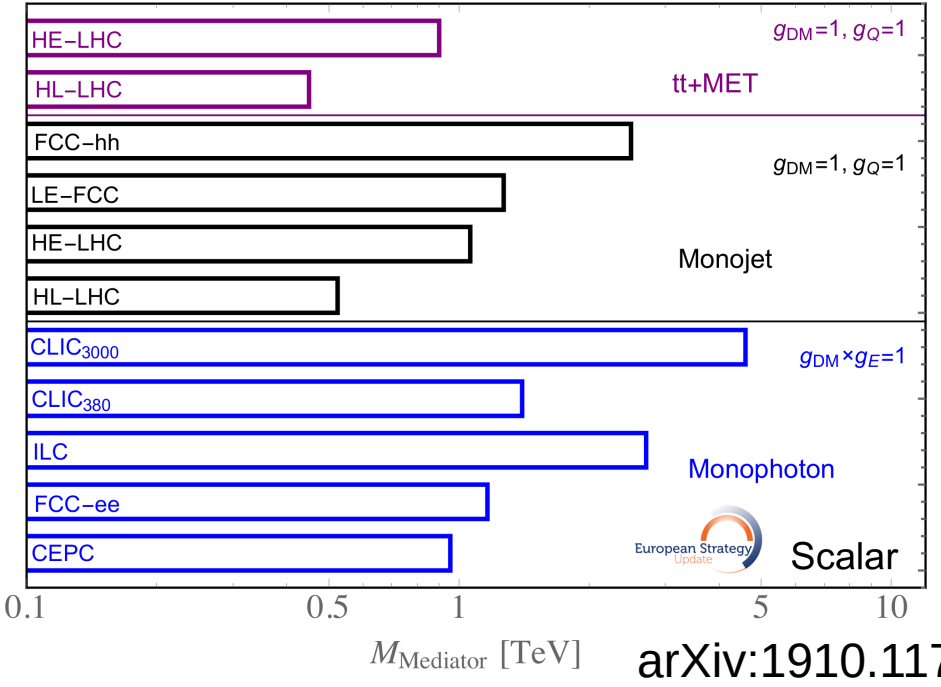
- Common approach:
  setting limits on mediator mass for given coupling structure/values

- This approach is suitable,
  if we can assume

$$M_{med} \gg \sqrt{s}$$

  but this does not need
  to be the case…

- Different approach needed
  for mediator masses ~ $\sqrt{s}$



arXiv:1910.11775

New approach to DM searches

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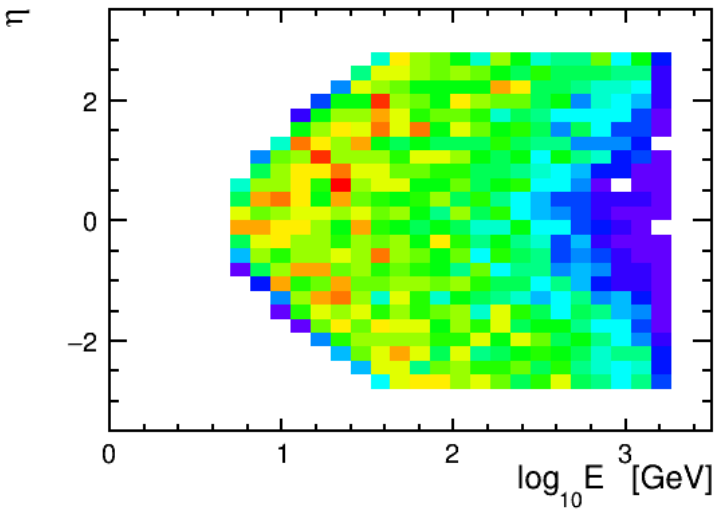
- Experimental approach:
  consider 2-D distribution of mono-photon event

- Main backgrounds (generator level cuts only) @ 3TeV CLIC:

$e^+e^- \rightarrow \nu\nu$



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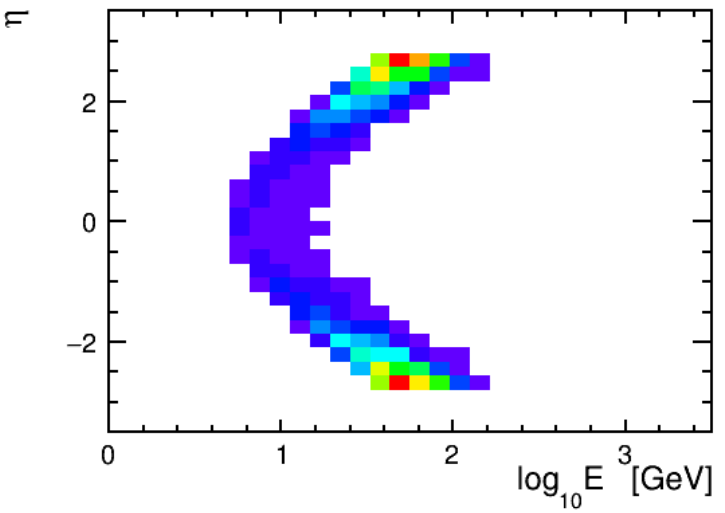

Prospects on DM searches

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- Experimental-like approach:
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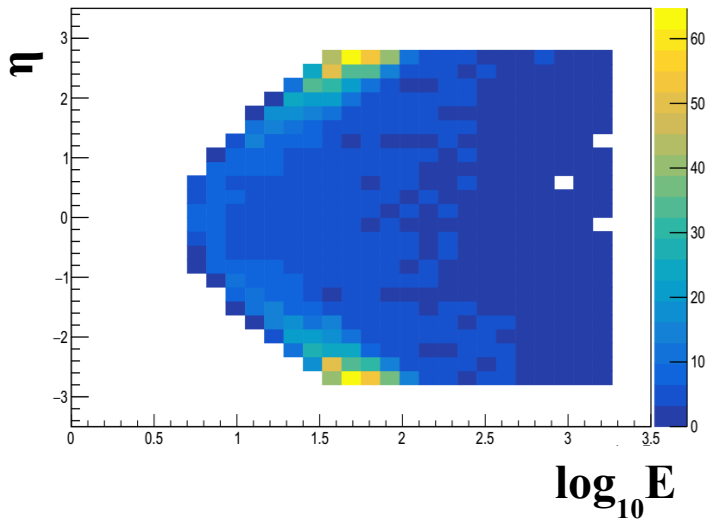

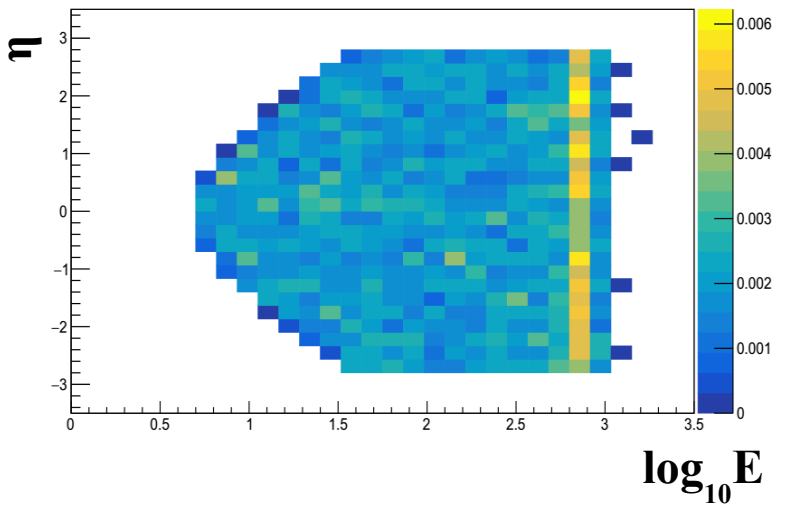

New approach to DM searches

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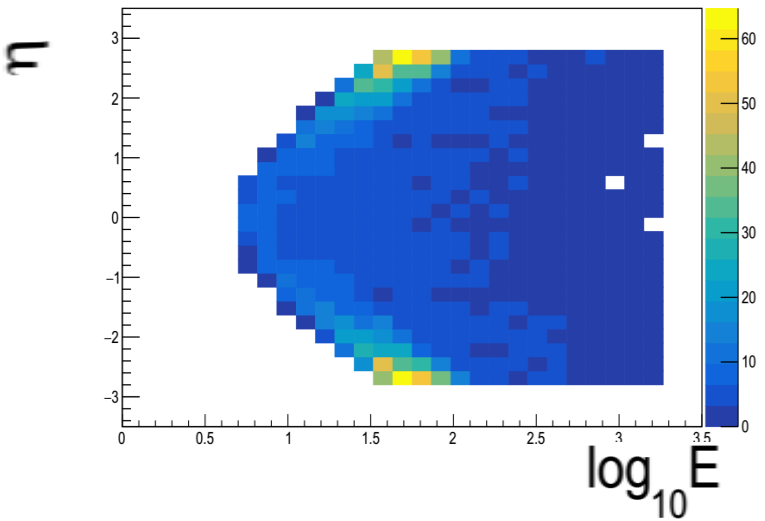

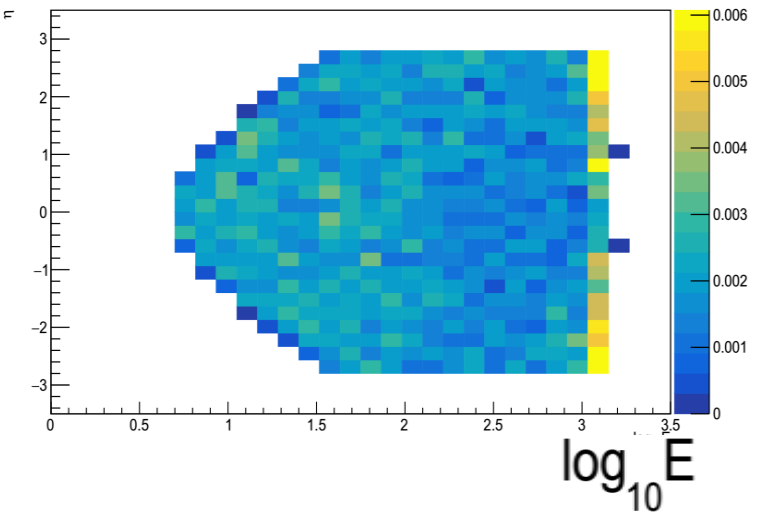

New approach to DM searches

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