XLIX Rencontres de Moriond
Electroweak Interactions and Unified Theories
March 15th-22nd 2014, La Thuile, Italy

Charm mixing and CP violation at LHCb

Angelo Di Canto (CERN) on behalf of LHCb

Why is charm charming?

- Unique and powerful probe of BSM flavor effects
- Charm quark is up-type: complements searches done in K and B systems, interplays with high-p_T (top physics) and low-energy (EDMs) probes
- SM effects are $<10^{-3}$ due to CKM/GIM suppressions: calls for O(1M) yields and control over systematics
- Predictions are hard: charm is a discovery tool not a precision probe
- Only recently reached sensitivity to possible BSM physics

Direct CP violation

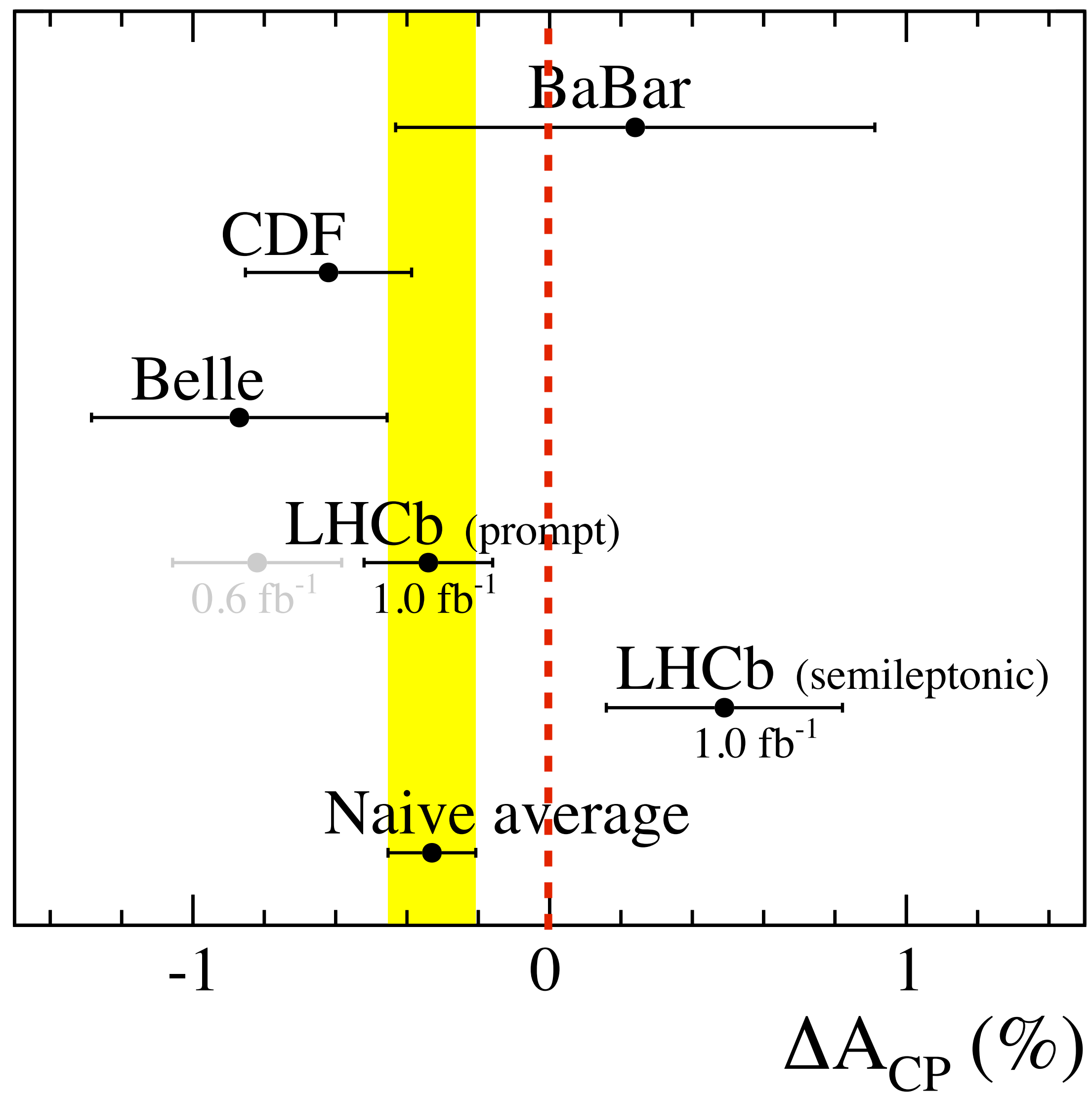
First evidence of direct CPV in charm?

- Intriguingly large difference between the asymmetries of neutral charm mesons decaying into pairs of charged pions and kaons

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

- At odds with expectations… but picture is still blurry
- Wrong expectations? Wrong measurements? Both? Something new sneaking in?

PRL 100 (2008) 061803, PRL 109 (2012) 111801, arXiv:1212.1975, PRL 108 (2012) 111602, LHCb-CONF-2013-003, PLB 723 (2013) 33

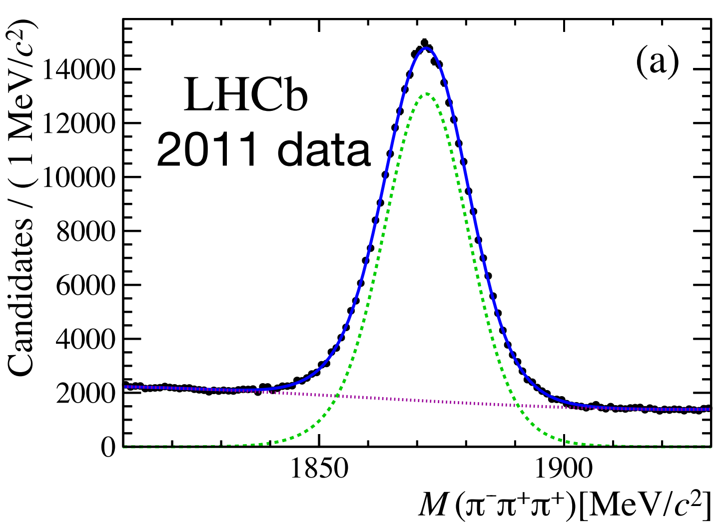


Update with full Run I dataset in progress

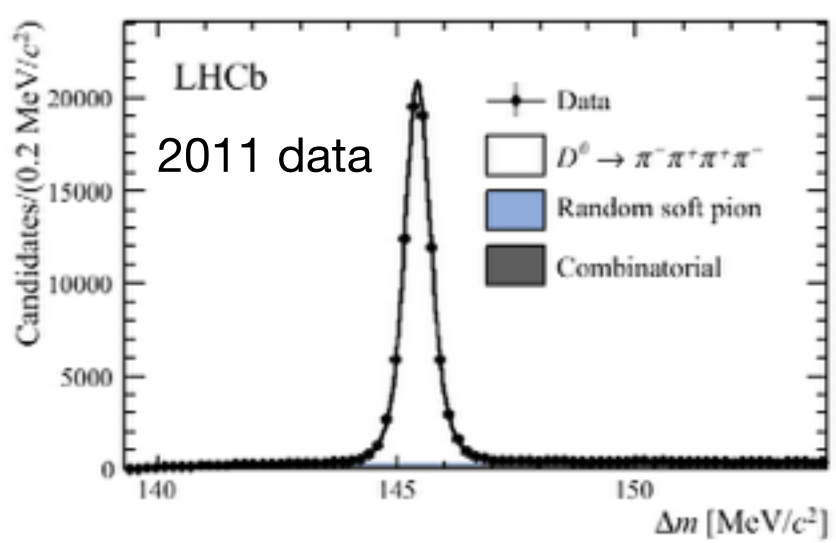
Search for CPV in multibody decays

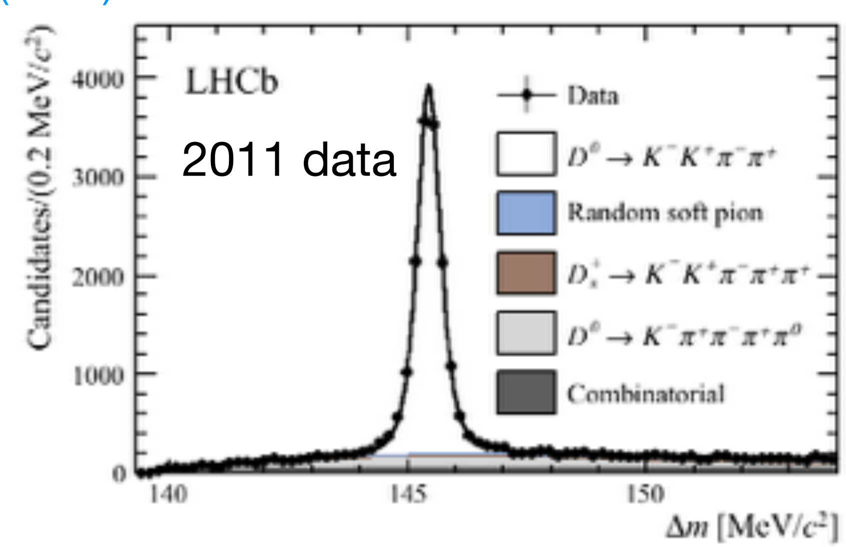
- Exploit enriched dynamics of multi-body decays to seek enhancements of CPV in subregions of the phase space. Could go unnoticed in measurements of global asymmetries
- Insensitive to global asymmetries (physical or spurious)
- Study phase-space-dependent production/detection asymmetries with CF decays (in the SM, direct CPV can only occur in SCS decays)

PLB 728 (2014) 585



PLB 726 (2013) 623



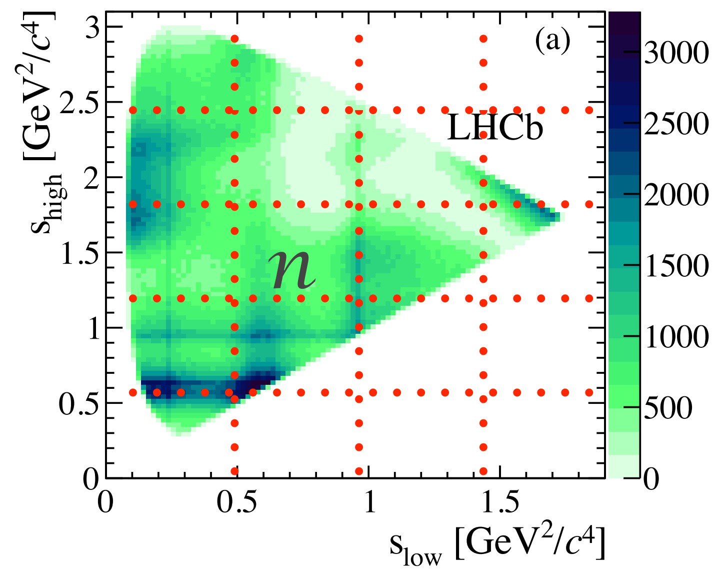


~3M $D^+ \to 3\pi$ ~300k $D^0 \to 4\pi$ ~57k $D^0 \to 2K2\pi$

Search for local CPV across Dalitz plot

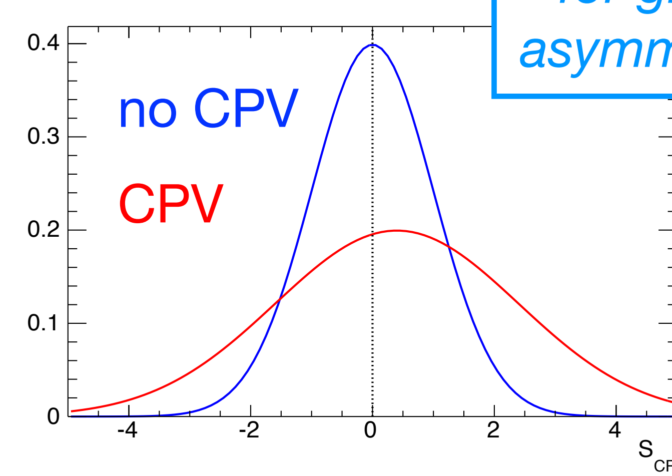
- Compute local CP asymmetry in different bins of the Dalitz plot
- No CPV means that distribution of local asymmetry is gaussian with zero mean and unit sigma
- Get p-value from $\chi^2 = \sum_i \left(S_{\rm CP}^i\right)^2$
- Test several binning schemes (same number of events/same strong phase)
- With 2011 data sensitive to 1°-10° differences in phase and 1-10% in magnitude

Binned (a.k.a. Miranda) method

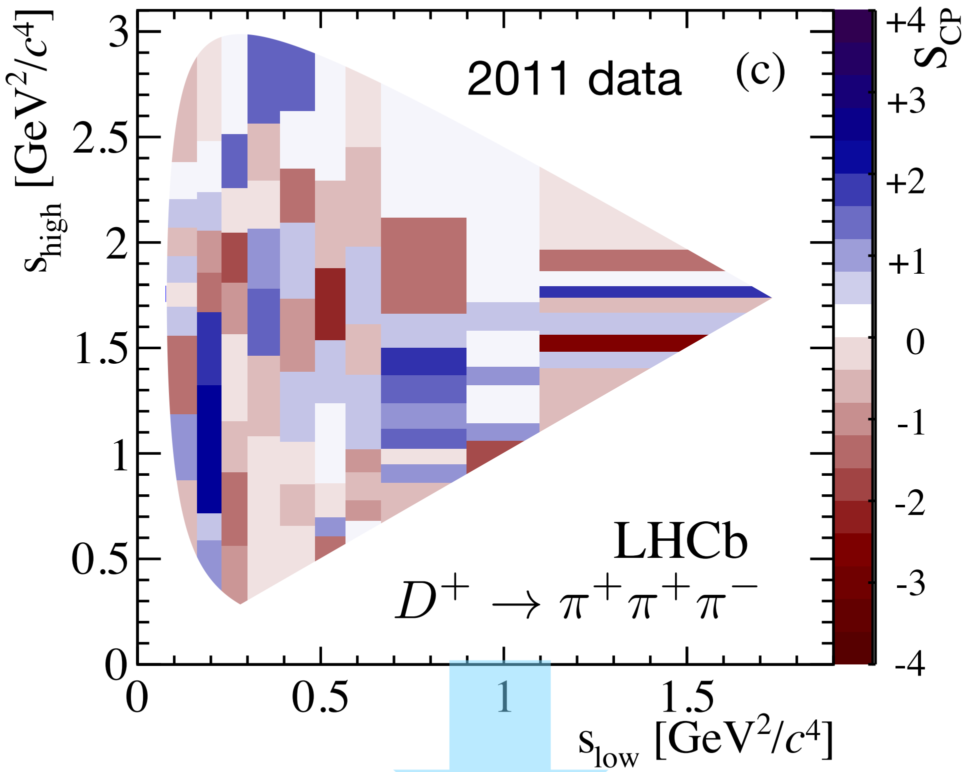


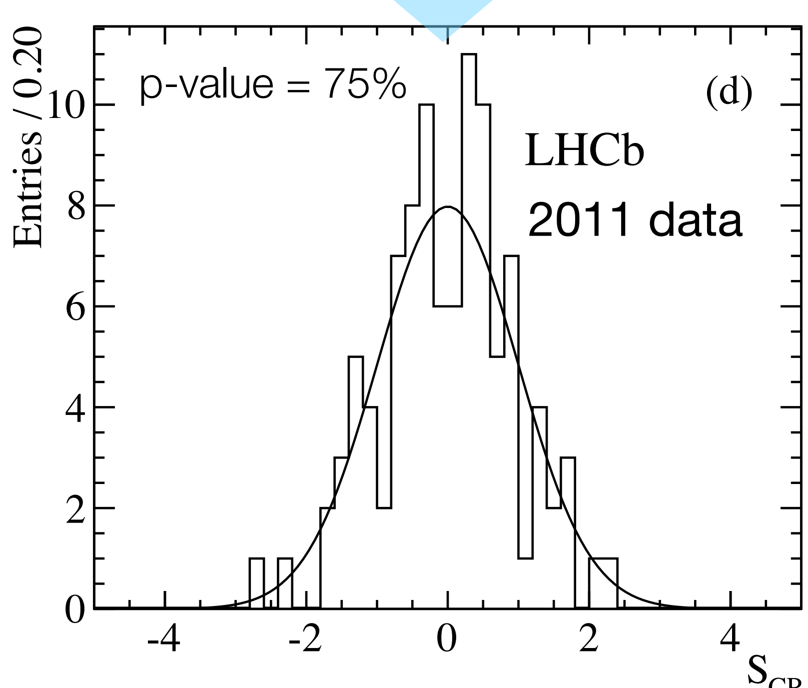
$$S_{\rm CP}^i = \frac{n^i(D^+) - \alpha n^i(D^-)}{\sqrt{n^i(D^+) + \alpha n^i(D^-)}}$$

to account for global asymmetries $\alpha = \frac{N(D^+)}{N(D^-)}$



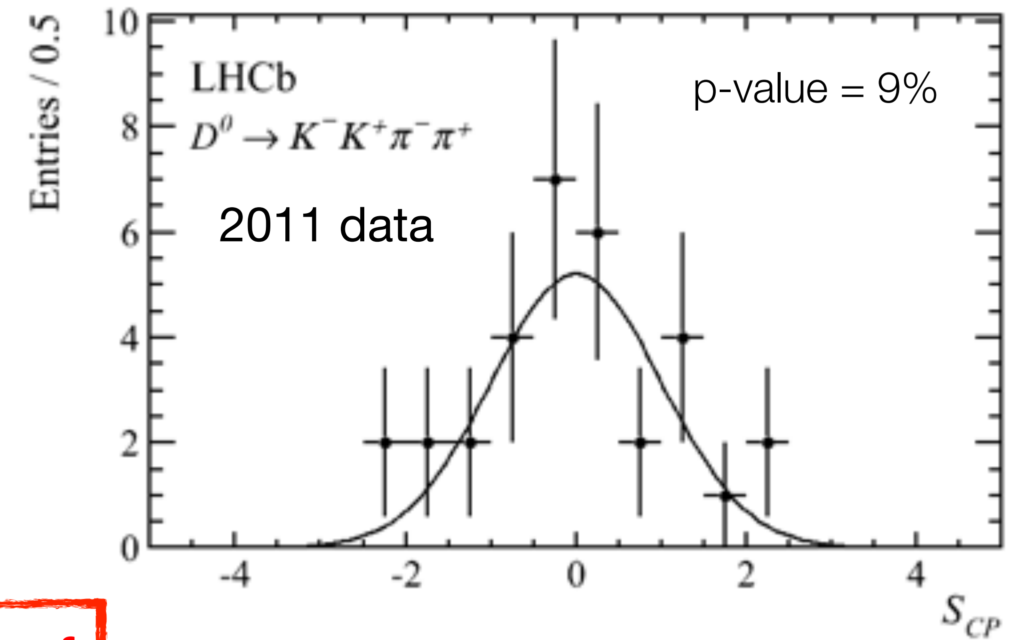
Local CPV in multibody decays — Results

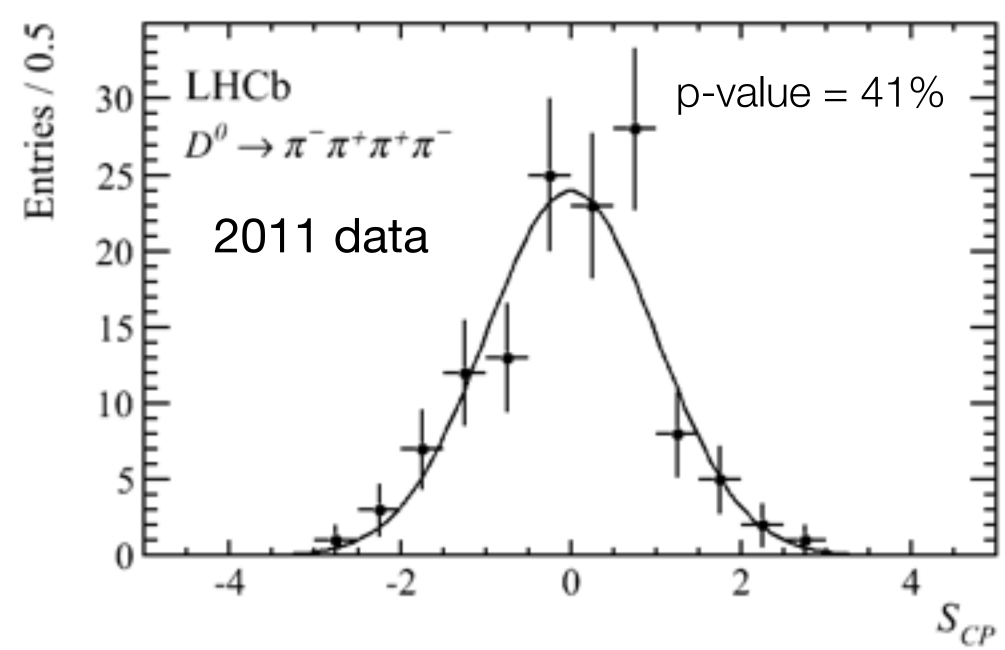




PLB 728 (2014) 585

No evidence of local CPV





PLB 726 (2013) 623

$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$$

$$x = (m_1 - m_2)/\Gamma$$

$$y = (\Gamma_1 - \Gamma_2)/2\Gamma$$

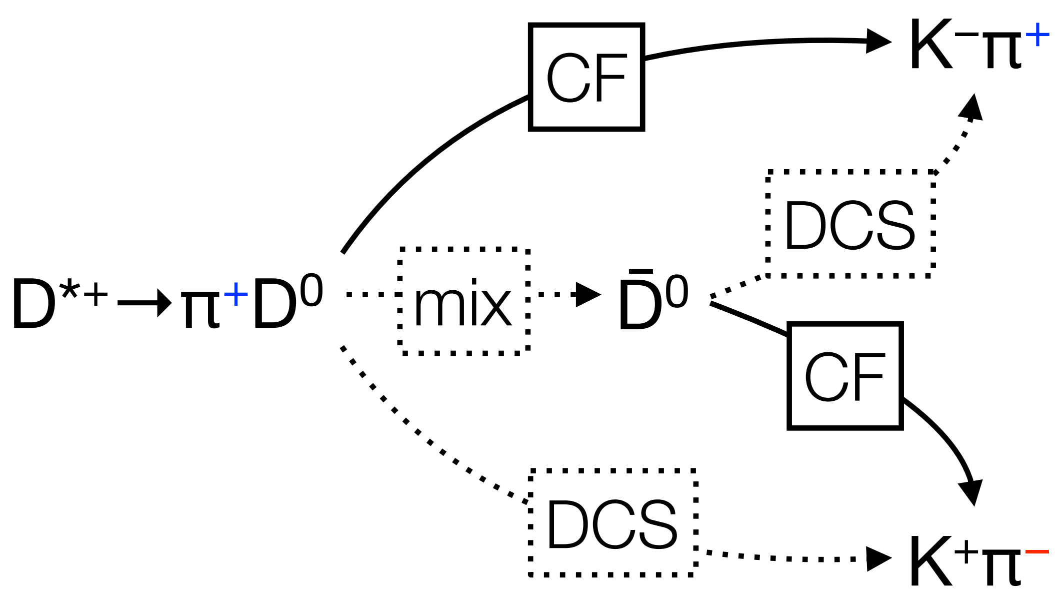
Mixing and indirect CP violation

PRL 111 (2013) 251801

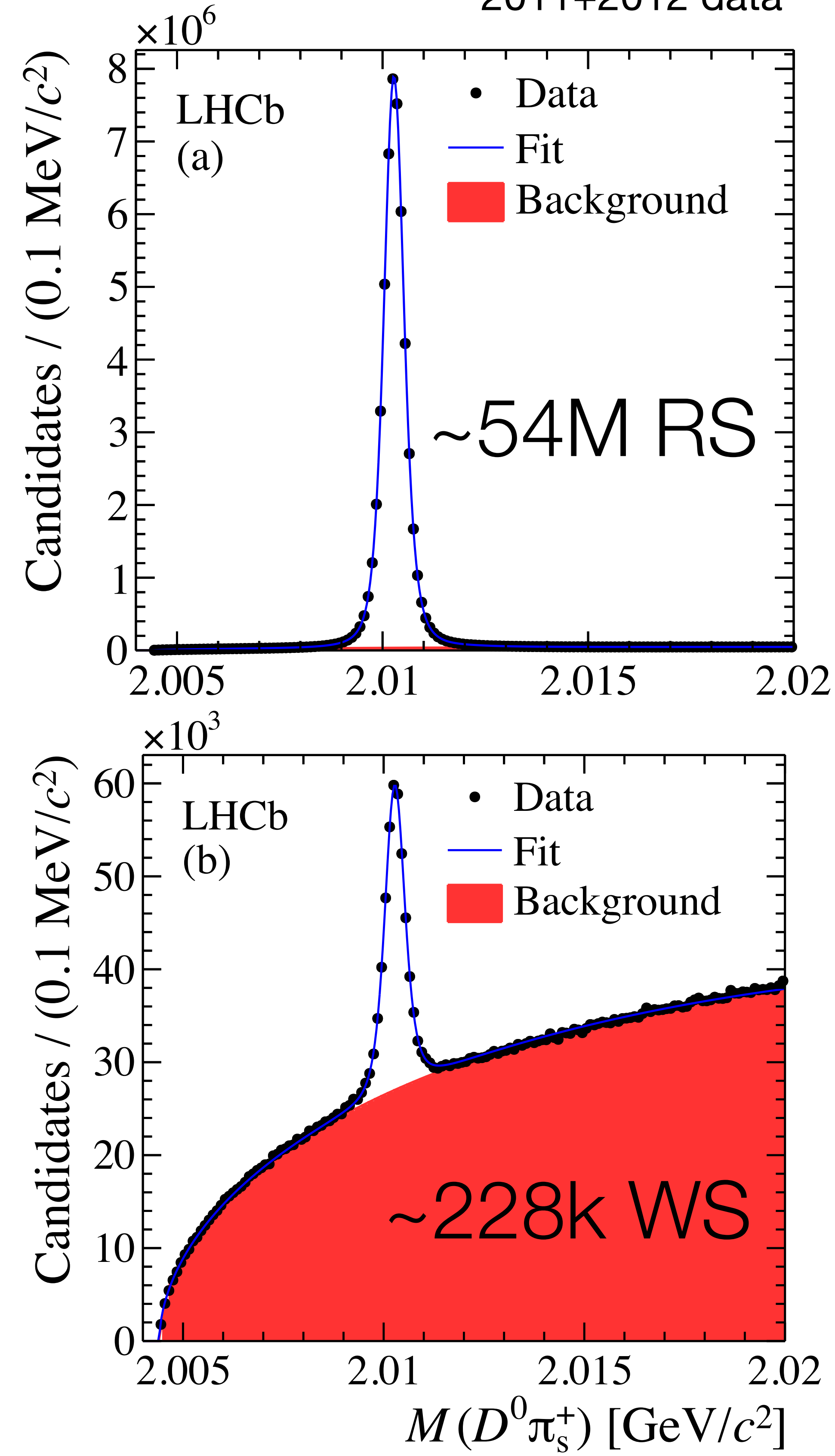
2011+2012 data

Mixing and CPV with $D^0 \to K^+\pi^-$

- Built upon previous iteration of the analysis [PRL 110 (2013) 101802] with full Run I dataset
- Reconstruct RS and WS decays using D* to identify flavor at production



- Fit ratio of WS/RS yields in bins of decay time to separate mixing from DCS contribution
- Fit D^{*+} and D^{*-} independently to search for CPV



Mixing and CPV with $D^0 \to K^+\pi^-$ — Results

- Time-dependent WS/RS ratio:

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

$$y'^{\pm} = |q/p|^{\pm 1} \left[y \cos(\delta \pm \phi) \mp \sin(\delta \pm \phi) \right]$$

$$R_D^{\pm} = R_D (1 \pm A_D)$$

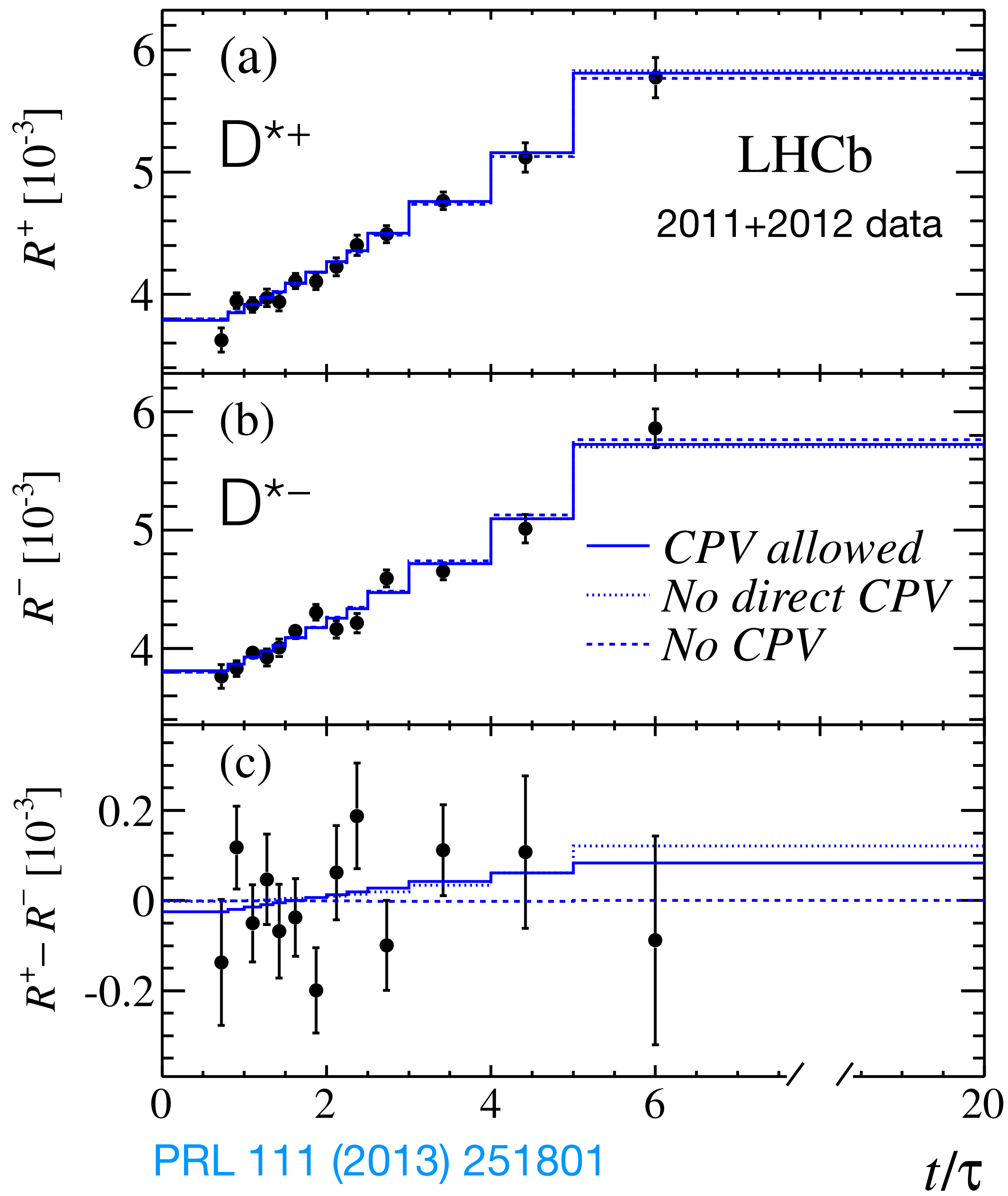
- Indirect CPV ($|q/p| \neq 1$ or $\phi \neq 0$) if difference between ratios varies vs time:

$$0.75 < |q/p| < 1.24 \text{ @ } 68.3\% \text{ CL}$$

- Direct CPV in DCS decay if nonzero intercept:

$$A_D = (-0.7 \pm 1.9)\%$$

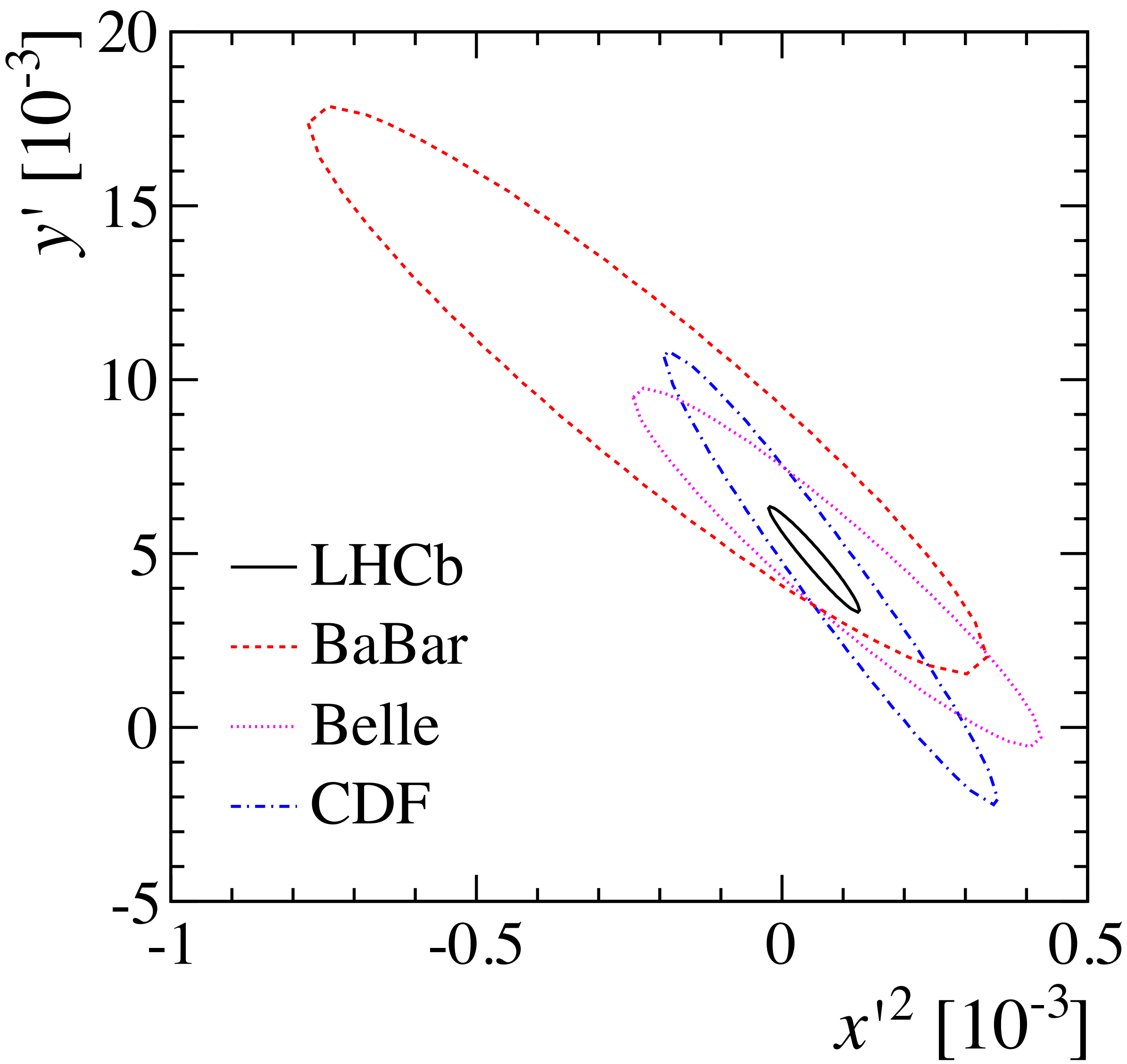
World's best bound on CPV in charm mixing and in DCS decays



PRL 111 (2013) 251801

WS mixing and CPV — Results

Precision on mixing parameters improved by 2.5×
wrt our previous result [PRL 110 (2013) 101802]



	R_D (10^{-3})	y' (10^{-3})	x'^2 (10^{-3})
LHCb	3.568 ± 0.066	4.8 ± 1.0	0.055 ± 0.049
BaBar	3.03 ± 0.19	9.7 ± 5.4	-0.22 ± 0.37
Belle	3.53 ± 0.13	4.6 ± 3.4	0.09 ± 0.22
CDF	3.51 ± 0.35	4.3 ± 4.3	0.08 ± 0.18

LHCb: PRL 111 (2013) 251801

BaBar: PRL 98 (2007) 211802

Belle: arXiv:1401.3402

CDF: PRL 111 (2013) 231802

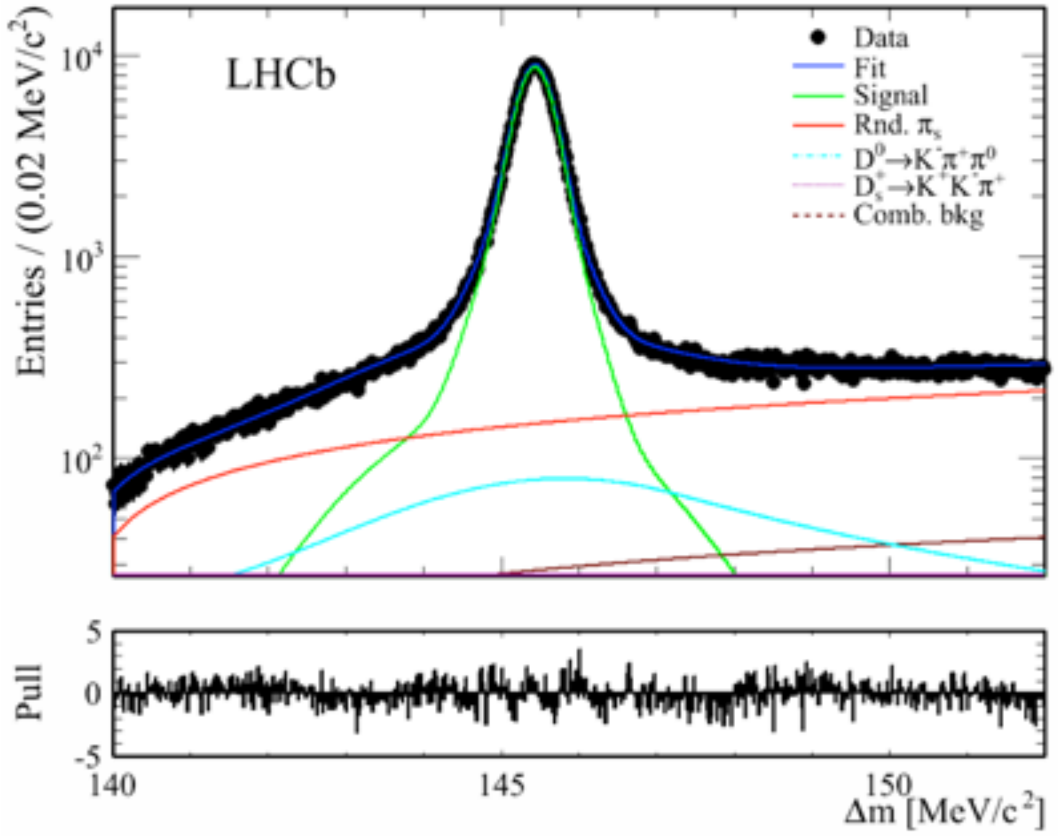
PRL 112 (2014) 041801

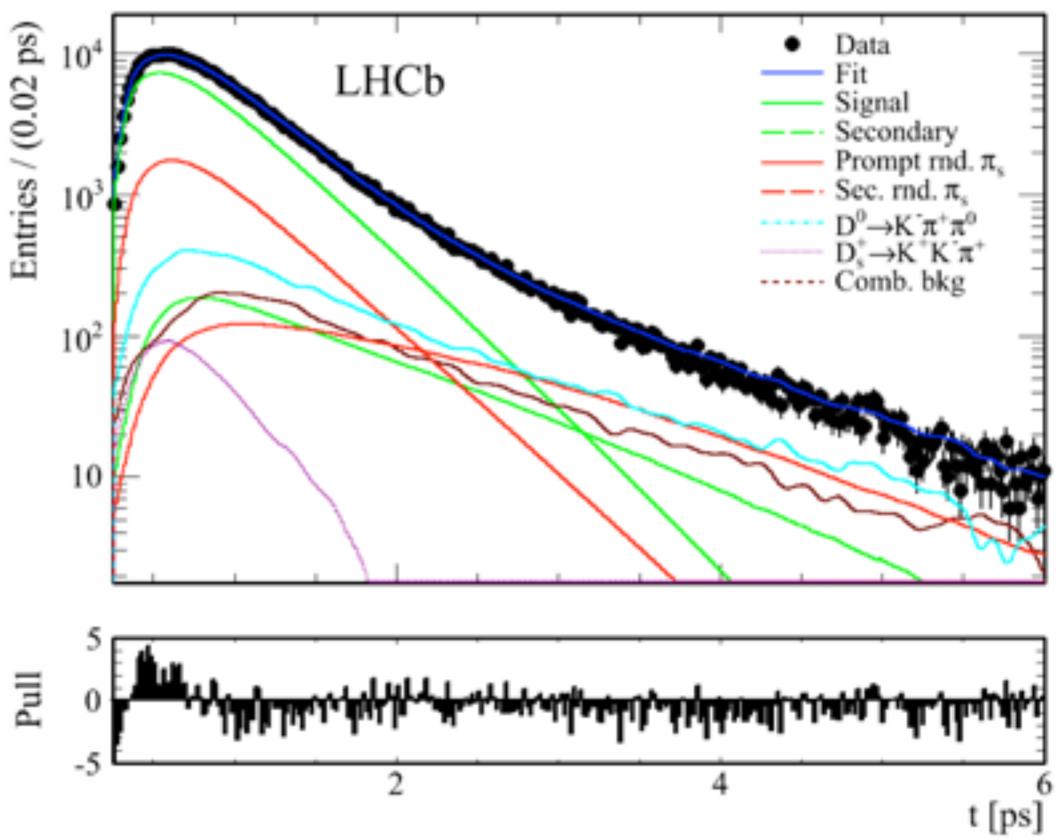
Effective-lifetime asymmetry

- Measure asymmetry between effective lifetimes of SCS D*-tagged $D^0 \to K^+K^-$ (~3M) and $D^0 \to \pi^+\pi^-$ (~1M) decays

$$A_\Gamma = \frac{\hat{\tau}(\overline{D}^0) - \hat{\tau}(D^0)}{\hat{\tau}(\overline{D}^0) + \hat{\tau}(D^0)}$$
$$\approx \frac{1}{2}\left[\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) y\cos\phi - \left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right) x\sin\phi\right]$$

- Nonzero if indirect CPV occurs
- Evaluate acceptance vs decay-time for each candidate using only data
- Validate analysis on larger sample of CF $D^0 \to K^-\pi^+$ decays

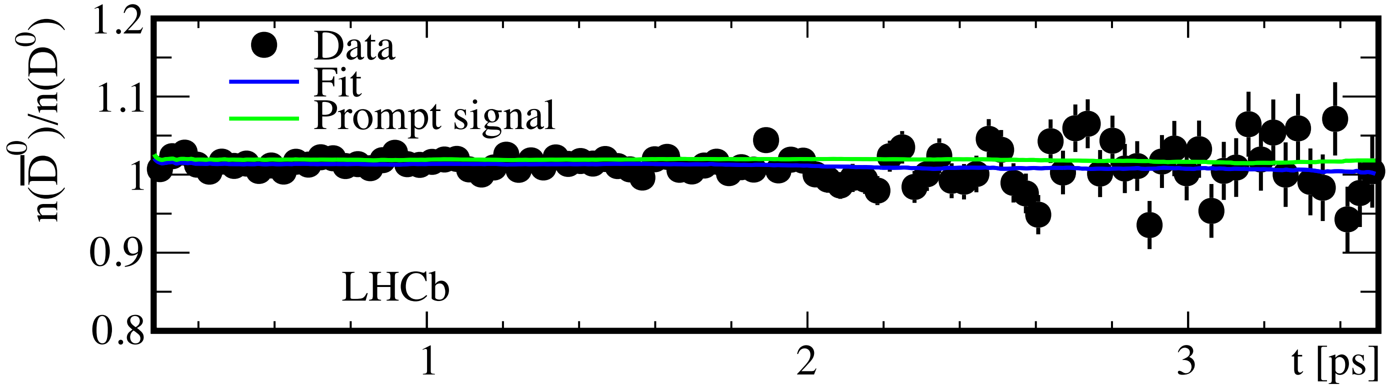




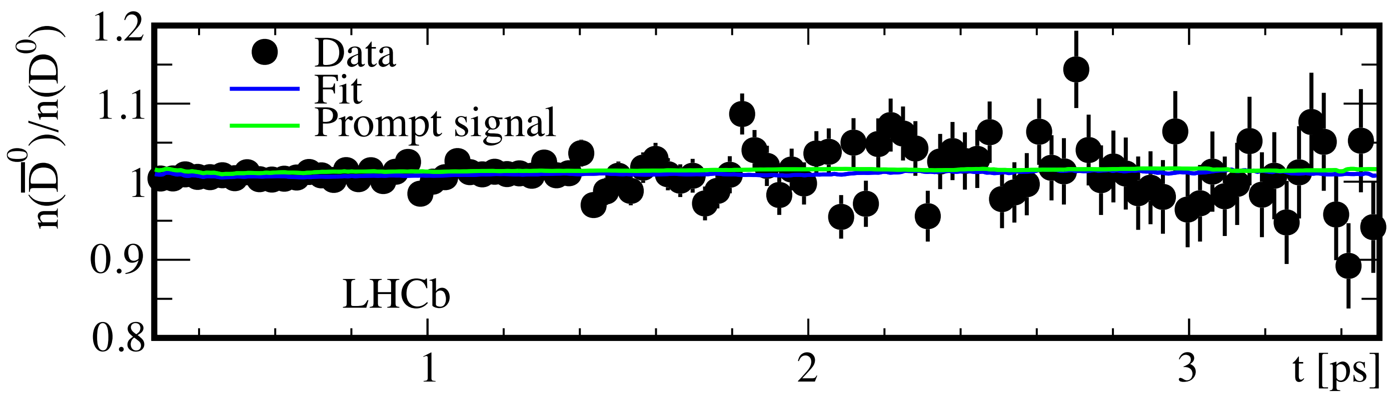
Effective-lifetime asymmetry — Results

- No signs of indirect CP violation at 0.1% level

PRL 112 (2014) 041801 2011 data

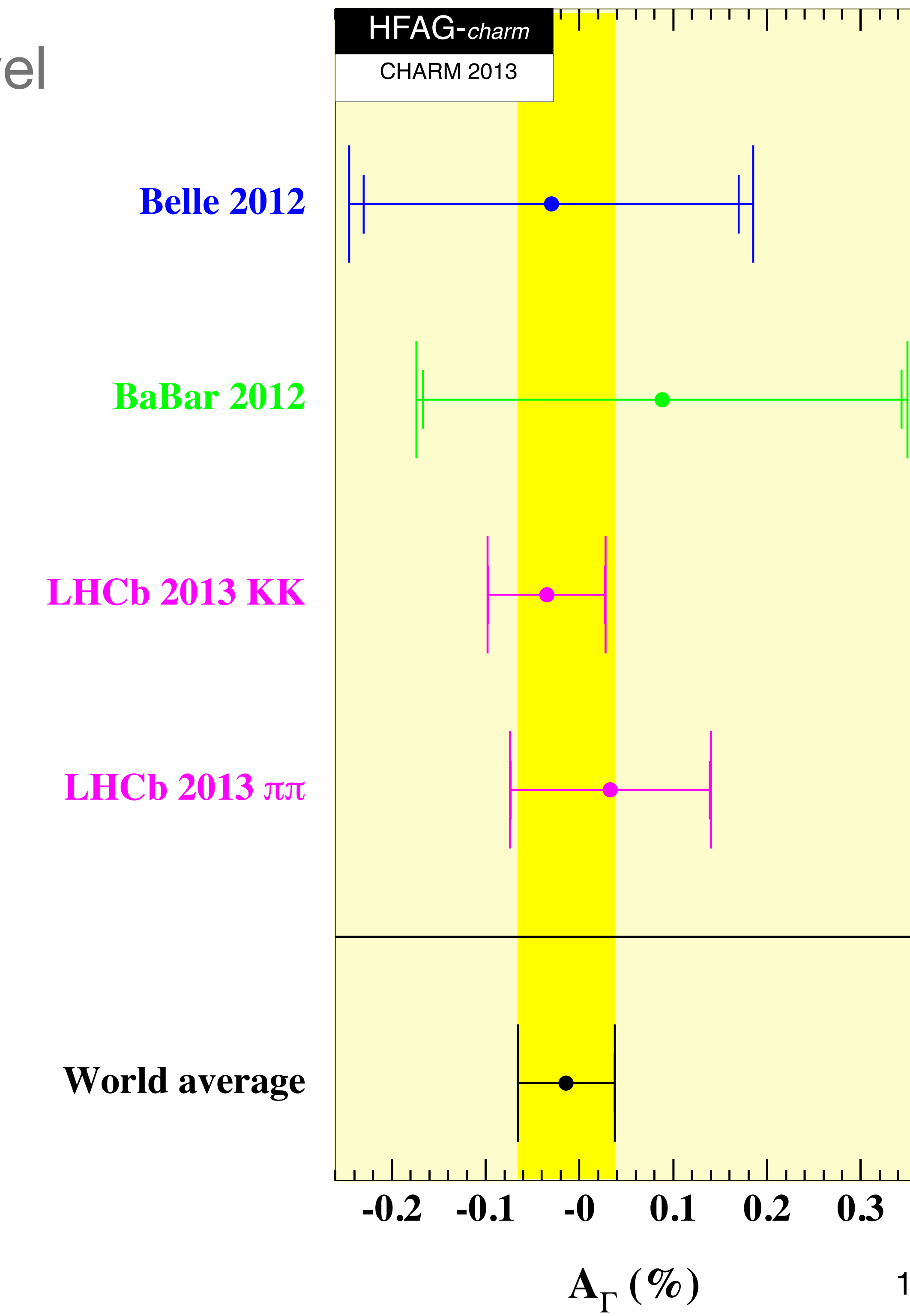


$$A_\Gamma(K^+K^-) = (-0.35 \pm 0.62 \pm 0.12) \times 10^{-3}$$

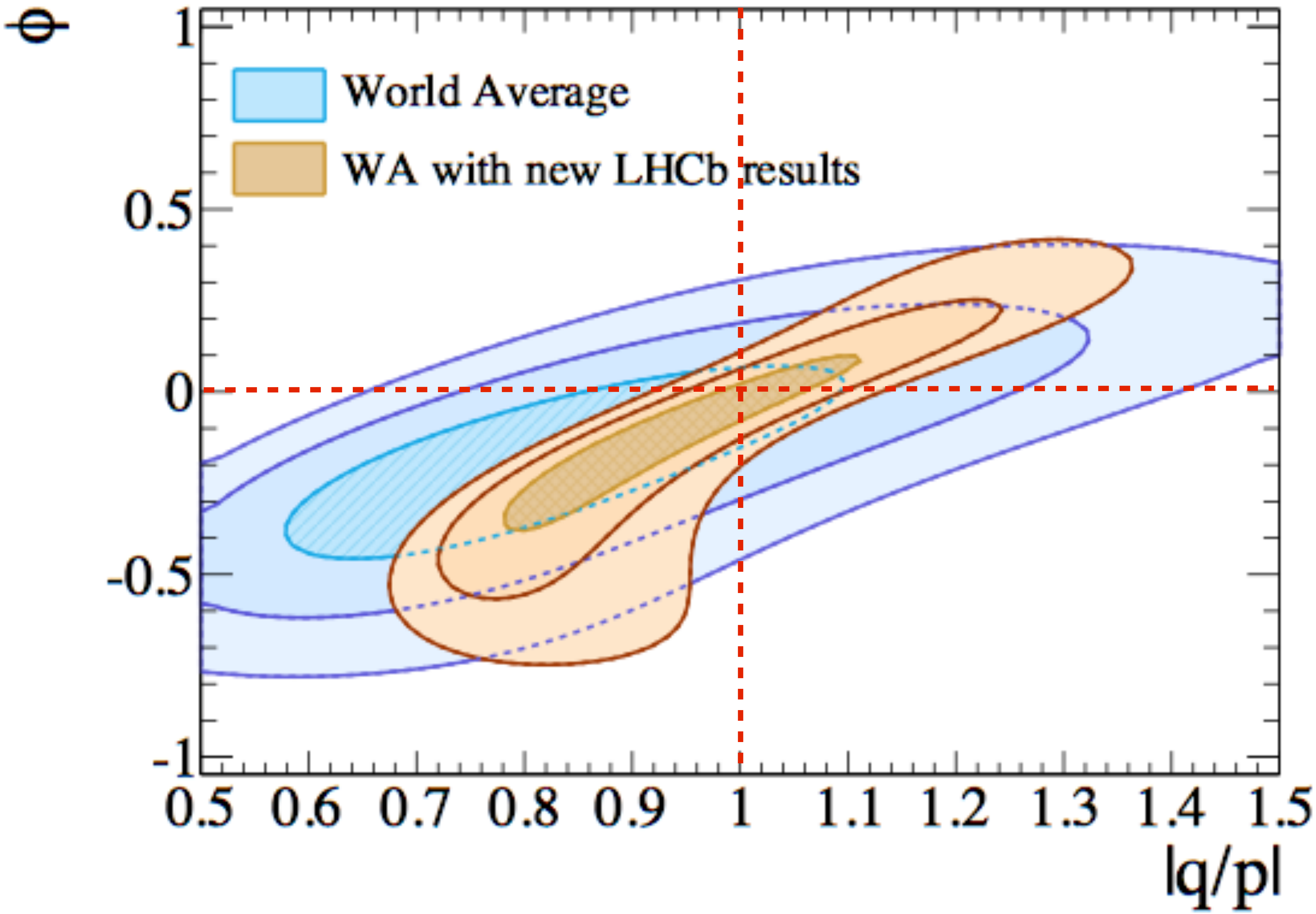


$$A_\Gamma(\pi^+\pi^-) = (0.33 \pm 1.06 \pm 0.14) \times 10^{-3}$$

World's best results with only ~1/3 of currently available data



Impact on world average

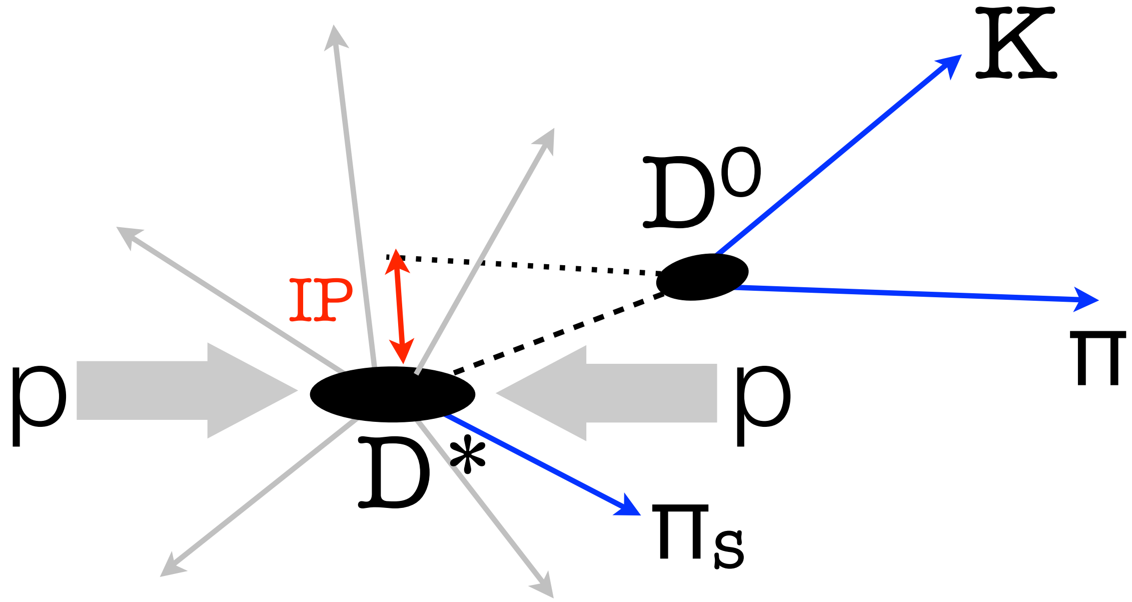


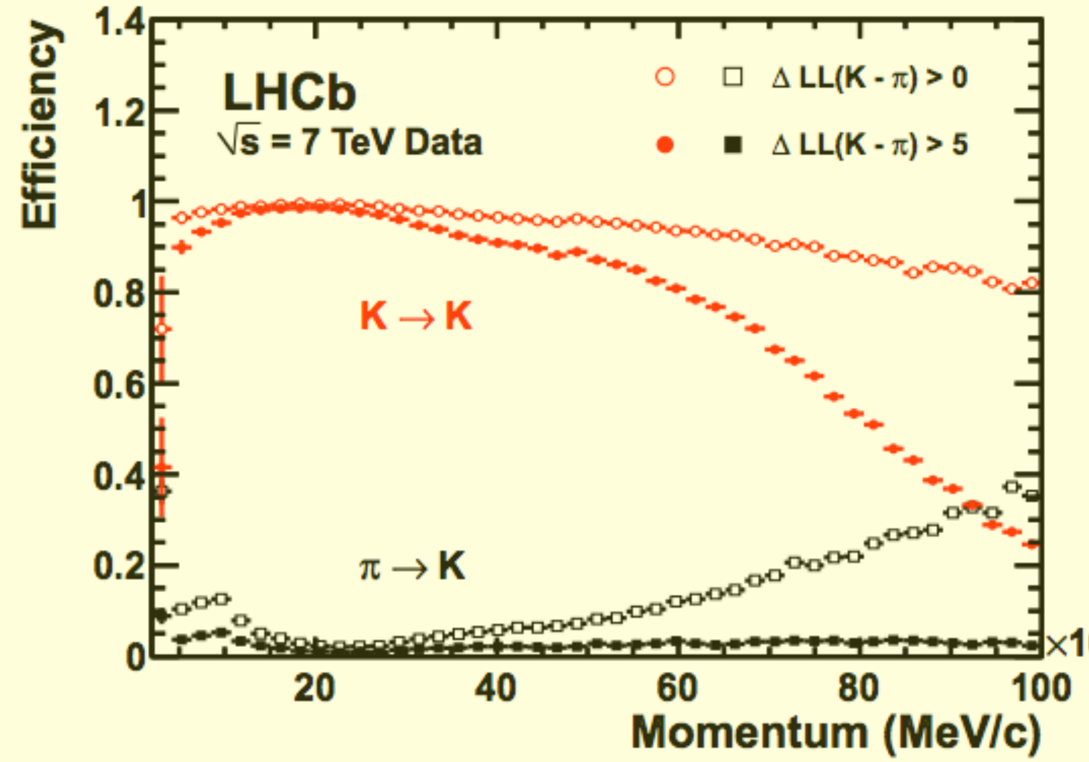
Conclusions

- Charm is a unique probe of BSM couplings to up-quark sector
- LHCb leads thanks to O(1M) charm decays collected
  - Shown today, world's best determination of mixing and bounds on CPV
- Much more to come as Run I dataset still being analyzed
- Getting ready for upcoming LHC runs and for challenging the SM with precision measurements of charm dynamics…

Backup slides

Hadronic charm decays at LHCb

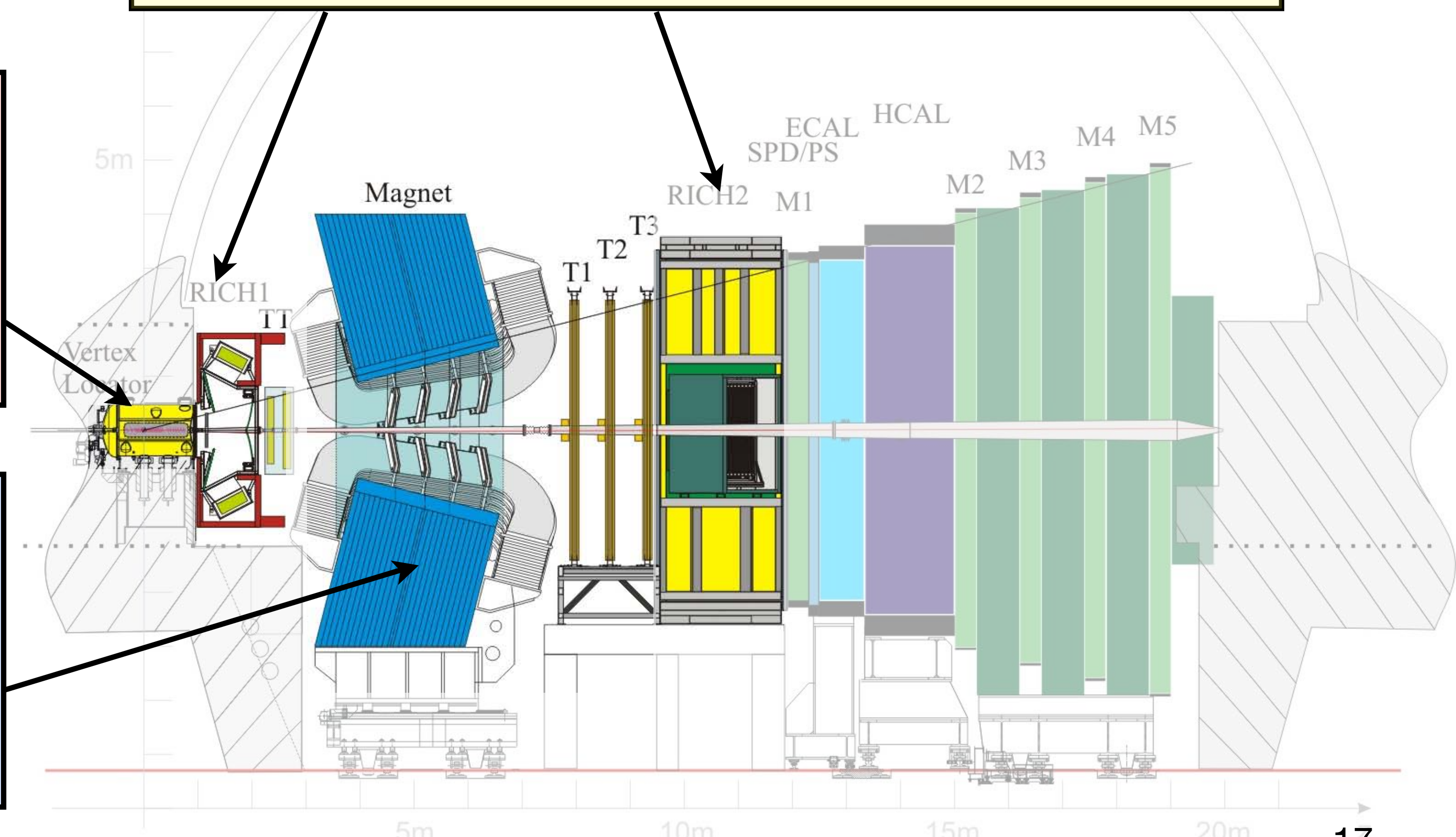




RICH detectors:
K-π separation in wide range of momentum

Silicon Vertex Locator:
20 μm impact parameter resolution, corresponding to ~45 fs decay-time resolution for a 2-body charm decay

Excellent tracking:
Δp/p = 0.4-0.6% at 5-100 GeV/c, corresponding to ~8 MeV/c² mass resolution for a 2-body charm decay



Trigger on hadronic charm decays

LHC rate ~ 15 MHz	$c\bar{c}$ fraction ~ 10%
Hardware E_T trigger ~ 1 MHz	$c\bar{c}$ fraction ~ 50%
High p_T, IP track ~ 80 kHz	efficiency ~ 50%
Exclusive D→hh/3h/4h ~ 2 kHz	efficiency ~ 50-90%

No possibility of an inclusive charm trigger!

Use exclusive triggers tuned for the needs of specific analyses to deliver high signal efficiency and purity

HFAG results

Parameter	No CPV	No direct CPV in DCS decays	CPV-allowed	CPV-allowed 95% CL Interval
x (%)	$0.53^{+0.16}_{-0.17}$	$0.43^{+0.15}_{-0.16}$	$0.39^{+0.16}_{-0.17}$	[0.03, 0.68]
y (%)	0.67 ± 0.09	0.65 ± 0.08	$0.67^{+0.07}_{-0.08}$	[0.50, 0.81]
$\delta_{K\pi}$ (°)	$14.0^{+9.3}_{-10.5}$	$11.2^{+10.2}_{-11.8}$	$12.5^{+9.4}_{-11.0}$	[−13.2, 30.5]
R_D (%)	0.350 ± 0.004	0.349 ± 0.004	0.349 ± 0.004	[0.342, 0.357]
A_D (%)	–	–	-0.95 ± 1.0	[−3.0, 1.0]
$\lvert q/p \rvert$	–	1.01 ± 0.01	$0.91^{+0.11}_{-0.09}$	[0.76, 1.14]
ϕ (°)	–	$-0.3^{+0.5}_{-0.6}$	$-10.8^{+10.5}_{-12.3}$	[−37.4, 9.9]
$\delta_{K\pi\pi}$ (°)	$19.6^{+22.8}_{-23.4}$	$23.6^{+23.7}_{-24.2}$	$26.8^{+24.2}_{-24.5}$	[−21.5, 74.7]
A_π	–	0.17 ± 0.15	0.18 ± 0.15	[−0.12, 0.47]
A_K	–	-0.16 ± 0.13	-0.15 ± 0.14	[−0.43, 0.12]
x_{12} (%)	–	$0.43^{+0.15}_{-0.16}$		[0.10, 0.71]
y_{12} (%)	–	0.65 ± 0.08		[0.49, 0.80]
ϕ_{12}(°)	–	$1.0^{+2.0}_{-1.7}$		[−3.0, 7.8]