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HIM

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Measurements of the R value at BESIII

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LeptonPhoton 2021 (online)

Jan. 10-14, 2022

Motivation

- Definition of R value

$$R \equiv \frac{\sigma^0(e^+e^- \rightarrow \text{hadrons})}{\sigma^0(e^+e^- \rightarrow \mu^+\mu^-)} \equiv \frac{\sigma_{\text{had}}^0}{\sigma_{\mu\mu}^0}$$

- Determination of running coupling constant of QED theory

$$\alpha \equiv \frac{\alpha_0}{1-\Delta\alpha}, \quad \Delta\alpha(s) = \Delta\alpha(s)_{\text{lep}} + \Delta\alpha(s)_{\text{had}}$$

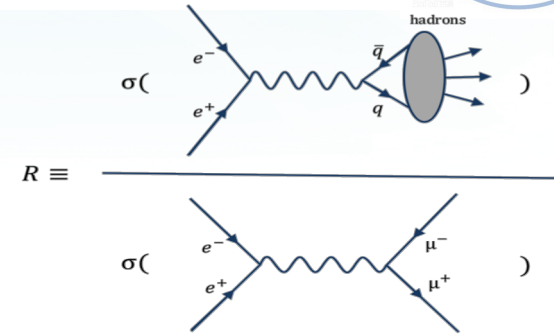
$$\Delta\alpha(M_Z^2) = -\frac{\alpha(0)M_Z^2}{3\pi} \text{Re} \int_{4M_\pi^2}^{\infty} \frac{ds R(s)}{s(s-M_Z^2)-i\epsilon}$$

- Anomalous magnetic moment of muon $g_\mu - 2$

$$a_\mu = \frac{g_\mu - 2}{2}, \quad a_\mu^{\text{SM}} = a_\mu^{\text{QED}} + a_\mu^{\text{weak}} + a_\mu^{\text{had}}$$

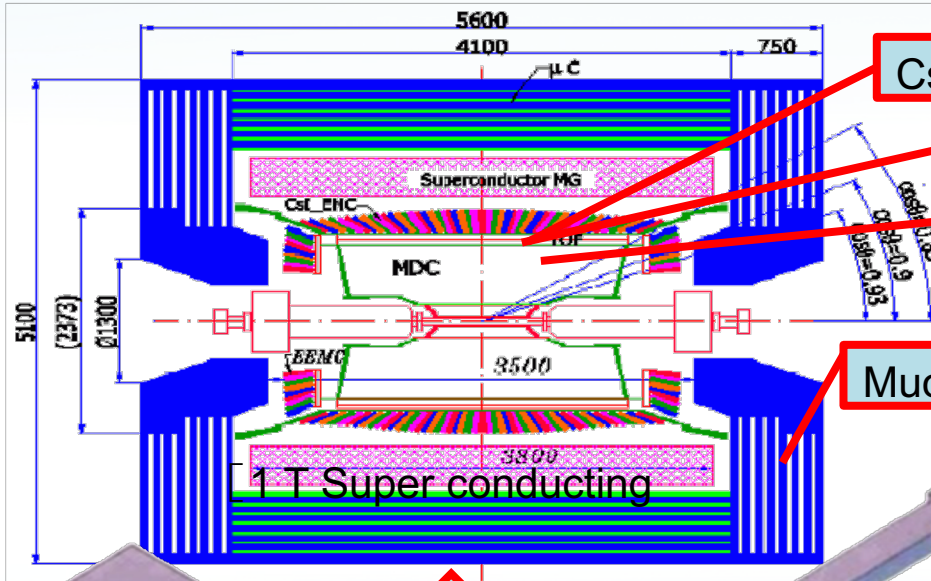
$$a_\mu^{\text{had}} = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{4m_\pi^2}^{\infty} ds \frac{K(s)}{s^2} R(s)$$

$$\Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}}: 4.2\sigma \rightarrow \text{new physics}$$



Source	Contribution ($\times 10^4$)
$\Delta\alpha_{\text{lepton}}(M_Z^2)$	314.979 ± 0.002
$\Delta\alpha_{\text{had}}^{(5)}(M_Z^2)$	276.0 ± 1.0
$\Delta\alpha_{\text{top}}(M_Z^2)$	-0.7180 ± 0.0054

Source	Contribution ($\times 10^{11}$)
a_μ^{QED}	116 584 718.931(104)
a_μ^{Weak}	153.6(1.0)
$a_\mu^{\text{had}}[\text{LO}]$	6931(40)
$a_\mu^{\text{had}}[\text{NLO}]$	-98.3(7)
$a_\mu^{\text{had}}[\text{NNLO}]$	12.4(1)
$a_\mu^{\text{had,l-l}}$	92(18)
a_μ^{SM}	116 591 810(43)
a_μ^{exp}	116 592 061(41)
Δa_μ	251(59)



CsI crystal, $\Delta E/E = 2.5\% @ 1 \text{ GeV}$

$\sigma_T = 100 \text{ ps}$ barrel, 65 ps endcaps

$\sigma_p/p = 0.5\% @ 1 \text{ GeV}$, $\sigma_{dE/dx} = 6\%$

Muon ID: RPCs

Linac



- Beam energy: 1.0 – 2.475 GeV
- Luminosity: $1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
- Optimum energy: 1.89 GeV

R in experiment



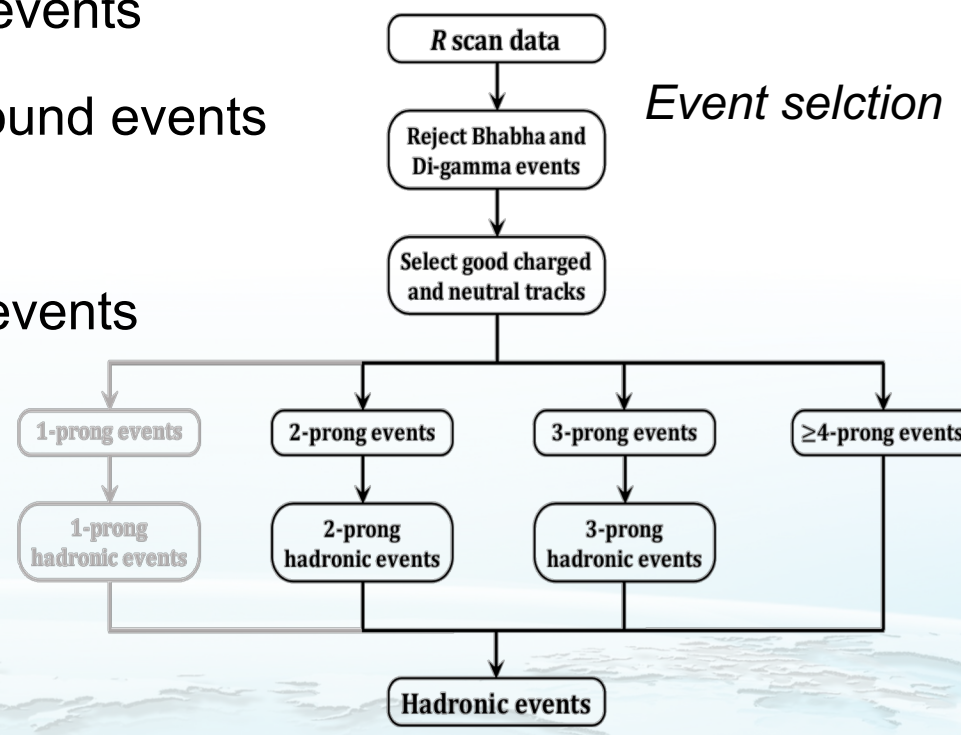
In experiment:

$$R = \frac{N_{\text{had}}^{\text{obs}} - N_{\text{bkg}}}{\mathcal{L}_{\text{int}} \epsilon_{\text{had}} \epsilon_{\text{trig}} (1 + \delta) \sigma_{\mu\mu}^0}$$

- $N_{\text{had}}^{\text{obs}}$: numbers of observed hadronic events
- N_{bkg} : numbers of the residual background events
- \mathcal{L}_{int} : integrated luminosity
- ϵ_{had} : detection efficiency of hadronic events
- ϵ_{trig} : trigger efficiency
- $(1 + \delta)$: ISR correction factor
- $\sigma_{\mu\mu}^0$: leading order QED cross section

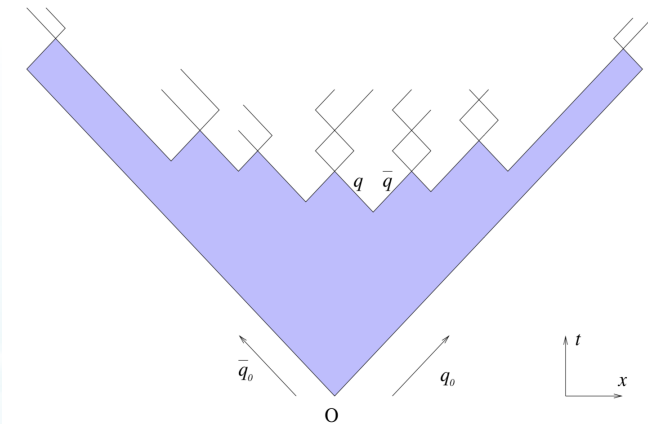
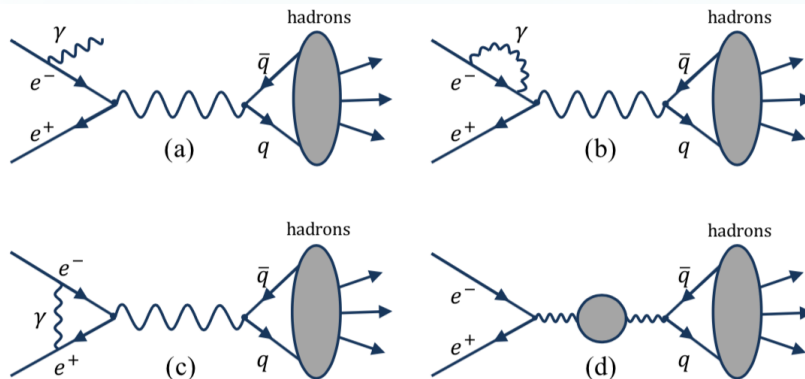
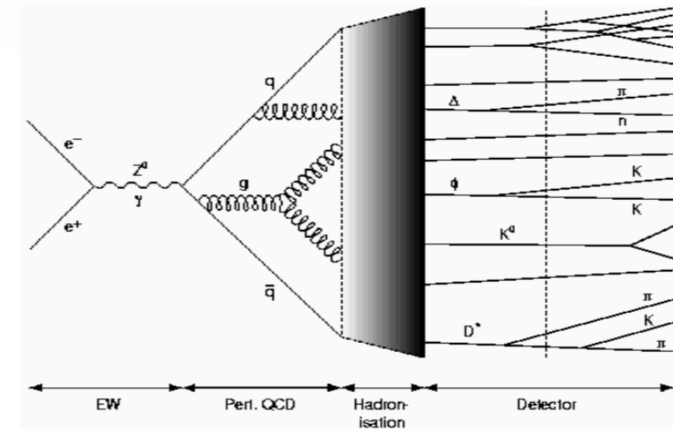
for $e^+e^- \rightarrow \mu^+\mu^-$

\sqrt{s} (GeV)	\mathcal{L}_{int} (pb ⁻¹)	\sqrt{s} (GeV)	\mathcal{L}_{int} (pb ⁻¹)	\sqrt{s} (GeV)	\mathcal{L}_{int} (pb ⁻¹)
2.2324	2.645	3.0800	31.02	3.5611	3.847
2.4000	3.415	3.4000	1.733	3.6002	9.502
2.8000	3.753	3.5000	3.633	3.6500	4.760
3.0500	14.89	3.5424	8.693	3.6710	4.628
3.0600	15.04	3.5538	5.562		



MC Simulation

- Signal simulation: LUARLW model [[arXiv:hep-ph/9910285](https://arxiv.org/abs/hep-ph/9910285)]
 - Development of JETSET for low E experiments
 - Both continuum and resonance states
 - Kinematics of initial hadrons determined by Lund Area Law
 - Phenomenological parameters should be tuned
 - Integrated the Initial-state radiation (ISR) and Vacuum Polarization (VP)



Hybrid MC

- R value: sum of hadronic processes
 - Good consistence below 2 GeV
 - Incomplete measurements above 2 GeV
- Hybrid model as an alternative model

- ConExc + Phokhara + LUARLW
- Phokhara: 10 modes

[Phys.Rev.D90, 114021]

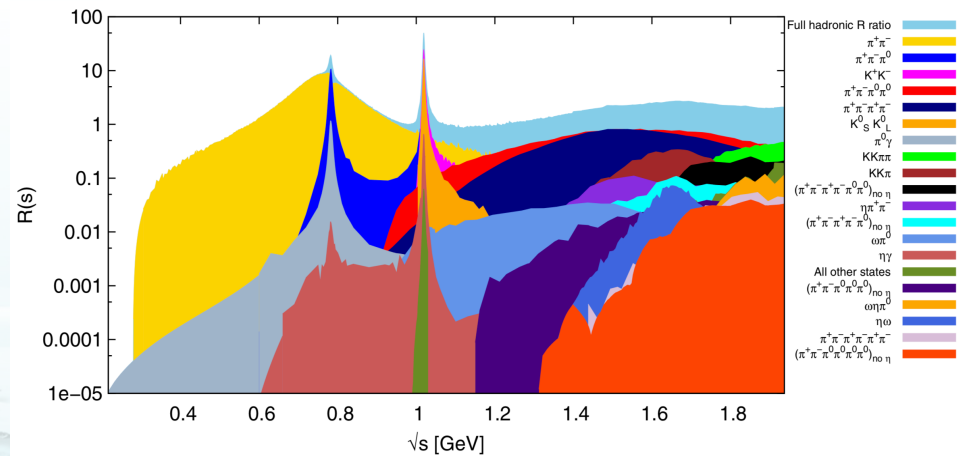
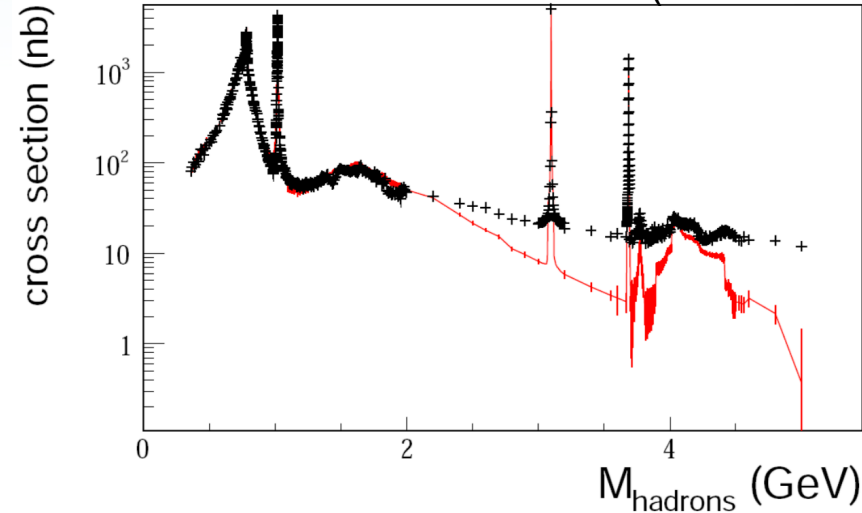
- ConExc: 47 modes

[Chin.Phys.C40, 113002]

- LUARLW: unknown processes

- Difference with LUARLW: < 2.3%

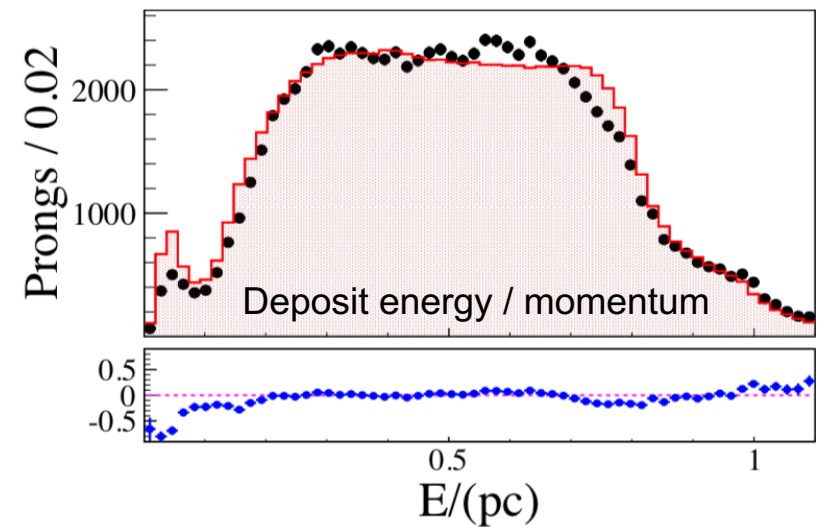
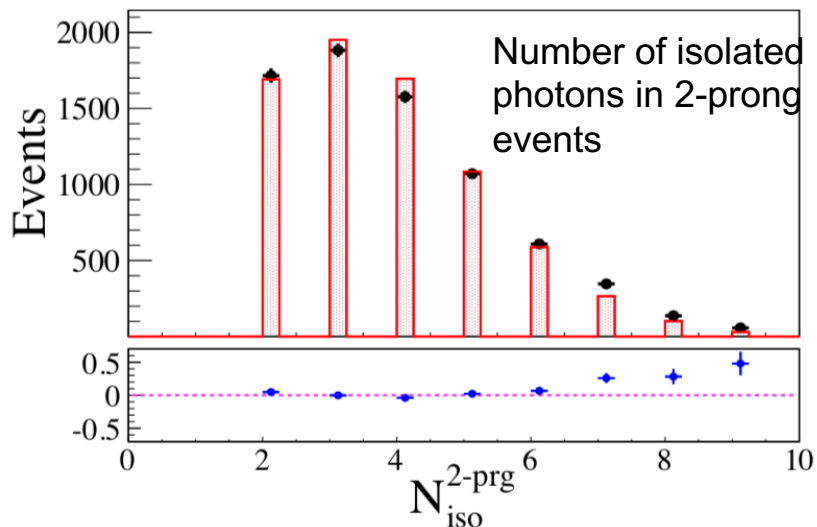
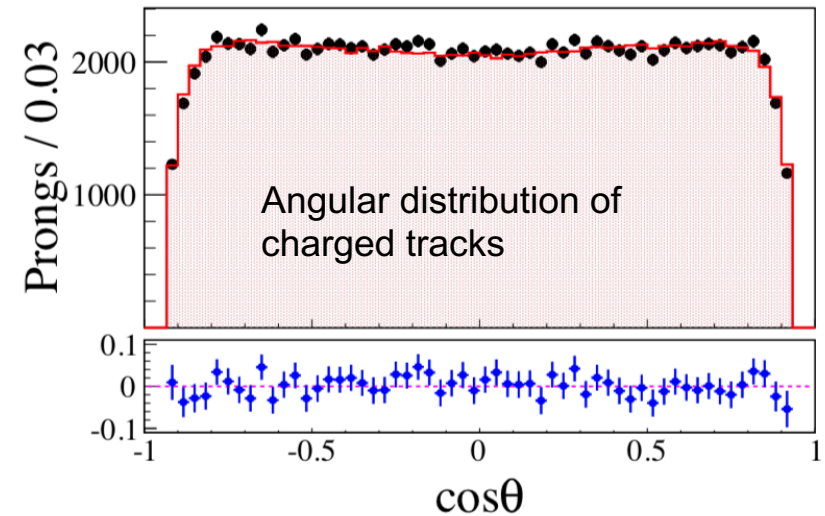
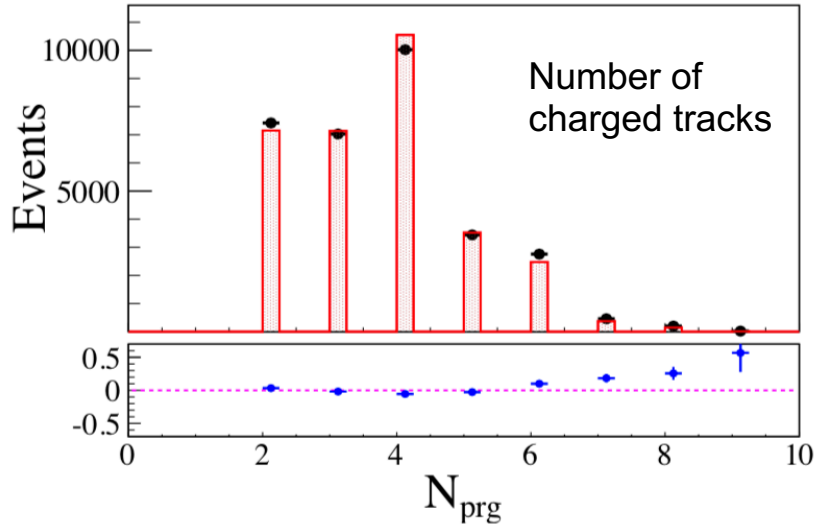
+ : cross section from R -value measurement
 + : Sum of exclusive cross section (76 modes)



(a) The hadronic R -ratio.

MC vs Data

- Comparison of MC and data (@3.4 GeV)
 - Data(black dot) are well reproduced by tuned LUARLW MC(red histogram)



- Based on experimental technique:

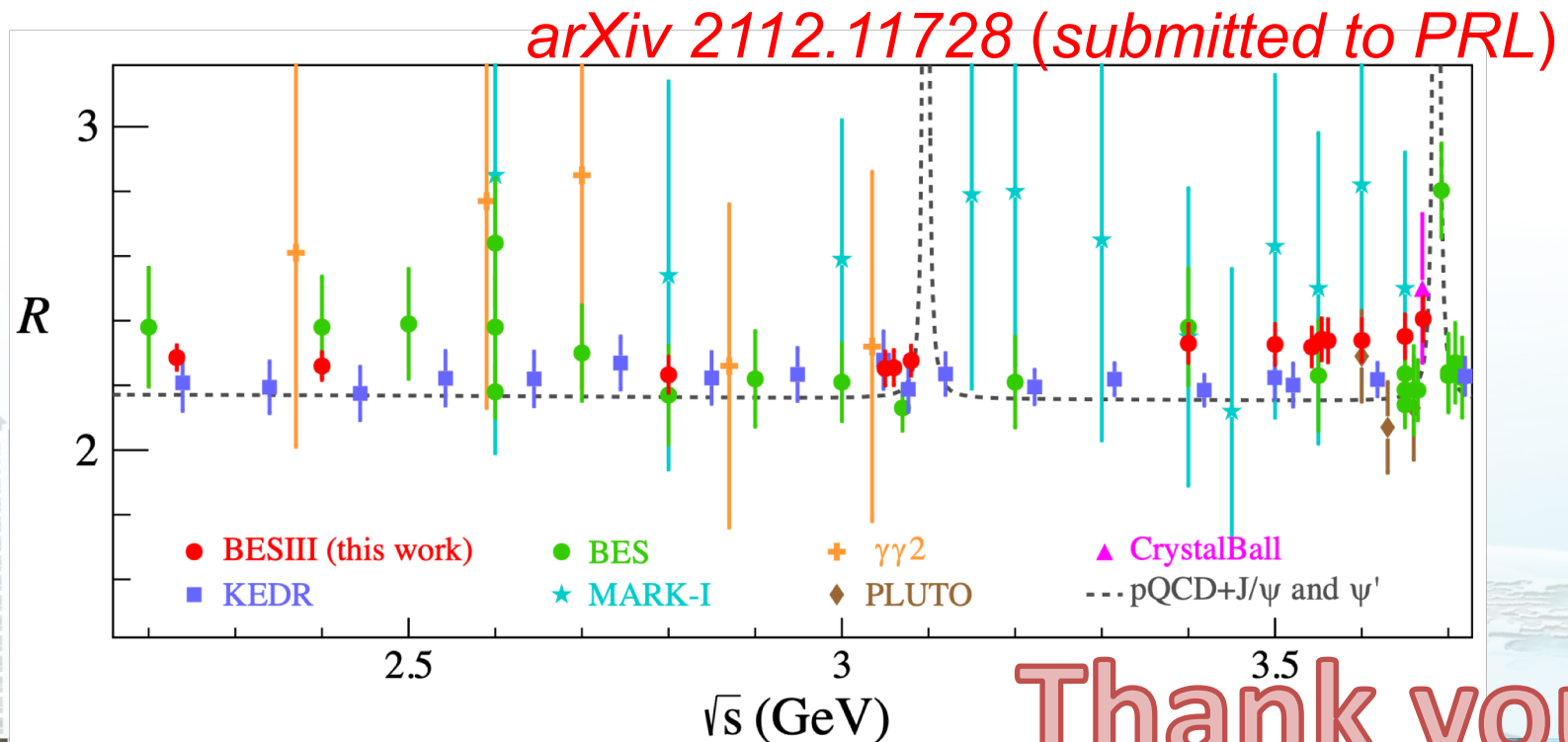
$$\left(\frac{\Delta R}{R}\right)_{\text{sys}}^2 = \left(\frac{\Delta N}{N}\right)^2 + \left(\frac{\Delta \mathcal{L}_{\text{int}}}{\mathcal{L}_{\text{int}}}\right)^2 + \left(\frac{\Delta \varepsilon_{\text{had}}}{\varepsilon_{\text{had}}}\right)^2 + \left(\frac{\Delta \varepsilon_{\text{trig}}}{\varepsilon_{\text{trig}}}\right)^2 + \left(\frac{\Delta(1 + \delta)}{(1 + \delta)}\right)^2$$

where $N = N_{\text{had}}^{\text{obs}} - N_{\text{bkg}}$

- Event selection: vary selection criteria, <0.8%
- Background estimation: different methods and background simulation model
- Integrated luminosity: quote the uncertainty in luminosity measurement, 0.8%
- **Signal simulation: hybrid model as a cross check, <2.3%**
- Trigger efficiency: approaches 100% with an uncertainty less than 0.1%
- ISR correction factor: considered in calculation precision, <1.3%

Summary

- Significant process of R measurement: MC tuning, simulation checking, ...
- Both LUARLW and Hybrid MC can describe data well
- R values obtained in (2.2, 3.7) GeV
- Good accuracy of R value: $<3.0\%$
- Whole R program will cover a wide energy range: 2.0 - 4.9 GeV



Thank you!