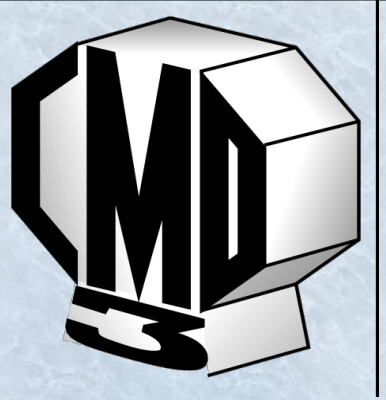


MCGPJ status:

e+e- → e+e-, e+e- → μ+μ-, ….

MC Generator with Photon Jets

Fedor Ignatov
BINP, Novosibirsk

Muon-electron scattering workshop, Padova 2017

e+e- -> π+π- by CMD3(Novosibirsk)

Very simple, but the most challenging channel due to high precision requirement.

Plans to reduce systematic error from 0.6-0.8% (by CMD2) -> 0.35% (CMD3)

Crucial pieces of analysis:

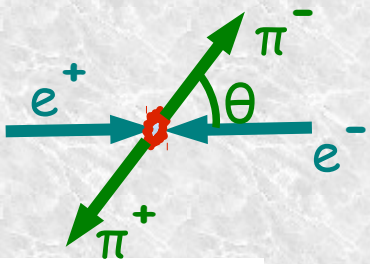
- ✗ e/μ/π separation
- ✗ precise fiducial volume
- ✗ **radiative corrections:** total cross-section, Momentum spectrums

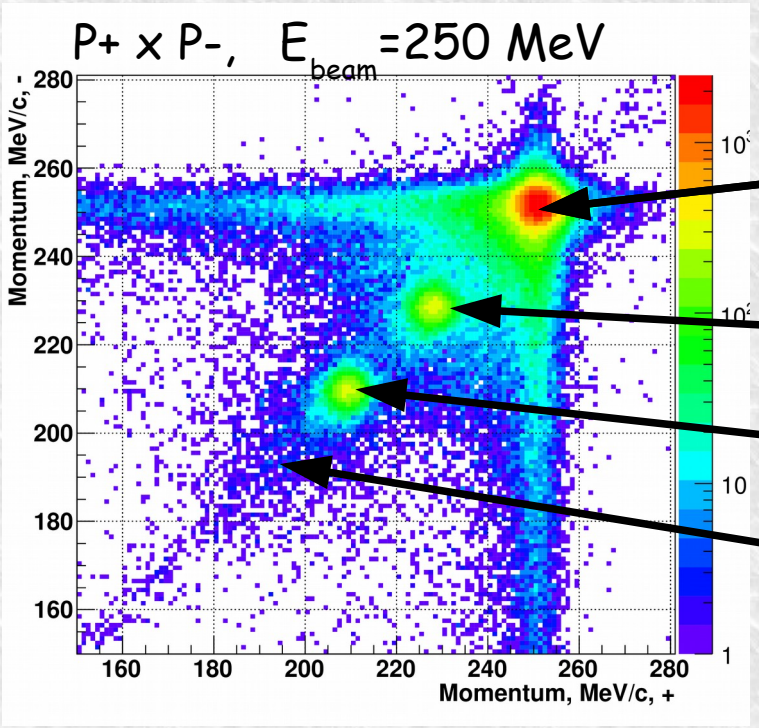
events separation either by momentum or by energy deposition

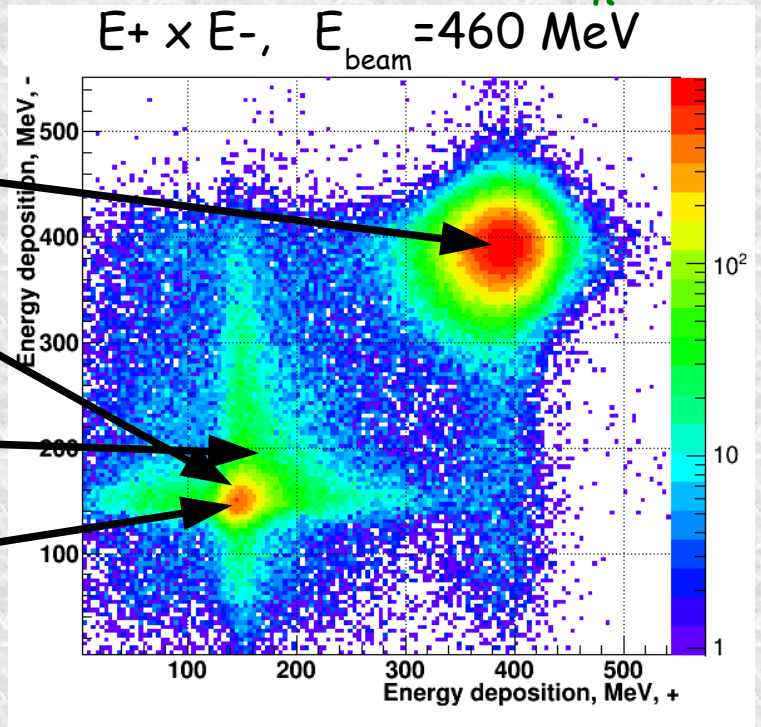
Momentums works better at low energy < 0.8 GeV

Energy deposition > 0.6 GeV

Simple event signature with 2 back-to-back charged particles







e^+e^-

$\mu^+\mu^-$

$\pi^+\pi^-$

cosmic

Many systematic studies rely on high statistics

MC generators e+e- → l+l-

High experimental precision relies on high theoretical precision of MC tools:

Several MC generators available with 0.1-0.5% precision.
Most recent e+e- -> e+e- (gamma) generators
include exact O(α) + some parts from High Order terms:

MCGPJ (VEPP-2000) – accuracy 0.2% for e+e-, μ+μ- , π+π- etc
1 real photon (from any particle)
+ photon jets along all particles (collinear Structure function)

BabaYaga@NLO (KLOE,BaBar) - 0.1% for e+e-, μ+μ-
Parton shower approach: n photons with angle distribution
interference for 1 photon radiation

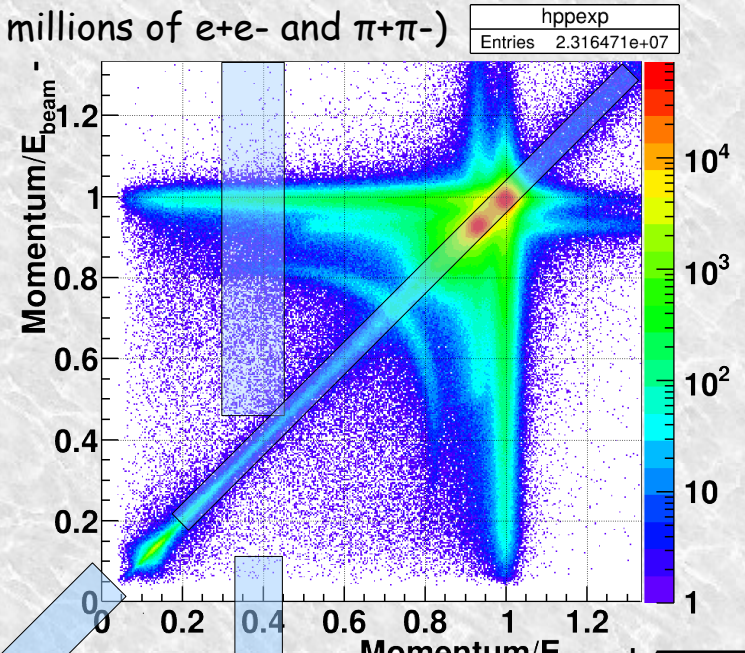
BHWIDE (LEP) – 0.5% (~0.1%?), e+e–
n real photons by Yennie-Frautschi-Suura (YFS) exponentiation method
interference on O(α) level

And there are other generators for different channels:
PHOKHARA (KLOE) μ+μ-, π+π- etc
KKMC (μ+μ-),
etc

MC generator, MCGPJ

High experimental precision relies on high theoretical precision of MC tools:

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

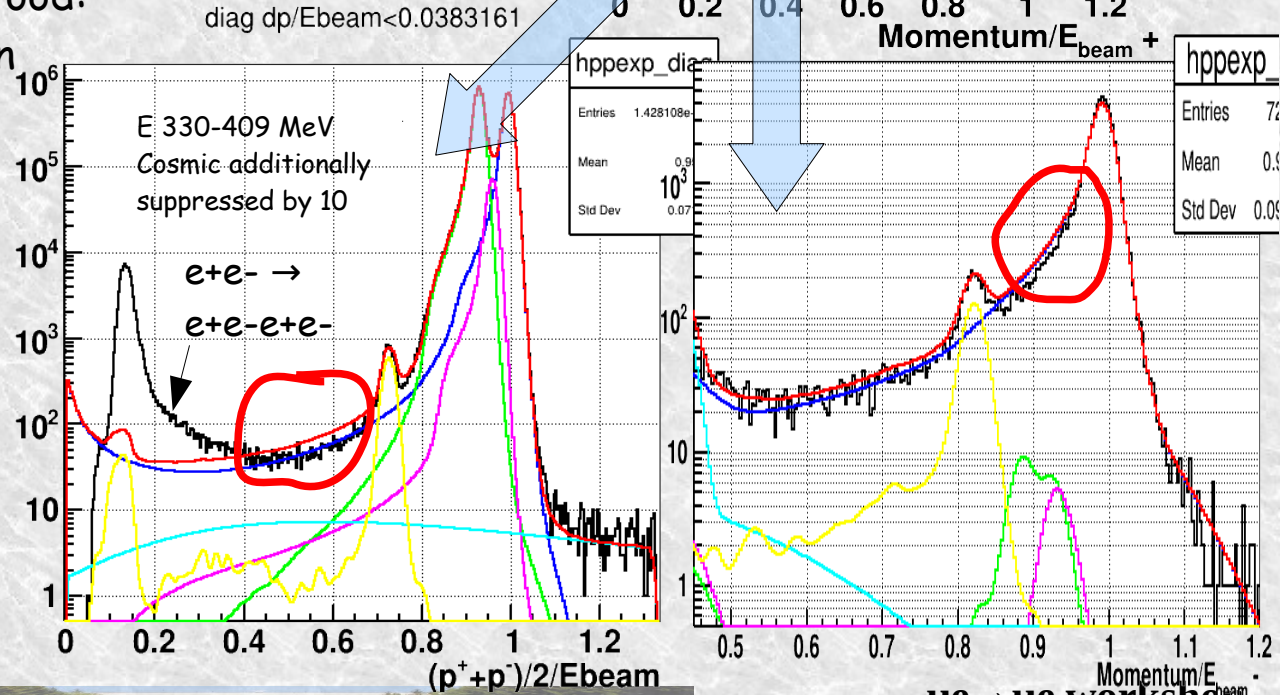


Several MC generators available with 0.1-0.5% precision.
MCGPJ generator (0.2%) is used by Novosibirsk group:
1 real γ + γ jets along all particles (with collinear Structures function)

High statistics allowed us to observe
a discrepancy in momentum distribution
of experimental data vs theoretical spectra from MCGPJ

The source of the discrepancy is understood:
also important γ jets angular distribution

Several steps for upgrading MCGPJ
were done.
But still some question under inspection



Exact e+e-→e+e-(γγ) NNLO generator will help to solve all our doubts (and to go below <0.1% precision)

MCGPJ modifications

Several steps for upgrading MCGPJ were done:

photon jets angular distribution with proper kinematic: $f(c=\cos(\theta), x=\omega/E) \sim \frac{1}{pk} - \frac{x(1-x)}{1+(1-x)^2}\frac{m^2}{(pk)^2}$

$$\sim \frac{1}{1-\beta c} - \frac{1-x}{1+(1-x)^2} * \frac{1-\beta^2}{(1-\beta c)^2}$$

Born cross-section boost shift rewritten with virtuality of lepton

? how well factorization is working now(|ISR|*|BornShift|*|FSR|)

In case jets along lepton → leptons was near real, but now it is not

Structure function for FSR: To be consistent with single photon behavior, it started to be used relative to energy of particle after radiation:

$$D(z,s) \sim \frac{1}{2} b (1-z)^{\frac{b}{2}-1} \ldots., b = \frac{2\alpha}{\pi}(L-1), L = \log\left(\frac{s}{m^2}\right), s \to s(1-x)^2$$

rebalance of jet compensator:

not necessary to keep minimal cone θ from which exact 1 photon Berends is used

some question still under inspection: (some effects of my(not theorist) not understanding at level ~ 0.05%)

1)? is it consistent definition of Berneds soft part versus Jets soft part….

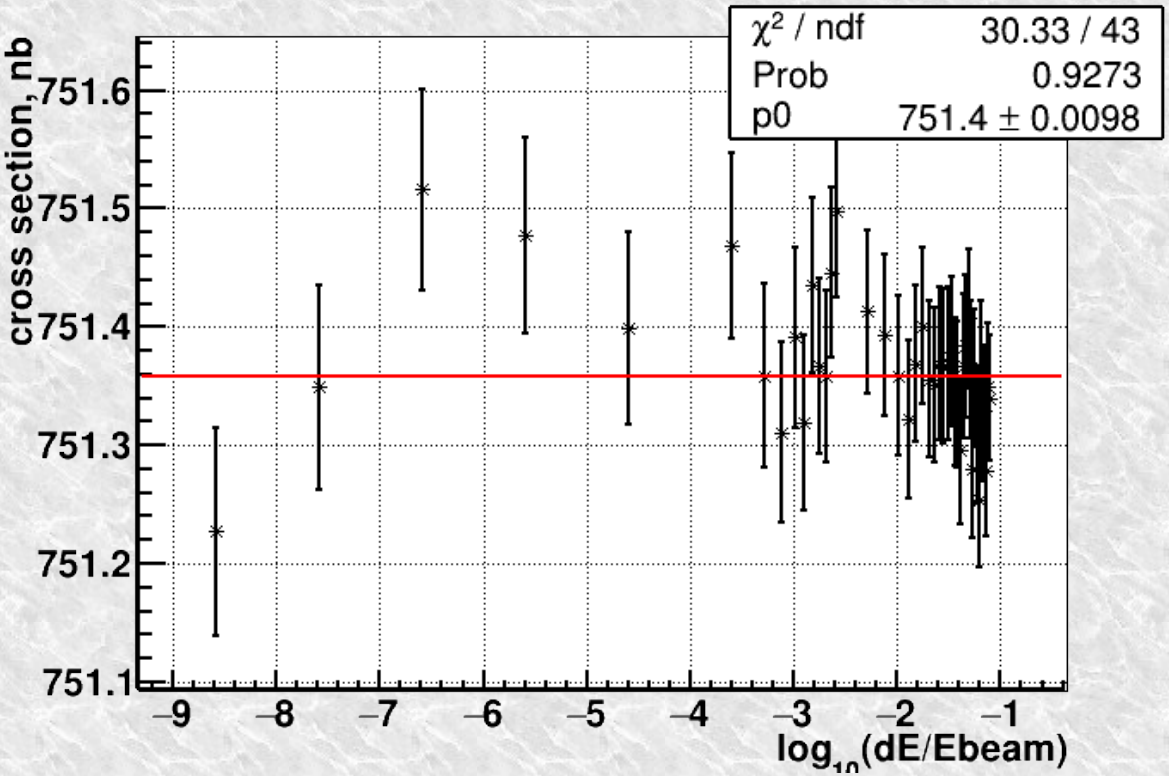
2) problem to construct generator…, now can be used in weighting mode

No positive balance of Matrix element between exact Berends 1 photon vs always 4 jet configuration: how to subtract only 1 photon from always 4 jet event…

Consistency checks

The generator has internal parameter "dE" :
Separation cut between soft and hard part of photon

<u>Variation of this cut on soft part:</u>
Very good test for consistency (sensitive to everything…)



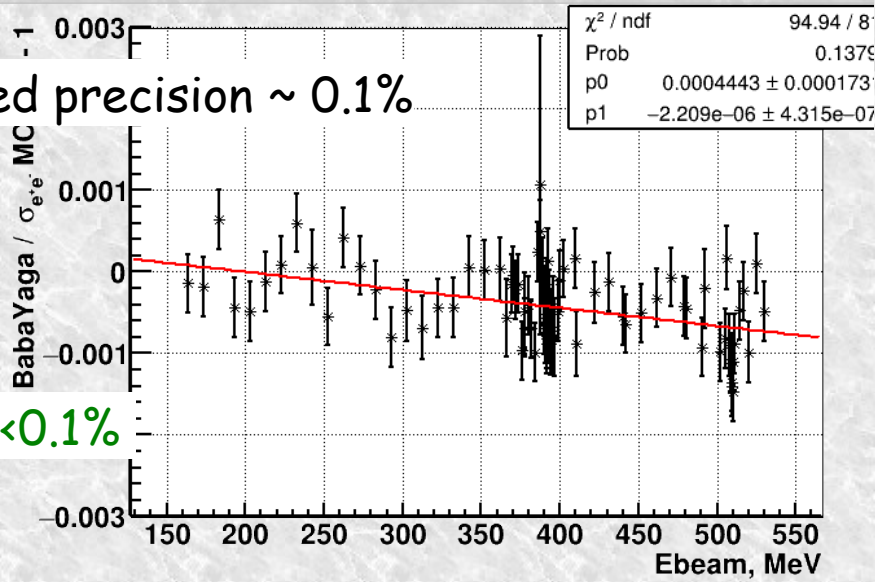
Original exact 1 photon Berends paper doesn't have exact soft part...
at level ~ $\alpha/\pi * \Delta$ (x2*(L-1))
If you have link to paper with exact 1-photon full formulas, please send me.

BabaYaga@NLO vs MCGPJ generators

Only two available e+e- → e+e- generators with claimed precision ~ 0.1%

BabaYaga@NLO used by KLOE, BaBar

MCGPJ used by Novosibirsk group



Integrated cross-section was consistent at the level <0.1%

(0.0-0.07% for 2E = 0.15-0.5 GeV)

In Selection cuts:

$|\Delta\varphi|<0.15$, $|\Delta\theta|<0.25$, $1< \theta_{average} <\pi -1$, $P^{+-} >0.45\ E_{beam}$

Calculated cross-section at E beam=391.48 MeV

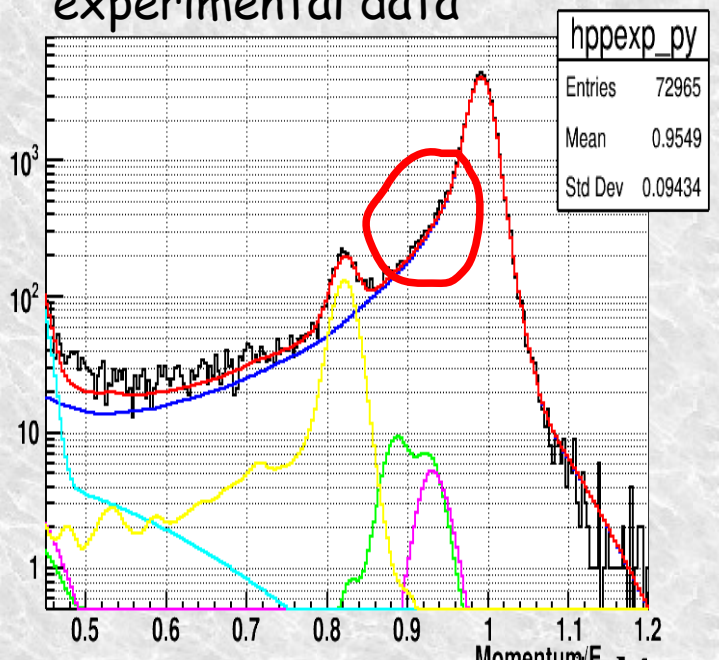
MCGPJ : 751.671 +- 0.034 nb

BabaYaga@NLO : 751.218 +- 0.059 nb

Δ ~ 0.06%

Recent MCGPJ modifications change cross-section: -0.06%

BabaYaga better describes momentum spectrum of experimental data



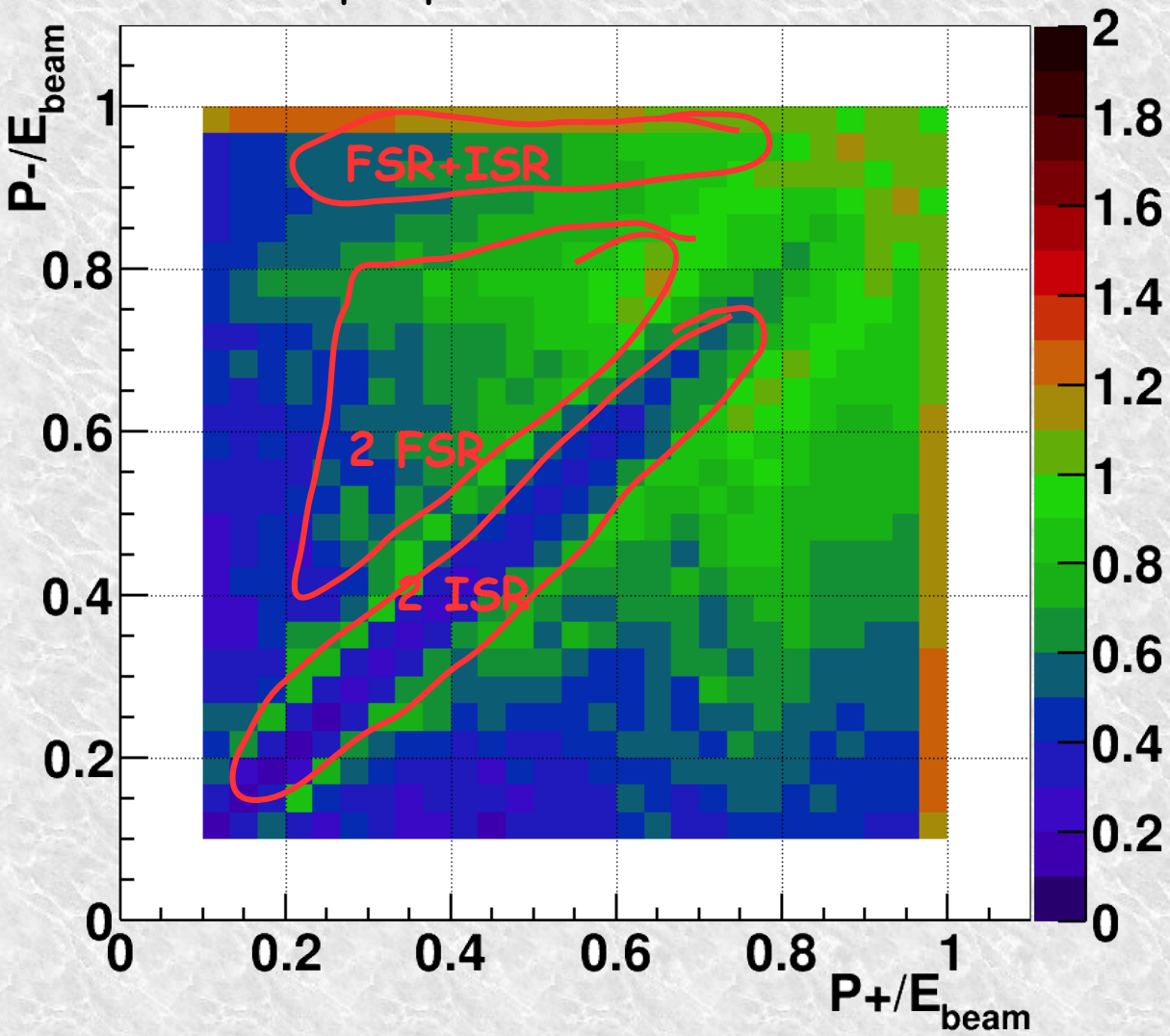
BabaYaga @ NLO vs MCGPJ

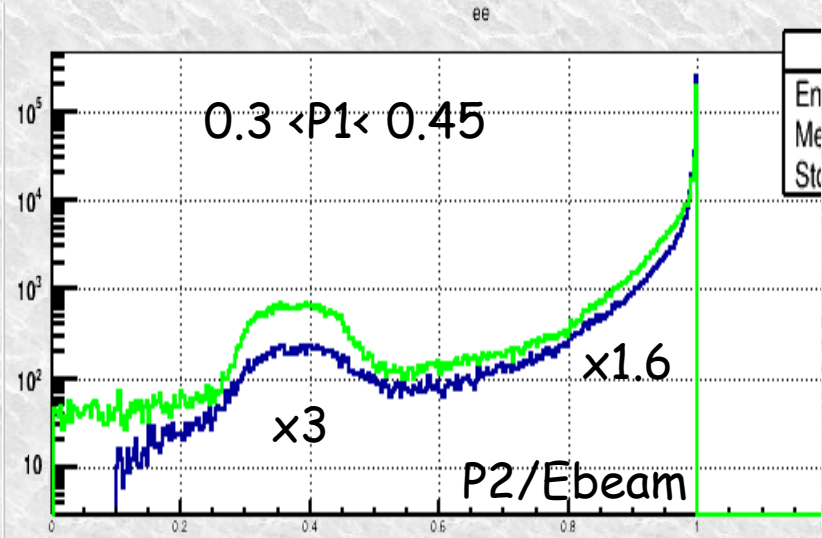
Ebeam = 391.48 MeV

Comparison of momentum spectra from generators

BabaYaga divided by MCGPJ(without γ-jets angles)

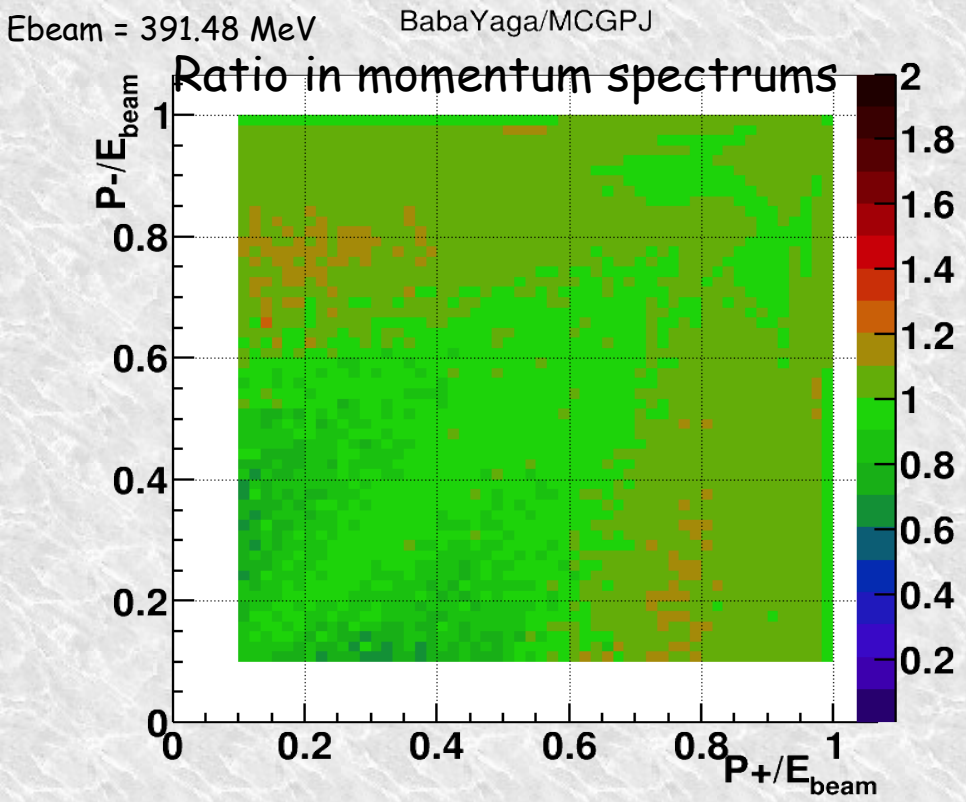
$$\frac{\partial^2\sigma}{\partial p^+ \partial p^-}$$ BabaYaga/MCGPJ

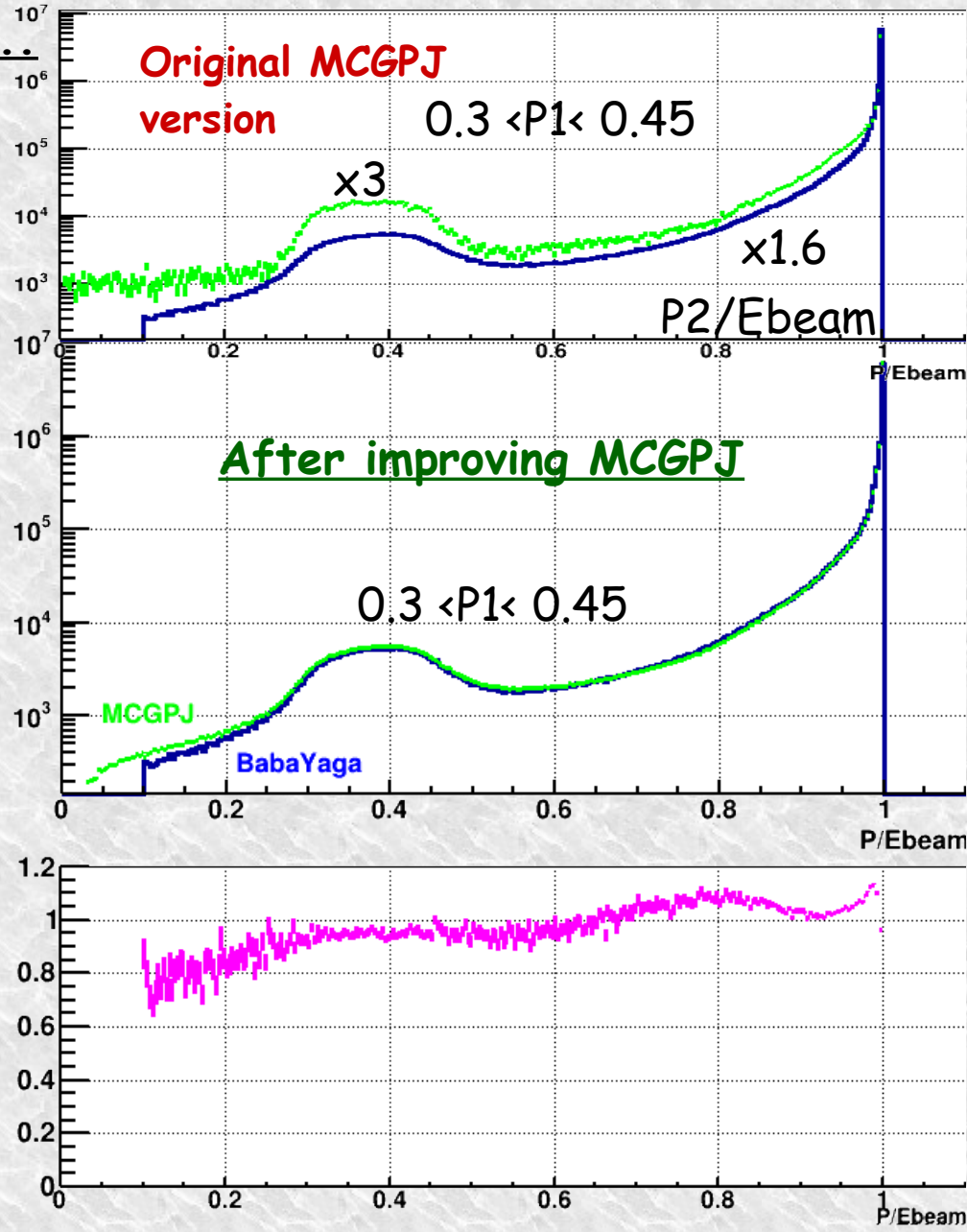




MCGPJ vs BabaYaga spectrums

After adding angle distribution for jets, etc ...





Momentum spectrum still disagree at level ~ 10%

Need more experimental data for cross-check

We need more theoretical input for MCGPJ

Result in systematic of π+π- measurement

→ 0.0 - 0.4%

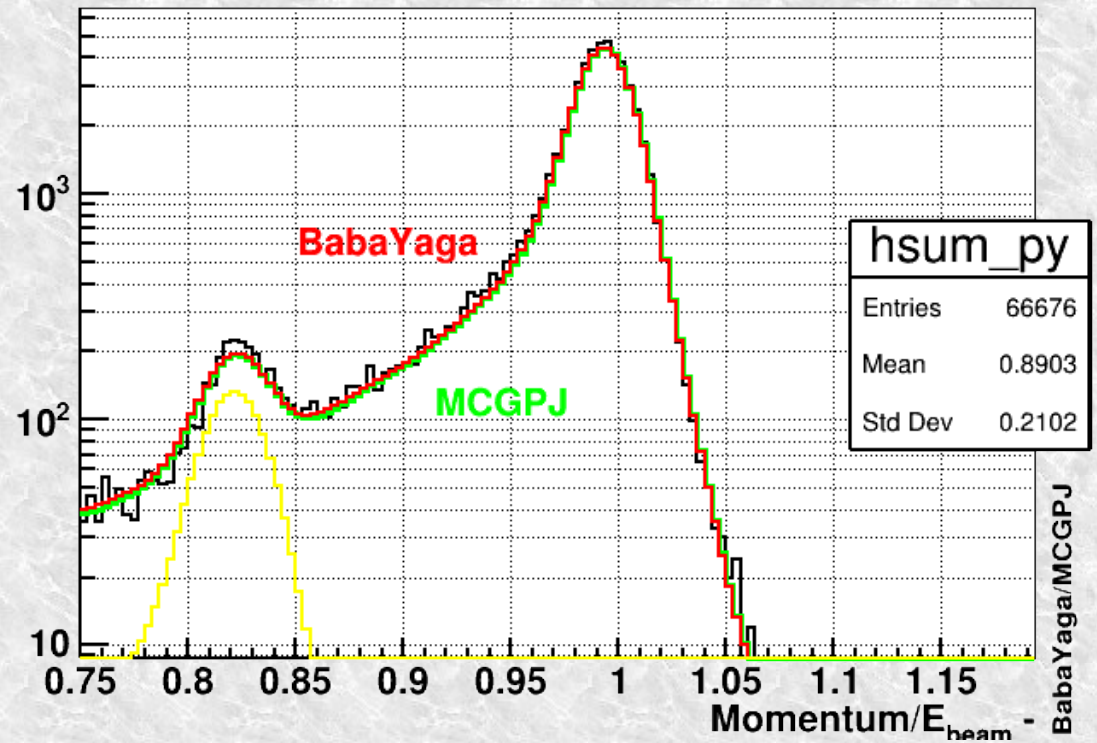
For precision ~<0.1% necessary to have exact e+e-→e+e-(γγ) NNLO generator

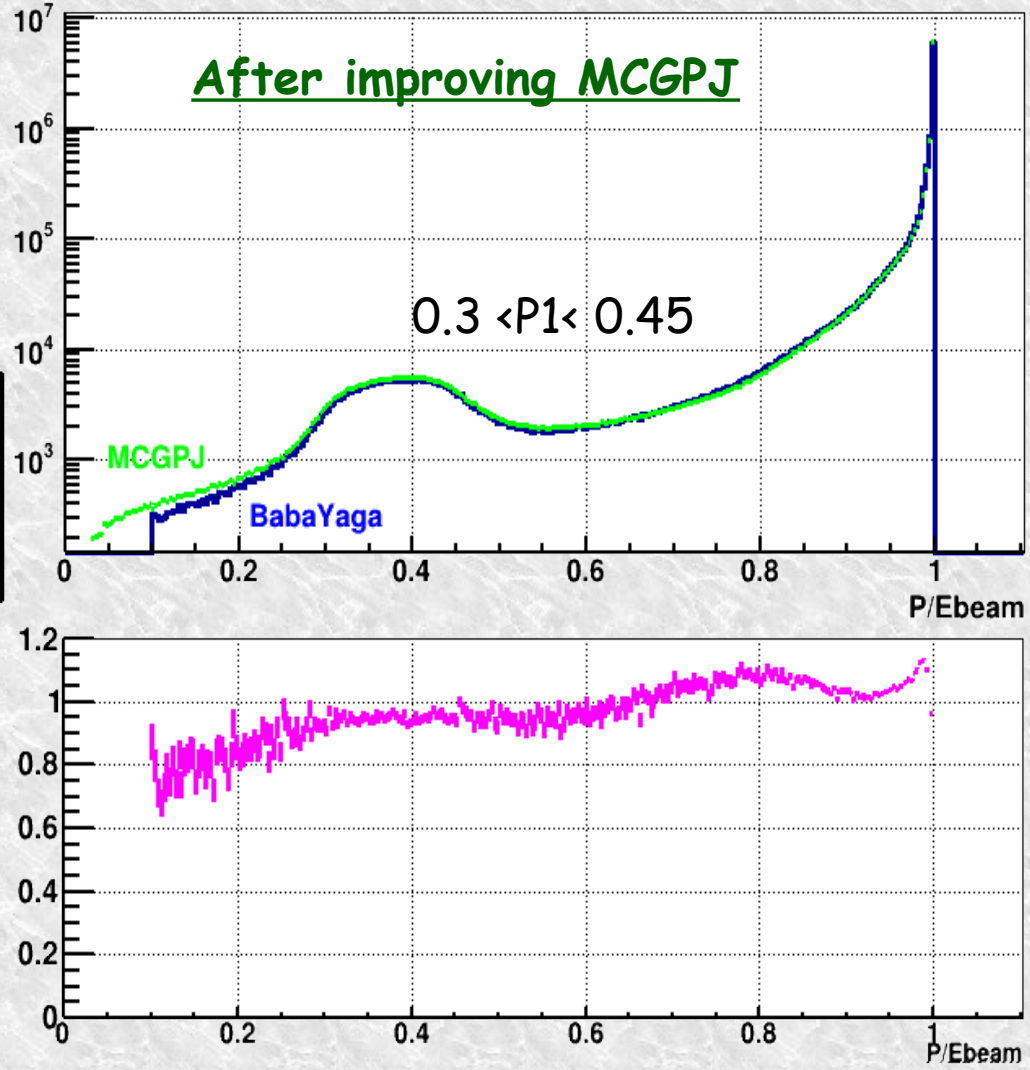
MCGPJ vs BabaYaga spectrums

After adding angle distribution for jets, etc ...

Momentum spectrum still disagree at level ~ 10%

Need more experimental data for cross-check



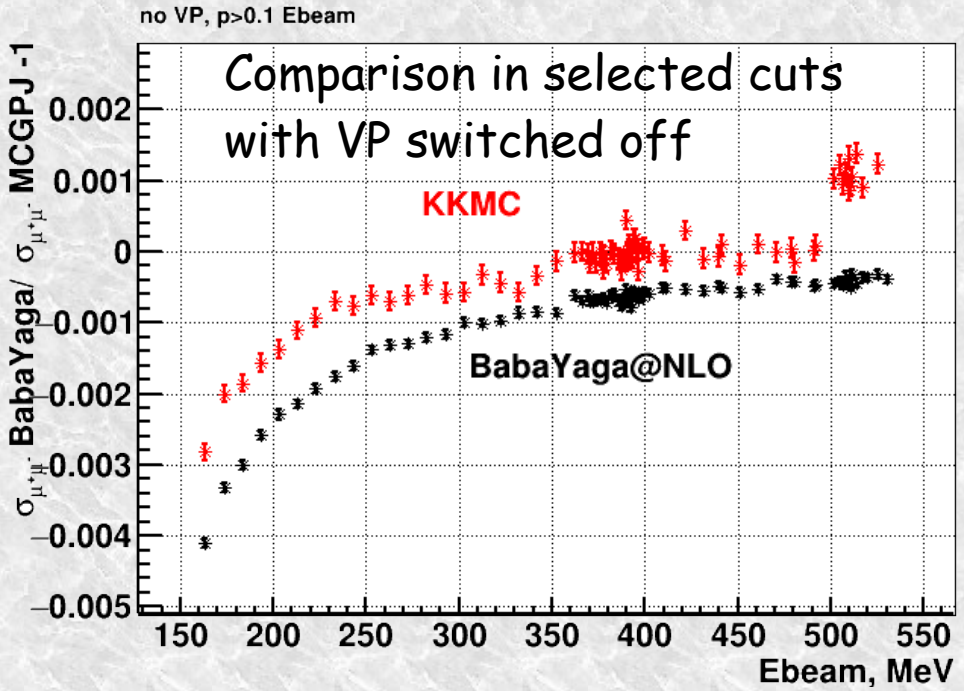


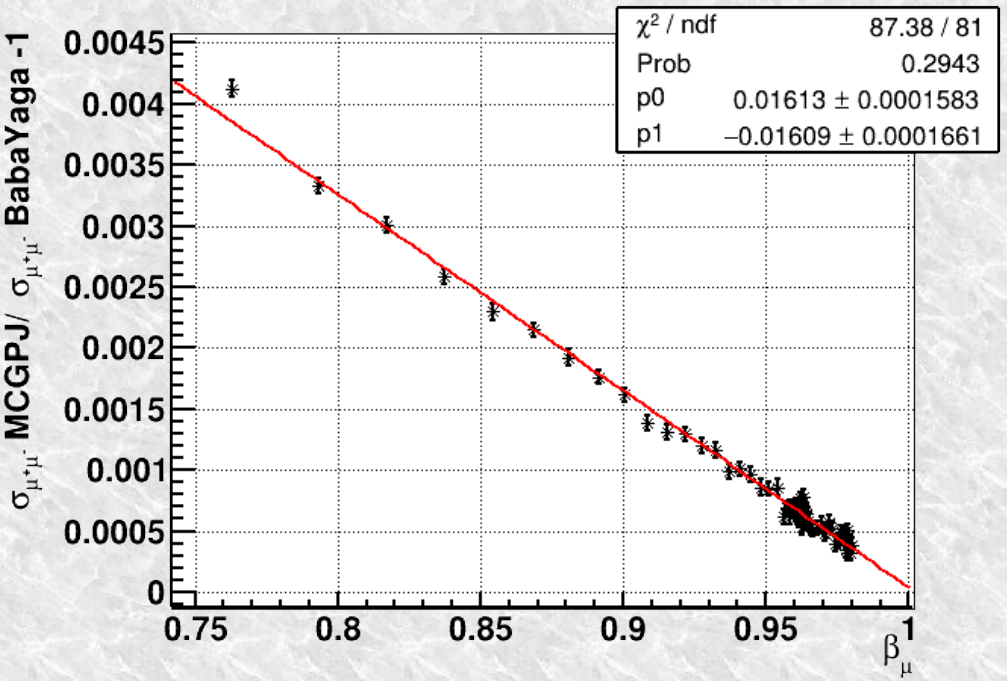
Can't separate models with CMD3 data...

~half of tail from bremsstrahlung,

Biggest difference at 3π peak

e+e- → μ+μ- total cross-section



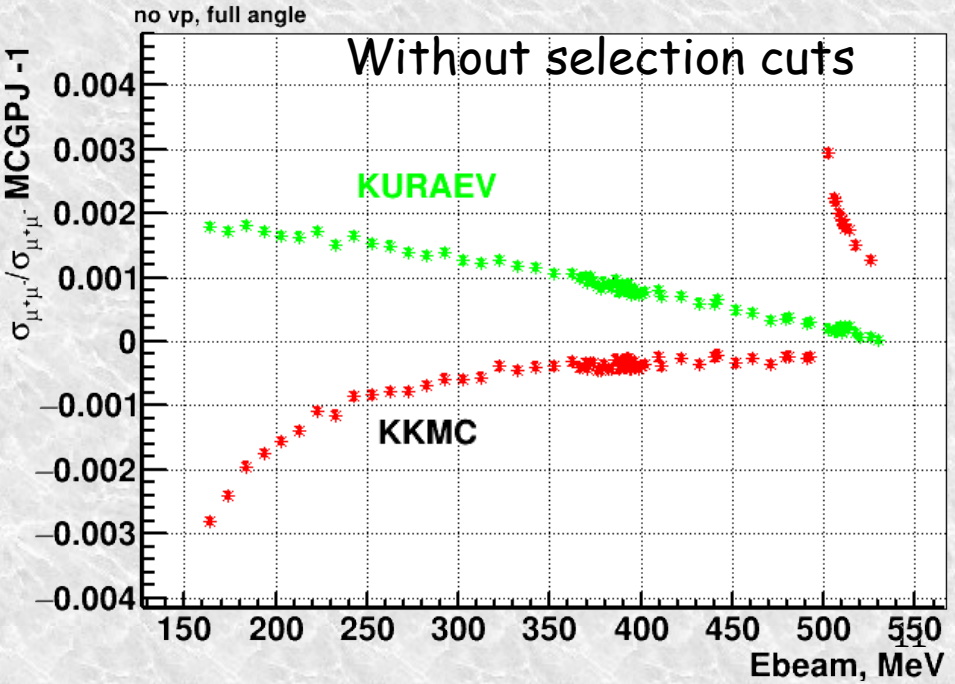


μe → μe: 150 GeV μ-beam → ~ 190 MeV in c.m.s

KKMC was design for LEP energies
MCGPJ for μ+μ- is still without jets angular distribution

Somewhere is missed term with $\beta_\mu \leftrightarrow 1$

KURAEV theoretical paper with analytical formula for e+e-→μ+μ- total cross-section:
Phys.Rev.D72:114019,2005(arXiv:hep-ph/0505236)



Vacuum Polarization

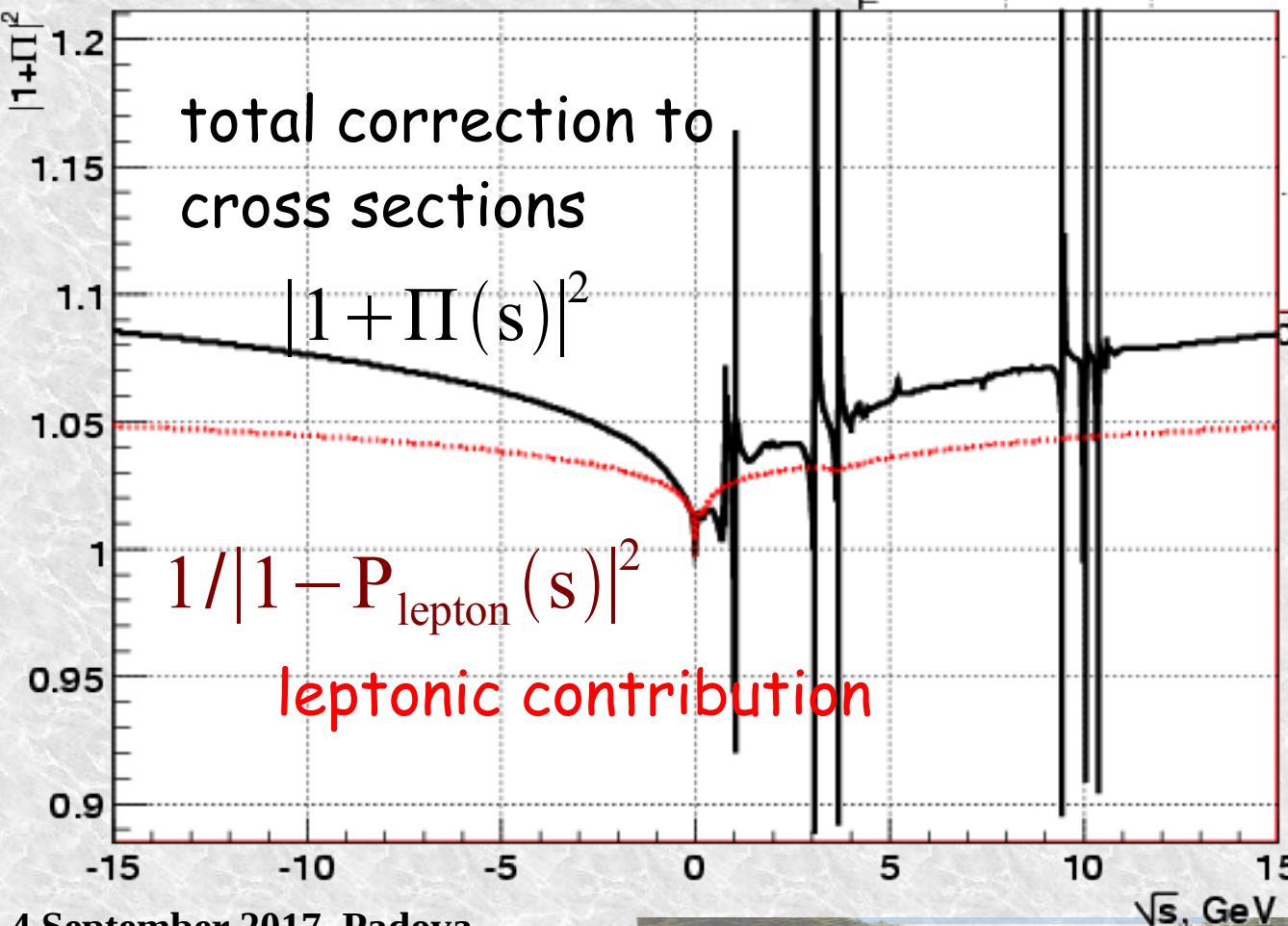
Novosibirsk version:

http://cmd.inp.nsk.su/~ignatov/vpl/

Also available

Hadr5n : F.Jegerlehner

HLMNT: T.Teubner et al.

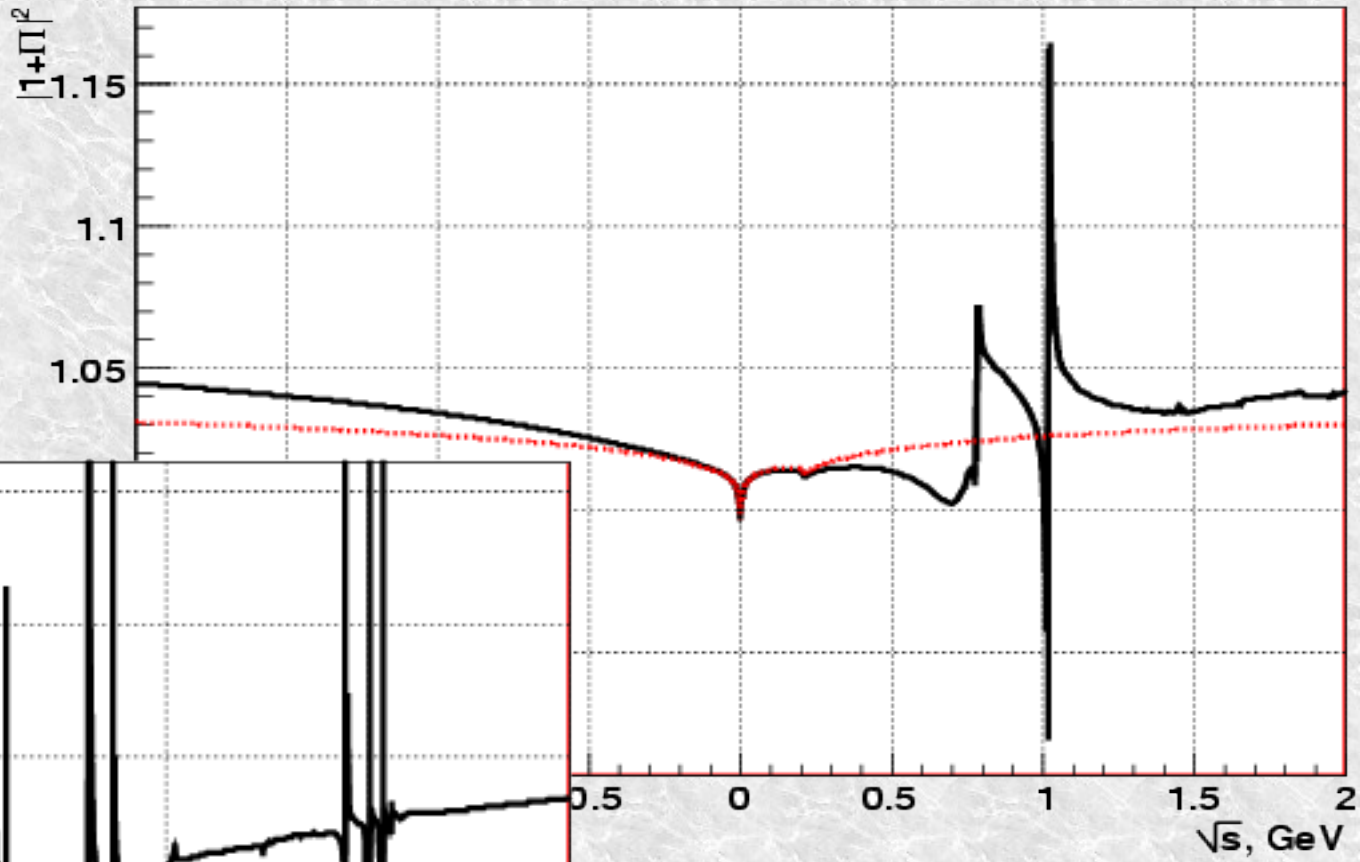


total correction to cross sections

$$|1+\Pi(s)|^2$$

$$1/|1-P_{lepton}(s)|^2$$

leptonic contribution



Vacuum polarization

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

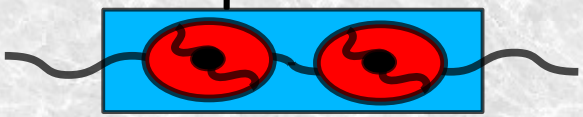
$$P(s),\Pi(s)=\frac{s}{4\pi^2\alpha}\left[PV\int_{4m_\pi^2}^{\infty}\frac{\sigma^{bare,dressed}_{ee\to\gamma\to everything}(s')ds'}{s-s'}-i\,\sigma^{bare,dressed}_{ee\to\gamma\to everything}(s)\right]$$

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

"bare" cross sections — result in — "dressed" cross sections

Polarization operator

Self-energy function of photon



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

It is necessary

"undress" experimental cross sections

nontrivial task to correct physical parameters of resonances

"dress" leptonic part and pQCD

"dress" experimental data which was normalized to 2 muons cross sections

Iterations is necessary in all case

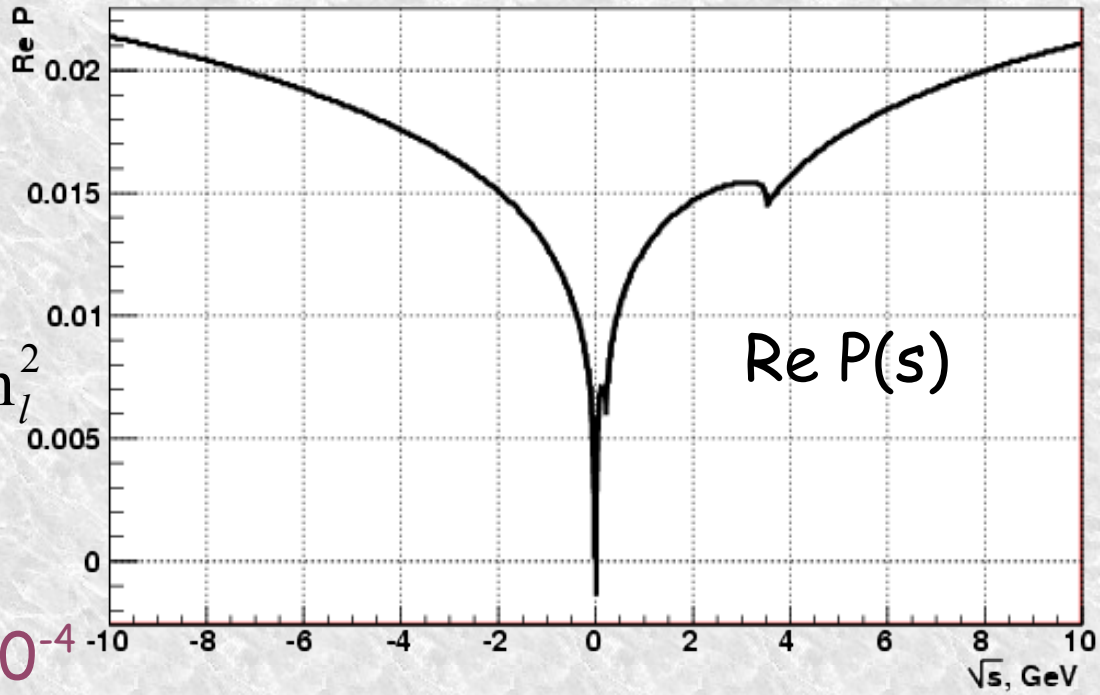
Leptonic contribution

$$P_l(s)=\frac{\alpha}{\pi}P_1(s)+\left(\frac{\alpha}{\pi}\right)^2 P_2(s)+\ldots$$

Exact analytical formula are known for first order,

??for 2nd and 3rd order at $|s|\gg m_l^2$

(M.Steinhauser Phys.Lett B 429 (1998) 158.
3-loop with m2/q2 term)



Contribution of second order ~ 10^{-4}

In our VP calculation the contribution was evaluated from dispersion integral with inclusion of FSR, Coulomb factor :

$$\sigma^{\text{bare}}_{ee\to\gamma^*\to ll(\gamma)}=\sigma^{\text{Born}}_{ee\to\gamma^*\to ll}\left(1+\frac{2\alpha}{\pi}\delta_l^{\text{FSR}}-\frac{z}{2}\right)f(z),\quad \delta_l^{\text{FSR}}\to 3/8$$

In case of self-energy function: full vacuum polarization was included iteratively

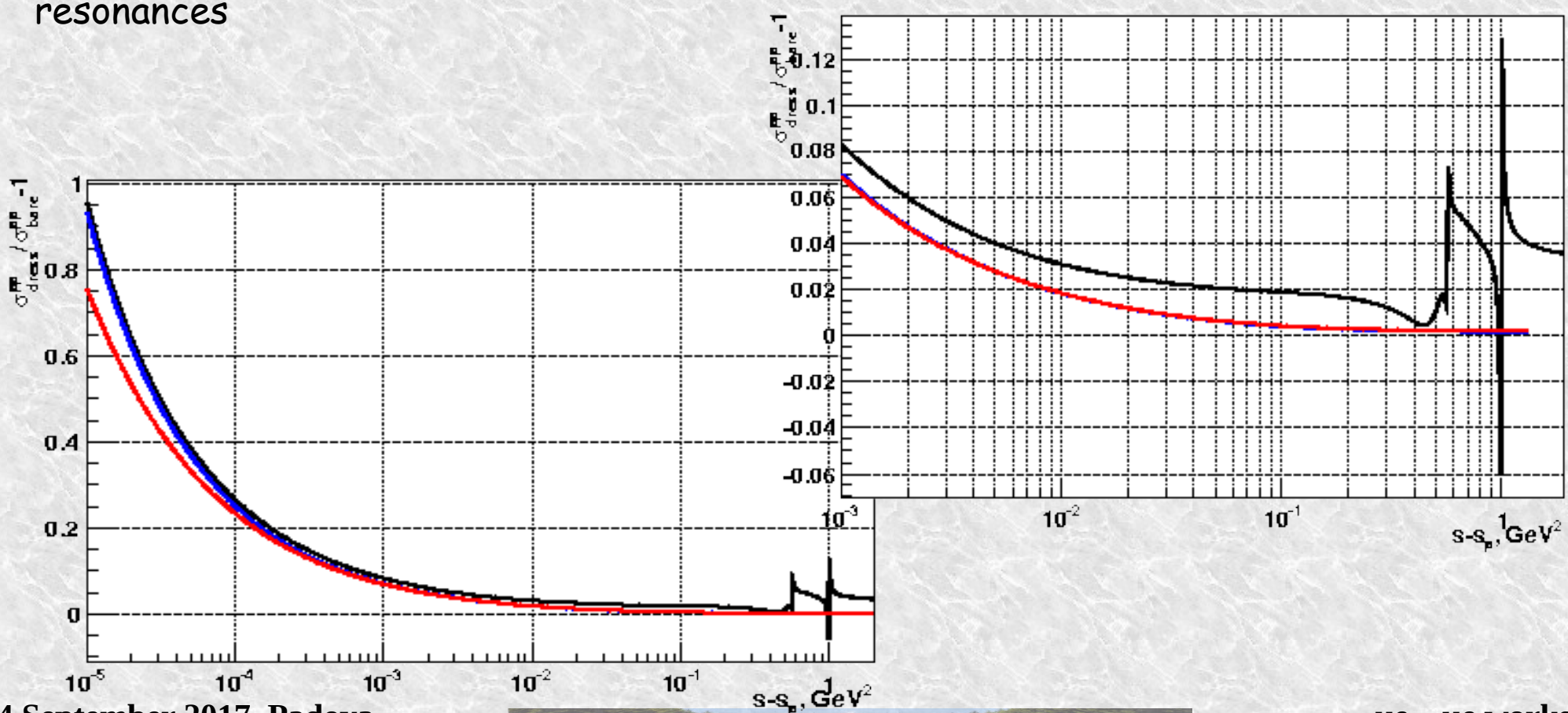
Leptonic contribution

with final state radiation

in addition exact Coulomb interaction

with vacuum polarization (for "dressed" cross sections)

Muons cross section are deviated by ~ 6% and ~25% near ω and ϕ resonances



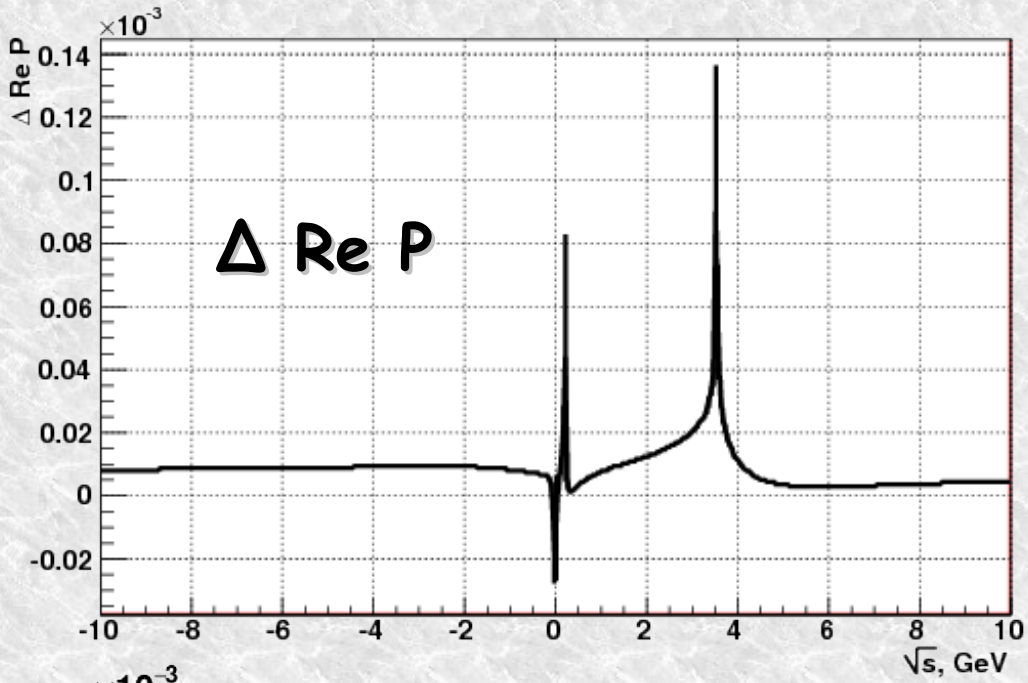
Leptonic P(s)

VP calculated from cross-section with FSR and Coulumb factor ~<10^{-4}

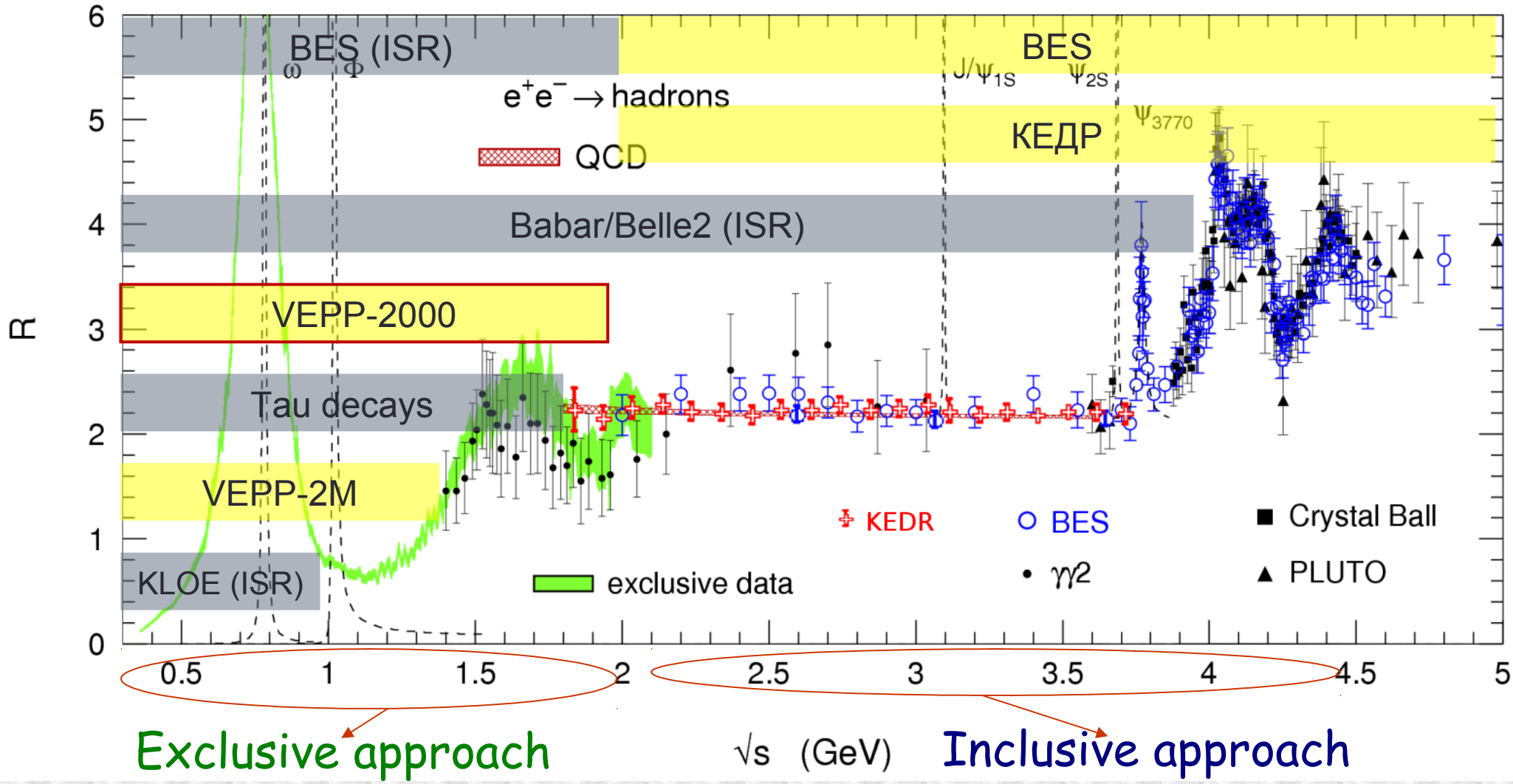
For -1 > t > 0 GeV2

Second order Δa ~ 3e-5

Mass term at 2nd order ~ 1e-5



R(s) measurements



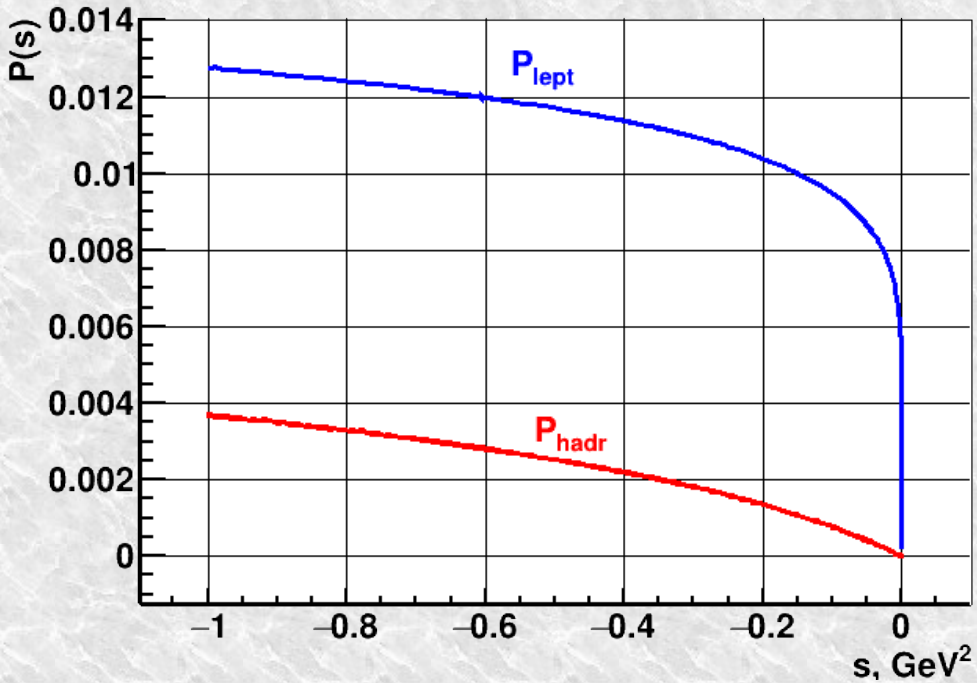
VEPP-2000: direct exclusive measurement of σ (e+e- → hadrons)
Only one working this days on scanning below <2 GeV
World-best luminosity below 2 GeV (1 GeV excluded – where KLOE outperfom everybody)

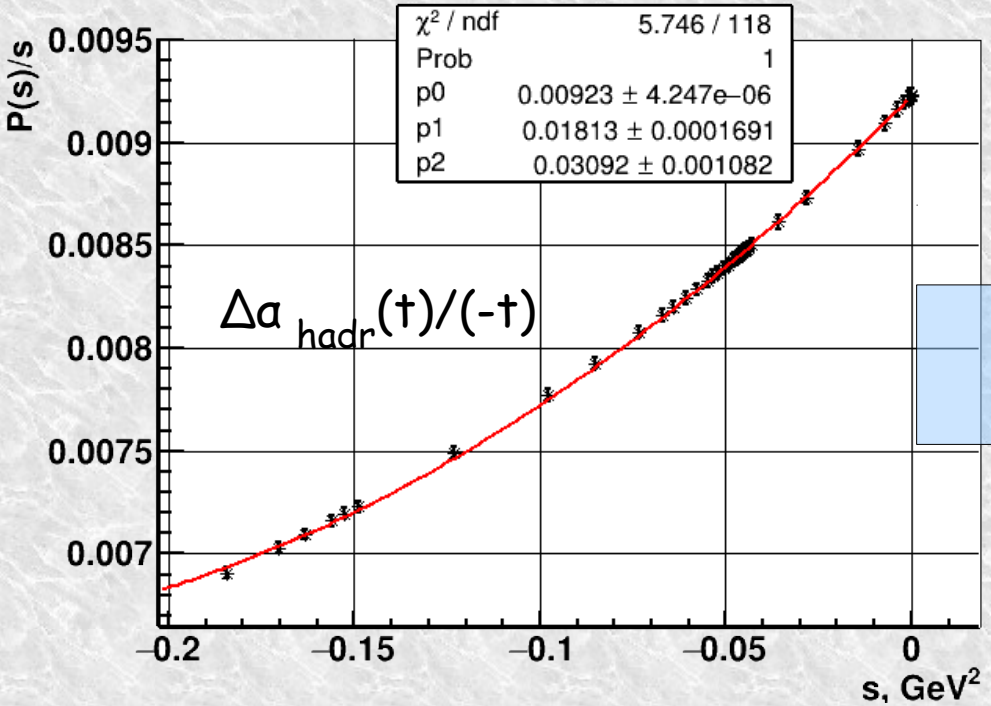
BESIII, KEDR – direst scan from 2 GeV to 5 GeV

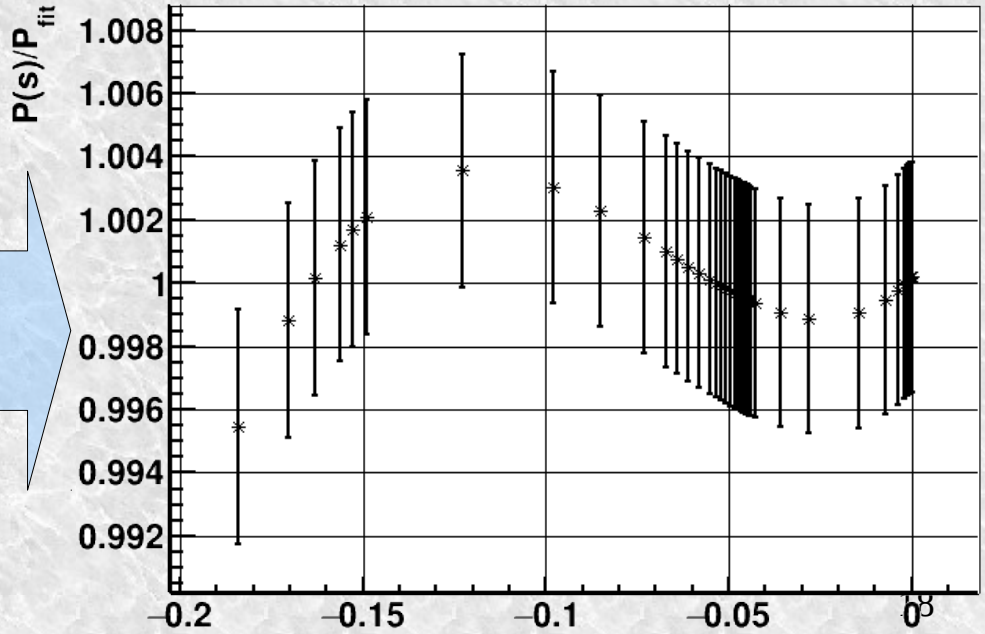
Vacuum polarization

Δa_{hadr} from time-like R(s) data
has precision ~ 0.4-0.5%
at -0.2 < t < 0 GeV2

Behavior is very smooth:
it is enough of 2rd order polynomial
to describe with precision ~< 0.3%







Summary

It is great that we have at least few independent MC generators

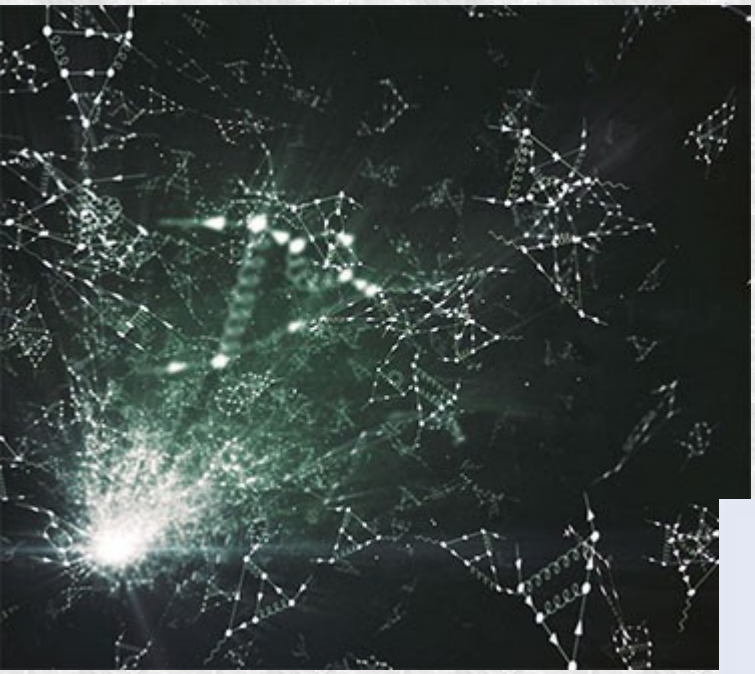
MCGPJ still is under improvements
Inconsistency in momentum spectra in e+e- → e+e-
of MCGPJ vs BabaYaga@NLO at ~ 10%

In e+e- → μ+μ- somewhere is missed term proportional to ~ $(1-\beta_\mu)$

To drop all doubts and If we want to go below **precision ~<0.1%:**
I think it is necessary to have exact e+e-→e+e-,μ+μ-(γγ) NNLO generator
(better produced semi-automatically)

μe→ μe NNLO should also help us for timelike generators

CERN Courier, Mar 17, 2017
"The two-loop explosion"



During last decade number of NNLO calculation in QCD is growing, probably QED is simpler