New approach to DM searches with mono-photon signature

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Snowmass 2021 Energy Frontier (EF)
Preparatory Joint Sessions on "Open questions and News Ideas"
07.07.2020

Outline

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- Motivation

- Simulating mono-photon events with WHIZARD
  - new procedure for merging ISR structure function with ME
  - arXiv: 2004.14486, accepted for EPJ C (in print)

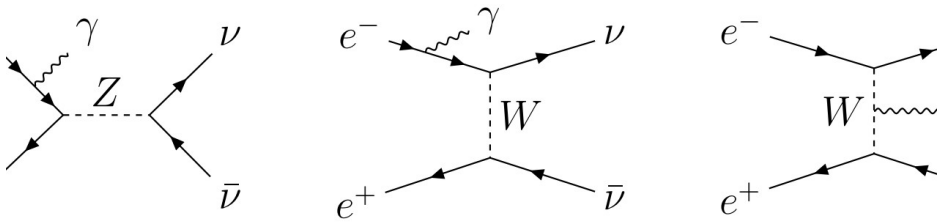
- New approach to DM searches with mono-photon signature

Motivation

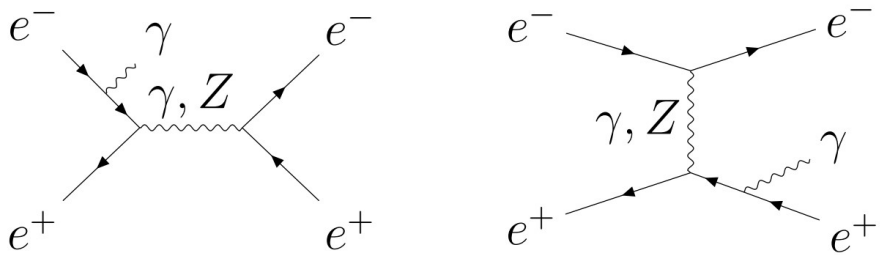
- Initial aim: preparation of background and signal samples for **Dark Matter analysis using a mono-photon signature. Following issues would need to be addressed:**
  - **To avoid double counting of photons from the ISR (γ^{ISR}) and those from matrix element (γ^{ME})**
  - **To have the same procedure for all backgrounds and DM signal,** successful generation of all processess in the first place: cutting out all of the singularities, stable cross sections calculations etc

- **Outcome: procedure general enough for any BSM searches with neutrino and Bhabha mono-photon events**
  - **NOTE: one cannot properly simulate all matrix element photons: t-channel W radiation events (mostly with high photon multiplicity) are not included in WHIZARD description of the ISR**

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



$e^+e^- \longrightarrow e^+e^-$



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Simulating mono-photon events with WHIZARD

WHIZARD mono-photons

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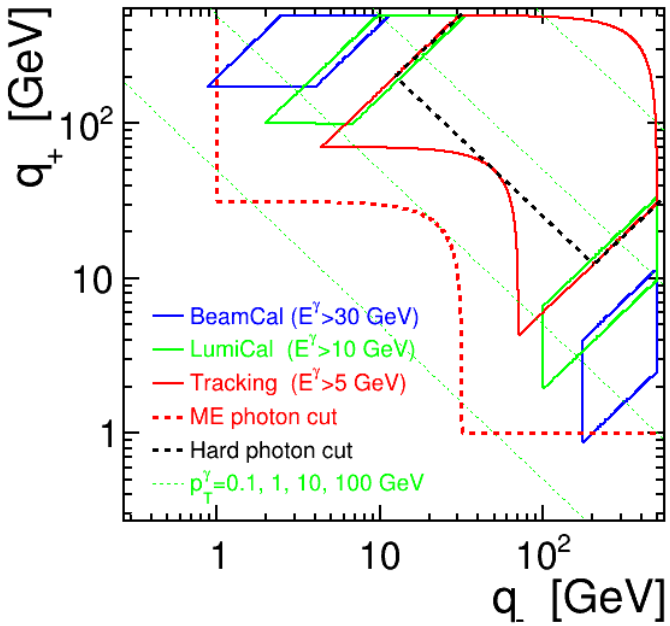
- **Lets define variables q^+ and q^- calculated for each photon in the event. e^-/e^+ fixed as beam energies:**

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

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

- **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 $7° < \theta < 173°$**



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

Neutrino sample

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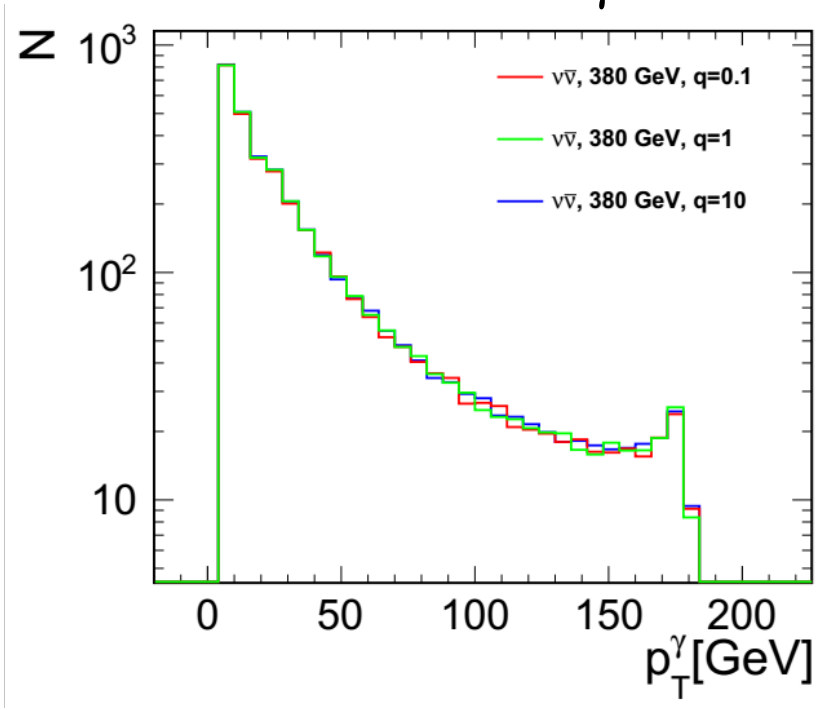
$$e^+e^- \longrightarrow \nu\bar{\nu} + N\gamma$$



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

$\sqrt{s}[GeV]$	$q_{min}[GeV]$	Whizard-2.8 $\sigma(e^+e^- \to \nu\bar{\nu})$ [fb]				$\sigma(e^+e^- \to \nu\bar{\nu})$ [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 $\sigma(e^+e^- \to \nu\bar{\nu})$ [fb]			$\sigma(e^+e^- \to \nu\bar{\nu})$ [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

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

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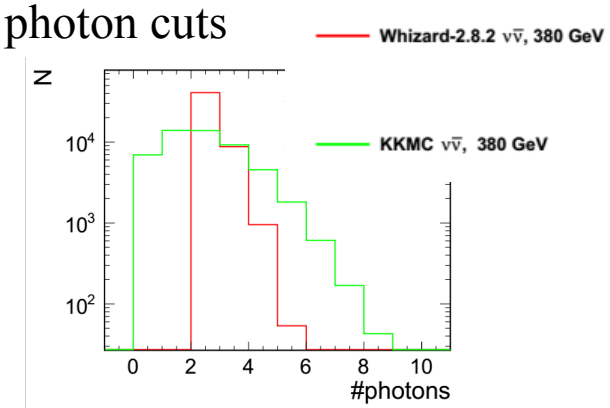
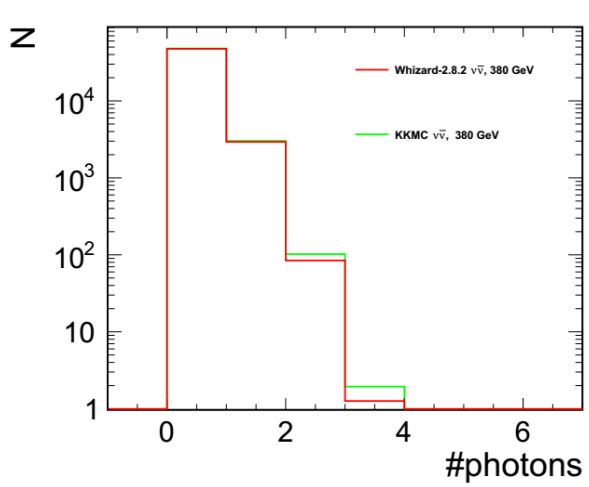
KKMC generator:
S. Jadach, B.F.L. Ward, Z. Wąs
Computer Physics Communications 130 (2000) 260–325

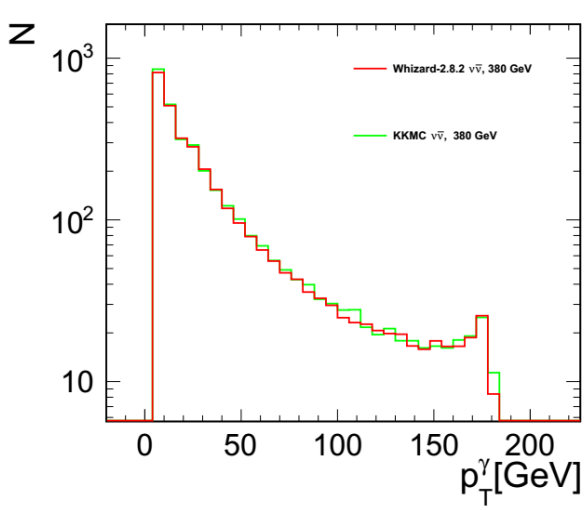
Comparison of WHIZARD and KKMC generators for neutrino sample at √s = 380 GeV

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



The same 'hard photon' selection imposed:





q^{min} set to 1 GeV

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New approach to DM searches with mono-photon signature

New approach to DM searches

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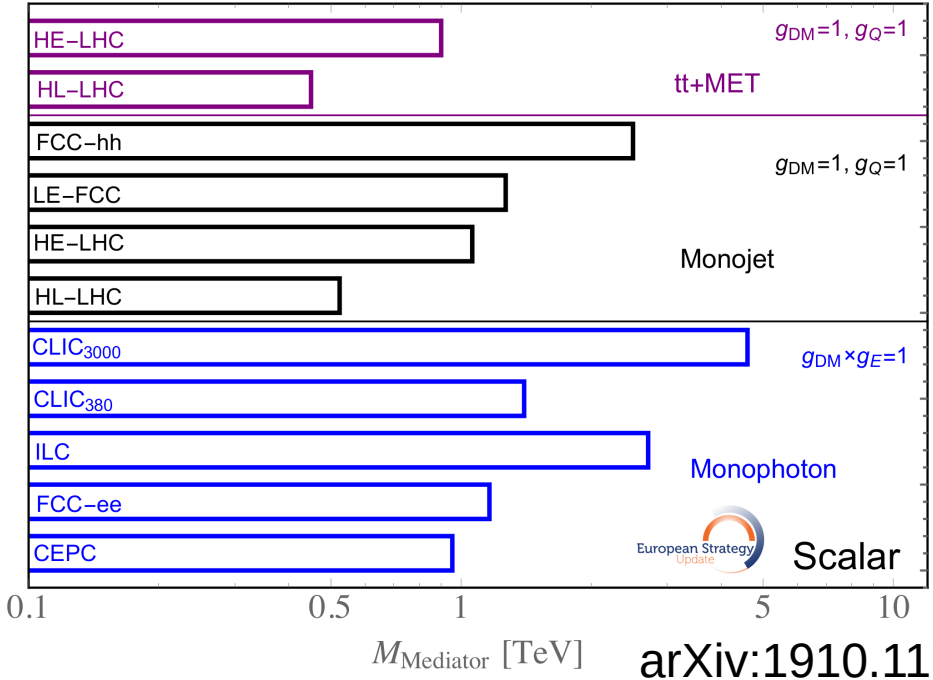
- Common approach:
  setting limits on mediator mass for given coupling structure/values

- 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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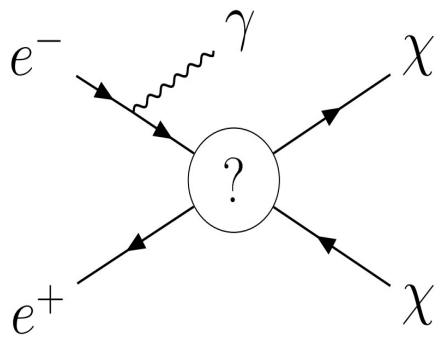
- Experimental approach:
  set limits on the DM production cross section
  - as a function of the assumed **mediator mass and mediator width**
    DM mass not relevant, if sufficiently light
  - depends on the assumed **coupling structure**, but coupling values not relevant
  - most model independent limits
    can be then interpreted in different models



New approach to DM searches

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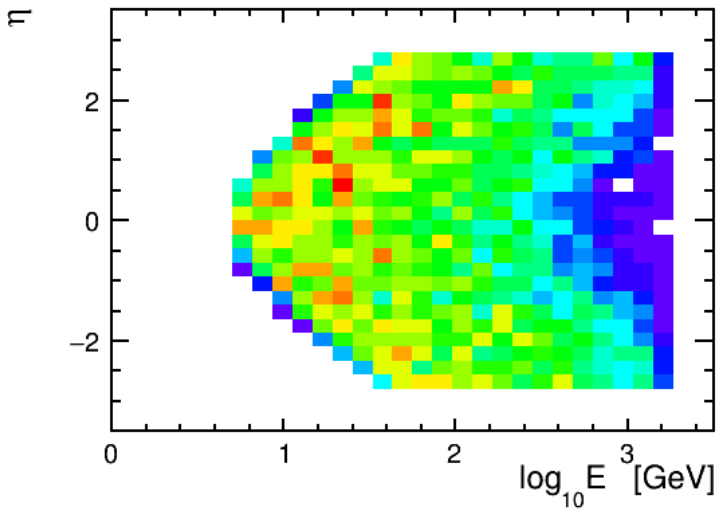
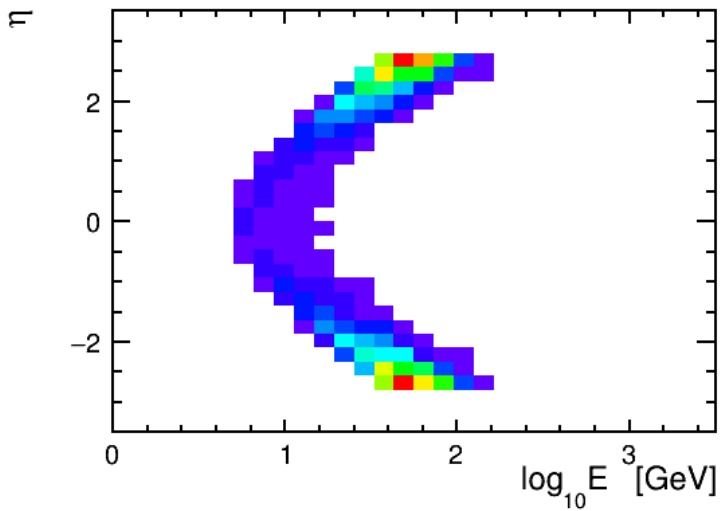
- Experimental approach:
  consider 2-D distribution of mono-photon event

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

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



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



New approach to DM searches

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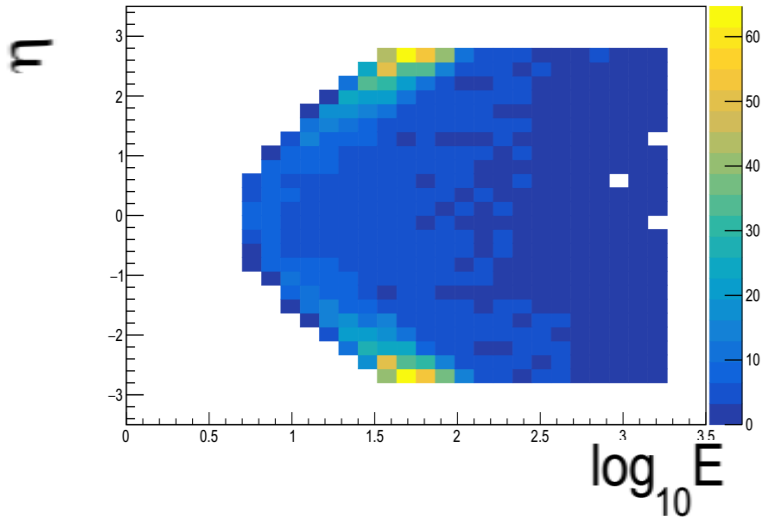
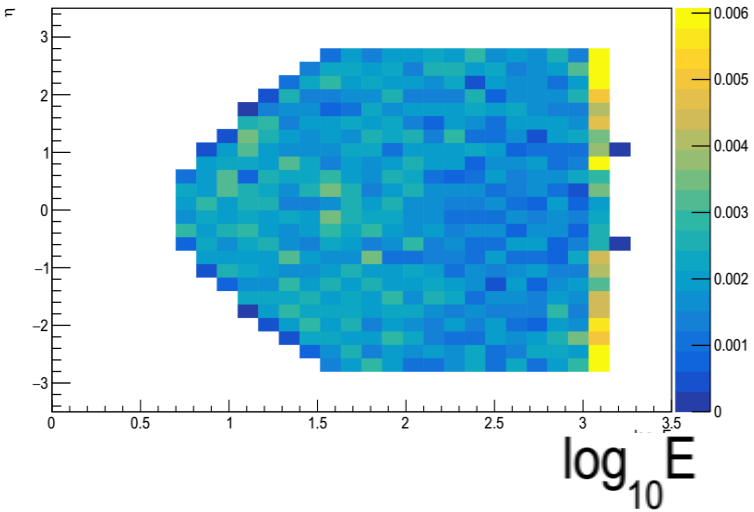
- Experimental approach:
  consider 2-D distribution of mono-photon event

- Main backgrounds vs signal @ 3TeV CLIC
  $e^+e^- \rightarrow \nu\bar{\nu}$ + $e^+e^- \rightarrow e^+e^-$ M_{DM}=50GeV M_{med}=1TeV Γ_{med}=50GeV





New approach to DM searches

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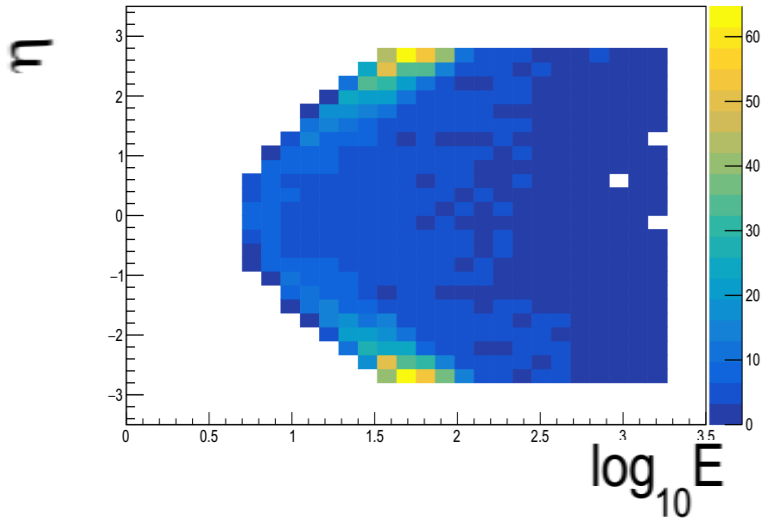
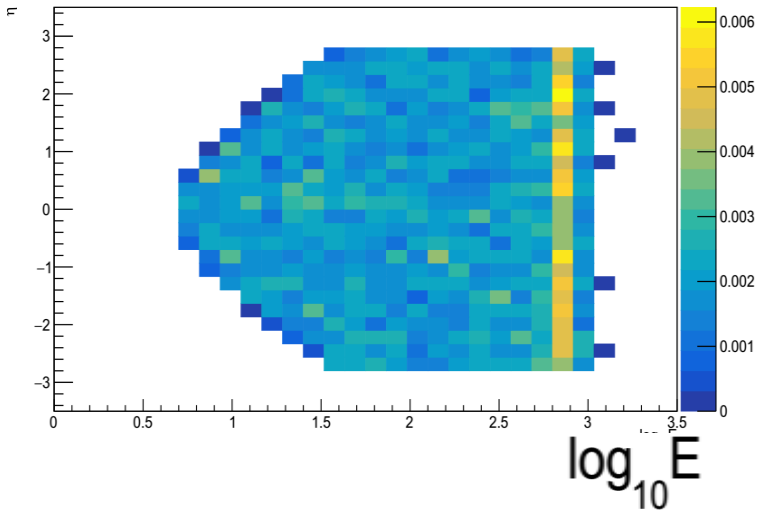
- Experimental approach:
  consider 2-D distribution of mono-photon event

- 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





New approach to DM searches

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- Experimental approach:
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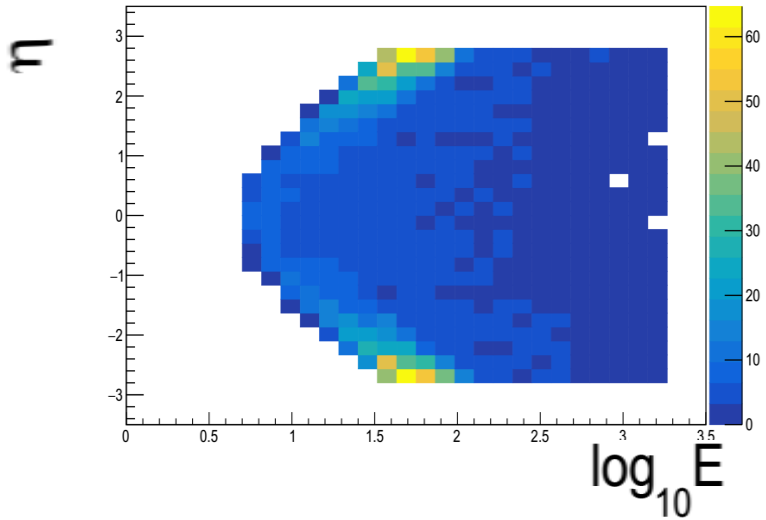

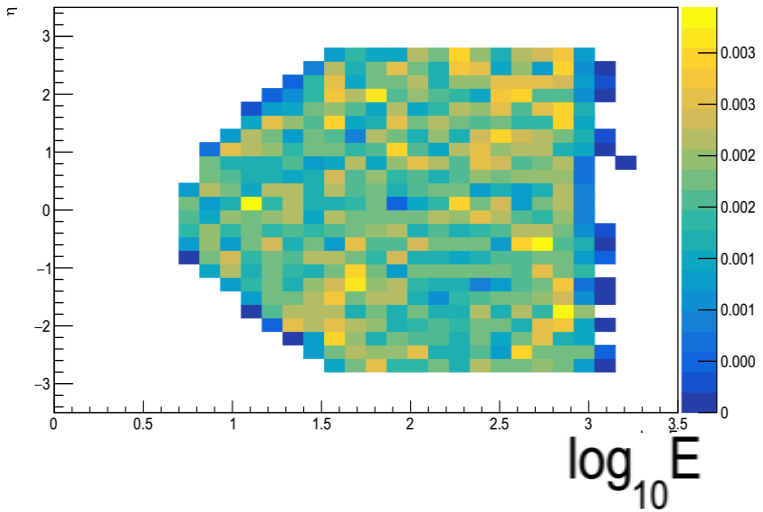

Conclusions

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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**
  - **Beam spectra crucial for high energy Bhabha samples**

- **Applied to Dark Matter analysis one can get model independent limits on cross sections of various scenarios**
  - **Wider range of mediator masses available**
  - **Exact coupling values not needed**
  - **Nice signal-background separation (i.e. RooStat test with hipothesis signal+bckg) and impact of the mediator width**

Backup

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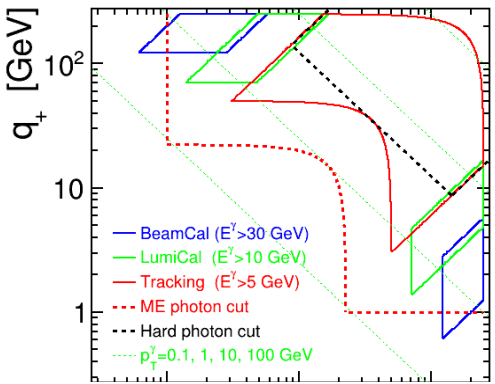
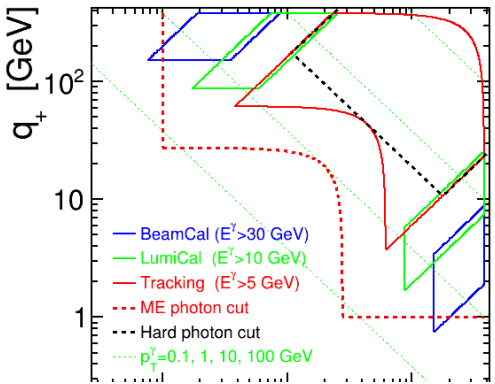
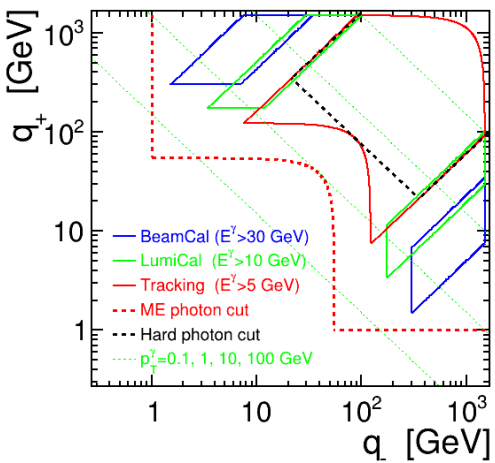
$\sqrt{s} = 250$ GeV



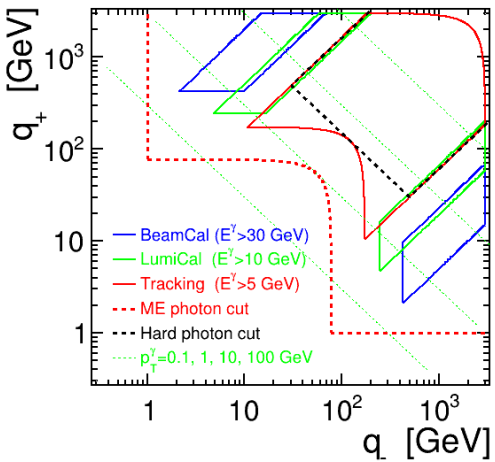
$\sqrt{s} = 380$ GeV



$\sqrt{s} = 1.5$ TeV



$\sqrt{s} = 3$ TeV



WIHZARD mono-photons: Bhabha

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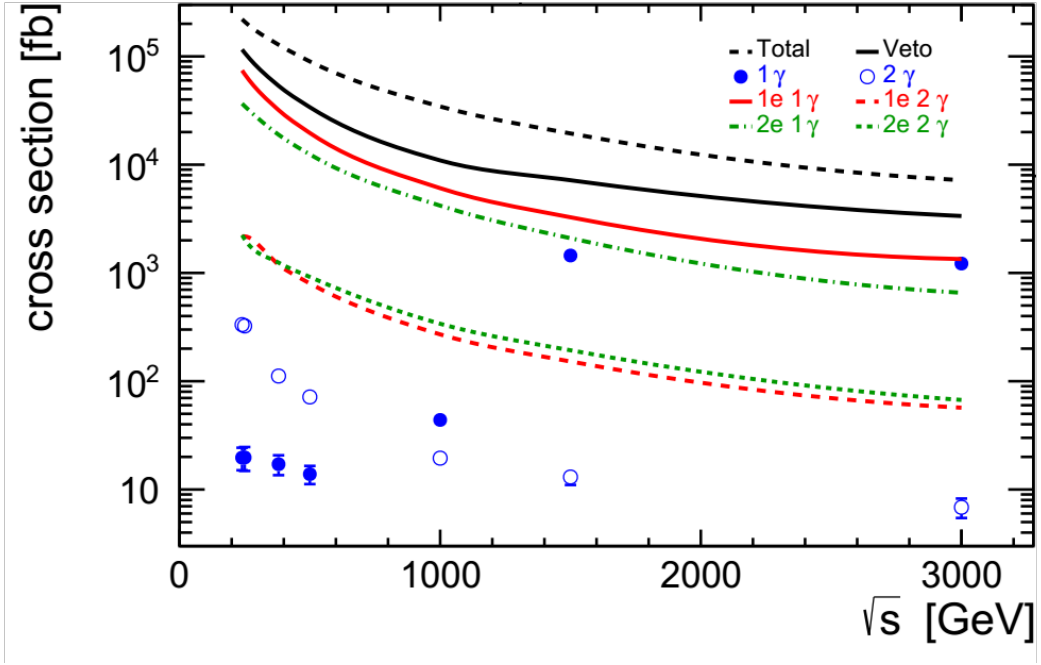
$\sqrt{s}[GeV]$	Whizard-2.8 $\sigma(e^+e^- \to e^+e^- + N\gamma)$ [fb]			$\sigma(e^+e^- \to e^+e^- + N\gamma)$ [fb]
	$e^+e^- + \gamma_{ME}$	$e^+e^- + 2\gamma_{ME}$	$e^+e^- + 3\gamma_{ME}$	after ISR rejection
240	236000	26100	1500	220000
250	224000	24900	1400	209000
380	140000	18400	1200	128000
500	100000	14600	1100	89800
1000	39800	7700	700	34400
1500	23000	5300	500	19400
3000	8800	2700	300	7200

$\sqrt{s}[GeV]$	$q_{min}[GeV]$	Whizard-2.8 $\sigma(e^+e^- \to e^+e^- + N\gamma)$ [fb]			$\sigma(e^+e^- \to e^+e^- + N\gamma))$ [fb]
		$e^+e^- + \gamma_{ME}$	$e^+e^- + 2\gamma_{ME}$	$e^+e^- + 3\gamma_{ME}$	after ISR rejection
380	q_{min}=0.1	141000	29500	3200	123000
	q_{min}=0.5	140000	21700	1500	126000
	q_{min}=1	140000	18400	1200	128000
	q_{min}=5	141000	10000	400	131000
	q_{min}=10	140000	5100	170	145000
	q_{min}=50	11200	160	2	11000
3000	q_{min}=0.1	8900	3700	420	6400
	q_{min}=0.5	9000	3000	230	7000
	q_{min}=1	8800	2700	300	7200
	q_{min}=5	8900	2000	140	7600
	q_{min}=10	8900	1300	90	7500
	q_{min}=50	7000	300	10	6100