Searching for Physics Beyond the Standard Model @ LHCb

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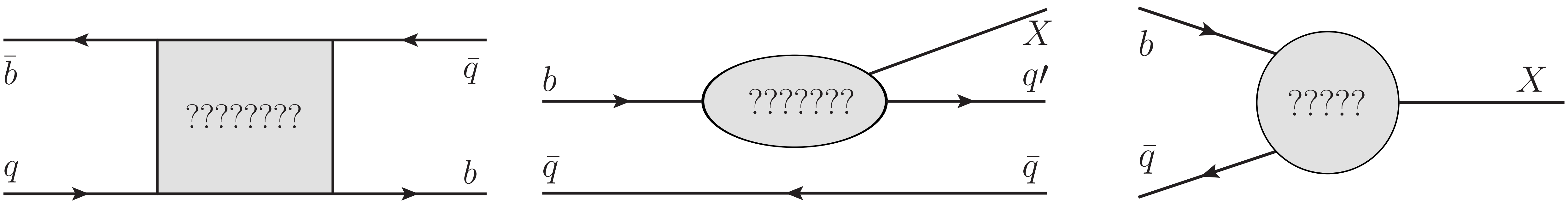
LHCb Overview

LHCb is performing precise tests of the SM, and searching for physics beyond the SM, by studying rare and CP-violating decays of b and c hadrons.

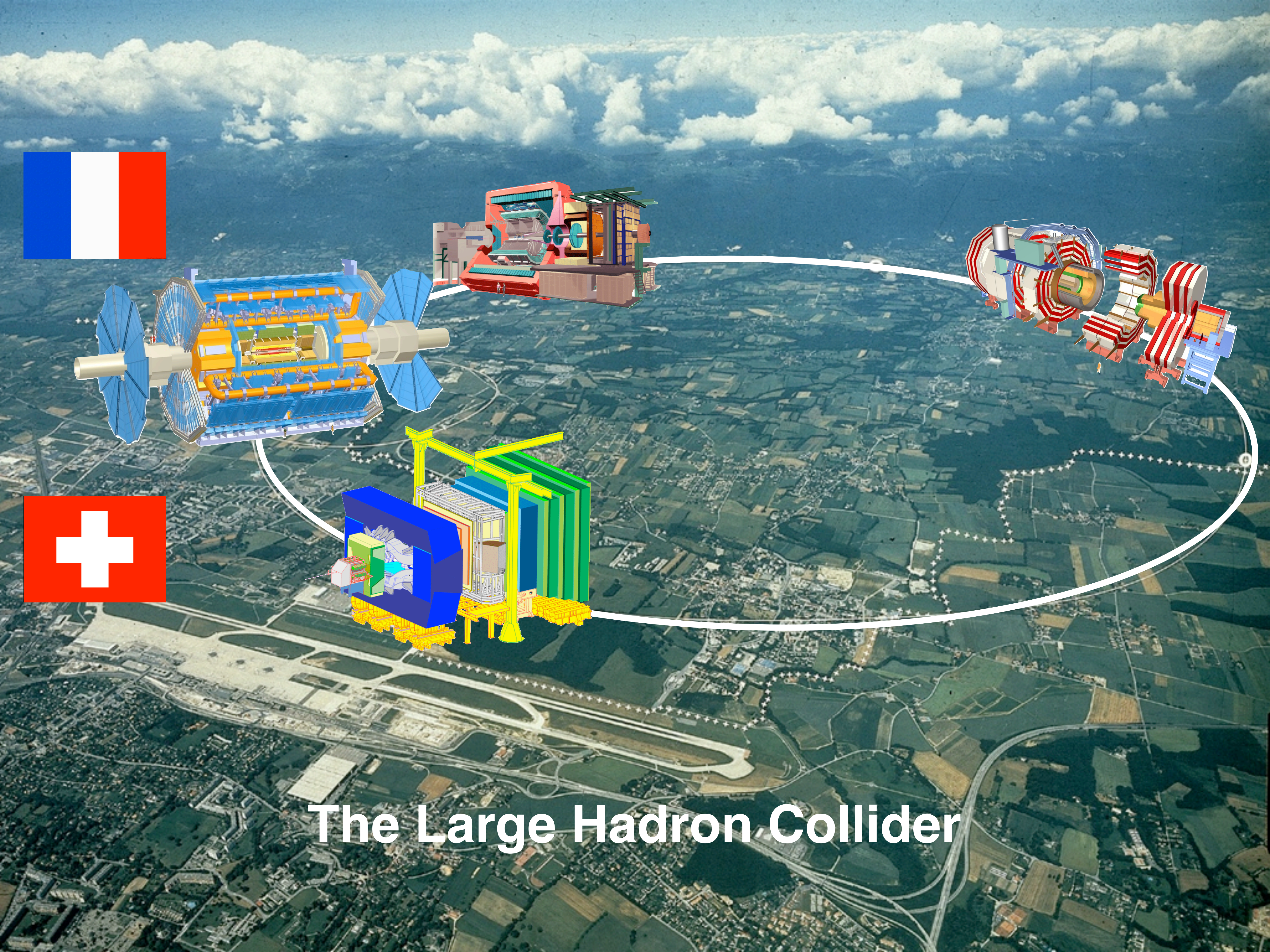
There are no tree-level FCNCs in the SM; FCNCs require loops.



TeV-scale particles can make significant contributions here:

- $\Delta|\mathcal{A}|$: compare *Br* vs SM;
- $\Delta\phi$: compare ϕ vs SM or from trees vs loops;
- Lorentz structure: compare angular distributions vs SM.

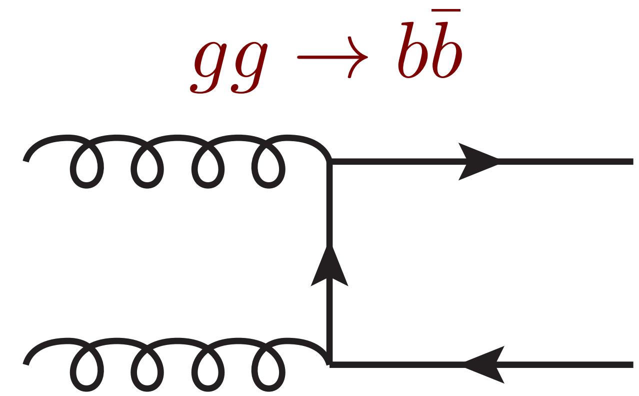
LHCb is also doing W,Z,t,..., physics, studying exotic spectroscopy, searching for rare τ decays, etc, etc, etc. We now have over 150 papers!


The Large Hadron Collider

Flavor Physics @ the LHC

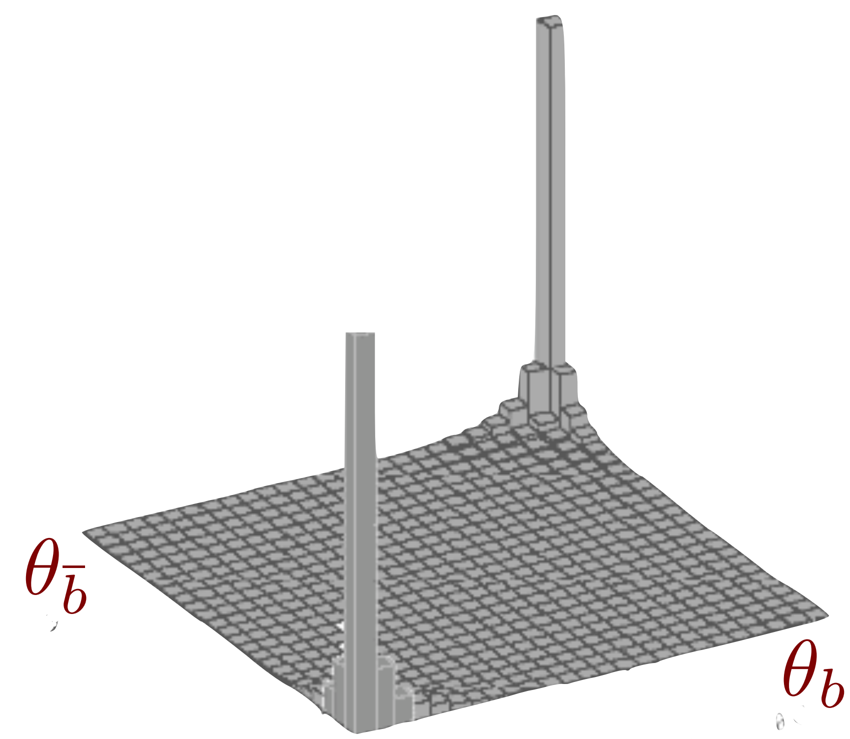
Advantages of B physics @ the LHC:

- Large cross section;
- Access to all b-flavored hadrons;
- large b-hadron flight distances O(1 cm).



Challenges of B physics @ the LHC:

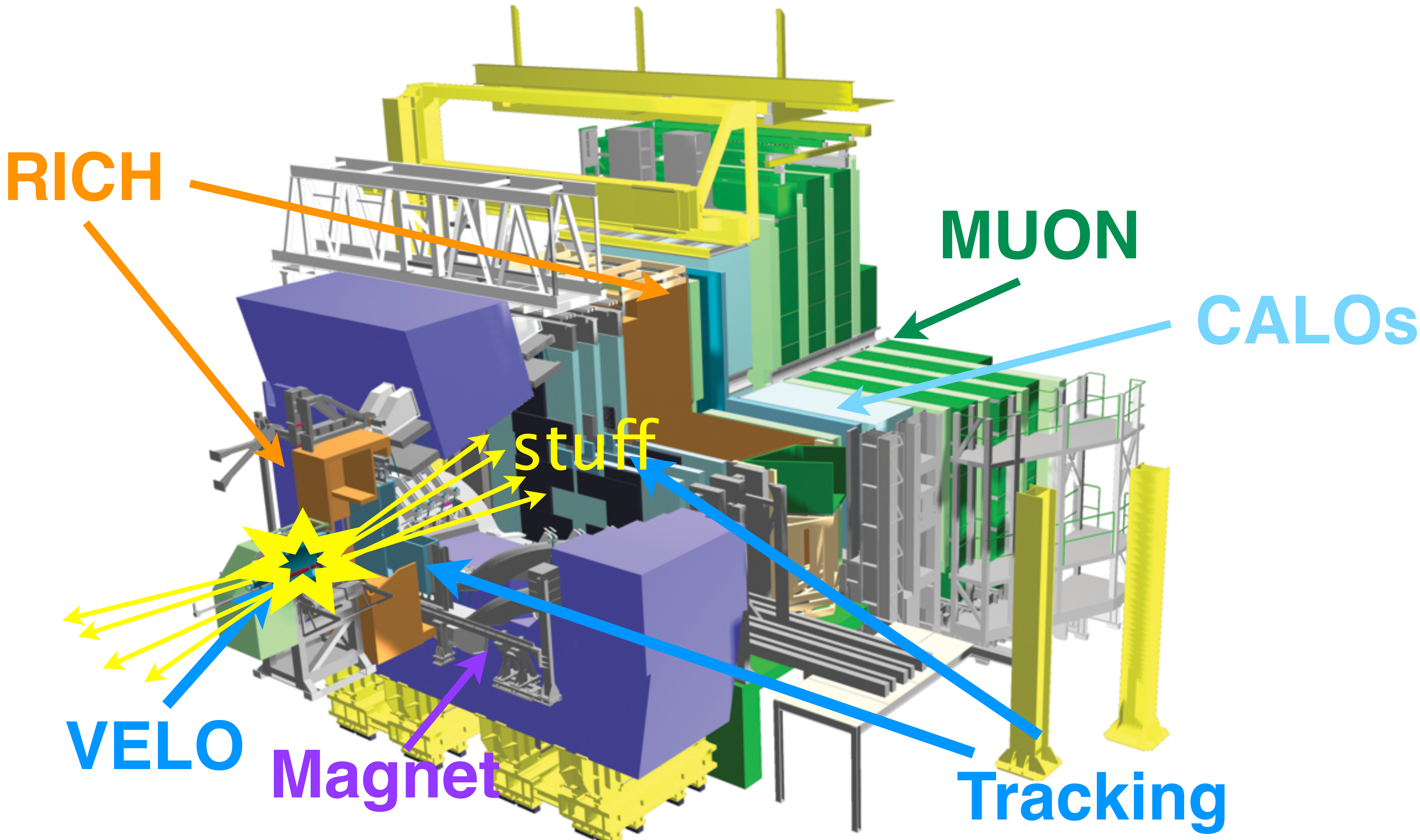
- High track multiplicity;
- BKGD rate ~200x bigger than signal rate!



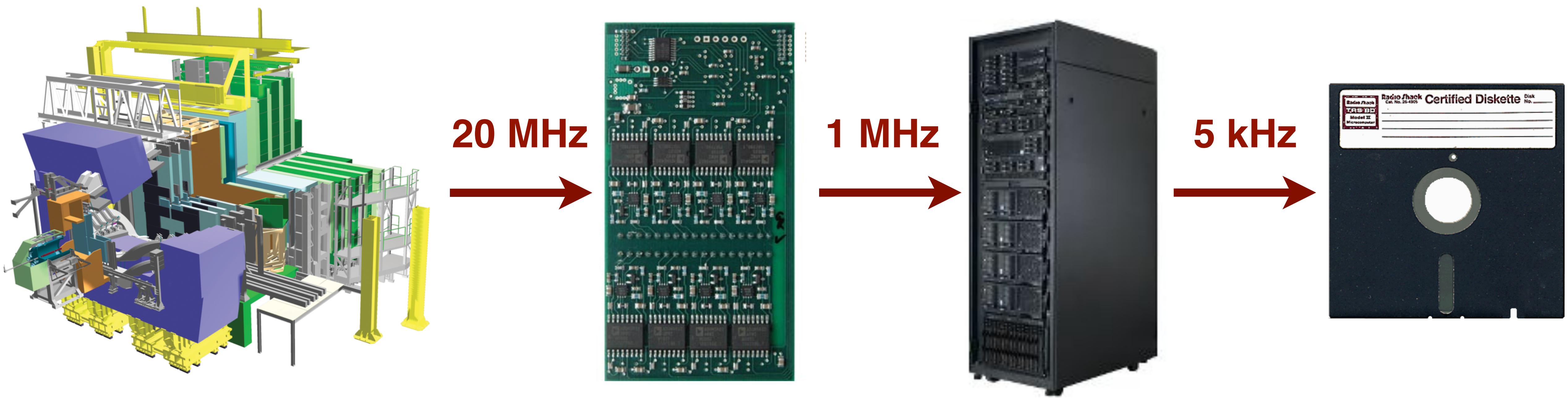
One trillion bb pairs produced @ LHCb so far!

LHCb Detector

LHCb is a FWD Spectrometer ($2 < \eta < 5$)



LHCb Trigger



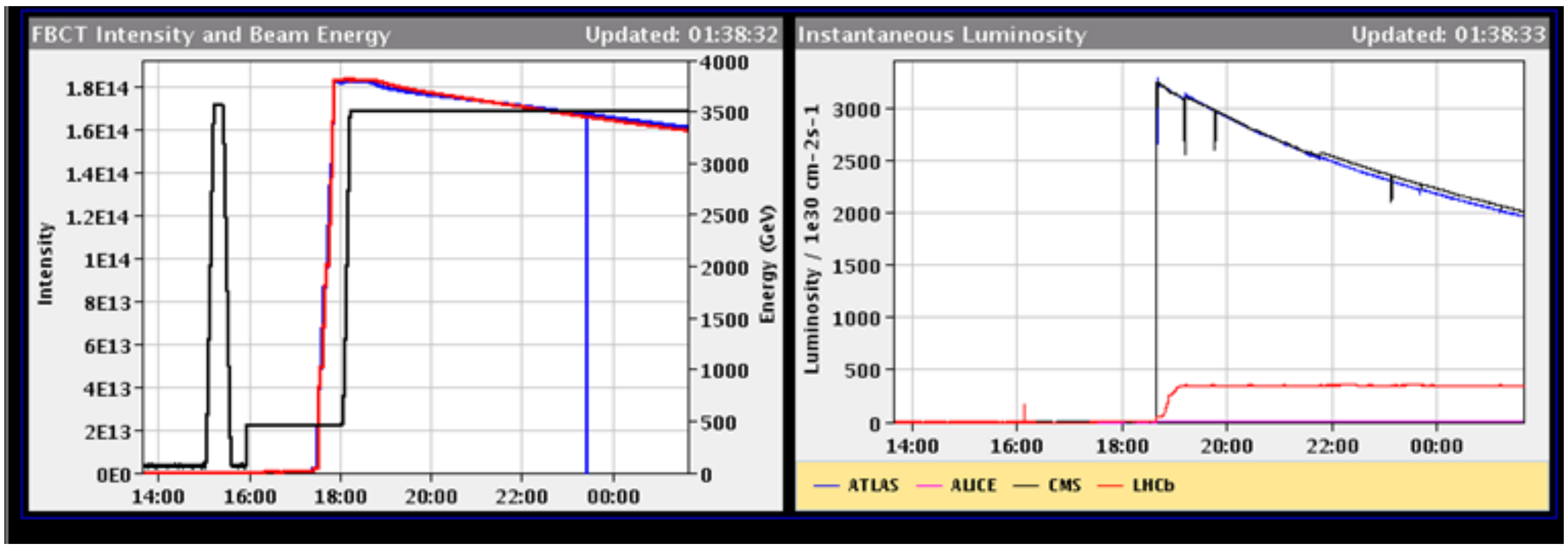
We can "only" read out the detector at 1 MHz; thus, a hardware trigger is required. The basic trigger strategy is

- hardware requires "large" ET in CALOs or "large" PT in the muon stations, along with low multiplicity;
- software runs ~30k PROCs (giving it 30 ms/event) to reduce the rate by ~200. It uses a combo of simple and inclusive BDT-based selections to produce a nearly 100% pure bb sample.

LHCb-DP-2012-004 [arXiv:1211.3055]
V.Gligorov & MW, JINST 8, P02013 (2013). [arXiv:1210.6861]

LHCb Data Samples

LHCb collected 1.0/fb of data in 2011 and 2.2/fb in 2012. To keep pile-up manageable, we do not take the maximum luminosity the LHC can deliver. We employ "lumi leveling" to keep L constant.

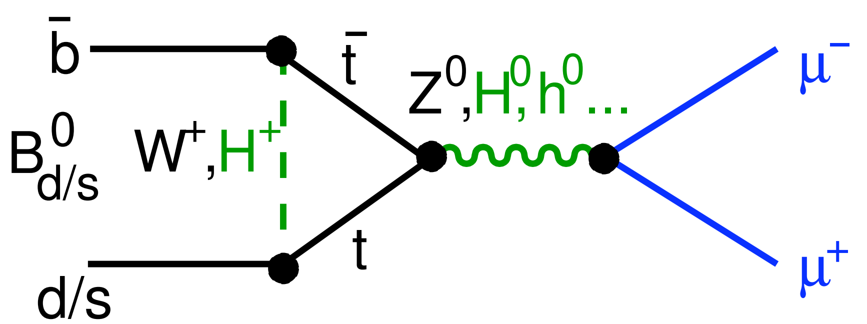


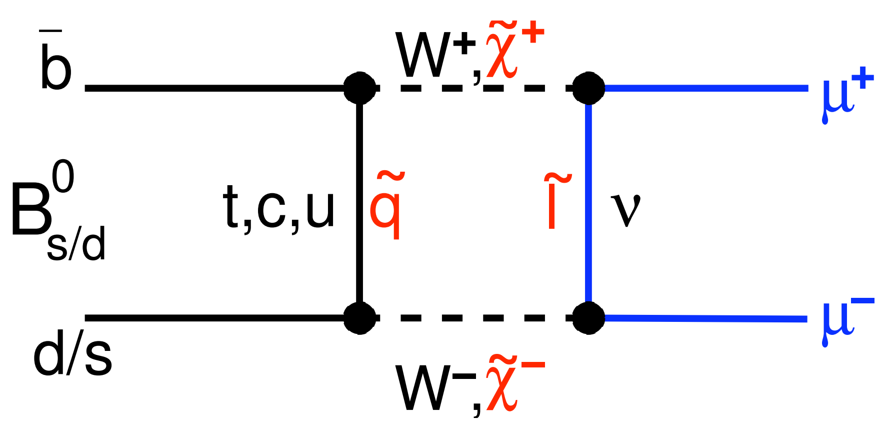
Most of the results I will show today use only 2011 data since most analyses have not yet been updated with the full 2011-2012 data set.

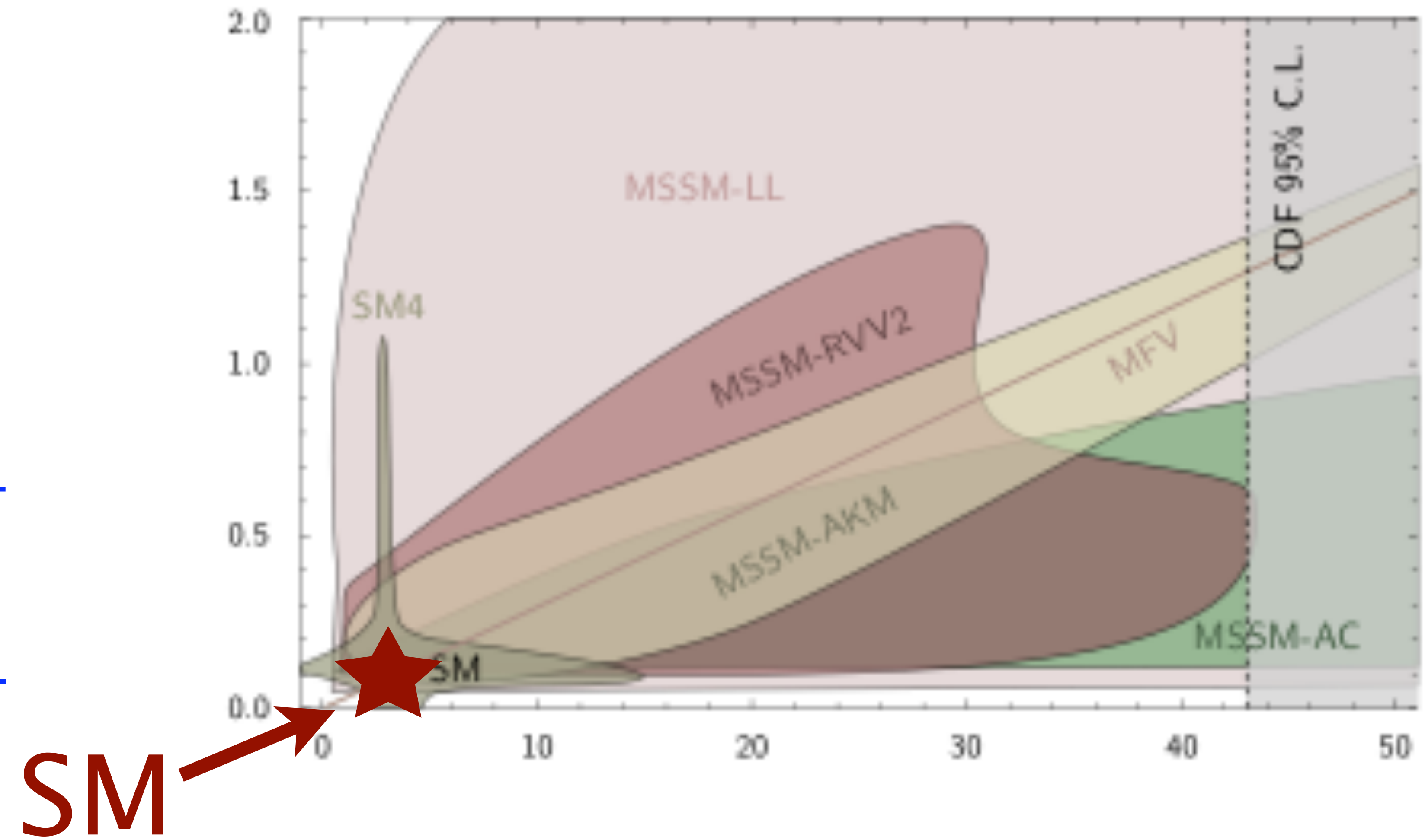
$B_{d,s} \to \mu^+\mu^-$

The SM predicts the B_s (sb meson) decays into two muons once every 3.4B decays ... but this can be enhanced greatly by BSM.

It works out to about 1/1.6 trillion pp collisions at LHCb!



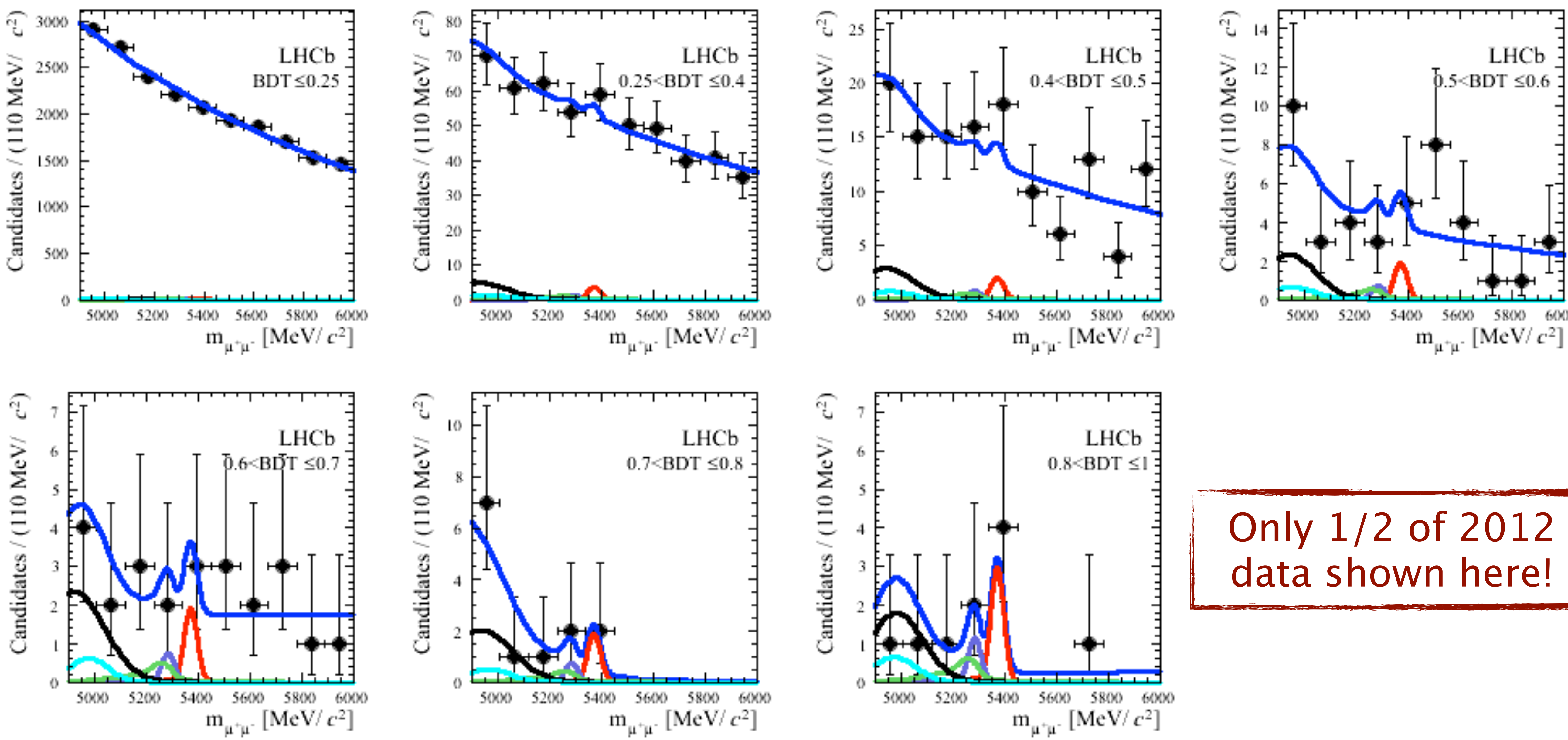




Very interesting channel to explore NP models with extended Higgs sectors. Sensitive to “any” mass scale. Pre-LHC limits not very restrictive.

$B_{d,s} \rightarrow \mu^+\mu^-$

BDT-based selection with data-driven constraints. Published results use the full 2011-2012 data set.



Only 1/2 of 2012 data shown here!

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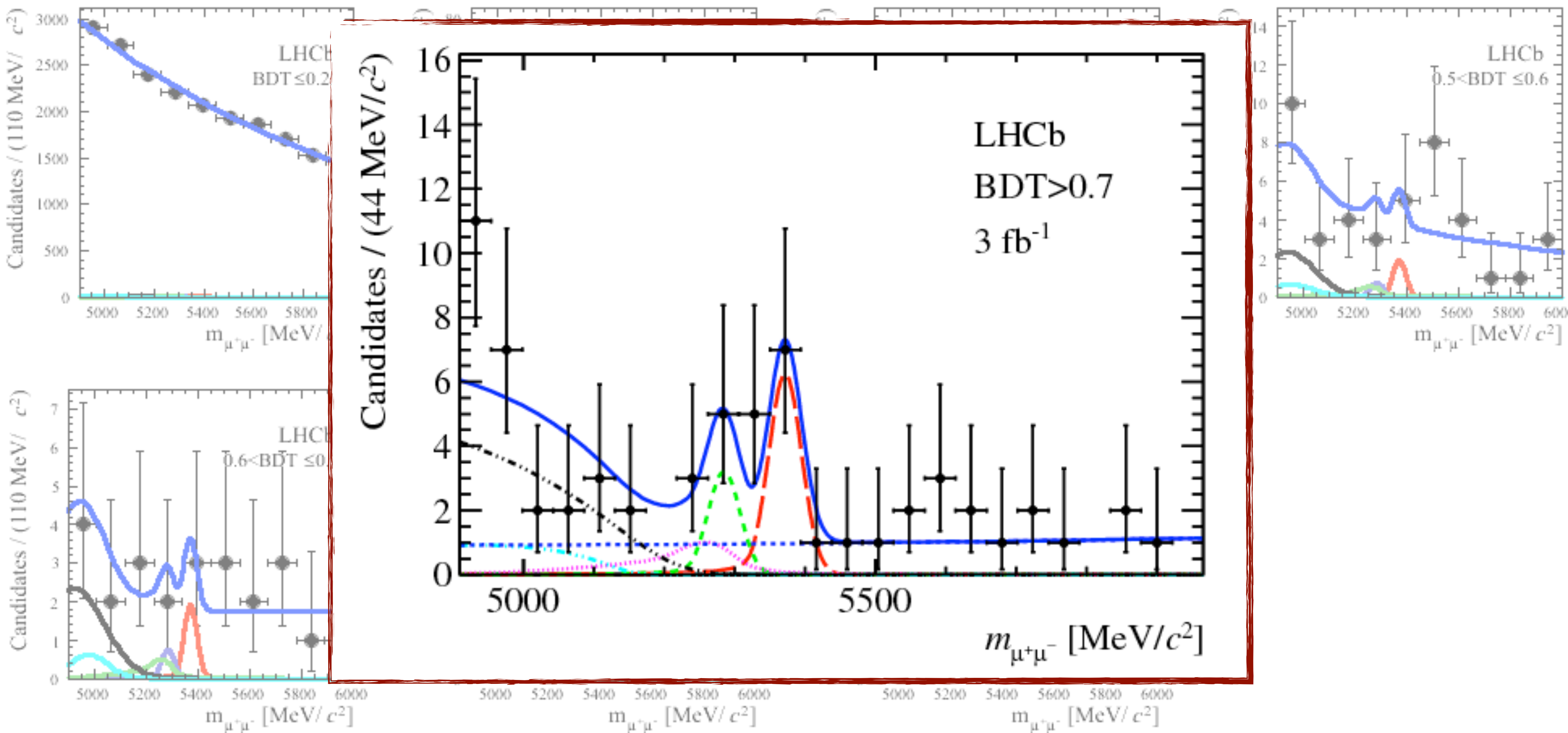
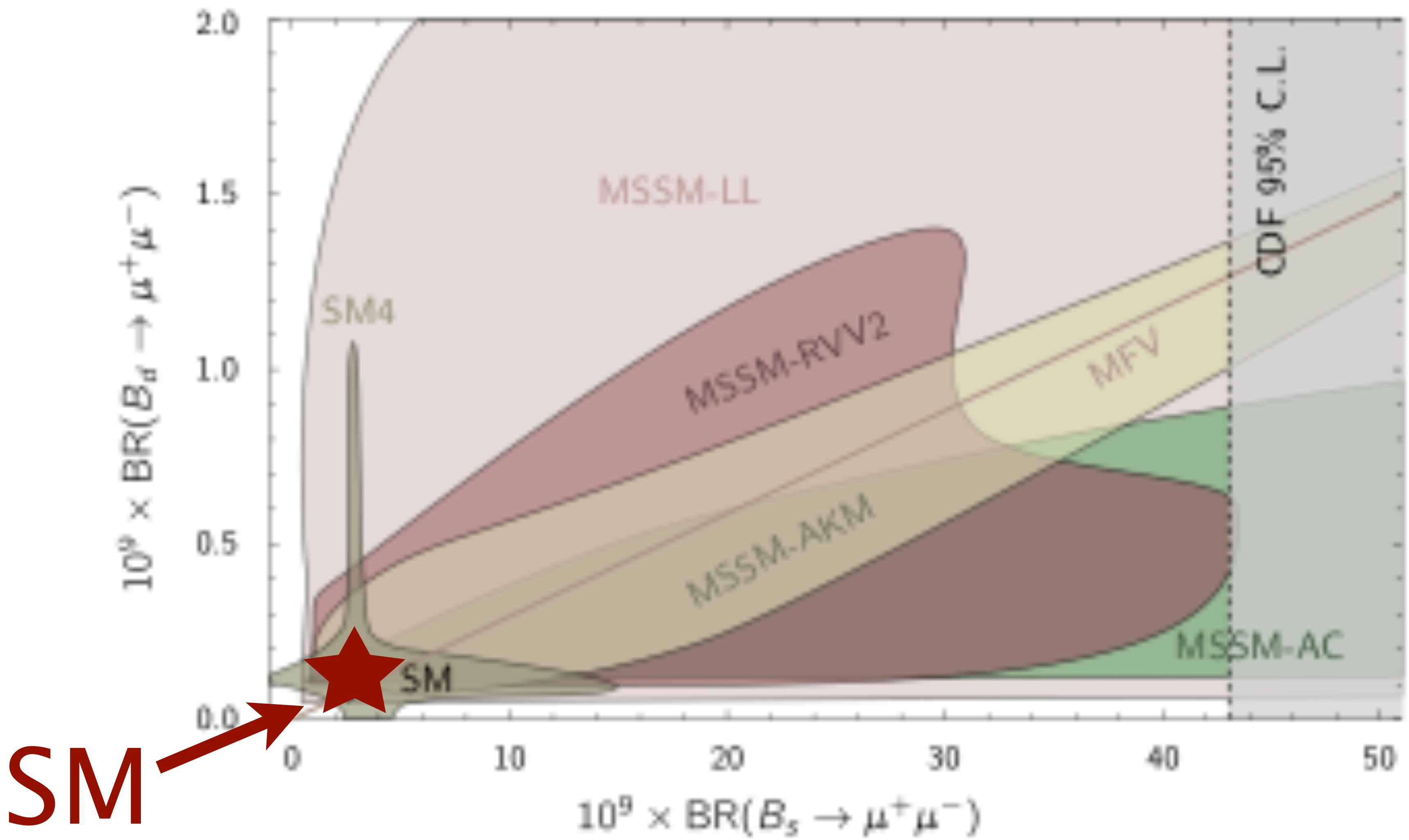


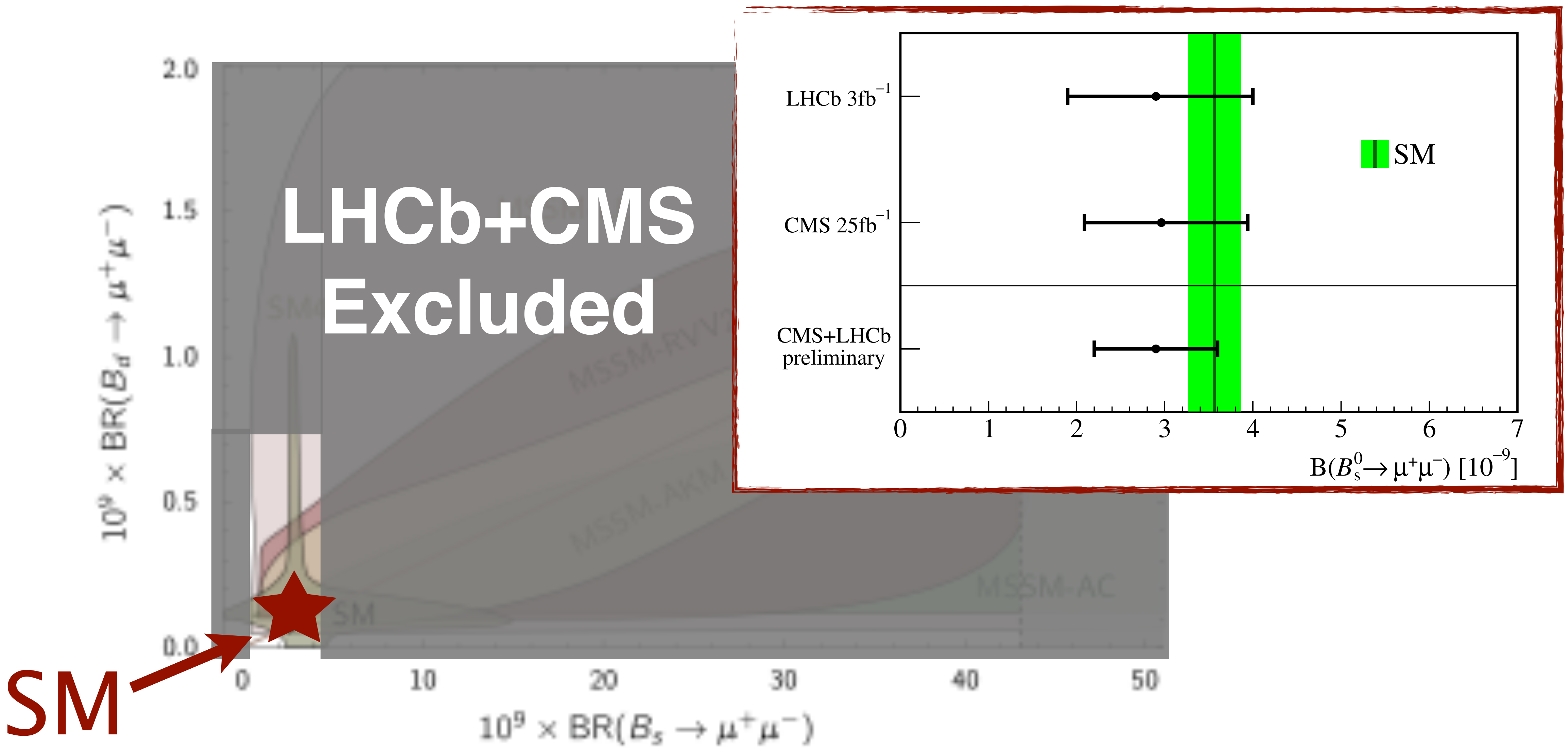
$B_{d,s} \to \mu^+\mu^-$

Pre-LHC limits on SUSY not very restrictive.



$B_{d,s} \to \mu^+\mu^-$

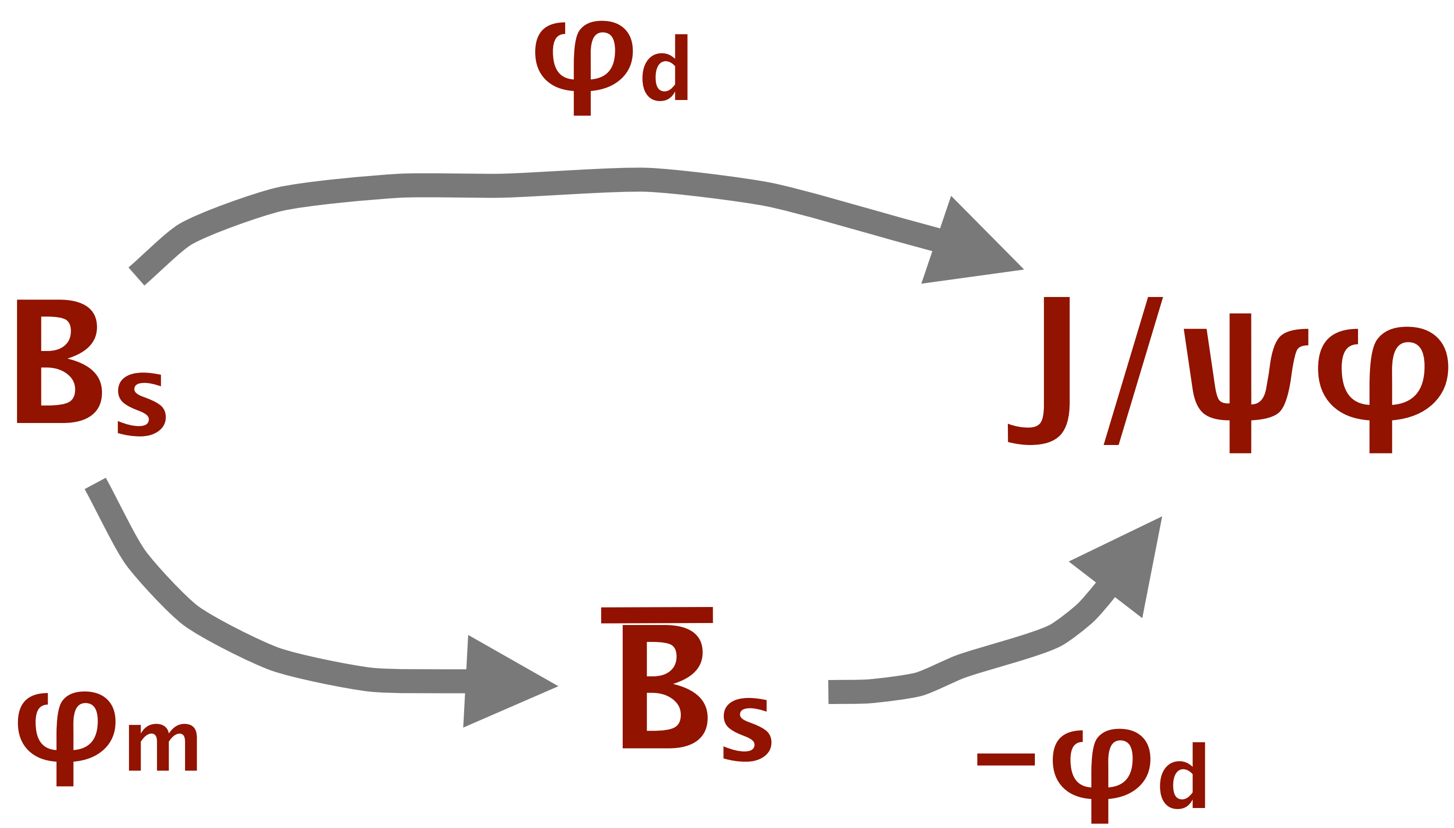
Both CMS & LHCb report > 4σ evidence.



Not the best result for SUSY fans.

$B_s \to J/\psi\phi$

Interference between mixing and decay amplitudes gives rise to a CPV phase $\phi_s = \phi_m - 2\phi_d$. BSM could give a non-SM measurement.



$$\phi_s^{\mathrm{SM}} = 2\left(\arg(V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)\right) = 0.036 \pm 0.002$$

This phase is accessible experimentally via a time-dependent angular analysis to measure the time-dependent CP asymmetry.

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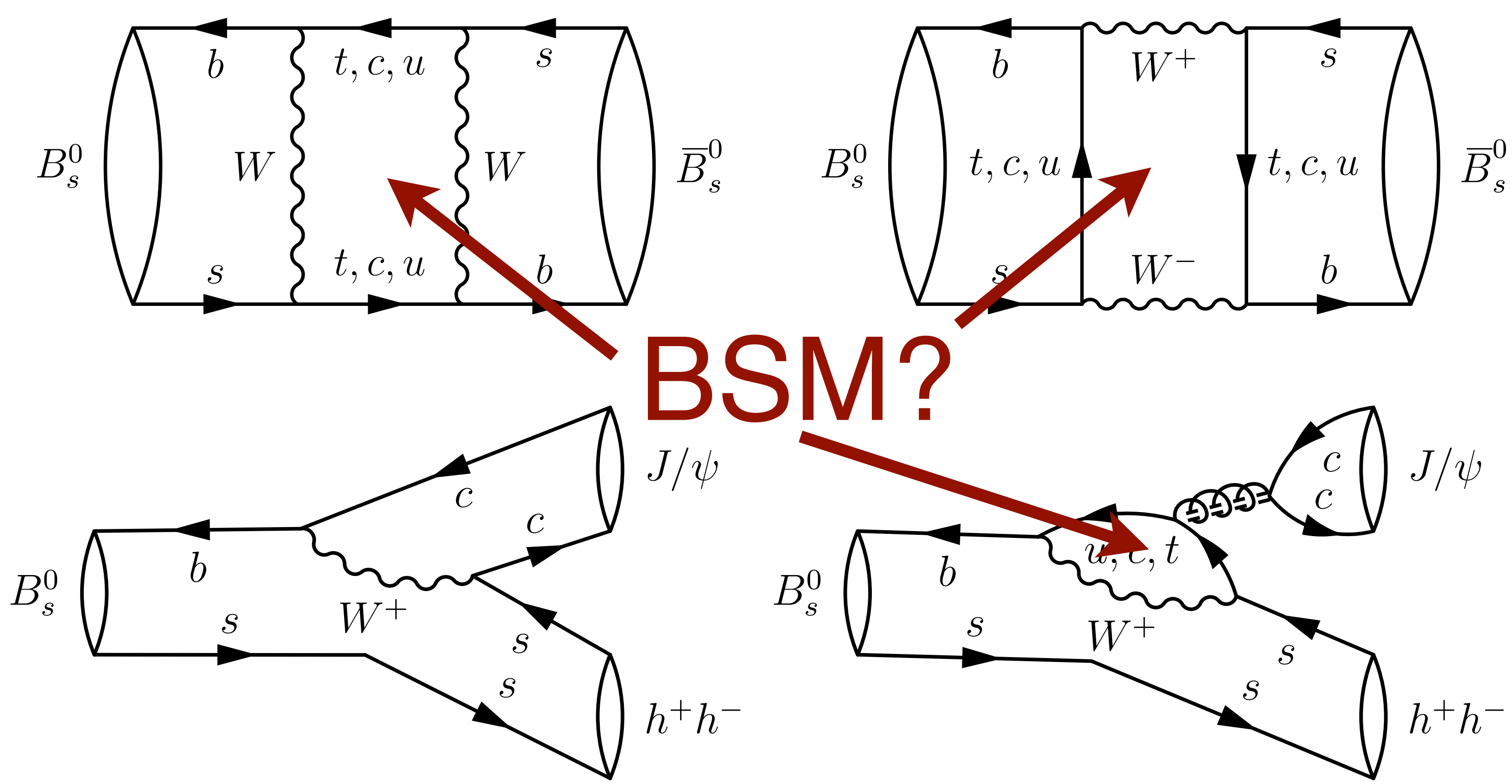

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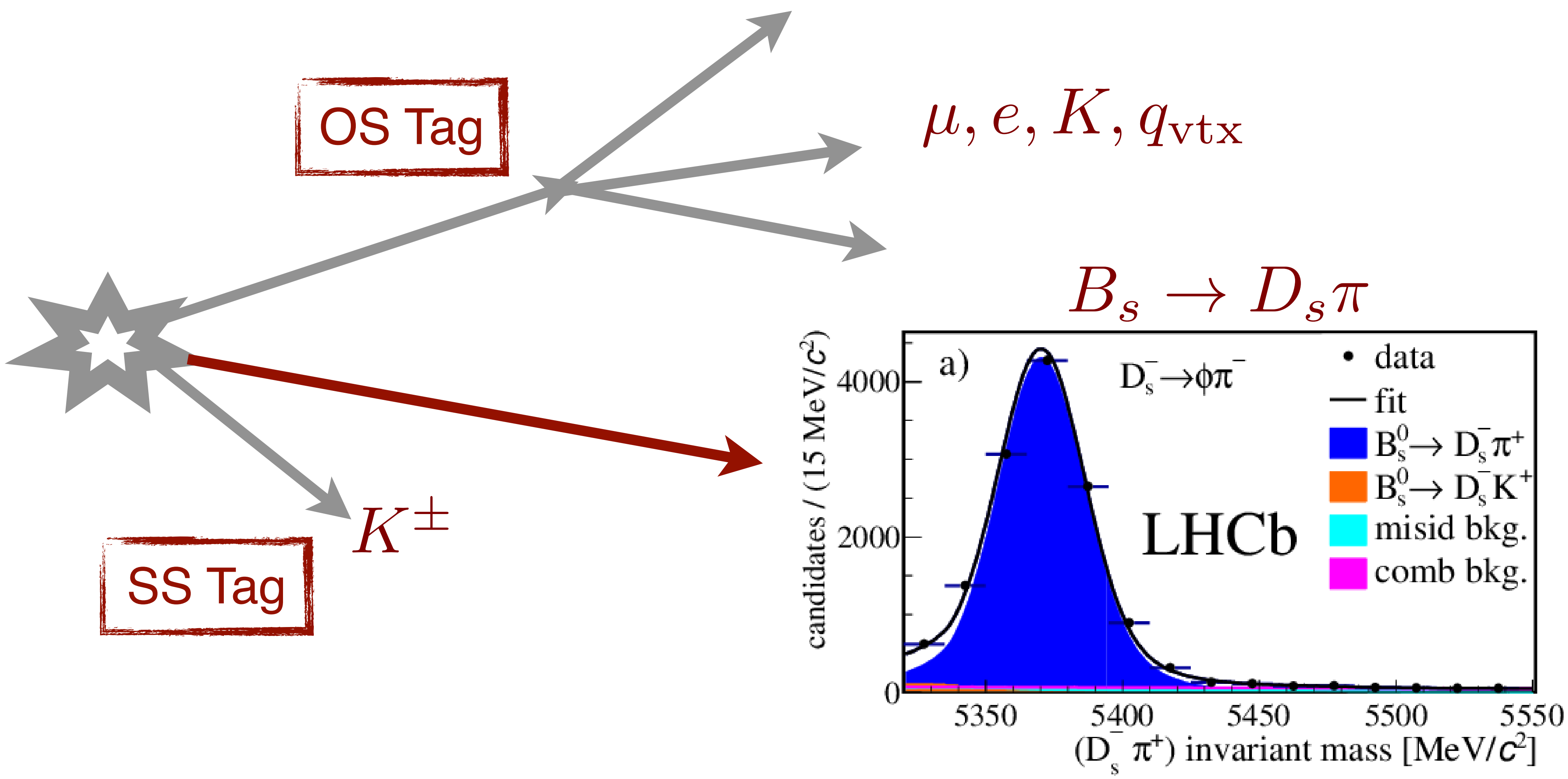
B_s Oscillations

Basic strategy to measure B_s oscillations: Reconstruct the B_s in a flavor-specific decay and also tag its flavor at production.



LHCb sees ~34k signal events in 1/fb of data (2011) with an effective tagging power of (2.6±0.4)% from OST and (1.2±0.3)% from SST.

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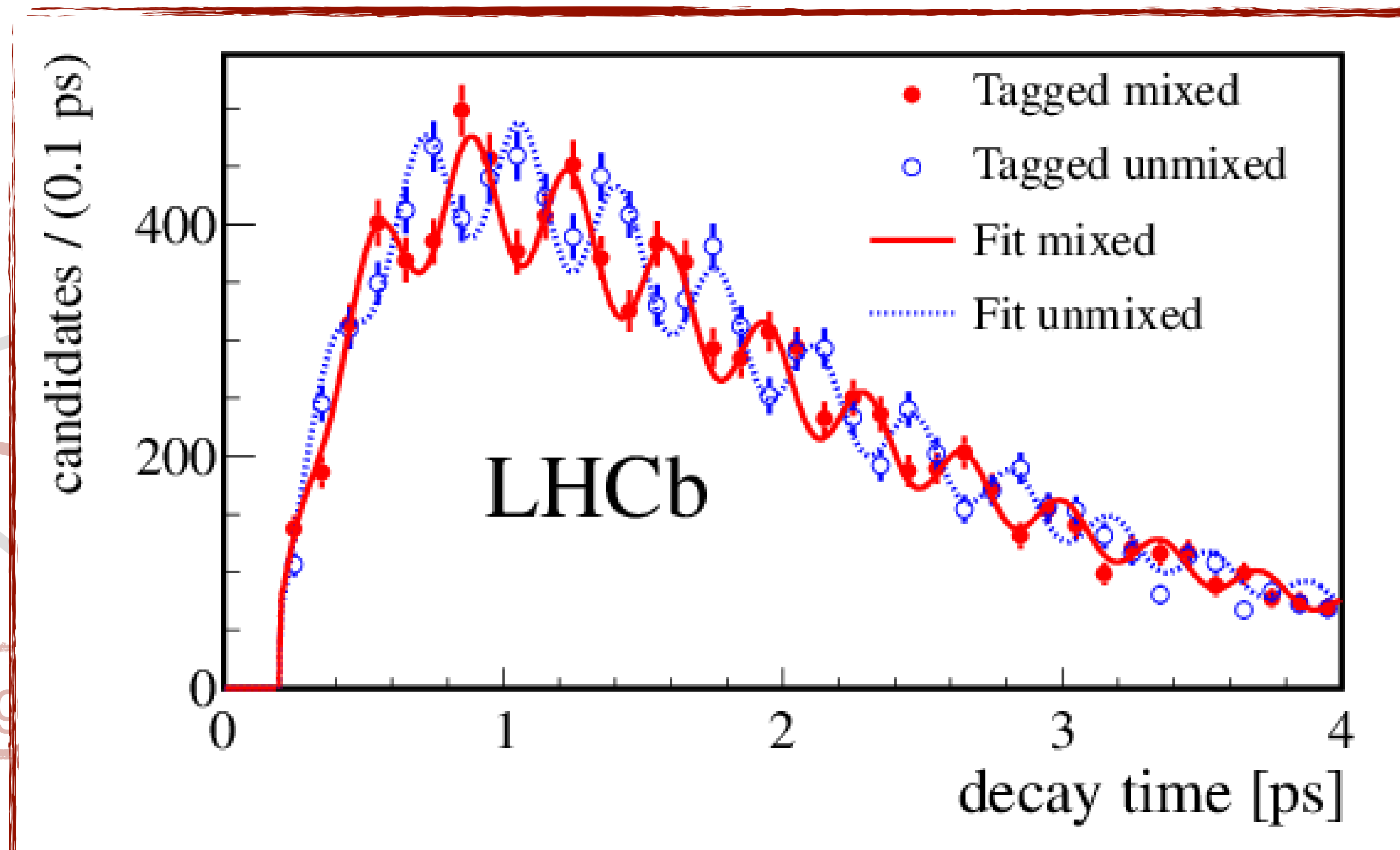

LHCb-PAPER-2013-006
[arXiv:1304.4741]

$$\Delta m_s = 17.768 \pm 0.023(\mathrm{stat}) \pm 0.006(\mathrm{syst})\,\mathrm{ps}^{-1}$$

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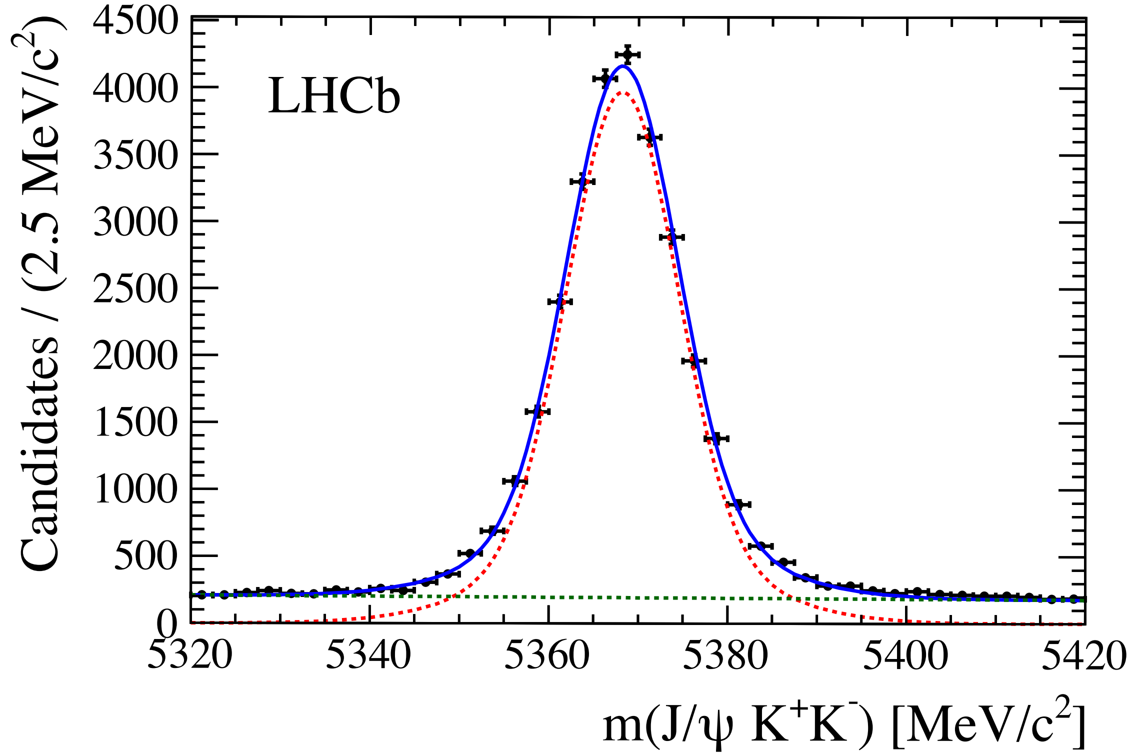
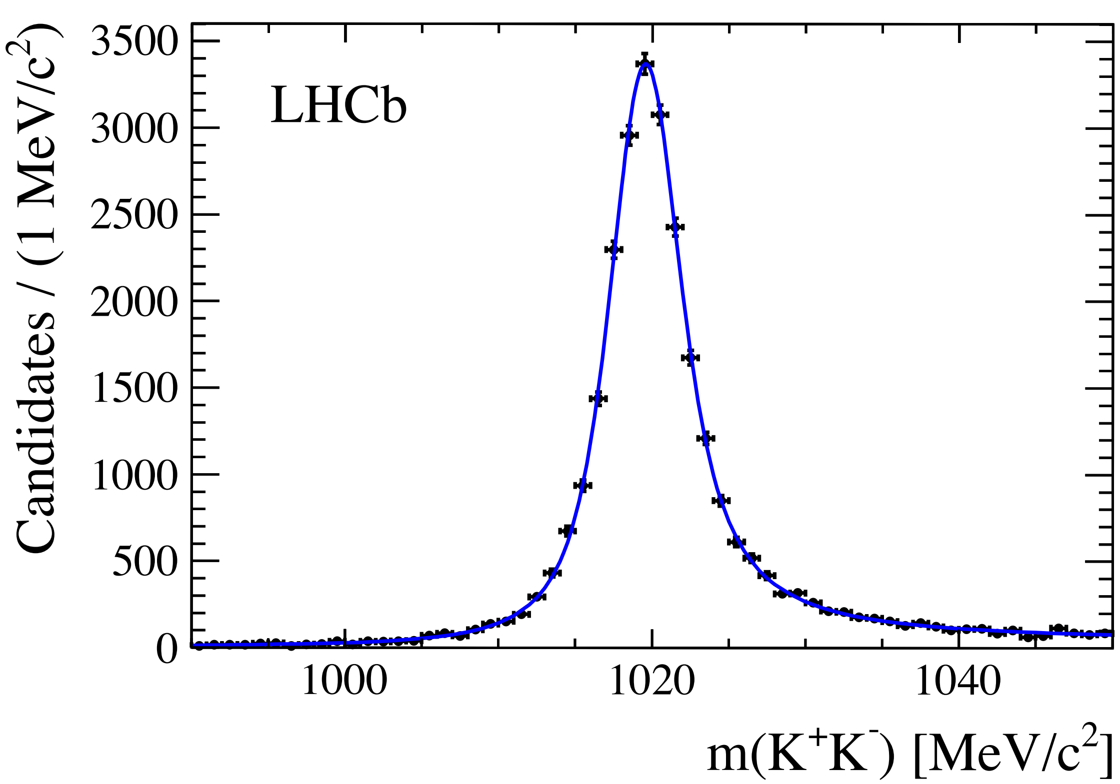
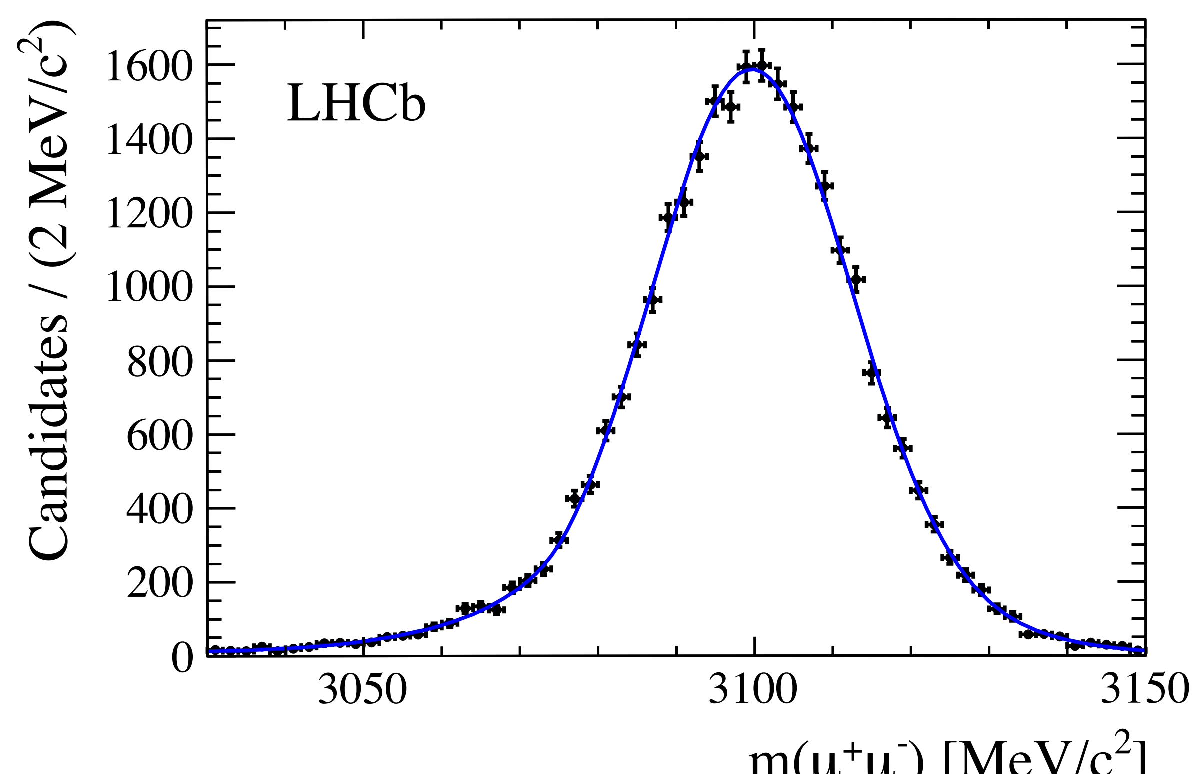
$B_s \rightarrow J/\psi\phi$

Signal is very clean despite “dirty” LHC environment.

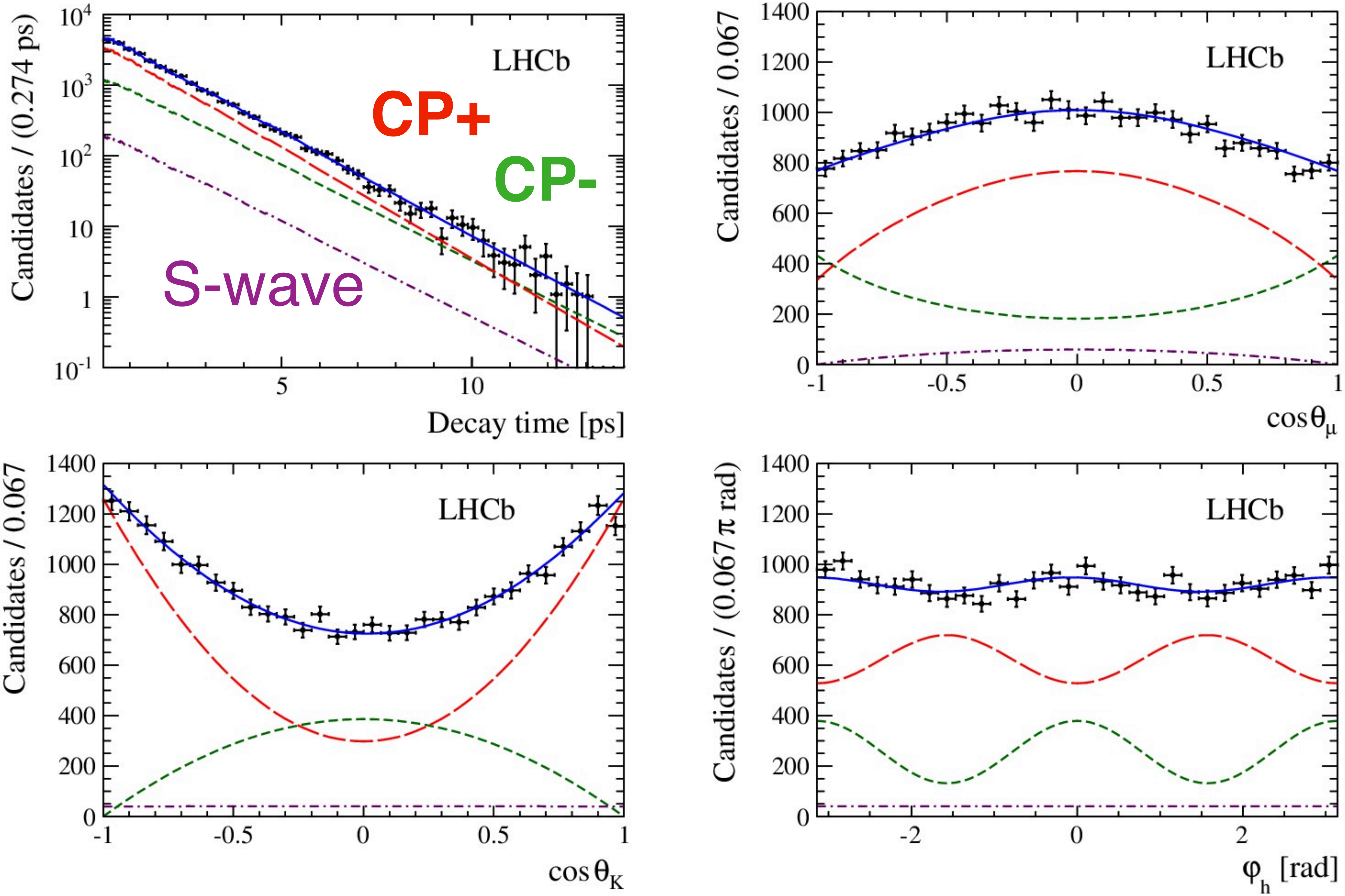


2011 data only



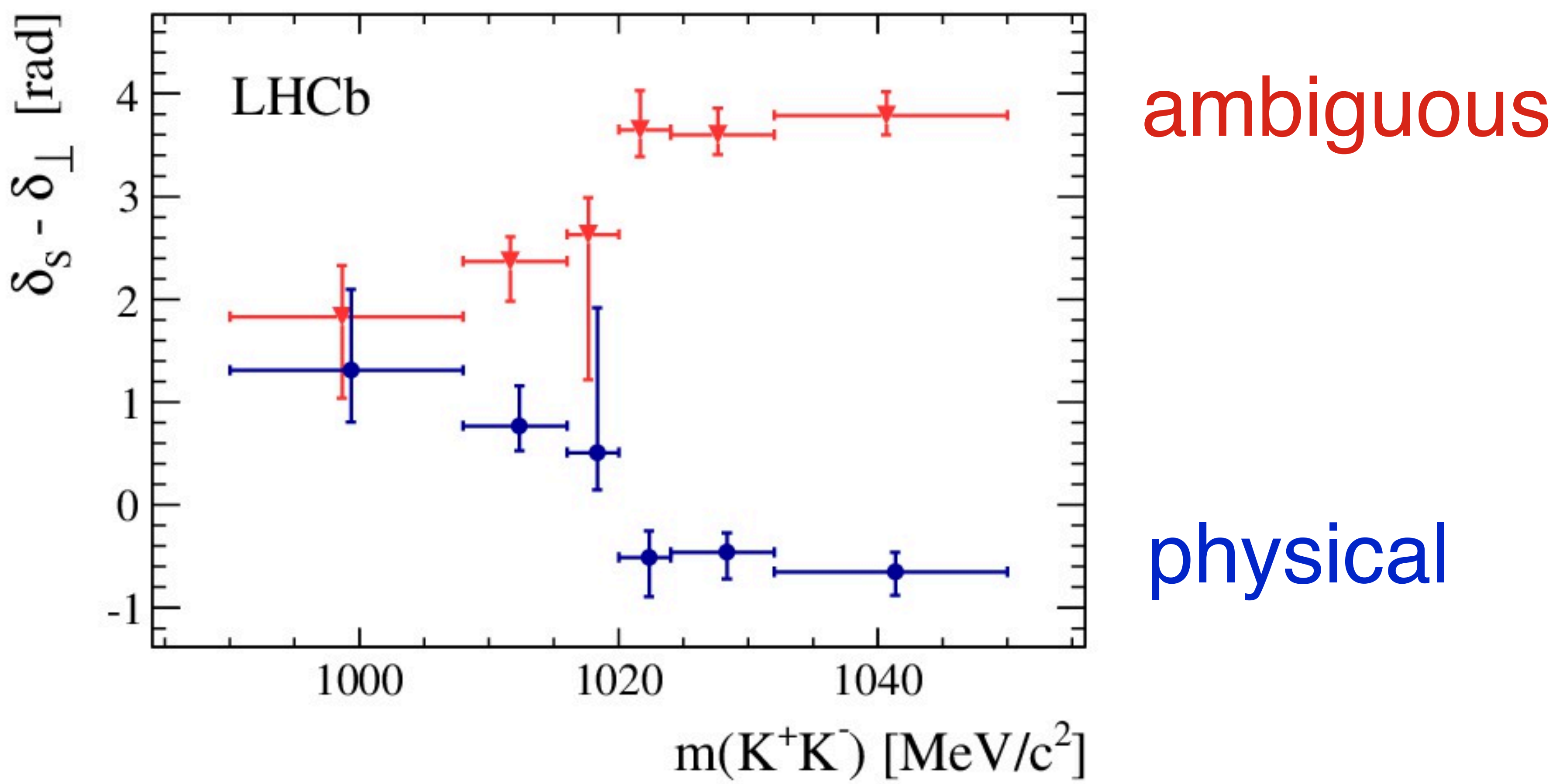


$B_s \to J/\psi\phi$



$B_s \to J/\psi\phi$

There is an ambiguity in the equations for $\phi_s = \phi_s+\pi$.



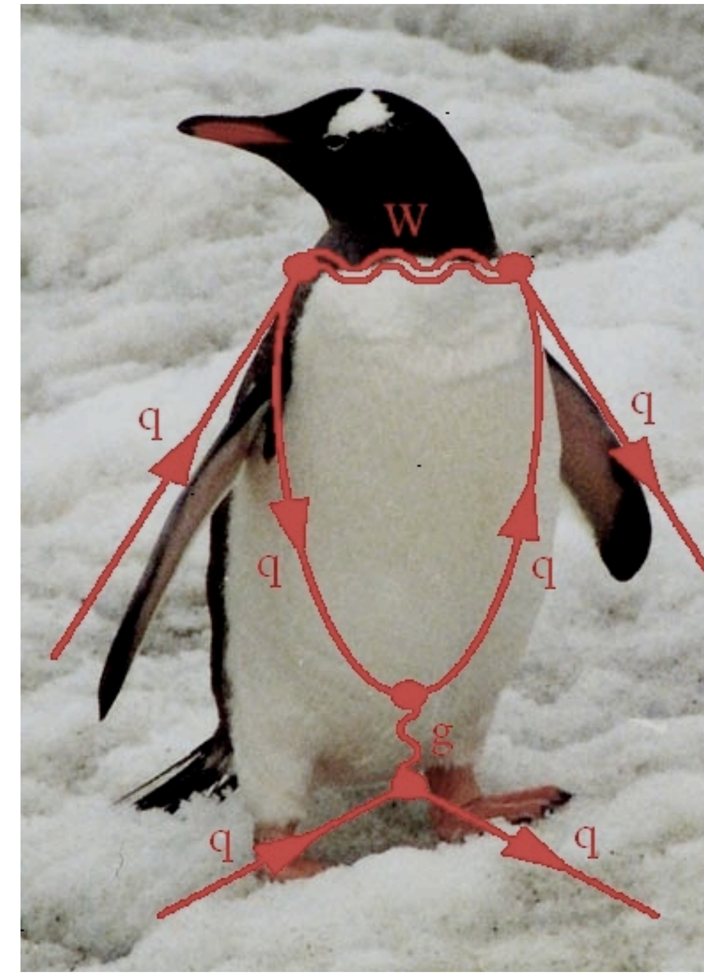
Use interference of ϕ with KK S-wave to break it!

$\phi_s = 0.01 \pm 0.07 \pm 0.01$

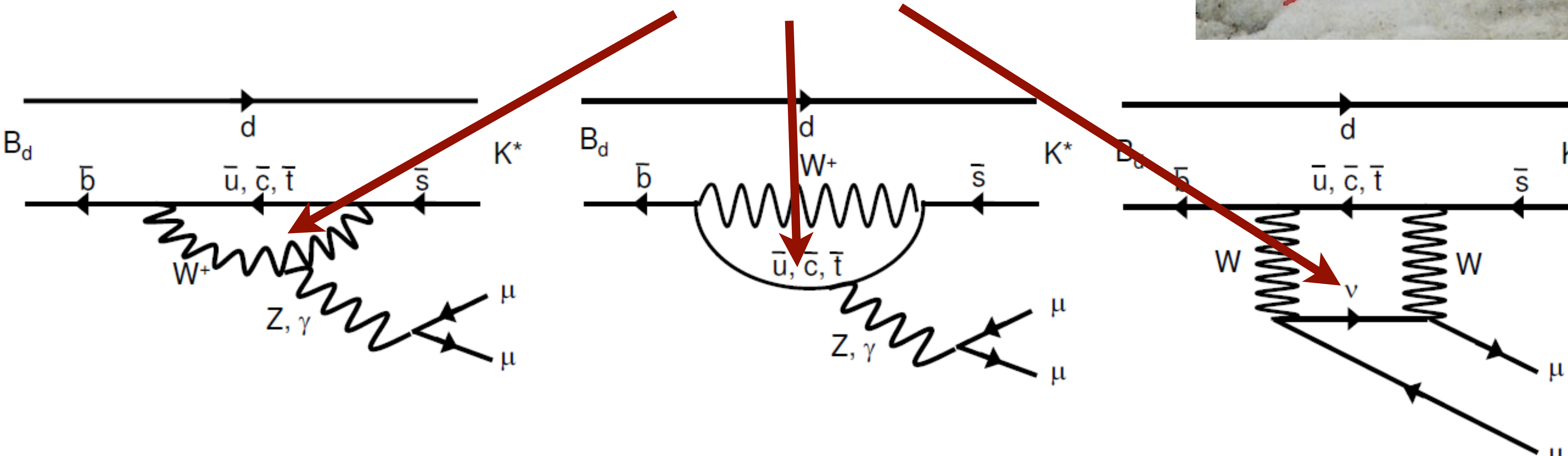
$B_d \to K^{*}\mu^{+}\mu^{-}$

A fairly rare "penguin" FCNC decay. BSM could enter into these loops and alter the Lorentz structure of the amplitudes.

Many angular observables are sensitive to BSM physics. LHCb has more stats in 2011 data than all previous experiments combined.

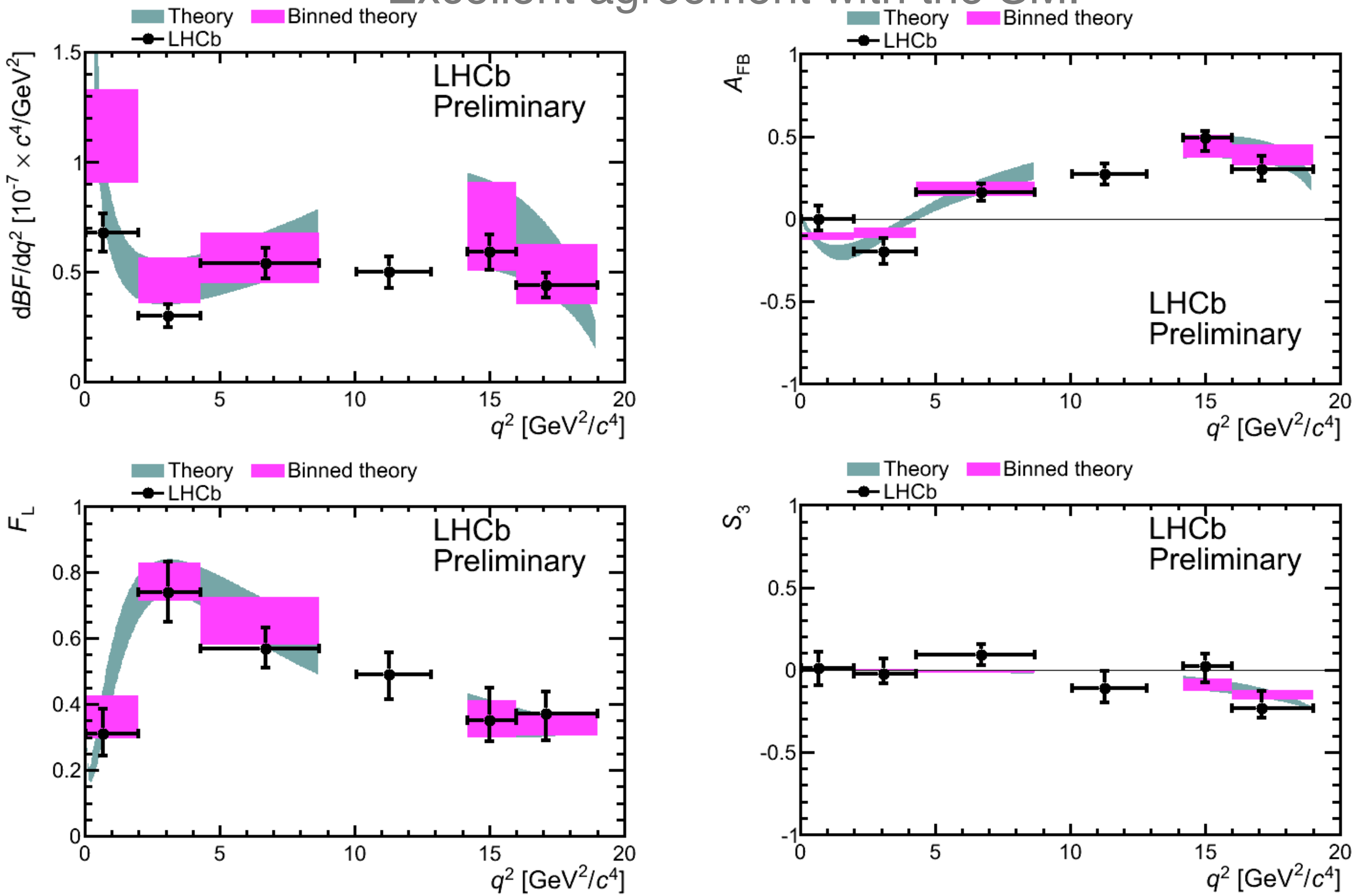


BSM?



$B_d \to K^*\mu^+\mu^-$

Excellent agreement with the SM.



Requires NP > ~50 TeV in $(sb)_{V-A}(\mu\mu)$ for unit couplings!

$B_d \rightarrow K^{*}\mu^{+}\mu^{-}$

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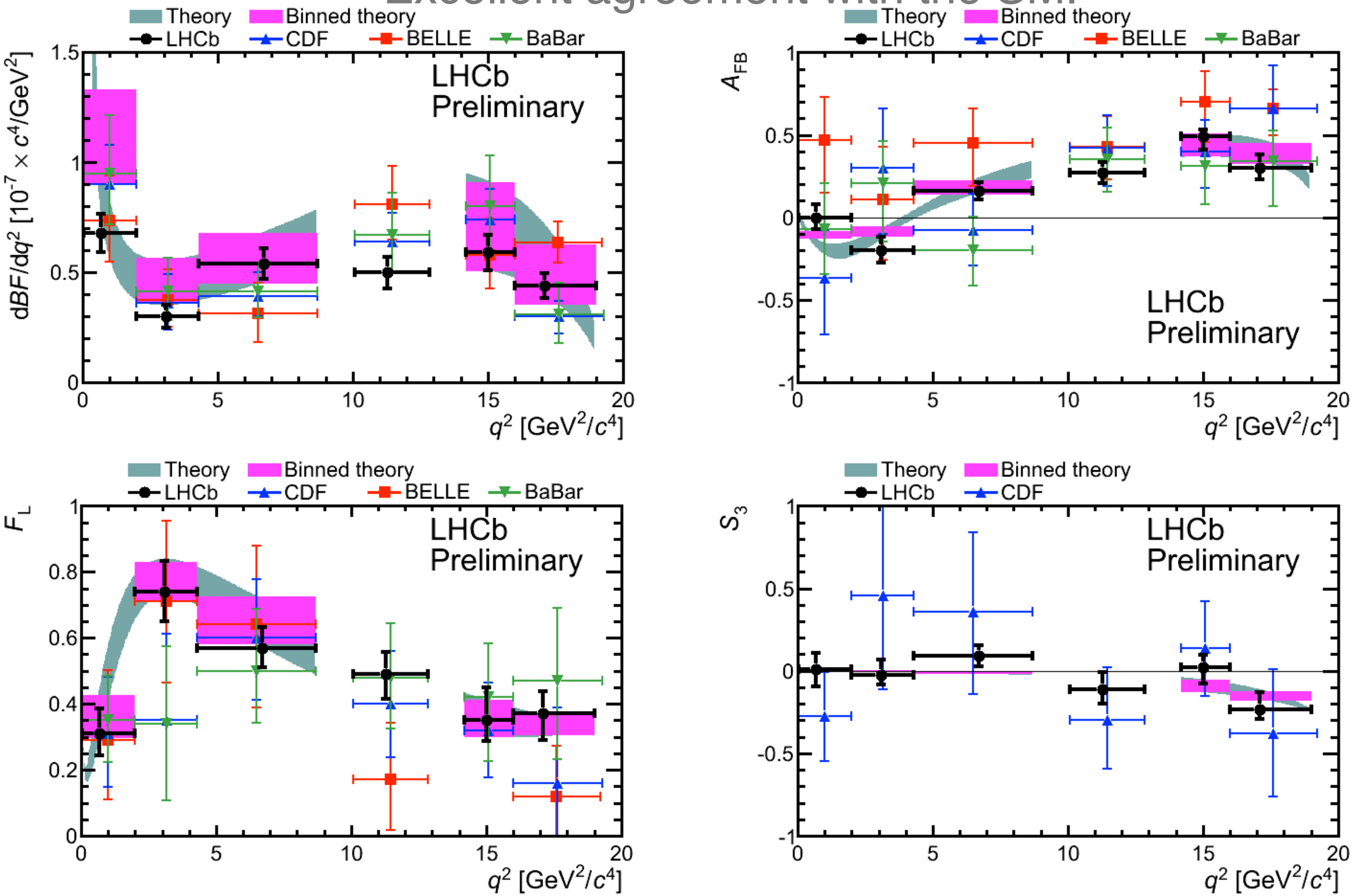

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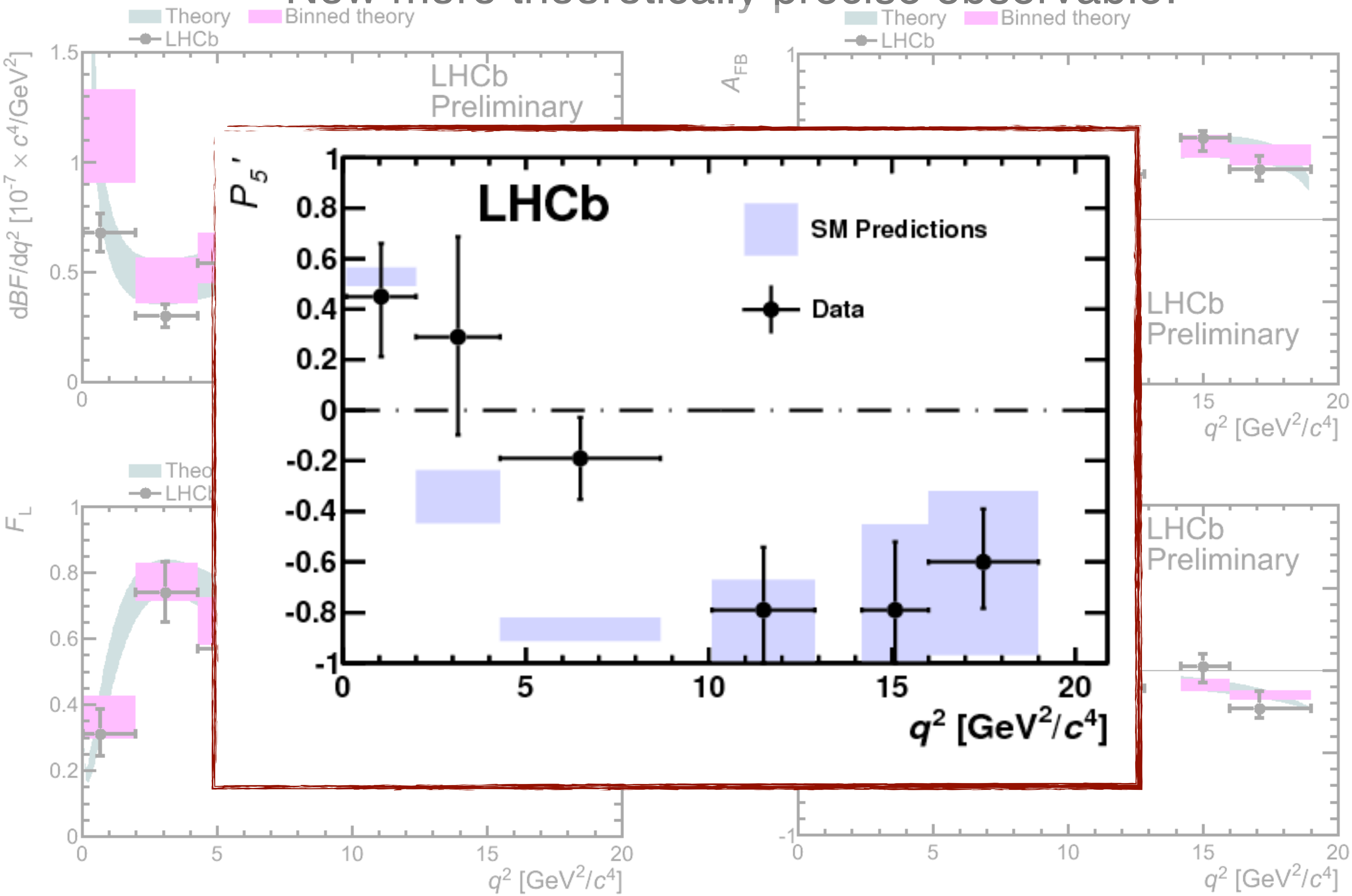
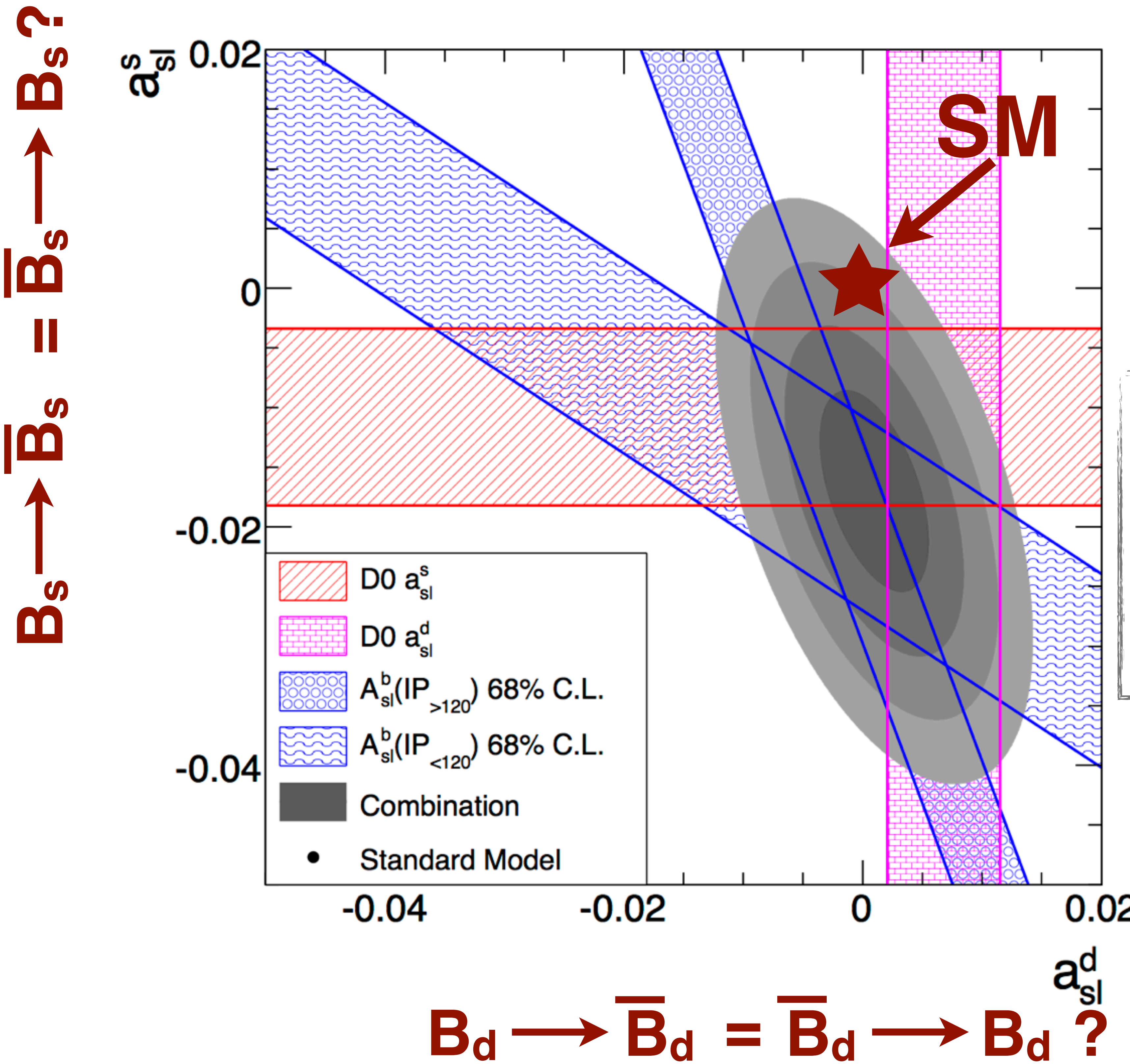
$B_d \to K^{*}\mu^{+}\mu^{-}$

New more theoretically precise observable:



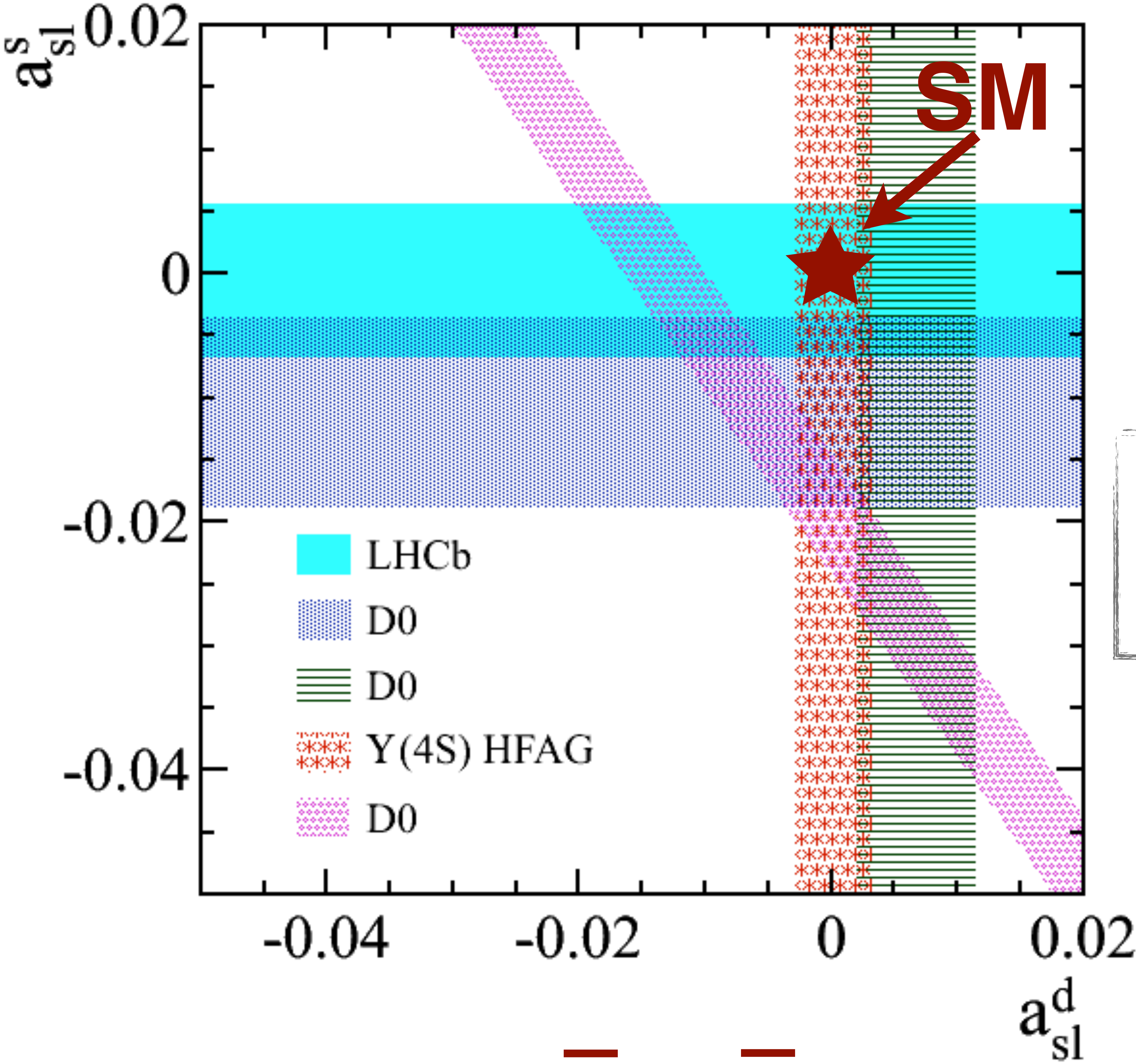
New physics? How much do you trust (these) theorists?

CPV in $B_{d,s}$



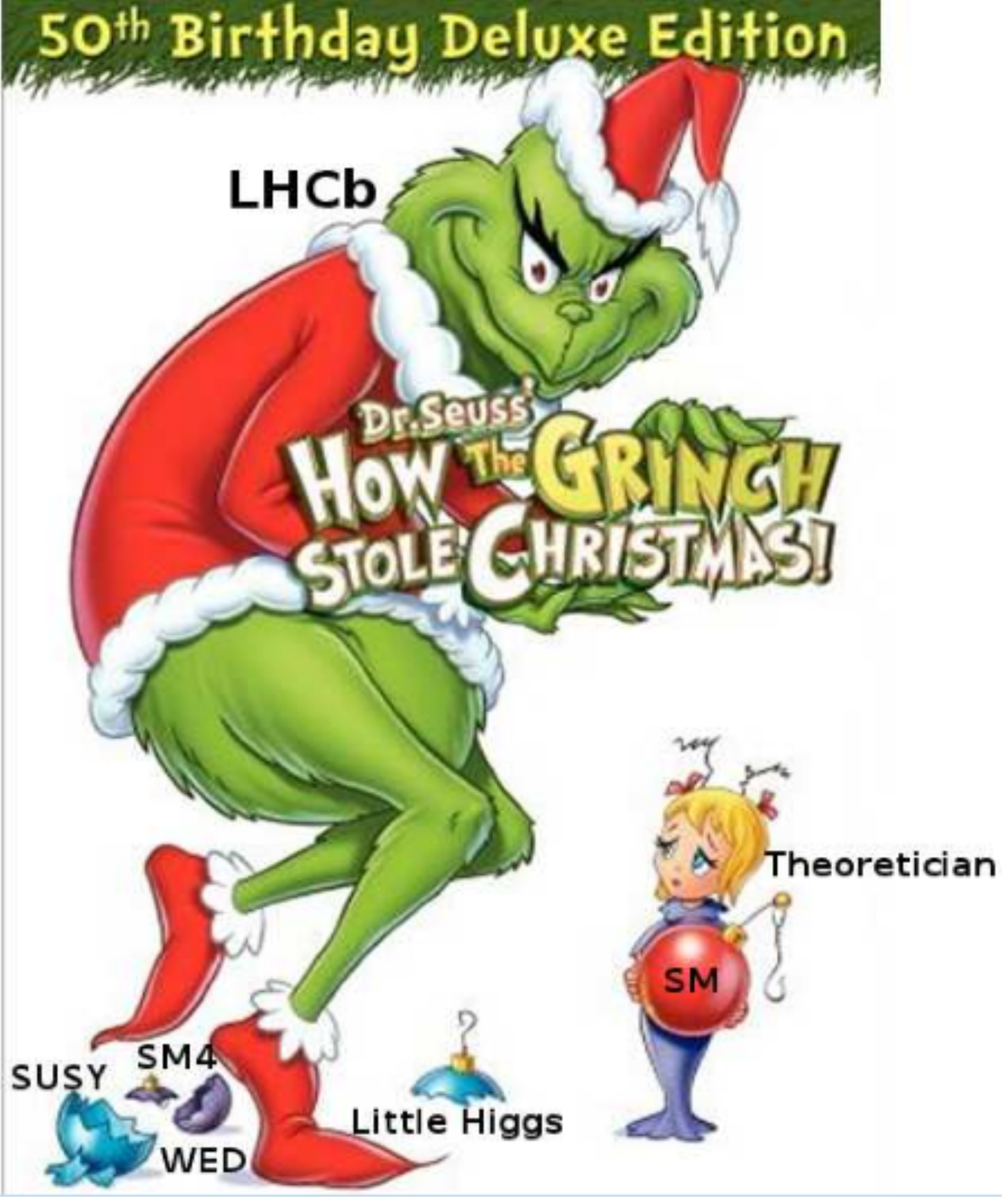
D0 sees 3σ deviation in like-sign di-muon charge asymmetry

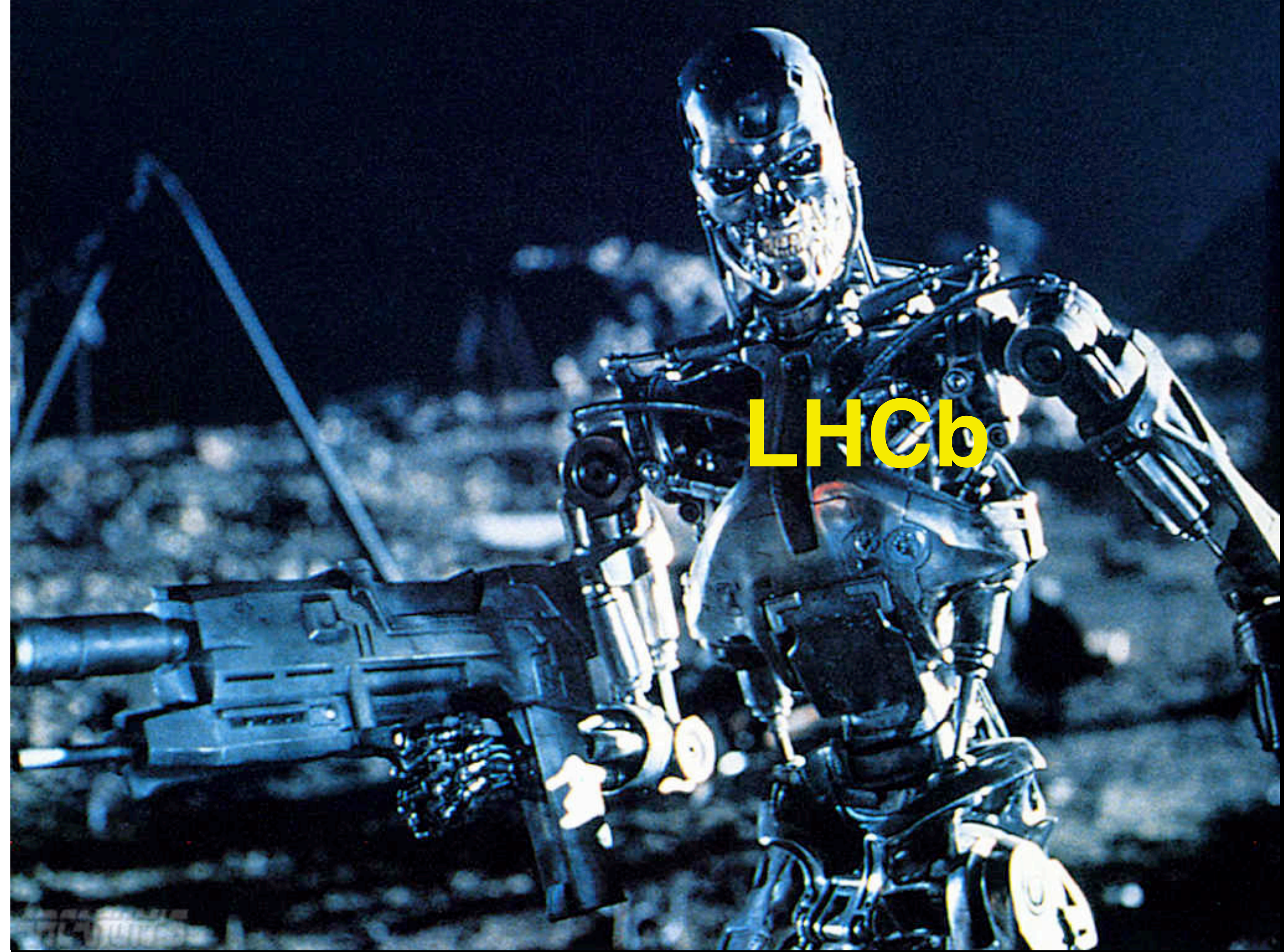
$B_s \longrightarrow \overline{B}_s = \overline{B}_s \longrightarrow B_s$?



$B_d \longrightarrow \overline{B}_d = \overline{B}_d \longrightarrow B_d$?

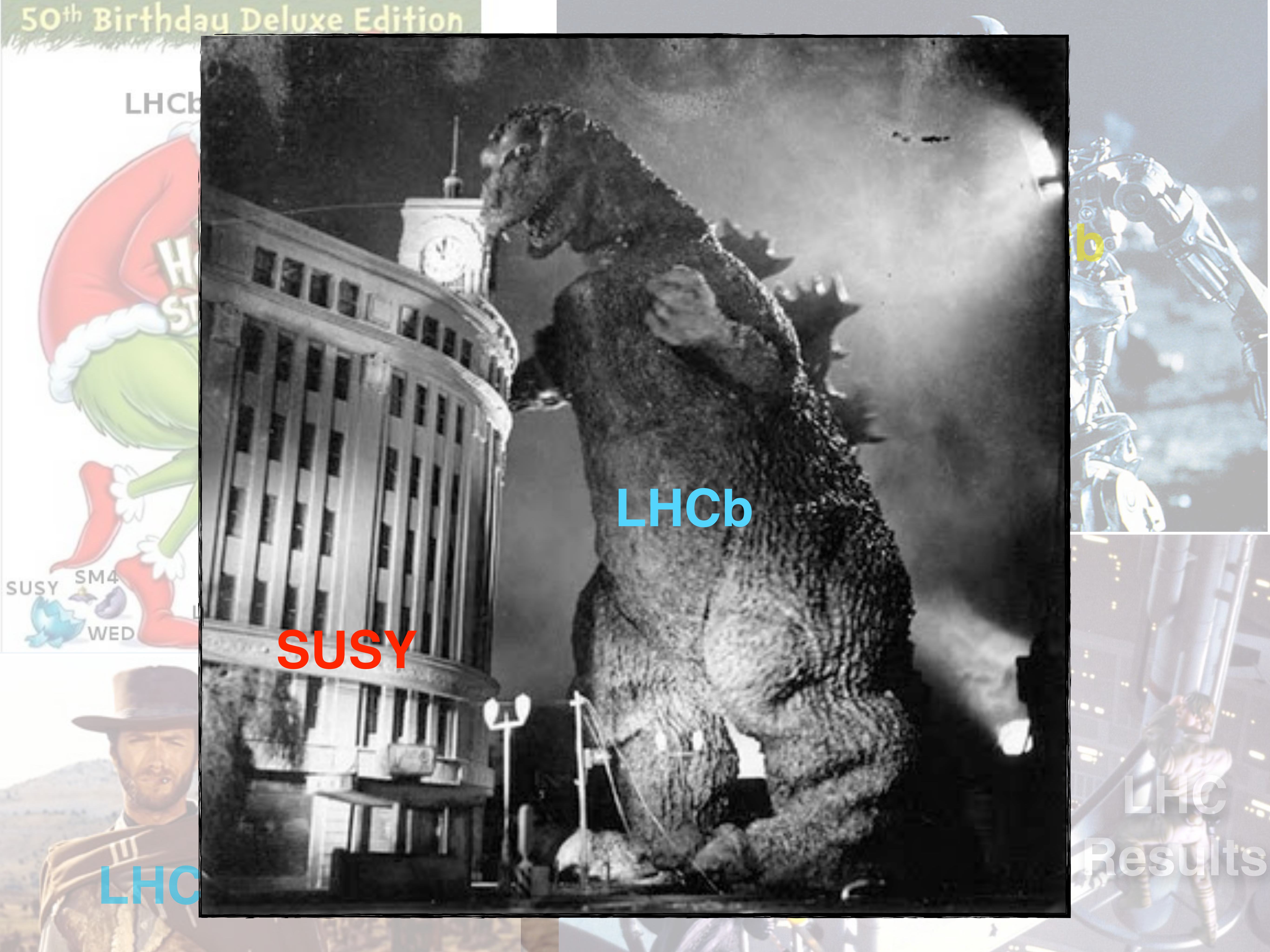
LHCb, Belle & BaBar agree with the SM.


50th Birthday Deluxe Edition
LHCb
Dr. Seuss' How The Grinch Stole Christmas!
Theoretician
SM
SUSY
SM4
WED
Little Higgs


LHCb


LHCb


SM
LHC
Results


50th Birthday Deluxe Edition
SUSY
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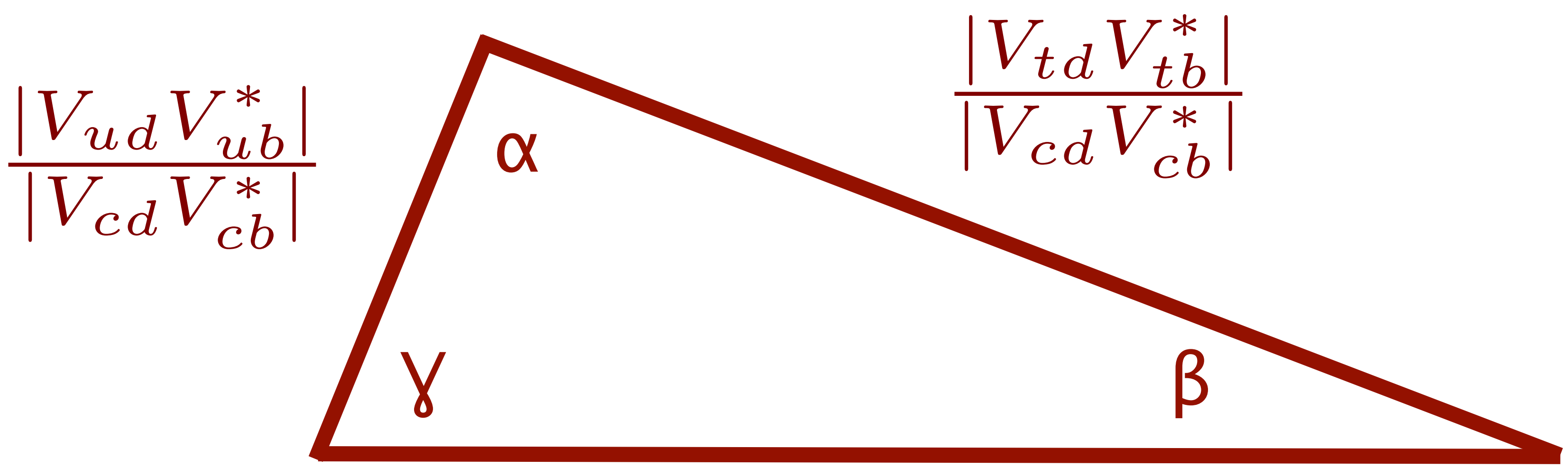
LHC Results
LHCb
SUSY

CKM

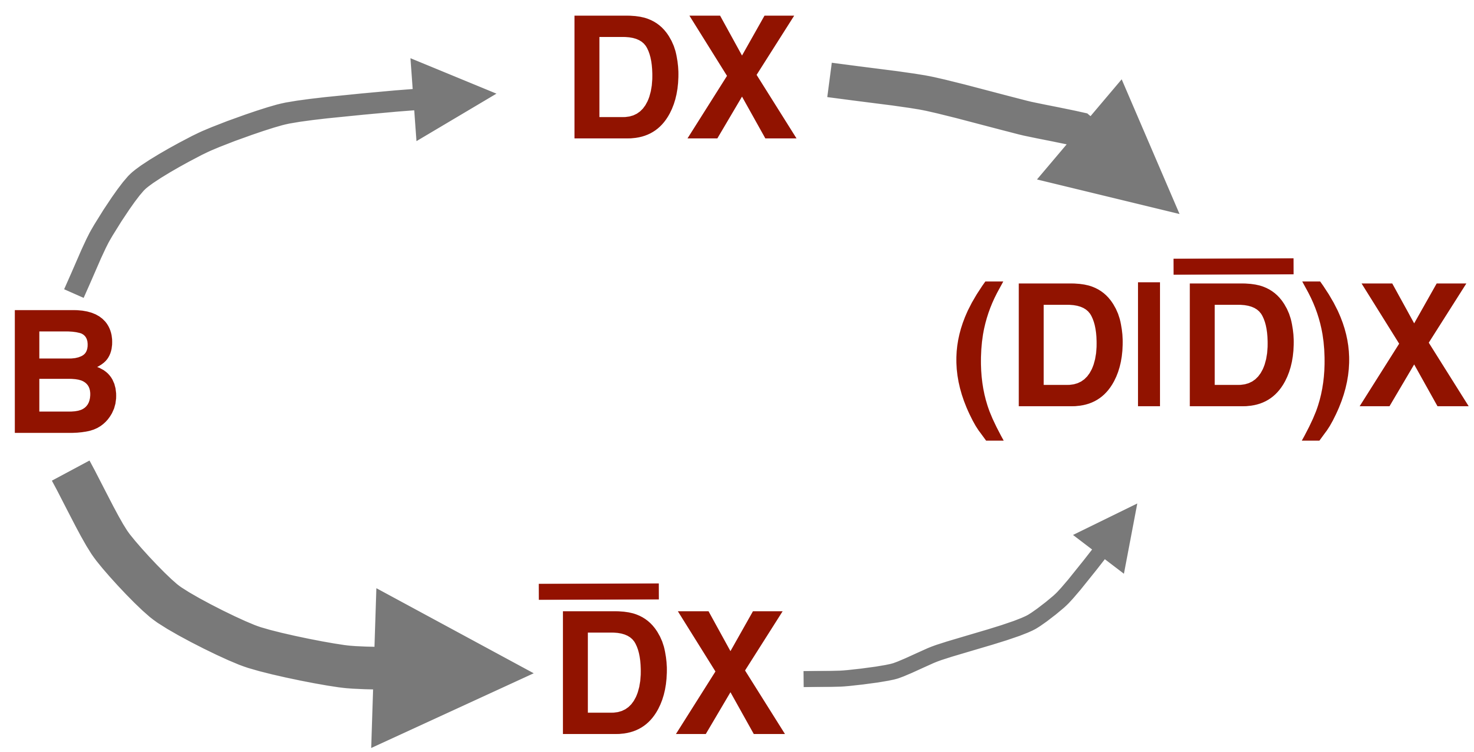
The CKM matrix describes the mixing between mass and weak quark eigenstates. In the SM, it is unitary providing 9 constraint equations that relate its elements to one another.



The most "popular" UT

Six of these constraint equations form "unitary triangles" (each of equal area, but different shapes). By measuring all "sides" and "angles", the unitary hypothesis and, thus, the SM can be tested (want to over-constrain!).

Use interference b/t $\mathcal{A}_{b\to u}^{\bar{b}\to\bar{u}} = \mathcal{A}_{bu} e^{\pm i\gamma}$ and $\mathcal{A}_{b\to c}^{\bar{b}\to\bar{c}} = \mathcal{A}_{bc}$ to extract γ.

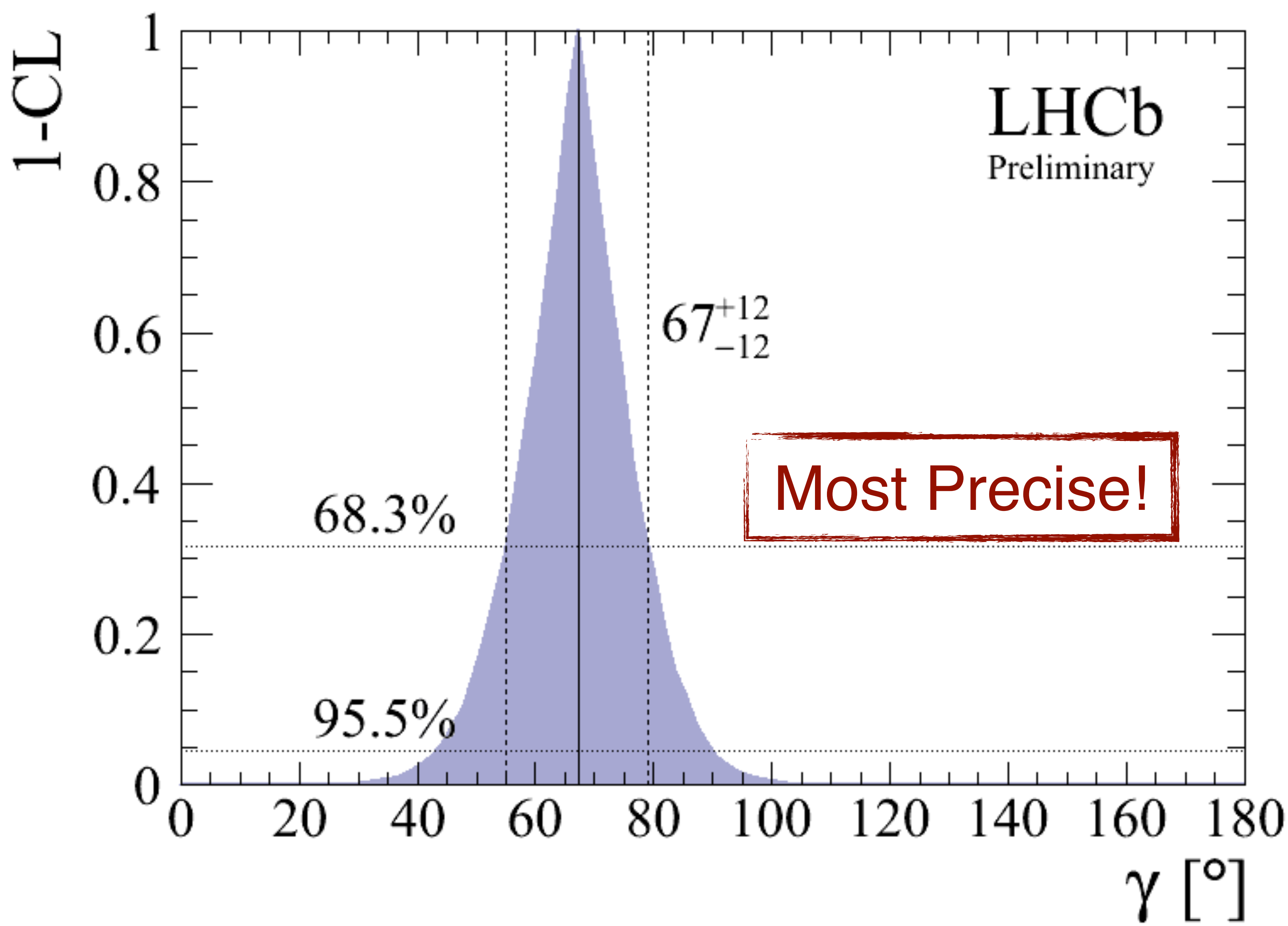


$$\mathcal{N}_{\pm} = |\mathcal{A}_{B\to DX} + \mathcal{A}_{B\to\bar{D}X}|^2$$
$$= |\mathcal{A}_D|^2 + |\mathcal{A}_{\bar{D}}|^2 + 2|\mathcal{A}_D||\mathcal{A}_{\bar{D}}|\cos(\Delta\theta_{\rm strong} \pm \gamma)$$

These are tree-level decays; no pollution from penguins, etc. This is SM ɣ. Can look for BSM by comparing to ɣ from loops.

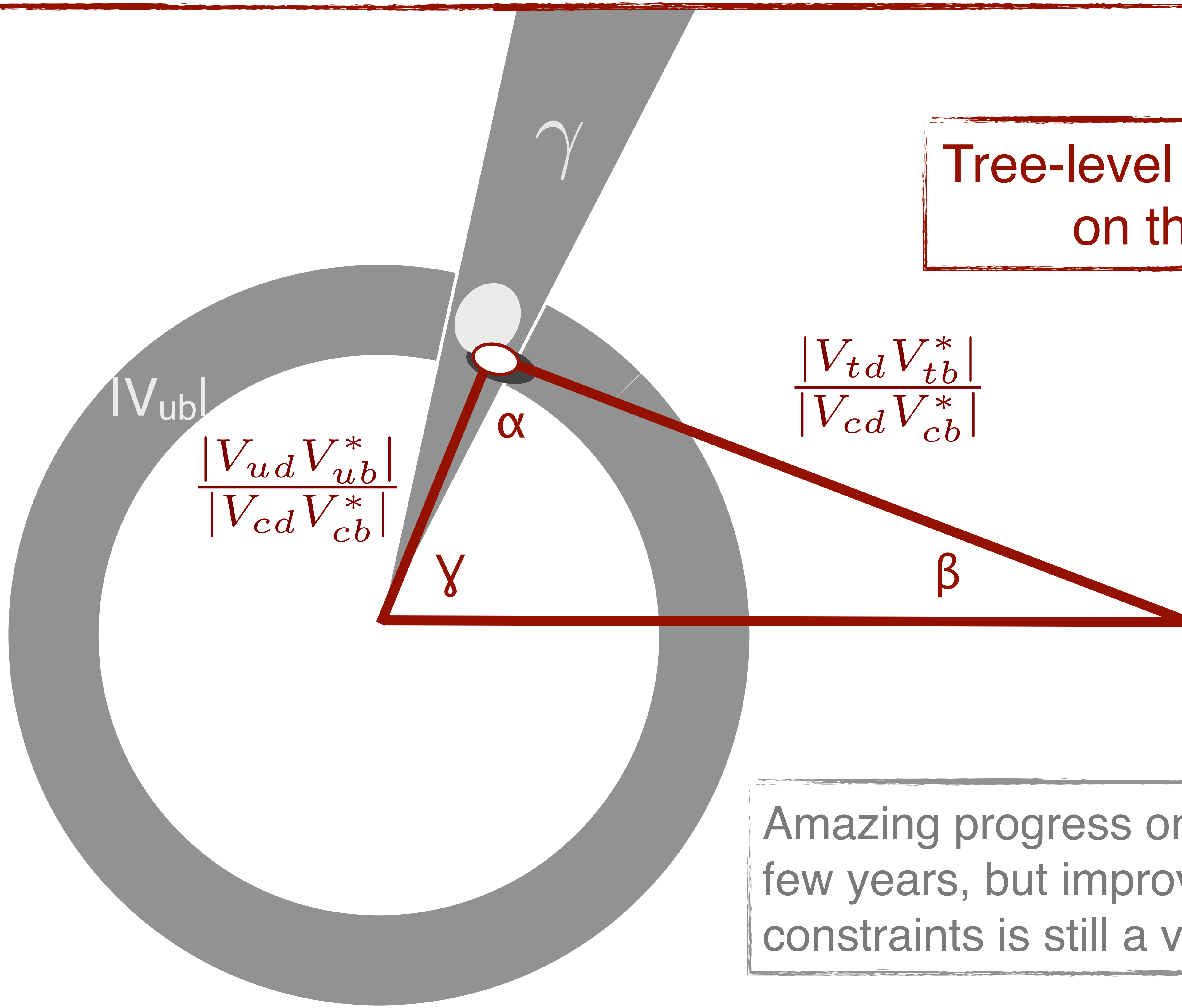
CKM γ

LHCb result combining many B→DK modes (only D→$K_S$hh uses 3/fb).



Belle and BaBar now have 14° and 16° uncertainties on γ.

CKM γ

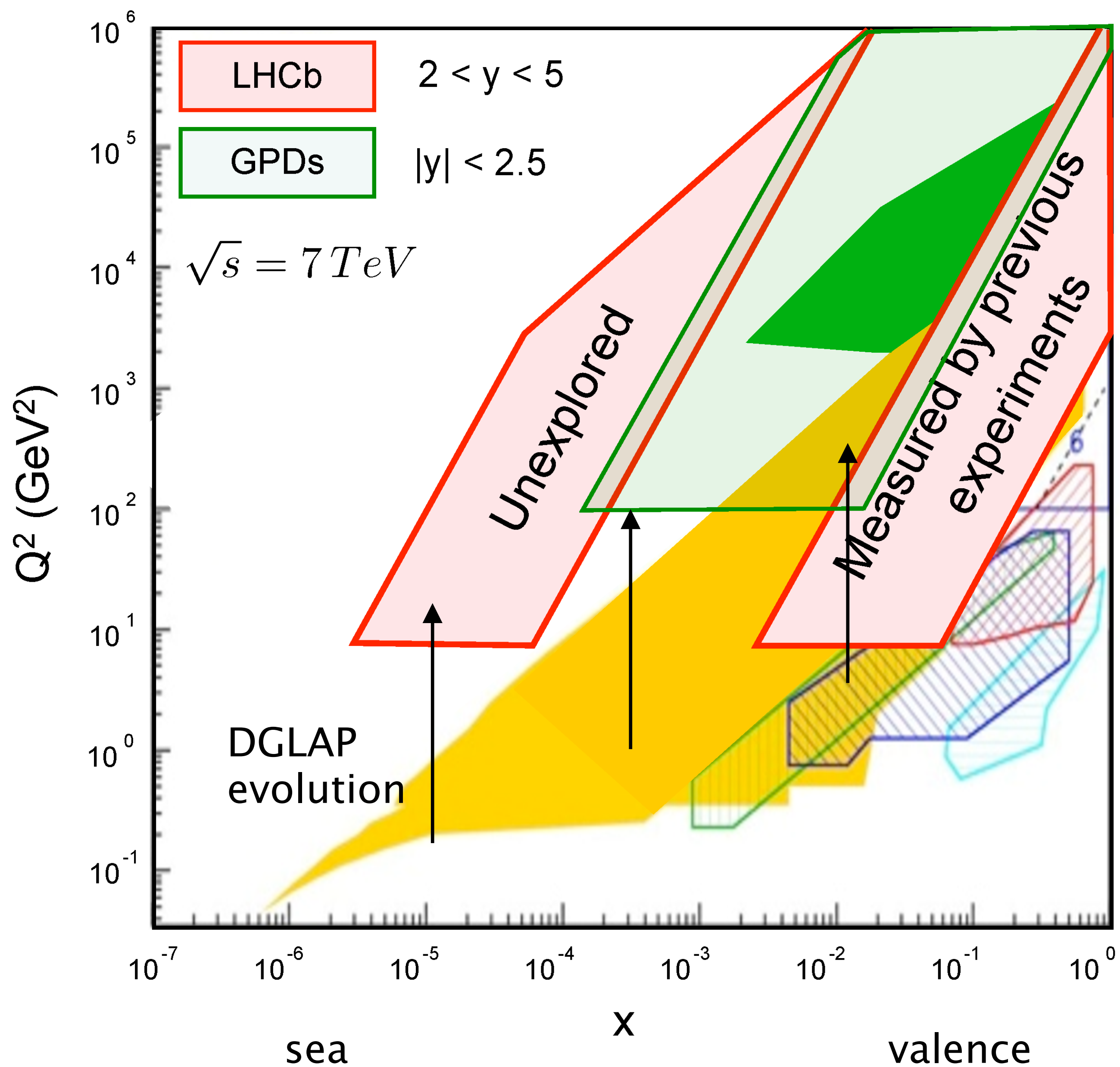


Tree-level constraints on the UT.

Amazing progress on γ in the past few years, but improving tree-level constraints is still a very high priority.

PDFs @ LHCb

LHCb collisions are one high-x and one low-x parton.

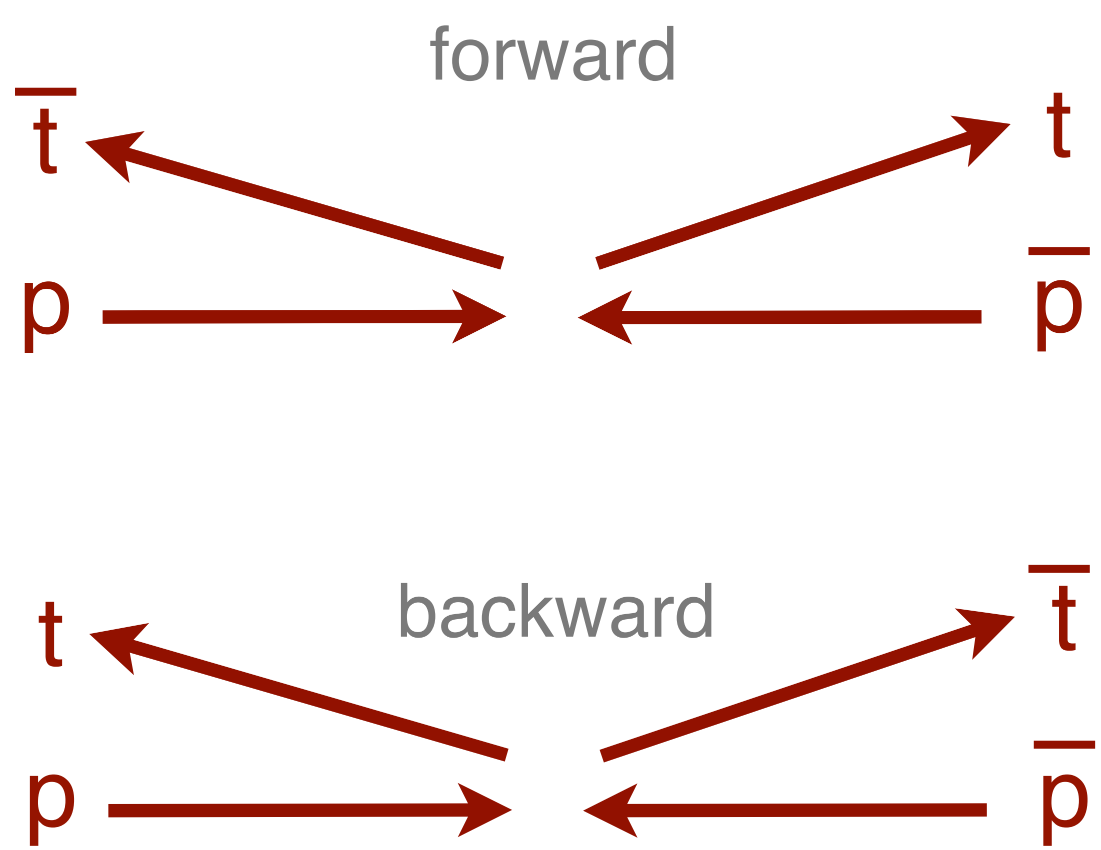


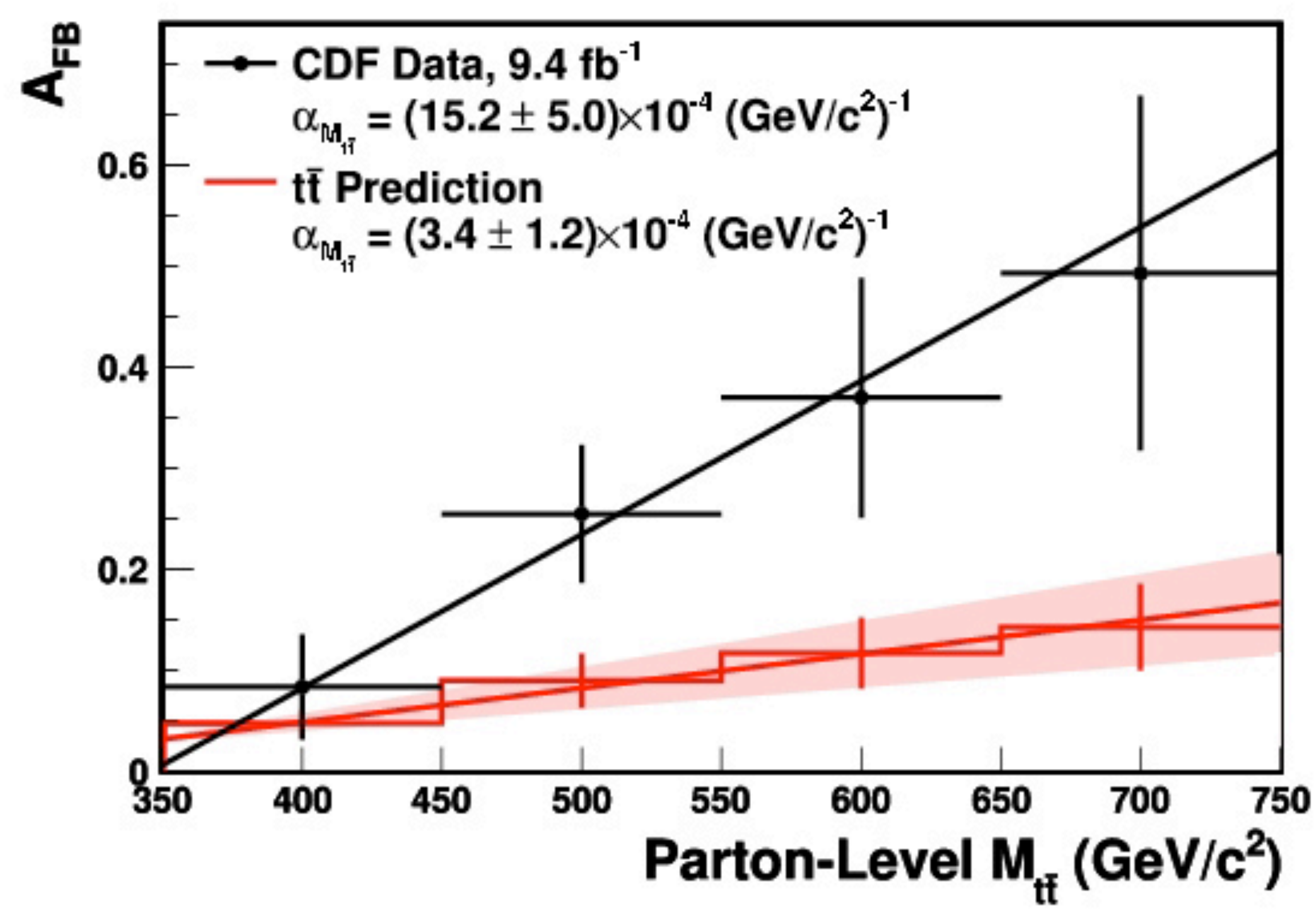
Small overlap with ATLAS/CMS for 2 < y < 2.5.

Top Asymmetry

CDF & D0 see an anomalous asymmetry in top quark production.

[one of the only surviving anomalies]





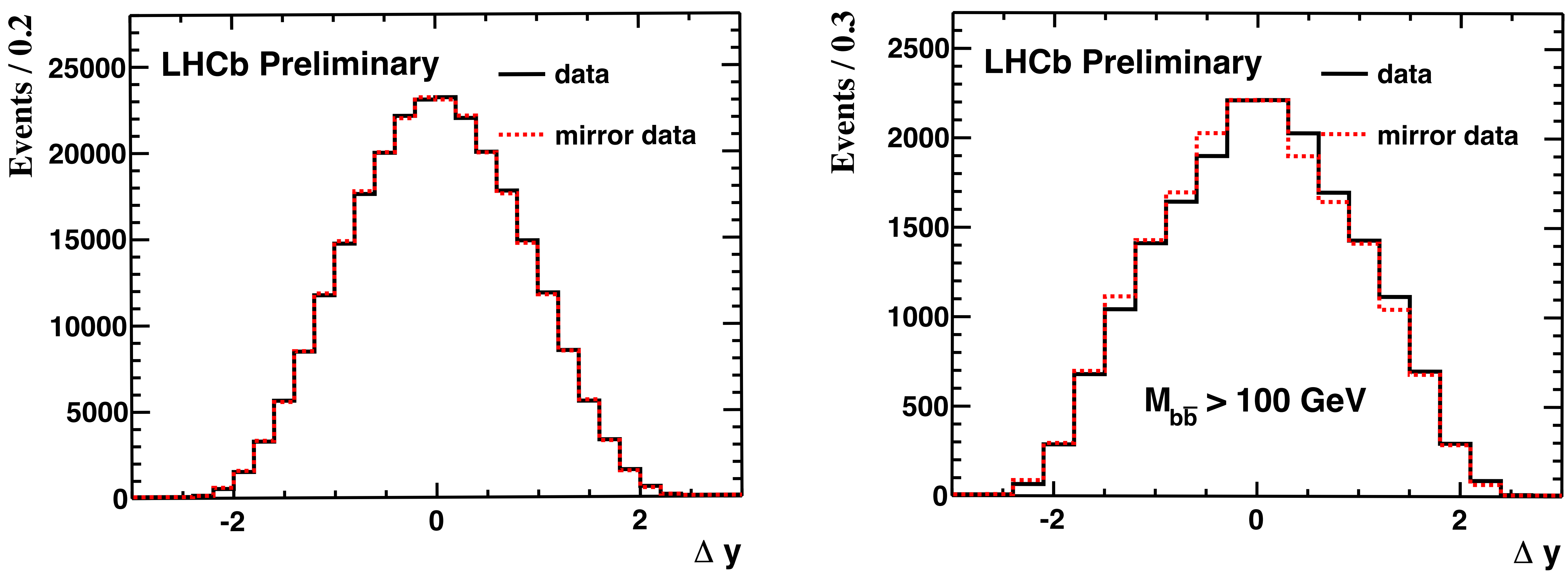
CMS & ATLAS don't see any evidence for a forward-central top asymmetry.

Beauty Asymmetry

"The beauty AFC could be used to search for similar effects as seen in AFB in truth." Kahawala, Krohn, Strassler, JHEP, 69 (2012).

"Raw" Delta y

all | Mbb > 100 GeV



(0.5±0.5±0.5)% | (4.3±1.7±2.4)%

Improved analysis of 2011 data (including unfolding) out by the end of this year. Analysis using 2012 data expected early 2014.

Top Asymmetry

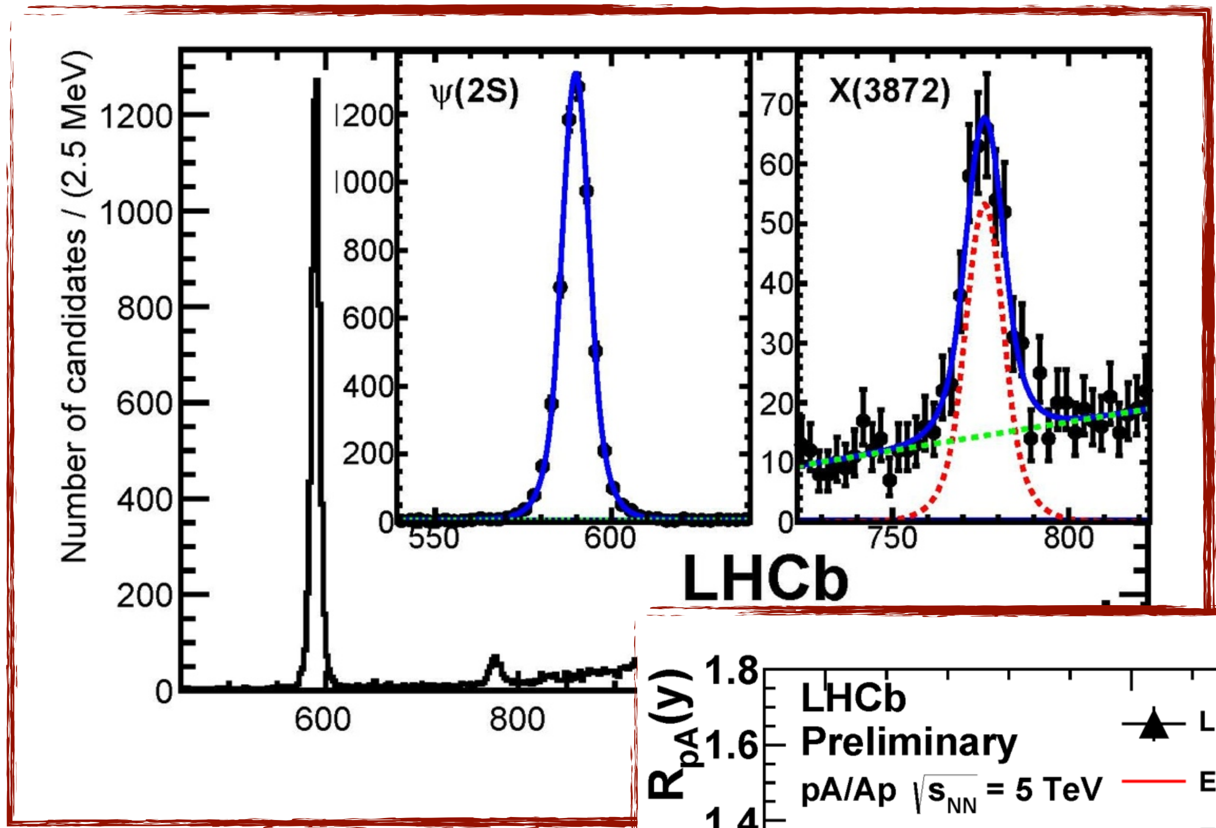
"LHCb may be able to measure a tt production rate asymmetry, and thus indirectly probe an anomalous forward backward tt asymmetry in the forward region" Kagan, Kamenik, Perez, Stone, PRL 107, 082003 (2011).

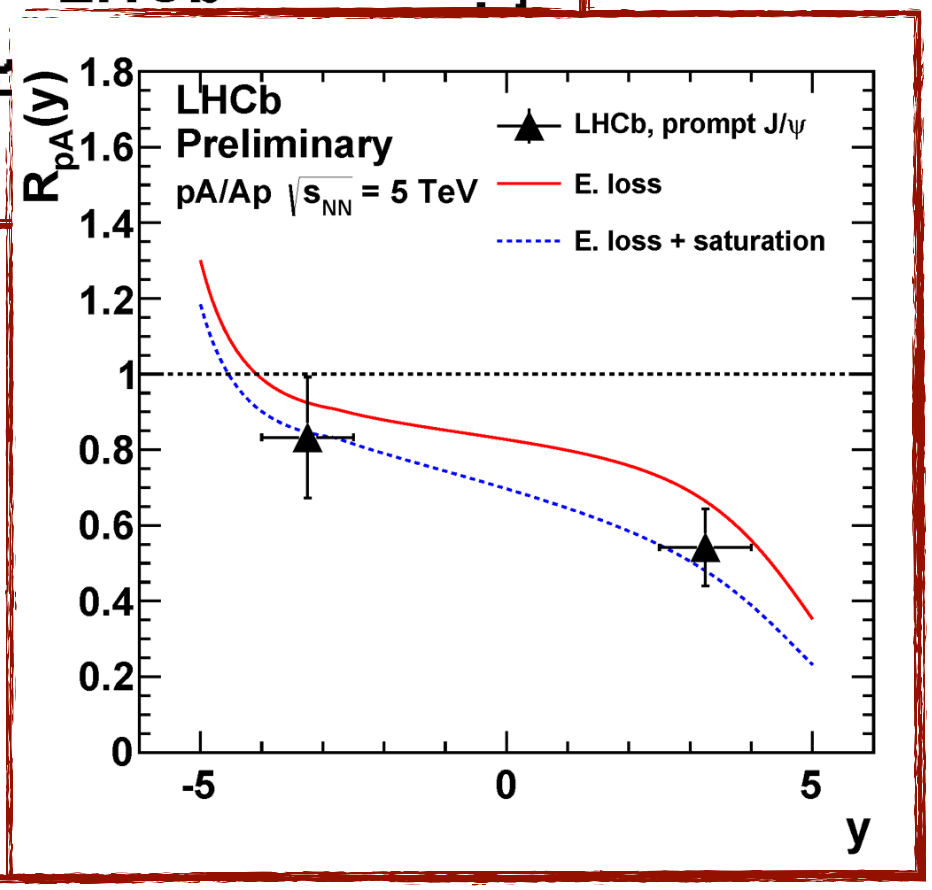
- The large y region is more sensitive to the charge asymmetry.
- Measuring the top rate asymmetry @ LHCb can indirectly probe top AFB physics.
- LHCb b jet performance is good (and improving); our beauty AFC analysis is a prototype for the top measurements (and interesting in its own right).
- Work now is focused on top RECO & cross sections. Moving towards a "real" measurement using post-LS1 data.

Etc

LHCb has a very broad physics program that also includes the following:

- exotic spectroscopy;
- p-Pb and Pb-p collisions;
- searches for LFV;
- searches for sterile neutrinos;
- etc.!

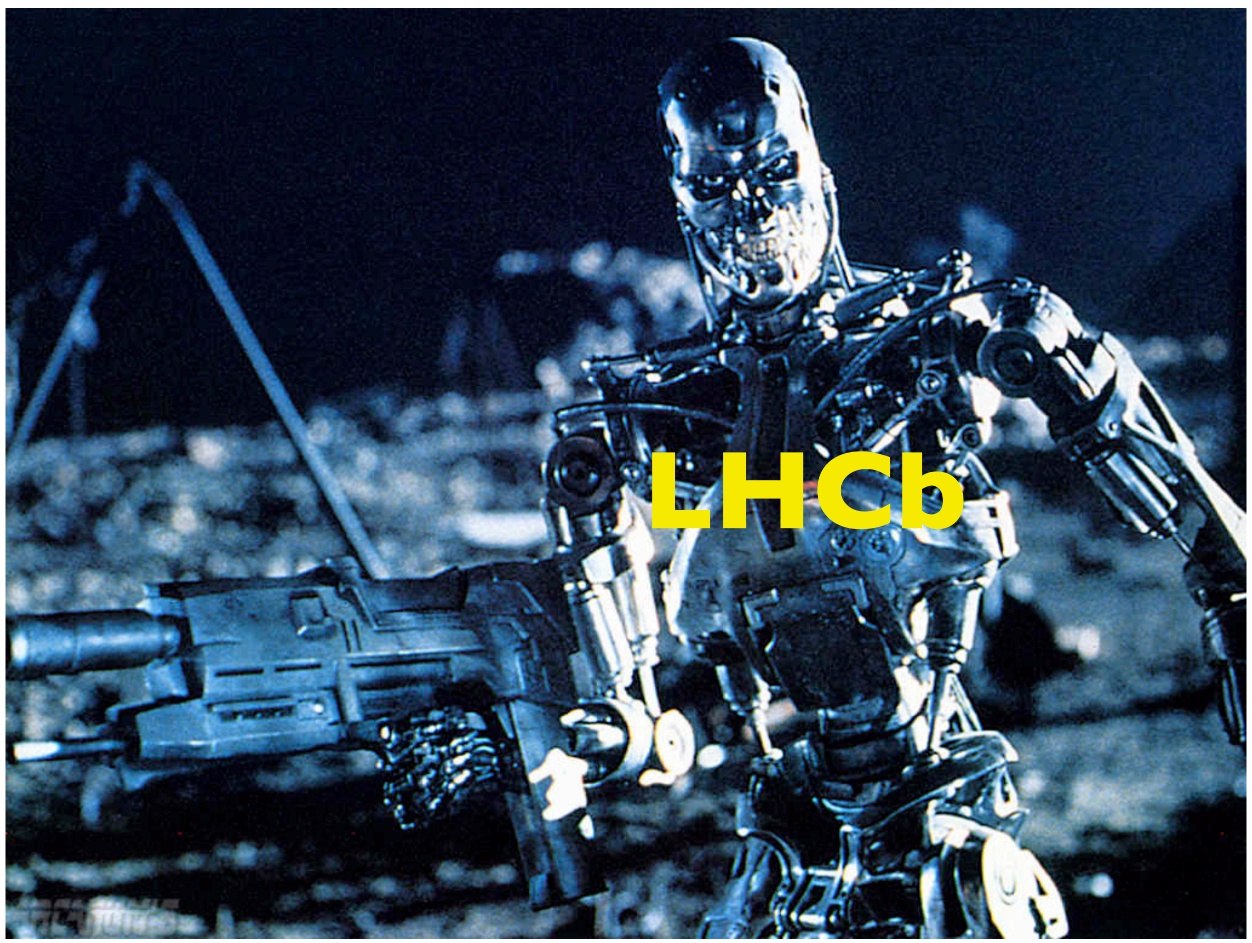




We have more physics potential than humanpower. Would you like to join?

Summary

LHCb has performed excellently and produced very nice results using 1/fb of 2011 data. Unfortunately so far we're the anomaly terminator.



We have 3x the statistics "in hand" with new results expected soon. Hopefully this time we're the good terminator from the sequel!

The optimist regards the future as uncertain.

Eugene Wigner