Hadronic cross section from ISR

H. CZYŻ, **Institute of Physics,**
University of Silesia

In collaboration with

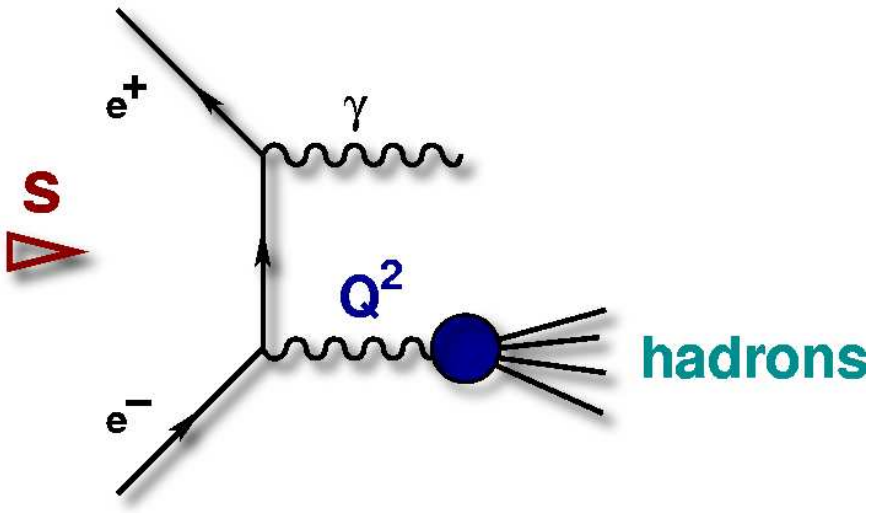
J.H. Kühn, A. Grzelińska, G. Rodrigo

I Basic Idea
II Monte Carlo Generators
III FSR at LO
IV FSR at NLO
V Perspectives and Conclusions

I BASIC IDEA

photon radiated off the initial e^+e^- (ISR) reduces the effective energy of the collision

$$d\sigma(e^+e^- \to \text{hadrons} + \gamma) = H(Q^2, \theta_\gamma)\; d\sigma(e^+e^- \to \text{hadrons})$$



- measurement of $R(s)$ over the full range of energies, from threshold up to $\sqrt{s}$
- large luminosities of factories compensate α/π from photon radiation
- radiative corrections essential (NLO)
- advantage over energy scan (BES, CMD2, SND): systematics (e.g. normalization) only once

High precision measurement of the hadronic cross-section at DAΦNE, CLEO-C,B-factories

particularly interesting the low energy region < 2 GeV

Rates :

$\pi^+\,\pi^-\,\gamma$: $E_\gamma > 100 MeV$

$\sqrt{s}$ $[GeV]$	$\int \mathcal{L}$ $[fb^{-1}]$	#events, $\theta_{min} = 7^\circ$
1.02	1.35	16 $\cdot 10^6$
10.6	100	3.5 $\cdot 10^6$

[actual values: KLOE = 0.5 fb^{-1}, BABAR = 131 fb^{-1} i BELLE = 159 fb^{-1}]

$4\pi\,\gamma$: $\sqrt{s} = 10.6\,GeV$, $\int \mathcal{L} = 100\ fb^{-1}$,

$7^\circ < \Theta_\gamma < 20^\circ$ and $30^\circ < \Theta_\pi < 173^\circ$

or $160^\circ < \Theta_\gamma < 173^\circ$ and $7^\circ < \Theta_\pi < 150^\circ$

	# events
$2\pi^+\,2\pi^-\,\gamma$	1.9 $\cdot 10^5$
$2\pi^0\,\pi^+\,\pi^-\,\gamma$	2.3 $\cdot 10^5$

II MONTE CARLO generators

Quantitative Analysis :

EVA: $e^+e^- \to \pi^+\pi^-\gamma$

- tagged photon ($\theta_\gamma > \theta_{cut}$)
- ISR at LO + Structure Function
- FSR: point-like pions

[Binner et al.]

$e^+e^- \to 4\pi + \gamma$

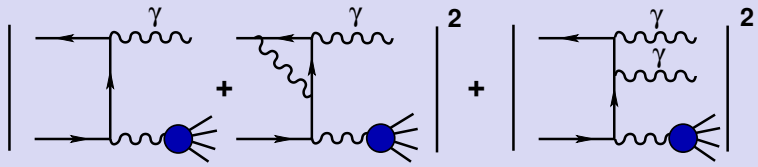
- ISR at LO + Structure Function

[Czyż, Kühn]

other exclusive channels: 3π, $K\bar{K}$

PHOKHARA 2.0: $\pi^+\pi^-$, $\mu^+\mu^-$, 4π

- **ISR at NLO:** virtual corrections to one photon events and two photon emission at tree level

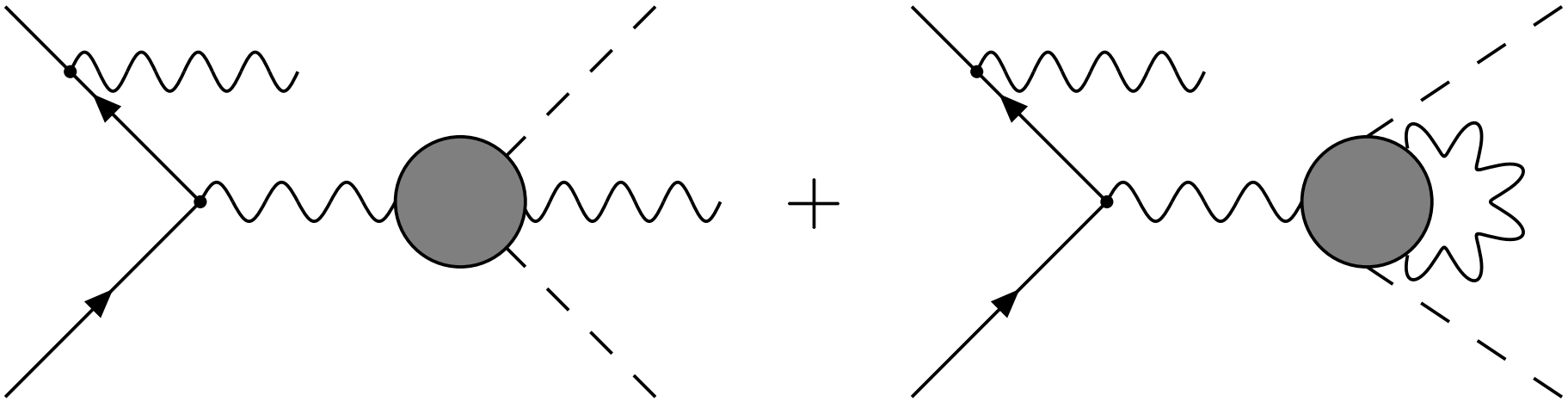


- FSR at LO: $\pi^+\pi^-$, $\mu^+\mu^-$
- tagged or untagged photons
- Modular structure

http://cern.ch/german.rodrigo/phokhara

new developments: PHOKHARA 3.0

include FSR at NLO:

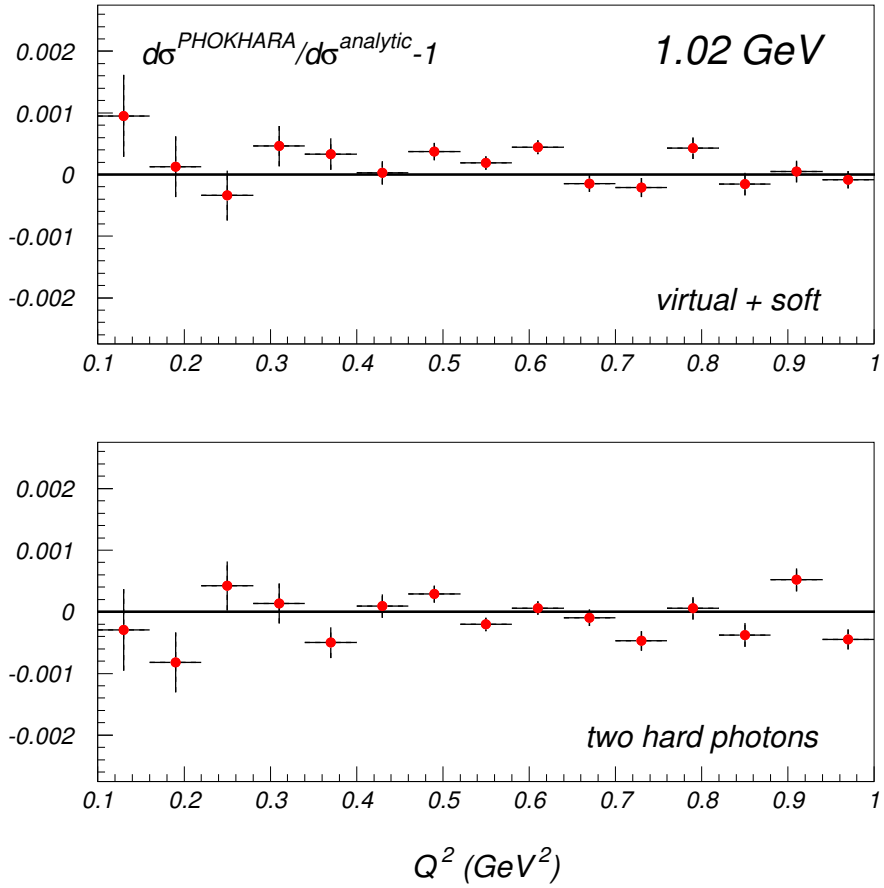


$\Rightarrow$ dominated by "two step process"

$$\mathbf{e^+e^-} \to \gamma\ \rho(\to \gamma\pi\pi)$$

Technical Precision of PHOKHARA

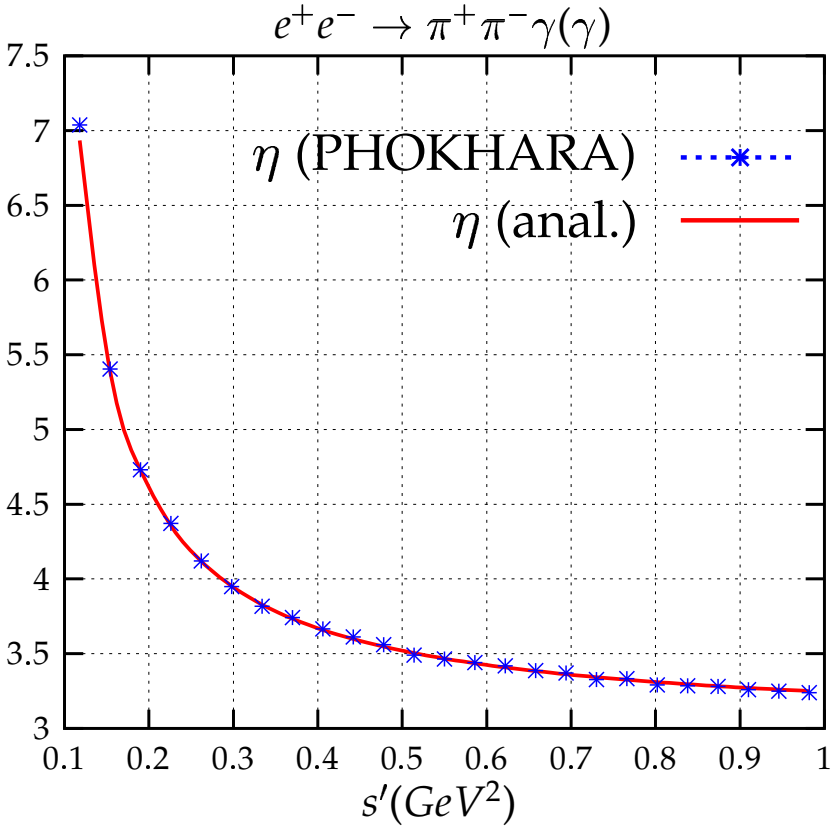
real and virtual contributions in perfect agreement with analytical results (Berends et al.)



nontrivial behaviour at small angles :

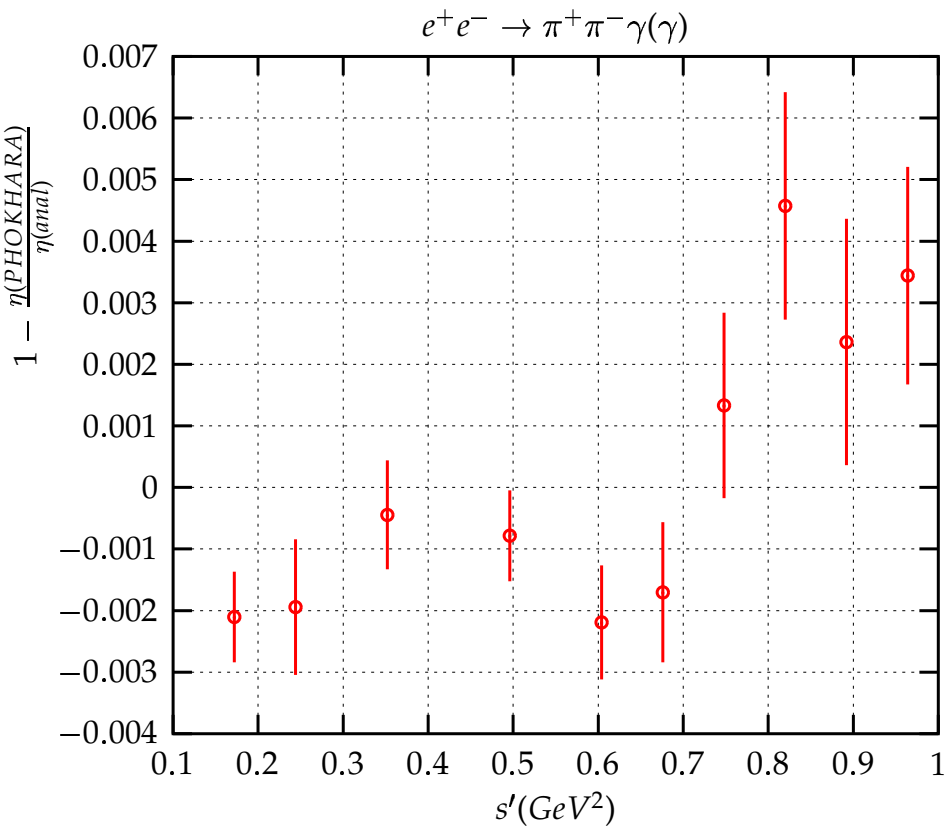
terms of order $\frac{m_e^2}{s}$ and $\frac{m_e^4}{s^2}$ are enhanced by singularities $\sim \frac{1}{\Theta_\gamma^4}$ and $\frac{1}{\Theta_\gamma^6}$!

Technical precision: of NLO FSR



Correction function $\eta(s')$

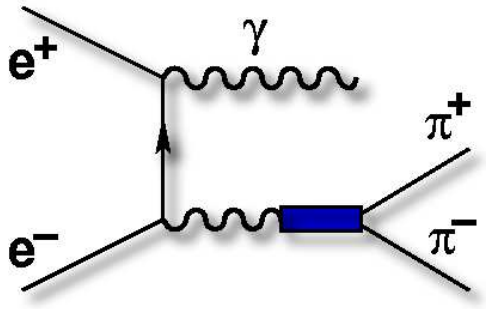
$s' = m^2(\pi^+\pi^-\gamma)$



MC vs. analytical result

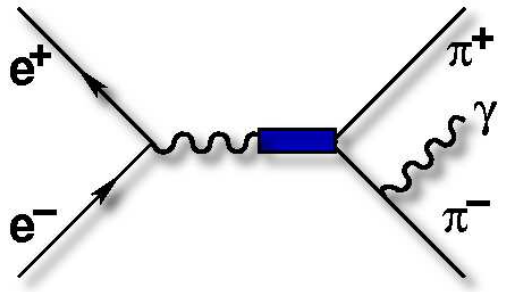
III FSR at LO : Basic Ingredients

- ISR



pion form factor ⇨ to be measured

- FSR

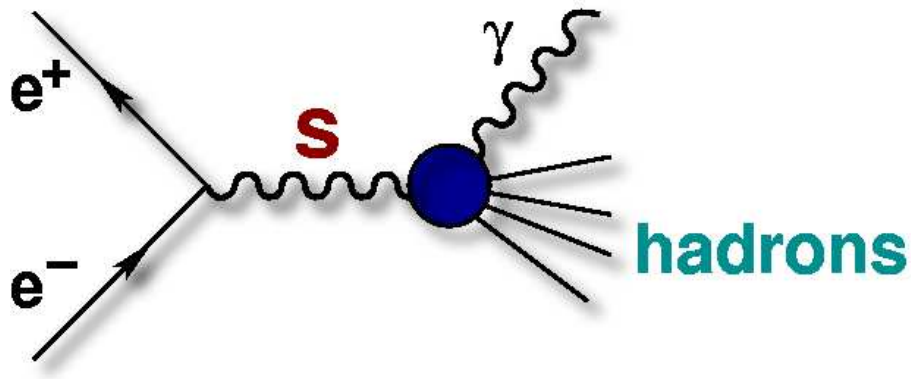


radiation from point-like pions (probably overestimated)
⇨ to be tested

- **additional radiation:** collinear (EVA MC)
  or NLO calculation (PHOKHARA MC)

FSR versus ISR

background for our process and Model dependent



Solutions:

❶ select configurations with dominantly ISR

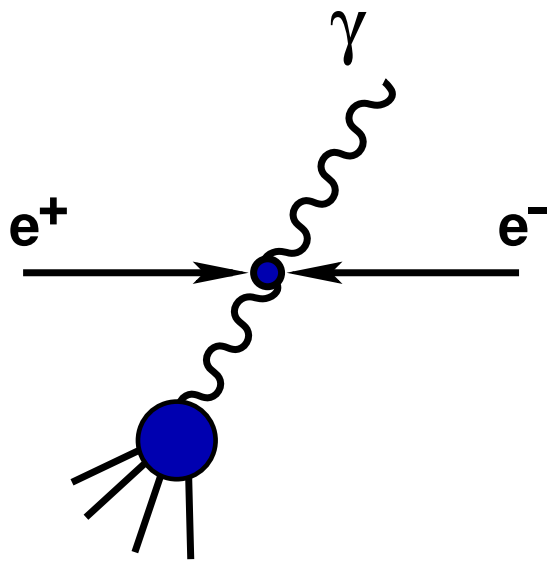
❷ allow only configurations where FSR is well predicted: γ soft, collinear

❸ identify distributions which test FSR model: angular distributions, charge asymmetry

✚ ISR-FSR interference is C-odd: cancels under C-symmetric cuts

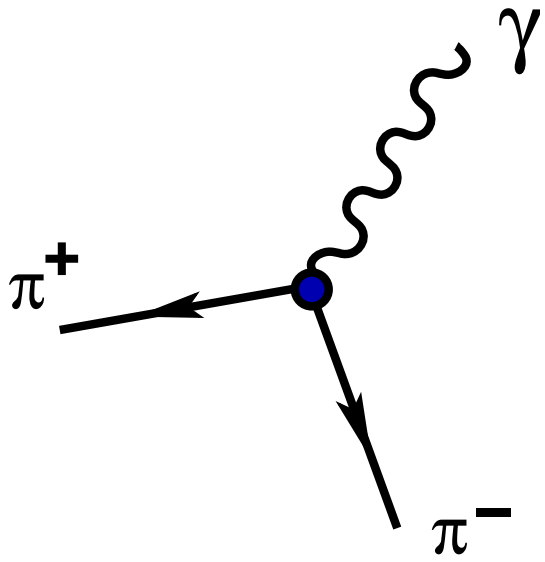
DAΦNE versus B-factories: FSR

10 GeV



very hard photon: clear kinematic separation between photon and hadrons

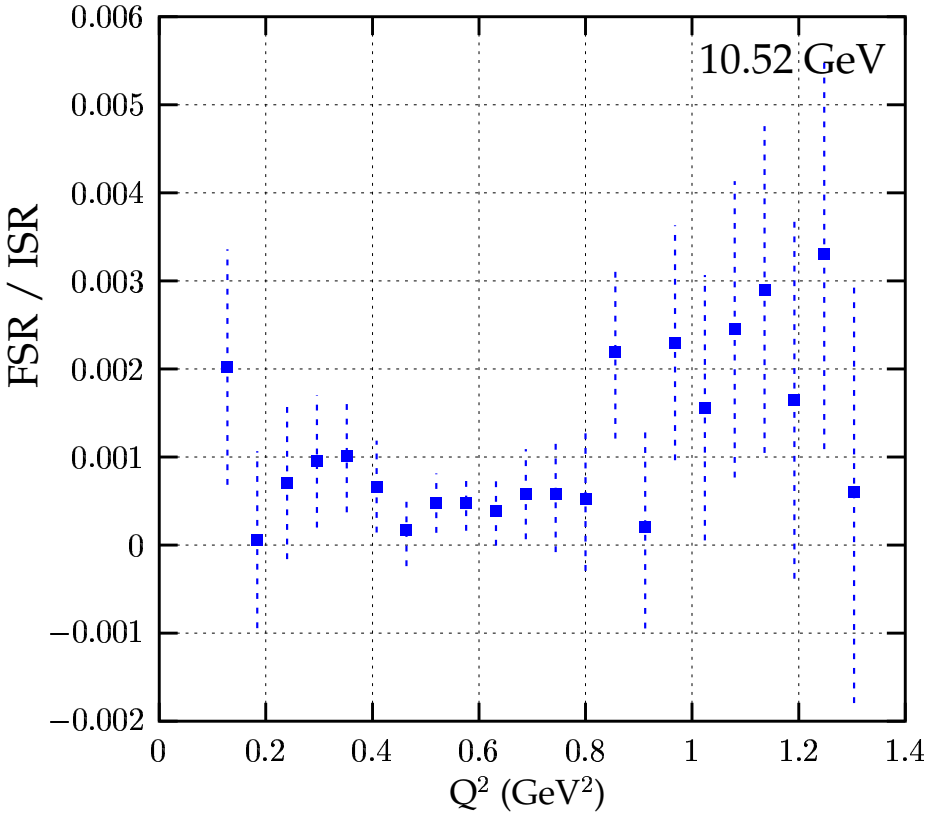
1 GeV

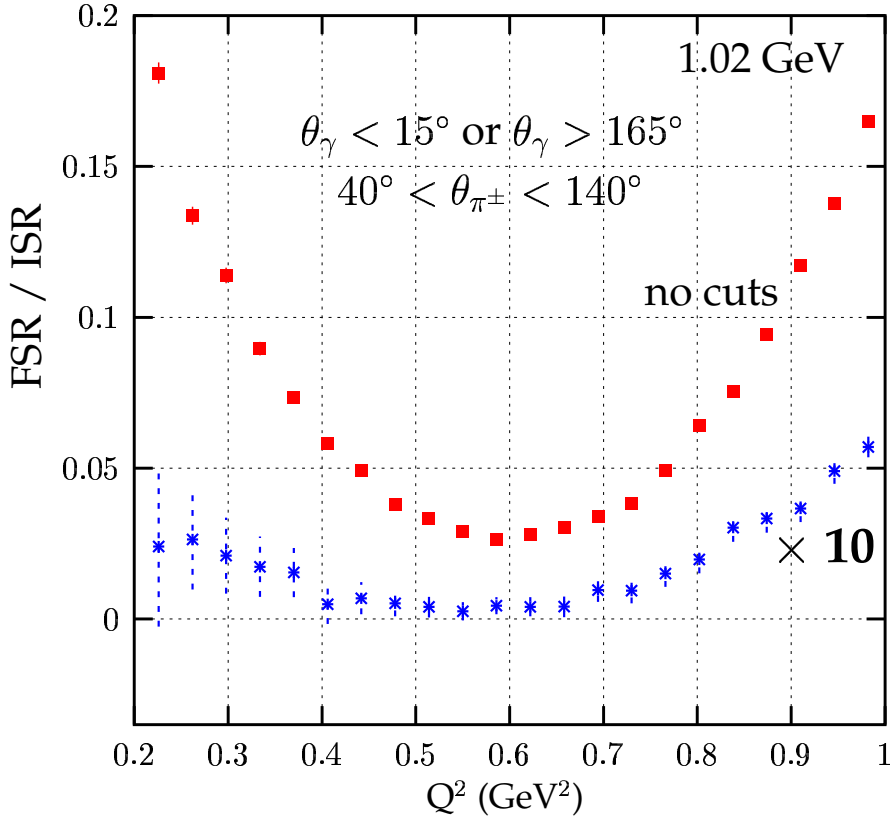


no natural kinematic separation

➪ cuts to control FSR versus ISR

reject FSR



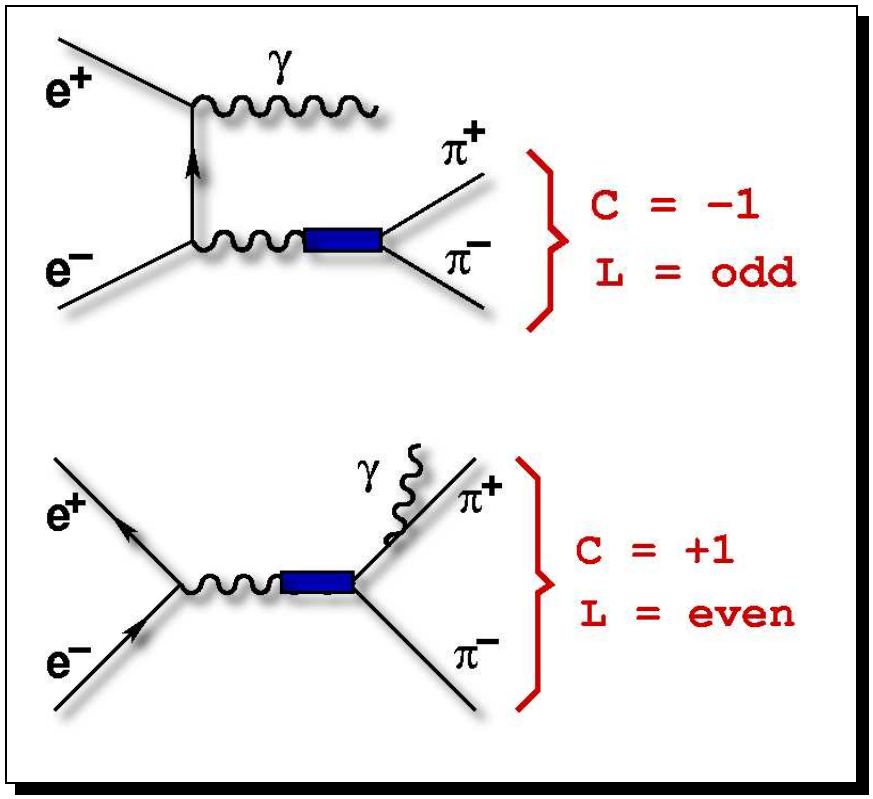


High energy (10.52GeV)

Low energy (1.02 GeV)

Test of FSR model

interference:

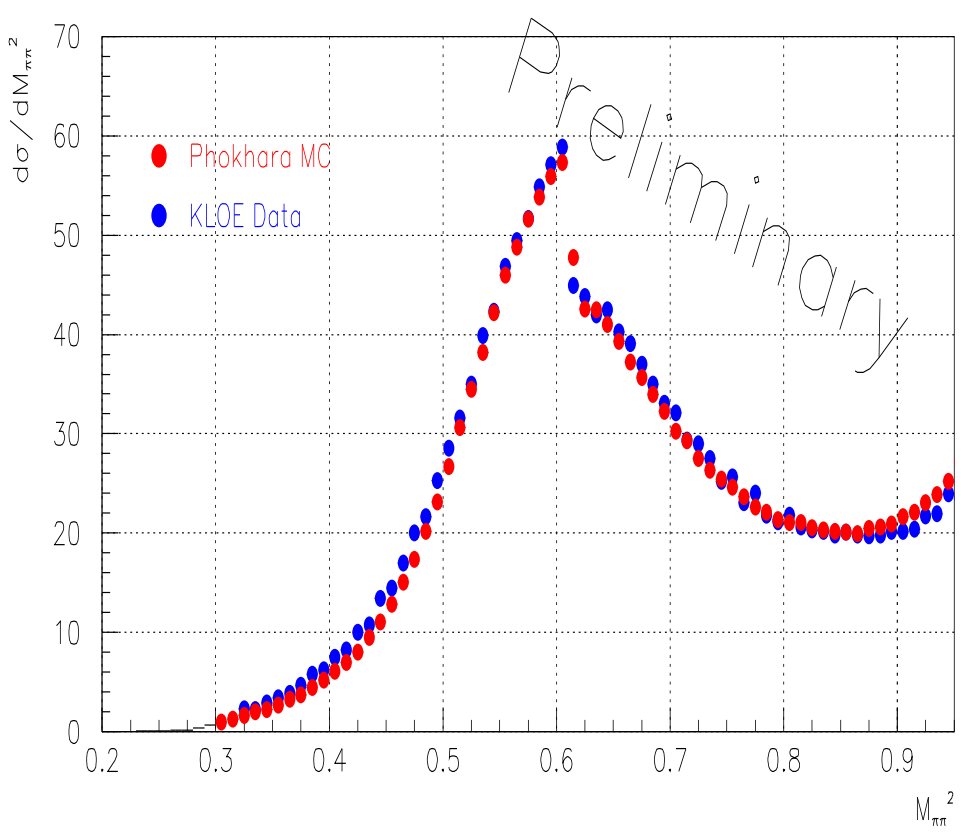


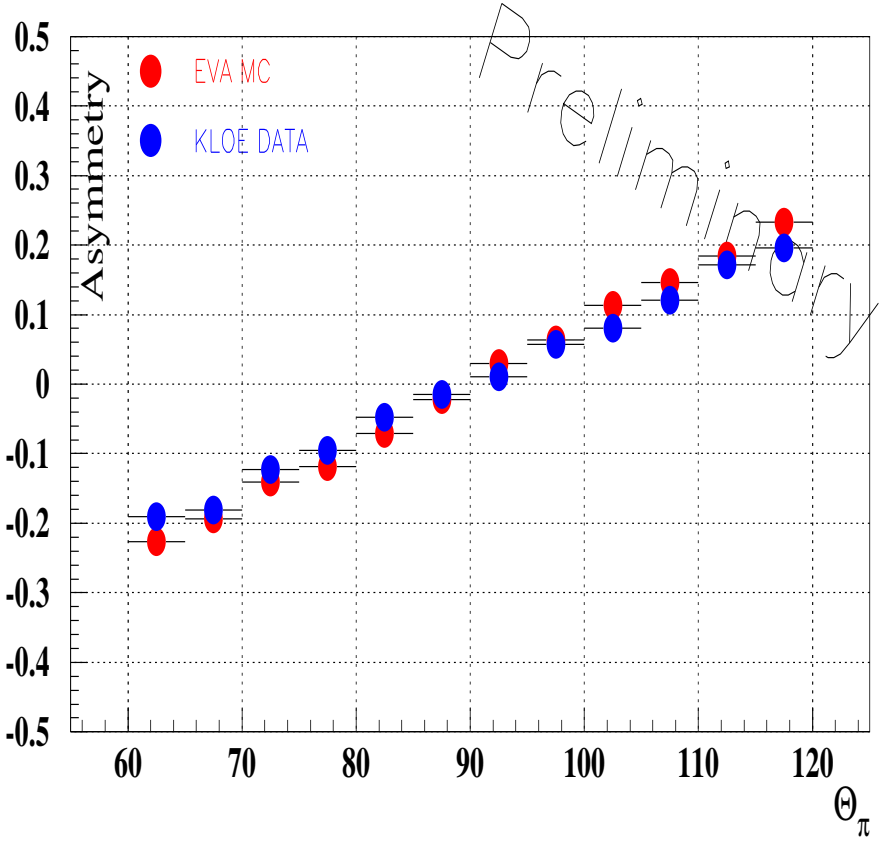
- interference odd under $\pi^+ \leftrightarrow \pi^-$
- asymmetric differential distribution: $\int$ interf. $= 0$

$$A(\theta) = \frac{N^{\pi^+}(\theta) - N^{\pi^-}(\theta)}{N^{\pi^+}(\theta) + N^{\pi^-}(\theta)}$$

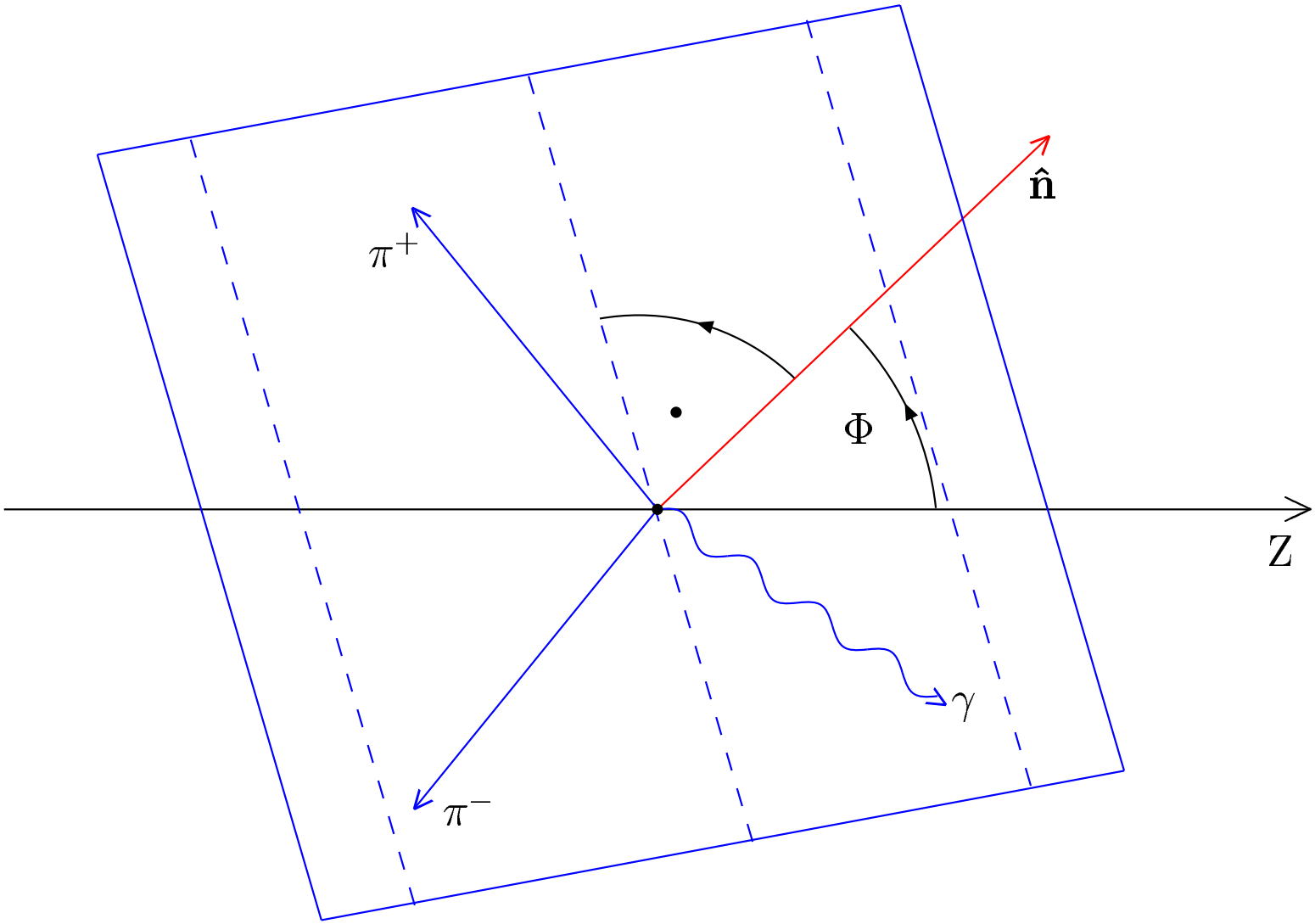
Test FSR

DAΦNE (talk by Marco Incagli at EPS Conference, Aachen 2003)

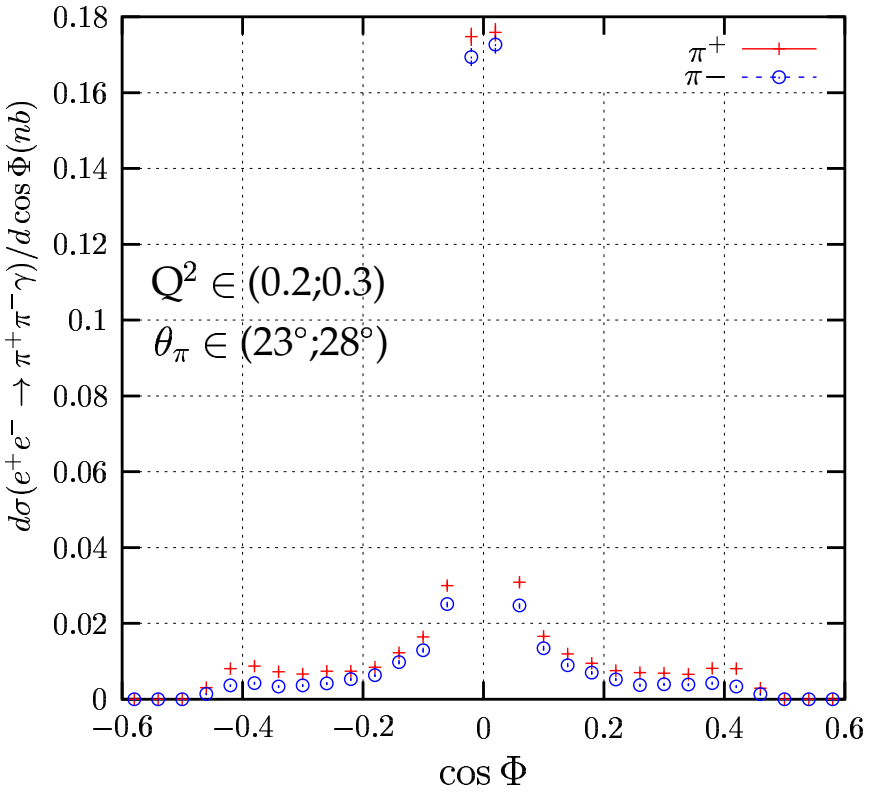


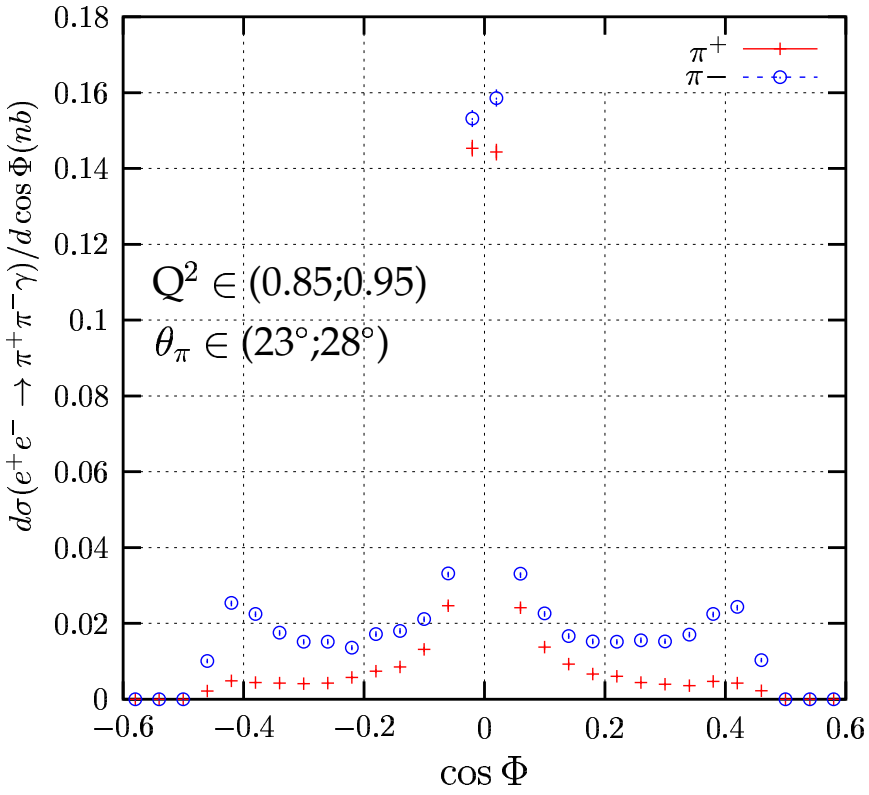


Test FSR



Test FSR

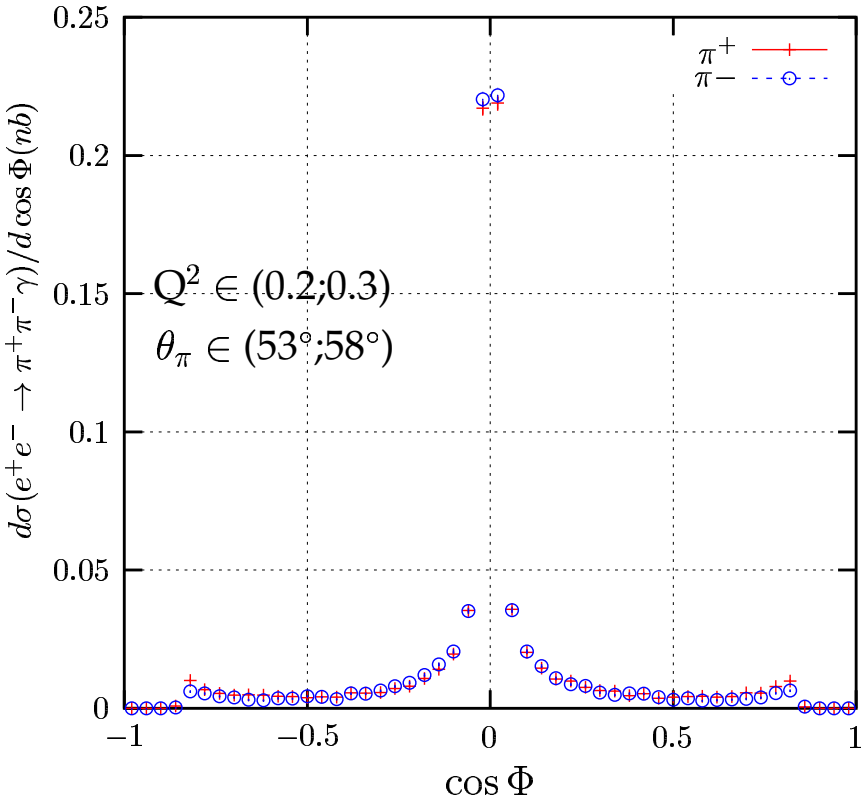


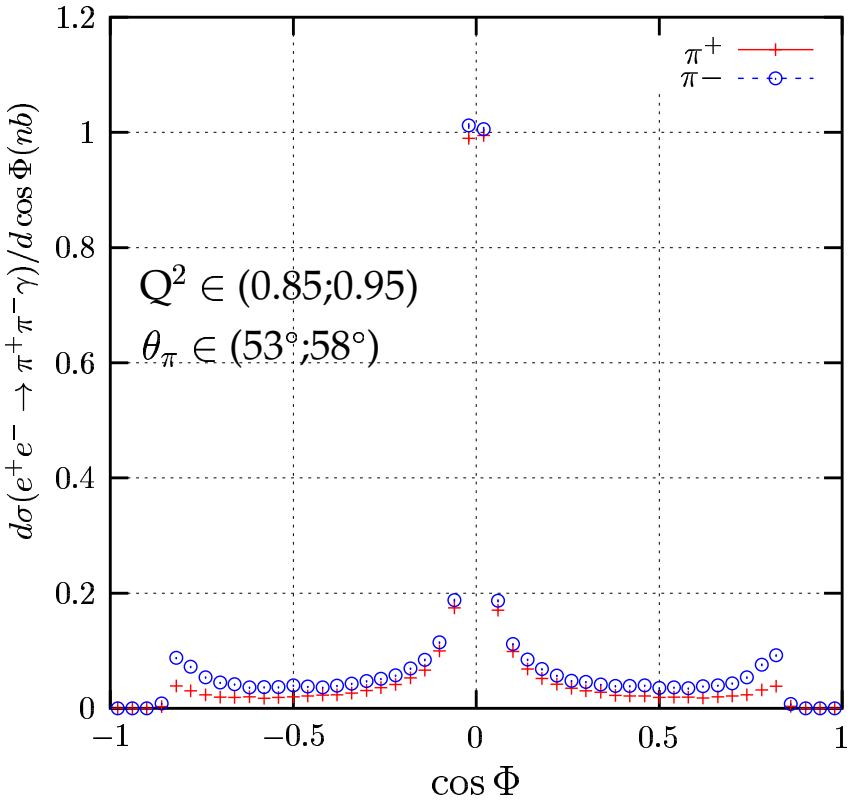


with 200 pb^{-1}

$\frac{0.1nb}{\Delta\cos\Phi} \equiv$ 800 events

Test FSR



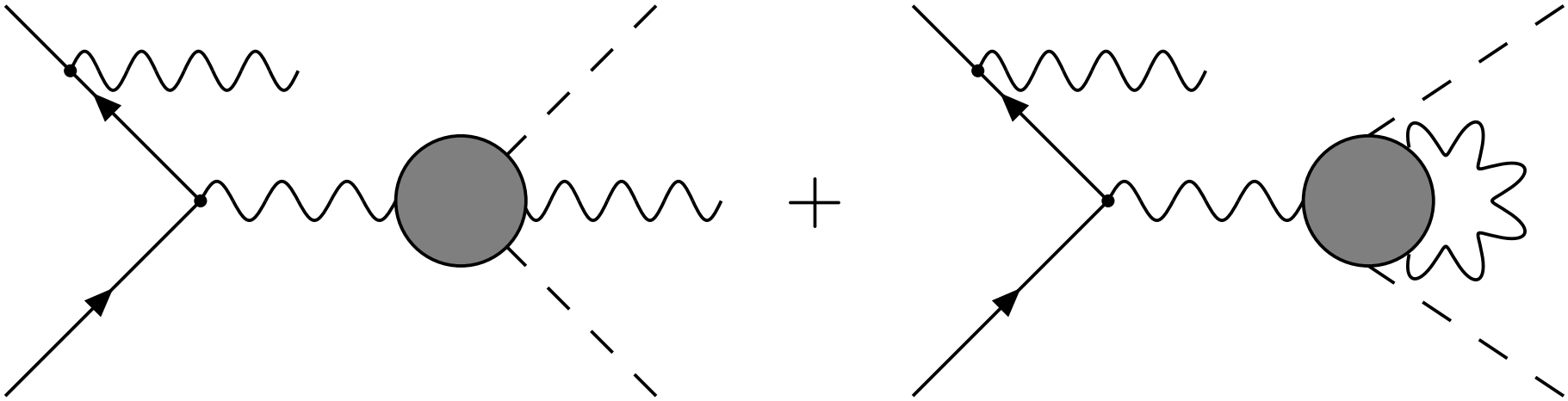


with 200 pb^{-1}

$\frac{0.1nb}{\Delta\cos\Phi} \equiv$ 800 events

IV FSR at NLO

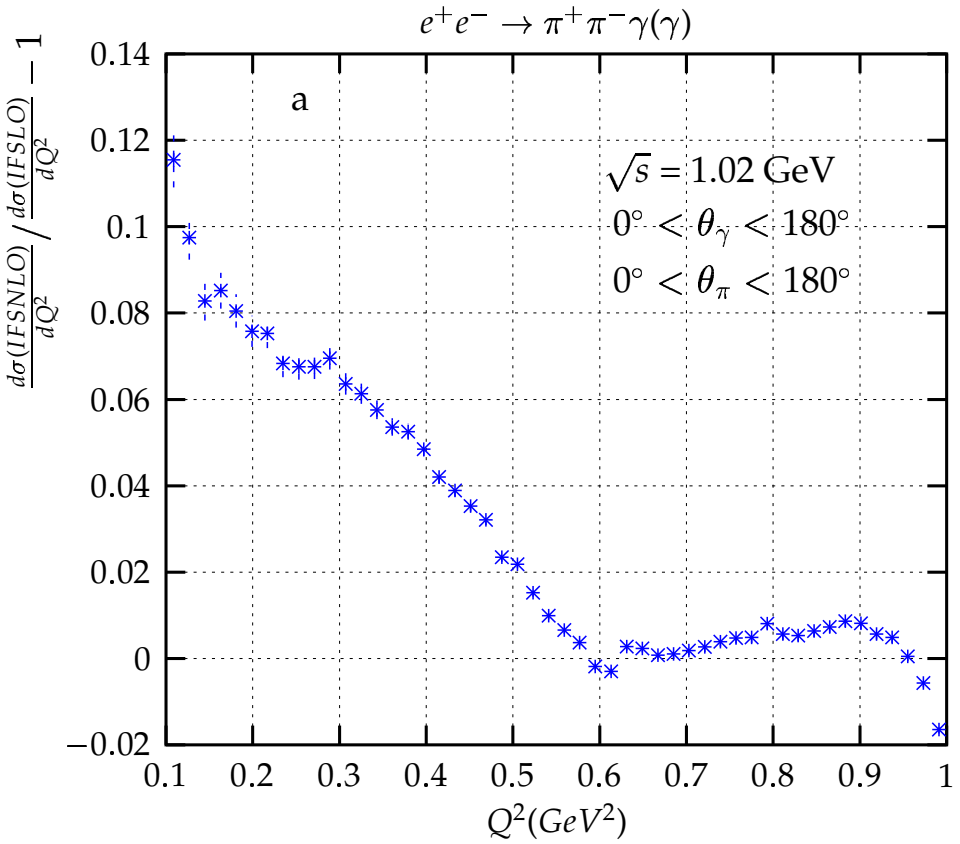
include FSR at NLO:

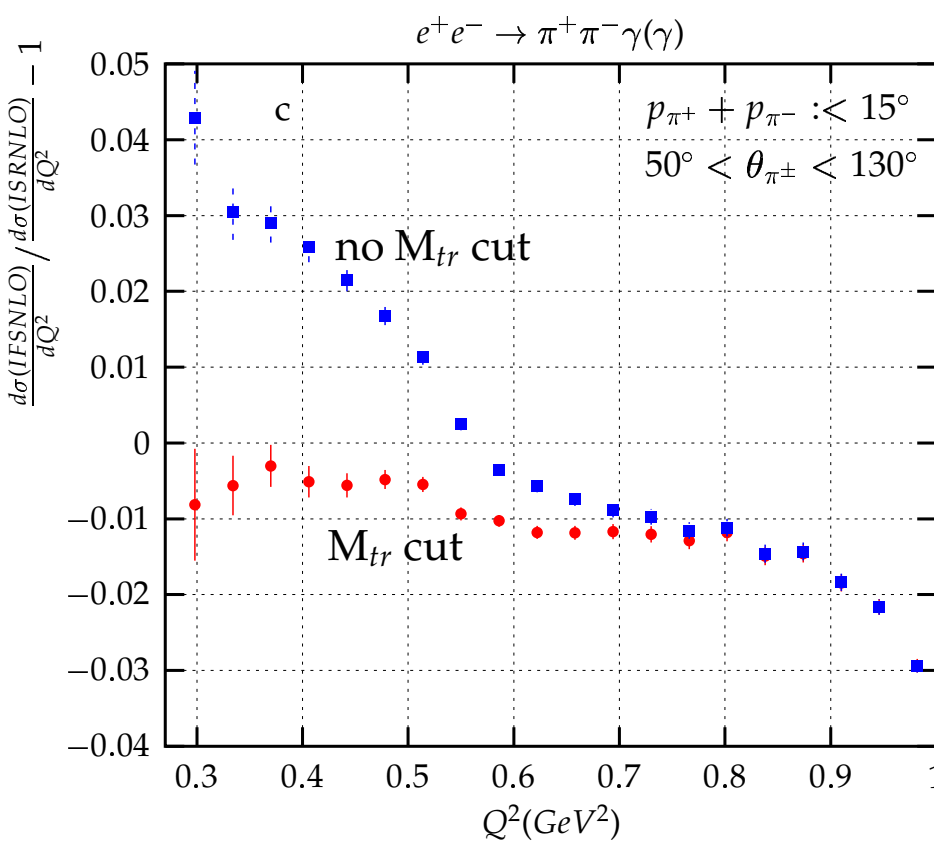


$\Rightarrow$ dominated by "two step process"

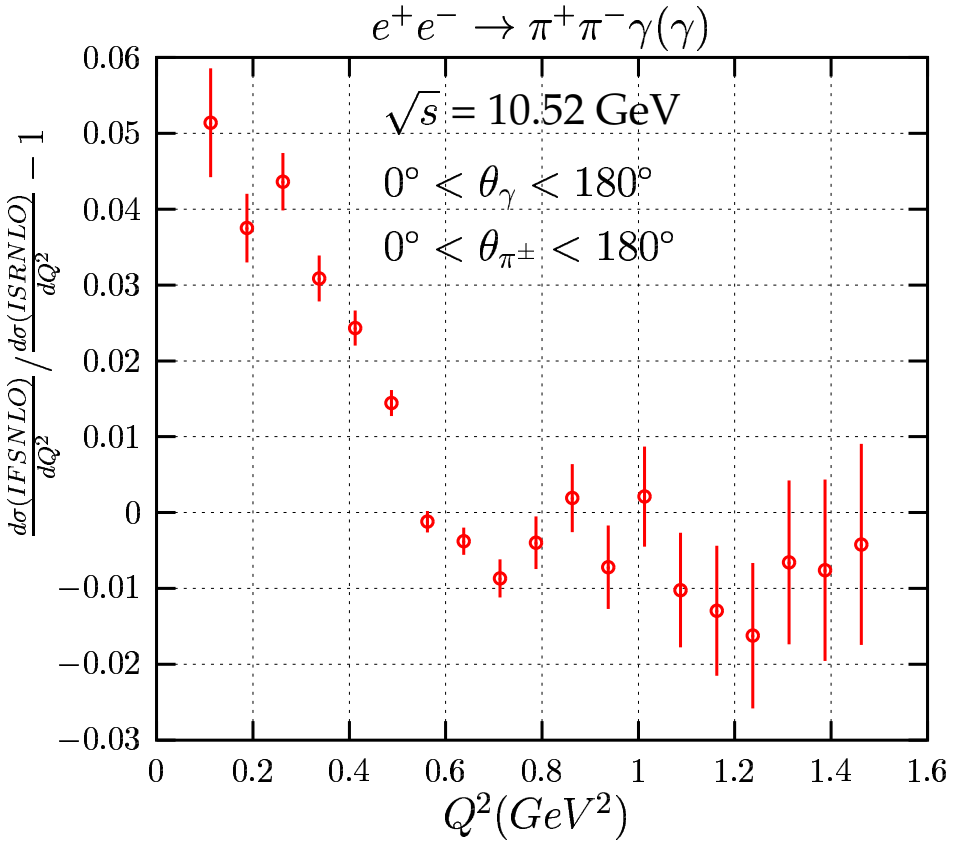
$$\mathbf{e^+e^-} \to \gamma\ \rho(\to \gamma\pi\pi)$$

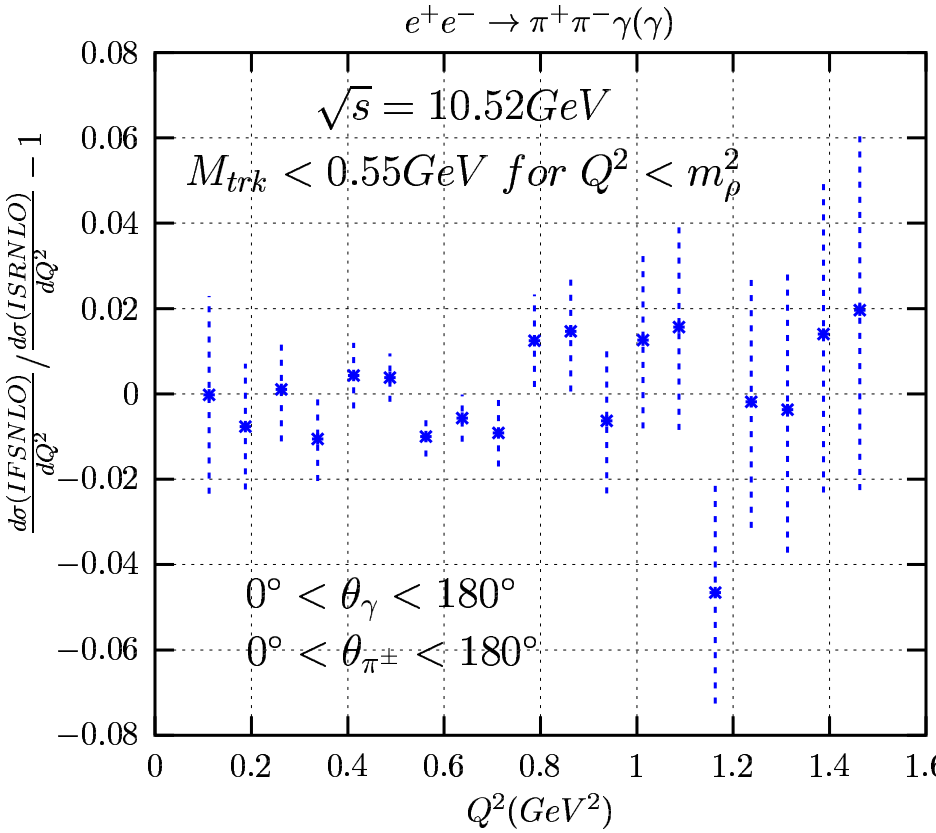
Large effect for $Q^2 < m_\rho^2$ eliminated by suitable cuts



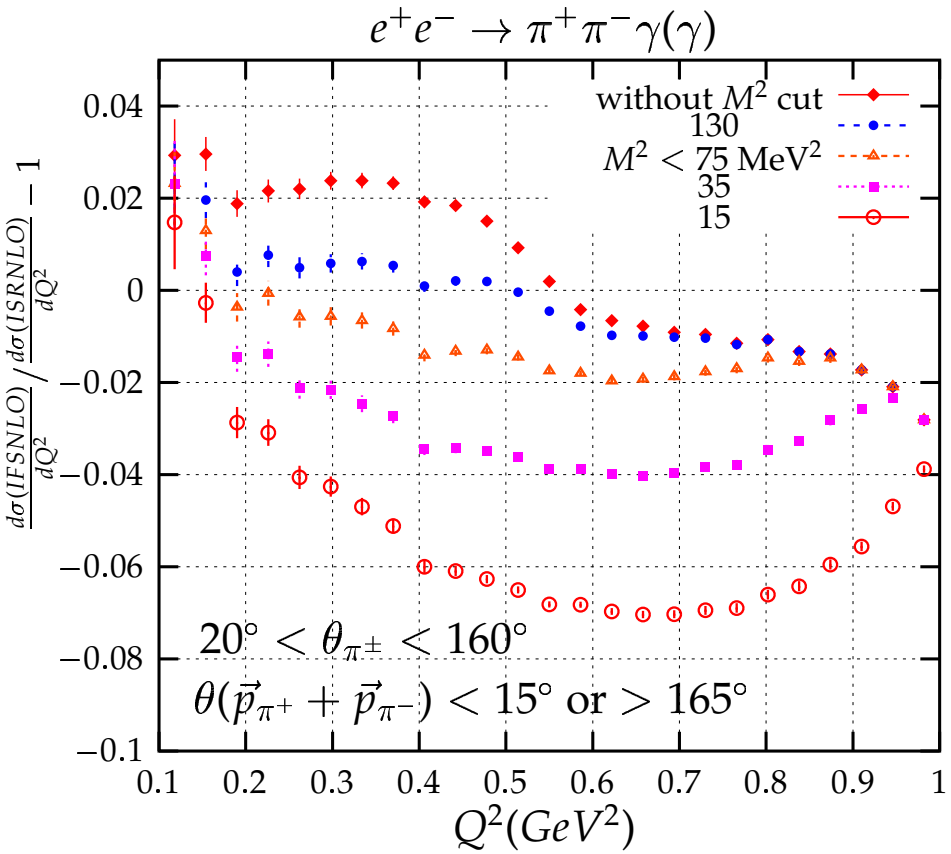


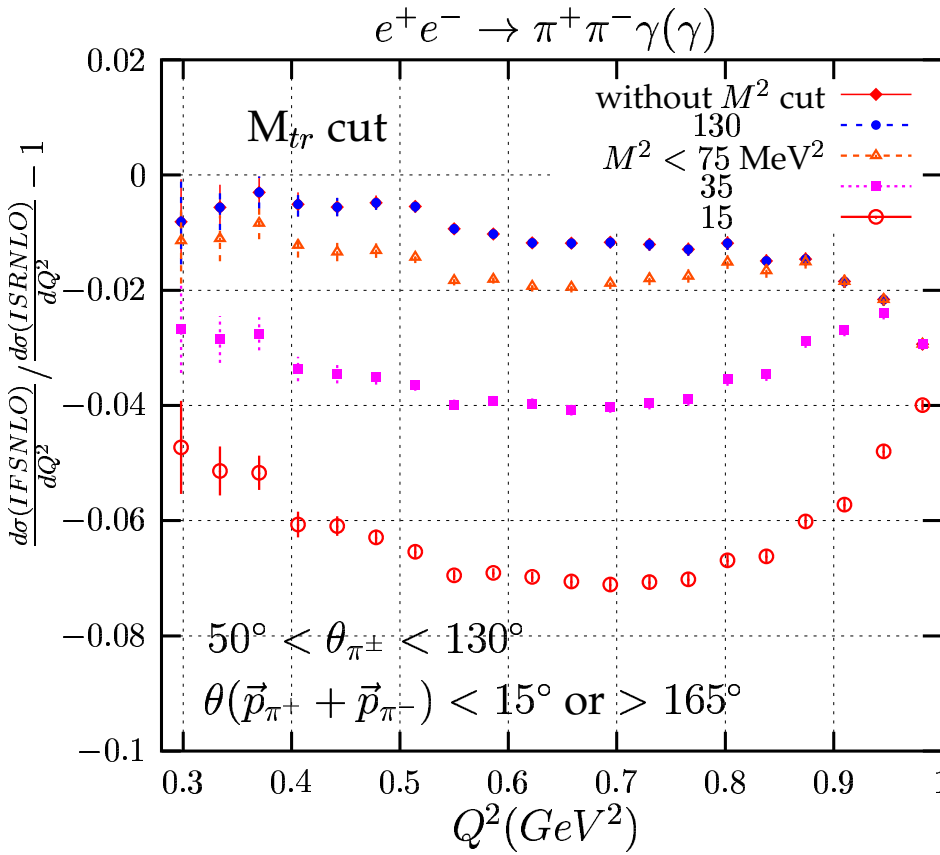
Large effect for $Q^2 < m_\rho^2$ eliminated by suitable cuts





Test FSR at NLO





V Future developments:

additional channels to be included:

$$K\,K, \quad 3\,\pi, \quad K\,K\,\pi$$

QED:

radiation of $e^+\,e^-$ - pairs

V CONCLUSIONS

Radiative Return at $\Phi-$ and $B-$ Factories

- gives huge event rates for R(Q^2) measurements in a large range of Q^2.

- Monte Carlo for precise measurements are important and are available.