The $\eta \to \pi^+\pi^- e^+e^-$ saga

If you can read this, you don't need glasses.

Episode I :

The Phantom Decay

(Status of the $\eta \to \pi^+\pi^- e^+e^-$ analysis)

S. Giovannella, R. Versaci

Episode II :

Attack of the efficiencies

(Tracking efficiency with a $\rho\pi$ sample on 2005 data)

A. De Santis, R. Versaci

Outline

Motivations

Data sample

Event and track selection

Background rejection

Fit of four tracks invariant mass

$\eta \to \pi\,\pi\,\gamma$ background

Work in progress

Tracking efficiency

Motivations

η structure, using virtual photon

Model comparison (VMD, χPT)

Test of CP violation: Gao model

Mod.PhysLett.A17
1583-1588.2002

Angular asymmetry between ee and $\pi\pi$ planes, A_{CP},

can be due to unconventional CPV mechanism

described by a T×V 4 quarks operator with $\Delta s=0$.

Within SM constrained by BR($\eta\to\pi\pi$),

using the experimental upper limit: $A_{CP} < 10^{-4}$

using theoretical prediction: $A_{CP} \sim 10^{-15}$

CPV model predicts an upper bound of 10^{-2}

BR: theory & experiment

Jarlskog, Pilkuhn 1967	$0.0065 \times BR(\eta \to \pi^+\pi^-\gamma)$		
Using PDG06	$(30.5 \pm 0.7) \times 10^{-5}$	$(25.7 \pm 1.3) \times 10^{-5}$	Using CLEO '07
Picciotto, Richardson 1993	$(32 \pm 3) \times 10^{-5}$		
Faessler et al. 2000	36×10^{-5}		
Borasoy, Nissler 2007	$(29.9^{+0.6}_{-0.9}) \times 10^{-5}$		

CMD-2 (4 events)	$(37\ ^{+25}_{\text{-18 stat}} \pm 3_{\text{syst}}) \times 10^{-5}$
CELSIUS-WASA (16 events)	$(43 \pm 13_{\text{stat}} \pm 4_{\text{syst}}) \times 10^{-5}$

Data sample

79 pb^{-1} data 2002

512 pb^{-1} data 2004

110 pb^{-1} data 2005

46×10^3 pb^{-1} MC signal only

529 pb^{-1} MC all_phys 2004

1194 pb^{-1} MC all_phys 2005

Using mrc stream ETA4C tag

Not used up to now

To have more data reprocessing with DBV ≥ 26 is needed.
Scheduled: will start after allphys3 production

More MC productions
allphys2: completed
allphys3: on-going

Event and Track selection

Event selection

EVCL algorithm ETA4CTAG:

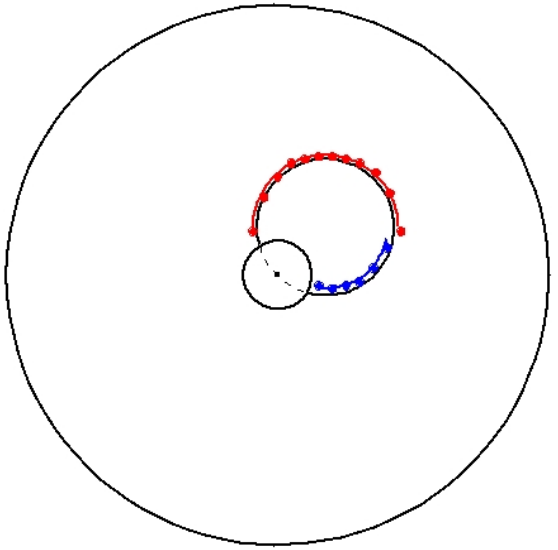
- ≥ 4 tracks from the Interaction Point
- 1 high energy neutral cluster ($E_{cl} \geq 250$ MeV)
- 0 medium energy neutral cluster ($50 \leq E_{cl} \leq 250$ MeV)

Downscaled sample of events with 3 tracks from the IP

Track selection

Tracks are required to came from a cylinder around the IP:

$R \leq 4$ cm $h/2 = 10$ cm



Check on broken tracks is applied:

$\Delta P_T < 4.5$ MeV $\Delta P_Z < 3$ MeV

$\geq$ 2 positive and $\geq$ 2 negative tracks are requested

Tracks are ordered by momentum (Always!)

Change wrt Capri07

Track selection

Tracks are required to came from a cylinder around the IP:

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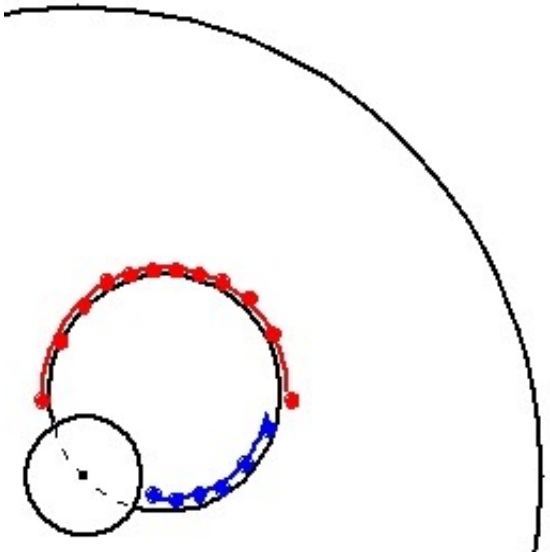

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$\Delta P_T < 4.5$ MeV $\Delta P_Z < 3$ MeV

$\geq$ 2 positive and $\geq$ 2 negative tracks are requested

Tracks are ordered by momentum (Always!)

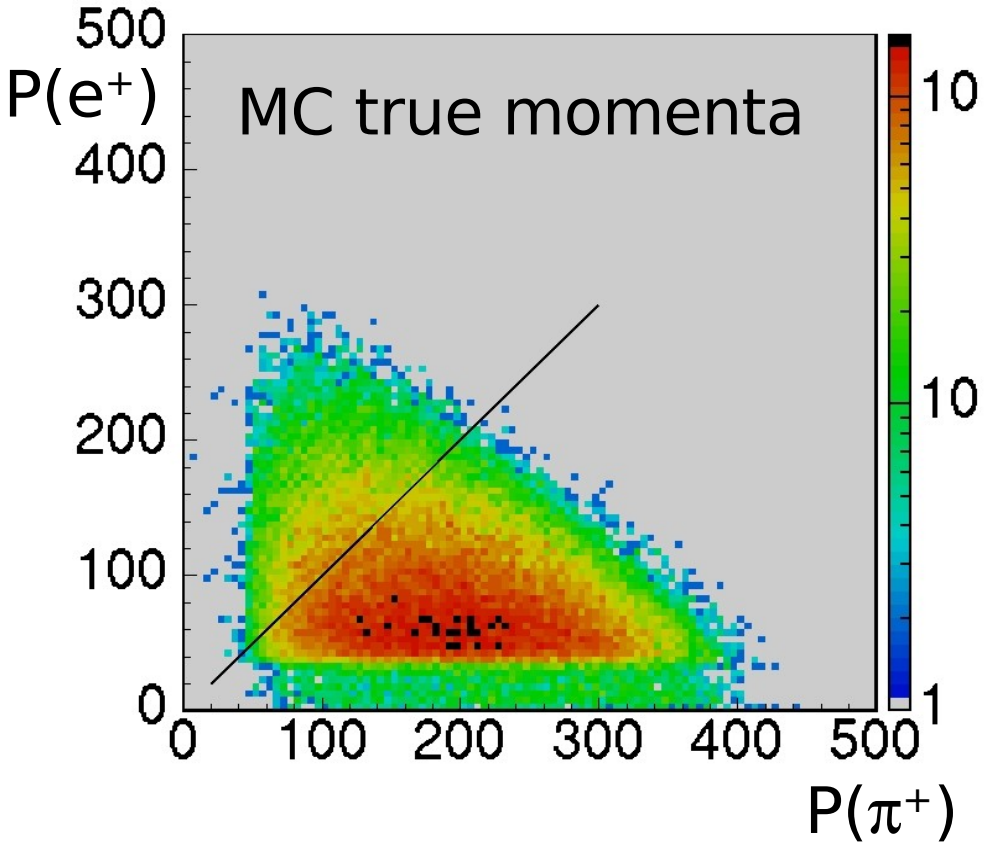
Change wrt Capri07

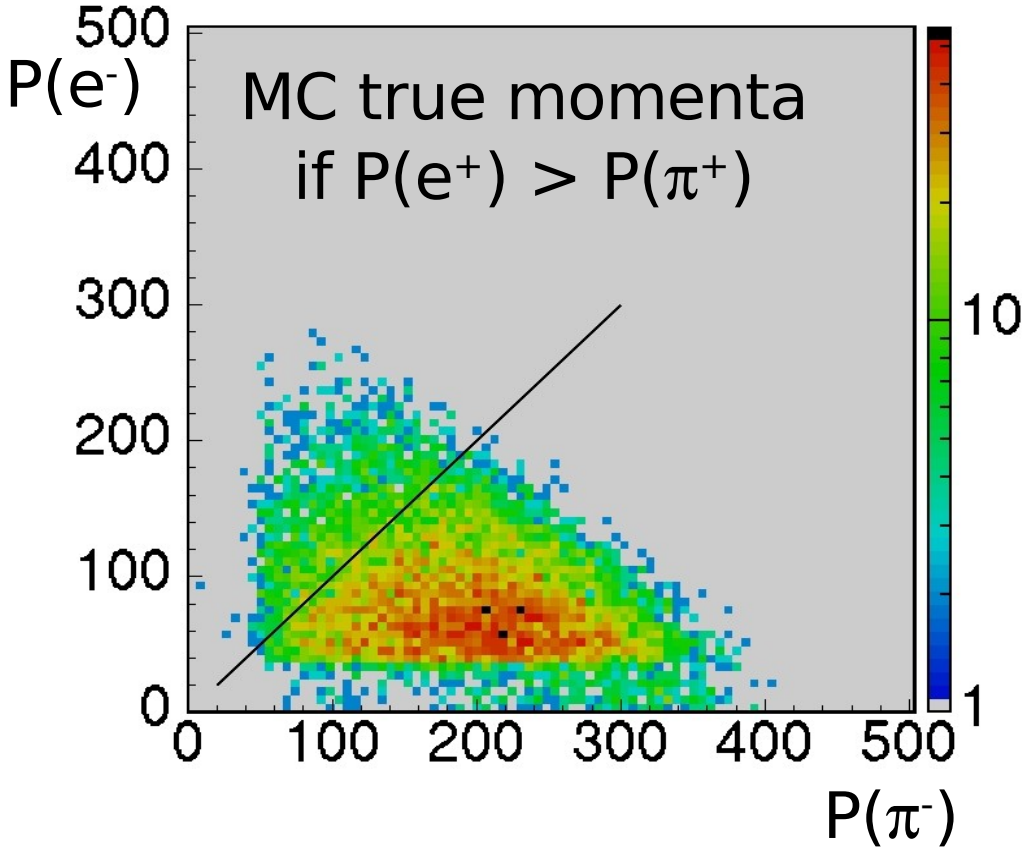
Track identification

Higher momentum tracks assigned to pion

Assumption correct on 84% of cases

Possible to improve with TOF





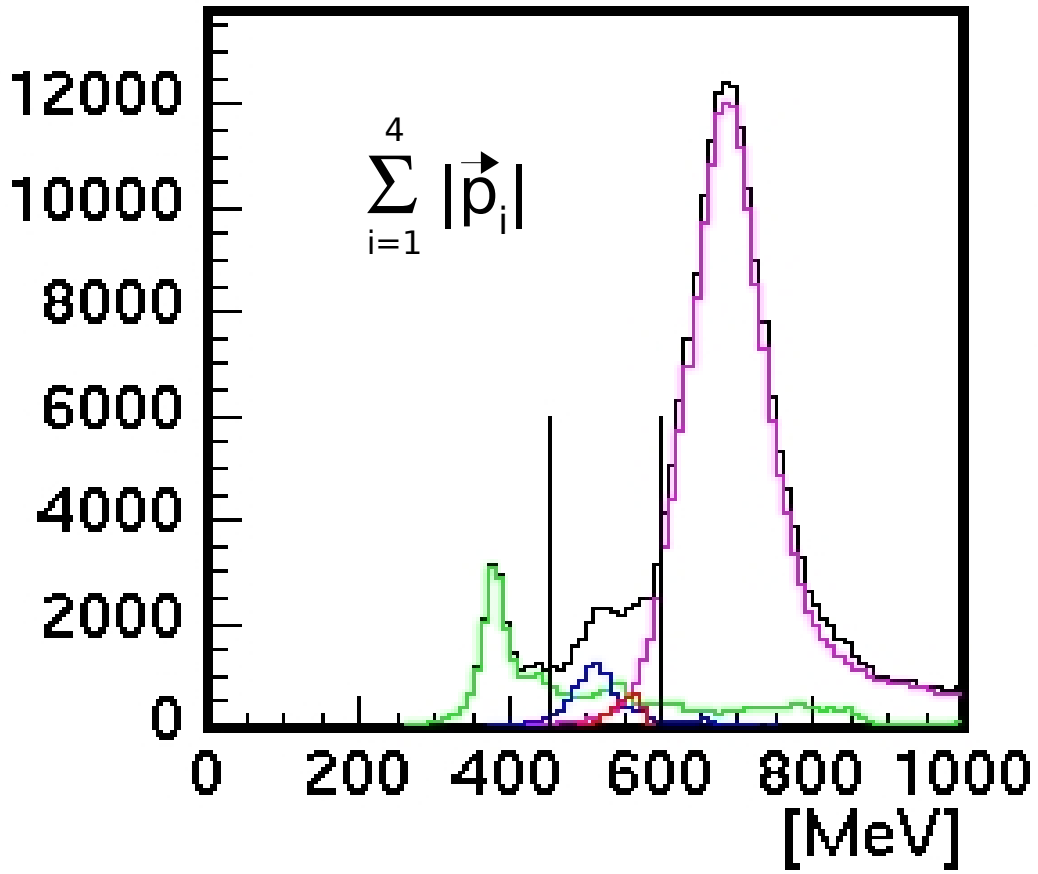
Three steps across background rejection

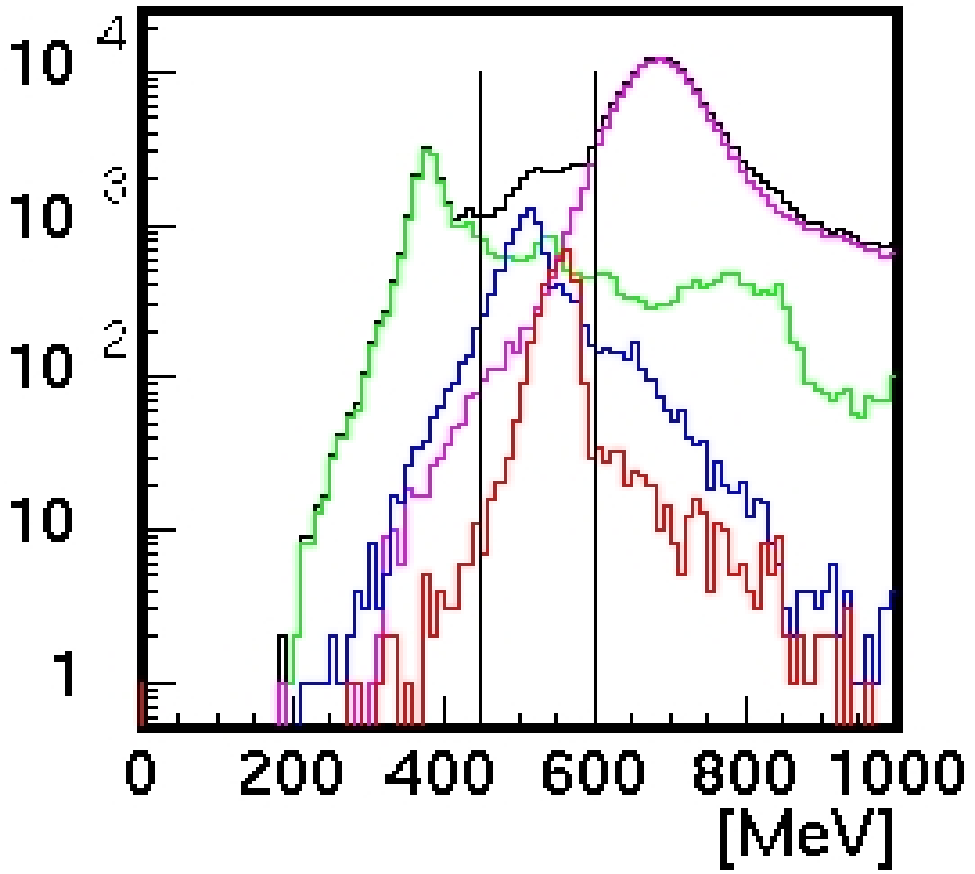
Background rejection - step 1

$$450 \text{ MeV} < \sum_{i=1}^{4} |\vec{p}_i| < 600 \text{ MeV}$$

Total $\phi \to \eta\gamma$ $\phi \to \rho\pi + \pi^+\pi^-\pi^0$

Signal $\eta \to \pi^+\pi^-e^+e^-$ Other backgrounds (mainly $K^\pm$)

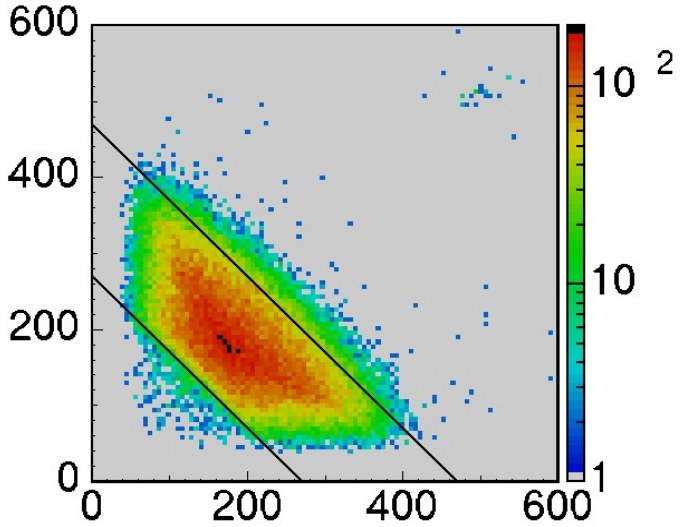


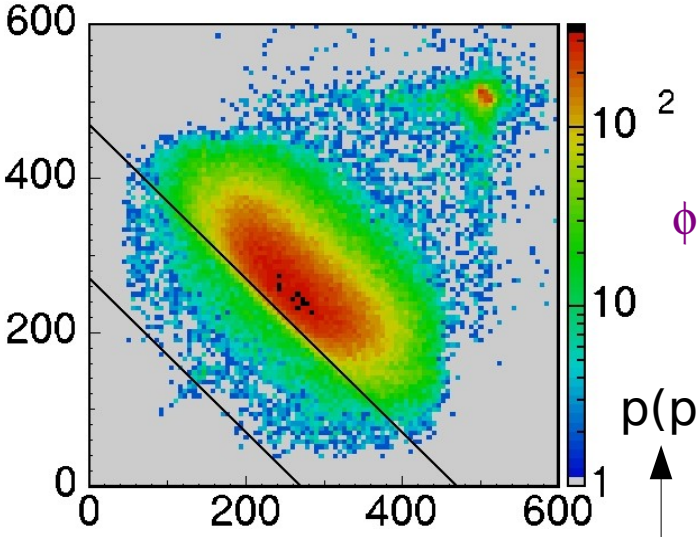


Background rejection - step 2

$270 < |P(p^+1)| + |P(p^-1)| < 470$ MeV

Signal
$\eta \to \pi^+\pi^-e^+e^-$



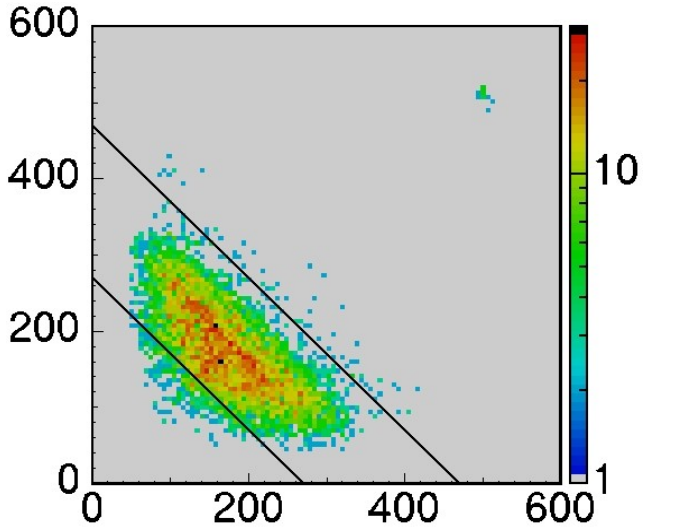


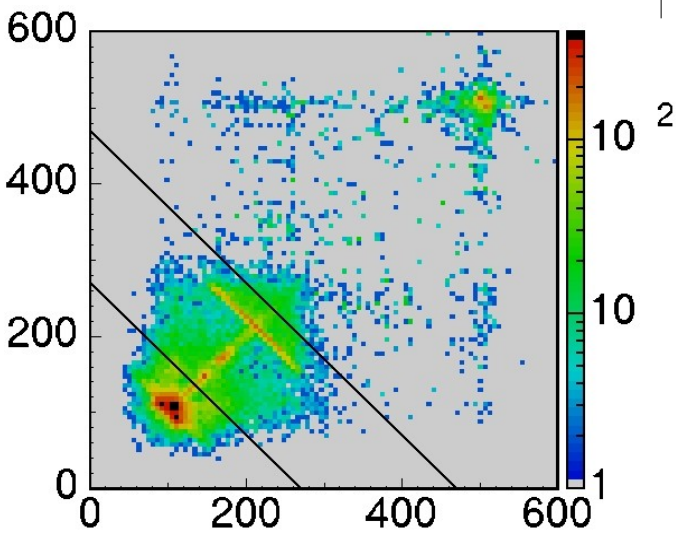
$\phi \to \rho\pi + \pi^+\pi^-\pi^0$

p(p1-)[MeV]

p(p1+)[MeV]

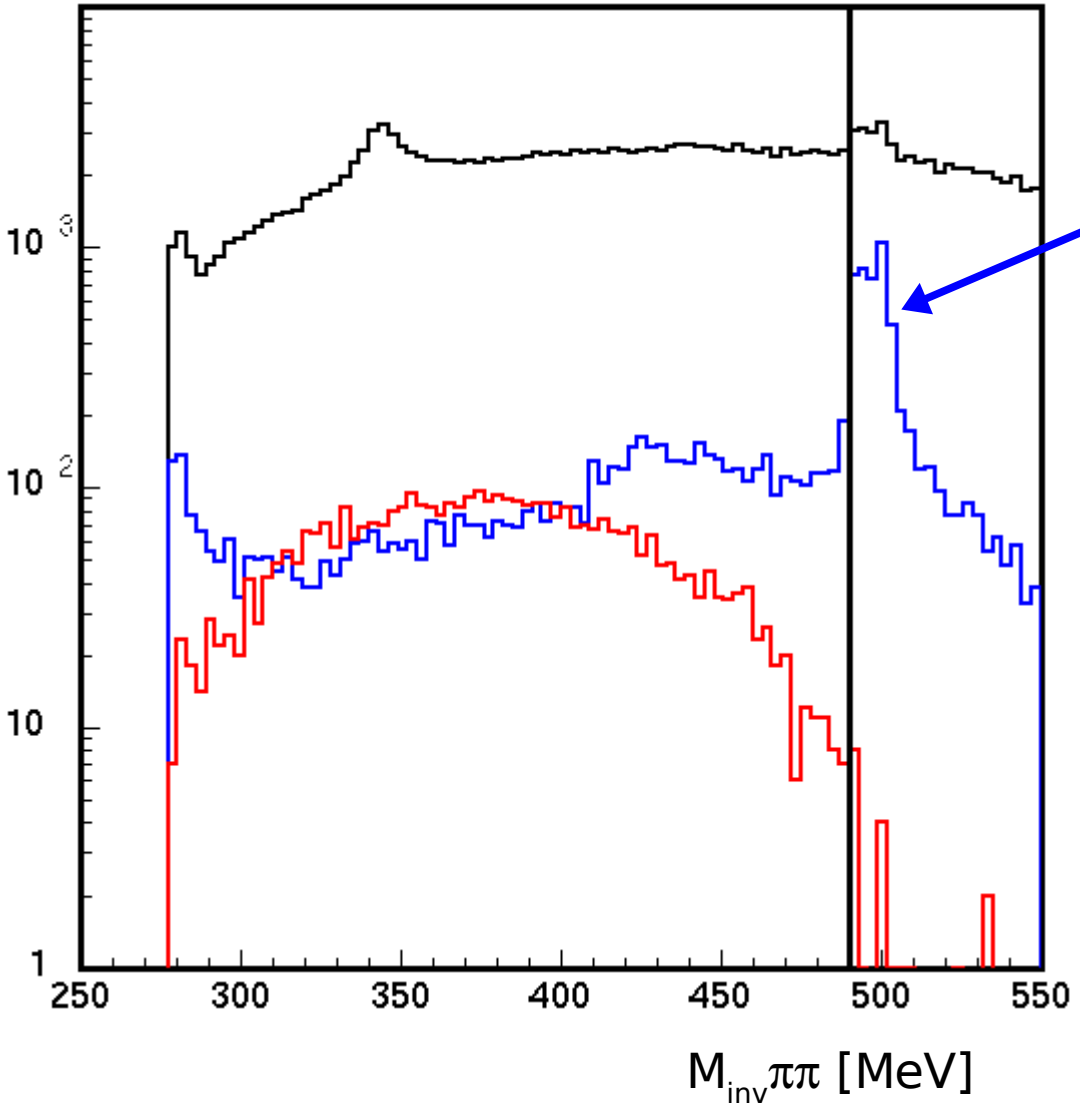
$\phi \to \eta\gamma$





Other backgrounds (Mainly $K^{\pm}$)

Background rejection - step 3



$K_S \rightarrow \pi^+\pi^-$

$M_{inv}\pi\pi < 490$ MeV

Total

Neutral kaons

Signal $\eta \rightarrow \pi^+\pi^-e^+e^-$

Fit of the $\pi\pi ee$ invariant mass

Kinematic fit

A kinematic fit to the ϕ meson is performed for all the events having # good tracks $\geq$ 4

Change wrt Capri07

Statistics almost x2

The 22 inputs are:

- 4 tracks x 3 momenta
- x,y,z,E,t of the neutral cluster
- x,y,z of the IP
- $\sqrt{s}$ and ϕ momentum

The 5 constraints are:

- Four momentum conservation
- Photon time of flight ($cT_\gamma = R_\gamma$)

Fit of the ππee invariant mass

The number of signal event is obtained
fitting the data spectrum of M_{inv}ππee
with the MC shapes for signal and backgrounds

The fit is performed with MIDNIGHT

Test of the stability of the fit have been performed

1. using different ranges
2. using different binning
3. using different bck modeling

Fit results

$\pi\pi ee$ invariant mass reconstructed using the output of the kinematic fit

Total

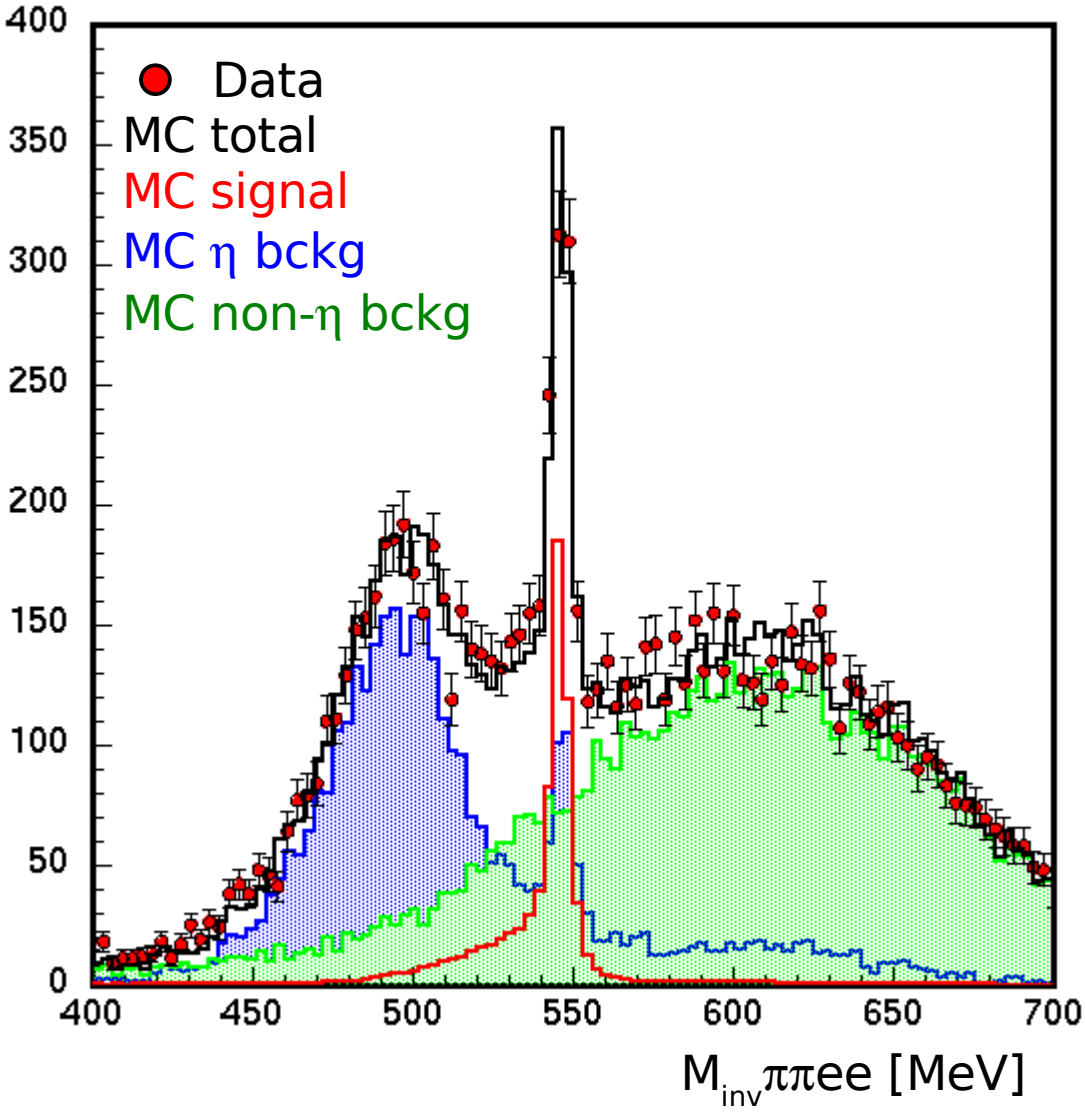
Signal $\eta \to \pi^+\pi^-e^+e^-$

Other η decays

(mainly: $\eta \to \pi^+\pi^-\pi^0 \oplus \eta \to \pi^+\pi^-\gamma$)

Other non η backgrounds

(mainly: $\rho\pi \oplus K^{\pm}$)



Fit results

$$BR(\eta \to \pi^+\pi^-e^+e^-) = (24 \pm 2_{Stat.} \pm 4_{Syst.}) \times 10^{-5}$$

 # events = 733(62)

$\chi^2 = 92/97$

$P(\chi^2) = 0.61$

Total

Signal $\eta \to \pi^+\pi^-e^+e^-$

Other η decays

(mainly: $\eta \to \pi^+\pi^-\pi^0 \oplus \eta \to \pi^+\pi^-\gamma$)

Other non η backgrounds

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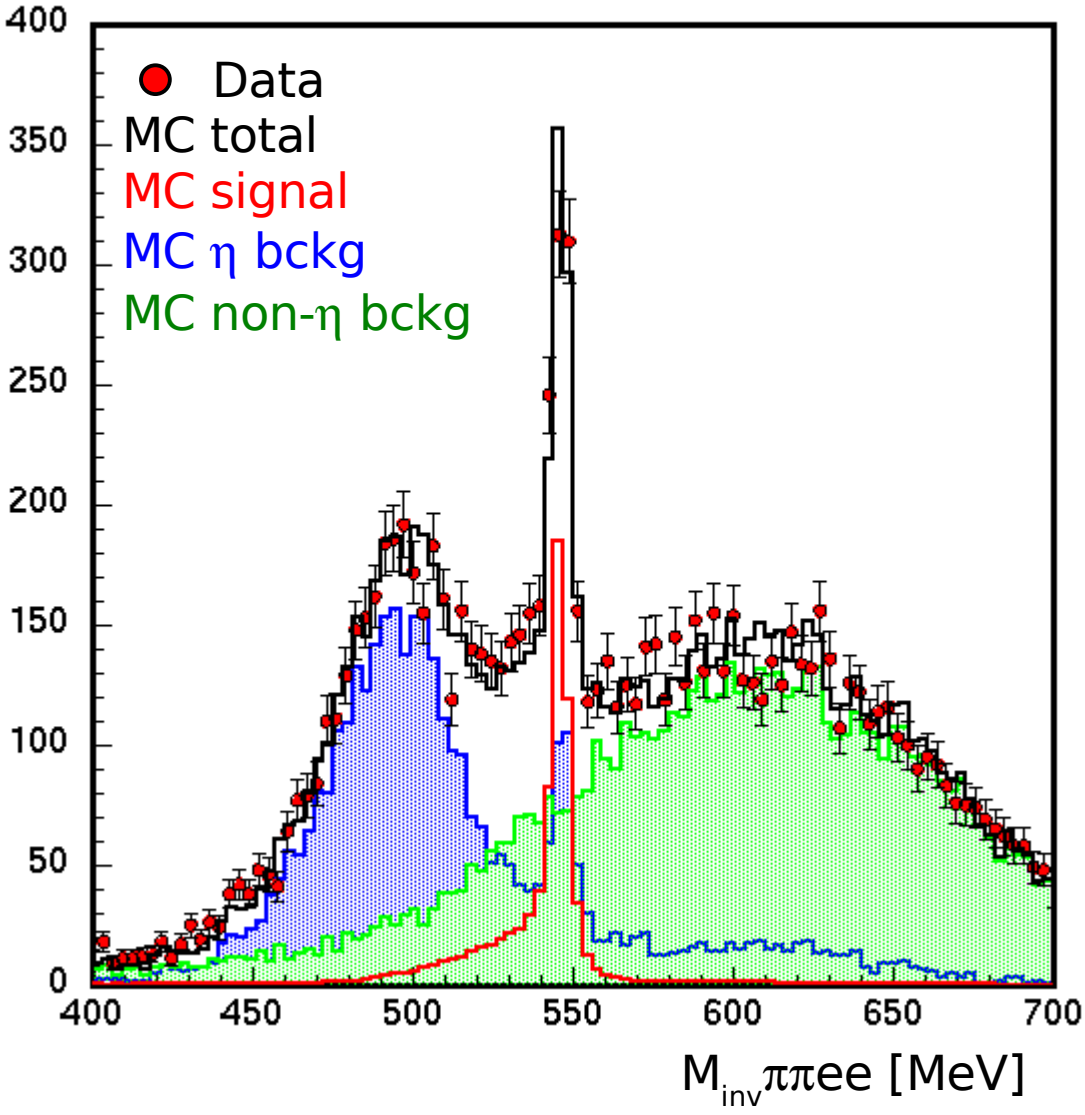
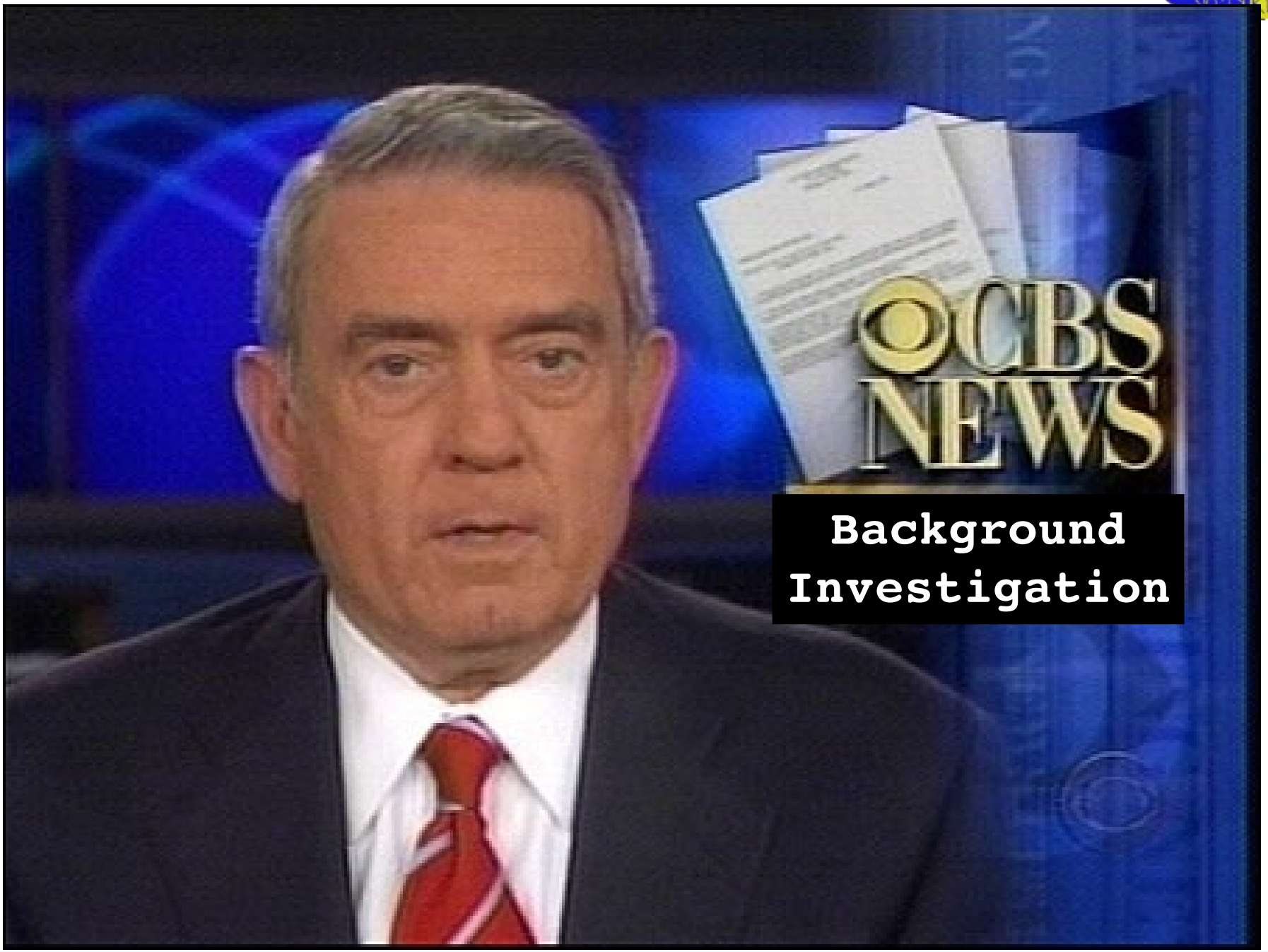
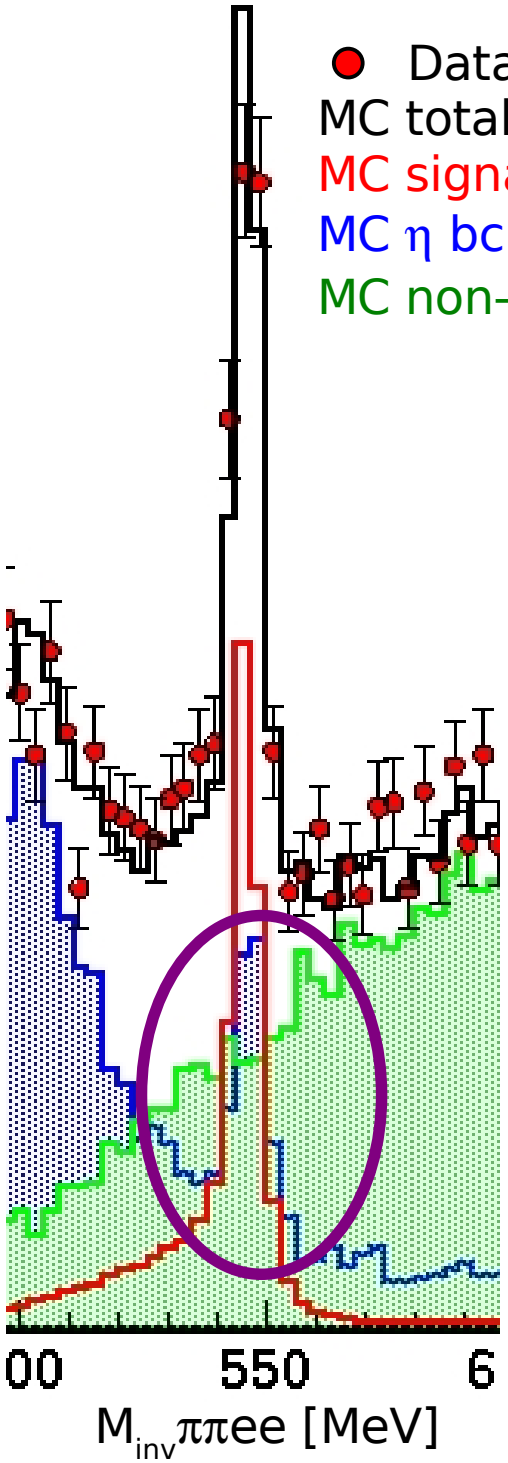


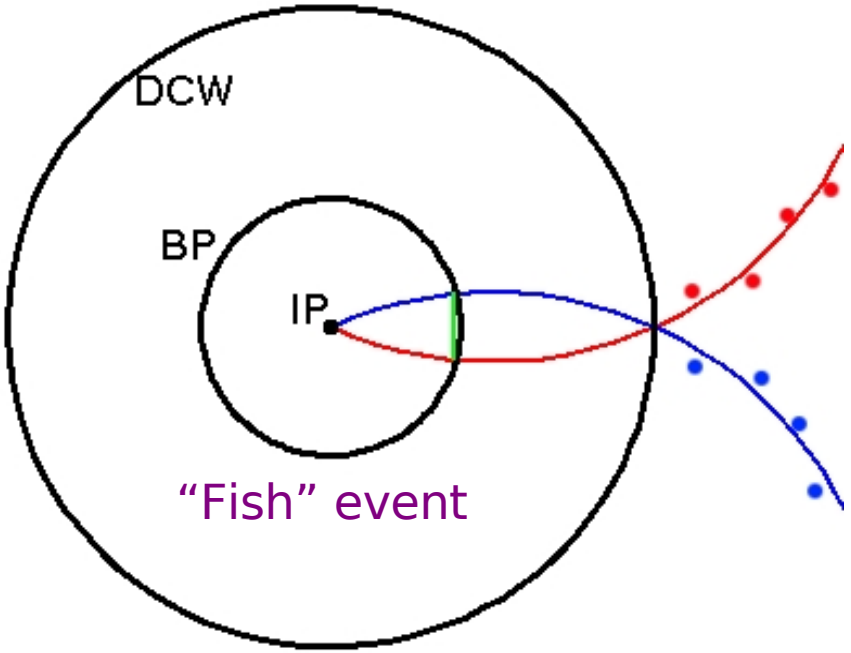

CBS NEWS
Background Investigation

$\eta \to \pi^+\pi^-\gamma$ bckg



Signal signature ($\eta \to \pi^+\pi^-\gamma \to \pi^+\pi^-e^+e^-$)

when photon converts on the BP or DCW



Disentangle

using $M_{inv}(e^+e^-)$

and $Dist(e^+e^-)$

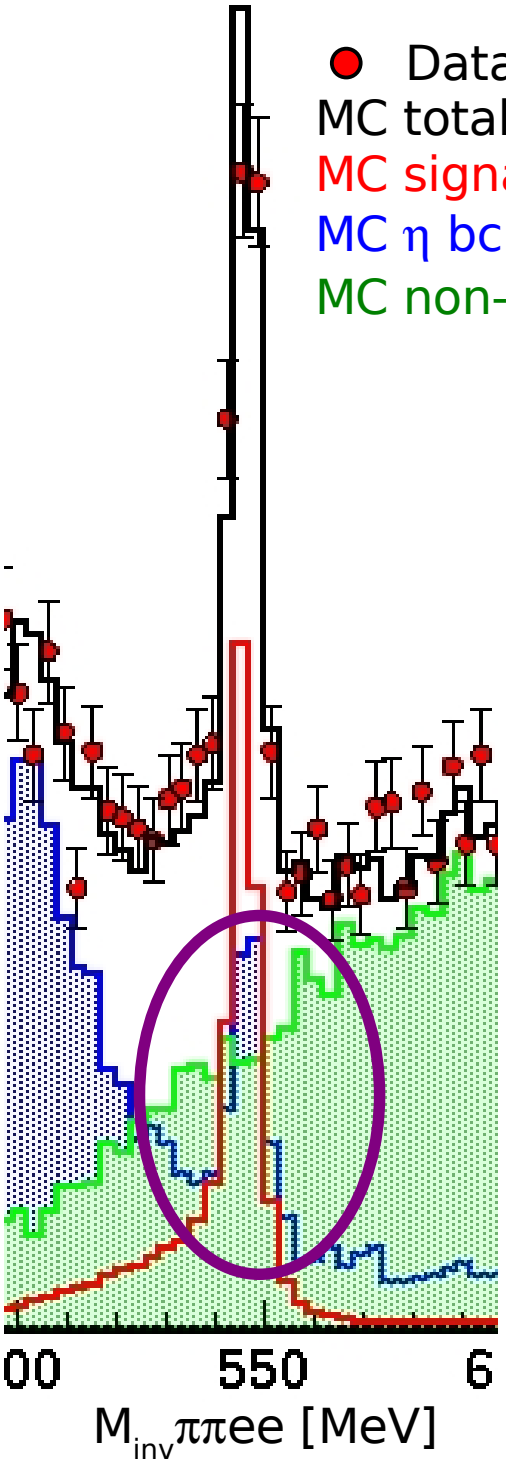
Should be zero

at the conversion

MC uses BR($\eta \to \pi^+\pi^-\gamma$) from PDG2002

reduced by 15% by CLEO arXiv:0707.1601

$\eta \to \pi^+\pi^-\gamma$ bckg



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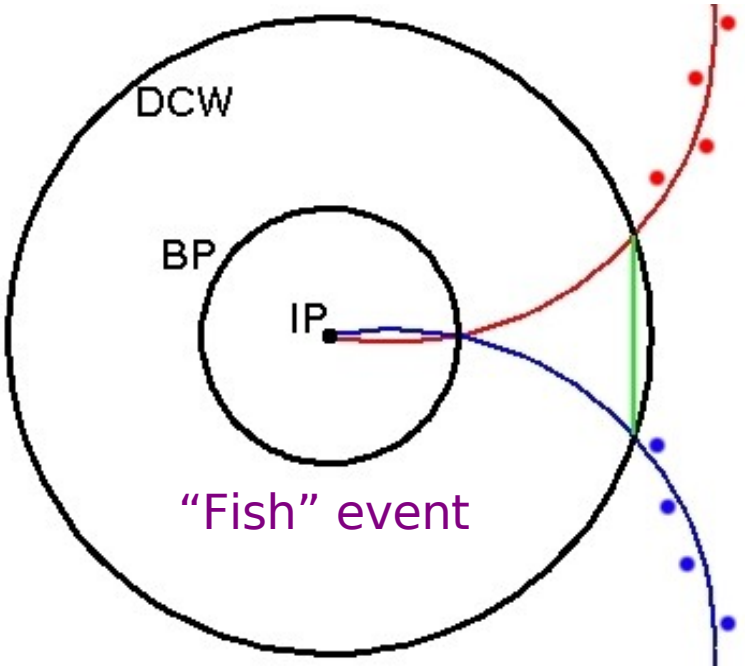

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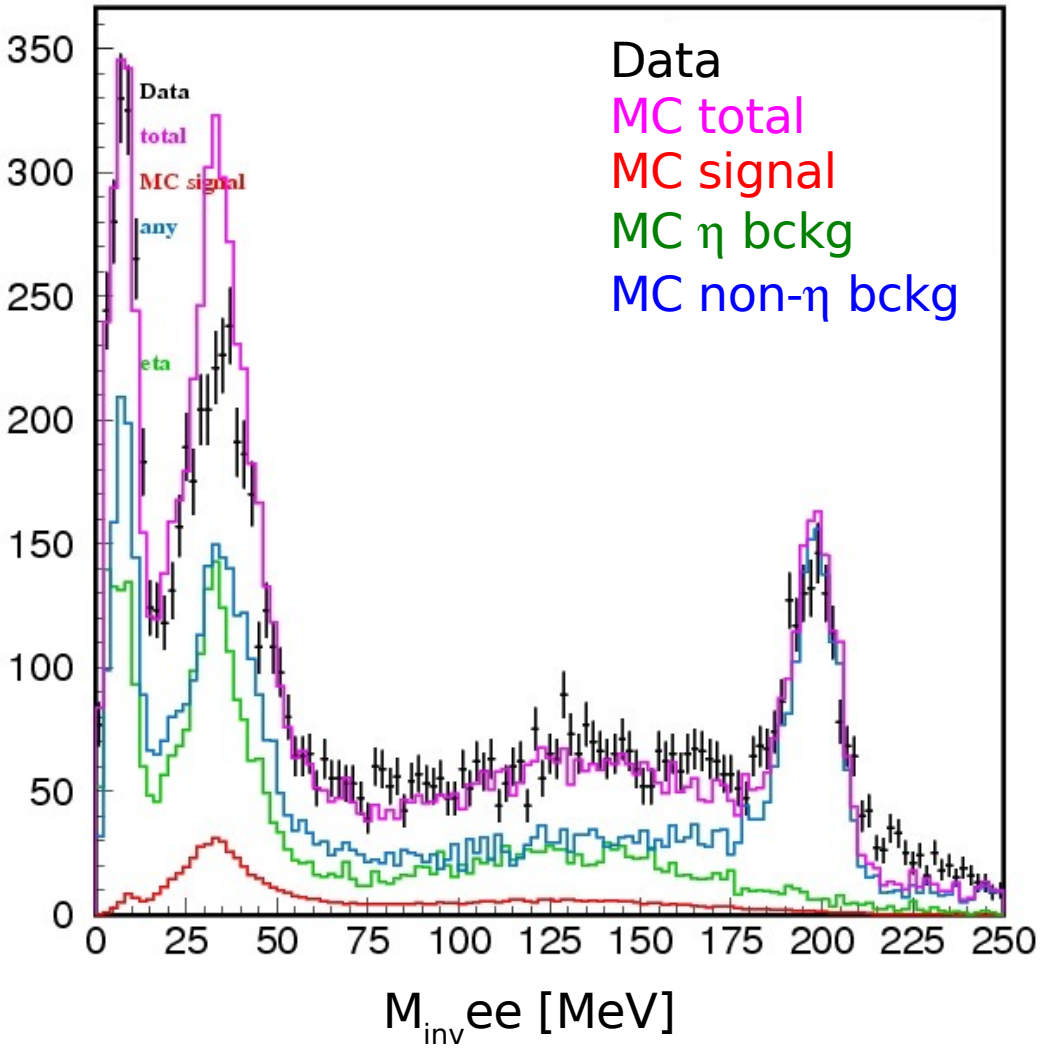
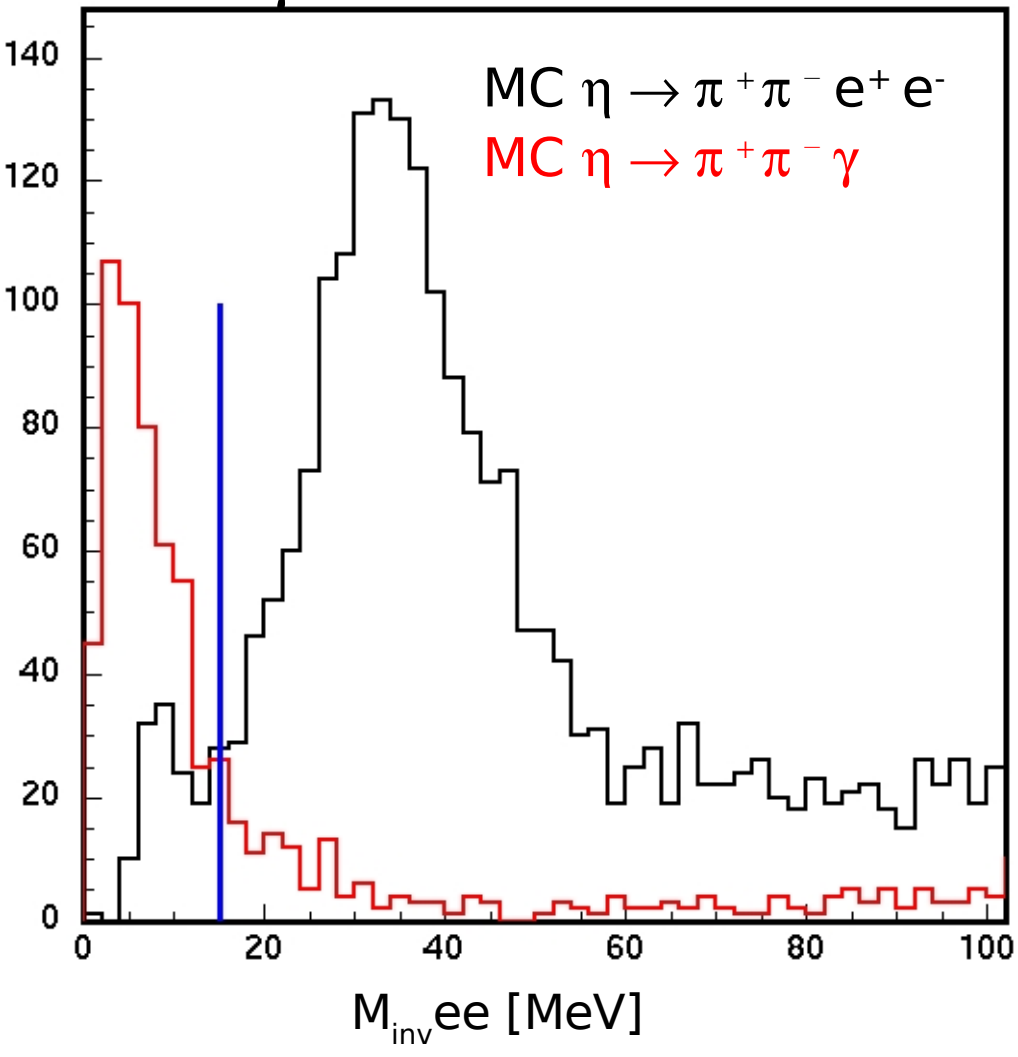
$M_{inv}(e^+e^-)$ @ BP

Data-MC comparison

Scale factors from $M_{inv}\pi\pi ee$ fit

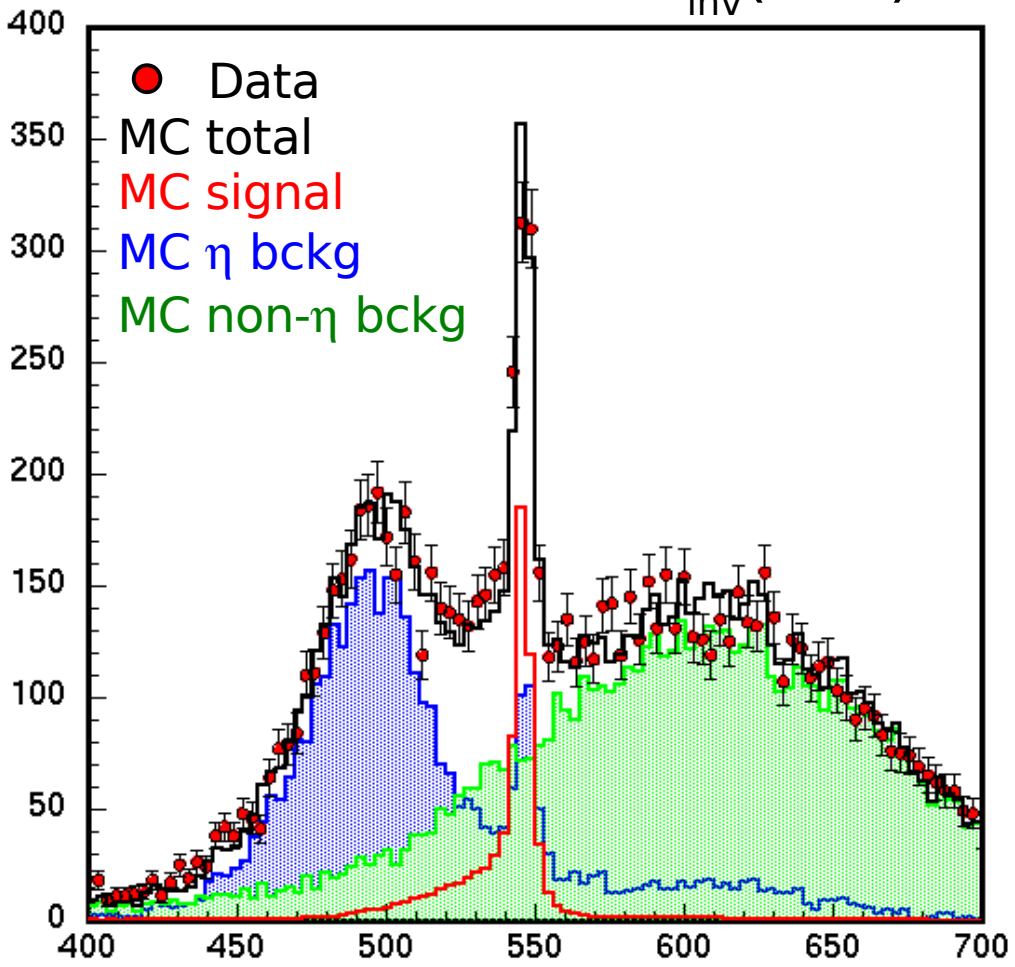


γ conversions filter

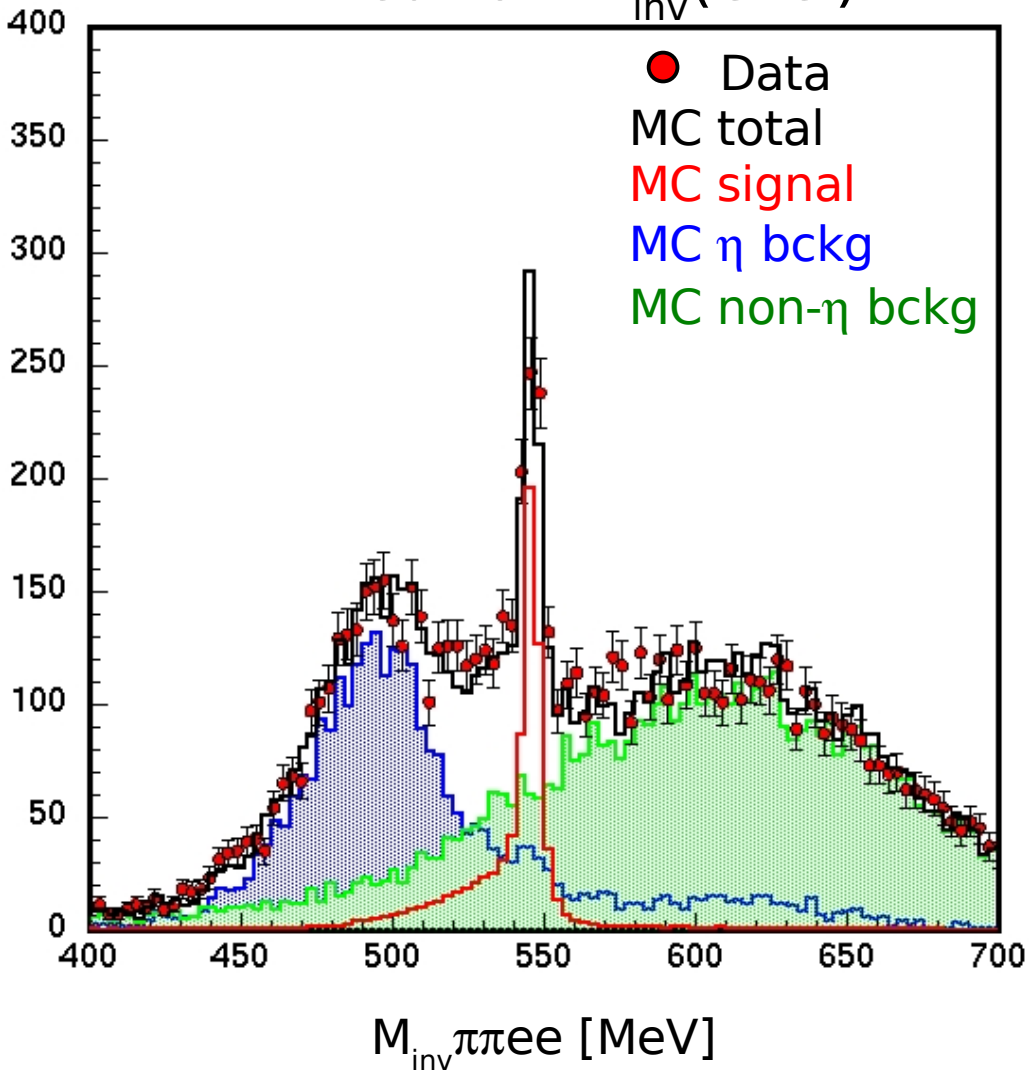


Rejection of $\eta \to \pi^+\pi^-\gamma$ background

Without cut on $M_{inv}(e^+e^-)$

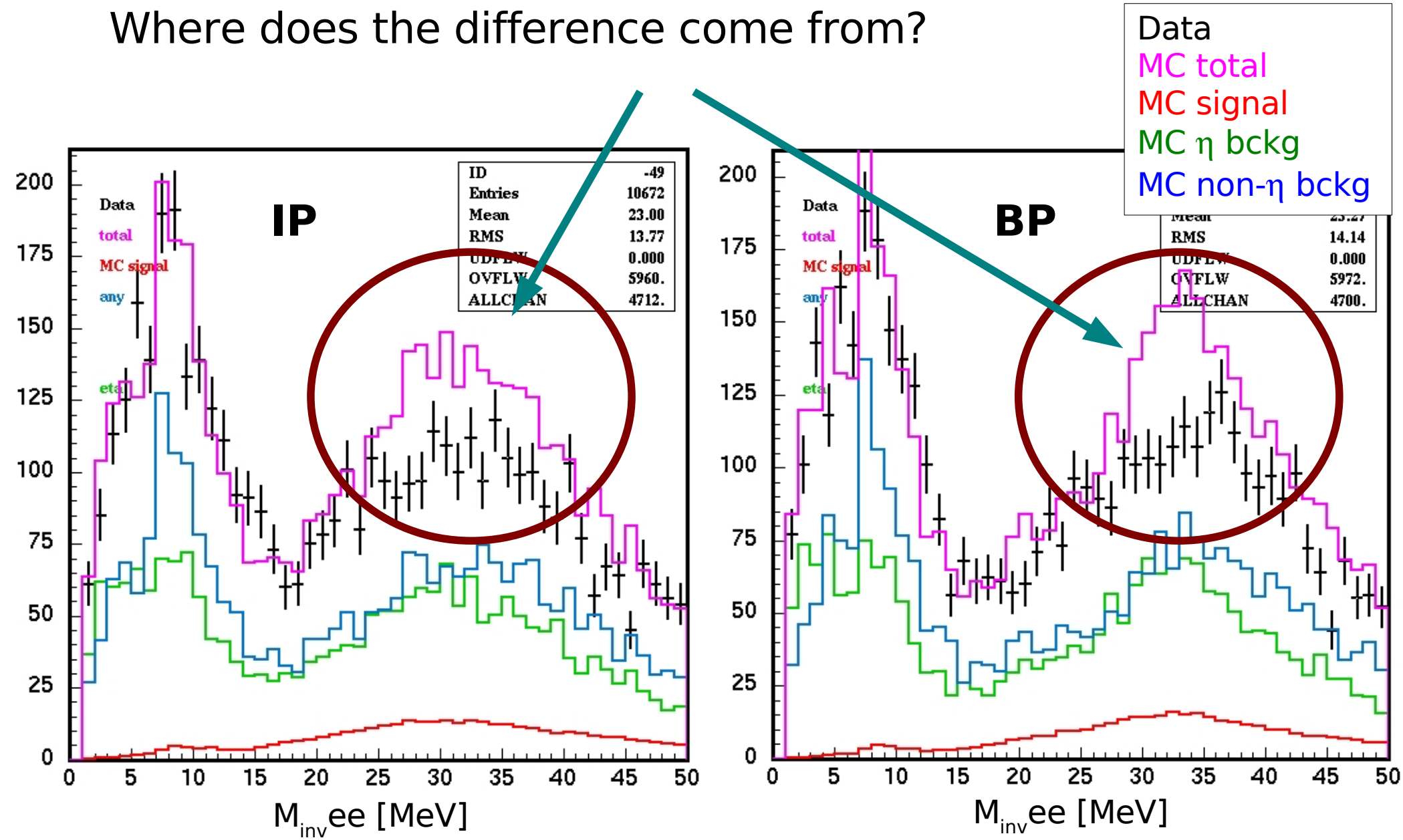


With cut on $M_{inv}(e^+e^-)$

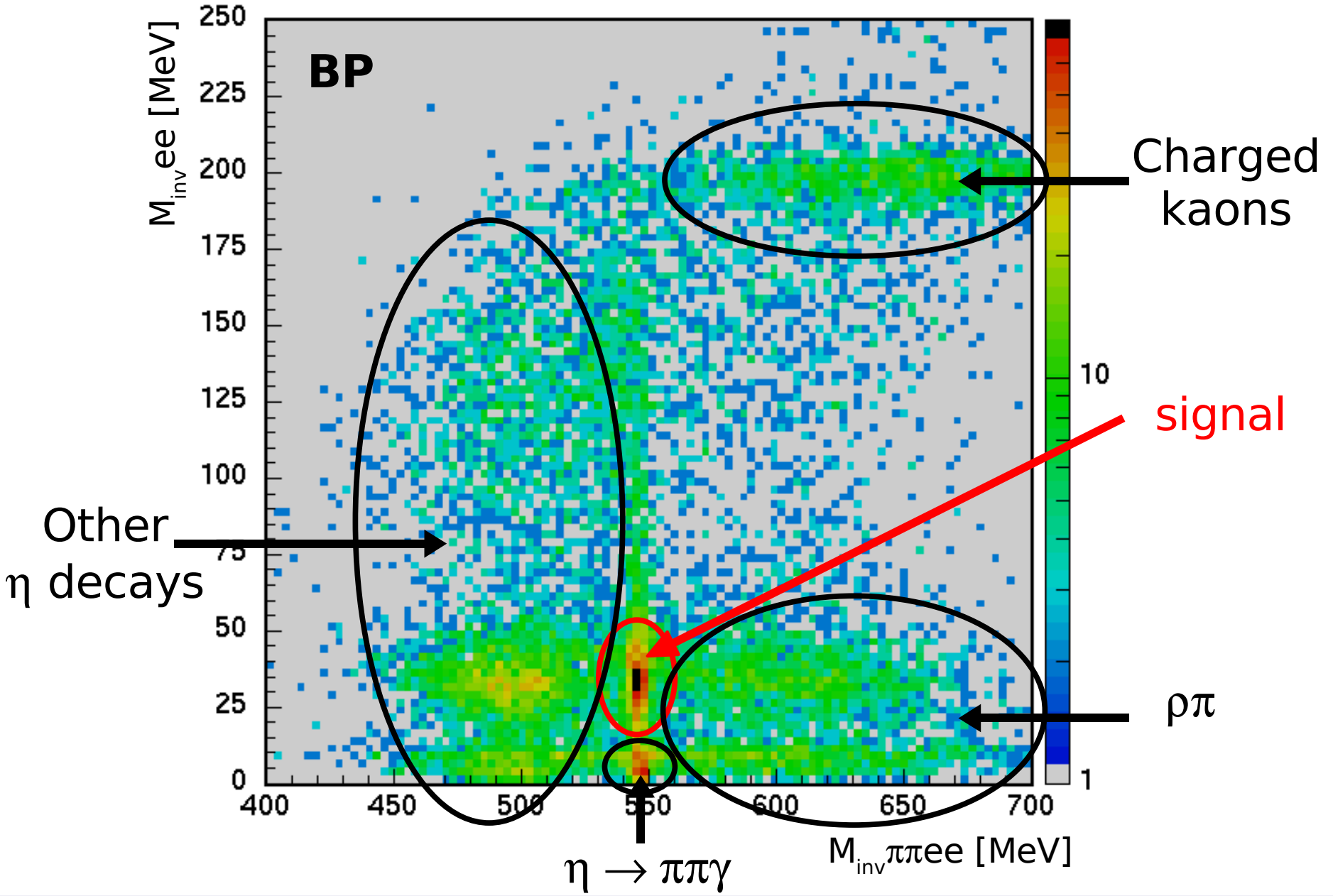


$M_{inv}(e^+e^-)$ puzzle

Where does the difference come from?



$M_{inv}(e^+e^-)$ puzzle



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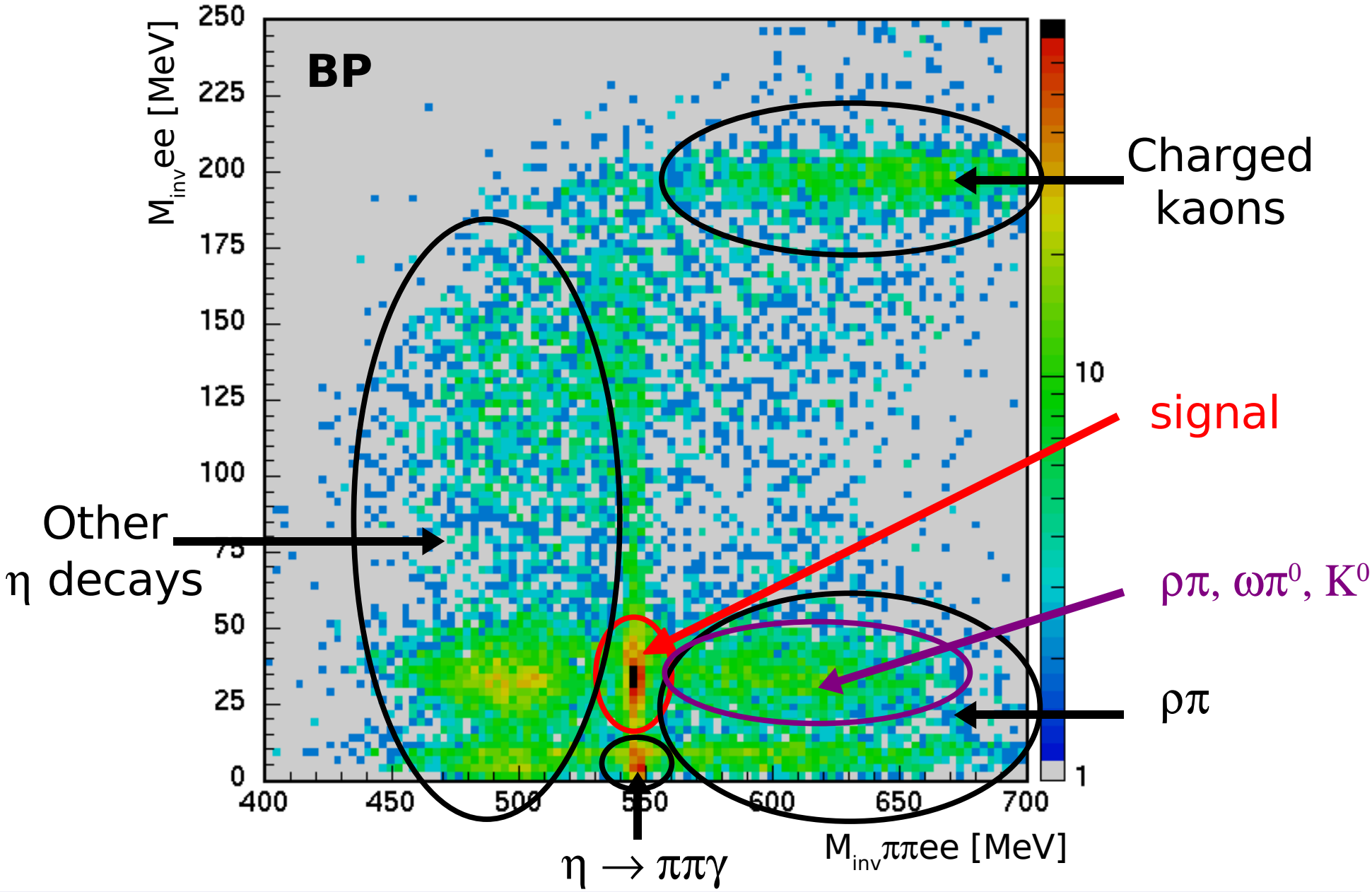
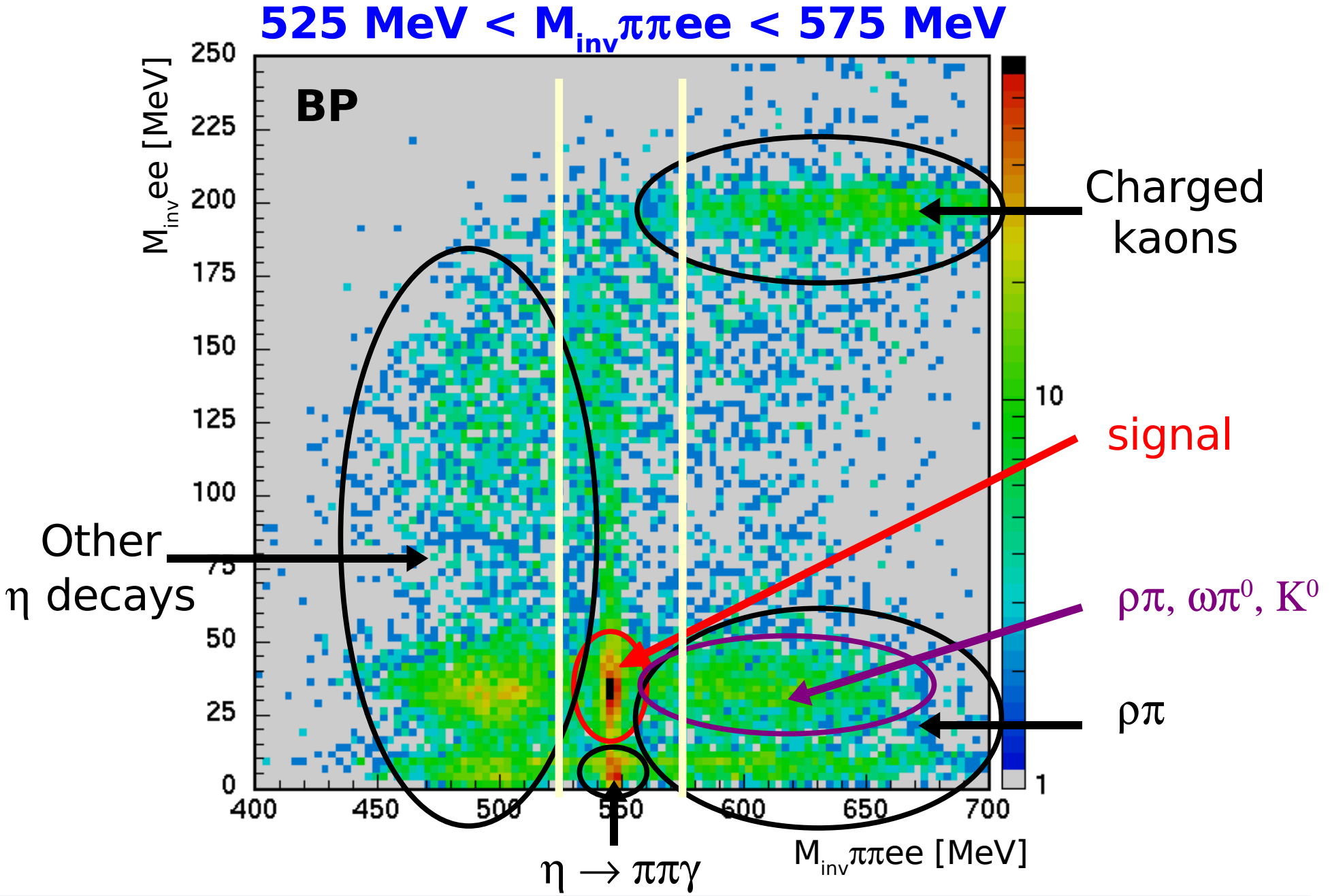


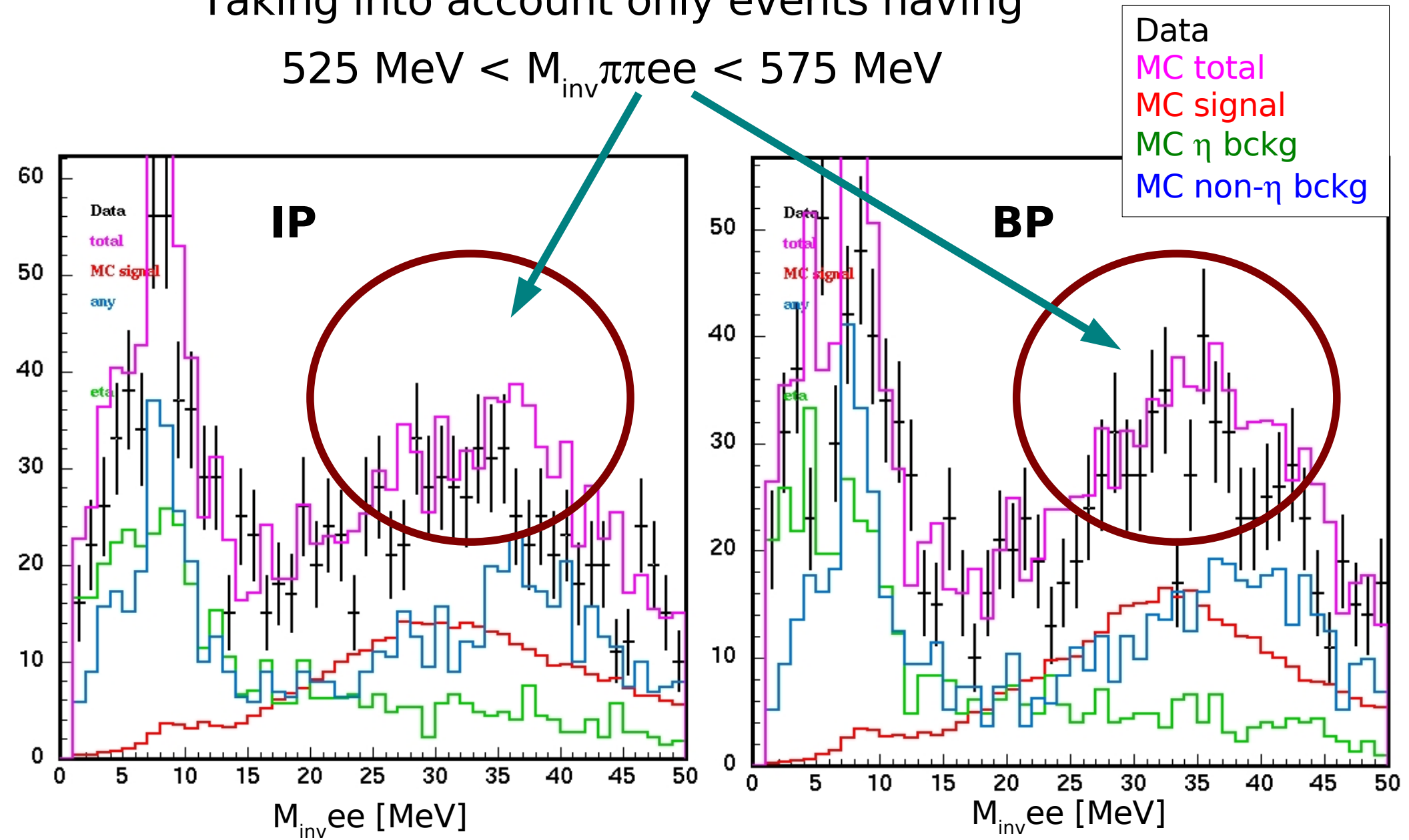
$M_{inv}(e^+e^-)$ puzzle



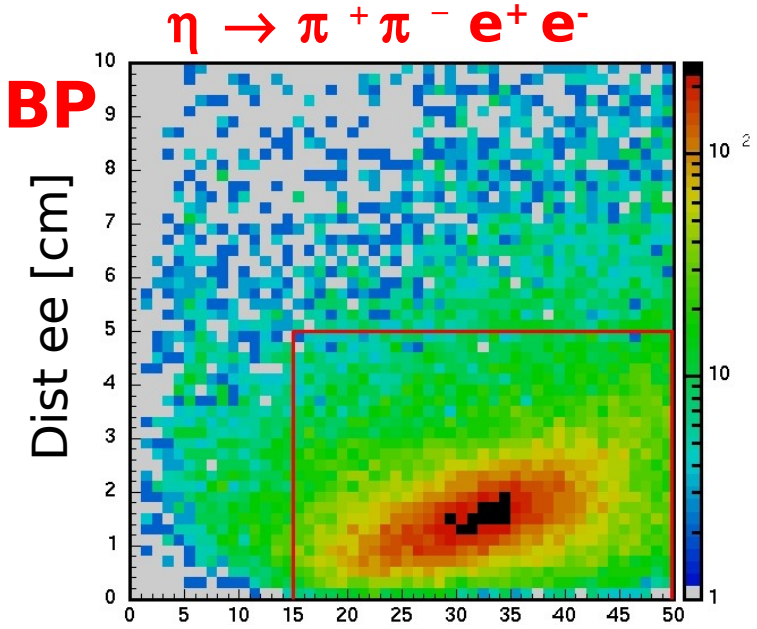
$M_{inv}(e^+e^-)$ puzzle

Taking into account only events having

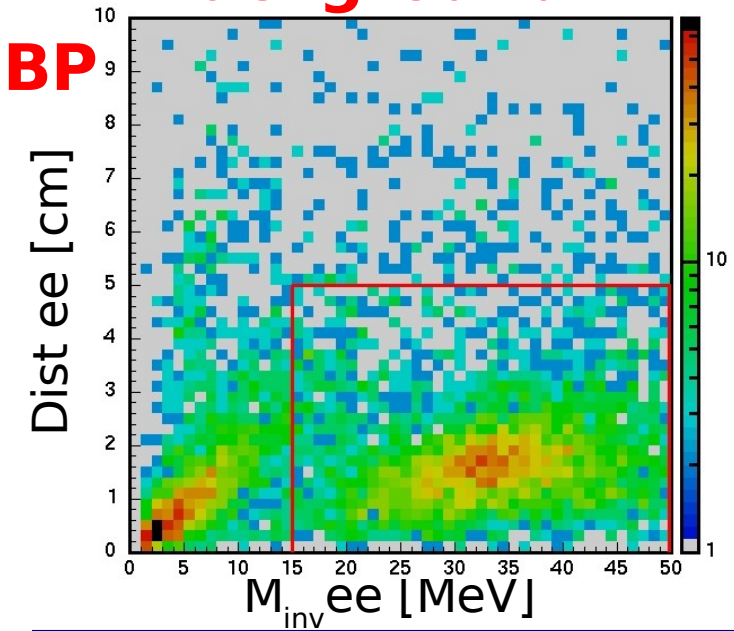
525 MeV < $M_{inv}\pi\pi ee$ < 575 MeV



$M_{inv}(e^+e^-)$ puzzle



Background

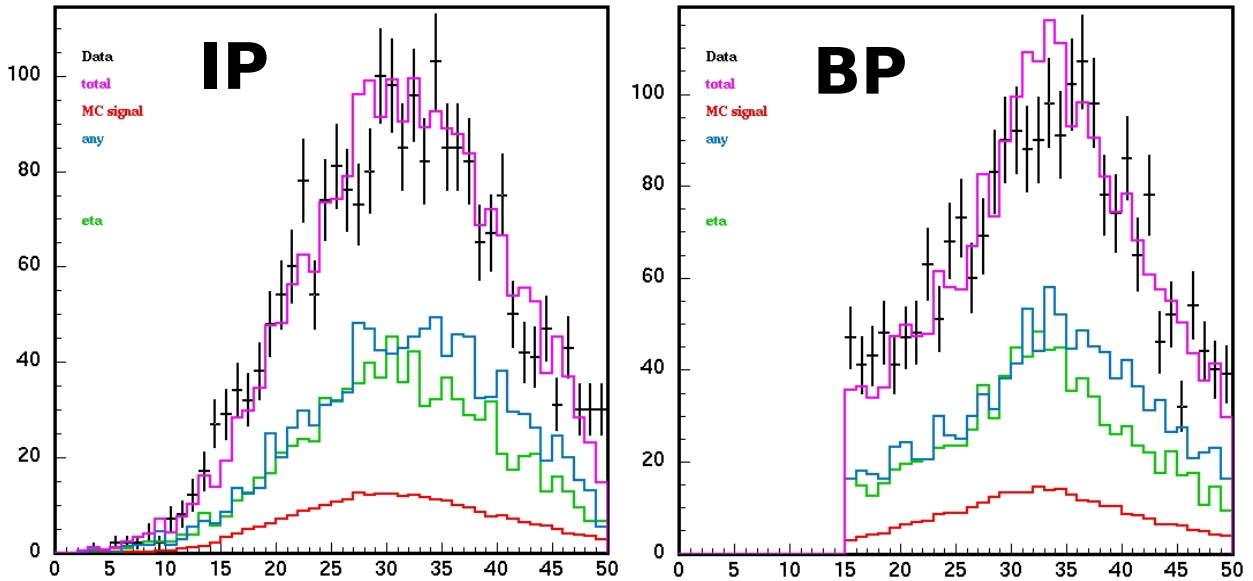


Cross check:

take a box around the signal @BP

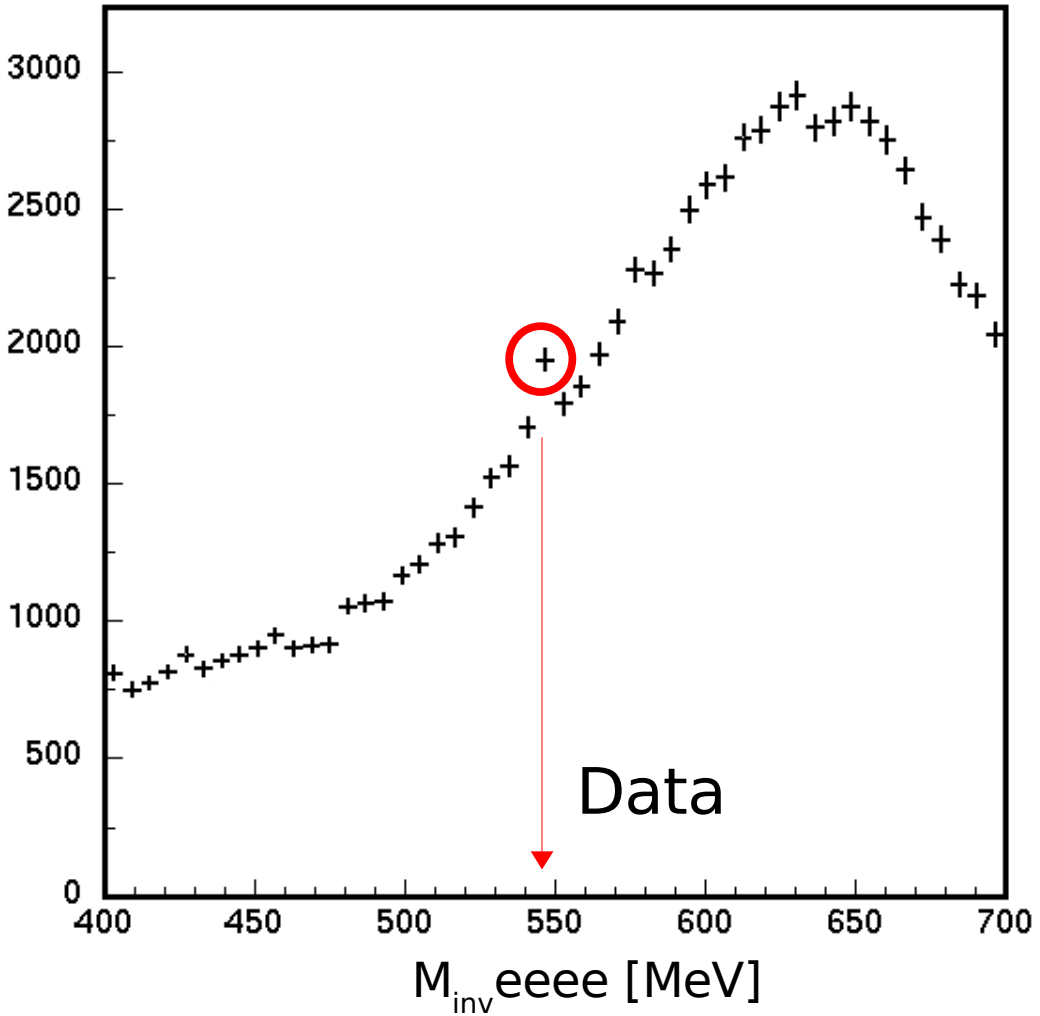
Dist ee < 5 cm

20 MeV < M_{inv}ee < 50 MeV

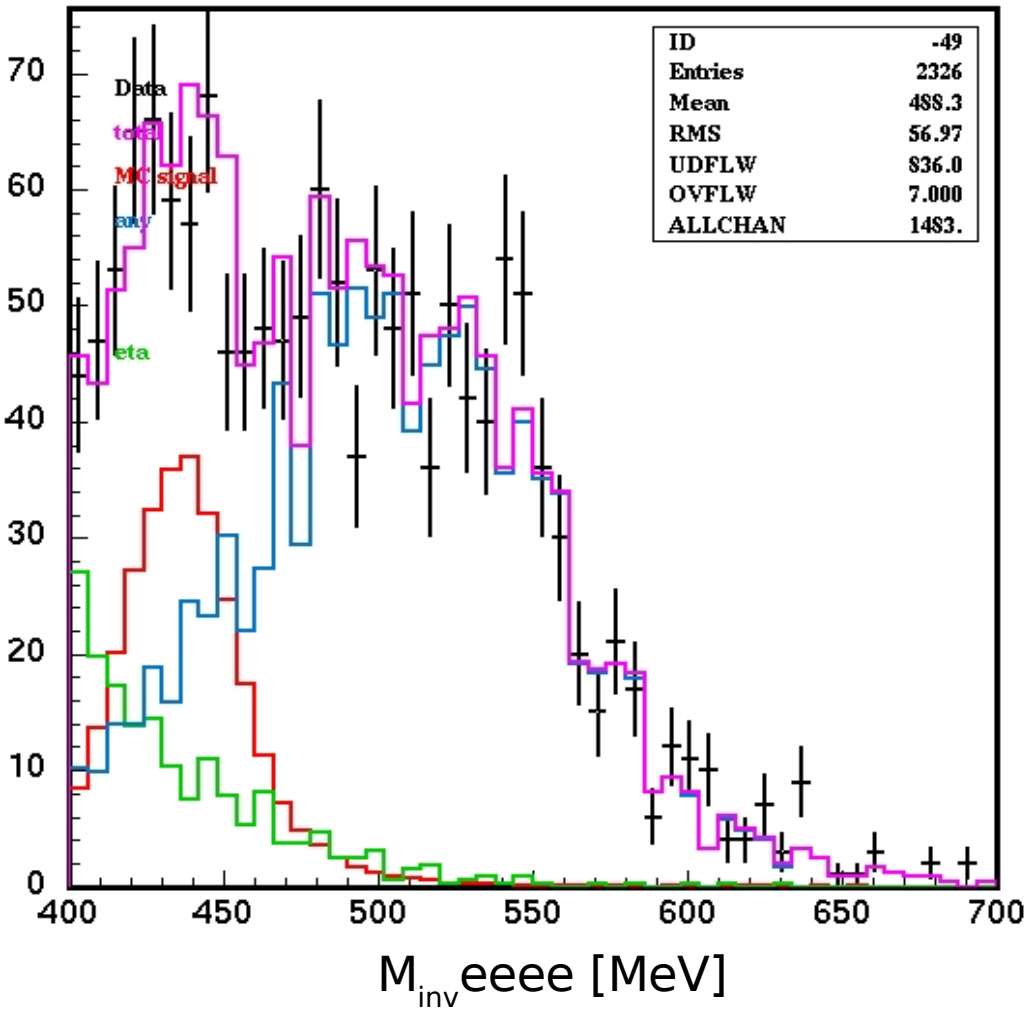


BTW.... $\eta \rightarrow e^+e^-e^+e^-$

Without any cut
Only EVCL



Cuts on momenta
Scale factors from
$M_{inv}\pi\pi ee$ fit



Tracking efficiency

Sample selection

#tracks from IP = 1 or 2

One and only cluster pair such that:

$t_{cl} - r_{cl}/c < \min(2\ \text{ns}, 3\sigma_t)$

$0.65 < \cos(\gamma\gamma) < 0.85$

$300 < E_{\gamma\gamma} < 600$ MeV

w/o associated tracks (Official TCLO)

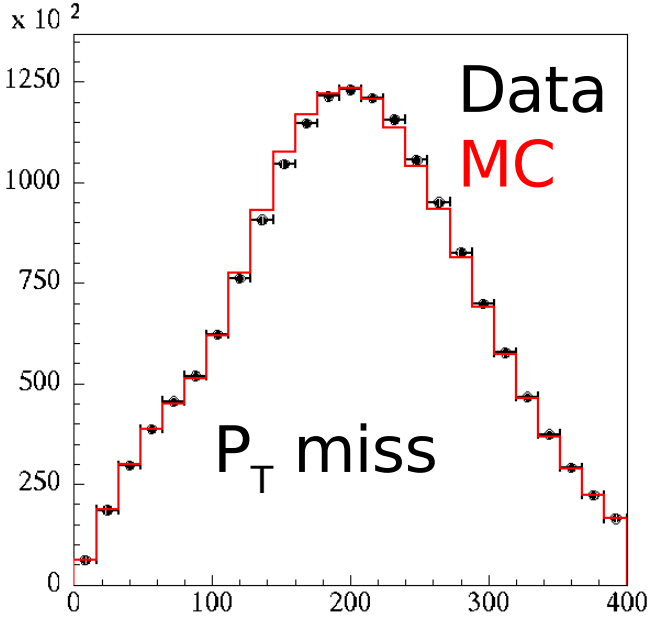
self-triggering (on the barrel and $E_{cl} > 70$ MeV)

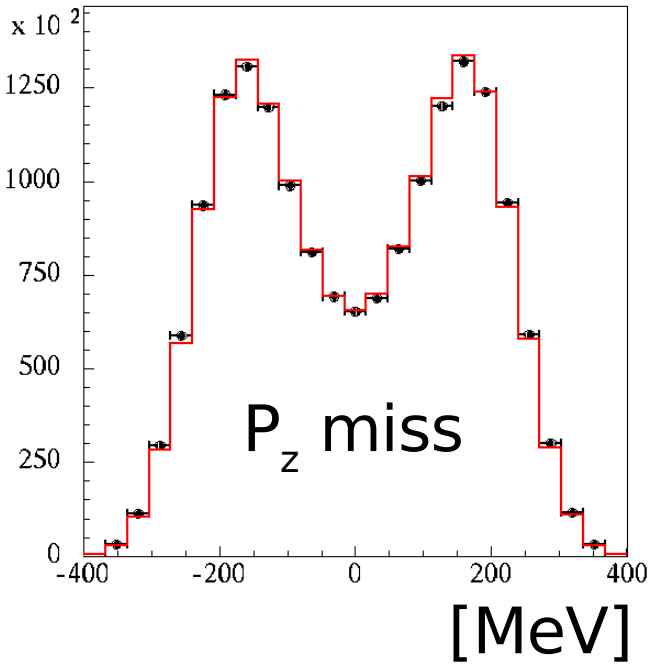
$|m_{\pi 0} - m_{\gamma\gamma}| < 40$ MeV

Efficiency on $\rho\pi$ stream ~ 0.046

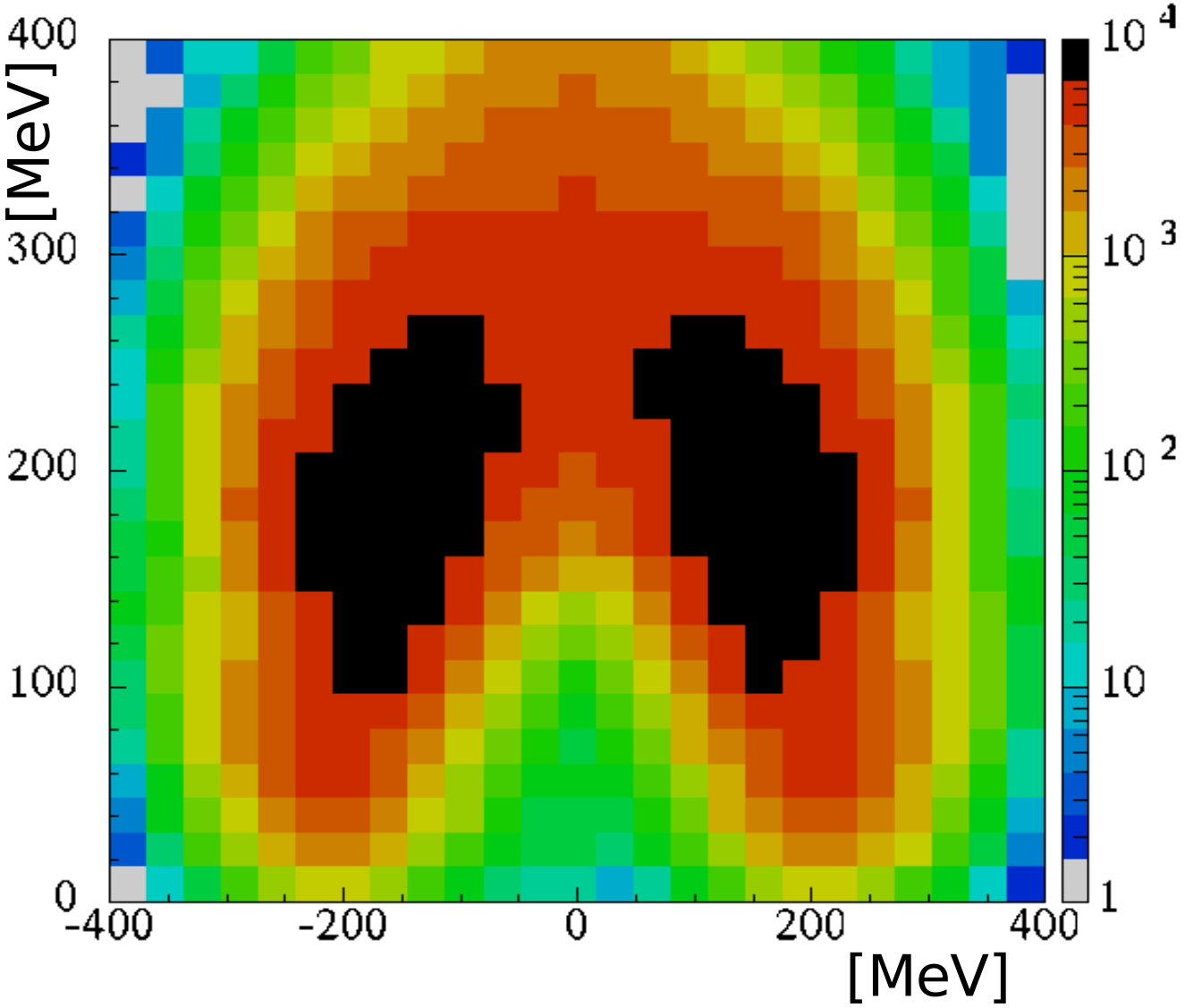
Sample purity ~ 0.997

Tracking efficiency





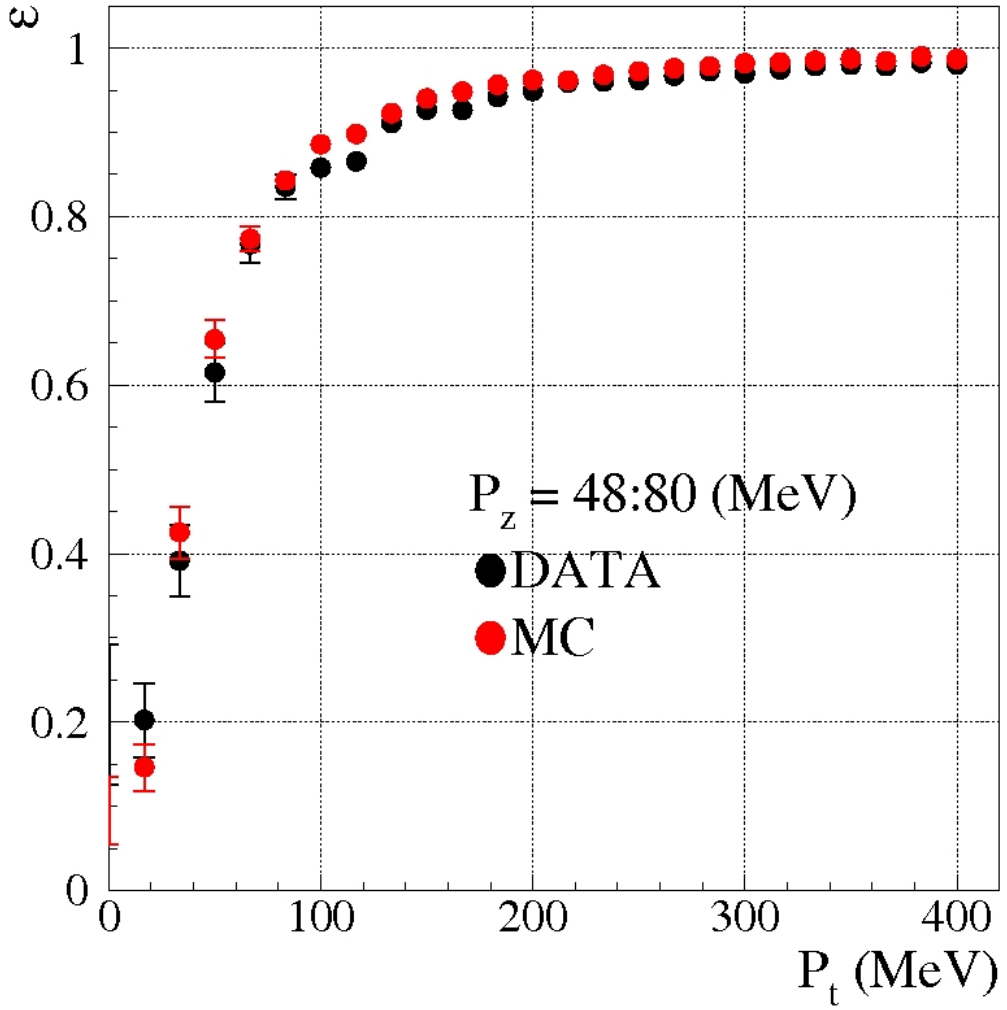
P_T miss vs P_z miss Data

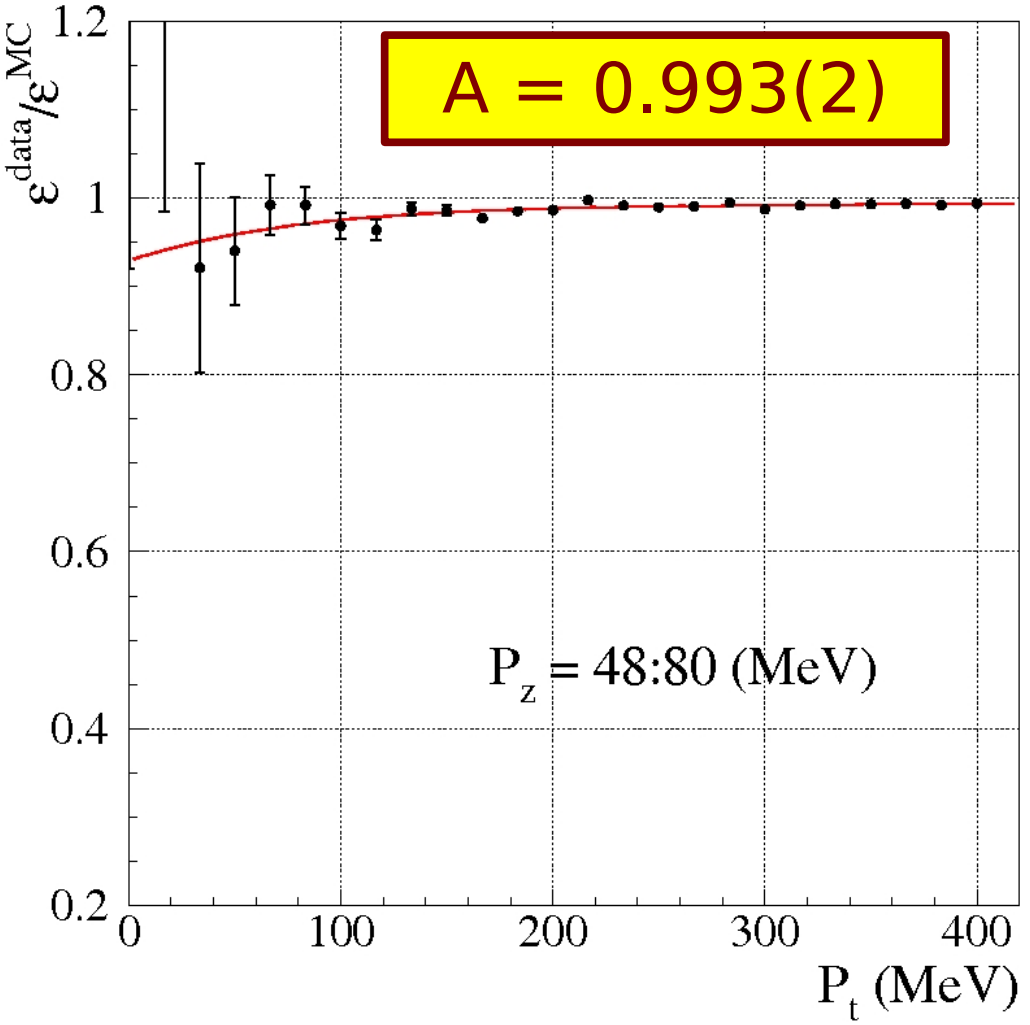


Memo in preparation

Tracking efficiency

$$f = A \{ 1 - 1 / [1 + \exp((X-X_0)/Delta)] \}$$





Conclusions

Many improvements since Capri/Hadron:

- increased statistics
- $\eta \to \pi\pi\gamma$ background rejected
- background much more understood
- tracking efficiency almost there

TOF still to be plugged in

Increase MC statistics

Data reprocessing will increase statistics

The End

Episode III: Revenge of the Fit

Backup slides

Motivations

Consider $\eta \to \pi\pi\gamma$: most general decay amplitude
using Lorentz and gauge invariance

$$A \propto \bar{u}(k_-)\gamma_\mu v(K_+)(M\,\epsilon^{\mu\nu\alpha\beta} p_{+\nu} p_{-\alpha} q_\beta + E_+ p_+^\mu + E_- p_-^\mu)$$

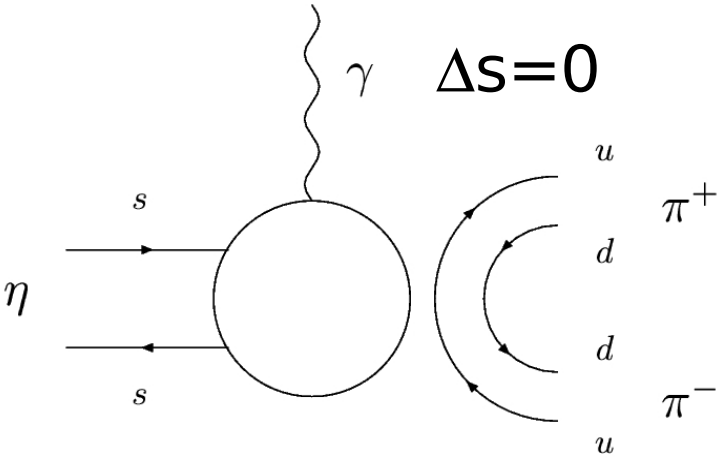
M parity conserving E+- parity violating
CP arises from E-M interference visible in the photon polarization

Summing over photon polarization CP not visible anymore
but still visible in decay plane asymmetry ee-$\pi\pi$

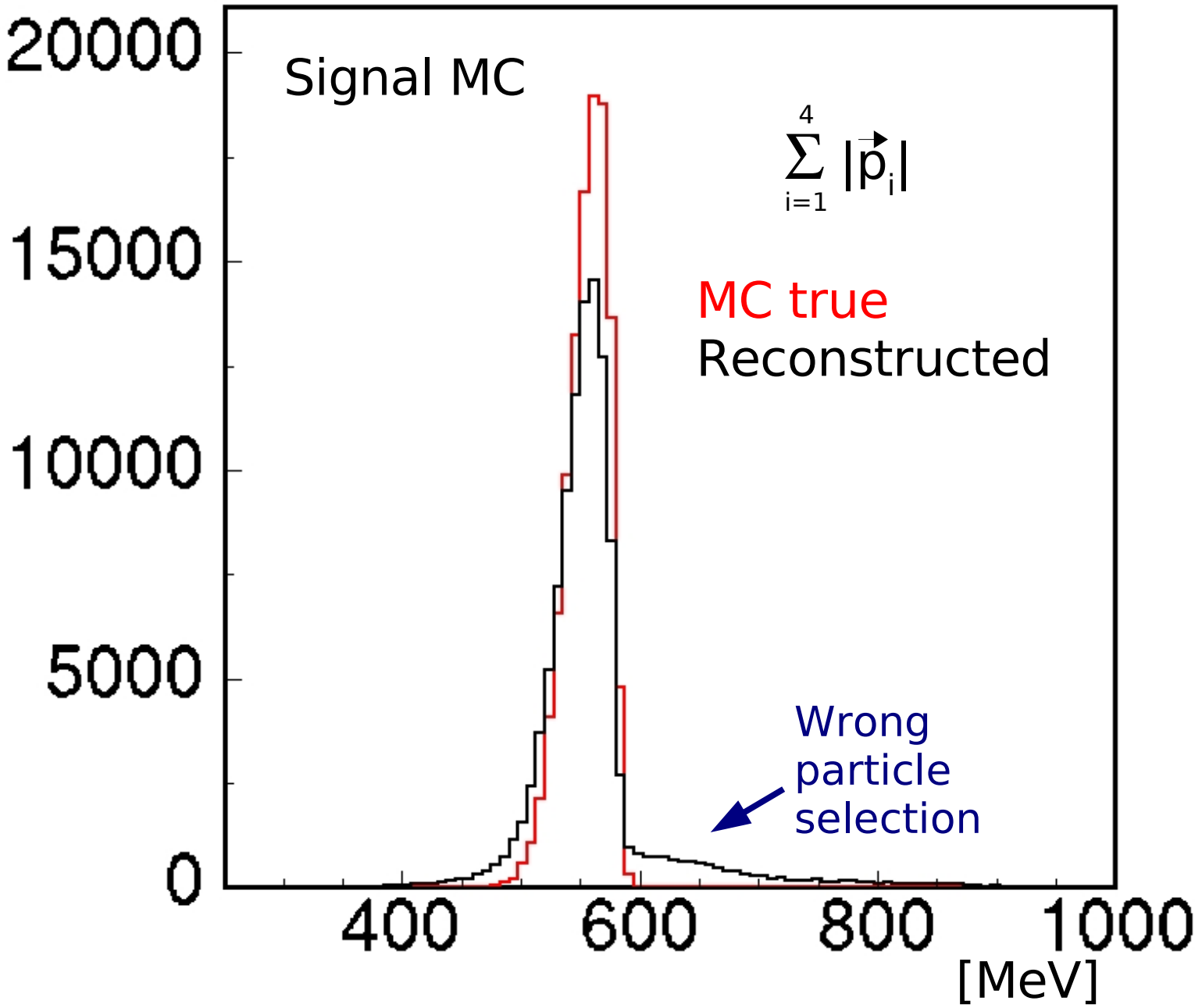
Non negligible CPV $\Leftrightarrow$ operator not contributing to ε,ε' and d_n

$$O = \frac{1}{m_\eta^3} G\,\bar{s}\,i\,\sigma_{\mu\nu}\gamma_5 (p-q)^\nu s\,\bar{\psi}\,\gamma^\mu\psi$$

$$\frac{G}{m_\eta^3}\langle\eta|\bar{s}\,i\,\sigma_{\mu\nu}\gamma_5(p-k)^\nu s|\gamma\rangle\langle 0|\bar{u}\,\gamma^\mu u|\pi^+\pi^-\rangle$$



Track selection



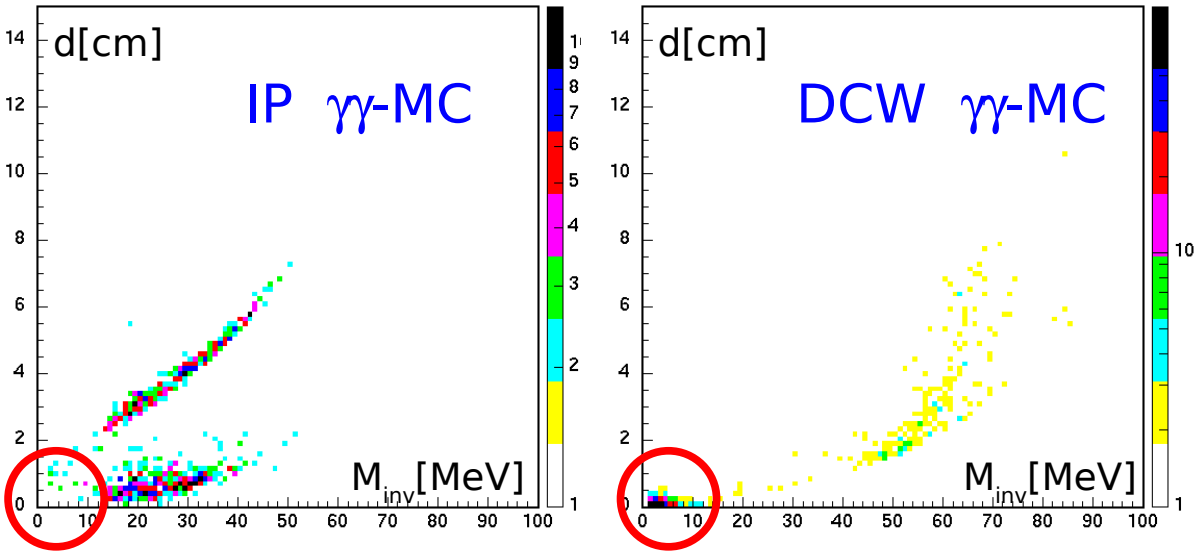
$\eta \to \pi^+\pi^-\gamma$ background

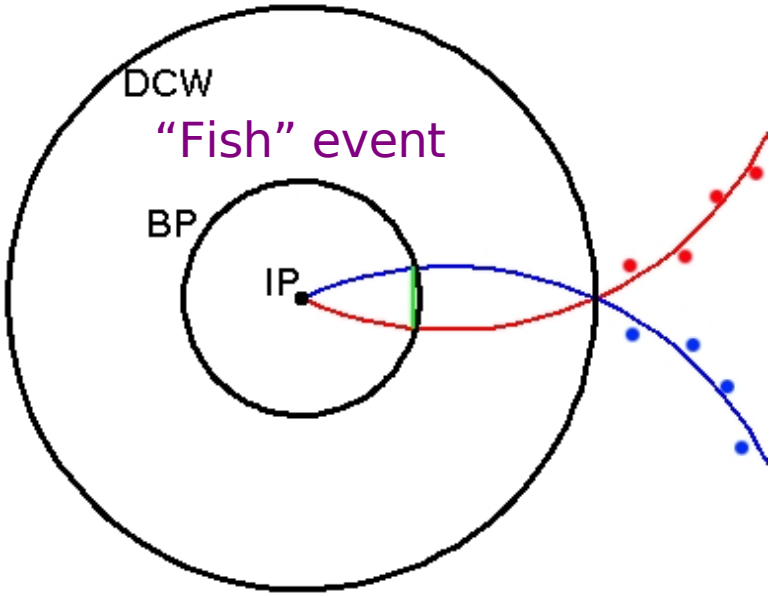
Has the same signature of the signal ($\eta \to \pi^+\pi^-\gamma \to \pi^+\pi^-e^+e^-$)

when photon converts on the Beam Pipe or on DC Wall

Disentangled using $M_{inv}(e^+e^-)$

and distance between tracks





arXiv:0707.1601

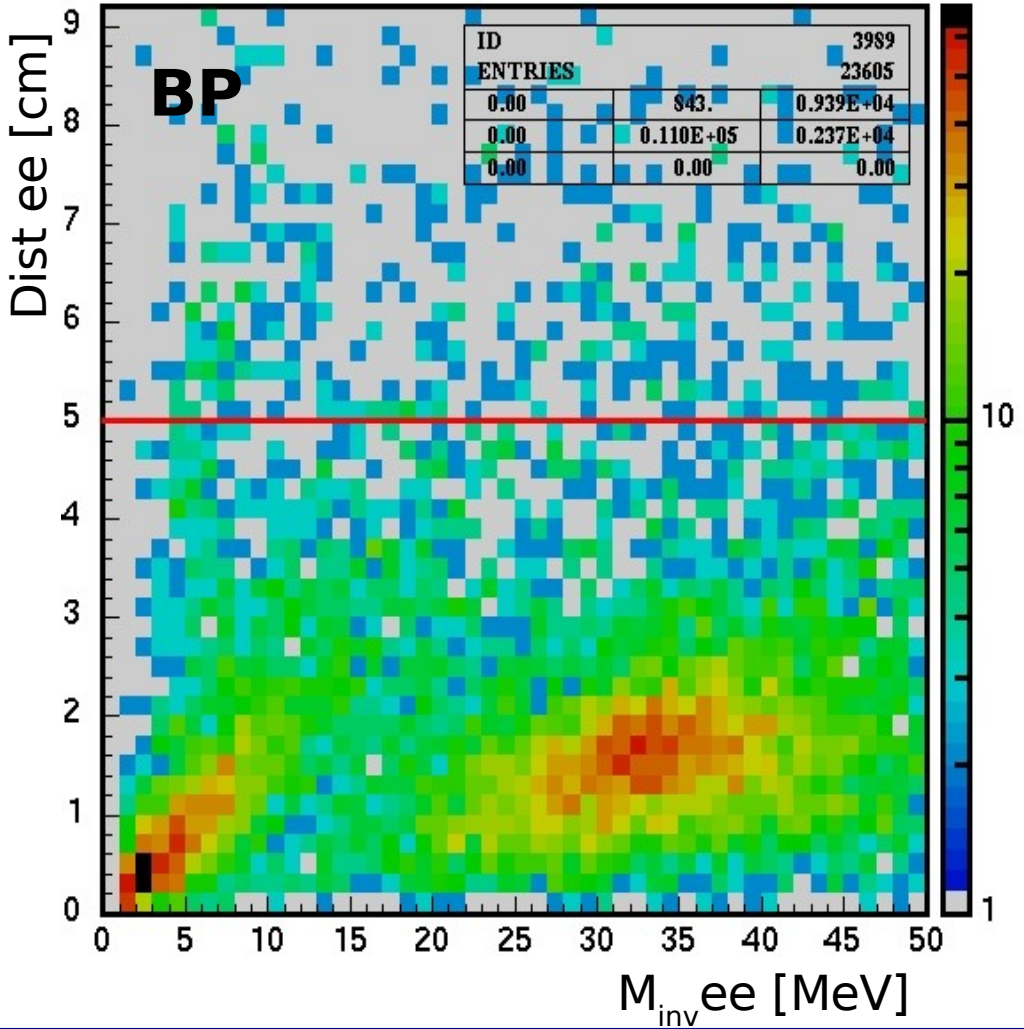
In MC BR($\eta \to \pi^+\pi^-\gamma$) from PDG reduced by 15% by CLEO

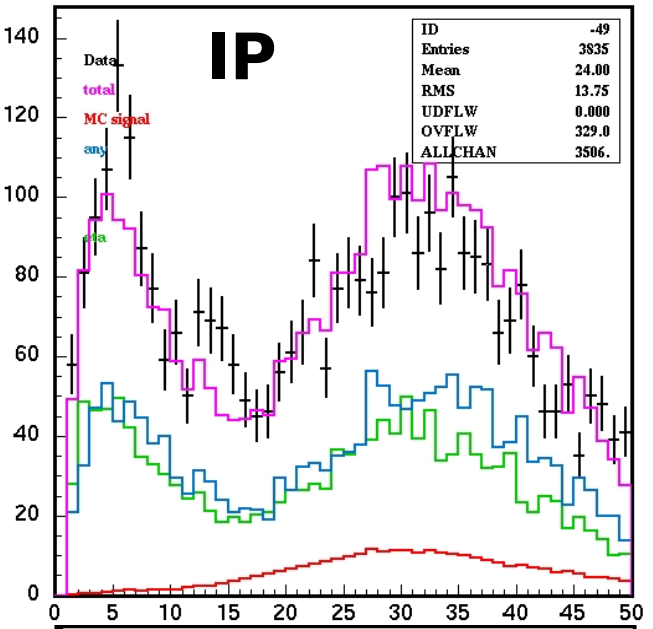
$M_{inv}(e^+e^-)$ puzzle

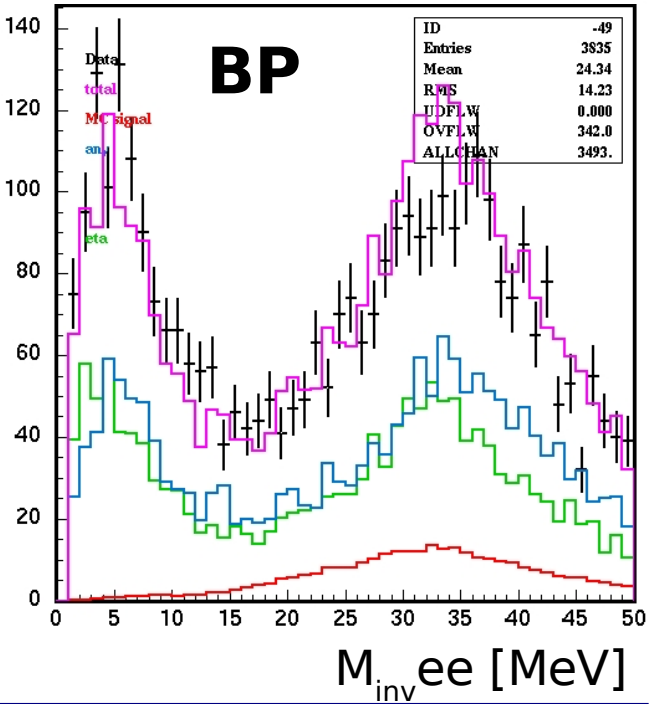
Dist(e^+e^-) vs $M_{inv}(e^+e^-)$ plane

Try cut events with large Dist(ee)

(before fit $m_{\pi\pi ee}$ spectrum)







Cross section dependence on √s

Using the numbers from PDG

$\sigma(\phi) = 3.3(1)\ \mu b^{-1}$ $\quad$ $BR(\phi \to \eta\gamma) = 0.0130(2)$

$\sigma(\phi \to \eta\gamma) = 42.9(7)\ nb^{-1}$

Using the Lineshape of $\eta\gamma \to 7\gamma$ 2001-2002 Kloe memo 319

fitted with gaussian $\quad$ $\sqrt{s} = 1019.5$ $\quad$ $\sigma = 0.128$

$\sigma(\phi \to \eta\gamma) = 41.5(6)\ nb^{-1}$

BR increases of ~3%

BR evaluation

$$BR = \frac{N_{\pi\pi ee}}{N_\eta} \cdot \frac{1}{\epsilon} = \frac{N_{\pi\pi ee\ \ Fit\ DATA}}{\sigma_\phi \cdot L \cdot BR(\phi \to \eta\gamma)} \cdot \frac{1}{\epsilon}$$

#events = 733(62)

efficiency = 0.1175(5)

Reconstruction efficiency from MC

Correction expected ~5-10%

Systematics

under evaluation

Normalization

Event counting

Efficiency

Cuts on momenta

$BR(\eta \to \pi^+\pi^- e^+ e^-) = (24 \pm 2_{Stat.} \pm 4_{Syst.}) \times 10^{-5}$

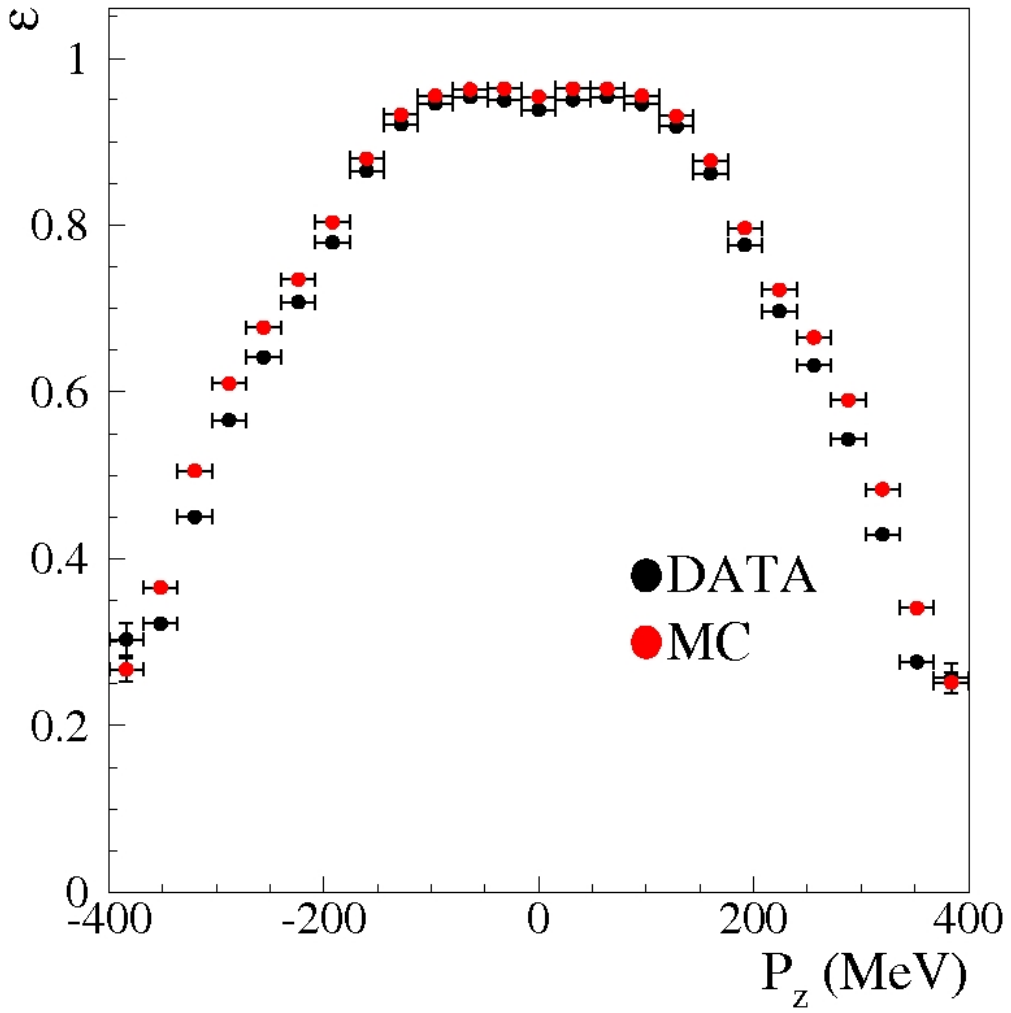
PRELIMINARY

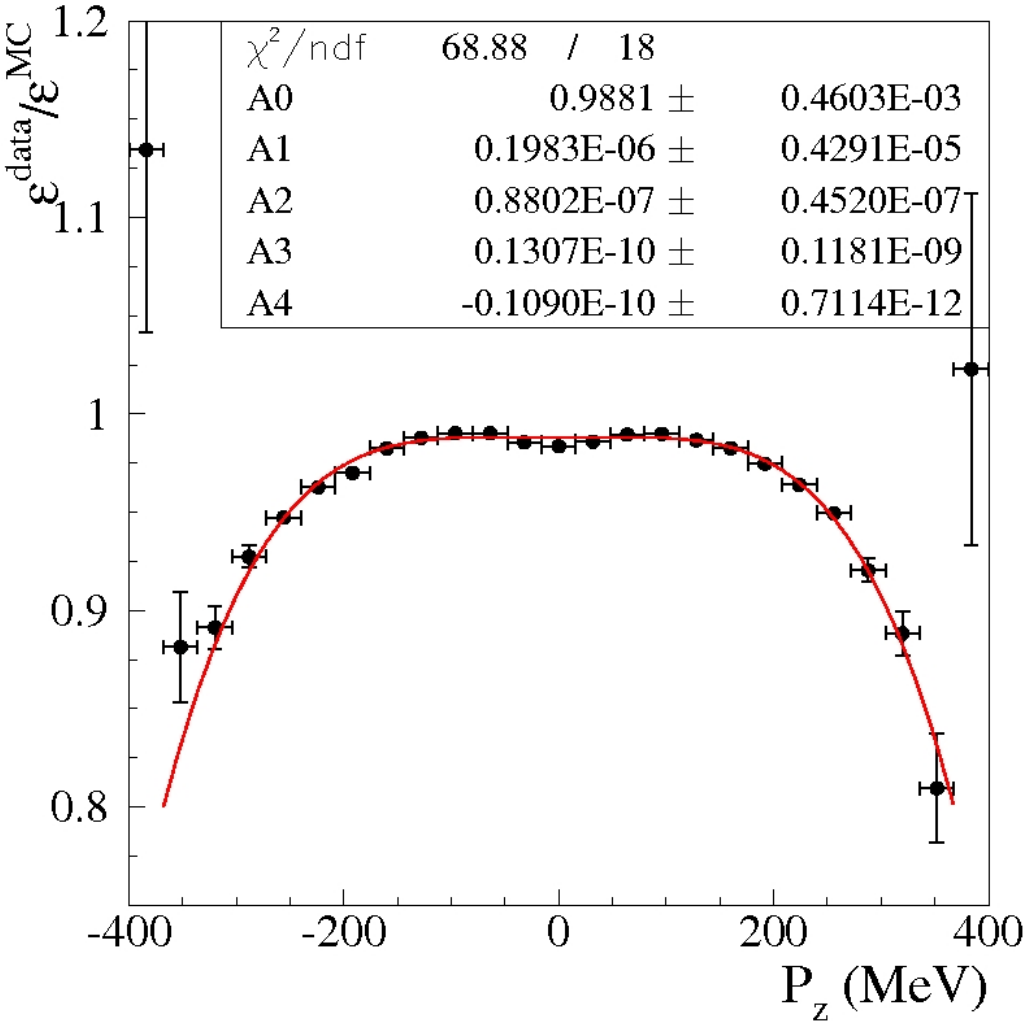
Uncertainties

Source	$\Delta x/x$
Luminosity	0.006
$\sigma(\phi)$	0.03
BR($\phi \to \eta\gamma$)	0.02
Event counting	0.08
Efficiency	< 0.1
cut on $\|P(p^+1)\| + \|P(p^-1)\|$ (±30 MeV)	0.1
cut on $\sum_1^4 \|p_i\|$ (±30 MeV)	0.05

Memo in preparation

Tracking efficiency





Check of the reconstruction efficiency

1. Track efficiency for both the pions

   using $\phi \to \rho\pi$ control sample selected with calorimeter

   requirements only (Purity = 0.99)

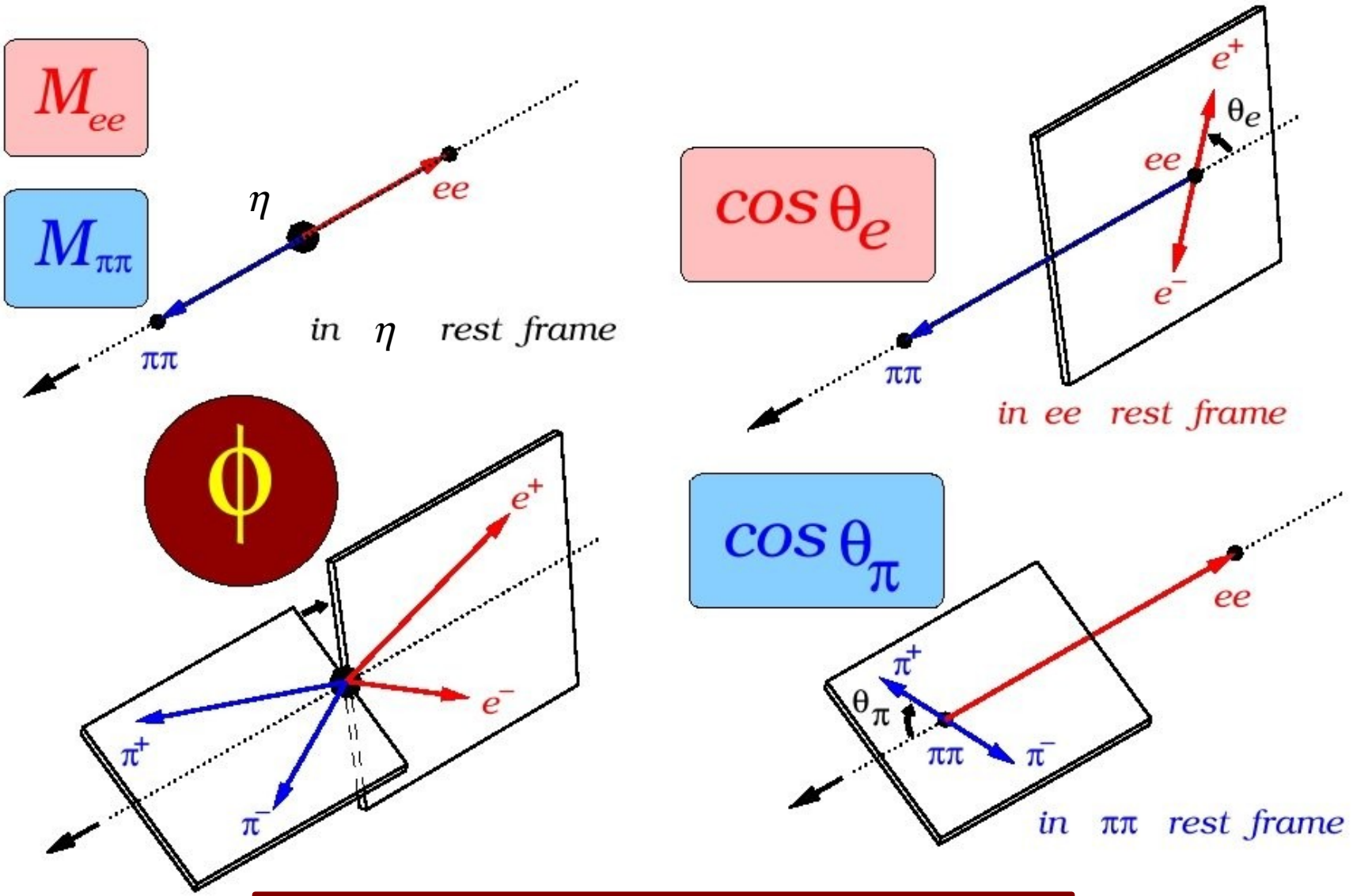
2. Track efficiency for electrons using

   the downscaled sample with 3 tracks from the IP

3. Cluster (veto) (in-)efficiency from $\eta \to \pi^+\pi^-\pi^0$ control sample

Remind

Asymmetry

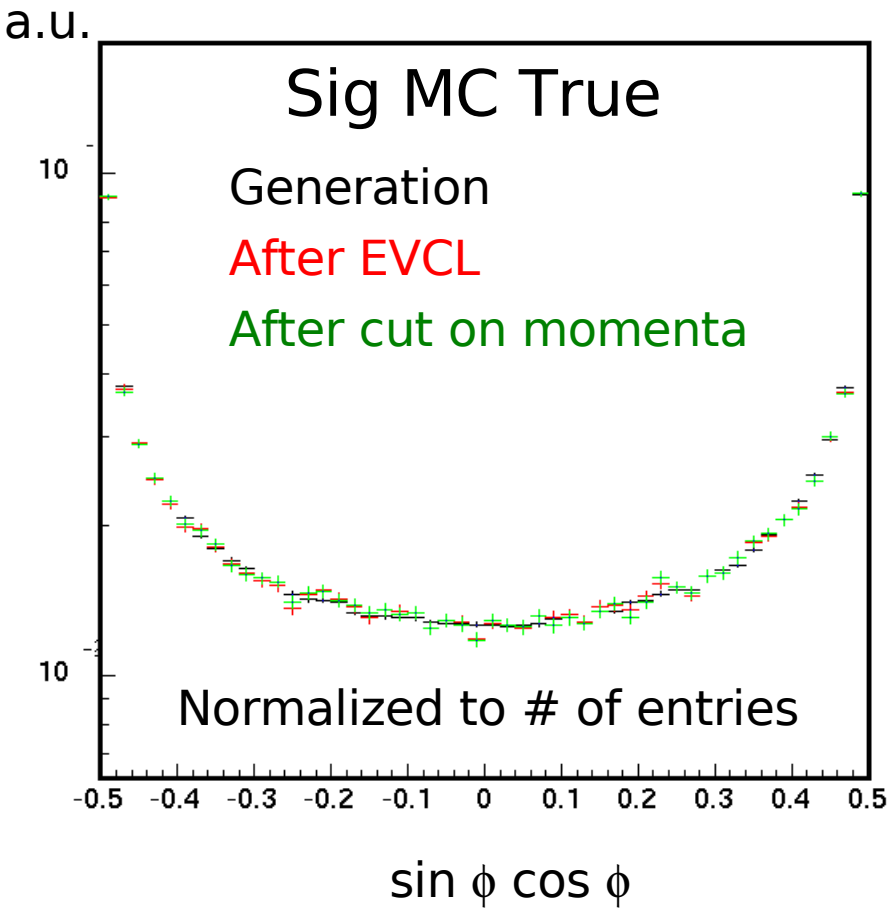


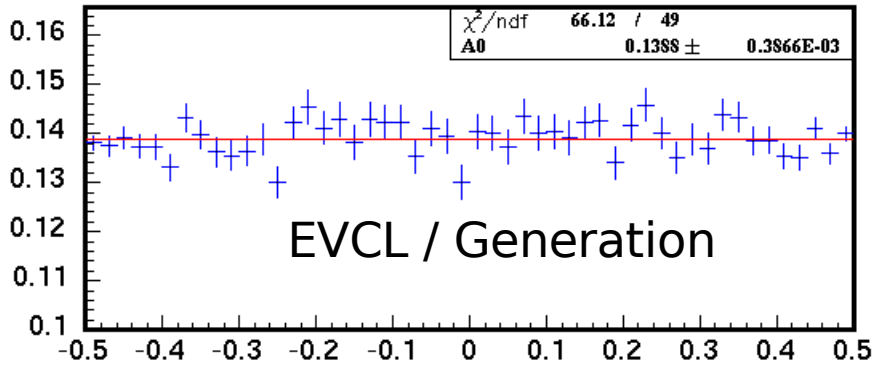
$$\sin\phi\cos\phi = (\hat{n}_{ee}\times\hat{n}_{\pi\pi})\hat{z}(\hat{n}_{ee}\cdot\hat{n}_{\pi\pi})$$

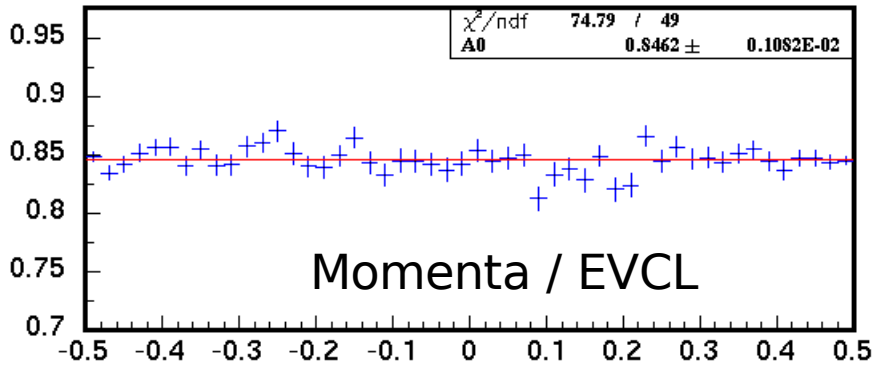
Asymmetry

$$\frac{N_{\sin\phi\cos\phi>0} - N_{\sin\phi\cos\phi<0}}{N_{\sin\phi\cos\phi>0} + N_{\sin\phi\cos\phi<0}}$$

Distortion at each step







The asymmetry is not affected by efficiencies

Asymmetry

The asymmetry is not affected by efficiencies

Can be obtained

either fitting data with MC spectra (sigmc+bckg)

or restricting to a cleaner sample:

- ordered momenta hypothesis has to correspond to the mass hypothesis from the kinematic fit (best χ^2 hp)
- apply cut on additional gammas
- restricting around the invariant mass peak