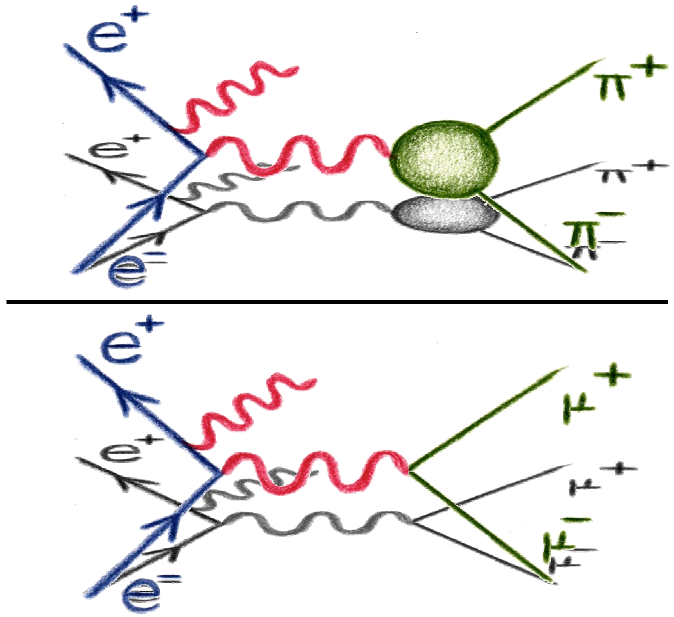
Towards an extraction of $|F_\pi|^2$ from the ratio of pions and muons



S. Müller

WG Meeting in Frascati, 25.6.2007

Extracting $|F_\pi|^2$:

a) Via absolute Normalisation to VLAB Luminosity (as in 2001 analysis):

Relation between $|F_\pi|^2$ and the cross section $\sigma(e^+e^- \to \pi^+\pi^-)$

$$\boxed{|F_\pi|^2 = \frac{3s}{\pi\alpha^2\beta_\pi^3}\sigma_{\pi\pi}(s)}$$

Obtain $\sigma_{\pi\pi}$ from (ISR) - radiative cross section $d\sigma_{\pi\pi\gamma(\gamma)}/dM^2$ via theoretical radiator function H(s):

$$\boxed{\sigma_{\pi\pi}(s) \approx M_{\pi\pi}^2 \frac{d\sigma_{\pi\pi+\gamma(\gamma)}^{obs}}{dM_{\pi\pi}^2} \cdot \frac{1}{H(s)}}$$

$d\sigma_{\pi\pi\gamma(\gamma)}/dM^2$ is obtained by subtracting background from the observed event spectrum and divide by selection efficiencies and ***int. luminosity***:

$$\boxed{\frac{d\sigma_{\pi\pi+\gamma(\gamma)}^{obs}}{dM_{\pi\pi}^2} = \frac{\Delta N_{Obs} - \Delta N_{Bkg}}{\Delta M_{\pi\pi}^2} \cdot \frac{1}{\varepsilon_{Sel}} \cdot \frac{1}{\int L dt}}$$

Extracting $|F_\pi|^2$:

b) Via bin-by-bin Normalisation to rad. Muon events (new!):

The statement $\boxed{\sigma_{\pi\pi}^{Born}(s') \approx \dfrac{d\sigma_{\pi\pi\gamma}^{obs}/ds'}{d\sigma_{\mu\mu\gamma}^{obs}/ds'}\,\sigma_{\mu\mu}^{Born}(s')}$ is exact only in the absence of FSR.

It can be rewritten as

$$\underbrace{|F_\pi(s')|^2 \cdot \underbrace{(1+\eta(s'))}_{\text{Corr. due to FSR}}}_{\text{„Bare“ pion formfactor}} = \frac{4\left(1+2m_\mu^2/s'\right)\beta_\mu}{\beta_\pi^3} \cdot \underbrace{\frac{\left(d\sigma_{\pi\pi\gamma}/ds'\right)^{ISR+FSR}}{\left(d\sigma_{\mu\mu\gamma}/ds'\right)^{ISR}}}_{\text{„Observed“ cross sections}}$$

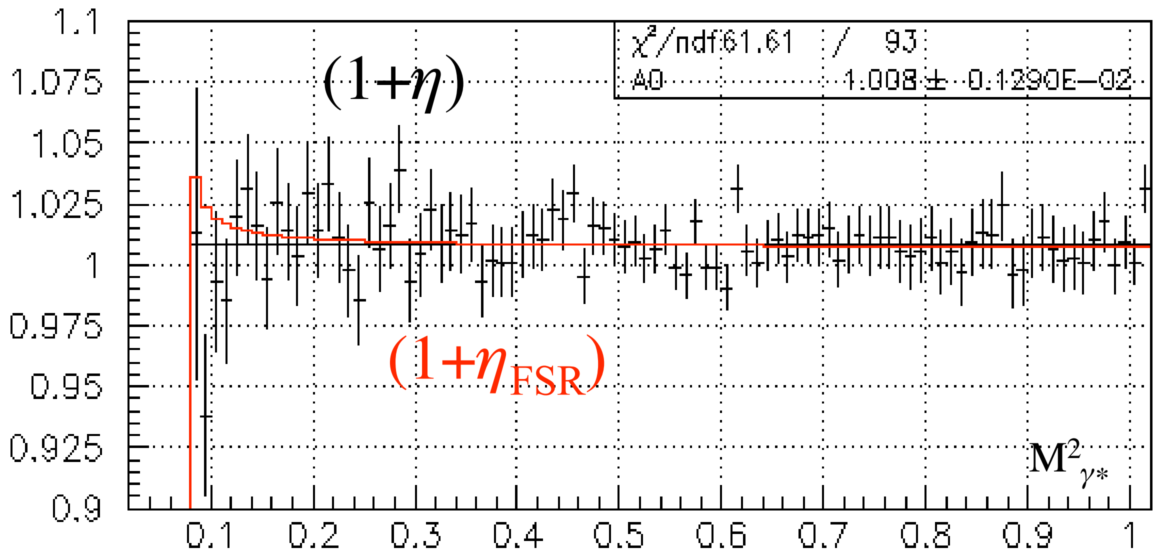
Inserting $d\sigma_{\pi\pi\gamma}/ds'$ *including* FSR-effects and $d\sigma_{\mu\mu\gamma}/ds'$ *excluding* FSR-effects gives $|F_\pi|^2 \cdot (1+\eta_{FSR})$ [i.e. a „bare“ pion formfactor].

- $|F_\pi|^2 \cdot (1+\eta_{FSR})$ is the quantity to be put in the a_μ^{had} dispersion integral (η_{FSR} for pointlike pions ~ 0.8%)
- The corrections needed to extract $d\sigma^{ISR}_{\mu\mu\gamma}/ds'$ are pure QED and can be obtained from MonteCarlo (PHOKHARA).

Prove of Concept with MC:

Using this approach with PHOKHARA MC samples:

$\pi\pi\gamma$ ISR + FSR nlo („unshifted“) and $\mu\mu\gamma$ ISR nlo,
divided by $|F_\pi|^2$:



Dividing for $(1+\eta_{FSR})$ and fitting with P0 gives A0 = (1.000 ±0.128E-02). Radiator H cancels, leaving only effects from (pionic) FSR.

→ Undress observed cross section for muons from (muonic) FSR!

First Conclusion:

Measuring $d\sigma_{\pi\pi\gamma}/ds'$ *including* FSR-effects and $d\sigma_{\mu\mu\gamma}/ds'$ *excluding* FSR-effects gives $|F_\pi|^2 \cdot (1+\eta_{FSR})$ [i.e. a „bare“ pion formfactor].

- $|F_\pi|^2 \cdot (1+\eta_{FSR})$ is the quantity to be put in the a_μ^{had} dispersion integral
- The corrections needed to extract $d\sigma^{ISR}_{\mu\mu\gamma}/ds'$ are pure QED and can be obtained from MonteCarlo (PHOKHARA).
- $d\sigma^{ISR+FSR}_{\pi\pi\gamma}/ds'$ is what we did for 2001 data. FSR MonteCarlo implementation for pions is model dependent - so would be desirable to obtain $|F_\pi|^2 \cdot (1+\eta_{FSR})$ from data...
- To minimize the effect of *leading order* FSR, $d\sigma/ds'$ should be measured with* $\boldsymbol{\theta_\Sigma < 15^0}$ **or** $\boldsymbol{> 165^0}$.

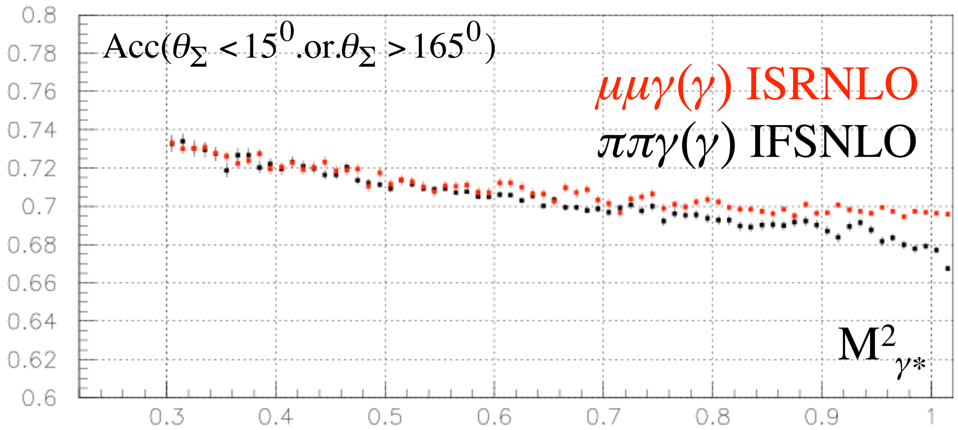
The Master-Formula becomes thus:

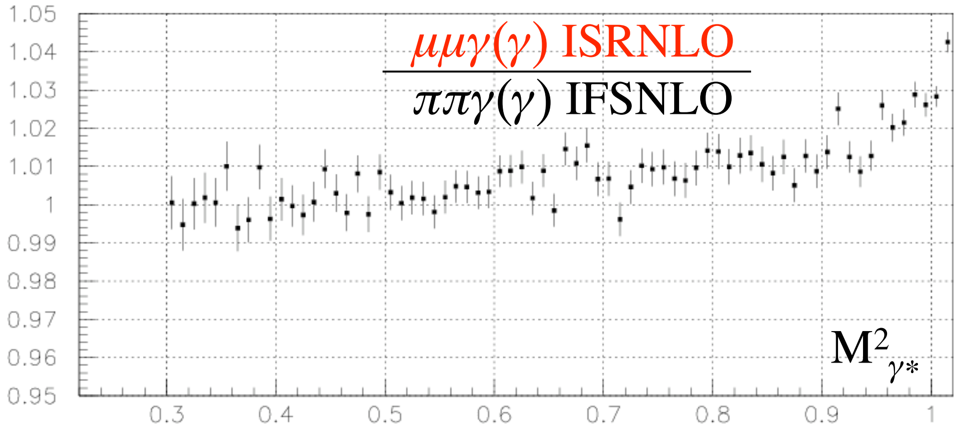
$$\boxed{|F_\pi(s')|^2 \cdot (1+\eta(s')) = \frac{4\left(1+2m_\mu^2/s'\right)\beta_\mu}{\beta_\pi^3} \cdot \frac{\left(d\sigma^{ISR+FSR}_{\pi\pi\gamma}(\theta^{\pi\pi}_\Sigma < 15^o)/ds'\right)}{\left(d\sigma^{ISR}_{\mu\mu\gamma}(\theta^{\mu\mu}_\Sigma < 15^o)/ds'\right)} \cdot \underbrace{Corr(\theta^{I+FSR}_\Sigma / \theta^{ISR}_\Sigma)}_{\text{Acceptance in } \theta_\Sigma \text{ is different for (I+FSR) and (ISR)}}}$$

* θ_Σ obtained from $\vec{p}_\Sigma = -\vec{p}_{miss} = -(\vec{p}_+ + \vec{p}_-)$

Acc. Correction θ_Σ:

$$\text{Factor } Corr(\theta_\Sigma^{I+FSR} / \theta_\Sigma^{ISR}) = \frac{\text{Acc}(\theta_\Sigma < 15^0 \text{.or. } \theta_\Sigma > 165^0)_{\mu\mu}^{\text{ISRnlo}}}{\text{Acc}(\theta_\Sigma < 15^0 \text{.or. } \theta_\Sigma > 165^0)_{\pi\pi}^{\text{IFSRnlo}}}$$

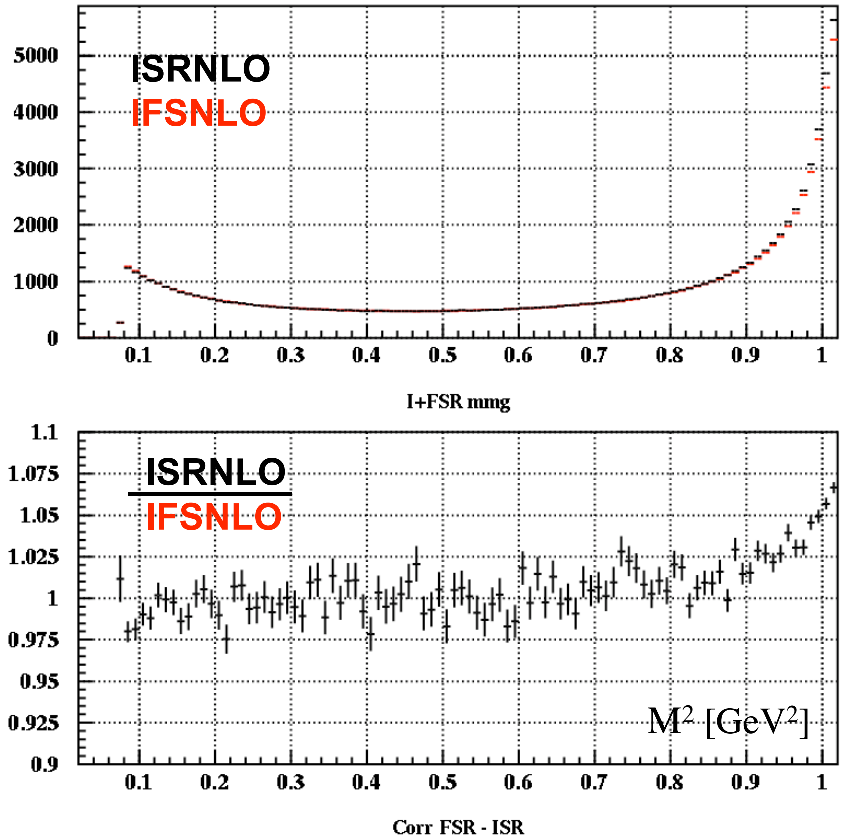




~1% correction for the ratio - ~70% correction for absolute measurements

FSR → ISR for muons:

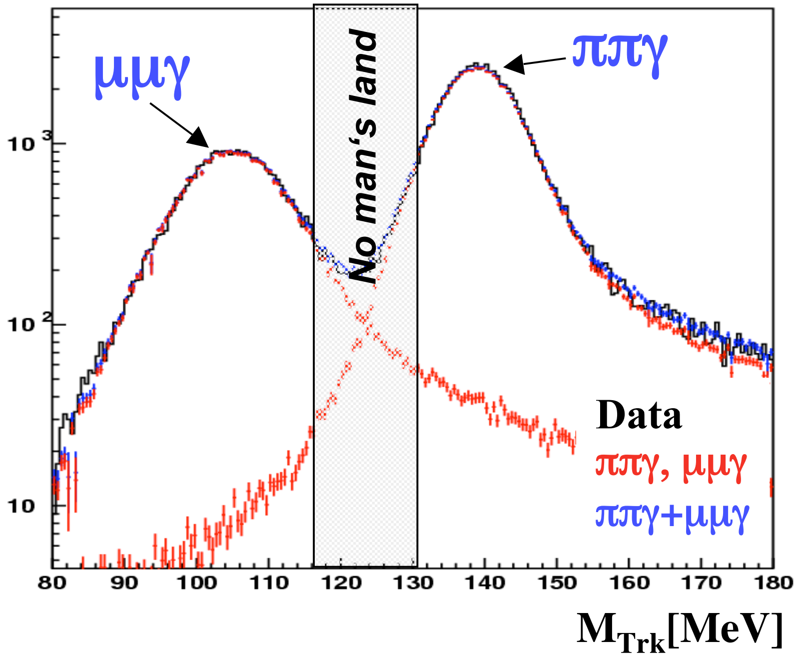
To correct the muon spectrum for FSR, the effect of FSR was estimated from PHOKHARA5 MC samples with ISRNLO and IFSNLO within the acceptance cuts of $\theta_\Sigma < 15^0$ **or** $> 165^0$. The correction was obtained from the ratio of the two spectra. This contains also the passage from $M^2_{\mu\mu} \rightarrow M^2_{\gamma*}$.



This method relies on the correctness and completeness of FSR for muons in the Monte Carlo generator (but contrary to pions, there is no model dependence!).

$\pi-\mu$ separation:

$\pi-\mu$ separation is achieved in the analysis by a rigid cut in M_{Trk}:



M_{Trk} obtained from solving

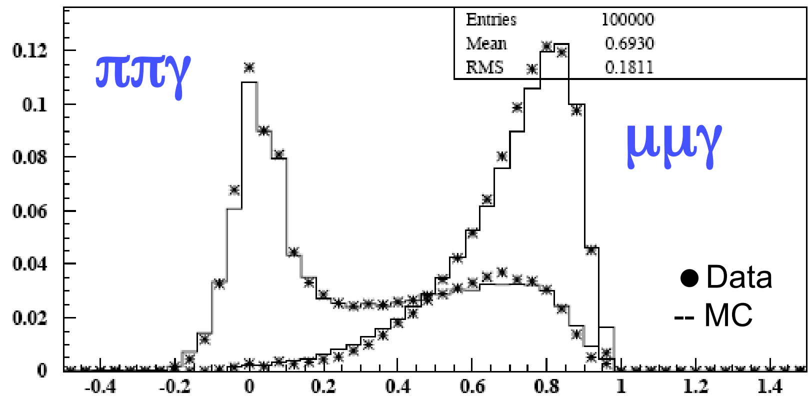
$$\left(M_\phi - \sqrt{\vec{p}_1^{\,2} + M_{trk}^2} - \sqrt{\vec{p}_2^{\,2} + M_{trk}^2}\right)^2 - (\vec{p}_1 + \vec{p}_2)^2 = q_\gamma^2 = 0$$

μμγ $M_{Trk} < 115$ MeV

ππγ $M_{Trk} > 130$ MeV

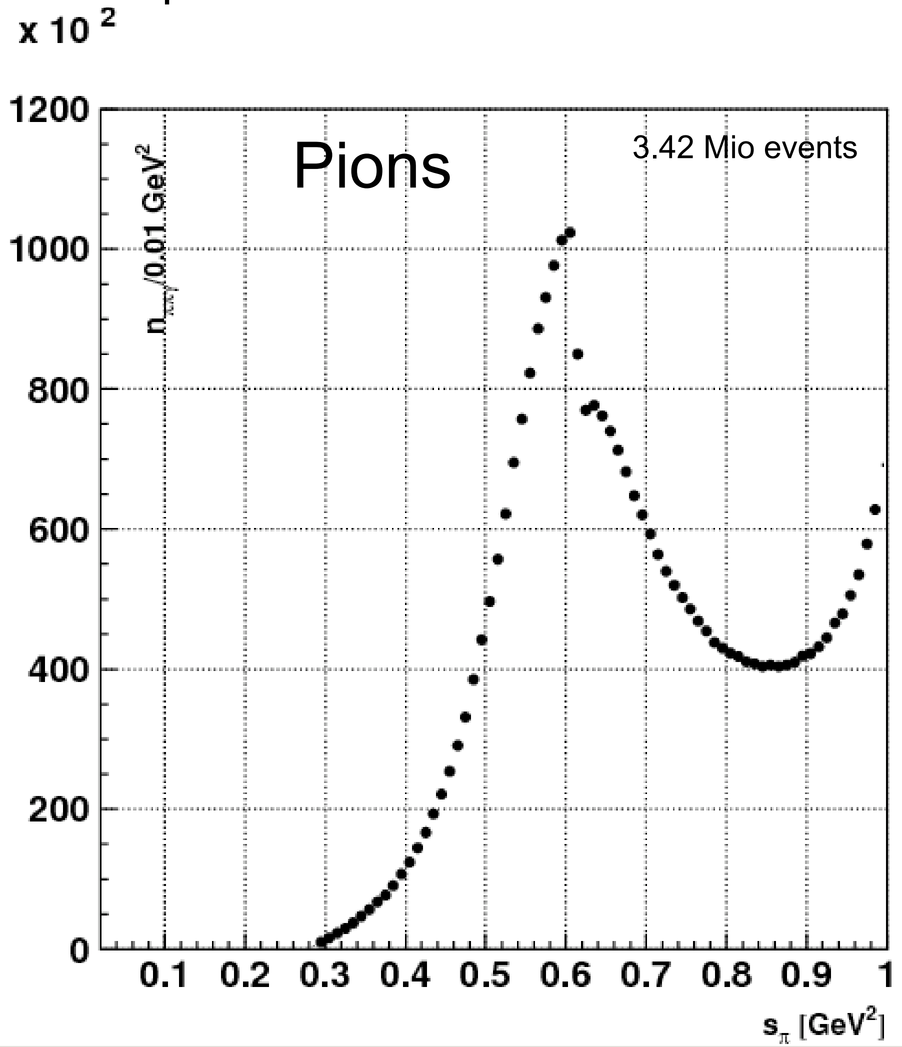
Additional tool used in evaluation of efficiencies: $\pi-\mu$ ID by means of a Neural Network (NN):

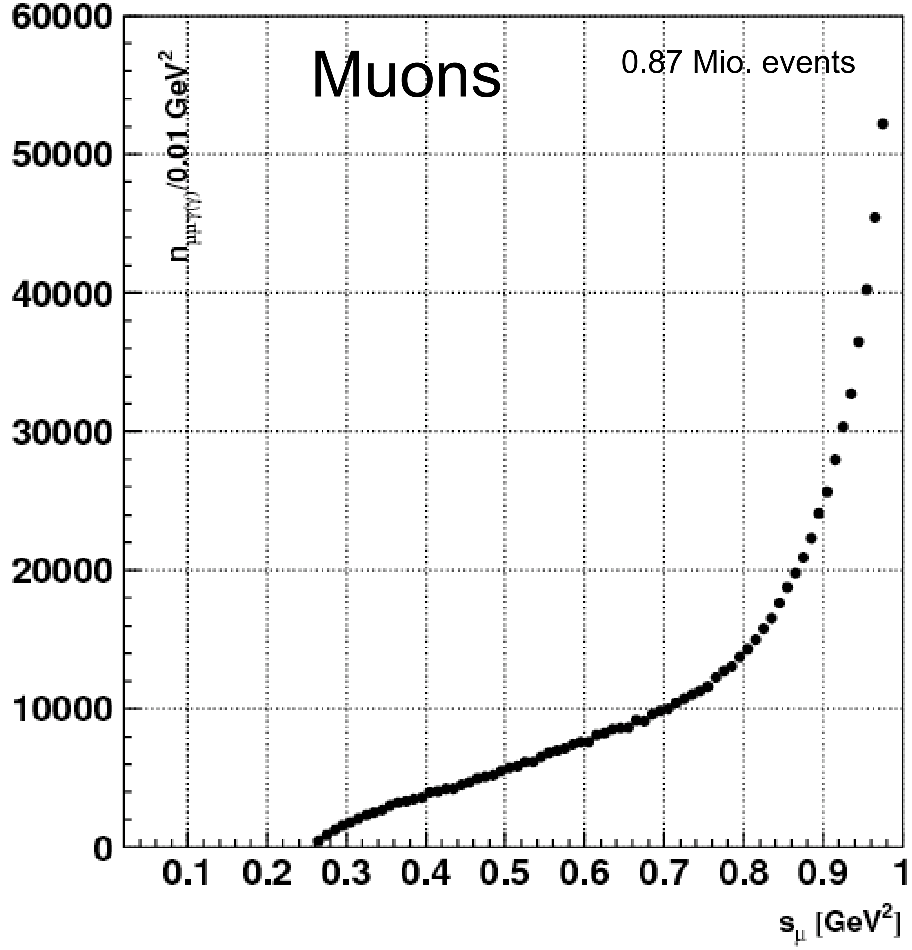
NN >0.7 for μμγ
NN <0.2 for ππγ



Spectra after SMA selection:

The spectra of selected events for the small angle analysis from 242.62 pb^{-1} of data taken in 2002:



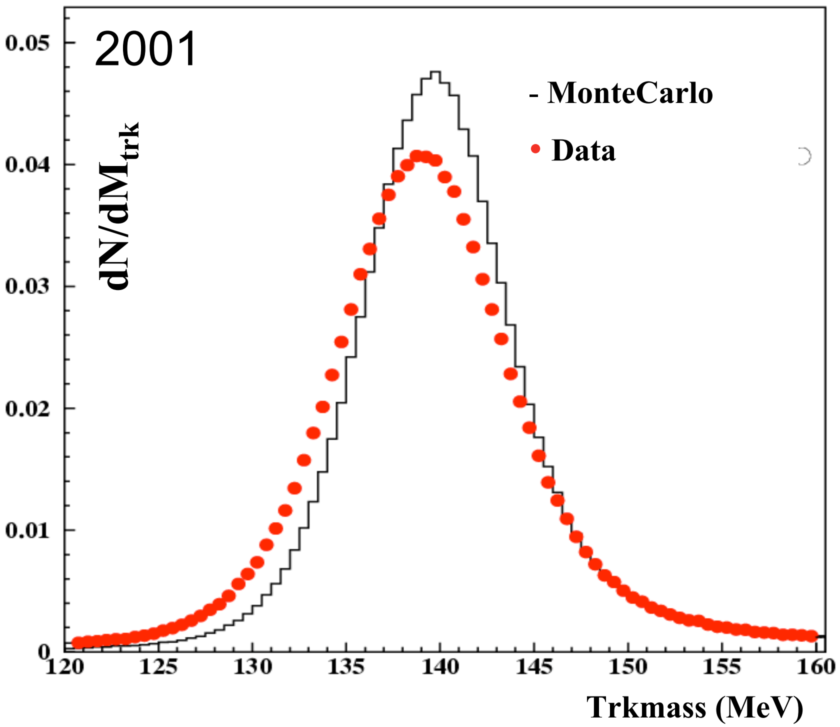


„Tuning“ of MC distr.:

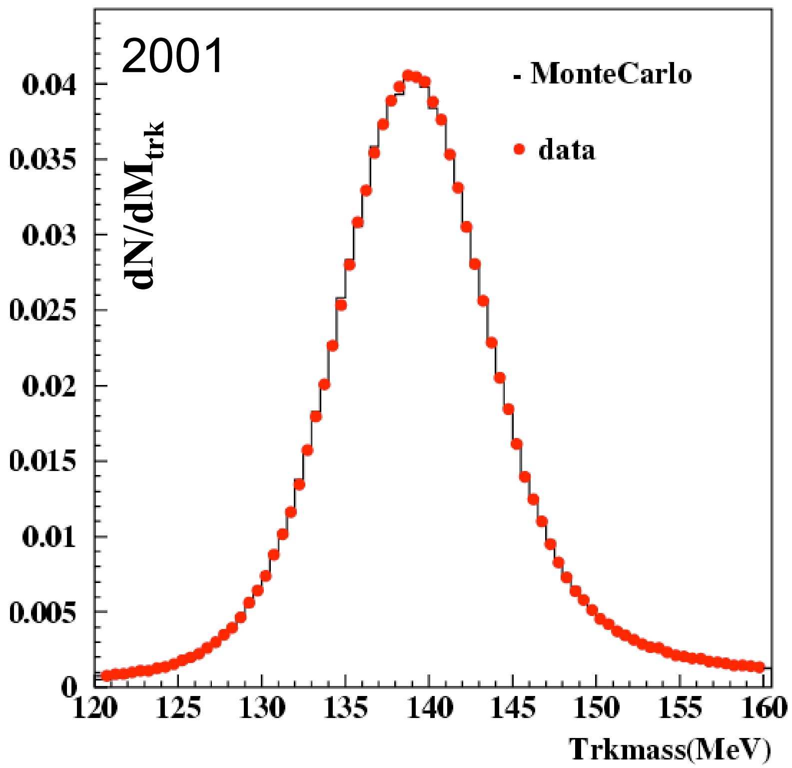
One needs to make sure that MC reproduces data distributions in a satisfactory way

- by matching individual datataking conditions *run-by-run* (int. Luminosity, $\sqrt{s}$, machine background,…)
- by *tuning* (smearing, shifting,…) MonteCarlo distributions in order to accommodate “hidden” effects (miscalibrations,…)

Before curing MC:



After curing MC:



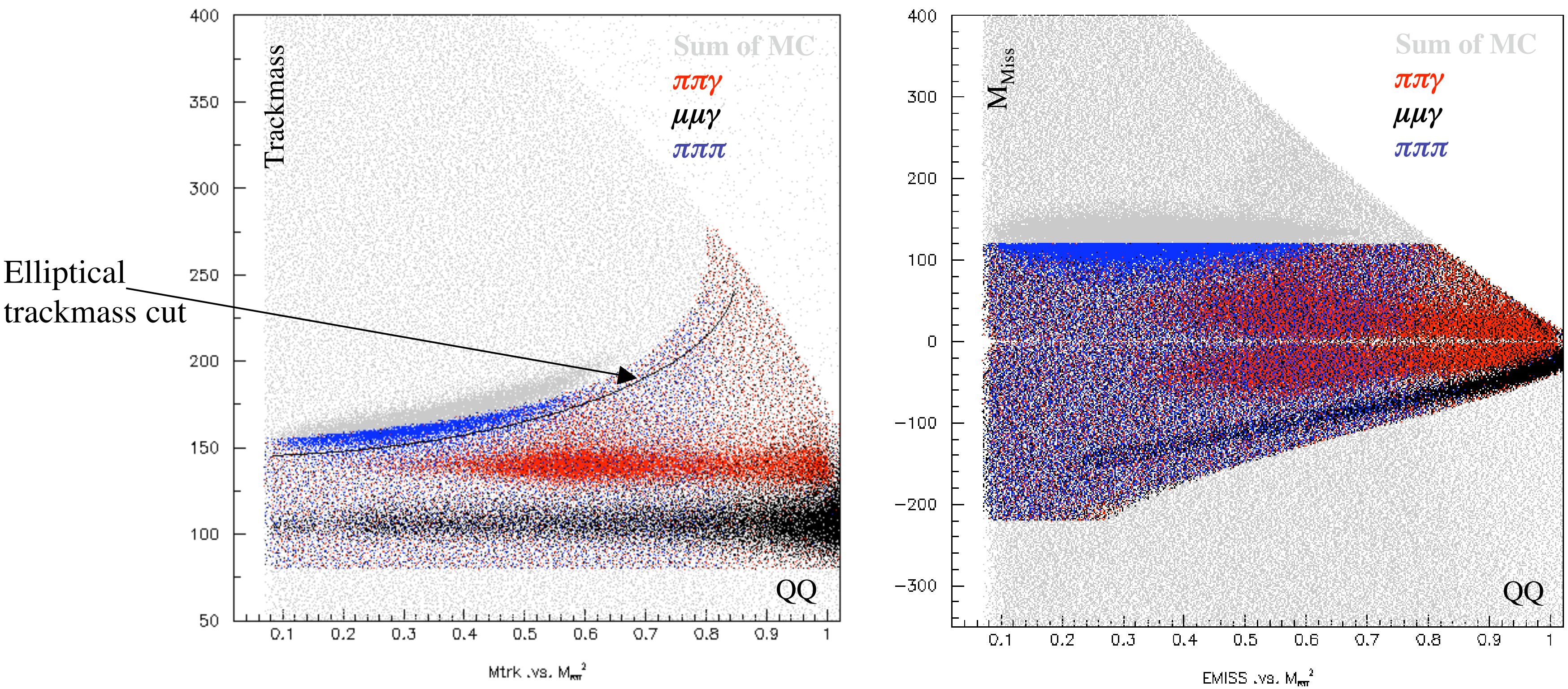
Effect of different “tuning”-methods on background eval., MC eff., etc. contributes to systematic error.

M_{Trk} and M_{miss} Eff.:

Effect of EVCL-cuts in M_{Trk} and* M_{Miss} from MC:

*defined by 4-momentum conservation under the hypothesis of $e^+e^- \to \pi^+\pi^- \mathbf{x}$

$$M_{miss} = \sqrt{E_X^2 - p_X^2}$$

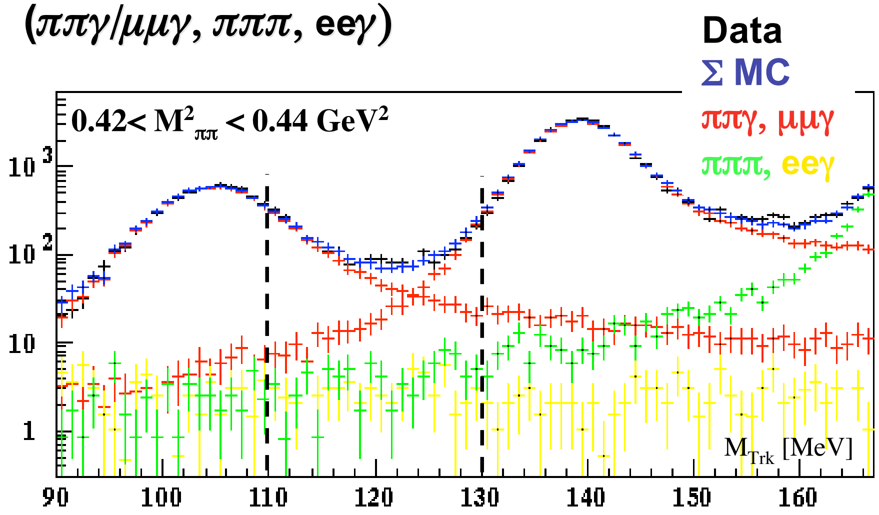


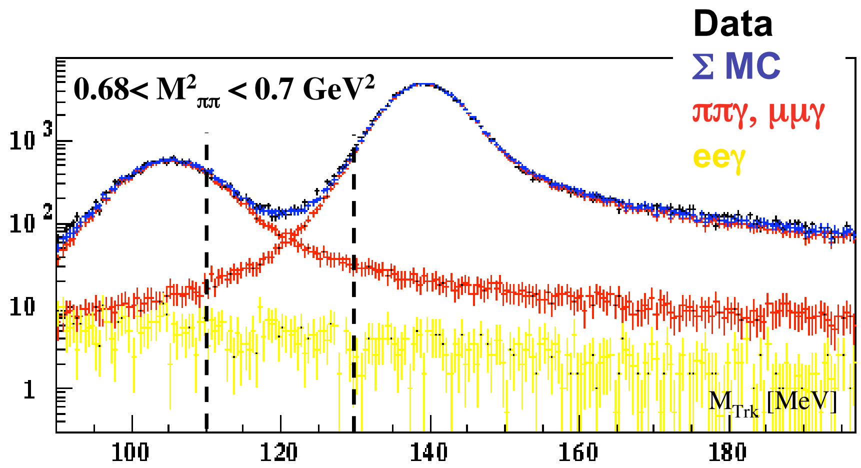
The elliptical cut in M_{Trk} (needed to cut away $\pi\pi\pi$ events) is partially rejecting also nlo-FSR events, and it is sensitive to effects from FSR.

- Cross check eff. with downscaled sample of unstreamed data (UFO events)?
- Possible to release cut in the analysis using 2006 data at $\sqrt{s}$=1 GeV??

Background:

Main backgrounds estimated from MC shapes fitted to data distribution in M_{Trk} ($\pi\pi\gamma/\mu\mu\gamma$, $\pi\pi\pi$, eeγ)

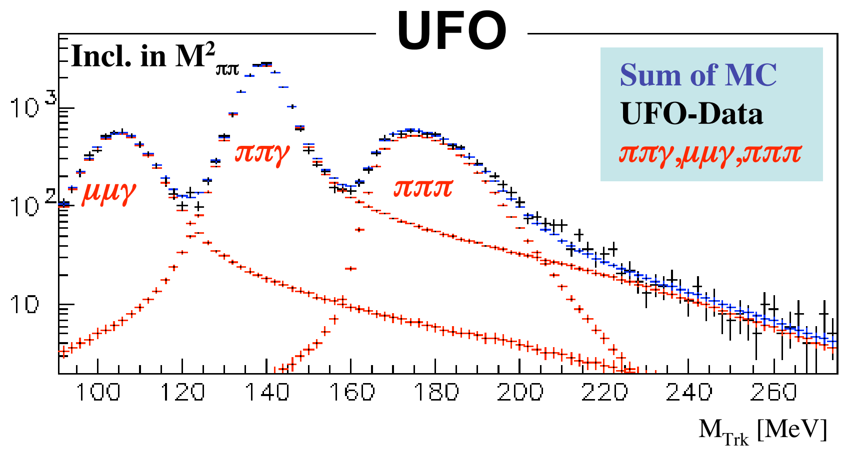




- Bhabha contamination small
- $\pi\pi\pi$ events only fitted below 0.6 GeV^2
- $\pi\pi\pi$-peak is cut by event streaming and ell.

Cut in M_{Trk}

- cross check with downscaled UFO evens →
- Systematic effects:
  - Tuning of MC
  - Differences between MC and data distributions
  - additional backgrounds... (see last Meeting)



“Unshifting“

Go from $M^2_{+-} \rightarrow M^2_{\gamma *}$

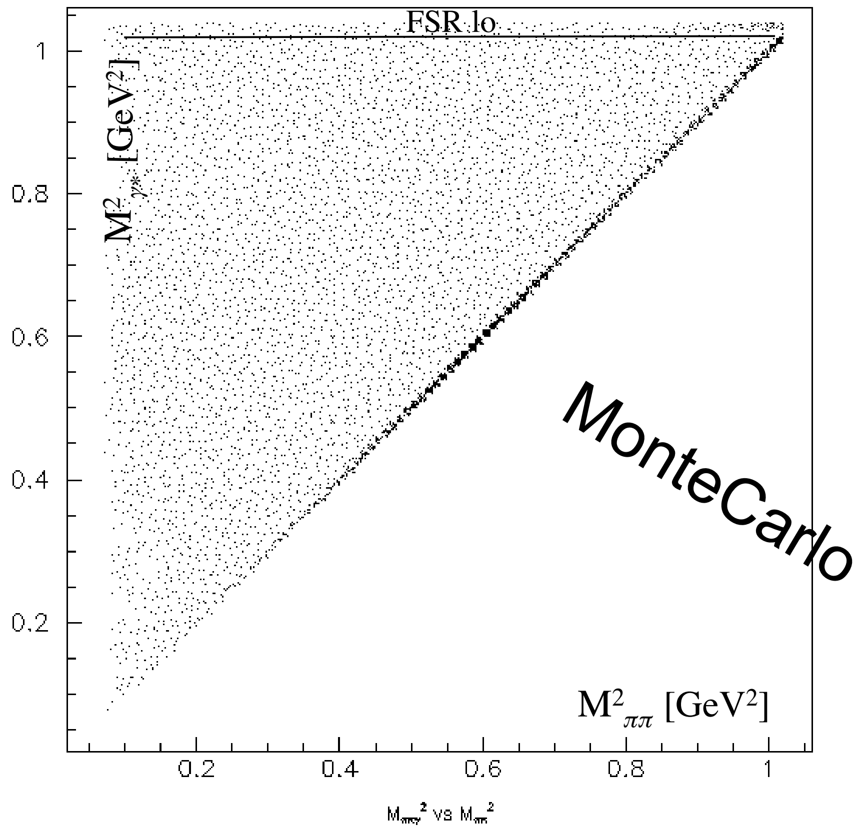
The presence of γ_{FSR} results in a shift of the measured quantity $M^2_{\pi\pi}$ towards lower values:

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

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

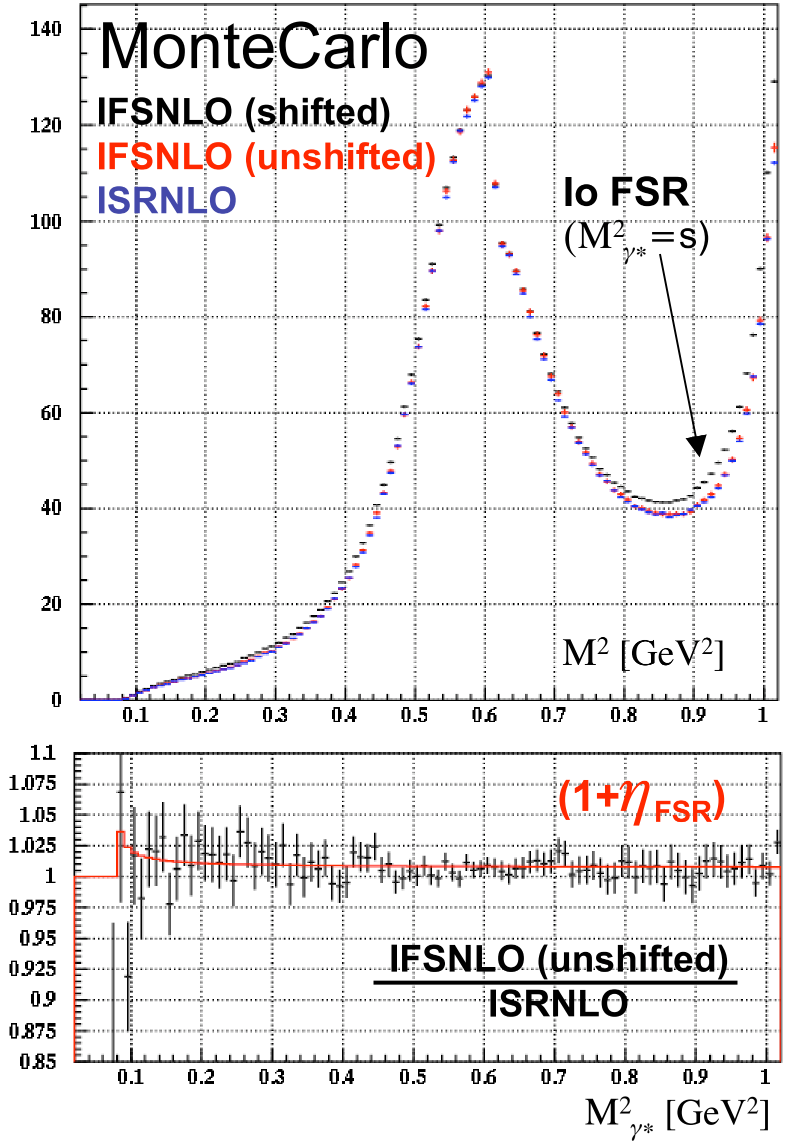
FSR photon present: $M^2_{\gamma *} = M^2_{\pi\pi\gamma(FSR)}$



"Unshifting" (2)

Monte Carlo example:

- Unshifting moves leading-order FSR-events to $M^2_{\gamma*}=s$
- unshifted spectrum then differs from ISRNLO-spectrum only by the factor $(1+\eta_{FSR})$



Questions:
- model-dependence of FSR
- effect of 2. FSR-photon (not present yet in MC)

Unfolding + Acceptance:

Unfolding:

Unfolding the detector resolution from the spectrum was a tricky procedure in the 2001 analysis, maybe overkill given the good momentum resolution of the KLOE drift chamber. Depends on how good detector simulation represents reality.
Very small effect on a_μ^{had}.

Needs iterative procedure for pions to overcome dependence on form factor parameters in MC.

Work in progress…

Acceptance:

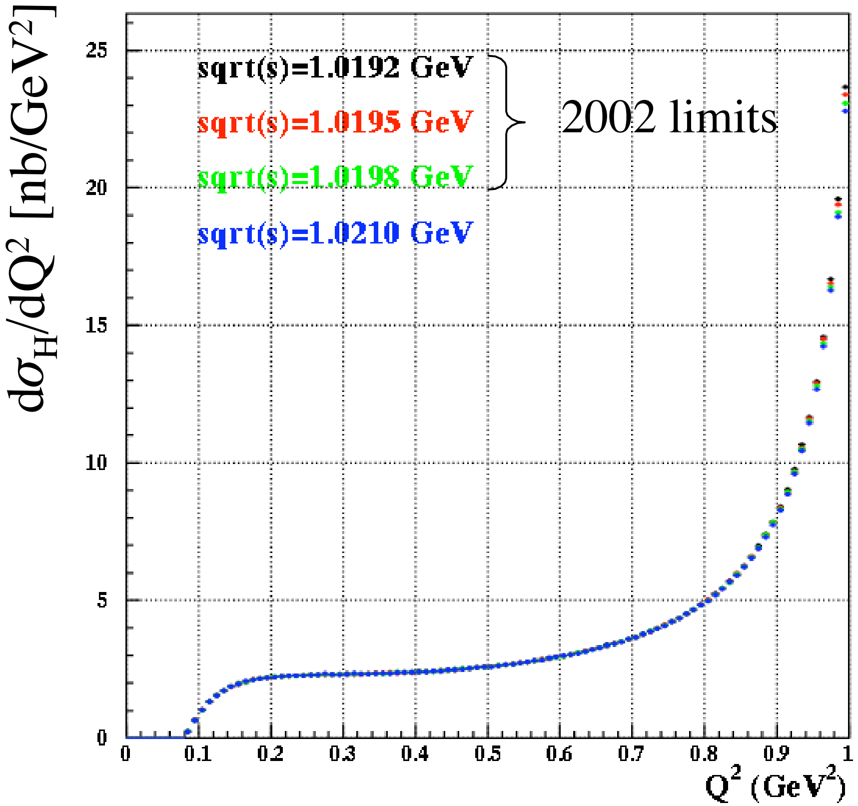
Acceptance is taken directly from MC. Differences found in comparisons between data and MC distributions (which have to be done on the reconstructed level) contribute to the systematic uncertainty of the acceptance. Depends on detector simulation and MC “tuning”.

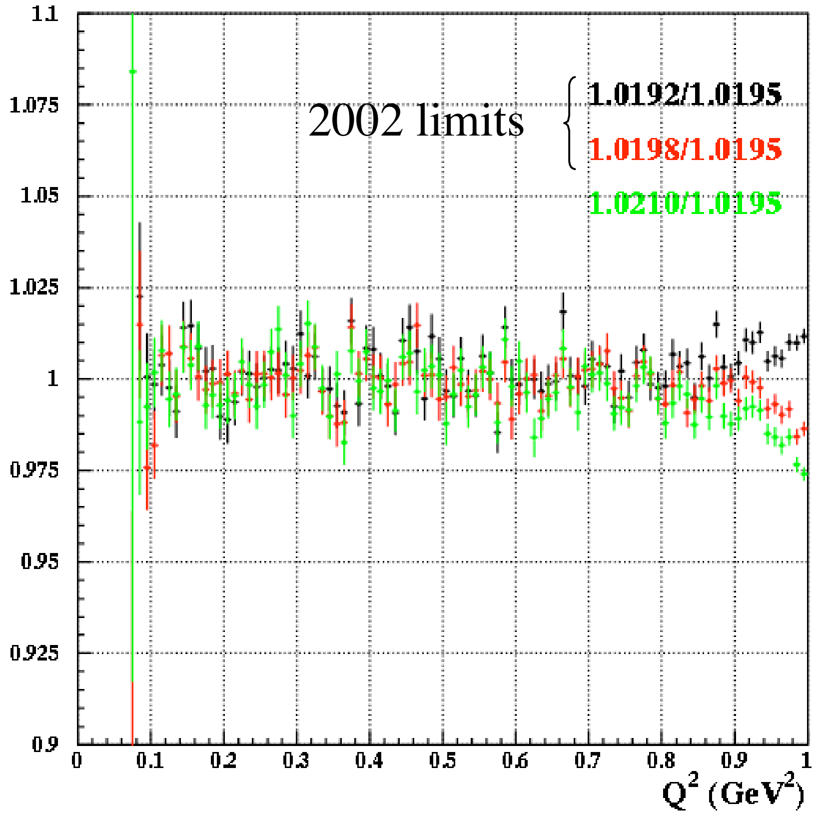
Work in progress…

Radiator function:

Taken from PHOKHARA MC (setting $|F_\pi|^2$=1.) - this yields an effective "radiator" cross section $d\sigma_H/dQ^2$.

Checks on dependence on √s:





No big deviation found below 0.90 GeV². In the ratio, the radiator should cancel. Cross check with muon data/MC comparison.

Luminosity + Vac. Pol.::

Luminosity:

Effective VLAB cross section of 428.8nb reduced by 7‰ according to new version of BABAYAGA-generator (Nucl. Phys. B758 (2006), 227)
→ Absolute measurements drop by 7‰ (but cancels in ratio)
→ Check differential distributions for data and MC
→ Needs BABAYAGA@NLO with all channels ($\gamma\gamma$,$\mu\mu$,..)

Vacuum Polarisation:

Found slightly different treatment of vacuum polarisation for pions and Muons in PHOKHARA5 (effect only near M_{ϕ}^2).

Vacuum Polarisation should cancel in the ratio.

We use Fred's code (I should check if I have the newest one!).

Conclusions:

Muons are signal now!!

- need to have a very good understanding of muonic FSR
- need the same treatment of muons in MC as pions
- need the same MC tools for muons as for pions

What we need:
(in addition to the things wishlisted at the last MC meeting)

- simulation of the process $e^+e^- \rightarrow \pi^+\pi^-(\gamma\gamma)_{FSR}$
- missing channels in BABAYAGA@NLO

Working Group name:

RADIO MONTECARlow

Working Group logo: