Simulating the phase space for the $\eta(\rightarrow \pi^+\pi^-\pi^0)\pi^-$ production at COMPASS

Waldemar Renz

Mathias Wagner, Mikhail Mikhasenko, Bernhard Ketzer

HISKP, University of Bonn

February 28, 2018

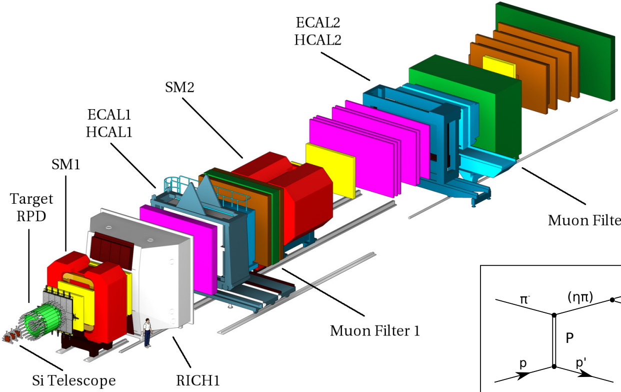
DPG - Frühjahrstagung, Bochum - HK 38.5.

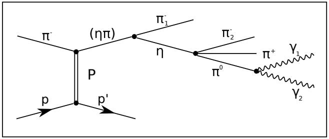
supported by **BMBF**

Content

Content:

The COMPASS experiment

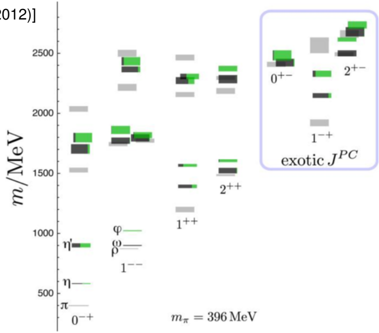


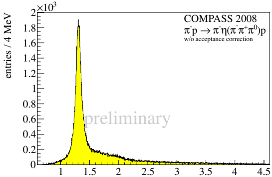


The $\eta\pi$ System

- dominant D-wave visible $\rightarrow J^{PC} = 2^{++}$
- spin exotic P-wave only slightly visible $\rightarrow 1^{-+}$
- hybrid meson expected in $\eta\pi/\eta'\pi$

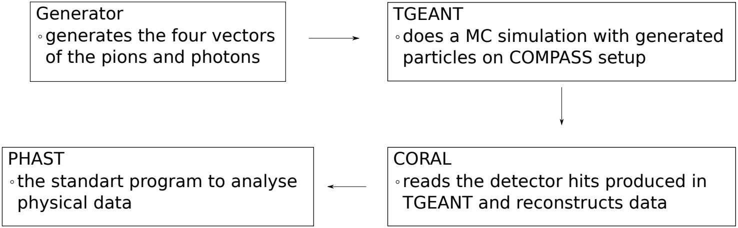
[Dudek et al.,EPJ A 48 08 (2012)]





[COMPASS]

2. Software


Generator
◦ generates the four vectors of the pions and photons
TGEANT
◦ does a MC simulation with generated particles on COMPASS setup
CORAL
◦ reads the detector hits produced in TGEANT and reconstructs data
PHAST
◦ the standart program to analyse physical data

3. Theory - The Propagator

- because η and π^0 are scalar, one can use Breit-Wigner-Propagator

3. Theory - The Propagator

- because η and π^0 are scalar, one can use Breit-Wigner-Propagator
- $\rightarrow \Delta = \frac{g}{m^2 - s - i\frac{g^2}{2}\Phi}$

- because η and π^0 are scalar, one can use Breit-Wigner-Propagator
- $\rightarrow \Delta = \frac{g}{m^2 - s - i\frac{g^2}{2}\Phi}$
- $|\Delta_{\eta,\pi^0}|^2 = \frac{g^2}{(m^2_{\eta,\pi^0} - s_{\eta,\pi^0})^2 - \frac{g^4}{4}\Phi^2} = \frac{2}{\Phi}\frac{m\Gamma}{(m^2_{\eta,\pi^0} - s_{\eta,\pi^0})^2 - m^2\Gamma^2}$
  This is the Cauchy-distribution, which behaves like $\delta(m^2_{\eta,\pi^0} - s_{\eta,\pi^0})$ for small Γ

- because η and π^0 are scalar, one can use Breit-Wigner-Propagator
- $\rightarrow \Delta = \frac{g}{m^2 - s - i\frac{g^2}{2}\Phi}$
- $|\Delta_{\eta,\pi^0}|^2 = \frac{g^2}{(m^2_{\eta,\pi^0} - s_{\eta,\pi^0})^2 - \frac{g^4}{4}\Phi^2} = \frac{2}{\Phi}\frac{m\Gamma}{(m^2_{\eta,\pi^0} - s_{\eta,\pi^0})^2 - m^2\Gamma^2}$
  This is the Cauchy-distribution, which behaves like $\delta(m^2_{\eta,\pi^0} - s_{\eta,\pi^0})$ for small Γ
- $\sigma \propto \int |M|^2 \mathrm{d}\Phi = \int |\tilde{M}|^2 |\Delta_\eta|^2 |\Delta_{\pi^0}|^2 \mathrm{d}\Phi$

3. Theory - Phase Space

Definition:

$$\mathrm{d}\Phi_N(P;p_1,\ldots,p_N) := (2\pi)^4\delta^{(4)}\left(P-\sum_{i=1}^{N}p_i\right)\prod_{j=1}^{N}\left(\frac{\mathrm{d}^3p_j}{(2\pi)^3\cdot 2E_j}\right)$$

one can prove

$$\mathrm{d}\Phi_N \propto \int \mathrm{d}\Phi_{N-1}(P;p_1,\ldots,p_{N-2},p_x)\mathrm{d}\Phi_2(p_x;p_{N-1},p_N)\mathrm{d}s_x$$

one can simplify two-body-phase-space:

$$\mathrm{d}\Phi_2(P; p_1, p_2) = \frac{\sqrt{\lambda(s, m_1^2, m_2^2)}}{2s}\mathrm{d}\Omega_1$$

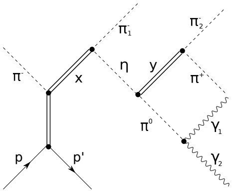


Figure: This diagram shows how the reaction is split up for the phase space used here. It is not meant to be a Feynman diagram.

- this results in the probability distributions:

$$\frac{\mathrm{d}N}{\mathrm{d}s_{\eta\pi}} = \frac{\sqrt{\lambda(s, s_{\eta\pi}, m_p^2)\lambda(s_{\eta\pi}, m_\eta^2, m_{\pi^-}^2)}}{s \cdot s_{\eta\pi}}$$

$$\frac{\mathrm{d}N}{\mathrm{d}s_{\pi^+\pi^-}} = \frac{\sqrt{\lambda(m_\eta^2, s_{\pi^+\pi^-}, m_{\pi^0}^2)\lambda(s_{\pi^+\pi^-}, m_{\pi^+}^2, m_{\pi^-}^2)}}{m_\eta^2 \cdot s_{\pi^+\pi^-}}$$

3. Theory - Limits

- and the limits of the type:

$$m_a + m_b \leq \sqrt{s_{x,y}} \leq \sqrt{s} - m_1$$

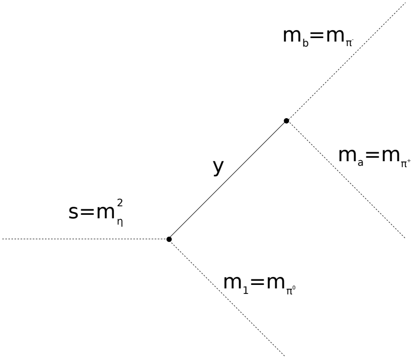


Figure: An example to illustrate the regions of s_y.

3. Theory - Kinematics

- need four vectors in LAB

3. Theory - Kinematics

- need four vectors in LAB
- generate energy, momentum and angular distribution in CMS

3. Theory - Kinematics

- need four vectors in LAB
- generate energy, momentum and angular distribution in CMS
- using Mandelstam variables s and t

$$s = (p_1 + p_2)^2$$

$$\Rightarrow \|\vec{p}\| = \sqrt{\frac{\lambda(s, m_1^2, m_2^2)}{4s}}$$

$$\Rightarrow E_1 = \frac{s + m_1^2 - m_2^2}{2\sqrt{s}}$$

- polar angle of $(2 \rightarrow 2)$-reaction is not uniformly distributed:

$$t = (p_{\pi^-} - p_x)^2$$
$$\leftrightarrow \cos\theta = \frac{t - m_{\pi^-}^2 - s_x + 2E_{\pi^-}E_x}{2||\vec{p}_{\pi^-}|| \cdot ||\vec{p}_x||}$$

- get distribution of $t' = |t| - |t|_{\mathrm{min}}$ from COMPASS data [COMPASS, PL B 740 pp. 303-311 (2015)]

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t'} \propto |t'| e^{-8.45\left(\frac{\mathrm{GeV}}{c^2}\right)^{-2}|t'|}$$

3. Theory - Generating Full Reaction

This is how the plug-in works:

1. Input: particle id, reaction and beam four momentum (LAB)

3. Theory - Generating Full Reaction

This is how the plug-in works:

1. Input: particle id, reaction and beam four momentum (LAB)
2. constructing probability distribution functions and draw random m_x and m_y

3. Theory - Generating Full Reaction

This is how the plug-in works:

1. Input: particle id, reaction and beam four momentum (LAB)
2. constructing probability distribution functions and draw random m_x and m_y
   - input vector/s is/are boosted into CMS with passive Lorentz transformation

3. Theory - Generating Full Reaction

This is how the plug-in works:

1. Input: particle id, reaction and beam four momentum (LAB)
2. constructing probability distribution functions and draw random m_x and m_y
   - input vector/s is/are boosted into CMS with passive Lorentz transformation
   - possibly drawing t' and using previous equations to construct four-vectors

3. Theory - Generating Full Reaction

This is how the plug-in works:

1. Input: particle id, reaction and beam four momentum (LAB)
2. constructing probability distribution functions and draw random m_x and m_y
   - input vector/s is/are boosted into CMS with passive Lorentz transformation
   - possibly drawing t' and using previous equations to construct four-vectors
   - boosting with active transformation back to LAB

3. Theory - Generating Full Reaction

This is how the plug-in works:

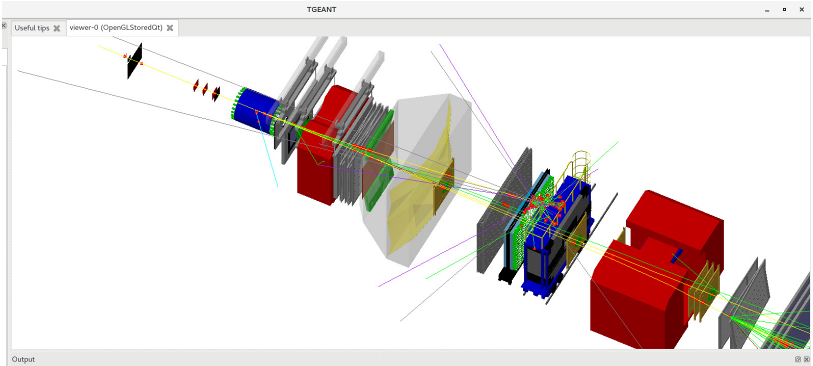
1. Input: particle id, reaction and beam four momentum (LAB)
2. constructing probability distribution functions and draw random m_x and m_y
   - input vector/s is/are boosted into CMS with passive Lorentz transformation
   - possibly drawing t' and using previous equations to construct four-vectors
   - boosting with active transformation back to LAB
   - saving resulting vectors as final states or input for next step

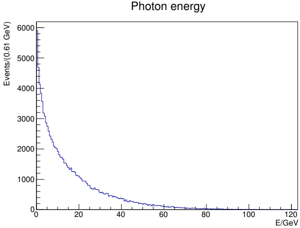
3. Theory - Generating Full Reaction

This is how the plug-in works:

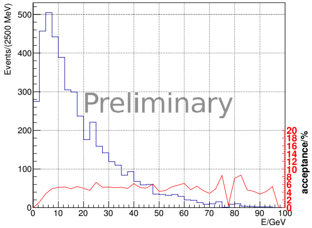
1. Input: particle id, reaction and beam four momentum (LAB)
2. constructing probability distribution functions and draw random m_x and m_y
   - input vector/s is/are boosted into CMS with passive Lorentz transformation
   - possibly drawing t' and using previous equations to construct four-vectors
   - boosting with active transformation back to LAB
   - saving resulting vectors as final states or input for next step
3. repeat last part with next “subreaction”

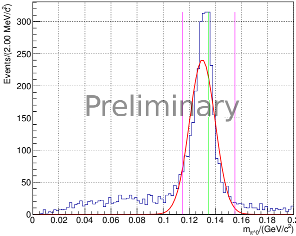
4. Prelimimary Results - TGEANT





- $\mu = (130.0 \pm 0.2)\mathrm{MeV}/c^2$
- $\sigma = (9.7 \pm 0.3)\mathrm{MeV}/c^2$





4. Preliminary Results

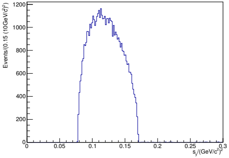


Figure: Distribution of $m_{\pi\pi}^2$ based on the model.

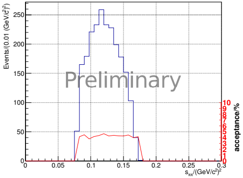


Figure: This diagram shows the distribution of m_y^2 and the acceptance curve in red.

4. Preliminary Results - Resolutions

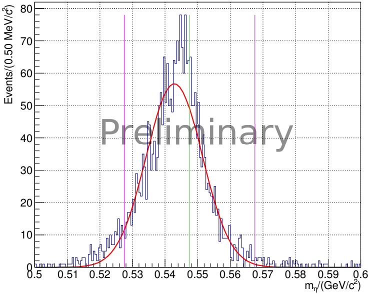


Figure: The reconstructed η mass is shown. The green line marks the initial value of 547.51MeV/c^2. The red curve is a Gauss fit with and shows the mass at $\mu = (543.0 \pm 0.2)$MeV/c^2 and a width of $\sigma = (8.6 \pm 0.2)$MeV/c^2. The purple lines show the filter.

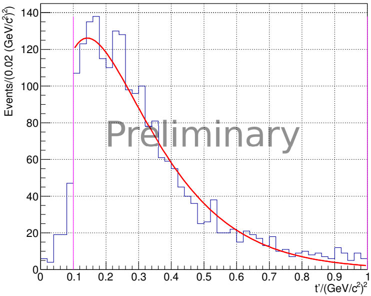


Figure: Here reconstructed data shows the t' distribution. A function of the form $At'e^{-Bt'}$ was fitted with $B = (7.0 \pm 0.1)(\mathrm{GeV/c^2})^2$.

Conclusion

- proof of principle the simulation and reconstruction works ($52k$ events)
- generator can be adapted to other reaction chains
- generator can be used as plug-in to TGEANT's “MC program“

- need to calculate acceptance of $\eta\pi$
- comparison with real data needed
- improve UI of event generator
- extension to higher mass regions

Thank you for your attention!

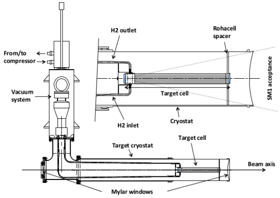
Additional Material

	inel.	el.	inel. nuclear	Bertini capture
π^+	x	x		
π^-	x	x		x
γ			x	

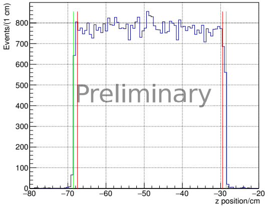
Table: This shows the hadronic processes for the final state particles.[GEANT4 support web page]

Additional Material

- Setup of the COMPASS experiment used
  - Liquid hydrogen target (cylinder with 40cm length and 3.5cm diameter)
  - RPD
  - ECAL1/2 and HCAL1/2
  - MWPC (PA,PB,PS)
  - Magnets SM1 and SM2
  - Muon Wall (MW1, MW2, MF3)
  - Straws (ST02, ST03, ST05)
  - DC (DC00, DC01, DC04)
  - GEM and PGEM
  - Micromegas (MM01, MM02, MM03)
  - Veto and Sandwich-Veto
  - H4M, H4L, H5I, H5M, H5L, H4O
  - FI, SI, W45
  - RICH and RichWall



a) Sketch of the target region in the COMPASS experiment.



b) z positions of the reconstructed vertices. The [redacted]

Additional Material

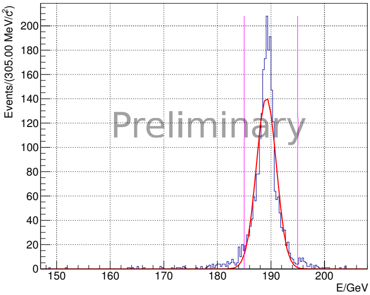


Figure: The energy of the reconstructed $(\eta\pi^-)$ state is shown. The red curve is a Gauss fit that shows a medium of $(189 \pm 4 \cdot 10^{-4})$ GeV with a width of $\sigma = (1.9 \pm 5 \cdot 10^{-4})$ GeV. The purple lines show the cut.

Additional Material

Cut	acc. events/%	acc. events total/%
primary vertex	99.1	99.1
z position	95	94.1
# outgoing charged particles	54.5	51.3
charge sum	90.4	46.4
# of showers	58.3	27
# γ above threshold	39.6	10.7
$m_{\gamma\gamma}$	51.6	5.5
$m_{\pi^+\pi^-\gamma\gamma}$	85	4.7
energy	91.1	4.3

Table: This table shows how many events pass the several cuts.

Additional Material

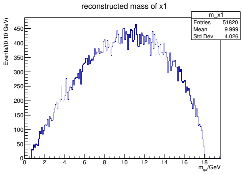


Figure: This is the model for $m_{\eta\pi}$.

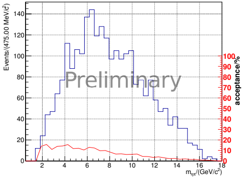


Figure: The reconstructed data show this $m_{\eta\pi}$ distribution, a hint to a bug in the plug-in.