MEASUREMENT OF R WITH THE KEDR DETECTOR AT THE VEPP-4M COLLIDER

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Conference: From Phi to Psi, 8 June 2026

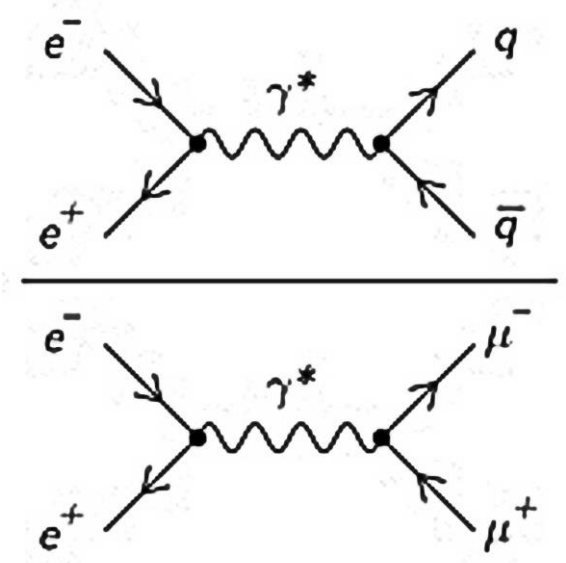
Talk Outline

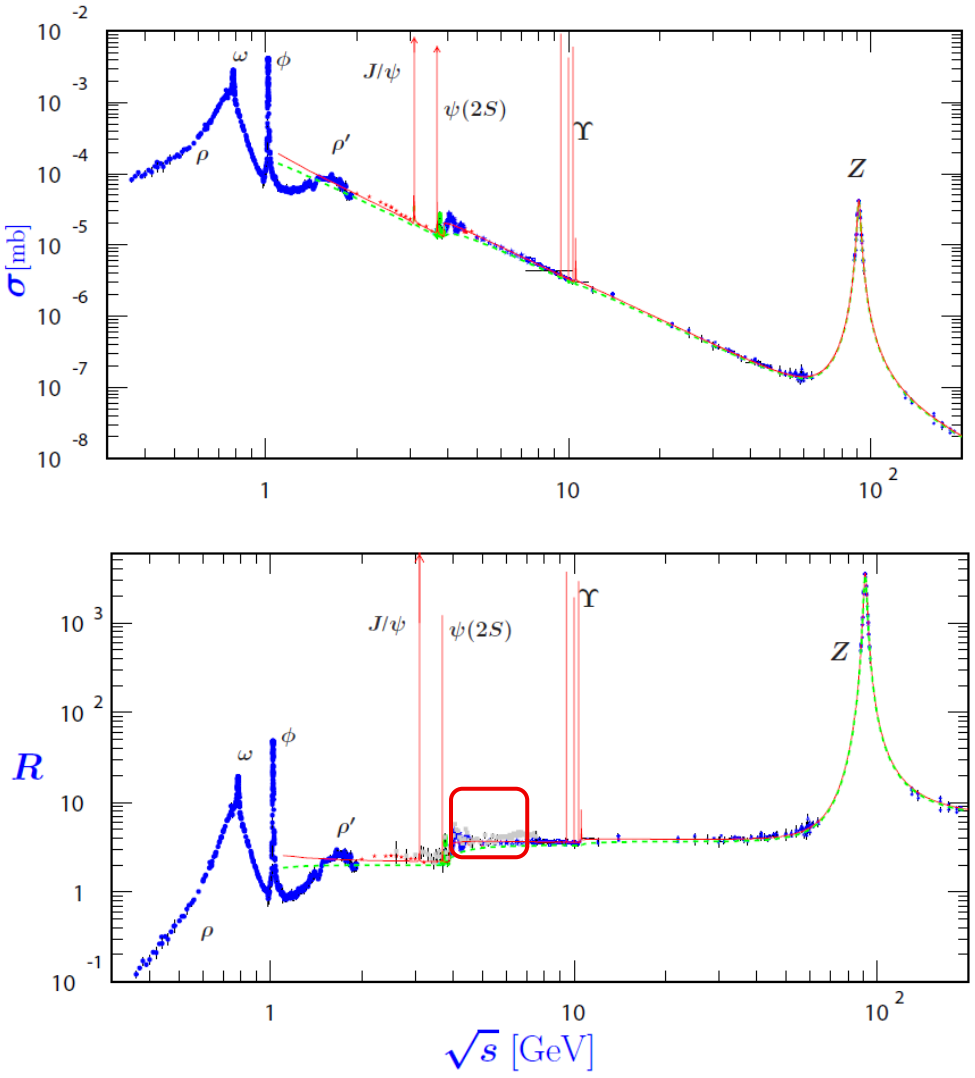
- Introduction & Motivation
- Experimental Setup (VEPP-4M & KEDR)
- Previous R Measurements (1.84–3.72 GeV)
- High-Energy Scan (4.56–6.96 GeV): Strategy & Data
- Analysis Method & Key Ingredients
- New Results & Systematics
- Impact & Applications of the Data
- Summary & Outlook

What is R?

Definition:

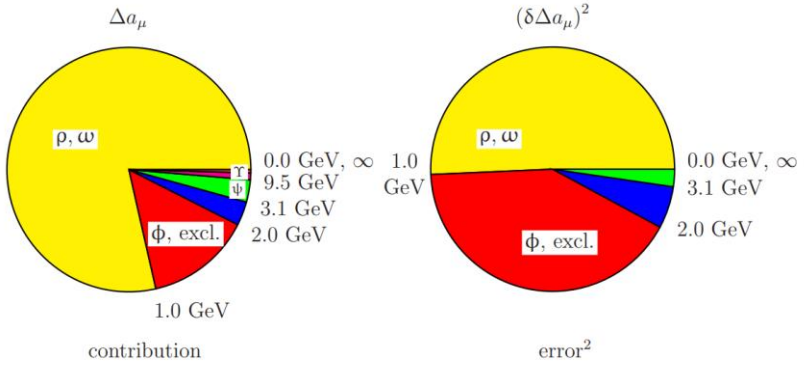
$$R = \frac{\sigma(e^-e^+ \to hadrons)}{\sigma(e^-e^+ \to \mu^-\mu^+)}$$



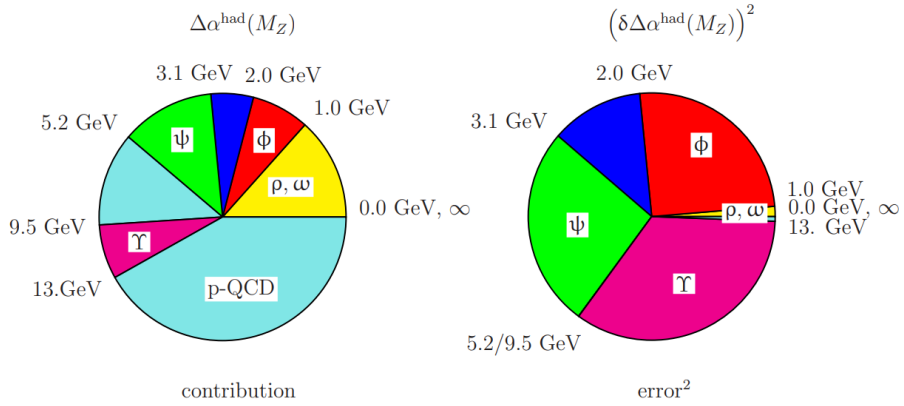


Why precise measurements of R matter?

Input for the hadronic vacuum polarisation (HVP) → muon g-2, $\alpha(M_Z^2)$



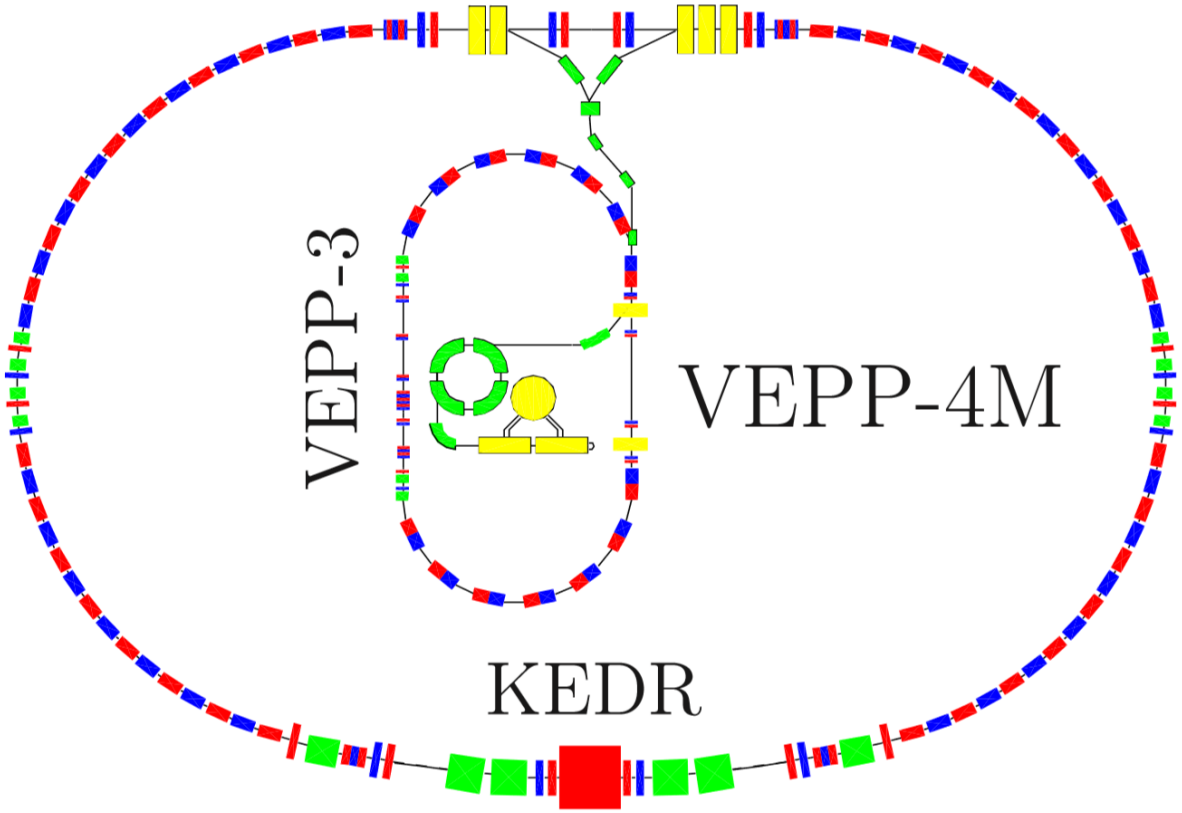
Tests of the SM (asymptotic freedom, α_s determination)



arXiv:1905.05078

Sensitive to "New Physics" beyond SM

The VEPP-4M Collider

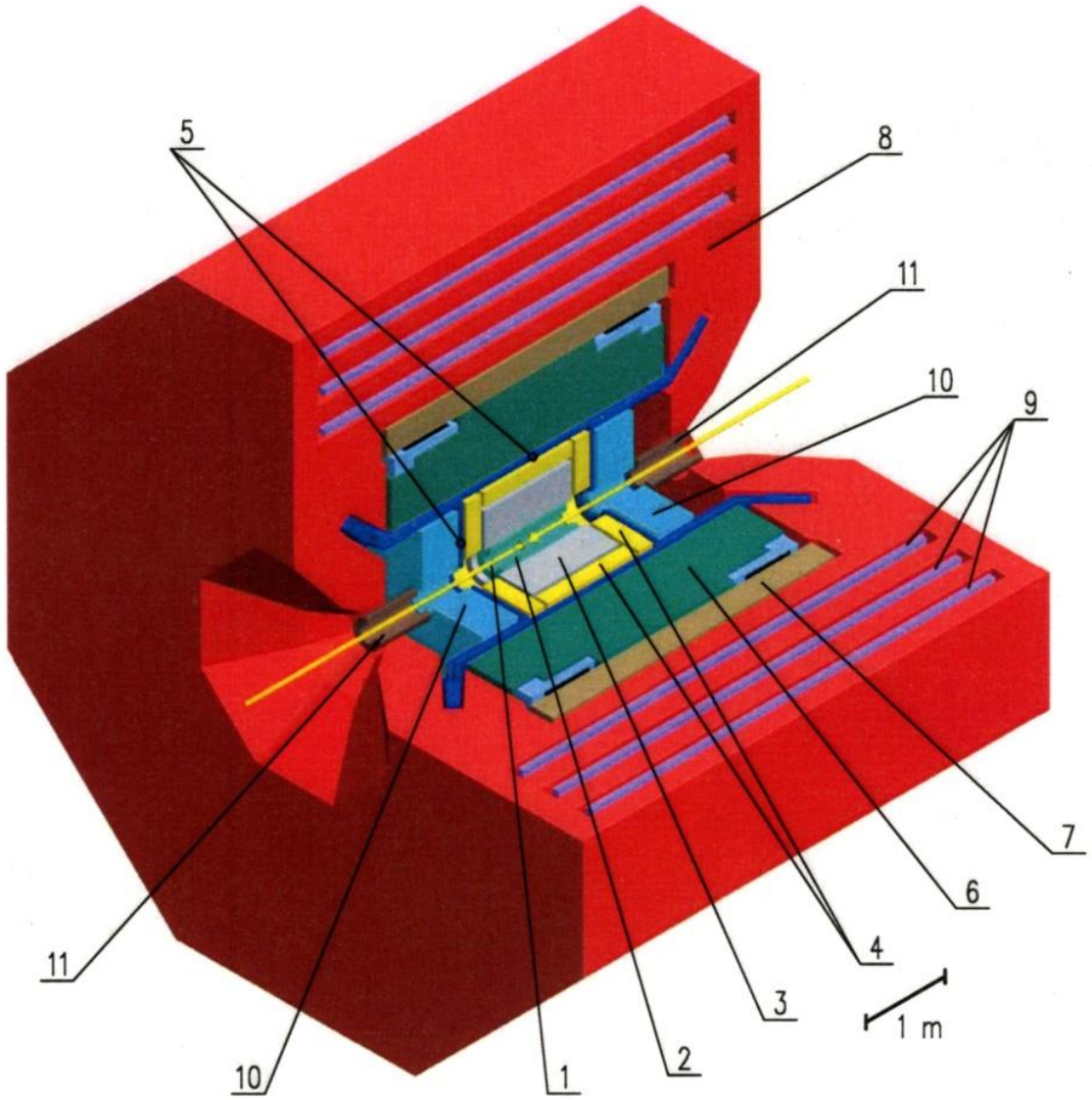


Beam energy: 1 – 5 GeV
Luminosity: up to
$2 \times 10^{31}\,cm^{-2}\,s^{-1}$ at 5 GeV

Key feature: Energy calibration with method of resonance depolarization

- *single-measurement accuracy* 10^{-6} *(1 keV at J/ψ)*
- *interpolation accuracy 10-30 keV*

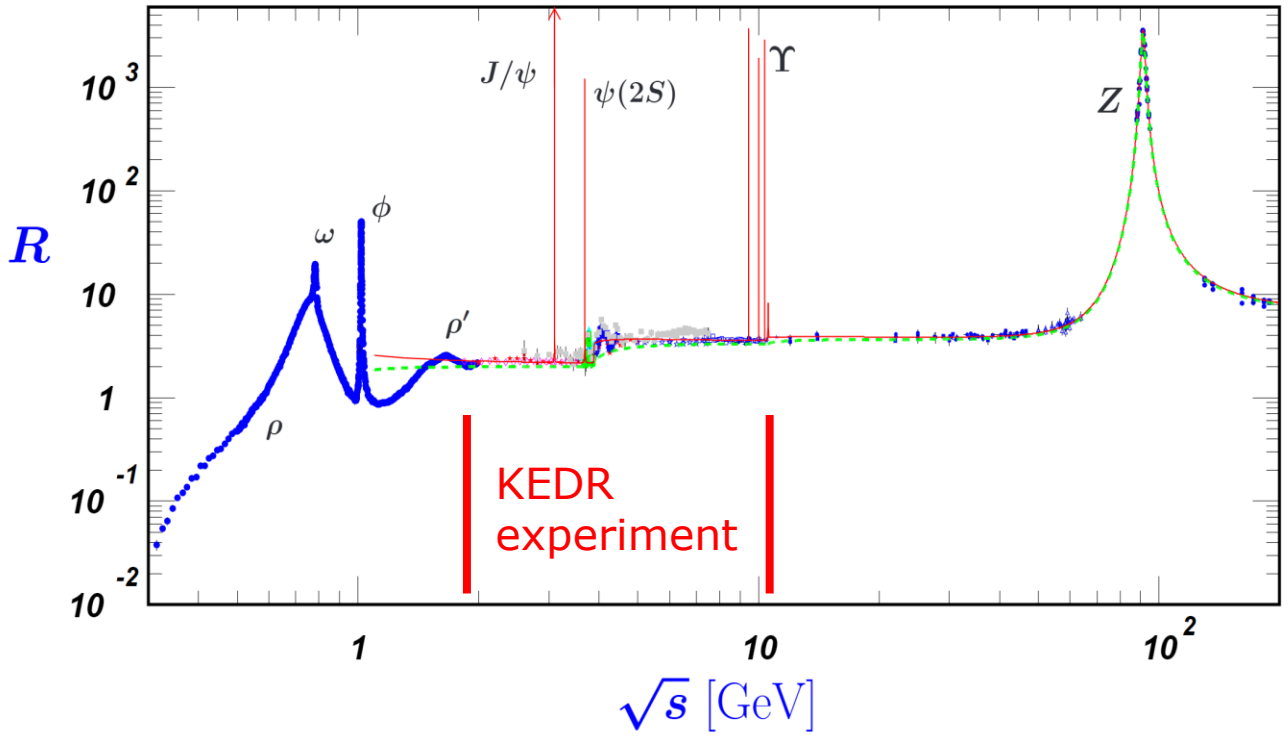
The KEDR detector



1. Beam vacuum pipe
2. Vertex detector
3. Drift chamber
4. Threshold aerogel Cherenkov counters
5. TOF counters
6. Barrel LKr calorimeter
7. Superconducting coil
8. Magnet yoke
9. Muon chambers
10. Endcap CsI calorimeter
11. Compensating coil

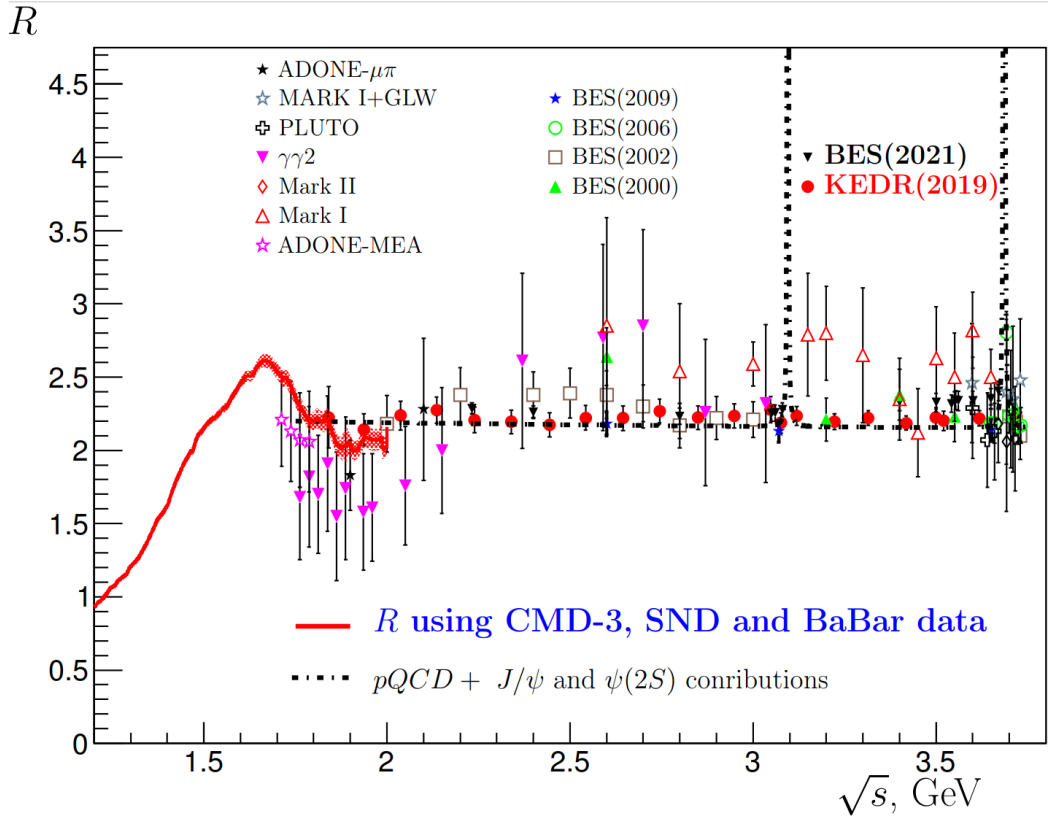
R measurements at KEDR

$\sqrt{s}$, GeV	N_{points}	$\int Ldt, pb^{-1}$
1.84 - 3.05	13	0.66
3.08 - 3.72	9	2.7
4.56 - 6.96	17	13.7



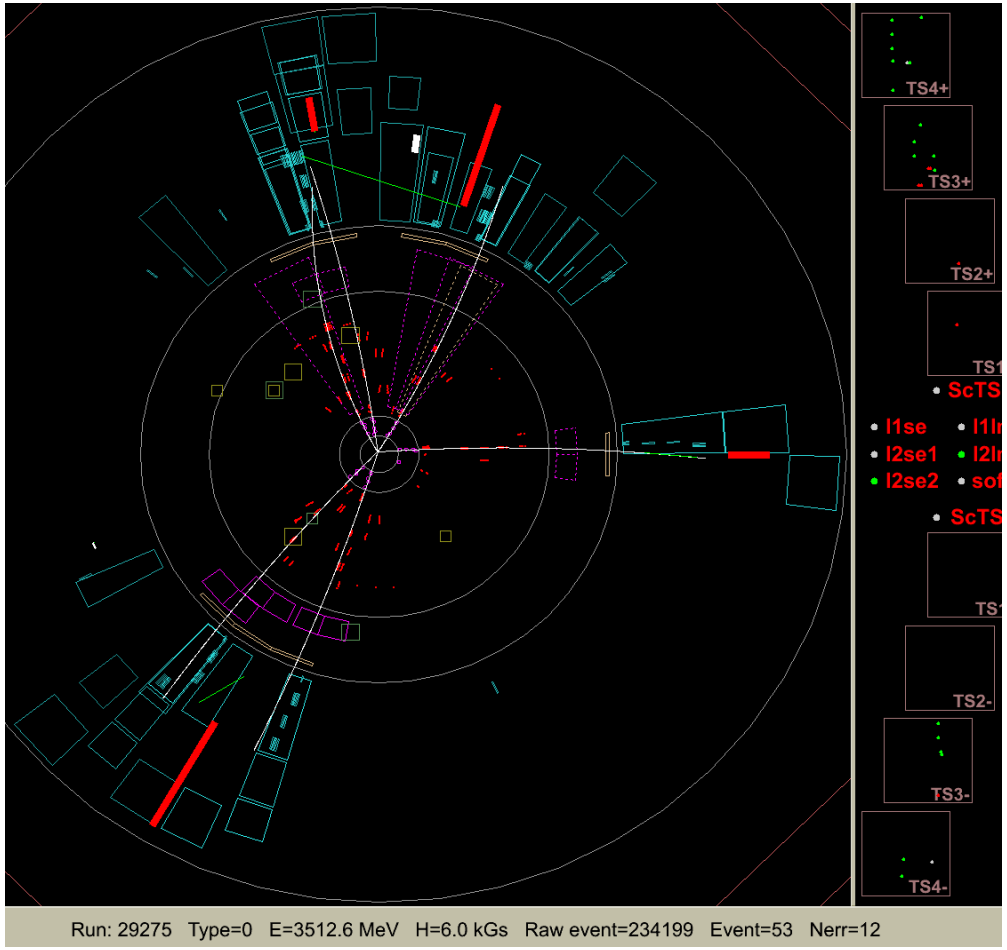
R scan in 2019-2020

2E = 4.56 – 6.96 GeV
17 energy points with a step ~ 0.15 GeV
Integrated luminosity 13.7 pb^{-1}

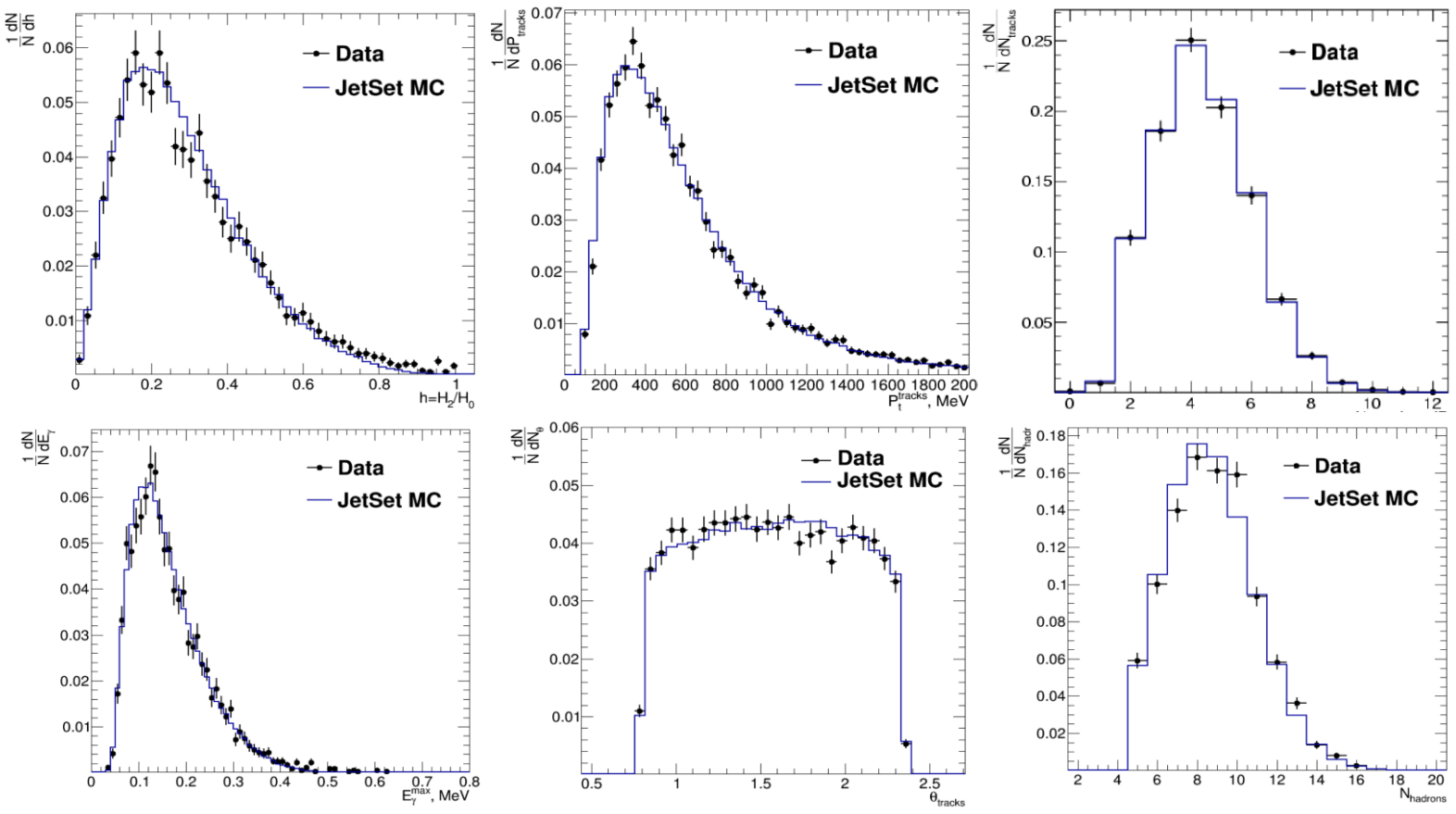


High-Energy Scan Strategy

- Total energy in center-of-mass frame: **4.56–6.96 GeV**
- **17 energy points** with step ≈ 0.15 GeV
- **Integrated luminosity:** ~13.7 pb^{-1}
- **Statistics:** ~5000 selected hadron events per point, total ~100,000 selected events
- **Goal:** Cover the region between ψ-family and ϒ-family



Event Selection and Simulation



Monte Carlo: Jetset (with tuned parameters)

$N_{IP} \geq 2$

$N_{particles} \geq 5$

$H_2/H_0 < 0.9$;

$E_\gamma^{max} < 0.35\ E_{run}$

$E_{vis} > 0.4\ E_{run}$

$E_{LKr} > 0.4\ E_{cal}$

$E_{cal} > 0.25\ E_{run}$

$P_z^{miss} < 0.3\ E_{run}$

Main Formula and Procedure

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

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

N^{mh} - number of selected events

N^{bkg} - number of background events

L – integrated luminosity

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

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

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

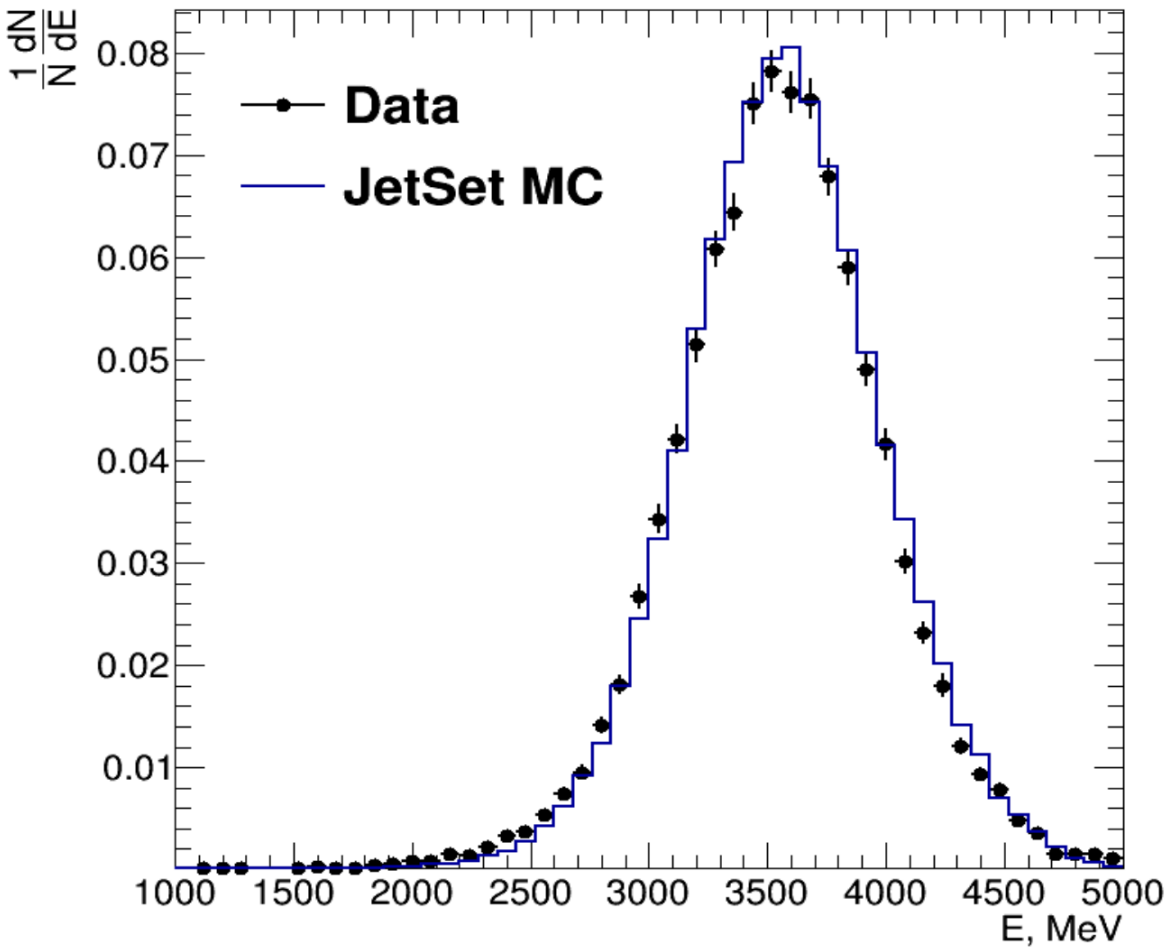
$\varepsilon(s)$ - detection efficiency

$1 + \delta(s)$ - radiative correction

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

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

Luminosity measurement



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

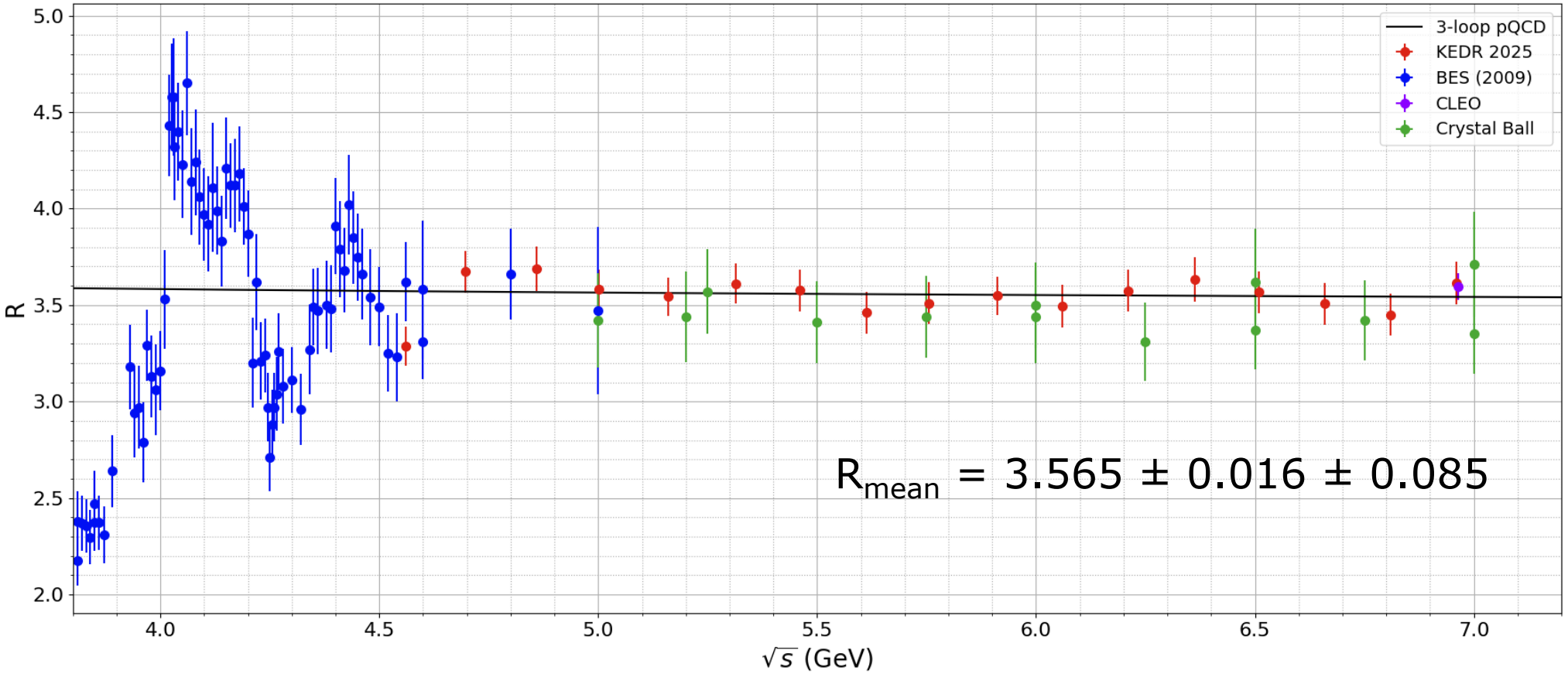
Systematic uncertainty ~ 1.2 %

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

Systematic Uncertainties

Source	Uncertainty (%)
Luminosity	1.2
Monte Carlo model	1.4
Track reconstruction	0.7
Nuclear interaction	0.6
Radiative correction	0.3
Beam background	0.2
Trigger	0.1
Cut variations	1.1
Total	**2.4**

R between 4.56 GeV and 6.96 GeV



Total uncertainty ~3% (systematic ~2.4%).

Applications of KEDR R Data (I) – QCD Coupling α_s

- **Shen et al. (2023):** Novel method using 22 KEDR points (1.84–3.72 GeV) → $\alpha_s(M_Z^2) = 0.1227_{-0.0132}^{+0.0117}$
  - Bayesian analysis for higher-order uncertainties
  - Removes renormalisation scale ambiguity
- **Boito & Caram (2025):** Study of duality violations; improves agreement between theory and data below 2.5 GeV
- **Kataev & Todyshev (2026):** Comparison of R values at different perturbative orders shows a trend originating from the massless approximation series behaviour.

Applications of KEDR R Data (II) – Muon g-2 and $\alpha(M_Z^2)$

- **Shen et al. (2023):** Hadronic contribution to muon anomalous magnetic moment determined with KEDR data in tau-charm region
  a_μ^{had} (1.84–3.72 GeV) reduces theoretical error in g-2 predictions
- **Perturbative QCD fits:** KEDR data constrain the running QED coupling $\alpha(M_Z^2)$ – crucial for electroweak precision tests
- **Kataev & Todyshev (2026):** Fixed-order pQCD expansions for R(s) compared with KEDR data to stabilise α_s extraction

Impact on Heavy-Quarkonium Physics

- **Charmonium threshold region** (3.08–3.72 GeV): KEDR's high-precision R values help disentangle:
  - ψ(2S), ψ(3770), ψ(4040), ψ(4160), ψ(4415) resonances
  - Continuum hadron production between resonances
- **Open charm production:** Direct constraint on σ($e^+e^- \to D\bar{D}$ etc.) at threshold
- **World data combination:** KEDR points fill critical gaps in the 4.6–7 GeV region, complementing BES, CLEO and Crystal Ball

Summary

- **New R measurement in 4.56–6.96 GeV** with ~3% total uncertainty (syst. 2.4%)
- **Combined with earlier KEDR results (1.84–3.72 GeV)** → 22+17 energy points from ~1.8 to 7 GeV
- **Key impact:**
  - $\alpha_s(M_Z)$ determination with reduced theoretical error
  - Improved hadronic vacuum polarisation for g-2 and $\alpha(M_Z^2)$
  - Benchmark data for pQCD tests and heavy-flavour production
- **VEPP-4M & KEDR** continue to deliver unique high-precision data in the tau-charm region

References

- **V.V. Anashin et al. (KEDR).** Precise measurement of R_{uds} and R between 1.84 and 3.72 GeV. *JHEP* (2023)
- **V.V. Anashin et al. (KEDR).** *Measurement of R between 1.84 and 3.05 GeV at the KEDR detector*. *Phys. Lett. B 770 (2017) 174-181*.
- **A. L. Kataev, K. Yu. Todyshev.** Perturbative QCD fitting of KEDR and BESIII data for R(s) and α_s determination. arXiv:2603.29803 (2026)

  https://indico.quarks.ru/event/2034/contributions/1563/
- **D. Boito, M. Caram.** Perturbative QCD below charm threshold: theory and tensions with e^+e^- data. *Phys. Rev. D* 112, 094052 (2025)
- **J.-M. Shen et al.** Novel method to determine the QCD coupling from R_{uds} and effects to muon g-2 and $\alpha(M_Z^2)$. *JHEP* 07 (2023) 109

THANKS

for your attention

Physical program of KEDR experiment

Elementary particle mass measurements:

$J/\psi, \psi(2S), \psi(3770), D^0, D^{\pm}, \Upsilon,$ τ – mesons

Leptonic width measurement for ψ- and Υ– mesons

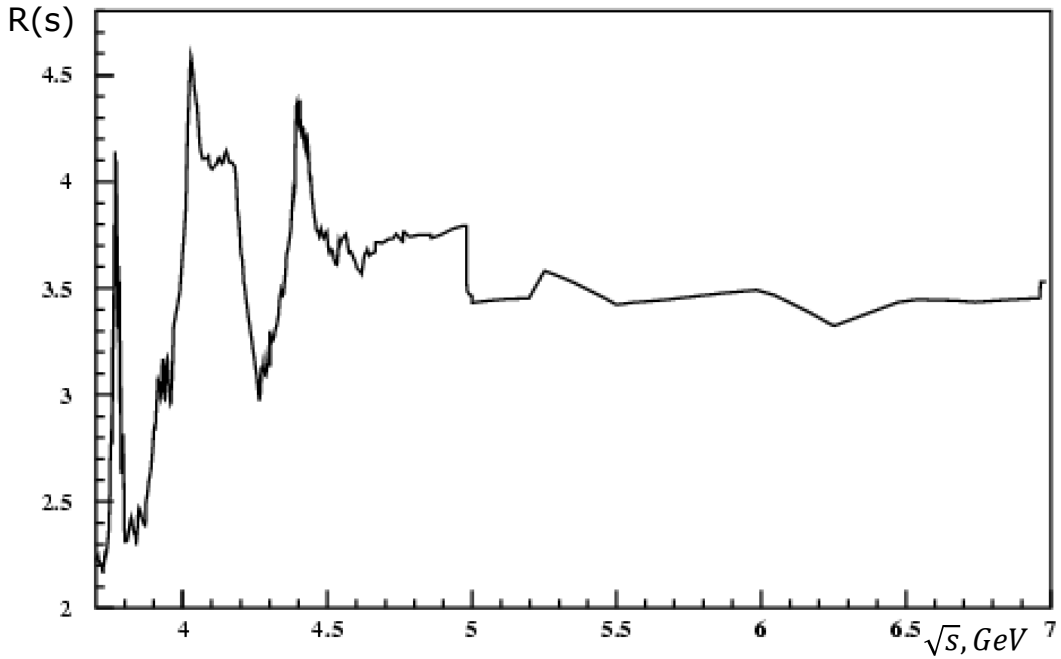
R measurements at $2E = 2 - 10$ GeV

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

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

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