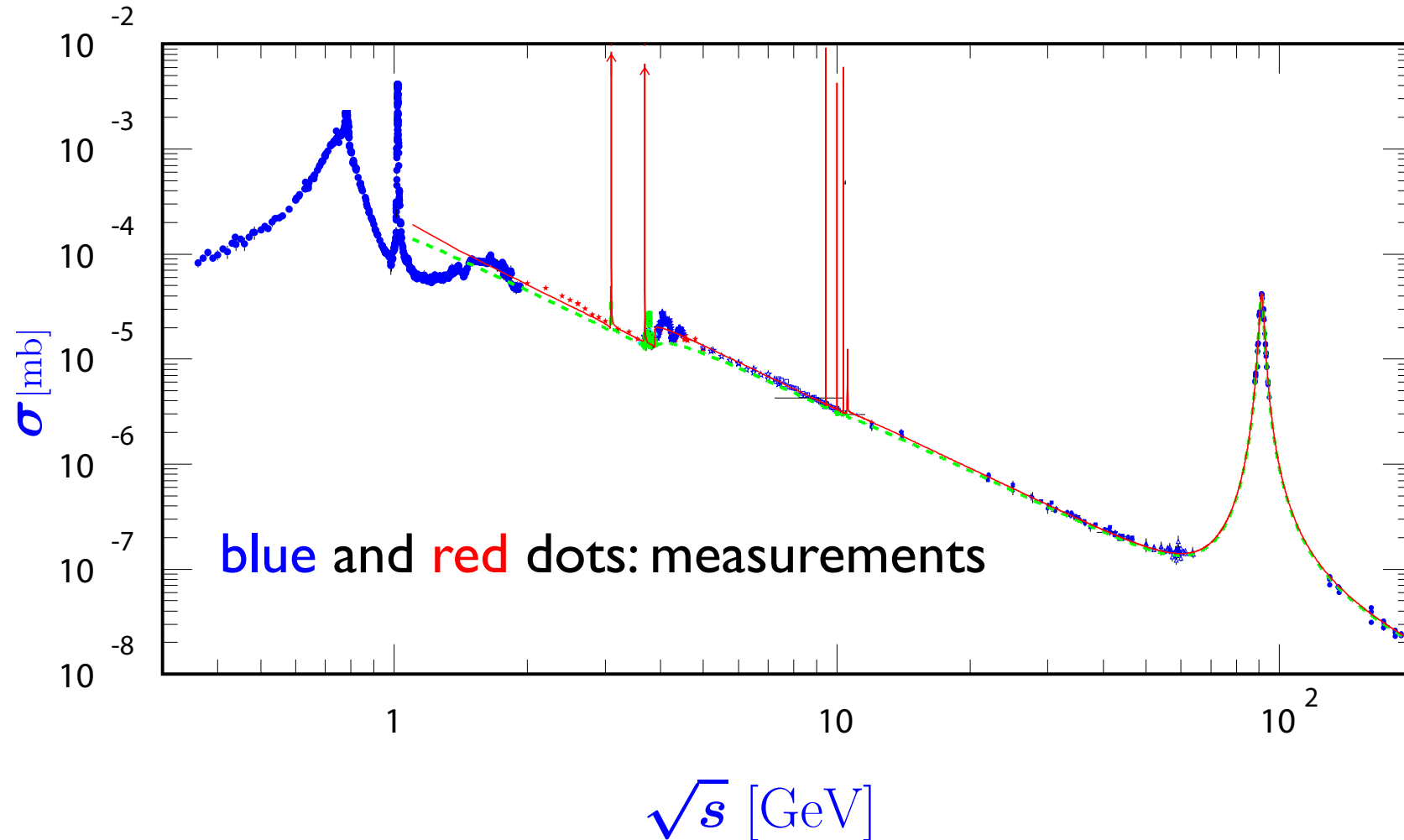


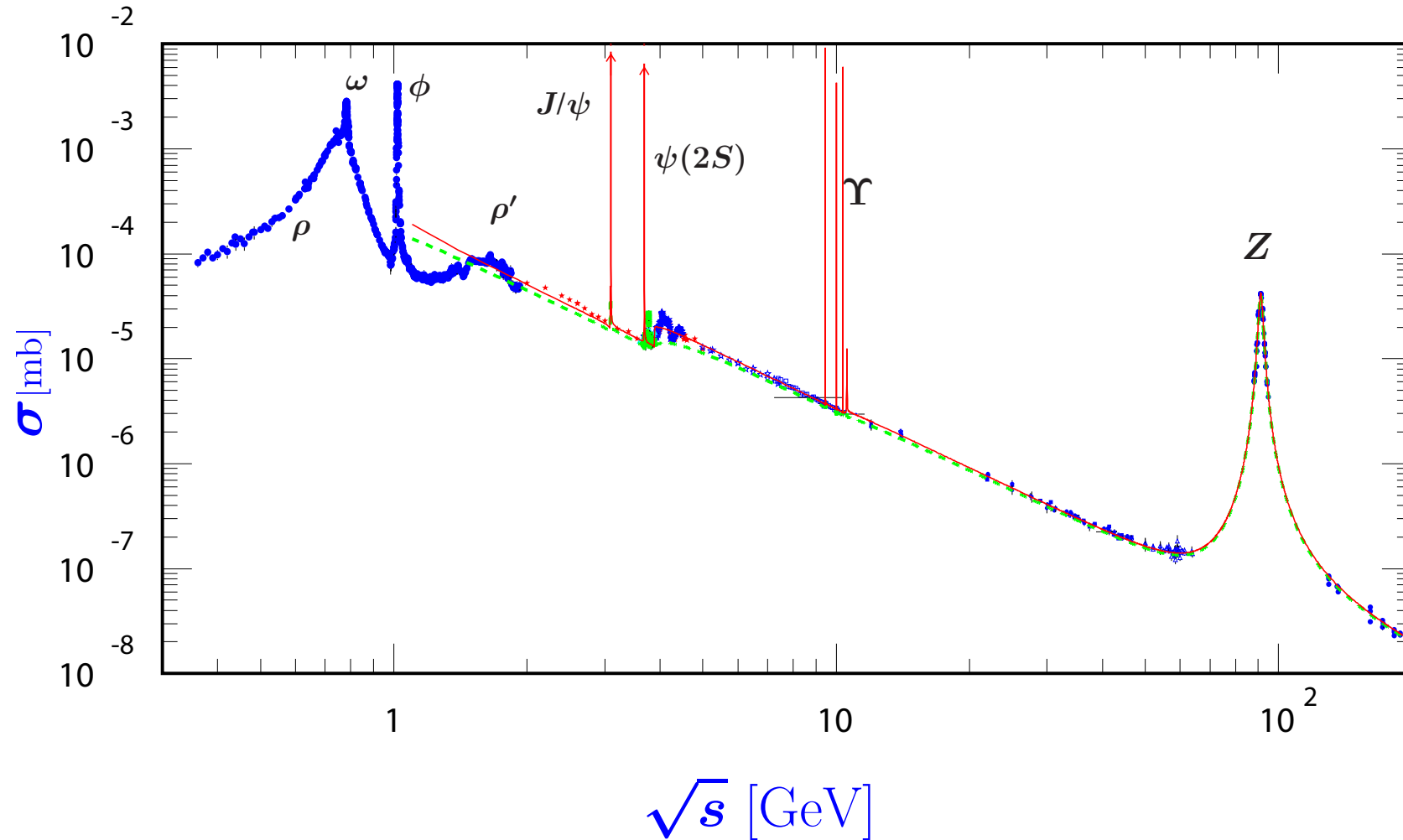
$$\sigma(e^+e^- \rightarrow \text{hadrons})$$

# $e^+e^- \rightarrow \text{hadrons}$ : cross section

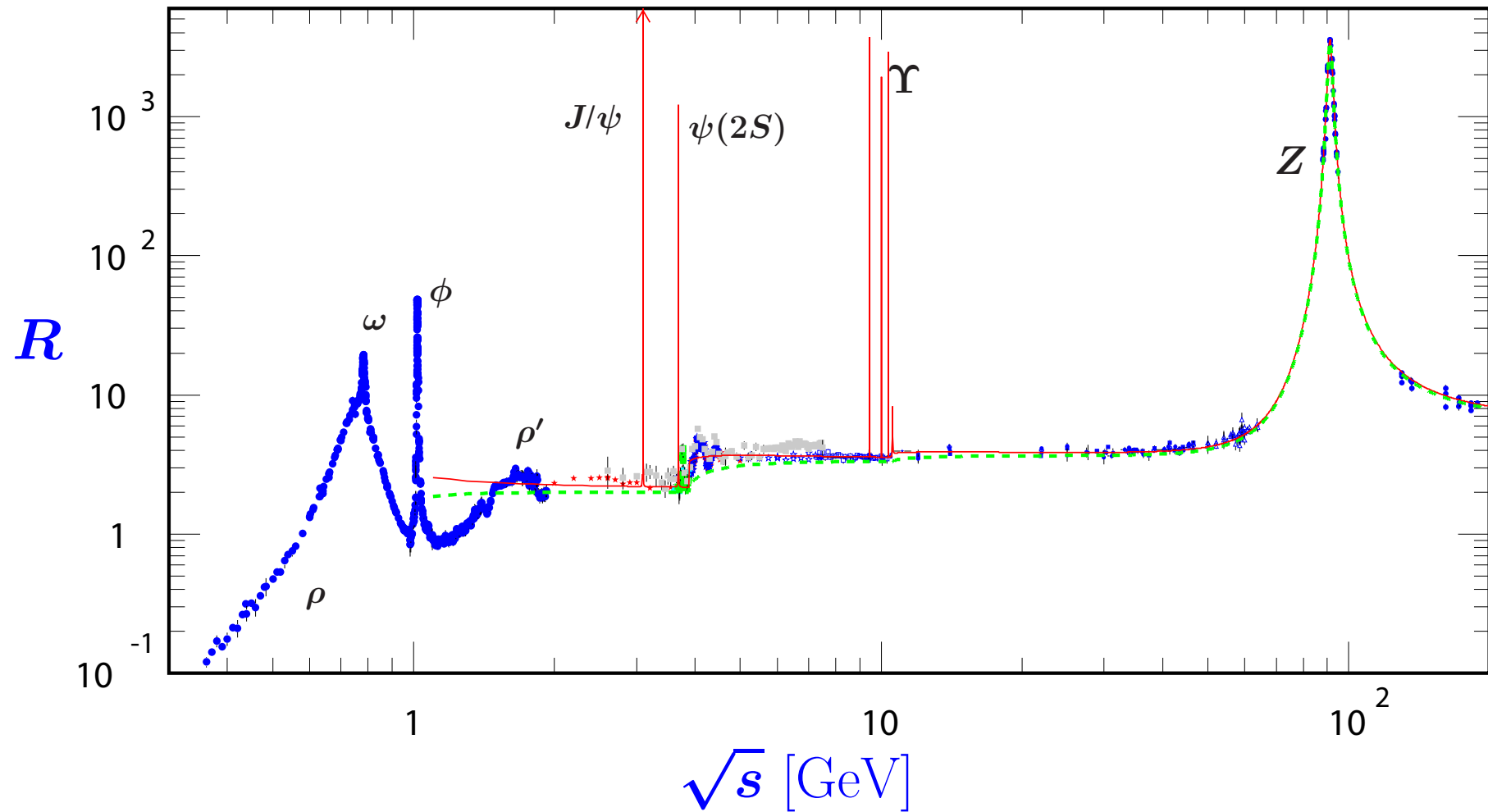


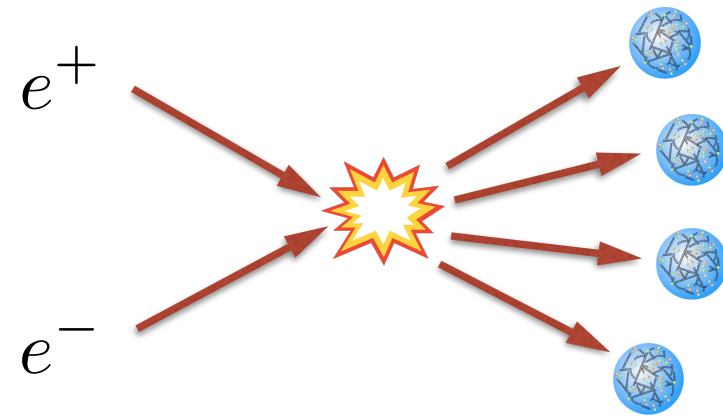
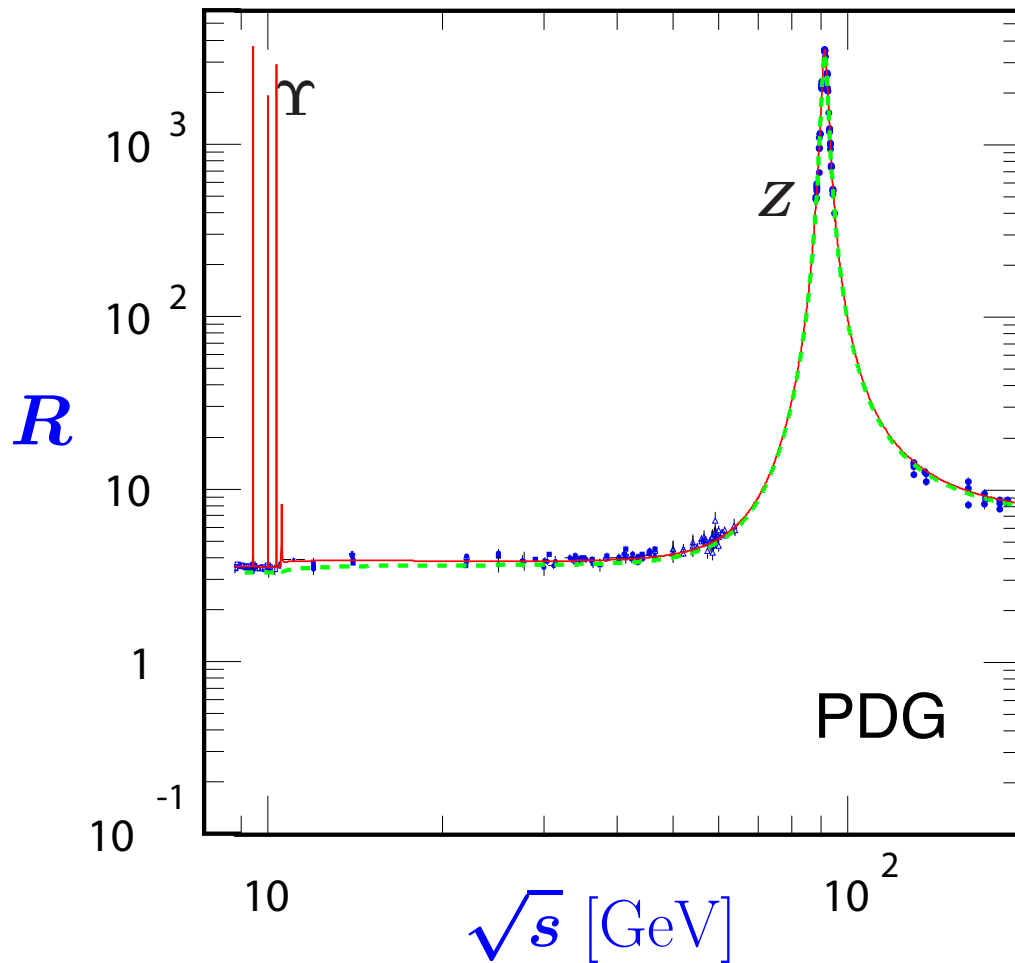
from the particle data group, <https://pdg.lbl.gov>

# $e^+e^- \rightarrow \text{hadrons}$ : cross section



# R-ratio





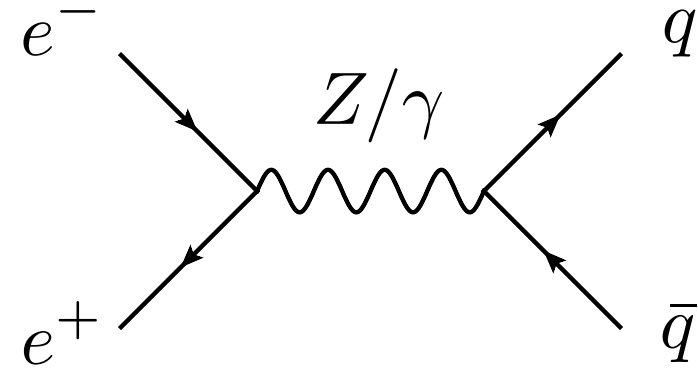
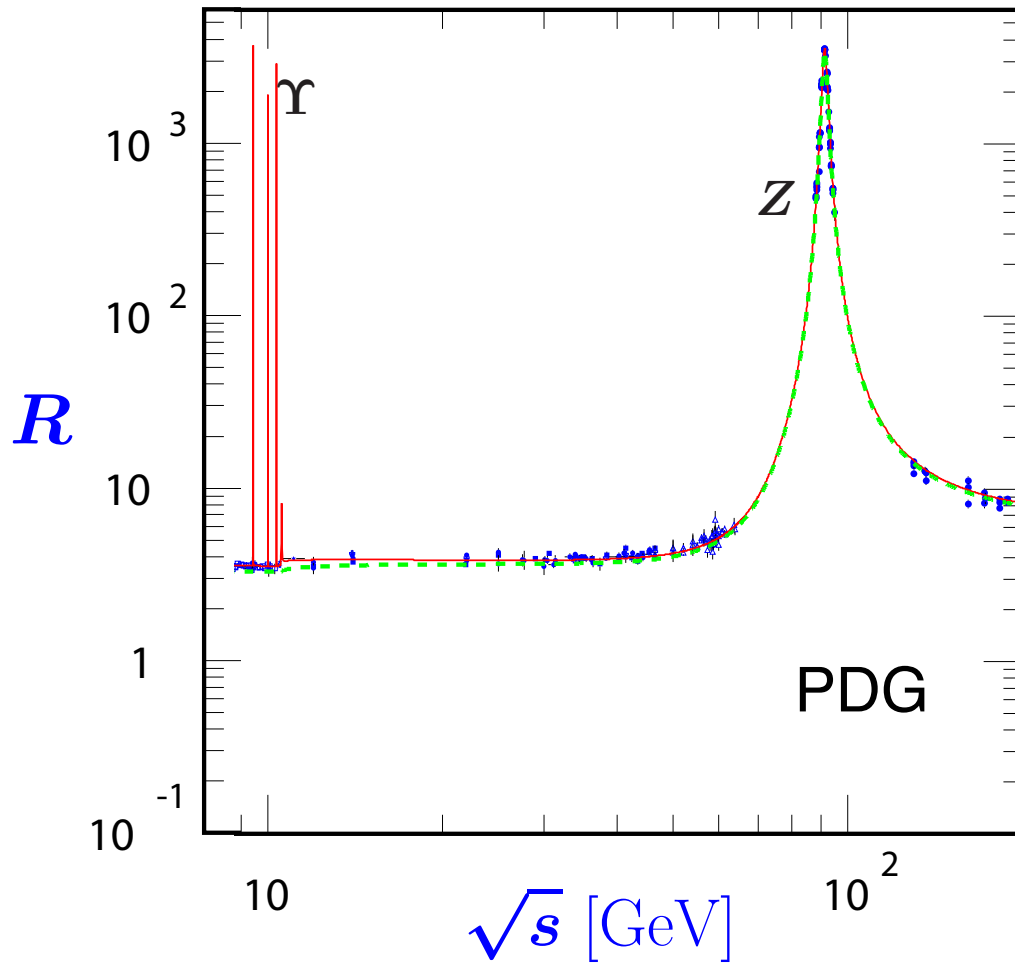
measurement

$$R = \frac{\sigma(e^+e^- \rightarrow Z/\gamma^* \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \gamma^* \rightarrow \mu^+\mu^-)}$$

theoretical expression  
w/o Z-boson exchange

Blue: experimental measurements

Green and red lines theoretical predictions



sum over colors and flavors of quarks

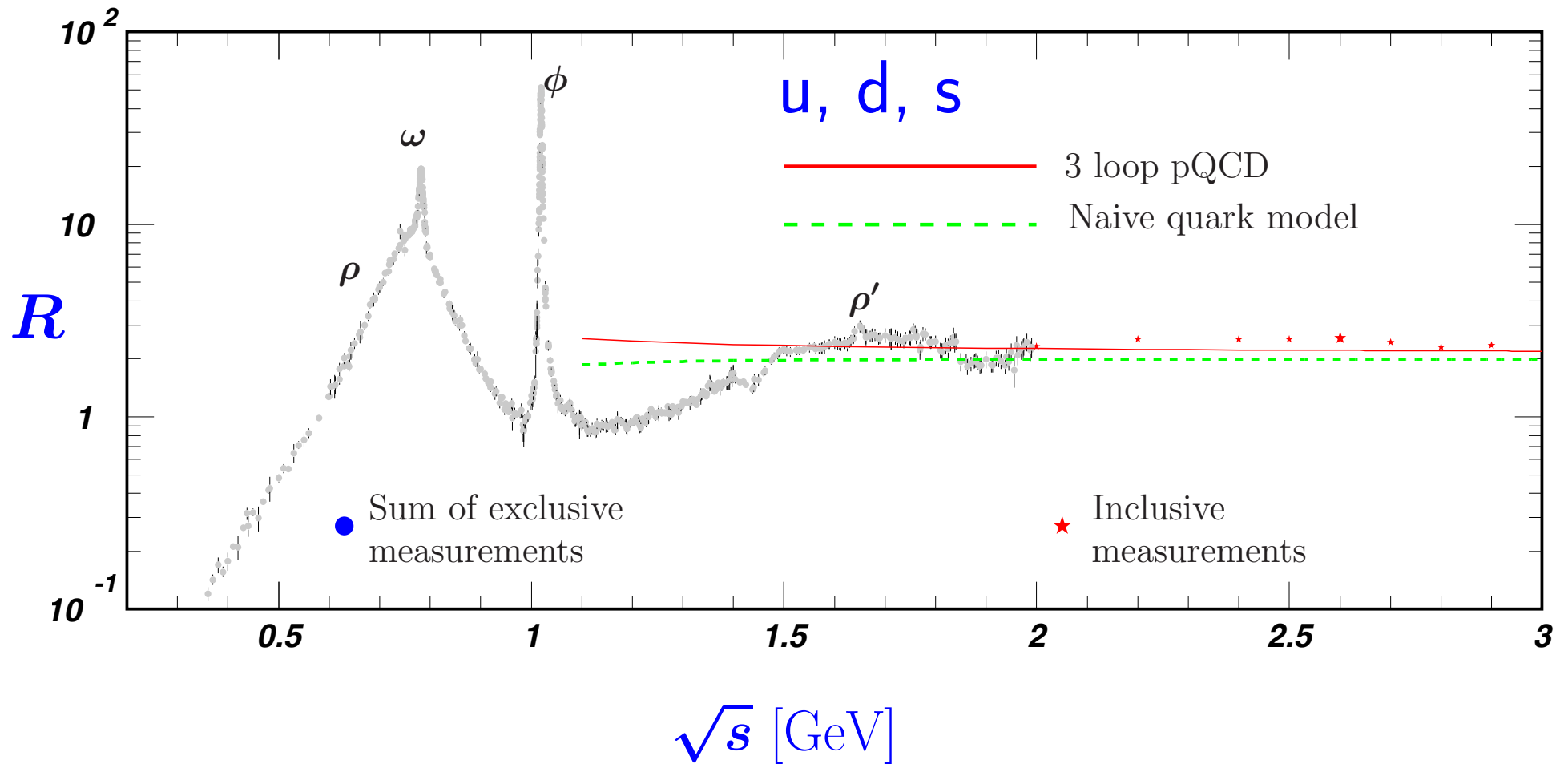
$$R_{\text{pert}} = \frac{\sigma(e^+e^- \rightarrow Z/\gamma^* \rightarrow q\bar{q})}{\sigma(e^+e^- \rightarrow \gamma^* \rightarrow \mu^+\mu^-)}$$

Dashed green: LO perturbation theory

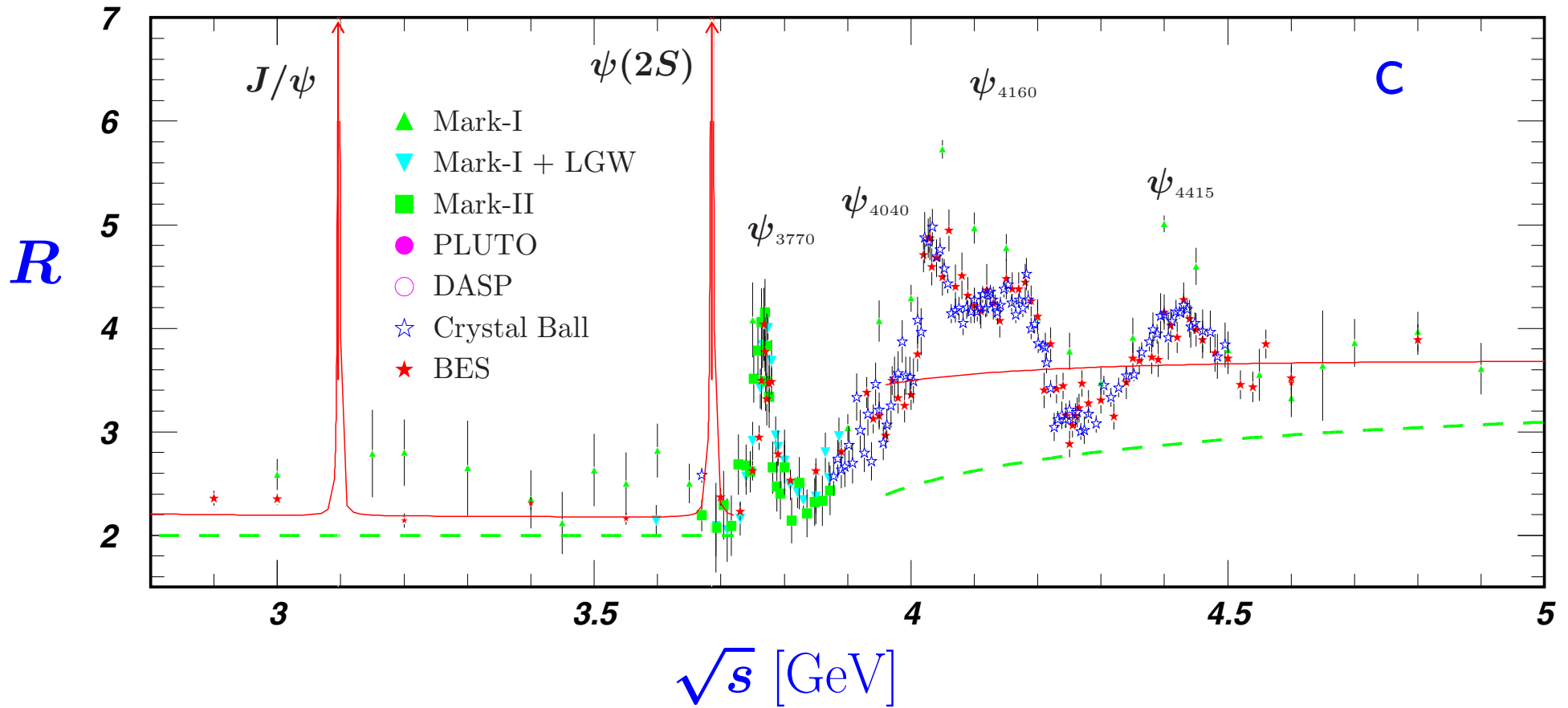
Solid red: N<sup>3</sup>LO perturbation theory

Remarkable agreement with data: asymptotic freedom

# Below charm threshold



# charm region





# b-quark threshold region

