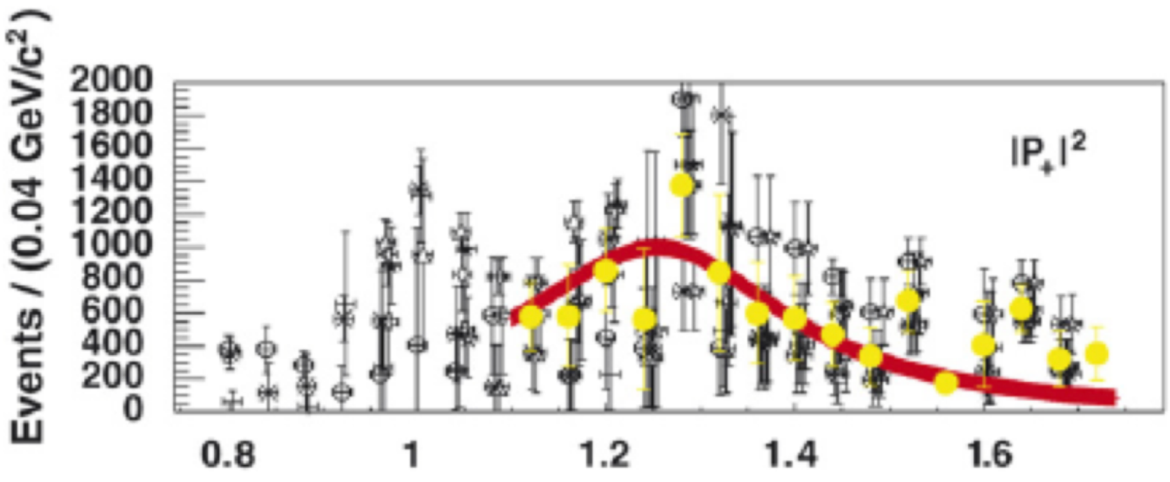
CLAS collaboration meeting

7 March 2019

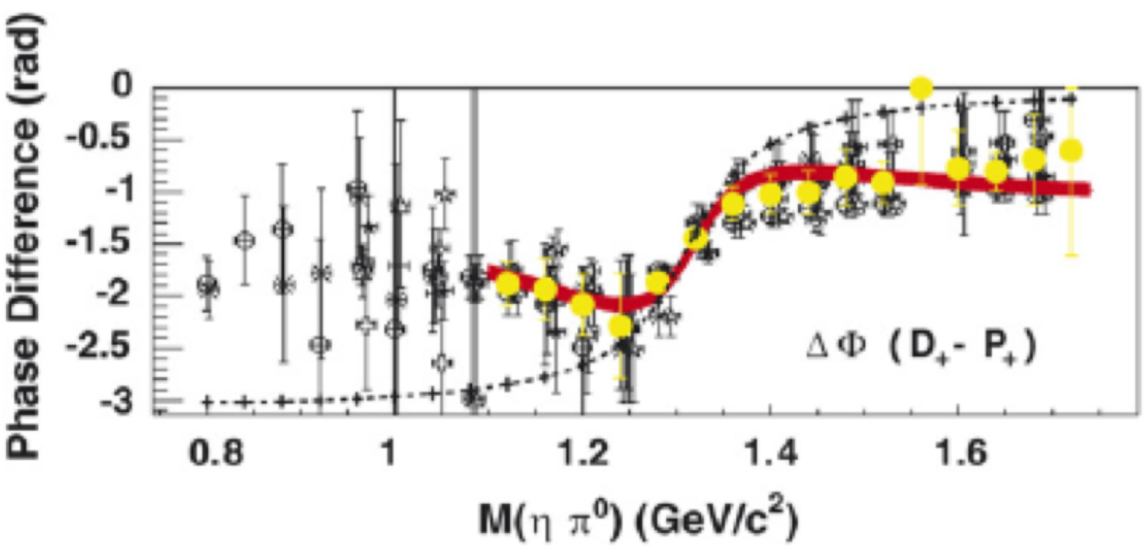
Analysis of the reaction $\gamma p \rightarrow p\pi^0\eta$ with the g12 dataset

Introduction and motivation

- Due to the pseudoscalar nature of the two mesons, the $\pi^0\eta$ final state is a good candidate to search for exotics. **Any P-wave resonance would be a 1^{-+} exotic state.**
- This channel has been investigated by past experiments (VES, **E852**, Crystal Barrel): a possible exotic signal - π_1 (1400) - has been seen but still a definite answer is missing.
- I analyze the photo-production $\gamma p \rightarrow p\pi^0\eta$ reaction using data from the CLAS-g12 dataset, exploiting the two-photons decay of both mesons
    - **Large statistics**
    - **High-energy photon beam**
    - **Trigger optimized for neutrals in the final state**



(b)



Events skimming

Runs selection:

- Using g12runs –t pass1 –t flux –i
- Selecting only runs after 56653 (trigger)
- 462 runs selected, 48403 BOS files

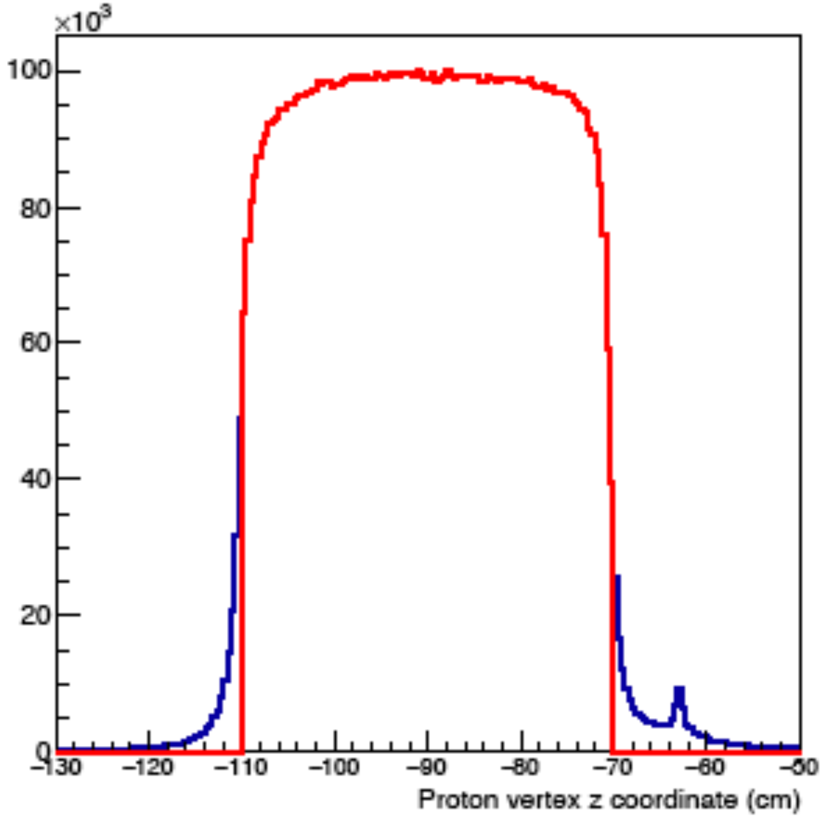
Events selection (PART bank):

- 1 positive, 0 negatives, **at least** 4 neutrals, asking the positive to be a proton
- 60.6 M events selected
- Only skim #4 "4-not 2ctrk 2pos1neg 1ckaon1ctrk" was used
  - The others have each event with more than 1 charged particle

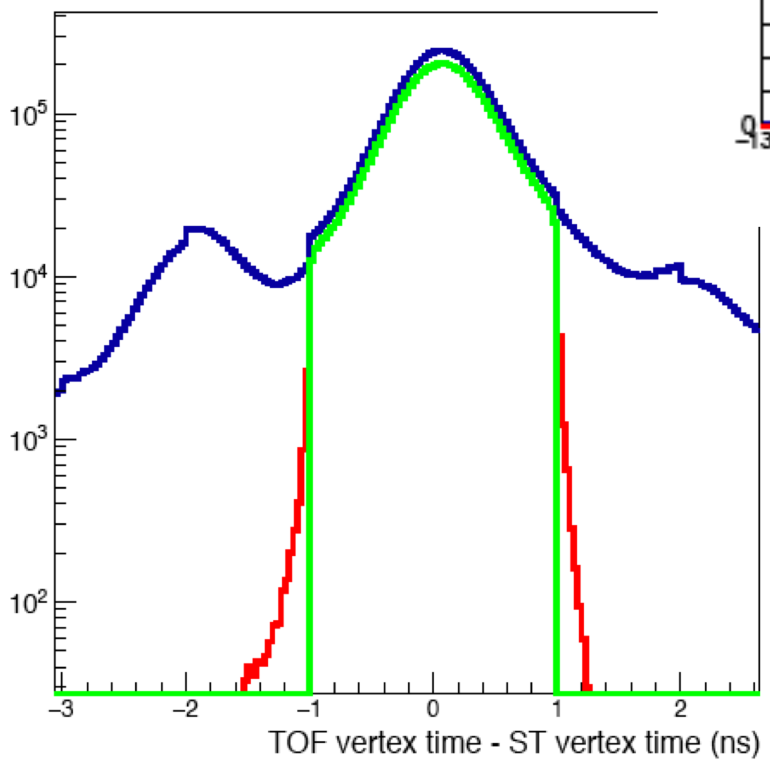
Events filtering

- All the procedures described in the official g12 analysis note have been strictly followed:
    - Eloss correction, momentum correction, beam energy correction, TOF knock-out fiducial cuts, EC cuts
- Other cuts include:
    - Proton vertex cut
    - TOF vertex time – ST-time cut – this cut is applied AFTER photon beam selection

Proton vertex cut:
-110 cm < vz < -70 cm



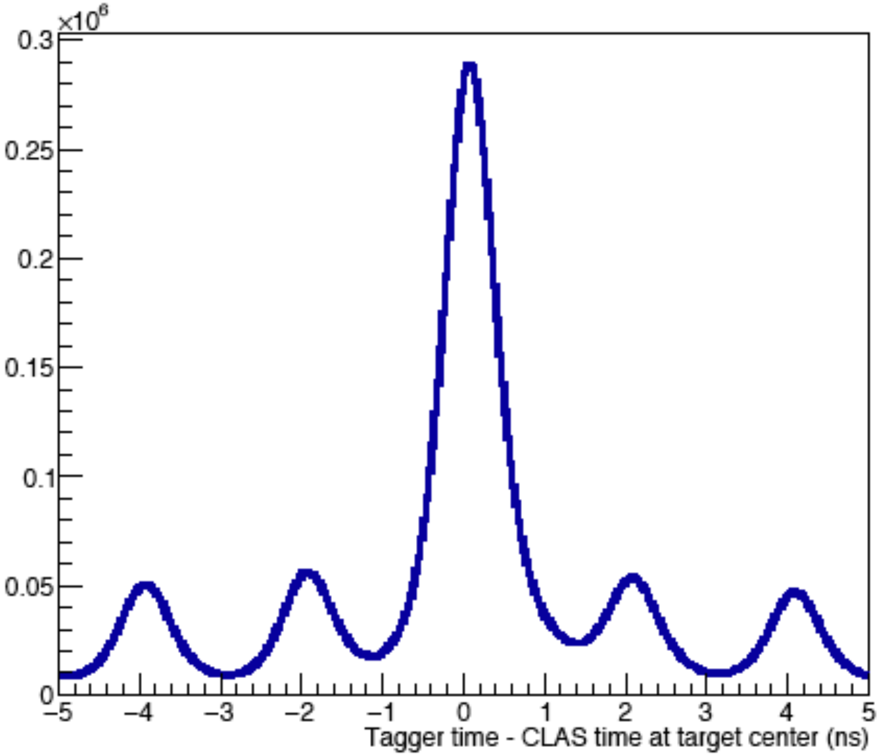
TOF vertex time – ST-time

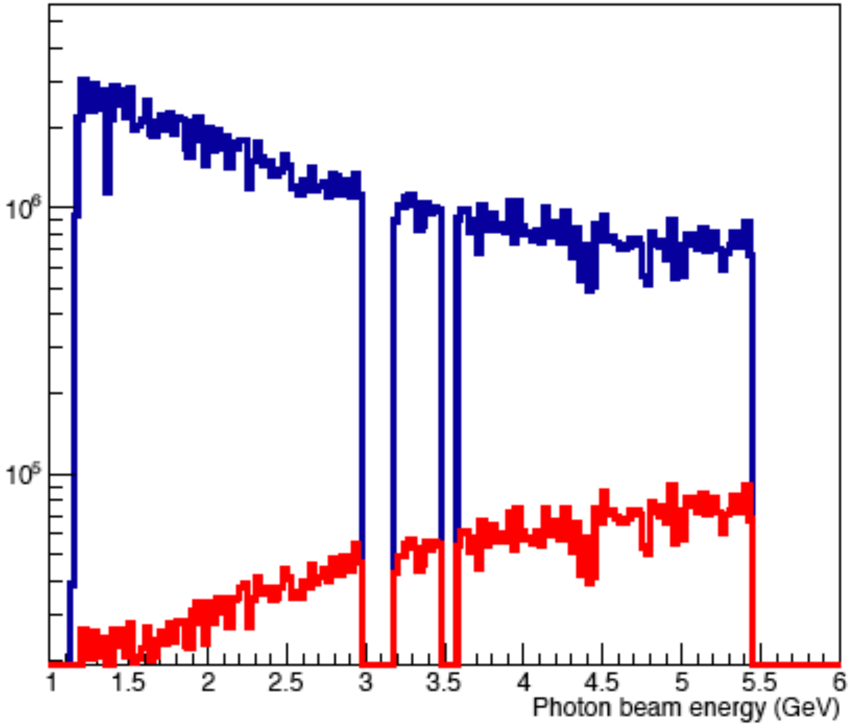


Events filtering – beam photon selection

Beam photon selection was performed by considering all entries in the TAGR bank and applying following cuts:

- Bad counters rejection
- Coincidence between tagger time at target center and CLAS time at target center - ± 1 ns window
- If more than 1 photon satisfy above conditions, **the event is rejected**
  - Same procedure is applied for MC: accidentals to the TAGR bank are added in GSIM





Events filtering – neutrals

- Only neutral particles measured in EC, with $\beta > 0$ were selected
- G12 specific fiducial cuts for neutrals were applied
- The energy of all neutrals in the fiducial region was recomputed by assuming the particle to be a photon:
  - $E = E_{EC}/0.272$ (0.272 is the so-called "EC_MAGIC_NUMBER", see PID, MakePart.c, gamma_energy function)
  - Angles from the original PART entry

SUMMARY:

Selection	Number of events kept	Percentage
All events	60.6 M	100%
Proton vertex z-cut	57.9M	95.5%
Proton TOF knockout and fid. cuts	51.6M	85.2%
Photon beam selection	33.9M	56.0%
Proton vertex time cut	33.8M	55.8%
Neutrals selection	8.32M	13.7%

EC photon corrections and covariance matrix

Goal: check and correct for systematic shifts in measured photon energy and angles

Method (1-D case, x variable)

- Make 2D plot of $\Delta = x_T - x_M \ vs \ x_T$
- Slice along y axis and fit with Gaus function – plot average value $\mu(x_T) \ vs \ x_T$
- Perform a best fit with "proper" function to get parameterization of $\mu(x_T)$
- Correct by iteration:

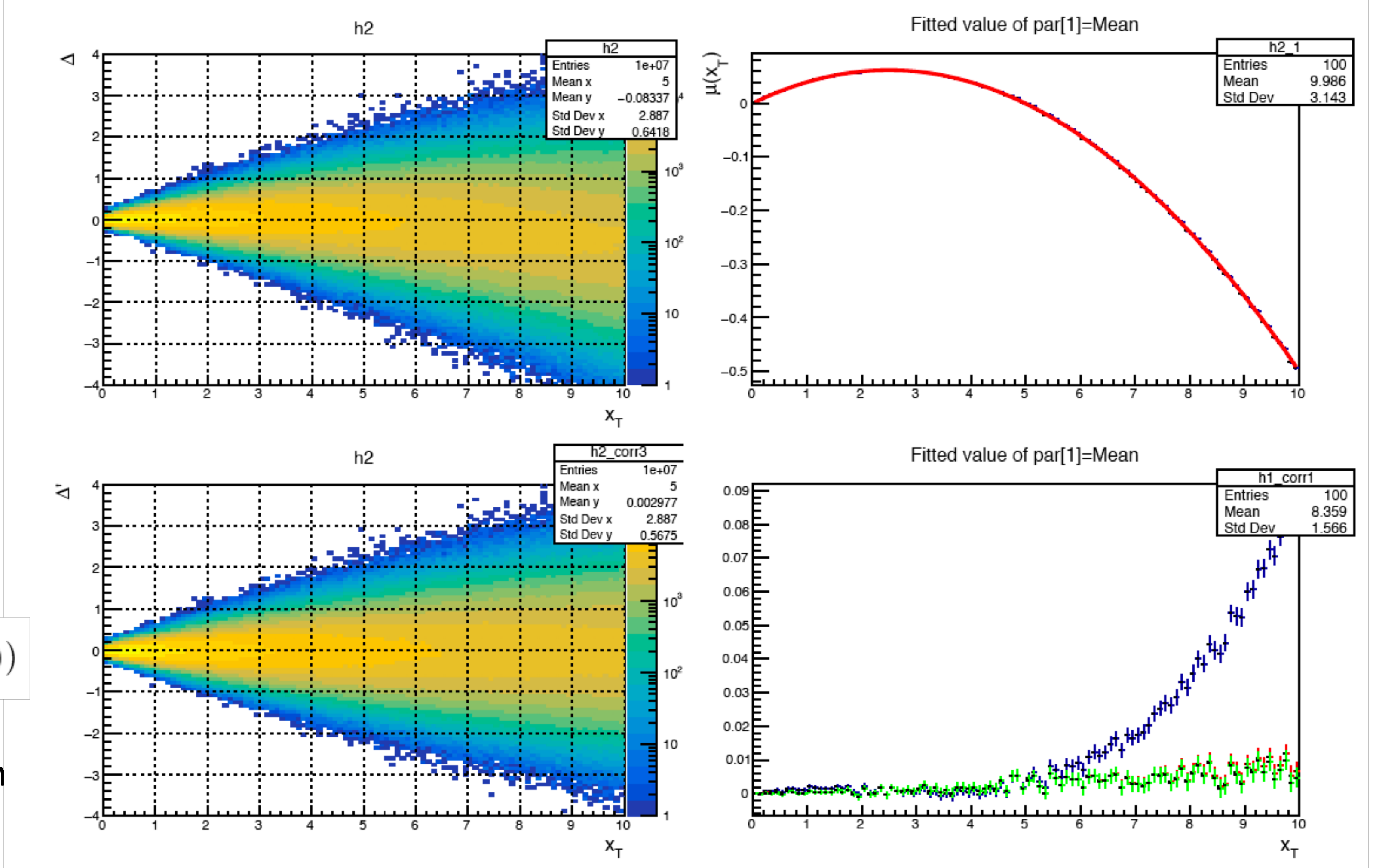
$$x_C = x_M + \mu(x_T)$$

$$x_C = x_M + \mu(x_M + \mu(x_M + \mu(x_M + \ldots)))$$

Method (3-D case)

- As above, involves matrix formalism

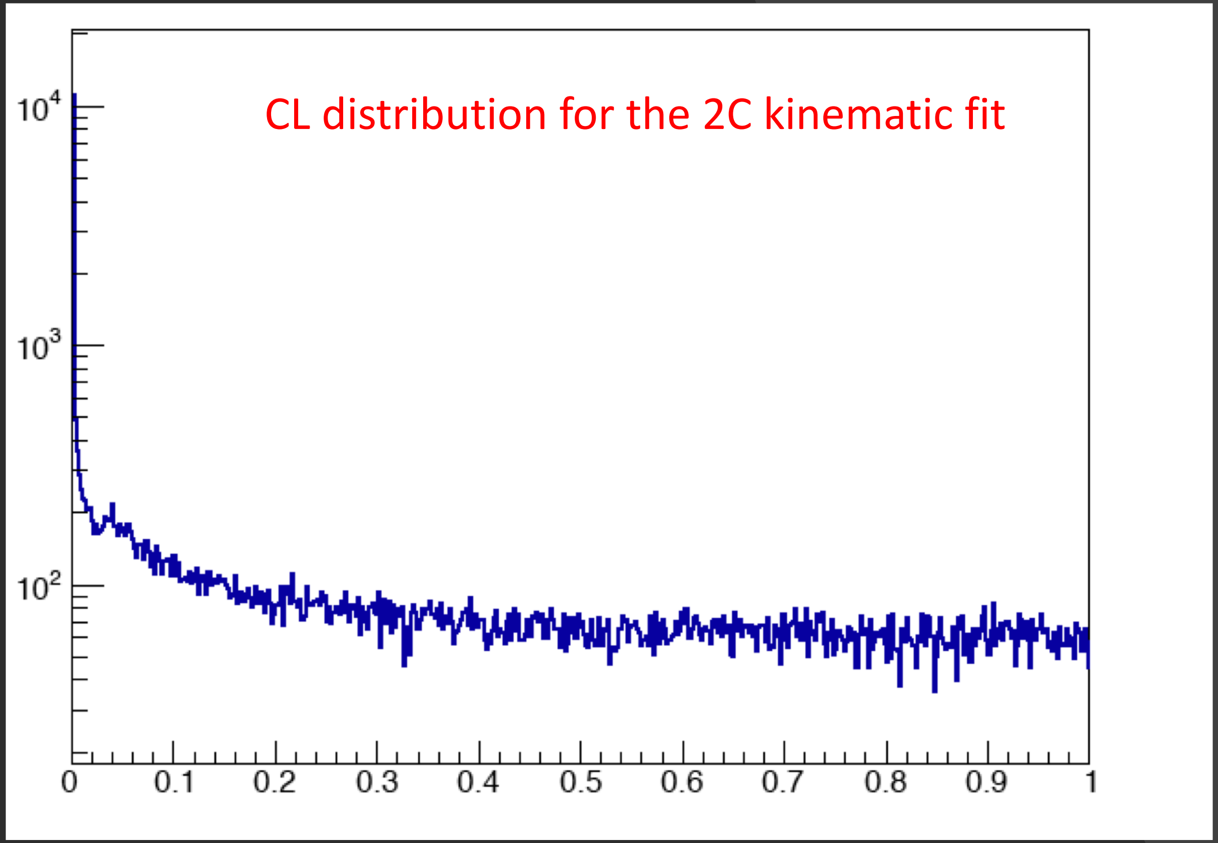
Toy model, events generated with systematic shift $x_M = 0.95x_T + 0.01{x_T}^2$



EC photon corrections and covariance matrix

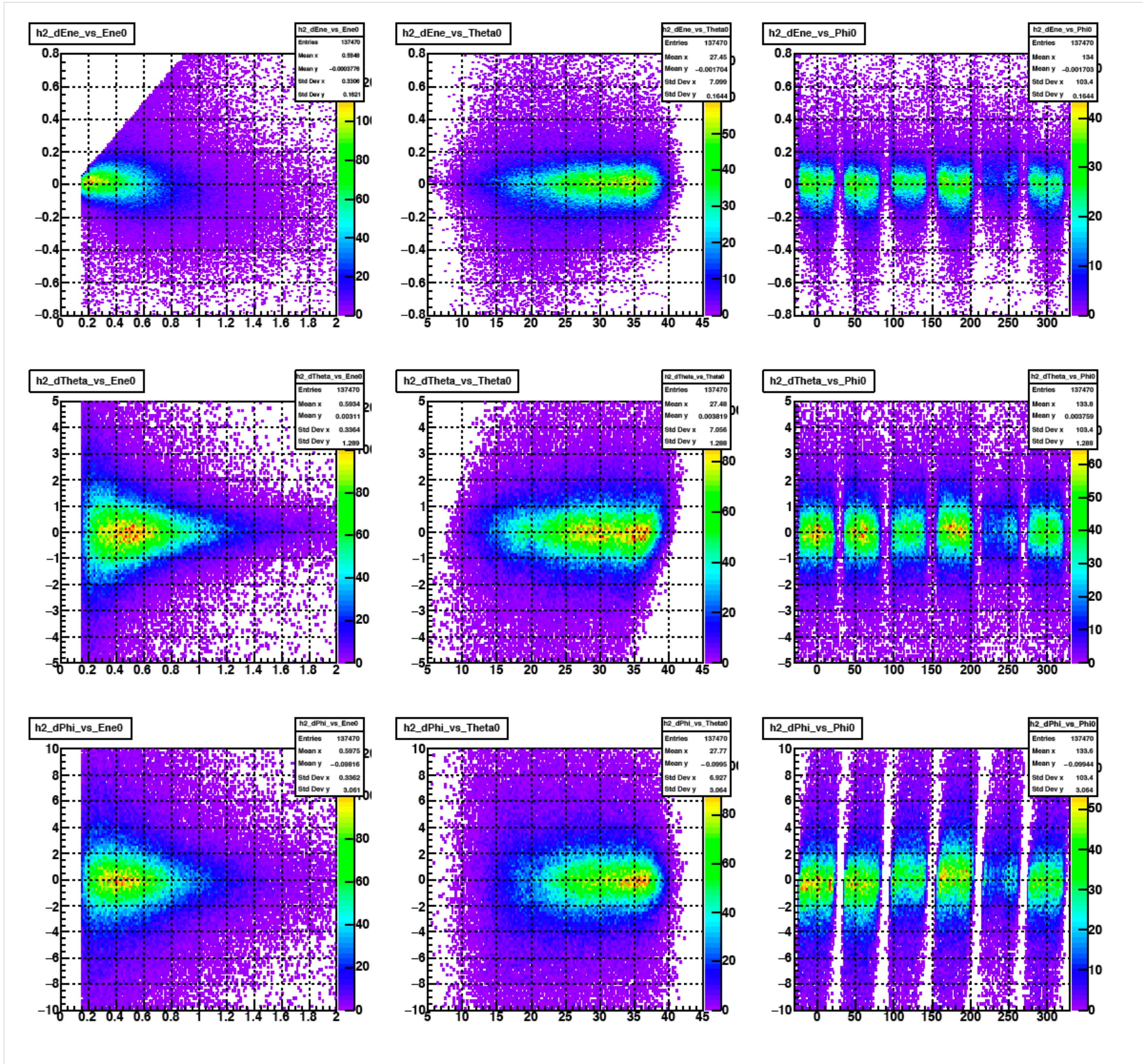
The method requires the knowledge of the “true” photon information to derive correction functions. This is trivial in MC. For data, I used the reaction $\gamma p \rightarrow p\pi^0 \rightarrow pe^+e^-\gamma$, threating the photon as missing and using the corresponding 4-momentum as the “true” information

- Events skimming / selection / corrections performed as before, following what was done in MK analysis
- 2-C kinematic fit to the $\gamma p \rightarrow p\pi^0 \rightarrow pe^+e^-(\gamma)$ hypothesis allows to determine event by event the “true” photon information
  - Thanks for MK for setting up the kin. fitter for electrons and positrons!



EC photon corrections and covariance matrix DATA

- $\Delta = x_T - x_M \; vs \; x_T$ for g12 photons, where "x" is $E \; - \; \theta - \varphi$
- No major shifts are present
- Following corrections have been implemented
  - $\mu_{EE} \, , \mu_{\theta\theta} \, , \mu_{\varphi\varphi} \; (first \; order)$
  - $\mu_{E\varphi} \, , \mu_{\theta\varphi} \; (second \; order)$



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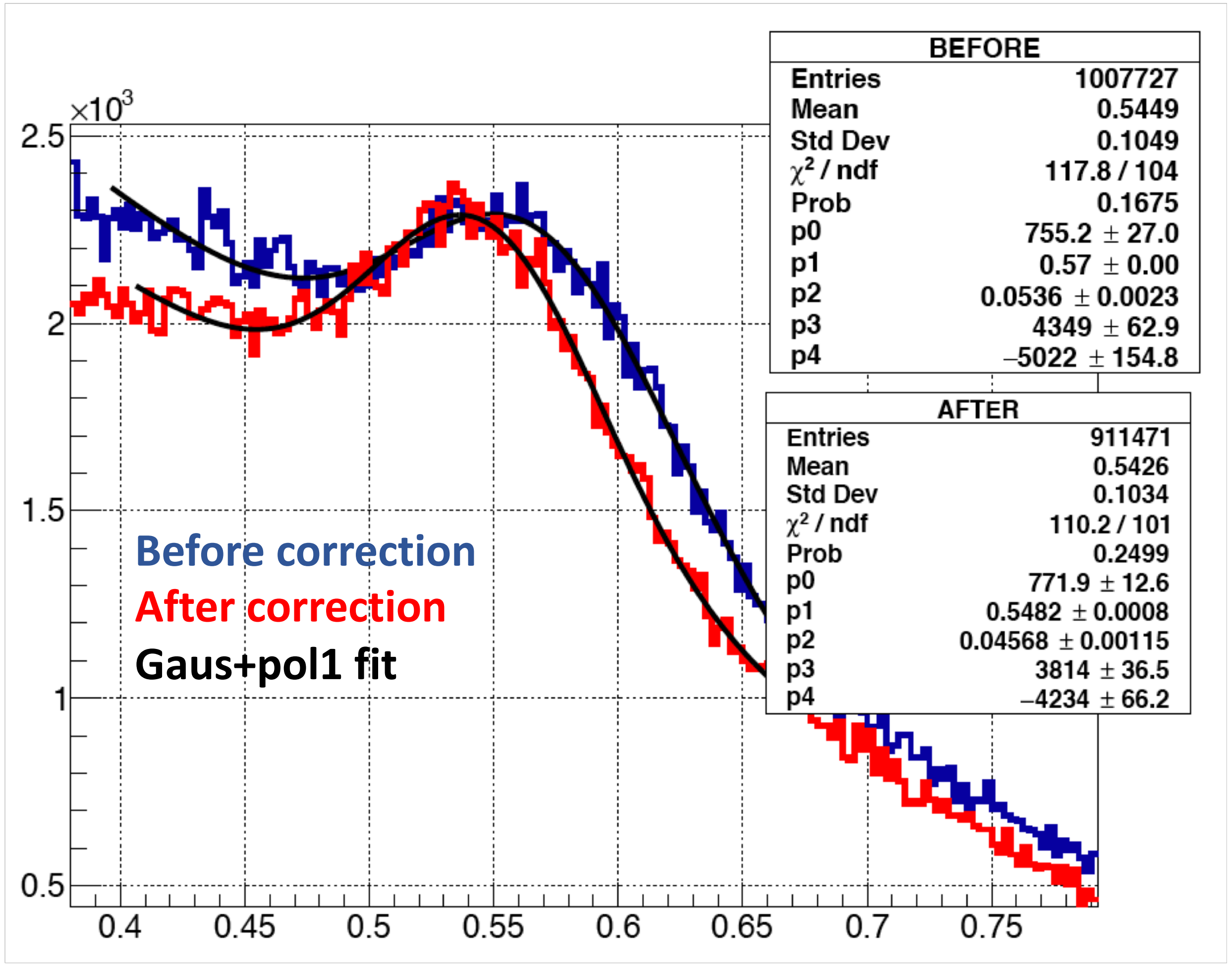
Corrections validation:

- π^0 and $\boldsymbol{\eta}$ invariant mass from two photons decay



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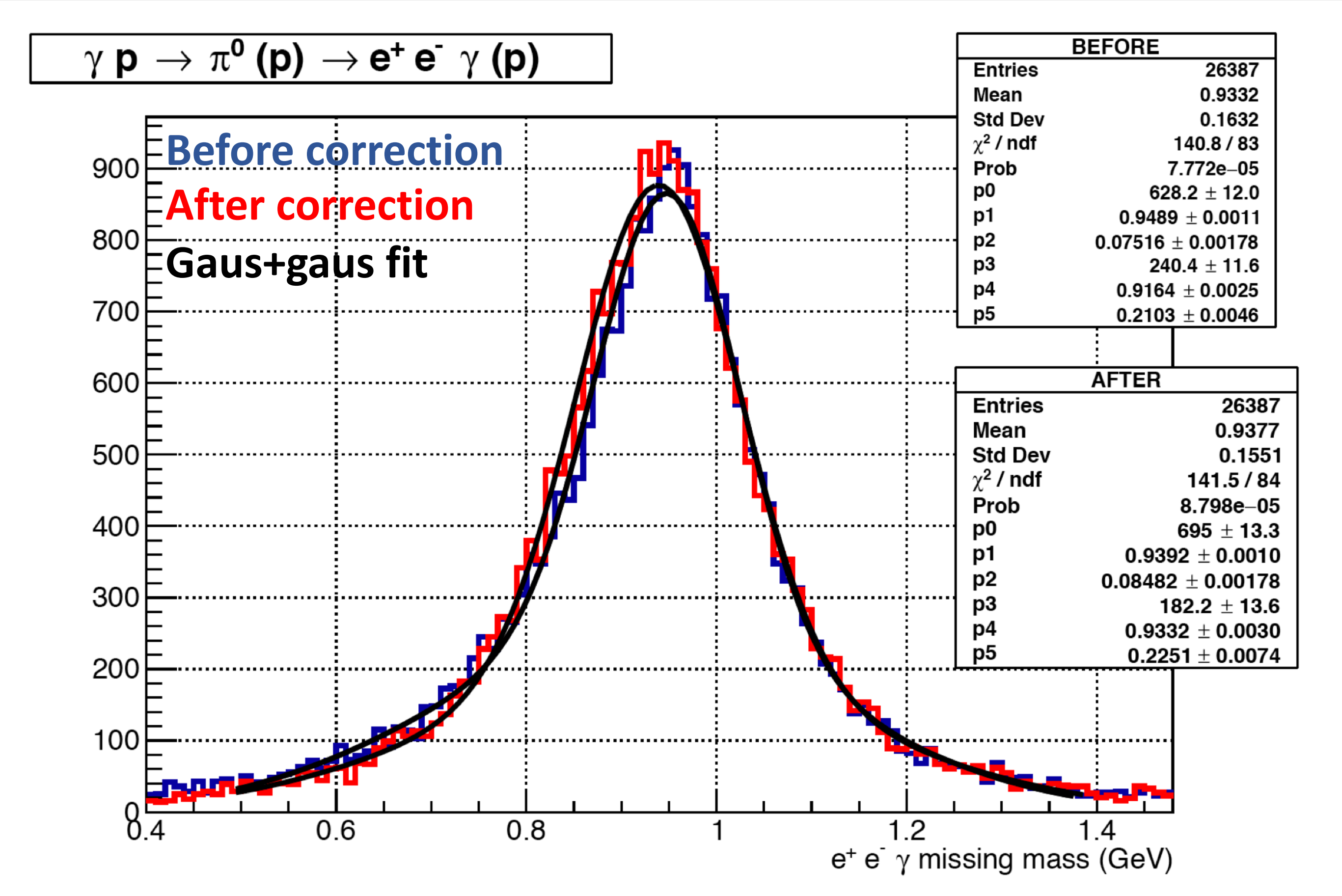
Corrections validation:

- π^0 and η invariant mass from two photons decay
- **Missing mass of the $e^+e^-\gamma$ system (equal to proton mass)**



EC photon corrections and covariance matrix MC

- $\Delta = x_T - x_M \; vs \; x_T$ for g12 photons, where "x" is $E - \theta - \varphi$
- Major shift present for energy (not from gpp!)
- Following corrections have been implemented
  - μ_{EE} , $\mu_{\theta\theta}$, $\mu_{\varphi\varphi}$ $(first\ order)$
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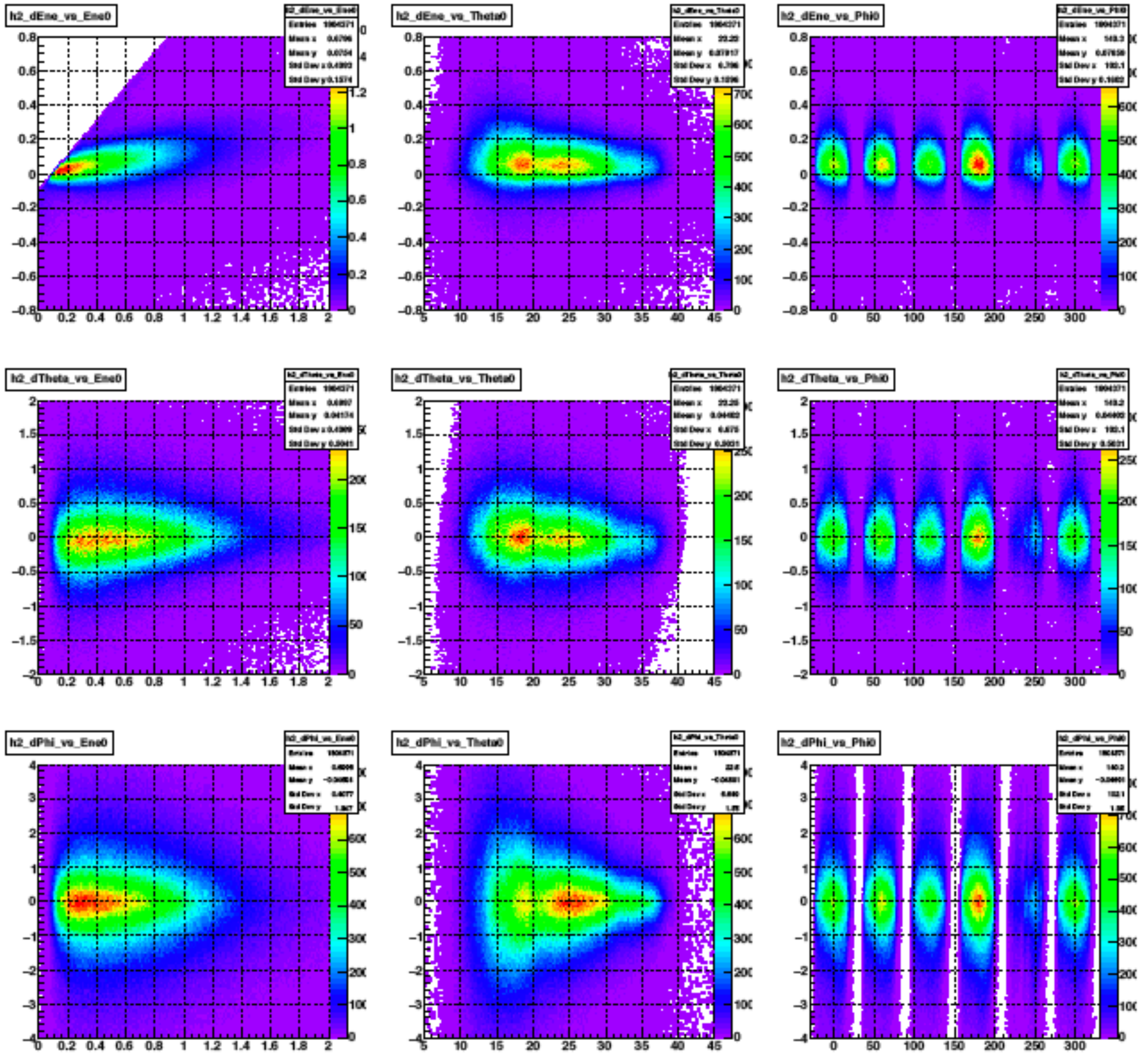

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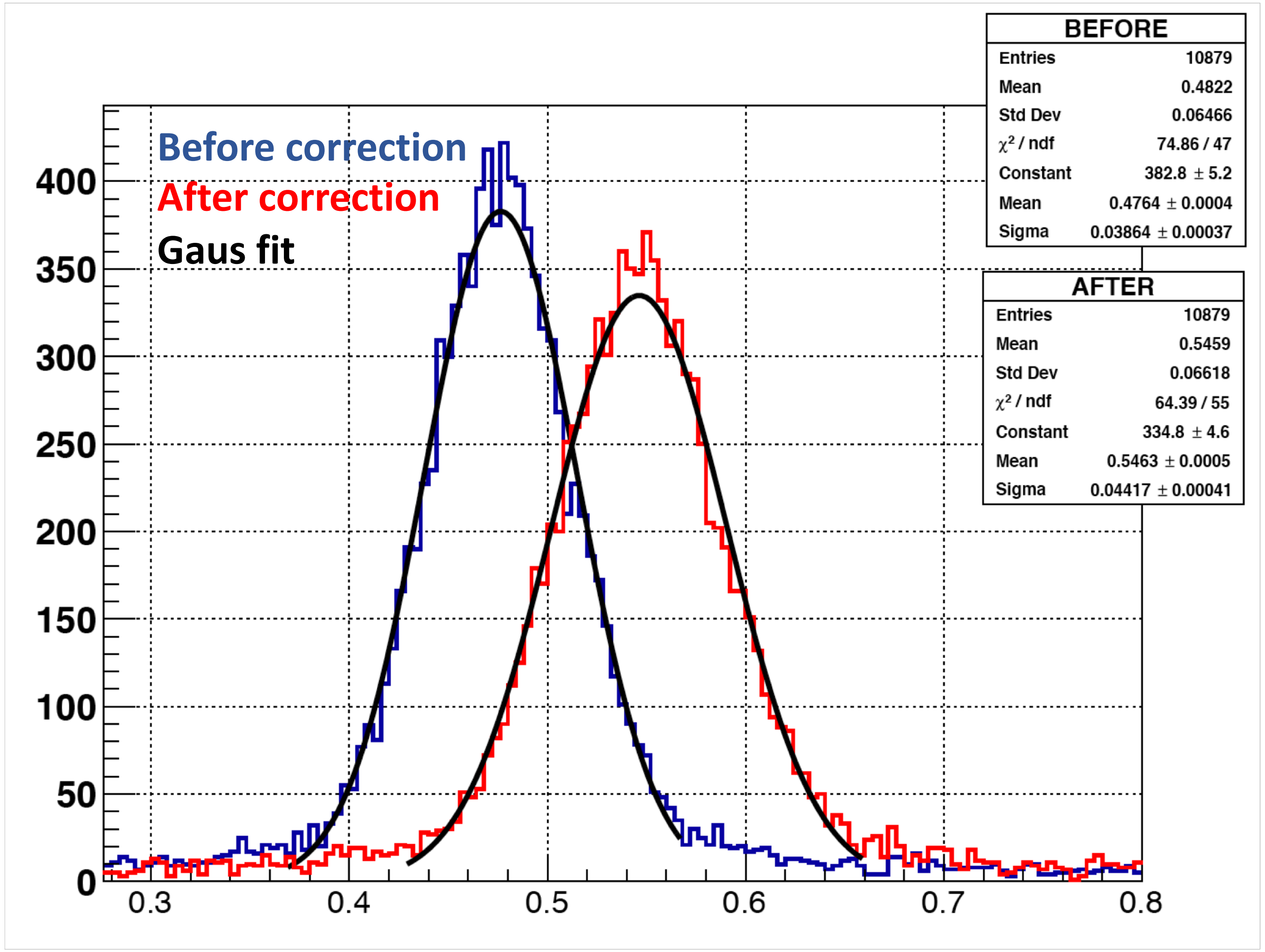


EC photon corrections and covariance matrix

The previous procedure also allow to determine the photon energy and angle resolution – by looking at the width of the Gaussian fits performed in each slice

DATA:

- Energy resolution parameterized as:

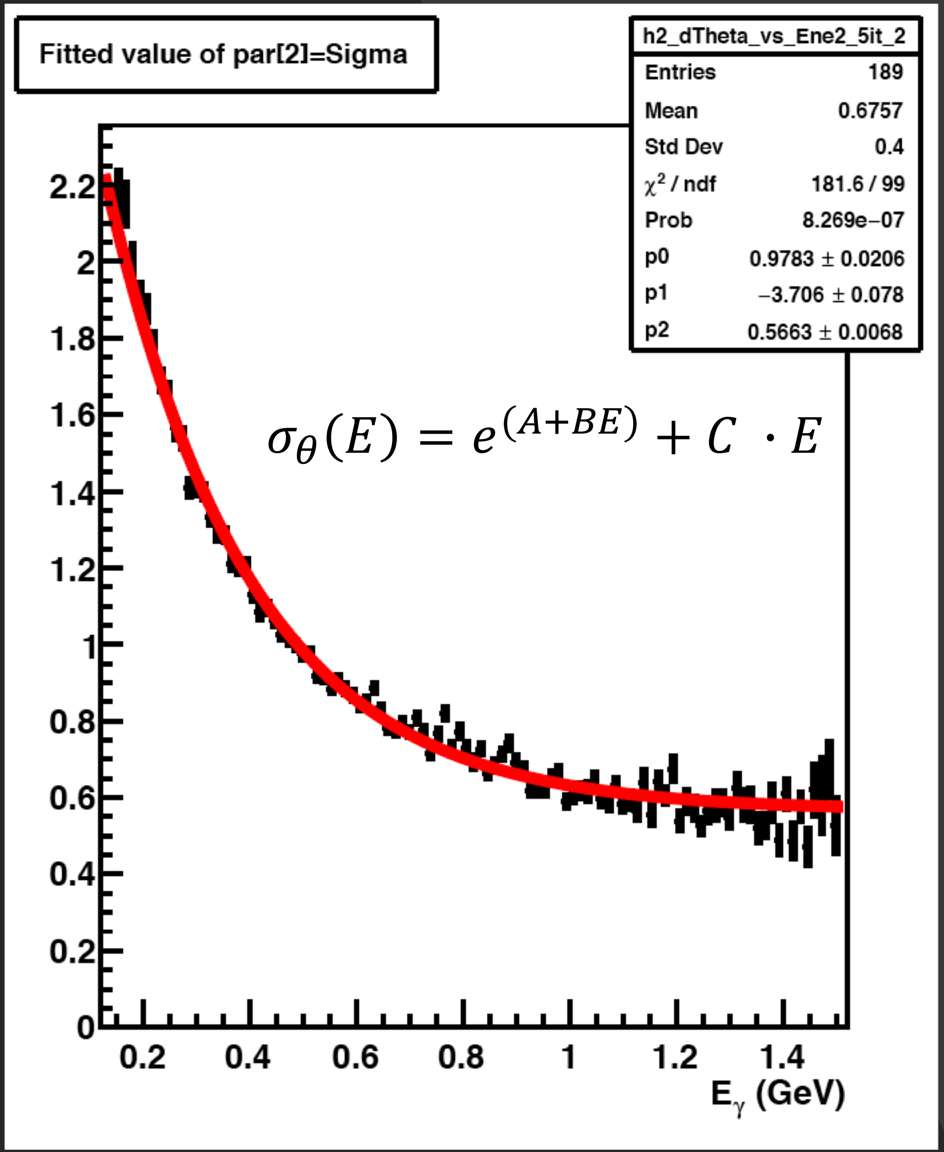
$$\sigma_E(E) = A\sqrt{E} \oplus B,$$

with independent parameterization per each sector and in 6 θ bins

- θ resolution parameterized as:

$$\sigma_\theta(E) = e^{(A+BE)} + C \cdot E$$

- φ resolution parameterized as a polynomial depending on θ , in 4 different energy bins



EC photon corrections and covariance matrix

The previous procedure also allow to determine the photon energy and angle resolution – by looking at the width of the Gaussian fits performed in each slice

MC:

- Energy resolution parameterized as:

$$\sigma_E(E) = A\sqrt{E} \oplus B,$$

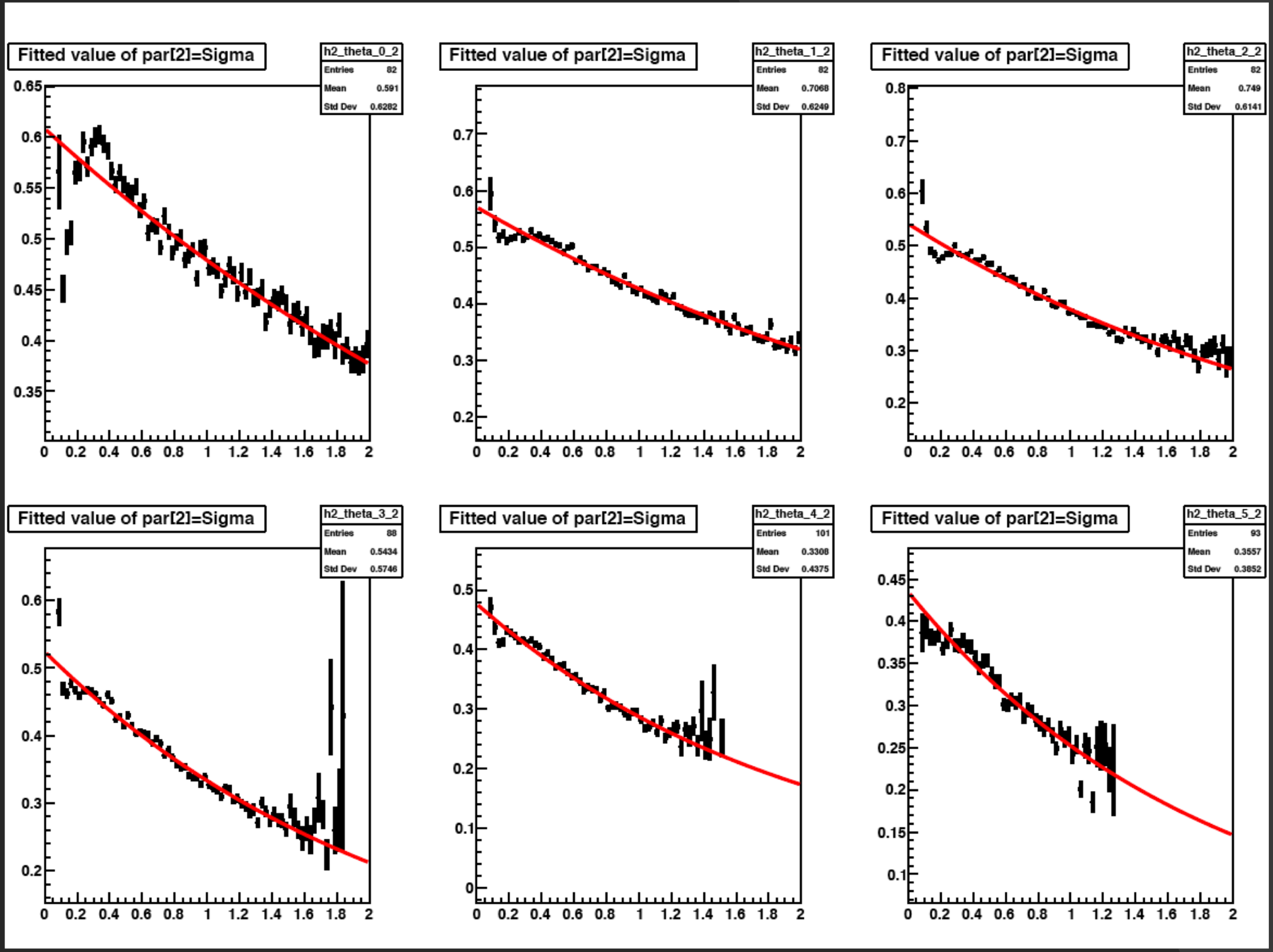
with independent parameterization per each sector and in 6 θ bins

- θ resolution parameterized as:

$$\sigma_\theta(E) = e^{(A+BE)}$$

with independent parameterization in 5 θ bins

- φ resolution parameterized as a polynomial depending on θ , in 4 different energy bins



EC photon corrections and covariance matrix

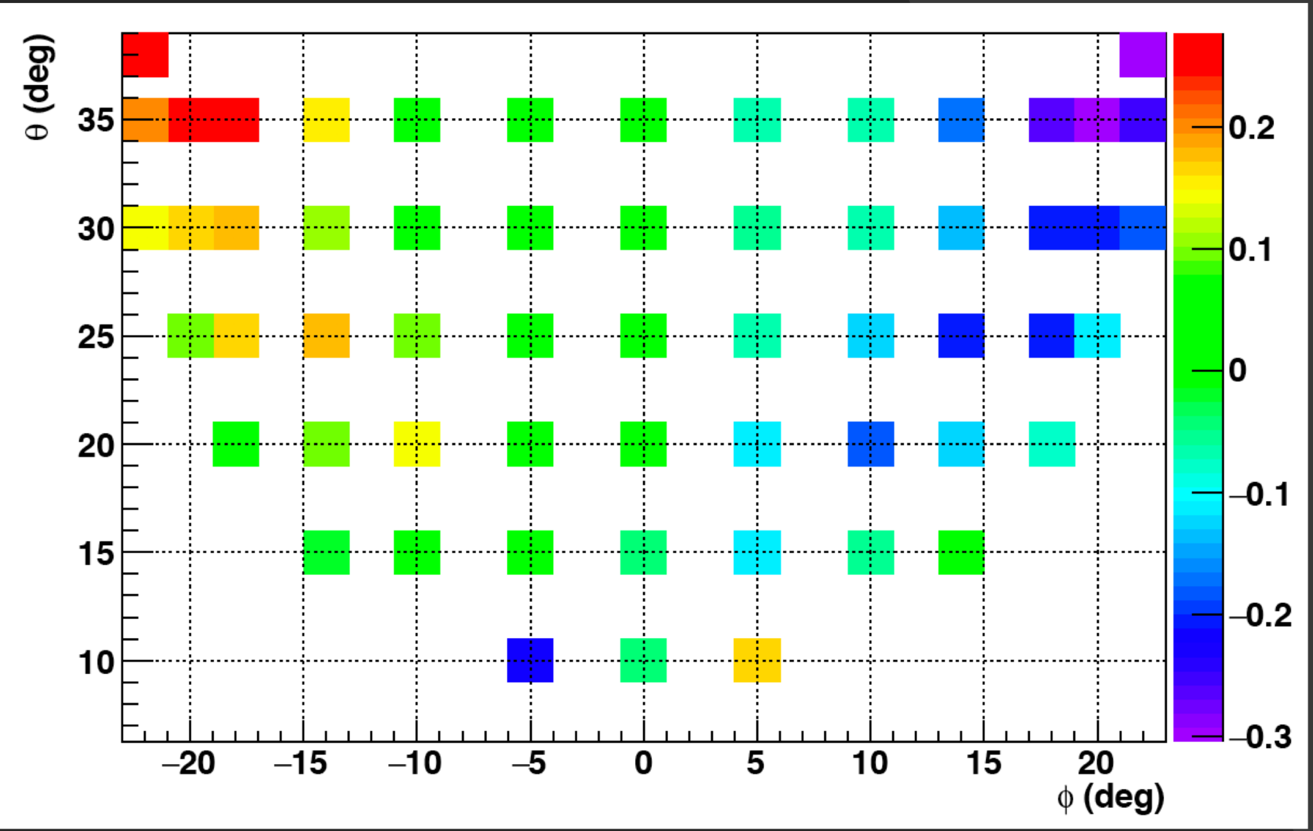
The knowledge of the photon resolutions allows to determine the diagonal elements of the corresponding covariance matrix.

Off-diagonal elements can be re-written by introducing correlations coefficients – this allows to decouple them from resolution

$$V_{p\theta} = \rho_{p\theta}\,\sigma_p\,\sigma_\theta$$
$$V_{p\phi} = \rho_{p\phi}\,\sigma_p\,\sigma_\phi$$
$$V_{\theta\phi} = \rho_{\theta\phi}\,\sigma_\theta\,\sigma_\phi$$

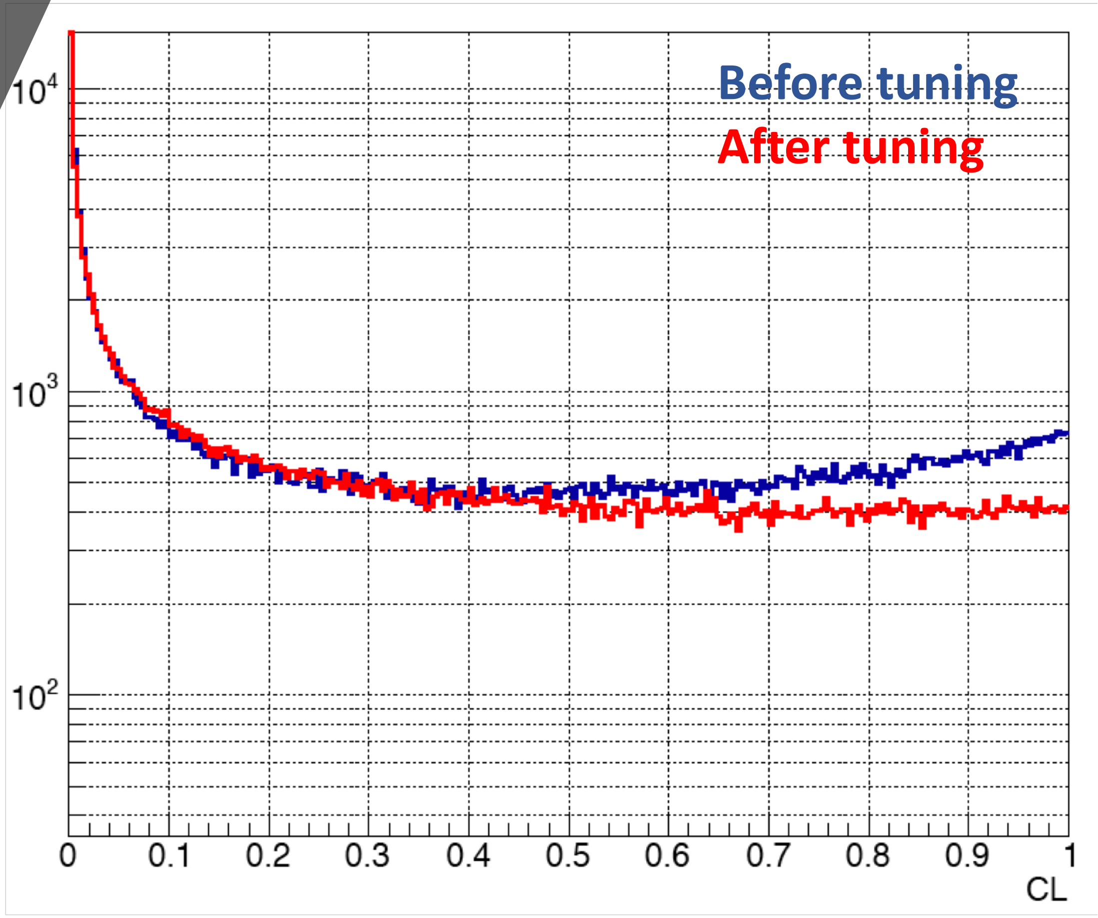
- $\rho_{\theta\varphi}$ is related to the EC geometry (UVW -> xyz transformation). I determined it from MC, simulating $\gamma p \rightarrow p\pi^0 \rightarrow pe^+e^-\gamma$ with the photon at fixed angles – in sector 1
  - I assumed $\rho_{\theta\varphi}$ is the same for all sectors
  - I assumed $\rho_{\theta\varphi}$ is the same for data and MC

- $\rho_{E\theta}$ and $\rho_{E\varphi}$ have a more complicate explanation. As first guess, I set them to 0



Kinematic fit with neutrals in g12

- g12 has a working package for kin. fit on reactions involving only charged particles
- I extended it to work for photons – using the covariance matrix I derived.
  - Resolutions factor are over-estimated: the contribution from missing photon obtained from the kin. fit in the $\gamma p \rightarrow p\pi^0 \rightarrow pe^+e^-(\gamma)$ reaction is re-absorbed in the measured photon resolution
  - I tuned the kin. fit with neutrals on the reaction $\gamma p \rightarrow p\gamma\gamma$, introducing 3 global scale factors for the resolution
  - Best configuration is that providing the smallest normalized CL slope in the range (0.5-1)



Best configuration found for:
(normalized slope: 3.3 10^{-5})

$$\sigma_E^{corr} = 0.825 \cdot \sigma_E$$
$$\sigma_\theta^{corr} = 0.8 \cdot \sigma_\theta$$
$$\sigma_\phi^{corr} = 0.8 \cdot \sigma_\phi$$

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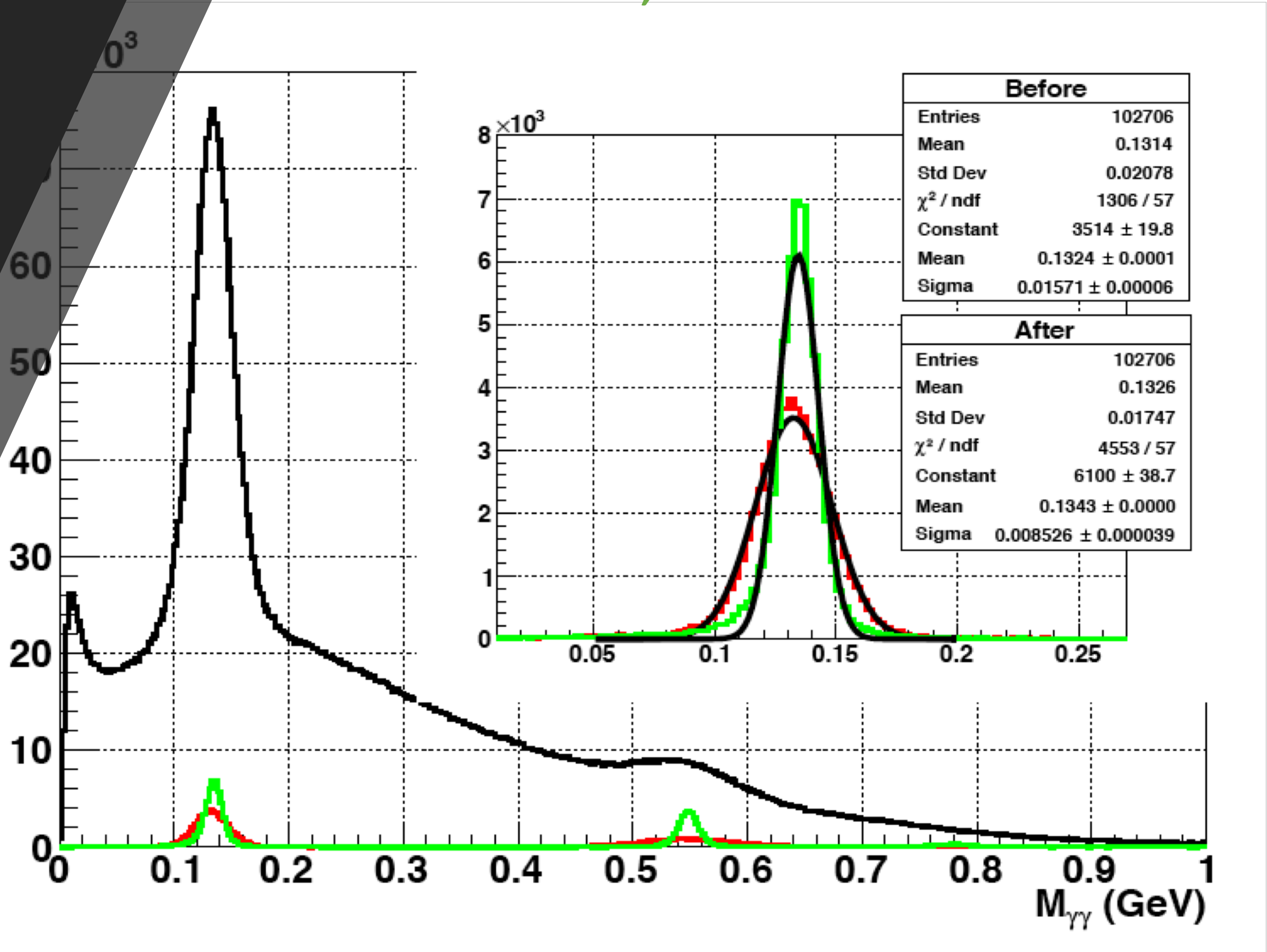
Two photons invariant mass

All events

CL> 0.1, original 4-momenta

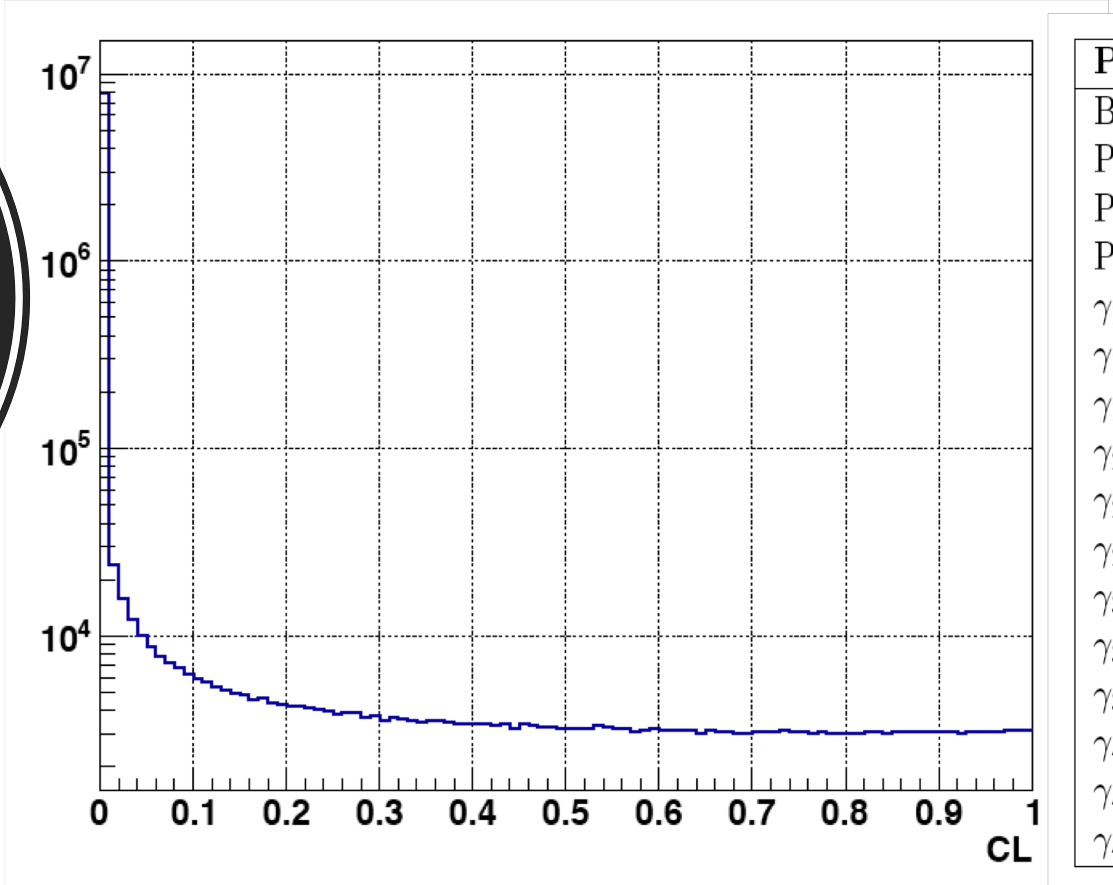
CL> 0.1, corrected 4-momenta



I applied a 4C kinematic fit to $\gamma p \rightarrow p\gamma\gamma\gamma\gamma$ to select exclusive 4-photons events

- CL distribution is flat (normalized slope: 0.021)
- Pull distributions all have mean equal to zero and standard deviation equal to one

Kinematic fit with neutrals in g12



Pull	Mean	Standard Deviation
Beam γ E pull	-0.062	1.042
Proton p pull	0.020	1.046
Proton λ pull	-0.058	1.005
Proton ϕ pull	0.035	1.052
γ_1 p pull	0.038	0.974
γ_1 θ pull	-0.02	1.062
γ_1 ϕ pull	0.032	0.976
γ_2 p pull	0.022	1.001
γ_2 θ pull	-0.025	1.038
γ_2 ϕ pull	0.032	0.968
γ_3 p pull	0.025	0.937
γ_3 θ pull	-0.006	1.054
γ_3 ϕ pull	0.003	0.986
γ_4 p pull	0.108	0.959
γ_4 θ pull	0.000	1.015
γ_4 ϕ pull	0.002	0.977

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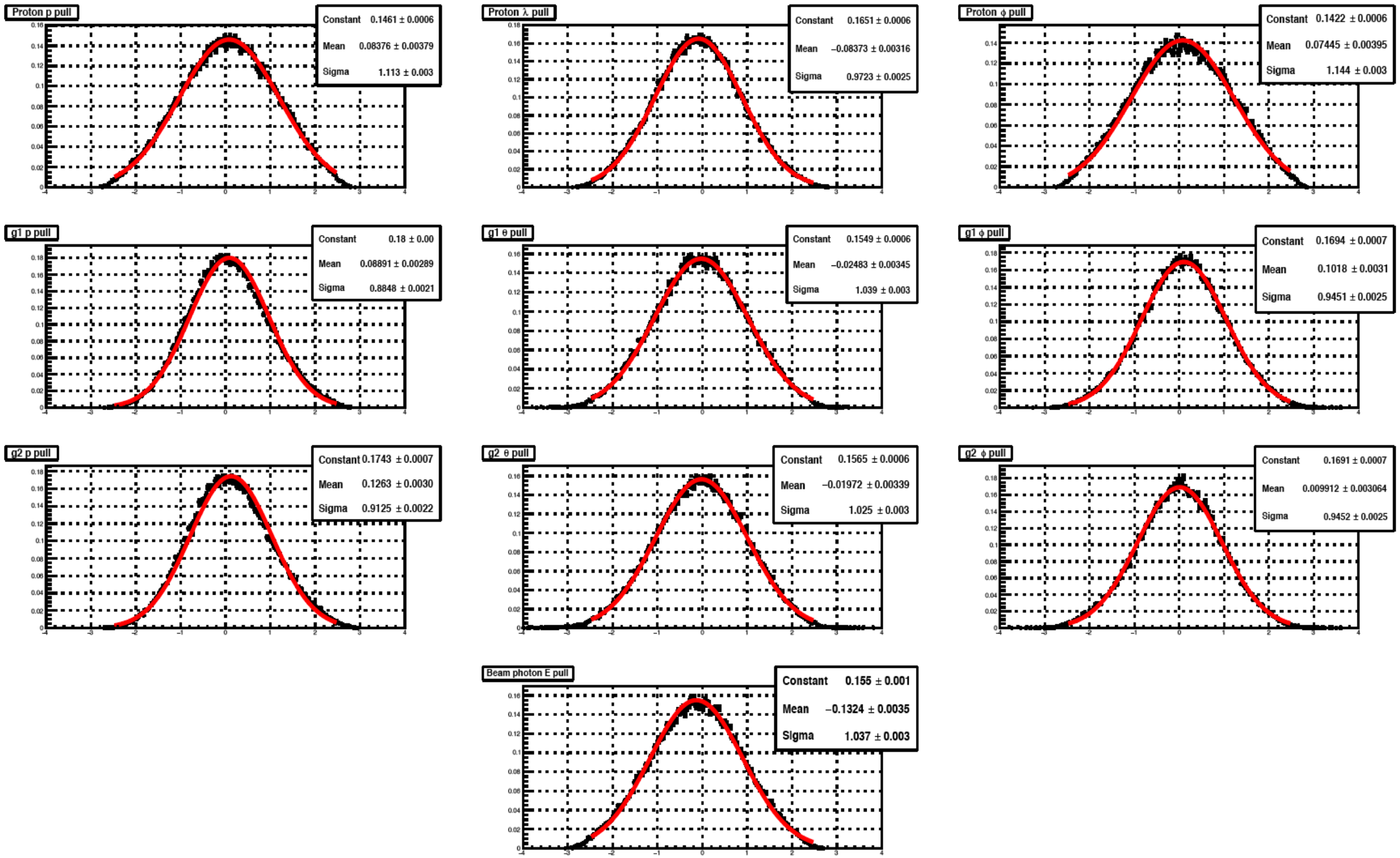
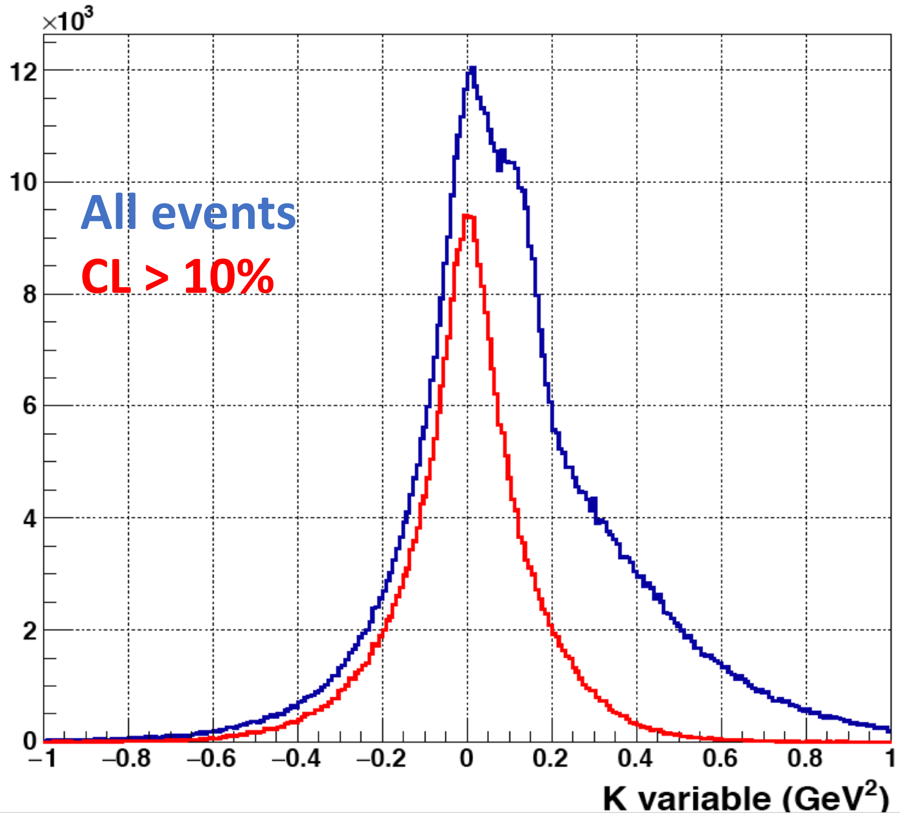
Kinematic fit with neutrals in g12

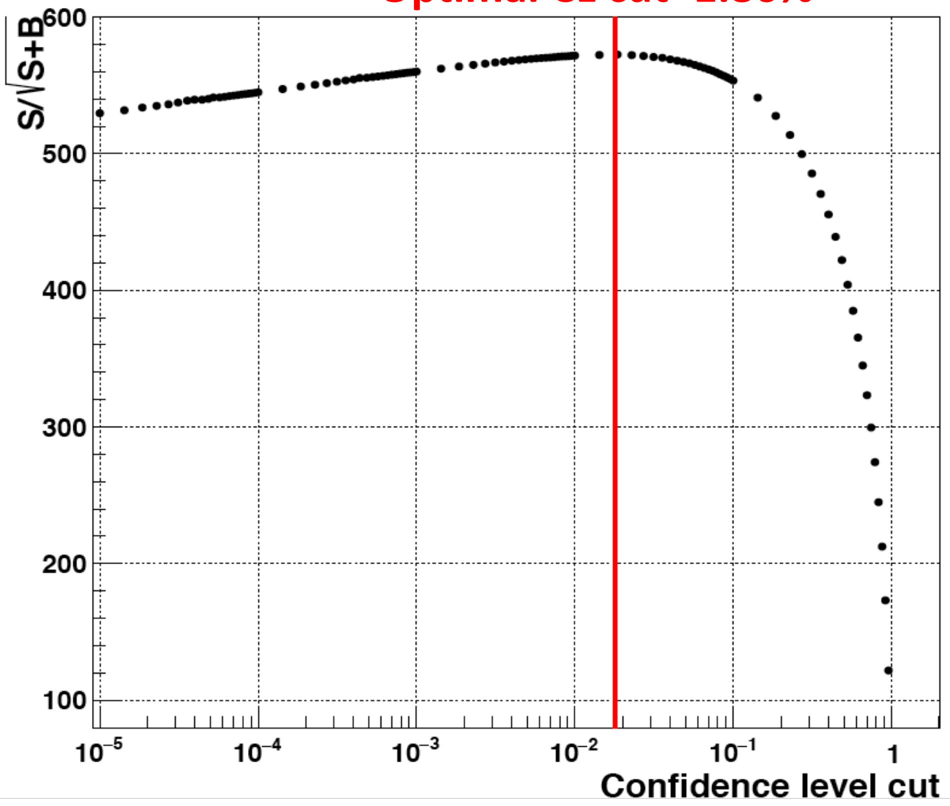


Kinematic fit with neutrals in g12

CL cut optimization:

- Consider the $K = (MM_p^2 - M_{4\gamma}^2)$ variable: should be 0 (>0) for exclusive (background) events
- Obtain an estimate for signal $S = 2N_{K<0}$ and background $B = N_{K>0} - N_{K<0}$
- Take CL cut with highest $S/\sqrt{S+B}$ value





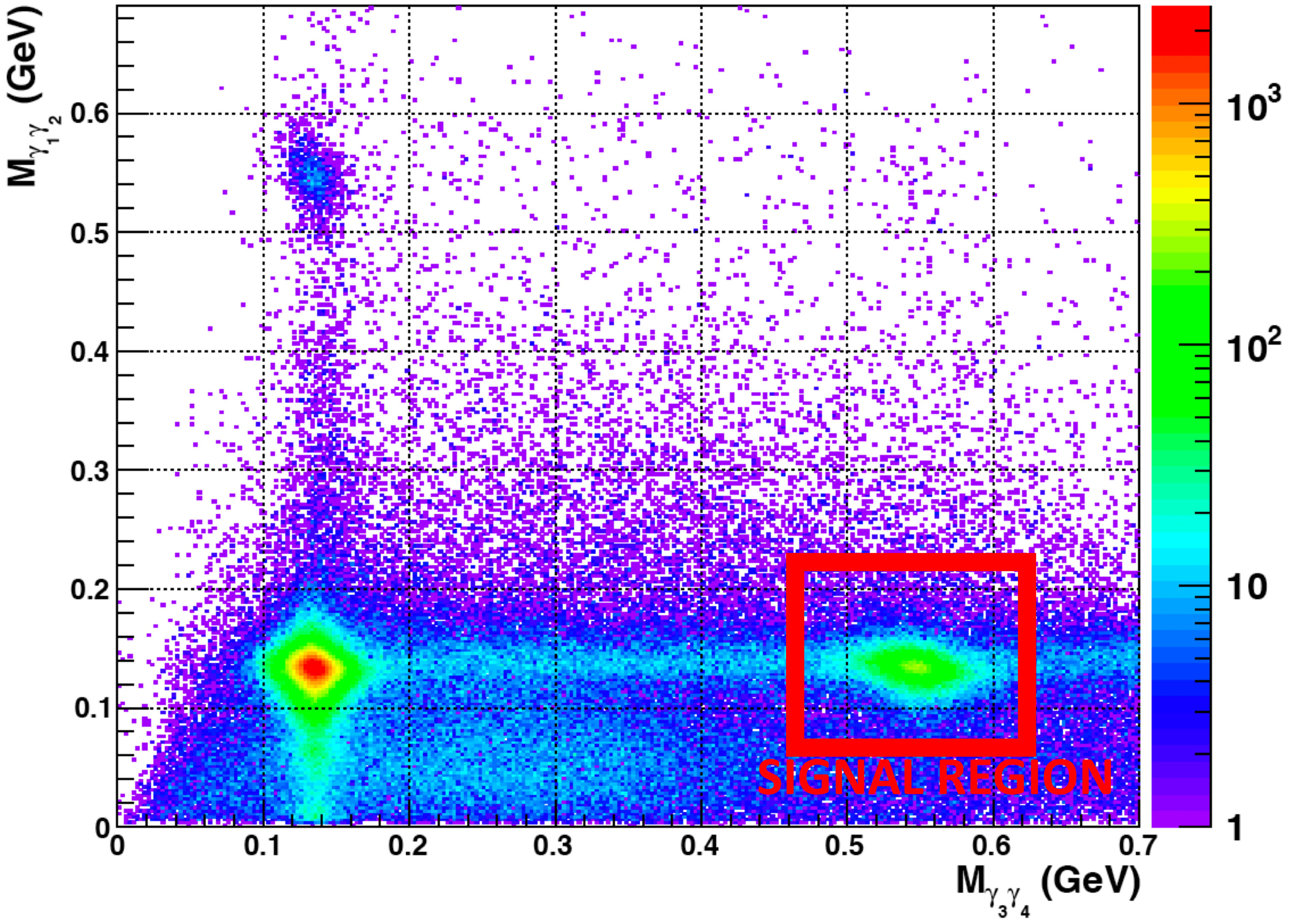
Reaction selection

Goal: isolate $\pi^0\eta$ signal from final state photons.

Photon ordering: exploits the fact that, on average, opening angle between π^0 photons is smaller than that of photons from η

$$\theta_{MIN} \sim \frac{4M}{E}$$

- γ_1, γ_2: photons with the smallest relative angle
- γ_3, γ_4: others



Reaction selection with sPlot technique

Technique used to isolate events belonging to the $\gamma p \rightarrow p\pi^0\eta$, based on the knowledge of the PDF for a "discriminating" variable (can be more than one)

Allows to determine event-by-event weight for each event source (typically signal and background)

Application to this reaction:

- Discriminating variable: $M_{\gamma_3\gamma_4}$
- Two events sources: signal / background
- Signal PDF: Gaus w exponential tails
- Background PDF: polynomial

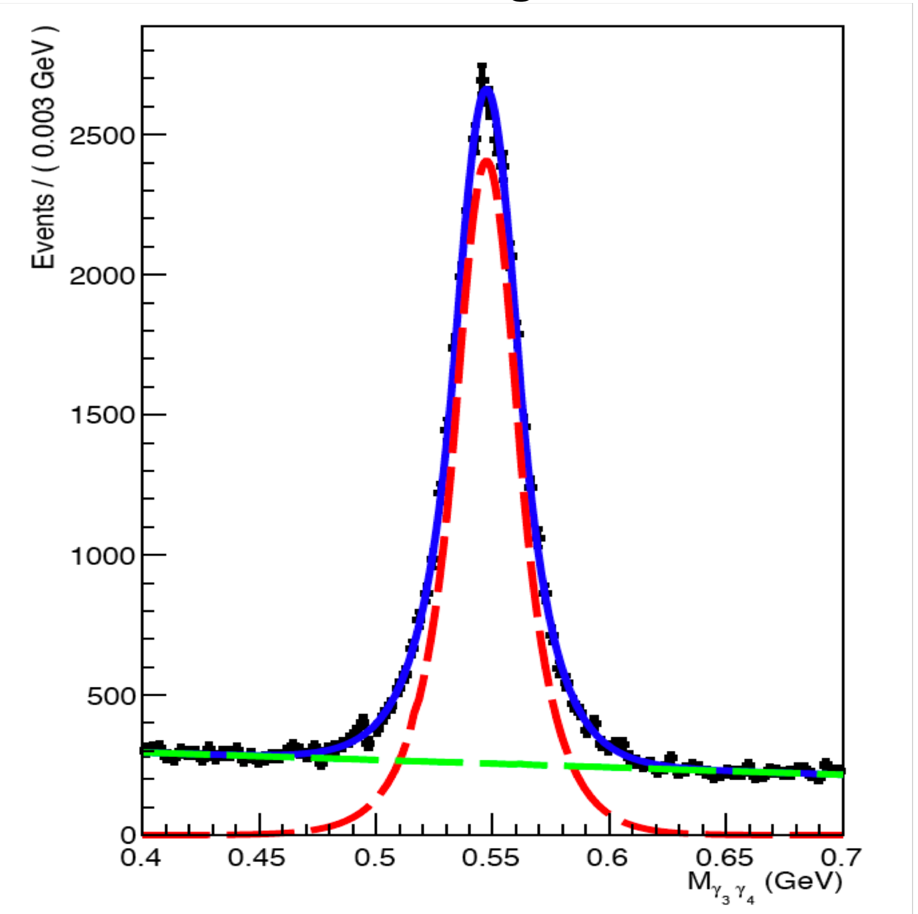
Only events with $M_{\gamma_3\gamma_4}$ in the range (0.4-0.7) GeV were considered

Event weight for source "n", among the Ns sources.
f_j is the PDF for source j, evaluated at event *e*

$${}_s\mathcal{P}_{\rm n}(y_e) = \frac{\sum_{j=1}^{\rm N_s} \mathbf{V}_{{\rm n}j} f_j(y_e)}{\sum_{k=1}^{\rm N_s} N_k f_k(y_e)}$$

Discriminating variable

Full PDF
Signal PDF
Background PDF



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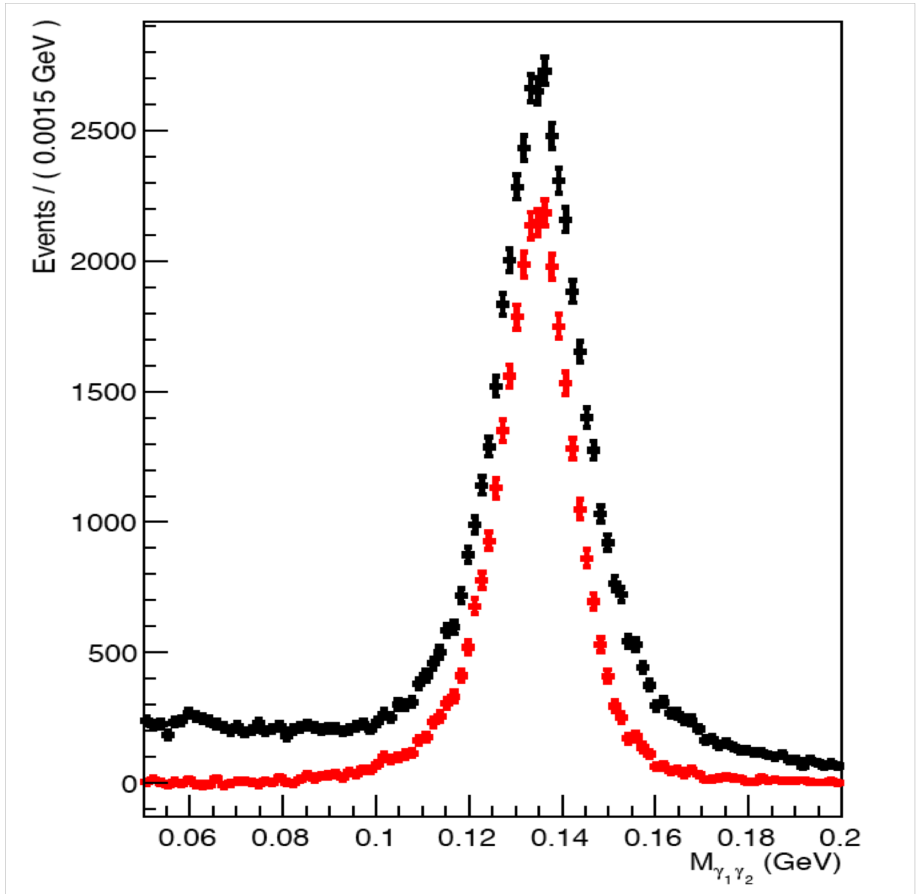
Other variables: $M_{\gamma_1\gamma_2}$

All events
Weighted events



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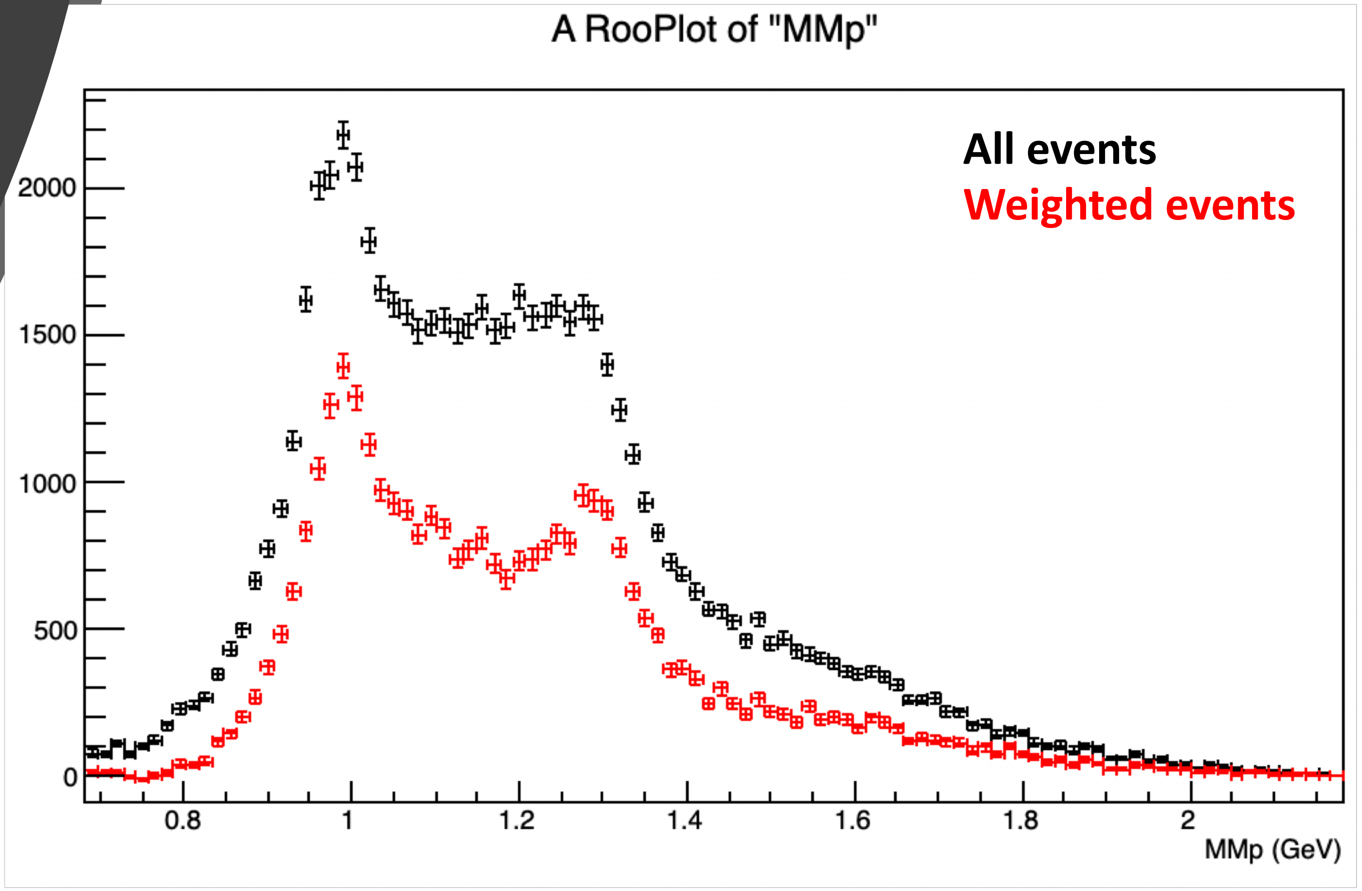
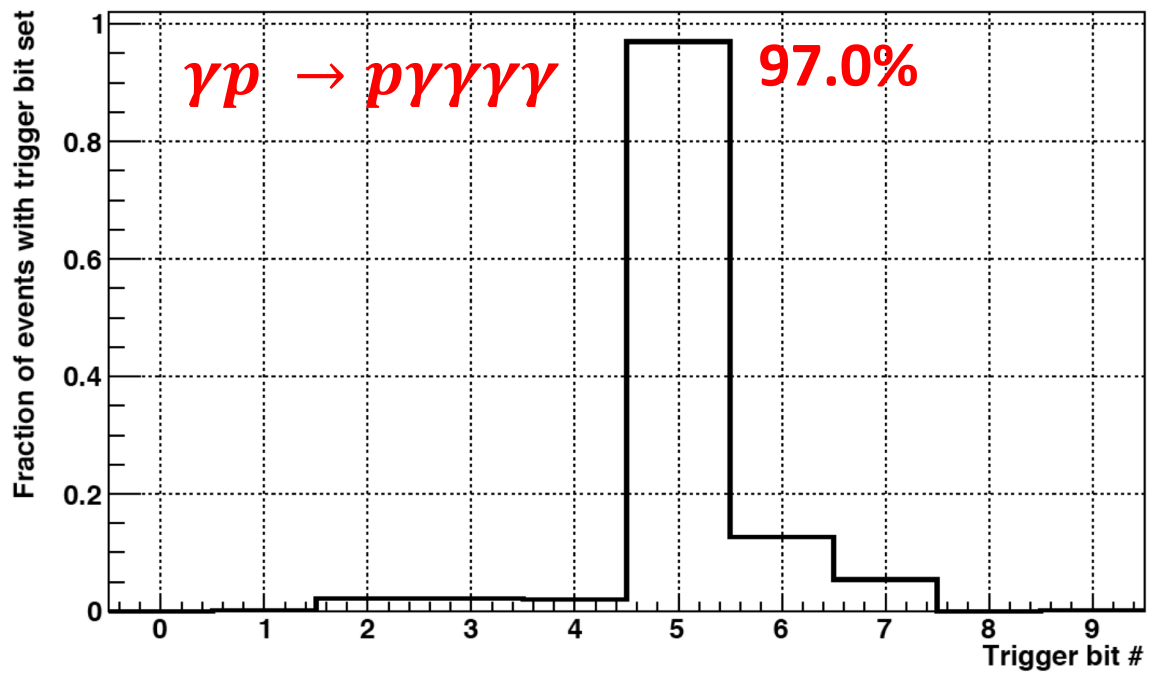
Other variables: MM_p



Trigger efficiency

- G12 used a trigger scheme with multiple parallel trigger conditions
  - FPGA based (v1495)
- **Limited information is stored in the trigger bank**
- Trigger bit #5: (ST*TOF)*(ECP>2)
  - ECP: EM cluster in EC, threshold applied to analogue sum of PMT signals
  - Tailored to neutral final states

g12 runs 56595–56607, 56648–57323			
Bit	Definition	L2 multiplicity[a]	Prescale
1	MORA·(ST×TOF)	1	1000/300[b]
2	MORA·(ST×TOF)×2	2/–[c]	1
3	MORB·(ST×TOF)×2	2	1
4	ST×TOF	1	1000/300
5	(ST×TOF)·ECP×2	1	1
6	(ST×TOF)·(EC×CC)	2	1
7	MORA·(ST×TOF)·(EC×CC)	–	1
8	MORA·(ST×TOF)×2	–	1
11	(EC×CC)×2	–	1
12	(ST×TOF)×3	–	1



Trigger efficiency

- Is the latching system reliable?

g12 runs 56595–56607, 56648–57323			
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4	ST×TOF	1	1000/300
5	(ST×TOF)·ECP×2	1	1
6	(ST×TOF)·(EC×CC)	2	1
7	MORA·(ST×TOF)·(EC×CC)	–	1
8	MORA·(ST×TOF)×2	–	1
11	(EC×CC)×2	–	1
12	(ST×TOF)×3	–	1

Events with beam photon in the MORA range, with trigger bit 2 **AND** 12 set

$$r = \frac{N_2^{12,\,\mathtt{MORA}}}{N_{all}^{12,\,\mathtt{MORA}}}$$ **= 98.5%**

Events with beam photon in the MORA range, with trigger bit 12 set

(Test performed for runs after bit2 L2 was removed)

Trigger efficiency

- Is the latching system reliable?
- What is the efficiency of bit #5?
  - This may be topology-dependent, so I evaluated it directly on the final state of interest.

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7	MORA·(ST×TOF)·(EC×CC)	–	1
8	MORA·(ST×TOF)×2	–	1
11	(EC×CC)×2	–	1
12	(ST×TOF)×3	–	1

Select events with trigger bit 1 or 4 set, having at least two photons in different EC sectors, both with large (>1 GeV) energy. These should satisfy by design trigger bit 5.

Events with bit #5 set

$$\varepsilon_{ECP\times2} = \frac{N_{(1-or-4)\&\&5}}{N_{1-or-4}}$$

= 83.6+ 0.7%

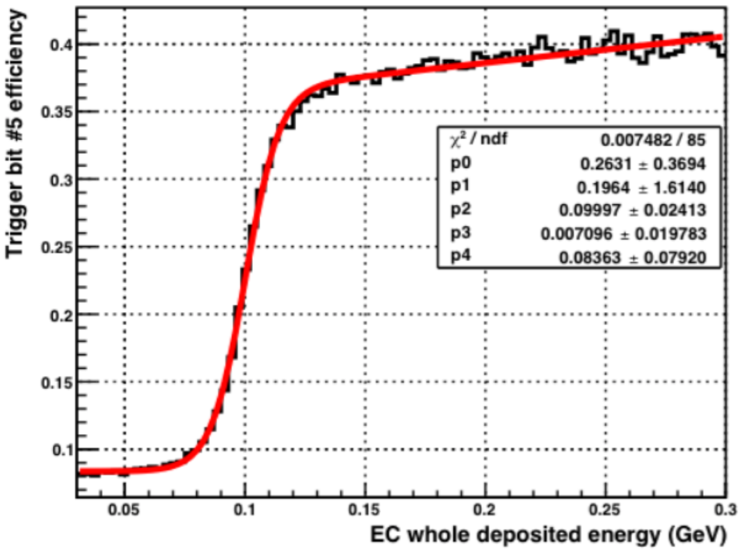
Total number of events

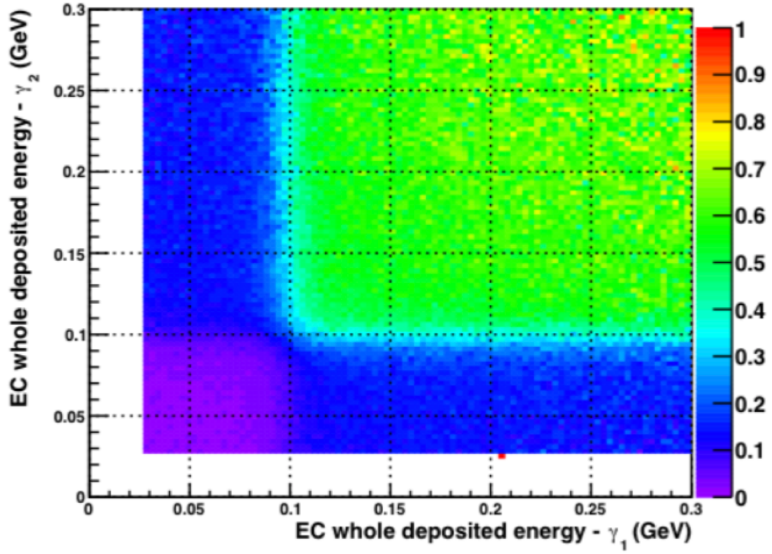
Trigger efficiency

- Is the latching system reliable?
- What is the efficiency of bit #5?
  - This may be topology-dependent, so I evaluated it directly on the final state of interest.
- What is the effective trigger threshold?

g12 runs 56595–56607, 56648–57323			
Bit	Definition	L2 multiplicity[a]	Prescale
1	MORA·(ST×TOF)	1	1000/300[b]
2	MORA·(ST×TOF)×2	2/–[c]	1
3	MORB·(ST×TOF)×2	2	1
4	ST×TOF	1	1000/300
5	(ST×TOF)·ECP×2	1	1
6	(ST×TOF)·(EC×CC)	2	1
7	MORA·(ST×TOF)·(EC×CC)	–	1
8	MORA·(ST×TOF)×2	–	1
11	(EC×CC)×2	–	1
12	(ST×TOF)×3	–	1

Select events with trigger bit 1 or 4 set, having at least two photons in different EC sectors. Study the trigger efficiency as a function of the EC deposited energy.





Trigger efficiency

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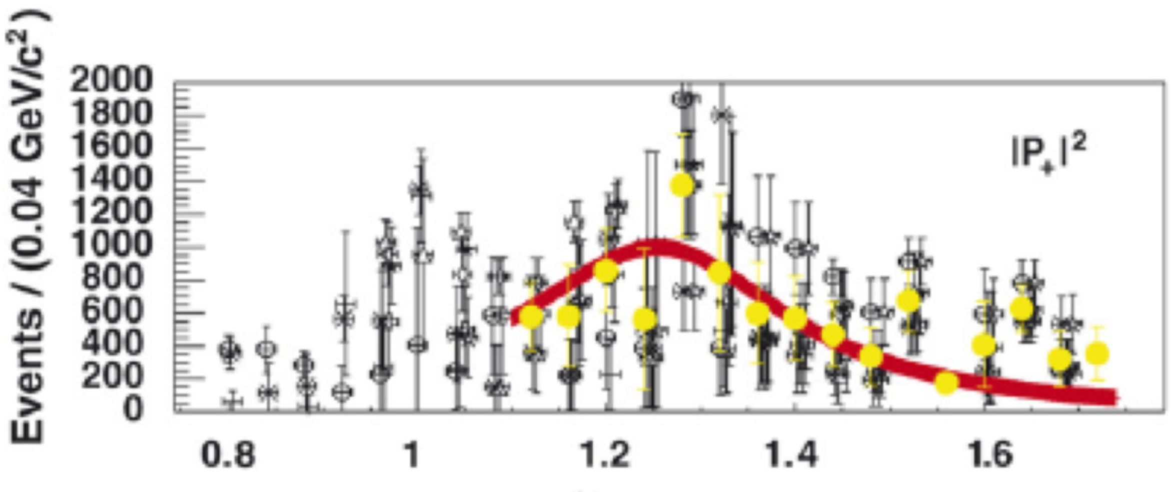
Select events with trigger bit 1 or 4 set, having at least two photons in different EC sectors. Study the trigger efficiency as a function of the EC deposited energy.

Sector	**EC-whole**		**EC-inner**	
	E_c	k	E_c	k
1	98.6 MeV	6.2 MeV	75.9 MeV	16 MeV
2	97.6 MeV	6.3 MeV	74.0 MeV	15.9 MeV
3	98.4 MeV	5.3 MeV	74.1 MeV	13.8 MeV
4	107.5 MeV	6.4 MeV	81.0 MeV	15.0 MeV
5	89.1 MeV	10.2 MeV	63.3 MeV	15.1 MeV
6	101.0 MeV	6.0 MeV	78.9 MeV	15.3 MeV

Conclusions

- I identified an exclusive set of ~ 30k events for the reaction $\gamma p \rightarrow p\pi^0\eta$ from the g12 dataset. The analysis exploited the official g12 procedure, plus methods specific to this channel:
  - EC-corrections
  - Kinematic fit (specifically tuned for neutrals)
  - Sweight
- Trigger efficiency has been worked out
- Next steps:
  - Acceptance evaluation trough eML fits (”a la M. Williams”)
  - PWA



(b)