UNIVERSITY OF LIVERPOOL

LEVERHULME TRUST

MCGPJ generator & Vacuum Polarisation

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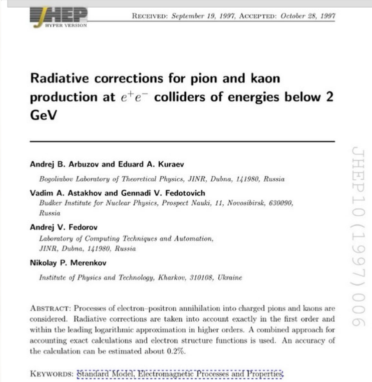
University of Liverpool

Radio MonteCarlo Low 2
Liverpool, 15 November 2024

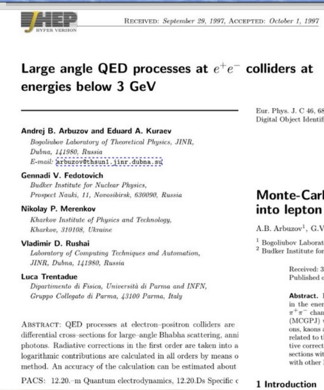
MCGPJ

MCGPJ


JHEP — Received: September 19, 1997, Accepted: October 28, 1997

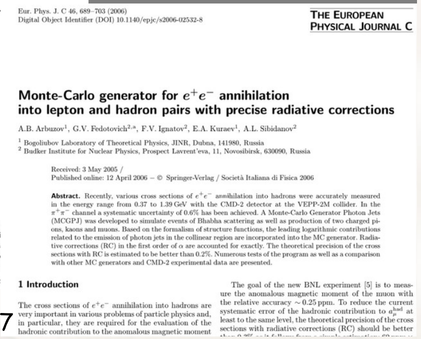
Radiative corrections for pion and kaon production at e^+e^- colliders of energies below 2 GeV

Andrej B. Arbuzov and Eduard A. Kuraev; Vadim A. Astakhov and Gennadi V. Fedotovich; Andrej V. Fedorov; Nikolay P. Merenkov


JHEP — Received: September 29, 1997, Accepted: October 1, 1997

Large angle QED processes at e^+e^- colliders at energies below 3 GeV

Andrej B. Arbuzov and Eduard A. Kuraev; Gennadi V. Fedotovich; Nikolay P. Merenkov; Vladimir D. Rushai; Luca Trentadue


Eur. Phys. J. C 46, 689–703 (2006) — The European Physical Journal C

Monte-Carlo generator for e^+e^- annihilation into lepton and hadron pairs with precise radiative corrections

A.B. Arbuzov, G.V. Fedotovich, F.V. Ignatov, E.A. Kuraev, A.L. Sibidanov

JHEP 10 (1997) 001
JHEP 10 (1997) 006
Eur.Phys.J.C 46 (2006) 689-703

The MCGPJ generator is based on the papers from 1997
Theoretical support from **Andrej Arbuzov** and **Eduard Kuraev** (JINR)
From Novosibirsk it was lead by ***Gennadi Fedotovich*** (BINP)
The code implementation by ***Alexey Sibidanov*** for CMD-2 experiment
F.Ignatov: maintenance and etc at CMD-3

MITP HVP Topical Workshop, Mainz, 06.06.24

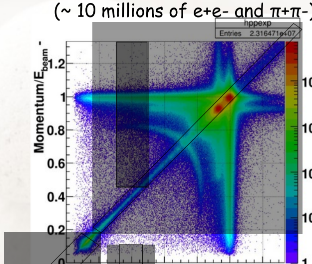
Collinear jets limitation

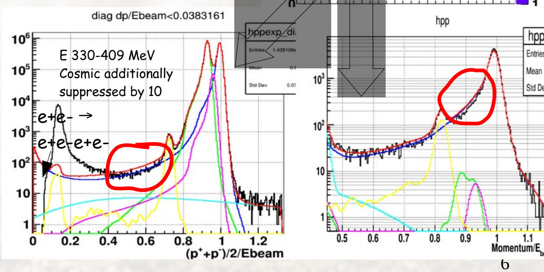
Thanks to high statistics collected by CMD-3
It was observed a discrepancy in momentum distribution of experimental data vs theoretical spectra from MCGPJ
Important only for differential distributions in tails when two-photons kinematic selections play role.
Integrated cross section for scan scenario is unaffected at ~0.06%.

Comes from collinear jets approximation
photon jets angular distribution in one photon approximation
(+ few other corrections):

$$f(c=\cos(\theta), x=\omega/E) \sim \frac{1}{pk} - \frac{x(1-x)}{1+(1-x)^2}\frac{m^2}{(pk)^2}$$
$$\sim \frac{1}{1-\beta c} - \frac{1-x}{1+(1-x)^2} * \frac{1-\beta^2}{(1-\beta c)^2}$$

All events from RHO2013 scan (~ 10 millions of e+e- and π+π-)



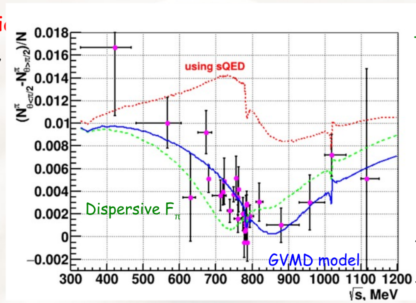


MCGPJ Bhabha – jets with angles
μ+μ- / π+π- - in collinear SF approximation

sQED limitations

Thanks to high statistics collected by CMD-3
It was observed a discrepancy in asymmetry from predicti
Integrated cross section for **scan scenario** is unaffected,
but very important for study and control of systematics!
1% effect is disaster if we talk about ~0.1% precision

Phys.Rev.Lett. 132, 231903 (2024)



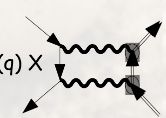
GVMD
Dispersive formalism JHEP 08 (2022) 295
Phys.Lett.B 833 (2022) 137283

Comes from limitations of sQED approach
The theoretical model within GVMD was introduced,
was confirmed by calculation in dispersive formalism

MCGPJ **π+π-** - above sQED corrections can be used via pre-calculated tables $\delta^V_{FF}(s,\cos\theta)$ either from GVMD or dispersive paper

Implemented as correction to sQED:
$d\sigma/dc = d\sigma_0/dc \times |F^2_\pi| \times (\delta_{sQED} + \delta_{FF})$

$\delta_{FF} \sim [F_\pi^{VMD}(q_1)F_\pi^{VMD}(q_2) - F_\pi^{VMD}(q)]/F_\pi^{VMD}(q) \times$



δ_{FF} – IR finite, can be calculated separately as correction

Based on paper from 1997, since that:
Angle distribution of jets only for e+e- → e+e-
GVMD & dispersive for the box diagram for π+π-

Limitations

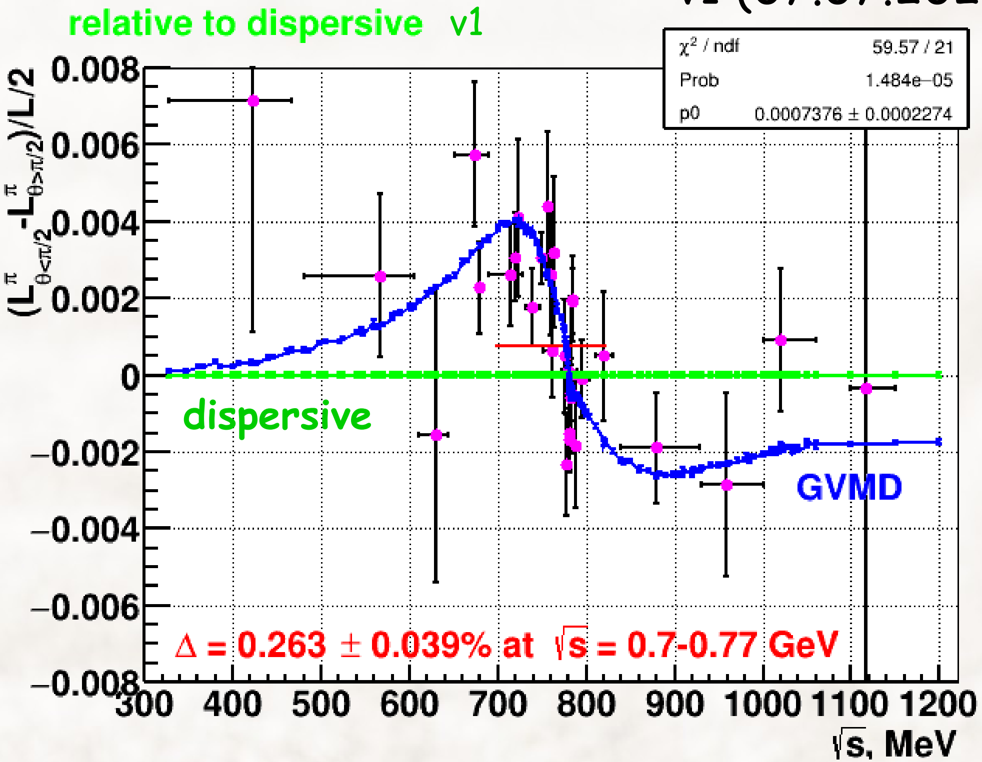
Additive matching between NLO & Collinear structures (exact NLO in some phase space)
No resummation of ISR&FSR interference

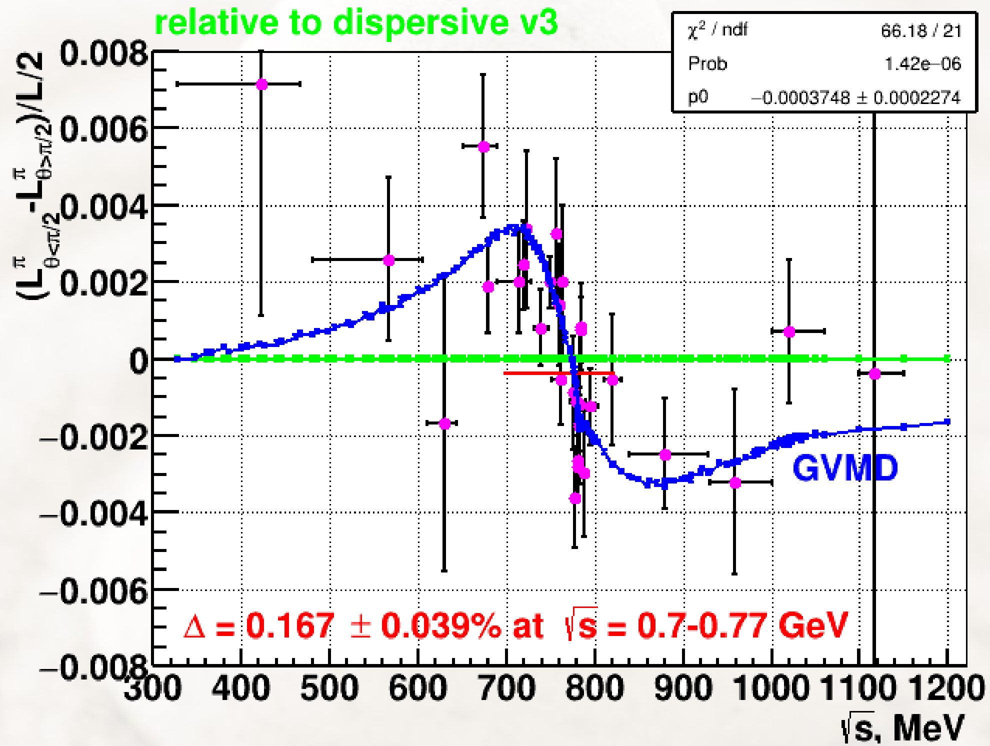
No further development is expected

Asymmetry in CMD3 π+π- data

Dispersive calculation in arXiv:2207.03495 was updated thanks to BabaYaga & Yannick

v1 (07.07.2022) → v4 (20.09.2024)



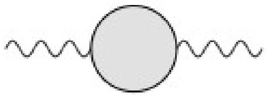


GVMD & dispersive disagree at ~0.3% -- GVMD & CMD-3 π+π- agree very well

Dispersive & data inconsistency, either :

1) systematic in data
2) something caught by GVMD but not by dispersive
3) better treatment of off-shell pion in box loop will change picture

Vacuum polarization

$$\Pi_h^{\mu\nu}(q) =$$

$$= i\,e^2 \int \mathrm{d}^4x\, e^{-iqx} \langle 0|T\{j^\mu_{\mathrm{em}}(x) j^\nu_{\mathrm{em}}(0)\}|0\rangle = \Pi_h(q^2)(g^{\mu\nu}q^2 - q^\mu q^\nu)$$

There is no any ambiguities,
the one-particle irreducible blob or the full photon propagator
is the fully defined physical tensor object

Vacuum polarization

Slide from 4th RMCL, Beijing, 2008

VP can be calculated from dispersion relation, based on analyticity and unitarity

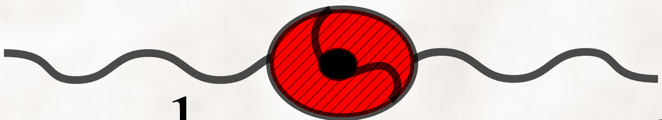
$$P(s),\Pi(s)=\frac{s}{4\pi^2\alpha}\left[PV\int_{4m_\pi^2}^{\infty}\frac{\sigma^{bare,dressed}_{ee\to\gamma\to everything}(s')ds'}{s-s'}-i\sigma^{bare,dressed}_{ee\to\gamma\to everything}(s)\right]$$

$$P(s)=P_{leptons}(s)+P_{hadrons}(s)$$

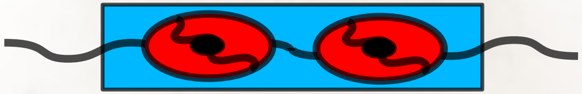
Using "bare" cross sections | "dressed" cross sections

results in

"Polarization operator"
one particle irreducible blob



"Self-energy function of photon"
Full photon propagator



$$\frac{1}{1-P(s)}=1+P+P^2+...=\quad 1+\Pi(s)$$

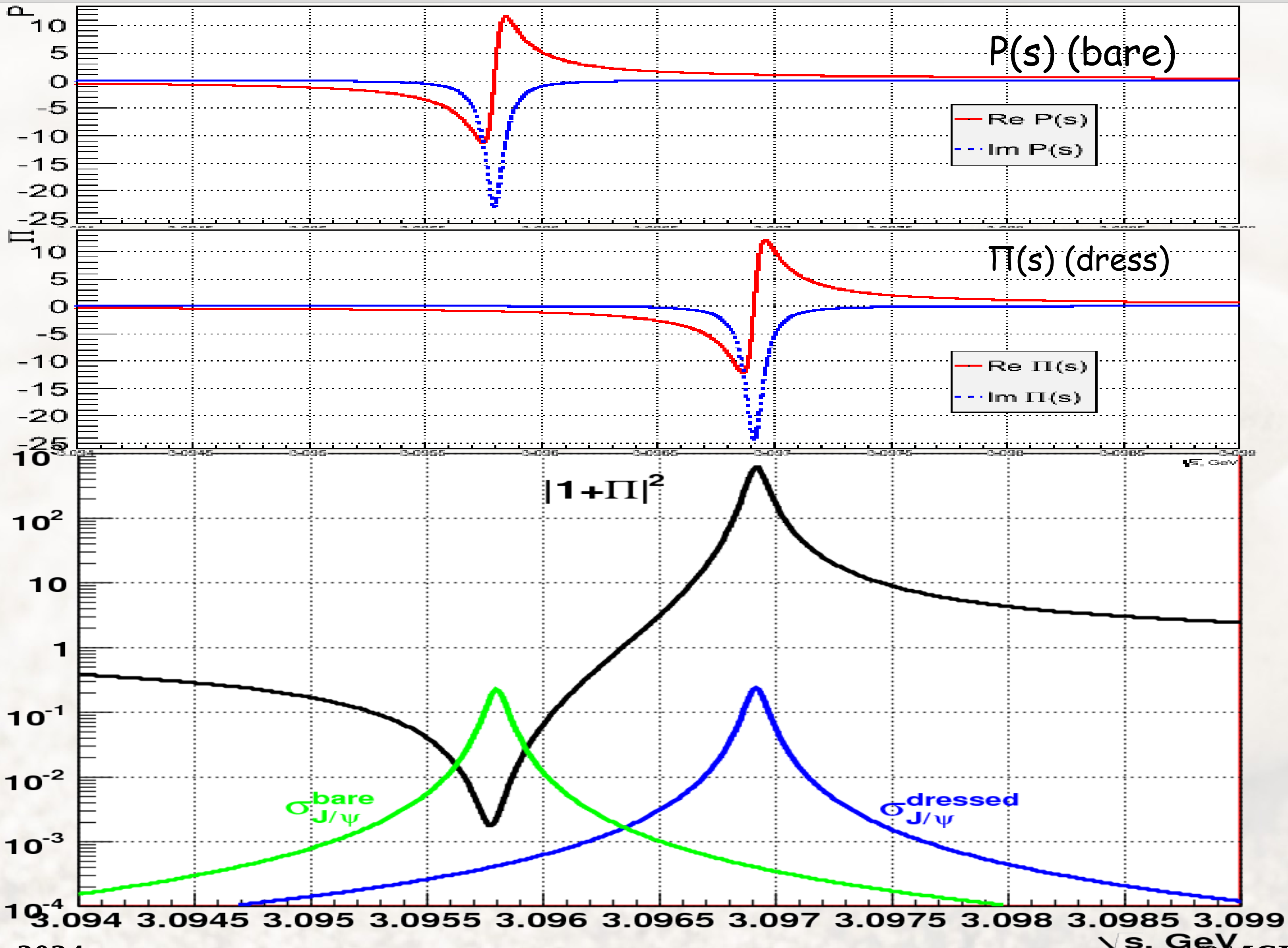
This require to use either

✗ "undress" experimental cross sections
✗ "nontrivial" task to correct physical parameters of resonances

✗ "dress" leptonic part and pQCD
✗ "dress" some of experimental data

Iterations are necessary in all cases

VP at J/Psi



P(s) (bare)
Re P(s)
Im P(s)
Π(s) (dress)
Re Π(s)
Im Π(s)
|1+Π|²
$\sigma^{bare}_{J/\psi}$
$\sigma^{dressed}_{J/\psi}$
3.094 3.0945 3.095 3.0955 3.096 3.0965 3.097 3.0975 3.098 3.0985 3.099
√s, GeV

VP

Whatever prescription of the VP will be chosen, the final objects, like

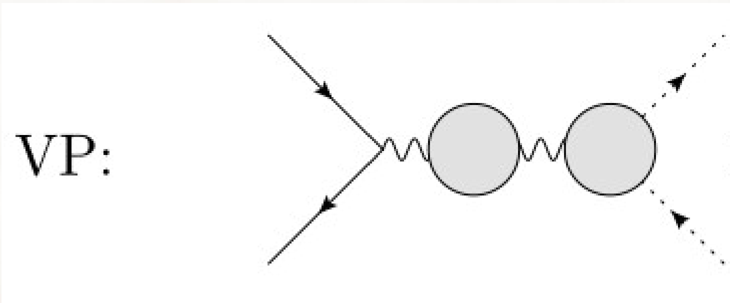
$$\mathrm{d}\sigma_{mm}(q_e^2\, q_m^2\, \Pi) = \frac{\mathrm{d}\sigma_{mm}(q_e^2\, q_m^2)}{|1 - \Pi^{\mathrm{ren}}(s)|^2}\,.$$

Should represent the physically observable resonance cross sections.

NSK VP via resummed form 1/(1-P(s)) provides this, others VP compilations do not

VP usage

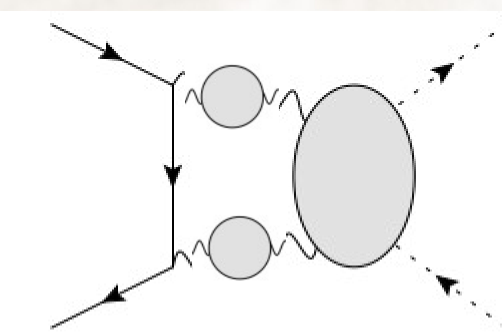
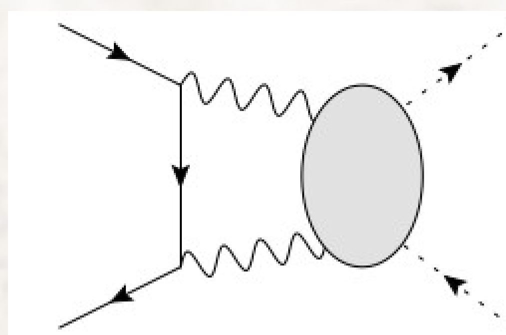
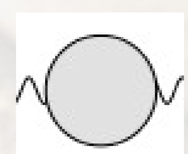
It seems, the most accurate approach is to use ressumed version of VP whenever possible



$$x\left(1+P(s)+P^2(s)+\ldots\right)=\frac{1}{1-P(s)}=1+\Pi^{resummed}(s)$$

Simplifications via order by order calculations, like
$\sigma \sim |M|^2 \times |1+\Pi(s)|^2 \sim |M|^2 \times (1+2*\mathrm{Re}\,\Pi(s))$
doesn't work on narrow resonances

Probably right now, the common approximation of VP usage in the more complicated cases is much similar like FxsQED for $\pi^+\pi^-$:

 =  X  $\sim M_{no\ VP} \times (1 + \Pi^{resum}(s))$

Way to improve