Status of Measurement of R Value at BESIII

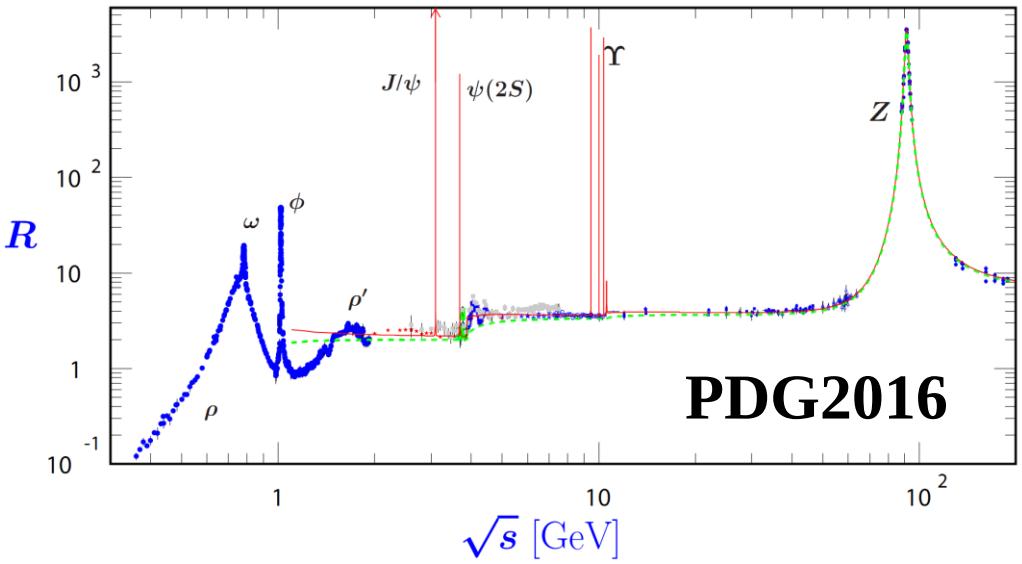
Wenbiao Yan

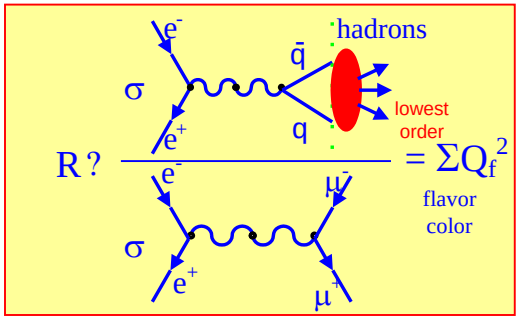
On behalf of BESIII Collaboration

R value

- **The Born cross section of e^+e^- annihilation into hadrons normalized by theoretical $\mu^+\mu^-$ cross sectiom**

$$R = \frac{\sigma^0_{had}(e^+e^- \to \gamma^* \to \text{hadrons})}{\sigma^0_{\mu\mu}(e^+e^- \to \gamma^* \to \mu^+\mu^-)}$$

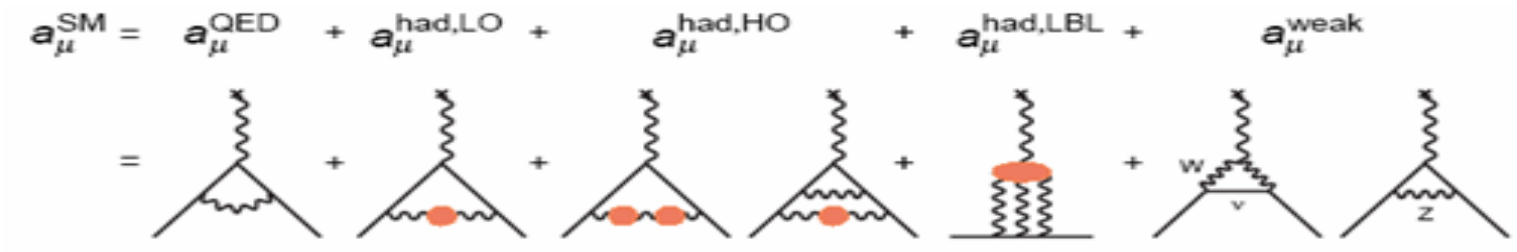




- **Precision !!!**

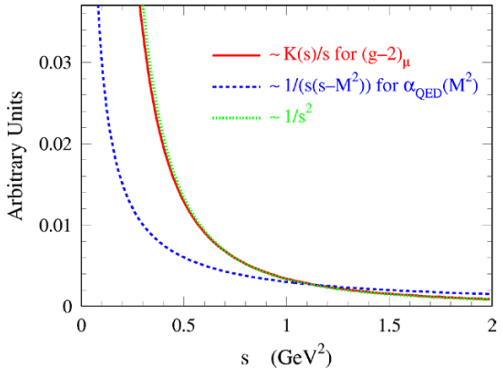
Muon magnetic moment $(g-2)_\mu$

- **The Standard Model prediction for muon $a_\mu=(g_\mu-2)/2$**



$$a_\mu^{Had}[LO] = \frac{1}{3}(\frac{\alpha}{\pi})^2 \int_{m_\pi^2}^{\infty} ds \frac{K(s)}{s} R(s)$$

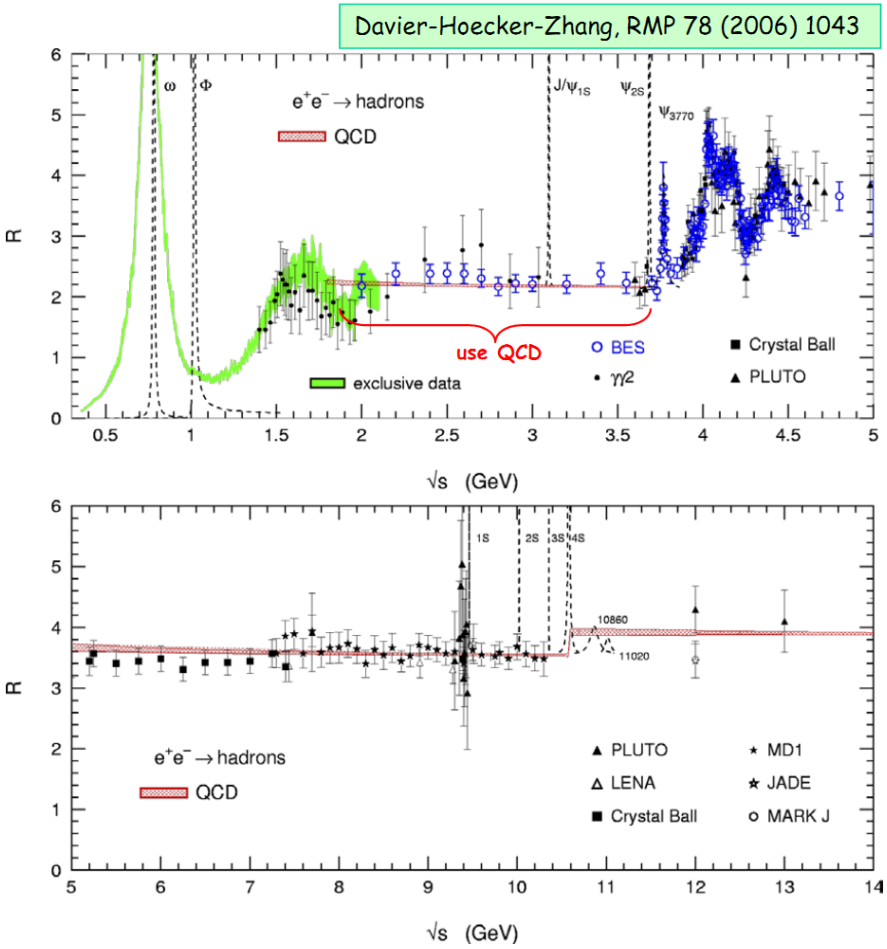
K(s): analytically known



Prof. Michel Davier @ Tau2016

QED	11658471.885	+- 0.004
EW	15.4	+- 0.1
had LBL	10.5	+- 2.6
had LO	692.8	+- 3.3
had NLO	-9.87	+- 0.09
had NNLO	1.24	+- 0.01
prediction	11659181.9	+- 4.2
exp BNL	11659208.9	+- 6.3

Muon magnetic moment $(g-2)_\mu$



Prof. Michel Davier at Tau2016

- $[\pi^0\gamma$-1.8GeV]
  - sum about 22→37 exclusive channels
  - estimate unmeasured channels using isospin relations
- [1.8-3.7] GeV
  - good agreement between data and pQCD calculation; previous extensive QCD tests with τ data
    → use 4-loop pQCD
  - J/ψ, ψ(2s): Breit-Wigner integrals
- [3.7-5] GeV
  charm particle thresholds
  → use data
- >5GeV
  use 4-loop pQCD calculation

- **BESIII: ISR and energy scan**

EM fine structure constant

- **The running of the electromagnetic fine structure constant is governed by the renormalized vacuum polarization function.**

$$\alpha(s) = \frac{\alpha(0)}{1 - \Delta\alpha_{lep}(s) - \Delta\alpha_{top}(s) - \Delta\alpha^{5}_{had}(s)}$$

$$\Delta\alpha_{lep}(M_Z^2) = 0.03142$$

$$\Delta\alpha_{top}(M_Z^2) = 0.00007(1)$$

$$\Delta\alpha^{5}_{had}(M_Z^2) = 0.0280 \pm 0.0009$$

$$\Delta\alpha^{5}_{had}(M_Z^2) = -\frac{\alpha(0)M_Z^2}{3\pi}\,\mathrm{Re}\int_{4m_\pi^2}^{\infty} ds\,\frac{R(s)}{s(s - M_Z^2) - i\varepsilon}$$

R value @ pQCD and charmonium

- **Test pQCD prediction on R values**

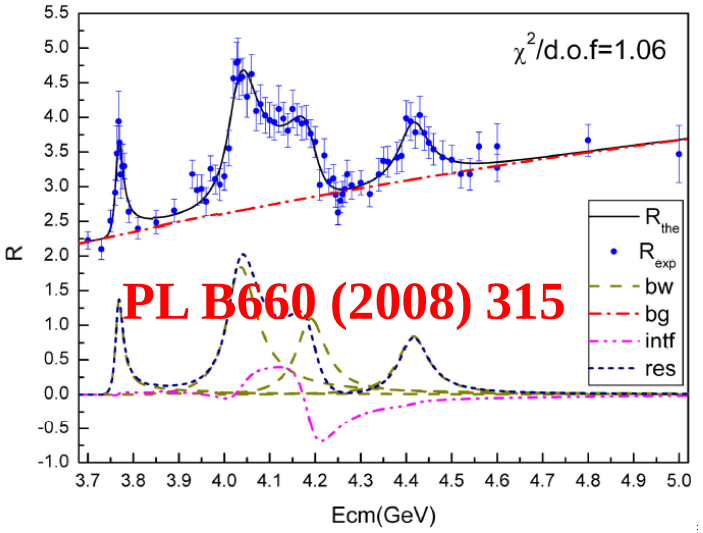
$$R = 3\sum_f Q_f^2[1 + (\frac{\alpha_s(s)}{\pi}) + 1.411(\frac{\alpha_s(s)}{\pi})^2 - 12.8(\frac{\alpha_s(s)}{\pi})^3 + ...]$$

- **Fitting to R values: resonance parameters of Ψ(3770), Ψ(4040), Ψ(4160) and Ψ(4410).**

$\psi(4040)$ $I^G(J^{PC}) = 0^-(1^{--})$

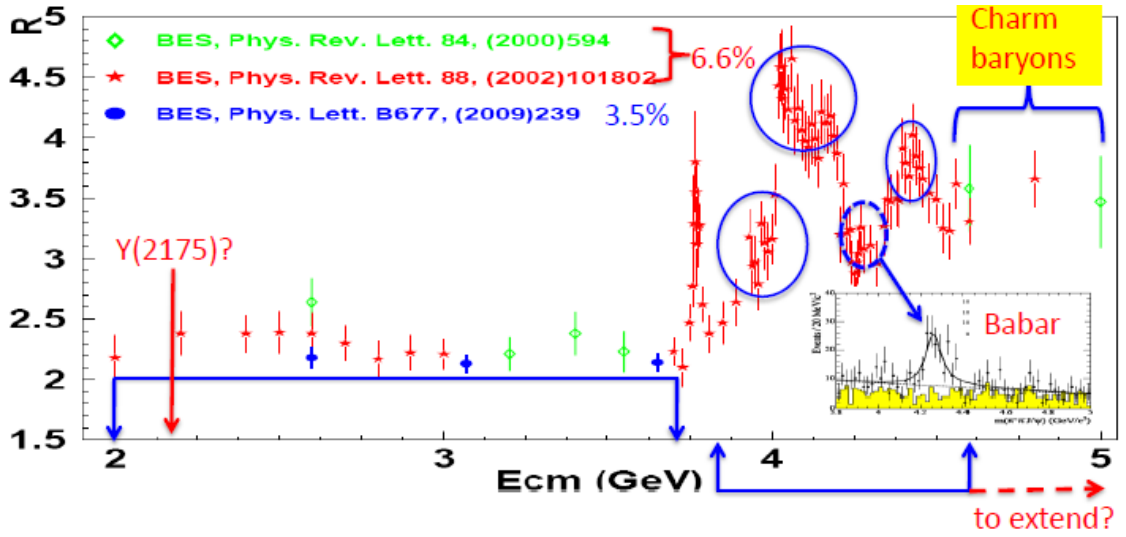
ψ(4040) MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
4039 ± 1 OUR ESTIMATE				
4039.6± 4.3	[1] ABLIKIM	08D	BES2	e^+e^- → hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •				
4034 ± 6	[2] MO	10	RVUE	e^+e^- → hadrons
4037 ± 2	[3] SETH	05A	RVUE	e^+e^- → hadrons
4040 ± 1	[4] SETH	05A	RVUE	e^+e^- → hadrons
4040 ±10	BRANDELIK	78C	DASP	e^+e^-



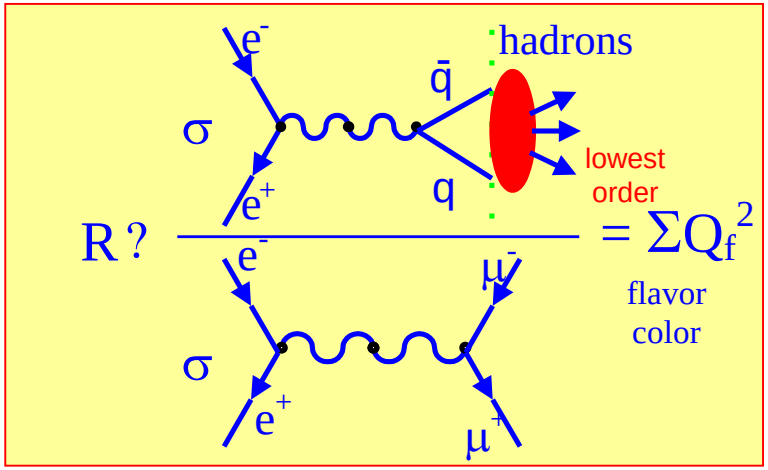
Data sets for R value

- **Phase I: test run @ 2012**
  - ✓ **Ecm = 2.232/2.400/2.800/3.400 GeV, ~12pb^{-1}**
- **Phase II: fine scan for heavy charm resonant @2013-2014**
  - ✓ **Ecm ∈ [3.800, 4.590]GeV, 104 energy points, ~800pb^{-1}**
- **Phase III: R & QCD scan @ 2015**
  - ✓ **Ecm ∈ [2.000, 3.080]GeV, 21 energy points, ~500pb^{-1}**



R value

- **R values are measured as**



$$R = \frac{1}{\sigma_{\mu+\mu-}} \cdot \frac{N_{had} - N_{bg}}{L \cdot \varepsilon_{had} \cdot (1+\delta)}$$

L **integrated luminosity**

1+δ **radiative correction factor**

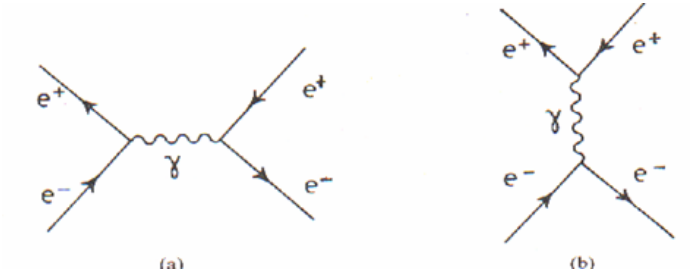
N_{had} **observed hadronic events**

N_{bg} **from background events**

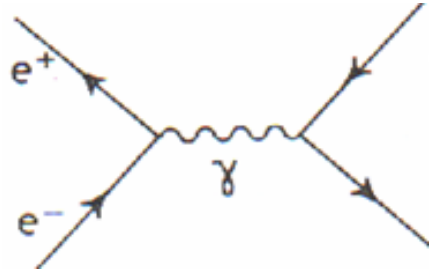
ε_{had} **selection efficiency**

$\sigma_{\mu\mu}$ **Born cross section of μ pair production in QED**

Generators @ R analysis

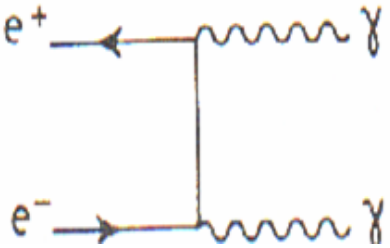


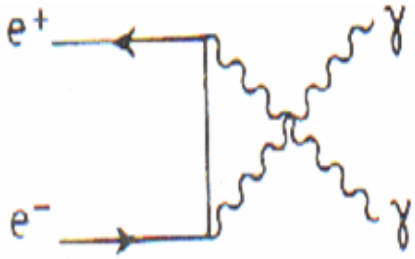
$e^+e^-\to(\gamma)e^+e^-$: **Babayaga**

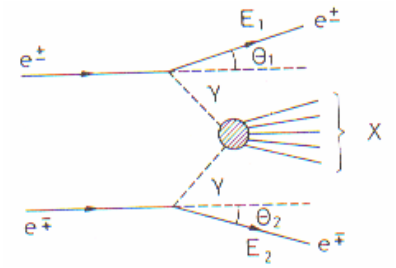


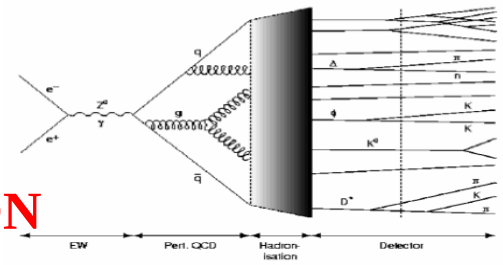
$e^+e^-\to(\gamma)\mu^+\mu^-$: **Babayaga**
$e^+e^-\to(\gamma)\tau^+\tau^-$: **KKMC**

$e^+e^-\to(\gamma)\gamma\gamma$: **Babayaga**









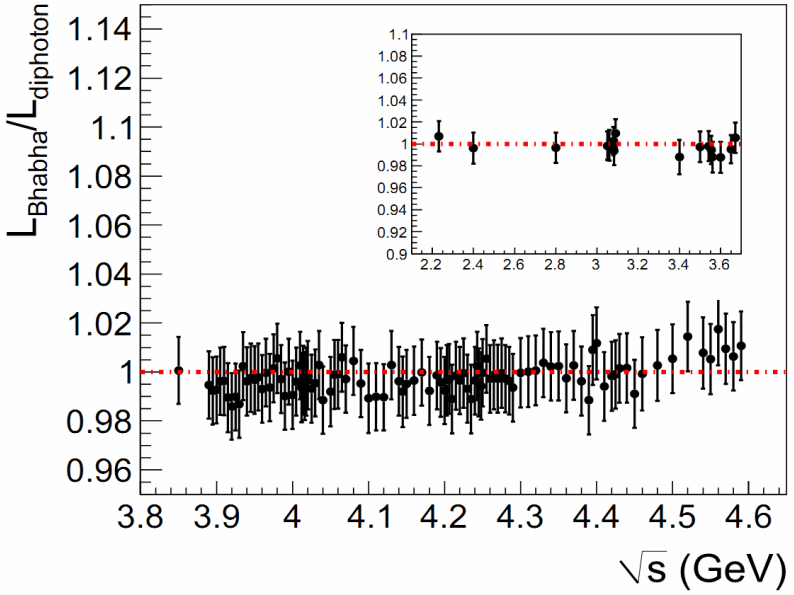
$e^+e^-\to e^+e^-X$: **TWOPHOTON**

$e^+e^-\to$**hadrons:**
ConExc & LUARLW

Luminosity

- **Large-angle Bhabha e^+e^- -> $(\gamma)e^+e^-$ and diphoton e^+e^- -> $(\gamma)\gamma\gamma$:**

about 0.8% uncertainty

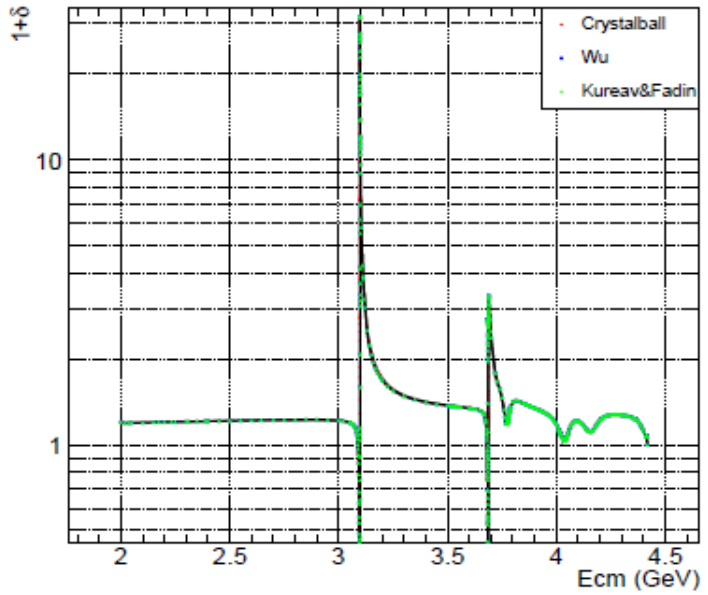


$\sqrt{s}$/GeV	$e^+e^- \to (\gamma)e^+e^-$/pb^{-1}	$e^+e^- \to (\gamma)\gamma\gamma$/pb^{-1}
2.2324	2.645±0.006±0.020	2.627±0.009±0.028
2.4000	3.415±0.007±0.024	3.428±0.011±0.040
2.8000	3.753±0.008±0.026	3.766±0.014±0.042
3.0500	14.893±0.030±0.103	14.919±0.029±0.158
3.0600	15.040±0.030±0.131	15.060±0.029±0.158
3.0800	31.019±0.060±0.189	30.942±0.044±0.338
3.0830	4.740±0.011±0.029	4.769±0.017±0.052
3.0900	15.709±0.031±0.099	15.558±0.030±0.162
3.0930	—	14.910±0.030±0.157
3.0943	—	2.143±0.011±0.023
3.0952	—	1.816±0.010±0.019
3.0958	—	2.135±0.011±0.023
3.0969	—	2.069±0.011±0.024
3.0982	—	2.203±0.011±0.023
3.0990	—	0.756±0.007±0.008

- **Chinese Physics C41 (2017) 063001**

Radiative correction factor (1+δ)

- **The Feynman diagrams scheme (CB) and structure function schemes (KF & WU) are used, results by there methods are consistent within 1.2%.**



- **R value @ PDG2016 as input**

$e^+e^- \rightarrow e^+e^- + X$

Measured quantity or reaction	Studied physical object or investigated problem	The $ee \rightarrow eeh$ cross section (cm^2) to be measured (at $\sqrt{s} \sim 5 - 10$ GeV)
$\gamma\gamma \rightarrow \pi^+\pi^-$	Threshold theorems, Born term	10^{-33}
$\pi^0\pi^0$	PCAC, current algebra	$10^{-35} - 10^{-36}$
	Two-particle unitarity approximation (Range of validity)	$10^{-34} - 10^{-35}$
	The number of essential partial waves	
	$\pi\pi$-phase and scattering lengths	$10^{-35} - 10^{-36}$
	Going out of mass shell	$10^{-35} - 10^{-36}$
	The first Weinberg sum rule	$10^{-33} - 10^{-34}$
	ϵ, f, S^*, Inelasticity	
$\gamma\gamma \rightarrow K\bar{K}$	Connection with the trace of energy-momentum tensor	
	FESR	
$\gamma\gamma \rightarrow n\pi; n > 2$	PCAC, chiral Lagrangians	$10^{-36} - 10^{-37}$
$\gamma\gamma \rightarrow \pi^0(\eta)$	π^0-lifetime	10^{-33}
	Triangle anomaly, q^2-dependence	
$\gamma\gamma \rightarrow R$	Resonance parameters (ϵ, f, A_s, etc.)	$10^{-33} - 10^{-35}$
(resonance)	Spin of X^0, E	$10^{-33} - 10^{-34}$
	FESR, symmetries	
	Parameters of A_1, etc	$\lesssim 10^{-35}$

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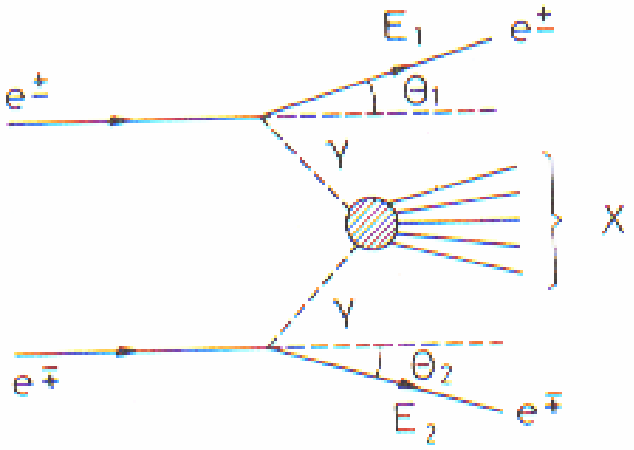
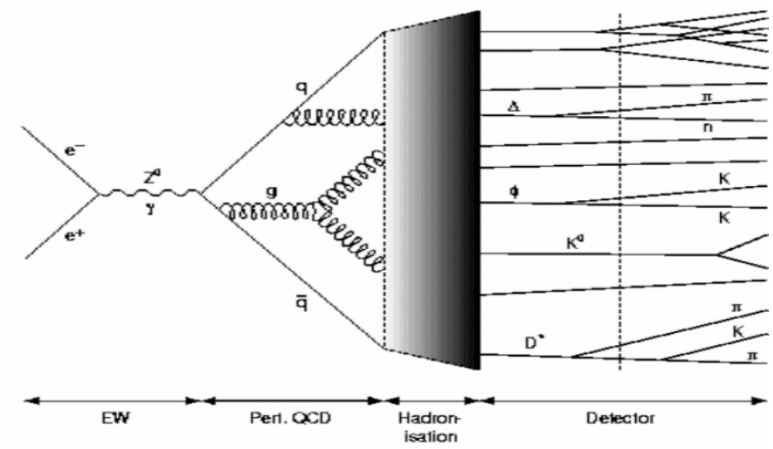
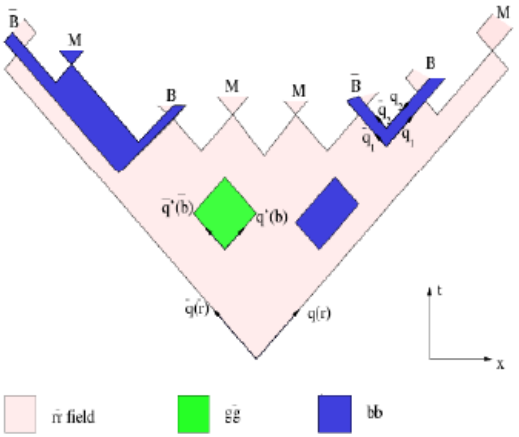


- **Background from two photon process**
  - ✓ **Underestimation by BesTwoGam MC**
  - ✓ **Use generator for (dominant) exclusive processes:**

  $e^+e^-e^+e^-$; $e^+e^-\mu^+\mu^-$; $e^+e^-\pi^+\pi^-$; $e^+e^-K^+K^-$; $e^+e^-\eta$ and $e^+e^-\eta'$
- **Other process: unclear but tiny**

MC generator for $e^+e^- \rightarrow$ hadrons

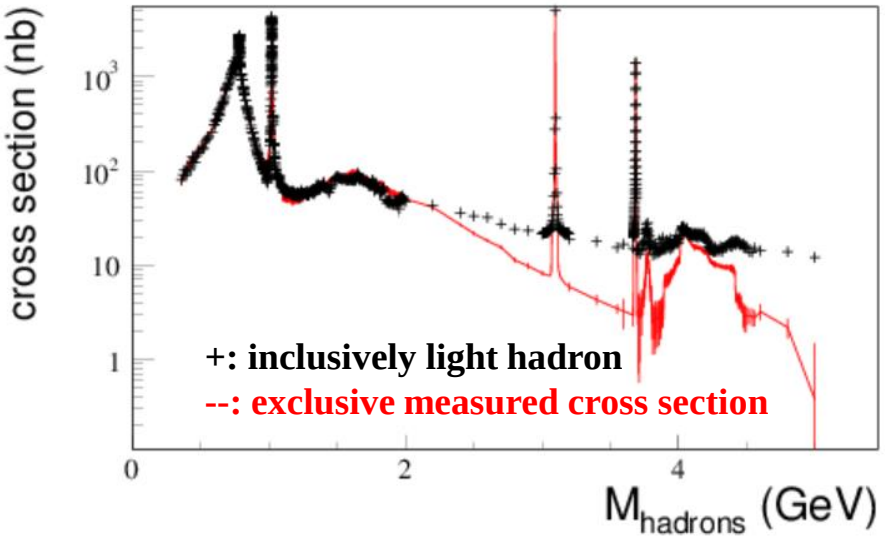




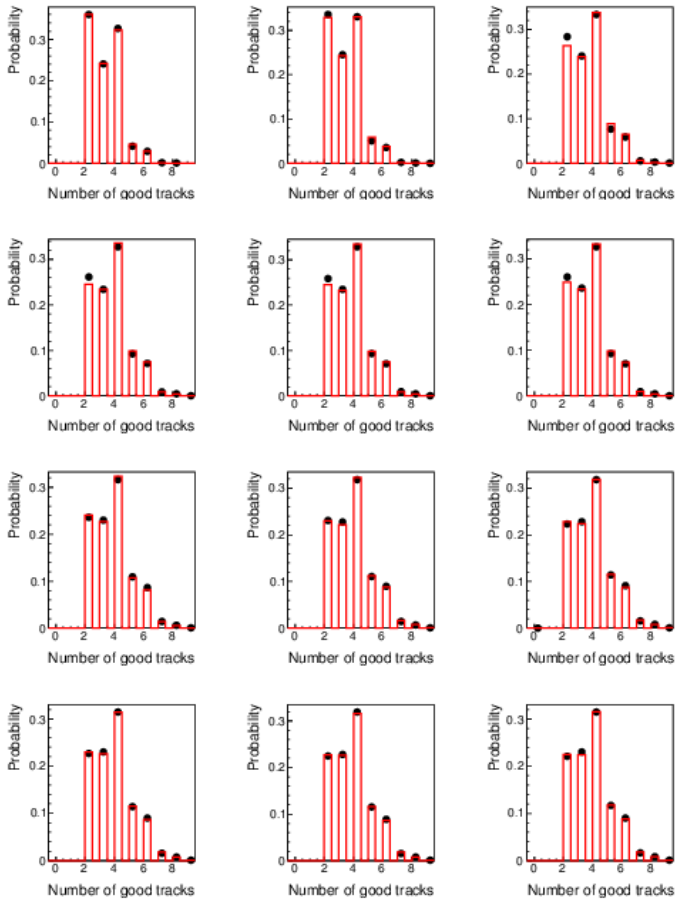
- **High energy e^+e^- collision: Herwig @ Cluster model; Jetset and Pythia @ String model**
- **Low energy e^+e^- collision: LUND Area Law, hep-ph/9910285**
  - ✓ **Simulate ISR inclusive continuous channels and $J^{PC}=1^-$ resonance between 2GeV and 5GeV. Need MC tuning**
  - ✓ **Left-right symmetry, NO**

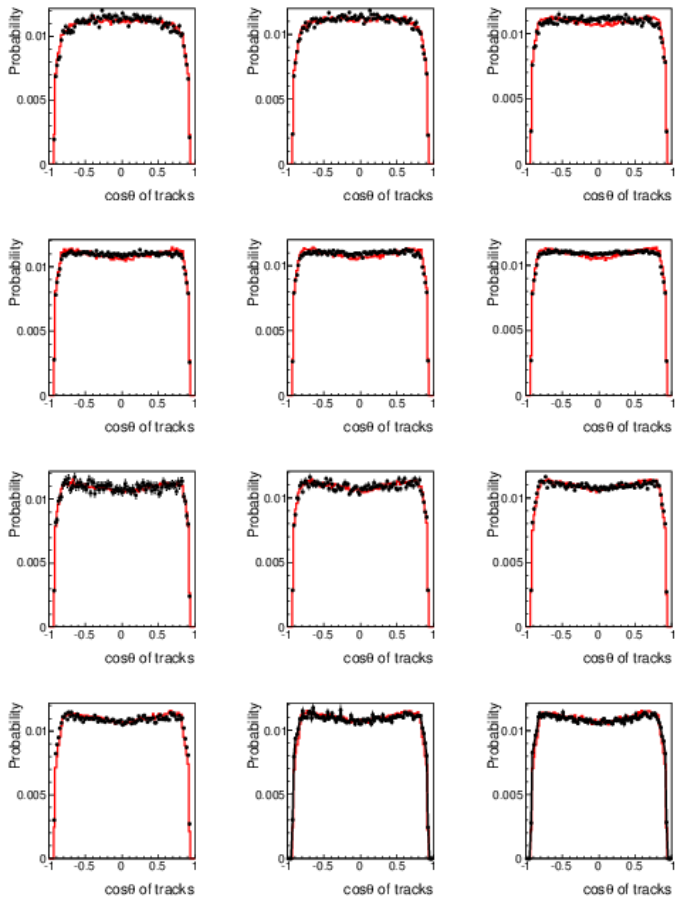
MC generator for $e^+e^- \rightarrow$ hadrons

- **LUARLW: 100% by LUARLW**
- **ConExc generator:**
  - ✓ **ConExc + Phokhara + LUARLW**
  - ✓ **Phokhara deal with 10 exclusive processes**
  - ✓ **Others measured processes with ConExc**
  - ✓ **unknown by LUNDARLW**



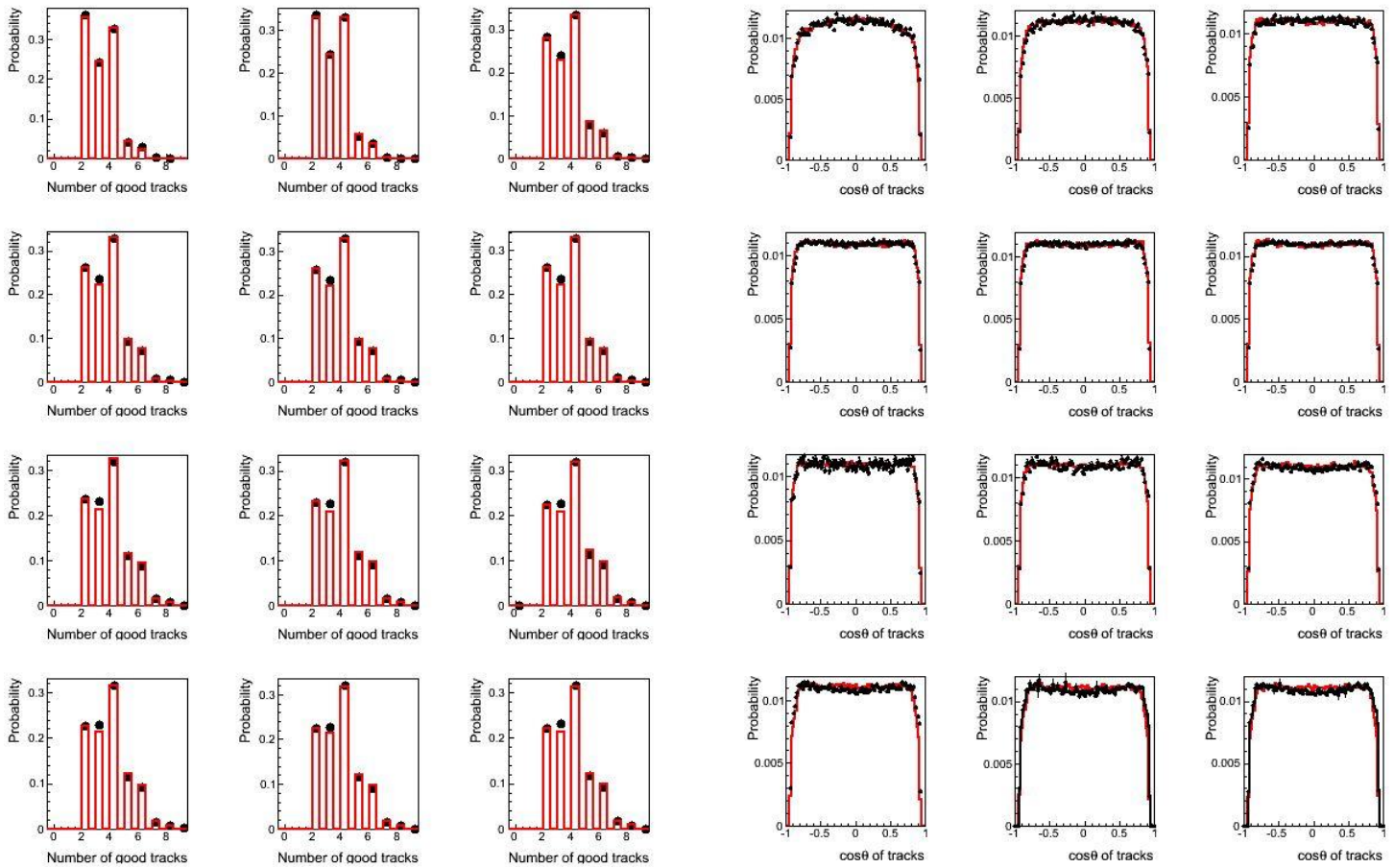
ConExc @[2.232, 3.671]GeV





- **ConExc could describe experimental data**

LUARLW @[2.232, 3.671]GeV



- **LUARLW could describe experimental data**

Status of R Measurement

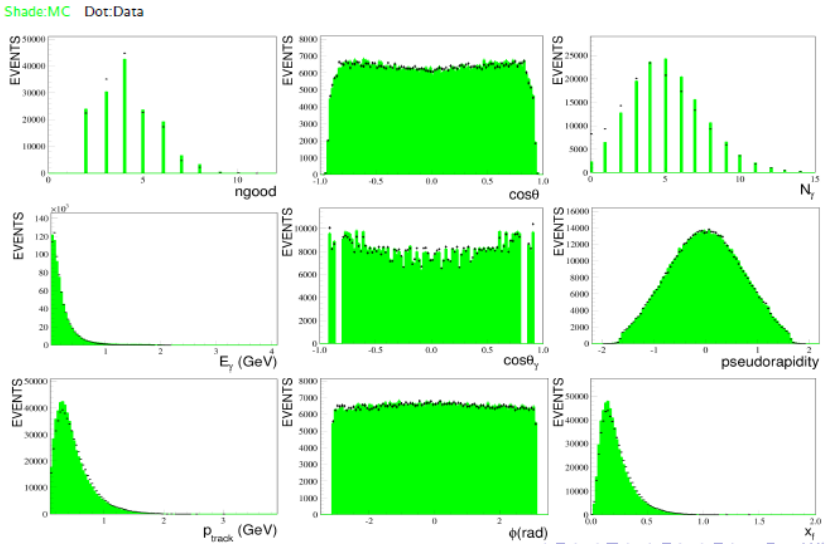
- **BESIII memo at Convener's review**

BESIII Analysis Memo

BAM-00XXX

June 13, 2017

The Measurements of R in e^+e^- Annihilation at Center-of-Mass Energy from 2.2324 to 3.6710 GeV at BESIII



- **MC tuning at [3.800, 4.590]GeV**

4.26GeV

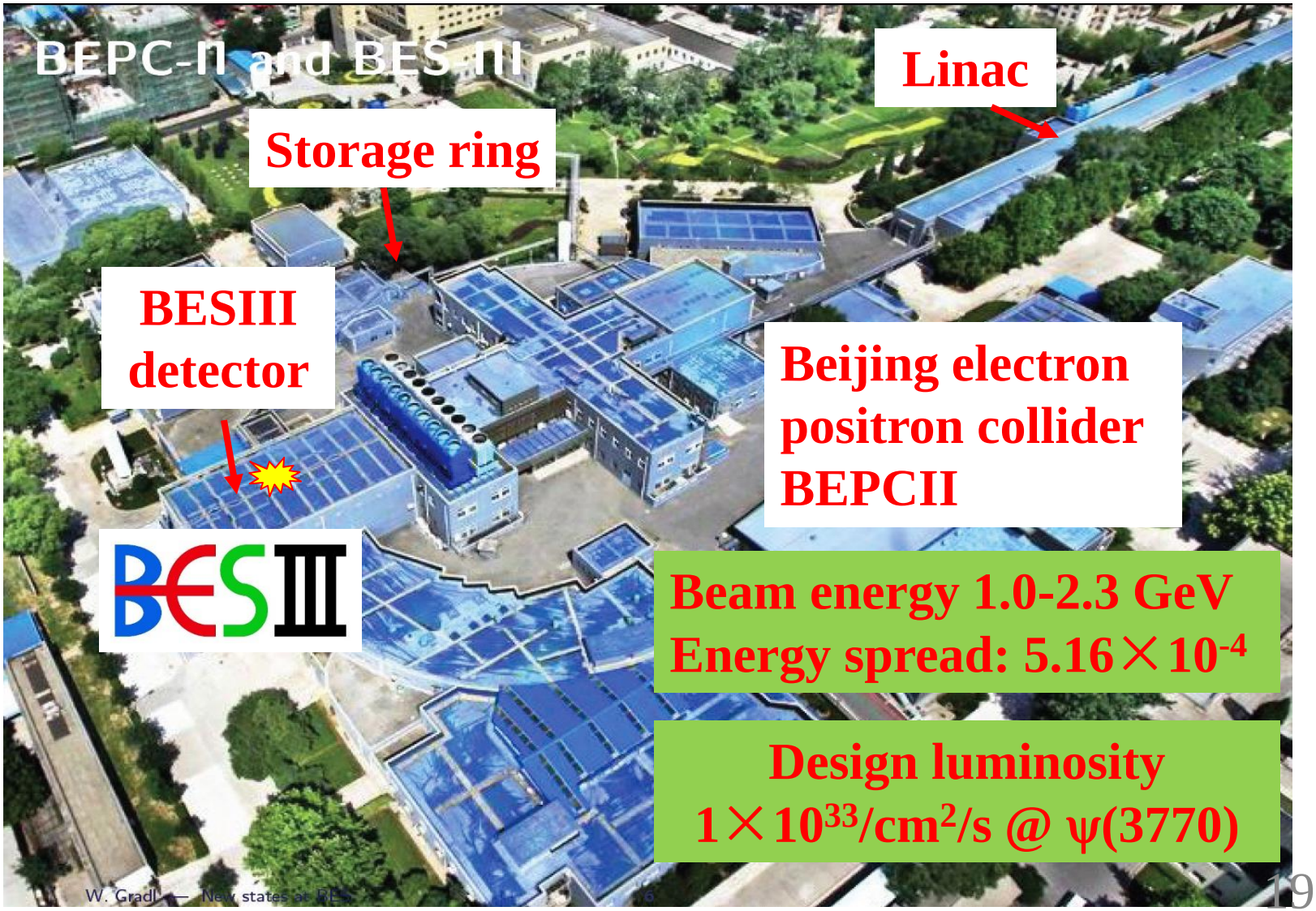
$$e^+e^- \Rightarrow \gamma^* \Rightarrow \begin{cases} \psi(4040) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s; \\ \psi(4160) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s, D_s\bar{D}_s^*; \\ \psi(4415) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s, D_s\bar{D}_s^*, D_s^*\bar{D}_s^*. \end{cases}$$

$$e^+e- \Rightarrow \gamma^* \Rightarrow X(4160), X(4260) \cdots \quad \text{with} \quad J^{PC} = 1^{--}$$

Summary

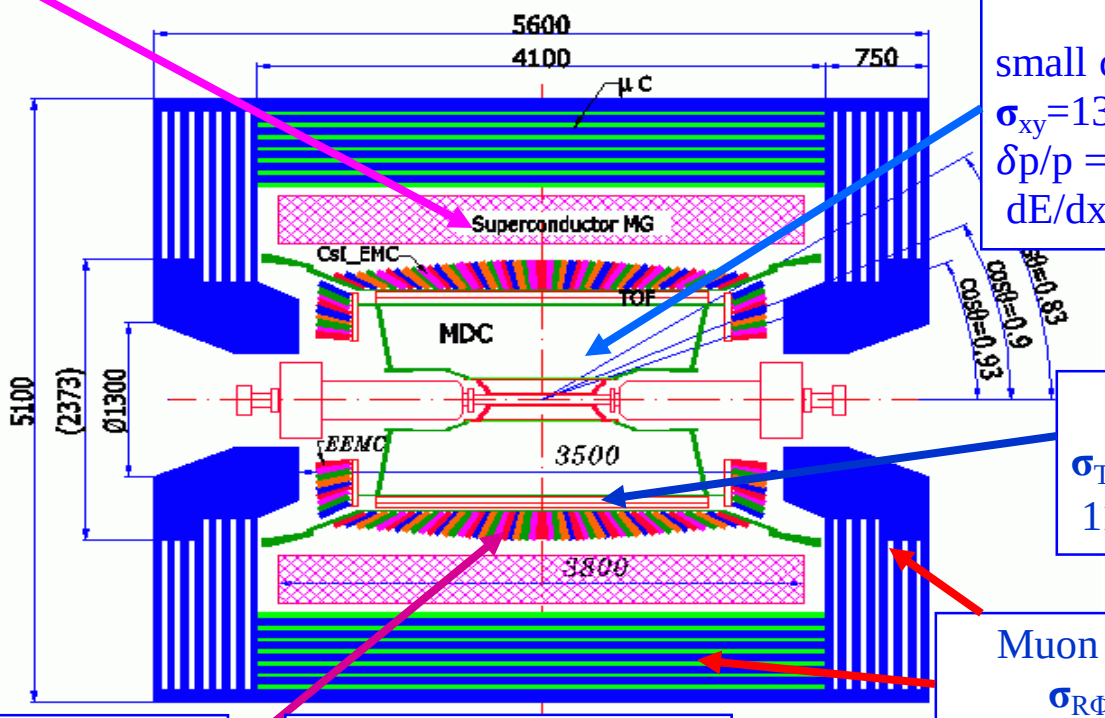
- **R values are important for $(g-2)_\mu$, $\alpha(M_z)$, $\alpha_s(s)$, and test pQCD prediction, and resonance parameters of charmonium states**
- **BESIII have collected with R scan data @ [2.0, 4.6]GeV**
- **Data analysis @ [2.232, 3.671]GeV is finished**
  - ✓ **Integrated luminosity: about 0.8% uncertainty**
  - ✓ **Radiative correction factor ($1+\delta$): 1.2% uncertainty**
  - ✓ **MC generator: ConExc and LUARLW**
- **Data analysis @ [3.800, 4.590]GeV is in progress**

Bird's View of BEPCII & BESIII



BESIII Detector

Solenoid Magnet: 1 T Super conducting



NIM A614 345 (2010)

MDC
small cell & He gas
σ_{xy}=130 μm
$\delta p/p$ = 0.5%@1GeV
dE/dx=6%

TOF
σ_T = 90 ps Barrel
110->80ps Endcap

Muon ID: 8~9 layer RPC
$\sigma_{R\Phi}$=1.4 cm~1.7 cm

EMCAL: CsI crystal
ΔE/E = 2.5% @1 GeV
$\sigma_{\varphi,z}$ = 0.5~0.7 cm/√E

Data Acquisition:
Event rate = 3 kHz
Throughput ~ 50 MB/s

Trigger: Tracks & Showers
Pipelined; Latency = 6.4 μs

Hermetic spectrometer for neutral and charged particle with excellent resolution, PID, and large coverage