BES-III Experiment

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FCPPL2009

CCNU, Wuhan

March 24, 2009

Outline

- Briefing on BEPC-II/BES-III
- Physics program at BESIII
- Detector performance check by physics channels
- Summary

Briefing on BEPCII/BESIII

Machine runs well, It is normal to take ~ 3 M $\psi(2S)$/day recently.

BESIII work well in general, most performance reach the designed values (better than low values in design).

Physics Data Taking Plan in 2009

- **March –April, one month for ψ(2S), expected hadronic events, 30 –50 M (CLEOc ~ 30 M) → 90-100 M.**

- **April – June, or 2nd half of the year, ~ two months for J/ ψ, 150-200 M events → > 250 M.**
- **Second half of 2009, another one-two months at ψ(2S), and scan ψ(3770), mainly to study ψ(3770) →non DDbar decays**

Charm productions per year at BEPCII

Average Lum: $\mathcal{L}$ = 0.5 × Peak Lum.; One year data taking: T = 10^7s

$$\sigma_{exp}(W) = \int_0^\infty dW' \sigma_{r.c.}(W') G(W', W)$$

N_{event}/year = σ_{exp} × L × T

Resonance	Mass(GeV) CMS	Peak Lum. ($10^{33}cm^{-2}s^{-1}$)	Physics Cross Section (nb)	#Nevents/year
J/ψ	3.097	0.6	3400	10×10^9
$\tau^+\tau^-$	3.670	1.0	2.4	12×10^6
$\psi(2S)$	3.686	1.0	640	3.2×10^9
D^0D^0bar	3.770	1.0	3.6	18×10^6
D^+D^-	3.770	1.0	2.8	14×10^6
DsDs	4.030	0.6	0.32	1.0×10^6
DsDs	4.170	0.6	1.0	2.0×10^6

BES-III

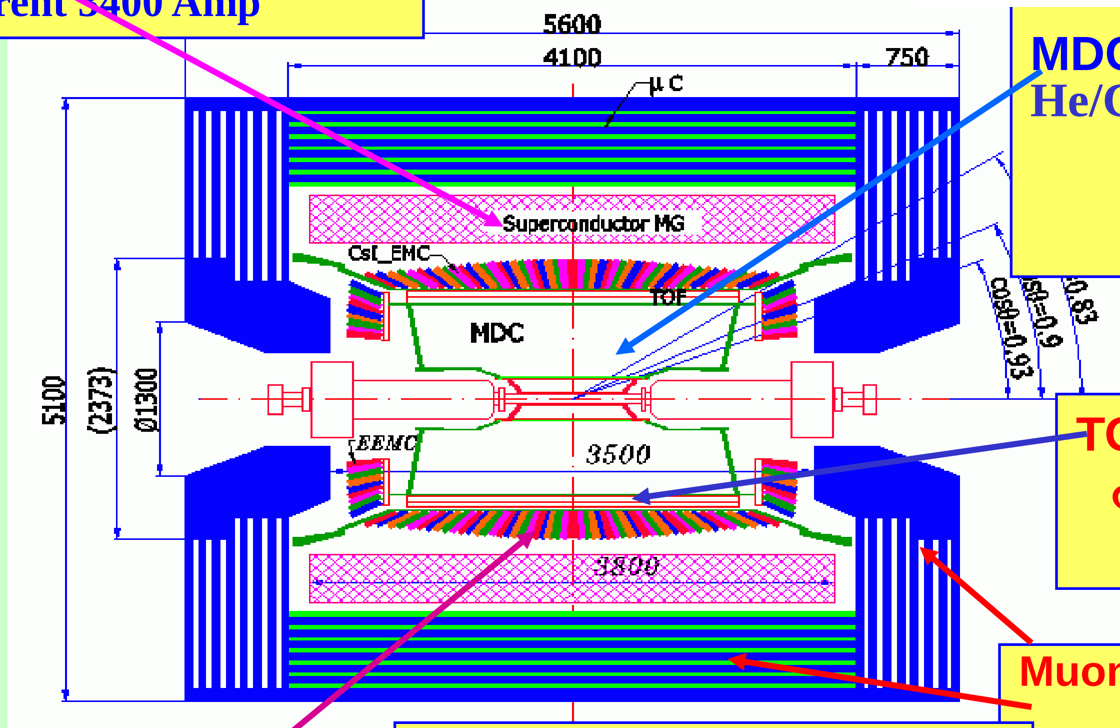
BESIII detector: all new !

CsI calorimeter

Precision tracking

Time-of-flight + dE/dx PID

Magnet: 1 T Super conducting
current 3400 Amp



MDC: small cell & Gas: He/C3H8 (60/40)
σ_{xy}=130 μm
σ_p/p = 0.5% @1GeV
dE/dx=6%

TOF:
σ_T = 100 ps Barrel
110 ps Endcap

Muon ID: 9 layers RPC
8 layers for endcap

EMC: CsI crystal
ΔE/E = 2.5% @1 GeV
σz = 0.6 cm/√E

Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s

The detector is hermetic for neutral and charged particle with excellent resolution, PID, and large coverage.

BESIII collaboration

Totally 38 institutions now

Europe (6)

- GSI, Germany
- University of Bochum, Germany
- University of Giessen, Germany
- JINR, Dubna, Russia
- Budker institute of Nuclear Physics Russia

One Italian group newly joined

USA (7)

- University of Hawaii
- University of Washington
- Carnegie Mellon University
- Univ. of Florida
- Univ. of Minnesota
- Rensselaer Polytechnic Institute
- University of Rochester

Japan (1)

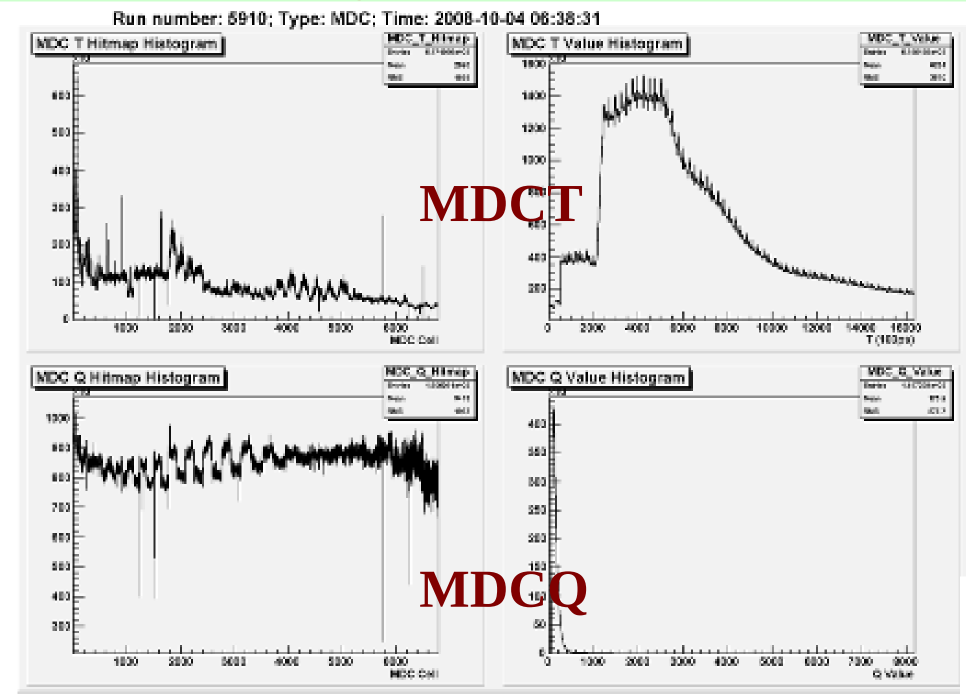
- Tokyo University

China (24)

IHEP, CCAST, GUCAS,
Univ. of Sci. and Tech. of China
Shandong Univ., Zhejiang Univ.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Hong Kong University
Chinese Univ. of Hong Kong

Physicists from France are welcome to join.

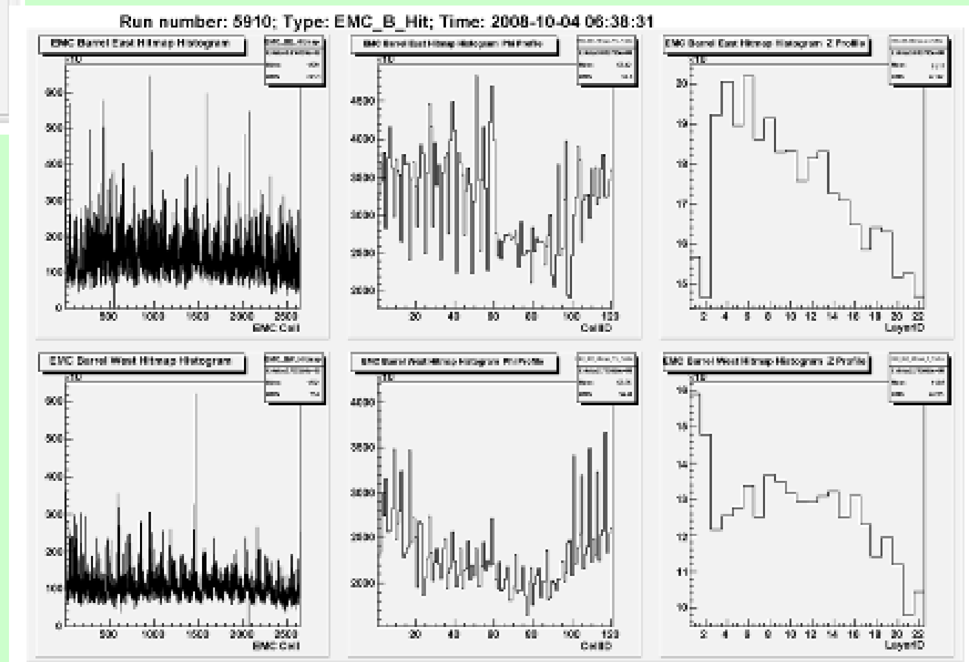
Typical online detector histograms



There are small number of dead channel in MDC.

No dead channel in EMC, a few with one photo diode reading.

EMC Barrel

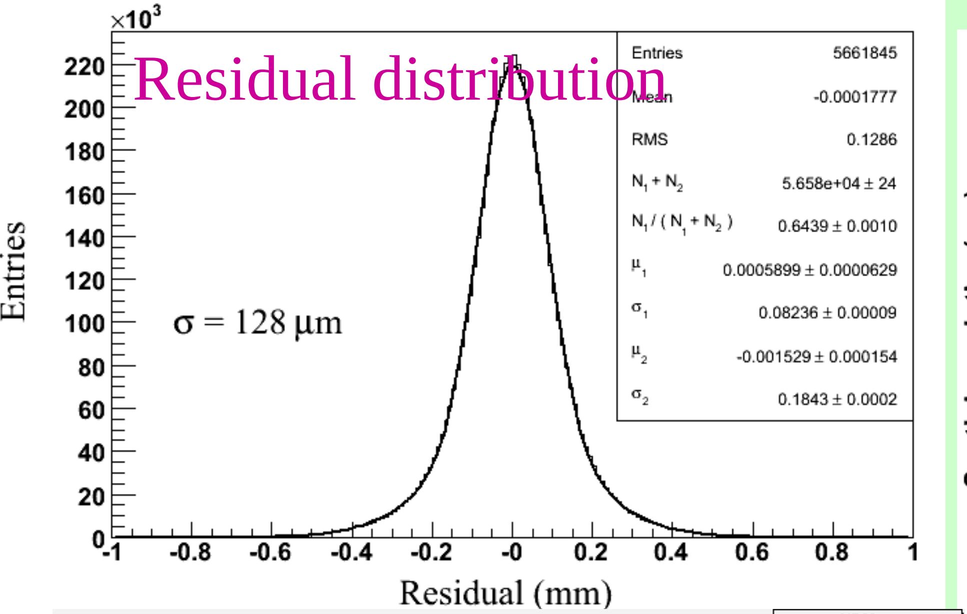


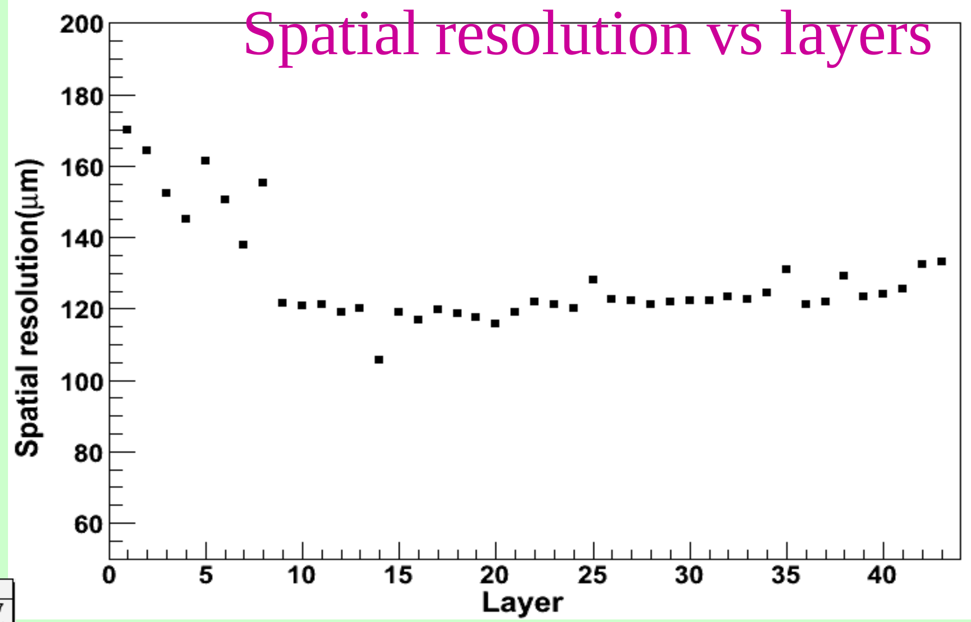
There is one dead phototube in the barrel (outer layer) TOF

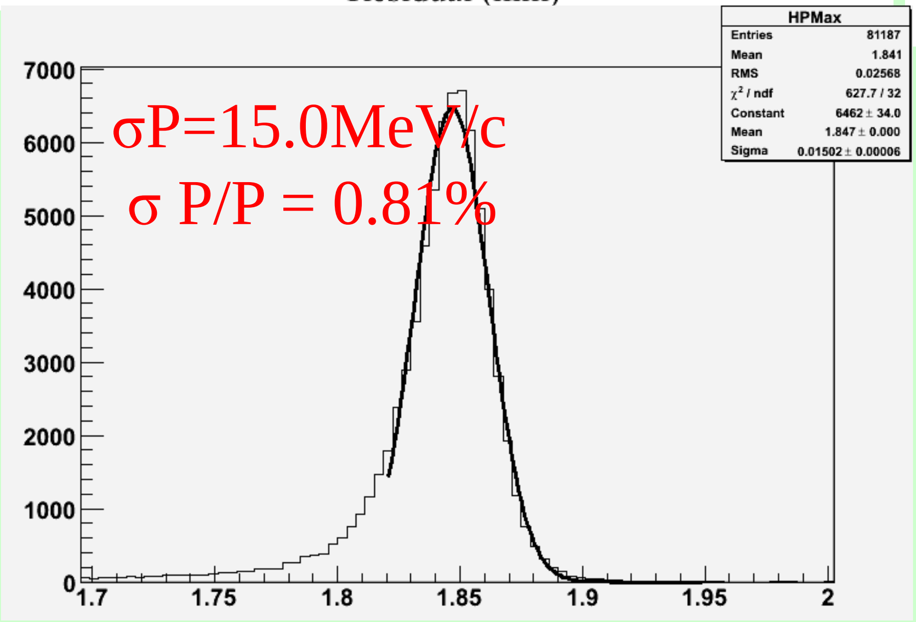
Some muon readout electronics problem in the endcap.

Try to fix in the summer.

Performance from collision data : meet design

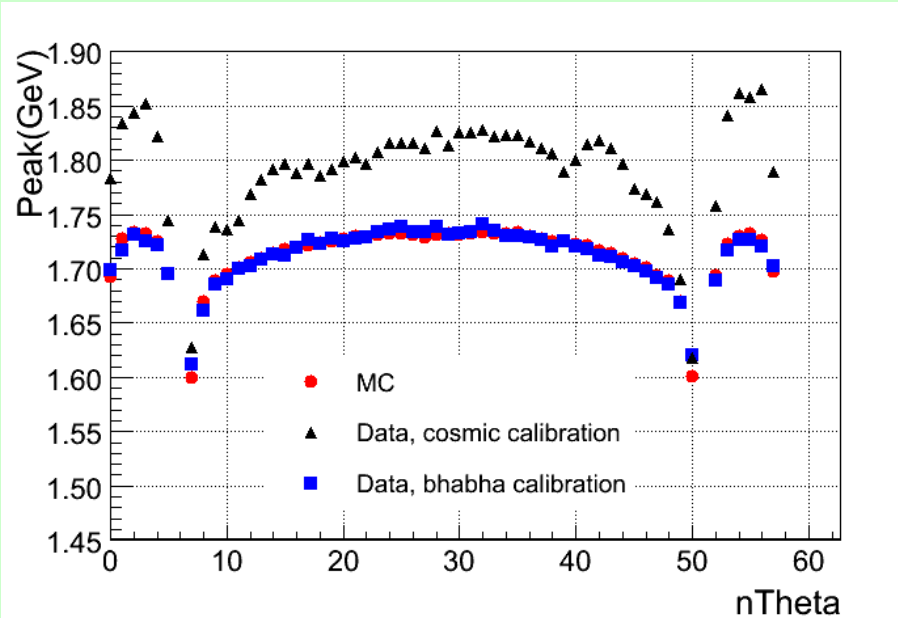


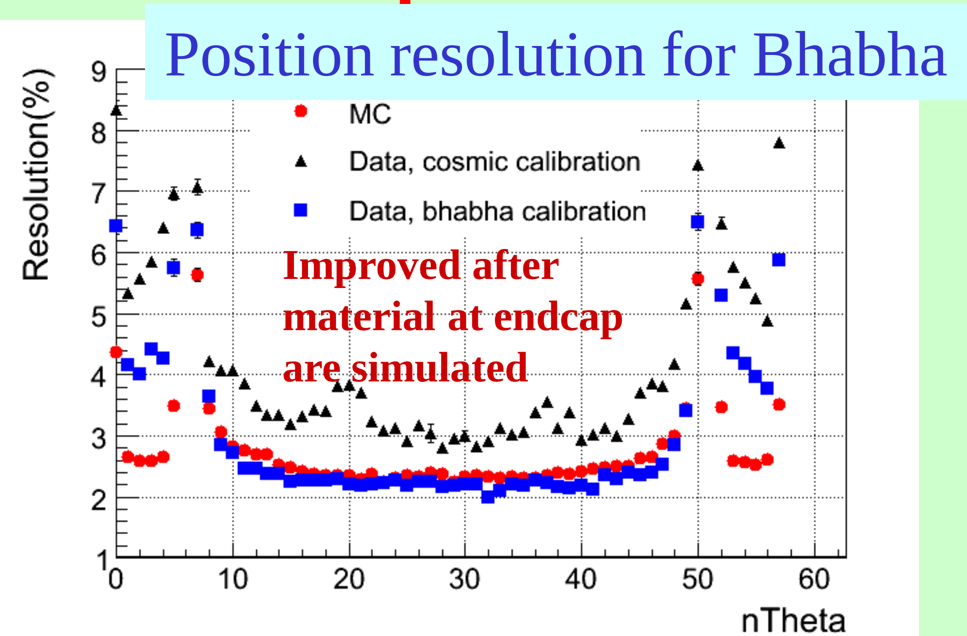


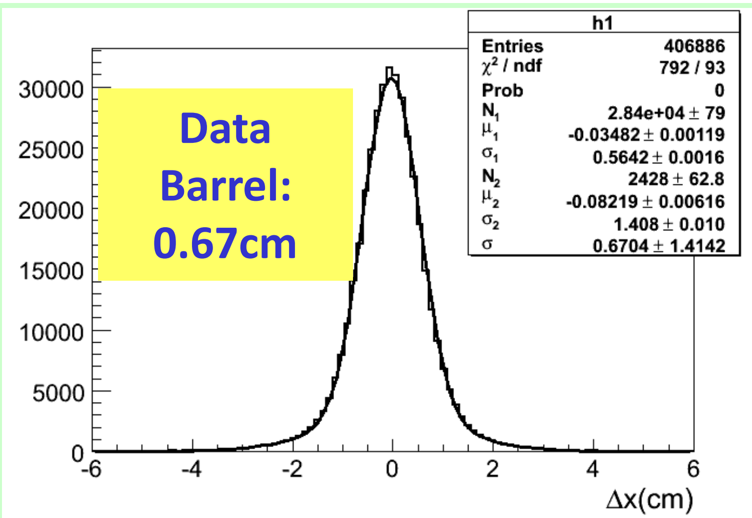


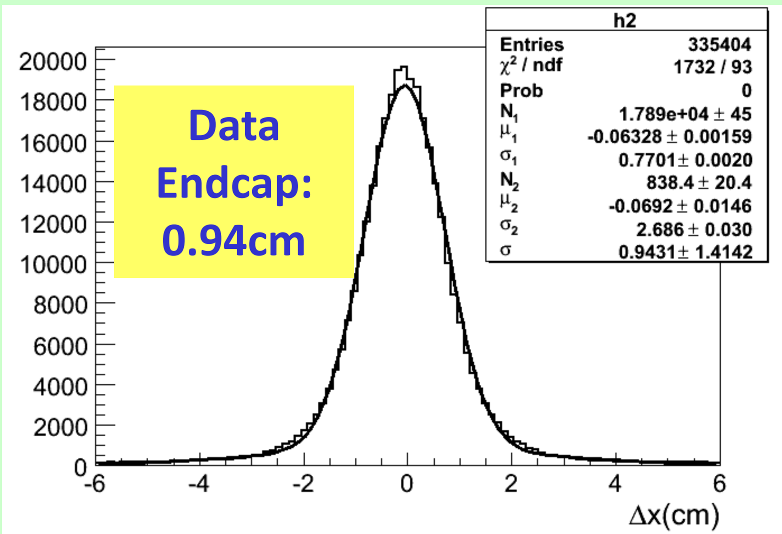
Momentum distribution of the track with the biggest momentum from BhaBha events at psi(2S)

Resolutions of barrel and endcap EMC





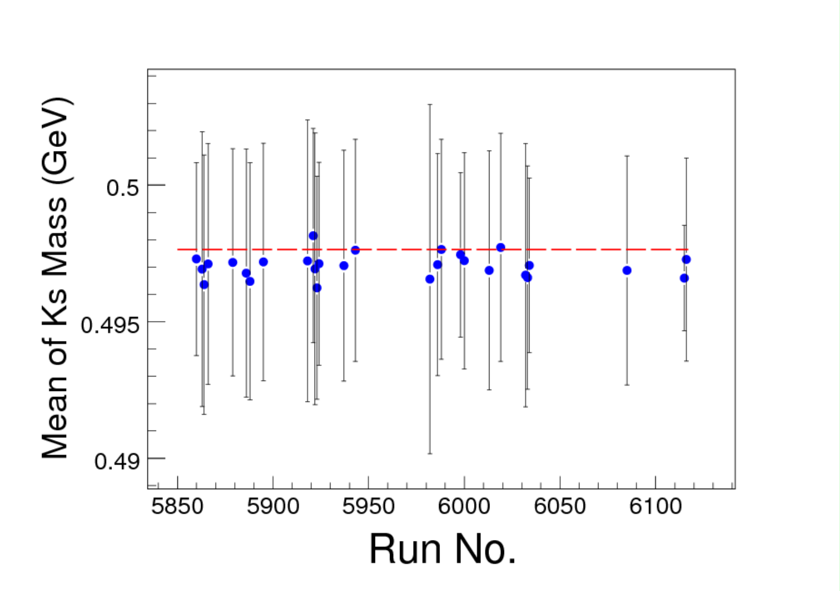


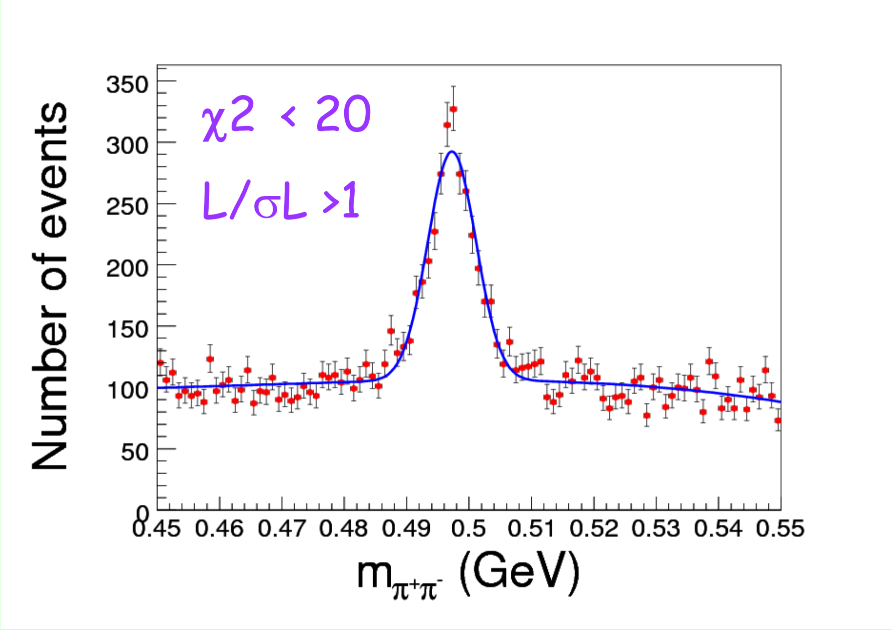


Good data/MC agreement in barrel, more calibration and MC tuning in endcap.

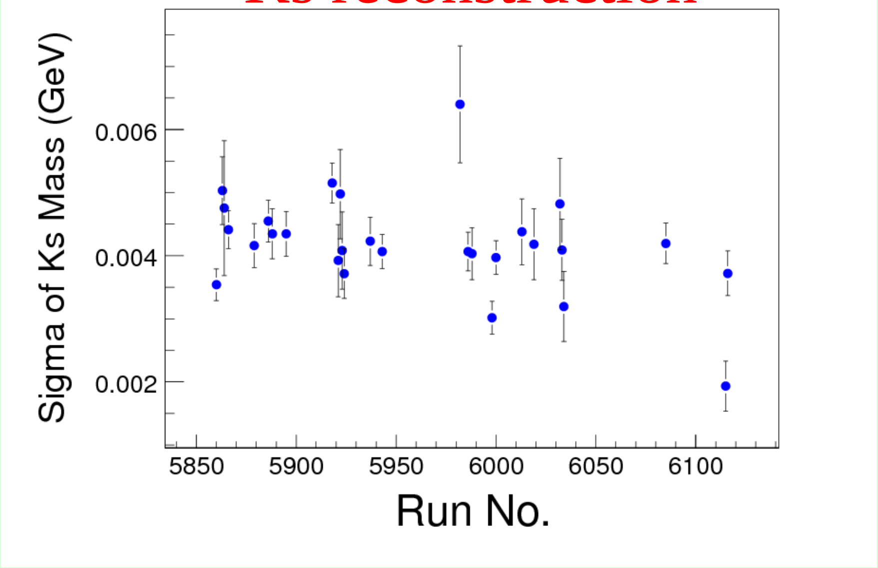
Physics analysis tools

Official particle identification
Particle lists: pion_list, Kaon_list,
Ks_list, pi0_list …
Kinematic fit
Vertex finding tools
Partial wave analysis
(FDC: feyman diagram calculations)
Dalitz plot analysis
Official D tagging algorithm (charm physics





Ks reconstruction



Main physics topics at BES-III

Main topics at BES-III

- **Light hadron spectroscopy:**
  meson, baryon, hybrid, glueball and other exotics in J/ψ and $\psi(2S)$ decays.
- **Charmonium states: $\eta_c(1S)$, $\eta_c(2S)$, J/ψ, $\psi(2S)$, χ_c, h_c,**
  $\psi(3770)$, new ccbar states above 4.0 GeV

- **Energy scan: R values, new resonances …**
- **Tau physics: precision tau mass**
- **Charm physics: D, Ds mesons**
  Leptonic Charm Decays $D \rightarrow l+\nu$
  Semileptonic decay rates & form-factors
  Charm Dalitz Decays, ……
  Charm Mixing. CP Violation and Rare charm decays …

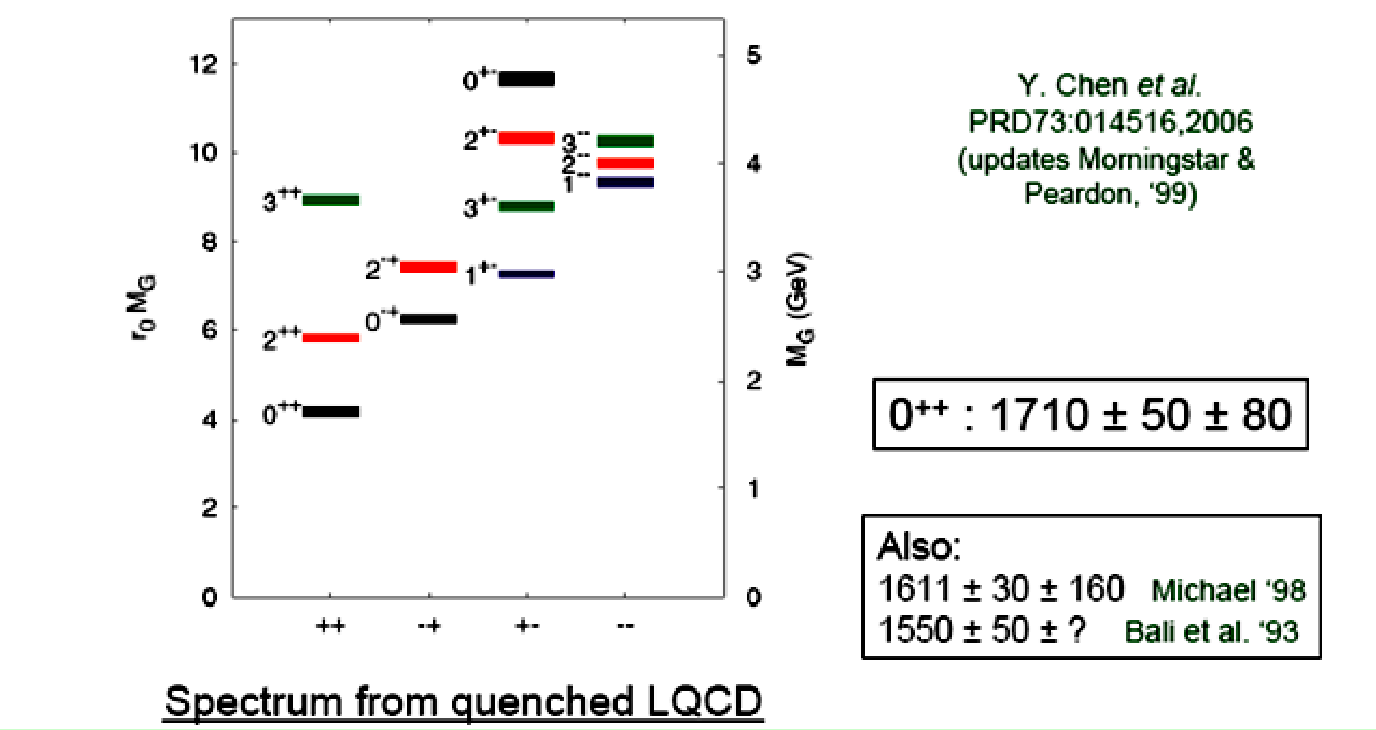
- **Rare charmonium decays:**
  LFV, invisible decays , ……

many more unexpected innovations

Light hadron spectroscopy

With 10^{10} J/ψ events with the state of art detector, we expect to learn more on:

- Baryon spectroscopy
- Glueballs
- Non-qqbar states



Spectrum of glueballs from LQCD

States with Exotic quantum number

Hybrid mesons and glueballs are always mixing with normal mesons with the same quantum numbers.
It is hard to us to separate them from normal mesons.

Quantum numbers of fermion-antifermion

1^{-+}:

$^{2s+1}L_J$		J^{PC}		Meson
$^1S_0$	$\pi\eta$ (s-wave)	0^{-+}	a_0	π
$^3S_1$	$\pi\eta$ (p-wave)	1^{--}	π_1	ρ
$^1P_1$	$\pi\eta$ (d-wave)	1^{+-}	a_2	b_1
$^3P_0$	$\pi\rho$ (p-wave)	0^{++}	π_1	a_0
$^3P_1$	πf_1 (s-wave)	1^{++}	π_1	a_1
$^3P_2$	πb_1 (s-wave)	2^{++}	π_1	a_2

Exotic quantum numbers

J^{PC}

0^{+-}

0^{--}

→ 1^{-+}

2^{+-}

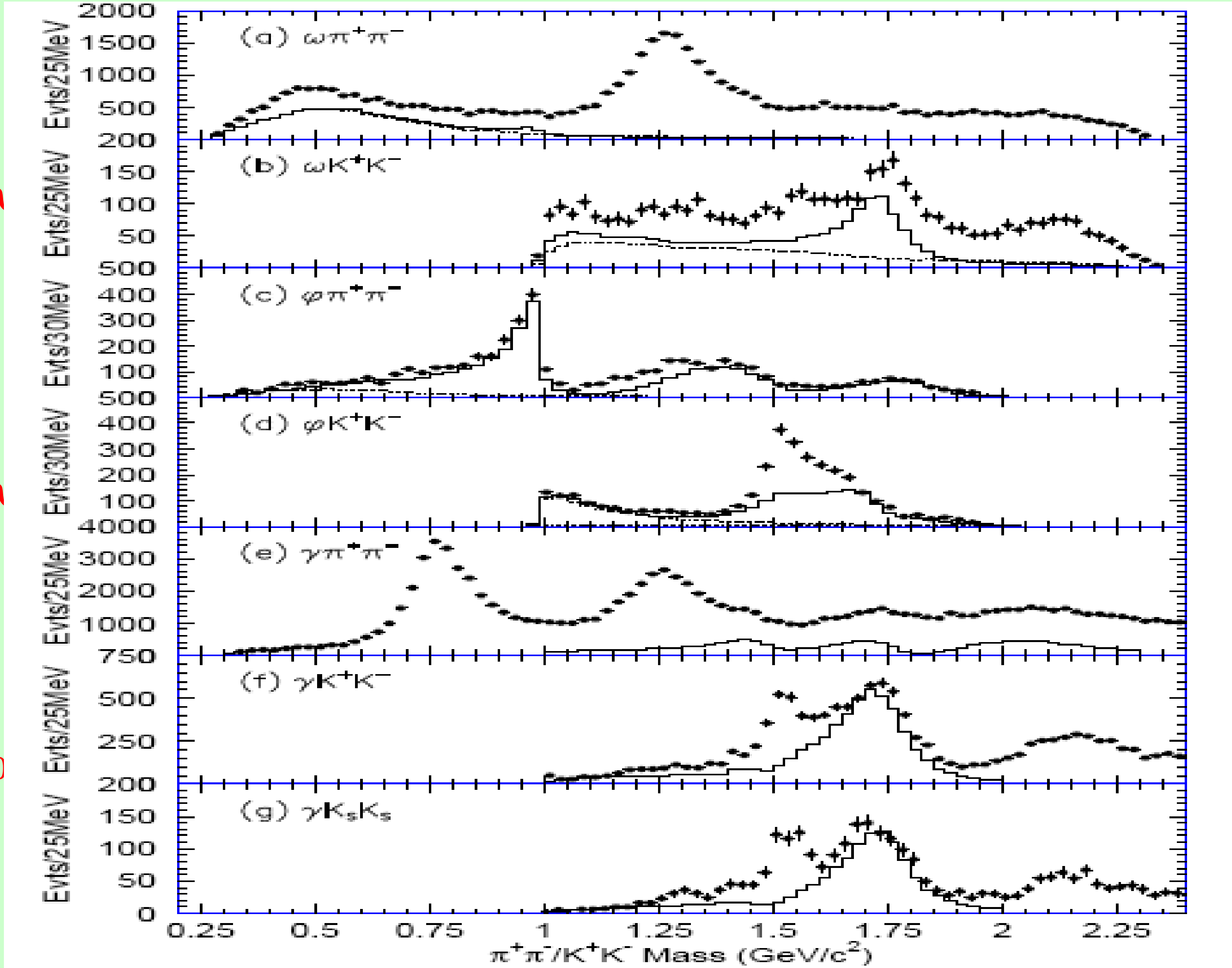
3^{-+}

0^{++} resonances at BESIII

J/

J/

χ_{c0}



Example

X(1835) at BESIII via $J/\psi \to \gamma\eta'\pi^+\pi^-, \eta' \to \eta\pi^+\pi^-$

58M J/ψ data

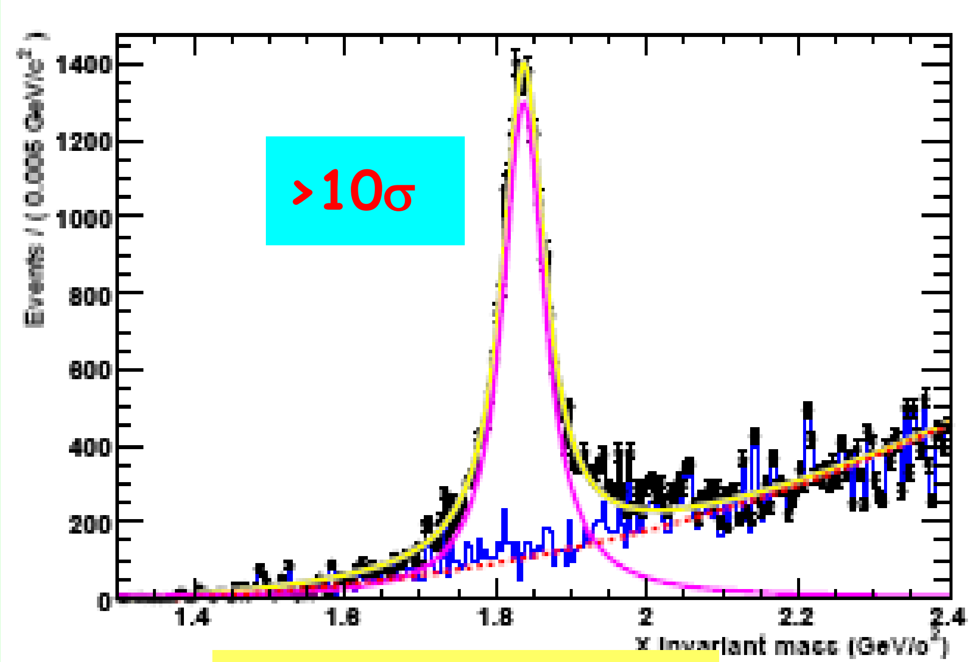
Phys.Rev.Lett.95:262001,2005

at BESIII

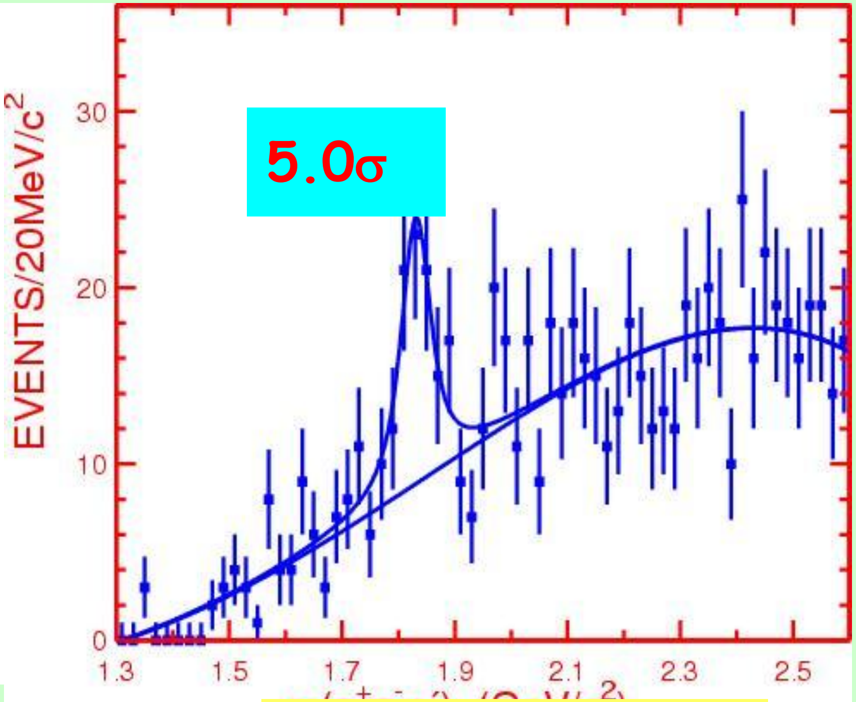
at BESII

3×10^9 J/psi events (50 times of BESII)

2 years' data taking



M(η'ππ) GeV/c²



M(η'ππ) GeV/c²

Charmonium physics in $\psi(2S)$ decays

- Understand charmonium spectroscopy and charmonium decay dynamics
  - Hadronic transition (54%)
  - Radiative transition (28%)
  - Study of spin-singlets (h_c, η_c, η_c')
  - Hadronic decays (15%)
  - Leptonic decay (2%)
  - Radiative decays (2%)
- Search for rare decays and new phenomena

3×10^9 $\psi(2S)$ events /year at BES-III

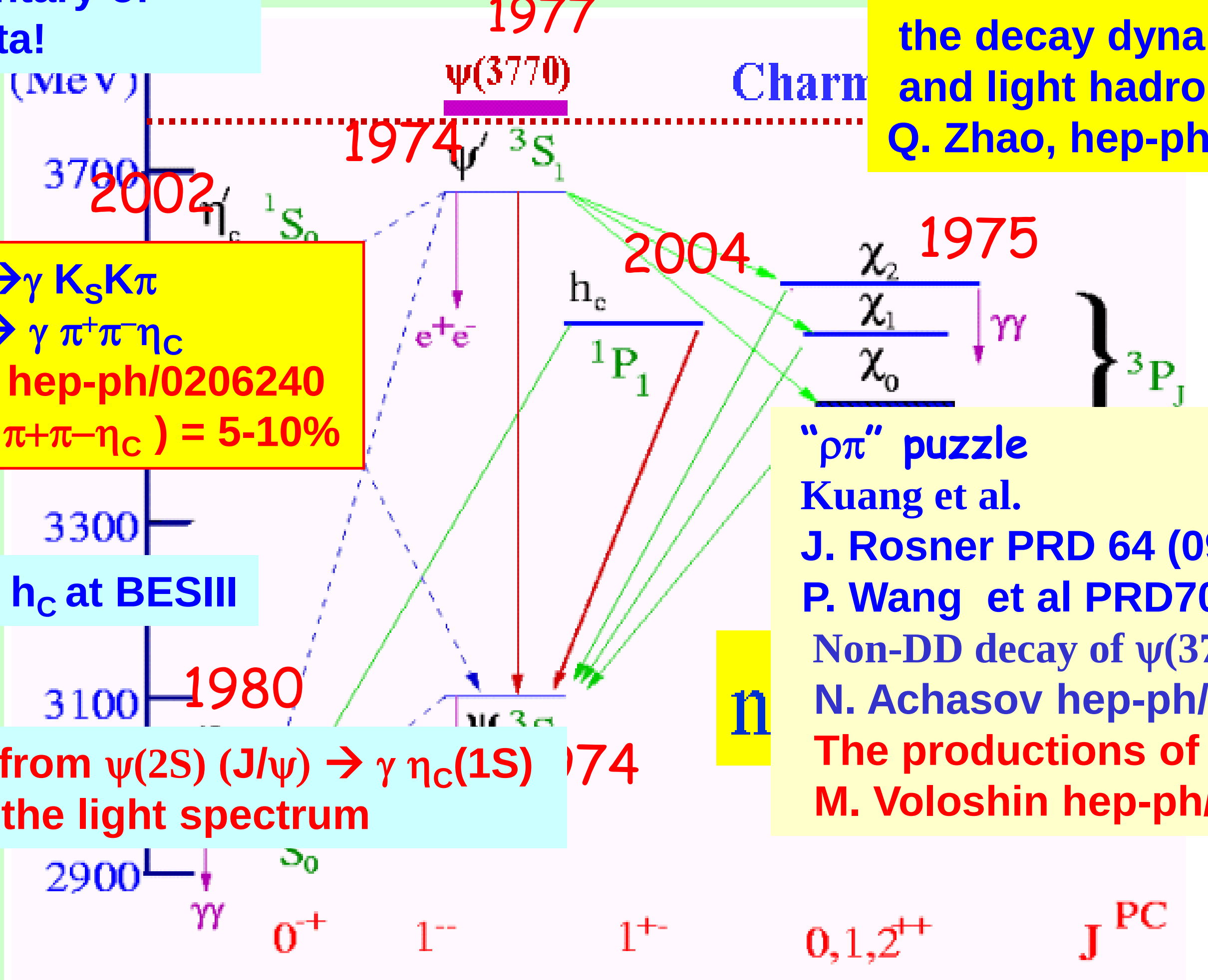
Charmonium states below open charm

What can we do with 3 billion $\psi(2S)$?

$\Psi(2S) \rightarrow \pi^+\pi^- J/\psi$ (31%)
really "pure" J/ψ sample
a complementary of
J/ψ peak data!

$\chi_{c,0,1,2}$ sample
useful to understand
the decay dynamics of ccbar
and light hadrons
Q. Zhao, hep-ph/0508086

η_c' in $\psi(2S) \rightarrow \gamma K_S K \pi$
$\psi(2S) \rightarrow \gamma \pi^+\pi^-\eta_C$
M. Voloshin hep-ph/0206240
$B(\eta_C(2S) \rightarrow \pi^+\pi^-\eta_C) = 5\text{-}10\%$



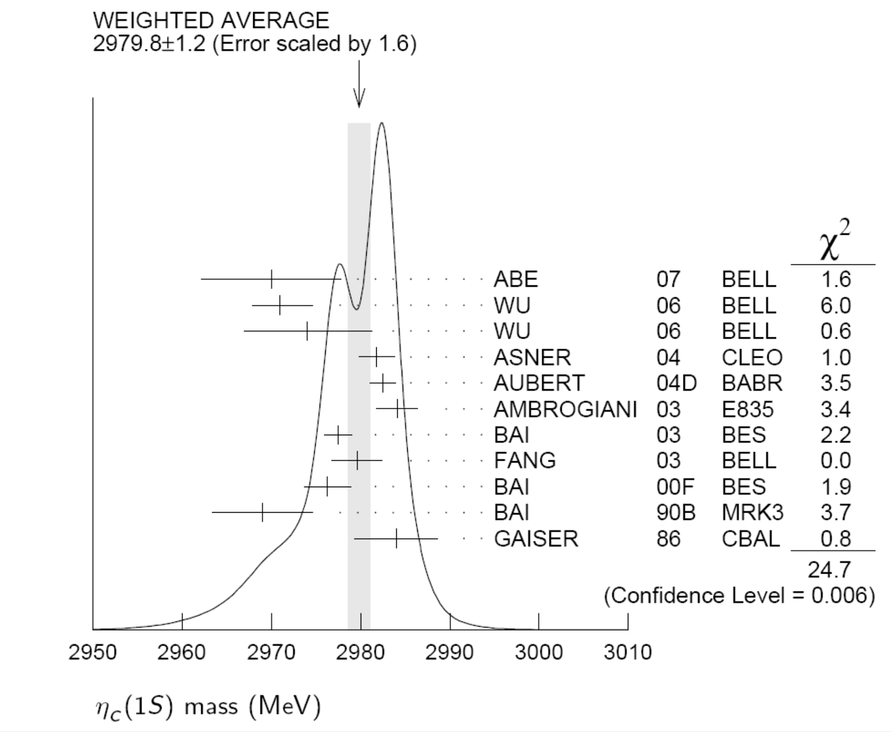
Detail study of h_C at BESIII

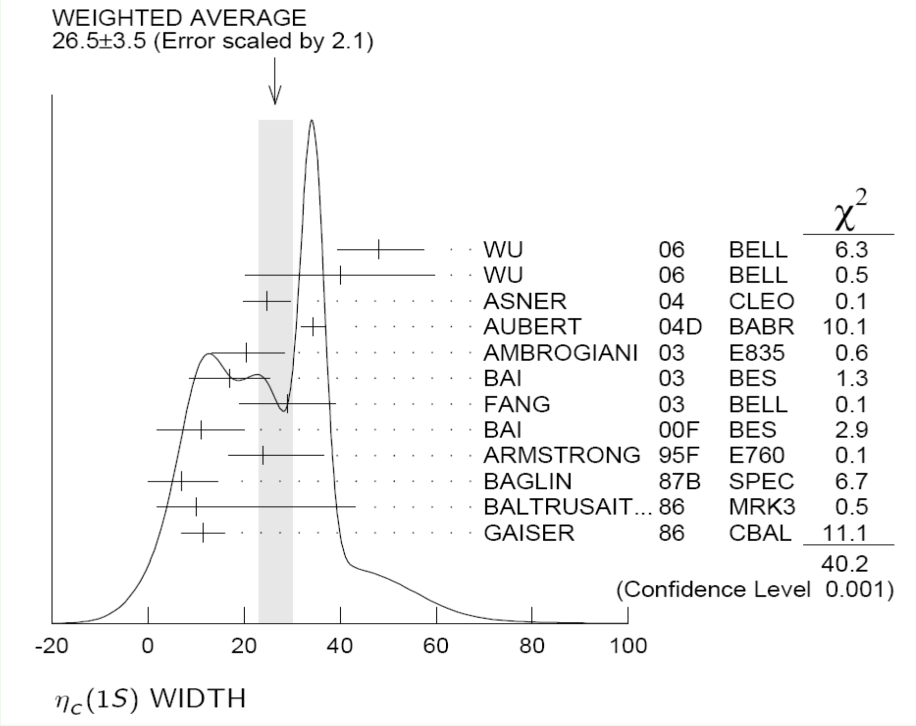
"$\rho\pi$" puzzle
Kuang et al.
J. Rosner PRD 64 (094002) 2001
P. Wang et al PRD70(114014)2004
Non-DD decay of $\psi(3770)$:
N. Achasov hep-ph/0505146
The productions of D^0D^0, D^+D^-
M. Voloshin hep-ph/0402171

$\eta_C(1S)$ sample from $\psi(2S)$ (J/ψ) $\rightarrow \gamma\, \eta_C(1S)$
used to study the light spectrum

A lab of η_C (0^{-+}) and $\chi_{C\{0,1,2\}}$

- η_C is not well measured :
  65 million η_C sample from 10^{10} J/psi decay at BES-III
- Mass/width spread in wide range





η_C is not well measured

Decays involving hadronic resonances

Γ_1	$\eta'(958)\pi\pi$	(4.1 ± 1.7) %	
Γ_2	$\rho\rho$	(2.0 ± 0.7) %	
Γ_3	$K^*(892)^0 K^- \pi^+ +$ c.c.	(2.0 ± 0.7) %	
Γ_4	$K^*(892)\overline{K}^*(892)$	$(9.2 \pm 3.4) \times 10^{-3}$	
Γ_5	$K^{*0}\overline{K}^{*0}\pi^+\pi^-$	(1.5 ±0.[illegible]) %	
Γ_6	$\phi K^+ K^-$	(2.9 [illegible] $\times 10^{-3}$	
Γ_7	$\phi\phi$	(2.[illegible] $\times 10^{-3}$	
Γ_8	$\phi 2(\pi^+\pi^-)$	< [illegible] $\times 10^{-3}$	90%
Γ_9	$a_0(980)\pi$	[illegible] %	90%
Γ_{10}	$a_2(1320)\pi$	[illegible] %	90%
Γ_{11}	$K^*(892)\overline{K} +$ c.c.	[illegible] 1.28 %	90%
Γ_{12}	$f_2(1270)\eta$	< 1.1 %	90%
Γ_{13}	$\omega\omega$	$< 3.1 \times 10^{-3}$	90%
Γ_{14}	$\omega\phi$	$< 1.7 \times 10^{-3}$	90%
Γ_{15}	$f_2(1270)f_2(1270)$	$(1.0 ^{+0.4}_{-0.5})$ %	

[illegible]ys into stable hadrons

Γ_{16}	$K\overline{K}\pi$	(7.0 ± 1.2) %	
Γ_{17}	$\eta\pi\pi$	(4.9 ± 1.8) %	
Γ_{18}	$\pi^+\pi^-$ [illegible]	(1.5 ± 0.6) %	
Γ_{19}	$K^+K^-2($[illegible]$\pi^-)$	$(10 \pm 4) \times 10^{-3}$	
Γ_{20}	$2(K^+K^-)$	$(1.5 \pm 0.7) \times 10^{-3}$	
Γ_{21}	$2(\pi^+\pi^-)$	(1.20 ± 0.30) %	
Γ_{22}	$3(\pi^+\pi^-)$	(2.0 ± 0.7) %	
Γ_{23}	$p\overline{p}$	$(1.3 \pm 0.4) \times 10^{-3}$	
Γ_{24}	$\Lambda\overline{\Lambda}$	$(1.04 \pm 0.31) \times 10^{-3}$	
Γ_{25}	$K\overline{K}\eta$	< 3.1 %	90%
Γ_{26}	$\pi^+\pi^- p\overline{p}$	< 1.2 %	90%

Radiative decays

Γ_{27}	$\gamma\gamma$	$(2.7 \pm 0.9) \times 10^{-4}$	

Less than 30% of decay modes

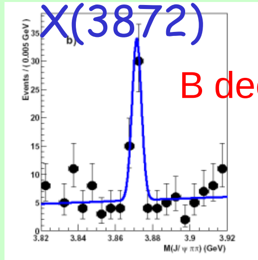
- Only a few final states observed
  - ηππ
  - η'ππ
  - KKπ
  - ππ ππ
  - ππ KK
  - ππ ππ ππ
  - ππ ππ KK
  - KK KK
  - ppbar
  - ΛΛbar
  - γγ

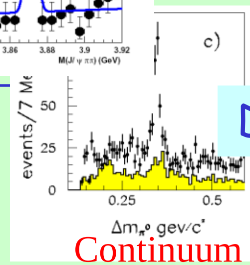
Hints for New Spectroscopy-Challenge QCD

Particle Zoo from
R. Faccini

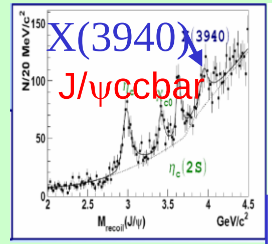
Belle

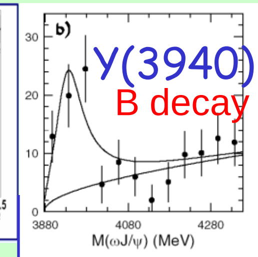
2003

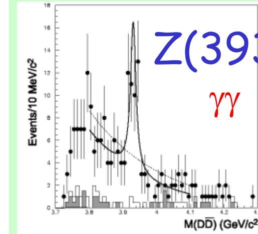




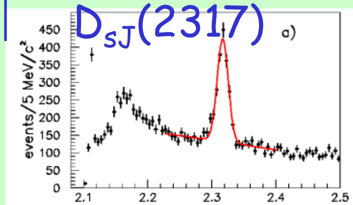
2004





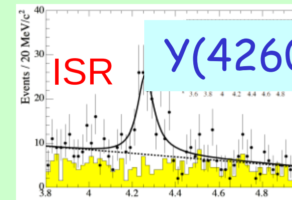


BaBar



$D_{sJ}(2458)$

2005



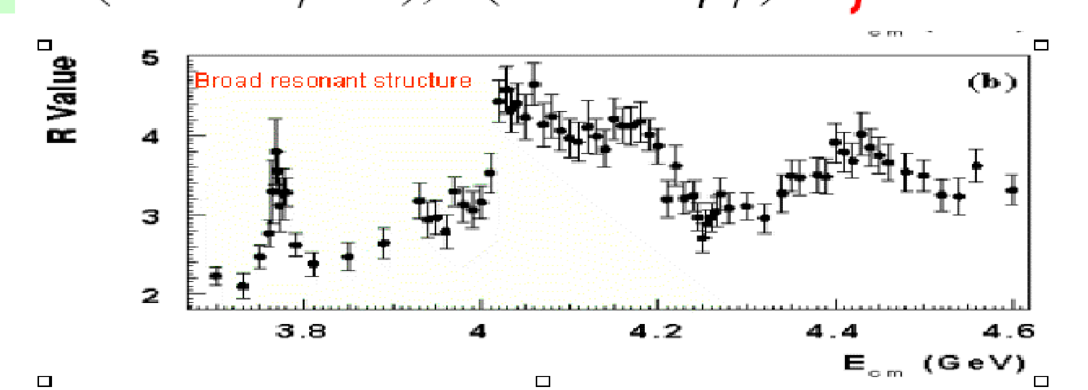
$$\sigma(e^+e^- \to D\overline{D}^{(*)}), \sigma(e^+e^- \to D_S^+ D_S^{-(*)}), \longrightarrow \text{Test QCD @ } 3.7 \div 4.6 \text{ GeV}$$

$$\sigma(e^+e^- \to J/\psi\pi^+\pi^-), \sigma(e^+e^- \to \chi_{cJ}\rho(\omega)) \longrightarrow \text{Search for exotic ccbar, Y(4260)}$$

$$\sigma(e^+e^- \to \phi\pi\pi), \sigma(e^+e^- \to \eta' J/\psi)$$

$$\sigma(e^+e^- \to \phi KK), \sigma(e^+e^- \to \eta'\phi)$$

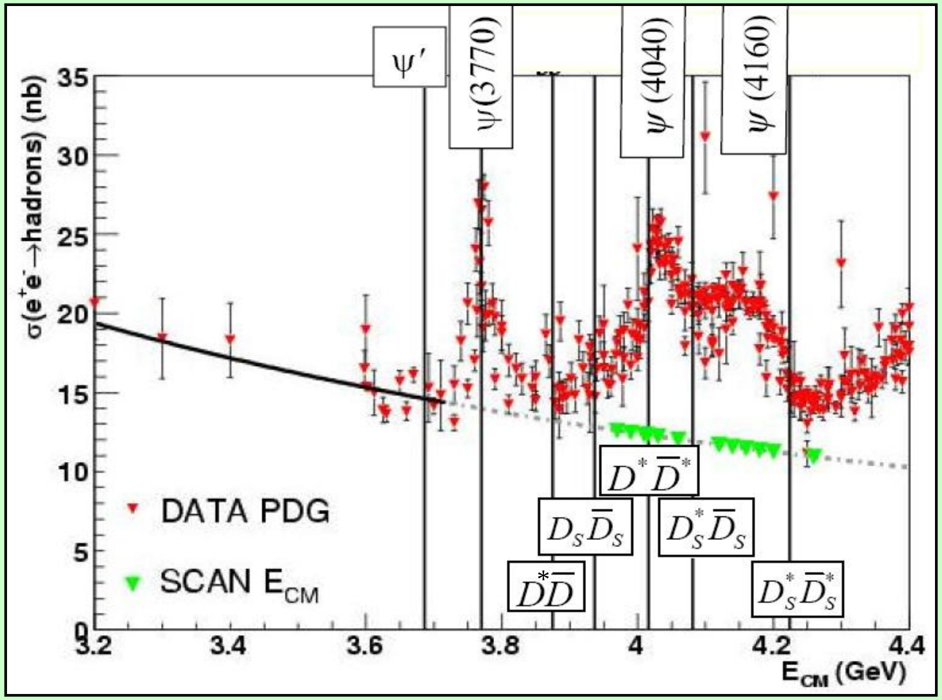
→ Probe gluon enhanced hidden ccbar states



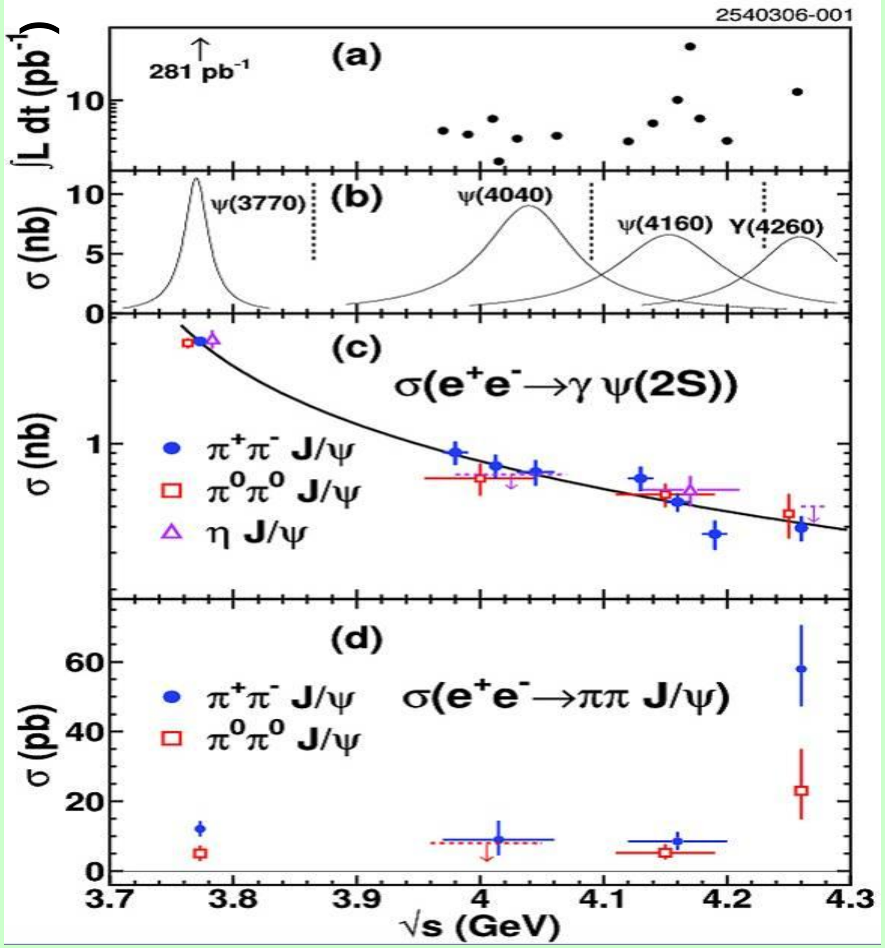
Opportunity at BESIII to look for new states near the open charm region.

Scan will be crucial at BES-III: E_{CM} = 3773-4600 MeV

Opportunity at BESIII to look for new states above the open charm region.



CLEO-c Preliminary
Ron Poling talk at Charm2006



CLEO-c PRL 96, 162003 (2006)

Rare and forbidden quarkonium decays

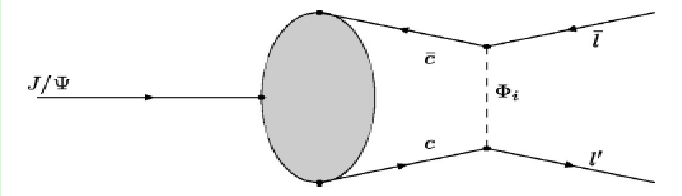
No any evidence beyond SM is found on the accelerators.
No any indication beyond SM in Quarkonium decays.

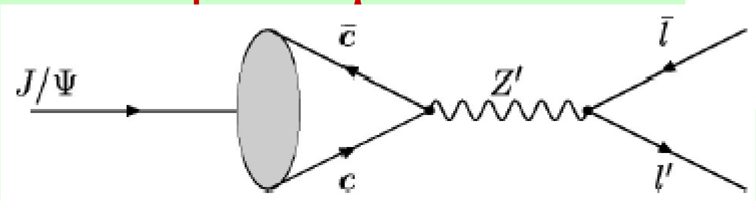
Rare and forbidden Charmonium decays :

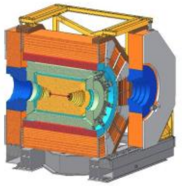
(1) Lepton Flavor/baryon number violating decays;

(2) Invisible decays .

Search for LFV in J/ψ→ μτ







LFV decays are forbidden in SM but can be easily generated in many theories where LF is not conserved (consequence of non-zero neutrino mass and mixing)

- **GUT inspired models with leptoquarks, SUSY with sleptons, technicolor model with special role for t quark (TC2):**
  Hou, Feng, and Yue, PRD 67, 114001 (2003):

  Model dependent: $B(J/\psi \to \mu\tau) < 10^{-8}$ -10^{-9} and $B(J/\psi \to \mu e) < 10^{-14}$ -10^{-15}
  Model independent: $B(J/\psi \to \mu\tau) < 10^{-7}$ and $B(J/\psi \to \mu e) < 10^{-13}$

- LFV decays can be induced by low scale quantum gravity effects or other new physics at TeV scale or by extra dimensions:

Silagadze, hep-ph/9907328

$B(\Upsilon \to \mu\tau) \approx 2\text{x}10^{-5}$ and $B(J/\psi \to \mu\tau) \approx 10^{-7}$

Even more optimistic estimates: *Datta et al., PRD 60, 014011, 1999*

$B(\Upsilon \to \tau\ell) \leq 10^{-2}$ and $B(J/\psi \to \tau\ell) \leq 6\text{x}10^{-7}$

PRD63, 016003, S. Nussinov, R.D. Peccei and X.M. Zhang

Lepton flavor violating processes in J/ψ decays

Lepton flavor violating (LFV) processes are strongly suppressed in the Standard Model by power of (small) neutrino masses. Such decays signal new physics. PRD63, 016003, S. Nussinov, R.D. Peccei and X.M. Zhang

BESII upper limit

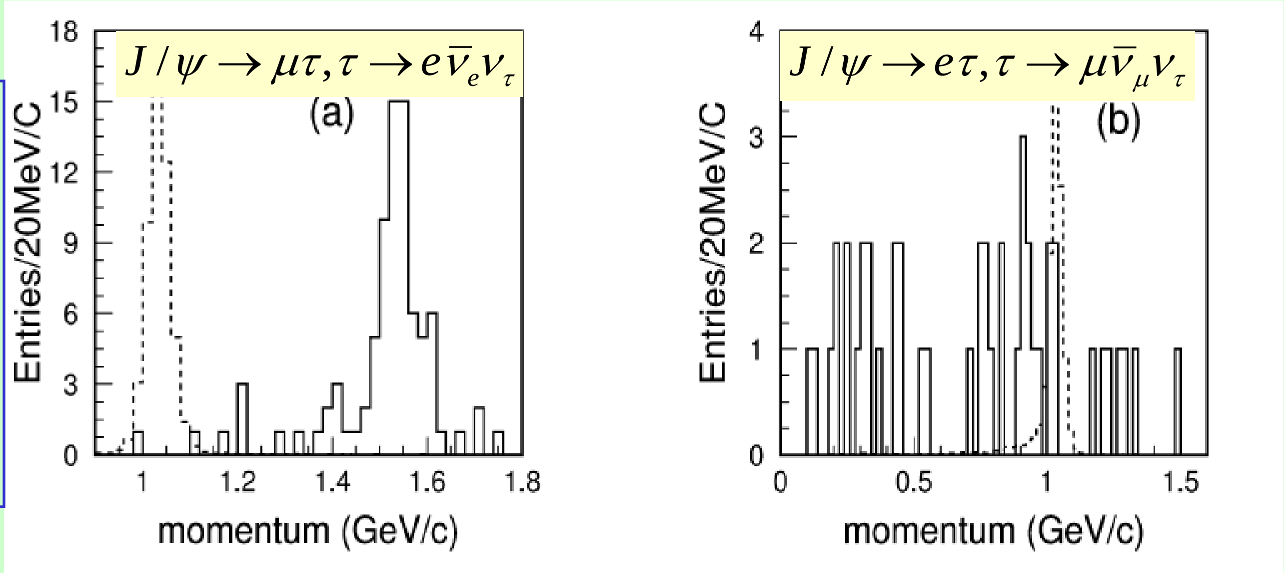
BR(J/ψ → eμ) < 1.1×10^{-6}

BR(J/ψ → eτ) < 8.3×10^{-6}

BR(J/ψ → μτ) < 2.0×10^{-6}

with 58M J/ ψ sample

BESII
PLB561, 49 (2003)
PLB598, 172(2004)



μ momentum distribution

J/ψ → eμ, eτ, τμ, the sensitivity can be **10^{-8} – 10^{-9}** at BES-III with 10^{10} J/ψ events per year

J/ψ → e^- proton +c.c, J/ψ → μ^- proton +c.c can also be searched for.

Invisible quarkonium decays

With in SM, the invisible quarkonium decays are predicted by:
hep-ph/9806487, L.N Chang, O.Lebedlev and J. N. Ng

$$\frac{\Gamma(\Upsilon \to \nu\bar{\nu})}{\Gamma(\Upsilon \to e^+e^-)} = \frac{27G^2M_\Upsilon^4}{64\pi^2\alpha^2}\left(-1+\frac{4}{3}\sin^2\theta_W\right)^2$$
$$= 4.14 \times 10^{-4} ,$$
$$\frac{\Gamma(J/\Psi \to \nu\bar{\nu}))}{\Gamma(J/\Psi \to e^+e^-)} = \frac{27G^2M_{J/\Psi}^4}{256\pi^2\alpha^2}\left(1-\frac{8}{3}\sin^2\theta_W\right)^2 ,$$
$$= 4.54 \times 10^{-7} ,$$

With 2-3% uncertainty!

One get:

$Br(Y(1S) \to \nu\bar{\nu}) = 1.0\times10^{-5}$

$Br(J/\psi \to \nu\bar{\nu}) = 2.69 \times10^{-8}$

Theoretical clean process can be used to test model and probe new physics!

New physics may enhance the production rate of the invisible decays of quarkonia. For example, MeV dark matter candidates.

hep-ph/0506151 **Bob McElrath**

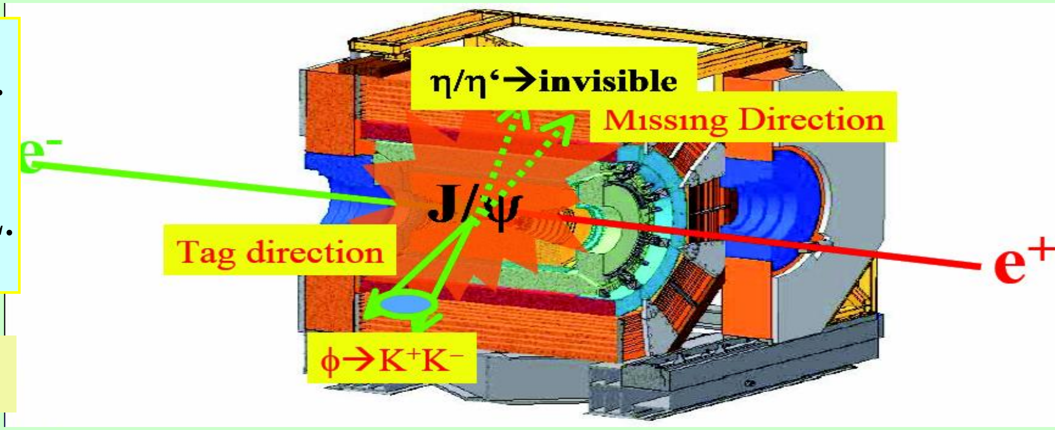
Invisible decays of mesons

➢ **Search for η/η' →Invisible Decays in J/ψ→φη/η'**

58 million J/ψ

$$\frac{BR(\eta \to invisible)}{BR(\eta \to \gamma\gamma)} < 1.65 \times 10^{-3} \,@\, 90\% C.L.$$

$$\frac{BR(\eta' \to invisible)}{BR(\eta' \to \gamma\gamma)} < 6.69 \times 10^{-2} \,@\, 90\% C.L.$$

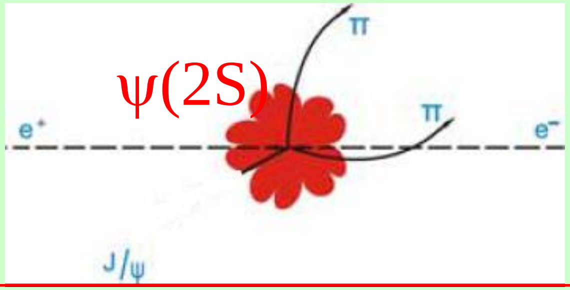


BES, Phys.Rev.Lett.97:202002,2006

➢ **Search for J/ψ Invisible Decays** by using **ψ(2S)→π⁺π⁻ J/ψ^{invisible} !**

14 million ψ(2S)

$$\frac{B(J/\psi \to invisible)}{B(J/\psi \to \mu^+\mu^-)} < 1.0 \times 10^{-2} \,@\, 90\% C.L.$$



BES, Phys. Rev. Lett. 100: (2008)

The sensitivity at BESIII will be 10^{-6} –10^{-7} for J/ψ, χ_C , η_C η, η'→ Invisible

ψ(3770) Scan

and

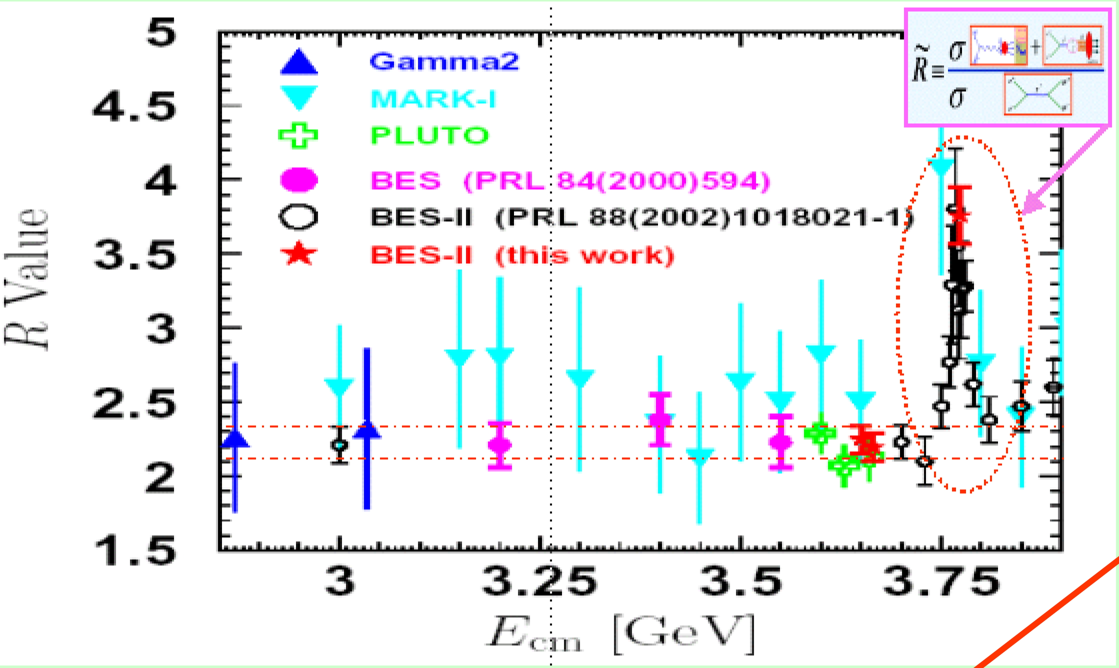
ψ(3770) non-DDbar decay

From BESII study, there are significant

non-DDbar in (3770) decays

R & $BF(\psi(3770) \to D\overline{D})$

Phys. Lett. B 641, 145(2006)



R values measured at three energy points

E_{CM} [GeV]	σ^{obs}_{had}	$\sigma^0(e^+e^- \to hadrons)$	R
3.650	18.98 ± 0.22	14.62 ± 0.16	2.25 ± 0.02
3.665	18.30 ± 0.27	14.15 ± 0.21	2.20 ± 0.03
3.773	27.68 ± 0.27	23.14 ± 0.22	3.75 ± 0.04

$$\sigma^{Born}_{\psi(3770)} = 9.28 \pm 0.25 \pm 0.80 \quad nb$$

$$g_{BES-II} = 0.764 \pm 0.014$$

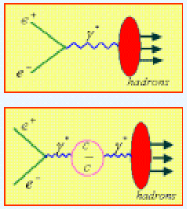
With BES previously measured cross sections for DD production.

$$BF(\psi(3770) \to D\overline{D}) = \frac{N^{prd}_{D\overline{D}}}{N^{prd}_{\psi(3770)}} = \frac{\sigma^{Born}_{D\overline{D}}}{\sigma^{Born}_{\psi(3770)}} = \frac{\sigma^{obs}_{D\overline{D}}}{g_{BES-II}\ \sigma^{Born}_{\psi(3770)}}$$

$$BF(\psi(3770) \to D^0\overline{D}^0) = (50.5 \pm 1.3 \pm 3.9)\%$$
$$BF(\psi(3770) \to D^+D^-) = (36.1 \pm 1.1 \pm 3.5)\%$$
$$BF(\psi(3770) \to D\overline{D}) = (86.6 \pm 1.7 \pm 5.9)\%$$

$$BF(\psi(3770) \to non-D\overline{D}) = (13.4 \pm 1.7 \pm 5.9)\%$$

Assuming that there are interference between the two amplitudes



Considering the possible interference between the two amplitudes …

$$BF(\psi(3770) \to D^0\overline{D}^0) = (53.0 \pm 1.3 \pm 4.1)\%$$
$$BF(\psi(3770) \to D^+D^-) = (37.9 \pm 1.2 \pm 3.6)\%$$
$$BF(\psi(3770) \to D\overline{D}) = (90.8 \pm 1.8 \pm 6.2)\%$$
$$BF(\psi(3770) \to non-D\overline{D}) = (9.2 \pm 1.8 \pm 6.2)\%$$

$BF(\psi(3770)\to D\overline{D})$

Phys.Rev.Lett.97: 121801(2006)

◆ Branching fractions

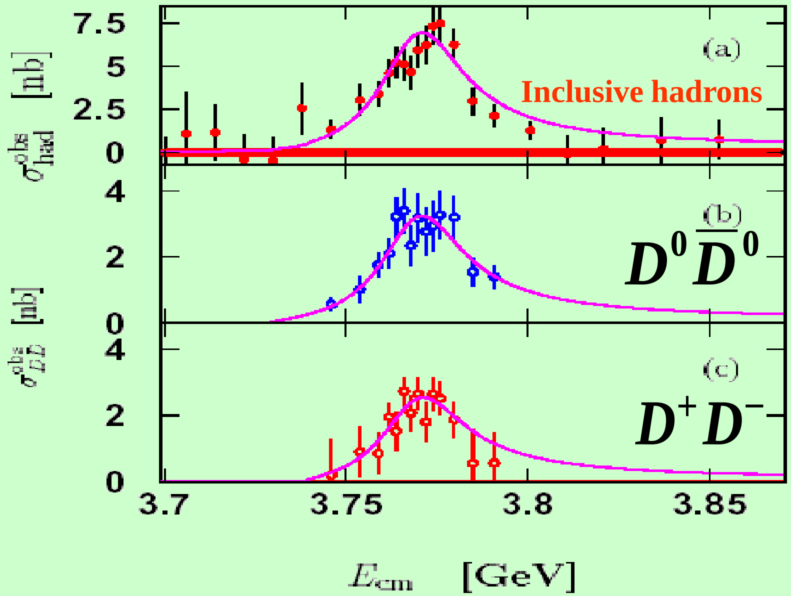


FIG. 4: The observed cross sections versus the nominal center-of-mass energies, where (a) shows the inclusive hadronic event production, (b) and (c) show the $D^0\bar{D}^0$ and D^+D^- event production, respectively; the points with error are the data, while the lines are the fits to the data.

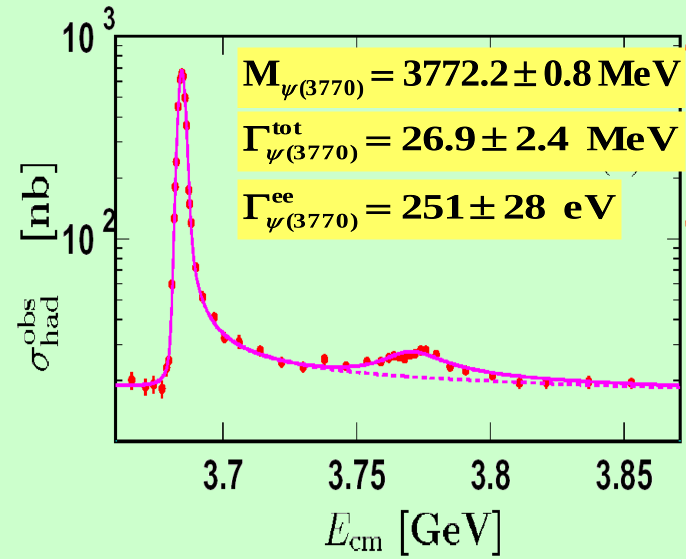
$$BF(\psi(3770)\to D^0\overline{D}^0)=(46.7\pm4.7\pm2.3)\%$$

$$BF(\psi(3770)\to D^+D^-)=(36.9\pm3.7\pm2.8)\%$$

$$BF(\psi(3770)\to D\overline{D})=(83.6\pm7.3\pm4.2)\%$$

$$BF(\psi(3770)\to non-D\overline{D})=(16.4\pm7.3\pm4.2)\%$$

◆ Resonance parameters



$M_{\psi(3770)} = 3772.2\pm0.8\,\text{MeV}$

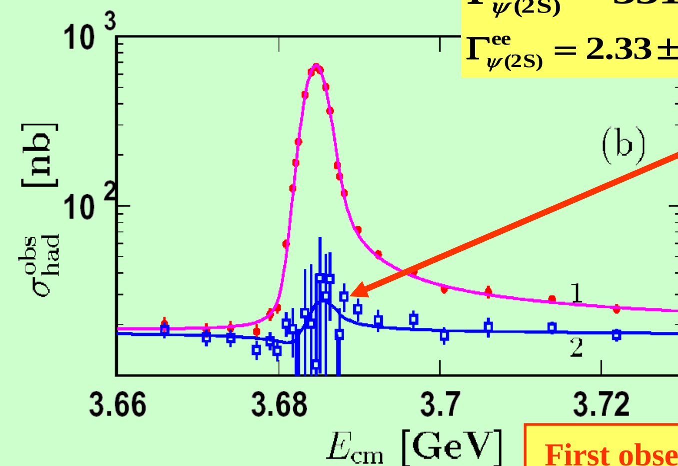
$\Gamma^{tot}_{\psi(3770)} = 26.9\pm2.4\ \text{MeV}$

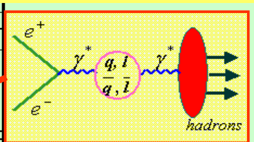
$\Gamma^{ee}_{\psi(3770)} = 251\pm28\ \text{eV}$

Better than PDG world average

$\Gamma^{tot}_{\psi(2S)} = 331\pm58\pm2\ \text{keV}$

$\Gamma^{ee}_{\psi(2S)} = 2.33\pm0.04\pm0.11\ \text{keV}$





Mainly due to vacuum polarization corrections

First observed this effects!

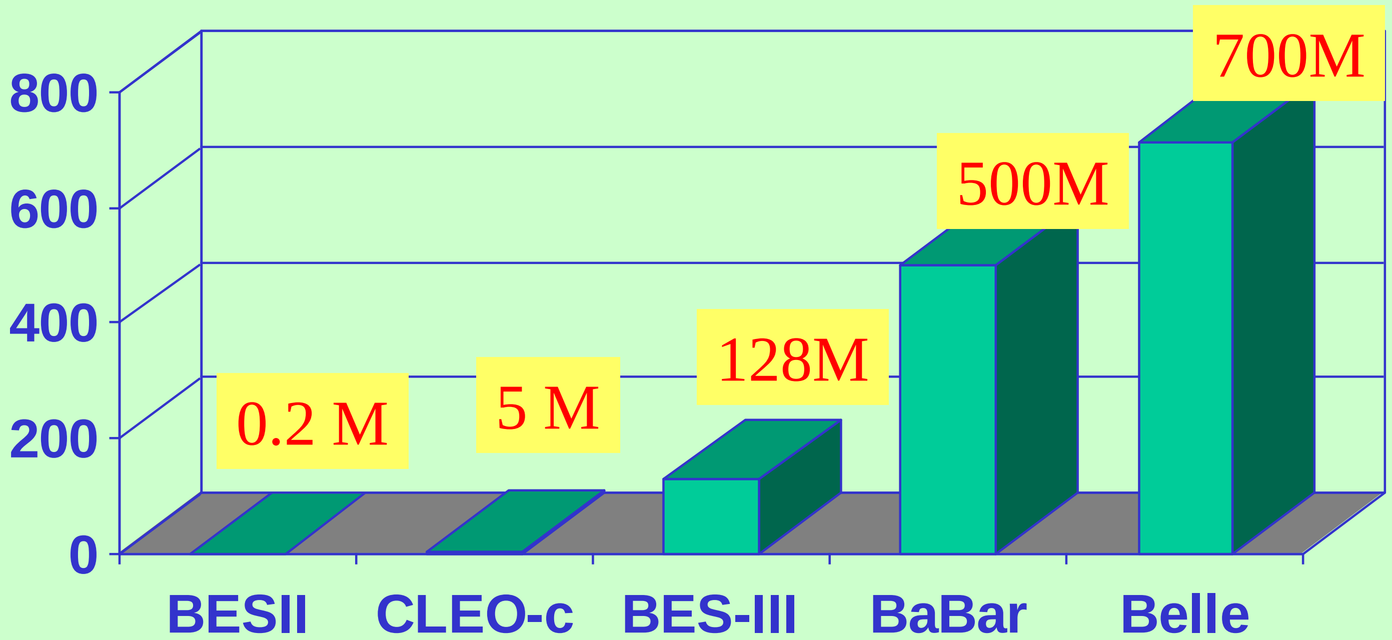
Because the limited data sample, the results are not very conclusive so far,

It is planned to do ψ(3770) scan in the second half of this year using BESIII, when the accurate beam energy measurement system will be installed, to better measure the BF of ψ(3770) →non-DDbar.

Charm physics at BES-III

$D\overline{D}$ Pairs at different Experiments

128 M is expected at BES-III with 4 years' luminosity.
5 M is expected at CLEO-c until 2008.



ψ(3770) peak
Background free

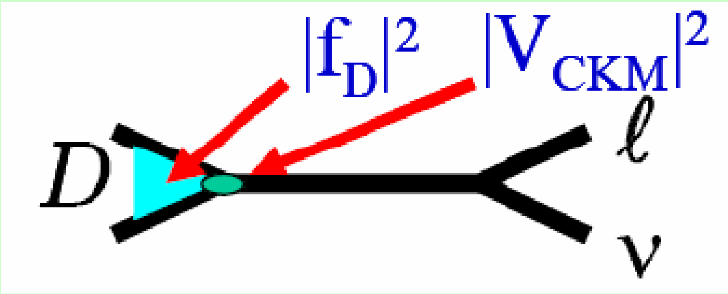
Υ(4S) Peak
Higher statistics

Impact of Charm Physics

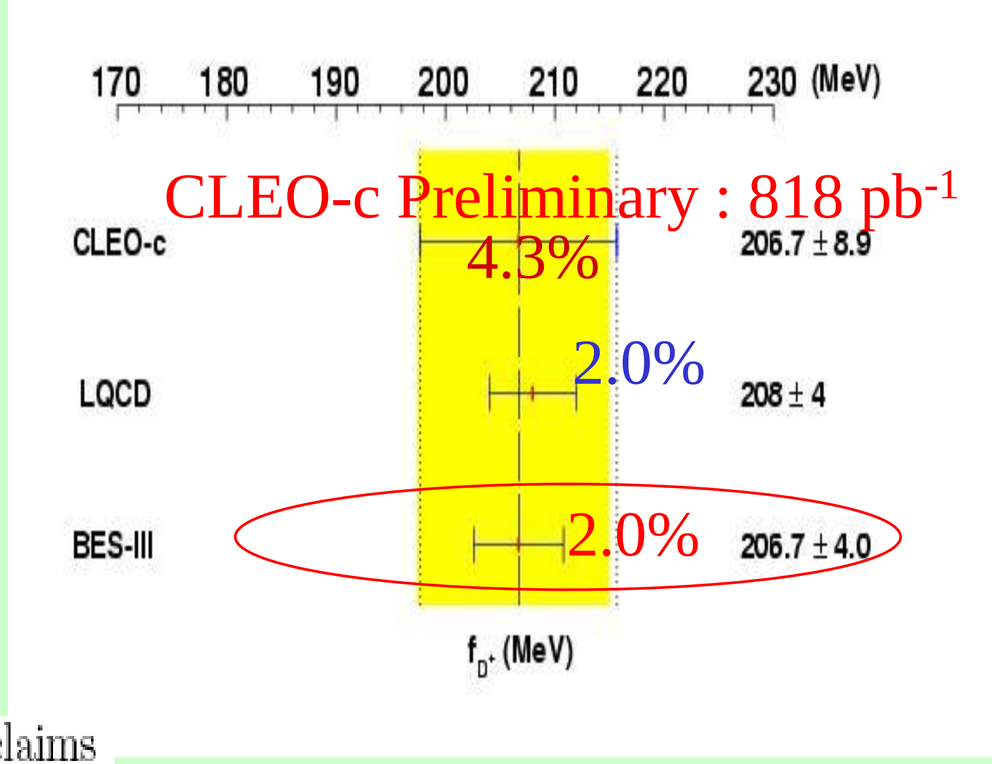
- **Precision CKM**
  - **Leptonic Charm Decays $D \rightarrow \ell^+ \nu$**
  - **Semileptonic decay rates & form-factors**
  - **Hadronic Charm Decays - $B \rightarrow$Charm is dominant**
- **Possible New Physics in Charm Sector**
  - **Rare Charm Decays**

    (Heavily GIM suppressed: BF($c \rightarrow ull$)~10^{-8})
  - **Charm Mixing.**
  - **CP Violation**

f_{D+} and challenge of QCD



$$\Gamma(D_s^+ \to l^+\nu) = \frac{G_F^2 m_{D_s^+} m_l^2 f_{D_s^+}^2}{8\pi} |V_{cs}|^2 \left(1 - \frac{m_l^2}{m_{D_s^+}^2}\right)^2$$



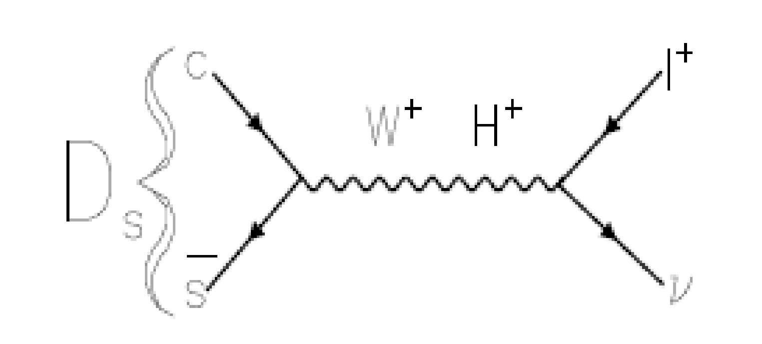
Recently, the HPQCD+UKQCD collaboration claims better than 2% precision for their unquenched calculations [11] **PRL 100, 062002(2008)**

$$(f_{D+})_{QCD} = (208 \pm 4)\text{MeV},$$
$$(f_{D_s^+})_{QCD} = (241 \pm 3)\text{MeV}, \quad (7)$$

BES-III can reach 2% with 20 fb^{-1} data @ psi(3770).

Precise determination of f_{Ds} –challenge LQCD

See Hewett [hep-ph/9505246] & Hou, PRD 48, 2342 (1993).



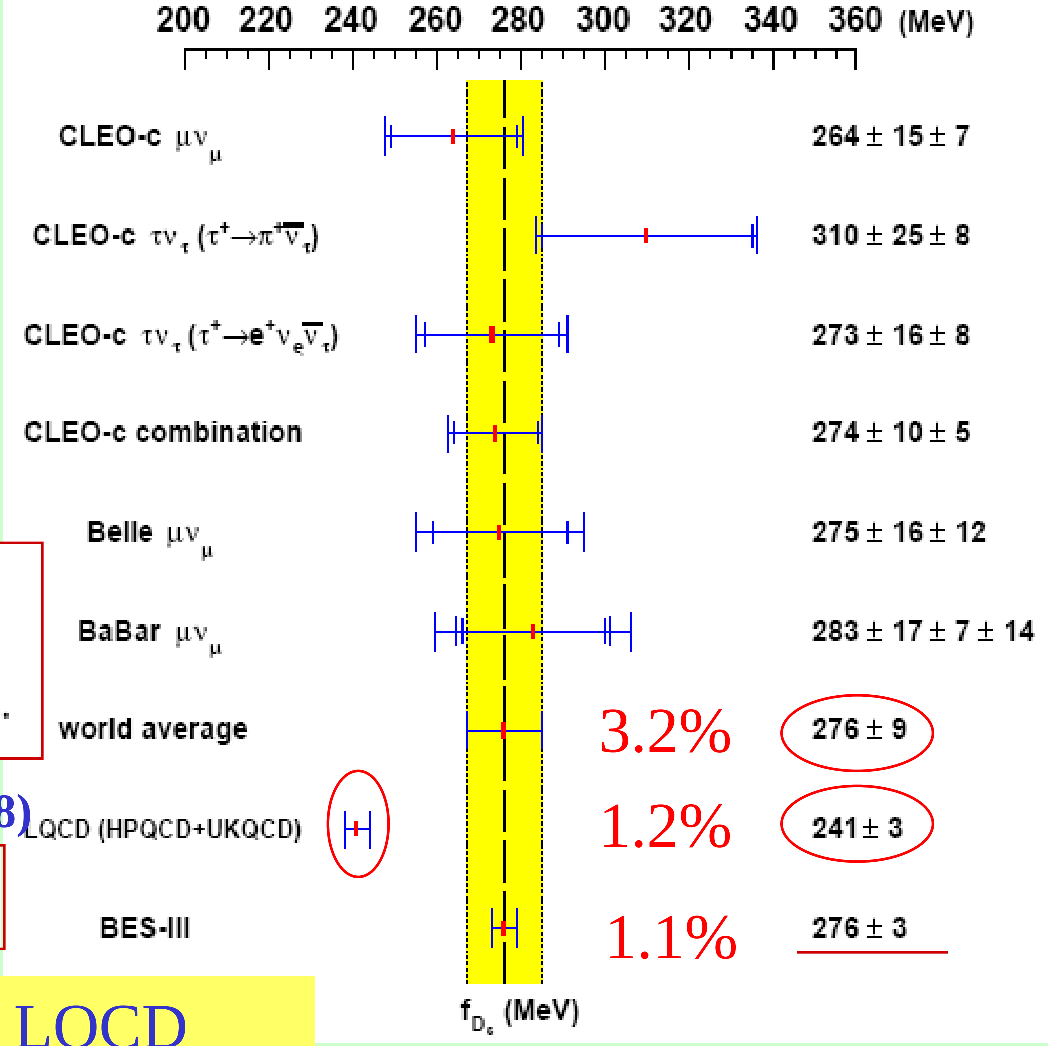
CLEO-c, Belle and BaBar:

The average of $\tau\nu_\tau$ and $\mu\nu_\mu$ values is

$$(f_{D_s^+})_{exp} = (276 \pm 9)\,\mathrm{MeV}.$$

HPQCD+UKQCD PRL 100, 062002(2008)

$$(f_{D_s^+})_{QCD} = (241 \pm 3)\,\mathrm{MeV},$$



4.0 sigma discrepancy between LQCD and experimental determination in the SM.

Probing new physics in leptonic decays

In the Standard model:

$$\mathcal{R}_\mu \equiv \frac{\mathcal{BR}(D_s^+ \to \mu^+\nu)}{\mathcal{BR}(D^+ \to \mu^+\nu)} = \left|\frac{f_{D_s^+}}{f_{D^+}}\right|^2 \left|\frac{V_{cs}}{V_{cd}}\right|^2 \frac{m_{D_s^+}}{m_{D^+}} \times \left(\frac{1-m_\mu^2/m_{D_s^+}^2}{1-m_\mu^2/m_{D^+}^2}\right) \times \frac{\tau_{D_s^+}}{\tau_{D^+}}.$$

$$r_s = \left[1 - m_{D_s^+}^2 \frac{\tan^2\beta}{m_{H^\pm}^2}\left(\frac{m_s}{m_c+m_s}\right)\right]^2 = \left[1 - m_{D_s^+}^2 R^2\left(\frac{m_s}{m_c+m_s}\right)\right]^2,$$

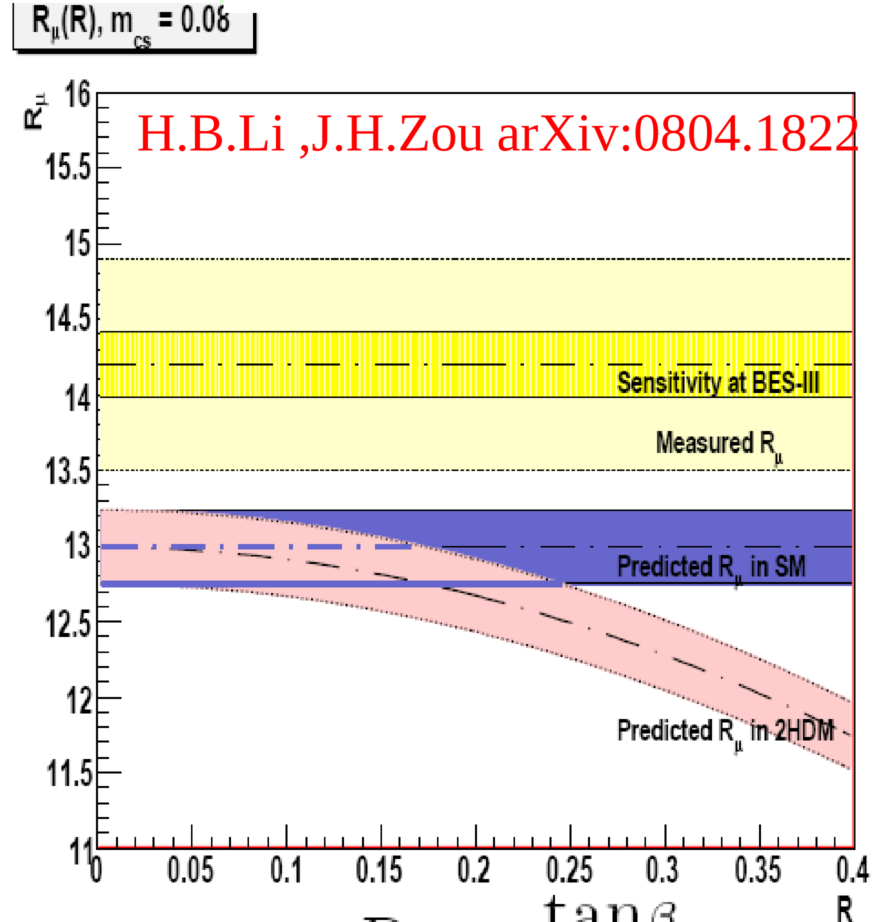
CLEO-c determination:

$$r_{D_s^+/D^+} \equiv \frac{f_{D_s^+}}{f_{D^+}} = 1.23 \pm 0.10,$$

HPQCD+UKQCD: **PRL 100, 062002(2008)**

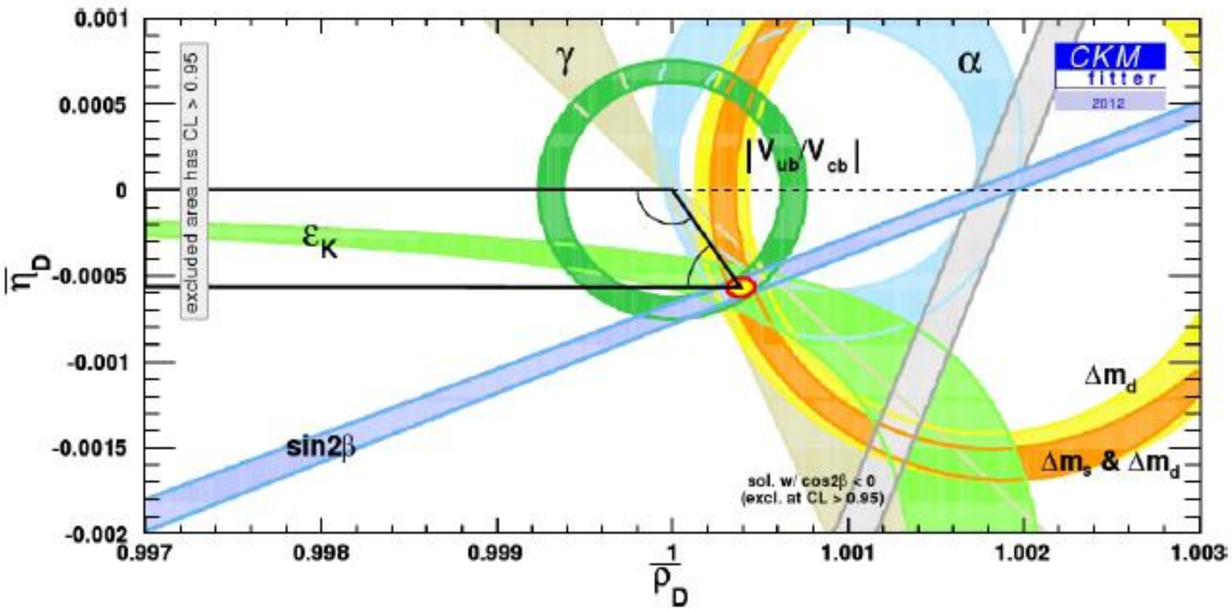
$$f_{D_s^+}/f_{D^+} = 1.164 \pm 0.011,$$

At BES-III, $\mathcal{R}_\mu$: 2.0% with 20fb^{-1} data at 4170 MeV.



$$R = \frac{\tan\beta}{m_{H^\pm}}$$

Precise test of CKM in D decays



BES accuracy

- For leptonic D decays

$$\sigma(|V_{cd}|)/(|V_{cd}|) = 2.3\%$$
$$\sigma(|V_{cs}|)/|V_{cs}| = 1.7\%$$
$$\frac{\sigma(|V_{cd}|/|V_{cs}|)}{|V_{cd}|/|V_{cs}|} = 1.3\%$$

- For semileptonic D decays ($D_s \to K$ and $D_s \to \phi$):

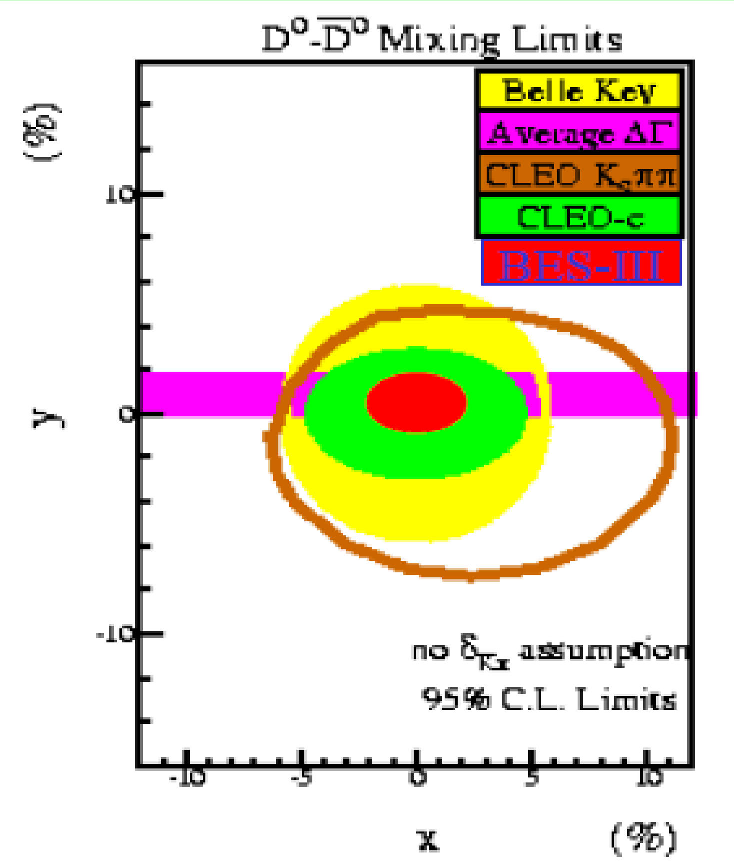
$$\sigma(|V_{cd}|)/(|V_{cd}|) = 2.4\%$$
$$\sigma(|V_{cs}|)/|V_{cs}| = 1.3\%$$

Observable	CKM	QCD	Lattice	Exp meas	Exp err
$Br(D \to \ell\nu)$	$\|V_{cd}\|$	f_D	2%	$f_D\|V_{cd}\|$	1.1%
$Br(D_s \to \ell\nu)$	$\|V_{cs}\|$	f_{Ds}	1.5%	$f_{Ds}\|V_{cs}\|$	0.7%
$\frac{Br(D_s\to\ell\nu)}{Br(D\to\ell\nu)}$	$\left\|\frac{V_{cs}}{V_{cd}}\right\|$	$\frac{f_{Ds}}{f_D}$	1%	$\left\|\frac{V_{cs}f_{Ds}}{V_{cd}f_D}\right\|$	0.8%
$d\Gamma(D^0 \to \pi^-)$	$\|V_{cd}\|$	$F_{D\to\pi}(0)$	4%	$\|V_{cd}\|F_{D\to\pi}(0)$	0.6%
$d\Gamma(D^0 \to K^-)$	$\|V_{cs}\|$	$F_{D\to K}(0)$	3%	$\|V_{cs}\|F_{D\to K}(0)$	0.5%
$d\Gamma(D_s \to K)$	$\|V_{cd}\|$	$F_{D_s\to K}(0)$	2%	$\|V_{cd}\|F_{D_s\to K}(0)$	1.2%
$d\Gamma(D_s \to \phi)$	$\|V_{cs}\|$	$F_{D_s\to\phi}(0)$	1%	$\|V_{cs}\|F_{D_s\to\phi}(0)$	0.8%

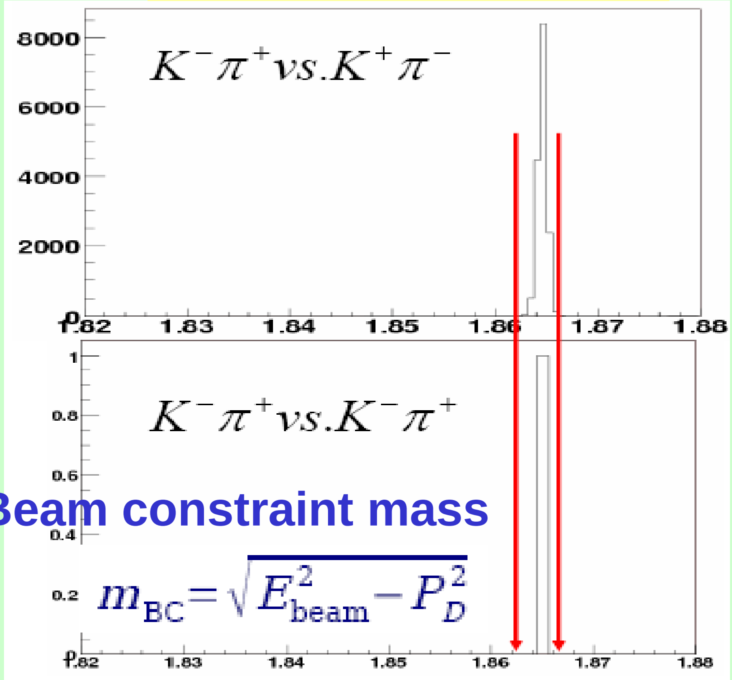
Mixing rate R_M from $\psi(3770) \to D^0\bar{D}^0 \to (K^-\pi^+)(K^-\pi^+)$

$$R_M = \frac{x^2 + y^2}{2} = \frac{N[(K^\pm\pi^\mp)(K^\pm\pi^\mp)]}{N[(K^\pm\pi^\mp)(K^\mp\pi^\pm)]}$$

Sensitivity from 20 fb^{-1} data at BES-III: $R_M < 1.5 \times 10^{-4}$



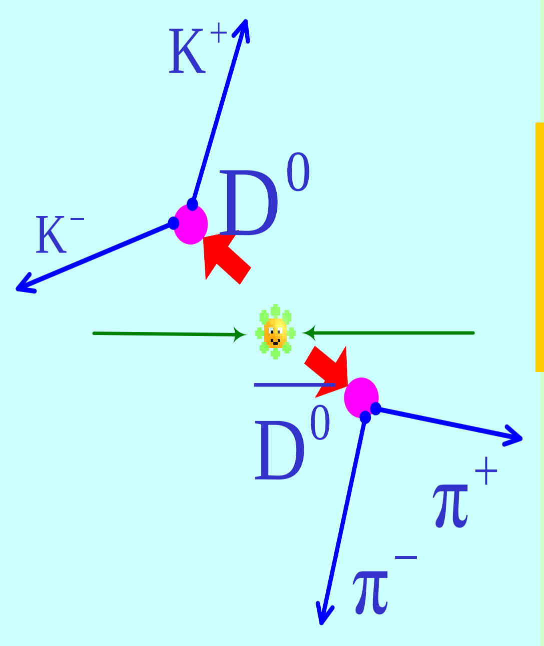
2 events in the signal region due to mis-ID. (the mis-ID rate for pi as a Kaon is 1%).



Beam constraint mass

$$m_{BC} = \sqrt{E_{beam}^2 - P_D^2}$$

CP Violation at ψ(3770) at BESIII



CP violating asymmetries can be measured by searching for events with two CP odd or two CP even final states:

$\pi^+\pi^-$, K^+K^-, $\pi^0\pi^0$, $K_s\pi^0$,

for the decay of $\psi'' \rightarrow f_1 f_2$

$$CP(f_1 f_2) = CP(f_1) \cdot CP(f_2) \cdot (-1)^L = -$$

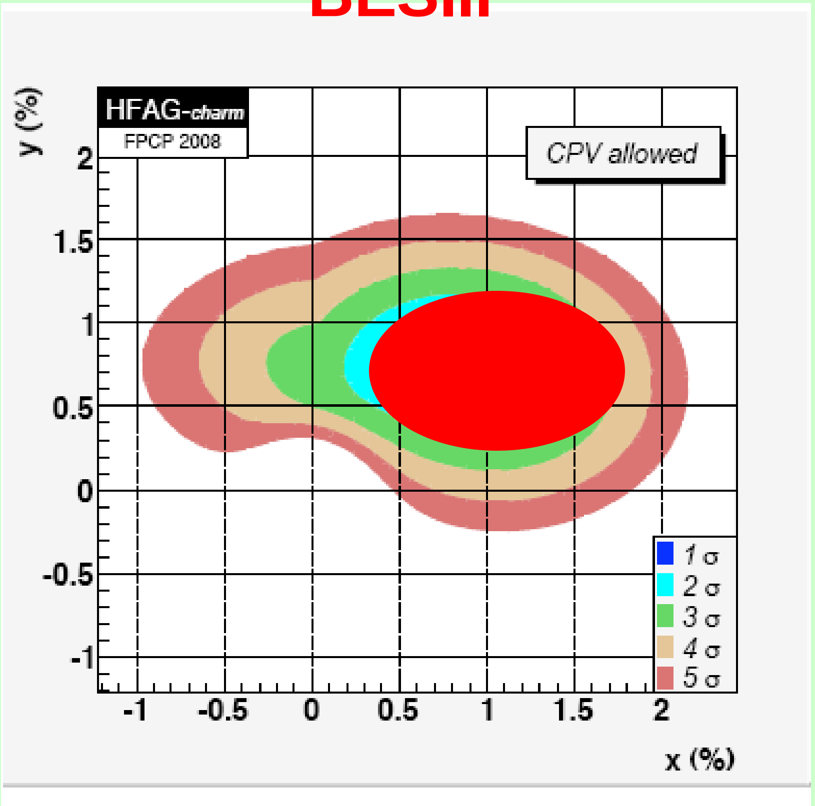
$$CP(\psi'') = +$$

A_{CP} sensitivity : $\Delta A \sim 10^{-3}$

Sensitivities (20 fb^{-1} at psi(3770) peak)

- Mixing parameters
  - $R_M=(x^2+y^2)/2 < 10^{-4}$ in $K\pi$ and $Ke\nu$ channels
  - Probe y: $\Delta y_{CP} < 0.7\%$,
  - $\Delta\cos\delta_{K\pi} < 0.06$
- CP Violation
  - $\Delta A_{CP} \sim 10^{-3}$ in D^+ decays (direct CPV),
- Improvement to ϕ_3/γ measurement in $B \rightarrow D^{(*)}K < 2^o$ (CLEO-c: ~5^o)

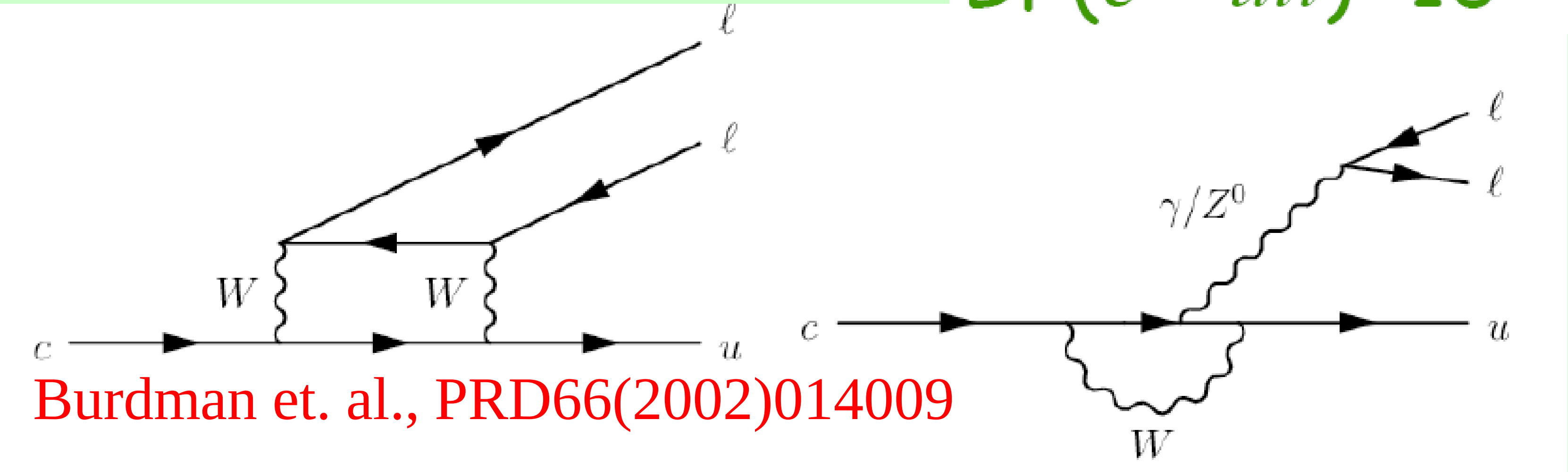
BESIII



Rare and forbidden Charm Decays

Charm FCNC decays heavily GIM suppressed in SM:

$BF(c \to ull) \sim 10^{-8}$



Burdman et. al., PRD66(2002)014009

New Physics can contribute in loop, which is different from the cases in B and Kaon mesons.

Lepton decays: $D^0 \to l^+l^-$ ($l = e,\mu$);

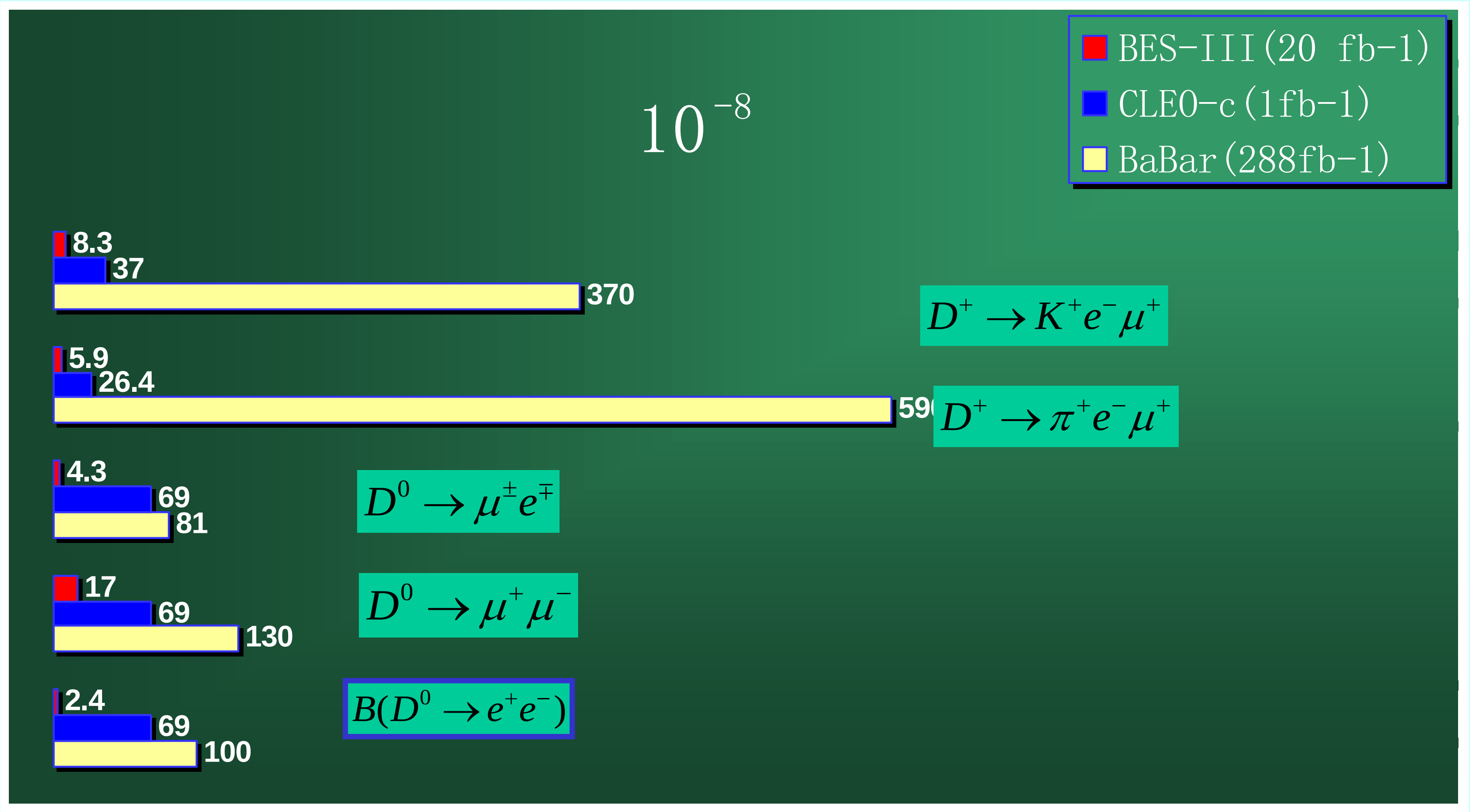
GIM suppressed decays: $D^{0(\pm)} \to M^{0(\pm)} l^+l^-$ (M is meson allowed);

LFV decays: $D^0 \to e^+\mu^-$, $D^{0(\pm)} \to M^{0(\pm)} e^+\mu^-$;

LNV decays: $D^\pm \to M^\pm l^+ l^+$ ($l = e, \mu$; the same signed-di-lepton) ;

Sensitivity of LFV

Improve the limits by more than order magnitude!



LFV and LNV are "smoking gun" , any indication of deviation from zero will indicate New Physics (NP).

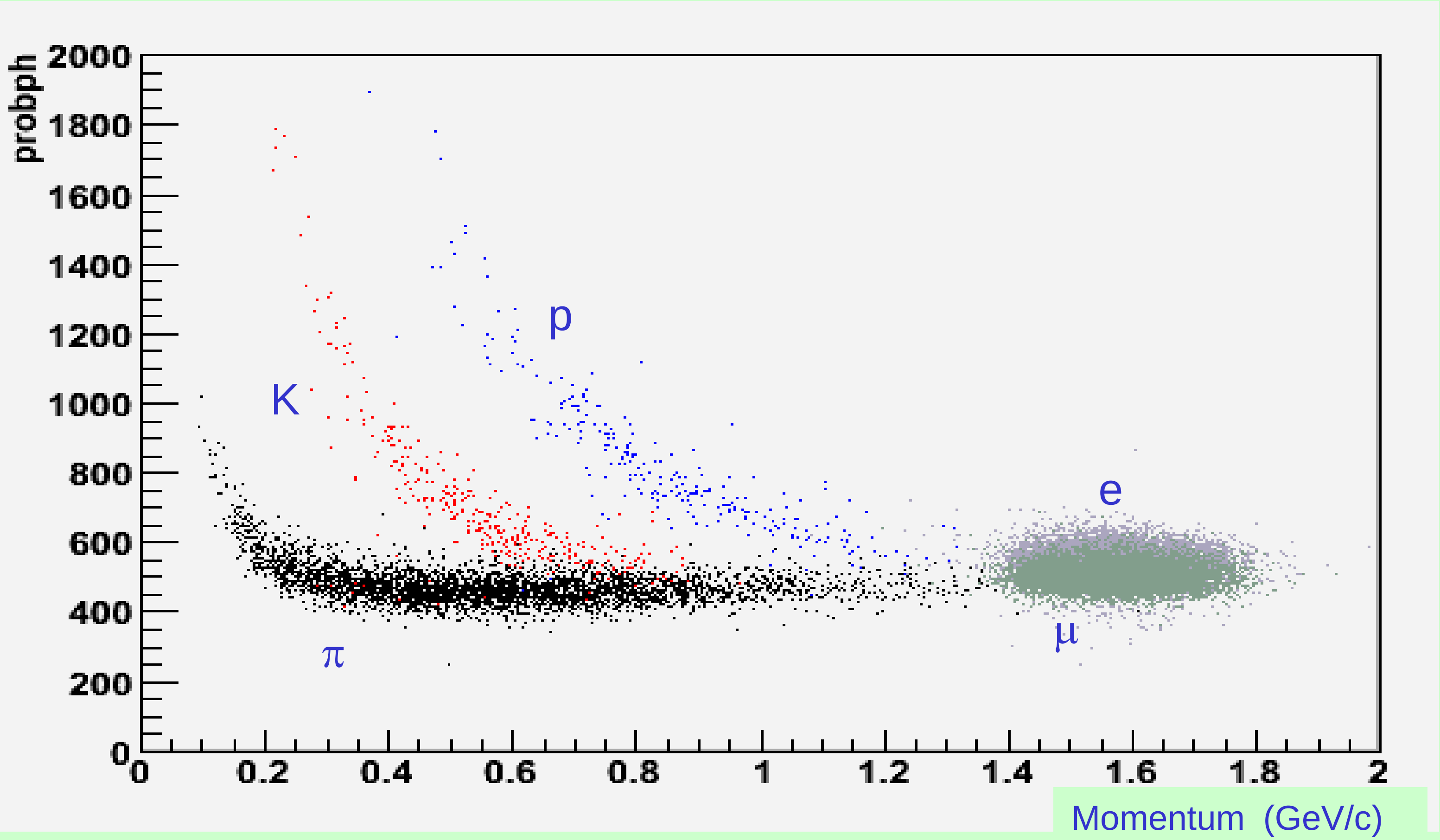
Data quality check using physics channels

Mainly use Bhabha events to calibrate the detector,

EMC energy scale by π^0;

Use some $\psi(2S)$ decays to check the data quality

dE/dx vs momentum for charged particles

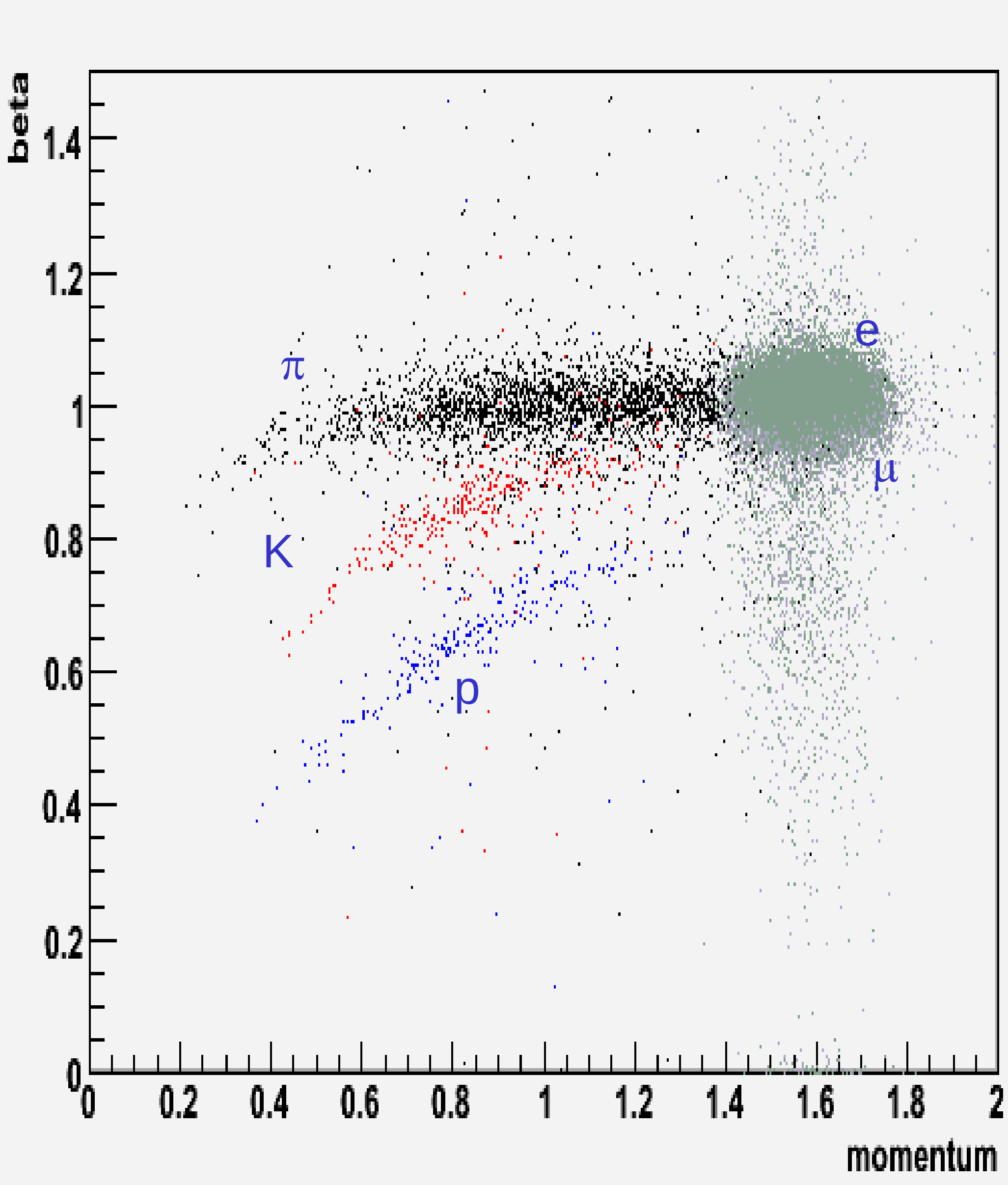


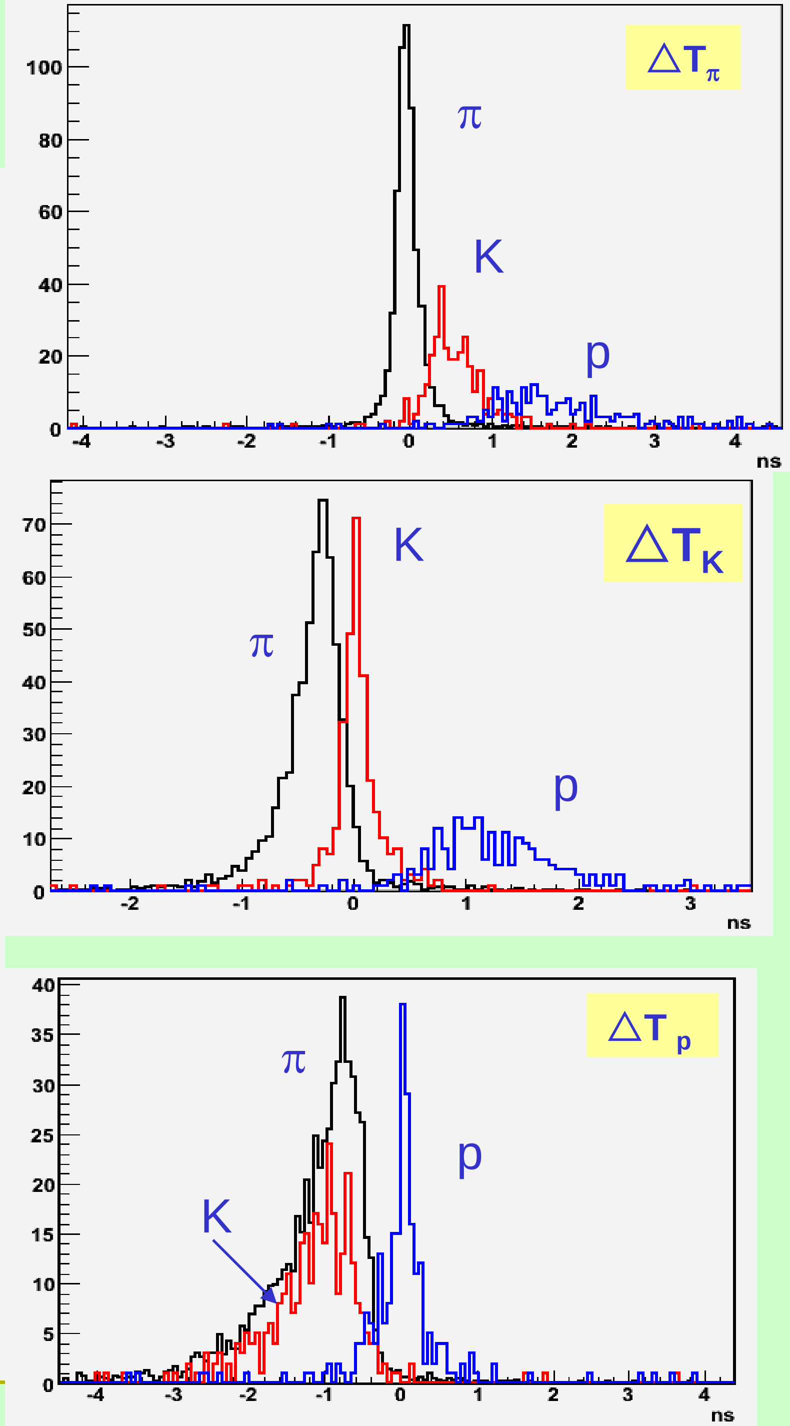
The dE/dx information can be used to separate between π, K, p particles with momentum less than 0.6 GeV/c. For high momentum, π, K can not be well separated with dE/dx.

dE/dx: χ distributions of particles to themselves

	offset	sigma
χ_e	0.098 ± 0.0064	1.062 ± 0.05
χ_μ	0.09 ± 0.0068	0.97 ± 0.0049
χ_π	-0.046 ± 0.007	0.97 ± 0.006
χ_K	-0.14 ± 0.022	0.78 ± 0.0162
χ_p	-0.21 ± 0.034	0.71 ± 0.0316

TOF Checking





TOF: $\triangle$T of particles

(barrel)	Offset (ns)	Sigma (ns)
$\triangle T_e$	-0.003±0.0006	0.104±0.0006
$\triangle T_\mu$	-0.07±0.0007	0.098±0.0006
$\triangle T_\pi$	-0.032±0.001	0.12±0.001
$\triangle T_k$	0.031±0.004	0.119±0.004
$\triangle T_p$	0.033±0.0089	0.1209±0.0083
$\triangle T_{pbar}$	0. 38±0.018	0.213±0.029

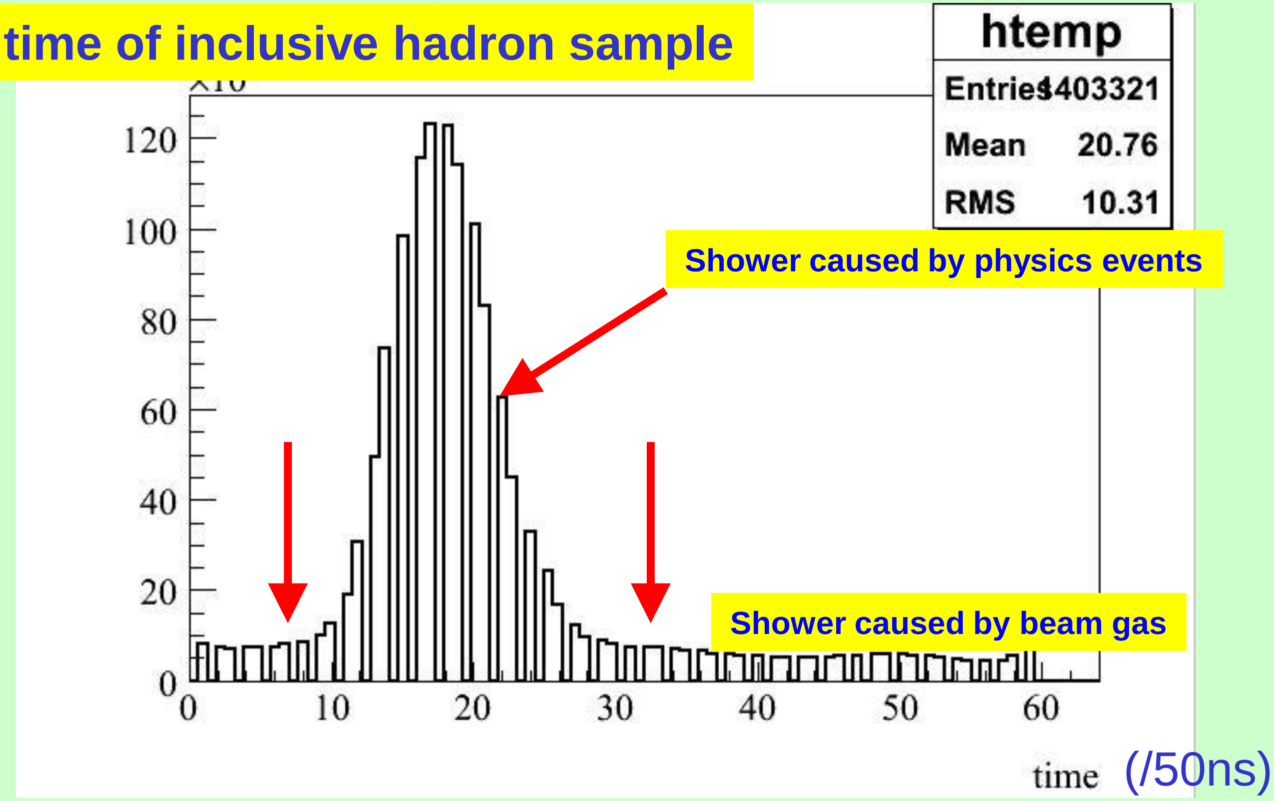
Fake photon veto using EMC TDC

EMC TDC is very useful to veto beam gas related fake photons

Do a EMC TDC calibration to improve performance of fake photon veto

Use $\psi' \rightarrow \pi^0\pi^0 J/\psi$, $J/\psi \rightarrow l^+l^-$ process to do the calibration

EMC time of inclusive hadron sample



The width and center value of TDC signal vary with trigger and photon energy,

→Smear the TDC signal

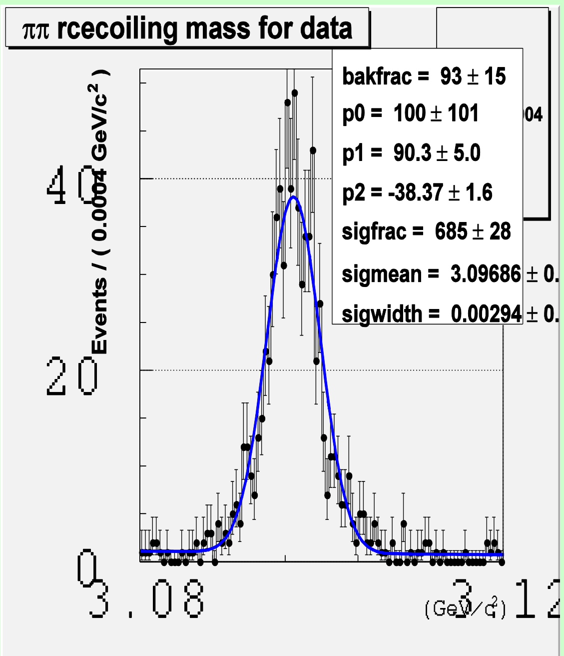
The time window is set to 5-35 now (BOSS6.4.1)

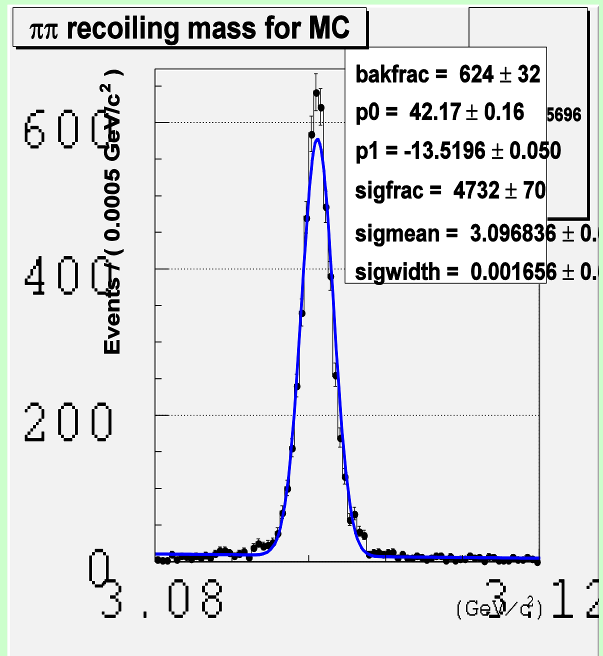
Calibration it can improve the performance of fake photon veto

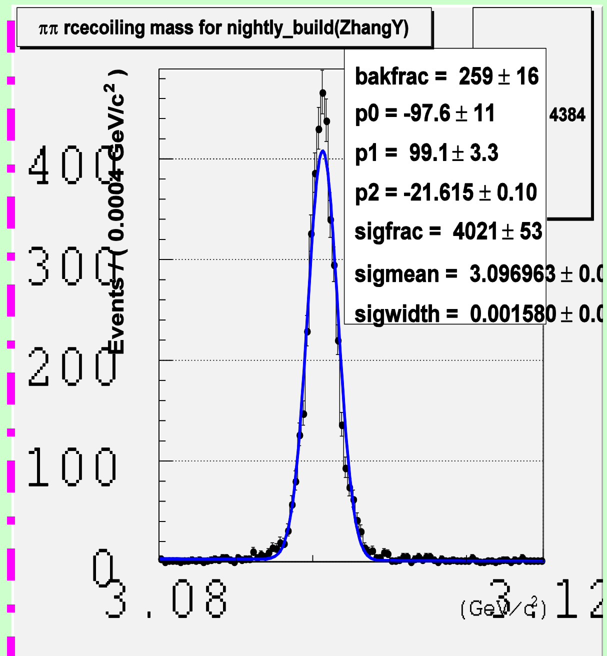
M(π+π-) recoiling J/ψ

Nightly_build version

Data Tracking I	MC Tracking II	MC BaBar based



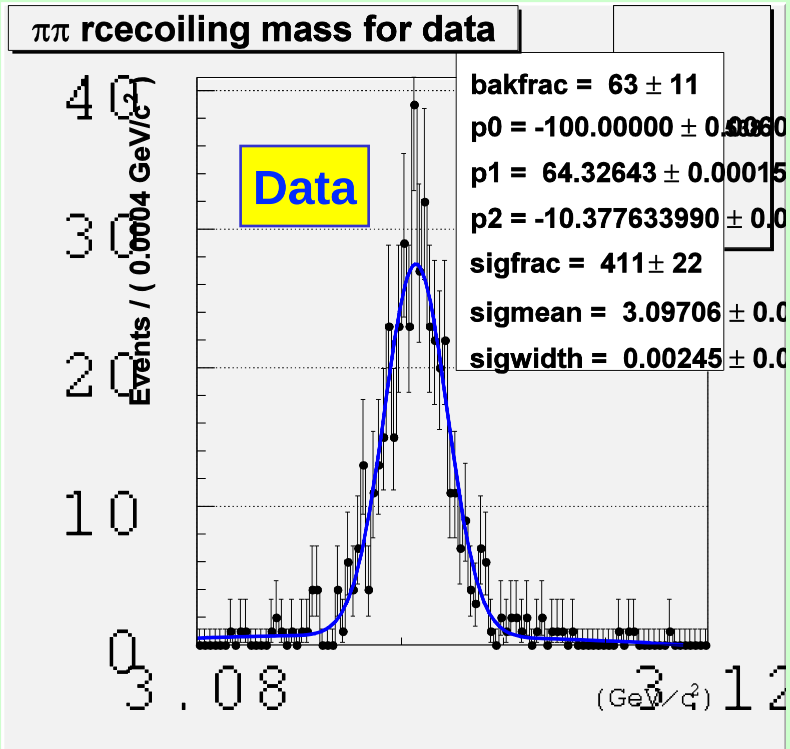




Data Tracking I	MC Tracking II	MC BaBar based
M=3096.9±0.2MeV	M=3096.8 ± 0.1MeV	M=3097 ± 0.1MeV
σ=2.9±0.2MeV	σ=1.7±0.1MeV	σ=1.6±0.1MeV

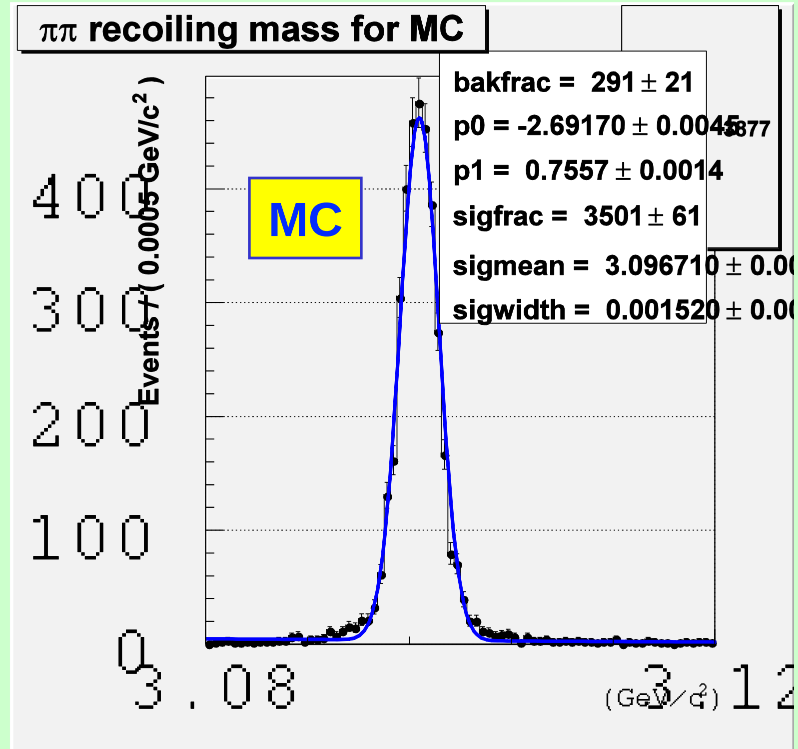
M(π+π-) recoiling J/ψ

6.4.1 version



M=3097.1± 0.1MeV

σ=2.5±0.1MeV

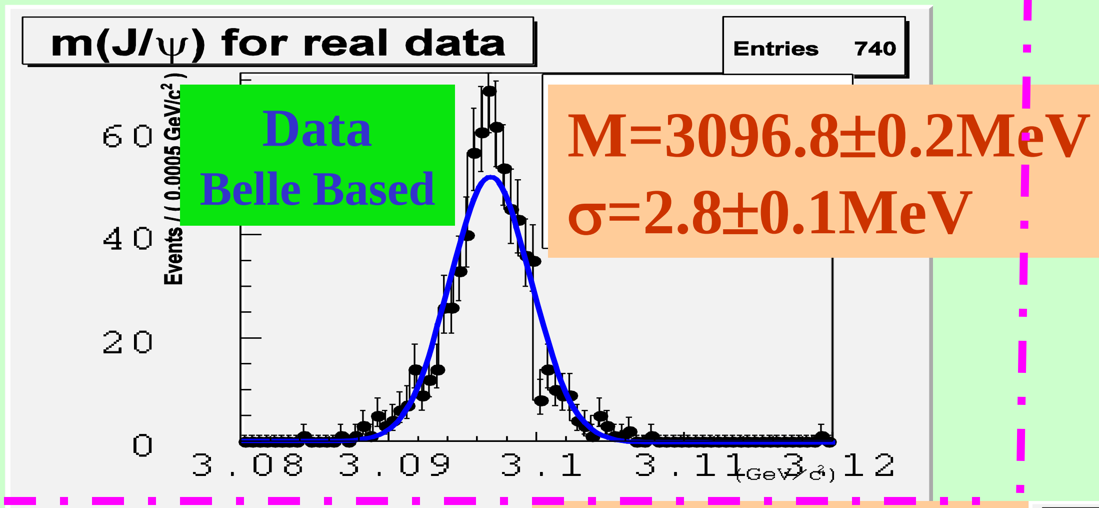


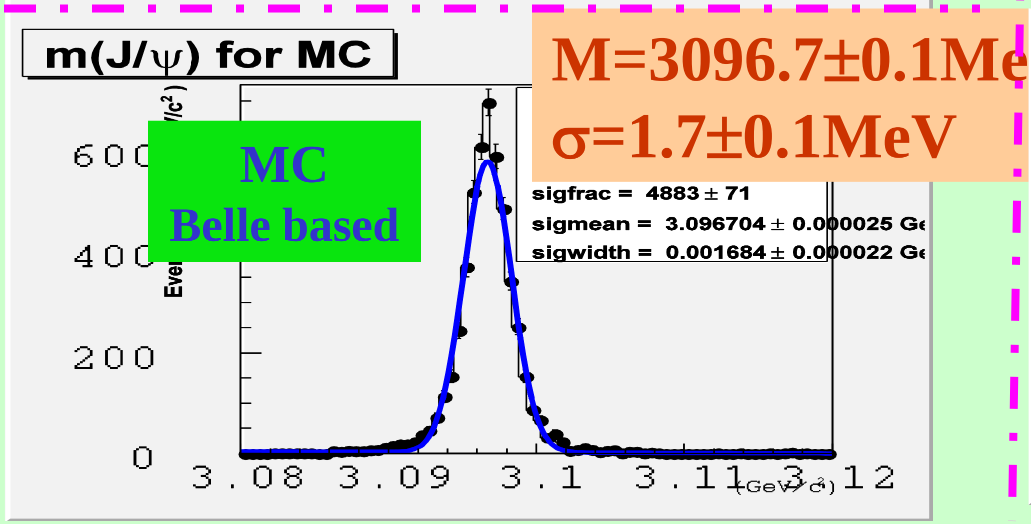
M=3096.7± 0.1MeV

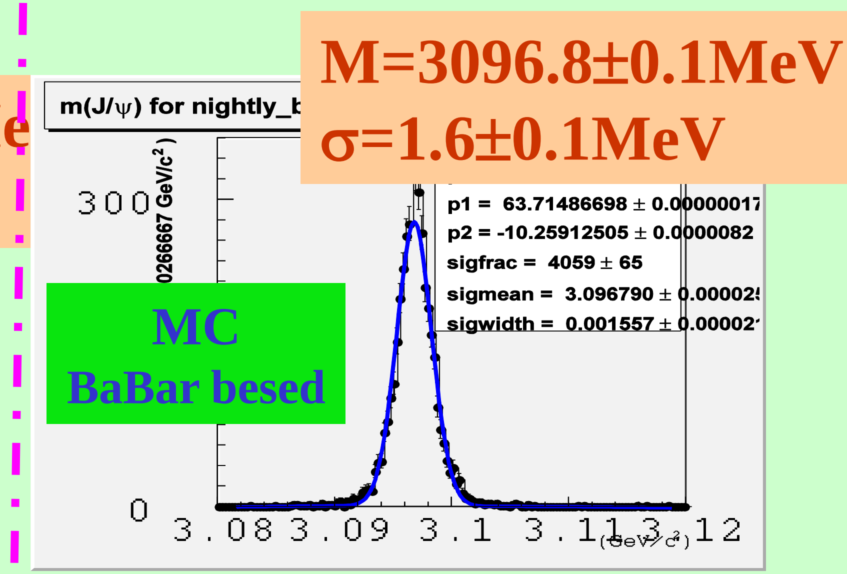
σ=1.5±0.1MeV

$M(\pi^0\pi^+\pi^-)$ Distribution

Nightly_build version



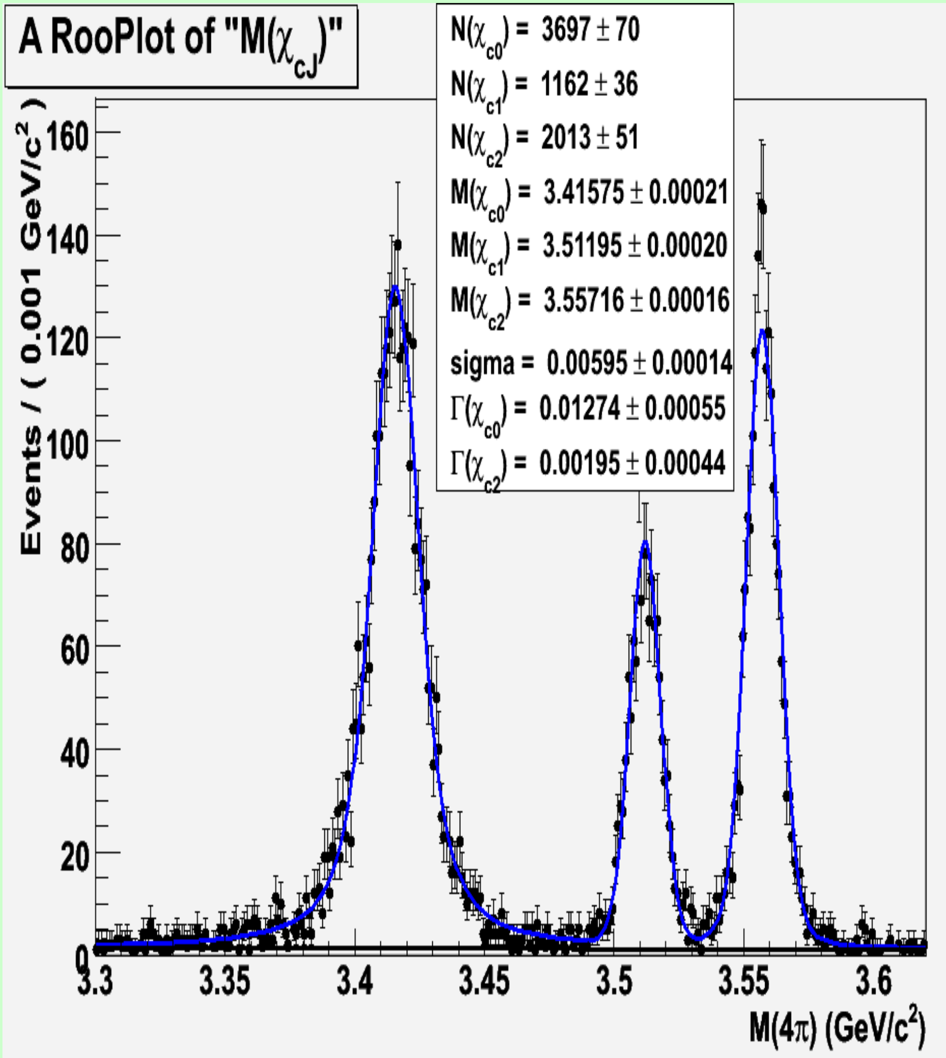




Event selection of $\psi(2S) \rightarrow \gamma \chi_{cJ} \rightarrow \gamma 4\pi$ used for vertex cut and γ information check.

- At least 1 gamma (without cut).
- At least 2 positive and 2 negative tracks (without vertex cut)
- Loop over all neutral and charged tracks to select the γ +2 $(\pi^+\pi^-)$ combination with smallest $\chi^2(4C)$, and require $\chi^2(4C)<20$

•The remaining tracks in the good event are considered to be fake tracks



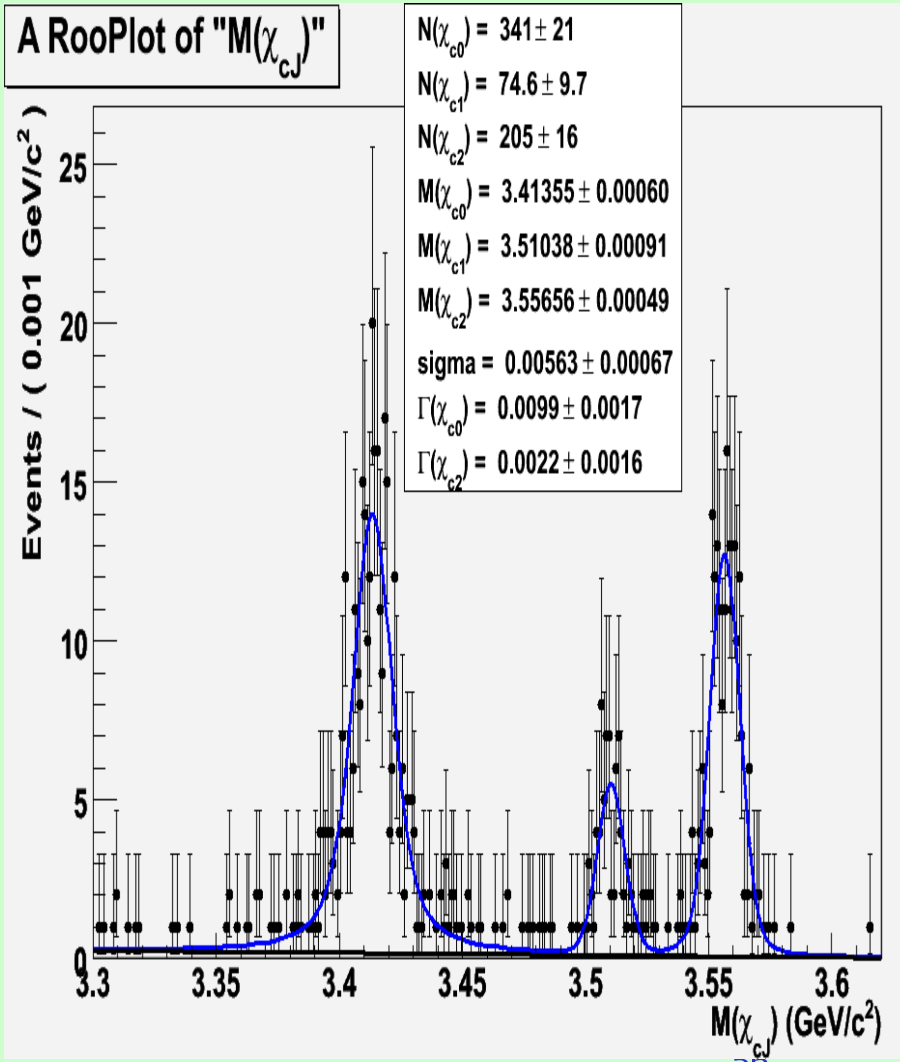
Event selection of $\psi(2S) \rightarrow \gamma\ \chi_{cJ} \rightarrow \gamma 4K$

2 positive 2 negative tracks
(|rvxy|<1cm, |rvz|<10cm),
more than 1 γ

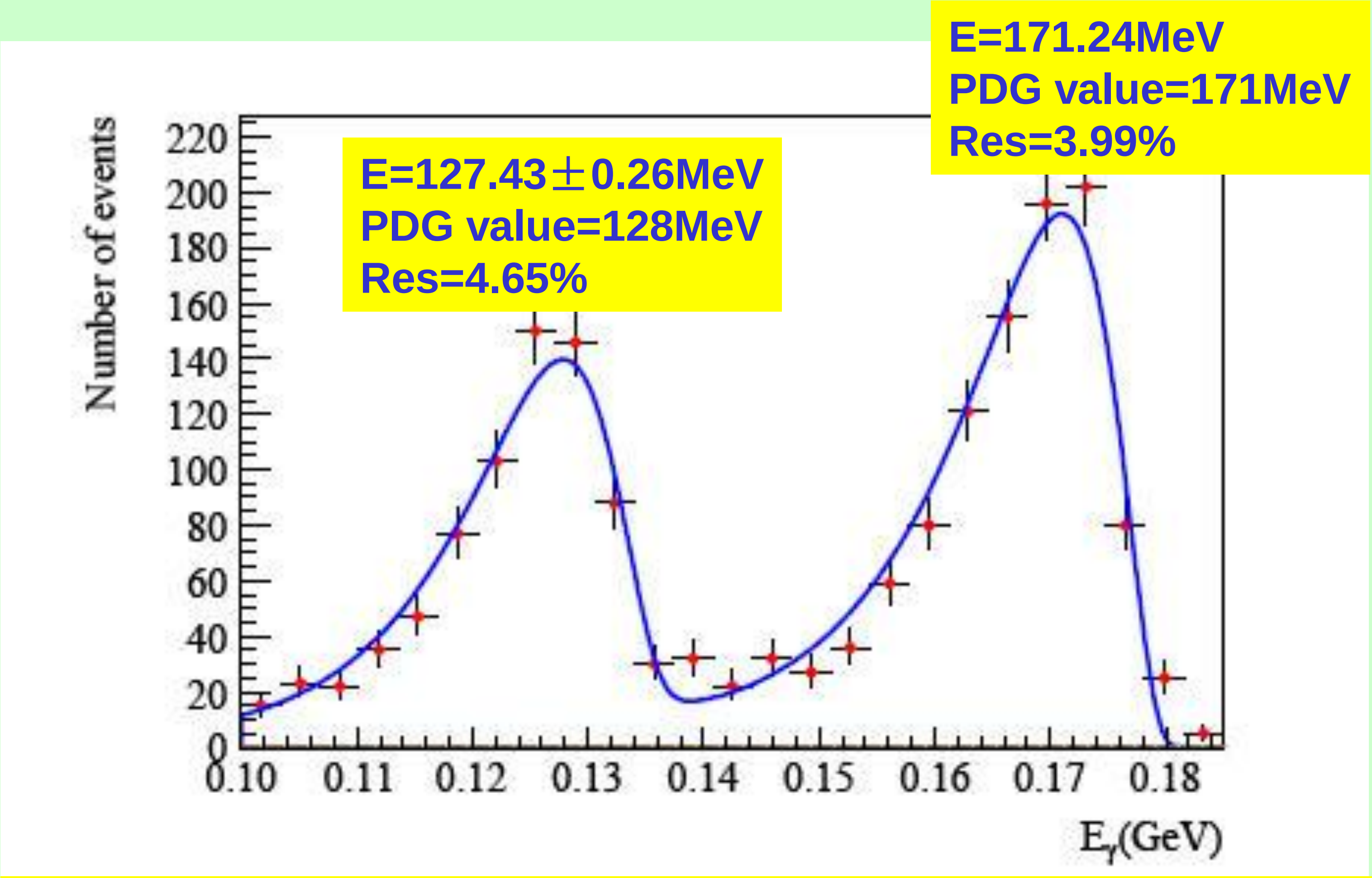
Give four charged tracks the mass of $K^{\pm}$

4C fit of $\psi(2S) \rightarrow \gamma 2(K^+K^-)$
$\chi^2(4C) < 20$.
cut $\pi\ \pi J/\psi$ background

1% backgrounds



Signal of $\chi_{c1,2}$

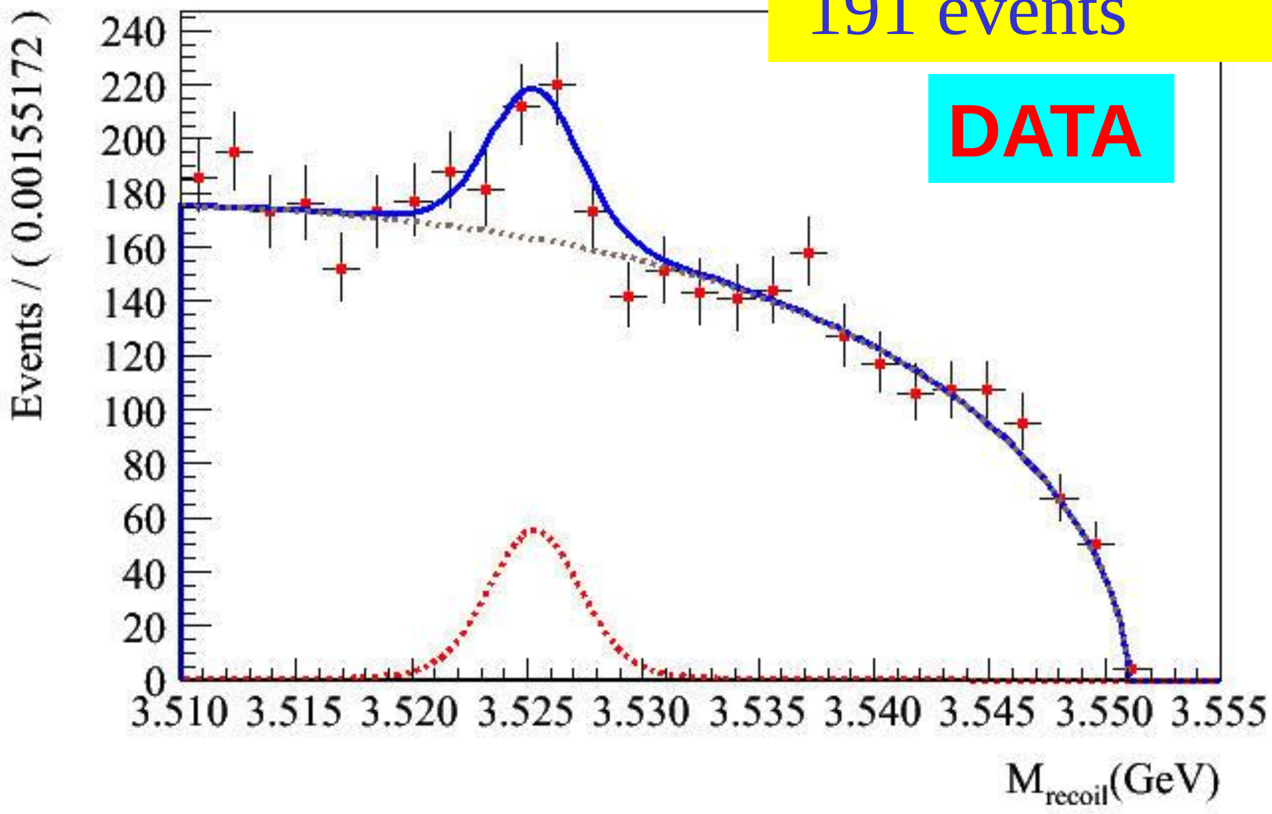


Transition photon energies consist with PDG value after π^0 calibration

h_c signal in DATA

Very preliminary,

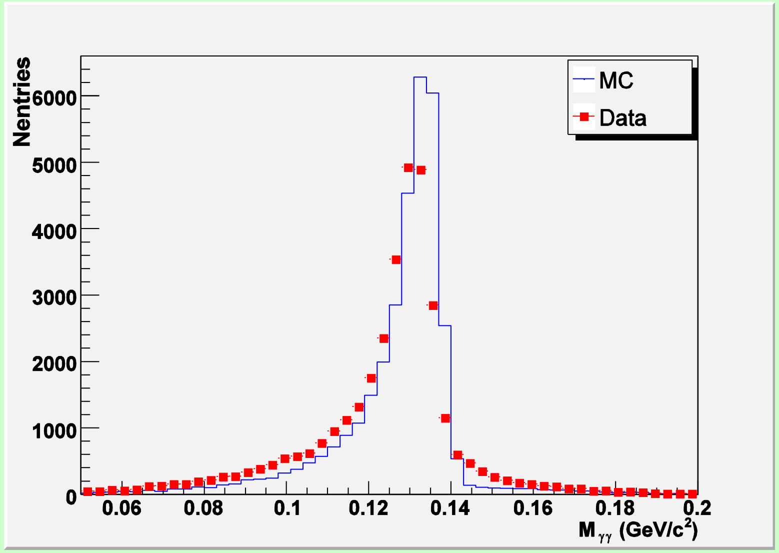
191 events

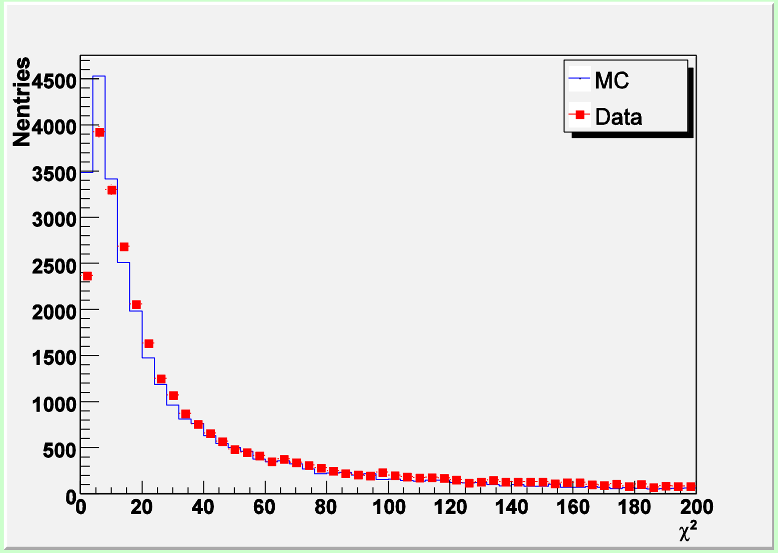


Significance S=5.5σ

Progress report, not for quoting

Some comparisons between Data and MC for $\psi(2S) \rightarrow \pi^0\pi^0 J/\psi$

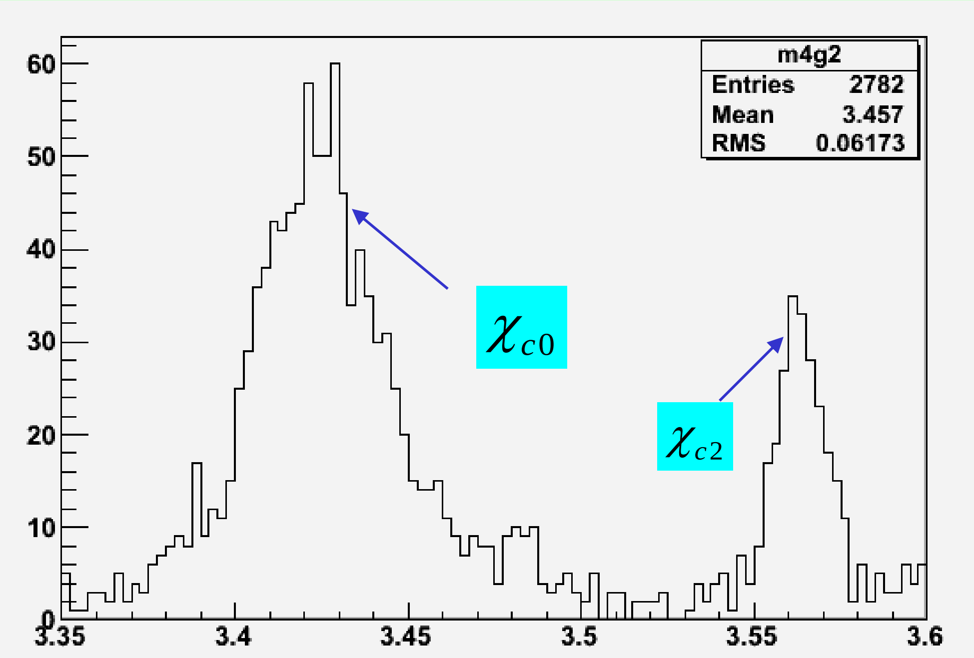




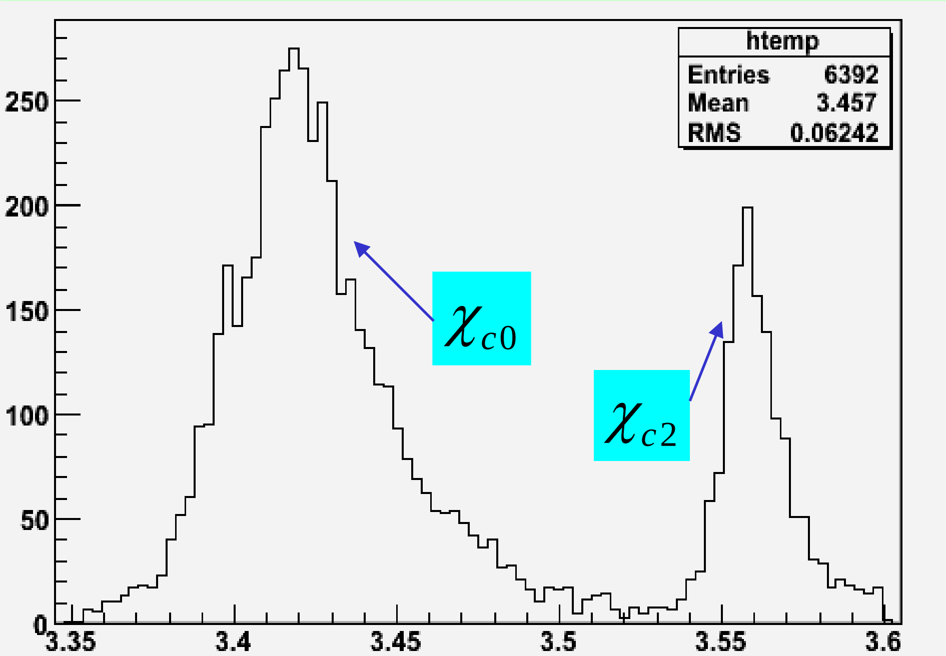
$M\gamma\gamma$ distribution

χ^2 distribution

The $M_{\pi^0\pi^0}$ distribution in high-mass side



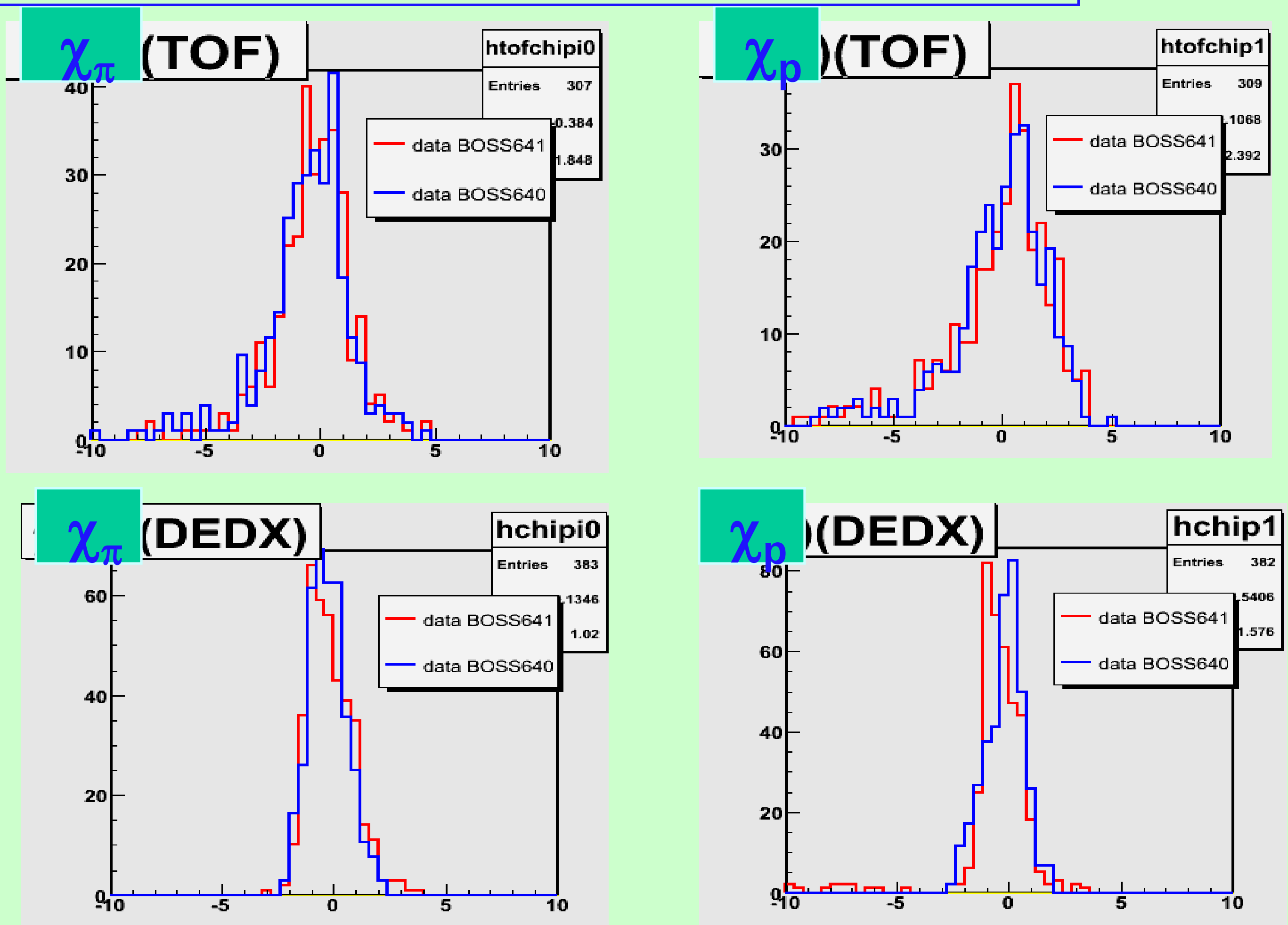
Data



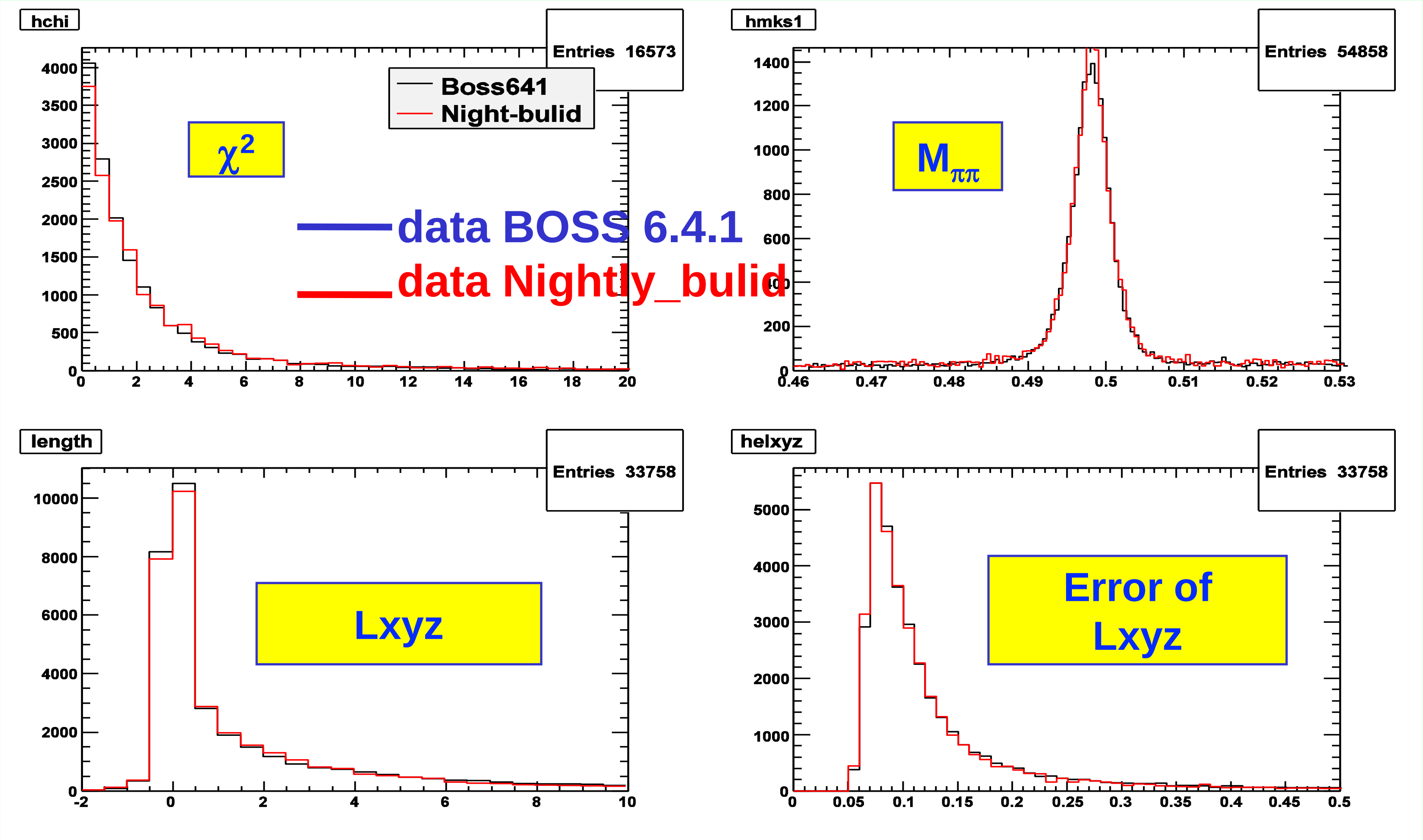
MC

$\psi(2S) \to \pi\pi\, J/\psi,\ J/\psi \to p\, \bar{p}\, \pi^0$

χ **distributions** — **data BOSS 6.4.1** (red), **data BOSS 6.4.0** (blue)



Inclusive Ks for the secondary vertex fit check



The focus of data checking and preparation for physics analysis

- **Improve the MDC calibration and alignment to improve momentum resolution and uniformity;**
- **Check the tracking efficiency, including K_S and Λ, etc;**
- **Check the trigger efficiency, no loss of good events;**
  now the trigger rate can reach ~ 5000 Hz; work with machine people to reduce the backgrounds;
- **Improve detector simulation, Data and MC comparison;**
  Especially for MDC and TOF;
- **Partial Wave analysis and Dalitz plot analysis, and other analysis methods and tools;**

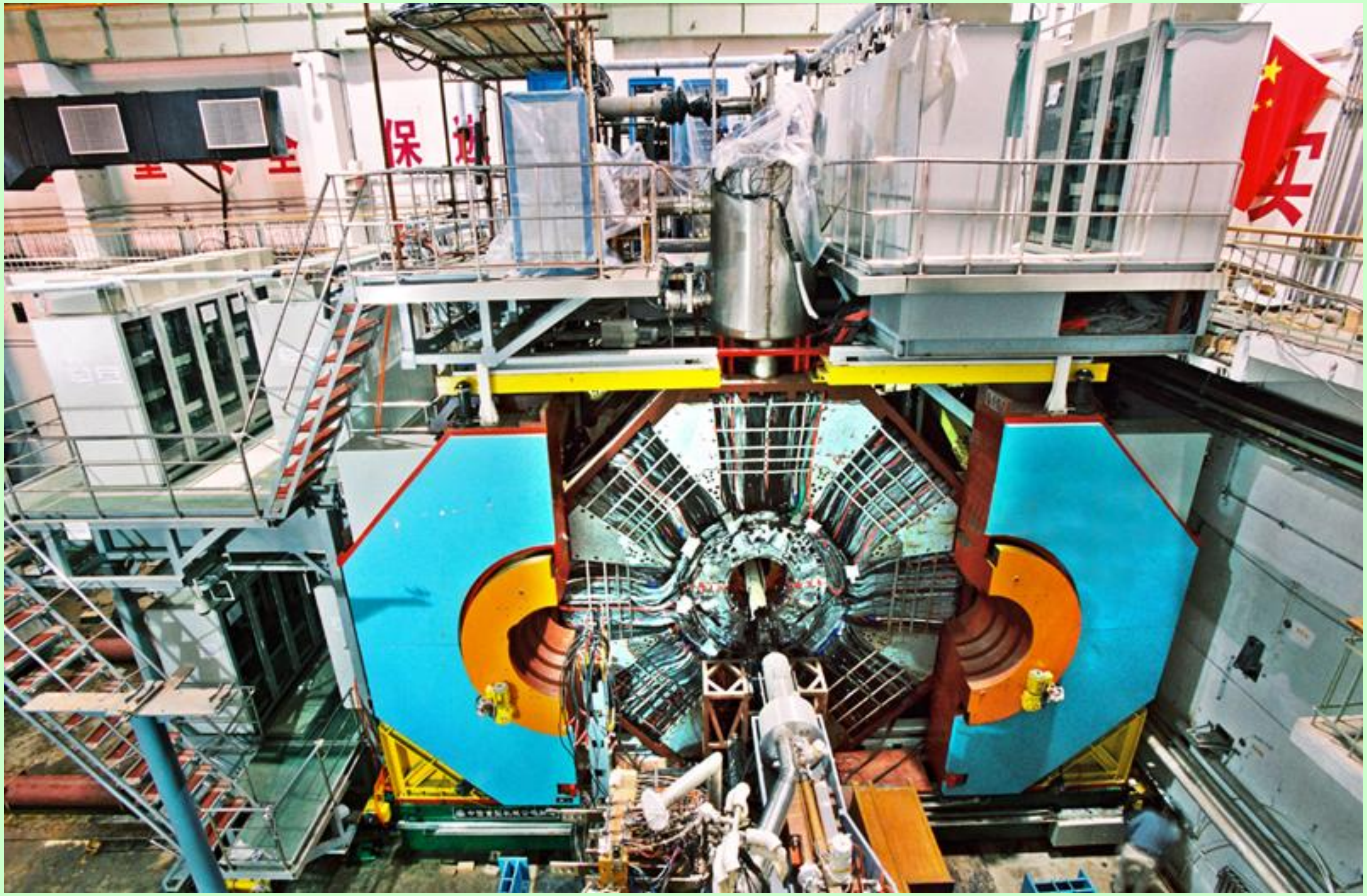
Summary

- **Machine and detector are in good shape, physics data taking started,**

- **More understanding of the detector, through calibration and physics analysis, data/MC consistent is important to reach measurement precision needed,**

- **Many interesting physics can be obtained in the coming years, this year 100 M ψ(2S), 250 M J/ ψ, and scan of ψ (3770) are likely to be collected. Large data sample for charm physics will follow as the machine luminosity keeps increasing.**

Thank you!



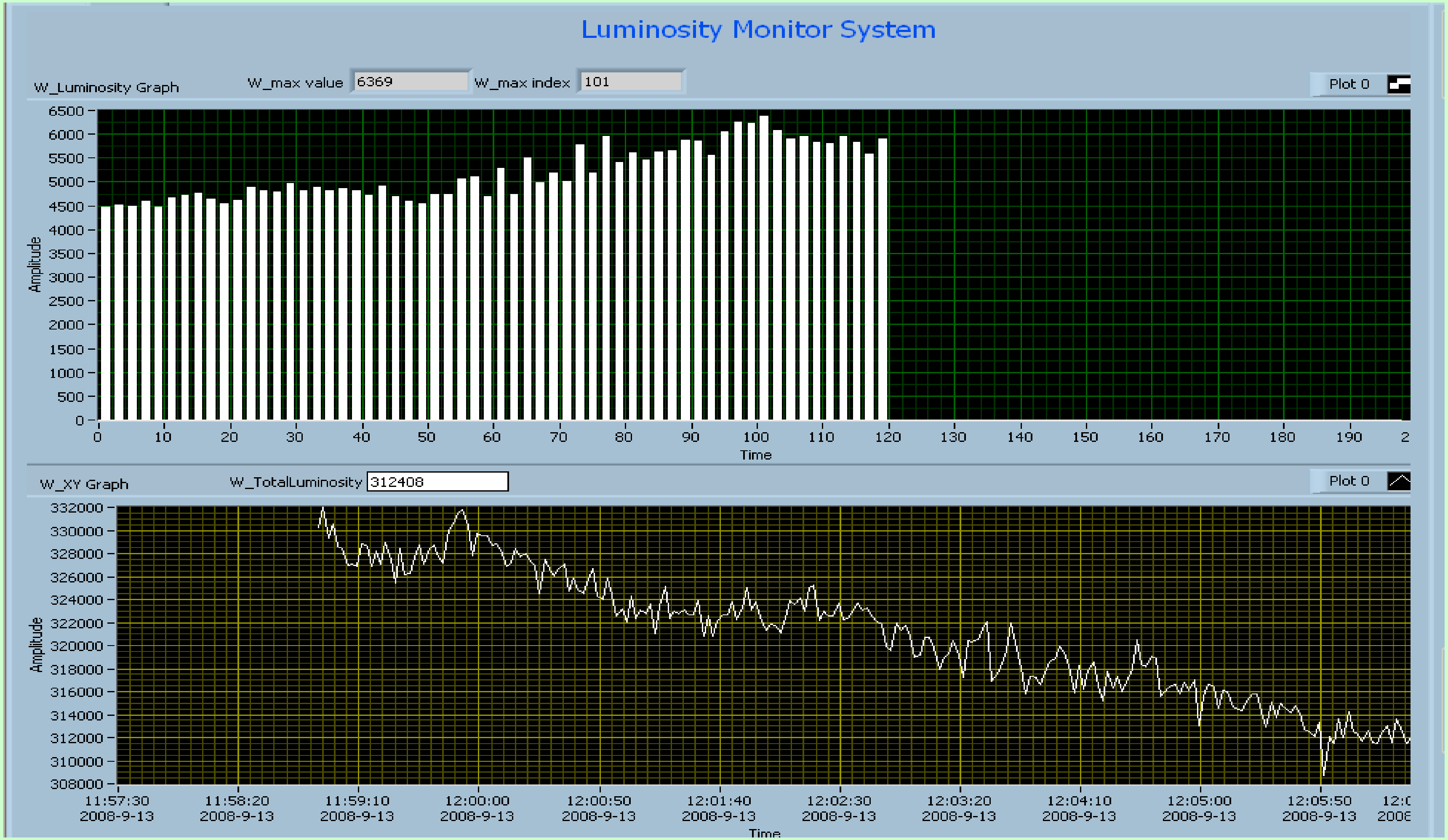
Luminosity Measurements

Two methods are used to measure the machine luminosity

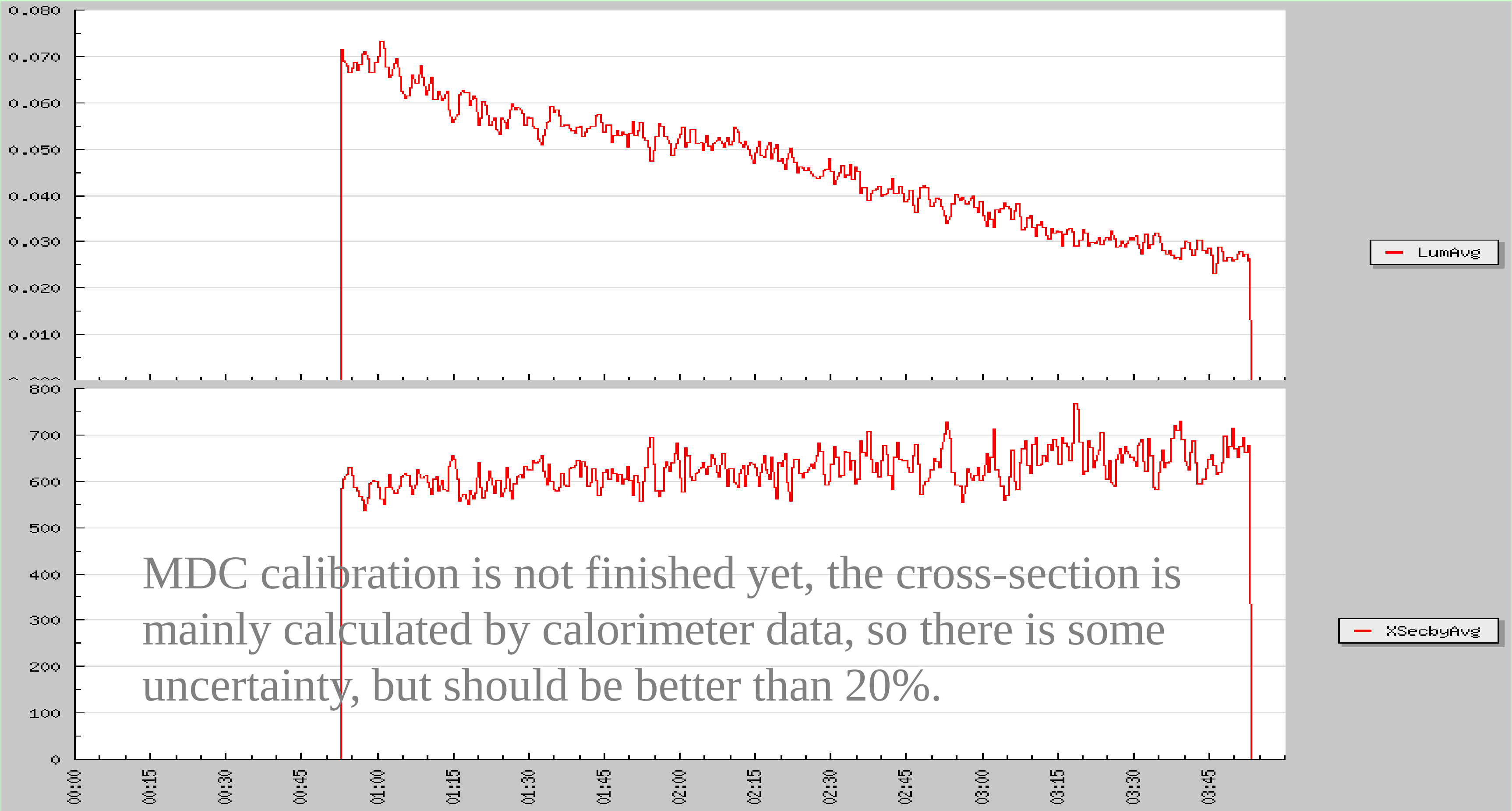
① Small angle luminosity monitor → for machine tune
Large statistics; fast response; bunch by bunch measurement; but subject to beam position variation and large uncertainty of absolute calibration of the luminosity.

② BESIII detector → give luminosity number
More understandable, ~15% and better measurement; can be cross-checked by offline and by different processes; relatively lower statistics, and can not do bunch by bunch measurement.

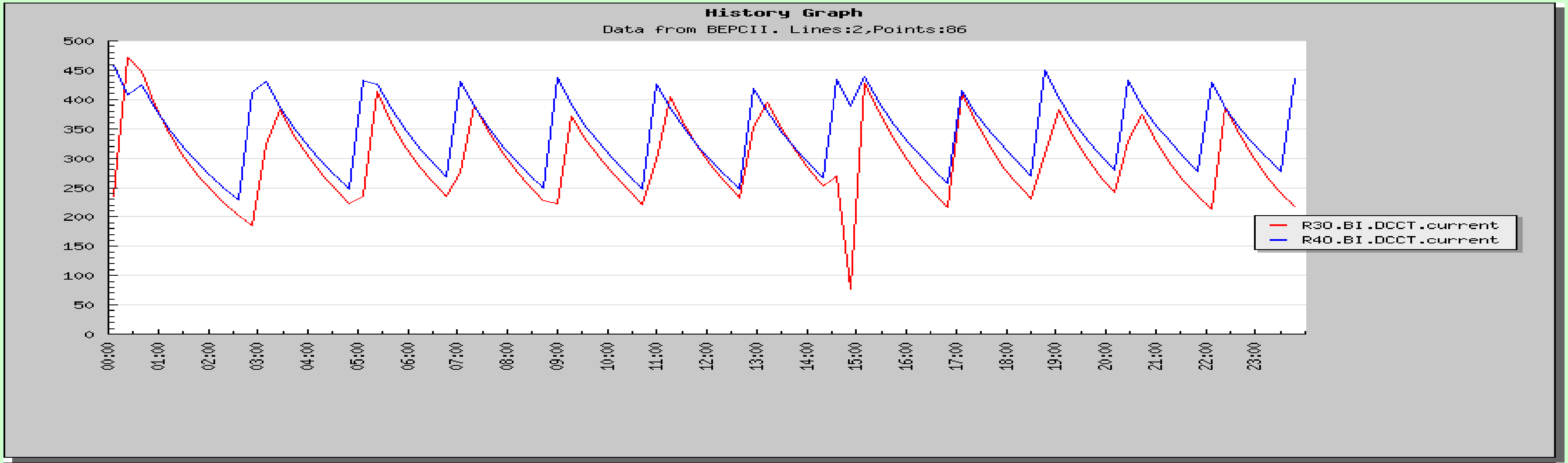
Luminosity measured by small angle monitor

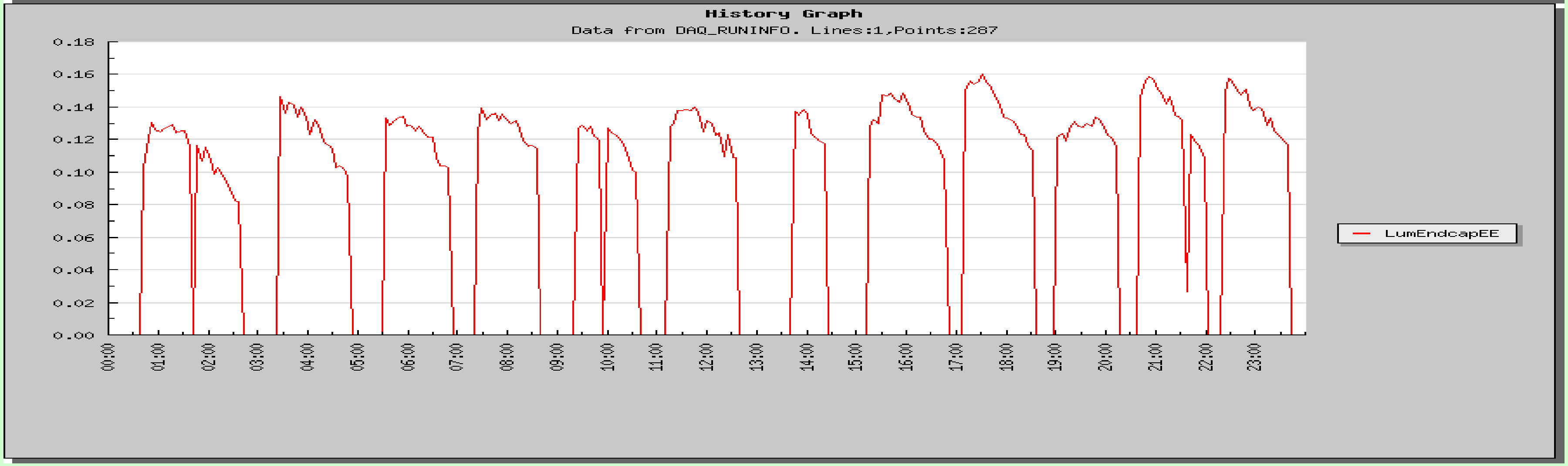


Luminosity measured by EMC



Results from offline and online data analysis are consistent, now the luminosity and cross-section are monitored when ever data are taken.



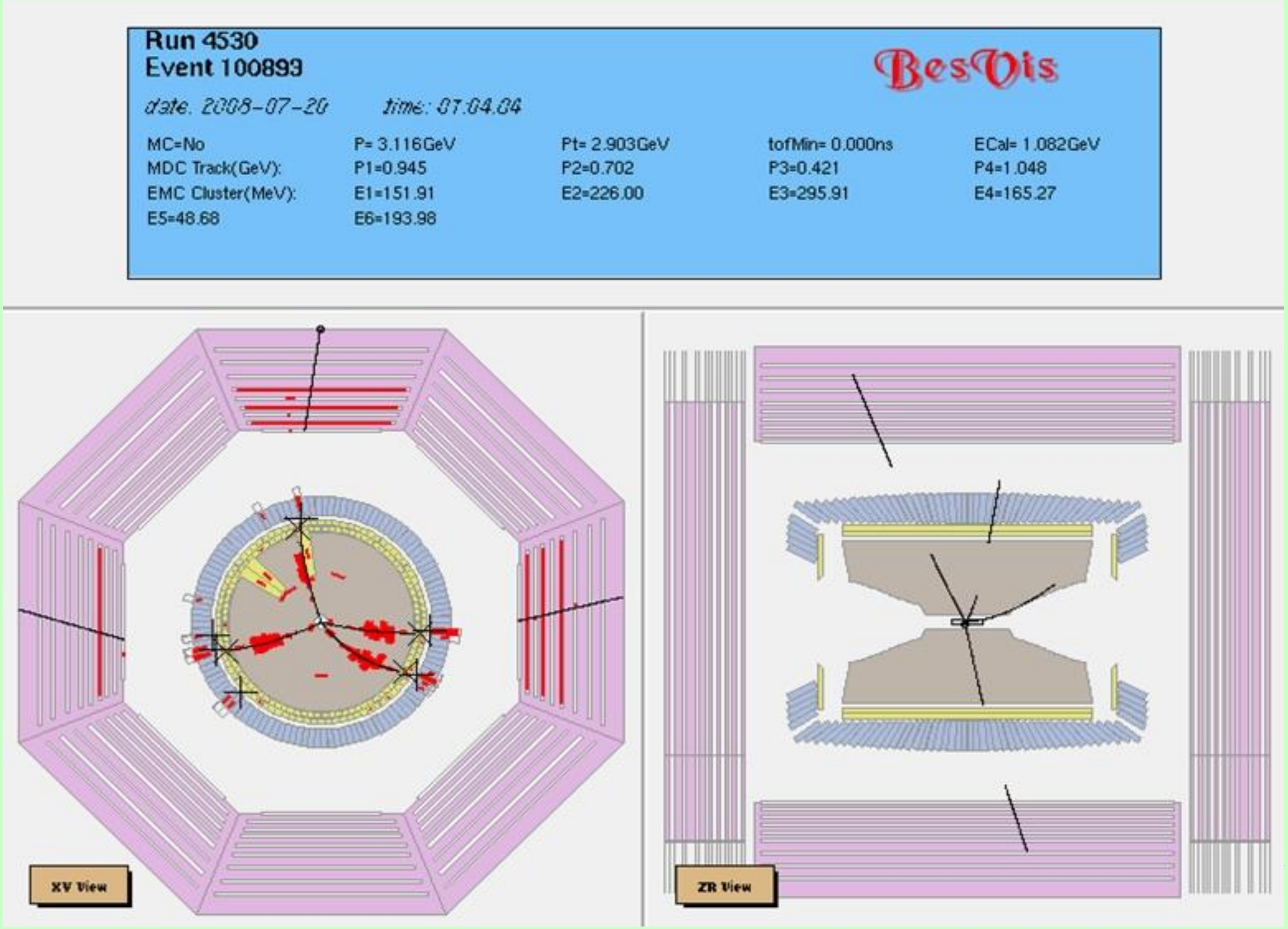


Luminosity curve of March 14, this is a very good period, the hadronic events are estimated to reach 3M/day.

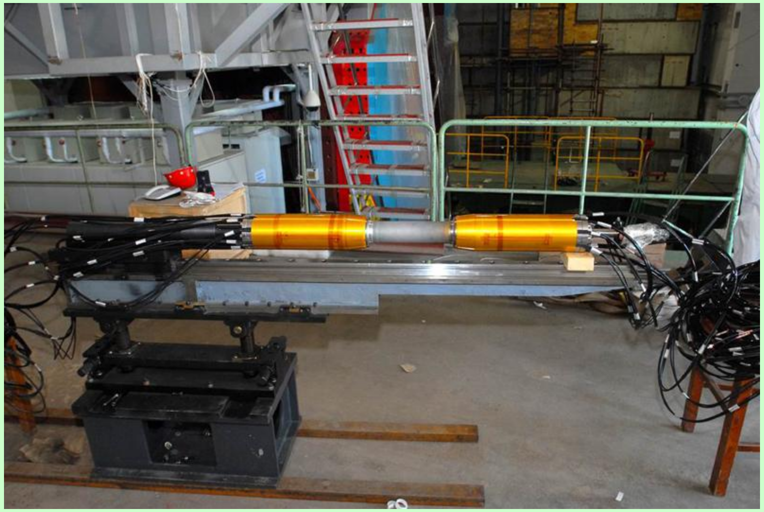
BESIII Status

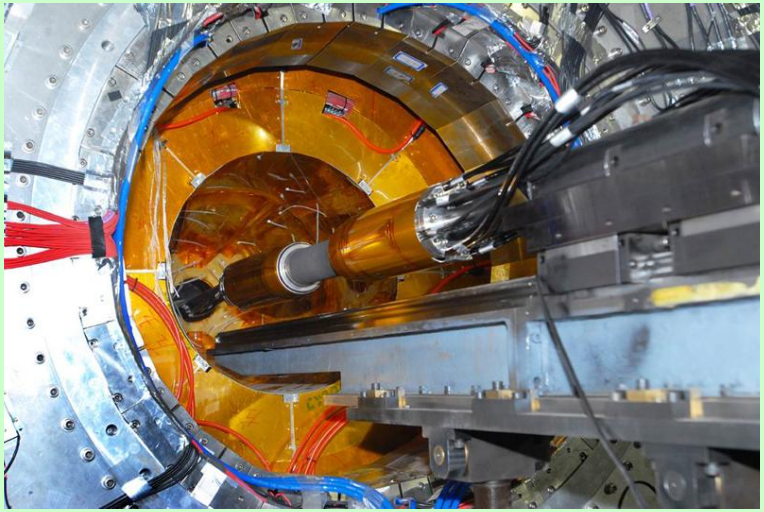
- ✓ Finish the installation of all the detector components.
  Beam pipe, MDC, Barrel and endcap TOF, barrel and endcap EMC, all muon chambers.
- ✓ Cosmic ray data from Dec. 2007 to March 15 2008, with DAQ, Trigger, and Slow control, fixing problems.
- ✓ BESIII detector into beam-line on May 6, 2008
- ✓ Collision on July 20, 2008
- ✓ In Oct. 2008, 11 million $\psi(2S)$ events for calibration
  Performances meet the design
- ✓ Starting $\psi(2S)$ physics data taking, in beginning of March.

The first hadronic event seen in BESIII, July 20, 2008



Be beam pipe





- Two Be cylinders (0.8 mm and 0.5 mm thick, 0.8mm gap), cold by paraffine-1
- 14.6 μm gold at the inner surface.
- The beam pipe was put in the place on March 27, 2008, it is the last component of the BES-III detectors installed.

Drift chamber

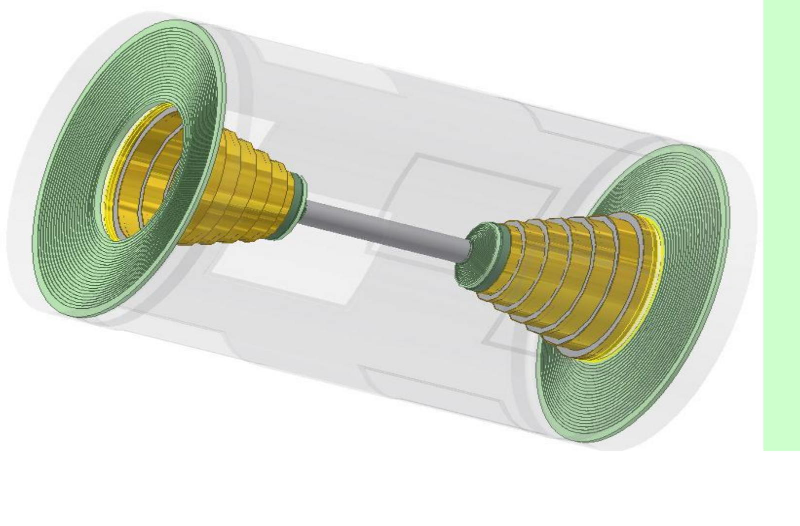
- **To measure the momentum of charged particles**
- **Design spec.:**

	Single wire reso.	dE/dx reso.
CLEO:	~110μm,	5.7%
Babar:	~110μm,	6.2%
Belle:	~130μm,	5.7%
BESIII	~120μm	6 .0%

- **R_{in} = 63mm; R_{out} = 810mm; length = 2400 mm**
- **7000 Signal wires: 25(3% Rhenium) μm gold-plated tungsten**
- **22000 Field wires: 110 μm Al**
- **Gas: He + C_3H_8 (60/40)**
- **Momentum resolution@1GeV:**

0.5%

$$\frac{\sigma_{P_t}}{P_t} = 0.32\% \oplus 0.37\%$$



BESIII CsI(Tl) crystal calorimeter

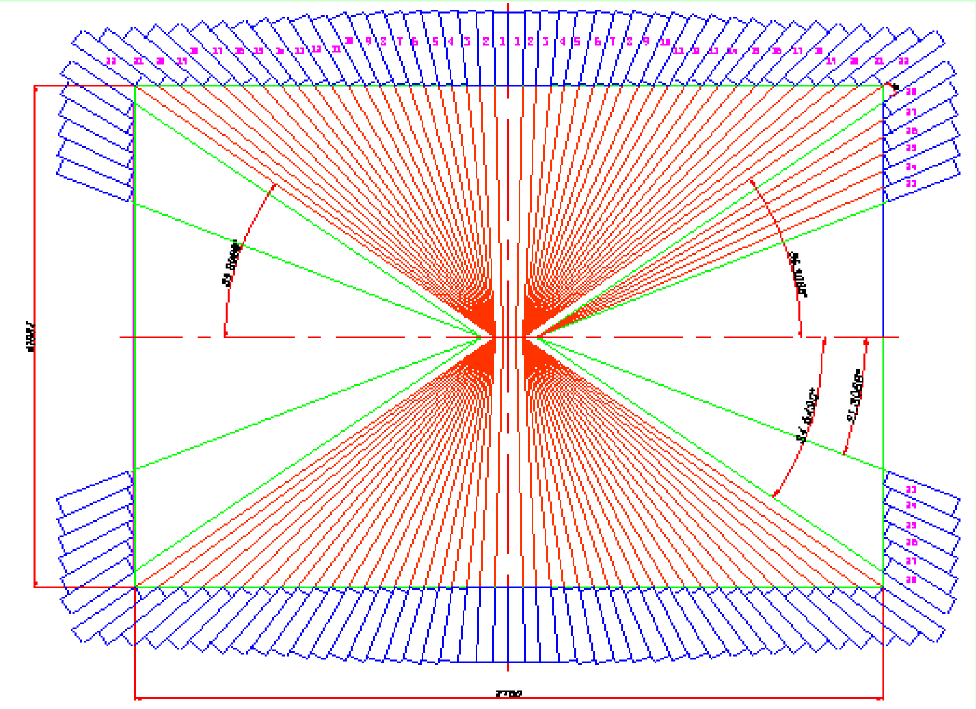
- To measure the energy of electromagnetic particles
- Barrel: 5280 crystals，Endcap: 960 crystals
- Crystal: (5.2x 5.2 – 6.4 x 6.4) x 28cm^3
- Readout: ~13000 Photodiodes, 1cm×2cm,
- Energy range：20MeV – 2 GeV
- position resolution: 6 mm@1GeV
- Tiled angle: theta ~ 1-3^o, phi ~ 1.5^o

Babar: 2.67% @1GeV

BELLE: 2.2% @1GeV

CLEO: 2.2% @1GeV

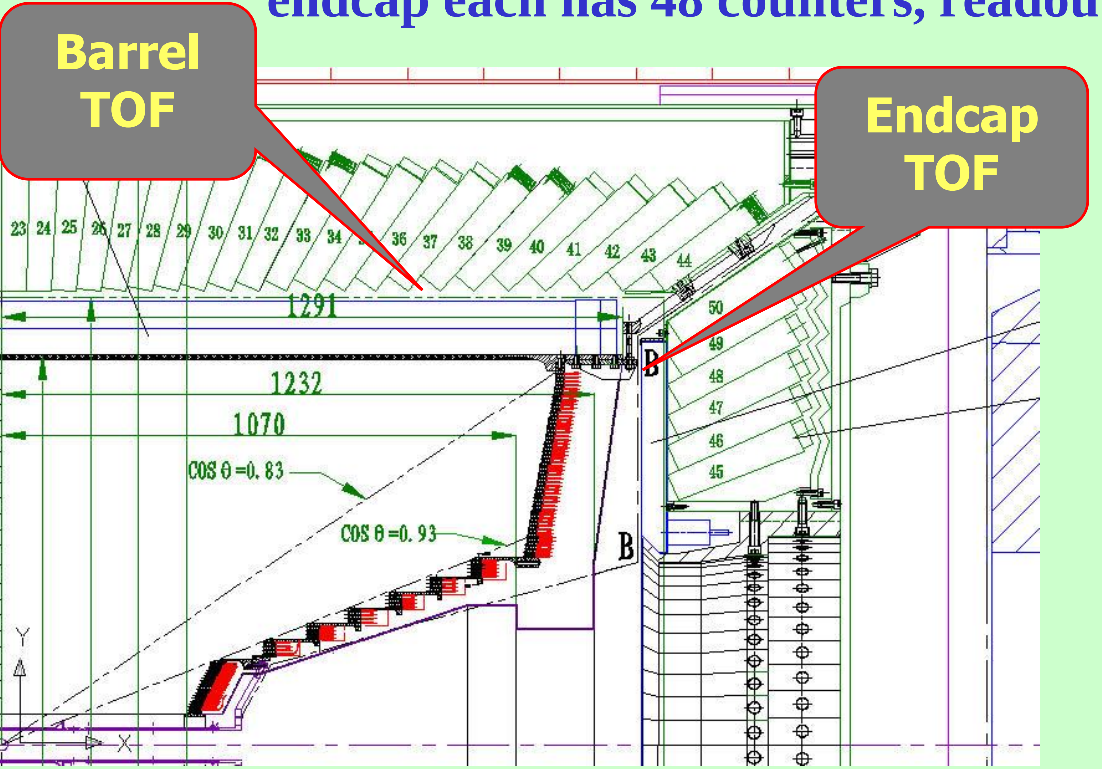
BESIII: 2.5%@1GeV

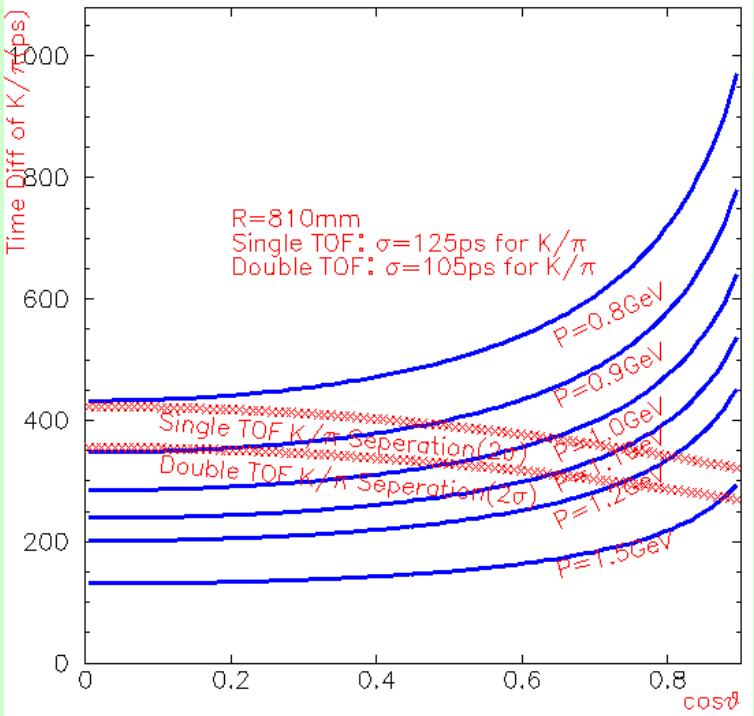


Crystal calorimeter without supporting wall between crystals

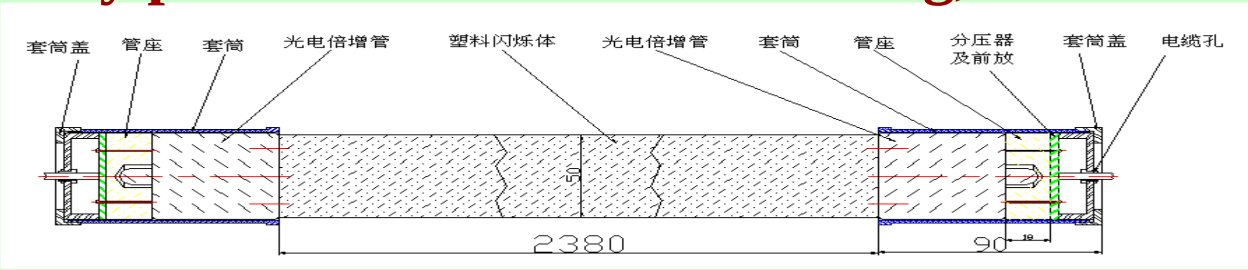
PID: Time-Of-Flight counters

- Double layers at barrel of 88 counters/layer, readout at both ends, endcap each has 48 counters, readout at the inner end.



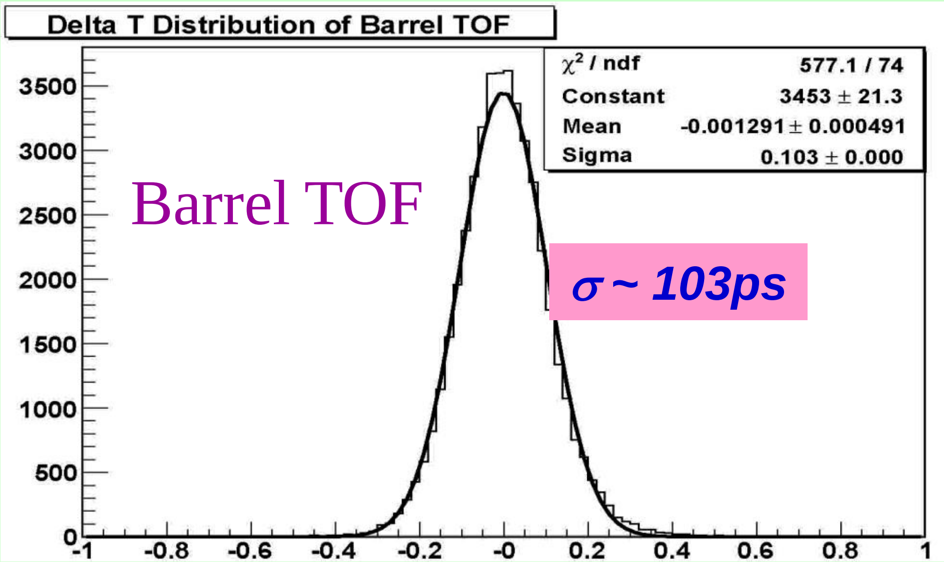


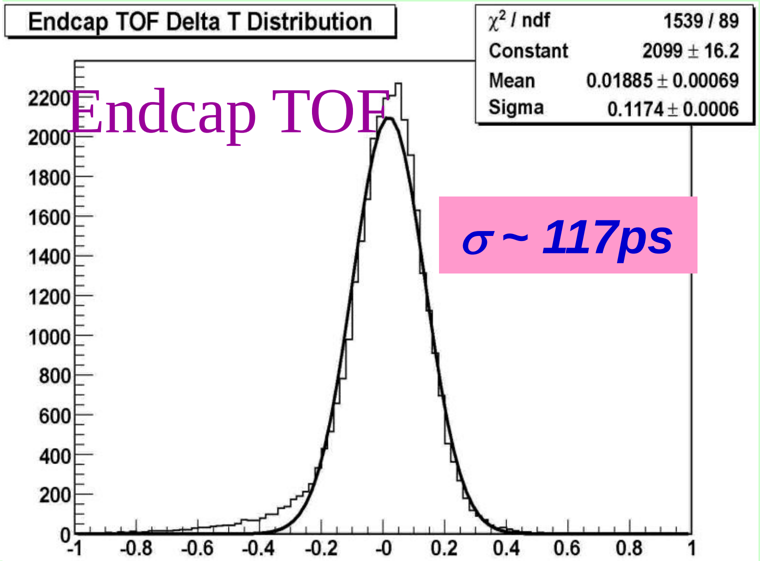
High quality plastic scintillator: 2.4 m long, 5cm thick



TOF

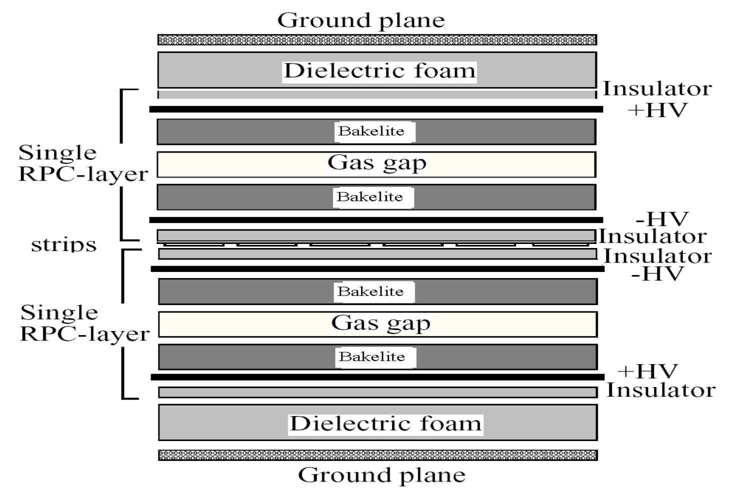
- All scintillator bars from Bicron. BC408 at barrel, BC404 at endcap, PMT:R5924;
- Laser light monitor system;
- All counters are assembled, tested and installed.
- Real data shows the system works.

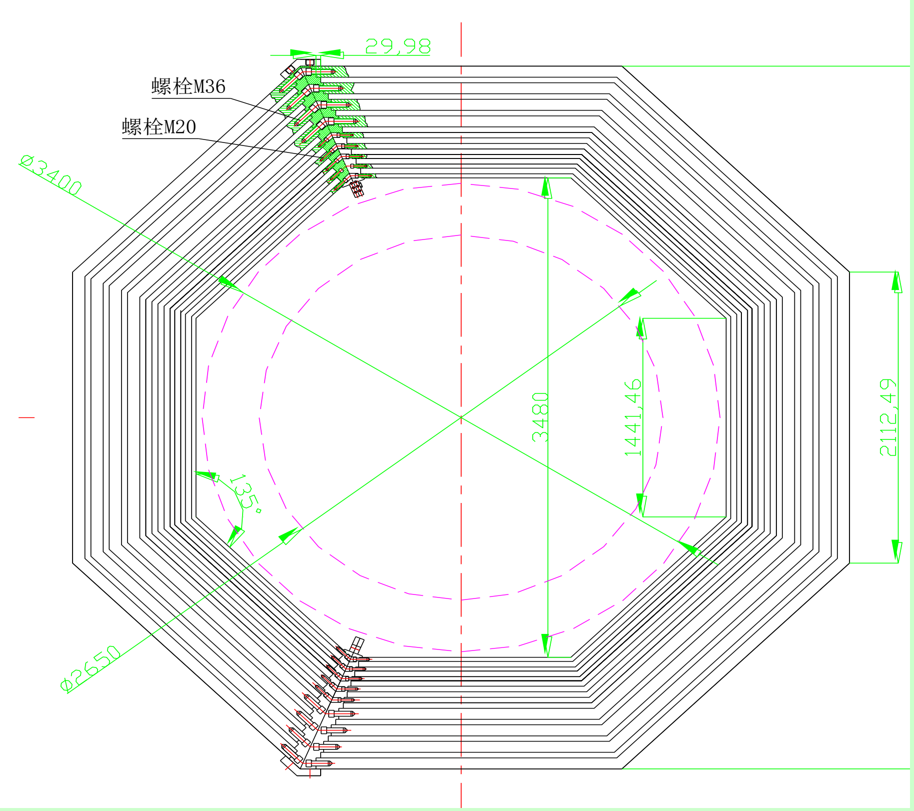




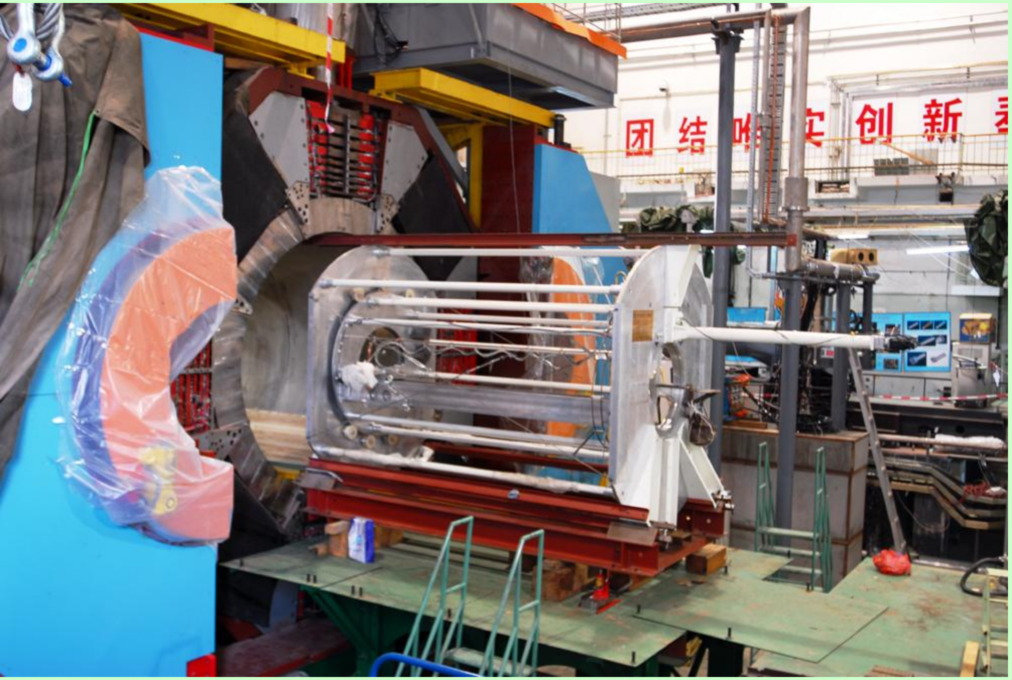
μ system : RPC

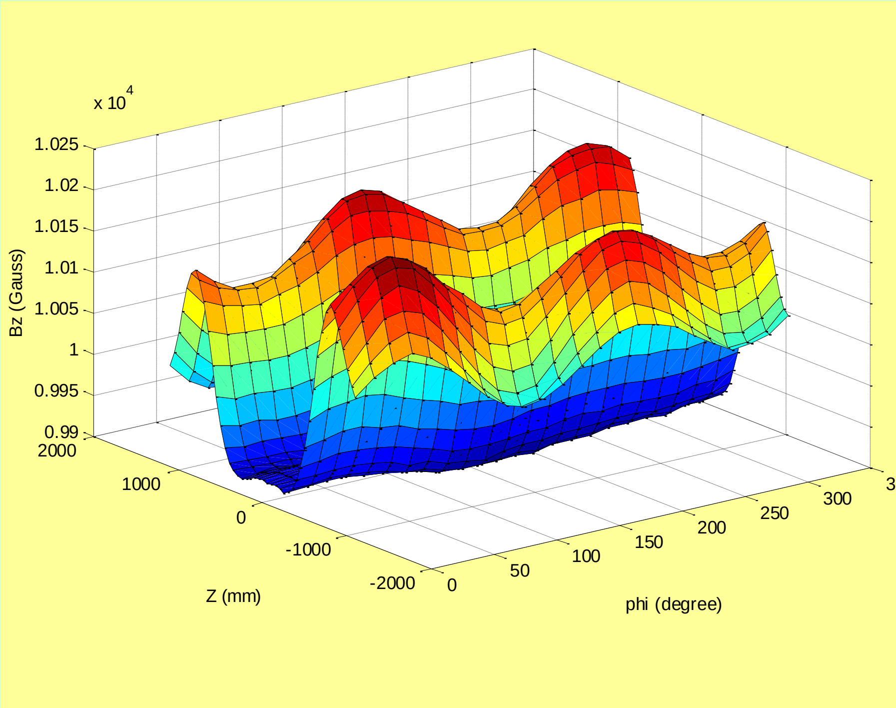
- 9 layer, 2000 m^2
- Special bakelite plate w/o linseed oil
- 4cm strips, ~10000 channels
- Noise less than 0.1 Hz/cm^2





Magnet reached 1 tesla （3364A)





- ✓Tests of QCD at low energy in various way:
  light hadron spectrum, charmonium decays and spectrum, light hadron decays, decay constants;
- ➢ Precise measurements: test of SM (R values, tau mass);
- ➢ New Physics probe at BES-III:

(0) Rare and forbidden decays of quarkonia

(1) Rare decays of Charm meson

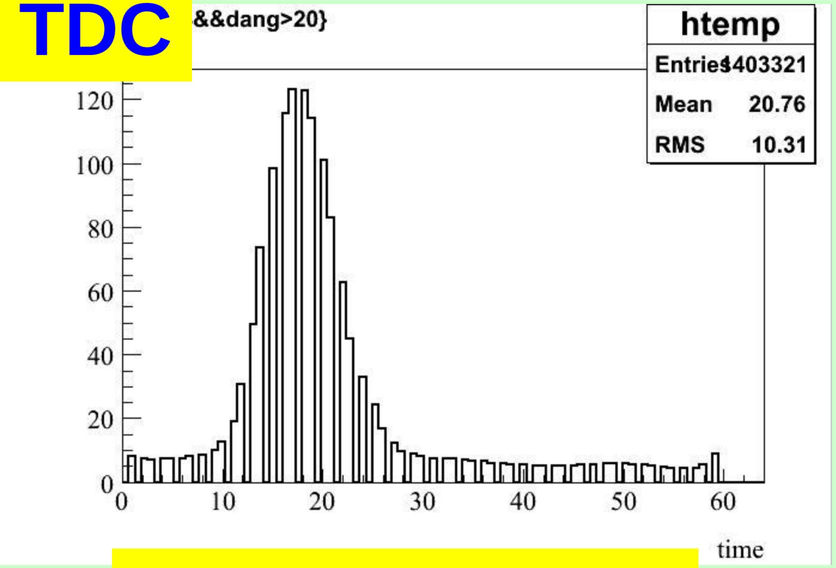
(2) D^0-D^0bar mixing

(3) CP violation in D meson decays

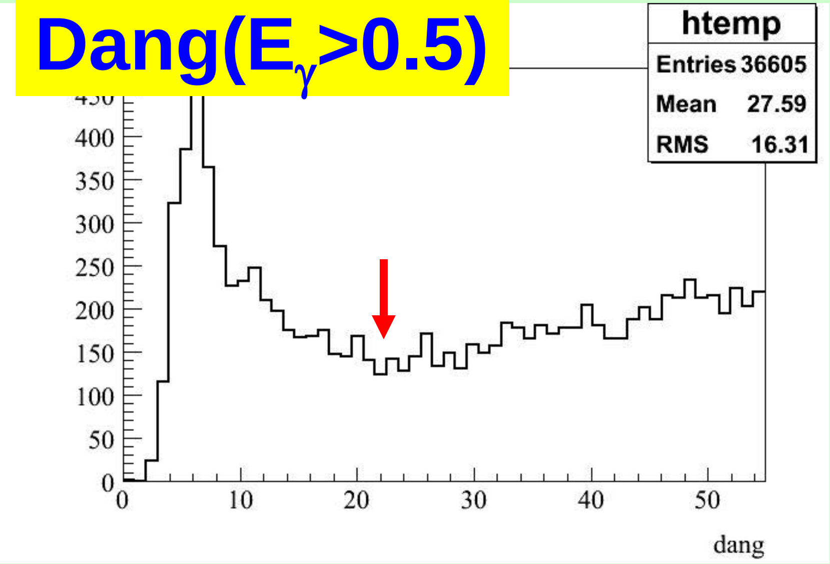
(4) Lepton Flavor/baryon number violated decays

Photon selection

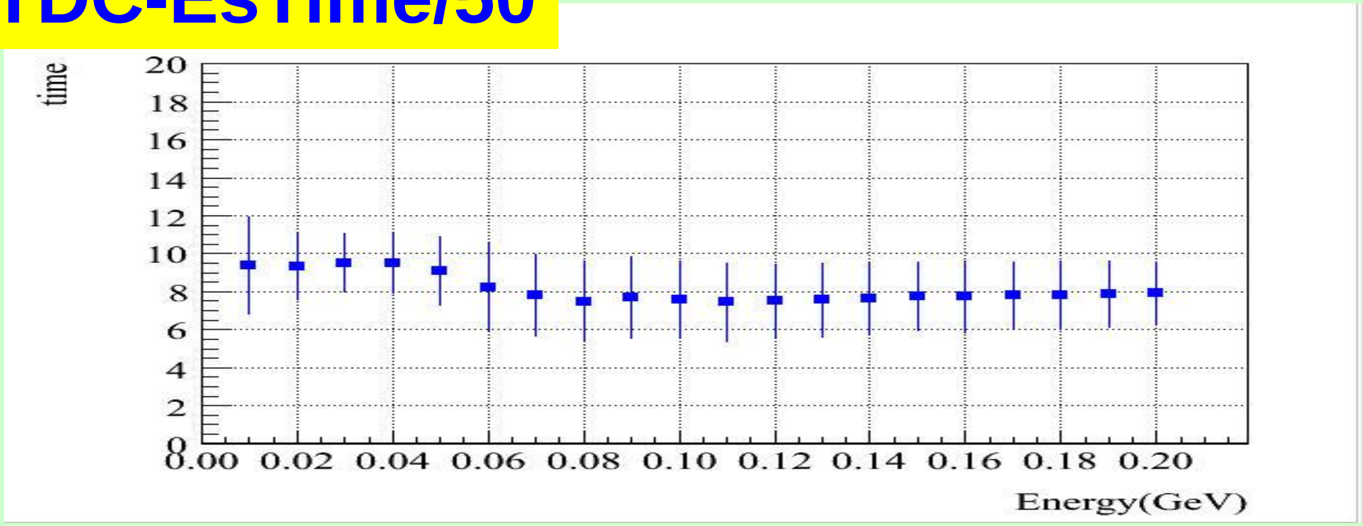
TDC



Dang(E_γ>0.5)



TDC-EsTime/50



The η/η' mesons

Production rate of η/η' :

20 M (η) **and 51 M (**η') **in J/ψ → $\gamma\eta(\eta')$, $\phi\eta(\eta')$**

93 M η sample in $\psi(2S)$ → J/$\psi\eta$ decay

High production rate of η/η' allows :

- Measurement of basic meson parameters
- Precise determination of kinematical distributions for processes with larger rate, thus providing an invaluable test-bed for QCD at low energy
- Search for rare decays

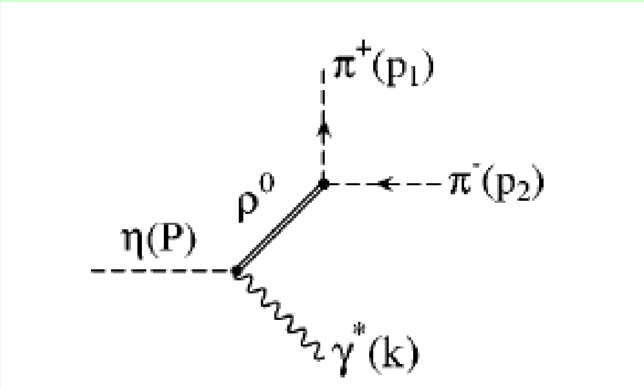
From S. Giovannella – Light Meson Spectroscopy – LP07

The η/η' mesons

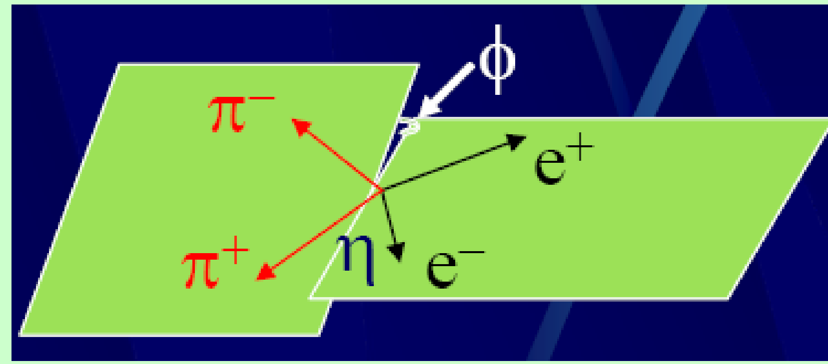
Physics of η and η' decays:

- $\eta, \eta' \rightarrow 3\pi$ decays $\Rightarrow m_u/m_s, m_d/m_s$
- $\eta' \rightarrow \eta\pi\pi$ $\Rightarrow$ scalars (a_0)
- $\eta' \rightarrow \pi^+\pi^-\gamma$ $\Rightarrow$ QCD anomaly
- η' radiative decays $\Rightarrow$ η' quark structure
- Dalitz decays $\Rightarrow$ formfactors
- $\eta \rightarrow e^+e^-$ $\Rightarrow$ new interactions
- $\eta \rightarrow \pi^\circ e^+e^-,\ \pi^+\pi^-e^+e^-$ $\Rightarrow$ C, CP tests

CP asymmetry in η (η' or η_c)→$\pi^+\pi^-l^+l^-$



Phys. Rev. C 61 (2000) 035206
η decay in two steps.



Gao Dao-neng

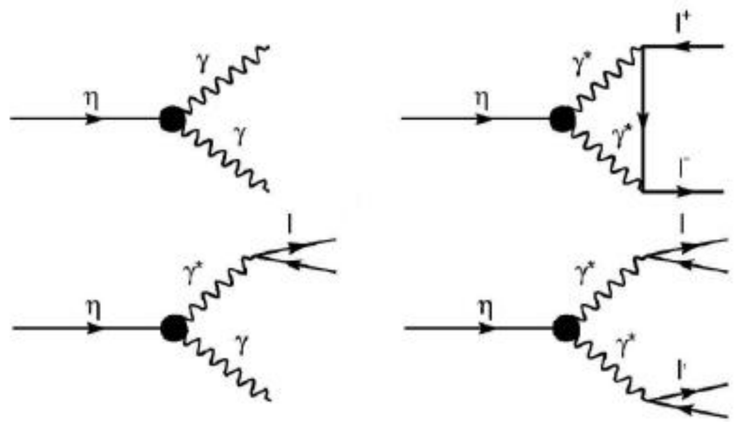
Mod. Phys. Lett. A 17, (2002) 1583

$$\mathcal{A}_{CP} = \langle \mathrm{sign}(\sin\phi\cos\phi)\rangle = \frac{\int_0^{2\pi} \frac{d\Gamma(\eta\to\pi^+\pi^-e^+e^-)}{d\phi} d\phi\, \mathrm{sign}(\sin\phi\cos\phi)}{\int_0^{2\pi} \frac{d\Gamma(\eta\to\pi^+\pi^-e^+e^-)}{d\phi} d\phi}.$$

Unconventional CPV: $$A_{CP} = \frac{N_+ - N_-}{N_+ + N_-}, \qquad N_\pm = sign(\sin\phi\cos\phi)$$

Rare η (η' or η_c) decays

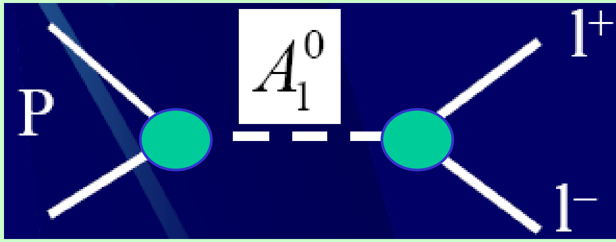
PRD75, 114007 (2007)
A.E.Dorokhov and M.A.Ivanov



PDG: $Br(\eta \rightarrow \mu^+\mu^-)=(5.8\pm0.8)*10^{-6}$

Fig. 1. Feynman diagrams for the various η decays. Letter l represents an electron or a muon.

CP odd Higgs may enhance the rare decay rates of $\eta\rightarrow l^+l^-$

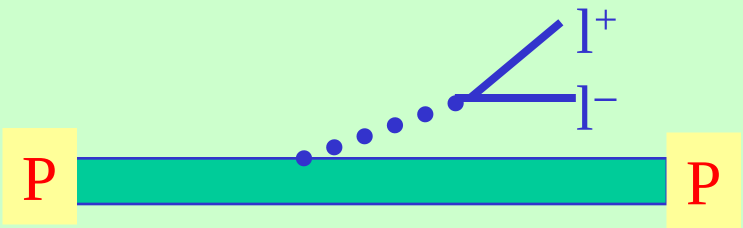


Bob and Shou-hua

Look for :

$\eta(\eta', \eta_c) \rightarrow e^+e^-, \mu^+\mu^-$

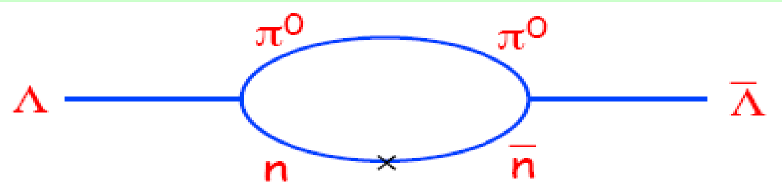
$\eta(\eta', \eta_c) \rightarrow \pi^0 e^+e^-, \pi^0\mu^+\mu^-$; C parity vidation



$\Lambda - \Lambda$bar oscillation in $\psi \to \Lambda\Lambda$bar

PRL 96, 061801 (2006)
PRL 97 131301
PRL 98 161301 R.N. Mohapatra et al

B number may not be conserved
Grand unification predictions:
$\Delta B = -1$, $\Delta L = -1$ in B-L conserving process proton → e+ pi0
B violating process: n-nbar oscillation
If n-nbar oscillation: Λ-Λbar oscillation exists!



The equation of motion in a static magnetic field is:

$$\frac{d}{dt}\begin{pmatrix}\Lambda \\ \overline{\Lambda}\end{pmatrix} = -\frac{i}{\hbar}\begin{pmatrix} m_\Lambda - \Delta E_\Lambda & \delta m_{\Lambda\overline{\Lambda}} \\ \delta m_{\Lambda\overline{\Lambda}} & m_{\overline{\Lambda}} - \Delta E_{\overline{\Lambda}} \end{pmatrix}\begin{pmatrix}\Lambda \\ \overline{\Lambda}\end{pmatrix}$$

where

$$\Delta E = -\vec{\mu}\cdot\vec{B}$$

The probability of oscillation is then given by

$$P_{\overline{\Lambda}}(t) = \left(\frac{\omega_m^2}{\omega_m^2 + \omega_B^2}\right)\sin^2\sqrt{\omega_m^2 + \omega_B^2}\,t$$

$\psi \to \Lambda\Lambda$bar coherent production
Looking for $\psi \to \Lambda_1\Lambda_2$
$\to (p\,\pi^-)(p\pi^-)$
or $(\bar{p}\,\pi^+)(\bar{p}\,\pi^+)$
at BES-III with 10^{10} :

$$\delta m = \frac{N[\psi \to (p\pi^-)(p\pi^-)]}{N[\psi \to (p\pi^-)(\bar{p}\pi^+)]} \times \frac{1}{\tau}$$

$$\delta m < \frac{2.3}{1.5\times 10^7} \times \frac{1}{10^{-9}} = 1.3\times 10^{-19}\, MeV$$

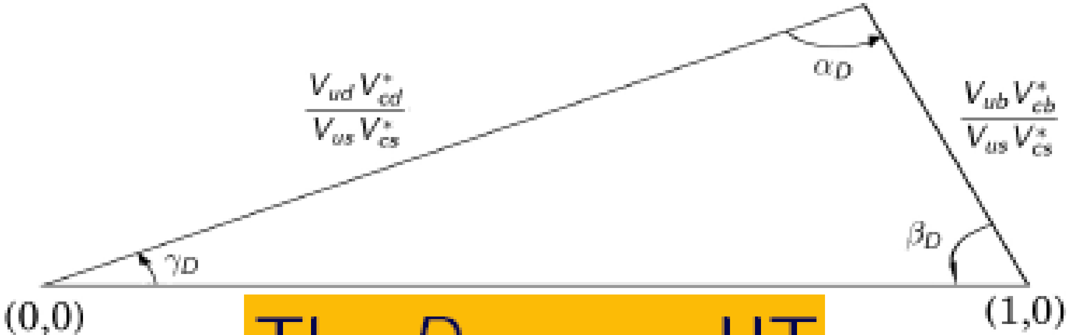
$$\delta m(n-\bar{n}) < 10^{-26}\, MeV\,(PDG)$$

The D-meson Unitarity triangle

Many unitarity relations, related to four hadrons (top excluded)

- B_d meson : $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \quad (\lambda^3, \lambda^3, \lambda^3)$
- B_s meson : $V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0 \quad (\lambda^4, \lambda^2, \lambda^2)$
- K meson : $V_{ud}V_{us}^* + V_{cd}V_{cs}^* + V_{td}V_{ts}^* = 0 \quad (\lambda, \lambda, \lambda^5)$
- D meson : $V_{ud}V_{cd}^* + V_{us}V_{cs}^* + V_{ub}V_{cb}^* = 0 \quad (\lambda, \lambda, \lambda^5)$

$$\frac{V_{ud}V_{cd}^*}{V_{us}V_{cs}^*} + 1 + \frac{V_{ub}V_{cb}^*}{V_{us}V_{cs}^*} = 0$$



The D-meson UT

can be used to define a (squashed) D-meson unitarity triangle

- $\bar{\rho}_D + i\bar{\eta}_D = -\frac{V_{ud}V_{cd}^*}{V_{us}V_{cs}^*}$
- $\alpha_D = \arg\left(-\frac{V_{ub}V_{cb}^*}{V_{ud}V_{cd}^*}\right) = \arg\left(-\frac{V_{ub}V_{ud}^*}{V_{cb}V_{cd}^*}\right) = -\gamma$
- $\gamma_D = \arg\left(-\frac{V_{ud}V_{cd}^*}{V_{us}V_{cs}^*}\right) = O(\lambda^4)$
- $\beta_D = \arg\left(-\frac{V_{us}V_{cs}^*}{V_{ub}V_{cb}^*}\right) = \pi - \alpha_D - \gamma_D = \pi + \gamma + O(\lambda^4)$

The first order sensitivity to strong phase

CP even:

$$D_1 = \frac{1}{\sqrt{2}}\left(D^0 + \overline{D}^0\right)$$

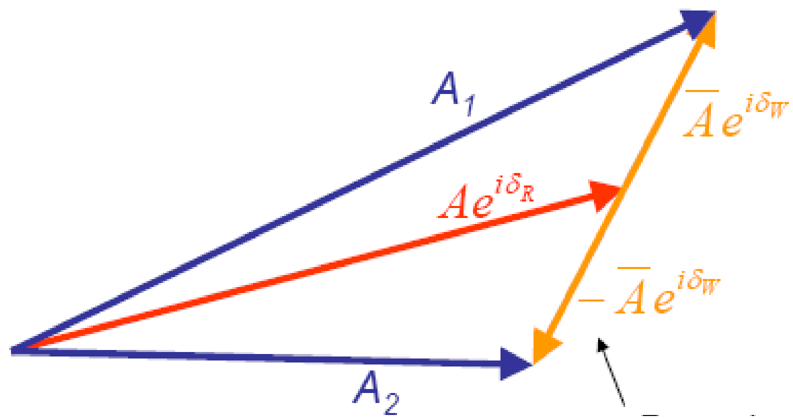
CP odd :

$$D_2 = \frac{1}{\sqrt{2}}\left(D^0 - \overline{D}^0\right)$$

Consider the amplitudes for these mass eigenstates decaying to $K^-\pi^+$:

$$A_1 = \langle K^-\pi^+ | D_1\rangle = \frac{1}{\sqrt{2}}\left(\langle K^-\pi^+ | D^0\rangle + \langle K^-\pi^+ | \overline{D}^0\rangle\right) \equiv \frac{1}{\sqrt{2}}\left(Ae^{i\delta_R} + \overline{A}e^{i\delta_W}\right)$$

$$A_2 = \langle K^-\pi^+ | D_2\rangle = \frac{1}{\sqrt{2}}\left(\langle K^-\pi^+ | D^0\rangle - \langle K^-\pi^+ | \overline{D}^0\rangle\right) \equiv \frac{1}{\sqrt{2}}\left(Ae^{i\delta_R} - \overline{A}e^{i\delta_W}\right)$$



i.e. the CP even & CP odd rates to a specific final state will not be the same !

$$r = \frac{\overline{A}}{A}, \quad \delta = \delta_R - \delta_W$$

CP tagged $K\pi$ decay:

$$\frac{B(D_{CP+} \to K^-\pi^+) - B(D_{CP-} \to K^-\pi^+)}{B(D_{CP+} \to K^-\pi^+) + B(D_{CP-} \to K^-\pi^+)} = 2r\cos(\delta)$$

$\Delta\cos\delta_{K\pi} < 0.06$

The model independent strong phase determination is useful for γ/ϕ_3

A. Bondar, A.Poluektov, Eur. Phys. J. C47 347-353 (2006), hep-ph/0510246].

Quantum Correlation

At BES-III:

$D\overline{D}$ pair with L =1 must be in anti-asymmetric state

$$|D^0\overline{D}^0\rangle^{C=-1} = \frac{1}{\sqrt{2}}\left[|D^0\rangle|\overline{D}^0\rangle - |\overline{D}^0\rangle|D^0\rangle\right]$$

the interference comes for free:

$$M_{ij}^2 = \left|\langle i|D^0\rangle\langle j|\overline{D^0}\rangle - \langle j|D^0\rangle\langle i|\overline{D^0}\rangle\right|^2$$

PRD 73, 034024 (2006)
Asner and Sun
I.I.Bigi SLAC report-33, 1989 page 169

(C=–1) $e^+e^- \to \psi(3770) \to$	D	$\overline{D}$
Forbidden if no mixing	$K^-\pi^+$	$K^-\pi^+$
Forbidden if no mixing	$K^-l^+\nu$	$K^-l^+\nu$
Forbidden by CP conservation	CP+	CP+
Forbidden by CP Conservation	CP–	CP–
Interference of CF with DCS	$K^-\pi^+$	CP±

X.D.Cheng, K.L.He, H.B.Li, Y.F.Wang and M.Z.Yang PRD, 75 094019 (2007)

Special menu at BES-III:

- **The mixing rate R_M can be measured at the first order;**
- **Strong phase $\delta_{K\pi}$ is from CP tagged $D \to K\pi$;**
- **CP violation is measured in a production rate.**