$\mathcal{KK}$MC Status Report

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Included are important contributions of Maarten Boonekamp, CERN

- Overview of $\mathcal{KK}$MC program and examples of LEP results.
- New low energy upgrade, RRes package for γ^* decay.
- Results from $\mathcal{KK}$MC on radiative return at KLOE.
- Theoretical uncertainty of ISR radiative return.

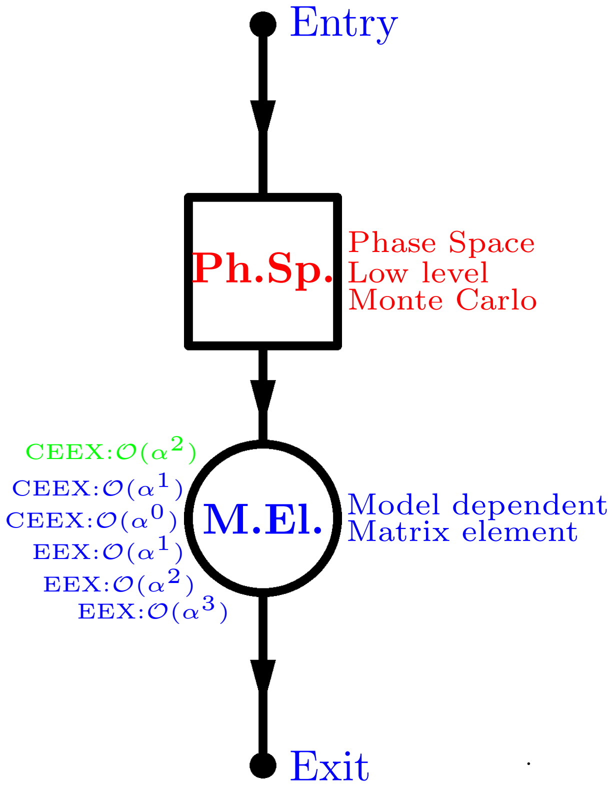
Related papers by S. Jadach, B.F.L. Ward and Z. Wąs:

Comput. Phys. Commun. 130 (2000) 260, DESY-99-106,

Phys. Rev. D **63**, 113009 (2001), Phys. Lett. B449 (1999) 97 and CERN-TH/98-235, EPJ in print.

These and related slides on http://home.cern.ch/jadach

General structure of $\mathcal{KK}$ MC (flowchart)



Entry

Ph.Sp.

Phase Space
Low level
Monte Carlo

M.El.

Model dependent
Matrix element

CEEX:$\mathcal{O}(\alpha^2)$
CEEX:$\mathcal{O}(\alpha^1)$
CEEX:$\mathcal{O}(\alpha^0)$
EEX:$\mathcal{O}(\alpha^1)$
EEX:$\mathcal{O}(\alpha^2)$
EEX:$\mathcal{O}(\alpha^3)$

Exit

- **Universal Phase-space Monte Carlo simulator**
- **Library of several types of SM/QED matrix elements**
- **Tau decays and hadronization come after**

CEEX features (terminology)

Why COHERENT? Because: Friendly to Quantum coherence;

Coherence among Feynman diagrams: Narrow resonances,

$\gamma \oplus Z$ exchanges, $t \oplus s$ channels, ISR$\oplus$FSR real emissions, etc.

Complete $\left| \sum_{diagr.}^{n} \mathcal{M}_i \right|^2$ rather then often incomplete $\sum_{i,j}^{n^2} \mathcal{M}_i \mathcal{M}_j^*$.

Why EXCLUSIVE?Because: Phase-Space $\times \sum_{spin} \left|\mathcal{M}\right|^2$

Contrary to Parton-Showers, Leading-Logs, Structure-Functions – all inherently inclusive.

Why EXPONENTIATION? Infrared (IR) contributions summed to $\mathcal{O}(\alpha^\infty)$

Going **beyond** Yennie-Frautschi-Suura (EEX):

Real IR singularities isolated/reorganized at the **spin amplitude** level, while IR cancellations occur for probabilities (integrated x-sections). Paradox???

CEEX is “backward compatible” with papers by Greco, Pancheri and Srivastava.

EEX= Exclusive EXponentiation = variant of YFS expon.

$e^-(p_1,\lambda_1)+e^+(p_2,\lambda_2)\to f(q_1,\lambda_1')+\bar f(q_2,\lambda_2')+\gamma(k_1,\sigma_1)+\ldots+\gamma(k_n,\sigma_n)$

EEX/YFS very schematically

$$\sigma=\sum_{n=0}^{\infty}\int_{m_\gamma} d\Phi_{n+2}\; e^{Y(m_\gamma)} D_n(q_1,q_2,k_1,\ldots,k_n)$$

$\mathcal{O}(\alpha^1)$ Example:

$$D_0=\bar\beta_0$$
$$D_1(k_1)=\bar\beta_0\tilde S(k_1)+\bar\beta_1(k_1)$$
$$D_2(k_1,k_2)=\bar\beta_0\tilde S(k_1)\tilde S(k_2)+\bar\beta_1(k_1)\tilde S(k_2)+\bar\beta_1(k_2)\tilde S(k_1)$$

Real soft factors:

$$\tilde S(k)=\sum_\sigma|\mathfrak{s}_\sigma(k)|^2=|\mathfrak{s}_+|^2(k)+|\mathfrak{s}_-(k)|^2=-\frac{\alpha}{\pi}\Big(\frac{q_1}{kq_1}-\frac{q_2}{kq_2}\Big)^2$$

IR-finite building blocks:

$\bar\beta_0=\sum_\lambda|\mathfrak{M}_\lambda|^2$, λ = fermion helicities, σ = photon helicity

$$\bar\beta_1(k)=\sum_{\lambda\sigma}|\mathfrak{M}^{1-\mathrm{PHOT}}_{\lambda\sigma}|^2-\sum_\sigma|\mathfrak{s}_\sigma(k)|^2\sum_\lambda|\mathfrak{M}^{\mathrm{Born}}_\lambda|^2$$

Everything in terms of $\sum_{spin}|\ldots|^2$!!!!

CEEX schematically

$$\sigma = \sum_{n=0}^{\infty} \int_{m_\gamma} d\Phi_{n+2} \sum_{\lambda,\sigma_1,\dots,\sigma_n} |e^{B(m_\gamma)} \mathfrak{M}^{\lambda}_{n,\sigma_1,\dots,\sigma_n}(k_1,\dots,k_n)|^2$$

$\mathcal{O}(\alpha^1)$ Example:

$\mathfrak{M}^\lambda_0 = \hat\beta^\lambda_0$, λ=fermion helicities,

$$\mathfrak{M}^\lambda_{1,\sigma_1}(k_1) = \hat\beta^\lambda_0 \mathfrak{s}_{\sigma_1}(k_1) + \hat\beta^\lambda_{1,\sigma_1}(k_1)$$

$$\mathfrak{M}^\lambda_{2,\sigma_1,\sigma_2}(k_1,k_2) = \hat\beta^\lambda_0 \mathfrak{s}_{\sigma_1}(k_1)\mathfrak{s}_{\sigma_2}(k_2) + \hat\beta^\lambda_{1,\sigma_1}(k_1)\mathfrak{s}_{\sigma_2}(k_2) + \hat\beta^\lambda_{1,\sigma_2}(k_2)\mathfrak{s}_{\sigma_1}(k_1)$$

IR-finite building blocks:

$$\hat\beta^\lambda_0 = \left(e^{-B}\mathfrak{M}^{\text{Born+Virt.}}_\lambda\right)\Big|_{\mathcal{O}(\alpha^1)},$$

$$\hat\beta^\lambda_{1,\sigma}(k) = \mathfrak{M}^\lambda_{1,\sigma}(k) - \hat\beta^\lambda_0 \mathfrak{s}_\sigma(k)$$

Everything in terms of $\mathfrak{M}$-spin-amplitudes !!!!

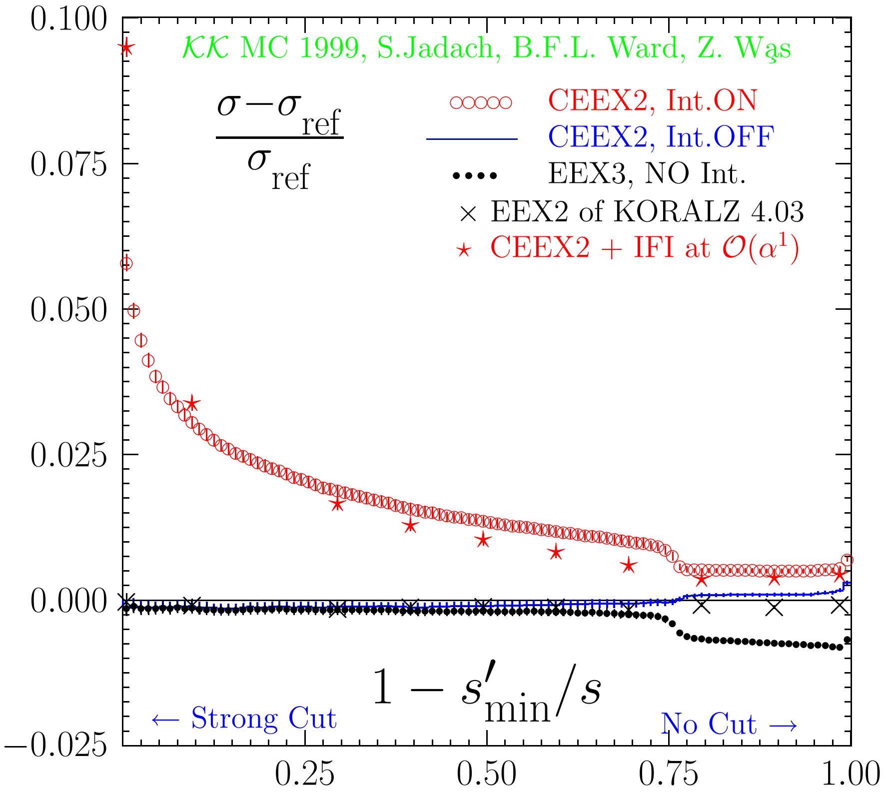
Evolution of $\mathcal{KK}$ MC and comparison with predecessors

Feature	KORALB	KORALZ	$\mathcal{KK}$MC 4.16	$\mathcal{KK}$ 2001+?
QED type	$\mathcal{O}(\alpha)$	EEX	CEEX, EEX	CEEX, EEX
CEEX(ISR+FSR)	none	none	$\{\alpha, \alpha L; \alpha^2 L^2, \alpha^2 L^1\}$	$\{...\alpha^2 L^1; \alpha^3 L^3\}$
EEX(ISR*FSR)	none	$\{\alpha, \alpha L, \alpha^2 L^2\}$	$\{\alpha, \alpha L, \alpha^2 L^2, \alpha^3 L^3\}$	$\{...\alpha^2 L^2, \alpha^3 L^3\}$
ISR-FSR int.	$\mathcal{O}(\alpha)$	$\mathcal{O}(\alpha)$	$\{\alpha, \alpha L\}_{\rm CEEX}$	$\{\alpha, \alpha L\}_{\rm CEEX}$
Exact bremss.	1 γ	1, 2coll. γ	1, 2, 3coll. γ	up to 3 γ
Electroweak	No Z-res.	DIZET 6.x	DIZET 6.x	2-nd EW libr.
Virt. pairs	None	None	Simple	Improved
Beam polar.	long+trans.	longit.	long+trans.	long+trans.
τ polar.	long+trans.	longit.	long+trans.	long+trans.
Hadronization	—	JETSET	PYTHIA	PYTHIA
$\gamma^* \to$ Reson.	—	—	RRes	RRes, Tauola
τ decay	TAUOLA	TAUOLA	TAUOLA	TAUOLA
Inclusive mode	—	No	Yes	Yes
Beamstrahlung	—	No	Yes	Yes
Beam spread	—	No	Yes	Yes
$\nu\nu$ channel	—	Yes	Yes	Yes
ee channel	—	No	No	Yes!
tt channel	—	No	No	yes?
WW channel	—	No	No	yes?

Selected Examples of $\mathcal{KK}$MC results from LEP

- **ISR and more: Test at 189GeV in Phys. Rev. D 63, 113009 (2001)**
- **ISR and FSR for muons: $\mathcal{KK}$MC – ZFitter, March-June 2000, LEP workshop. At 189GeV**
- **ISR QUARKS: $\mathcal{KK}$MC – ZFitter, March-June 2000**
- **The initial-final interference: $\mathcal{KK}$MC – ZFitter, March-June 2000**

ISR and more: Test at 189GeV in Phys. Rev. D 63, 113009 (2001)

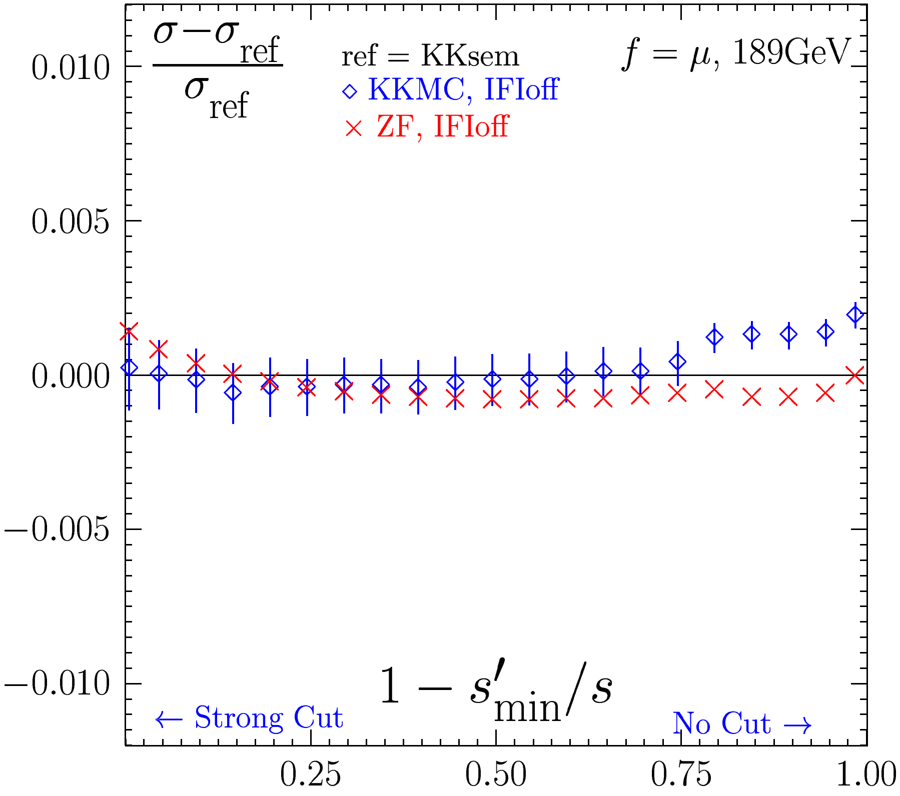


Blue MC line is complete $\mathcal{O}(\alpha^2)$ ISR, totaly independent of classic analytic Berends, Burgers, Van Neerven, 1988 (BBvN).

Reference $\mathcal{KK}$sem is semianalytical based on BBvN and YFS exponentiation.

Comparing several calculations, we concluded total precision $< 0.2\%$.

ISR and FSR: $\mathcal{KK}$MC – ZFitter, March-June 2000, LEP workshop. At 189GeV

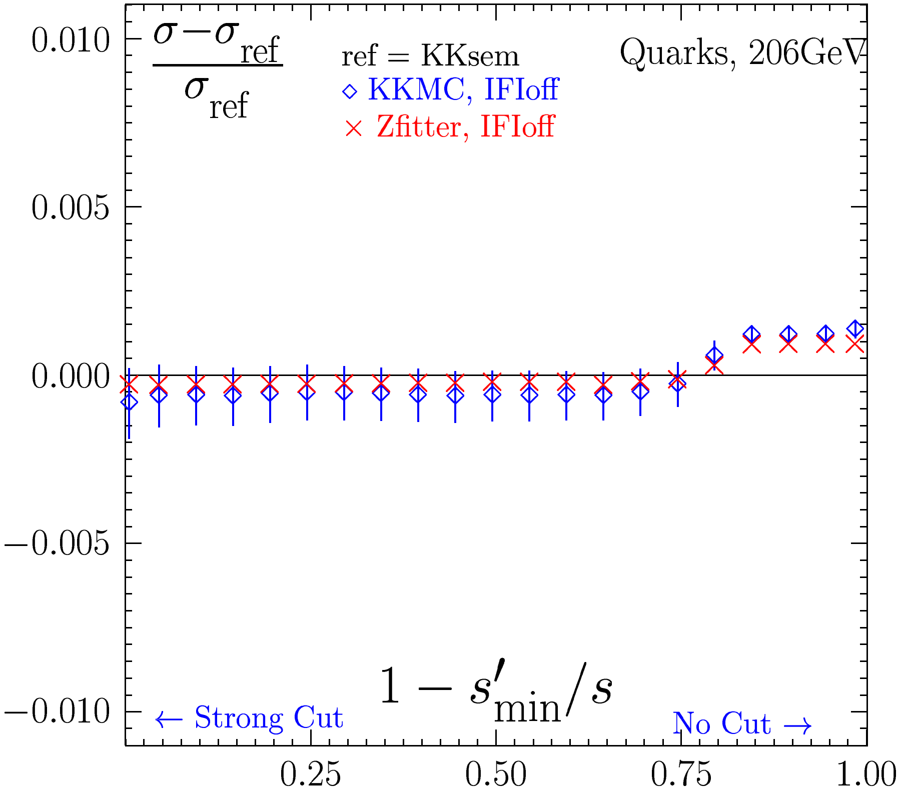


The initial-final interference IFI is OFF in all three calculations:

$\mathcal{KK}$MC, ZFitter and the reference $\mathcal{KK}$sem.

The agreement is $< 0.2\%$

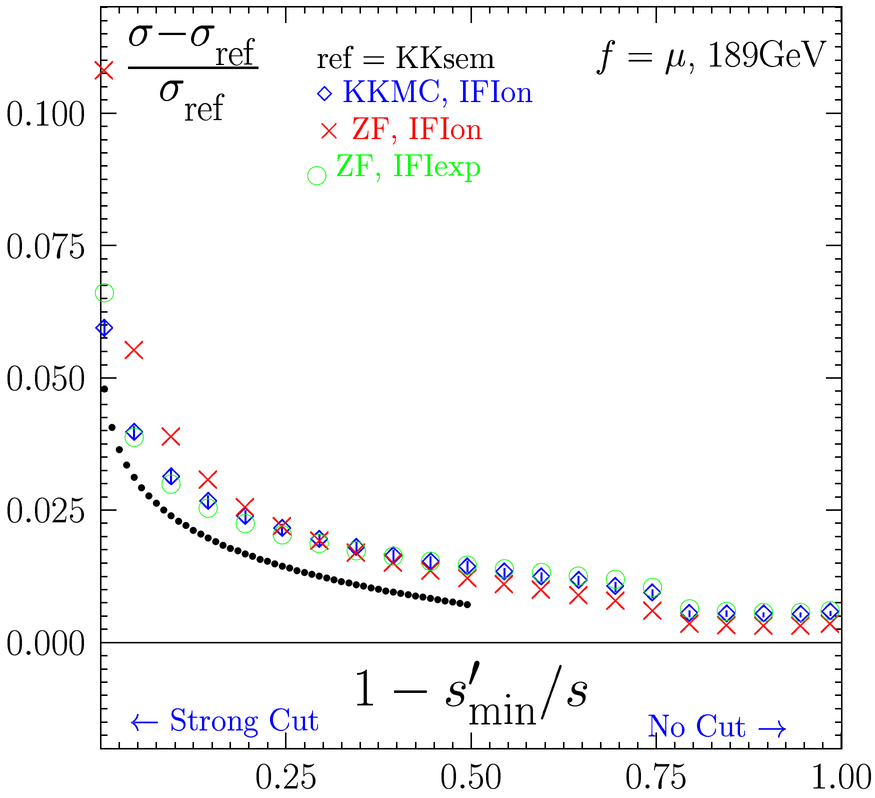
ISR QUARKS: $\mathcal{KK}$MC – ZFitter, March-June 2000



Systematic comparison for quarks (at 206GeV). IFI is OFF.

The agreement for x-section better than 0.2%.

The initial-final interference: $\mathcal{KK}$MC – ZFitter, March-June 2000



The IFI is ON for $\mathcal{KK}$MC and ZFitter and OFF for the reference $\mathcal{KK}$sem, at 189GeV.

Black dots represent:

$$\delta_{IFI}(v_{\max}) = 1 - 2A_{FB}\kappa \ln v_{\max} + \kappa^2 \ln^2 v_{\max}\left(\frac{1}{2}+\frac{\pi^2}{6}\right) + const.$$

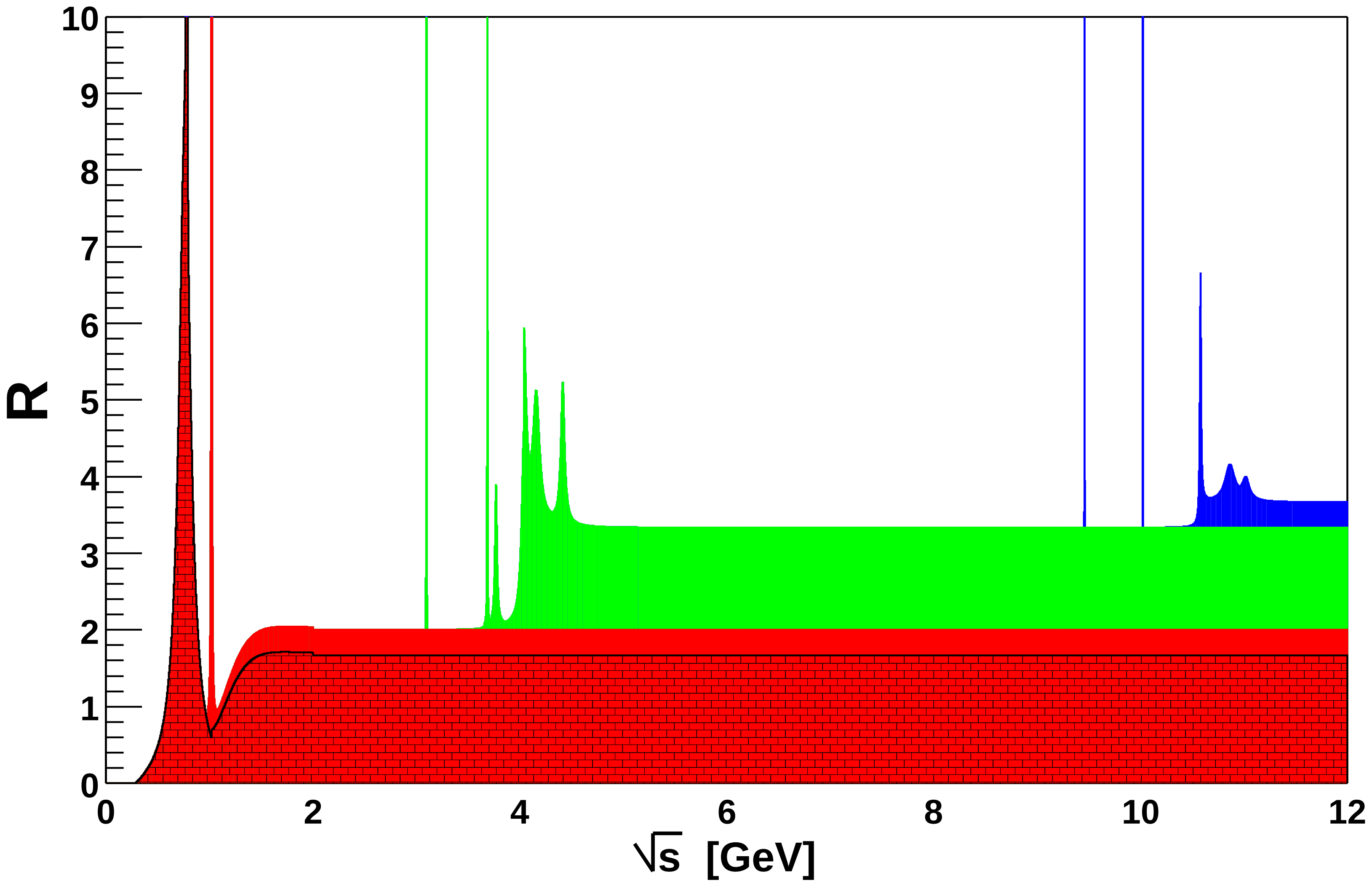
IFI at LEP2 under perfect control.

RRes package of M. Boonekamp, now included in $\mathcal{KK}$MC

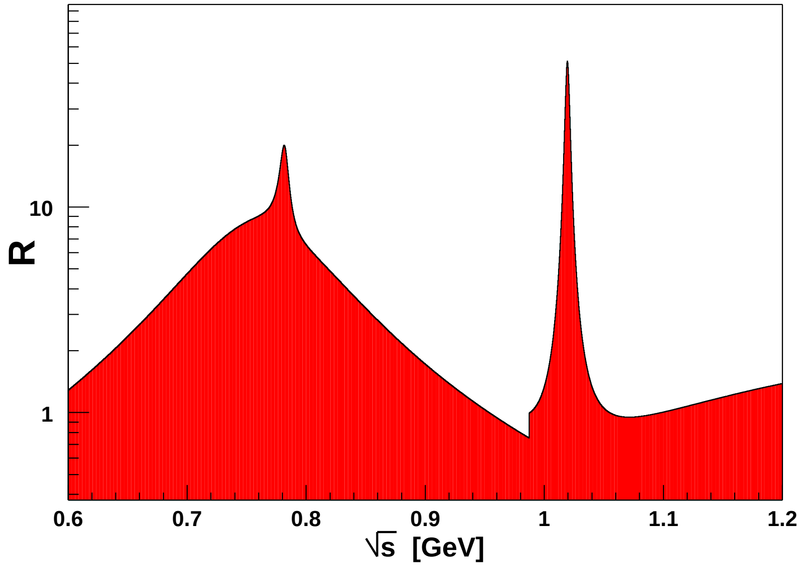
- $R(s)$ from most available hadronic data, old ones (SLAC, Orsay) and new (Novosibirsk).
- In particular ρ and ω region parametrized using new Novosibirsk data, hep-ex/9904027.
- In MC generation $R(s)$ split into resonant and non-resonant parts. $R(s)$ is also split among available $q_i\bar{q}_i$ pairs, for resonances and continuum.
- Resonance decays (from ρ to Υ) generated using Pythia tool.
- Non-resonant "continuum" part modelled using Pythia tool for $q_i\bar{q}_i$ string. At $\sqrt{s} < 2GeV$ for (small) non-resonant component flat phase space is used experimental data are used to determine the type of final state (any channel).
- No naive QCD applied for "continuum", for the moment.

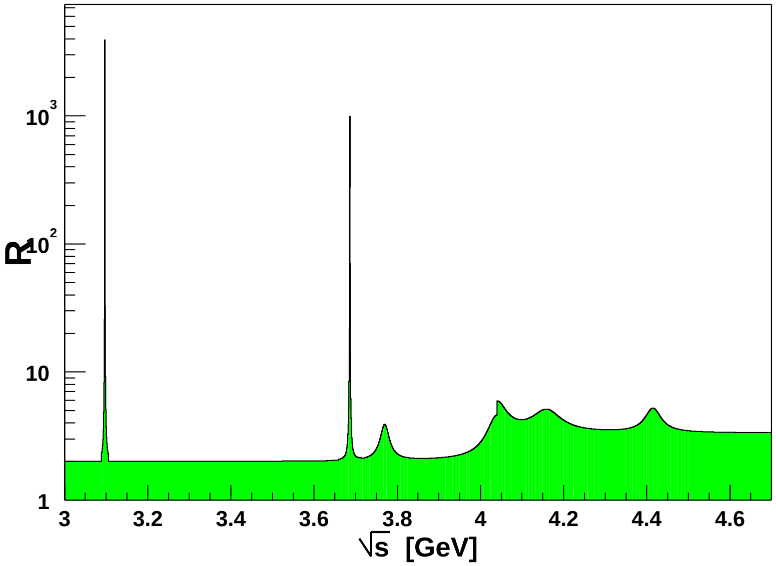
To be improved: for continuum part replace flat phase space with more realistic description of $n\pi$ state, better matching with perturbative QCD and QED (FSR).

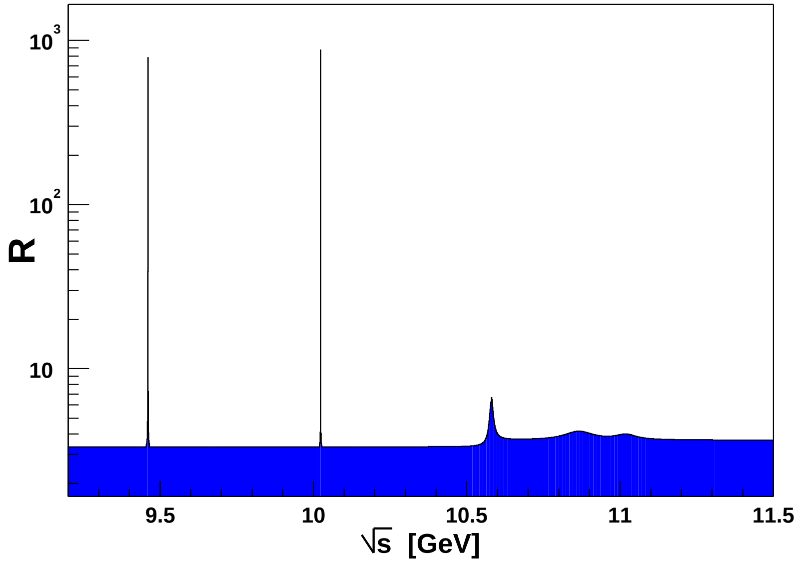
$Q\bar{Q}$ **SKYLINE (RRes package)**



Zoom on resonances (RRes package)

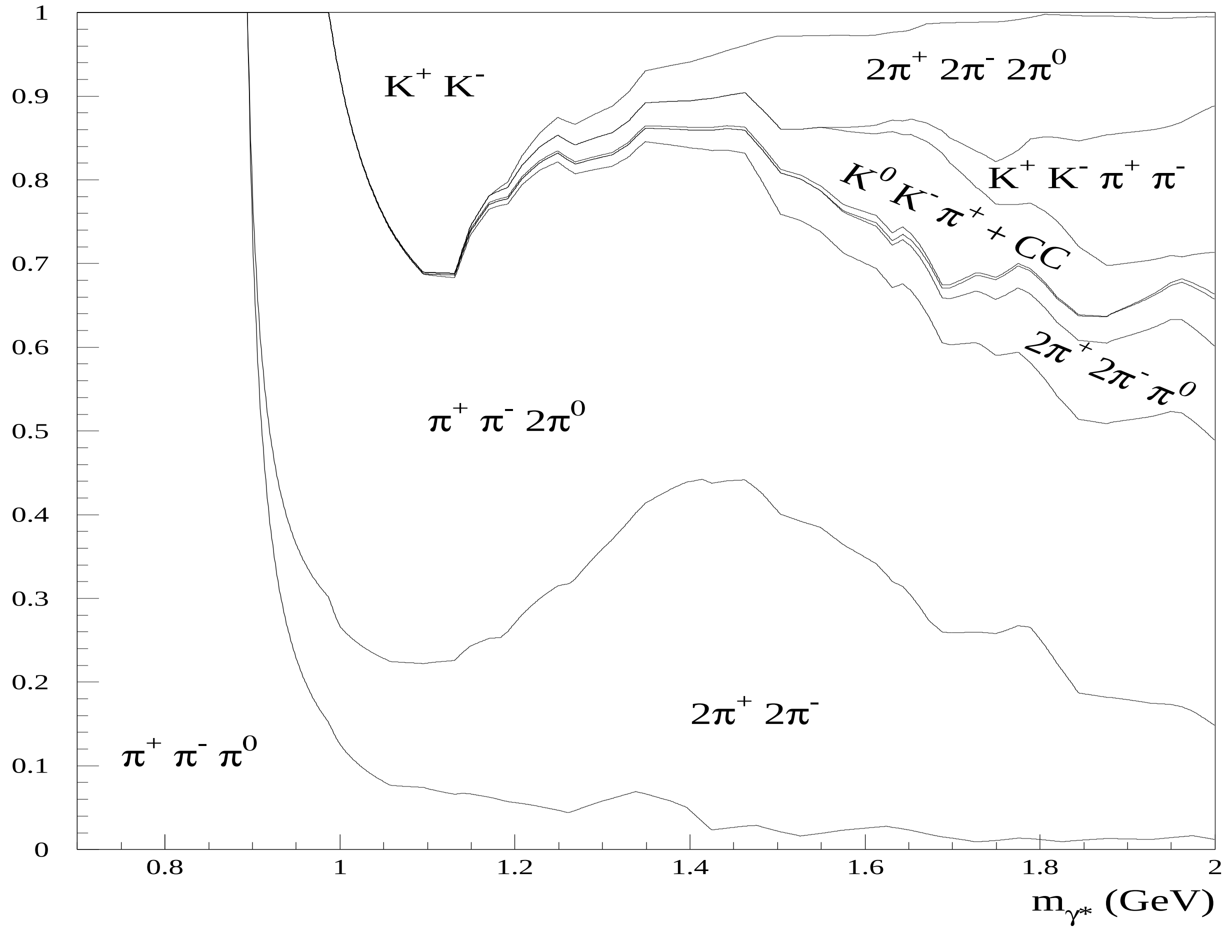






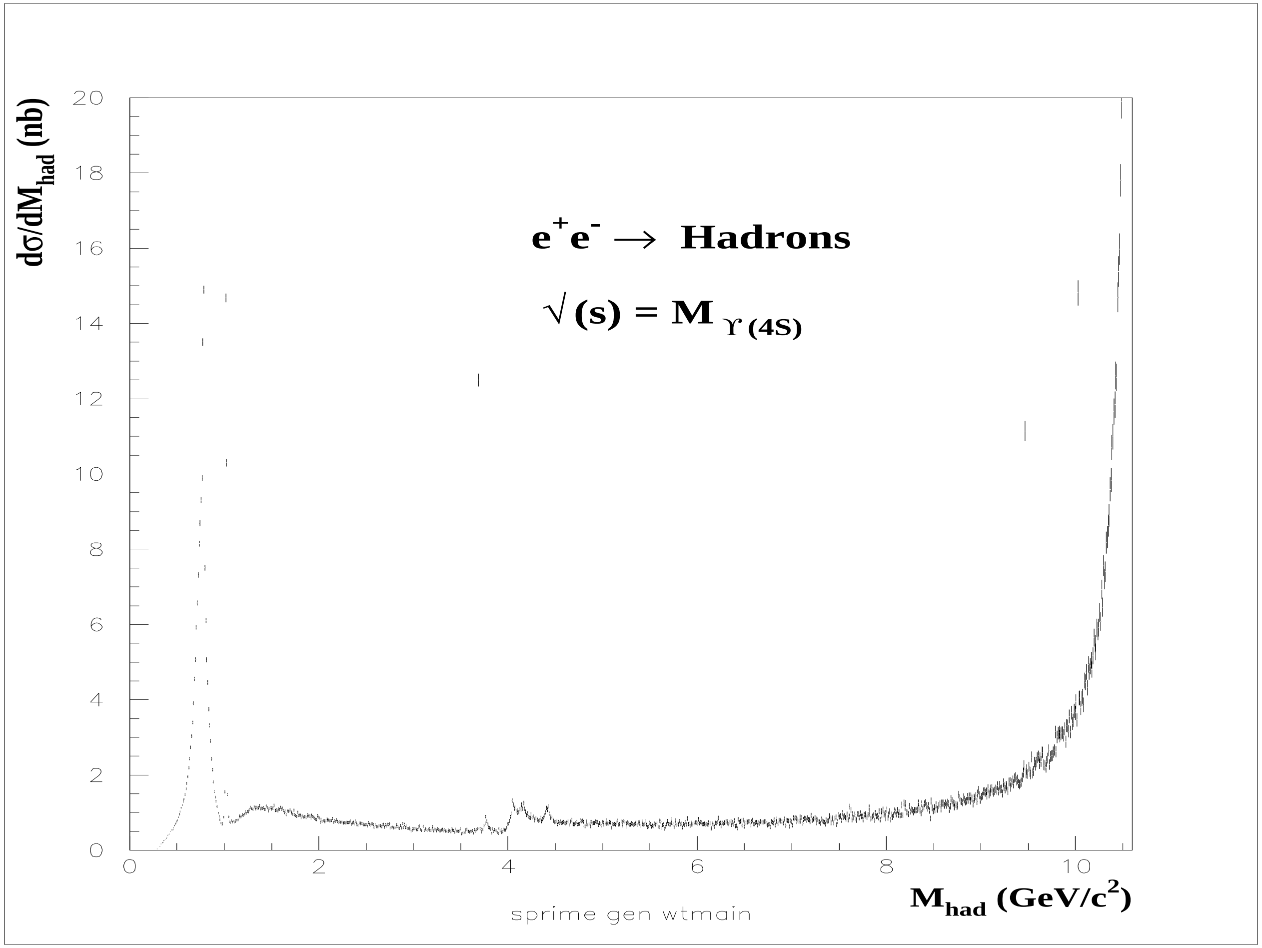
This hadronic experimental distribution $R(s)$ is now implemented in package RRes by M. Boonekamp and used in $\mathcal{KK}$MC for low Q^2 quark-pair spectrum

Split of continuum into channels



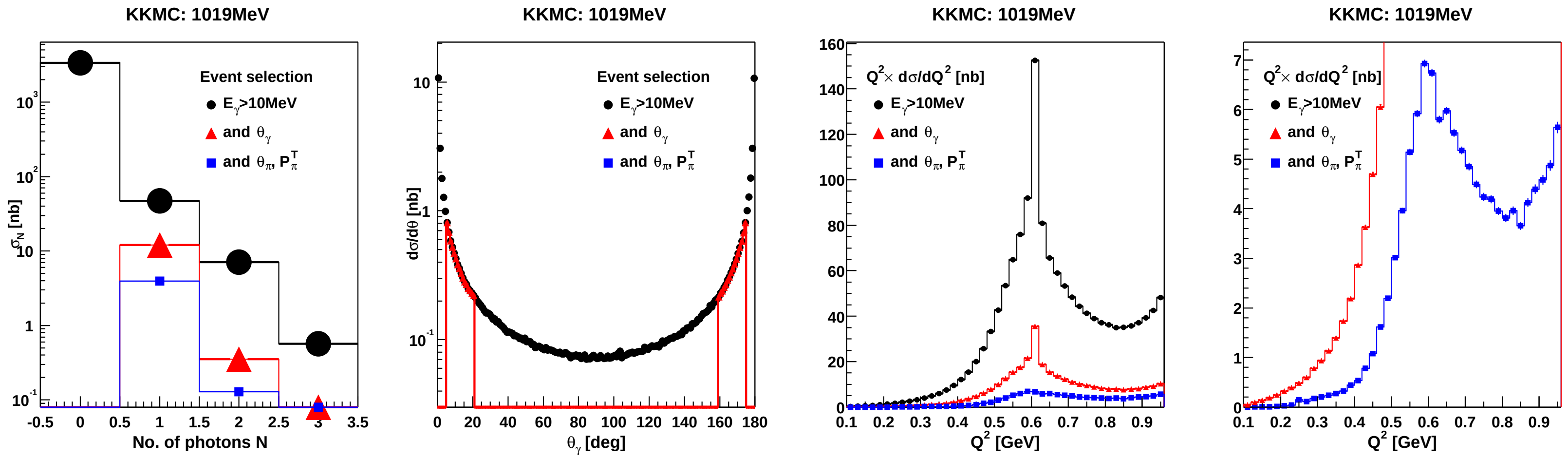
Experimental data are used to determine channel in the non-resonant part below 2GeV.

Narrow resonances in $\mathcal{KK}$MC



Example of $\mathcal{KK}$MC radiative return for close to $b\bar{b}$ threshold, sitting on the $\Upsilon(4S)$.

Radiative return at KLOE, as seen with $\mathcal{KK}$MC. PRELIMINARY!

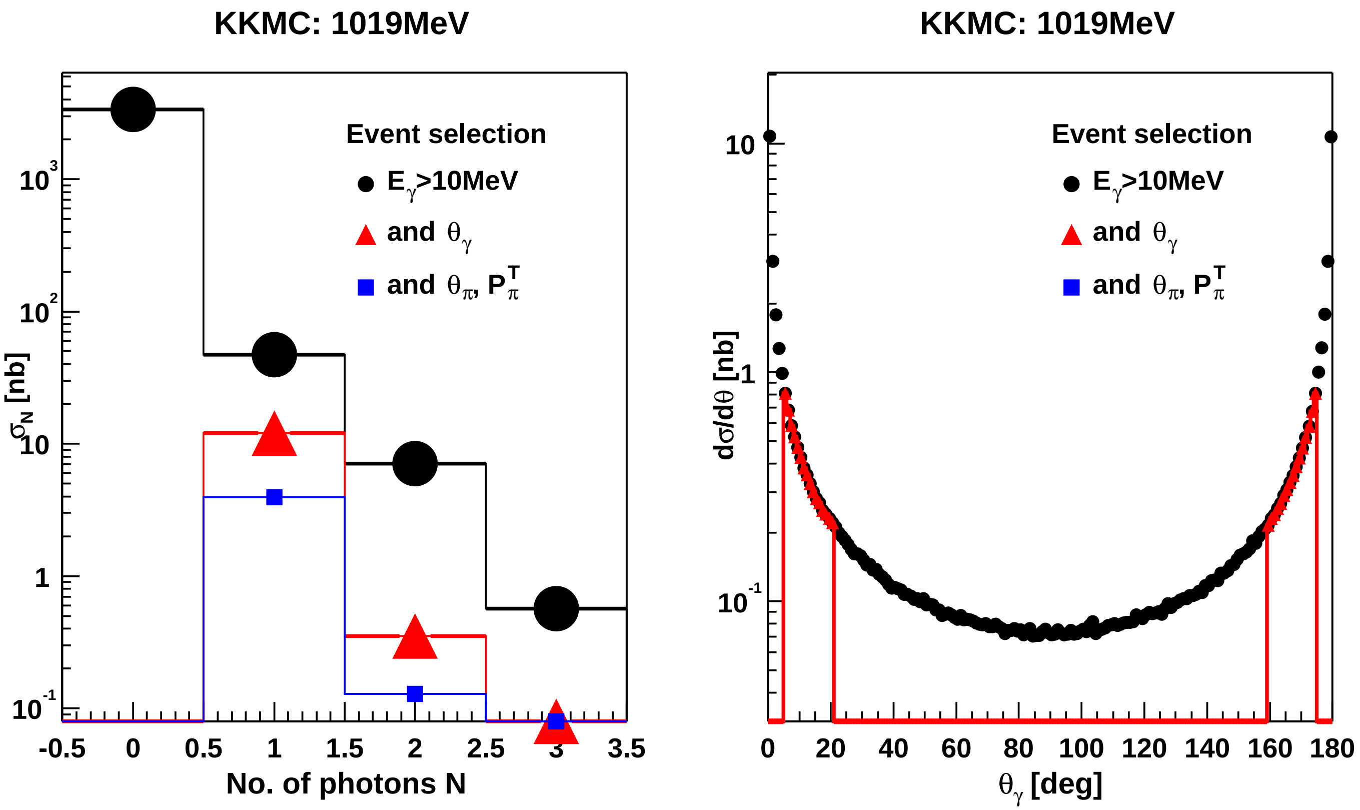


Event selection as in KLOE paper hep-ex/0106100:

$$5^\circ < \Theta_\gamma < 21^\circ, \quad 159^\circ < \Theta_\gamma < 175^\circ, \quad E_\gamma > 10MeV$$

$$55^\circ < \Theta_\pi < 125^\circ, \quad p^T_\pi > 200MeV.$$

Radiative return at KLOE with $\mathcal{KK}$MC. PHOTON DISTRIBUTIONS



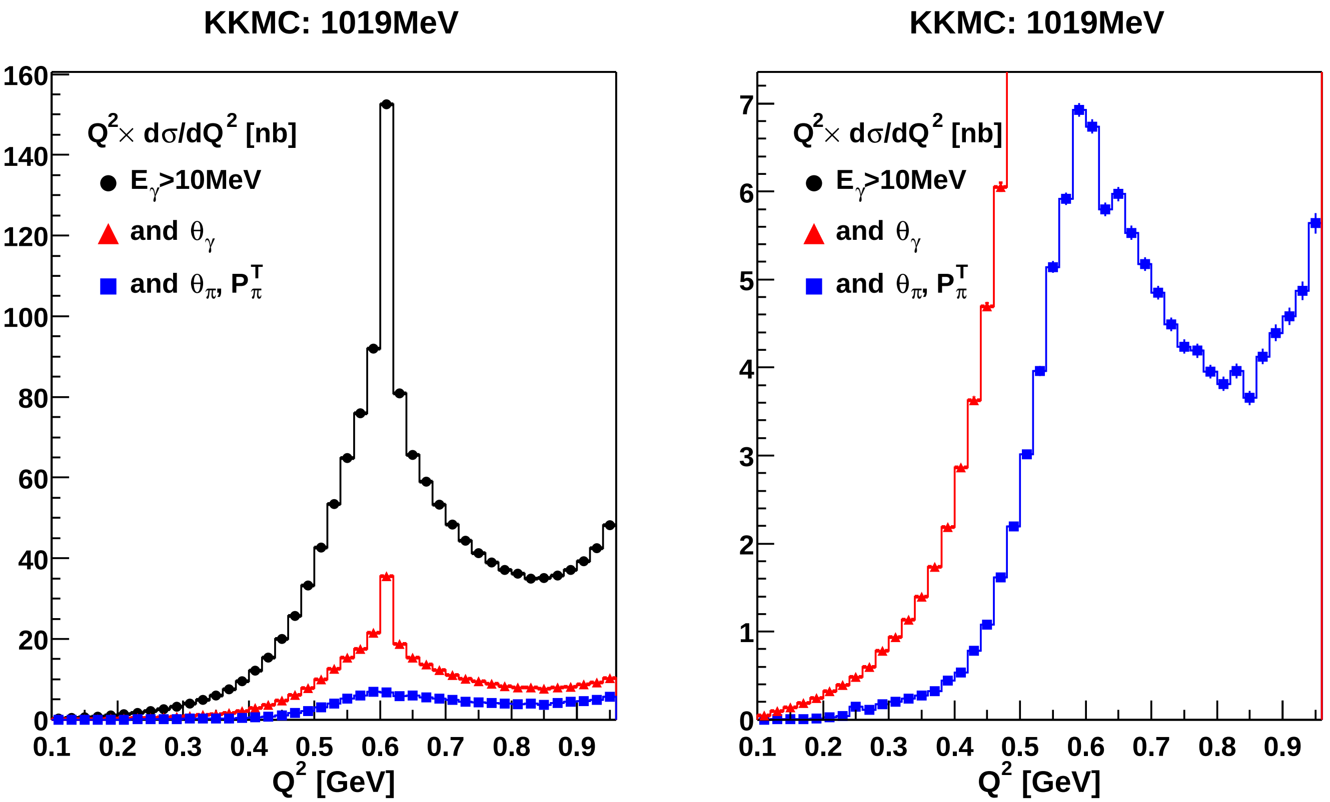
Event selection as in KLOE paper hep-ex/0106100:

$$5^\circ < \Theta_\gamma < 21^\circ, \quad 159^\circ < \Theta_\gamma < 175^\circ, \quad E_\gamma > 10MeV$$

$$55^\circ < \Theta_\pi < 125^\circ, \quad p^T_\pi > 200MeV.$$

N.B. TWO photons within the “detection window” with $\sim 3\%$ probability!

Radiative return at KLOE with $\mathcal{KK}$MC. $Q^2_{\pi^+\pi^-}$ DISTRIBUTIONS



Event selection as in KLOE paper hep-ex/0106100:

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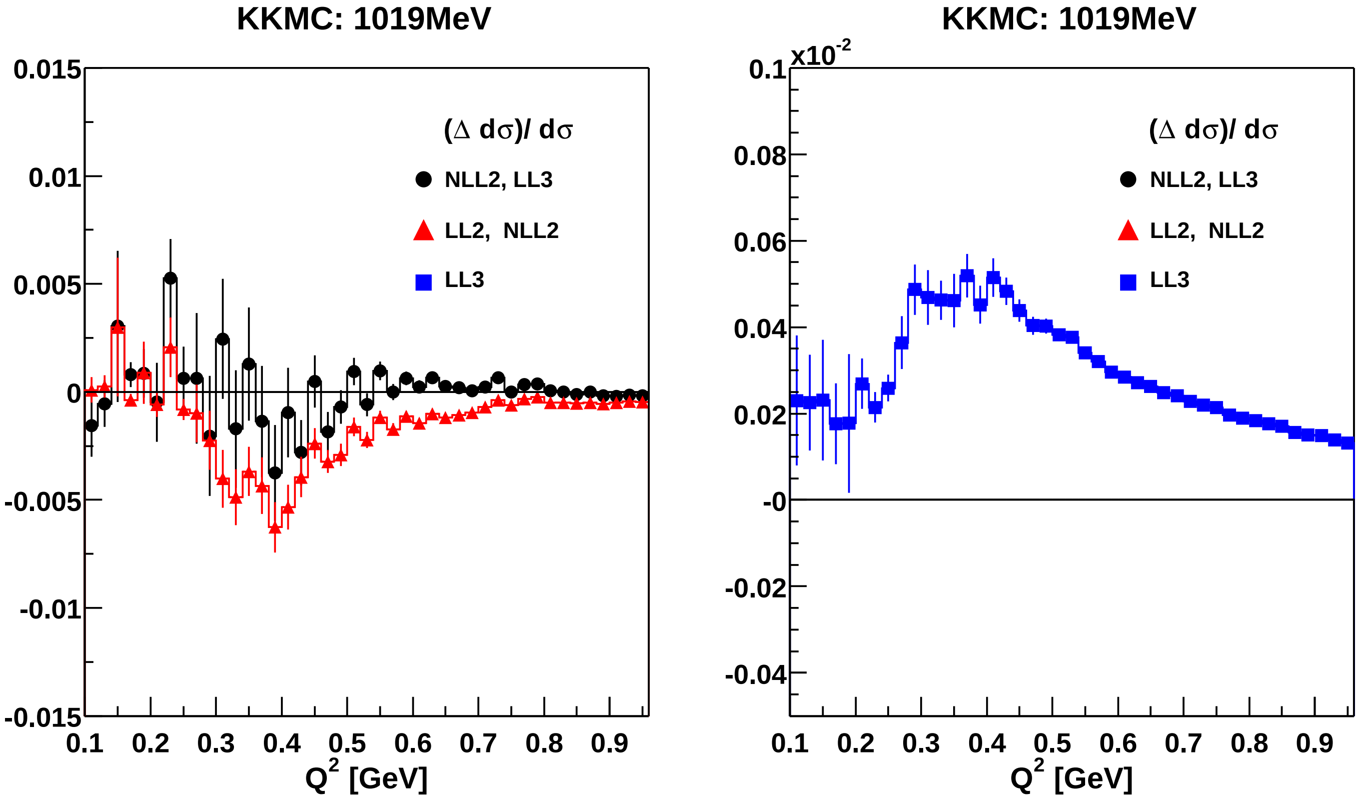
$$55^\circ < \Theta_\pi < 125^\circ, \quad p^T_\pi > 200MeV.$$

CEEX $\mathcal{O}(\alpha^2)$ matrix element.

Radiative return: Estimate of ISR higher orders



● $\mathcal{O}(\alpha^3L^3,\alpha^2L^2,\alpha^1L^0)_{\rm EEX} - \mathcal{O}(\alpha^2L^2,\alpha^2L^1....)_{\rm CEEX}$

△ $\mathcal{O}(\alpha^1L^1,\alpha^1L^0)_{\rm CEEX} - \mathcal{O}(\alpha^2L^2,\alpha^2L^1...)_{\rm CEEX}$

□ $\mathcal{O}(\alpha^2L^2,\alpha^1L^0)_{\rm EEX} - \mathcal{O}(\alpha^3L^3,\alpha^2L^2,\alpha^1L^0)_{\rm EEX}$

In the range $Q^2 > 0.5GeV^2$, theoretical uncertainty of ISR in $\mathcal{KK}$MC looks 0.25% at most. It this true?

$\mathcal{KK}$MC: What next?

- **Migration to c++**
- **Bhabha, low+wide angle**
- **Top quark pair**
- **Virtual pairs (better hadronic contr.)**
- **New EW library**
- **Improvements in phase space integration.**

Latest version 4.16 of $\mathcal{KK}$ MC of Oct. 30-th available.

Check **http://home.cern.ch/jadach** for programs, slides etc.

Conclusions

- **$\mathcal{K}\mathcal{K}$MC is now effectively replacing KORALB and KORALZ (BHLUMI and BHWIDE are next).**
- **$\mathcal{K}\mathcal{K}$MC has got new interesting functionalities for the low energy experiment.**
- **More work is needed (the usual statement).**