Search for X17 in the $\eta \rightarrow e^+e^-\pi^+\pi^-$ decay at pp@4.5 GeV with HADES

Workshop at 1 GeV scale:
from mesons to axions
CRACOW 19.09.2024

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Motivations

- Bing Bang should create the same amount of matter and antimatter
- but we observe more baryons than antibaryons (baryogenesis puzzle)
- Standard Model includes **CP symmetry violation** in weak interactions, but it is not sufficient to explain observed asymmetry
- according to Peccei-Quinn-Wilczek's theory axion explains no CP violation in strong interactions and helps to understand baryon-antibaryon asymmetry

$$\frac{N_B - N_{\bar{B}}}{N_\gamma} \approx 6 \cdot 10^{-10}$$

N_B - number of baryons

$N_{\bar{B}}$ - number of antibaryons

N_γ - number of photons

Theoretical hypothesis: existence of axions or axion-like-particles (ALP)

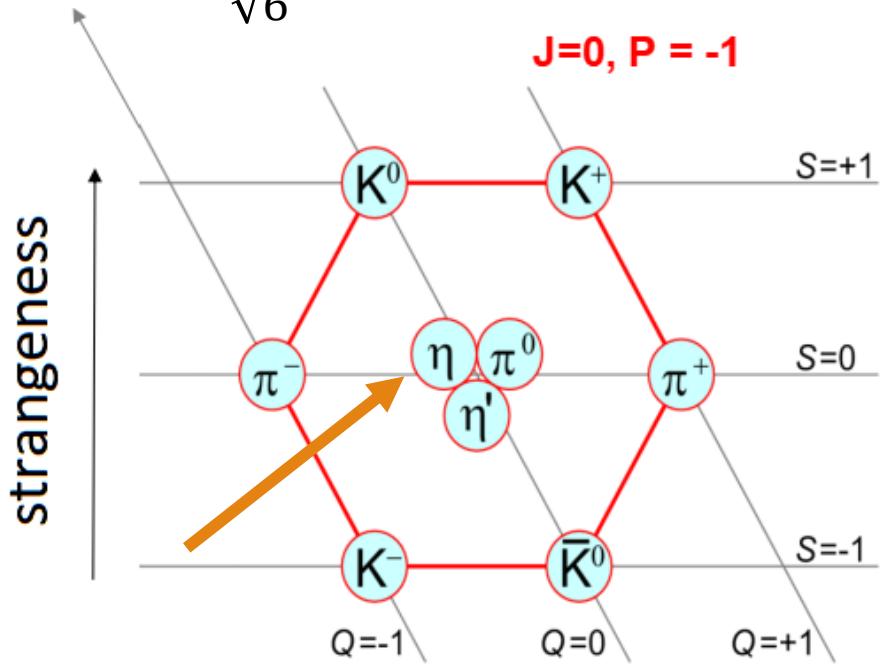
Ref. : R. Co, K. Harigaya, Phys. Rev. Lett. 124, 111602 (2020)

η meson properties

mass	547.862 ± 0.018 $\frac{MeV}{c^2}$
electric charge	0
spin	0
P parity	-1
C parity	+1
Example decays	η → γ γ (39.36%)
	η → π^0 π^0 π^0 (32.57%)
	η → π^+ π^- π^0 (23.02%)
	η → π^+ π^- γ (4.28%)
	η → π^+ π^- e^+ e^- (0.03%)

Ref.: *pdg.lbl.gov* website, access: 05 IX 2024

$$\eta \approx \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s})$$



Nonet formed by pseudoscalars mesons consisting of u, d, s quarks.

X17 search in η decay

- QCD Axion couples predominantly to the first generation of SM fermions
- Suppressed mixing-angle results in the isoscalar couplings of the axion
- Hadronic decay channels of η and η' could be coupled to ALP's:

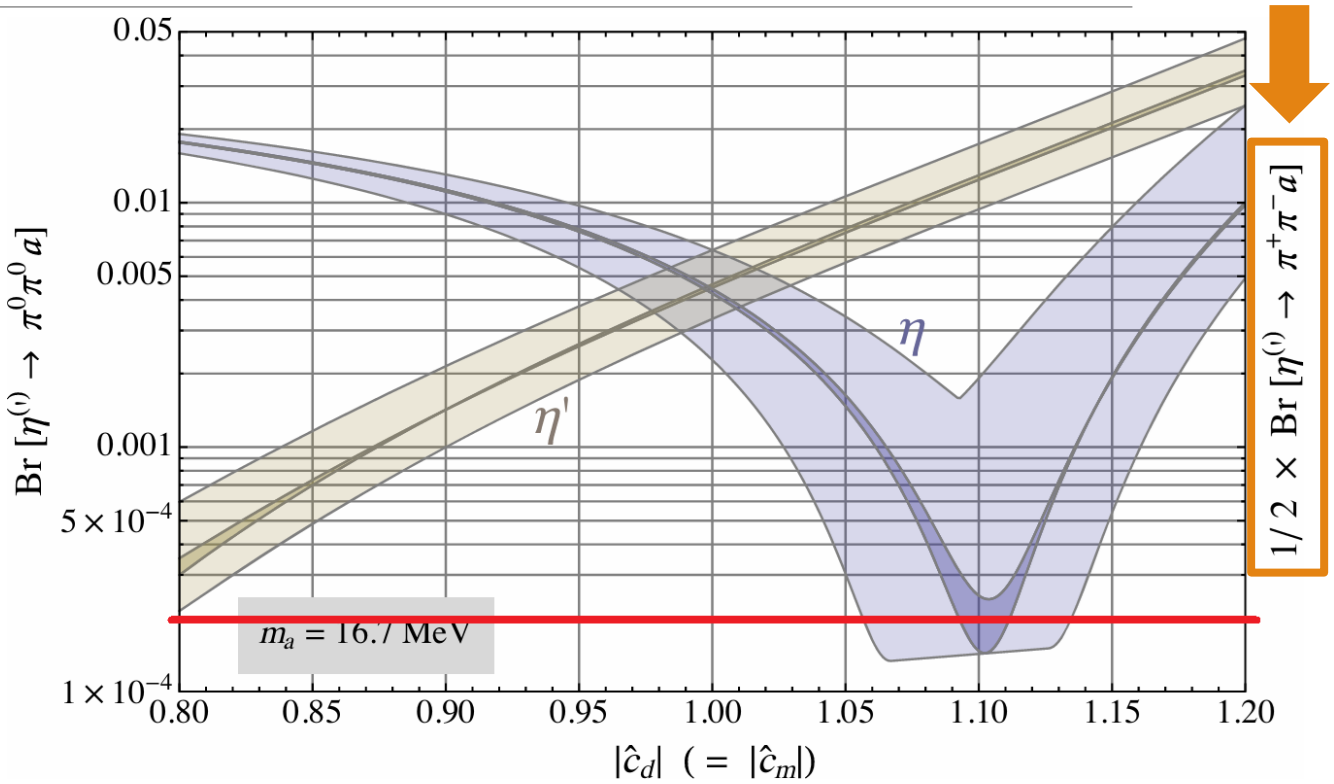
$\eta(\eta') \rightarrow \pi^+\pi^- a\ (\rightarrow e^+ e^-)$

"axio-hadronic decay"

$\Gamma \sim \underline{4 \cdot 10^{-14}\ s}$

$BR \sim \underline{1 \cdot 10^{-4}}$

(for decay $\eta \rightarrow \pi^+\pi^- e^+ e^-(\text{no X17})$ - $BR_{PDG} = 2.68 \cdot 10^{-4}$)

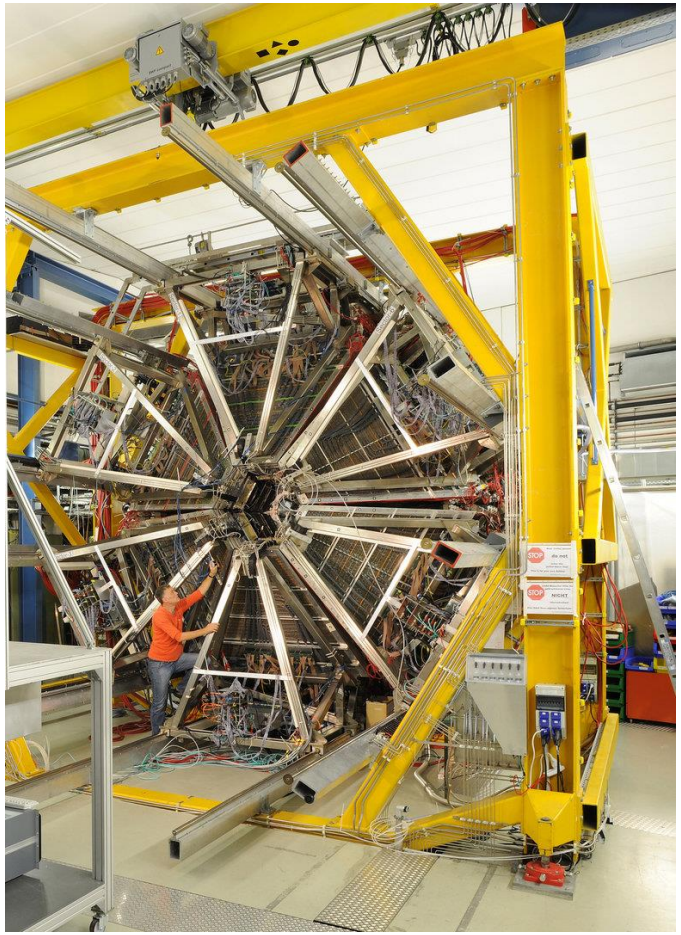


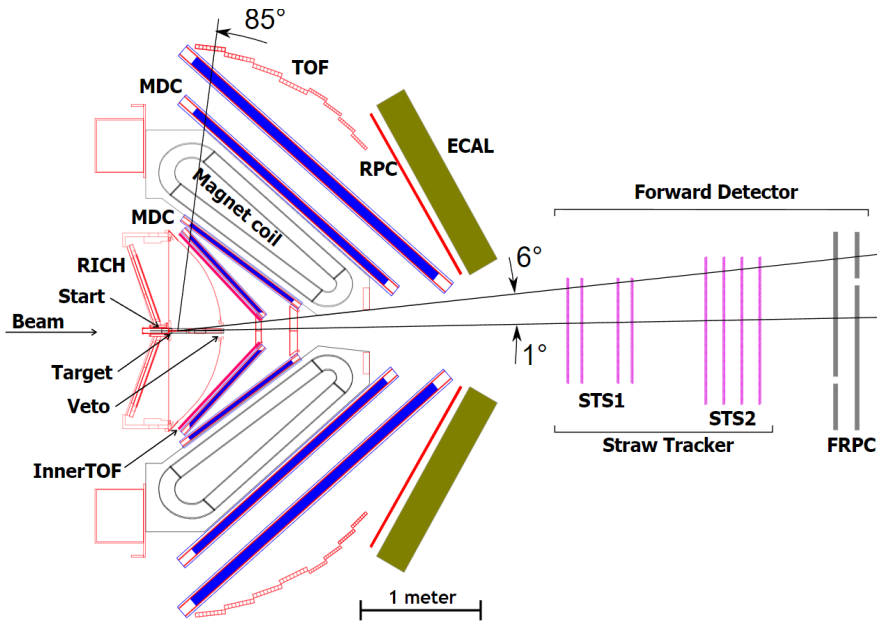
Ref. : D. Alves et al., PHYS. REV. D 103, 055018 (2021)

REDTOP proposal: C. Gatto et al. arXiv. 1910.08505 (2019)

Sergi Gonzalez-Solis morning talk

HADES detector





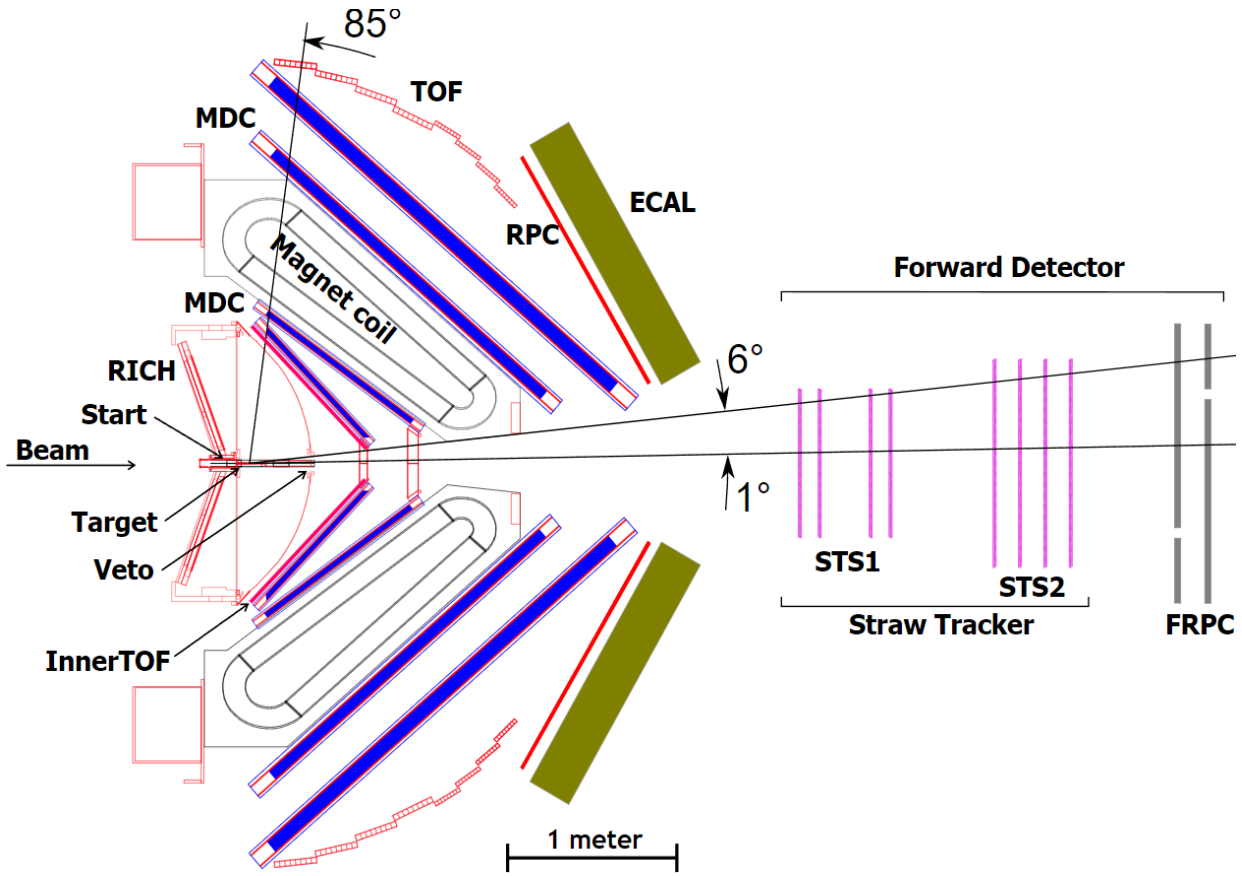
High Acceptance Di-Electron Spectrometer

- START – T0 reaction start time for the time-of-flight system
- RICH – Cherenkov detector (di-electron e^+e^-)
- MDC – track reconstruction
- magnet coil – generates magnetic field
- ToF & RPC – time-of-flight META detectors
- ECAL – electromagnetic calorimeter (photons)

Trigger logic based on InnerToF and Meta.

(very efficient and selective)

February 2022 experiment



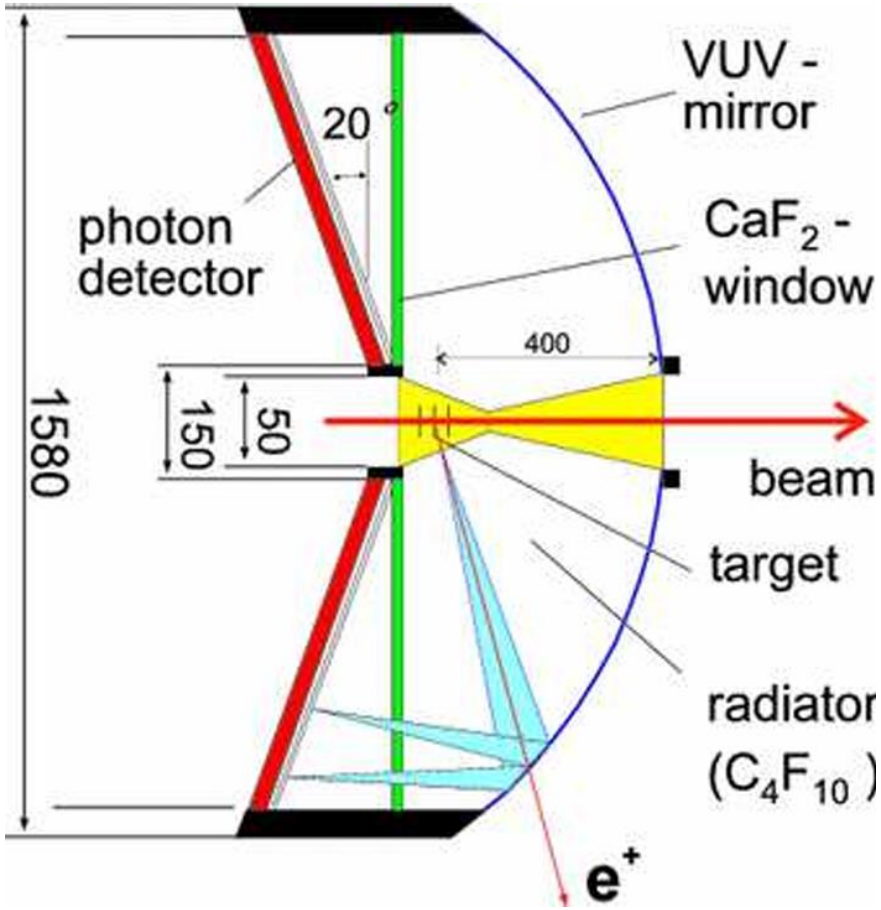
Scheme of the HADES detector.

February 2022 experiment:

- proton – proton collisions at 4.5 GeV
- liquid hydrogen target LH_2
- 28 days of experiment
- total integrated luminosity ~6 $\frac{1}{pb}$

Ref.: J. Adamczewski-Musch et al. Eur. Phys. J. A (2021) 57:138

Identification of leptons in RICH



Ref.: G. Agakishiev et al. Eur. Phys. J. A (209) 41:243-277

For particles heavier then electrons:

$m_\pi > m_e$

$\beta_\pi < \beta_e$

We can choose material where:

$\beta_\pi < \beta_{Cher} < \beta_e$

electrons and positrons create Cherenkov radiation

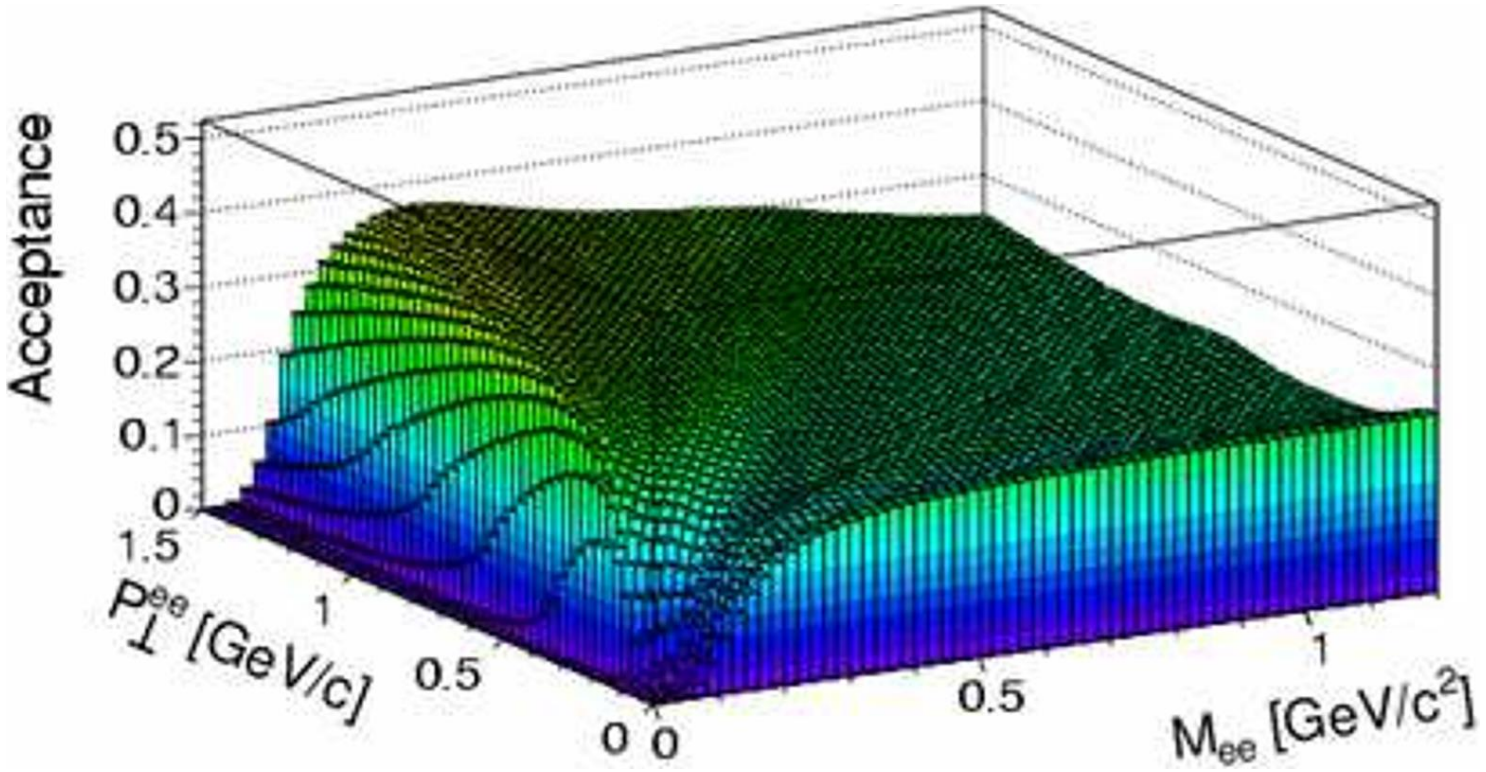
at SIS18 Energy rangy only leptons can create Cherenkov radiation

Threshold momentum for electrons 9.18 MeV and for pions 2 508.38 MeV

HADES detector – dielectron acceptance

Previous lepton identification:

- based on signal in RICH
- acceptance as a function of transverse momentum and invariant mass
- in standard HADES analysis e^+e^- opening angle > 9° to subtract conversion
- reduction of acceptance for low invariant masses



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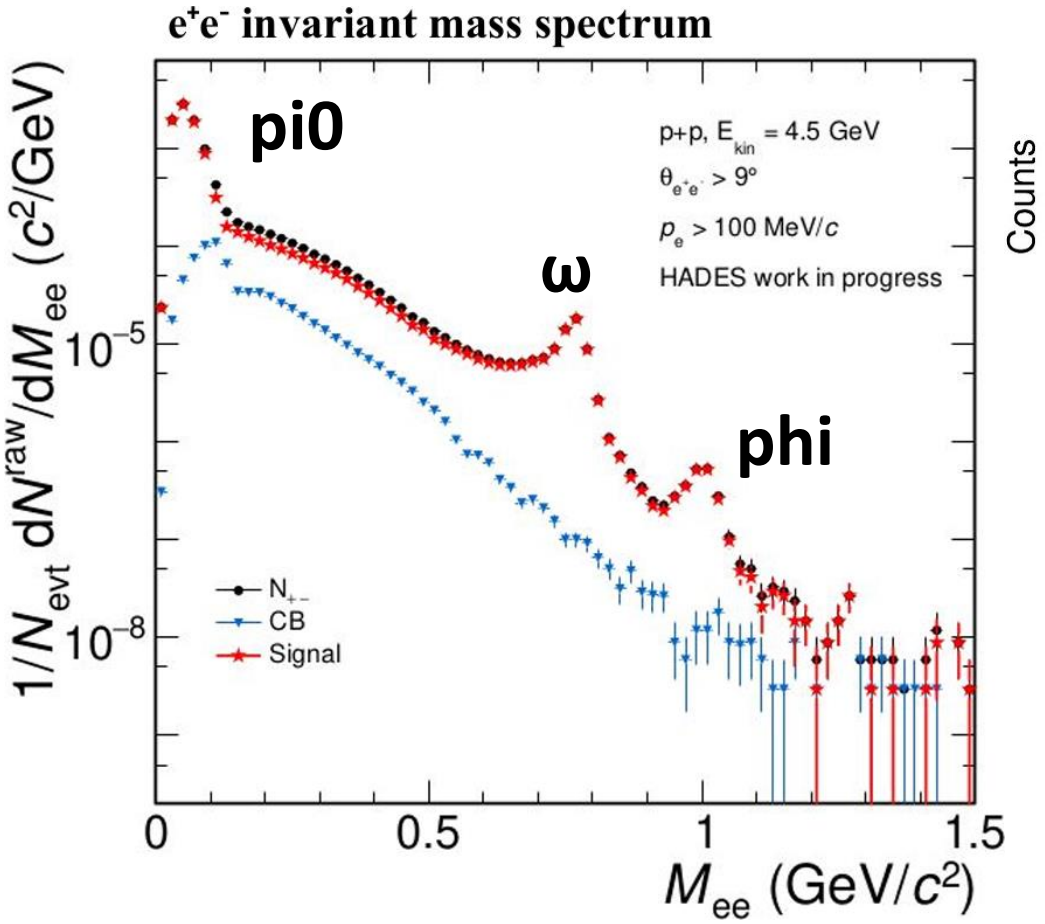
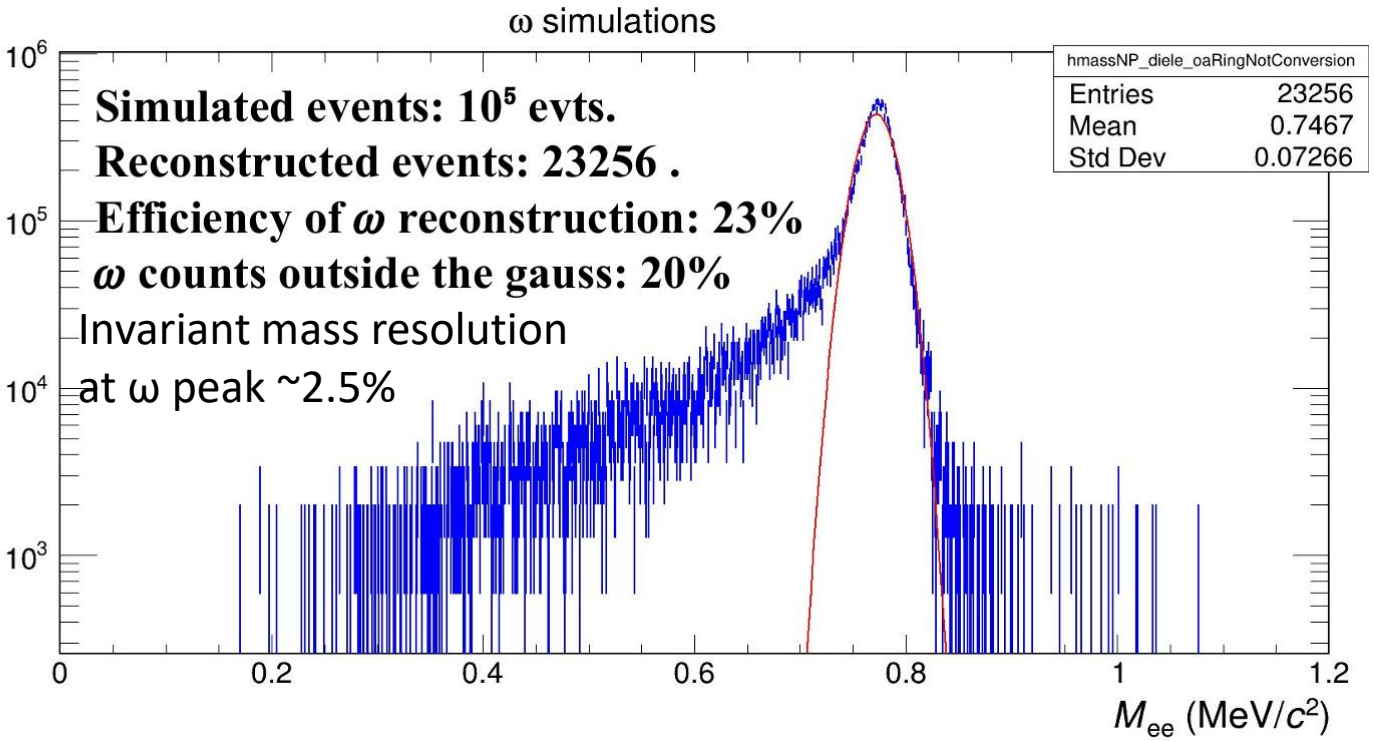
HADES detector





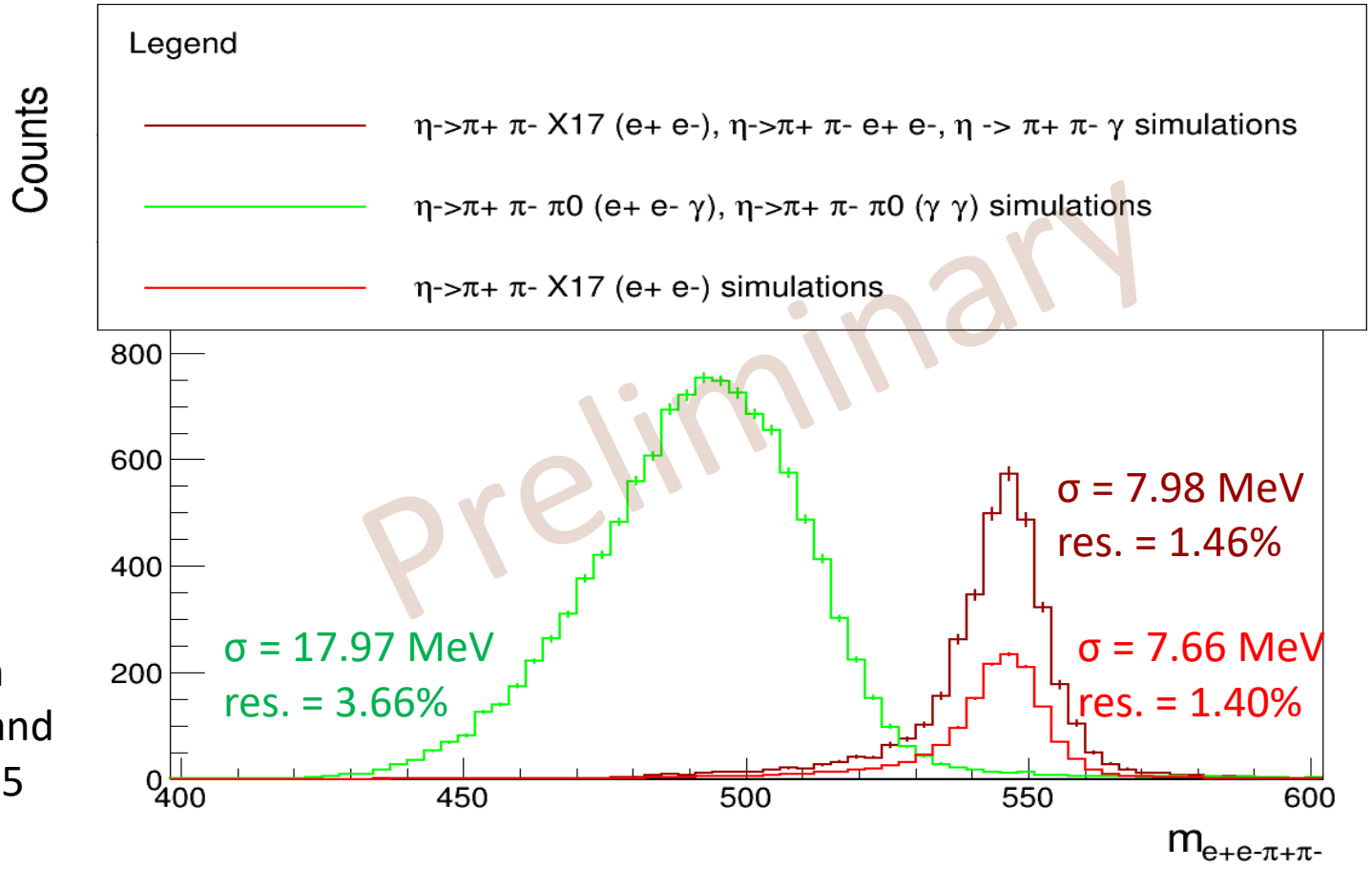
Ref.: R. Abou Yassine presentation at 6th HADES analysis meeting

Simulations of signals

Simulations conducted for signal reaction and some background reactions:

- $pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,e^+\,e^-$
- **$pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,X17\,(e^+\,e^-)$**
- $pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,\pi^0\,(e^+\,e^-\,\gamma)$
- $pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,\pi^0\,(\gamma\,\gamma)$
- $pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,\gamma$

Ratio between events in left and right peak: 3.25



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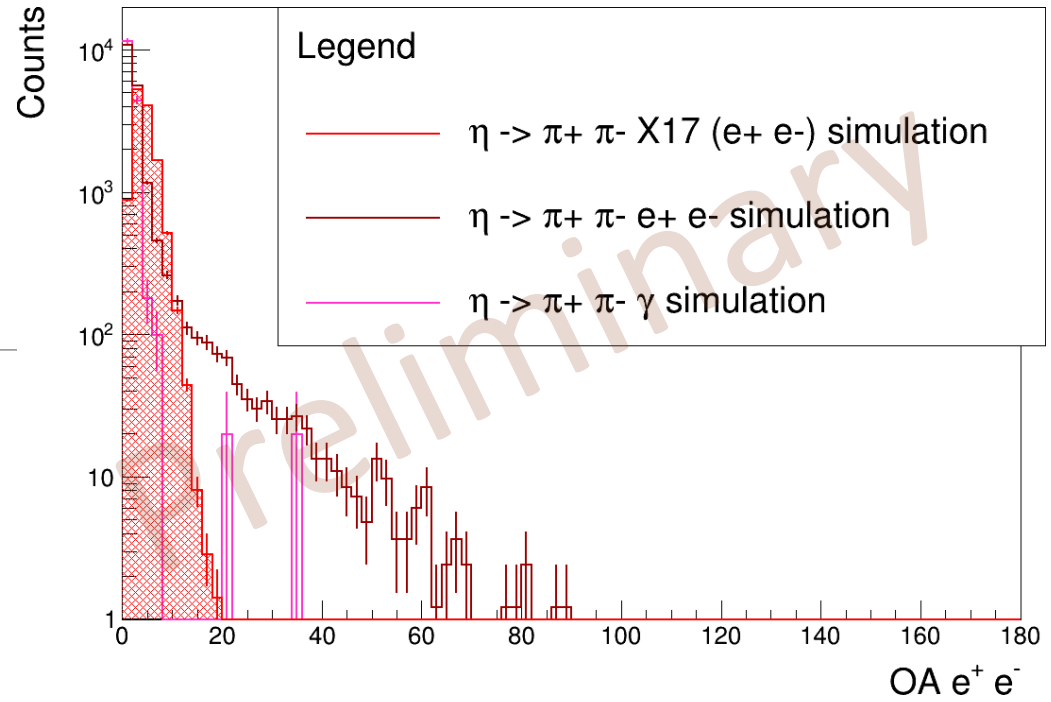
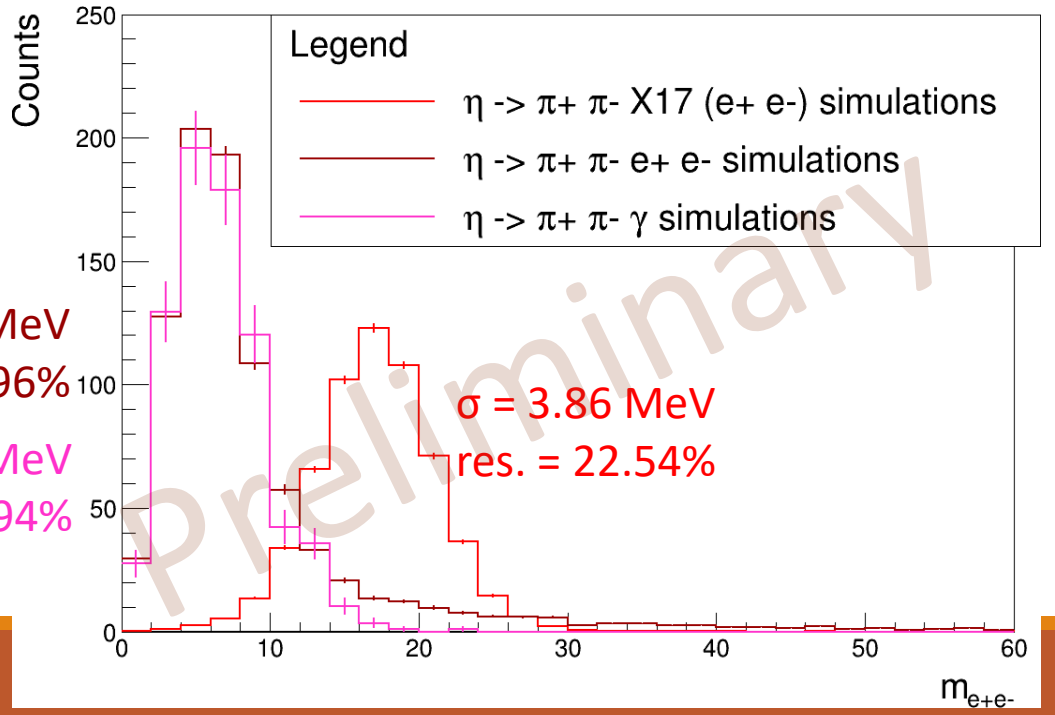
- $pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,\gamma$

- e^+e^- opening angle for reaction with X17 mainly below 20°
- Conclusion: X17 can be reconstructed in HADES

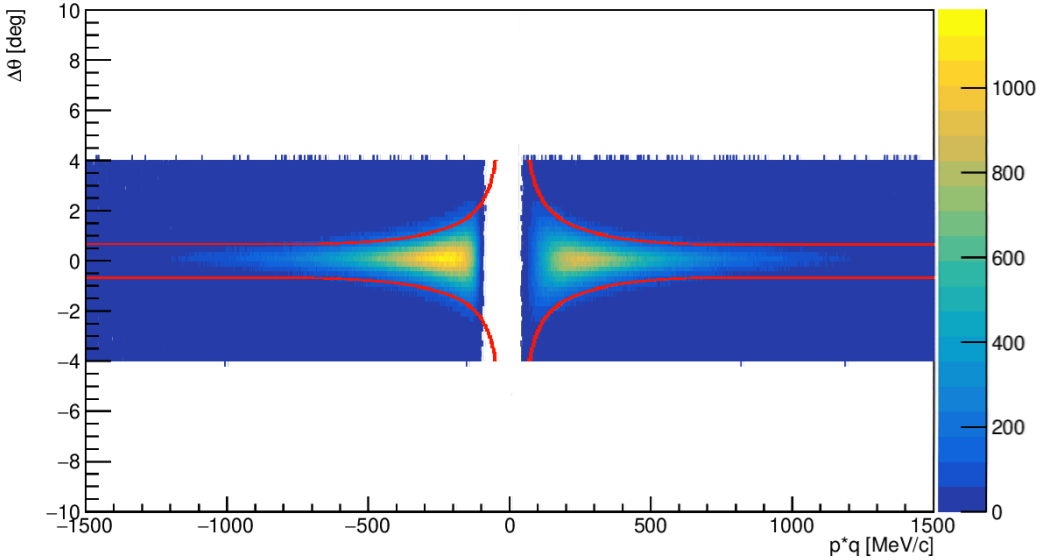


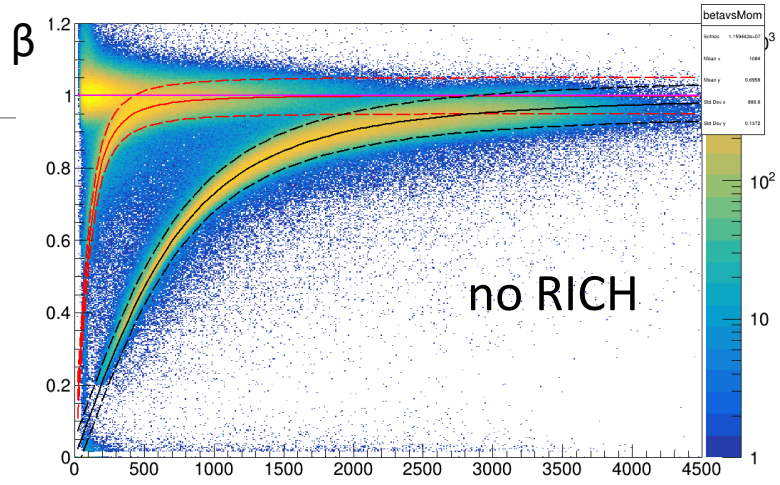


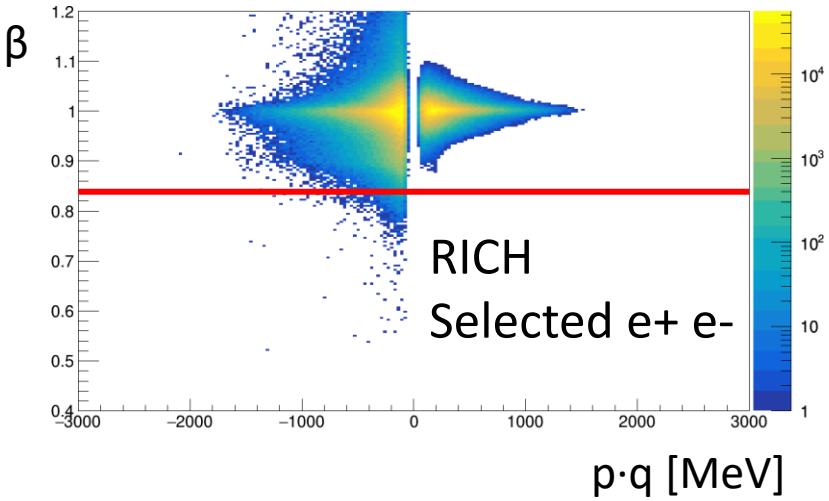
Main selection criteria

Following particles have to be selected: π^+ π^- e^+ e^-

- leptons selected by correlation windows in RICH and MDC
- pions selected by cuts on beta vs momentum distribution
- additional cuts for leptons: $\beta > 0.85$







Event selection: hypothesis (e^+,e^-,π^+,π^-)

Analysis strategy

charge	Ring in RICH	particle
+	1	lepton+
-	1	lepton-
+	0	hadron+
-	0	hadron-

Initial particle identification.

Hyphoteses:

- (e^+,e^-,π^+,π^-) – opposite leptons sign
- (e^+,e^+,π^+,π^-) – like leptons sign
- (e^-,e^-,π^+,π^-) – like leptons sign

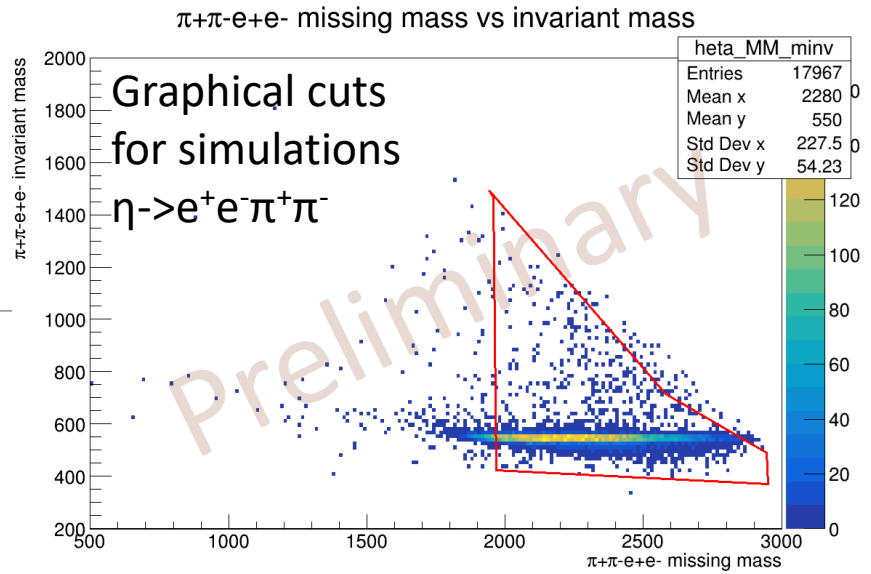
Best combination chosen (isBest = 1): all particles satisfy selection criteria and this combination has the smallest calculated chi2.

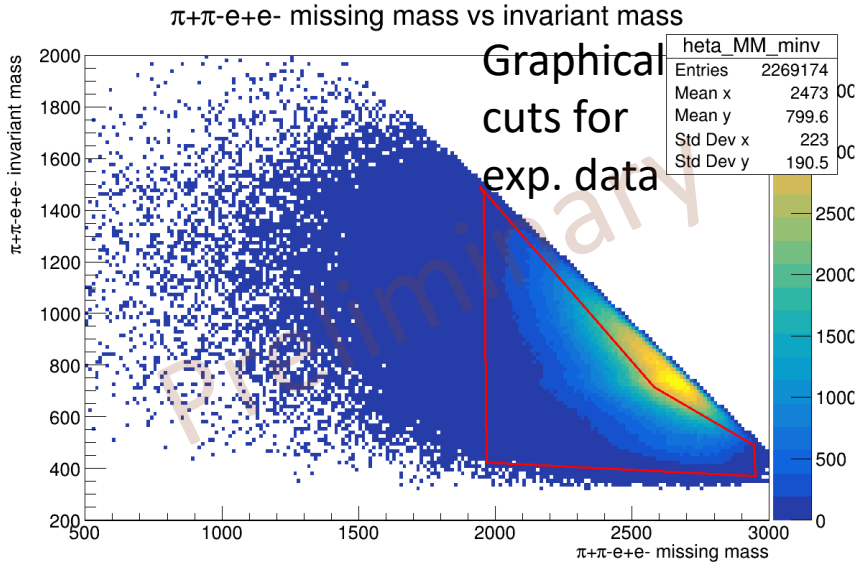
$$\chi^2 = \sum_i \left(\frac{t_{exp} - t_{theor}(p,m)}{sigma^2}\right)^2$$

Applied cuts to select η

- vertexReco z ∈ (-200 mm, 0)
- **$\pi^+\pi^-e^+e^-$ missing mass vs invariant mass (graphical cut)**
- $(e^+e^-)(\pi^+\pi^-)$ opening angle < 50°
- $\pi^+\pi^-$ invariant mass < 480 MeV
- $(e^+e^-)(\pi^+\pi^-)$ opening angle in C.o.M. > 140°

Cuts found according to simulations of signal and backround channels.





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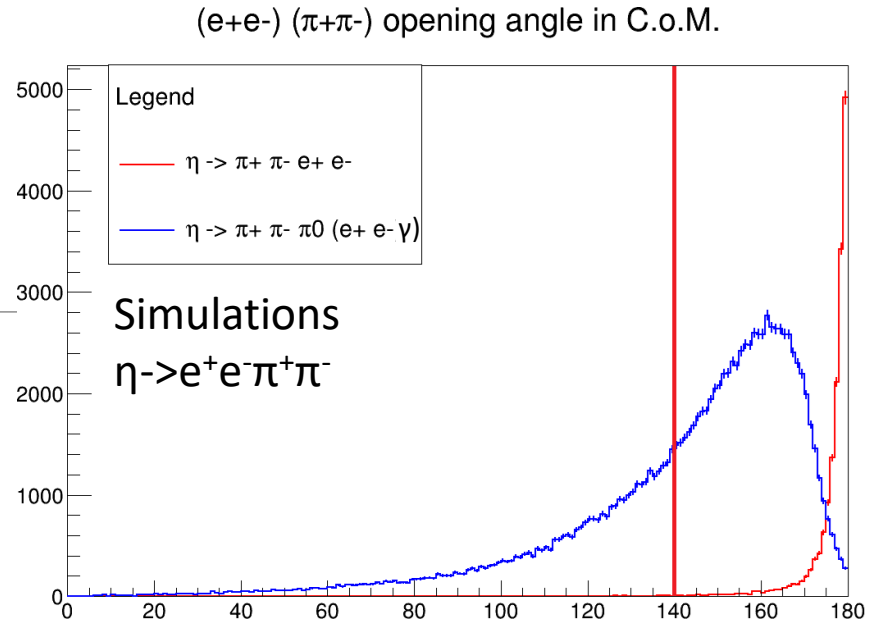
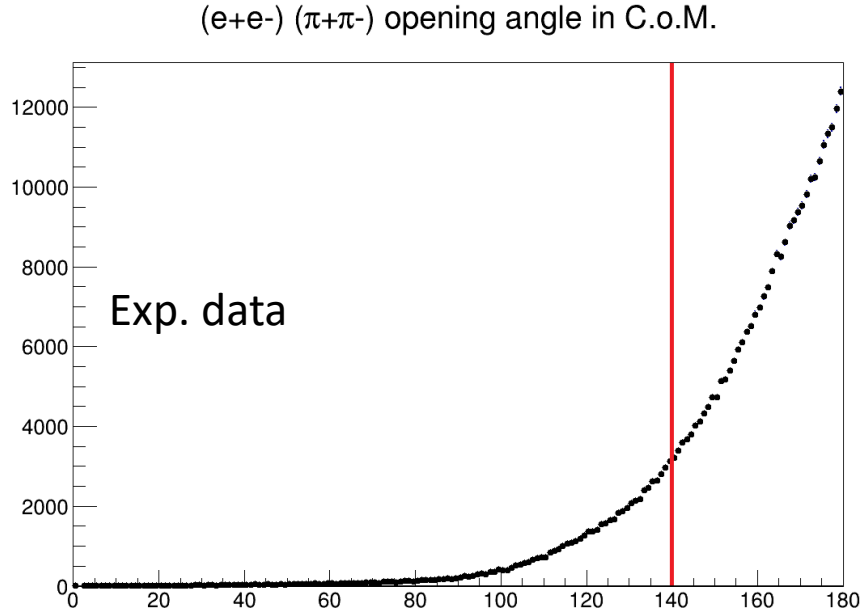
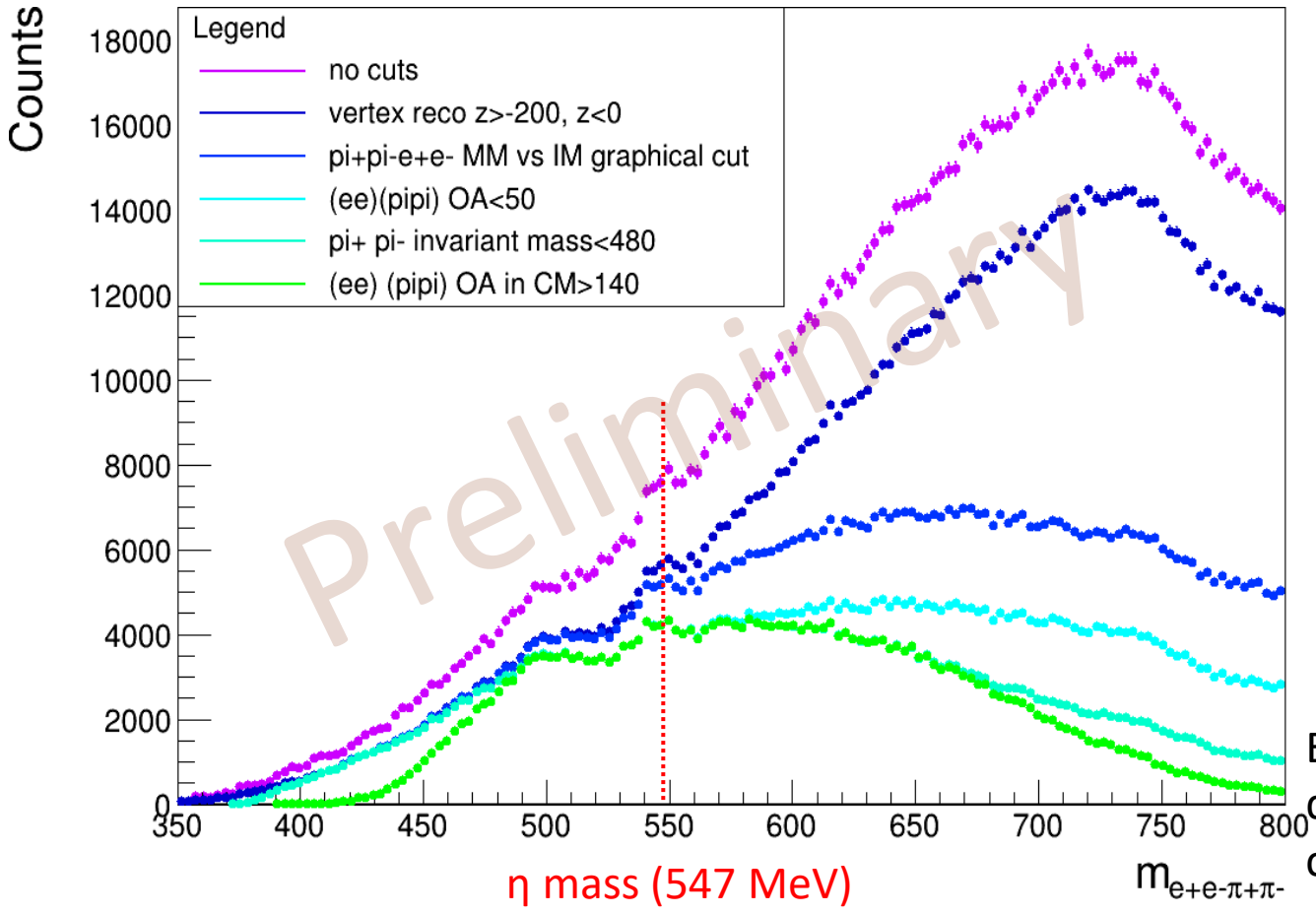
C.o.M. frame found assuming $e^+e^-\pi^+\pi^-$ invariant mass is equal η mass





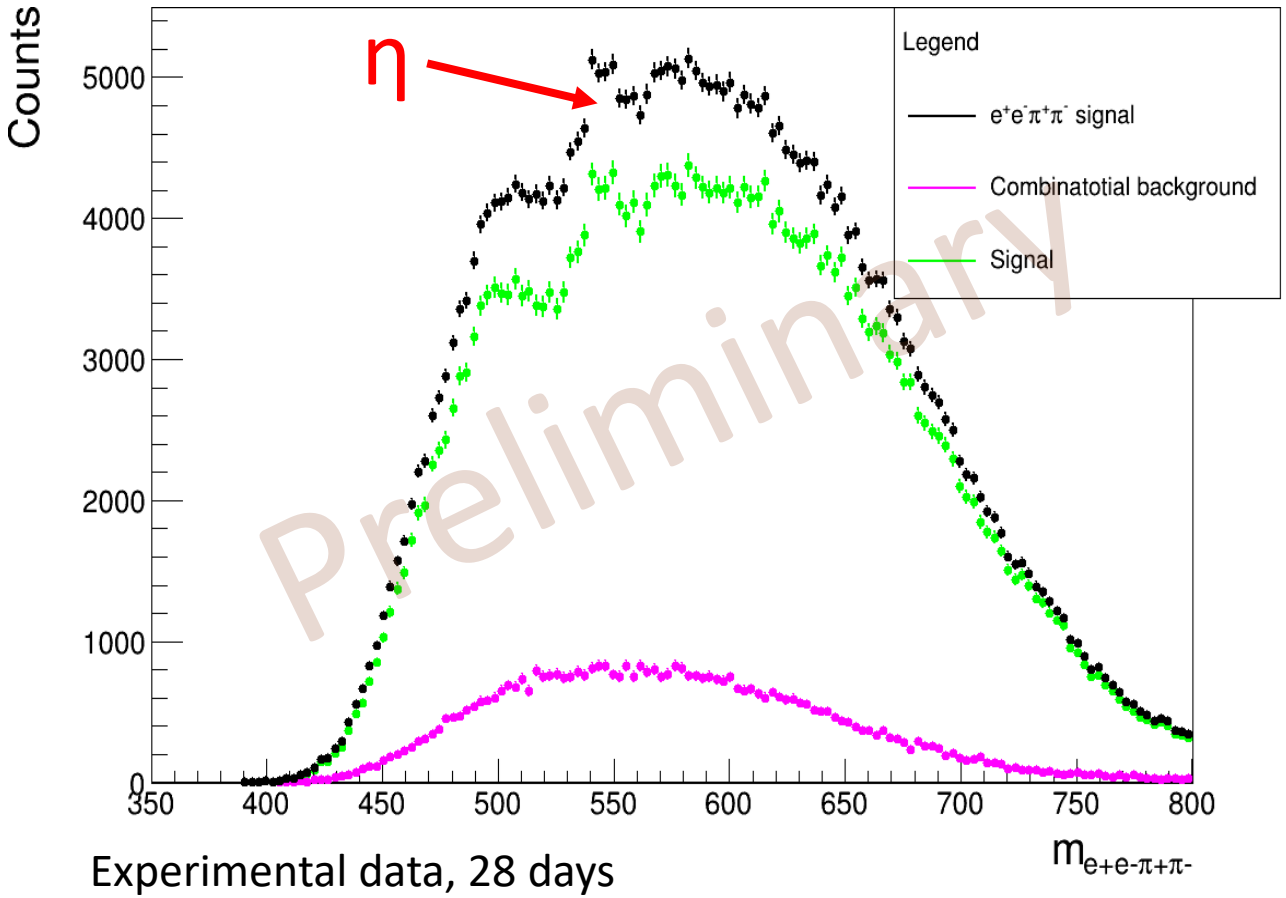
π+ π- e+ e- invariant mass after consecutive cuts

- all cuts were compared using $e^+e^-\pi^+\pi^-$ invariant mass
- reduction of 86.78% events in total range of $e^+e^-\pi^+\pi^-$ invariant mass distribution (data)
- reduction of 10.16% events in η signal range (SIM)

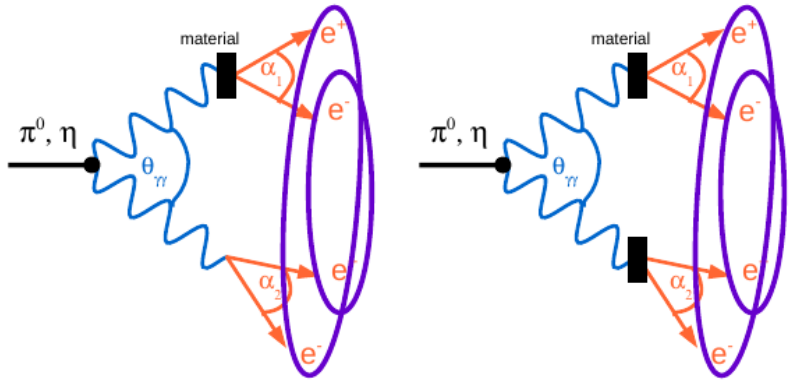


Experimental data (28 days) for consecutive cuts.

Combinatorial background subtraction



Experimental data, 28 days



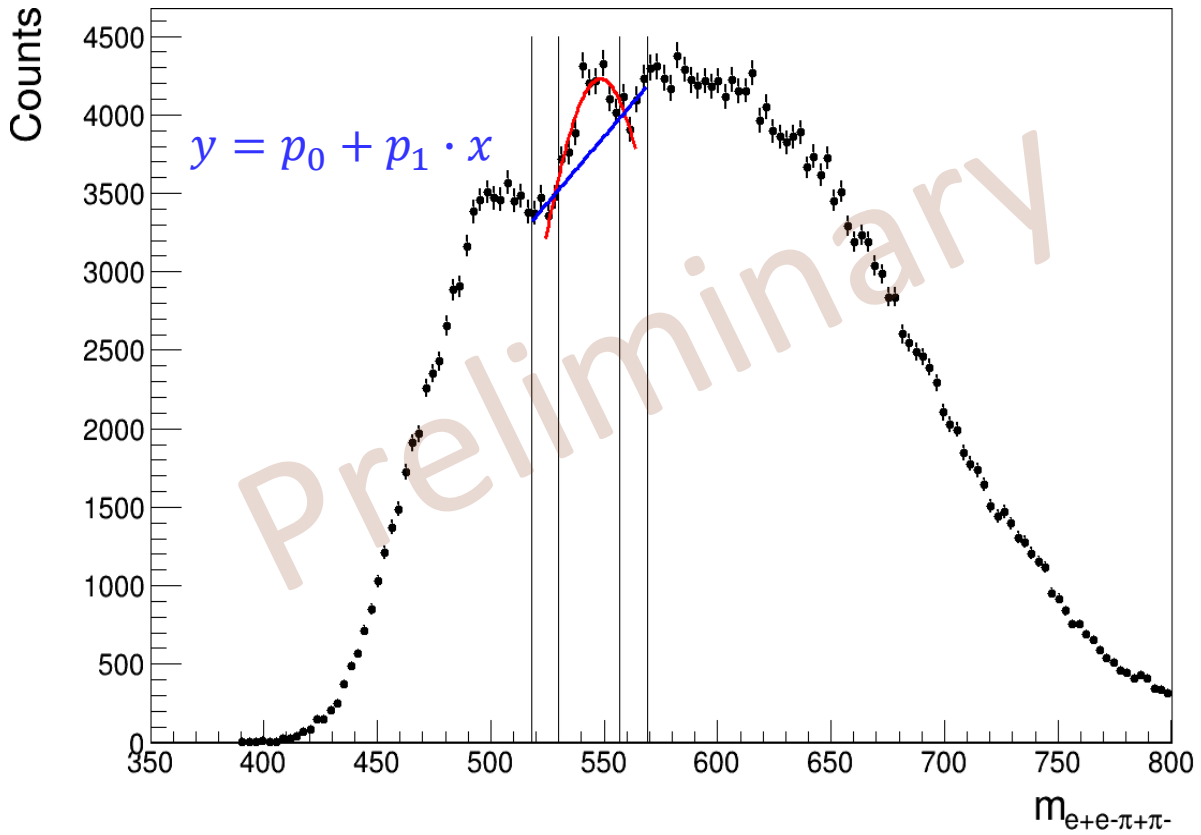
Combinatorial background:

$$\langle N_{CB} \rangle = 2\sqrt{\langle N_{\pi^+\pi^-e^+e^+} \rangle \langle N_{\pi^+\pi^-e^-e^-} \rangle}$$

$$\langle N_{signal} \rangle = \langle N_{\pi^+\pi^-e^+e^-} \rangle - \langle N_{CB} \rangle$$

Ref.: Szymon Harabasz PhD thesis

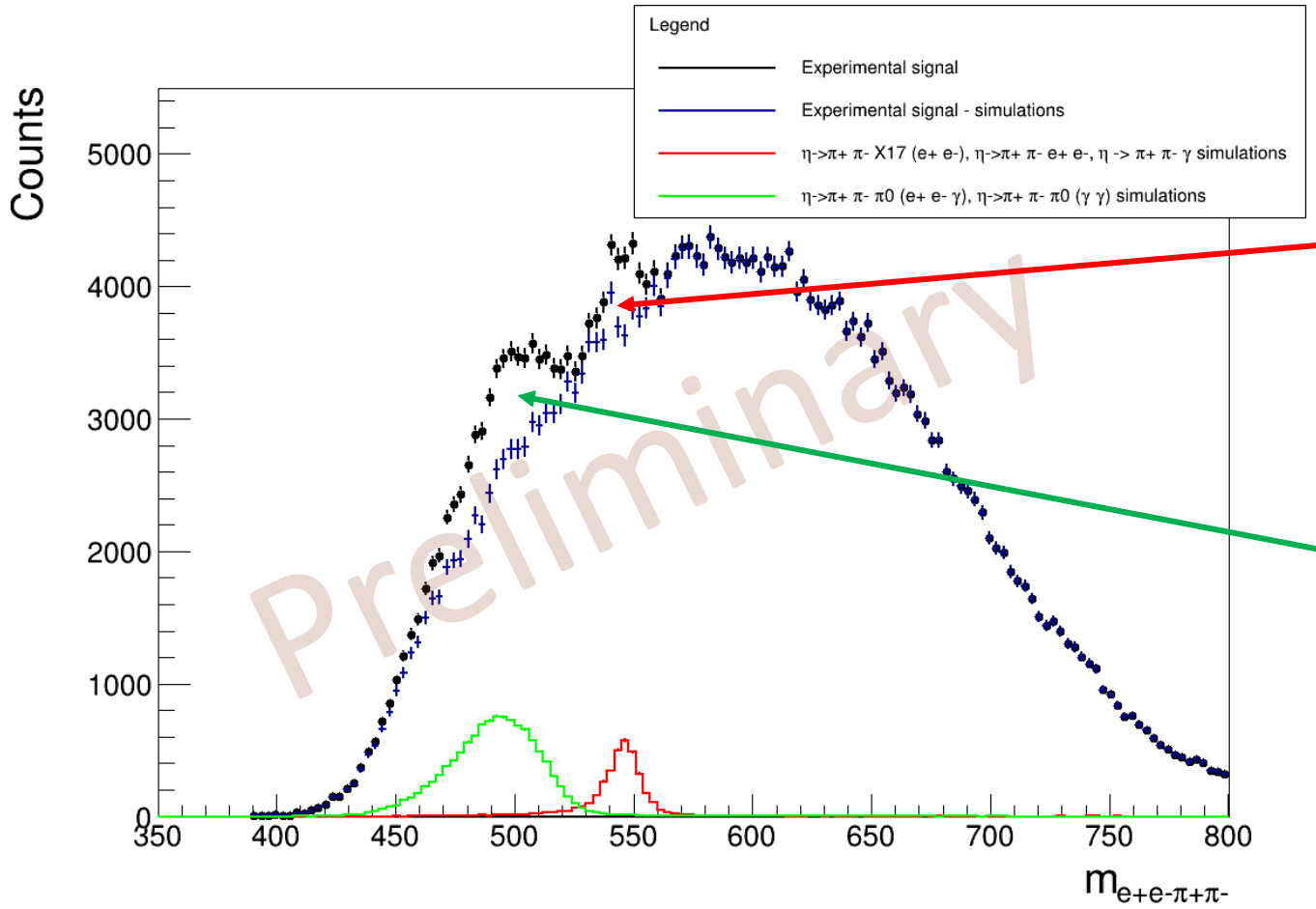
Extraction of numer of signal events



- Selected signal and background regions shown on the picture
- Linear function fitted to background regions

Estimated numer of signal events	2 758
η peak mean	548.40
η peak sigma	32.59

Data to SIM scaling (with X17)



- Right peak (R)

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

$\eta \rightarrow \pi^+ \pi^- \gamma$

$\eta \rightarrow \pi^+ \pi^- X17\ (e^+ e^-)$

3 524 events (2 919 in peak region)

- Left peak (L)

$\eta \rightarrow \pi^+ \pi^- \pi^0\ (e^+ e^- \gamma)$

$\eta \rightarrow \pi^+ \pi^- \pi^0\ (\gamma\gamma)$

11 200 events

$$\frac{N_L}{N_R}\ (SIM) = 3.25$$

Extraction of number of expected X17 events

Estimation of X17 contribution to signal region

Reaction	Contribution	Branching ratio
$\eta \rightarrow \pi^+ \pi^- e^+ e^-$	39.95%	$2.68 \cdot 10^{-4}$
$\eta \rightarrow \pi^+ \pi^- X17\ (e^+ e^-)$	26.28%	$1 \cdot 10^{-4}$
$\eta \rightarrow \pi^+ \pi^- \gamma$	33.77%	$4.28 \cdot 10^{-2}$ *

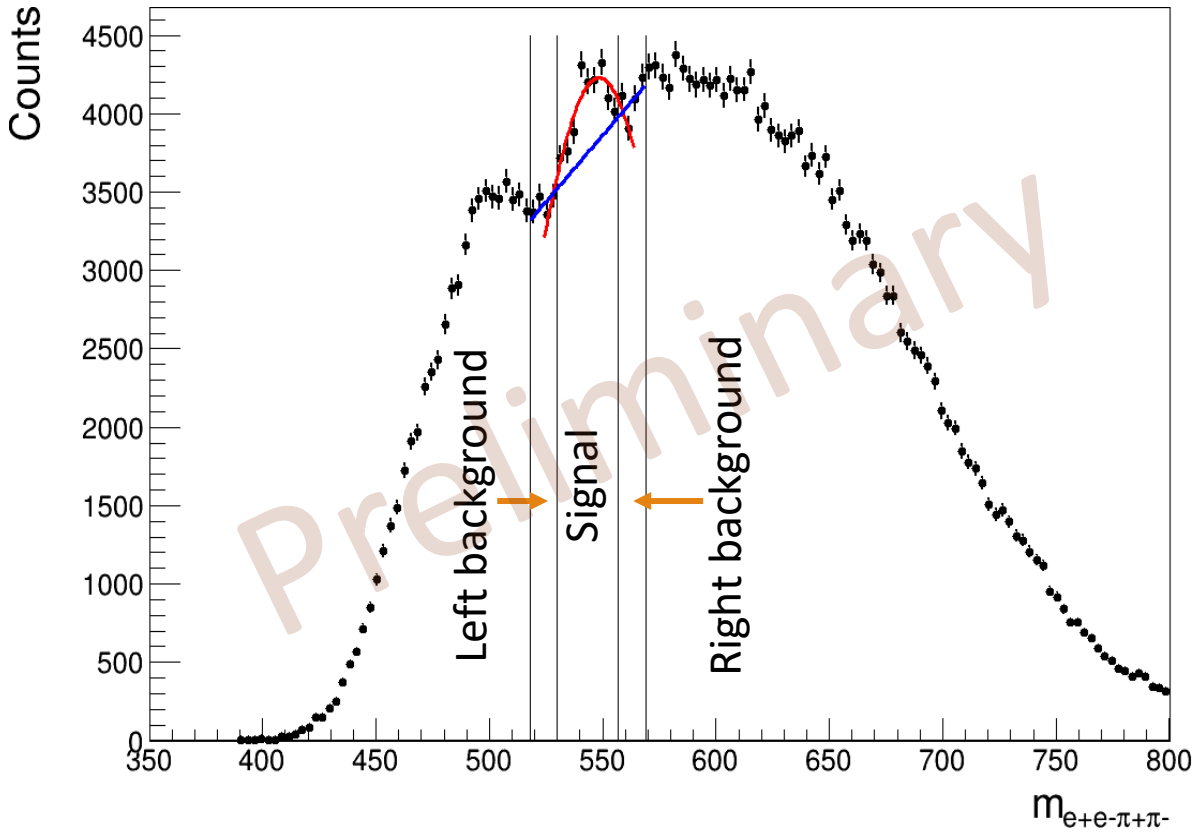
expected numer of X17 in signal peak

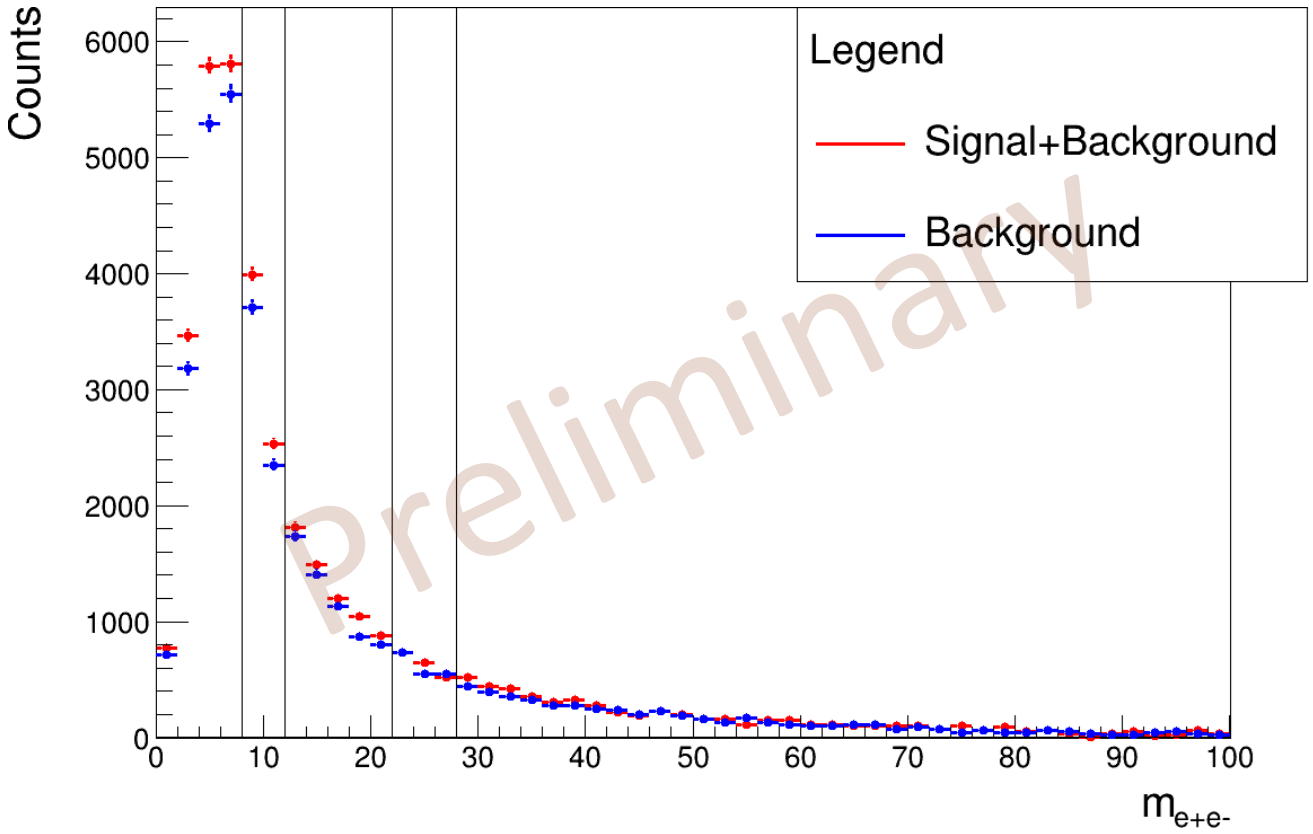
$$N_{X17} = N_{ALL} \cdot f_{X17}$$

$$N_{X17} = 2758 \cdot 26.28\% = 725$$

* - not including gamma conversion

Sideband method for background estimation





Extraction of number of expected X17 events

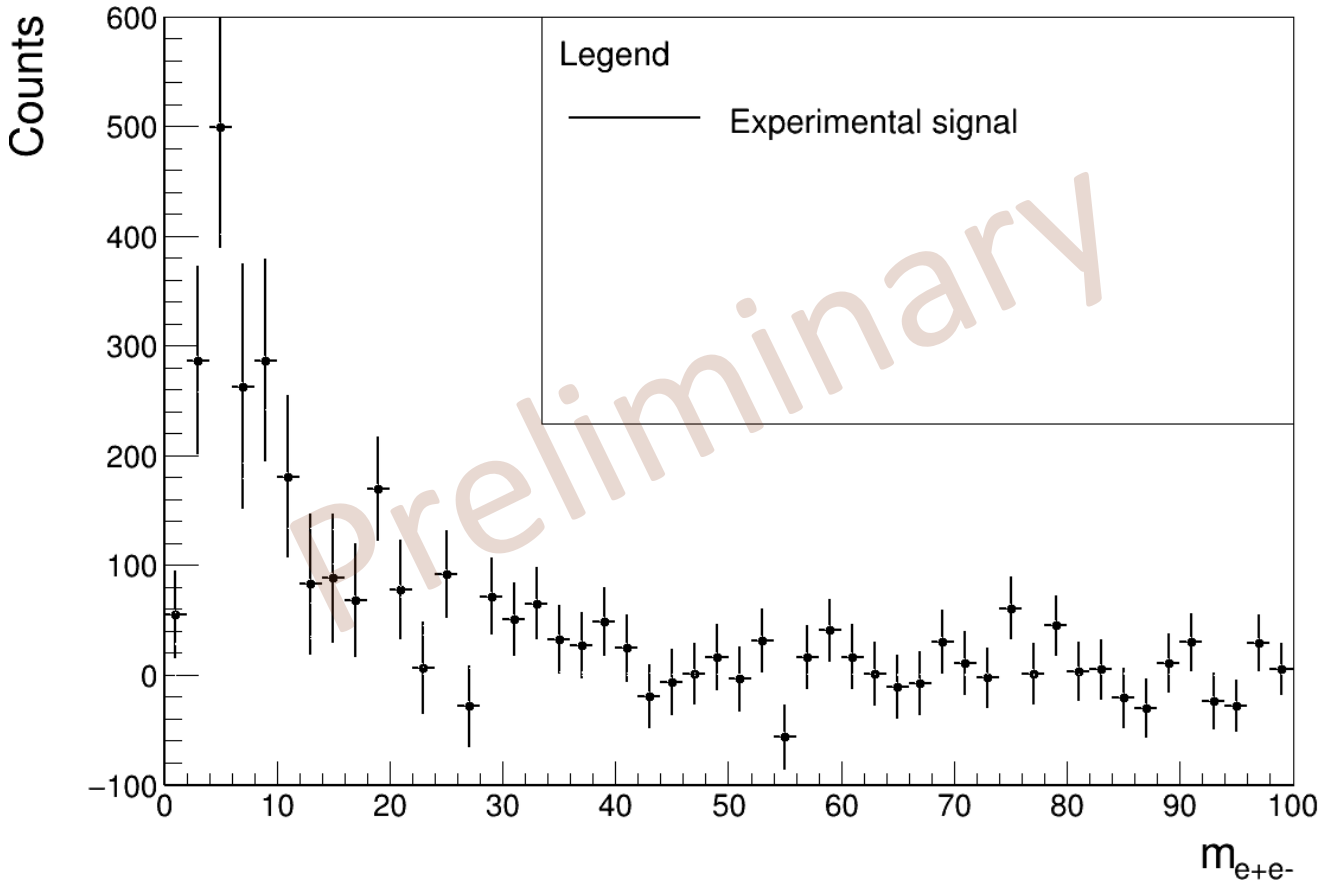
- Final distribution of e^+e^- invariant mass after background subtraction
- No visible peak in signal region
- Prediction of upper limit for X17 events according to **W. Rolke et al., Nucl. Phys. A, 551, 493-503 (2005)**

efficiency · acceptance = $1.1 \cdot 10^{-3}$

$UL_{X17} = 255$ (CL=90%)

$BR_{\eta->\pi+\pi-X17} < 2.5766 \cdot 10^{-5}$

$BR_{th} \sim \underline{1 \cdot 10^{-4}}$



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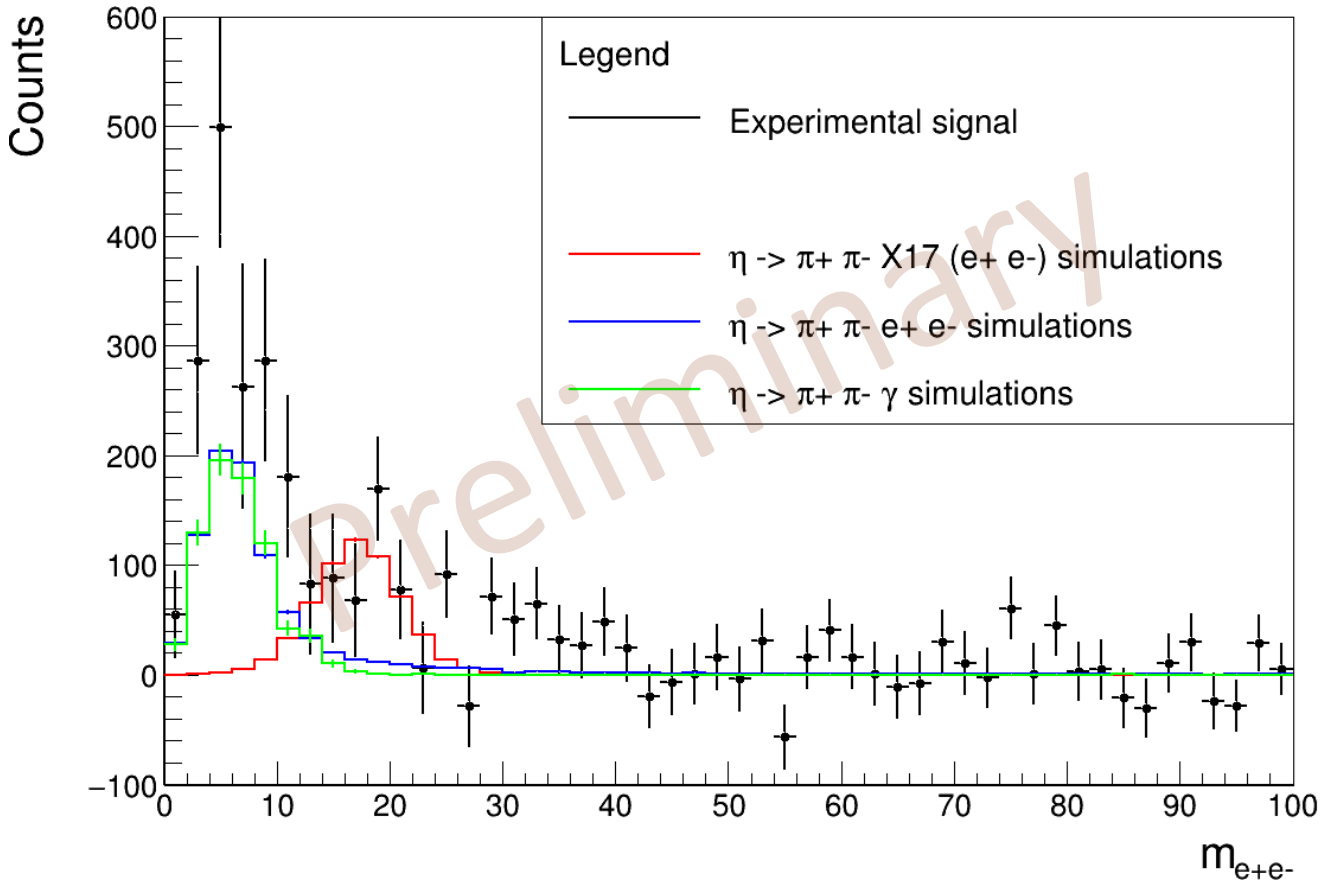

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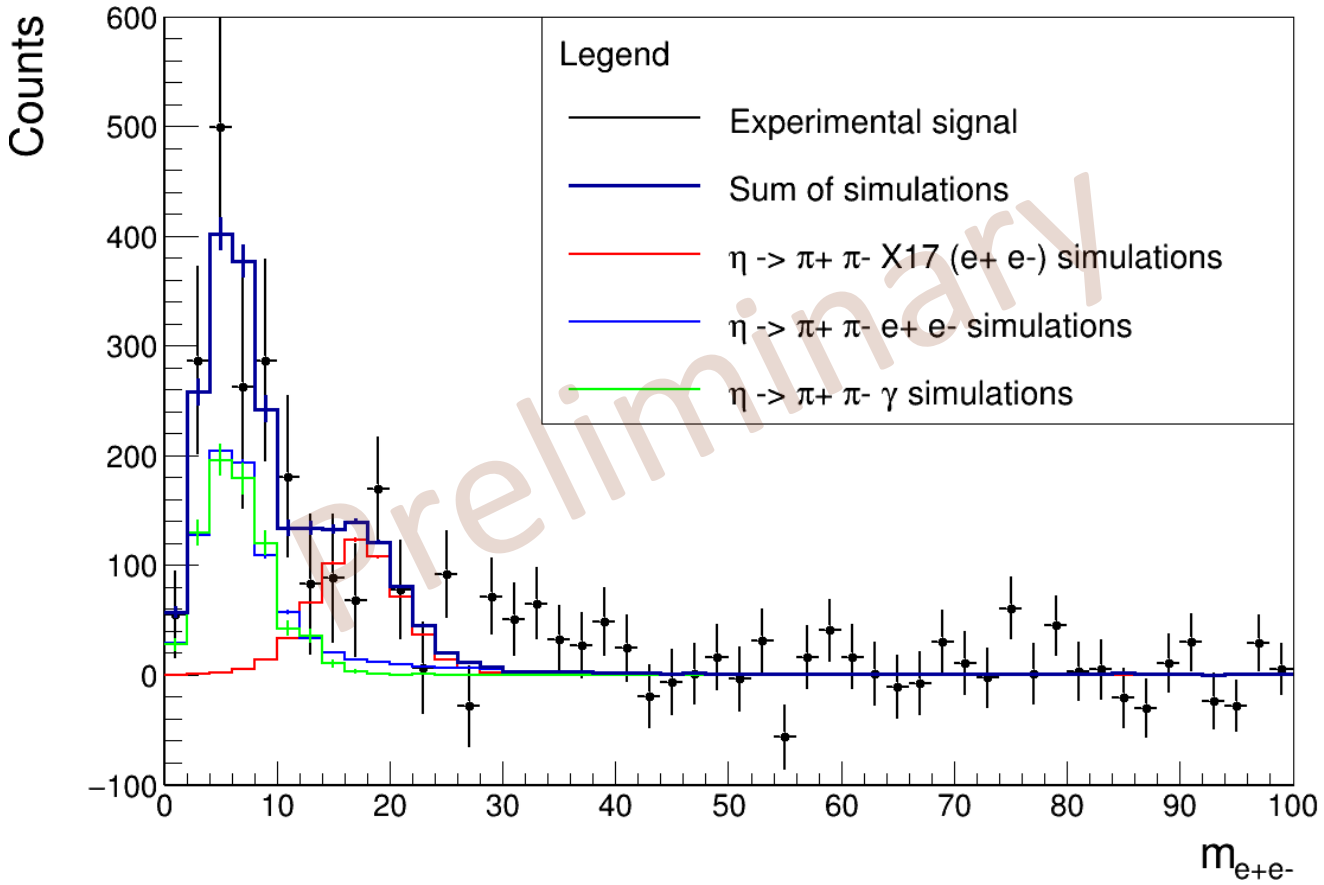


X17 upper limit extraction

Cuts			Results		
π+ π- invariant mass	**(π+ π-)(e+ e-) OA in C.o.M.**	**e+ e- OA**	**Signal events in the η peak**	**Upper limit on X17 signal number of events**	**Upper limit on X17 branching ratio**
<480	**>140°**		**2 758**	**255**	**$2.58 \cdot 10^{-5}$**
<480			2 756	255	$2.58 \cdot 10^{-5}$
<480	>140°	>2°	1 892	204	$2.06 \cdot 10^{-5}$
<480		>2°	1 890	204	$2.06 \cdot 10^{-5}$
<420	>140°		2 688	263	$2.66 \cdot 10^{-5}$
<420			2 689	251	$2.54 \cdot 10^{-5}$
<420	>140°	>2°	1 806	209	$2.12 \cdot 10^{-5}$
<420		>2°	1 807	209	$2.12 \cdot 10^{-5}$

Summary

Further steps:

- studies of systematical effects
- simulations of η decays using transport models SMASH/GiBUU
- machine learning analysis (MVA, BDT) to reduce background

SMASH – Simulating Many Accelerated Strong-interacting Hadrons
ref.: H. Petersen et al., Nucl. Phys. A, 982, 399 (2019)
GiBUU – the Giessen Boltzmann-Uehling-Uhlenbeck Project
ref.: O. Buss et al., Phys. Rept., 512, 1 (2012)

Thank you for attention!

Backup

Predictions of number of events

$$N = \epsilon \cdot I \cdot \rho \cdot t \cdot a_{DAQ} \cdot a_{beam} \cdot \sigma \cdot BR$$

ϵ – efficency times acceptance factor

I – beam intensity

ρ – target density

t – measurement time (28 days)

a_{DAQ} – factor related to dead time of the DAQ system

a_{beam} – factor related to beam structure

Total integrated luminosity (6 $\frac{1}{pb}$ according to elastic scattering analysis)

σ – cross section

BR – branching ratio

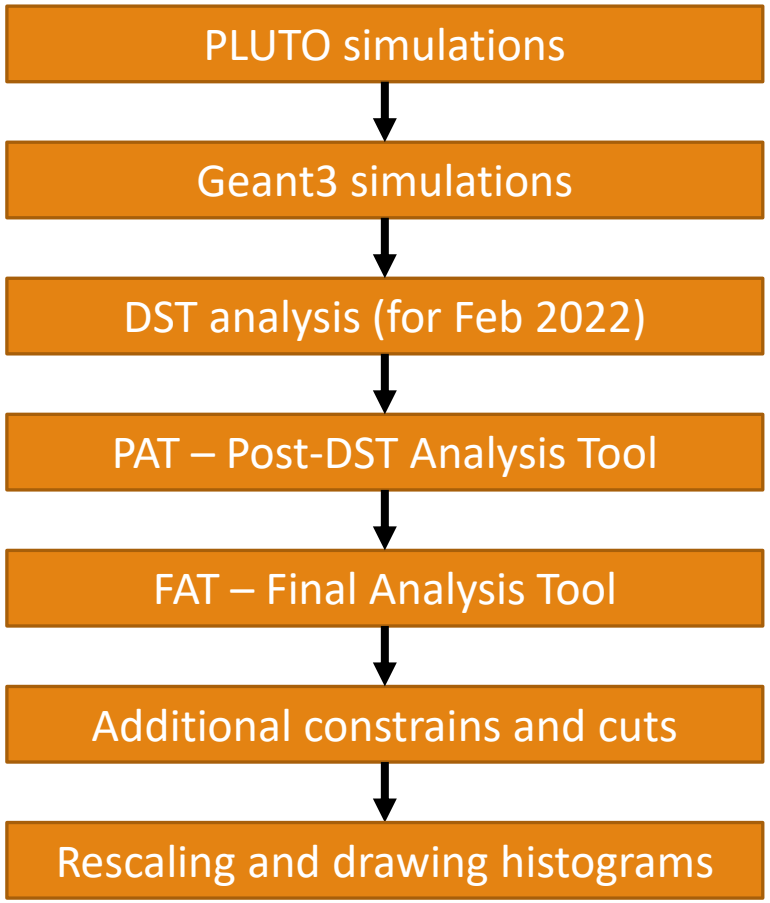
Estimated number of events for 6 [1/pb] (28 days): After ALL cuts

	Reaction	Cross section (mb)	ε (%)	BR (%)	Number of events for 28 days (4π)	Number of events (HADES acc., all cuts)
η decays, decays from ppη	$pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,e^+\,e^-$	1.5*	0.7816	0.0268	2 412 000	19 093
	$pp\,\eta \rightarrow pp\,\pi^+\,\pi^-$ X17 ($e^+\,e^-$)	**1.5**	**1.3957**	**0.01**	**900 000**	**12 561**
	$pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,\pi^0$ ($e^+\,e^-\,\gamma$)	1.5	0.3661	0.27	24 322 932	89 052
	$pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,\pi^0$ ($\gamma\,\gamma$)	1.5	0.0032	22.75	2 047 414 914	66 409
	$pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,\gamma$	1.5	0.0042	4.28**	385 200 000	16 142
multi-pion decays, not complete list	$p\,p\,\pi^+\,\pi^-\,\pi^0$ ($e^+\,e^-\,\gamma$)	1.84	0.0876	1.17	129 609 600	113 579
	$p\,p\,\pi^+\,\pi^-\,\pi^0$ ($\gamma\,\gamma$)	1.84	0.0006	98.82**	10 910 059 200	68 400
	$p\,n\,\pi^+\,\pi^+\pi^-\,\pi^0$ ($e^+\,e^-\,\gamma$)	0.3	0.1491	1.17	21 132 000	31 478
	$p\,n\,\pi^+\,\pi^+\pi^-\,\pi^0$ ($\gamma\,\gamma$)	0.3	0.0015	98.82**	1 778 814 000	26 775
	$p\,p\,\pi^+\,\pi^-\,\pi^0\,\pi^0$ ($e^+\,e^-\,\gamma$)	0.3	0.0962	1.17	21 132 000	20 320
	$p\,p\,\pi^+\,\pi^-\,\pi^0\,\pi^0$ ($\gamma\,\gamma$)	0.3	0.0029	98.82**	1 778 814 000	52 258

* - 1.1 mb measured by HADES pp@3.5 ** - not including gamma conversion

Analysis of simulations

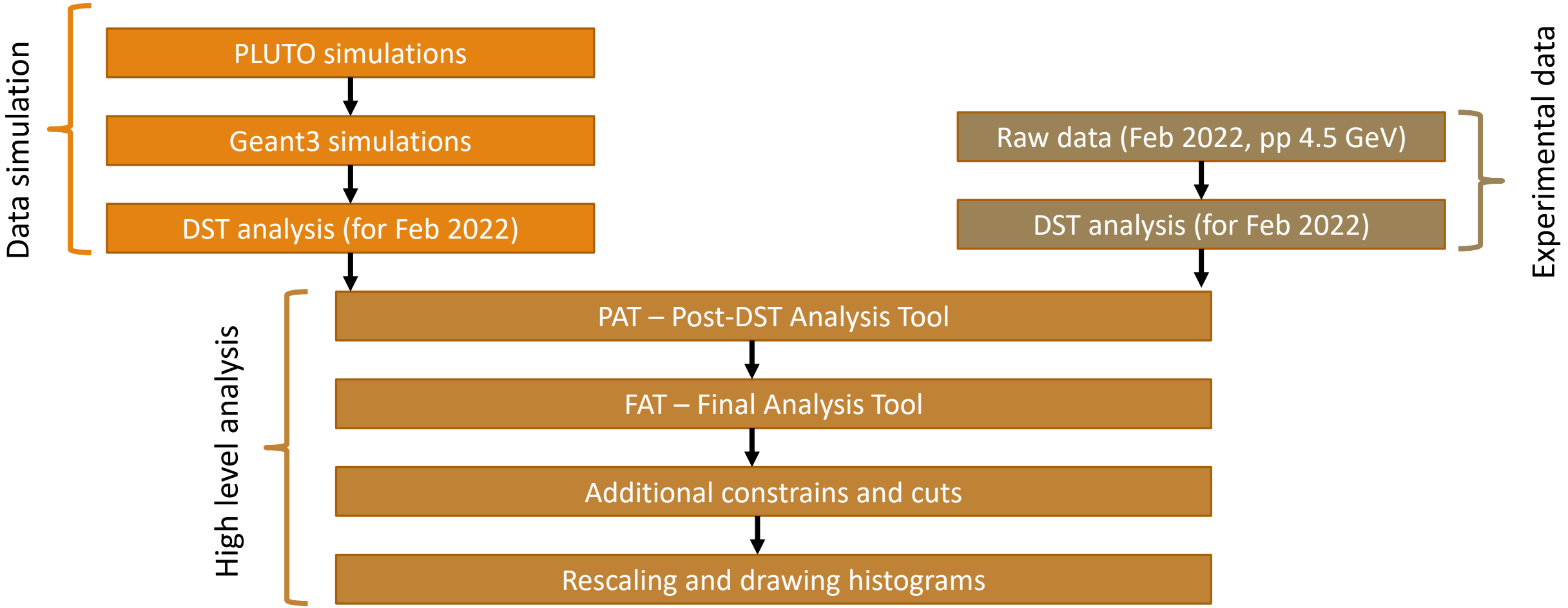
Simulation analysis chain.



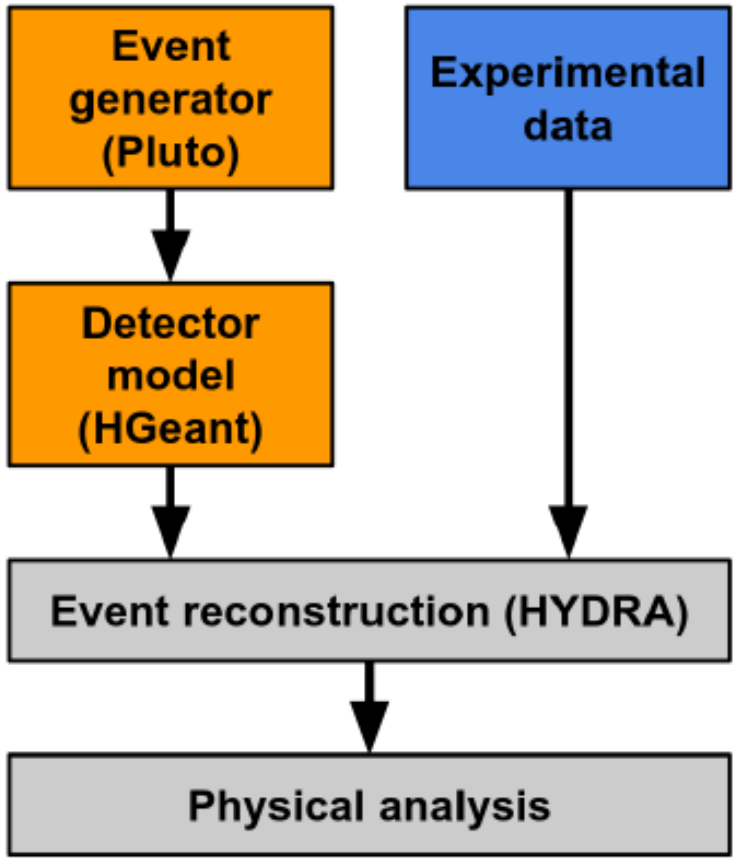
	Reaction	Branching ratio
Signal	$\eta \rightarrow \pi^+ + \pi^- + e^+ + e^-$	$2.68 \cdot 10^{-4}$ *
	$\mathbf{\eta \rightarrow \pi^+ + \pi^- + X17}$	$\mathbf{1 \cdot 10^{-4}}$ **
	$\mathbf{X17 \rightarrow e^+ + e^-}$	**1**
Main background	$\eta \rightarrow \pi^+ + \pi^- + \pi^0$	$2.302 \cdot 10^{-1}$ *
	$\pi^0 \rightarrow e^+ + e^- + \gamma$	$1.174 \cdot 10^{-2}$ *
	$\pi^0 \rightarrow \gamma + \gamma$	$9.882 \cdot 10^{-1}$ *
	$\eta \rightarrow \pi^+ + \pi^- + \gamma$	$4.28 \cdot 10^{-2}$ *

Branching ratios for simulated decays.
* - from PDG website
** - from Alves et al. (2022)

Analysis method



Analysis method



Physical analysis:

Two tools developed by Witold Przygoda

- PAT – Post-DST Analysis Tool

selects particles according to defined criteria

- FAT – Final Analysis Tool

calculates more complex observables, like invariant masses and opening angles

Simulated reactions

$p + p \rightarrow p + p + \eta$
$\quad \hookrightarrow \pi^+ + \pi^- + e^+ + e^-$

- signal with direct η decay

$p + p \rightarrow p + p + \eta$
$\quad \hookrightarrow \pi^+ + \pi^- + X17$
$\quad\quad \hookrightarrow e^+ + e^-$

- signal with X17 resonance

$p + p \rightarrow p + p + \eta$
$\quad \hookrightarrow \pi^+ + \pi^- + \pi^0$
$\quad\quad \hookrightarrow e^+ + e^- + \gamma$

- background

$p + p \rightarrow p + p + \eta$
$\quad \hookrightarrow \pi^+ + \pi^- + \pi^0$
$\quad\quad \hookrightarrow \gamma + \gamma$

- background

$p + p \rightarrow p + p + \eta$
$\quad \hookrightarrow \pi^+ + \pi^- + \gamma$

- background

Simulated reactions – without η

$$p + p \rightarrow p + p + \pi^+ + \pi^- + \pi^0$$
$$\hookrightarrow e^+ + e^- + \gamma$$
$$p + p \rightarrow p + p + \pi^+ + \pi^- + \pi^0$$
$$\hookrightarrow \gamma + \gamma$$

$$p + p \rightarrow p + n + \pi^+ + \pi^- + \pi^0 + \pi^+$$
$$\hookrightarrow e^+ + e^- + \gamma$$
$$p + p \rightarrow p + n + \pi^+ + \pi^- + \pi^0 + \pi^+$$
$$\hookrightarrow \gamma + \gamma$$

$$p + p \rightarrow p + p + \pi^+ + \pi^- + \pi^0 + \pi^0$$
$$\hookrightarrow e^+ + e^- + \gamma$$
$$p + p \rightarrow p + p + \pi^+ + \pi^- + \pi^0 + \pi^0$$
$$\hookrightarrow \gamma + \gamma$$

Table 3.: Number of events after each cut.

Reaction	Simulated events	isBest cut	vertexZ cut	graphical cut	OA cut	Minv (ππ) cut	OA cut in C.o.M.
$\mathbf{pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,e^+\,e^-}$	2 000 000	17 640	17 632	16 612	16 172	15 931	15 832
$\mathbf{pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,X17\,(e^+\,e^-)}$	1 900 000	29 517	29 507	27 822	27 019	26 658	26 519
$pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,\pi^0\,(e^+\,e^-\,\gamma)$	19 500 000	113 798	113 733	110 153	109 330	108 766	71 394
$pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,\pi^0\,(\gamma\,\gamma)$	19 300 000	1 026	1 024	989	979	972	626
$pp\,\eta \rightarrow pp\,\pi^+\,\pi^-\,\gamma$	19 400 000	910	909	857	826	816	813
$p\,p\,\pi^+\,\pi^-\,\pi^0\,(e^+\,e^-\,\gamma)$	1 900 000	4 554	4 549	3 740	2 954	2 061	1 665
$p\,p\,\pi^+\,\pi^-\,\pi^0\,(\gamma\,\gamma)$	19 300 000	357	355	290	229	141	121
$p\,n\,\pi^+\,\pi^+\pi^-\,\pi^0\,(e^+\,e^-\,\gamma)$	1 900 000	8 926	8 939	5 933	4 462	3 330	2 832
$p\,n\,\pi^+\,\pi^+\pi^-\,\pi^0\,(\gamma\,\gamma)$	19 200 000	839	835	549	412	329	289
$p\,p\,\pi^+\,\pi^-\,\pi^0\,\pi^0\,(e^+\,e^-\,\gamma)$	1 900 000	5 242	5 240	3 653	2 676	2 102	1 827
$p\,p\,\pi^+\,\pi^-\,\pi^0\,\pi^0\,(\gamma\,\gamma)$	19 300 000	1 846	1 844	1 199	899	656	567

Analysis of real data

Data collected in february 2022

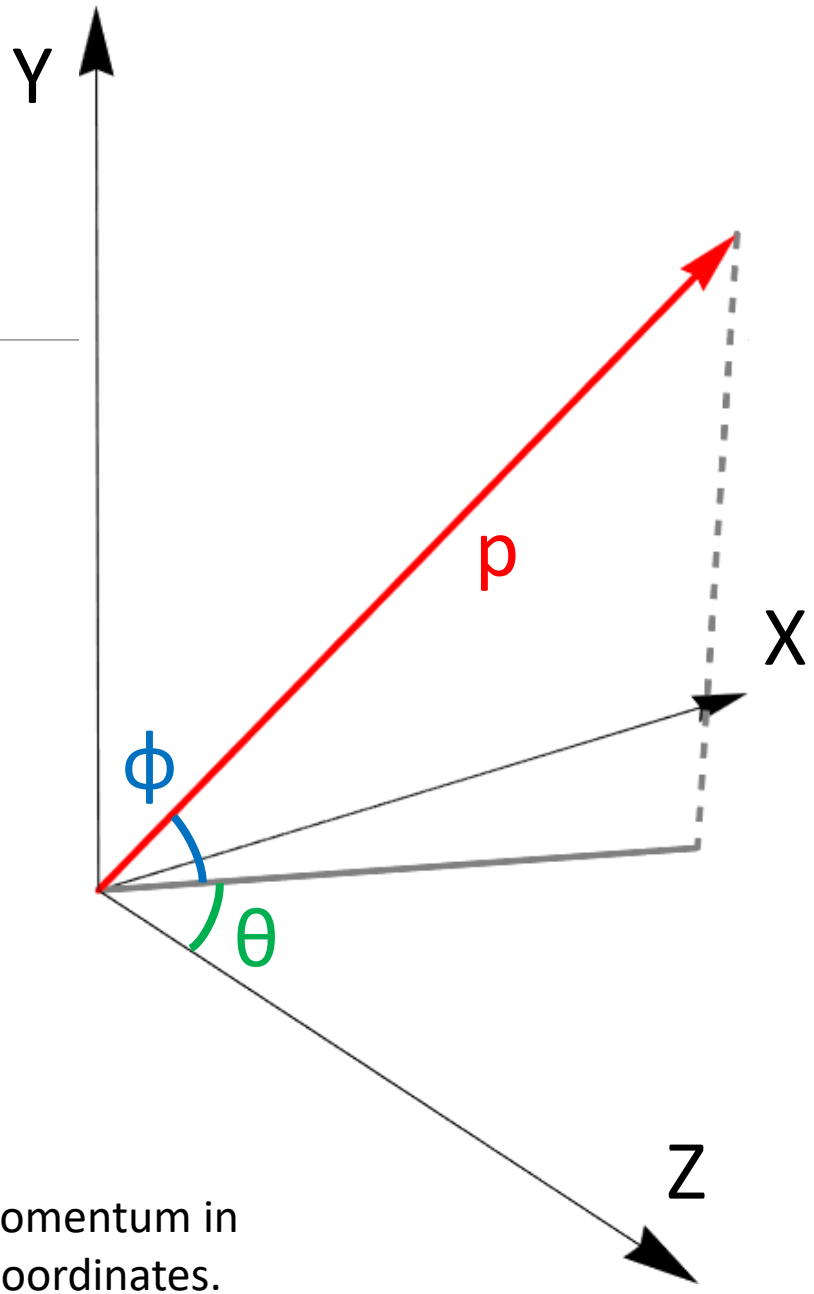
The main goal is to study η meson resonstructed from $\pi^+ \pi^- e^+ e^-$.

This requires proper identification of each particle.

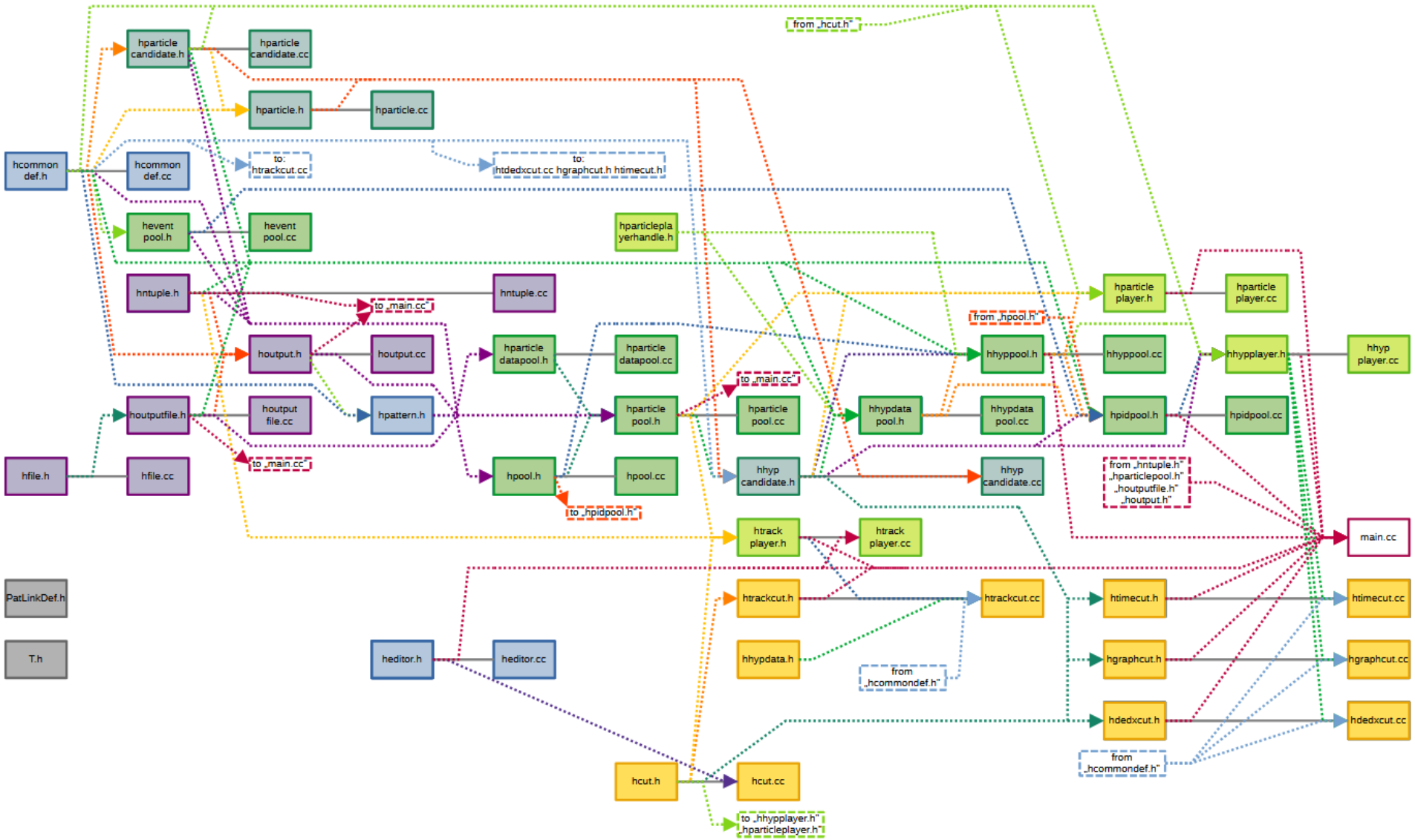
Selection of electrons and positrons can be improved by implementing certain parametrized cuts.

Selection according to momentum:

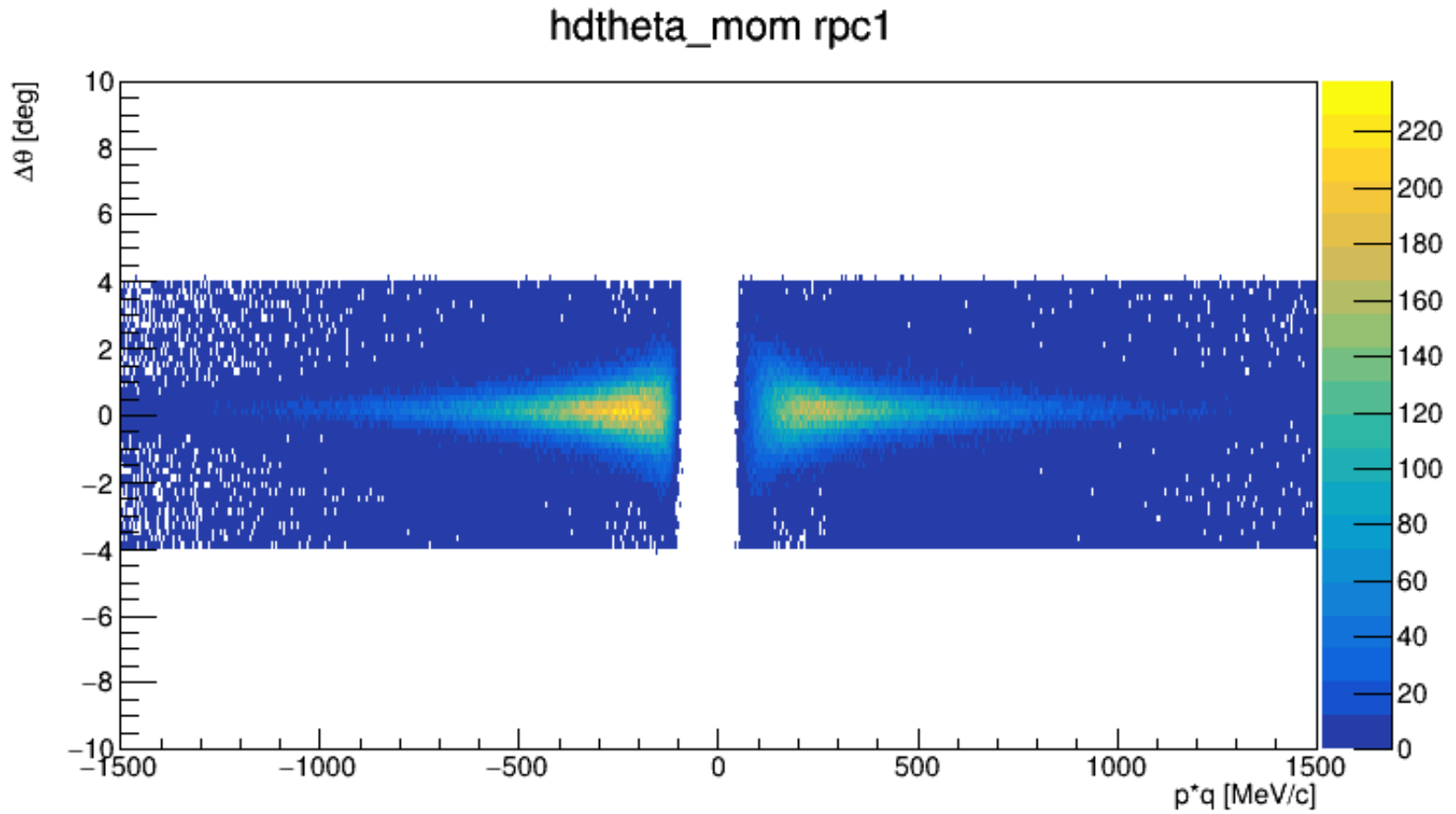
$\vec{p}$ = (p, θ, ϕ)



Pic. 22.: Momentum in spherical coordinates.

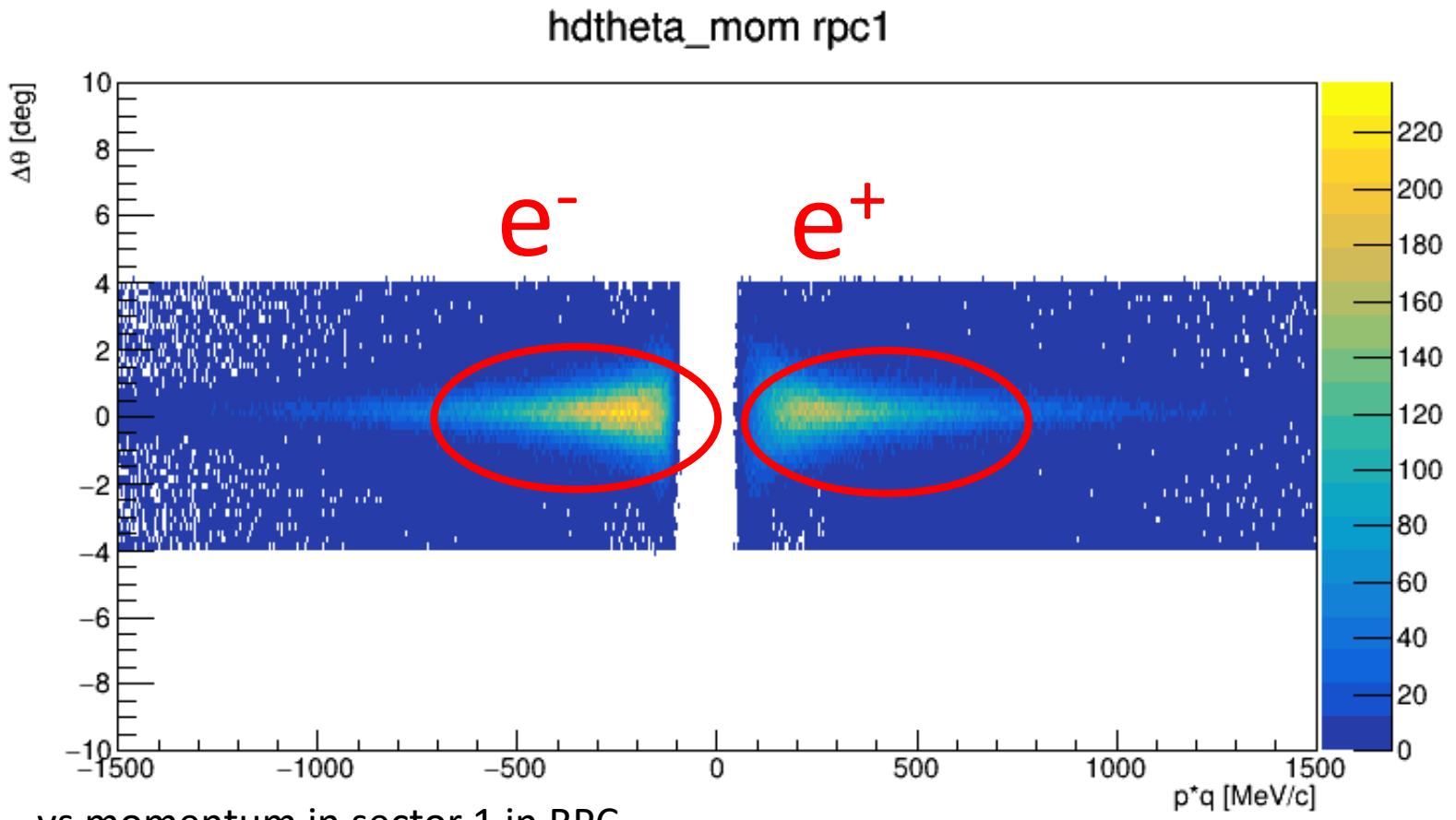

from „hcut.h"
hparticle candidate.h
hparticle candidate.cc
hparticle.h
hparticle.cc
hcommon def.h
hcommon def.cc
to: htrackcut.cc
to: htdedxcut.cc hgraphcut.h htimecut.h
hevent pool.h
hevent pool.cc
hparticlepla yerhandle.h
hntuple.h
hntuple.cc
to „main.cc"
houtput.h
houtput.cc
houtputfile.h
houtput file.cc
hpattern.h
to „main.cc"
hfile.h
hfile.cc
hparticle datapool.h
hparticle datapool.cc
hparticle pool.h
hpool.h
hpool.cc
to „hpidpool.h"
to „main.cc"
hparticle pool.cc
hhyp candidate.h
htrack player.h
htrack player.cc
htrackcut.h
hhypdata.h
heditor.h
heditor.cc
hcut.h
hcut.cc
to „hhypplayer.h" „hparticleplayer.h"
from „hpool.h"
hhyppool.h
hhypdata pool.h
hhypdata pool.cc
hhyp candidate.cc
htrackcut.cc
from „hcommondef.h"
hparticle player.h
hparticle player.cc
hhyppool.cc
hpidpool.h
hpidpool.cc
from „hntuple.h" „hparticlepool.h" „houtputfile.h" „houtput.h"
hhypplayer.h
hhyp player.cc
main.cc
htimecut.h
htimecut.cc
hgraphcut.h
hgraphcut.cc
hdedxcut.h
hdedxcut.cc
from „hcommondef.h"
PatLinkDef.h
T.h

$\theta_{RICH} - \theta_{MDC}$ vs momentum



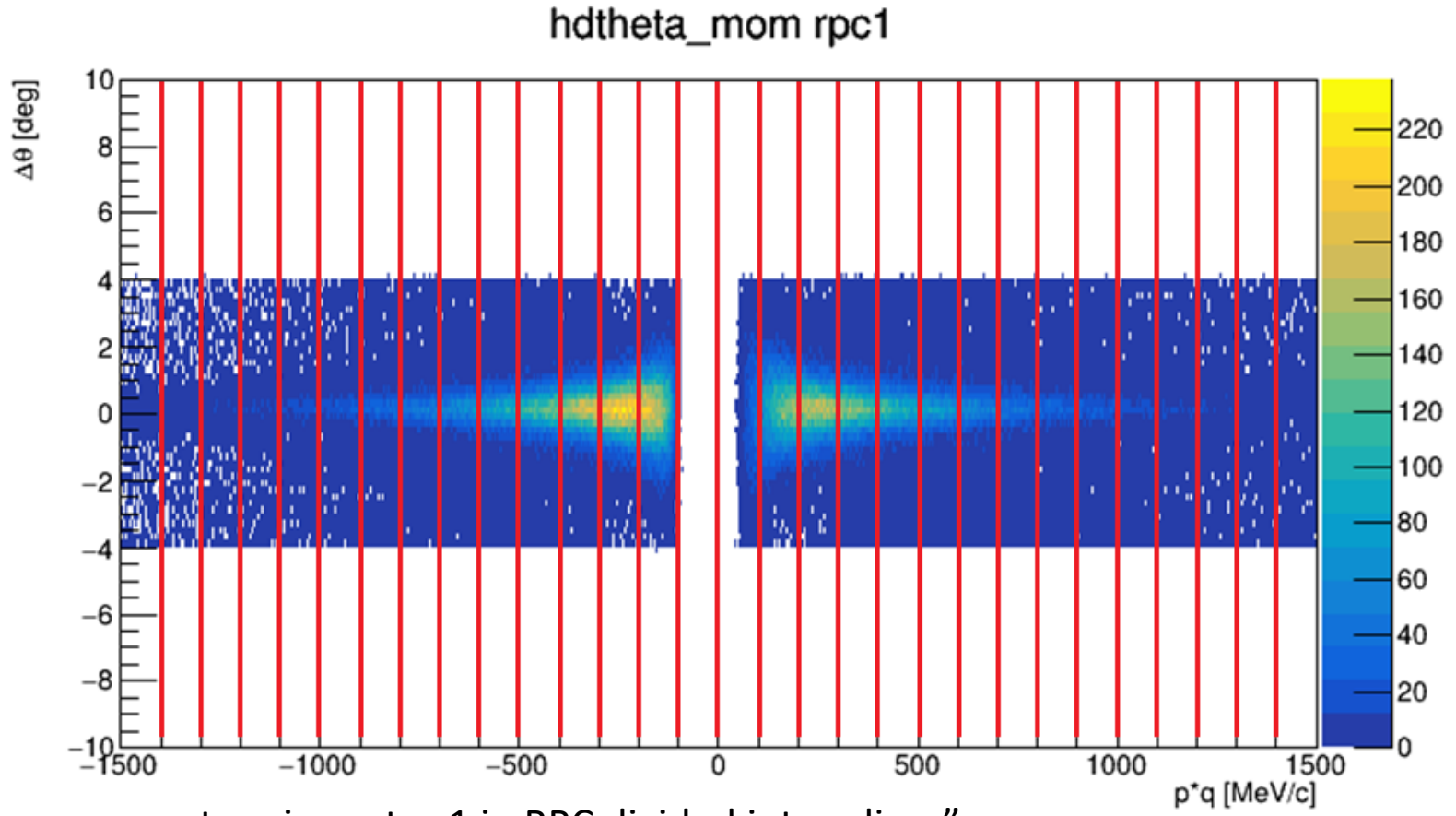
Pic. 26.: $\theta_{RICH} - \theta_{MDC}$ vs momentum in sector 1 in RPC.

$\theta_{RICH} - \theta_{MDC}$ vs momentum



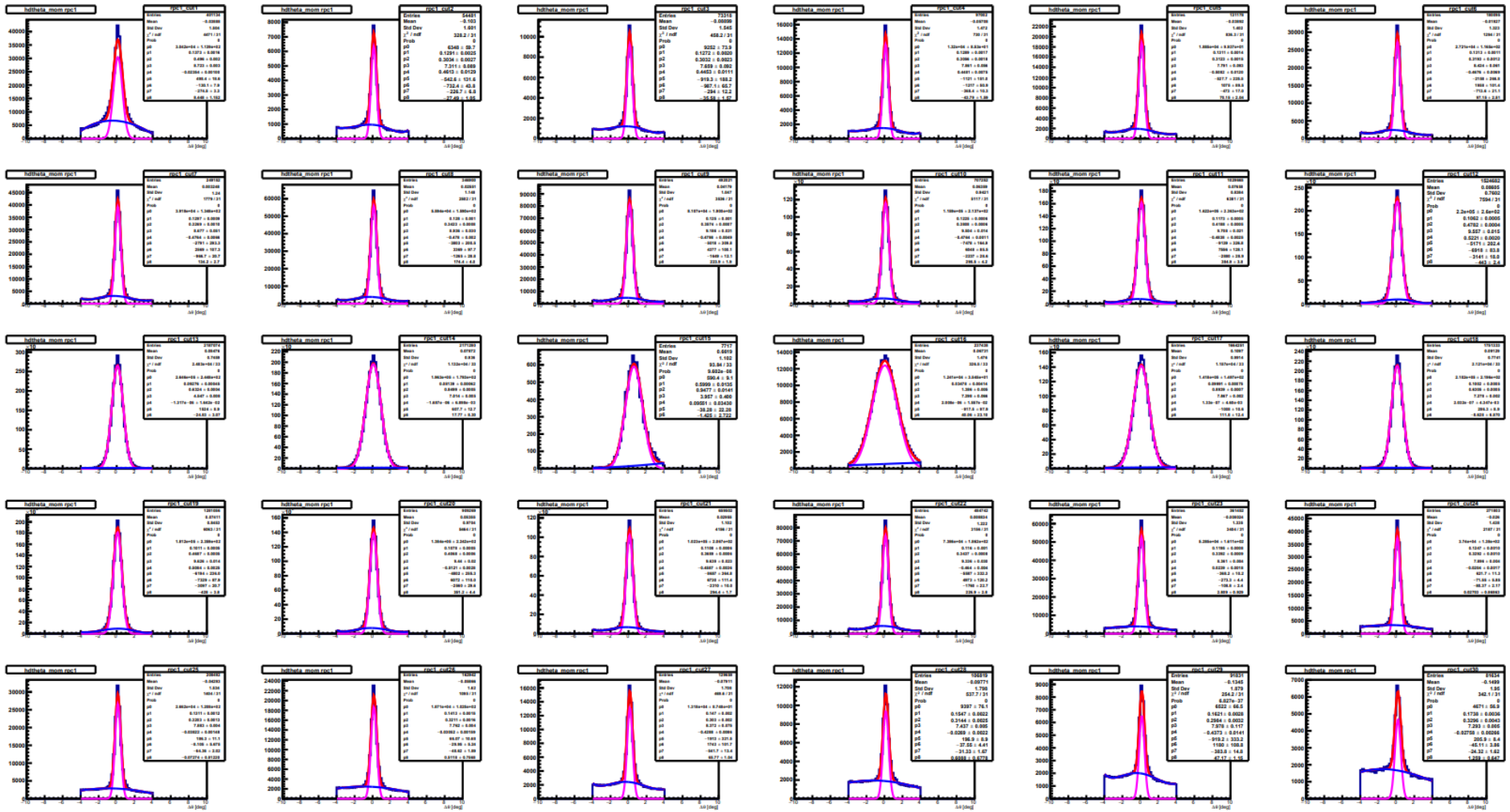
Pic. 27.: $\theta_{RICH} - \theta_{MDC}$ vs momentum in sector 1 in RPC.

$\theta_{RICH} - \theta_{MDC}$ vs momentum



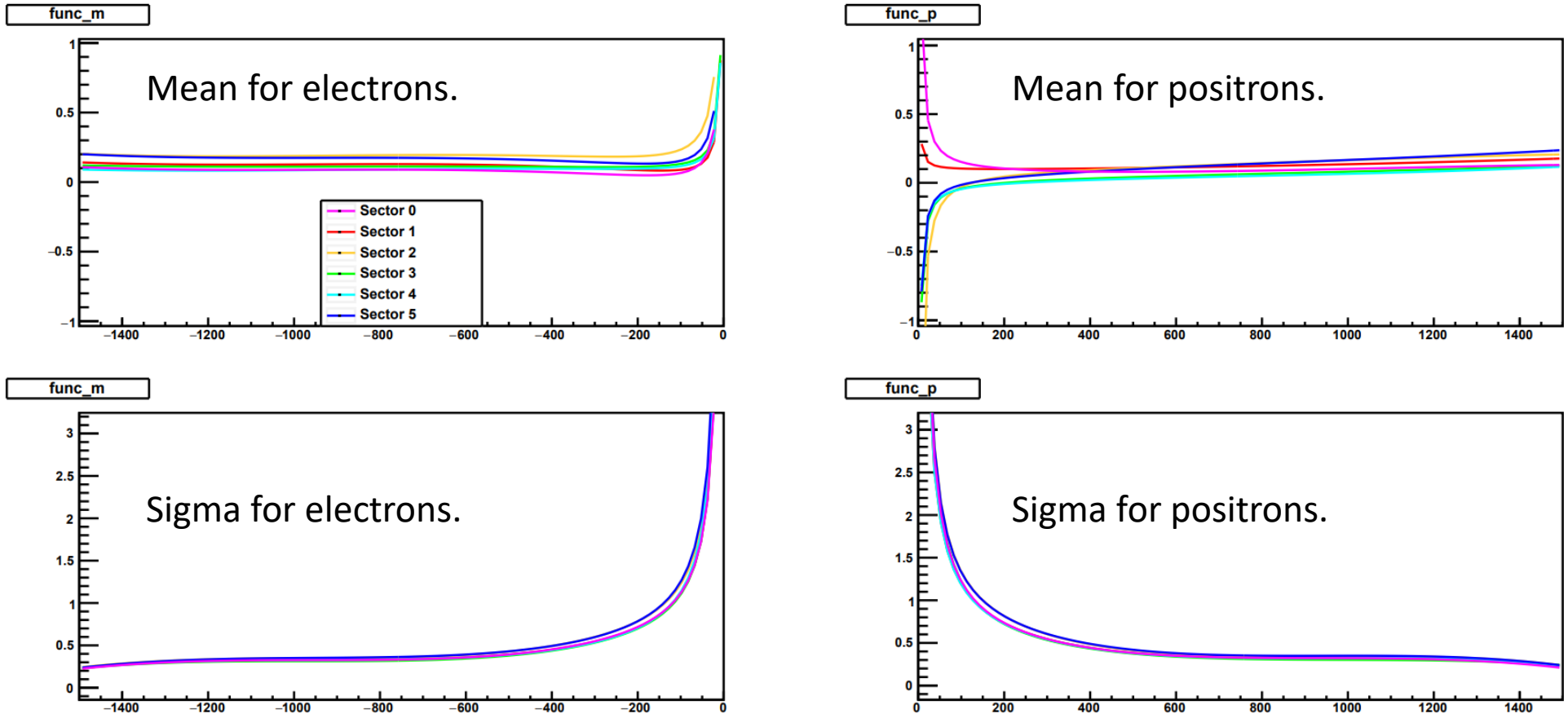
Pic. 28.: $\theta_{RICH} - \theta_{MDC}$ vs momentum in sector 1 in RPC divided into „slices”.

Gaussian fit for each slice



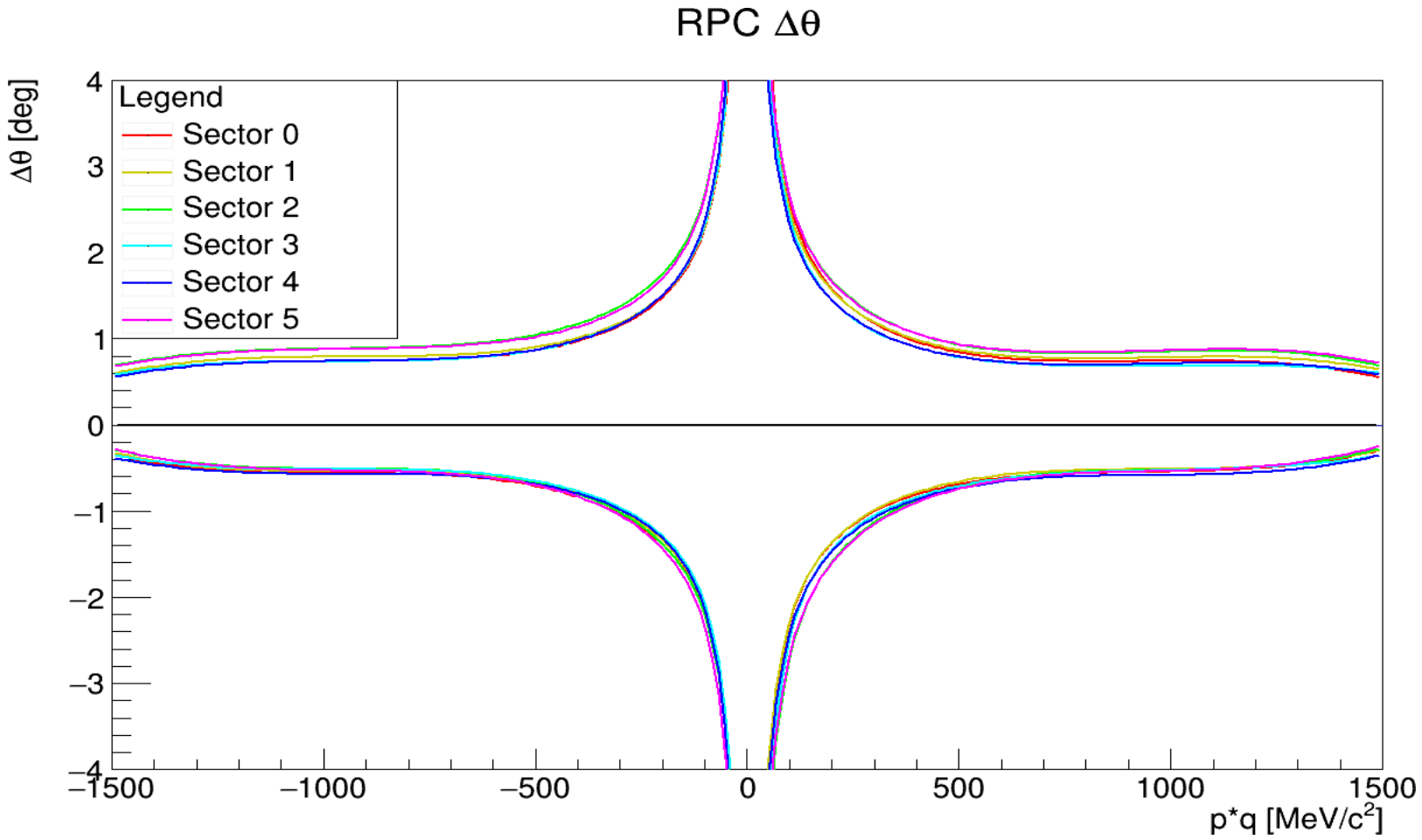
Pic. 29.: Results of fits for each slice.

Mean and sigma parametrization



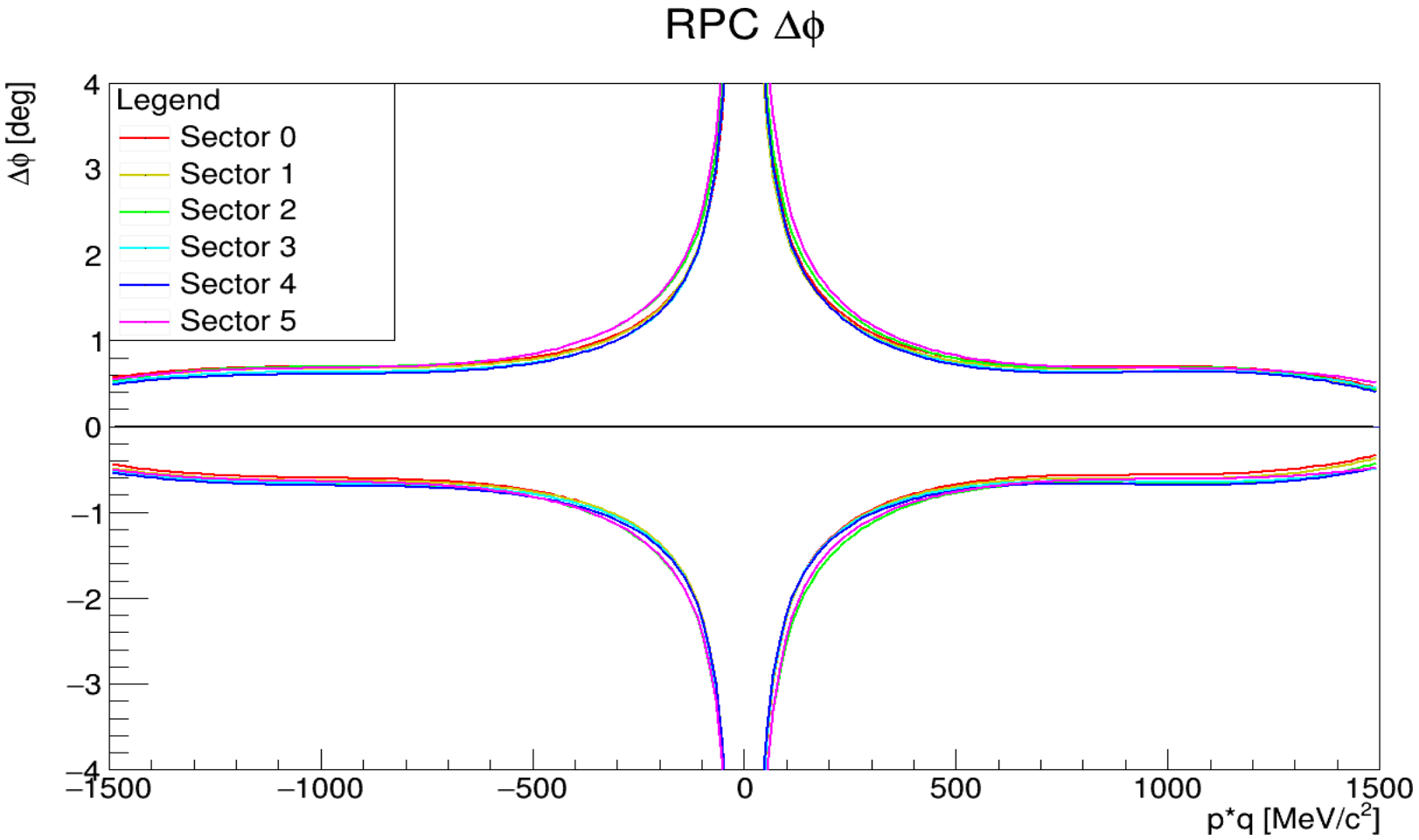
Pic. 30.: Parametrisation of sigma and mean values in distribution of θ_{RICH}- θ_{MDC} vs momentum for RPC.

RPC Δθ



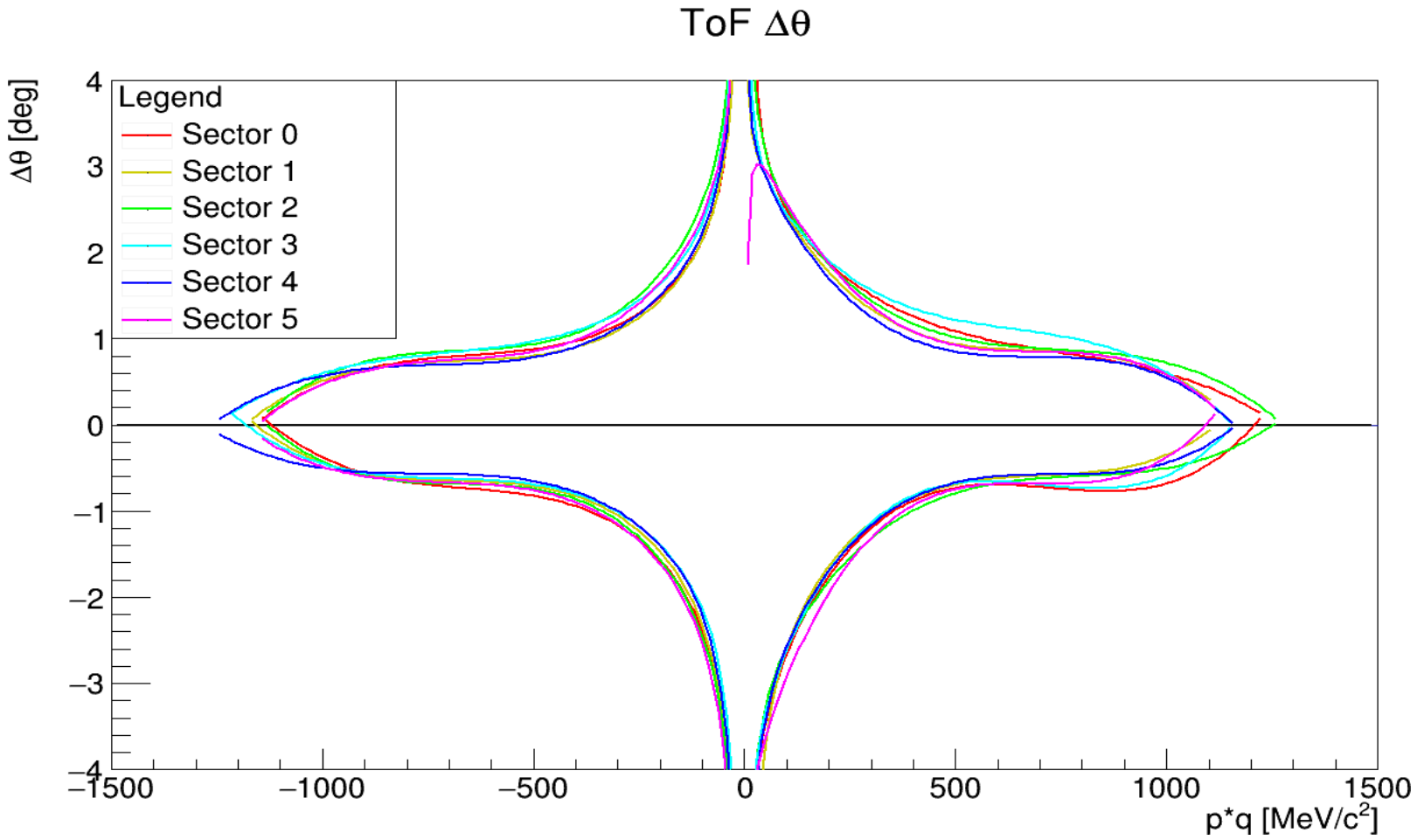
Pic. 31.: Plots of μ+2σ and μ-2σ for every sector in RPC Δθ.

RPC Δϕ



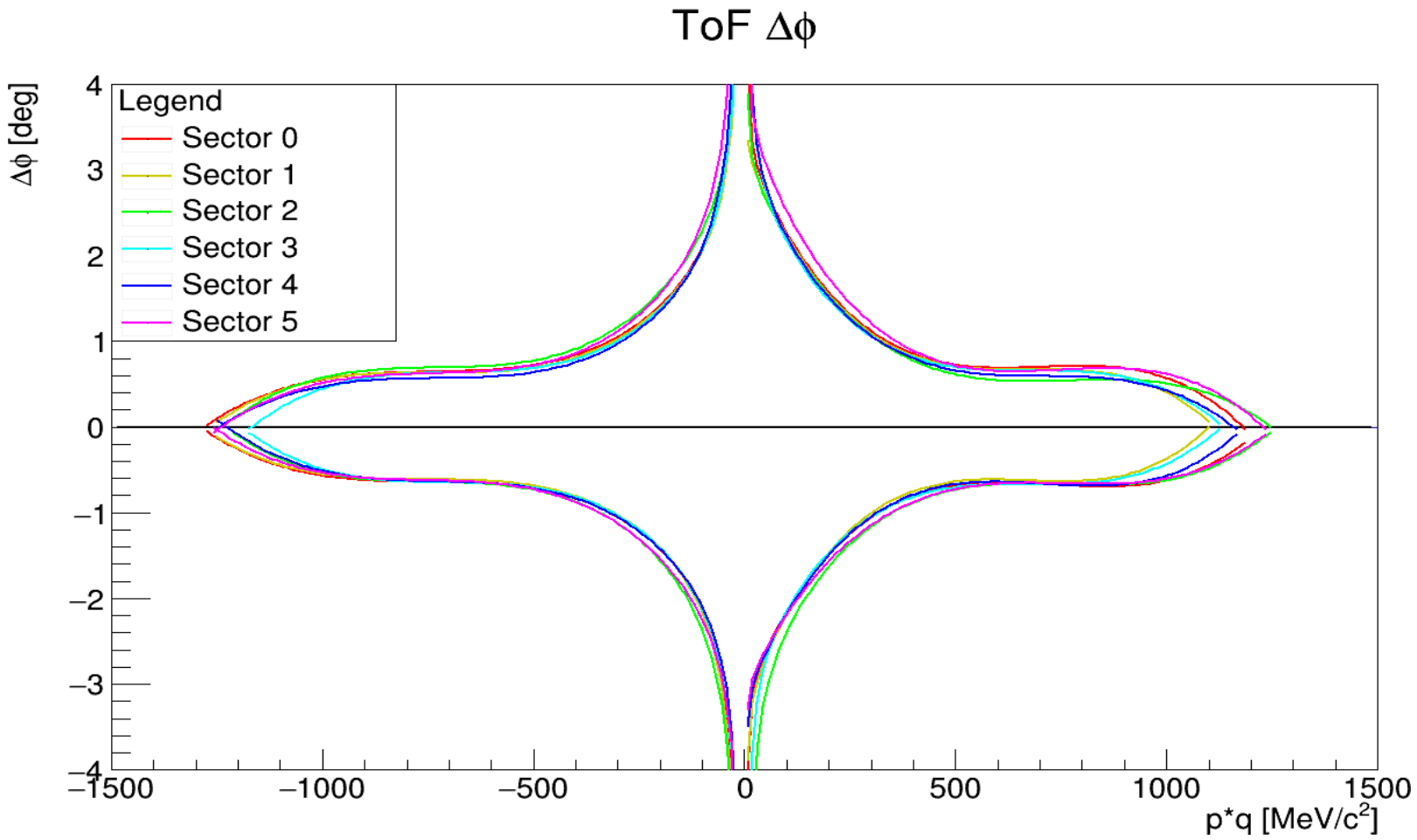
Pic. 32.: Plots of μ+2σ and μ-2σ for every sector in RPC Δϕ.

ToF Δθ



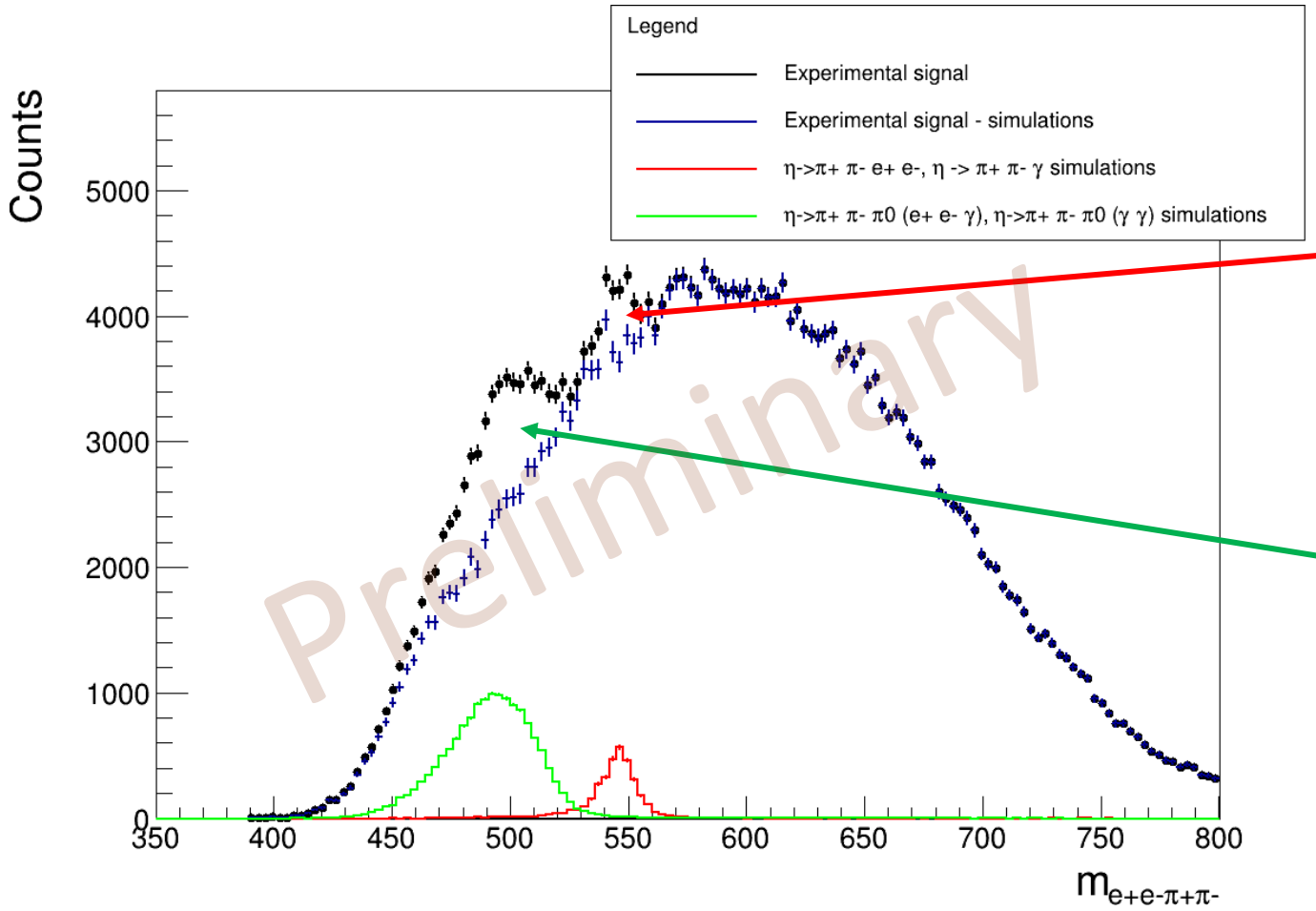
Pic. 33.: Plots of μ+2σ and μ-2σ for every sector in ToF Δθ.

ToF Δϕ



Pic. 34.: Plots of μ+2σ and μ-2σ for every sector in ToF Δϕ.

Data to SIM scaling (no X17)



- Right peak (R)

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

$\eta \rightarrow \pi^+ \pi^- \gamma$

3 446 events
(2 834 in peak region)

- Left peak (L)

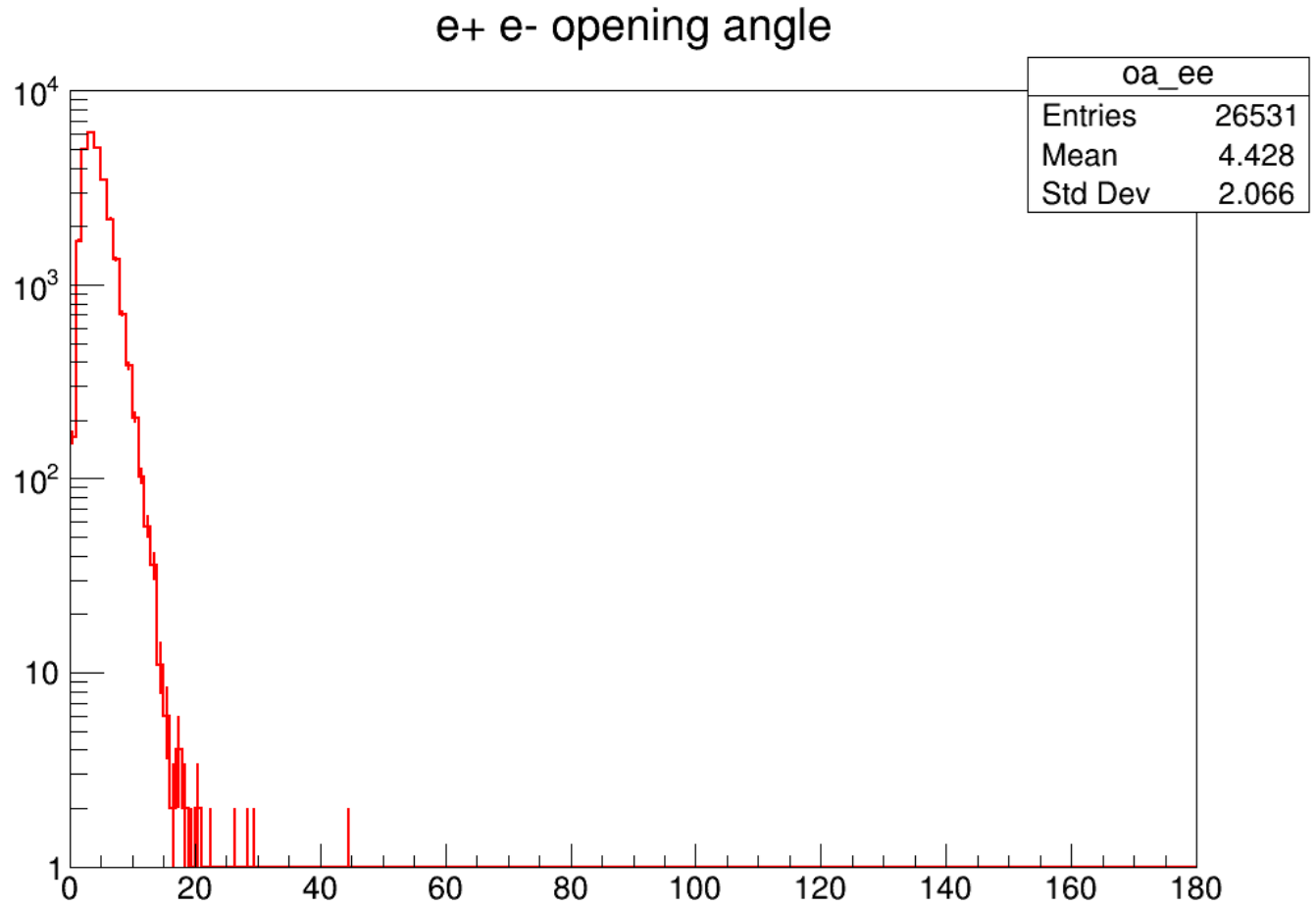
$\eta \rightarrow \pi^+ \pi^- \pi^0 (e^+ e^- \gamma)$

$\eta \rightarrow \pi^+ \pi^- \pi^0 (\gamma\gamma)$

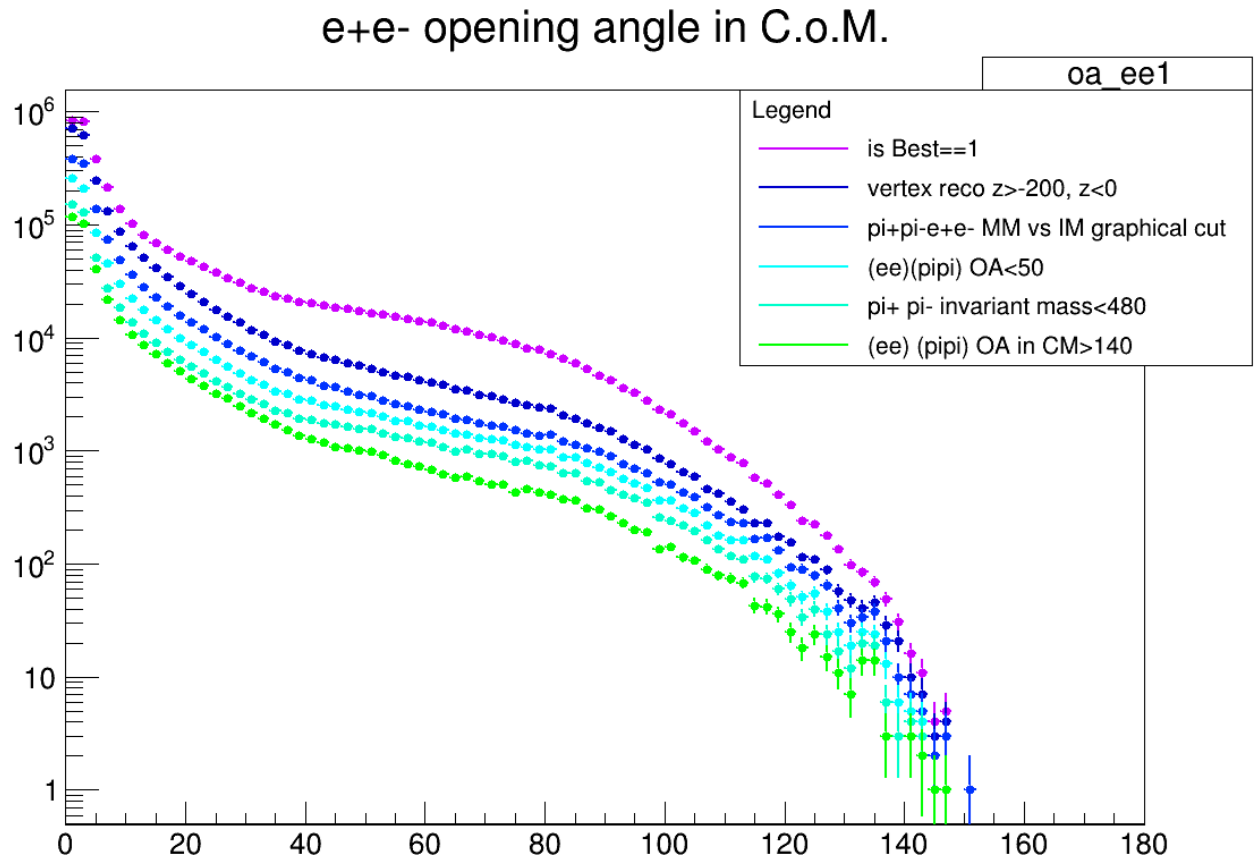
15 204 events

$$\frac{N_L}{N_R}(SIM) = 4.41$$

e^+ e^- opening angle for X17 reaction



e+ e- opening angle



Method for upper limit extraction

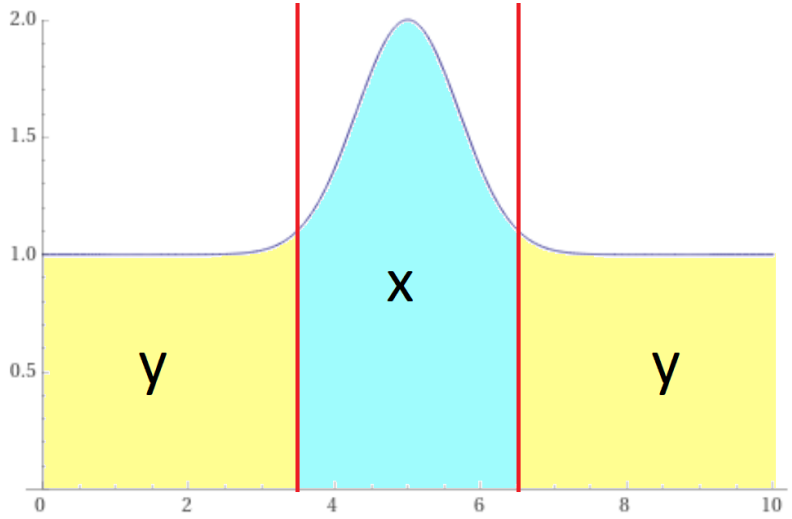
Method developed by Wolfgang A. Rolke (Nuclear Instruments and Methods in Physics Research Section A, Volume 551, Issue 2-3, p. 493-503.)

Parameters for Poisson background and binomial efficiency:

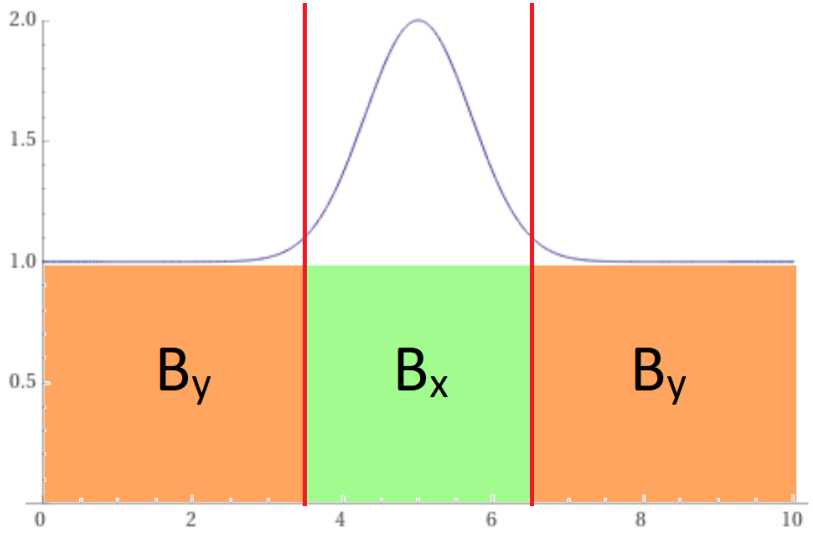
- x – events in the signal region
- y – events in the background region
- τ – number of background events in the background region divided by number of background events in the signal region ($\frac{B_y}{B_x}$)
- e – efficiency for signal

Assumed confidence level: 0.9

Remark: this method gives value in 4π, not in detector acceptance.

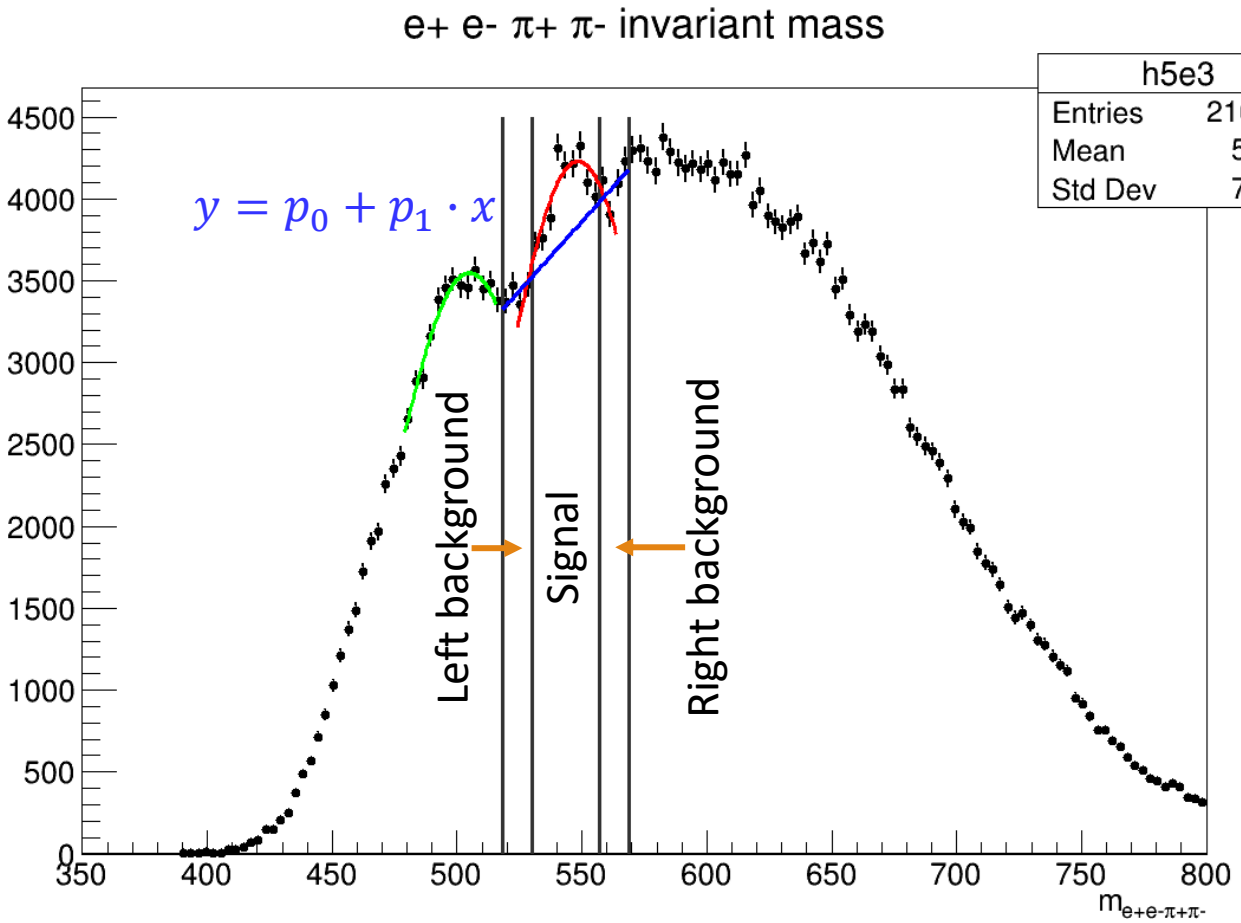


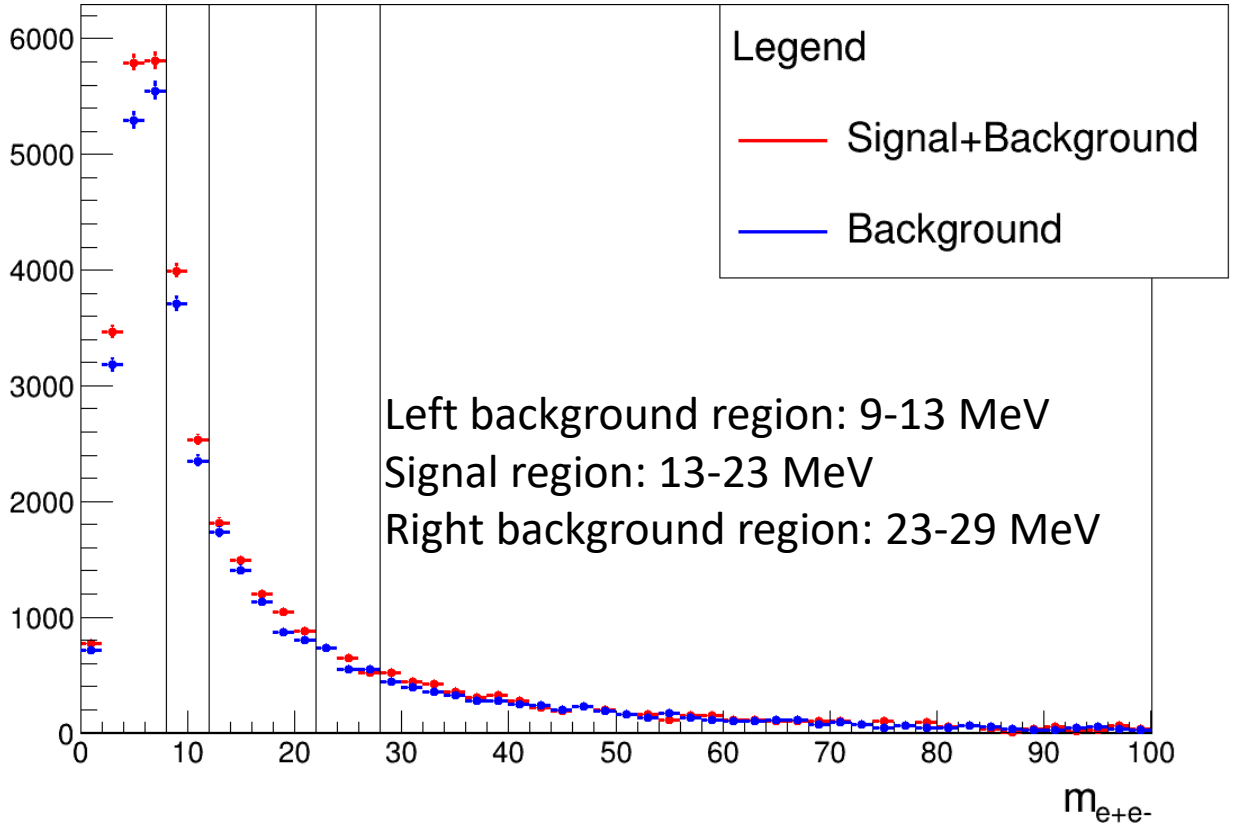
Determination of x and y values.



Determination of B_x and B_y values.

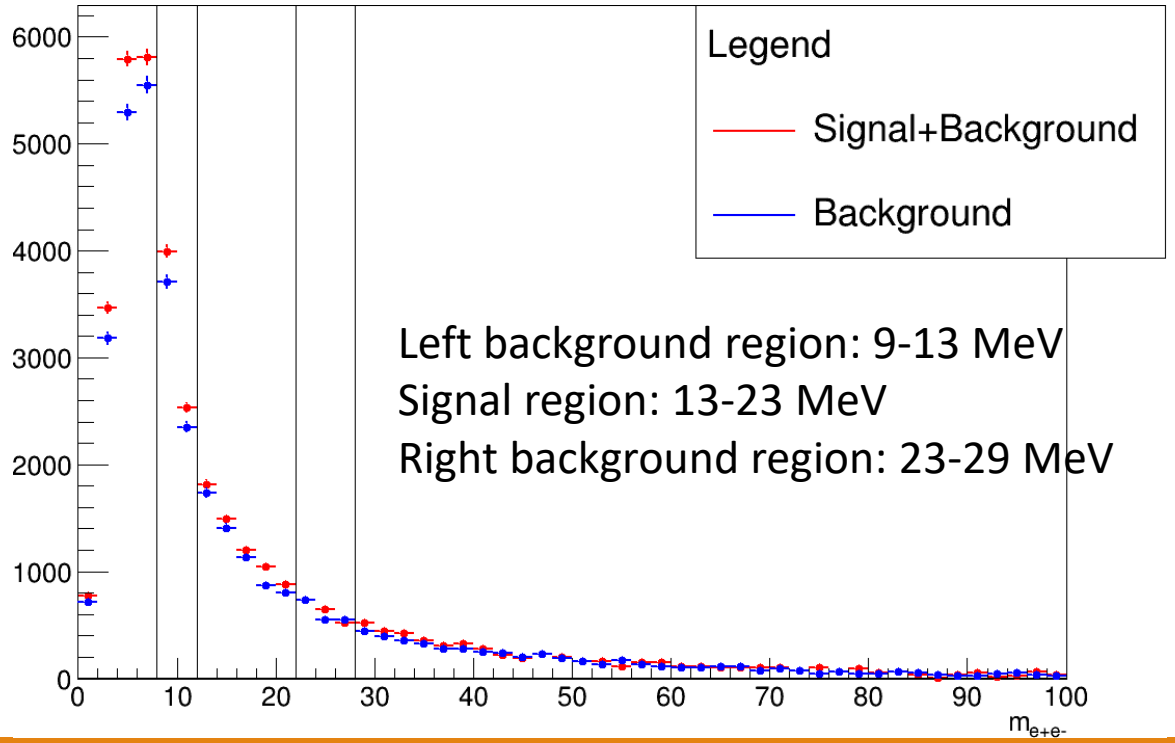
X17 upper limit extraction





X17 upper limit extraction

Method developed by Wolfgang A. Rolke (Nuclear Instruments and Methods in Physics Research Section A, Volume 551, Issue 2-3, p. 493-503.)



x	6 439
y	8 429
B_x	5 954
B_y	7 892
τ	1.3255
e	0.014030526

UL_{X17} = 255 (CL=90%)

$BR_{\eta->\pi+\pi-X17} < 2.0275 \cdot 10^{-6}$

$BR_{th} \sim \underline{1 \cdot 10^{-4}}$

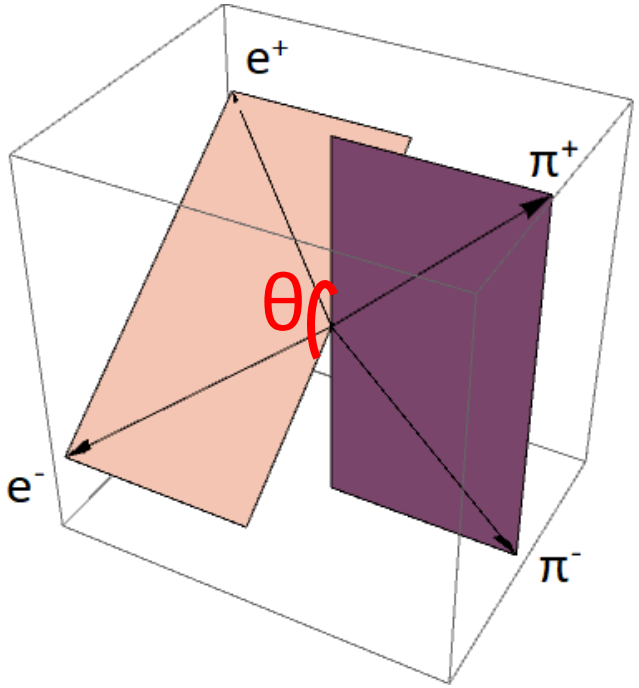
CP symmetry study

P(x,y,z) = (-x,-y,-z)

C(q) = $\bar{q}$

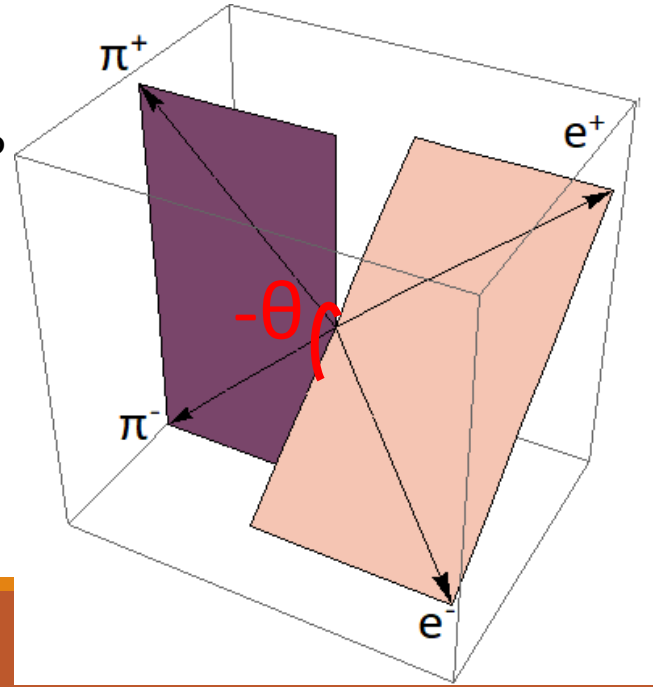
CP(sin(θ)cos(θ)) = -sin(θ)cos(θ)

if distribution of sin(θ)cos(θ) is symmetric in respect to 0, then CP symmetry is conserved

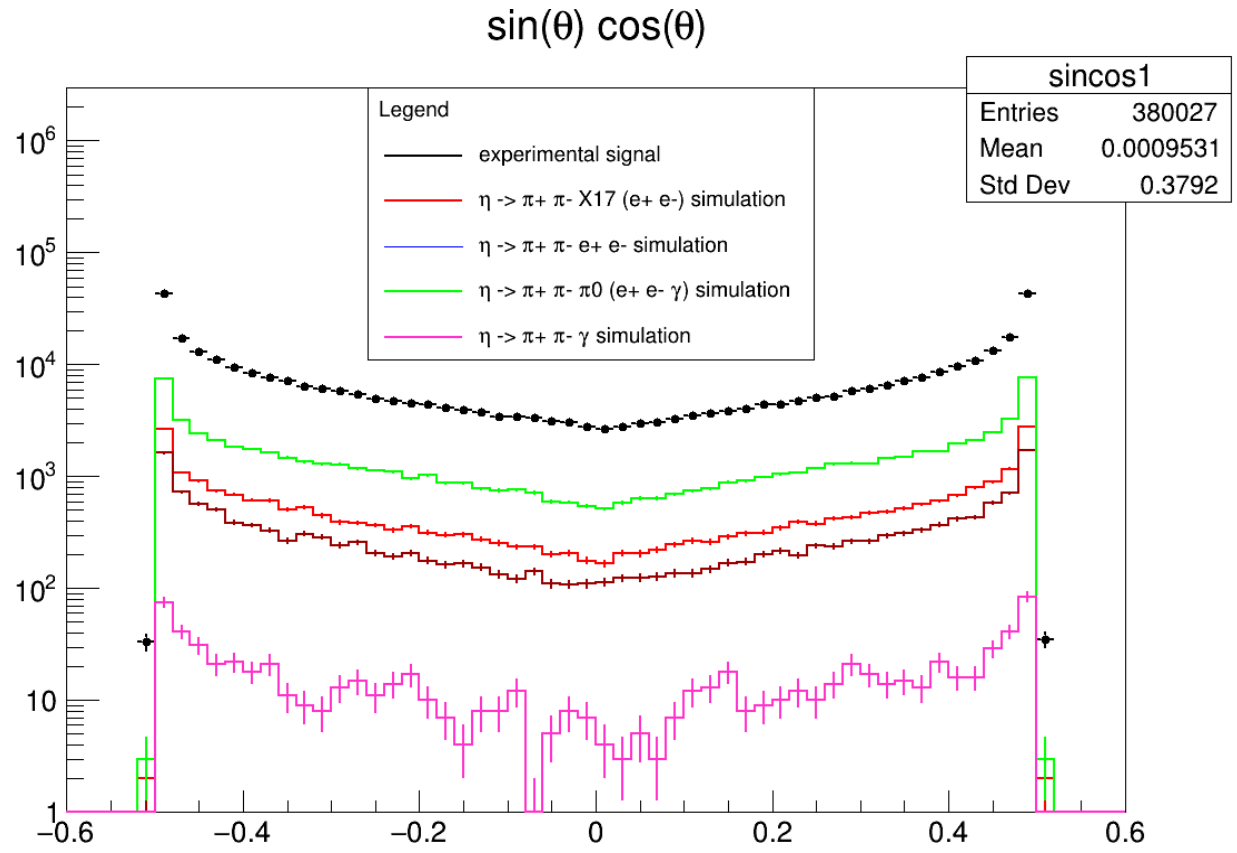


Example system of $\pi^+ \pi^- e^+ e^-$ momenta and planes spanned by them.

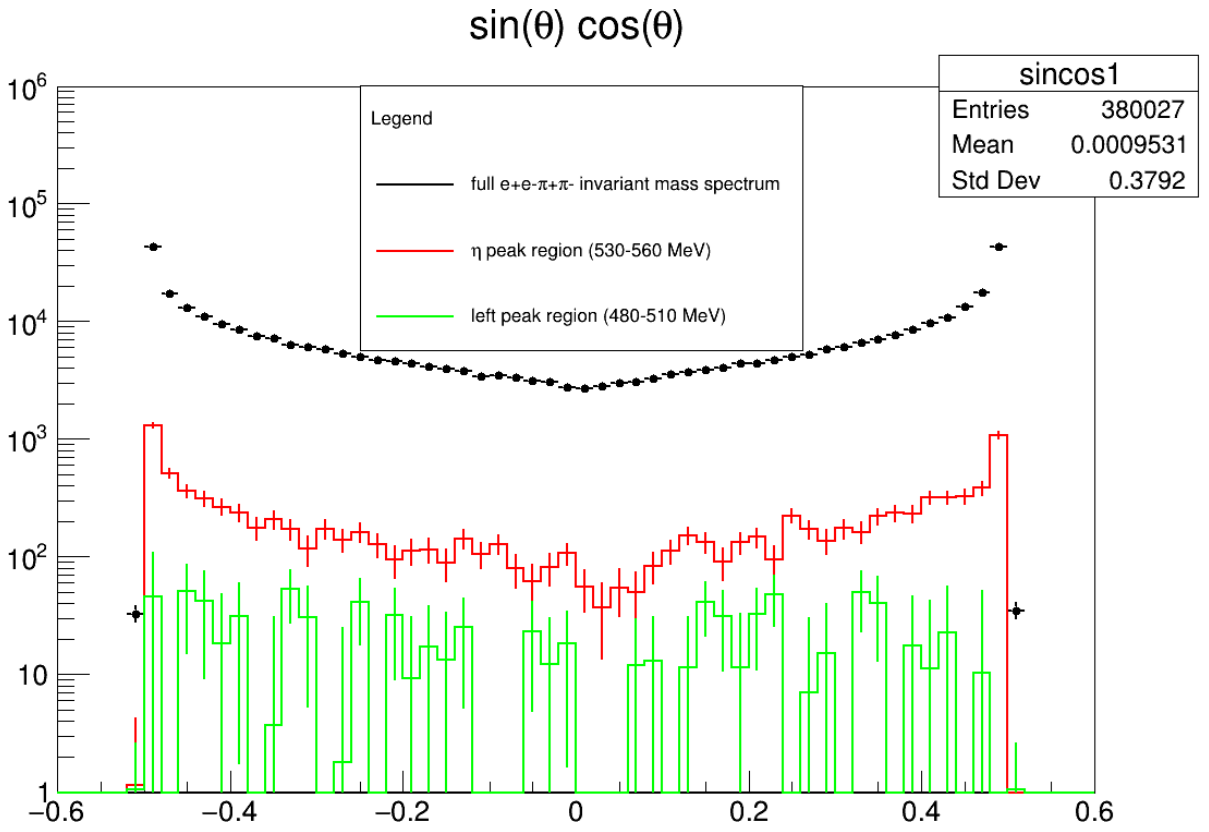
System from the picture 1 after CP transformation.



CP symmetry study



Simulations compared with experimental data



Distributions in peaks after sideband analysis