ISR studies at flavour factories

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CSIC

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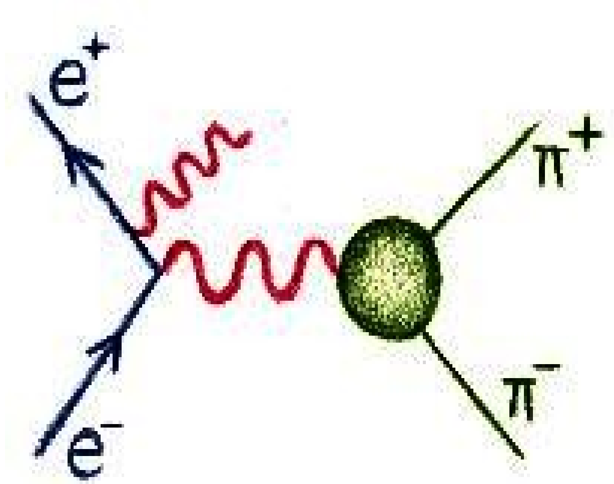
radiative return

The way to get the hadronic cross section at a fixed energy machine



Photon radiated off the initial e^+e^- (**ISR**) reduces the effective energy of the collision ($s \Rightarrow Q^2$)

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

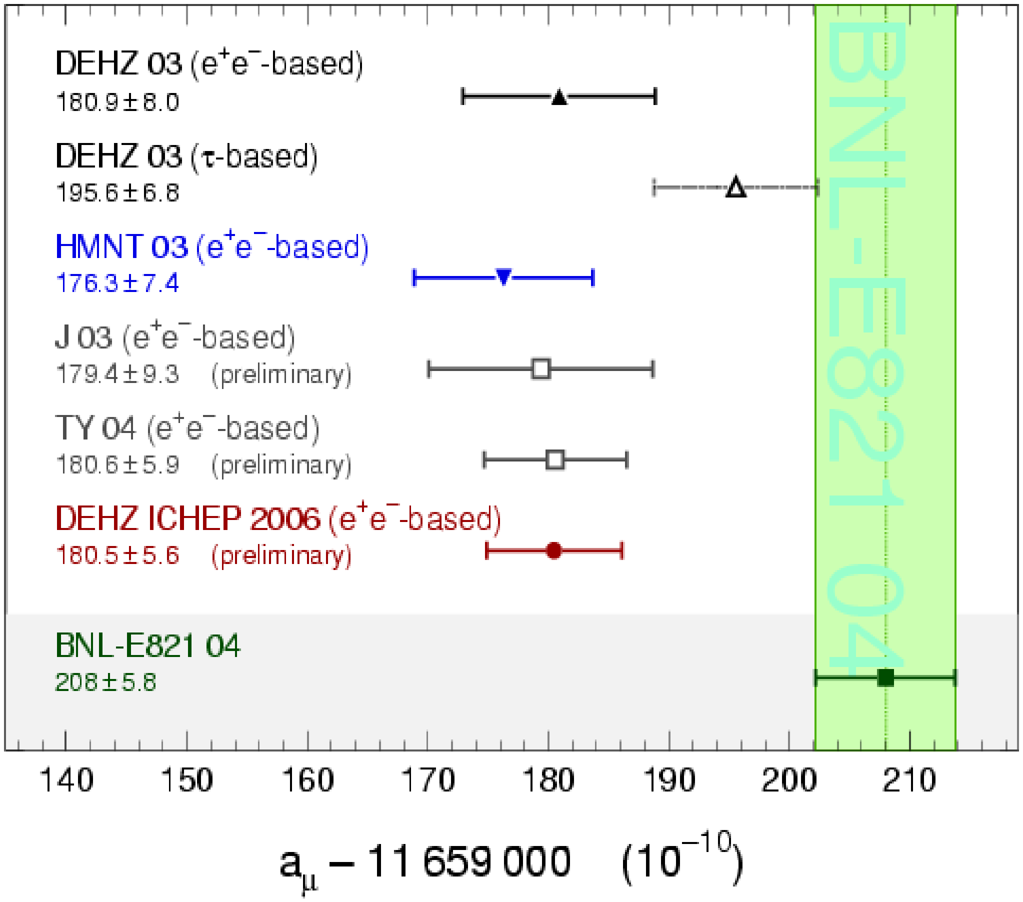
✔ Large luminosities of flavour factories:

- **KLOE @ DAPHNE**
- **CLEO-C @ CESR**
- **BaBar @ PEPII and BELLE @ KEK-B** ⇒ SuperB

compensate factor α/π from photon radiation

✔ High precision measurement of *R(s)* over the full range of energies, from threshold up to $\sqrt{s}$ **in an homogeneous data set**

$(g-2)_\mu$



$$a_\mu^{had,LO} = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{4m_\pi^2}^{\infty} \frac{ds}{s^2} K(s) R(s)$$

$$\Delta\alpha_{had}(m_Z^2) = -\frac{\alpha m_Z^2}{3\pi} \int_{4m_\pi^2}^{\infty} \frac{ds}{s} \frac{R(s)}{s - m_Z^2 - i\eta}$$

Davier (TAU06) ($\times 10^{-11}$)

a_μ^{BNL} = 11 659 2080 ± 63

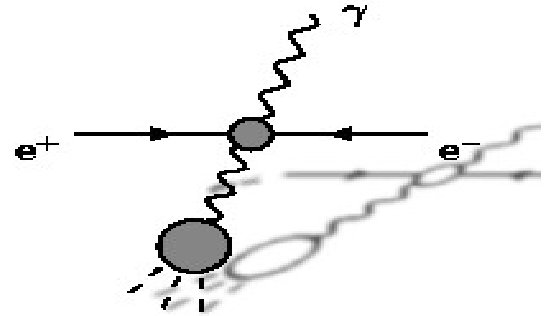
$a_\mu(e^+e^-)$ = 11 659 1805 ± 44_{had} ± 35_{lbl} ± 2_{QED+EW} (56)

$a_\mu^{had,LO}$ = 6909 ± 44

a_μ^{lbl} = 120 ± 35

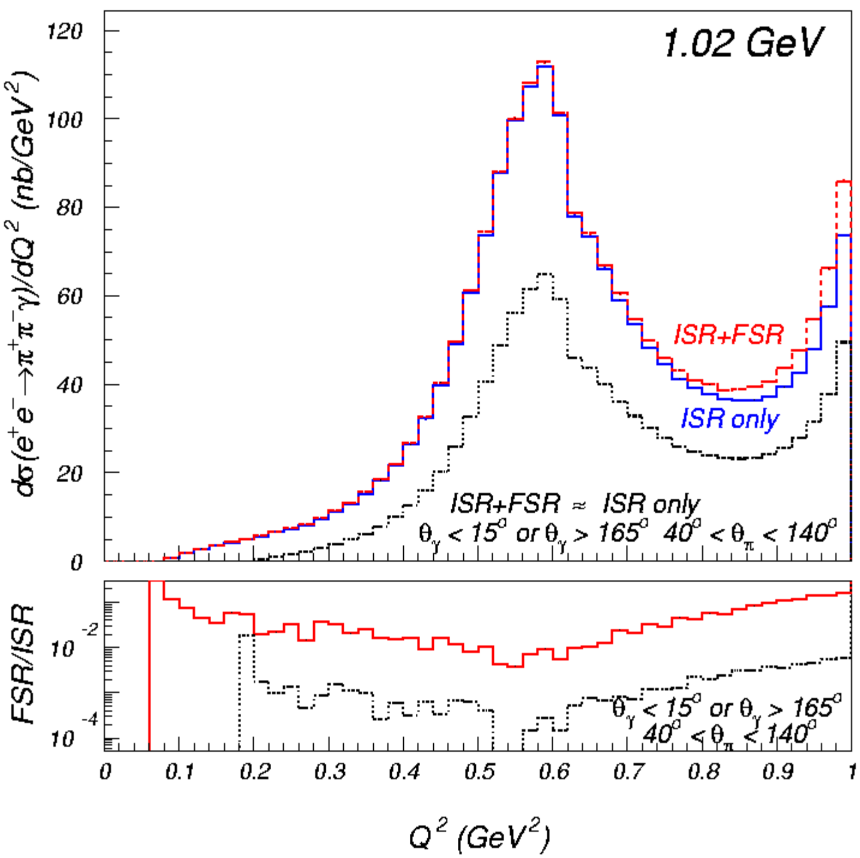
$a_\mu^{exp} - a_\mu^{SM}$ = 273 ± 83 (3.3 σ)

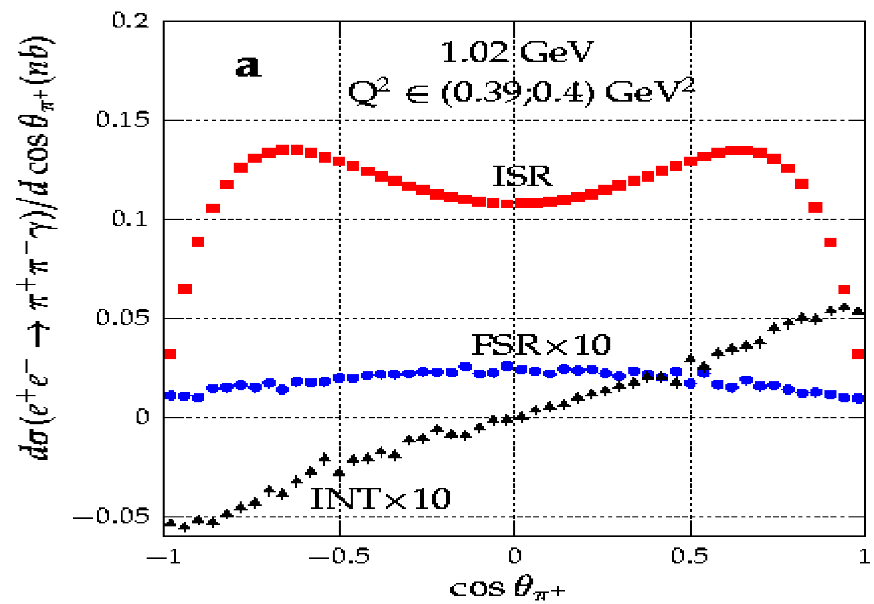
FSR



suppressed at **B-factories:**
very hard photons for low hadronic invariant masses

DAPHNE: ISR dominates for untagged photons (small angle), but suppress threshold tail tagged photons (large angle) FSR 10-20%





$$A_{FB}(Q^2)=\frac{N(\theta_{\pi^+}>\pi/2)-N(\theta_{\pi^+}<\pi/2)}{N(\theta_{\pi^+}>\pi/2)+N(\theta_{\pi^+}<\pi/2)}(Q^2)$$

$$A_C(\theta_\pi)=\frac{N(\pi^+)-N(\pi^-)}{N(\pi^+)+N(\pi^-)}(\theta_\pi)$$

radiative phi decays

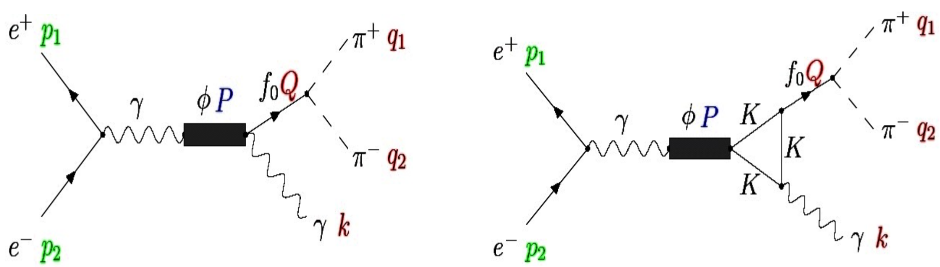
Czyż,Grzelinska,Kühn,PLB611(05)116, KLOE PLB634(05)148

$e^+e^- \to \phi \to \pi^+\pi^-\gamma$ pollutes the extraction of $\sigma(e^+e^- \to \pi^+\pi^-)$ close to the phi mass

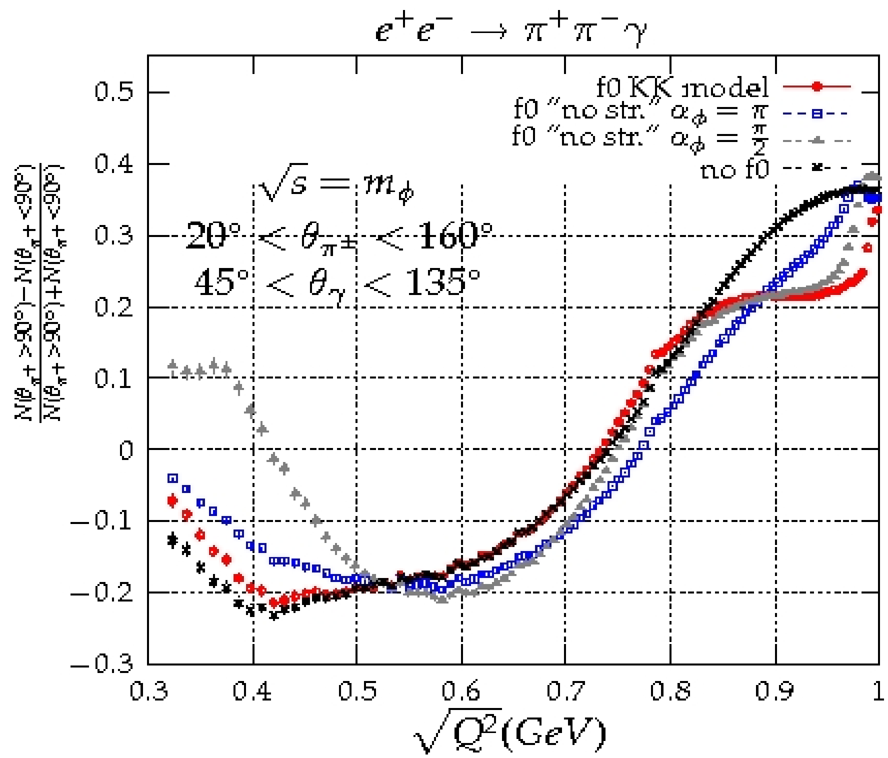
charge asymmetry allows to discriminate between different models of the radiative decay

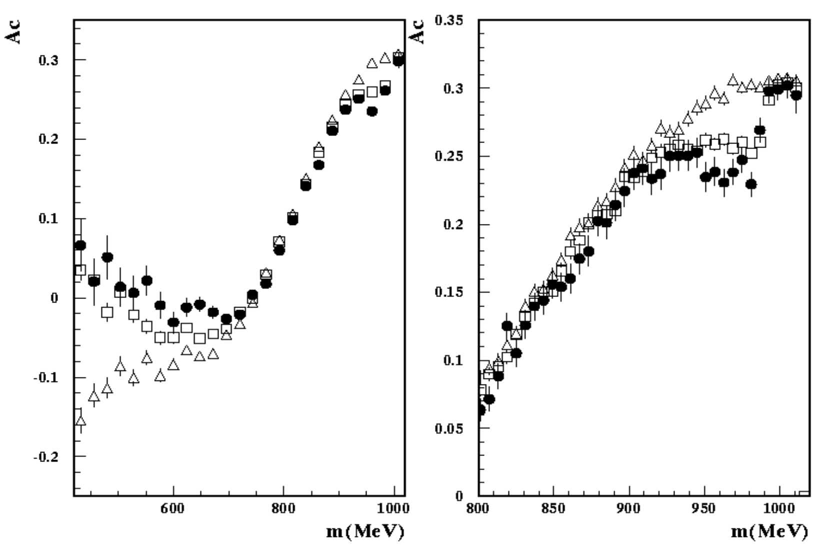
$$\phi \to \pi^+\pi^-\gamma,\ \pi^0\pi^0\gamma,$$

$$\phi \to (f_0(980)+f_0(600))\gamma \to \pi\pi\gamma$$

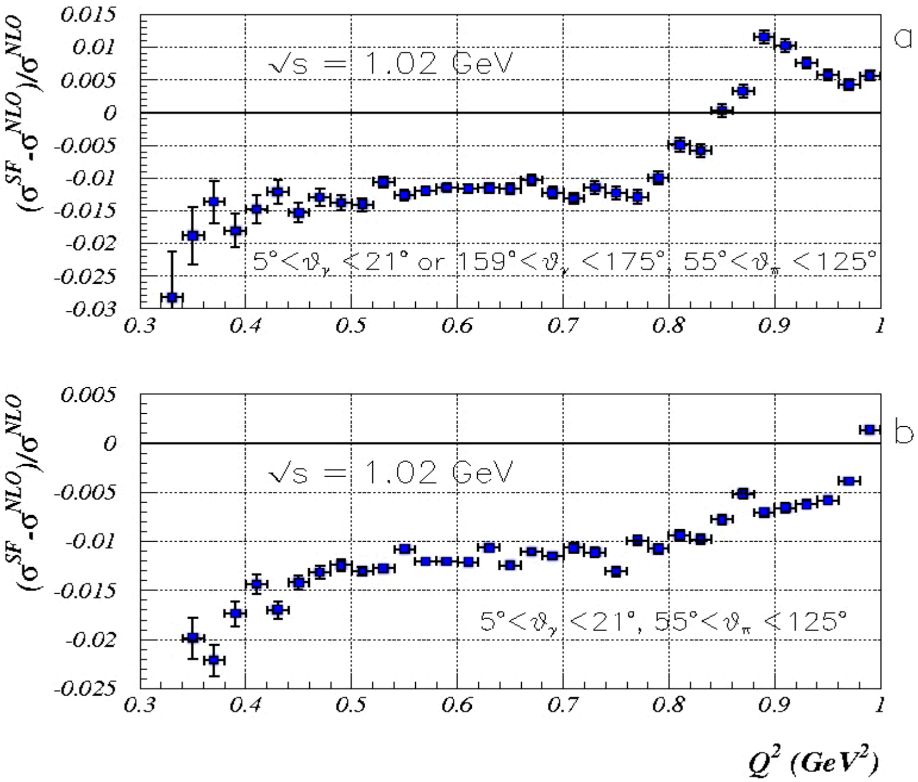


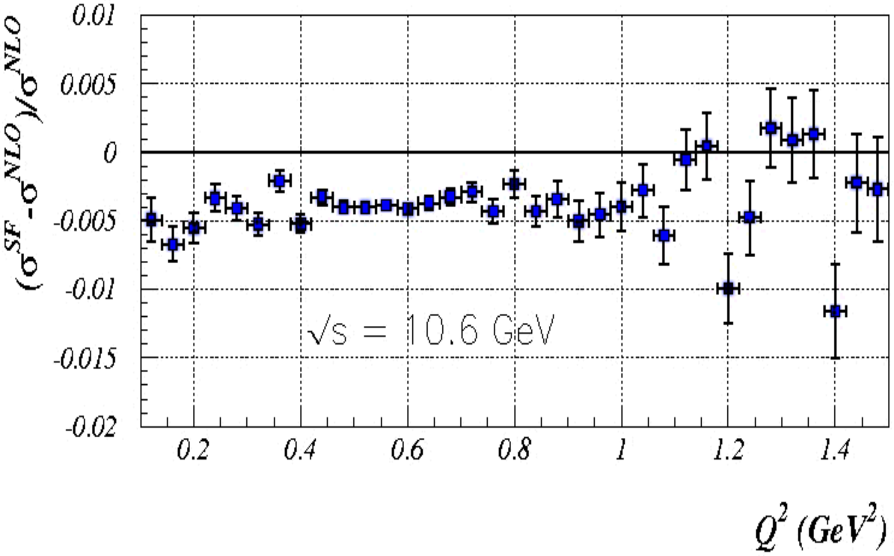
other contributions (beyond sQED + VMD + radiative phi decays) might be important in the threshold region [Pancheri,Shekhovtsova,Venanzoni]





NLO vs SF





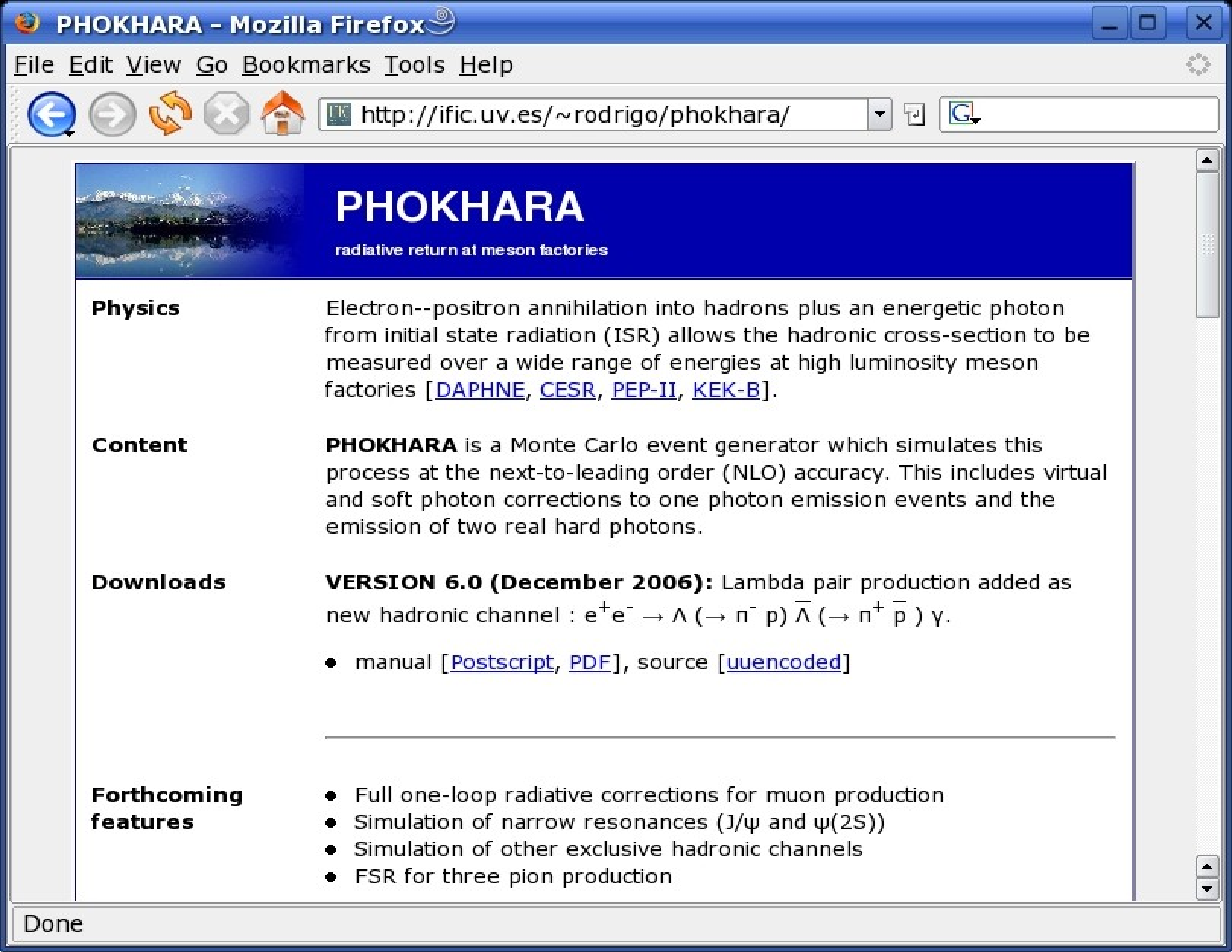
LL: EVA [Binner, Melnikov,Kühn]
EVA4π [Czyż,Kühn]

- resums big logs L=Log(s/m_e^2) to all orders
- Extra collinear emission integrated out: no momentum conservation
- Untagged photon: double counting

NLO: PHOKHARA

- LL+subleading terms (1%)
- Full angular dependence
- Momentum conservation
- Tagged or untagged photons
- ISR accuracy 0.5% (conservative)

(goal: 0.1-0.2% by adding LL two-loop)


PHOKHARA - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

http://ific.uv.es/~rodrigo/phokhara/

PHOKHARA

radiative return at meson factories

Physics	Electron--positron annihilation into hadrons plus an energetic photon from initial state radiation (ISR) allows the hadronic cross-section to be measured over a wide range of energies at high luminosity meson factories [DAPHNE, CESR, PEP-II, KEK-B].
Content	**PHOKHARA** is a Monte Carlo event generator which simulates this process at the next-to-leading order (NLO) accuracy. This includes virtual and soft photon corrections to one photon emission events and the emission of two real hard photons.
Downloads	**VERSION 6.0 (December 2006):** Lambda pair production added as new hadronic channel : $e^+e^- \to \Lambda\, (\to \pi^- p)\, \overline{\Lambda}\, (\to \pi^+ \overline{p})\, \gamma$. • manual [Postscript, PDF], source [uuencoded]
Forthcoming features	• Full one-loop radiative corrections for muon production • Simulation of narrow resonances (J/ψ and $\psi(2S)$) • Simulation of other exclusive hadronic channels • FSR for three pion production

Done

PHOKHARA 6.0 (December 2006)

Fixed order radiative corrections: NLO accuracy

Hadronic channels

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

$$\mu^+\mu^-$$

$$2\pi^0\pi^+\pi^-, 2\pi^+2\pi^-$$

$$p\bar{p}, n\bar{n}$$

$$\pi^0\pi^+\pi^-, K^+K^-, K^0\bar{K}^0$$

$$\Lambda(\to\pi^- p)\bar{\Lambda}(\to\pi^+\bar{p})$$

+ *radiative phi decays*

background and normalization

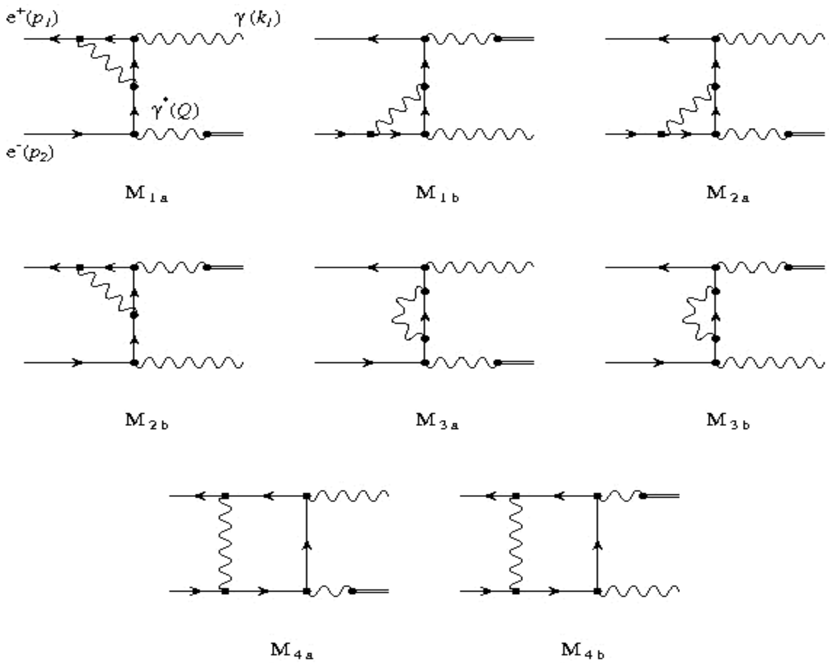
Pauli and Dirac Form Factors

new channels

Tagged or untagged photons

Modular structure:
easy replacement of hadronic form factors

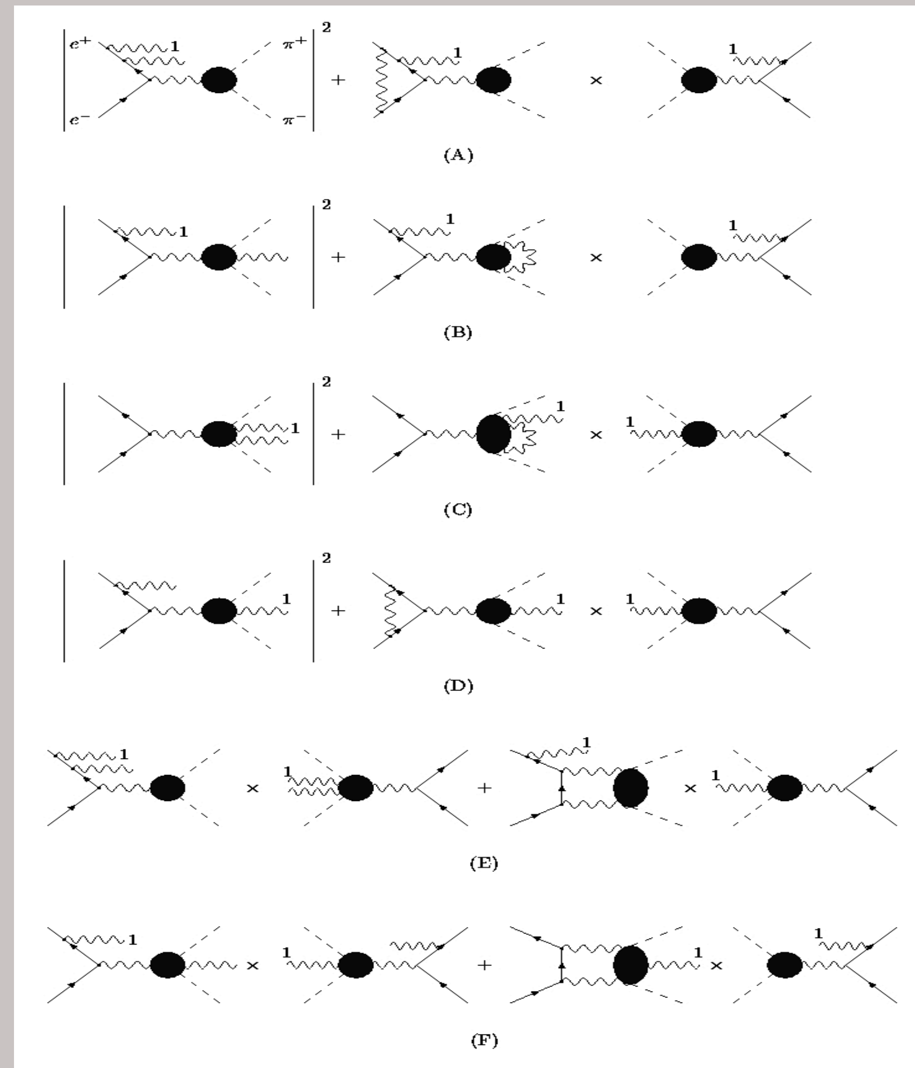
NLO



ISR virtual+soft corrections to $e^+e^- \rightarrow$ hadrons + γ factorizable

$$\sigma = \int L_{ISR}^{\mu\nu} H_{\mu\nu}$$

independent of the hadronic channel

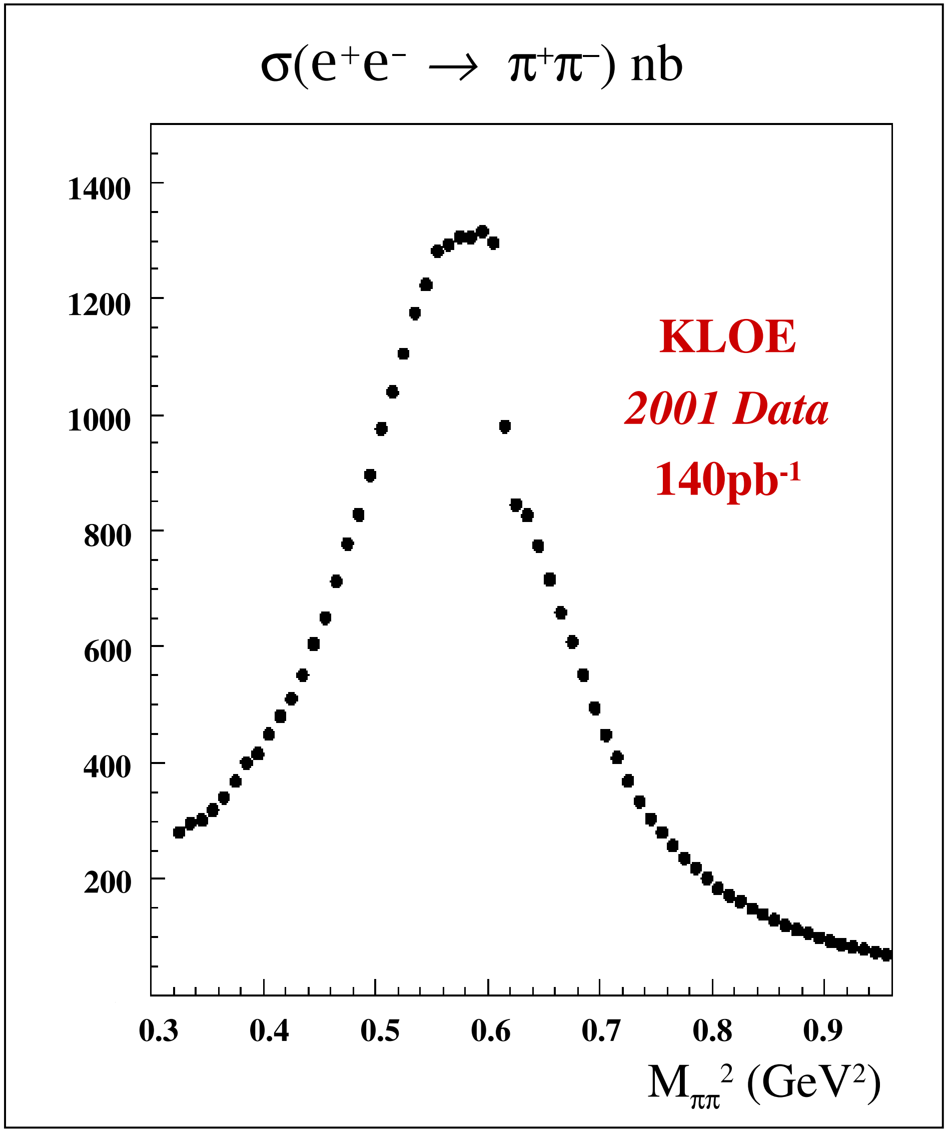


FSR @ NLO dominated by simultaneous emission of one photon from FSR and another one from ISR (+ virtual corrections)

PHOKHARA includes at present gauge invariant sets of *amplitudes* which lead to infrared-finite charge-even combinations for $\pi^+\pi^-$, ***KK*** and $\mu^+\mu^-$

pion form factor

Phys. Lett. B606 (2005) 12



Statistical error negligible (1.5 Million events)
total systematic error 1.3%

ongoing analysis at large and small
photon angles with systematics below 1%

nucleon form factors

Dirac (F_1) and Pauli (F_2) form factors

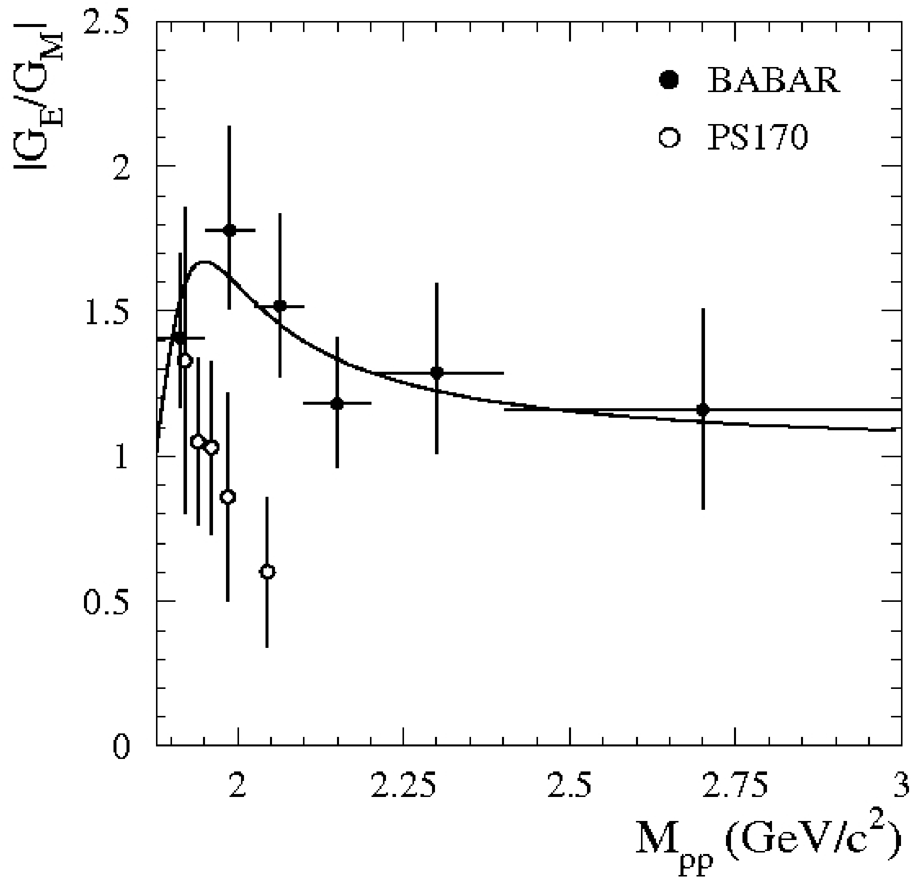
$$J_\mu = -ie\,\bar{u}(q_2)\left(F_1^N(Q^2)\gamma_\mu - \frac{F_2^N(Q^2)}{4m_N}[\gamma_\mu, Q]\right)v(q_1)$$

Electric and magnetic Sachs FF

$$G_M^N = F_1^N + F_2^N \quad , \qquad G_E^N = F_1^N + \frac{Q^2}{4m_N^2} F_2$$

at threshold $|G_M|=|G_E|$

disagreement in the space-like region on the ratio G_E/G_M between Rosenbluth and recoil polarization methods

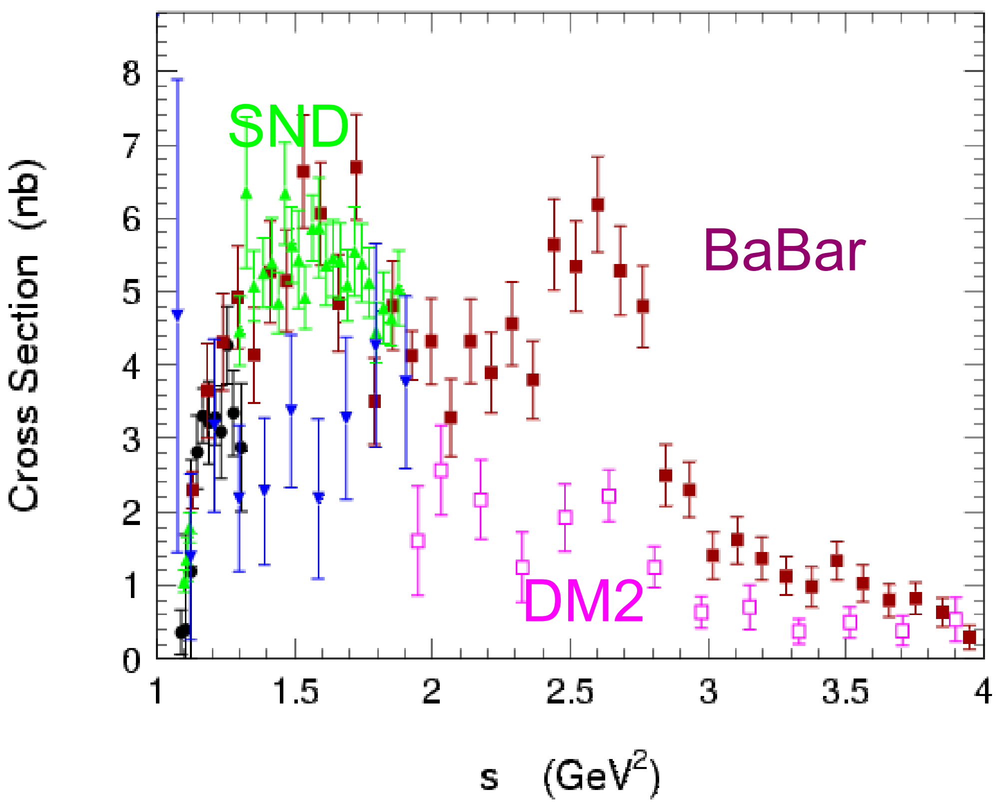


radiative return in the **time-like** region

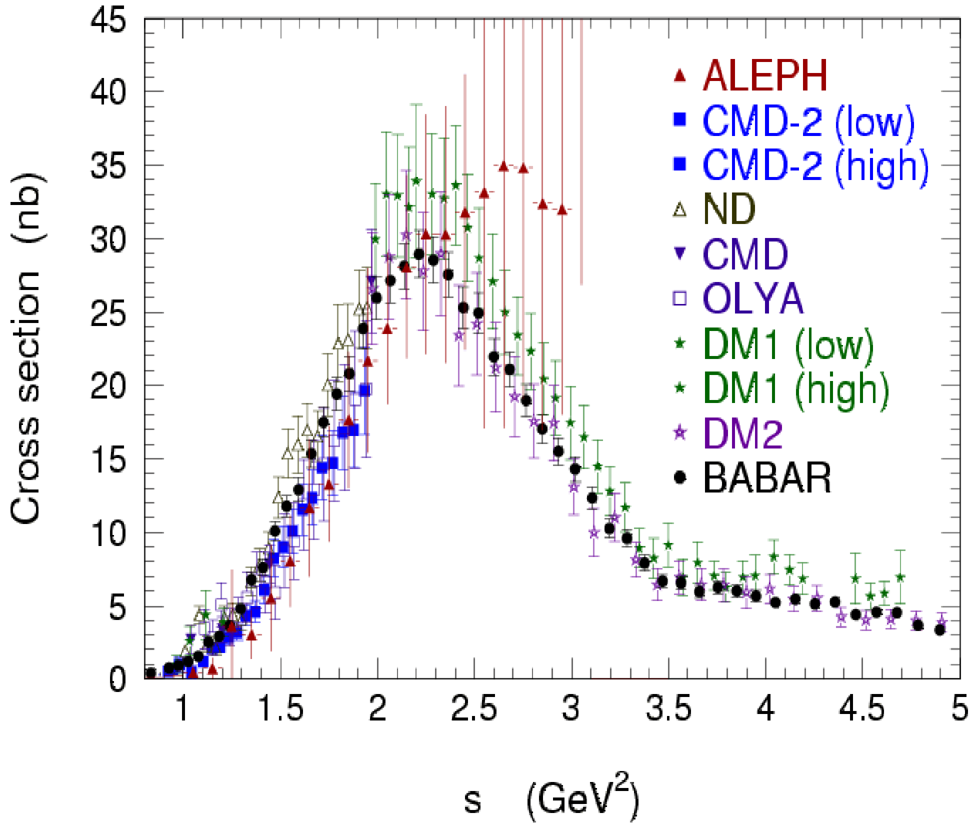
[Czyż,Kühn,Nowak,GR EPJC35(04)527]

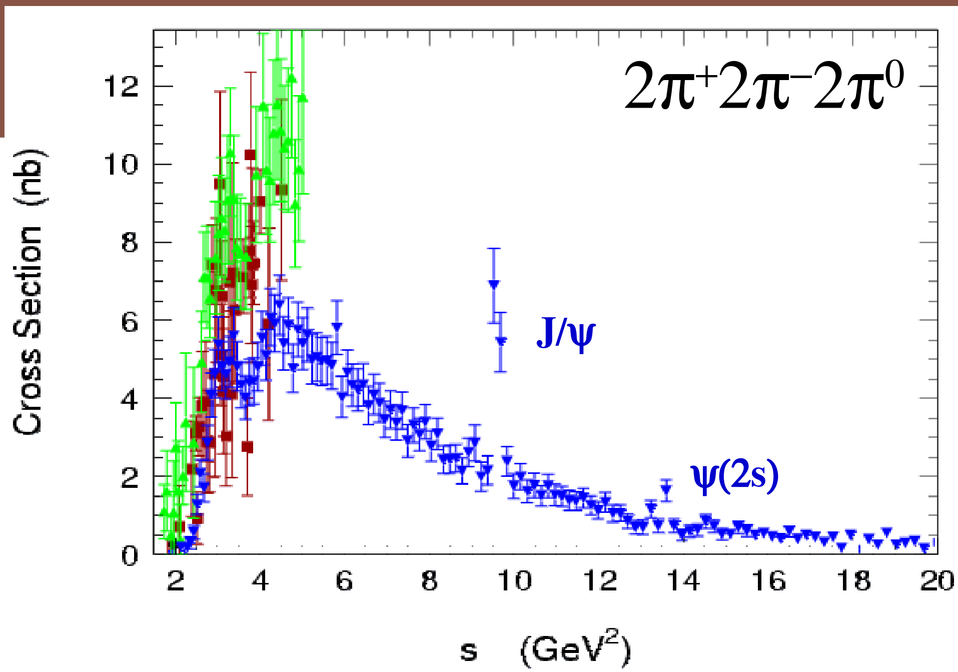
relative fase between G_E and G_M requires access to Nucleon spin

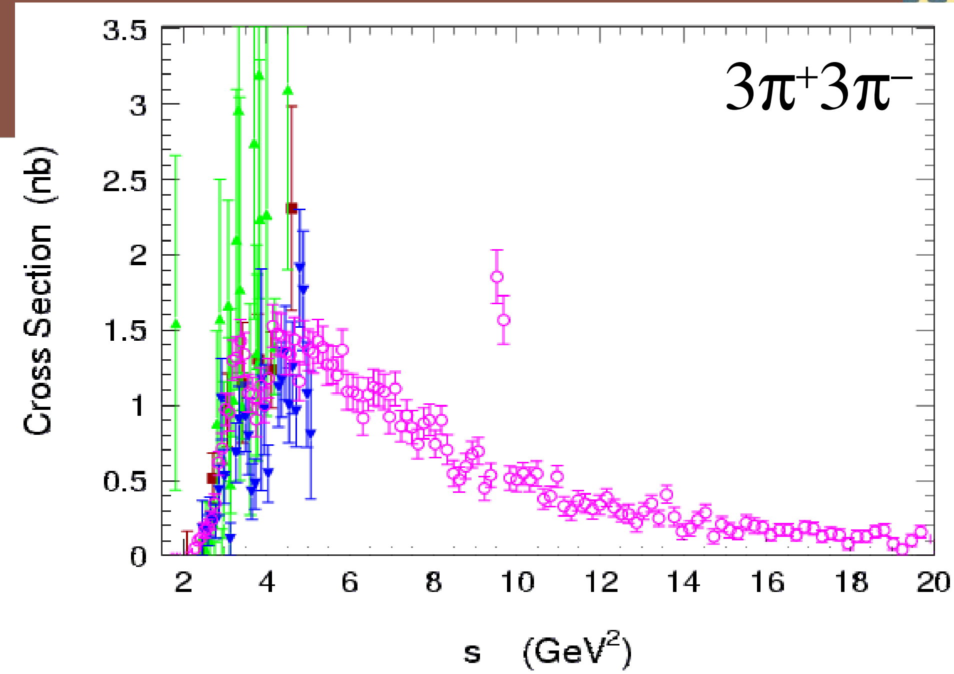
$\pi^+\pi^-\pi^0$

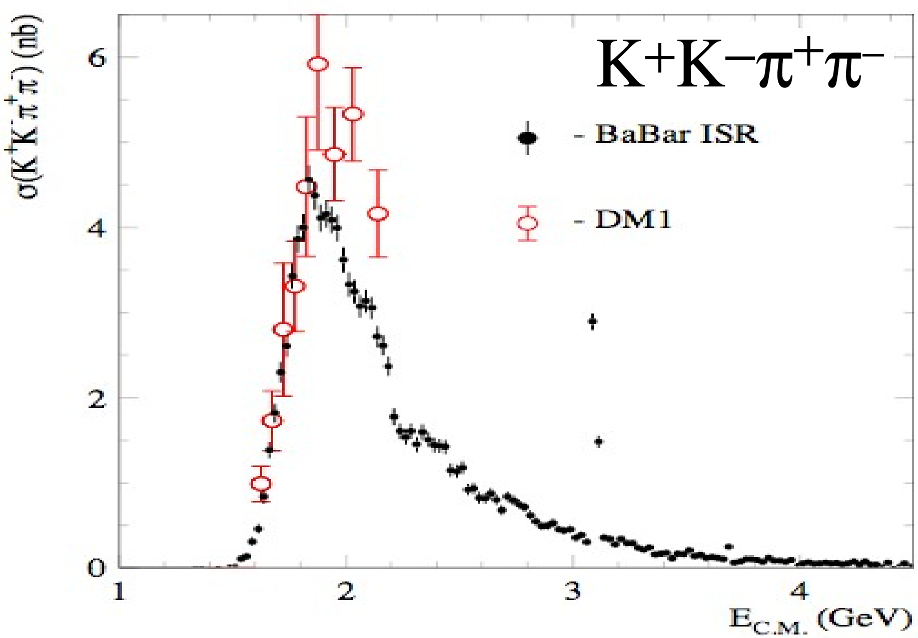


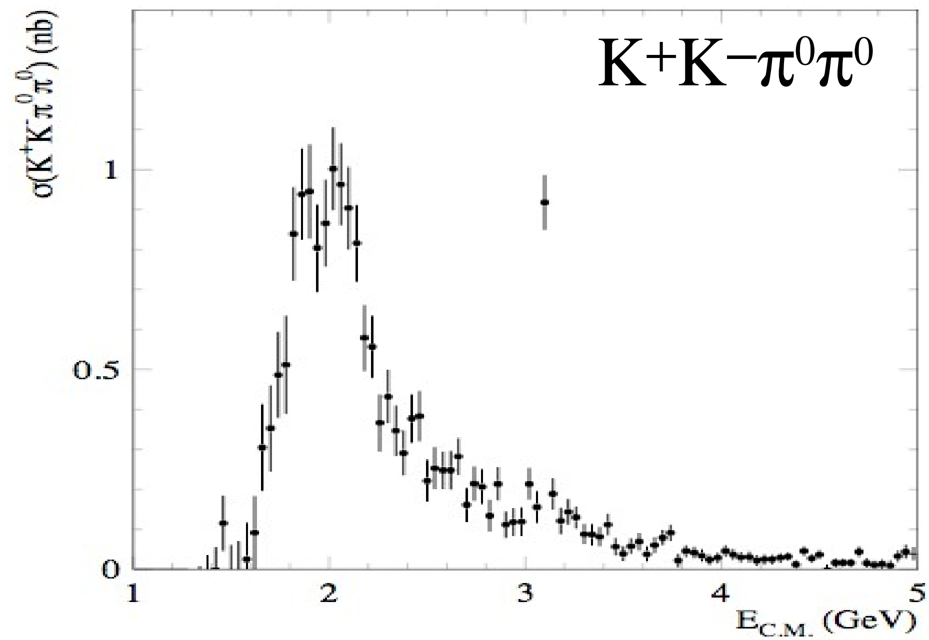
$2\pi^+2\pi^-$









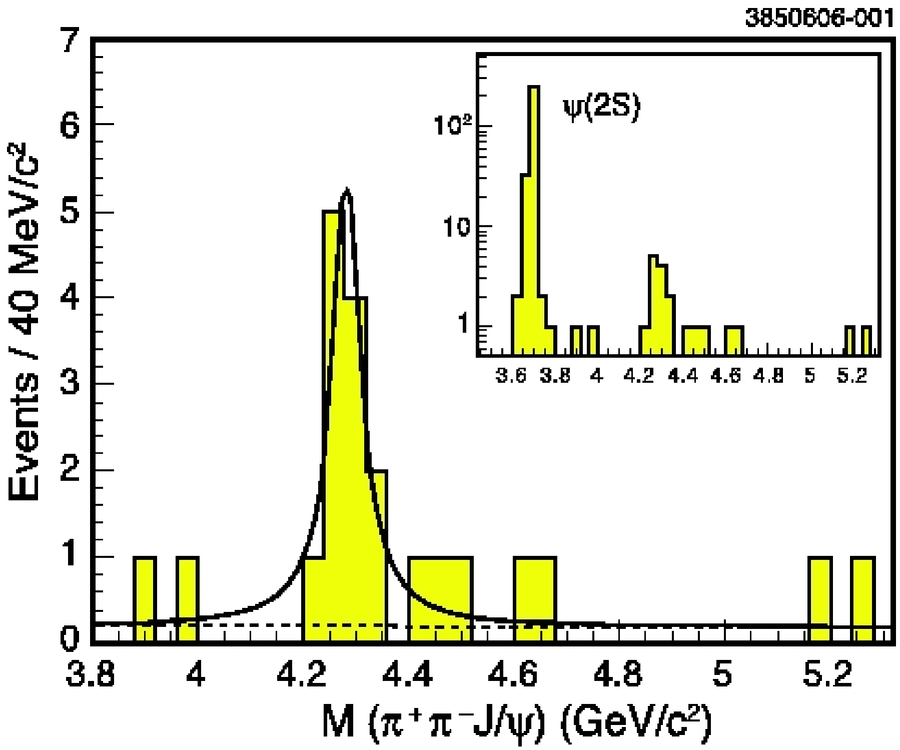


errors are statistical only

systematic errors 5-15% (25% for $K^+K^-K^+K^-$)

Y(4260) resonance

CLEO PRD74(2006)091104



$$M_{Y(4260)} = 4284^{+17}_{-16}(stat) \pm 4(syst) \quad MeV$$
$$\Gamma_{Y(4260)} = 73^{+39}_{-25}(stat) \pm 5(syst) \quad MeV$$

New vector resonance with $J^{PC}=1^{--}$

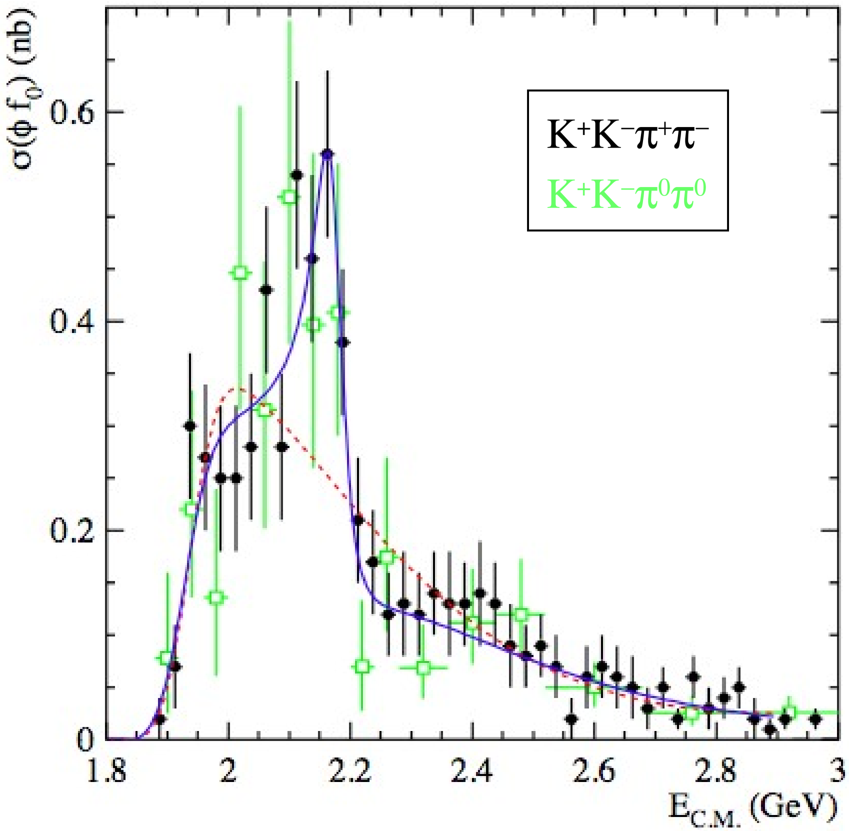
First reported by BaBar PRL95(2005)142001

$$M_{Y(4260)} = 4259 \pm 8(stat)^{+2}_{-6}(syst) \quad MeV$$
$$\Gamma_{Y(4260)} = 88 \pm 23(stat)^{+6}_{-4}(syst) \quad MeV$$

no evidence in *e+e-*→*pp*γ
BaBar PRD73(2006)012005

Theoretically challenging (not predicted by theoretical calculations of charmonium spectra)

A structure at 2175 MeV in $e^+e^- \to \Phi\ f_0(980)$



BaBar PRD74(2006)091103

another vector resonance with $J^{PC}=1^{--}$

$$M_X = 2175 \pm 10 \pm 15 \quad MeV$$

$$\Gamma_X = 58 \pm 16 \pm 20 \quad MeV$$

No Y(4260) signal

Summary

- **radiative return:** not only hadronic cross-section and $(g-2)_\mu$ but also valuable information on hadronic physics
- **statistics** is not an issue at flavour factories (Super B) but **systematics**
- Many exclusive channels at **B-factories at 5-15% accuracy and new resonances**
- for measurements aimed at **few %**
  NLO event generators (PHOKHARA) are mandatory
  J/Ψ and Ψ(2S) simulations coming soon