Measurement of R at the KEDR detector

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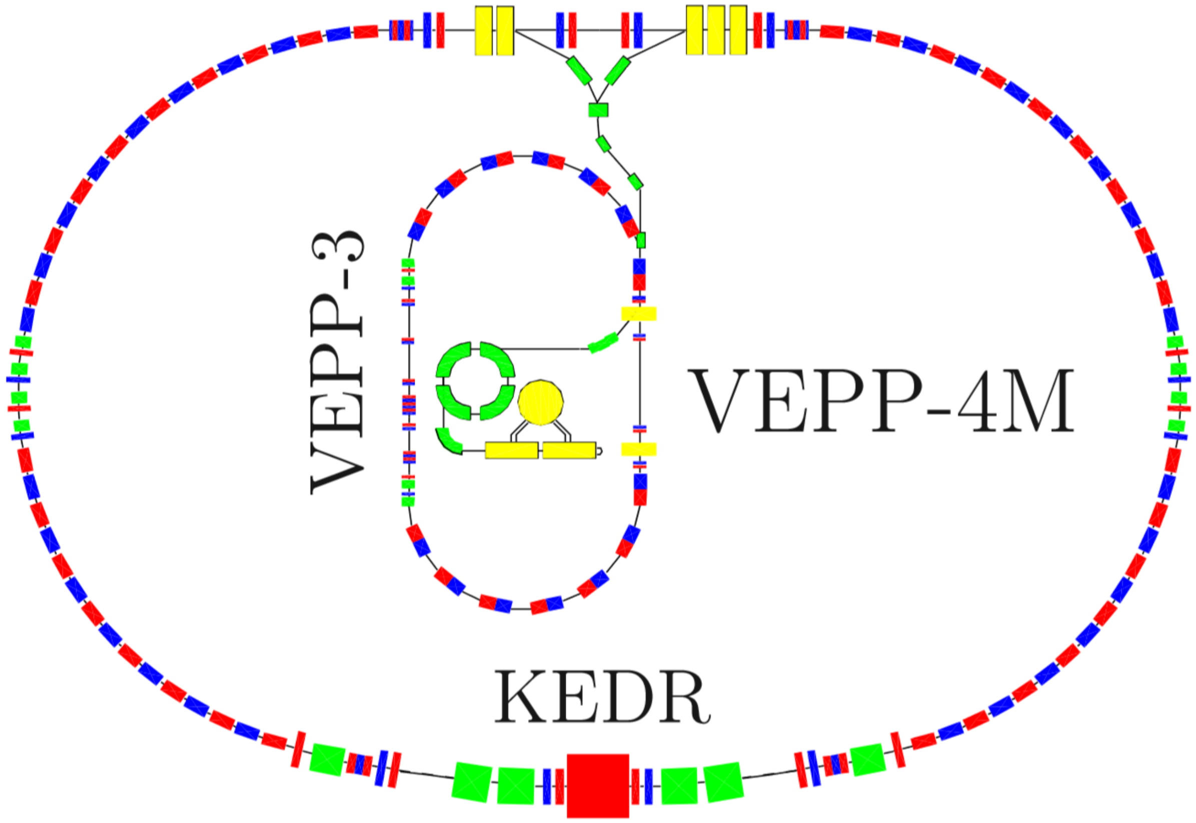
19.02.2025

Collider VEPP-4M



Beam energy	1 – 5 GeV
Number of bunches	2 x 2
Luminosity at 1.5 GeV	$2\cdot10^{30}$ cm^{-2} s^{-1}
Luminosity at 5.0 GeV	$2\cdot10^{31}$ cm^{-2} s^{-1}

Beam energy measurement:

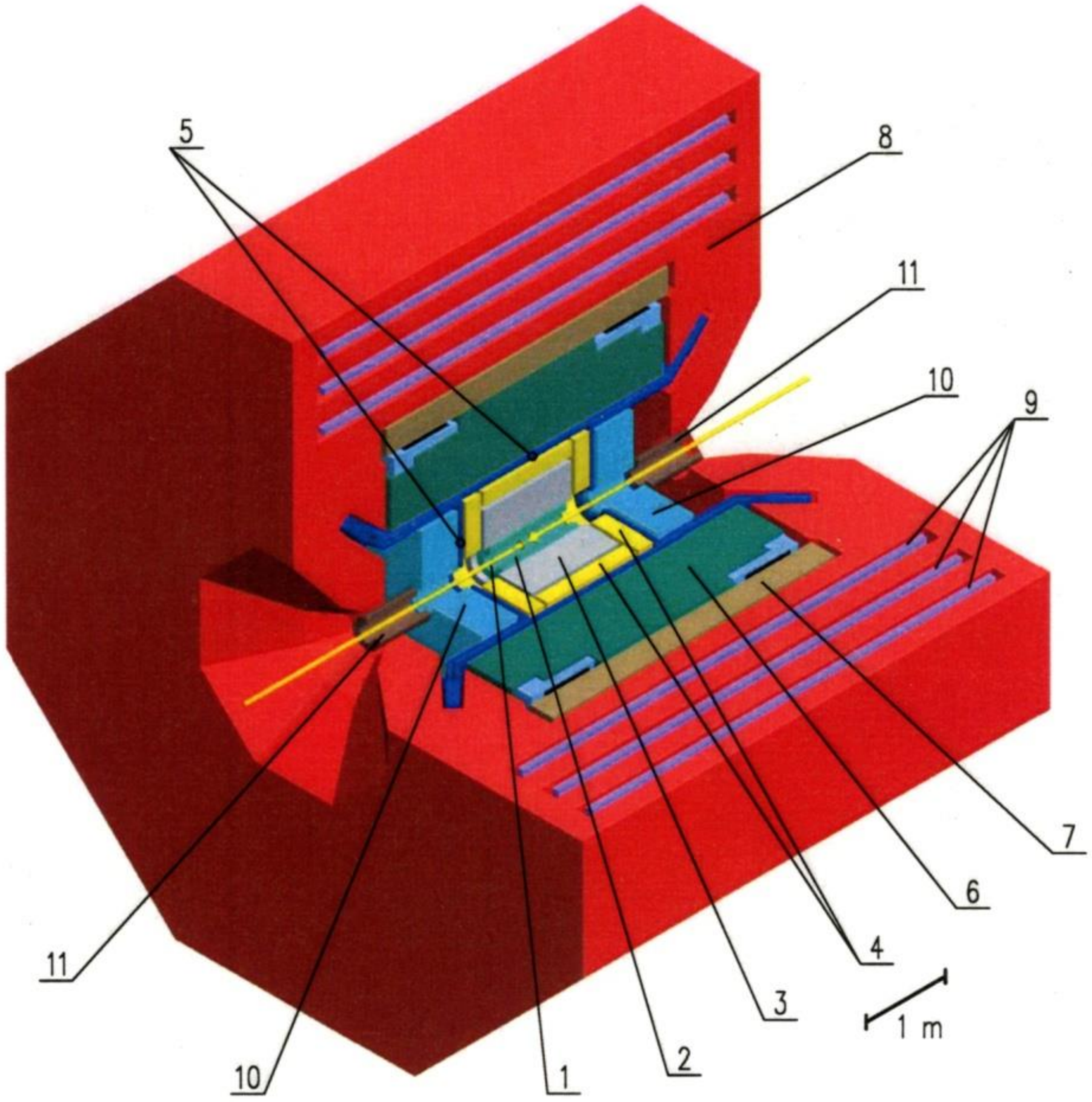
- Resonant depolarization method

  Instant measurement accuracy 1 keV

  Energy interpolation accuracy 10-30 keV

- Infrared light Compton backscattering

  Monitoring with accuracy 100 keV



KEDR detector

1. Vacuum chamber
2. Vertex detector
3. Drift chamber
4. Threshold aerogel counters
5. ToF counters
6. Liquid krypton calorimeter
7. Superconducting coil
8. Magnet yoke
9. Muon tubes
10. CsI calorimeter
11. Compensating s/c solenoid

Physical program of KEDR experiment

Elementary particle mass measurements:
J/ψ, ψ(2S), ψ(3770), D^0, $D^{\pm}$, τ, Υ – mesons

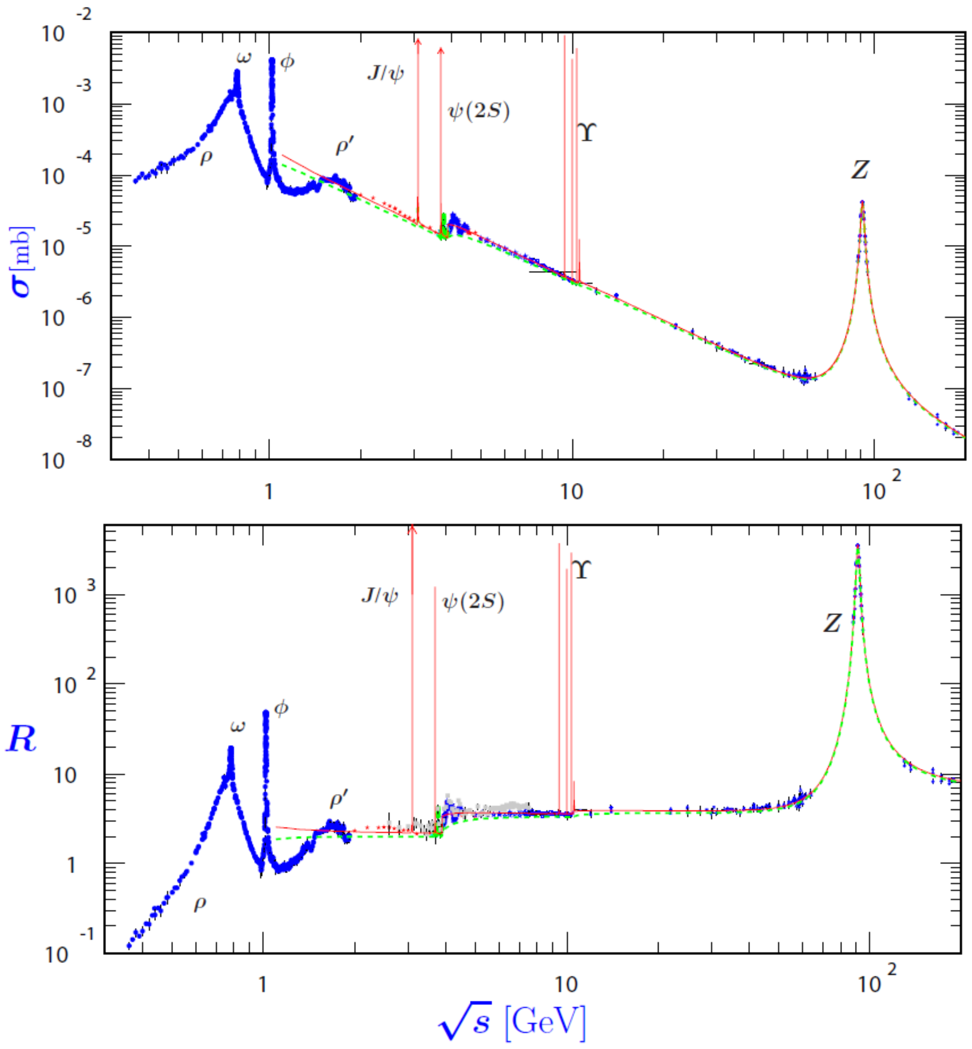
Leptonic width measurement for ψ- and Υ – mesons

R measurements at 2E = 2 - 10 GeV

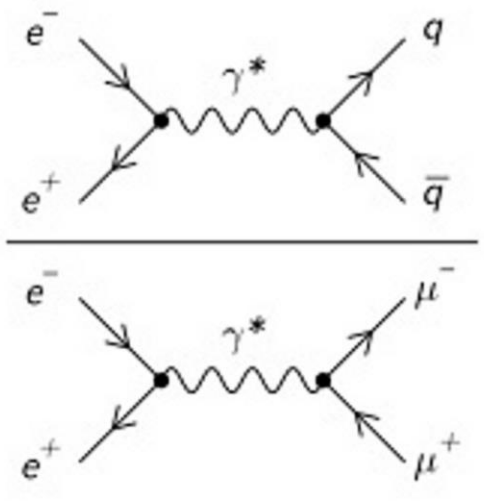
Cross section measurement for process $\gamma\gamma \to$ hadrons

Branching fraction measurements $J/\psi \to \gamma\eta_c$, ρη, ρη, etc.

Motivation of R measurement

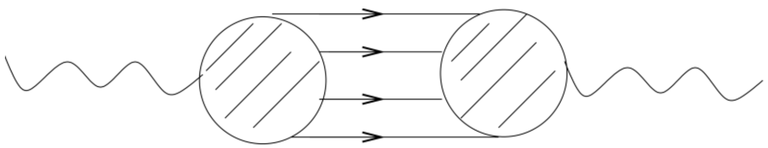


$$R = \frac{\sigma(e^-e^+ \to hadrons)}{\sigma(e^-e^+ \to \mu^-\mu^+)} \approx$$



R(s) is used to determine:

- $\alpha_s(s)$
- $(g_\mu - 2)/2$
- $\alpha\ (M_Z^2)$
- m_q



Predictions

Naive quark model:

$$R_0(s) = \frac{\sigma(e^-e^+ \to hadrons)}{\sigma(e^-e^+ \to \mu^-\mu^+)} = N_c \sum e_q^2$$

At energy $3.77 \leq \sqrt{s} \leq 10.58$ GeV (u, d, s, c) : $R_0 \approx {}^{10}/_{3}$

pQCD in 3-loops: $R(s) = R_0(s)\left(1 + C_1\frac{\alpha_s}{\pi} + C_2\left(\frac{\alpha_s}{\pi}\right)^2 + C_3\left(\frac{\alpha_s}{\pi}\right)^3 + C_4\left(\frac{\alpha_s}{\pi}\right)^4\right)$

At $n_f = 4:\ C_1 = 1, C_2 = 1.525, C_3 = -11.686\ , C_4 =$ -89.822

P. A. Baikov et al. Nucl. And Part. *Phys. Proceed.* 261-262 (2015)

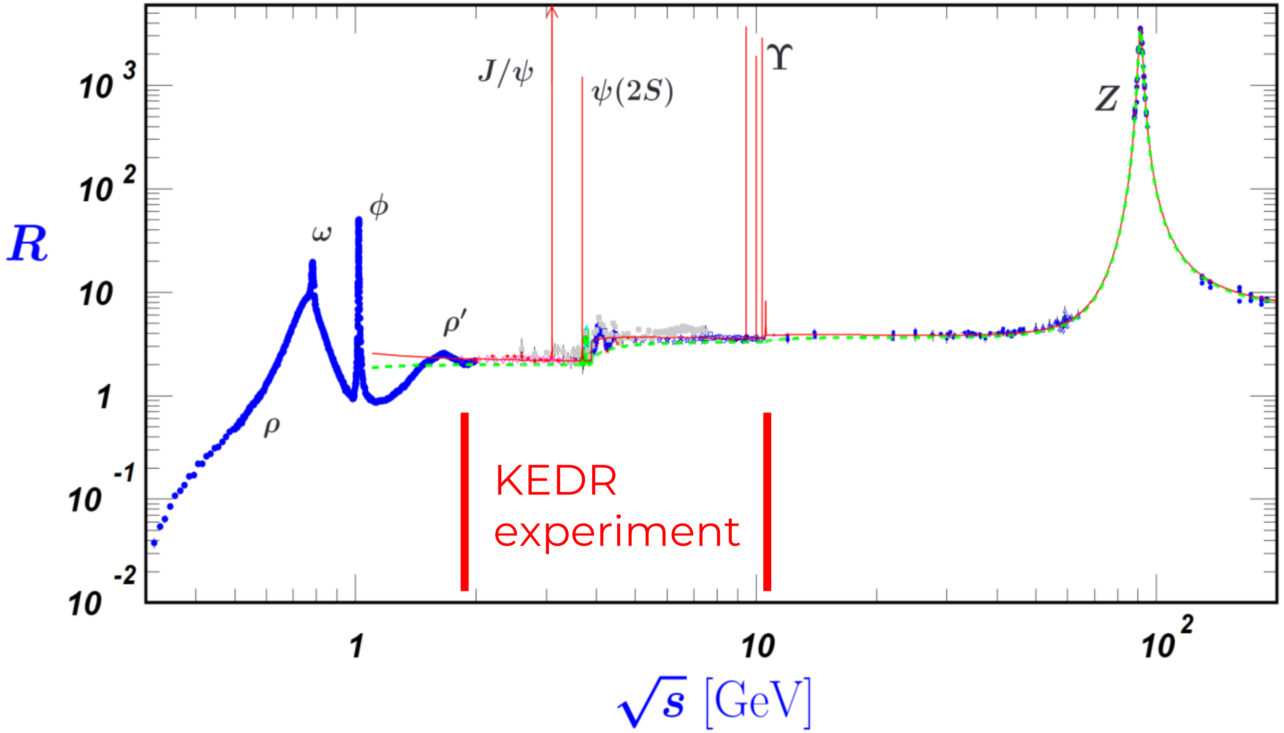
$$\alpha_s = \frac{1}{\beta_0 L} - \frac{b_1}{(\beta_0 L)^2}\ln L + \frac{1}{(\beta_0 L)^3}\left[b_1^2(\ln^2 L - \ln L - 1) + b_2\right] + \\ + \frac{1}{(\beta_0 L)^4}\left[b_1^3\left(-\ln^3 L + \frac{5}{2}\ln^2 L + 2\ln L - \frac{1}{2}\right) - 3b_1 b_2 \ln L + \frac{b_3}{2}\right]$$

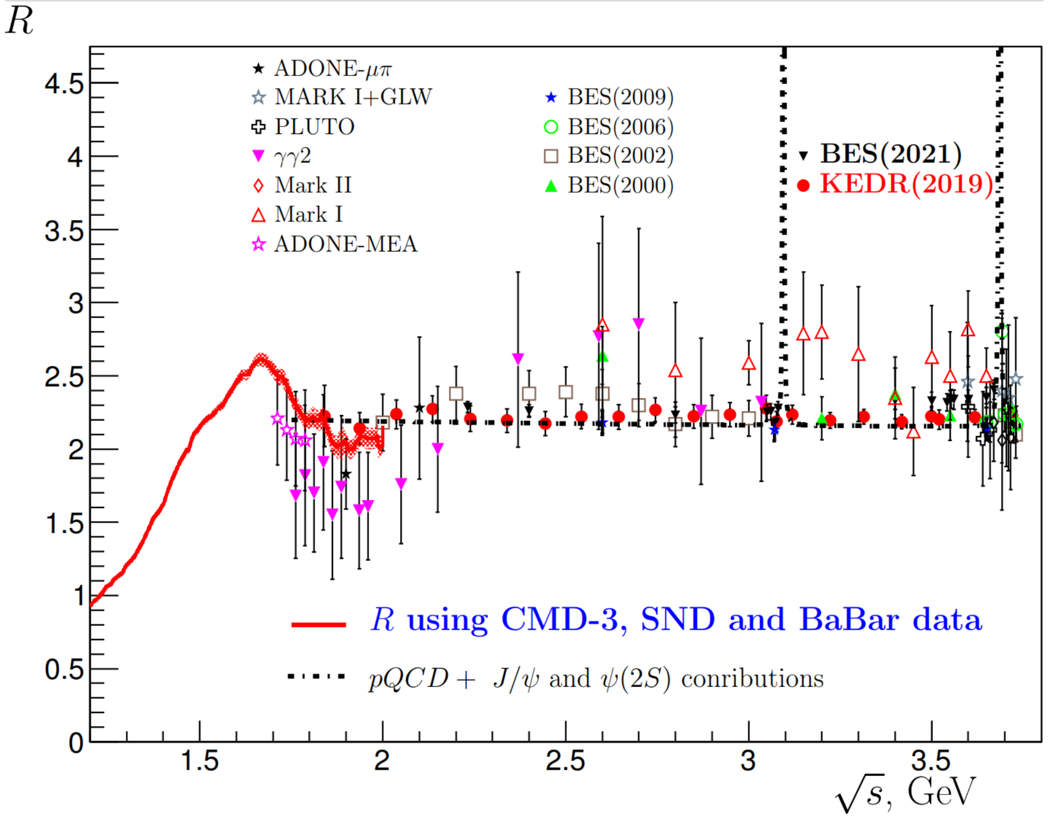
At $n_f = 4 : \beta_0 = 2.083, b_1 = -1.540\ , b_2 = 3.048, b_3 = 179.558;\ L = \ln\frac{s}{\Lambda^2}$

Chetyrkin, Kniehl, Steinhauser, Nucl. Phys. B 510 (1998) 61

R measurements at KEDR

$\sqrt{s}$, GeV	N_{points}	$\int Ldt, pb^{-1}$
1.84 - 3.05	13	0.66
3.08 - 3.72	9	2.7
4.69 - 6.98	17	13.7





R scan in 2019-2020

2E = 4.69 – 6.98 GeV
17 energy points with a step ~ 0.15 GeV
Integrated luminosity 13.7 pb^{-1}

Determination of R ratio

$$R(s) = \frac{\sigma_{obs}^{mh}(s) - \sigma^{ee\to ee}(s) - \sigma^{ee\to\mu\mu}(s) - \sigma^{ee\to\tau\tau}(s)}{\varepsilon(s)(1+\delta(s))\sigma_{\mu\mu}^{0}}$$

$\sigma_{obs}^{mh}(s) = \frac{N^{mh} - N^{bkg}}{L}$ - observed hadronic cross section

N^{mh} - number of selected events

N^{bkg} - residual machine background

L – integrated luminosity

$\sigma^{ee\to ee}(s)$ - contribution from the process $ee \to ee$ (< 0.01 %)

$\sigma^{ee\to\mu\mu}(s)$ - contribution from the process $ee \to \mu\mu$ (~ 0.01%)

$\sigma^{ee\to\tau\tau}(s)$ - contribution from the process $ee \to \tau\tau$ (~ 0.2%)

$\varepsilon(s)$ - detection efficiency

$1 + \delta(s)$ - ISR correction factor

$$\sigma_{\mu\mu}^{0} = \frac{4\pi\alpha^2}{3s}$$

Born cross section for process $e^+e^- \to \mu^+\mu^-$

Hadron selections

~ 5k events at each point
~ 100k events in total

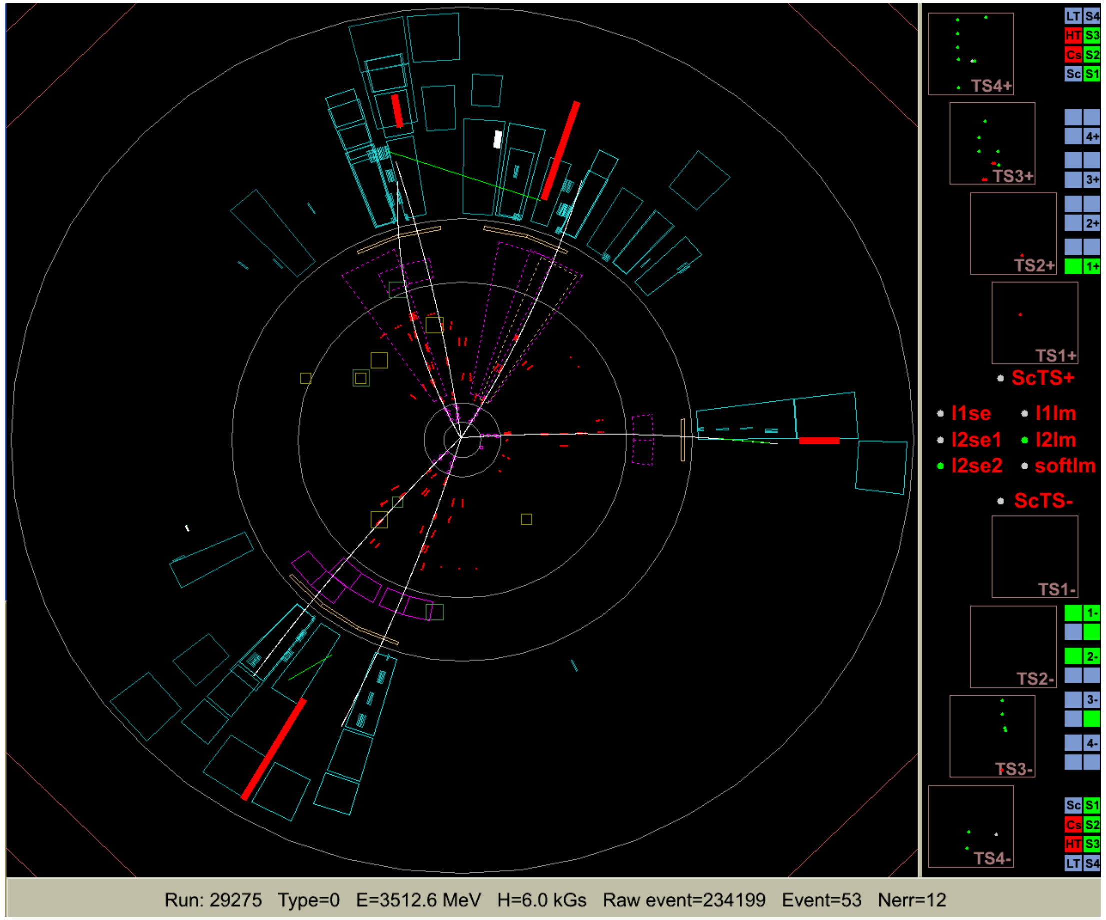
- PT and ST triggers
- At least 2 tracks from IP

(ρ < 1.5 cm, $|z_0|$ < 10 cm, P_t > 100 MeV)

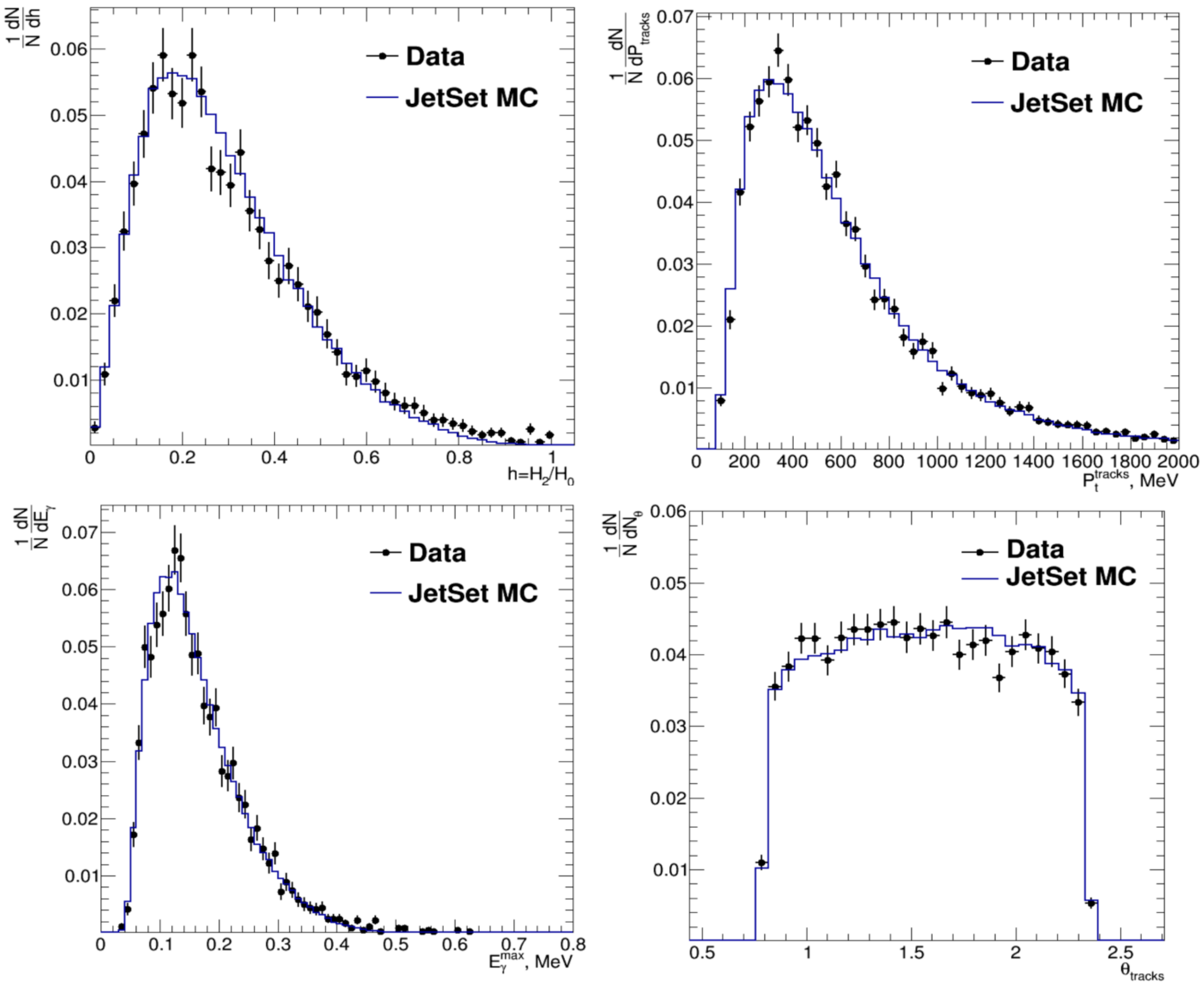
- At least 5 particles in detector;
- Fox-Wolfram moments

  $H_2/H_0<0.9$;

- $E_\gamma^{max}<0.35\ E_{run}$
- $E_{vis}>0.4\ E_{run}$
- $E_{LKr}>0.4\ E_{cal}$, $E_{cal}>0.25\ E_{run}$
- $P_z^{miss}<0.3\ E_{run}$
- “No cosmic” from muon system



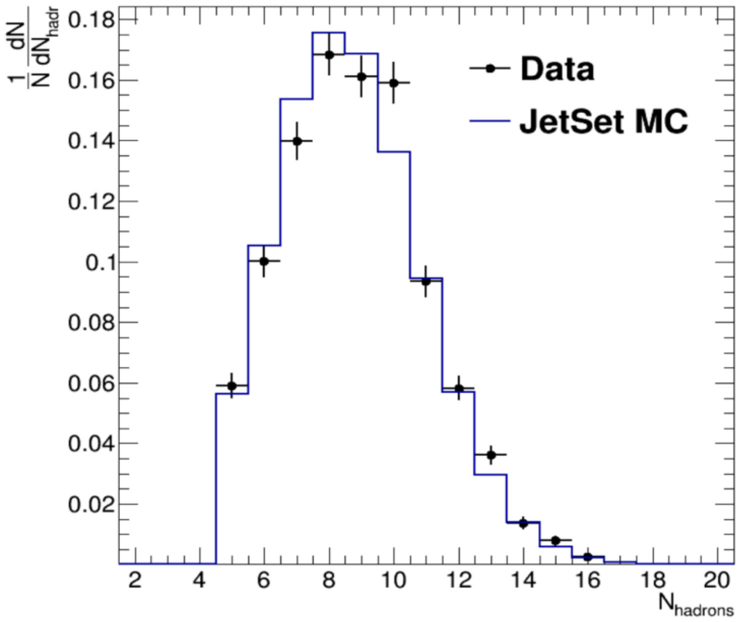
Simulation of hadronic events at 6.96 GeV

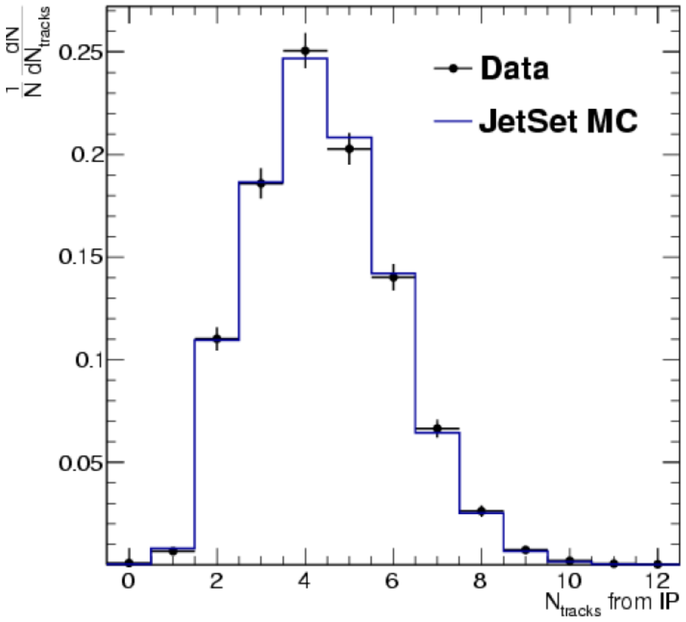


Experimental distributions and tuned JetSet MC

Good agreement of simulation with data is obtained

Simulation of hadronic events at 6.96 GeV - 2





Experimental distributions and tuned JetSet MC

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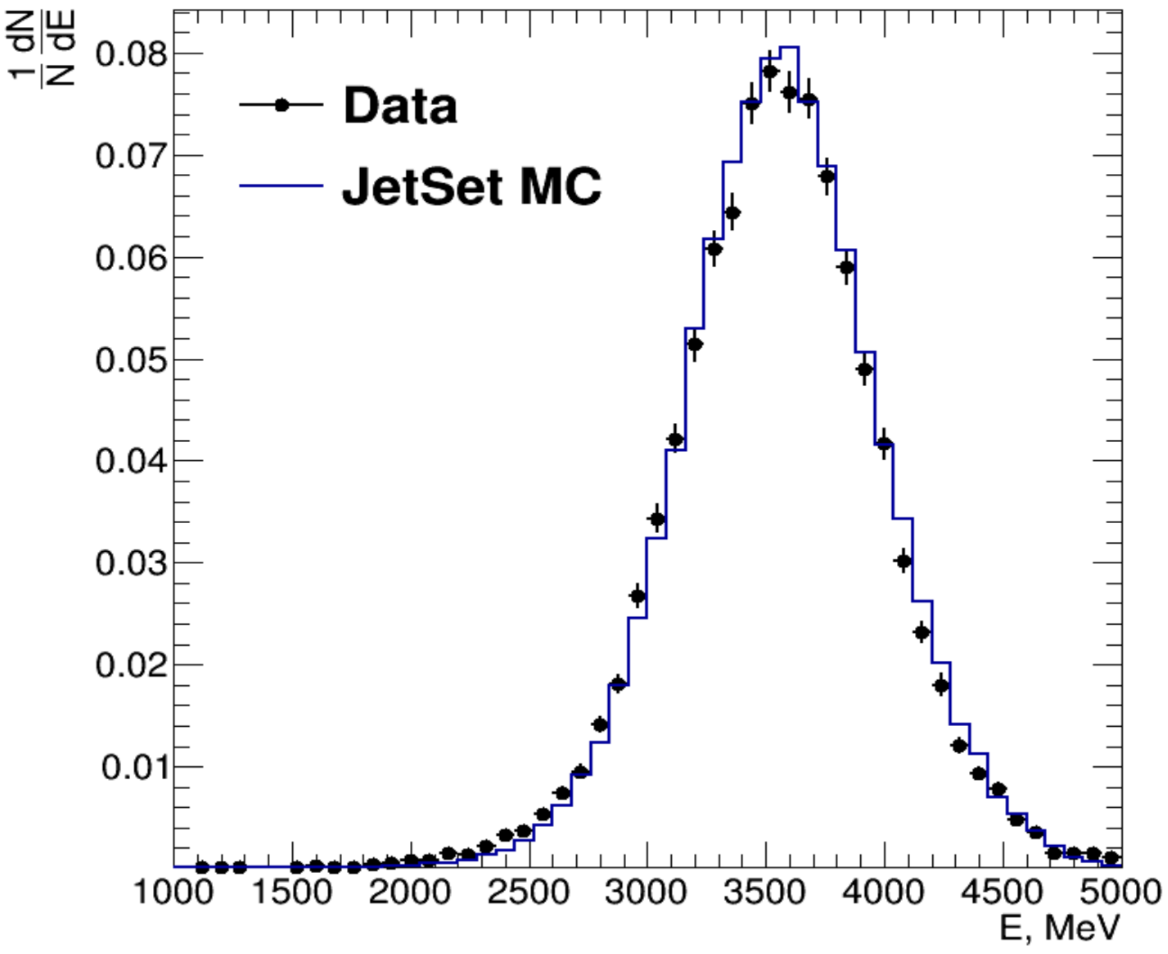
Luminosity measurement



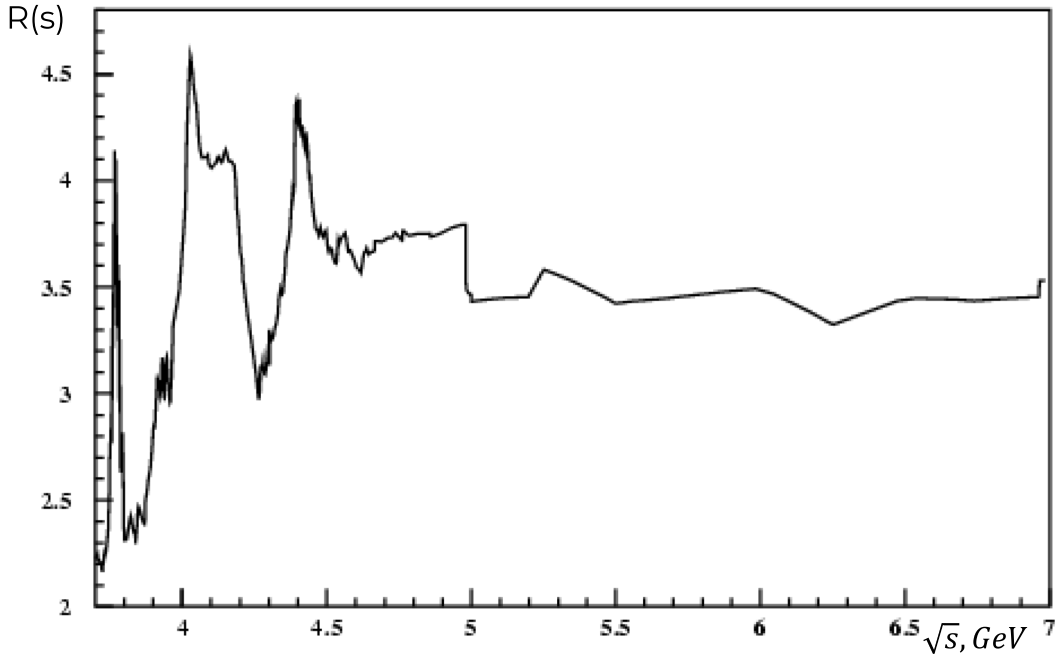
The absolute luminosity was calculated using e^+e^- events in the barrel LKr calorimeter

Systematic uncertainty ~ 1.2 %

Selection criteria:
≥ 2 clusters registered in LKr calorimeter
E_1+E_2 > 2 GeV
$E_{cal} - (E_1+E_2) < 0.1\ E_{cal}$
$\Delta\theta \leq 15°$, $\Delta\phi \leq 15°$
Sphericity <0.05

ISR correction calculation

$$1 + \delta(s) = \int \frac{dx}{1-x} \frac{F(s,x)}{|1-\Pi((1-x)s)|^2} \frac{R((1-x)s)\varepsilon((1-x)s)}{R(s)\varepsilon(s)}$$

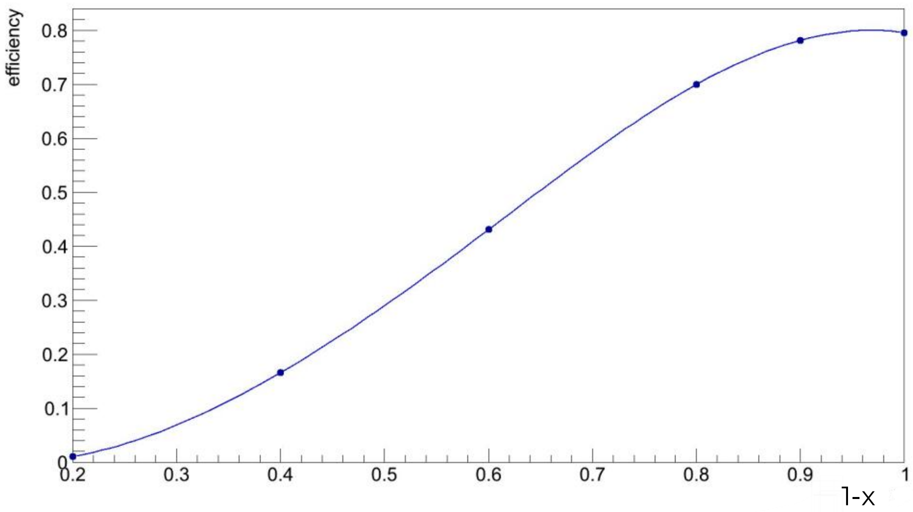


compilation of the vacuum polarization data by the CMD-2 group
S. Actis, *et al.*
Eur. Phys. J. C, 66 (2010), p. 585

F(s, x) - radiative correction kernel
[E. A. Kuraev, V. S. Fadin. Sov. J. Nucl. Phys. 41, 466 (1985)]

$$R(s) = -\frac{3}{\alpha}\, Im\, \Pi_{hadr}(s)$$

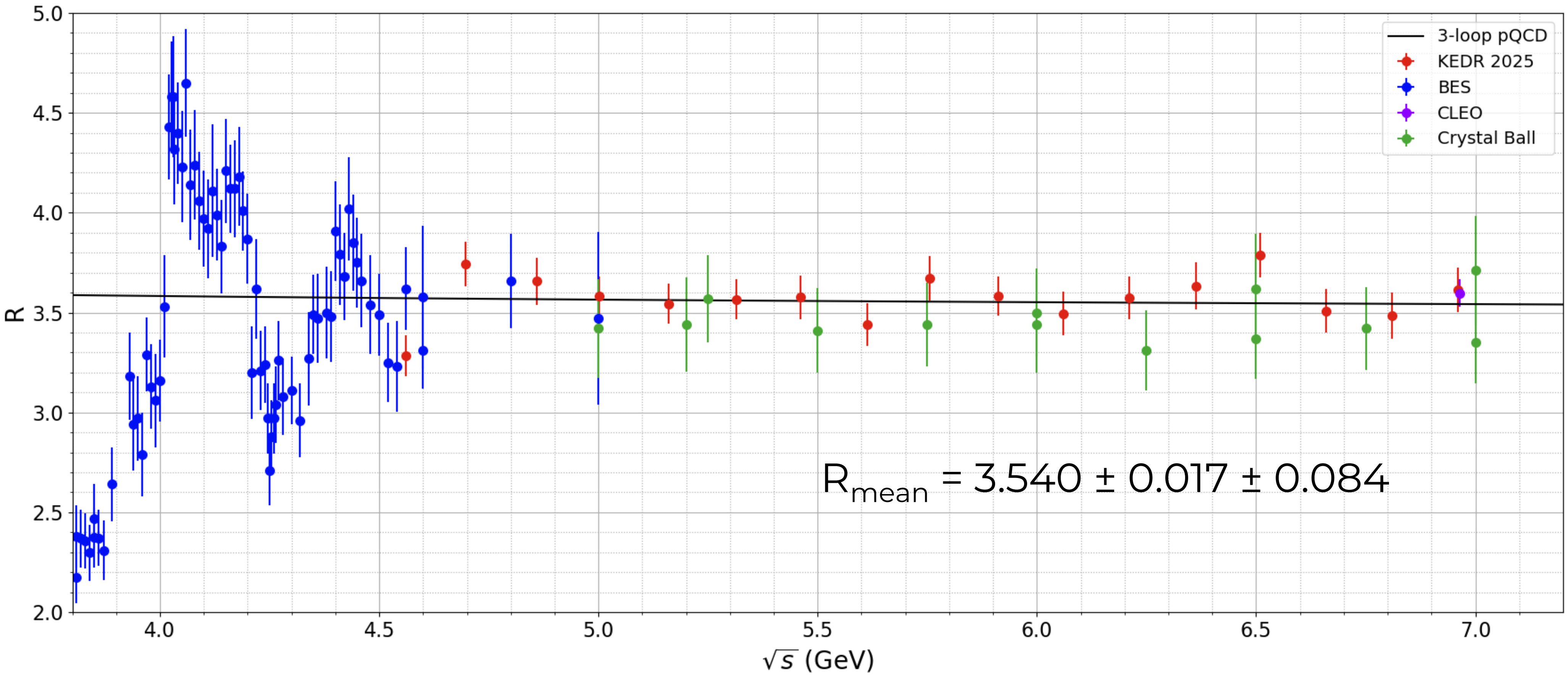
$\Pi_{hadr}(s)$ - hadronic part of the vacuum polarization



Systematic uncertainty estimation

Source	Syst. Uncertainty, %
Luminosity	1.2
Simulation	1.4
Track reconstruction	0.7
Nuclear interaction	0.6
Rad. correction	0.3
Machine background	0.2
Trigger	0.1
Cuts variation	1.1
Total	2.4

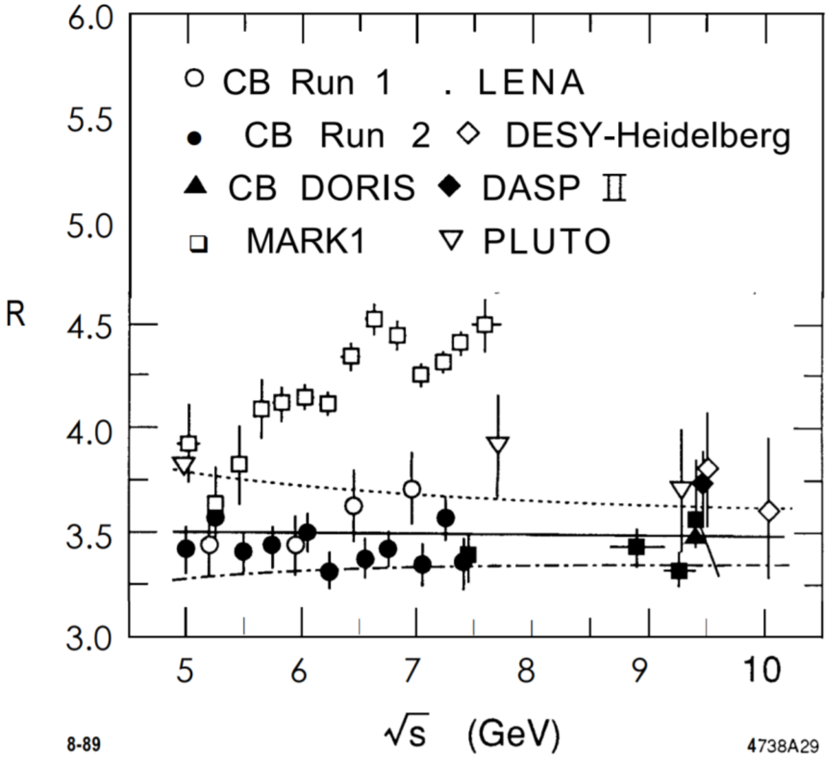
R measurement between 3.8 and 7.0 GeV



Estimated total uncertainty is about 3 % (systematic uncertainty about 2.4%).

R measurement at Crystal Ball

- 2E = 5.0 – 7.4 GeV
- Integrated luminosity 4.2 pb^{-1}
- 15 energy points



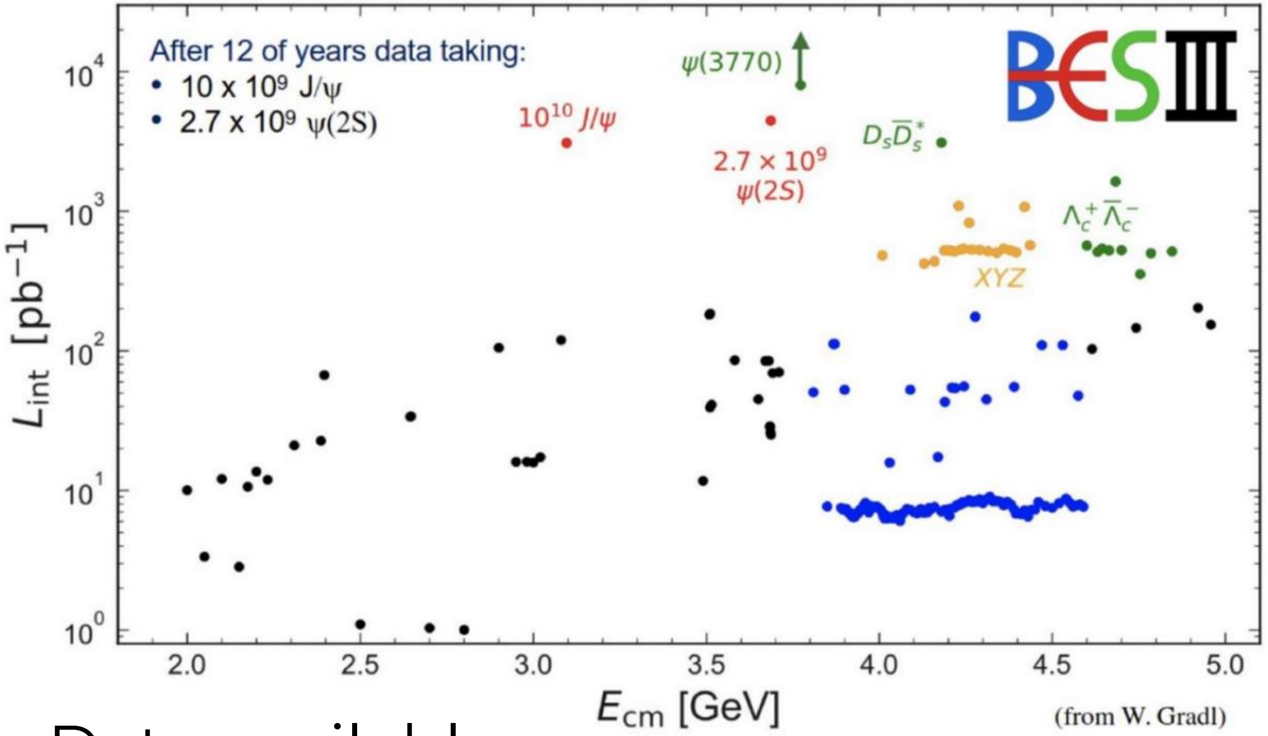
$R_{average}$ = 3.44 ± 0.03 ± 0.18

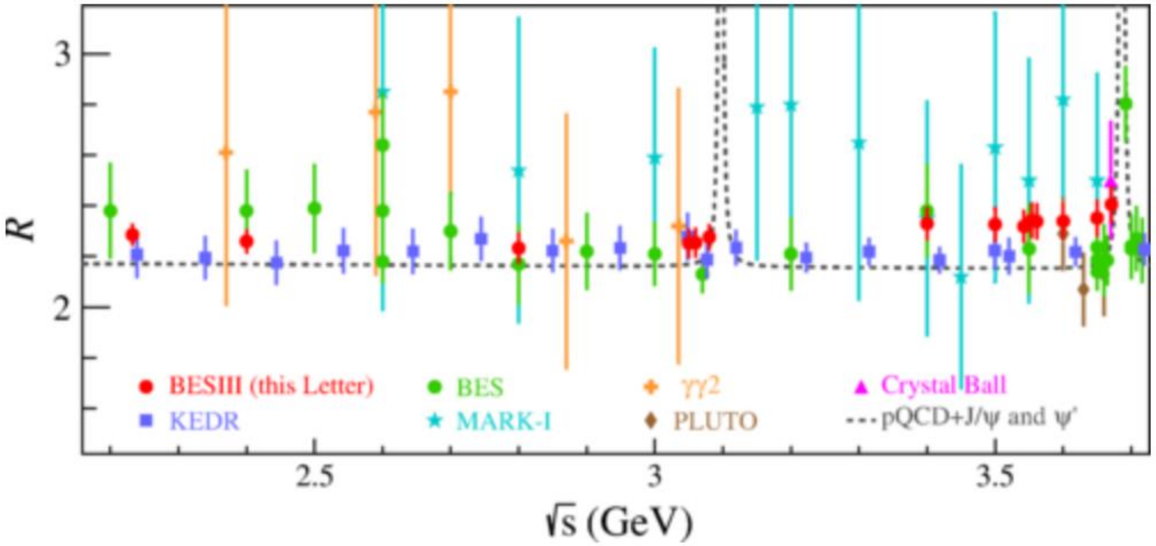
Source	% Error
Hadron efficiency estimate:	±3.3
Luminosity:	±2.7
Beam-gas subtraction:	±2.2
Radiative corrections:	±1.3
Tau-subtraction:	±1.2
Two-photon subtraction:	±1.0
Systematic error quadrature sum:	±5.2

Statistic uncertainty ~ 3-4 %

SLAC-PUB-5160, 1990.
https://doi.org/10.17182/hepdata.18758

R measurement at BESIII





Data available:
21 energy points
2.00 – 3.08 GeV
~ 550 pb^{-1}

3.85 – 4.59 GeV
104 energy points
~ 800 pb^{-1}

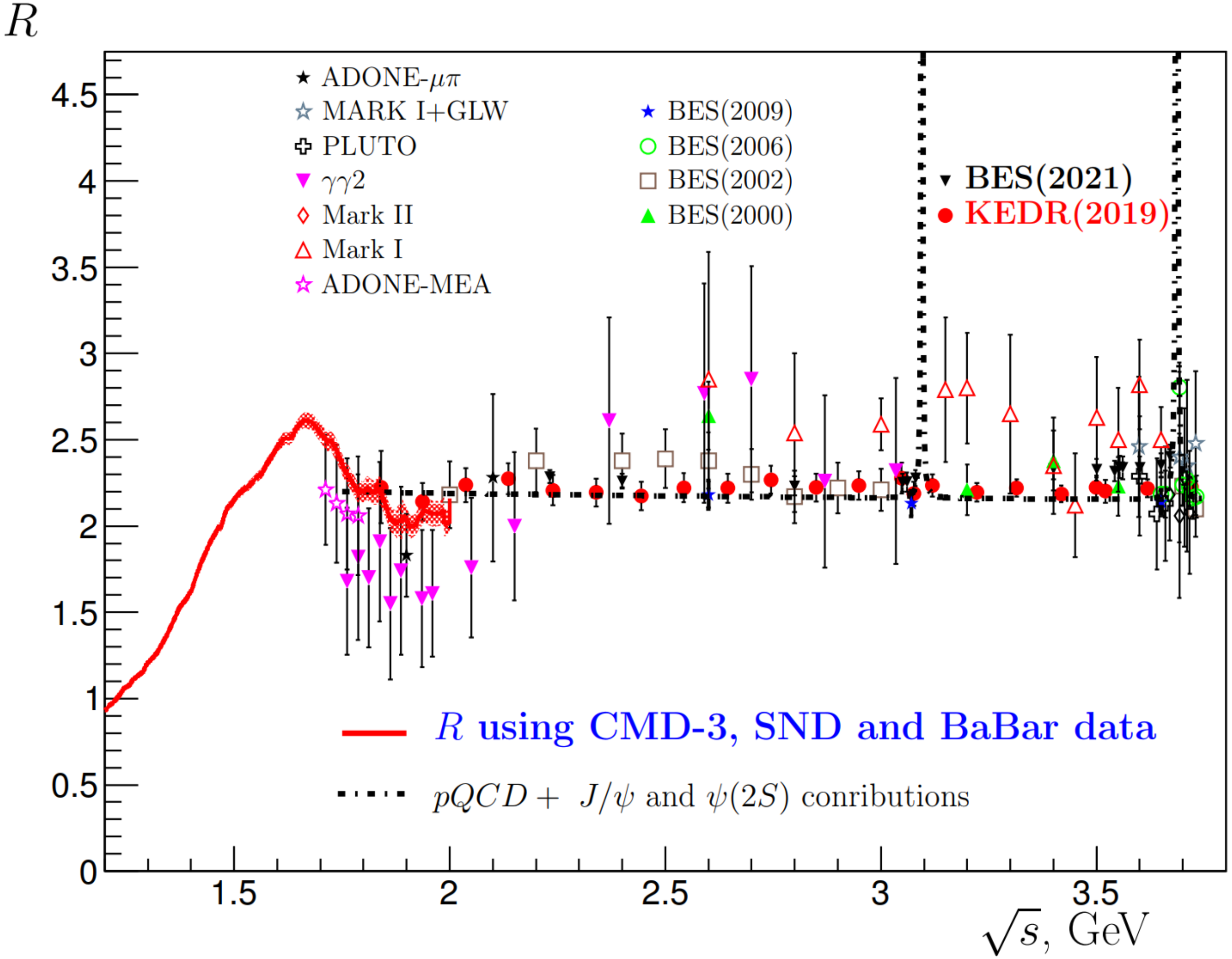
Data analyzed:
2.23 – 3.67 GeV
10 energy points
~110 pb^{-1}

M. Ablikim *et al.* (BESIII)
Phys. Rev. Lett. **128**, 062004

Conclusions

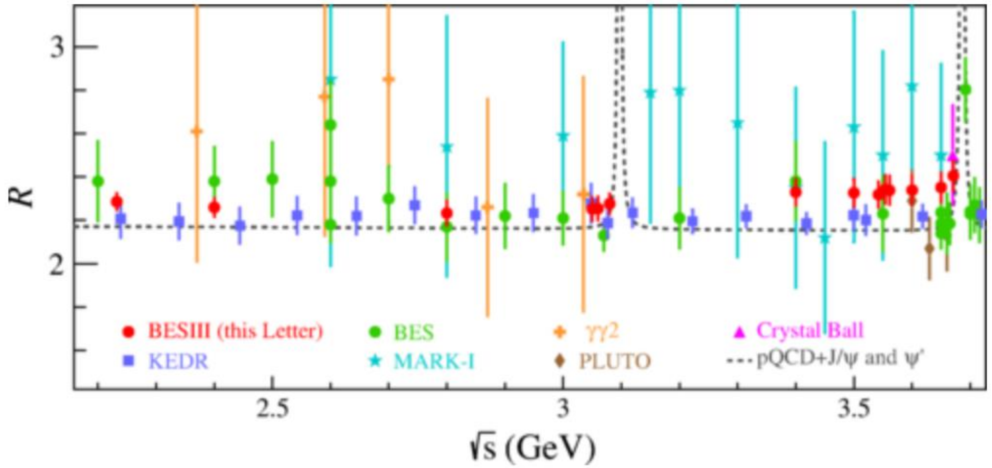
- KEDR has measured the R values at 22 center-of-mass energies between 1.84 and 3.72 GeV.
- Preliminary results in the energy range between 4.56 and 6.96 GeV were obtained. Estimated systematic uncertainty is about 2.4% and total is about 3%.
- Analysis of data is ongoing

R measurement between 1.8 and 3.8 GeV at KEDR - 2



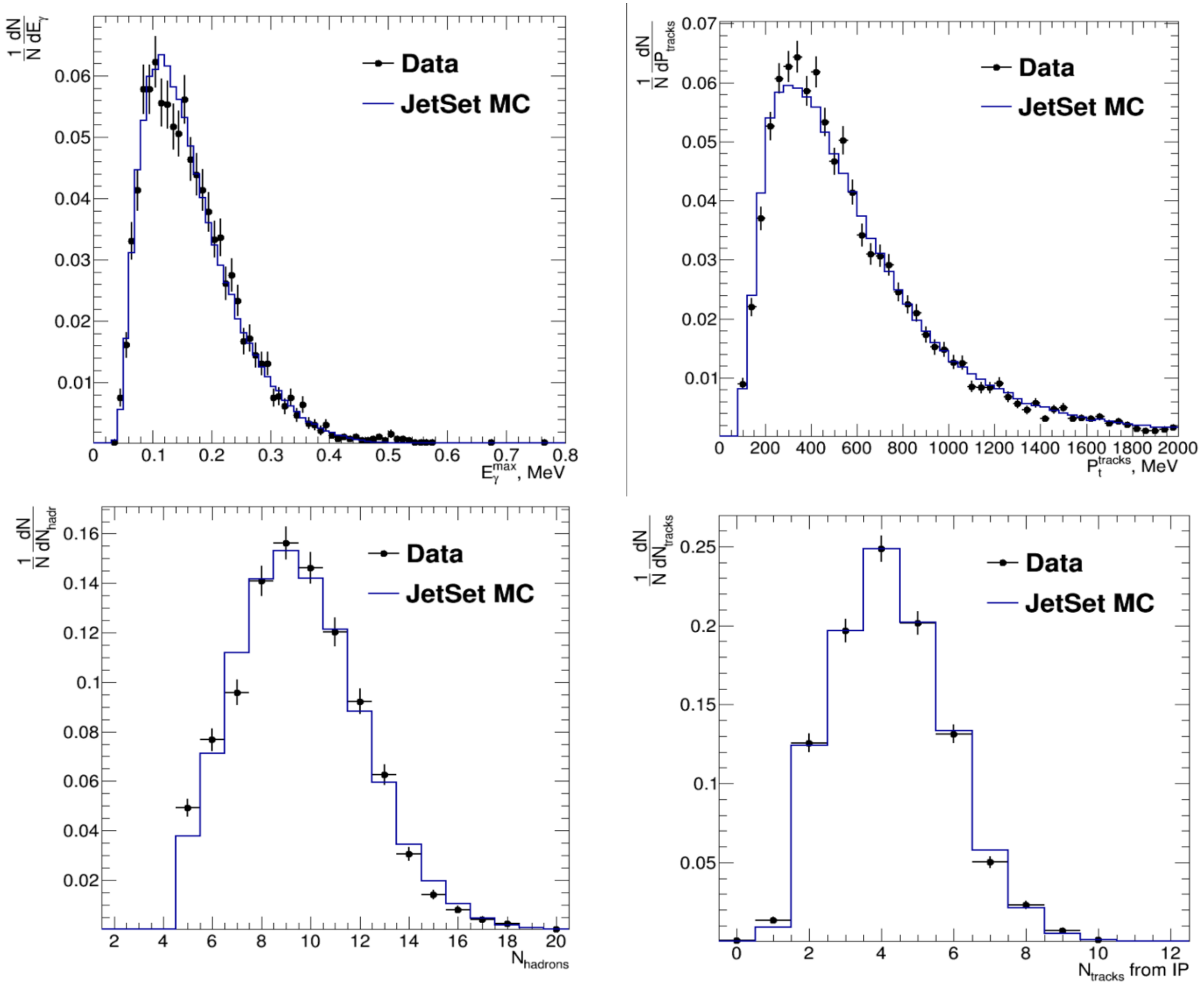
V.V. Anashin. Phys.Lett. B 770 (2017) 174

V.V. Anashin. Phys.Lett. B 788 (2019) 42



M. Ablikim *et al.* (BESIII)
Phys. Rev. Lett. **128**, 062004

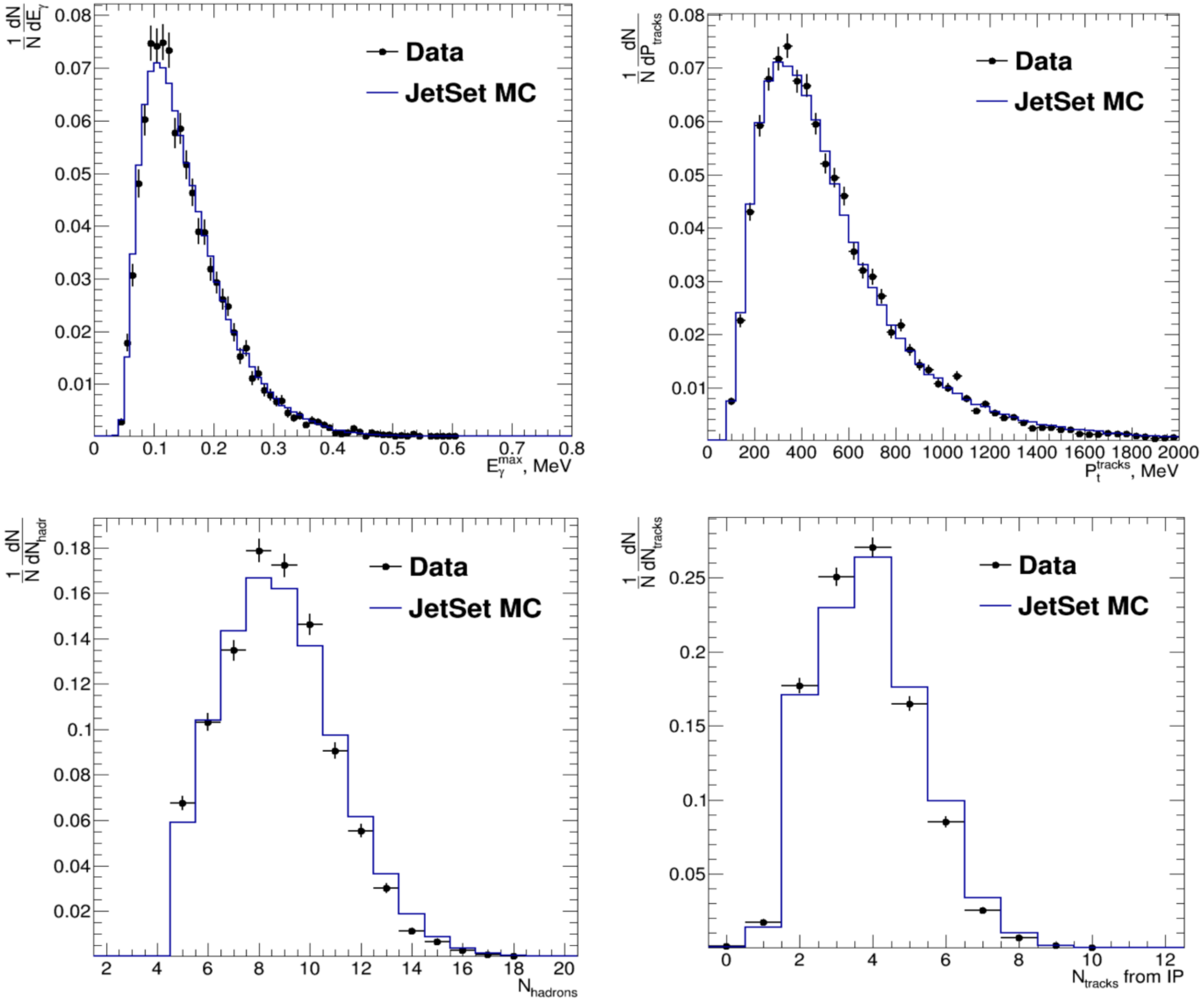
Simulation of hadronic decays at 6.66 GeV



Experimental distributions and tuned JetSet MC

Fair agreement of simulation with data is obtained

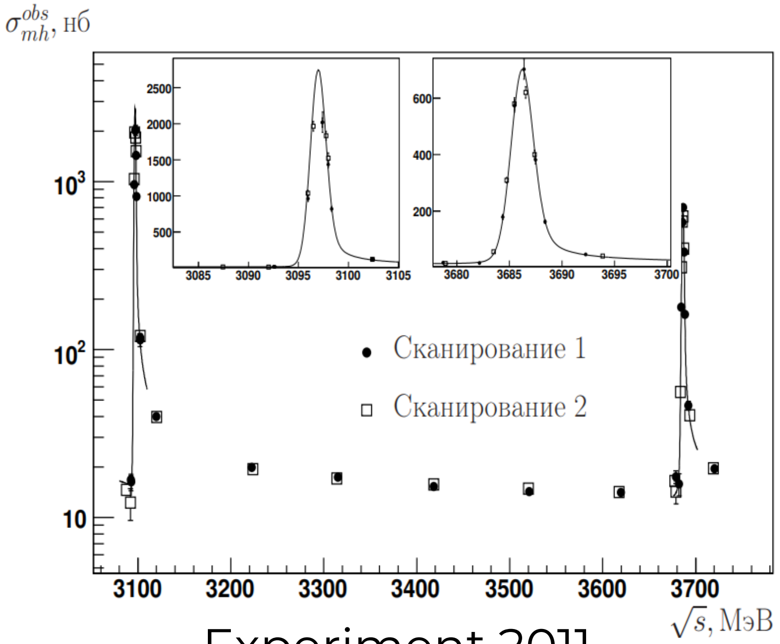
Simulation of hadronic decays at 5.16 GeV



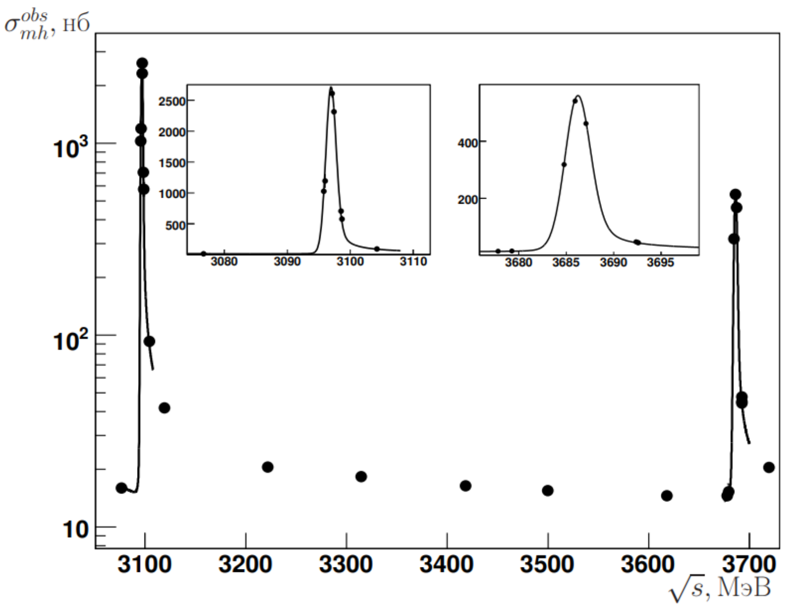
Experimental distributions and tuned JetSet MC

Fair agreement of simulation with data is obtained

R measurement between 1.8 and 3.8 GeV at KEDR -1



Experiment 2011



Experiment 2014-2015

$\sqrt{s}$, GeV	N_{points}	$\int Ldt, pb^{-1}$	Unc., %	Ref.
1.84 – 3.05	13	0.66	≤ 3.9 total (≈2.4 syst.)	Phys.Lett. B 770 (2017) 174
3.08 – 3.72	9	2.7	≤ 2.6 total (≈1.9 syst.)	Phys.Lett. B 788 (2019) 42