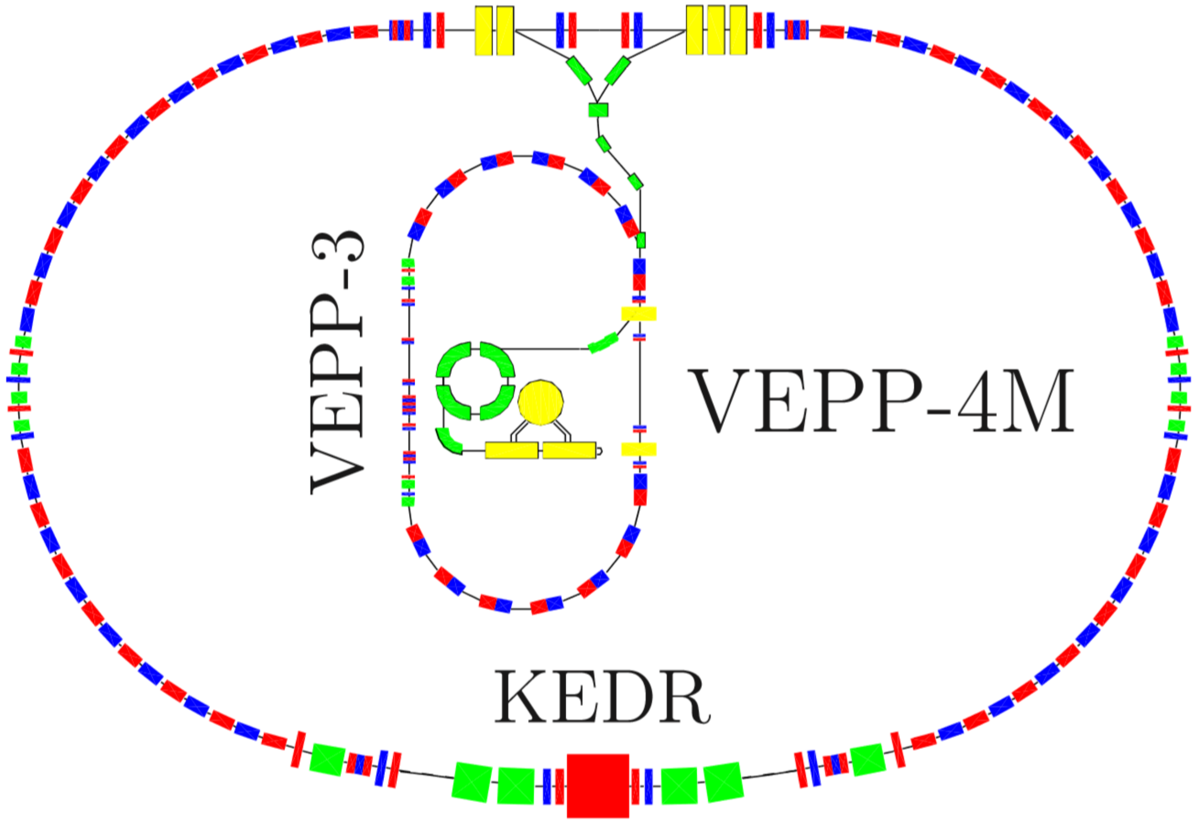
R measurements at KEDR

Tatyana Kharlamova
for the KEDR collaboration
28.02.2024

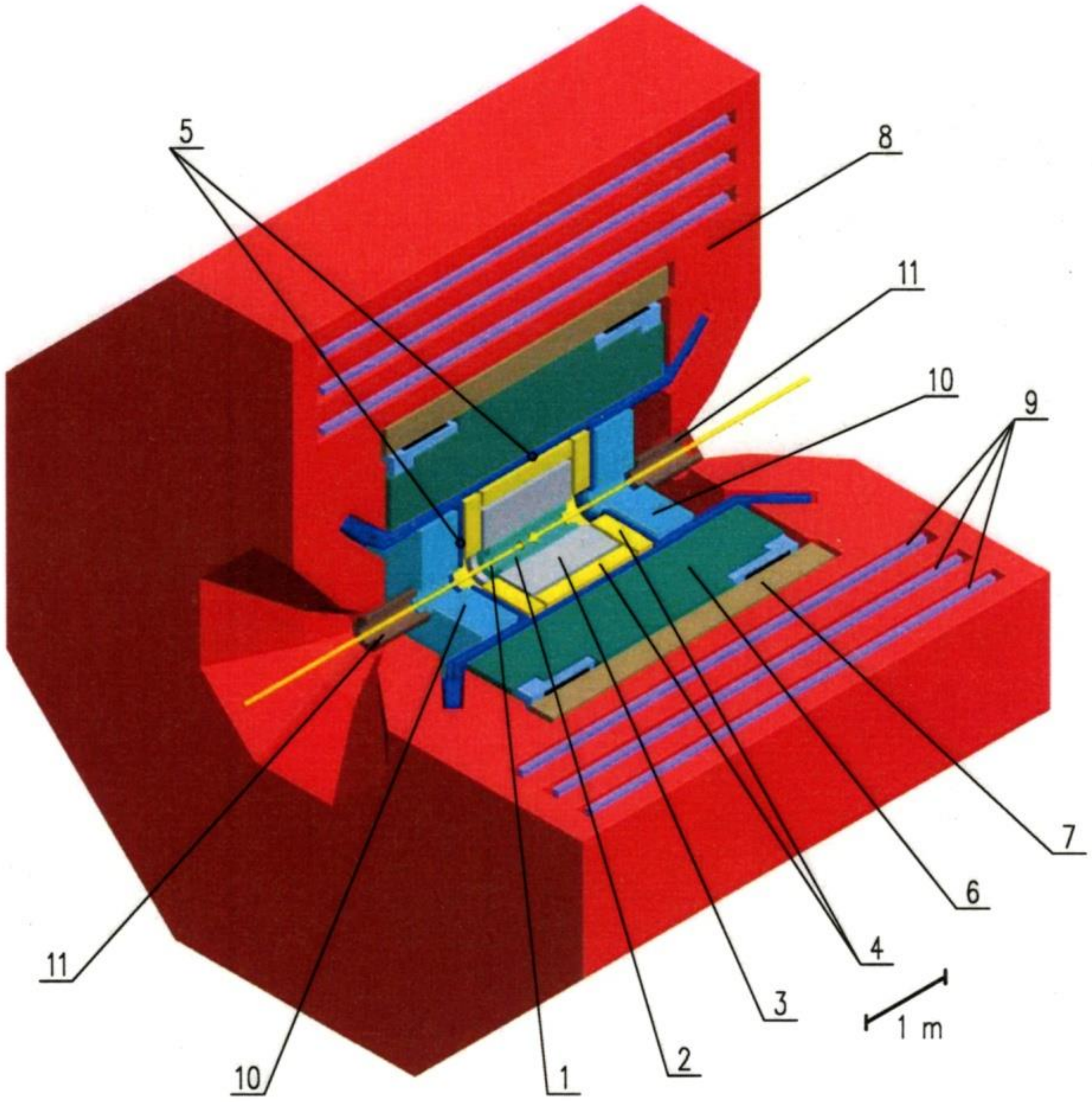
Collider VEPP-4M



Beam energy	1 – 5 GeV
Number of bunches	2 x 2
Luminosity at 1.5 GeV	$2{\cdot}10^{30}$ cm^{-2} s^{-1}
Luminosity at 5.0 GeV	$2{\cdot}10^{31}$ cm^{-2} s^{-1}

Beam energy measurement:

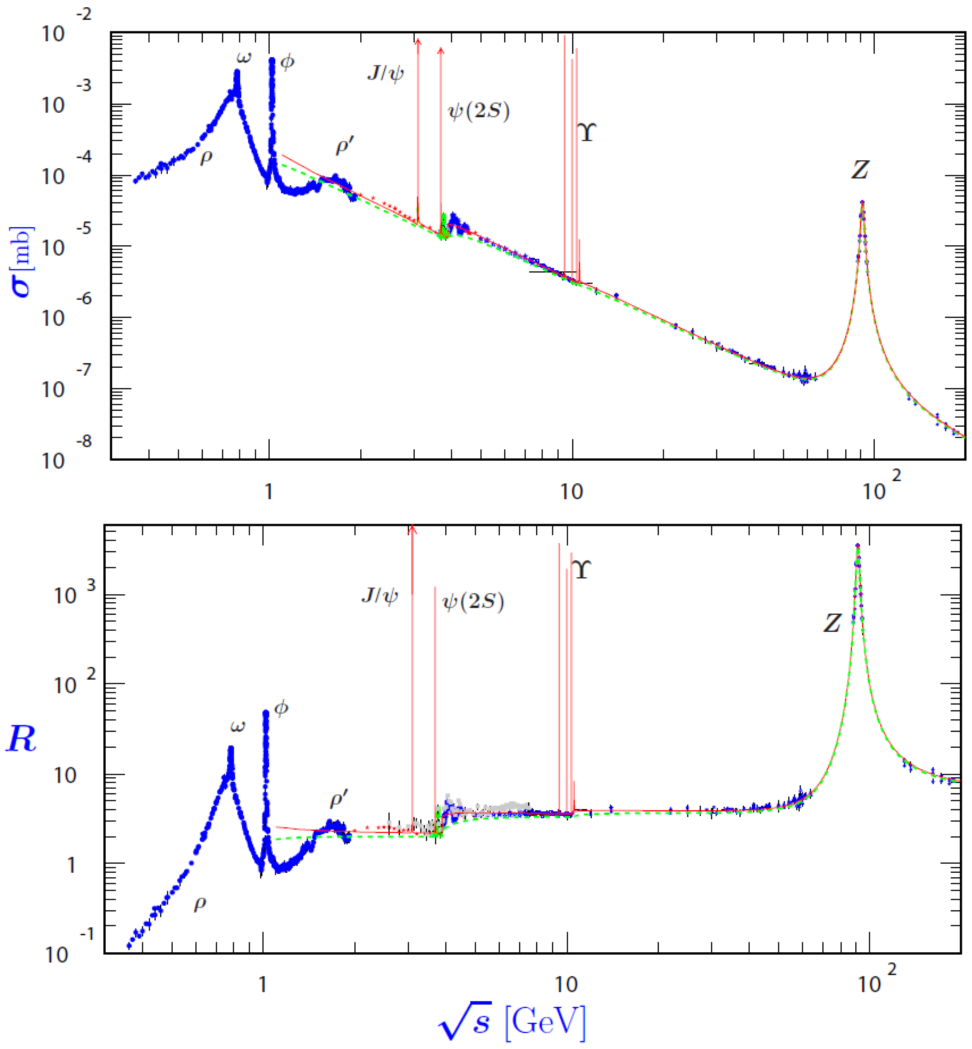
- Resonant depolarization method
  - Instant measurement accuracy 1 keV
  - Energy interpolation accuracy 10-30 keV
- Infrared light Compton backscattering
  - Monitoring with accuracy 100 keV



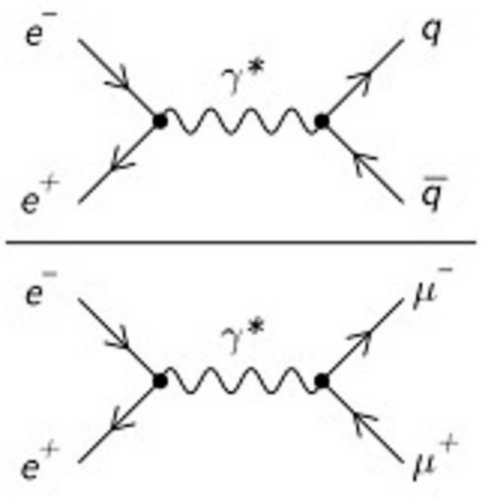
KEDR detector

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

Motivation of R measurement



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



In first approximation:

$$R(s) \simeq 3\sum e_q^2$$

R(s) is used to determine:

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

Predictions

Naive quark model: $cross\ section\ \sigma(e^-e^+ \to q\bar{q}) = \frac{4\pi\alpha^2 \sum e_q^2}{s} = \frac{4\pi\alpha^2 N_c \sum e_q^2}{3s}$

$$and\ ratio\ \frac{\sigma(e^-e^+ \to q\bar{q})}{\sigma(e^-e^+ \to \mu^-\mu^+)} = N_c \sum e_q^2$$

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

At energy $\sqrt{s} \gtrsim 1.02$ GeV (u, d, s) : $R \approx 3\left(({}^2/_3)^2+({}^1/_3)^2+({}^1/_3)^2\right) = 2$

At energy $\sqrt{s} \gtrsim 3.77$ GeV (u, d, s, c) : $R \approx {}^{10}/_3$

At energy $\sqrt{s} \gtrsim 10.58$ GeV (u, d, s, c, b) : $R \approx {}^{11}/_3$

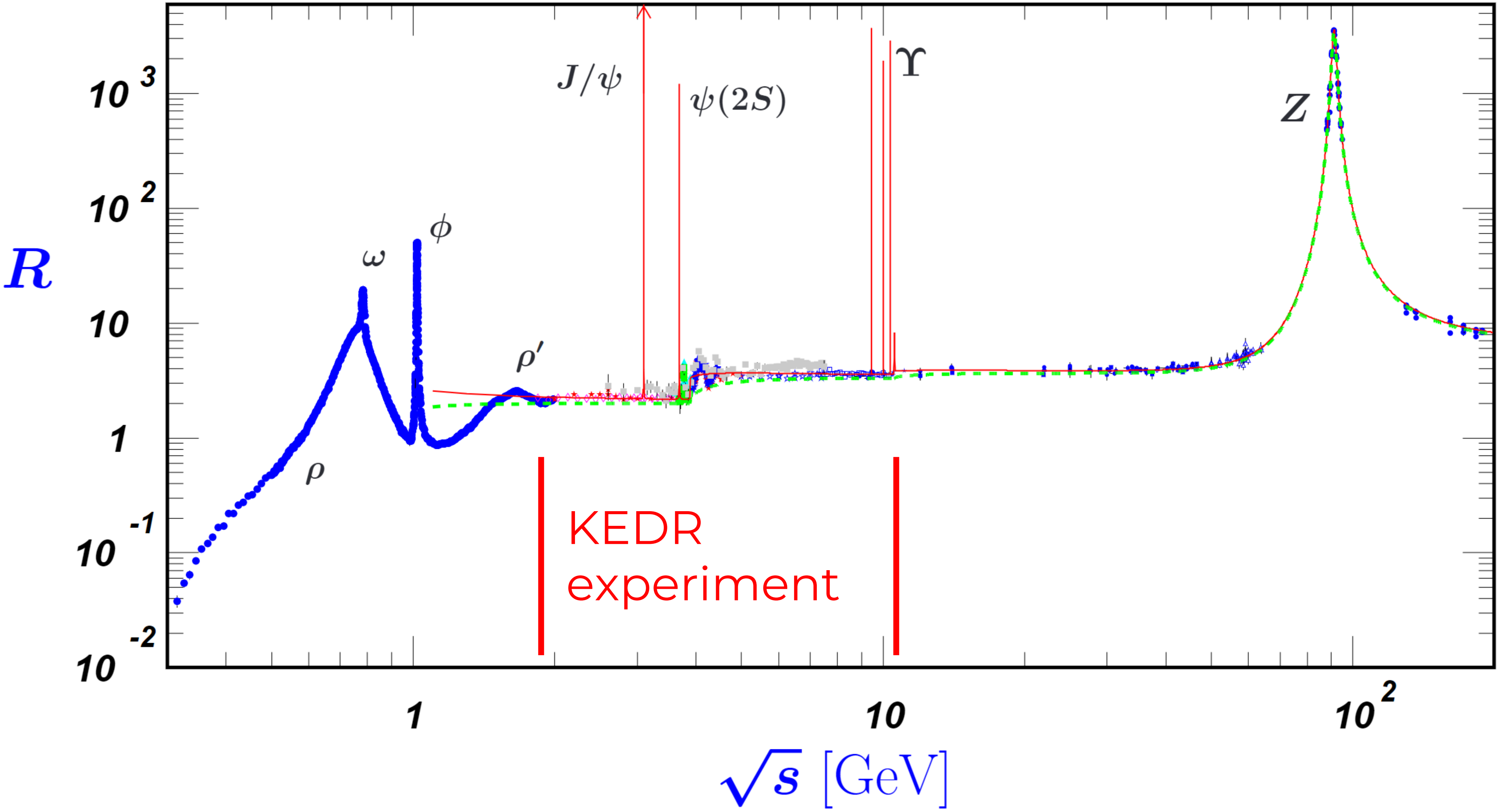
$$R(s) = R_0(s)\left(1 + C_1\frac{\alpha_s}{\pi} + C_2\left(\frac{\alpha_s}{\pi}\right)^2 + C_3\left(\frac{\alpha_s}{\pi}\right)^3 + O(\alpha_s^4)\right)$$

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

L. R. Surguladze, M. A. Samuel, *Phys.Rev.Lett.* 66 (1991) 560-563

S.G. Gorishny, A.L. Kataev, S.A. Larin, *Phys.Lett.B* 259 (1991) 144-150

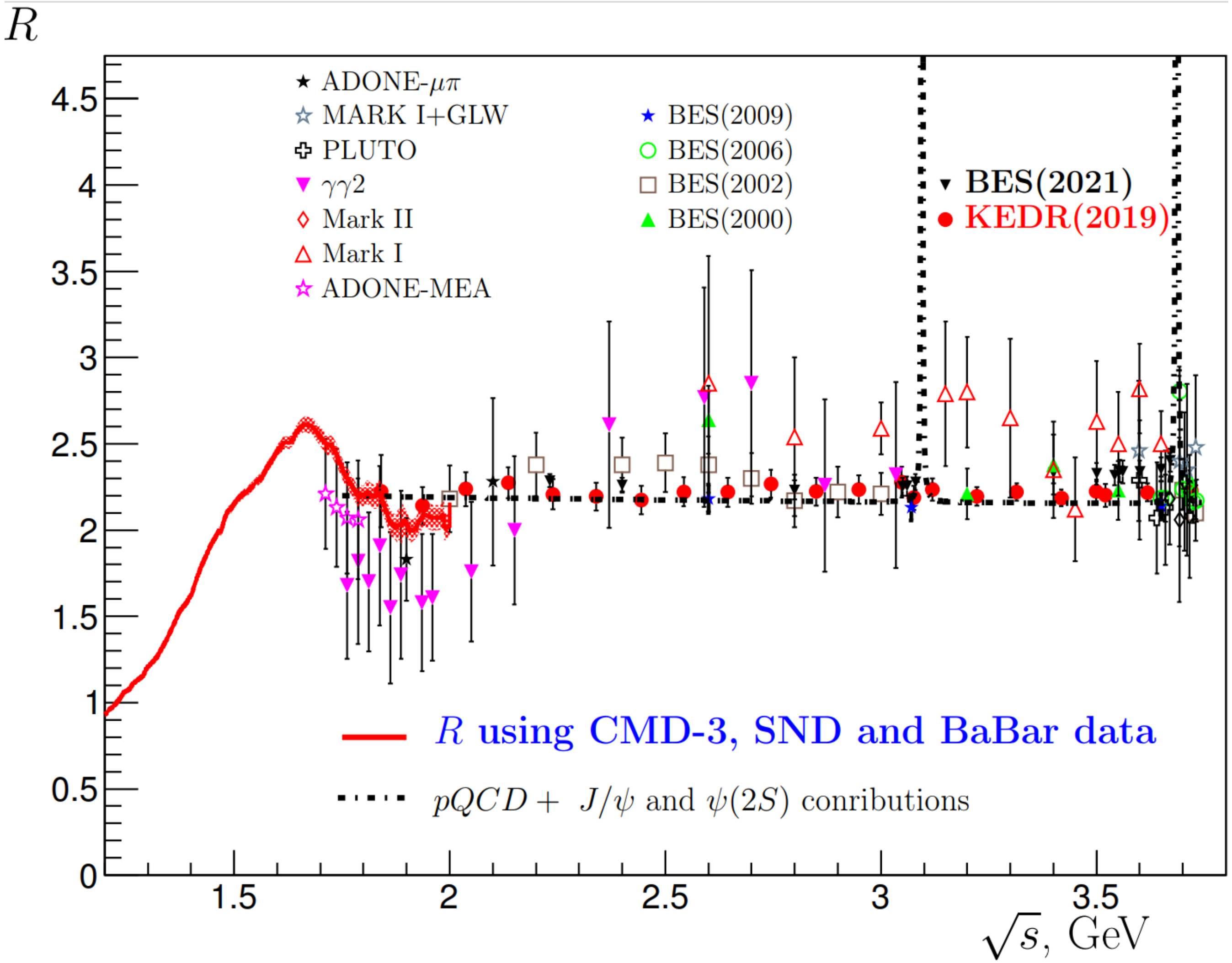
R measurements



R measurement between 1.8 and 3.8 GeV at KEDR -1

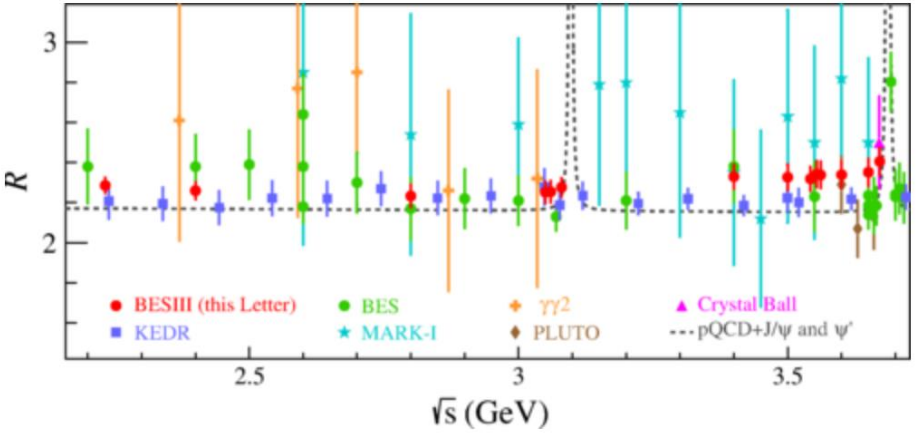
$\sqrt{s}$, GeV	N_{points}	$\int Ldt, pb^{-1}$	Unc., %	Ref.
1.84 – 3.05	13	0.66	≤ 3.9 total (≈2.4 syst.)	V.V. Anashin. Phys.Lett. B 770 (2017) 174
3.08 – 3.72	9	2.7	≤ 2.6 total (≈1.9 syst.)	V.V. Anashin. Phys.Lett. B 788 (2019) 42

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

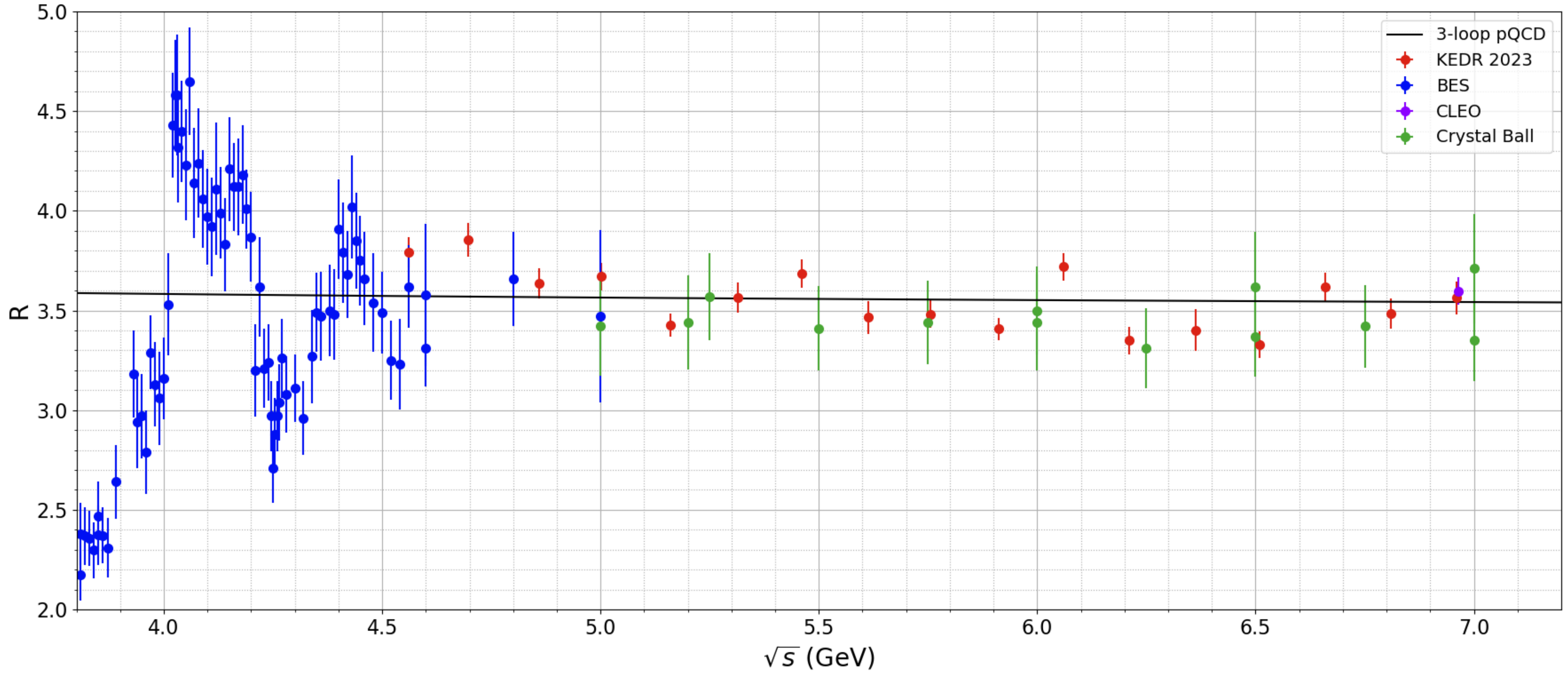


M. Ablikim *et al.* (BESIII)
Phys. Rev. Lett. **128**, 062004

R scans at KEDR 2019-2020

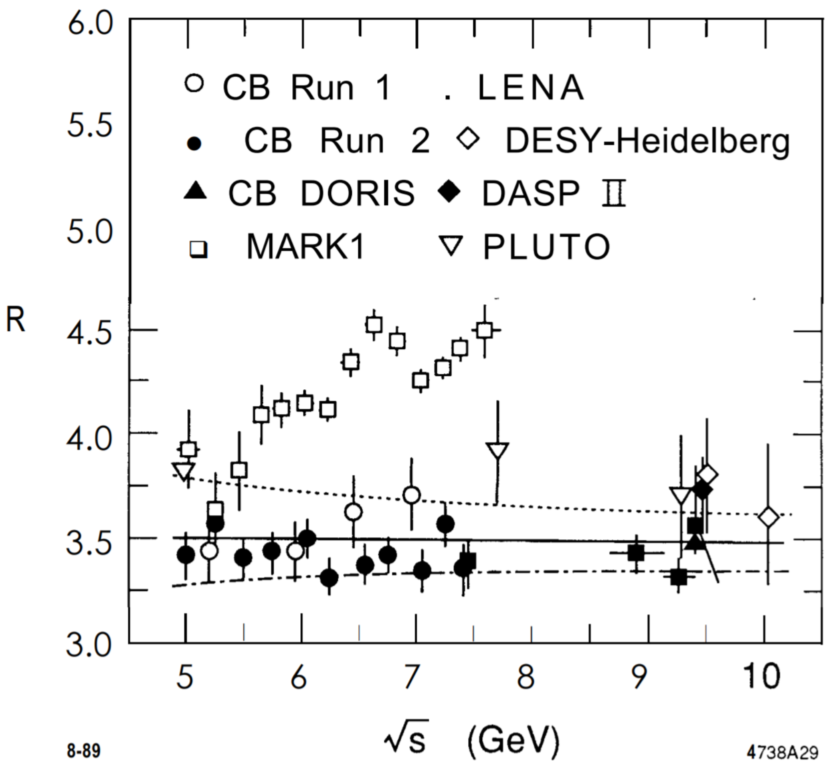
- 2E = 4.69 – 6.98 GeV
- Integrated luminosity 13.7 pb^{-1}

17 energy points
with a step ~ 0.15 GeV



R measurement at Crystal Ball

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



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 ~ 0.9%

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

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

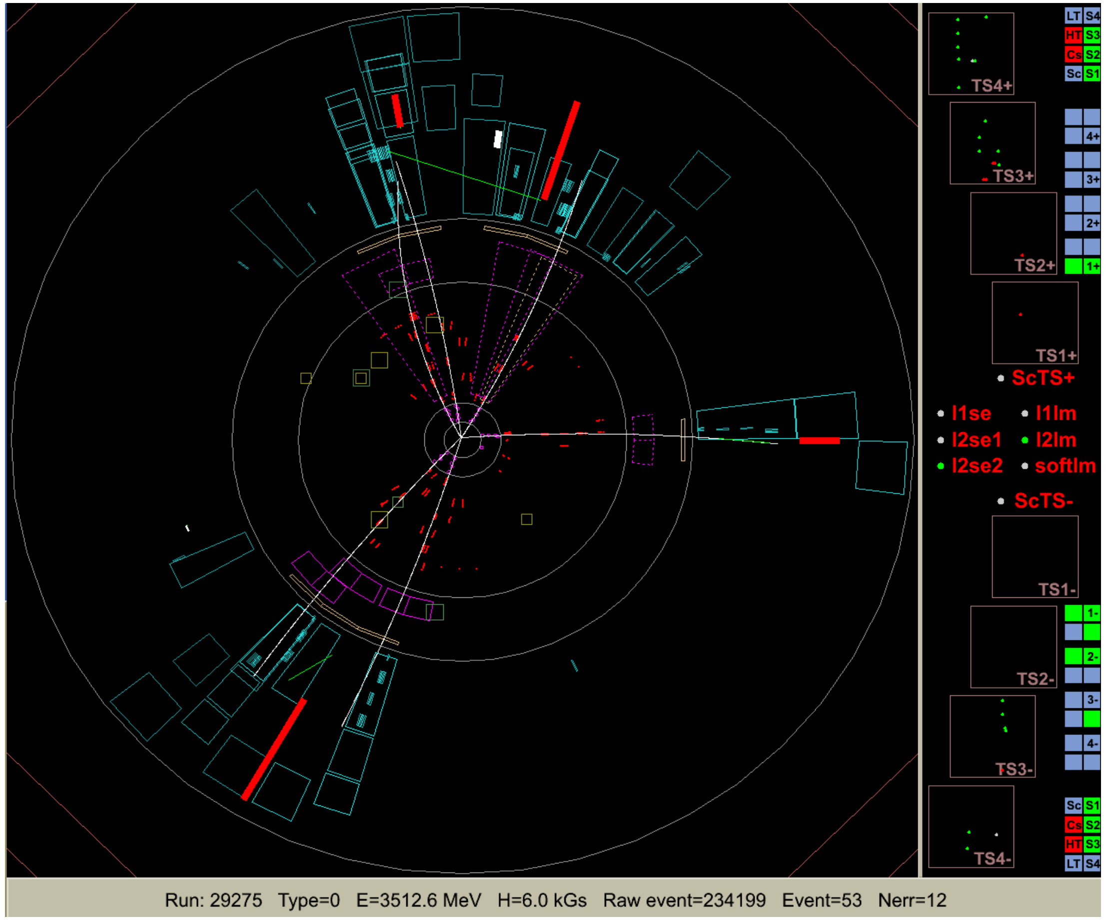
$$\sigma_{\mu\mu}^{0} = \frac{4\pi\alpha^2}{3s}$$

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

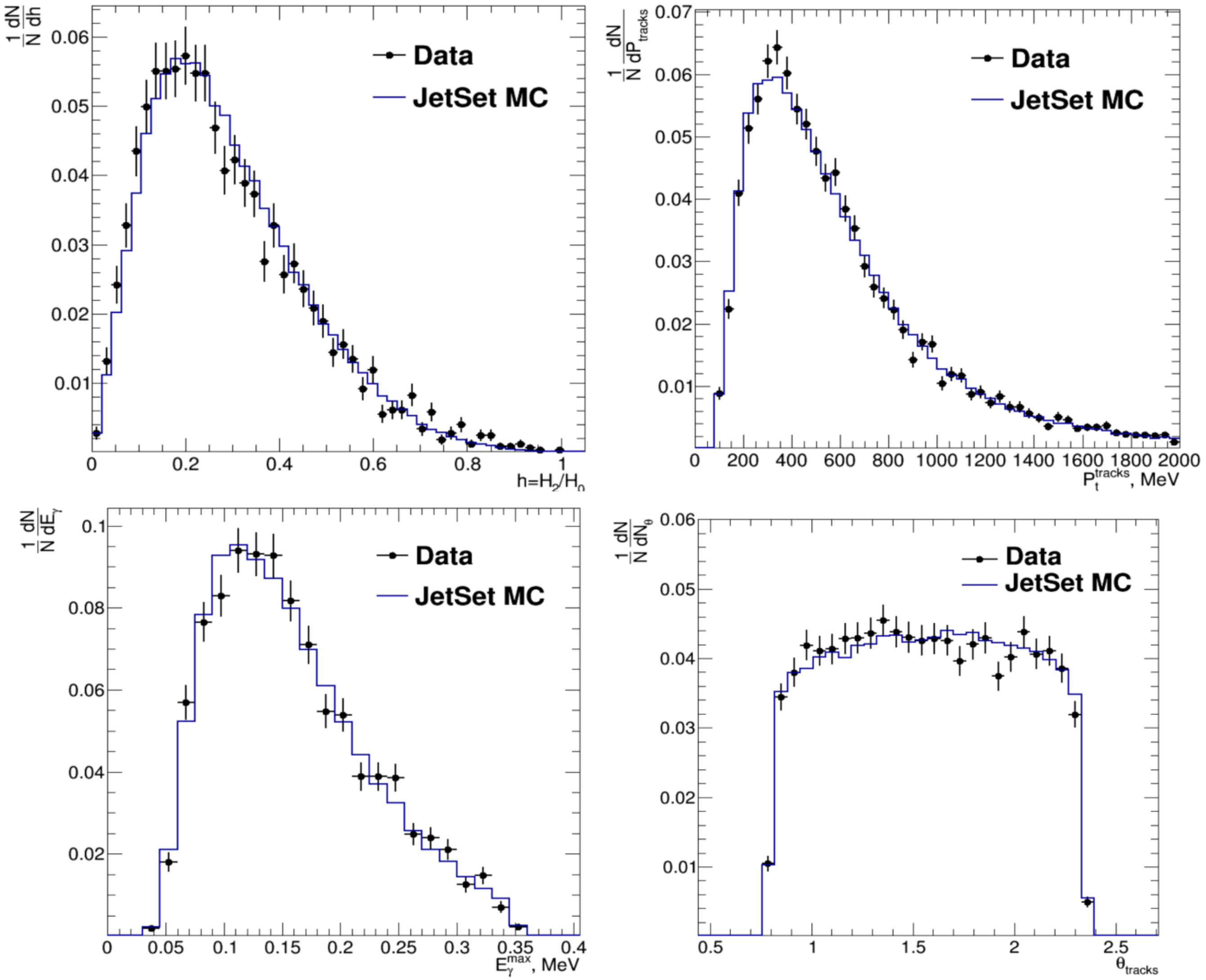
Hadron selections

~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 $H_2/H_0<0.9$;
- $E_\gamma^{max}<0.35\ E_{run}$
- $E_{vis}>0.4\ E_{run}$
- $E_{LKr}>0.4\ E_{cal}$
- $P_z^{miss}<0.3\ E_{run}$
- Veto from muon system



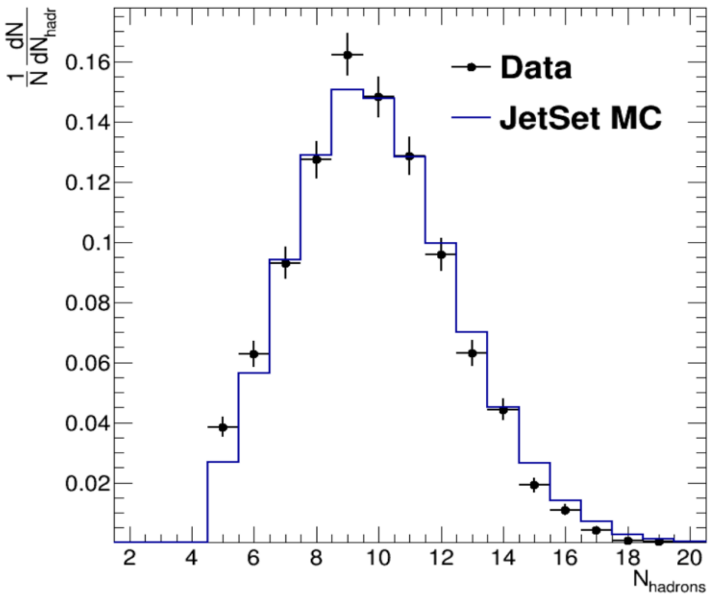
Simulation of hadronic decays at 7 GeV

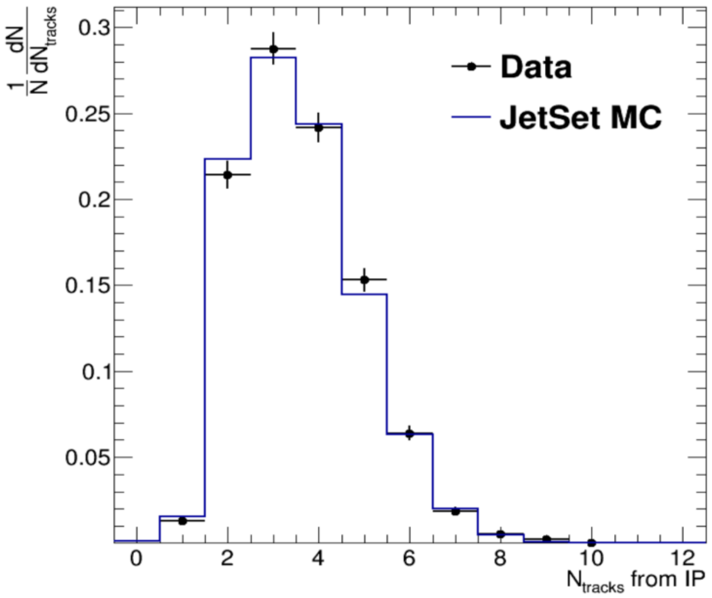


Experimental distributions and tuned JetSet MC

Fair agreement of simulation with data is obtained

Simulation of hadronic decays at 7 GeV - 2

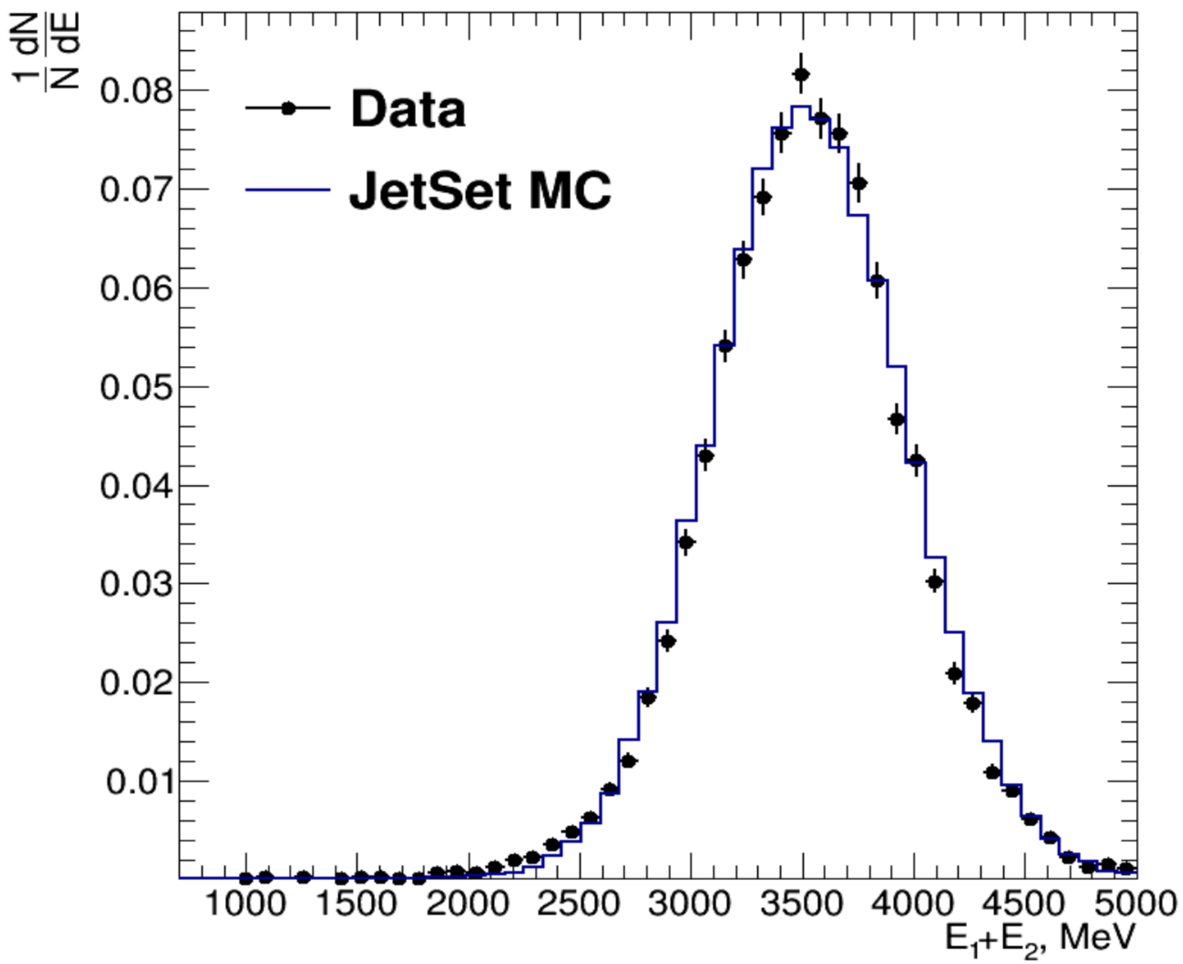




Experimental distributions and tuned JetSet MC

Fair agreement of simulation with data is obtained

Luminosity measurement



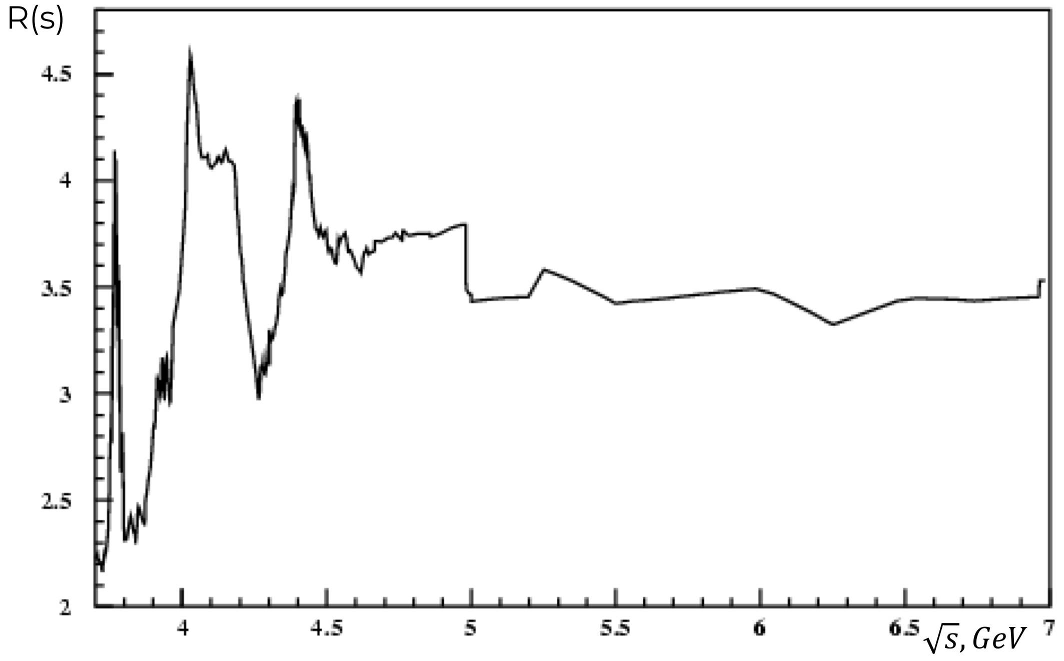
The absolute luminosity was calculated using e^+e^- events in the barrel LKr calorimeter

Expected systematic uncertainty ~ 1%

Selection criteria:
≥ 2 photons 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

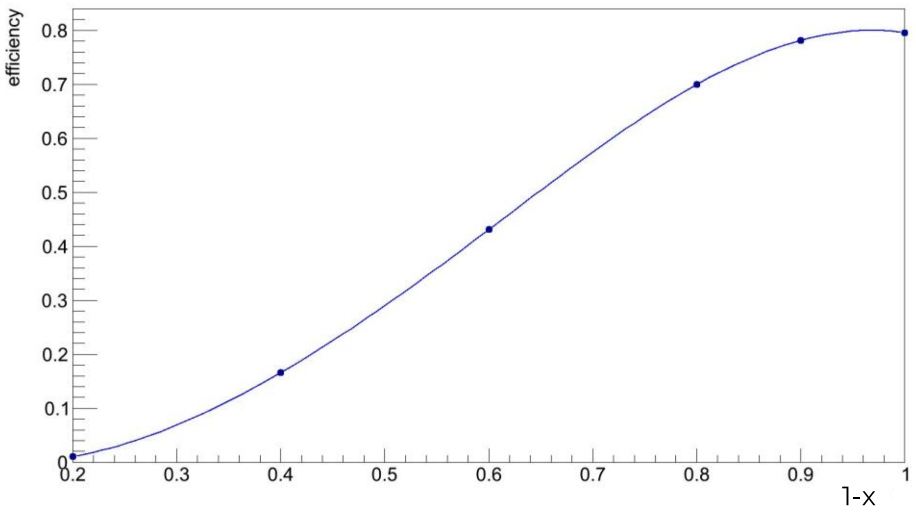
$$1 + \delta(s) = \int \frac{dx}{1-x} \frac{F(s,x)}{|1-\Pi((1-x)s)|^2} \frac{R((1-x)s)\varepsilon((1-x)s)}{R(s)\varepsilon(s)}$$



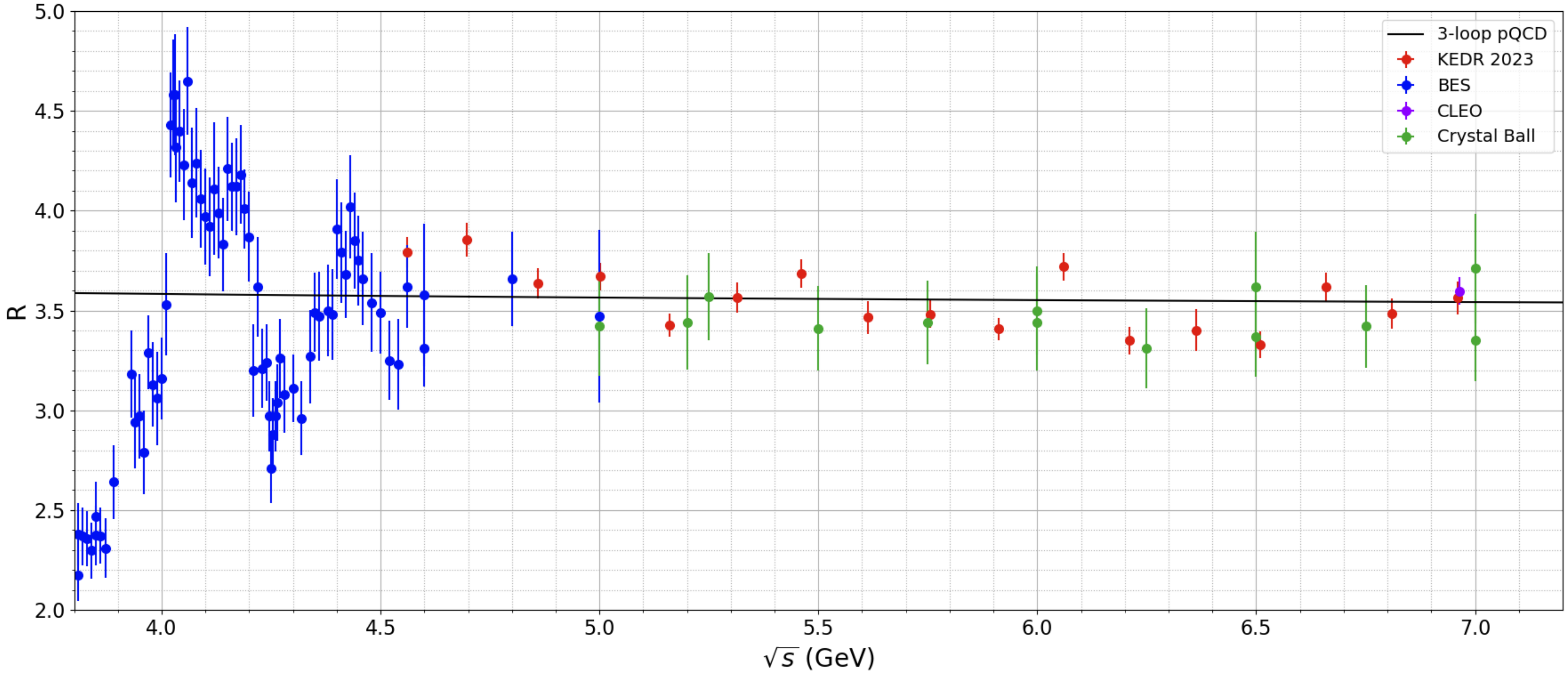
compilation of the vacuum polarization data by the CMD-2 group
S. Actis, *et al.*
Eur. Phys. J. C, 66 (2010), p. 585

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

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



R measurement between 3.8 and 7.0 GeV



Expected total uncertainty is about 3 % (systematic uncertainty about 2.5%). Results shown are very preliminary. MC is tuned at several energy points.

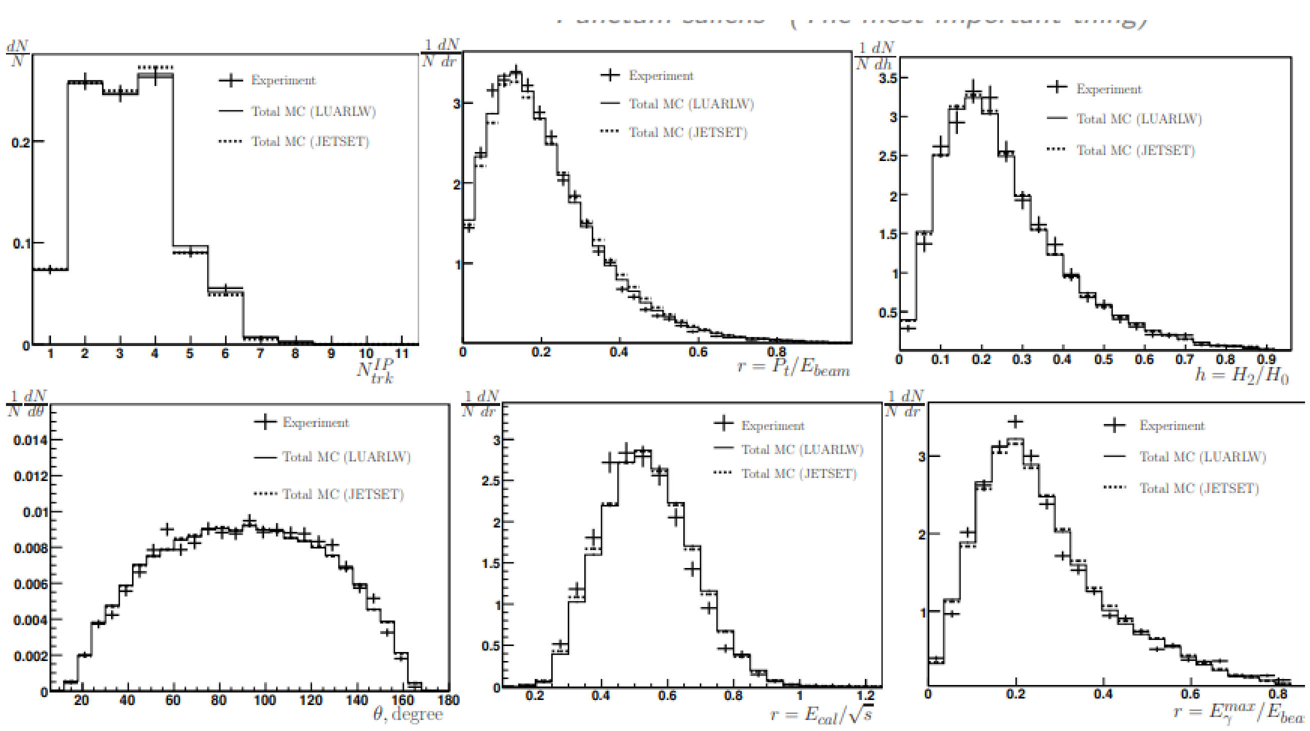
Conclusions

- KEDR has measured the R values at 22 center-of-mass energies between 1.84 and 3.72 GeV.
- Analysis of data in the energy range between 4.56 and 6.96 GeV is ongoing, expected accuracy is less than 3%.

Systematic uncertainties (KEDR)

Source	Syst. uncertainty, %		
	Scan 1 and 2 (2010-2011)	Scan 2014-2015	Correlated
Luminosity	1.1	0.9	0.4
Rad. corr.	$0.4 \div 0.6$	$0.5 \div 0.8$	$0.2 \div 0.4$
uds simulation	$1.3 \div 2.0$	1.1	0.9
Track reconstruction	0.5	0.4	–
J/ψ	$0.1 \div 2.7$	$0.1 \div 1.8$	–
$\psi(2S)$ (at 3.72 GeV)	1.4	1.1	–
l^+l^-	$0.1 \div 0.2$	$0.3 \div 0.4$	$0.1 \div 0.2$
e^+e^-X	$0.1 \div 0.2$	0.1	0.1
Trigger	0.2	0.2	0.2
Nuclear interaction	0.2	0.2	0.2
Machine background	$0.5 \div 1.1$	$0.4 \div 0.8$	–
Cuts	0.6	0.6	–
Total	$2.1 \div 3.6$ (correlated $1.8 \div 2.5$)	$1.9 \div 2.7$	1.1

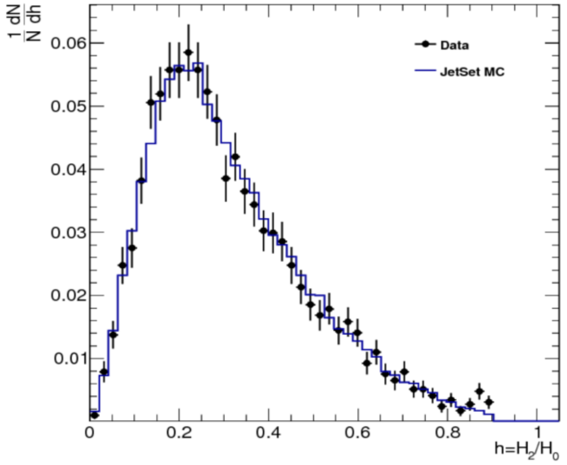
R measurement between 1.8 and 3.8 GeV at KEDR - 3

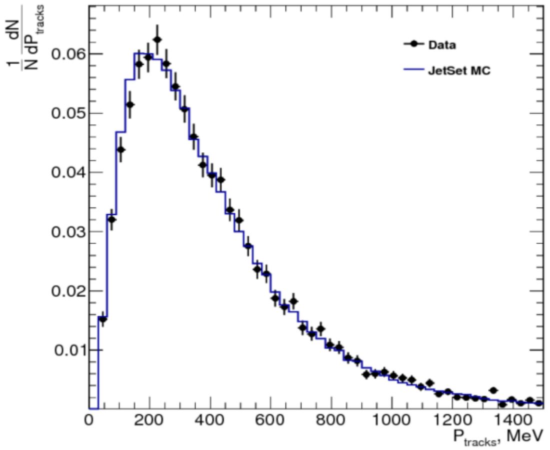


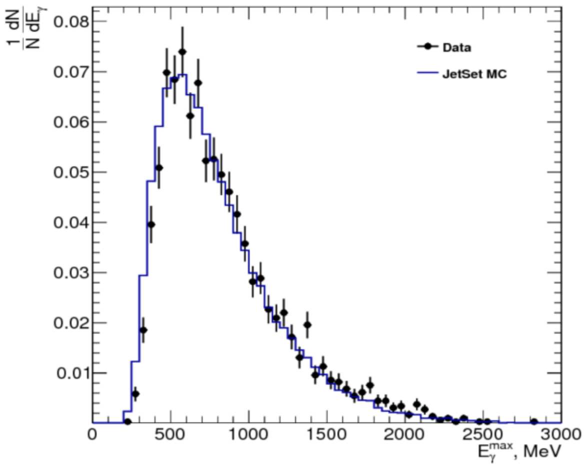
Properties of hadronic events produced in the uds continuum at 3.119 GeV (2014-2015).

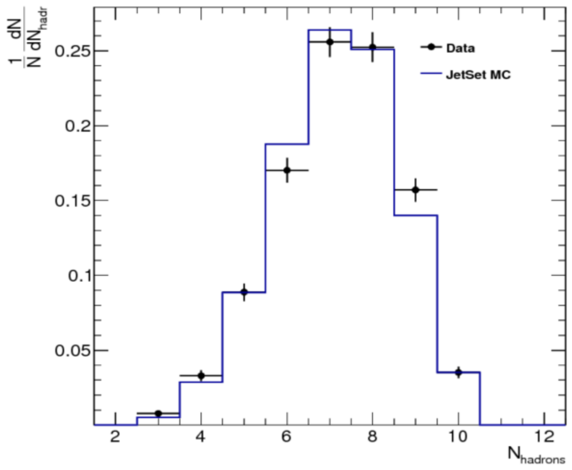
Here N is the number of events, N_{trk}^{IP} is the number of tracks originated from IP, P_t is a transverse momentum of the track, H_2 and H_0 are Fox-Wolfram moments, θ is a polar angle of the track, E_{cal} is energy deposited in the calorimeter, E_γ^{max} is energy of the most energetic photon.

Simulation of hadronic decays at 5.160 GeV





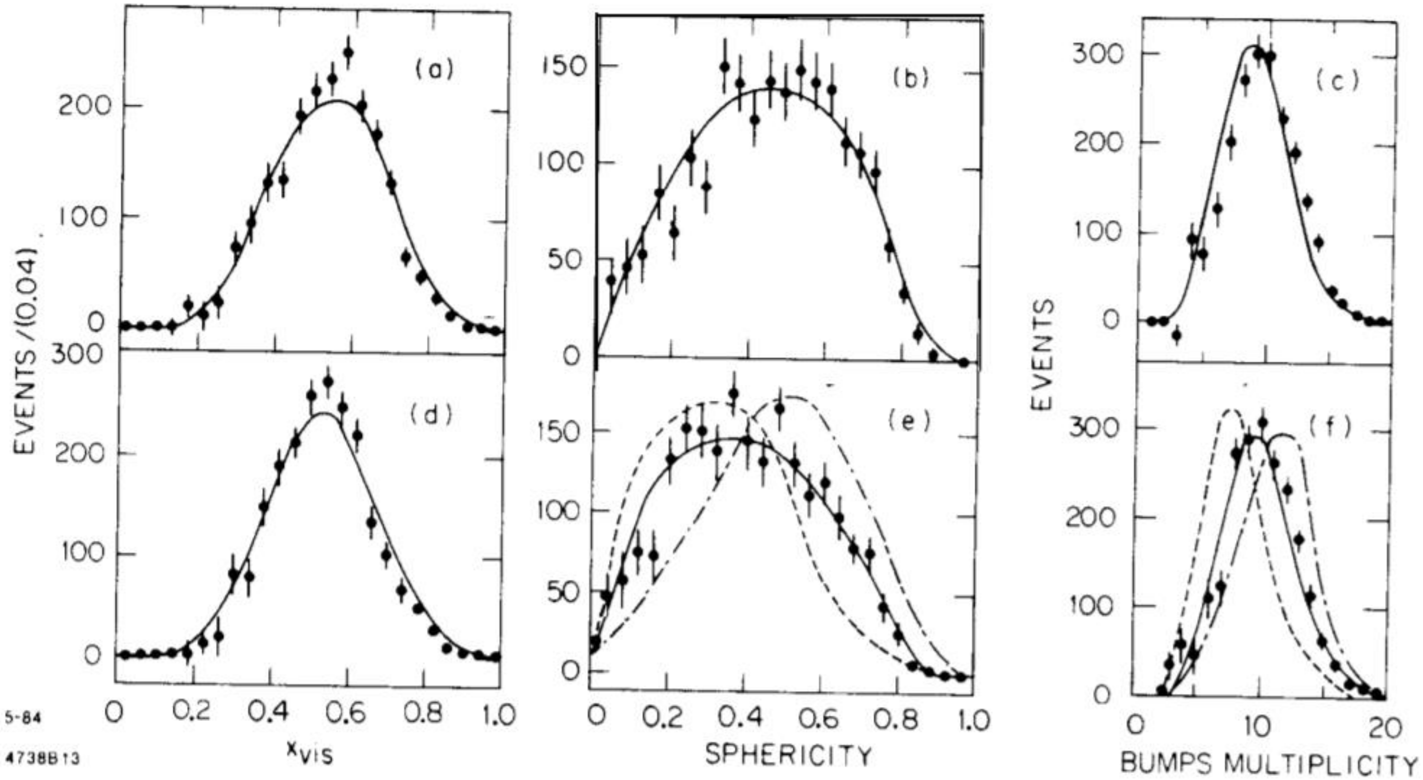




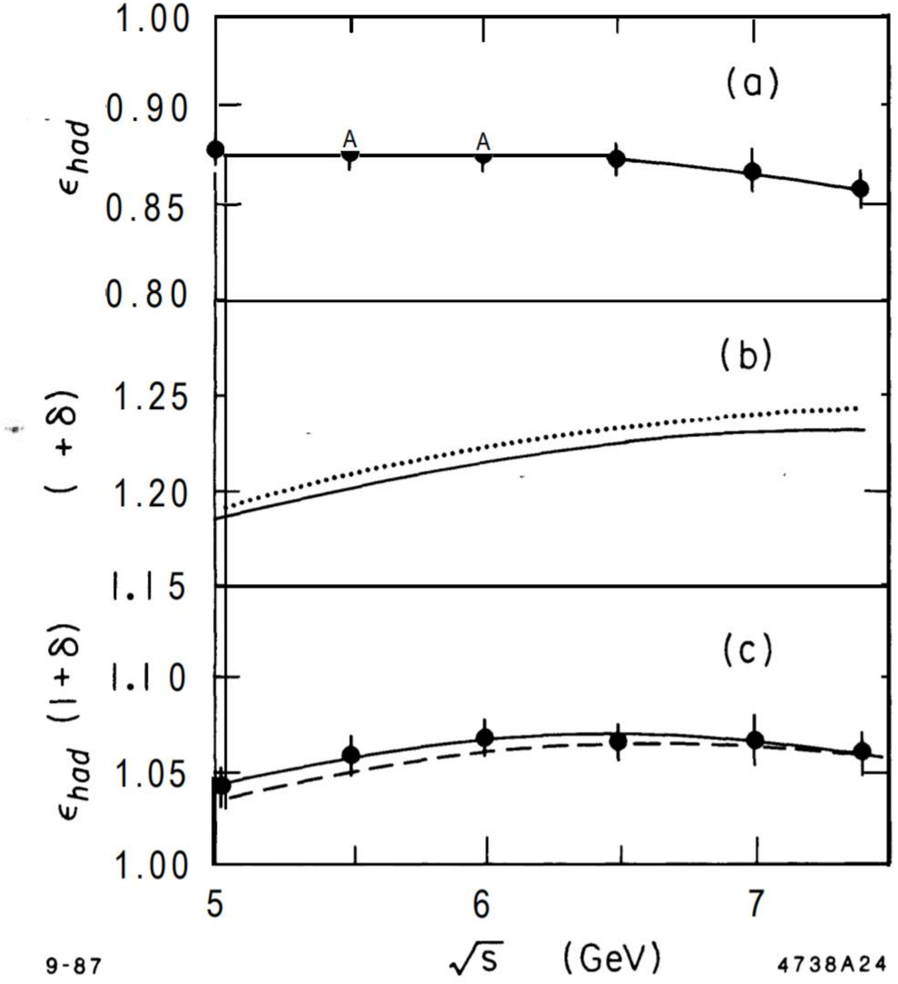
Experimental distributions and tuned JetSet MC

Fair agreement of simulation with data is obtained

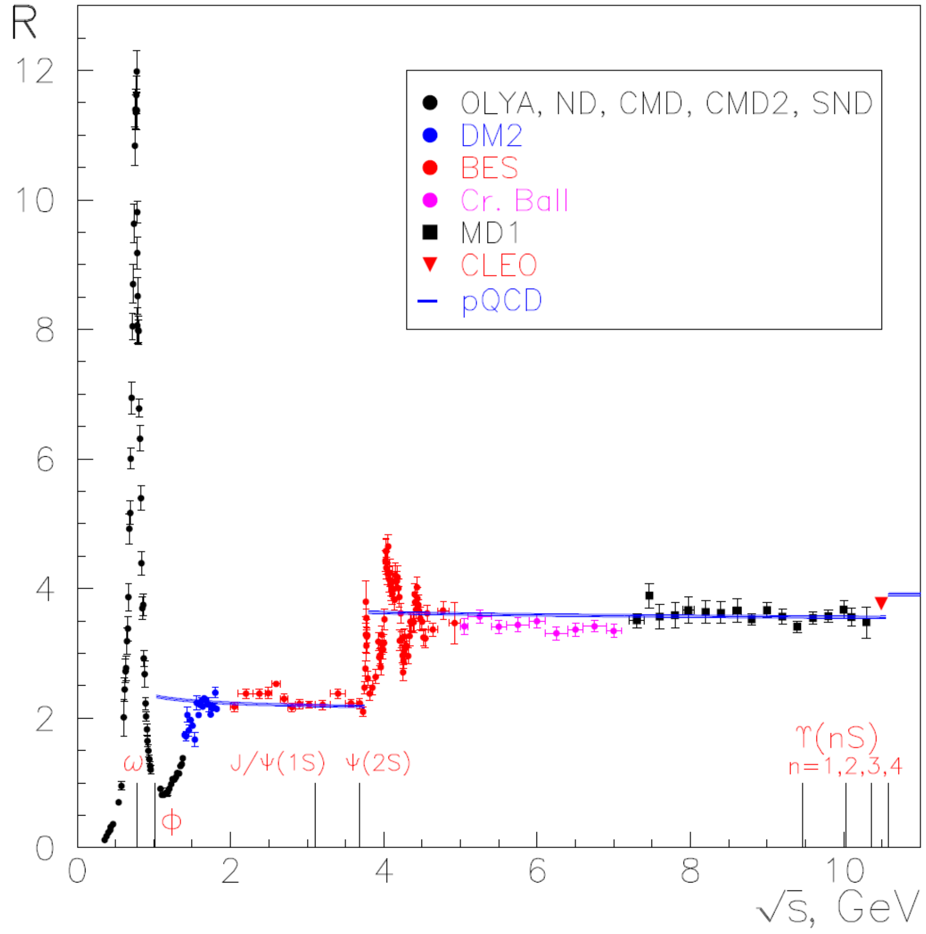
R measurement at Crystal Ball - 2

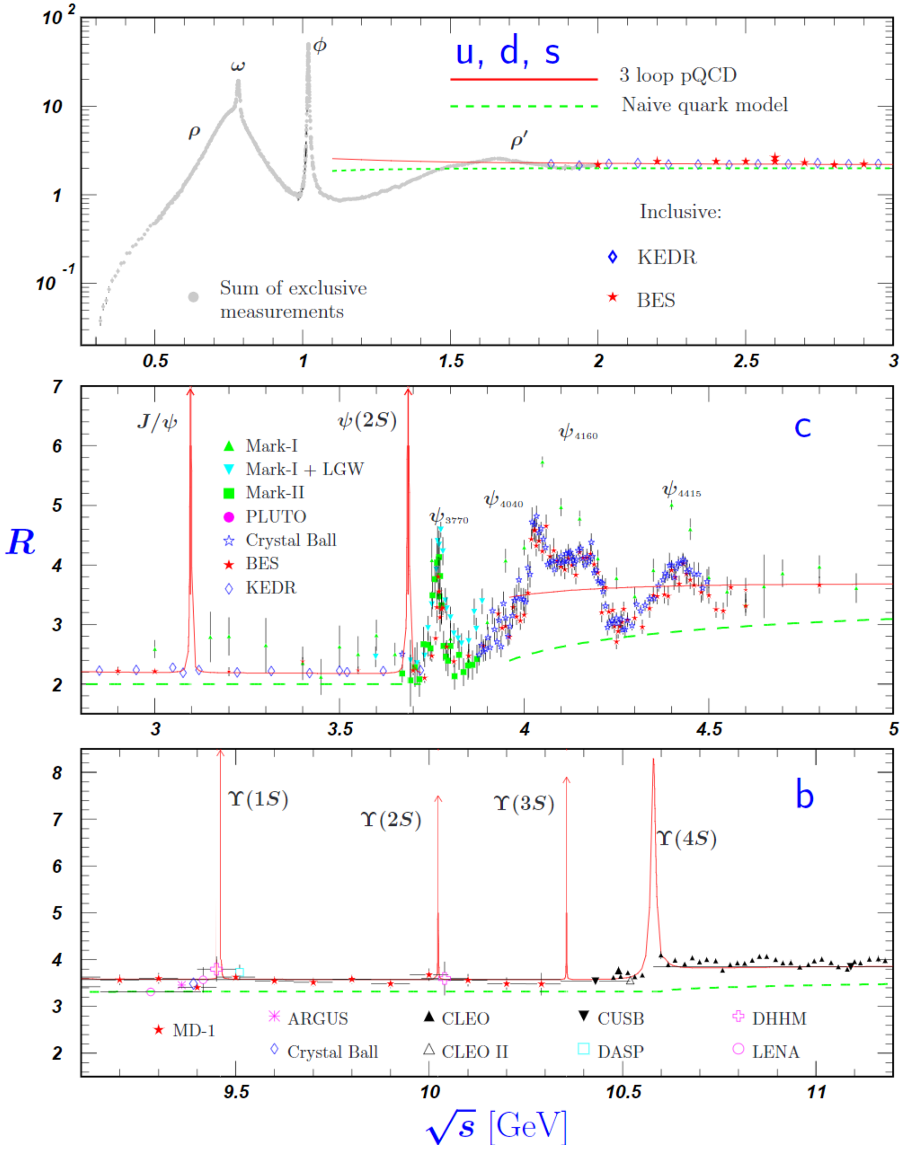


LUND 4.3 simulation



R measurements





R measurements