Experimental Review on rare charm decays (Belle/BaBar/LHCb) and prospect at Belle II

Chengping Shen

Beihang University

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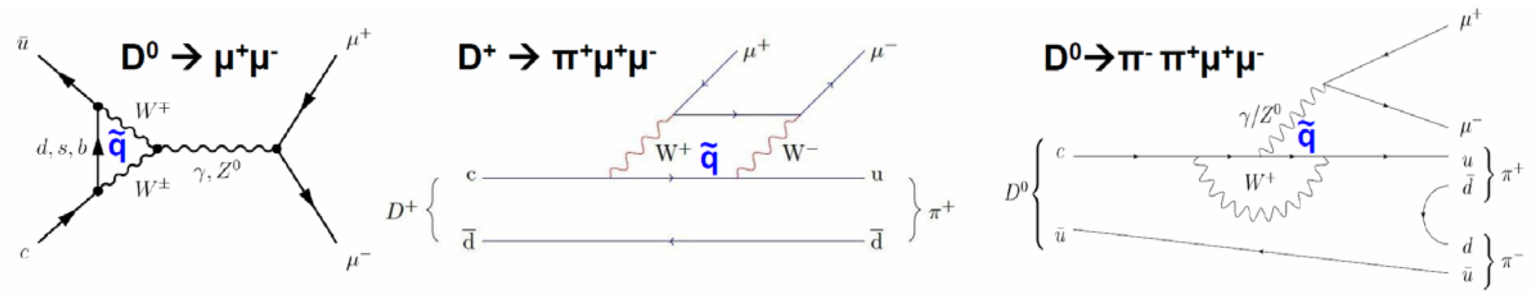
Motivation

- Flavor Changing Neutral Currents (FCNC) are suppresses in the Standard Model (SM), only possible via loops. Like:



- However, there are many compelling reasons to believe SM can not be the full story.
- Rare decays can be used for indirect searches of NP since they are suppresses or forbidden in SM and highly sensitive to NP effects.
- Charm provides an interesting test bed for NP as SM footprints in this sector are tiny owing to large GIM/CKM suppression

For theoretical review, please see Fajfer's talk below

Experimental requirements

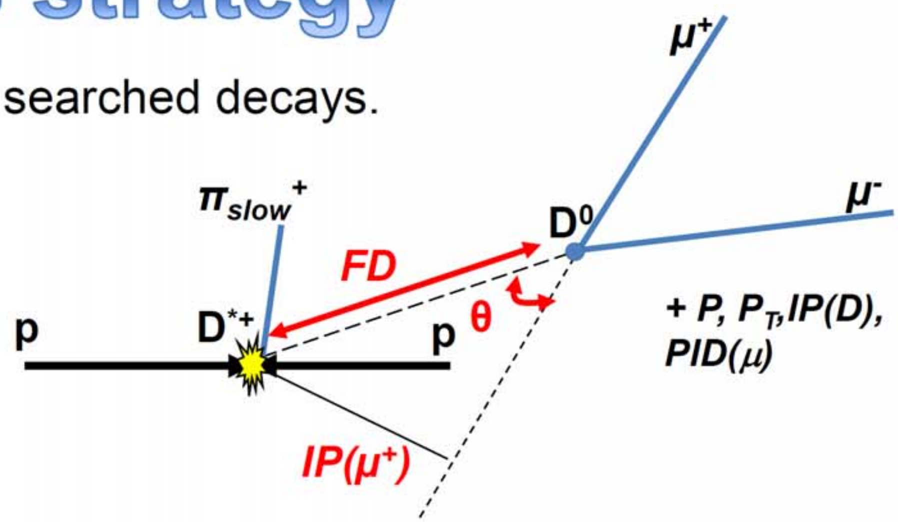
- Large samples of charm
- Good background rejection and high signal efficiency
  - excellent particle identification
  - large boost ➜ displaced vertex
  - excellent reconstruction of photons and neutral pions
  - hermeticity of detector

Overview of measurements of selected rare decays

Future estimation

General analysis strategy

- Selection using the typical features for the searched decays.



- Very rare means very high relative combinatorial background
  → Use Multivariate Analysis

- Another difficulty with charm decays: very high peaking backgrounds (Ex: $D \to \pi\pi > 10^6 \times D \to \mu\mu$)
  → Use particle identification to fight against $\pi \to \mu$ misID

- Normalized Measurements to help controlling the systematics

$$BF_{(signal)} = BF_{(norm)} \frac{\varepsilon_{(norm)}}{\varepsilon_{(signal)}} \frac{N_{(signal)}}{N_{(norm)}}$$

Ex. : $D^+ \to \pi^+\mu^+\mu^-$ and $D^+ \to \pi^+ \varphi(\mu^+\mu^-)$

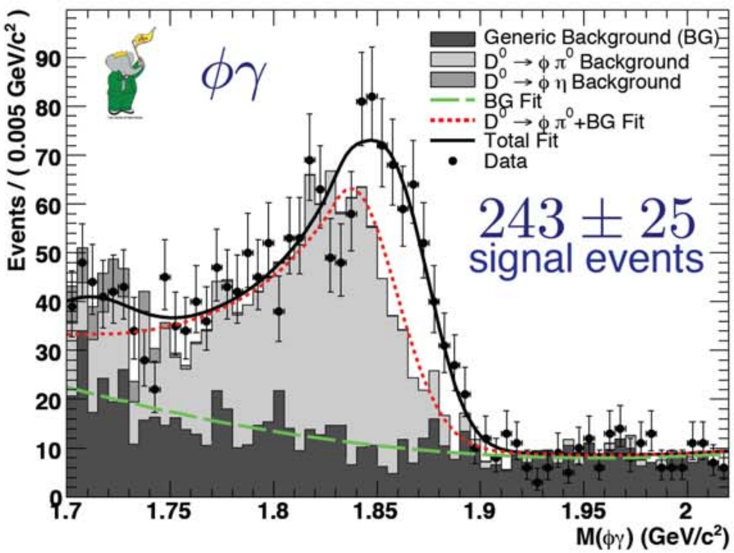
- Blind analyses, Upper limits from the CLs method *[A. Read, J. Phys. G28 (2002)]*

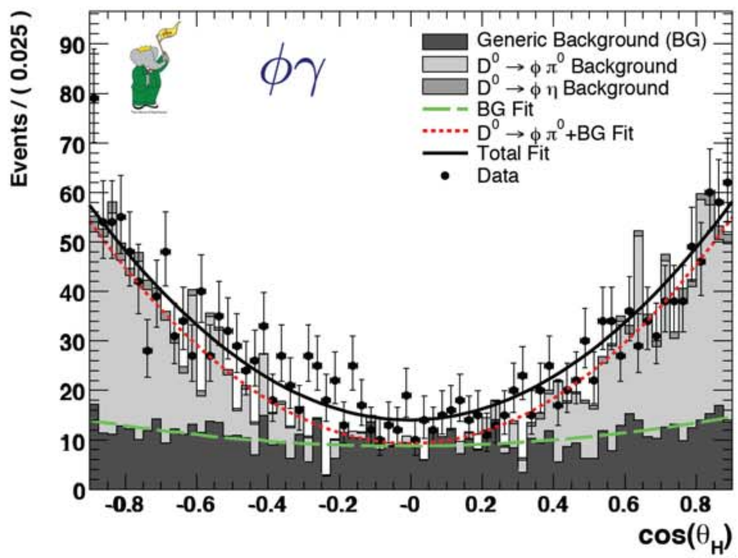
$D^0 \to \phi\gamma$

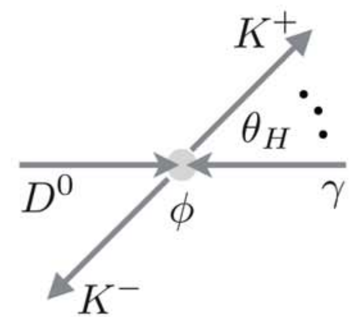
Belle $78\ fb^{-1}$ @ $\Upsilon(4S)$
PRL92,101803(2004)
$\mathcal{B}(D^0 \to \phi\gamma) = [2.60^{+0.70+0.15}_{-0.61-0.17}] \times 10^{-5}$

BaBar $387\ fb^{-1}$ @ $\Upsilon(4S)$
PRD78,071101(2008)

- Use a D* tag
- Large contamination from $D^0 \to V\pi^0,\ hh'\pi^0$
  - π^0 veto ➽ reject all γ's that can be used for a good π^0
  - extract signal from 2-dimensional fit to $m(V\gamma)$ and $\cos(\theta_H)$





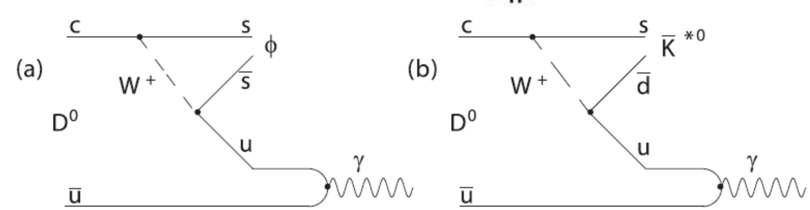


$$\mathcal{B}(D^0 \to \phi\gamma) = (2.78 \pm 0.30 \pm 0.27) \times 10^{-5},$$

$$\mathcal{B}(D^0 \to \bar{K}^{*0}\gamma) = (3.28 \pm 0.20 \pm 0.27) \times 10^{-4}.$$

Dominated by Long Distance effects.

Not a New Physics search.

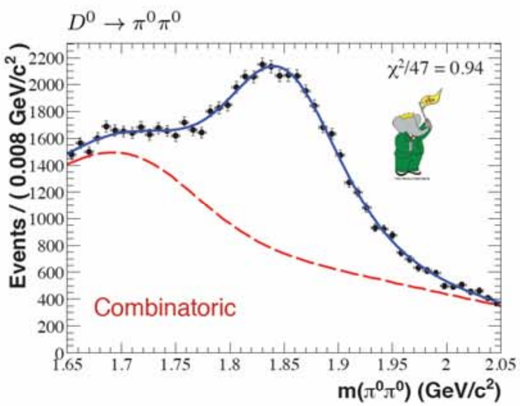


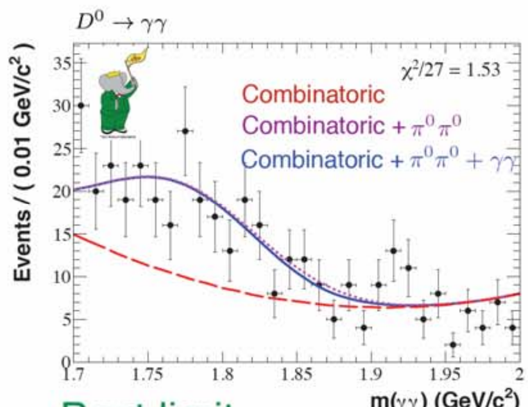
Cabibbo-suppressed

$D^0 \to \gamma\gamma$

BaBar $470 fb^{-1}$@$\Upsilon(4S)$
PRD85,091107(2012)

- Use a D* tag
- Normalisation to $D^0 \to K_S^0\pi^0$
- Measure main background as well $D^0 \to \pi^0\pi^0$
  - π^0 veto ➻ reject all γ's that can be used for a good π^0



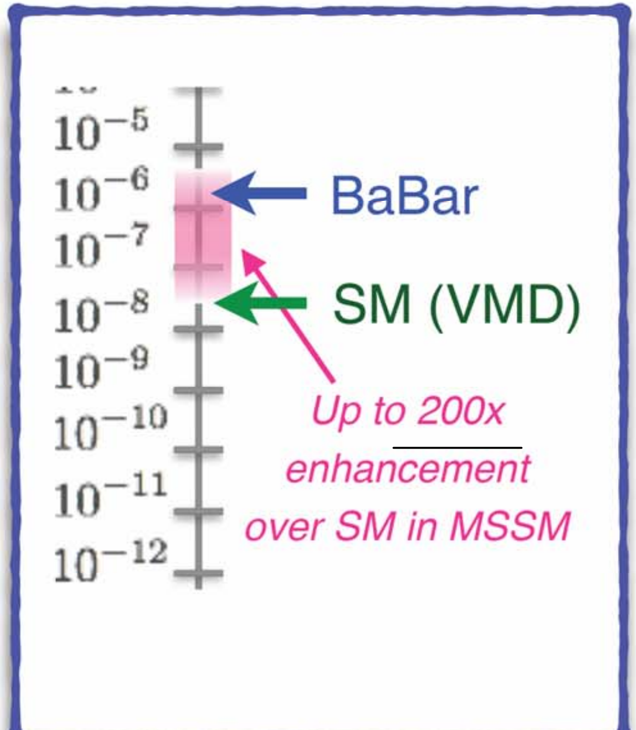


Best limit

$\mathcal{B}_{D^0\to\pi^0\pi^0} = (8.4 \pm 0.1 \pm 0.3) \cdot 10^{-4}$

$\mathcal{B}_{D^0\to\gamma\gamma} < 2.2 \cdot 10^{-6}$ @ 90% $C.L.$

BESIII $2.9\ fb^{-1}$ @ $\psi(3770)$
$\mathcal{B}_{D^0\to\gamma\gamma} < 4.7 \cdot 10^{-6}$ @ 90% $C.L.$
arXiv:1208.4744

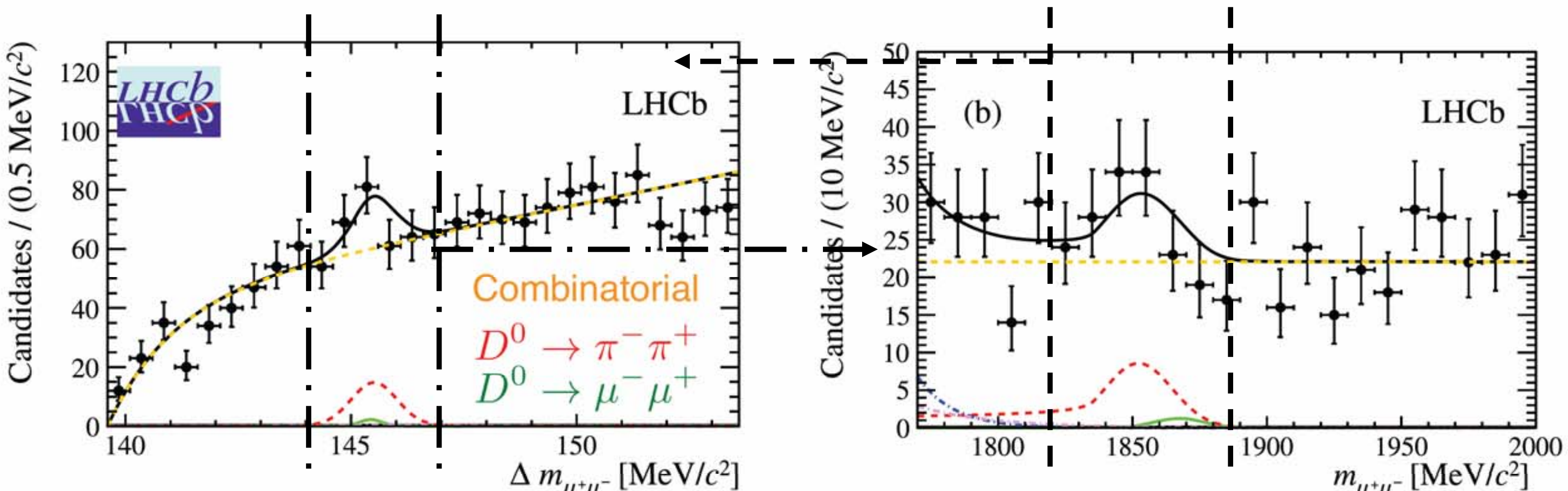


$$B(D^0 \to \gamma\gamma)^{(\mathrm{VMD})} \simeq (3.5^{+4.0}_{-2.6}) \times 10^{-8}.$$

$D^0 \to \mu^- \mu^+$

PLB 725, 15 (2013)
0.9 fb^{-1} @ 7 TeV

- Use a D* tag
- Normalization to $D^0 \to \pi^- \pi^+$
  - main physics background as well (double $\pi^\pm \to \mu^\pm$ mis-ID)
  - single $\pi^\pm \to \mu^\pm$ mis-ID probability estimated with $D^0 \to K^- \pi^+$
    - Double mis-ID $p(D^0 \to \pi^- \pi^+ \to \mu^- \mu^+) = (27.43 \pm 3.4 \pm 2.0) \times 10^{-6}$
  - Boosted-Decision-Tree trained to suppress combinatorial bkg.

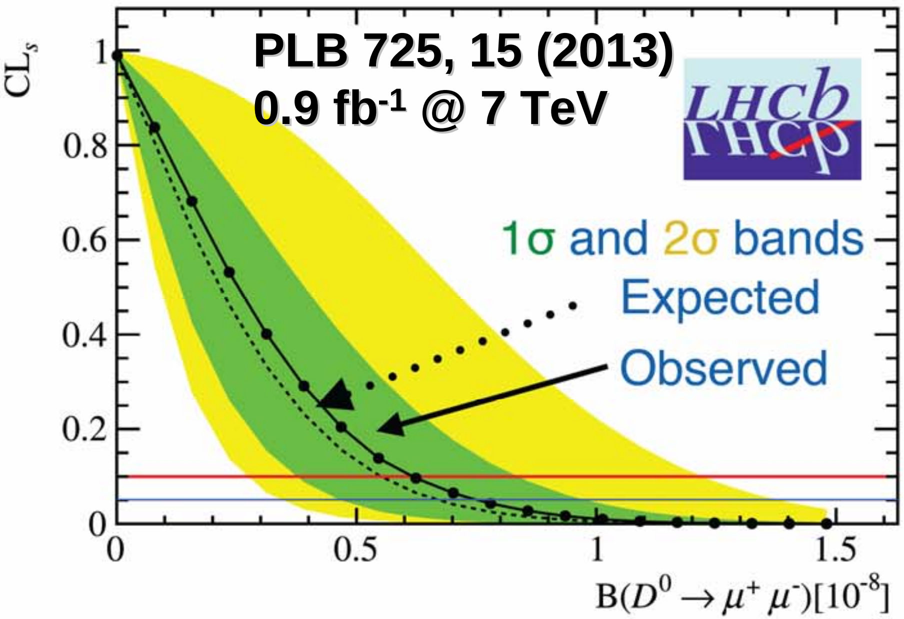


$\Delta m_{h^+h^{(\prime)-}} \equiv m_{h^+h^{(\prime)-}\pi^+} - m_{h^+h^{(\prime)-}}$

No significant signal is observed

$D^0 \to \mu^- \mu^+$

U.L. set using CLs method



$\mathcal{B}(D^0 \to \mu^+\mu^-) < 6.2\ (7.6) \times 10^{-9}$ at 90% (95%) CL.

World's best

SM: 6x10^{-11}

Experiments still ~100xSM and ~10xNP predictions

BaBar PRD86,032001(2012)
$B(D^0 \to \mu^+ \mu^-)$=[0.6, 8.1] $\times 10^{-7}$

Upper Limits @ 90% C.L.

Belle PRD81,091102(2010)
$\mathcal{B}(D^0 \to \mu^-\mu^+) < 1.4 \times 10^{-7}$

CDF PRD82,091105(2010)
$\mathcal{B}(D^0 \to \mu^-\mu^+) < 2.1 \times 10^{-7}$

CMS PAS BPH-11-017
$\mathcal{B}(D^0 \to \mu^-\mu^+) < 5.4 \times 10^{-7}$

LHCb Upgrade
$50\ fb^{-1}$ @ $14\ TeV (2 \times \sigma_{c\bar{c}})$
$\mathcal{B}(D^0 \to \mu^-\mu^+) < 5 \times 10^{-10}$

$D^0 \to \ell^- \ell^+$

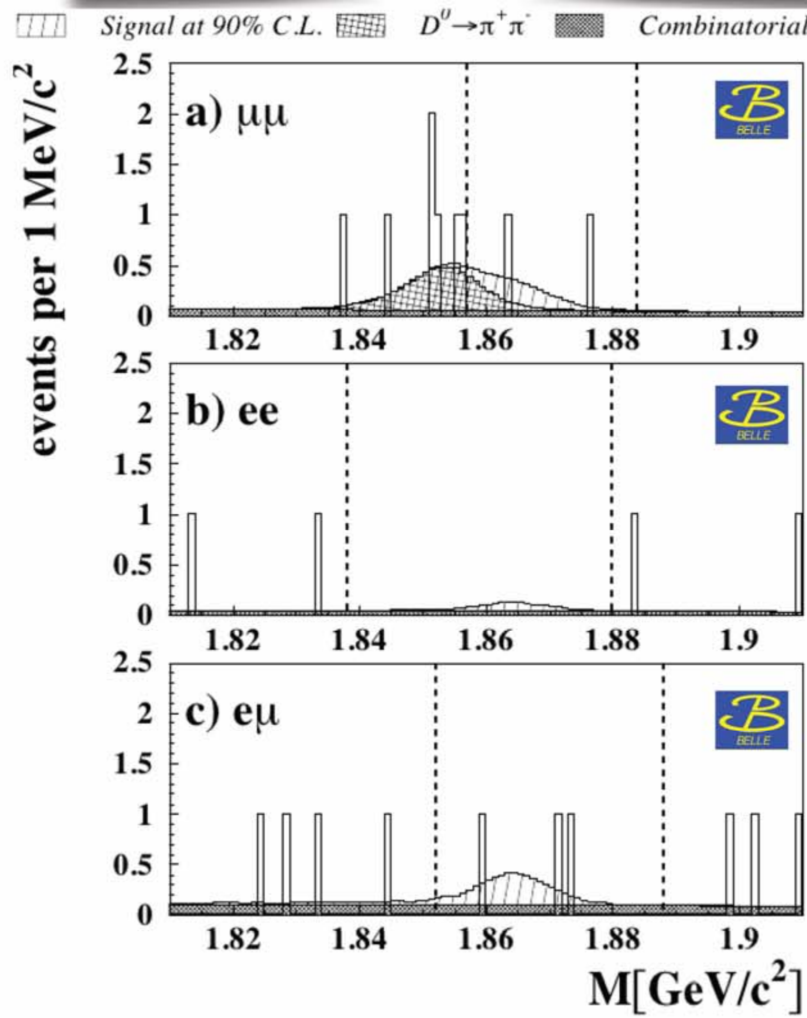
Belle 660 fb^{-1} @ $\Upsilon(4S)$
PRD81,091102(2010)

- Use a D* tag
- Normalization to $D^0 \to \pi^- \pi^+$
  - main physics background as well
  - mis-ID probability estimated with $D^0 \to K^- \pi^+$

U.L. @ 90% C.L.

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

World's best



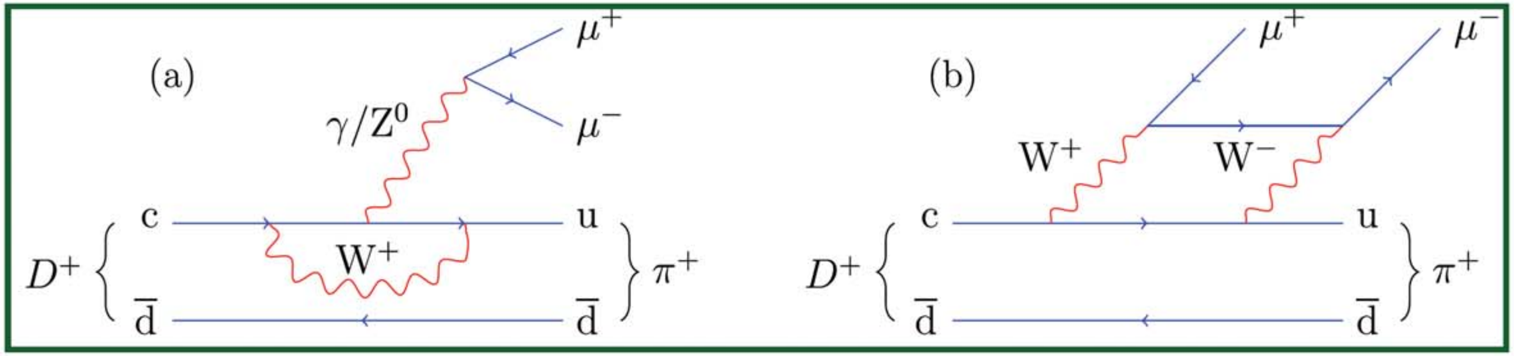
BaBar PRD86,032001(2012)
$B(D^0 \to e^+e^-) < 1.7 \times 10^{-7}$
$B(D^0 \to e\mu) < 3.3 \times 10^{-7}$

$D^+_{(s)} \to \pi^+\mu^-\mu^+$

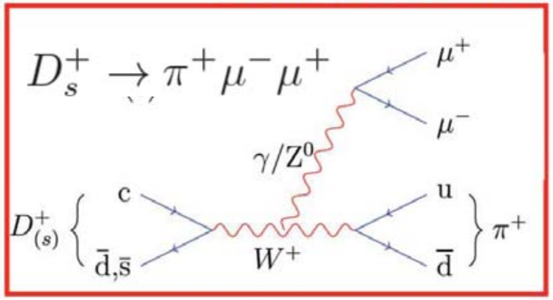
LHCb $1\ fb^{-1}$ @ $7\ TeV$
PLB724,203(2013)

- Include $D_s^+ \to \pi^+\mu^-\mu^+$ (not FCNC decay) to control (normalize) possible weak annihilation contributions in $D^+ \to \pi^+\mu^-\mu^+$ decays

FCNC



weak annihilation



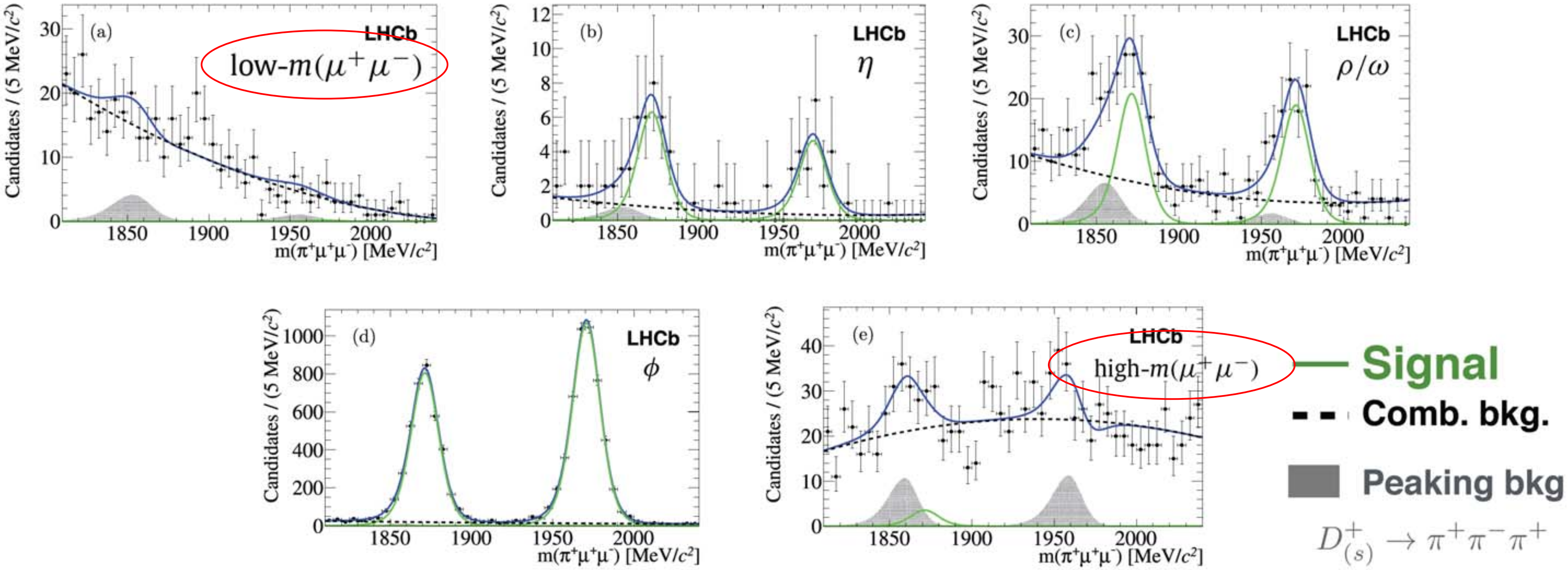
- Branching ratios dominated by long distance (**LD**) effects, via intermediate states
- The solution adopted by present searches is to measure BF's far from the resonances

- SM short distance (SD) contributions predict tiny BF's
- New physics can enhance the SD contributions. Ex.: R-Parity Violation SUSY

$D^+_{(s)} \to \pi^+ \mu^- \mu^+$

LHCb $1\ fb^{-1}$ @ $7\ TeV$
PLB724,203(2013)

- Same approach used as for $D^0 \to \mu^- \mu^+$
- Use $D^+_{(s)} \to \pi^+ \phi(\to \mu^- \mu^+)$ as a reference channel
  - serves as signal proxy to optimize the selection (BDT & muon ID)
- Extract signal in 5 $m(\mu^- \mu^+)$ bins



$D^+_{(s)} \to \pi^+ \mu^- \mu^+$

LHCb $1\ fb^{-1}$ @ $7\ TeV$
PLB724,203(2013)

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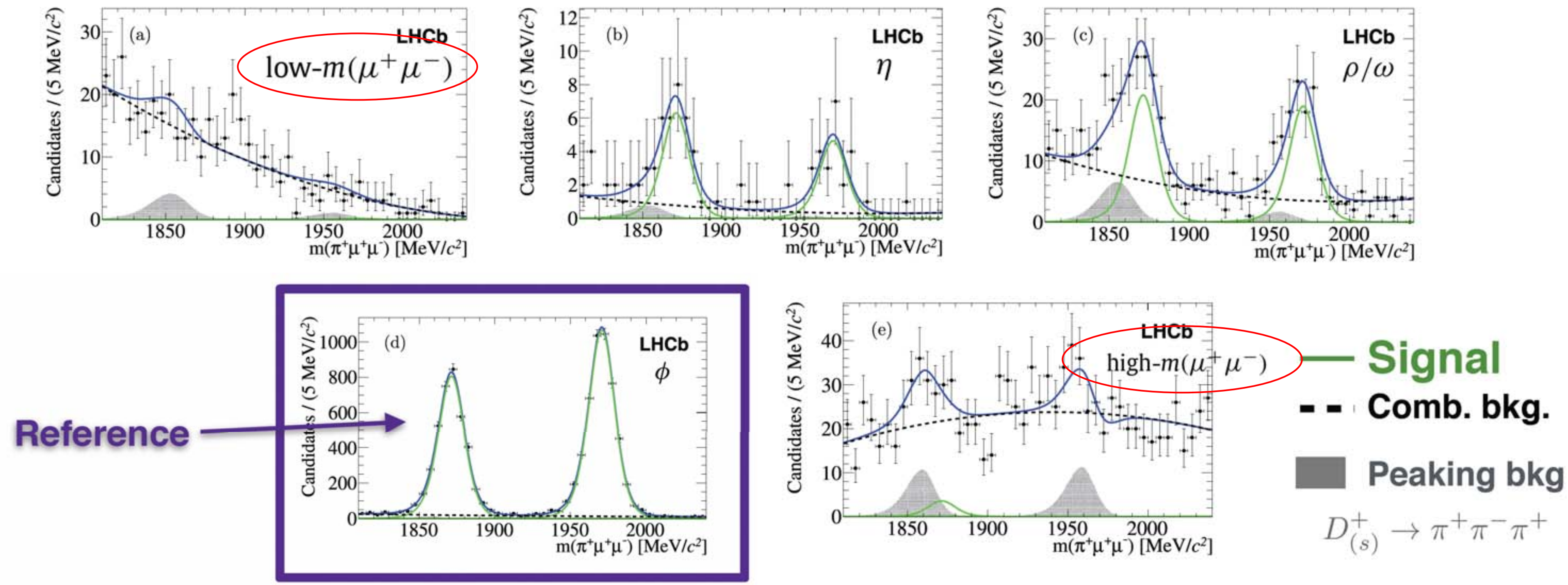

$D^+_{(s)} \to \pi^+\mu^-\mu^+$

LHCb 1 fb^{-1} @ 7 TeV
PLB724,203(2013)

- Same approach used as for $D^0 \to \mu^-\mu^+$
- Use $D^+_{(s)} \to \pi^+\phi(\to \mu^-\mu^+)$ as a reference channel
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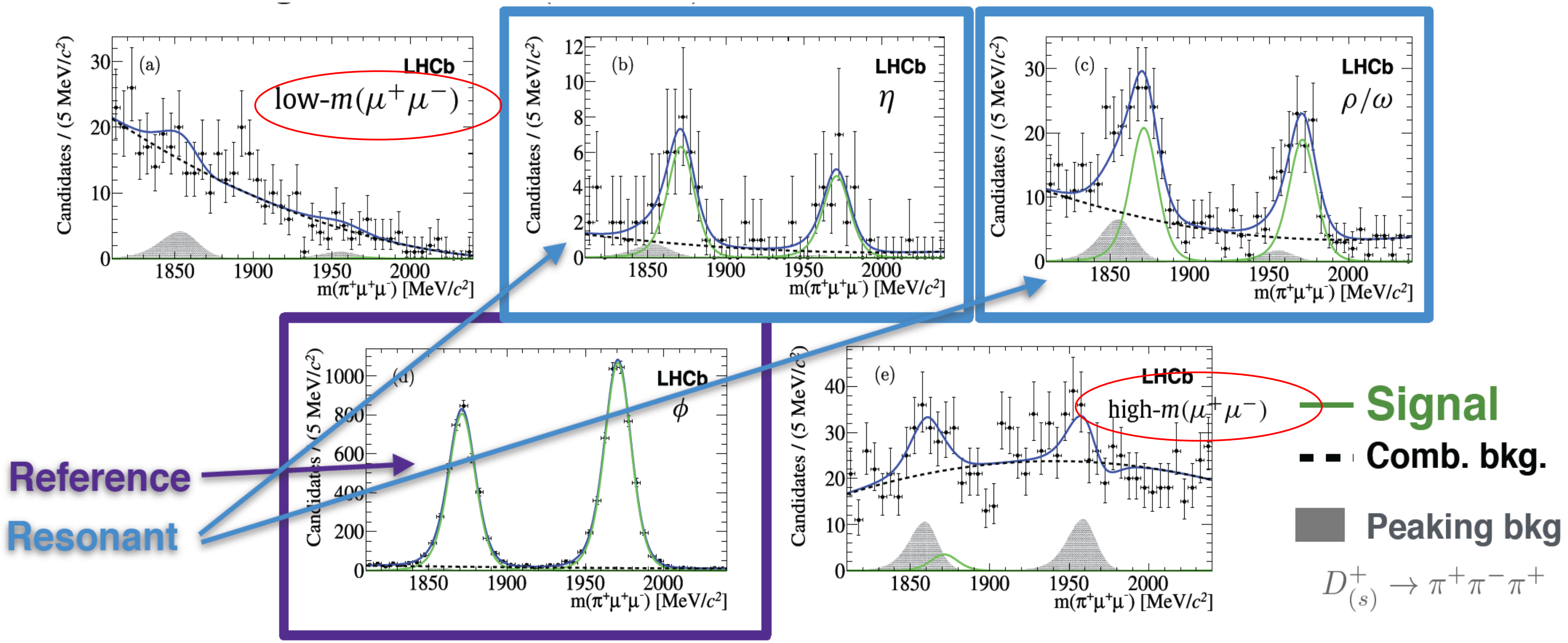

$D^+_{(s)} \to \pi^+ \mu^- \mu^+$

LHCb $1\ fb^{-1}$ @ $7\ TeV$
PLB724,203(2013)

- Same approach used as for $D^0 \to \mu^- \mu^+$
- Use $D^+_{(s)} \to \pi^+ \phi(\to \mu^- \mu^+)$ as a reference channel
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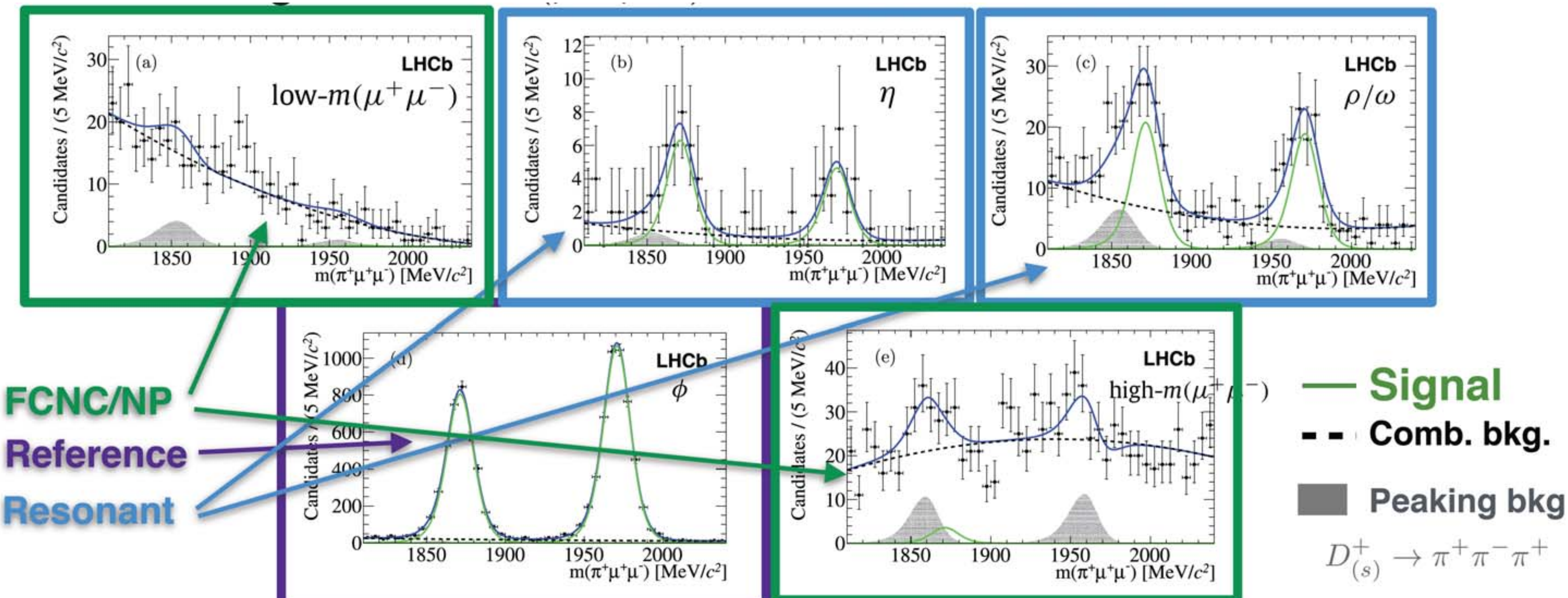


$D^+_{(s)} \to \pi^+ \mu^- \mu^+$

LHCb $1\ fb^{-1}$ @ $7\ TeV$
PLB724,203(2013)

- S
- U
  - uon ID)
- E

No signal observed
in the non-resonant regions

background
hypothesis

Decay	Bin	90% [$\times 10^{-8}$]	95% [$\times 10^{-8}$]	p-value
$D^+ \to \pi^+\mu^+\mu^-$	low-$m(\mu^+\mu^-)$	2.0	2.5	0.74
	high-$m(\mu^+\mu^-)$	2.6	2.9	0.42
	Total	7.3	8.3	0.42
$D^+_s \to \pi^+\mu^+\mu^-$	low-$m(\mu^+\mu^-)$	6.9	7.7	0.78
	high-$m(\mu^+\mu^-)$	16.0	18.6	0.41
	Total	41.0	47.7	0.42

World's best, 50-100x better than BaBar and D0

FC
Re
Re

Signal
Comb. bkg.
Peaking bkg $\to \pi^+\pi^-\pi^+$

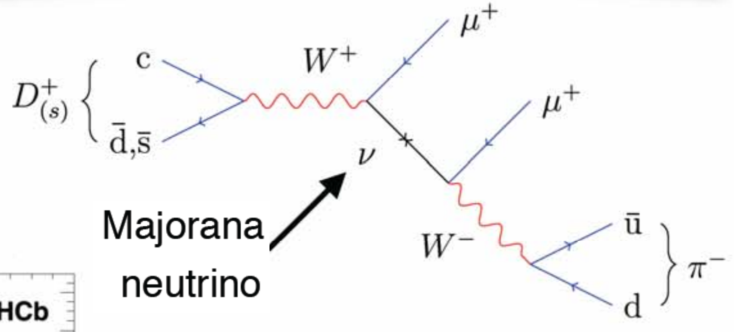
Still above the highest NP predictions $\mathcal{O}(10^{-8})$

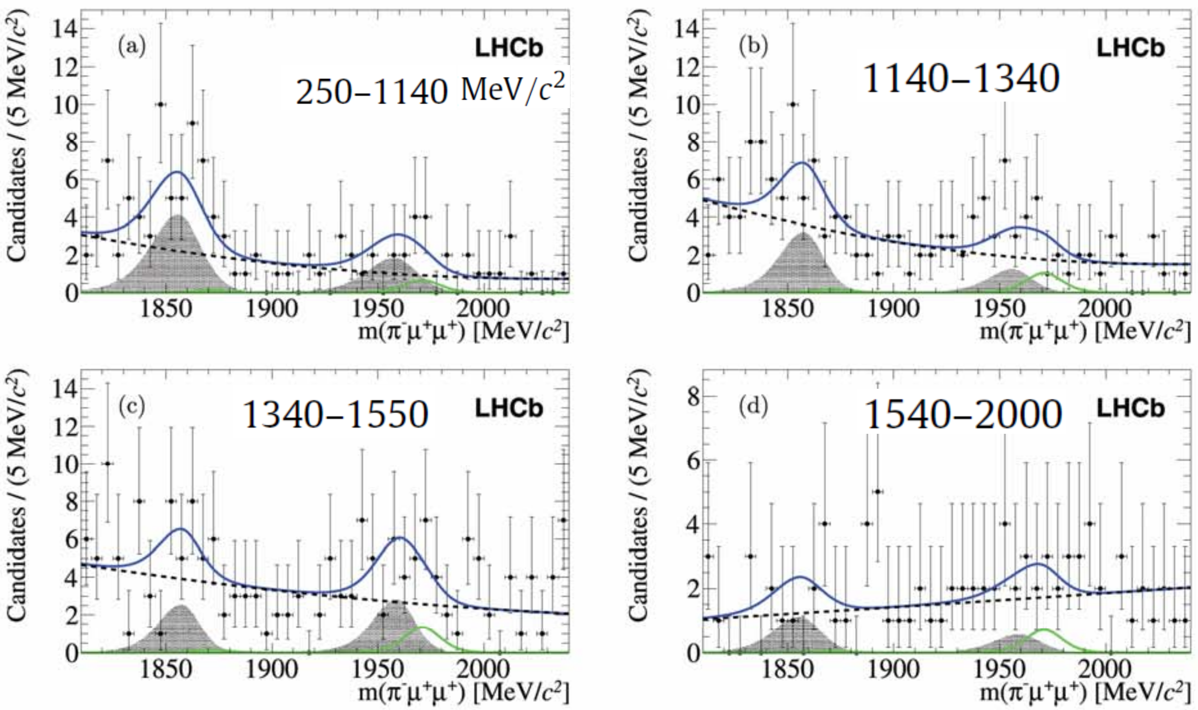
- $D_{(s)}^+ \to K^+\mu^+\mu^-$ **on going activities**

$D^+_{(s)} \to \pi^-\mu^+\mu^+$

LHCb $1\ fb^{-1}$ @ $7\ TeV$
PLB724,203(2013)

- Lepton Number Violating process
- extract signal in 4 bins of $m(\pi\mu)$
- same approach as $D^+_{(s)} \to \pi^+\mu^-\mu^+$





— Signal - - Comb. bkg. Peaking bkg $D^+_{(s)} \to \pi^+\pi^-\pi^+$

U.L. @ 90% C.L.

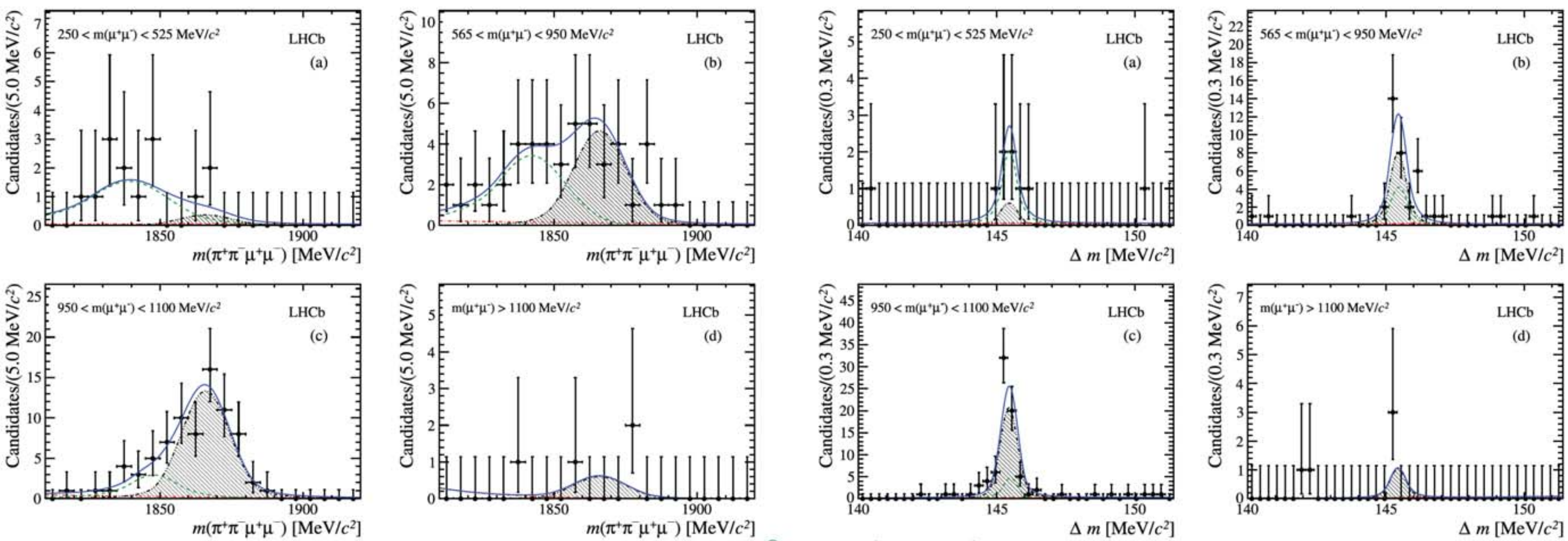
$$\mathcal{B}(D^+ \to \pi^-\mu^+\mu^+) < 2.2 \times 10^{-8}$$
$$\mathcal{B}(D^+_s \to \pi^-\mu^+\mu^+) < 12 \times 10^{-8}$$

Two orders of magnitude below $h^-e^+e^+$ modes studied by BaBar and CLEO-c

$D^0 \to \pi^-\pi^+\mu^-\mu^+$

LHCb 1 fb^{-1} @ 7 TeV
PLB728,234(2014)

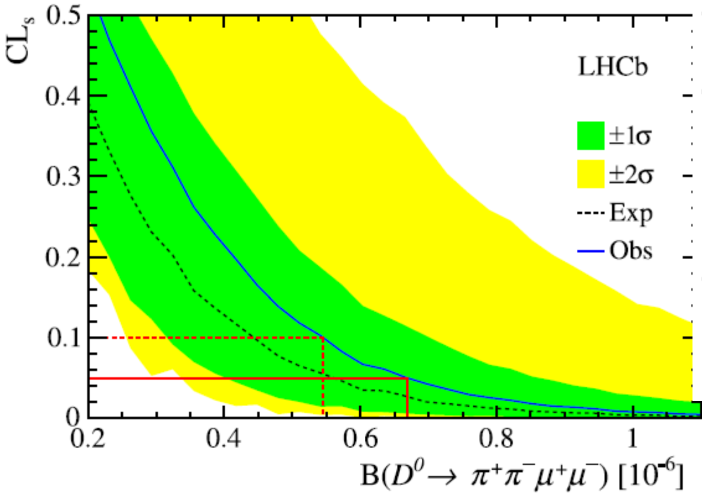
- Essentially the same approach as for $D^+_{(s)} \to \pi^+\mu^-\mu^+$
- Use a D* tag (cleans up the sample, but eff. x 1/10)
- Use $D^0 \to \pi^+\pi^-\phi(\to \mu^-\mu^+)$ as a reference channel
  - only 100 events expected (lower eff., $\mathcal{B} \sim 5 \times 10^{-7}$, D* x-section)
- Dominant background from $D^0 \to \pi^+\pi^-\pi^+\pi^-$



Comb. bkg.   Peaking bkg. $D^0 \to \pi^+\pi^-\pi^+\pi^-$ Signal

No signal observed in the non-resonant regions

Range description	$m(\mu^+\mu^-)$ [MeV/c^2]	$D^0 \to \pi^+\pi^-\mu^+\mu^-$ yield
low-$m(\mu^+\mu^-)$	250–525	2 ± 2
ρ/ω	565–950	23 ± 6
ϕ	950–1100	63 ± 10
high-$m(\mu^+\mu^-)$	> 1100	3 ± 2



Region	U.L. @ 90% [$\times 10^{-7}$]
low-$m(\mu^+\mu^-)$	2.3
high-$m(\mu^+\mu^-)$	1.0
Total	5.5

World's best

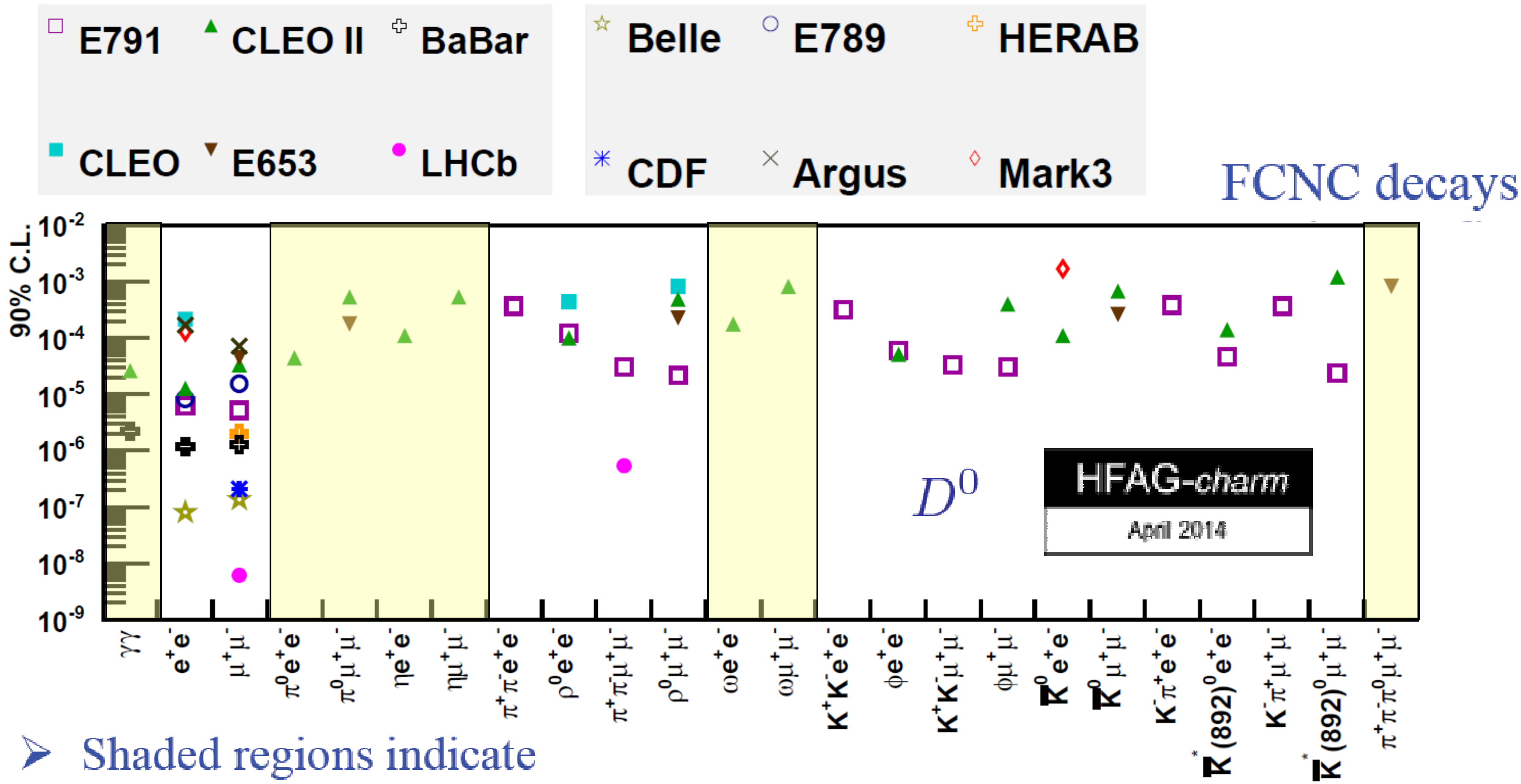
SM: (1-3) $\times 10^{-9}$

Still 1 or 2 order of magnitude above NP predictions

- $D^0 \to K^-K^+\mu^+\mu^-$, $D^0 \to K^+\pi^-\mu^+\mu^-$ **on going activities**

+ Many more

- references and limits of all rare decay searches can be found at the HFAG web-page: http://www.slac.stanford.edu/xorg/hfag/charm/April14/Rare/rare_charm.html



- Shaded regions indicate the decays with a γ or π^0, where Belle II will have an edge

+ Many more

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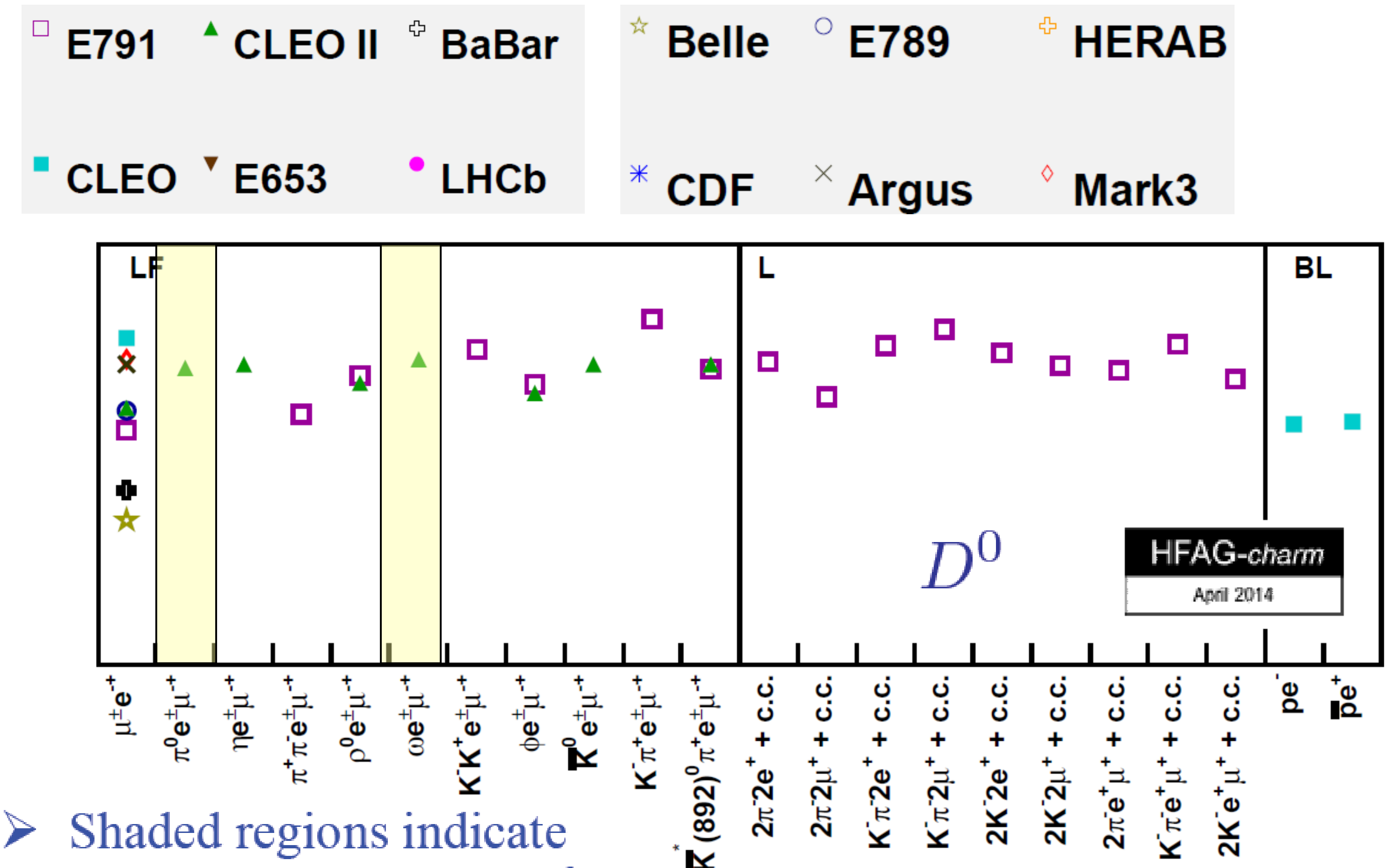

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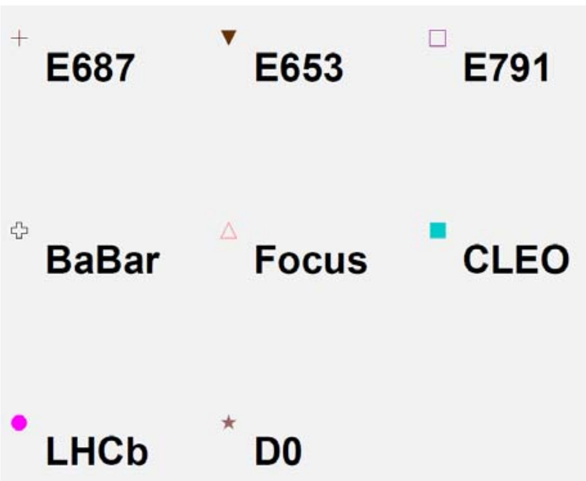

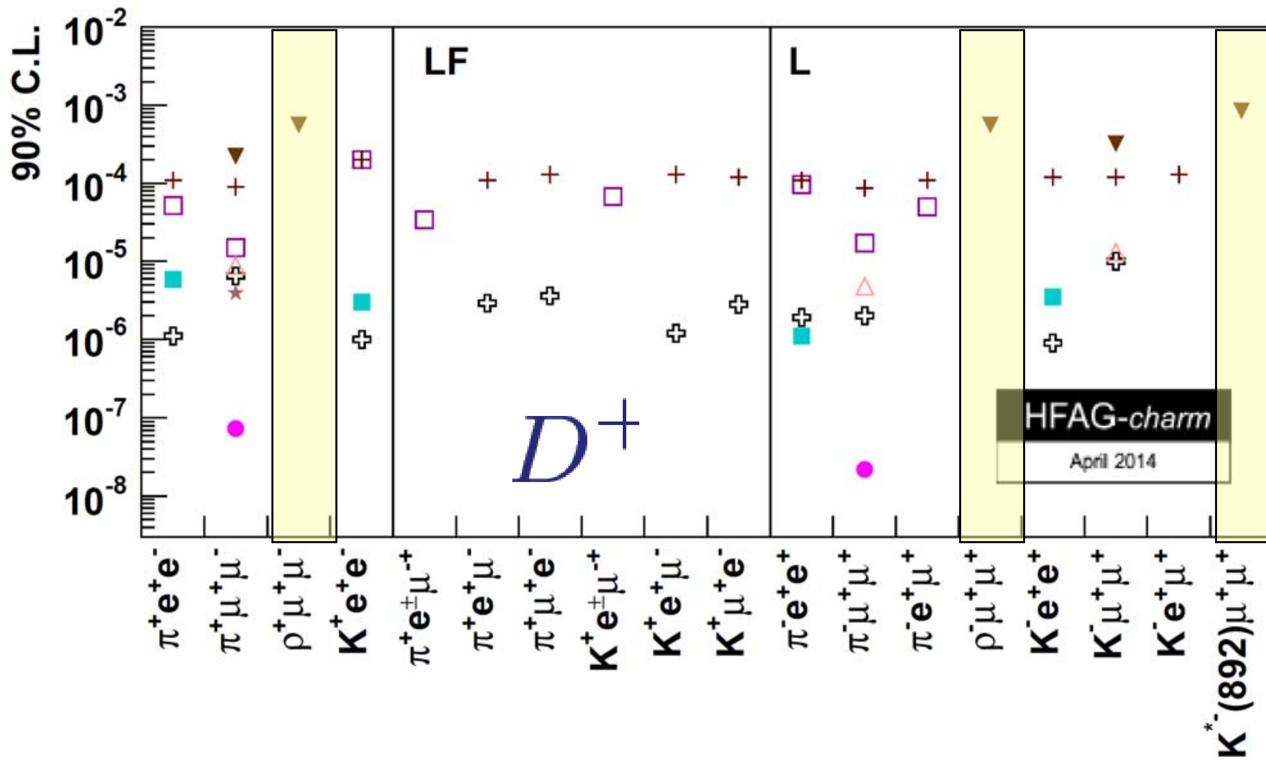

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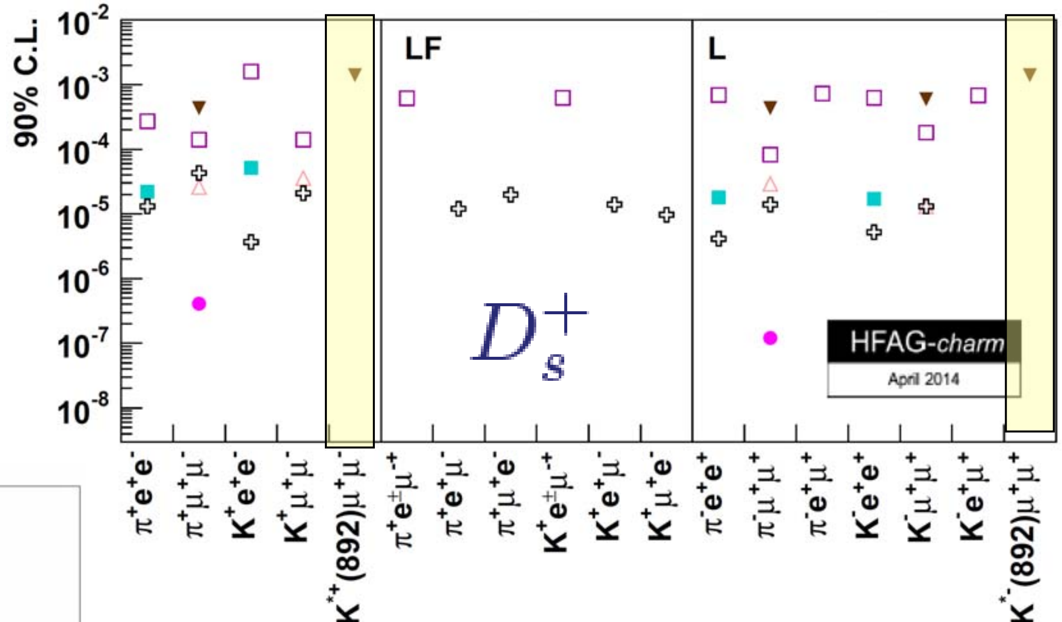
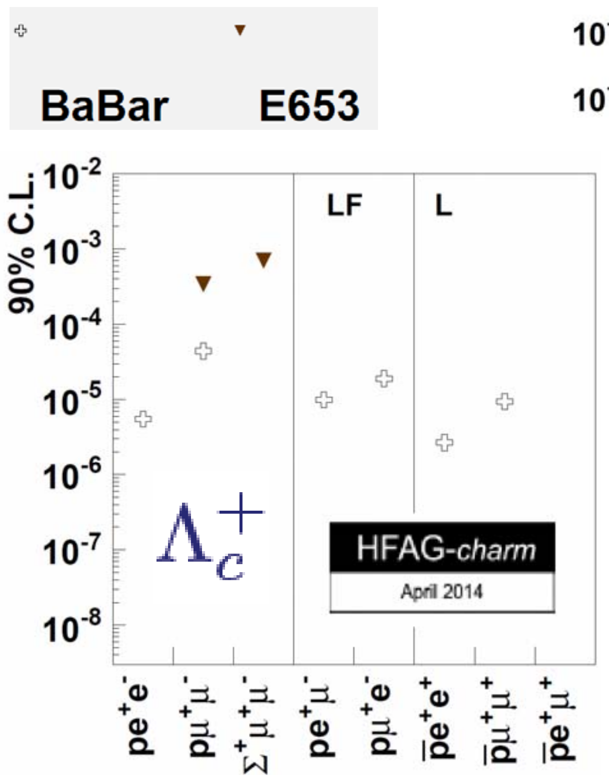
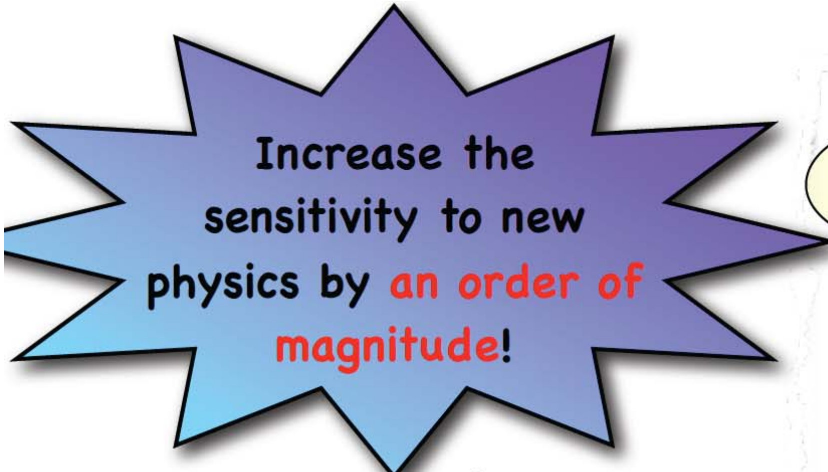


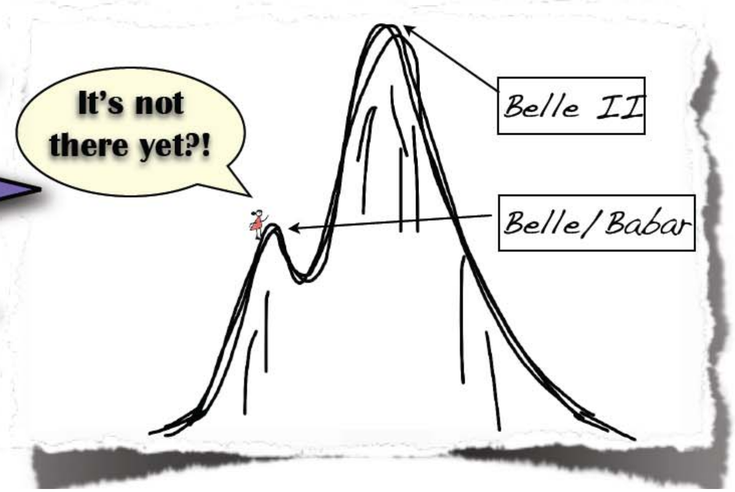


➤ Shaded regions indicate the decays with a γ or π^0, where Belle II will have an edge

we need to improve the sensitivity



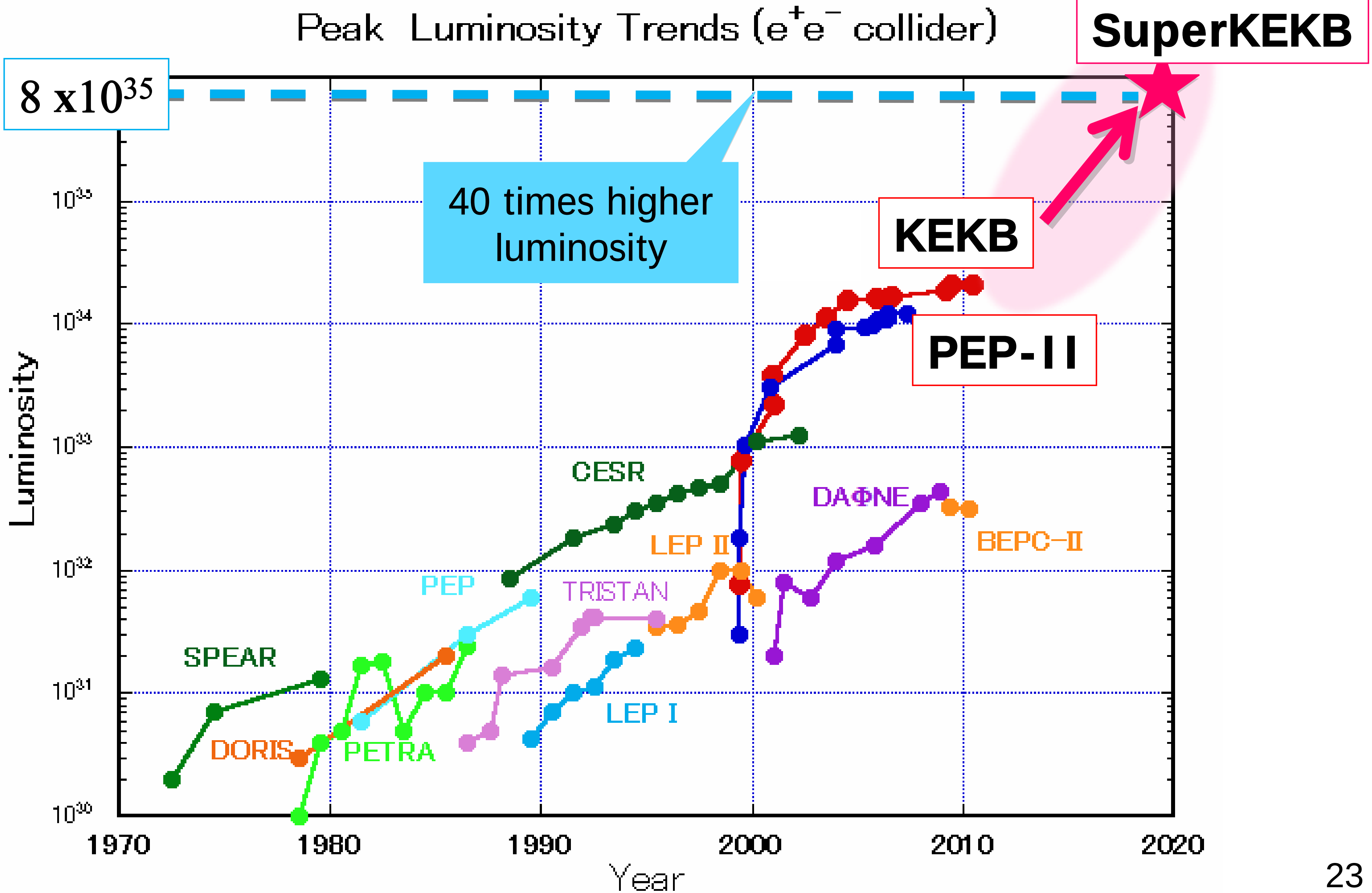
SuperKEKB/Belle II



➡ B Factory advantages over hadron collider detectors:

- ☆ clean event environment
- high trigger efficiency
- ☆ high-efficiency detection of neutrals (γ, π^0, η, η', ...)
- many control samples to study systematics
- good kinematic resolution (Dalitz plots analysis)
- missing energy and missing mass analysis are straightforward

Need O(100x) more data →Next generation B-factories



High-Luminosity Asymmetric B Factory

- Target luminosity is $\mathscr{L}$ = 8x10^{35} cm^{-2}s^{-1} (x40 w.r.t. BELLE)
- Achievable in the *nano-beam scheme* (P. Raimondi for SuperB)
  - double beam currents
  - squeeze beams @ IP by 1/20

$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{y\pm}}{\beta_{y\pm}^*}\left(\frac{R_L}{R_{\xi_y}}\right)$$

Lorentz factor

beam current

beam-beam parameter

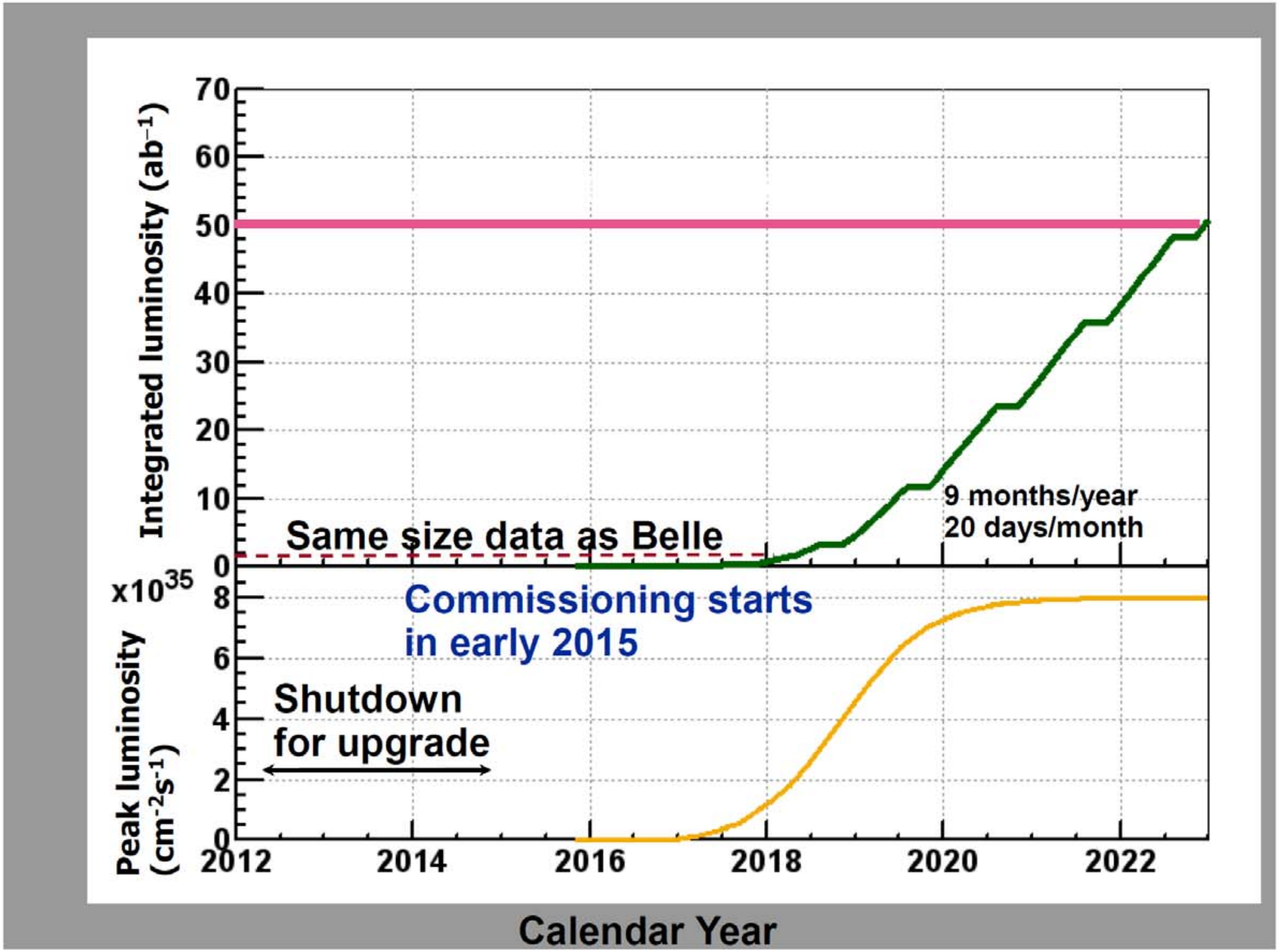
geometrical reduction factors

beam aspect ratio at the IP

vertical beta-function at the IP

parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
beam energy	E_b	3.5	8	4	7	GeV
CM boost	$\beta\gamma$	0.425		0.28		
half crossing angle	φ	11		41.5		mrad
horizontal emittance	ε_x	18	24	3.2	4.6	nm
emittance ratio	κ	0.88	0.66	0.37	0.40	%
beta-function at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam parameter	ξ_y	129	90	0.0881	0.0807	
beam size at IP	σ_x^*/σ_y^*	100/2		10/0.059		μm
Luminosity	$\mathscr{L}$	2.1x10		8x10^{35}		cm^{-2}s^{-1}

SuperKEKB luminosity projection



- Aim to reach 50 ab^{-1} by the end of 2022

D^0 Mode	BEST (90% C.L.)	BESIII ($20\ fb^{-1}$)	Belle II ($50\ ab^{-1}$)
$\gamma\gamma$	2.2×10^{-6}	5×10^{-8}	2×10^{-7}
$\mu^+\mu^-$	6.2×10^{-9}	1.7×10^{-7}	1.6×10^{-8}
μ^+e^-	2.6×10^{-7}	4.3×10^{-8}	3.0×10^{-8}
e^+e^-	7.9×10^{-8}	2.4×10^{-8}	1.0×10^{-9}
$\pi^0\mu^+\mu^-$	1.8×10^{-4}	1.2×10^{-7}	1.6×10^{-6}
$\pi^0e^+e^-$	4.5×10^{-5}	7.9×10^{-8}	3.5×10^{-9}
$\pi^0\mu^+e^-$	8.6×10^{-5}	9.7×10^{-8}	7.5×10^{-7}
$K^0\mu^+\mu^-$	2.6×10^{-4}	1.1×10^{-7}	5.9×10^{-6}
$K^0e^+e^-$	1.1×10^{-4}	7.5×10^{-8}	8.5×10^{-9}
$K^0\mu^+e^-$	1.0×10^{-4}	9.6×10^{-8}	7.7×10^{-9}
$\eta\mu^+\mu^-$	5.3×10^{-4}	1.0×10^{-7}	4.1×10^{-8}
ηe^+e^-	1.1×10^{-4}	1.0×10^{-7}	8.5×10^{-9}
$\eta\mu^+e^-$	1.0×10^{-4}	1.0×10^{-7}	7.7×10^{-9}

D^+ Mode	BEST (90% C.L.)	BESIII (20 fb^{-1})	Belle II (50 ab^{-1})
$\pi^+e^+e^-$	1.1×10^{-6}	5.6×10^{-8}	9.6×10^{-8}
$\pi^+\mu^+\mu^-$	7.3×10^{-8}	8.7×10^{-8}	5.7×10^{-7}
$\pi^+\mu^+e^-$	2.8×10^{-6}	8.3×10^{-8}	2.3×10^{-7}
$\pi^-e^+e^+$	1.1×10^{-6}	5.6×10^{-8}	1.7×10^{-7}
$\pi^-\mu^+\mu^+$	2.2×10^{-8}	8.7×10^{-8}	1.7×10^{-7}
$\pi^-\mu^+e^+$	2.0×10^{-6}	5.9×10^{-8}	1.7×10^{-7}
$K^+e^+e^-$	1.0×10^{-6}	6.7×10^{-8}	8.8×10^{-8}
$K^+\mu^+\mu^-$	4.3×10^{-6}	1.1×10^{-7}	3.8×10^{-7}
$K^+\mu^+e^-$	2.8×10^{-6}	8.3×10^{-8}	2.5×10^{-7}
$K^-e^+e^+$	9.0×10^{-7}	6.7×10^{-8}	7.9×10^{-8}
$K^-\mu^+\mu^+$	1.0×10^{-5}	1.1×10^{-7}	8.8×10^{-7}
$K^-\mu^+e^+$	1.9×10^{-6}	8.3×10^{-8}	1.7×10^{-7}

Conclusions

- Rare charm decays are the good tools for the search of the New Physics
- Charm decays are new territory to the strange and beauty rare decays
- Many rare charm decays are searched for by Belle, BaBar, BESIII, LHCb, …Many limits have been pushed further.
- No evidence of New Physics has been found. Present upper limits are still above SM predictions
- Order(s) of magnitude larger samples collected by LHCb.
- BelleII construction is ongoing. The first physics run is expected in 2017 (hope so). 50 ab-1 data is expected by 2023 which could improve the limits by order of magnitude, especially for the mode with neutral track.

Thanks!

SM short distance (SD) contributions predict tiny BF's

$BF(D^0 \to \mu^+\mu^-) \sim 10^{-18}$ *[1]*
$BF(D^+ \to \pi^+\mu^+\mu^-) \sim 10^{-11} - 10^{-9}$ *[2]*
$BF(D^0 \to \pi^-\pi^+\mu^+\mu^-) \sim 10^{-9}$ *[3]*
$BF(D^0 \to K^+\pi^-\mu^+\mu^-) \sim 10^{-10}$ *[3]*

New physics can enhance the SD contributions. Ex.: R-Parity Violation SUSY

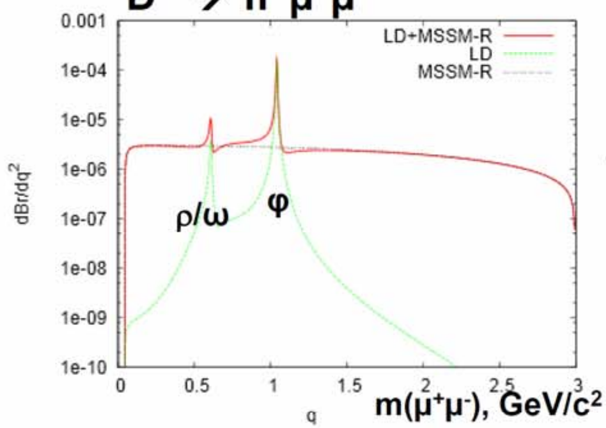
$D^0 \to \mu^+\mu^-$

Relating to the D^0- $\overline{D^0}$ mixing

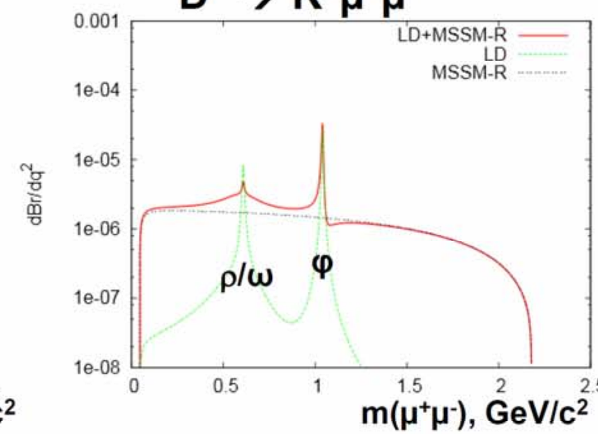
$$\mathcal{B}^{\not R_p}_{D^0\to\mu^+\mu^-} \le 4.8\times10^{-9}\left(\frac{300\ \text{GeV}}{m_{\tilde{d}_k}}\right)^2$$

$BF(D^0 \to \mu^+\mu^-) \sim 10^{-9}$ *[4]*

$D^+ \to \pi^+\mu^+\mu^-$



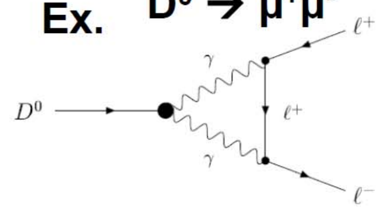
$D^+ \to K^+\mu^+\mu^-$



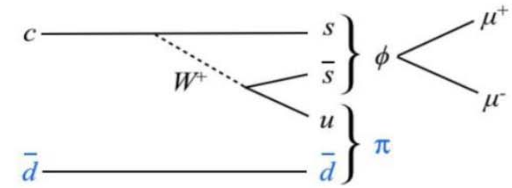
$BF(D^+ \to \pi^+\mu^+\mu^-) \sim 10^{-6}$ *[5]*

[1] G. Burdman et al. PR D66, 014009 (2002)
[2] G. Buchalla et al. EPJC57,309(2008),S. Fajfer et al, PRD64 (2001) 114009,
[3] L.Cappiello et al. arXiv:1209.4235v1
[4] E. Golowich, PRD79(2009)114030
[5] S. Fajfer et al, PRD76 (2007),074010

Ex. $D^0 \rightarrow \mu^+\mu^-$

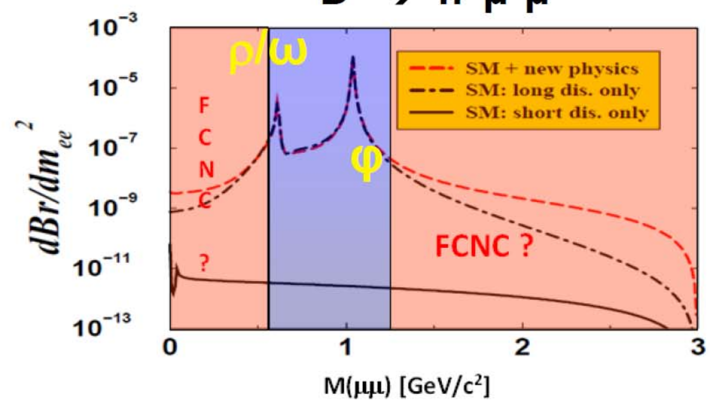


$D^+ \rightarrow \pi^+\mu^+\mu^-$



- Branching ratios dominated by long distance (**LD**) effects, via intermediate states

$D^+ \rightarrow \pi^+\mu^+\mu^-$



- The solution adopted by present searches is to measure BF's far from the resonances

- Recent literature suggests to use **asymmetries** (CP, T-odd, FB,…): **SD** *amplitudes* are more likely to compete with **LD** in an interference than in a BF. In that case, even the resonant regions are useful.

Mode	T-odd asym	FB asym
$K^-\pi^+\mu^+\mu^-$ (CF)	~ 7%	~ 0.06%
$K^+\pi^-\mu^+\mu^-$ (DCS)	~ 7%	~ 3%
$K^+K^-\mu^+\mu^-$	~ 6%	~ 0.5%
$\pi^-\pi^+\mu^+\mu^-$	~ 8%	~ 0.5%

Ex:arXiv:1209.4235v2

We measure the total BF's with present data to predict our future sensitivity (e.g. upgrade).

L.Cappiello et al. arXiv:1209.4235 (2013)
S.Fajfer et al. PRD87, 054026 (2013)
I.Bigi et al. JHEP03, 021 (2012)

High-Luminosity Asymmetric B Factory

Belle II

- Target luminosity is $\mathscr{L} = 8\text{x}10^{35}\ cm^{-2}s^{-1}$ (x40 w.r.t. BELLE)
- Achievable in the *nano-beam scheme* (P. Raimondi for SuperB)
  - double beam currents
  - squeeze beams @ [illegible]

Lorentz factor

beam

beam-beam

beam aspect [illegible] at the IP

vertical beta-function at the IP

reduced CM boost

- reduced vertex separation, Δt resolution
- increased detector hermeticity

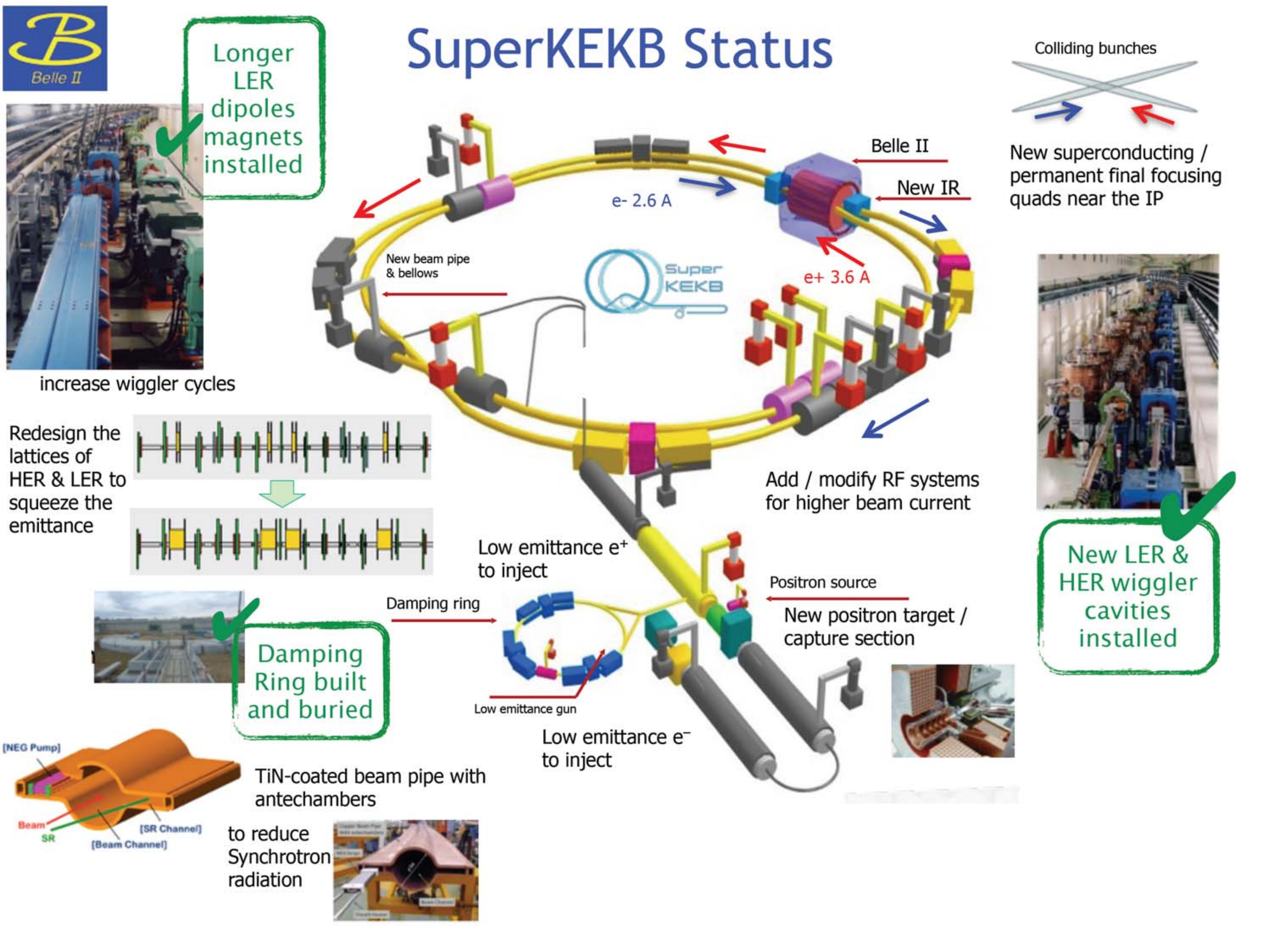
squeezed beams @ IP

- greatly improved constraint for decay chain vertex fitting

parame[illegible]		[illegible]		SuperKEKB		units
		LER	[illegible]	LER	HER	
beam energy	E_b	3.5	8	4	7	GeV
CM boost	$\beta\gamma$	0.425		0.28		
h[illegible]	[illegible]	[illegible]		41.5		mrad
ho[illegible]	[illegible]	[illegible]	24	3.2	4.6	nm
[illegible]	[illegible]	[illegible]	0.66	[illegible]37	0.40	%
b[illegible]	[illegible]	[illegible]	5.9	32/0.27	25/0.30	mm
[illegible]	[illegible]	[illegible]	1.19	3.6	2.6	A
bea[illegible]	[illegible]	[illegible]	[illegible]90	0.0881	0.0807	
[illegible]	[illegible]	[illegible]	[illegible]2	10/0.059		μm
[illegible]	[illegible]	[illegible]	[illegible]0	$8\text{x}10^{35}$		$cm^{-2}s^{-1}$

x40 luminosity

- higher background rates (~10-20x)
  - detectors occupancy, radiation damage, fake hits, pile-up noise in the calorimeter
- higher event rate
  - higher trigger rate, DAQ, computing
- x40 produced signal events



Belle II
SuperKEKB Status
Longer LER dipoles magnets installed
increase wiggler cycles
Colliding bunches
Belle II
New IR
New superconducting / permanent final focusing quads near the IP
e- 2.6 A
e+ 3.6 A
New beam pipe & bellows
Super KEKB
Add / modify RF systems for higher beam current
New LER & HER wiggler cavities installed
Redesign the lattices of HER & LER to squeeze the emittance
Low emittance e+ to inject
Damping ring
Positron source
New positron target / capture section
Damping Ring built and buried
Low emittance gun
Low emittance e− to inject
[NEG Pump]
Beam
SR
[SR Channel]
[Beam Channel]
TiN-coated beam pipe with antechambers
to reduce Synchrotron radiation

The *Belle II* Detector