# Status of Radiative Corrections for $e^+e^-$ data



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INFN-Pisa

Fifth Plenary Workshop of the Muon g-2 Theory Initiative

5-9 September 2022
James Clerk Maxwell Building
Europe/Rome timezone

# Why we need Radiative Corrections

"Visible" cross section
$\sigma(e^+e^-(\gamma) \to X(\gamma))$

Here we correct for all detector effects

Adjust for radiative corrections (ISR, FSR)
$\sigma(e^+e^- \to X)$

This one is used to get parameters of the resonances (mass, width,...)

Adjust for vacuum polarization and return back FSR
$\sigma^0(e^+e^- \to X(\gamma))$

This one is used in the $a_\mu$ integral

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

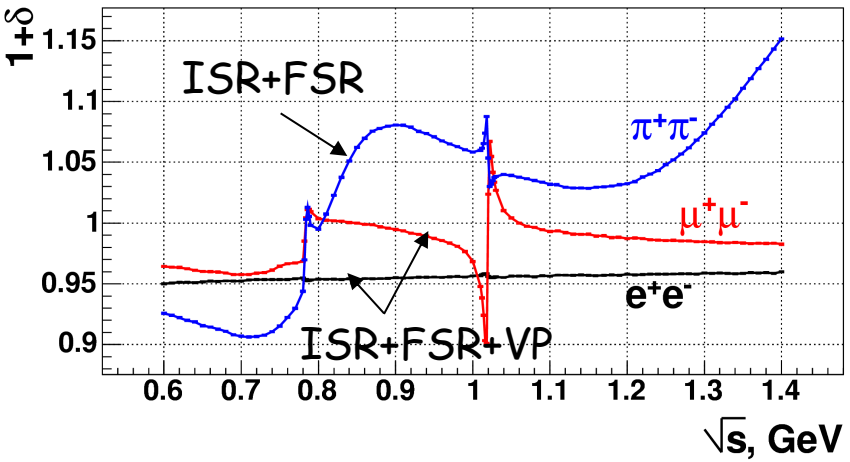
[I. Logashenko]

# Radiative corrections for **energy scan**:

## All modes except 2π

$$\sigma\left(e^+e^- \to H\right) = \frac{N_H - N_{bg}}{L \cdot \varepsilon \cdot (1+\delta)}$$

- Luminosity L is measured using Bhabha scattering at large angles
- Efficiency ε is calculated via Monte Carlo + corrections for imperfect detector
- Radiative correction δ accounts for ISR effects only




## 2π

$$\left|F_\pi\right|^2 = \frac{N_{2\pi}}{N_{ee}} \cdot \frac{\sigma_{ee} \cdot (1+\delta_{ee})}{\sigma_{2\pi}(\text{point-like } \pi) \cdot (1+\delta_{2\pi})}$$

- Ratio N(2π)/N(ee) is measured directly ⇒ detector inefficiencies are (partially) cancelled out
- Virtually no background
- Analysis does rely mostly on data
- Radiative corrections account for ISR and FSR effects
- Formfactor is measured to better precision than L (true VEPP2M; in VEPP2000 ~same precision )

# Radiative corrections for ISR (KLOE)

## Radiator-Function $H(s,s_p)$ (ISR):

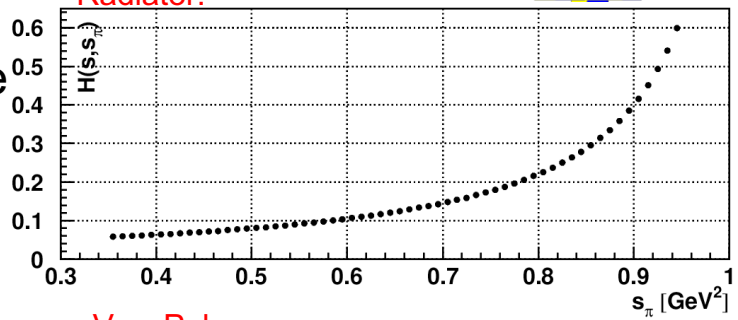
It cancels in the ratio to μμγ

- ISR-Process calculated at NLO-level
  *PHOKHARA* generator
  (H.Czyż, A.Grzelińska, J.H.Kühn, G.Rodrigo, EPJC27,2003)

Precision: *0.5%*

$$s \cdot \frac{d\sigma_{\pi\pi\gamma}}{ds_\pi} = \sigma_{\pi\pi}(s_\pi) \times H(s,s_\pi)$$

Radiator:

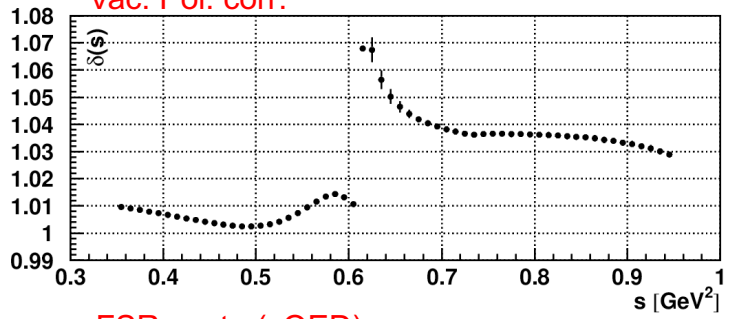



## Radiative Corrections:

**i) Bare Cross Section**

divide by Vacuum Polarisation $d(s)=(a(s)/a(0))^2$

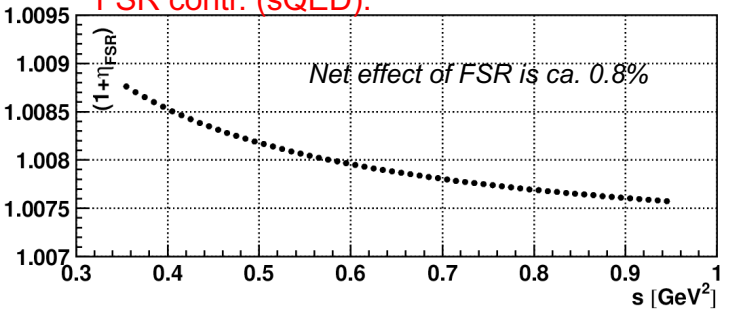
Vac. Pol. corr:

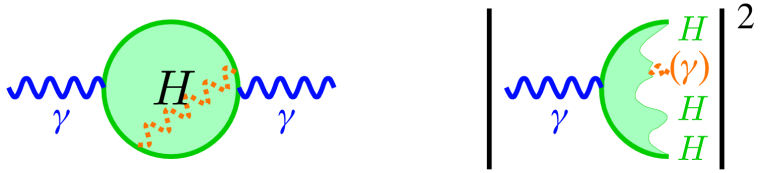



**ii) FSR**

Cross section $s_{pp}$ must be incl. for FSR
for use in the dispersion integral of $a_m$

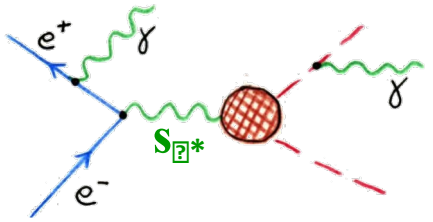
FSR contr. (sQED):




FSR corrections have to be taken into account in the efficiency eval. (Acceptance, $M_{Trk}$) and in the mapping $s_\pi \rightarrow s_{\gamma*}$

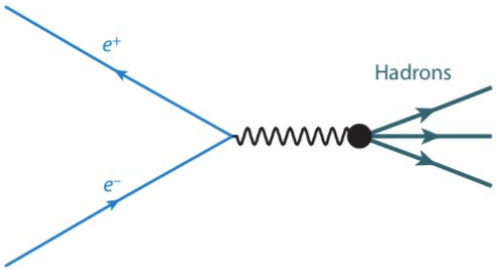
(H.Czyż, A.Grzelińska, J.H.Kühn, G.Rodrigo, EPJC33,2004)




$s_{\gamma*} > s_p$

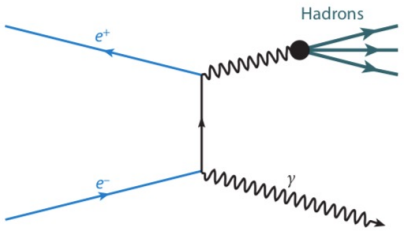
# MC generators for exclusive channels (exact NLO + Higher Order terms in some approx)

| MC generator | Channel | Precision | Comment |
|---|---|---|---|
| MCGPJ (VEPP-2M, VEPP-2000) | $e^+e^- \rightarrow e^+e^-, \mu^+\mu^-, \pi^+\pi^-, \ldots$ | 0.2% | photon jets along all particles (collinear Structure function) with exact NLO matrix elements |
| BabaYaga@NLO (KLOE, BaBar, BESIII) | $e^+e^- \rightarrow e^+e^-, \mu^+\mu^-, \gamma\gamma$ | 0.1% | QED Parton Shower approach with exact NLO matrix elements |
| BHWIDE (LEP) | $e^+e^- \rightarrow e^+e^-$ | (0.1%?) | Yennie-Frautschi-Suura (YFS) exponentiation method with exact NLO matrix elements |



# MC generators for ISR
## (from approximate to exact NLO)

| MC generator | Channel | Precision | Comment |
|---|---|---|---|
| EVA (KLOE) | $e^+e^- \to \pi^+\pi^-\gamma$ | O(%) | Tagged photon<br>ISR at LO + Structure Function<br>FSR: point-like pions |
| AFKQED (BaBar) | $e^+e^- \to \pi^+\pi^-\gamma$, … | depends on the event selection (can be as good as Phokhara) | ISR at LO +Structure Function |
| PHOKHARA (KLOE, BaBar BESIII) | $e^+e^- \to \pi^+\pi^-\gamma$, $\mu^+\mu^-\gamma$, $4\pi\gamma$, … | 0.5% | ISR and FSR(sQED+Form Factor) at NLO |
| KKMC | $e^+e^- \to f^+f^-(n)\gamma$ | High accuracy only for muon pairs | YFS exponentiation for soft photons + hard part and sub-leading terms in some approximation |



# PHOKHARA MC generator

**EVA:** $e^+e^- \to \pi^+\pi^-\gamma$

- tagged photon ($\theta_\gamma > \theta_{cut}$)
- ISR at LO + Structure Function
- FSR: point-like pions

[Binner et al.]

$e^+e^- \to 4\pi + \gamma$

- ISR at LO + Structure Function

[Czyż, Kühn,2000]

F. Campanario, H.C., J. Gluza,

A. Grzelińska, M. Gunia, P. Kisza,

J. H. Kühn, E. Nowak-Kubat, T. Riemann,

G. Rodrigo, Sz. Tracz, A. Wapienik,

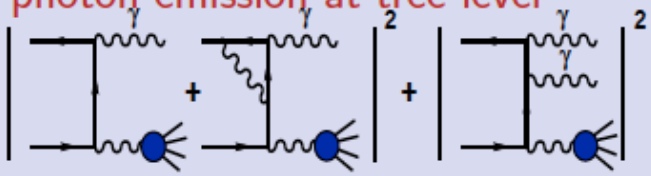
V. Yundin, D. Zhuridov

**PHOKHARA 10.0:** $\pi^+\pi^-$,$\mu^+\mu^-$,

$4\pi$, $\bar{N}N$, $3\pi$, $KK$,$\Lambda\bar{\Lambda}$, $P\gamma$

$J/\psi, \psi(2S), \chi_{c1}, \chi_{c2}$

- **ISR at NLO:** virtual corrections to one photon events and two photon emission at tree level

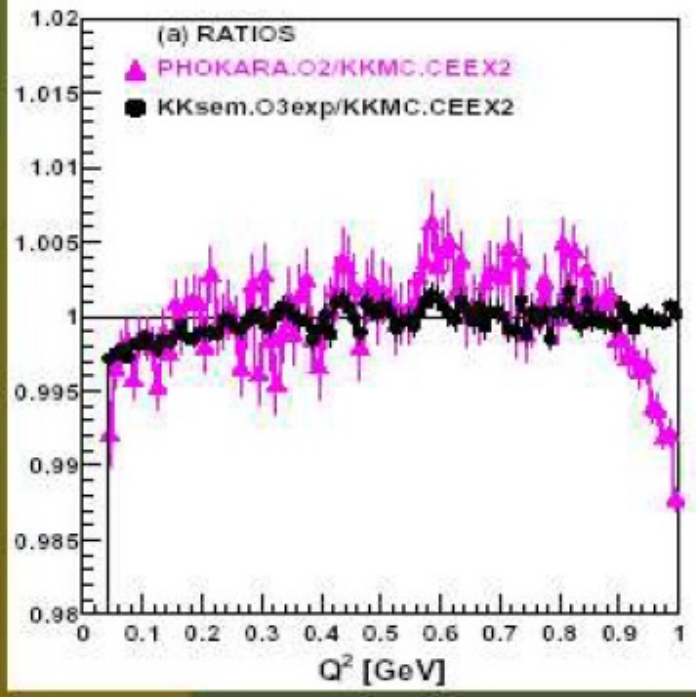


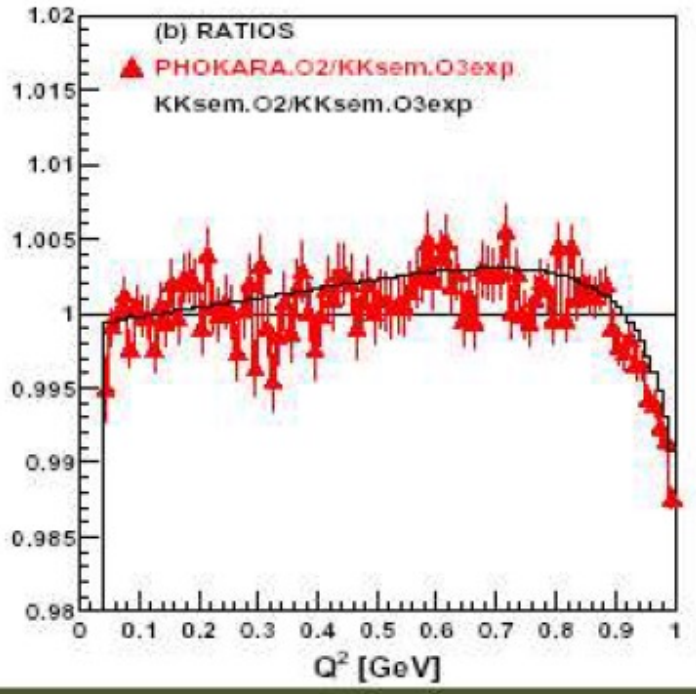

- FSR at NLO:$\pi^+\pi^-$, $\mu^+\mu^-$,$K^+K^-$, $\bar{p}p$
- tagged or untagged photons
- $e^+e^- \to hadrons\ (muons)$ ISR at NNLO
- Modular structure

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

# PHOKHARA vs KKMC $\mu\mu\gamma$

## PHOKHARA included in the game, $\mu$-pairs again




PHOKHARA agrees to within 0.3% with KKMC and KKsem.

Discrepancy at high $Q^2$ reflects lack of exponentiation in PHOKHARA

# "Tuned" comparisons are essential!

Theoretical accuracies of these generators were estimated, whenever possible, by evaluating missing higher-order contributions. From this point of view, the great progress in the calculation of two-loop corrections to the Bhabha scattering cross section was essential to establish the high theoretical accuracy of the existing generators for the luminosity measurement. However, usually only analytical or semi-analytical estimates of missing terms exist which don't take into account realistic experimental cuts. In addition, MC event generators include different parameterisations for the VP which affect the prediction (and the precision) of the cross sections and also the RC are usually implemented differently.

# Radio MonteCarLow: "Working Group on Radiative Corrections and MC Generators for Low Energies"

- An informal room and a valuable platform to exchange ideas
- Meetings with theorists and experimentalists sitting together.
- First meeting in Oct 2006. 20 meetings since then. More than 60 participants from more than 10 different countries. Last meeting on March 2019
- 2 WG coordinators (H. Czyz, G. Venanzoni)
- 7 Subgroups
- A first report in 2010.

Web page:

http://www.lnf.infn.it/wg/sighad/

# Report from RMCWG: a common effort for RC and Monte Carlo tools

Eur. Phys. J. C (2010) 66: 585–686
DOI 10.1140/epjc/s10052-010-1251-4

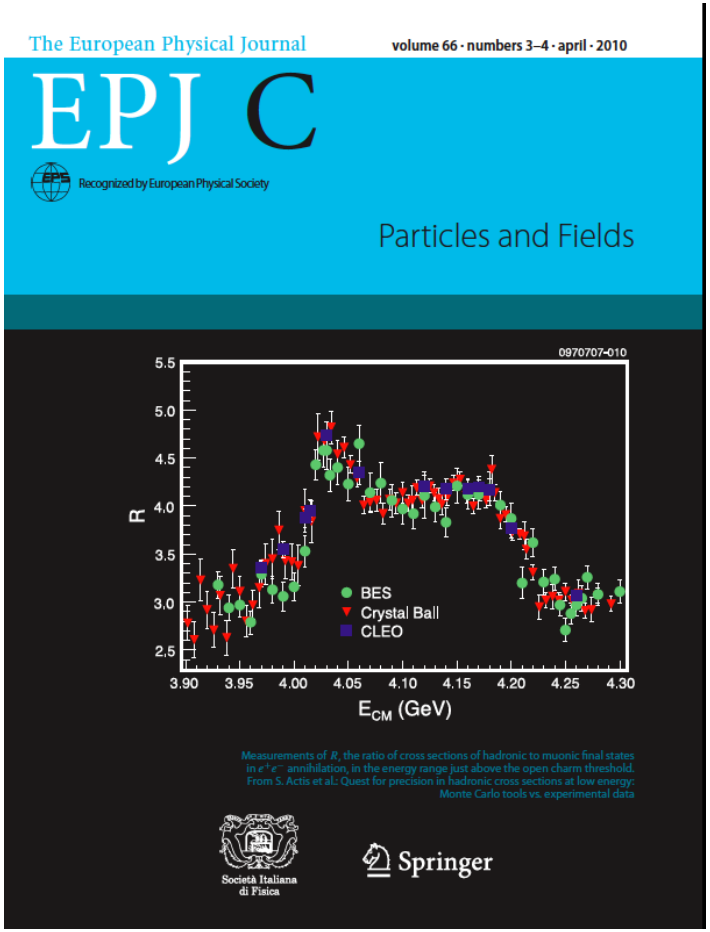
THE EUROPEAN PHYSICAL JOURNAL C

Review

**Quest for precision in hadronic cross sections at low energy: Monte Carlo tools vs. experimental data**

Working Group on Radiative Corrections and Monte Carlo Generators for Low Energies

S. Actis[38], A. Arbuzov[9,e], G. Balossini[32,33], P. Beltrame[13], C. Bignamini[32,33], R. Bonciani[15], C.M. Carloni Calame[35], V. Cherepanov[25,26], M. Czakon[1], H. Czyż[19,a,f,i], A. Denig[22], S. Eidelman[25,26,g], G.V. Fedotovich[25,26,e], A. Ferroglia[23], J. Gluza[19], A. Grzelińska[8], M. Gunia[19], A. Hafner[22], F. Ignatov[25], S. Jadach[8], F. Jegerlehner[3,19,41], A. Kalinowski[29], W. Kluge[17], A. Korchin[20], J.H. Kühn[18], E.A. Kuraev[9], P. Lukin[25], P. Mastrolia[14], G. Montagna[32,33,b,d], S.E. Müller[22,f], F. Nguyen[34,d], O. Nicrosini[33], D. Nomura[36,h], G. Pakhlova[24], G. Pancheri[11], M. Passera[28], A. Penin[10], F. Piccinini[33], W. Płaczek[7], T. Przedzinski[6], E. Remiddi[4,5], T. Riemann[41], G. Rodrigo[37], P. Roig[27], O. Shekhovtsova[11], C.P. Shen[16], A.L. Sibidanov[25], T. Teubner[21,h], L. Trentadue[30,31], G. Venanzoni[11,c,i], J.J. van der Bij[12], P. Wang[2], B.F.L. Ward[39], Z. Was[8,g], M. Worek[40,19], C.Z. Yuan[2]




Eur. Phys. J. C. Volume 66, Issue 3 (2010), Page 585

(for more details on results see https://agenda.hepl.phys.nagoya-u.ac.jp/indico/getFile.py/access?contribId=16&sessionId=4&resId=0&materialId=slides&confId=1691)

# Moving forward…

- New data/measurements from VEPP-2000, BaBar, BelleII, BESIII with better quality and refined systematic errors
- New theoretical calculations and tools from LHC and MUonE theory communities (see Massimo's presentation)
- Discrepancy between lattice and dispersive approach for $a_\mu^{HLO}$
- Radiative corrections and MC generators for e+e- → hadrons, leptons should aim at 0.1% uncertainty → **NNLO** calculation **needed**!
- Test of FSR model (BaBar using charge asymmetry and KLOE using F.B. asymmetry; tests undergoing at CMD3); New theoretical developments (see next slides)

# Moving forward…

- RC and Radio MC activity is still very important!! →

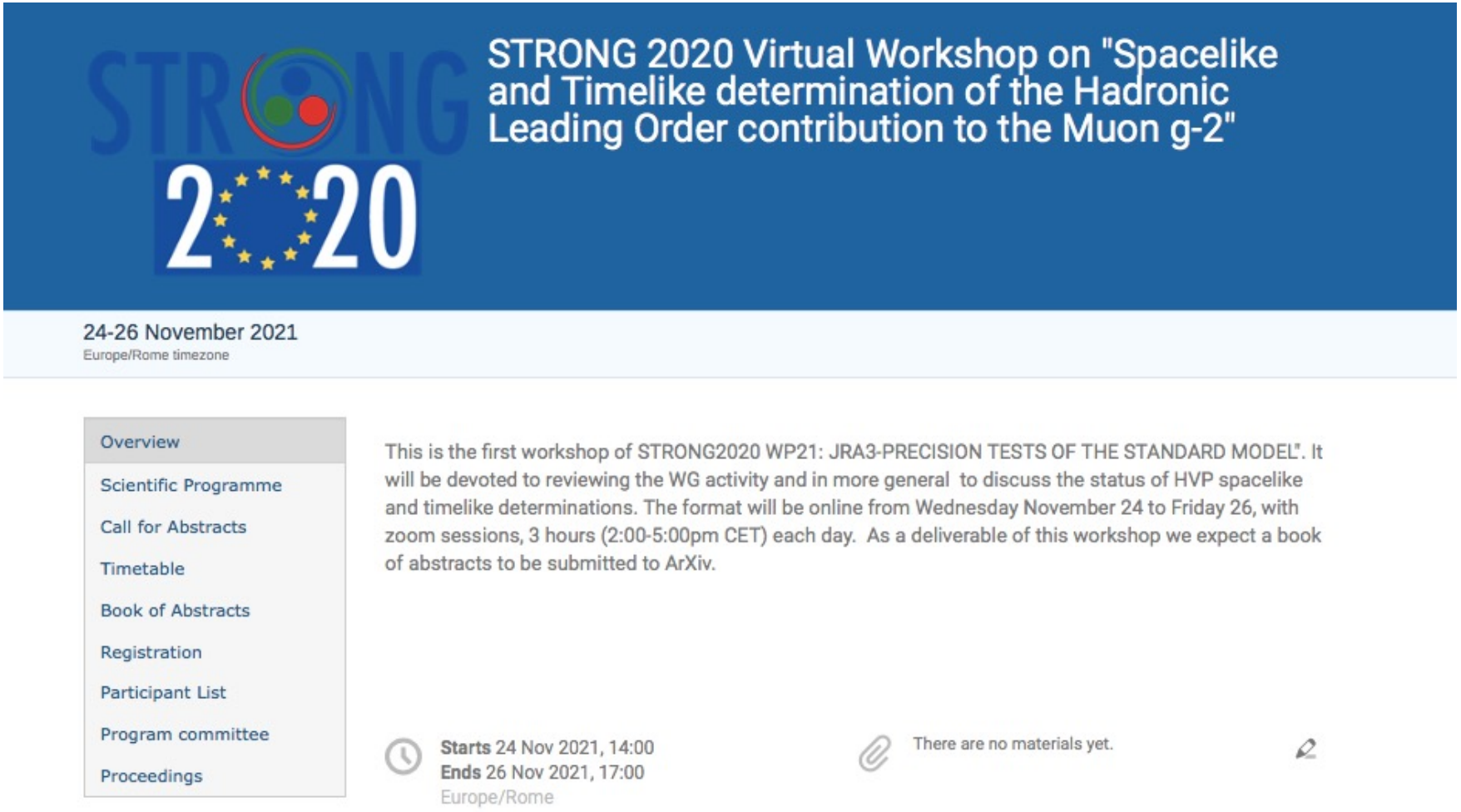
- STRONG2020 (Virtual) meeting: 24-26 November 2021 (https://agenda.infn.it/event/28089/ )

- N³LO kick-off workstop / thinkstart 3-5 August 2022, IPPP Durham (https://conference.ippp.dur.ac.uk/event/1104/)

- WorkStop on **"Radiative corrections and Monte Carlo tools for low-energy hadronic cross sections in e+e- collision"** on **05-09 June 2023** at the University of Zurich

# (Virtual) meeting: 24-26 November 2021

https://agenda.infn.it/event/28089




>100 participants; very reach agenda!

Proceedings at arXiv:2201.12102 [hep-ph]

# (Virtual) meeting: 24-26 November 2021

# Review of the $e^+e^-$ generators

| | | |
|---|---|---|
| MCGPJ and ReneSANCe MC event generators: status and perspectives | *Andrej Arbuzov* | 14:00 - 14:15 |
| BABAYAGA MC generator: status and prospects | *Carlo Michel Carloni Calame* | 14:15 - 14:30 |
| PHOKHARA MC generator: status and prospects | *Henryk Czyz* | 14:30 - 14:45 |
| KKMCee/BHLUMI/BHWIDE MC generators: status and prospects | *Staszek Jadach* | 14:45 - 15:00 |
| KKMC: new tau decays, New Physics vector/scalar resonances | *Zbigniew Andrzej Was* | 15:00 - 15:15 |
| Coffee Break | | 15:15 - 15:25 |
| Discrepancies between current MC generators | *Fedor Ignatov* | 15:25 - 15:40 |
| Radiative corrections to e+e- -> pi+pi- based on a dispersive approach | *Gilberto Colangelo* | 15:40 - 16:00 |
| Perspectives from theory on $e^+e^-\to 2\pi$ and $e^+e^-\to 3\pi$ | *Martin Hoferichter* | 16:00 - 16:20 |
| Mix leptonic and hadronic contribution to a_mu^HLO | *Thomas Teubner* | 16:20 - 16:30 |
| Discussion: Towards NNLO MC generators for e+e- -> hadrons, leptons | | 16:30 - 17:00 |

MCGPJ and ReneSANCe MC event generators: status and perspectives

Andrej Arbuzov

*BLTP, JINR, Dubna*

The BabaYaga event generator: overview and future prospects

C.M. Carloni Calame

INFN Pavia, Italy

**Monte Carlo generator Phokhara**

H. CZYŻ, IP, US, Chorzów, Poland

**KKMCee/BHLUMI/BHWIDE MC generators: status and prospects**

Stanisław Jadach

**KKMC: new tau decays, vector/scalar resonances of New Physics**

Sw. Banerjee[a], D. Biswas[a], T. Przedzinski[b], Z. Was*

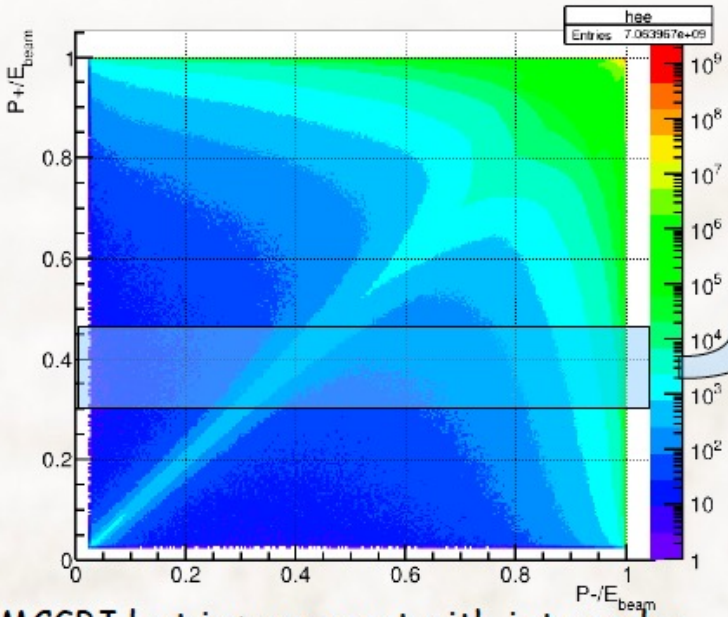
# Bhabha: MCGPJ vs Babayaga@NLO

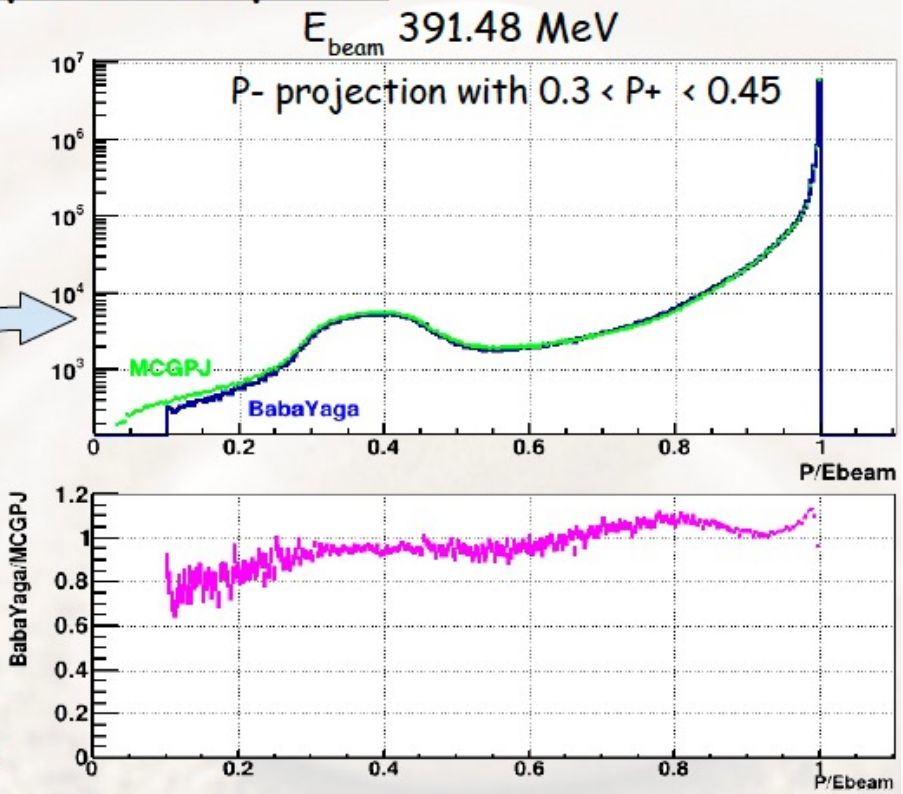
F. Ignatov

(CDM3 selection cuts)

## MCGPJ vs BabaYaga bhabha P+ vs P- spectrum

**Differential over momentum spectrum comparison**




MCGPJ last improvement with jets angles reduce discrepancy from x1.6-3 to x1.1

Momentum spectrum still disagree at level ~ 10%

Tails comes from e+e- → e+e- γγ , NNLO order

Very desirable to have more precise generators

Such discrepancy gives 0.3% systematic for π+π- at ρ-peak using momentum analysis at CMD3

# ISR: NLO $e^+e^- \to \pi^+\pi^-\gamma$

RADIO MONTECARLOW

H. Czyz

**Status - finished**

PHYSICAL REVIEW D 100, 076004 (2019)

Francisco Campanario, Henryk Czyż , Janusz Gluza, Tomasz Jeliński, German Rodrigo, Szymon Tracz, and Dmitry Zhuridov

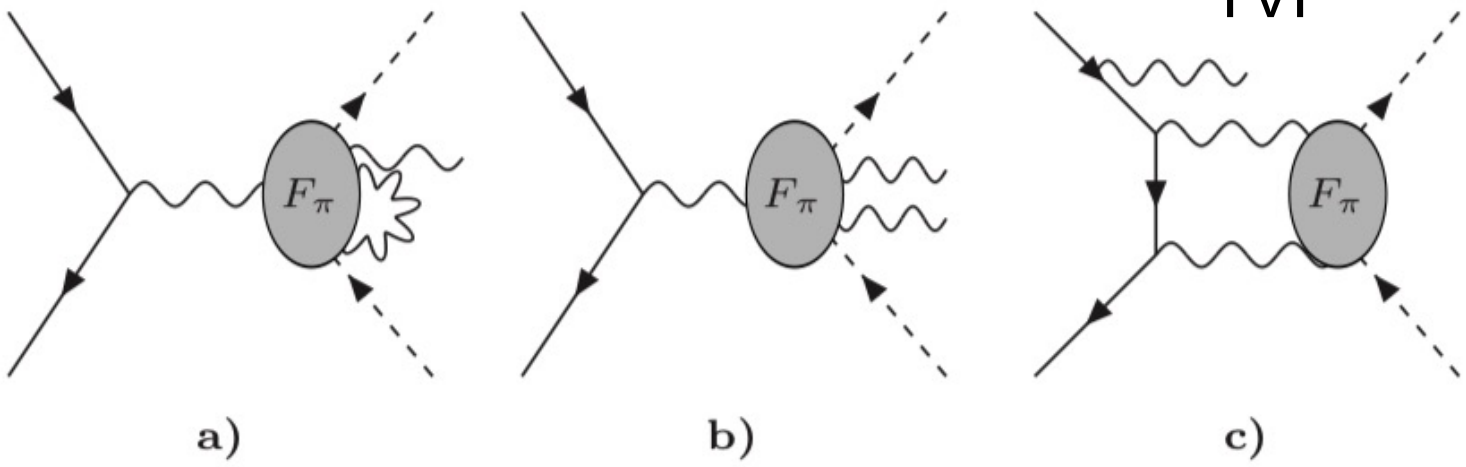
⇒ sQED + form factors:
FSR at NLO and pentaboxes ready and fully tested

⇒ Phokhara10.0
http://ific.uv.es/∼ rodrigo/phokhara/

ıario et al.
PRD100 (2019) 7, 076004

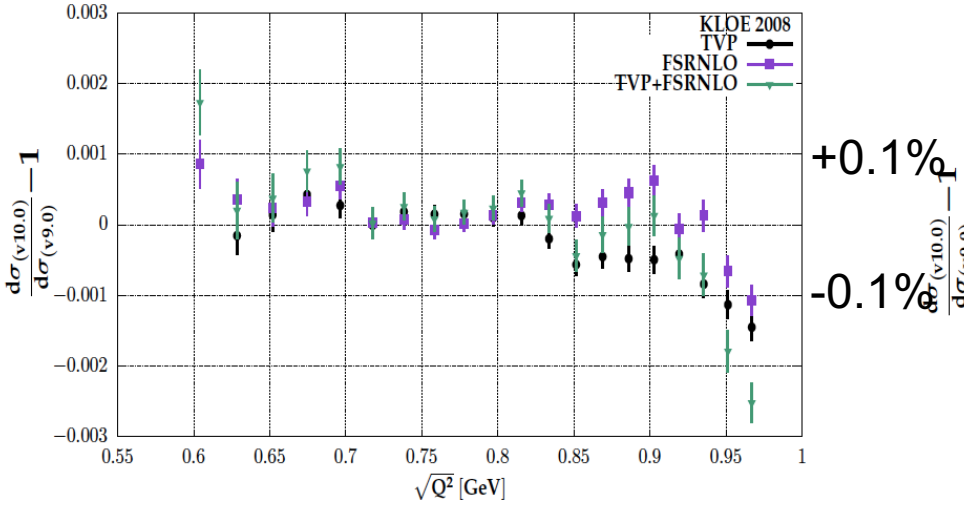
FSRNLO

TVP




Effect of NLO missing corrections in previous version of PHOKHARA (used by experiments)

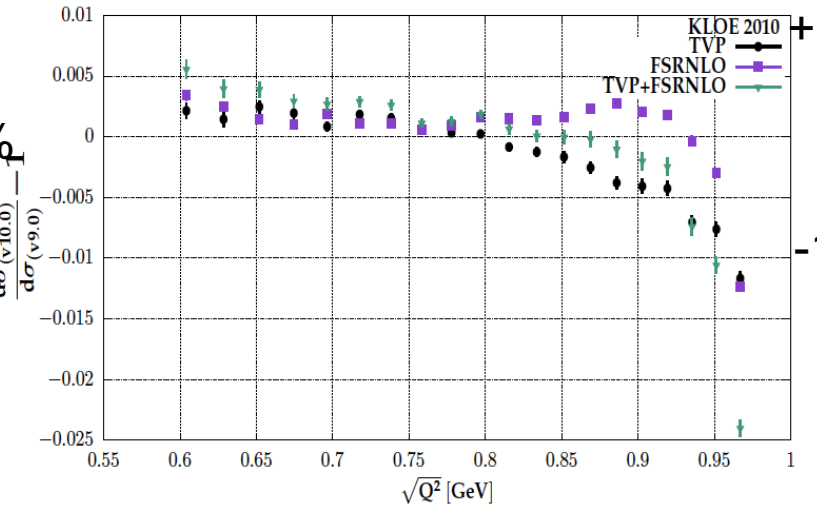
## Complete NLO: KLOE-small




+0.1%

-0.1%

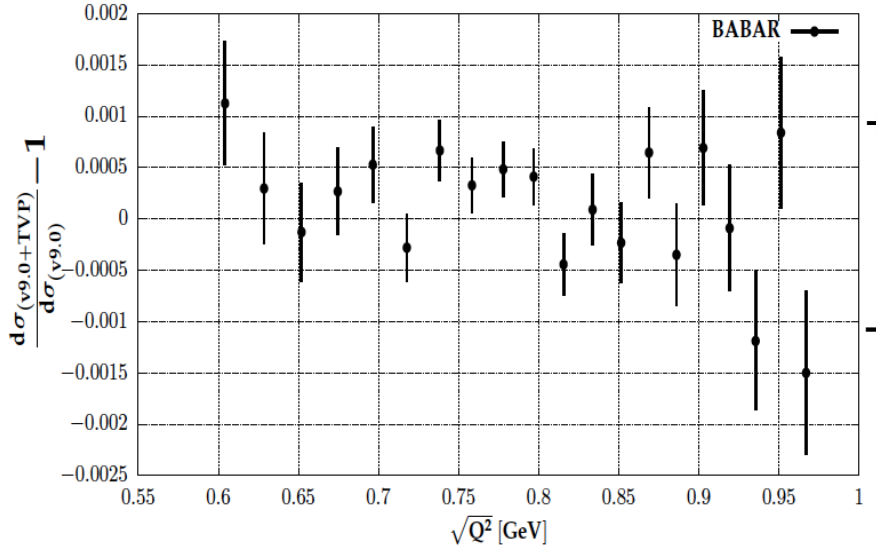
## Complete NLO: KLOE-large




+1%

-1%

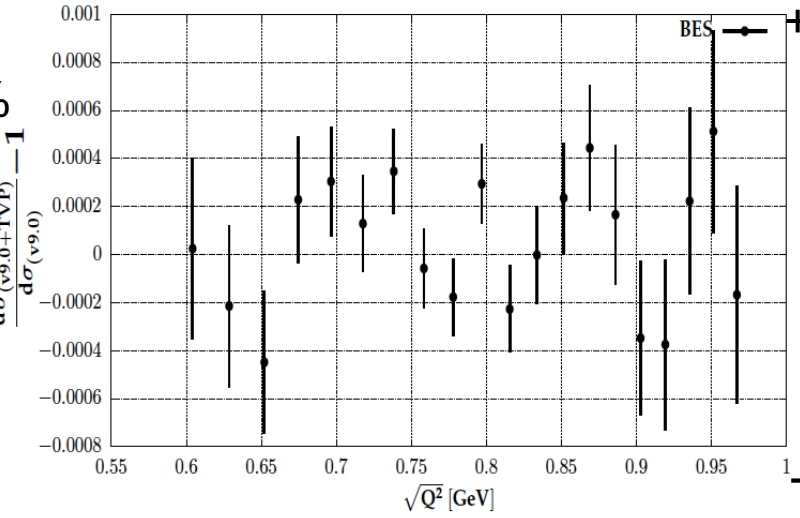
## Complete NLO: BaBar




+0.1%

-0.1%

## Complete NLO: BES




+0.1

-0.1

# Conclusions

H. Czyz,
TI Workshop 2019

$\Rightarrow$ arXiv:1903.10197(tbp in PRD) and JHEP 1402 (2014) 114

show that missing NLO radiative corrections

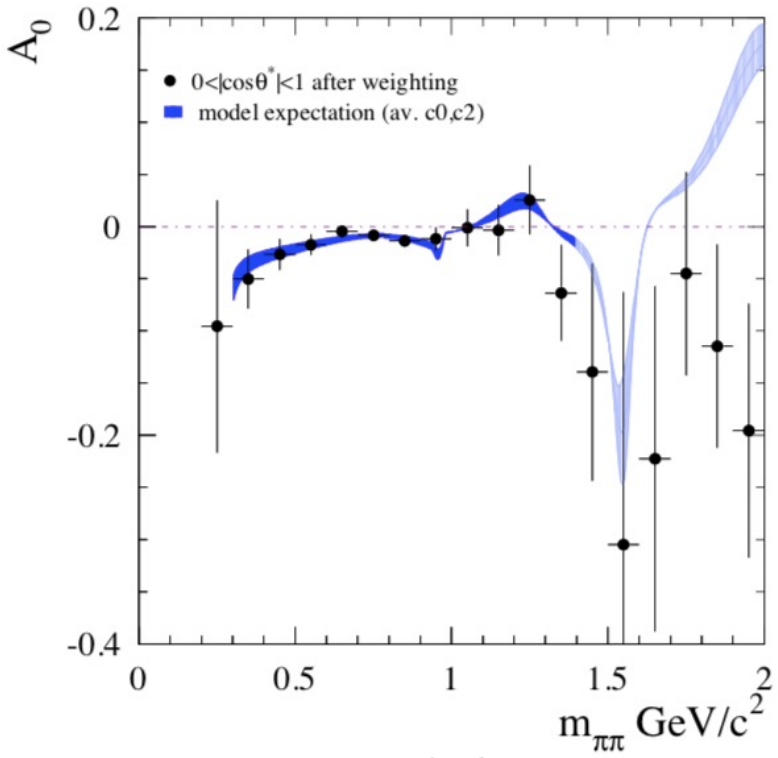
cannot be the source of the discrepancies between

the different extractions of the pion form factor

performed by BaBar, BES and KLOE

# Test of FSR model for pions

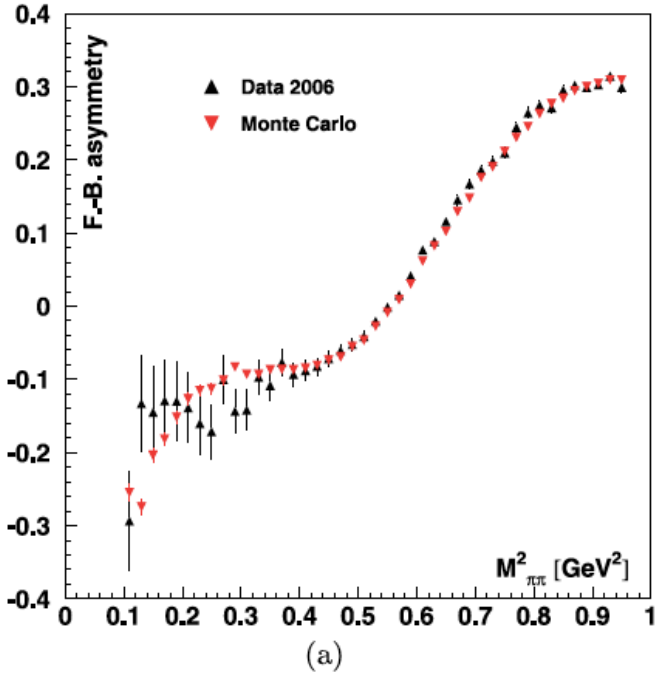
## Charge asymmetry




BaBar vs AfkQed
PRD92 (2015) 7, 072015

Quark model for FSR by pions

## F.B. asymmetry



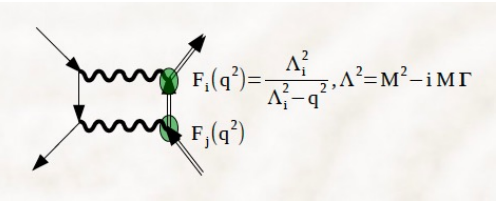

KLOE vs Phokhara
PLB634 (2006) 148
EPJC 66 (2010) 585

sQED model (pointlike pions) for FSR

Effect from FSR NLO can be as large as 5-10% at low $m_{\pi\pi}$ (EPJC33(2004) 333)

# FSR parametrization

## Inclusion of double Photon exchange



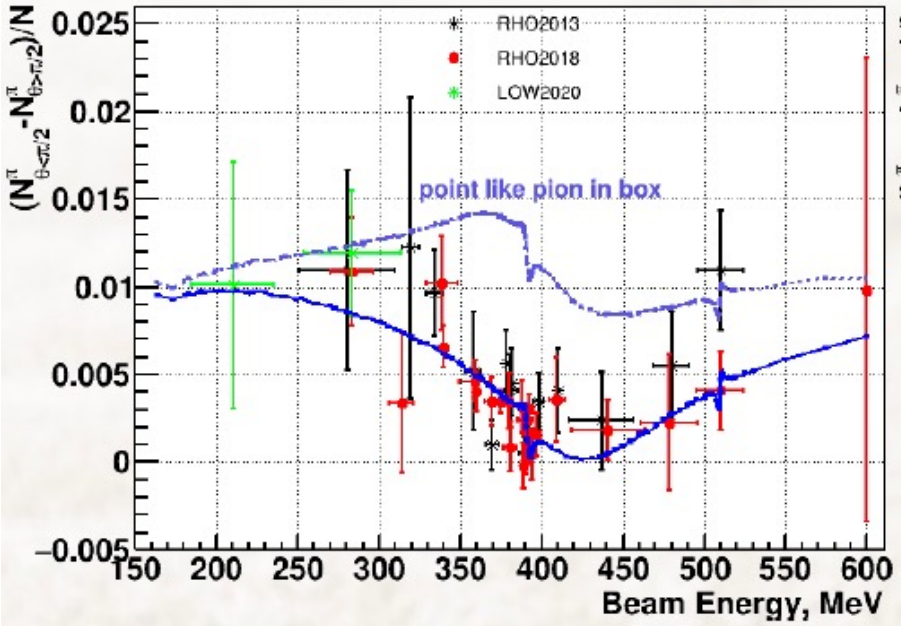

## Asymmetry

F. Ignatov

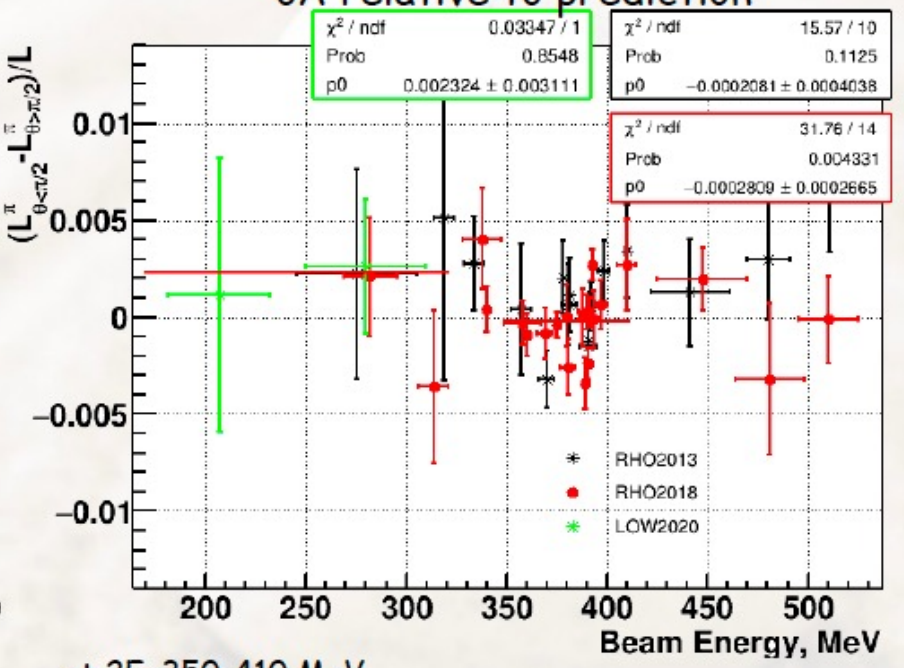
$$A=\frac{N_{\theta<\pi/2}-N_{\theta>\pi/2}}{N_{\theta<\pi/2}+N_{\theta>\pi/2}}.$$

After plugging δvFF in MCGPJ generator

Asymmetry




δA relative to prediction




at 2E=350-410 MeV

<δA> = -1.035 ± 0.022 %

<δA> = -0.026 ± 0.022 %

F. Ignatov, R. N. Lee

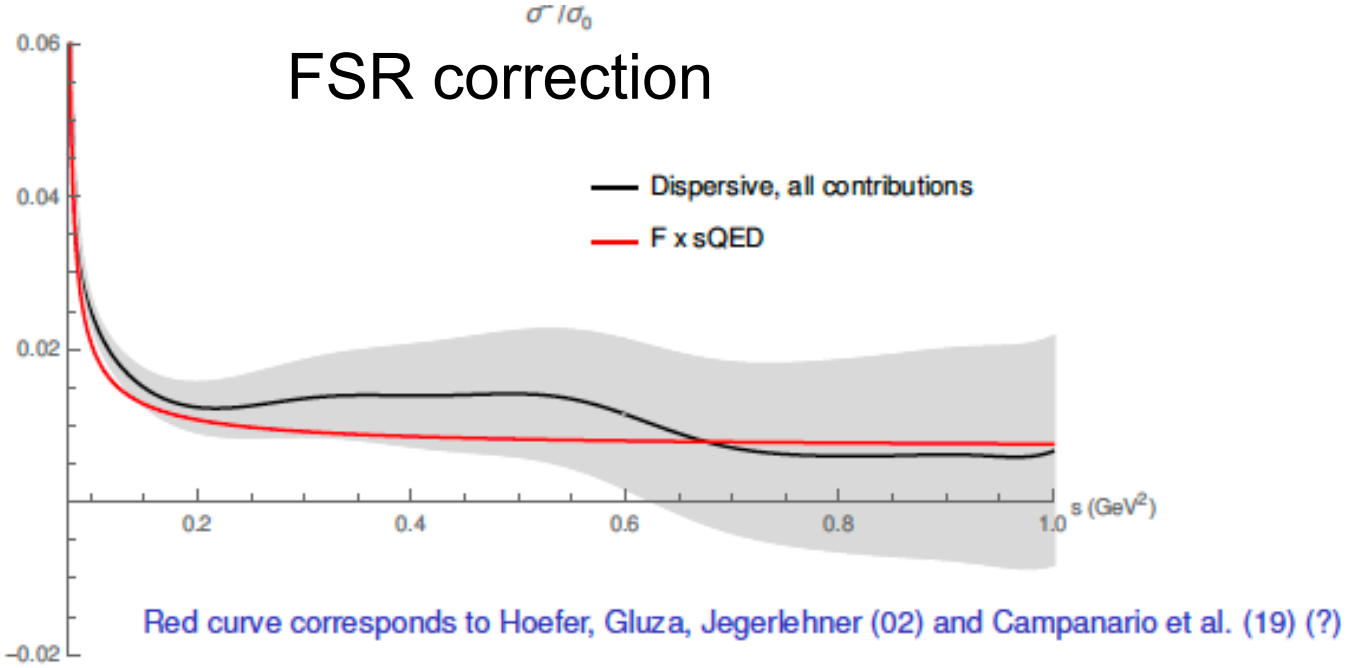
arXiv:2204.12235 [hep-ph]

# Form factor parametrization

G. Colangelo

## Dispersive treatment of FSR in $e^+e^- \to \pi^+\pi^-$

FSR correction




See also G. Colangelo et al, arXiv:2207.03495

# Moving forward…

➢**WorkStop** on "**Radiative corrections and Monte Carlo tools for low-energy hadronic cross sections in e+e- collision**" **05-09 June 2023,** University of Zurich (LOC: A. Signer, G. Stagnitto, Y. Ulrich)

- Structure: Three-day in-person WorkStop/ThinkStart with a small group of people (~25) possibly followed by a two-day conference-style event (with possible remote participation)
- Work packages:

- WP1: Leptonic processes at NNLO [T. Engel, W. Torres Bobadilla]
- WP2: Form factor contributions at N3LO [M. Fael, Y. Ulrich]
- WP3: Processes with hadrons [P. Stoffer, T. Teubner]
- WP4: Parton showers [C. M. Carloni Calame, M. Schonherr, A. Price]
- WP5: Experimental input [ BaBar, BelleII, BESIII, KLOE, Novosibirsk]

Teams starts to work around October, meet three days in Zurich

Aim to write a report by Autumn 2023 (authors not restricted to participants to the WorkStop)

# Going forward: Strong2020: a database for $e^+e^-$ into hadrons

- European project (http://www.strong-2020.eu)
- WP21 — JRA3 PrecisionSM: "*Hadron Physics for Precision Tests of the Standard Model*"
- Goal: combine theory and experiment for precision tests SM & BSM
- **Task 2: Hadronic Effects in Precision Tests of the electromagnetic sector of the Standard Model: Muon g-2:**
  - 2.1 Hadronic Vacuum Polarization from spacelike and timelike processes
  - 2.2 Hadronic Light-by-Light Scattering Contribution to $(g-2)\mu$
- Deliverable for Task 2.1:
  - Annotated database for low-energy hadronic cross sections in e+e- collisions.

Conveners (Task 2): A. Kupsc (Uppsala), GV

# Procedure

- Web page (https://precision-sm.github.io/)
- Input data (from HEPData)
- Check of «consistency» of input data
- Annotate the data according  the treatment of RC,…
- Responsive Plots (cross section, covariance matrix,…)
- (Possible) Production of useful quantities (VP, $\alpha_{EM}$, Adler Function…)
- Maintenance of the web page and polling to HEPData

Currently review of $e^+e^- \rightarrow \pi^+\pi^-$ data  in progress

# PrecisionSM web site (work in progress)

- Measurements Database
- HEPData submissions
  - cured by PrecisionSM
- HEPData submissions checks
- Plots



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# Measurements Database

(download)

| channel | experiment | year | ref | hepdata | details |
|---|---|---|---|---|---|
| $\pi^+\pi^-$ | BCF (ADONE, Frascati) | 1975 | ref | hepdata | details |
| $\pi^+\pi^-$ | MEA (ADONE, Frascati) | 1977 | ref | hepdata | details |
| $\pi^+\pi^-$ | MEA (ADONE, Frascati) | 1980 | ref | hepdata | details |
| $\pi^+\pi^-$ | CLEOc (CESR, Cornell) | 2005 | ref | | details |
| $\pi^+\pi^-$ | CLEOc (CESR, Cornell) | 2013 | ref | | details |
| $\pi^+\pi^-$ | CLEOc (CESR, Cornell) | 2018 | ref | | details |
| $\pi^+\pi^-$ | ACO (Orsay) | 1972 | ref | hepdata | details |
| $\pi^+\pi^-$ | ACO (Orsay) | 1976 | ref | hepdata | details |
| $\pi^+\pi^-$ | NA7 (Fixed target, CERN) | 1984 | ref | hepdata | details |

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## $\pi^+\pi^-$, BCF (ADONE, Frascati), 1975

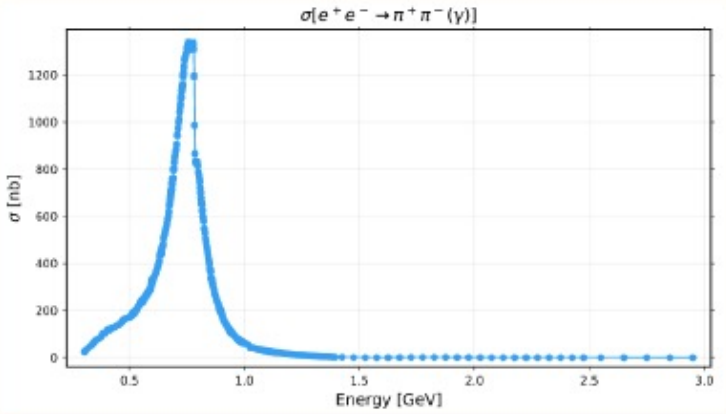
- hepdata: ins100180
- method: Direct
- quotes: $F_\pi$
- energy [GeV]: 1.44 - 9
- rad_corr:
  - No Mention
- comment:
  - Errors not divided

# Web site, read BaBar $e^+e^- \to \pi^+\pi^-(\gamma)$ and make plots

## cross-section

In [56]:
```
##
## plot cross-section vs. energy (stat. unc. only)
##
curpl = @df sigma_df plot(
  :E,
  :sigma_val,
  yerror = :sigma_unc,
  title = L"$\sigma[e^+e^- \rightarrow \pi^+\pi^-(\gamma)]$",
  xlabel = "Energy [GeV]",
  ylabel = L"$\sigma$ [nb]",
  markerstrokecolor = :auto,
  legend = false
)
## mysavefig(curpl, "curpl.pdf")
## display(curpl)
```

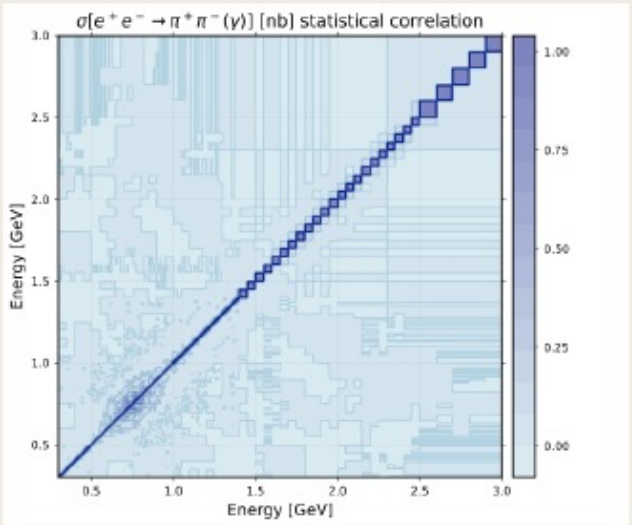
Out[56]:




## correlation

In [65]:
```
##
## plot statistical correlation contour plot
##
curpl = @df sigma_df contourf(
  range(extrema(vcat(:E_l, :E_h))..., length=500),
  range(extrema(vcat(:E_l, :E_h))..., length=500),
  sigma_stat_corr,
  ## clims = sigma_stat_corr_clims,
  color = :blues,
  title=L"$\sigma[e^+e^- \rightarrow \pi^+\pi^-(\gamma)]$ [nb] statistical correlation",
  xlabel="Energy [GeV]",
  ylabel="Energy [GeV]",
  size=(600, 500)
)
```

Out[65]:



# Web site, example of responsive plot

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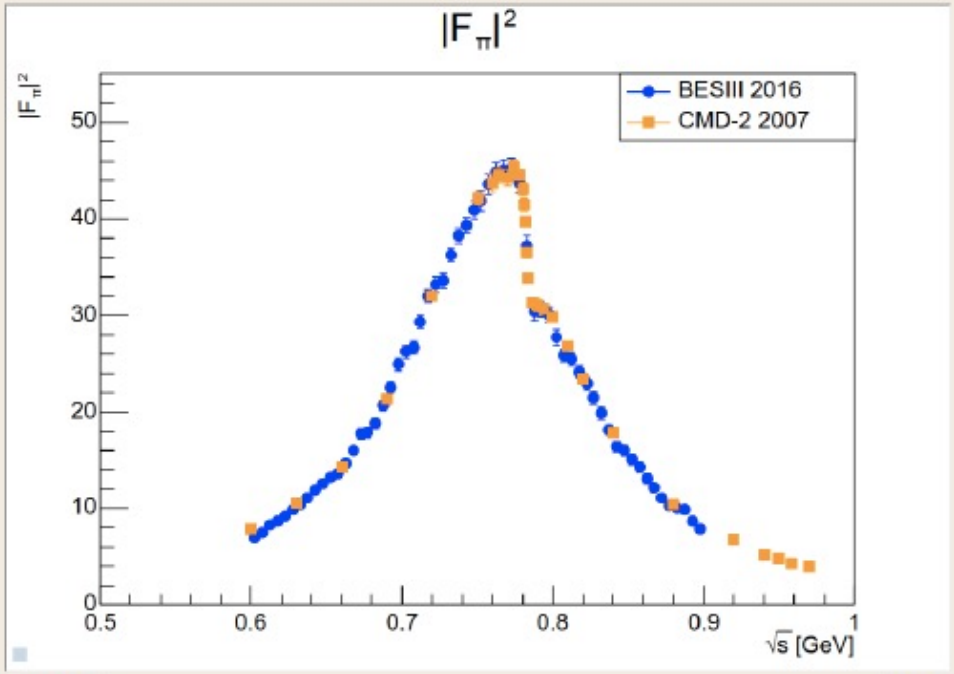
PrecisionSM Group — 2020-09-06 14:36

## Example responsive plot

Hovering the cursor above the points reveals the respective x and y values.

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# Conclusions

- A lot of effort in the last 20 years to improve MC generators and RC to $e^+e^-$ into leptons/hadrons at low energy :
  - Accuracy between 0.2 and 0.5%
- New data and improved evaluation of $a_\mu^{HLO}$ requires improvement on MC generators at ~0.1% → **NNLO needed!**
- **Radio MonteCarLow** activity still important!

➢ **WorkStop** on **"Radiative corrections and Monte Carlo tools for low-energy hadronic cross sections in e+e- collision"** is planned on for the week **05-09 June 2023** at the University of Zurich (LOC: A. Signer, G. Stagnitto, Y. Ulrich)

- **Strong2020** project will contribute with a database for low-energy hadronic cross sections in $e^+e^-$ collisions with relevant information (RC treatment, syst errors,…)

*If you are interested to contribute you are welcome!*

END

# Submit HEPData BaBar 2012 $\sigma(e^+e^- \to \pi^+\pi^-(\gamma))$

PrecisionSM Group — 2021-11-22 12:00

## HEPData submit BaBar 2012 $\sigma(e^+e^- \to \pi^+\pi^-(\gamma))$

### Paper

- Phys.Rev.D 86 (2012) 032013, 2012
- InspireHEP 1114155

### HEPData documentation for submissions

- https://hepdata-submission.readthedocs.io/en/latest/

### Requirements

- hepdata_lib python3 library
  - ROOT with Python3 libraries
  - ImageMagick
  - Make sure that you have `ROOT` in your `$PYTHONPATH` and that the `convert` command is available by adding its location to your `$PATH` if needed.

### Notes

In the supplementary material, numbers are printed into strings. We do not convert these strings to numeric format when reading the supplementary material, since the hepdata_lib code works with strings as well.

In [

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# Plot BaBar 2012 $\sigma(e^+e^- \to \pi^+\pi^-(\gamma))$

PrecisionSM Group — 2020-06-10 19:52

## Plot BaBar $\sigma(e^+e^- \to \pi^+\pi^-(\gamma))$

The latest BaBar measurements are published in two papers, a PRL and a later PRD containing more detailed information. Both papers report the cross-section information in the supplemental material, in ASCII files that are identical.

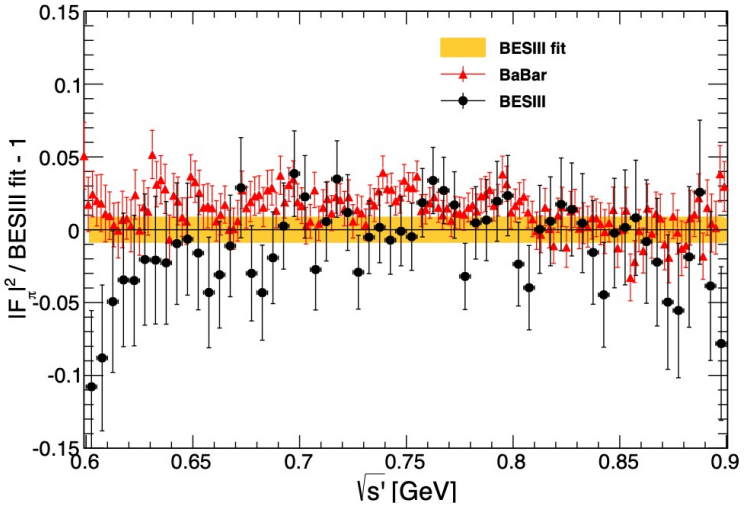
- B. Aubert et al. [BaBar Collaboration], Phys. Rev. Lett. 103 (2009) 231801, inspirehep,
  "Precise measurement of the e+ e- ---> pi+ pi- (gamma) cross section with the Initial State Radiation method at BABAR"
- J. P. Lees et al. [BaBar Collaboration], Phys. Rev. D 86 (2012) 032013, inspirehep,
  "Precise Measurement of the e+e− → π+π−(γ)e+e−→π+π−(γ) Cross Section with the Initial-State Radiation Method at BABAR"
  - supplemental material folder
    - BABAR_ISR2pi_EPAPS.txt

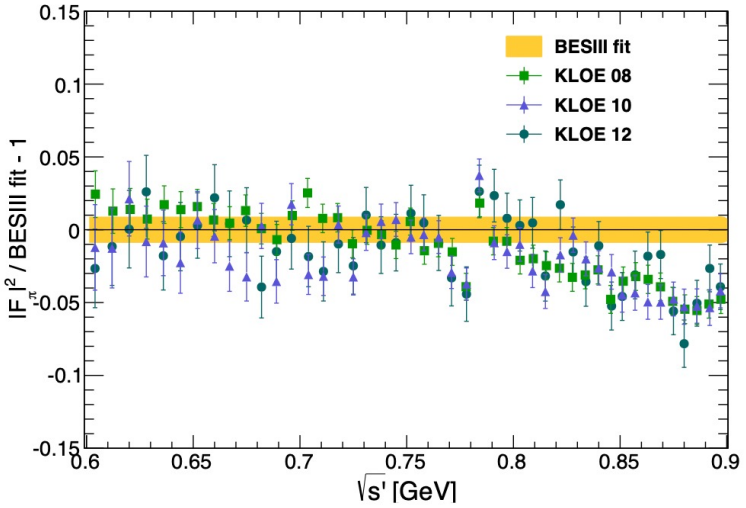
The data report the "**bare cross section including FSR**" in nb, and in detail:

- the cross-section and its total undertainty in variable-width bins of energy
- the per-mil relative systematic uncertainty (per energy bin, 100% correlated on all bins)
- the statistical correlation between any two bins of cross-section

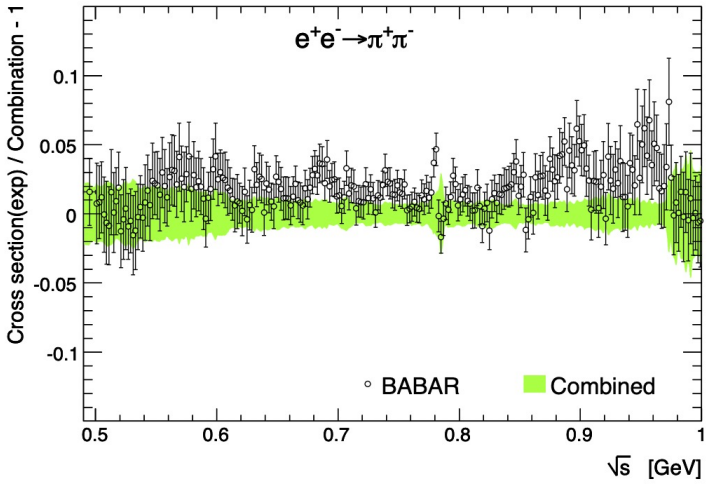
In the following the data are used to show a few plots using the Julia language.

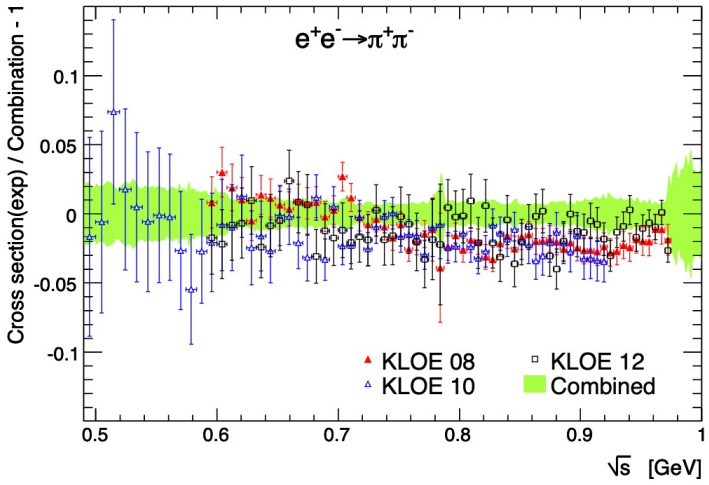
# ISR measurements





# HEPData submissions cured by PrecisionSM

PrecisionSM Group — 2022-04-30 00:00

$e^+e^- \to \pi^+\pi^-(\gamma)$

**Novosibirsk Experiments**

- Investigation of the ϱ-meson resonance with electron-positron colliding beams
  - Phys.Lett.B 25 (1967) 433-435, 1967.
  - *https://www.hepdata.net/record/ins1392895*
- Investigation of the rho-meson resonance with electron-positron colliding beams
  - Yad.Fiz. 9 (1969) 114-119, 1969.
  - *https://www.hepdata.net/record/18687*
- Electromagnetic Pion Form-Factor in the Timelike Region
  - *https://www.hepdata.net/record/6886*
- Measurement of the pion form-factor in the range 1.04-GeV to 1.38-GeV with the CMD-2 detector
  - *https://www.hepdata.net/record/41807*
- Pion Form-factor Measurement in the Reaction e+e−→π+π− for Energies Within the Range From 0.4-{GeV} to 0.46-{GeV}
  - *https://www.hepdata.net/record/18823*
- Measurement of the e+e−→π+π− process cross section with the SND detector at the VEPP-2000 collider in the energy region 0.525\<s\<0.883 GeV
  - *https://www.hepdata.net/record/114983*

HEPData

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# HEPData submissions

RSS feed

- 2021-11-22 12:00 — Submit HEPData BaBar 2012 $\sigma(e^+e^- \rightarrow \pi^+\pi^- (\gamma))$