

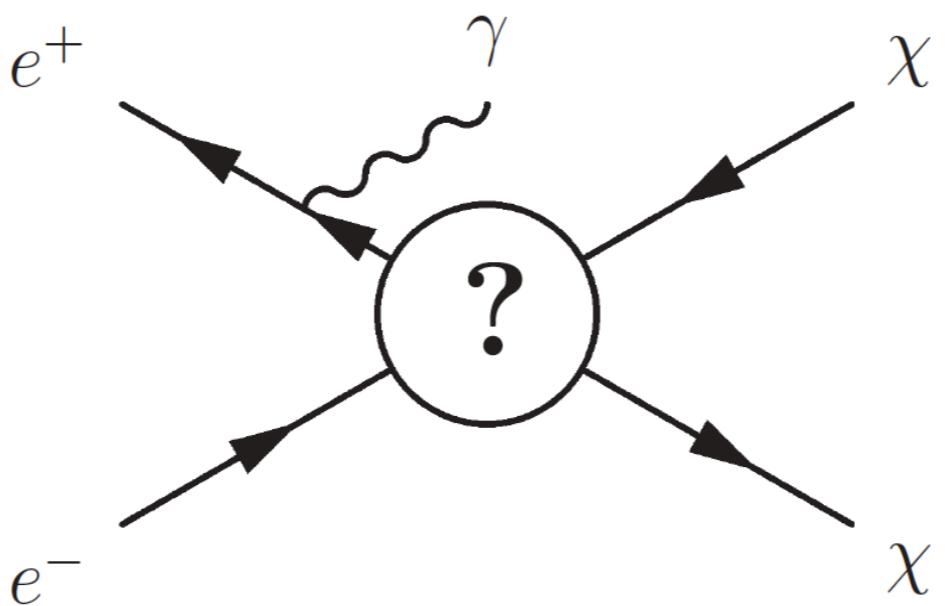
Review of WIMP search at mono photon channel at 500 GeV ILC

Ahmed Mustahid
Tohoku University

DOI 10.1140/epjc/s10052-012-2213-9
Cristoph Bartels, Mikael Berggren, Jenny List

Relic Abundance

- In the early Universe, at high temperature $T \gg m_\chi$ massive and energetic particles were created and existed $\chi\bar{\chi} \leftrightarrow l\bar{l}$ in thermal equilibrium $\Gamma \gg H(t)$ where $\Gamma = nv\sigma$
- Expansion of the universe diluted the interaction rate (\rightarrow) density of heavier particles became too low $\Gamma \ll H(t)$
- Particle density freezes out \Rightarrow constant number density

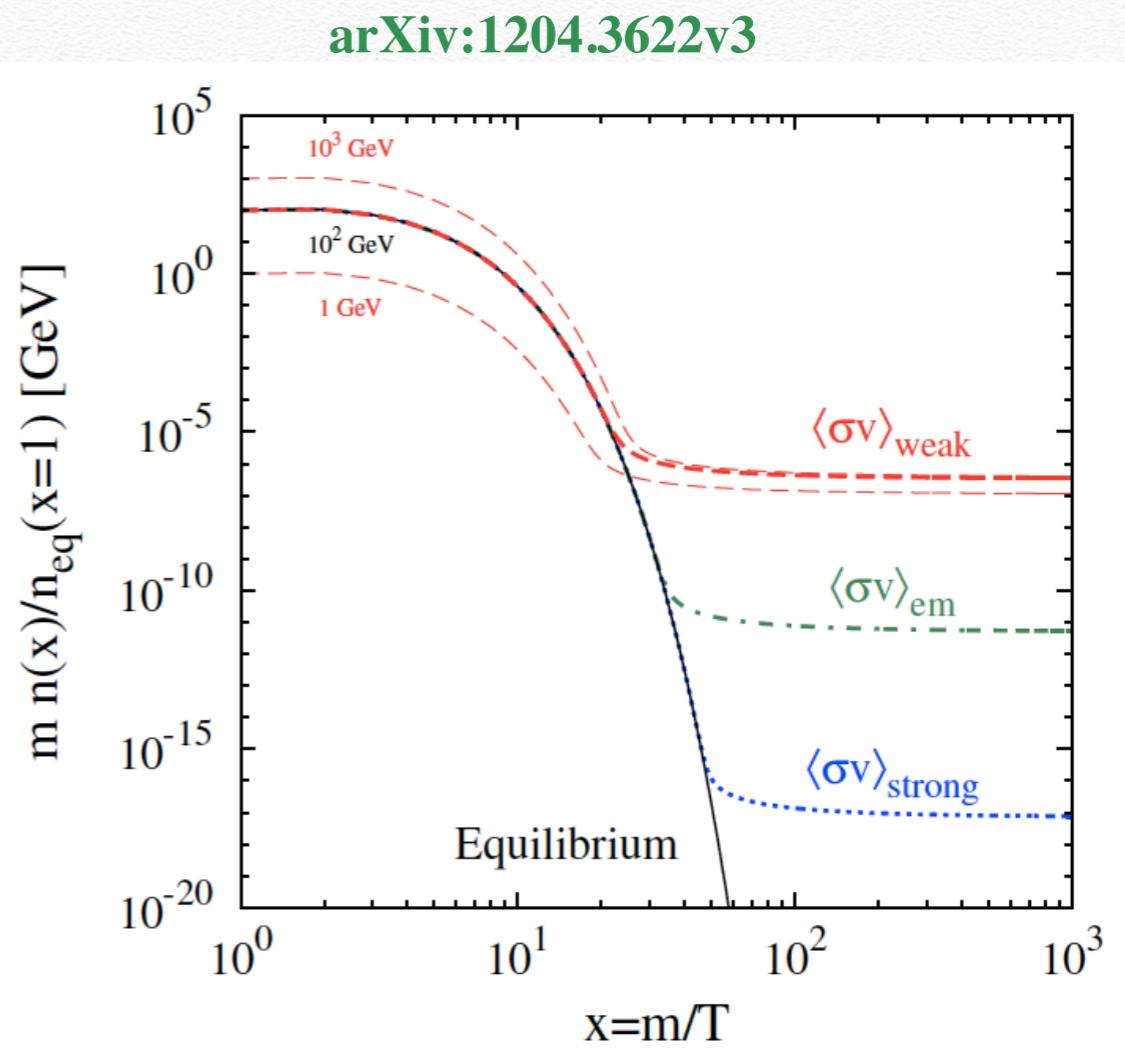


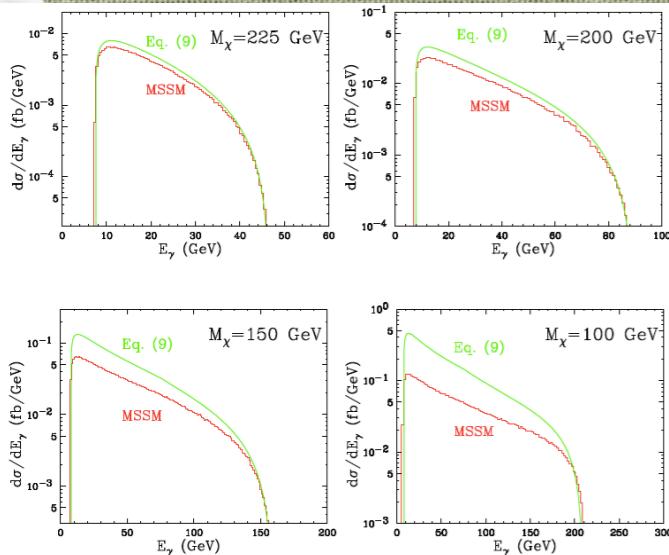
WIMP relic abundance

- Distribution factor $f(p) = \frac{1}{e^{(E-\mu)/T} \pm 1}$ where $E = \sqrt{m^2 + p^2}$
- Number density $n = \frac{g}{(2\pi)^3} \int f(p) d^3 p$
- For non-relativistic cold DM $n = g \left(\frac{mT}{2\pi}\right)^{3/2} e^{-m/T}$
=>The equilibrium term is exponentially suppressed
- Boltzmann transport equation

$$\frac{dn}{dt} = -3Hn - \langle \sigma_{an} v \rangle (n^2 - n_{EQ}^2)$$
- Approximate solution of Boltzmann equation is given by

$$\Omega_\chi h^2 = \frac{m_\chi n_\chi}{\rho_c} \simeq \left(\frac{3 \times 10^{-27} \text{ cm}^3 \text{ sec}^{-1}}{\sigma_A v} \right)$$
- From WMAP, difference of matter and baryon density $\Omega_\chi h^2 = 0.11425 \pm 0.00311$
- Annihilation cross-section roughly=>
 10^{-9} GeV^{-2}
- Weak scale $\sigma_{\text{weak}} \simeq \frac{\alpha^2}{m_{\text{weak}}^2}$, $\alpha \approx \mathcal{O}(0.01)$
 $m_{\text{weak}} \approx \mathcal{O}(100 \text{ GeV})$





Model Independent approach

arXiv:hep-ph/0403004v2

- WIMPs can annihilate into SM particle pair

$$\chi + \chi \rightarrow X_i + \bar{X}_i; \quad X_i = l, q, g, \dots$$

- In the non-relativistic limit, for a relative velocity \mathcal{V} of two χ each cross section

$$\sigma_i v = \sum_{J=0}^{\infty} \sigma_i^{(J)} v^{2J}$$

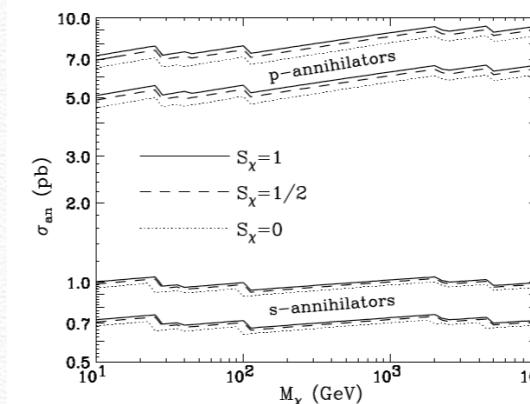
- Analysis restricted to for s and p wave respectively. For low velocities

$$J^{(0)} = 0, 1$$

- Annihilation fraction is defined as $\kappa_i = \frac{\sigma_i^{(J_0)}}{\sigma_{\text{an}}}$

- The constraint on σ_{an} is provided by cosmology

$$\sigma_{\text{an}} = \sum_i \sigma_i^{(J_0)}$$



- For general kinematics of $e^+ e^- \rightarrow \chi\chi\gamma \Rightarrow$ no model independence. Model independence \Rightarrow only for collinear photon
- Using $x = 2E_\gamma/\sqrt{s}$ The relevant cross section can be computed from \Rightarrow valid $\sqrt{s} \geq 2m_\chi$

$$\frac{d\sigma}{dxd\cos\theta}(e^+e^- \rightarrow 2\chi + \gamma) \approx \frac{\alpha\kappa_e\sigma_{\text{an}}}{16\pi} \frac{1+(1-x)^2}{x} \frac{1}{\sin^2\theta} 2^{2J_0} (2S_\chi + 1)^2 \left(1 - \frac{4M\chi^2}{(1-x)s}\right)^{1/2+J_0}$$

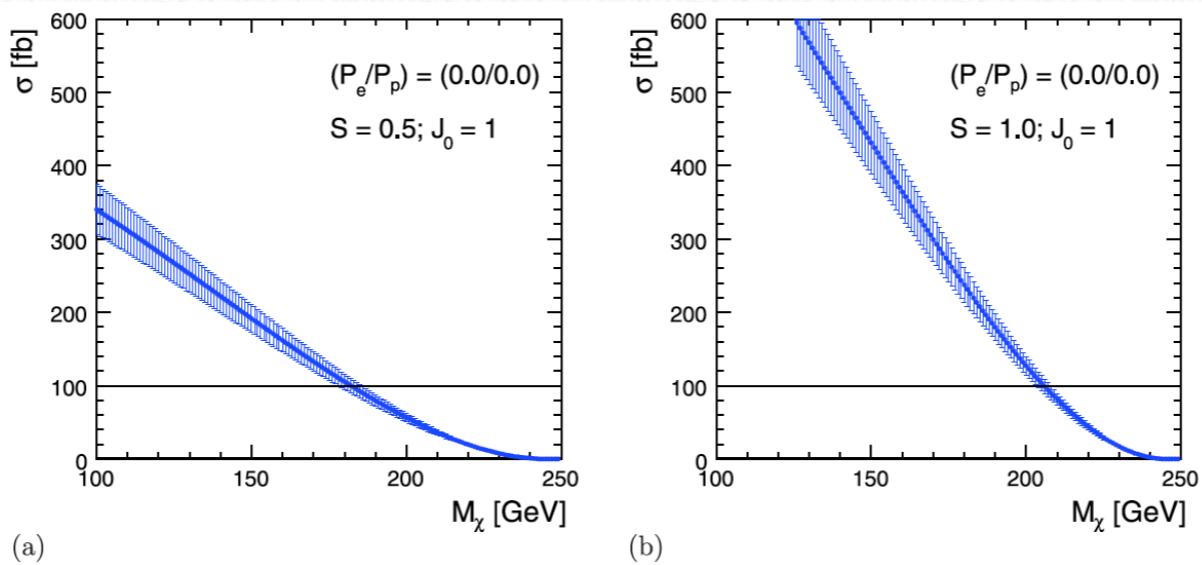
Polarization

$$\begin{aligned}\kappa_e \rightarrow & \frac{1}{4}(1 + P_-) [(1 + P_+) \kappa(e_-^R e_+^L) + (1 - P_+) \kappa(e_-^R e_+^R)] \\ & + \frac{1}{4}(1 - P_-) [(1 + P_+) \kappa(e_-^L e_+^L) + (1 - P_+) \kappa(e_-^L e_+^R)]\end{aligned}$$

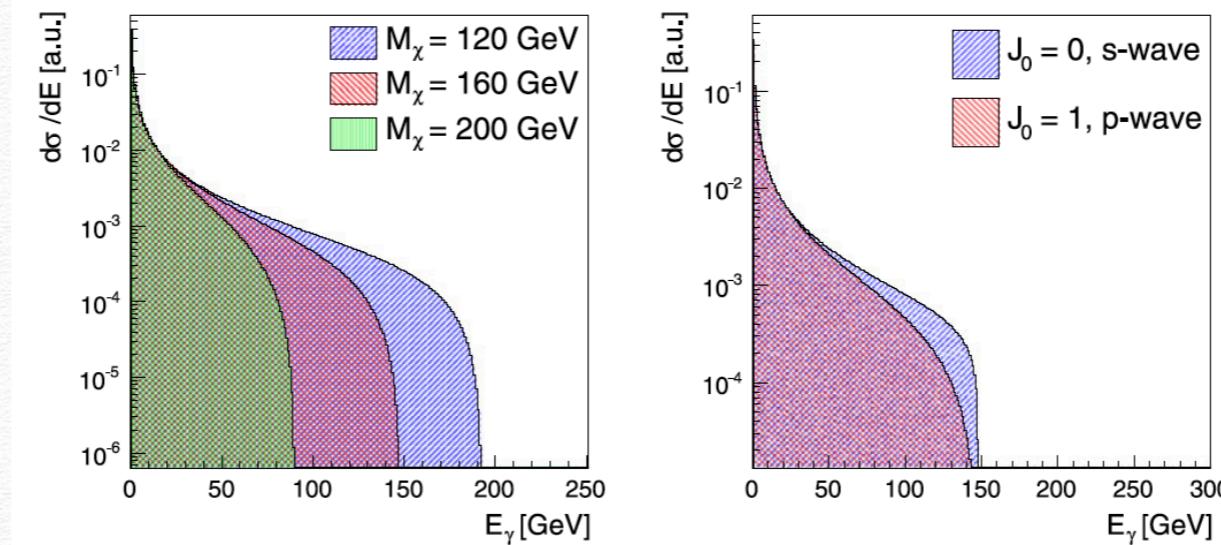
- Equal: Independent of helicity $\kappa(e_R^-, e_L^+) = \kappa(e_R^-, e_R^+) = \kappa(e_L^-, e_L^+) = \kappa(e_L^-, e_R^+)$
- Helicity: Conserves helicity and parity $\kappa(e_R^-, e_L^+) = \kappa(e_L^-, e_R^+); \quad \kappa(e_R^-, e_R^+) = \kappa(e_L^-, e_L^+) = 0.$
- Anti-SM: WIMPs couple to only right handed electrons and left-handed positrons. $\kappa(e_R^-, e_L^+);$ All others $\kappa(e^-, e^+) = 0$
- The reach of ILC can be increased by polarizing the beams
- Polarization of electron and positron $\Rightarrow P_-$ and P_+ respectively
- WIMP spin is not directly accessible and is subsumed under the normalization of the total cross section which is left as a free parameter alongside the WIMP mass

Expected Cross-section

- Total unpolarised cross section at COM energy 500 GeV for p-wave and spin 1 and spin 1/2.
- Photon phase space restricted to experimentally accessible $E_\gamma > 9 \text{ GeV}$ and $|\cos\theta| < 0.998$

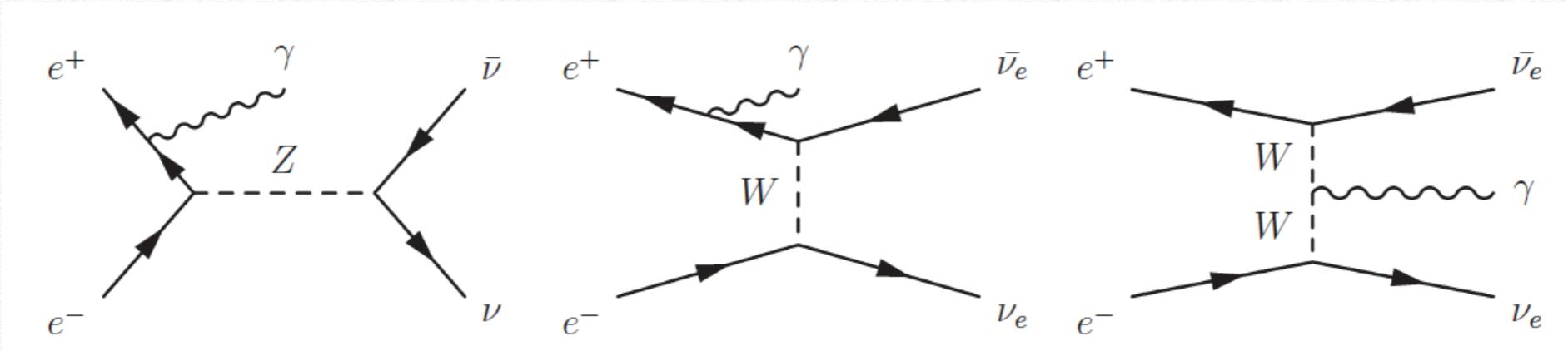


- Generator level photon spectra for different WIMP masses
- Second figure shows for both s and p wave

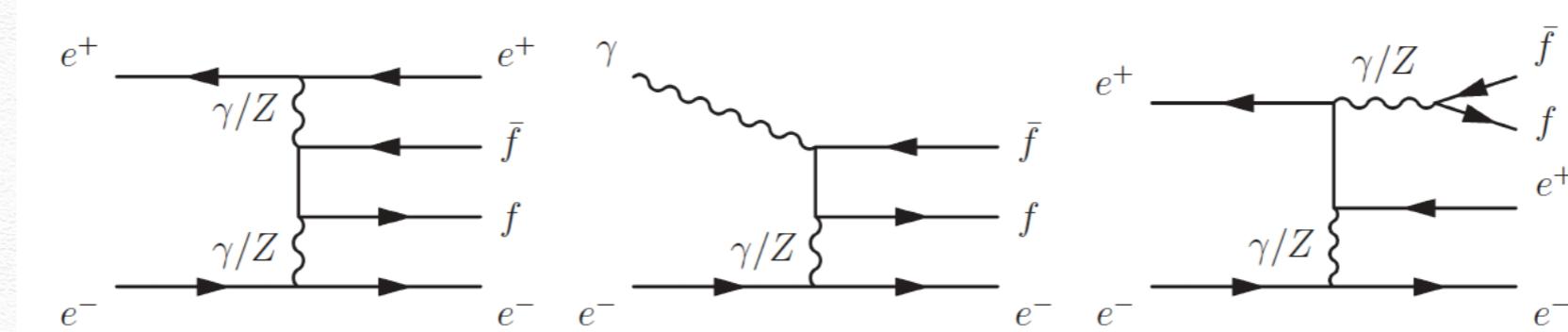


Background processes

- Irreducible: $e^+e^- \rightarrow \nu\bar{\nu}\gamma \Rightarrow$ Dominated by W-fusion at t channel at above COM energy above Z mass



- Reducible: $e^+e^- \rightarrow e^+e^-\gamma \Rightarrow$ Dominated by radiative Bhabha scattering
- Large background of $e^+e^- \rightarrow \gamma\gamma$ in the order of $5 \times 10^8 \text{ fb}^{-1}$



Analysis Strategy

- ❖ WIMP signature is indistinguishable from the dominant $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ background
- ❖ Signal events are created from background $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ weighted with $w_{sig} = \sigma(\chi\chi\gamma)/\sigma(\nu\bar{\nu}\gamma)$
- ❖ Luminosity and polarization weights $w_{pol} = (1 \pm P_{e^-})(1 \pm P_{e^+})/4$

$$\begin{aligned}\sigma_{P_{e^-}P_{e^+}} &= \frac{1}{4} \{(1 + P_{e^-})(1 + P_{e^+})\sigma_{RR} + (1 - P_{e^-})(1 - P_{e^+})\sigma_{LL} \\ &\quad + (1 + P_{e^-})(1 - P_{e^+})\sigma_{RL} + (1 - P_{e^-})(1 + P_{e^+})\sigma_{LR}\} \quad w_{event} = \frac{\mathcal{L}_{exp}}{\mathcal{L}_{MC}} \times w_{pol} \times w_{sig}\end{aligned}$$

Signal Definition

A signal like event contains at least one photon with $10 \text{ GeV} < E_\gamma < 220 \text{ GeV}$ and

$|\cos\theta| < 0.98$ to reduce soft photons and exclude the radiative Z return

- Within the tracking acceptance of the ILD detector to distinguish from charged particle

Subsystem	Coverage in $ \cos(\Theta) $	Coverage in Θ [deg]
ECAL Barrel	$ \cos(\Theta) < 0.787$	$\Theta > 38.1$
ECAL EndCap	$0.761 < \cos(\Theta) < 0.987$	$9.25 < \Theta < 40.45$
ECAL Ring	$0.988 < \cos(\Theta) < 0.995$	$5.7 < \Theta < 9.0$
LumiCal		$1.8 < \Theta < 4.5$
BeamCal		$0.3 < \Theta < 2.4$
Active region	Radial r [mm]	Longitudinal z [mm]
Calorimeters	$r > 1843$	$z > 2450$
Tracking in TPC	$395.0 < r < 1739.0$	$z < 2247.5$

Event Sample Generation

- ❖ SM Background generated by WHIZARD
- ❖ Beam energy spectrum and beamstrahlung calculated for nominal beam parameters with GUINEA PIG=> passed to WHIZARD

Parameter	Value	Units
Center of mass energy	500	GeV
Peak luminosity	$2 \cdot 10^{34}$	$\text{cm}^{-1}\text{s}^{-1}$
Repetition rate	5	Hz
Accelerating gradient in cavities	31.5	MV/m
Length of each Main Linac	11	km
Beam pulse length	1	ms
Average beam current in pulse	9.0	mA
Total site power consumption	230	MW

Event sample definition

- ❖ $e^+e^- \rightarrow \nu\bar{\nu}\gamma(N)\gamma$ Background required to have at least one photon with $E_\gamma > 9 \text{ GeV}$
 $|cos\theta| < 0.98$
- ❖ and beam polarization $(P_{e^-}, P_{e^+}) = (+1, -1)$ $(P_{e^-}, P_{e^+}) = (-1, +1) \Rightarrow$ others vanish
- ❖ For Bhabha $\Rightarrow (P_{e^-}, P_{e^+}) = (\pm 1, \mp 1)$

Data Samples

Process	Generator: WHIZARD				
	P_{e^-}	P_{e^+}	N_{events}	σ [fb]	\mathcal{L} [fb^{-1}]
$\nu_e \nu_e \gamma$	-1.0	+1.0	3,832,650	14990.0	255.7
$\nu_e \nu_e \gamma$	+1.0	-1.0	198,643	397.3	500.0
$\nu_e \nu_e \gamma\gamma$	-1.0	+1.0	988,847	1977.7	500.0
$\nu_e \nu_e \gamma\gamma$	+1.0	-1.0	38,897	77.8	500.0
$\nu_e \nu_e \gamma\gamma\gamma$	-1.0	+1.0	67,453	134.9	500.0
$\nu_e \nu_e \gamma\gamma\gamma$	+1.0	-1.0	4,414	7.6	580.8
$\nu_\mu \nu_\mu \gamma$	-1.0	+1.0	310,232	620.5	500.0
$\nu_\mu \nu_\mu \gamma$	+1.0	-1.0	197,947	395.9	500.0
$\nu_\mu \nu_\mu \gamma\gamma$	-1.0	+1.0	60,632	121.3	499.9
$\nu_\mu \nu_\mu \gamma\gamma$	+1.0	-1.0	38,752	77.5	500.0
$\nu_\mu \nu_\mu \gamma\gamma\gamma$	-1.0	+1.0	5,878	11.8	498.1
$\nu_\mu \nu_\mu \gamma\gamma\gamma$	+1.0	-1.0	4,407	7.6	579.9
$\nu_\tau \nu_\tau \gamma$	-1.0	+1.0	309,482	619.0	500.0
$\nu_\tau \nu_\tau \gamma$	+1.0	-1.0	197,361	394.7	500.0
$\nu_\tau \nu_\tau \gamma\gamma$	-1.0	+1.0	60,535	121.1	499.9
$\nu_\tau \nu_\tau \gamma\gamma$	+1.0	-1.0	38,827	77.7	499.7
$\nu_\tau \nu_\tau \gamma\gamma\gamma$	-1.0	+1.0	5,937	11.9	498.9
$\nu_\tau \nu_\tau \gamma\gamma\gamma$	+1.0	-1.0	4,364	7.5	581.9

Process	Generator: WHIZARD				
	P_{e^-}	P_{e^+}	N_{events}	σ [fb]	\mathcal{L} [fb^{-1}]
$\gamma\gamma$	-1.0	+1.0	51994	12998.3	4.0
$\gamma\gamma$	+1.0	-1.0	129912	12991.2	10.0
$\gamma\gamma\gamma$	-1.0	+1.0	21580	2158.0	10.0
$\gamma\gamma\gamma$	+1.0	-1.0	21594	2159.4	10.0
$\gamma\gamma\gamma\gamma$	-1.0	+1.0	1941	194.1	10.0
$\gamma\gamma\gamma\gamma$	+1.0	-1.0	1942	194.2	10.0
$e^+ e^- \gamma$	+1.0	-1.0	1738455	17469600.0	0.1
$e^+ e^- \gamma$	+1.0	+1.0	1718495	17275000.0	0.1
$e^+ e^- \gamma$	-1.0	+1.0	1750065	17525700.0	0.1
$e^+ e^- \gamma$	-1.0	-1.0	1723995	17265000.0	0.1

Detector Simulation

- ❖ Detector simulation has bee done by MOKKA=>Simulated detector model=>ILD_00 & LDC_PrimeSc_02=>Differs only in forward region

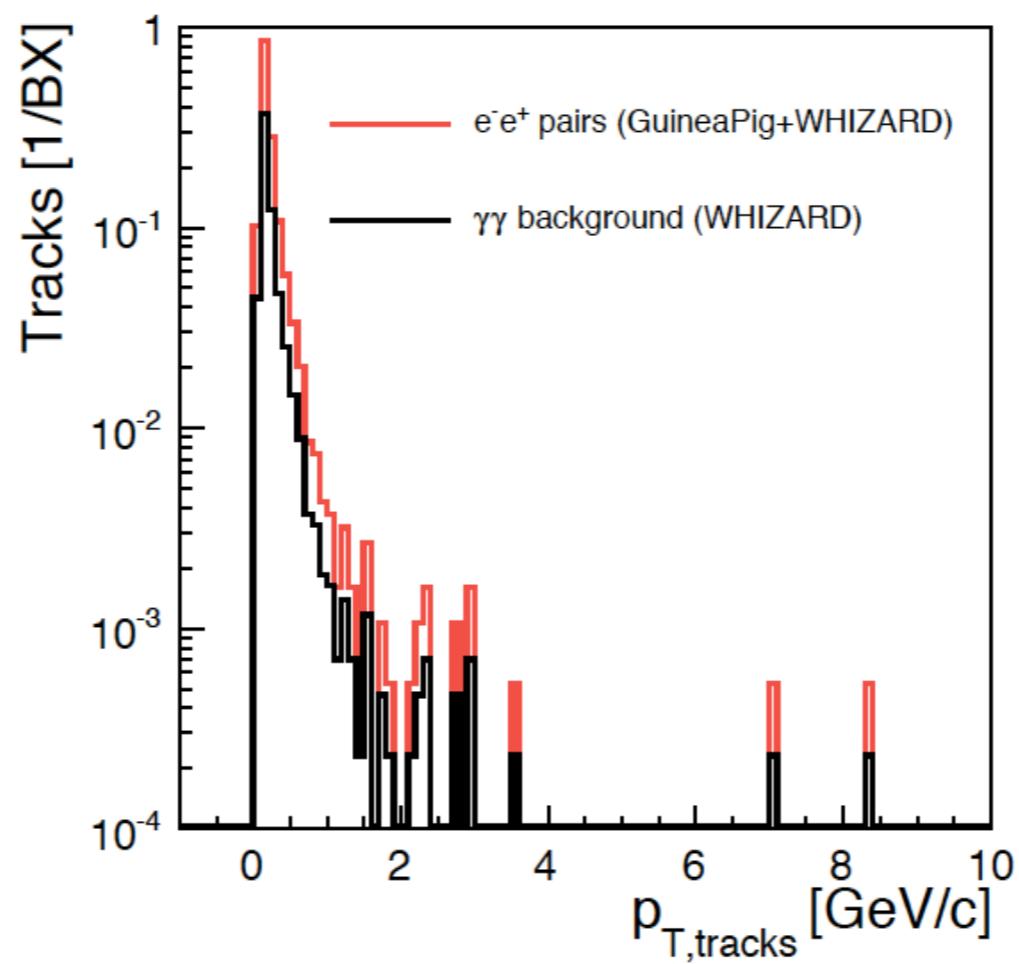
Subsystem		Letter of Intent	Simulation MOKKA
Magnetic Field, B [T]		3.5	3.5
ECAL Barrel	R_{min}	1847.4	1843
	z_{max}	2350	2350
	Layers	20 + 9	20 + 9
	Total X_0	23.6	—
Coverage		$ \cos(\Theta) < 0.786$	$ \cos(\Theta) < 0.787$
ECAL endcap	R_{min} (square)	—	400.0
	R_{max} (oct.)	2090	2088.8
	z_{min}	2450	2450
	Coverage	$0.761 < \cos(\Theta) < 0.987$	$0.761 < \cos(\Theta) < 0.987$
ECAL ring	R_{min}	280.0	250.0
	R_{max} (oct.)	390.0	390.0
	z_{min}	2450	2450
	Coverage	—	100 ... 157.8 mrad
Lumical	R_{min}	80.0	80.0
	R_{max}	196	195.2
	z_{min}	2450	2506.9
	Coverage	32.6 ... 79.8 mrad	31.9 ... 77.7 mrad
BeamCal	R_{min}	(out beam) 20.0	(out beam) 20.0
	R_{max}	(supp.) 220.0	(sens.) 150.0
	z_{min}	3595	3595
	Coverage	5 ... 40 mrad	5.6 ... 41.7 mrad

Reconstruction

- ❖ Reconstruction was done by MARLIN
=>Particle Flow Algorithm=>PandoraPFA

Beam Induced backgrounds and $\gamma\gamma$

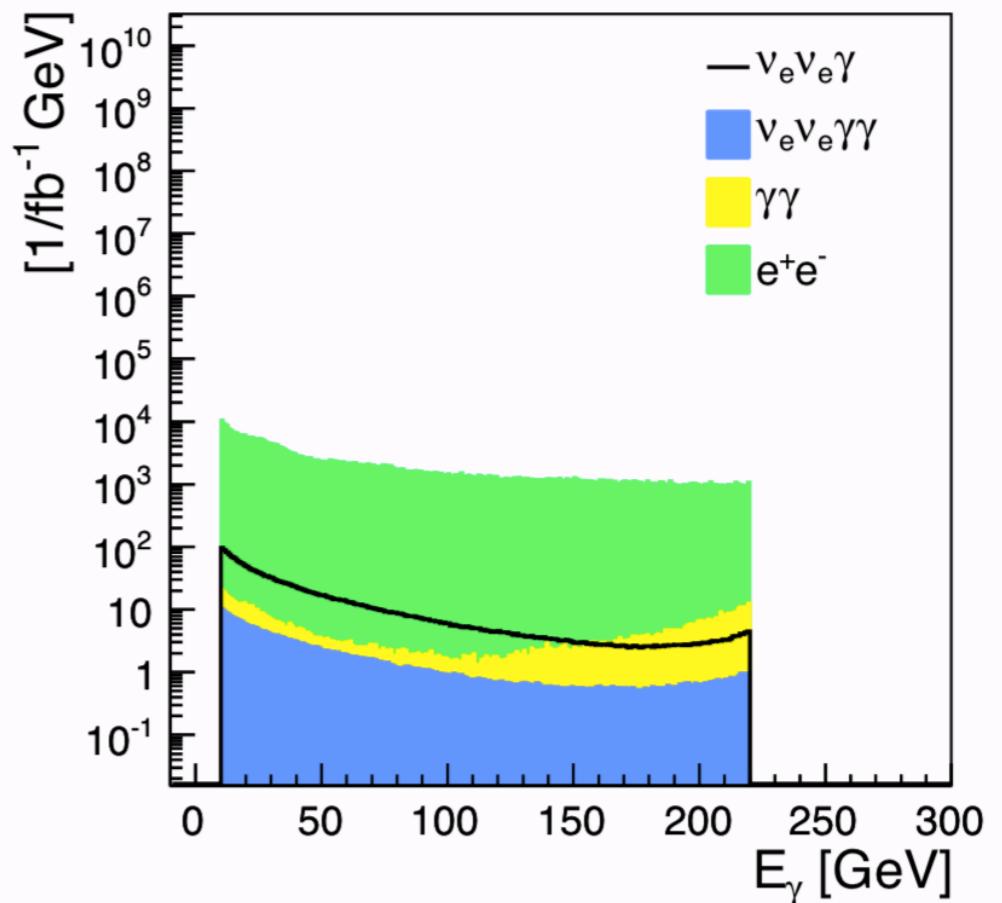
- ❖ Tight selection on $\gamma\gamma$, $e^+e^- \Rightarrow$ might lower the significance S/\sqrt{B}
- ❖ A veto of $p_T < 3.0 \text{ GeV}$ causes a loss of 0.27% signal



Event selection

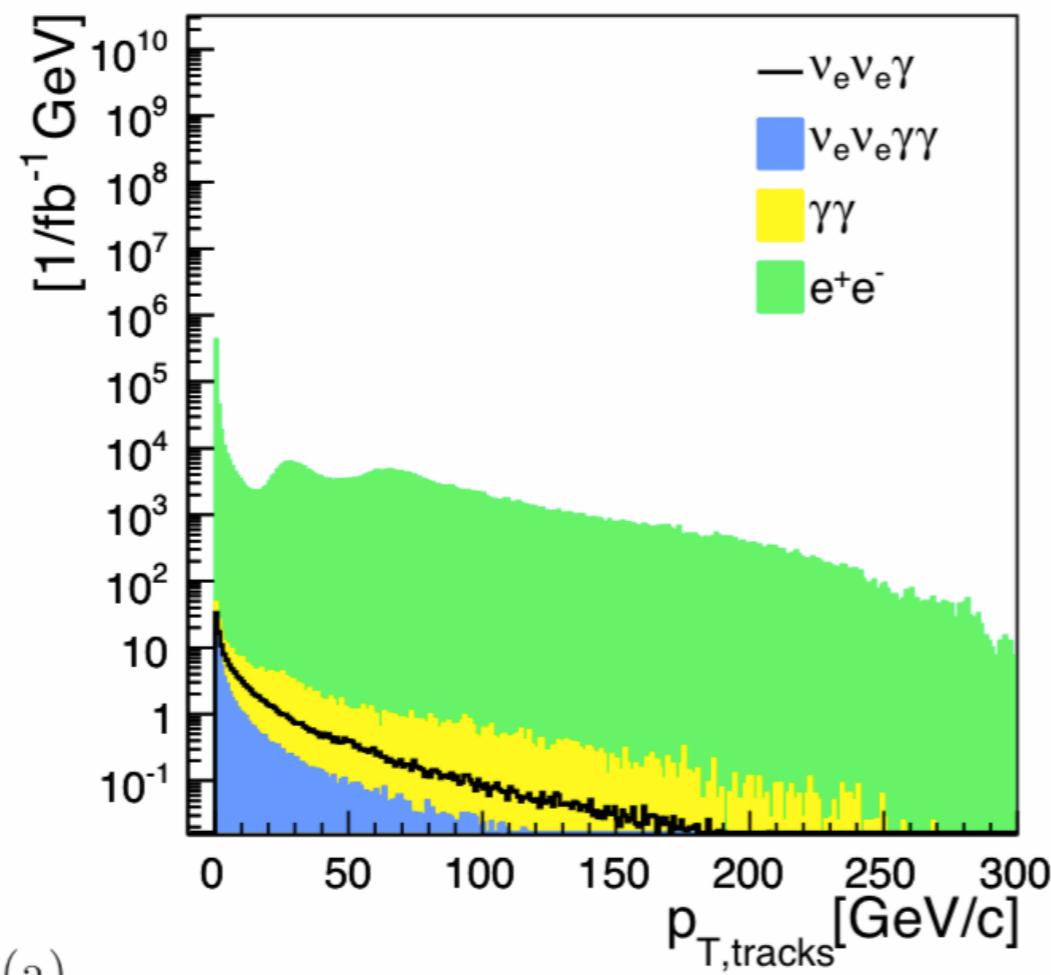
Discriminating variables

- Transverse track momentum
 $p_T < 3.0 \text{ GeV}$
- Visible energy $E_{vis} - E_\gamma < 20.0 \text{ GeV}$
- Rejection by detecting in BeamCal
- Blue $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma$ Yellow $e^+e^- \rightarrow \gamma\gamma$
Green => Radiative Bhabha
- Black irreducible background $e^+e^- \rightarrow \nu\bar{\nu}\gamma$

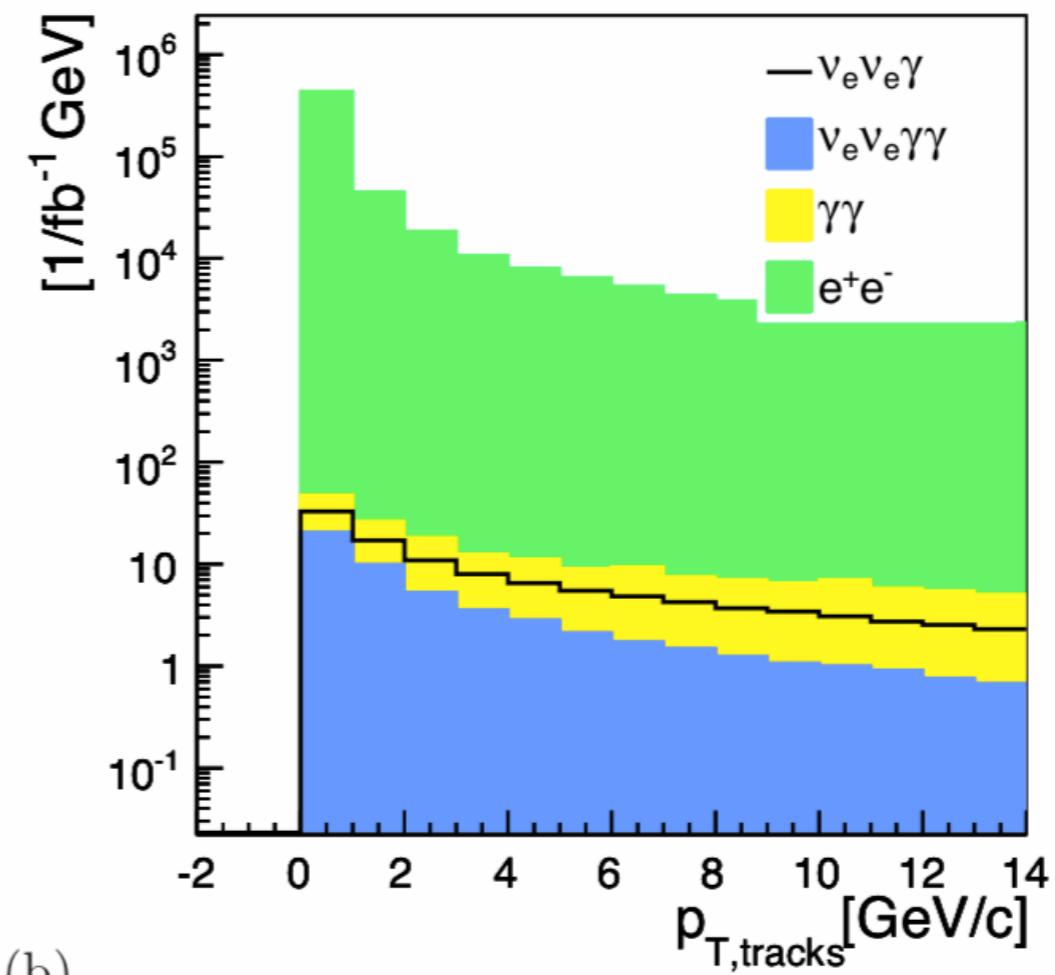


Event Selection

- The distributions are dominated by low p_T tracks after the veto of $p_T < 3.0 \text{ GeV}$ is applied



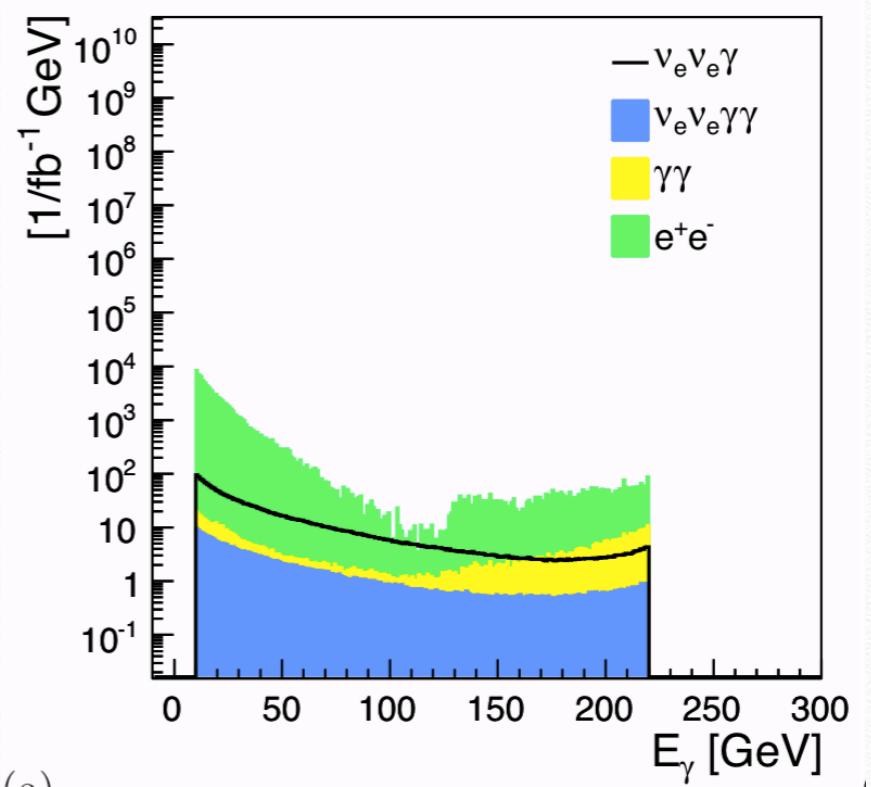
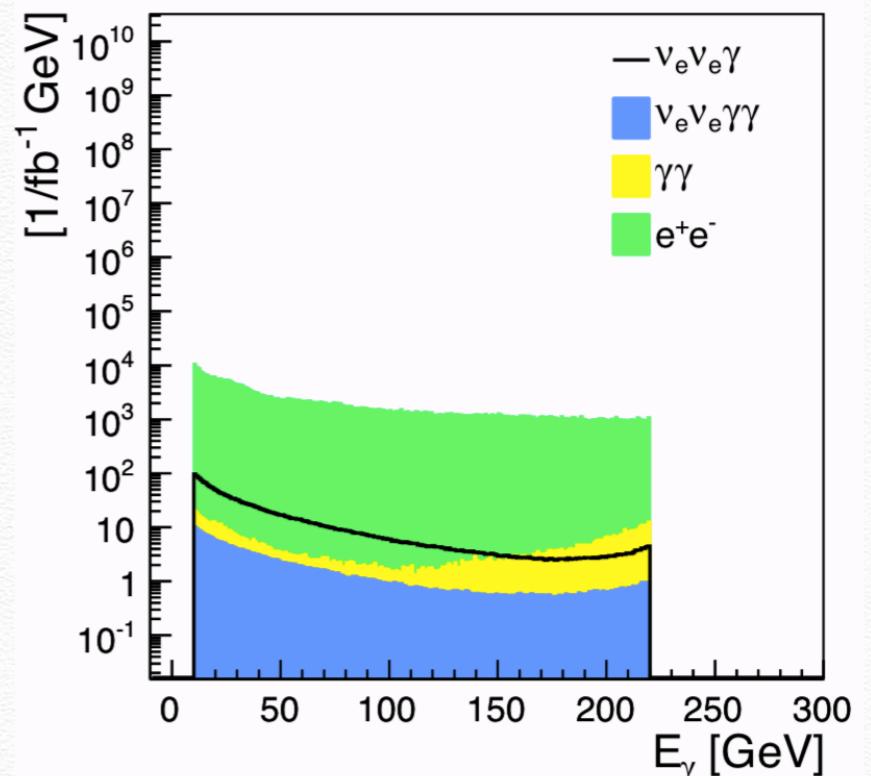
(a)



(b)

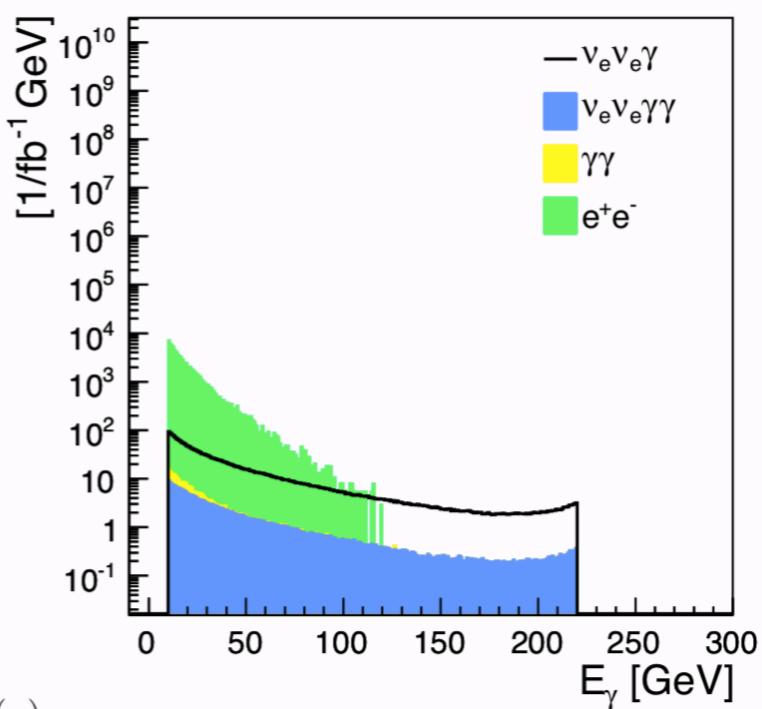
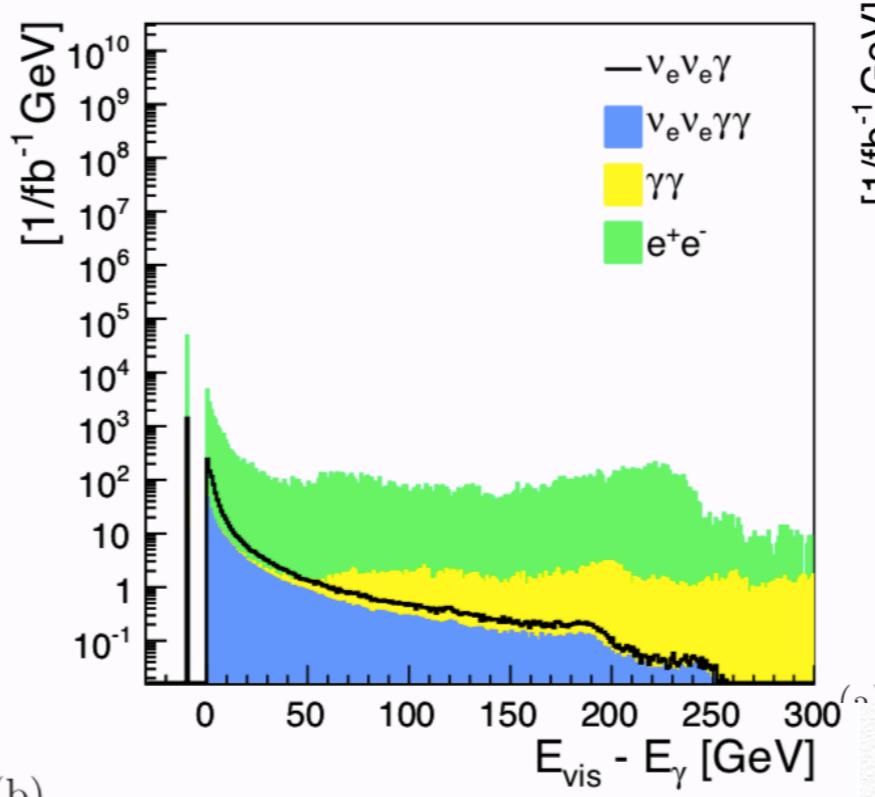
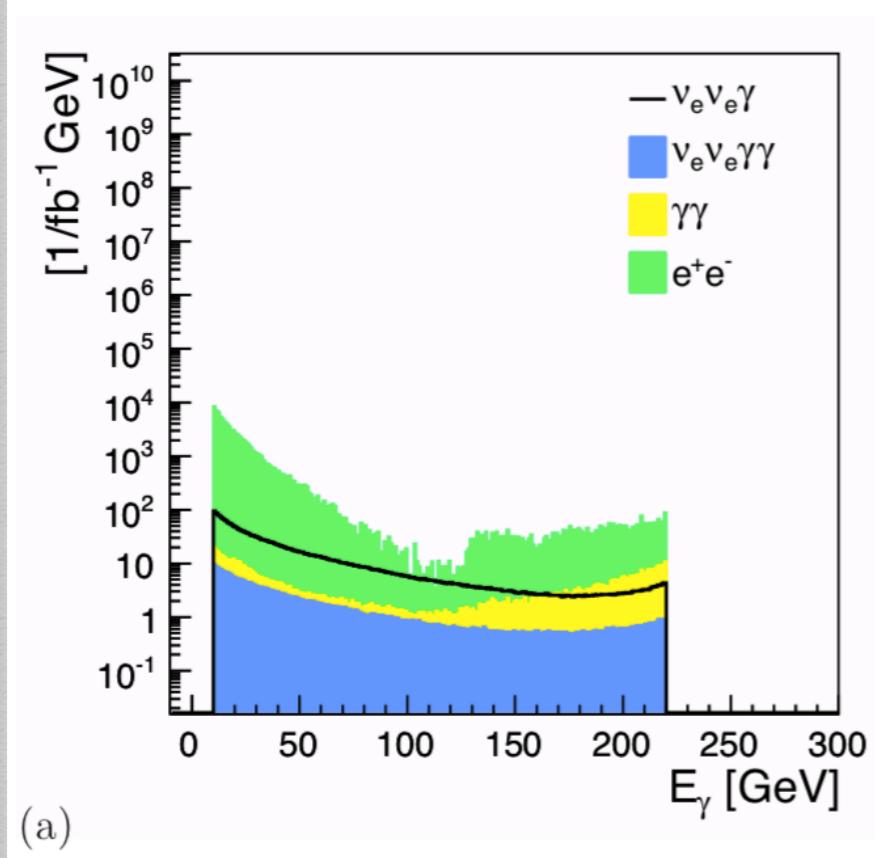
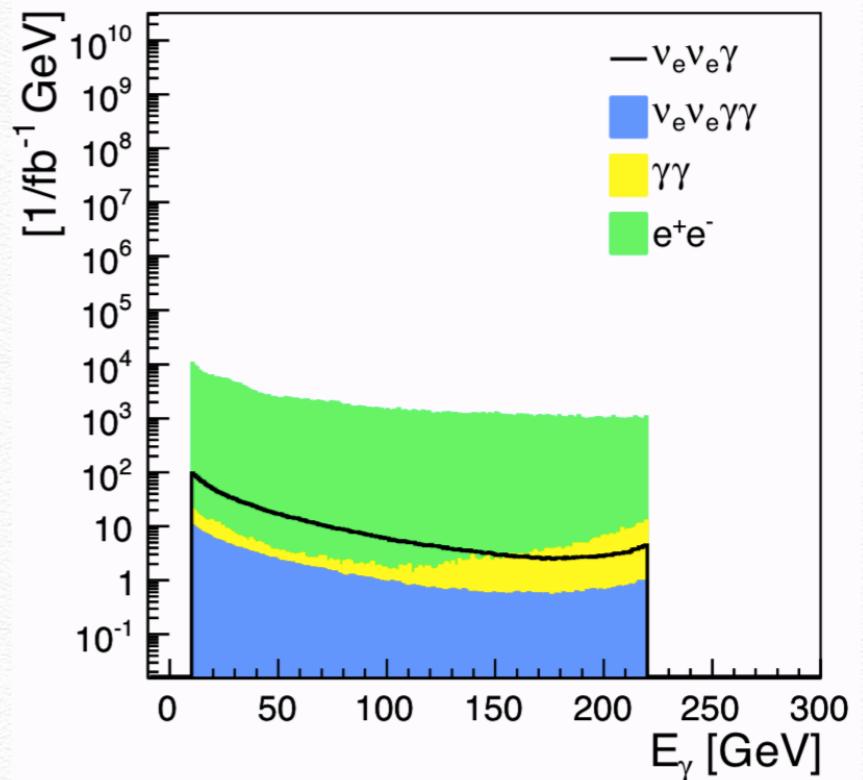
Event Selection

- A veto on events with events containing tracks of $p_T > 3.0 \text{ GeV}$ reject Bhabha and $e^+e^- \rightarrow \gamma\gamma$ events apart from muon and hadronic events (second figure)
- Signal rejected => 0.25%



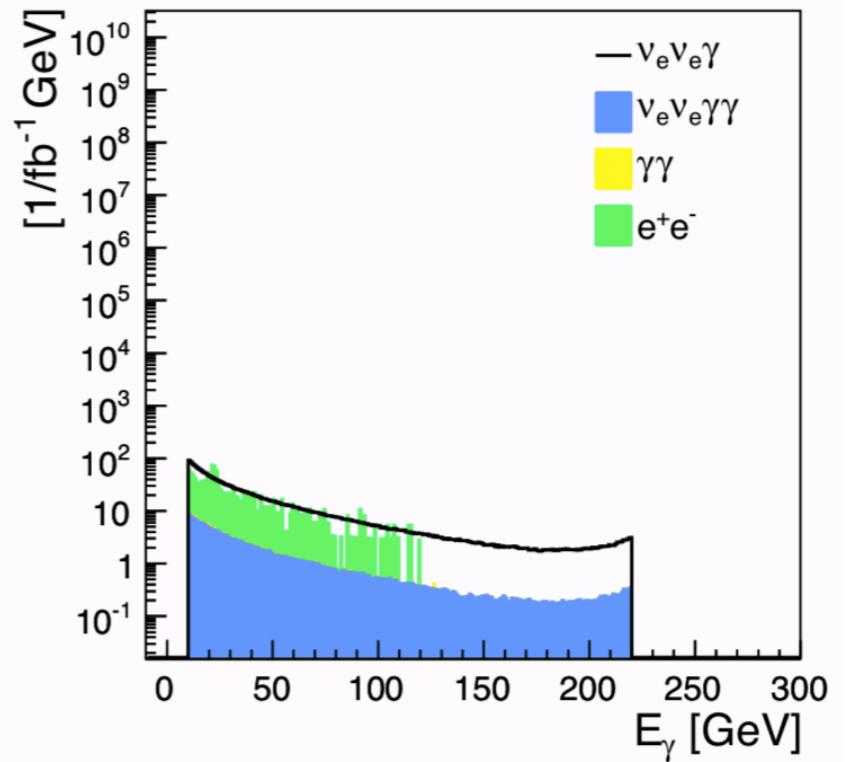
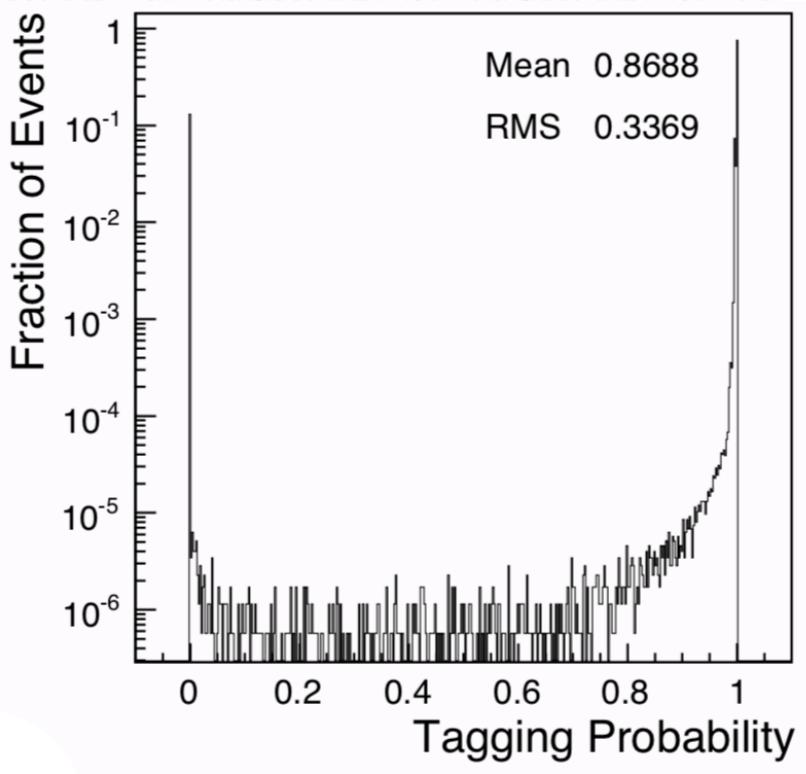
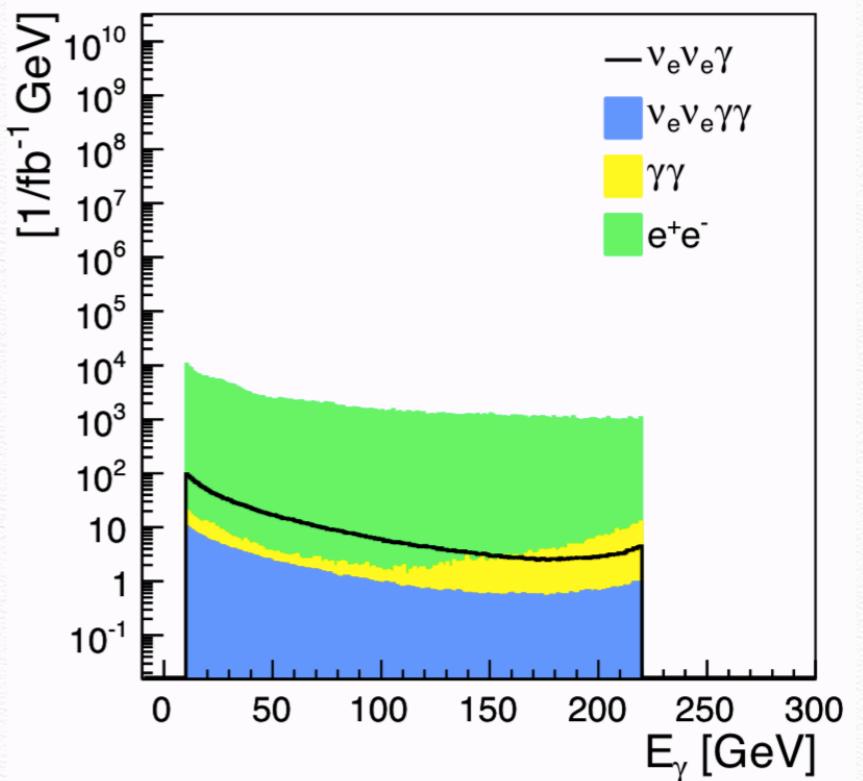
Event Selection

- Visible event energy excluding the most energetic photon is applied to reduce further hadronic and muonic backgrounds
- A veto of $E_{vis} - E_\gamma < 20.0 \text{ GeV}$ reduces $e^+e^- \rightarrow \gamma\gamma$ events completely and reduces Bhabha by 10%



Event Selection

- BeamCal effect is considered by assigning a relative probability corresponding to be tagged by the BeamCal to each event.
- Selection efficiency is 87%

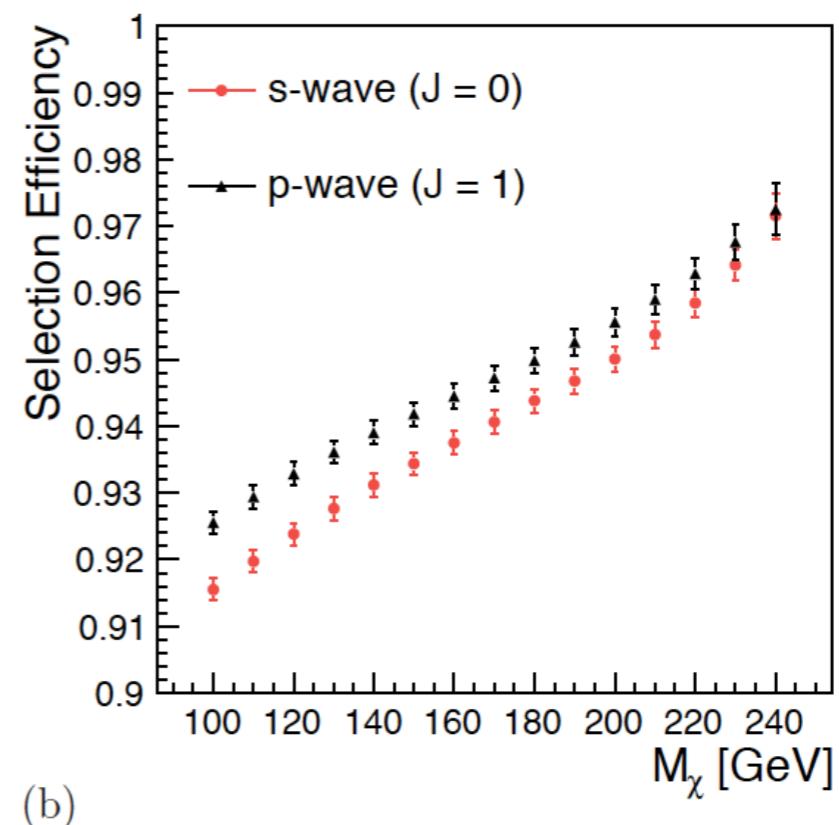
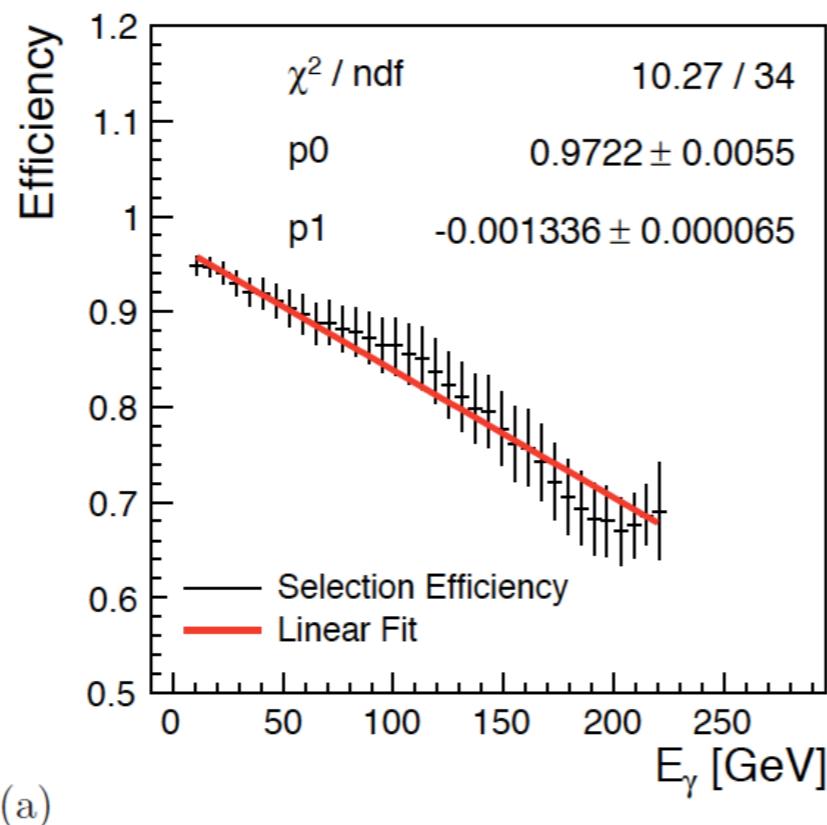


Event Selection Efficiency

Process	simulated	signal def.	$p_{T,track}$	$E_{vis} - E_\gamma$	BeamCal tag	Eff. [%]
Polarization Configuration $(P_{e^-}; P_{e^+}) = (+0.0; +0.0)$						
$\nu\nu\gamma$	4354	2493.3	2435.4	2283.88	2239.63	89.8
$\nu\nu\gamma\gamma$	613	344.3	325.4	238.52	228.51	66.4
$\nu\nu\gamma\gamma\gamma$	45	25.4	23.2	11.82	11.05	43.5
$\gamma\gamma$	6497	578.1	457.3	60.74	5.80	1.0
$\gamma\gamma\gamma$	1079	145.0	112.7	4.65	0.10	0.1
$\gamma\gamma\gamma\gamma$	97	19.5	14.7	0.15	0.03	0.2
Bhabha	17377544	421533.1	88935.9	67389.80	1228.70	0.3
Polarization Configuration $(P_{e^-}; P_{e^+}) = (+0.8; -0.3)$						
$\nu\nu\gamma$	1263	548.1	526.7	460.99	438.01	79.9
$\nu\nu\gamma\gamma$	214	97.4	89.4	49.51	43.45	44.6
$\nu\nu\gamma\gamma\gamma$	19	9.2	8.1	2.53	2.05	22.3
$\gamma\gamma$	8055	715.4	571.3	75.71	7.13	1.0
$\gamma\gamma\gamma$	1339	187.1	138.5	5.60	0.13	0.1
$\gamma\gamma\gamma\gamma$	120	25.2	19.5	0.13	0.06	0.2
Bhabha	17382269	423848.9	89074.7	67016.50	1204.30	0.3
Polarization Configuration $(P_{e^-}; P_{e^+}) = (-0.8; +0.3)$						
$\nu\nu\gamma$	9536	5635.3	5513.1	5203.03	5116.28	90.7
$\nu\nu\gamma\gamma$	1307	757.2	717.7	542.03	523.26	69.1
$\nu\nu\gamma\gamma\gamma$	95	53.7	49.4	26.79	25.35	47.2
$\gamma\gamma$	8059	718.4	562.7	74.91	7.26	1.0
$\gamma\gamma\gamma$	1338	184.8	141.1	5.93	0.13	0.1
$\gamma\gamma\gamma\gamma$	120	23.1	16.9	0.24	0.00	< 0.1
Bhabha	17424441	425324.9	88734.4	67761.60	1226.50	0.3

WIMP Selection Efficiency

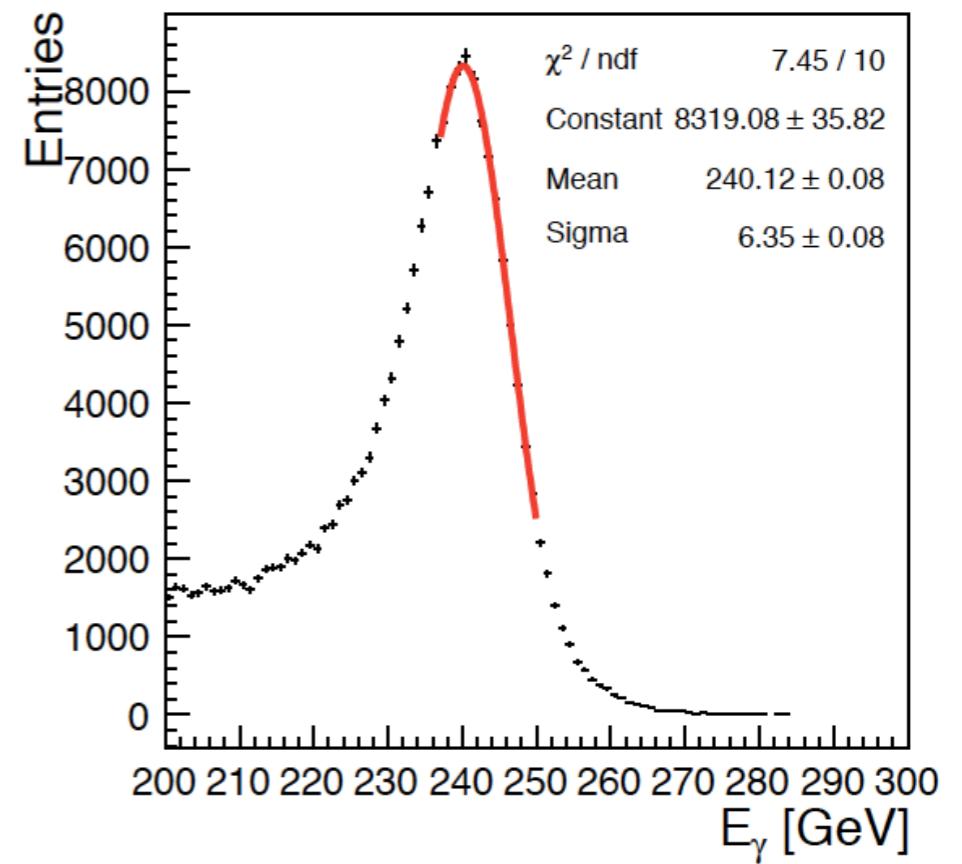
- Selection efficiency of the $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ background depends on photon energy spectrum
- photon energy spectrum depends on mass => selection efficiency depends on mass
- For a fixed total cross section, p-wave peaks sharper at low photon energy, resulting in higher selection efficiency for p-waves of all masses



Systematic Uncertainties

- Signal efficiency $\epsilon = \frac{N}{\mathcal{L}\sigma}$ calibrated by radiative Z-return for an integrated luminosity $\mathcal{L} = 500 \text{ fb}^{-1}$ after event selection without vetoes on photon
- Uncertainty of normalization of Gaussian fit => given by data statistics => upper bound of error (photon reconstruction efficiency)
- Statistical uncertainty of polarization for observed data events N_D , $\Delta\sigma_{P_{e^-}-P_{e^+}} = \frac{\sqrt{N_D}}{\mathcal{L}\epsilon}$

- 200 fb^{-1} with $(+|P_{e^-}|; -|P_{e^+}|)$,
- 200 fb^{-1} with $(-|P_{e^-}|; +|P_{e^+}|)$,
- 50 fb^{-1} with $(+|P_{e^-}|; +|P_{e^+}|)$,
- 50 fb^{-1} with $(-|P_{e^-}|; -|P_{e^+}|)$.



Parameter	value	$\delta\sigma [\text{fb}]$
$\delta P/P$	0.25%	5.7
$\delta\varepsilon/\varepsilon$	1.75%	1.7
$\delta\mathcal{L}/\mathcal{L}$	0.01%	0.01
Total		5.9

Event Selection

$$\begin{aligned}\sigma_{P_{e^-} P_{e^+}} &= \frac{1}{4} \{(1 + P_{e^-})(1 + P_{e^+})\sigma_{RR} + (1 - P_{e^-})(1 - P_{e^+})\sigma_{LL} \\ &\quad + (1 + P_{e^-})(1 - P_{e^+})\sigma_{RL} + (1 - P_{e^-})(1 + P_{e^+})\sigma_{LR}\}.\end{aligned}$$

$$\begin{aligned}\sigma_{+-} &= \frac{1}{4} \{(1 + |P_-|)(1 - |P_+|)\sigma_{RR} + (1 - |P_-|)(1 + |P_+|)\sigma_{LL} \\ &\quad + (1 + |P_-|)(1 + |P_+|)\sigma_{RL} + (1 - |P_-|)(1 - |P_+|)\sigma_{LR}\} \\ \sigma_{-+} &= \frac{1}{4} \{(1 - |P_-|)(1 + |P_+|)\sigma_{RR} + (1 + |P_-|)(1 - |P_+|)\sigma_{LL} \\ &\quad + (1 - |P_-|)(1 - |P_+|)\sigma_{RL} + (1 + |P_-|)(1 + |P_+|)\sigma_{LR}\} \\ \sigma_{++} &= \frac{1}{4} \{(1 + |P_-|)(1 + |P_+|)\sigma_{RR} + (1 - |P_-|)(1 - |P_+|)\sigma_{LL} \\ &\quad + (1 + |P_-|)(1 - |P_+|)\sigma_{RL} + (1 - |P_-|)(1 + |P_+|)\sigma_{LR}\} \\ \sigma_{--} &= \frac{1}{4} \{(1 - |P_-|)(1 - |P_+|)\sigma_{RR} + (1 + |P_-|)(1 + |P_+|)\sigma_{LL} \\ &\quad + (1 - |P_-|)(1 + |P_+|)\sigma_{RL} + (1 + |P_-|)(1 - |P_+|)\sigma_{LR}\},\end{aligned}$$

- For individual cross sections, coupling structure can be determined
- Unpolarized cross section σ_0 is defined as $\sum_{(i,j) \in \{R,L\}} \sigma_{(i,j)} = 4 \times \sigma_0$

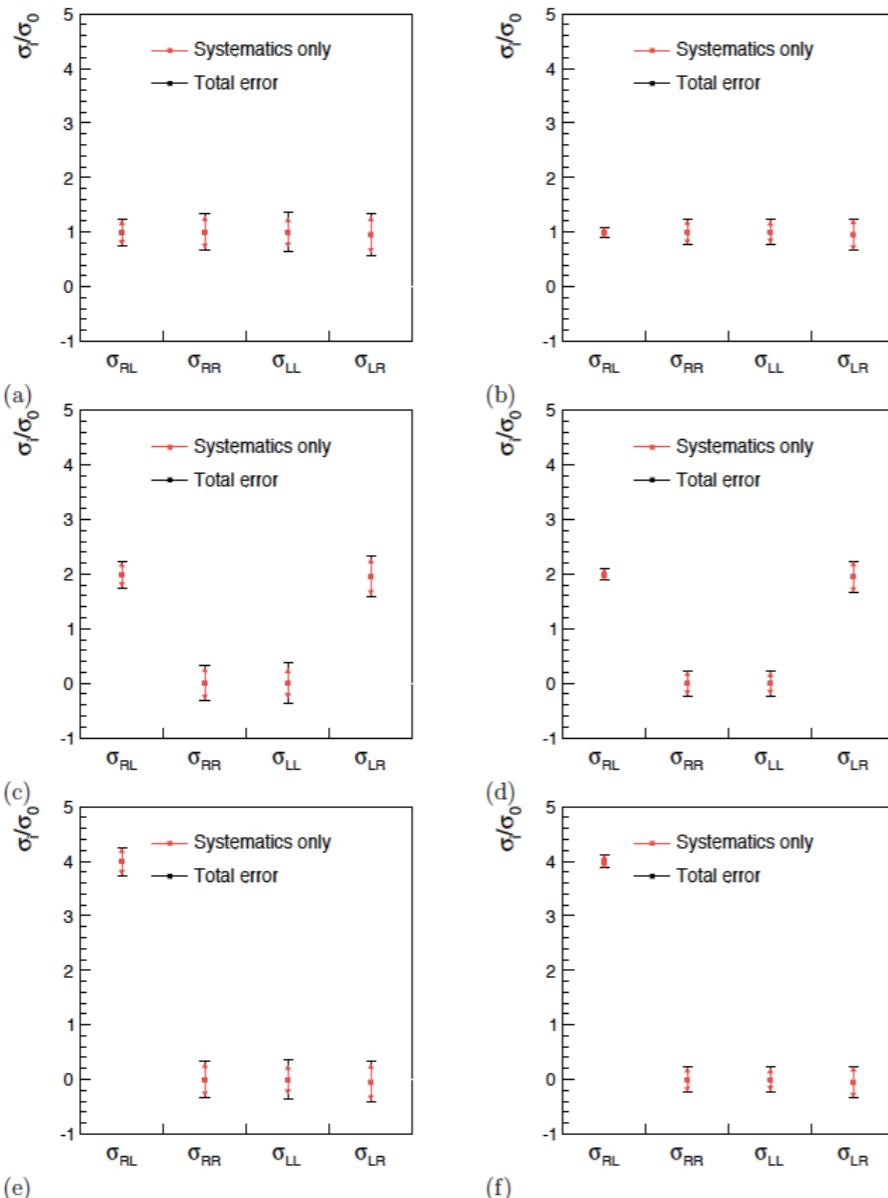
Polarization

- Equal: Independent of helicity $\kappa(e_R^-, e_L^+) = \kappa(e_R^-, e_R^+) = \kappa(e_L^-, e_L^+) = \kappa(e_L^-, e_R^+)$
- Helicity: Conserves helicity and parity $\kappa(e_R^-, e_L^+) = \kappa(e_L^-, e_R^+); \quad \kappa(e_R^-, e_R^+) = \kappa(e_L^-, e_L^+) = 0.$
- Anti-SM: WIMPs couple to only tight handed electrons and left-handed positrons. $\kappa(e_R^-, e_L^+);$ All others $\kappa(e^-, e^+) = 0$

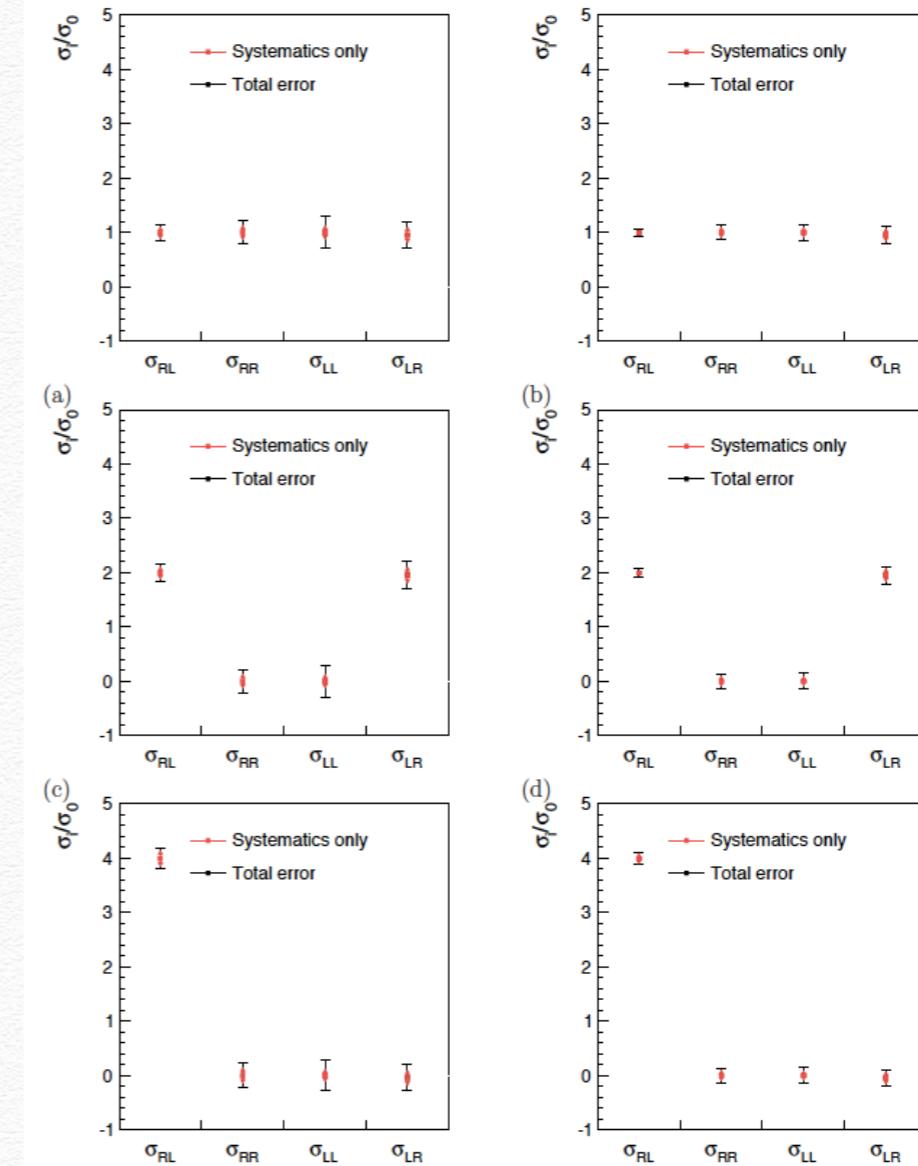
Polarization configuration

Pol. config. $(P_{e-}; P_{e+})$	\mathcal{L} [fb $^{-1}$]	σ [fb]	$\pm\delta\sigma$ [fb]	stat. syst. contributions			total $\pm\delta\sigma$ [fb]
				$\pm\delta P$	$\pm\delta\varepsilon$	$\pm\delta\mathcal{L}$ [fb]	
"Equal" scenario and $\mathcal{L} = 50.0 \text{ fb}^{-1}$							
(+0.8; -0.3)	20	99.4	10.4	5.7	1.7	0.01	12.0
(-0.8; +0.3)	20	97.3	20.5	11.9	1.7	0.01	23.8
(+0.8; +0.3)	5	99.5	22.1	10.6	1.7	0.01	24.6
(-0.8; -0.3)	5	98.5	32.5	7.9	1.7	0.01	33.5
"Equal" scenario and $\mathcal{L} = 500.0 \text{ fb}^{-1}$							
(+0.8; -0.3)	200	99.4	3.3	5.7	1.7	0.01	6.8
(-0.8; +0.3)	200	97.3	6.5	11.9	1.7	0.01	13.7
(+0.8; +0.3)	50	99.5	7.0	10.6	1.7	0.01	12.8
(-0.8; -0.3)	50	98.5	10.3	7.9	1.7	0.01	13.1
"Helicity" scenario and $\mathcal{L} = 500.0 \text{ fb}^{-1}$							
(+0.8; -0.3)	200	123.4	3.3	5.7	2.1	0.01	7.0
(-0.8; +0.3)	200	121.3	6.5	11.9	2.1	0.01	13.7
(+0.8; +0.3)	50	75.5	7.0	10.6	1.3	0.01	12.8
(-0.8; -0.3)	50	74.5	10.2	7.9	1.3	0.01	13.0
"Anti-SM" scenario and $\mathcal{L} = 500.0 \text{ fb}^{-1}$							
(+0.8; -0.3)	200	233.4	3.4	5.7	4.0	0.02	7.8
(-0.8; +0.3)	200	11.3	6.4	11.9	0.2	0.00	13.6
(+0.8; +0.3)	50	125.5	7.0	10.6	2.2	0.01	12.9
(-0.8; -0.3)	50	24.5	10.2	7.9	0.4	0.00	12.9

Determining coupling scenario



$$\begin{aligned} |P_{e^-}| &= 0.8 & |P_{e^-}| &= 0.8 \\ |P_{e^+}| &= 0.3 & |P_{e^+}| &= 0.6 \\ \delta P/P &= 0.25\% \end{aligned}$$



$$\begin{aligned} |P_{e^-}| &= 0.8 & |P_{e^-}| &= 0.8 \\ |P_{e^+}| &= 0.3 & |P_{e^+}| &= 0.6 \\ \delta P/P &= 0.1\% \end{aligned}$$

Determining coupling scenario

	$(P_{e^-} ; P_{e^+}) = (0.8; 0.3)$	$(P_{e^-} ; P_{e^+}) = (0.8; 0.6)$
”Equal” scenario		
σ_{RL}/σ_0	0.99 ± 0.24 (0.16)	0.99 ± 0.10 (0.07)
σ_{RR}/σ_0	1.00 ± 0.33 (0.21)	1.00 ± 0.23 (0.14)
σ_{LL}/σ_0	1.00 ± 0.37 (0.29)	1.00 ± 0.23 (0.15)
σ_{LR}/σ_0	0.95 ± 0.38 (0.25)	0.95 ± 0.28 (0.15)
”Helicity” scenario		
σ_{RL}/σ_0	1.99 ± 0.24 (0.16)	1.99 ± 0.10 (0.08)
σ_{RR}/σ_0	0.00 ± 0.33 (0.21)	0.00 ± 0.23 (0.14)
σ_{LL}/σ_0	0.00 ± 0.37 (0.29)	0.00 ± 0.23 (0.15)
σ_{LR}/σ_0	1.95 ± 0.38 (0.25)	1.95 ± 0.29 (0.16)
”Anti-SM” scenario		
σ_{RL}/σ_0	3.99 ± 0.26 (0.18)	3.99 ± 0.12 (0.10)
σ_{RR}/σ_0	0.00 ± 0.33 (0.22)	0.00 ± 0.23 (0.14)
σ_{LL}/σ_0	0.00 ± 0.36 (0.28)	0.00 ± 0.23 (0.15)
σ_{LR}/σ_0	-0.05 ± 0.37 (0.24)	-0.05 ± 0.28 (0.15)

”Equal : ” $\sigma_{P_{e^-} P_{e^+}} = \sigma_0$

”Helicity : ” $\sigma_{P_{e^-} P_{e^+}} = \sigma_0[1 - P_{e^-} P_{e^+}]$

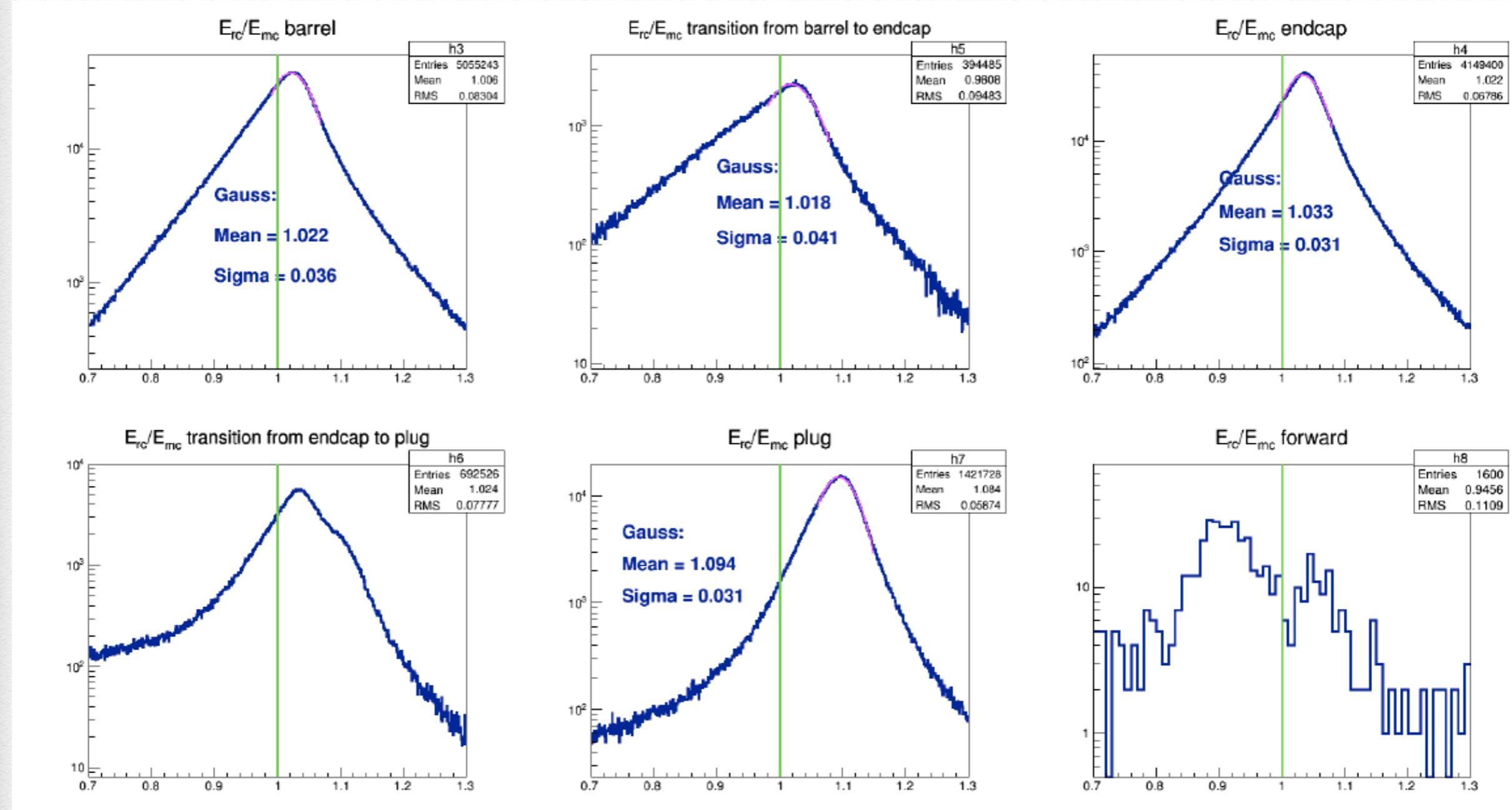
”Anti – SM : ” $\sigma_{P_{e^-} P_{e^+}} = \sigma_0[1 - P_{e^-} P_{e^+} + P_{e^-} - P_{e^+}].$

P-Values and coupling scenarios

Data Scenario	<i>p</i> -values (χ^2/ndf) for different Theory Scenarios					
	"Equal"		"Helicity"		"Anti-SM"	
"Equal"	≈ 1.0	(0.0)	$< 10^{-8}$	(14.0)	$< 10^{-8}$	(60.0)
"Helicity"	$< 10^{-8}$	(13.4)	≈ 1.0	(0.0)	$< 10^{-8}$	(31.9)
"Anti-SM"	$< 10^{-8}$	(53.0)	$< 10^{-8}$	(29.9)	≈ 1.0	(0.0)

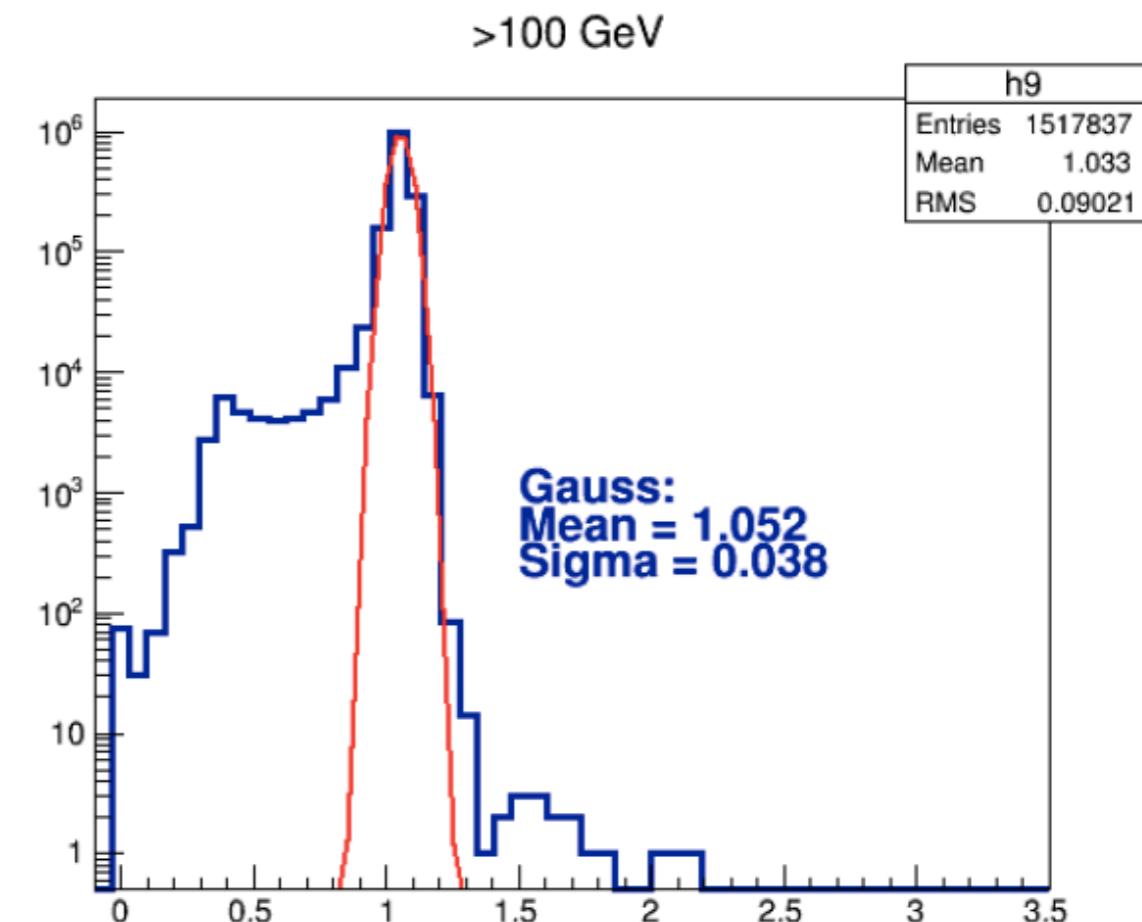
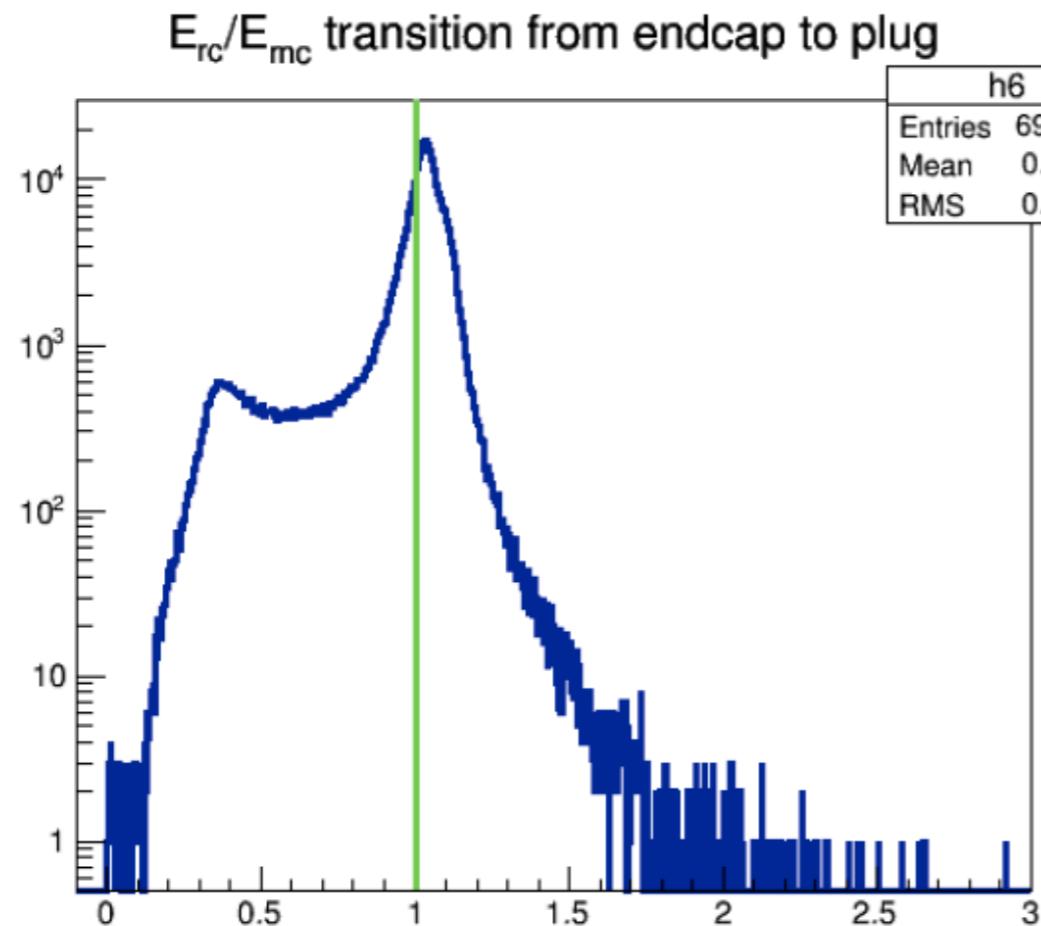
"Equal : "	$\sigma_{P_{e^-} P_{e^+}} = \sigma_0$
"Helicity : "	$\sigma_{P_{e^-} P_{e^+}} = \sigma_0[1 - P_{e^-} P_{e^+}]$
"Anti - SM : "	$\sigma_{P_{e^-} P_{e^+}} = \sigma_0[1 - P_{e^-} P_{e^+} + P_{e^-} - P_{e^+}]$.

Work at $\sqrt{s} = 500 \text{ GeV}$ by Moritz : Reconstruction at ECal



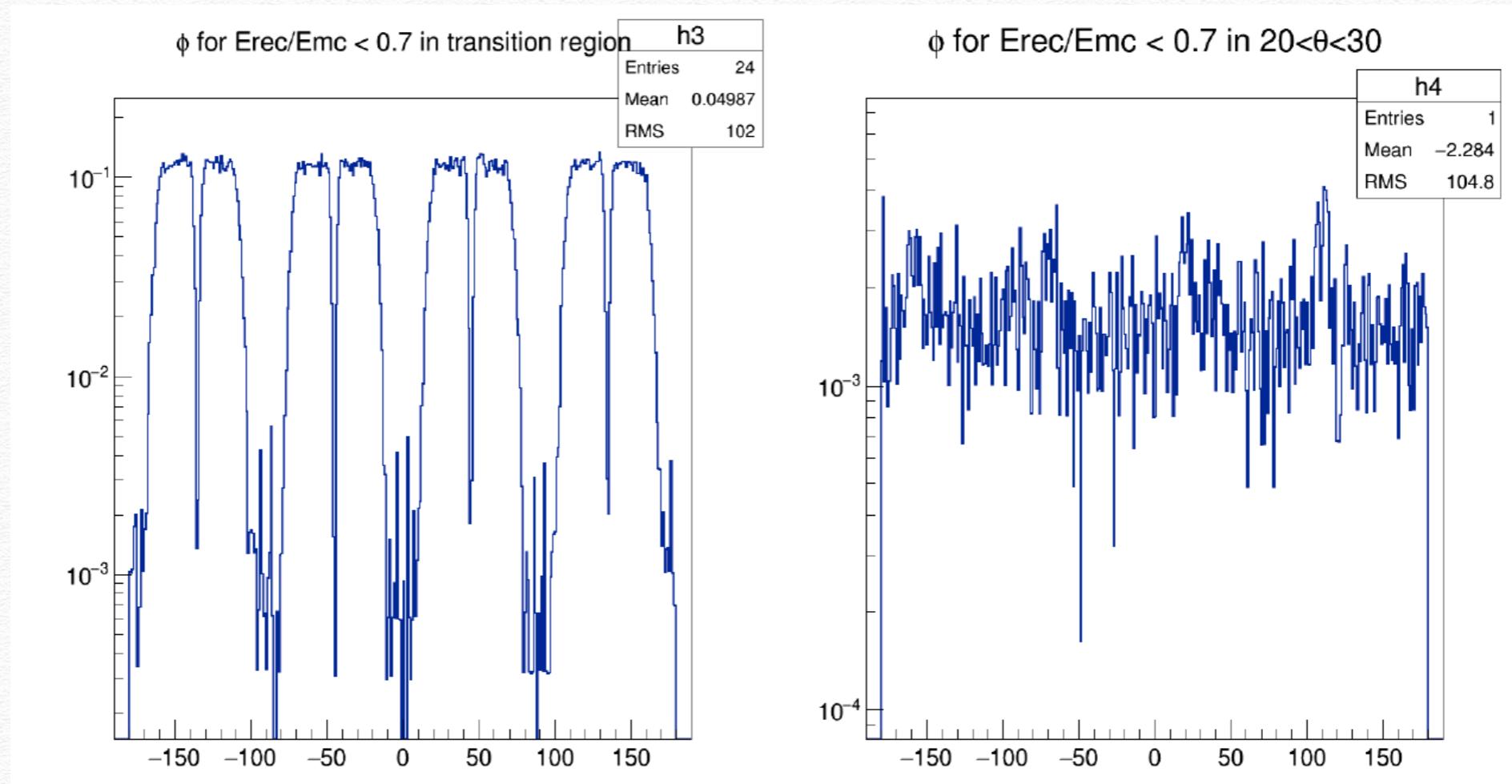
In plug reconstructed energy 10% too high

Reconstruction at transition region of endcap and plug



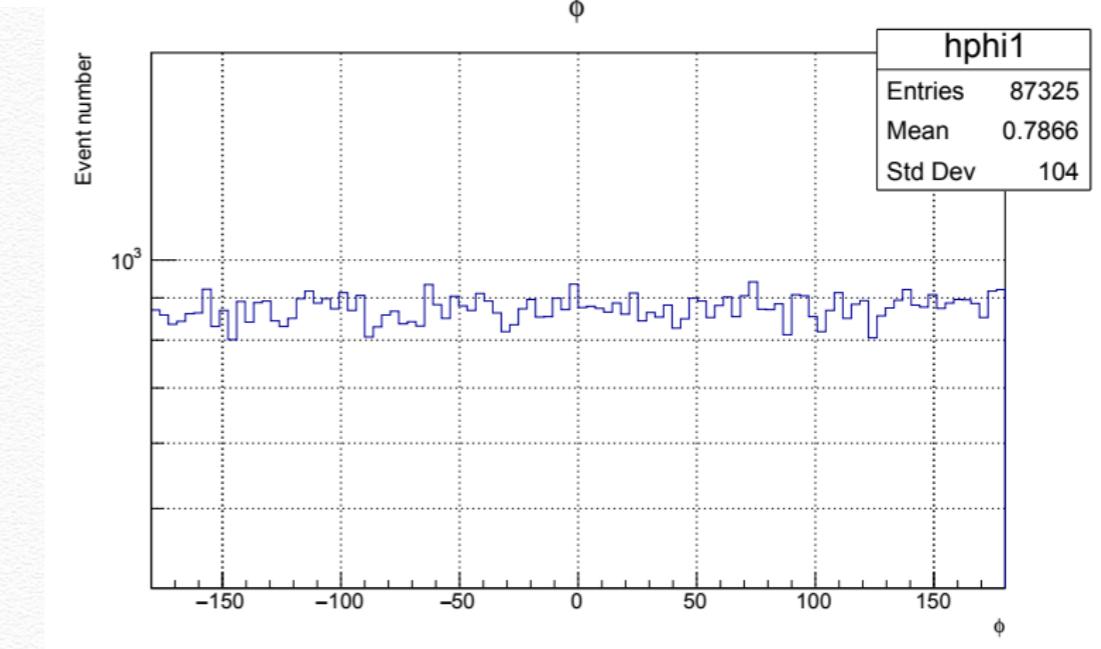
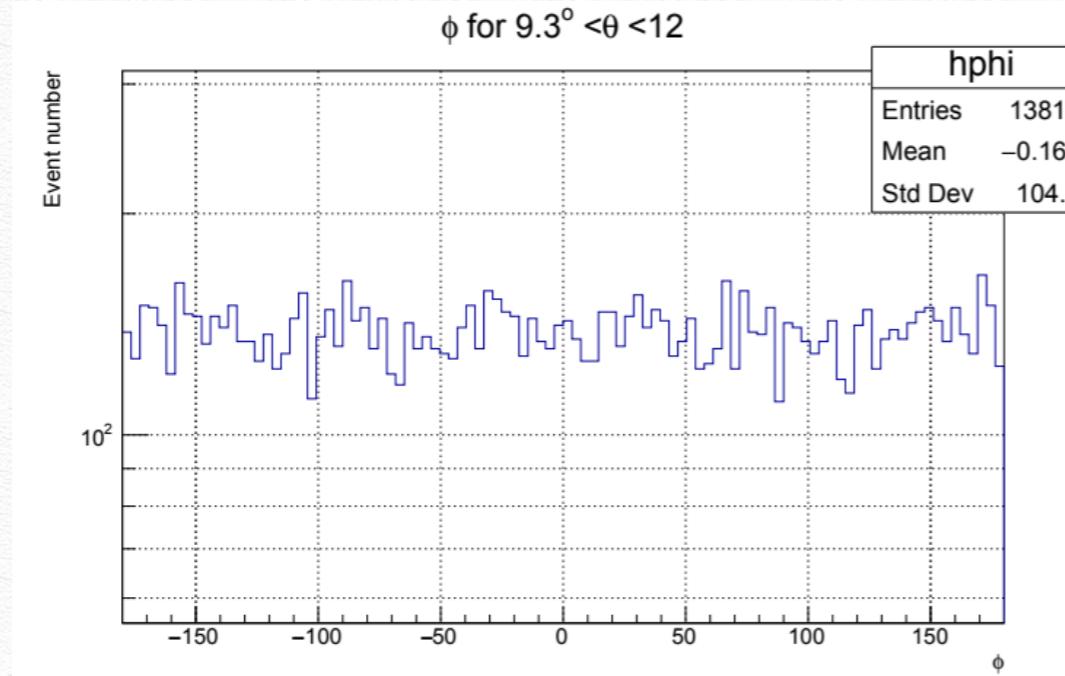
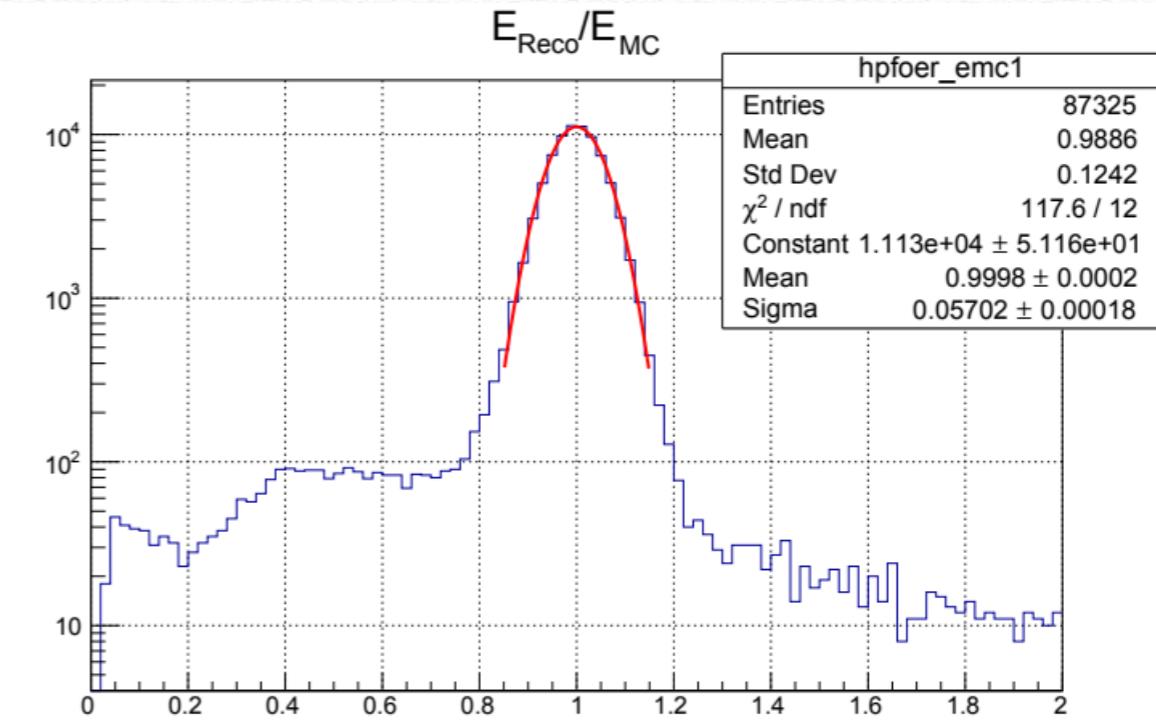
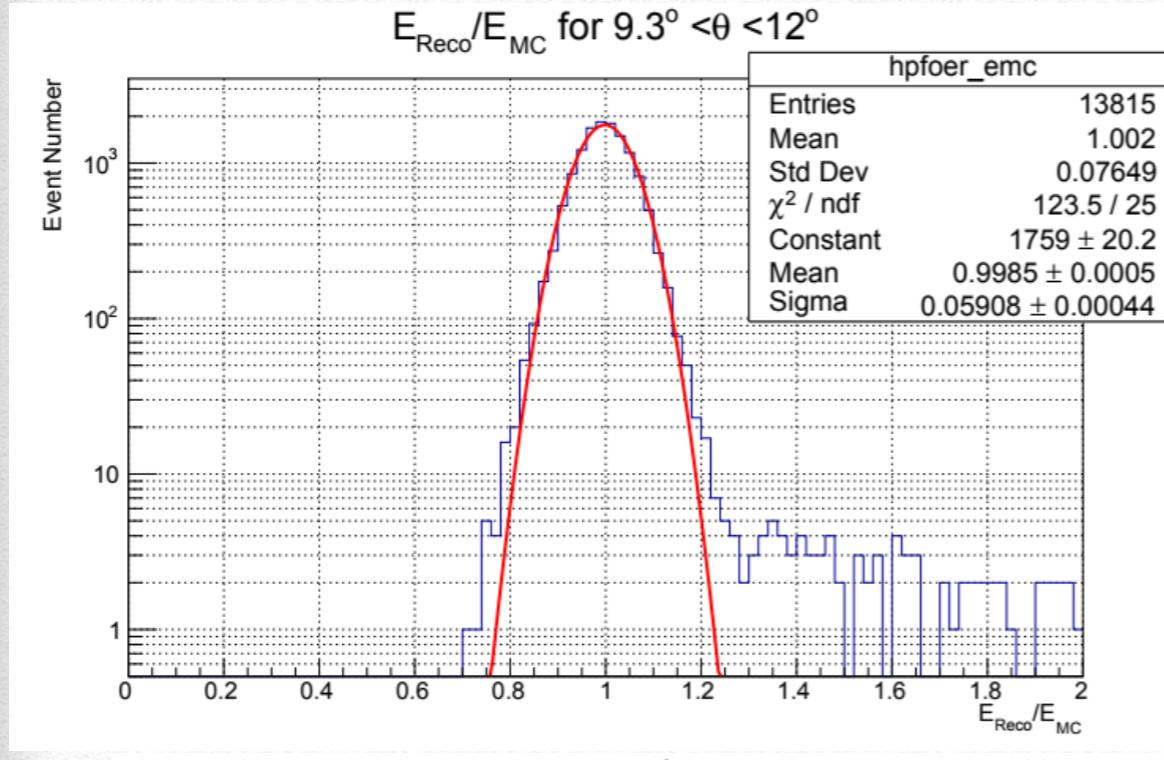
- in some cases photon reconstruction fails in the transition region of endcap and plug
- Azimuthal angle dependence can be expected because of the square shape of plug

ϕ behaviour

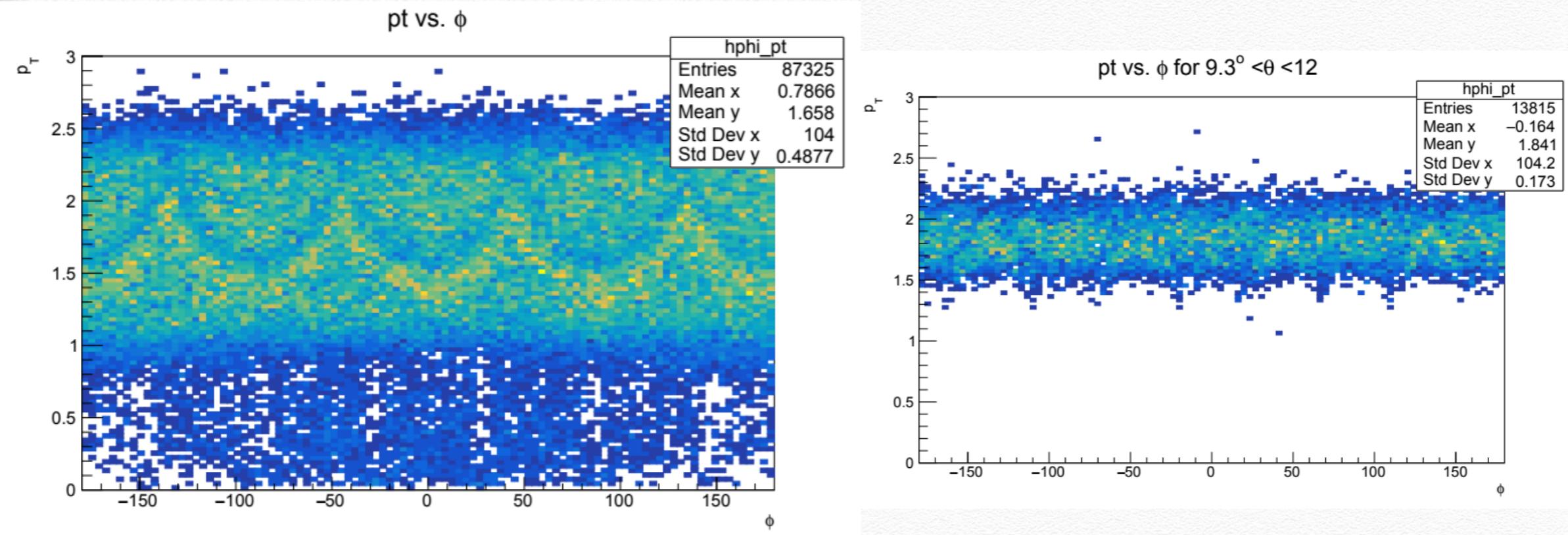


- ❖ Alright when equals 0,90,180,270 (Photon completely at endcap)
- ❖ Alright when ϕ equals 45,135,.. (Photon completely at plug)
- ❖ Peaks at transition region $9.3^\circ < \theta < 12^\circ$

My test sample



Future Plans



- ❖ Produce new corrected physics samples
- ❖ Carry out the WIMP search at ILC $\sqrt{s} = 250 \text{ GeV}$