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e^+e^- Physics at Intermediate Energies
Stanford, 30 April - 2 May 2001

Measurement of the Hadronic Cross Section at KLOE using the Radiative Return

- Radiative Return at DAΦNE (ISR / FSR)
- Measurement of $e^+e^- \rightarrow \pi^+\pi^-\gamma$ with the KLOE detector
- Summary & Outlook

σ_{hadr} at DAΦNE: $e^+ e^- \to \pi^+ \pi^- \gamma$

DAΦNE: Electron - Positron Collider on ϕ - mass $\sqrt{s} = 1.02\ GeV$

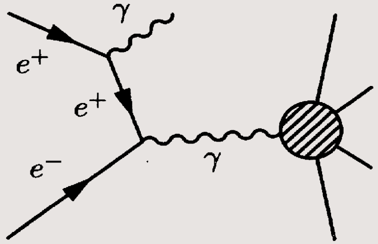
Energy - Scan at short hand not possible due to special Interaction - Region

⇩

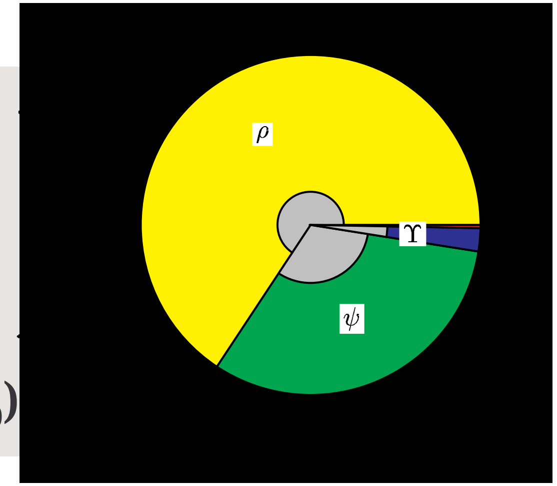
ISR

$e^+ e^- \to \gamma + \text{Hadrons}$

$(2m_\pi)^2 < Q^2_{\text{-Hadrons}} < (m_\phi)^2$



$$d\sigma\,(e^+e^- \to \text{hadrons}+\gamma)\,/\,dQ^2 = \sigma\,(e^+e^- \to \text{hadrons}, Q^2)\ H\,(Q^2, \cos\theta_0)$$



⇨ **This measurement is a complementary approach to the standard energy scan (e.g. Novosibirsk)**

Restricted to $Q^2 < (M_\phi)^2$ **ρ -Resonance**

Requires good suppression of FSR

Requires precise calculations of ISR

→ **EVA** MC Generator (Kühn et al.)

61% of hadronic contribution a_μ comes from ρ mass region

Data comes as by-product of KLOE standard program

Errors of beam energy and luminosity the same for each point of Q^2

$e^+ e^- \to \rho\,\gamma \to \pi^+ \pi^- \gamma$

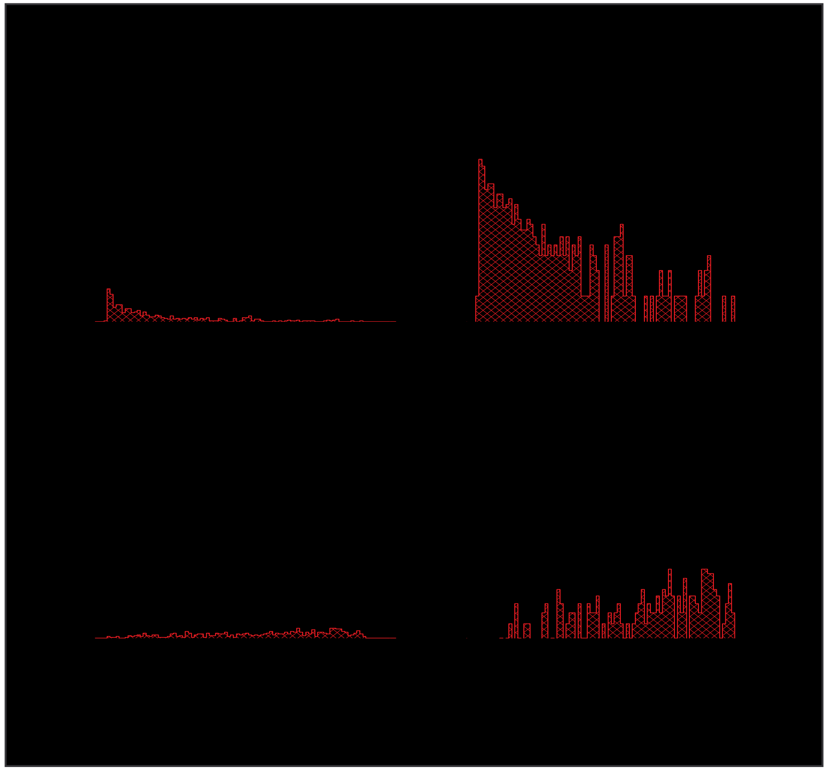
ISR / FSR (EVA - MC *)

* S. Binner, J.H. Kühn, K. Melnikov
Phys. Lett. B 459 (1999)

➩ **FSR is Background for our Process** $e^+ e^- \longrightarrow \pi^+ \pi^- \gamma$

ISR is peaked at small angles of the photon
and is enhanced by the ρ-resonance

FSR follows pion angular distribution; enhanced at small E_γ
and larger photon angles



➩ **Cut in E_γ-θ_γ-plane:**

- E_γ>20 MeV
- 5°<θ_γ<21°
- 55°<θ_π<125°
- more kinematical cuts

ISR/(ISR+FSR)>99%

⇩

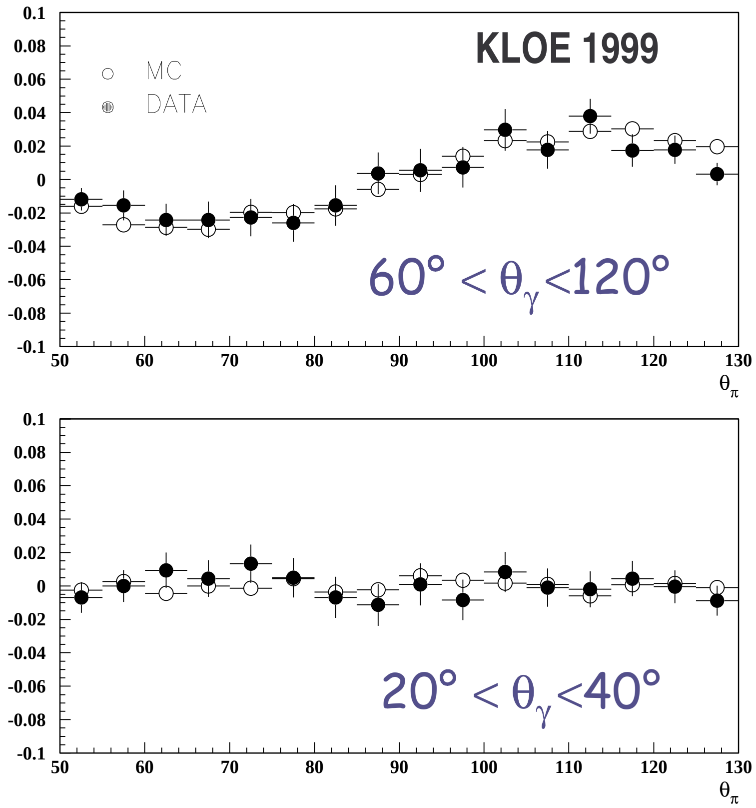
Select events with θ_γ as low as possible

➩ $\sigma_{ISR} \approx$ 3.5 nb

ISR / FSR

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

We can test the model of FSR in MC by looking at the charge asymmetry of the pion pairs:



Comparison for Asymmetry betw. Data and MC looks good

EVA -MC seems to describe FSR on the some % - level

$\phi \to f_0(980)\,\gamma \to \pi^+\pi^-\gamma$

⇨ **The direct decay $\phi\to\pi^+\pi^-\gamma$ gives an additional background which has to be subtracted to the *1%* - level**

Problem:	Poorly known parameters of the f_0-Meson through which the decay proceeds: $\phi \to f_0\,\gamma \to \pi^+\pi^-\gamma$

constr./destr. Interference with FSR ?

Information from $\phi \to f_0\,\gamma \to \pi^0\pi^0\gamma$

⇨ **Study decay experimentally at large photon angle !**

⇨ $60° < \Theta_\gamma < 120°$
complementary analysis
to hadronic cross section (ISR)

Experimental values:

$BR(\phi\to\pi^+\pi^-\gamma)_{Exp} = (0.41\pm0.13)\cdot10^{-4}$
$BR(\phi\to f_0\,\gamma)_{Exp} = (1.93\pm0.68)\cdot10^{-4}$ (→ destr. Interference?) } CMD2 coll

$BR(\phi\to f_0\,\gamma)_{Exp} < 1.6\cdot10^{-4}$ @95% C.L. } KLOE coll 1999 data

The DAΦNE Complex

- **Design Philosophy:**

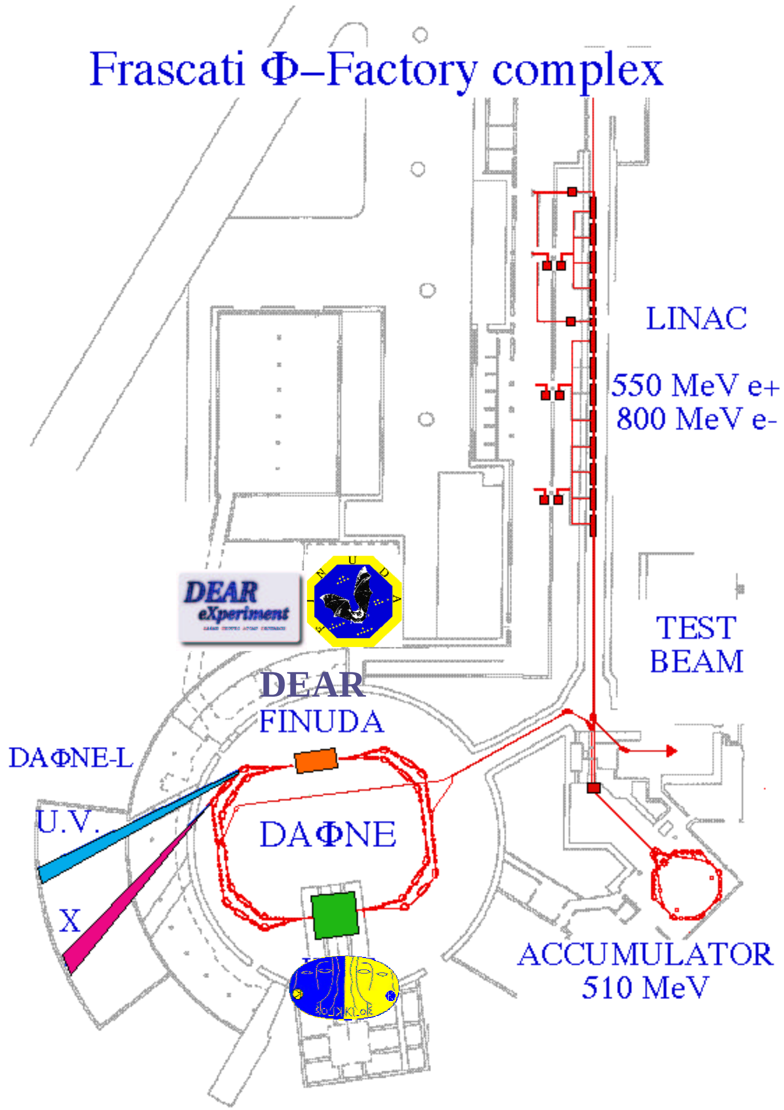
Moderate Single Bunch Luminosity	*	Large Number of Bunches
$5 \cdot 10^{30}$ (VEPP-2M)	*	120 Bunches 2.7 ns spacing

- 2 independent beam lines for e^-, e^+
  2 interaction points: KLOE & DEAR/FINUDA

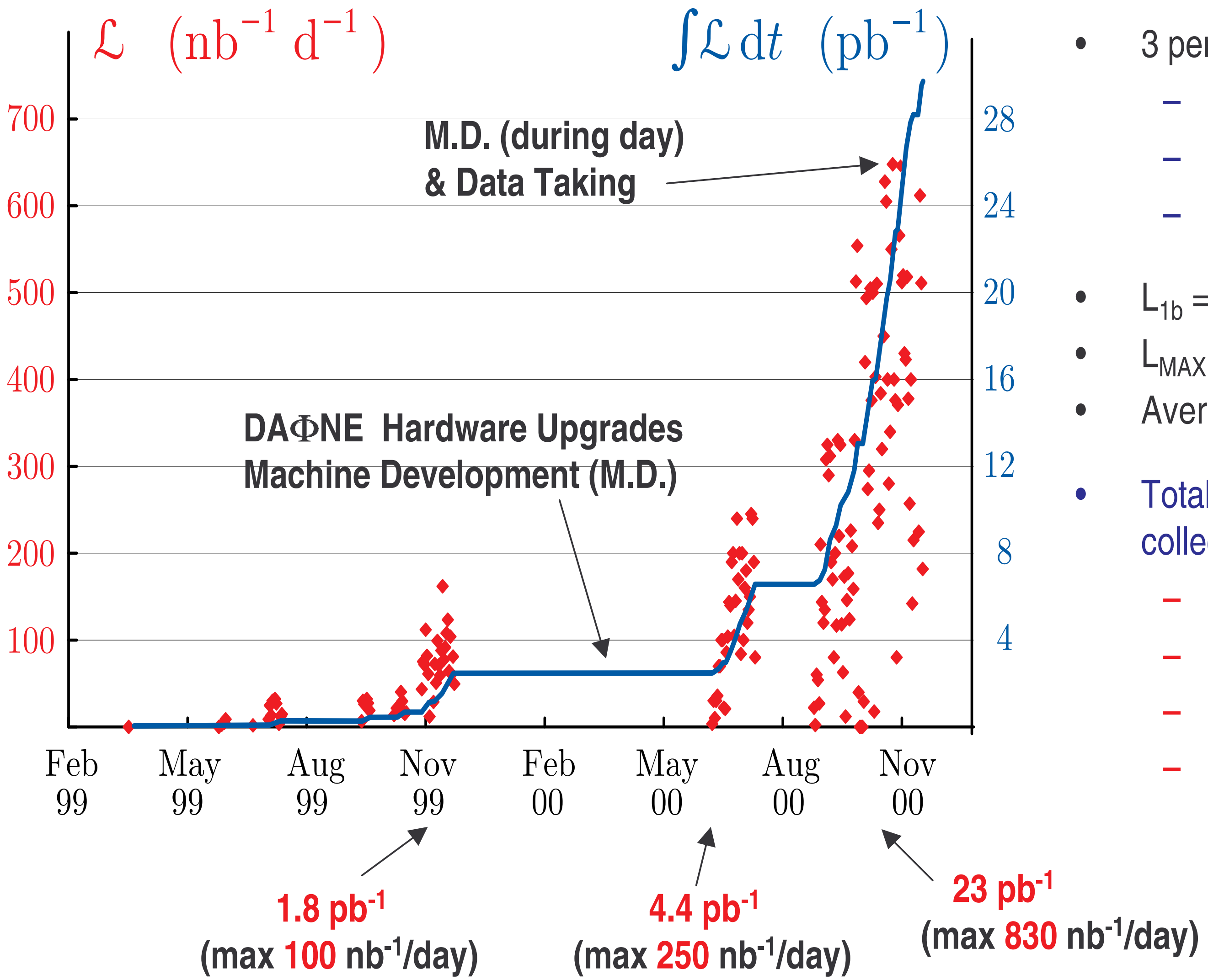
- BR's for main ϕ decays

BR's for main ϕ decays	
K^+K^-	49.1%
K_SK_L	34.1%
$\rho\pi + \pi^+\pi^-\pi^0$	15.5%

$$p_{K^{+-}} = 127 MeV/c$$
$$p_{K_{L,S}} = 110 MeV/c$$



DAΦNE & KLOE History



- 3 periods of continuous data taking:
  - Dec. 1999
  - July 2000
  - Sept.-> Dec. 2000
- $L_{1b} = 4\times10^{29}$ @ 25 mA/bunch
- $L_{MAX} = 1.8\times10^{31}$ @ 600 mA/beam
- Average beam lifetime ~1h
- Total integrated luminosity collected: L~28 pb^{-1}
  - 130 M Bhabhas
  - 67M ϕ decays
  - 25M $K_S K_L$ tagged events
  - 19.5M K^+K^- events w/ vertex

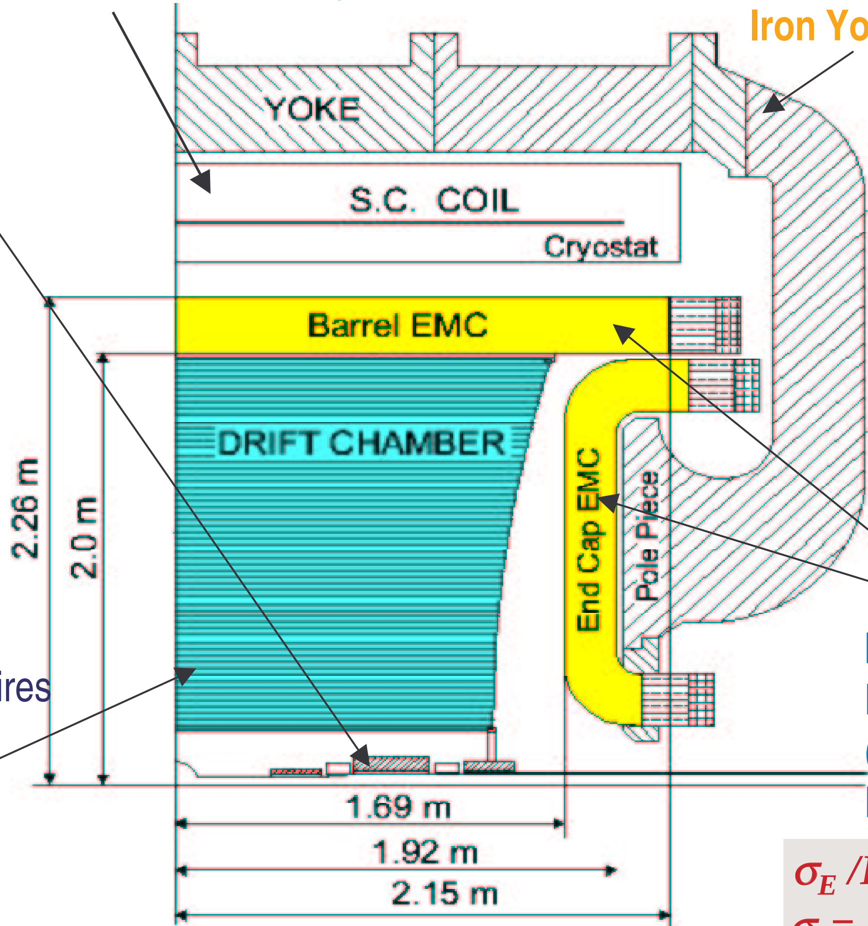
The KLOE Detector

➩ **Design:** Measurement of Events, like : $K_L \to \pi^+\pi^-$ $K_S \to \pi^0\pi^0$

Be beam pipe
(0.5 mm thickness)
permanent Quad's instru-
mentation (32 PMTs)

Superconducting Coil $B=0.6\ T$

Iron Yoke



Cylindrical Drift Chamber
4 m ∅, *3.3 m* Length
90% Helium, *10%* Isobutane
12582 / 52140 sense / total wires
all stereo wires

$\sigma_p / p < 0.4\%$
$\sigma_z = 2\ mm$

Electromagnetic Calorimeter
Pb / Scintillating Fibres
(4880 PMTs)
Endcap - Barrel - Modules

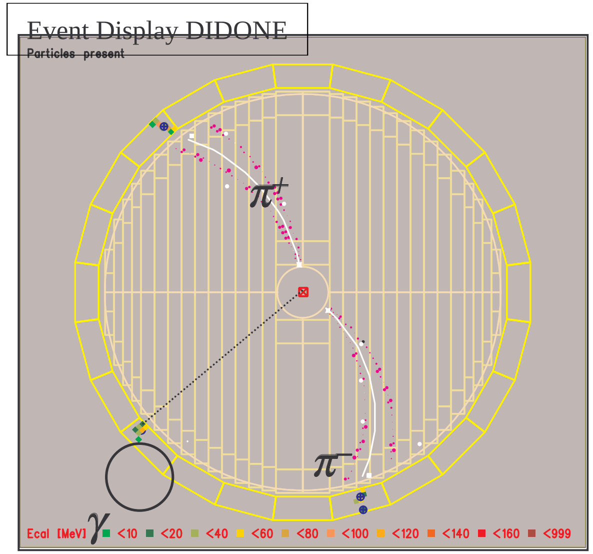
$\sigma_E / E = 5.7\% / \sqrt{E(GeV)}$
$\sigma_t = 57\ ps / \sqrt{E\ (GeV)} + 50\ ps$

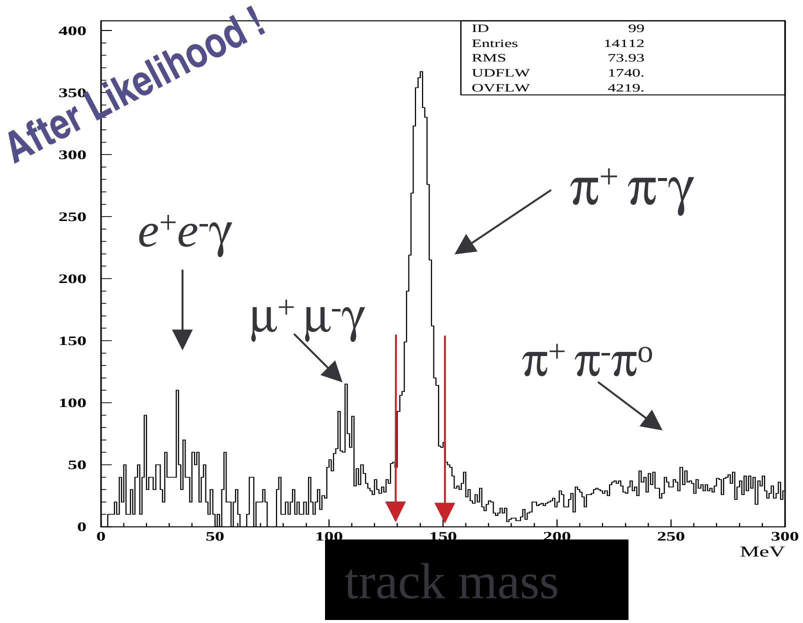
$e^+ e^- \to \pi^+ \pi^- \gamma$ Event Selection

- $e^+ e^- \to \pi^+ \pi^- \gamma$ **Events with polar angle Θ_γ of photon as small as possible:**

$\Theta > 21°$: Electromagnetic Calorimeter
$\Theta > 5°$: Quadrupole Instrumentation (only tag ?!)

Efficient Photon Detection not possible at very small angles where ISR is enhanced





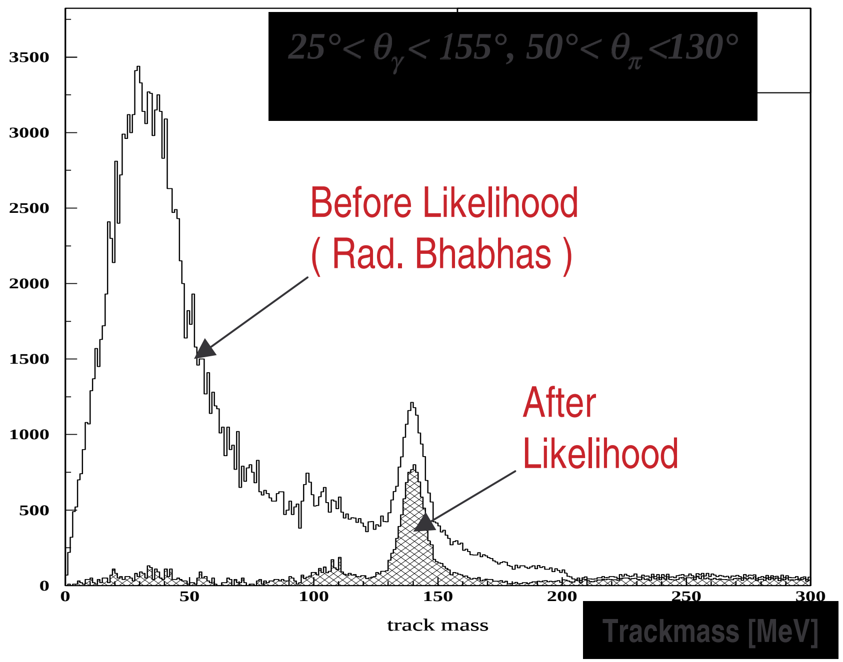
Select $\pi\pi\gamma$ by using only information from the high resolution drift chamber: calculate Θ_γ from missing momentum
no explicit photon detection !

- 1 charged vertex close to I.R. with 2 tracks
- Likelihood Method for Bhabha Suppression
- cut on kinematical variables (track mass)

Bhabha Separation

To reduce Bhabha contamination, a Likelihood-Method has been developed based on:

- TOF of charged clusters in EmC
- Shape and energy deposition of the “charged” cluster

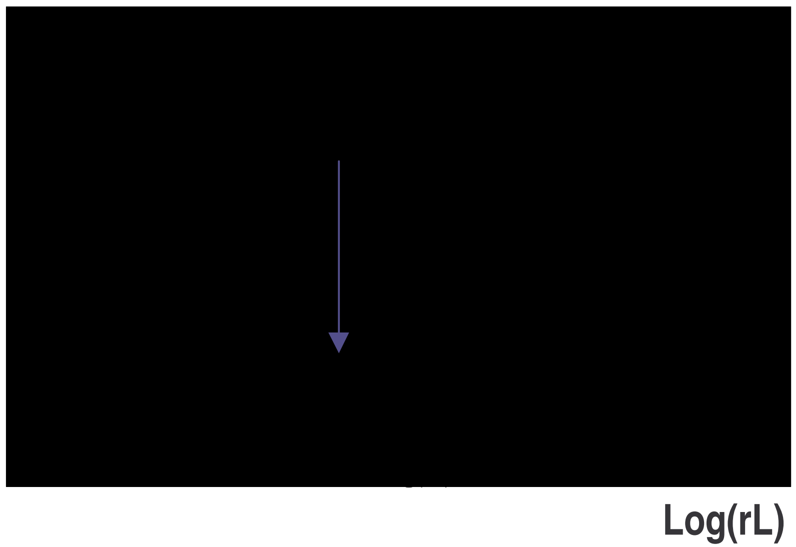


Two control samples have been taken from data in order to find suitable variables to separate electrons and pions:

⇨
- $\pi^+\pi^-\pi^0$ are used for Pion information
- $e^+e^-\gamma$ are used for Electron information

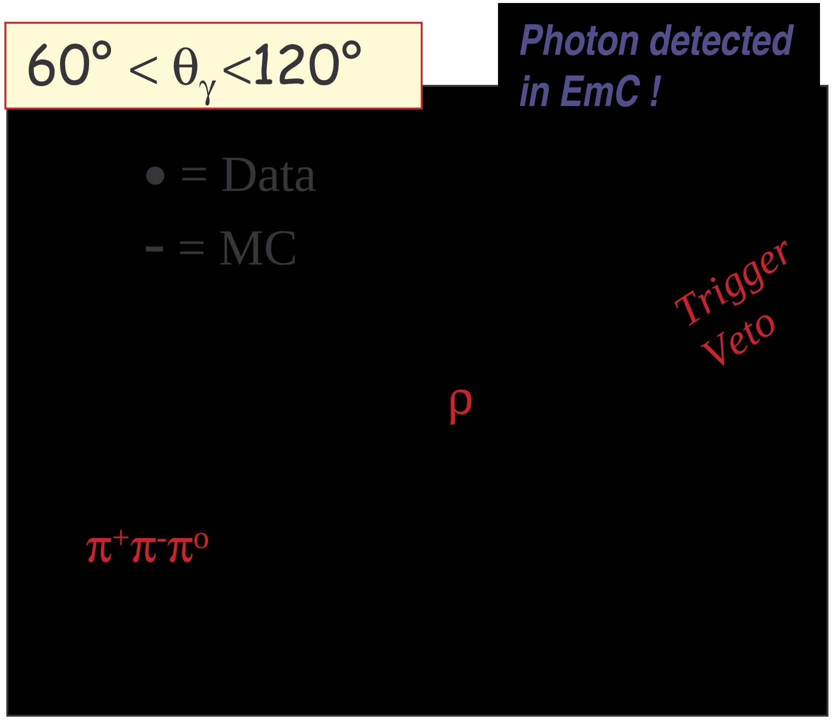
$$aL^{e,\pi} = \prod f_i^{e,\pi}(x_i) \quad \text{abs. Likelihood}$$

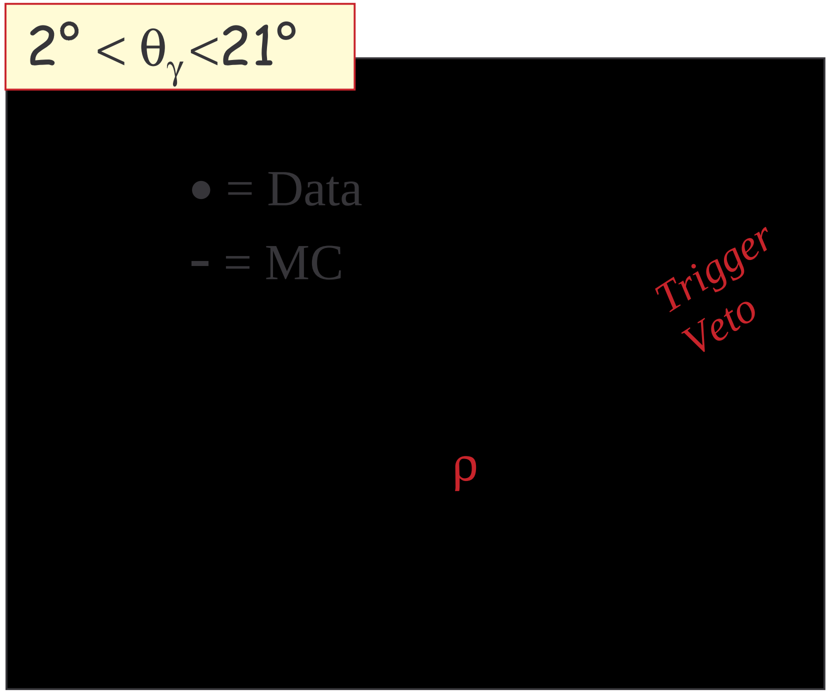
$$rL = aL^{\pi}/aL^{e} \quad \text{rel. Likelihood}$$



First Comparison

- After the application of the Likelihood -Method, the cut $|mass_{trk}-139.5|<10$ MeV is applied
- We compare the distributions with MC for Large Photon Angle & Small Photon Angle ("Online") and normalize both distributions to the same number of events around ρ - peak



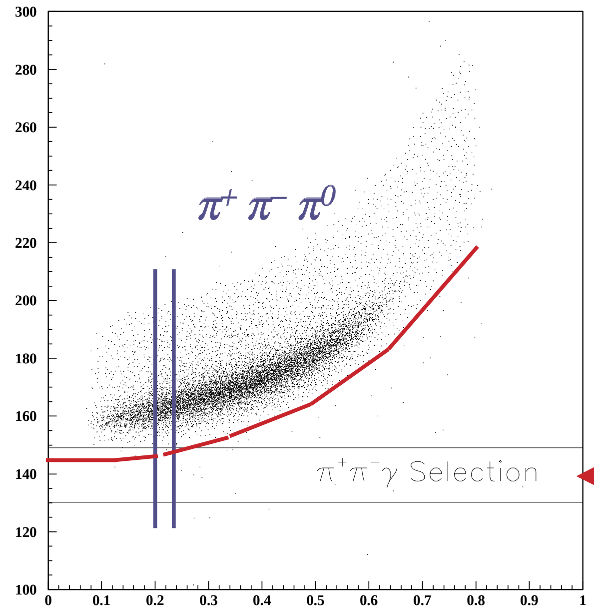


- the **background contributions** have to be taken into account
  the **various efficiencies** have to be checked & calculated **using data as function of Q^2**

Background from $\phi \to \pi^+ \pi^- \pi^0$

- $\phi \to \pi^+ \pi^- \pi^0$ has a 15.5% BR. and is separated during the selection phase by applying a cut in the 2dim. Plane $Mass_{track}$ vs. Q^2

- Look at the events which fall in $\pi^+ \pi^- \gamma$ -Se= lection - Interval (as function of Q^2)

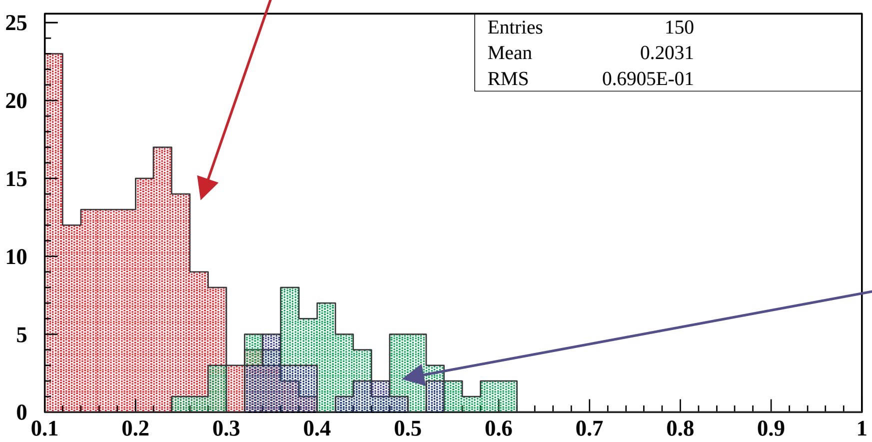


$\pi^+ \pi^- \gamma$

$Mass_{track}$ vs. Q^2

$60° < \Theta_\gamma < 120°$

$\pi^+ \pi^- \pi^0$ is dominating the very low Q^2 - region



$\pi^+ \pi^- \pi^0$ Background in $6.5\ pb^{-1}$

$5° < \Theta_\gamma < 21°$

$\pi^+ \pi^- \pi^0$ background almost negligible

Selection Efficiencies

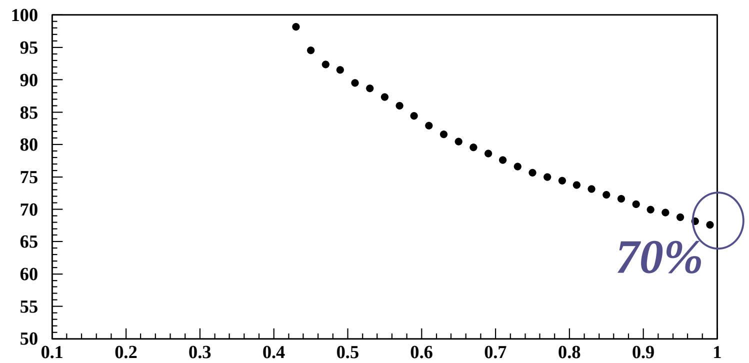
Numbers in Blue: Data
Numbers in Green: MC

Trigger

• "HW -Cosmic Veto"* at high Q^2
loss in efficiency for data $Q^2 > 0.7$ GeV^2

⇨
- downscaled Anti-Veto Events
- parametrize probab. for single pions as Function of p_π and Θ_π

⇨



70% @ 1GeV^2 ; 100% @ 0.45 GeV^2

• standard Trigger - Efficiency → ≈ 95% …… 99%, some Q^2 - Dependance

Reconstruction - Filter

• Filter for machine background + cosmics

⇨ downscaled Anti-Filter Events → ≈ 98%, flat in Q^2

Event Selection

• Vertex efficiency
• likelihood method
•other kinematic cuts

⇨
- Bhabha Events (sel. indep. from DC) ≈ 98% loss at small Q^2
- constructed from data (see before) → ≈ 98%, flat in Q^2
- taken from MC

Acceptance

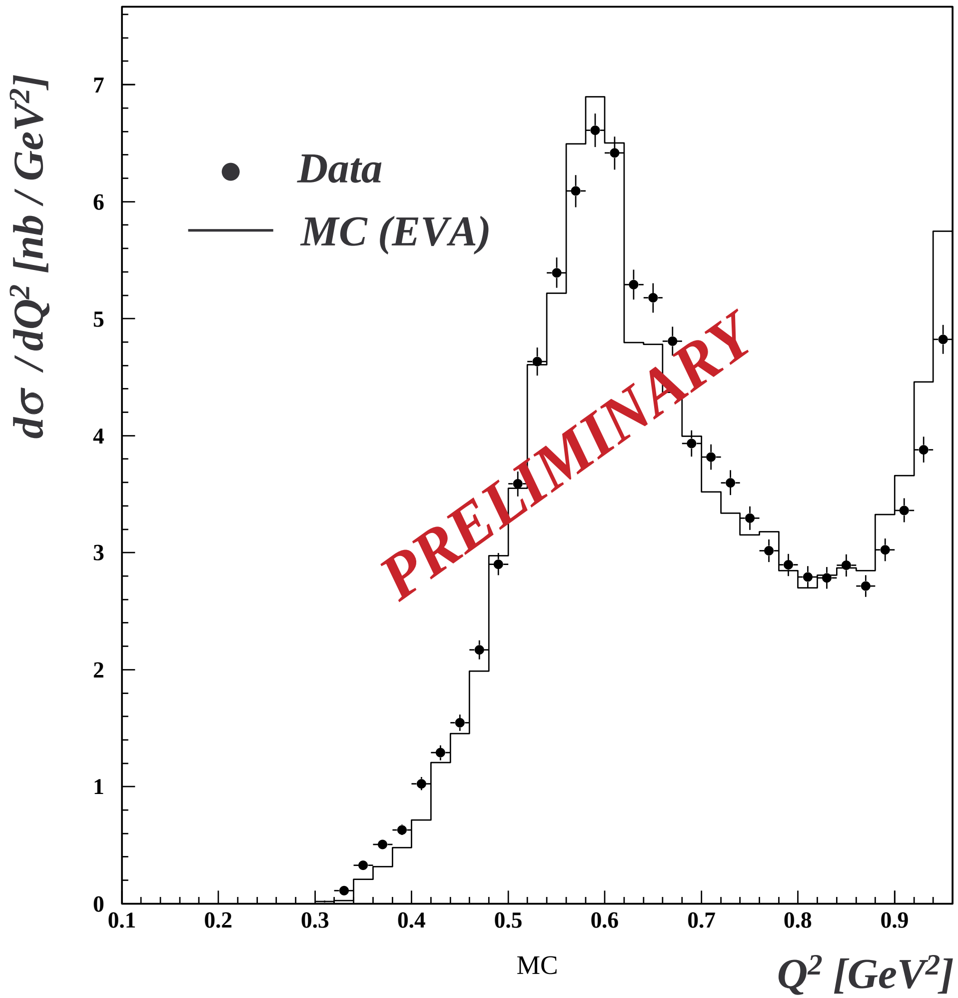
⇨ Still taken from MC, losses at small Q^2 due to kinematics

* 2 Energy depositions > 40MeV in outer plane of EmC

Differential Cross Section

- **16.1 pb^{-1}** of Nov./Dec. 2000 Data have been analyzed (1/2 of full data set 1999 + 2000)

$e^+ e^- \rightarrow \rho\,\gamma \rightarrow \pi^+ \pi^- \gamma$



Data is not corrected for smearing (Tracking Resolution effect) !

Acceptance Cuts:

$5° < \Theta_\gamma < 21°$
$E_\gamma > 10$ MeV
$55° < \Theta_\pi < 125°$
$p_T > 200$ MeV

Luminosity Measurement

DAΦNE does not have Luminosity
Monitors at small angles

⇨ **use KLOE itself for measurement :**
Large Angle Bhabhas (σ_{eff} = 425nb)

- $55° < \theta_{+-} < 125°$
- Acoll. < 9 °
- $E_{+-} \geq$ 400 MeV

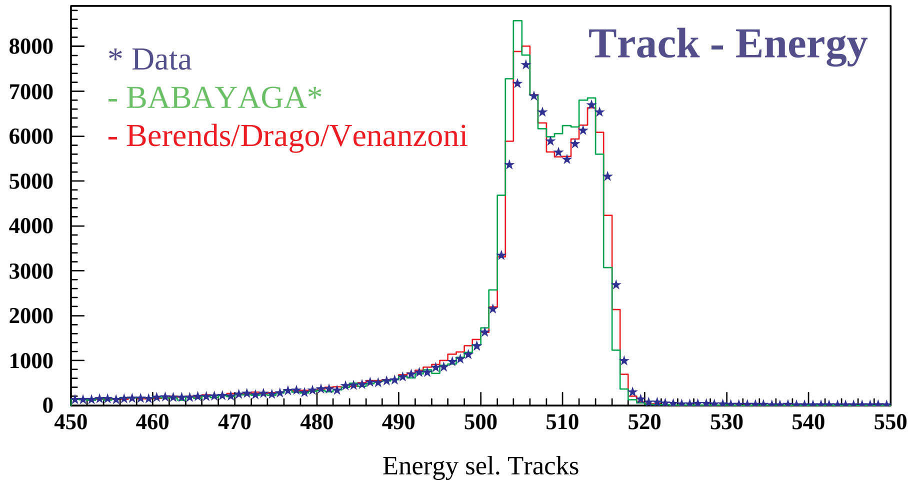
$$\int L dt = \frac{N_{LAB}(\Theta)\cdot(1-\delta_{Background})}{\sigma^{MC}_{LAB}(E)}$$

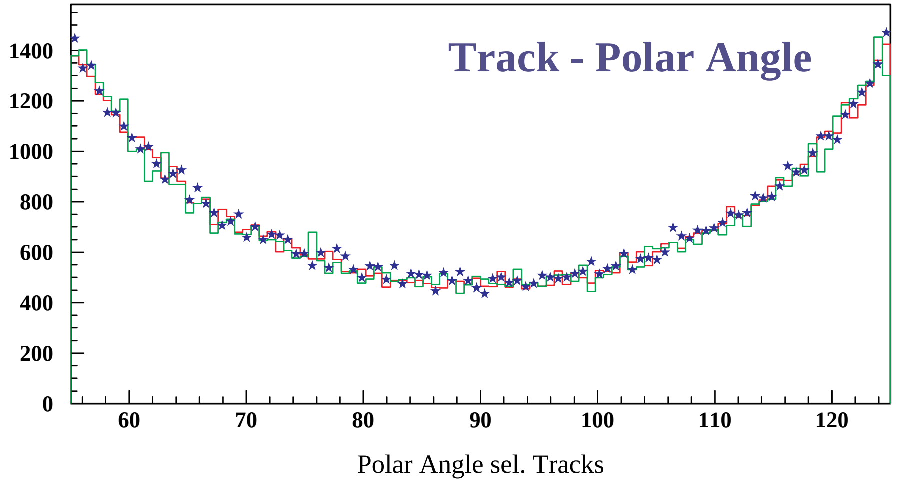
LAB - Candidates
(Systemat., Accept.)

Background
(γγ, ππγ, ...)

Theoret. Generators
with rad. corrections

Berends/Drago/Venanzoni
BABAYAGA*





⇨ **Luminosity- Measurement on Percent Level**
agreement with independent γγ-Counter < 1%

* *C.M.C. Calame et.al. Nucl. Phys., B 584 (2000)*

Summary & Outlook

- Preliminary results for the measurement of the **differential cross section** $e^+ e^- \longrightarrow \pi^+ \pi^- \gamma$ with the KLOE detector have been presented, where the Photon is coming from **ISR**
- Results are in **good agreement** with the MC prediction EVA (Kühn et.al.); **Efficiencies , Systematics** and **Background** (evaluated from data) are under control ;
- What will bring the future ?

$$\frac{d\sigma}{dQ^2} = \frac{dN^{obs} - dN^{Bkg}}{dQ^2} \cdot \frac{1}{\varepsilon_{Eff}\ \varepsilon_{Syst}\ L}$$

Efficiencies: already few % now , independent from MC

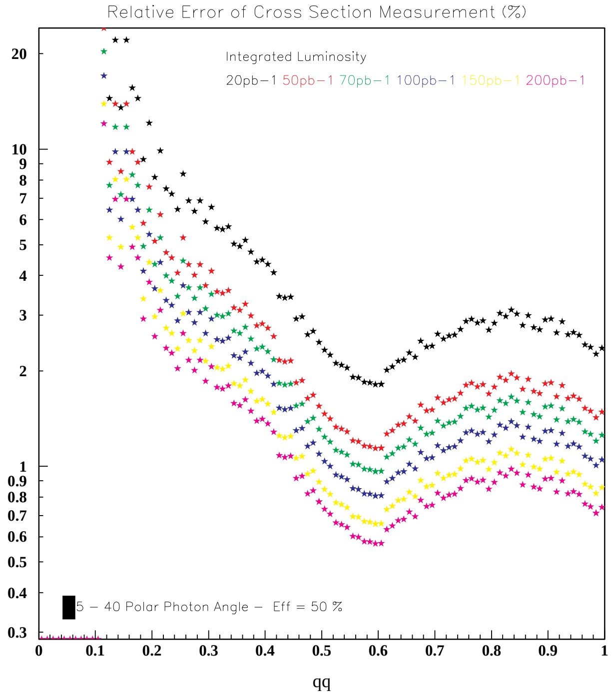
Background: very small Background from Bhabhas, $\mu\mu\gamma$

Systematics: Effect from $\delta\sqrt{s}$, δQ^2, $\delta\Theta_\pi$, $\delta\Theta_\gamma$ has been studied with MC, more emphasis needed to look at data, esp. $\delta\Theta_\gamma$

Luminosity: Precision already on percent level (<2%) more test are going on

Statistics: < 1% level for integrated Lumi. of $200pb^{-1}$

(**Theory:** NLO Generator from Kühn et.al (Θ_γ=0))



- **Extract the hadronic cross section** $e^+ e^- \longrightarrow \rho \longrightarrow \pi^+ \pi^-$ (compare with Novosibirsk results)