Charm physics prospects at the Belle II experiment

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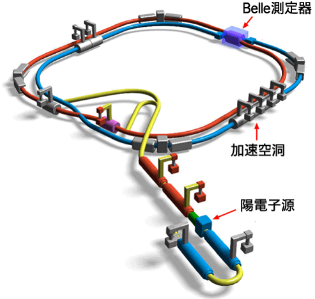
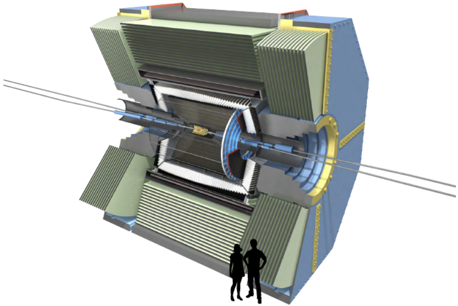
Outline

- Super KEKB and Belle II
- Status of the detector and accelerator
- Selection of Belle II prospects on charm

Belle II experiment

- Successor of Belle experiment (KEK, Tsukuba, Japan)





SuperKEKB accelerator

- upgraded KEKB
- luminosity 40 $\times$ KEKB ($8 \times 10^{35} \mathrm{cm}^{-2}\mathrm{s}^{-1}$)
- nano-beam optics

Belle II detector

- upgraded Belle detector
- majority of components replaced

Belle II environment

Critical issues at $\mathcal{L} = 8 \times 10^{35} \mathrm{cm}^{-2}\mathrm{s}^{-1}$

- Higher background ($\times$10 - 20)
  - radiation damage and occupancy
  - fake hits and pile-up noise in EM calorimeter
- Higher event rate ($\times$40)
  - affects trigger, DAQ and computing

Have to employ and develop new technologies to make such an apparatus work efficiently.

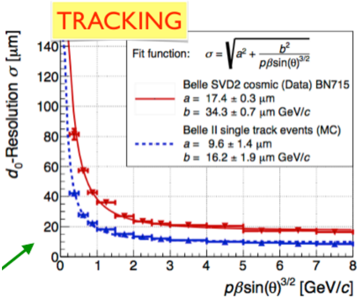
Belle II detector upgrade → almost completed

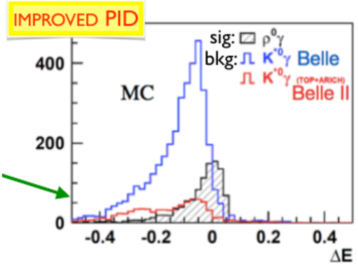
- Vertex detector
  - 4-layer DSSD replaced with 2 DEPFET layers + 4 DSSD layers
  - smaller inner radius, larger outer radius
    → better vertex resolution
    → improved efficiency for slow pions and K_S
- Central drift chamber
  - smaller cells, larger outer radius
    → improved momentum resolution and dEdx
- Hadron ID
  - ACC + TOF replaced with TOP (barrel) and aerogel RICH (forward)
    → less material in front of calorimeter
    → improved hadron ID
- Electromagnetic calorimeter
  - waveform sampling technique to cope with increased background
- K-long and muon detector
  - RPC's in endcaps and first two layers of barrel replaced with scintillator counters to cope with increased neutron background

Belle II performance improvements

Improvements w.r.t Belle

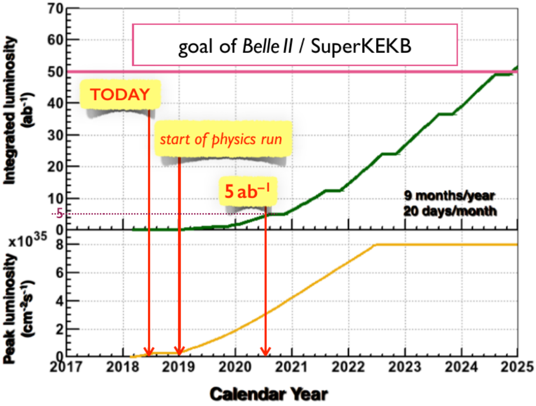
- primary and secondary vertex resolution
- K_S and π^0 reconstruction
- hadron and muon ID in the end caps
- K/π separation



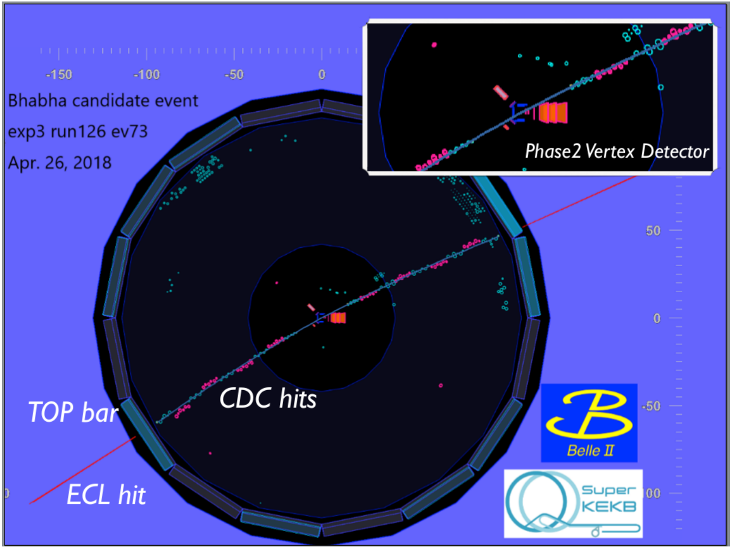


Belle II schedule

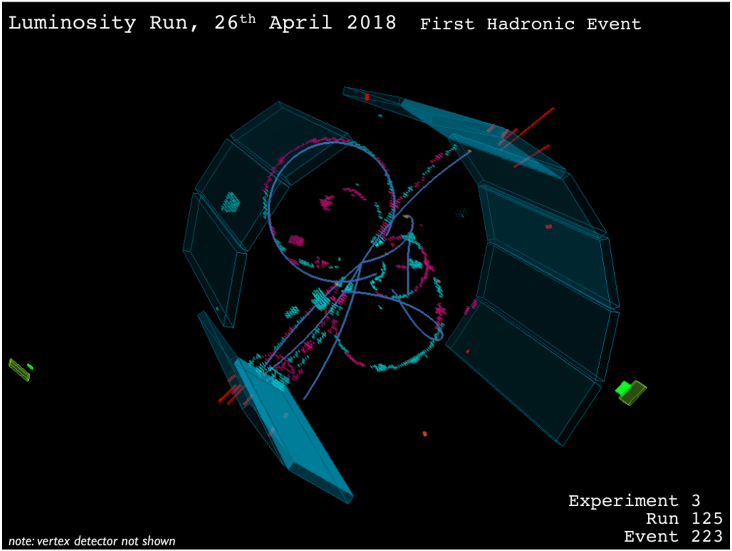
- 2018 (phase 2): first collisions on April 26$^{\mathrm{th}}$
- 2019 (phase 3): start of physics run
- collect $\sim$ 5 ab^{-1} by mid 2020
- collect 50 ab^{-1} by 2025



First collisions: Bhabha candidate

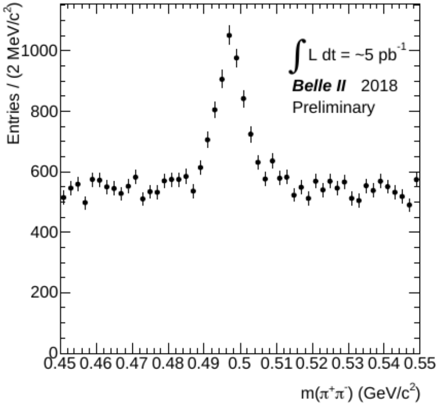


First collisions: Hadronic event

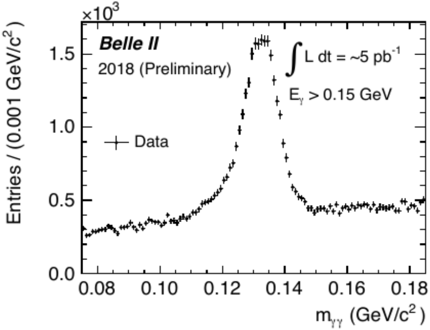


First bumps observed

$K_S \to \pi^+\pi^-$



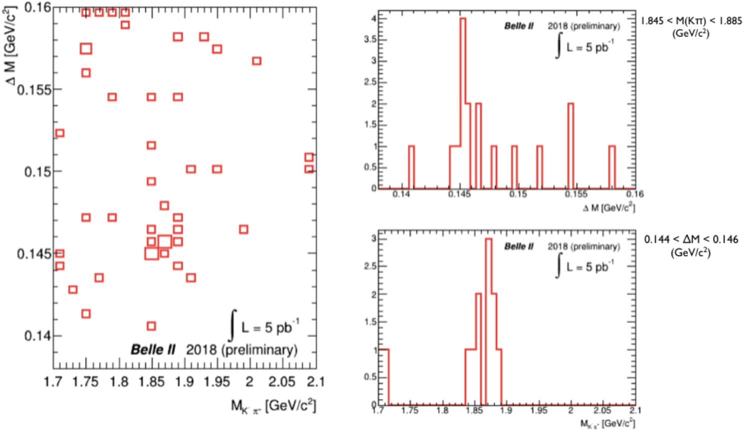
$\pi^0 \to \gamma\gamma$



- Evidence of K_S and π^0 in the collected data sample of 5 pb^{-1}
- Calibrations at a very early stage

We got charm

$$D^{*+} \to D^0(\to K^-\pi^+)\pi^+$$



- Evidence of D^{*+} and D^0 in the collected data sample of 5 pb^{-1}
- Calibrations at a very early stage, no PID requirements

Prospects for charm at Belle II

Mixing and CPV

- Belle measurements extrapolated to 50 ab^{-1}
- Systematic uncertainties primarily scale with integrated luminosity, with two exceptions:
  - model related systematics of t-dependent Dalitz analysis (resonance parameters - masses, widths, form factors, angular dependence etc.)
  - A_{CP} of modes with K_s^0: asymmetry of $K^0/\overline{K}^0$ interactions in material (PRD 84, 111501 (2011)), $\sigma_{\mathrm{ired}} \approx 0.02\%$
- Extrapolation:

$$\sigma_{BelleII} = \sqrt{(\sigma_{stat}^2 + \sigma_{sys}^2)\frac{\mathcal{L}_{Belle}}{50\ \mathrm{ab}^{-1}} + \sigma_{\mathrm{ired}}^2}$$

Detector performance improvements are not included in the extrapolation

Mixing and indirect CPV

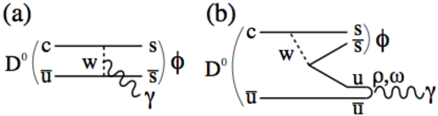
	Belle	Belle II
$D^0 \to K^{(*)-}\ell^+\nu$	492 fb^{-1} (2008)	50 ab^{-1}
R_M	$(1.3 \pm 2.2 \pm 2.0) \times 10^{-4}$	$\pm 0.3 \times 10^{-4}$
$D^0 \to K^+K^-, \pi^+\pi^-$	976 fb^{-1} (2016)	50 ab^{-1}
y_{CP}	$(1.11 \pm 0.22 \pm 0.11)\%$	$\pm 0.04\%$
A_Γ	$(-0.03 \pm 0.20 \pm 0.08)\%$	$\pm 0.03\%$
$D^0 \to K^+\pi^-$	400 fb^{-1} (2006)	50 ab^{-1}
x'^2	$(1.8 \pm 2.2 \pm 1.1) \times 10^{-4}$	$\pm 0.22 \times 10^{-4}$
y'	$(0.06 \pm 0.40 \pm 0.20)\%$	$\pm 0.04\%$
A_M	0.67 ± 1.20	± 0.11
$\|\phi\|$	0.16 ± 0.44	± 0.04
$D^0 \to K_s^0\pi^+\pi^-$	921 fb^{-1} (2014)	50 ab^{-1}
x	$(0.56 \pm 0.19 \pm 0.06 \pm 0.08)\%$	$\pm 0.08\%$
y	$(0.30 \pm 0.15 \pm 0.06 \pm 0.04)\%$	$\pm 0.05\%$
$\|q/p\|$	$0.90 \pm 0.16 \pm 0.04 \pm 0.06$	± 0.06
ϕ	$-0.10 \pm 0.19 \pm 0.04 \pm 0.07$	± 0.07

$$|q/p| = 1 + \tfrac{1}{2}A_M \Rightarrow \delta|q/p| = \tfrac{1}{2}\delta A_M$$

Time-integrated measurements (A_{CP})

mode	$\mathcal{L}$ (fb^{-1})	A_{CP} (%)	Belle II at 50 ab^{-1}
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	± 0.03
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	± 0.05
$D^0 \to \pi^0\pi^0$	966	$-0.03 \pm 0.64 \pm 0.10$	± 0.09
$D^0 \to K_S^0 K_S^0$	921	$-0.02 \pm 1.53 \pm 0.02 \pm 0.17$	± 0.21
$D^0 \to K_s^0\pi^0$	966	$-0.21 \pm 0.16 \pm 0.07$	± 0.03
$D^0 \to K_s^0\eta$	791	$+0.54 \pm 0.51 \pm 0.16$	± 0.07
$D^0 \to K_s^0\eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	± 0.09
$D^0 \to \pi^+\pi^-\pi^0$	532	$+0.43 \pm 1.30$	± 0.13
$D^0 \to K^+\pi^-\pi^0$	281	-0.60 ± 5.30	± 0.40
$D^0 \to K^+\pi^-\pi^+\pi^-$	281	-1.80 ± 4.40	± 0.33
$D^+ \to \phi\pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	± 0.04
$D^+ \to \eta\pi^+$	791	$+1.74 \pm 1.13 \pm 0.19$	± 0.14
$D^+ \to \eta'\pi^+$	791	$-0.12 \pm 1.12 \pm 0.17$	± 0.14
$D^+ \to K_s^0\pi^+$	977	$-0.36 \pm 0.09 \pm 0.07$	± 0.03
$D^+ \to K_s^0 K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.05
$D^+ \to \pi^+\pi^0$	921	$+2.31 \pm 1.24 \pm 0.23$	± 0.17
$D_s^+ \to K_s^0\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29
$D_s^+ \to K_s^0 K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

Direct CPV in $D^0 \to \phi\gamma, \rho^0\gamma$

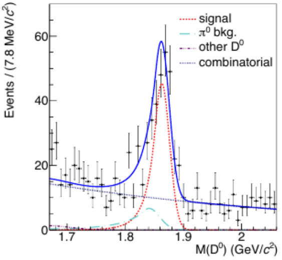


- Direct CPV in radiative decays can be enhanced by chromomagnetic dipole operators (G. Isidori and J. F. Kamenik, PRL 109, 171801 (2012))
  - $D^0 \to \phi\gamma$: A_{CP} up to 2%
  - $D^0 \to \rho^0\gamma$: A_{CP} up to 10%

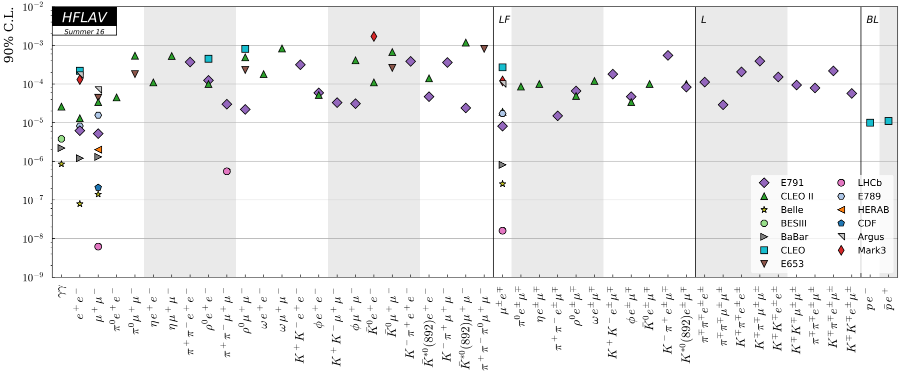
- Belle, 943 fb^{-1}, PRL 118, 051801 (2017)
  - $A_{CP}(D^0 \to \phi\gamma) = (-9.4 \pm 6.6 \pm 0.1)\%$
  - $A_{CP}(D^0 \to \rho^0\gamma) = (5.6 \pm 15.2 \pm 0.6)\%$

  $\to$ consistent with no CPV
- Sensitivity at 50 ab^{-1}
  - $A_{CP}(D^0 \to \phi\gamma)$: 0.9%
  - $A_{CP}(D^0 \to \rho^0\gamma)$: 2.1%

$D^0 \to \phi\gamma$



Rare and forbidden decays

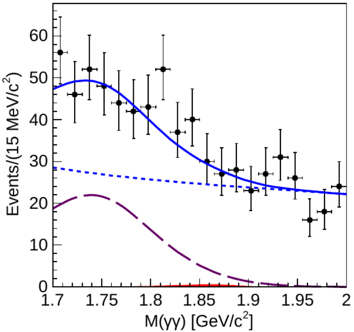


- Decays involving π^0, η and ω mostly done by CLEO
- Belle II can improve these UL by several orders of magnitude

$D^0 \to \gamma\gamma$ on the next slide

$D^0 \to \gamma\gamma$

- SM predictions: long distance effects dominate
  $Br \sim \text{few} \times 10^{-8}$
- Belle, 832 fb^{-1} — PRD 93, 051102 (2016)
  $Br < 8.5 \times 10^{-7}$ @ 90% CL



- Belle II at 50 ab^{-1}:
  $\rightarrow$ depends how background behaves
  - if UL would scale with $\mathcal{L}$:
    $UL \sim 2 \times 10^{-8}$
  - if UL would scale with $\sqrt{\mathcal{L}}$:
    $UL \sim 1 \times 10^{-7}$

Conclusions

- SuperKEKB is completing commissioning phase
  - first collisions achieved a month ago
- Phase 2 data taking started
  - understand the machine and the backgrounds
  - detector and software checkout
  - possible initial physics studies
- Physics run will start in less than a year, at beginning of 2019
- A rich charm physics program ahead, ready to improve precision on
  - CP asymmetries, mixing and CPV parameters
  - limits on rare and forbidden decays
  - decay constants f_D and f_{Ds} from semileptonic decays
  - measurements of charm baryons