Achim Denig
Benedikt Kloss

Trient 2013

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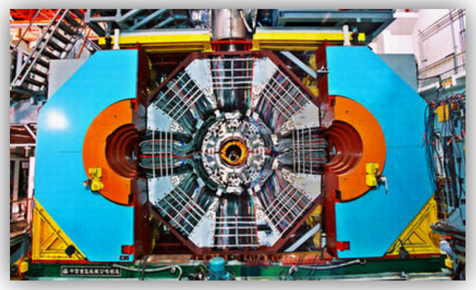
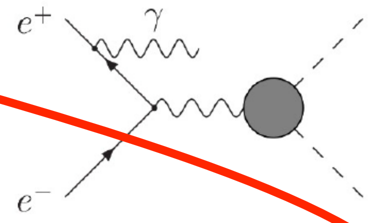


Measurements of Hadronic Cross Sections Using ISR at BES-III

Feasabilities and First Results

Outline

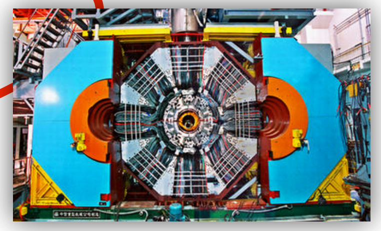


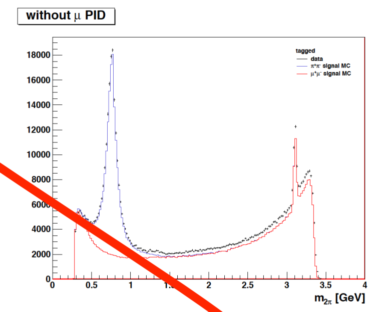
① Hadronic cross sections and ISR

② The BES-III experiment

③ Comparison to BaBar and KLOE

④ First results and outlook





Hadronic cross sections and ISR

very short Motivation: g-2 ➔ I think you know this

- $a_\mu^{SM} = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{hadr}$
- a_μ^{QED} and a_μ^{weak} can be calculated with perturbation theory
- but a_μ^{hadr} not
- get a_μ^{hadr} from $\sigma(e^+e^- \rightarrow hadr)$
- experimental uncertainty in $\sigma(e^+e^- \rightarrow hadr)$ limits standard model prediction completely

Dispersion integral:

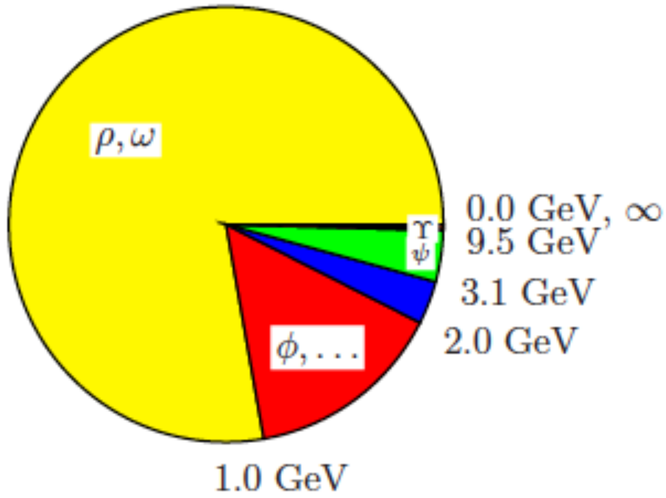
$$a_\mu^{hadr} \cong \frac{1}{4\pi^3} \int_{4m_\pi^2}^{\infty} K(s)\sigma(e^+e^- \rightarrow hadr)ds$$

Kernel function $K(s) \propto \frac{1}{s}$

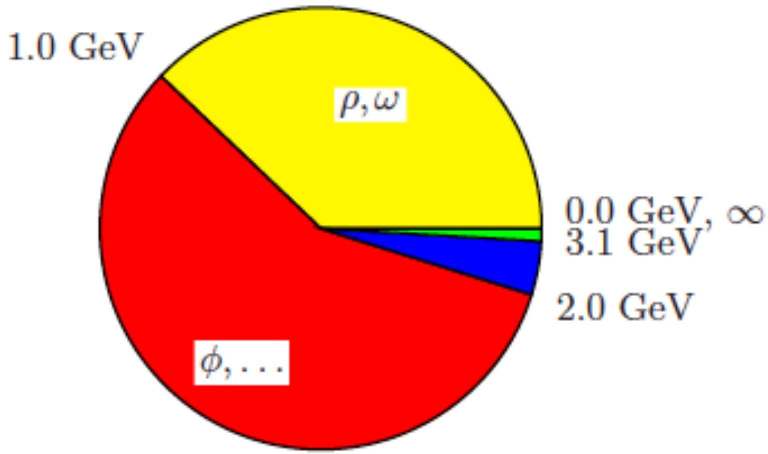
Hadronic cross sections and ISR

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

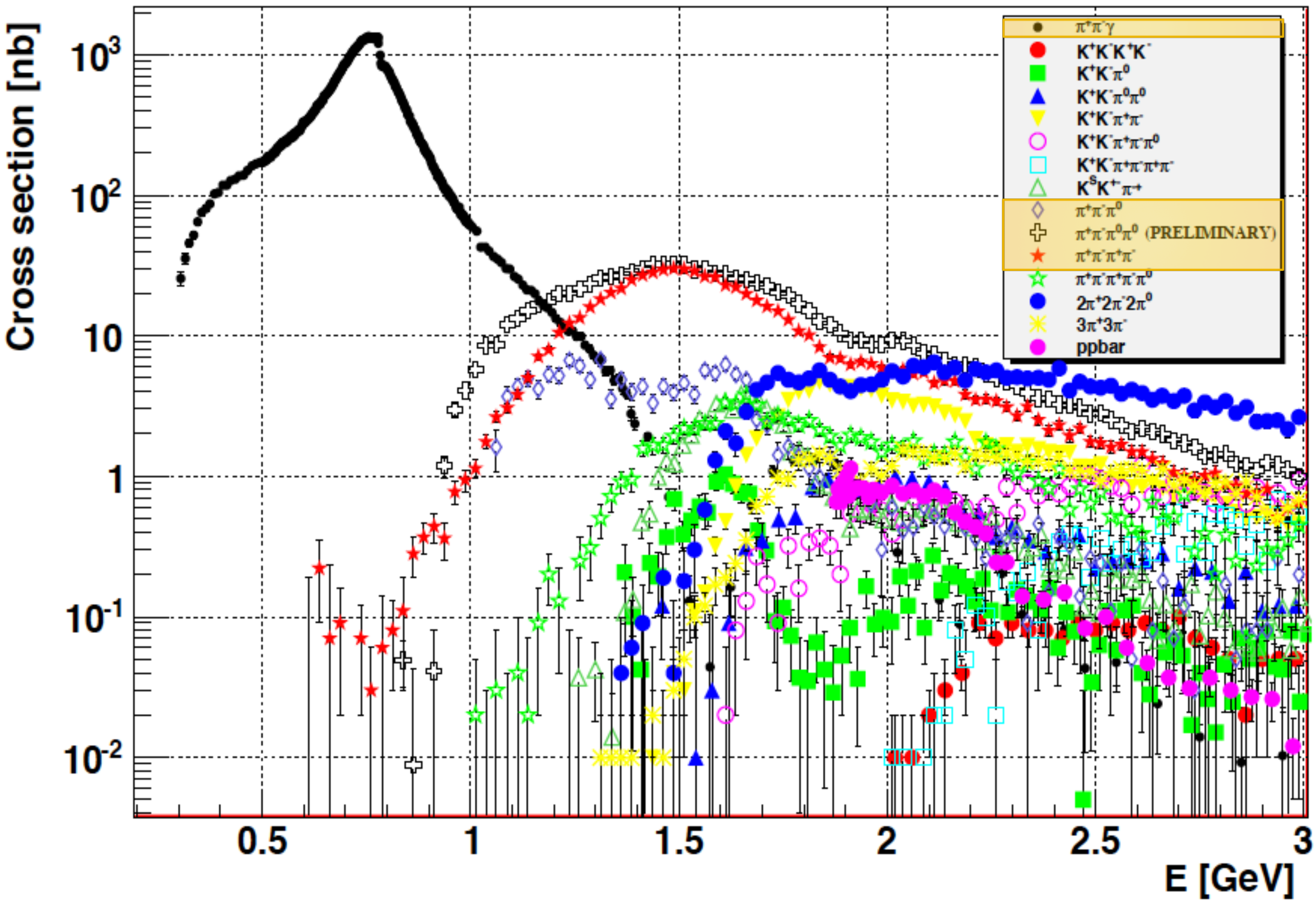
$\mathbf{a}_\mu^{\text{had}}$



$\Delta \mathbf{a}_\mu^{\text{had}}$

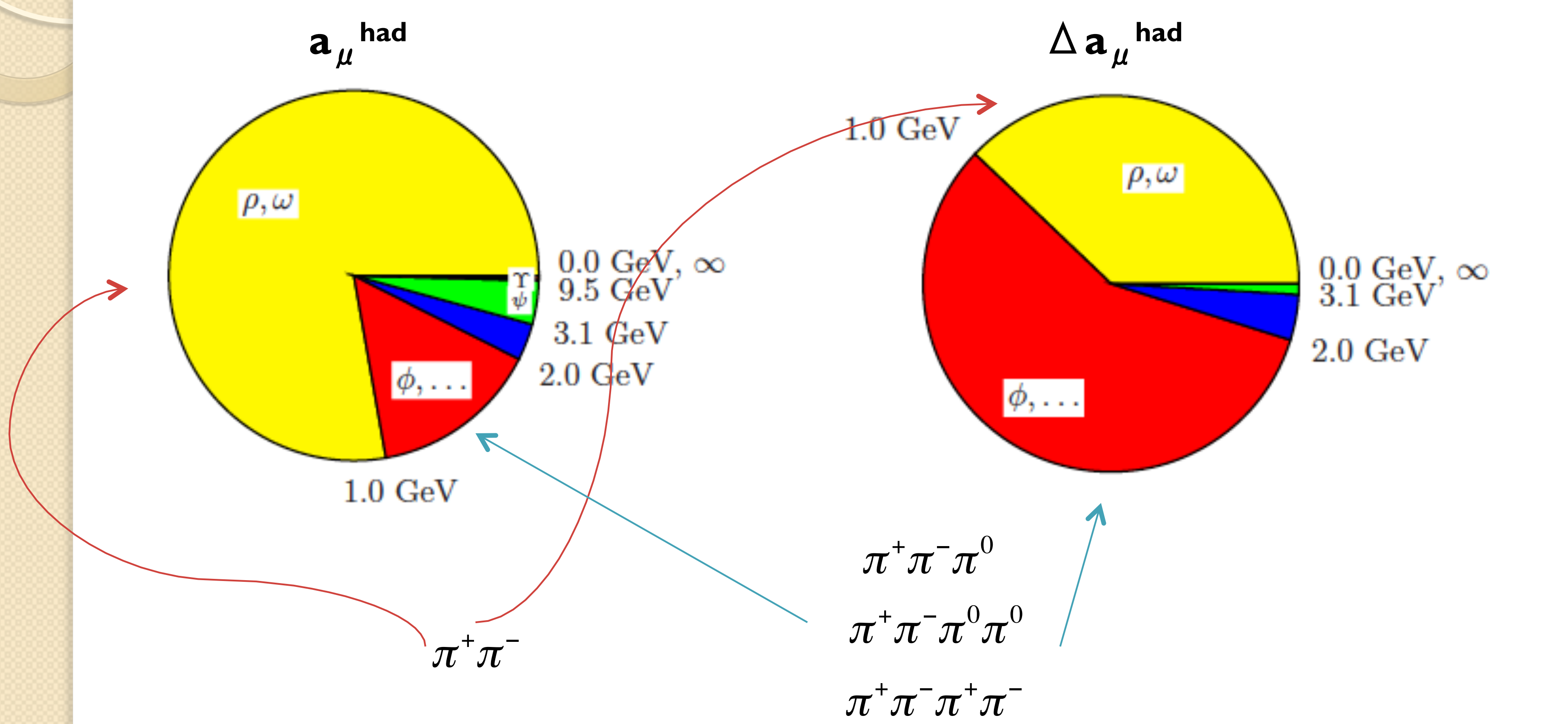


Hadronic cross sections and ISR



Hadronic cross sections and ISR

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



Hadronic cross sections and ISR

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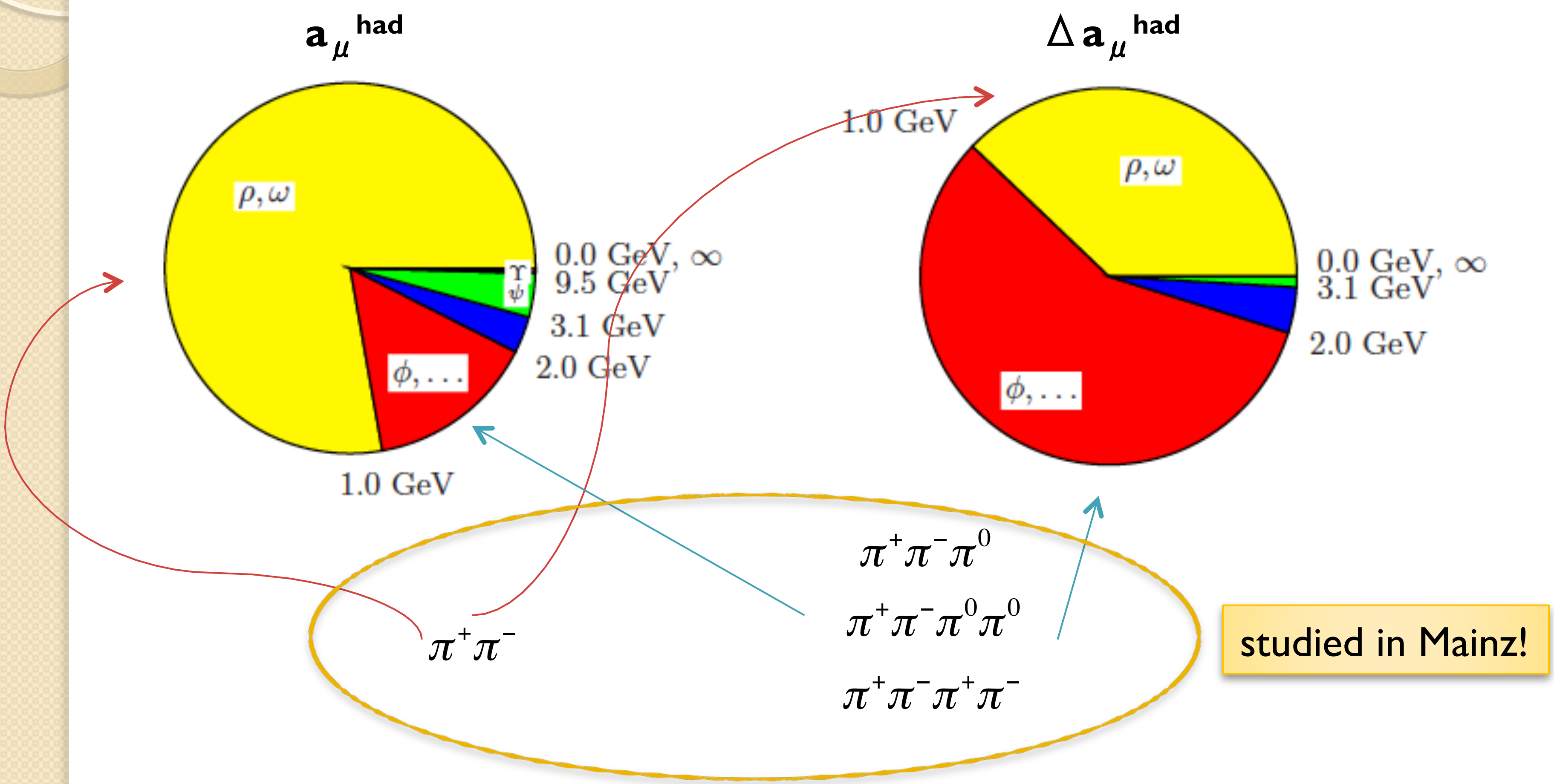


Hadronic cross sections and ISR

ISR analysis in Mainz

Big bosses: Achim Denig and Frank Maas

hadronic cross sections

channel	name	experiment
$\pi^+\pi^-$	Benedikt Kloss	BES-III
$\pi^+\pi^-\pi^0$	Yaqian Wang	BES-III
$\pi^+\pi^-\pi^0\pi^0$	Martin Ripka	BES-III
$\pi^+\pi^-\pi^0\pi^0$	Konrad Griesinger	BaBar
$\pi^+\pi^-\pi^+\pi^-$	Andreas Hafner	BaBar

form factor measurements

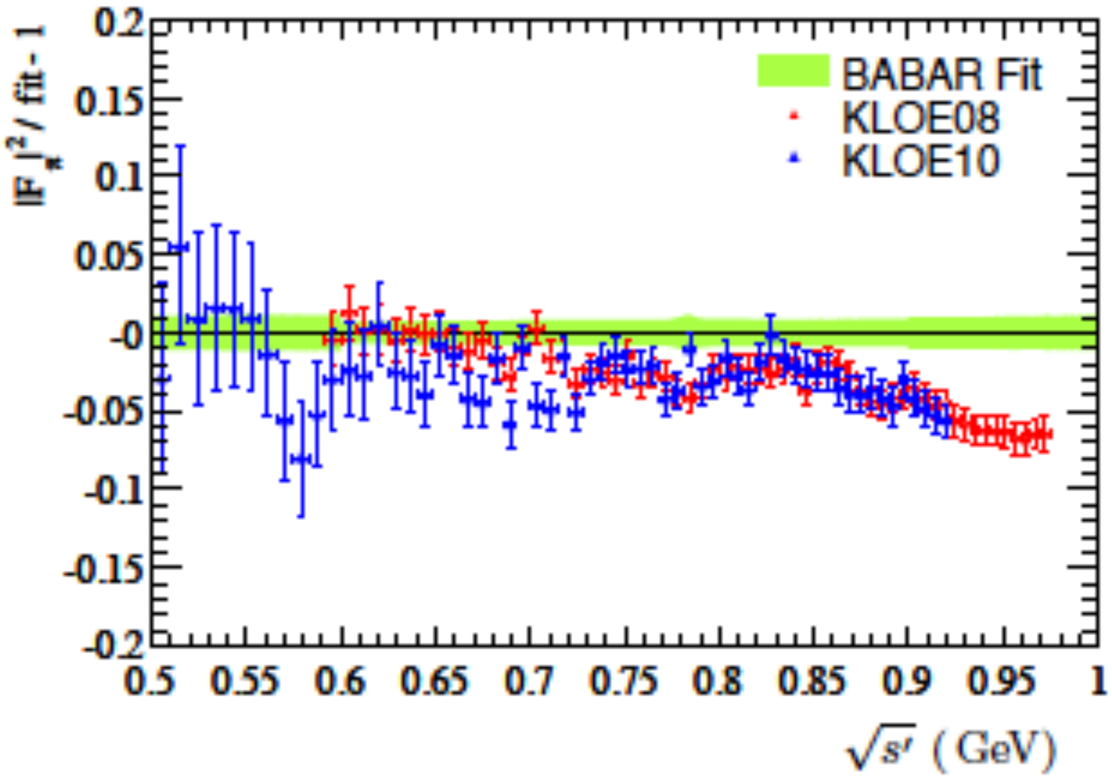
$p\ \bar{p}$	Cristina Morales	BES-III
$n\ \bar{n}$	Paul Larin	BES-III

Hadronic cross sections and ISR

Why measuring these cross sections at BES-III?

pi+pi- cross section: very precisely measured at the BaBar and KLOE experiments

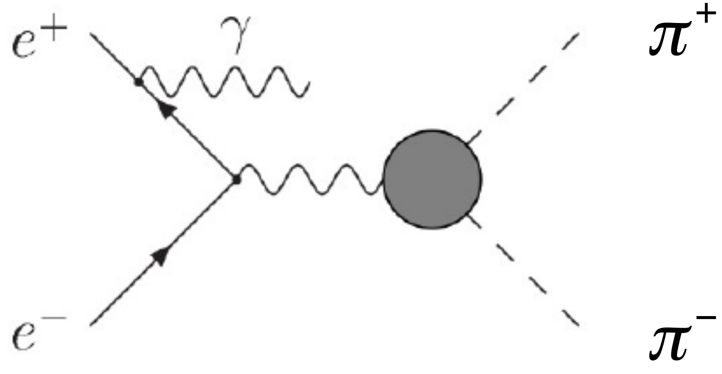
⇒ difference up to 2.0 standard devieations is observed
⇒ a reference experiment is needed! ➔ BES-III



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

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

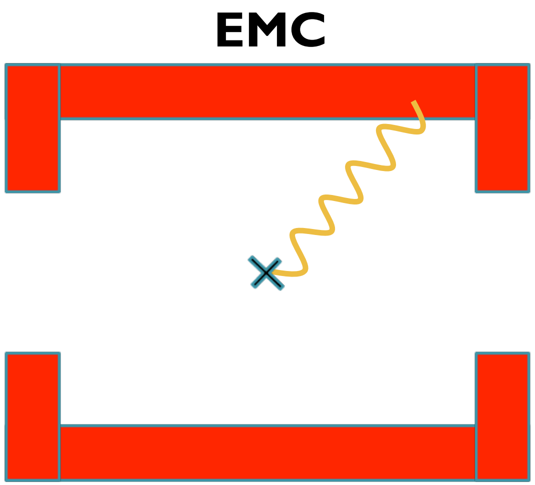
invariant mass of 2π

Radiator function

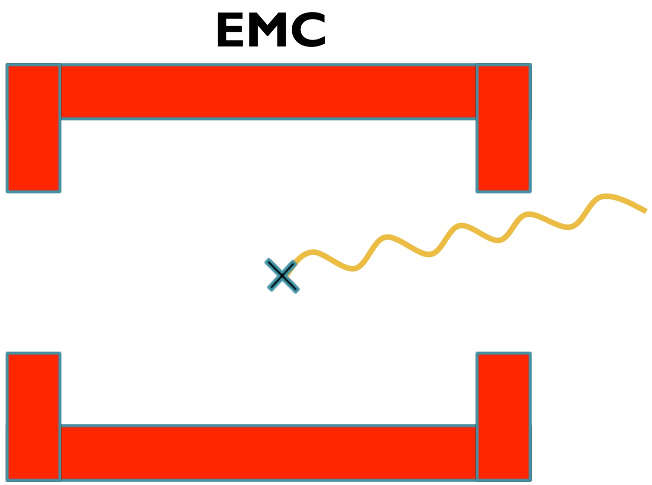
Initial State Radiation

Two different analysis types:

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

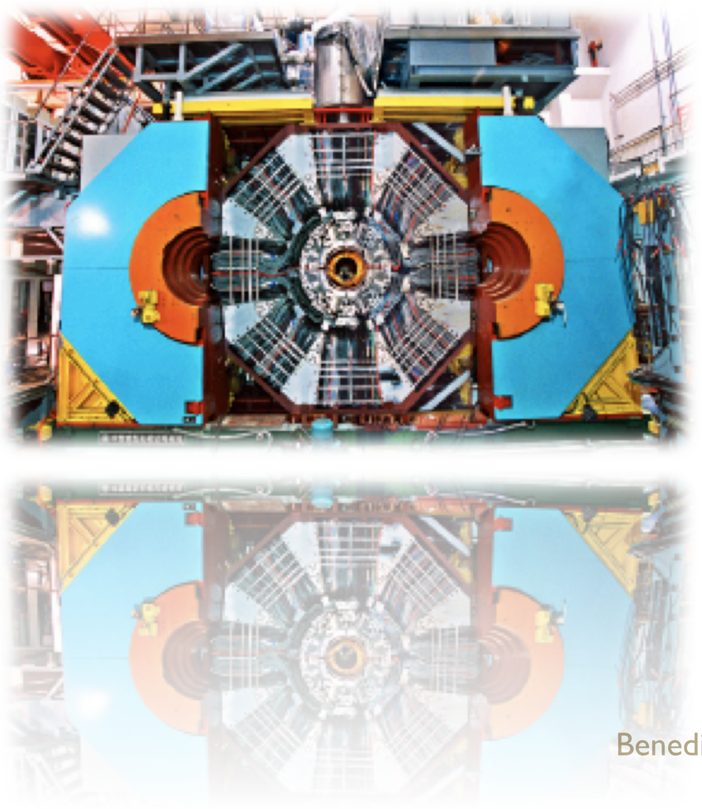


tagged:
photon hits EMC



untagged:
photon leaves the detector

The BES-III experiment

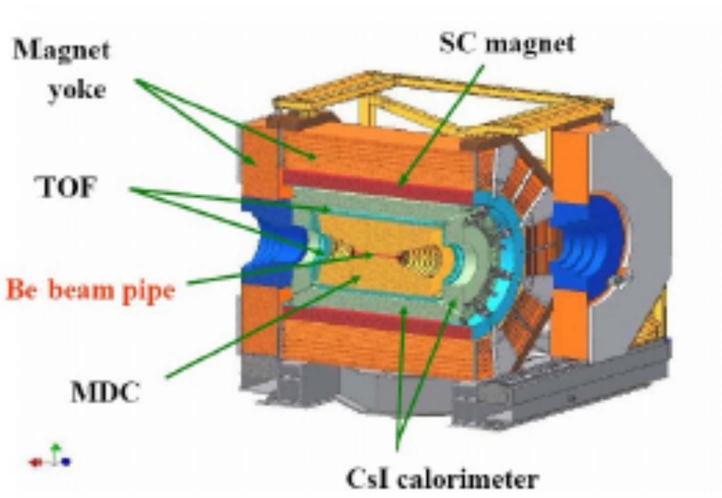


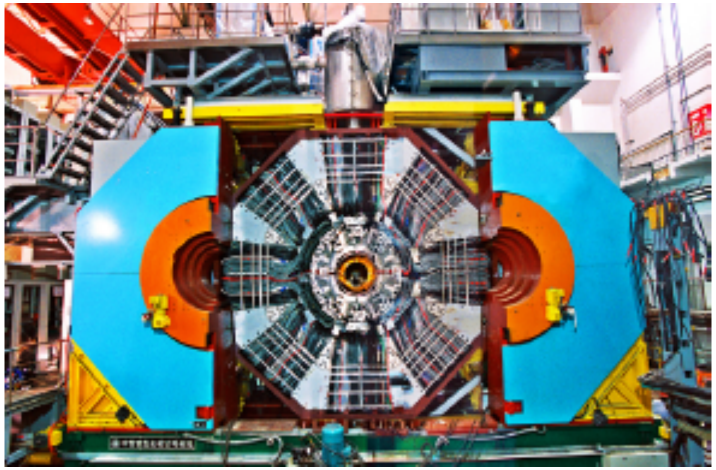
The BES-III experiment

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.)
- design luminosity: 10^{33} $cm^{-2}s^{-1}$
- data taken at $\sqrt{s} = 3.770 GeV$: 2.9 fb^{-1}

The BES-III experiment

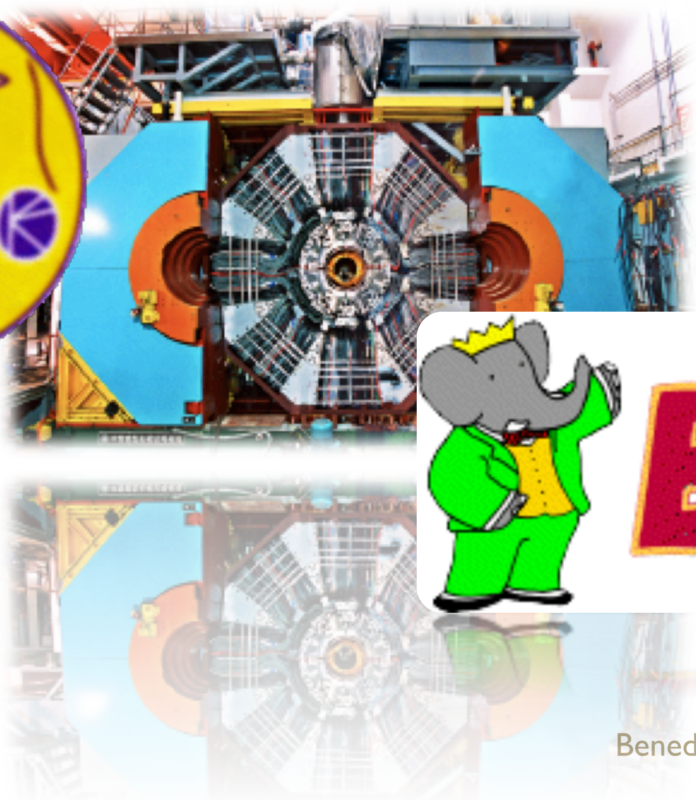




BES-III Detector:

- cylindrical drift chamber
- CsI(Tl) crystal calorimeter
- Time-Of-Flight system
- muon chamber
- 1T superconducting solenoid magnet

Comparison to BaBar and KLOE



Comparison of the experiments

	KLOE	BaBar	BES-III
CMS energy	1.02 GeV	10.58 GeV	3.77 GeV
integrated luminosity	2.5 fb^{-1}	454 fb^{-1}	2.9 fb^{-1} (10fb^{-1})
σ_p / p **, 1GeV tracks**	0.4 %	0.5 %	0.5 %
σ_E / E **, 1GeV tracks**	5.7 %	3.0 %	2.5 %
ISR methods	tagged and untagged	tagged	tagged and untagged

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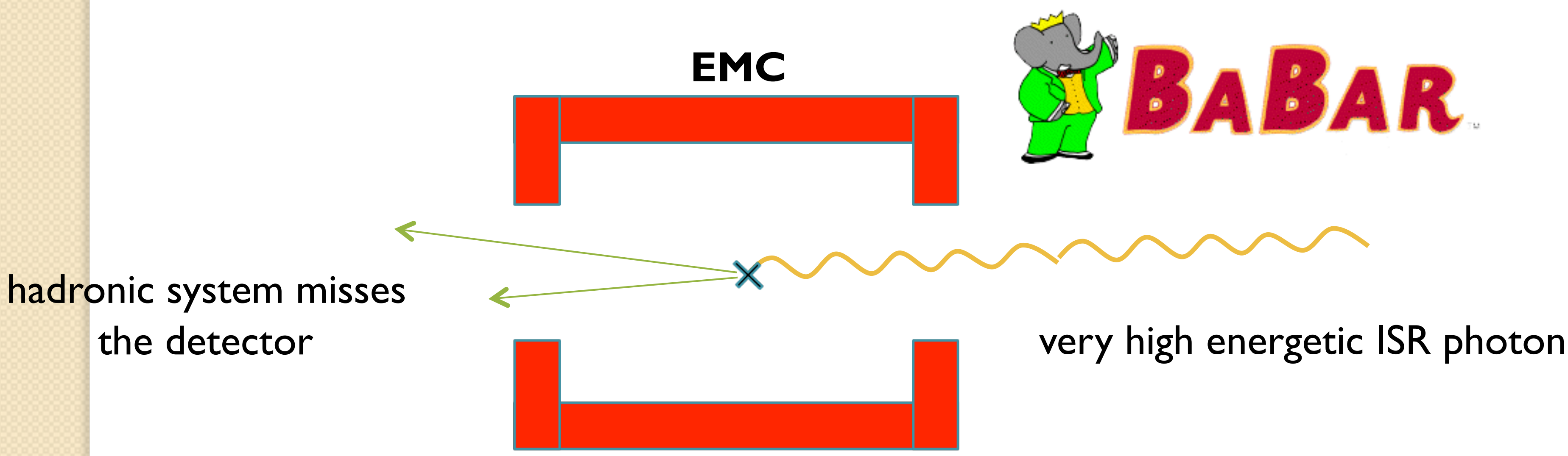
Comparison to BaBar

- BES-III: high statistics ➔ only limited by systematics
- luminosity smaller than the one of BaBar

  ⇒ but softer ISR-Bremsstrahlung ➔ higher probability
  ⇒ second effect outweights first one
  ⇒ comparable results to BaBar



⇒ **no untagged measurement possible at BaBar**

Comparison to BaBar

- BES-III; high statistics ➔ only limited by systematics
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  ⇒ but softer ISR-Bremsstrahlung ➔ higher probability
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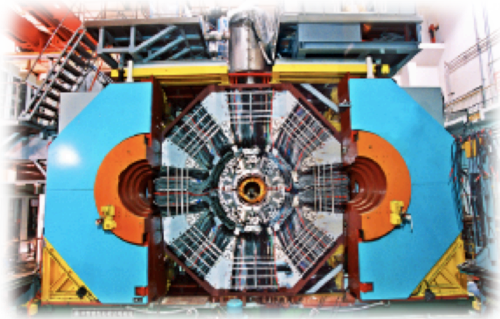
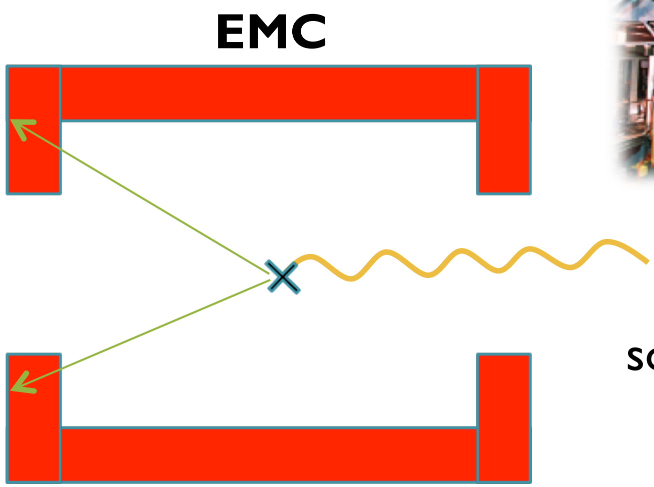
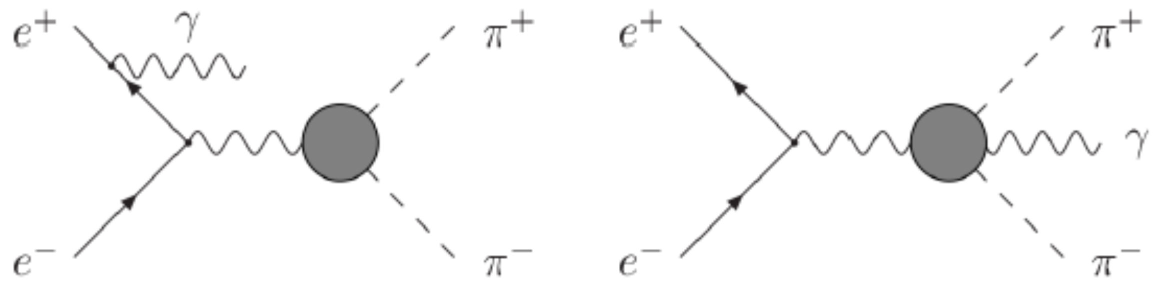




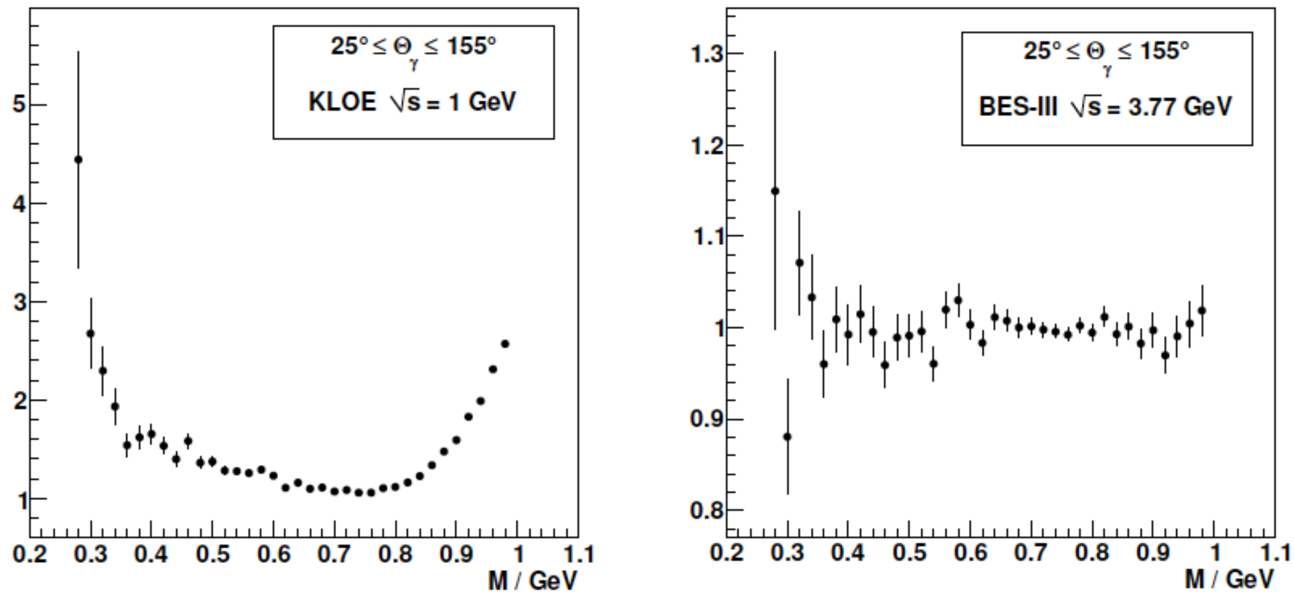
⇒ **untagged measurements possible ➔ increases statistics**

Comparison to KLOE



- **unavoidable background**: photon emitted in the final state (FSR)
- **BES-III vs. KLOE**: supressed FSR in the $\pi^+\pi^-$ channel

$$\frac{\sigma_{ISR+FSR}}{\sigma_{ISR}}$$



FSR is modell dependent

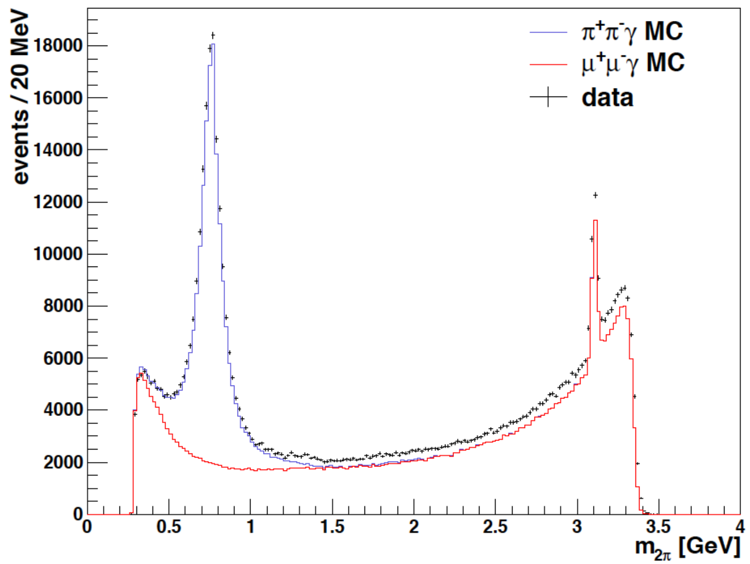
Comparison of the experiments

Conclusion:

feasibility studies of ISR physics at BES-III are promising

⇒ competitive results to BaBar and KLOE can be expected

First Results

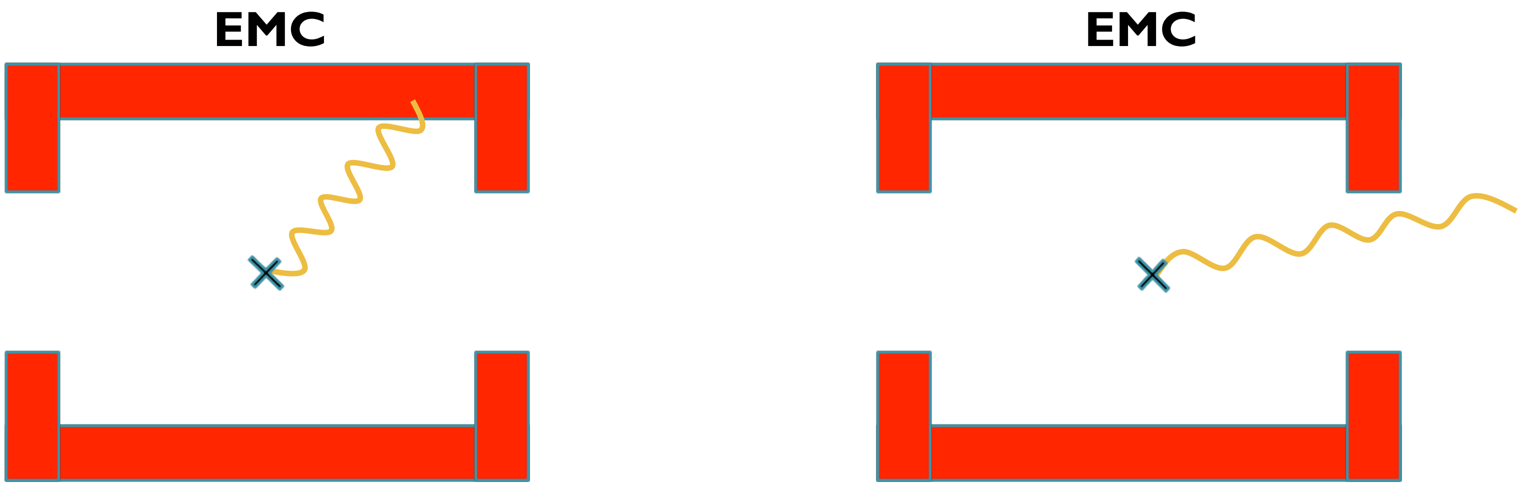


$\pi^+\pi^-\gamma$ analysis (my job)

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

E / p	< 0.8
distance to interaction point	R_{xy} < 1.0 cm R_z < 5.0 cm
acceptance	0.4 rad < θ < π – 0.4 rad
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)

$\pi^+\pi^-\gamma$ analysis (my job)



tagged:
photon hits EMC

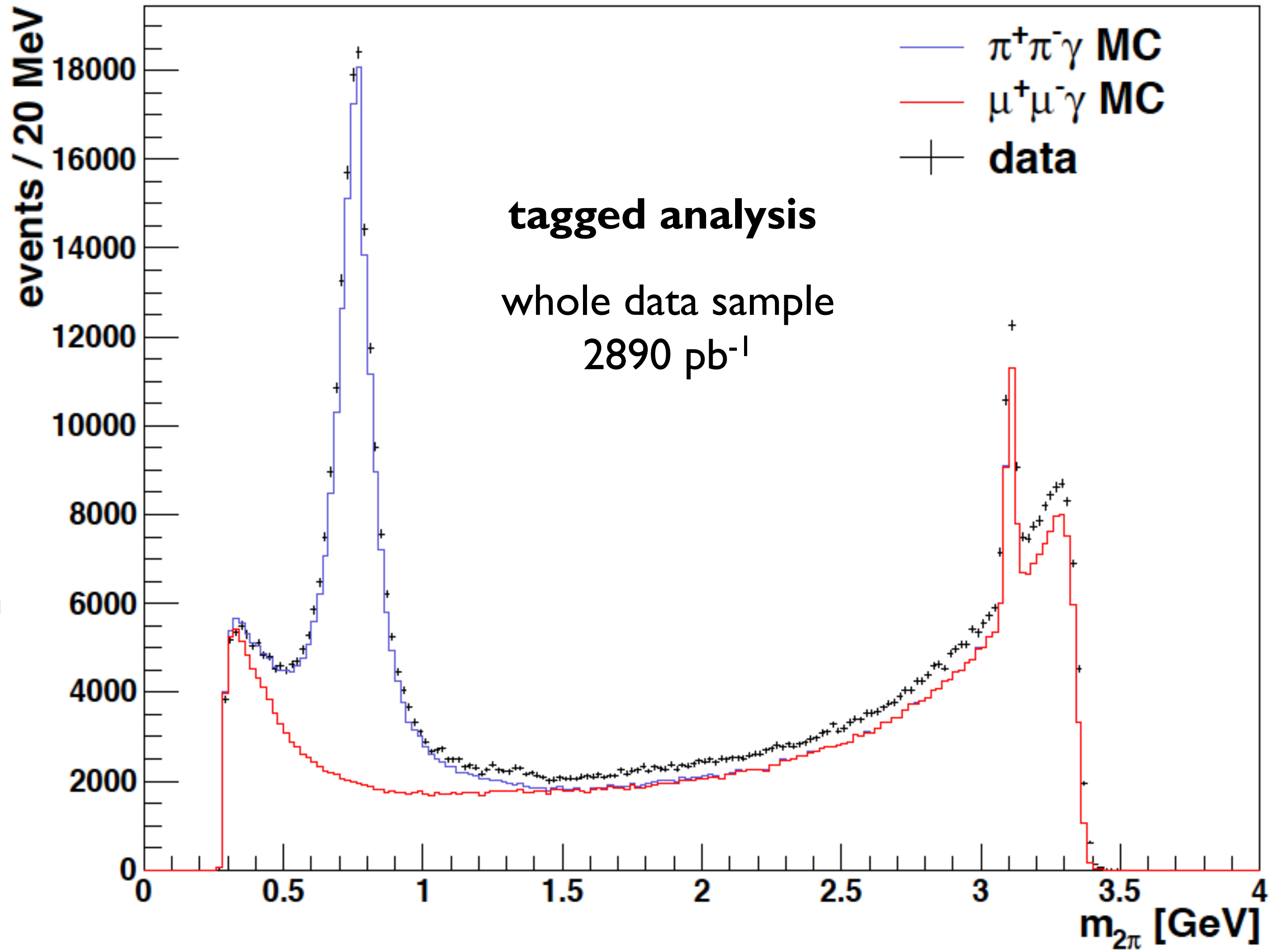
untagged:
photon leaves the detector

photon energy	> 0.4 GeV
# photons	= 1 (in tagged analysis) = 0 (in untagged analysis)

$\pi^+\pi^-\gamma$ analysis (my job)

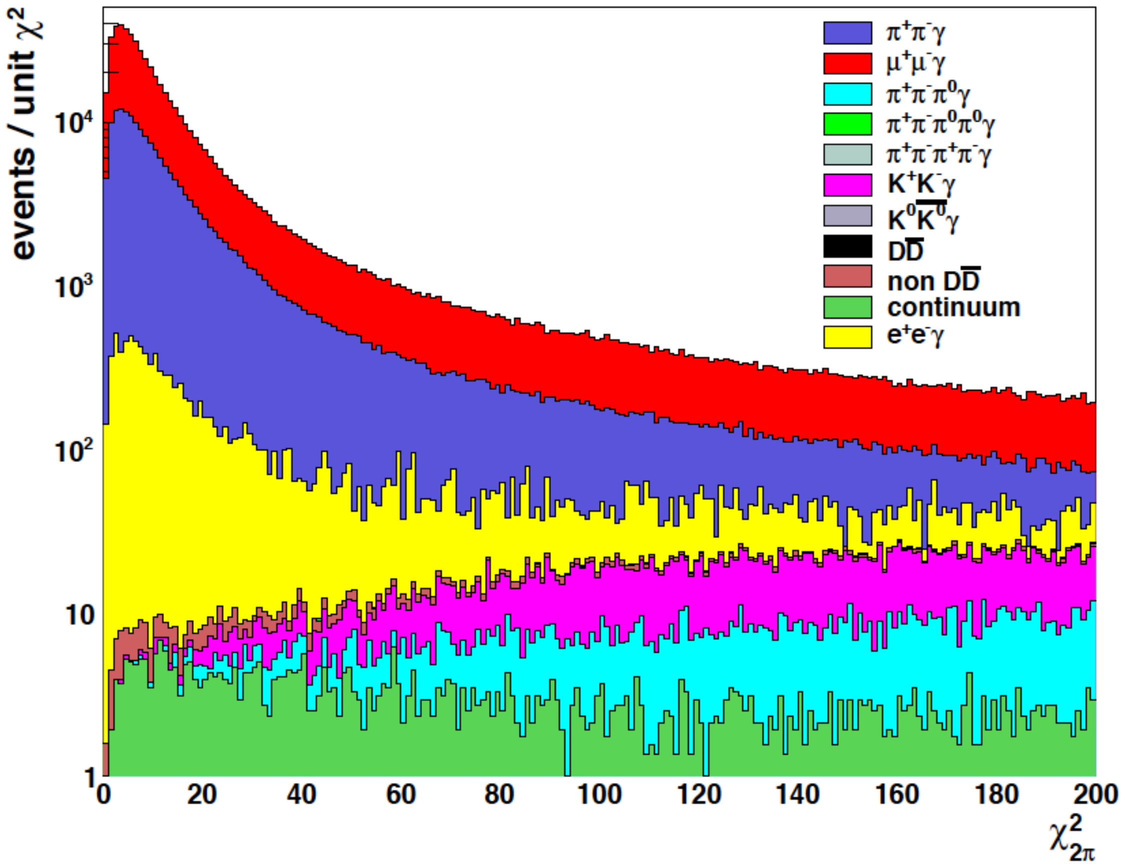
MC produced with PHOKHARA 7.0

⇒ good mu/pi seperation needed!



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.

Training an Artificial Neural Network

Idea of an Artificial Neural Network:

- from human brain structure
- find connections between several input variables
- calculate a likelihood for signal and background events

Use the TMVA package which is implemented in the ROOT framework.

TMVA

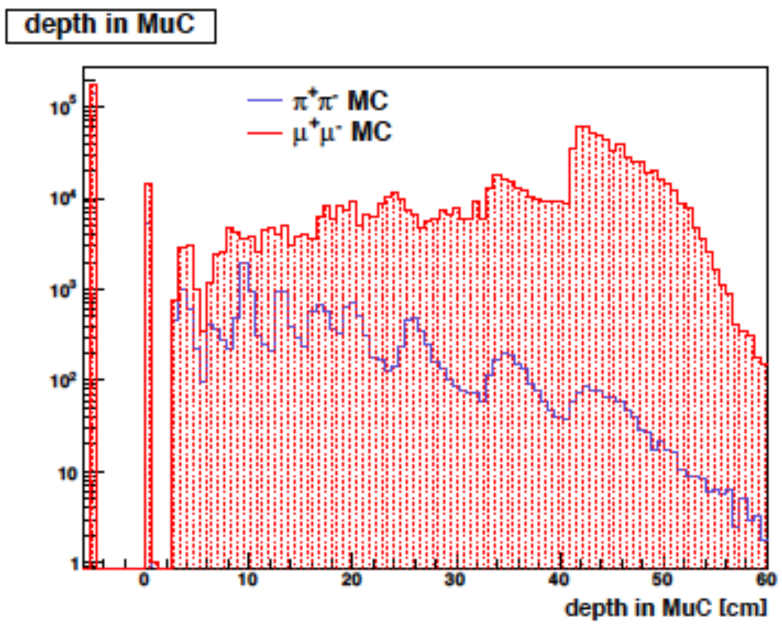
Strategy:

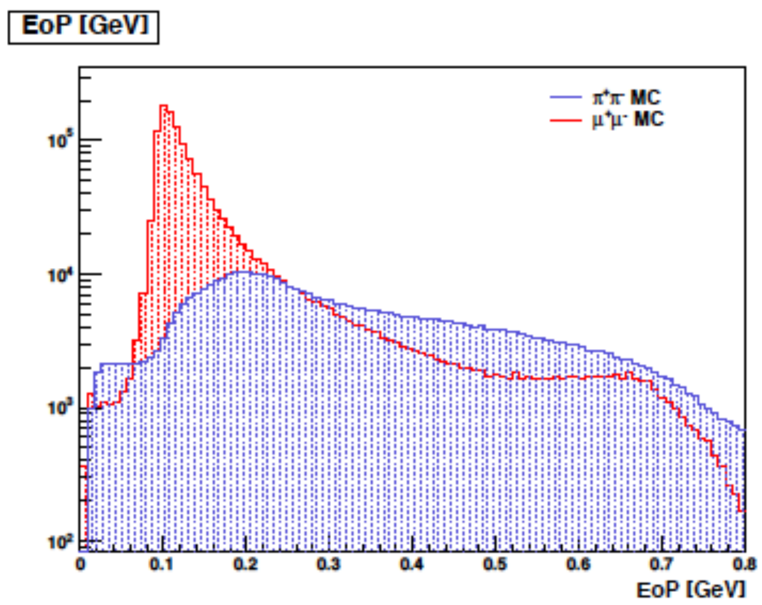
1. train the ANN with $\pi^+\pi^-\gamma_{ISR}$ and $\mu^+\mu^-\gamma_{ISR}$ MC samples
2. select a clear pion and a clear muon sample in data and study the efficiency differences between data and MC

Training an Artificial Neural Network

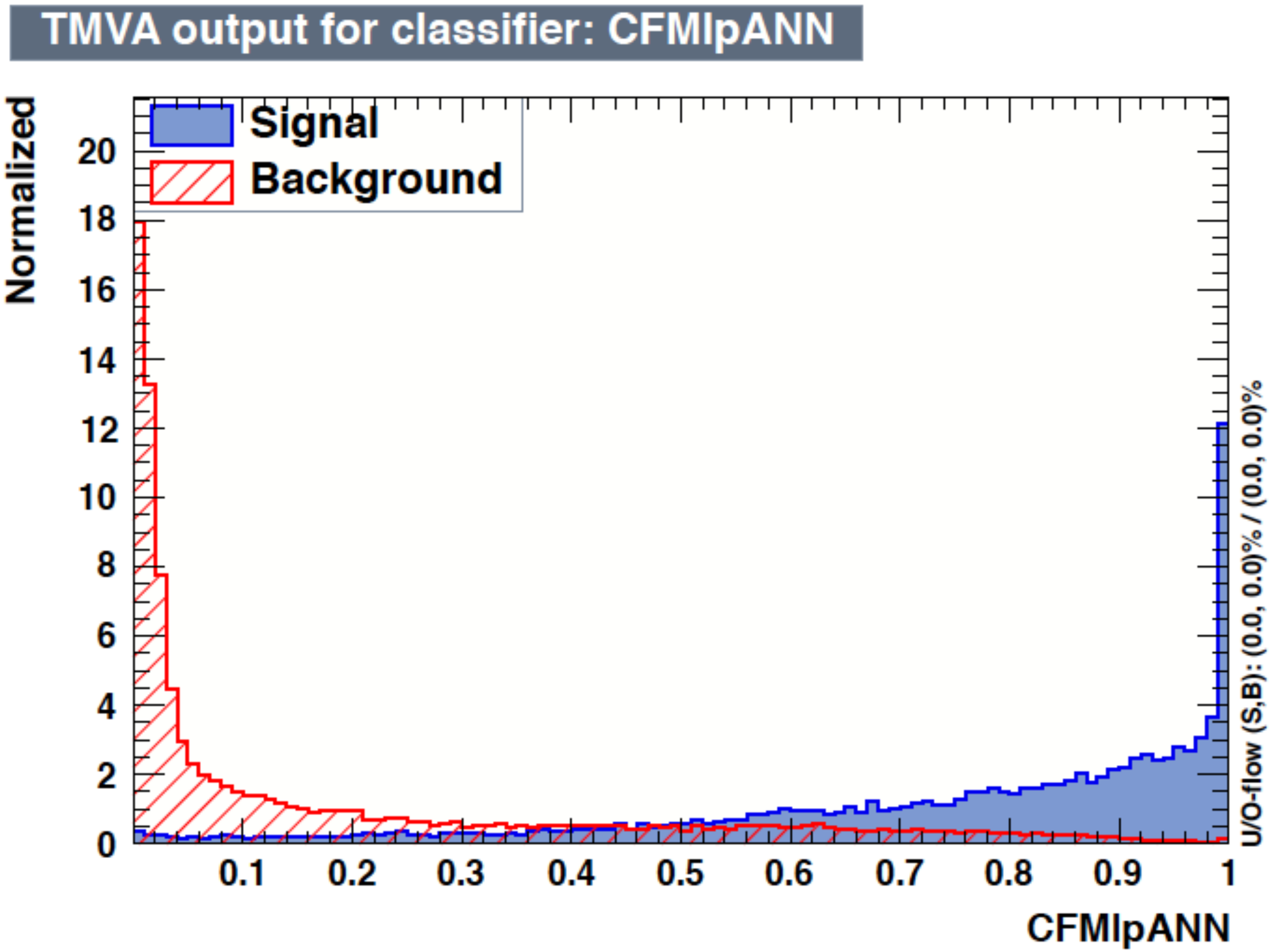
Input variables:

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



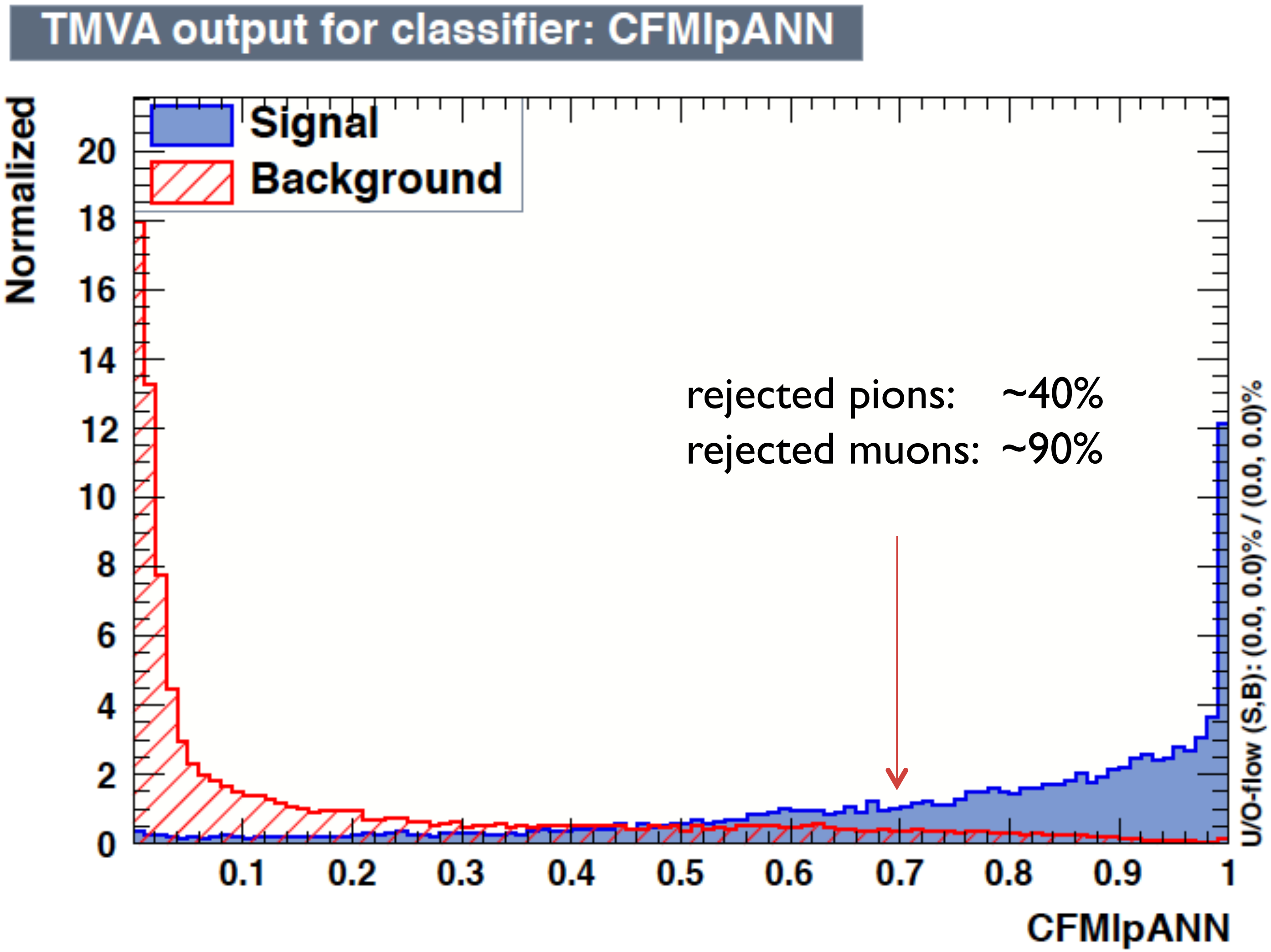


Training an Artificial Neural Network



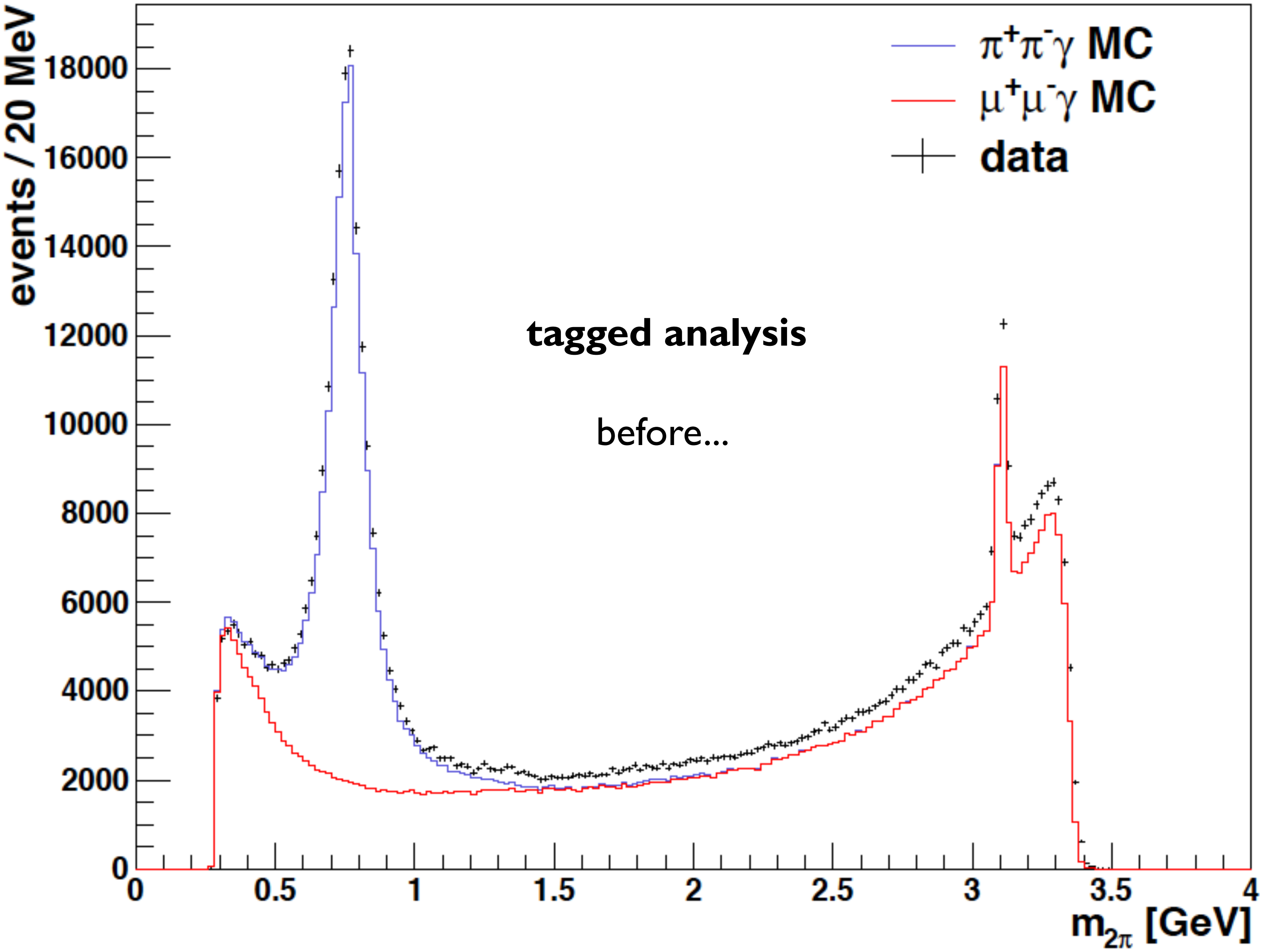
output of the Artificial Neural Network

Training an Artificial Neural Network

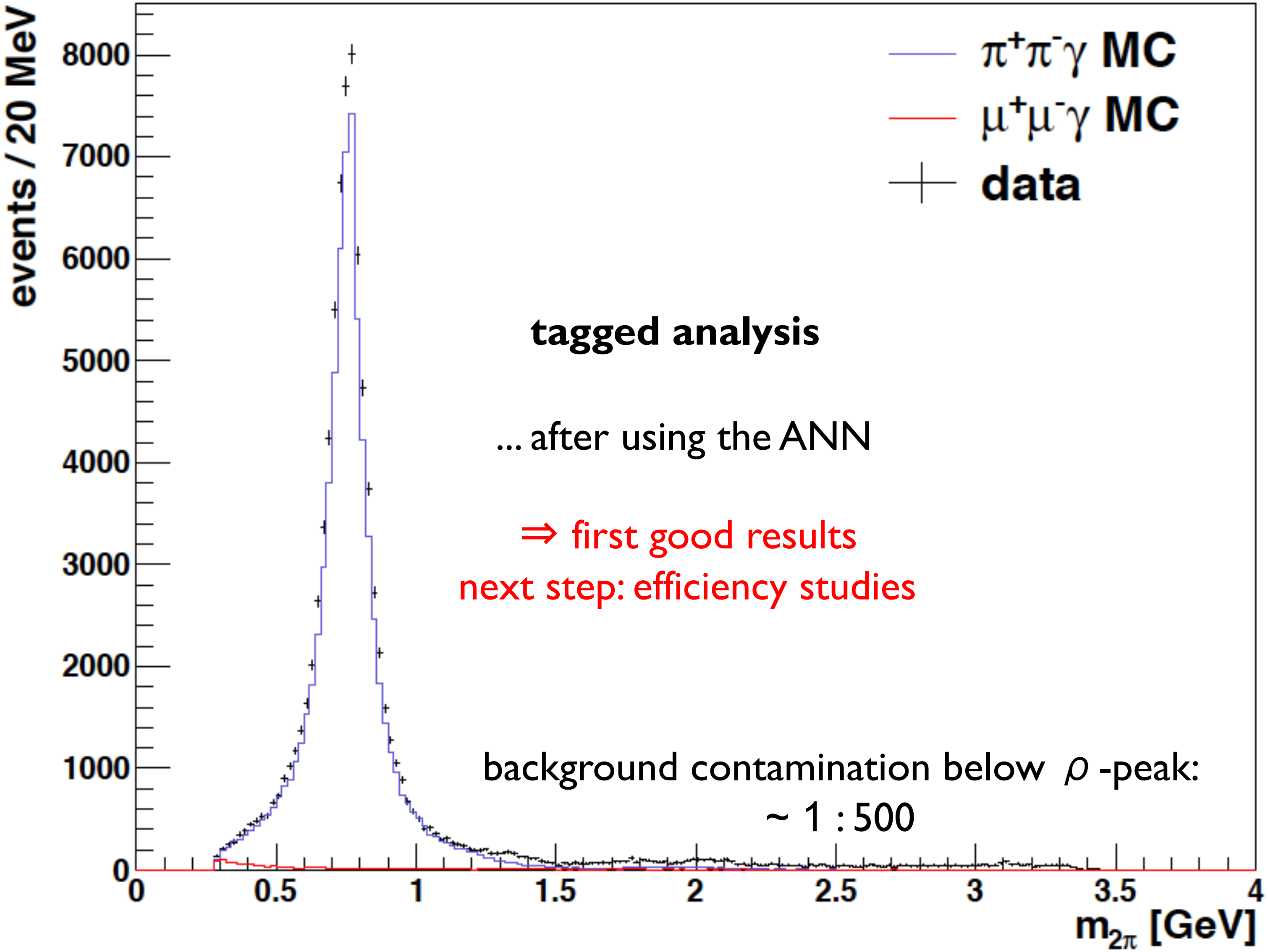


output of the Artificial Neural Network

Using the ANN in my analysis



Using the ANN in my analysis



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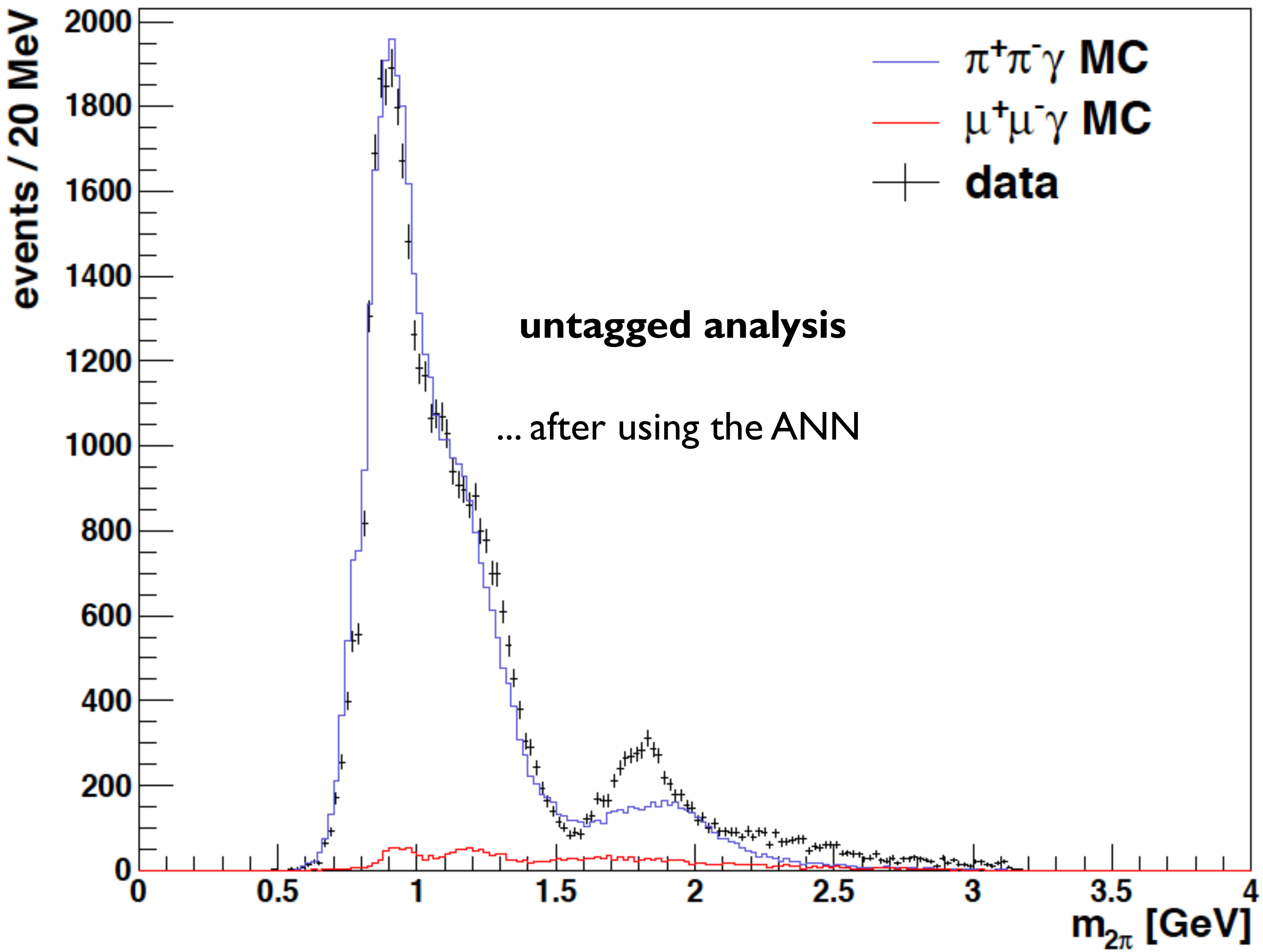


Conclusion:

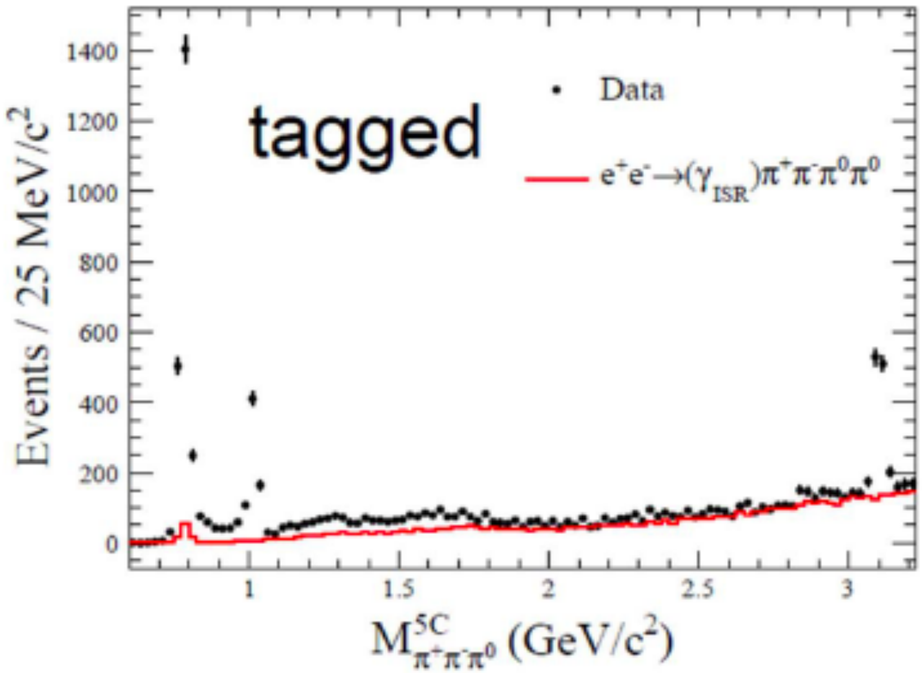
ANN seems to achieve good results

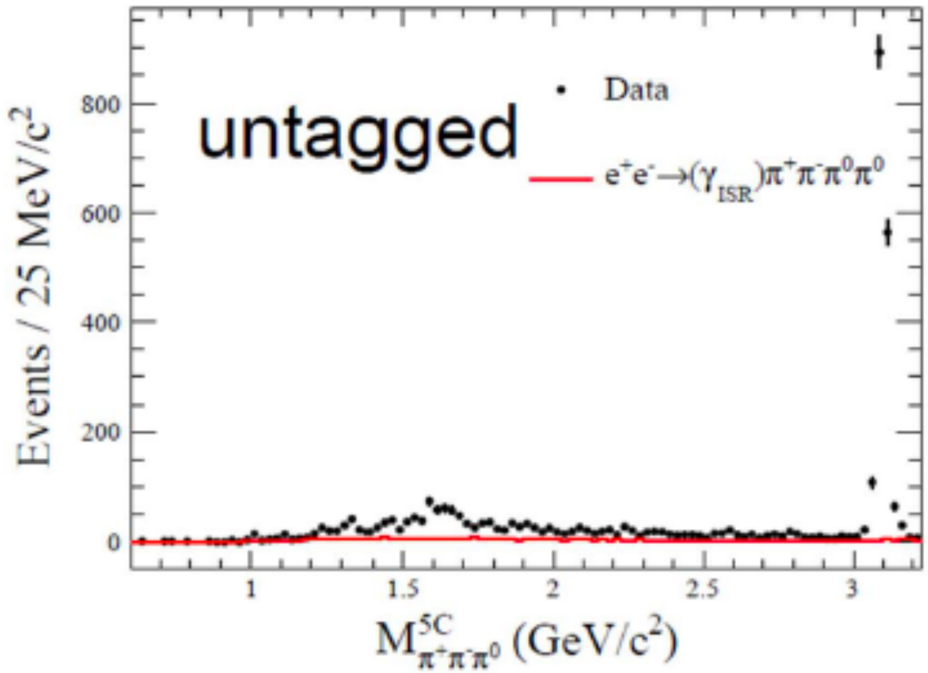
Next steps:

1. select clear muon and pion samples in data
2. study the PID efficiency differences between data and MC
3. study the with these samples also photon and tracking efficiency

⇒ ongoing at the moment

$\pi^+\pi^-\pi^0\gamma$ analysis (Yaqian Wang)



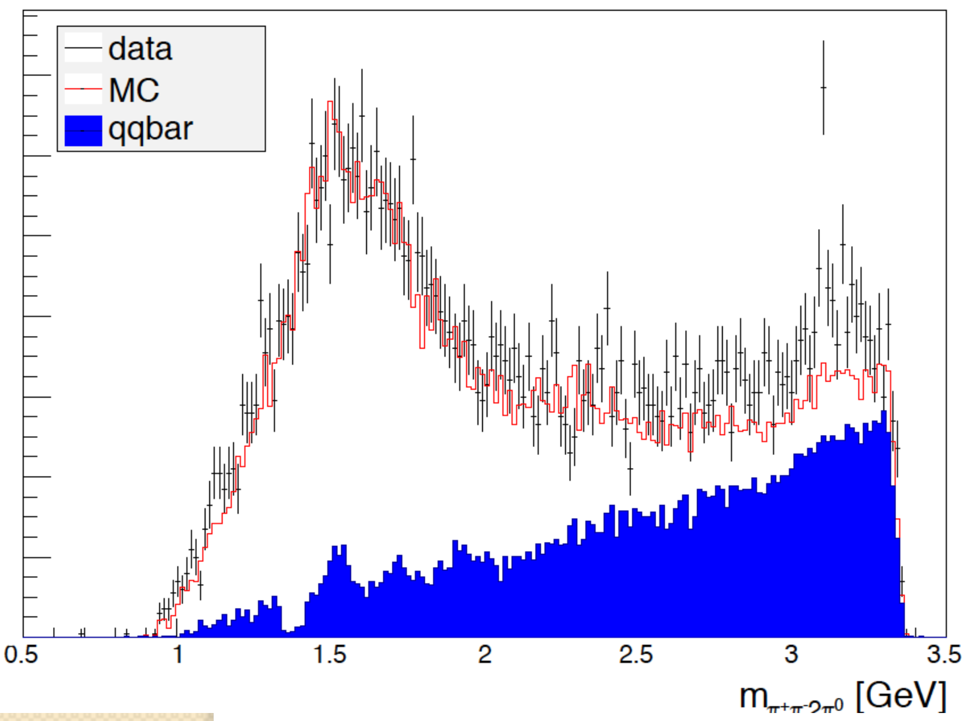


- ω-, ϕ- and J/ψ - resonance clearly visible

- nearly background free
- J/ψ - resonance visible

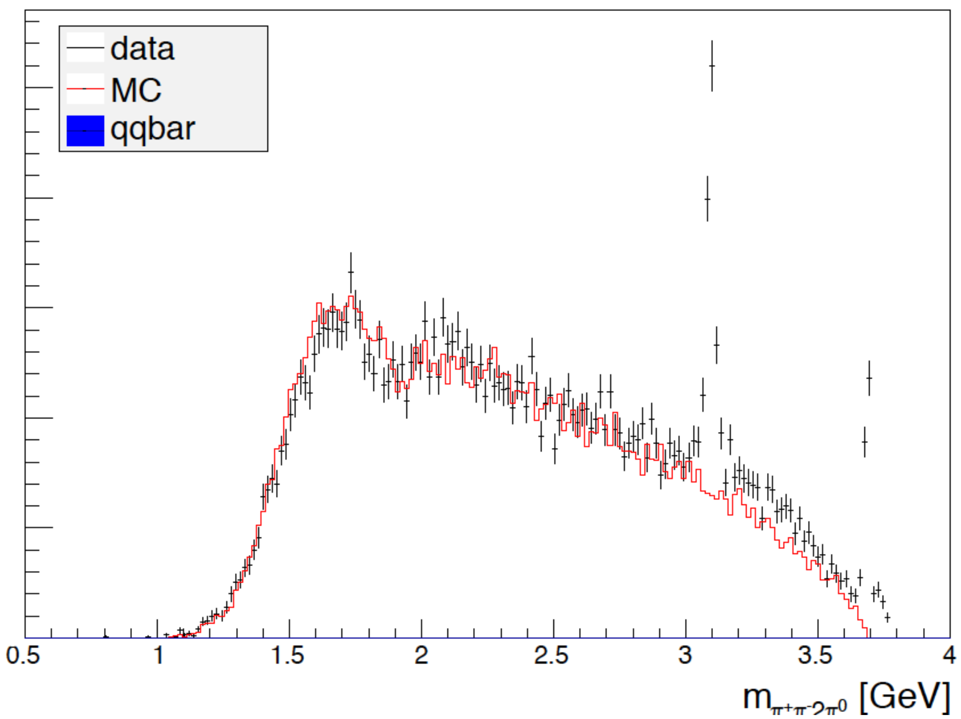
$\pi^+\pi^-\pi^0\pi^0\gamma$ analysis (Martin Ripka)

mass of $2\pi 2\pi^0$ $\chi^2 < 50$ (tagged)



- huge amount of continuum background

mass of $2\pi 2\pi^0$ $\chi^2 < 10$ and $|\cos(\theta_{ISR})| > 0.999$ (untagged)



- nearly background free
- J/ψ - and $\psi(2s)$- resonance visible

Next to do

Study	Status
tracking efficiency	ongoing ✓
photon efficiency	ongoing ✓
PID efficiency (neural network)	ongoing ✓
background	ongoing ✓
systematic uncertainties	ongoing ✓
unfolding	after corrections ✗

⇒ **huge progress in the last months!**

Summary

- feasibility studies of ISR physics at BES-III are promising
  ⇒ competitive results to BaBar and KLOE can be expected

- tagged and untagged measurements can be performed at BES-III

- final states under study in Mainz: $e^+e^- \rightarrow \pi^+\pi^-$
  $e^+e^- \rightarrow \pi^+\pi^-\pi^0$
  $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$

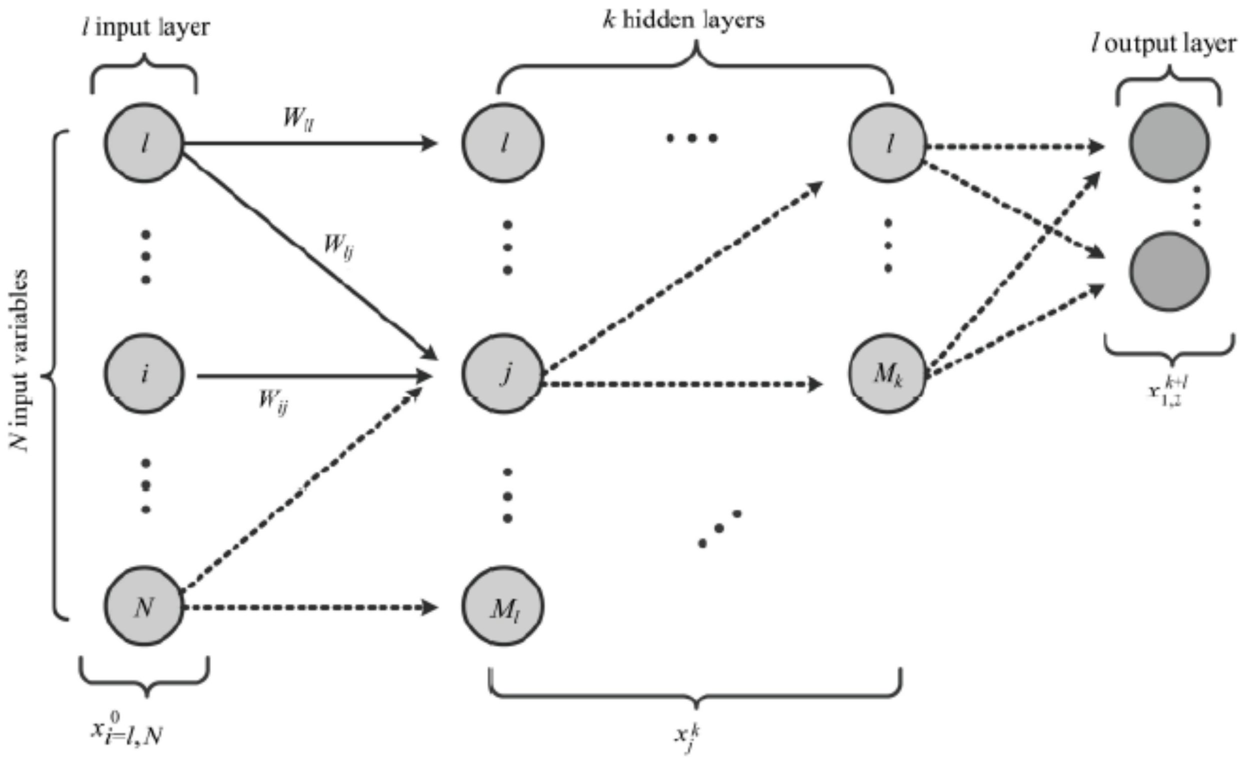
- great progress was made in the last few months

- next to do: systematic corrections and study of uncertainties and backgrounds

Thank you for your attention!

Backup

the Clermont-Ferrand ANN



$$y_{ANN} = \sum_{j=1}^{n_h} y_j^{(2)} w_{j1}^{(2)} = \sum_{j=1}^{n_h} A\left(\sum_{i=1}^{n_{var}} x_i w_{ij}^{(1)}\right) \cdot w_{j1}^{(2)}$$

$$\alpha : x \longmapsto \frac{1}{1+e^{-x}}$$

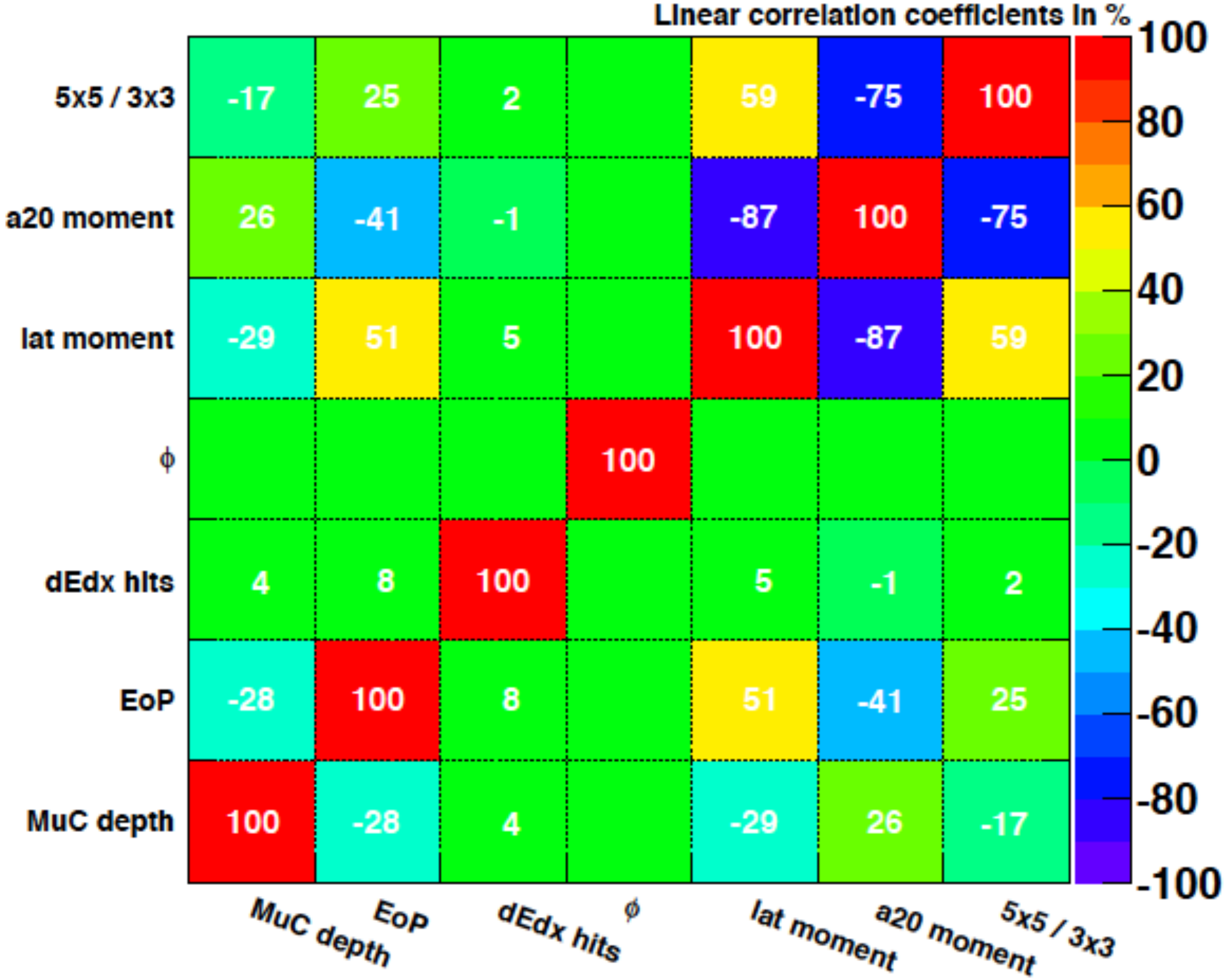
the Clermont-Ferrand ANN

Rank	Variable	Separation
1	MuC depth	$4.74 \cdot 10^{-1}$
2	lateral moment	$3.13 \cdot 10^{-1}$
3	5×5 / 3×3	$3.03 \cdot 10^{-1}$
4	a20 moment	$2.81 \cdot 10^{-1}$
5	second moment	$2.80 \cdot 10^{-1}$
6	E/p	$2.76 \cdot 10^{-1}$
7	5×5 / Seed	$1.31 \cdot 10^{-1}$
8	3×3 / Seed	$8.97 \cdot 10^{-2}$
9	ϕ	$3.87 \cdot 10^{-2}$
10	dE/dx	$1.03 \cdot 10^{-2}$

Seperation power of the input variables.
Top variable is best ranked.

Training the Artificial Neural Network

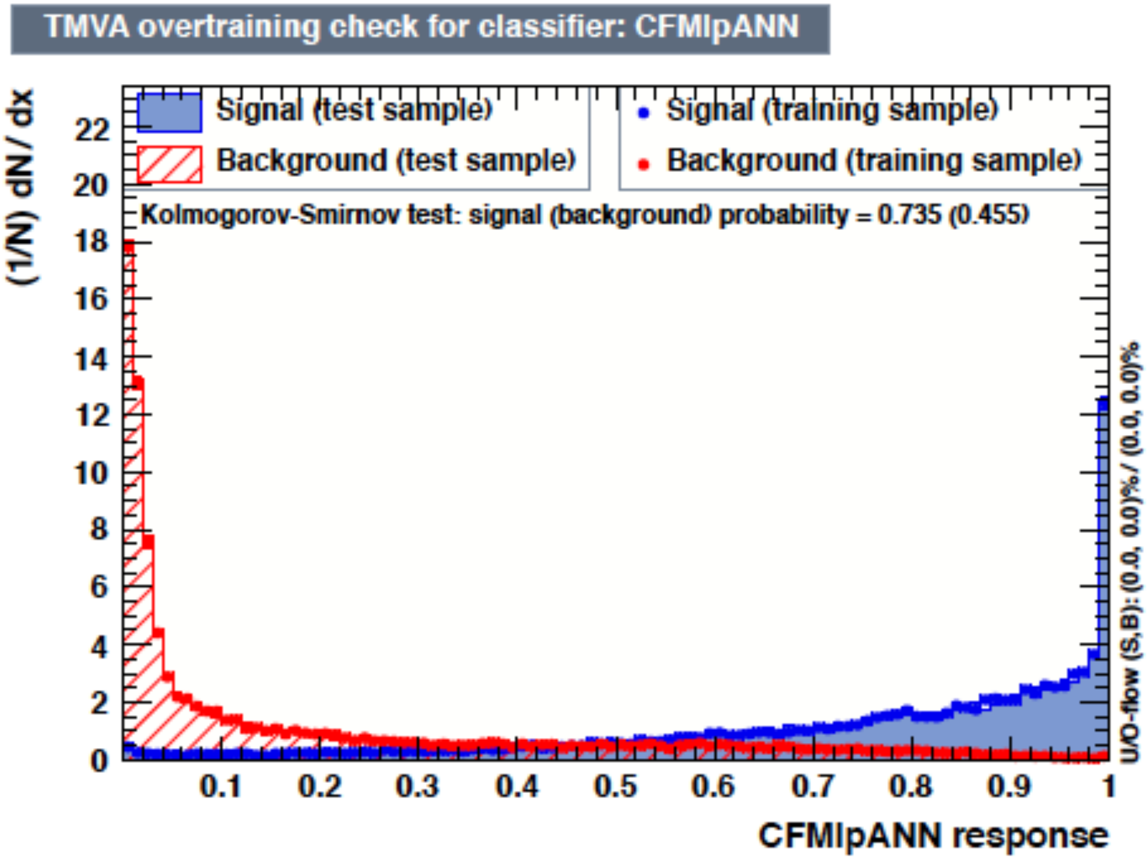
Correlation Matrix (signal)



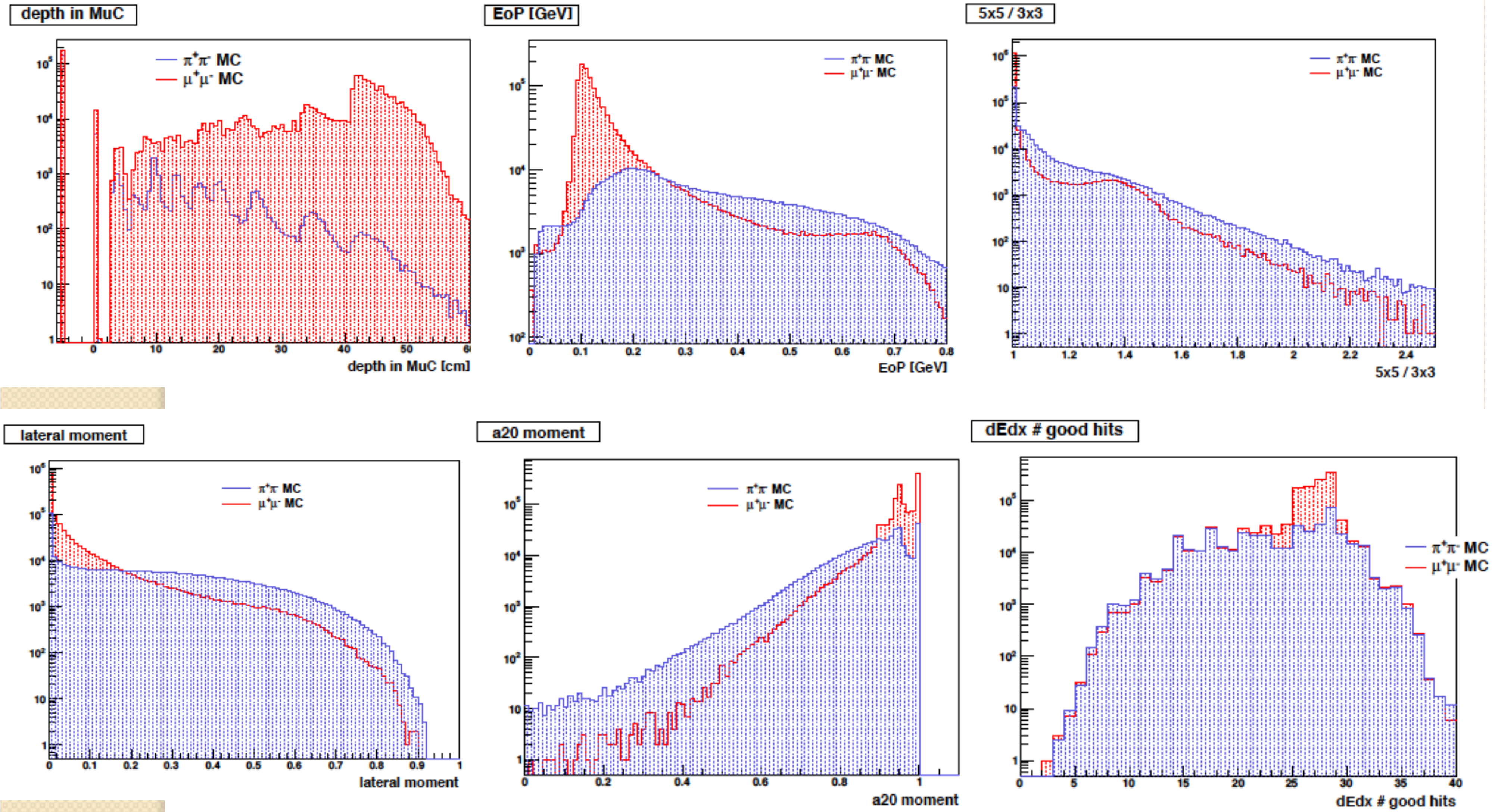
Training the Artificial Neural Network

- input sample is split into training and test sample
- output of training and test sample have to agree

⇒ overtraining check



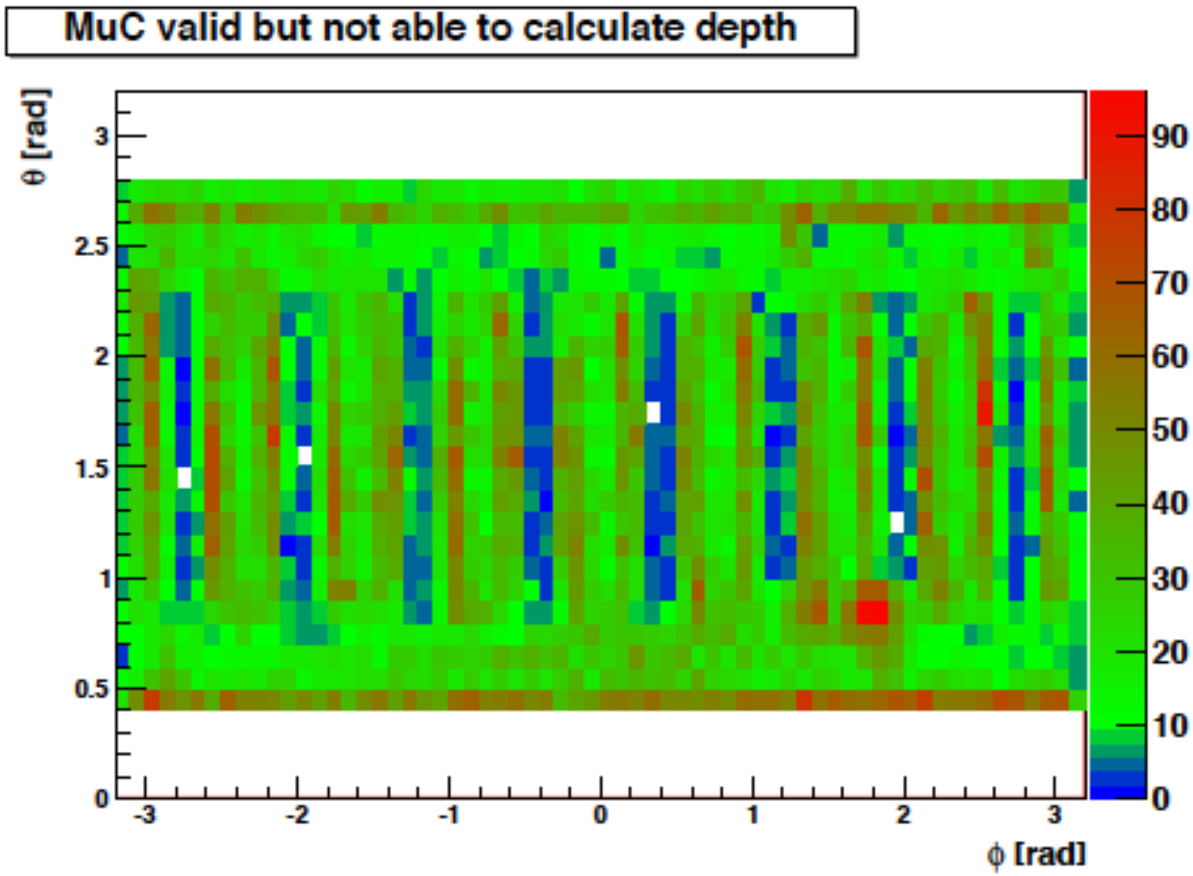
Training the Artificial Neural Network



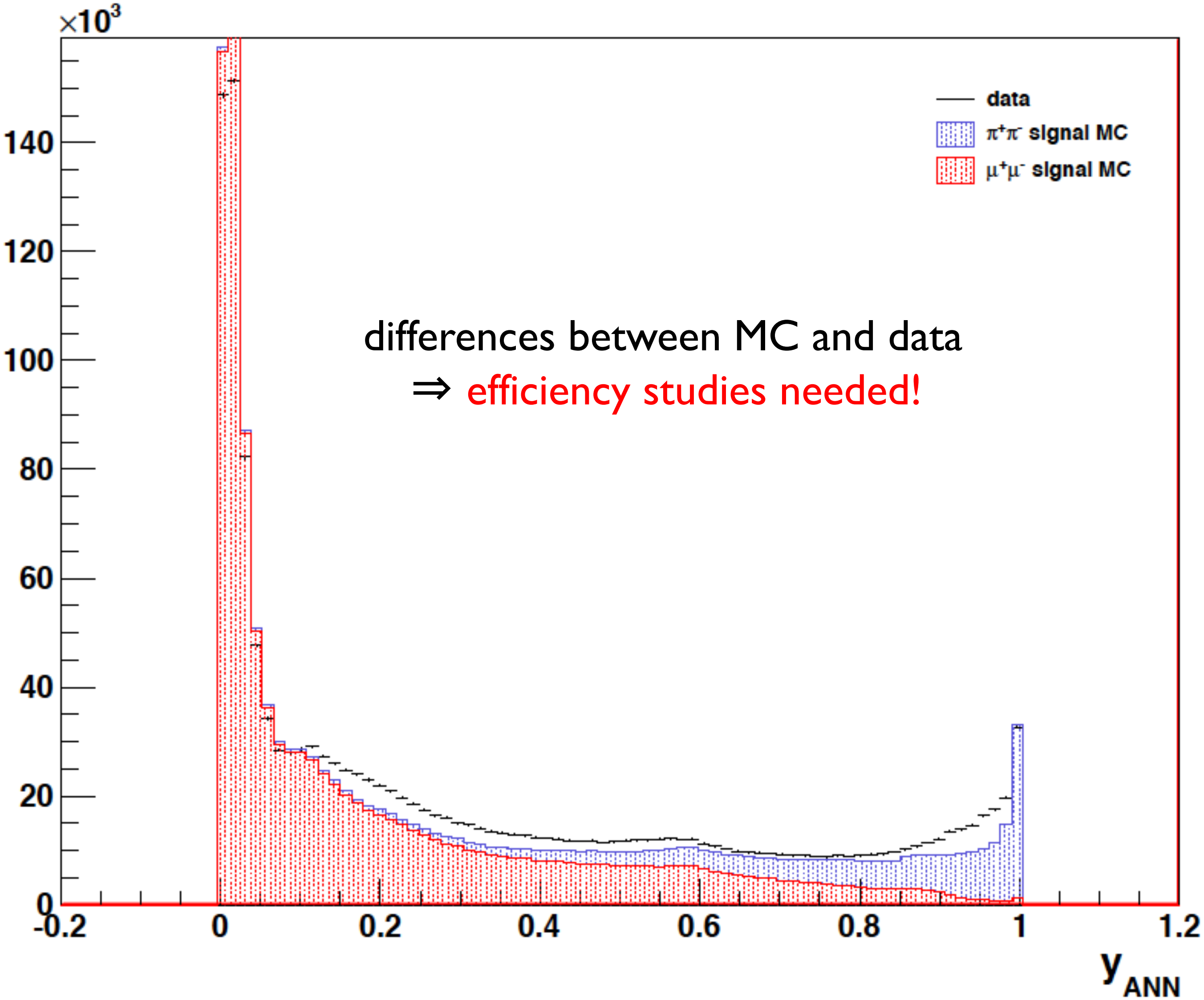
input variables

Training the Artificial Neural Network

also chosen as input: phi angle
⇒ phi dependence in the Muon Chamber



Using the ANN in my analysis



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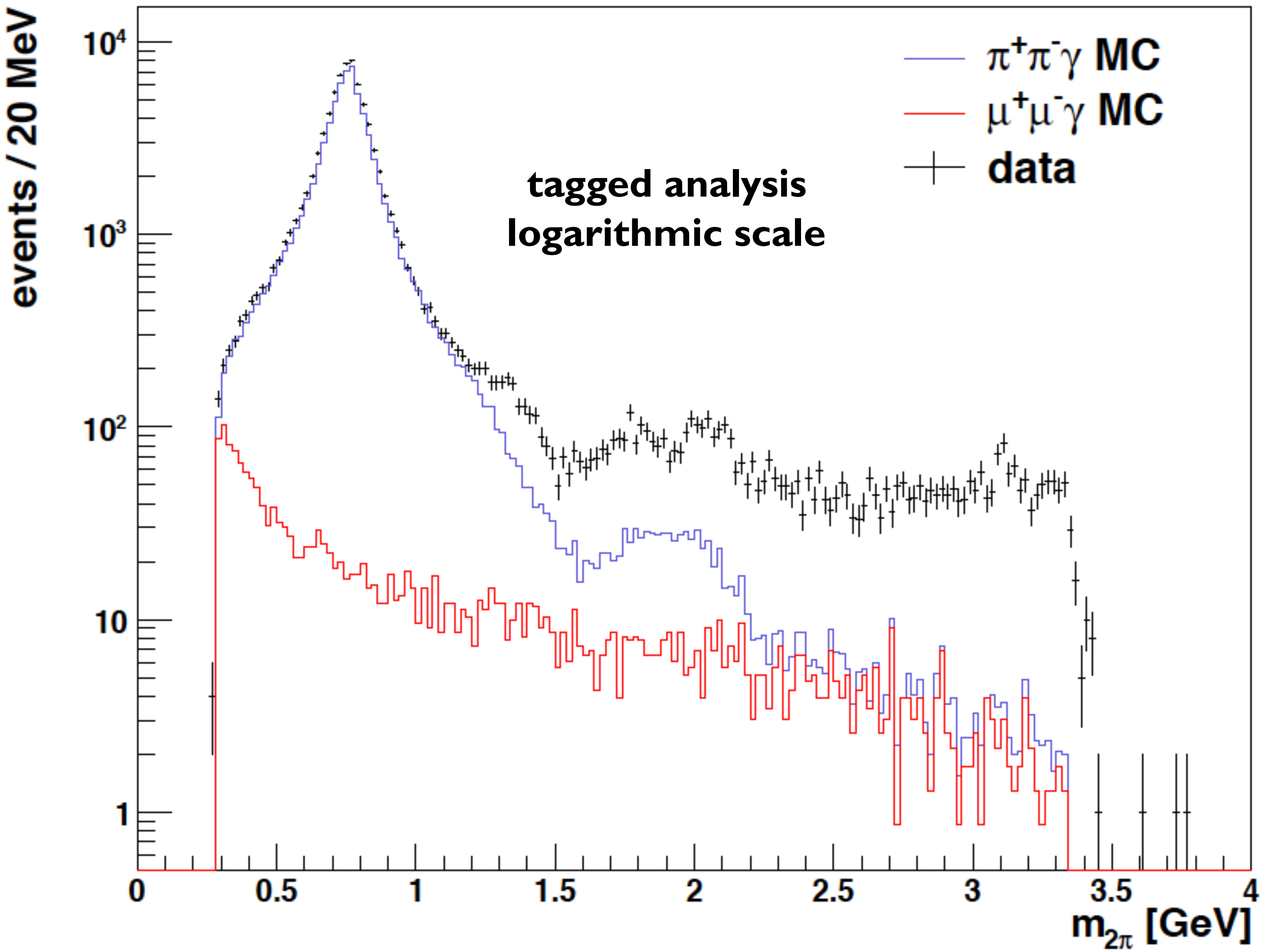
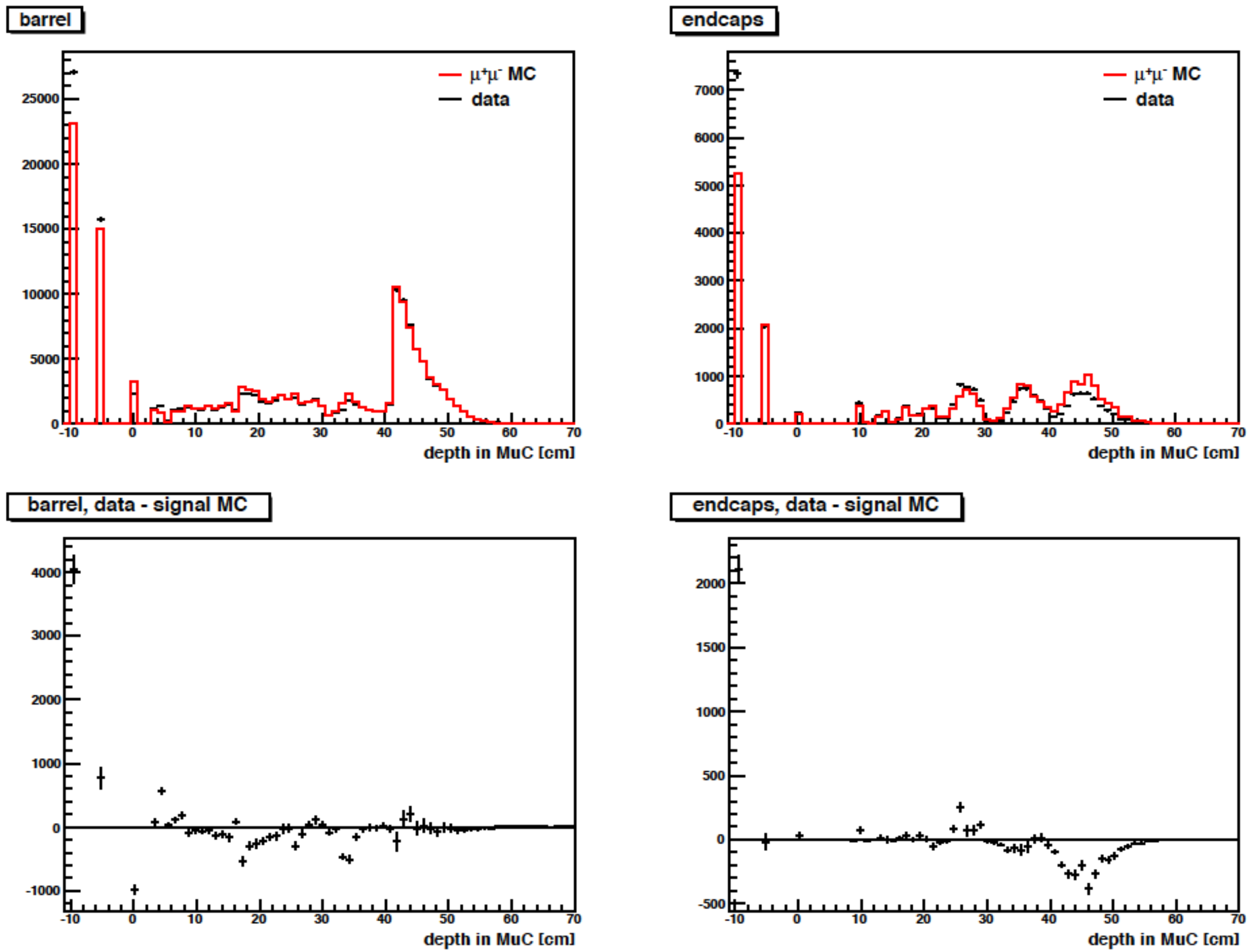


reason for efficiency differences



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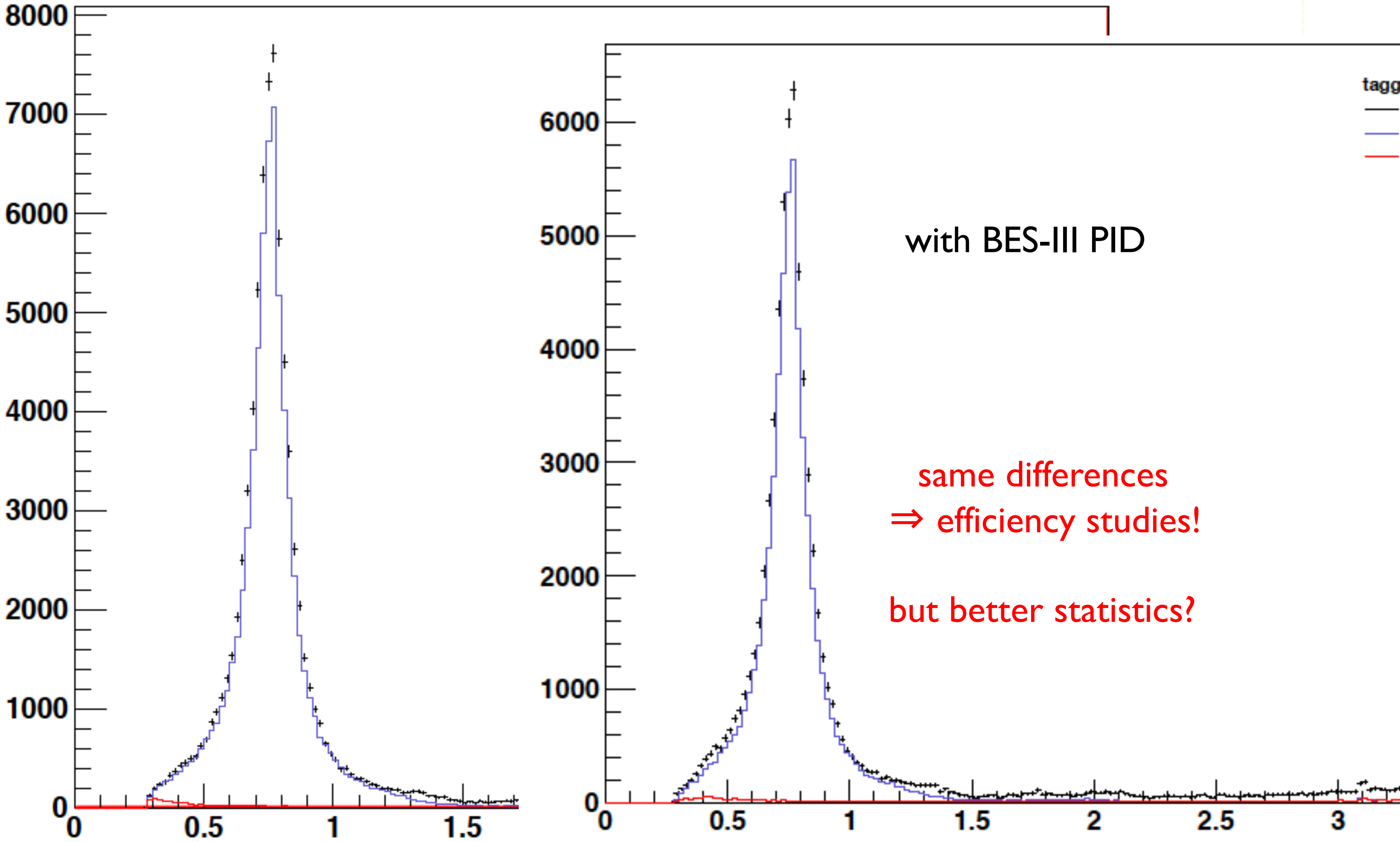

with BES-III PID

same differences
⇒ efficiency studies!

but better statistics?