CHARM 2018: The 9th International Workshop on Charm Physics

https://indico.inp.nsk.su/event/10/timetable/#20180521

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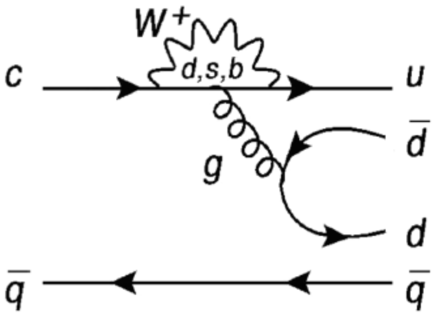
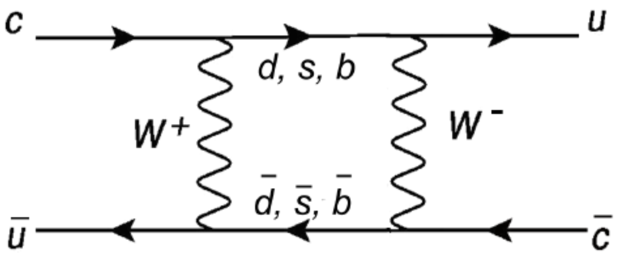
Семинар ОФВЭ \ 29 мая 2018

CPV at charm sector & New Physics in loops

$$V^{(\mathrm{CK})}_{\mathrm{Wolf}} = \begin{array}{cc} \begin{matrix} \quad d \quad & \quad s \quad & \quad b \quad \end{matrix} & \\ \begin{pmatrix} \begin{gathered} 1-\frac{\lambda^2}{2}-\frac{\lambda^4}{8} \\ -\frac{\lambda^6}{16}[1+8A^2(\rho^2+\eta^2)]\ , \end{gathered} & \lambda\ , & A\lambda^3(\rho-i\eta) \\ -\lambda+\underline{\frac{\lambda^5}{2}A^2(1-2\rho-2i\eta)}\ , & \begin{gathered} 1-\frac{\lambda^2}{2}-\frac{\lambda^4}{8}(1+4A^2) \\ \underline{-\frac{\lambda^6}{16}[1-4A^2(1-4\rho-4i\eta)]}\ , \end{gathered} & A\lambda^2 \\ \begin{gathered} A\lambda^3(1-\rho-i\eta) \\ +\frac{\lambda^5}{2}A(\rho+i\eta)\ , \end{gathered} & \begin{gathered} -A\lambda^2+\frac{\lambda^4}{2}A(1-2\rho-2i\eta) \\ +\frac{\lambda^6}{8}A\ , \end{gathered} & \begin{gathered} 1-\frac{\lambda^4}{2}A^2 \\ -\frac{\lambda^6}{2}A^2(\rho^2+\eta^2) \end{gathered} \end{pmatrix} & \begin{matrix} u \\ \\ c \\ \\ t \end{matrix} \end{array}$$

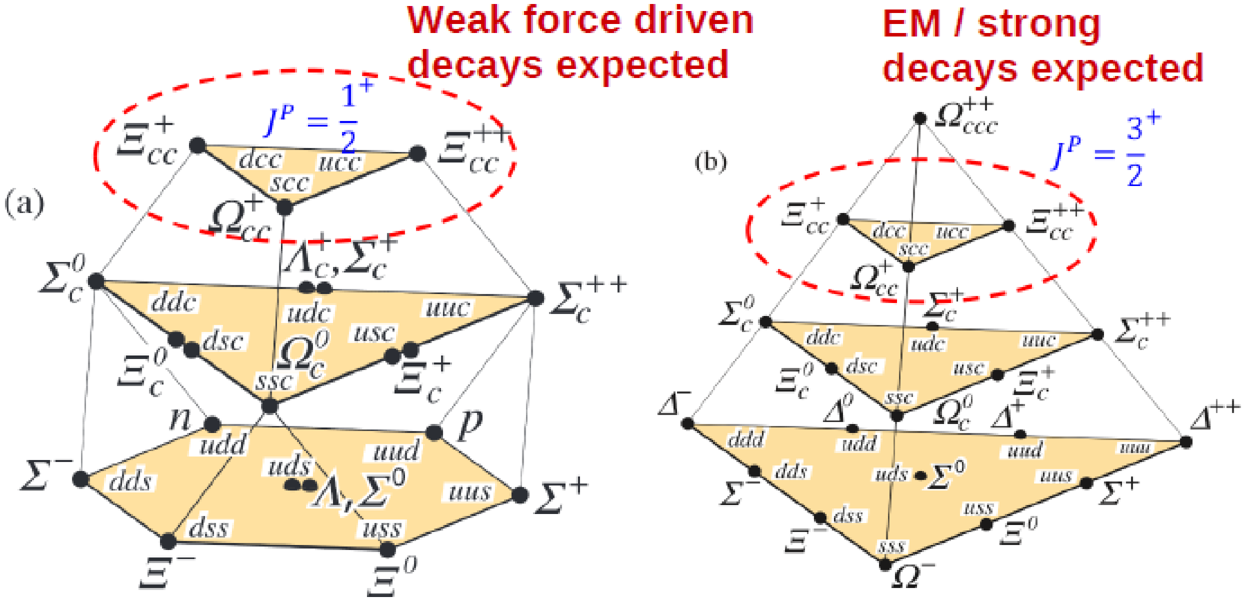
$$+\,\mathcal{O}(\lambda^7)$$





- CKM matrix provides clear prediction of very small CPV in charm sector (*D*-mesons are the only up-type quark system, where mixing and CPV can occur)
- New Physics in loop-diagrams driven processes, which are very suppressed in the SM (Keeping in mind: long-distance contributions, for which precise theoretical predictions are difficult, but can play important role)
- Need a lot of $c\bar{c}$ for discoveries

Better understanding of QCD



Weak force driven decays expected

EM / strong decays expected

- QCD is a natural part of the SM

- Chiral perturbation theory valid between 0.1 and 1 GeV
- Perturbative QCD calculations >> 1 GeV

- Although charm hadrons are in between of these two regimes, due to high ***c*** mass double and triple charm systems, as well as exotica are kind of natural bridges for QCD development

- Need intensive charm source to produce such bound systems

Machines for charm studies (Luminosity / $N_{c\bar{c}}$)

At threshold

Higher energies

e^+e^- colliders

CLEO-c (0.8 fb^{-1} / $5*10^6$) / **BESIII** ($3fb^{-1}$ / $2*10^7$)

In future **Super-tau-charm Factories**

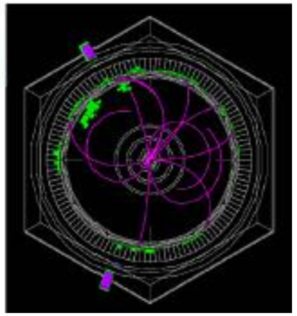
- at *$\psi(3770)$* resonance
- Quantum coherence, which allows to measure strong phase
- Almost no background

- No boost – no lifetime measurements
- Small sample size

Belle (1 ab^{-1} / $13*10^8$) / **BaBar** (550 fb^{-1} / $8*10^8$)

In future **Belle2** (50 ab^{-1})

- Neutrals / neutrino studies
- Clean environment
- Lifetime studies possible



hadron machines

In future **PANDA**

- Selective to hadron production thresholds
- Production cross sections measurements
- Polarization studies possible

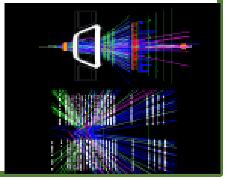
- no lifetime measurements / not large sample

CDF (10 fb^{-1} / $23*10^{10}$) / **LHCb** (5 fb^{-1} / $8*10^{12}$)

In future **LHCb Upgraded** (→ 50 fb^{-1} → 300 fb^{-1})

- **Huge rates**
- **Excellent lifetime resolution due to the boost**

- **Large backgrounds**
- **Difficult to work with neutral**



Обзор новых результатов представленных на Конференции CHARM’18 + Перспективы

- Спектроскопия
- Смешивание, CPV, Редкие распады
- Рождение чарма
- Интересные результаты

- **Экзотика**
- **In Medium**
- **Теория**

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Спектроскопия

- Время жизни дважды очаровательного бариона

- Обнаружение новых мод распадов

Ξ_{cc}^{++} - Lifetime

Reference	Ξ_{00}^{++} (ps)	Ξ_{00}^{+} (ps)	Ω_{00}^{+} (ps)
Karliner, Rosner, 2014	0.185	0.053	
Kiselev, Likhoded, Onishchenko, 1998	0.430 +/- 0.100	0.110 +/- 0.010	
Kiselev, Likhoded, 2002	0.460 +/- 0.050	0.160 +/- 0.050	0.270 +/- 0.060
Guberina, Melic, Stefancic, 1998	1.050	0.200	0.300
Chang, Li, Li, Wang, 2007	0.670	0.250	0.210

Lifetime measurement

- ☐ We perform a lifetime measurement, using the $\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$ decay, relative to the control channel of same topology, $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^- \pi^+ \pi^-$

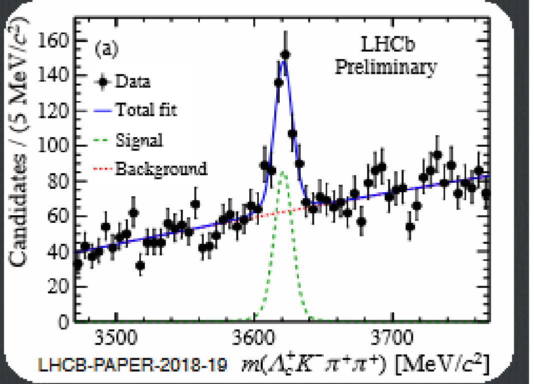
- ☐ Unbinned maximum likelihood fit of the background subtracted Ξ_{cc}^{++} decay time distribution (sFit)

$$f_{\Xi_{cc}^{++}}(t) = h_{\Lambda_b^0}(t) \times \frac{\epsilon_{\Xi_{cc}^{++}}(t)}{\epsilon_{\Lambda_b^0}(t)} \times e^{-\left(\frac{1}{\tau_{\Xi_{cc}^{++}}} - \frac{1}{\tau_{\Lambda_b^0}}\right)t}$$

- ☐ Λ_b^0 data and acceptances incorporated to PDF as histograms

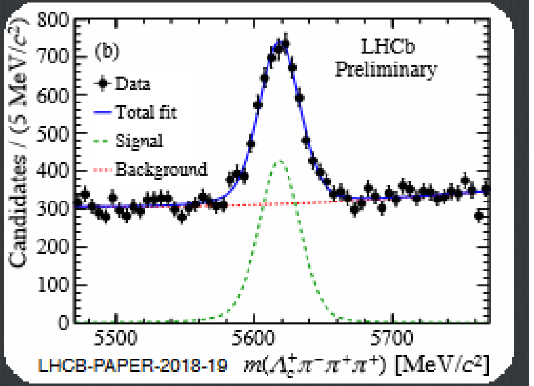
- ☐ PDG Λ_b^0 lifetime (1.470 +/- 0.010 ps) used as input

- ☐ Measurement performed with Λ_b^0 and result consistent with PDG value



LHCB-PAPER-2018-19

$$N_{\Xi_{cc}^{++}} = 304 \pm 35$$

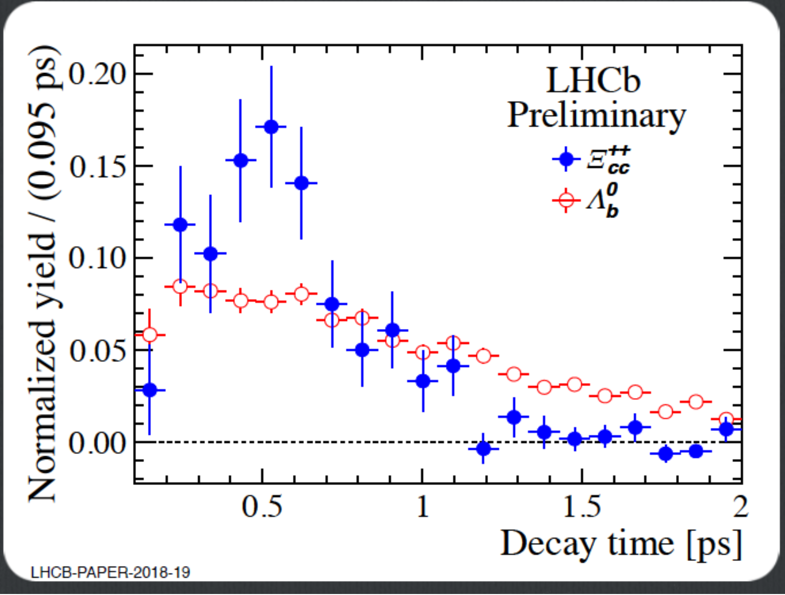


LHCB-PAPER-2018-19

$$N_{\Lambda_b^0} = 3397 \pm 119$$

- ☐ LHCb 2016 (~1.7 fb^{-1} - 13TeV)
- ☐ Mostly same selection criteria of observation
- ☐ Specific hardware trigger:
  - Large hadronic ET deposit from decay products;
  - Or large ET deposit in calorimeters or muon stations from tracks other than the decay products
- ☐ Decay time range: 0.10-2.00 ps

Decay time



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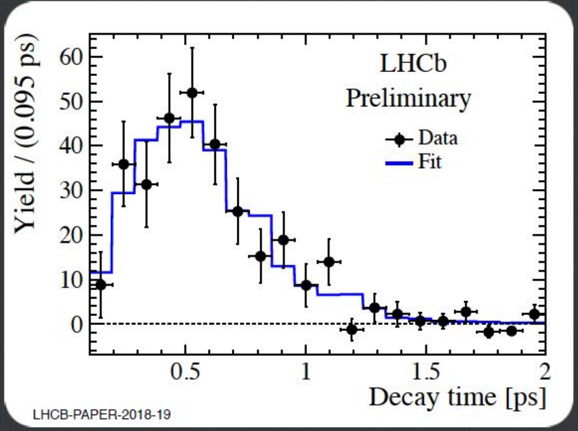
Results



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$$\tau_{\Xi_{cc}^{++}} = 0.256^{+0.024}_{-0.022} \text{ ps (stat. only)}$$

$$\sigma_{MC} = 0.007 \text{ ps}$$
$$\sigma_{\Lambda_b^0} = 0.006 \text{ ps}$$

Statistical errors from MC and Λ_b^0 samples obtained from pseudoexperiments

Ξ_{cc}^{++} - Lifetime

Reference	Ξ_{oo}^{++} (ps)	Ξ_{oo}^{+} (ps)	Ω_{oo}^{+} (ps)
Karliner, Rosner, 2014	0.185	0.053	
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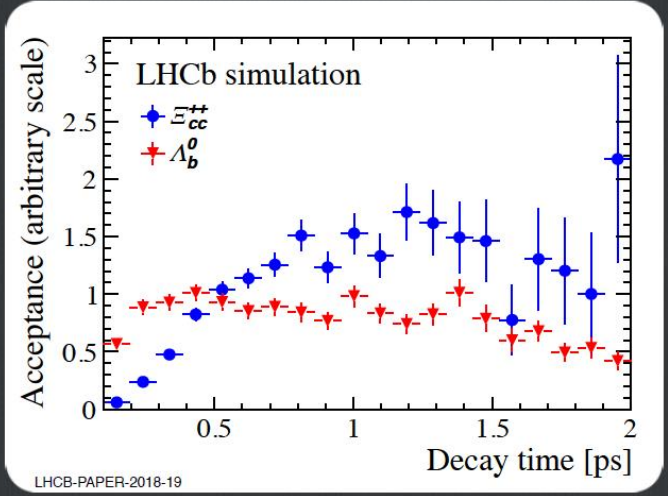
Decay time and acceptance



LHCB-PAPER-2018-19

$$\epsilon(t) = \frac{N_{rec}(t)}{N_{gen}(t)}$$

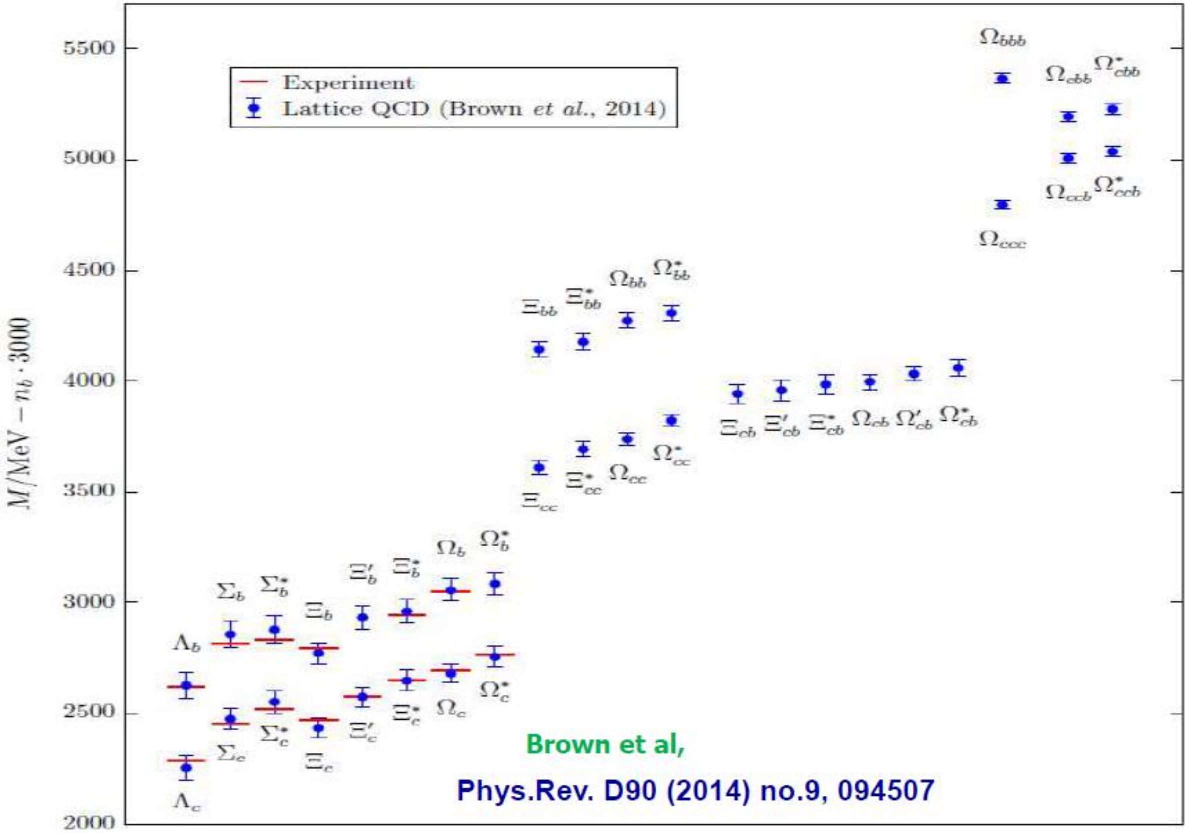
☐ MC samples reweighted to match PT distributions in data

Systematic uncertainties

Source	Uncertainty (ps)
Signal and background mass models	0.005
Correlation of mass and decay-time	0.004
Binning	0.001
Data-simulation differences	0.004
Resonant structure of decays	0.011
Hardware trigger threshold	0.002
Simulated Ξ_{cc}^{++} lifetime	0.002
Λ_0^b lifetime uncertainty	0.001
Sum in quadrature	0.014

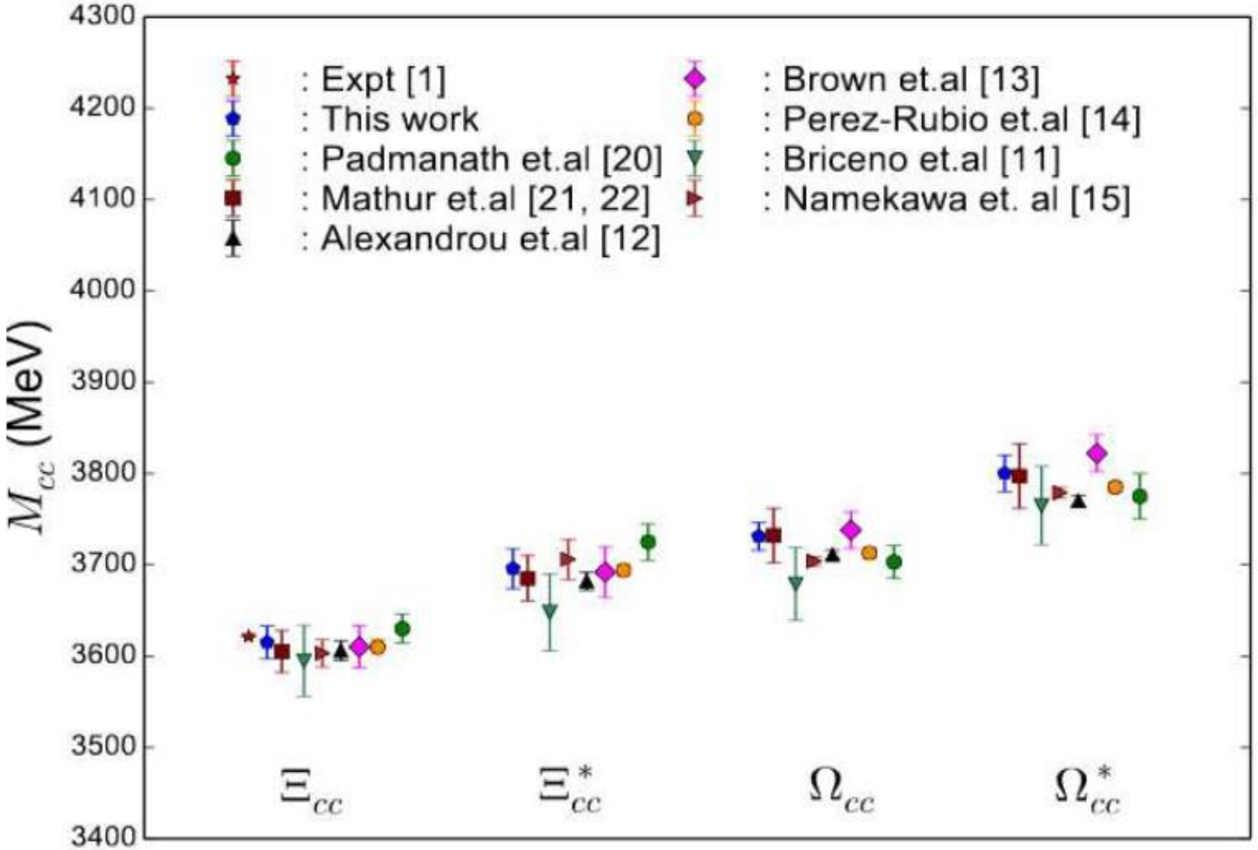
Total systematic uncertainties significantly lower than statistical uncertainties

Предсказания КХД на решетках



Brown et al,

Phys.Rev. D90 (2014) no.9, 094507

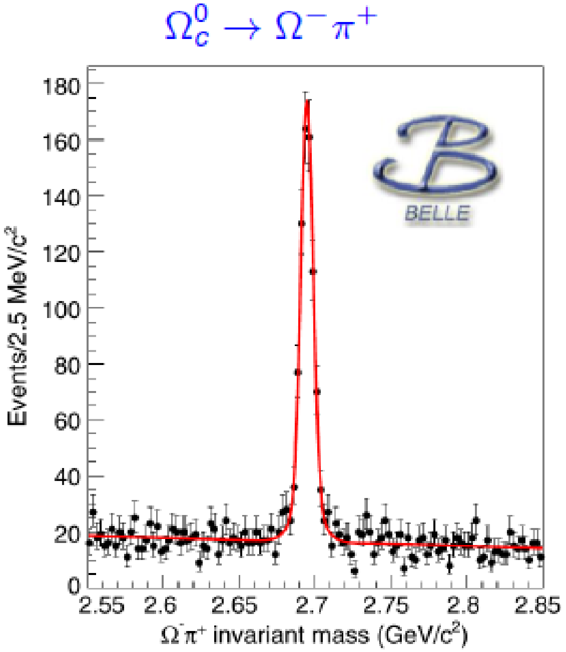


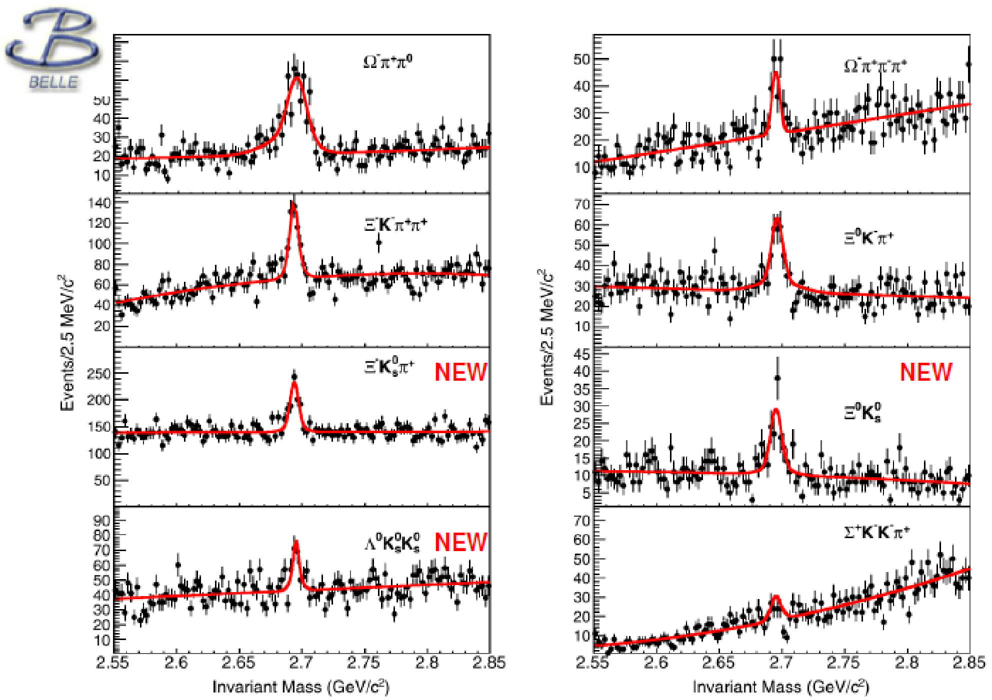
Hadronic decays of Ω_c

- Among 4 ground state charmed baryons, $\Omega_c(css)$ is not studied well as cross section is small.

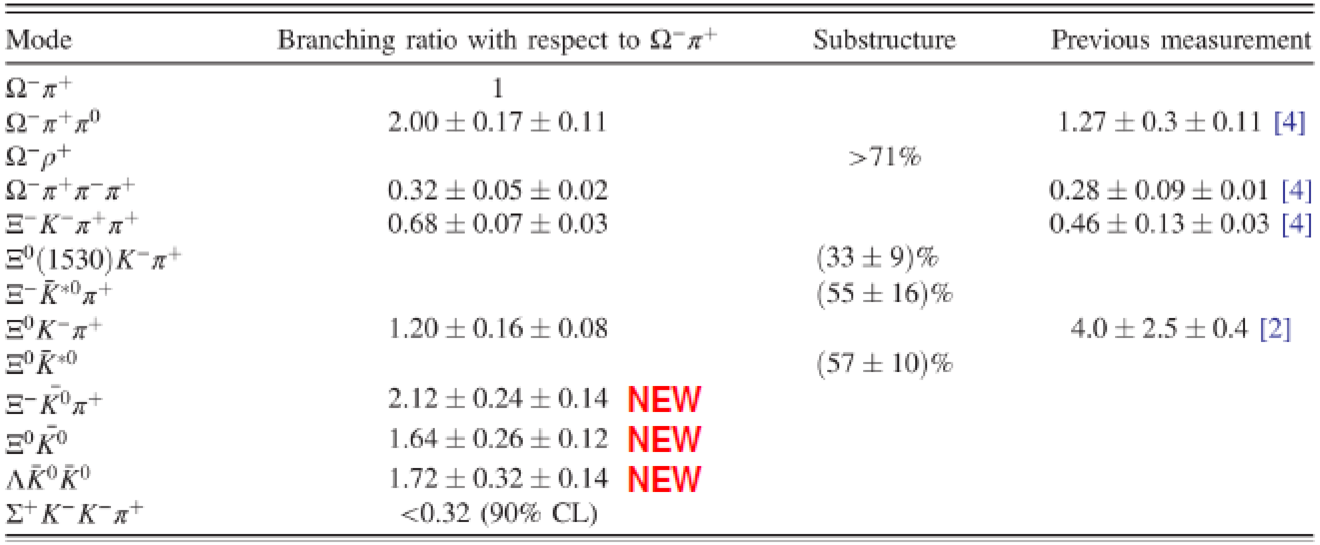
State	Λ_c^+	Ξ_c^0	Ξ_c^+	Ω_c
$\tau(ps)$	200 ± 6	112^{+13}_{-10}	442 ± 26	69 ± 1
$\Delta\tau/\tau$ (%)	3	1	6	17

- Only Ω_c has the same flavor light quarks (ss). Constructive interference is thought to be the origin of its short life time.
- Precise measurements will shed light on the dynamics of baryon weak decays.
- Belle performed measurements of 8 decay modes relative to the bench mark mode: $\Omega^-\pi^+$.
    - Most precisements: $\Omega^-\pi^+\pi^0$, $\Omega^-\pi^+\pi^-\pi^+$, $\Xi^-K^-\pi^+\pi^+$, and $\Xi^0K^-\pi^+$.
    - First measurements: $\Xi^-\bar{K}^0\pi^+$, $\Xi^0\bar{K}^0$ and $\Lambda\bar{K}^0\bar{K}^0$.



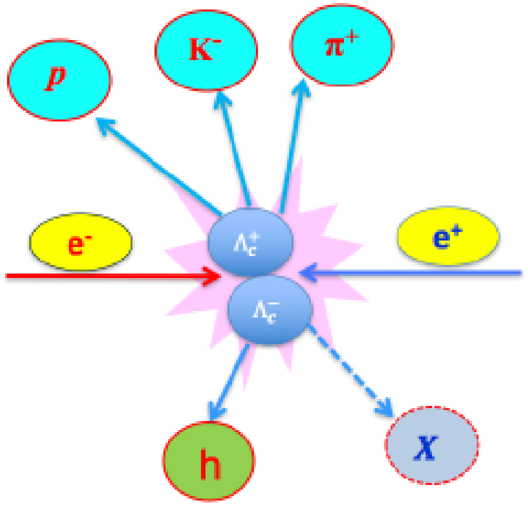


J. Yelton *et al.*, Phys. Rev. D 97, 032001(2018)



Mode	Branching ratio with respect to $\Omega^-\pi^+$	Substructure	Previous measurement
$\Omega^-\pi^+$	1		
$\Omega^-\pi^+\pi^0$	$2.00 \pm 0.17 \pm 0.11$		$1.27 \pm 0.3 \pm 0.11$ [4]
$\Omega^-\rho^+$		>71%	
$\Omega^-\pi^+\pi^-\pi^+$	$0.32 \pm 0.05 \pm 0.02$		$0.28 \pm 0.09 \pm 0.01$ [4]
$\Xi^-K^-\pi^+\pi^+$	$0.68 \pm 0.07 \pm 0.03$		$0.46 \pm 0.13 \pm 0.03$ [4]
$\Xi^0(1530)K^-\pi^+$		$(33 \pm 9)\%$	
$\Xi^-\bar{K}^{*0}\pi^+$		$(55 \pm 16)\%$	
$\Xi^0K^-\pi^+$	$1.20 \pm 0.16 \pm 0.08$		$4.0 \pm 2.5 \pm 0.4$ [2]
$\Xi^0\bar{K}^{*0}$		$(57 \pm 10)\%$	
$\Xi^-\bar{K}^0\pi^+$	$2.12 \pm 0.24 \pm 0.14$ NEW		
$\Xi^0\bar{K}^0$	$1.64 \pm 0.26 \pm 0.12$ NEW		
$\Lambda\bar{K}^0\bar{K}^0$	$1.72 \pm 0.32 \pm 0.14$ NEW		
$\Sigma^+K^-K^-\pi^+$	<0.32 (90% CL)		

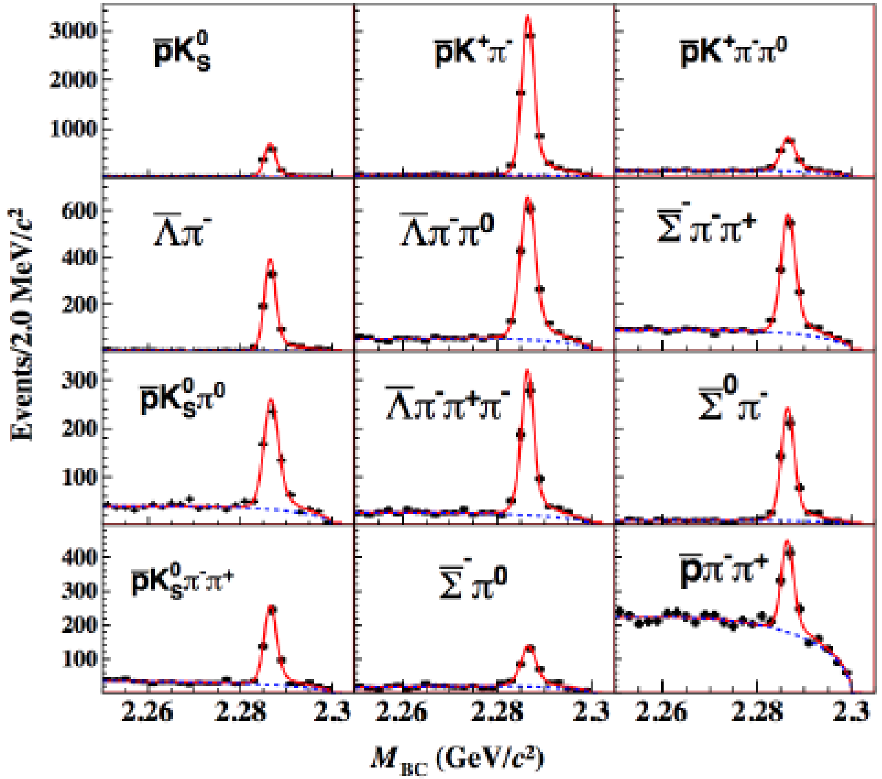
Key variables and ST modes



- $E_{\rm miss}=E_{\rm beam}-E_{\rm h}$; $\vec{p}_{\rm miss}=\vec{p}_{\Lambda c}-\vec{p}_{\rm h}$
- $\vec{p}_{\Lambda c}=-\vec{p}_{\rm tag}\cdot\sqrt{E_{\rm beam}^2-m_{\Lambda c}^2}$
- $U_{\rm miss}=E_{\rm miss}-|\vec{p}_{\rm miss}|$
- $M^2_{\rm miss}=E^2_{\rm miss}-|\vec{p}_{\rm miss}|^2$

- $\hat{p}_{\rm tag}$ is the direction of the momentum of the singly tagged Λ_c .
- $E_{\rm h}(p_{\rm h})$ are the energy(momentum) of h which are measured in e^+e^- system.
- $m_{\Lambda_c^+}$ is the mass of the Λ_c^+ quoted from the PDG.

ST modes



Beam-Constrained-Mass;

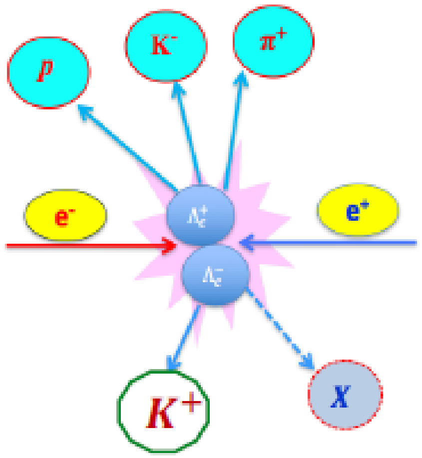
$$M_{\rm BC}=\sqrt{E_{\rm beam}^2-|\vec{p}_{\Lambda c}|^2}$$

$$\sigma\sim 2{\rm MeV}/c^2$$

W-exchange-only process $\Lambda_c^+ \to \Xi^{0(*)}K^+$

arXiv:1803.04299

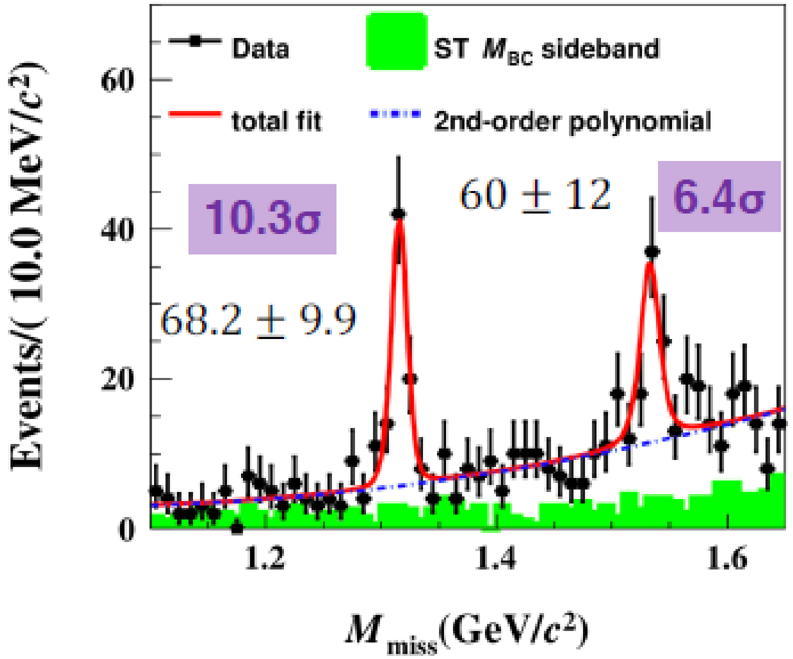
- Double tag and missing $\Xi^{0(*)}$ to increase the detection efficiency
- Low backgrounds because the anti-strangeness of K^+



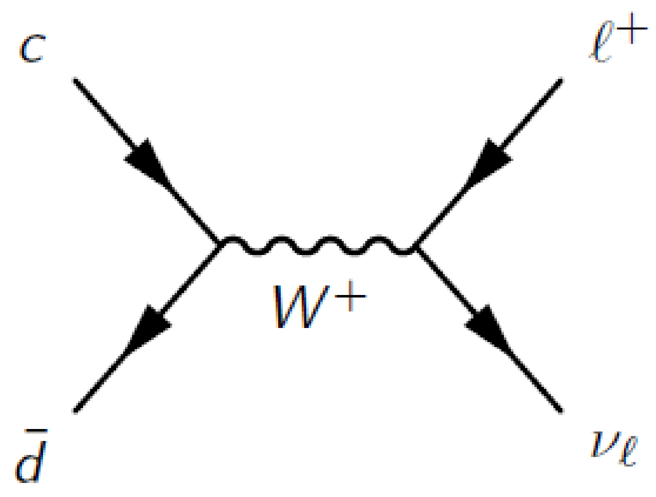
$$\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+) = (5.90 \pm 0.86 \pm 0.39) \times 10^{-3}$$

$$\mathcal{B}(\Lambda_c^+ \to \Xi(1530)^0 K^+) = (5.02 \pm 0.99 \pm 0.31) \times 10^{-3}$$

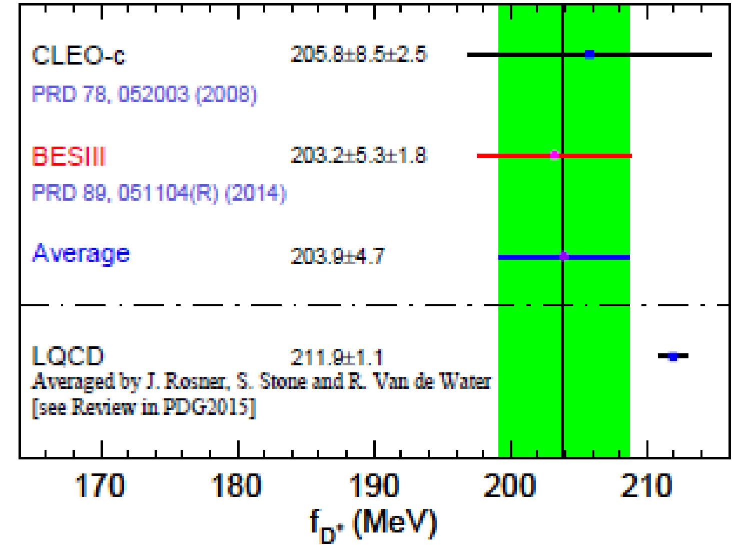
- First absolute measurement of the decay BF
- Improved precision
- No models can accommodate the both rates



Charmed leptonic decays

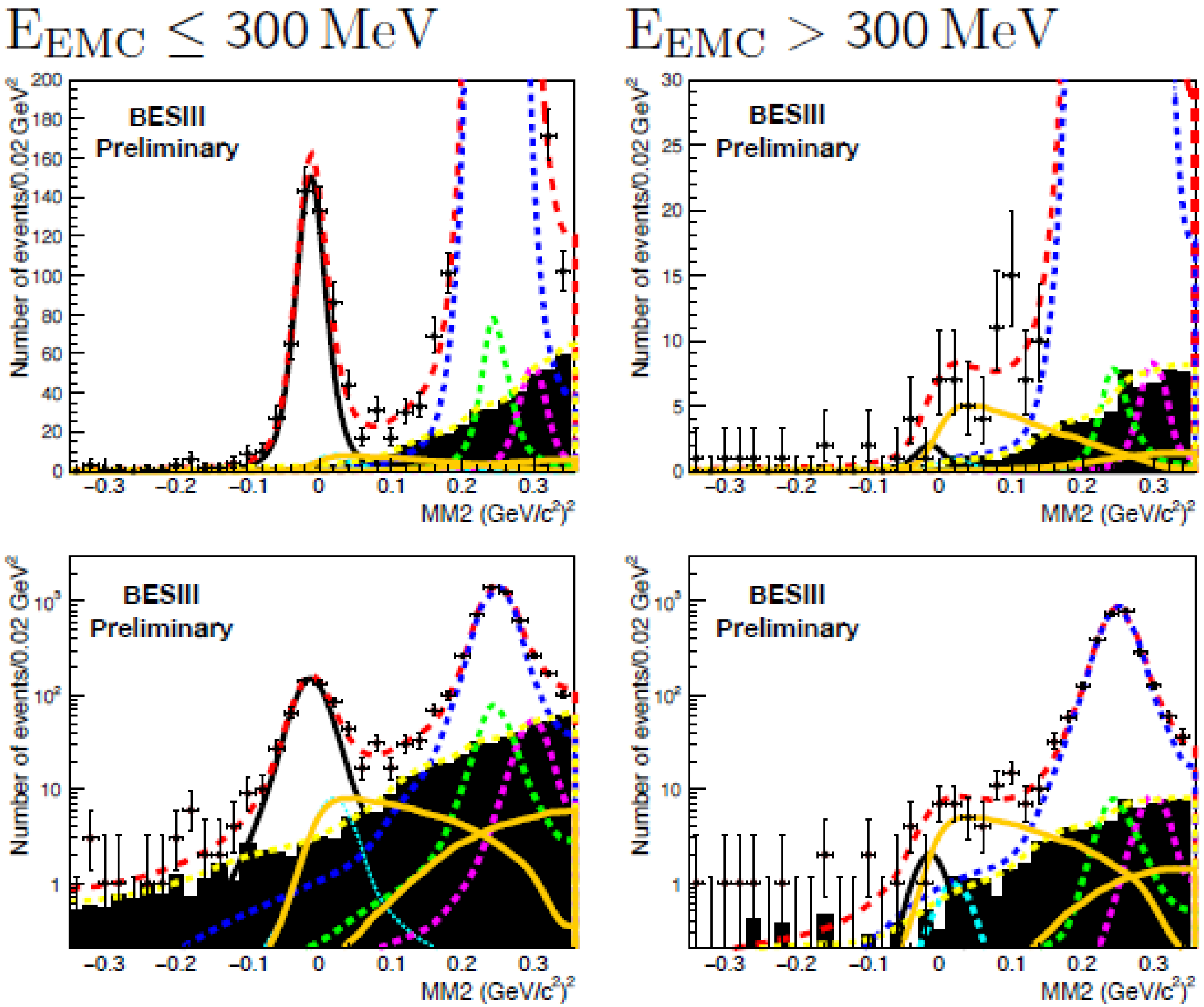


$D^+ \to \mu^+\nu_\mu$



- $\Gamma(D^+ \to \ell^+\nu_\ell) = \frac{G_F^2 f_{D+}^2}{8\pi}|\mathrm{V}_{cd}|^2 m_\ell^2 m_{D+}\left(1 - \frac{m_\ell^2}{m_{D+}^2}\right)^2$
- determine the decay constant f_{D+} and $|\mathrm{V}_{cd}|$
- $\mathcal{B}_{D^+\to\mu^+\nu_\mu} = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}$ by BESIII [PRD 89, 051104 (2014)]
- $\mathcal{B}_{D^+\to\tau^+\nu_\tau} < 1.2 \times 10^{-3}$@90% C.L. by CLEO [PRD 78, 052003 (2008)]
- $R = \frac{\Gamma(D^+\to\tau^+\nu_\tau)}{\Gamma(D^+\to\mu^+\nu_\mu)} = \frac{m_\tau^2\left(1-\frac{m_\tau^2}{m_{D+}^2}\right)^2}{m_\mu^2\left(1-\frac{m_\mu^2}{m_{D+}^2}\right)^2} = 2.66 \to \mathcal{B}_{D^+\to\tau^+\nu_\tau} = (9.99 \pm 0.45) \times 10^{-4}$

Search for $D^+ \to \tau^+\nu_\tau,\ \tau^+ \to \pi^+\bar{\nu}_\tau$



$D^+ \to \tau^+\nu_\tau$

$D^+ \to \mu^+\nu_\mu$

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

$D^+ \to \pi^+K^0_L$

$D^+ \to \pi^+\eta$

$D^+ \to \pi^+K^0_S$

the rest

- $N_{sig} = 137 \pm 27$
- $\mathcal{B}_{D^+\to\tau^+\nu_\tau} = (1.20 \pm 0.24_{stat.}) \times 10^{-3}$
- significance $>4\sigma$

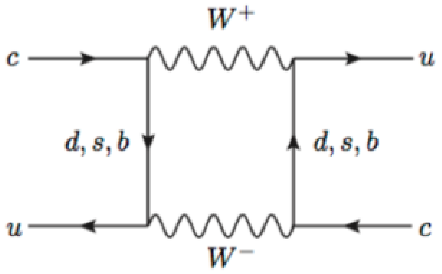
$$M^2_{\mathrm{miss}} = (E_{\mathrm{beam}} - E_{\pi^+})^2 - (-\vec{p}_{D^-} - \vec{p}_{\pi^+})^2$$

R$=3.21 \pm 0.64$, consistent with SM prediction 2.66 within 0.9σ

Смешивание, CP-нарушение, редкие распады

- Параметры смешивания и CPV (WS-анализ)
- ΔA_{CP} в распадах нейтральных мезонов
- CPV в редких распадах

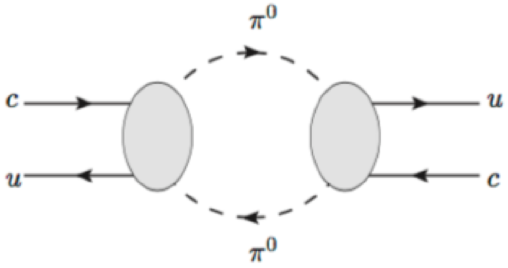
D^0 mixing



"Short distance"

Short distance contribution is CKM + GIM suppressed. NP might manifest in the loop

CKM suppression: b quark
GIM suppression: d,s quark



"Long distance"

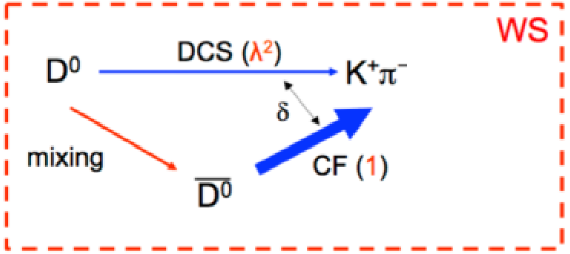
Real particle in the loop

Long distance contribution is dominant but hard to predict

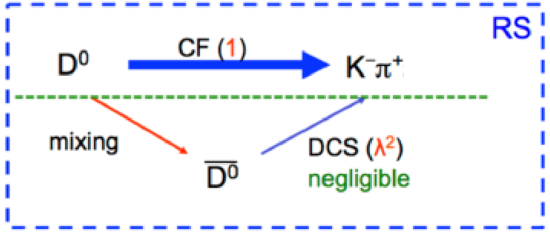
- The D^0 flavor at the production is tagged by $D^{*+} \to D^0\pi^+_s$
- Measure the time dependent ratio of Wrong-Sign $D^{*+}\to[K^+\pi^-]\,\pi^+_s$ and Right-Sign (RS) $D^{*+}\to[K^-\pi^+]\,\pi^+_s$

$$R(t) = \frac{N(D^0\to K^+\pi^-)}{N(D^0\to K^-\pi^+)}$$

For WS two processes interfere:
- Mixing then Cabibbo-Favoured decay
- Doubly-Cabibbo-Suppressed decay



For RS only one process dominates:
- Cabibbo-Favoured decay



Considering negligible CP violation and in the limit of x,y<<1, to second order in t/τ, the time-dependence of the phase-space integrated decay rate ratio R(t) is approximated by:

$$R(t) \approx R_D + \sqrt{R_D}\, y' \,\frac{t}{\tau} + \frac{x'^2 + y'^2}{4}\left(\frac{t}{\tau}\right)^2$$

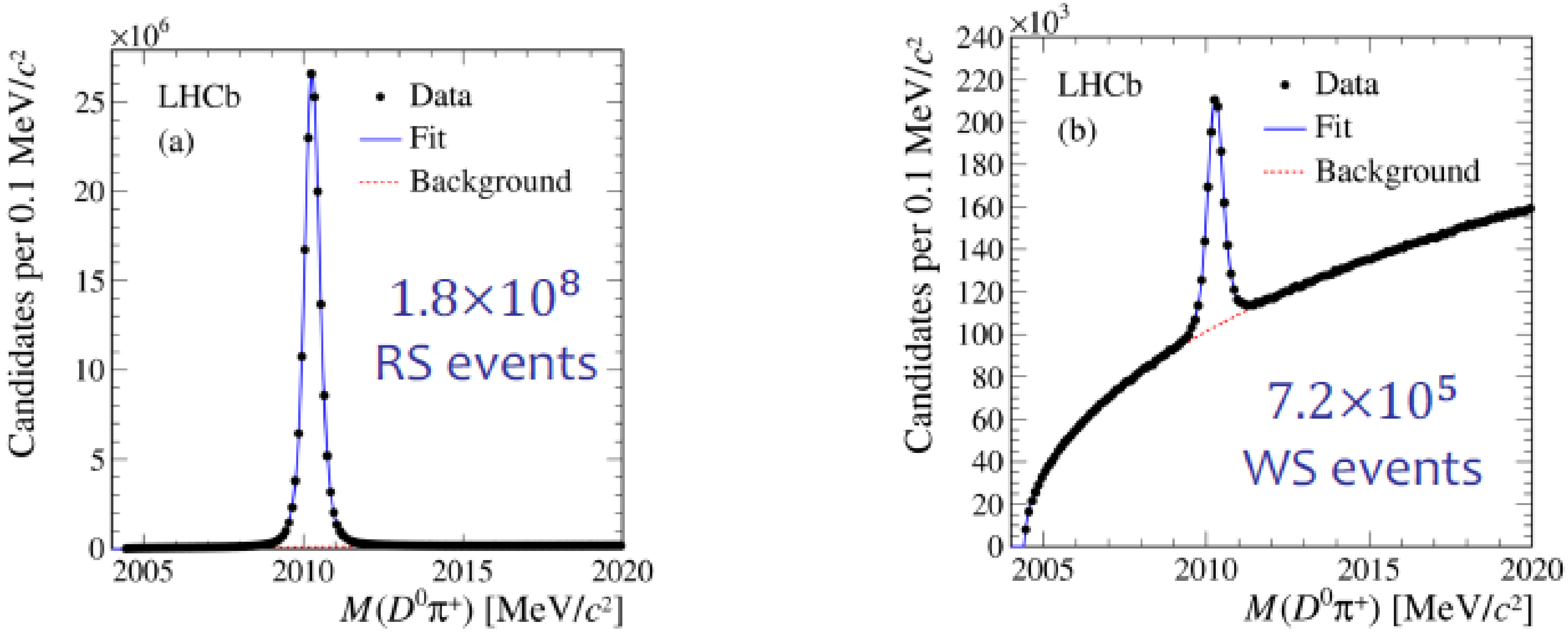
$$\mathcal{A}(D^0 \to K^+\pi^-)/\mathcal{A}(\overline{D}^0 \to K^+\pi^-) = -\sqrt{R_D}e^{-i\delta}$$

$$x' \equiv x\cos\delta + y\sin\delta$$
$$y' \equiv y\cos\delta - x\sin\delta$$

LHCb results with $D^0 \rightarrow K^+\pi^-$

PRD 97 (2018) 031101

- Use tagged (π) $D^0 \rightarrow K^+\pi^-$ decay from $D^{*+} \rightarrow D^0\pi^+$ decay
- Data sample of 5 fb^{-1} of integrated luminosity (2011-2016)
- Constrain $D^0\pi_s^+$ vertex to measured position of primary vertex ⇒ 0.3 MeV/c² invariant-mass resolution
- Fix WS signal shape parameters from RS fits in each decay time bin
- Run 2 signal yields (2015-2016) ~ 2 times larger than Run 1 (2011-2012)



1.8×10^8 RS events

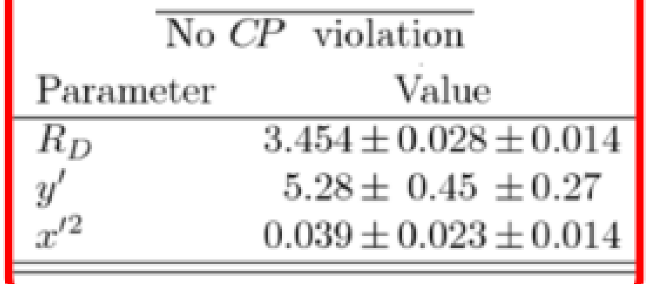
7.2×10^5 WS events

Result on search for CP violation in mixing

PRD 97 (2018) 031101

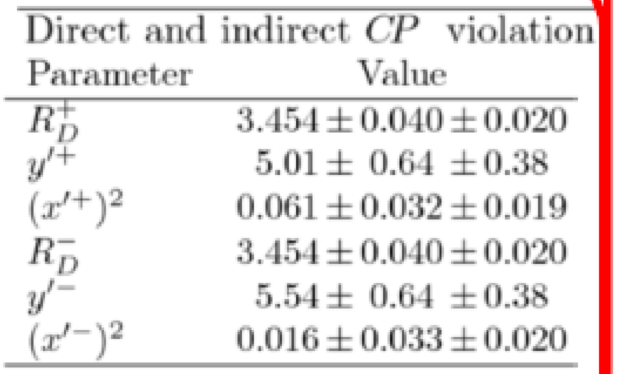
Fit efficiency-corrected data to extract ($x'^{\pm}$, $y'^{\pm}$, $R_D^{\pm}$) under three hypotheses:

- No CPV
- No direct CPV ($R_D^+ = R_D^-$)
- All CPV allowed



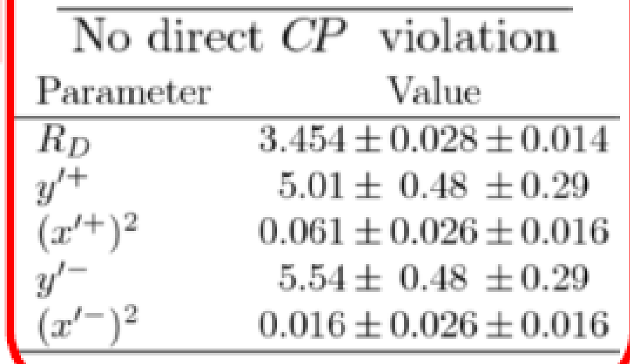
No *CP* violation

Parameter	Value
R_D	$3.454 \pm 0.028 \pm 0.014$
y'	$5.28 \pm\ 0.45\ \pm 0.27$
x'^2	$0.039 \pm 0.023 \pm 0.014$



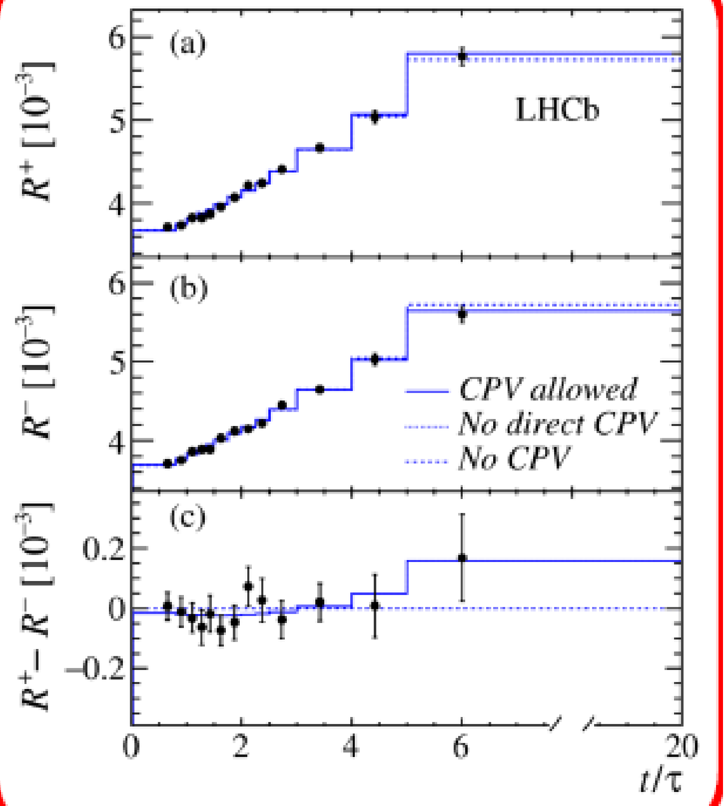
Direct and indirect *CP* violation

Parameter	Value
R_D^+	$3.454 \pm 0.040 \pm 0.020$
y'^+	$5.01 \pm\ 0.64\ \pm 0.38$
$(x'^+)^2$	$0.061 \pm 0.032 \pm 0.019$
R_D^-	$3.454 \pm 0.040 \pm 0.020$
y'^-	$5.54 \pm\ 0.64\ \pm 0.38$
$(x'^-)^2$	$0.016 \pm 0.033 \pm 0.020$



No direct *CP* violation

Parameter	Value
R_D	$3.454 \pm 0.028 \pm 0.014$
y'^+	$5.01 \pm\ 0.48\ \pm 0.29$
$(x'^+)^2$	$0.061 \pm 0.026 \pm 0.016$
y'^-	$5.54 \pm\ 0.48\ \pm 0.29$
$(x'^-)^2$	$0.016 \pm 0.026 \pm 0.016$



Allowing for CP violation, the WS rates $R_-(t)$ and $R_+(t)$ of initially produced D^0 and $\overline{D}^0$ mesons are functions of independent sets of mixing parameters

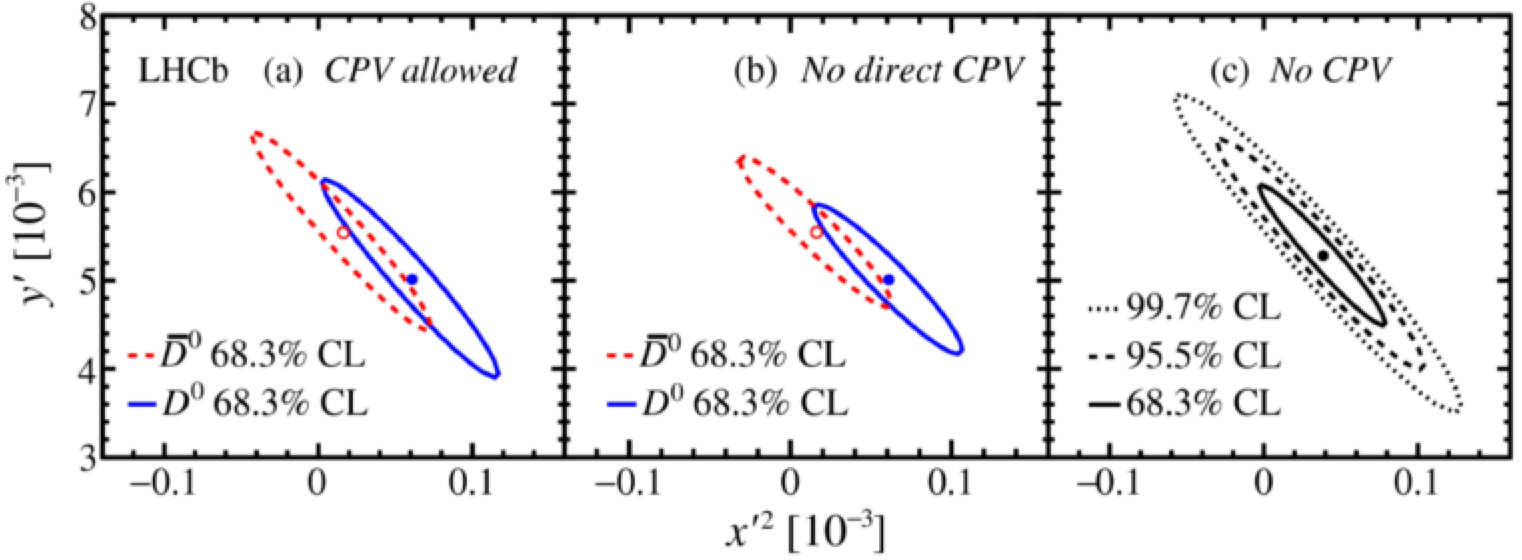
$$(R_D^{\pm}, x'^{2\pm}, y'^{\pm})$$

Direct CP

$$A_D = \frac{R_D^+ - R_D^-}{R_D^+ + R_D^-} = (-0.1 \pm 8.1(stat) \pm 4.2(syst))\times 10^{-3}$$

Two-dimensional confidence regions in the y' and x'^2

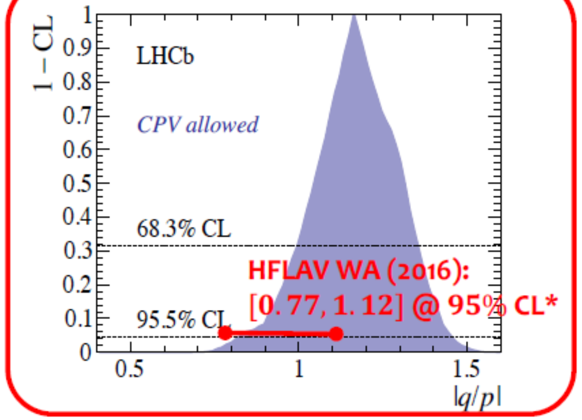
PRD 97 (2018) 031101



- Assuming CP conservation

	R_D (10^{-3})	y' (10^{-3})	x'^2 (10^{-3})
CDF[1]	3.51 ± 0.35	4.3 ± 4.3	0.08 ± 0.18
Belle[2]	3.53 ± 0.13	4.6 ± 3.4	0.09 ± 0.22
BaBar[3]	3.03 ± 0.19	9.7 ± 5.4	-0.22 ± 0.37
LHCb Run 1+2[4]	3.454 ± 0.031	5.28 ± 0.52	0.039 ± 0.027

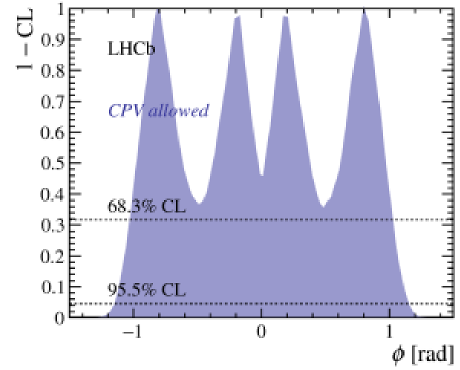
- LHCb completely dominating the scene

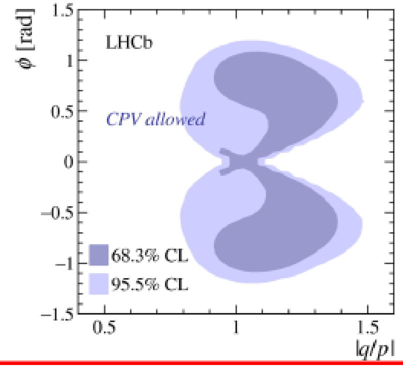


HFLAV WA (2016): [0.77, 1.12] @ 95% CL*

$1.00 < |q/p| < 1.35$ @ 68.3% C.L.

$0.82 < |q/p| < 1.45$ @ 95.5% C.L.





A_{CP} in $D^0 \to K_S^0 K_S^0$ decays

[LHCb-PAPER-2018-012]

- Dataset : 2.0 fb^{-1}, 2015-2016
- Production mode : $D^{*+} \to D^0 \pi^+$
- Raw asymmetry :

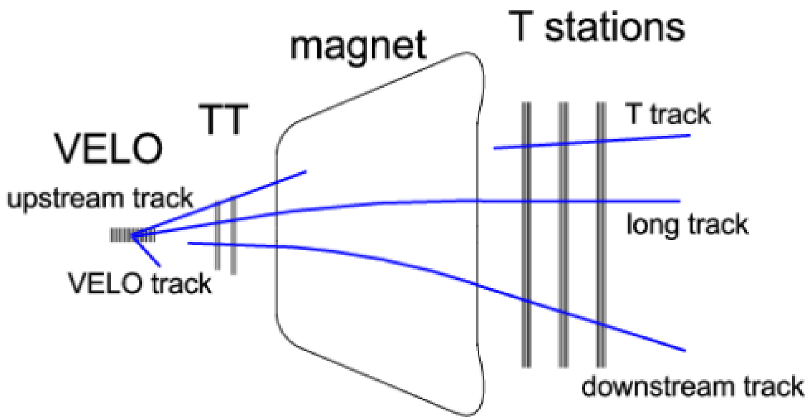
$$A_{\text{raw}}(K_S^0 K_S^0) = A_{CP}(K_S^0 K_S^0) + A_P(D^{*+}) + A_{\text{tag}}(\pi^+)$$

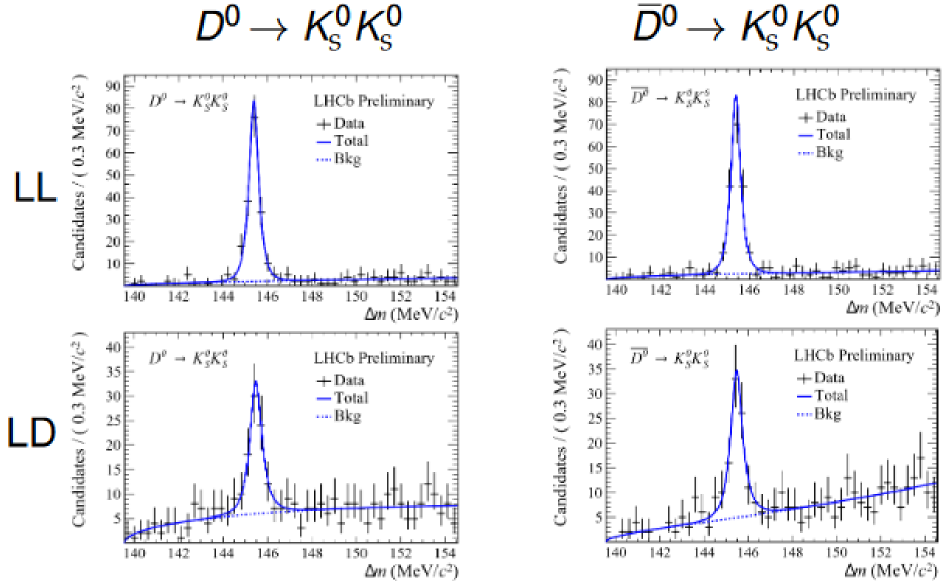
- No detection asymmetries from the daughters of the D^0 since they are symmetric
- Removing production and tagging asymmetries by using a control channel $D^0 \to K^+ K^-$:

$$\Delta A_{CP} = A_{\text{raw}}(K_S^0 K_S^0) - A_{\text{raw}}(K^+ K^-)$$
$$= A_{CP}(K_S^0 K_S^0) - A_{CP}(K^+ K^-)$$

For this analysis:

- LL: the two K_S^0 decay in the VELO and have long tracks
- LD: one K_S^0 has a long track and one decays downstream of the VELO (downstream track)

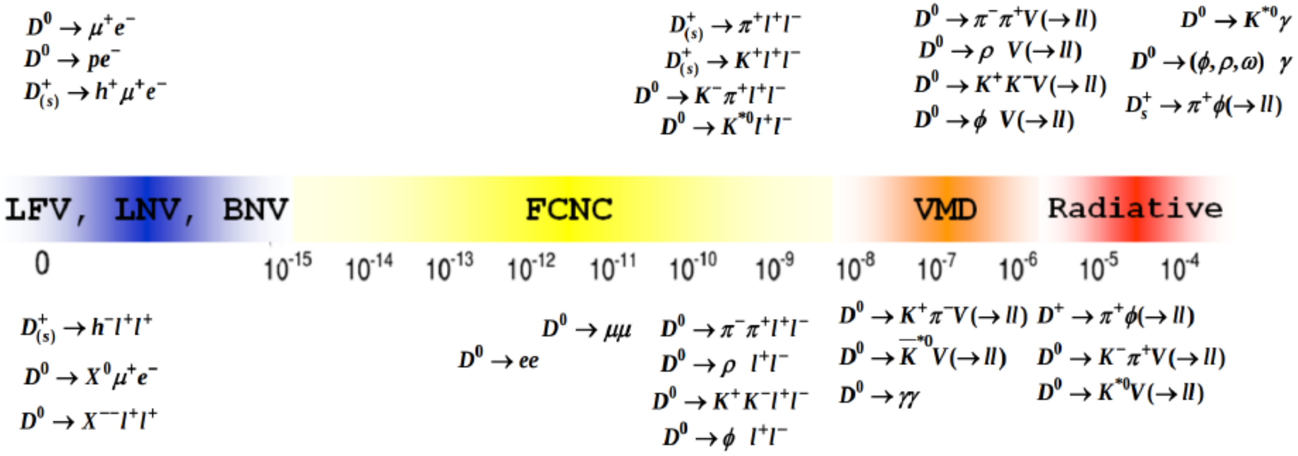




- $A_{CP} = (4.2 \pm 3.4 \pm 1.0)\%$
- Compatible with Run 1 result: $A_{CP} = (-2.9 \pm 5.2 \pm 2.2)\%$
- Average : $A_{CP} = (2.0 \pm 2.9 \pm 1.0)\%$

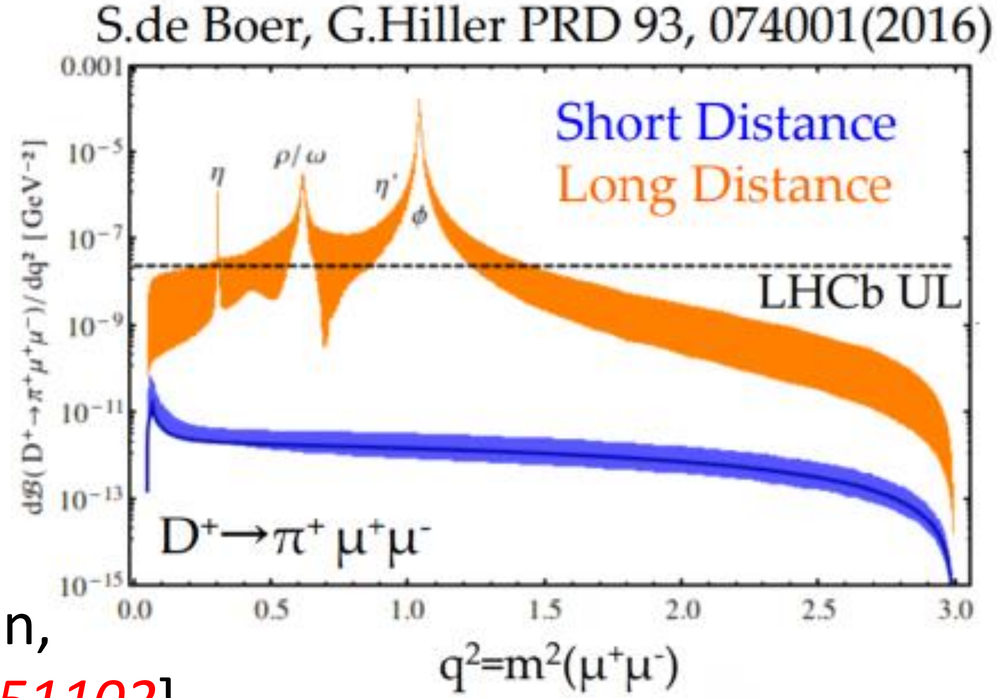
→ Catching up with the Belle result

Impact for rare decays (what can be done?)



[PRD 66 (2002) 014009]

Intermediate vector resonances in the dimuon spectrum can hide short distance (SM) contribution


S.de Boer, G.Hiller PRD 93, 074001(2016)

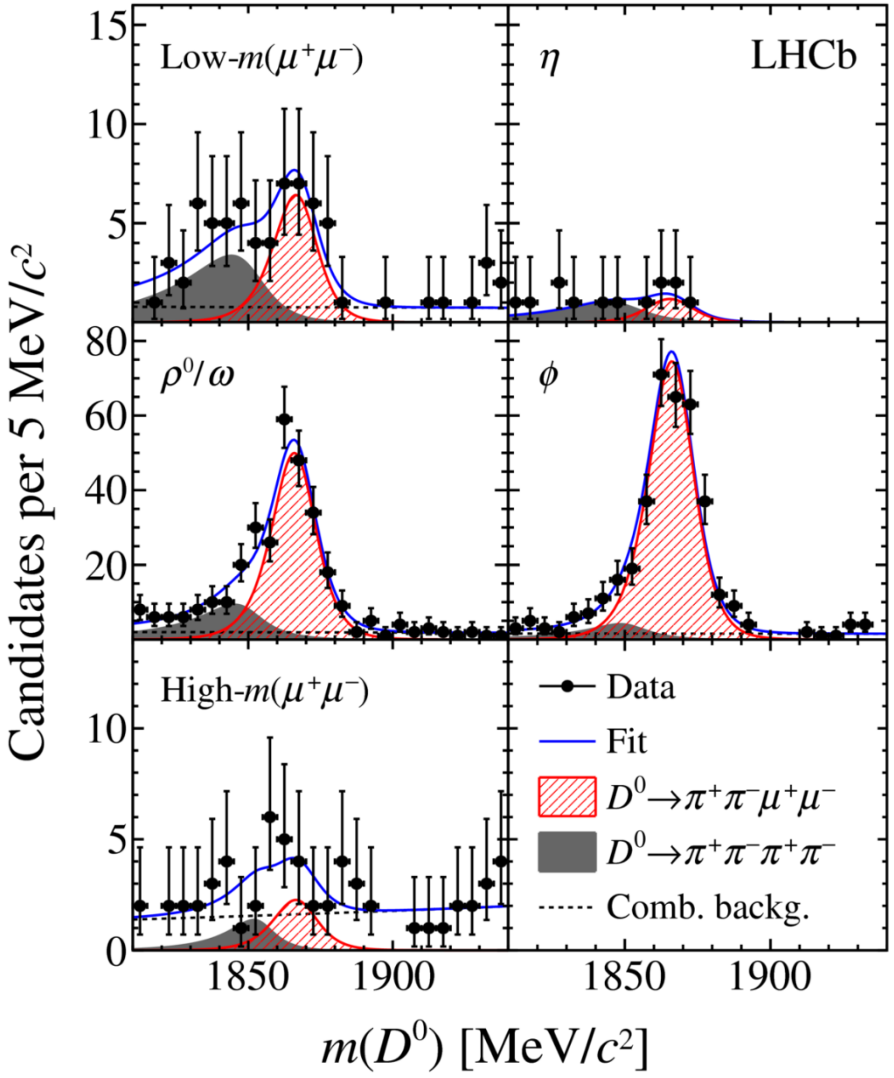
LHCb will keep pushing down the limits as there is still some room for New Physics:

- BR($D^0 \to \mu^+ \mu^-$) < 7.6 x 10^{-9} (90% CL) with 1 fb^{-1}
  PLB 725 (2013) 15 (working on update)
- SM predictions ~ 10^{-12} [long distance $\gamma\gamma$ recombination, based on Belle limits on BR($D^0 \to \gamma\gamma$), *PRD 93 (2016) 051102*]

Impact for rare decays (what can be done?)

Phys. Rev. Lett. 119, 181805 (2017)

- *CP*- and *T*-asymmetries for rare decays
- Lepton Flavor Violation (LFV) to be examined
- Lepton Universality (LU) in charm sector
- Angular and amplitude analyses



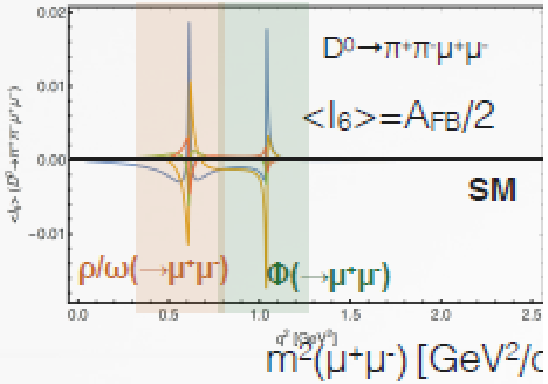
Asymmetries in $D^0 \rightarrow \pi^+\pi^-(K^+K^-)\mu^+\mu^-$

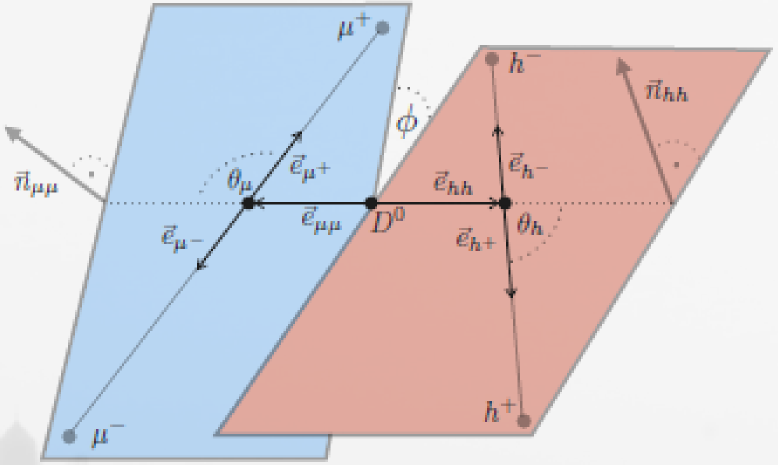
[LHCb-PAPER-2018-020]

- for the first time, measurements of angular and CP asymmetries in these decays
  - conceptual new and complementary to BF measurements
- asymmetries are sensitive to **SD** in full range due to **SD**-**LD** interference
  - observables are SM null tests
  - O(few%) predictions for some NP models

JHEP 1304 135 (2013)
PRD 87 054026 (2013)
D 93, 074001 (2016)
[arXiv:1805.08516]

[arXiv:1805.08516]





- angular asymmetries
  - forward backward asymmetry

$$A_{\mathrm{FB}} = \frac{\Gamma(\cos\theta_\mu > 0) - \Gamma(\cos\theta_\mu < 0)}{\Gamma(\cos\theta_\mu > 0) + \Gamma(\cos\theta_\mu < 0)}$$

  - triple product asymmetry

$$A_\phi = \frac{\Gamma(\sin 2\phi > 0) - \Gamma(\sin 2\phi < 0)}{\Gamma(\sin 2\phi > 0) + \Gamma(\sin 2\phi < 0)}$$

- CP asymmetry

$$A_{CP} = \frac{\Gamma(D^0 \to h^+h^-\mu^+\mu^-) - \Gamma(\overline{D}^0 \to h^+h^-\mu^+\mu^-)}{\Gamma(D^0 \to h^+h^-\mu^+\mu^-) + \Gamma(\overline{D}^0 \to h^+h^-\mu^+\mu^-)}$$

Asymmetries in $D^0 \to \pi^+\pi^-(K^+K^-)\mu^+\mu^-$

[LHCb-PAPER-2018-020]

Measurement strategy

- measure A_{FB}, A_{Φ} and A_{CP} binned and integrated in dimuon mass
  - quote results where significant signal was observed in BF measurement
  - split bins at resonance peak positions (for $D^0 \to \pi^+\pi^-\mu^+\mu^-$)

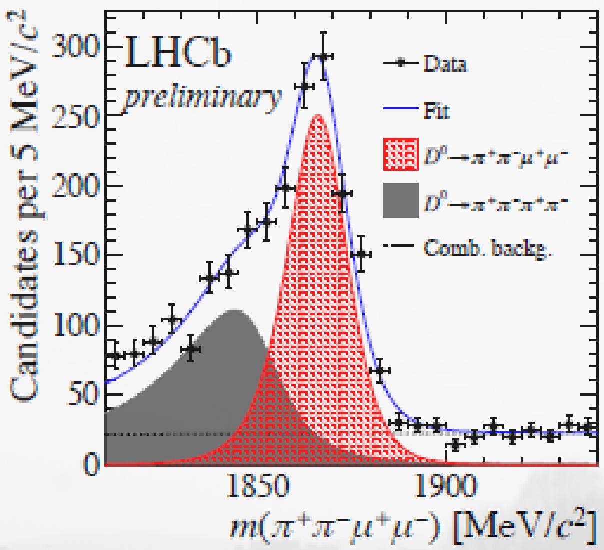
	$m(\mu^+\mu^-)$ [MeV/c^2]						
Decay mode	low mass	η	ρ/ω		ϕ		high mass
$D^0 \to K^+K^-\mu^+\mu^-$	< 525	NS	> 565		NA		NA
$D^0 \to \pi^+\pi^-\mu^+\mu^-$	< 525	NS	565-780	780-950	950-1020	1020-1100	NS

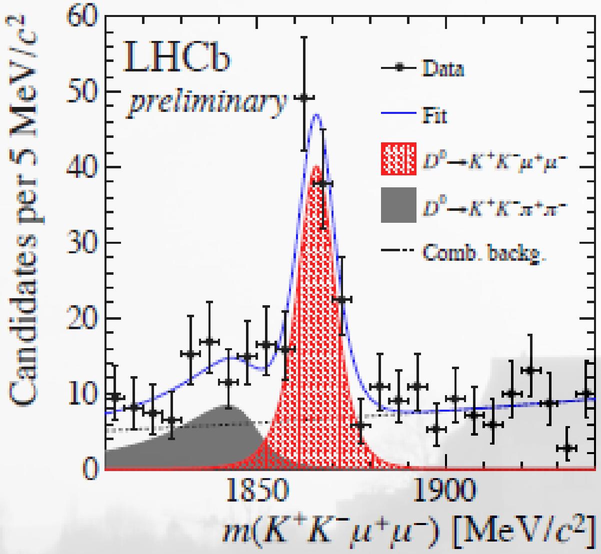
Experimental details

- select D^0 from flavour sepecific $D^{*+} \to D^0\pi^+$ decays
- increased data statistics: 5/fb recorded 2011-2016

- total yields
  - $D^0 \to \pi^+\pi^-\mu^+\mu^-$: 1.1k
  - $D^0 \to K^+K^-\mu^+\mu^-$: 110

- sensitivity on asymmetries of a few % already now!





Asymmetries in $D^0 \to \pi^+\pi^-(K^+K^-)\mu^+\mu^-$

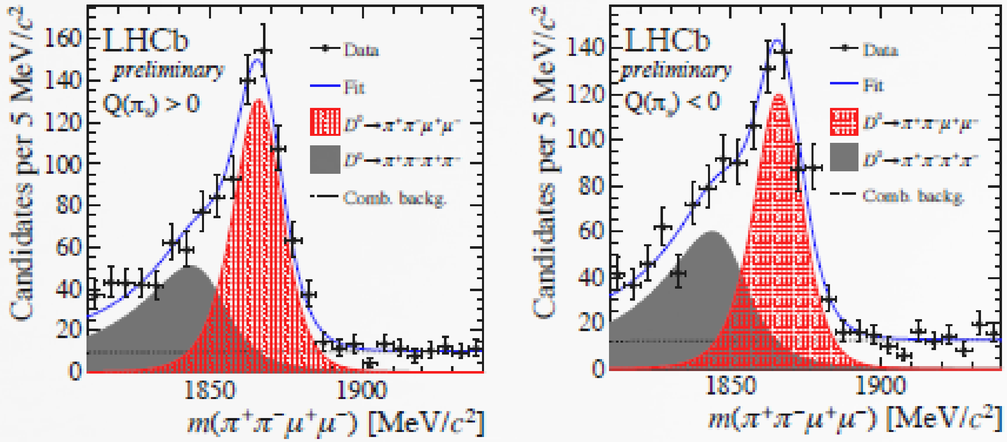
[LHCb-PAPER-2018-020]

Determination of the asymmetries

- split data set according to *tag*

A_{FB}	A_{Φ}	A_{CP}
$\cos(\theta_\mu) > 0$	$\sin(2\Phi)>0$	$Q(\pi^+) < 0$
$\cos(\theta_\mu) < 0$	$\sin(2\Phi)<0$	$Q(\pi^+) > 0$

- perform simultaneous fit to efficiency corrected m(D^0) with asymmetry as shared parameter

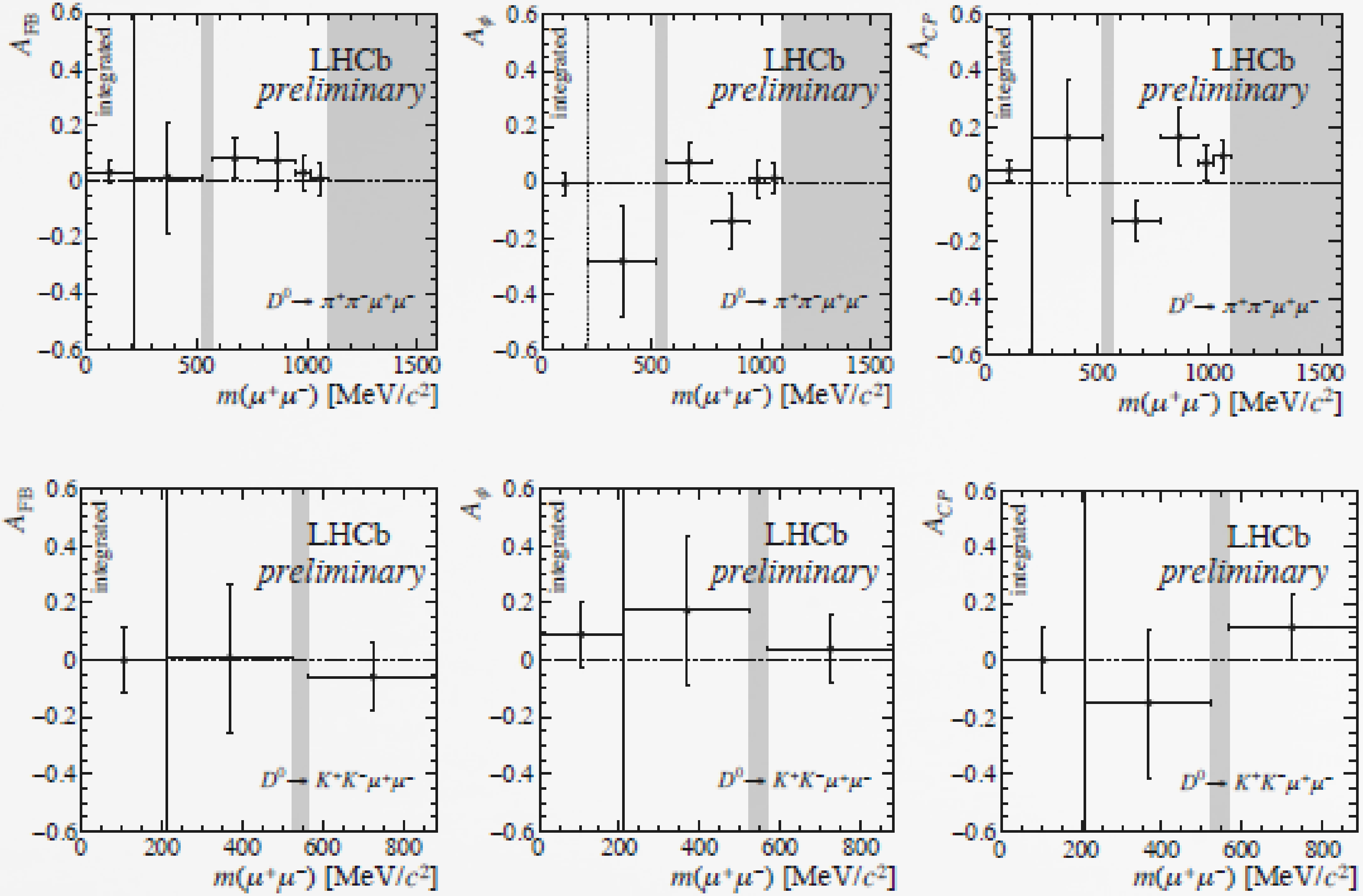


- use control samples of $D^{+*}\to D^0(\to K^+K^-)\pi_s^+$ decays to correct for production and charge dependent detection asymmetries

$$A_{CP}^{\mathrm{raw}}(f) = \frac{N[D^{*+}\to D^0(\to f)\pi^+] - N[D^{*-}\to \overline{D}^0(\to f)\pi^-]}{N[D^{*+}\to D^0(\to f)\pi^+] + N[D^{*-}\to \overline{D}^0(\to f)\pi^-]} \approx A_{CP}(f) + A_d(\pi^+) + A_P(D^{*+})$$

$$A_{CP}(h^+h^-\mu^+\mu^-) = A_{CP}^{\mathrm{raw}}(h^+h^-\mu^+\mu^-) - A_{CP}^{\mathrm{raw}}(K^+K^-) + A_{CP}(K^+K^-)$$

JHEP 07 041 (2014)



Total asymmetries

$$A_{\rm FB}(D^0 \to \pi^+\pi^-\mu^+\mu^-) = (3.3 \pm 3.7 \pm 0.6)\%,$$
$$A_\phi(D^0 \to \pi^+\pi^-\mu^+\mu^-) = (-0.6 \pm 3.7 \pm 0.6)\%,$$
$$A_{CP}(D^0 \to \pi^+\pi^-\mu^+\mu^-) = (4.9 \pm 3.8 \pm 0.7)\%,$$
$$A_{\rm FB}(D^0 \to K^+K^-\mu^+\mu^-) = (0 \pm 11 \pm 2)\%,$$
$$A_\phi(D^0 \to K^+K^-\mu^+\mu^-) = (9 \pm 11 \pm 1)\%,$$
$$A_{CP}(D^0 \to K^+K^-\mu^+\mu^-) = (0 \pm 11 \pm 2)\%.$$

- uncertainties are statistical and systematic

compatible with SM predictions
[JHEP 04 135 (2013)]

- all asymmetries consistent with zero
- no dependency on dimuon mass observed

Измерение сечение рождения очаровательных частиц

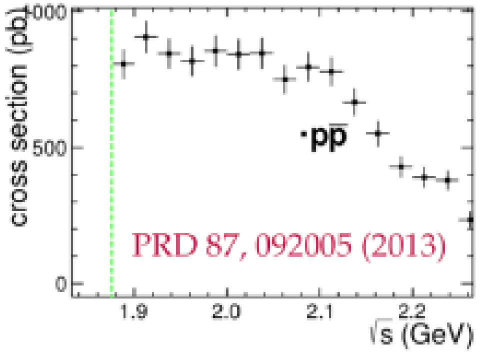
- Рождение барион-антибарионных пар
- Свойства чармония
- Рождение пар (*R*)

The cross-section of baryon pair

The Born cross section of the reaction $e^+e^- \to \gamma^* \to B\bar{B}$ can be parameterized in terms of electromagnetic form factors:

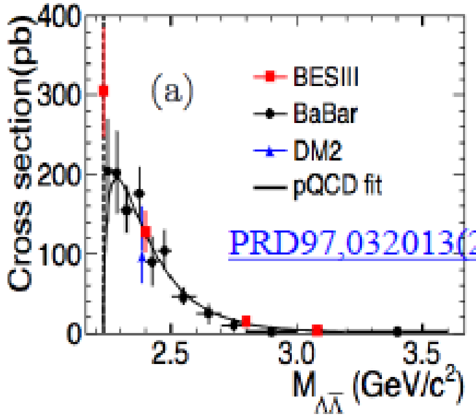
$$\sigma_{B\bar{B}}(q) = \frac{4\pi\alpha^2 C\beta}{3q^2}[|G_M(q)|^2 + \frac{1}{2\tau}|G_E(q)|^2]$$

- Baryon velocity $\beta = \sqrt{1 - 4m_B^2c^4/q^2}$, $\tau = q^2/(4m_B^2c^4)$
- For charged B, the Coulomb factor C will results in a non-zero cross section at threshold



PRD 87, 092005 (2013)

- $e^+e^- \to p\bar{p}$: an enhancement and wide-range plateau in the line-shape
- $e^+e^- \to \Lambda\bar{\Lambda}$: non-zero cross section near threshold
- It can be anticipate that Λ_c^+ has a similar behaviour with proton
- Belle collaboration has measured the cross section of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ using ISR technique PRL 101, 172001 (2008)

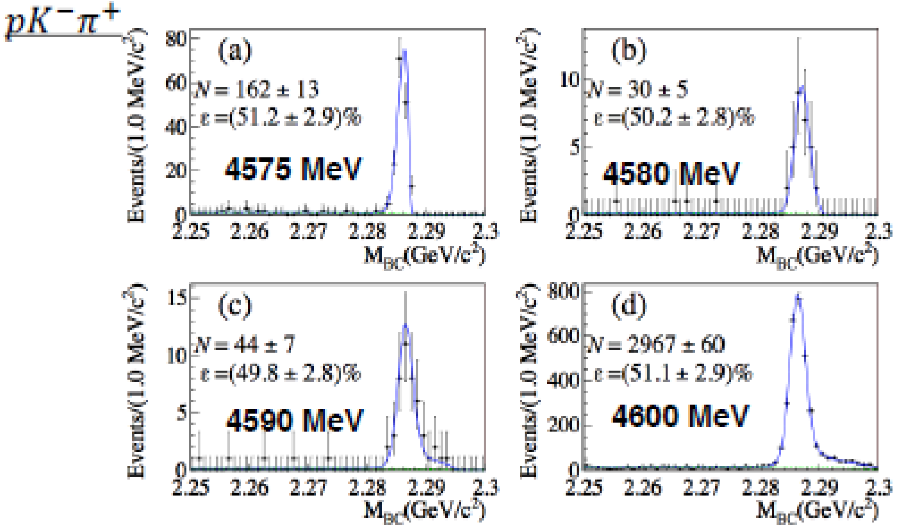


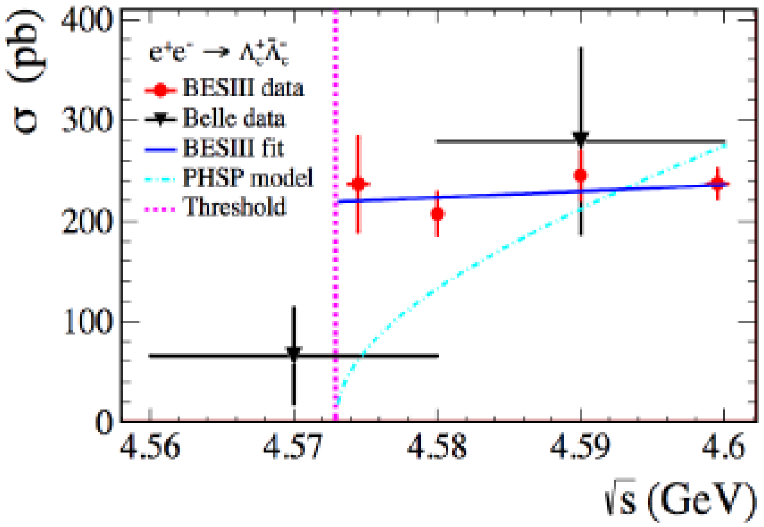
PRD97,032013(2018)

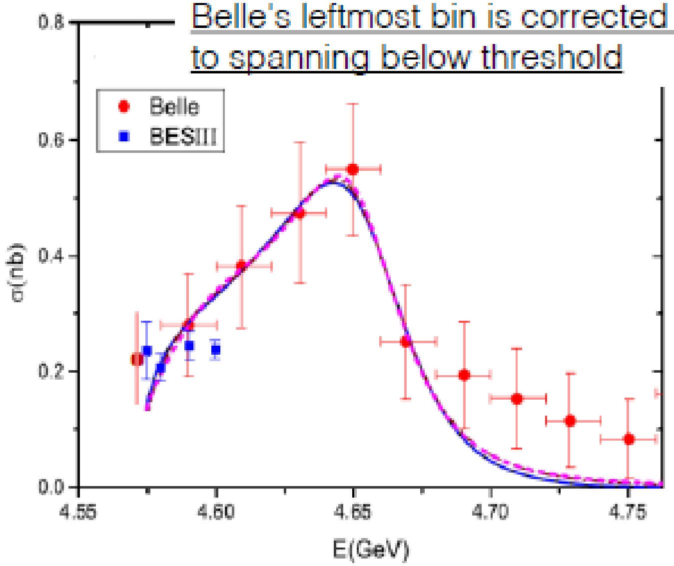
Study of $e^+e^-\to \Lambda_c^+\Lambda_c^-$ near threshold

Combined analysis of 10 ST hadronic modes

PRL 120, 132001 (2018)





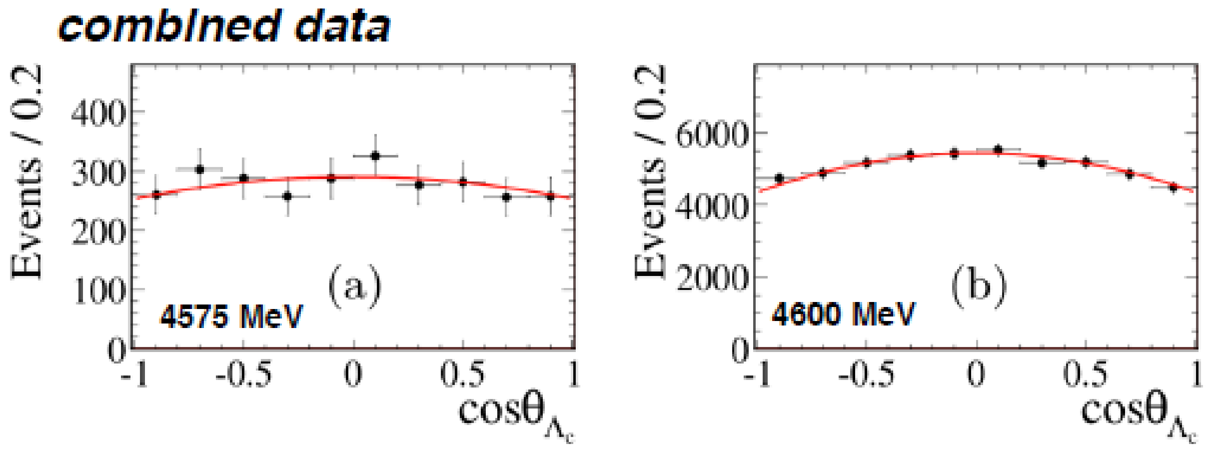


Belle's leftmost bin is corrected due to spanning below threshold

- The cross sections are measured with unprecedented precision
- Enhanced cross section of reaction $e^+e^-\to\Lambda_c^+\bar{\Lambda}_c^-$ near threshold is discerned for the first time
- The Coulomb enhanced factor?

Angular dependence analysis of $e^+e^- \to \Lambda_c^+\Lambda_c^-$ near threshold

PRL 120, 132001 (2018)



$$f(\theta) \propto (1+\alpha_{\Lambda_c}\cos^2\theta)$$

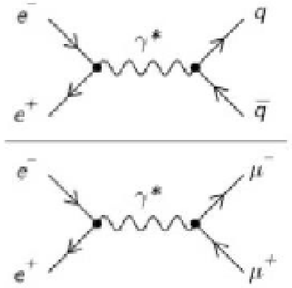
$$|G_E/G_M|^2(1-\beta^2) = (1-\alpha_{\Lambda_c})/(1+\alpha_{\Lambda_c}).$$

$\sqrt{s}$ (MeV)	α_{Λ_c}	$\lvert G_E/G_M\rvert$
4574.5	$-0.13 \pm 0.12 \pm 0.08$	$1.14 \pm 0.14 \pm 0.07$
4599.5	$-0.20 \pm 0.04 \pm 0.02$	$1.23 \pm 0.05 \pm 0.03$

- One of the most basic observables that intimately related to the internal structure of the nucleon.
- One of the most challenging questions in contemporary physics is why and how quarks are confined into hadrons.
- The electromagnetic form factors (EMFFs) have been a powerful tool in understanding the structure of nucleons.
- First measurements of the EMFFs of the Λ_c^+

R measurement

$$R = \frac{\sigma(e^-e^+ \to \mathrm{hadrons})}{\sigma(e^-e^+ \to \mu^-\mu^+)} \approx$$



Precise R measurement at low energies is important in calculation of fundamental values:

- $\alpha_s(s)$
- $(g_\mu-2)/2$
- $\alpha(M_Z^2)$
- Heavy quark masses

At first approximation:

$$R(s) \simeq 3\sum e_q^2$$

3.12 – 3.72 GeV, data 2011, L = 1.4 pb-1

Phys. Lett. B 753 (2016) 533

1.84 – 3.05 GeV, data 2010, L = 0.65 pb-1

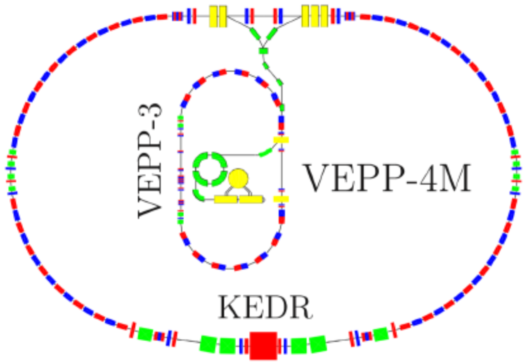
Phys. Lett. B 770 (2017) 174

New measurement:

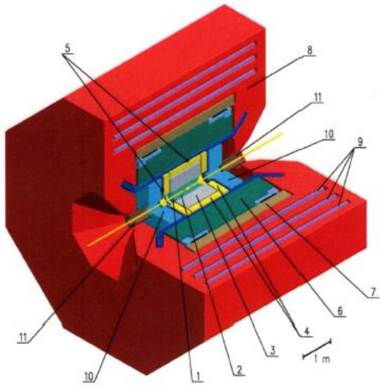
3.08 – 3.72 GeV, data 2014-15 (after detector repair), 8 points, $L = 1.3\ \mathrm{pb}^{-1}$

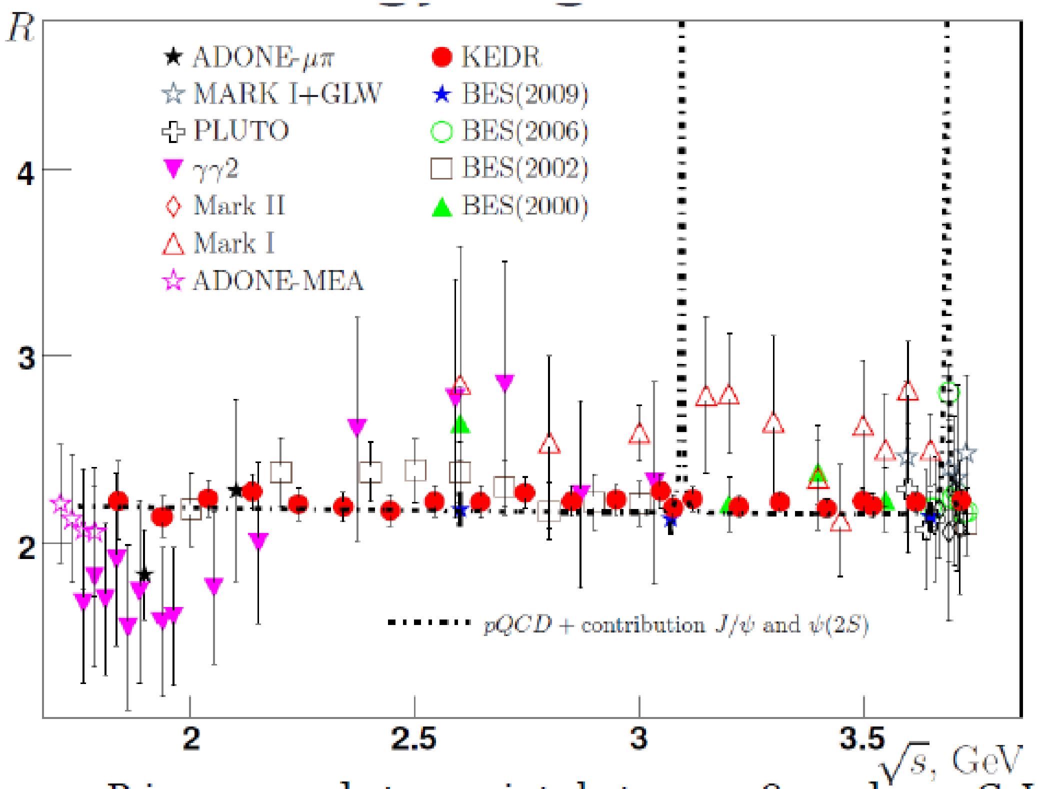
Submitted to Phys. Lett. B [arXiv:1805.06235]

Collider VEPP-4M



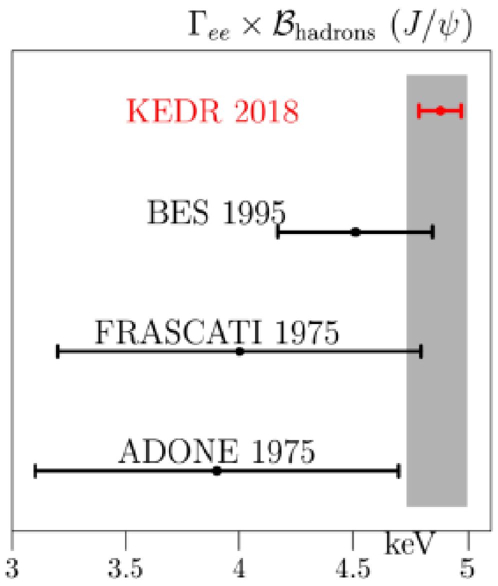
Detector KEDR

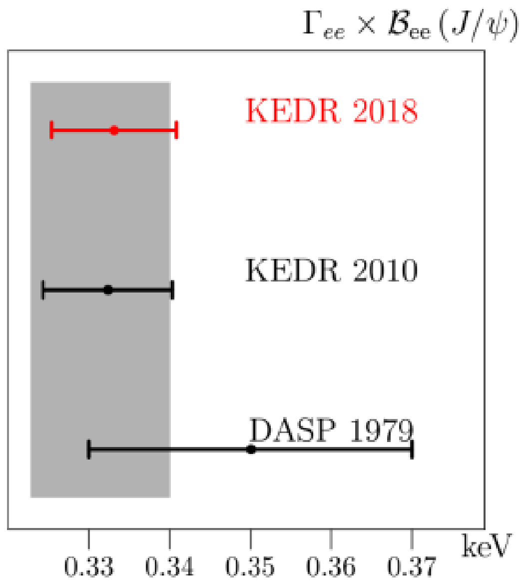




- R is measured at 22 points between 1.84 and 3.72 GeV
- Between 3.08 and 3.72 GeV syst. error 1.9%, total 2.6%

Measurement of $\Gamma_{ee} \cdot B_h$ and $\Gamma_{ee} \cdot B_{ee}(J/\psi)$



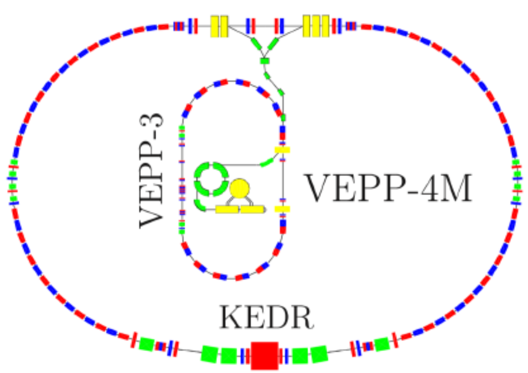


$$\Gamma_{ee}(J/\psi) \cdot \mathcal{B}_{\text{hadrons}}(J/\psi) = 4.884 \pm 0.048 \pm 0.078\,\text{keV}$$

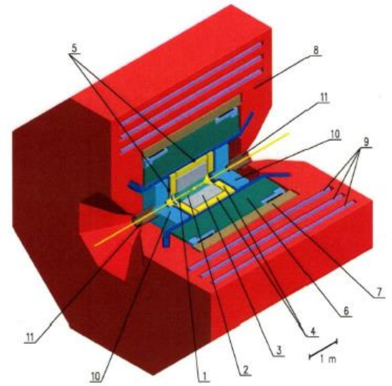
$$\Gamma_{ee}(J/\psi) \cdot \mathcal{B}_{ee}(J/\psi) = 0.3331 \pm 0.0066 \pm 0.0040\,\text{keV}$$

J. High Energ. Phys. (2018) 2018: 119

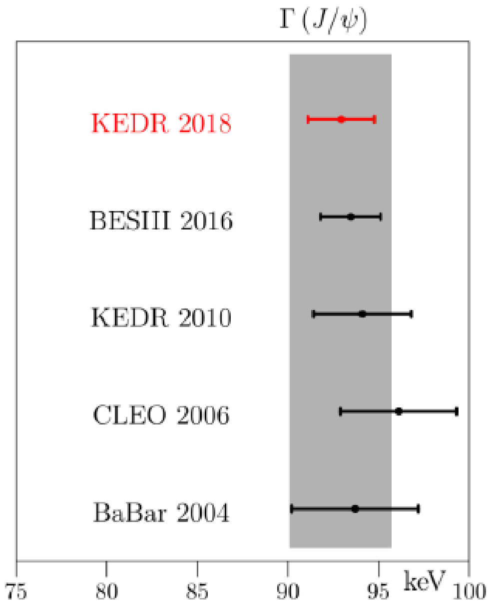
Collider VEPP-4M



Detector KEDR



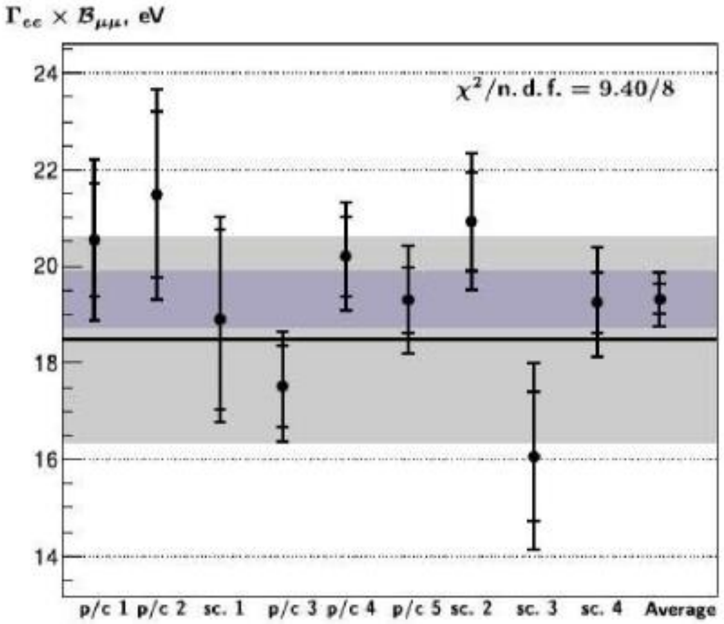
Determination of $\Gamma(J/\psi)$



Taking into account $\mathcal{B}_{ee}(J/\psi) = (5.971 \pm 0.032)\%$ from PDG :

$$\Gamma = 92.94 \pm 1.83\,\text{keV}$$

$\Gamma_{ee} \cdot B_{\mu\mu}(\psi(2S))$ measurement

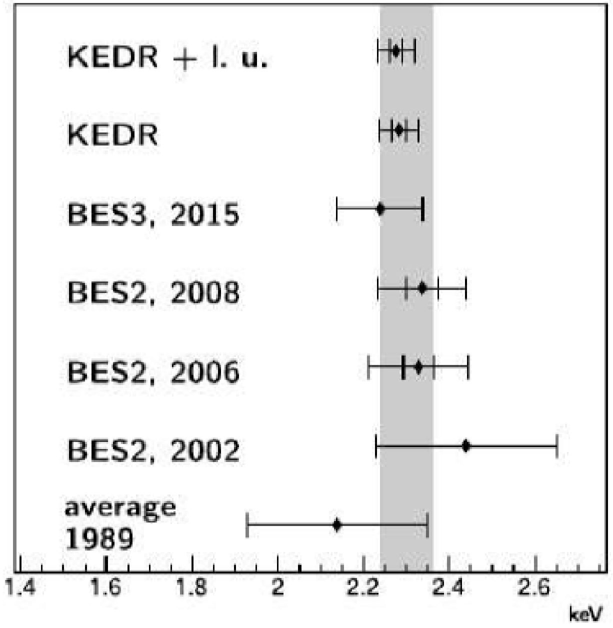


$$\Gamma_{ee} \times \mathcal{B}_{\mu\mu} = 19.3 \pm 0.3 \pm 0.5 \text{ eV}$$

World average taking Γ_{ee} and $B_{\mu\mu}(\psi(2S))$ from PDG: $\Gamma_{ee} \times \mathcal{B}_{\mu\mu} = 18.5 \pm 2.1$ eV

Phys. Lett. B V. 781, 10 June 2018, pp. 174-181

Γ_{ee} $(\psi(2S))$ measurement



- With lepton universality and KEDR result on hadronic channel

$\Gamma_{ee} \times \mathcal{B}_{\text{hadrons}} = 2.233 \pm 0.015 \pm 0.042$ keV

Phys. Lett. B, 711 (2012), p. 280

$$\boxed{\Gamma_{ee} = 2.279 \pm 0.015 \pm 0.042 \text{ keV}}$$

- Summing up hadronic and 3 leptonic channels from KEDR:

$\Gamma_{ee} \times \mathcal{B}_{ee} = 21.2 \pm 0.7 \pm 1.2$ eV

Phys. Lett. B V. 781 (2018) pp. 174

$\Gamma_{ee} \times \mathcal{B}_{\tau\tau} = 9.0 \pm 2.6$ eV

JETP Lett., 85 (2007), p. 347

$$\boxed{\Gamma_{ee} = 2.282 \pm 0.015 \pm 0.042 \text{ keV}}$$

«Интересные измерения с чармом»

- Регистрация смешивания $a_0/f_0(980)$

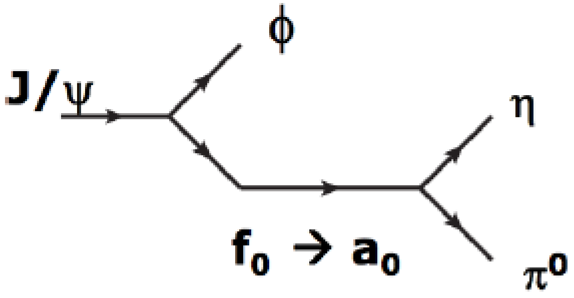
- Новый прелестный барион

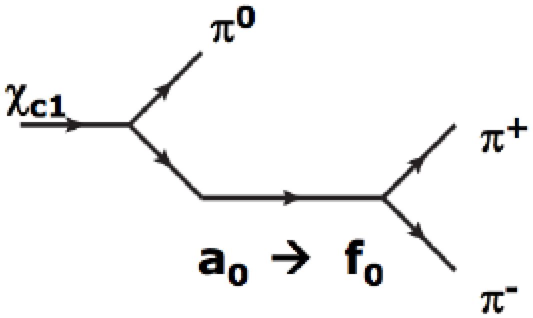
a_0(980) and f_0(980) mixing

hep-ex/1802.00583

$$J/\psi \to \phi f_0(980) \to \phi a_0^0(980) \to \phi\eta\pi^0$$

- a_0(980)-f_0(980) mixing was first proposed theoreticall in 1979 N.N. Achasov, PLB88,367(1979)
- searched in various different reactions
- a search was performed by BESIII in 2011

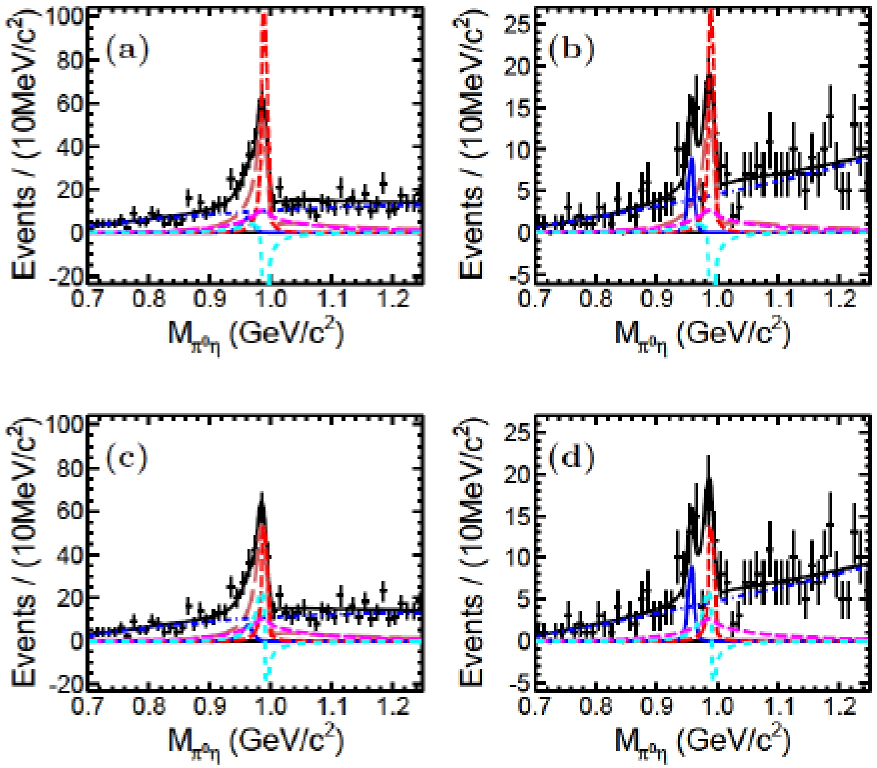




J.Wu, Q.Zhao, B.Zou PRD75,114012(2007)

J.Wu, Q.Zhao, B.Zou PRD78,074017(2008)

$\eta \to \gamma\gamma$ $\eta \to \pi^+\pi^-\pi^0$



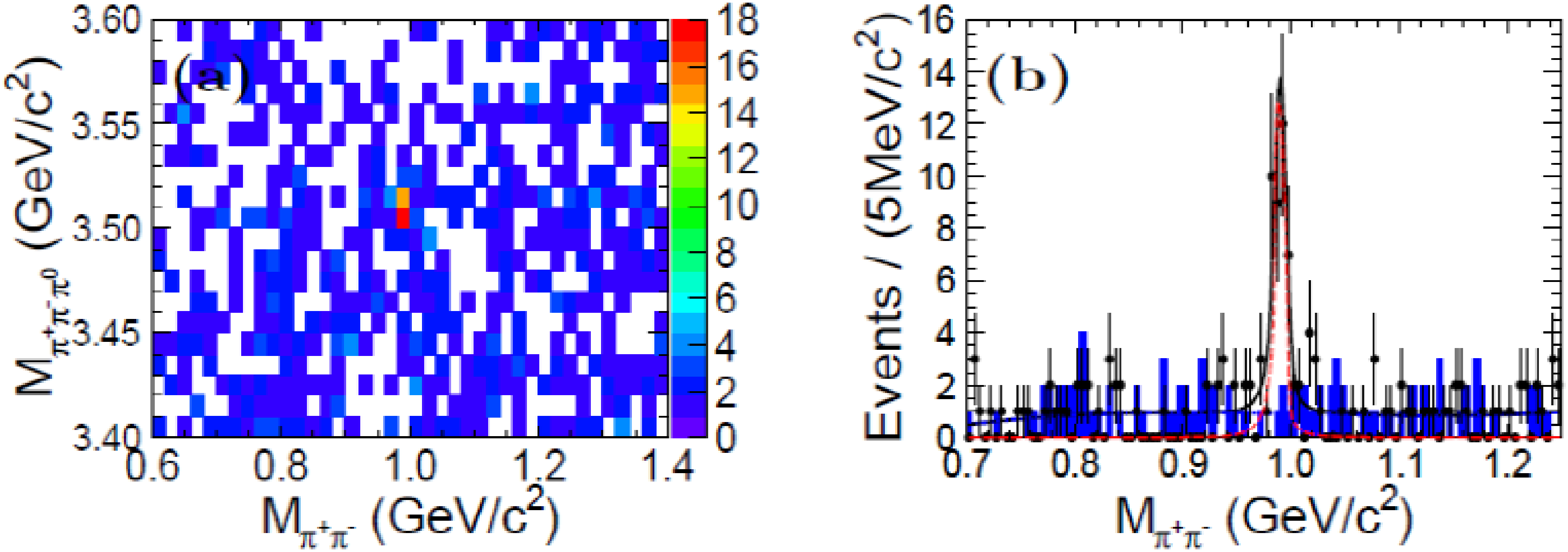
1.3 bliion J/ψ events in 2009+2012

Observation of $a_0(980)$ and $f_0(980)$ mixing

hep-ex/1802.00583

$$\chi_{c1} \to \pi^0 a_0^0(980) \to \pi^0 f_0(980) \to \pi^0\pi^+\pi^-$$

448M ψ(3686) events



Channel	$f_0(980) \to a_0^0(980)$ Solution I	 Solution II	$a_0^0(980) \to f_0(980)$
$\mathcal{B}$(mixing) (10^{-6})	$3.18 \pm 0.51 \pm 0.38 \pm 0.28$	$1.31 \pm 0.41 \pm 0.39 \pm 0.43$	$0.35 \pm 0.06 \pm 0.03 \pm 0.06$
$\mathcal{B}$(EM) (10^{-6})	$3.25 \pm 1.08 \pm 1.08 \pm 1.12$	$2.62 \pm 1.02 \pm 1.13 \pm 0.48$	—
$\mathcal{B}$(total) (10^{-6})	$4.93 \pm 1.01 \pm 0.96 \pm 1.09$	$4.37 \pm 0.97 \pm 0.94 \pm 0.06$	—
ξ (%)	$0.99 \pm 0.16 \pm 0.30 \pm 0.09$	$0.41 \pm 0.13 \pm 0.17 \pm 0.13$	$0.40 \pm 0.07 \pm 0.14 \pm 0.07$

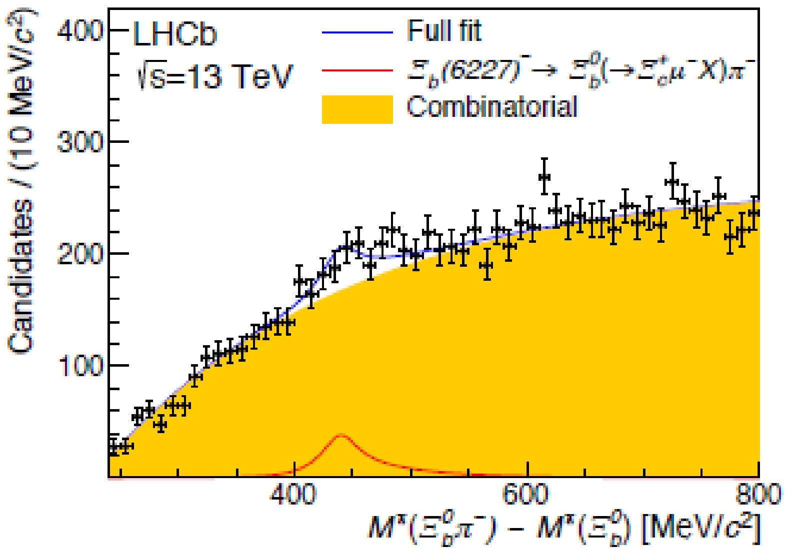
EVEN NEWER Ξ_b^- RESONANCE

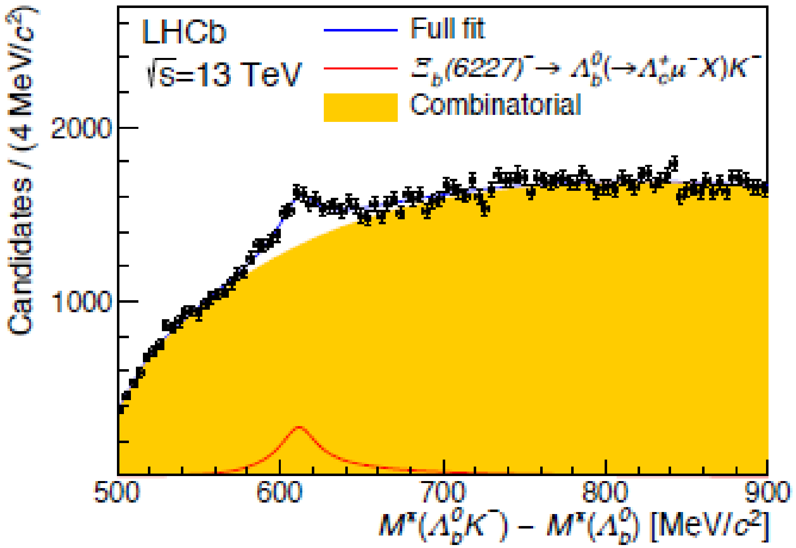
LHCb-PAPER-2018-013, all material preliminary

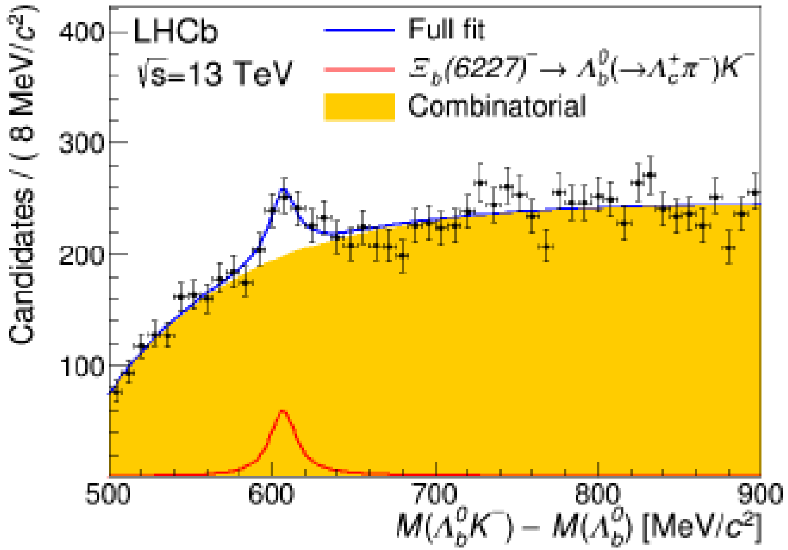
New $\Xi_b(6227)^-$ state observed decaying to both $\Xi_b^0\pi^-$ and $\Lambda_b^0 K^-$.

Three independent reconstructed decay chains,

- $\Xi_b(6227)^- \to \Xi_b^0(\Xi_c^+\mu^- X)\pi^-$,
- $\Xi_b(6227)^- \to \Lambda_b^0(\Lambda_c^+\mu^- X)K^-$,
- $\Xi_b(6227)^- \to \Lambda_b^0(\Lambda_c^+\pi^-)K^-$.







MASS, WIDTH, AND PRODUCTION

LHCb-PAPER-2018-013, all material preliminary

Mass and width measured with fully reconstructed $\Xi_b(6227)^- \to \Lambda_b^0(\Lambda_c^+\pi^-)K^-$ mode:

$$m(\Xi_b(6227)^-) - m(\Lambda_b^0) = 607.3 \pm 2.0 \pm 0.3\,\mathrm{MeV}$$

$$\Gamma(\Xi_b(6227)^-) = 18.1 \pm 4.5 \pm 1.8$$

$$m(\Xi_b(6227)^-) = 6226.9 \pm 2.0 \pm 0.3 \pm 0.2\,\mathrm{MeV}$$

Relative production rates measured with semileptonic Λ_b^0 and Ξ_b^0 modes for pp at 13 TeV and at a combination of 7 and 8 TeV

$$\begin{aligned} R(\Lambda_b^0 K^-) &\equiv \frac{f_{\Xi_b(6227)^-}}{f_{\Lambda_b^0}} \mathcal{B}(\Xi_b(6227)^- \to \Lambda_b^0 K^-) \\ &= (3.0 \pm 0.3 \pm 0.4) \times 10^{-3} \text{ at } 7,\, 8\,\mathrm{TeV} \\ &= (3.4 \pm 0.3 \pm 0.4) \times 10^{-3} \text{ at } 13\,\mathrm{TeV} \end{aligned}$$

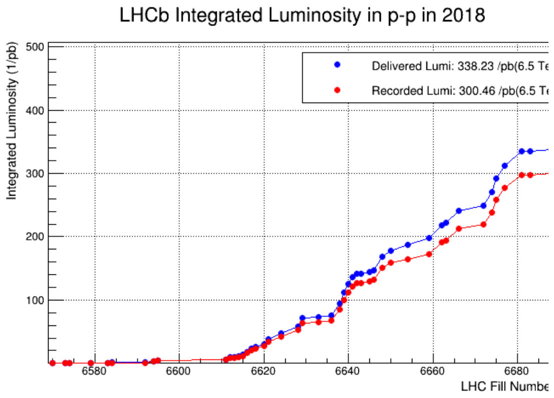
$$\begin{aligned} R(\Xi_b^0 \pi^-) &\equiv \frac{f_{\Xi_b(6227)^-}}{f_{\Xi_b^0}} \mathcal{B}(\Xi_b(6227)^- \to \Xi_b^0 \pi^-) \\ &= (47 \pm 10 \pm 7) \times 10^{-3} \text{ at } 7,\, 8\,\mathrm{TeV} \\ &= (22 \pm 6 \pm 3) \times 10^{-3} \text{ at } 13\,\mathrm{TeV} \end{aligned}$$

Перспективы физики очаровательных адронов

Timeline

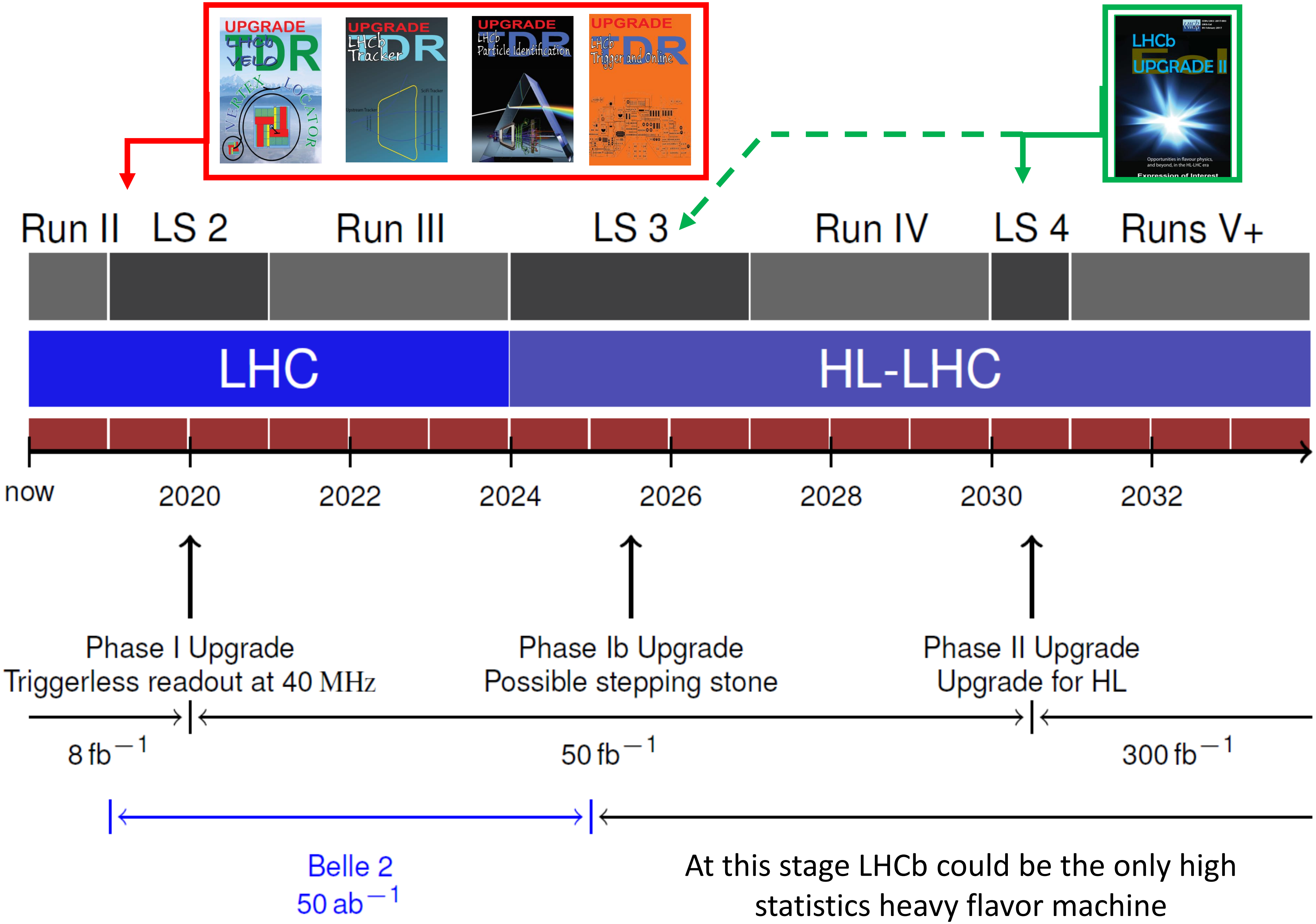
LHCb is currently in last year of operation (Run-II)

Performing well



Upgrade I is under construction for installation from 2019

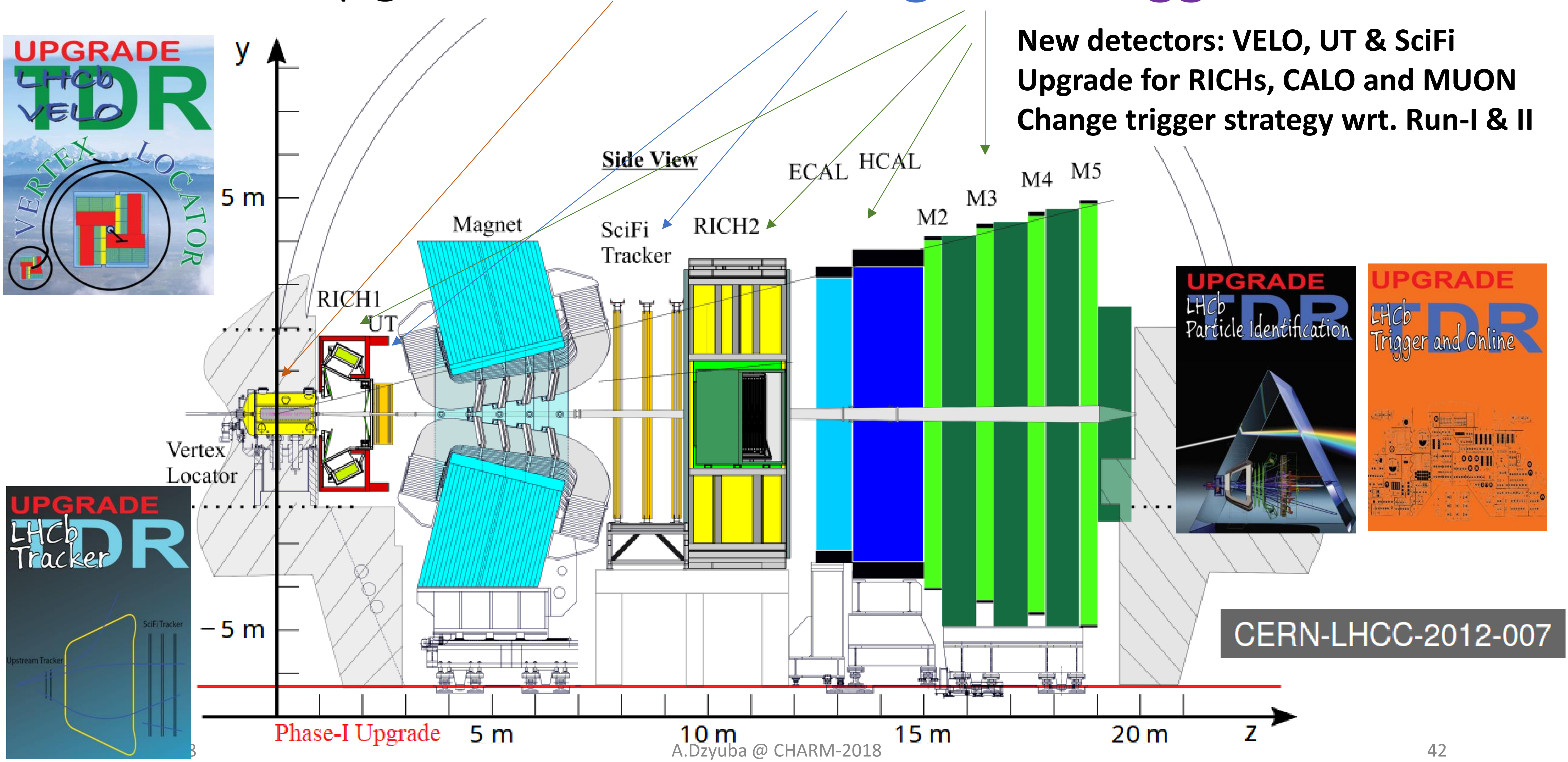
Expression of Intent for the second phase



At this stage LHCb could be the only high statistics heavy flavor machine

New after Upgrade: VELO, Tracking, PID, Trigger

New detectors: VELO, UT & SciFi
Upgrade for RICHs, CALO and MUON
Change trigger strategy wrt. Run-I & II



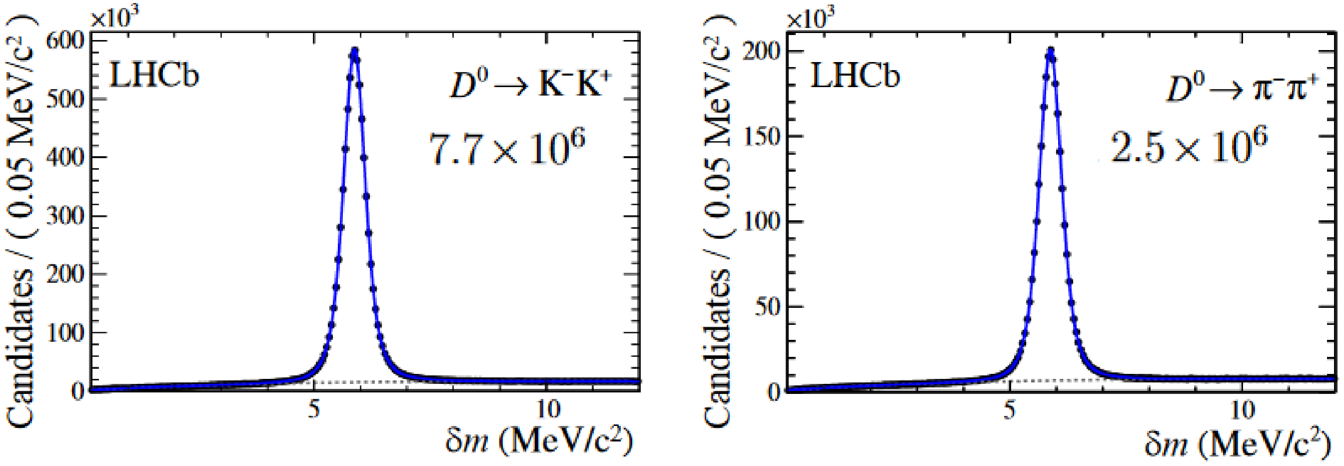
CERN-LHCC-2012-007

Projections for CPV observables: ΔA_{CP}

$$\Delta A_{CP} = A_{\rm raw}(K^-K^+) - A_{\rm raw}(\pi^-\pi^+).$$

$$A_{\rm raw}(f) \approx A_{CP}(f) + \underbrace{A_{\rm D}(f)}_{\text{Cancel}} + \underbrace{A_{\rm D}(\pi_s^+) + A_{\rm P}(D^{*+})}_{\text{Almost cancel}},$$

$$\begin{aligned}\Delta A_{CP} &\equiv A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+)\\ &\approx \Delta a_{CP}^{\rm dir}\left(1 + \frac{\overline{\langle t\rangle}}{\tau} y_{CP}\right) + \frac{\Delta\langle t\rangle}{\tau} a_{CP}^{\rm ind},\end{aligned}$$



Run-I dataset:

$$\boxed{\Delta A_{CP} = (-0.10 \pm 0.08\ ({\rm stat}) \pm 0.03\ ({\rm syst}))\,\%,}$$

Phys. Rev. Lett. 116, 191601 (2016)

- The statistics in Run-II can be increased roughly factor of ten
- **Another factor of 10 for Runs III & IV (50 fb^{-1})**

Projected statistical uncertainty (LHCb-PUB-2014-040):

Type	Observable	LHC Run 1	LHCb 2018	LHCb upgrade *
CP violation	ΔA_{CP} (10^{-3})	0.8	0.5	0.1

*** we expect that systematical uncertainly also will scale down, as data driven methods are used**

A_Γ projections

Time integrated CP asymmetries as well as mixing parameters are small:

$$A_{CP}(t) \equiv \frac{\Gamma(D^0(t)\to f) - \Gamma(\bar{D}^0(t)\to f)}{\Gamma(D^0(t)\to f) + \Gamma(\bar{D}^0(t)\to f)} \simeq a^f_{\text{dir}} - A_\Gamma \frac{t}{\tau_D}$$

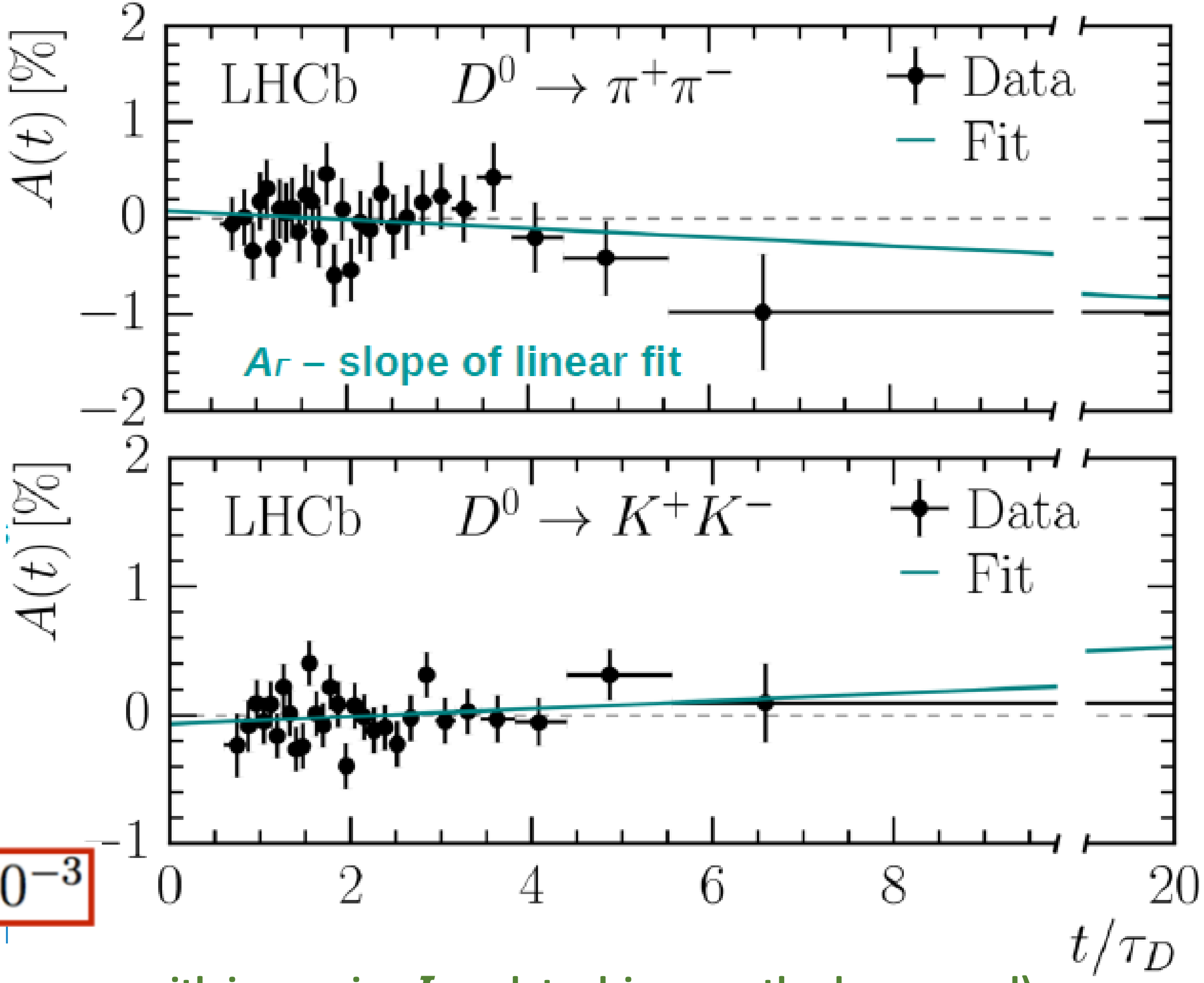
CPV in decay close-to-zero

CPV in mixing / interference

Expected to be less 0.005

$$A_\Gamma \equiv \frac{\hat{\Gamma}_{D^0\to f} - \hat{\Gamma}_{\bar{D}^0\to f}}{\hat{\Gamma}_{D^0\to f} + \hat{\Gamma}_{\bar{D}^0\to f}}$$

Inverse of effective lifetime



A_Γ – slope of linear fit

PRL 118 (2017) 261803

Combination of prompt and semileptonic tagging gives most precise CPV measurement:

$$\boxed{A_\Gamma = (-0.29 \pm 0.28) \times 10^{-3}}$$

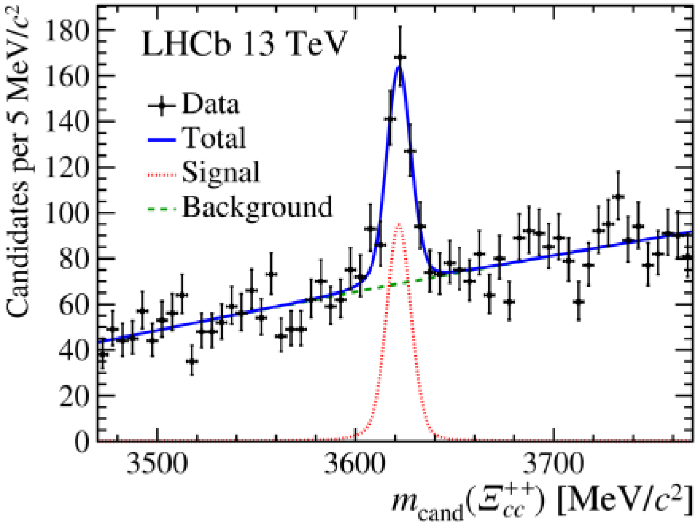
More improvement after Upgrade (we expect that systematics will improve with increasing L as data driven methods are used):

Observable	LHC Run 1	LHCb 2018	LHCb upgrade
$A_\Gamma(D^0 \to K^+K^-)$ (10^{-4})	3.4	2.2	**0.4**

For more details about LHCb CPV studies see talks of Maxime Schubiger and Angelo Carbone

LHCb-PUB-2014-040

Spectroscopy with high luminosity



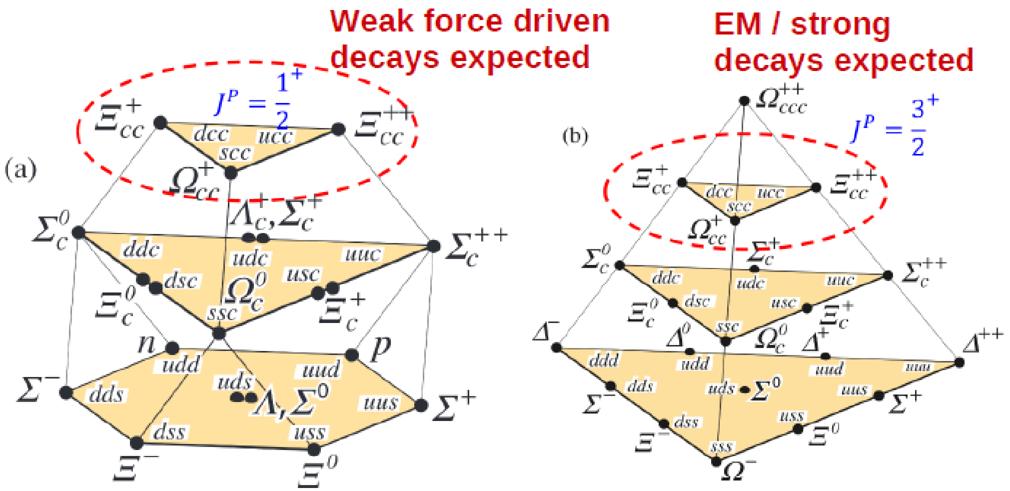
LHCb will continue to study charmed heavy baryons

Possible to have ~9k sample of Ξ_{cc}^{++} at 50 fb^{-1}

(under assumption that data scales with luminosity

~300 candidates \ √s = 13 TeV \ 1.7 fb^{-1})

Search for other decays channels


Weak force driven decays expected

EM / strong decays expected

Precise investigations of decay properties

Search for partners: Ξ_{cc}^{+}, Ω_{cc}^{+}

Wide program for exotica (**will be discussed by Tomasz Skwarnicki and Anton Poluektov**)

Very high precision can be achieved with 300 fb^{-1}

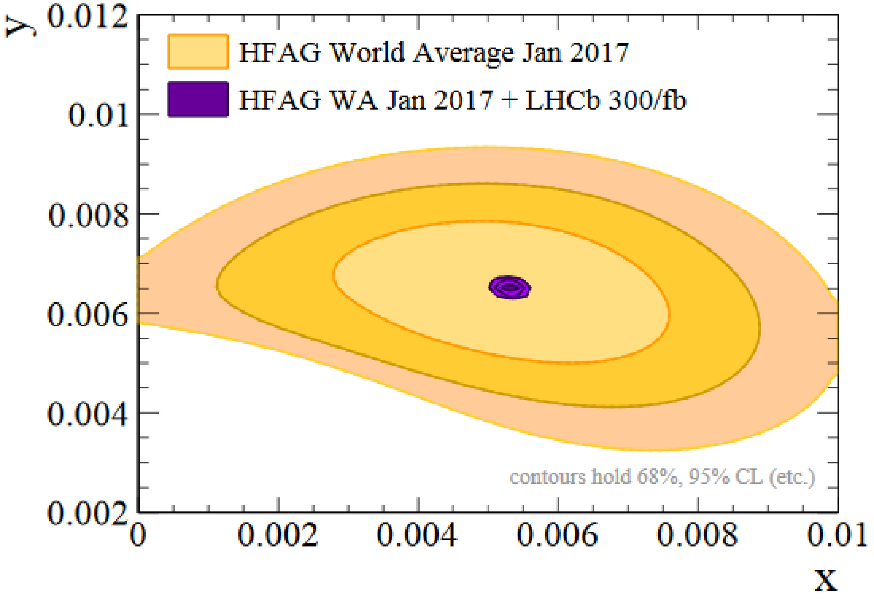
LHCb

UPGRADE II

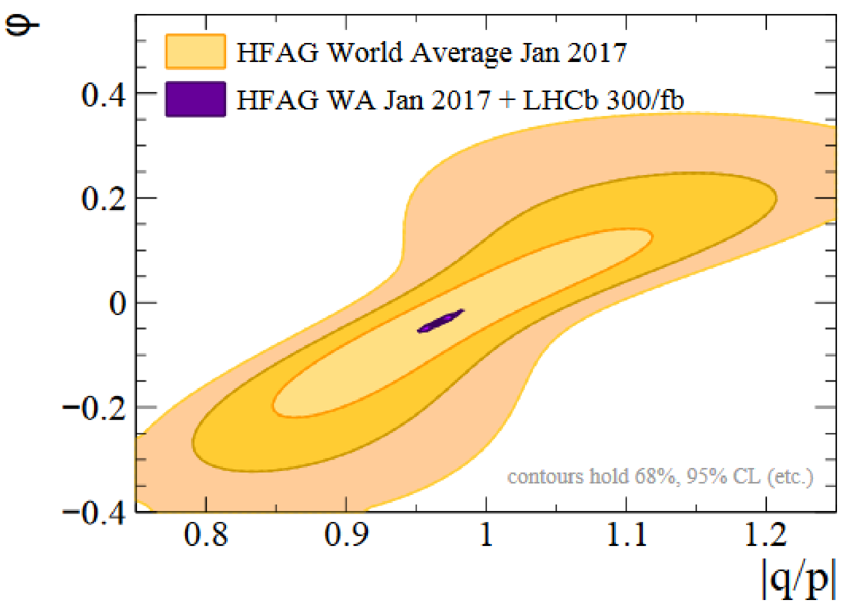
Opportunities in flavour physics, and beyond, in the HL-LHC era

Expression of Interest

Mixing parameters



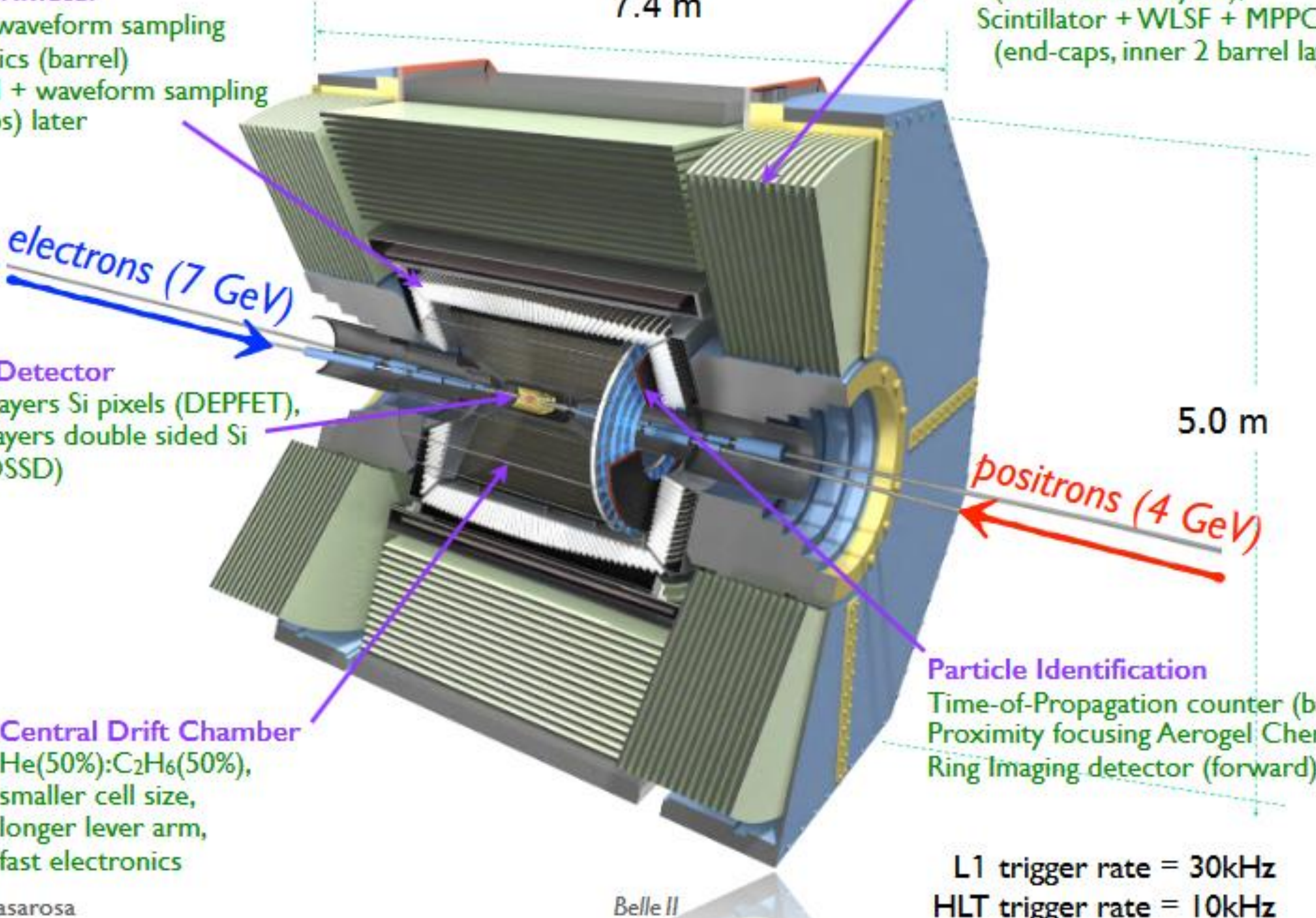
Indirect CPV parameters in charm



- We expect that systematical uncertainty will scale down together with statistical one.
- All chances to find CPV in charm sector

Topics and observables	Experimental reach	Remarks
Charm		
CP-violation studies with $D^0 \to h^+h^-$, $D^0 \to K^0_S\pi^+\pi^-$ and $D^0 \to K^\mp\pi^\pm\pi^+\pi^-$	*e.g.* 4×10^9 $D^0 \to K^+K^-$; Uncertainty on $A_\Gamma \sim 10^{-5}$	Access CP violation at SM values.

The *Belle II* Detector



EM calorimeter
CsI(Tl), waveform sampling electronics (barrel)
Pure CsI + waveform sampling (end-caps) later

K_L & μ Detector
Resistive Plate Counter (barrel outer layers),
Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

Vertex Detector
PXD: 2 layers Si pixels (DEPFET),
SVD: 4 layers double sided Si strips (DSSD)

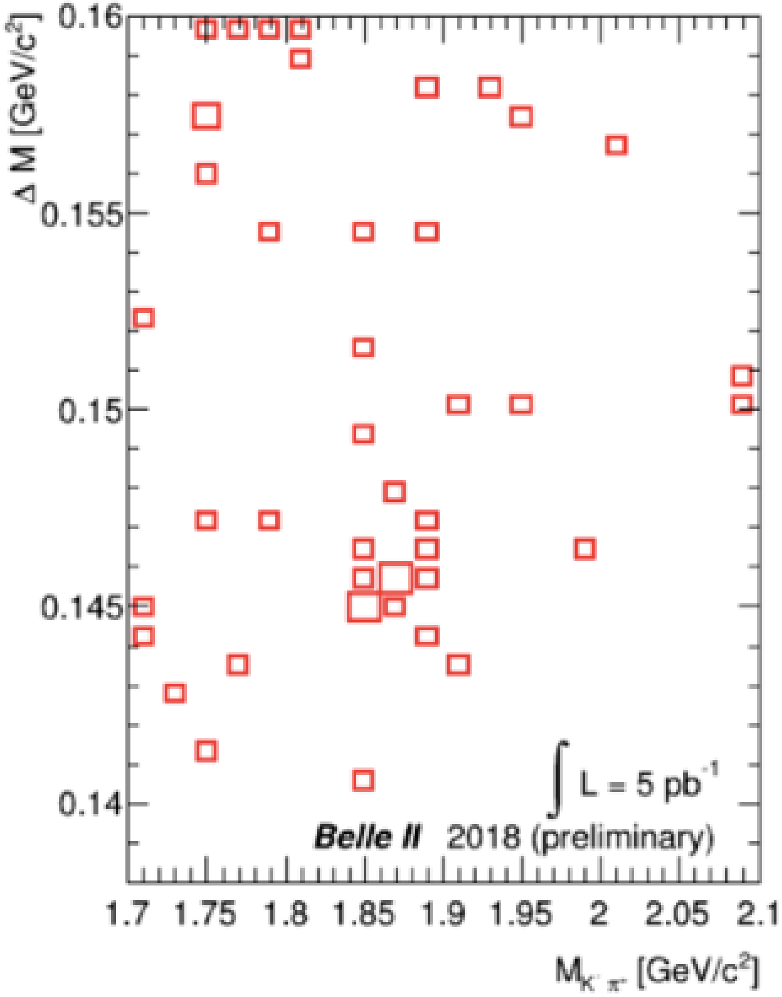
Particle Identification
Time-of-Propagation counter (barrel),
Proximity focusing Aerogel Cherenkov Ring Imaging detector (forward)

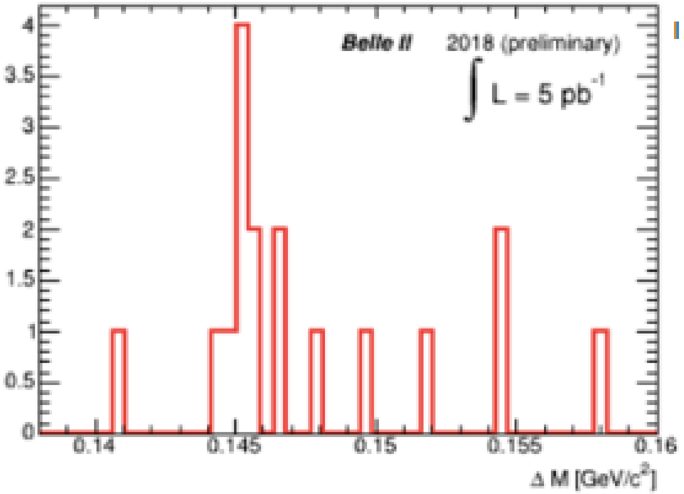
Central Drift Chamber
He(50%):C_2H_6(50%),
smaller cell size,
longer lever arm,
fast electronics

L1 trigger rate = 30kHz
HLT trigger rate = 10kHz

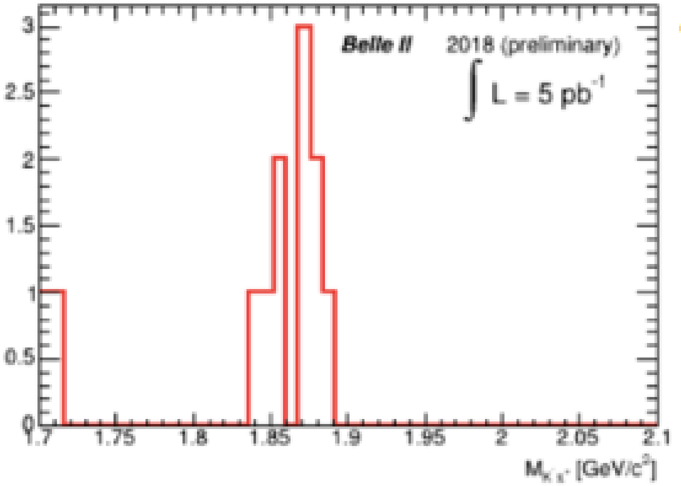
We got Charm :)

$D^* \rightarrow D^0(\rightarrow K^- \pi^+)\ \pi$





$1.845 < M(K\pi) < 1.885$ (GeV/c²)



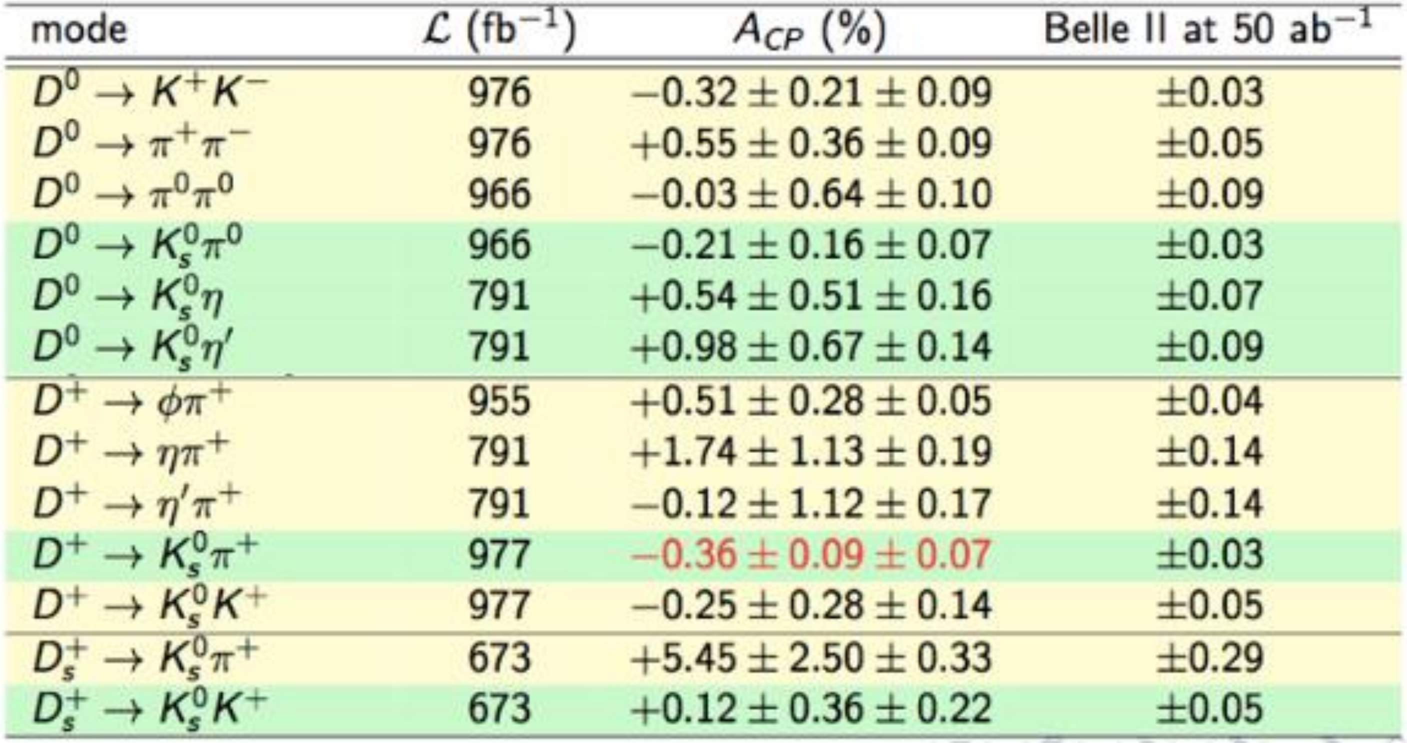
$0.144 < \Delta M < 0.146$ (GeV/c²)

- Evidence of D^* and D^0 in the collected data sample of 5/pb
- First preliminary plots, calibrations at a very early stage, no PID cuts applied

Prospects for CP Asymmetries

M. Staric @ KEK FF 2014

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



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
$D^0 \to K_s^0\pi^0$	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
$D^+ \to \phi\pi^+$	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
$D^+ \to K_s^0K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.05
$D_s^+ \to K_s^0\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29
$D_s^+ \to K_s^0K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

- A$_{CP}$ precision will reach o(10^{-4}), also in channels with neutrals in the final state
- *Belle II* is favoured on measurements with neutrals in the final state
- Other interesting channels not included in this table: $D^+ \to \pi^+\pi^0$, $D^0 \to K_SK_S$, 3-body final states (DP analysis), radiative decays (in the next slide)

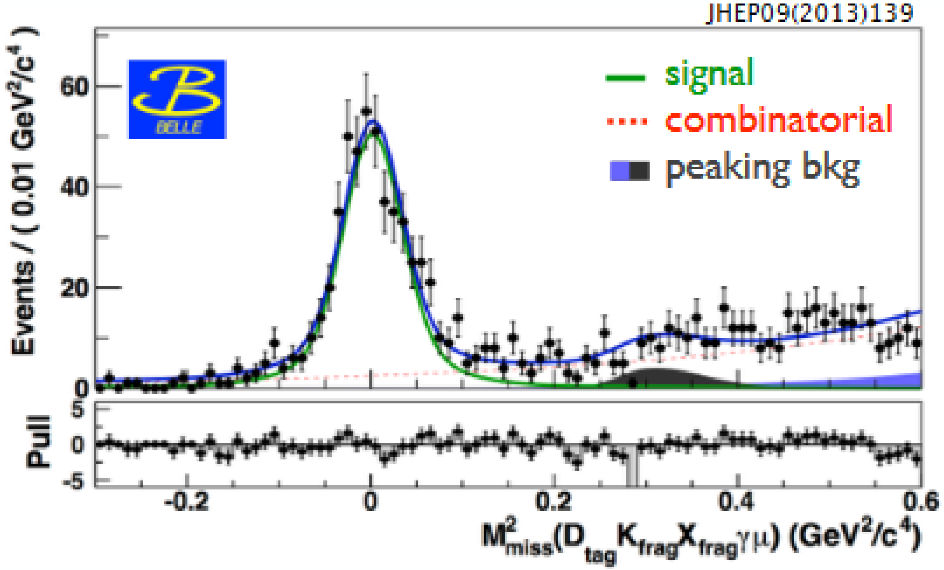
Leptonic Decays: $D_{(s)}^- \to \mu^- \nu$

- ➡ $D_s^+ \to \mu^+ \nu$ Belle Analysis:

$$e^+e^- \to D_{\text{tag}} X_{\text{frag}} K D_s^{*+}$$

$$D_s^{*+} \to D_s^+ \gamma$$

  - require one charged track passing muon-ID pointing the IP
  - fit the missing mass distribution.



JHEP09(2013)139

- ➡ Same analysis method for the D^+ channel
  - Belle simulation with 5.5 ab^{-1}, scaled to 50 ab^{-1}, yields:

yields	$D_s^+ \to \mu^+\nu$		$D^+ \to \mu^+\nu$	
	inclusive	exclusive	inclusive	exclusive
Belle, 913 fb^{-1}	94400	490	–	–
BelleII, 50 ab^{-1}	5.2×10^6	27×10^3	3.5×10^6	1250
	$\delta(\lvert V_{cs}\rvert) = 0.004$, $\delta(\lvert f_{D_s}\rvert) = 0.9$ statistical error ~1/3 of the theory error		$\delta(f_d \lvert V_{cd}\rvert) = 1.3$ competitive with CLEOc and BESIII	

Accelerator complex with colliding electron-positron beams (Super Charm-Tau Factory, SCT)

https://indico.inp.nsk.su/event/13/other-view?view=standard

SCT physics case: challenges for Particle Physics

- D-Dbar mixing
- CP violation searches in charm decays
- Rare and forbidden charm decays
- Standard Model tests in τ leptons decays
- Searches for lepton flavor violation $\tau \rightarrow \mu\gamma$
- CP/T violation searches in τ leptons decays
- …

high complementarity with
Belle-II at Super KEKB,
LHCb at LHC,
PANDA at FAIR,
first of all – flavor physics,
study of nucleon matter and antimatter,
search for new phenomena
beyond the Standard Model.

SCT technology case: accelerator S&T

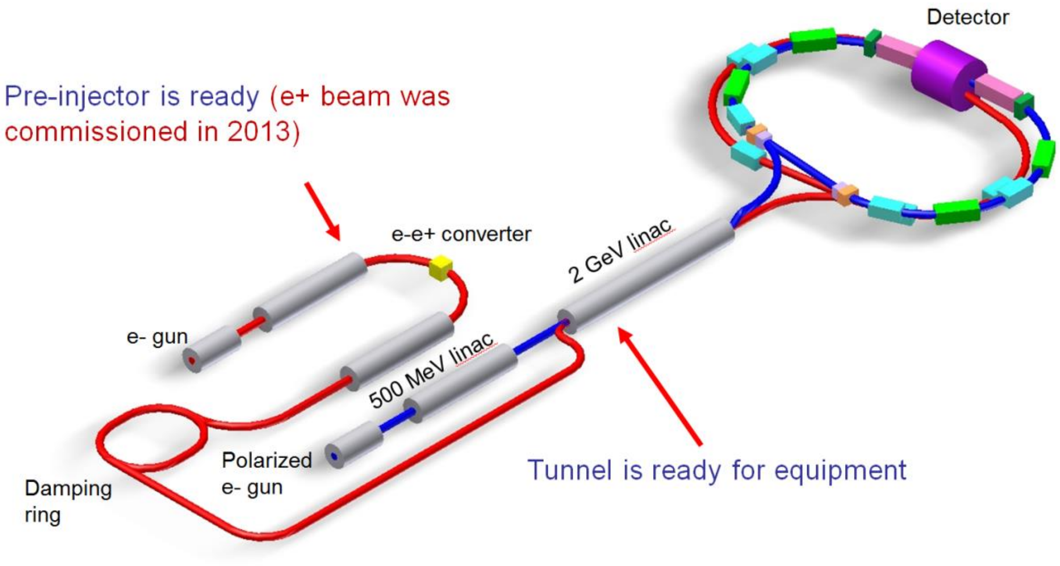
- Two rings, 800 m each
- Crab waist
- Collision energy from 2 GeV to 5 (6) GeV
- Luminosity: $5 \cdot 10^{34}$ cm^{-2}s^{-1} at 2 GeV
  and 10^{35} cm^{-2} s^{-1} at 4 GeV
- Longitudinally polarized electron beam at IP
- Extensive use of SC wigglers to control damping parameters and tune optimal luminosity in the whole energy range

The concept of the new collider is based on a new method to increase the luminosity, which was proposed by physicists from INFN (Italy) and developed by INFN and BINP experts

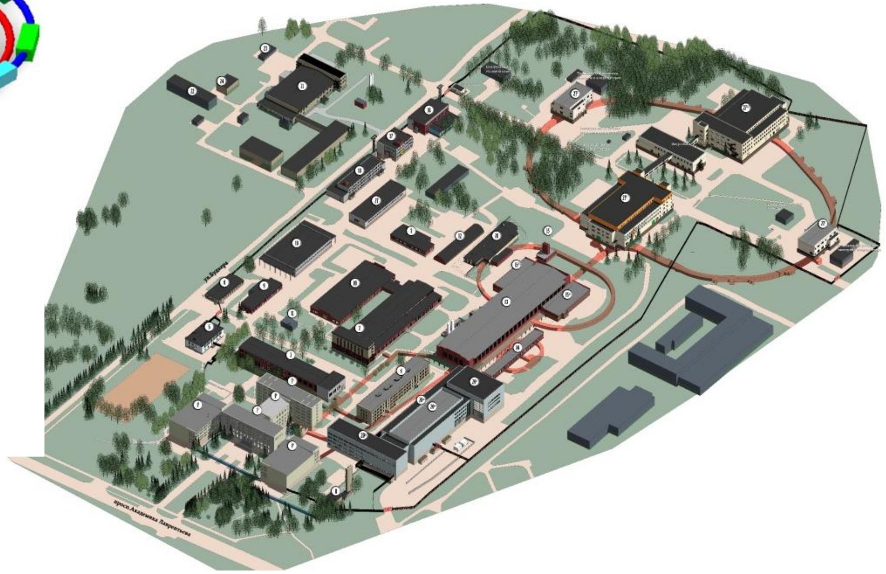
Similar accelerator approaches are used at SCT, Super KEK-B and FCCe

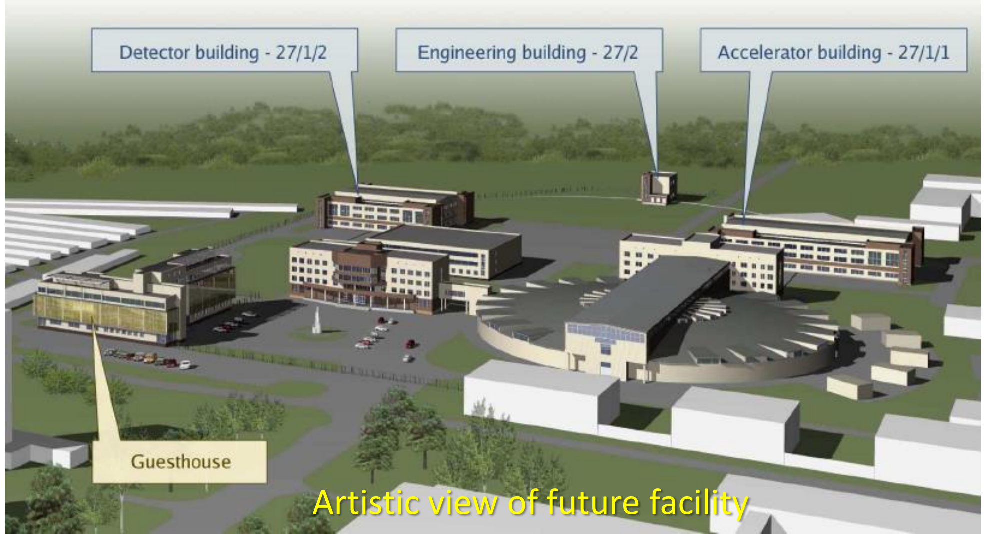
Accelerator technologies developed for SCT are very demand for other Russian mega science projects: NICA, SSRS-4

SCT current status: R&D and design



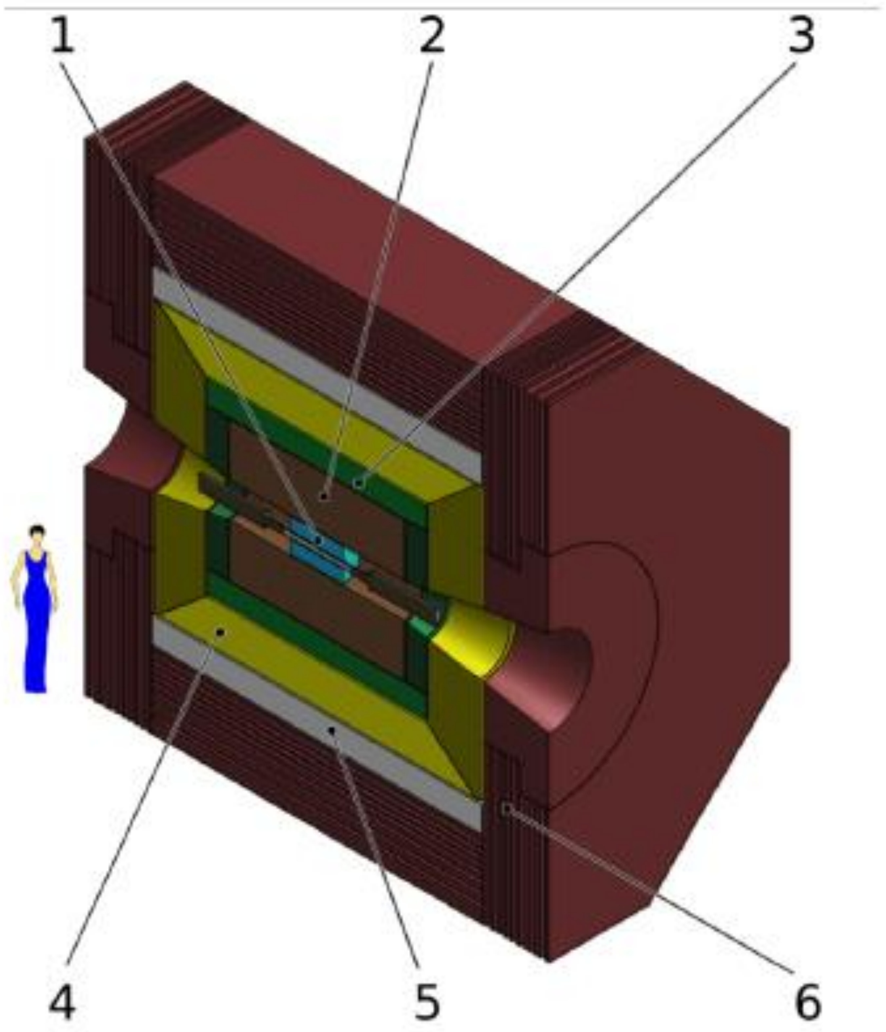
Future facility at the Budker Institute landscape





- Detailed physics program is developed
- Preliminary CDR was issued (in 2011), is updated in 2018, is go on …
- R&D for accelerator and detector is in progress, prototypes and key elements were designed and produced
- Preliminary civil engineering and infrastructure design is completed
- IT requirements are identified
- …

Classical detector concept for colliding beam experiments is suitable for SCTF



Collider limitations

- $W = 2 \div 5\text{GeV}$
- l_{bunch} – 1÷1.8 cm
- Δt^{bunch} – 6 ns
- CVC: ø 30/l=300 mm
- FF: ±10°
- L: $10^{35}\text{cm}^{-1}\text{s}^{-1}$
  → 50÷300 kHz event rate

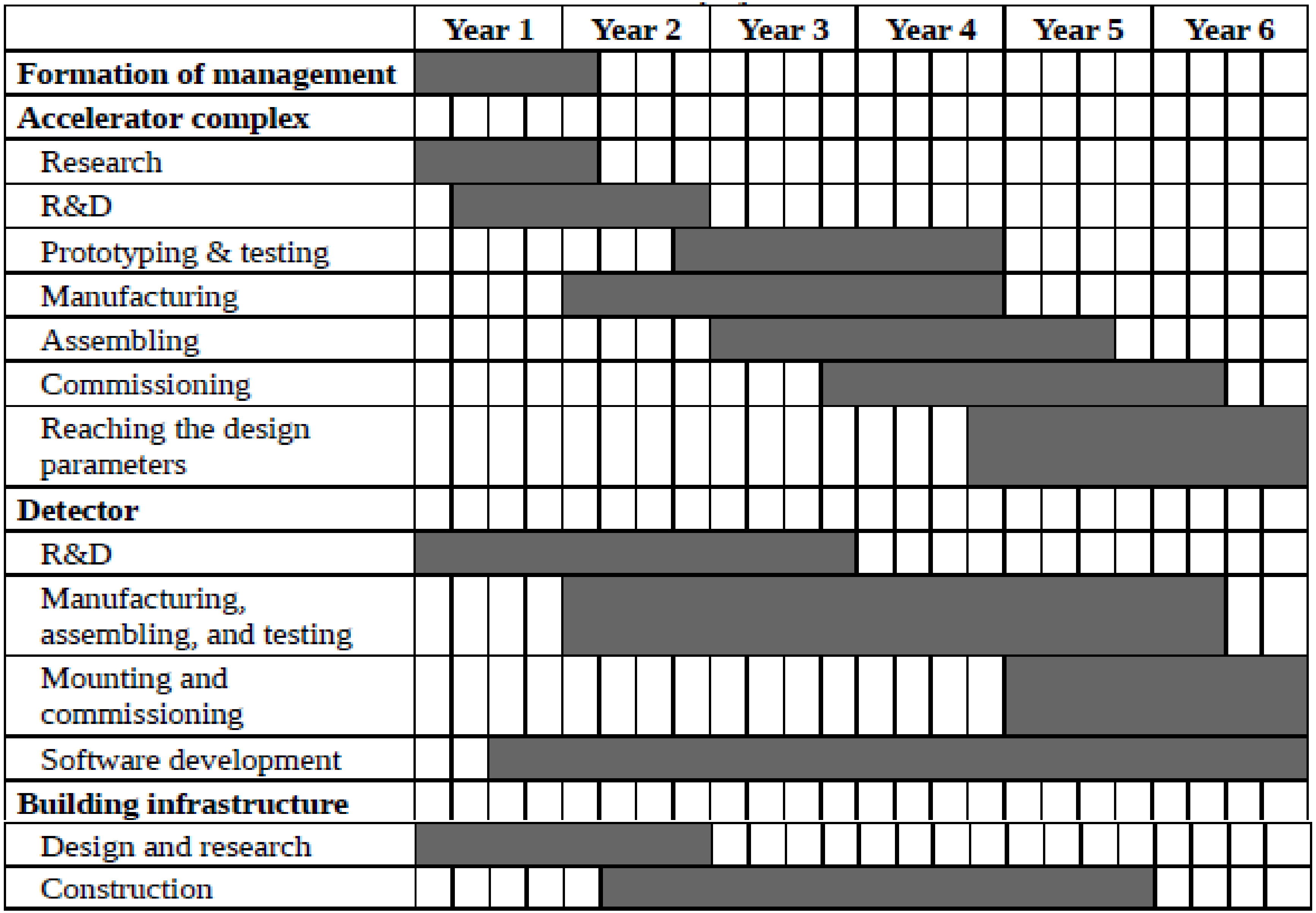
1. Vertex detector
2. Drift chamber
3. PID system
4. Calorimeter
5. SC coil (B∼1 T)
6. Yoke and MU chambers

1. **For realization of physics potential of the SCTF we have to built the detector with excellent performance- it is very interesting and difficult task**

1. **Most of subdetectors can be constructed on the base of existing detector technologies but we have to choice the optimal ones among many options (extensive R@D is needed)**

1. **But FARICH for PID is very challenging and probably we need to have more simple option for PID at the beginning**

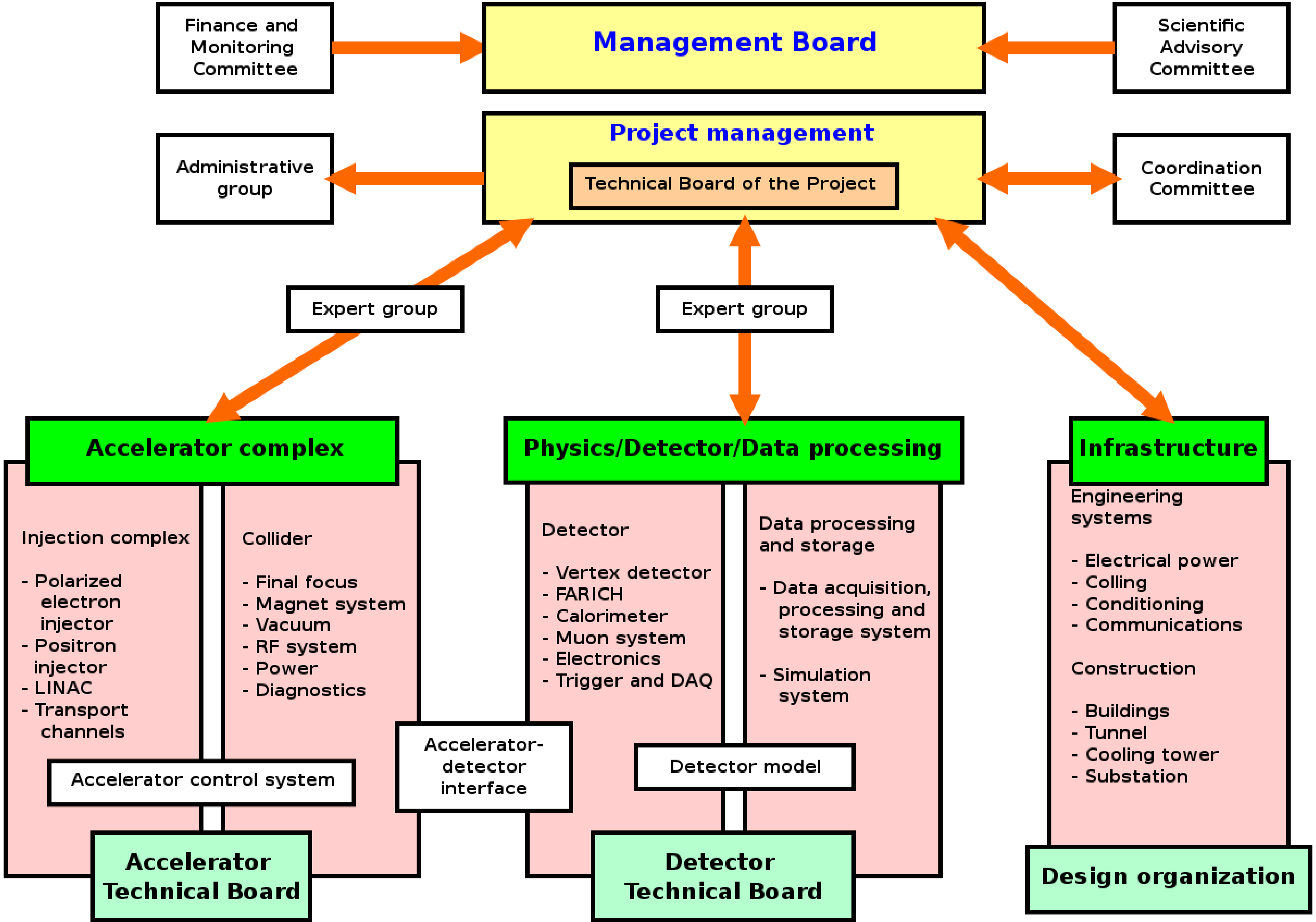
SCT road map of construction



	Year 1				Year 2				Year 3				Year 4				Year 5				Year 6			
Formation of management	▨	▨	▨	▨	▨																			
Accelerator complex																								
Research	▨	▨	▨	▨	▨																			
R&D		▨	▨	▨	▨	▨	▨	▨																
Prototyping & testing								▨	▨	▨	▨	▨	▨	▨	▨	▨								
Manufacturing					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨								
Assembling									▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨					
Commissioning												▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
Reaching the design parameters																▨	▨	▨	▨	▨	▨	▨	▨	▨
Detector																								
R&D	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨												
Manufacturing, assembling, and testing					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
Mounting and commissioning																	▨	▨	▨	▨	▨	▨	▨	▨
Software development			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Building infrastructure																								
Design and research	▨	▨	▨	▨	▨	▨	▨	▨																
Construction						▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨				

SCT is expected to have a life span of at least 15 years,
it may be expanded to more than 25 years

SCT management structure at the construction stage



Finance and Monitoring Committee

Management Board

Scientific Advisory Committee

Administrative group

Project management

Technical Board of the Project

Coordination Committee

Expert group

Expert group

Accelerator complex

Injection complex

- Polarized electron injector
- Positron injector
- LINAC
- Transport channels

Collider

- Final focus
- Magnet system
- Vacuum
- RF system
- Power
- Diagnostics

Accelerator control system

Accelerator Technical Board

Accelerator-detector interface

Physics/Detector/Data processing

Detector

- Vertex detector
- FARICH
- Calorimeter
- Muon system
- Electronics
- Trigger and DAQ

Data processing and storage

- Data acquisition, processing and storage system
- Simulation system

Detector model

Detector Technical Board

Infrastructure

Engineering systems

- Electrical power
- Colling
- Conditioning
- Communications

Construction

- Buildings
- Tunnel
- Cooling tower
- Substation

Design organization