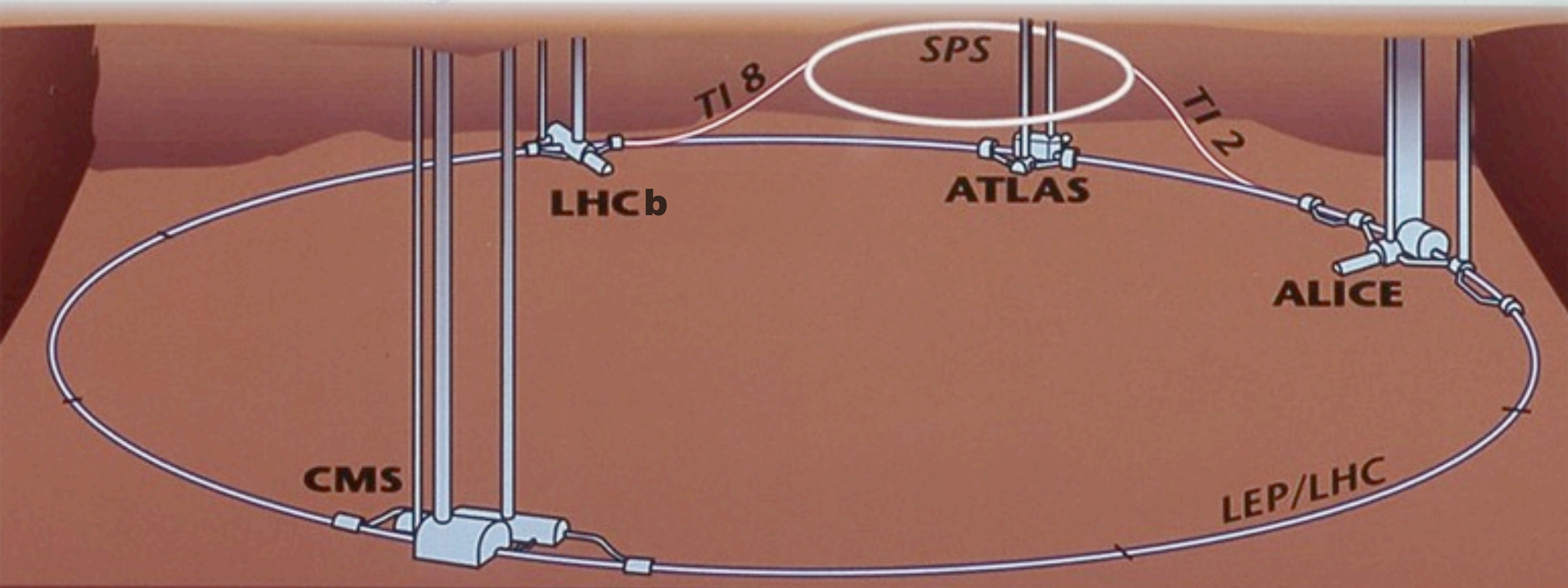
The Charm Physics Programme at the LHCb upgrade, and Atlas and CMS upgrades

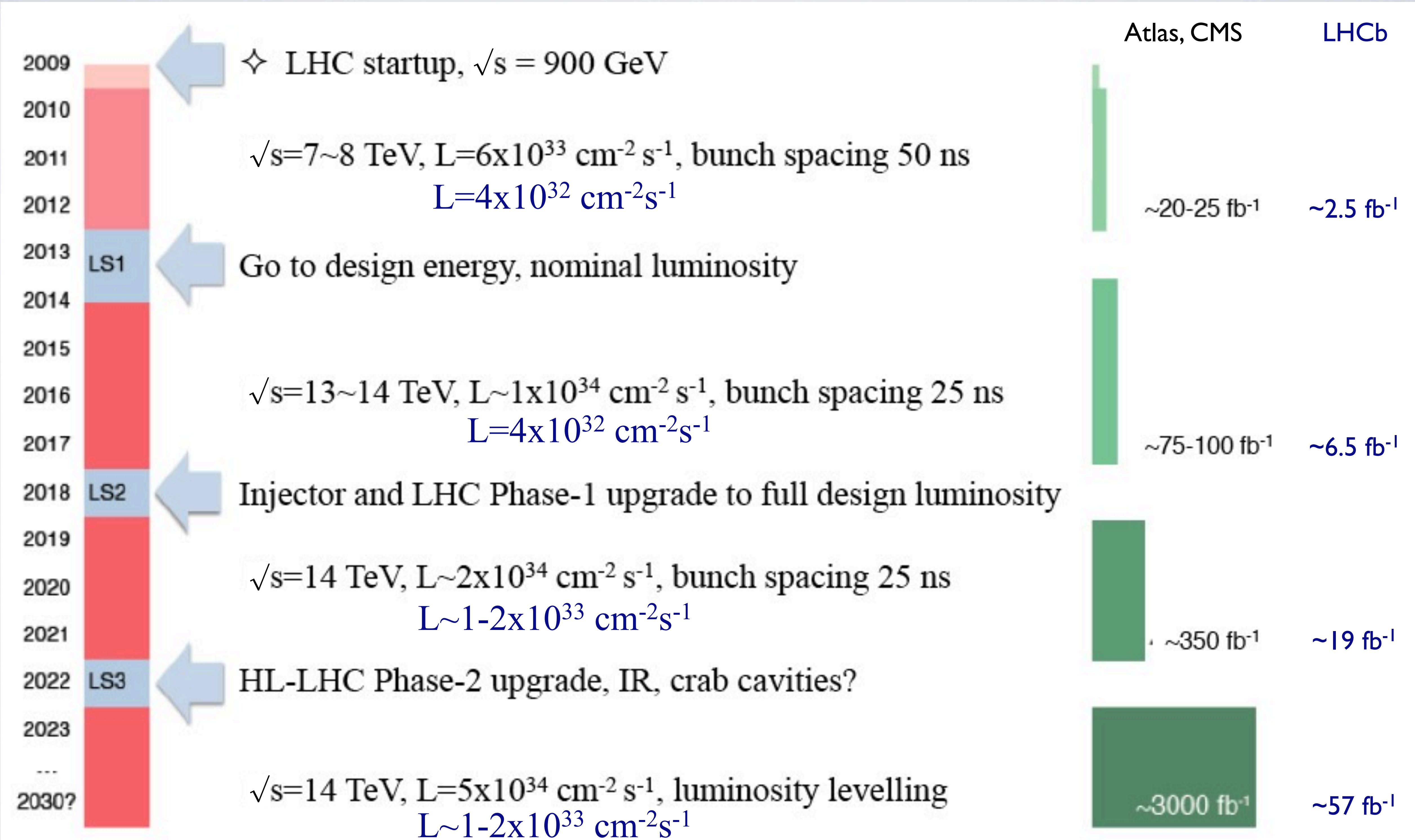
Marco Gersabeck (CERN)
for the LHCb Collaboration

Charm 2012 - The 5th International Workshop on Charm Physics
14-17 May 2012, Honolulu, Hawai'i

THE INFRASTRUCTURE



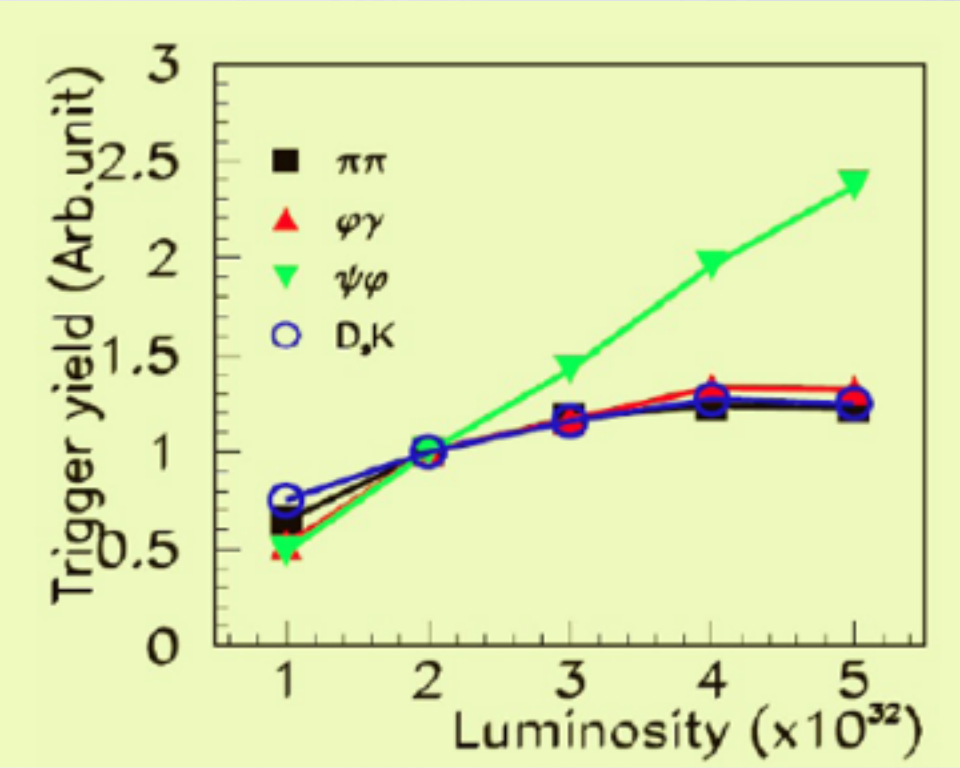
THE LHC SCHEDULE



adapted from M. Nessi, Chamonix 2012

LHCb UPGRADE TARGETS

- Collect **50 fb^{-1}**
- Increase annual yield:
  - leptonic channels: **x5**
  - hadronic channels: **x10**
- Reach experimental sensitivities comparable or better than theoretical uncertainties



- Physics reach beyond beauty and charm:
  - Lepton flavour violation (Majorana neutrino, LFV in **τ** decays)
  - Electroweak physics ($\sin 2\theta_{eff}^{lept}$, M_W)
  - Exotic searches (hidden valleys, ...)
  - QCD (central exclusive production, ...)

TRIGGER UPGRADE

2012

40 MHz

read out Pileup, Calorimeter, Muon

Level 0
p_T of h,μ,e,γ
Custom electronics

1 MHz
Full detector readout

High Level Trigger
Full event reconstruction:
tracking and vertexing
p_T and impact parameter cuts
inclusive/exclusive selections
CPU farm

to storage

4.5 kHz

Upgrade

Fully flexible software trigger

40 MHz

read out Pileup, Calorimeter, Muon

Low level trigger
p_T of h,μ,e,γ
Custom electronics

up to 40 MHz
Full detector readout

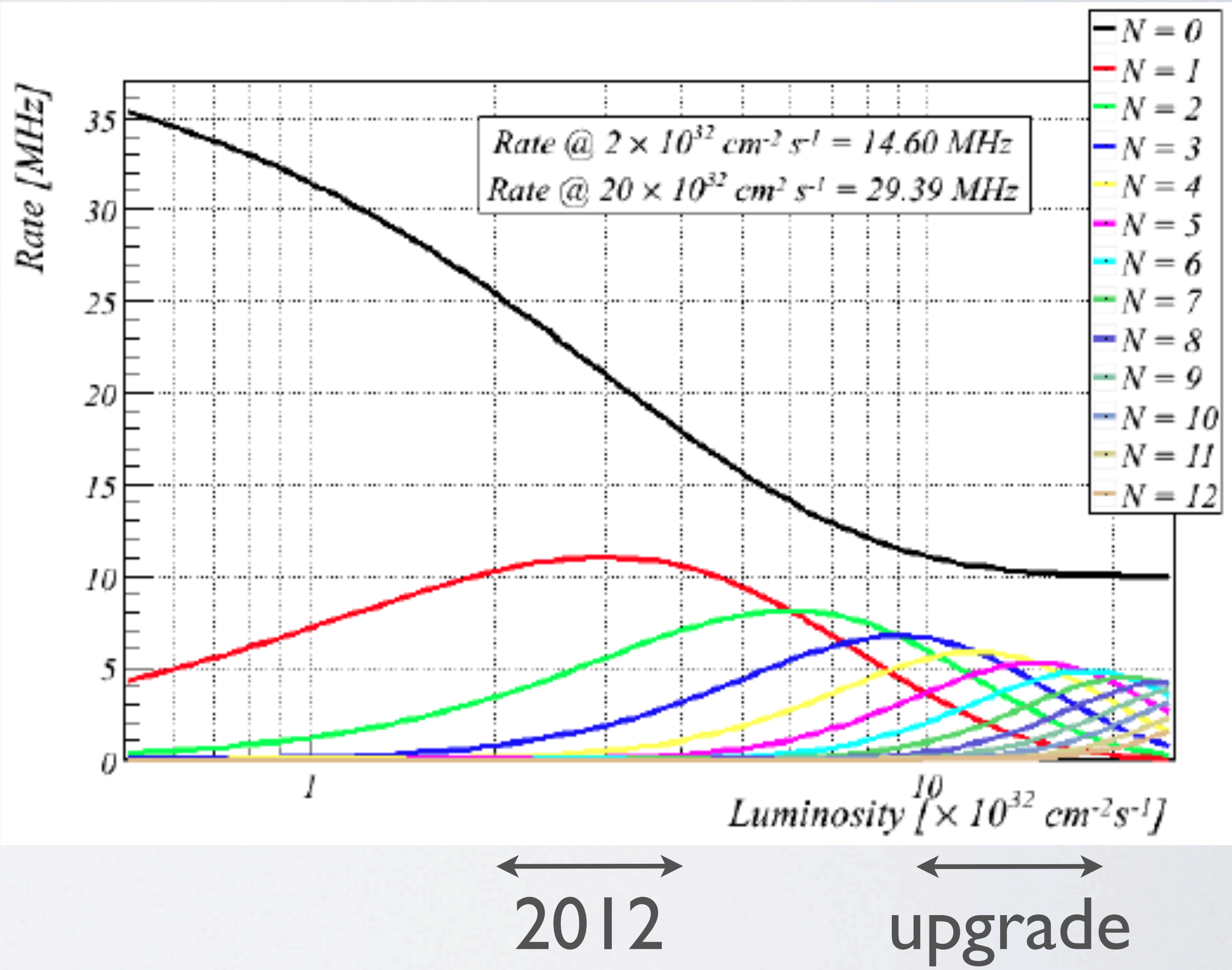
High Level Trigger
Full event reconstruction:
tracking and vertexing
p_T and impact parameter cuts
inclusive/exclusive selections
CPU farm

to storage

20 kHz

PILE UP AND TRACKING

- *Maintain current performance level:*
- High momentum resolution
  → **$\sigma_p/p \sim 4x10^{-3}$**
- High tracking efficiency
  → **90% for p>5 GeV**
- Low ghost rate
  → **~10%**
- Fast processing time in HLT
  → **~25ms**
- Low material budget
  → **similar to current**



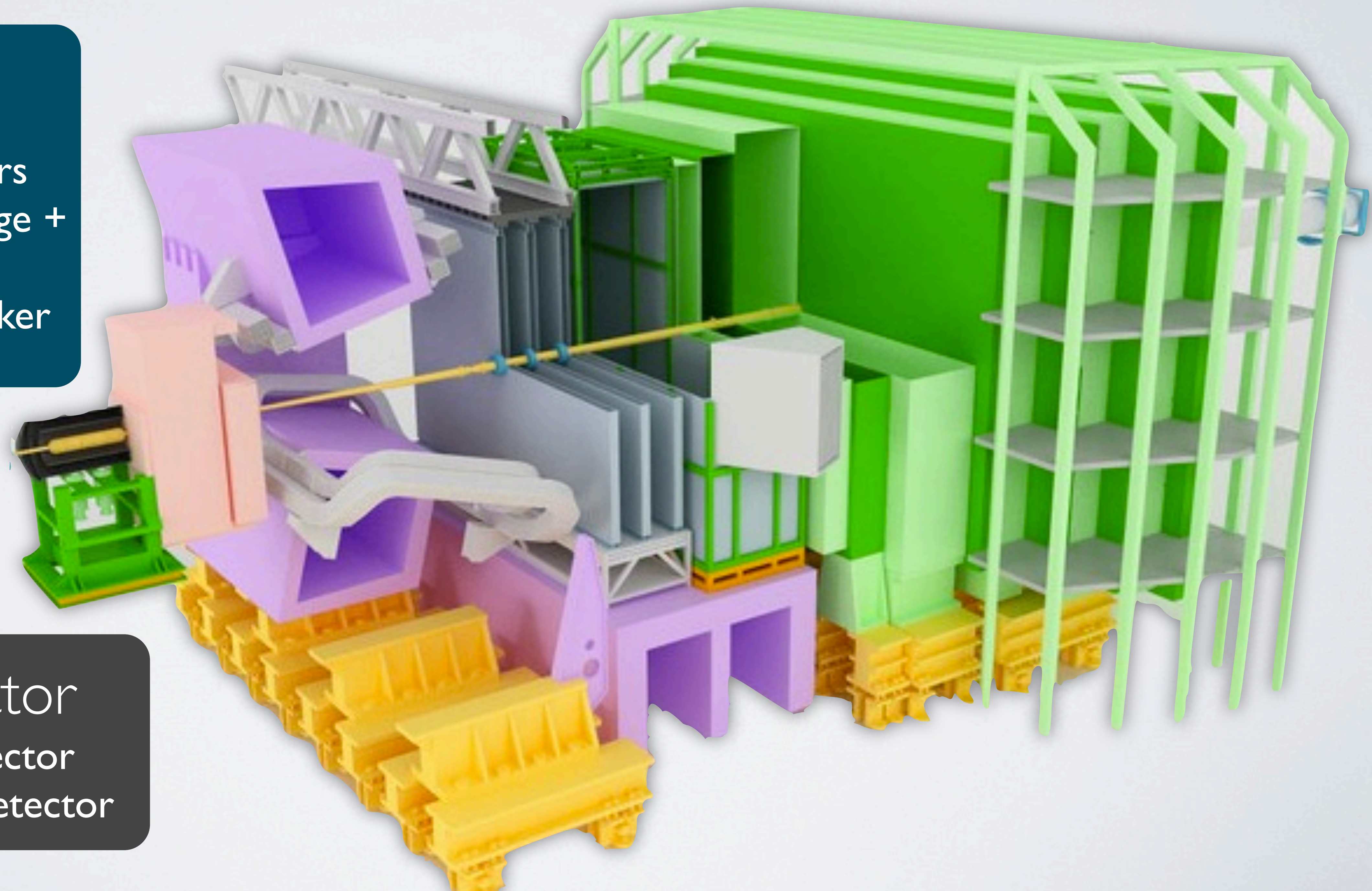
FULL 40 MHz FE READOUT

RICH
New photon detectors

Calorimeter+Muon
Remove M1, SPD, PS
New calorimeter FE electronics

Tracking
New silicon trackers
Reduce straw coverage +
a) fiber tracker
b) larger silicon tracker

Vertex Locator
a) New pixel detector
b) Improved strip detector



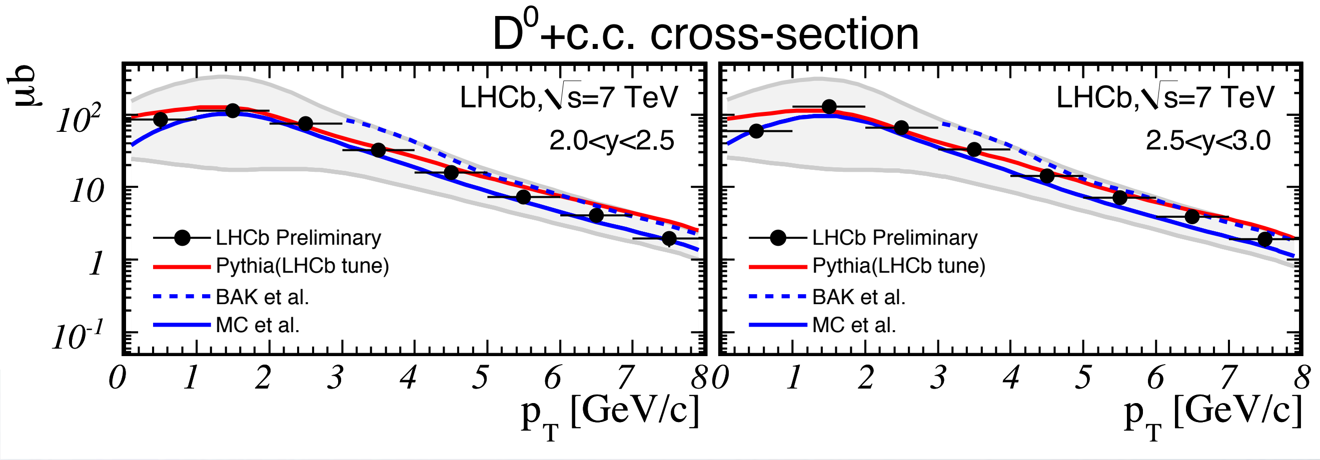
TIMELINE

- Letter of Intent submitted March 2011
  → **Physics case fully endorsed by LHCC**
  → **Encouraged to proceed to detector TDRs with 40 MHz front-end electronics**
- Framework TDR to be submitted in June 2012
  → **Defining cost, milestones and institutes' interests**
- TDR in 2013
  → **Decide on technical choices**
- Production and QA in 2014-2017
- Installation and commissioning in 2018
  → **Use LHC LS2**

New institutes welcome!

CHARM AND THE FUTURE

- $c\bar{c}$-cross-section increases by 1.8 from $\sqrt{s}$ = 7 TeV to 14 TeV



LHCb-CONF-2010-013

- Expect roughly a factor of 2 in charm trigger efficiency for LHCb
  → multibody decays may benefit even more
- Charm signal yield per fb^{-1} to increase by a factor 3.6
- Luminosity per year to increase by about a factor 3-5
- → **Charm yield per year up by about an order of magnitude**
- Example reach:
  → With **50 fb^{-1}** expect **~4×10^{10}** offline selected **$D^0 \to K\pi$** decays
  (use 50 fb^{-1} as luminosity beyond 2018, i.e. with upgrade detector)

ATLAS planned upgrades

Element	Phase 0&1 (now through LS2)	Phase2 (after LS2)
Tracking	4th barrel pixel layer (IBL), new pixels services (nSQP), New evaporative cooling plant, CO2 cooling plant for IBL, FTK level 1+ tracking. New tracking detector at 220 m (AFP)	Major revision, new Inner Detector, including possible LVL1 trigger capability + all new services
Calorimetry	Change all power suppliers, New LVL1 trigger electronics LAr. Additional better trigger capability for muons in the Hadron Tiles calorimeter.	New Front and back-end electronics, including trigger. New Forward calorimeter if proven necessary. Fix LAr hadronic cold electronics if neces.
Muon System	Install EE-chambers staged. Add additional chambers in key positions inside the barrel. Sharpen LVL1 muon trigger. New muon small wheels.	Increase trigger capability in the big wheels, add additional trigger inner layers in the barrel. New front-end electronics
Trigger/DAQ	New LVL1 trigger processors which make use of better detector granularity. Add a trigger level (FTK) between LVL1 and LVL2.	Major revision
Common systems	New forward pipes in Aluminum, new small radius Be beam pipe. More neutron shielding in the forward region and in between caverns. UPS extension. Consolidate cryogenics.	New TAS and forward shielding. Major infrastructure consolidation, including safety systems

from M. Nessi, Chamonix 2012

LHCb

Atlas

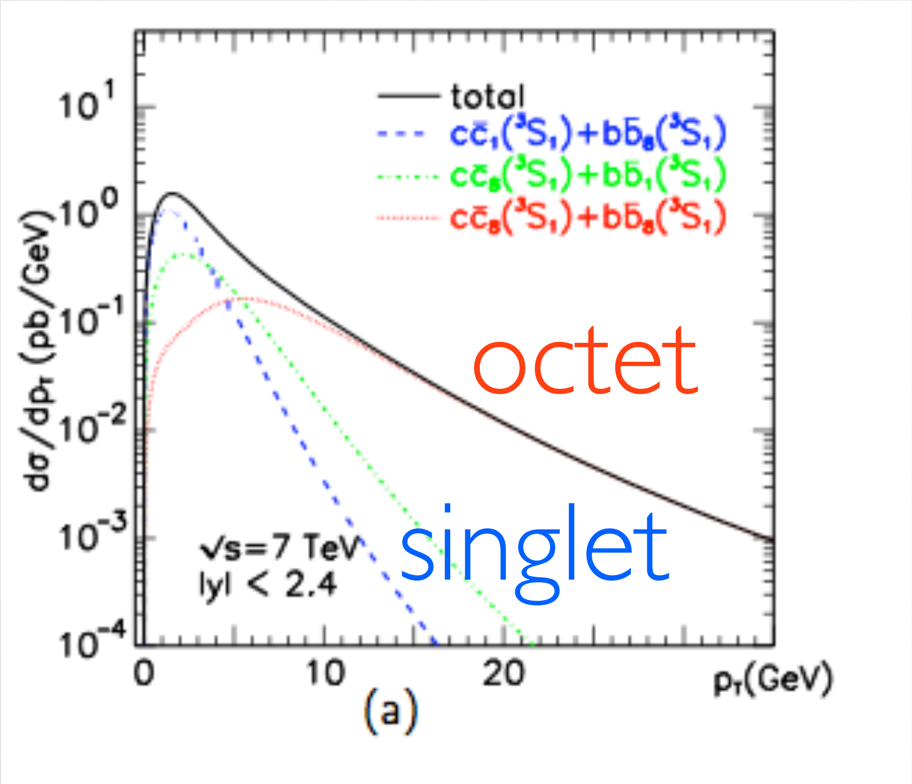
CHARM PRODUCTION AND SPECTROSCOPY

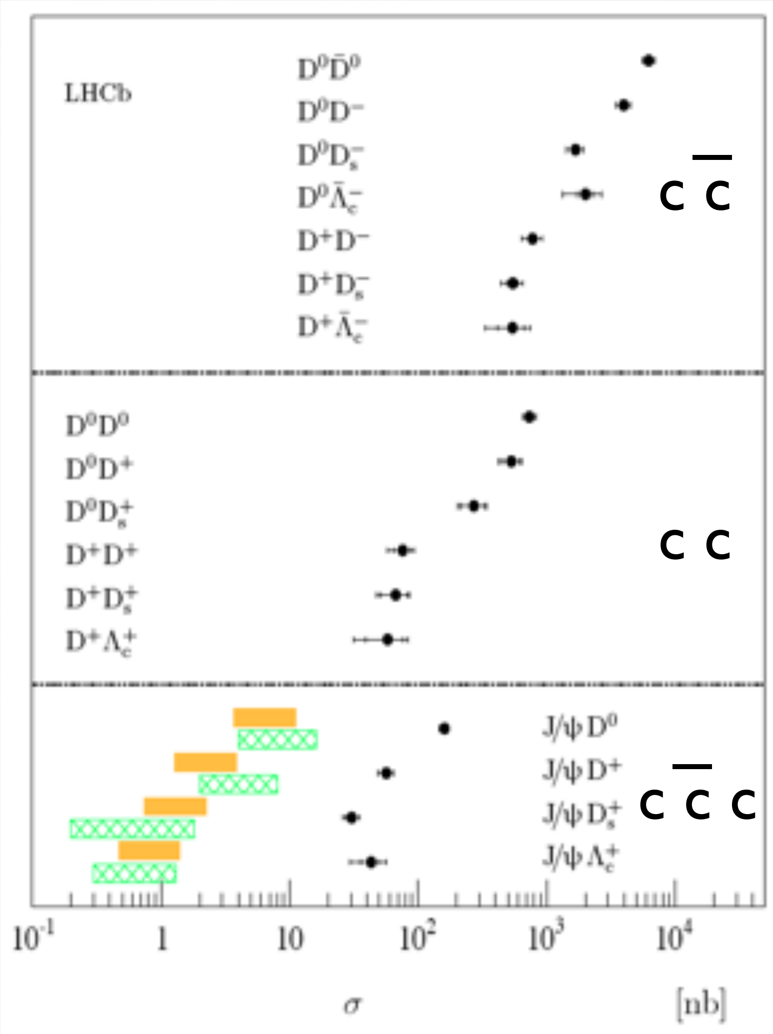
CHARMONIUM+DOUBLE CHARM

see P. Robbe

arXiv:1205.0975

- Recent LHCb paper on double-charm production → observed as double-charmonium, charmonium+open charm, and double-open charm
- Extend studies to charmonium + bottomonium   LHCb   Atlas
- Onia+jets, onia+vector bosons   Atlas



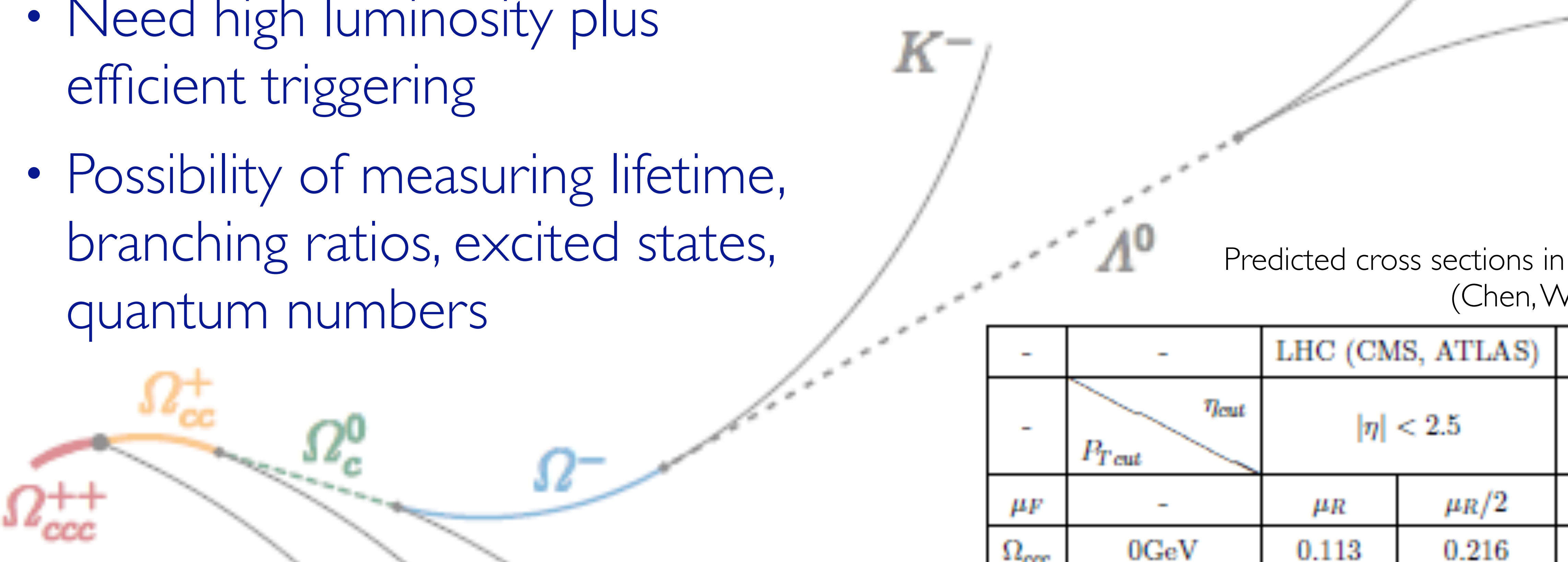


HEAVY BARYONS

LHCb

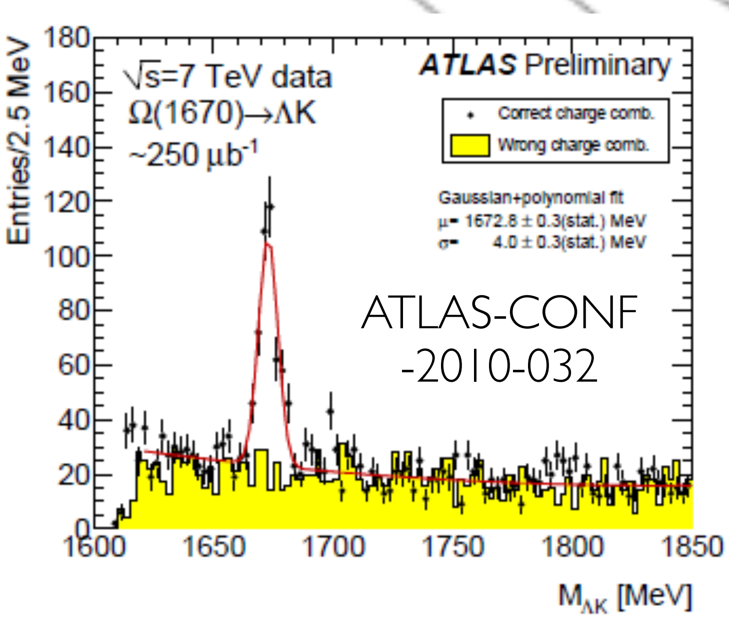
Atlas

- Production cross-sections for doubly- or triply heavy baryons are very low
- Need high luminosity plus efficient triggering
- Possibility of measuring lifetime, branching ratios, excited states, quantum numbers



Predicted cross sections in nb for 14 TeV LHC
(Chen, Wu arXiv:1106.0193)

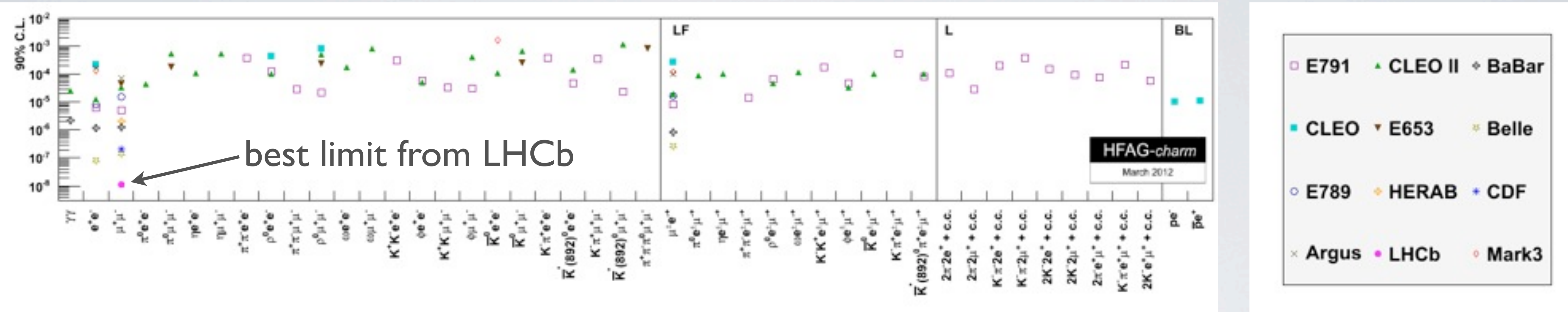
-	-	LHC (CMS, ATLAS)		LHCb	
-	η_{cut} / $P_{T\,cut}$	$\lvert\eta\rvert < 2.5$		$1.9 < \eta < 4.9$	
μ_F	-	μ_R	$\mu_R/2$	μ_R	$\mu_R/2$
Ω_{ccc}	0GeV	0.113	0.216	0.0684	0.135
-	5GeV	0.0123	0.0258	0.00412	0.00906
-	10GeV	0.000625	0.00136	0.000145	0.000349
Ω^*_{ccb}	0GeV	0.00320	0.00677	0.00175	0.00378
-	5GeV	0.00143	0.00307	0.000521	0.00114
-	10GeV	2.34E-4	5.03E-4	0.625E-4	1.38E-4
Ω_{ccb}	0GeV	0.00105	0.00222	0.000527	0.00115
-	5GeV	0.000544	0.00117	0.000190	0.000419
-	10GeV	0.000109	0.000236	0.289E-4	0.639E-4



ATLAS-CONF
-2010-032

RARE DECAY SEARCHES AND ANALYSES

RARE DECAYS



- $D^0 \to \mu\mu$
  - Very rare in SM; correlation with mixing in some models
  - Current limit 1.1×10^{-8}, can expect $O(10^{-9})$ for 50 fb^{-1}
- $D^\pm \to h^\pm(K^\pm,\pi^\pm)\mu^-\mu^+$ see F. Dettori
  - Study full $\mathbf{m(\mu^-\mu^+)}$ spectrum
  - Look for sGoldstinos at low end of $\mathbf{m(\mu^-\mu^+)}$ spectrum, ...
- $D^\pm \to h^{-/+}\mu^\pm\mu^\pm$
  - Search for same-sign muon pairs: Majorana neutrinos, ...

MORE RARE DECAYS

- $D^0 \rightarrow K^- K^+ \mu^- \mu^+$
  - Assuming BF = 10^{-6}, expect few 100 events per fb^{-1}
  - → Expect several thousand candidates with LHCb upgrade
  - Clean channel for studying T-odd correlations $\langle \vec{p}_1 \cdot (\vec{p}_2 \times \vec{p}_3) \rangle$
  - Search for CP violation
  - Can also perform model-dependent searches
  - Study forward-backward asymmetry
- $D^0 \rightarrow K^- K^+ \pi^- \pi^+$
  - Another channel for studying T-odd correlations
  - Sensitivity expected for 50 fb^{-1} (BF = 2.4×10^{-3}): 2.5×10^{-4}

Ikaros Bigi
arXiv:0902.3048

LHCb

MIXING AND CP VIOLATION MEASUREMENTS

LHC reveals hints of 'new physics' in particle decays

By Jason Palmer
Science and technology reporter, BBC News

BBC News
15 November 2011

REALLY? AND NOW?

- **Mixing established**
  → but no precise determination of individual parameters
- **Evidence of direct CP violation**
  → but source not identified
- **No indication for direct CP violation in other charm decays**
  → **$D^+ \to \phi\pi^+$** maybe, **$D^+ \to K_S\pi^+$** shows no charm CPV
- **Indirect CP violation still out of reach**
  → although maybe only just

see J. Marks

MIXING

R. Aaij et al. (LHCb collaboration), JHEP04(2012)129

- First LHCb mixing measurement published:

$$y_{CP} = (5.5 \pm 6.3_{\text{stat}} \pm 4.1_{\text{syst}}) \times 10^{-3}$$

2010

- Statistical uncertainty in ballpark of best measurements
- Systematic uncertainty limited by available statistics → will shrink
- Other measurements on the way
- Candidates:
  - **$D^0 \to K_S \pi\pi$**: time-dependent Dalitz plot measurement: **x, y**
  - **$D^0 \to K^+ \mu^- \nu$**: time-integrated WS/RS ratio: **$x^2 + y^2$**
  - **$D^0 \to K^+ \pi^-$**: time-dependent WS/RS ratio: **x'^2, y'**
  - **$D^0 \to K^+ \pi^- \pi^0$**: time-dependent WS/RS Dalitz plot: **x'', y''**

MIXING - II

- Full upgrade sensitivity estimates (50 fb^{-1})
- Statistical uncertainties only
- Ratio-based measurements should have controllable systematics

Decay	Observable	Expected sensitivity in 10^{-3}
$D^0 \to K^+K^-$	y_{CP}^*	0.04
$D^0 \to \pi^+\pi^-$	y_{CP}^*	0.08
$D^0 \to K^+\pi^-$	x'^2, y'	0.01, 0.1
$D^0 \to K_S\pi^+\pi^-$	x, y	0.15, 0.1
$D^0 \to K^+\mu^-\nu$	$R_M = x^2+y^2$	0.0001

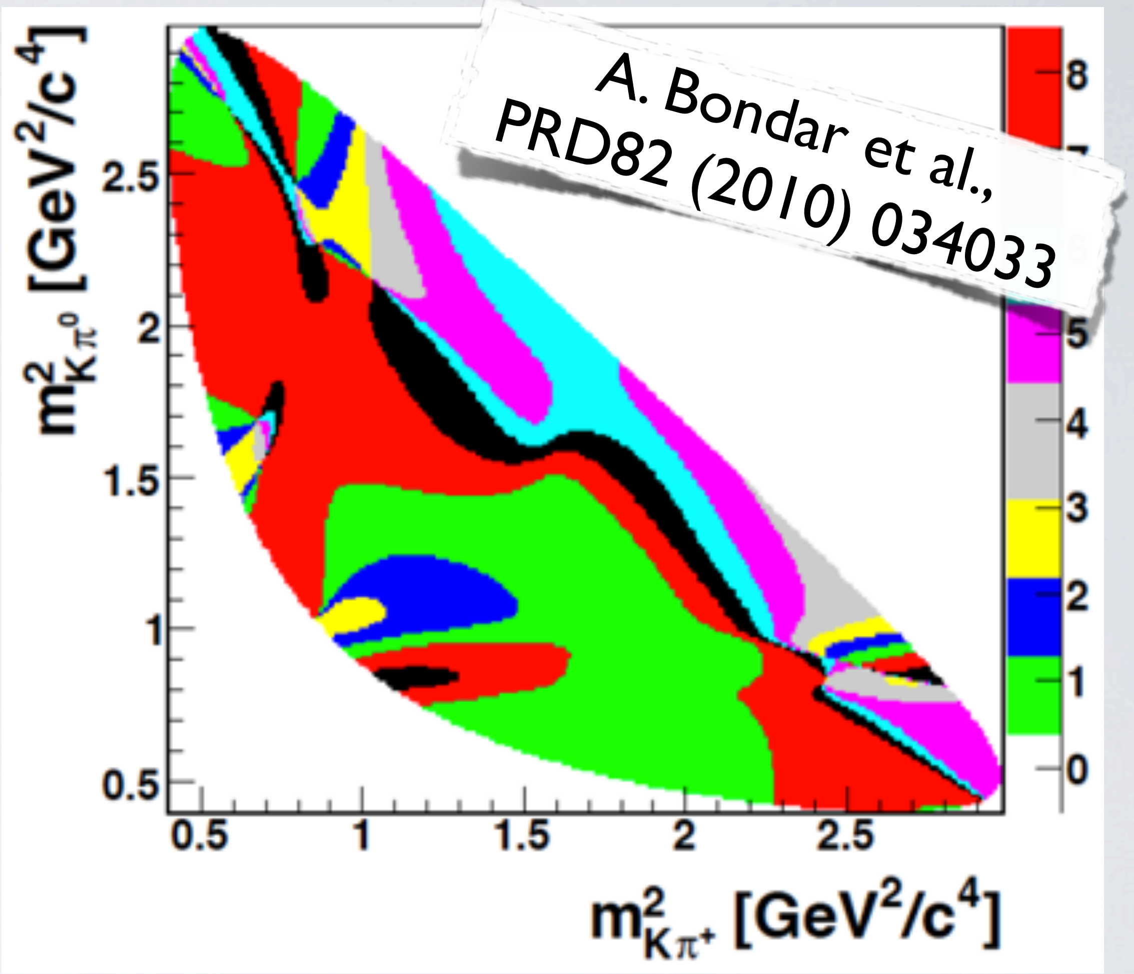
see M. Sokoloff, 2nd LHCb-Theory workshop

*from D^*-tagged decays

$D^0 \to K_S\pi\pi$

see H. Gordon

- Time-dependent Dalitz plot measurement:
  → x, y, |q/p|, ϕ
- Two approaches:
  - Model-dependent
  - Using input from measurements at threshold
    → CLEOc



- Need to improve on both fronts to avoid limiting sensitivity
- BESIII ideally placed to take over from CLEOc for making precision measurements of model-independent Dalitz structures

INDIRECT CP VIOLATION

- Prime candidate: A_Γ

MG et al., J.Phys.G 39 (2012) 045005

- Almost clean measure of indirect CPV: $A_\Gamma = -a_{CP}^{ind} - a_{CP}^{dir} \cdot y_{CP}$
- Lifetime asymmetry measurements in CP eigenstates
- Systematically very clean measurements, provided mis-tagging is small and under control
- First LHCb measurement underlines potential at hadron collider

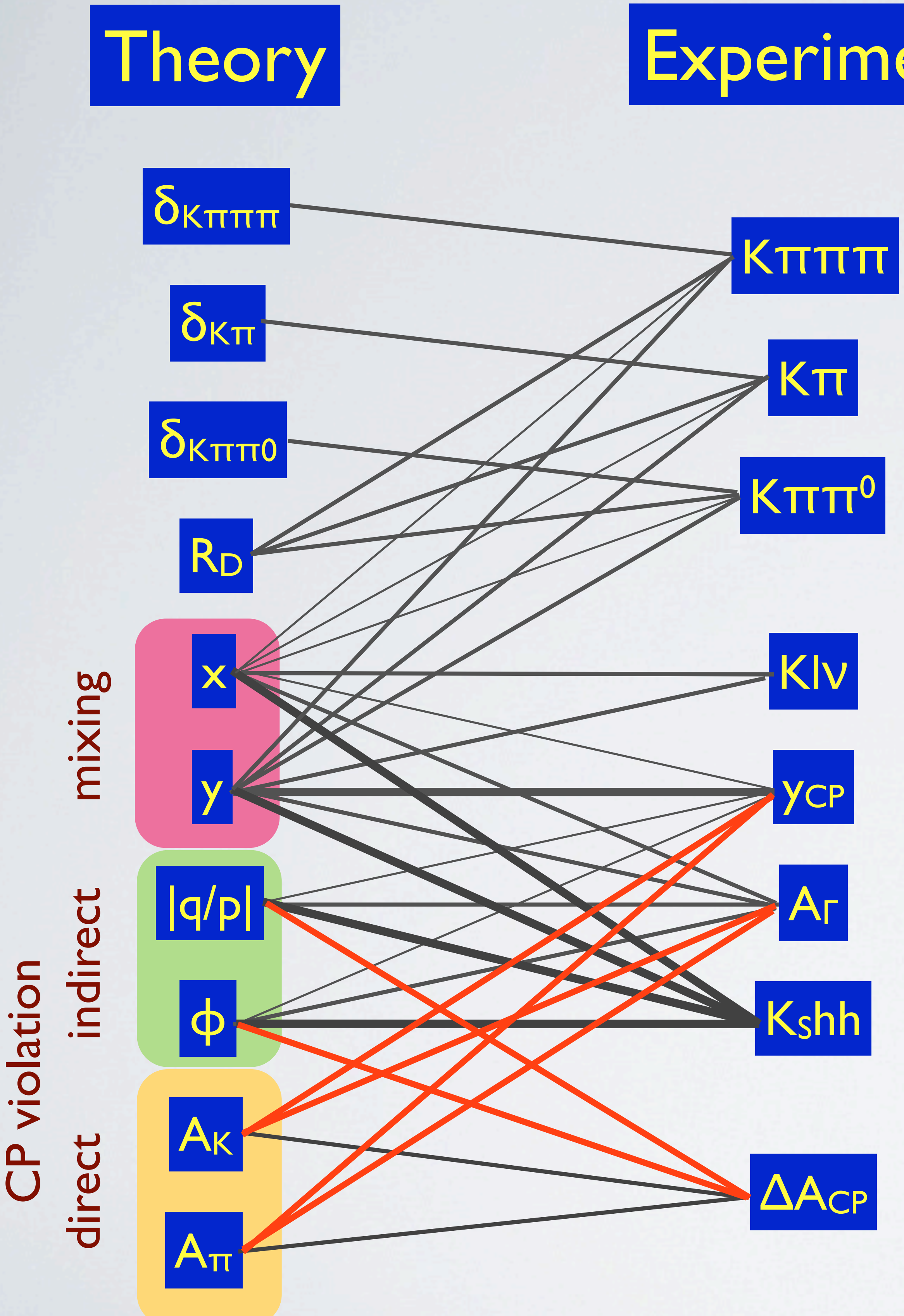
$$A_\Gamma = (-5.9 \pm 5.9_{\text{stat}} \pm 2.1_{\text{syst}}) \times 10^{-3}$$

2010

R. Aaij et al. (LHCb collaboration), JHEP04(2012)129

- Expectation for full upgrade luminosity: **$\sigma(A_\Gamma) = 0.04\ (0.08) \times 10^{-3}$** for **KK** ($\pi\pi$) final state

see J. Marks, A. Carbone



$$A_\Gamma \approx \left[\frac{1}{2}(\mathrm{A_m} + \mathrm{A_d})y\cos\phi - x\sin\phi\right]\frac{1}{1+y_{CP}}$$
$$\approx \frac{1}{2}(\mathrm{A_m} + \mathrm{A_d})y\cos\phi - x\sin\phi.$$

- Relative uncertainty of x & y limits sensitivity to CP violation observables
- Aim at **$\sigma(x,y)/x,y$ < 10%**
  → $\sigma(x,y) = O(10^{-4})$
  → matched by LHCb upgrade
- Need to measure both indirect and direct CP violation parameters
- Interpretation also requires precise theory predictions
  → establish how measurements can help reduce theory uncertainties

DIRECT CP VIOLATION

- General challenge at proton-proton collider:
  → Production asymmetries
- Need to also control detection asymmetries
  → Either in tagging (**D^0** modes) or in final state (**$D_{(s)}^+$**, some **D^0**)
- Use control modes to measure differences
  → Measure difference in CP violation: **ΔA_{CP}**
  → Assume no CP violation in Cabibbo-favoured modes
- Use other measurements of production/detection asymmetries
  → Usually not as precise

DIRECT CP VIOLATION - II

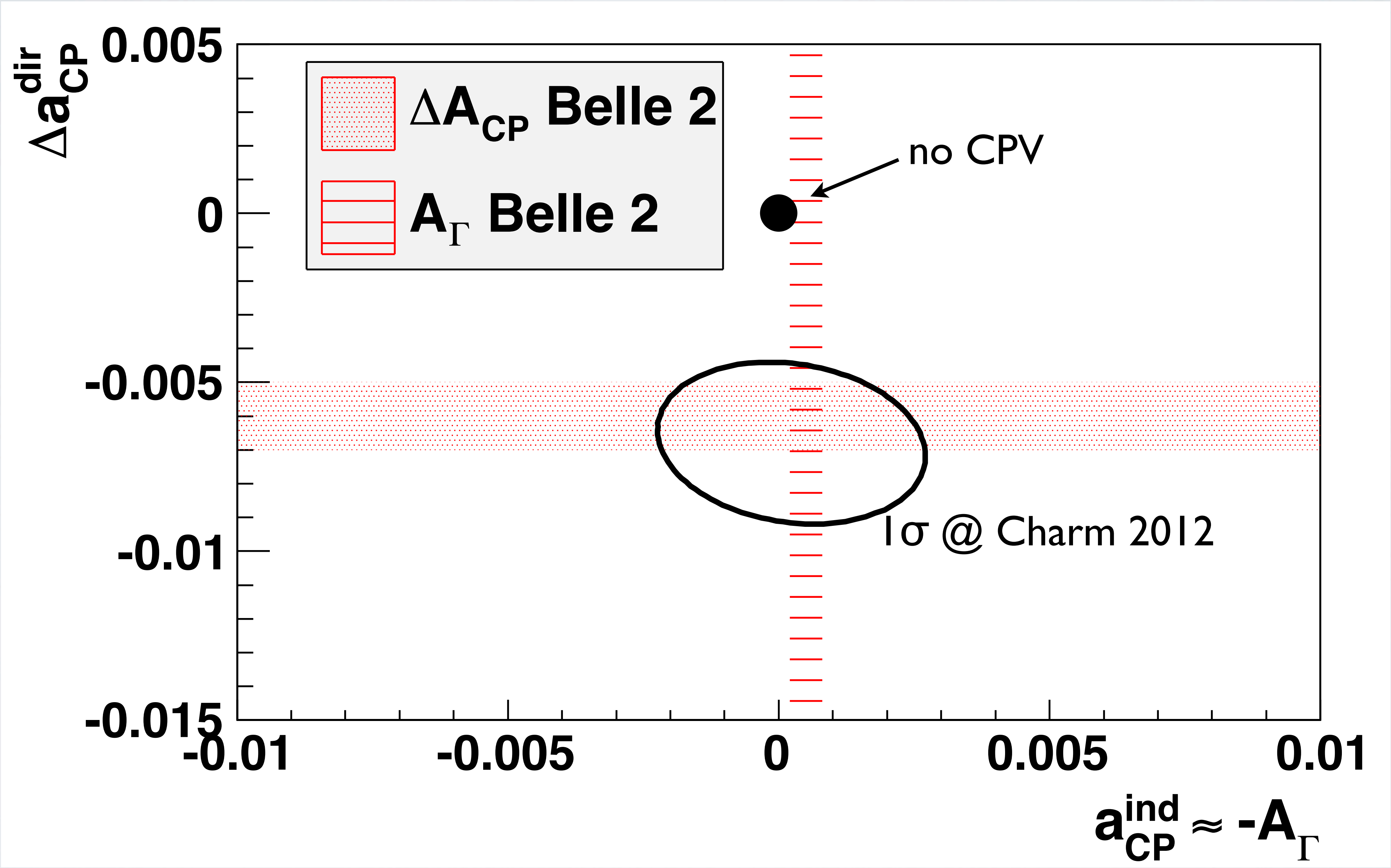
- Attempt measurements in as many modes as possible
- Dalitz plot integrated as well as sensitive to resonances
- Expected sensitivities with 50 fb^{-1}

Decay	Observable	Expected sensitivity in 10^{-3}
$D^0 \to K^+K^-, \pi^+\pi^-$	ΔA_{CP}	0.15
$D^+ \to K_S K^+$	A_{CP}	0.1
$D^+ \to K^-K^+\pi^+$	A_{CP}	0.05
$D^+ \to \pi^-\pi^+\pi^+$	A_{CP}	0.08
$D^+ \to h^-h^+\pi^+$	CPV in phases	(0.01-0.10)°
$D^+ \to h^-h^+\pi^+$	CPV in fractions	0.1-1.0

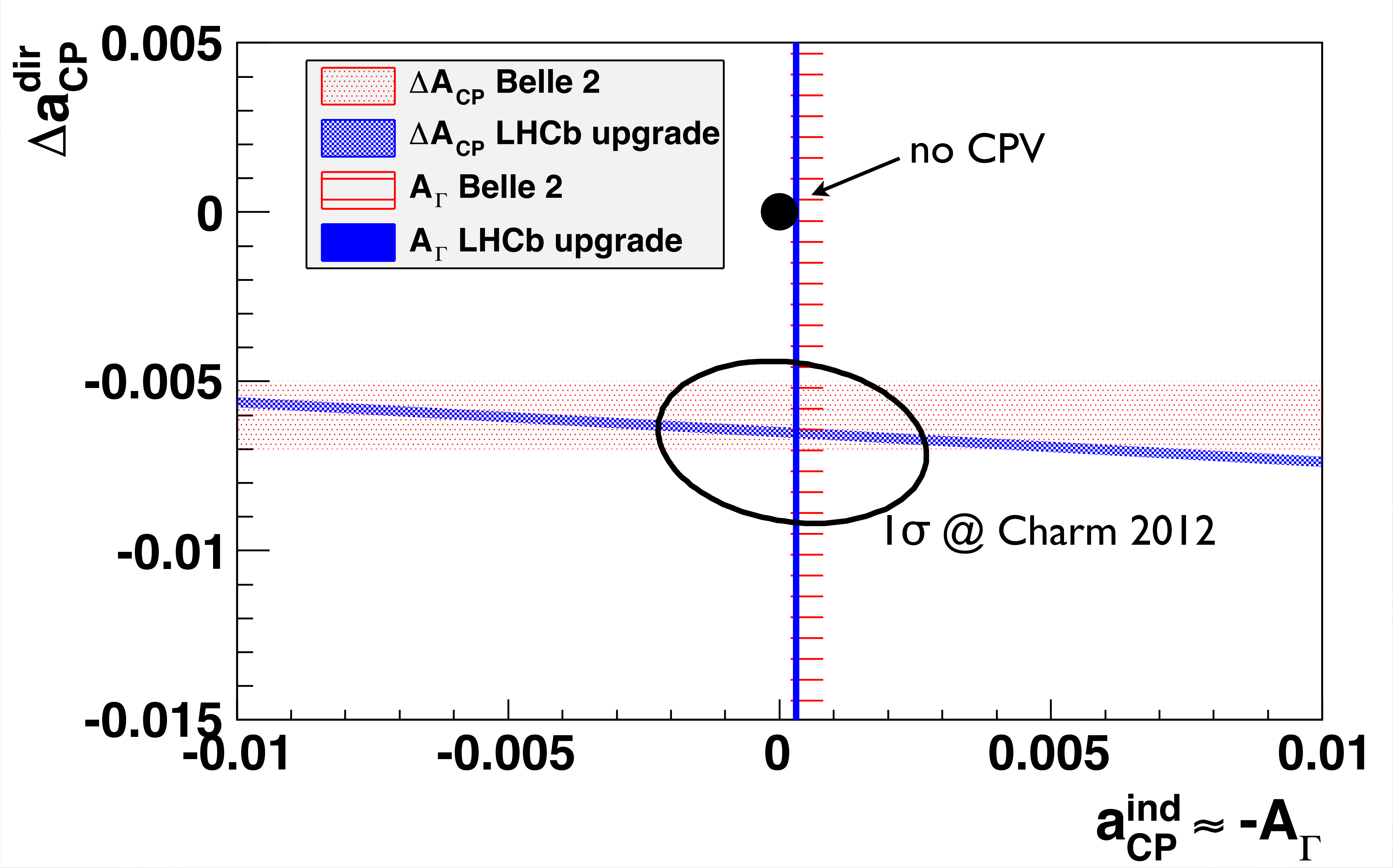
see M. Sokoloff, 2nd LHCb-Theory workshop

FUTURE INTERPLAY

see A. Schwartz



FUTURE INTERPLAY



CONCLUSIONS

CONCLUSIONS

- LHC measurements have shown the feasibility of charm physics at a proton-proton collider
- Particularly sub-% precision measurements at LHCb show the way to a high precision future
- Significant steps in precision expected until 2017
- **LHCb upgrade is needed to achieve precision not only to discover CP violation but also to determine its origin**
- Many complementary analyses of mixing, indirect and direct CP violation will allow the extraction of underlying theory parameters
- Enormous reach for rare decay measurements
- Explore charm baryon spectrum and multi-charm production