Charm physics in LHCb (part one-time independent measurements)

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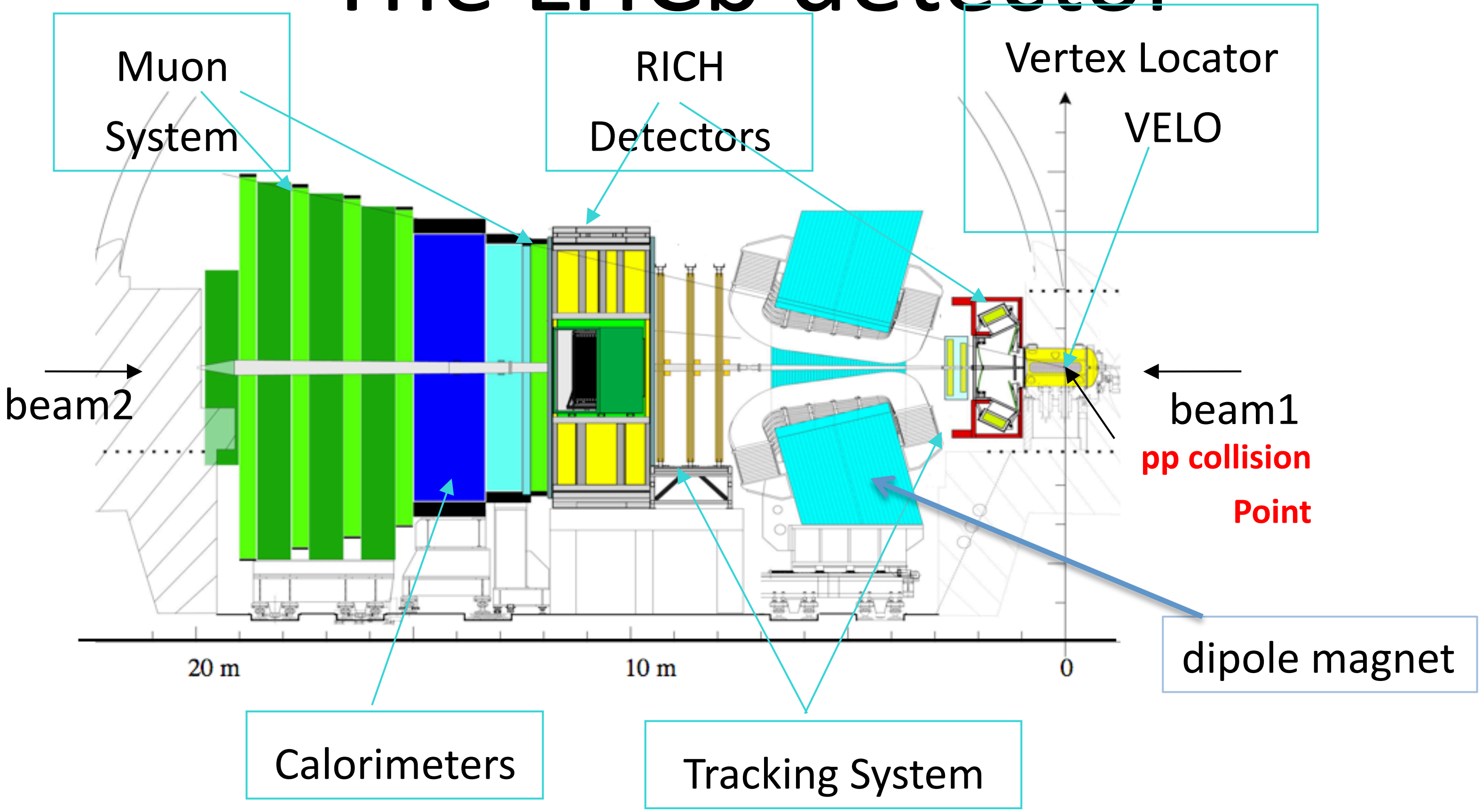
Outline

- LHCb detector
- Experimental approach
- Charm cross section and spectroscopy
- Time integrated CPV measurements
- Rare Decays
- Charm input to CKM $\gamma/\Phi3$ angle measurement

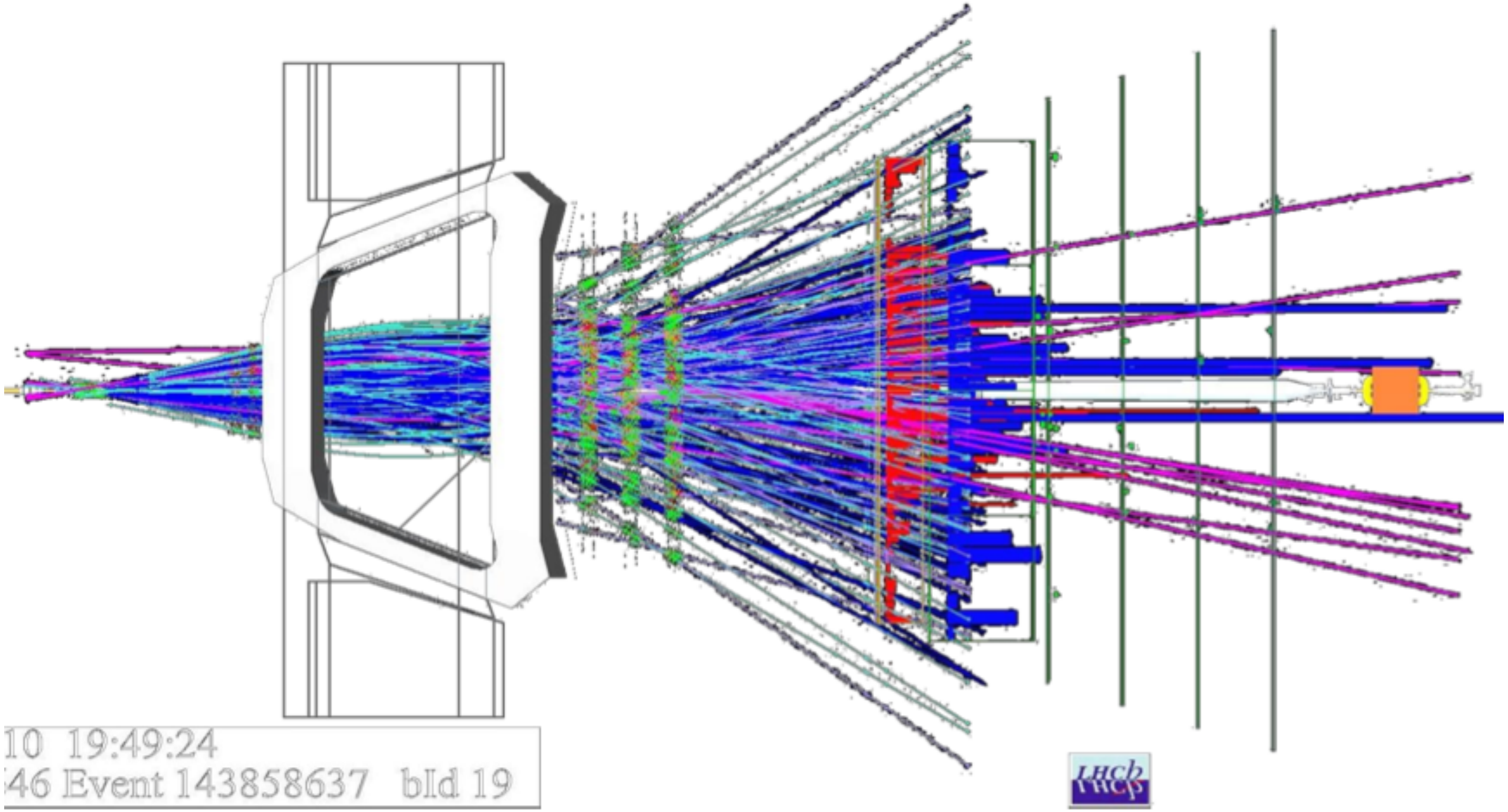
- second LHCb talk: S.Bachmann time dependent CPV and mixing

The LHCb detector



CERN LHC: pp machine with √s=7TeV (due to the 2008 accident)
Pseudo-rapidity coverage → 1.9-4.9
Originally designed for b physics, but now is pursuing a wide charm physics program (out of 4 physics WGs, one is Charm)

A typical event!



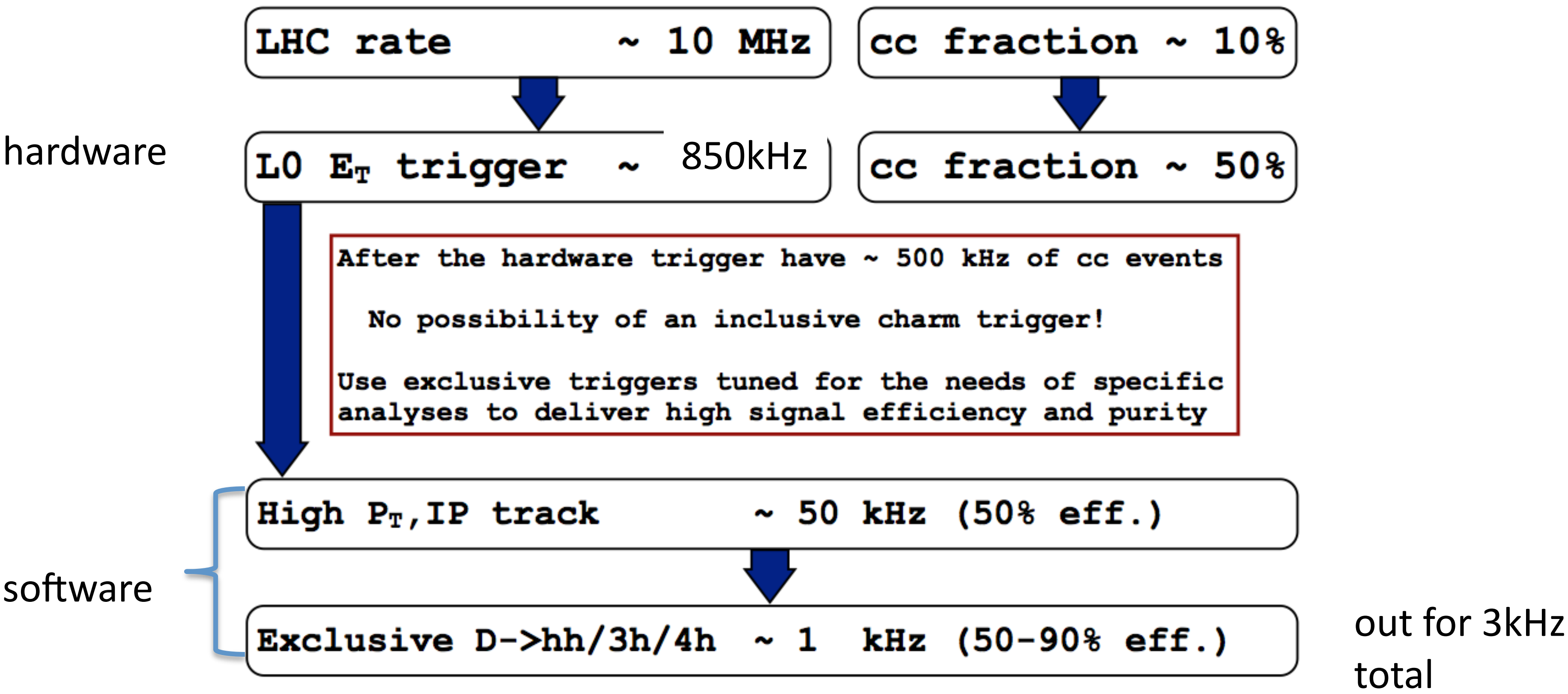
Challenges and goodies of charm physics in LHCb (1)

- at 7TeV σ(ccbar) ≈ 6mb, σ(bbar) ≈ 0.3mb, σ(pp inelastic)≈60mb
  - huge σ(ccbar); background from secondary charm from b already low from the start of the selection
  - and very favorable ratio to inelastic σ (only a factor of 10!)
  - → high purity selections with few and soft IP, displaced vertex and p_T cuts
  - → very large yields (the highest on the market)
- however due to lower D meson daughter p_T and IP wrt B mesons, trigger thresholds have to be kept low
  - → tough requirements for trigger, tracking, online and offline reconstruction, both for bandwidth and timing, and last but not least storage!

Challenges and goodies of charm physics in LHCb (2)

- yields (and competition with other experiments) decrease with # of tracks in the final state due to tracking efficiency (a factor/track) and to trigger efficiency (the meson p_T is divided among the n---tracks)
  - the competition with the B factories for channels with ≥4 tracks is tough
- we mostly concentrate on channels with charged tracks in the final state (due to the large number of π^0 in the event and to the modest resolution EM Calorimeter)
- the large data yields are also a problem for MC → very tough to get equivalent MC statistics of full simulation (to test for e.g. detector effects in CPV asymmetries)
    - toy studies need to be extensively used
- Charm physics at hadron colliders has been successfully pioneered by the Tevatron experiments!

The trigger and charm physics



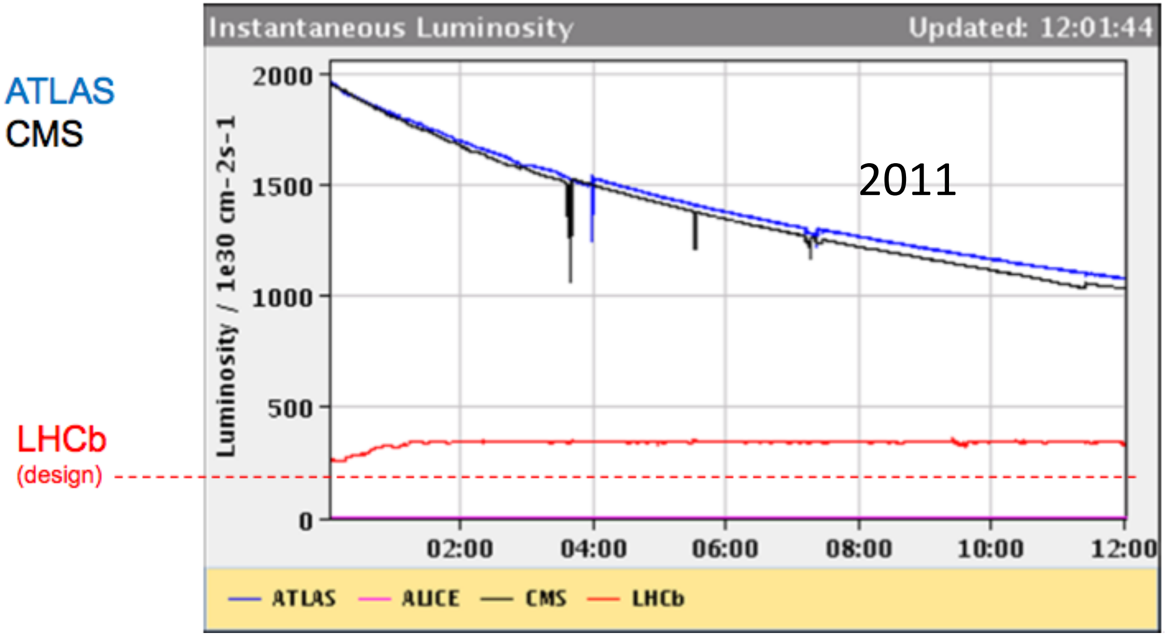
Already at trigger level selections very similar to offline (S/B about 1)!!!
Then we write down to disk at 200Hz rate (stripping)
at present instantaneous luminosity we collect:

$5 * 10^3$ tagged $D^{*\pm} \rightarrow (D0 \rightarrow K^{\pm}K^{\mp})\ \pi^{\pm}$

$3 * 10^5$ untagged $D^0 \rightarrow K^-\pi^+$ per pb^{-1} (now we have >1fb^{-1}) !!

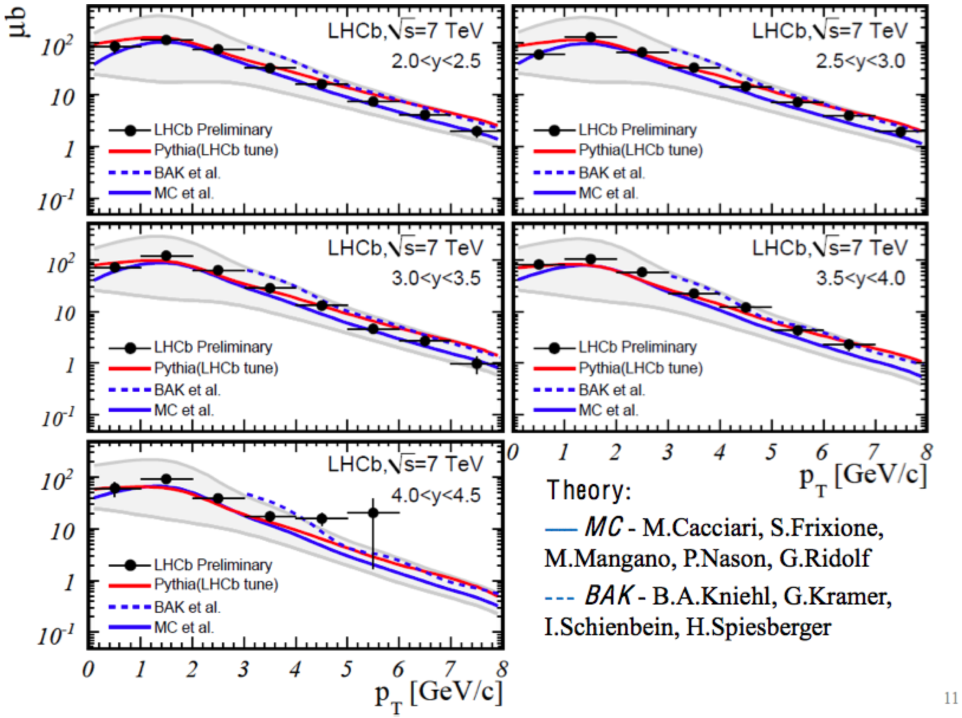
The LHCb running conditions

2010 was a "learning phase" year with fast varying running conditions and luminosity at the end of it we collected $37pb^{-1}$ and we were running at a pile-up of up to 2.5 collisions/event in average (with the design being 0.4) but we coped well with it!



In 2011 we've been running with more steady conditions of ≈1.5collisions/event with $L=3.5\bullet10^{-32}\,cm^{-1}s^{-1}$ (1.5x the design value) with luminosity leveling collecting up to more than $1fb^{-1}$ by now (while GPE collected about $5pb^{-1}$)

Prompt open charm cross section



D^0 cross section

Preliminary: 2010 data
$2nb^{-1}$

no pile-up data
minimum bias trigger

Total production cross-section σ(pp → ccX) in 4π:

- combined average of D0, D+, D*+, Ds+
- charm from b subtracted out
- using average of transition probabilities measured at ϒ(4S) and at Z^0

  → LHCb: σ(pp → ccX) in 4π = (6100 ± 934) μb

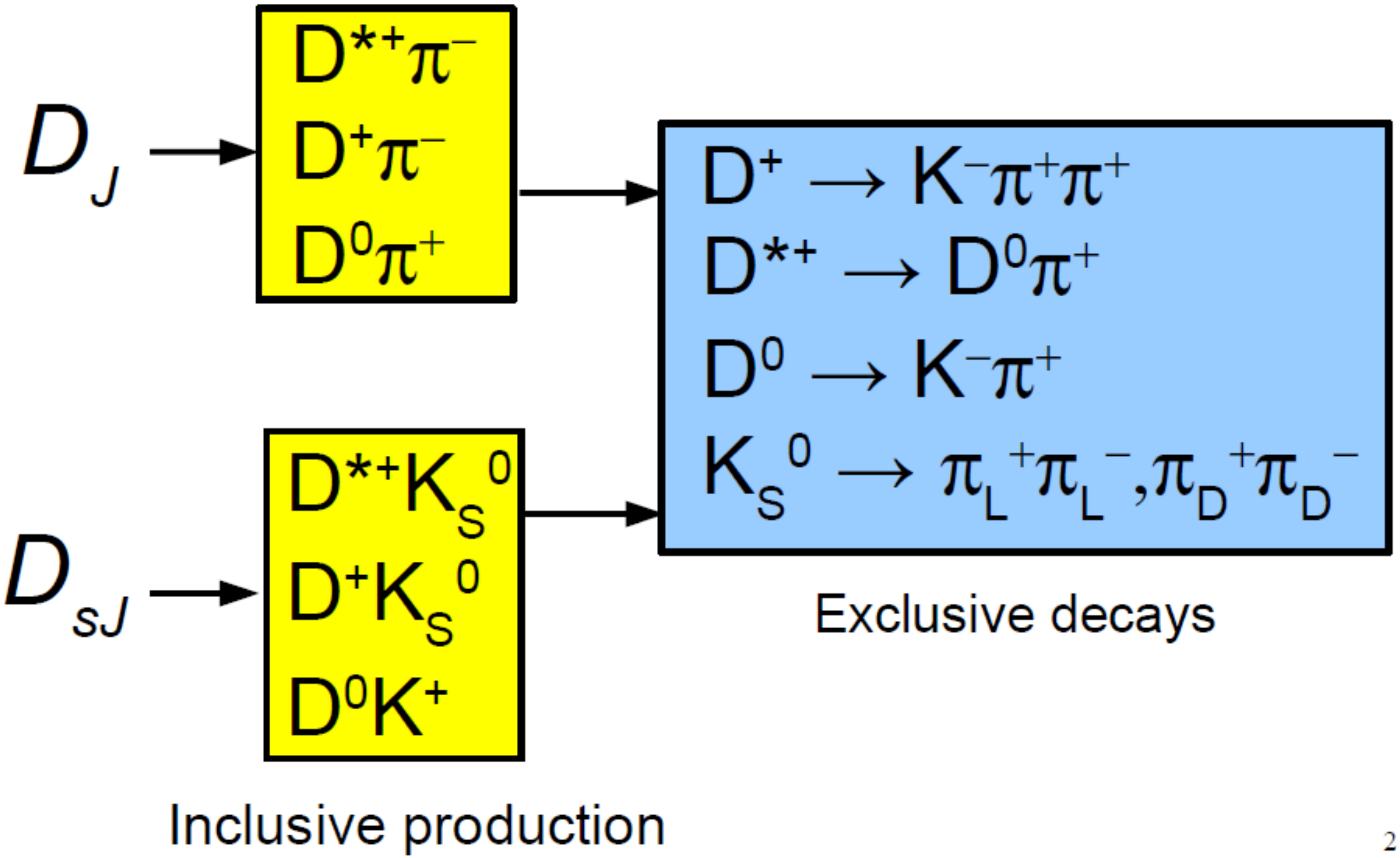
    - 20 times higher than σ(bb)!

Double charm cross section in the pipeline

Charm meson spectroscopy

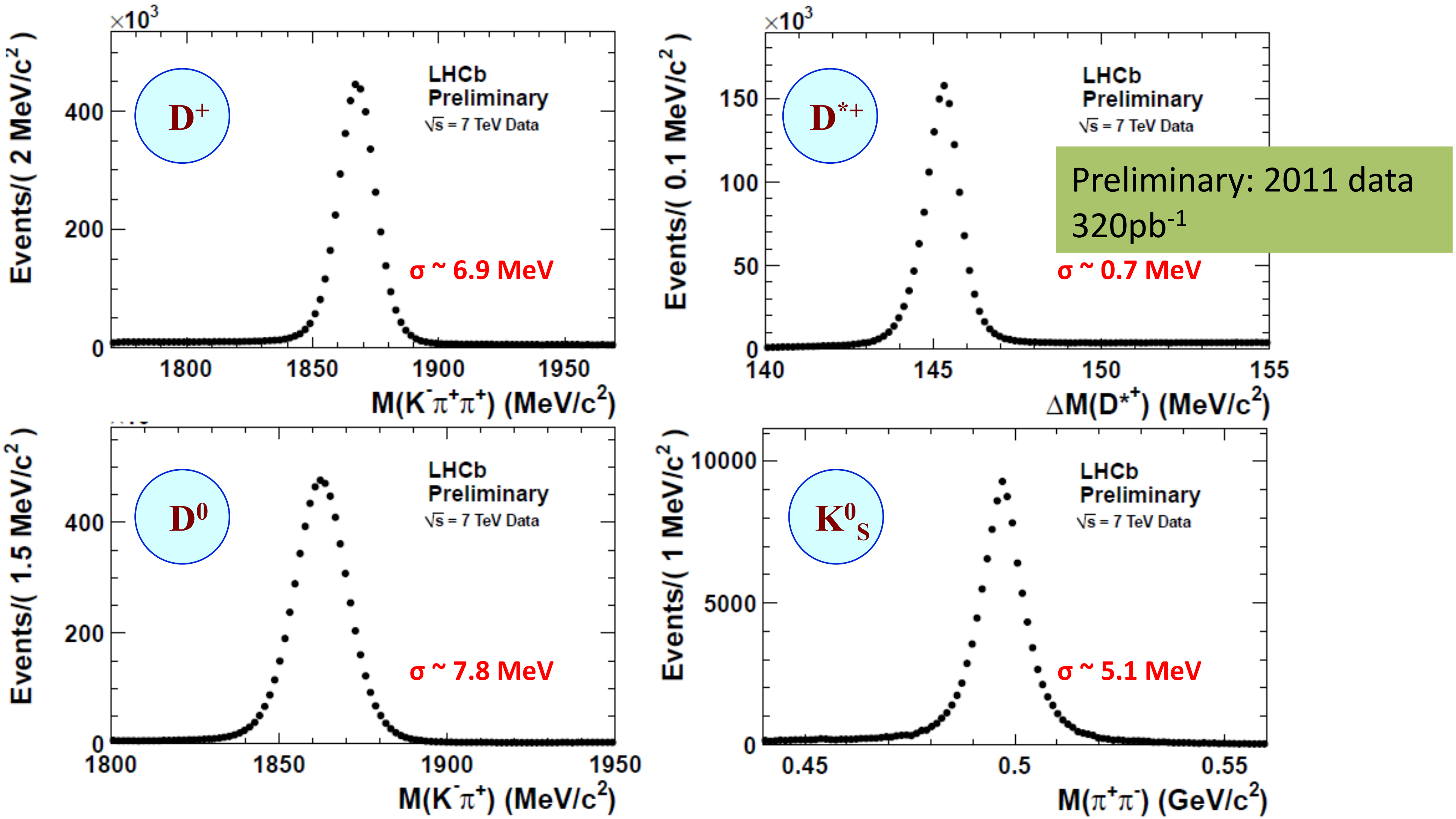
- Predictions of the D and D_s mass eigenstates were performed in 1985 using QCD potential models.
- The masses of $D_{(s)1}$ and $D^*_{(s)2}$ states were successfully predicted before their discoveries.
- In 2003 observation of two unexpected new states: $D^*_{s0}(2317)$ and $D_{s1}(2460)$.
- Recently BaBar and Belle observed new D_J and D_{sJ} states: D(2550), $D^*(2600)$, D(2750), $D^*(2760)$, $D_{s1}^*(2710)$, $D_{sJ}^*(2860)$, $D_{sJ}(3040)$. Many of them need to be confirmed.

Decay modes

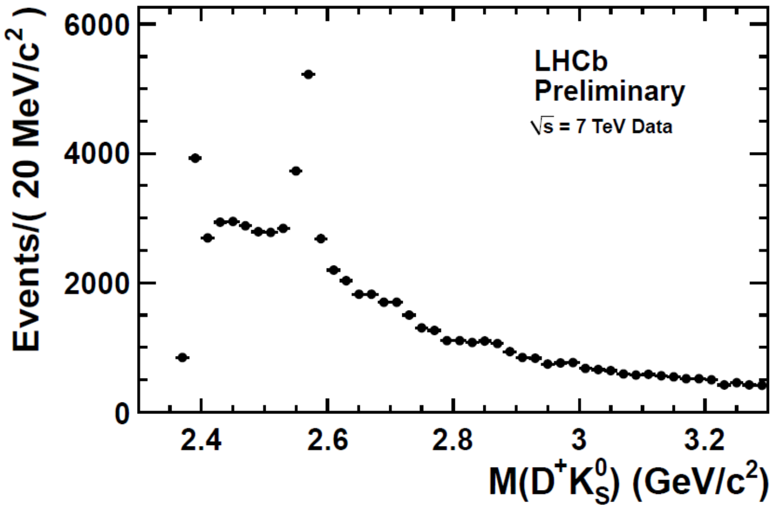


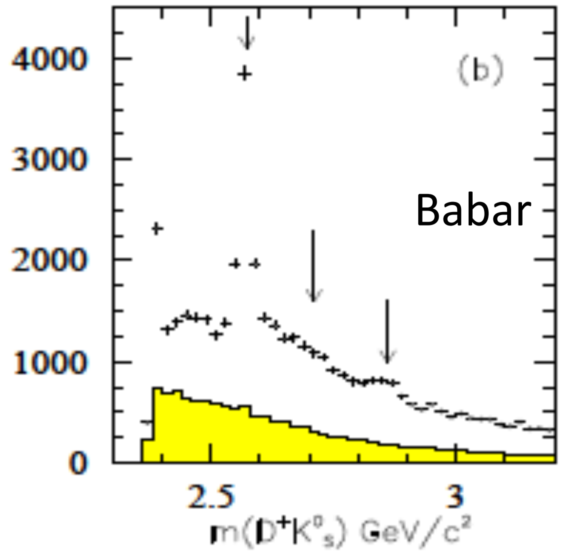
D_J
$D^{*+}\pi^-$
$D^+\pi^-$
$D^0\pi^+$
D_{sJ}
$D^{*+}K_S^0$
$D^+K_S^0$
D^0K^+
$D^+ \rightarrow K^-\pi^+\pi^+$
$D^{*+} \rightarrow D^0\pi^+$
$D^0 \rightarrow K^-\pi^+$
$K_S^0 \rightarrow \pi_L^+\pi_L^-, \pi_D^+\pi_D^-$
Exclusive decays
Inclusive production
2

Selected meson final states



$D^+K_s^0$





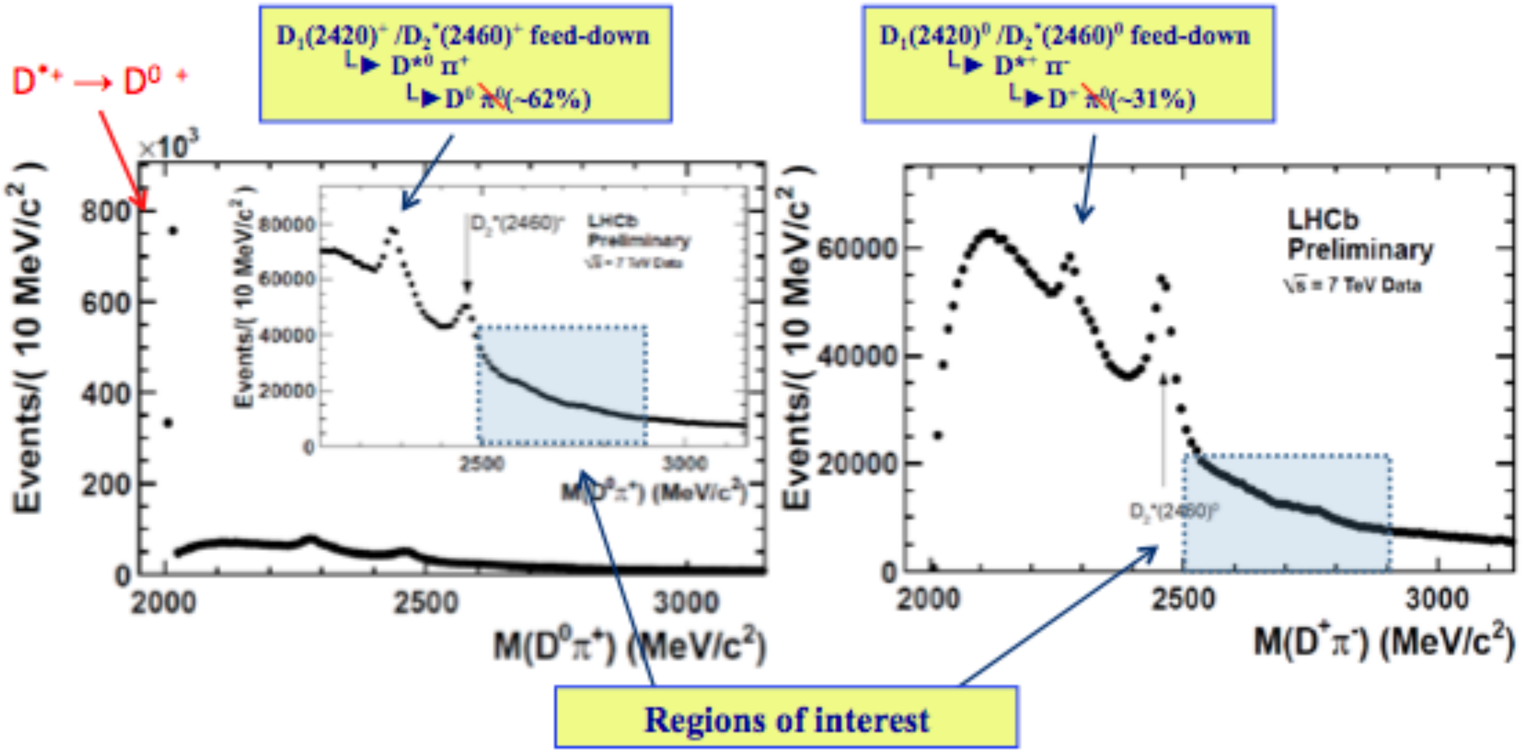
Preliminary: 2011 data
$320pb^{-1}$

Thank to the excellent performances of LHC and LHCb detector, D_J and D_{sJ} spectroscopy feasible with the same sensitivity of the B-factories

Phys.Rev.D 80, 092003(2009)

Resonance	Mass (MeV/c²)	Width (MeV)
$D_{s1}^*(2700)$	$2710 \pm 2 ^{+12}_{-7}$	$149 \pm 7 ^{+39}_{-52}$
$D_{sJ}^*(2860)$	$2862 \pm 2 ^{+5}_{-2}$	$48 \pm 3 \pm 6$

Dπ



BaBar found two new D_J states
(+ isospin partners)

[Phys.Rev.D 82, 111101(2010)]

Resonance	Mass (MeV/c²)	Width (MeV)
$D^*(2600)^0$	2608.7 ±2.4 ±2.5	96 ± 6 ± 3
$D^*(2760)^0$	2763.3 ±2.3 ±2.3	60.9 ± 5.1± 3.6

7

CP Violation

- 3 types of CP violation:
  - In mixing: rate of $D^0 \rightarrow D^0$bar and D^0bar$\rightarrow D^0$ differ ← indirect
  - In decay: amplitudes for a process and its conjugate differ
  - In interference: between mixing and decay diagrams ← direct
- In the SM, indirect CP violation in charm is expected to be very small and universal between CP eigenstates
  - Exactly how small is a matter of debate... but for sure well below present limit of several 10^{-3}
- Direct CP violation can be larger in SM, very dependent on final state (therefore we must search wherever we can)
  - in singly-Cabibbo-suppressed modes O (few 10^{-3}) possible
- Both can be enhanced by NP, in principle up to O(%)
- In LHCb we have now the statistics to make O(0.1%) measurements!

Experimental issues of time integrated CPV in LHCb

- Experimentally, we have to cope with fake asymmetries:
  - production asymmetries (pp collider)
  - detection asymmetries (different K+/K- interaction lengths, soft pion efficiency asymmetry)
  - backgrounds
- Moreover the dipole magnet makes the detector left-right asymmetric for + charge and – charge particles
  - a localized detector inefficiency translates into a fake CPV asymmetry

  1) we developed robust observables:
    - Miranda technique for SCS decay $D^+ \rightarrow K^+K^-\pi^-$
    - difference of two CPV asymmetries in SCS decays into CP eigenstates $D^0 \rightarrow KK$ and $D^0 \rightarrow \pi\pi$

  2) swap the magnetic field from time to time

- signal purity is a must → excellent detector performance

D->KKπ: the method

- Model-independent search for CPV in Dalitz plot distribution
- Compare binned, normalized Dalitz plots for D^+ and D^-
  - Production asymmetry cancels completely after normalization.
  - Efficiency asymmetries that are flat across Dalitz plot also cancel.

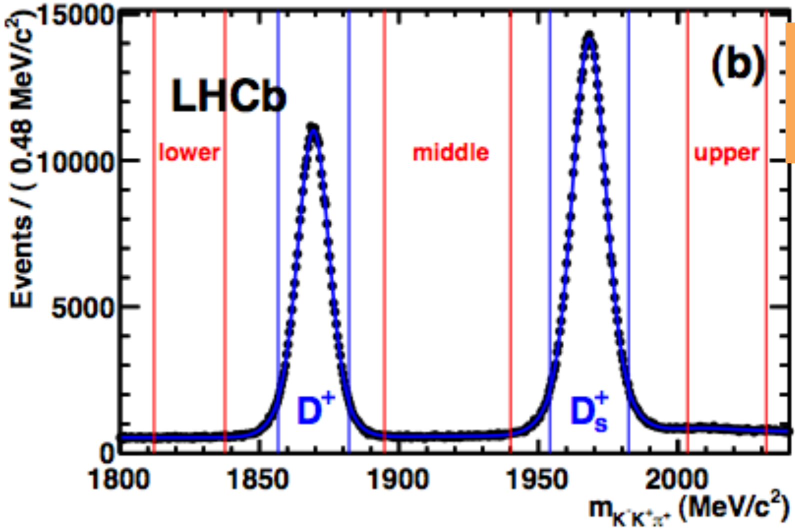
$$\mathcal{S}^i_{CP} = \frac{N^i(D^+) - \alpha N^i(D^-)}{\sqrt{N^i(D^+) + \alpha^2 N^i(D^-)}} , \qquad \alpha = \frac{N_{\rm tot}(D^+)}{N_{\rm tot}(D^-)}$$

- Method based on "Miranda" (*)approach -- asymmetry significance
  - In absence of asymmetry, values distributed as Gaussian(μ=0, σ=1)
  - Figure of merit for statistical test: sum of squares of S^i_{CP} is a $\chi 2$

(*) Phys. Rev. D80 (2009) 096006
See also BaBar: Phys.Rev. D78:051102 (2008); our dataset contains 10x more events and is of comparable size of Belle analysis of $D \rightarrow \phi\pi$:(arXiv:0807.4545)

D→KKπ: mass and Dalitz plot

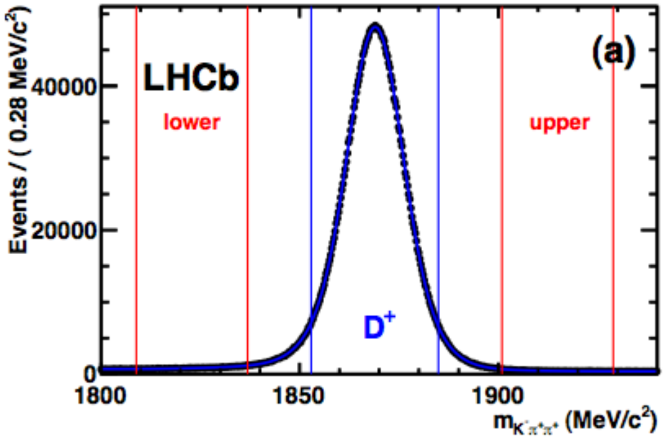
Yield of 400k in window
Purity of ≈91%



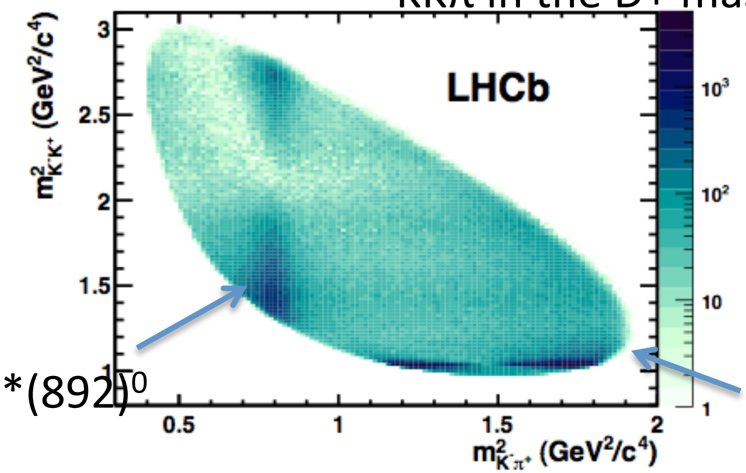
http://arxiv.org/abs/1110.3970
LHCb 35pb^{-1}

KKπ signal (D^+) and control mode (D_s^+)

Kππ control mode (D^+)
purity ~ 98%



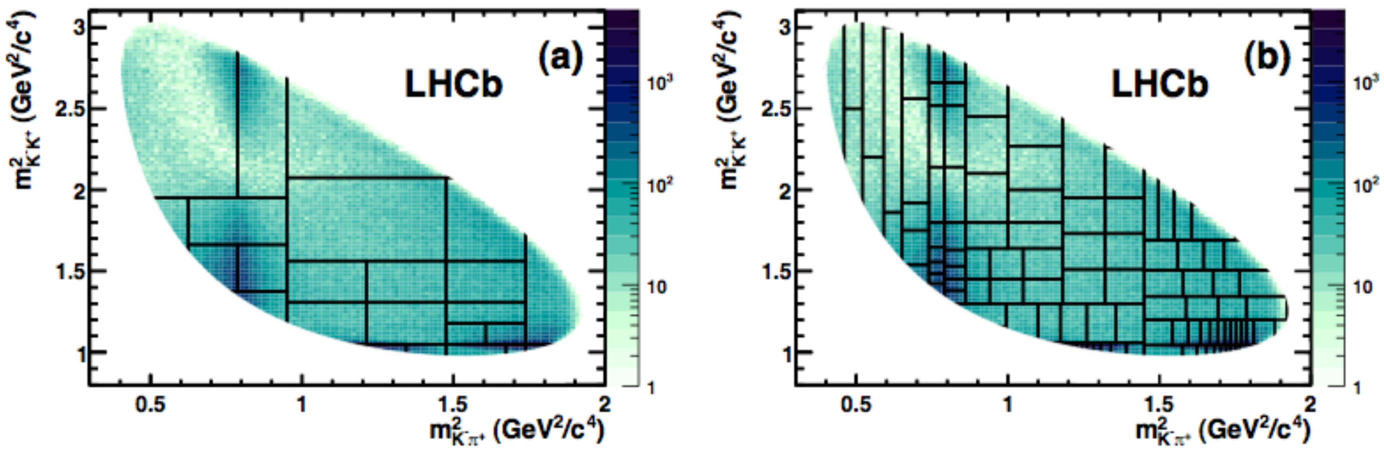
KKπ in the D+ mass window



K*(892)^0
ϕ(1020)

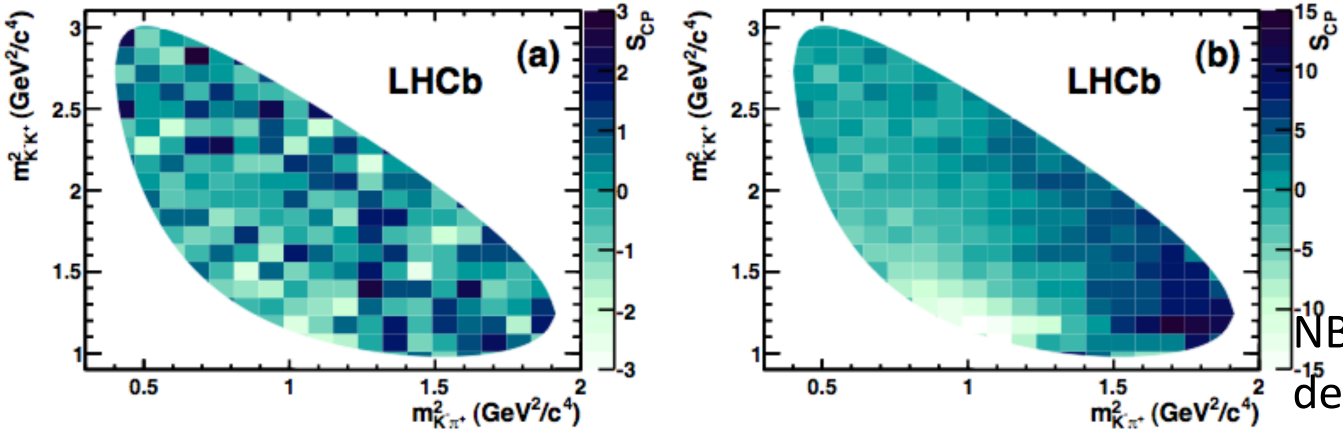
Sensitivity to NP

- With this binning and 2010 statistics, run a set of toys with various CP asymmetries and see how often we get a 3-sigma signal.
- We implemented the CLEO-c Dalitz model to generate the toys
- We implemented both uniform binning and "adaptive"



Sensitivity to NP

no CPV
p=5%



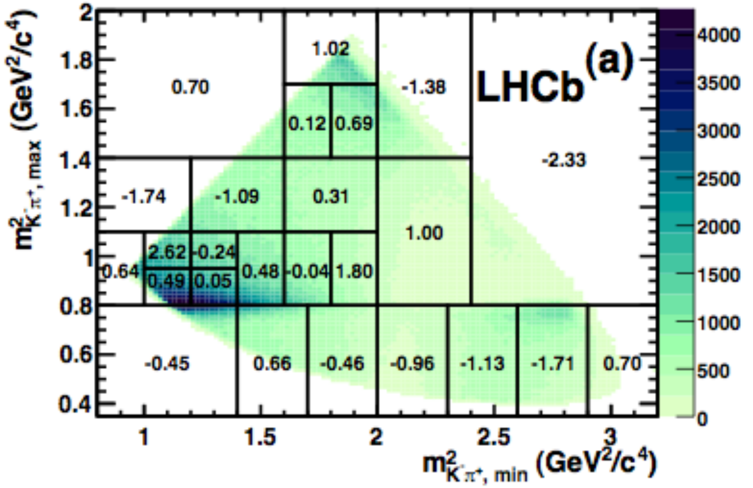
4^o in ϕ phase
p=10^{-100}!!

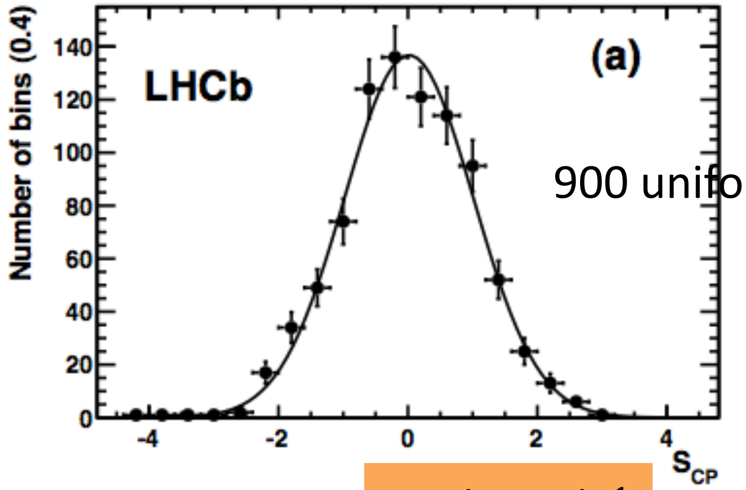
NB: on the total decay asymmmetry the effect would be 0.1%!!

CPV	Adaptive I		Adaptive II	
	$p(3\sigma)$	$\langle S \rangle$	$p(3\sigma)$	$\langle S \rangle$
no CPV	0	0.84σ	1%	0.84σ
6° in $\phi(1020)$ phase	99%	7.0σ	98%	5.2σ
5° in $\phi(1020)$ phase	97%	5.5σ	79%	3.8σ
4° in $\phi(1020)$ phase	76%	3.8σ	41%	2.7σ
3° in $\phi(1020)$ phase	38%	2.8σ	12%	1.9σ
2° in $\phi(1020)$ phase	5%	1.6σ	2%	1.2σ
6.3% in $\kappa(800)$ magnitude	16%	1.9σ	24%	2.2σ
11% in $\kappa(800)$ magnitude	83%	4.2σ	95%	5.6σ

- With no CPV, method does not produce a signal (good!)
- If we do see a signal, it will mean big CPV and thus new physics.

$D^+ \rightarrow K\pi\pi$ control mode





900 uniform bins

LHCb 35pb^{-1}

	1300 bins	900 bins	400 bins	100 bins	25 bins
Uniform	73.8	17.7	72.6	54.6	1.7
Adaptive	81.7	57.4	65.8	30.0	11.8

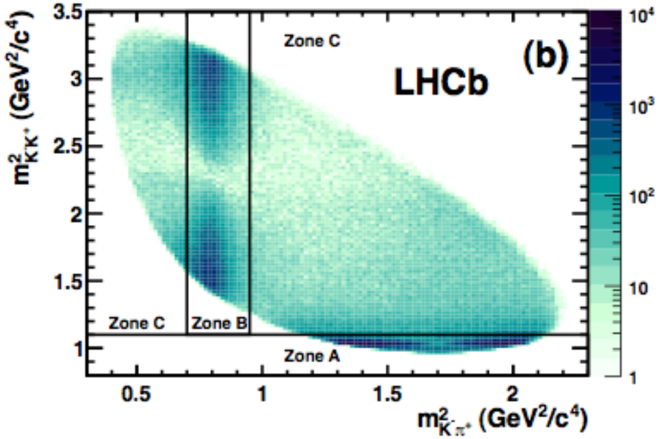
p-Values

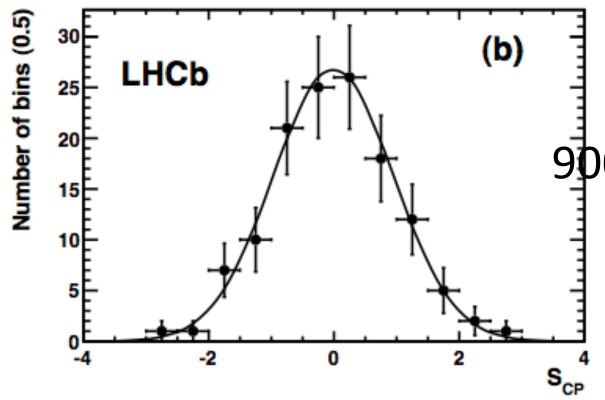
NB: in $D^+ \rightarrow K^- \pi^+ \pi^+$ there is a mechanism for a fake asymmetry that doesn't apply to the signal mode (kaon efficiency)
Here the statistics is 10x larger than in the signal mode.

Ds→KKπ control mode

CF mode → expect no CPV

LHCb 35pb^{-1}



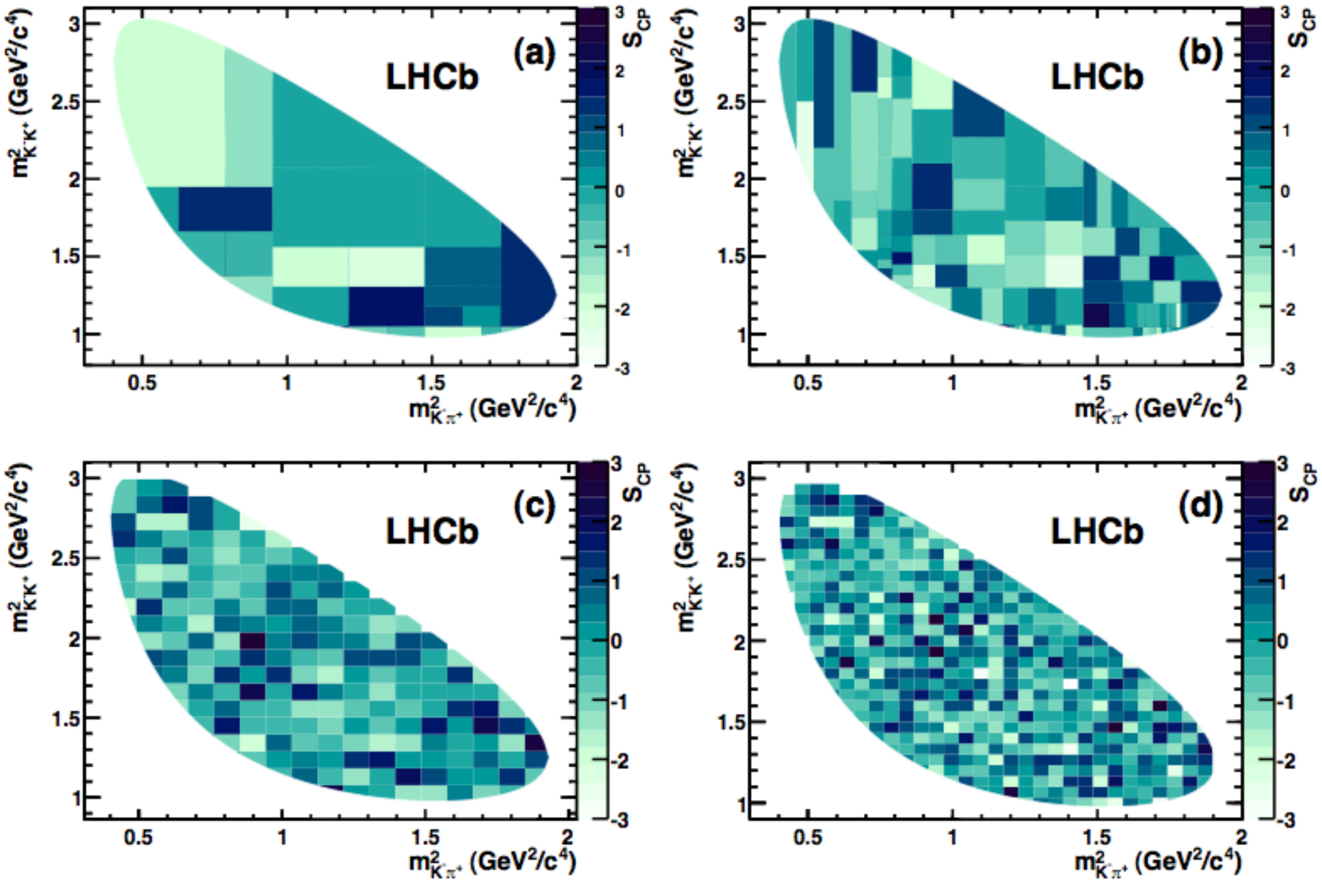


900 uniform bins

bins	Zone A	Zone B	Zone C
300	20.1	25.3	14.5
100	41.7	84.6	89.5
30	66.0	62.5	24.6

p-Values

Results for D→KKπ

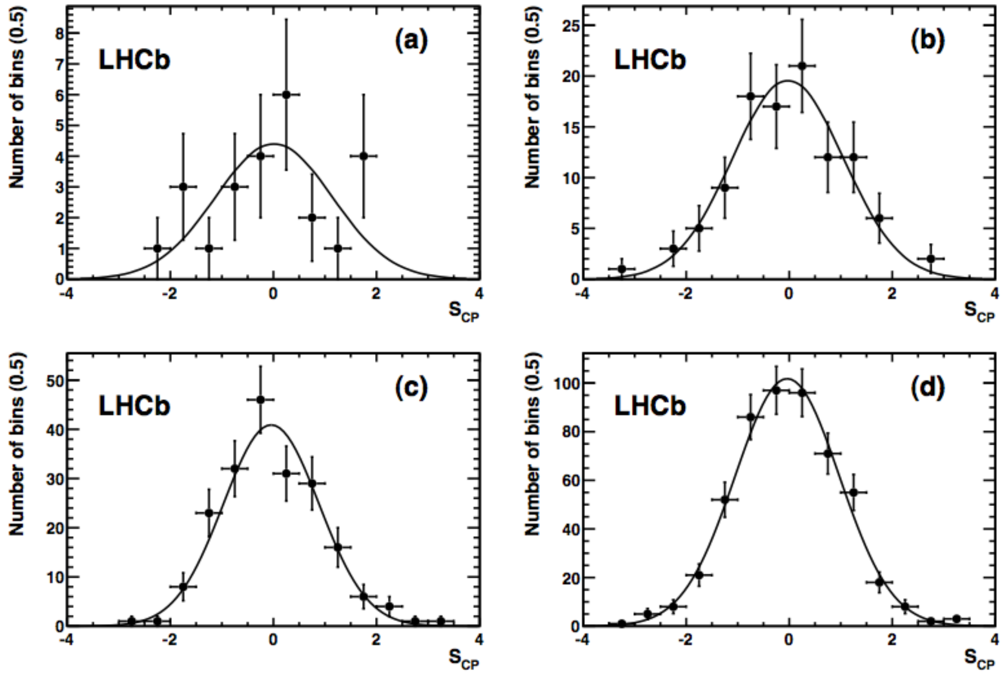


LHCb 35pb^{-1}

Distributions of S^i_{CP} with different binning

Results for D→KKπ

Binning	Fitted mean	Fitted width	χ^2/ndf	p-value (%)
Adaptive I	0.01 ± 0.23	1.13 ± 0.16	32.0/24	12.7
Adaptive II	-0.024 ± 0.010	1.078 ± 0.074	123.4/105	10.6
Uniform I	-0.043 ± 0.073	0.929 ± 0.051	191.3/198	82.1
Uniform II	-0.039 ± 0.045	1.011 ± 0.034	519.5/529	60.5

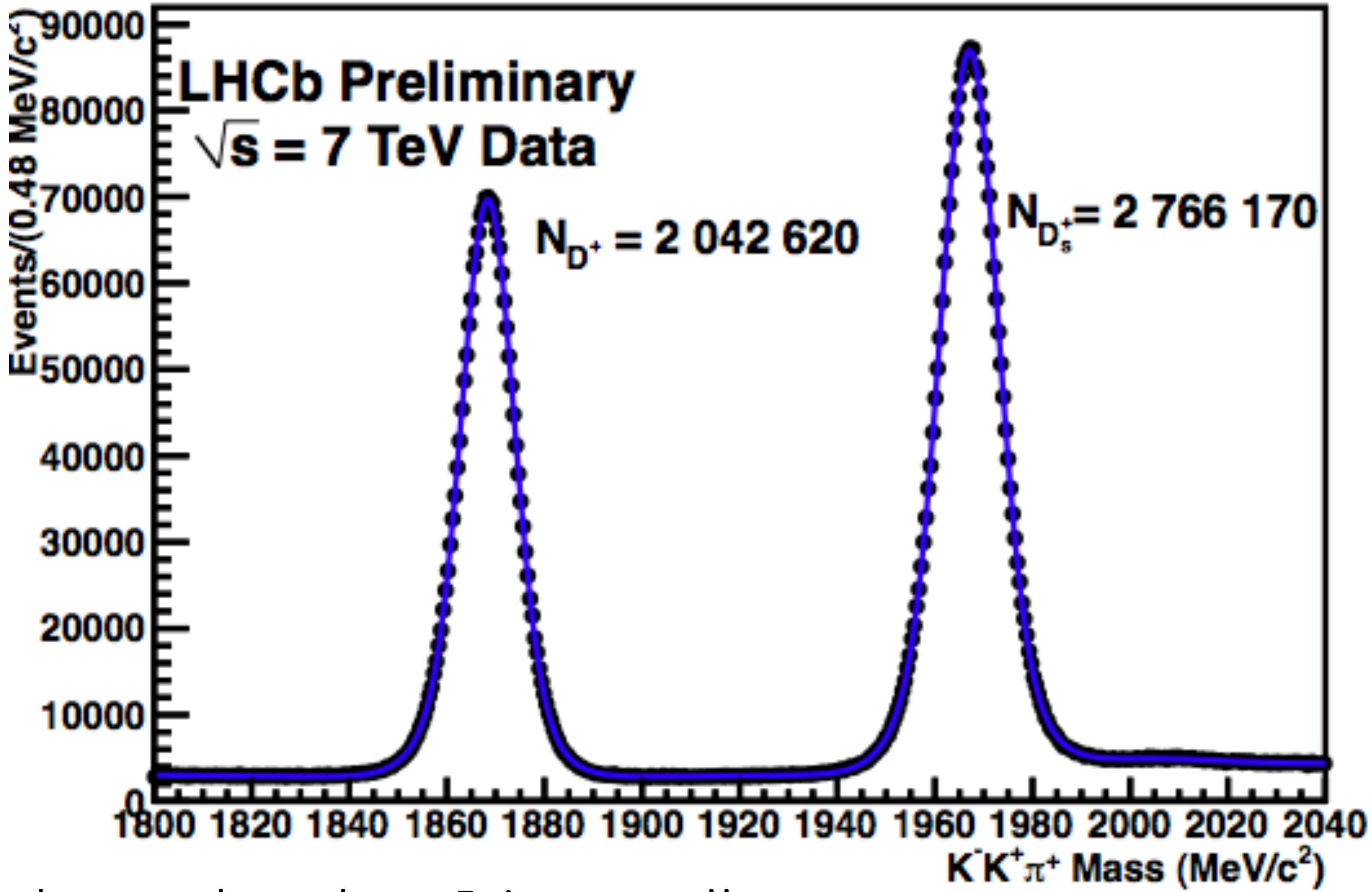


No evidence for CP violation in the 2010 dataset

LHCb 35pb^{-1}

Preview on 2011 statistics

Preliminary: 2011 data
220pb-1



and now we have almost 5 times more!!

$\Delta A_{CP}=A_{CP}(D^0\rightarrow KK)-A_{CP}(D^0\rightarrow \pi\pi)$

$$A_{RAW}(f) \equiv \frac{N(D^0 \to f) - N(\overline{D}^0 \to \bar{f})}{N(D^0 \to f) + N(\overline{D}^0 \to \bar{f})}$$

$$A_{RAW}(f)^* \equiv \frac{N(D^{*+} \to D^0(f)\pi^+) - N(D^{*-} \to \overline{D}^0(\bar{f})\pi^-)}{N(D^{*+} \to D^0(f)\pi^+) + N(D^{*-} \to \overline{D}^0(\bar{f})\pi^-)}$$

$$A_{RAW}(f) = A_{CP}(f) + A_D(f) + A_P(D^0)$$

$$A_{RAW}(f)^* = A_{CP}(f) + A_D(f) + A_D(\pi_s) + A_P(D^{*+})$$

physics CP asymmetry ($A_{CP}(f)$)

Detection asymmetry of D^0 ($A_D(f)$)

Detection asymmetry of soft pion ($A_D(\pi_s)$)

Production asymmetry ($A_P(D^0)$, $A_P(D^{*+})$)

For a two-body decay of a spin-0 particle to a self-conjugate final state, no D^0 detector efficiency asymmetry, $A(K^-K^+) = A(\pi^-\pi^+) = 0$

Look at difference in CP asymmetry between KK and ππ: very robust against systematics

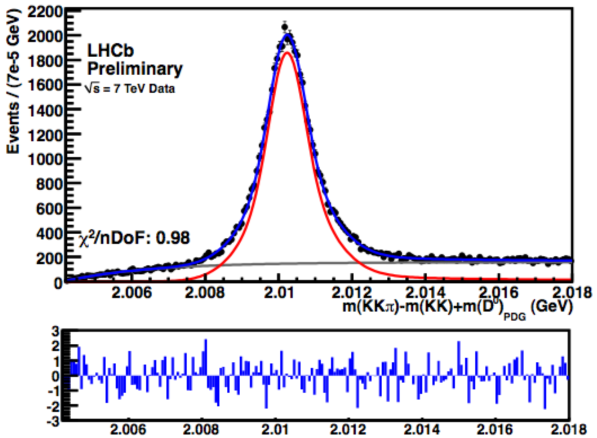
$$A_{RAW}(K^-K^+)^* - A_{RAW}(\pi^-\pi^+)^* = A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+)$$

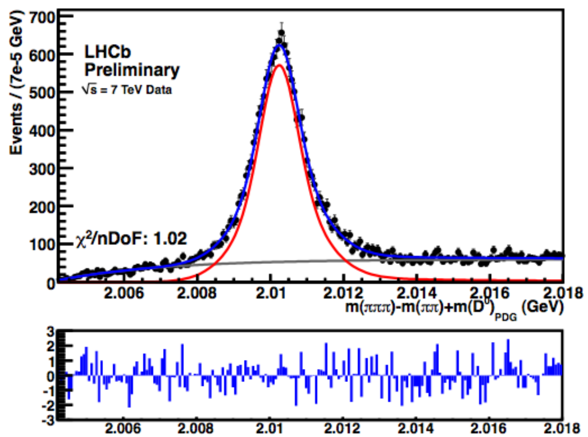
A_{CP}(KK) and A_{CP}(ππ) receive contributions from both indirect CPV (universal) and direct CPV (final state dependent) → taking the difference we are sensitive (almost) only to the direct CPV contribution

Fits to the data

Second order effects can however sneak in at second order through correlations between e.g. production and detection asymmetries, which might be p_T dependent → to make the cancellation more effective the analysis is performed in bins of p_T and a weighted average is taken

Divide data up according to magnet polarity, trigger conditions.
Fit (Δm + constant). Here are two example fits:





Total signal yield:
116k tagged $D^0 \rightarrow K^+ K^-$
36k tagged $D^0 \rightarrow \pi^+ \pi^-$

Preliminary: 2010 data
$38 pb^{-1}$

Systematics and preliminary result

Effect	Uncertainty
Modeling of lineshapes	0.06%
D^0 mass window	0.20%
Multiple candidates	0.13%
Binning in (p_t, η)	0.01%
Total systematic uncertainty	0.25%
Statistical uncertainty (for comparison)	0.70 %

Preliminary: 2010 data
38pb-1

$$A_{CP}(KK) - A_{CP}(\pi\pi) = (-0.275 \pm 0.701 \pm 0.25)\%$$

Note: already competitive with the B-factories!
Statistical error for BABAR 0.62%, Belle 0.60%
But for CDF: 0.33%
Expect systematic error to scale well with integrated lumi.
Estimates very conservative, with large statistical component.

D^0 production asymmetry

LHC is a pp machine and asymmetry may exist in D and B production.
Knowledge of such an asymmetry important for CPV measurements and for QCD models.

$$
\begin{aligned}
A_{CP}^{RAW}(K\pi) &= A_{CP}(K\pi) + A_D(K\pi) + A_P(D^0) \\
A_{CP}^{RAW}(K\pi)^* &= A_{CP}(K\pi) + A_D(K\pi) + A_D(\pi_s) + A_P(D^*) \\
A_{CP}^{RAW}(KK)^* &= A_{CP}(KK) + A_D(\pi_s) + A_P(D^*) \\
A_{CP}^{RAW}(\pi\pi)^* &= A_{CP}(\pi\pi) + A_D(\pi_s) + A_P(D^*)
\end{aligned}
$$

4 observables

3 ext. inputs
Physics CP asymmetries.

3 unknowns:
Detection asymmetry of D^0.
Detection asymmetry of soft pion.
D^0 and D^* production asymmetries.

The only external inputs are $A_{CP}(KK)$ and $A_{CP}(\pi\pi)$.

- $A_{CP}(K\pi)$ assumed negligible.
- Solving the system of equations for the unknowns allows to determine the production asymmetry $A_P(D^0)$.

Preliminary: 2010 data
$38 pb^{-1}$

$A_P(D^0) = (-1.08 \pm 0.32 \pm 0.12)$ %
No evidence of pT dependence so far

Other channels under study

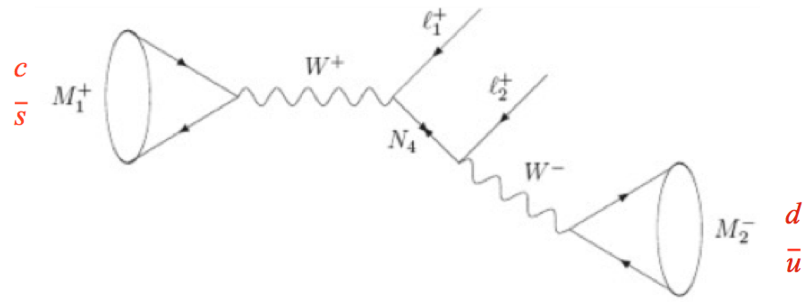
- Beyond updating with 2011 statistics (>30x 2010) the above mentioned analysis of 2010 data, we have data on tape and we are analyzing :
  - Direct CPV in $D^+ \rightarrow K_s h$
  - T-odd correlations in $D^0 \rightarrow KK\pi\pi$
  - Direct CPV in Dalitz plot in other SinglyCabibboSuppressed D,Ds decays

The charm RD measurements in LHCb

- LHCb is well suited for measurements with muons in the final state, a bit less with e- (bremsstrahlung, modest resolution ECAL)
- High efficiency triggering on muons in LHCb
- Two main channels are being investigated:
  - $D \rightarrow \mu\mu$ FCNC, best limit Belle $1.7*10^{-7}$ @ 90% C.L.
    - SM predicts, even including a long range term $<10^{-13}$

The charm RD measurements in LHCb

– D(s)+→πμμ with SS muons → forbidden in SM, sensitive to Majorana neutrinos

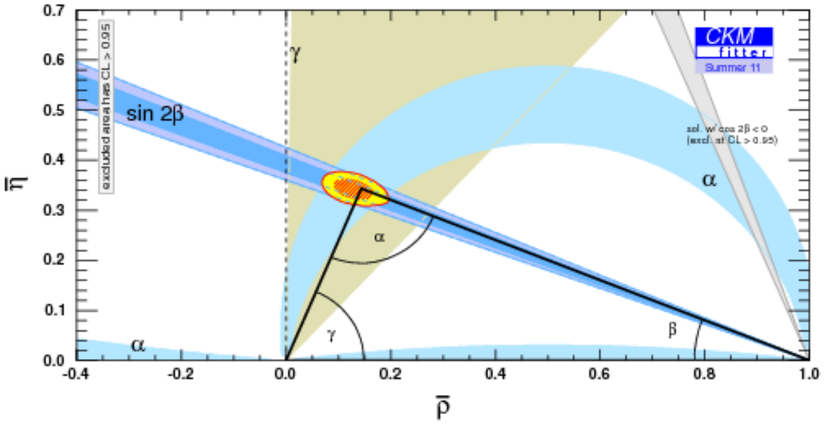


present limits on the order of 10^{-6} for D+ modes and 10^{-5} for Ds modes

– D(s)+→πμμ with OS muons →FCNC, sensitive to RPV SUSY →need to study μμ invariant mass distribution to exclude regions of long range contributions

- Analyses with 2011 data in preparation

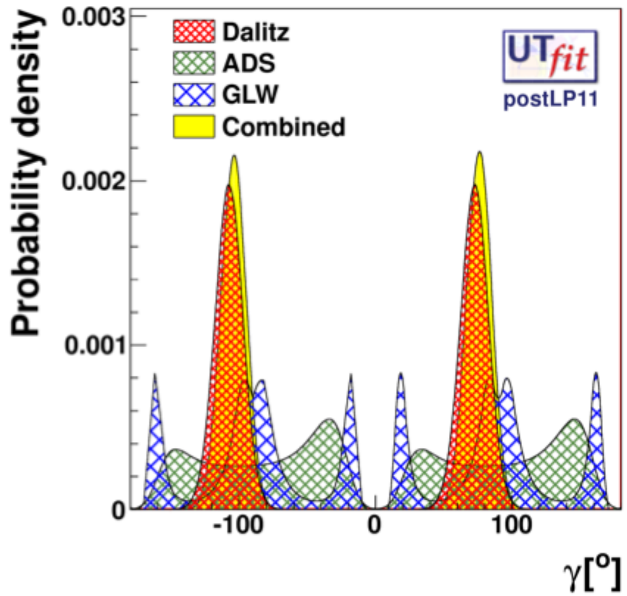
Status of γ/ϕ_3 measurements



from CKMFItter web site

γ is the least well known angle ~20°

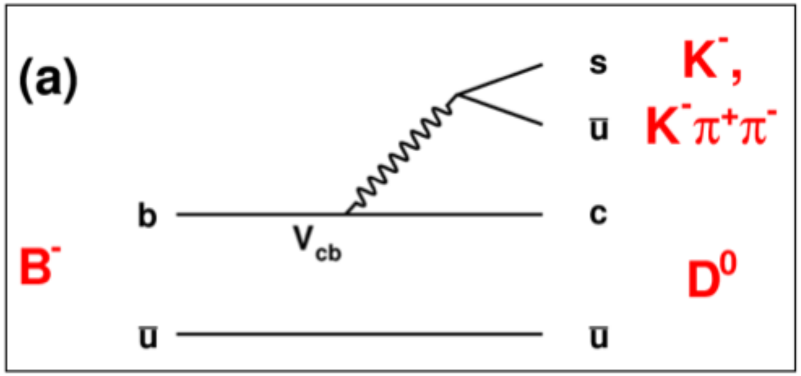
contributions to the WA
courtesy UTFIT collaboration

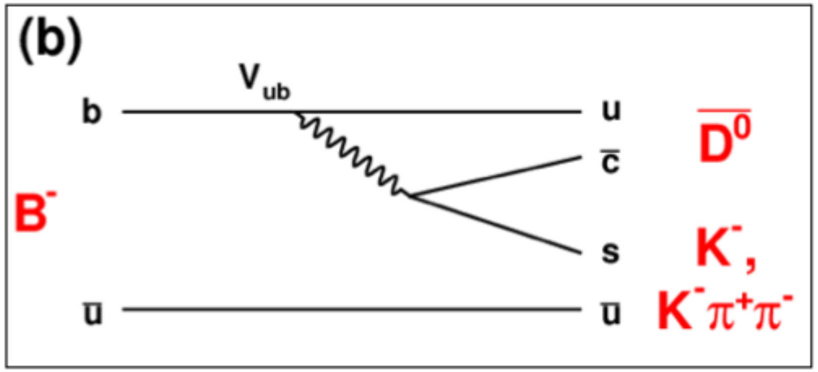


Tree level γ/ϕ_3 measurements

CKM suppressed

color and CKM suppressed





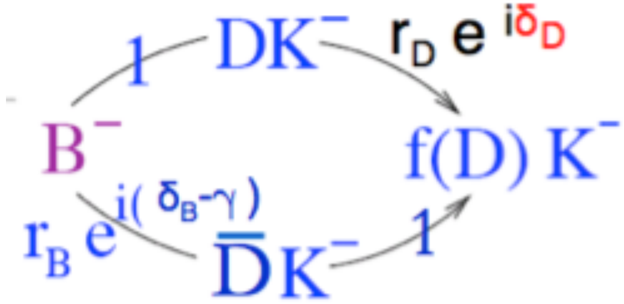
CKM angle γ can be accessed through the interference of these b->c and b->u diagrams, where the D^0 and D^0bar decay to a common final state:

ADS (Flavor specific): Kπ, Kπππ, KsKπ, $K^+\pi\pi^0$

GLW (CP Eigenstates): KK, ππ, KKππ

GGSZ Dalitz: Ksππ, KsKK

Measurement can be extended to final state K*0 with B0 decays



In practice compare B+ and B- rates, i.e. measure direct CPV

In LHCb we also measure γ with the time dependent $A_{CP}(B_s \rightarrow D_s K)$

for multi-body decays r_D and δ_D vary over the Dalitz space

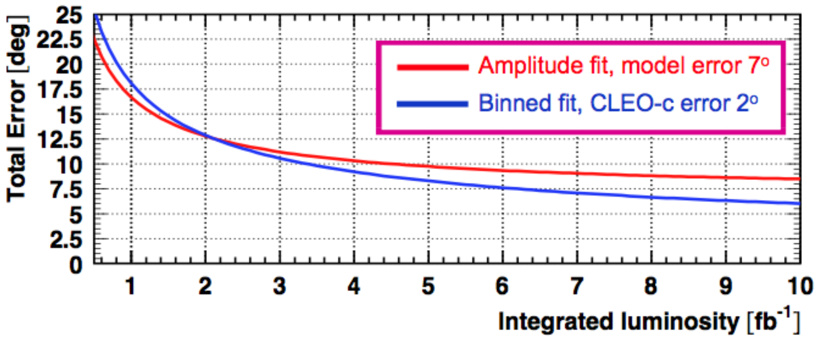
Input from charm physics to the γ measurements

Quantum correlated decays give access to the strong phase difference

- strong phase $\delta_D^{K\pi}$ for ADS→2body
  - From both quantum correlated measurements and single tag yields
    - also related to mixing parameters
- mean strong phase δ_D^f and coherence factor R_f for ADS in D→3-4 body
  - $K\pi\pi^0$ turns out to be of high coherence →useful for ADS
  - $K3\pi$ of low coherence →useful to measure r_B

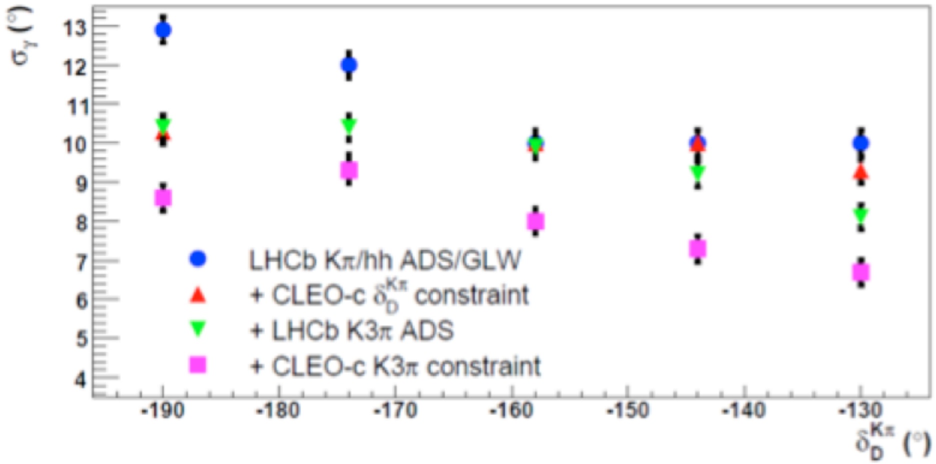
Input from charm physics to the γ measurements

– strong phase difference across the Dalitz plot in Dalitz analysis (GGSZ) D→$K_S$hh
  - Amplitude model has good statistical sensitivity but give rise to a systematic of σ(γ)=3-9° which would be limiting for LHCb
  - With model independent (binned) approach + input from quantum correlated measurement at Ψ(3770) → σ(γ)=1.7-3.9° for K_s^0ππ and 3.2 → 3.9° for K_S^0KK (dominated by Ψ(3770) statistics so it can improve with BES3)



Impact on LHCb measurement of γ

Expected γ precision using ADS/GLW modes (excluding $K\pi\pi^0$) at LHCb 2fb-1



end of 2012
maybe $3fb^{-1}$?

tree decays only
time integrated

An extension of the combined sensitivity study included Dalitz method with $K_S\pi\pi$. Trend suggests that sensitivity is dominated by B statistics with current charm constraints

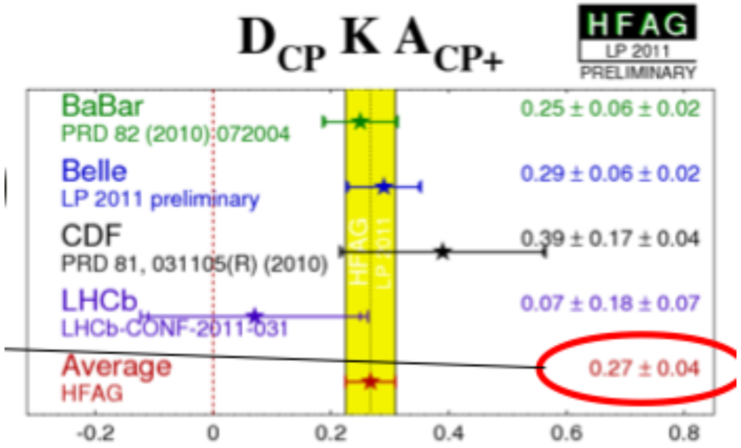
The inclusion of the time-dependent analysis brings σ to about 5°

<u>Current strong phase precision for these modes satisfactory until SuperBFactories/LHCb upgrade</u> (however this statement does not include the potential benefit of a binned analysis with K3π)

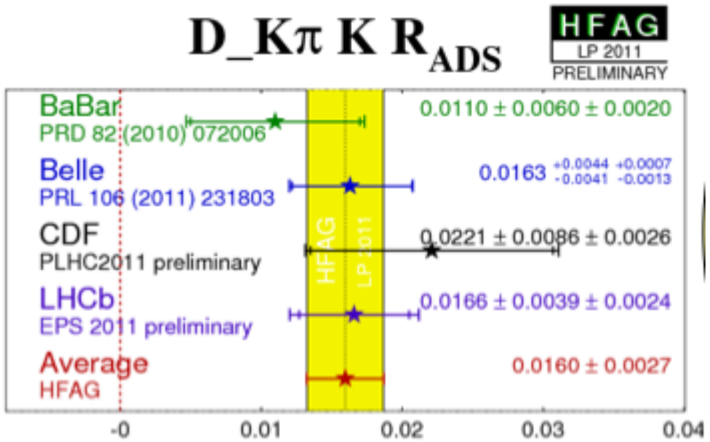
The field is actually evolving and new channels are being considered

LHCb today

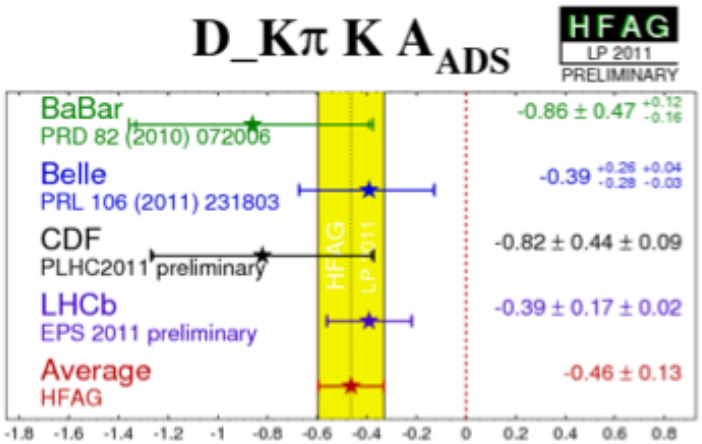
Preliminary: 2011 data
343pb[-1]



GLW



ADS



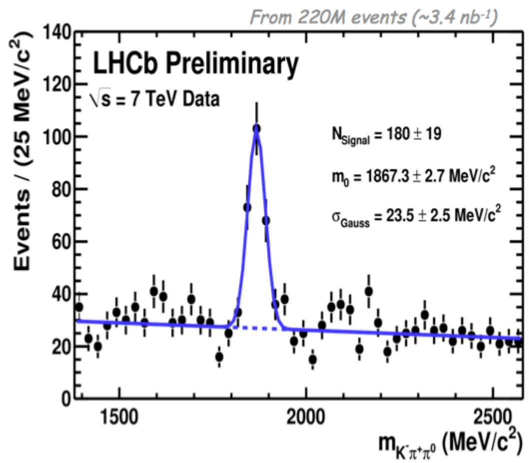
Conclusion(1)

- LHCb has a very rich charm physics program ranging from mixing/CPV to rare decays and spectroscopy, mostly with decays to charged particles in the final state
- With 2011 data ($1fb^{-1}$)we already have the world highest statistics in many channels
- We expect to collect $5fb^{-1}$ up to 2017 (phase 1) and $50fb^{-1}$ (2019-2029?) with the upgrade
- For many years to come, at least until 2018, LHCb will be (together with BES3) the leading experiment in the field: statistical sensitivity to many observables such to rule out NP contributions (e.g. some channels of direct CPV)
- Still systematics such as production asymmetries in CPV and lifetime acceptance have to be treated with care and more new ideas on that need to be developed

Conclusion(2)

- In general, we have not tried yet to address channels with neutrals in the final state but things are starting, though it is not guaranteed it will be competitive.
- Channels with neutrinos remain peculiar to the e^+e^- machines
- For tree level measurement of γ we need very much inputs from quantum correlated measurements at threshold to achieve the best precision

$D^0 \rightarrow K\pi\pi^0$
2010 data



BACKUP: the equations for extracting γ from time-integrated tree level processes

Rate Equations for ADS/GLW

$$\begin{aligned}
\Gamma(B^- \to (K^-\pi^+)_D K^-) &= N^{K\pi}(1 + (r_B r_D) + 2r_B r_D \cos(\delta_B - \delta_D^{K\pi} - \gamma)),\\
\Gamma(B^- \to (K^+\pi^-)_D K^-) &= N^{K\pi}(r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D^{K\pi} - \gamma)),\\
\Gamma(B^+ \to (K^+\pi^-)_D K^+) &= N^{K\pi}(1 + (r_B r_D) + 2r_B r_D \cos(\delta_B - \delta_D^{K\pi} + \gamma)),\\
\Gamma(B^+ \to (K^-\pi^+)_D K^+) &= N^{K\pi}(r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D^{K\pi} + \gamma)),\\
\Gamma(B^- \to (h^+h^-)_D K^-) &= N^{hh}(1 + r_B^2 + 2r_B \cos(\delta_B - \gamma)),\\
\Gamma(B^+ \to (h^+h^-)_D K^+) &= N^{hh}(1 + r_B^2 + 2r_B \cos(\delta_B + \gamma)).
\end{aligned}$$

GLW

$$R_{CP\pm} \equiv \frac{2\left[\Gamma(B^- \to D^0_{CP\pm} K^-) + \Gamma(B^+ \to D^0_{CP\pm} K^+)\right]}{\Gamma(B^- \to D^0 K^-) + \Gamma(B^+ \to D^0 K^+)} = 1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma$$

$$A_{CP\pm} \equiv \frac{2\left[\Gamma(B^- \to D^0_{CP\pm} K^-) - \Gamma(B^+ \to D^0_{CP\pm} K^+)\right]}{\Gamma(B^- \to D^0 K^-) + \Gamma(B^+ \to D^0 K^+)} = \pm 2 r_B \sin\delta_B \sin\gamma$$

ADS

$$R_{ADS} \equiv \frac{1}{2}\left[\frac{\Gamma(B^- \to (K^+\pi^-)_D K^-)}{\Gamma(B^- \to (K^-\pi^+) K^-)} + \frac{\Gamma(B^+ \to (K^-\pi^+)_D K^+)}{\Gamma(B^+ \to (K^+\pi^-) K^+)}\right] = r_B^2 + r_D^2 \pm 2 r_B r_D \cos(\delta_B + \delta_D)\cos\gamma$$

$$A_{ADS} \equiv \frac{2\left[\Gamma(B^- \to (K^+\pi^-)_D K^-) - \Gamma(B^+ \to (K^-\pi^+)_D K^+)\right]}{\Gamma(B^- \to (K^-\pi^+) K^-) + \Gamma(B^+ \to (K^+\pi^-) K^+)} = 2 r_B r_D \pm 2 r_B r_D \sin(\delta_B + \delta_D)\sin\gamma / R_{ADS}$$

- Unknowns:
  B: r_B, δ, γ **D**: r_D, δ_D → Use r_B from PDG, δ_D from CLEO-c
- CP- hard for LHCb (maybe ϕK_s?)
  With only CP+, we have 4 equations and 3 unknowns

How does this change if one has a multi-body final state?

[See M. Gronau, PLB 557, 198 (2003) for a nice paper]

$$R_{CP\pm}(X_s) = 1 + r_s^2 \pm 2\kappa r_s \cos\delta_s \cos\gamma \ ,$$
$$A_{CP\pm}(X_s) = \pm 2\kappa r_s \sin\delta_s \sin\gamma \ .$$

Similar change for ADS observables

$$\Rightarrow \quad \sin^2\gamma \leq R_{CP\pm}(X_s) \ .$$

Here, κ is a "dilution" or "coherence factor", $0 \leq \kappa \leq 1$, and δ_s is the average strong phase over the Dalitz plot.

We acquire an additional parameter κ though.

- In principle solvable (4 eq & 4 unknowns), but weakly constrained fit.

Another option:

- Split $DK\pi\pi$ Dalitz plot into N kinematic regions.
- #Unknowns → 3N + 1 (== 7, 10 for N = 2, 3)
- #Eqn's: 4N (== 8, 12 for N = 2, 3)