Workstop activities: towards a NNLO MC generator for low-energy e^+e^- to hadrons

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Workstop/Thinkstart – Zürich June 5-9, 2023

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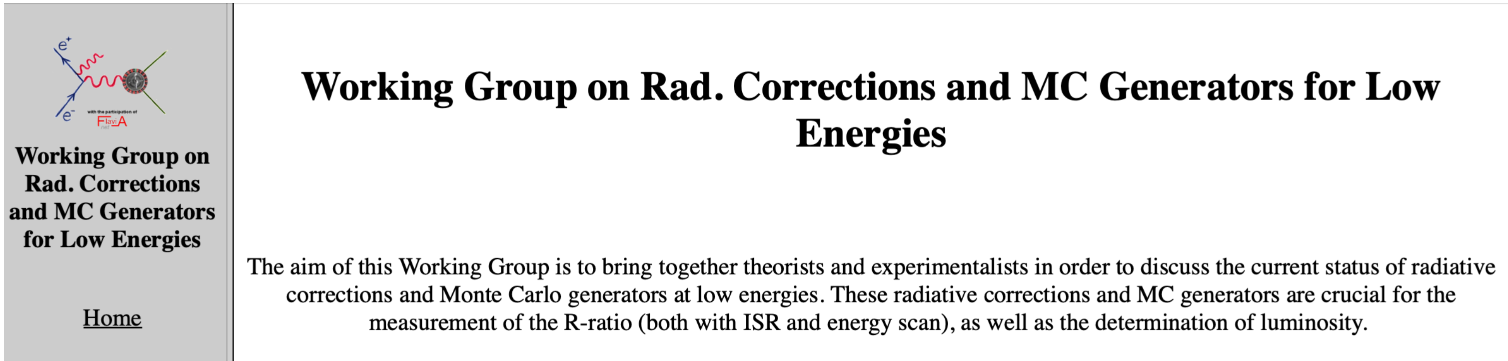
RADIO MONTECARLOW

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.

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

Web page:


Working Group on Rad. Corrections and MC Generators for Low Energies

Home

Working Group on Rad. Corrections and MC Generators for Low Energies

The aim of this Working Group is to bring together theorists and experimentalists in order to discuss the current status of radiative corrections and Monte Carlo generators at low energies. These radiative corrections and MC generators are crucial for the measurement of the R-ratio (both with ISR and energy scan), as well as the determination of luminosity.

The Subjects covered:

- Monte Carlo generators for Luminosity
- Monte Carlo generators for e+e- into hadrons and leptons
- Monte Carlo generators for e+e- into hadrons and leptons plus photon (ISR)
- Monte Carlo generators for τ production and decays
- Hadronic Vacuum Polarization, $\Delta\alpha_{em}$(Z0) and $(g-2)_{\mu}$
- Gamma-gamma physics
- FSR models and Transition Form Factors

Each of them has 2 convenors

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

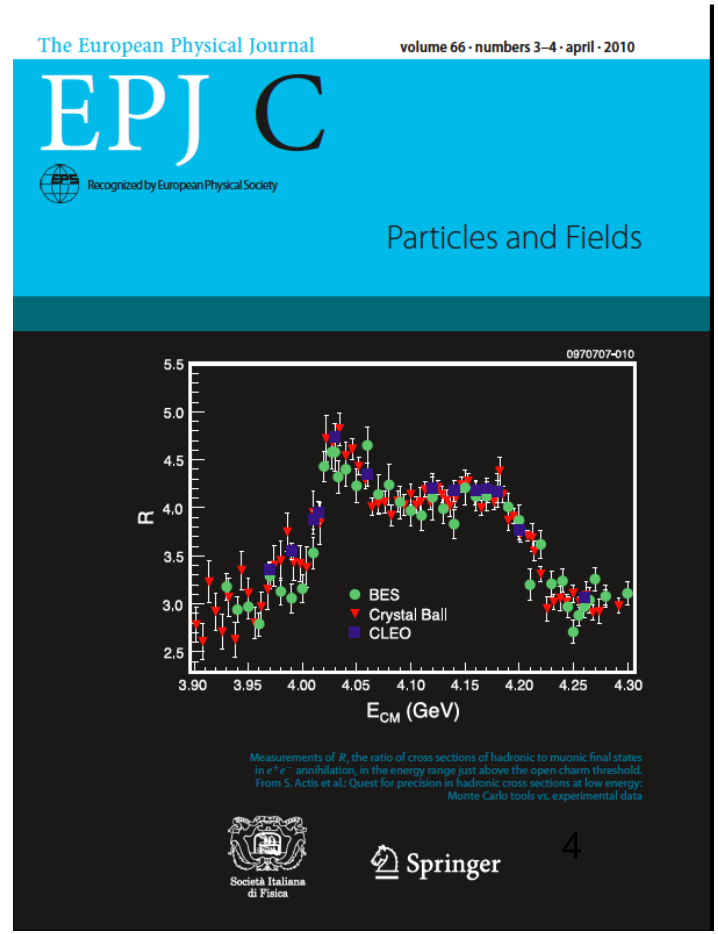
THE EUROPEAN PHYSICAL JOURNAL C

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

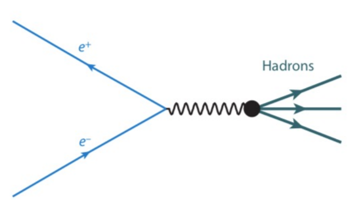
(360 citations)

2020: Moving forward…

- New data/measurements from VEPP-2000, BaBar, Belle-II, BESIII with better quality and refined systematic errors
- New theoretical calculations and tools from LHC and MUonE theory communities
- Discrepancy between lattice and dispersive approach for a_μ^{HLO}
- Discrepancy between CMD3 and previous measurements
- 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; KLOE using FB asymmetry; FB asymmetry at CMD3)

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
CARLOMAT	$e^+e^- \rightarrow$ hadrons	?	automatic computation of LO cross sections



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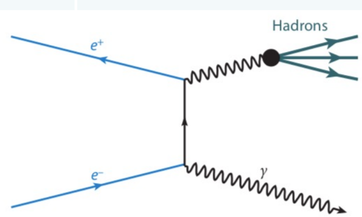
MC generators for ISR
(from approximate to exact NLO)

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



"Tuned" comparisons are essential!

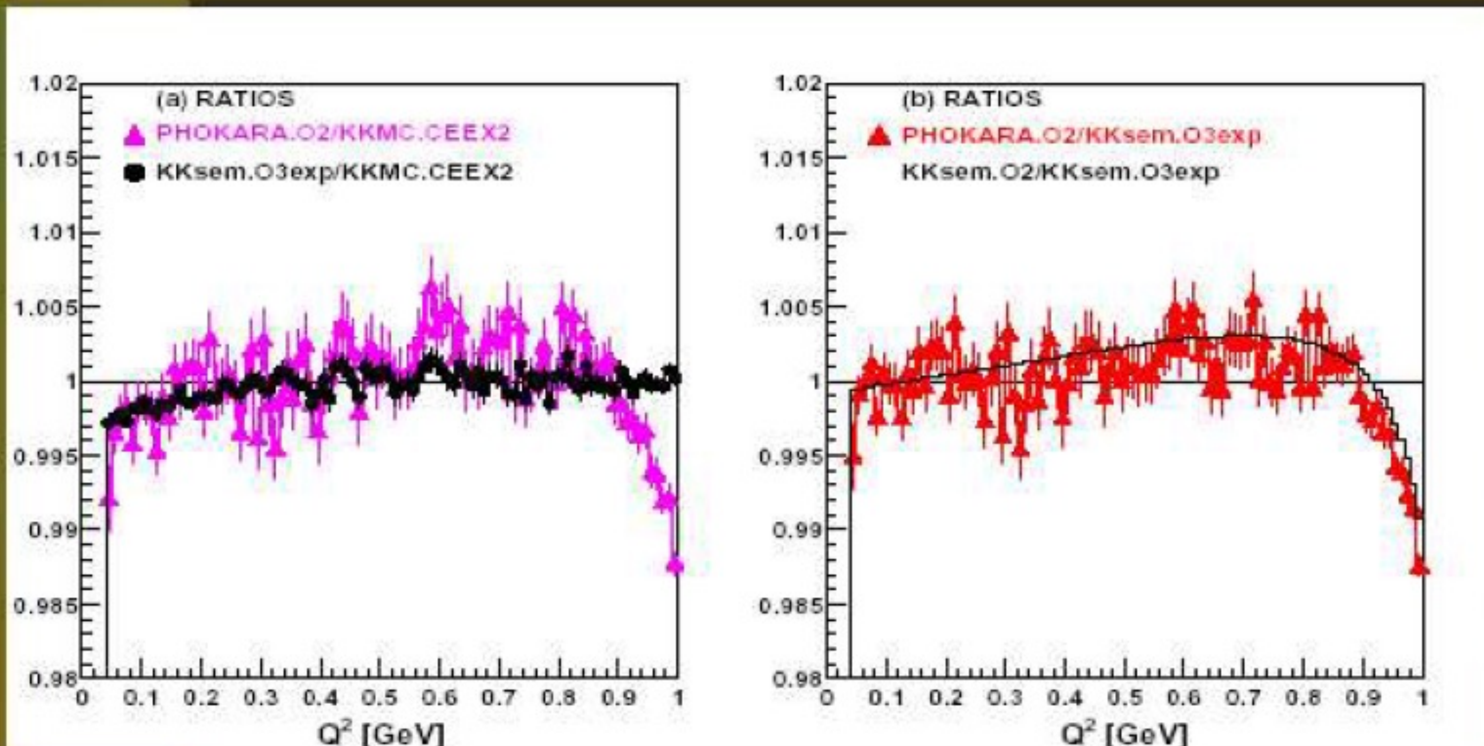
Theoretical accuracies of these generators were estimated, whenever possible, by evaluating missing higher-order contributions. From this point of view, the great progress in the calculation of two-loop corrections to the Bhabha scattering cross section was essential to establish the high theoretical 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.

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

TUNED COMPARISON are important!

PHOKHARA vs KKMC $\mu\mu\gamma$

PHOKHARA included in the game, μ-pairs again



PHOKHARA agrees to within 0.3% with KKMC and KKsem.

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

TUNED COMPARISON

PHOKHARA vs MCGPJ

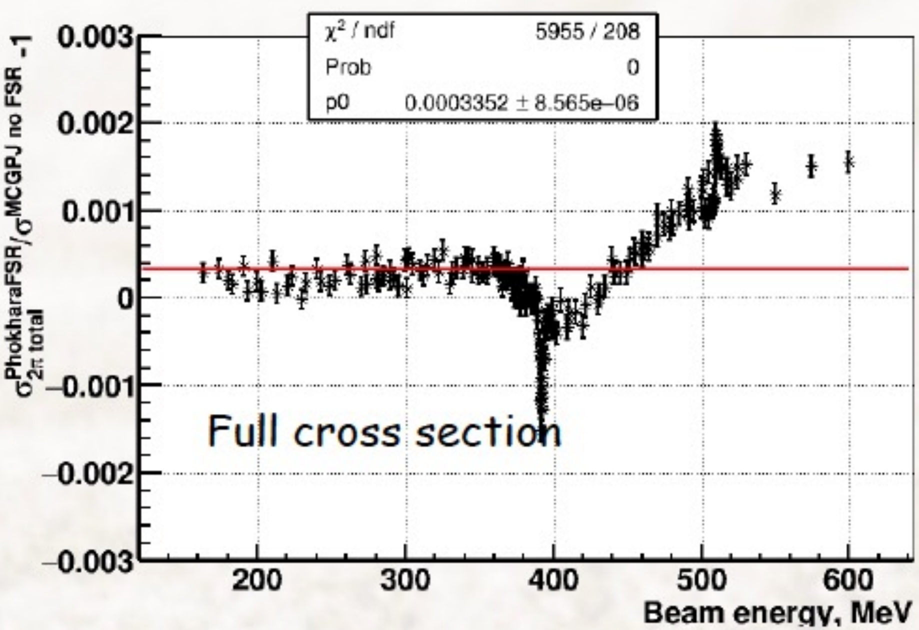
MCGPJ/Phokara

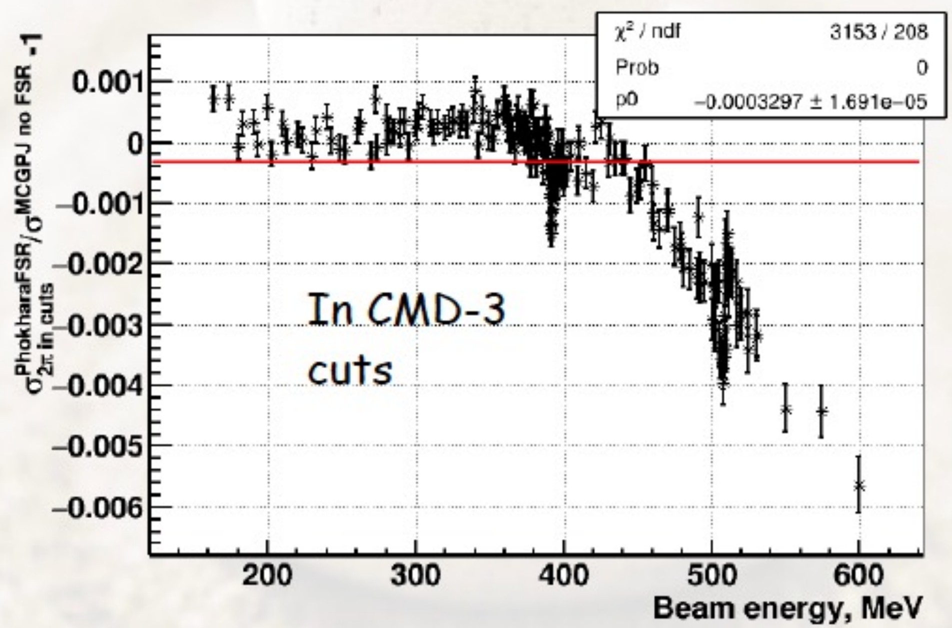
Phokara 10.0: For scan mode doesn't have FSR

CMD-3 cuts:
|Δφ|<0.15 rad,|Δθ|<0.25 rad
$1<(\theta^+ + \pi - \theta^-)/2<\pi-1$ rad
$P^{+-} > 0.45\ E_{beam}$

ISR and Fπ cross check

MCGPJ with FSR off,
Phokara 10 with same Fπ as in MCGPJ





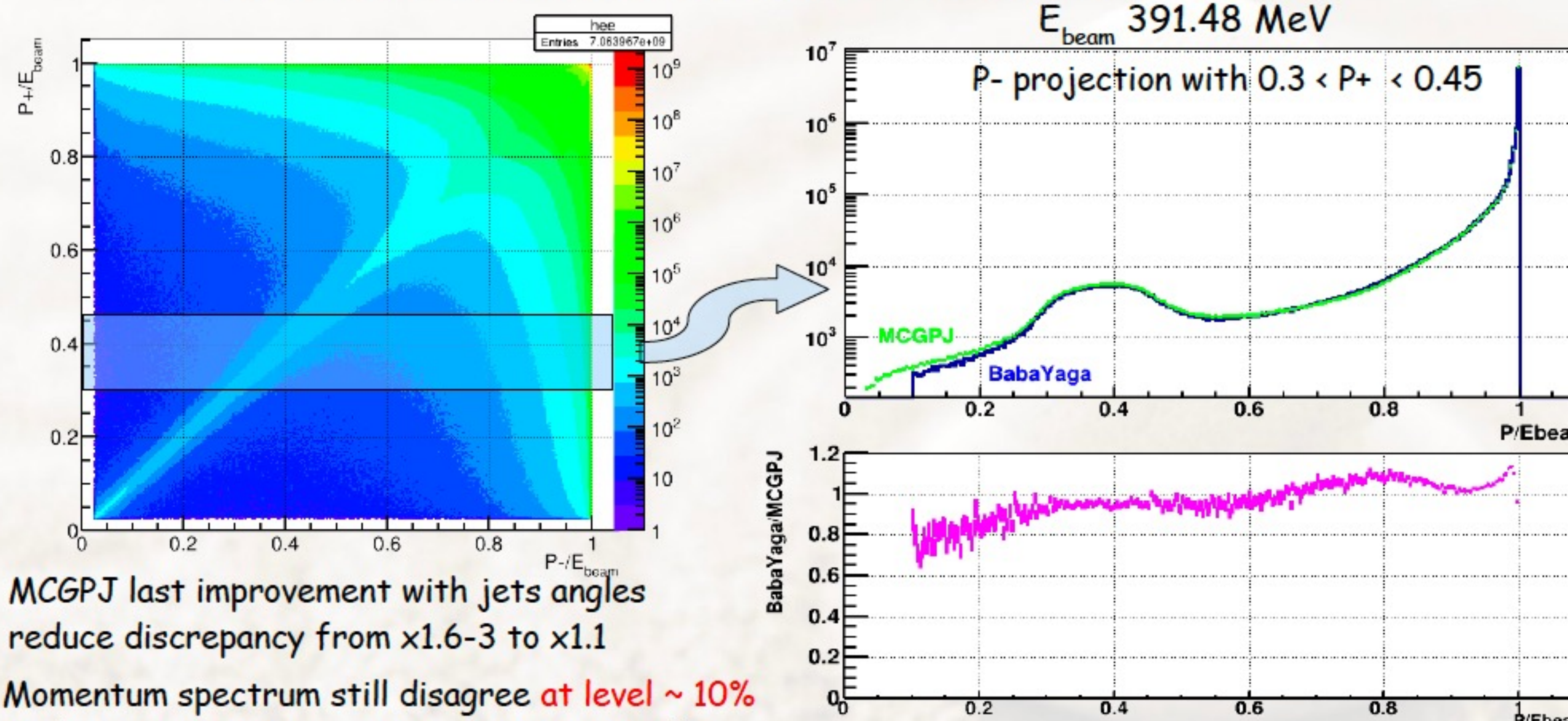
Cross section is consistent at ~0.05% at ρ-peak
(at phi ~ 0.25%)

TUNED COMPARISON

BabaYaga@NLO vs MCGPJ

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 ~0.1-0.2% systematic for π+π- at ρ-peak using momentum analysis at CMD3

TUNED COMPARISON

BabaYaga@NLO vs MCGPJ

$N_{\mu\mu}/N_{ee}$ $N_{\pi\pi}/N_{ee}$

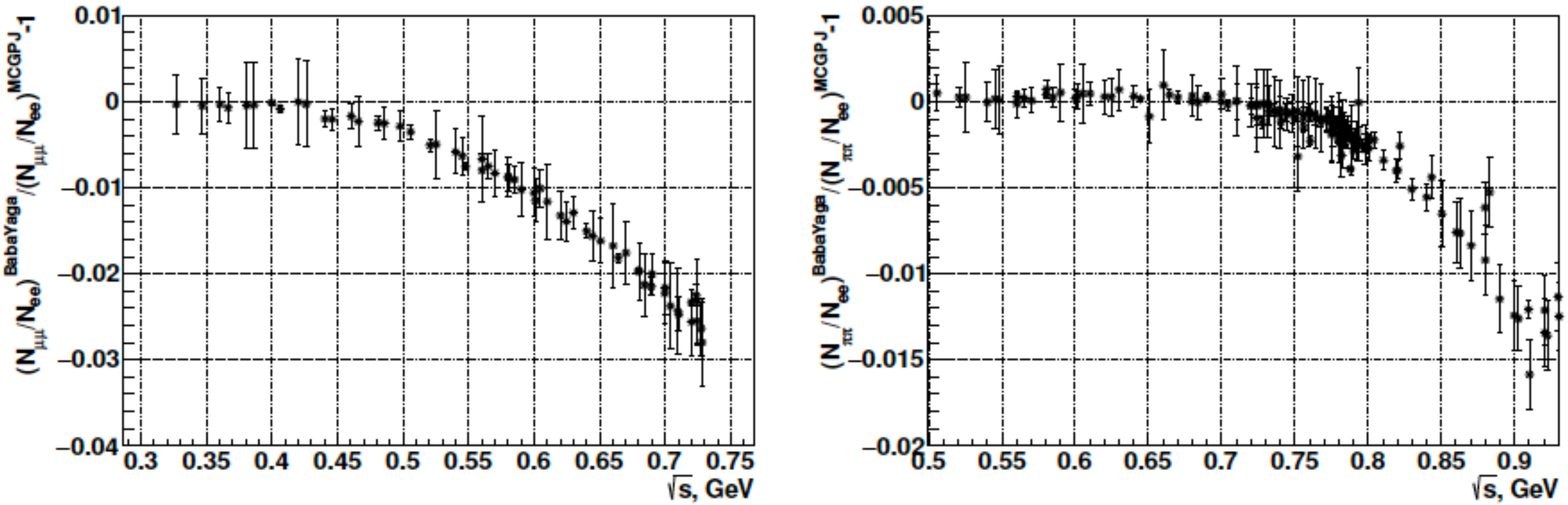
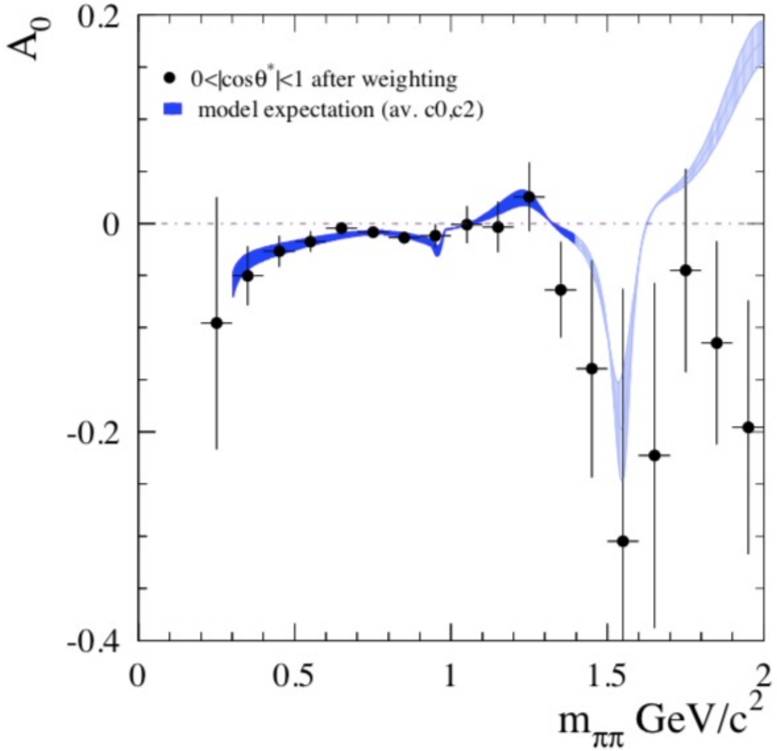


Figure 20: The relative effect on the $N_{\mu\mu}/N_{ee}$ (left) and on the $N_{\pi\pi}/N_{ee}$ (right) ratios from using the $\mu^+\mu^+$, e^+e^- momentum spectra from either the BaBaYaga@NLO or the MCGPJ generators as input for the event separation based on momentum information.

F. Ignatov et al. 2302.08834

Test of FSR model for pions

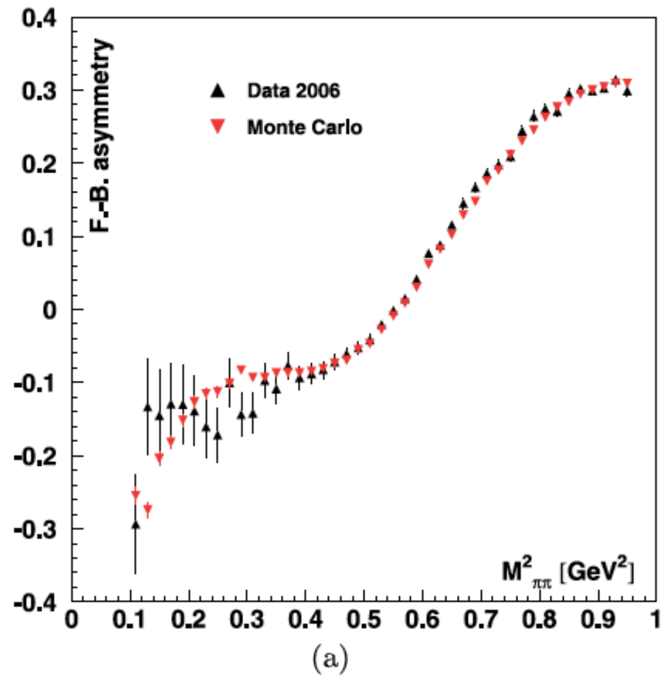
Charge asymmetry



BaBar vs AfkQed
PRD92 (2015) 7, 072015

Quark model for FSR by pions

F.B. asymmetry



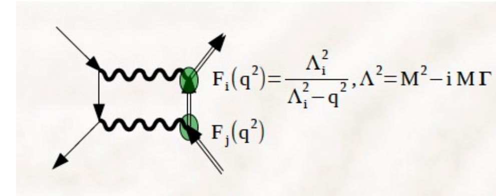
KLOE vs Phokhara
PLB634 (2006) 148
EPJC 66 (2010) 585

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)

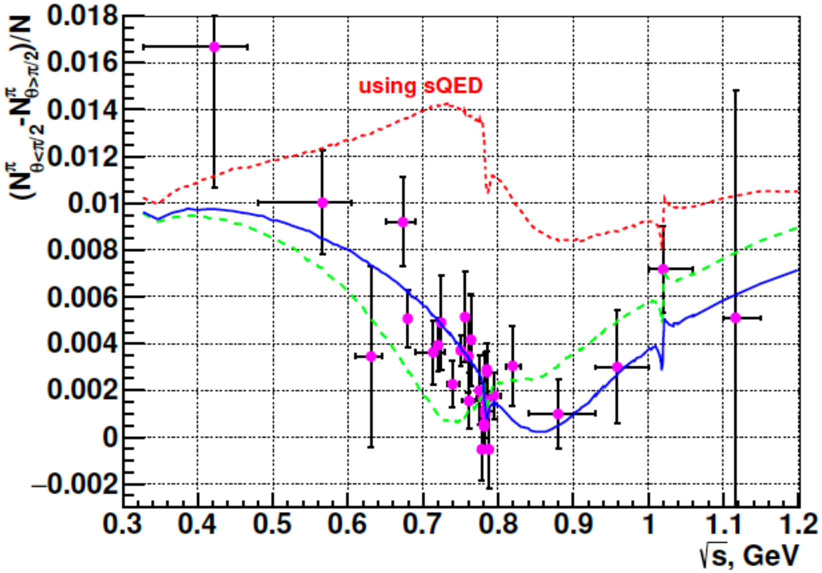
Test of FSR model for pions: CMD3

Inclusion of double Photon exchange

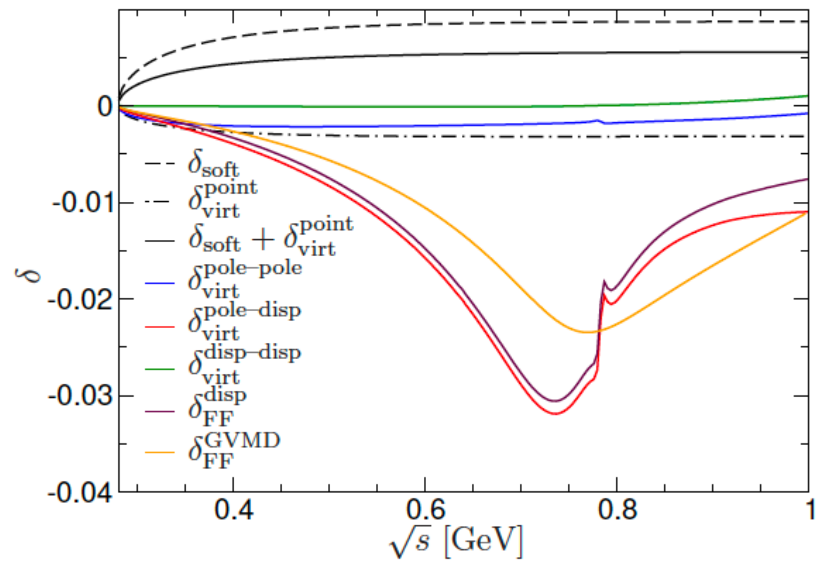


$$A = \frac{N_{\theta<\pi/2} - N_{\theta>\pi/2}}{N_{\theta<\pi/2} + N_{\theta>\pi/2}} .$$

GVMD model



Dispersive formalism



F. Ignatov, R. N. Lee

Phys. Lett. B 833 (2022) 137283

G. Colangelo *et al.*

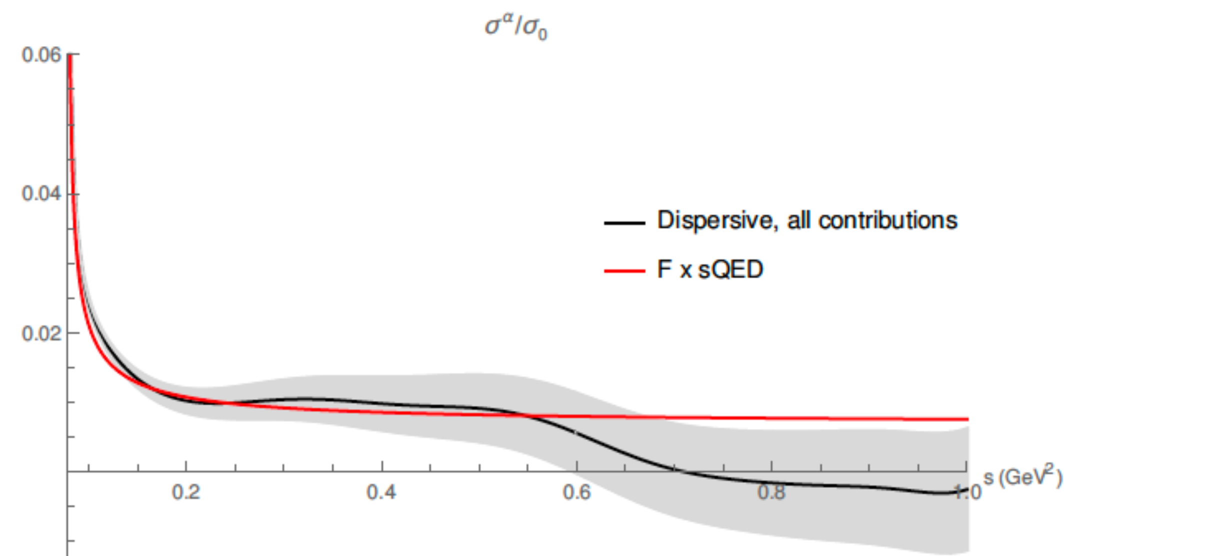
JHEP 08 (2022) 295

Test of FSR model for pions

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

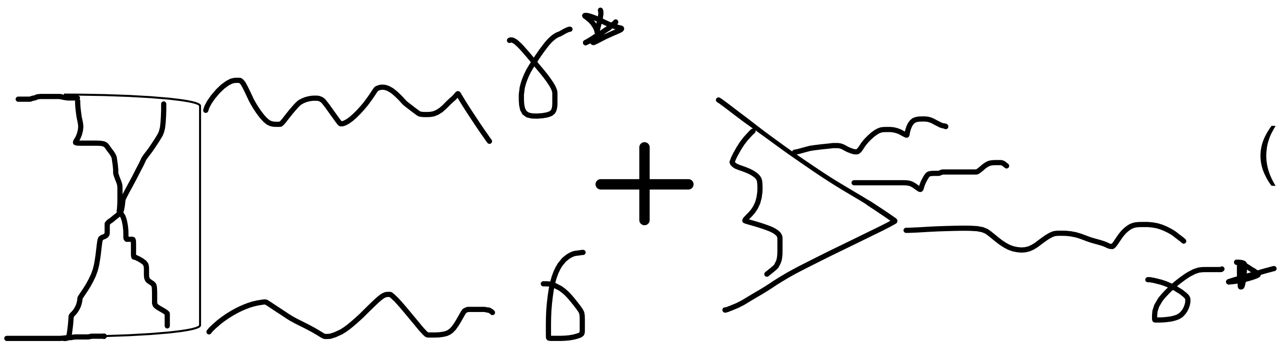
FSR correction

J. Monnard, PhD thesis 2021



Red curve corresponds to Hoefer, Gluza, Jegerlehner (02) and Campanario et al. (19) (?)

Towards NNLO MC generator ….



(+ others…)

- STRONG2020 (Virtual) meeting: 24-26 November 2021 (https://agenda.infn.it/event/28089/)
- N^3LO 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

(Strong interplay with MUonE theory activities)

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)

https://indico.psi.ch/event/13707/

- Structure: Three-day in-person WorkStop/ThinkStart with a small group of people (~25) 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]

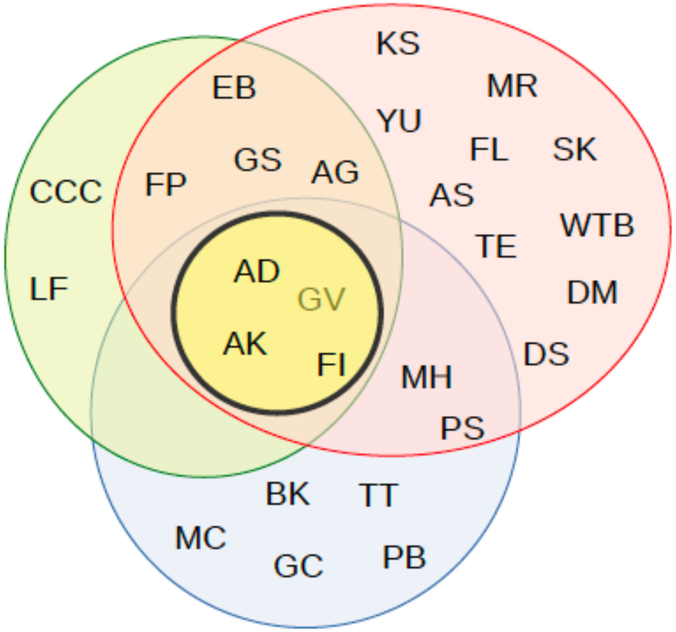
Teams started to work around October 2022, meet three days in Zurich

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

5th WorkStop

Team: P. Beltrame, E. Budassi, C. Carloni Calame, G. Colangelo, M. Cottini, A. Driutti, T. Engel, L. Flower, A. Gurgone, M. Hoferichter, F. Ignatov, S. Kollatzsch, B. Kubis, A. Kupsc, F. Lange, D. Moreno, F. Piccinini, M. Rocco, K. Schönwald, A. Signer, G. Stagnitto, D. Stöckinger, P. Stoffer, T. Teubner, W. Torres Bobadilla, Y. Ulrich, G. Venanzoni

WP1:	QED for leptons at NNLO
WP2:	Form factor contributions at N^3LO
WP3:	Processes with hadrons
WP4:	Parton showers
WP5:	Experimental input



- in the WorkStop, we 'just' want to take stock what is available and improve the theoretical description for $e^+ e^- \to$ hadrons
- main processes (input from WP5)

$$\begin{aligned} e^+ e^- &\to \pi^+ \pi^- \quad \gamma\{+\gamma\} \\ e^+ e^- &\to \mu^+ \mu^- \quad \gamma\{+\gamma\} \\ e^+ e^- &\to e^+ e^- \quad \gamma\{+\gamma\} \end{aligned}$$

- there are more processes and $(e + e-)$ in final state
- cross links with $\mu e^- \to \mu e^-$ and $\ell p \to \ell p$
- here: link WP1/2 – WP3 – WP4

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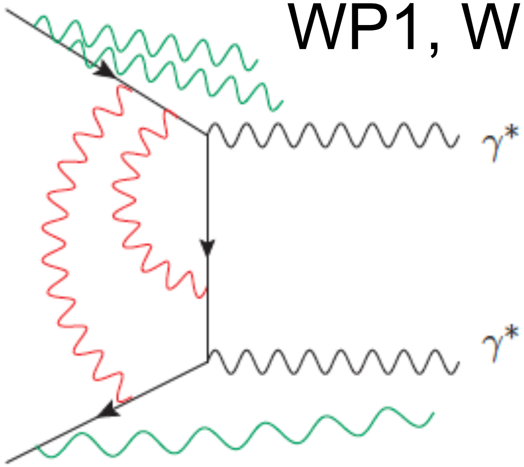
Workstop activities… (drawings from A. Signer)

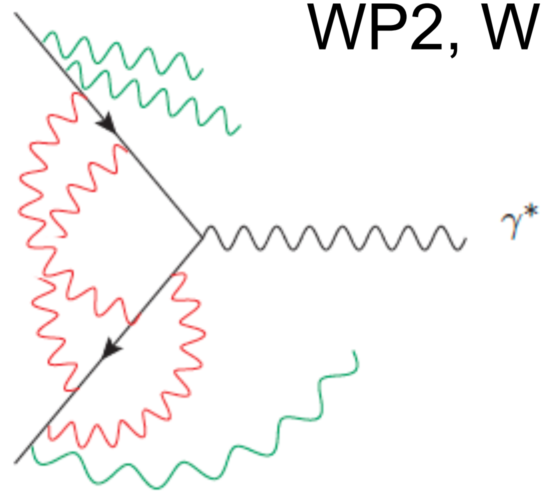
Buliding block $e^+ e^- \to \gamma^* \gamma^*$

WP1, WP4



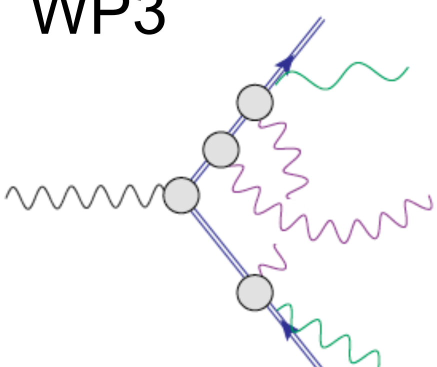
Buliding block $e^+ e^- \to \gamma^*$

WP2, WP4



Buliding block $\gamma^* \to \pi^+ \pi^-$

WP3



WP5:

Input from experiments

CMD3, SND,
CMD2, CLEO,….

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WP5: Experimental inputs

BES-III

1) which are the processes which need progress from the theory?

- ππ,ππg (QED and effects beyond sQED)
- μμ(g) (QED)
- ee(g) (add the generation of events where one or both tracks are emitted at small angles)
- 3π and 4π (FSR + new fit of FF to available data)

2) a set of "useful" observables to test the theory prediction (for example: FB asymmetry, charge asymmetry, etc…);

Effects to be included and tested:

- interference for ππ at NLO (2ISR with 1ISR+1FSR)
- radiative production and/or decay of hadrons

3) a minimum set of experimental conditions and cuts which apply to "your" experiment where to compare the theory prediction.

- angular acceptance: 21-159 degree for charged particles, 25-155 degree for photons
- momentum acceptance: > 200 MeV for charged particles, > 25 MeV for photons (50 MeV below 37 and above 143 deg)
- in untag analysis: missing momentum along the beam axis (< 5 deg)
- kinematic fit, roughly equivalent to requesting the mass recoiling against the hadronic system < 20 MeV

WP5: Experimental inputs **CMD3/SND**

List of crucial process for pi+pi- analysis are (listed in order of importance by my opinion):
1)e+e+ -> pi+pi-(gamma)
2)e+e+ -> e+e-(gamma)
3)e+e+ -> mu+mu-(gamma)

All of them looks like better to have in the NNLO order with proper matching to the next orders resummation of logarithmically enhanced corrections.
Also looks like the iterative generation of photons (as done in the BabaYaga@NLO) gives better result for some of differential cross sections.

Required predictions include (which affect analysis and part of measurable variables):
1) cross sections in used cuts,
2) differential cross section over polar angle of event and corresponding quantity as the forward backward charge asymmetry,
(in CMD-3 the polar angle is defined as average over charge particles (theta^+ + pi - theta^-)/2)
3) 2D differential cross section over momenta of charge particles, especially behavior separately in the soft photon region and in far tails.
…

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. https://precision-sm.github.io

A. Driutti, L. Cotrozzi, F. Ignatov, A. Kupsc, A. Lusiani, S. Mueller, G.V.

PrecisionSM Contents Docs About RSS feed Search

Low energy e^+e^- channels database

- Measurements Database:
  - $e^+e^- \to \pi^+\pi^-$
- HEPD...

Con...

Database for $e^+e^- \to \pi^+\pi^-$ channels

Experiment	Year	Reference (link to INSPIRE-HEP)	Link to Hepdata	Details	Status
BESIII (BEPC, Beijing)	2016	Phys.Lett.B 753(2016) 629-638 [errata: Phys.Lett.B 812 (2021) 135982]	ins1385603	details	Finalized
BaBar (SLAC, Stanford U.)	2016	Phys.Rev.D 86 (2012) 032013		details	In Preparation
CLEO (CESR, Cornell U.)	2018	Phys.Rev.D 97 (2018) 3, 032012	ins1643020	details	Finalized
CLEO (CESR, Cornell U.)	2013	Phys.Rev.Lett. 110 (2013) 2, 022002	ins1189656	details	Finalized
CLEOc (CESR, Cornell U.)	2005	Phys.Rev.Lett. 95 (2005) 261803	ins693873	details	Finalized
KLOE (DAPHNE, Frascati)	2017	JHEP 03 (2018) 173			
KLOE (DAPHNE, Frascati)	2012	Phys.Lett.B 720 (2013) 336-343			
KLOE (DAPHNE, Frascati)	2010	Phys.Lett.B 700 (2011) 102-110			
KLOE (DAPHNE, Frascati)	2008	Phys.Lett.B 670 (2009) 285-291	ins7974...		
KLOE (DAPHNE, Frascati)	2004	Phys.Lett.B 606 (2005) 12-24, 2005	ins6552...		

PrecisionSM Contents Docs Abou...

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

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

See Anna Driutti presentation

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_μ^{HLO} requires improvement on MC generators at ~0.1% → **NNLO needed!**

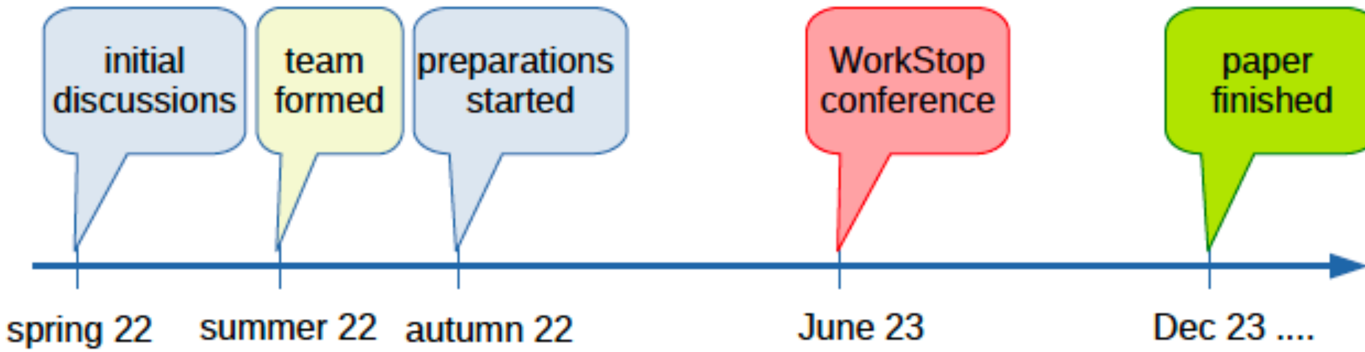
- **WorkStop** on "**Radiative corrections and Monte Carlo tools for low-energy hadronic cross sections in e+e- collision**"
  - ➢Aim to write a report by Winter 2023 (authors not restricted to participants to the WorkStop)
  - ➢Strong synergy with MuonE theoretical activities
- **Strong2020** project 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!

5^{th} WorkStop

Timeline

We are here



input / contributions most welcome

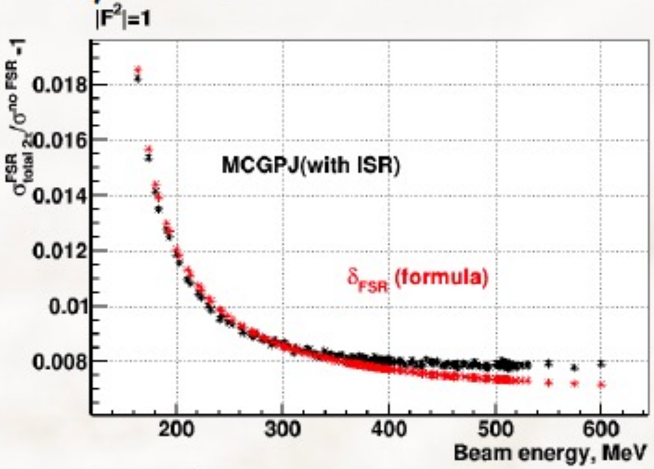
if you want to join (this means **work !**), please contact team members

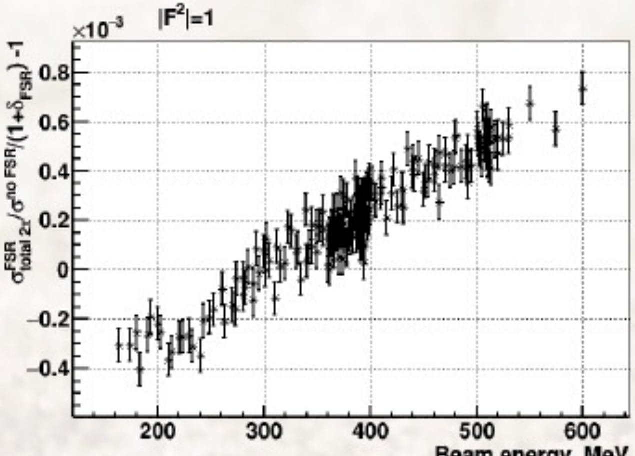
END

TUNED COMPARISON
PHOKHARA vs MCGPJ

MCGPJ FSR contribution

With Fpi=1 FSR is consistent with analytical formula at < 0.05%





$$\frac{\sigma^{FSR}}{\sigma^{no\,FSR}}-1$$

With full formfactor behaviour is different because of ISR return.
But looks reasonable