Prospect of search for doubly charm exotic hadron at Belle (II)

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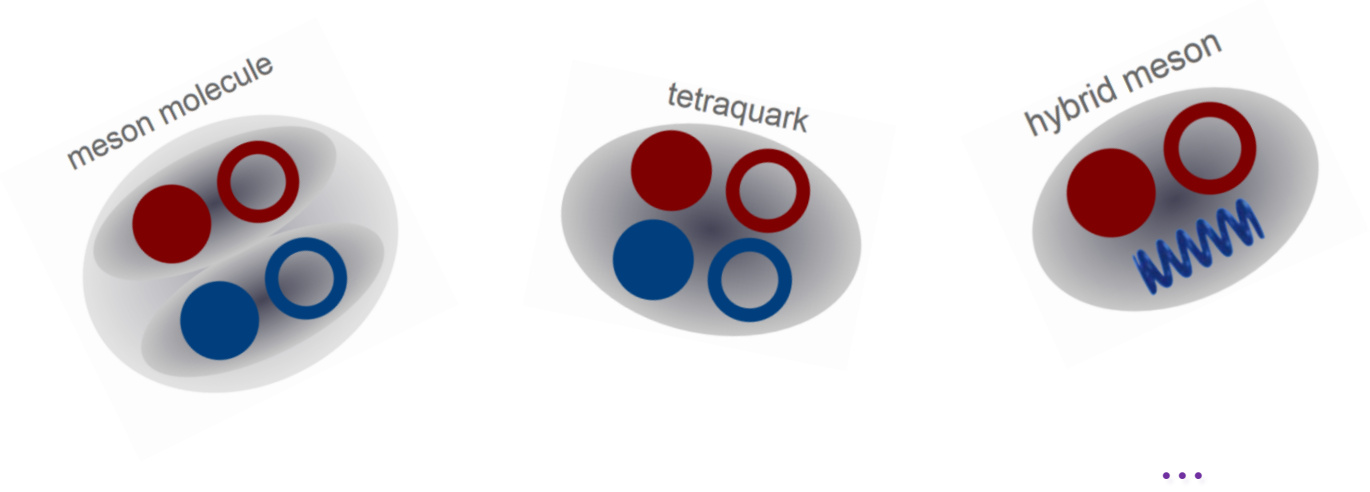
Motivation

- Multiquark states beyond usual meson/baryon picture has been actively studied in the past decade
  - They either doesn't fit into the convectional quarkonium spectra with well-predicted mass/width/quantum numbers
    - X(3872), Y(4260), ...
  - Or they are charged despite its quarkonium content
    - Zc(3900), Z(4430), Pc, ...
- Many possible interpretations of their nature



Motivation

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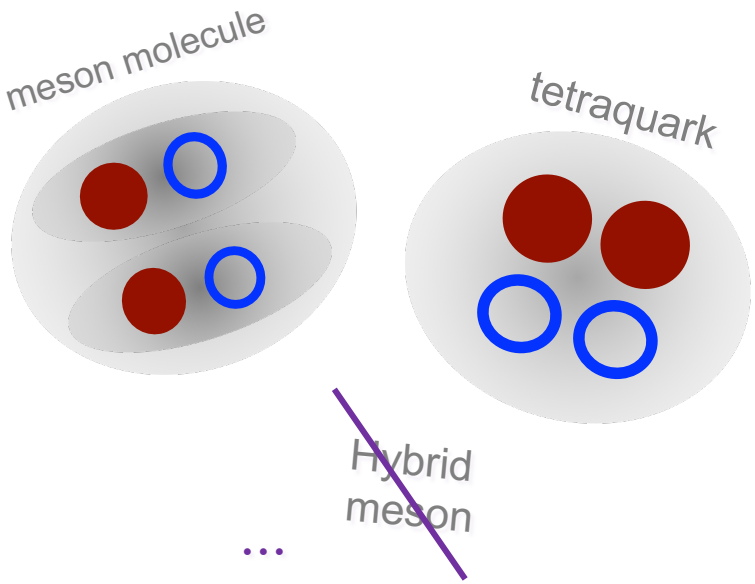
- All such exotic states are observed in hidden charm/bottom states $(c\bar{c}q\bar{q}, b\bar{b}q\bar{q})$
- Doubly heavy hadrons like Tcc $(cc\,\bar{q}\bar{q})$ will extend such picture, and help us narrow down the options of their multiquark nature



Implication of doubly charmed baryons

- LHCb recently observed a doubly charmed baryon Ξ_{cc}^{++} (ccu)
  - Mass 3621.40 $\pm$ 0.78 MeV PRL 119, 112001 (2017)
  - Anticipated by quark model for long, first doubly heavy baryon to be confirmed
  - Belle had a try but didn't see it with current data

    PRD 89, 052003 (2014)

- In the heavy quark limit the two heavy quarks (QQq) can be related to analogous states with one heavy anti-quark $(\bar{Q}q)$
- Along this line theoretical predictions have emerged for Tcc states based on the Xicc baryon information (and indication on QQ di-quark system)
  - Actually predictions for all sorts of $QQ\bar{q}\bar{q}$: $cc\bar{q}\bar{q}, bc\bar{q}\bar{q}, bb\bar{q}\bar{q}$ ...

Theoretical predictions


PRL 119, 202001 (2017) PHYSICAL REVIEW LETTERS week ending 17 NOVEMBER 2017

EDITOR'S SUGGESTION

Discovery of the Doubly Charmed Ξ_{cc} Baryon Implies a Stable $bb\bar{u}\bar{d}$ Tetraquark

Marek Karliner[1,*] and Jonathan L. Rosner[2,†]

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[2]Enrico Fermi Institute and Department of Physics, University of Chicago, 5620 South Ellis Avenue, Chicago, Illinois 60637, USA

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- Various mass predictions for lowest lying $J^P = 1^+$ state:
  - 3882 ± 12 MeV, Q = 7 (148) MeV for D^0D^{*+} ($D^0D^+\gamma$) (*Karliner, Rosner, PRL 119, 202001 (2017)*)
  - 3978 MeV, Q = 102 MeV for D^+D^{*0} (*Eichten, Quigg, PRL 119, 202002 (2017)*)
  - 3804 MeV (below DD* threshold), (*Hyodo et al, PLB 721, 56 (2013)*)

- Production cross-section in B factory:
  - 4~14 fb (*Hyodo et al, PLB 721, 56 (2013)*)
    - => ~10k Tcc produced, taking D decay Br and efficiencies
      => up to ~100 reconstructed in Belle I data
    - Much more promising with 50 times more statistics in Belle II

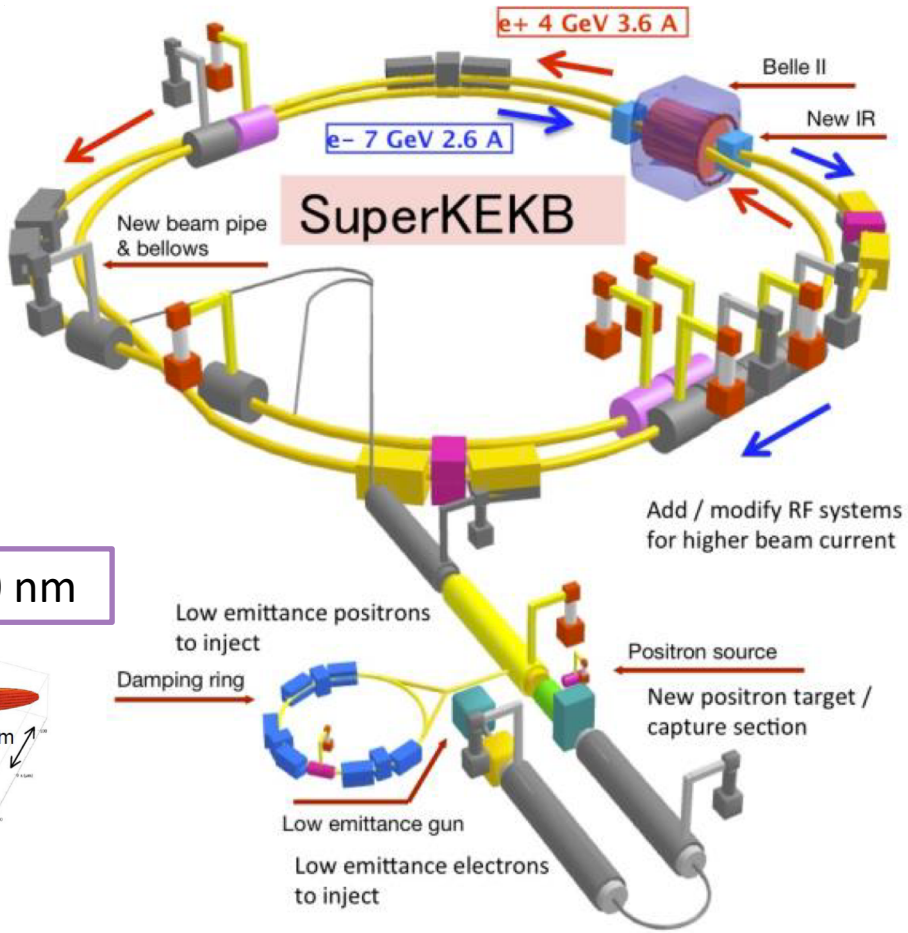
Belle @ KEKB

- 1 ab^{-1} integrated luminosity, great success in flavour physics

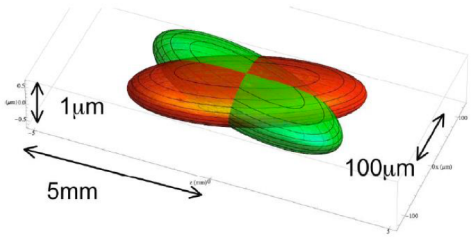
→ *Belle II @ SuperKEKB*

- Ecm still at 10.58 GeV m(Y(4S))
- Peak luminosity 8×10^{35} $cm^{-2}s^{-1}$
  - $40 \times \mathcal{L}$(KEKB)!

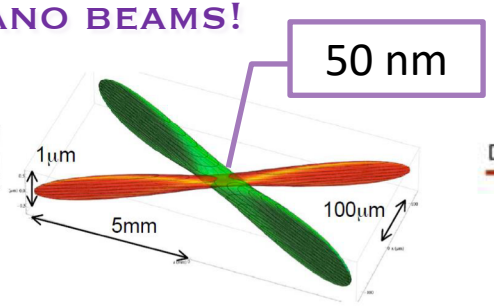
$$\mathcal{L} \sim \frac{N_1 N_2}{\sigma_1 \sigma_2}$$



NANO BEAMS!



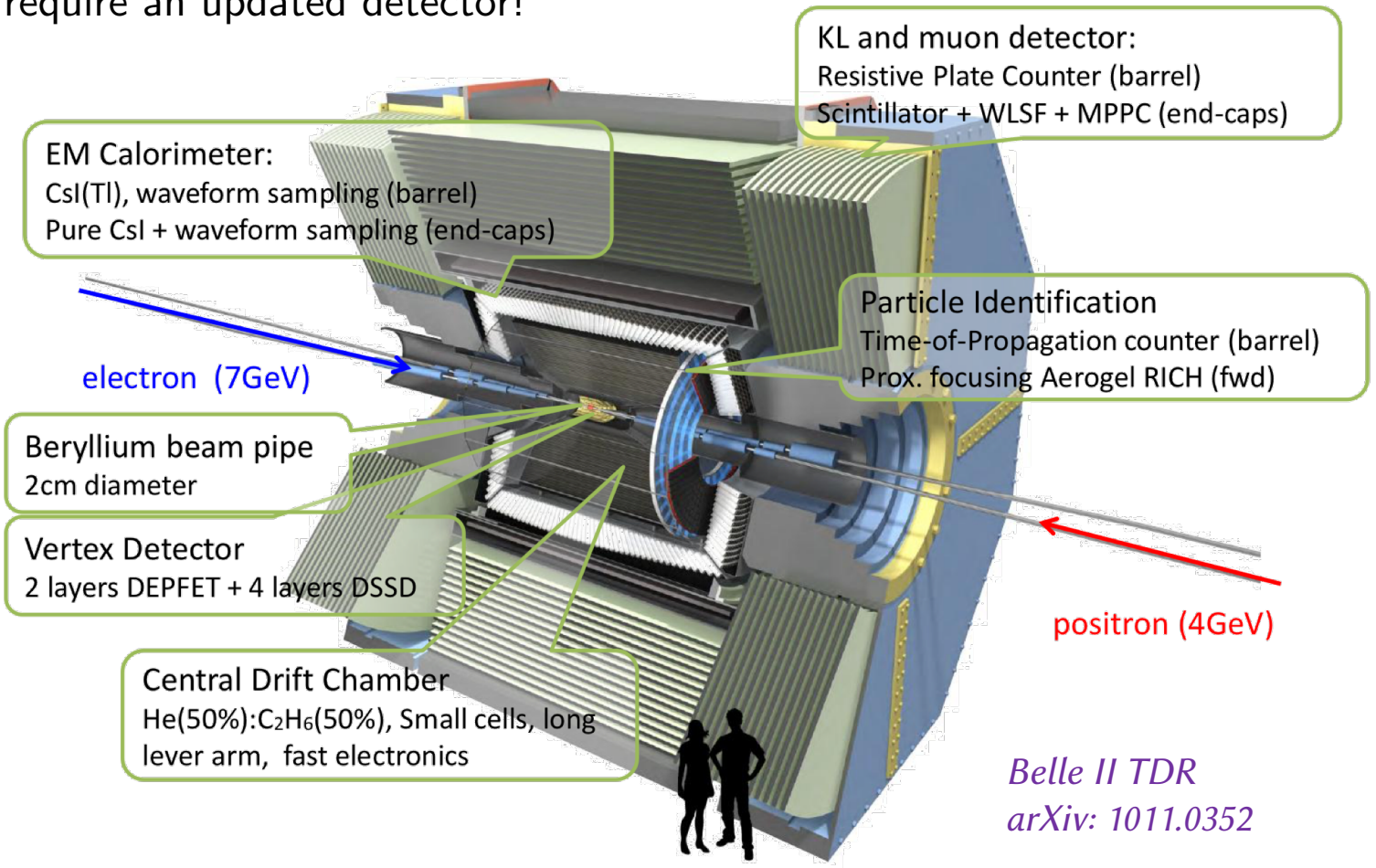
KEKB



SuperKEKB

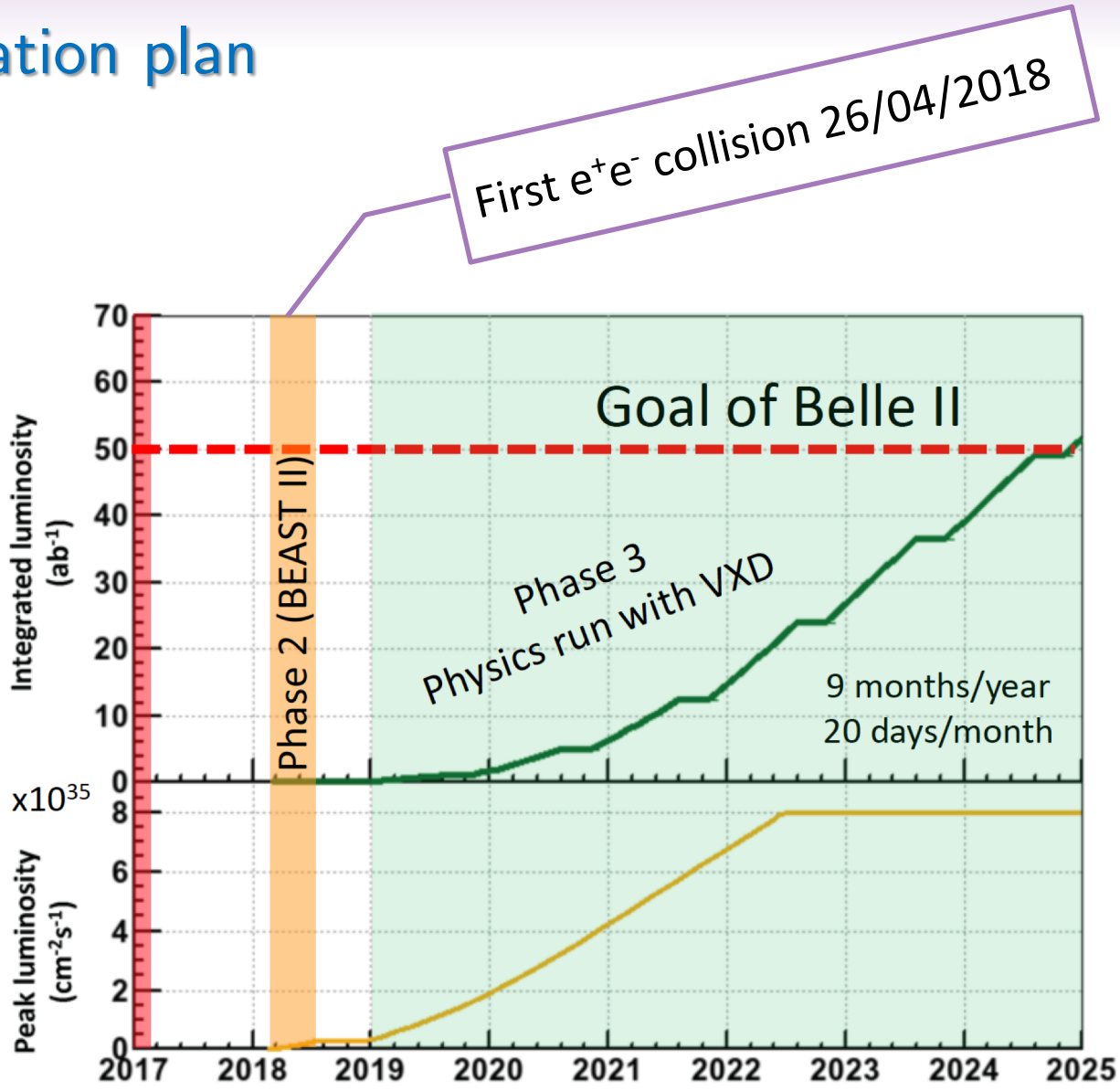
Belle II detector

- Higher event rate; higher background; reduced forward boost...
  require an updated detector!



Belle II TDR
arXiv: 1011.0352

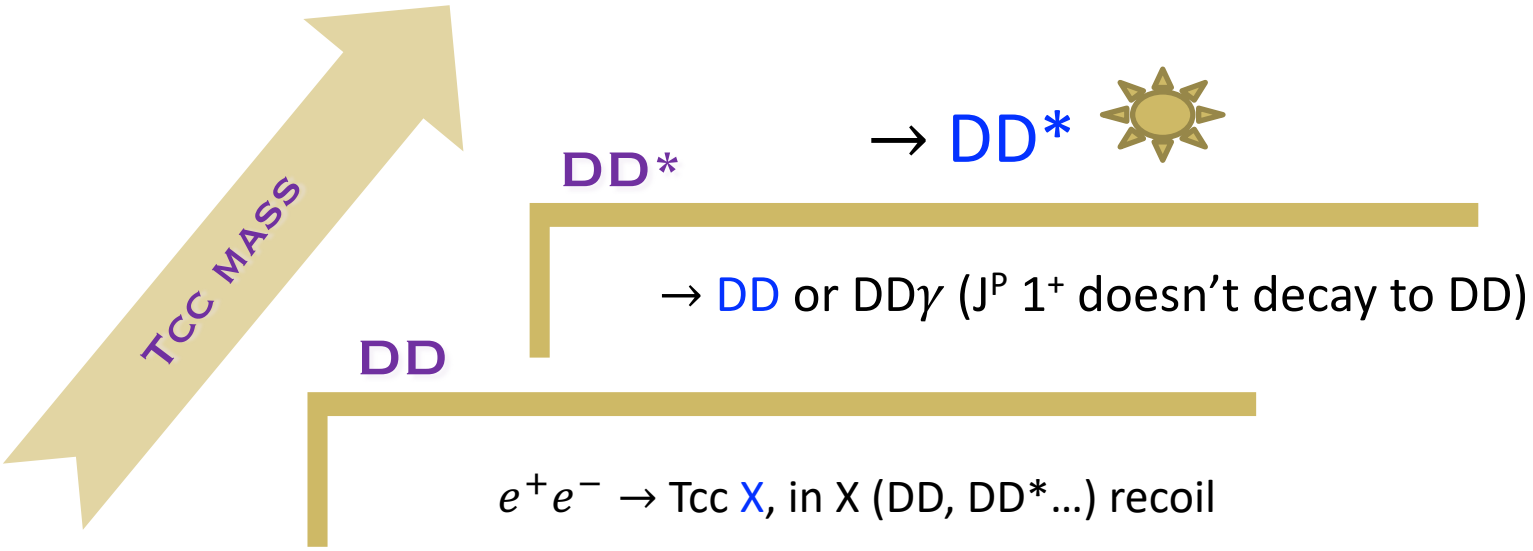
Operation plan



Search strategy for Tcc at Belle (II)

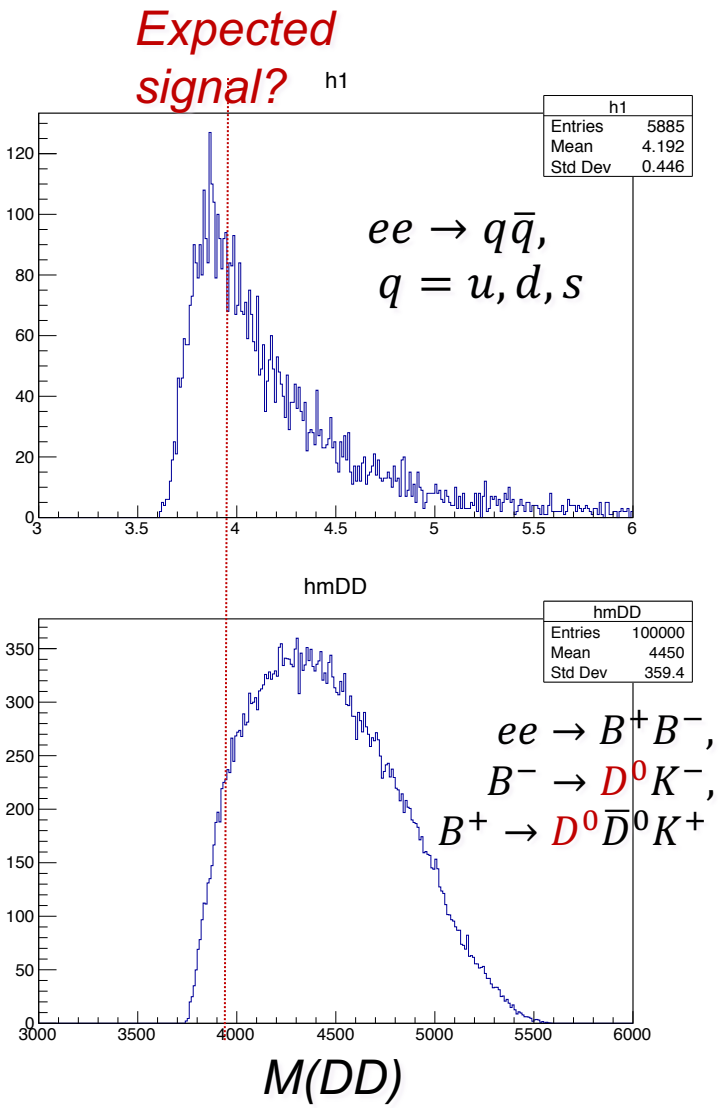
- T_{cc}^{+} most promising (isospin 0)
  - straight-forward to extended to T_{cc}^{0}, T_{cc}^{++}

- **What final states?** Depending on the Tcc mass



Search strategy – which Ecm?

- In order to fully exploit the available dataset, the main challenge is the true double charm background from B decays
- The DD from B background behave different from general combinatorial background
- Should start with C.O.M. energy below Y(4S) to better understand the uds/charm background



** Phase space MC, w/o full detector simulation*

Signal MC samples

- MC samples generated for various Tcc decay channel and mass assumption
- Each sample contains 1M events
- $e^+e^- \to T_{cc}\overline{D}\overline{D}X$ (X is a super wide state to allow more realistic kinematics)

Sample name	Decay
Tcc0S1ToDD	$T_{cc}^0(3882) \to D^0D^0$
Tcc01ToDDst	$T_{cc}^0(3882) \to D^0D^{*0}, D^{*0} \to D^0\pi^0$
Tcc02ToDDst	$T_{cc}^0(3978) \to D^0D^{*0}, D^{*0} \to D^0\pi^0$
Tccp1ToDDst†	$T_{cc}^+(3882) \to D^+D^{*0}(50\%), D^0D^{*+}(50\%), D^{*0} \to D^0\pi^0, D^{*+} \to D^+\pi^0$
Tccp2ToDDst†	$T_{cc}^+(3978) \to D^+D^{*0}(50\%), D^0D^{*+}(50\%), D^{*0} \to D^0\pi^0, D^{*+} \to D^+\pi^0$
TccpS1ToDD	$T_{cc}^+(3882) \to D^+D^0$
Tccpp1ToDDst†	$T_{cc}^{++}(3882) \to D^+D^{*+}, D^{*+} \to D^+\pi^0$
Tccpp2ToDDst†	$T_{cc}^{++}(3978) \to D^+D^{*+}, D^{*+} \to D^+\pi^0$
TccppS1ToDD	$T_{cc}^{++}(3882) \to D^+D^+$

Skimming

- Dedicated skim requiring at least two D(*) candidates in the events, largely reducing the data samples to be processed
- Skimmed data include:
  - Full 1/ab experimental data + generic MC ($ee \to q\bar{q}, ee \to c\bar{c}$)

Particle	Cut
	$N(\text{charged}) \geq 3$
K	PID $\mathcal{L}_K/(\mathcal{L}_K + \mathcal{L}_\pi) > 0.6$ ≥ 1 SVD hits in $r\phi$ and z plane
π	PID $\mathcal{L}_\pi/(\mathcal{L}_K + \mathcal{L}_\pi) > 0.6$ ≥ 1 SVD hits in $r\phi$ and z plane
π^0	$\chi^2 < 50$ mass window (115, 150) MeV $p_{lab} > 150$ MeV
K^0_S	nisKsFinder, mass window ± 10 MeV
D^0, D^+	mass window 100 MeV $\chi^2/\text{ndf} < 100$ in vertex fit $N(D) \geq 2$

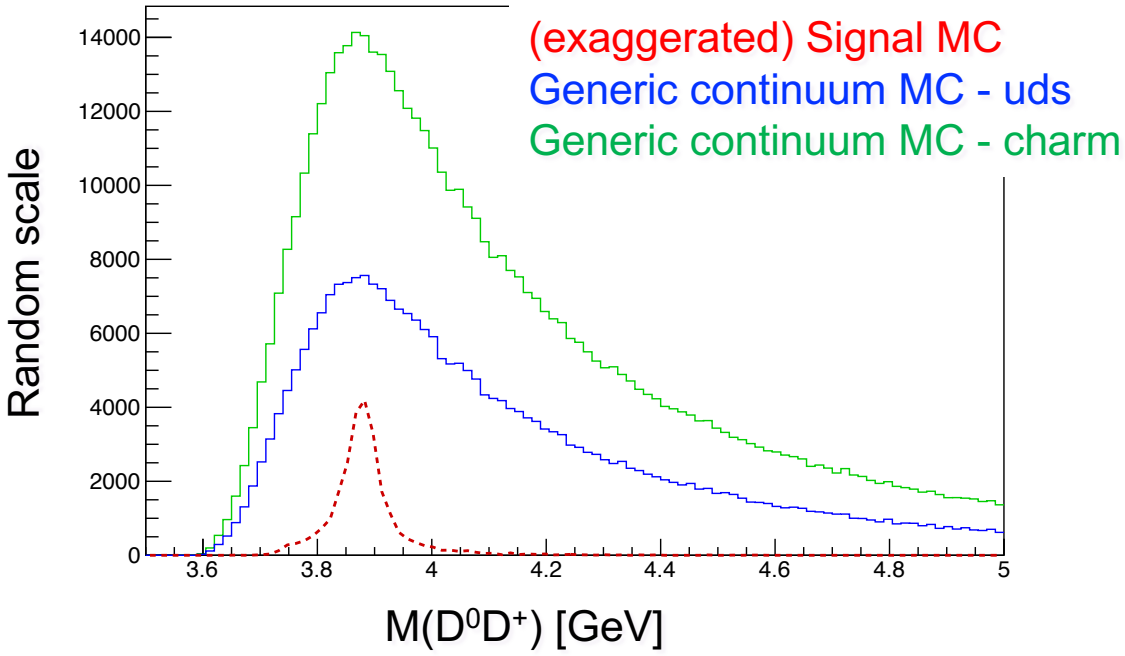
$$D^0 \to K^-\pi^+(3.93\%), K^-\pi^+\pi^0(14.30\%), K^-2\pi^+\pi^-(8.06\%)$$
$$D^+ \to K^-2\pi^+(9.46\%), K^-2\pi^+\pi^0(6.14\%), K^0_S\pi^+(1.53\%),$$
$$K^0_S\pi^+\pi^0(7.24\%), K^0_S2\pi^+\pi^-(3.05\%), K^+K^-\pi^+(0.996\%),$$
$$K^+K^-\pi^+\pi^0(2.62\%)$$

Key components in place for analysis with Belle data

Preparation of MC and skim allows comparison of signal and various backgrounds, and optimization of reconstruction and selection procedures

Aiming at setting an UL on its production with Belle data

Take Tcc → D^+D^0 as an example (just to give a flavour)



Summary and plans

- Search for exotic states in same-sign double charm final state is a new way to pursue the nature of hadrons containing multiple quarks
- Promising at Belle II if we believe theoretical predictions on its production, intriguing to have a go with current Belle data

- The most likely would be Tcc^{+} search in DD* final state
- Background of continuum and true DD pair from BB should be treated separately

- The simulation sample and skimming is in place
- Aiming at setting an UL on its production with Belle data