# Heavy-flavour production in proton-proton collisions at $\sqrt{s} = 7$ TeV

## Estimation of $\gamma$, $\pi^0$ and $\eta$ ratios in the photonic background




Università degli studi di Torino

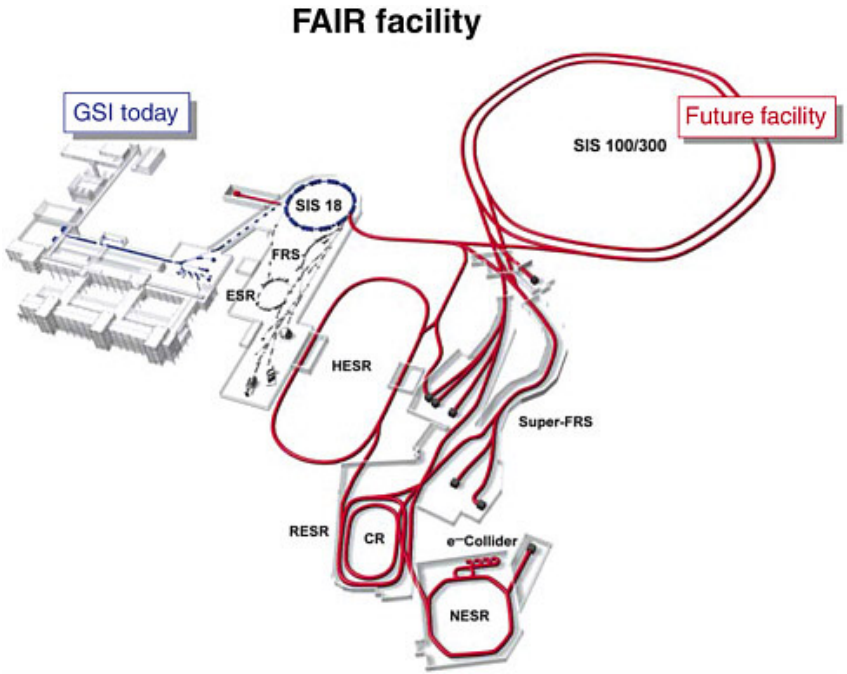
Dipartimento di Fisica

Candidato: Fabrizio Grosa

Relatore: Prof.ssa Stefania Beolè

# Summer Student Program at GSI

- The Summer Student program at GSI consists in 15 lectures about different subjects and in a project with a reaserch group

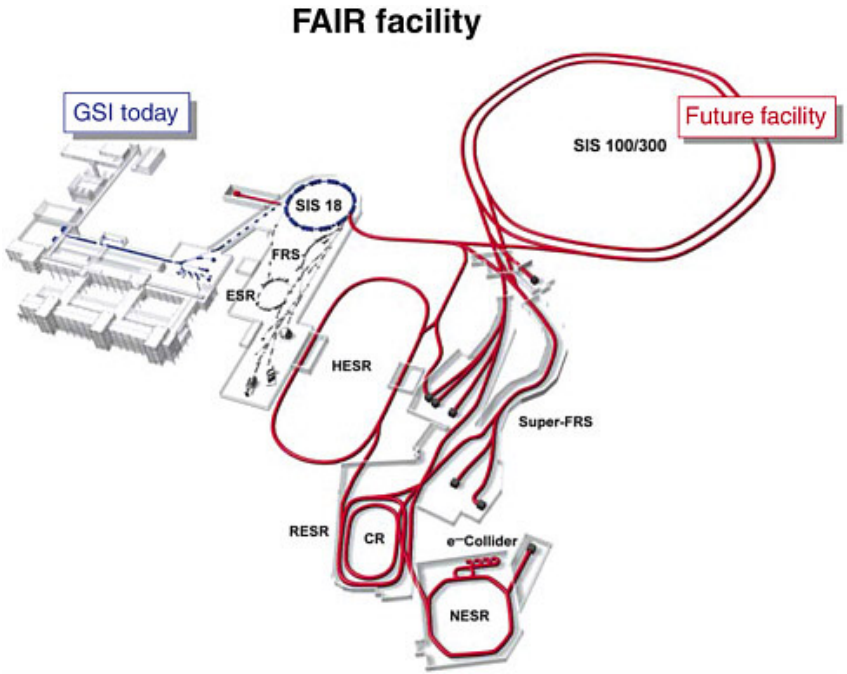



## Research areas at GSI:

- Atomic, Plasma physics and applications
- Astrophysics
- Biophysics
- Nuclear Quark Matter
  - ALICE at LHC/CERN
  - CBM at SIS100-300/FAIR
  - HADES and FOPI at SIS18/GSI

# Summer Student Program at GSI

- The Summer Student program at GSI consists in 15 lectures about different subjects and in a project with a reaserch group

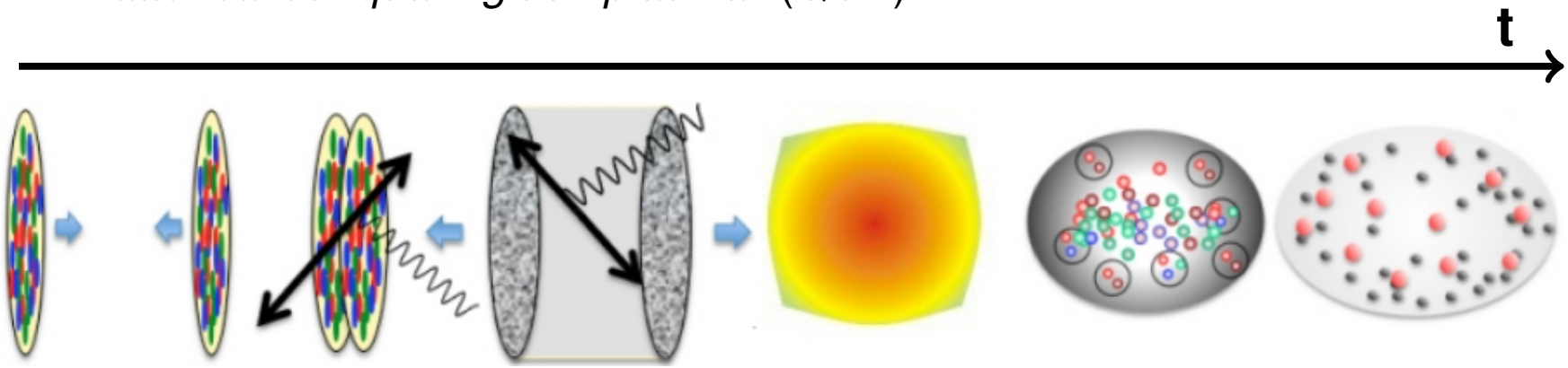



## Research areas at GSI:

- Atomic, Plasma physics and applications
- Astrophysics
- Biophysics
- Nuclear Quark Matter
  - ALICE at LHC/CERN
  - CBM at SIS100-300/FAIR
  - HADES and FOPI at SIS18/GSI

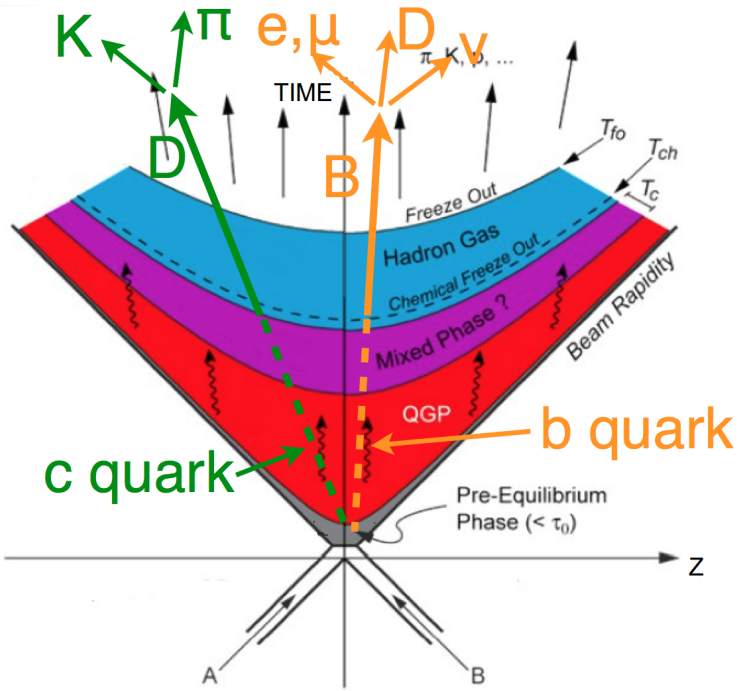
# Quark-gluon plasma in laboratory

- QCD predicts that under extreme conditions of very high temperature or energy densities, hadronic matter transit to a deconfined phase of matter called *"quark-gluon plasma"* (QGP)



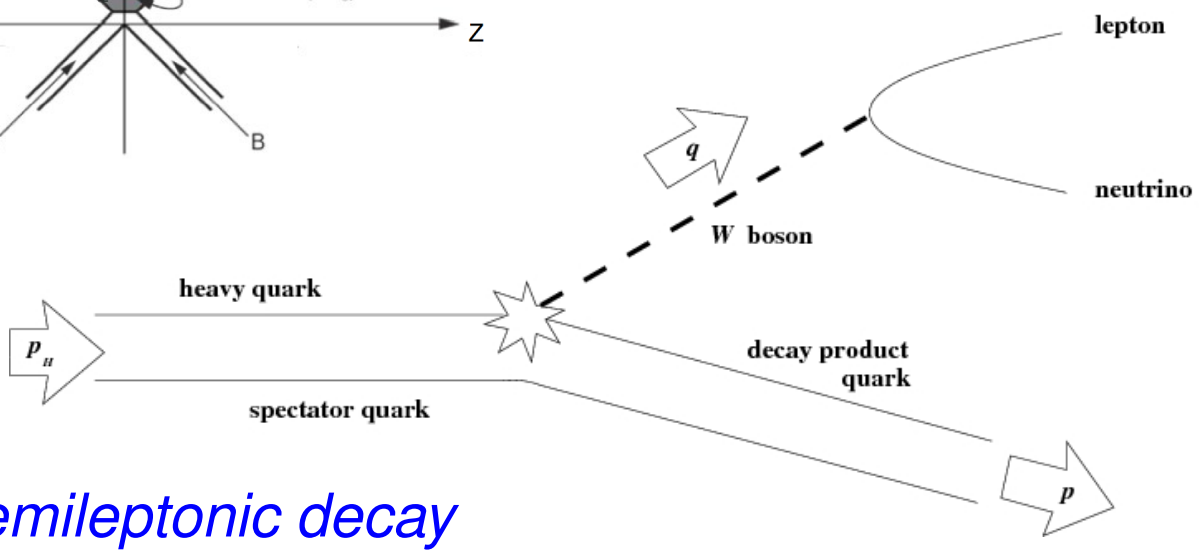

- **Collision**: large number of hard scatterings between partons.
- **Thermalization** : the thermal equilibrium is reached.
- **QGP**: the fireball is created, in which quarks and gluons are free.
- **Hadronization** : the quarks and the glouns are recombined in hadrons.
- **Chemical freeze-out**: inelastic scattering cease.
- **Kinetic freeze-out** : elastic scattering cease.

# Heavy-flavour production



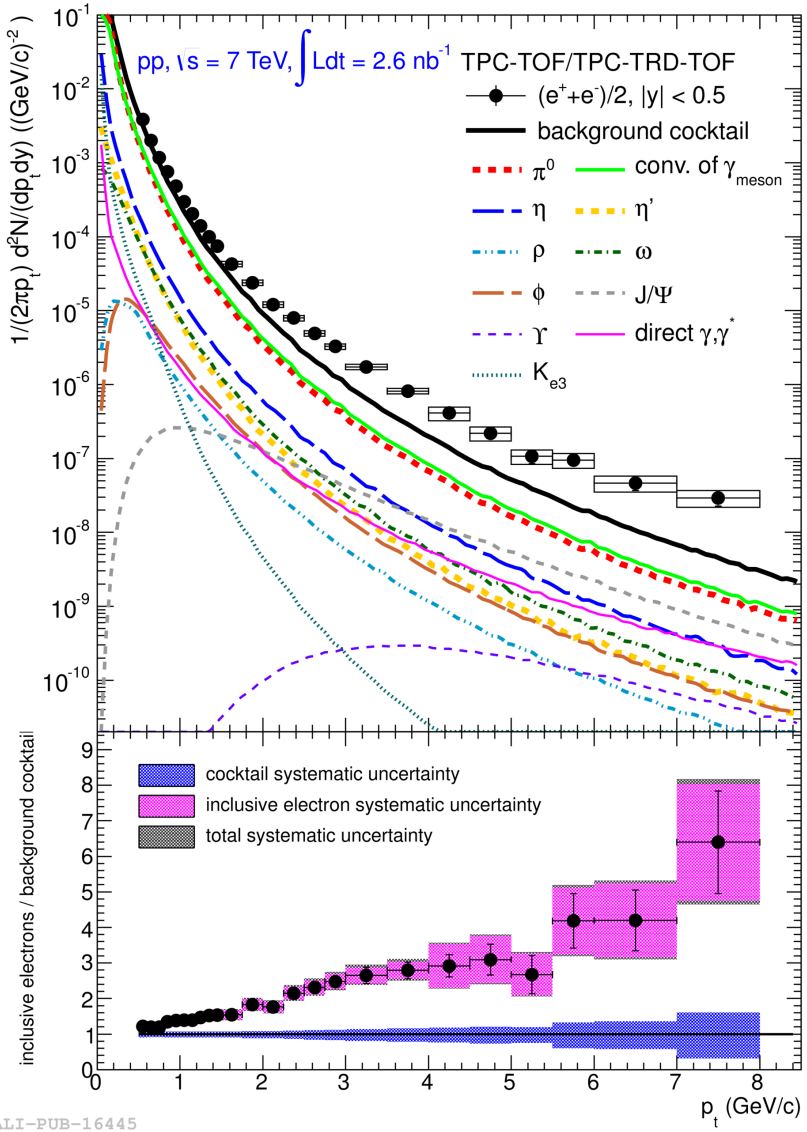

- Heavy-flavour production happens through initial hard partonic scattering processes when the medium is more dense
- Heavy-flavour quarks lose energy travelling in the QGP

Probe for the QGP



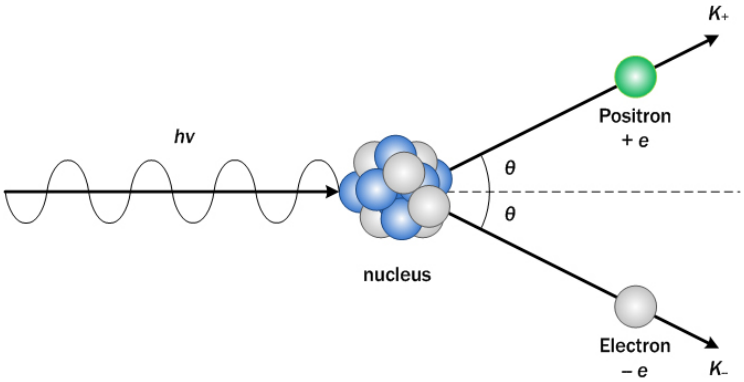

*semileptonic decay*

# Heavy-flavour cocktail background

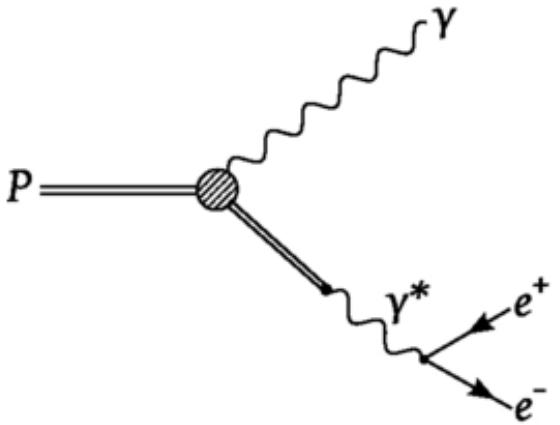



- There are other sources of leptons which form the background for the heavy-flavour hadron semileptonic decay.
- The *inclusive* electrons and positrons are all the $e^{\pm}$ measured, which are decay products of both hadrons carrying heavy quarks, and the background sources.
- After the subtraction of the background only the remaining $p_T$ spectrum contains electrons from heavy-flavour hadron decays only.

# Main sources of the photonic background



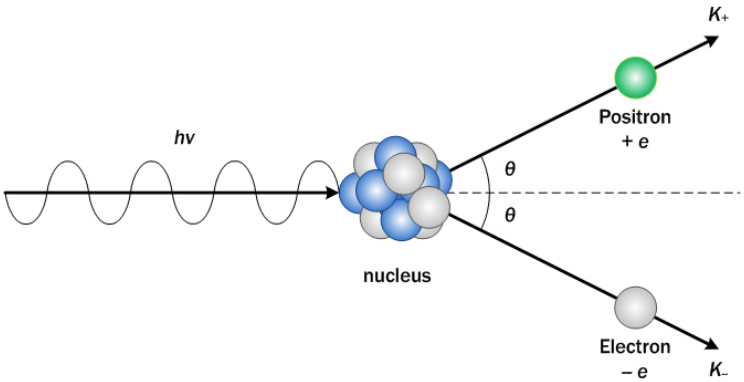

- Photon conversion: $\gamma \rightarrow e^+e^-$



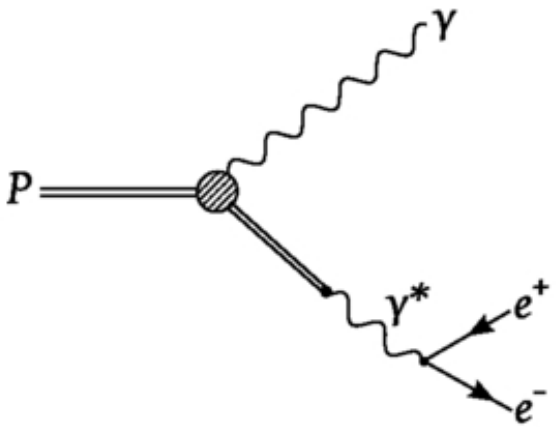

- Dalitz decays:

$$\pi^0 \rightarrow e^+e^-\gamma$$
$$\eta \rightarrow e^+e^-\gamma$$
$$\eta' \rightarrow e^+e^-\gamma$$
$$\omega \rightarrow e^+e^-\pi^0$$
$$\phi \rightarrow e^+e^-\eta$$

# Main sources of the photonic background




- Photon conversion: $\gamma \rightarrow e^+ e^-$



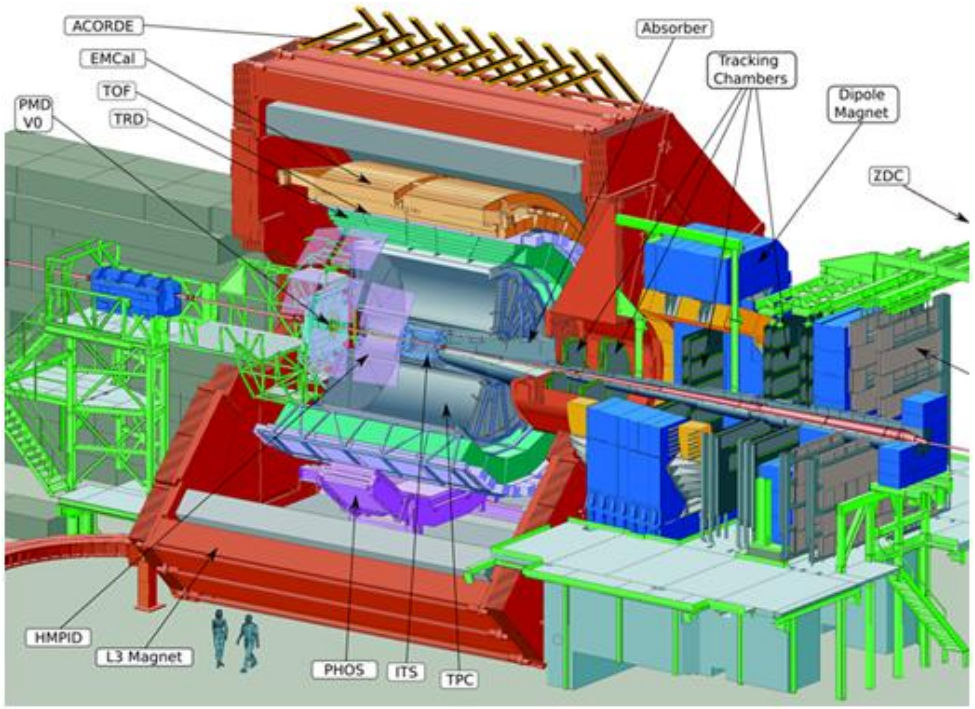

- Dalitz decays:

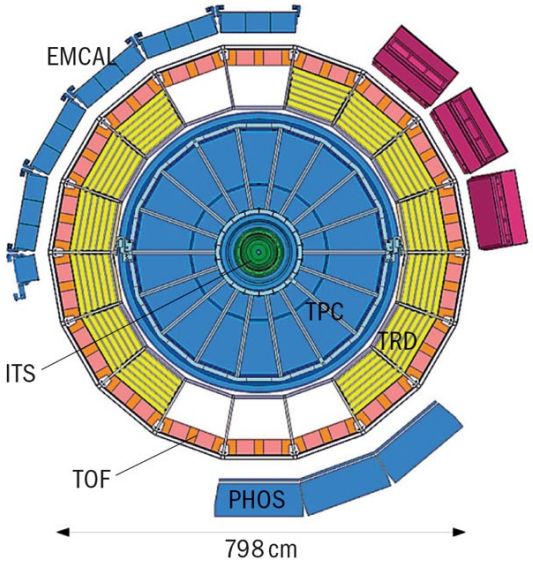
$$\pi^0 \rightarrow e^+ e^- \gamma$$
$$\eta \rightarrow e^+ e^- \gamma$$
$$\eta' \rightarrow e^+ e^- \gamma$$
$$\omega \rightarrow e^+ e^- \pi^0$$
$$\phi \rightarrow e^+ e^- \eta$$

The aim of this study is to calculate the ratio between photon conversions and Dalitz decays in the photonic background

# The ALICE detector

- ALICE is the experiment at LHC dedicated to heavy-ion collisions




- **I**nner **T**racking **S**ystem: first sub detector reached by the particles originating in the primary vertex
- **T**ime **P**rojection **C**hamber: the main tracking detector

# Data samples

- Simulated proton-proton collision events at $\sqrt{s} = 7\,TeV$
  - decayed with *Pythia 6*
  - propagation through detectors described with ***GE****ometry* ***AN****d* ***T****racking* 3
  - tracks reconstructed with AliRoot
- This study is focused on proton-proton collisions because they are the reference system for the Pb-Pb collisions

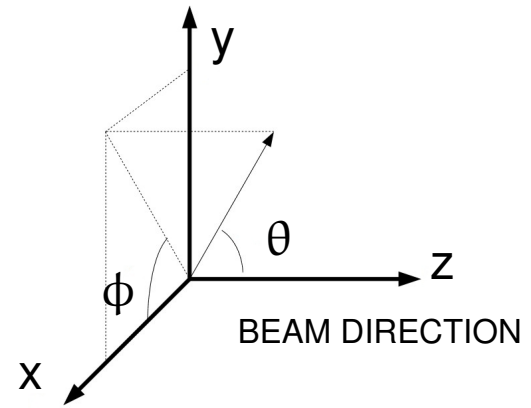
# $e^{\pm}$ identification

- Cuts for $e^{\pm}$ tracks

| | |
|---|---|
| $\chi^2$/cluster in the TPC track fit | $< 4$ |
| ITS/TPC refit | yes |
| number of TPC clusters | $\geqslant 120$ |
| number of ITS clusters | $\geqslant 4$ |
| number of TPC cluster for PID | $\geqslant 80$ |
| TPC Ratio found/findable clusters | $> 0.6$ |
| Transverse momentum | $0.1 < p_T < 20$ |
| Pseudorapidity | $\mid \eta \mid < 0.8$ |
| Reject Kink daughter | yes |
| DCA in $\mid \vec{r} \mid$-direction [cm] | $< 1$ |
| DCA in z-direction [cm] | $< 2$ |
| ITS SPD layer hit | First |

- Tranverse momentum:

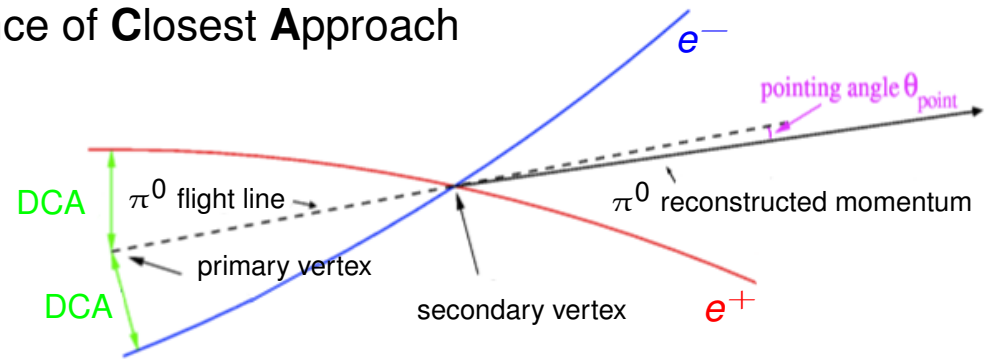
$$p_T = \sqrt{p_x^2 + p_y^2}$$




- Pseudorapidity:

$$\eta = -ln\left[tan\left(\frac{\theta}{2}\right)\right] = \frac{1}{2}ln\left(\frac{\mid \vec{p} \mid + p_L}{\mid \vec{p} \mid - p_L}\right)$$

- **D**istance of **C**losest **A**pproach (DCA)

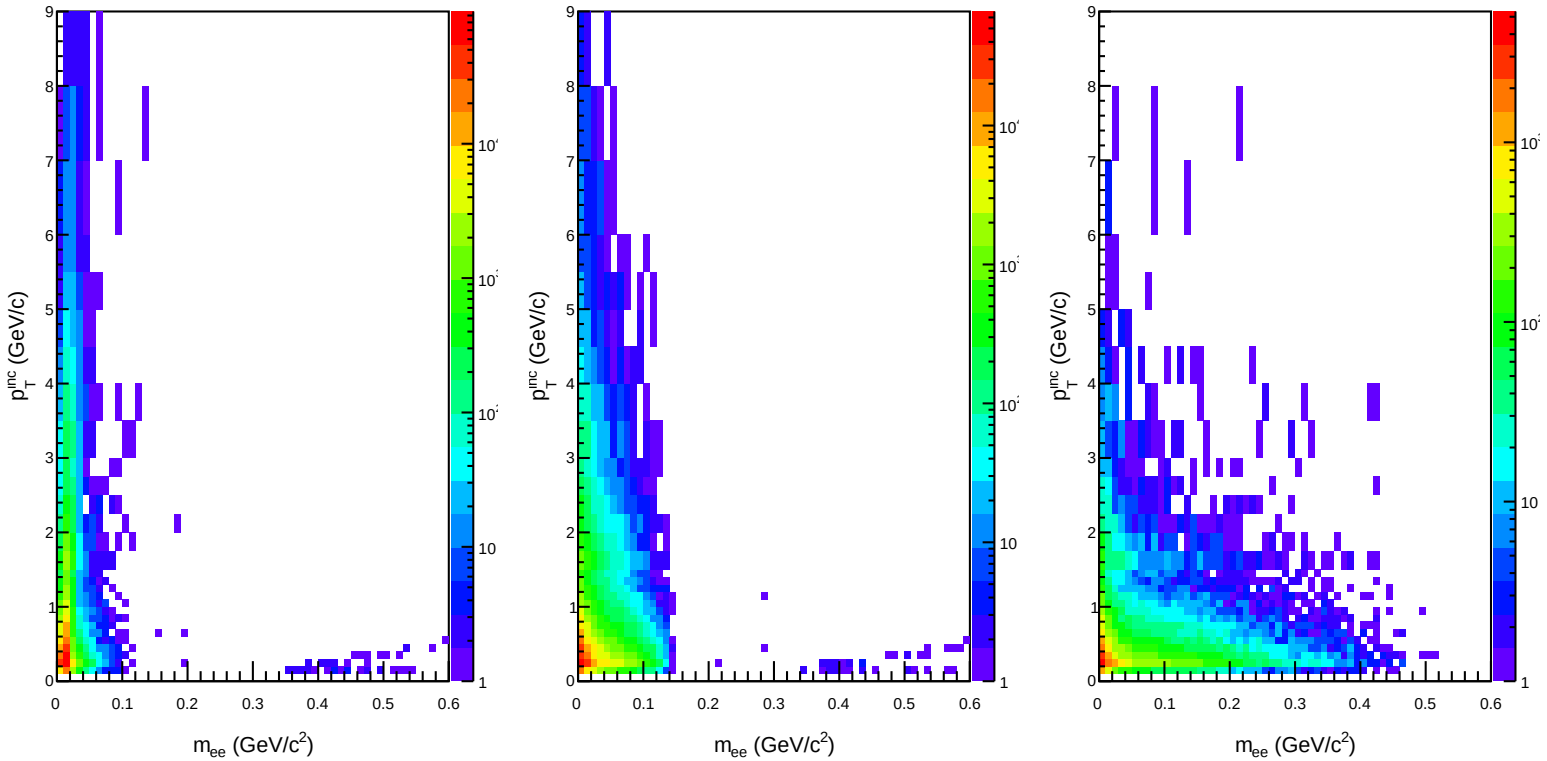



Finally, using the MC truth information, only the tracks that really belong to $e^{\pm}$ are selected

# Correlation between $p_T$ and $m_{ee}$ from MC truth

→ Using the MC truth it is possible to know the mother particle of every $e^+e^-$ pair → for each sources the correlation between the $p_T$ of the inclusive electron and the $m_{ee}$ of the $e^+e^-$ can be obtained

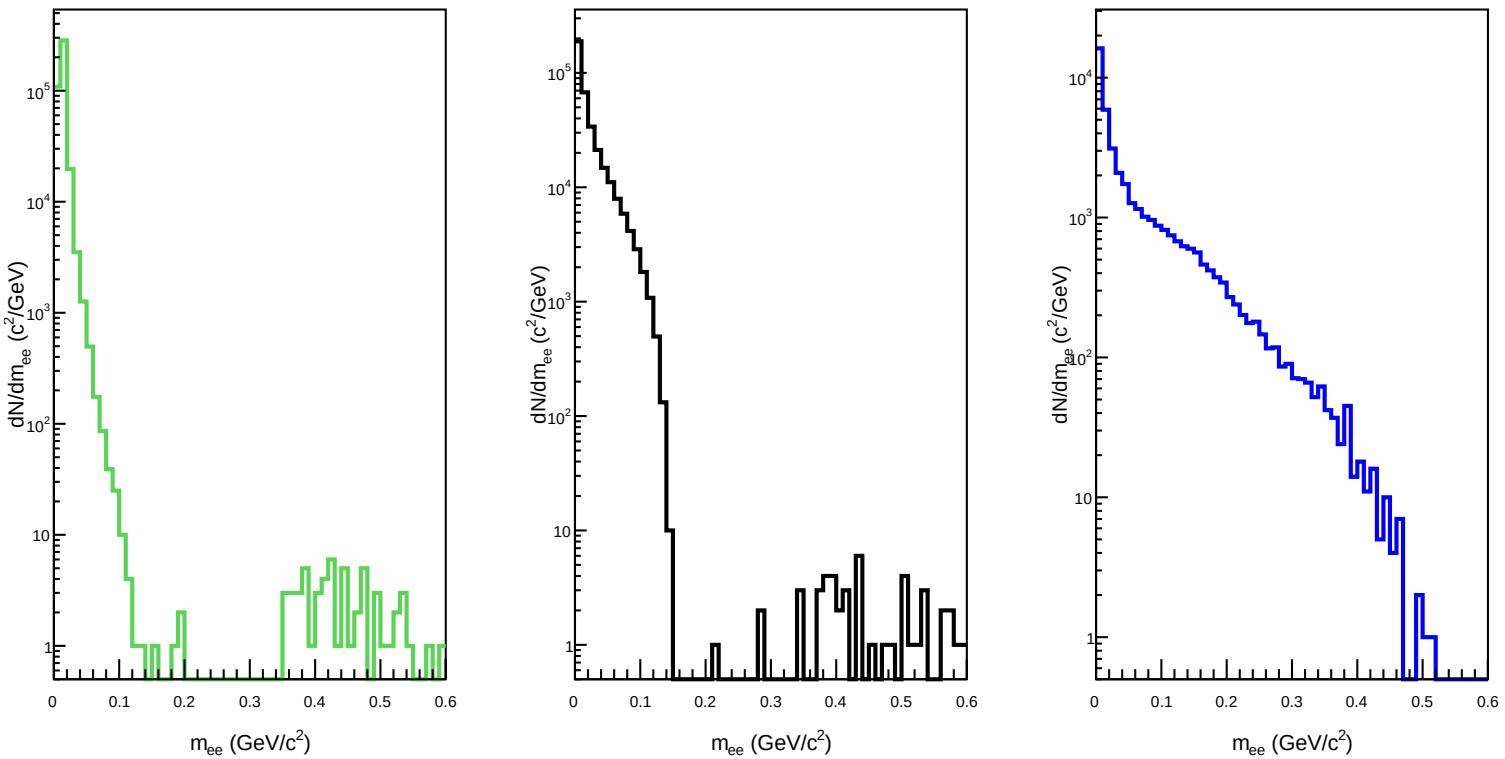
$\gamma$ $\pi^0$ $\eta$



# Invariant mass distributions from MC truth

→ Knowing the mother particle of every $e^+e^-$ pair from MC truth, it is possible to obtain the invariant mass distribution for each source

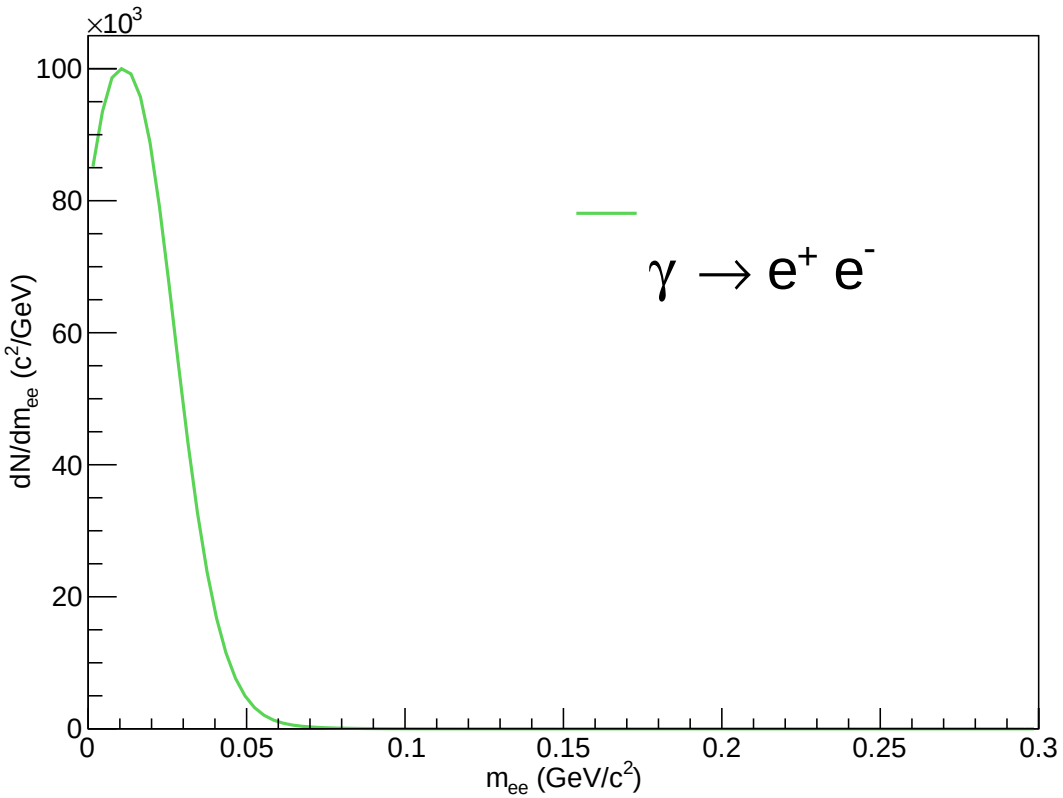
$\gamma$ $\pi^0$ $\eta$



# Distribution for photons

- For the photon conversion ⟶ exponentially modified Gaussian distribution:

$$\frac{dN}{dm_{ee}} = N_\gamma \cdot e^{-\frac{(m_{ee}-M_\gamma)^2}{2\sigma^2}} + \Theta(m_{ee}-M_\gamma)\, e^{\frac{m_{ee}-M_\gamma}{\tau}}$$



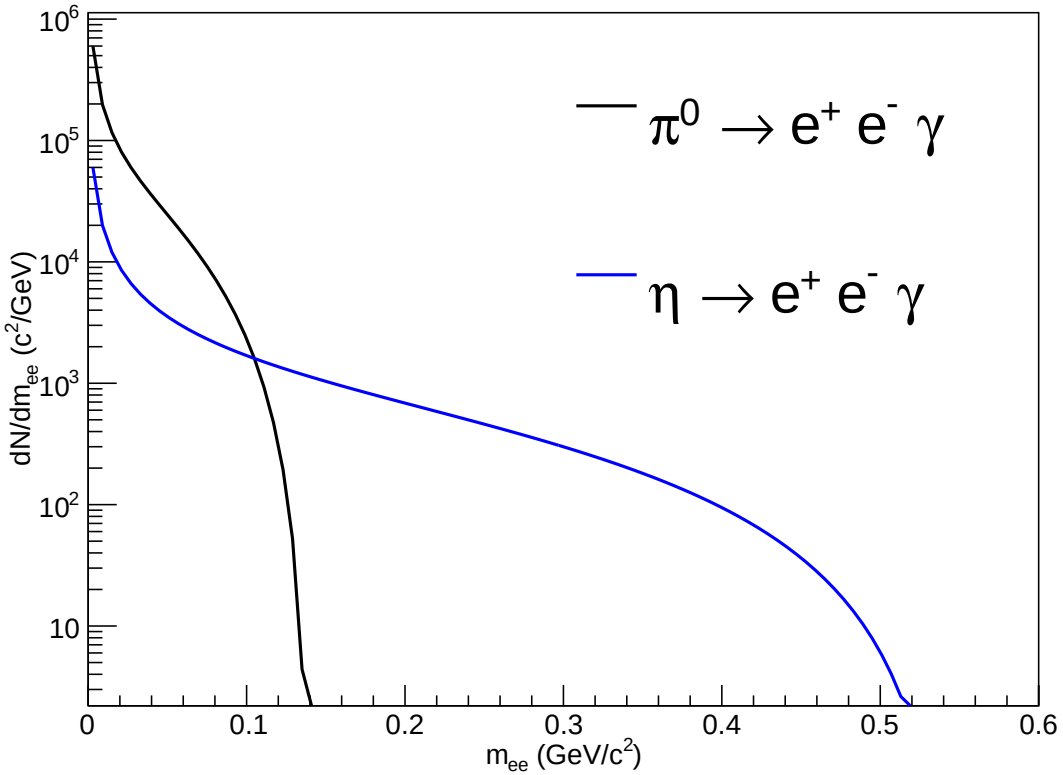

Free parameters:

- $N_\gamma \rightarrow$ normalisation factor
- $M_\gamma \rightarrow$ "pseudomass" of the photon
- $\sigma \rightarrow$ resolution of the detector
- $\tau \rightarrow$ slope of the esponential

# Kroll-Wada distribution

- For the Dalitz decays ⟶ Kroll-Wada distribution:

$$\frac{dN}{dm_{ee}} = N_X \cdot \frac{2}{m_{ee}} \left\{ (1+(m_{ee}/M_X)^2)^2 - 4(m_{ee}/M_X)^2 \right\}^{3/2} \sqrt{1 - \frac{4(m_e/M_X)^2}{(m_{ee}/M_X)^2}} \cdot \left\{ 1 + \frac{2(m_e/M_X)^2}{(m_{ee}/M_X)^2} \right\} \cdot F_X(m_{ee}^2)$$



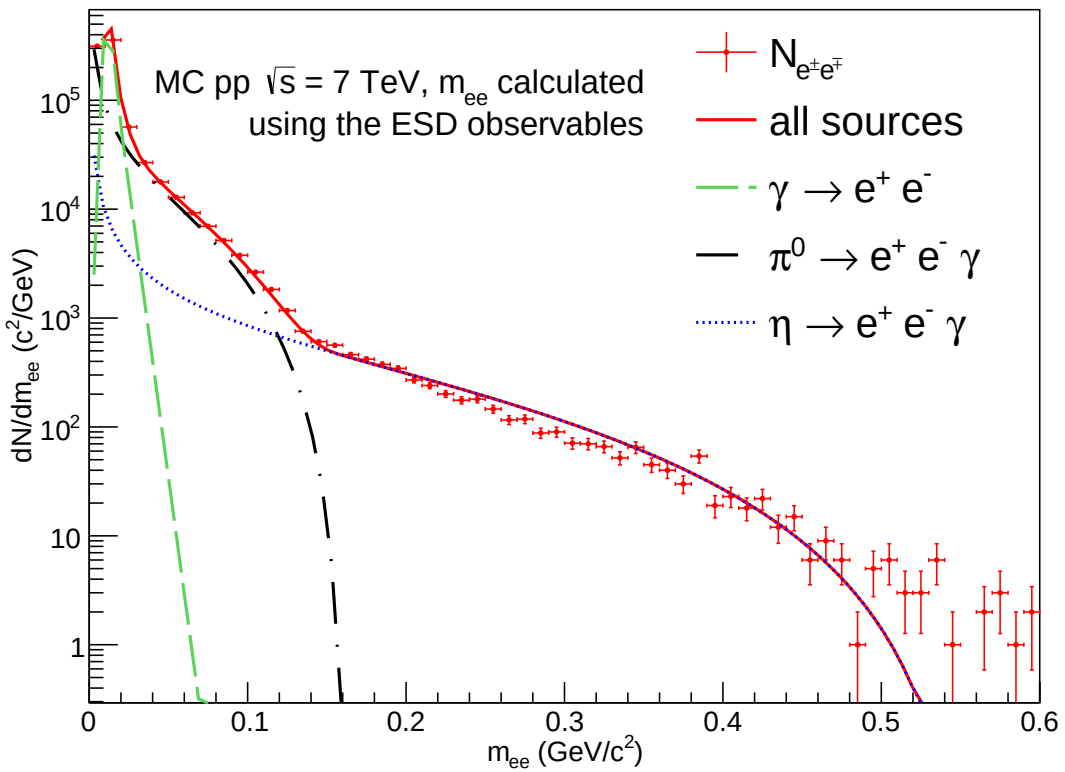

where $\begin{cases} F_{\pi^0}(m_{ee}^2) = \frac{1}{(1-5.5 \cdot m_{ee}^2)^2} \\ F_{\eta}(m_{ee}^2) = \frac{1}{(1-1.9 \cdot m_{ee}^2)^2} \end{cases}$

Free parameters:

- $N_X \to$ normalisation factor
- $M_X \to$ mass of the meson

# Fit template

- Select $e^+e^-$ pair with same $\gamma$, $\pi^0$ or $\eta$ mother particle from MC truth
- Calculate their invariant mass and obtain the relative distribution
- Fit with the function which is the sum of the three contributions




## From MC truth

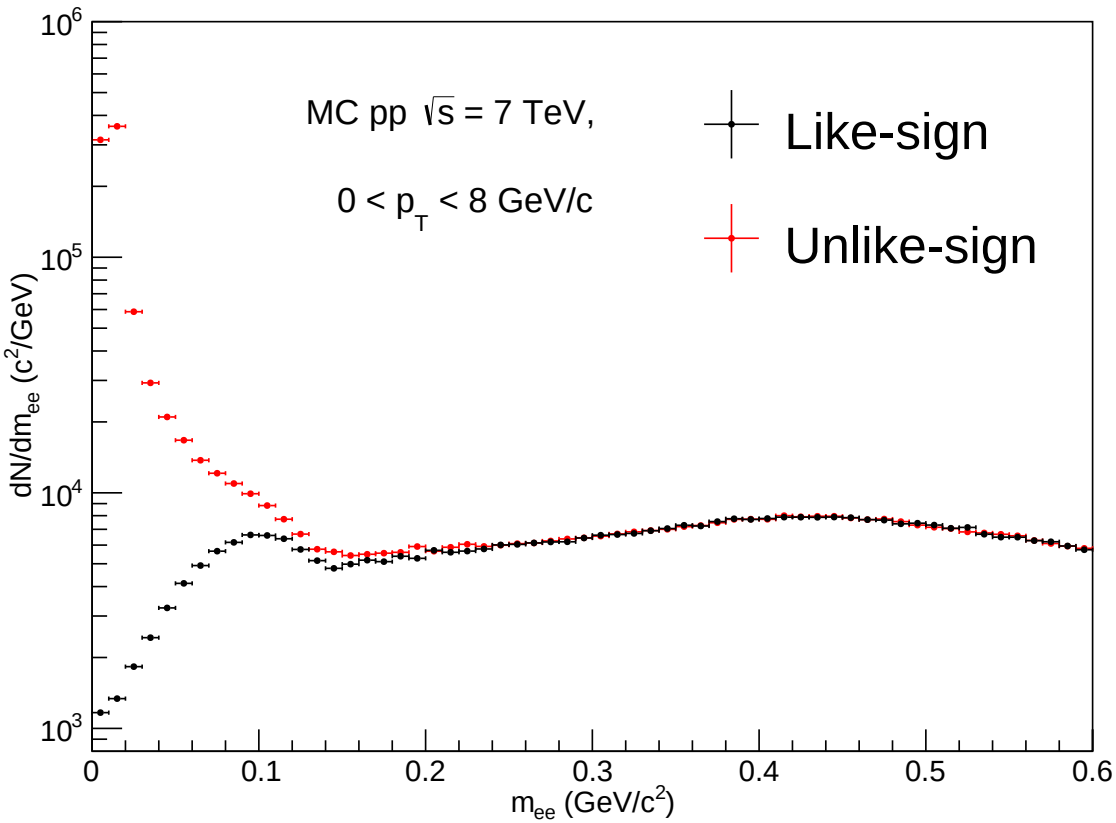
| | |
|---|---|
| number of $\gamma$ | 418300 $\pm$ 600 |
| number of $\pi^0$ | 362000 $\pm$ 600 |
| number of $\eta$ | 42100 $\pm$ 200 |
| $n_\gamma/n_{\pi^0}$ | 1.156 $\pm$ 0.003 |
| $n_\gamma/n_\eta$ | 9.94 $\pm$ 0.05 |
| $n_\gamma/(n_{\pi^0}+n_\eta)$ | 1.035 $\pm$ 0.002 |

## From the Fit

| | |
|---|---|
| $M_\gamma$ | 0.01107 $\pm$ 0.00018 $GeV/c^2$ |
| $M_{\pi^0}$ | 0.1611 $\pm$ 0.0003 $GeV/c^2$ |
| $M_\eta$ | 0.558 $\pm$ 0.004 $GeV/c^2$ |
| Integral of $\gamma$ | 418300 $\pm$ 1100 |
| Integral of $\pi^0$ | 355000 $\pm$ 2000 |
| Integral of $\eta$ | 49200 $\pm$ 600 |
| $I_\gamma/I_{\pi^0}$ | 1.179 $\pm$ 0.007 |
| $I_\gamma/I_\eta$ | 8.50 $\pm$ 0.11 |
| $I_\gamma/(I_{\pi^0}+I_\eta)$ | 1.035 $\pm$ 0.006 |

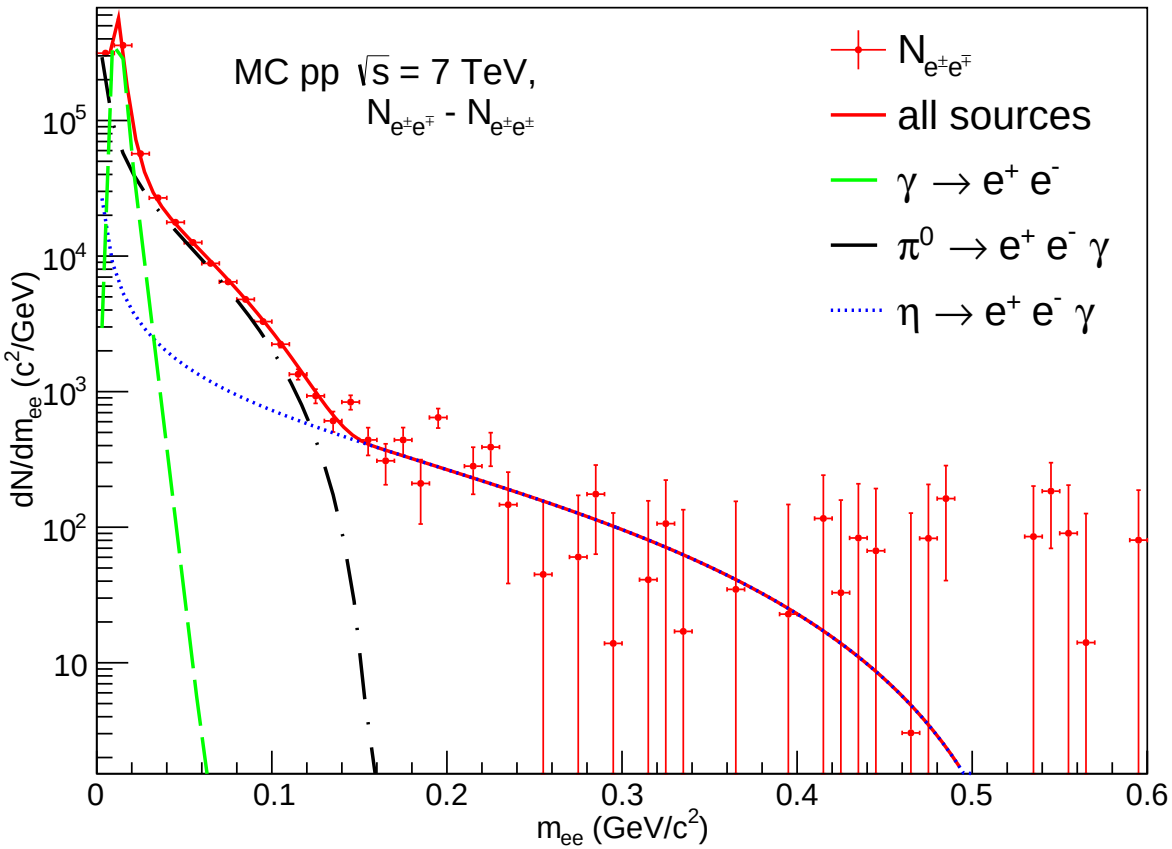
# Like-sign and Unlike-sign distributions

- Unlike-sign distribution
  - → photonic signal + combinatorial background
- Like-sign distribution
  - → combinatorial background



# Fit of the photonic background

- The like-sign distribution is subtracted to the unlike-sign distribution




- The resulting photonic signal is fitted with the template obtained from the MC truth

| | |
|---|---|
| Integral of $\gamma$ | 423000 $\pm$ 6000 |
| Integral of $\pi^0$ | 354000 $\pm$ 4000 |
| Integral of $\eta$ | 42000 $\pm$ 3000 |
| $I_\gamma / I_{\pi^0}$ | 1.19 $\pm$ 0.02 |
| $I_\gamma / I_\eta$ | 10.0 $\pm$ 0.8 |
| $I_\gamma / (I_{\pi^0} + I_\eta)$ | 1.07 $\pm$ 0.02 |

# Results

**RESULT:** the amount of the three sources obtained with the fit of the photonic signal is consistent within the statistical error with the numbers known from MC

| Particle | Number from MC truth | Relative statistical error | Integral from photonic signal fit | Relative statistical error |
|---|---|---|---|---|
| $\gamma$ | 418300 $\pm$ 600 | 0.14% | 423000 $\pm$ 6000 | 1.4% |
| $\pi^0$ | 362000 $\pm$ 600 | 0.17% | 354000 $\pm$ 4000 | 1.1% |
| $\eta$ | 42100 $\pm$ 200 | 0.48% | 42000 $\pm$ 3000 | 7.1% |

| Ratios | MC truth | Photonic signal fit | Gaussian test (num of $\sigma$) |
|---|---|---|---|
| $\gamma/\pi^0$ | 1.156 $\pm$ 0.003 | 1.19 $\pm$ 0.02 | 1.68 |
| $\gamma/\eta$ | 9.94 $\pm$ 0.05 | 10.0 $\pm$ 0.8 | 0.07 |
| $\gamma/(\pi^0+\eta)$ | 1.035 $\pm$ 0.002 | 1.07 $\pm$ 0.02 | 1.73 |

# Results

**RESULT:** the amount of the three sources obtained with the fit of the photonic signal is consistent within the statistical error with the numbers known from MC

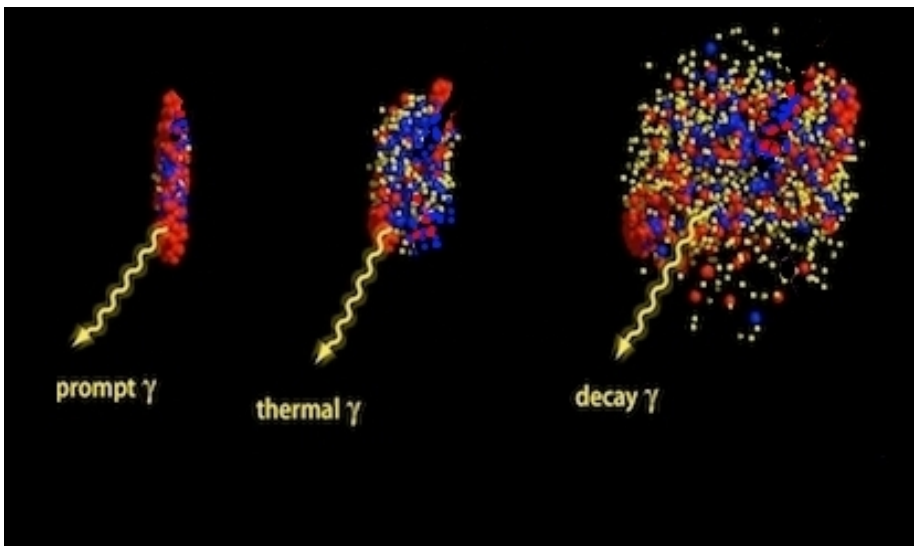
| Particle | Number from MC truth | Relative statistical error | Integral from photonic signal fit | Relative statistical error |
|---|---|---|---|---|
| $\gamma$ | 418300 $\pm$ 600 | 0.14% | 423000 $\pm$ 6000 | 1.4% |
| $\pi^0$ | 362000 $\pm$ 600 | 0.17% | 354000 $\pm$ 4000 | 1.1% |
| $\eta$ | 42100 $\pm$ 200 | 0.48% | 42000 $\pm$ 3000 | 7.1% |

| Ratios | MC truth | Photonic signal fit | Gaussian test (num of $\sigma$) |
|---|---|---|---|
| $\gamma/\pi^0$ | 1.156 $\pm$ 0.003 | 1.19 $\pm$ 0.02 | 1.68 |
| $\gamma/\eta$ | 9.94 $\pm$ 0.05 | 10.0 $\pm$ 0.8 | 0.07 |
| $\gamma/(\pi^0+\eta)$ | 1.035 $\pm$ 0.002 | 1.07 $\pm$ 0.02 | 1.73 |

→ LARGE STATISTICAL ERROR

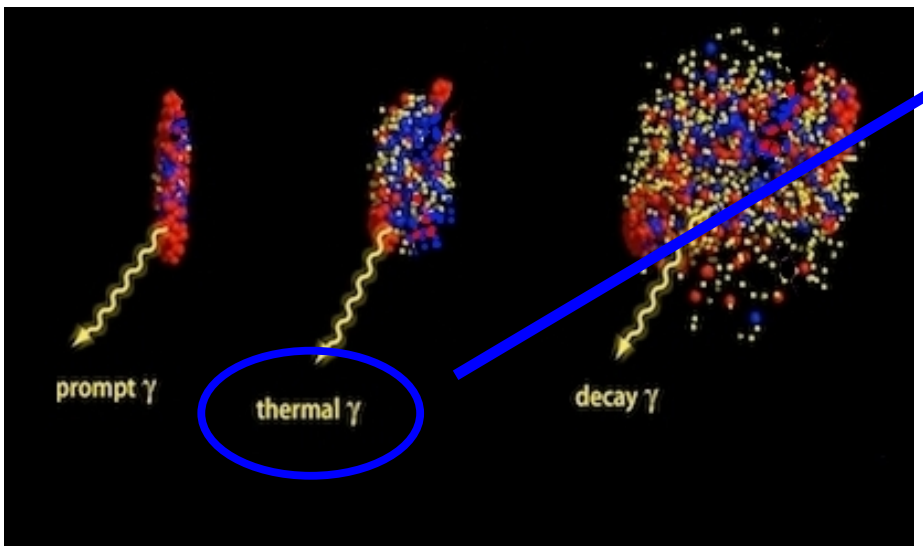
# Proton-proton and Pb-Pb data

- Look into proton-proton real data and verify that the same ratios are found
- Pb-Pb events : What would be different?



# Proton-proton and Pb-Pb data

- Look into proton-proton real data and verify that the same ratios are found
- Pb-Pb events : What would be different?




An excess of $\gamma$, due to the thermal photons generated by the fireball, is expected

the ratio between gamma conversion and Dalitz decays should be larger

# Acknowledgements

I would like to express my deep gratitude to all the ALICE group at GSI, and in particular a special thank to:

- my tutor, Prof. Ralf Averbeck
- Prof. Silvia Masciocchi
- Dr. Jochen Thäder
- Dr. Jan Wagner

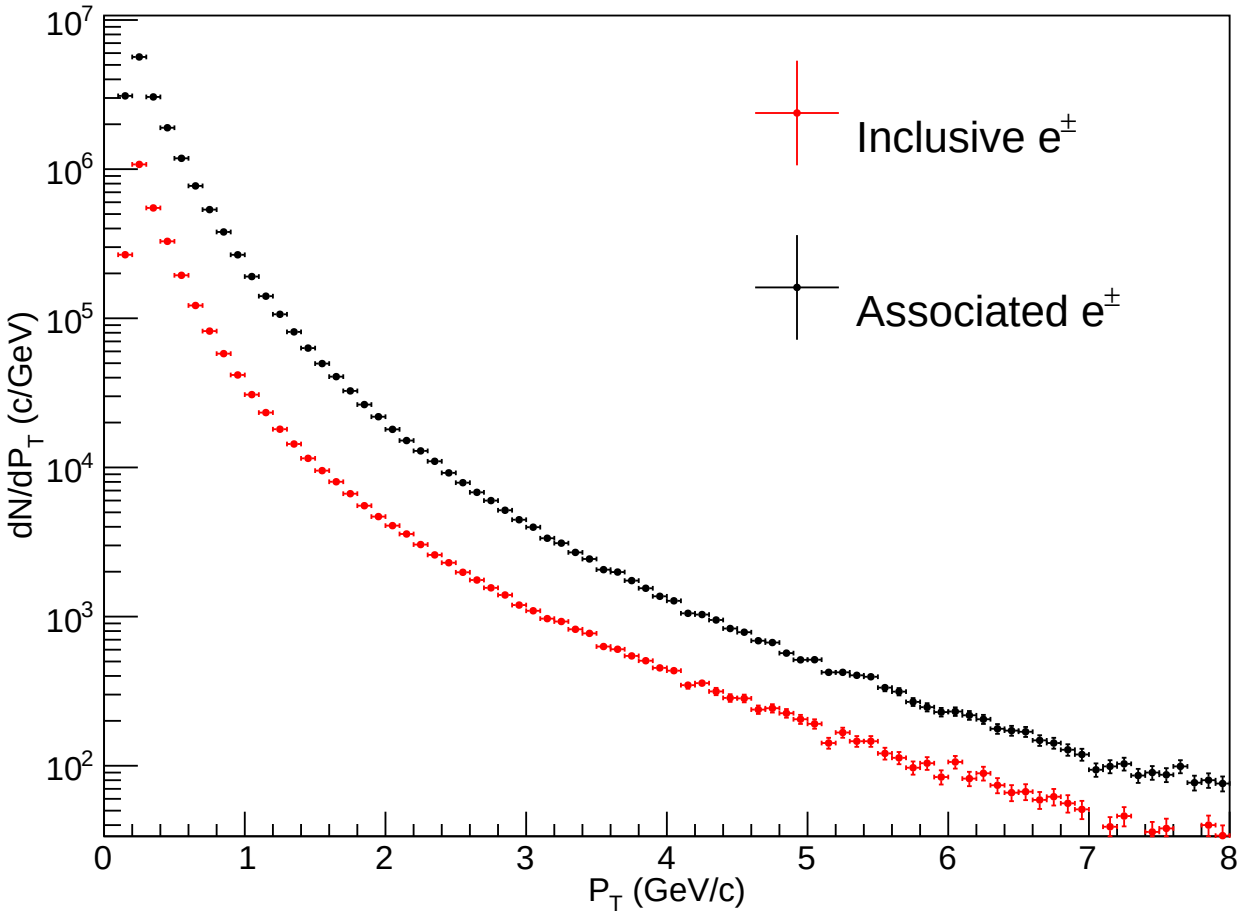
Thank you for your attention!!

# BACKUP

Fabrizio Grosa

# $e^{\pm}$ identification 2

- Inclusive $e^{\pm}$ → stringent cuts are required
- Associated $e^{\pm}$ → relaxed cuts are required:
  tracks resolution is lost, but efficiency is maximised




Finally, using the MC truth information, only the tracks that really belong to $e^{\pm}$ are selected

# Invariant mass analysis

According to Special Relativity the four-momentum $p = (E, \vec{p})$ of a physics system is always conserved, and the mass of a particle is equal to:

$$m_i^2 = E_i^2 - \vec{p_i}^2 \equiv p_i^2$$

$\longrightarrow$ we can calculate the invariant mass of a particle from its decay products

$$m_{ee} = \sqrt{(p_1 + p_2)^2} = \sqrt{(E_1 + E_2)^2 - (\vec{p_1} + \vec{p_2})^2}$$