Initial State Radiation: A success story

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My message is short:

*Initial State Radiation (ISR)* and the subsequent *Radiative return* have become an impressively successful, powerful and guiding tool in low and intermediate energy hadron physics (competitive with and independent on an energy scan):

- to measure *hadronic cross sections* and the ratio $R$ from the reaction threshold up to the maximum centre of mass energy of fixed energy colliders
- to clarify *reaction mechanisms* and reveal *substructures* (intermediate states)
- to detect totally *new highly excited states* with $J^{PC} = 1^{--}$
- to improve knowledge on the *structure* and *decay mechanisms* of those states

To add a personal remark:
While being discussed since the sixties-seventies *ISR* became a powerful tool for the analysis of experiments in low and intermediate energy hadron physics only with the development of *EVA-PHOKHARA*, a series of codes which are user friendly, flexible and easily to implement into the software of the existing detectors.
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3. Summary and outlook
1. Initial State Radiation (Radiative return): The idea

Run at fixed energy \( \sqrt{s} \) and exploit the process \( e^+ e^- \rightarrow \text{hadrons} + n \gamma \) with the \( \gamma \) emitted in the initial state (ISR) to reduce the centre of mass energies of the colliding \( e^+ e^- \) and consequently the energy of the hadronic final state.

Measurement of hadronic cross sections or \( R(s) \) over the full range of energies, from threshold up to \( \sqrt{s} \) with systematic errors different of those from an energy scan (e.g. no point to point errors on beam energy and luminosity).

Particularly suited for modern meson factories. The large luminosities compensate for \( \alpha / \pi \) suppression of the emission of photons

\[
2m^2_\pi < M^2_{\text{hadr}} < s
\]

\[
M^2_{\text{hadr}} = s - 2\sqrt{s} \ E_{\gamma}
\]
Radiative return to $\rho$, $\omega$, $\phi$, ... (energies below $3\,\text{GeV}$)
Radiative return to $J/\psi, \psi(2S), \ldots$ (energies between 3 and 5 GeV)
Building $R$ from the sum over exclusive final states (*Monte Carlo*) (most have been studied).
The hadronic cross section, resp. ratio $R$

($\text{DAΦNE, VEPP, CESR, BES, PEP-II, KEK-, LEP-2}$)

studies of the energy region below $\sim 4\ldots5$ GeV by Radiative return

**KLOE:** energies $< 1$ GeV, dominated by $2\pi$-channel ($\rho, \omega$-resonances)

**BaBar, Belle:** energy region $1 \ldots 4.5$ GeV (studies of higher multiplicities $4\pi$,\ldots restricted by hard photon emission)
2. History and success of Initial State Radiation

2.1. The pre-

2. PHOKHARA era

Early literature (selection):

Photon emission in muon pair production in electron-positron collisions
\((e^+ e^- \rightarrow \mu^+ \mu^- \gamma, \sigma_{tot}, ISR, FSR, \text{interference})\)
V. N. Baier, V. A. Khoze, ZhETF 48 (1965) 946, Yad. Fiz. 2 (1965) 287

Radiation accompanying two particle annihilation of an electron - positron pair
(scalar final states \(e^+ e^- \rightarrow \pi^+ \pi^- \gamma, \sigma_{tot}, ISR, FSR, \text{interference, formfactors}\)
V. N. Baier, V. A. Khoze, Sov. Phys. JETP 21 (1965) 629, 1145
[Zh. Eksp. Theor. Fiz. 48 (1965) 946]

Infra-red radiative corrections for resonant processes \((\rho, \omega, \phi \text{ intermediate states})\)

Radiative Corrections for Colliding Beam Resonances
(application to \(\psi(3.1), \psi'(3.7) \text{ intermediate states}\)

Secondary Reactions in electron - positron (electron) Collisions
(pion form factor)
M. S. Chen, P. M. Zerwas, Phys. Rev. D 11 (1975) 58
**HERA:**  *ISR* events used to measure the structure function $F_2(x, Q^2)$
(to reach lower $Q^2$ values and correspondingly lower $x$ values)

**LEP 2:** measurements of energies between 189 and 209 GeV:
Radiative return to the region of the $Z$-resonance with an impressive enhancement

** Literature (theory)  

**ZFITTER:** semi-analytical code
D. Bardin et al., Z. Phys. **C 44** (1989) 493
D. Bardin et al., Nucl. Phys. **B 351** (1991) 1

**KK2f:** Photon radiation modeled using Coherent Exclusive Exponentiation (CEEX)
and complete $O(\alpha^2)$ matrix elements for *ISR*
**OPAL** collaboration:
OPAL Physics Note PN 467, Nov. 2000
hep-ex/0309053v1, August 2003

**ALEPH** collaboration:
hep-ex/0609051v1, September 2006

**DELPHI** collaboration:
hep-ex/0512012

**L3** collaboration:
hep-ex/0603022

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**Figure 10:** Measured total cross-sections ($\sigma'/s > 0.01$) for hadronic events at lower energies [2, 3, 39] and this analysis. Cross-section measurements for $\sigma'/s > 0.7225$ from this analysis and from [2, 3] are also shown; the values at 161 GeV and 172 GeV have been corrected from $\sigma'/s > 0.6$ to $\sigma'/s > 0.7225$ by adding the prediction of ZFITTER for the difference before plotting. The curves show the predictions of ZFITTER. The insets show the percentage differences between the measured values and the ZFITTER predictions for the high energy points. The error bars on the differences represent statistical errors only; the size of the experimental systematic error is indicated by the shaded band.
Application to low and intermediate energies (to determine hadronic cross sections): 
(KLOE-DAΦNE)

Radiative corrections for pion and kaon production of $e^+ e^-$ colliders of energies below 2 GeV

Hadronic Cross Sections in Electron-Positron Annihilation with Tagged Photon

Detection of hard photons (pion form factor)
The hadronic contribution to the muon $g-2$ from $e^+ e^-$ annihilation at $\sqrt{s} < m_\phi$ with the DAFNE Collider, KLOE memo #139, march 1998;

Measuring $\sigma (e^+ e^- \rightarrow \text{hadrons})$ using tagged photon
S. Binner, H. Kühn, K. Melnikov

Detection of charged particles (pions) by the drift chamber
(excellent energy resolution, application of EVA)
G. Cataldi, A. Denig, W. K., G. Venanzoni, KLOE memo #195, August 1999,

Bottomonium $\Upsilon(ns)$ spectroscopy at $B$- Factories via hard photon emission
M. Benayoun, S. I. Eidelman, V. N. Ivanchenko, Z. K. Silagadze

Born cross-section and electromagnetic corrections
V. A. Khoze, M. I. Konchatnij, N. P. Merenkov, G. Pancheri, L. Trentadue, O. N. Shekhovzova,
2.2. A new era (since one decennium): **EVA-PHOKHARA**

**MONTE CARLO** Generators **EVA, PHOKHARA, FEVA, EKHARA:** → talk of H. Czyż

measurement of hadronic cross sections by Radiative Return
to determine the hadronic contribution to the muon magnetic anomaly

Collaboration **ITT Karlsruhe, US Kattowice, IFIC Valencia**
(J. H. Kühn, H. Czyż, A. Grzelińska, G. Rodrigo et al.)

- developed during the last 10 years to meet the needs of the experimenters at the high luminosity meson factories **DAFNE (KLOE), CESR (CLEO), PEP-II (BaBar), KEK-B (Belle)** etc.

- implementation in Monte Carlo simulations of the detectors, **for the first time realized with KLOE**

- **ISR, FSR,** and their interference
- increasing complexity due to **NLO** contributions in the initial and final states
- modular structure to implement more and more final states
Radiative return: *PHOKHARA* for the first time applied at **DAΦNE (KLOE):**

radiative return to ρ, ω:
\[ e^+ e^- \rightarrow \gamma^* \gamma \rightarrow q \bar{q} \gamma \rightarrow \rho (\omega) \gamma \rightarrow \pi^+ \pi^- \gamma \]

\[
M^2_{\pi\pi} \frac{d\sigma_{\pi\pi\gamma}}{dM^2_{\pi\pi}} = \sigma_{\pi\pi}(s) \times H(s)
\]

\[
\sigma_{\pi\pi}
\]

non-radiative cross section

\[
\rho, \omega \text{ resonances}
\]

\[
\sigma_{\pi\pi}(s) \times H(s)
\]

courtesy A. Denig
2.2.1. The hadronic contribution to the anomalous magnetic moment of the muon, running $\alpha_{QED}(M_Z)$, cross sections $e^+ e^- \rightarrow \gamma^* \rightarrow q \bar{q} \rightarrow \text{hadrons}$

Measurement of $\sigma(e^+ e^- \rightarrow \text{hadrons} \gamma)$ to determine $\sigma(e^+ e^- \rightarrow \text{hadrons})$ and $a_{\mu}^{\text{had}}$ by applying PHOKHARA, ‘Radiative return’ to resonances with $J^{PC}=1--$

Important motivation:

Determination of the *hadronic vacuum polarisation* $\gamma^* \rightarrow q \bar{q} \rightarrow \gamma^*$, a contribution to precision tests of the *SM* of particle physics

a) Precision experiment $(g-2)_\mu$ *(Brookhaven E821)*

b) Running fine structure constant $\alpha_{QED}(M_Z)$
   - constrains Higgs mass $m_{\text{Higgs}}$
   - effective Weinberg angle etc.

→ major topic of this conference

Constraining the *Higgs* boson

Figure elaborated artistically to become an element of the conference poster by Claudio Federici LNF
Anomalous magnetic moment of the muon

\[ a_\mu = (g_\mu - 2) / 2 = \alpha / 2\pi + \ldots \]
\[ a_\mu^{\text{theor}} = a_\mu^{\text{QED}} + a_\mu^{\text{had}} + a_\mu^{\text{weak}} + a_\mu^{\text{new}} \]

- QED
- weak contribution
- hadronic vacuum polarisation
- contribution beyond SM
Figure elaborated artistically to become an element of the conference poster by Claudio Federici LNF

$\alpha_{\mu}^{QED}$

$\rightarrow$ talk of E. Remiddi
Hadronic vacuum polarisation

- The hadronic contribution to vacuum polarisation is dominated by low energy effects which cannot be obtained by perturbative QCD but rather by experimental data of $e^+ e^- \text{ annihilation into hadrons}$ and / or by $\tau-$decays evaluating the dispersion integral

\[
ad_{\mu}^{\text{had}} = \left( \frac{\alpha m_\mu}{3 \pi} \right)^2 \int_{4 m_\pi^2}^{\infty} ds \frac{R(s) \tilde{K}(s)}{s^2}
\]

\[
R(s) = \frac{\sigma_{\text{tot}}(e^+ e^- \rightarrow \gamma^* \rightarrow q \bar{q} \rightarrow \text{hadrons})}{\sigma_{\text{tot}}(e^+ e^- \rightarrow \gamma^* \rightarrow \mu^+ \mu^-)}
\]

up to some sufficiently high energies, typically 2...5 GeV
2.2.2. **KLOE-ISR at DAΦNE**

Determination of $\sigma(e^+ e^- \rightarrow \pi^+ \pi^-)$ by emission of photons in the initial state $\sigma(e^+ e^- \rightarrow \pi^+ \pi^- \gamma)$ and by applying PHOKHARA, ‘radiative return’ to the resonances $\rho$, $\omega$

to determine the hadronic contribution to the muon magnetic anomaly $a_{\mu}^{\text{had}}$
below 1 GeV two analyses have been carried out:

**Small photon angle analysis:**
No photon detection, only detection of two charged pions

$$\theta_{\Sigma(\gamma)} < 15^\circ \ (> 165^\circ), \ 50^\circ < \theta_\pi < 130^\circ, \ E_\Sigma > 10 \text{ MeV}$$

$\rightarrow$ talk of F. Nguyen

**Large photon angle analysis:**
Photon detection (tagging) and detection of two charged pions

at least one photon with $50^\circ < \theta_\gamma < 130^\circ$ and $E_\gamma > 50 \text{ MeV}, \ 50^\circ < \theta_\pi < 130^\circ$
Figure elaborated artistically to become an element of the conference poster by Claudio Federici LNF.
**KLOE-ISR** small photon angle analysis:

KLOE-ISR small photon angle analysis:

**KLOE-ISR** small photon angle analysis:


**KLOE-ISR** small photon angle analysis:

- high statistics
- high resolution

Low $M_{\pi\pi}^2$ kinematically suppressed $M_{\pi\pi}^2 [GeV^2]$

2001 (updated): $\mathcal{L} = 140 \text{ pb}^{-1}$

2002: $\mathcal{L} = 240 \text{ pb}^{-1}$

→ talk of F. Nguyen
**KLOE-ISR** large photon angle analysis: \( \mathcal{L} = 240 \text{ pb}^{-1} \)

- **2002 data (small angles)**
- **2002 data (large angles)**

Grey error band: statistical and systematic errors, the latter dominated by the contribution of \( f_0 \)

\[ e^+ e^- \rightarrow \phi \rightarrow f_0 \gamma \rightarrow \pi^+ \pi^- \gamma \]
Results for $a_{\mu}^{\pi\pi}$:

published results (small angle analysis):
$$a_{\mu}^{\pi\pi} \ (0.35-0.95 \text{ GeV}^2) = (388.7 \pm 0.8_{\text{stat}} \pm 4.9_{\text{syst}}) \cdot 10^{-10}$$

updated for trigger efficiency and revised Bhabha cross section* (small angles):
$$a_{\mu}^{\pi\pi} \ (0.35-0.95 \text{ GeV}^2) = (384.4 \pm 0.8_{\text{stat}} \pm 4.9_{\text{syst}}) \cdot 10^{-10}$$

this conference (small angles):
$$a_{\mu}^{\pi\pi} \ (0.35-0.95 \text{ GeV}^2) = (389.2 \pm 0.8_{\text{stat}} \pm 3.0_{\text{syst}} \pm 3.5_{\text{th}}) \cdot 10^{-10}$$


EPS Manchester 2007 (small angles)
$$a_{\mu}^{\pi\pi} \ (0.50-0.85 \text{ GeV}^2) = (255.4 \pm 0.4_{\text{stat}} \pm 2.5_{\text{syst}}) \cdot 10^{-10}$$

preliminary analysis of 2002 data (large angle analysis):
$$a_{\mu}^{\pi\pi} \ (0.50-0.85 \text{ GeV}^2) = (252.5 \pm 0.6_{\text{stat}} \pm 2.0_{\text{syst}} \pm 3.1_{\text{syst, fo}}) \cdot 10^{-10}$$

in agreement with results from energy scan (CMD-2 and SND)
Hadronic contribution to the vacuum polarisation

Figure elaborated artistically to become an element of the conference poster by Claudio Federici LNF
2.2.3. *BaBAR-ISR, Belle-ISR*: Determination of $\sigma (e^+ e^- \rightarrow \text{hadrons})$ emission of photons in the initial state $e^+ e^- \rightarrow \text{hadrons} \gamma$, ‘radiative return’ to $\rho, \omega, \phi, \ldots, J/\psi, \ldots$

*PEP-II*
Study of $e^+ e^-$ collisions in the 1.5 - 3 GeV c.m. energy region using ISR at BaBar

E. P. Solodov, SLAC, April 2001 hep-ex/0107027

\[ e^+ e^- \rightarrow \mu^+ \mu^- \gamma, \pi^+ \pi^- \gamma, K^+ K^- \gamma, 3\pi \gamma, 4\pi \gamma, 5\pi \gamma, 6\pi \gamma, 7\pi \gamma, \text{ etc.} \]

\[ e^+ e^- \rightarrow J/\psi \gamma \rightarrow \mu^+ \mu^- \gamma \]

final hadronic states < 4.5 GeV:

\[ e^+ e^- \rightarrow \pi^+ \pi^- \pi^0 \gamma \]  \hspace{1cm} \text{Phys. Rev. D 69 (2004) 011103}

\[ e^+ e^- \rightarrow \pi^+ \pi^- \pi^+ \pi^- \gamma, \pi^+ \pi^- K^+ K^- \gamma, K^+ K^- K^+ K^- \gamma \]  \hspace{1cm} \text{Phys. Rev. D 70 (2004) 072004}

\[ e^+ e^- \rightarrow \pi^+ \pi^- \pi^+ \pi^- \pi^+ \pi^- \gamma, \pi^+ \pi^- \pi^0 \pi^+ \pi^- \pi^0 \gamma, \pi^+ \pi^- \pi^+ \pi^- \pi^+ \pi^- K^+ K^- \gamma \]  \hspace{1cm} \text{Phys. Rev. D 71 (2005) 052001}

\[ e^+ e^- \rightarrow \phi f_0(980) \gamma \]  \hspace{1cm} \text{Phys. Rev. D 73 (2006) 052003}

\[ e^+ e^- \rightarrow J/\psi \pi^+ \pi^- \gamma, J/\psi K^+ K^- \gamma, J/\psi \gamma \gamma \gamma \] (search for $c\bar{c}$ states)  \hspace{1cm} hep-ex/0608004v1

→ talk of A. Denig
More final hadronic states $< 4.5$ GeV:

\[ e^+ e^- \rightarrow \pi^+ \pi^- K^+ K^- \gamma, \pi^o \pi^o K^+ K^- \gamma, K^+ K^- K^+ K^- \gamma \]

\[ e^+ e^- \rightarrow \pi^+ \pi^- \pi^+ \pi^- \pi^0 \gamma, \pi^+ \pi^- \pi^+ \pi^- \eta \gamma, \pi^+ \pi^- \pi^o K^+ K^- \gamma, \pi^+ \pi^- \eta K^+ K^- \gamma \]

\[ e^+ e^- \rightarrow \Lambda \bar{\Lambda} \gamma, \Lambda \bar{\Sigma}^o \gamma, \Sigma^o \bar{\Sigma}^o \pi^o \gamma \]

\[ e^+ e^- \rightarrow D \bar{D} \gamma \]

\[ e^+ e^- \rightarrow \pi^- K^+ K_S \gamma, \pi^o K^- K^+ \gamma, \eta K^+ K^- \gamma \]

\[ e^+ e^- \rightarrow p \bar{p} \gamma \]

\[ e^+ e^- \rightarrow \pi^+ \pi^- \pi^0 \pi^o \gamma, \pi^+ \pi^+ \pi^- \pi^- \pi^0 \gamma \]

\[ e^+ e^- \rightarrow \pi^+ \pi^- \gamma, K^+ K^- \gamma, \pi^+ \pi^- \pi^o \pi^o \pi^o \gamma \]

\[ \text{in preparation} \]

→ talk of A. Denig
**BaBar-ISRa**: $e^+ e^- \to \text{pions } \gamma$ (study of reaction mechanisms, identification of intermediate states)

- consistent with previous results
- best measurement for $E_{cm} < 0.75$ GeV
- competitive for $0.75 - 1.4$ GeV
- best for $1.4 - 2.0$ GeV
- only measurement for $E_{CM} > 2.0$ GeV

$J/\psi(1S)$

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

$\psi(2S)$ due to $\mu^\pm$ misidentified as $\pi^\pm$

$\sim 20 \% \pi^+ \pi^- \eta$, mostly $\rho^0 \eta$

$\sim 40 \% \pi^+ \pi^- \omega$, rest $\rho^0 \rho^\pm \pi^\mp$

**PHOKHARA**


BaBar-ISR: $e^+ e^- \rightarrow \text{pions} \gamma$ (study of reaction mechanisms, identification of intermediate states)

$$e^+ e^- \rightarrow \eta \left( \rho^0 \rightarrow \pi^+ \pi^- \right) \gamma$$
$$\omega \pi \pi \gamma$$
$$a_1(1260) \rho \gamma \text{ or } \pi(1300) \rho \gamma$$

\[
\left\{ \begin{array}{c}
\rightarrow \pi^+ \pi^- \pi^+ \pi^- \pi^0 \gamma \\
\end{array} \right. \]

\[\sigma(e^+ e^- \rightarrow \pi^+ \pi^- \eta \gamma)\]

\[\sigma(e^+ e^- \rightarrow \pi^+ \pi^- \eta \rho^o \gamma)\]

\[\sigma(e^+ e^- \rightarrow \pi^+ \pi^- \eta \pi^+ \pi^- \gamma)\]

\[\sigma(e^+ e^- \rightarrow \pi^+ \pi^- \omega \pi^+ \pi^- \gamma)\]

\[\sigma(e^+ e^- \rightarrow \pi^+ \pi^- \eta \pi^+ \pi^- \gamma)\]

\[\sigma(e^+ e^- \rightarrow \pi^+ \pi^- \omega \pi^+ \pi^- \gamma)\]

**BaBar-ISR**: $e^+ e^- \rightarrow pions \gamma$ (study of reaction mechanisms, identification of intermediate states)

$e^+ e^- \rightarrow \omega \pi^0 \gamma$

$\alpha_1(1260) \pi \gamma$

$\rho^+ \rho^- \gamma$

$\rho^0f_0(980)\gamma$

$\rightarrow \pi^+\pi^-\pi^0\pi^0\gamma$

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**PHOKHARA**

Competitive / best / first measurement for $E_{CM} < 1.4 / < 2.4 / > 2.4$ GeV
Summary *BaBar- ISR*

\[ E_{cm} \text{ [GeV]} \]

→ talk of A. Denig
Figure elaborated artistically to become an element of the conference poster by Claudio Federici LNF
Belle-ISR

Determination of $\sigma(e^+ e^- \rightarrow \text{hadrons})$ by emission of photons in the initial state $e^+ e^- \rightarrow \text{hadrons} \gamma$ and by applying PHOKHARA, ‘radiative return’ to $\rho, \omega, \phi, \ldots, J / \psi, \ldots$

\begin{align*}
e^+ e^- & \rightarrow J / \psi K^+ K^\gamma \\
e^+ e^- & \rightarrow D \bar{D} \gamma (D^+ D^- \gamma) (D^0 \bar{D}^0 \gamma) \\
e^+ e^- & \rightarrow \pi^+ \pi^- \psi(2S) \gamma \\
e^+ e^- & \rightarrow \pi^+ \pi^- J / \psi \gamma \\
e^+ e^- & \rightarrow D^{*\pm} \bar{D}^{*\mp} \gamma \\
e^+ e^- & \rightarrow D^0 D^- \pi^+ \gamma
\end{align*}

- Phys. Rev. D-RC, hep-ex/07092565
- hep-ex/07073699
- hep-ex/07072541

→ talk of G. Pakhlova
Belle-ISR

$e^+ e^- \rightarrow D^+ D^* - \gamma$

$\psi(4040)$

$e^+ e^- \rightarrow D^+ D^* - \gamma$

$M(D^{(*)}D^*)$ [GeV/$c^2$]

→ talk of G. Pakhlova

2.3. *PHOKHARA* and hadron spectroscopy

(search for new hadronic states)

2.3.1. *KLOE*

(structure studies of light scalar mesons $\sigma(500), f_0(980), a_0(980)$
by their decay into pairs of pseudoscalars)

example: $e^+ e^- \rightarrow f_0 \gamma \rightarrow \pi^+ \pi^- \gamma$

large irreducible backgrounds from *ISR, FSR* determined by *PHOKHARA*
$f_o(980) \rightarrow \pi^+ \pi^-$


$\pi^0 \pi^0 \gamma$: Phys. Lett. B 634 (2006) 148, hep-ex/0511031

2.3.2. **BaBar, Belle-ISR, CLEO-c:**

New neutral meson states with $J^{PC} = 1^{--}$

Charmonium spectroscopy $c\bar{c}$:
*first discovery with ISR by BaBar*

\[ e^+ e^- \rightarrow Y(4260) \gamma \rightarrow J/\psi \pi^+ \pi^- \gamma \]

\[ M = 4259.2 \pm 8 \text{ MeV} \]
\[ \Gamma = 88 \pm 8 \text{ MeV} \]

*Y(4050) Y(4260) Y(4360) Y(4660) …*

no $c\bar{c}$ assignment, probably not a glueball, because no decay into $\phi \pi^-\pi^+$, 4 quark $[cs][\bar{c}\bar{s}]$, hybrid meson, $\omega_{\chi_c}$ molecule?
Belle-ISR, CLEO-c: New neutral meson states with $J^{PC} = 1^{--}$

$e^+ e^- \to Y(4260) \gamma \to J/\psi \pi^+ \pi^- \gamma$

$M = 4295 \pm 15 \text{ MeV}$  
$\Gamma = 133 \pm 30 \text{ MeV}$

CLEO-c scan around 4.26 GeV, no ISR

$M = 4284 \pm 18 \text{ MeV}$  
$\Gamma = 73 \pm 40 \text{ MeV}$

hep-ex/0612006v1, hep-ex/0707.2541v2

**Belle-ISR**: total exclusive cross section

impressive parallelism between **ISR (Belle)** and energy scan (**BES**)

\[ Y(4260) \]

\[ \sqrt{s}, \text{GeV/c}^2 \]

→ talks of G. Pakhlova, P. Wang
**BaBar-ISR:** new neutral meson state $Y(2175)$ with $J^{PC} = 1^{--}$

$$e^+ e^- \rightarrow Y(2175) \gamma \rightarrow \phi f_0(980) \gamma$$

$M = 2175 \pm 10 \pm 15$ MeV

$\Gamma = 58 \pm 16 \pm 20$ MeV

- A new state?
- To be interpreted as a “strange” partner of $Y(4260)$ with c-quark replaced by s-quark? or it is a $s \bar{s} \bar{s}$ state?
**Belle-ISR:** New neutral meson states with $J^{PC} = 1^{--}$

**Belle:**

$M = 4080 \pm 40$ MeV \hspace{1cm} $\Gamma = 226 \pm 44 \pm 87$ MeV

**(BaBar)**

$M = 4247 \pm 12$ MeV \hspace{1cm} $\Gamma = 108 \pm 19 \pm 10$ MeV

$M = 4361 \pm 9 \pm 9$ MeV \hspace{1cm} $\Gamma = 74 \pm 15 \pm 10$ MeV

$M = 4664 \pm 11 \pm 5$ MeV \hspace{1cm} $\Gamma = 48 \pm 15 \pm 3$ MeV

\[ e^+ e^- \rightarrow Y(4360, 4660) \gamma \rightarrow \psi(2S) \pi^+ \pi^- \gamma \]

distinct peaks at 4.36 and 4.66 GeV


\[ e^+ e^- \rightarrow Y(4050, 4250) \gamma \rightarrow J/\psi \pi^+ \pi^- \gamma \]

distinct peaks at 4.05 and 4.25 GeV

2.4. **BaBar-ISR: Formfactors** $e^+ e^- \rightarrow N \bar{N} \gamma$

$$\sigma(e^+ e^- \rightarrow N\bar{N}\gamma) = \frac{4\pi\alpha^2\beta_N C}{3m_{p\bar{p}}^2} (|G_M|^2 + \frac{1}{2\tau} |G_E|^2)$$  

$$\beta_N = \sqrt{1 - \frac{4m_N^2}{m_{p\bar{p}}^2}} \quad \tau = \frac{m_{p\bar{p}}^2}{4m_N^2}$$

*C Coulomb correction factor*

nontrivial structure observed:

![Graph showing effective proton form factor vs. $M_{p\bar{p}} [GeV/c^2]$ with BABAR data and thresholds at 2.25 GeV and 3.0 GeV.]


→ talk of F. Maas
3. Summary and outlook

- *ISR* was originally thought to be an alternative (to energy scans) to determine hadronic cross sections from the reaction threshold up to the maximum centre of mass energy of fixed energy meson (φ, τ/charm, B) factories in order to determine the hadronic contribution to the muon magnetic anomaly and to the running fine structure constant $\alpha_{QED}(m_Z)$, and it was very successful in that respect.

- But being more than a *poor man’s* alternative to scan energies is turned out to be an extremely competitive tool to clarify reaction mechanisms and to reveal substructures (intermediate states and their decay mechanisms) leading to hadronic final states.

- Finally it opened a totally new and unexpected access to highly excited states (with $J^{PC} = 1^{--}$) the structure of many of them is still to be determined.

Again my personal remark:

While being discussed since the sixties/seventies *ISR* became a powerful tool for the analysis of experiments in low and intermediate energy hadron physics only with the development of *EVA/PHOKHARA*, a series of codes which are user friendly, flexible and easily to implement into the software of the existing detectors.
Thanks to Claudio Federici, LNF, for the permission to use elements of the conference poster designed by him showing figures related to this talk and well known to the community of this conference in an artistically elaborated manner.