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Measurement of Hadronic Cross Sections Using Initial State Radiation at BESIII

What are we doing?

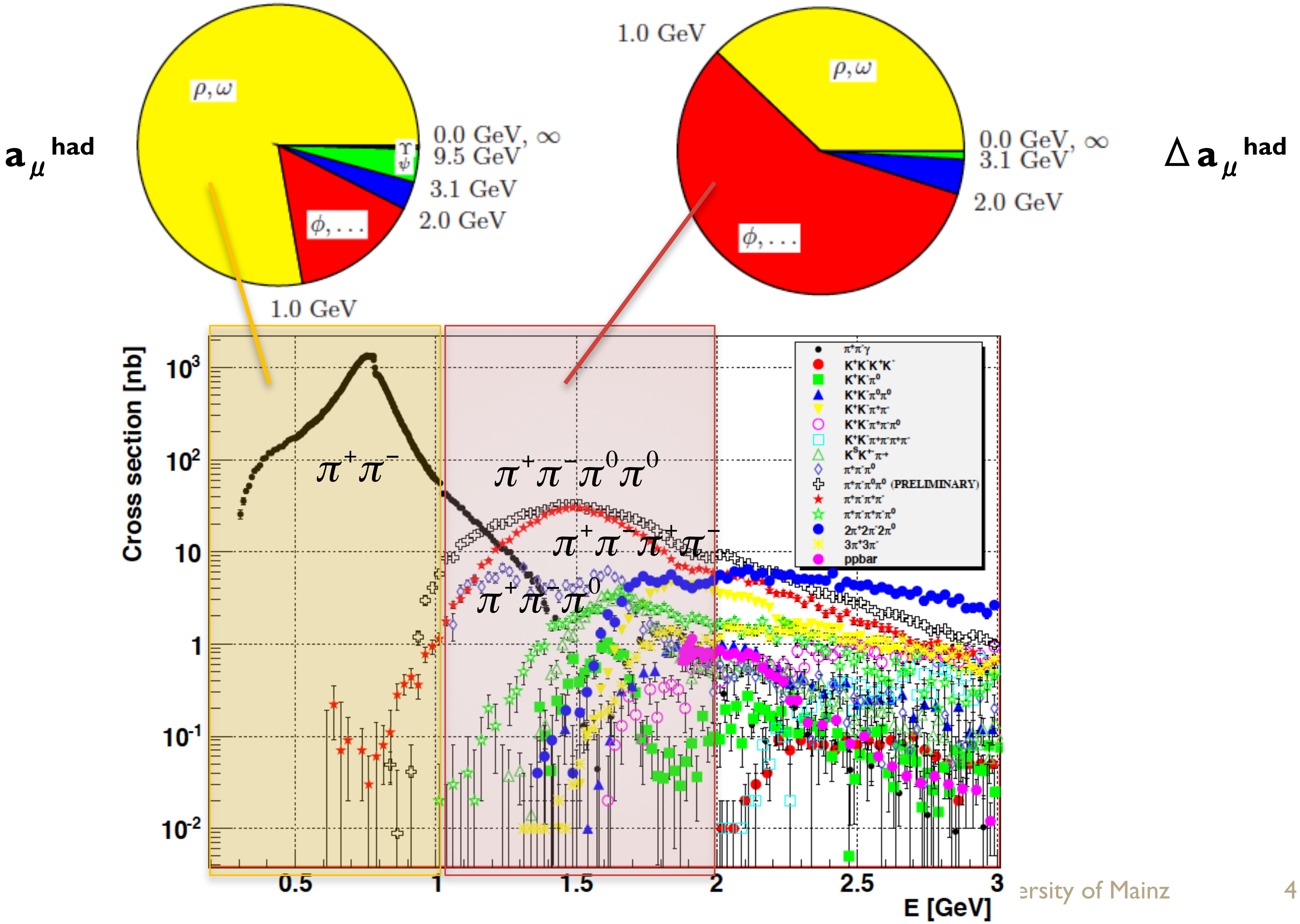
Motivation

The reason why we are here!

$$a_\mu^{hadr,VP}[LO] = \frac{1}{4\pi^3}\int_{4m_\pi^2}^{\infty} K(s)\sigma(e^+e^- \to hadr)ds$$

Hadronic cross sections

Distribution of contributions to $\mathbf{a}_\mu^{\mathbf{had}}$ and $\Delta \mathbf{a}_\mu^{\mathbf{had}}$:



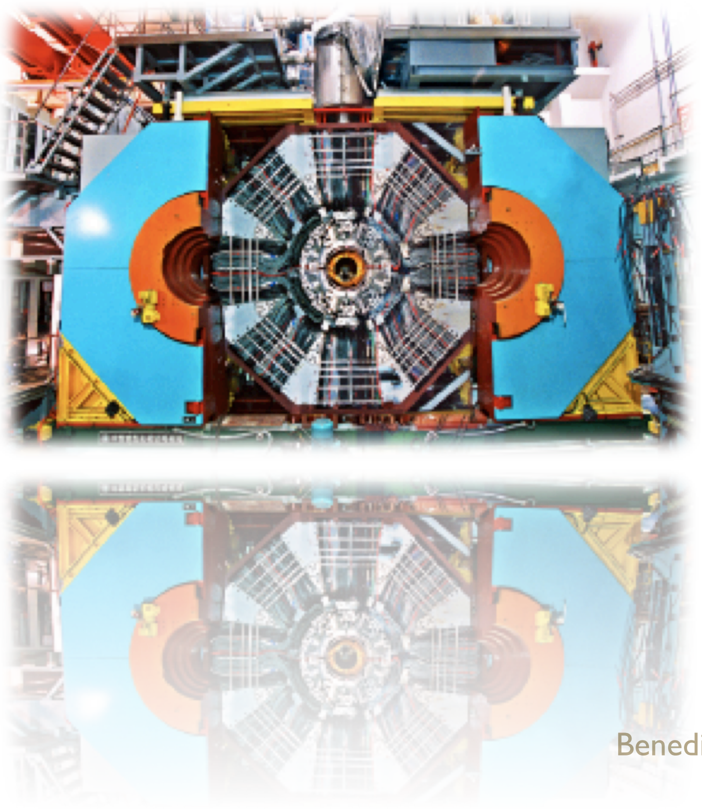
Hadronic cross sections

Our goal:

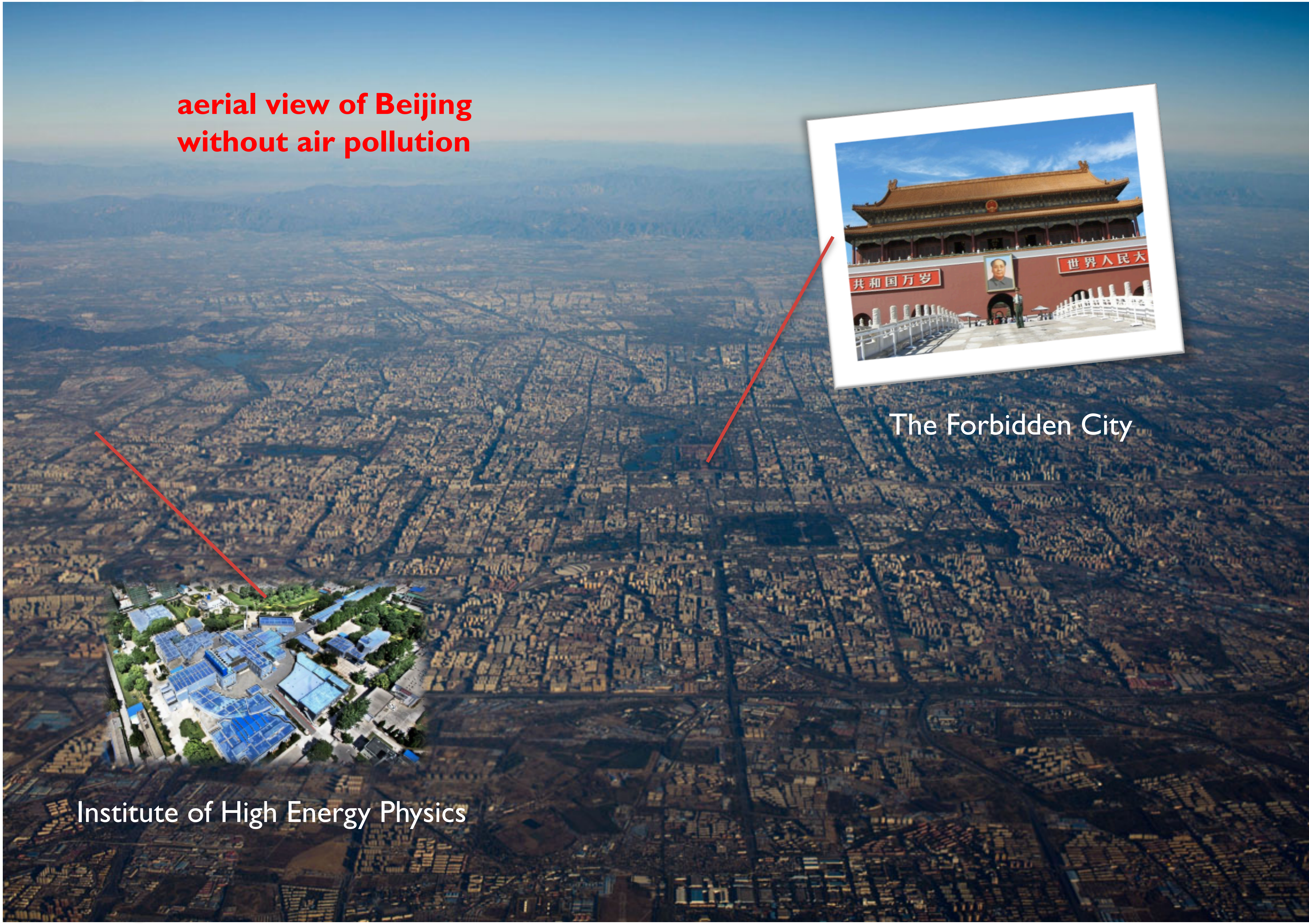
Measurement of hadronic cross sections
at the BESIII experiment
with the highest possible precision.

final state	studied by
$\pi^+\pi^-$	Benedikt Kloss
$\pi^+\pi^-\pi^0$	Yaqian Wang
$\pi^+\pi^-\pi^0\pi^0$	Martin Ripka

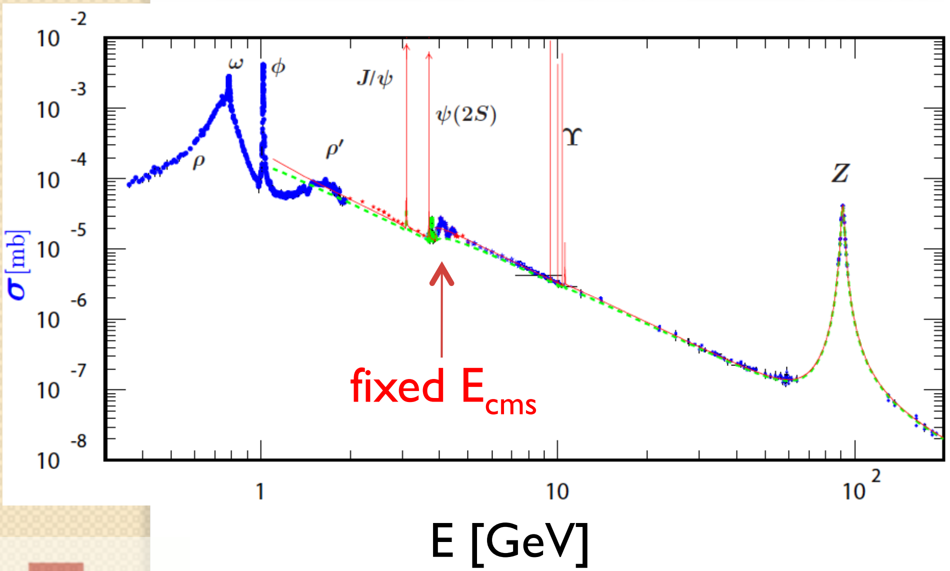
The BESIII experiment




aerial view of Beijing


aerial view of Beijing
without air pollution
世界人民大
共和国万岁
The Forbidden City
Institute of High Energy Physics

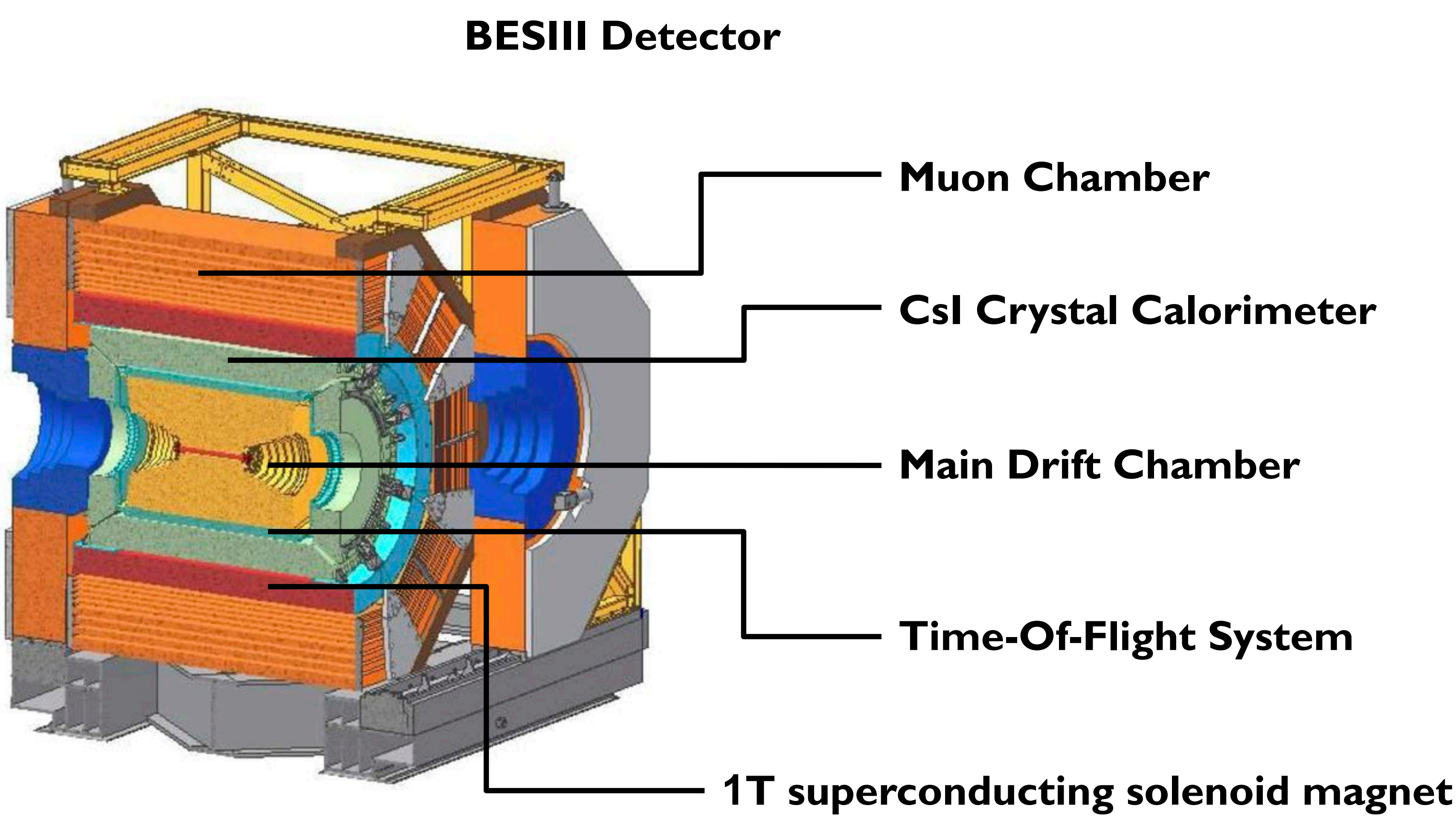
The BESIII experiment



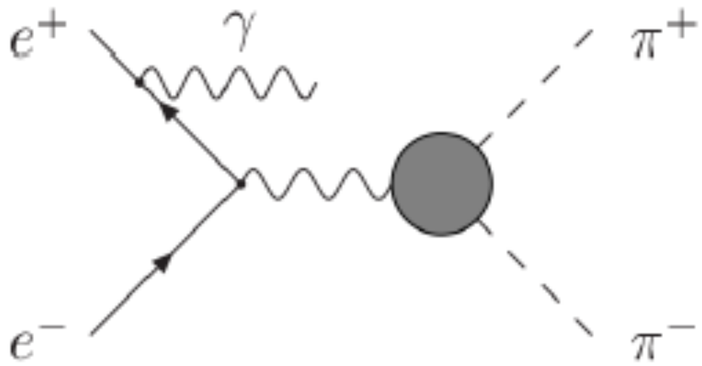
BEPC-II Collider:

- located in Beijing, China
- symmetric e+e⁻ collider
- 2 GeV < E_{CMS} < 4.6 GeV
- typically fixed CMS energy (J/ψ (3.096 GeV), ψ (3770), etc.)
- data taken at $\sqrt{s} = 3.770 GeV$: 2.9 fb^{-1}

The BESIII experiment

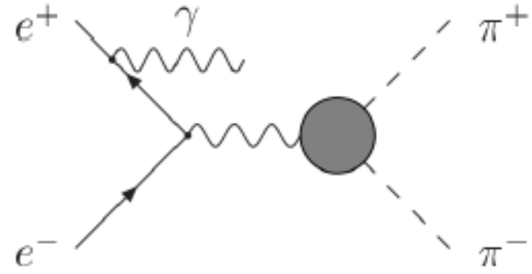


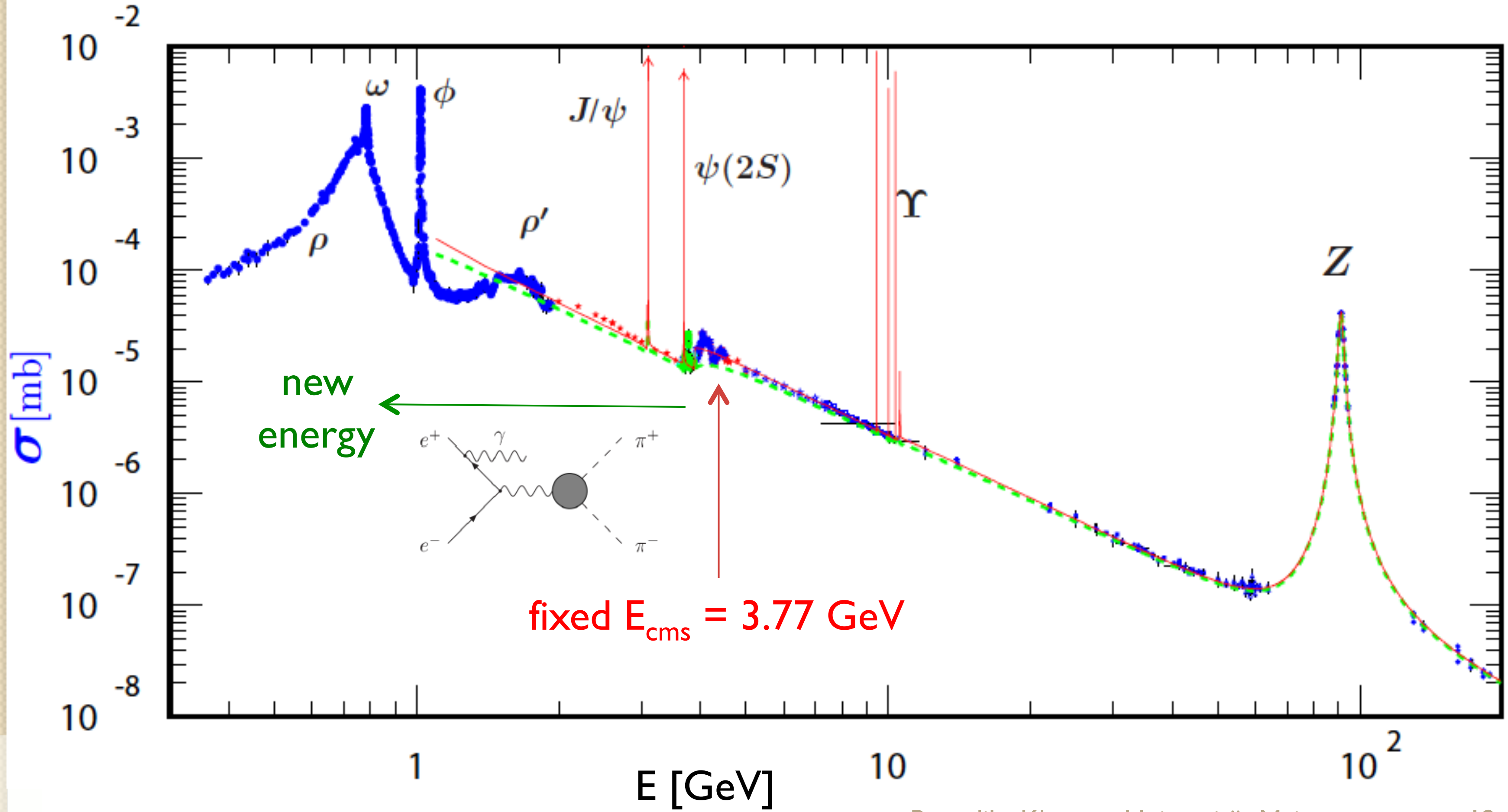
Initial State Radiation at BESIII



Initial State Radiation

- photon emitted in the initial state
- CMS energy lowered by the energy of the emitted photon
  ⇒ measurements at different energies possible

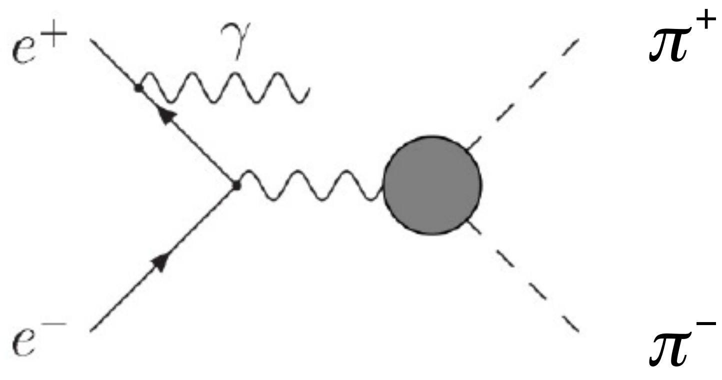




Initial State Radiation

Study the channel

$$e^+e^- \to \pi^+\pi^-\gamma_{ISR}$$



to measure the cross section of $e^+e^- \to \pi^+\pi^-$

via

$$\frac{d\sigma_{ISR}(M_{2\pi})}{dM_{2\pi}} = \frac{2M_{2\pi}}{s} W(s,x,\theta_\gamma)\cdot \sigma(M_{2\pi})$$

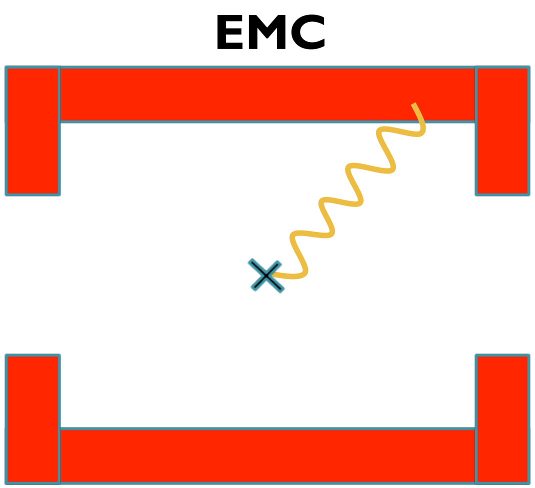
invariant mass of 2π

Radiator function

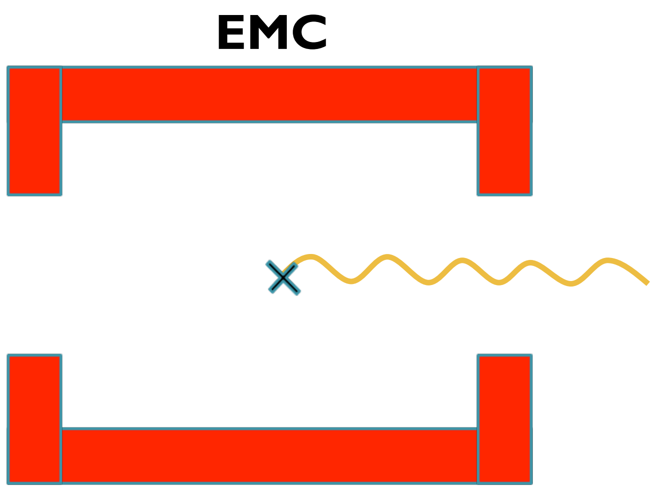
Initial State Radiation

Two different analysis types:

- tagged: photon is detected in the Electromagnetic Calorimeter
- untagged: photon leaves the detector (most probable case)



tagged:
photon hits EMC

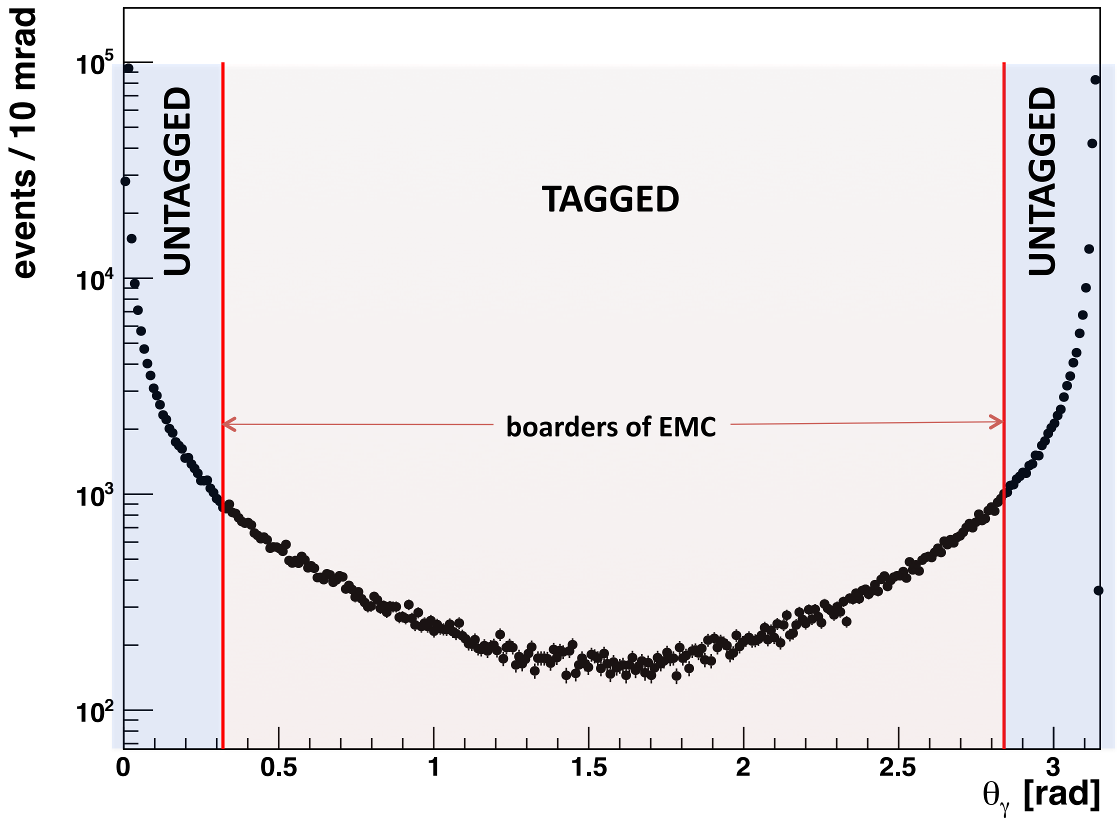


untagged:
photon leaves the detector

Initial State Radiation

Two different analysis types:

- tagged: photon is detected in the Electromagnetic Calorimeter
- untagged: photon leaves the detector (most probable case)



First results

$$\pi^+\pi^-$$

nota bene: study in progress
no official BESIII plots

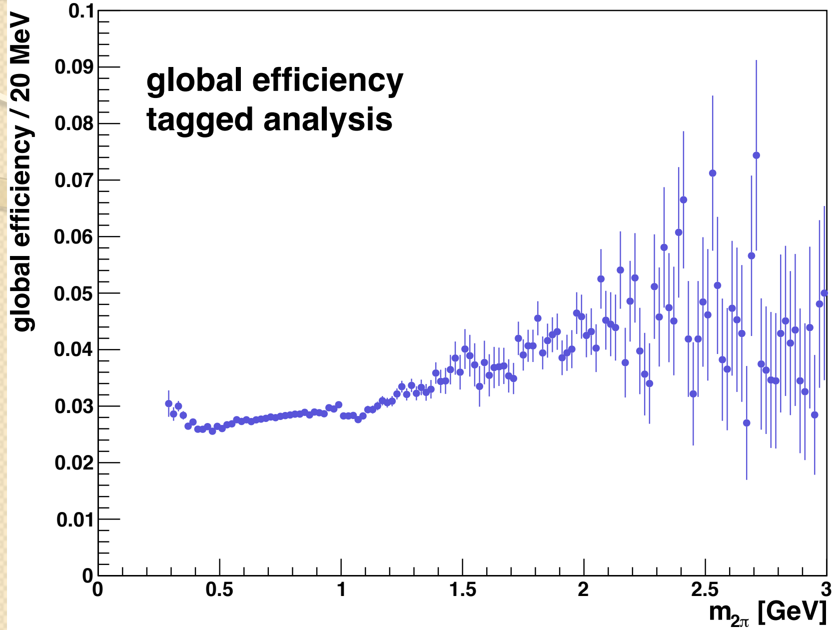
BESIII

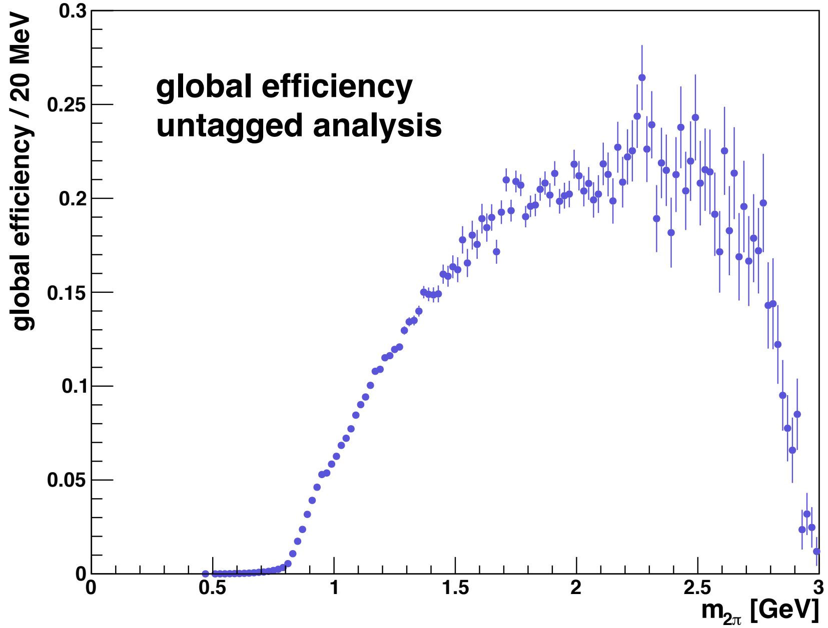
Event Selection

Typical event selection: $e^+e^- \to \pi^+\pi^-\gamma_{ISR}$

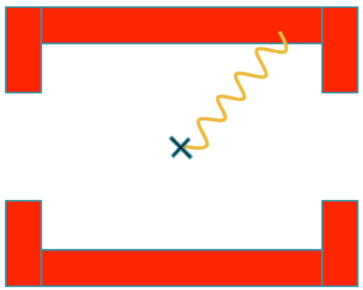
distance to interaction point	R_{xy} < 1.0 cm R_z < 10.0 cm
to supress $e^+e^- \to e^+e^-\gamma_{ISR}$	electron PID
# charged tracks	= 2
total charge	= 0
photon energy	> 0.4 GeV
# photons	= 1 (in tagged analysis) = 0 (in untagged analysis)

Global Efficiency

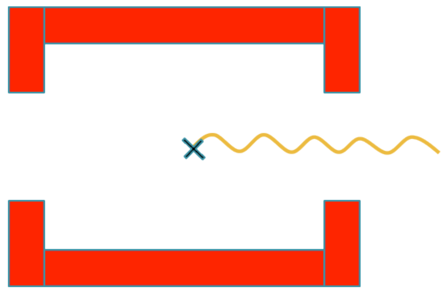




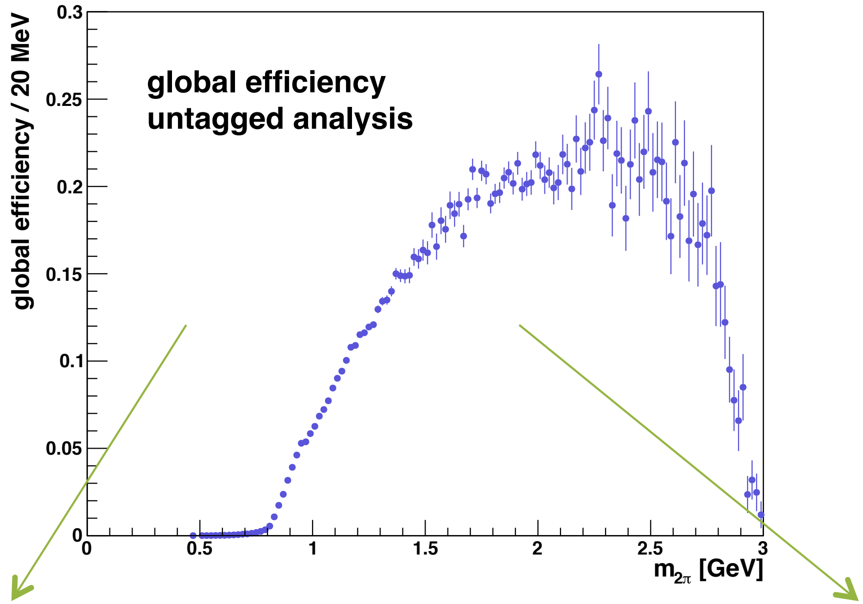
EMC

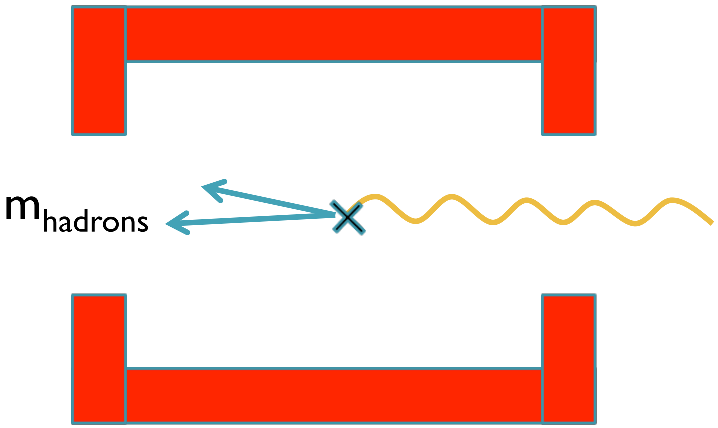


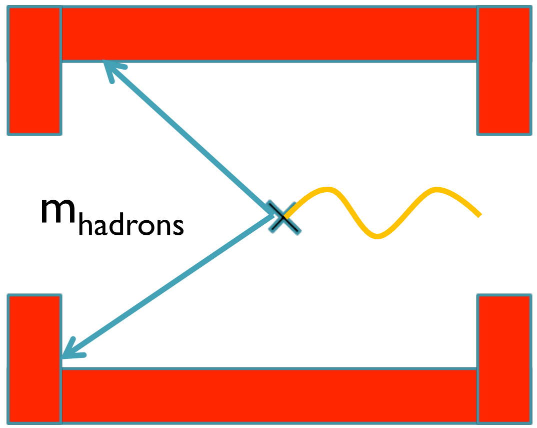
EMC



Global Efficiency



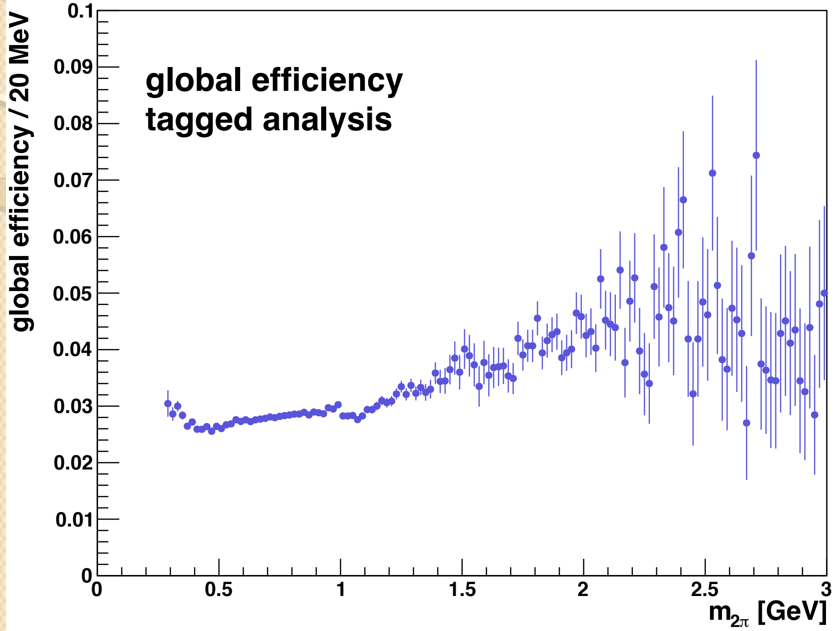


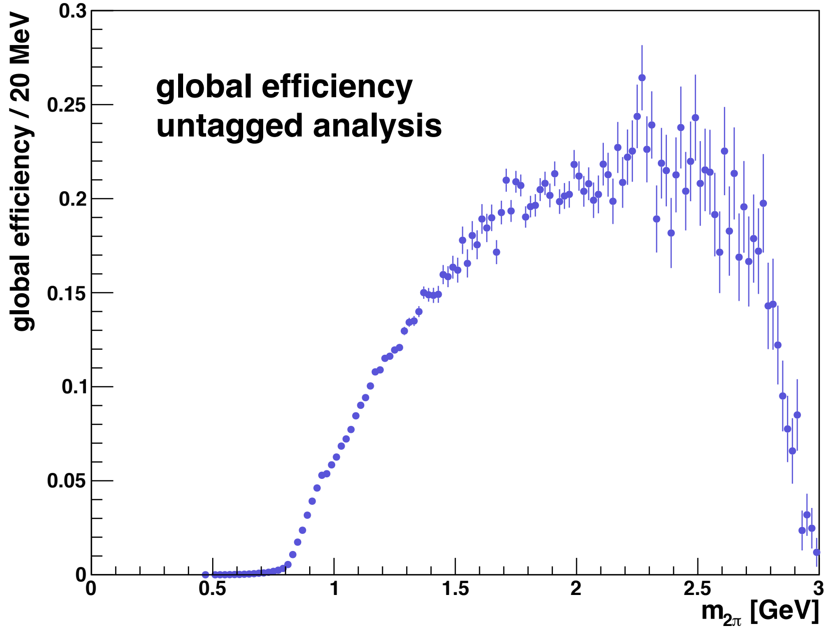


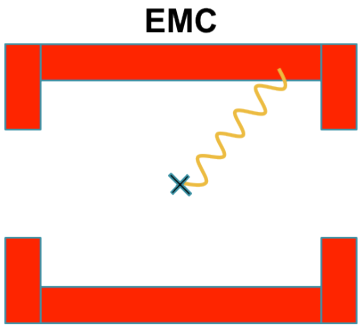
high energetic photon
small hadronic invariant mass

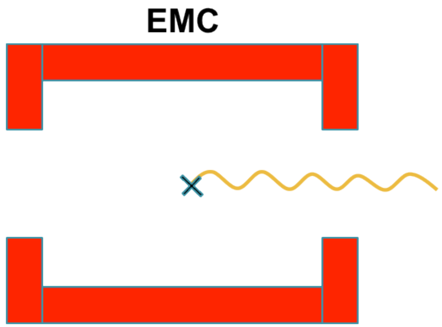
low energetic photon
high hadronic invariant mass

Global Efficiency







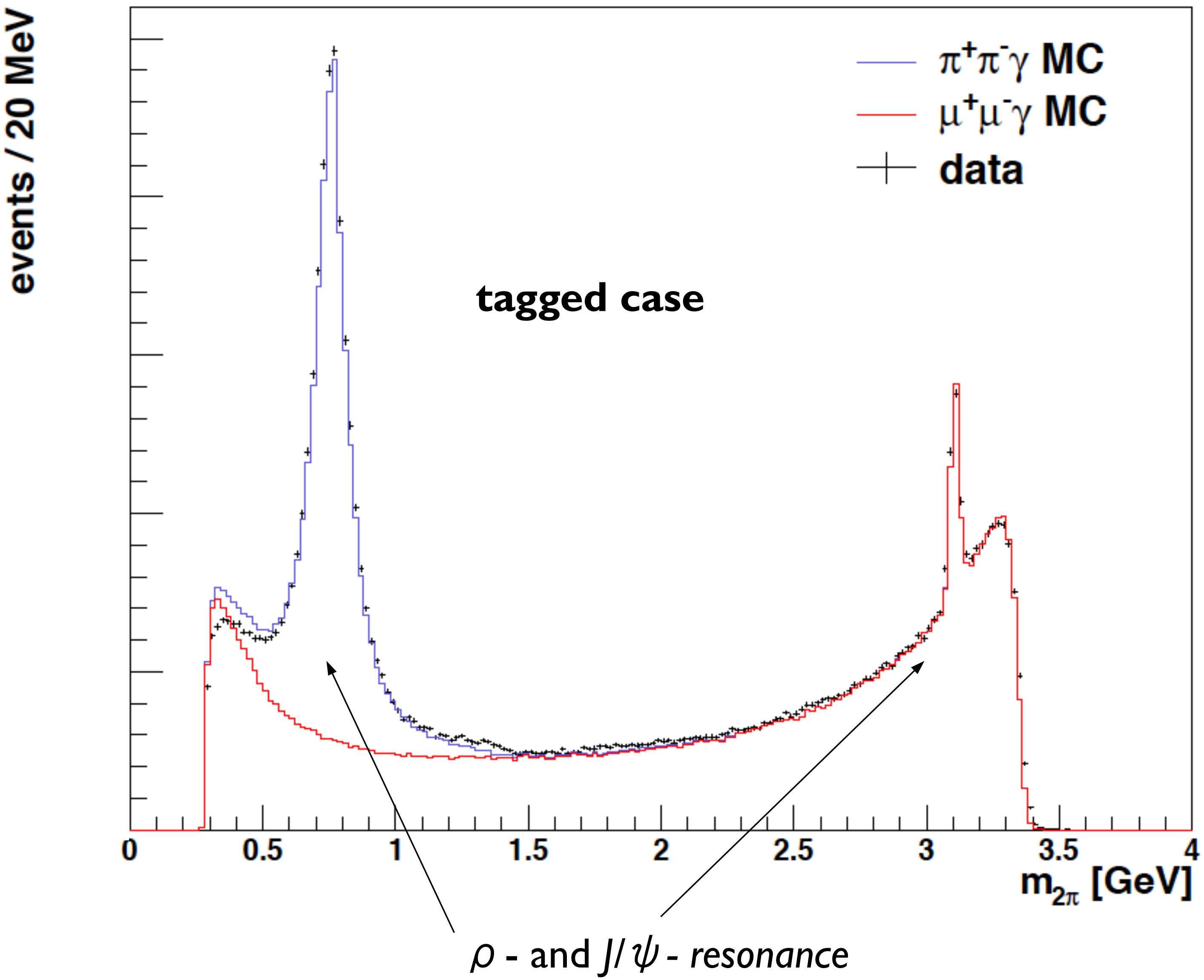


⇒ the ρ -peak can only be studied in the tagged analysis

Event Selection

MC produced with PHOKHARA

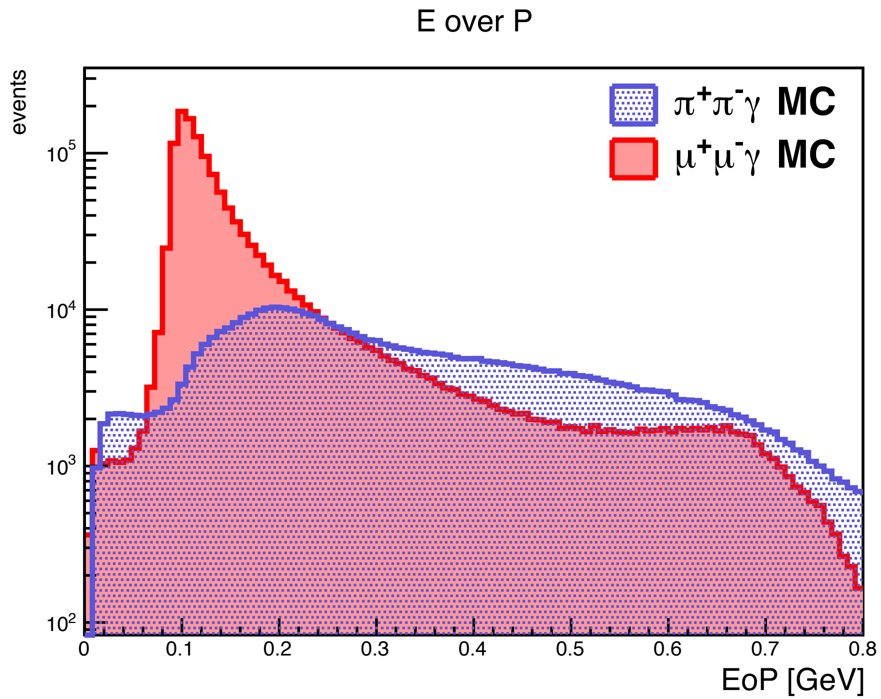
⇒ good mu/pi seperation needed!



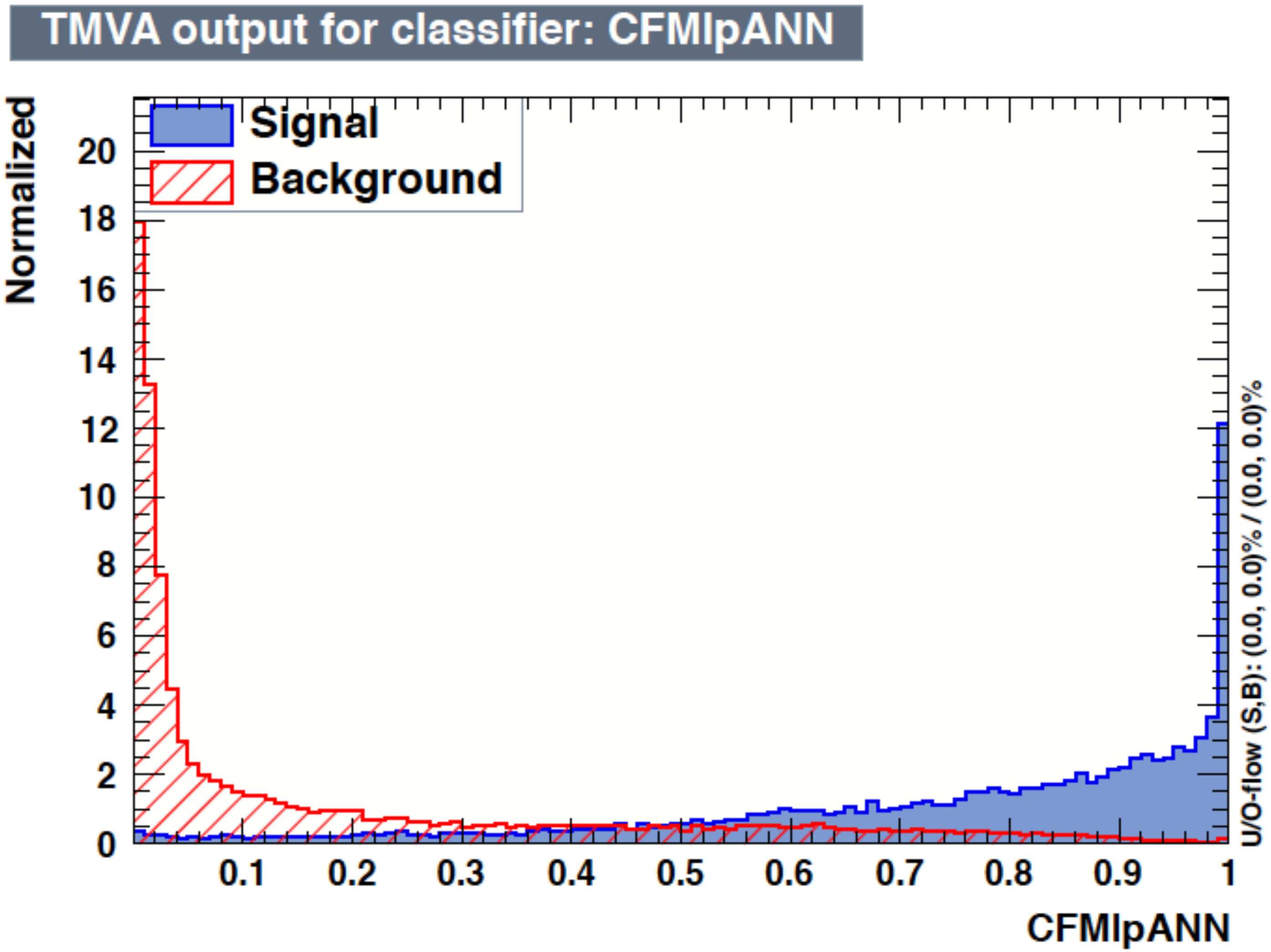
Training an Artificial Neural Network

- Idea: Training an Artificial Neural Network

- Input variables:
  - **Muon Chamber:** depth
  - **Electromagnetic Calorimeter:** shower shapes and E/p
  - **Drift Chamber:** dE/dx

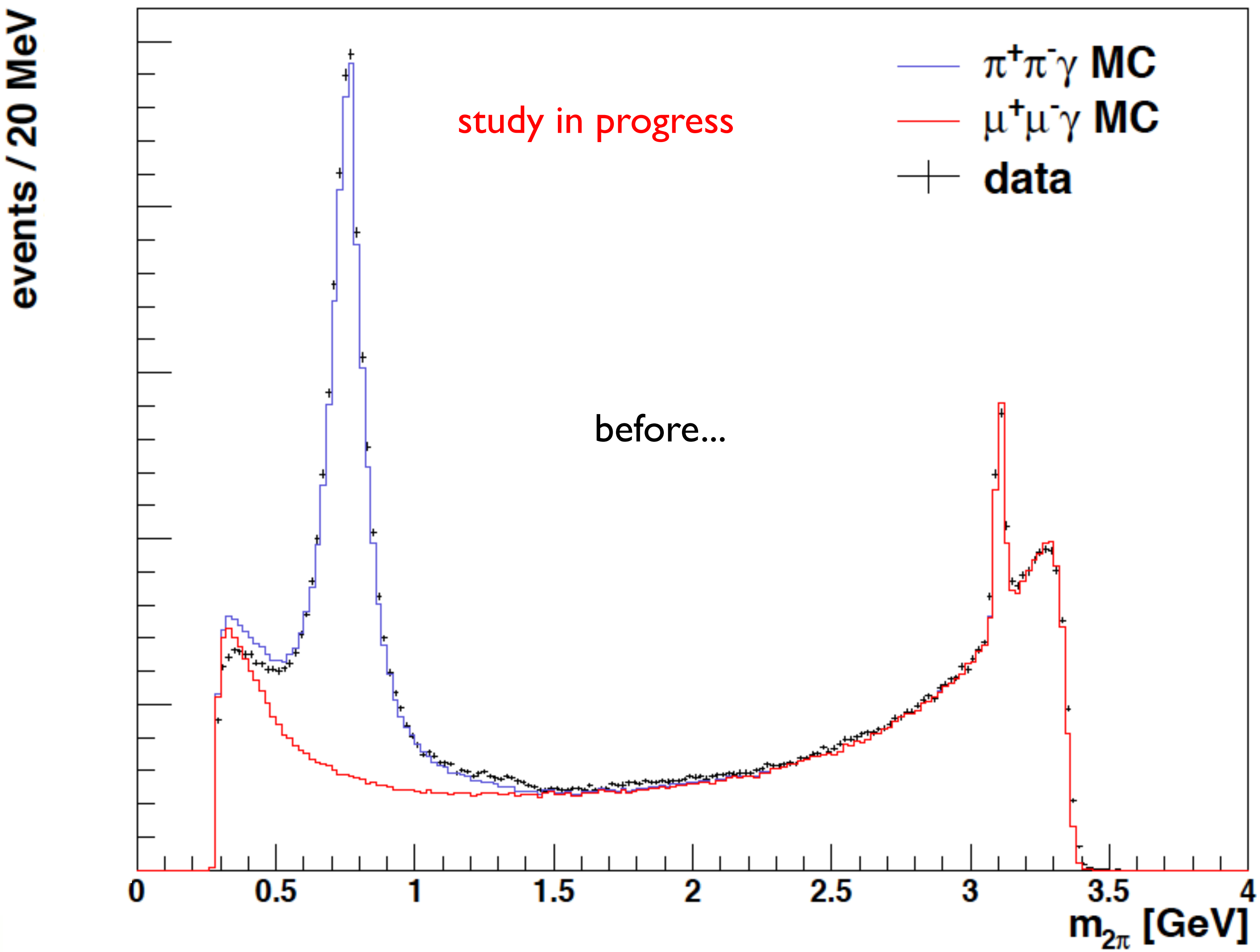


Training an Artificial Neural Network

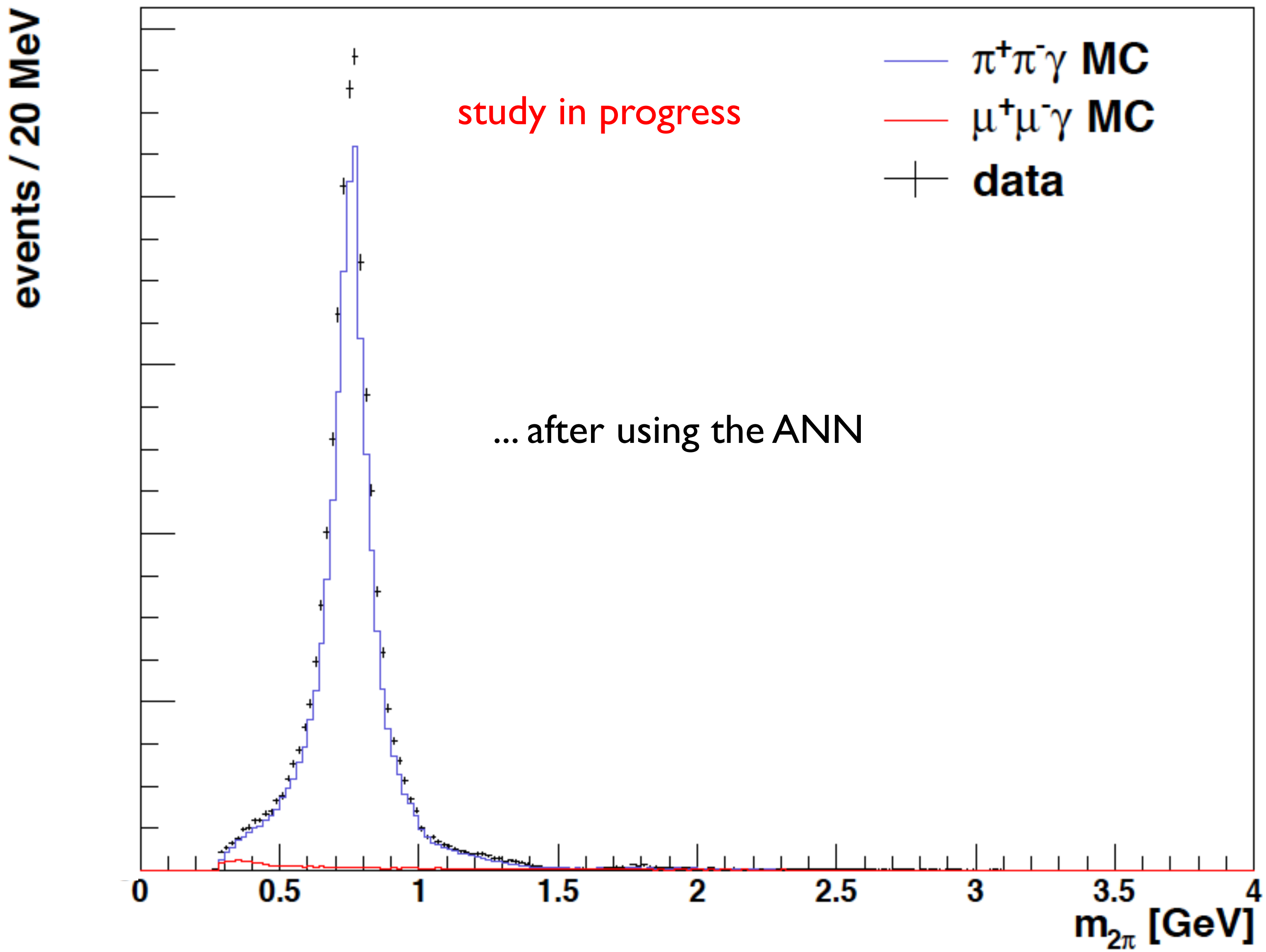


output of the Artificial Neural Network

Using the ANN in my analysis

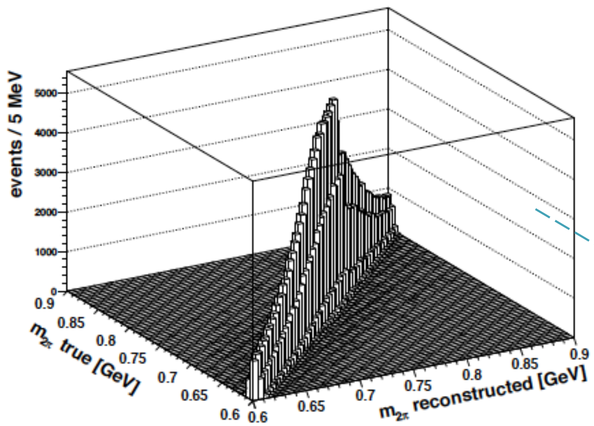


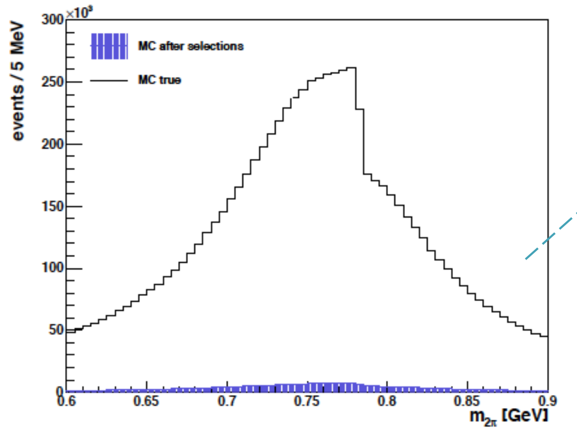
Using the ANN in my analysis



Analysis steps

BESIII ψ (3770) data set

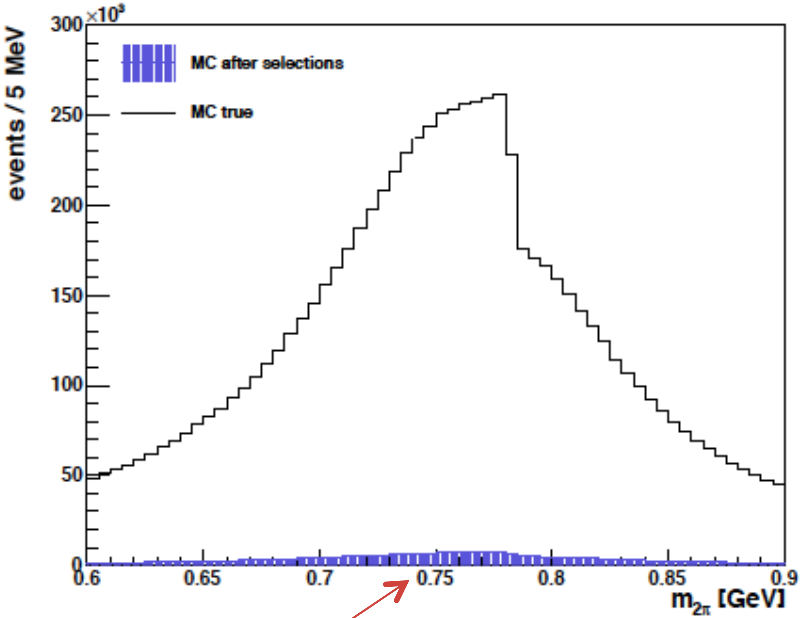


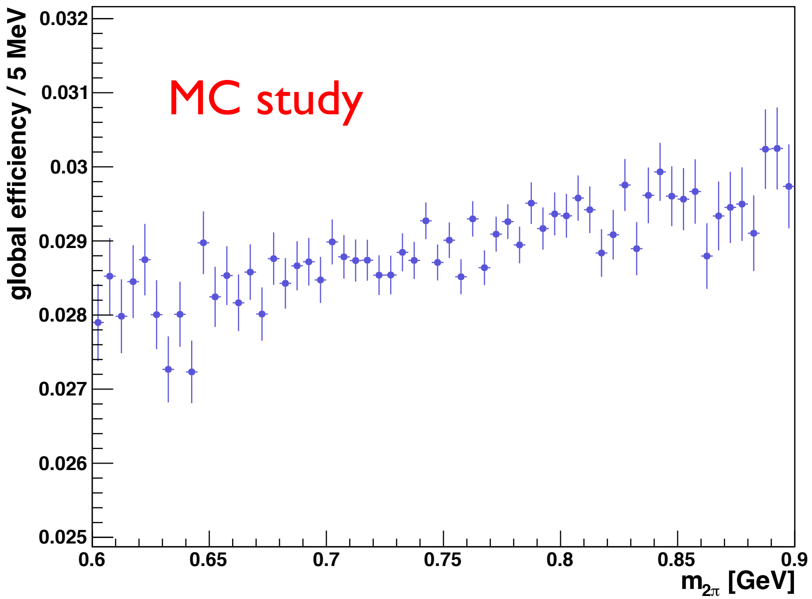


1. event selection
2. background subtraction
3. unfolding
4. divide by global efficiency (data-MC correction)
5. normalize to luminosity and radiator function
6. vacuum polarization and FSR correction

$$\sigma^{bare}(e^+e^- \to \pi^+\pi^-(\gamma_{FSR}))$$

Heart of the analysis - global efficiency





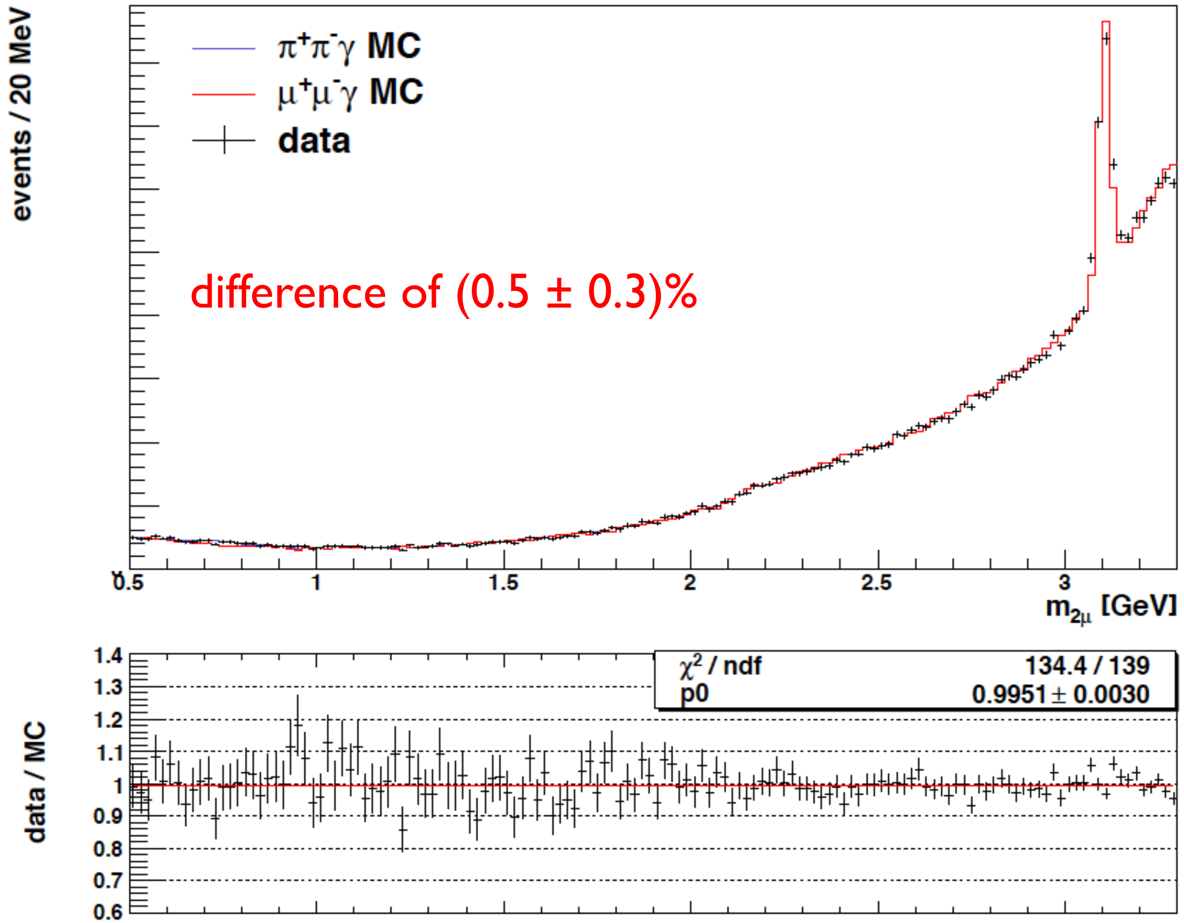
HIGH PRECISION:
data-MC efficiency corrections

Efficiency Study	Status
pion tracking efficiency	✓
muon tracking efficiency	✓
photon efficiency	✓
pion PID efficiency (neural network)	✓
muon PID efficiency (neural network)	✓
electron PID efficiency	✓

QED test

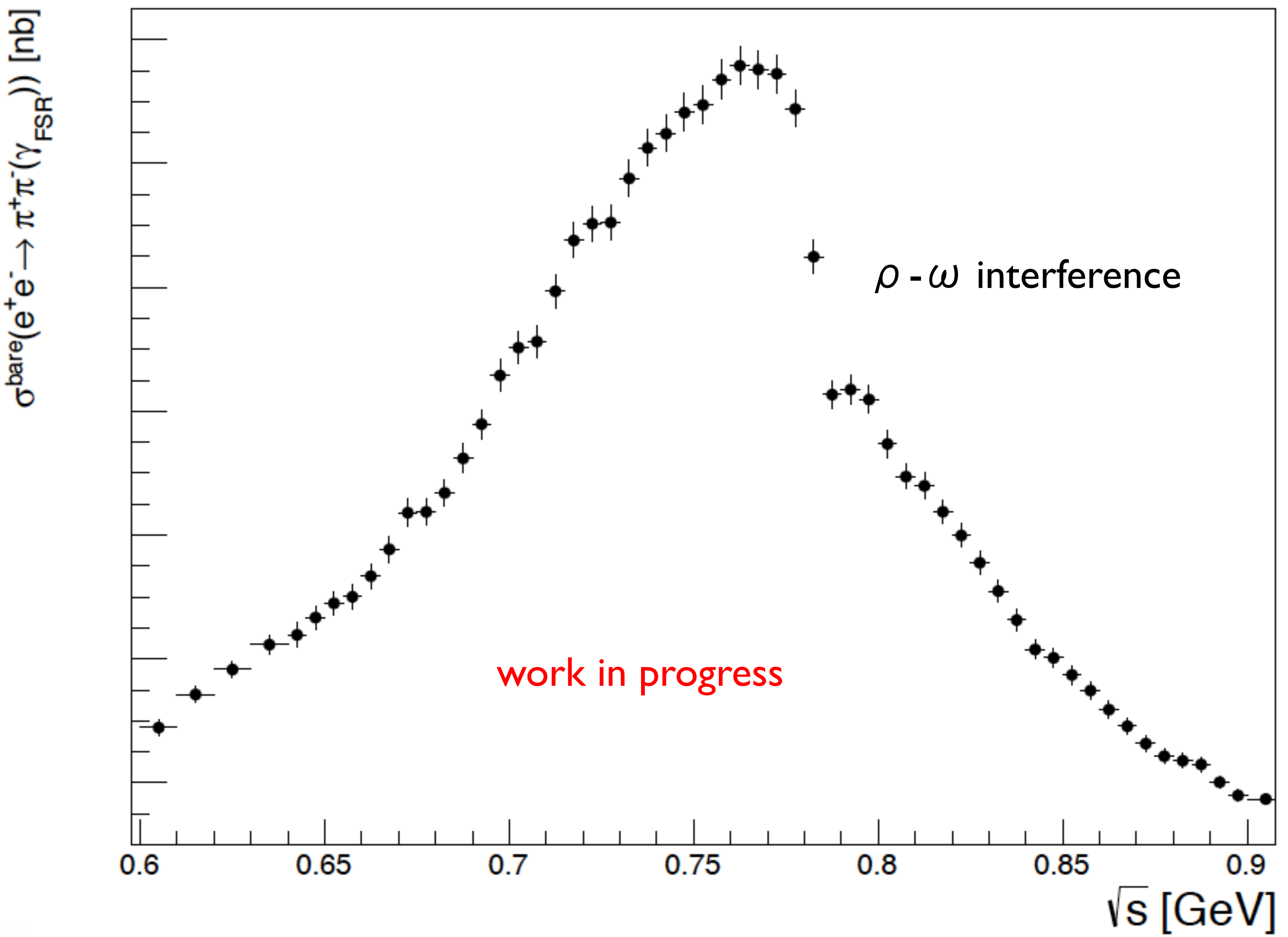
One can do now a **cross check** if the efficiency corrections work correctly.

The process $e^+e^- \to \mu^+\mu^-\gamma_{ISR}$ is a pure QED process and so the MC prediction has an accuracy much better than 1%.



all efficiency corrections are applied on the MC

Result



$\sigma^{bare}(e^+e^- \to \pi^+\pi^-(\gamma_{FSR}))$ [nb]
ρ - ω interference
work in progress
0.6
0.65
0.7
0.75
0.8
0.85
0.9
$\sqrt{s}$ [GeV]

First results

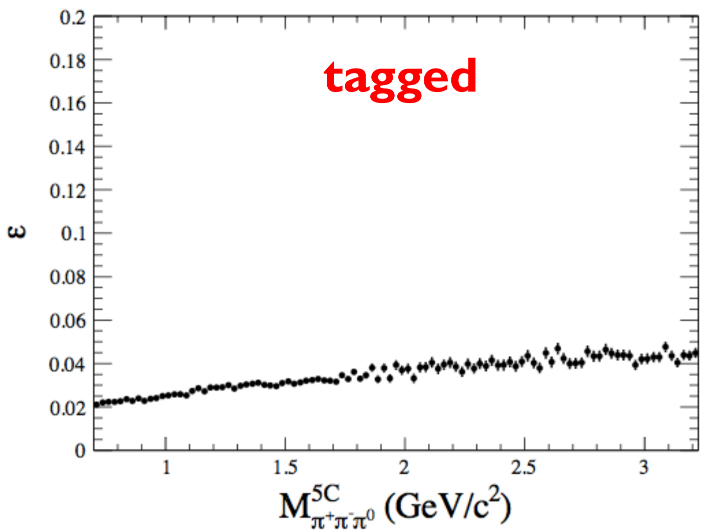
$$\pi^{+}\pi^{-}\pi^{0}$$

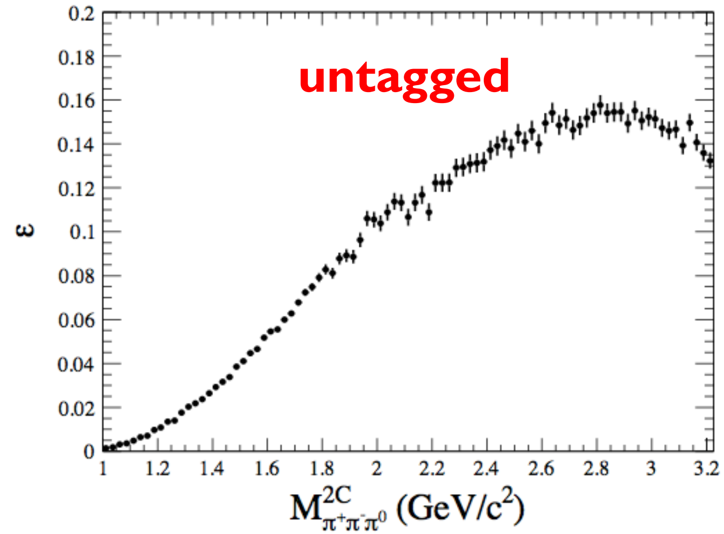
nota bene: study in progress
no official BESIII plots

BESIII

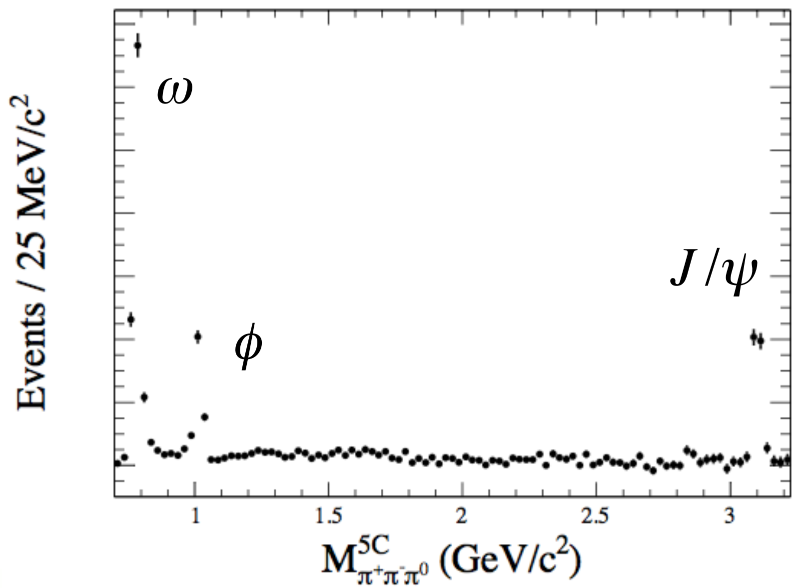
First Results

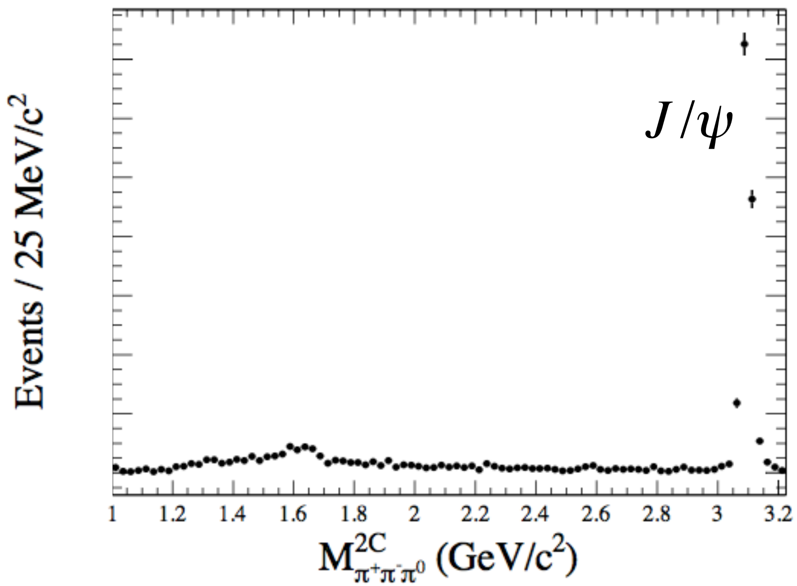
efficiency





invariant mass





First results

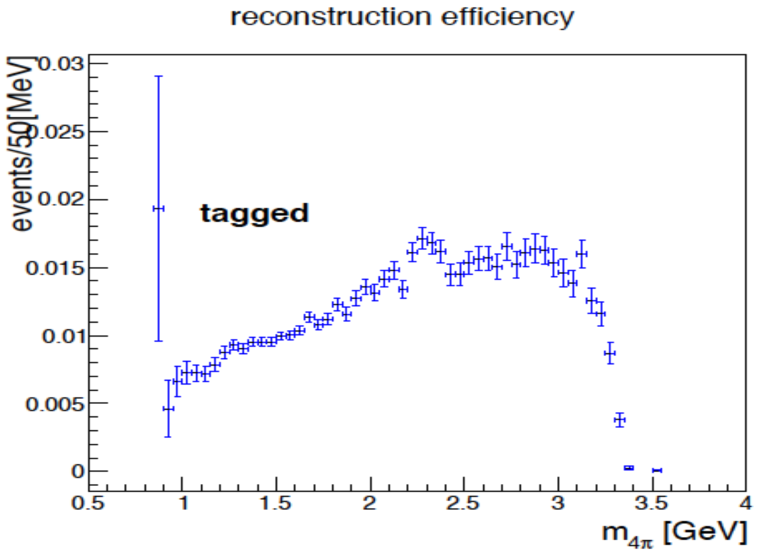
$$\pi^+\pi^-\pi^0\pi^0$$

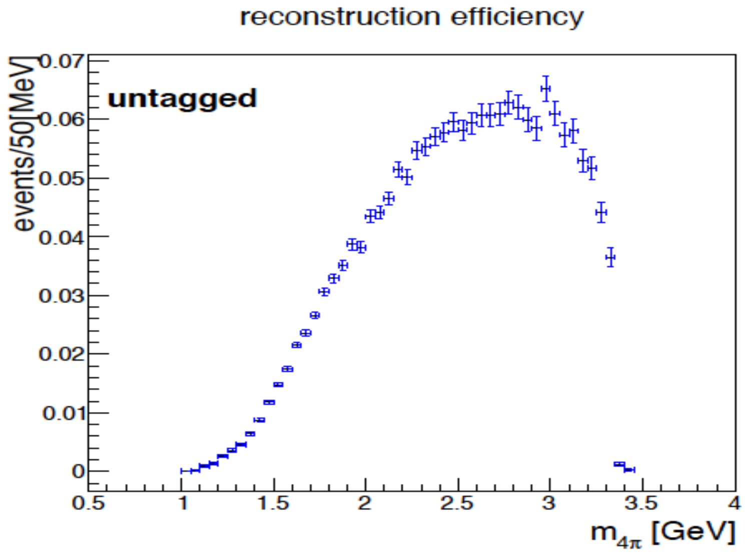
nota bene: study in progress
no official BESIII plots

BESIII

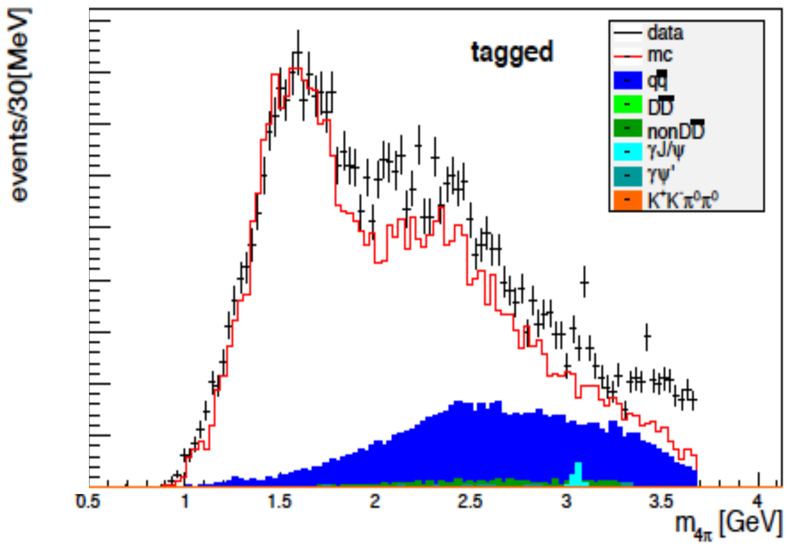
First Results

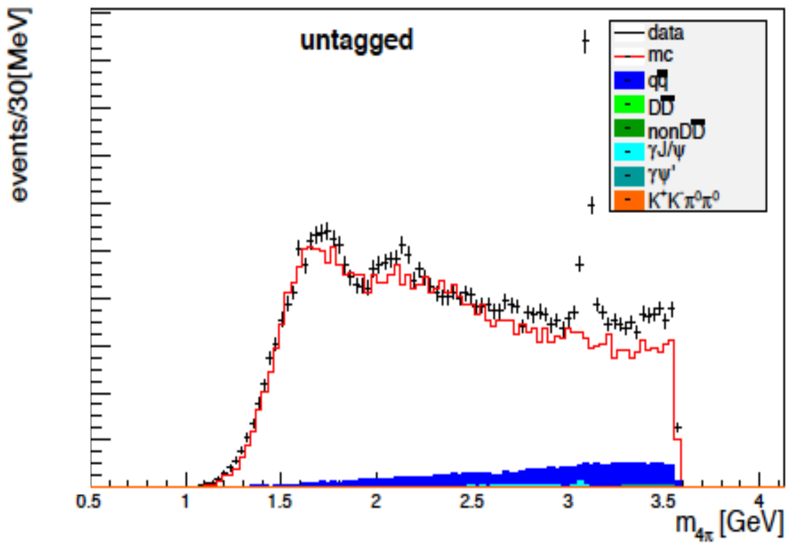
efficiency





invariant mass





Summary

- hadronic cross sections are an important contribution to the anomalous magnetic moment of the muon

- a high precision experiment is needed
  ⇒ this we want to do at BESIII via the ISR technique

- studies in progress are $e^+e^- \to \pi^+\pi^-$, $e^+e^- \to \pi^+\pi^-\pi^0$ and $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$

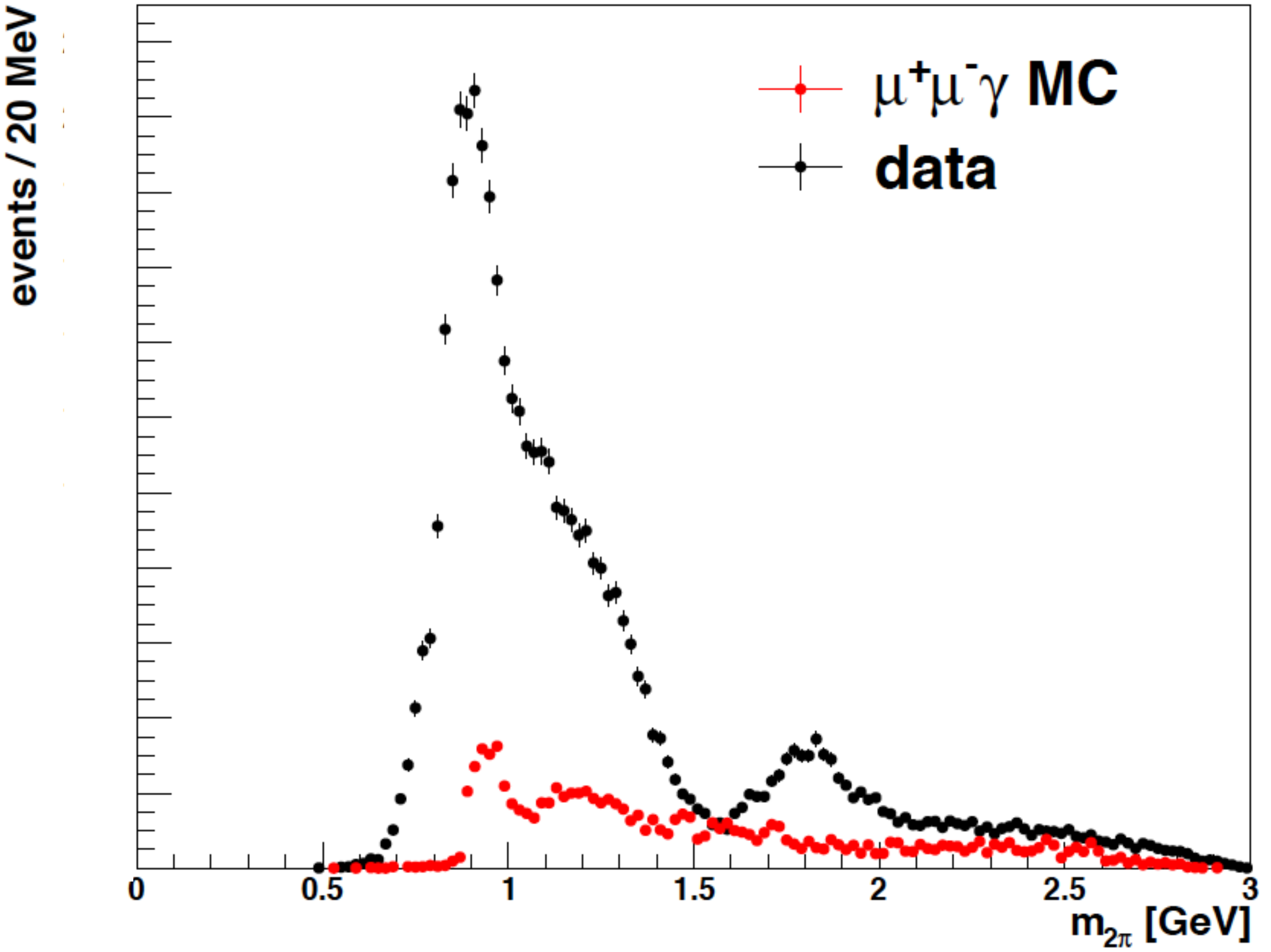
- first good results have been achieved

- the $\pi^+\pi^-$ cross section shall be published as soon as possible

Thank you for your attention!

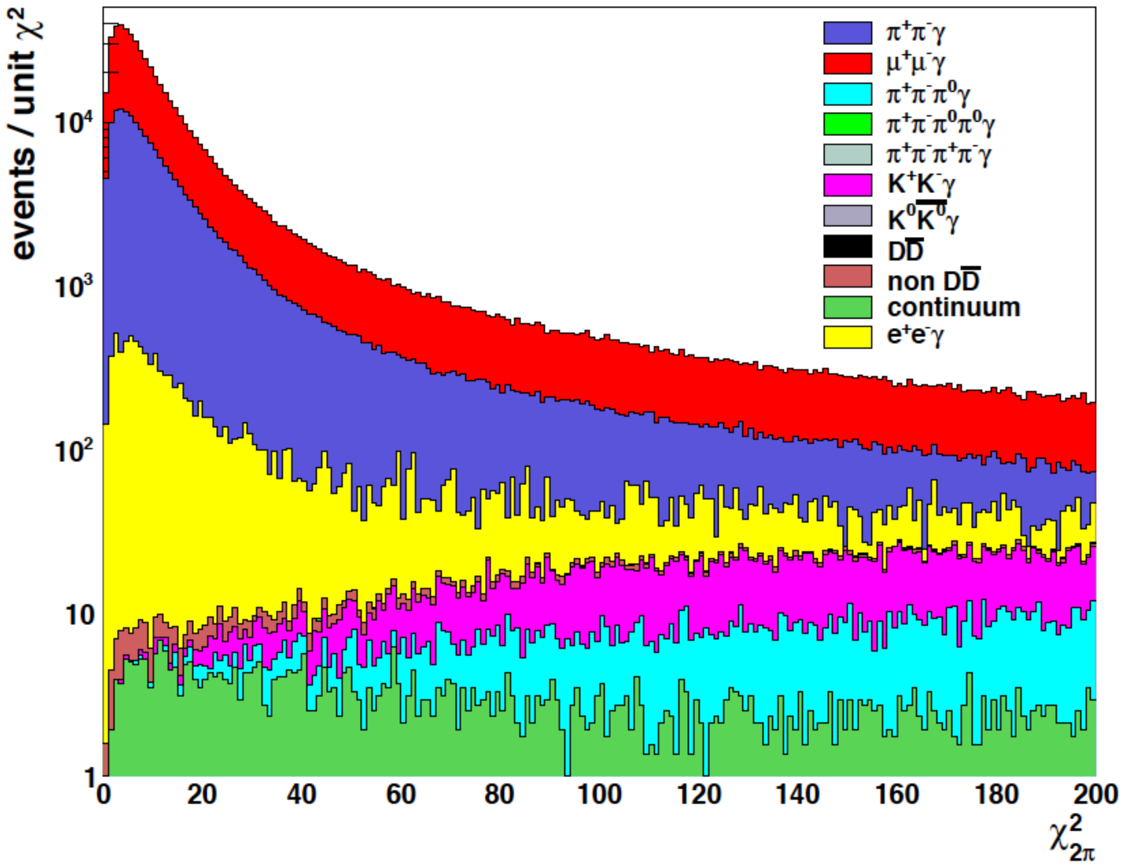
Backup

Untagged analysis



Tagged analysis – 4C kinematic fit

4C kinematic fit with hypothesis $e^+e^- \rightarrow \pi^+\pi^-\gamma_{ISR}$



scaled to same luminosity

Pions and muons have very similar distributions because of their simalar masses. They can not be seperated with a kinematic fit.

Method

number of $\pi^+\pi^-\gamma_{ISR}$ events after background subtraction and unfolding the spectrum

FSR correction

$$\sigma^{bare}(e^+e^- \to \pi^+\pi^-(\gamma_{FSR})) = \frac{N_{2\pi\gamma}}{\mathcal{L} \cdot \epsilon_{global} \cdot \frac{2m}{s} \cdot H \cdot \delta_{vac} \cdot (1 + \delta^{2\pi}_{FSR})}$$

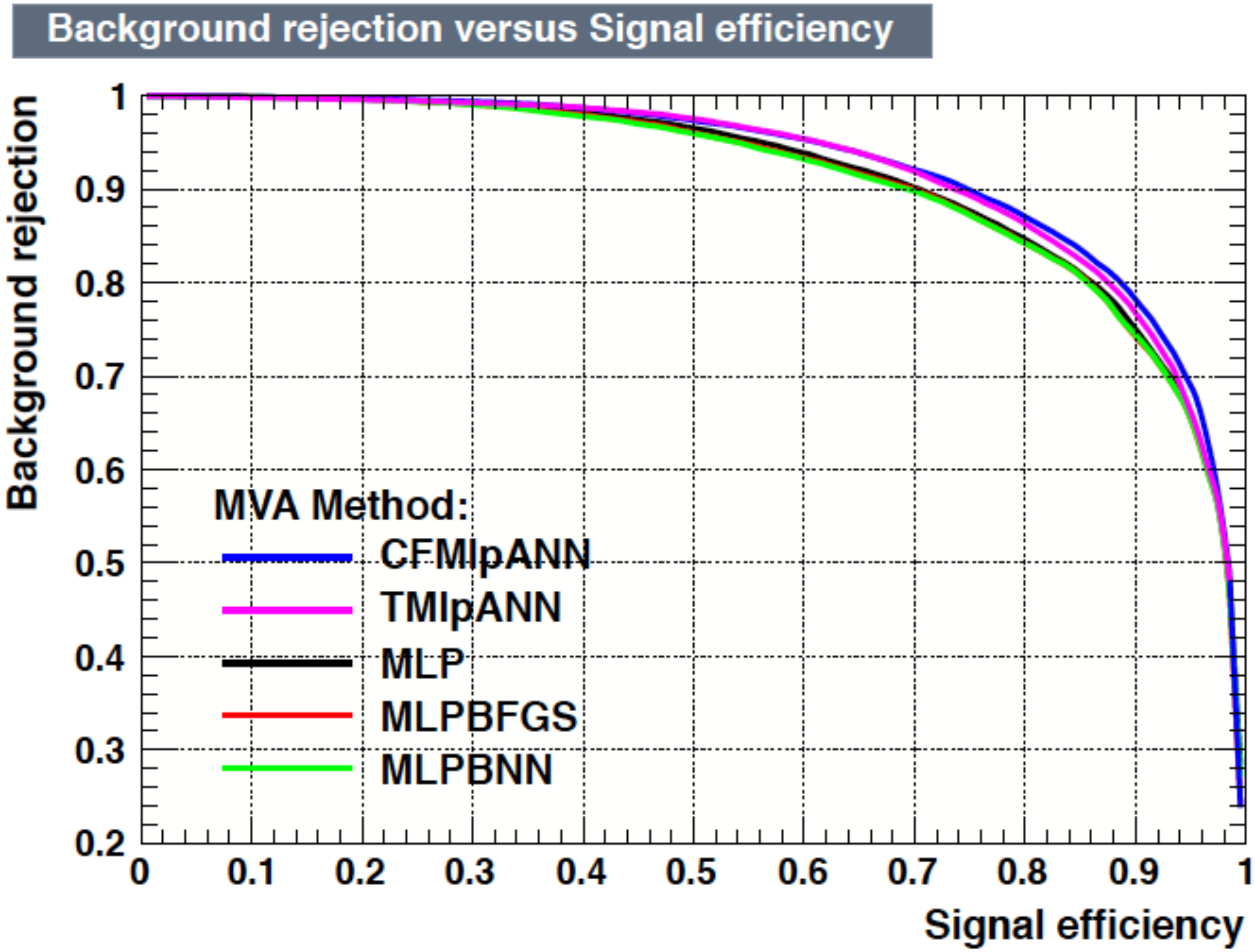
Luminosity

global efficiency of the event selection after all efficiency corrections

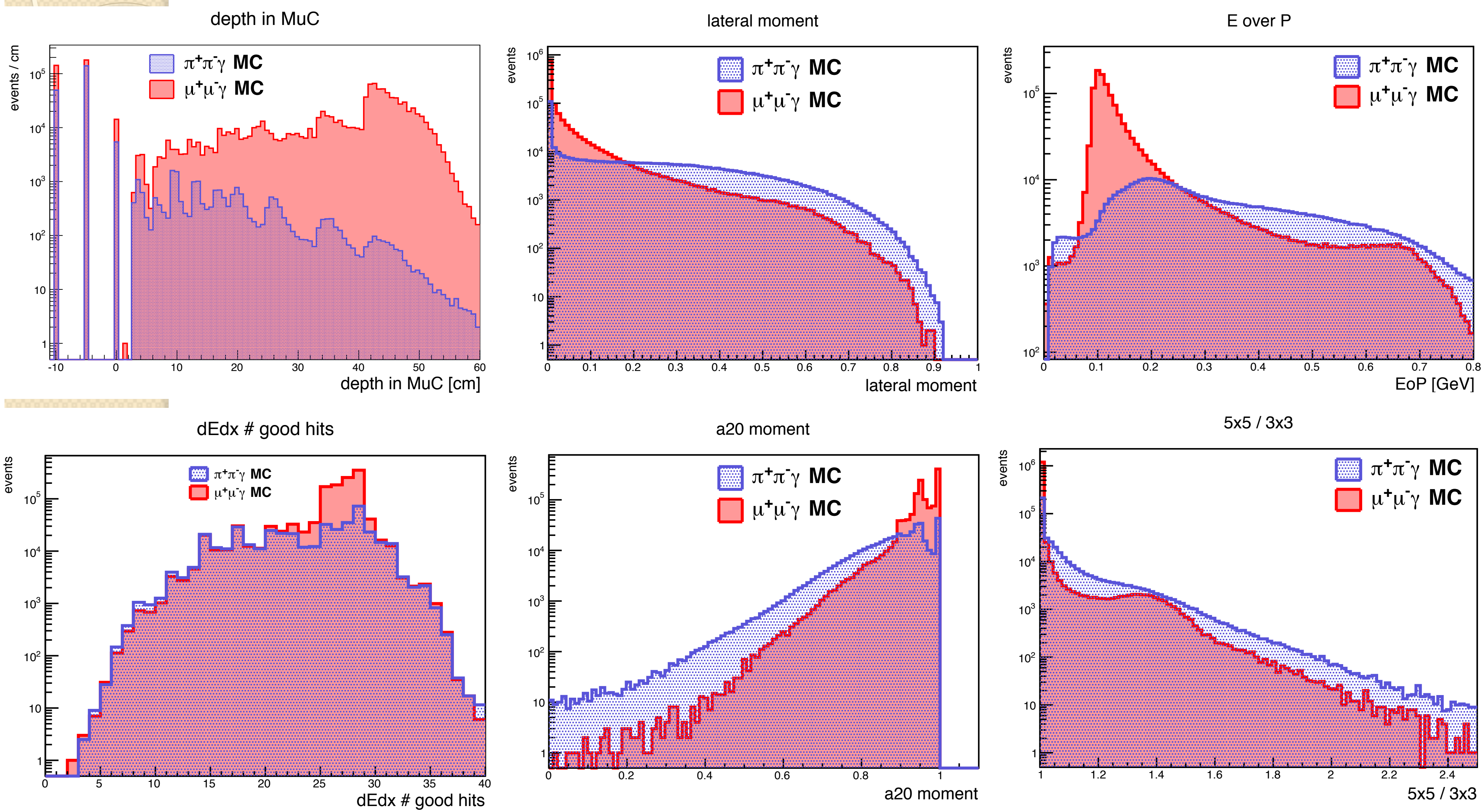
vacuum polarization correction

Radiator function

the Clermont-Ferrand ANN



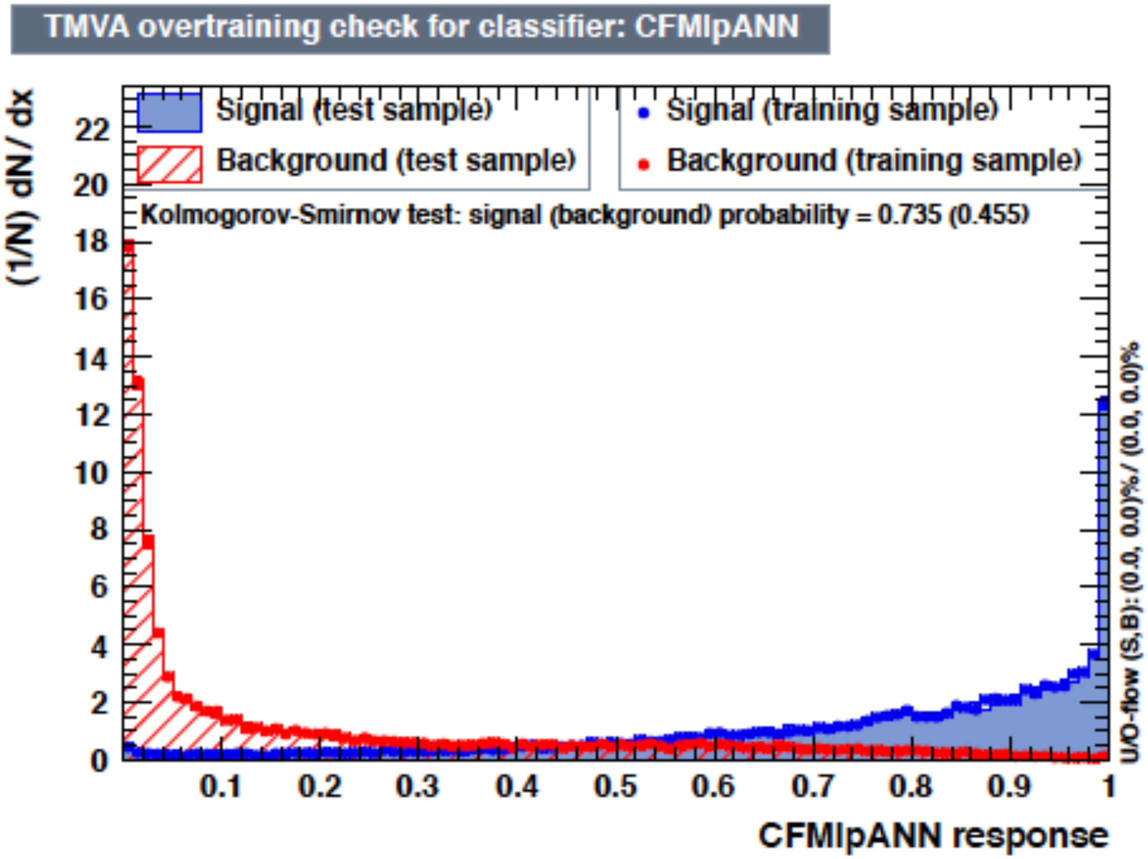
Training the Artificial Neural Network



input variables

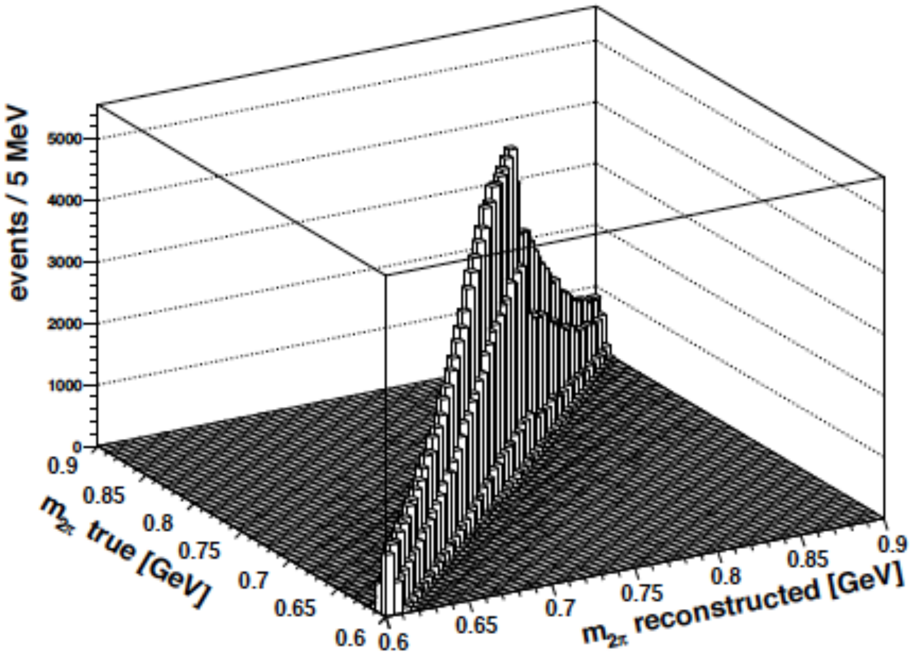
Training the Artificial Neural Network

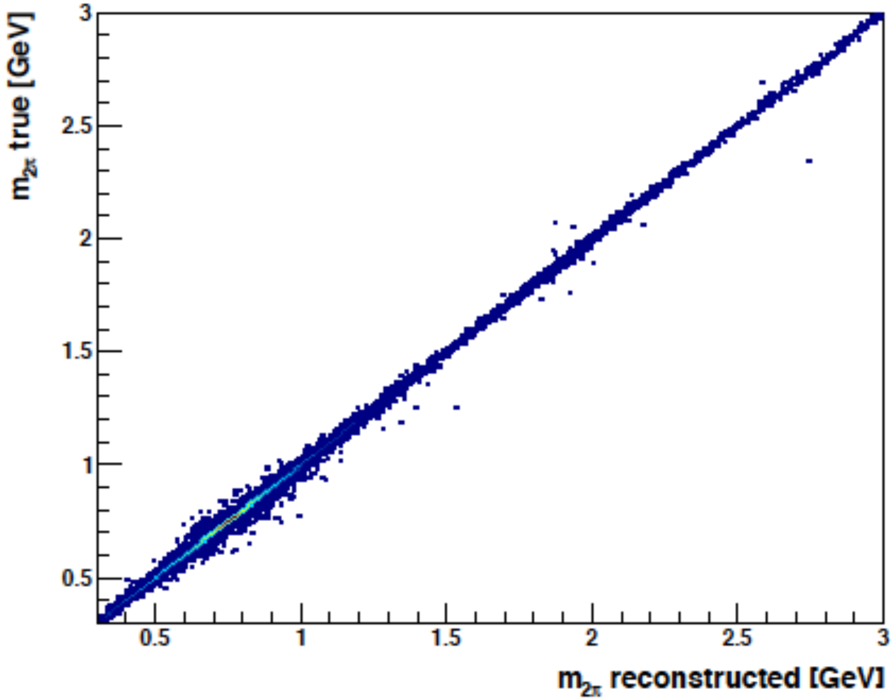
• input sample is split into training and test sample
• output of training and test sample have to agree
⇒ overtraining check



Unfolding

Response Matrix

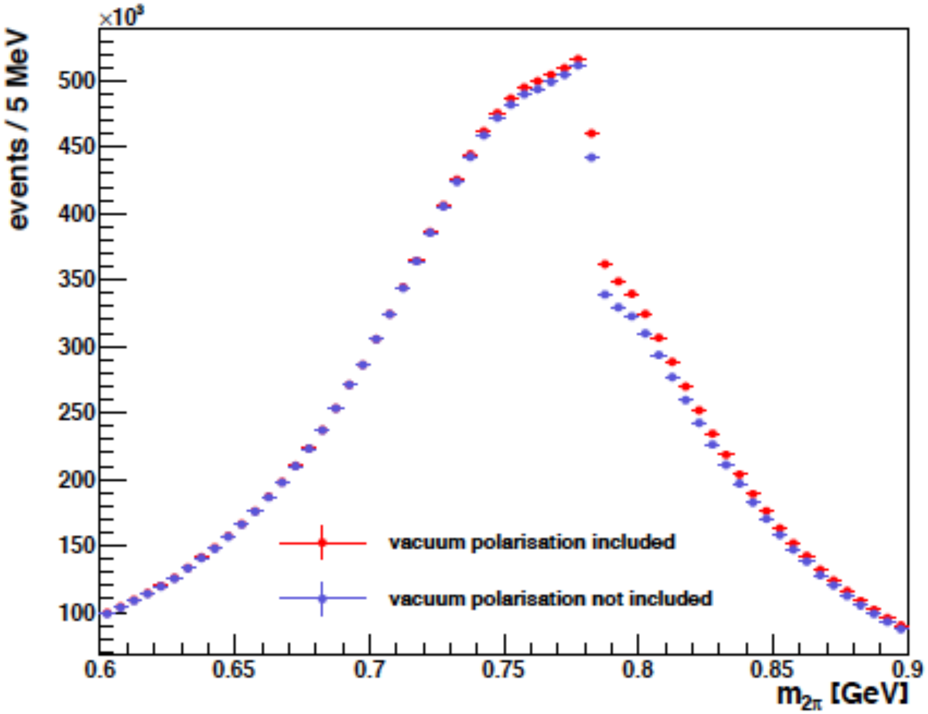


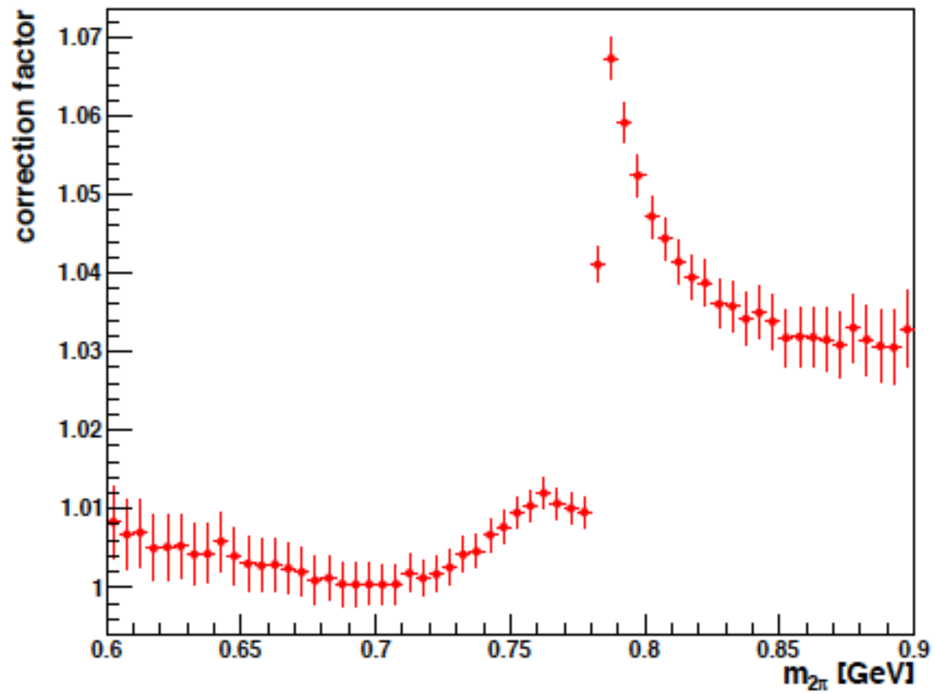


Easy: Simply MC true vs. MC reconstructed

Vacuum Polarization Correction

Theoretical calculation from Fred Jegerlehner
(see http://www-com.physik.hu-berlin.de/~fjeger/)





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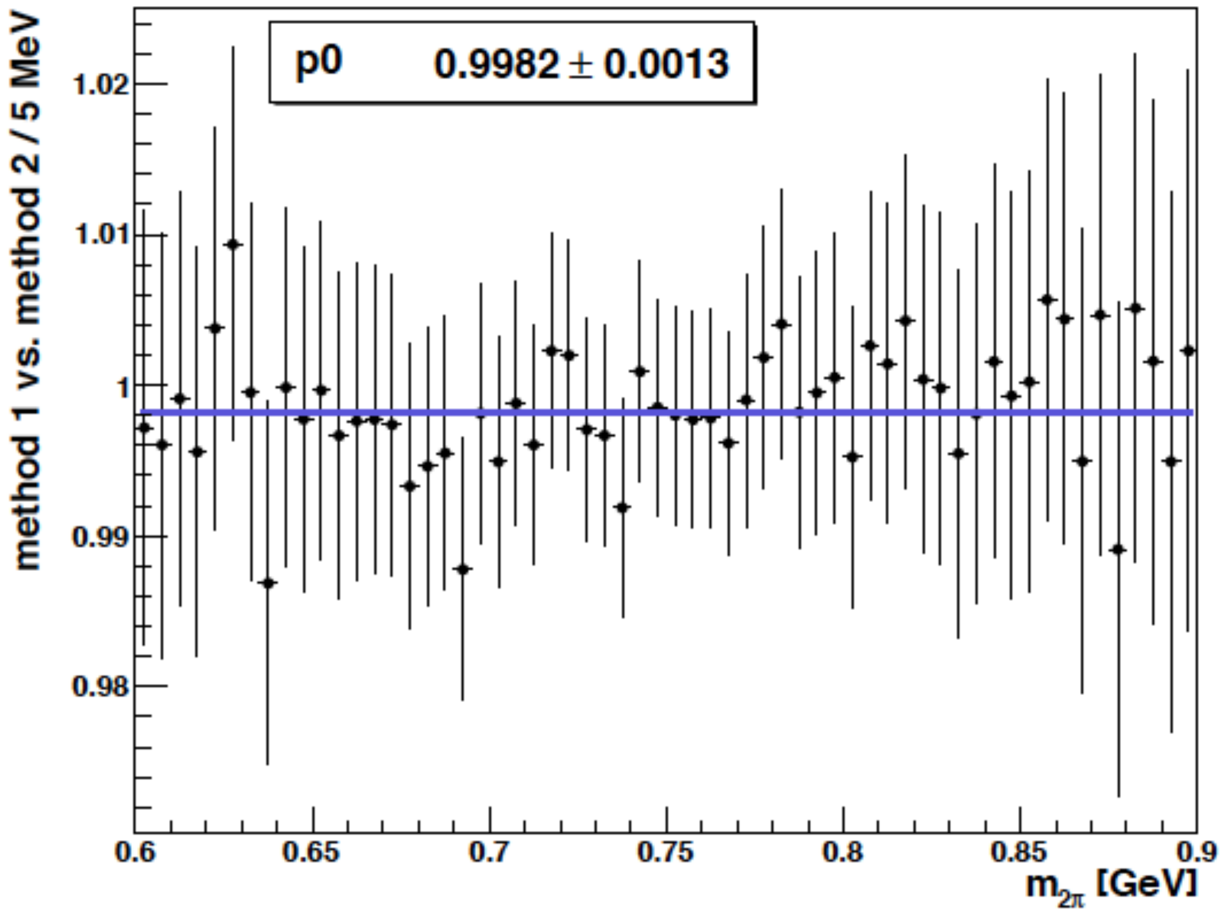
FSR correction



Radiator function

Taken from **PHOKHARA**

⇒ Precise description in NLO