Data-driven low-energy generator for CMD-3

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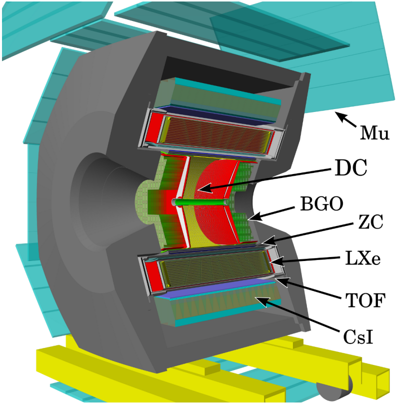
Outline

- Motivation
- Data
- Structure
- Input and output
- Some applications
- Conclusion

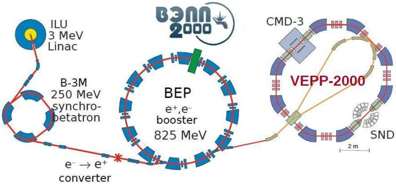
CMD-3 and VEPP-2000

CMD-3



Collider VEPP-2000

$L = 4 * 10^{31} cm^{-2} s^{-1}$ at 2.0 GeV



Motivation

- MHG2000-MultiHadronic Generator for VEPP-2000
- pQCD fails at the energy range $\sqrt{s} < 2$ GeV
- One of CMD-3's goals is the precision measurement of exclusive hadron cross section
- Evaluation of the background for hadronic processes
- It is data-driven generator based on the bulk of measured exclusive cross sections

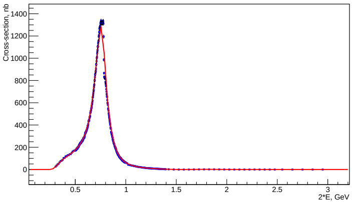
MHG2000's features

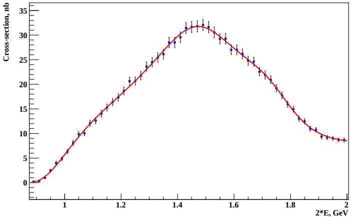
- An event is sampled with one ISR photon: $d\sigma/d\omega_\gamma dE_\gamma$ proportional $f(E_\gamma, cos\theta_{\gamma)})$
- Currently near 30 different final states
- Matrix elements are added whenever possible, output compared to PHOKHARA for N=3,4
- Use phase volume model otherwise
- We approximate the data by functions for each final state
- Energy dependence of σ_i, $\sigma_{tot} = \sum_i \sigma_i$, a final state number i is sampled with a weight of $\frac{\sigma_i}{\sigma_{tot}}$

Data samples

Process	Data	Process	Data
$\pi^+\pi^-$	BaBar	$\pi^+\pi^-\pi^0\pi^0$	DM2, CMD2
$\pi^0\gamma$	SND	$\pi^+\pi^-\pi^0\eta$	CMD-3
$\eta\gamma$	SND, CMD2	$K^+K^-\pi^+\pi^-$	CMD-3, BaBar
$p\bar{p}$	BaBar, CMD-3	$K^+K^-\pi^0\pi^0$	BaBar
$n\bar{n}$	SND	$K^-K^0\pi^+\pi^0$	BaBar
K^+K^-	BaBar CMD2	$K^0_SK^0_L\pi^+\pi^-$	BaBar
$K^0_SK^0_L$	BaBar, CMD3, SND	$K^0_SK^0_S\pi^+\pi^-$	BaBar
$\pi^+\pi^-\pi^0$	SND, CMD2, BaBar	$K^0_LK^0_S\pi^0\pi^0$	BaBar
$\pi^+\pi^-\eta$	SND	$K^+\overline{K^0}\pi^-\pi^0$	BaBar
$K^+K^-\pi^0$	BaBar	$2\pi^+2\pi^-\pi^0$	BaBar
$K^+K^-\eta$	BaBar	$\pi^+\pi^-3\pi^0$	BaBar
$K^\pm K^0_S\pi^\mp$	BaBar	$3\pi^+3\pi^-$	CMD3, BaBar
$K^\pm K^0_L\pi^\mp$	BaBar	$2\pi^+2\pi^-2\pi^0$	BaBar
$\pi^+\pi^-\pi^+\pi^-$	BaBar	$\pi^+\pi^-4\pi^0$	IR

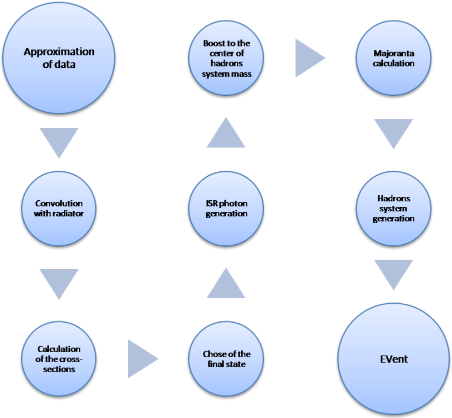
Examples of cross section approximations





Left: $\pi^+\pi^-$
Right: $\pi^+\pi^-\pi^0\pi^0$

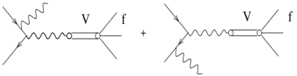
MHG2000 structure



modular structure based on C++, HEPMC, ROOT.

ISR photon

- Convolution of the Born cross section with radiator function
- Choose the final state using corrected cross section
- Generate ISR photon
- Boost to the center-of-mass frame of hadron system and generate hadrons

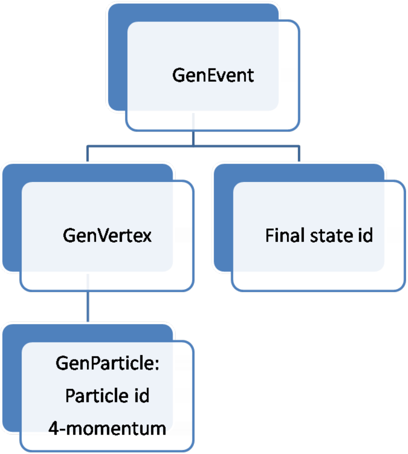


$$\frac{d\sigma(s,x)}{dx\, d\cos\theta} = \frac{2\alpha}{\pi x} \cdot \frac{(1 - x + \frac{x^2}{2})\sin^2\theta}{(\sin^2\theta + \frac{m_e^2}{E^2}\cos^2\theta)^2} \cdot \sigma_0(s(1-x)),$$

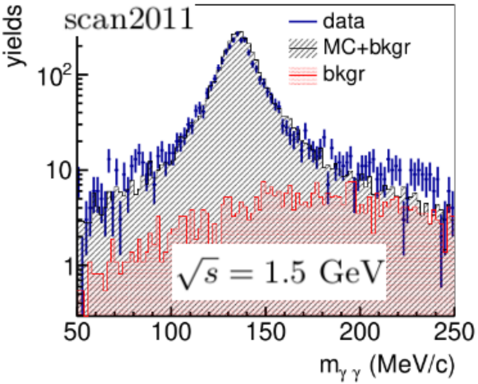
Input parameters

- center-of-mass energy in GeV
- isrkey=1 isr is on; isrkey=0 isr is off
- list of required processes

MHG2000 Output



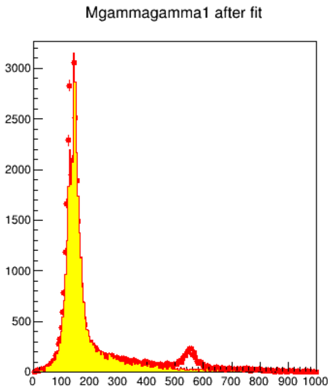
Application at CMD-3: $\pi^+\pi^-\pi^0\pi^0$

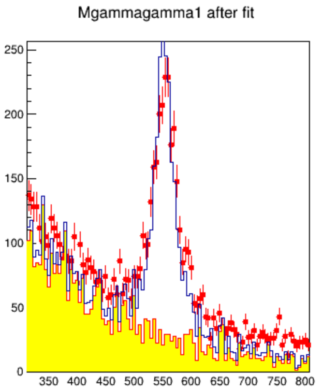


Two photon invariant mass: Red for MHG2000 without signal dots for data

CMD-3 preliminary

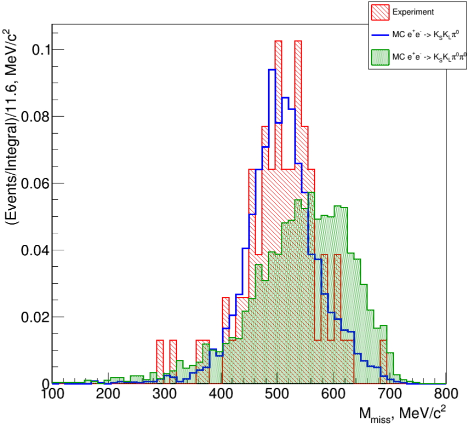
Application at CMD-3: $\pi^+\pi^-\pi^0\eta$





Two photon invariant mass: Yellow for MHG2000; dots for data CMD-3 preliminary

Application at CMD-3: $K_L^0 K_S^0 \pi 0$

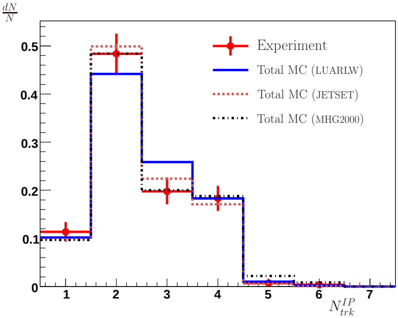


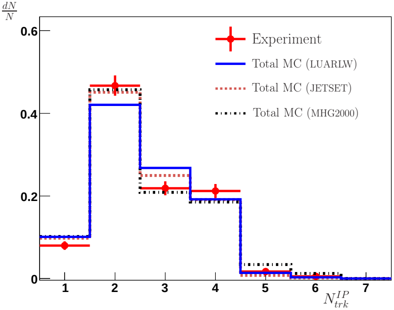
$K_S\pi^0$ missing mass; Green for MHG2000; Red for data CMD-3 preliminary

MHG2000 Generator for R Measurement at KEDR

- $R = \frac{\sigma_{e^+e^- \to hadrons}}{\sigma_{e^+e^- \to \mu^+\mu^-}}$
- KEDR performed several measurements of R from 1.84 to 3.72 GeV: V.V. Anashin et al., Phys. Lett. B770 (2017) 174 (13 points, 1.84-3.05 GeV)(last one)
- They use LUARLW and JETSET 7.4 for efficiency calculations, input parameters tuned by comparing 20 parameters with data
- To calculate radiative corrections MHG2000 is used in the region up to 2 GeV

Comparison of three MC generators (charged multiplicity)





Fair agreement of MHG2000 with data at 1.84 and 1.94 GeV

Conclusion and plans

- A data-driven generator of multihadronic final states MHG2000 is based on the measured cross sections at $\sqrt{s} < 2$ GeV
- MHG2000 is used to simulate background in experiments at VEPP-2000
- MHG2000 has been also used in R measurement at KEDR
- Its development is currently in progress: new modes and matrix elements added
- Planning to expand the energy range up to 2.5 GeV using Babar and BESIII data

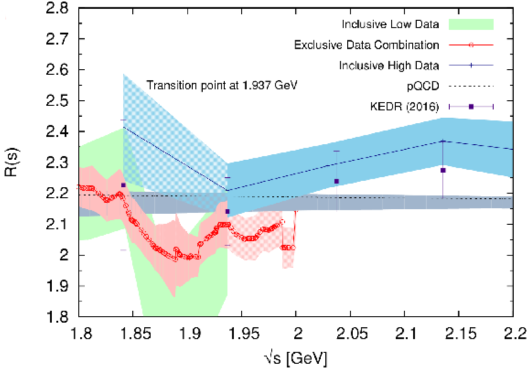
Back up

Radiator

- $D(x,s) = \frac{1}{2}\beta(1-x)^{\beta/2-1}(1+\frac{3}{8}*\beta - \frac{1}{48}\beta^2(\frac{1}{3}L+\pi^2-\frac{47}{8})) - \frac{1}{4}\beta(1+x) + \frac{1}{32}\beta^2(4(1+x)ln\frac{1}{1-x} + \frac{1+3x^2}{1-x}ln\frac{1}{x} - 5 - x)$ with $\beta = \frac{2\alpha}{\pi}(L-1); L = ln\frac{s}{m^2}$

$$\sigma(s) = \int_{\varepsilon_1}^{1}\int_{\varepsilon_2}^{1} dx_1\, dx_2\, \mathcal{D}(x_1,s)\mathcal{D}(x_2,s)\tilde{\sigma}(sx_1x_2)\left(1+\frac{\alpha}{\pi}\left(\frac{\pi^2}{3}-\frac{1}{2}\right)\right)$$

Exclusive vs Inclusive R measurement)

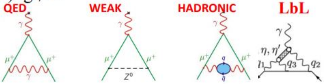


A. Keshavarzi, D. Nomura and T. Teubner.
The muon $g-2$ and $\alpha(M_Z^2)$: a new data-based analysis.
Phys. Rev. D **97**, 114025 (2018).[arXiv:1802.02995].

Anamalous magnetic moment of muon

- Magnetic moment of muon: $\vec{\mu} = g\frac{e\hbar}{2mc}\vec{s}$
- Gyromagnetic factor g for
  - Dirac particles (point-like fermions): g = 2
  - Higher order contributions (QFT): g ≠ 2
- Muon anomaly
  - $a_\mu = (g-2)_\mu/2$

$a_\mu^{theory(SM)} = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{had}$

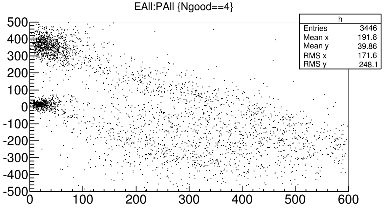


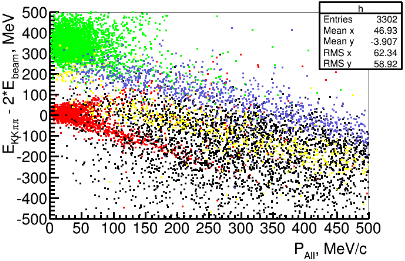
Source	Value (10^{-10})	Uncertainty (10^{-10})
QED	11 658 471.895	0. 008
Weak	15.4	0.2
Hadronic $+LbL$	693.0	4.9
BNL E821	11 659 208.9	6.4
BNL – SM Theory	28.7	8.0

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

$$R(s) = \frac{\sigma(e^+e^- \to \gamma^* \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

$a_\mu^{EXP} - a_\mu^{SM} = 3.6\sigma$ **(M. Davier et al., EPJC71(2011)1515)**

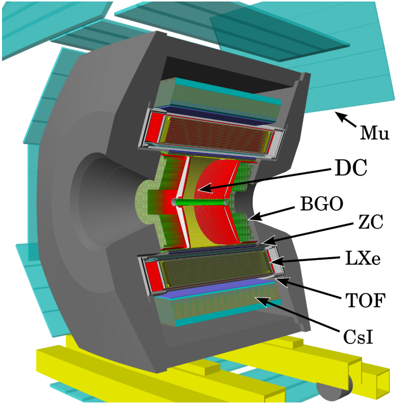




Energy difference vs total momentum
Left EXP
Right MHG2000 simulation(red-4pi(signal), black-6pi,blue-5pi, yellow-KsKpi)

CMD-3 and VEPP-2000

CMD-3



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