Highlights from BESIII

(charm physics @ threshold)

Roy A. Briere

Carnegie Mellon

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Outline

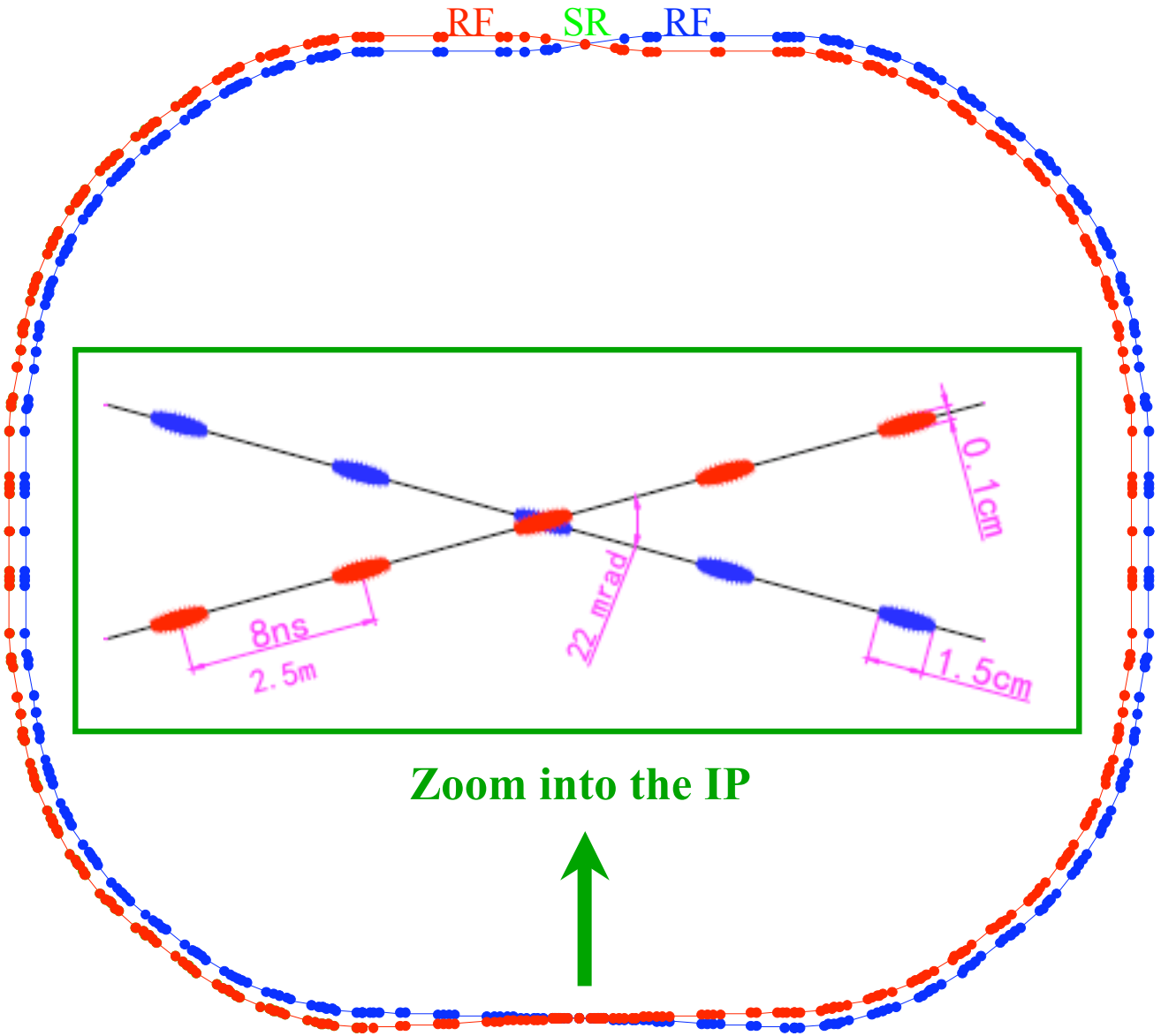
- **BESIII, BEPCII & our Datasets**
- **$Z_c^+(3900)$**
- **Selected Charmonium Topics:**
  $J/\psi \rightarrow \mu e$ search
  & a brief tour of the $\{ \chi_{cJ}, h_c, \eta_c \}$
- **D Physics: Leptonic, Semileptonic**
- **Future Prospects & Conclusions**

IHEP, Beijing

~13 km due west of Tiananmen Square

BEPCII

Two-ring, large crossing angle, multi-bunch, high-current



- Design -

Beam energy:
1 - 2.3 GeV

Luminosity:
1×10^{33} $cm^{-2}s^{-1}$

Optimum energy:
1.89 GeV

Energy spread:
5.16×10^{-4}

No. of bunches:
93

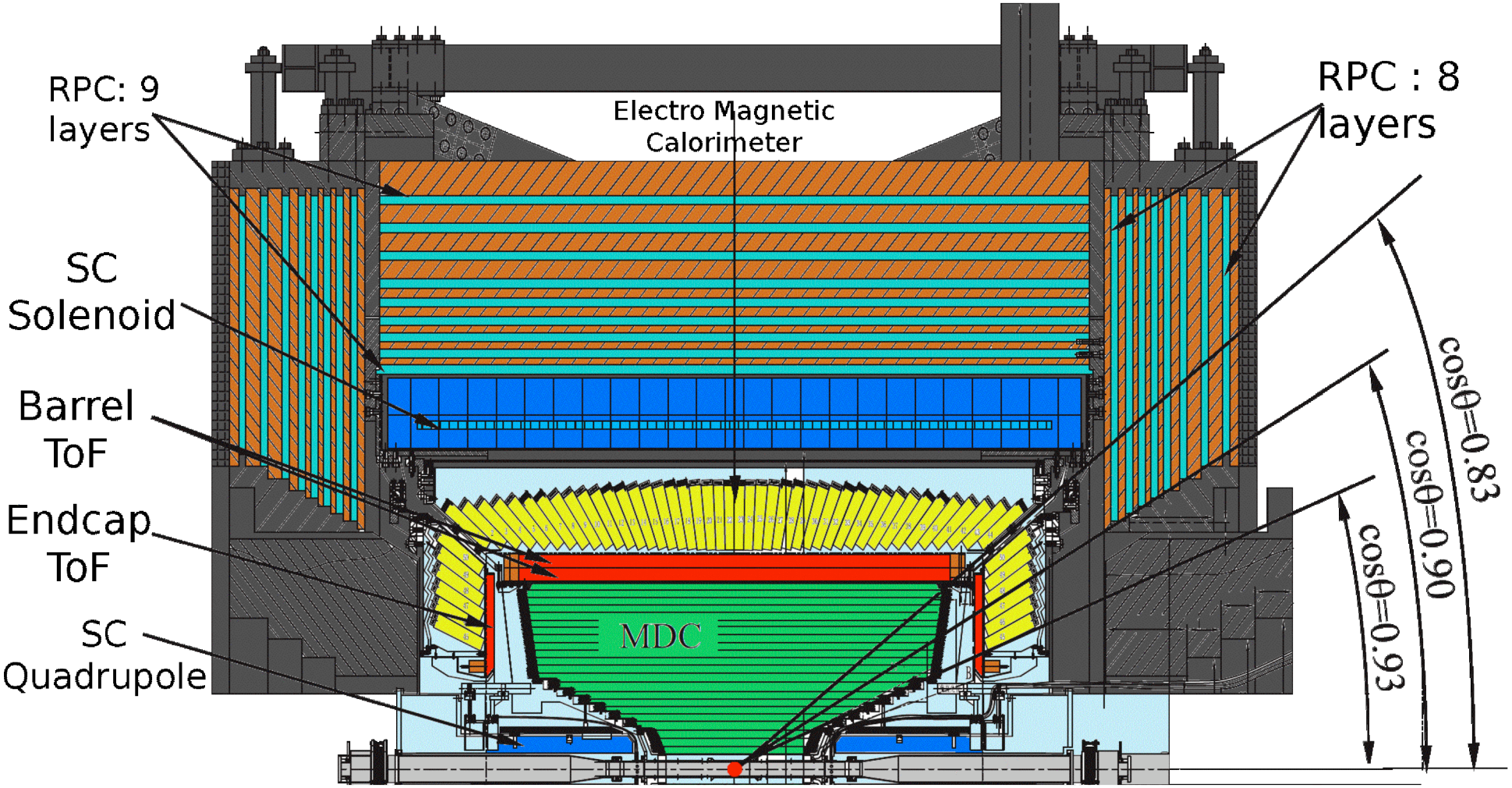
Bunch length:
1.5 cm

Total current:
0.91 A

SR mode:
0.25A @ 2.5 GeV

BESIII

51 institutions
21 outside China



Wire tracker (no Si); TOF + dE/dx for PID; CsI Ecal; RPC muon

Key Points I

Direct, high-statistics production of $J^{PC} = 1^{--}$ charmonium

J/ψ ψ' $[\,^3S_1\,]$

also: $\psi(3770)^*$ $Y(4260)$

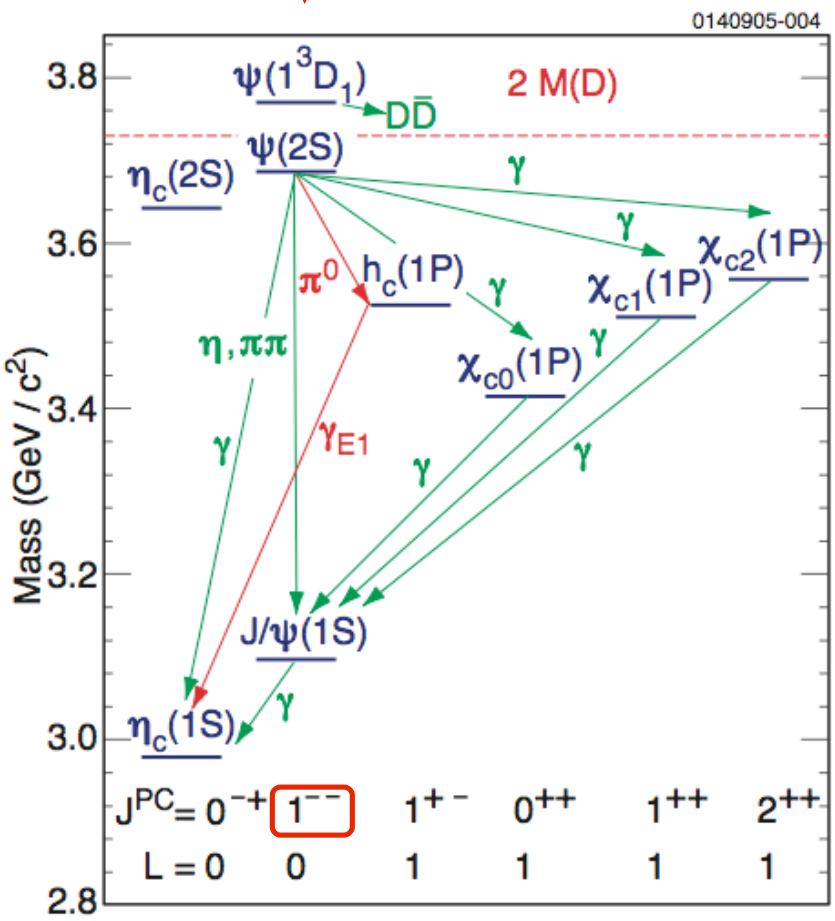
σ_{eff} ~ 2500 nb for J/ψ ; ~4x smaller for ψ'

Depends on beam energy spread:
BEPCII a bit narrower than CESR-c)

Radiative (γ, π^0 , $\pi\,\pi$, η) transitions give access to other states:

χ_{cJ} h_c η_c $[\,^3P_{0,1,2}$ $^1P_1$ $^1S_0\,]$

(more on $\psi(3770)$ & D physics later)



Datasets

2008: First collisions w/ BESIII ! (in summer; now data runs are ~Dec-Jun)

2009: -- machine studies --
225 M J/ψ (4x BESII)
106 M ψ′ (4x CLEO-c)

2010: 0.9 fb^{-1} @ ψ(3770)
2011: +2.0 fb^{-1} @ ψ(3770) (3.5x CLEO-c)
0.5 fb^{-1} @ 4010 MeV

Rapidly obtained world's largest samples

2012: + 400 M ψ′
+1000 M J/ψ

2013: >>0.5 fb^{-1} @ Y(4260)
0.5 fb^{-1} @ Y(4360)
(plus off-energy points)

Unique Datasets !

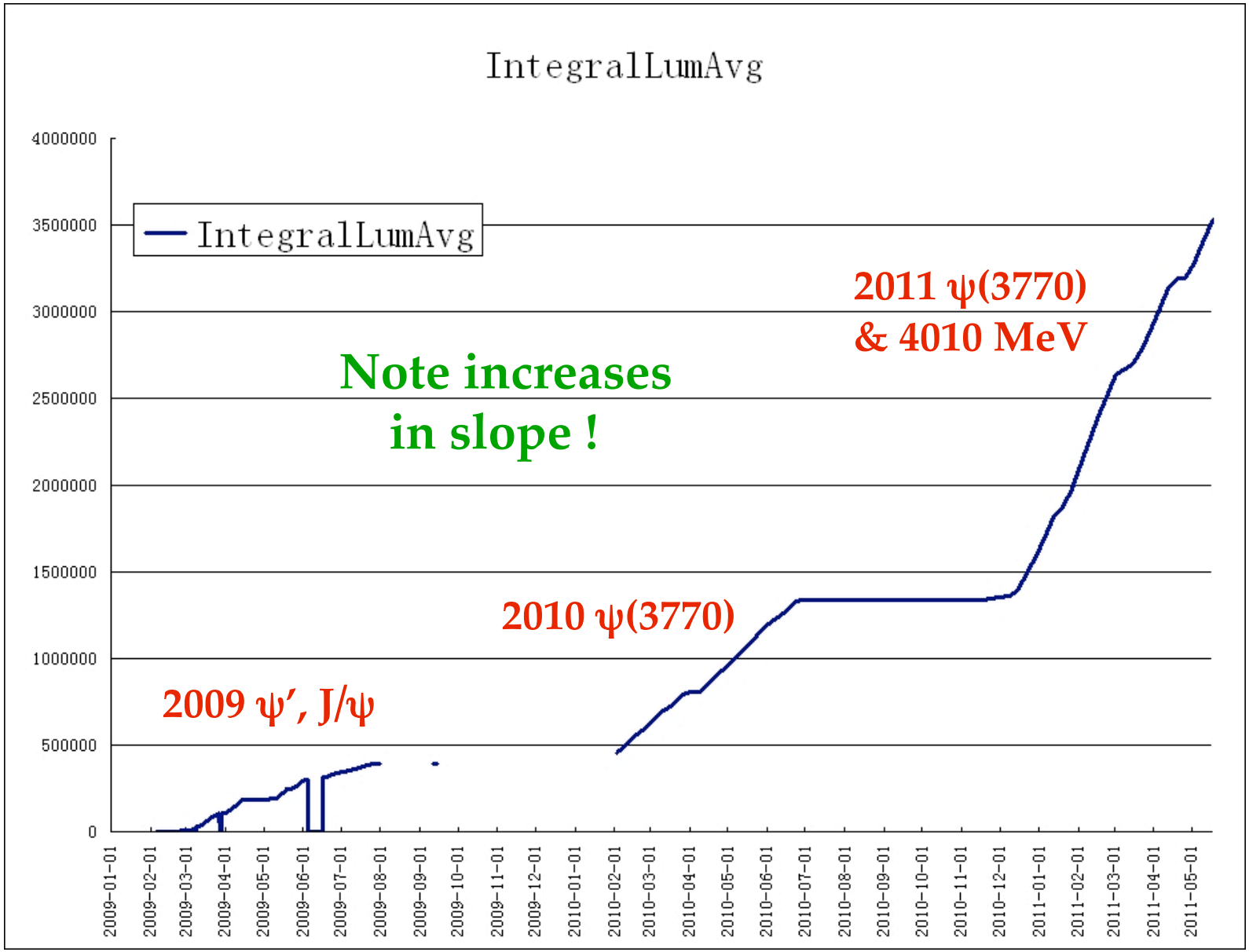
2014: high-E R scan, … ?

Future: low-E R scan, more tau mass,
D_s @ 4170 MeV, more ψ(3770)

Many more useful years !

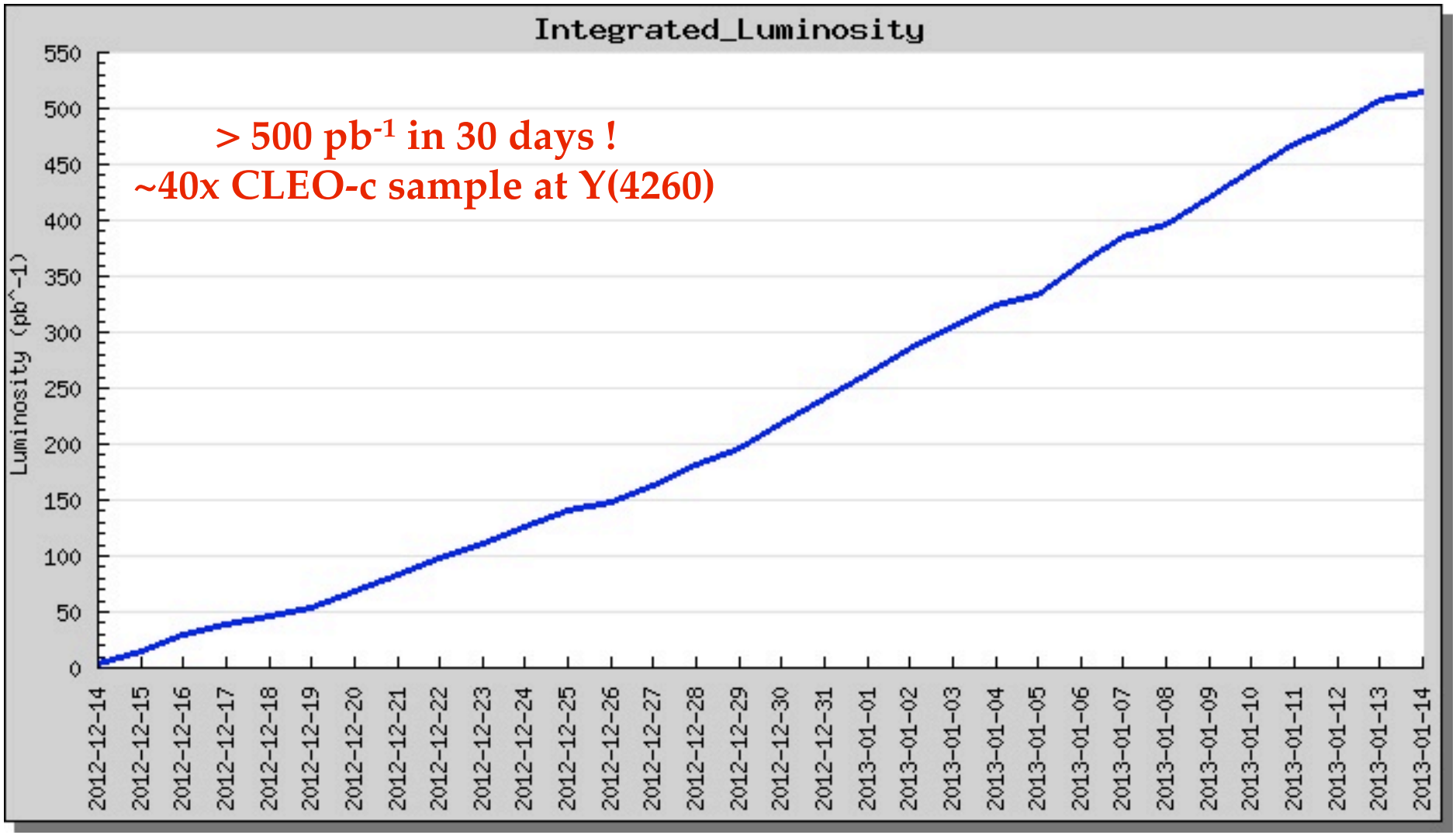
$\mathcal{L}$ ~ 0.7 x 10^{33}/cm^2/s @ ψ(3770) (70% of design)

Integrated Lumi: 2009-11



Start of Current Run

Y(4260)



> 500 pb^{-1} in 30 days !

~40x CLEO-c sample at Y(4260)

BESIII Publications

~45 in print or accepted : first few in 2010 ; 12 in 2013 (+4 in review)

10 each on J/ψ, ψ′, χ_{cJ} states :
Many concern BF & structures in exclusive decays;
some on radiative transitions, …

2 on the h_c :
BF w/ incl. vs excl. E1 rates; reconstruct via exclusive η_c decays

4.5 on the η_c : $\eta_c(1S)$ mass, width; M1 transition to $\eta_c(2S)$; …

2 on ψ(3770), 4010 decays

2 on number of produced J/ψ, ψ′

4.5 on η & η′

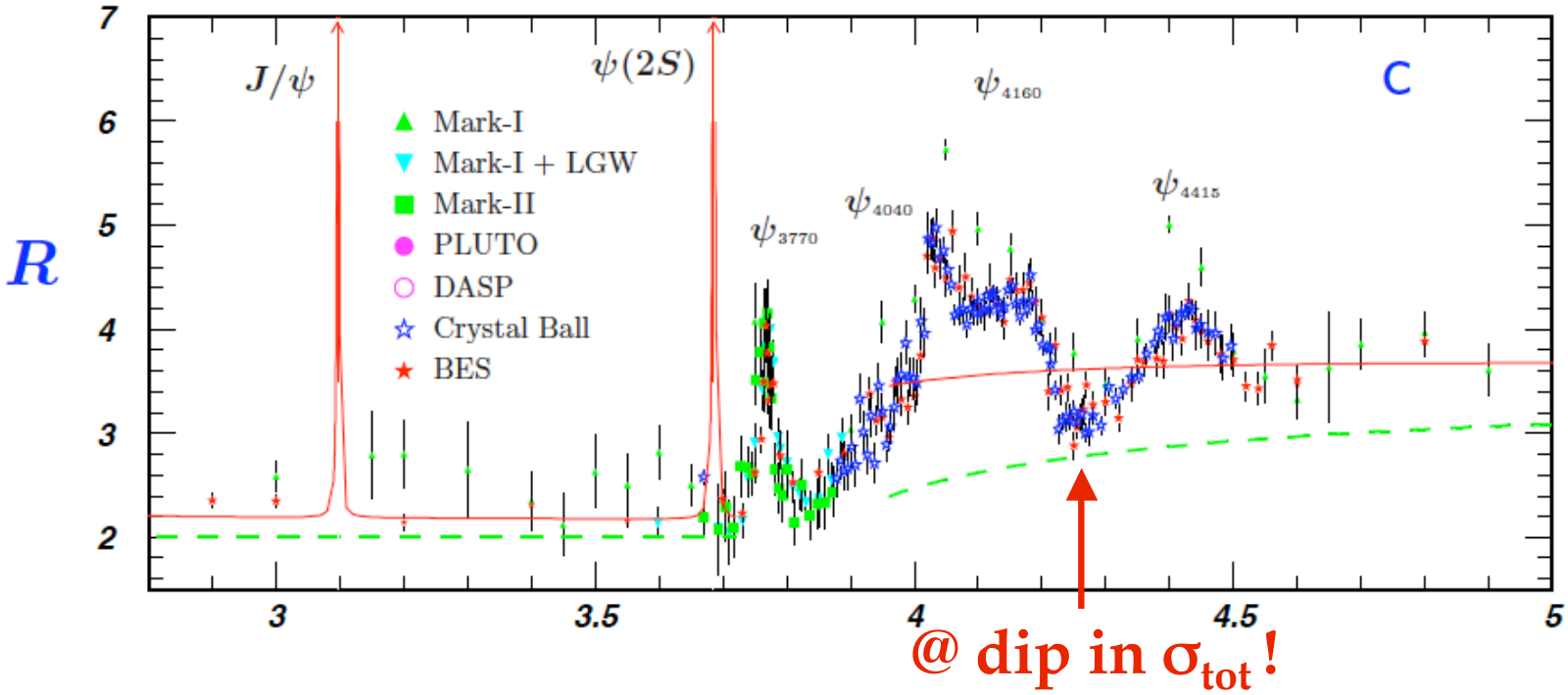
3 others (low-mass hadrons, light boson search)

2013 XYZ runs: 1 submission already ! (discussed today)

D physics: preliminary conference results, papers soon…
[precision results with 3.5x the data of CLEO-c's ψ(3770) sample]

Y(4260) Data

2013: Large dataset at Y(4260)



Charm cross-section @4260: ~4.3 nb (CLEO-c scan)

e+e- → J/ψππ c-section @4260: ~ 70 pb (BaBar/Belle)

PDG Y(4260) data: $\Gamma = (95 \pm 14)$ MeV

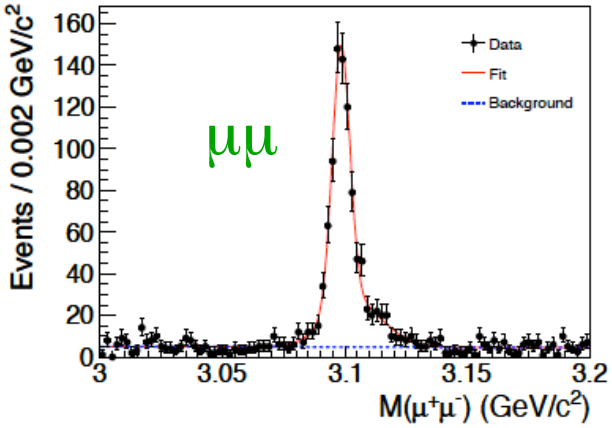
$\Gamma_{J/\psi\pi\pi}\,\Gamma_{ee}/\,\Gamma = 5.9\,^{+1.2}_{-0.9}$ eV

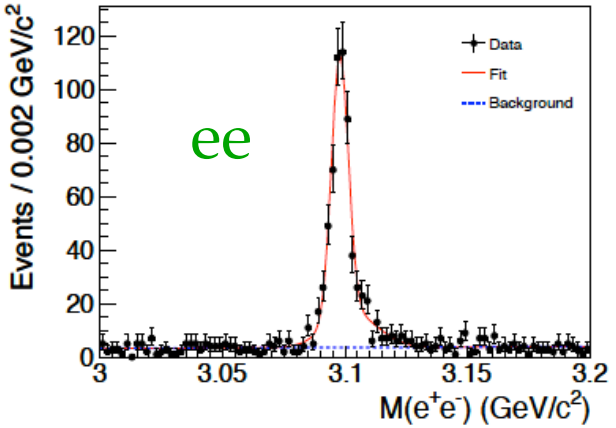
Y(4260) → π π J/ψ

BESIII 525 pb^{-1}
arXiv:1303.5949

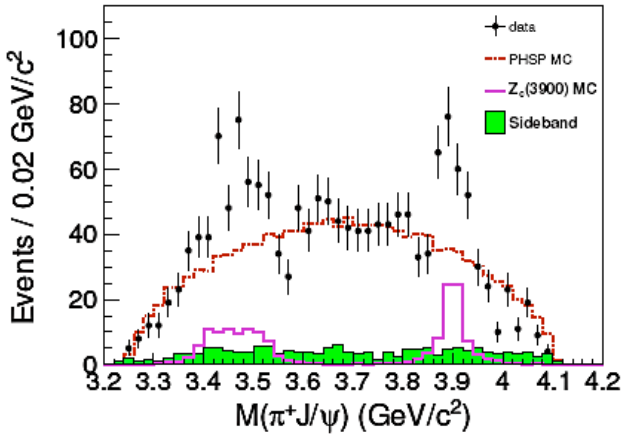
Study **525 pb^{-1}** collected at E_{cm} = 4260 MeV ;
look at well-known **J/ψ π π** decay of Y(4260)

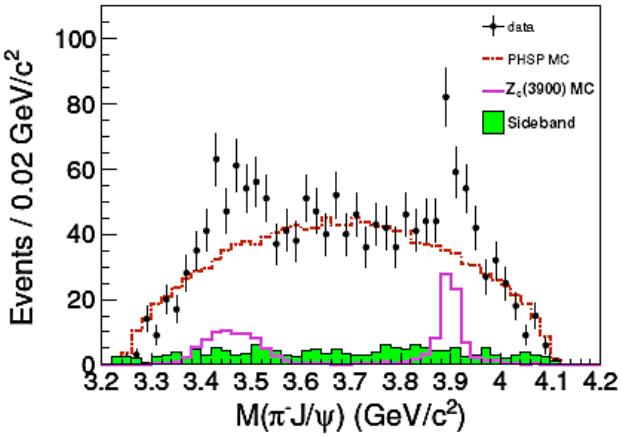
J/ψ di-lepton peaks:

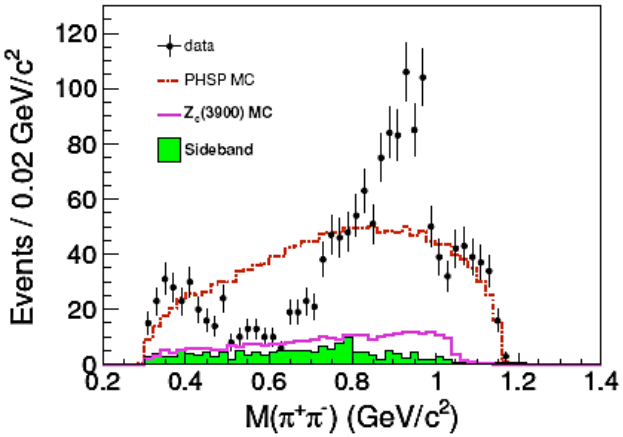




Pair-wise invariant masses: (of π π J/ψ)





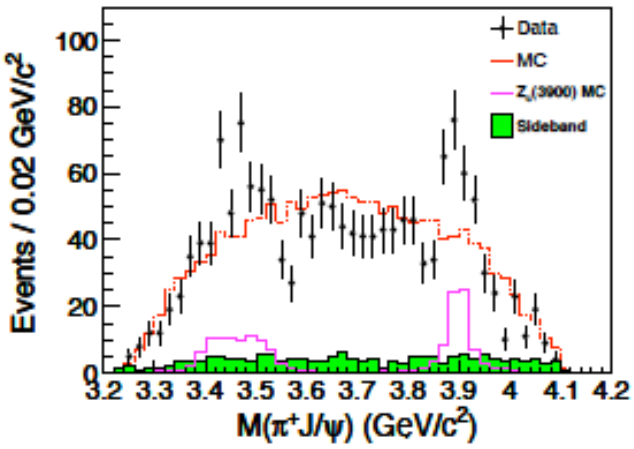


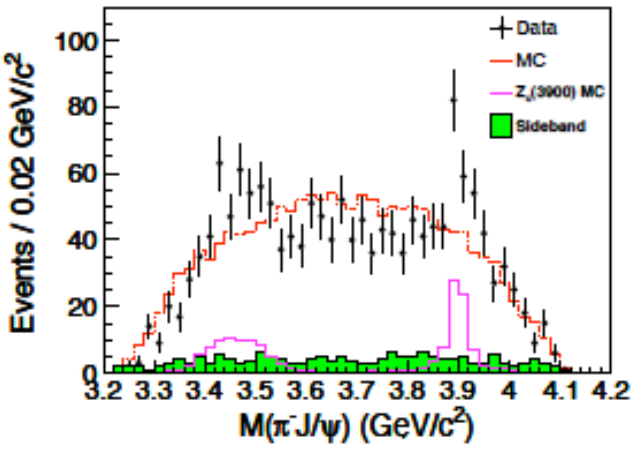
$Z_c^+(3900)$

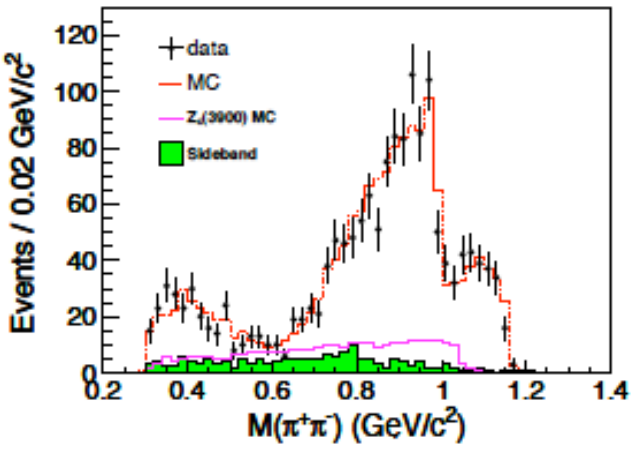
BESIII 525 pb^{-1}
arXiv:1303.5949

Peak(s) in J/ψ π masses:
really only one (next page)
in both π charges
not due to π π structure
(not even if D-wave π π)

Structure in di-pion mass:
well-modeled via
$f_0(980)$ + σ(500) + non-res.







Now, red curve is MC w/ π π structure

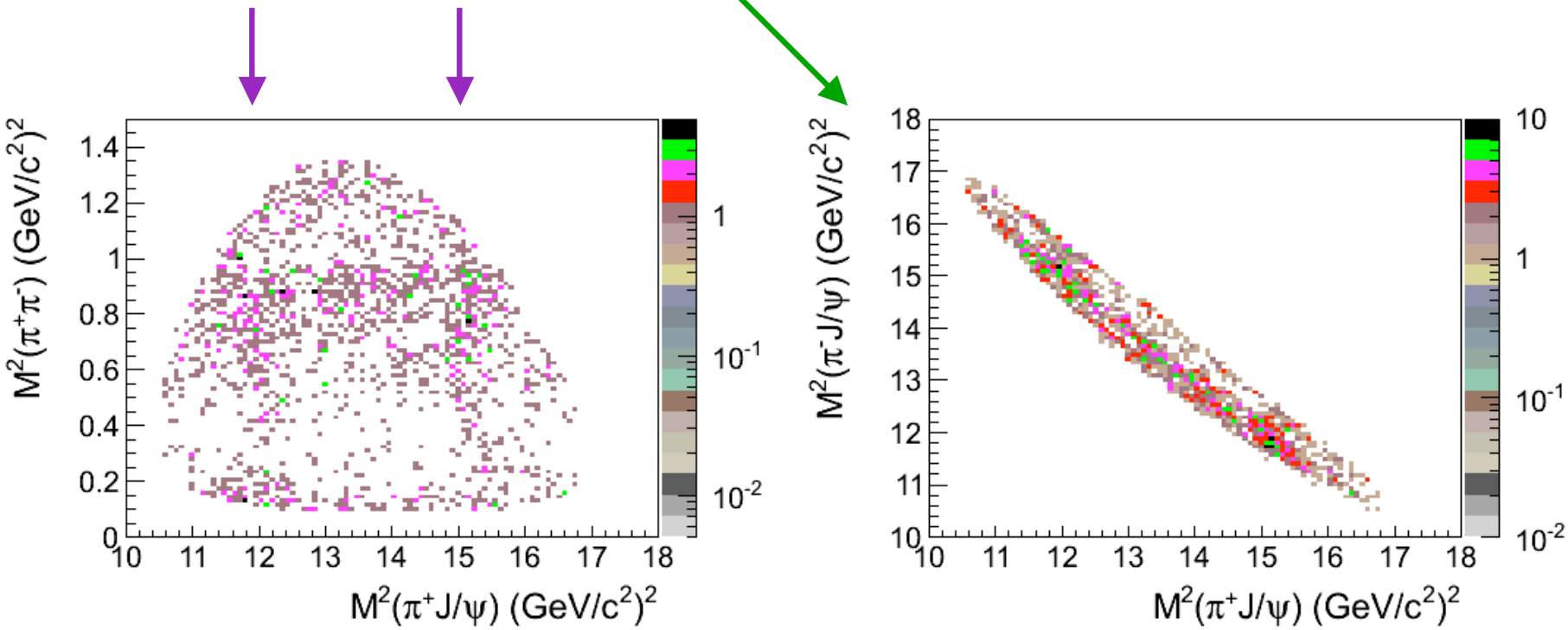
$Z_c^+(3900)$

BESIII 525 pb^{-1}
arXiv:1303.5949

Dalitz Plots

Two stripes in J/ψ π mass
one is a reflection of the other:
correlation in two J/ψ π axes

Fold over Dalitz plot !
[plot "M_{max}(J/ψ π)"]

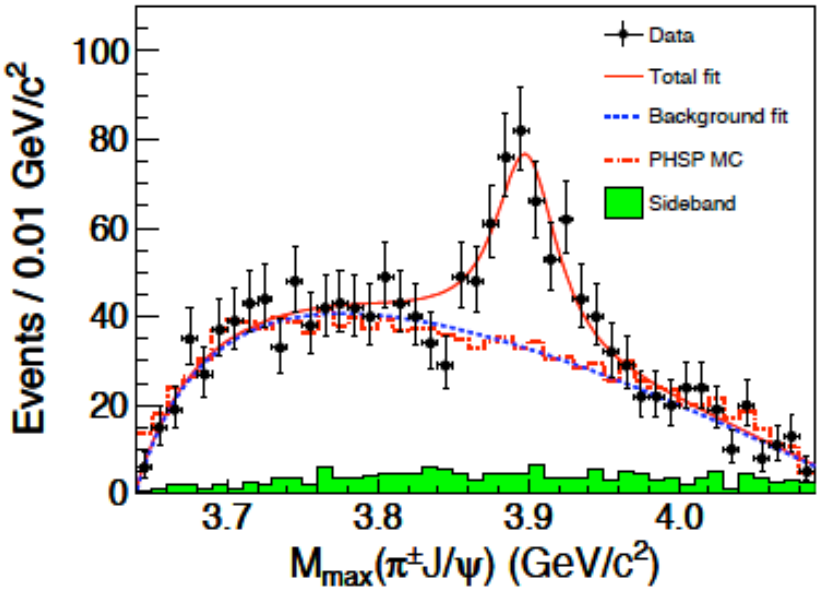


$Z_c^+(3900)$

BESIII 525 pb^{-1}
arXiv:1303.5949

Fit To:

S-wave BW + MC resolution
+ empirical background function (4 parameters)



$e^+e^- \to \pi\pi J/\psi$ Born-level cross-section: $(62.9 \pm 1.9 \pm 3.7)$ pb

Consistent with Y(4260)

$Z_c^+(3900)$ peak in $\pi^+ J/\psi$:

$M = (3899.0 \pm 3.6 \pm 4.9)$ MeV $\quad \Gamma = (46 \pm 10 \pm 20)$ MeV

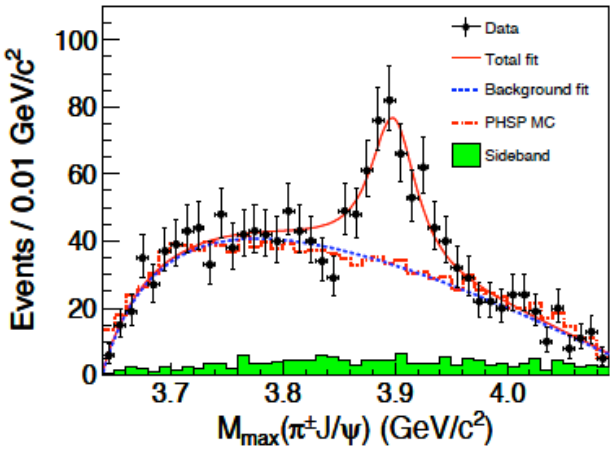
Fractional rate of $Z_c^+(3900)$ peak :

$$R = \frac{\sigma(e^+e^- \to \pi^\pm Z_c(3900)^\mp \to \pi^+\pi^- J/\psi))}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)} = (21.5 \pm 3.3 \pm 7.5)\,\%$$

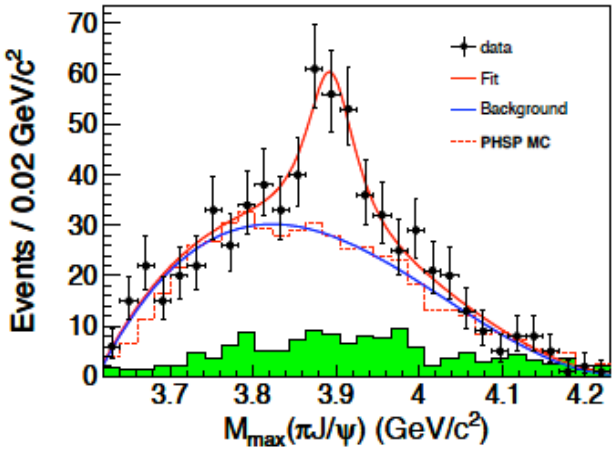
BESIII, Belle, NWU

We present : the (Z_c) ^{3}

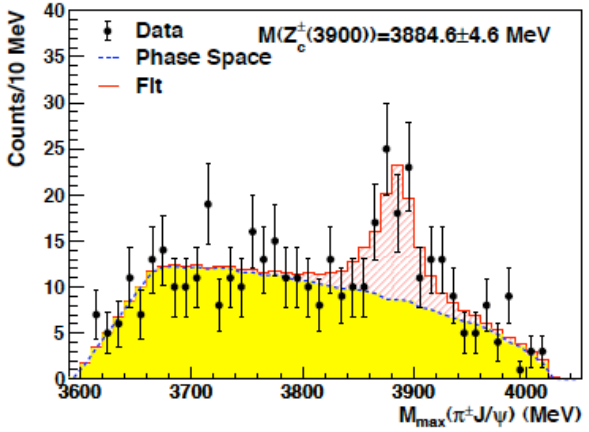
BESIII $Z_c^+(3900)$
arXiv:1303.5949



Belle $Z_c^+(3895)$
arXiv:1304.0121



Northwestern U.
$Z_c^+(3900)$
arXiv:1304.3036



Note horizontal range differences, especially for Belle

BESIII: 525 pb^{-1} at E_{cm} = 4260 MeV
BelleII: ISR from ~10 GeV, cut on 4.15 < M(J/ψππ) < 4.45 GeV
(hence, higher upper endpoint on mass above…)
NWU: 586 pb^{-1} at E_{cm} = 4170 MeV (CLEO-c legacy data)

$J/\psi \rightarrow e\ \mu$

BESIII 225M J/ψ
arXiv:1304.3205
(subm. to PRD)

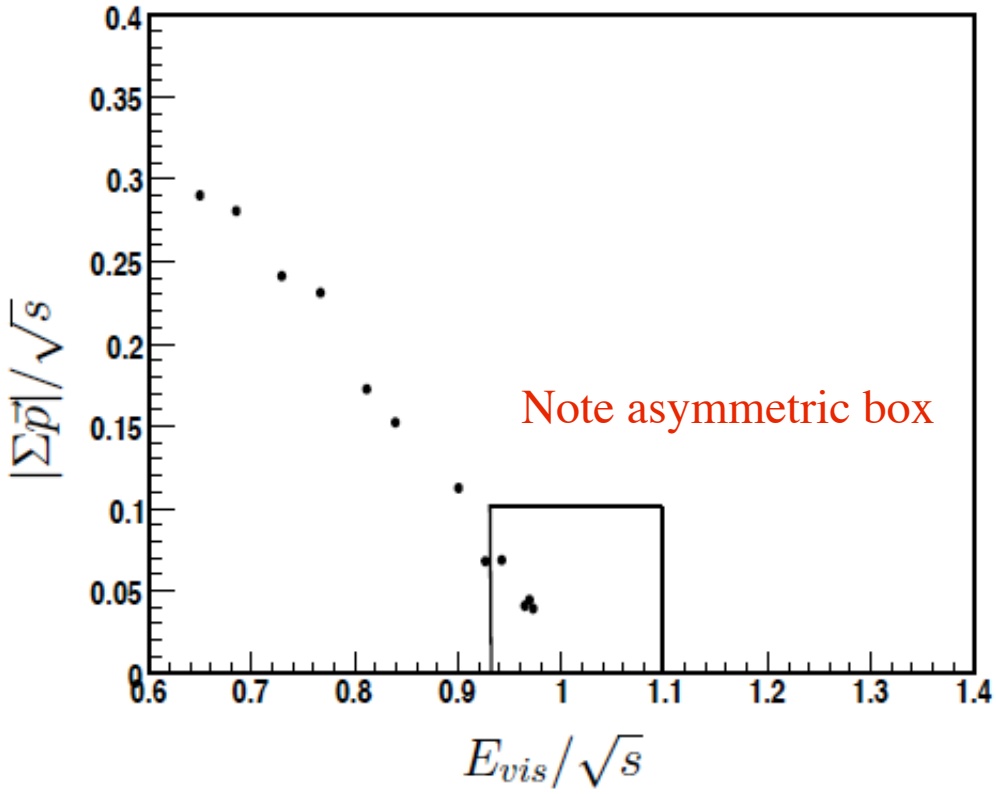
Lepton flavor violation: negligible in SM

Analysis keys:
Lepton ID, Kinematics

Efficiency = (18.99 ± 0.12)%
Background: expect 4.75 ± 1.09
[from MC sample of 4x data]

See 4 candidates; set limit

Result:
B(J/ψ → e μ) < 1.5 x 10^{-7} (90% CL)

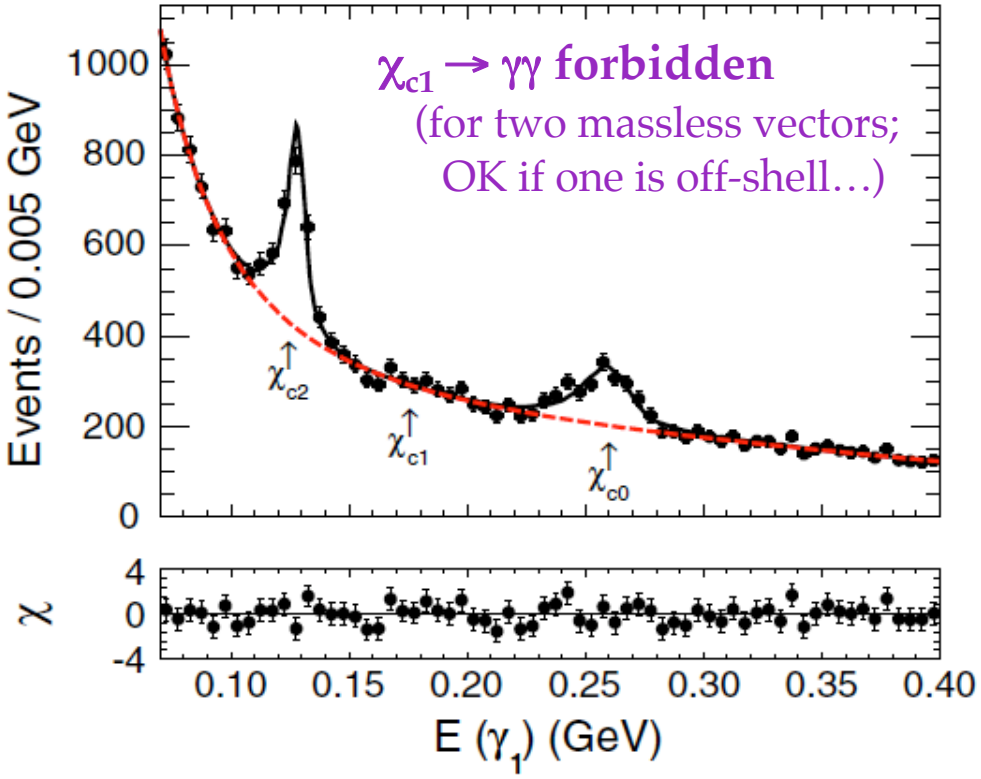


General rare decay sensitivity:

225M J/ψ ⊕ 20% effic. ⊕ no candidates → limit of < 0.5 x 10^{-7} (90% CL)
Future: more rare modes, total J/ψ dataset now 5x greater !

$\gamma\gamma$ Widths of $\chi_{c0,2}$

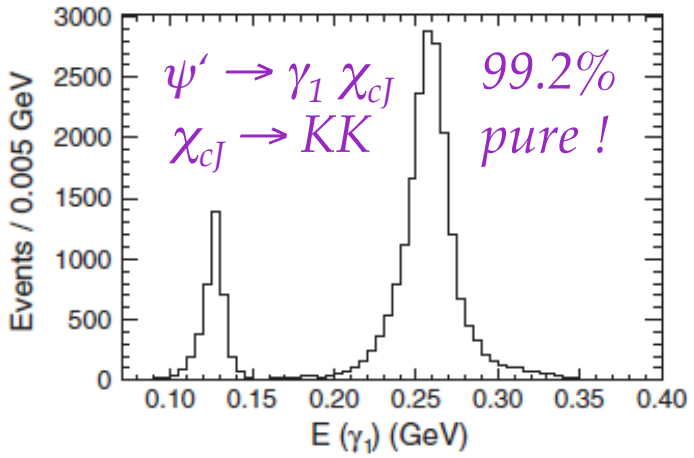
BESIII 106M ψ'
PRD 85, 112008 (2012)



3 photon signal:

$\psi' \to \gamma_1 \chi_{cJ}$; $\chi_{cJ} \to \gamma_2\gamma_3$

Lineshape extraction with data:



$B(\chi_{c0} \to \gamma\gamma) = (2.24 \pm 0.19 \pm 0.12 \pm 0.08) \times 10^{-4}$

$B(\chi_{c2} \to \gamma\gamma) = (3.21 \pm 0.18 \pm 0.17 \pm 0.13) \times 10^{-4}$

± stat ± syst ± PDG BF, Γ

$R = \Gamma_{2\to\gamma\gamma}/\Gamma_{0\to\gamma\gamma} = (0.271 \pm 0.029 \pm 0.013 \pm 0.027)$ (expect ~0.27)

Also, first helicity analysis on J=2 decay:

fraction of (helicity 0/helicity 2) is $f_{0/2} = 0.00 \pm 0.02 \pm 0.02$

$\psi' \to \pi^0 h_c : h_c \to \gamma\, \eta_c(\mathrm{excl})$

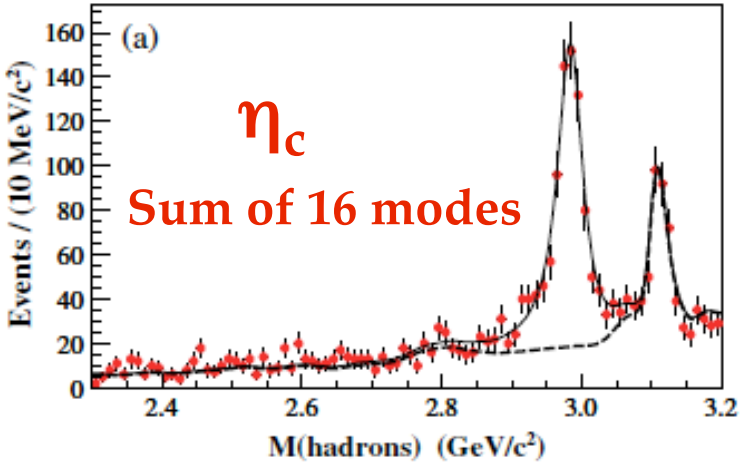
BESIII 106M ψ'
PRD 86, 092009 (2012)

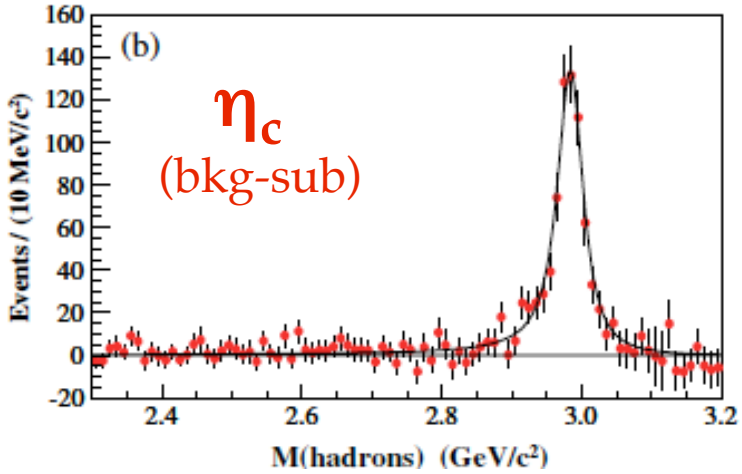
Most precise h_c mass & width

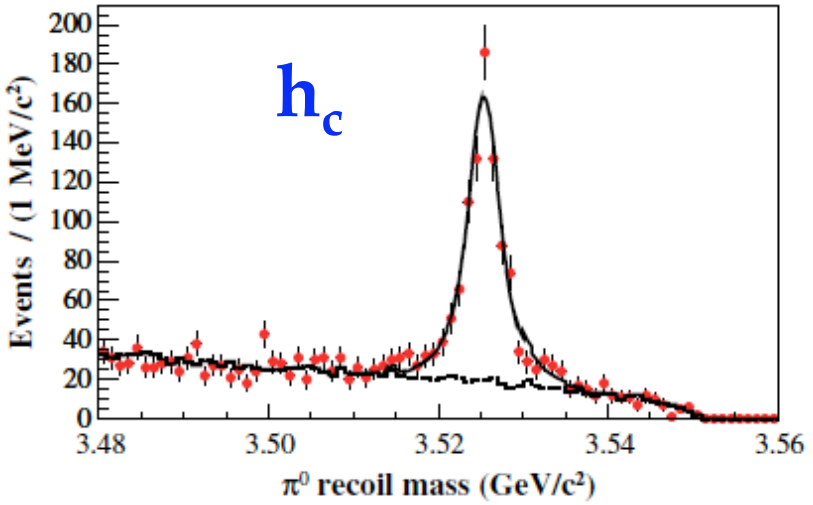
+ 5 of the 16 η_c modes: first report of the BF (not shown here)

+ η_c mass & width, with negligible interference effects

(best future systematic control ?)







$$M(h_c) = 3525.31 \pm 0.11 \pm 0.14 \text{ MeV}/c^2,$$
$$\Gamma(h_c) = 0.70 \pm 0.28 \pm 0.22 \text{ MeV},$$

$$M(\eta_c) = 2984.49 \pm 1.16 \pm 0.52 \text{ MeV}/c^2,$$
$$\Gamma(\eta_c) = 36.4 \pm 3.2 \pm 1.7 \text{ MeV}.$$

$\psi' \to \gamma\eta_c(2S)$

BESIII 106M ψ'
PRL 109, 042003 (2012)

First observation of M1 transition (48 MeV photon)

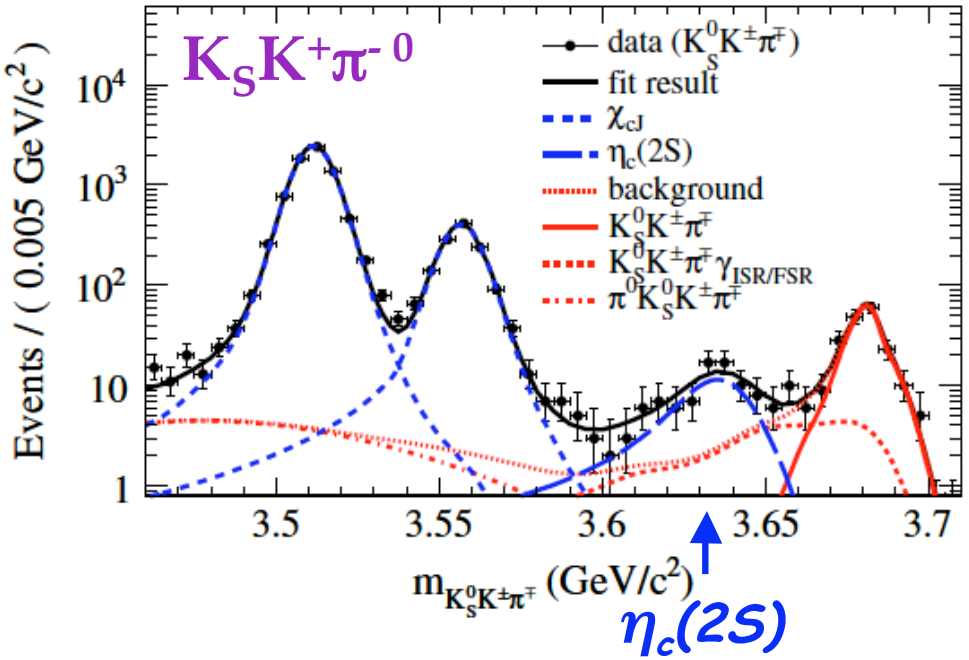
Use $K_S K^+\pi^{-0}$ & $K^+K^-\pi$ modes

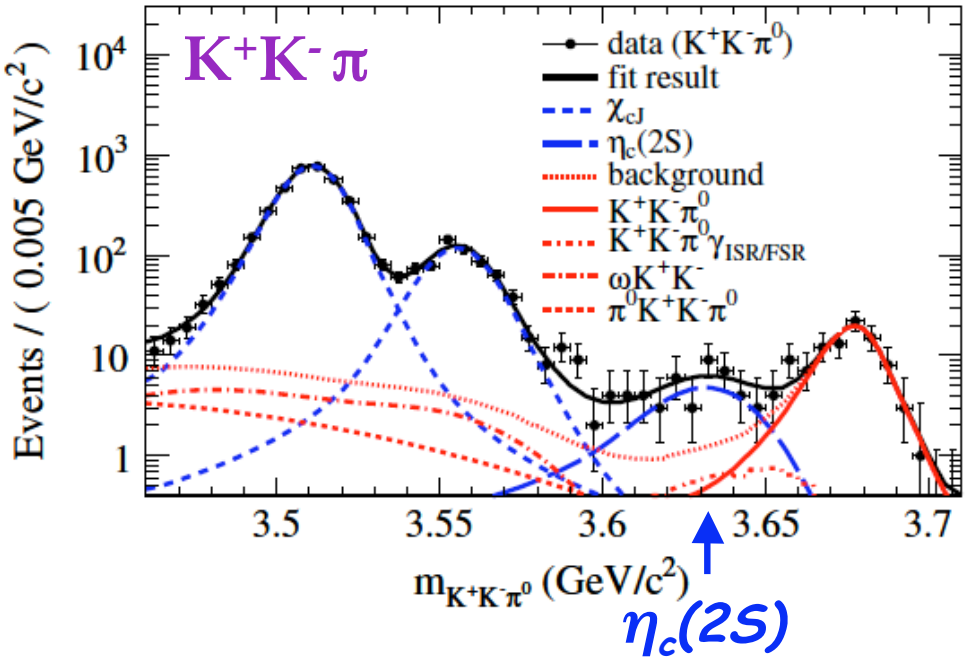
Larger peaks from ψ' & 2 χ_{cJ} decays,
plus several other backgrounds

Obtain mass & width comparable in precision to PDG average !

M = (3637.6 ± 2.9 ± 1.6) MeV Γ = (16.9 ± 6.4 ± 4.8) MeV

PDG12 : M = (3637 ± 4) (s=1.7) MeV Γ = (14 ± 7) MeV





Key Points II

$\psi(3770)$: $\sigma_{DD} \sim 6.6$ nb

Only D pairs: no phase space for even *one* extra pion

Reconstruct one D in a set of hadronic "tag" modes:

Reduces backgrounds

Find the other D's direction (produce a "tagged D beam" !)

→ can now solve for neutrino 4-vector

"Familiar" tag variables (also used in B physics)

Conservation of momentum & energy

$$M_{bc} = (E_{beam}^2 - p_{cand}^2)^{1/2} \qquad \Delta E = E_{cand} - E_{beam}$$

("cand" is the candidate D: a sum over decay daughters…)

Measure (# tags + signal) / (# tags) :

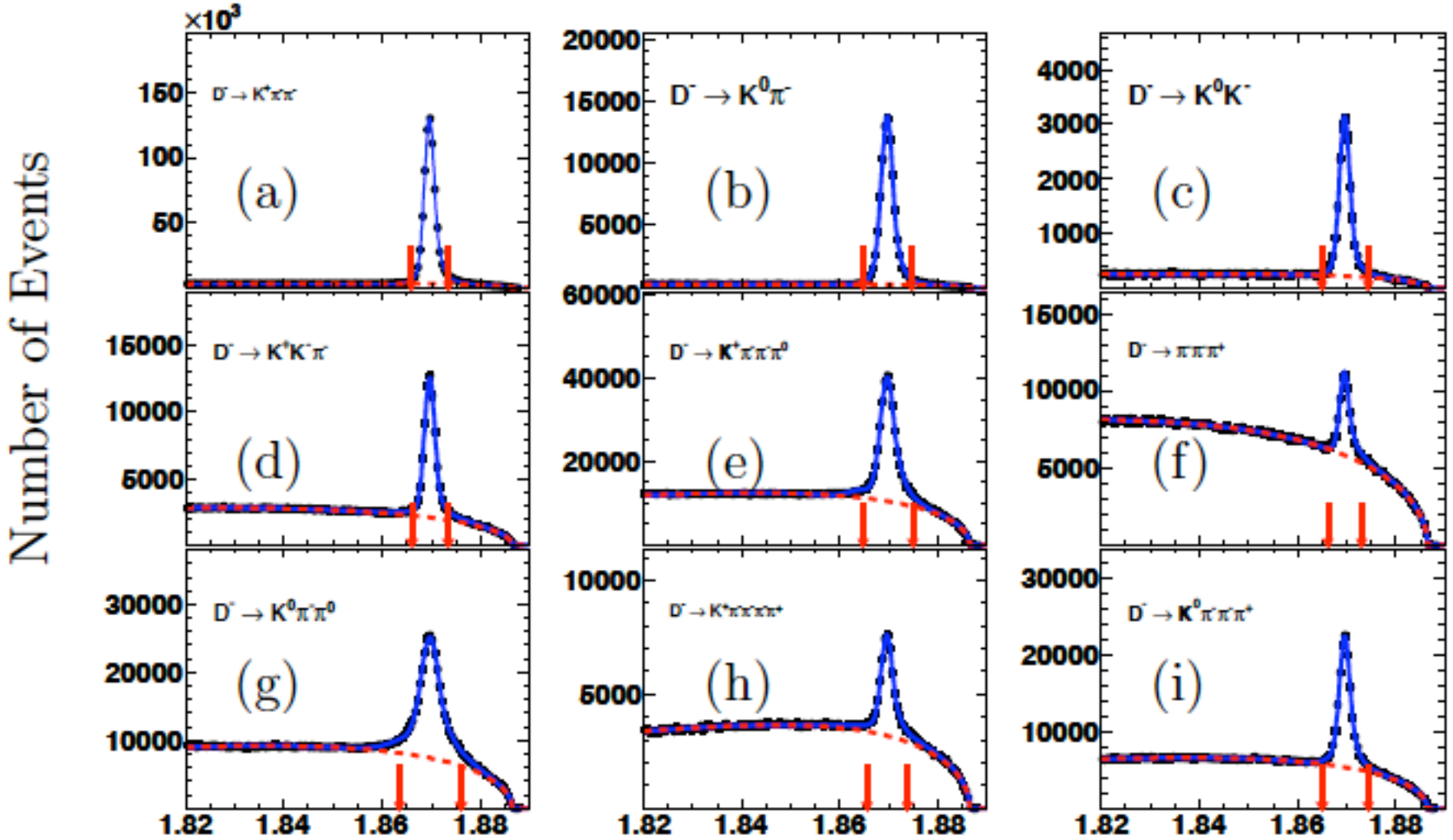
tag-side efficiency mostly cancels; tag systematics cancel

$D^+ \to \mu\nu$

BESIII 2.9 fb^{-1}
CHARM2012
arXiv:1209.0085

Uses 9 tag modes (for reference, CLEO-c used 6)

Even includes Cabibbo-suppressed modes !



$D^+ \to \mu\nu$

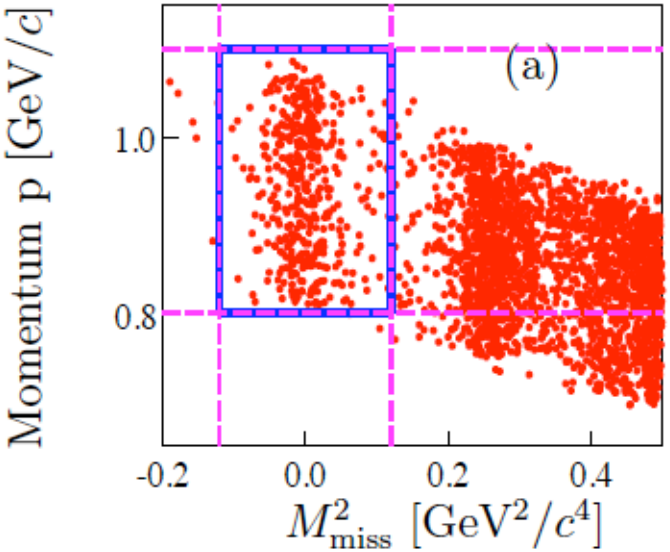
BESIII 2.9 fb^{-1}
CHARM2012
arXiv:1209.0085

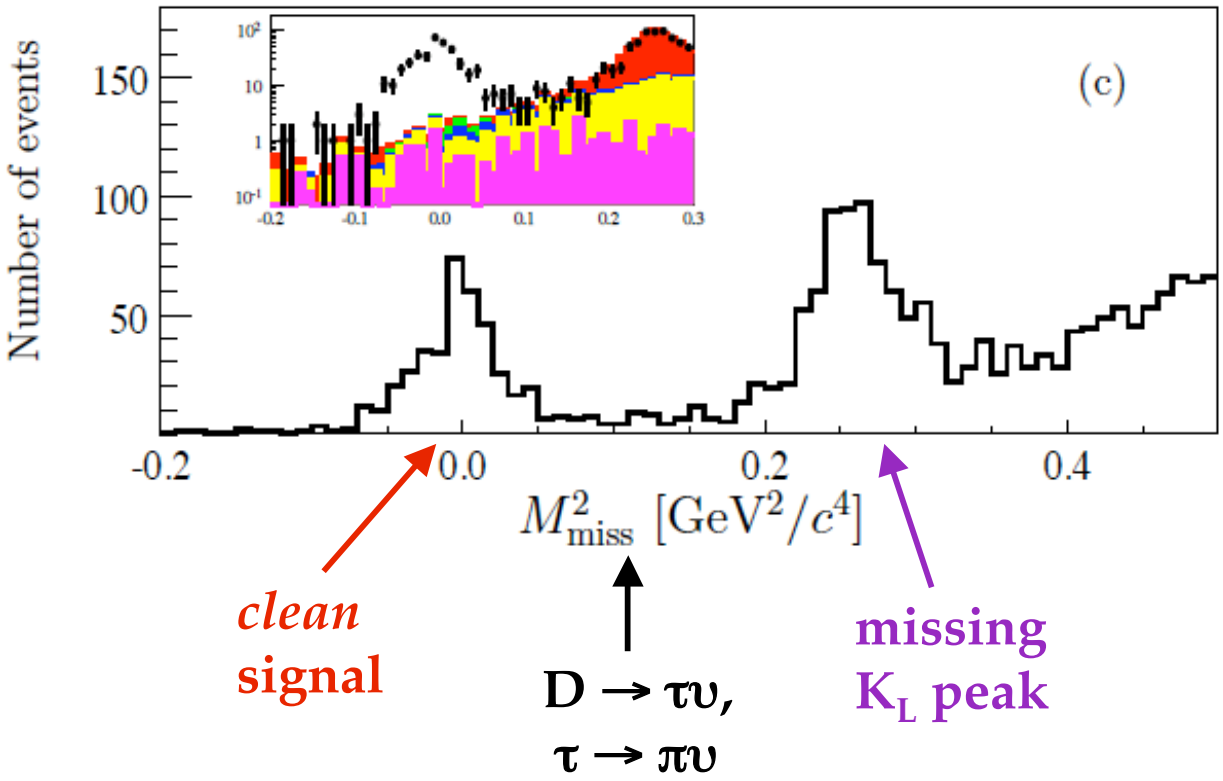
Signal side: ONE track !

Veto on extra tracks, and un-matched showers with E > 300 MeV

Reconstruct " MM^2 " = (missing-mass)^2

presumably just a neutrino: signal peaks at 0





$D^+ \to \mu\nu$

BESIII 2.9 fb^{-1}
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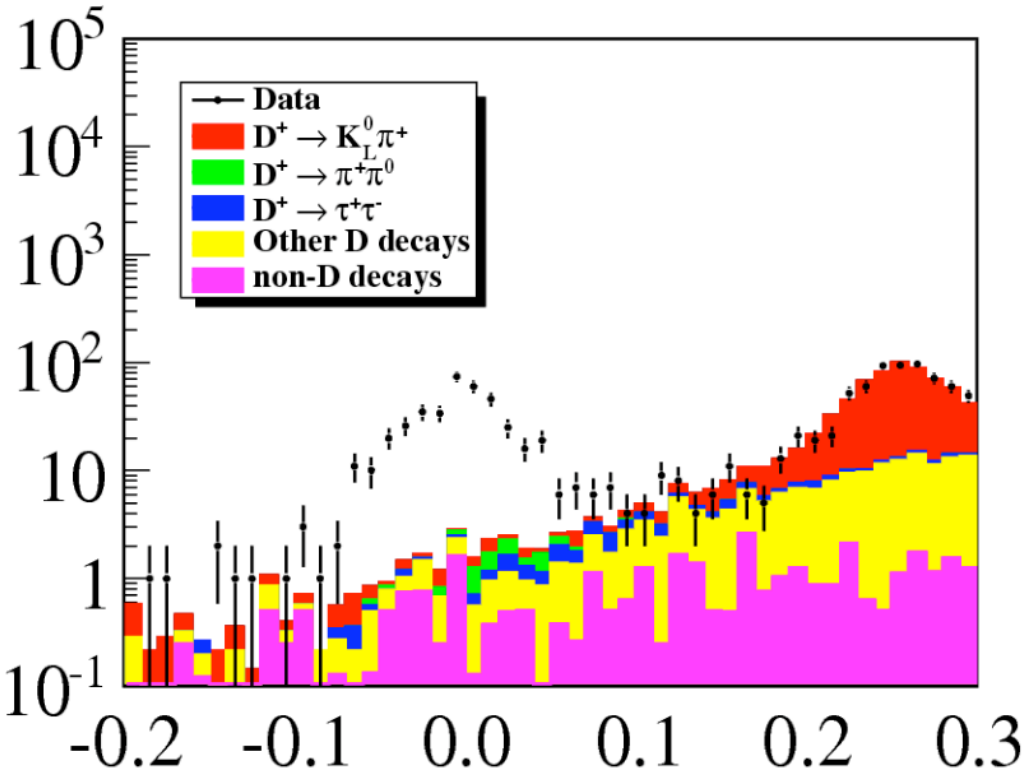


Estimated with Monte Carlo events

Source mode	Number of events
$D^+ \to K_L^0\pi^+$	7.9 ± 0.8
$D^+ \to \pi^+\pi^0$	3.8 ± 0.5
$D^+ \to \tau^+\nu_\tau$	6.9 ± 0.7
Other decays of D mesons	17.9 ± 1.1
$e^+e^- \to \gamma\psi(3686)$	0.2 ± 0.2
$e^+e^- \to \gamma J/\psi$	0.0 ± 0.0
$e^+e^- \to light\ hadron$ (continuum)	8.2 ± 1.4
$e^+e^- \to \tau^+\tau^-$	1.9 ± 0.5
$\psi(3770) \to non - D\bar{D}$	0.9 ± 0.4
Total	47.7 ± 2.3

Result:

377.3 ± 20.6 ± 2.6 events above background

B($D^+ \to \mu\nu$) = (3.74 ± 0.21 ± 0.06) x 10^{-4}

Combining with V_{cd}, G_F, τ_D, m_D :

f_D = (203.01 ± 5.72 ± 1.97) MeV (± 2.8 ± 1.0)% *most precise !*

previous best: CLEO-c : (205.8 ± 8.5 ± 2.5) MeV

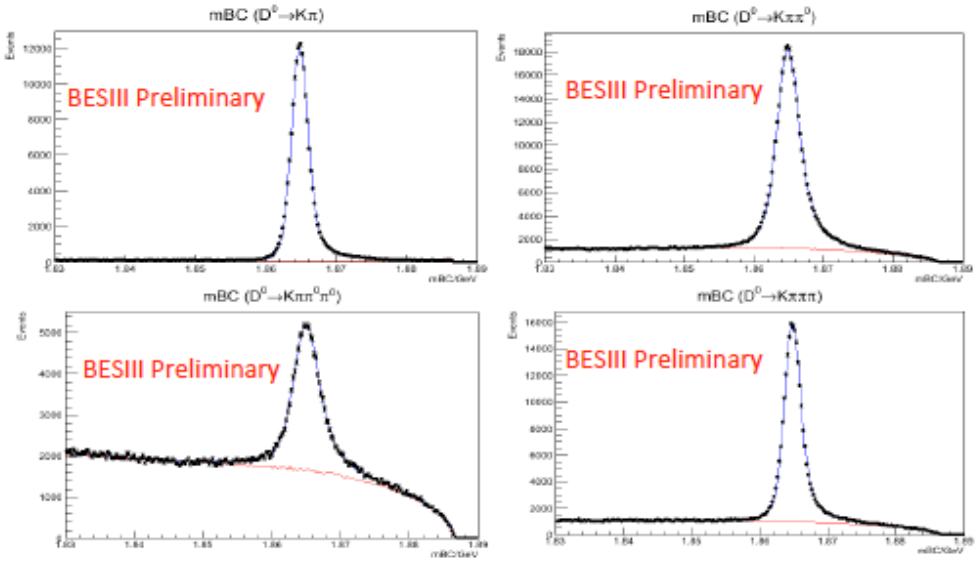
$D^0 \to Ke\nu, \pi e\nu$

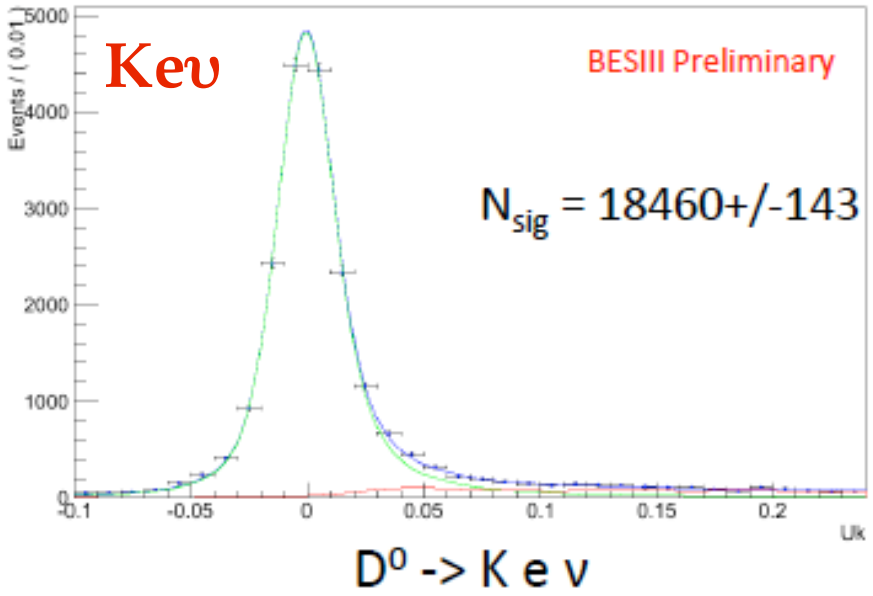
BESIII 2.9 fb^{-1}
CHARM2012
arXiv: 1207.1171

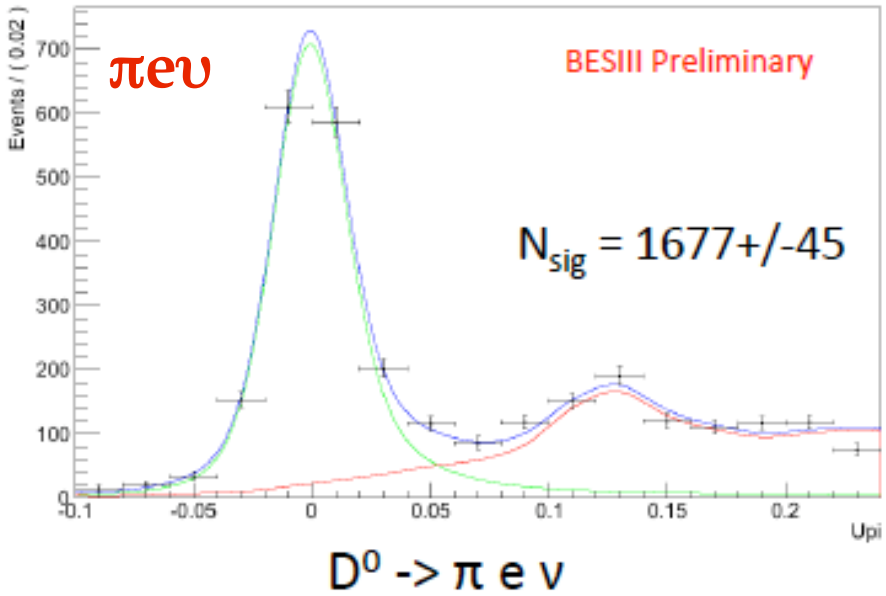
Use 4 hadronic tag modes

Signal side:
two tracks, e & K/π

Signal variable:
$U = E_{miss} - p_{miss}$
(peaks @ zero, similar to MM^2)





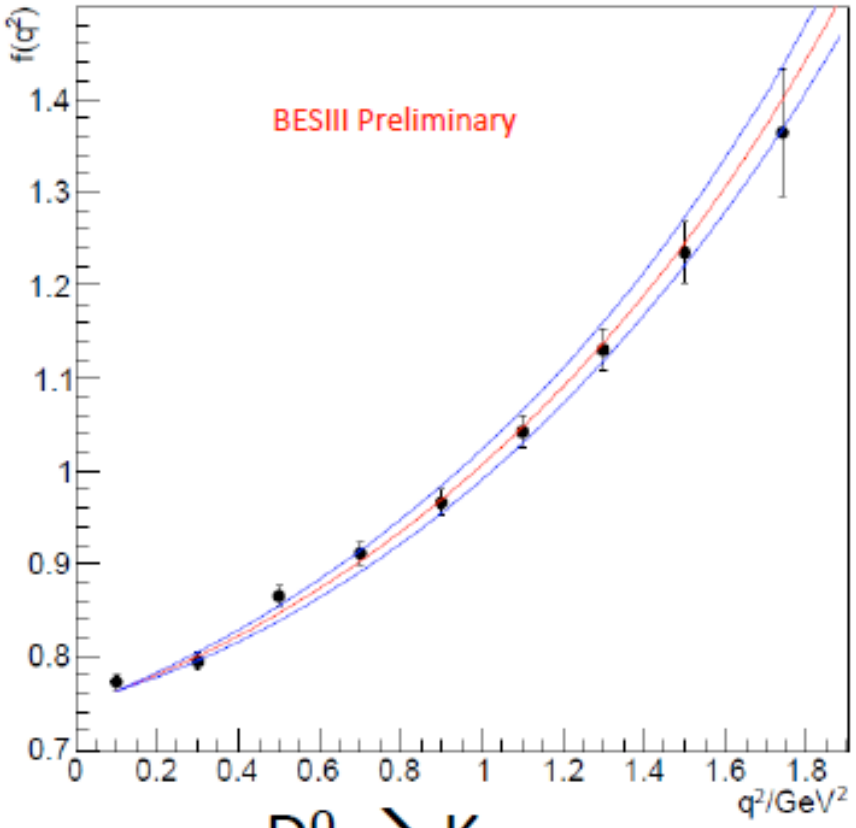


$D^0 \to K e \nu, \pi e \nu$

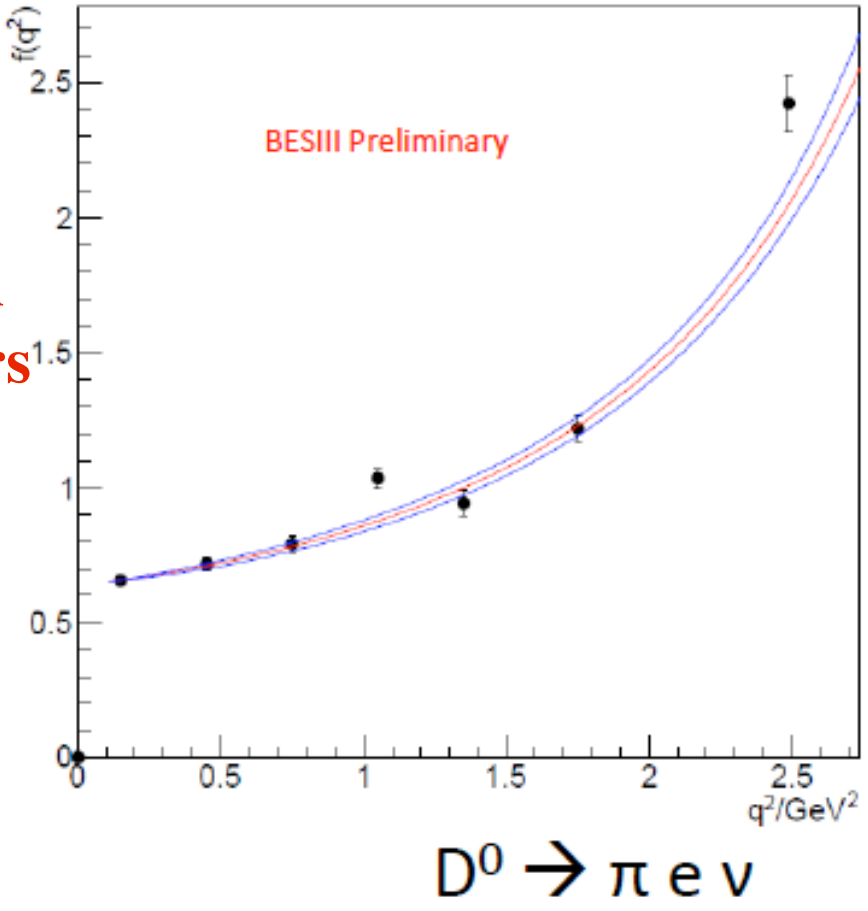
BESIII 2.9 fb^{-1}
CHARM2012
arXiv: 1207.1171

- Points: data with stat. error only
- Curves: from Fermilab-MILC within one stat. error, preliminary, **arXiv:1111.5471** (XXIX International Symposium on Lattice Field Theory);
- Other theoretical work: HPQCD, arXiv:1111.0225
- Comparing shape only here ($f_+(0)$ not known)

Slide directly from CHARM2012, for illustration
No attempt to update Lattice QCD…



Form Factors $f(q^2)$



$D^0 \to Ke\nu, \pi e\nu$

BESIII 2.9 fb^{-1}
CHARM2012
arXiv: 1207.1171

Numerical results
Only 1/3 of current data!

BESIII Preliminary

Mode	measured branching fraction(%)	PDG	CLEOc
$\bar{D}^0 \to K^+ e^- \bar{\nu}$	3.542 $\pm$0.030$\pm$0.067	3.55 $\pm$0.04	3.50 $\pm$0.03 $\pm$0.04
$\bar{D}^0 \to \pi^+ e^- \bar{\nu}$	0.288 $\pm$0.008$\pm$0.005	0.289 $\pm$0.008	0.288 $\pm$0.008$\pm$0.003

BESIII Preliminary

Simple Pole	$f_+(0)\lvert V_{cd(s)}\rvert$	m_{pole}	
$D^0 \to Ke\nu$	0.729$\pm$0.005$\pm$0.007	1.943$\pm$0.025$\pm$0.003	
$D^0 \to \pi e\nu$	0.142$\pm$0.003$\pm$0.001	1.876$\pm$0.023$\pm$0.004	
Modified Pole	$f_+(0)\lvert V_{cd(s)}\rvert$	α	
$D^0 \to Ke\nu$	0.725$\pm$0.006$\pm$0.007	0.265$\pm$0.045$\pm$0.006	
$D^0 \to \pi e\nu$	0.140$\pm$0.003$\pm$0.002	0.315$\pm$0.071$\pm$0.012	
2 par. series	$f_+(0)\lvert V_{cd(s)}\rvert$	r_1	
$D^0 \to Ke\nu$	0.726$\pm$0.006$\pm$0.007	$-$2.034$\pm$0.196$\pm$0.022	
$D^0 \to \pi e\nu$	0.140$\pm$0.004$\pm$0.002	$-$2.117$\pm$0.163$\pm$0.027	
3 par. series	$f_+(0)\lvert V_{cd(s)}\rvert$	r_1	r_2
$D^0 \to Ke\nu$	0.729$\pm$0.008$\pm$0.007	$-$2.179$\pm$0.355$\pm$0.053	4.539$\pm$8.927$\pm$1.103
$D^0 \to \pi e\nu$	0.144$\pm$0.005$\pm$0.002	$-$2.728$\pm$0.482$\pm$0.076	4.194$\pm$3.122$\pm$0.448

(Semi)-Leptonic Future

Finalize $D^+ \to \mu\nu$
Update $D^0 \to K e \nu$, $\pi e \nu$ to full dataset
Will also present $D^+ \to K e \nu$, $\pi e \nu$
More related modes: $D^+ \to \tau \upsilon$, vector meson semi-leptonic modes, …
(modest dataset @ 4010 MeV in hand for D_s physics; dedicated 4170 in future)

More Open Charm

Strong $K\pi$ phase
Other quantum correlation results ($K_S\pi^+\pi^-$, …)
D-D^{bar} "y" oscillation parameter
Rate asymmetries in $D \to K_{L,S}\, n\pi$
Non-DD^{bar} cross-section @ $\psi(3770)$
etc.

Key results in charm flavor physics
& many also feed into B flavor program

Conclusions

Quarkonium physics is very active at BESIII

Today:

- **New $Z_c^+(3900)$**
- **J/ψ LFV search**
- **Selected χ_{cJ}, h_c, η_c, $\eta_c(2S)$ results**

MUCH more in addition:

- **More core quarkonium physics**
- **States are also used as a source for light-hadron spectroscopy**

  J/ψ & χ_{cJ} decays are a "glue factory"

…and open-charm Physics as well

Today: Key precision results

- **$D^+ \to \mu\,\nu$ decay constant f_D**
- **$D^0 \to K\,e\,\nu$, $\pi\,e\,\nu$ form factors $f_{K\pi}(q^2)$**

Many more open-charm results due out soon !

Thanks to:

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