Triangle singularity in the reaction $\gamma p \to p \pi^0 \eta$??

Volker Metag, Mariana Nanova

II. Physikalisches Institut

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

for the CBELSA/TAPS collaboration

in contact with V. Debastiani, E. Oset and S. Sakai // V. Nikonov, A. Sarantsev // B. Kubis

- de-excitation of higher lying nucleon resonances via multiple meson emission
- unexplained structures in Dalitz plots
- experimental evidence for a triangle singularity in the $\gamma p \to p \pi^0 \eta$ reaction ??
- summary and outlook

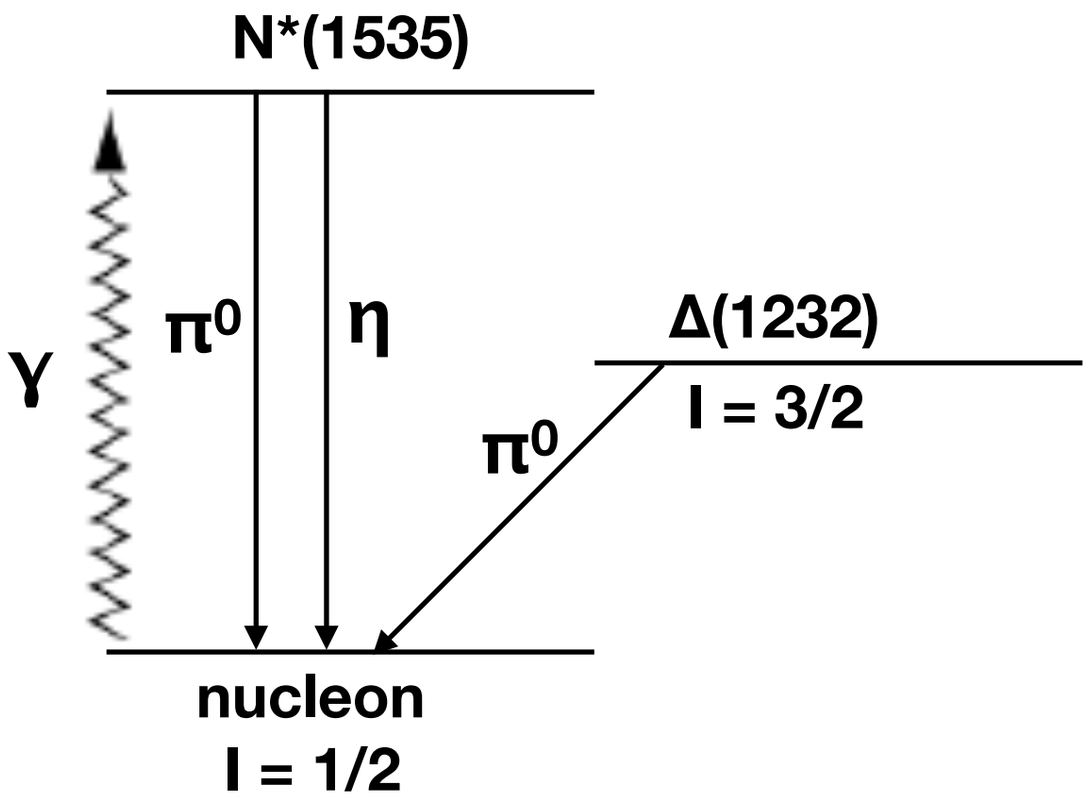
*funded by the DFG within SFB/TR16

Meson 2018
June 7-12, Cracow, Poland

HIC for FAIR
Helmholtz International Center

decay of higher nucleon resonances

- low lying resonances like Δ(1232) and S_{11}(1535) well studied

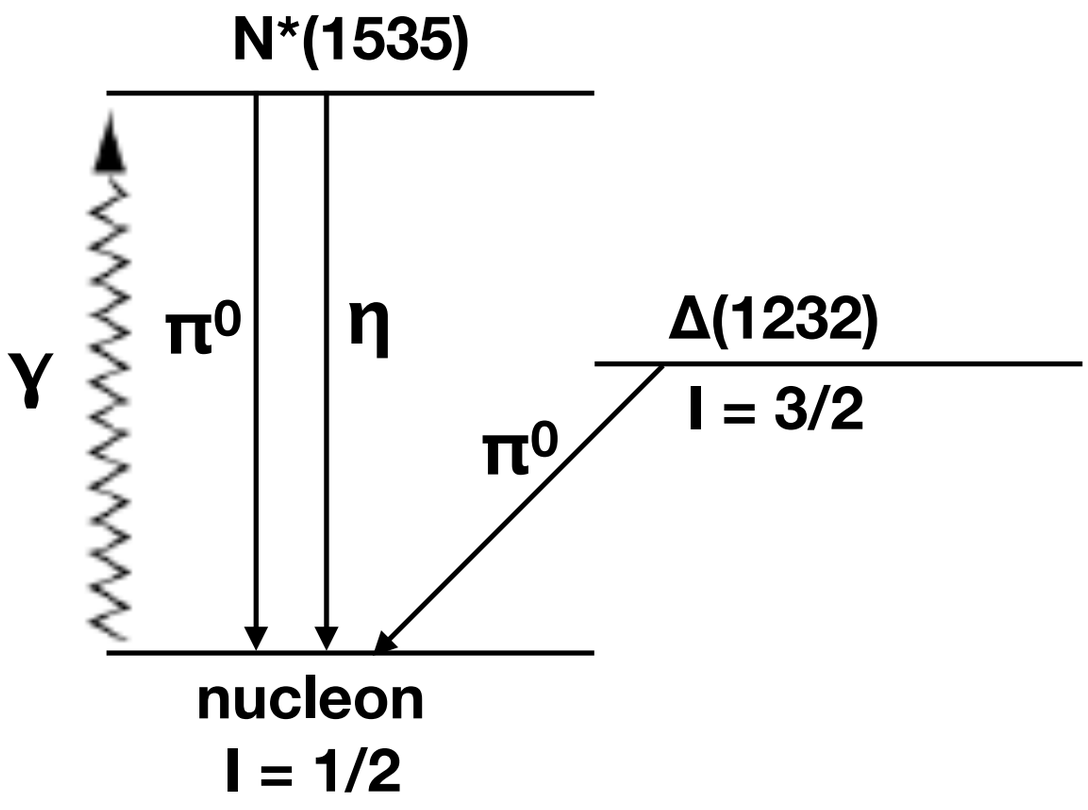


de-excitation by single meson emission

final states: $p\pi^0$, $p\eta \rightarrow p\,2\gamma$

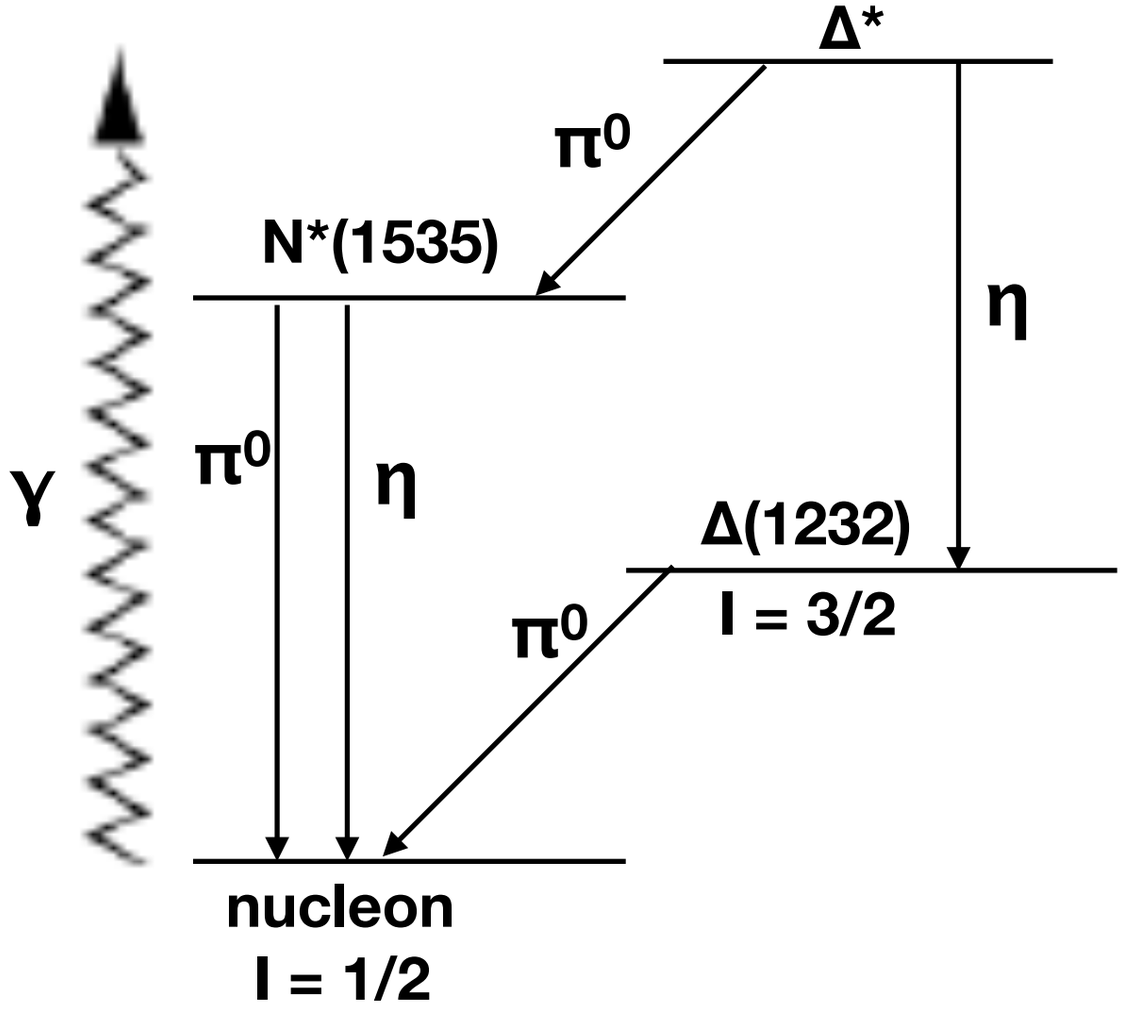
decay of higher nucleon resonances

- low lying resonances like Δ(1232) and S_{11}(1535) well studied
- knowledge of higher lying resonances still to be improved



de-excitation by single meson emission

final states: $p\pi^0$, $p\eta \rightarrow p\,2\gamma$

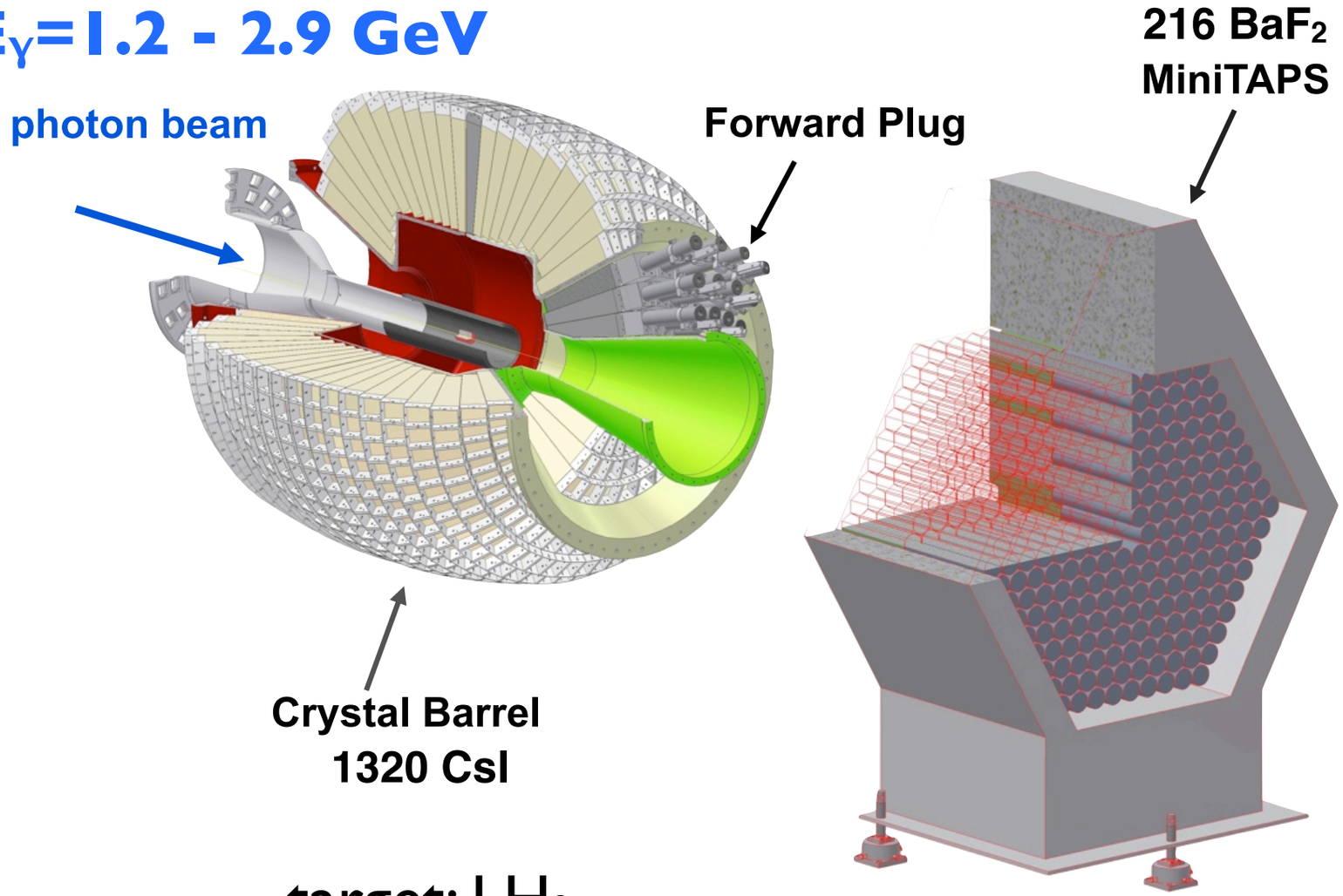


de-excitation by meson decay chains

final states: $p\pi^0\pi^0$, $p\pi^0\eta \rightarrow p\,4\gamma$

CBELSA/TAPS Experiment (Bonn)

E_γ=1.2 - 2.9 GeV



target: LH_2

4π photon detector: ideally suited for identification of multi-photon final states

$\gamma p \rightarrow p\eta\pi^0 \rightarrow p\ 4\gamma$ BR 38.9%

$\gamma p \rightarrow p\pi^0\pi^0 \rightarrow p\ 4\gamma$ BR 97.6% dominant !!

Data analysis: identification of $\gamma p \rightarrow p \pi^0 \eta$

- meson reconstruction in the decay channel: $\pi^0 \rightarrow \gamma\gamma$ and $\eta \rightarrow \gamma\gamma$

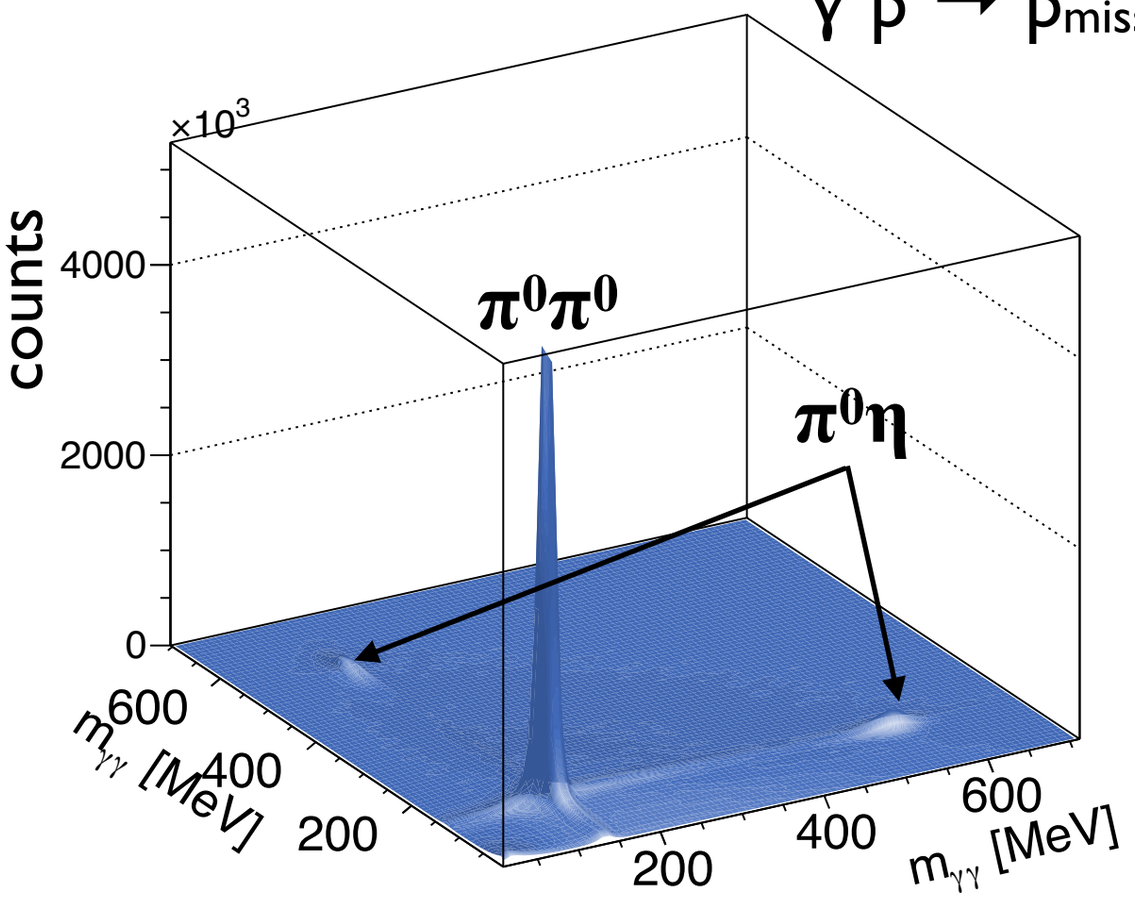
4 photons in the final states

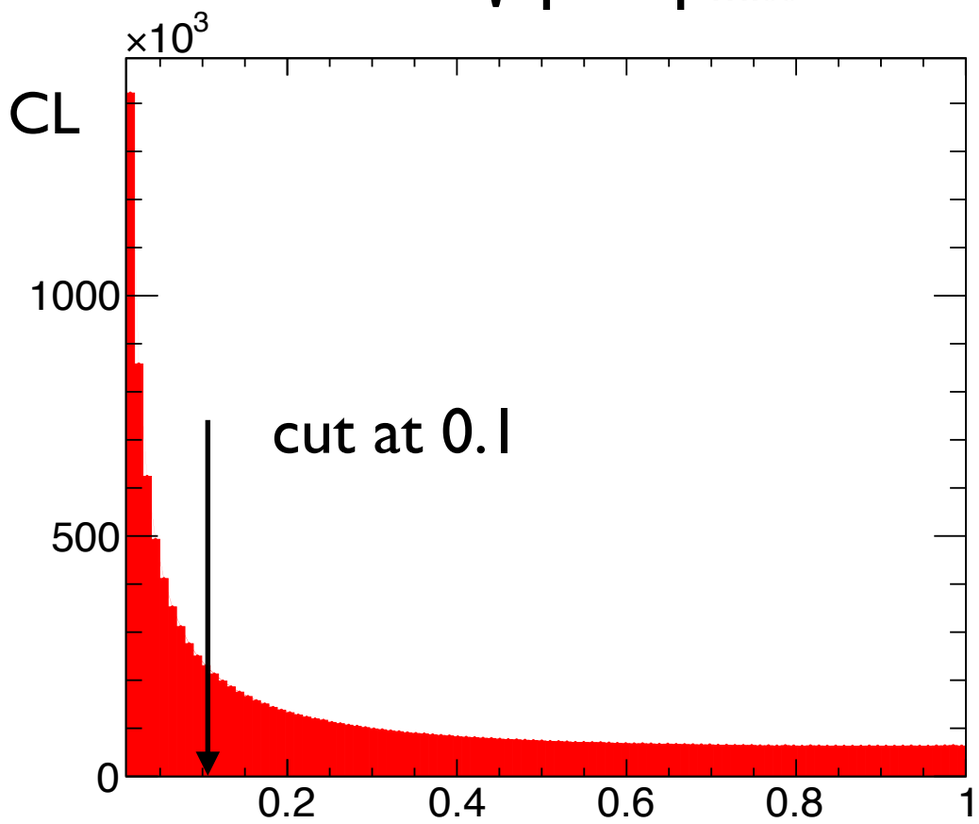
$4 \cdot 10^8$ $\pi^0\pi^0$; $2 \cdot 10^7$ $\pi^0\eta$

- kinematic fit with hypothesis:

$\gamma p \rightarrow p_{miss}\, 4\gamma$; $\gamma p \rightarrow p_{miss}\, \pi^0\eta$

anticut: $\gamma p \rightarrow p_{miss}\, \pi^0\pi^0$





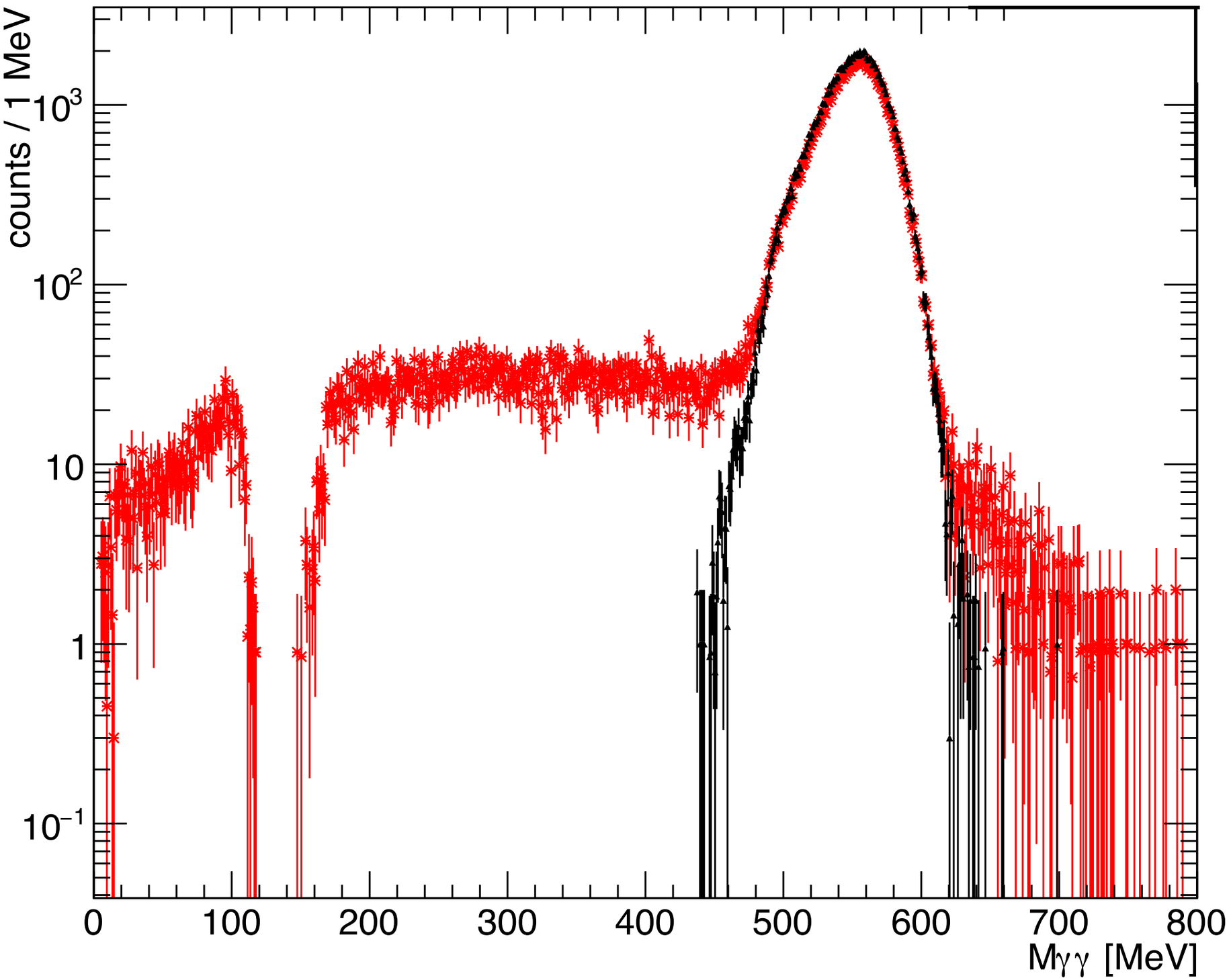
proton treated as missing particle

- coplanarity cut: $\Delta\Phi = \Phi_{4\gamma} - \Phi_p = 180° \pm 9$
- polar angle difference: $\Delta\theta = \theta_p^{meas} - \theta_p^{miss} = \pm 8$

selection of $\gamma p \rightarrow p \pi^0 \eta$ events

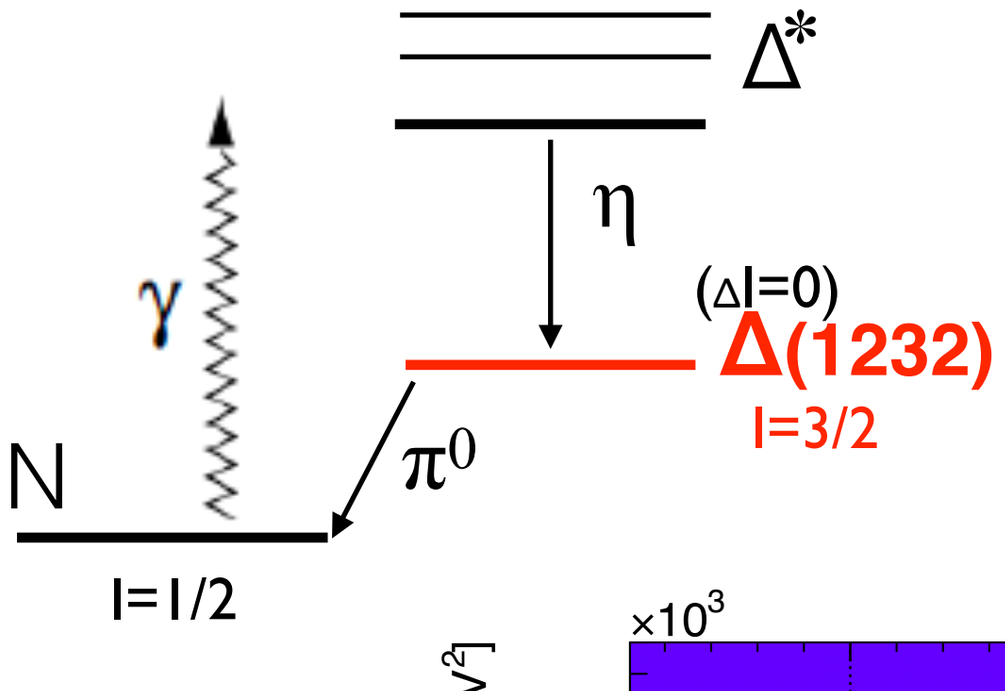
all $\gamma p \rightarrow p\pi^0\pi^0$ events with CL > 0.01 removed

events meeting the $\gamma p \rightarrow p\pi^0\gamma\gamma$ hypothesis with CL > 0.1

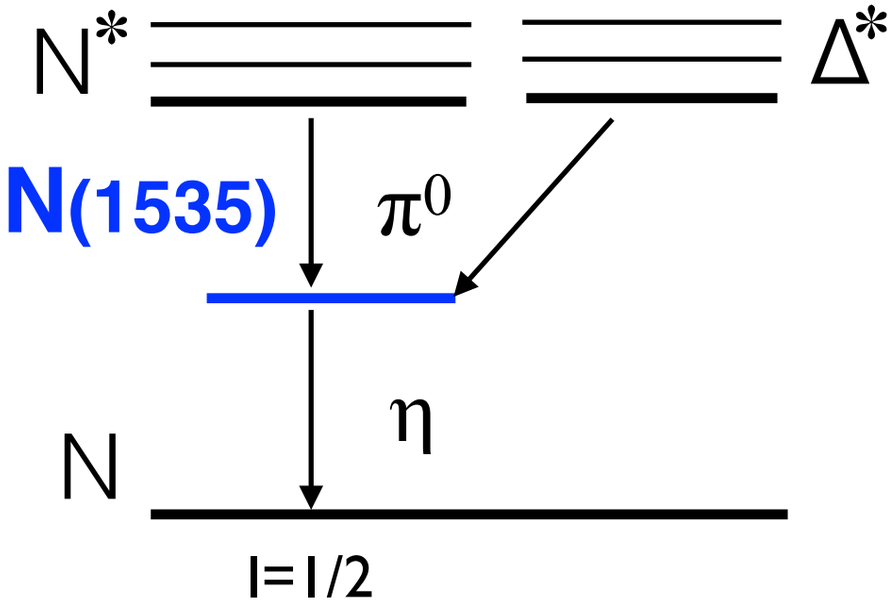


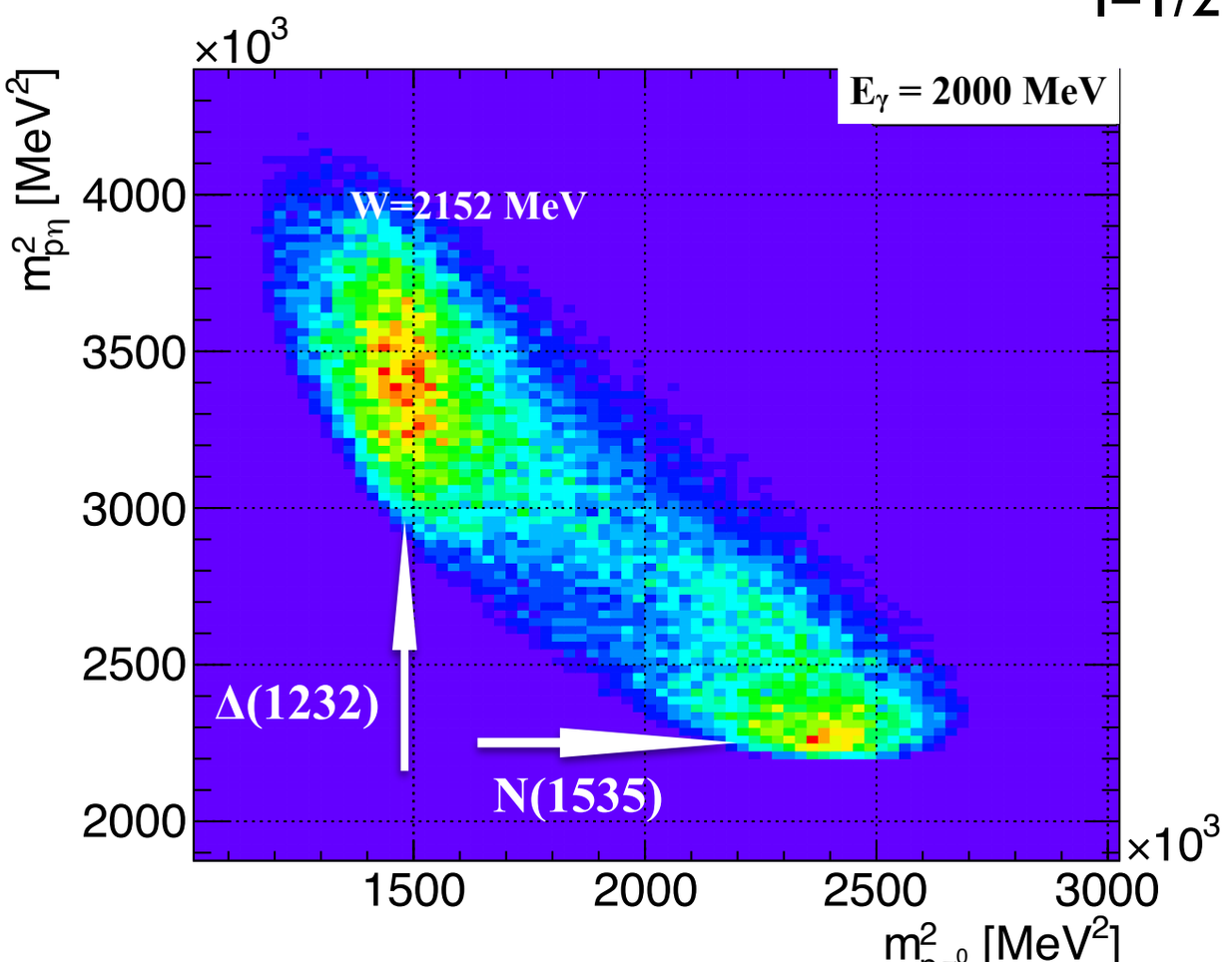
γ p → p π⁰ η: cascade decays

Δ*→Δ(1232)η→Nπ⁰η;



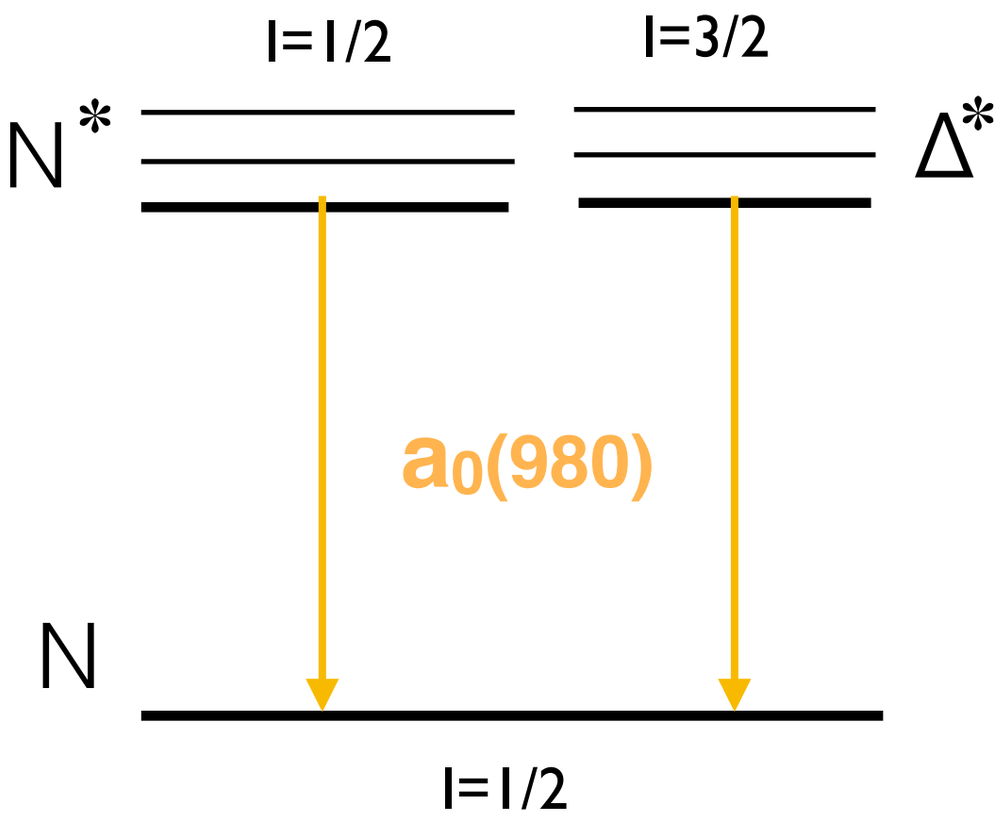
N*,Δ*→N(1535)π⁰ → Nπ⁰η;

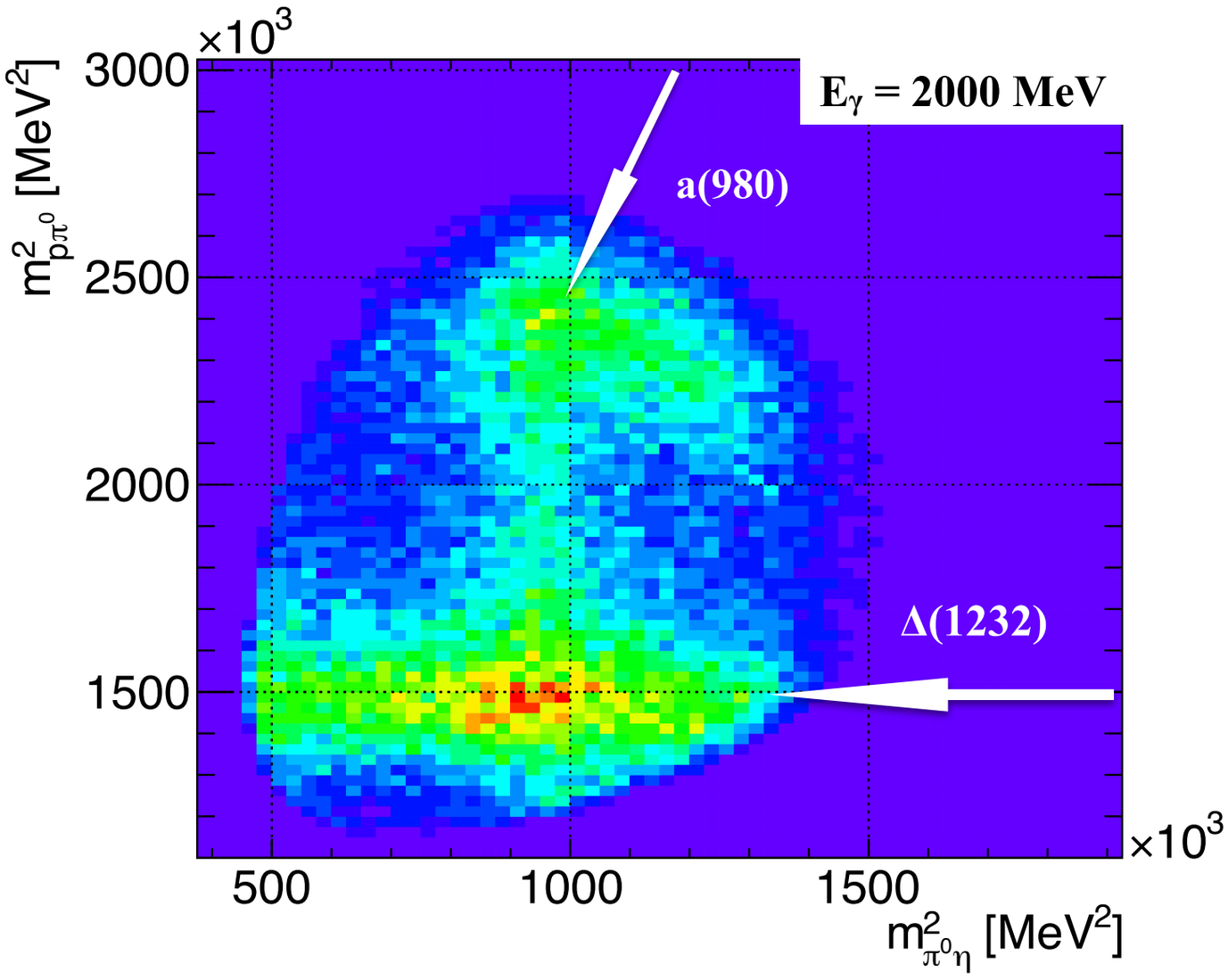




$\gamma p \rightarrow p \pi^0 \eta$: direct decay via $a_0(980)$

$N^*, \Delta^* \rightarrow N\, a_0(980) \rightarrow N\pi^0\eta$

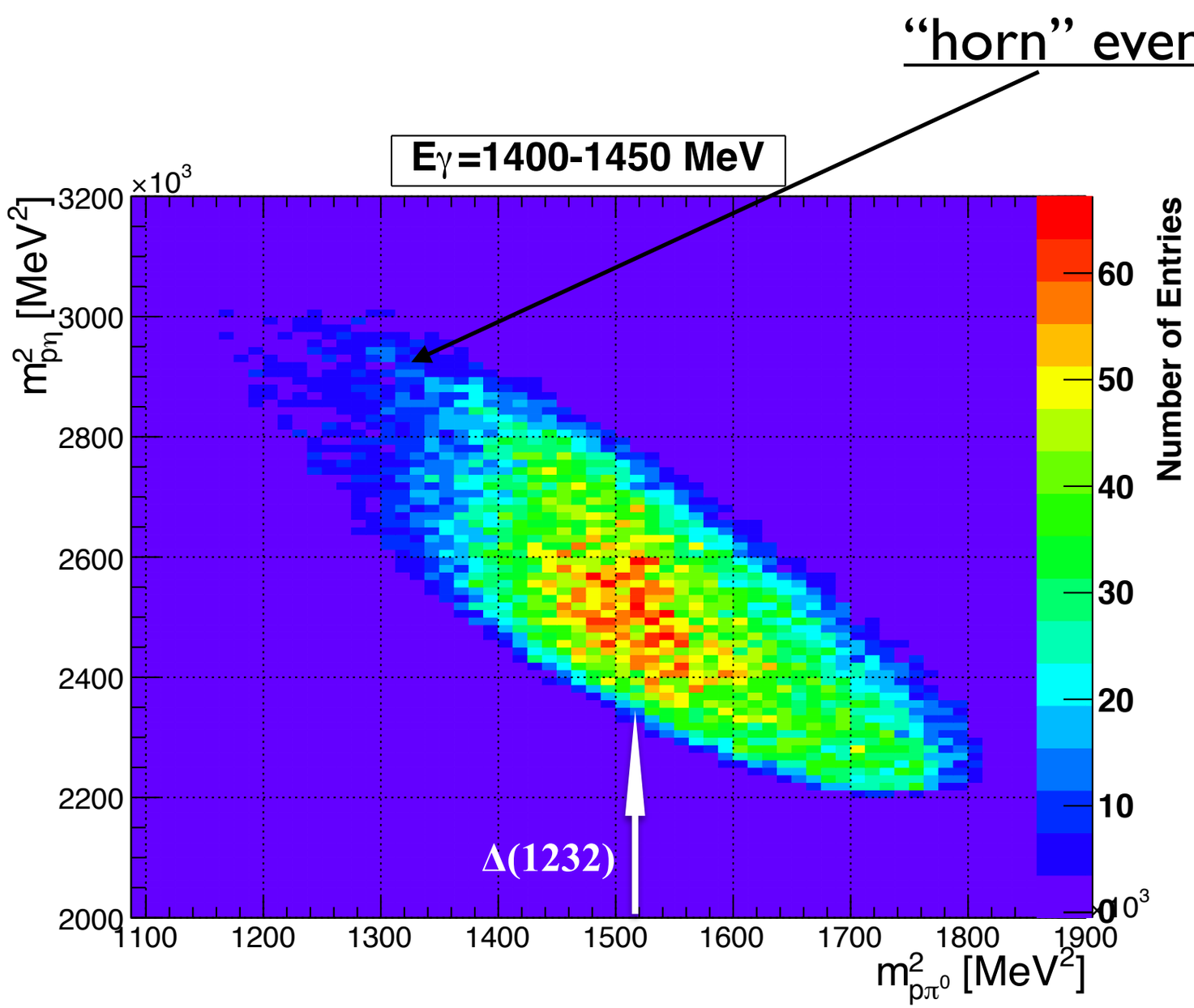




$a_0(980) \rightarrow \pi^0\, \eta \rightarrow 4\gamma$

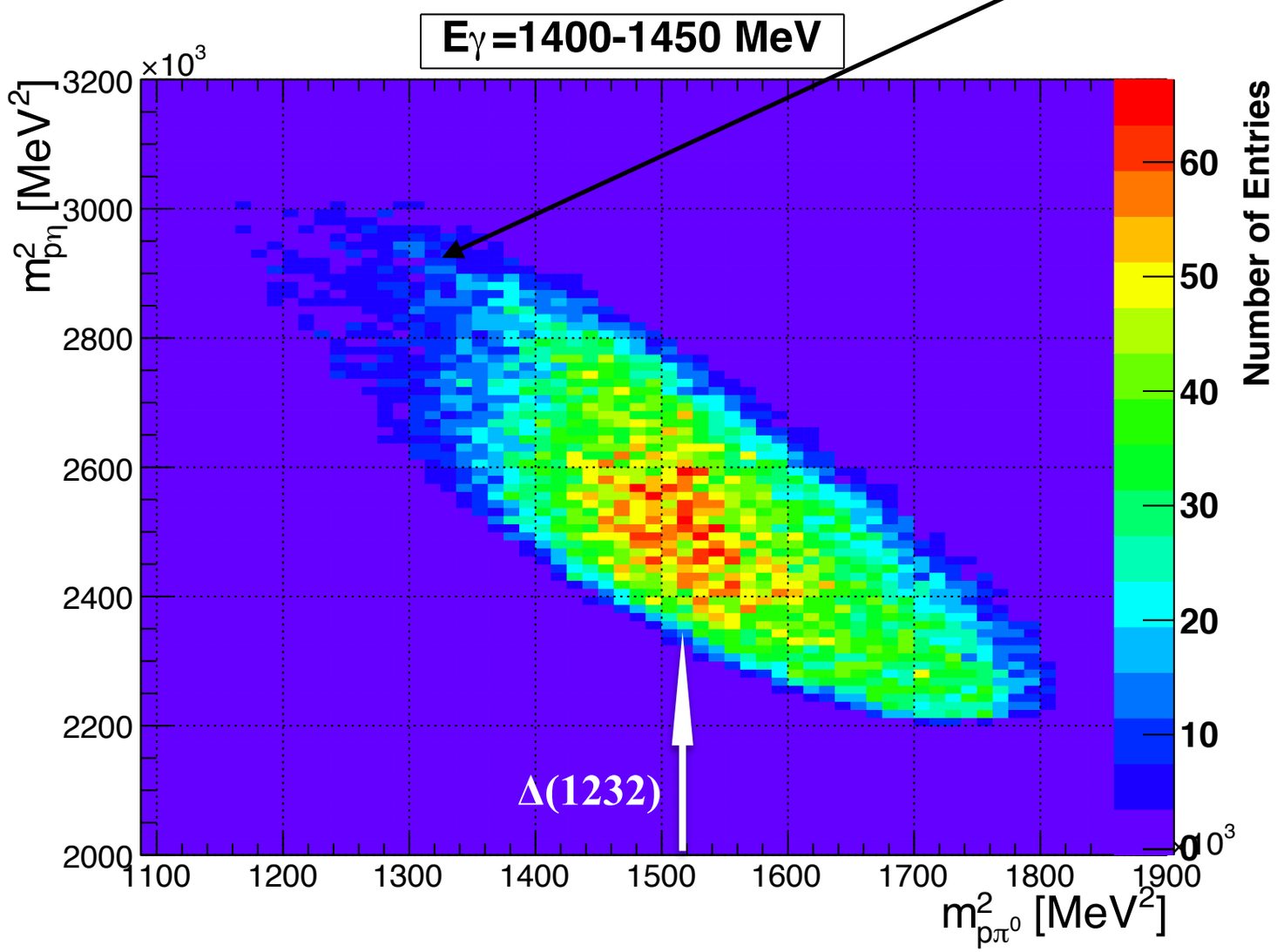
non-resonant t-channel production also possible

Dalitz plots: $\gamma p \rightarrow p\ \pi^0\ \eta$



Dalitz plots: $\gamma p \rightarrow p\ \pi^0\ \eta$

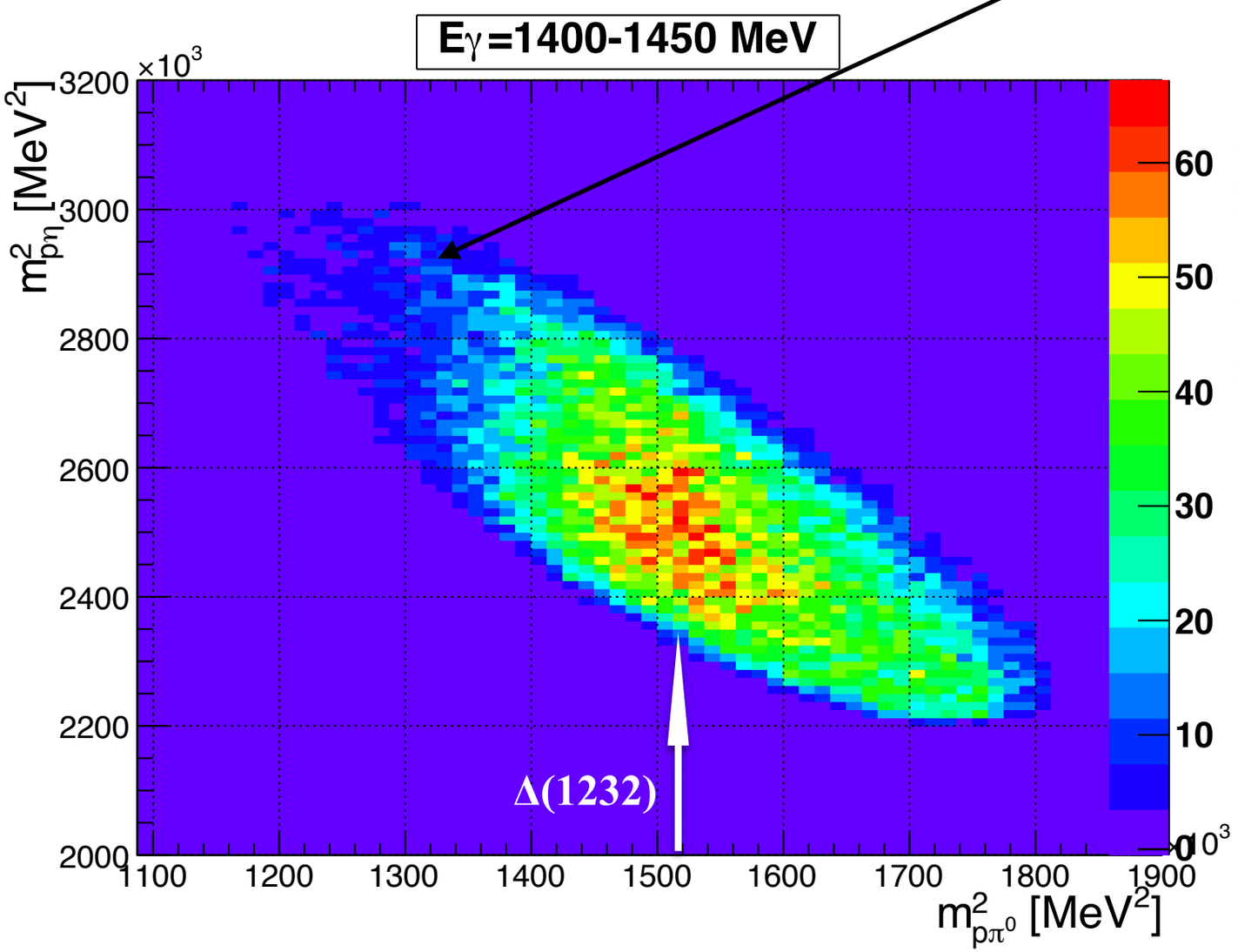
"horn" events

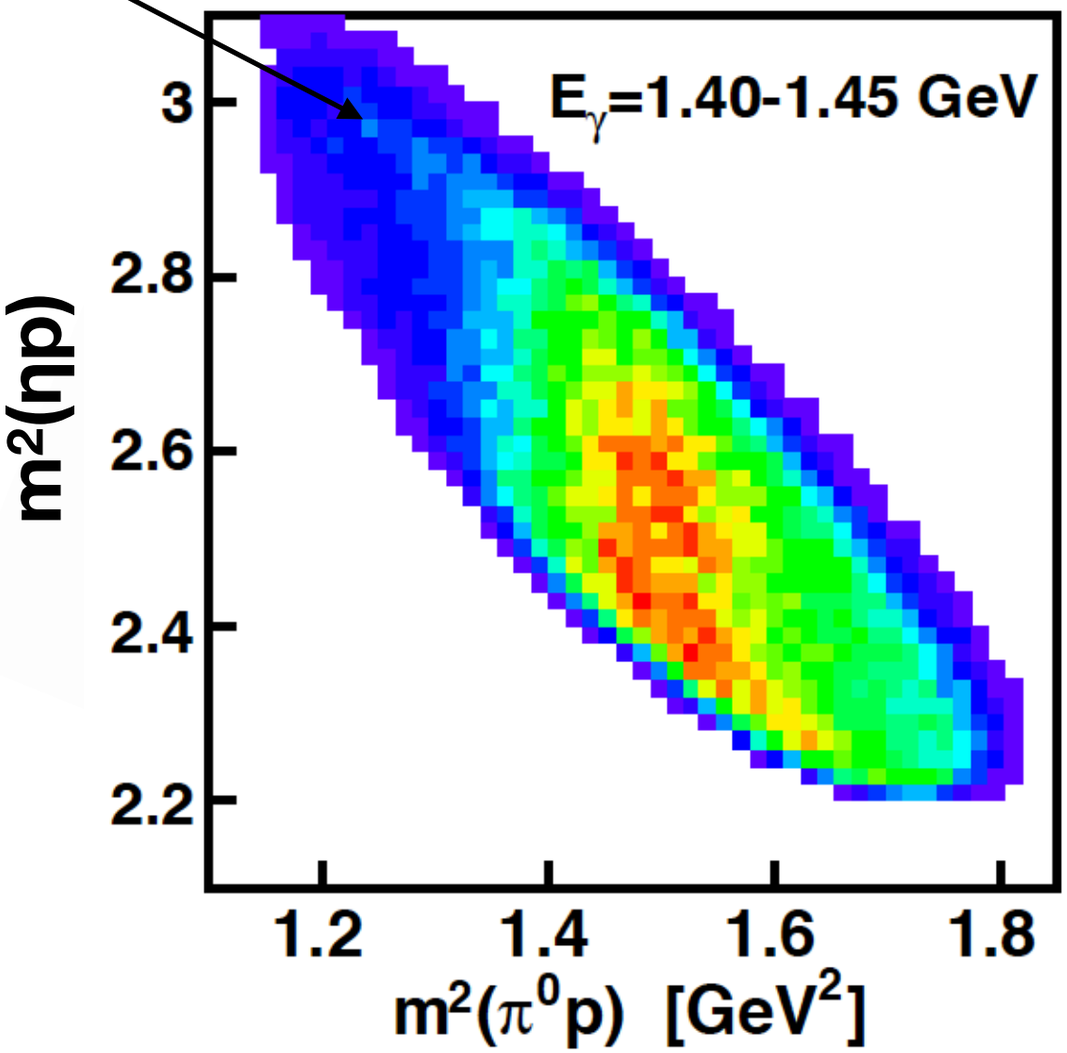


Dalitz plots: $\gamma p \to p\, \pi^0\, \eta$

"horn" events

V. Sokhoyan et al.,
PRC 97 (2018) 055212
MAMI-A2 data





"horn" events:

diagonal structure in Dalitz plot indicating a $\pi^0\eta$ correlation near $m_{\pi 0\eta} \approx 720$ MeV

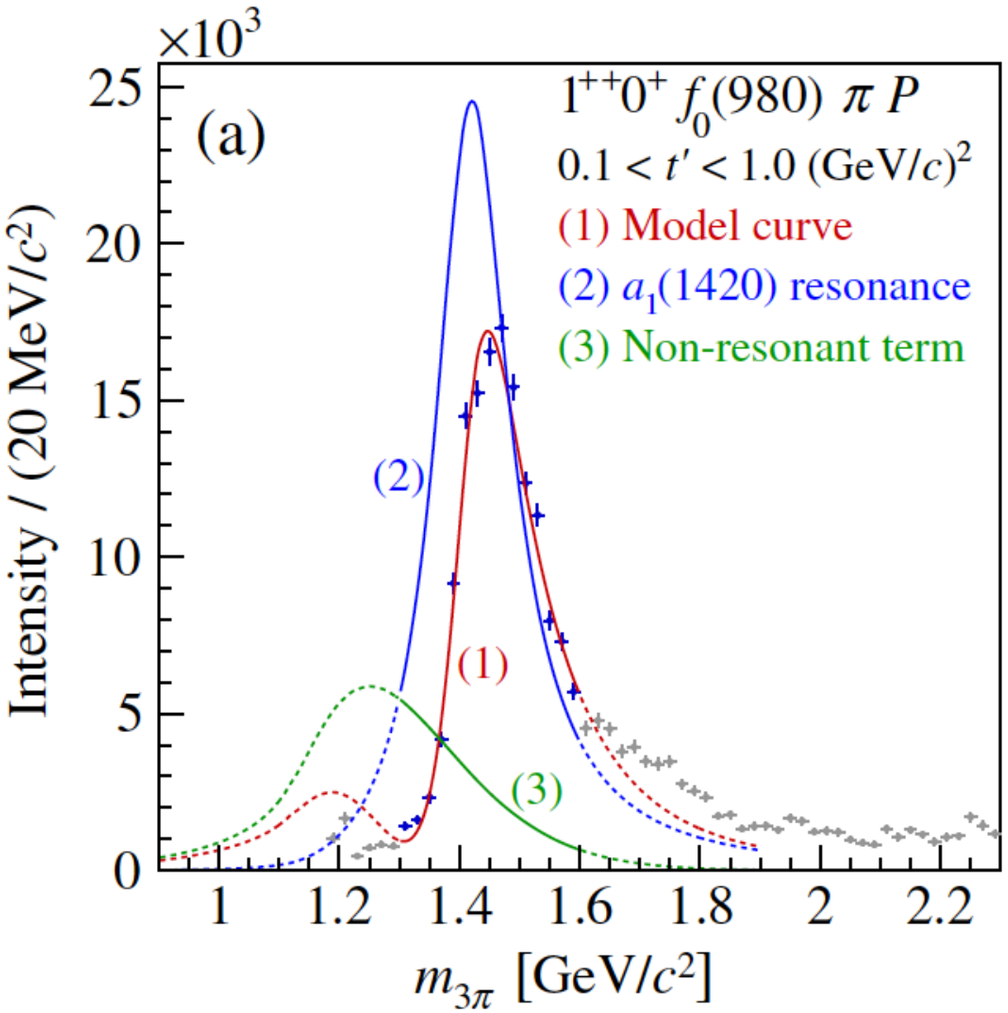
preliminary PWA analysis by V. Nikonov, A. Sarantsev:
indication for a triangle singularity contribution ??

$a_1(1420)$: new axial-vector meson or kinematic effect ??

Compass collaboration:

π^- (190 GeV/c) + p → p $\pi^-\pi^-\pi^+$

C. Adolph et al., PRL 115 (2015) 082001



exotic meson: $J^{PC} = 1^{++}$

m = 1414±15 MeV; Γ = 153+8-23 MeV,

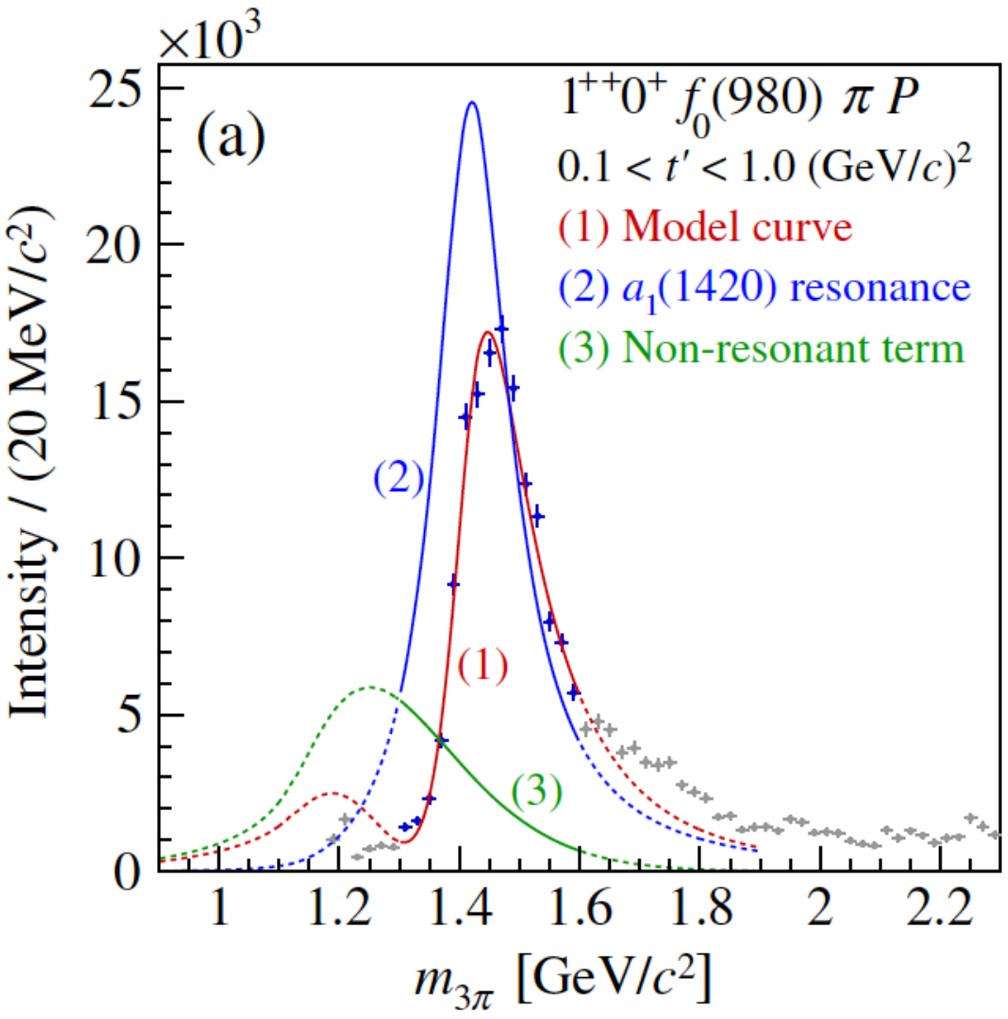
decaying into $f_0(980)\ \pi^-$

$a_1(1420)$: new axial-vector meson or kinematic effect ??

Compass collaboration:

π^- (190 GeV/c) + p → p $\pi^-\pi^-\pi^+$

C. Adolph et al., PRL 115 (2015) 082001



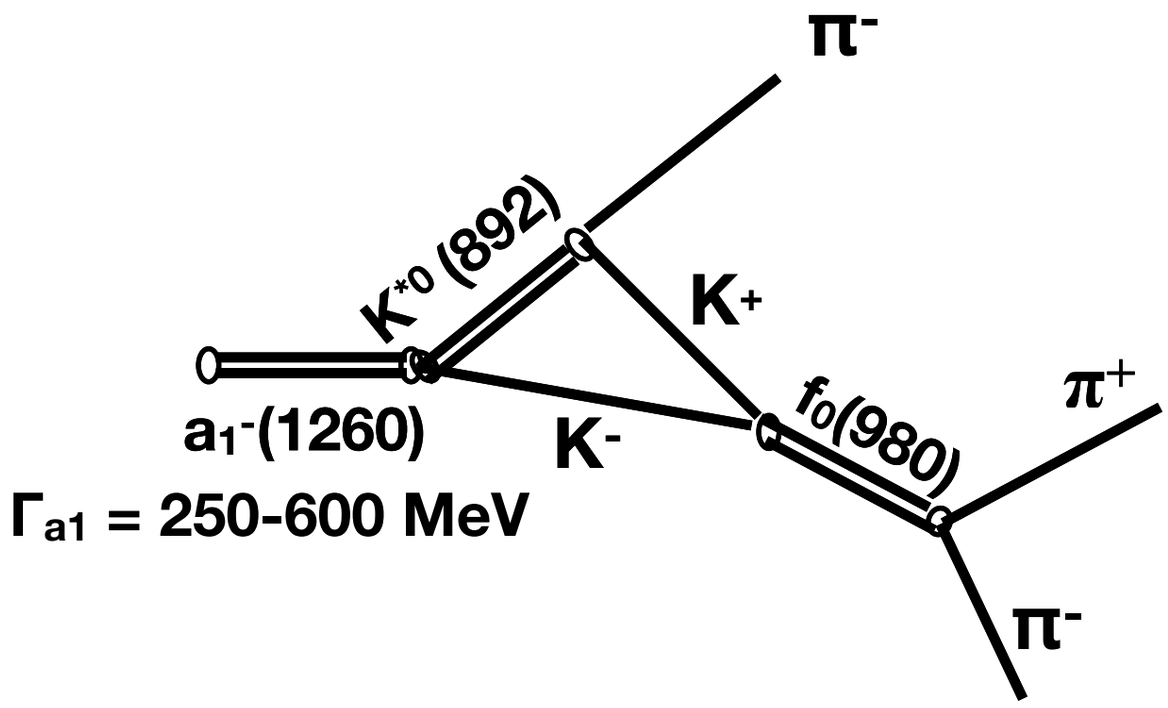
exotic meson: $J^{PC} = 1^{++}$

m = 1414±15 MeV; Γ = 153+8-23 MeV,

decaying into $f_0(980)\ \pi^-$

M. Mikhasenko, B. Ketzer, A. Sarantsev,
PRD 91 (2015) 094015

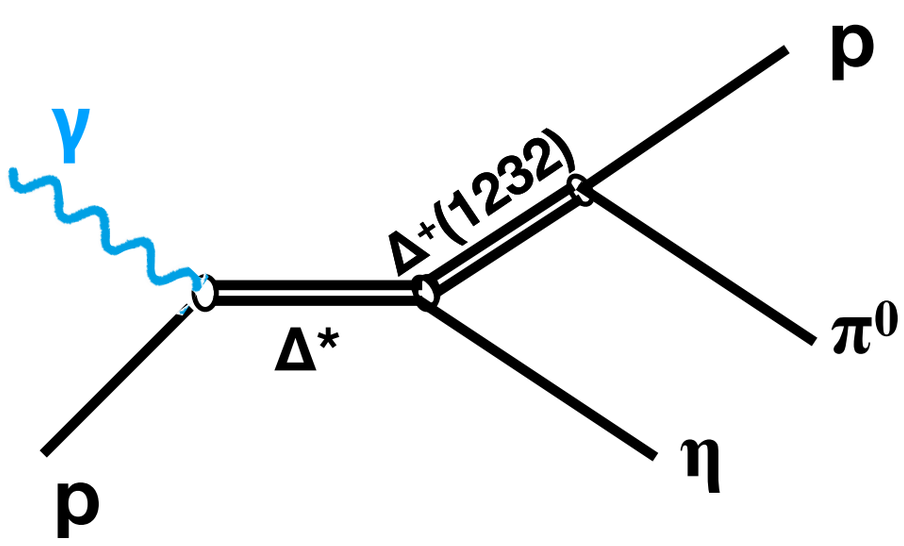
F. Aceti, L.R. Dai, E. Oset, PRD 94 (2016) 096015



triangular loop develops singularity
at W≈1420 MeV
→ observed peak = kinematic effect

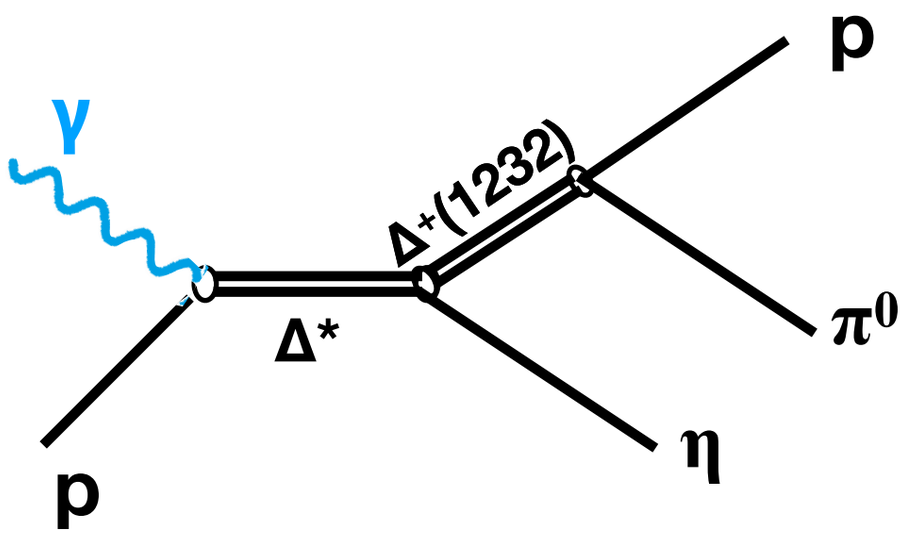
Different reaction amplitudes: $\gamma p \rightarrow p\ \pi^0\ \eta$

resonance production via $\Delta^+(1232)$



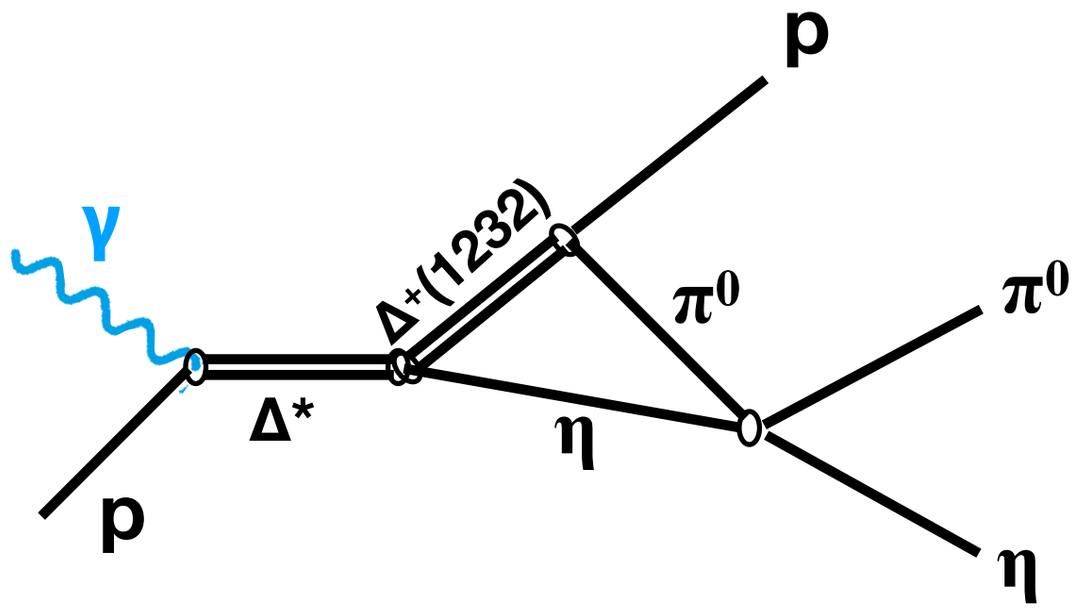
Different reaction amplitudes: $\gamma p \to p\ \pi^0\ \eta$

resonance production via $\Delta^+(1232)$

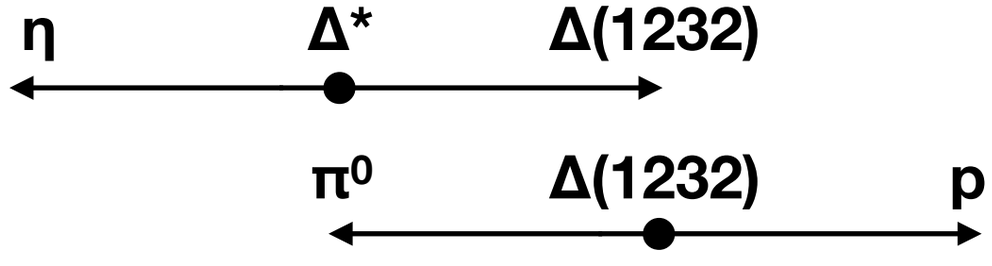


triangular singularity

final state (π^0,η) elastic scattering



singularities in reaction amplitude occur when all particle in triangle are on-shell and their momenta are collinear with $\beta_\pi > \beta_\eta$ so that π^0 and η rescatter:



for E_γ = 1425 MeV: triangle singularity: Δ^* cms: $\beta_\pi = 0.786 > \beta_\eta = 0.468$

Kinematic conditions for singularities

C. Schmid, Phys. Rev. 154 (1967) 1363

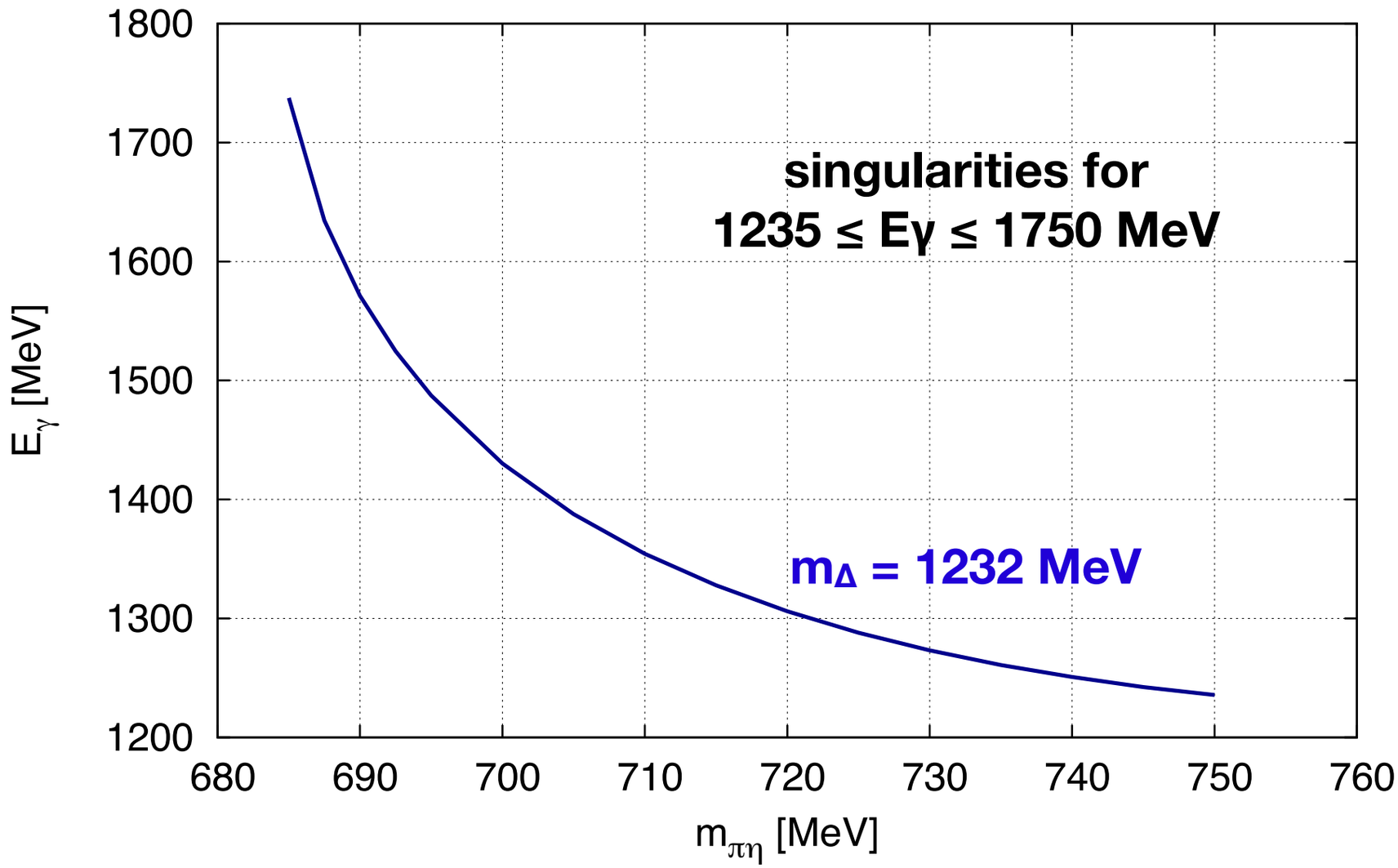
energy and momentum balance of external particles and particles within triangle

$$E_\Delta = (m_\Delta^2 - m_p^2 - m_\pi^2)/2m_\pi ; \quad E_\eta = (m_{\pi\eta}^2 - m_\eta^2 - m_\pi^2)/2m_\pi$$

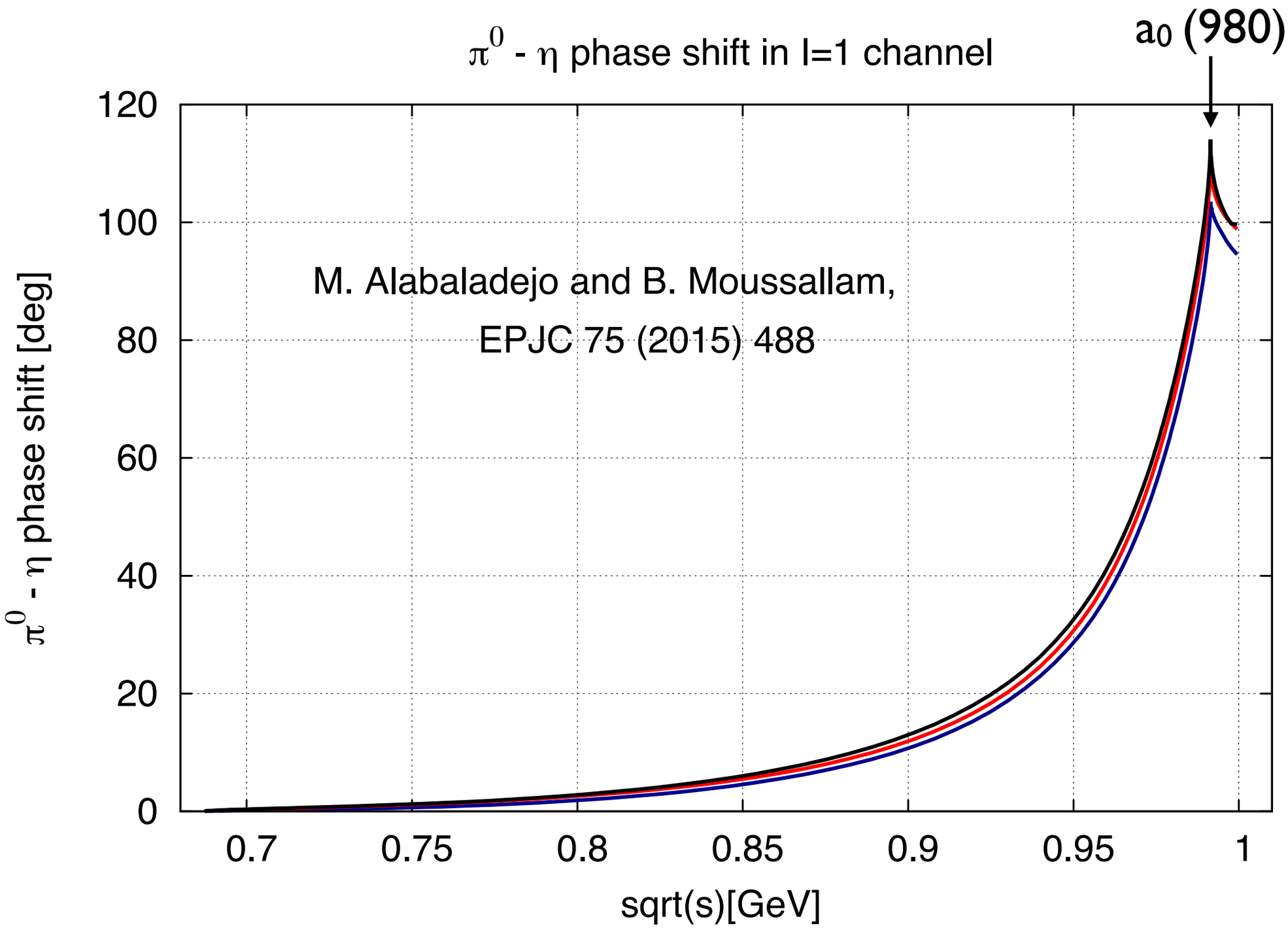
$$p_\Delta = 1/2m_\pi \cdot \sqrt{(m_\Delta^2 - (m_p+m_\pi)^2)\,(m_\Delta^2 - (m_p-m_\pi)^2)}$$

$$p_\eta = 1/2m_\pi \cdot \sqrt{(m_{\pi\eta}^2 - (m_\eta+m_\pi)^2)\,(m_{\pi\eta}^2 - (m_\eta-m_\pi)^2)}$$

$$W^2 = m_\Delta^2 + m_\eta^2 + 2\,E_\Delta \cdot E_\eta - 2\,p_\Delta \cdot p_\eta$$



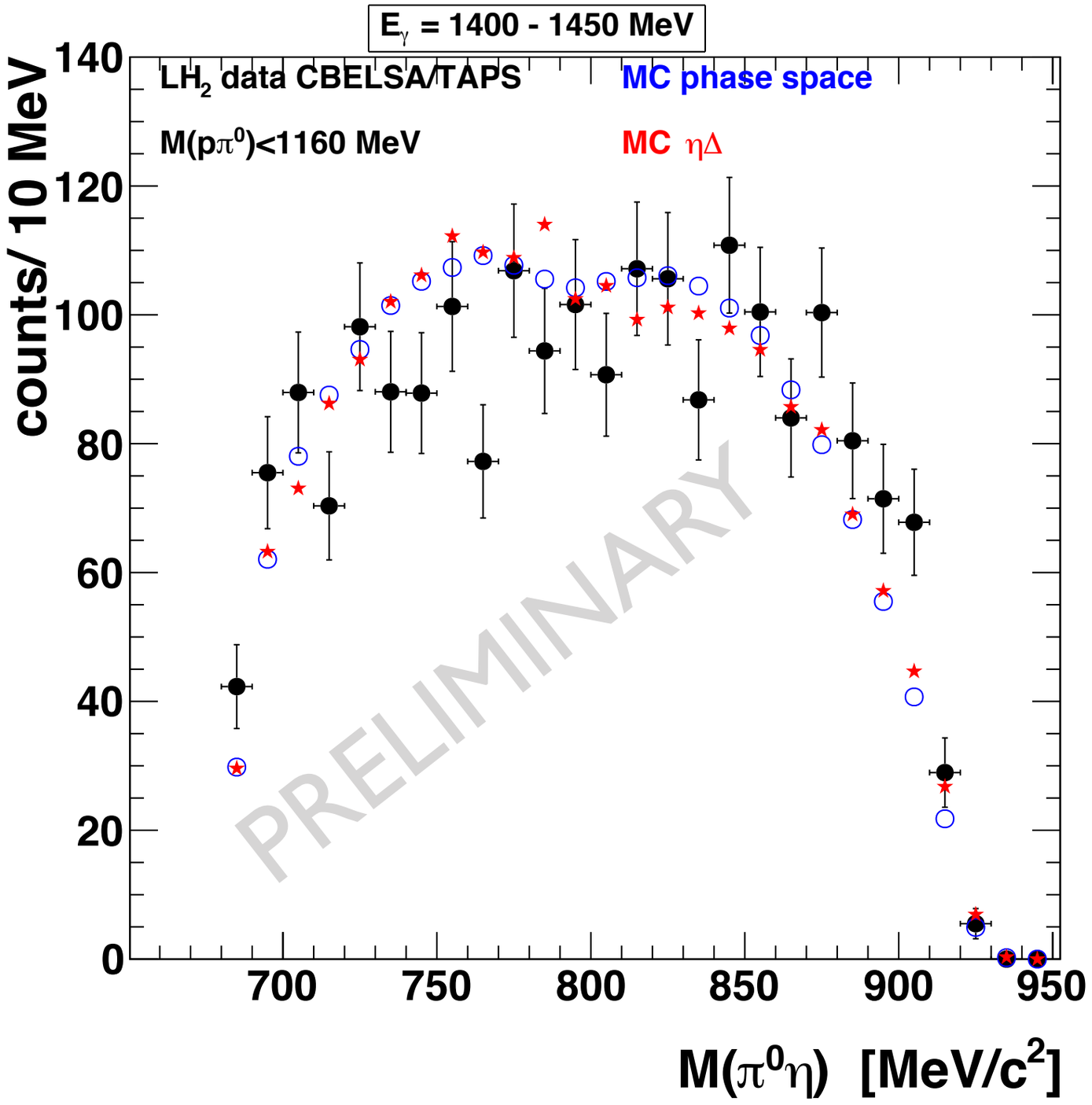
strength of the π^0-η interaction



π^0-η interaction quite weak at low $\sqrt{s}$ (B. Kubis)

triangle singularity amplitude quite small (V. Debastiani, E. Oset, S. Sakai)

π^0-η invariant mass spectrum



no significant deviation of measured $\pi^0\eta$ invariant mass spectrum from spectrum simulated for $\gamma p \rightarrow \Delta^* \rightarrow \eta\Delta(1232) \rightarrow \eta\pi^0 p$

no evidence for a triangle singularity contribution !!

summary

- meson cascade decays dominate de-excitation of higher nucleon resonances → multi photon final states → 4 π detectors

- clear evidence for η Δ(1232) and π^0 S_{11}(1535) cascade events:
  $\gamma p \rightarrow \Delta^* \rightarrow \eta\, \Delta(1232) \rightarrow \eta\pi^0 p$; $\gamma p \rightarrow \Delta^*, N^* \rightarrow \pi^0\, S_{11}(1535) \rightarrow \pi^0 \eta p$

- kinematic fit essential for identifying the $\gamma p \rightarrow p\, \pi^0\eta$ reaction and for removing residual $\pi^0\pi^0$ events;
  final checks of the data analysis in progress

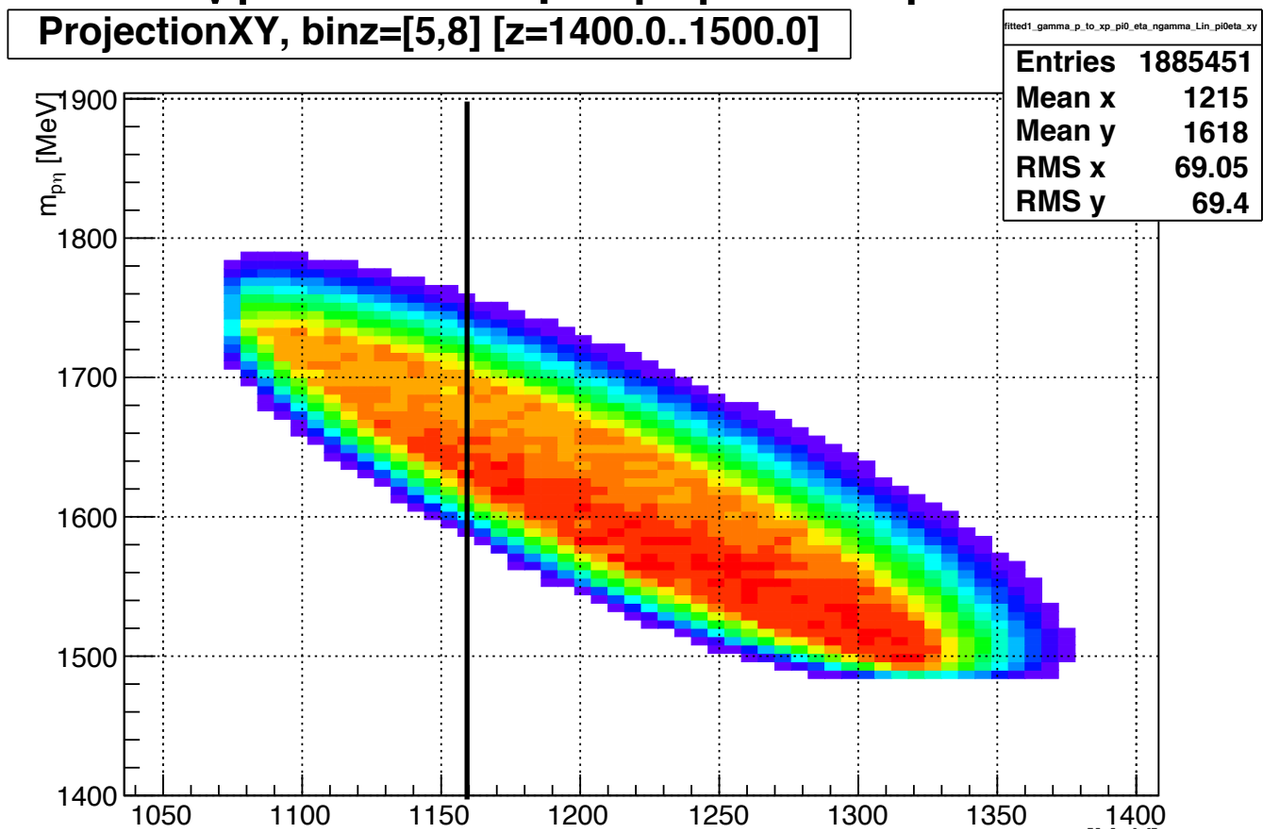
- triangle singularity kinematically possible in $\gamma p \rightarrow p\, \pi^0\eta$ for E_γ= 1300-1500 MeV

- triangle singularity contribution insignificant due to weak π^0-η interaction near threshold

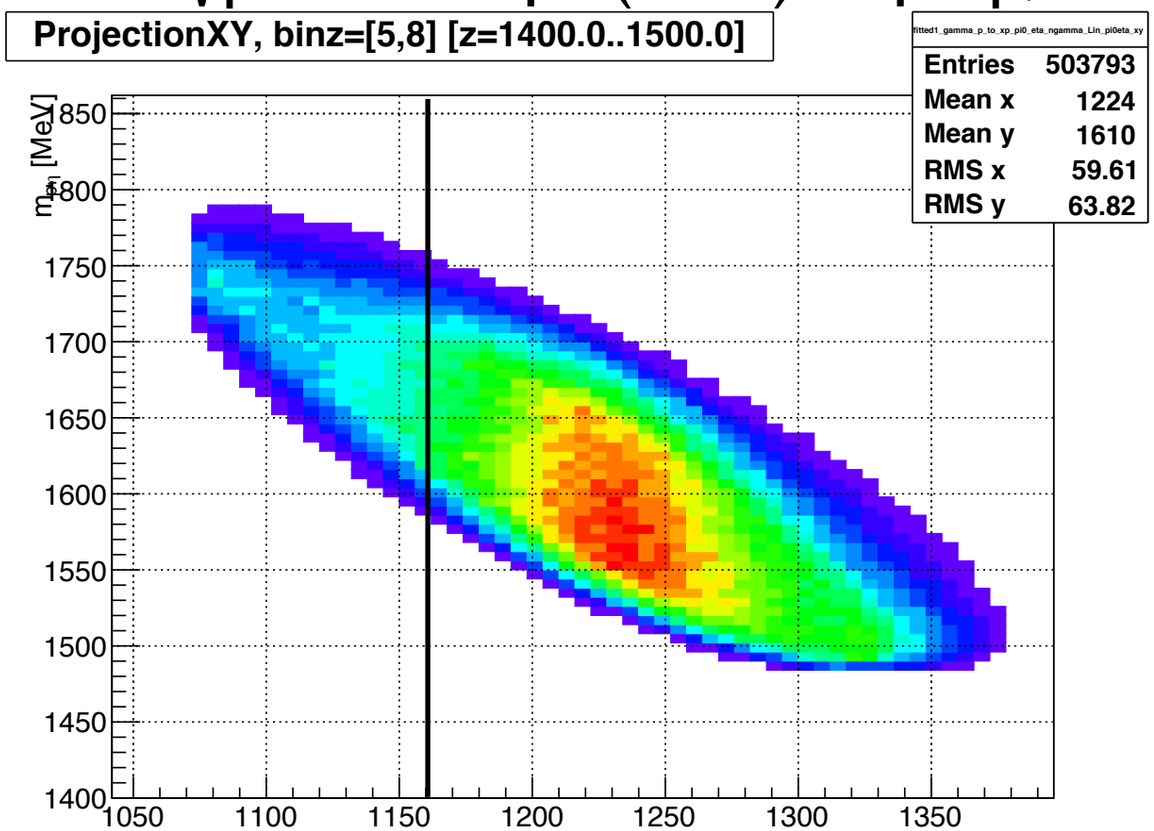
back up

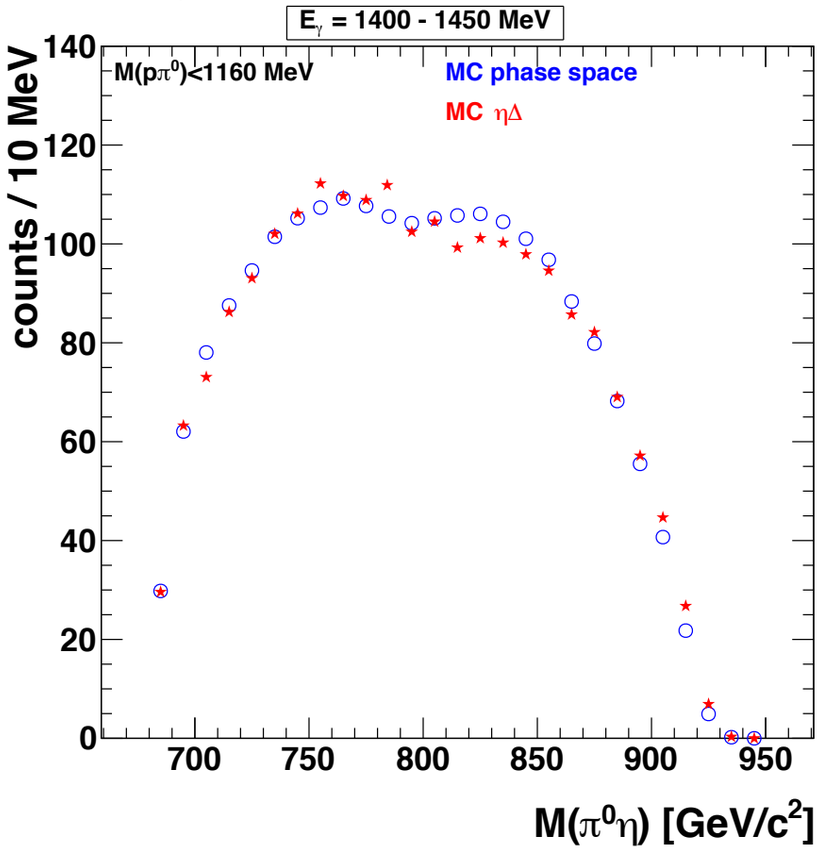
Monte-Carlo simulations: E_γ = 1.40- 1.45 GeV

$\gamma p \rightarrow \Delta^* \rightarrow \eta\pi^0 p$; phase space



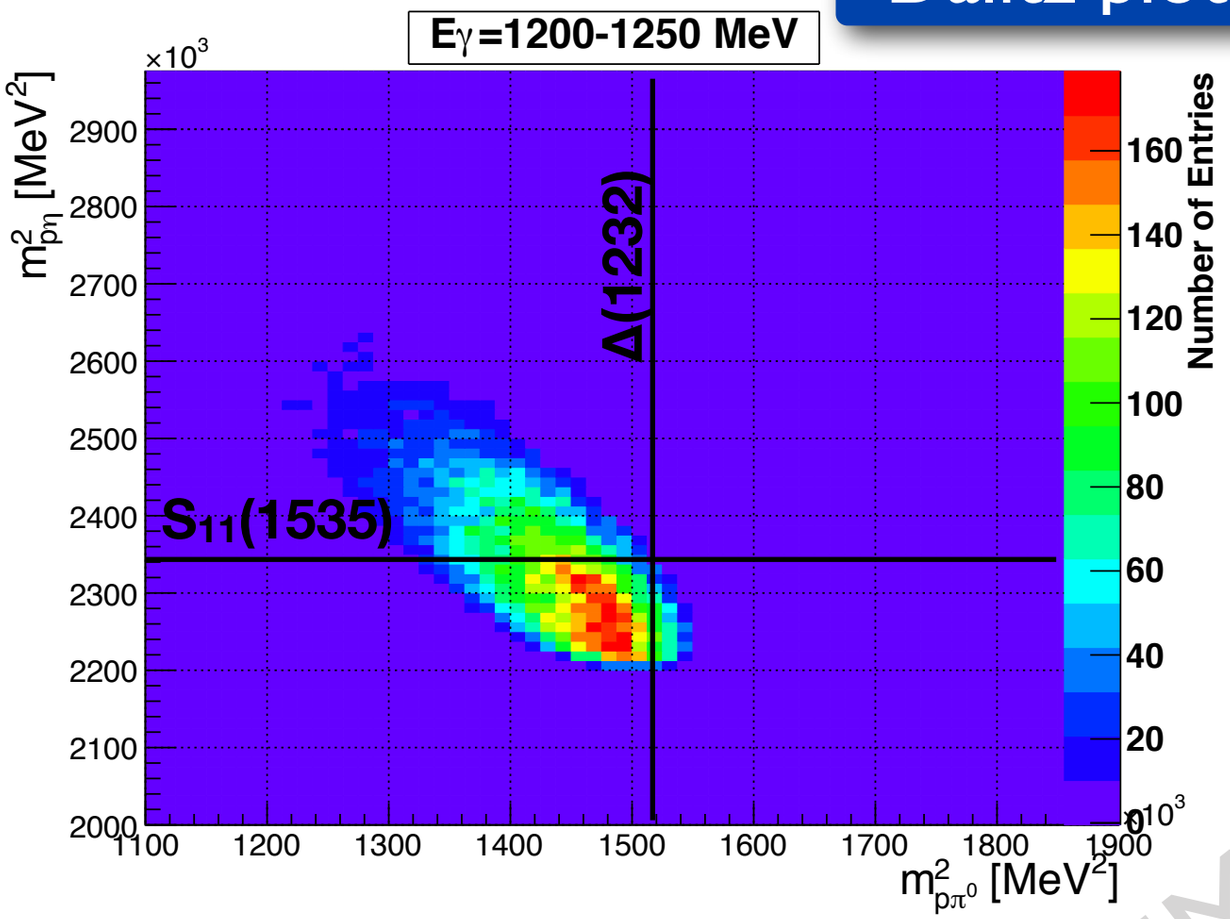
$\gamma p \rightarrow \Delta^* \rightarrow \eta\, \Delta(1232) \rightarrow \eta\pi^0 p$;

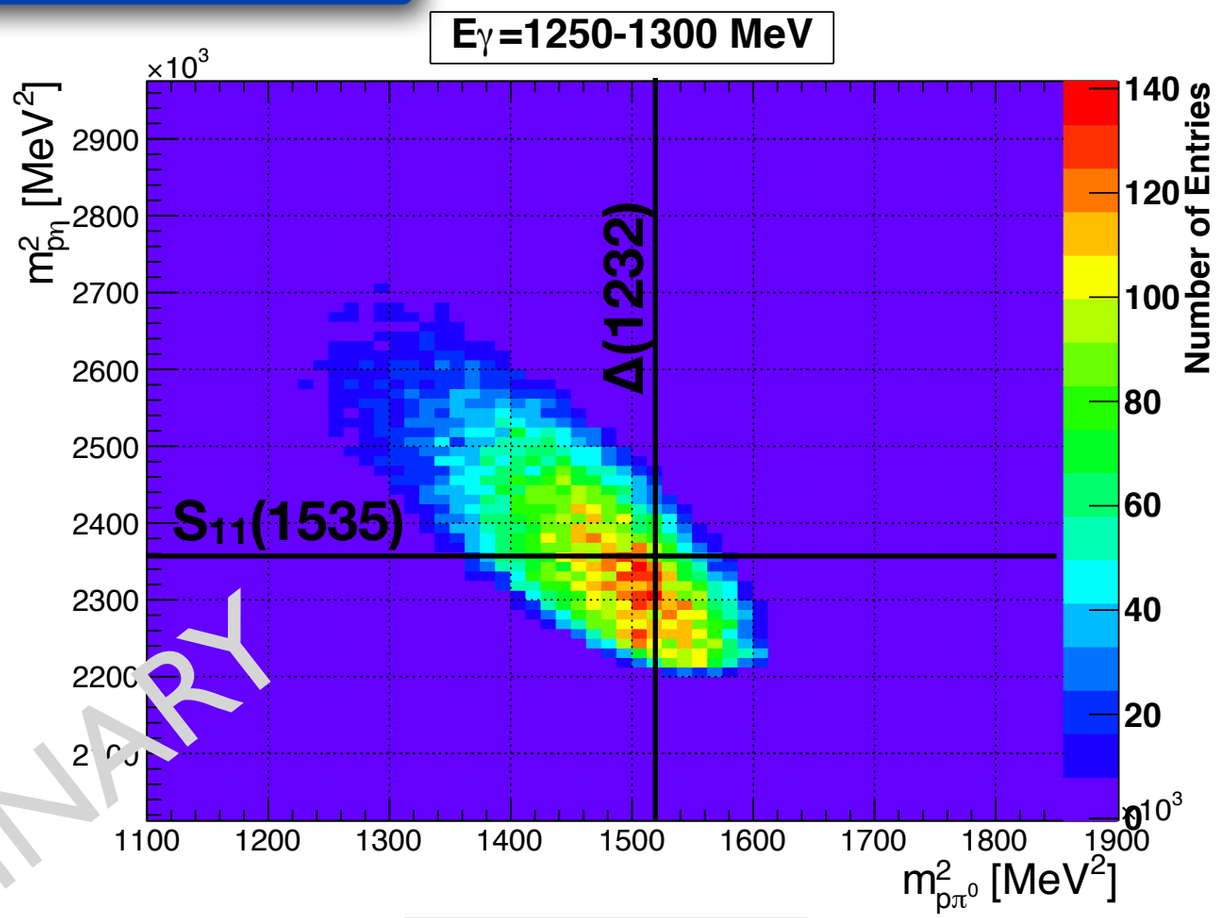


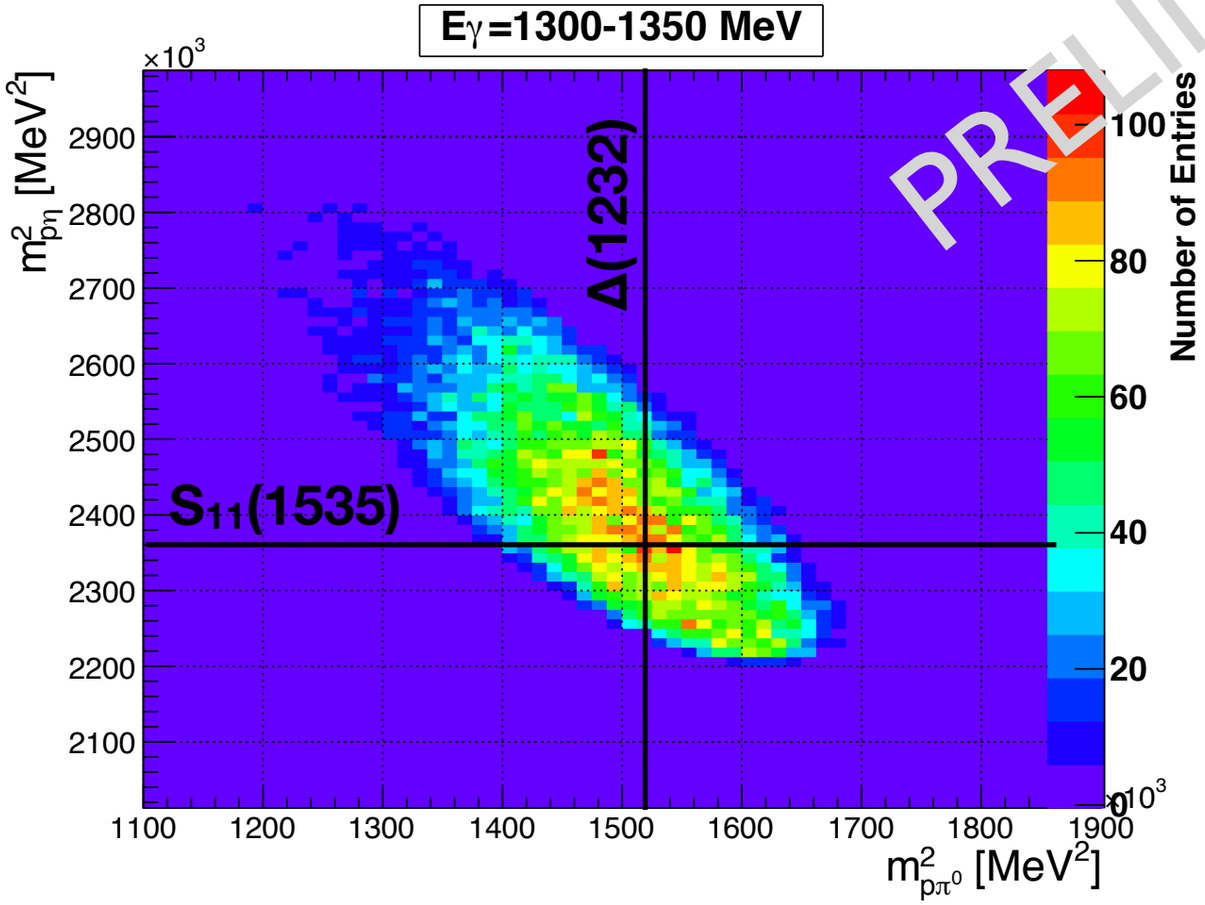


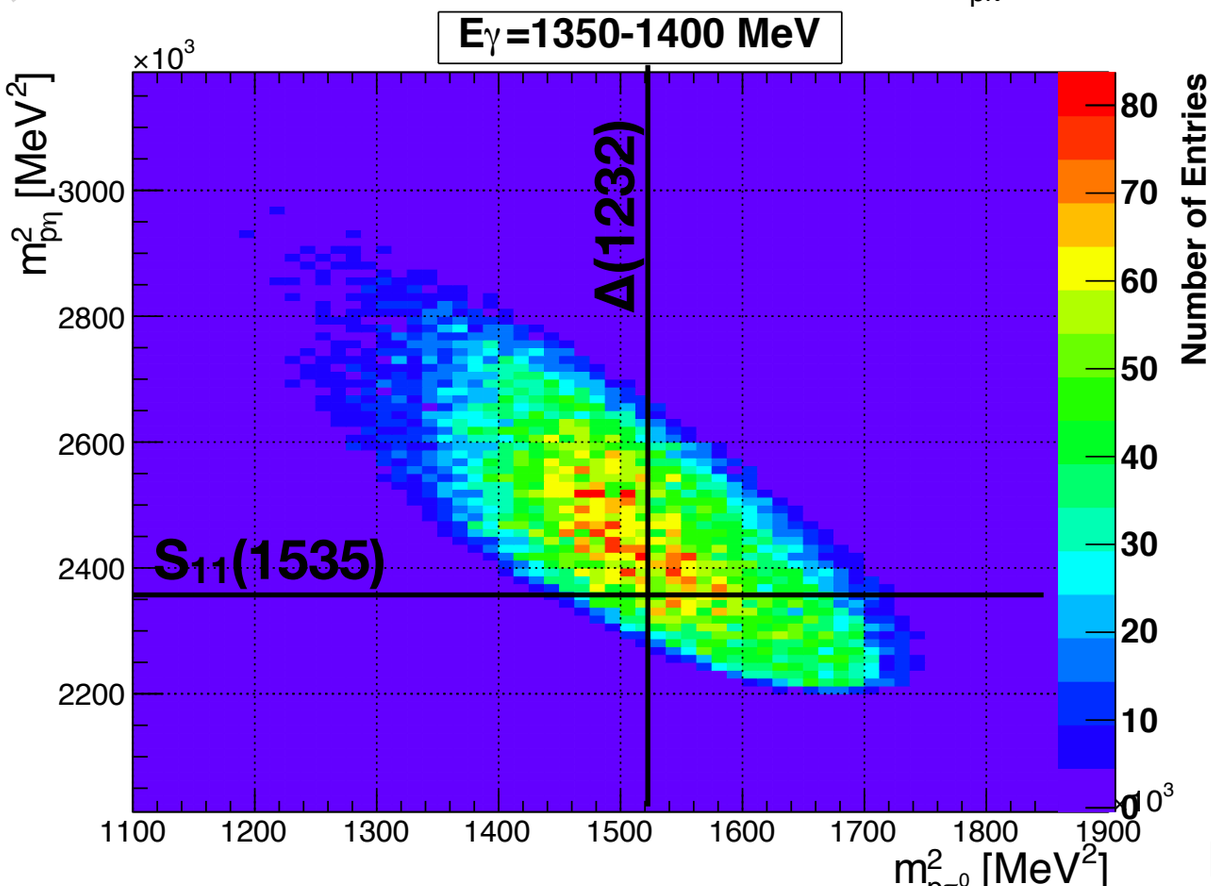
$\pi^0\eta$ invariant mass spectrum for $m_{p\pi 0} < 1160$MeV

Dalitz plots: $\gamma p \rightarrow p\ \pi^0\ \eta$

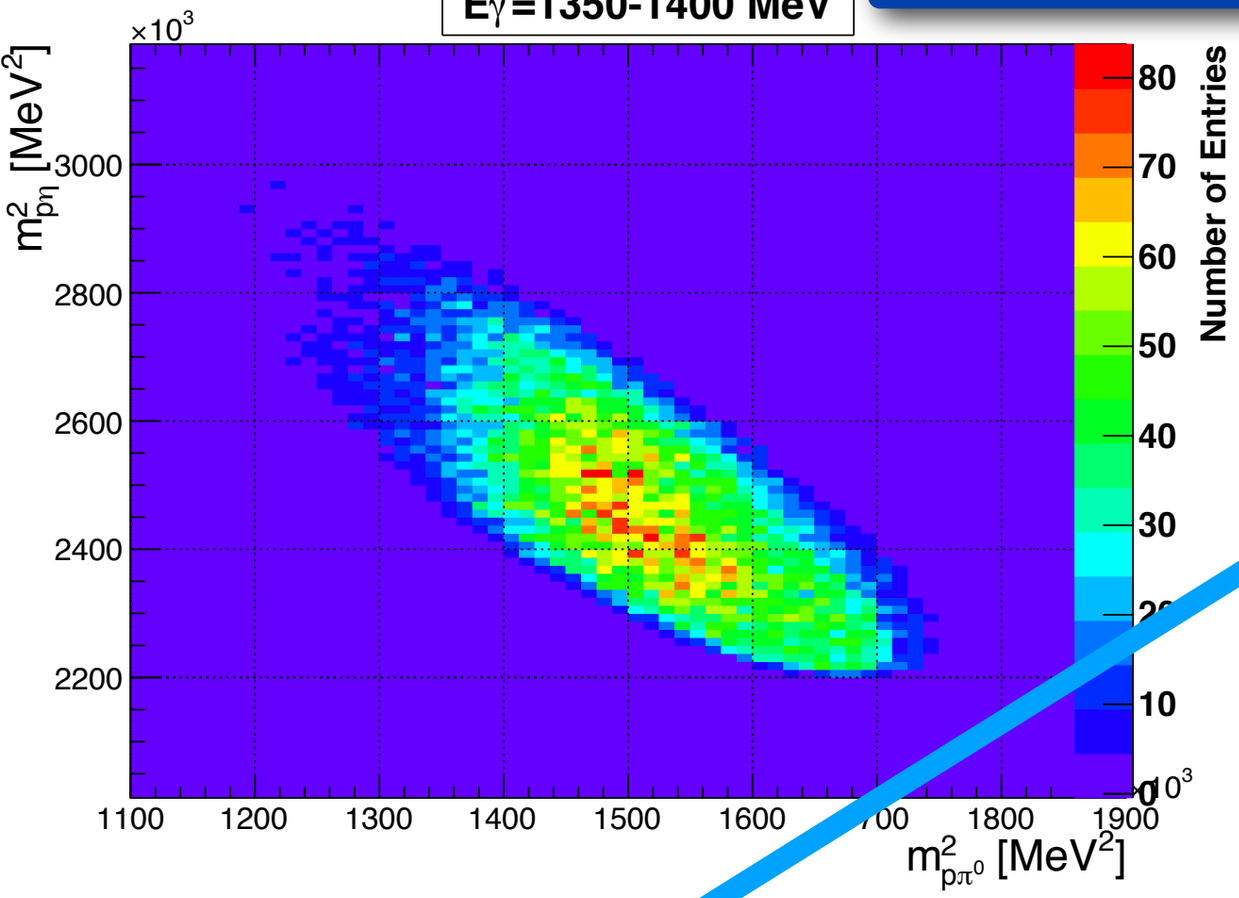


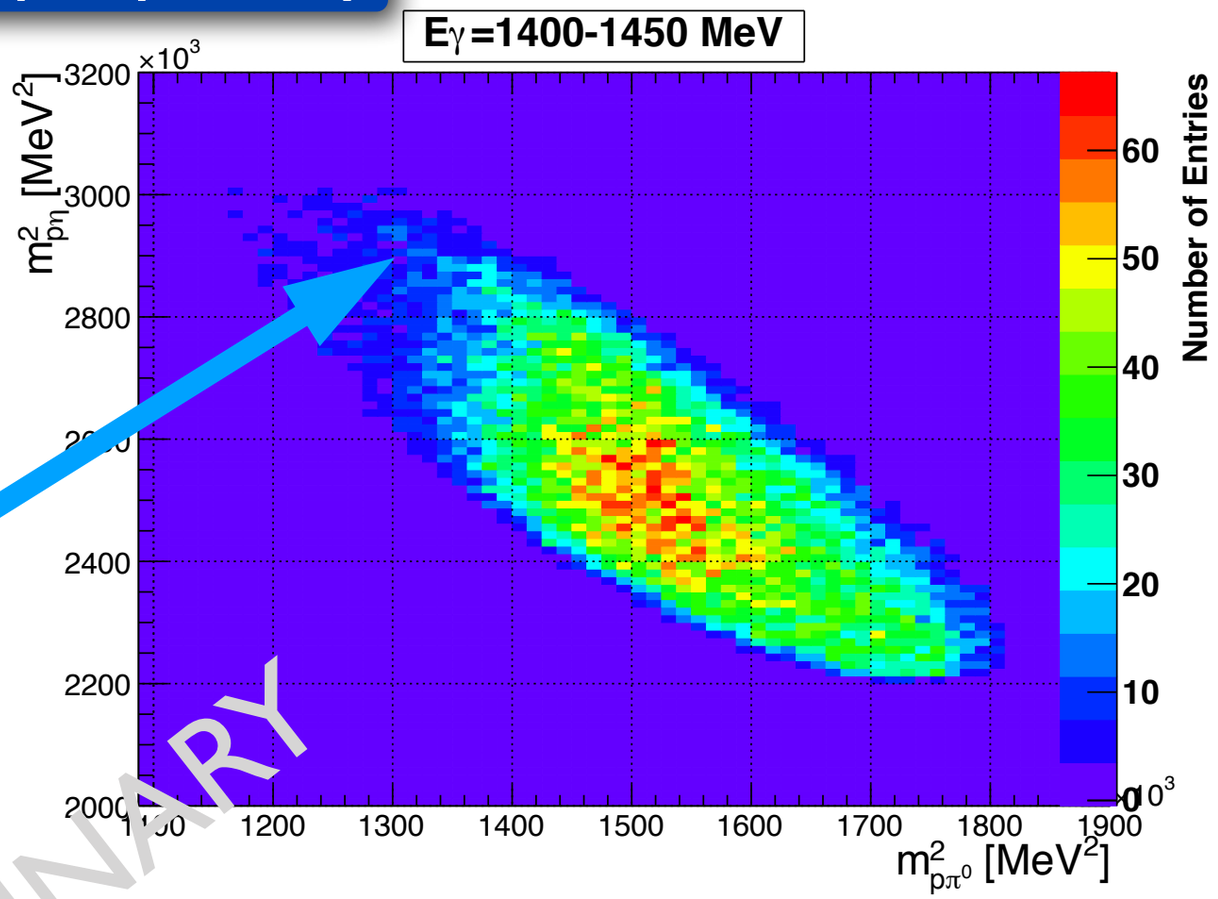


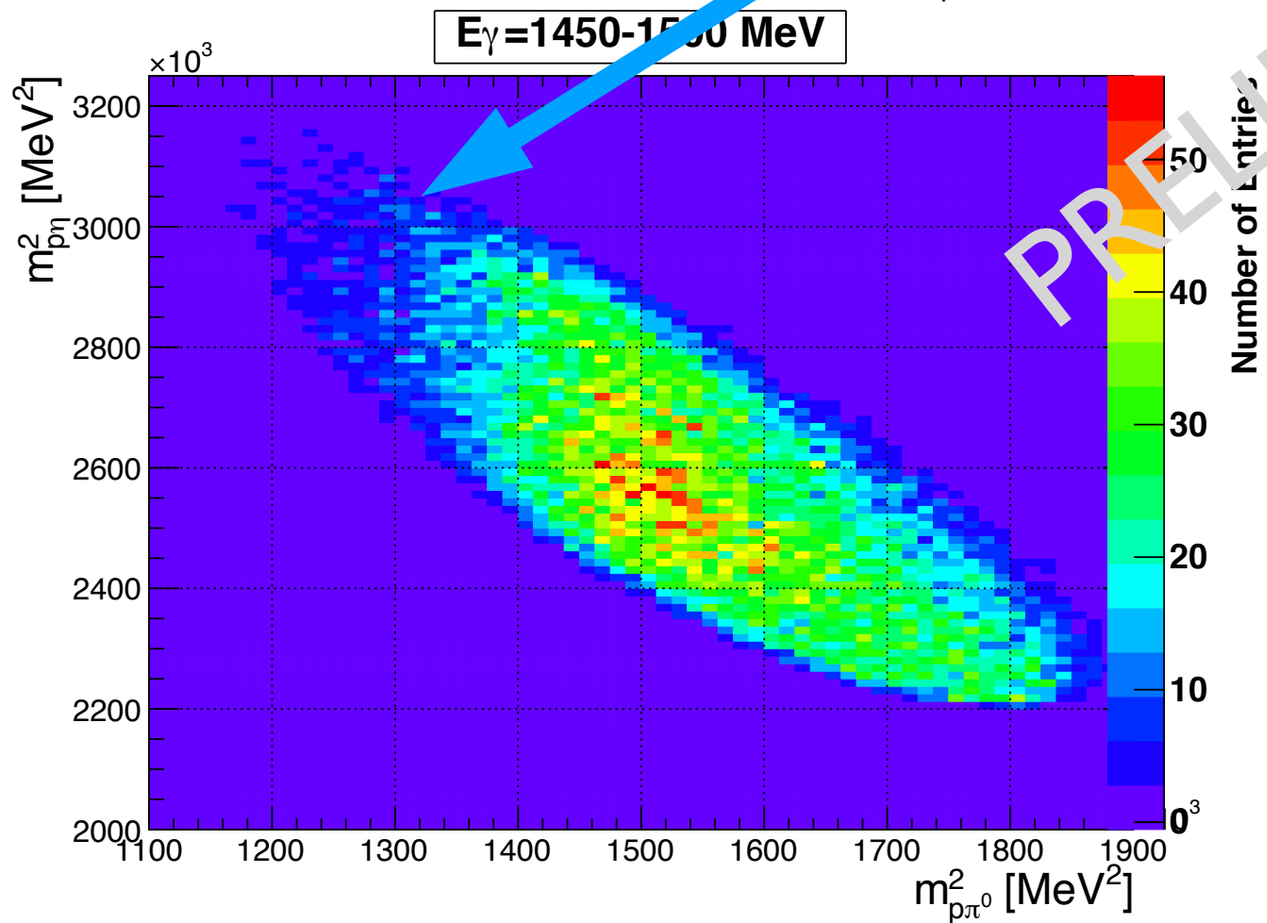


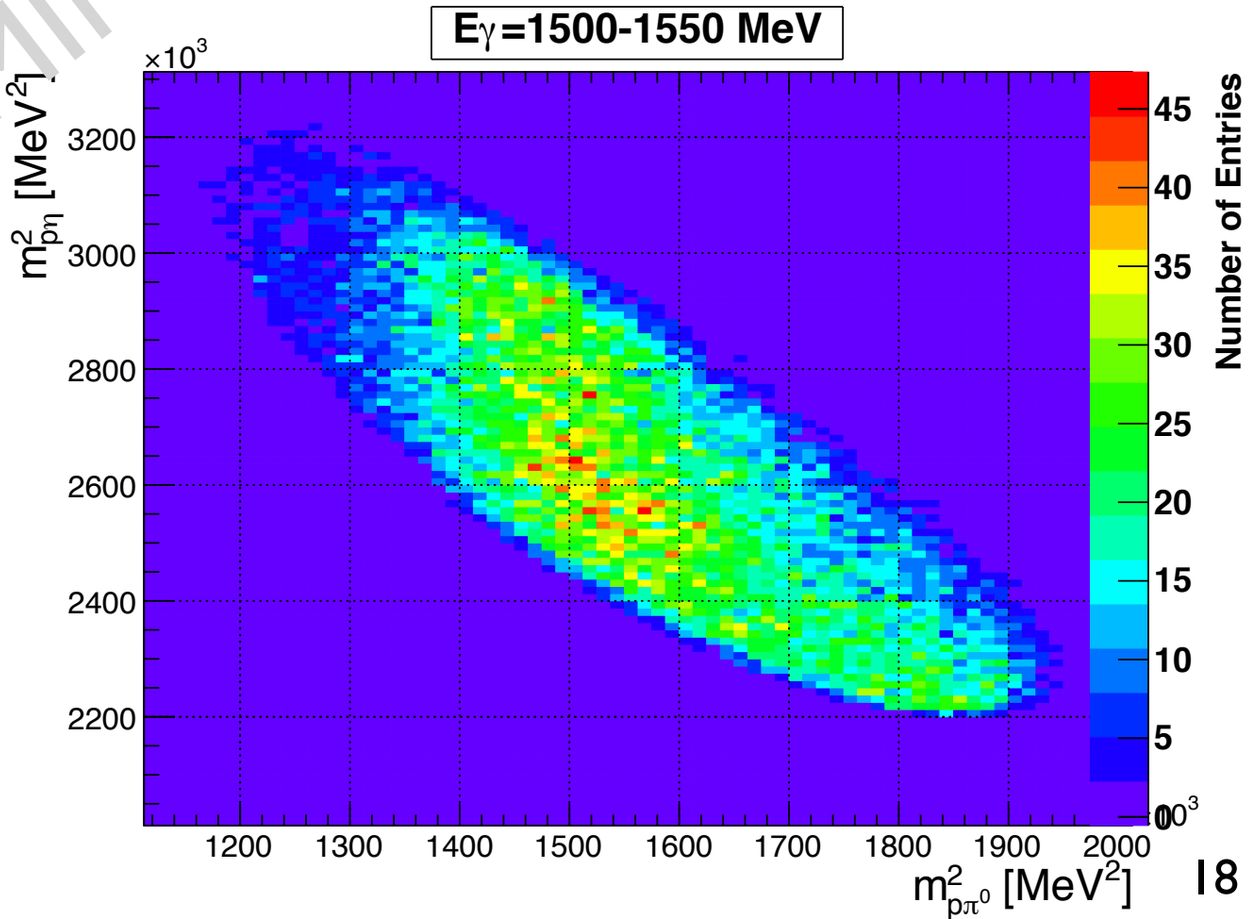


Dalitz plots: $\gamma p \rightarrow p\ \pi^0\ \eta$

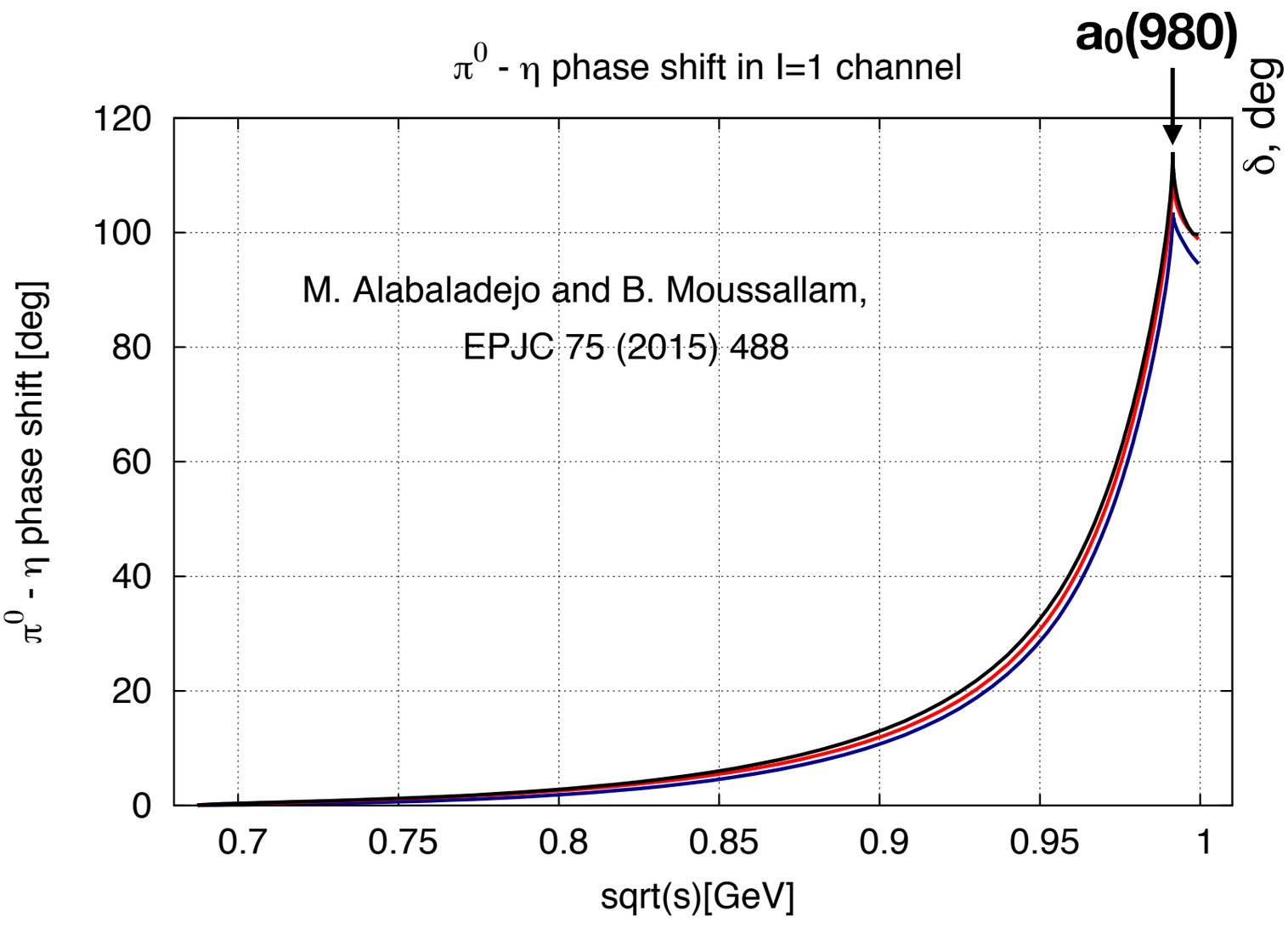




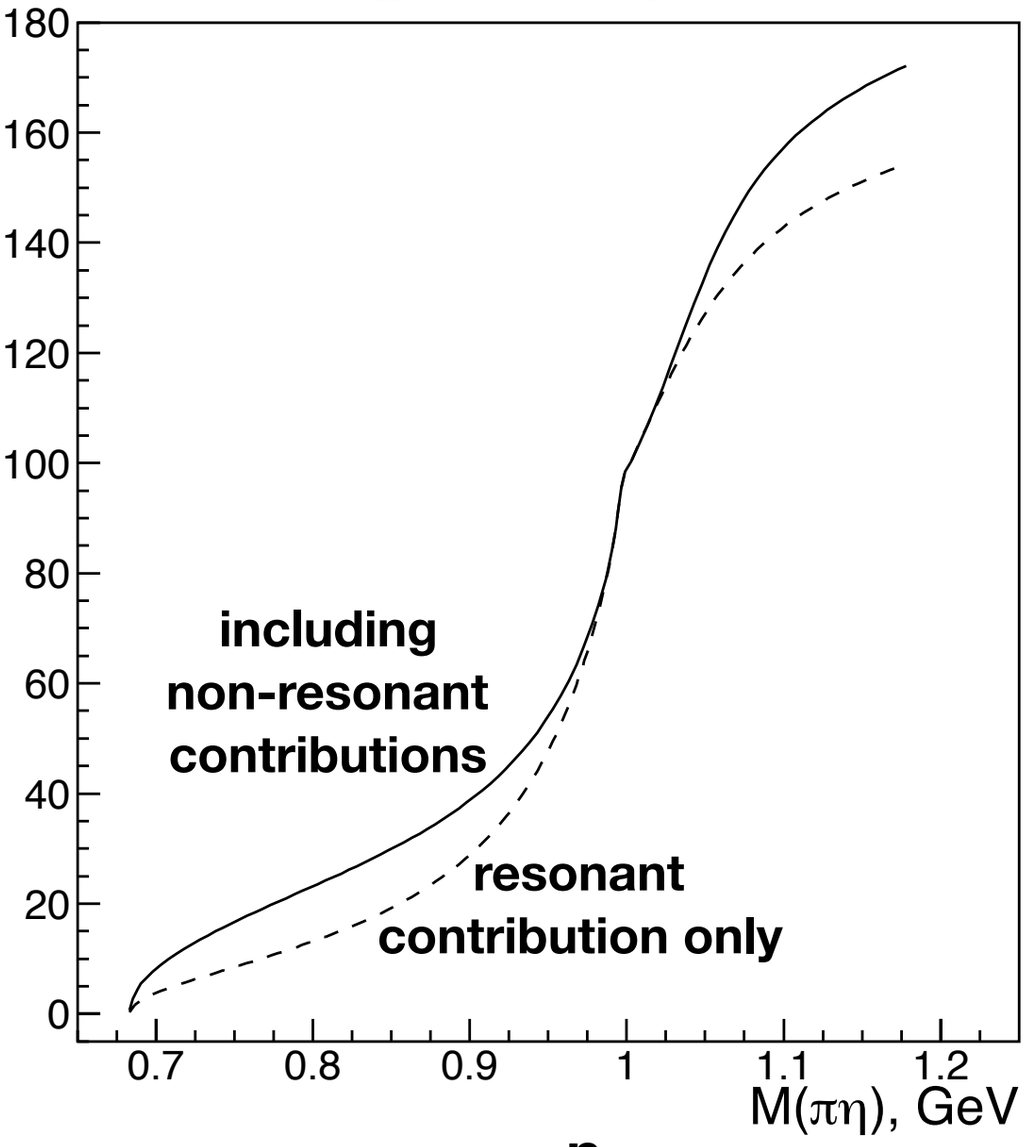




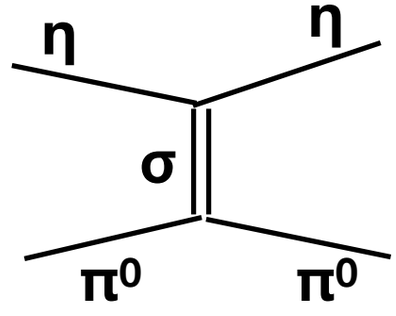
phase shift in the I=1 system



V. Nikonov, A. Sarantsev (priv. com)

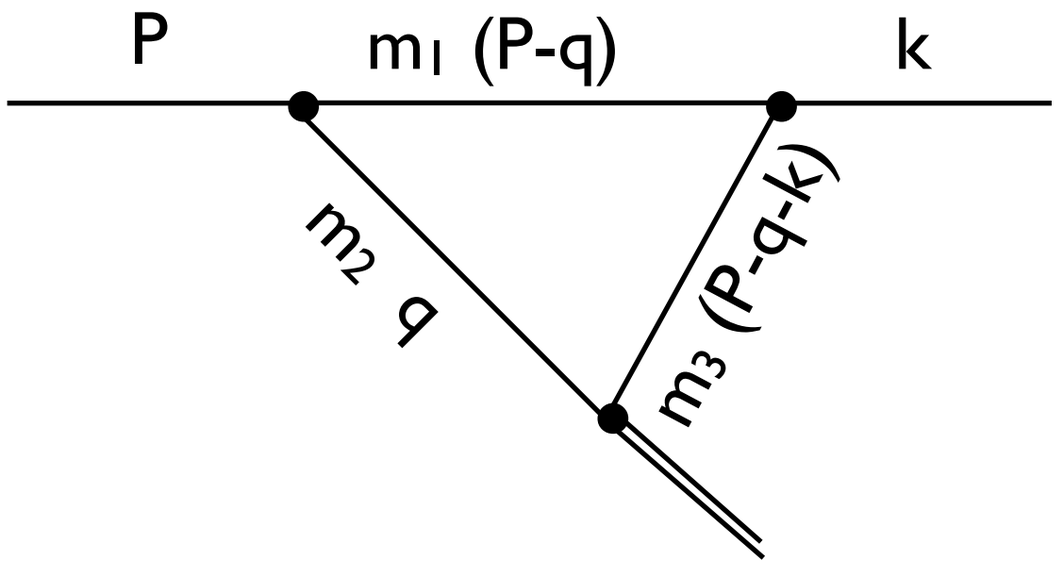


non-resonant contribution



singularities in reaction amplitude

M. Bayar et al., PRD 94 (2016) 074039

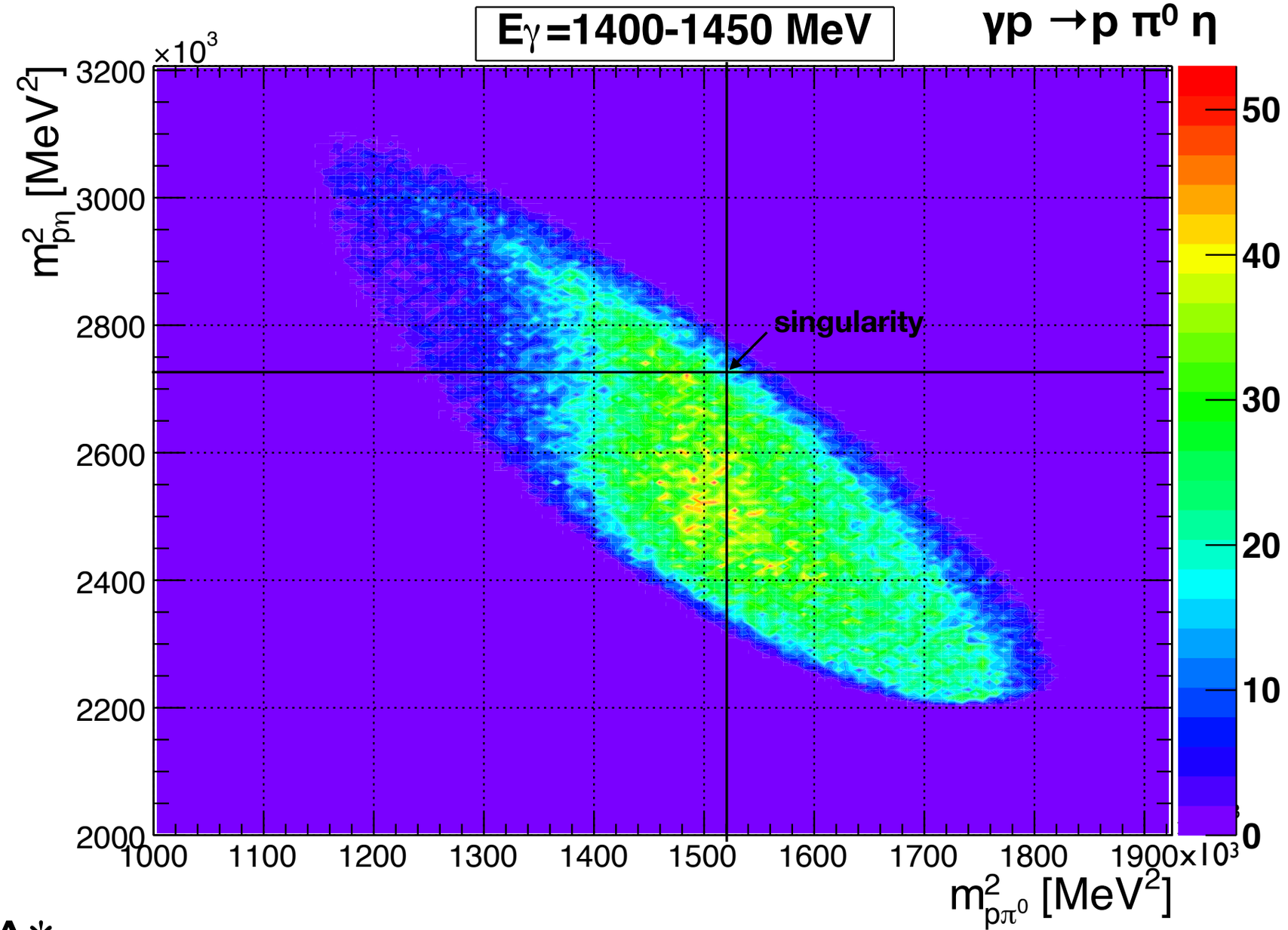


scalar three-point loop integral:

$$A = i \int \frac{d^4q}{(2\pi)^4\,[q^2-m_2^2+i\varepsilon][(P-q)^2-m_1^2+i\varepsilon][(P-q-k)^2-m_3^2+i\varepsilon]}$$

singularities occur when particles in triangle become on-shell

experimental evidence for singularity: "horn" events?



singularity: Δ* cms

β_η=0.468

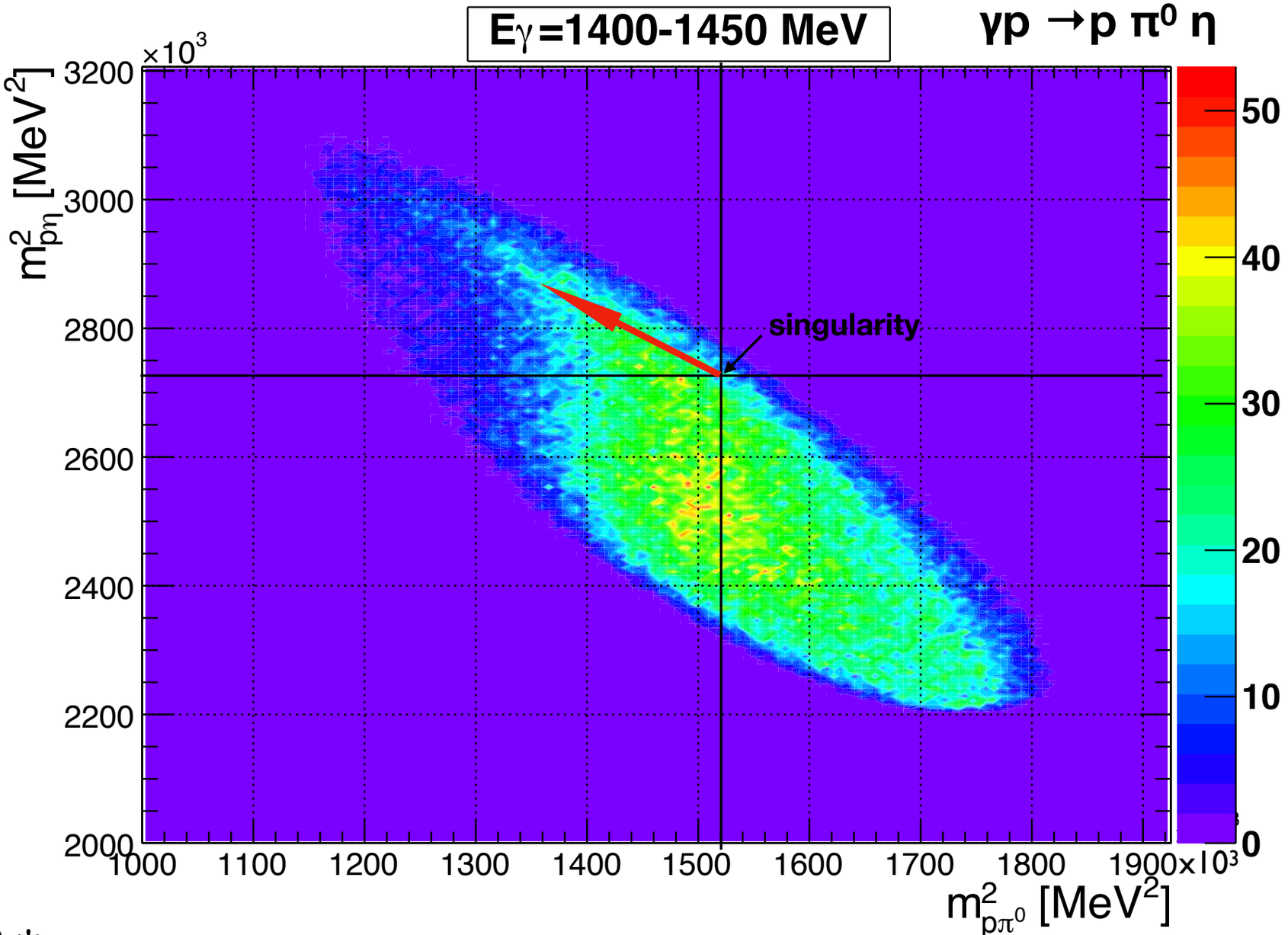
p_η= 619.7

p_p= 462.3

p_π= 172.5

β_π= 0.786

experimental evidence for singularity: "horn" events?



singularity: Δ* cms

β_η=0.468

p_η= 619.7 p_p= 462.3

p_π= 172.5

β_π= 0.786

in rescattering $m_{\pi\eta}$ = const;

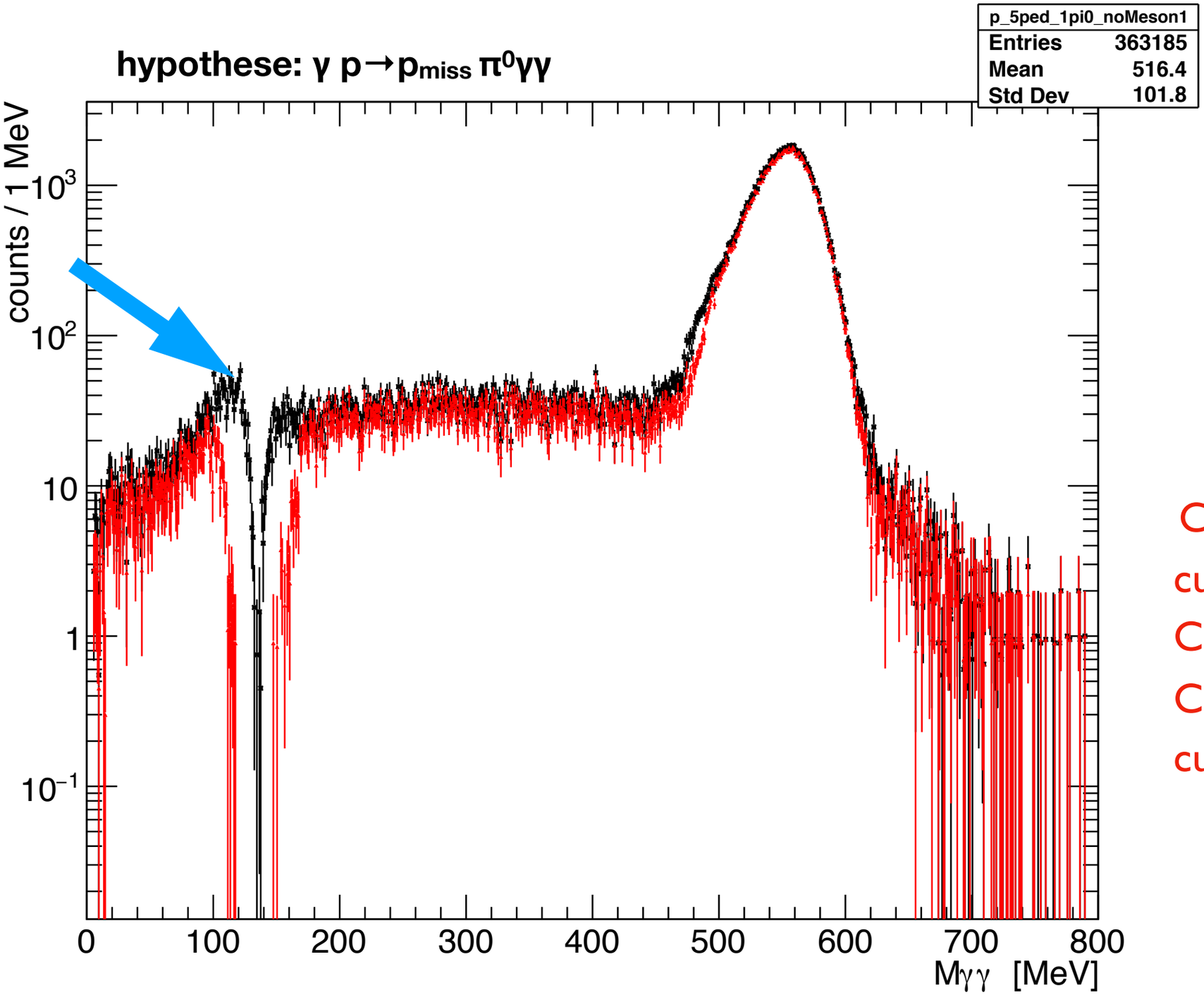
π^0 slowed down and η speeds up: $m_{p\pi}$ ↘ and $m_{p\eta}$ ↗

one moves along the line

$m_{p\eta}^2 = W^2 + m_\pi^2 + m_\eta^2 + m_p^2 - m_{\pi\eta}^2 - m_{p\pi}^2$

and reaches points in "horn" region

kinematic fit



CL Antihypothese: γ p→p$_{miss}$ π^{0}π^0

cut: parallel

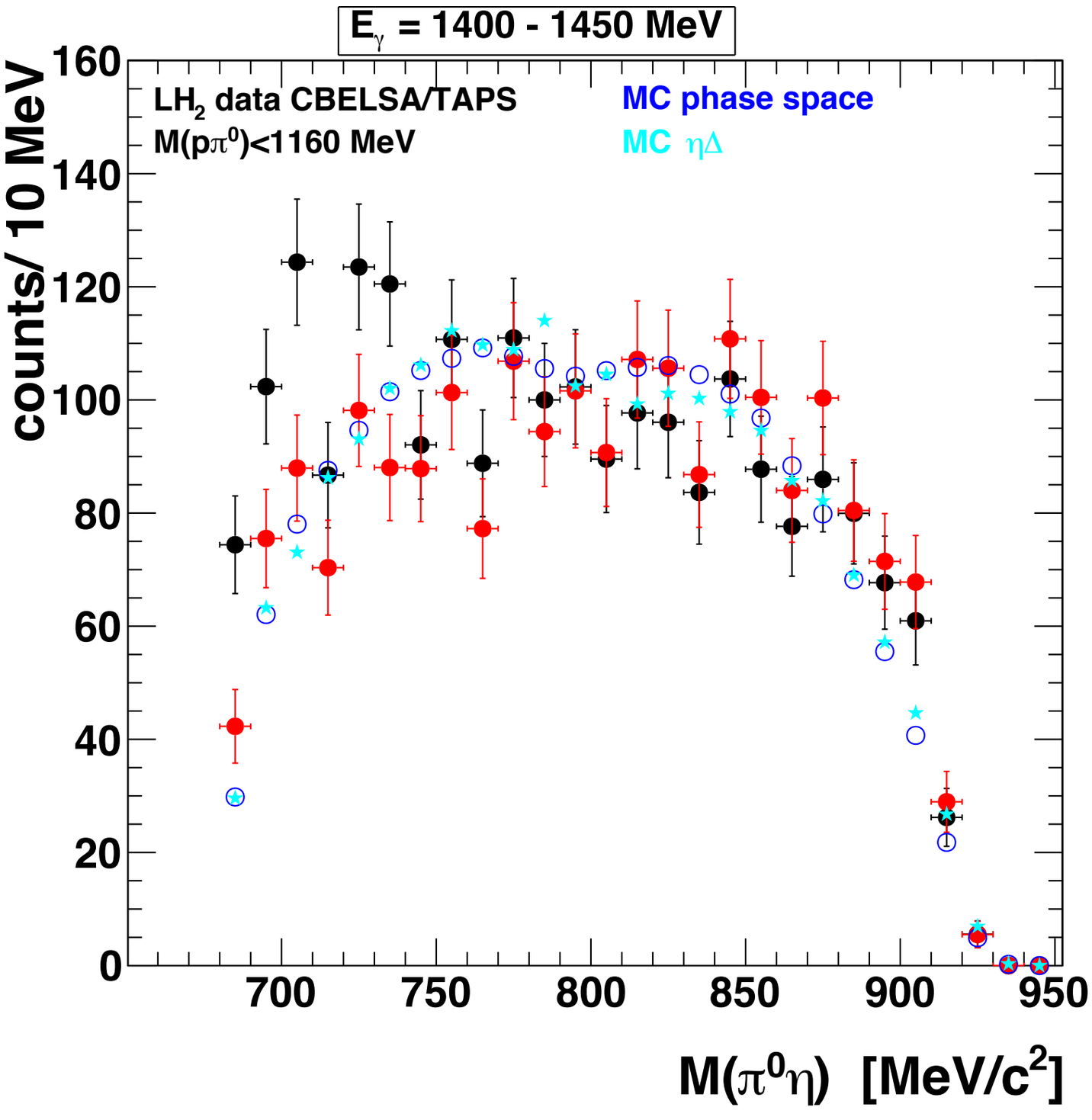
CL > 0.01 and factor=0.1

CL Hypothese: γ p→p$_{miss}$ π^{0}η

cut: CL > 0.1

kinematic fit

$\pi^0\eta$ invariant mass distributions for different rejections of $\gamma p \rightarrow p\pi^0\pi^0$ events



LH$_2$ data 2013

hypothesis: $\gamma\ p \rightarrow p_{miss}\ \pi^0\pi^0$

CL($\pi^0\pi^0$) anti-cut: diagonal;

hypothesis: $\gamma\ p \rightarrow p_{miss}\ \pi^0\eta$

cut: CL > 0.1

hypothesis: $\gamma\ p \rightarrow p_{miss}\ \pi^0\pi^0$

anti-cut: parallel

CL < 0.01 and factor=0.1

hypothesis: $\gamma\ p \rightarrow p_{miss}\ \pi^0\eta$

cut: CL > 0.1

kinematic fit: $\pi^0\pi^0$ rejection

Dalitz plots: $m_{p\eta}^2$ vs. $m_{p\pi 0}^2$ for different rejections of $\gamma p \rightarrow p\pi^0\pi^0$ events

LH_2 data 2013

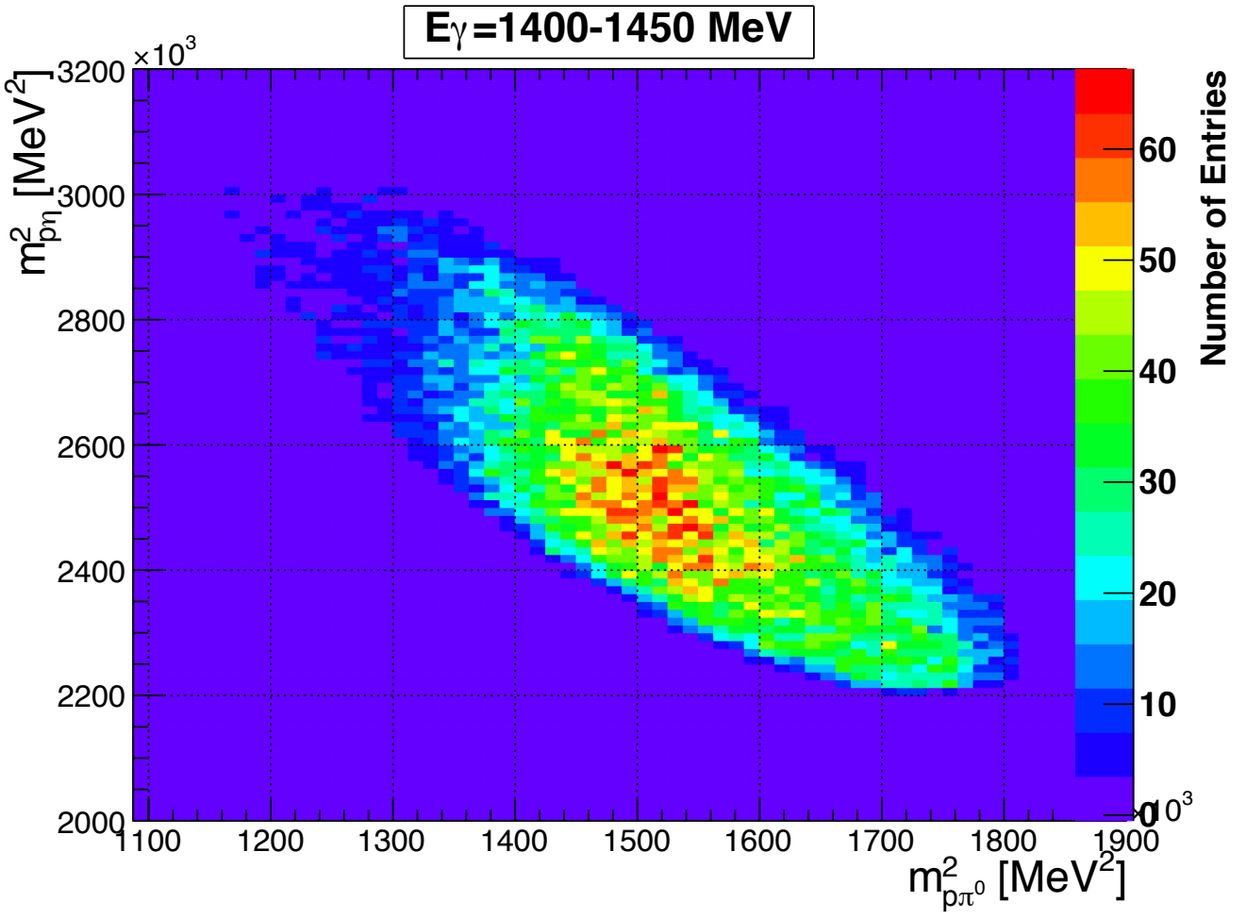
hypothesis: $\gamma\ p \rightarrow p_{miss}\ \pi^0\pi^0$

anti-cut: parallel

CL < 0.01 and factor=0.1

hypothesis: $\gamma\ p \rightarrow p_{miss}\ \pi^0\eta$

cut: CL > 0.1

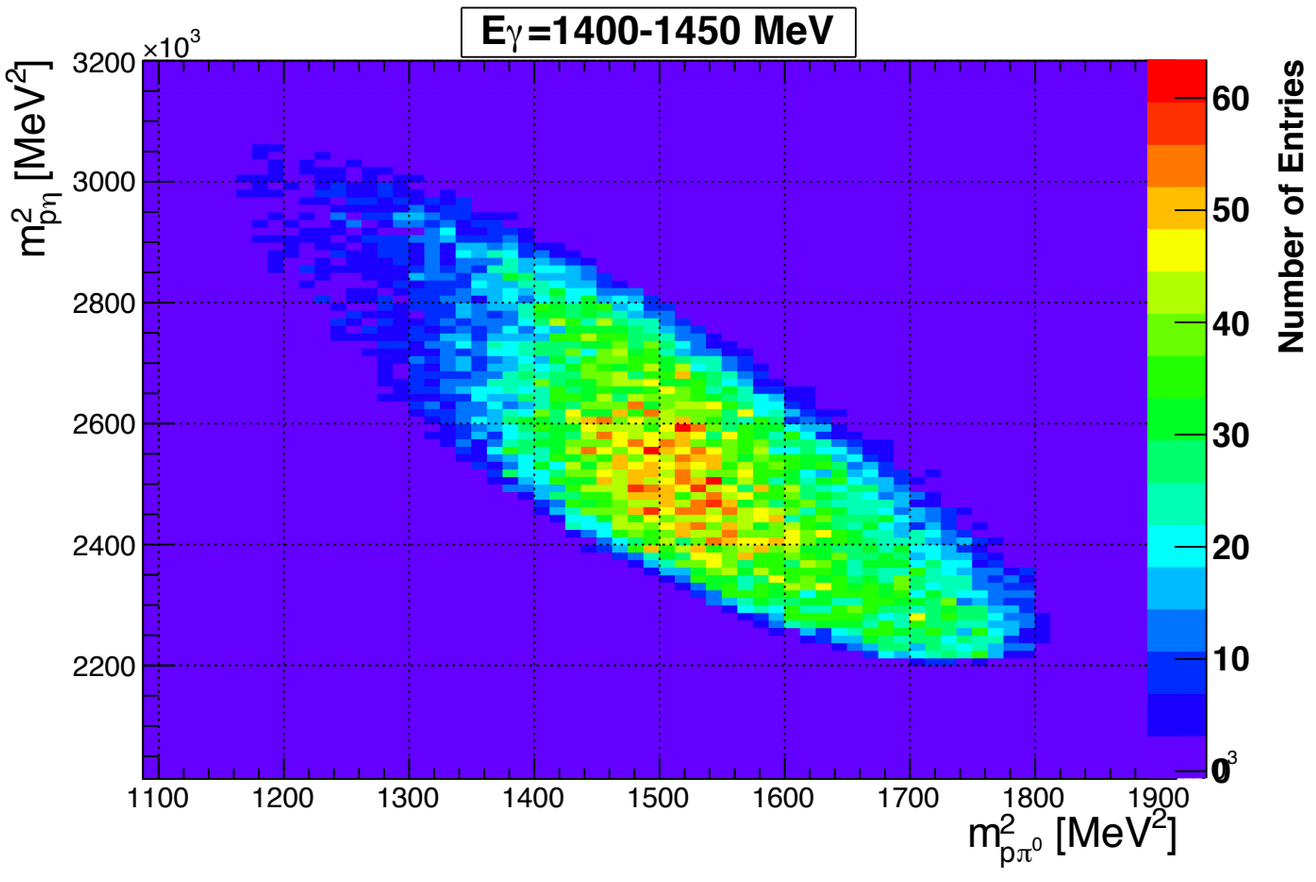


hypothesis: $\gamma\ p \rightarrow p_{miss}\ \pi^0\pi^0$

CL($\pi^0\pi^0$) anti-cut: diagonal;

hypothesis: $\gamma\ p \rightarrow p_{miss}\ \pi^0\eta$

cut: CL > 0.1



"horn" events more pronounced