Some Thoughts on the Future of Charm

(experimentalist's version)

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*Full disclosure:
CLEO-c / BESIII / BelleII

Opening Comments

Now ⇒ 2020:

- Several relevant running experiments & new ones in construction
- Some well-known hot topics, plus great breadth and diversity
- But… hard to predict what will pan out & how future may need to adapt

Post 2020:

- Soon, our decisions will directly impact, given long time-scales of HEP
- There will still be strong charm programs at B phyiscs machines
- What is the case for a charm factory, post-BESIII ?

Is charm OK as a symbiotic hitchhiker, or do we need a charm machine?

Feed information up the food chain

charm ⇒ heavy quark ⇒ intensity frontier ⇒ US agencies

In part, I think my job is to give you some points to react to;
I don't know the answers, but I think I can start a discussion.

(even if it's a mob with pitchforks saying that I'm way off-base…)

Charm is Broad and Active

From a corner store on the information super-highway… Apologies if your favorite item is missing or small (ask Al Gore)

CKM Elements: $|V_{cs}|$ & $|V_{cd}|$

If we search for new physics, we should avoid assuming CKM unitarity

- Charm physics can give direct CKM matrix elements.

There are many ways of using the data:

- Ratio of semileptonic / leptonic: cancel CKM for pure LQCD (theory) tests
- Given theory, can extract CKM elements from both mode types

Key modes:

semileptonic $D^0 \to K e \upsilon,\ \pi e \upsilon$

leptonic $D^+ \to \mu^+ \upsilon$ & $D_s^+ \to \mu^+ \upsilon, \tau^+ \upsilon$

Neutrino modes:

the province of Charm threshold, and (for most modes) B factories

A Worker Bee, Working for B

Lattice Verification *(threshold + B factories)*

Modes on the previous page can be used to test LQD in charm

Give confidence in:

- decay constant $f_{B(s)}$, for extractions of $|V_{ts}|$, $|V_{td}|$ **from** $B_{(s)}$ **mixing**
- form factor $f_{B\to\pi}(q^2)$, for exclusive extraction mode $B \to \pi l \nu$ & $|V_{ub}|$

Currently experiment is ahead of theory.

$B^+ \to \tau \nu$ will improve as a source of f_B, but ***no direct method*** for f_{Bs} !

(And some have argued that strong-coupling may appear again in new physics, making the lattice a wise investment…)

Strong Phases for B Physics *(threshold only)*

CP-tags of DD^{bar} pairs: can watch decays of $D_{1,2} = (D \pm D^{bar})/\sqrt{2}$

- Unique sensitivity to strong phase differences in D decay

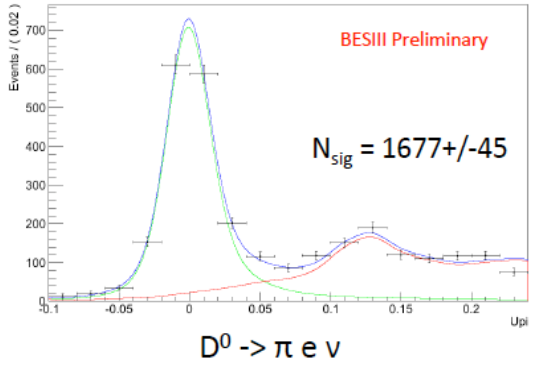
Useful inputs to **CKM** γ **extractions from** $B \to D^{(*)} K^{(*)}$:

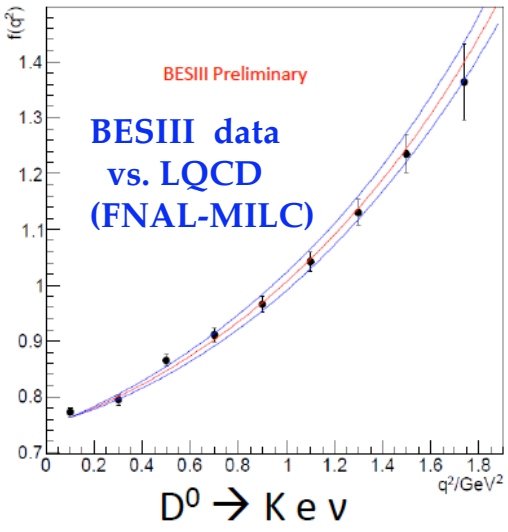
- have BaBar+Belle, LHCb will surpass them, then BelleII will appear…

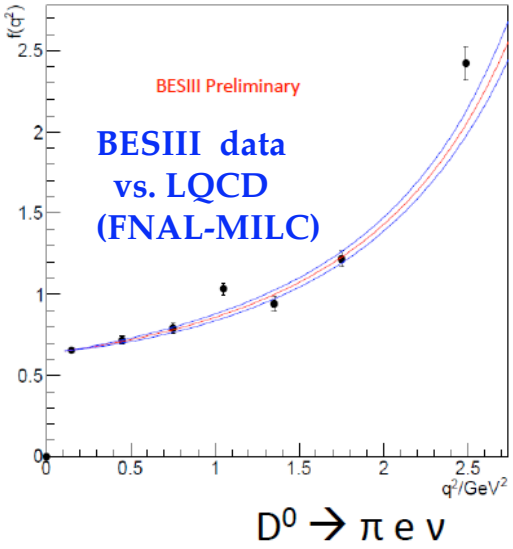
In both cases, what accuracy is needed, and when ?

Semileptonic FF; f_D

$D^0 \to K e \nu$, $\pi e \nu$ (BESIII 0.9 fb^{-1}, from CHARM2012)





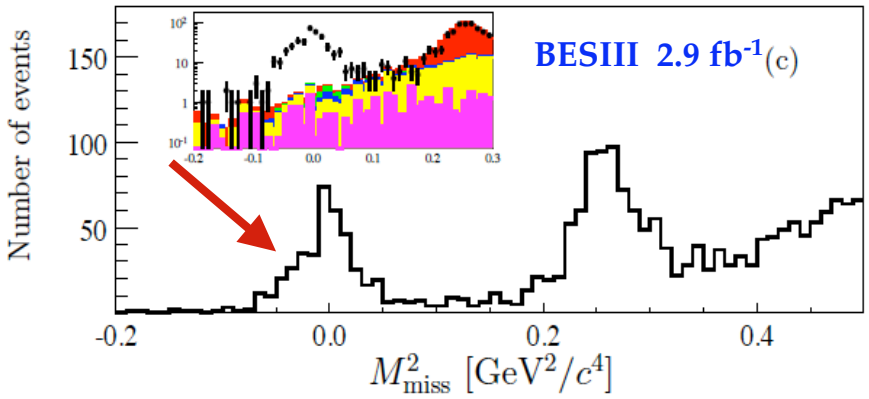


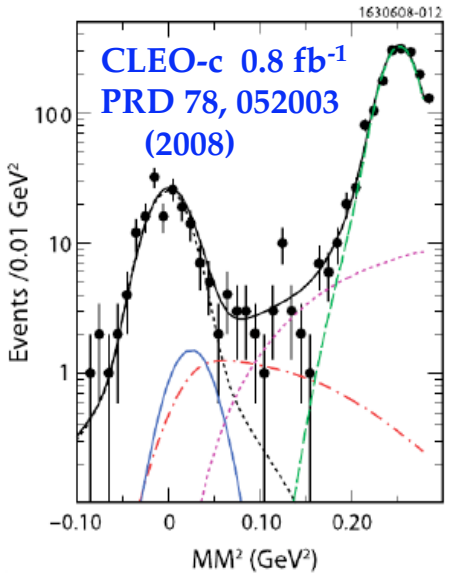
$D^+ \to \mu^+ \nu$ Still statistics limited; *(ONLY done at threshold)*

BESIII *preliminary* 2.9 fb^{-1} at $\psi(3770)$ (from CHARM2012)

f_D = (203.9 ± 5.7 ±2.0) MeV (± 2.8 ± 1.0)%

BESIII can take more $\psi(3770)$ data !





D_s Decay Constants

$D_s^+ \to \mu^+ \upsilon, \tau^+ \upsilon$ *Systematics have become key !*

[see Rosner & Stone review in PDG for more details, refs]

Several modes for each of 3 experiments

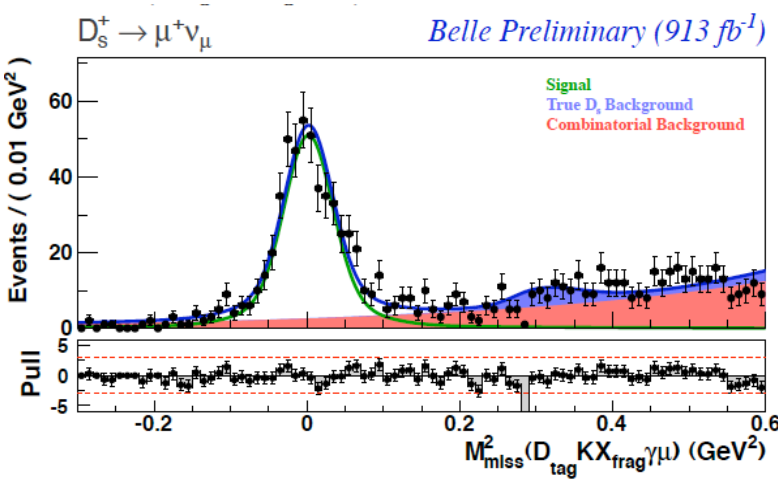
World average: $f_D = (260 \pm 5.4)$ MeV *± 2.1 %*

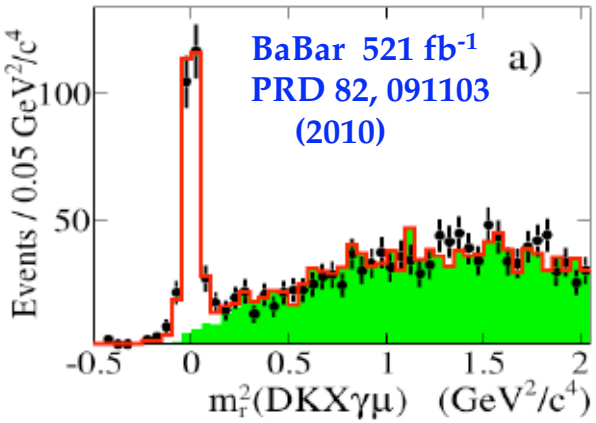
best single: (± 1.6 ± 2.0)% (Belle, @ CHARM2012) 913 fb^{-1} D_s^* DK nπ

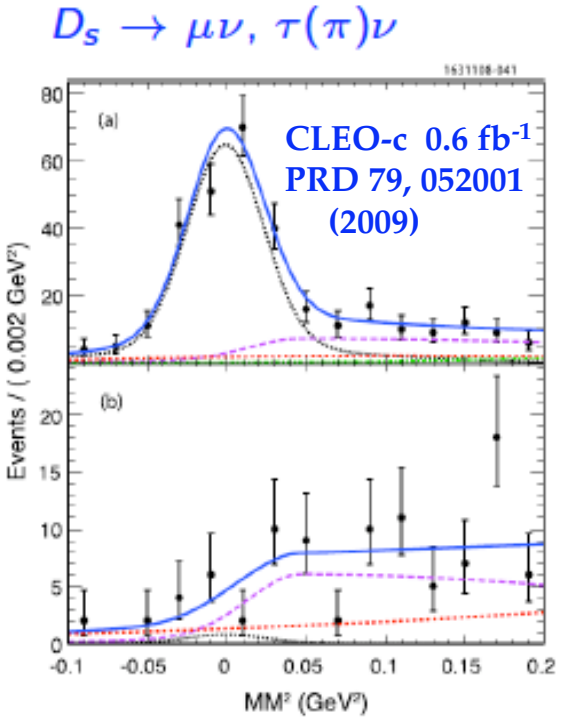
(± 3.2 ± 2.9)% (BaBar) 520 fb^{-1} D_s^* DK nπ

(± 4.0 ± 1.7)% (CLEO-c) 0.6 x fb^{-1} D_s^* D_s @ 4170 MeV

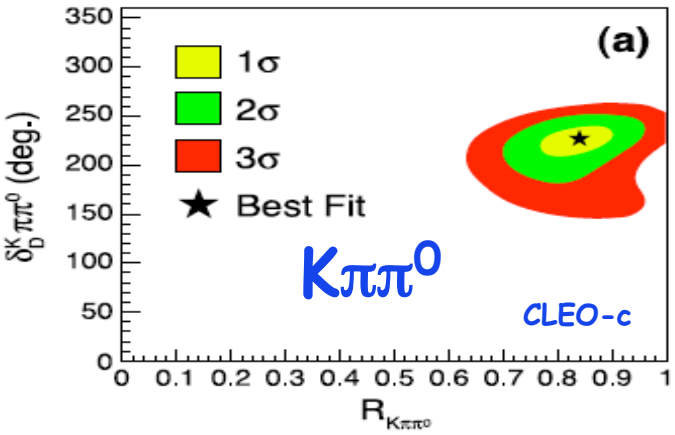
Try to improve at BESIII, and BelleII …

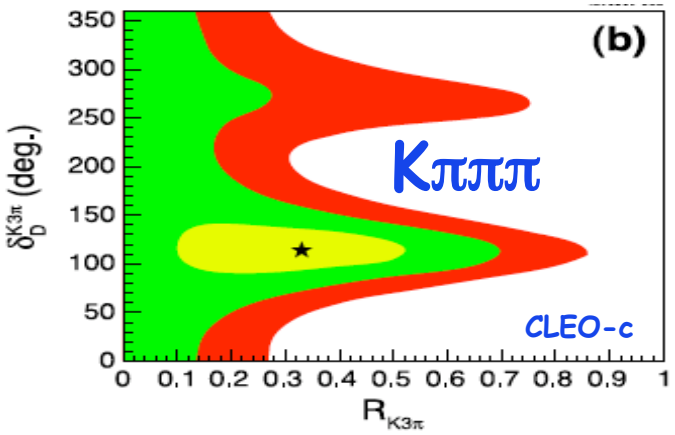


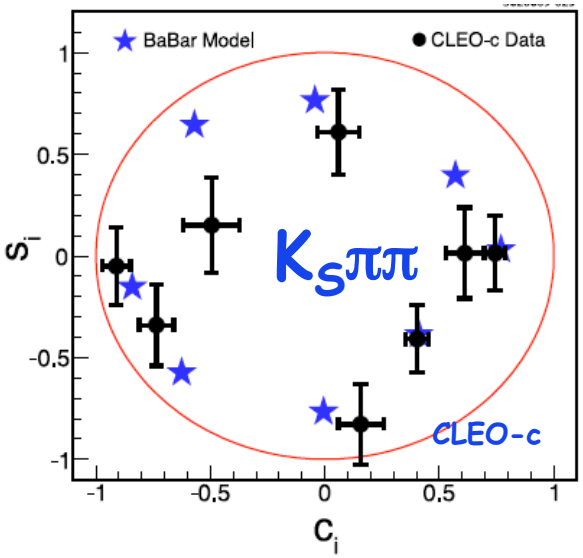




Strong Phases







BESIII

Charm: D^0, D^+ 3.5x CLEO-c's ψ(3770) (D_s: modest low-E sample)
2013 Y(4260) run: evidence for $Z^+(3900)$

Breadth: light hadron and more quarkonium spectroscopy
dedicated R scan, tau mass, …

Spectroscopy

Conventional charmonium now joined by exotics ?

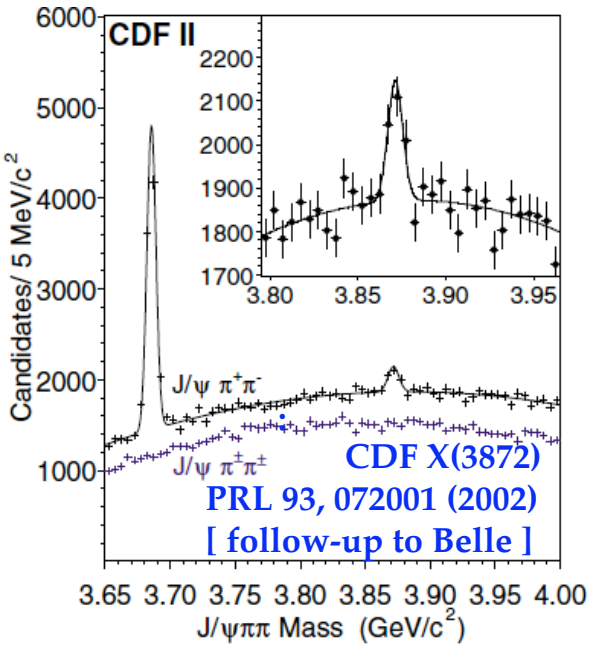
(J/ψ & χ_{cJ} also are glue sources for low-E hadron work)

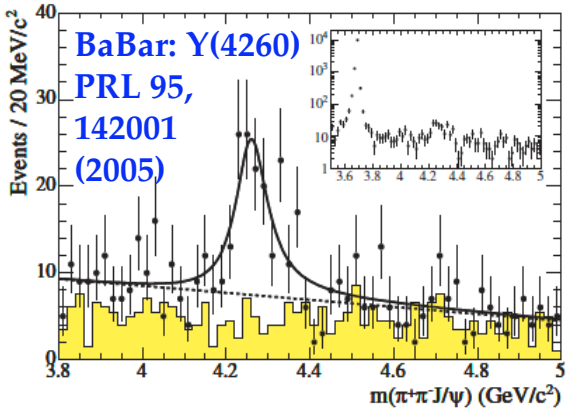
Soon, PANDA @ GSI: pp^{bar} production, nice line-shape scans, …

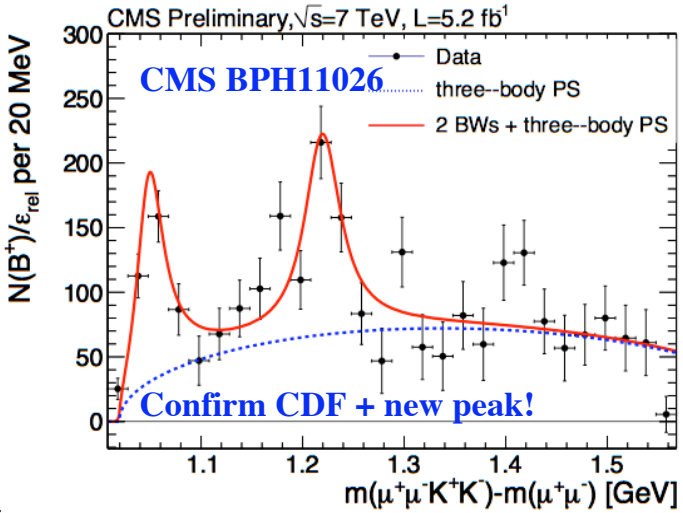
Very Active Area: Quarkonium Working Group meeting NOW in Beijing

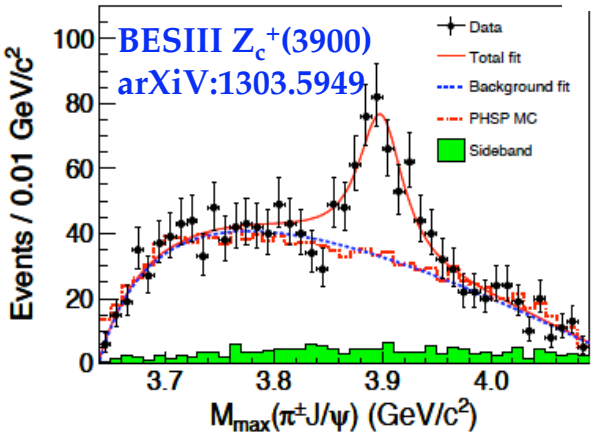
How important is this among charm topics?

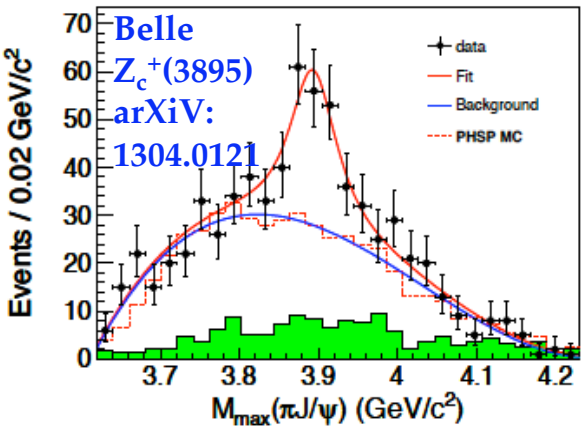
Does is sometimes get lost between HEP & Nuclear?











Rare Decays & CPV

For me, this is the place to look for the "killer apps"

Much of recent flavor-physics history was over-constraining CKM.
The SM was frustratingly successful…
But there remain more plausible places to look for surprises !

Processes like $b \to s\gamma$ have a long history in the hunt,
but now we have access to the *incredible statistics*
at LHCb and BelleII:

- Rarer modes are accessible
- Some interesting modes can be studied in detail

Our bane: long-distance effects often obscure the view
of new physics from our charming window
(But let's see what Alexey has to say, and also the Lattice folks…)

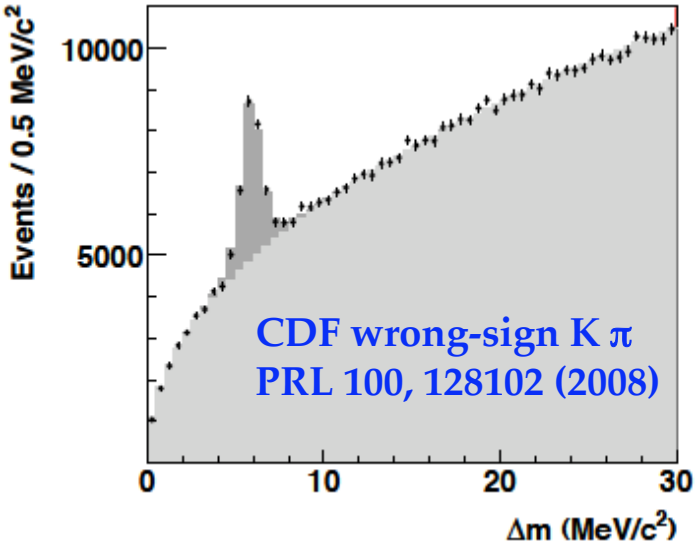
Charm at The Energy Frontier

CDF

Detatched vertex trigger, di-leptons

- D^0 oscillations with $K\pi$
- ΔA_{CP} in $D^{0(bar)} \rightarrow KK$ vs. $\pi\pi$
- Spectroscopy: $J/\psi\,\phi$ peak, X(3872), D**, …

Notable impact on charm
(smaller portfolio at DO)

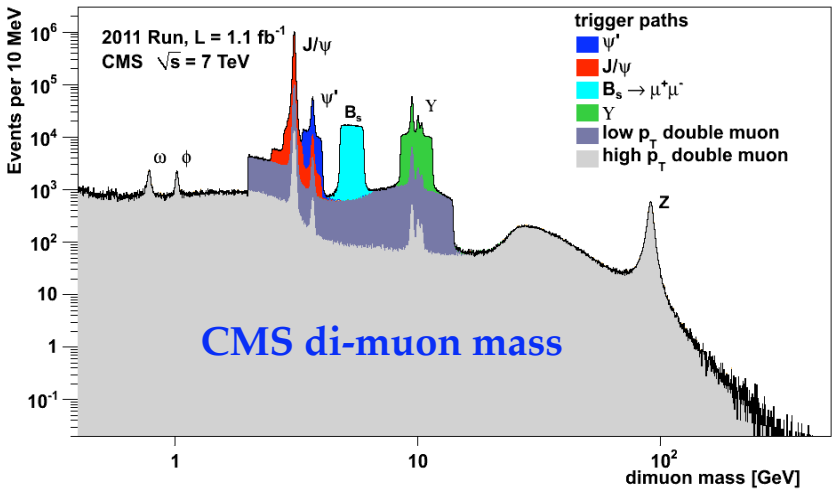


ATLAS & CMS

"An Exercise in muon triggers"

- Spectroscopy with di-muon J/ψ ($J/\psi\,\phi$ peaks)
- $D^0 \rightarrow \mu\mu$ limits

Trigger bandwidth, priorities :
Phasing out in the future…



"On the way out…" Well, except for *dedicated* work :

LHCb !

Really "LHCbc": lots of possibilities with charm

Large production rates ⊕ powerful triggers

Current results: ~ 1 fb^{-1} from 2011

High statistics with access to many modes

D^0 oscillations

- wrong-sign Kπ

Rare decays:

- $D^0 \rightarrow \mu\mu, \mu e$
- $D_{(s)}^+ \rightarrow h\,\mu\,\mu$
- $D^0 \rightarrow h\,h'\,\mu\,\mu$

CP Violation

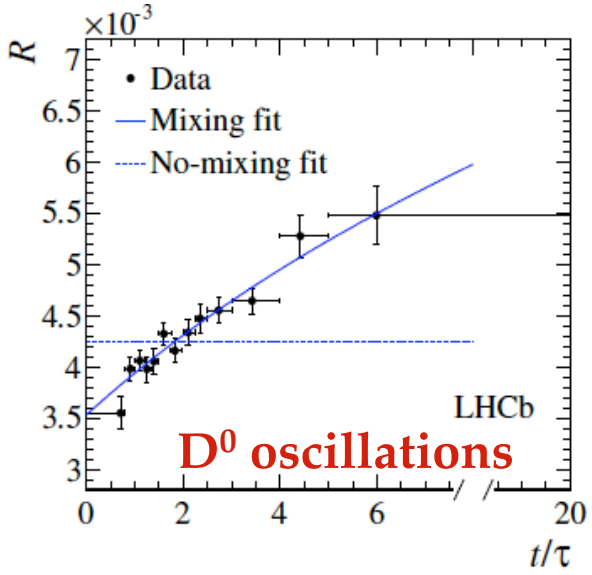
- ΔA_{CP} in $D^{0(bar)} \rightarrow KK$ vs. ππ

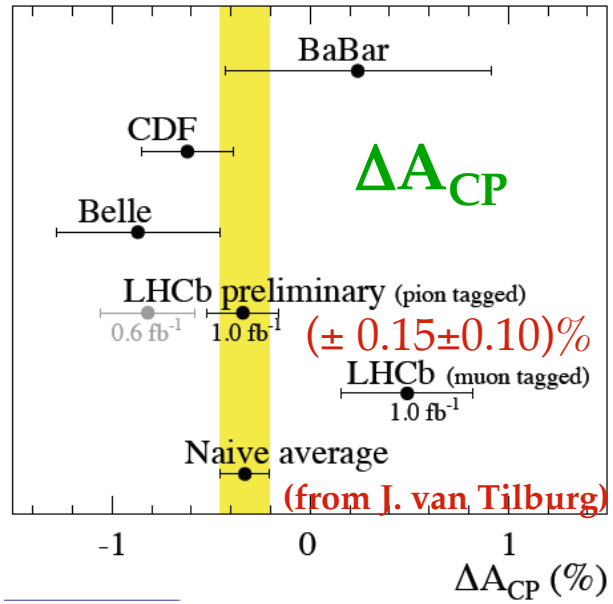
  LHCb D* tags only: (± 0.15 ± 0.10)%

Other

- ccq baryons ?

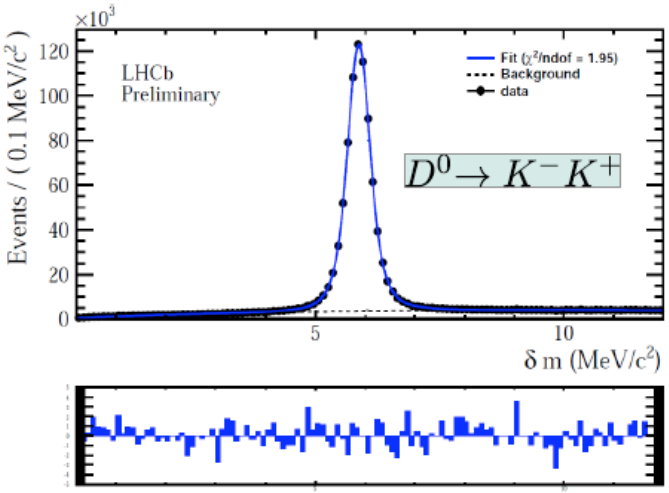
PRL 110, 101802 (2013) 1.0 fb^{-1}

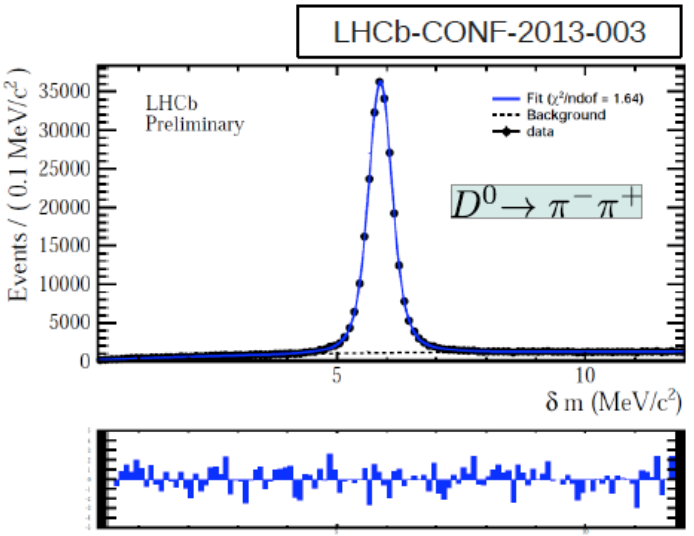




LHCb

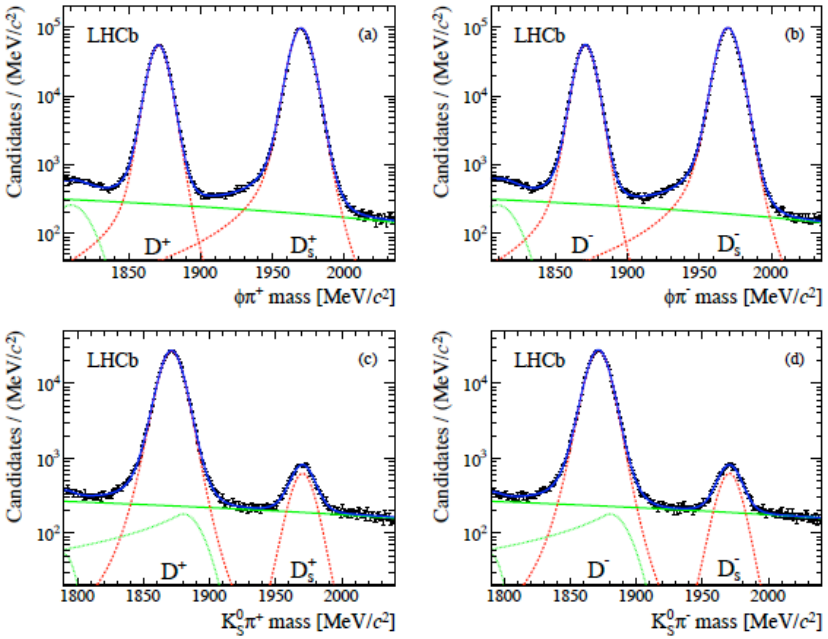
Clean, high statistics mass peaks





ΔA_{CP} in
$D^{0(bar)} \to KK$ vs. $\pi\pi$

arXiV:1303.4906
Search for CP Violation
in $D^+ \to \varphi\pi$ $D_s^+ \to K_S\pi$
(log scales !)



LHCb: Now & Upgrade

Rare Decays with 1 fb^{-1} :

$B(D^0 \to \mu^+\mu^-) < 1.1 \times 10^{-8}$ (90% CL) [LHCb = best limit]
SM: $< 6 \times 10^{-11}$, from $D^0 \to \gamma\gamma$ limit [long distance strikes again…]

$D_{(s)}^+ \to h^+\mu^+\mu^-$: long-distance effects, from vectors V =ρ,ω,ϕ ~ 10^{-6}
Far from V resonances: SM ~ 10^{-11}
Expect to reach 10^{-8} (10^{-7}) for D^+ (D_s^+)

$D^0 \to h\, h'\, \mu\, \mu$ A_{FB}, T-odd asymmetries
May detect modes soon ? (but need full stats to exploit)

Major Upgrade ~2018

- 5 fb^{-1}/yr for ~10 years
- 10^{33} /cm^2/s @ 25 ns spacing, σ ~ 80 mb
  → # interactions / crossing: μ = 2
- Continue analysis magnet polarity flips, but more balanced in lumi
- Hadron/photon/electron triggers: x2 in efficiency (muons marginally improved)

Still a "young experiment" :

Can expect many more new ideas and excitement…

BaBar & Belle

I can't do justice to the broad charm programs at these experiments …

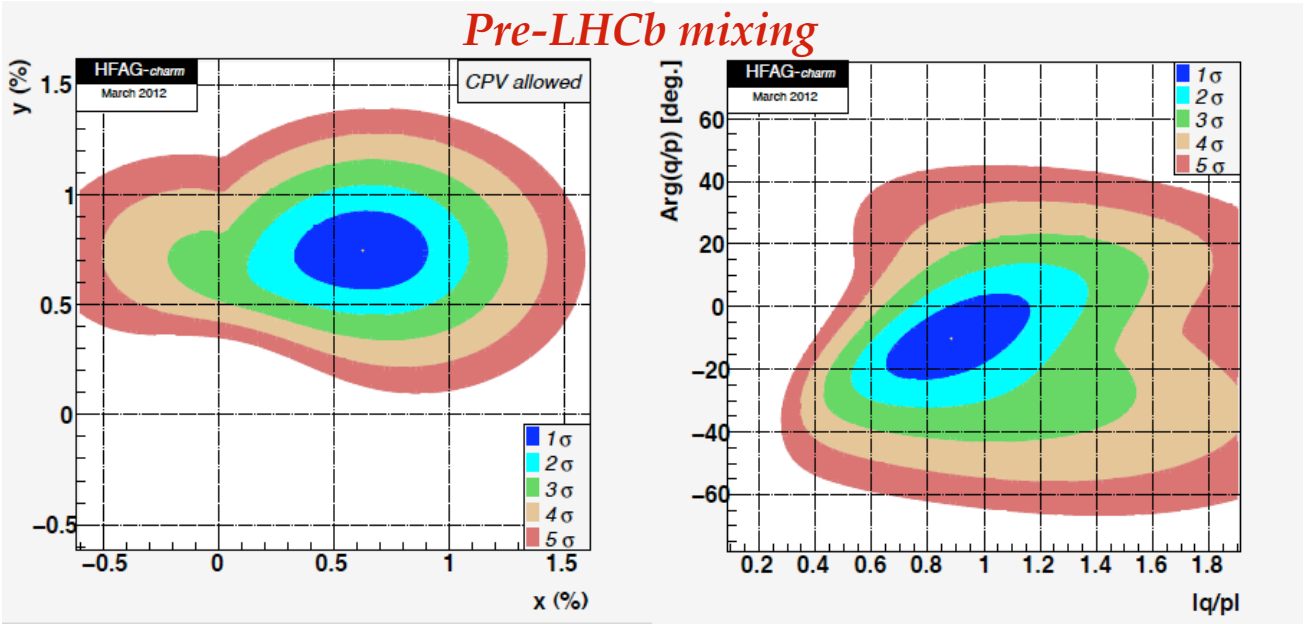
BaBar / Belle contributed to many charm topics; BelleII will do the same

(I didn't see much on rare charm in the BelleII physics book?)

High statistics, plus access to (most) neutrino modes:

- Any limiting systematics? Help by trading luminosity for cleaner methods?
- But are noise, higher occupancy an issue for any modes?

Decay constants and form factors from neutrino modes
Rare decays and CPV
D oscillations
Spectroscopy
etc.



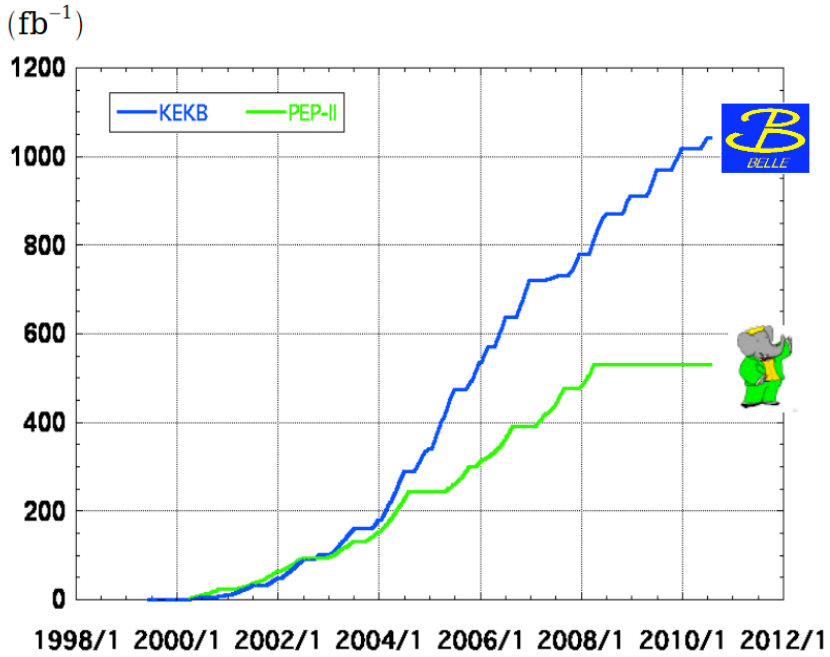
BelleII CPV Prospects

CPV in mixing

Observable	Current Expt.	LHCb ($5\ \text{fb}^{-1}$)	Super Flavor Factories ($50\ \text{ab}^{-1}$)	LHCb Upgrade ($50\ \text{fb}^{-1}$)
x	$(0.63 \pm 0.20)\%$	$\pm 0.06\%$	$\pm 0.02\%$	$\pm 0.02\%$
y	$(0.75 \pm 0.12)\%$	$\pm 0.03\%$	$\pm 0.01\%$	$\pm 0.01\%$
y_{CP}	$(1.11 \pm 0.22)\%$	$\pm 0.02\%$	$\pm 0.03\%$	$\pm 0.01\%$
$\lvert q/p \rvert$	0.91 ± 0.17	± 0.085	± 0.03	± 0.03
$\arg(q/p)$	$(-10.2 \pm 9.2)^\circ$	$\pm 4.4^\circ$	$\pm 1.4^\circ$	$\pm 2.0^\circ$

We <u>still</u> have two B factories:
They just use different production methods…

Integrated luminosity of B factories



> 1 ab^{-1}
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 25 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

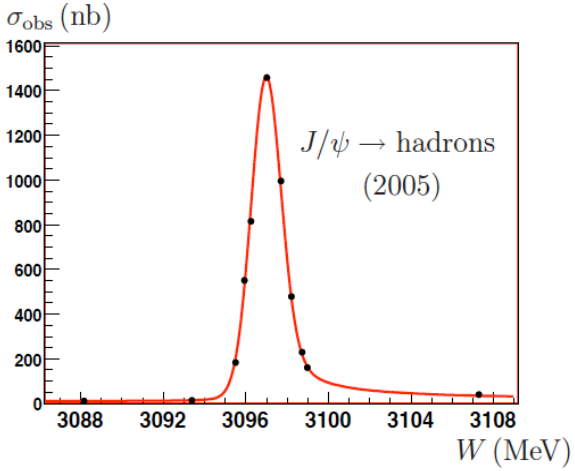
BelleII: 50 ab^{-1}
50x increase !

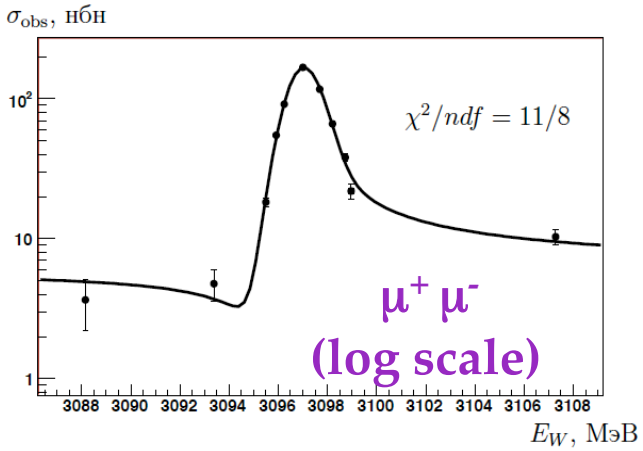
second-generation
= mature techniques

New Threshold Machine ?

Novosibirsk: already active in charm physics

KEDR detector at VEPP-4M has already done precision width scans :





Much discussion of Super tau-charm machine at Novosibirk;

funding prospects ?

Cabibbo Lab, in Italy: (Workshop at Elba 27-30 May !)

after cancellation of Super-B, now tau-charm is under consideration

(Meeting at Elba 27-30 May !)

Luminosity scale: ~1 x 10^{35}/cm^2/s → 1 ab^{-1}/Snowmass year

A Few "Pet Topics"

FOCUS dominates charm lifetime :

possible to check ? (even if only ratios or differences ?)

(not that I doubt them, but these are key to connect experimental BF to theoretical Γ_i)

T-odd quantities :

like triple products in 4-body decays, …

Absolute BF for $\Lambda_c \rightarrow pK\pi$:

no good normalization of charm baryon BFs

(actually, ∃ 4 baryonic weak ground-states, but let's not get ahead of ourselves…)

And a check of CLEO-c for D^0, D^+, D_s^+ ? (If I want to check FOCUS, fair is fair!)

Charm CKM triangles :

Alexey tells me I should adopt this new pet from the shelter…

Theoretical Uncertainties

D^0 Oscillations:

Plagued by uncertainty on long-distance effects; will this *ever* improve ?

Rare Decays:

Long-distance effects in many cases (e.g., from vectors in hl^+l^- final states)

How clean are the new physics windows? (away from said vectors, or other cases?)

CPV in Charm:

After initial excitement, what will we learn ?

What are the best modes ?

CPV in Oscillations:

Is this cleaner ?

Do we need to clean up assumptions? (e.g., sometimes ignoring CPV, …)

I have no answers … *(and perhaps even poor questions?)*

But, see Alexey's talk; then tell us what *you* think in our discussion session !

Selected References I

Our process :

Nov 2011 Intensity Frontier Workshop final report (arXiV:1205.2671)
http://www.intensityfrontier.org/docs/intensityFrontierReport-080912.pdf

Nov 2011 Intensity Frontier Workshop: Documents for Heavy Quarks
http://www.ph.utexas.edu/~heavyquark/

2013 "Snowmass on Mississippi" Heavy Quark Page
http://www.snowmass2013.org/tiki-index.php?page=Quark+Flavor+Physics

Conferences :

CHARM 2012: 5th Int'l Workshop on Charm Physics May 2012 Honolulu
http://www.phys.hawaii.edu/charm2012

Workshop on Charm Physics at Threshold Oct 2011 Beijing
http://bes3.ihep.ac.cn/conference/threshold2011

Workshop On Future Opportunities For Open Charm Physics At PANDA Nov 2009 Mainz
http://www.kph.uni-mainz.de/open_charm.php

Workshop On Tau-Charm at High Luminosity May 2013 Elba
http://agenda.infn.it/conferenceDisplay.py?confId=6193

Selected References II

General Reviews :

A Cicerone for the Physics of Charm,
S. Bianco, F.L. Fabbri, D. Benson, I. Bigi, Riv.Nuovo Cim. **26** (7), 1 (2003)

D^0 D^{0bar} Mixing and Rare Charm Decays
G. Burdman, I. Shipsey, Ann. Rev. Nucl. Part. Sci. 53, 431 (2003)

Heavy Quarkonium: Progress, Puzzles, and Opportunities,
N. Brambilla *et al.*, Eur. Phys. Jour. C 71, 1534 (2011)

Experiment-Based Papers :

Physics at BESIII, D.M. Asner *et al.*, arXiV:0809.1869

Physics at Super B Factory, T. Aushev *et al.*, arXiV:1002:5102

Implications of LHCb measurements and future prospects,
LHCb Collab., arXiV: 1208.3355 .

The charm physics programme at the LHCb upgrade, and Atlas and CMS upgrades,
M. Gersabeck, arXiV:1209.5878 (presented at CHARM2012

Physics Performance Report for PANDA: Strong Interaction Studies with Antiprotons
PANDA Collab., arXiV:0903.3905

Prospects for PANDA in Charmonium and Charm Physics,
M. Pelizaeus, arXiV:1210.4701

My Open Questions

Menu: LHCb + upgrade, BelleII, PANDA, more BESIII + developing ideas (?)

What are the "Killer Apps" that help drive a physics program?

Flavor: If it's CP violation & rare decays , which analyses are the key ones ?

Spectroscopy: is the program at forseeable experiments the right type and amount ?

There are many "boutique topics" beyond: add excellent breadth, but aren't drivers.

Does LQCD need more "ν modes" $f_{K,\pi}(q^2)$, $f_{D(s)}$ after current experiments?

Does B -> $D^{(*)}K^{(*)}$ (for CKM γ) need more strong phase input after … ?

Will full BESIII datasets be enough precision ?

New threshold @ Cabibbo Lab, or Novisibirsk… (and, is ***asymmetric*** worthwhile ?!?)

Does charm @ B machines suffice? Or should the US support work at the above ?

Will LQCD help with oscillations and rare decays?

Would forward flavor work at a higher-energy "SuperLHC" ?

LHCb is first-generation; might the concept continue beyond ?

Can one get higher statistics while avoiding pile-up ?

Will DOE and NSF continue to support the breadth added by symbiotic charm?

i.e., a university group doing charm at LHCb/BelleII/BESIII ?