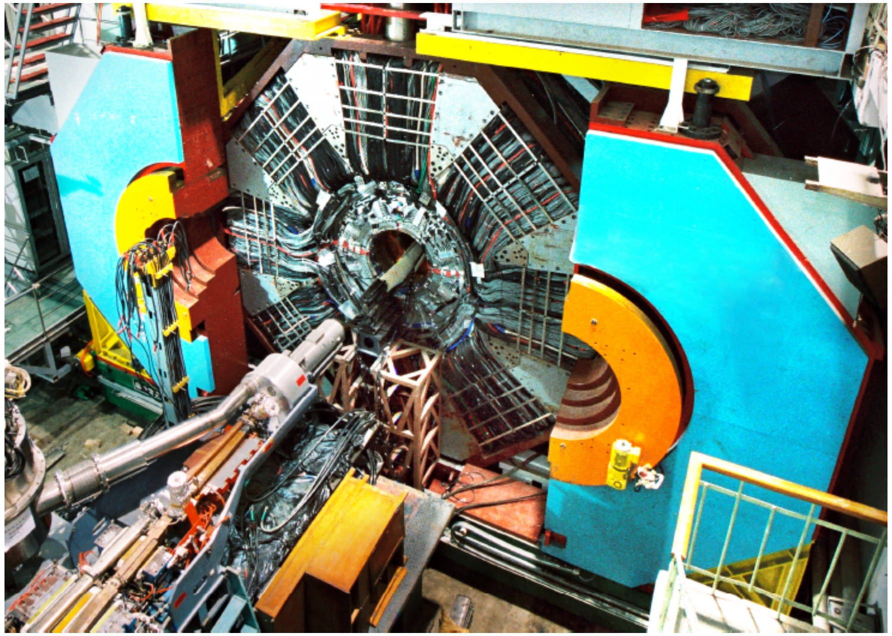
Prospects for charm physics at BESIII



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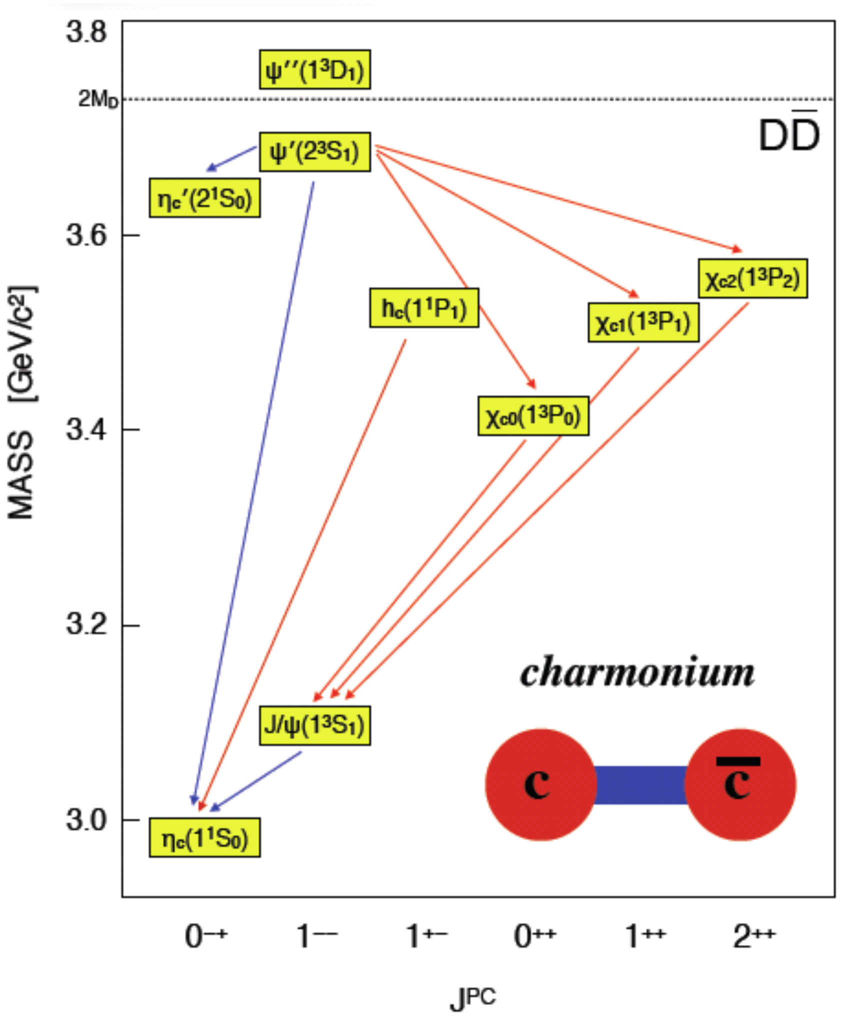
XVII SuperB Workshop and Kick Off Meeting, May 28 - June 2, 2011 in La Biodola, Isola d'Elba , Italy

Outline

- Status of BEPCII/BESIII
- 2009: Charmonium data samples... two sample results
- 2010-11: First open charm runs
- Charm Physics: advantage near threshold
- Rare charm program at BESIII

BESIII - physics using "charm"



Charmonium physics:
- Spectroscopy
- transitions and decays

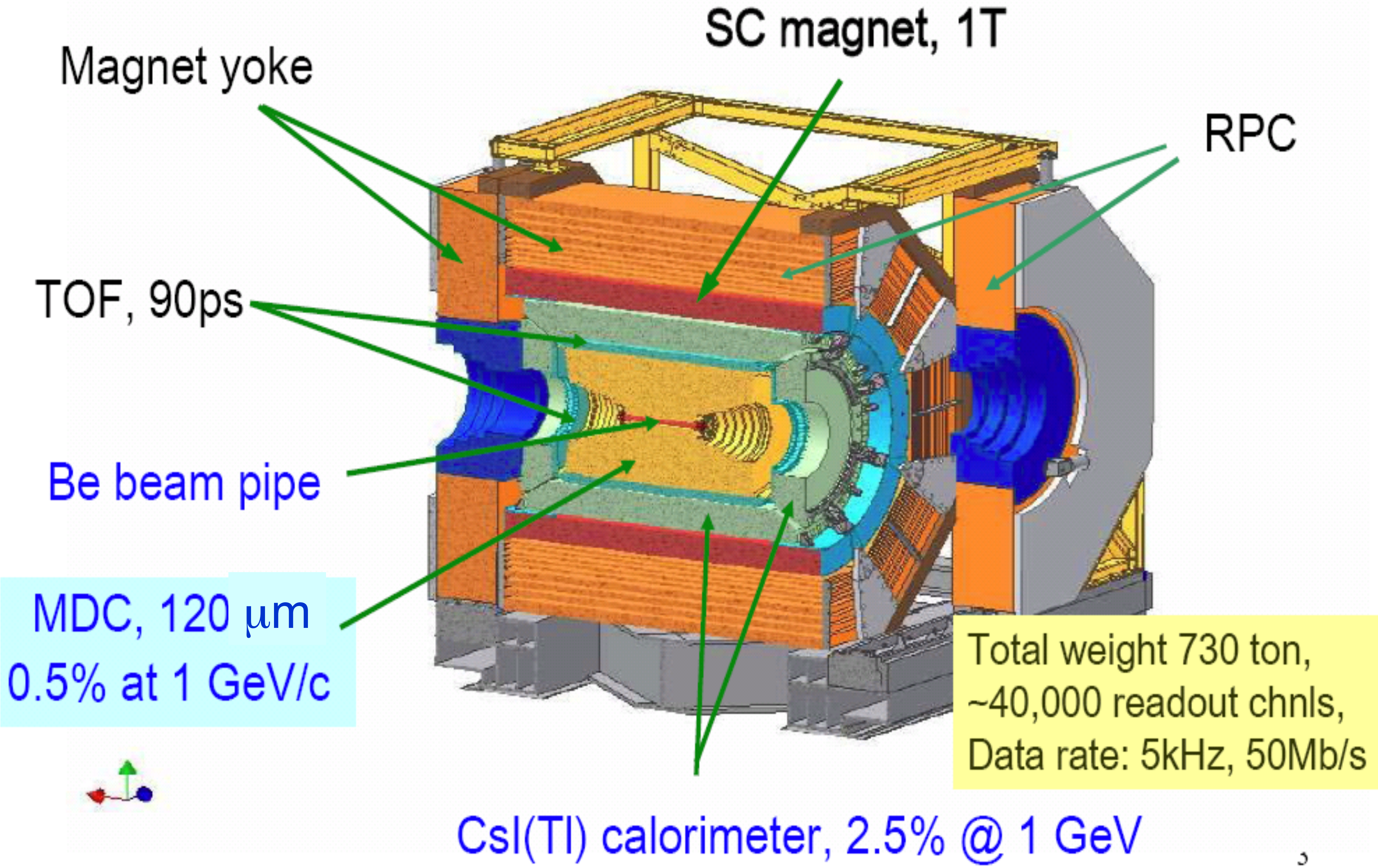
Light hadron physics:
- meson & baryon spectroscopy
- glueball & hybrid
- two-photon physics
- e.m. form factors of nucleon

Charm physics:
- (semi)leptonic + hadronic decays
- decay constant, from factors
- CKM matrix: Vcd, Vcs
- D^0-D^0bar mixing and CP violation
- rare/forbidden decays

Tau physics:
- Tau decays near threshold
- tau mass scan

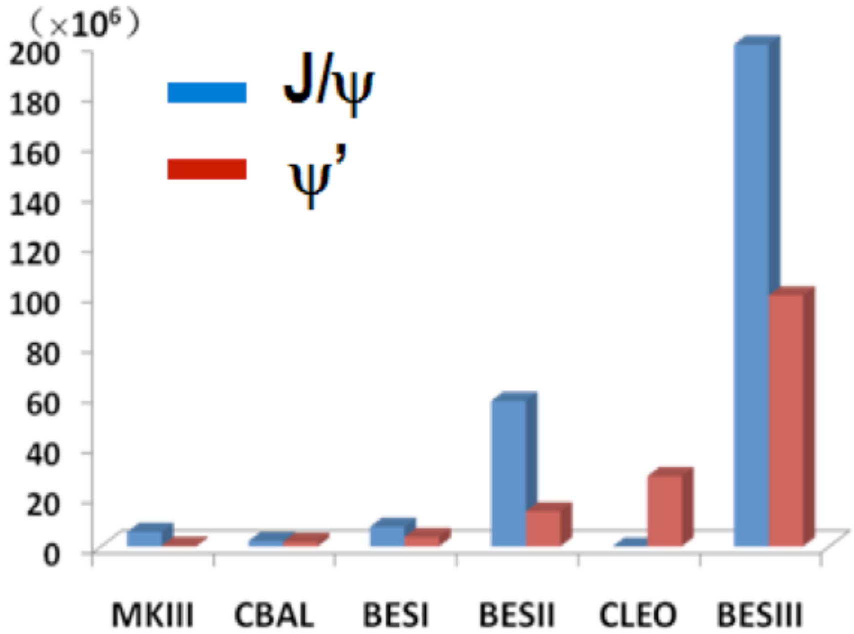
…and many more.

BESIII detector

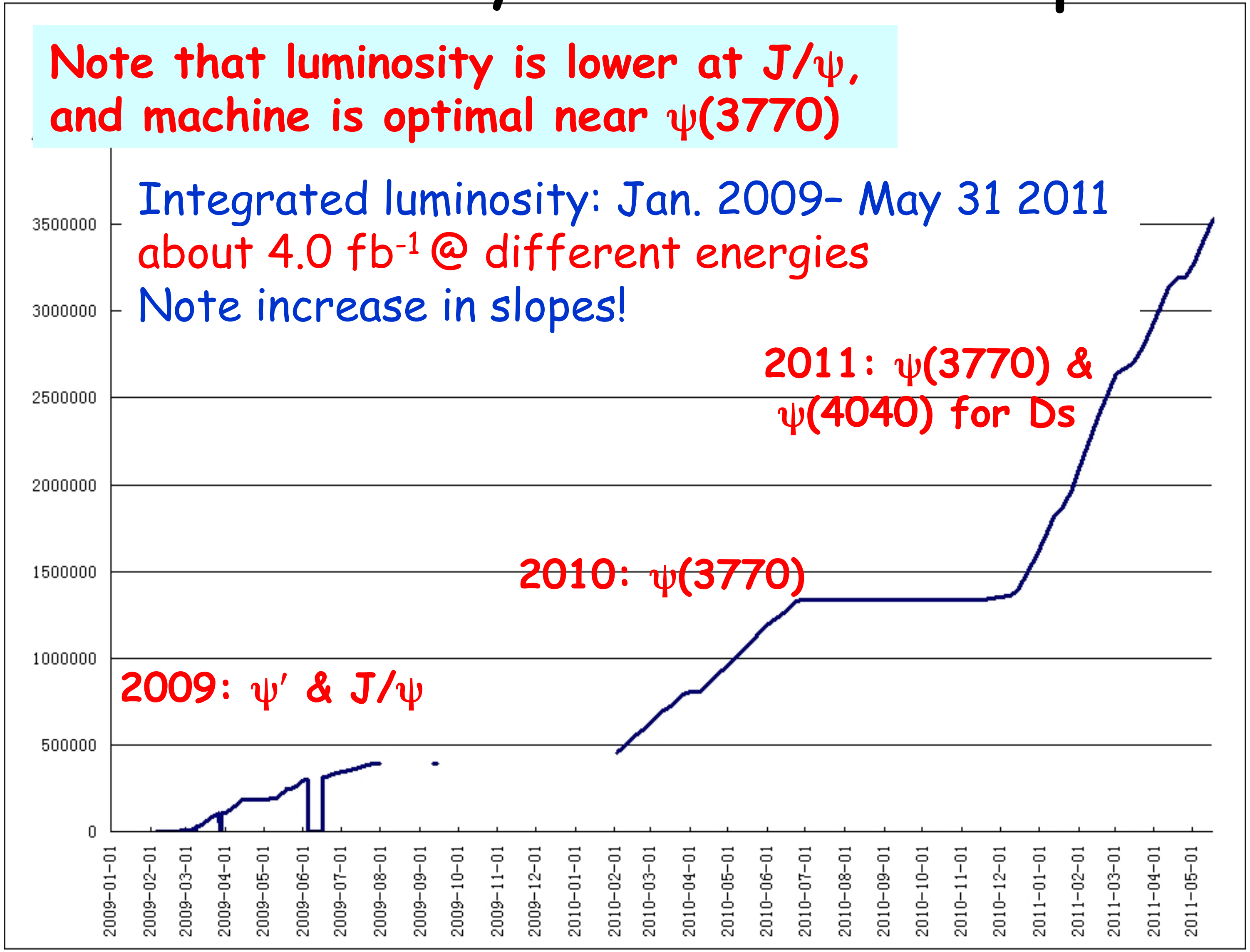


Data samples

- So far BESIII has collected :
  - 2009: 220 Million J/ψ
  - 2009: 106 Million ψ'
  - **2010-11: 2.74 fb^{-1} $\psi(3770)$ (3.5 × CLEO-c 0.818fb^{-1})**
  - **May 2011: 0.5fb^{-1} @4010 MeV (one month) for Ds and XYZ spectroscopy**
- BESIII will also collect:
  - more J/ψ, ψ', $\psi(3770)$
  - data at higher energies （for XYZ searches, R scan and Ds physics）

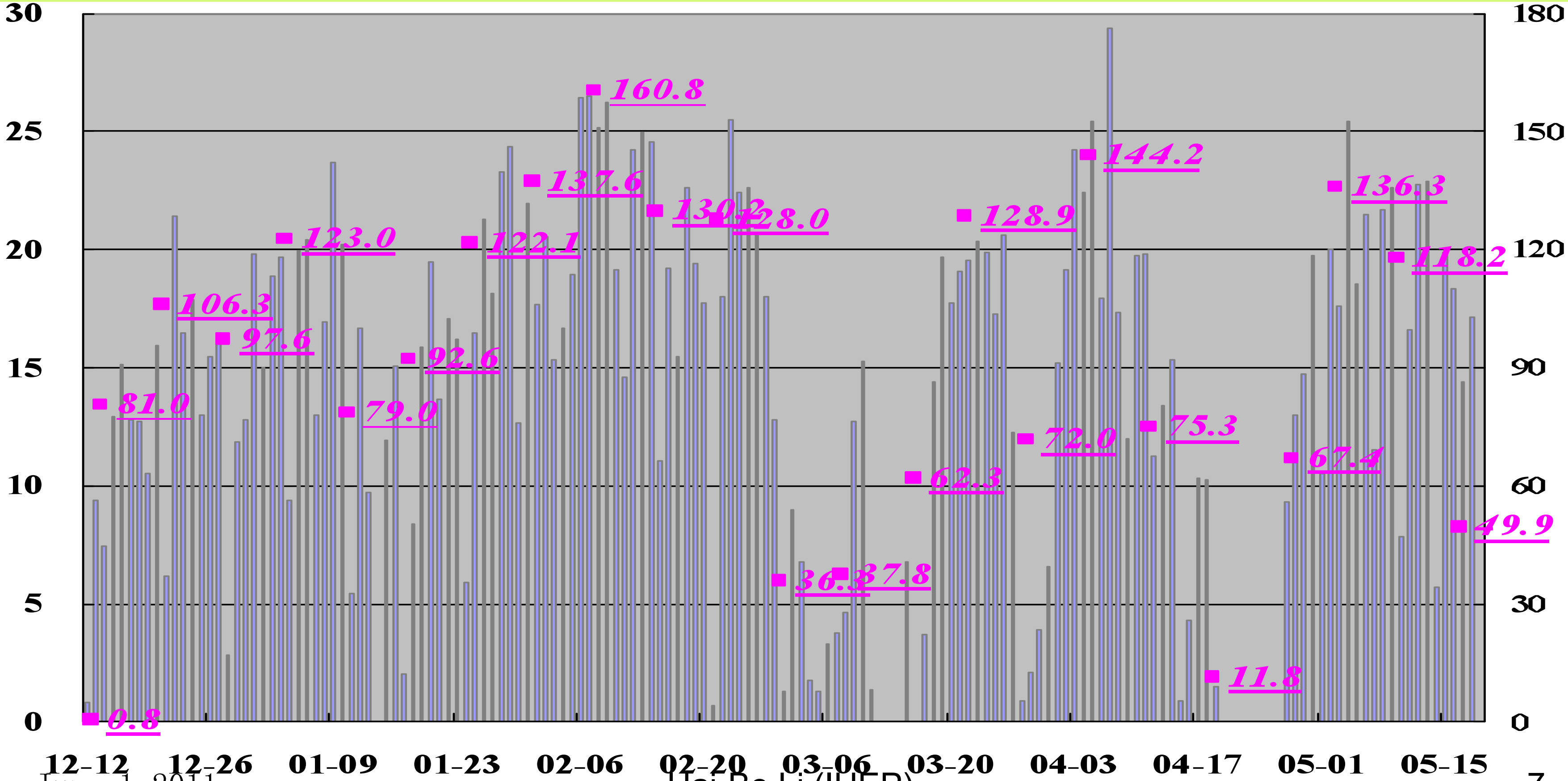


luminosity since startup

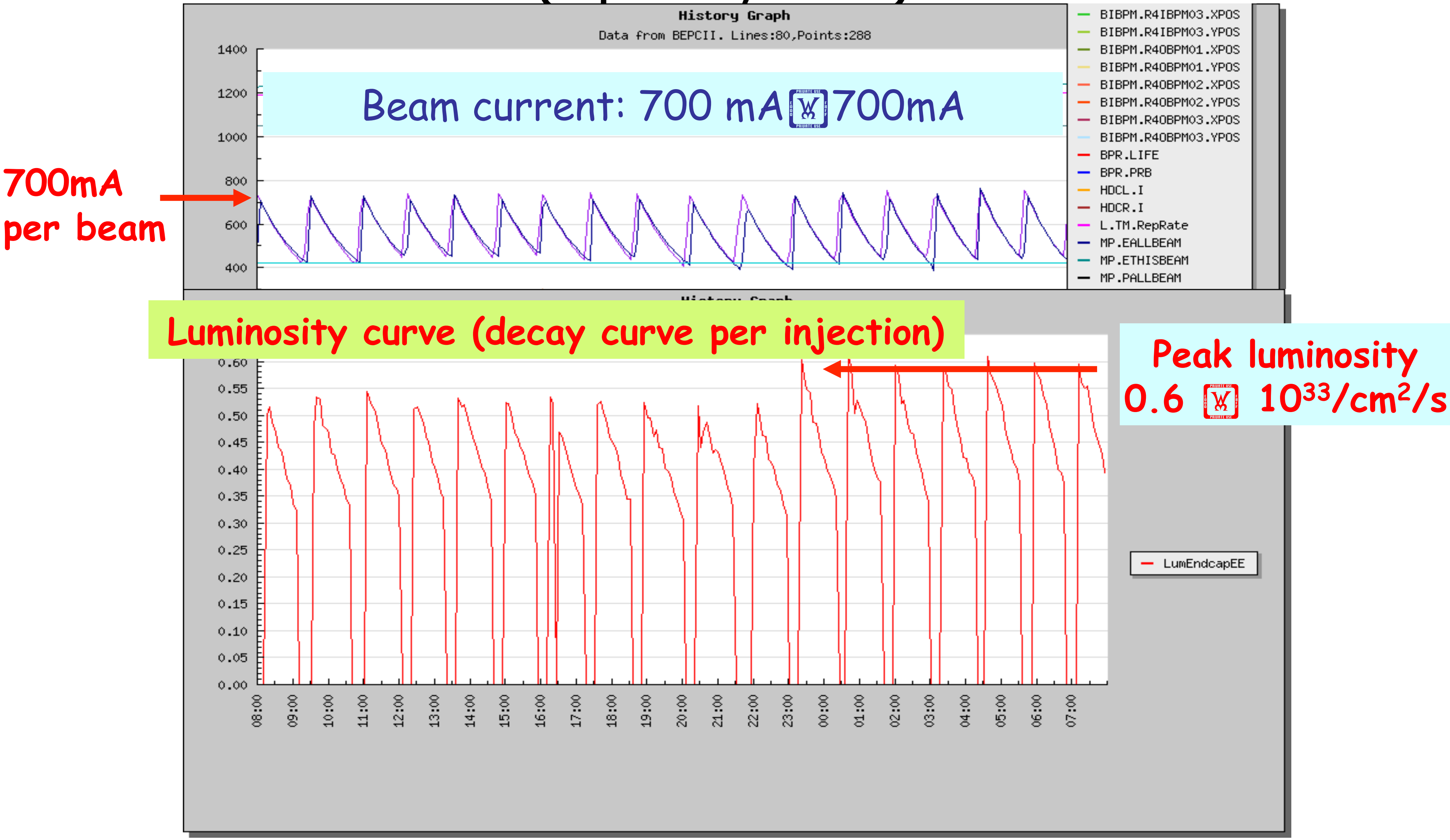


Recent ψ(3770) running

Reference point: L = 0.5 × 10^{33} /cm^2/s (maximum 0.65 × 10^{33})
theoretically lumi: 43 pb^{-1} /day
But, filling beam, HV ramp, lumi. decay and down time loss 40%
Best week : 160.8 pb^{-1}
Best day : 29 pb^{-1}



Luminosity vs beam current for best day (April 7, 2011)



Released results of BESIII

- Charmonium Spectroscopy and Transitions
  - Properties of the hc *(PRL 104, 132002 (2010))*
  - $\psi(2S) \to \gamma\gamma J/\psi$ *(preliminary)*

9 papers published

- Charmonium Decays
  - $\chi_{cJ} \to \pi^0\pi^0, \eta\eta$ *(PRD 81, 052005 (2010))*
  - $\chi_{cJ} \to \gamma\rho, \gamma\omega, \gamma\phi$ *(accepted by PRD)*
  - $\chi_{cJ} \to \omega\omega, \phi\phi, \omega\phi$ *(submitted to PRL)*
  - $\psi(2S) \to \gamma\pi^0, \gamma\eta, \gamma\eta'$ *(PRL 105, 261801 (2010))*
  - $\chi_{cJ} \to 4\pi^0$ *(PRD 83, 012006 (2011))*
  - **Observation of χ_{cJ}-> ppbarK^+K^- (submitted to PRD)**
- Light Quark States
  - $a_0(980) - f_0(980)$ mixing *(PRD 83, 032003 (2011))*
  - $\eta' \to \eta\pi^+\pi^-$ matrix element *(PRD 83, 012003 (2011))*
  - $X(1860)$ in $J/\psi \to \gamma(pp)$ *(Chinese Physics C 34, 4 (2010))*
  - $X(1835)$ in $J/\psi \to \gamma(\eta'\pi^+\pi^-)$ *(PRL 106, 072002 (2011))*
  - $X(1870)$ in $J/\psi \to \omega(\eta\pi^+\pi^-)$ *(preliminary)*

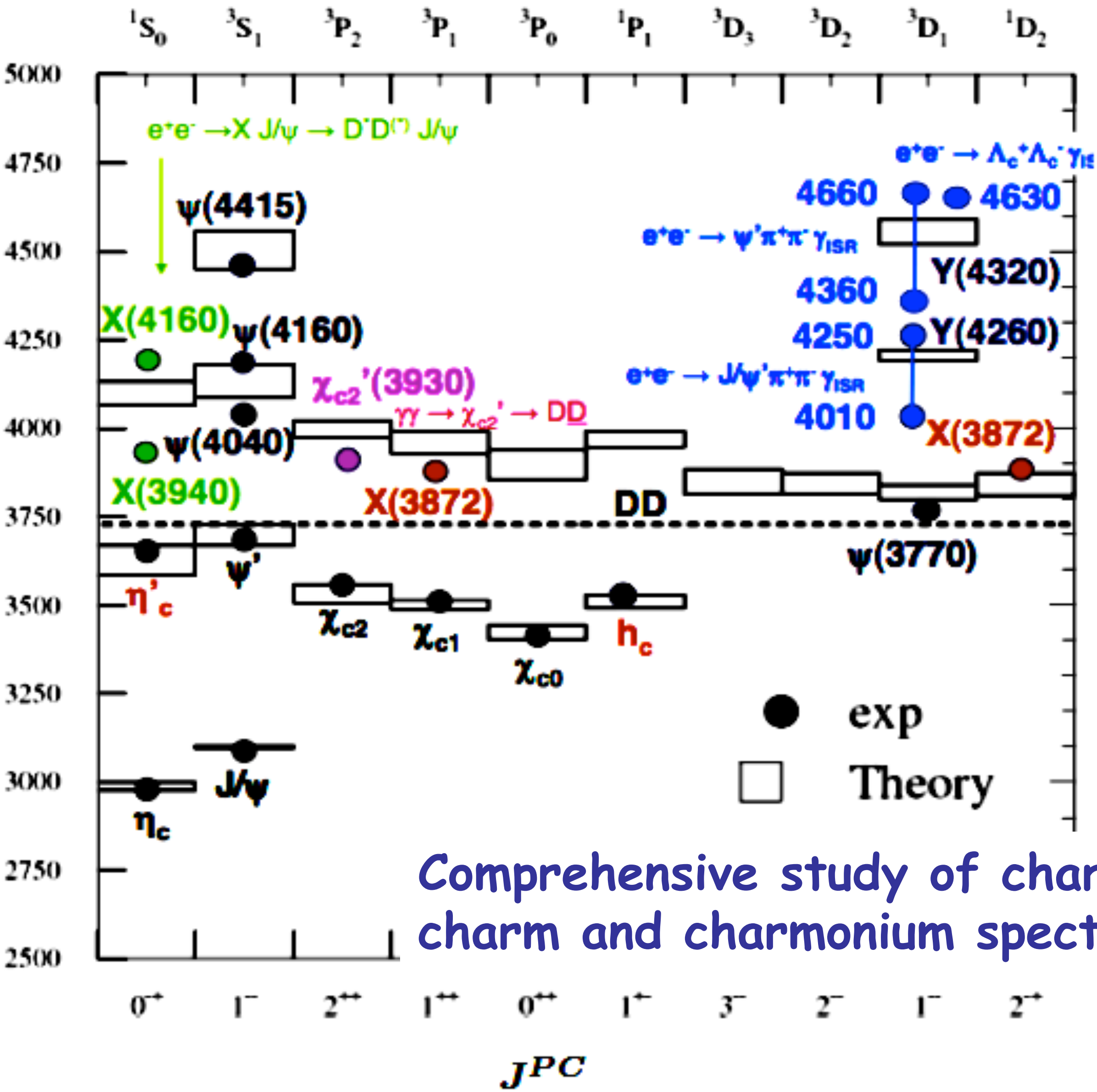
More than 20 analyses are under internal review!

Running plan

- **The luminosity of BEPCII is better than expected.**
- **Data taking for open charm:**
  - **$\psi(3770)$: 1.82 fb^{-1} (2011)+0.923 fb^{-1} (2010) = 2.743 fb^{-1}**
  - **4010 MeV : 0.5 fb^{-1} in May 2011 for Ds physics**

Year	Running
2012	J/ ψ: 1 billion / $\psi(2S)$: 0.5 billion (approved)
2013	4170 MeV: Ds decay + R scan (E > 4 GeV)
2014	$\psi(2S)/\tau$ / R scan (E > 4 GeV)
2015	$\psi(3770)$: 5-10 fb^{-1} (our final goal)

Charmonium spectroscopy after the B-factories



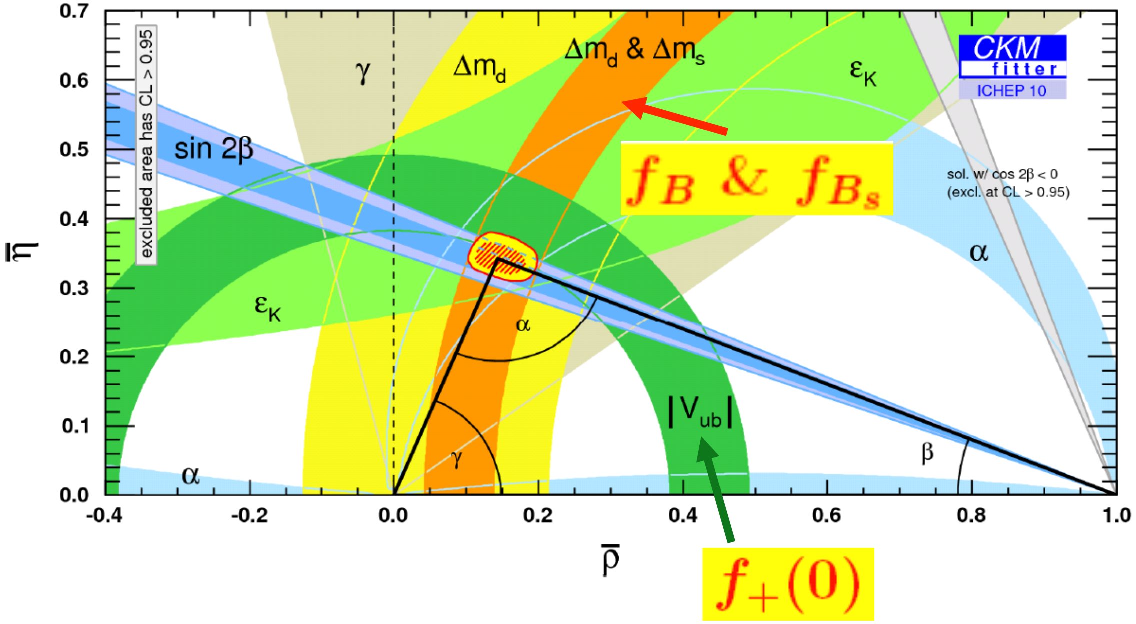
BESIII final goal
J/ψ - 10^{10}
$\psi(2S)$ - 3×10^9
$\psi(3770)$ - 6×10^8
Higher ψ's - 10^7

In decays:
$\eta_c(1S)$-10^8
χ_{cJ} - 10^8
h_c - 10^7
$(\psi(2S)\to h_c\pi^0)$
10^8 η/η' samples
Rare η/η' decays

Comprehensive study of charmonium decays
charm and charmonium spectroscopy

Prospect of charm physics at BESIII

Charm role in flavor physics



Theoretical errors dominate width of bands

$|V_{ub}|$ from $B \to \pi \ell \nu$:

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{ub}|^2 p_\pi^3 |f_+(q^2)|^2$$

Form factor $f(q^2)$:

- Hard to calculate
- Limits $|V_{ub}|$ precision
- Lattice QCD can do from first principles

precision QCD calculations tested with
precision charm data at threshold
➔theory errors of a few % on B system
decay constants & semileptonic form factors

Charm decay measurements
decay constants
form factors
V_{CKM} clean extraction
validate QCD.

over-constrain V_{CKM}
Inconsistency → New Physics

Advantage of open charm at threshold

e^+e^- Colliders@threshold: CLEO-c, BESIII, Super-tau-charm

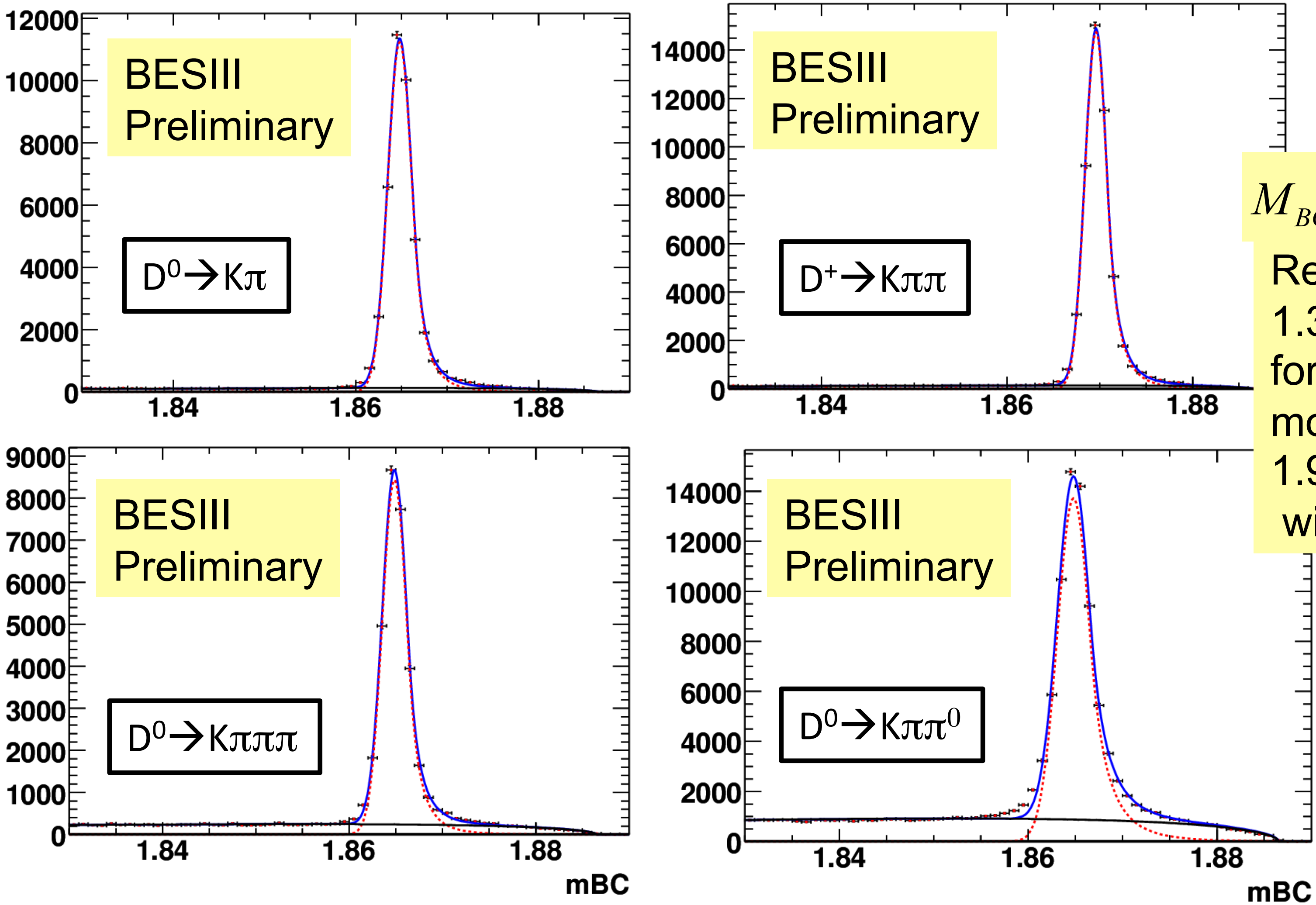
$$e^+e^- \to \psi(3770) \to D^0\overline{D}^0 \quad [C = -1] \qquad \text{OR} \qquad e^+e^- \to \gamma^* \to D^0\overline{D}^0\gamma \quad [C = +1]$$

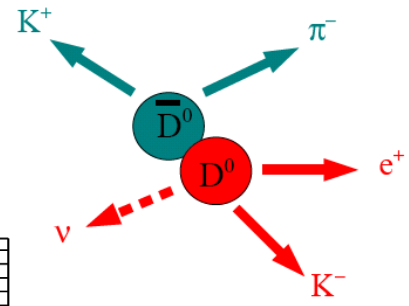
Good for charm flavor physics:

- Threshold production: clean
- Known initial energy and quantum numbers
- Both D and Dbar fully reconstructed (double tag)
- Absolute measurements

Clean single tag at BESIII

@ψ(3770) with $420pb^{-1}$ first clean single tagging sample:





$$M_{BC} = \sqrt{E_{beam}^2 - |p_D|^2}$$

Resolution:
1.3 MeV for pure charged modes;
1.9 MeV for modes with one π^0.

Prospects for Charm at BESIII

Look for the size of the statistics/systematic/FSR errors for precision measurements at BESIII after CLEO-c.

CLEO-c errors for D^0 /D^+ physics with 818 pb^{-1}@3770		BESIII ($5fb^{-1}$)
f_{D+} ($D^+ \to \mu^+ \nu$):	±4.1% (stat.) ± 1.2% (sys.)	±2.0% (stat.)
$f_\pi(0)$ ($D^0 \to \pi l \nu$):	±5.3% (stat.) ± 0.7%(sys.)	±2.3% (stat.)
BR($D^0 \to K\pi$):	±0.9% (stat.) ± 1.8%(sys.)	limited by sys.
BR($D^+ \to K\pi\pi$):	±1.1% (stat.) ± 2.0%(sys.)	limited by sys.

CLEO-c errors for Ds physics with 600pb^{-1}@4170 MeV		
f_{Ds} ($Ds^+ \to \mu^+ \nu, \tau \nu$):	±2.5% (stat.) ± 1.2% (sys.)	±0.8% (stat.)
BR($Ds^+ \to KK\pi$):	±4.2% (stat.) ± 2.9%(sys.)	±2.0% (stat.)

For Ds physics, BESIII are taking data at both 4010 and 4170 MeV:
4010 MeV (clean single tag, lower cross section 0.3 nb) 0.5 fb^{-1} in May 2011
4170MeV (dirty single tag, maximum cross section 0.9 nb) → CLEO-c 0.6 fb^{-1}

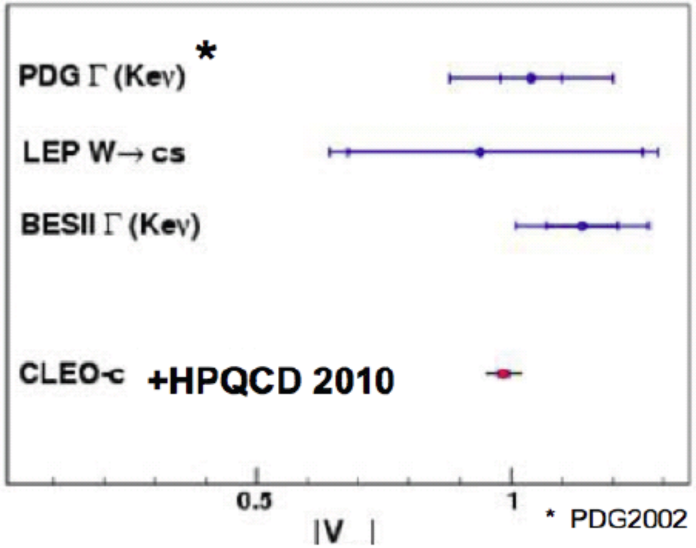
Significant gains will be made with increased luminosity at BESIII.

Vcs / Vcd from semileptonic D decays   From Bo Xin

The data determine $|V_{cs(d)}|f_+(0)$.
To extract $|V_{cs(d)}|$, *we combine the measured* $|V_{cs(d)}|f_+(0)$ *values using the Becher-Hill parameterization with (FNAL-MILC-HPQCD) for* $f_+(0)$

CLEO-c: the most precise *direct* determination of $|V_{cs}|$ $\sigma(|V_{cs}|)/|V_{cs}| \sim 1.1\%(\text{expt}) \oplus 2.5\%(\text{theory})$

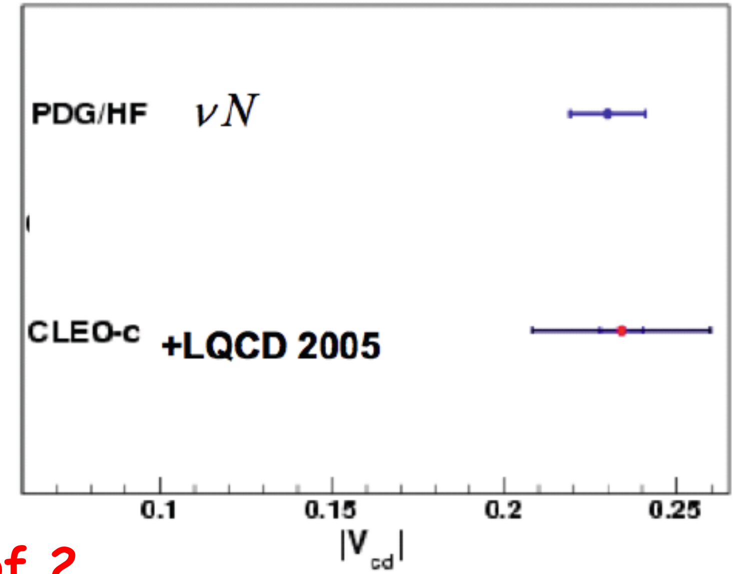
$CLEO-c$	$\lvert V_{cs} \rvert$
$(818\ \text{pb}^{-1})$	$0.963 \pm 0.009 \pm 0.006 \pm 0.024$
	stat syst theory



CLEO-c: $\sigma(|V_{cd}|)/|V_{cd}| \sim 3.1\%(\text{expt}) \oplus 10\%(\text{theory})$

νN remains most precise determination

$CLEO-c$	$\lvert V_{cd} \rvert$
$(818\ \text{pb}^{-1})$	$0.234 \pm 0.007 \pm 0.002 \pm 0.025$
	stat syst theory



Vcd will be improved at BESIII by a factor of 2.

Production cross sections for DsDs$^{(*)}$

Maximum production rates:

σ(DsDs) = 0.269±0.030±0.015 nb @ 4010 MeV

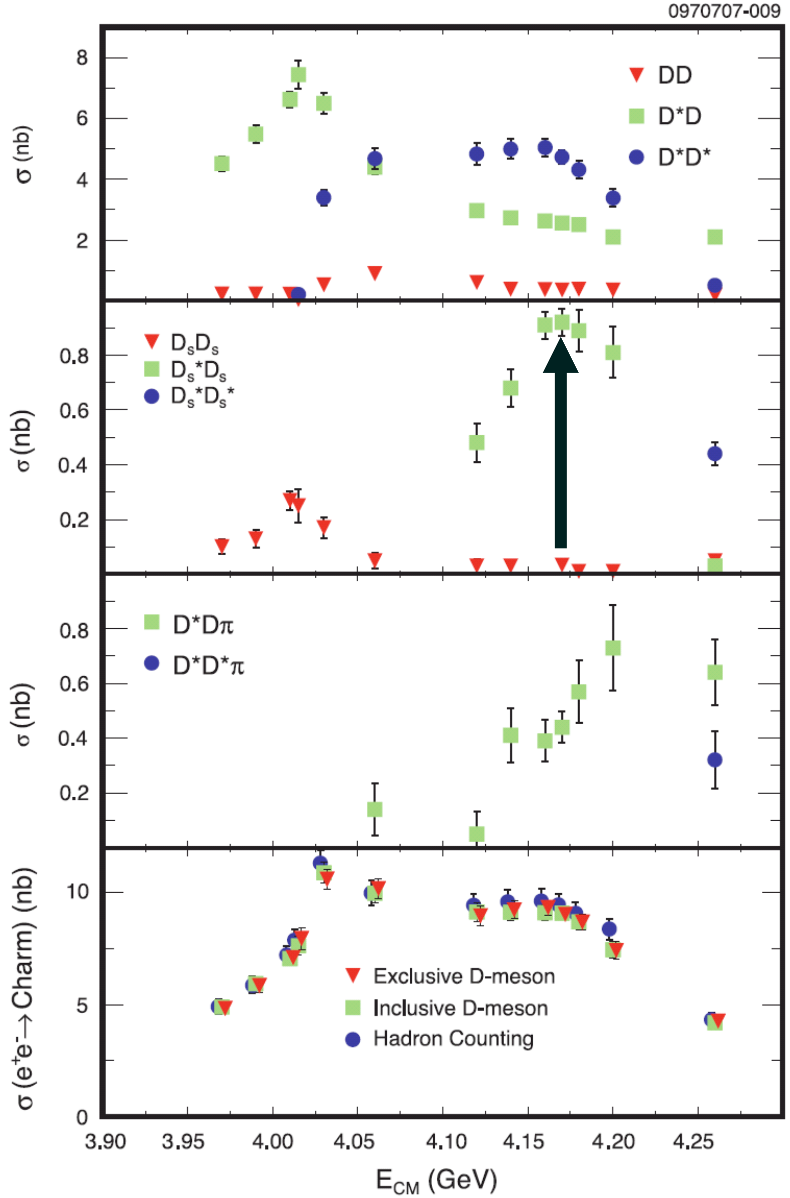
σ(DsDs*) = 0.916±0.011±0.049 nb @ 4170 MeV

CLEO-c took 600 pb^{-1}data @ 4170MeV

Data@4170 MeV

$e^+e^- \to Ds^+Ds^{*-}$, $Ds^{-*} \to \gamma Ds^+$

on top of uds *plus* other* charm continuum (DDbar, DD*bar, D*D*bar)



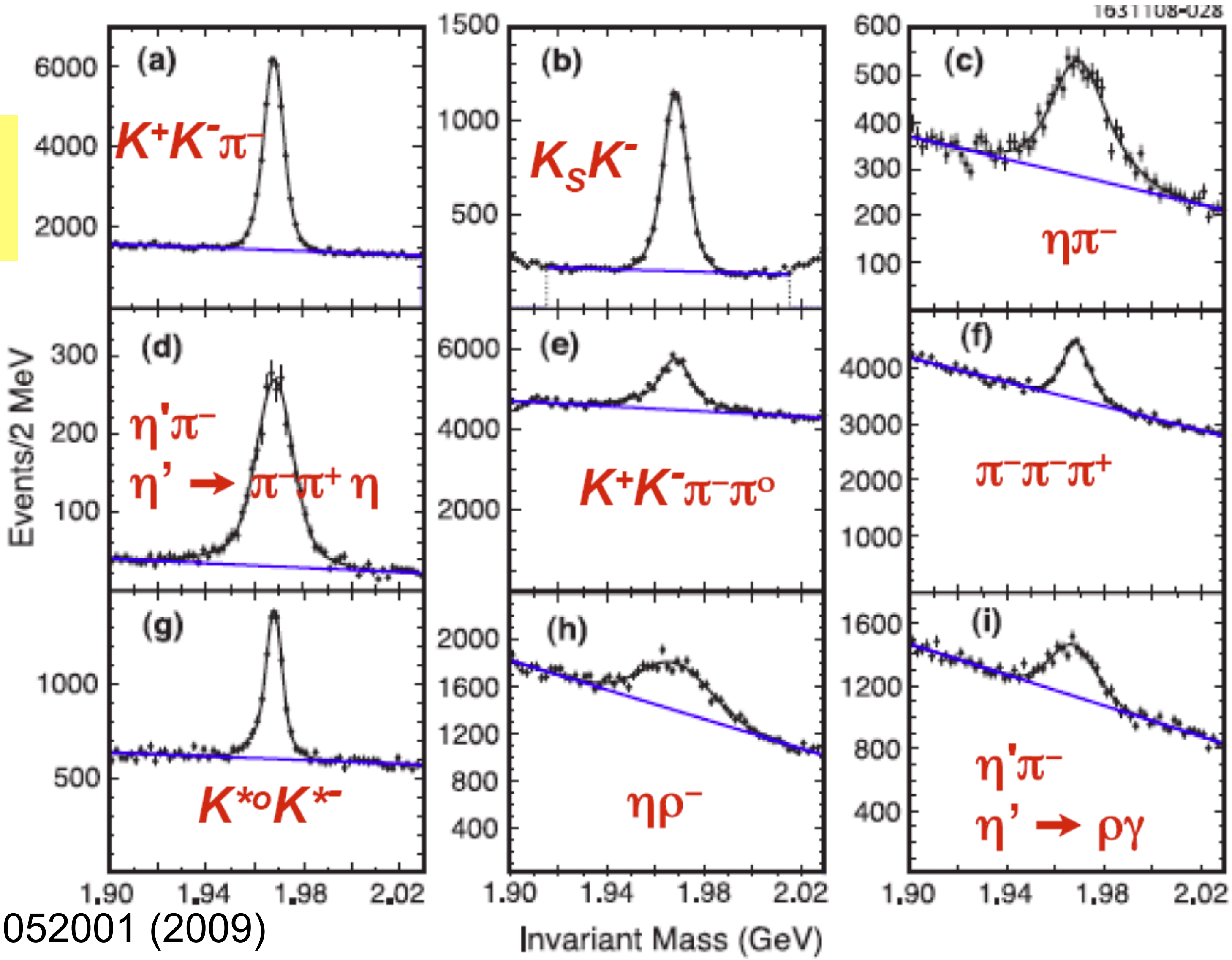
CLEO-c PRD 80, 072001 (2009)

Ds tag modes

Fully reconstruct Ds γ, to look for another Ds.

Invariant mass of 9 tag modes

In the fit:
Signal: Double Gaussian center at zero;
Bakgrd: linear Poly.



CLEO: PRD 79, 052001 (2009)

Missing-mass*^{2} against Ds+γ system – Ds γ tag

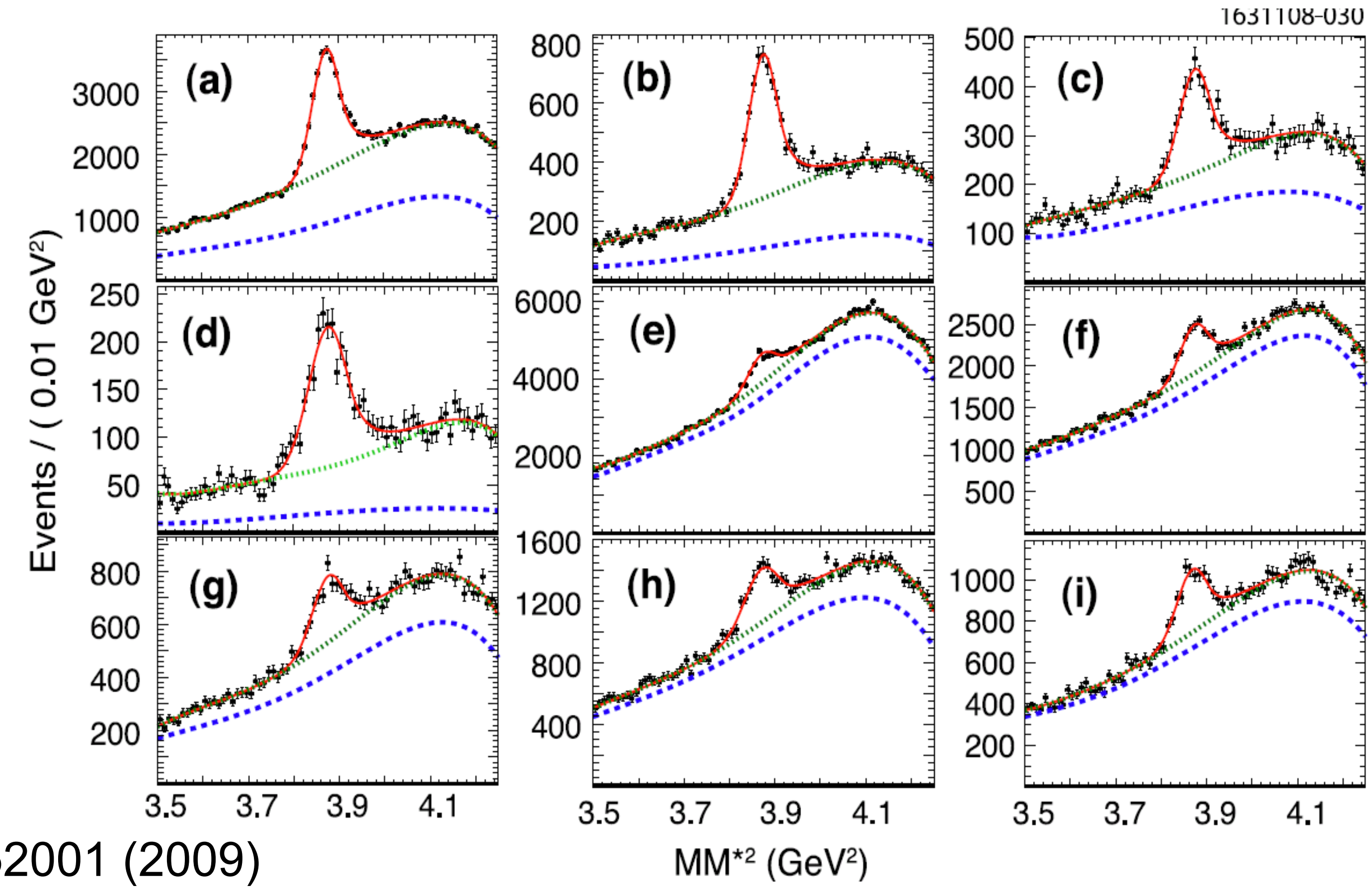
Look at missing mass after adding photon (from Ds*→Dsγ)
Plot missing-mass^2 against Ds γ system.

$$MM^{*2} = (E_{CM} - E_{D_s} - E_\gamma)^2 - (\mathbf{p}_{CM} - \mathbf{p}_{D_s} - \mathbf{p}_\gamma)^2$$

Peak at $(M_{Ds})^2$

Need photon to fully constrain the other Ds….

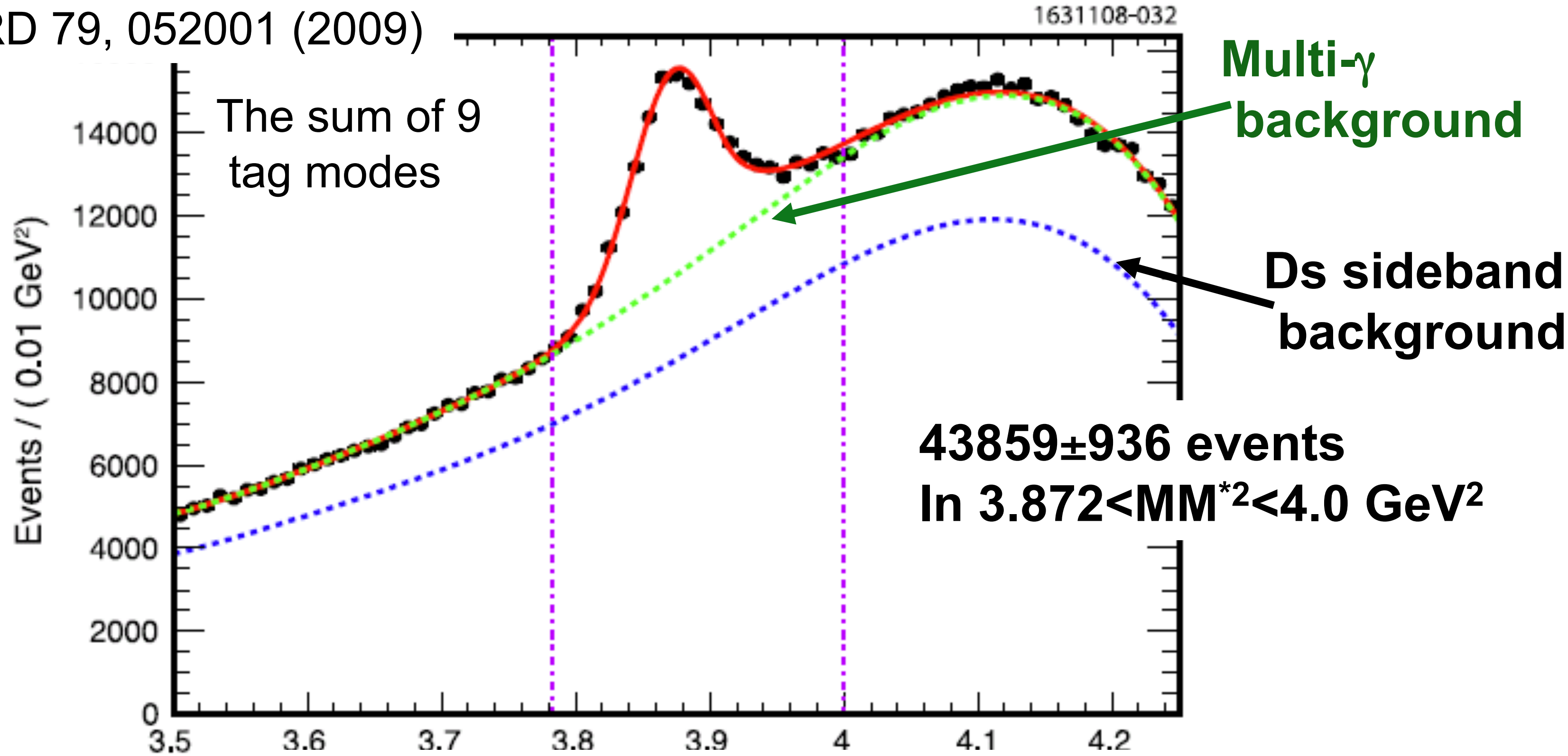
Signal: CB function
Backg: Chebychev Poly.;



CLEO: PRD 79, 052001 (2009)

Combined Ds *plus* γ tag

CLEO: PRD 79, 052001 (2009)



Peak at $(M_{Ds})^2$ $MM^{*2} = (E_{CM} - E_{D_s} - E_\gamma)^2 - (\mathbf{p}_{CM} - \mathbf{p}_{D_s} - \mathbf{p}_\gamma)^2$

FIG. 7 (color online). The MM^2 distribution summed over all modes. The curves are fits to the number of signal events using the Crystal-Ball function and two 5th order Chebychev background functions (see text). The vertical lines show the region of events selected for further analysis.

Ds tag samples

Mode	Invariant Mass		MM^{*2}	
	Signal	Background	Signal	Background
$K^+K^-\pi^-$	$26\,534 \pm 274$	25 122	$16\,087 \pm 373$	39 563
K_SK^-	6383 ± 121	3501	4215 ± 228	6297
$\eta\pi^-$; $\eta \to \gamma\gamma$	2993 ± 156	5050	2005 ± 145	5016
$\eta'\pi^-$; $\eta' \to \pi^+\pi^-\eta$, $\eta \to \gamma\gamma$	2293 ± 82	531	1647 ± 131	1565
$K^+K^-\pi^-\pi^0$	$11\,649 \pm 754$	78588	6441 ± 471	89 284
$\pi^+\pi^-\pi^-$	7374 ± 303	60 321	5014 ± 402	43 286
$K^{*-}K^{*0}$; $K^{*-} \to K^0_S\pi^-$, $K^{*0} \to K^+\pi^-$	4037 ± 160	10 568	2352 ± 176	12 088
$\eta\rho^-$; $\eta \to \gamma\gamma$, $\rho^- \to \pi^-\pi^0$	5700 ± 281	24 444	3295 ± 425	24 114
$\eta'\pi^-$; $\eta' \to \rho^0\gamma$,	3551 ± 202	19 841	2802 ± 227	17 006
Sum	$70\,514 \pm 963$	227 966	$43\,859 \pm 936$	238 218

CLEO: PRD 79, 052001 (2009)

PRD 79, 052001 (2009) 600 pb^{-1}

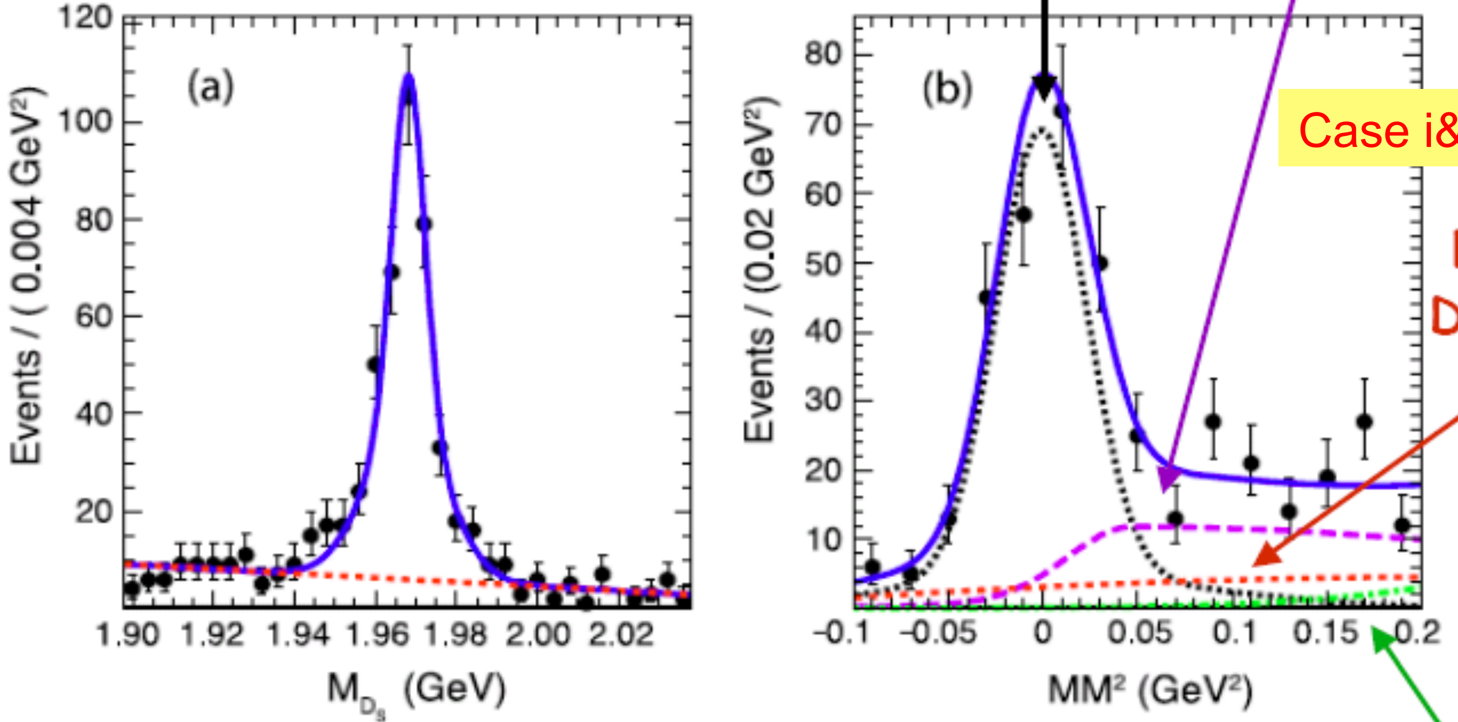
$D_s \to \mu^+\upsilon$ & $\tau^+\upsilon$ ($\tau^+ \to \pi\upsilon$)

Combined case i and case ii data:

2-dimensional fit to D_s Tag mass and missing-mass-squared

Two signal modes

$\mu^+\nu$ $\tau^+\nu$



Background D_s sidebands

Real D_s background

Fix the ratio $\tau\nu/\mu\nu$ =9.76 to SM:

$Ds\to\mu\nu$: 235.5±13.8

Systematic Errors

PRD 79, 052001
(2009) 600 pb^{-1}

Error on f_{D_s} is 1/2 on this

TABLE III. Systematic errors on determination of the $D_s^+ \to \mu^+ \nu$ branching fraction.

Error Source	Size (%)
Track finding	0.7
Particle identification of μ^+	1.0
MM^2 width	0.2
Photon veto	0.4
Background	1.0
Number of tags	2.0
Tag bias	1.0
Radiative Correction	1.0
Total	3.0

Largest single error
is # tags:
might be better at
4030 MeV, with no D_s^*
(but only 30%
of cross-section!)

Optimal energy points for Ds

- **For Ds physics, BESIII are taking data at both 4010 and 4170 MeV:**

@4010 MeV : clean single tag, lower cross section 0.3 nb

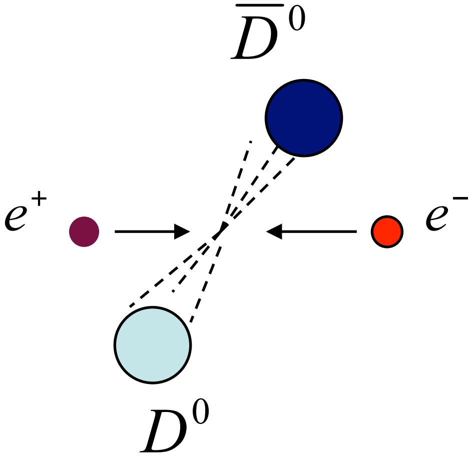
BESIII collected 0.5 fb^{-1} in May 2011

@4170MeV : dirty single tag, maximum cross section 0.9 nb

CLEO-c 0.6 fb-1

$D^0 D^0$bar quantum correlation @$\psi(3770)$

For a physical process producing $D^0\ \bar{D}^0$ such as



$$e^+e^- \to \psi'' \to D^0\overline{D}^0$$

The quantum number of ψ'' is $J^{PC} = 1^{--}$

∴ For a correlated state C=-1:

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

$$\hat{C}|D^0\rangle = |\overline{D}^0\rangle$$
$$\hat{C}|\overline{D}^0\rangle = |D^0\rangle$$

Z.Z . Xing, PRD55, 196(1997)

The correlated amplitude:

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

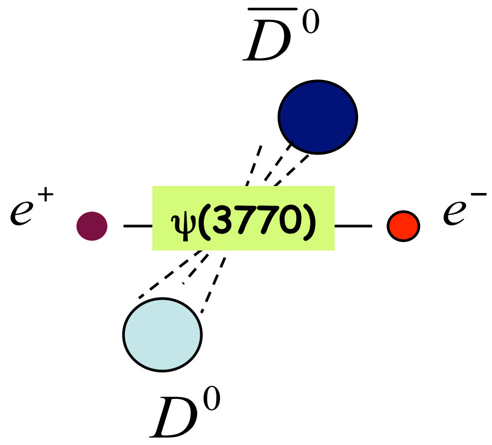
$$\frac{\langle K^-\pi^+|\overline{D^0}\rangle_{\text{DCS}}}{\langle K^-\pi^+|D^0\rangle_{\text{CF}}} = -r_{K\pi}e^{-i\delta_{K\pi}}$$

~0.06

D^0 strong phase is necessary input for D^0 mixing and CKM measurements at B factories and LHCb

$\delta_{K\pi}$ connects measurements of y and y'

Coherence physics @threshold



D^0 mixing: $R_M = (x^2+y^2)/2 \sim 10^{-4}$

Strong phase can be accessed, helpful for mixing measurements at super-B factories:

- Sensitivity on x will be improved by a factor 3 (Brain Meadows ICHEP2010
  see back-up slides and discussion in morning session on June 1);
- Uncertainty of γ due to unknown ralative phase on Dalitz decay $D^0 \rightarrow K_s h^+h^-$ will be reduced to less than 1^0.

CP violation in D sector : 10^{-3}

D^0 mixing at threshold

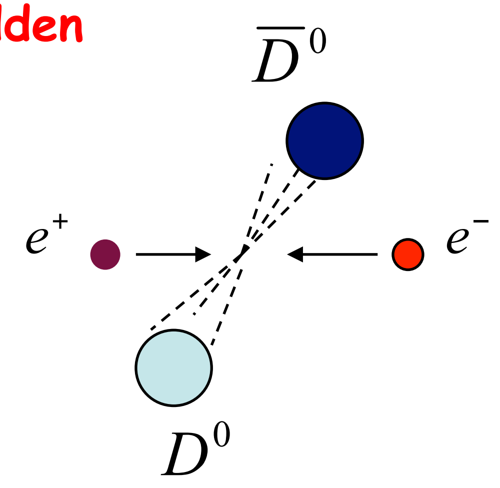
Z.Z . Xing, PRD55, 196(1997)

Without mixing in D^0, the following process is forbidden due to Boson-Einstein statistics :

$$e^+e^- \to \psi(3770) \to D^0\overline{D}^0 \to (K^\pm\pi^\mp)(K^\pm\pi^\mp)$$

With mixing happened, it is allowed:

$$e^+e^- \to \psi(3770) \to D_H^0 D_L^0 \to (K^\pm\pi^\mp)_H (K^\pm\pi^\mp)_L$$



At $\psi(3770)$ $R_M=(x^2+y^2)/2$ can be measured using the ratios

$$R_M = \frac{N[D^0\overline{D}^0 \to (K^-\pi^+)(K^-\pi^+)]}{N[D^0\overline{D}^0 \to (K^-\pi^+)(K^+\pi^-)]}, \quad \frac{N[D^0\overline{D}^0 \to (K^-e^+\nu)(K^-e^+\nu)]}{N[D^0\overline{D}^0 \to (K^-e^+\nu)(K^+e^-\nu)]}$$

For 10^8 D-pairs about 10 events will be detected.
Sensitivity for R_M is about 1×10^{-4}

Expected sensitivity to mixing parameters:
$1\ ab^{-1}$ at tau-charm factory = $10\ ab^{-1}$ at Super B-factory

CPV in D decay at BESIII

Direct CP violation in D decays is expected to be small in SM.

For CF and DCS decays direct CP violation requires New Physics.
Exception: $D^{\pm} \to K_{S,L}\pi^{\pm}$ with $A_{CP}=-3.3\times10^{-3}$.

For Singly Cabibbo Suppressed (SCS) decays SM CPV could reach 10^{-3}.

$$A_{CP} = \frac{\Gamma(D \to f) - \Gamma(\bar{D} \to \bar{f})}{\Gamma(D \to f) + \Gamma(\bar{D} \to \bar{f})}$$

D.S.Du , EPJC5,579(2007)
Y. Grossman et al PRD75, 036008(2007)

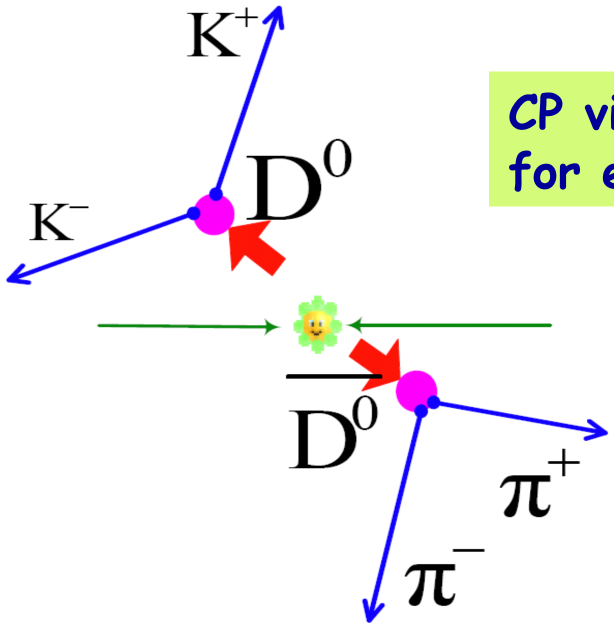
Best limits:

Belle: $D^0 \to K^+K^-, \pi^+\pi^-$
$A_{CP}(K^+K^-)=(0.43\pm0.30\pm0.11)\%$
$A_{CP}(\pi^+\pi^-)=(0.43\pm0.52\pm0.12)\%$

BABAR: $D^+ \to K_S\pi^+$
$A_{CP}(K_S\pi^+)=(-0.44\pm0.13\pm0.10)\%$
CLEO-c : $K_S \pi^+\pi^0$
$A_{CP}(K_S\pi^+\pi^0)=(0.3\pm0.9\pm0.3)\%$

At BESII, CP asymmetry can be tested with 10^{-3} sensitivity for many final states.

CP violation near threshold



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 $\psi'' \to D^0\overline{D}^0 \to f_1 f_2$

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

$CP(\psi'') = +$

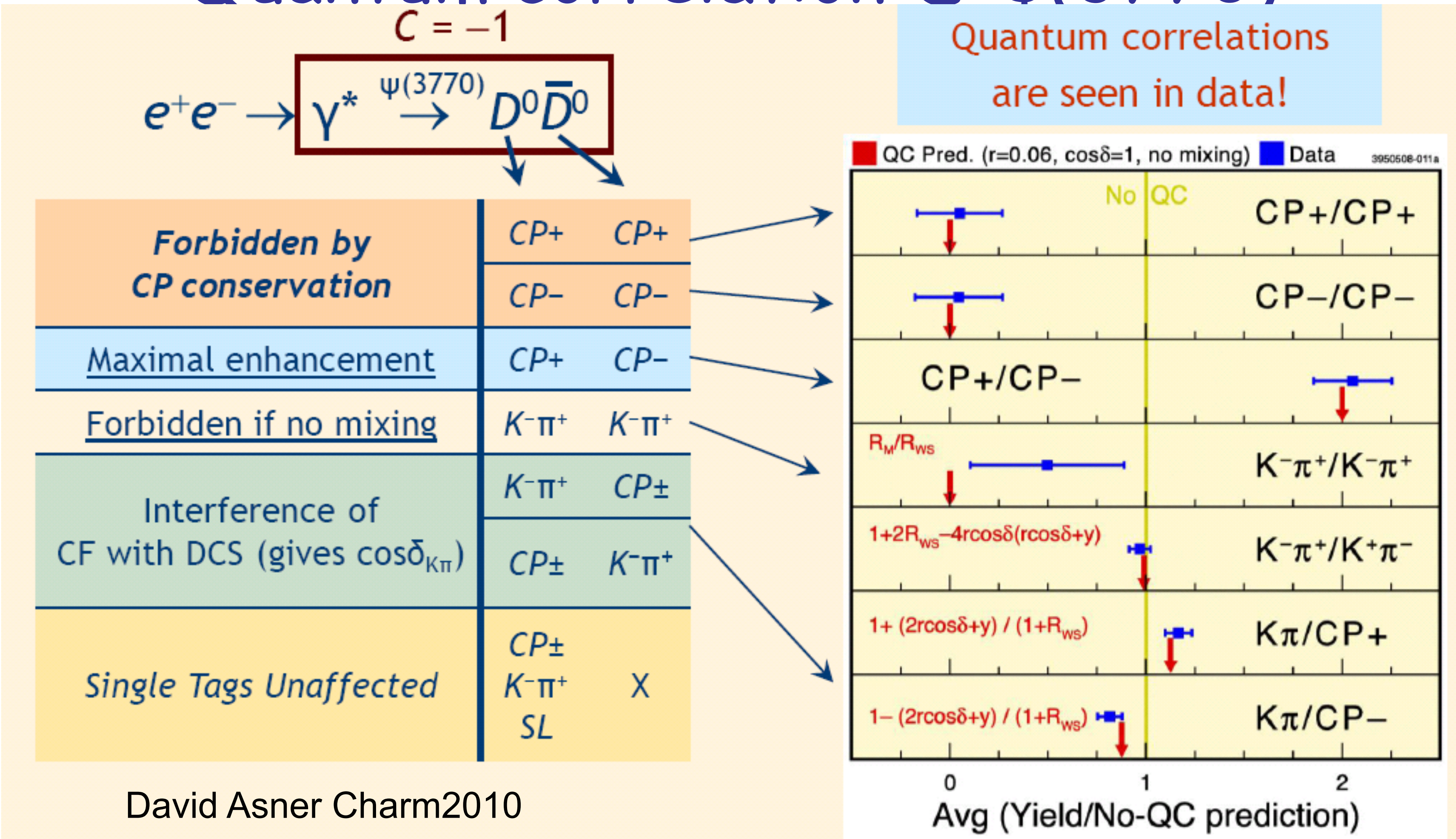
A_{CP} sensitivity : $\Delta A \sim 10^{-3}$

CP violation in mixing can be measured with:

$$A_{SL} = \frac{\Gamma_{l^+l^+} - \Gamma_{l^-l^-}}{\Gamma_{l^+l^+} + \Gamma_{l^-l^-}} = \frac{1 - |q/p|^4}{1 + |q/p|^4}$$

With 10^8 D pairs in $(K^+e^-\nu)(K^+e^-\nu)$ mode, $|q/p|$ can be measured with (20-30)% accuracy. Current world averaged value is 0.86±0.16 .

Quantum correlation @ ψ(3770)



CLEO-c did a simultaneous fit to these combinations
PRL 100, 221801(2008)

Quantum correlation: decay rates @$\psi(3770)$

From D. Asner, CHARM2010

Evaluating $\Gamma_{ij}^2 = \left| \langle i | D^0 \rangle \langle j | \overline{D^0} \rangle - \langle j | D^0 \rangle \langle i | \overline{D^0} \rangle \right|^2$ Anti-symmetric wavefunction

with $\frac{\langle i | \overline{D}^0 \rangle}{\langle i | D^0 \rangle} = -re^{-i\delta}$ gives

Final States			Time-Integrated Rate (x $A_i^2 A_j^2$)
Exclusive	i	$\bar{j}$	$1 + r_i^2 r_j^2 - 2 r_i r_j \cos(\delta_i + \delta_j)$
	i	j	$r_i^2 + r_j^2 - 2 r_i r_j \cos(\delta_i - \delta_j)$
Inclusive	i	X	$1 + r_i^2 + 2 y r_i \cos\delta_i$

~1400 $K^0_S\pi^+\pi^-$ vs. $K\pi$ $\rightarrow \sin\delta_{K\pi}$

~3000 *CP*-tagged $K\pi$ $\rightarrow \cos\delta_{K\pi}$

Flavored hadronic	CP+	CP–	Semilep	Mixed
$K^-\pi^+$	K^-K^+	$K^0_S\pi^0$	$K^-e^+\nu$	$K^0_S\pi^+\pi^-$ (bin 0)
$K^+\pi^-$	$\pi^-\pi^+$	$K^0_S\eta$	$K^+e^-\bar{\nu}$	$K^0_S\pi^+\pi^-$ (bin 1)
	$K^0_S\pi^0\pi^0$	$K^0_S\omega$	$K^-\mu^+\nu$	$K^0_S\pi^+\pi^-$ (bin 2)
	$K^0_L\pi^0$	$K^0_L\pi^0\pi^0$	$K^+\mu^-\bar{\nu}$	$K^0_S\pi^+\pi^-$ (bin 3)
	$K^0_L\eta$			$K^0_S\pi^+\pi^-$ (bin 4)
	$K^0_L\omega$	New in update		$K^0_S\pi^+\pi^-$ (bin 5)
				$K^0_S\pi^+\pi^-$ (bin 6)
				$K^0_S\pi^+\pi^-$ (bin 7)

~3500 *CP*-tagged $Kl\nu$ $\rightarrow y$

~30 WS $Kl\nu$ vs. $K\pi$ $\rightarrow r_{K\pi}^2$

Selected references:

- Goldhaber & Rosner, PRD 15, 1254 (1977)
- Bigi & Sanda, PLB 171, 320 (1986)
- Xing, PRD 55, 196 (1997)
- Gronau, Grossman, Rosner, PLB 508, 37 (2001)
- Atwood & Petrov, PRD 71, 054032 (2005)
- Asner & Sun, PRD 73, 034024 (2006); PRD 77, 019901(E) (2008)

D. Asner Charm2010

CLEO-c Preliminary

Fit Results [$\delta_{K\pi}$]

- 51 free parameters
  - N_{DD}, 21 branching fractions
  - 24 amplitude/phase parameters for $K^0_S\pi^+\pi^-$
  - 5 $K\pi$ and mixing parameters
- Fit performed with and without external measurements of y, x, y' (same as in HFAG May 2010 avg)
- Statistical uncertainties on **y** and $\boldsymbol{r_{K\pi}\cos\delta_{K\pi}}$ (w/o ext. meas.) 3x smaller than 2008 analysis.
  - Estimated impact on HFAG average: $\sigma(y)$ reduced by ~10%
  - First direct measurements of $r_{K\pi}^2$ and $\sin\delta_{K\pi}$
- Preliminary systematic uncertainties

Parameter	Previous: PDG, HFAG, or CLEO	Fit: no ext. meas.	Fit: with ext. **y**, **x**, **y'**
y (10^{-2})	0.79 ± 0.13	3.0 ± 2.0 ± 1.2	**0.635 ± 0.118**
x^2 (10^{-3})	0.037 ± 0.024	1.5 ± 2.0 ± 0.9	0.022 ± 0.017
$r_{K\pi}^2$ (10^{-3})	3.32 ± 0.08	4.12 ± 0.92 ± 0.23	3.32 ± 0.08
$\cos\delta_{K\pi}$	1.10 ± 0.36	**$0.98^{+0.27}_{-0.20} \pm 0.08$**	**1.15 ± 0.16 ± 0.12**
$\sin\delta_{K\pi}$	---	**-0.04 ± 0.49 ± 0.08**	**$0.55^{+0.36}_{-0.40} \pm 0.08$**
$\delta_{K\pi}$ (°) [derived]	$22^{+11}_{-12}{}^{+9}_{-11}$	0 ± 22 ± 6	$15^{+11}_{-17} \pm 7$

Average of y and $y' = y\cos\delta_{K\pi} - x\sin\delta_{K\pi}$ (now limited by $\sin\delta_{K\pi}$)

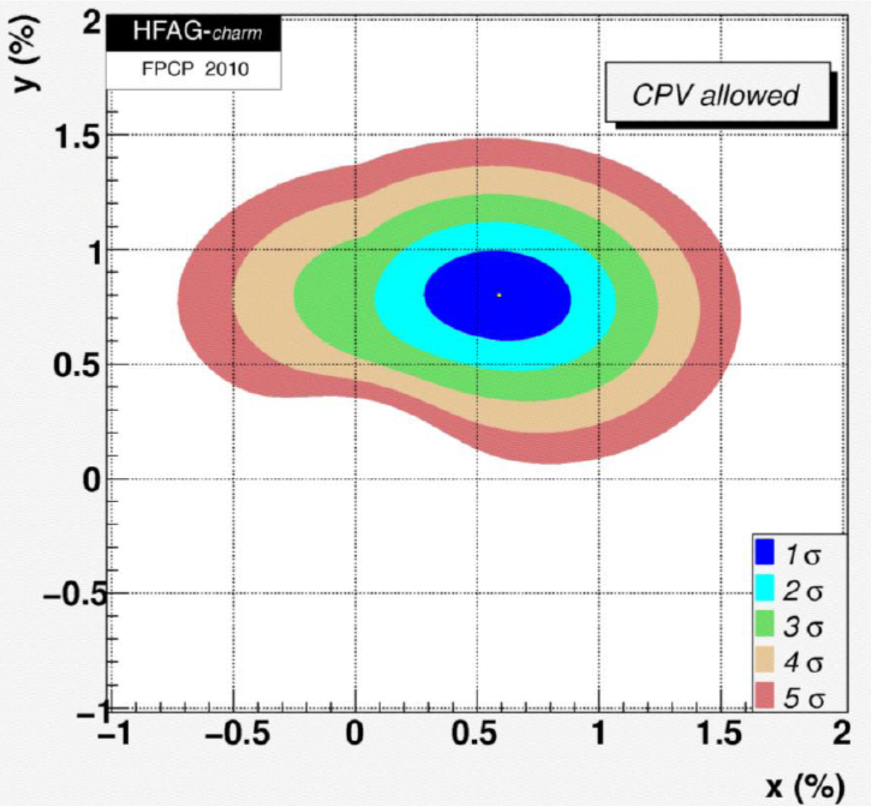
HFAG: new charm mixing with CLEO-c

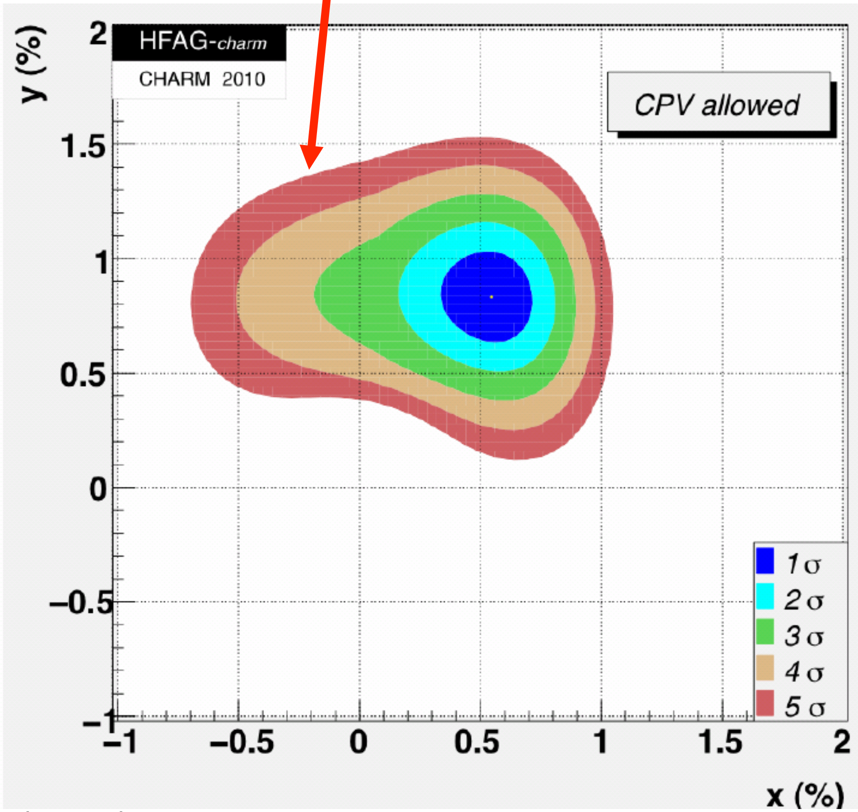
D. Asner
Charm 2010

Parameter	HFAG:FPCP2010	HFAG:CHARM2010
y (10^{-2})	0.79 ± 0.13	0.83 ± 0.13
x (10^{-2})	0.59 ± 0.20	$0.55^{+0.12}_{-0.13}$
$r_{K\pi}^2$ (10^{-3})	3.32 ± 0.08	3.32 ± 0.08
$\delta_{K\pi}$ ($^\circ$)	$27.6^{+11.2}_{-12.2}$	$31.0^{+10.7}_{-12.2}$

Consider CLEO-c results

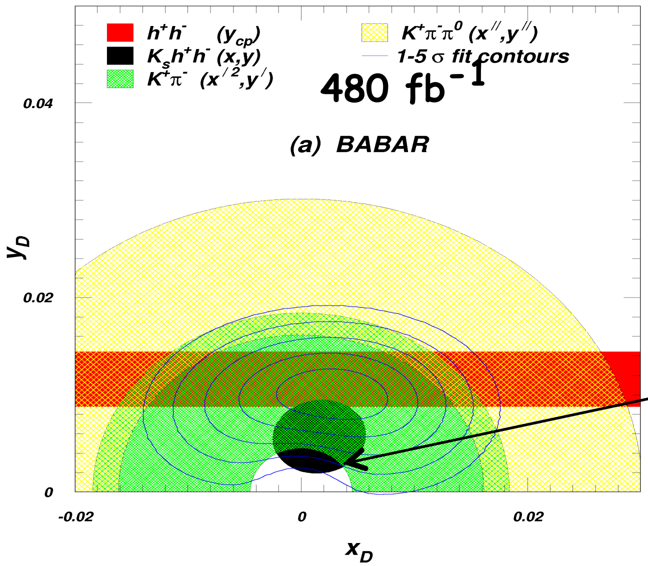
Surprising? Large impact on x uncertainty

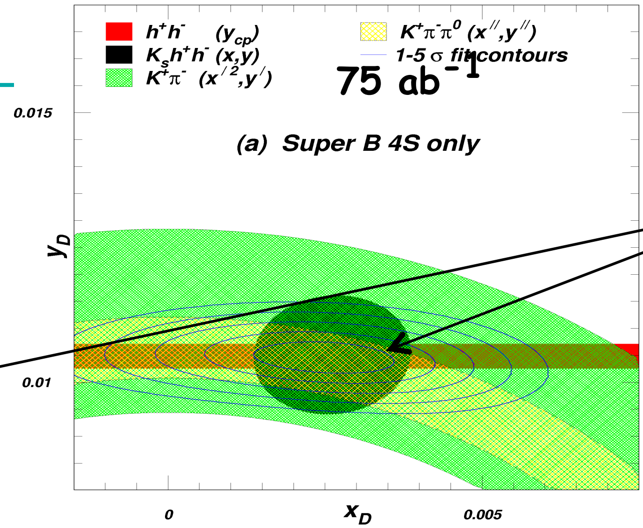




Brian Meadows ICHEP2010

Project to 75ab^{-1}@Υ(4S):





Golden channels

Min. χ^2 fits (blue contours)

$$x_D = (5.5 \pm^{1.3}_{1.2}) \times 10^{-3}$$
$$y_D = (8.3 \pm 1.3) \times 10^{-3}$$

→

$$x_D = (xxx^{+0.72}_{-0.75}) \times 10^{-3}$$
$$y_D = (xxx \pm 0.19) \times 10^{-3}$$

Uncertainties shrink: but are limited by the irreducible model uncertainty (biggest effect on x_D)

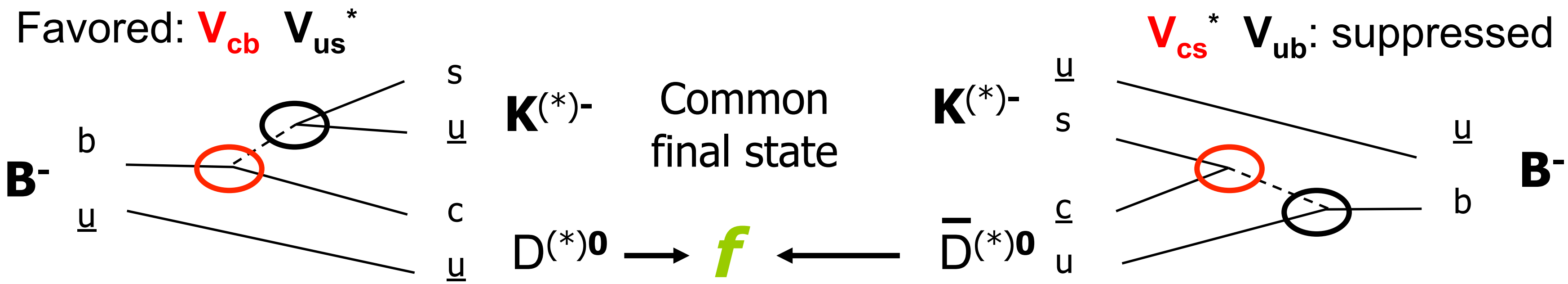
Strong phase measurement from ψ(3770) can greatly reduce this.

$$x_D = (xxx \pm 0.20) \times 10^{-3}, \quad y_D = (xxx \pm 0.12) \times 10^{-3}$$

The weak phase γ (ϕ_3)

From A. Bondar CHARM2010

Interference between tree-level decays; theoretically clean



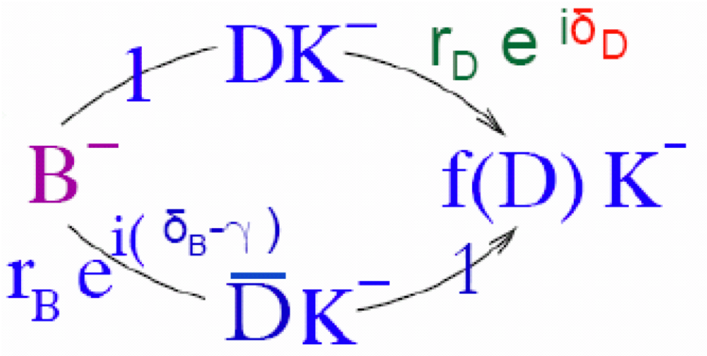
$$\frac{A\left(B^- \to \overline{D}^0 K^-\right)}{A\left(B^- \to D^0 K^-\right)} = r_B e^{i\delta} e^{-i\phi_3}$$

Parameters: ϕ_3, (r_B, δ) per mode

Three methods for exploiting interference (choice of D^0 decay modes):

- Gronau, London, Wyler (GLW): Use CP eigenstates of $D^{(*)0}$ decay, e.g. $D^0 \to K_s\pi^0$, $D^0 \to \pi^+\pi^-$
- Atwood, Dunietz, Soni (ADS): Use doubly Cabibbo-suppressed decays, e.g. $D^0 \to K^+\pi^-$
- Giri, Grossman, Soffer, Zupan (GGSZ) / Belle: Use Dalitz plot analysis of 3-body D^0 decays, e.g. $K_s\pi^+\pi^-$

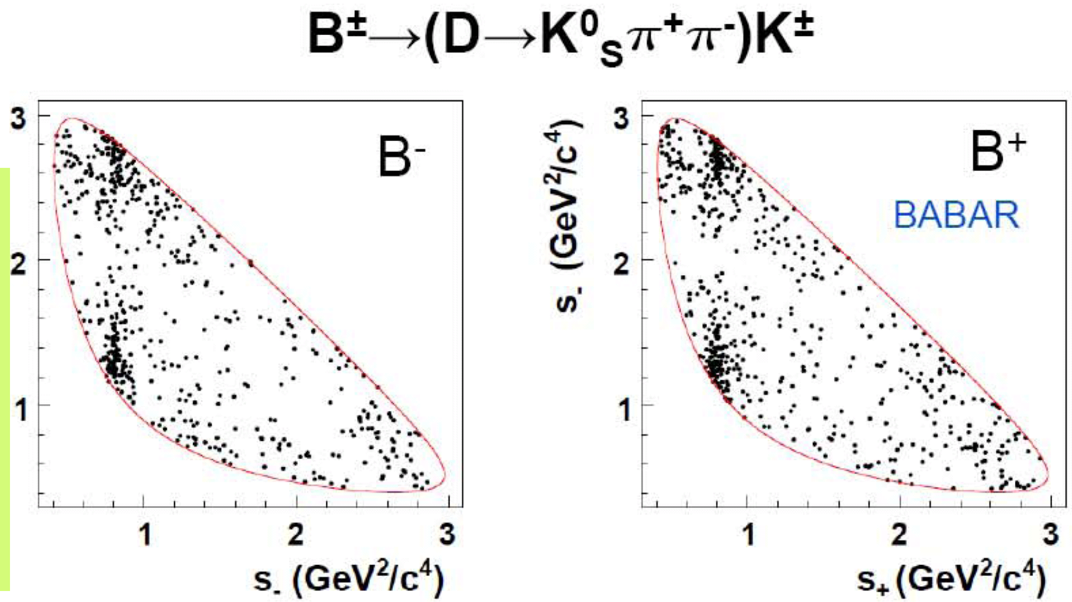
$B^- \to D(K_s h^+ h^-) K^-$ Dalitz plot for γ at B factory



A powerful choice of common state f(D) in $K_s h^+ h^-$

BABAR: PRL 105, 121801 (2010)

Belle : PRD 81, 112002 (2010)



Differents between B^- and B^+ Dalitz plots allow γ extracted in unbinned fit. However, need to understand different amplitudes from D^0 and D^0bar decay modes across Dalitz space, esp. variation in strong phase.

Approach of B factories: construct Dalitz plot model of D with flavor-tagged decays, estimated model uncertainty of 30-90, which is << statistical error.

But super-B and LHC-b will start to be limited by this model uncertainty –

Highly desirable to have precision model independent approach!

Binned Model-Independent Fit

Binned fit proposed by Giri *et al.* [PRD 68 (2003) 054018] and developed by Bondar & Poluektov [EPJ C 55 (2008) 51; EPJ C47 (2006) 347] removes model dependence by relating events in bin i of Dalitz plot to *experimental observables.*

$B^{\pm}$ events in bin i of Dalitz plot

Number of events for flavour-tagged D sample

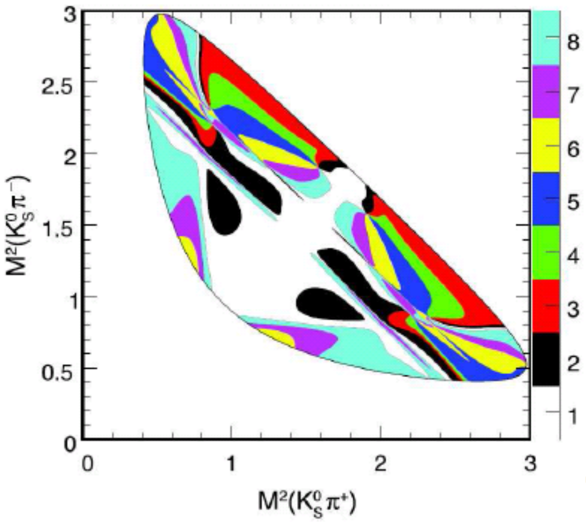
$x_{\pm} = r_B\cos(\delta_B \pm \gamma)$

$y_{\pm} = r_B\sin(\delta_B \pm \gamma)$

$$N_i^{\pm} = h(K_{\pm i} + r_B^2 K_{\mp i} + 2\sqrt{K_i K_{-i}}(x_{\pm}c_i \pm y_{\pm}s_i))$$

c_i, s_i : average in bin of cosine, sine of strong phase δ_D

Can be measured in quantum correlated decays at ψ(3770)!



Choosing bins of *expected* similar strong phase difference maximises statistical precision

Here take 8 bins of equal spacing in $\Delta\delta_D$ (using as reference model: BaBar, PRL 95 (2005) 121802)

Loss in statistical sensitivity w.r.t. unbinned result…(here ~20%) but no model error!

From Jim Libby CHARM2010

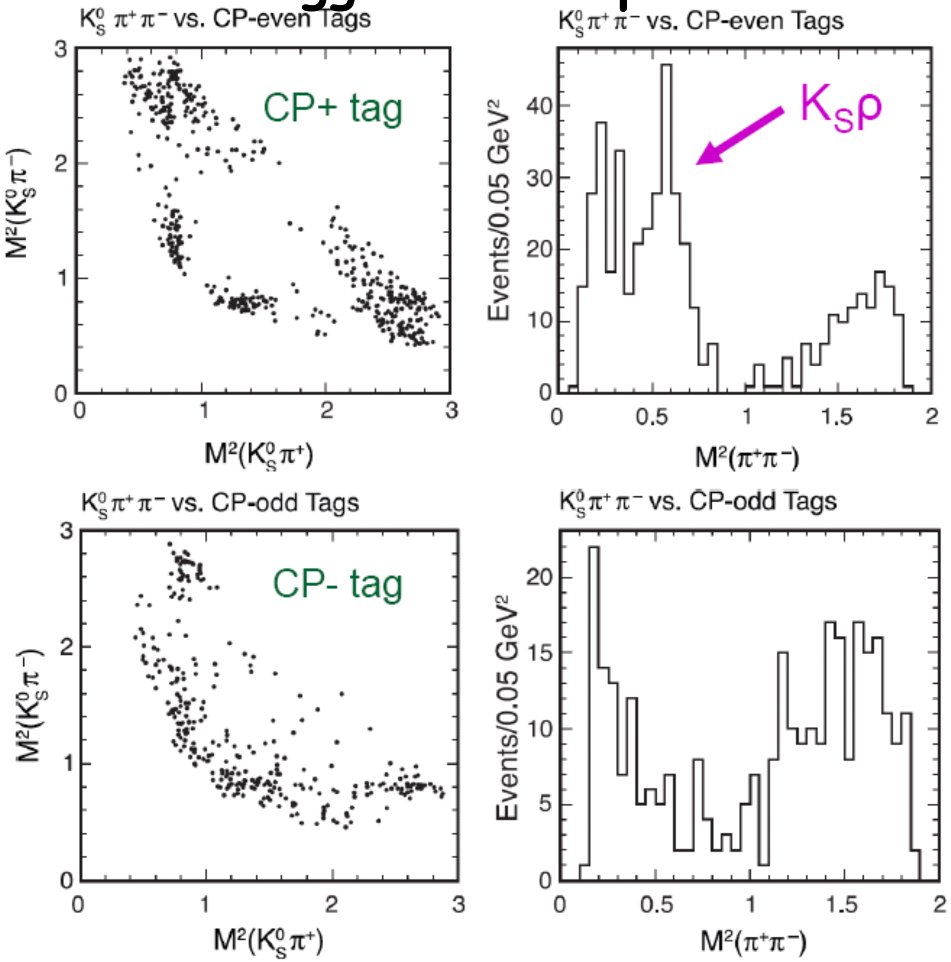
CP-tagged Dalitz plots

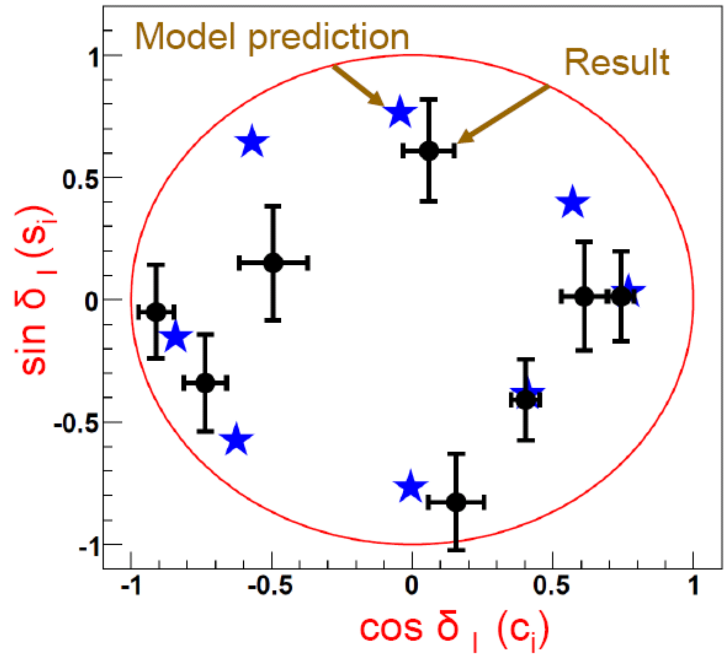
Clear difference between CP-even and CP-odd tagged Dalitz plots.

R. Briere *et al.*, PRD 80 (2009) 032002

(model = BABAR PRL 95 (2005) 121802)

CLEO-c, PRD 80 (2009) 032002





Projected uncertainty on γ arising from uncertainty on c_i & s_i is 1.7^o :

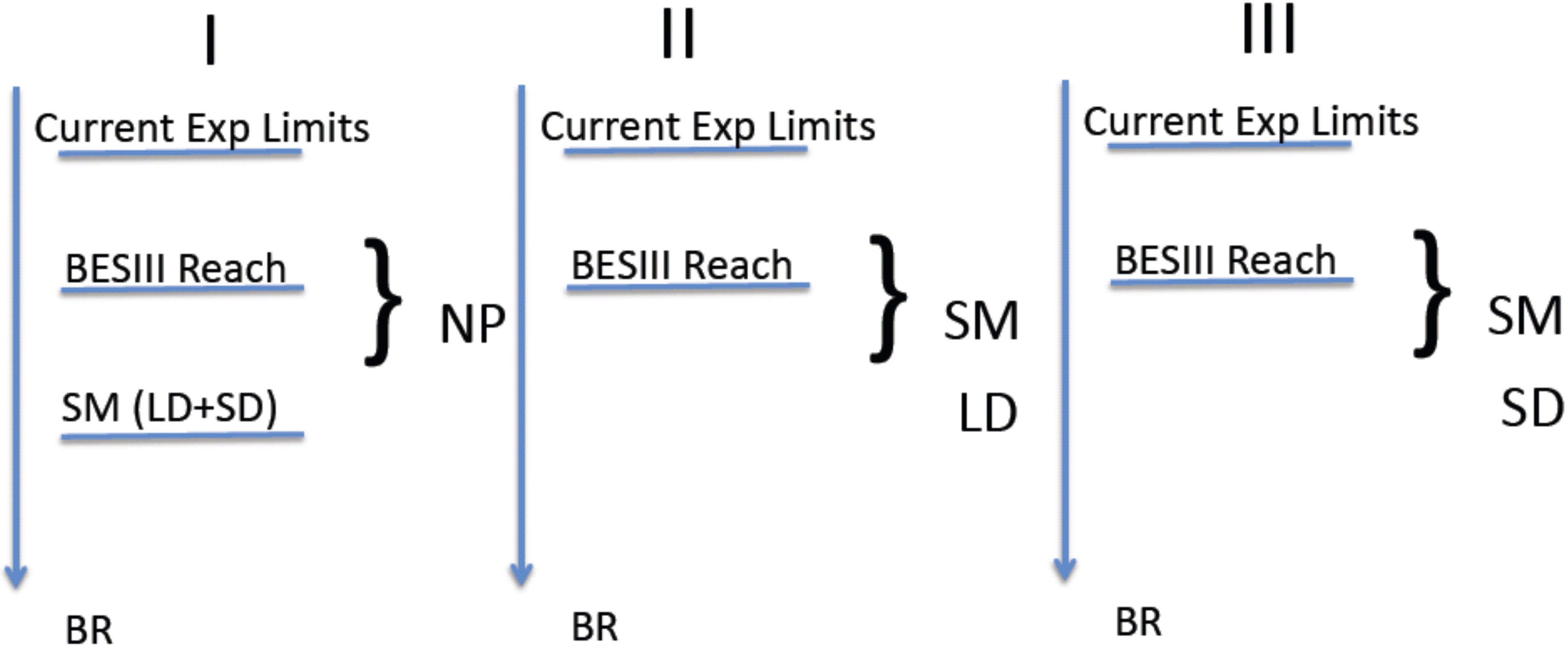
- Smaller than model error

BESIII will reduce this error to less than 1^0

What's rare at BESIII?

- Suppressed or Forbidden by SM
  - FCNC ($c \rightarrow u$) GIM suppressed:
    - $D^+ \rightarrow \pi^+ e^+ e^-$, $D \rightarrow X \gamma$
  - LNV/LFV:
    - $D^+ \rightarrow \pi^- e^+ e^+$, $D^+ \rightarrow \pi^+ e^+ \mu^-$
  - BNV:
    - $D \rightarrow X\, p$
- Not so exotic but interesting (BESIII targets)
  - $D \rightarrow \tau\nu$ (SM consistency)
  - $D \rightarrow l\nu\gamma$ (Validate radiative contributions, x10^{-5})
- Small Deviations rather than small rates (BESIII target)
  - Lepton Universality ($D \rightarrow Xe\nu$ versus $D \rightarrow X\mu\nu$)
- D-mixing and CPV

What's the rare program?



$D \rightarrow X l^+ l^-$
$D \rightarrow \gamma\gamma$

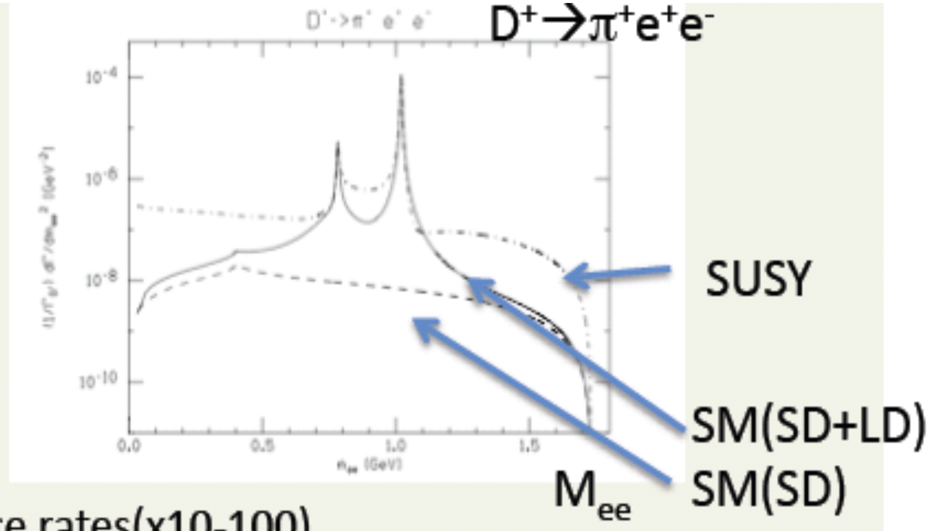
$D \rightarrow V\gamma$

$D \rightarrow \tau\nu$

IV: Forbidden($Xe\mu$, Xl^+l^+)

Expected rate

- Standard Model SD contributions
  - Range
    - $D^+ \to X_u\, e^+e^-$: 10^{-8}
    - $D^0 \to e^+e^-$:10^{-24}
    - $D^0 \to e\mu$: =0
- Exotic contributions
  - NSM contributions can significantly enhance rates(x10-100).
  - $D^+ \to \pi^+e^+e^-$ (at high M_{ee})
- SM LD contributions:
  - Enhancement in rate due to vector resonances (x100).



G. Burdman, I. Shipsey,
Ann.Rev.Nucl.Part.Sci.53:431-499,2003

Experimental limits

Mode	Reference Experiment	Best Upper limits(10^{-6})
$\pi^+e^+e^-$	CLEO-c [436]	7.4
$\pi^+\mu^+\mu^-$	FOCUS [437]	8.8
$\pi^+\mu^+e^-$	E791 [438]	34
$\pi^-e^+e^+$	CLEO-c [436]	3.6
$\pi^-\mu^+\mu^+$	FOCUS [437]	4.8
$\pi^-\mu^+e^+$	E791 [438]	50
$K^+e^+e^-$	CLEO-c [436]	6.2
$K^+\mu^+\mu^-$	FOCUS [437]	9.2
$K^+\mu^+e^-$	E791 [438]	68
$K^-e^+e^+$	CLEO-c [436]	4.5
$K^-\mu^+\mu^+$	FOCUS [437]	13
$K^-\mu^+e^+$	E687 [439]	130

Mode	Reference Experiment	Best Upper limits(10^{-6})
$\gamma\gamma$	CLEO [442]	28
$\mu^+\mu^-$	D0 [444]	2.4
μ^+e^-	E791 [438]	8.1
e^+e^-	E791 [438]	6.2
$\pi^0\mu^+\mu^-$	E653 [445]	180
$\pi^0\mu^+e^+$	CLEO [443]	86
$\pi^0e^+e^-$	CLEO [443]	45
$K_S\mu^+\mu^-$	E653 [445]	260
$K_S\mu^+e^-$	CLEO [443]	100
$K_Se^+e^-$	CLEO [443]	110
$\eta\mu^+\mu^-$	CLEO [443]	530
$\eta\mu^+e^-$	CLEO [443]	100
ηe^+e^-	CLEO [443]	110

CLEO-c for $D \to Xe^+e^-$ ($281 pb^{-1}$)

Branching-fraction UL values are all at 90% C.L.

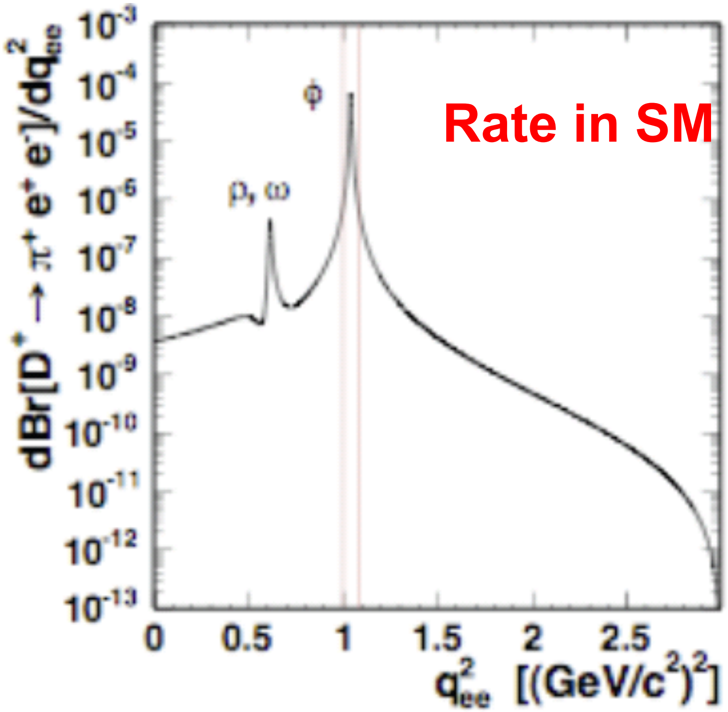
Mode	ϵ (%)	N	n	σ_{syst} (%)	$\mathcal{B}$ (10^{-6})
$\pi^+e^+e^-$	36.41	1.99	2	8.7	<7.4
$\pi^-e^+e^+$	43.85	0.48	0	7.1	<3.6
$K^+e^+e^-$	26.18	1.47	0	10.0	<6.2
$K^-e^+e^+$	35.44	0.50	0	7.2	<4.5
$\pi^+\phi(e^+e^-)$	46.22	0.04	2	7.4	$2.7^{+3.6}_{-1.8} \pm 0.2$

CLEO
PRL 95 (2005) 221802

First observation of D→Xee type decay.
Rate consistent with expectations.

Efficiency and resolution are very good:
$\sigma_{\Delta E}$ ~ 6 MeV
σ_{Mbc}~1.5 MeV

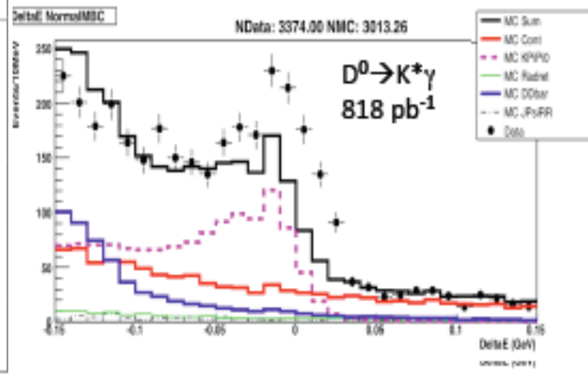
Backgrounds:
double-semileptonic, conversions, Dalitz, QED
*Suppressed with other side energy requirement.
*Reject low Mee

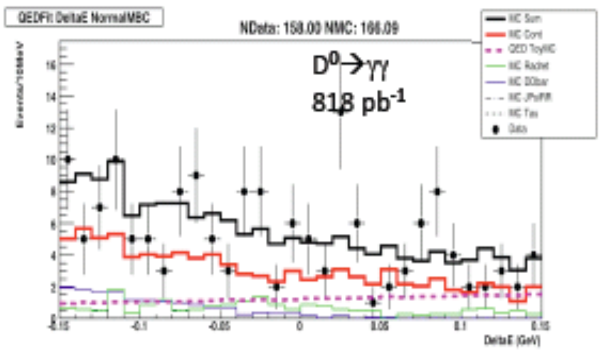


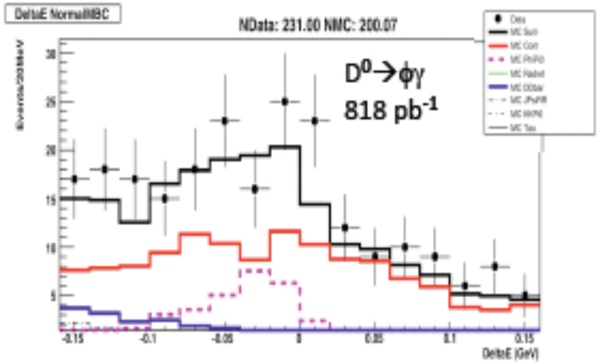
D→Vγ with CLEO-c full dataset

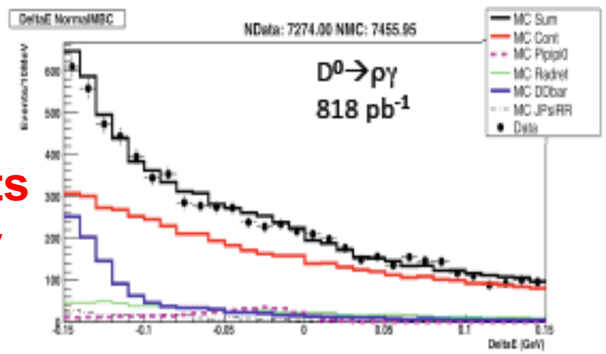
- Modes: $D^0 \to K^*\gamma$, $D^0 \to \phi\gamma$, $D^0 \to \rho\gamma$, $D^0 \to \omega\gamma$, $D^0 \to \gamma\gamma$
- Luminosity: 818 pb^{-1}
- Comprehensive: Modes with low measurement resolution and broad resonances are not measured by B-factories.
- Easy to compare ratios (remove LD physics) and look for NP contributions
- Improved upper limits
- Confirm: K^*, ϕ observations

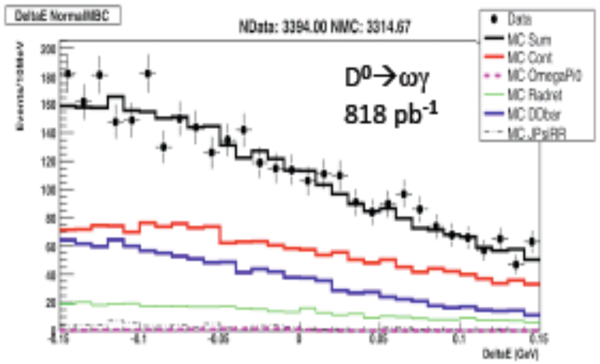
Channel	$\epsilon[\%]$	N_{Bknd}	$N_{observed}$	$\mathcal{B}$
$D \to \bar{K}^*\gamma$	12.29	355.79 ± 2.55	677	$[4.37 \pm 0.37 \pm 0.52] \times 10^{-4}$
$D \to \phi\gamma$	11.61	28.66 ± 1.08	44	$[2.21 \pm 0.95 \pm 0.29] \times 10^{-5}$
$D \to \gamma\gamma$	19.90	15.79 ± 0.81	17	$< 8.63 \times 10^{-6}$ (UL @90% CL)
$D \to \rho\gamma$	23.41	615.4 ± 4.9	625	$< 3.63 \times 10^{-5}$ (UL @90% CL)
$D \to \omega\gamma$	11.37	247.8 ± 4.5	235	$< 3.00 \times 10^{-5}$ (UL @90% CL)











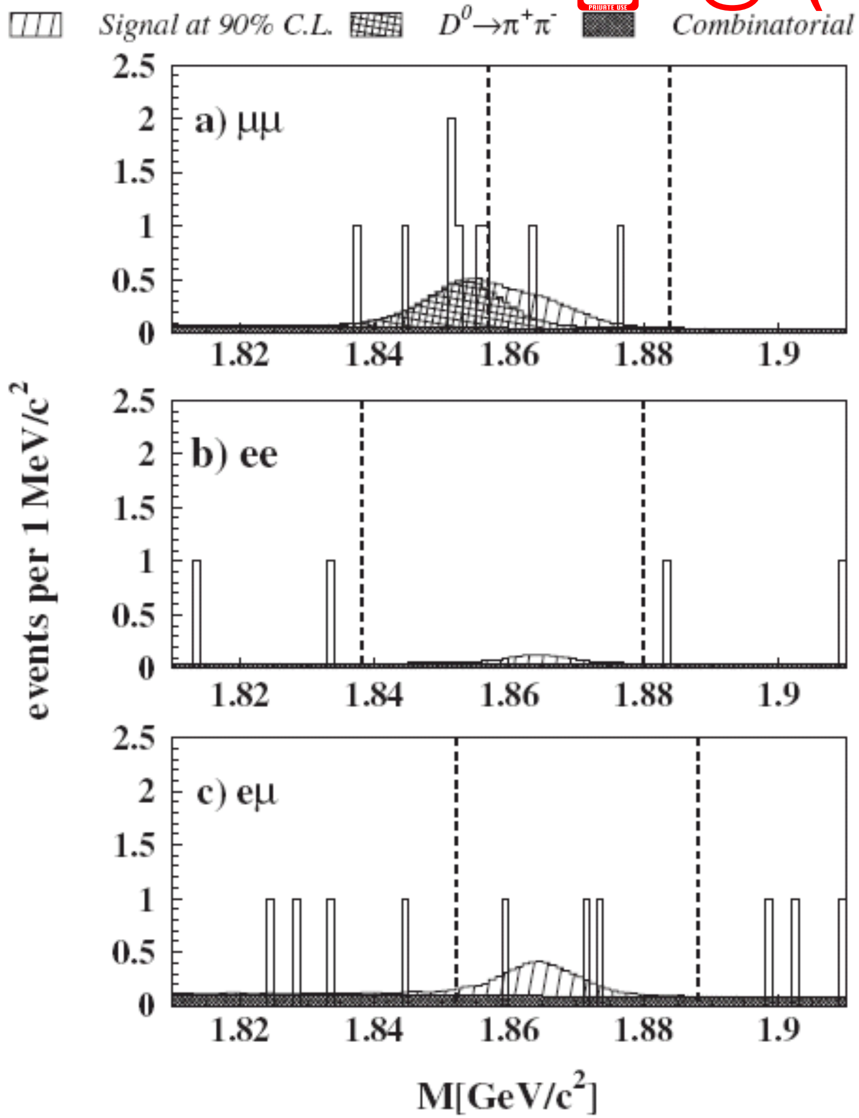
CLEO-c preliminary results from D. Cronin-Hennessy

D Dileptonic decay from Belle

Belle PRD81, 091102 (R) (2010)

660 fb^{-1} @Y(4S)

$$\mathcal{B}(D^0 \to \mu^+\mu^-) < 1.4 \times 10^{-7},$$
$$\mathcal{B}(D^0 \to e^+e^-) < 7.9 \times 10^{-8},$$
$$\mathcal{B}(D^0 \to e^\pm\mu^\mp) < 2.6 \times 10^{-7}.$$



Outlook for rare decays at BESIII

- Assuming 10 fb^{-1} we have a viable rare decay program
  - **NP**: Will improve UL on FCNC and Forbidden decays.
  - **LD**: May have first observations in $V\gamma$ modes.

    Will improve precision of observed modes with better control of systematics
  - **SD**: $D \to \tau\ \nu$ may be established.
- Some lessons from CLEO-c
  - Backgrounds are indeed low for lepton analyses (untagged analysis is optimal).
  - Photon modes are hard. Innovative techniques are required to exploit the full potential of the data.
  - Well designed control samples of data are useful in uncovering deficiencies of MC.
  - MC physics needs to be checked.
  - We should encourage creative approaches to data selection (we are not required to use standard selection).
  - Expect the unexpected.

Sensitivities for rare charm decay at BESIII

- **$D \to V\gamma$ will be reached at 10^{-7}**
  $D^0 \to \phi\gamma$, $K^*\gamma$ will be confirmed and improved
  $D^0 \to \rho\gamma$, $\omega\gamma$ will be improved or found

- **$D^0 \to \gamma\gamma$ can be measured with tag or without tag**
  the sensitivity will be 10^{-7}

- **$D \to X l^+ l^-$ can be reached at 10^{-7}**
  BESIII will reach contribution from long distance

- **$D^0 \to l^+ l^-$ will be reached at 10^{-7}**

- **$D^+ \to e^+\nu$** : 10^{-7} (SM: 10^{-8})

Thank you!