Mono-Photon WIMP Benchmark – Introduction to the Analysis

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DESY

Benchmarking Days, KEK

24 February 2019

Mono-Photon WIMP Benchmark

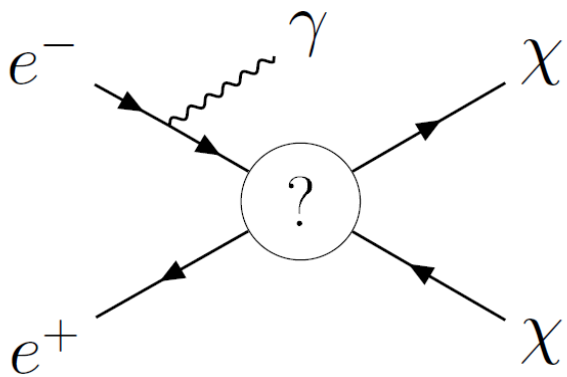
- analyser: Ryo Yonamine
- referees: Filip Zarnecki, me

- introduction to analysis
- analysis report
- referee report

WIMP Detection at the ILC

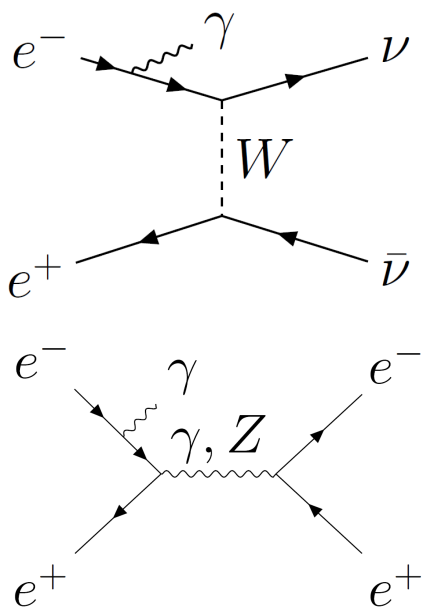
Signal

- WIMP pair production with ISR photon: $e^+e^- \to \chi\chi\gamma$
  - quasi model-independent
  - single photon in an "empty" detector
  - observables: E_γ, θ_γ, $p_{T,\gamma}$



Background Processes

- Neutrino pairs: $e^+e^- \to \nu\bar{\nu}\gamma$
  - irreducible
  - polarisation: enhance or suppress
- Bhabha scattering: $e^+e^- \to e^+e^-\gamma$
  - huge cross section
  - cross section rises for low polar angles
  - mimics signal if leptons in forward region are undetected



Background events: Neutrinos and Bhabhas

The data samples

- 500 GeV
- event generation: Whizard 2 with circe2 beam spectrum
  (dedicated samples for WIMP study with several ISR photons)
- first used in Moritz' PhD thesis
  $\Rightarrow$ reference for this benchmark analysis

Differences between benchmark and "Moritz' samples"

- simulation: Mokka (ILD_o1_v05)
- reconstruction
  - ilcsoft v01-17-11
  - with updated Pandora photon reconstruction
  - with `BeamCalClusterReco`

$\Rightarrow$ not DBD

Signal definition and event selection

Single photon...

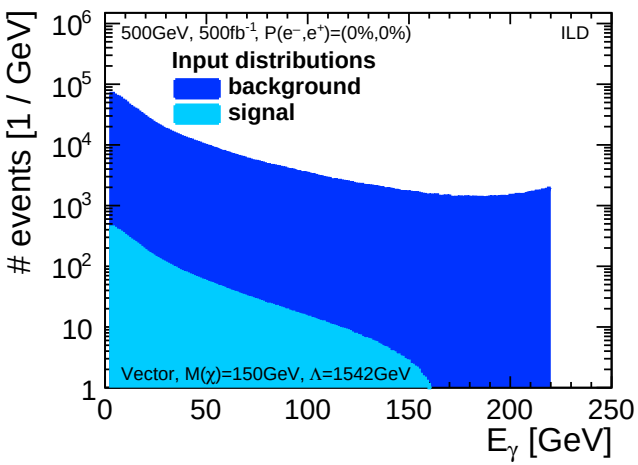
- $\theta_\gamma > 7^\circ$: no tracker in forward region
- minimum $p_{T,\gamma}$: Bhabha lepton outside BeamCal openings
- $2 < E_\gamma < 220\,\text{GeV}$: avoid radiative return to Z

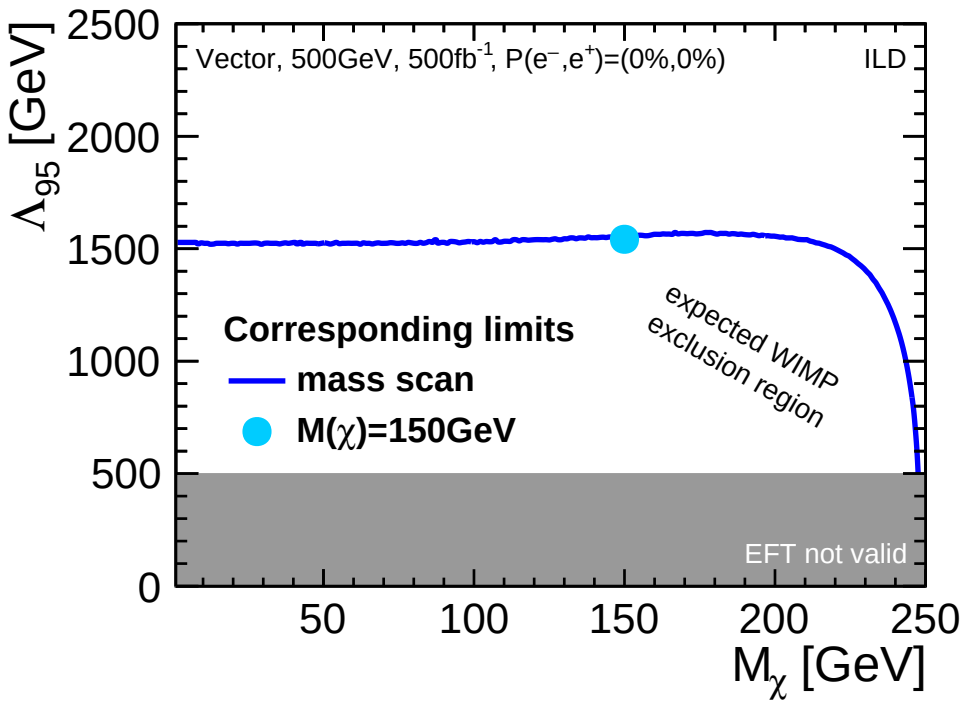
...in an empty detector

- allow low-p_T overlay
  - no charged $p_T > 3\,\text{GeV}$ in event
  - no electron with $p_{T,e} > 0.5\,\text{GeV}$ in event
- maximum visible energy
- no reconstructed cluster in BeamCal
  $\rightarrow$ hermeticity for Bhabha rejection down to lowest angles

Presentation of Results

- approach: effective operators
- energy scale: $\Lambda = M_{mediator} / \sqrt{g_{SM} \cdot g_{DM}}$





signal events from re-weighting neutrinos

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–
Referee Report

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Questions to be addressed in the talk

- the most important questions raised and how they were addressed
- your general assessment of the status of the analysis
- your general assessment of the status of the note
- the selection of material for the IDR
- remaining points to be addressed before material can be included in the IDR

Questions that were asked

- kind of review which took place: intense comparison with my analysis
  - $\Rightarrow$ reproduction of previous results / plots
  - $\Rightarrow$ have issues been fixed ?
- topics
  - photon reconstruction
  - cut flow
  - features in BeamCal
  - WIMP exclusion limits

$\Rightarrow$ detailed study of observables

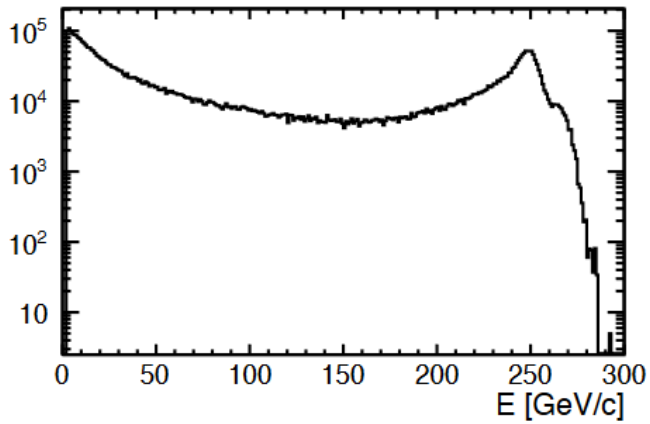
$\Rightarrow$ benchmark analysis in good shape

Questions that were asked

Ryo Phone Meeting 12 December 2018 (link)

Photon energy in signal events

(1) Moritz sample

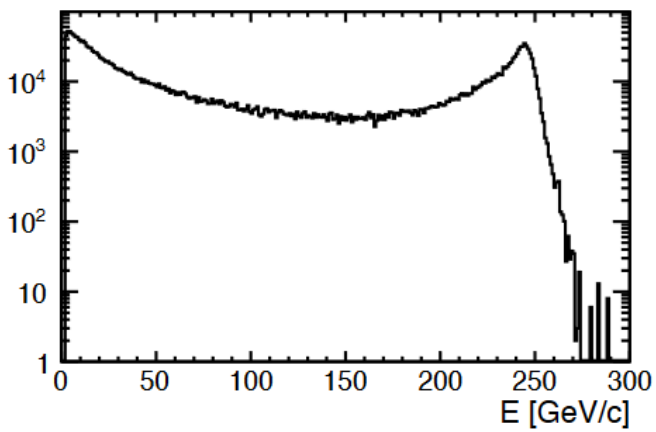


signal event definition

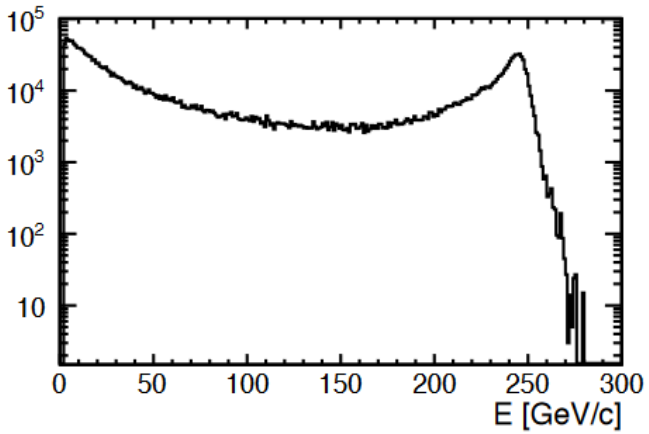
	signal definition	preselection
distinguish from charged electromagnetic particles	$\lvert\cos(\theta_\gamma)\rvert < 0.992546$ ($\Leftrightarrow 7° < \theta_\gamma < 173°$)	$\lvert\cos(\theta_\gamma)\rvert < 0.9975$ ($\Leftrightarrow 4.05° < \theta_\gamma < 175.95°$)
ensure identification of Bhabha scattering events	$p_{T,\gamma} > 1.92\,\text{GeV}$ for $\lvert\phi_\gamma\rvert > 35°$ $p_{T,\gamma} > 5.65\,\text{GeV}$ for $\lvert\phi_\gamma\rvert \leq 35°$ (in BeamCal coordinates)	$p_{T,\gamma} > 1\,\text{GeV}$
distinguish from noise	$E_\gamma > 2\,\text{GeV}$	-
avoid Z return	$E_\gamma < 220\,\text{GeV}$	-

Table 5.1: Criteria for the signal definition and the corresponding preselection cuts at the event generation.

(2) l5 sample



(3) s5 sample



Status of the analysis and the note

- code: available on github
- documentation: my thesis, phone meeting talks
- note on overleaf (link)
  - 13 pages
  - many plots
  - some text

$\Rightarrow$ material is ready, relatively simple things to add

$\Rightarrow$ now focus on writing

Suggestions for Material

general: comparison of large and small ILD (and with my thesis)

performance plots

- 95% CL limit (5 sigma discovery reach) in Lambda vs M plane for vector (axial) operator done
- (uncertainty on WIMP mass vs mass)
- (chi2 of vector vs axial vector separation vs mass)

performance aspects

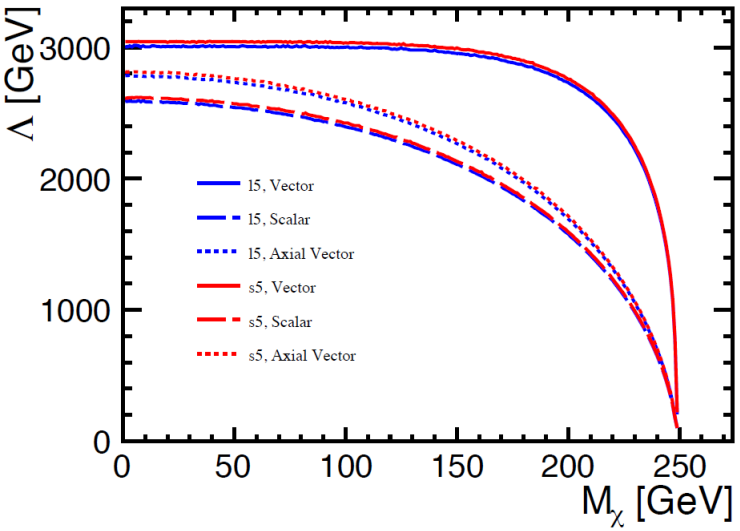
- photon: efficiency, purity, energy and angular resolution

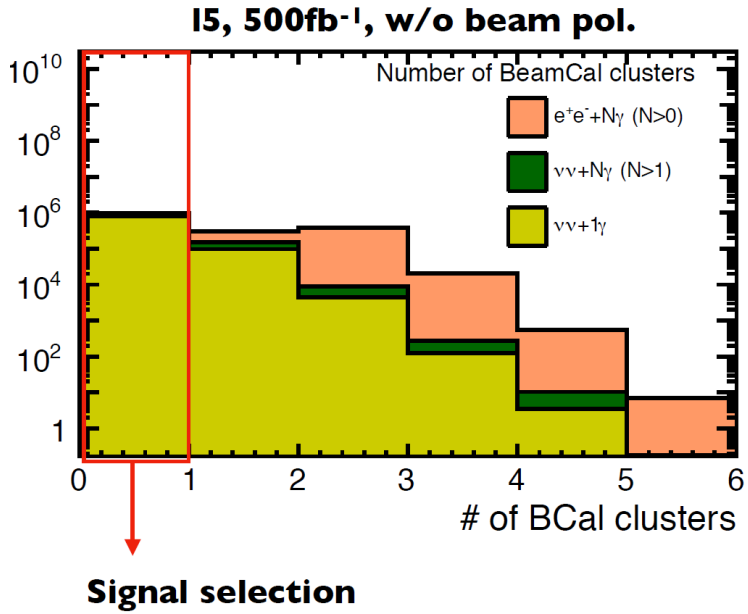
  which to show?

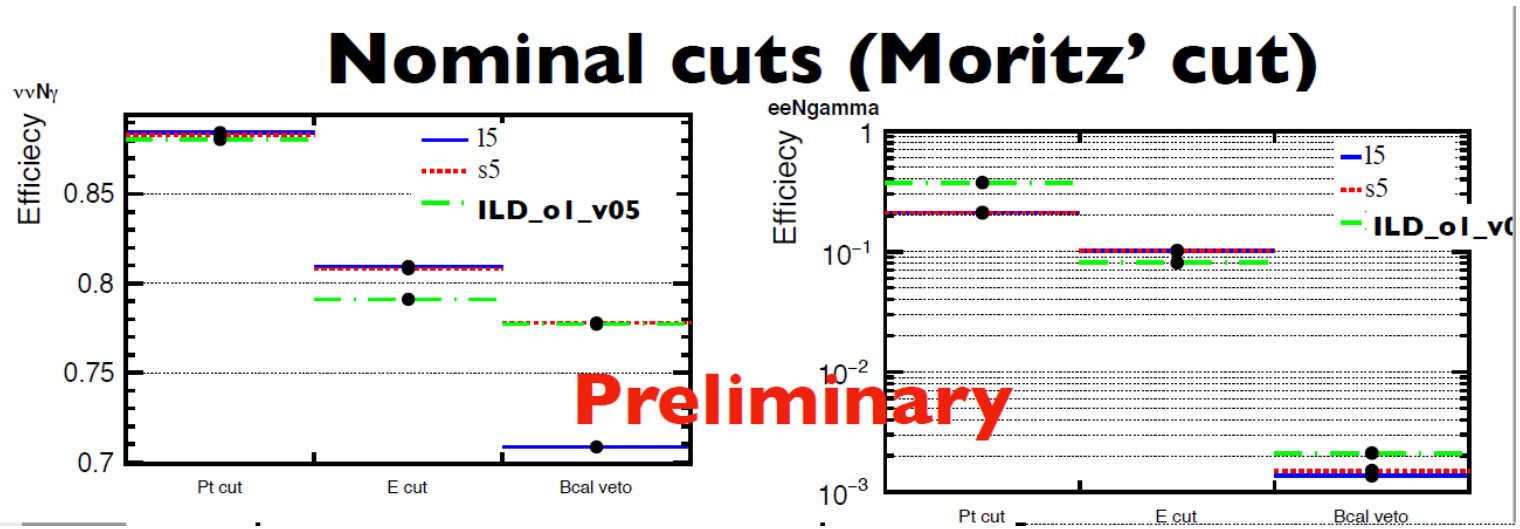
- Bhabha veto in BeamCal
- track veto in presence of beam backgrounds

  done, plot?

IDR Plot Suggestions







Things to be Learned from the Differences to my Analysis

why are selection efficiencies different

- transverse momentum cuts reject more Bhabha background
  - does NOT seem to be better electron tagging
  - probably due to different low p_T overlay
  - $p_{T,e} > 3\,\text{GeV}$ instead of $0.5\,\text{GeV}$ needs to be tested for RL
- visible energy cuts: now less visible energy in the detector
  - Bhabhas: small (= neglible) difference
  - neutrinos: again due to overlay ?
- BeamCal veto
  - Bhabhas: factor 2 different

    $\Rightarrow$ could be explained by different setup
    (new L*, new field maps, varying cell sizes, parameters of the BeamCal reconstruction)
  - neutrinos: large detector significantly worse

    $\Rightarrow$ true ?

    $\Rightarrow$ explains lower limits

BeamCalClusterReco: Conditions for BeamCal Clusters

select **pads**

- energy 2σ above ...
- ... and energy threshold

... above average expected energy deposition from pairs

$\rightarrow$ build **towers**

- pads in 6 consecutive layers
- first layer is ignored

$\rightarrow$ build **clusters**

- energy threshold
- if found $\rightarrow$ reject event

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- now shorter L* (BeamCal closer to IP)
  - $\Rightarrow$ new field maps, new pair background files

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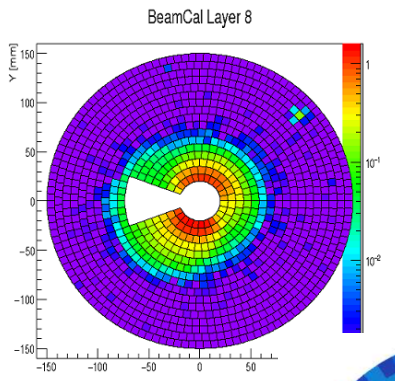
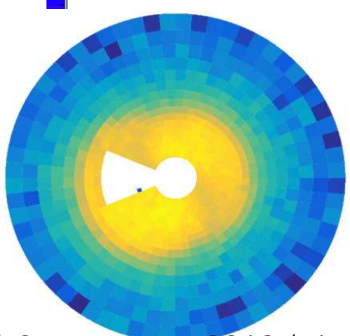
Differences between benchmark and "Moritz' samples"

- now shorter L* (BeamCal closer to IP)
  $\Rightarrow$ new field maps, new pair background files
- BeamCal now with varying cell size
  $\Rightarrow$ pad threshold: unclear what value to use
  $\Rightarrow$ benchmark: $5 \cdot 10^{-5}$ GeV, before: 0.01 GeV





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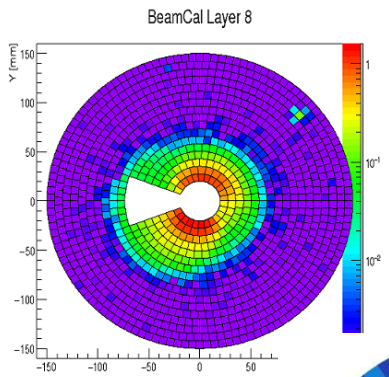
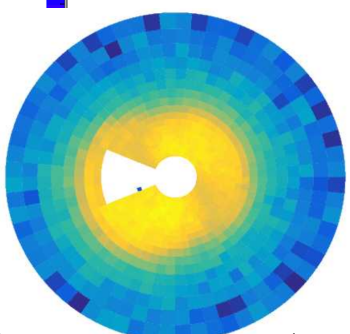
Differences between benchmark and "Moritz' samples"

- now shorter L* (BeamCal closer to IP)
  - $\Rightarrow$ new field maps, new pair background files
- BeamCal now with varying cell size
  - $\Rightarrow$ pad threshold: unclear what value to use
  - $\Rightarrow$ benchmark: $5 \cdot 10^{-5}$ GeV, before: 0.01 GeV
- (minor) issue: cluster energy threshold fairly low
  - $\Rightarrow$ benchmark: 0.06 GeV, before $0.5 \cdot 72 = 36$ GeV
  - $\Rightarrow$ fix: apply cut (E>32 GeV) after reconstruction





Open Issues

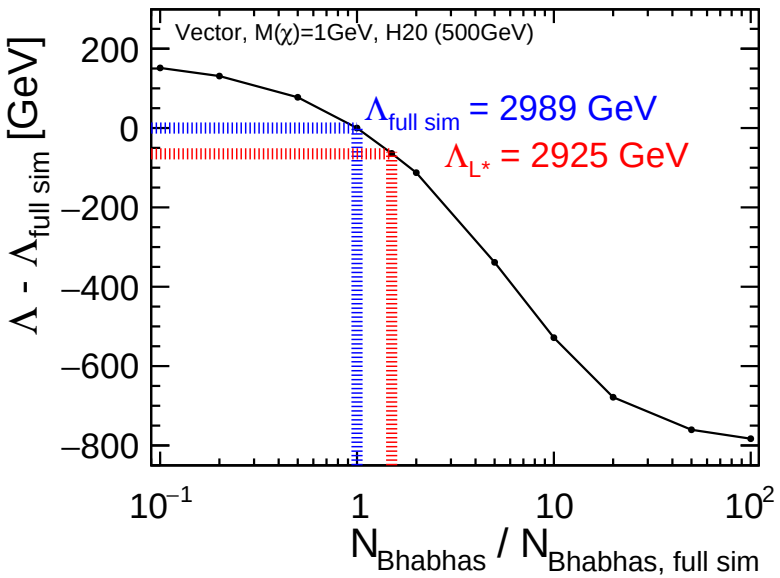
- BeamCal: cluster energy threshold has to be set by hand (maybe try 36 GeV instead of 32 GeV)
- BeamCal: hit energy threshold too low (?)
- BeamCal: no truth link
- photon reconstruction: non-linear response, reconstructed energies too high at highest energies

remaining points to be addressed before material can be included in the IDR

- BeamCal issues do not have sizeable effect on results
- ... but lead to the (wrong ?) conclusion that the performance of the larger detector is worse

Suggestions for Additional Material

- how sensitive are the results to the level of Bhabha background?
  - study with old samples
  - worthwhile to repeat with new samples ?



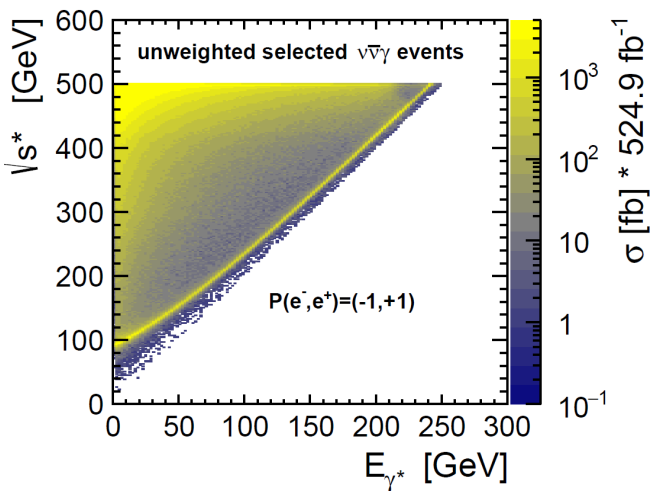
backup material

Obtaining the Signal Events

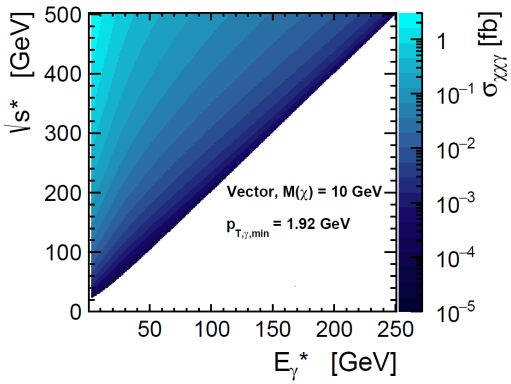
- $\nu\bar{\nu}\gamma$ looks like $\chi\chi\gamma$ on an event-by-event basis
  - $\Rightarrow$ instead of producing WIMP samples for each tested model
  - $\Rightarrow$ reweigh neutrino events to WIMP events:

WIMP events =

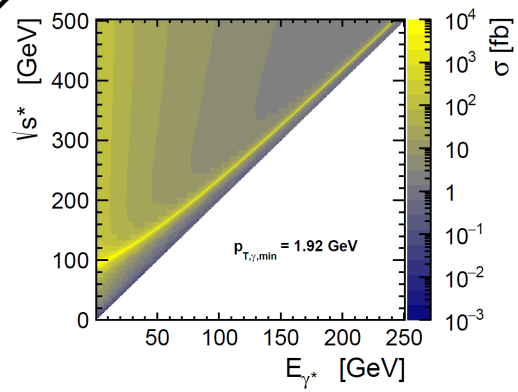
"neutrino Monte Carlo" $\times$ **weight** $\dfrac{\mathbf{d}\sigma_{\chi\chi\gamma,\mathbf{pol}}/\mathbf{dE}_\gamma}{\mathbf{d}\sigma_{\nu\bar{\nu}\gamma}/\mathbf{dE}_\gamma}$



$\times$



effective operators

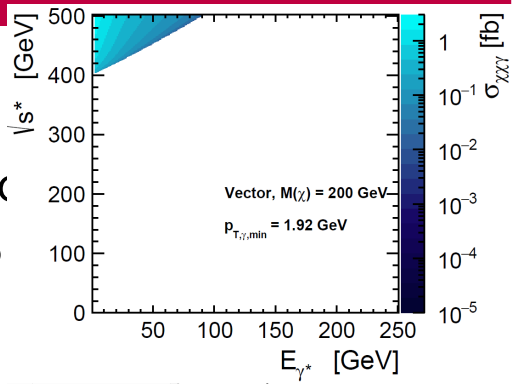


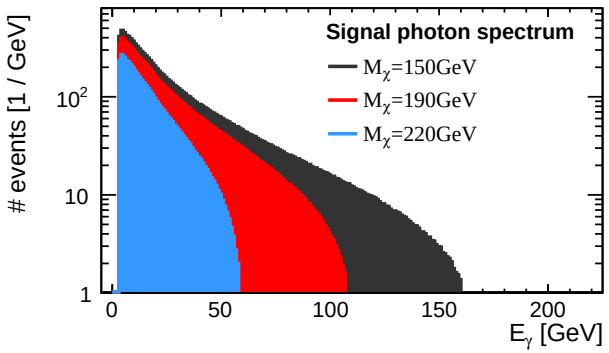
centre-of-mass energy $\sqrt{s^*}$
and photon energy E_γ^*
in reference frame of $\nu\bar{\nu} + 1\gamma$

Obtaining the Signal Events

E_γ range depends on M_χ

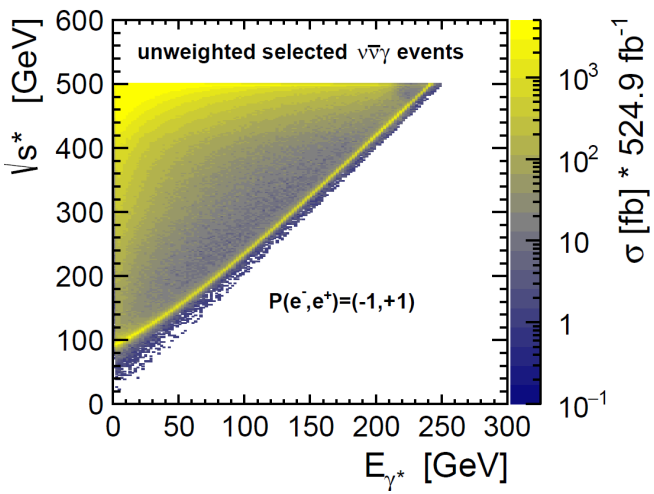
$\Rightarrow$ reweigh neutrino





WIMP events =

"neutrino Monte Carlo" $\times$ **weight** $\dfrac{d\sigma_{\chi\chi\gamma,pol}/dE_\gamma}{d\sigma_{\nu\bar{\nu}\gamma}/dE_\gamma}$



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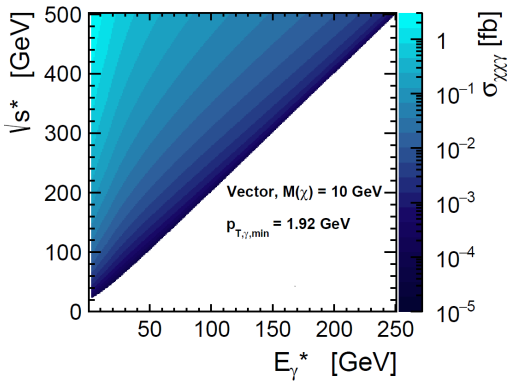

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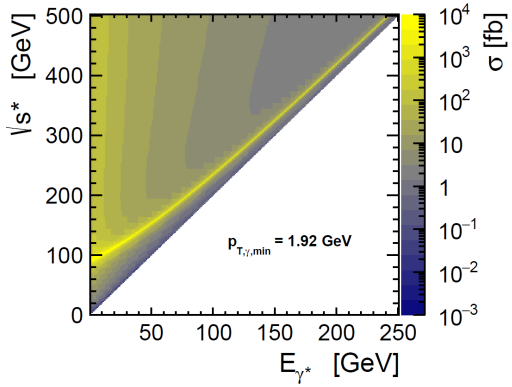

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