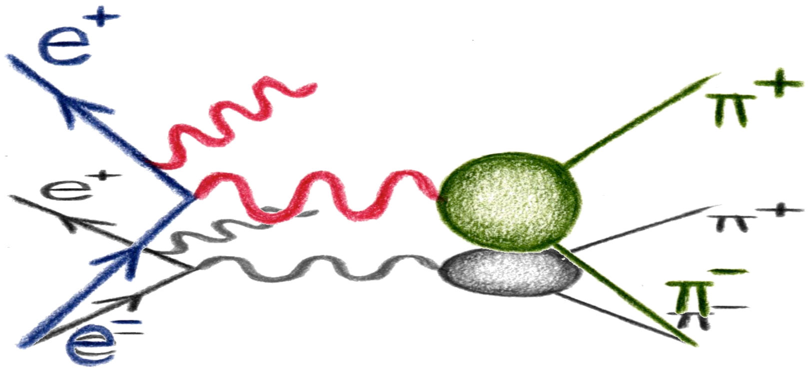
Monte Carlo generators and radiative corrections used and needed in the KLOE ISR analyses



S. Müller
(for the KLOE $\pi\pi\gamma$-group)

Radio MONTE CARlow WG Meeting in Beijing, October 2008

Abs. Norm. vs ratio $\pi\pi\gamma/\mu\mu\gamma$

Measure the (ISR) - radiative cross section $d\sigma_{\pi\pi\gamma(\gamma)}/dM_{\pi\pi}^2$: using as normalization the integrated luminosity $\int Ldt$ obtained from Bhabha events:

$$\frac{d\sigma^{obs}_{\pi\pi+\gamma(\gamma)}}{dM^2_{\pi\pi}} = \frac{\Delta N_{\text{Obs}} - \Delta N_{\text{Bkg}}}{\Delta M^2_{\pi\pi}} \cdot \frac{1}{\varepsilon_{\text{Sel}}} \cdot \frac{1}{\int Ldt}$$

Then extract $\sigma_{\pi\pi}$ from $d\sigma_{\pi\pi\gamma(\gamma)}/dM^2$ via theoretical radiator function $H(s, M_{\pi\pi}^2)$:

$$\sigma_{\pi\pi}\left(M^2_{\pi\pi}\right) \approx s\,\frac{d\sigma_{\pi\pi\gamma(\gamma)}\left(M^2_{\pi\pi}\right)}{dM^2_{\pi\pi}} \cdot \frac{1}{H(s,M^2_{\pi\pi})}$$

OR

Obtain $\sigma_{\pi\pi}$ from the ratio of $d\sigma_{\pi\pi\gamma(\gamma)}/\, d\sigma_{\mu\mu\gamma(\gamma}$:

$$\sigma^{Born}_{\pi\pi}(M^2_{\pi\pi}) \approx \frac{d\sigma^{obs}_{\pi\pi\gamma}/dM^2_{\pi\pi}}{d\sigma^{obs}_{\mu\mu\gamma}/dM^2_{\pi\pi}}\,\sigma^{Born}_{\mu\mu}(M^2_{\pi\pi})$$

Small angle event selection

2 pion tracks at large angles
$50^o < \theta_\pi < 130^o$

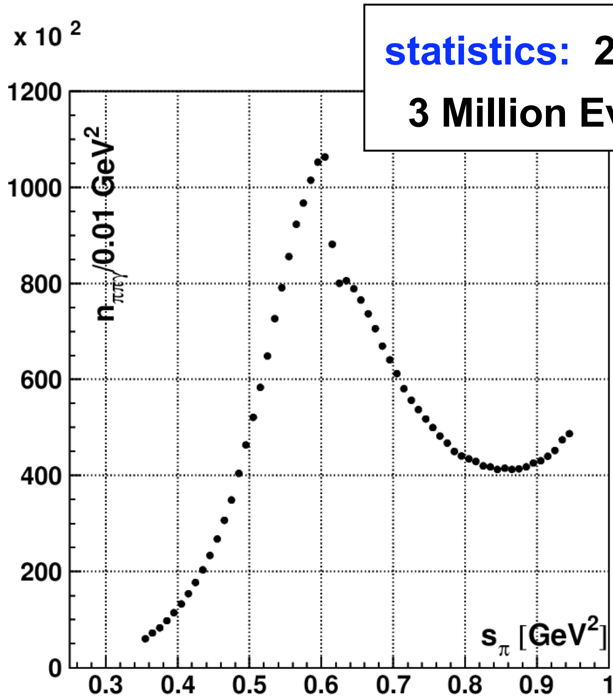
Photons at small angles
$\theta_\gamma < 15^o$ or $\theta_\gamma > 165^o$

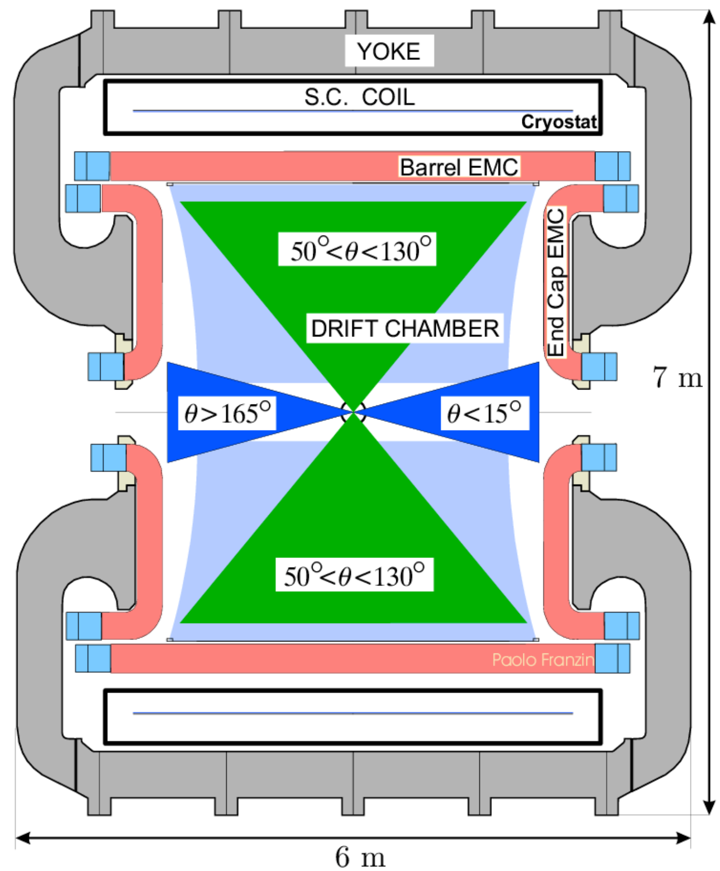
➔ **photon momentum from kinematics:**

$$\vec{p}_\gamma = \vec{p}_{miss} = -(\vec{p}_+ + \vec{p}_-)$$

- ✓ high statistics for ISR events
- ✓ low relative FSR contribution
- ✓ suppression of $\phi \to \pi^+\pi^-\pi^0$ background
- ☹ Region below 0.35 GeV2 kinematically suppressed

statistics: 240pb^{-1}
3 Million Events

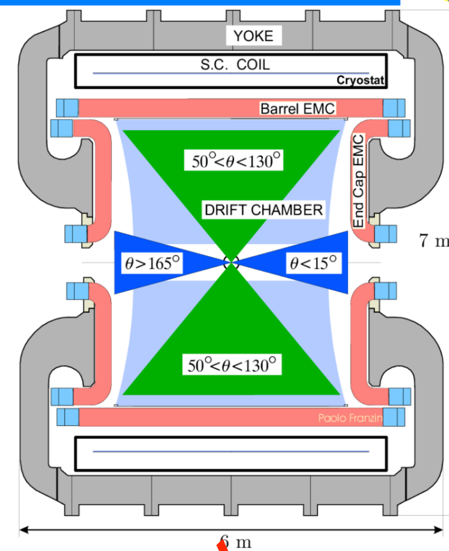




Large angle event selection

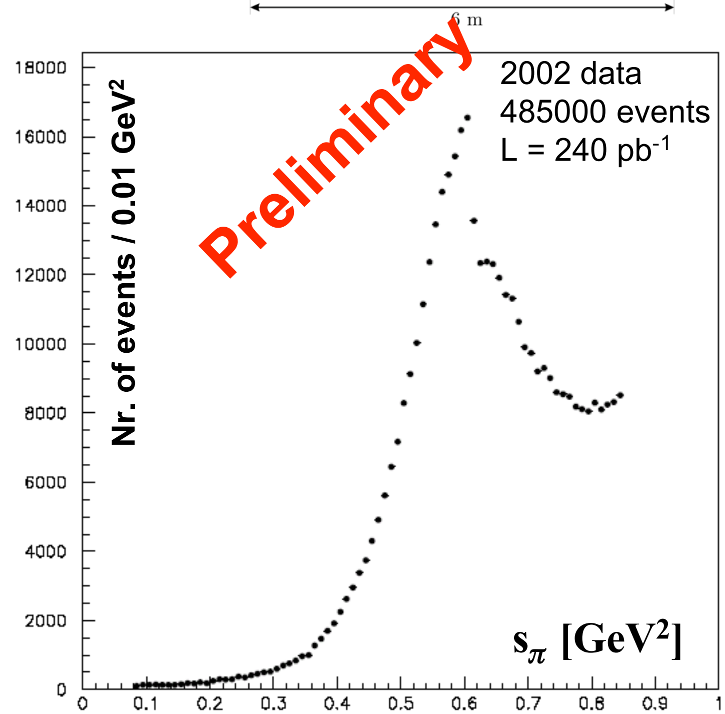
2 pion tracks at large angles
$50^o < \theta_\pi < 130^o$

At least 1 photon with $50^o < \theta_\gamma < 130^o$
and $E_\gamma > 50$ **MeV ➔ photon detected**



- ✓ **independent complementary analysis**
- ✓ **threshold region $(2m_\pi)^2$ accessible**
- ✓ **γ_{ISR} photon detected (4-momentum constraints)**

- ✓ **lower signal statistics**
- ✓ **larger contribution from FSR events**
- ✓ **large $\phi \to \pi^+\pi^-\pi^0$ background contamination**
- ✓ **irreducible background from ϕ decays ($\phi \to f_0\,\gamma \to \pi\pi\,\gamma$)**



KLOE analyses symmary

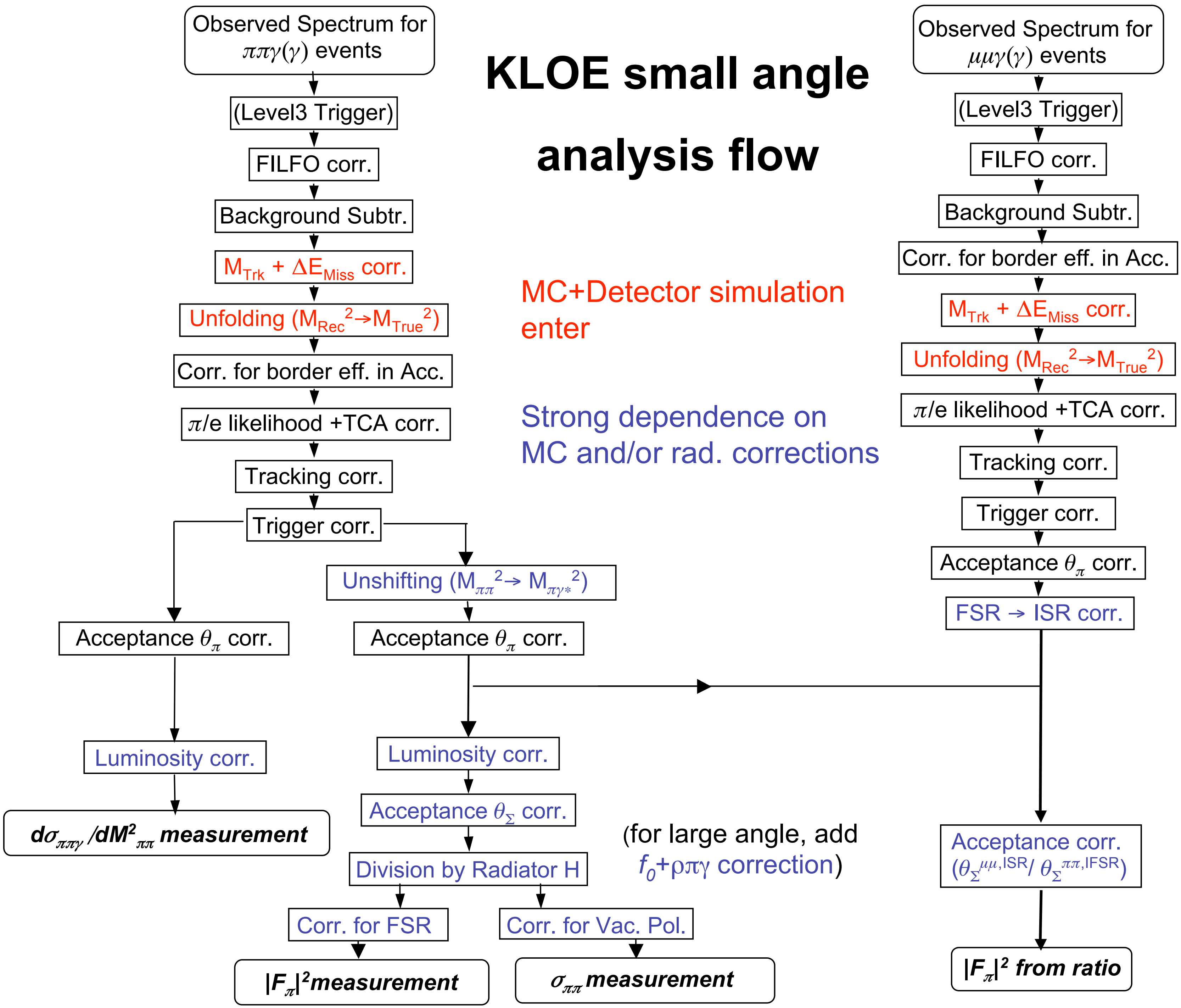
- **Small angle photon, absolute normalization with Bhabha events using 140pb^{-1} of 2001 data** ✓ Phys. Lett. B 606 (2005) 12
- **Small angle photon, absolute normalization with Bhabha events using 240pb^{-1} of 2002 data** ✓ arXiv: hep-ex/0809.3950 subm. to Phys. Lett. B

In progress

- Large angle photon, absolute normalization with Bhabha events using 240pb^{-1} of 2002 data
- Large angle photon, absolute normalization with Bhabha events using 200pb^{-1} of 2006 data (outside ϕ-resonance)
- Small angle photon, normalization with $\mu\mu\gamma$ events from data using 240pb^{-1} of 2002 data

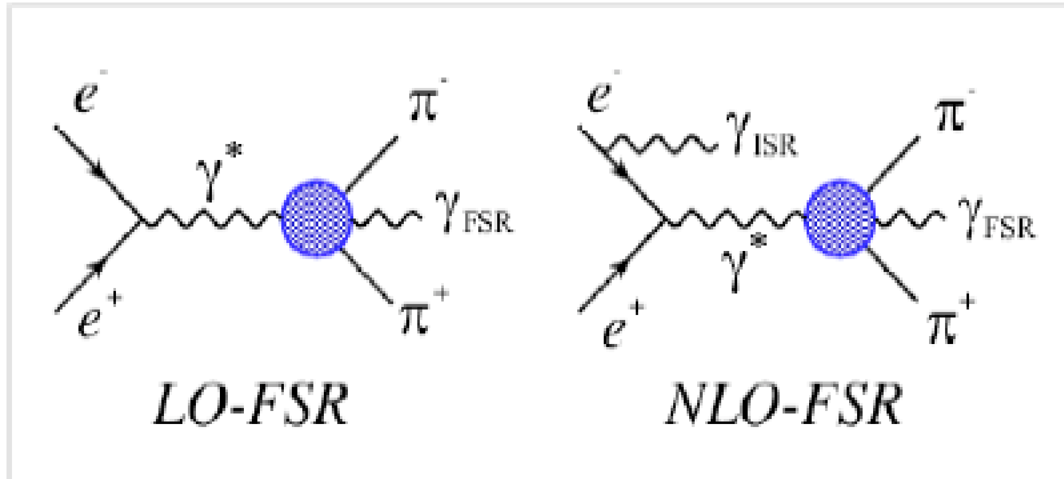
Future

- *Large angle photon, normalization with $\mu\mu\gamma$ events from data using 240pb^{-1} of 2006 data (outside ϕ-resonance)*
- *$|F_\pi|^2$ from π/μ using coll. events for 4 points around M_ϕ*


KLOE small angle analysis flow
Observed Spectrum for $\pi\pi\gamma(\gamma)$ events
(Level3 Trigger)
FILFO corr.
Background Subtr.
M_{Trk} + ΔE_{Miss} corr.
Unfolding ($M_{Rec}^2 \rightarrow M_{True}^2$)
Corr. for border eff. in Acc.
π/e likelihood +TCA corr.
Tracking corr.
Trigger corr.
Acceptance θ_π corr.
Luminosity corr.
$d\sigma_{\pi\pi\gamma}/dM^2_{\pi\pi}$ measurement
Unshifting ($M_{\pi\pi}^2 \rightarrow M_{\pi\gamma*}^2$)
Acceptance θ_π corr.
Luminosity corr.
Acceptance θ_Σ corr.
Division by Radiator H
Corr. for FSR
Corr. for Vac. Pol.
$|F_\pi|^2$measurement
$\sigma_{\pi\pi}$ measurement
MC+Detector simulation enter
Strong dependence on MC and/or rad. corrections
(for large angle, add f_0+ρπγ correction)
Observed Spectrum for $\mu\mu\gamma(\gamma)$ events
(Level3 Trigger)
FILFO corr.
Background Subtr.
Corr. for border eff. in Acc.
M_{Trk} + ΔE_{Miss} corr.
Unfolding ($M_{Rec}^2 \rightarrow M_{True}^2$)
π/e likelihood +TCA corr.
Tracking corr.
Trigger corr.
Acceptance θ_π corr.
FSR → ISR corr.
Acceptance corr.
($\theta_\Sigma^{\mu\mu,ISR}/\theta_\Sigma^{\pi\pi,IFSR}$)
$|F_\pi|^2$ from ratio

Final State radiation:

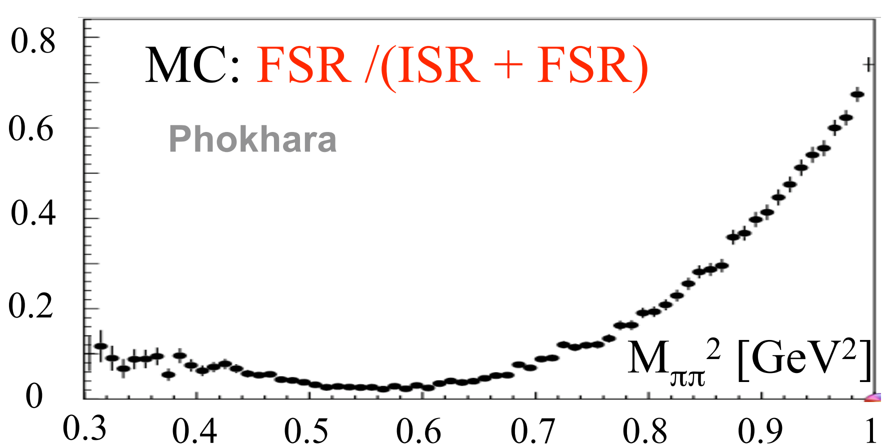
The cross section for $e^+e^- \rightarrow \pi^+\pi^-$ has to be inclusive with respect to final state radiation events in order to evaluate a_μ. We consider two kinds of FSR contributions:



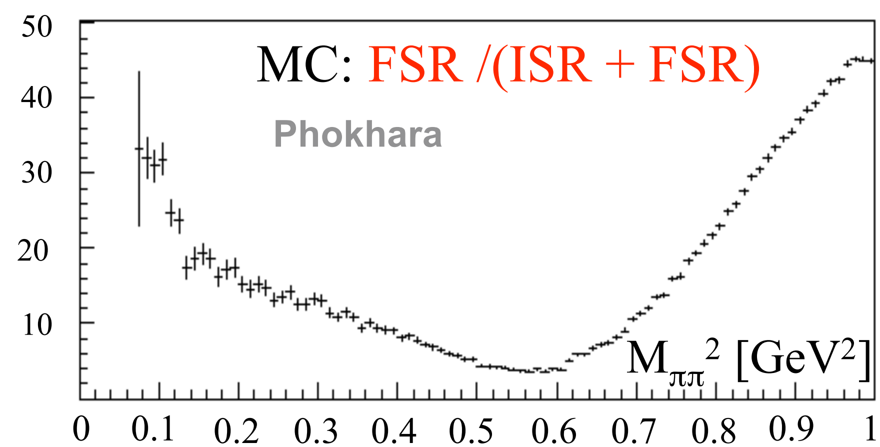
LO-FSR: No initial state radiation, e^+ and e^- collide at the energy M_ϕ=1.02 GeV
This is clearly the dominant part, and it enters our spectrum since
$M^2_{\pi\pi} < M^2_{\gamma*}$

NLO-FSR: Simultaneous presence of one photon from initial state radiation and one photon from final state radiation

%
Small angle cuts:

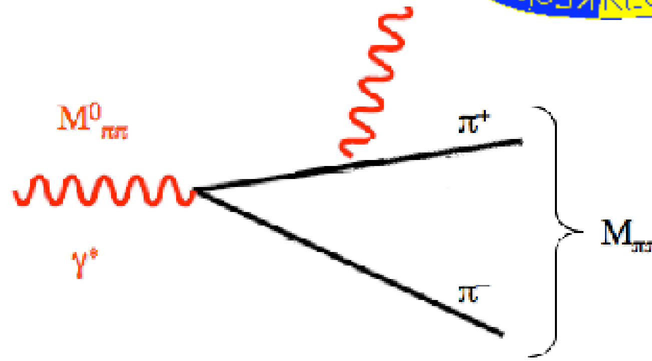


%
Large angle cuts:



„Unshifting“: $M^2_{\pi\pi} \rightarrow M^2_{\gamma*}$

Photon emissions from the pions changes the measured value of $M^2_{\pi\pi}$ from the invariant mass squared of the virtual photon produced in the $e^+ e^-$ collision, $M^2_{\gamma*}$



$$\boxed{M^2_{\pi\pi} \leq M^2_{\gamma*}}$$

Use special version of PHOKHARA which allows to determine whether photon comes from initial or final state → build matrix which relates $M^2_{\pi\pi}$ to $M^2_{\gamma*}$.

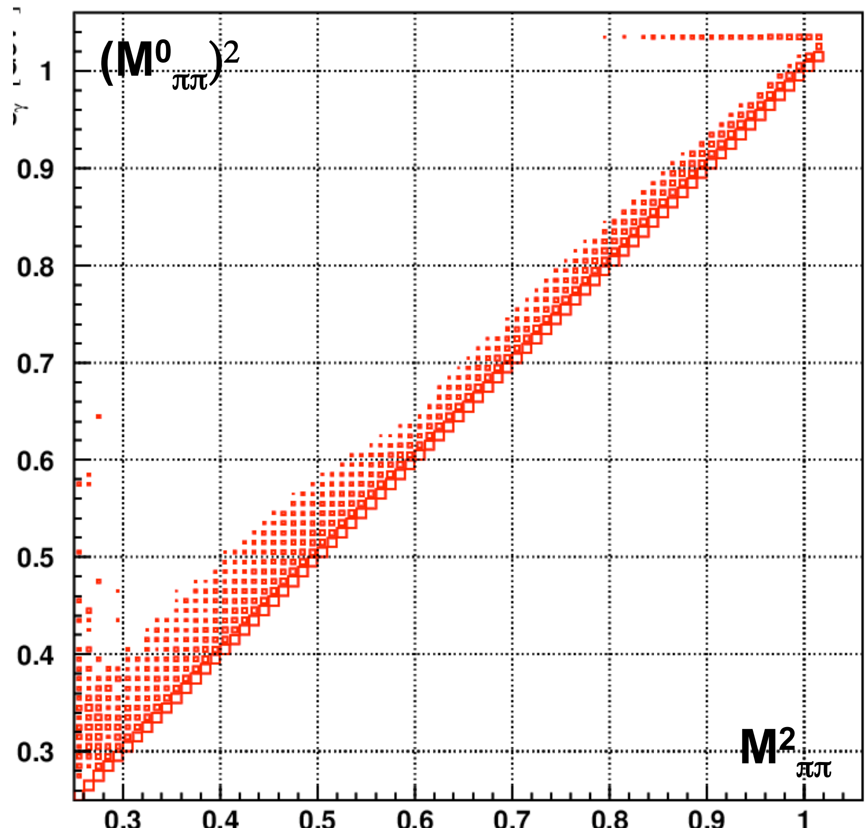
ISR only:

$$M^2_{\gamma*} = M^2_{\pi\pi}$$

FSR photon present:

$$M^2_{\gamma*} = M^2_{\pi\pi\gamma(FSR)}$$

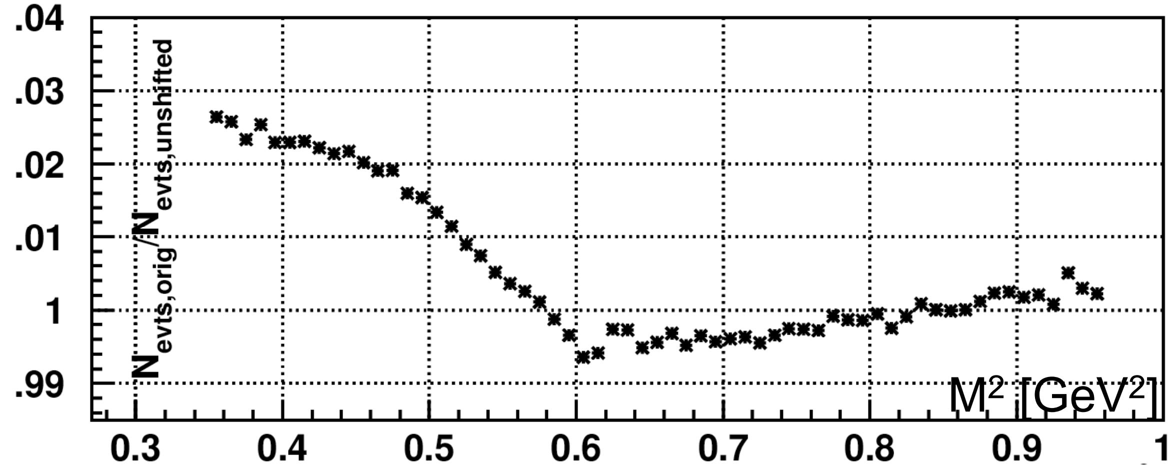
e+e- →π+π-γ



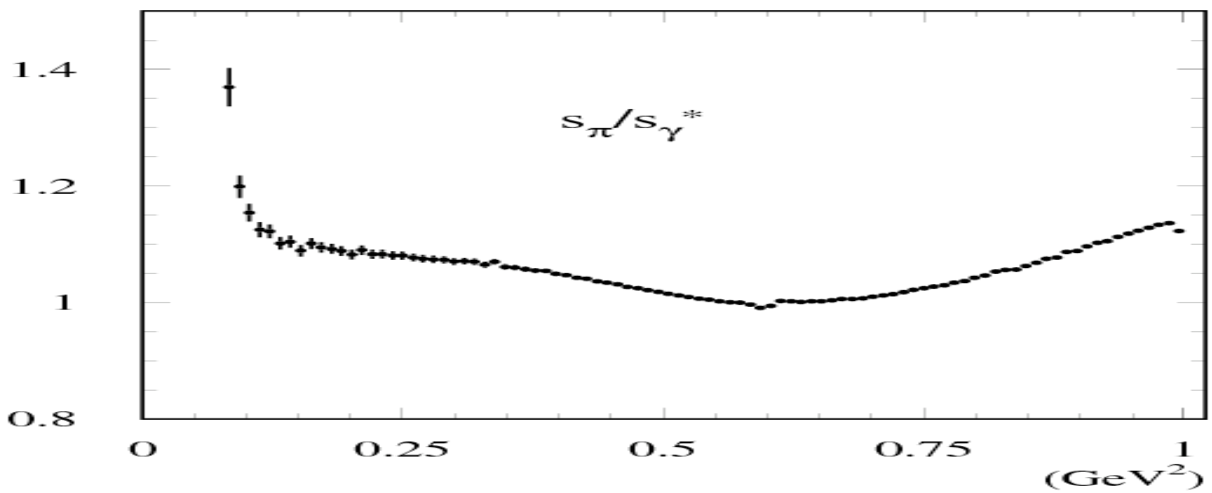
Would be nice to have also for μμγ channel!

„Unshifting“: $M^2_{\pi\pi} \rightarrow M^2_{\gamma*}$

Relative increase of events with 1 γ_{ISR} and 1 γ_{FSR} over pure ISR events at low values of $M^2_{\pi\pi}$ increases the effect in this region for small angle analysis.

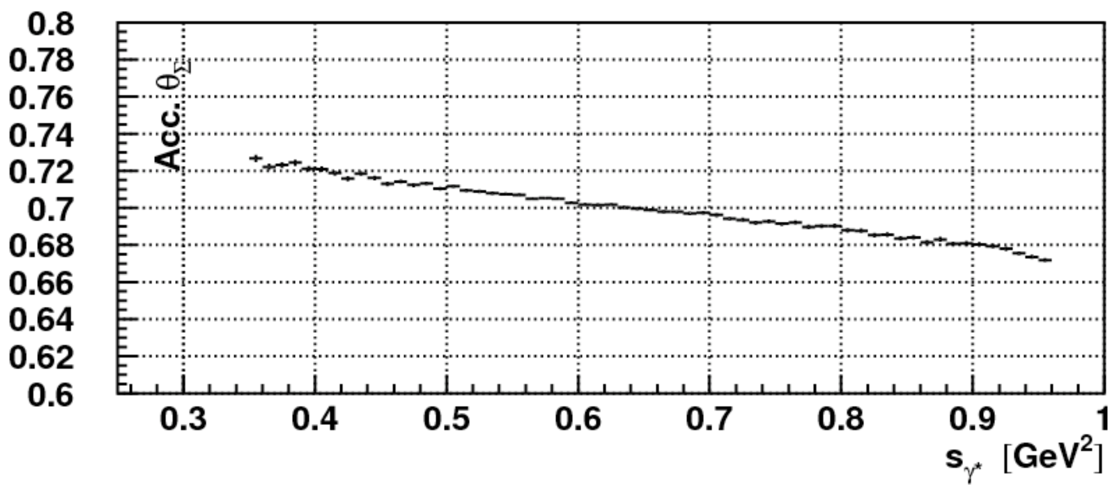


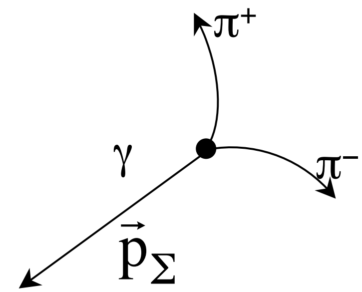
Effect is higher for large angle analysis due to the greater presence of FSR, especially at very high and very low $M^2_{\pi\pi}$



θ_Σ correction (Acceptance)

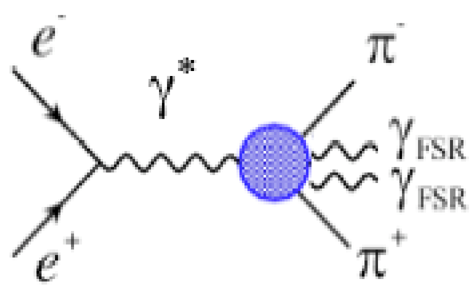
θ_Σ is the angle of the photon (system) obtained from the momenta of the two charged tracks in the small angle analysis: $\vec{p}_\Sigma = \vec{p}_{miss} = -(\vec{p}_+ + \vec{p}_-)$





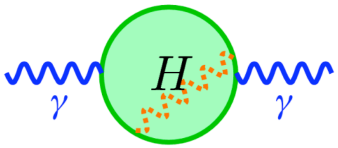
This acceptance depends on FSR (as does the acceptance for θ_γ in the large angle analysis) ⇒ strong dependence on the implementation of FSR in PHOKHARA5/6/6.1...

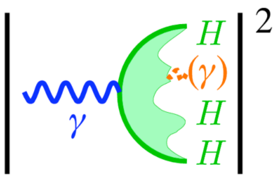
Effect of second hard photon from FSR???



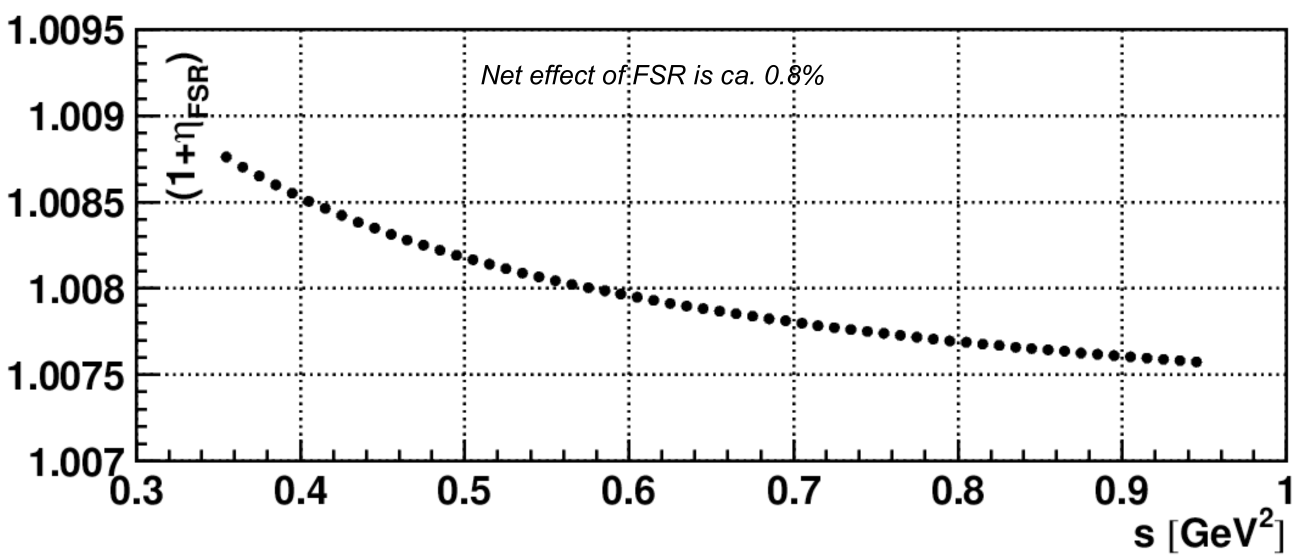
Final State Radiation (FSR)

$\sigma_{\pi\pi}$ needs to be inclusive with respect to final state radiation when used in the dispersive integral. Therefore the analysis has been designed to provide a final spectrum which is inclusive in FSR@($M^2_{\gamma*}$).





Concerning the $|F_\pi|^2$, we undress the spectrum from FSR by dividing for $(1+\eta_{FSR})$, which is calculated assuming radiation from pointlike pions (sQED)



Radiator function

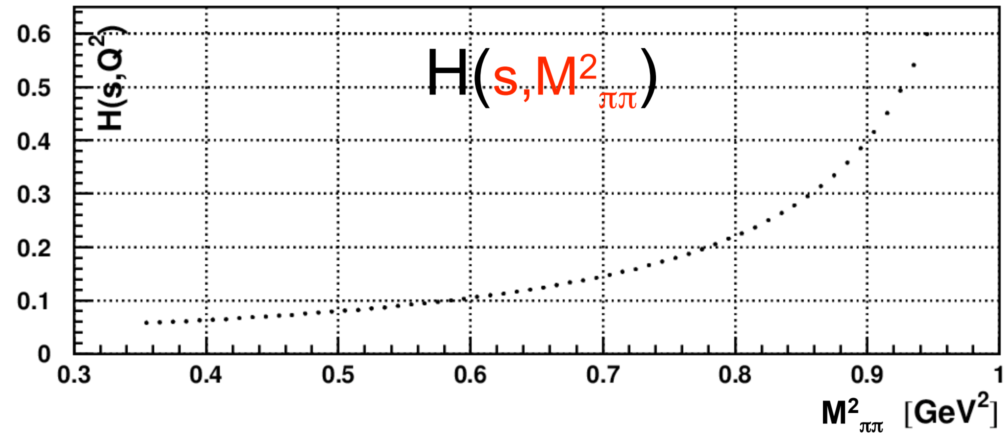
- **ISR-Process calculated at NLO-level**

PHOKHARA generator (*Czyż, Kühn et.al*)

Theoretical Precision: *0.5%*

Biggest theor. uncertainty in SA analysis

$$s \cdot \frac{d\sigma_{\pi\pi\gamma}}{dM^2_{\pi\pi}} = \sigma_{\pi\pi}(s) \times H(s, M^2_{\pi\pi})$$



s is the collider energy.

We obtain the radiator function technically by setting $|F_\pi|^2=1$ in the PHOKHARA Monte Carlo generator, and generate ISR events inclusive in θ_π and θ_Σ:

$$H(s, M^2_{\pi\pi}) = s \times \frac{3M^2_{\pi\pi}}{\pi\alpha^2\beta^3_\pi} \times \left.\frac{d\sigma_{\pi\pi\gamma}(M^2_{\pi\pi})}{dM^2_{\pi\pi}}\right|^{MC}_{\left|F_\pi(M^2_{\pi\pi})\right|^2=1}$$

How well does the factorization of H work in the presence of FSR?

Luminosity:

KLOE measures $\mathcal{L}$ with Bhabha scattering at large angles

F. Ambrosino et al. (KLOE Coll.)
Eur.Phys.J.C47:589-596,2006

$55° < \theta < 125°$

acollinearity $< 9°$

$p \geq 400$ MeV

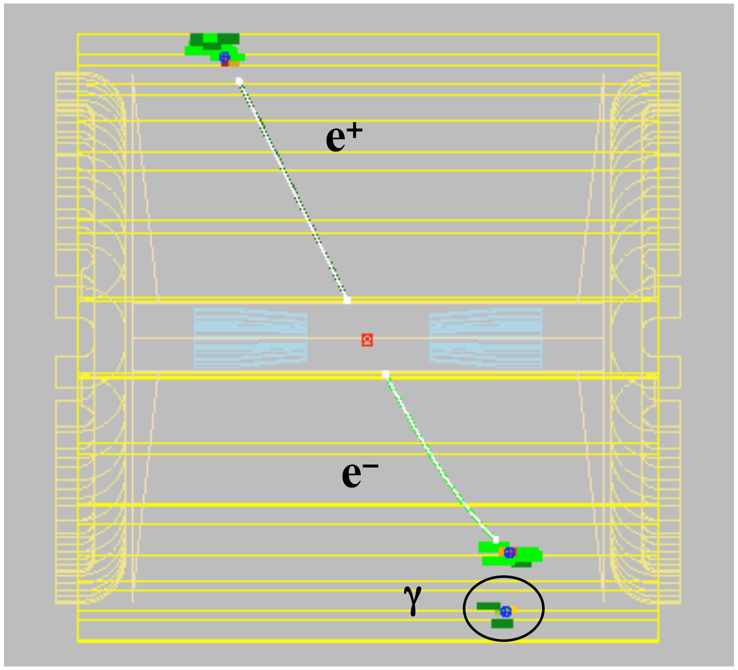
$$\int \mathcal{L}\,dt = \frac{N_{obs} - N_{bkg}}{\sigma_{eff}}$$

generator used for σ_{eff}

BABAYAGA (Pavia group):

C. M.C. Calame et al., NPB584 (2000) 459

New: *C. M.C. Calame et al., NPB758 (2006) 22*



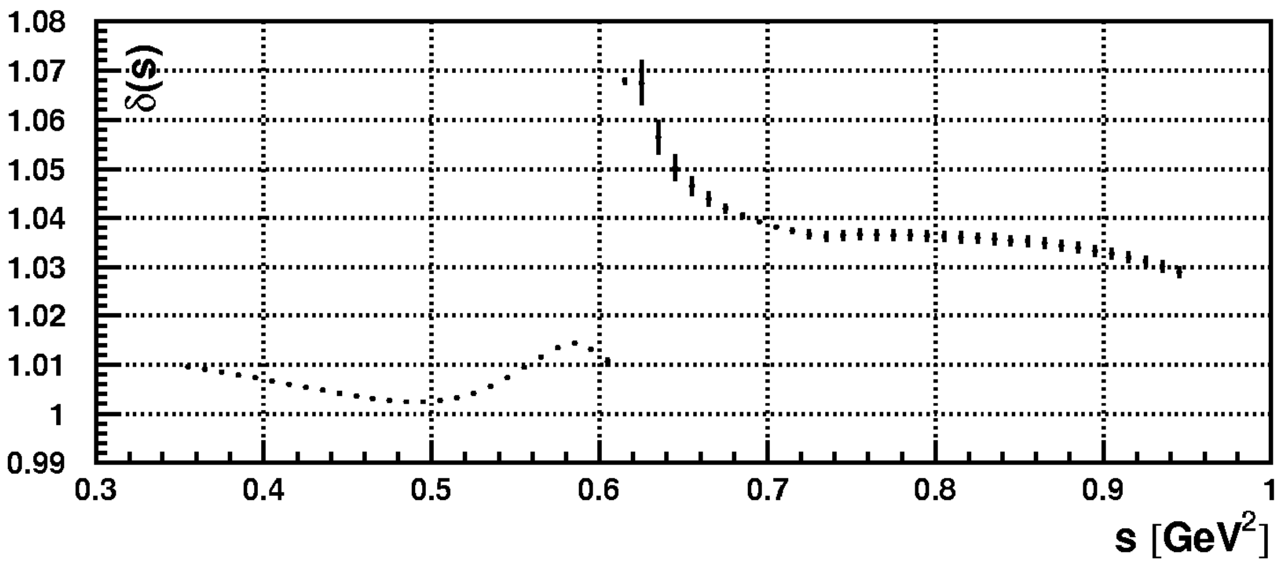
new version (**BABAYAGA@NLO**) gives 0.7% decrease in cross section, and better accuracy: 0.1%

Systematics on Luminosity	
Theory	0.1 %
Experiment	0.3 %
TOTAL 0.1 % th $\oplus$ 0.3% exp = 0.3%	

Vacuum Polarisation

For use in the dispersive integral for $\Delta^{\pi\pi}a_\mu$, one needs to subtract effects from vacuum polarization (VP) to obtain a *bare* cross section $\sigma^0_{\pi\pi}$:

$$\sigma^0_{\pi\pi}(s) = \sigma^{\text{dressed}}{}_{\pi\pi}(s)\left(\frac{\alpha(0)}{\alpha(s)}\right)^2 = \sigma_{\pi\pi}(s)/\delta(s)$$



Points obtained from F. Jegerlehner's webpage *(the only points which are publically available!)*

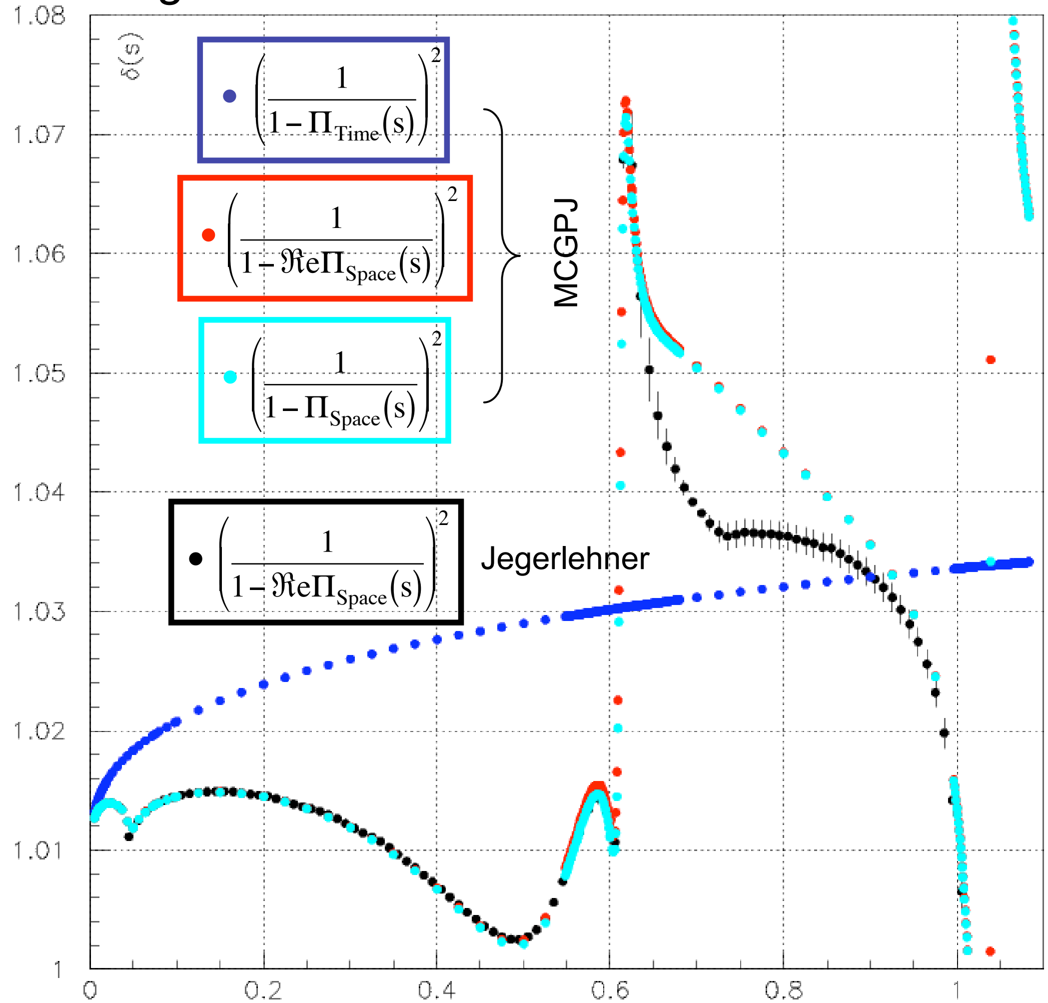
Correction is applied only to the cross section $\sigma^0_{\pi\pi}$ (not on $\sigma_{\pi\pi\gamma}$ and $|F_\pi|^2$).

NOT APPLIED when comparing with $|F_\pi|^2$ from CMD2/SND!

Error on VP points introduces an relative error on the value of $\Delta^{\pi\pi}a_\mu$ of 0.1%.

Vacuum Polarisation

Confronting the VP points from F. Jegerlehner‘s webpage with the one in MCGPJ shows some disagreement between 0.6 and 1 GeV^2:

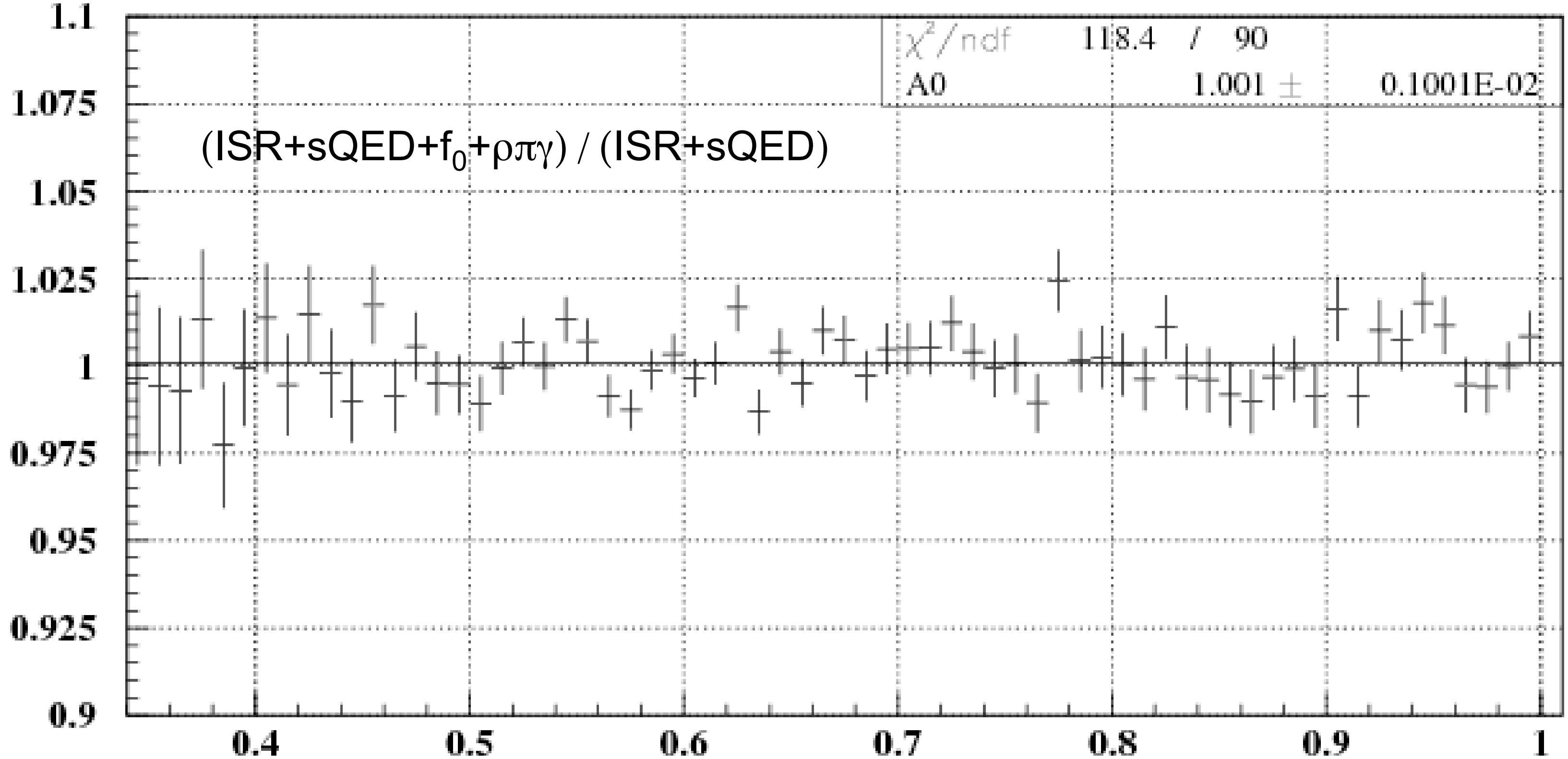


Fred is currently updating his function, as it does not yet include the recent results from BaBar in that region.

$f_0+\rho\pi$ correction

$\phi \to (f_0+\sigma)\gamma \to \pi\pi\gamma$: Checked with PHOKHARA 6.1 generator, latest Achasov model
$\phi \to \pi\rho \to \pi(\pi\gamma)$: with parameters from KLOE $f_0 \to \pi^0\pi^0$ analysis

Contribution negligible in small angle analysis:



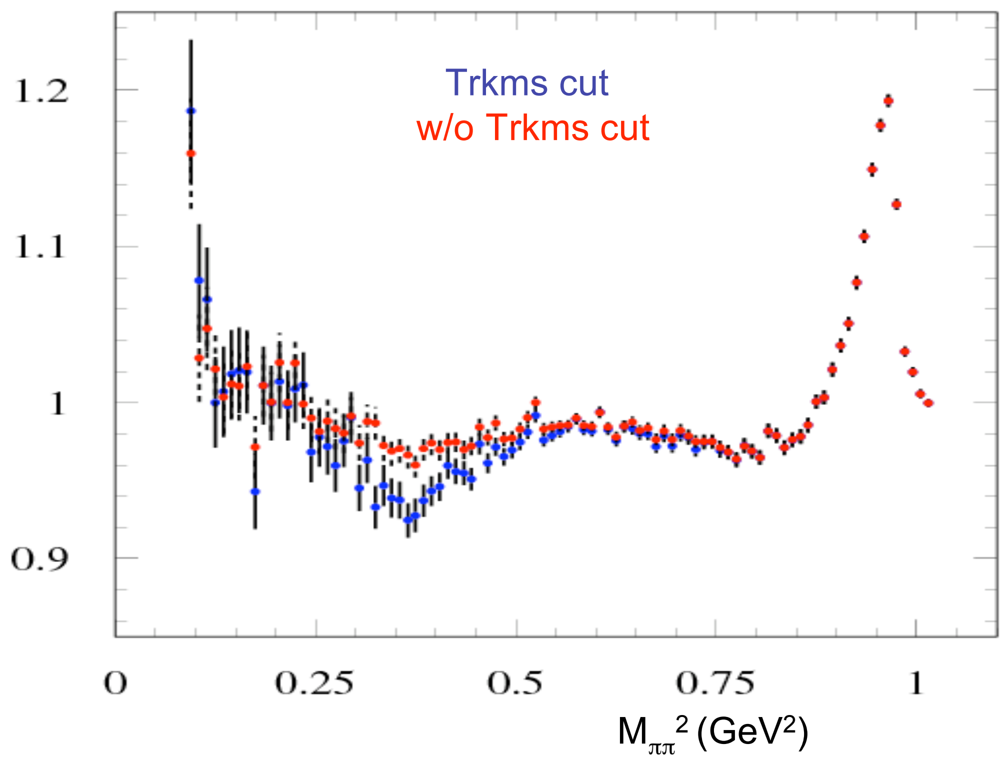
$f_0+\rho\pi$ correction

$\phi \to (f_0+\sigma)\gamma \to \pi\pi\gamma$:
$\phi \to \pi\rho \to \pi(\pi\gamma)$:

Checked with PHOKHARA 6.1 generator, latest Achasov model with parameters from KLOE $f_0 \to \pi^0\pi^0$ analysis

Contribution relevant in large angle analysis:

(ISR+sQED+f_0+$\rho\pi\gamma$) / (ISR+sQED)

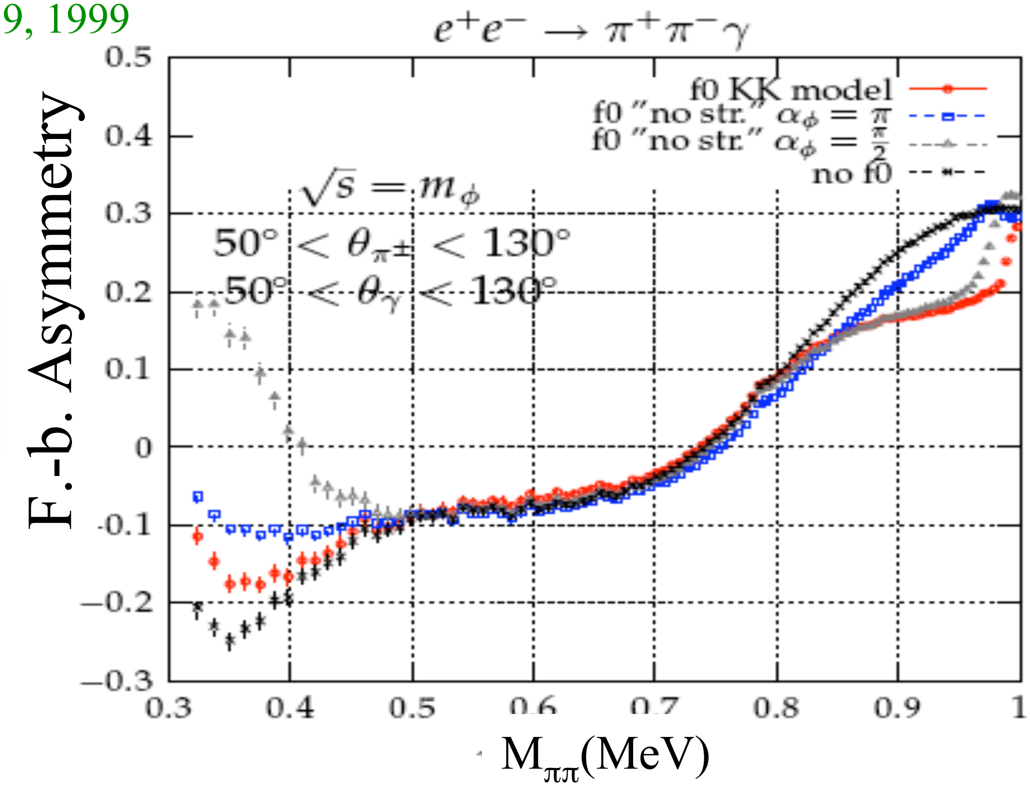


$f_0+\rho\pi$ correction

As the interference between ISR and (FSR+f_0) leads to a non-vanishing forward-backward asymmetry, one can use this asymmetry to further optimize/scrutinize the model parameters

Binner, Kühn, Melnikov, Phys. Lett. B 459, 1999
Czyz, Grzelinska, Kühn, hep-ph/0412239

$$A = \frac{N(\theta^+ > 90^o) - N(\theta^+ < 90^o)}{N(\theta^+ > 90^o) + N(\theta^+ < 90^o)}$$



For this a (semi)analytical parametrization of the asymmetry as a function of the model parameters would be very welcome!!

Conclusions

After the large improvement in the precision of the luminosity reference cross section with BABAYAGA@nlo, the biggest theoretical uncertainties for the small angle analyses come from the radiator function and the knowledge of FSR.

- Radiator function contributes 0.5% uncertainty

  Box graphs?

  Factorization?

- FSR enters in many places in the analysis (Unshifting, θ_Σ,...)

  Second hard photon?

  FSR for muons (PHOKHARA Omega)?

The same holds for the large angle analysis, where in addition one needs to control the contribution from scalar mesons.

(Semi)analytic description of asymmetry?

Both large angle analyses using the absolute normalization with 2002 data („on-peak“) and 2006 data („off-peak“) are in a very advanced state.

Manpower?