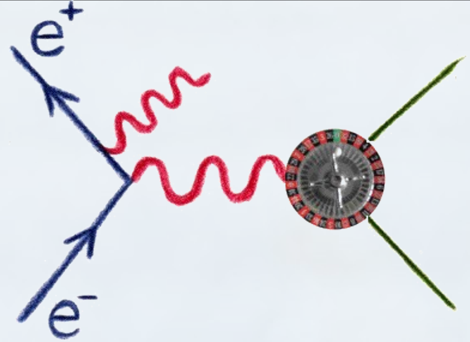

Comparison of MC generators

($e^+e^- \to e^+e^-, \mu^+\mu^-, \ldots$)

from 2π analysis at CMD3 point of view

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STRONG2020 virtual Workshop

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Introduction

- Current level of analysis require knowledge of integrated cross-section of main channels $e^+e^- \to e^+e^-$, $\pi\pi$, $\mu\mu$ with precision <= 0.1%

- Having increased luminosity, some of the analysis are based on predicted differential distributions

This presentation is brief reminder on what was presented before at 12th Radio MonteCarlo WG meeting(2019):
https://agenda.infn.it/event/18136/contributions/84910/attachments/61384/73190/RadCor19_MCGPJ.pdf

$e^+e^- \to \pi^+\pi^-$ by CMD3

Original plans was to reach systematic ~0.35-0.5%,
which means to keep under 0.1% level different contributions to it

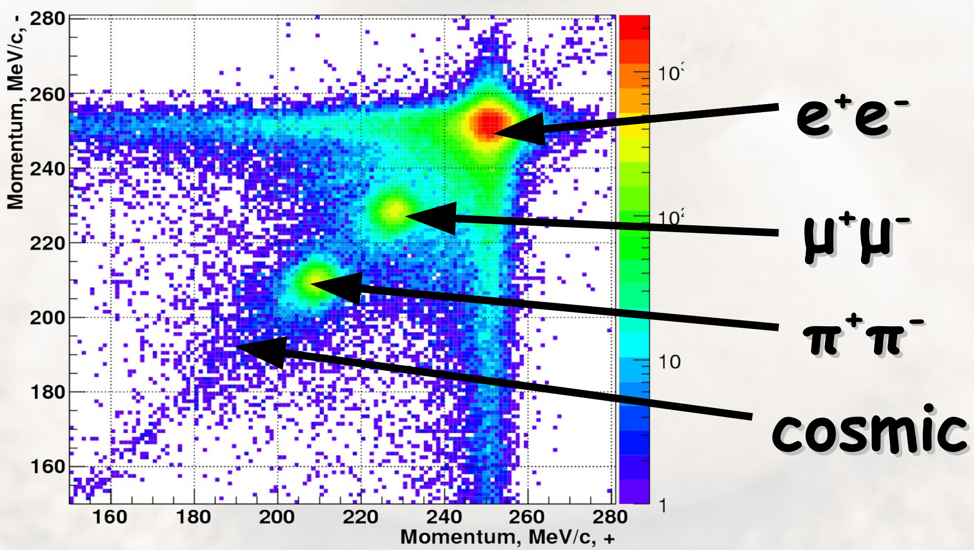
PID either by momentum or by energy deposition

Momentums works better at low energy < 0.8 GeV, Energy deposition > 0.6 GeV

PID by momentum based on likelihood minimization, where:
PDF taken as generated MC distributions convolved with detector response function
(momentum resolution, bremsstrahlung, pion decay, etc..)

This method rely on precise knowledge of initial differential spectra from MC

P+ x P-, E_{beam}=250 MeV



MC generators e+e- → e+e-

0.1%
e+e-, μ+μ-

Accuracy 0.2%
e+e-, μ+μ-, π+π-,
etc

0.5% (~0.1%?)
e+e-

<0.1%
e+e-, etc

under development
e+e-, μ+μ- , ZH, ...

Several MC generators available with 0.1-0.5% precision.
Most recent e+e- -> e+e- (gamma) generators
include exact NLO + Higher Order terms in some approximation:

BabaYaga@NLO (KLOE,BaBar, BESIII)
Parton shower approach: n photons with angle distribution,
interference for 1 photon radiation

MCGPJ (VEPP-2000)
1 real photon (from any particle)
+ photon jets along all particles (collinear Structure function)
v2: + jets angle distributions

BHWIDE (LEP)
n real photons by Yennie-Frautschi-Suura (YFS) exponentiation method
interference on O(α) level

McMule
Fixed order NNLO

ReneSANCe (from Dubna)
NLO + leading log corrections for ISR

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

MC generators e+e- → π+π-

Most precised 2π MC generator:

PHOKHARA

has limited precision for scanned mode (w/o γ)

developed for ISR process with 1 real photon + addition

Has different models for φ→ f0γ

Complete set of NLO to e+e- → π+π-γ:

most recent 10.0 version includes NNLO FSR,

and 1real + two virtual photon box diagram in sQED approx.

quoted accuracy 0.5%

MCGPJ

Not supposed to be used for ISR studies

exact NLO with sQED pion + ISR jets along beam with structure functions

accuracy 0.2%

Both generators has different region of applicability

Other less precise generators O(%)

(in some use cases can be at same precision as above generators)

AFKQED(BaBar)

EVA(KLOE)

BaBaYaga 3.5 (KLOE)

FASTERD(KLOE)

BabaYaga@NLO vs MCGPJ generators

Only two e+e- → e+e- generators available with claimed precision ~ 0.1%
BabaYaga@NLO & MCGPJ

Integrated cross-section is consistent at the level <0.1%
(0.06-0.% for 2E = 0.3-1.0 GeV)

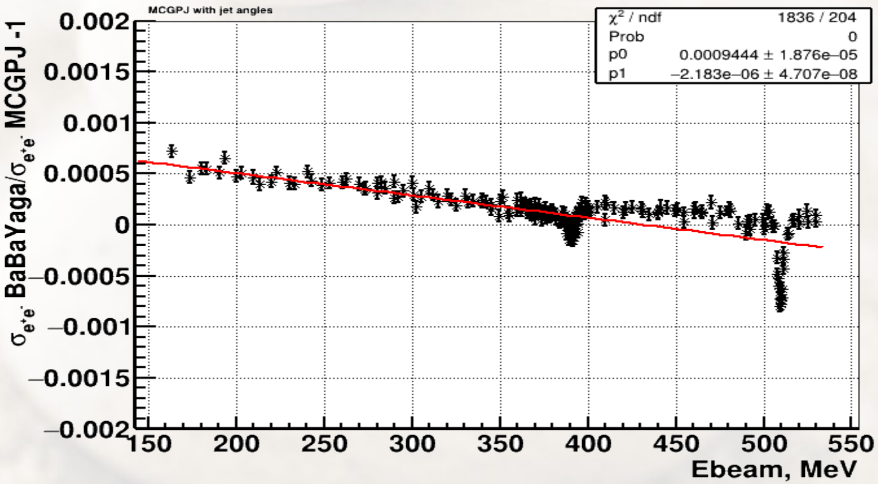
In CMD3 Selection cuts:

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

Calculated cross-section at E beam=391.48 MeV

MCGPJ : 751.269 +- 0.007 nb
BabaYaga@NLO : 751.223 +- 0.009 nb

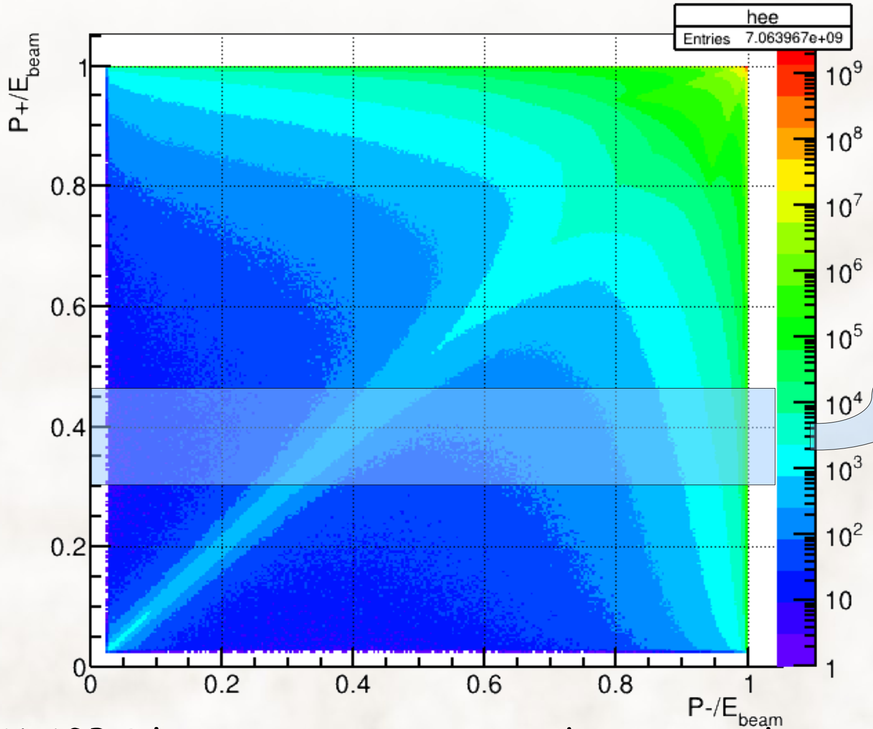
Δ ~ 0.01%



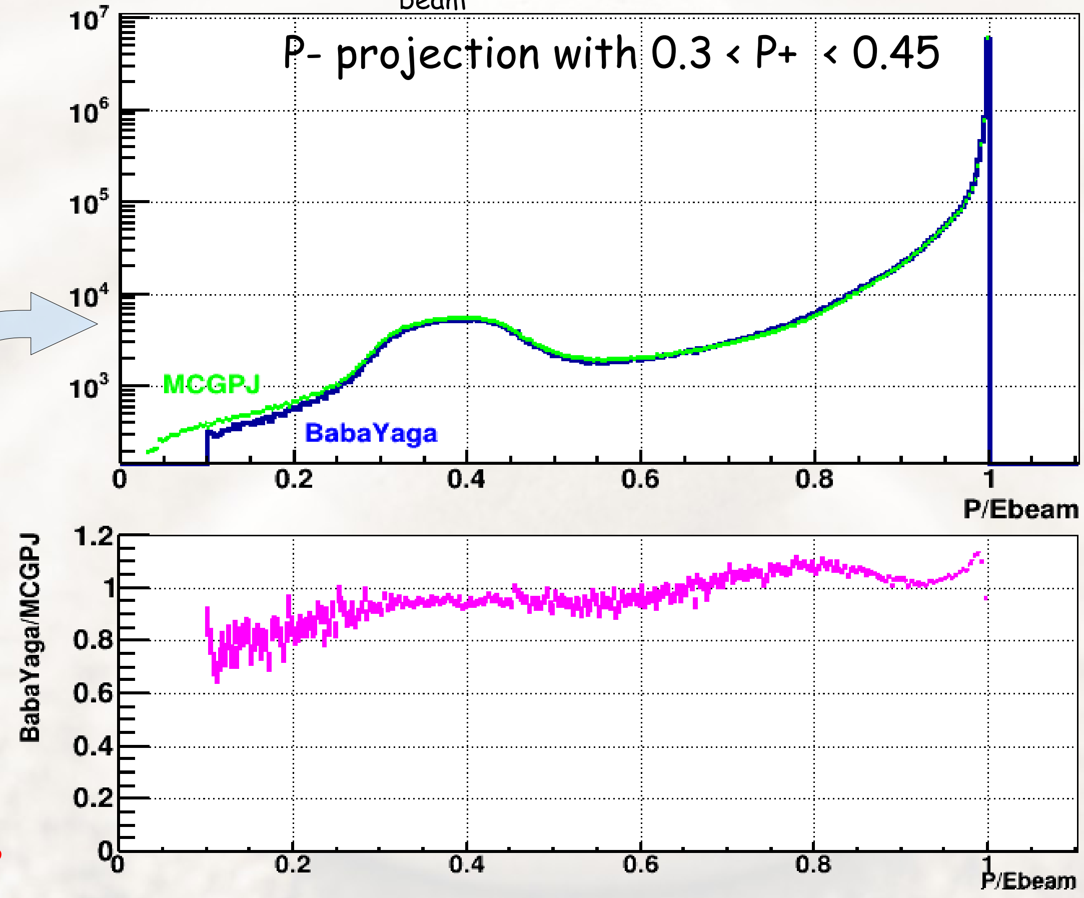
N.B. MCGPJ last improvement with introduction of jet angle distribution
greatly improved differential distribution, but gives only
modest change of total cross-section: -0.06%

MCGPJ vs BabaYaga bhabha P+ vs P- spectrum

Differential over momentum spectrum comparison



E_{beam} 391.48 MeV



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

Momentum spectrum still disagree at level ~ 10%

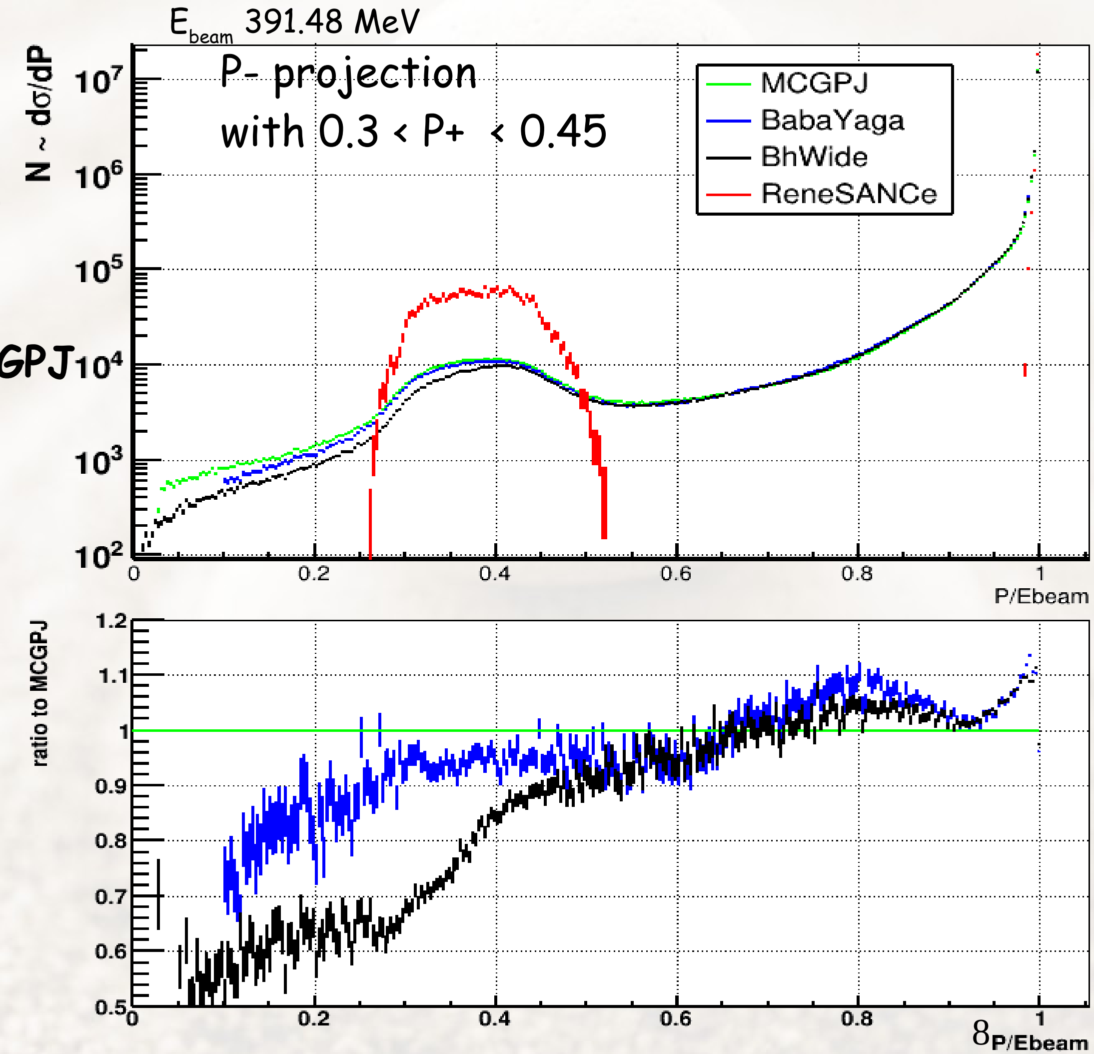
Tails comes from e+e- → e+e- γγ , NNLO order

Very desirable to have more precise generators

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

Other e+e- generators

Differential momentum spectrum comparison



Integrated cross-section (in CMD3 selection cuts) at E beam=391.48 MeV:

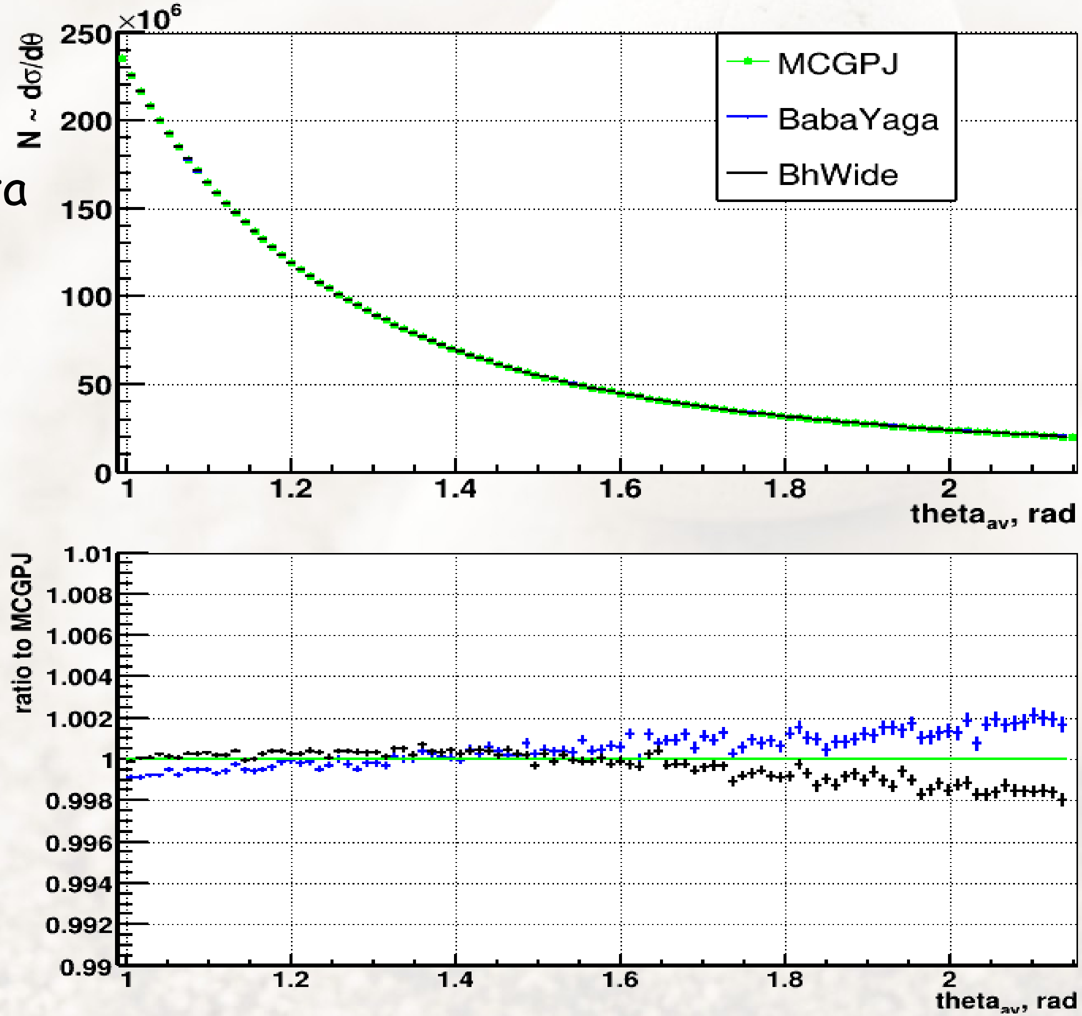
		Δ to MCGPJ
MCGPJ vs jetangles	: 751.269 +- 0.007 nb	
BabaYaga@NLO	: 751.223 +- 0.009 nb	<0.01%
BHWIDE v1.05	: 751.428 +- 0.006 nb	0.02%
SANCe v1.2.0	: 754.75 +- 0.05 nb	0.5%

Differential over angle spectrum comparison

Differential cross section over theta
consistent/or inconsistent
at level ~0.1-0.2%

But we are already sensitive to it
in the asymmetry study with CMD3
as shown in presentation yesterday

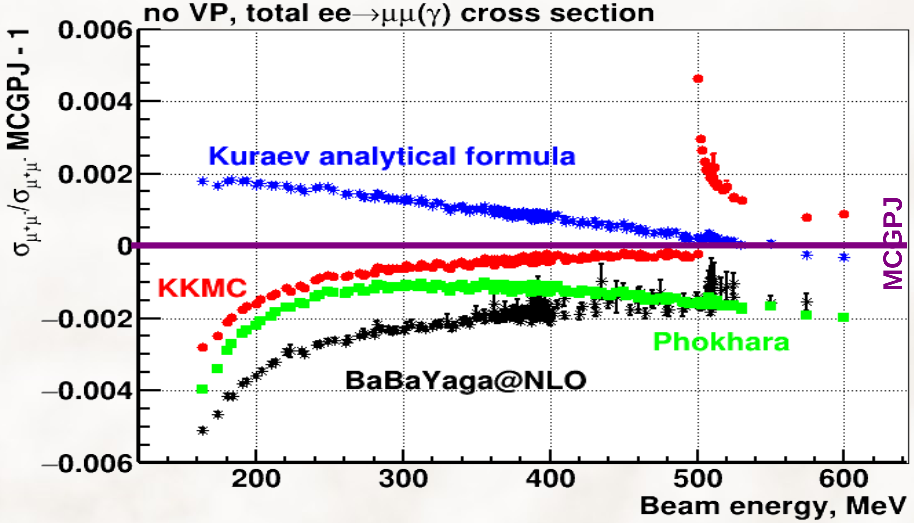
E_{beam} 391.48 MeV



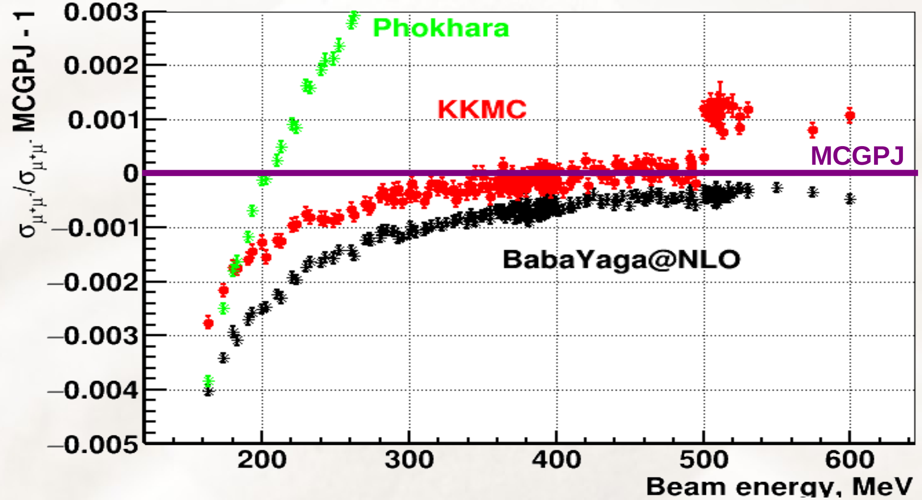
e+e- → μ+μ-(γ) cross-section

Comparison relative to MCGPJ, VP off

Total cross section



in CMD3 selection cuts



KKMCe v 4.32, Phokhara v10.0, BabaYaga@NLO, MCGPJ

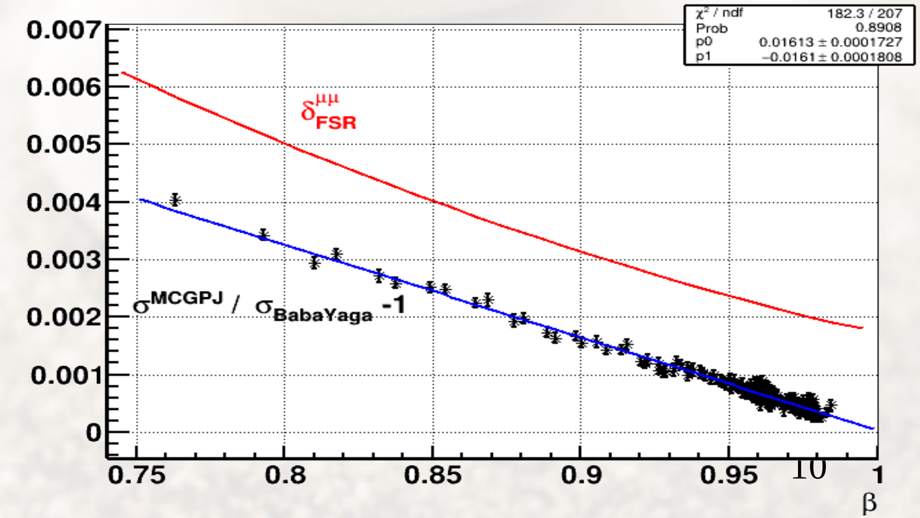
KURAEV analytical formula for e+e-→μ+μ-(γ)

total cross-section: Phys.Rev.D72:114019,2005(arXiv:hep-ph/0505236)

KKMC was design for LEP energies

MCGPJ for μ+μ- is still without jets angular distribution

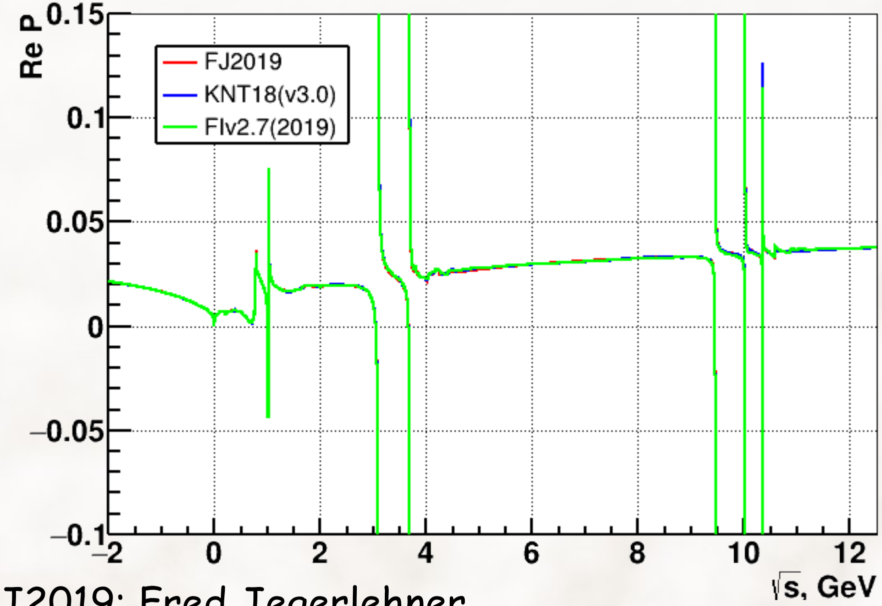
Phokhara has limited precision for scanned mode (w/o ISR γ)



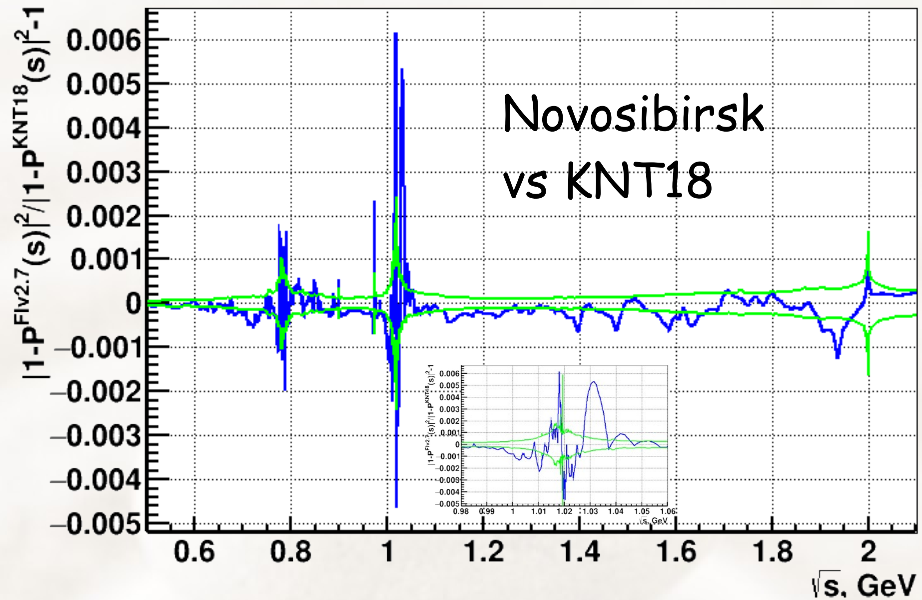
It is commonly used FSR correction in approx. with E>>Mμ:

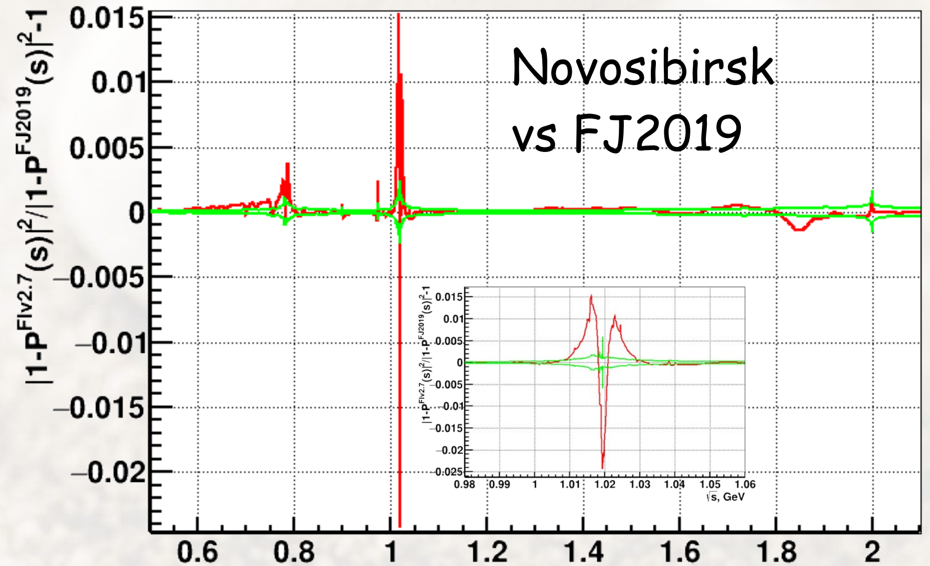
missed dependency δ_{FSR} virtual ~ $2\alpha\pi/\beta_\mu$ with $\beta_\mu \to 0$

Vacuum polarization



✗ FJ2019: Fred Jegerlehner
http://www-com.physik.hu-berlin.de/~fjeger/software.html
✗ KNT18(v3.0): A Keshavarzi, D Nomura, T Teubner
✗ FIv2.7(2019): Novosibirsk VP
https://cmd.inp.nsk.su/~ignatov/vpl/

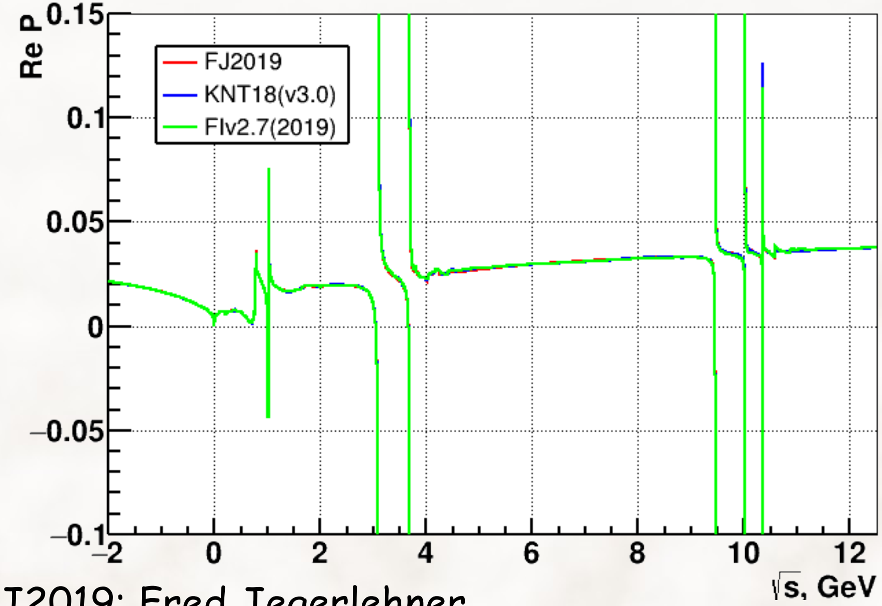




VP consistent at 0.05-0.1% outside of narrow resonances
At phi – statistical inconsistency ~0.5%, FJ up to 1.5-2.%

Fred is using dressed phi with PDG parameters
(should be bare Mφ, which shifted by 254 keV)

Vacuum polarization



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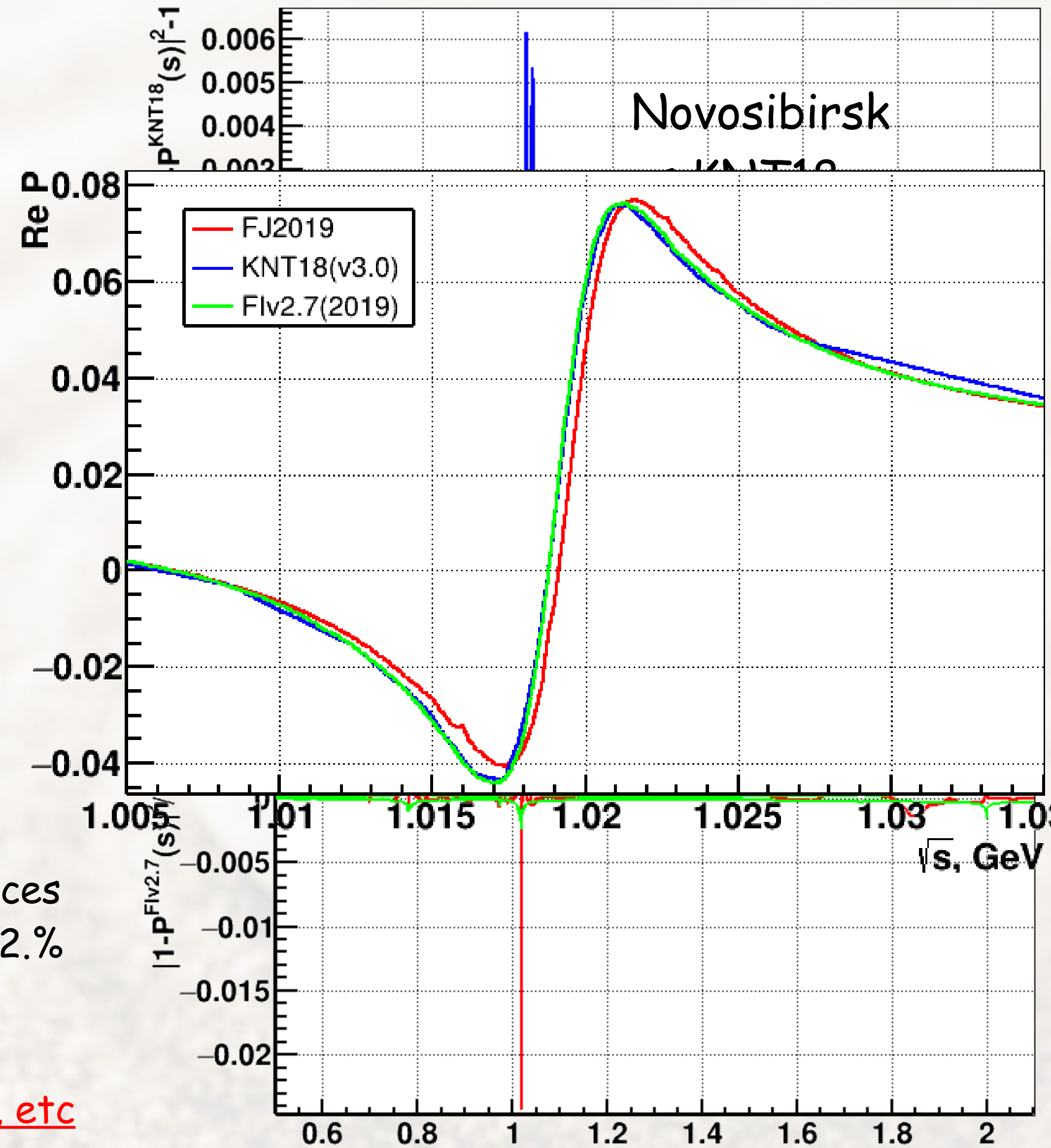


VP consistent at 0.05-0.1% outside of narrow resonances
At phi – statistical inconsistency ~0.5%, FJ up to 1.5-2.%
Fred is using dressed phi PDG parameters
(should be bare Mφ, which shifted by 254 keV)
Be careful with VP using at narrow resonances φ, J/ψ, etc

Summary

Current and future experiment will have increased collected luminosity, which allow to do analysis based on some differential quantities.

Inconsistency in e+e- → e+e- spectra:
of MCGPJ vs BabaYaga@NLO vs Bhwide is at ~ 10% in momentum tails
at ~0.1-0.2% in angle distribution

It's commonly missed dependency with β_μ in FSR virtual correction for e+e- → μ+μ-

For future experiments (but even now) to have experimental precision ~<0.1%:
<u>NNLO e+e-→e+e-,μ+μ-(γγ), ... generators will be highly demanded tools</u>

Backup

MCGPJ vs BabaYaga spectrums

2013+2018 data

Can be looked

region where no 2π events:

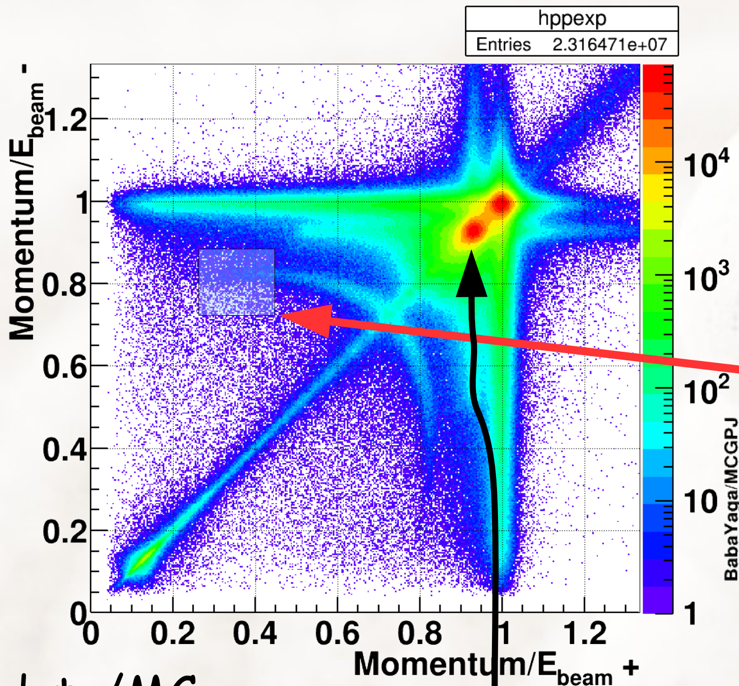
0.3 ‹P1 ‹ 0.4 &&

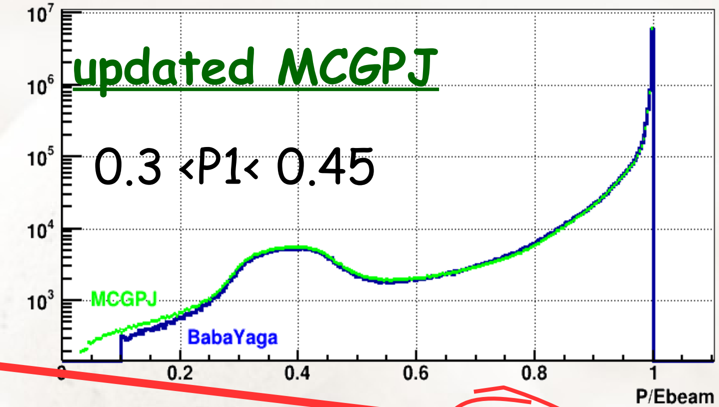
0.75 ‹ P2 ‹0.85

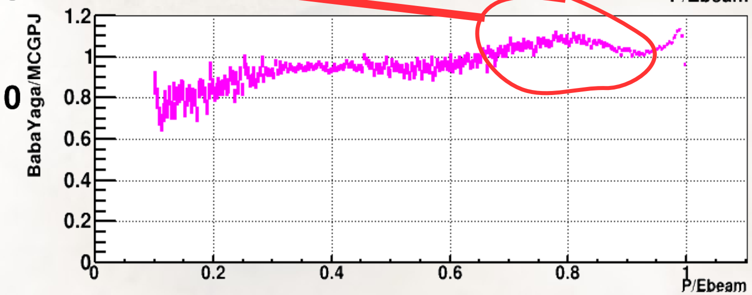
+ box vise-versa

Ebeam ‹ 375 MeV

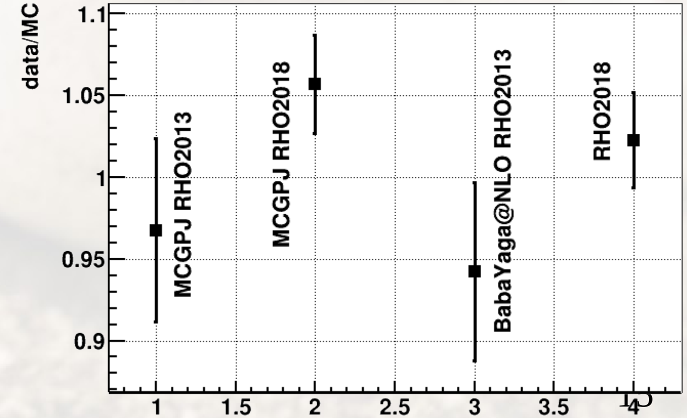
to suppress 3π







	data/MC
MCGPJ	1.038 +- 0.026
BabaYaga@NLO	1.006 +- 0.026



It is necessary to have statistic ~ x10 more
(or somehow to suppress 3π events)

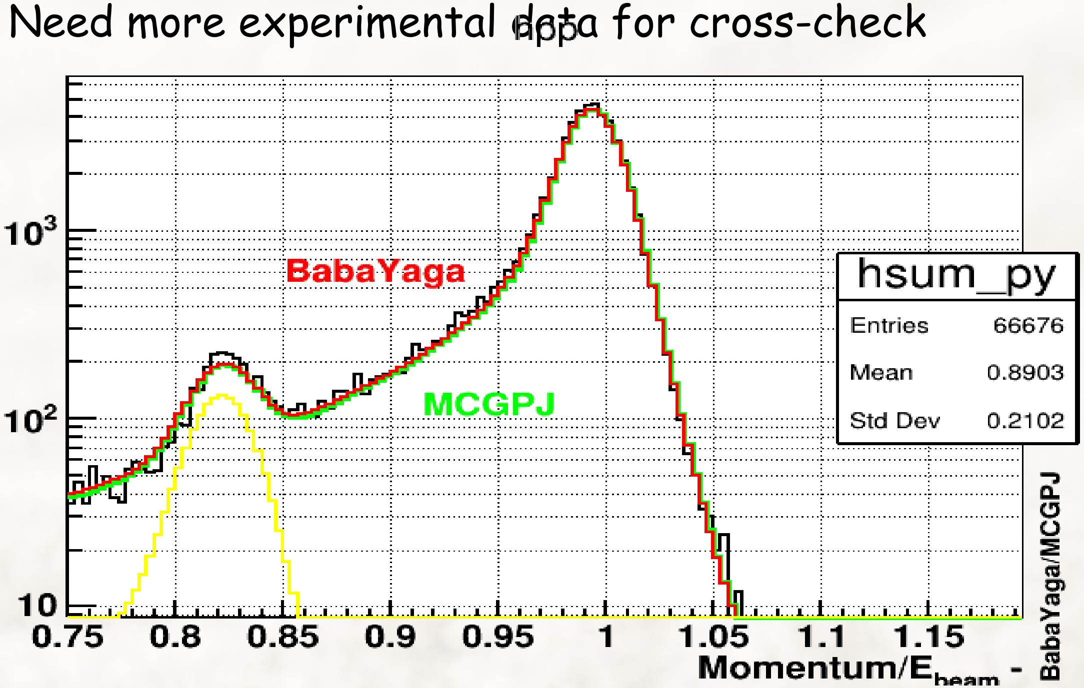
And for 2π analysis more crucial spectrum in another part, where pion peaks: P1,P2 ~ 0.9 E_{beam}

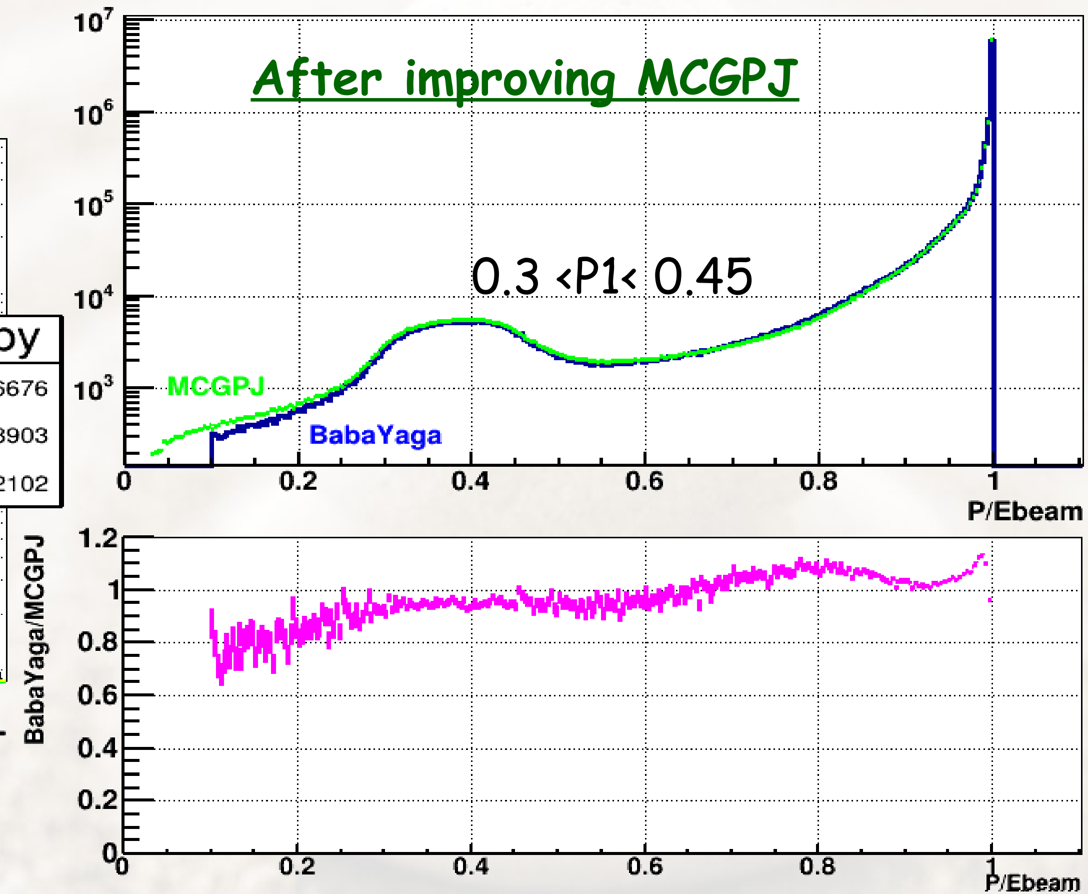
MCGPJ vs BabaYaga spectrums

After adding angle distribution for jets, etc ...

Momentum spectrum still disagree at level ~ 10%

Need more experimental data for cross-check





Momentum spectrum disagree at level ~ 10%

Need more experimental data for cross-check

We need more theoretical input for MC

Result in systematic of π+π- measurement → 0.0 - 0.4%

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:

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

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…

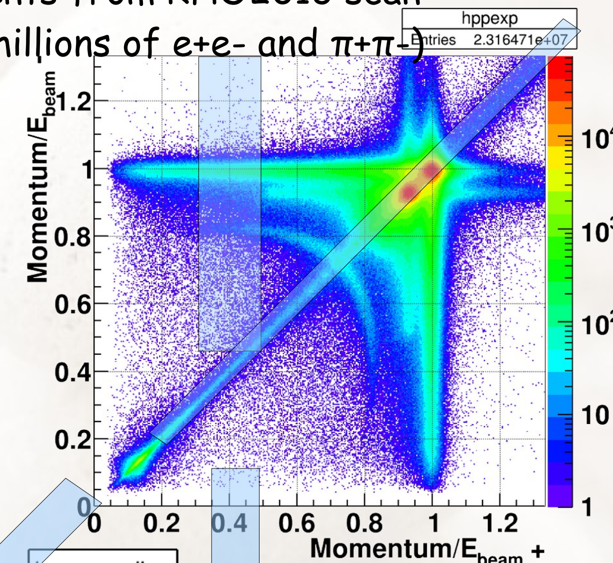
MC generator, MCGPJ

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

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

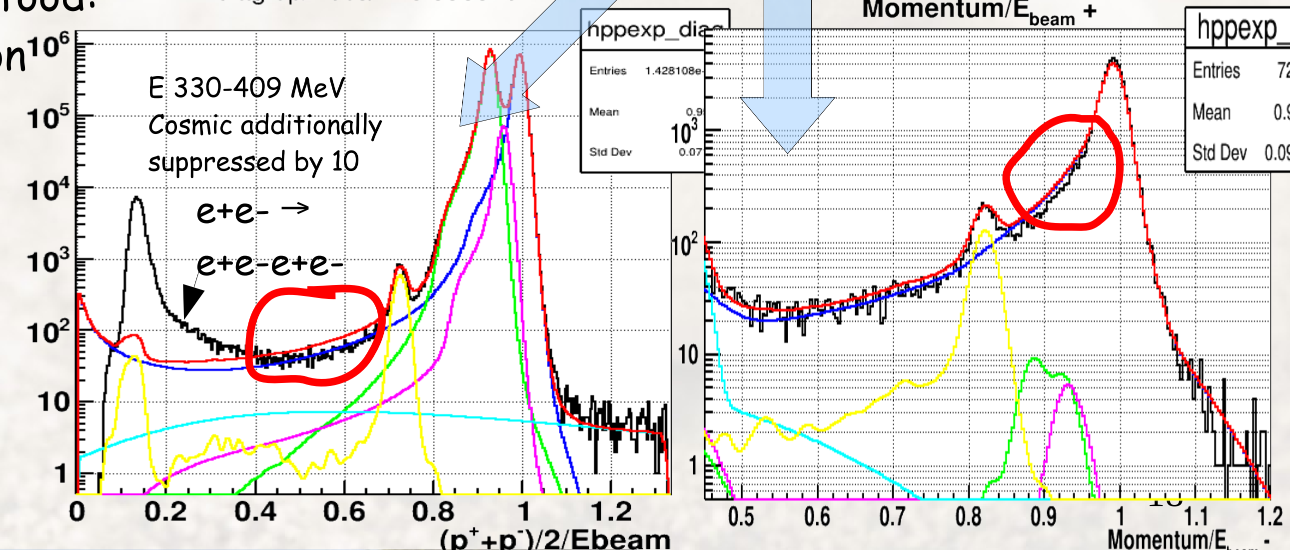
Several MC generators available with 0.1-0.5% precision.
MCGPJ generator (0.2%) is used by Novosibirsk group:
1 real γ + γ jets along all particles (with collinear Structures function)

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

diag dp/Ebeam<0.0383161

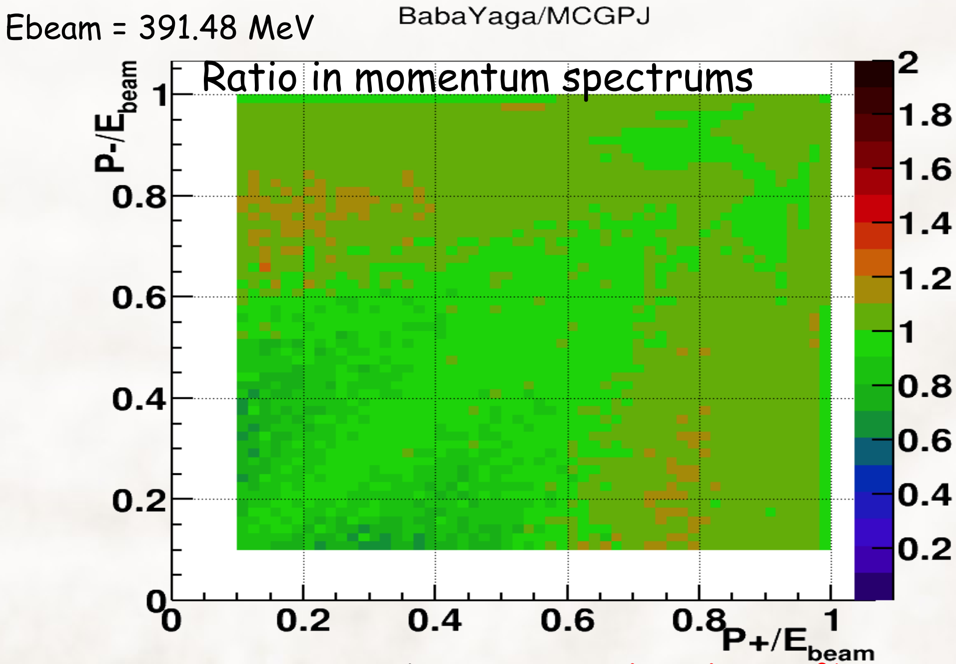


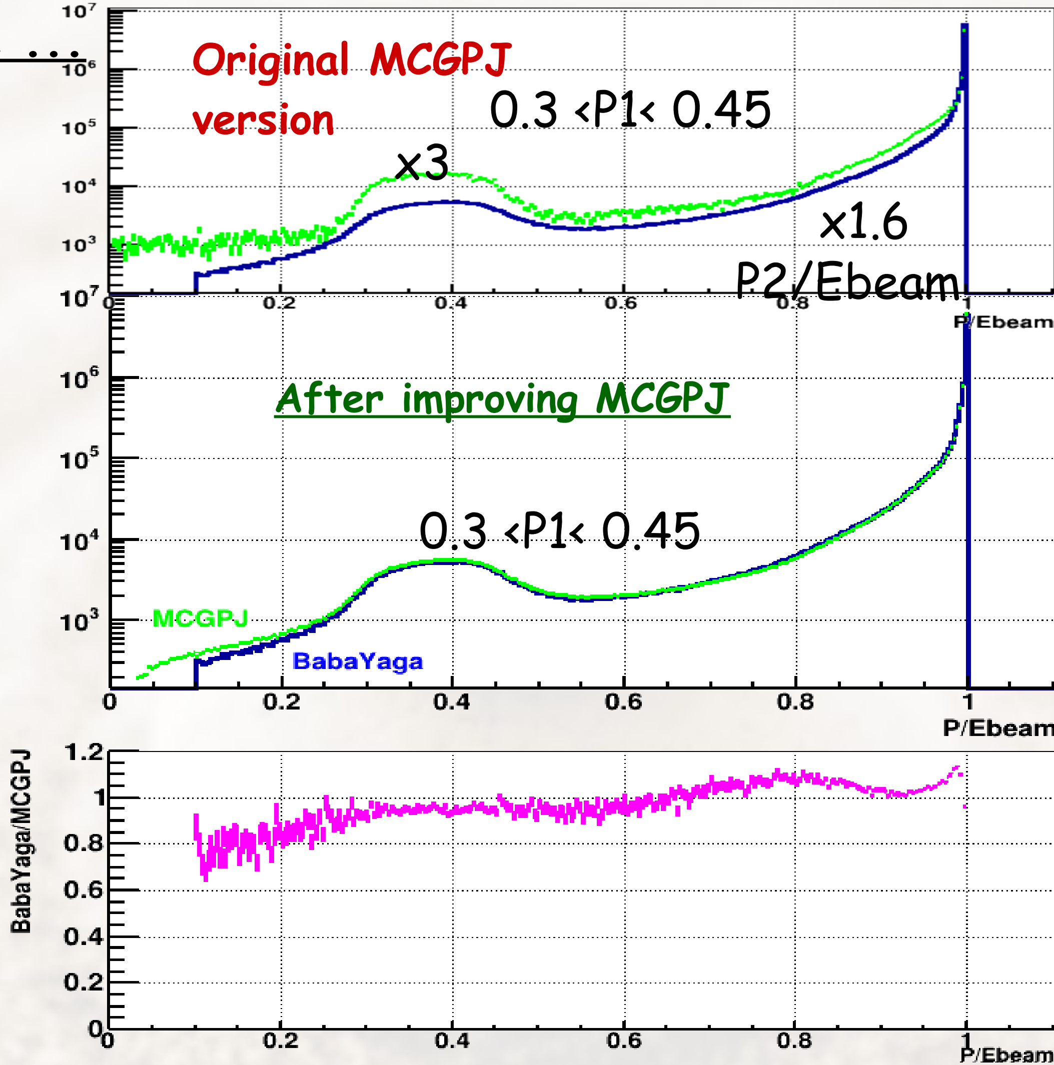
Several steps for upgrading MCGPJ
were done.

But still some question under inspection

MCGPJ vs BabaYaga spectrums

After adding angle distribution for jets, etc ...





Momentum spectrum disagree at level ~ 10%

Need more experimental data for cross-check

We need more theoretical input for MCGPJ

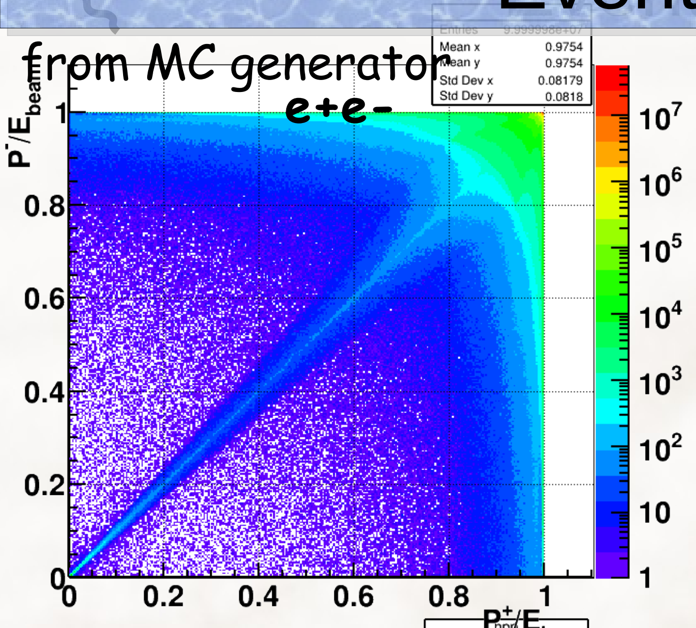
Result in systematic of π+π- measurement

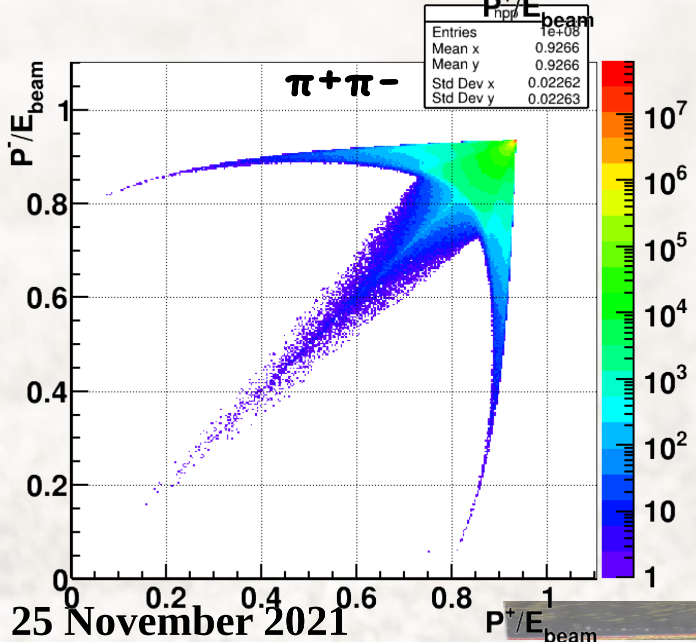
→ 0.0 - 0.4%

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

Event separation by momentum

from MC generator





For particle separation:

As input: momentum spectra for ee,ππ,μμ events from MC generator (in applied selection criteria) + cosmic from data,3π background from MC

Generated distributions are convolved with detector response function which includes:
momentum resolution, bremsstrahlung,
pion decay, etc..

This method rely on precise knowledge of initial differential spectra from MC