Flavor Physics at Belle II and BESIII

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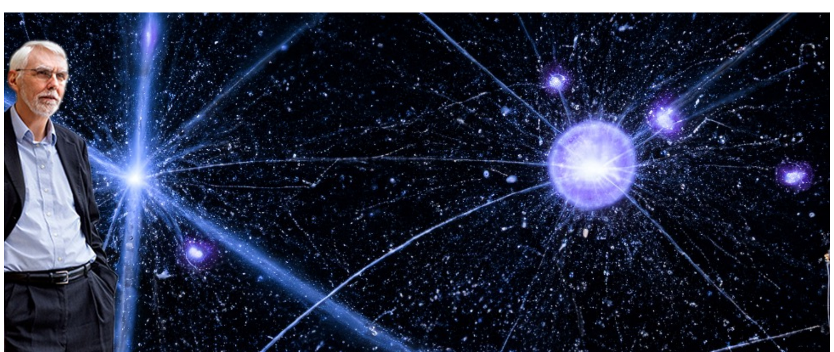
Carnegie Mellon

Future of Heavy Quark Physics – LepageFest

14 Oct 2024

Belle II



BESIII

Introduction

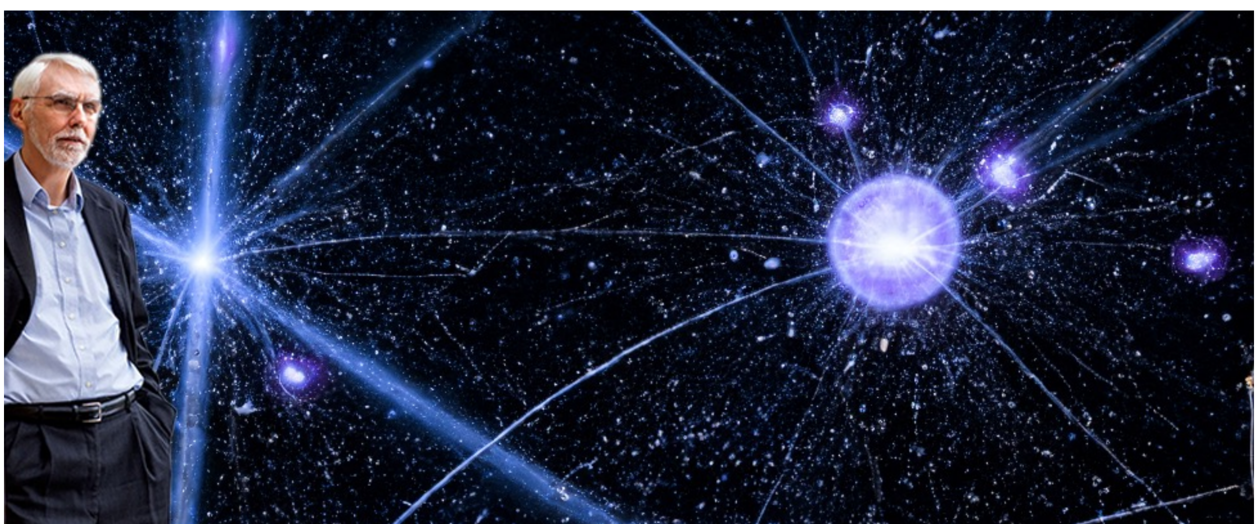
Some remarks about our Guest of Honor

Today's Flavor Menu

Belle II Status
Belle II Results

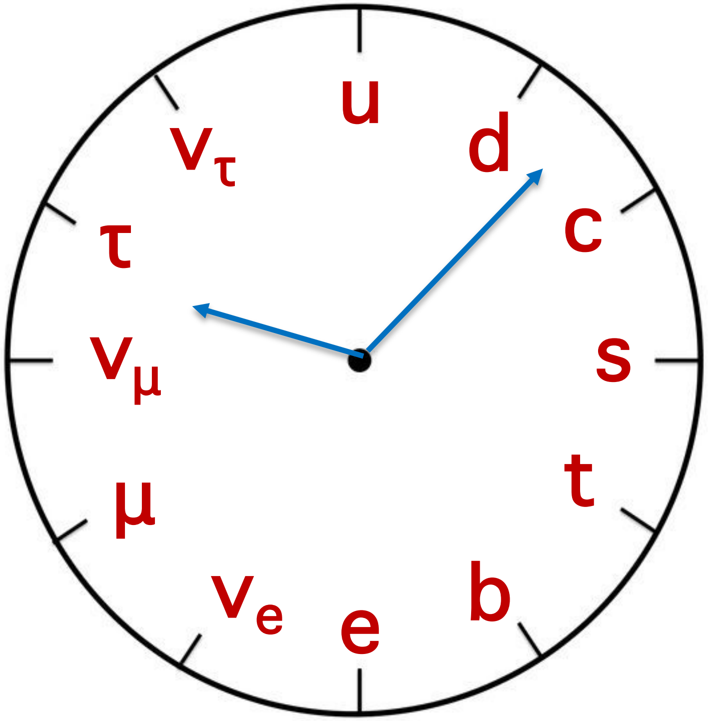
BESIII Status
BESIII Results

Emphasis is on flavor physics & not even all of that fits !
Much more is going in in both experiments…



Flavor Flav: The Hype Man

Our Man to Hype Today



If I was better with graphics,
you'd be wearing this, Peter !

Meeting Peter

CLEO sent me to the 1998 Pre-APS Lattice QCD Workshop

Even the CLEOAC needs a Lattice primer, and *everyone* recommended Lepage, so we met for an hour…

Most notable to me: Peter was very conscientious about separating widely-help beliefs vs. his personal opinions

(even though most of those opinions were likely correct…)

CLEO-c and (not) Me

I went to CMU in 1999, and was learning the faculty game

By the time I was settled in, CLEO-c was all planned out.

Others will no doubt tell more of this great story…

But thanks to Ian & friends for saving my research program !

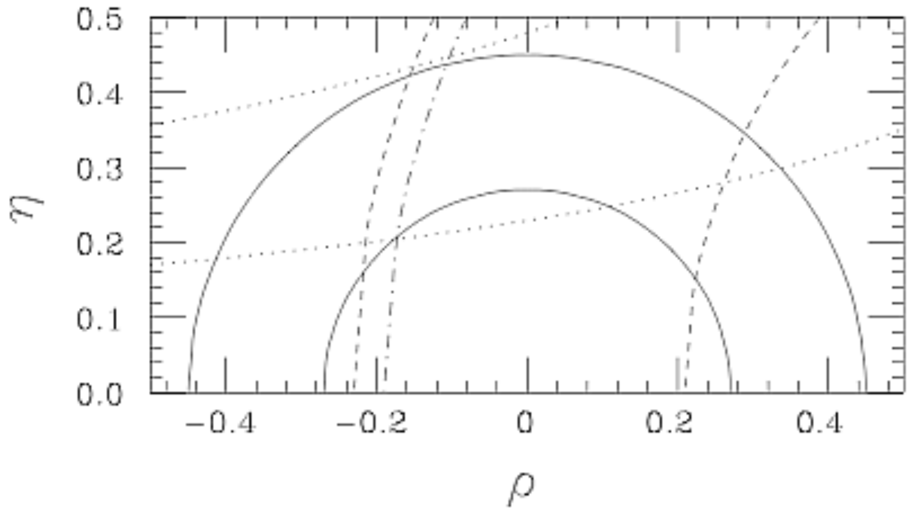
Later I joined BESIII @ BEPCII, just before first data-taking ;

a CLEO-c quality detector (*except for RICH -> TOF !*)

at a machine built for charm

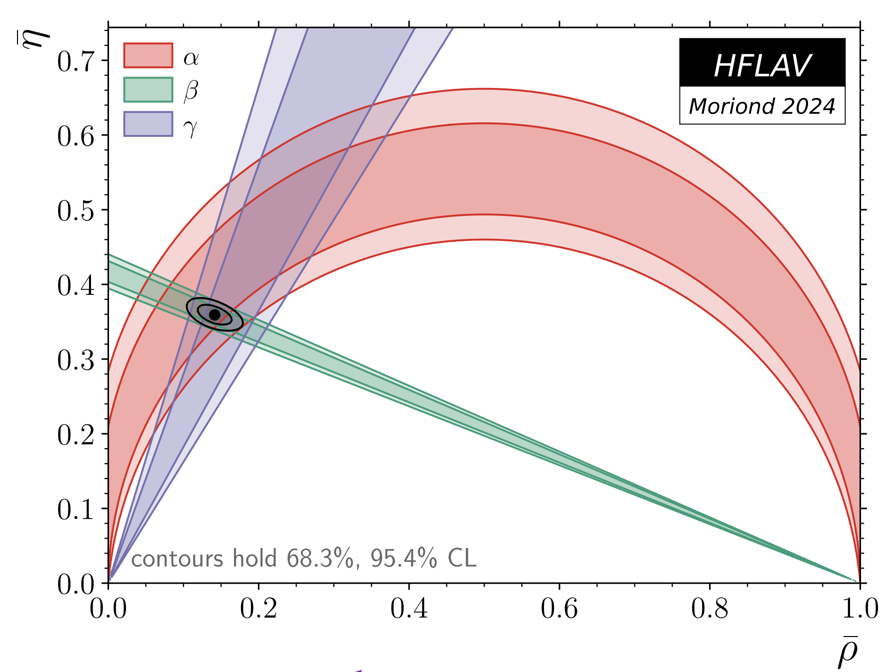
I Met Peter THIS Long Ago…

Unitarity Triangle, 1998
from Rosner, hep/ph 9801201,
as I showed at that 1998 workshop



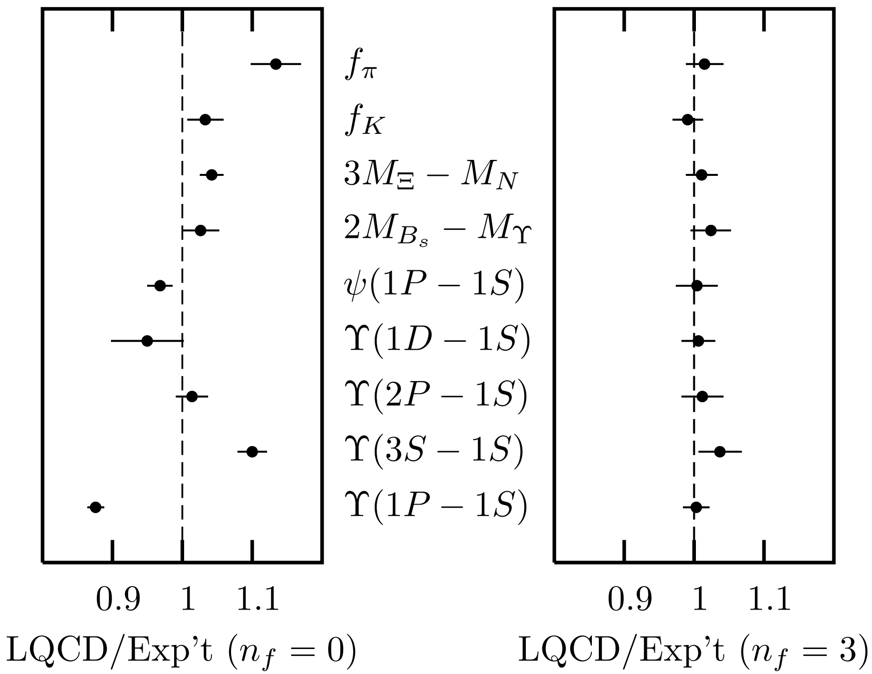
NOTE:
the η & ϱ scales are ~*same* for plots;
just a shift and vertical expansion

Unitarity Triangle, 2024
remarkable progress !



Of course, part of this improvement was due to …

LQCD Comes of Age



Every time someone shows this plot, you have to take a drink !

The message: quench your thirst, but unquench your lattice

High-Precision Lattice QCD Confronts Experiment

C. T. H. Davies,[1] E. Follana,[1] A. Gray,[1] G. P. Lepage,[2] Q. Mason,[2]
M. Nobes,[3] J. Shigemitsu,[4] H. D. Trottier,[3] and M. Wingate[4]
(HPQCD and UKQCD Collaborations)

C. Aubin,[5] C. Bernard,[5] T. Burch,[6] C. DeTar,[7] Steven Gottlieb,[8] E. B. Gregory,[6]
U. M. Heller,[9] J. E. Hetrick,[10] J. Osborn,[7] R. Sugar,[11] and D. Toussaint[6]
(MILC Collaboration)

M. Di Pierro,[12] A. El-Khadra,[13] A. S. Kronfeld,[14] P. B. Mackenzie,[14] D. Menscher,[13] and J. Simone[14]
(HPQCD and Fermilab Lattice Collaborations)

Peter, plus many friends celebrating here with us today !

Belle II

SuperKEKB & Belle II Status
Leptonic Decays & Decay Constants
Charm Lifetimes
CKM Angle $\gamma = \varphi_3$
$B^+ \to K^+ \nu \nu$

Advertisement: new on arXiv:

Observation of time-dependent CP violation and measurement of the branching fraction of B0 → J/ψ π0 decays https://arxiv.org/abs/2410.08622

Additional Reference

Belle II Physics Book
E. Kuo *et al.*, PTEP 2019, 123C01 (2019)

SuperKEKB Status

Instantaneous Luminosity :

- **Good news**: world records, surpassing KEK-B [Belle]
  record: 4.5×10^{34} July 2024
- **Bad news**: we need >10x more ! We're aiming for $65. \times 10^{34}$
  (and, typical luminosity often below peak…)

Machine Issues :

- Sudden beam losses : due to dust; sources identified & being mitigated
- Beam size blow-up at high currents (beam-beam effect) : more tuning
- Noise in detector : large, dedicated efforts since turn-on
  shielding, collimators, monitoring, simulation, …

Also, electricity costs in Japan remain high: affects annual running time

SuperKEKB
Parameters @ best lumi so far

Peak luminosity $L_p = 4.47\times10^{34}$ cm^{-2}s^{-1}

- Specific luminosity $L_{sp} = 5.9\times10^{31}$ cm^{-2}s^{-1}/mA^2
- $\beta_y^* = 0.9$ mm
- Beam current: HER/LER = 1.18/1.45 A
- Number of bunches: 2249
- Bunch current product ($I_{b+}I_{b-}$): 0.338 mA^2
- Crab waist ratio: HER/LER = 60/80%

Belle II Status

Dataset thus far :

- Total integrated luminosity 531 fb^{-1} [mostly "On-4S"]
- Significant faction of Belle total, but only ~1% of current goal
- New run underway currently (machine start-up)

Detector Status :

VXD = 2-layer DEPFET **PXD** + 4-layer DSSD **SVD**

- Initial data had only 1/8 of 2^{nd} PXD layer
- Full PXD installed during long shutdown 2022-24…

… but, spent part of recent run turned off due to danger from beam losses

Central drift chamber: aging mitigation (add water to 50/50 He/ethane gas)

Other typical hiccups with new systems, but nothing serious.

Publications by year : **2020 / '21 / '22 / '23 / '24 = 3 + 2 + 1 + 20 + 15 ***

** + 5 accepted & 6 submitted by 01 Oct*

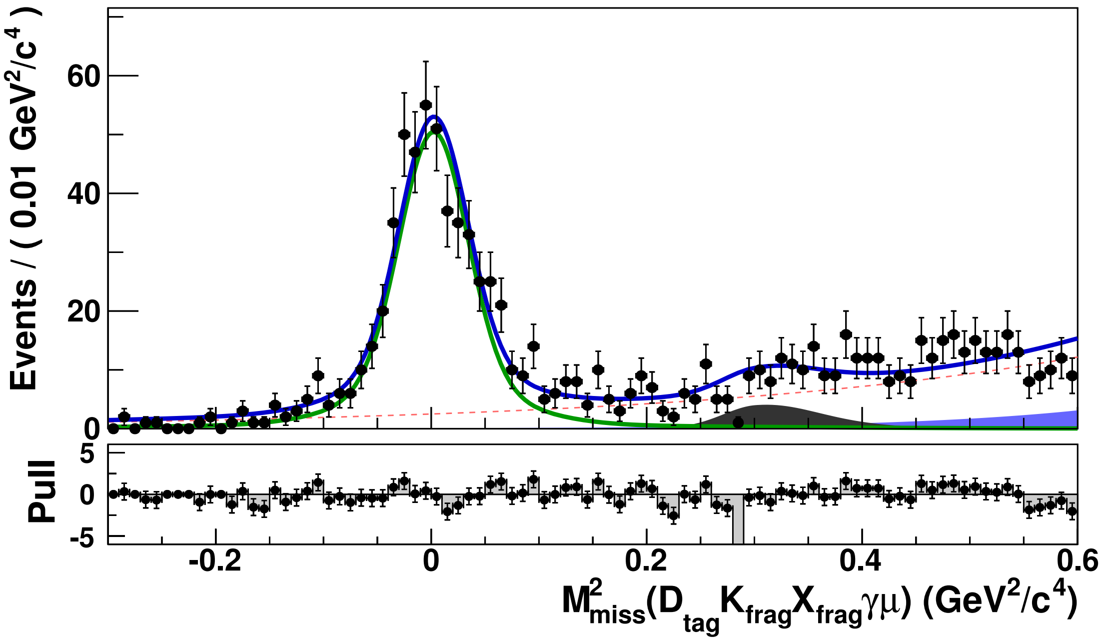
So, a first stage of ramping up is done; another upward push to come…

Despite the modest dataset, there are very nice results !

Leptonic Decays at a B Factory

Belle II

$D_s^+ \to \mu^+ \nu$ Missing-mass^2



Belle $D_s^+ \to \mu\nu$
Old result, for context
from 913 fb^{-1}

"Continuum tagging": reconstruct

- charm meson in opposite jet
- all fragmentation particles

$B(D_s^+ \to \mu^+ \nu) = (0.531 \pm 0.028_{stat} \pm 0.020_{syst})\,\%$

Also, $B(D_s^+ \to \tau^+ \nu) = (5.70 \pm 0.021_{stat} \pm 0.031_{syst})\,\%$ (different fit!)

Combined, these give: $f_{D_s} = (255.5 \pm 4.2 \pm 5.1)$ MeV

7 ab^{-1} gives 2% BF $\mu^+ \nu$ alone; headroom for systematics improvement

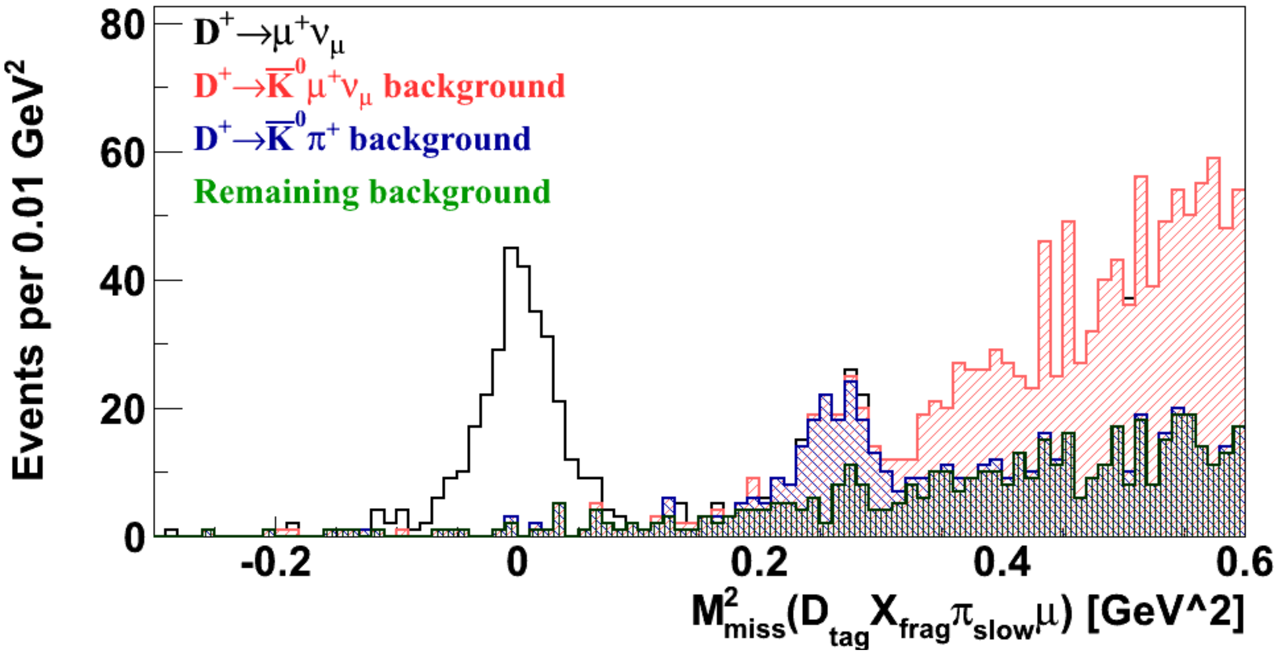
JHEP 1309, 139 (2013)

Leptonic Decays at a B Factory

$D^+ \to \mu^+ \nu$ **Cabibbo-suppressed: not yet done @ B factory**

But studies with Belle MC some years ago show that it works:

- D^+ is longer-lived → BF "only" ~13x smaller
- But, D^+ is also more common than the D_s^+
- And backgrounds & combinatorics differ; need to simulate !



Lower statistics than BESIII, even with 50 fb^{-1}, BUT nice to have a cross-check!

BESIII threshold: 140/fb^{-1} * 20 fb^{-1} gives 2800 events ~ 1.0% stat on f_D

Belle II continuum: 25/ab^{-1} * 50 ab^{-1} gives 1250 events ~ 1.5% stat on f_D

A. Zupanc @ B2TIP, Oct, 2014

BelleII & Charm Lifetimes

7 Weakly-decaying ground-states:

3 mesons: D^+ D^0 D_s^+ 4 baryons: Λ_c^+ Ξ_c^+ Ξ_c^0 Ω_c^0

Weakly-decaying states have a rich variety of decays

Lifetimes connect theory (partial widths) to experiment (BFs)

BF $= \Gamma_i / \Gamma_{tot} = \tau \Gamma_i$ via $\tau = \hbar / \Gamma_{tot}$ need to limit systematics

BelleII has recently measure 5 of these 7 lifetimes

These include the world's best measurements for the D^+ D^0 D_s^+ Λ_c^+

D^+ & D_s^+ results are a bit lower than previous average

Also interesting for lifetime hierarchy:

Corrections to naïve spectator decay

Belle confirmation of *a new hierarchy established by LHCb* :

Ω_c^0 has a longer lifetime, as they first revealed

Charm Lifetimes

Current Best Measurements (*all in fs*)

Particle	BelleII	LHC-b	FOCUS
D^+	*1030.4 ±4.7 ±3.1*	-----	1039.4±4.3±7.0
D^0	*410.5 ±1.1 ±0.8*	-----	409.6±1.1±1.5
D_s^+	*499.5 ±1.7 ±0.9*	506.4±3.0±1.7±1.7 *	507.4±5.5±5.1
Λ_c^+	*203.20 ±0.89 ±0.77*	202.1 ±1.7 ±0.9	204.6±3.4±2.5
Ξ_c^+	-----	*454 ± 5 ±2*	439±22±9
Ξ_c^0	-----	*153.4 ± 2.4 ±0.7*	$118^{+14}_{-12}\pm5$
Ω_c^0	243±48±11**	*276.5 ±13.4 ±4.5*	72±11±11 ***

Many sub-1% single measurements;

ALL of the best results are <u>still</u> statistics limited

* Uses $B^0_s \rightarrow D_s^{(*)-} \mu^+ \nu_\mu$ & $B^0 \rightarrow D^{(*)-} \mu^+ \nu_\mu$; 3rd error from τ_D (pre-Belle II)

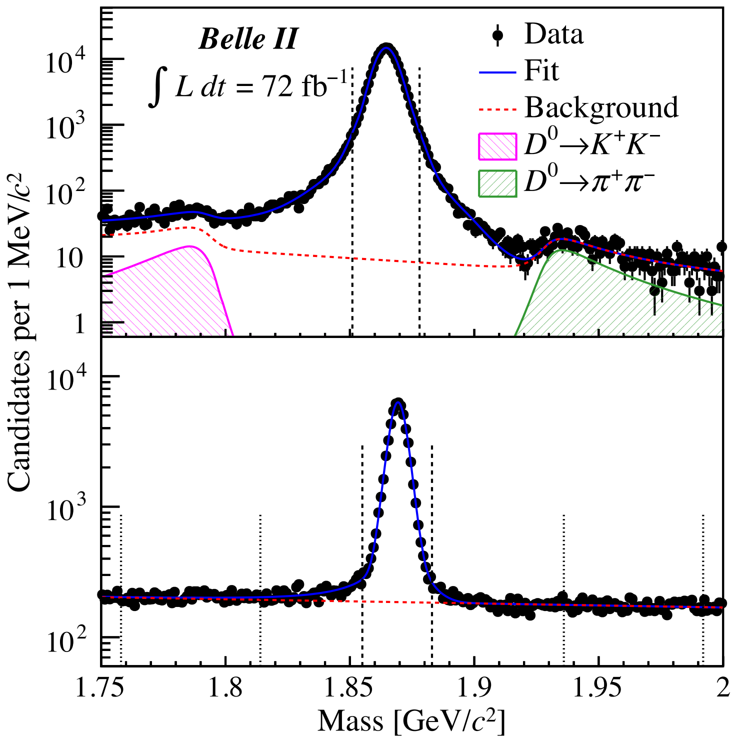
** 3.4σ from old average & 3.3σ from FOCUS , *but consistent with LHCb*

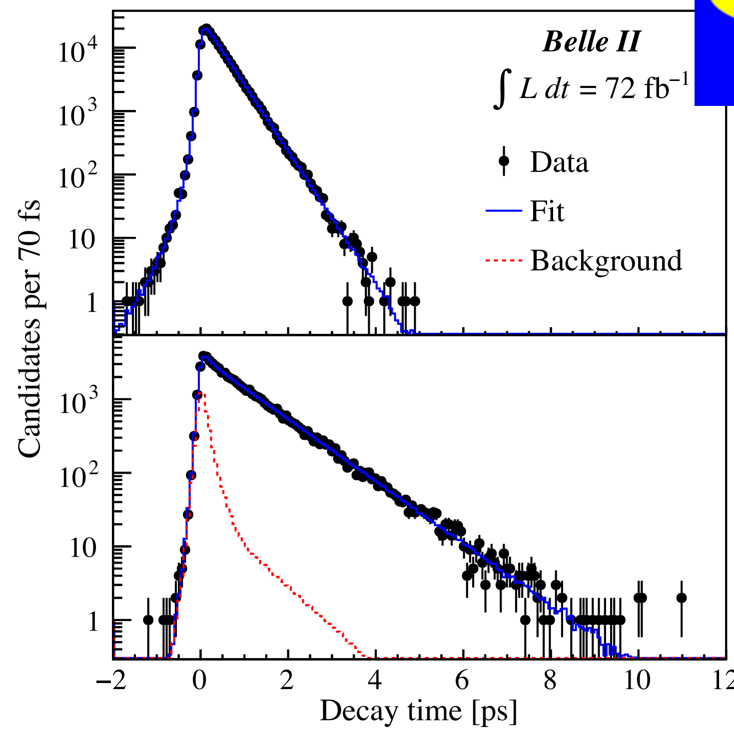
*** Average of 3 old experiments, including FOCUS : 69 ±12 fs

D^0 & D^+ Lifetimes

D^0

D^+





D^0

D^+

TABLE I. Systematic uncertainties.

Source	$\tau(D^0)$ [fs]	$\tau(D^+)$ [fs]
Resolution model	0.16	0.39
Backgrounds	0.24	2.52
Detector alignment	0.72	1.70
~~Momentum scale~~	~~0.19~~	~~0.48~~
Total	0.80	3.10

$$\tau(D^0) = 410.5 \pm 1.1(\text{stat}) \pm 0.8(\text{syst})\ \text{fs}$$
$$\tau(D^+) = 1030.4 \pm 4.7(\text{stat}) \pm 3.1(\text{syst})\ \text{fs}$$

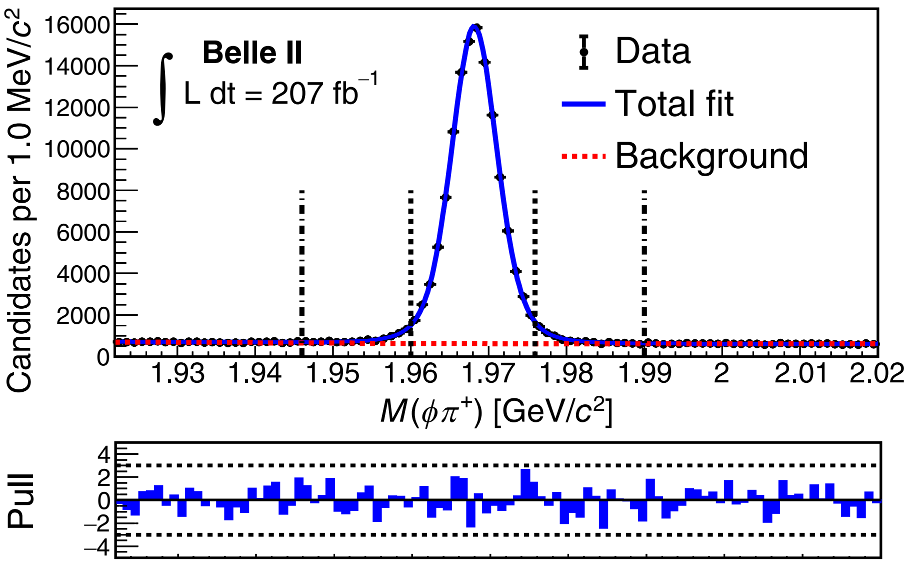
Vertex resolution:

70 ps, 60 ps for D^0, D^+

0.54% for D^+, so 0.3% effect on f_D or $f(0)|V_{cs}|$

72 fb^{-1} *PRL 127, 211801 (2023)*

D_s^+ Lifetime



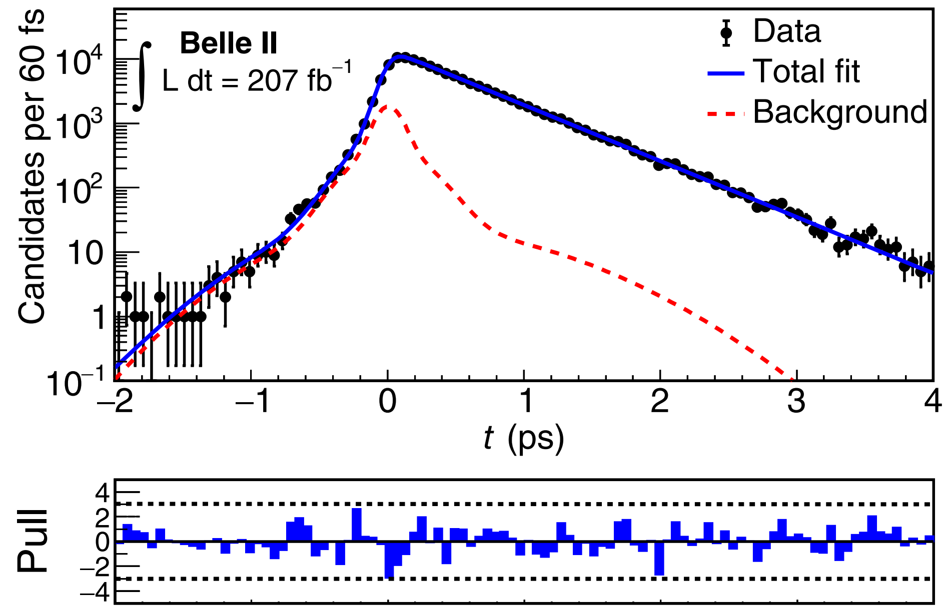


TABLE I. Summary of systematic uncertainties.

Source	Uncertainty (fs)
Resolution function	±0.43
Background (t, σ_t) distribution	±0.40
Binning of σ_t histogram PDF	±0.10
Imperfect detector alignment	±0.56
Sample purity	±0.09
Momentum scale factor	±0.28
D_s^+ mass	±0.02
Total	±0.87

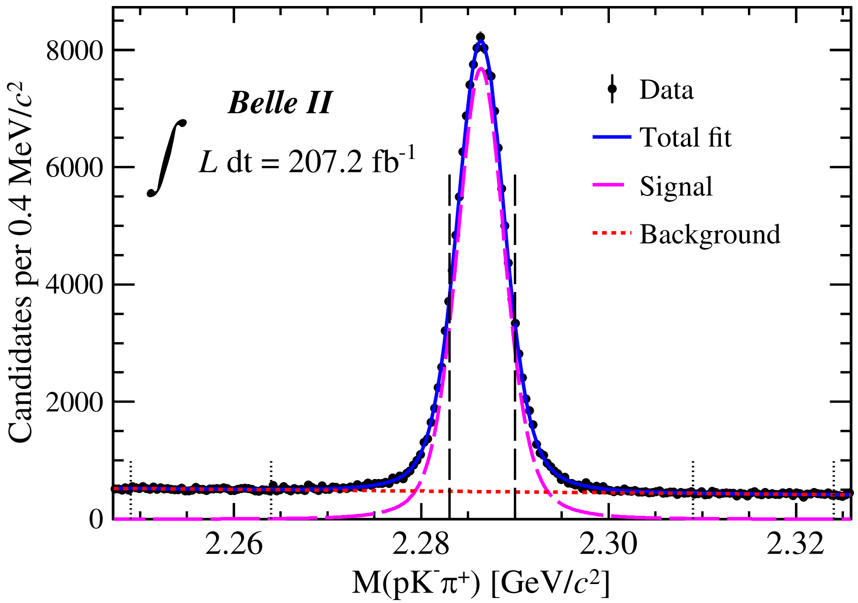
$$\tau_{D_s^+} = (499.5 \pm 1.7 \pm 0.9)\ \text{fs}$$

0.4%, so 0.2% effect on f_{Ds} & $f(0)|V_{cs}|$

[was 0.7% pre Belle, LHCb]

207 fb^{-1} *PRL 131, 171803 (2023)*

Λ_c^+ Lifetime



$$\tau(\Lambda_c^+) = 203.20 \pm 0.89 \pm 0.77\ \text{fs}$$

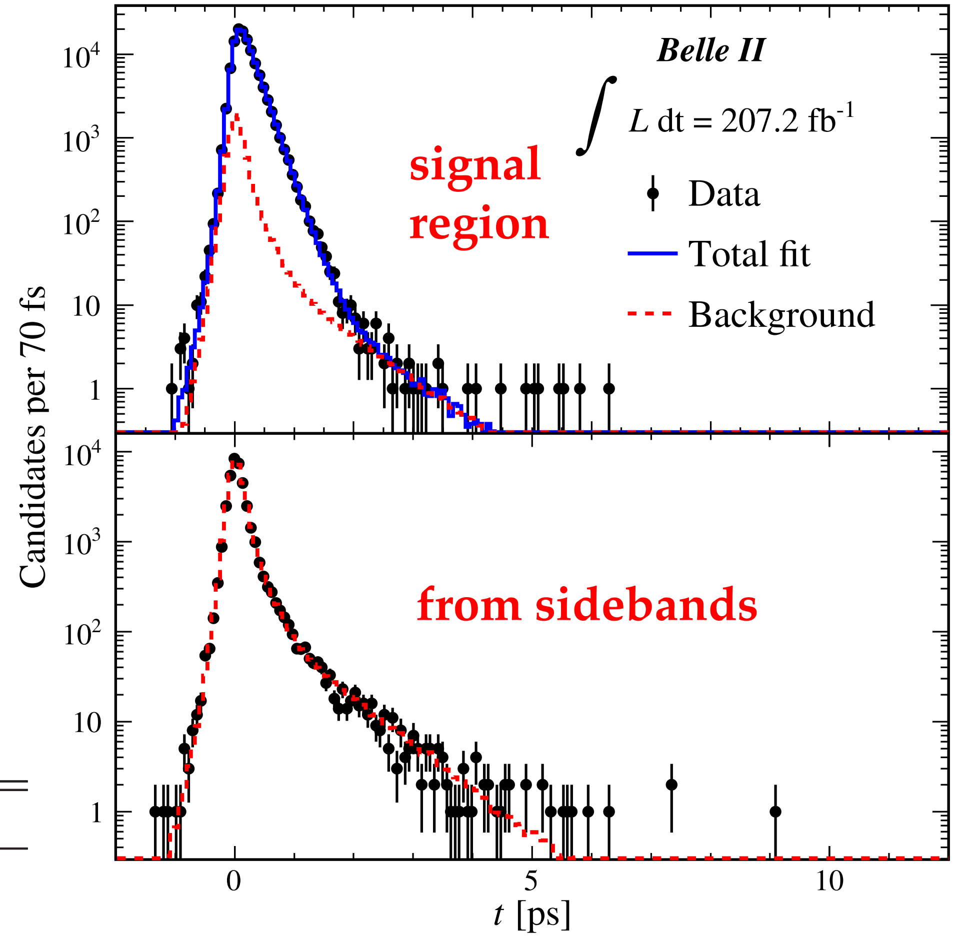
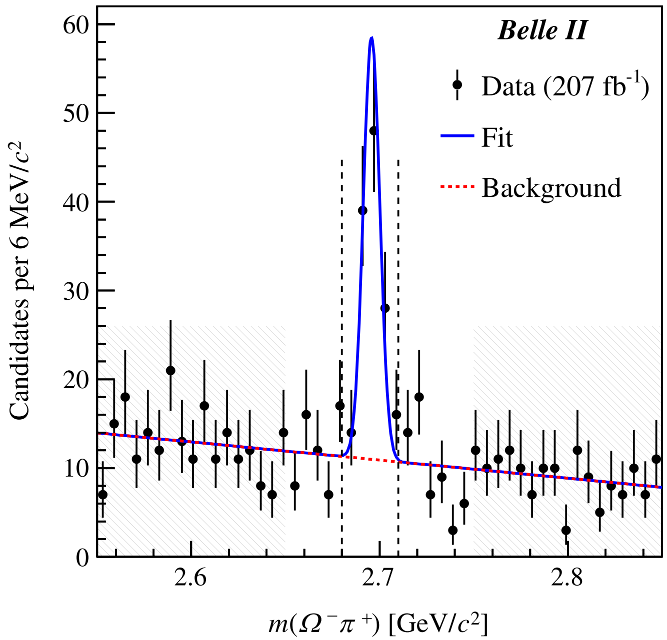


TABLE I. Systematic uncertainties on the Λ_c^+ lifetime.

Source	Uncertainty (fs)
Ξ_c contamination	0.34
Resolution model	0.46
Non-Ξ_c backgrounds	0.20
Detector alignment	0.46
Momentum scale	0.09
Total	0.77

207 fb^{-1} *PRL 130, 071802 (2023)*

Ω_c^0 Lifetime

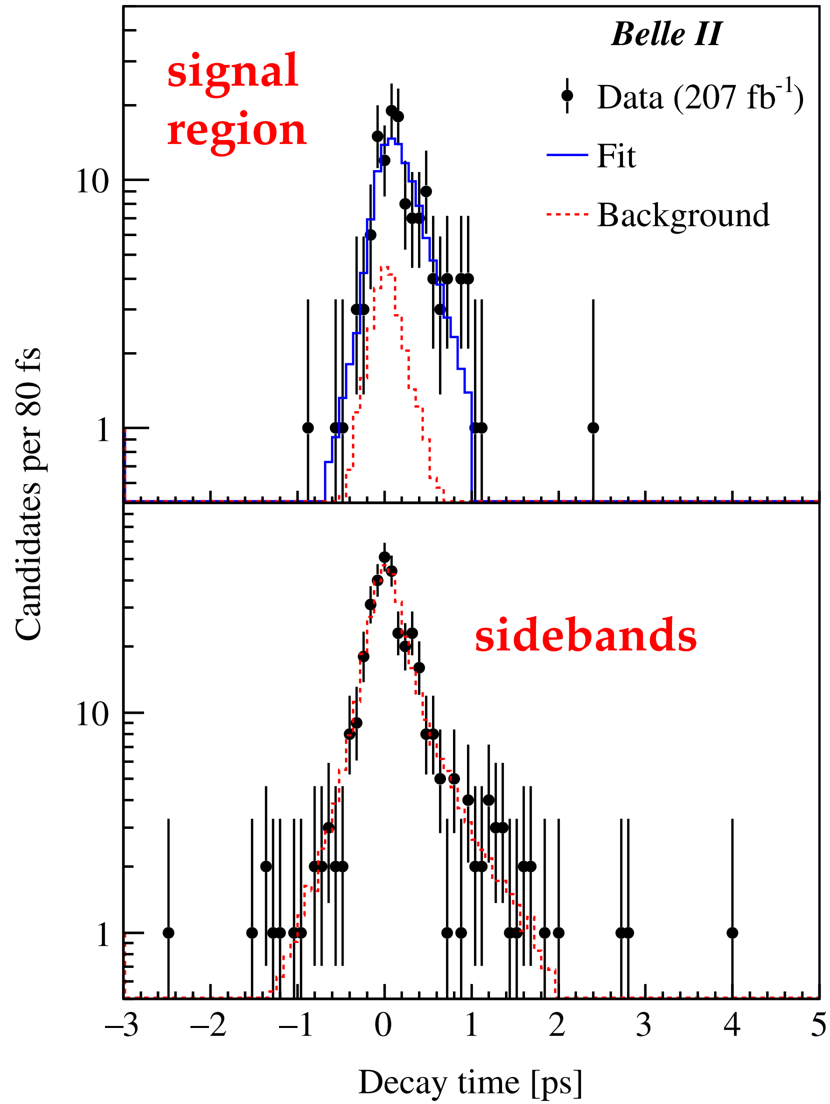


$$\tau(\Omega_c^0) = 243 \pm 48(\text{stat}) \pm 11(\text{syst})\ \text{fs}$$

Very statistics-limited

TABLE I. Systematic uncertainties.

Source	Uncertainty (fs)
Fit bias	3.4
Resolution model	6.2
Background model	8.3
Detector alignment	1.6
Momentum scale	0.2
Input Ω_c^0 mass	0.2
Total	11.0



207 fb^{-1} *PRD 107, L031103 (2023)*

CKM Angle $\gamma = \varphi_3$

Average of "alphabet soup" methods

D^0 strong phase, coherence factors from BESIII, CLEO-c feed into this !

B decay	D decay	Method	Data set (Belle + Belle II)[fb^{-1}]
$B^+ \to Dh^+$	$D \to K_S^0\pi^0, K^-K^+$	GLW	$711 + 189$
$B^+ \to Dh^+$	$D \to K^+\pi^-, K^+\pi^-\pi^0$	ADS	$711 + 0$
$B^+ \to Dh^+$	$D \to K_S^0K^-\pi^+$	GLS	$711 + 362$
$B^+ \to Dh^+$	$D \to K_S^0h^-h^+$	BPGGSZ (m.i.)	$711 + 128$
$B^+ \to Dh^+$	$D \to K_S^0\pi^-\pi^+\pi^0$	BPGGSZ (m.i.)	$711 + 0$
$B^+ \to D^*K^+$	$D^* \to D\pi^0, D \to K_S^0\pi^0, K_S^0\phi, K_S^0\omega,$ $K^-K^+, \pi^-\pi^+$	GLW	210+0
$B^+ \to D^*K^+$	$D^* \to D\pi^0, D\gamma, D \to K_S^0\pi^-\pi^+$	BPGGSZ (m.d.)	$605 + 0$

Belle + Belle II average : $\gamma = \varphi_3 = (75.2 \pm 7.6)^{\circ}$

… still chasing LHCb average : $(67 \pm 4)^{\circ}$

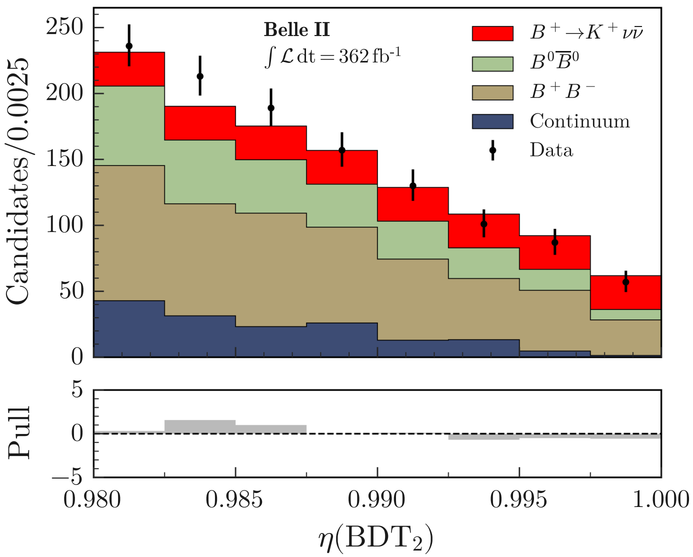
to appear in JHEP

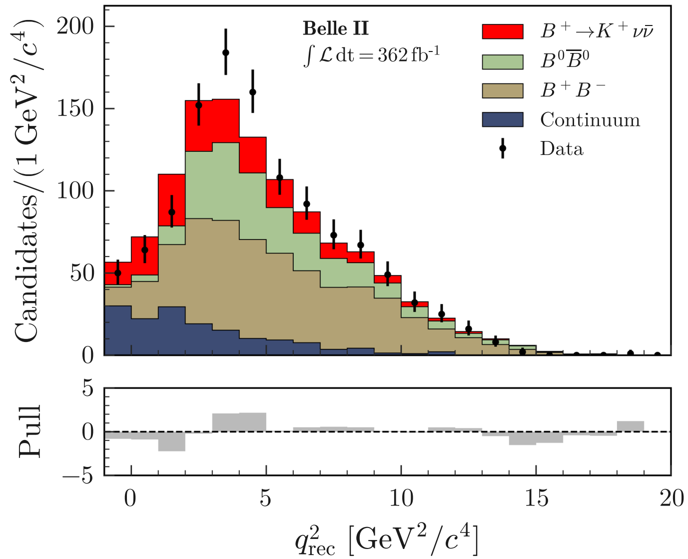
Belle II : $B^+ \rightarrow K^+ \nu \nu$

First a new limit : PRL 127, 181802 (2021) BF $<$ 4.1 x 10^{-5}

Then 3.5σ evidence : PRD 109, 112006 (2024) BF $= (2.3 \pm 0.5^{+} \pm {}^{0.5}_{-0.4}) \times 10^{-5}$

Uses Inclusive Tagging Analysis (ITA) & Boosted Decision Tree (BDT)





Hard cut:
BDT>0.98
Left plot: BDT
Right plot: q^2
(data, sig, bkg)

Very detailed PRD; uses several control modes to establish technique, resolution, …
Shows many control mode plots, more signal-related plots, etc.

NOTE: NA62 has recent $K^+ \rightarrow \pi^+ \nu \nu$ update ! (& previous B787, B949)

BESIII

BESIII

Datasets & Publications
Spectroscopy
Strong Phases 7 CP-Even Fractions
Leptonic Decays & Decay Constants *w/ new result from Thursday !*
Glueball Candidate
Absolute BFs

Additional References

- **Physics at BESIII**
  D.M. Asner *et al.*, Int J Mod Phys A 2009; 24: S1
- **Accomplishments and Future Prospects of the BES Experiments at the BEPC Collider**
  Briere, Harris & Mitchell, Ann, Rev. Nucl. Part. Sci. 66, 143 (2016)
- **Future Physics Programme of BESIII**
  M. Ablikim *et al.*, Chin. Phys. C 44, 040001 (2020)
- **Special Topic: Physics of the BESIII Experiment**
  National Science Review 8: nwab201, 2021
  Introduction by Yifang Wang, plus six topical reviews

BESIII

BESIII & BEPC-II

- Much better detector than BESII (similar to CLEO-c)
- Much better accelerator than BEPC ,
  & designed for charm energy region (unlike CESR-c)
- More international collaborators than BESII (esp. Europe)
- ***Symmetric*** machine & detector

Flavor physics is popular, but it's not as dominant as you might think…

- Spectroscopy and other physics were popular from the start
- Then "XYZ" physics exploded !

BEPC-II: 1.8 – 4.95 GeV; but upgrade to 5.6 GeV in progress

BESIII Datasets

About 50 fb^{-1} in total

[CLEO-c: < 2 fb^{-1} total, but still impactful!]

Core Flavor Physics

20.3 fb^{-1} $\psi(3770)$ *[3 fb^{-1} 2010-11; rest 2022-24]*

3 fb^{-1} 4170 MeV *[for $D_s^* D_s$ prod'n; also add other datasets]*

Λ_c threshold data

Many high-statistics "XYZ" datasets (exotic hadrons) :

0.5 fb^{-1} per energy point, 10-20 MeV spacing

(including data at 4.04, 4.23+4.26, up to 4.95 GeV)

Charmonium: 10×10^9 J/ψ 2.7×10^9 $\psi(3686)$

Dedicated scans:

Tau mass @ threshold

R_{had} scans (2.0 – 3.08 GeV; > 3.74 GeV)

BESIII Publications

Publications by year (601 total as of 01 Oct 2204)

2010-2014	3 / 11 / 18 / 26 / 19	Σ = 77
2015-2019	34 / 23 / 38 / 36 / 61	Σ = 192
2020-2024	38 / 62 / 71 / 80 / 81*	Σ = 332, so far

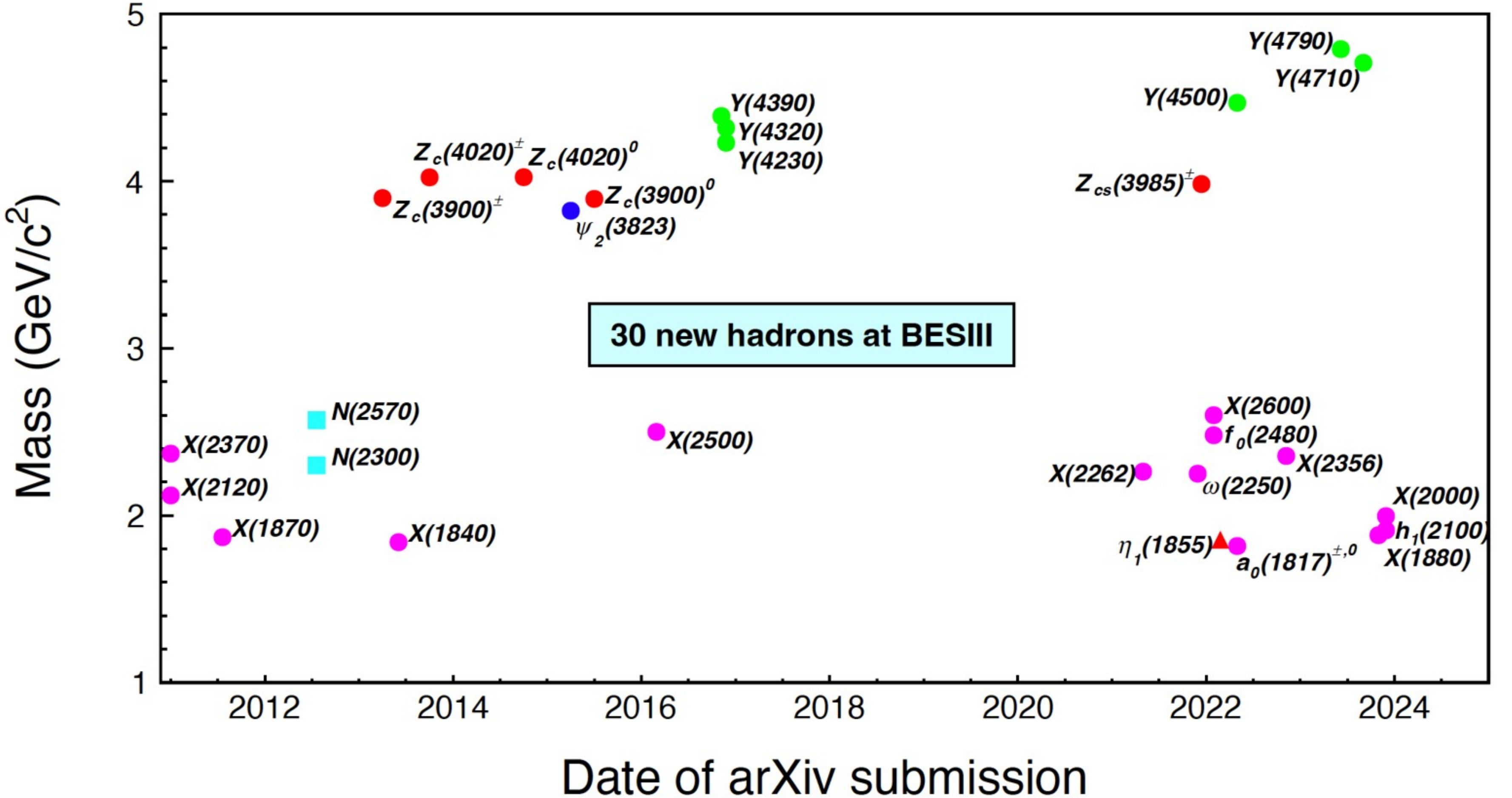
* *partial year: should hit 100 ! [10 more accepted already…]*

Publications by Journal

365 PRD 116 PRL 34 PLB 48 JHEP 4 EPJ 29 CPC
1 PRC 1 Nature 2 Nature Phys 1 SciChina

http://bes3.ihep.ac.cn has highlights…

BESIII Spectroscopy



Updated version of a plot from: "New hadrons discovered at BESIII", Zhiqing Liu & Ryan E. Mitchell, Science Bulletin 68, 2148 (2023)

Note: LHCb is another spectroscopy powerhouse…

Strong Phases

Measurements made possible by CP-tagging of D^0 pairs

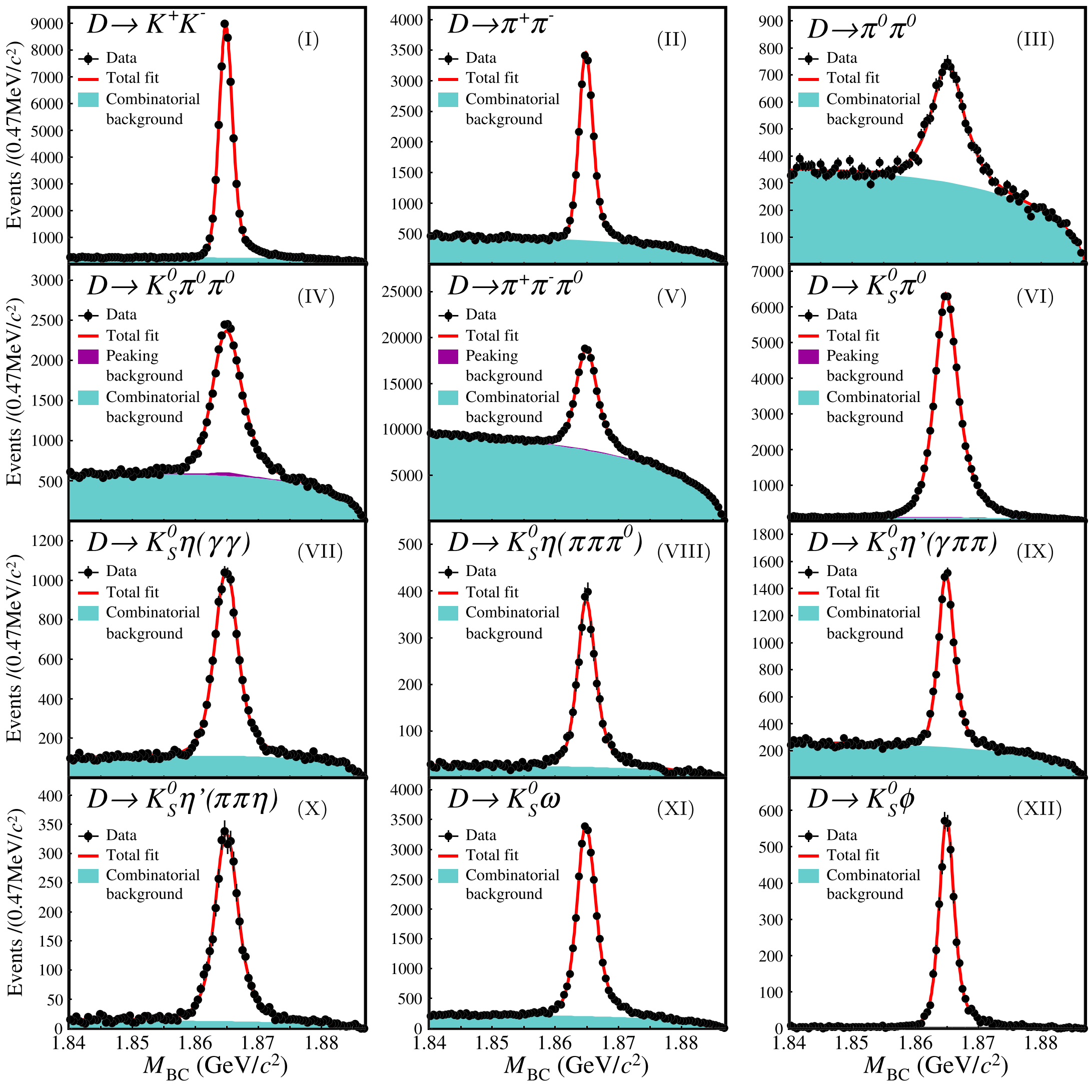


Fig. 2 Fits to M_{BC} distributions of single-tag candidates for the *CP*-even (I–IV), quasi *CP*-even eigenstate (V) and *CP*-odd eigenstates (VI–XII)

Mass peaks for:

4 CP-even,
1 mostly-even,
& 7 CP-odd
final states
(States with K_L are also used)

2.93 fb^{-1}

(7x now in hand!)

Strong Kπ phase:

$\delta^{K\pi} = (187.6^{+8.9}_{-9.7}{}^{+5.4}_{-7.4})^o$

Relevant for D mixing!

EPJC 82, 1009 (2023)

CP-Even Fractions

BESIII

CP-even fractions for multi-body states

All 2.93 fb^{-1}

$D^0 \to K^+ K^- \pi^+ \pi^-$ — PRD 107, 032009 (2023)

$F_+ = 0.730 \pm 0.037 \pm 0.021$ — 2.93 fb^{-1}

$D^0 \to K_S^+ \pi^+ \pi^- \pi^0$ — PRD 108, 032003 (2023)

$F_+ = 0.235 \pm 0.010 \pm 0.002$ — 2.93 fb^{-1}

$D^0 \to \pi^+ \pi^- \pi^0$ — PRD 107, 032009 (2023)

$F_+ = 0.9406 \pm 0.0036 \pm 0.0021$ — 7.93 fb^{-1}

$D^0 \to K^+ K^- \pi^0$ — " "

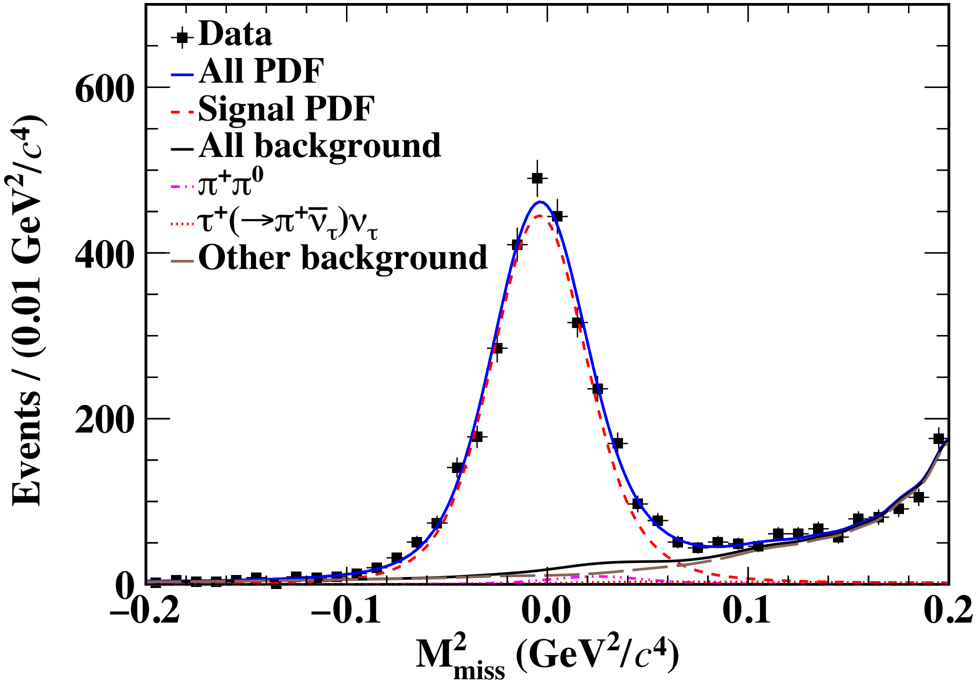
$F_+ = 0.631 \pm 0.014 \pm 0.011$ — " "

Also measure "coherence factors" for Knπ final states :

an average Re$^{-i\delta}$ factor that "generalizes the 2" in interference cross-terms

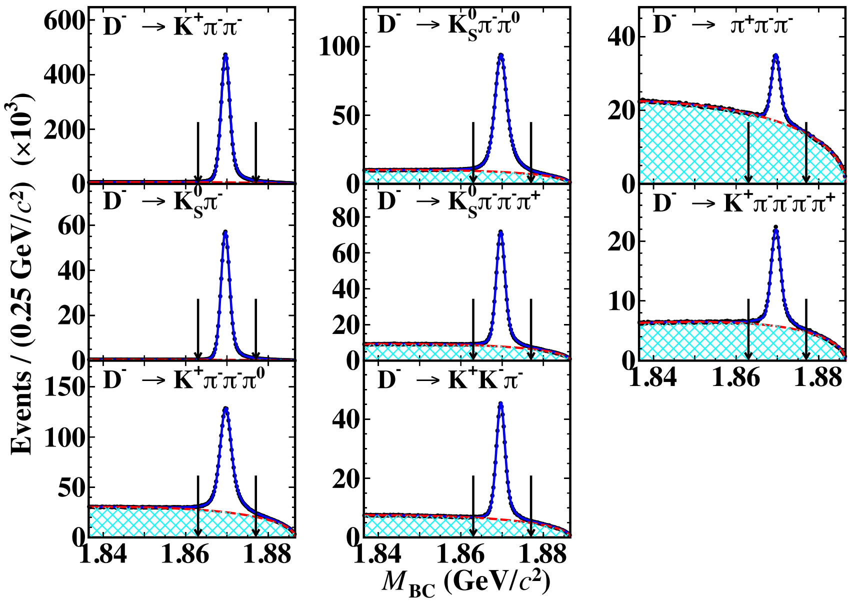
Leptonic Decays

$D^+ \to \mu^+ \nu_\mu$ Missing-mass²



On arXiV last Thursday
20.3 fb^{-1}

Tag mode mass peaks



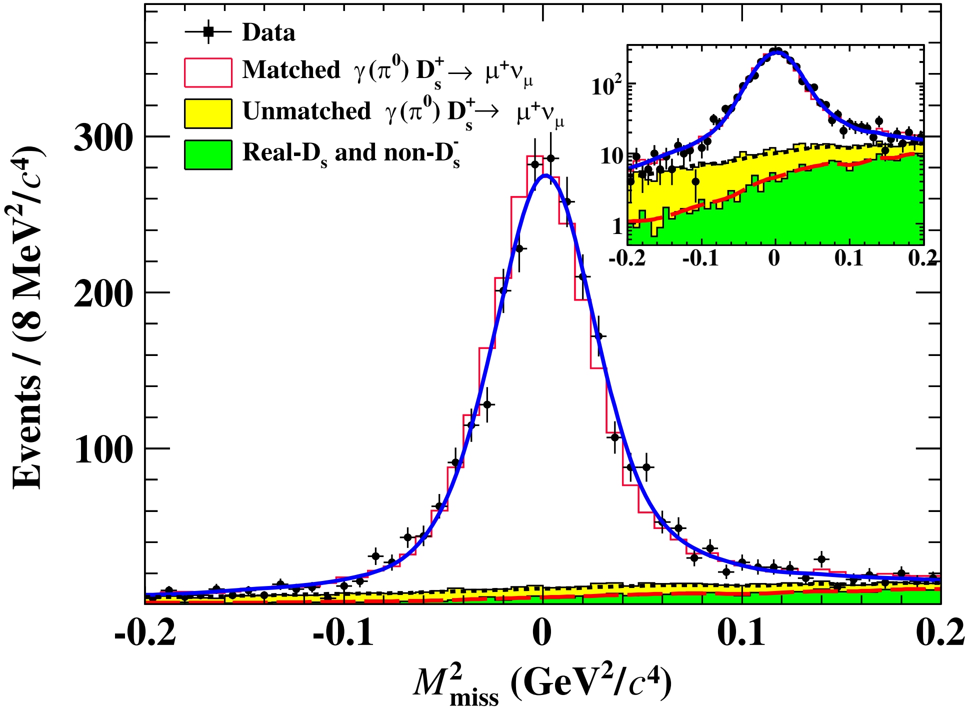
$$B(D^+ \to \mu^+\nu) = (3.981 \pm 0.079_{stat} \pm 0.040_{syst}) \times 10^{-4}$$

$$f_D = (211.5 \pm 2.3_{stat} \pm 1.1_{syst} \pm 0.8_{input})\ \text{MeV}$$

arXiv:2410:07626; subm. to PRL

Leptonic Decays

$D_s^+ \to \mu^+ \nu_\mu$ Missing-mass²



Based on 7.33 fb^{-1}
$e^+e^- \to D_s^{*\pm} D_s^{\mp}$
@ E_{CM}: 4.128 – 4.226 GeV

$B(D_s^+ \to \mu^+ \nu) = (0.5294 \pm 0.0108_{stat} \pm 0.0085_{syst})\ \%$
$f_{Ds} = (248.4 \pm 2.5_{stat} \pm 2.2_{syst})$ MeV

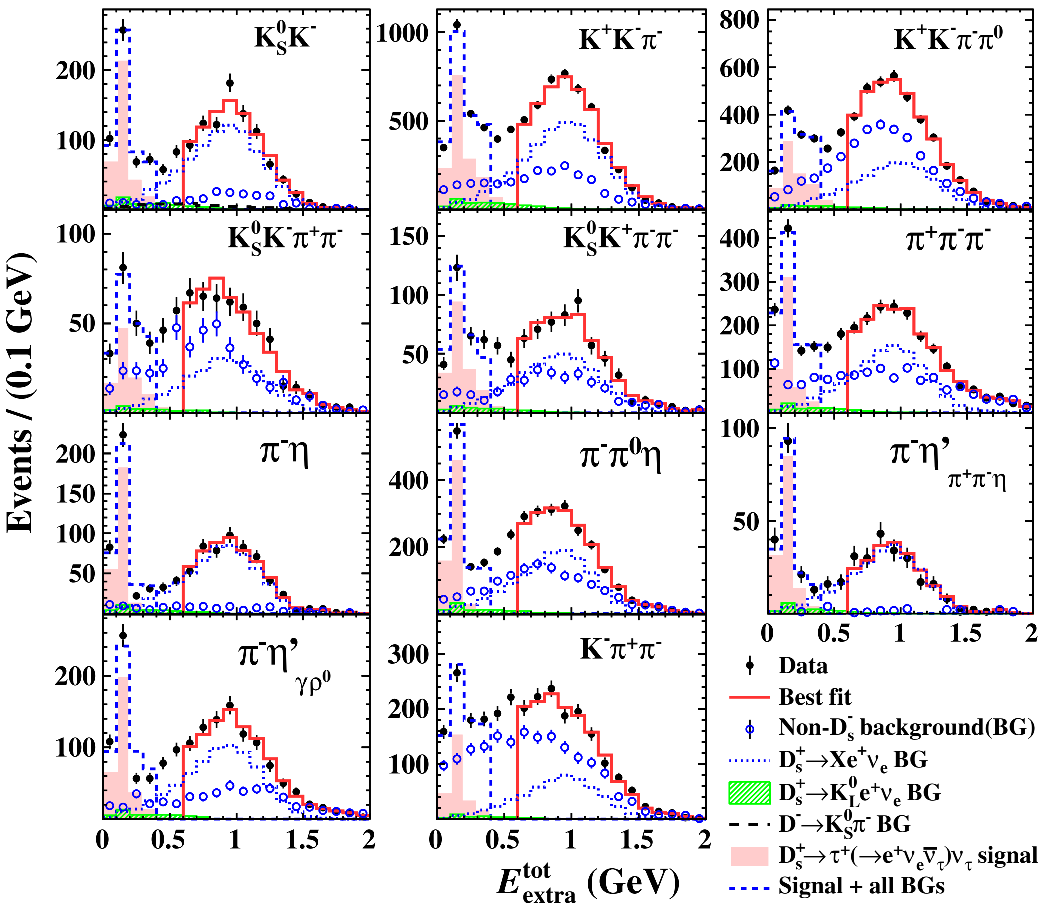
NOTE: here and later, results not updated for D_s lifetime, |V_cs|, since we mostly care about uncertainties !

PRD 108, 112001 (2023)

Leptonic Decays

$D_s^+ \to \tau^+ \nu_\tau$ with $\tau^+ \to e^+ \nu_e \nu_\tau$

Based on 6.32 fb^{-1}
$e^+e^- \to D_s^{*\pm} D_s^{\mp}$
@ E_{CM}: 4.178 – 4.226 GeV



Signal Variable:
Extra energy in calorimeter
or various D_s tag modes

"Extra" = beyond the tag and e^+
i.e., neutrals, incl. D_s^* transition

Fit backgrounds @ E > 0.6GeV
Signal: shaded pink @ lower E

$B(D_s^+ \to \tau^+ \nu) = (5.37 \pm 0.10_{stat} \pm 0.12_{syst})$ %
$f_{Ds} = (251.1 \pm 2.4_{stat} \pm 3.0_{syst})$ MeV

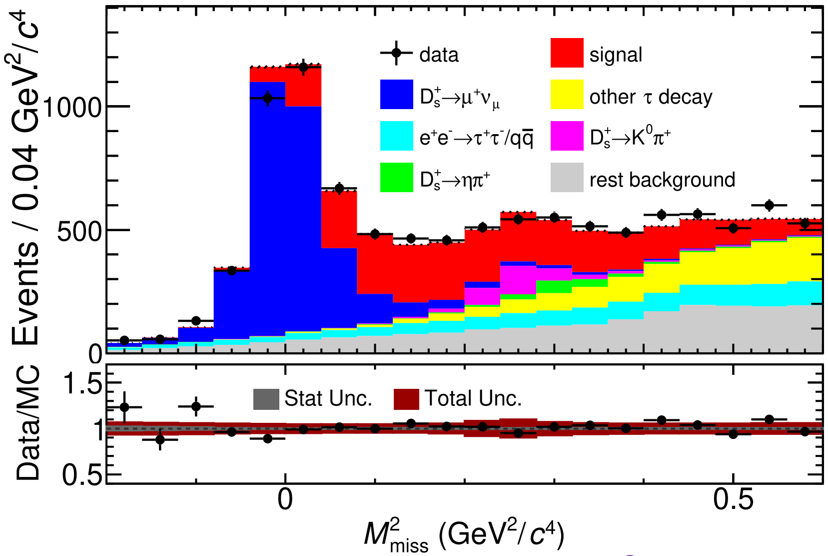
PRL 127, 171801 (2021)

Leptonic Decays

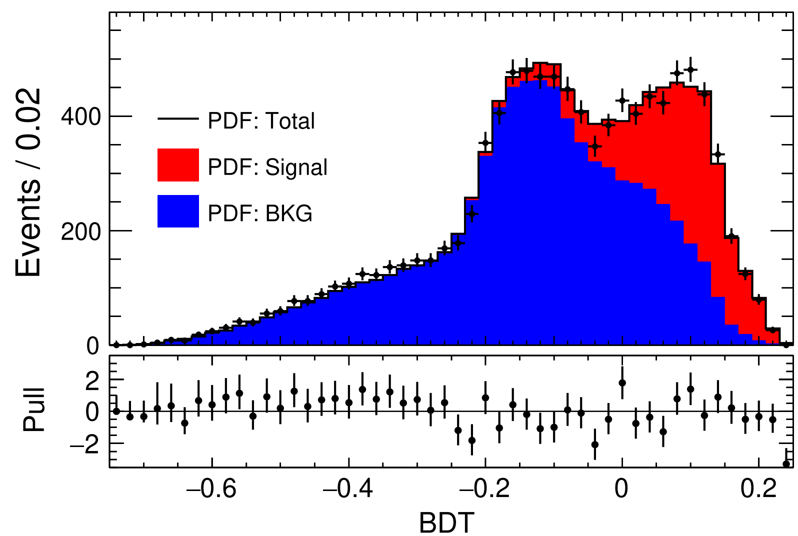
$D_s^+ \to \tau^+ \nu_\tau$ with $\tau^+ \to \pi^+ \nu_\tau$

Based on 7.33 fb^{-1}
$e^+e^- \to D_s^{*\pm} D_s^{\mp}$
@ E_{CM}: 4.128 – 4.226 GeV

Missing-mass² + 8 other variables → BDT for final signal fit



Missing-mass²



BDT

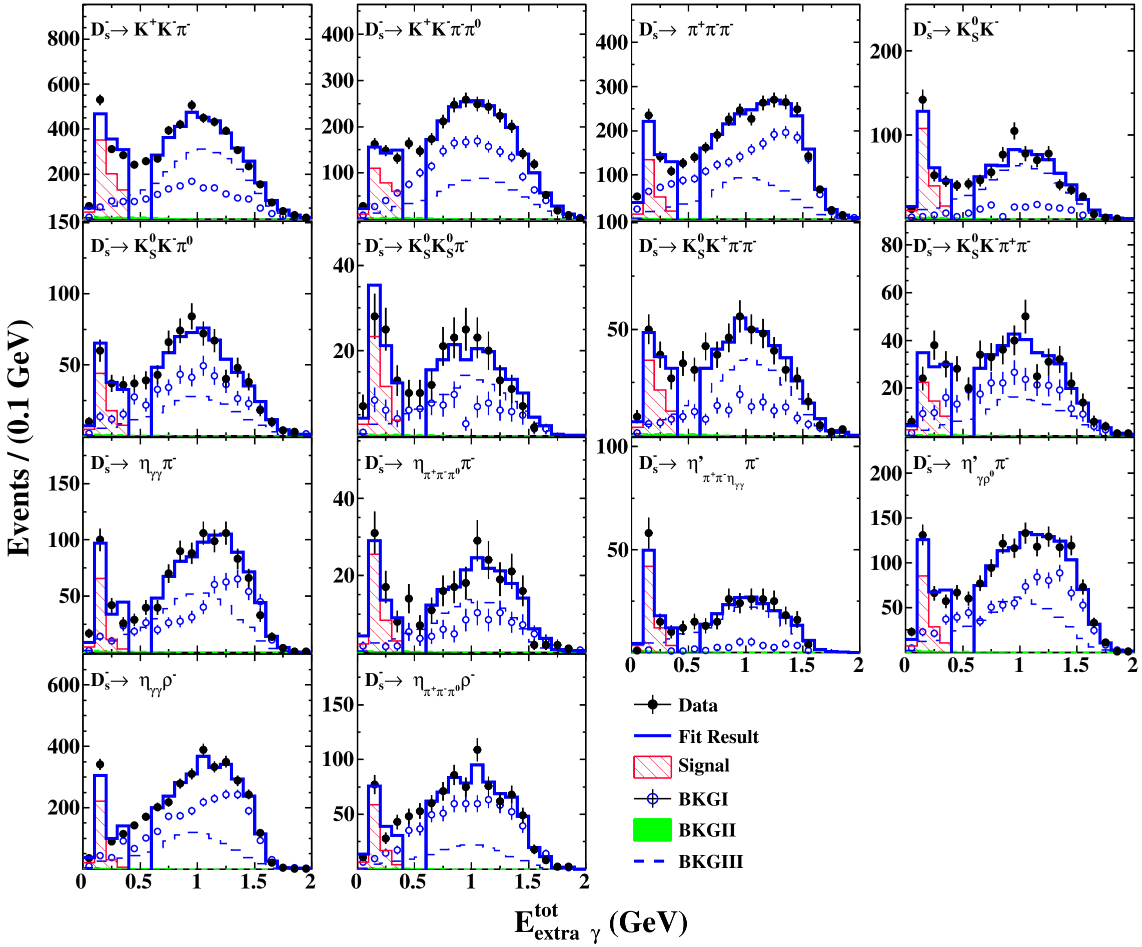
$$B(D_s^+ \to \tau^+ \nu) = (5.44 \pm 0.17_{stat} \pm 0.13_{syst})\ \%$$

$$f_{D_s} = (255.0 \pm 4.0_{stat} \pm 3.2_{syst} \pm 1.0_{input})\ \text{MeV}$$

PRD 108, 092014 (2023)

Leptonic Decays

$D_s^+ \to \tau^+ \nu_\tau$ with $\tau^+ \to \mu^+ \nu_\mu \nu_\tau$



Based on 7.33 fb^{-1}
$e^+e^- \to D_s^{*\pm} D_s^{\mp}$
@ E_{CM}: 4.128 – 4.226 GeV

Signal variable:
Extra energy in calorimeter for various D_s tag modes

"Extra" = beyond the tag and μ^+ i.e., neutrals, incl. D_s^* transition

Fit backgrounds @ E > 0.6GeV
Signal: open pink @ lower E

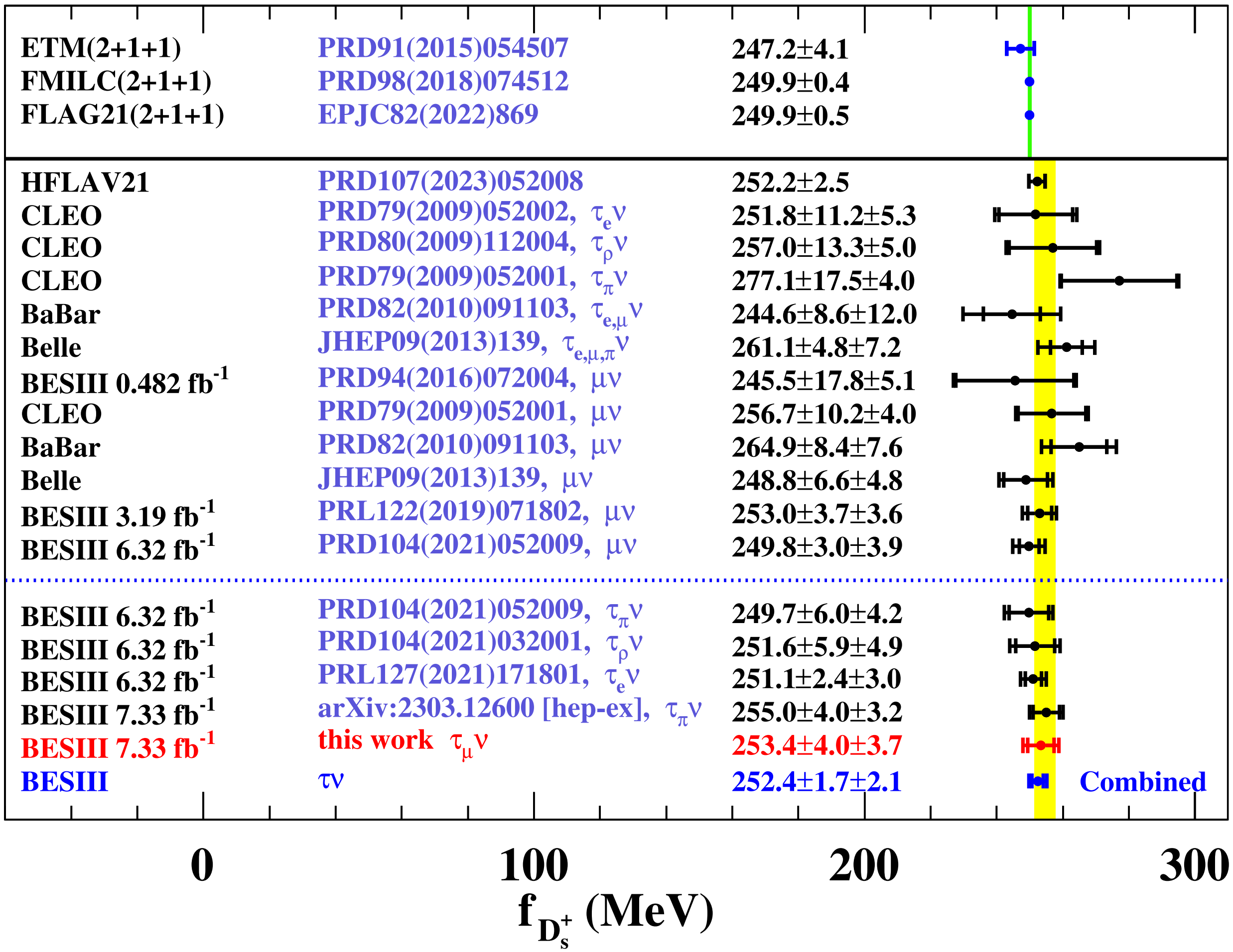
$$B(D_s^+ \to \tau^+ \nu) = (5.37 \pm 0.17_{stat} \pm 0.15_{syst})\ \%$$
$$f_{D_s} = (253.4 \pm 4.0_{stat} \pm 3.7_{syst})\ \text{MeV}$$

JHEP 09, 124 (2023)

Leptonic Decays

$D_s^+ \to \mu^+ \nu_\mu$, $\tau^+ \nu_\tau$ Summary

(from the previous paper...)



- $D_s^+ \to \mu^+ \nu_\mu$ *in this talk supersedes related BESIII results in table*
- *arXiV:2303.12600 = PRD 108, 092014 (2023), presented 2 pages ago*

JHEP 09, 124 (2023)

Leptonic Decay Systematics

BESIII

Systematics will be important in the future

In some cases, more data will help studies

TABLE V. Relative systematic uncertainties in the measurement of the BF of $D_s^+ \to \mu^+\nu_\mu$.

$D_s^+ \to \mu^+\nu_\mu$

Source	Uncertainty (%)
ST yield	0.44
μ^+ tracking	0.24
μ^+ PID	0.19
Transition $\gamma(\pi^0)$ reconstruction	1.00
Least $\|\Delta E\|$ selection	0.70
$E_{\rm max}^{\rm extra\gamma}$ & $N_{\rm ncharged}^{\rm extra}$ requirements	0.29
$M_{\rm miss}^2$ fit	0.72
Quoted BFs	0.34
Contribution from $D_s^+ \to \gamma\mu^+\nu_\mu$	0.30
Total	1.61

$D_s^+ \to \tau^+\nu_\tau$

$\tau^+ \to \mu^+\nu_\mu\nu_\tau$

Source	Uncertainty (%)
ST yield	0.48
Tag bias	0.37
MC sample size	0.29
μ^+ tracking	0.18
μ^+ PID	0.33
$\gamma(\pi^0)$ reconstruction	1.00
$M_{3\nu}^2$ requirement	1.75
$N_{\rm extra}^{\rm charge}$ requirement	0.41
$E_{{\rm extra}\,\gamma}^{\rm tot}$ fit	1.56
$\mathcal{B}(\tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau)$	0.23
Total	2.70

Table 3. Systematic uncertainties in the BF measurement.

TABLE VII. Relative systematic uncertainties in the branching fraction measurement.

$D_s^+ \to \tau^+\nu_\tau$

$\tau^+ \to \pi^+\nu_\tau$

Source	Uncertainty (%)
ST yield	0.52
Tag bias	0.41
π^+ tracking	0.35
π^+ PID	0.32
$\gamma(\pi^0)$ reconstruction	1.00
MC sample size	0.19
Input branching fractions	0.52
Basic event selections	1.06
$M_{\rm miss}^2$ range	Negligible
$D_s^+ \to \gamma\mu^+\nu_\mu$ background	Negligible
$D_s^+ \to \pi^+\pi^0$ background	Negligible
Background estimate	1.50
Input shape for BDT	0.69
Total	2.41

$D_s^+ \to \tau^+\nu_\tau\,;\, \tau^+ \to e^+\nu_e\nu_\tau$: **no table** ☹

Typical dominant issues:

- signal fits
- transition γ, π^0 reconstruction (from Ds* decay)
- often selection cut(s), best candidate selection
- sometimes backgrounds

More Leptonic Decays…

BESIII

Also now using $D_s^{*\pm} D_s^{*\mp}$ final states… **[2 vector mesons]**

Based on 10.64 fb^{-1} $e^+e^- \rightarrow D_s^{*\pm} D_s^{*\mp}$ @ E_{CM}: 4.237 – 4.699 GeV

$B(D_s^+ \rightarrow \mu^+ \nu) = (0.547 \pm 0.026_{stat} \pm 0.016_{syst})\%$

$f_{Ds} = (253.2 \pm 6.0_{stat} \pm 3.7_{syst} \pm 0.6_{input})$ MeV

$B(D_s^+ \rightarrow \tau^+ \nu) = (5.60 \pm 0.16_{stat} \pm 0.20_{syst})\%$

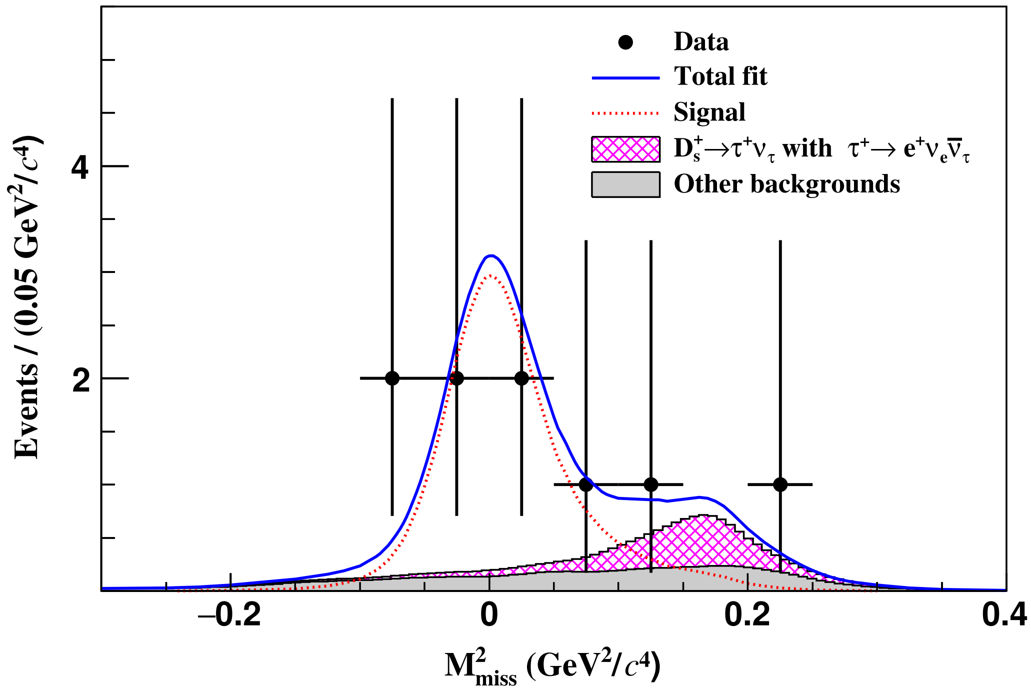
$f_{Ds} = (259.6 \pm 3.7_{stat} \pm 4.6_{syst} \pm 0.6_{input})$ MeV

PRD 110, 052002 (2024)

Leptonic Decays: Vectors !

No helicity supression & Cabibbo-favored

$B(D_s^{*+} \to e\,\nu) = (2.1 \pm^{+1.2}_{-0.9} \pm 0.2) \times 10^{-5}$ **2.9σ**



Based on 7.33 fb^{-1}
$e^+e^- \to D_s^{*\pm} D_s^{\mp}$
@ E_{CM}: 4.128 – 4.226 GeV

Uses tagging ,
& missing-mass^2
as a signal variable

PRL 131, 141802 (2023)

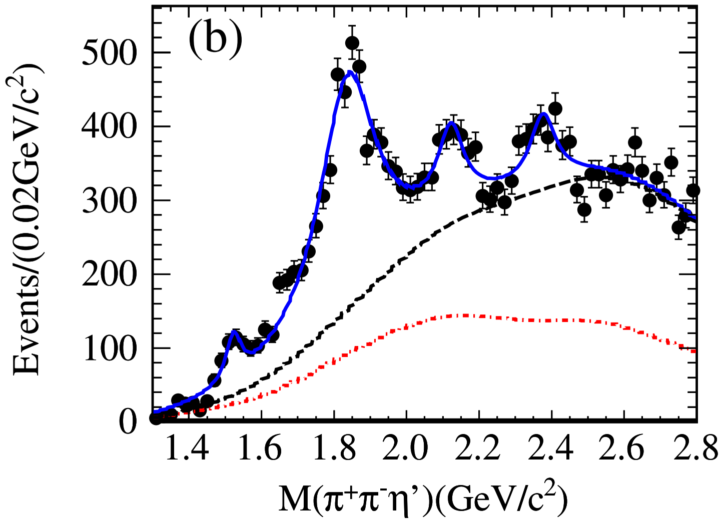
Also, limits on the Cabibbo-suppressed version, D^{*+} decays:

$B(D^{*+} \to e\,\nu) < 1.1 \times 10^{-5}$ $B(D^{*+} \to \mu\,\nu) < 4.3 \times 10^{-6}$

PRD 110, 012003 (2024)

Glueball Candidate

2011: X(2370) first seen in $J/\psi \rightarrow \gamma\, \pi\, \pi\, \eta'$



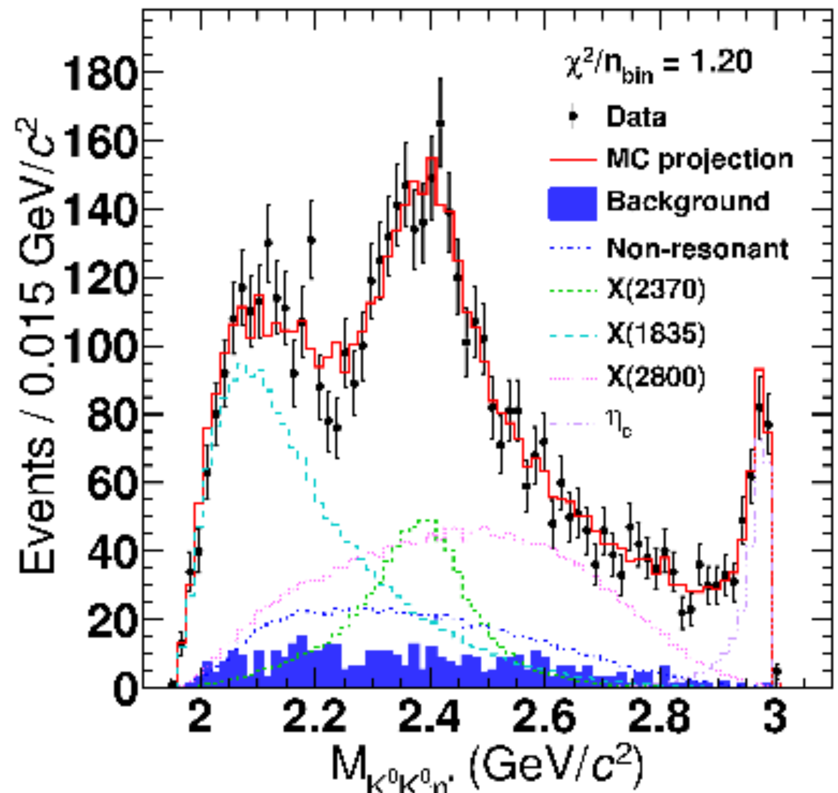
Three peaks:

X(1835), X(2120) & X(2370)

2024: A partial-wave analysis with a low background mode:

$J/\psi \rightarrow \gamma\, K_S\, K_S\, \eta'$

→ ***Establishes*** $J^P = 0^-$



PRL 106, 072002 (2011);
PRL 132, 181901 (2024)

Absolute BFs

7 Weakly-decaying ground-states :

3 mesons: D^+ D^0 D_s^+ 4 baryons: Λ_c^+ Ξ_c^+ Ξ_c^0 Ω_c^0

Near threshold production of pairs allows absolute BF measurements:

Measure "Single Tags" (ST) I n some mode i : $N_i = N_{pair}\ BF_i\ \varepsilon_i$

Measure "Double Tags" (DT) + ST signal j : $N_{ij} = N_{pair}\ BF_i\, BF_j\ \varepsilon_{ij}$

Number of produced pairs is canceled algebraically between ST & DT :

$BF_j = [\, N_{ij} / N_i \,][\, \varepsilon_{ij} / \varepsilon_i \,]$ where $\varepsilon_{ij} / \varepsilon_i \sim= \varepsilon_j$ (not assumed: use MC)

CLEO-c did for 3 meson golden modes & BESIII for D^0, D_s^+ golden modes :

$D^0 \rightarrow K^- \pi^+$ $D^+ \rightarrow K^- \pi^+ \pi^+$ $D_s^+ \rightarrow K^+ K^- \pi^+$

& both did many other modes…

Now, BESIII is *extending to baryons*, starting with Λ_c^+

$\Lambda_c^+ \rightarrow p K^- \pi^+$ & many other modes

Tagging also gives clean samples for structure analysis (PWA)

SUMMARY

Flavor physics is alive and well
at electron-positron colliders,
both Charm and B factories
Expect many more intriguing results

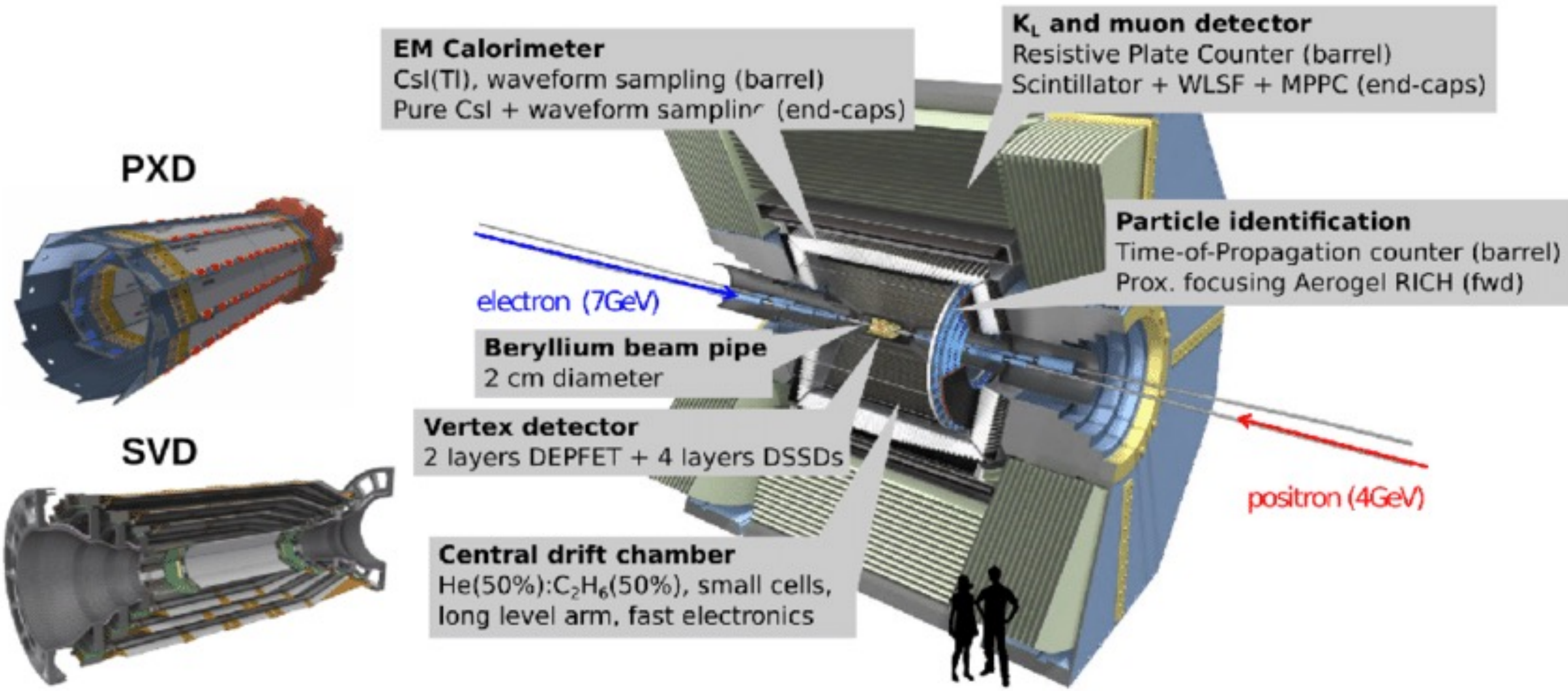
The flavor physics of quarks
involves weak interactions that are
partly obscured by strong interactions:
We could always "parametrize our ignorance",
but it's much nicer to have Lattice QCD results.

Today we celebrate not only a *fellow traveler*, but a *guide* :

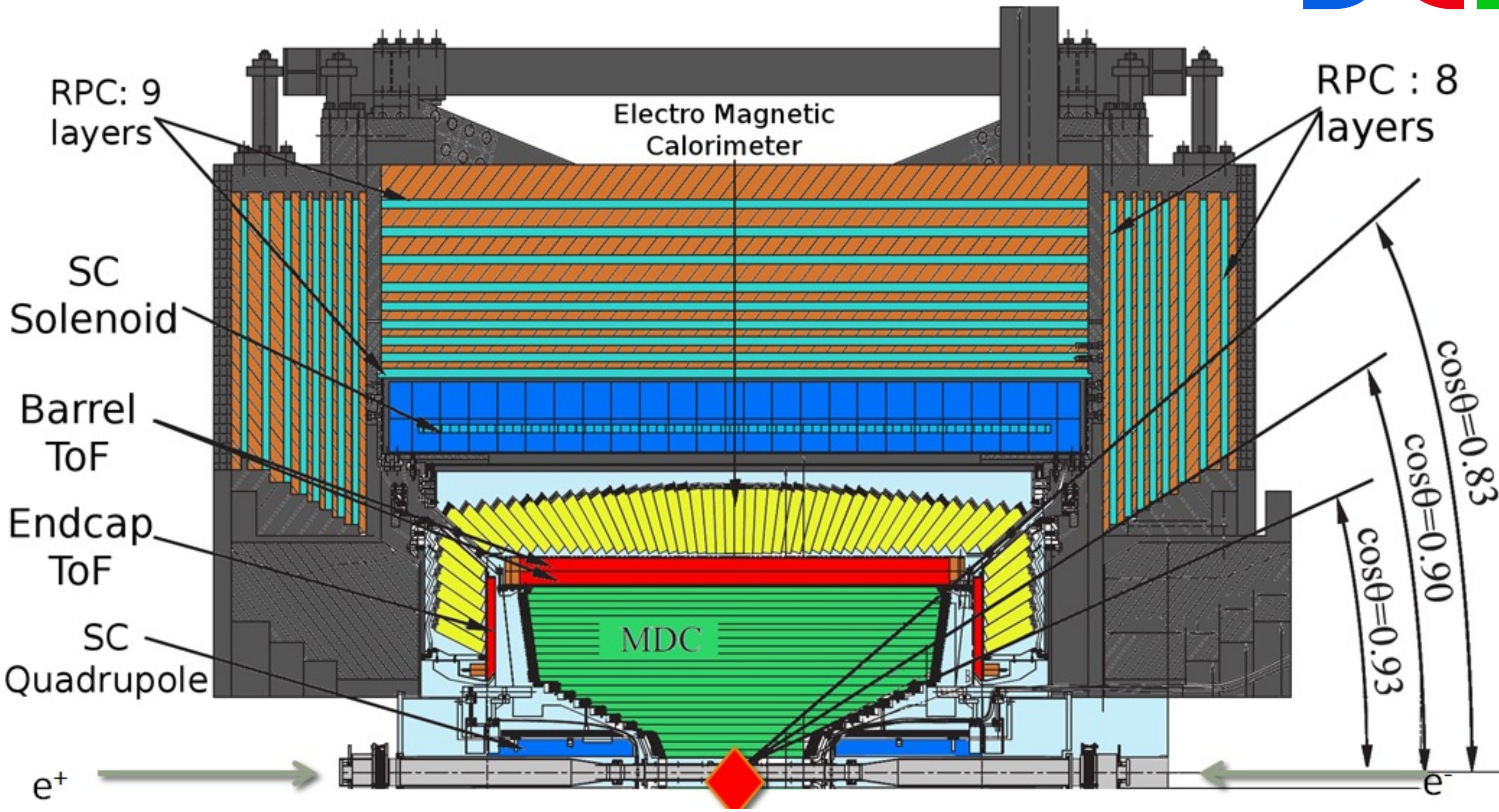
Happy 72.5th Birthday, Peter, and many more !

BACKUPS

Belle II Detector



BESIII Detector



BESIII Collaboration

Europe (18)

Germany(6): Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen, University of Münster

Italy(3): Ferrara University, INFN, University of Turin,

Netherlands(1):KVI/University of Groningen

Russia(2): Budker Institute of Nuclear Physics, Dubna JINR

Sweden(1): Uppsala University

Turkey (1): Turkish Accelerator Center Particle Factory Group

UK(3): University of Manchester, University of Oxford, University of Bristol

Poland(1): National Centre for Nuclear Research

Pakistan(2)

COMSATS Institute of Information Technology
University of the Punjab

India(1)

Indian Institute of Technology madras

China (54)

Beihang University, Central China Normal University, Central South University, China Center of Advanced Science and Technology, China University of Geosciences, Fudan University, Guangxi Normal University, Guangxi University, Hangzhou Normal University, Hebei University, Henan University, Henan Normal University, Henan University of Science and Technology, Henan University of Technology, Huangshan College, Hunan University, Hunan Normal University, Inner Mongolia University, Institute of High Energy Physics, Institute of Modern Physics, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University,Peking University, Qufu Normal University, Renmin University of China, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Normal University, Shandong University, handong University of Technology,Shanghai Jiao Tong University, Soochow University,South China Normal University, Southeast University, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xinyang Normal University, Yantai University , Yunnan University , Zhejiang University, Zhengzhou University

Thailand(1)

Suranaree University of Technology

Mongolia(1)

Institute of Physics and Technology

Korea(1)

Chung-Ang University

USA(3)

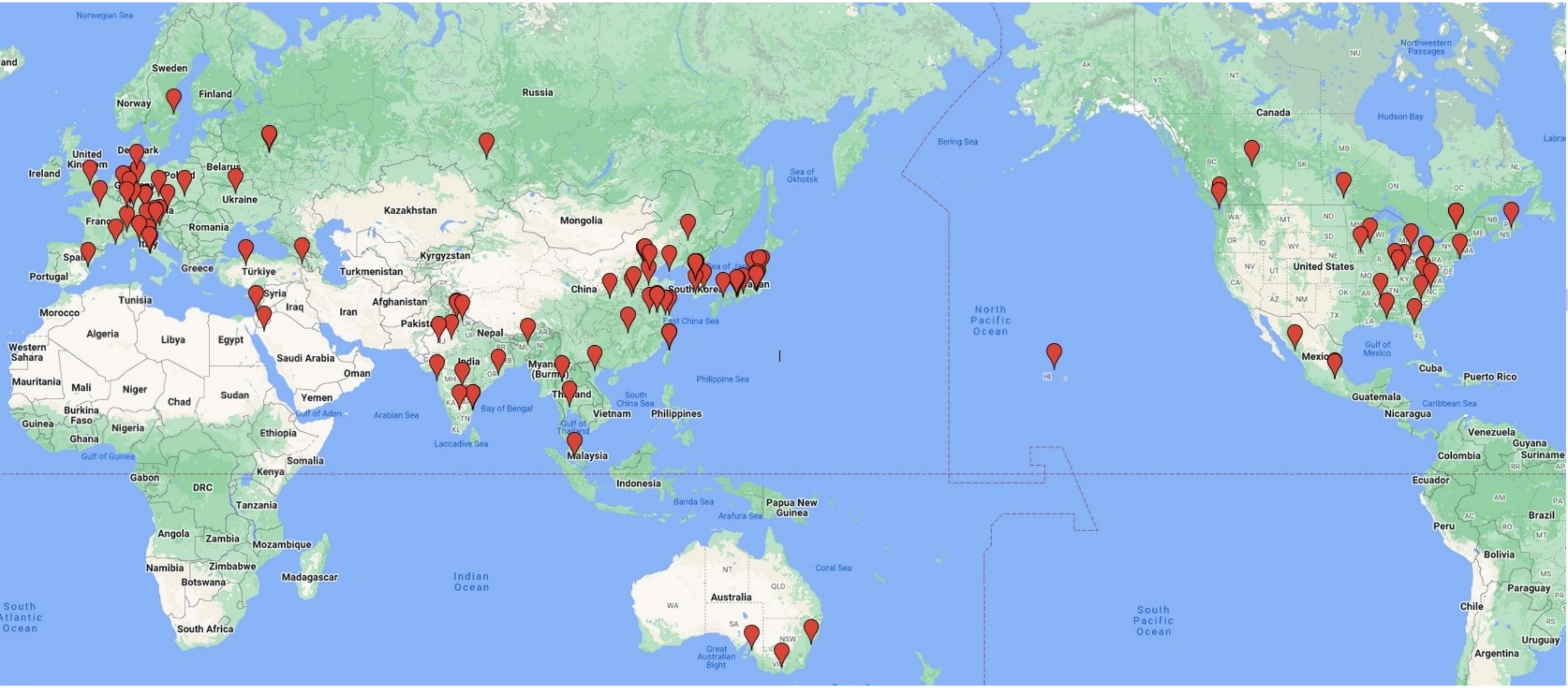
Carnegie Mellon University
Indiana University
University of Hawaii

Chile(1)

University of Tarapaca

>600 members
From 82 institutions in 16 countries

Belle II Collaboration Map



Charm Factories vs. B Factories

Charm Factories

- Charm threshold data using tagging:
  - Precision hadronic BFs
  - Leptonic and semileptonic "easy"
  - CP-tags for D^0 - D^{0bar} phases
- "XYZ" physics
- Precision tau mass
- No charm lifetimes
- Limited statistics for rare decays, D mixing, CPV
- No B physics

B Factories

- Large charm stats: good for rare, mixing , CPV, & lifetimes
- "Continuum charm tagging" for (semi-) leptonics works well !
  (but less efficient than threshold reconstruction…)
- And, of course, all of B physics !

SuperKEKB Paramters vs. KEKB

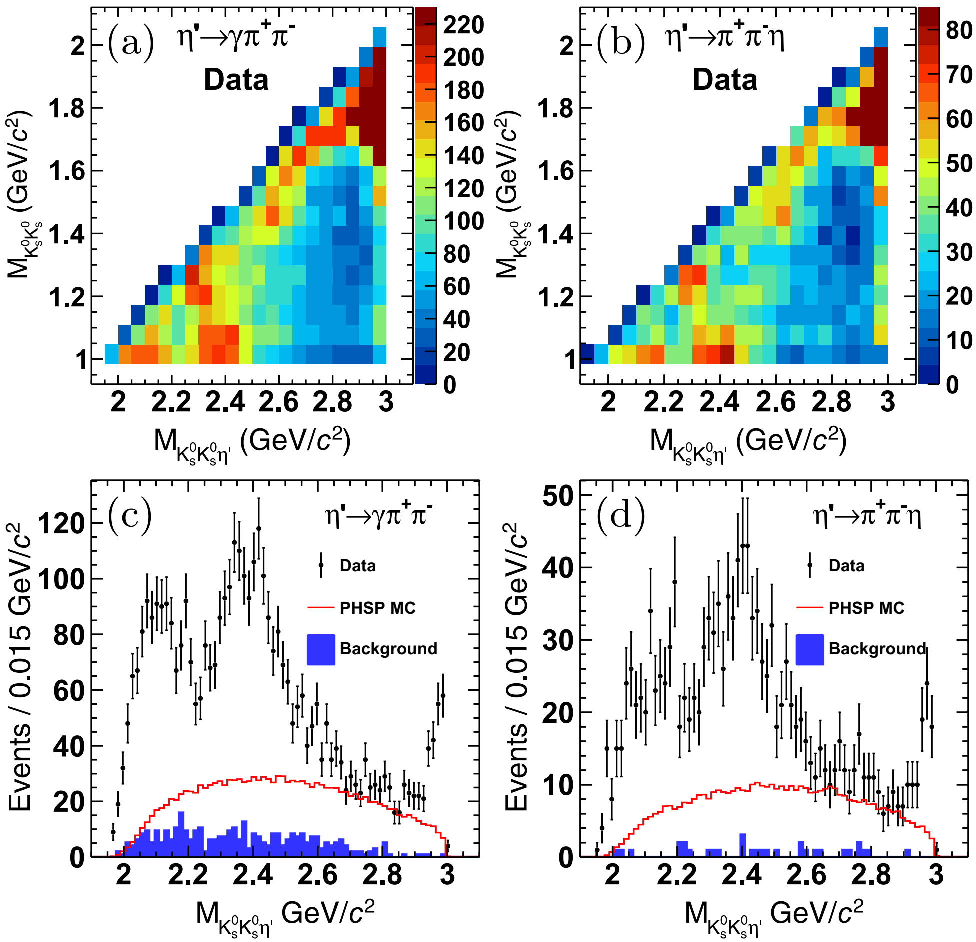
Table 1: Machine Parameters of KEKB and SuperKEKB. Values in parentheses for SuperKEKB denote parameters without intrabeam scattering. Note that horizontal emittance increases by 30% owing to intrabeam scattering in the LER. The KEKB parameters are those achieved at the crab crossing [2], where the effective crossing angle was 0. (*)Before the crab crossing, the luminosity of $1.76 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ was achieved at the half crossing angle of 11 mrad, where $\phi_{\mathrm{Piw}} \sim 1$ [6].

		KEKB		SuperKEKB		
		LER (e+)	HER (e-)	LER (e+)	HER (e-)	Units
Beam energy	E	3.5	8.0	4.0	7.007	GeV
Circumference	C	3016.262		3016.315		m
Half crossing angle	θ_x	0 $(11^{(*)})$		41.5		mrad
Piwinski angle	ϕ_{Piw}	0	0	24.6	19.3	rad
Horizontal emittance	ε_x	18	24	3.2 (1.9)	4.6 (4.4)	nm
Vertical emittance	ε_y	150	150	8.64	12.9	pm
Coupling		0.83	0.62	0.27	0.28	%
Beta function at IP	β_x^*/β_y^*	1200/5.9	1200/5.9	32/0.27	25/0.30	mm
Horizontal beam size	σ_x^*	147	170	10.1	10.7	μm
Vertical beam size	σ_y^*	940	940	48	62	nm
Horizontal betatron tune	ν_x	45.506	44.511	44.530	45.530	
Vertical betatron tune	ν_y	43.561	41.585	46.570	43.570	
Momentum compaction	α_p	3.3	3.4	3.20	4.55	10^{-4}
Energy spread	σ_ε	7.3	6.7	7.92(7.53)	6.37(6.30)	10^{-4}
Beam current	I	1.64	1.19	3.60	2.60	A
Number of bunches	n_b	1584		2500		
Particles/bunch	N	6.47	4.72	9.04	6.53	10^{10}
Energy loss/turn	U_0	1.64	3.48	1.76	2.43	MeV
Long. damping time	τ_z	21.5	23.2	22.8	29.0	msec
RF frequency	f_{RF}	508.9		508.9		MHz
Total cavity voltage	V_c	8.0	13.0	9.4	15.0	MV
Total beam power	P_b	$\sim$3	$\sim$4	8.3	7.5	MW
Synchrotron tune	ν_s	-0.0246	-0.0209	-0.0245	-0.0280	
Bunch length	σ_z	$\sim$7	$\sim$7	6.0 (4.7)	5.0 (4.9)	mm
Beam–beam parameter	ξ_x/ξ_y	0.127/0.129	0.102/0.090	0.0028/0.088	0.0012/0.081	
Luminosity	L	2.108×10^{34}		8×10^{35}		$\mathrm{cm}^{-2}\mathrm{s}^{-1}$
Integrated luminosity	$\int L$	1.041		50		ab^{-1}

Note: original design parameters…

Glueball Candidate

2024: A partial-wave analysis with a low background mode:
$J/\psi \to \gamma$ KS KS η' $\rightarrow$ ***Establishes*** $J^P = 0^-$



Alternate plot....

PRL 132, 181901 (2024)