Quark Flavor Physics @ LHCb

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on behalf of the LHCb Collaboration

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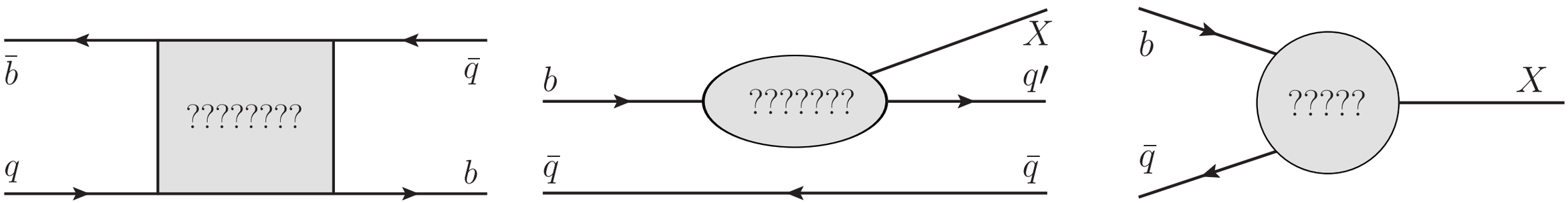
LHCb Overview

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.

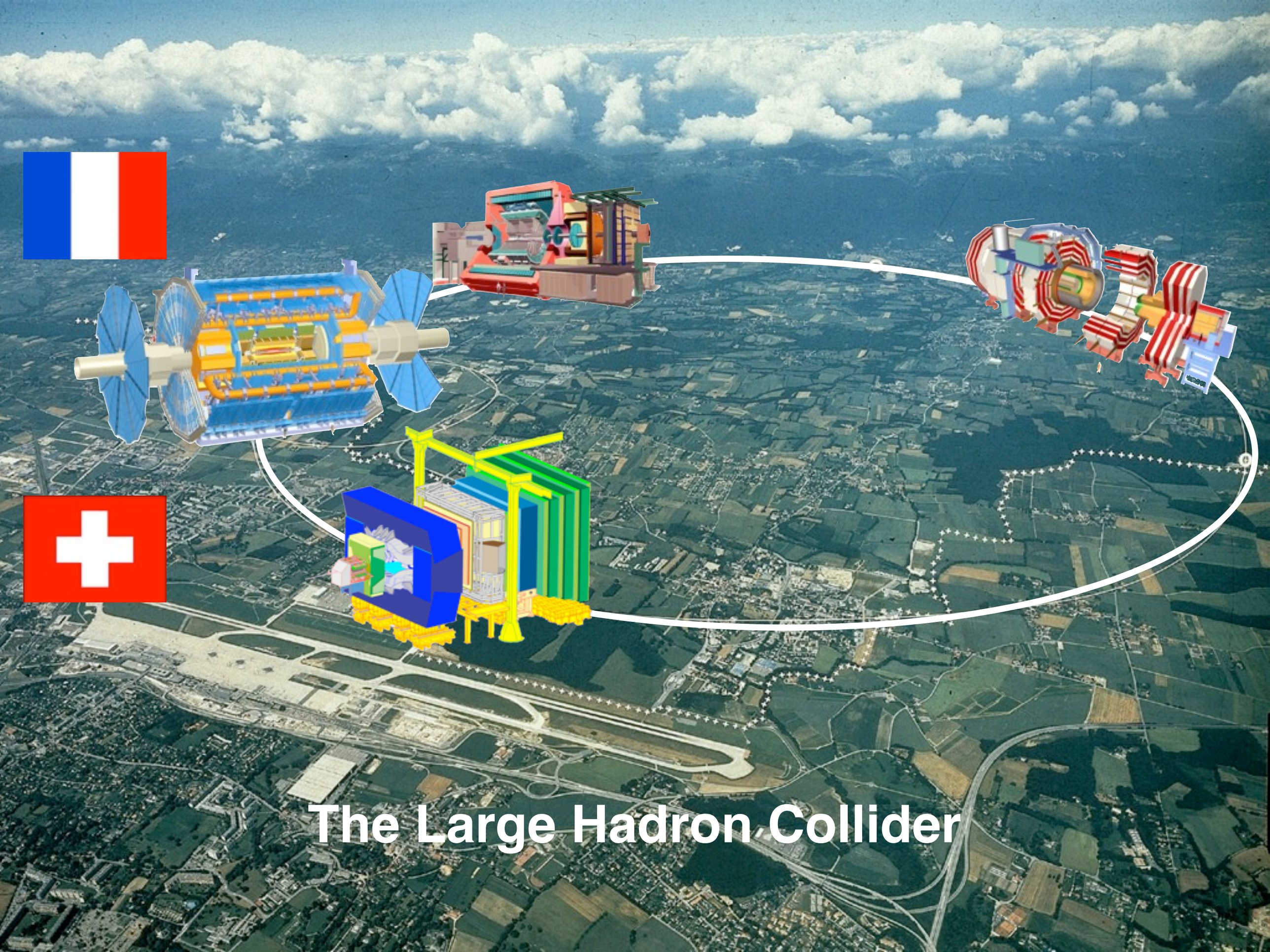
There are no tree-level FCNCs in the SM; FCNCs require loops.



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 170 papers!


The Large Hadron Collider

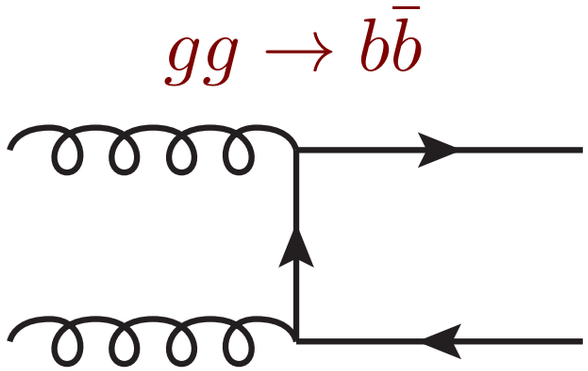
Flavor Physics @ the LHC

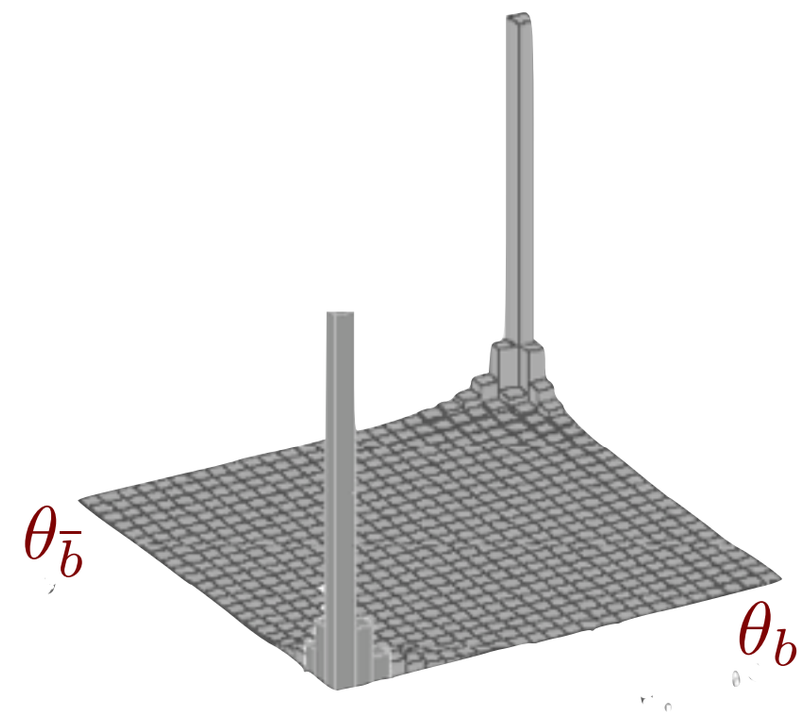
Advantages of B physics @ the LHC:

- 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!

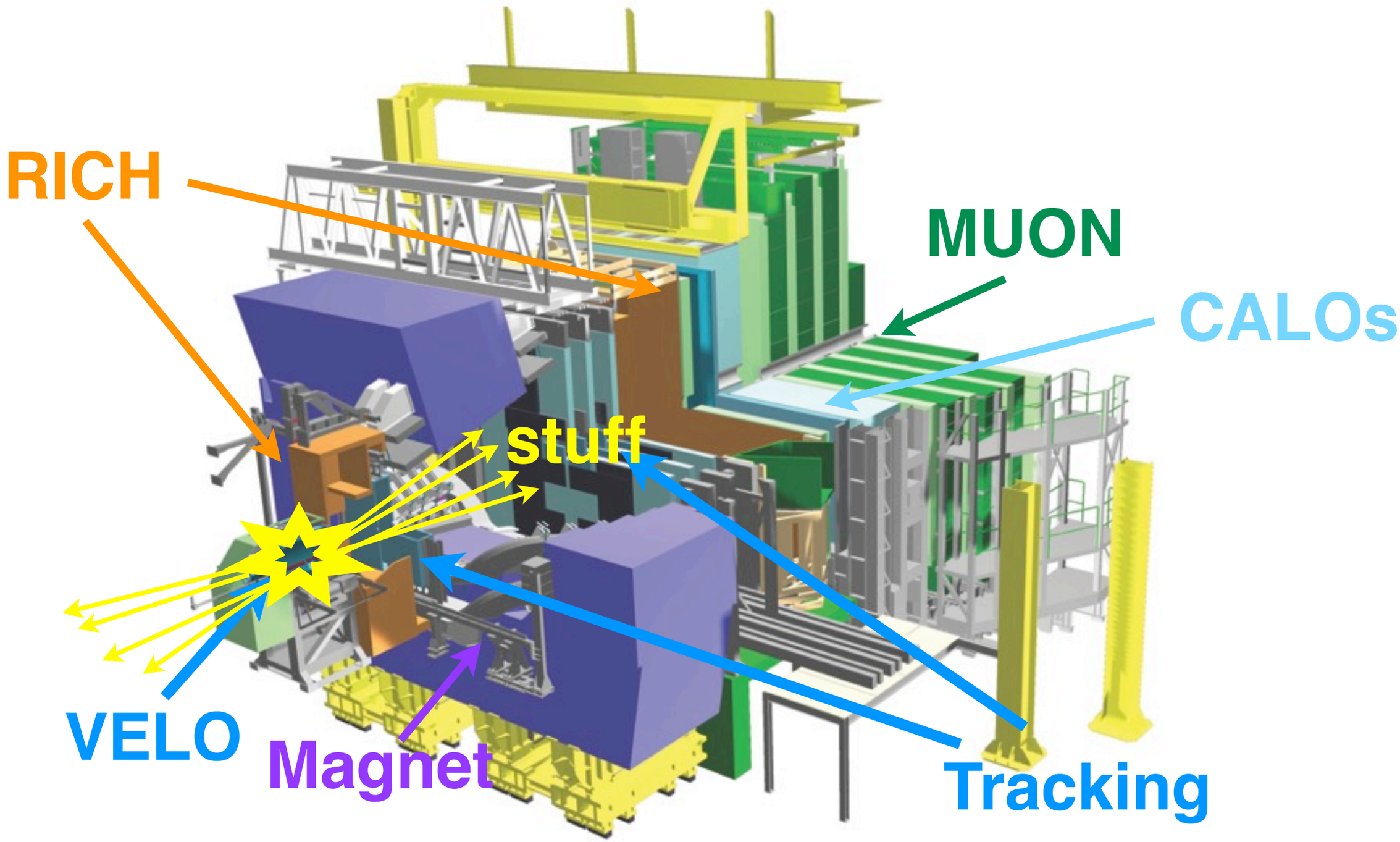




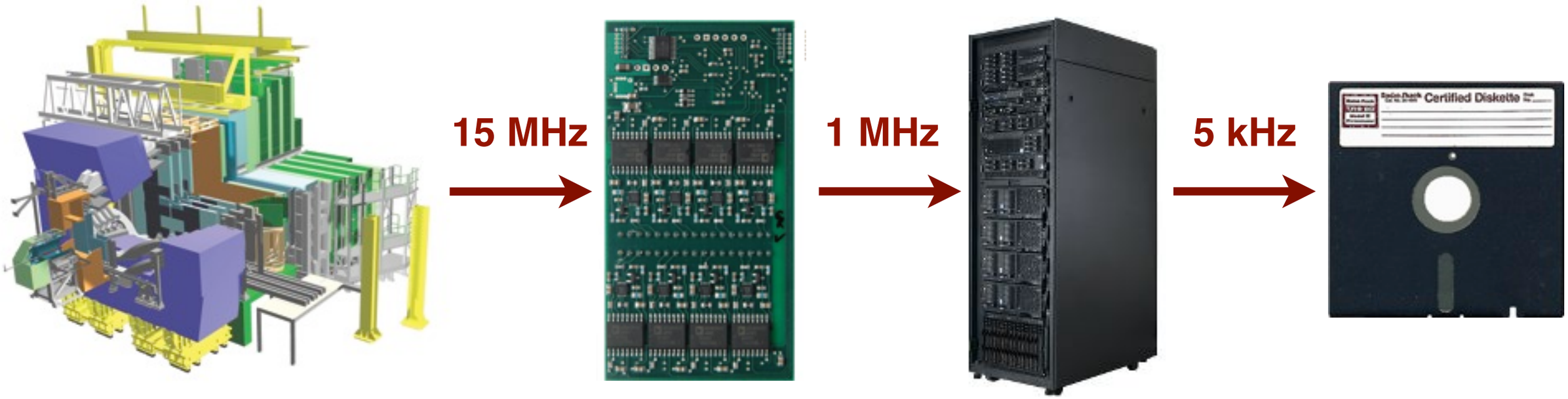
One trillion bb pairs produced @ LHCb so far!

LHCb Detector

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



LHCb Trigger



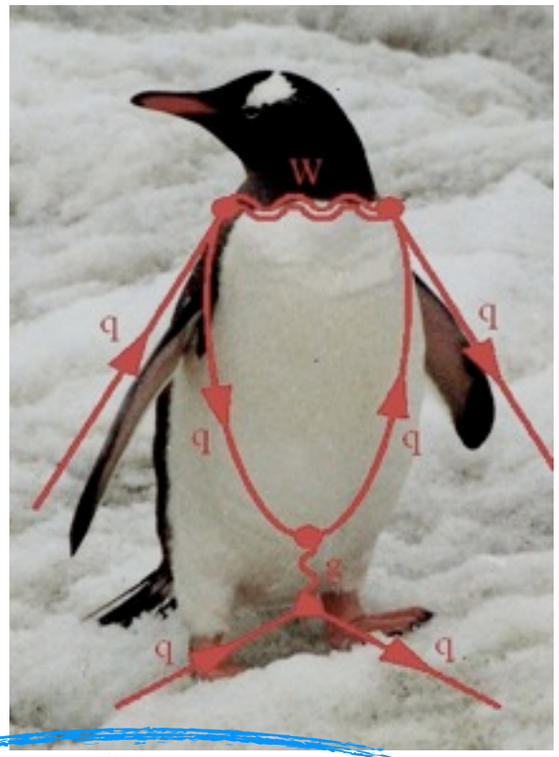
We can “only” read out the detector at 1 MHz; thus, a hardware trigger is required. The basic trigger strategy is

- 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]

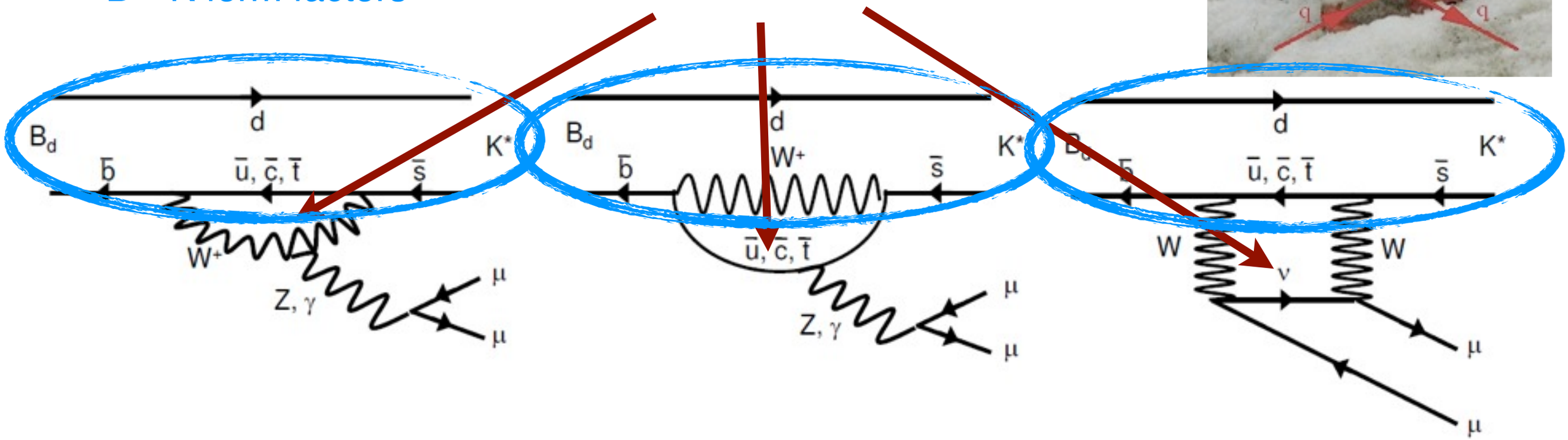
b → s Penguins

The b → s "penguin" (FCNC) decays are an excellent laboratory for looking for BSM physics. The loop suppression in the SM makes it possible for BSM contributions to have sizable effects.



SM calculations need B→K form factors

BSM can alter Lorentz Structure

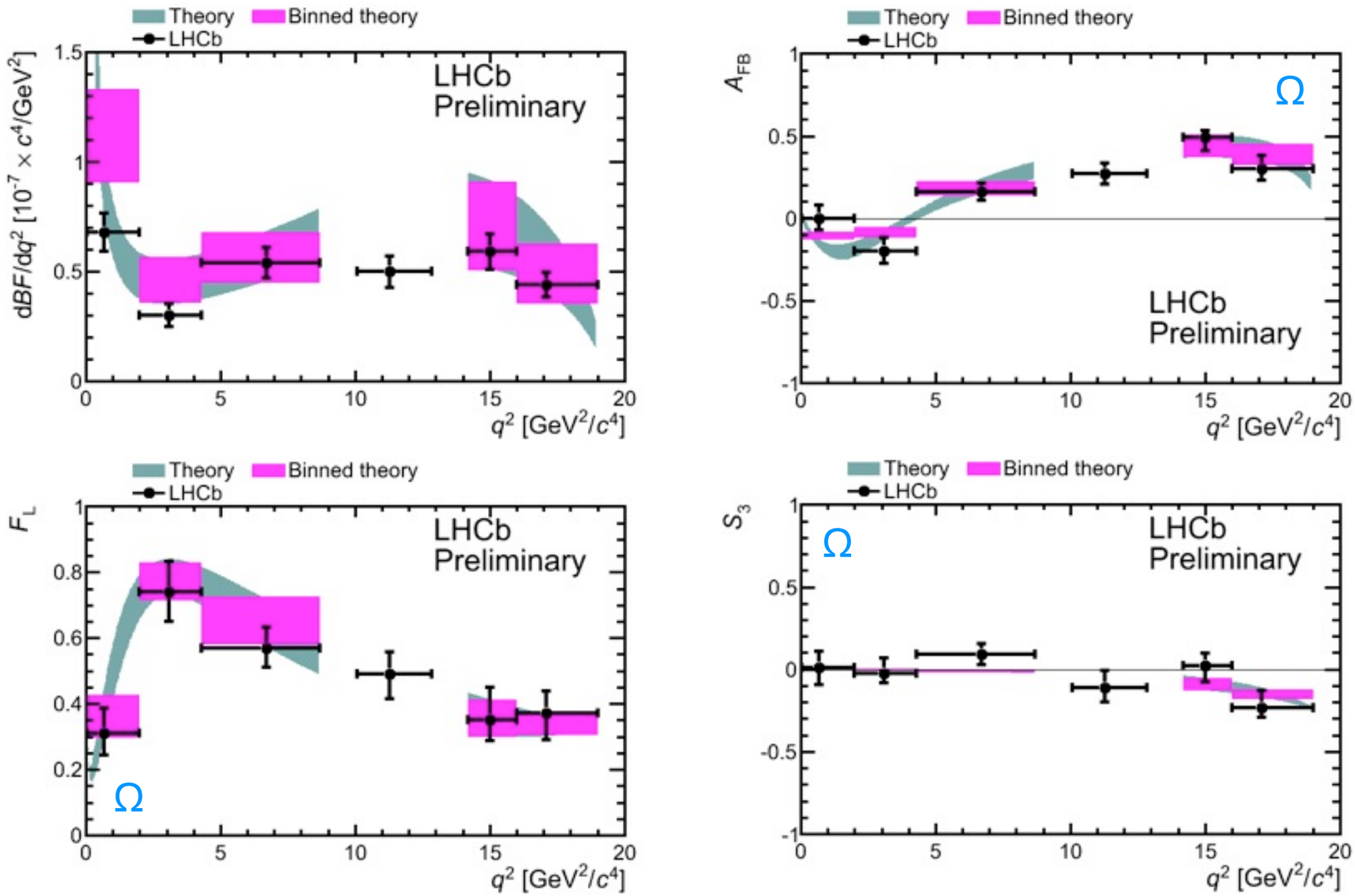


The B(s) → K(ϕ)μμ family of decays are all accessible at LHCb and provide many sensitive observables (accessible via angular analysis) to measure.

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

2011 Data Only! 3x stats in hand.

Ω=angular observable



LHCb-PAPER-2013-019 [1304.6325]

Requires NP > ~15-50 TeV in $(sb)_{V-A}(\mu\mu)$ for unit couplings!

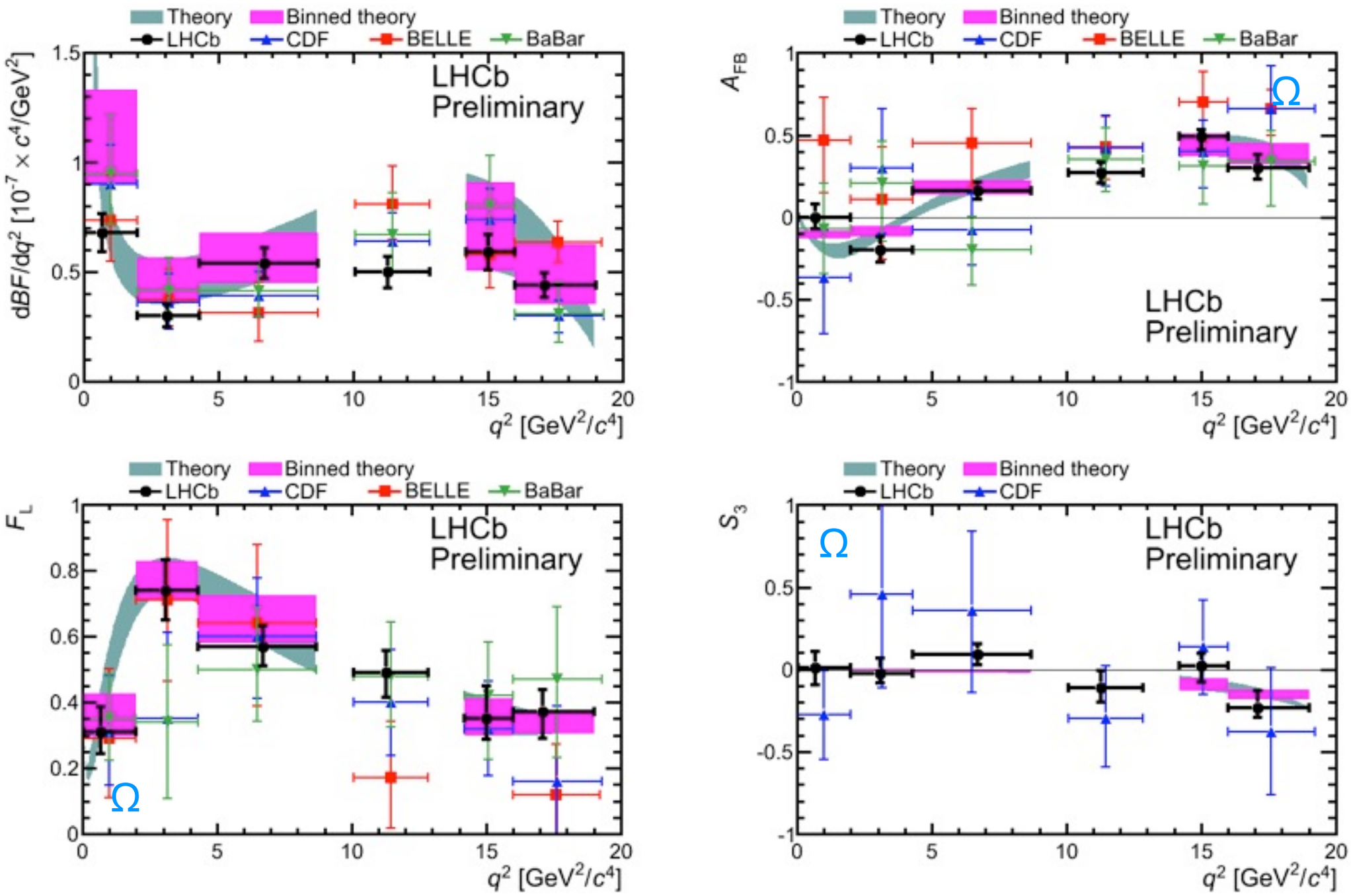
Bobeth,Hiller,van Dyk,Wacker [1111.2558]

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

2011 Data Only! 3x stats in hand.

Ω=angular observable

LHCb stats > all previous experiments combined



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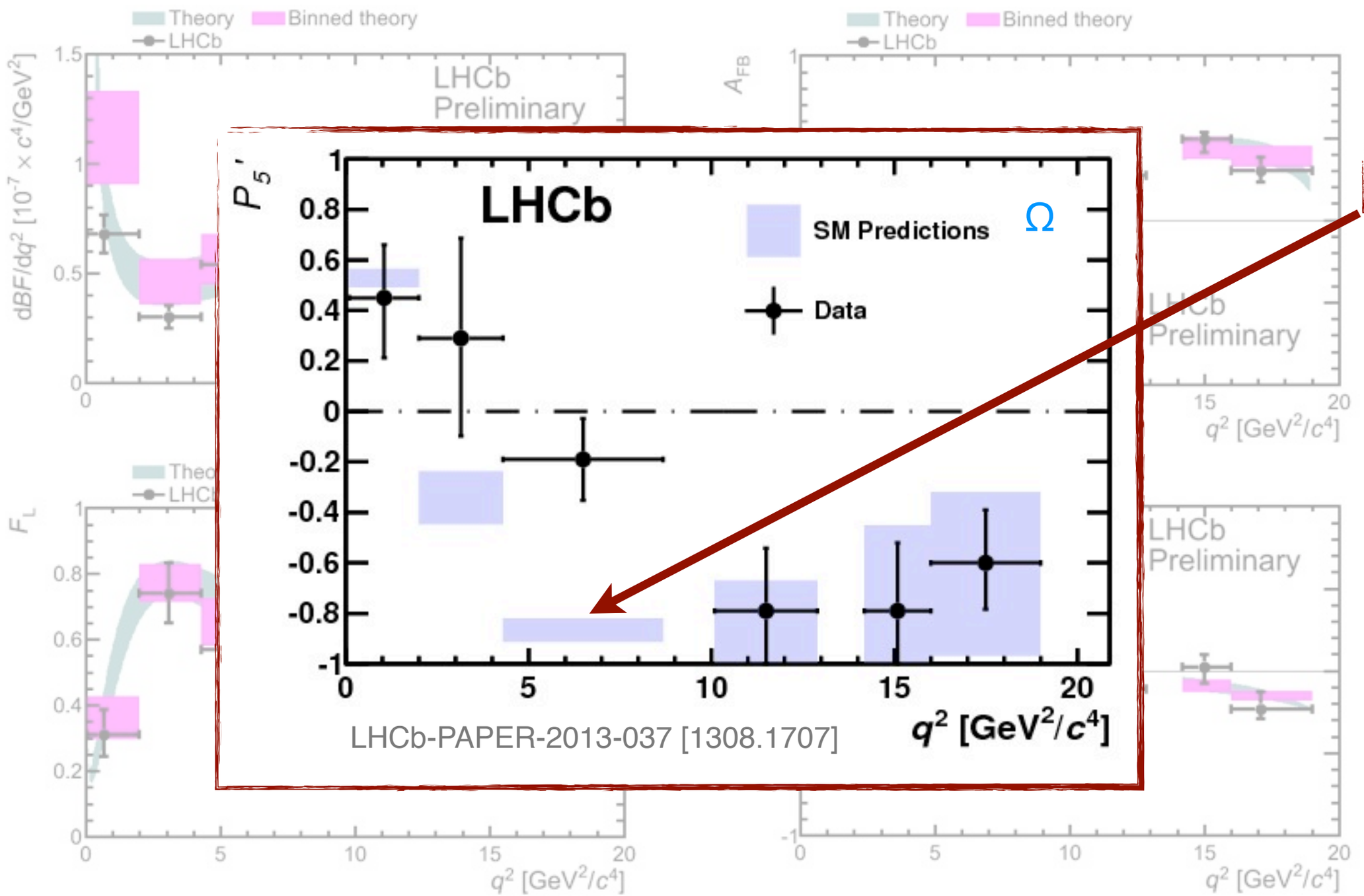
$B_d \to K^*\mu^+\mu^-$

New more theoretically precise observable:



BSM?

TH: Descotes-Genon, Hurth, Matias, Virto [1303.5794]

2011+2012 (3x stats) expected late spring/early summer!

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

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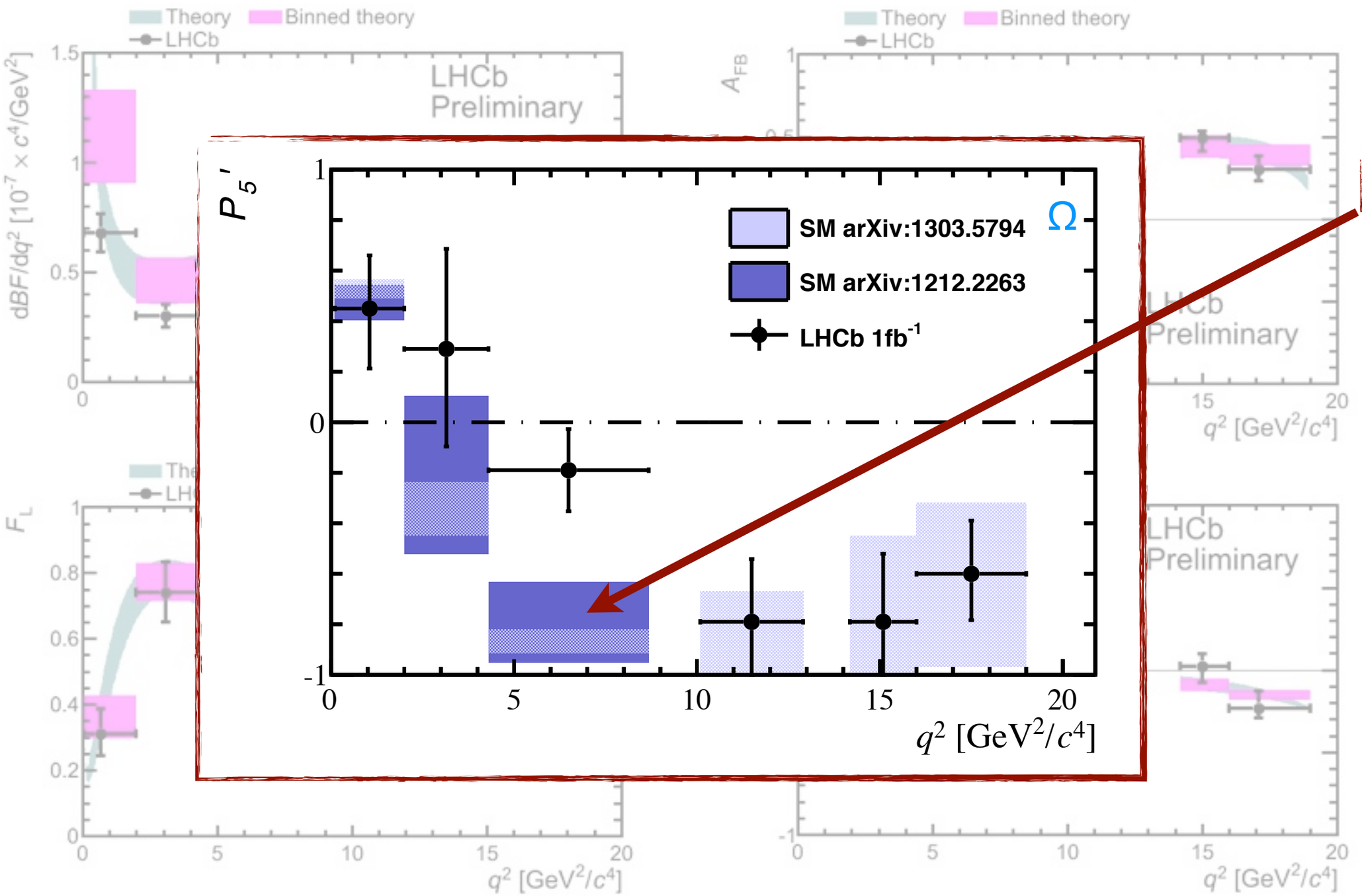


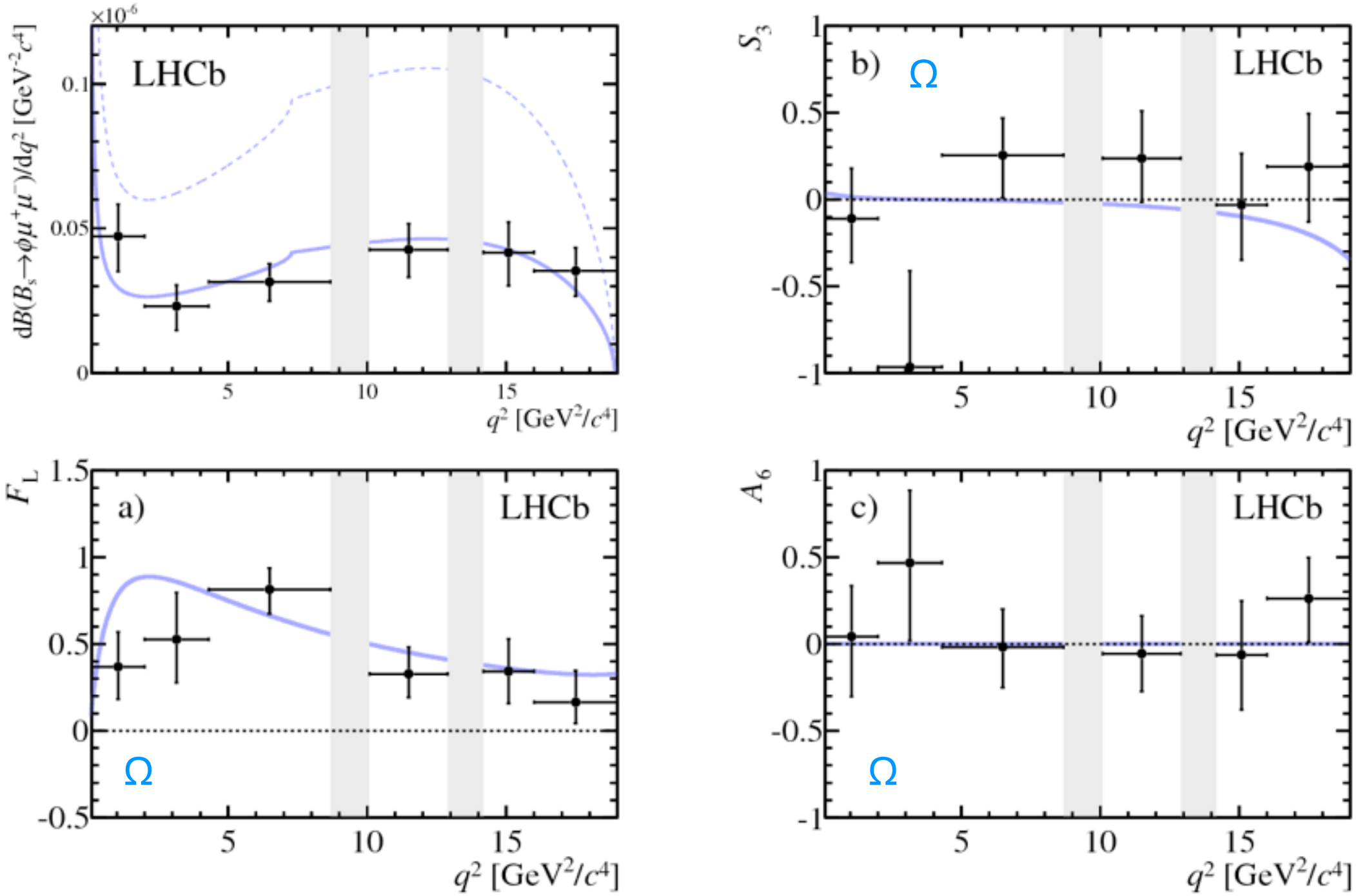
BSM?

2011+2012 (3x stats) expected late spring/early summer!

$B_s \to \phi\mu^+\mu^-$

2011 Data Only! 3x stats in hand.

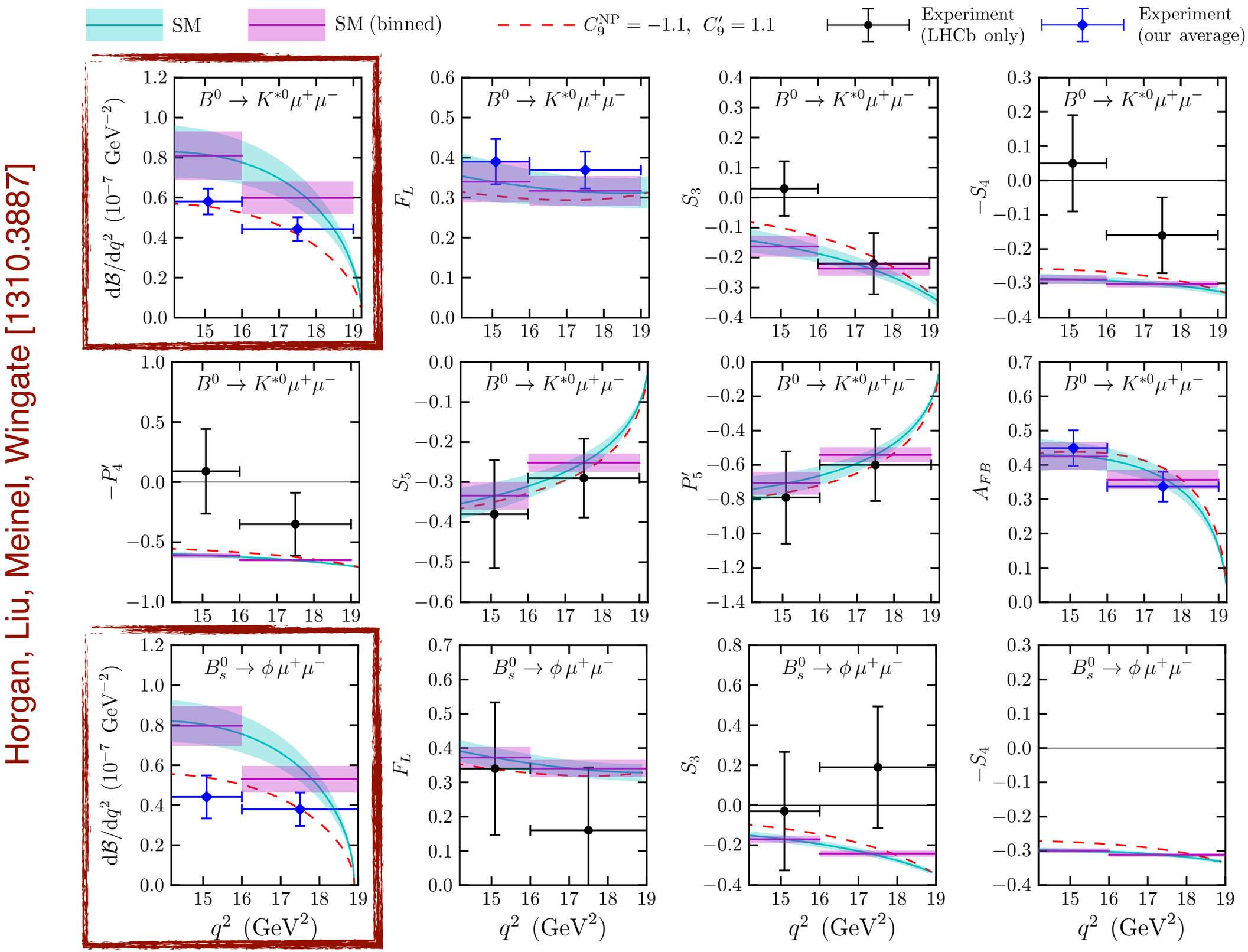
LHCb-PAPER-2013-078 [1305.2168]



TH: Ball,Zwicky [hep-ph/0412079]

2011+2012 (3x stats) expected later this year!

b → sμ⁺μ⁻

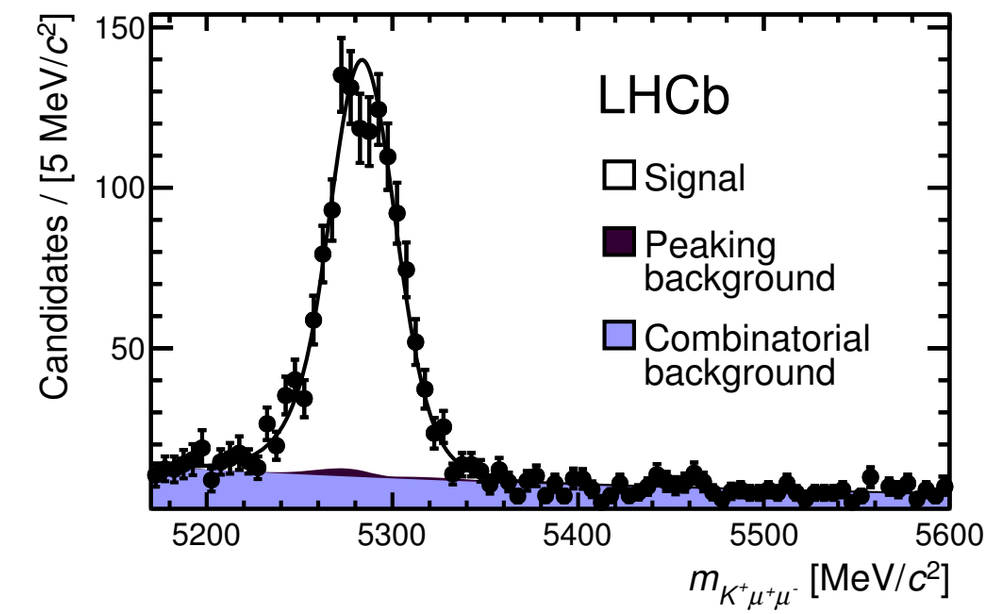


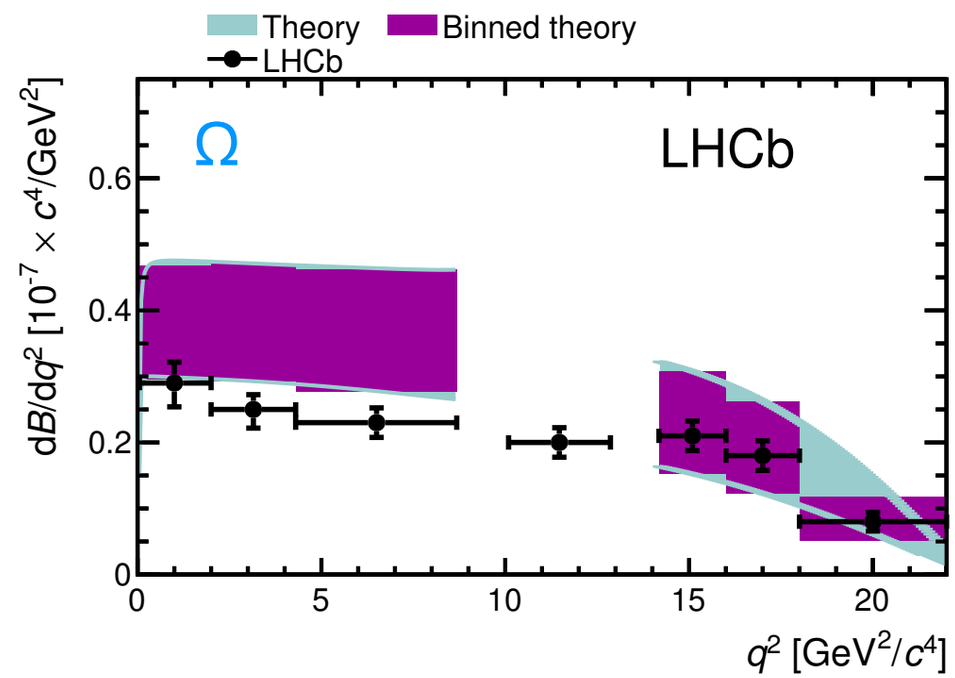
Horgan, Liu, Meinel, Wingate [1310.3887]

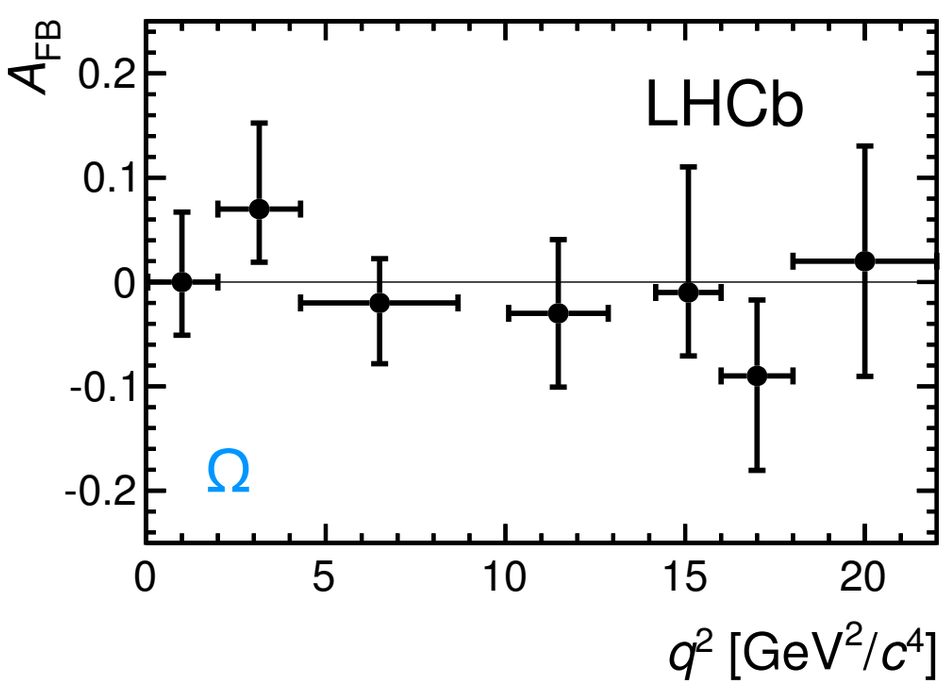
$B_d \rightarrow K\mu^+\mu^-$

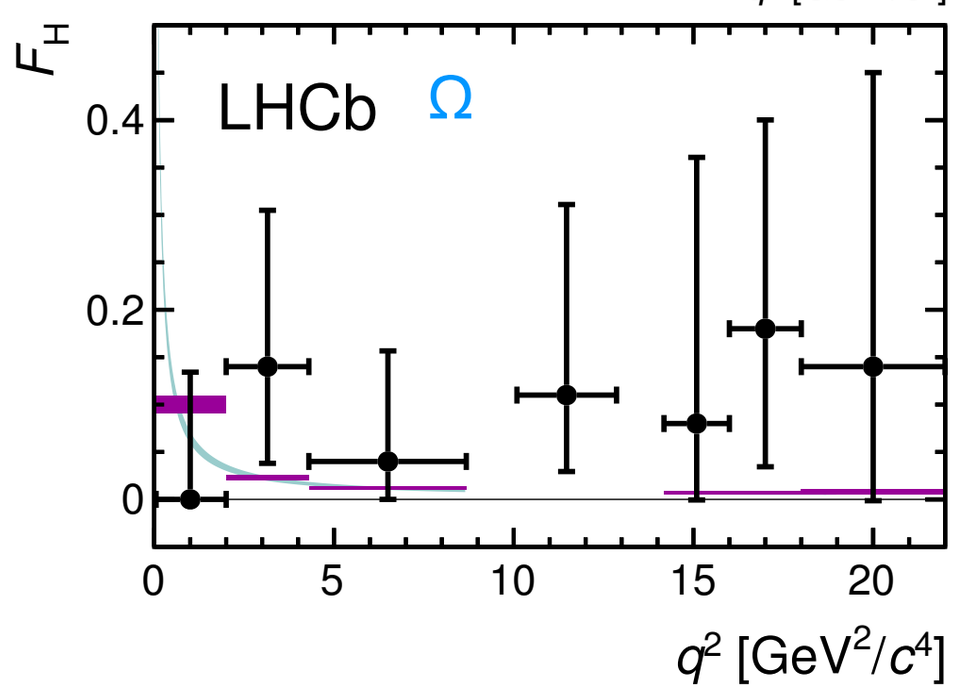
2011 Data Only! 3x stats in hand.

LHCb-PAPER-2012-024 [1209.4284]









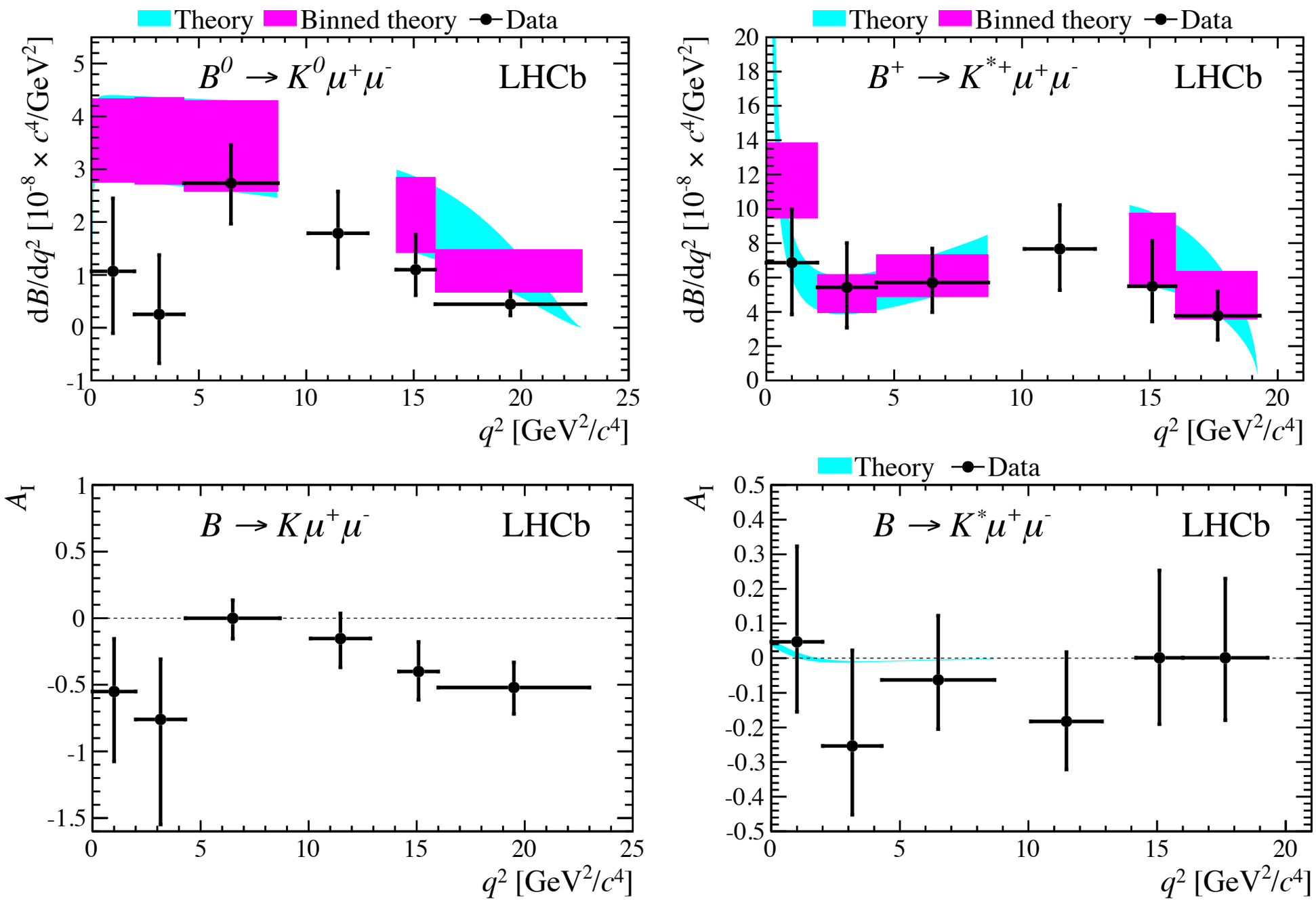
Bobeth, Hiller, van Dyk, Wacker [1111.2558]

Recent LQCD Work: Bouchard, Lepage, Monahan, Ha, Shigemitsu [1306.0434]

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

2011 Data Only! 3x stats in hand.

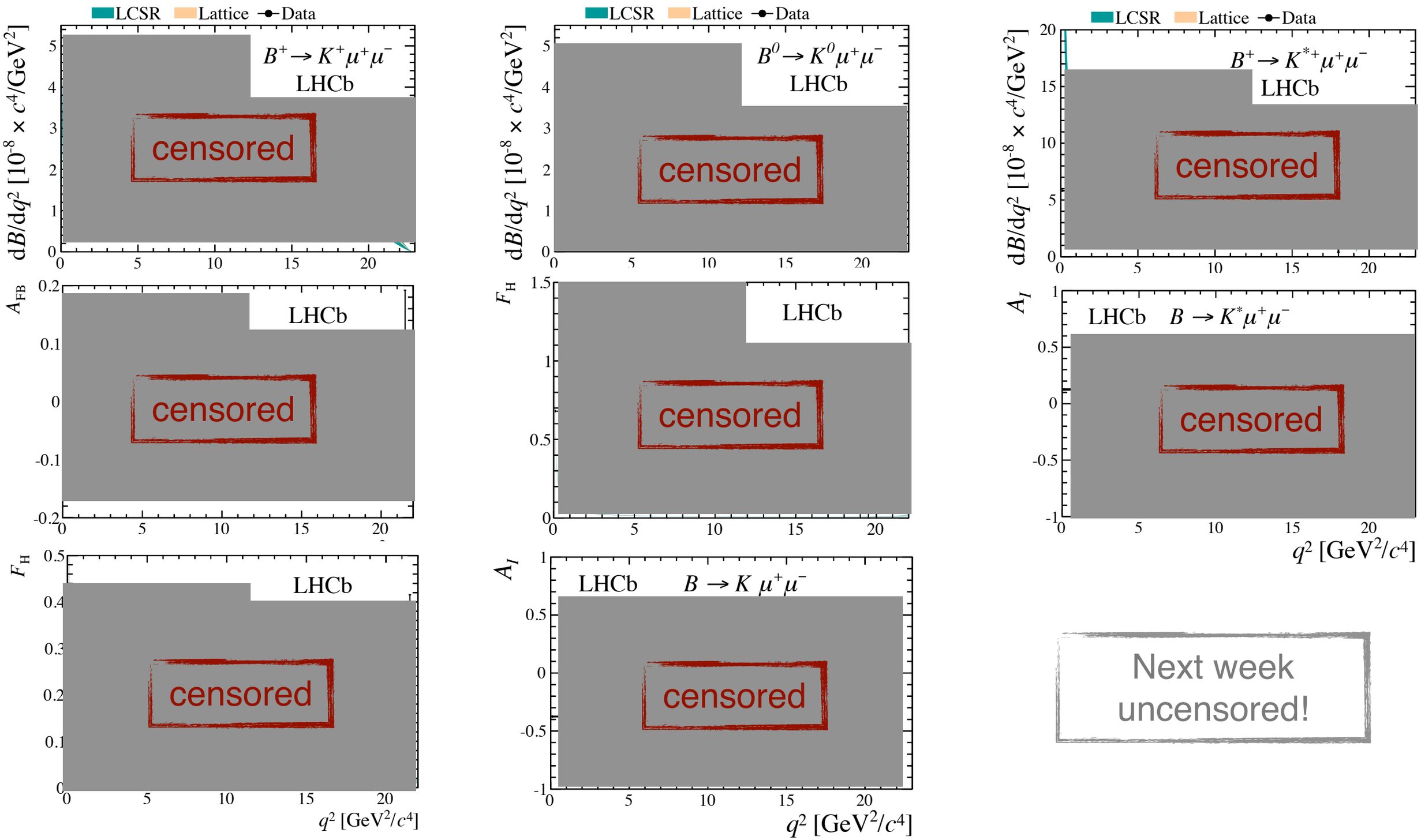
LHCb-PAPER-2012-011 [1205.3422]



TH: Bobeth,Hiller, van Dyk [1111.2558]

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

2011+2012 updates for Moriond:



Next week uncensored!

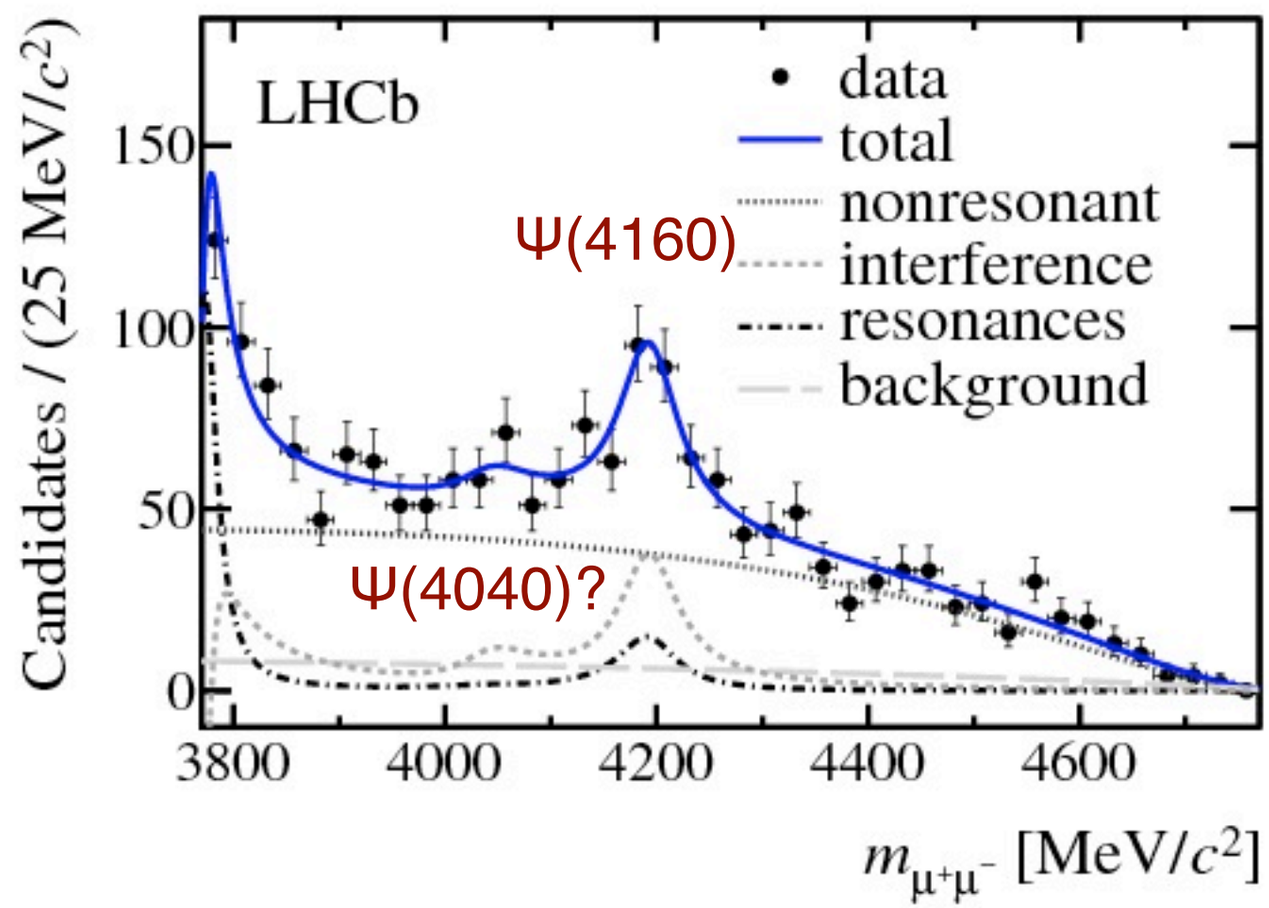
$B_d \to K^{(*)}\psi$

LHCb recently observed an unexpectedly large resonant contribution in B→Kμμ. Even the golden modes cannot escape QCD!

LHCb-PAPER-2013-039 [1307.7595]

We could measure these ... is it helpful?

$$B \to \psi(4160)K \to \mu\mu K, \quad B \to \psi(4160)K \to DD'K$$

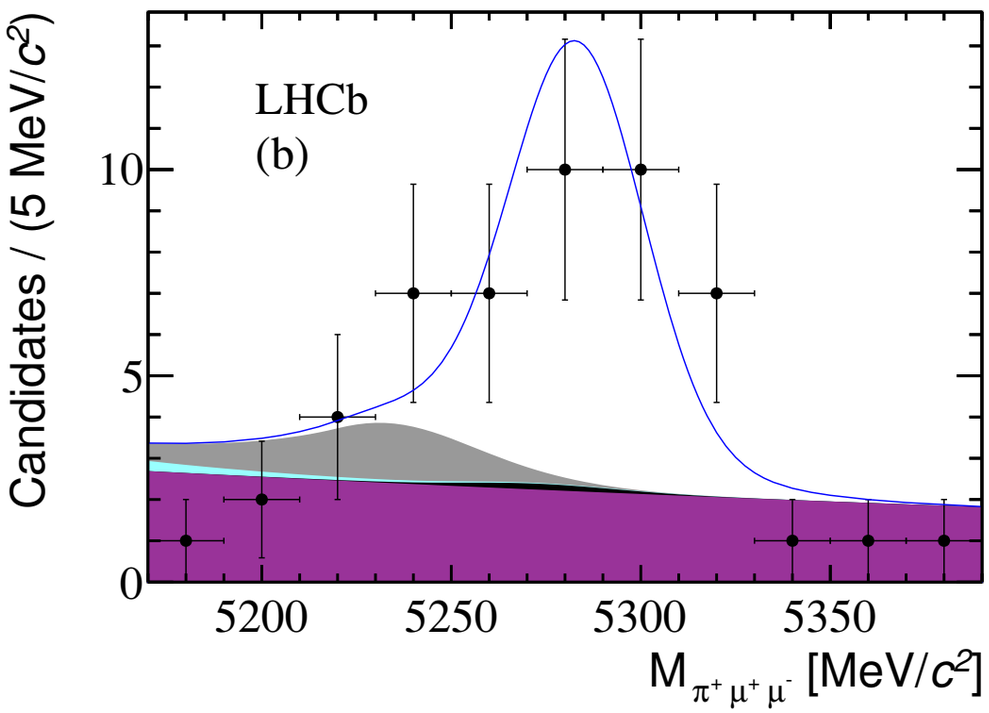


Need cc components properly included (central values + error budget).

More Penguins

2011 Data Only! 3x stats in hand.

$B_d \to \pi\mu^+\mu^-$



LHCb-PAPER-2012-020 [1210.2645]

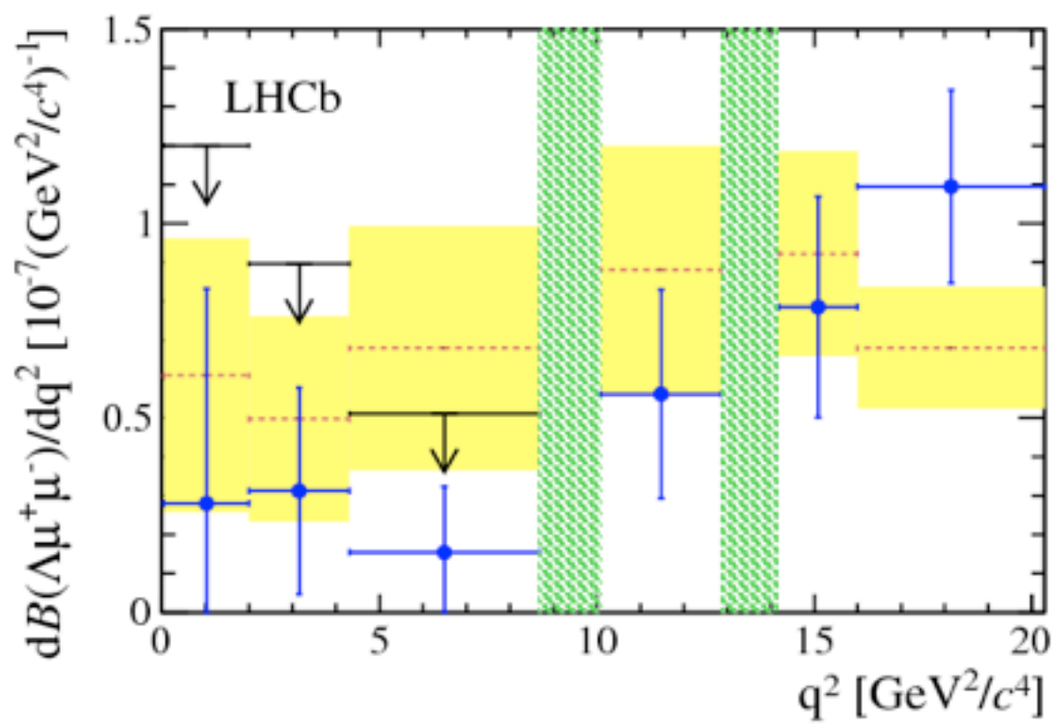
$$\frac{\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)} = 0.053 \pm 0.014\ (\text{stat.}) \pm 0.001\ (\text{syst.})\,.$$

Update to 3/fb early summer. With theory help can obtain a nice measurement of |Vtd|/|Vts|.

$\Lambda_b \to \Lambda\mu^+\mu^-$

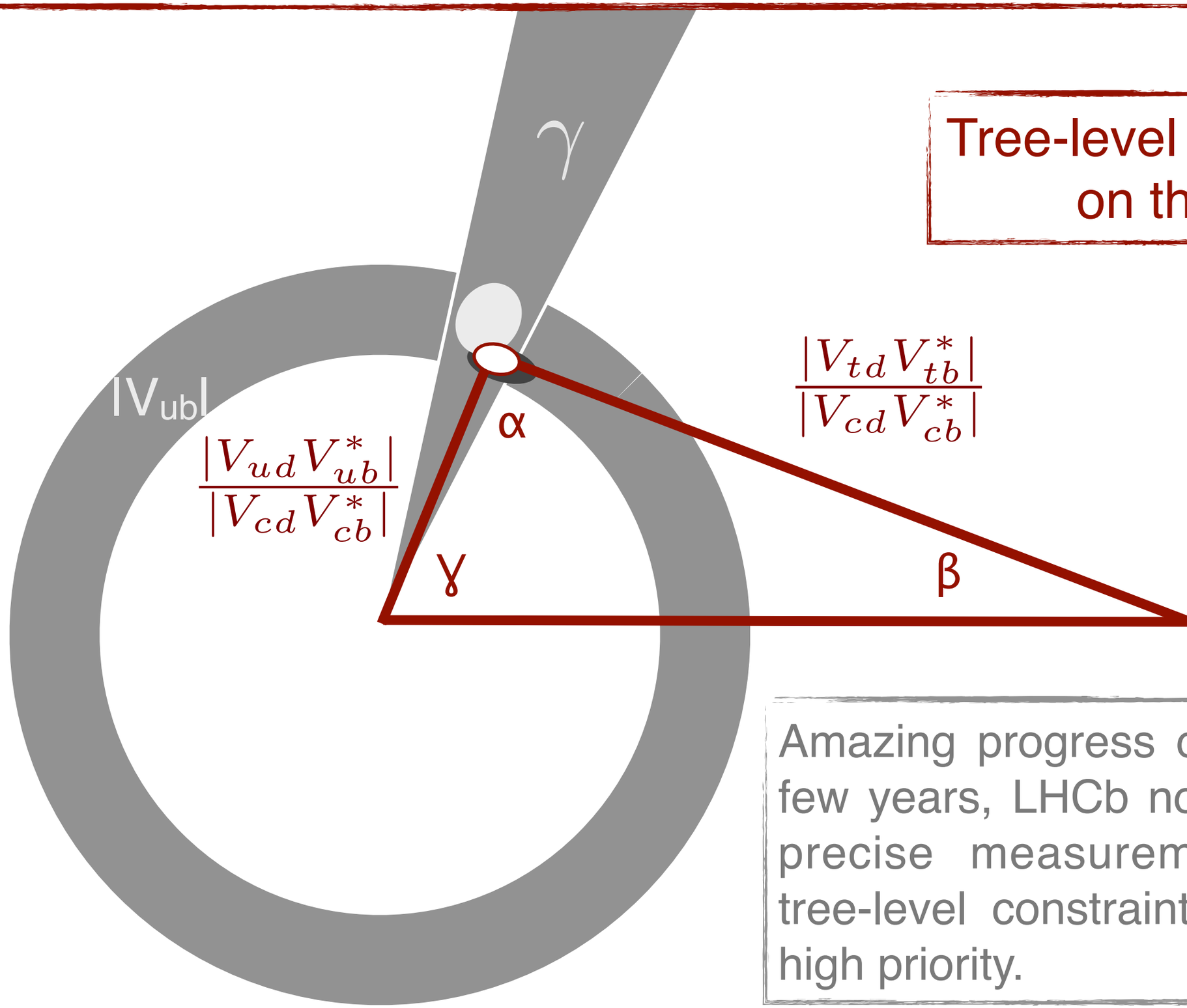
Update to 3/fb early summer.

LHCb-PAPER-2013-025 [1306.2577]



TH: Detmold, Lin, Meinel, Wingate [1212.4872]

Unitarity Triangle

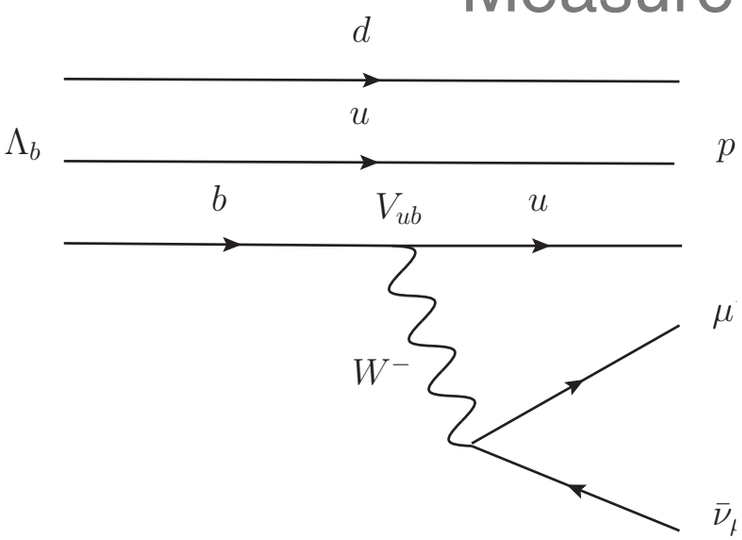


Tree-level constraints on the UT.

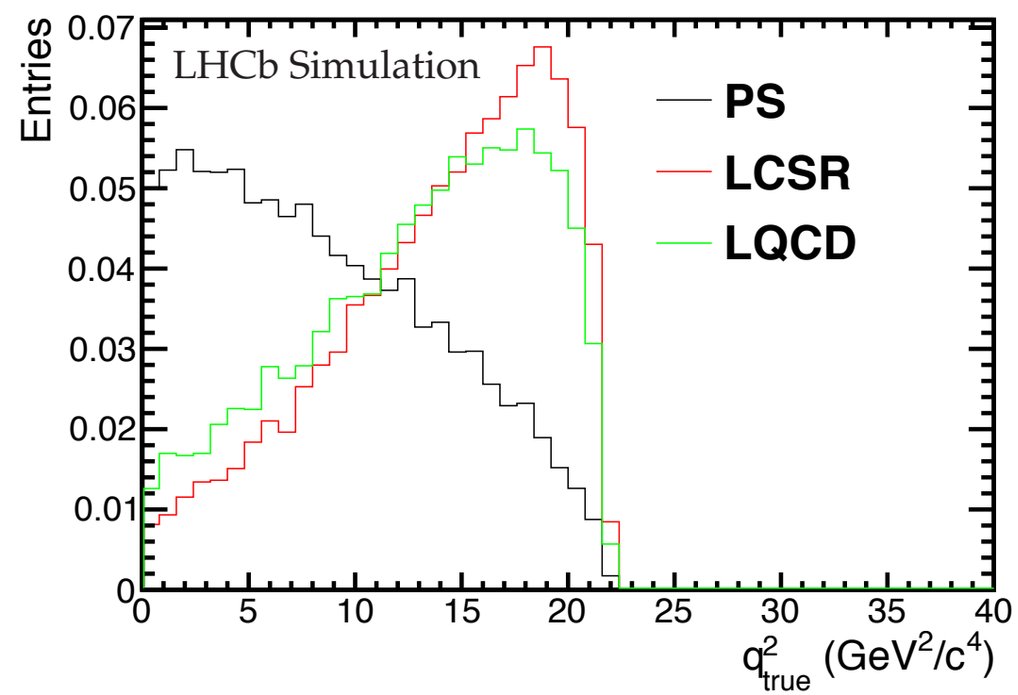
Amazing progress on γ in the past few years, LHCb now has the most precise measurement. Improving tree-level constraints is still a very high priority.

Vub

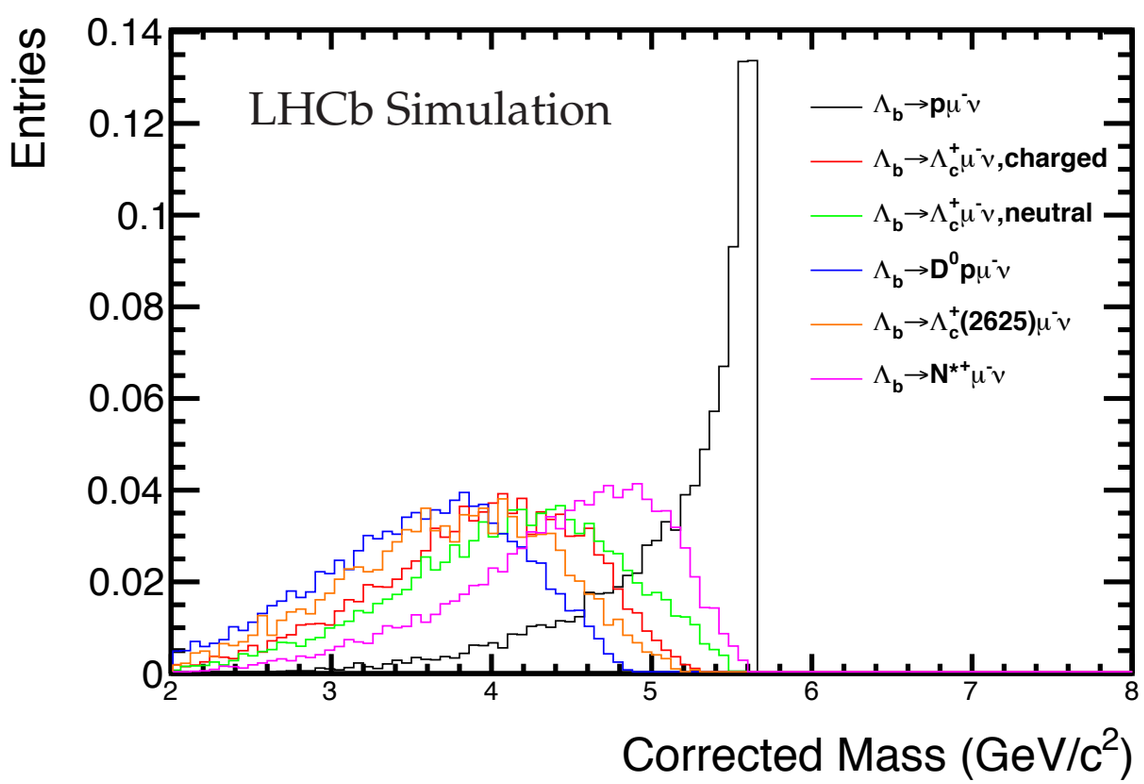
Measure |Vub|/|Vcb| via B(Λb→pμν)/B(Λb→Λcμν):



LCSR: Khodjamirian,Klein,Mannel,Wang [1108.2971]
LQCD: Detmold,Lin,Meinel,Wingate [1306.0446]



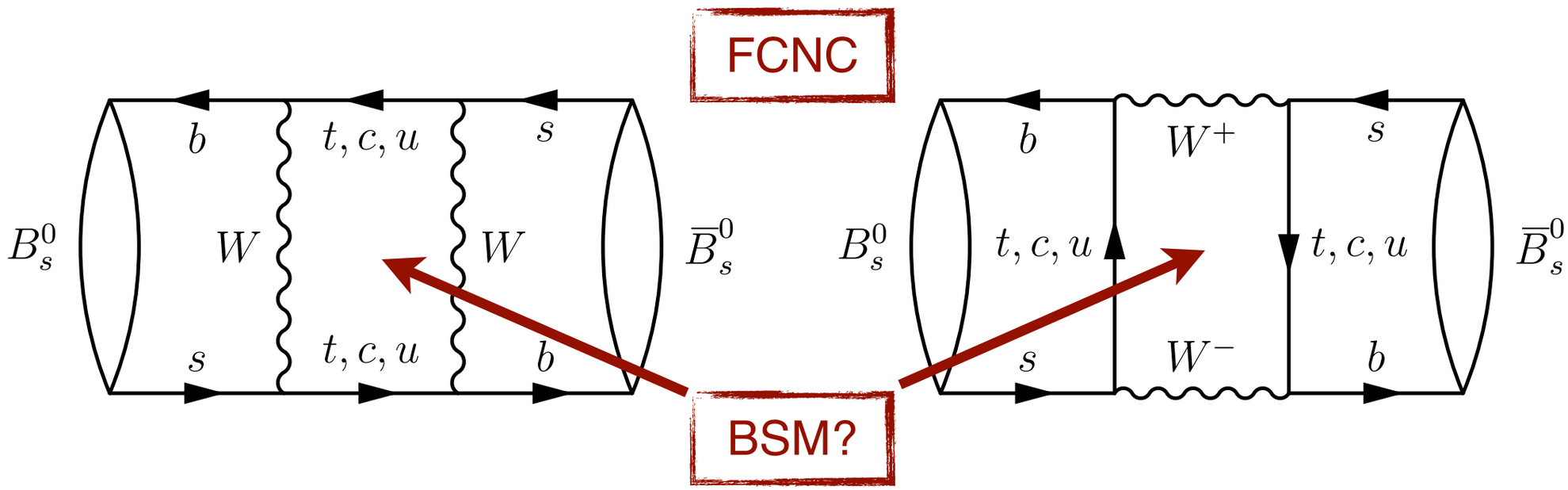
use PV→SV direction to correct for missing ν and determine q2 (with 2-fold ambiguity)



Need FF to convert B/B → CKM ratio and to understand BKGD shapes.

$\Delta m_{d,s}$

Neutral meson oscillations have now been observed in the K, B_d, B_s and D systems. The B_s has the highest oscillation frequency and changes flavor on average 9 times between production and decay.

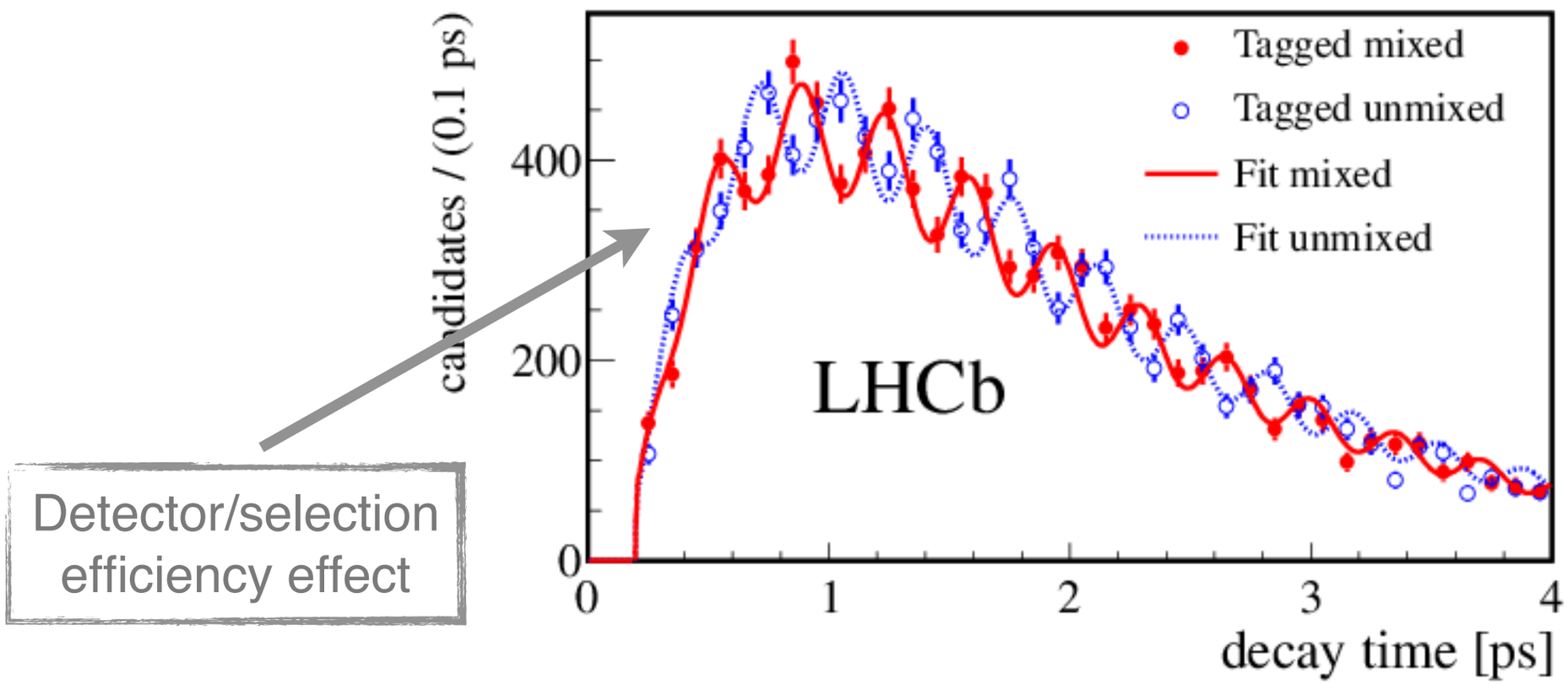


Measuring the B_d and B_s oscillations frequencies provides direct constraints on the UT and also vital input to many BSM searches, e.g., $B_s \to \mu\mu$ and $B_s \to J/\psi\phi$.

$\Delta m_{d,s}$

LHCb achieves a mean decay-time resolution in this mode of 44 fs!

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



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

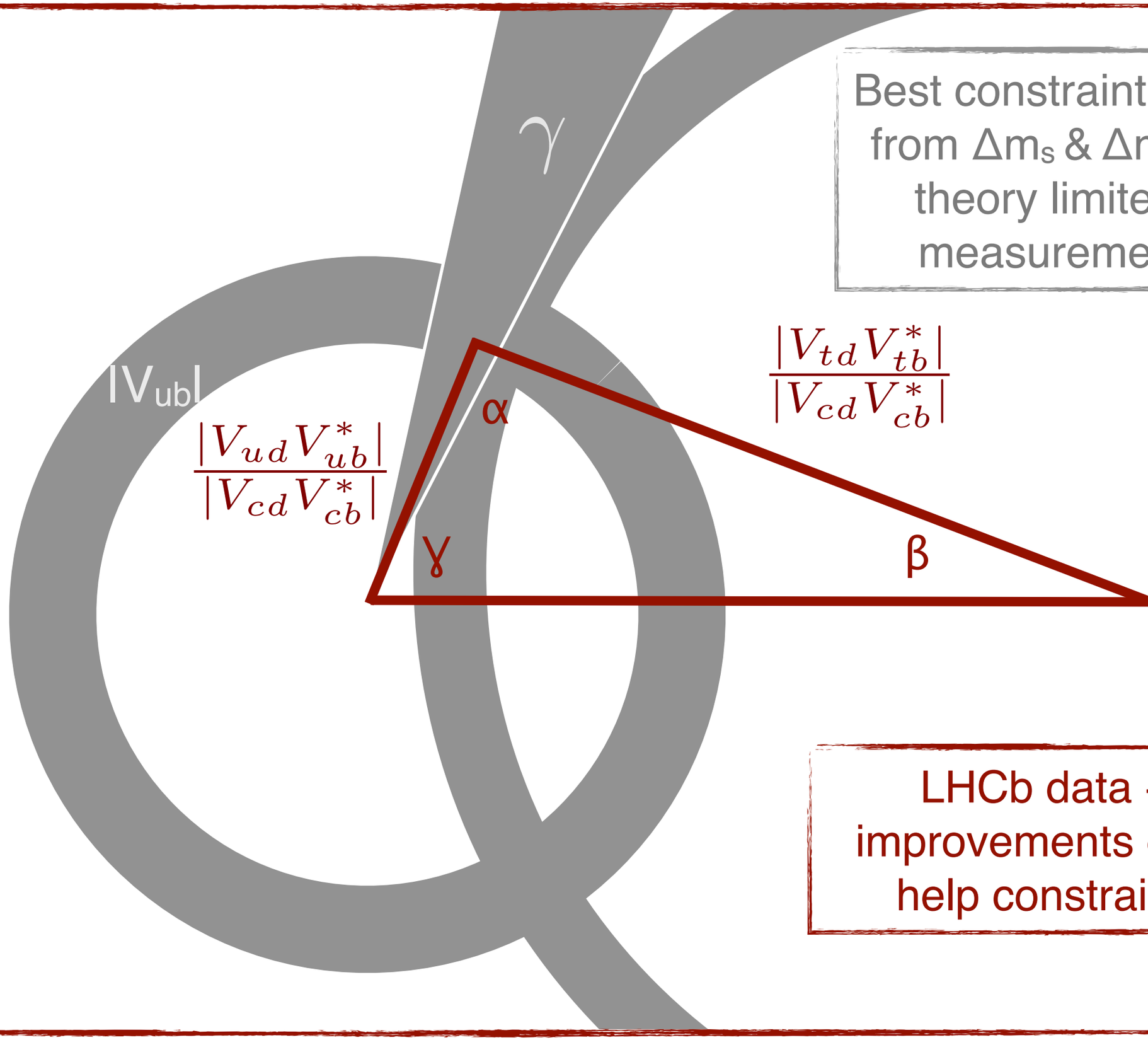
LHCb-PAPER-2013-006
[arXiv:1304.4741]

LHCb has also made the most precise measurement of the B_d frequency:

$$\Delta m_d = 0.5156 \pm 0.0051(\text{stat}) \pm 0.0033(\text{syst})\,\text{ps}^{-1}$$

$\Delta m_{d,s}$

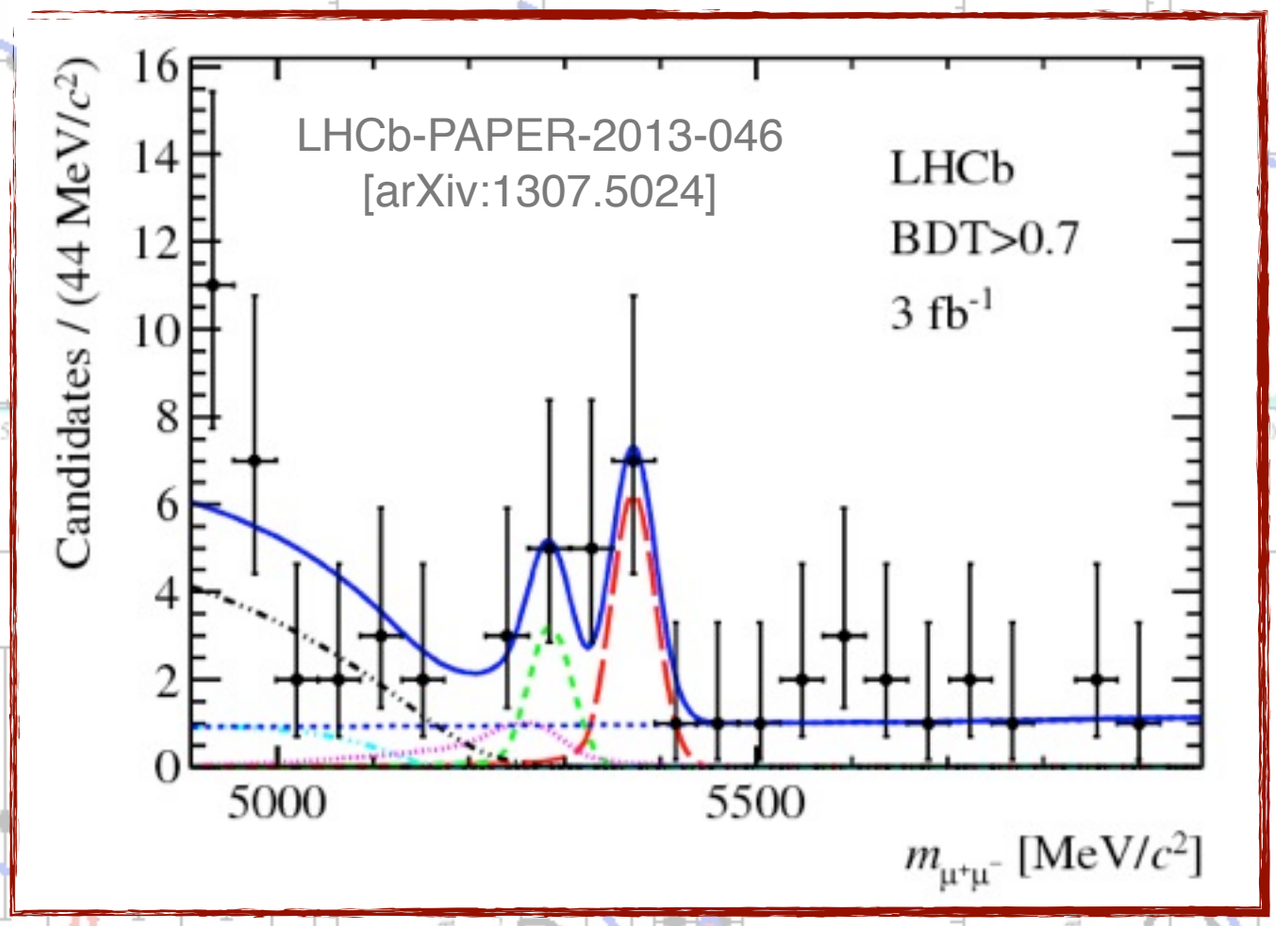
Best constraints on $|V_{td}|$ and $|V_{ts}|$ from Δm_s & Δm_d. Unfortunately, theory limited so improved measurements don't help.

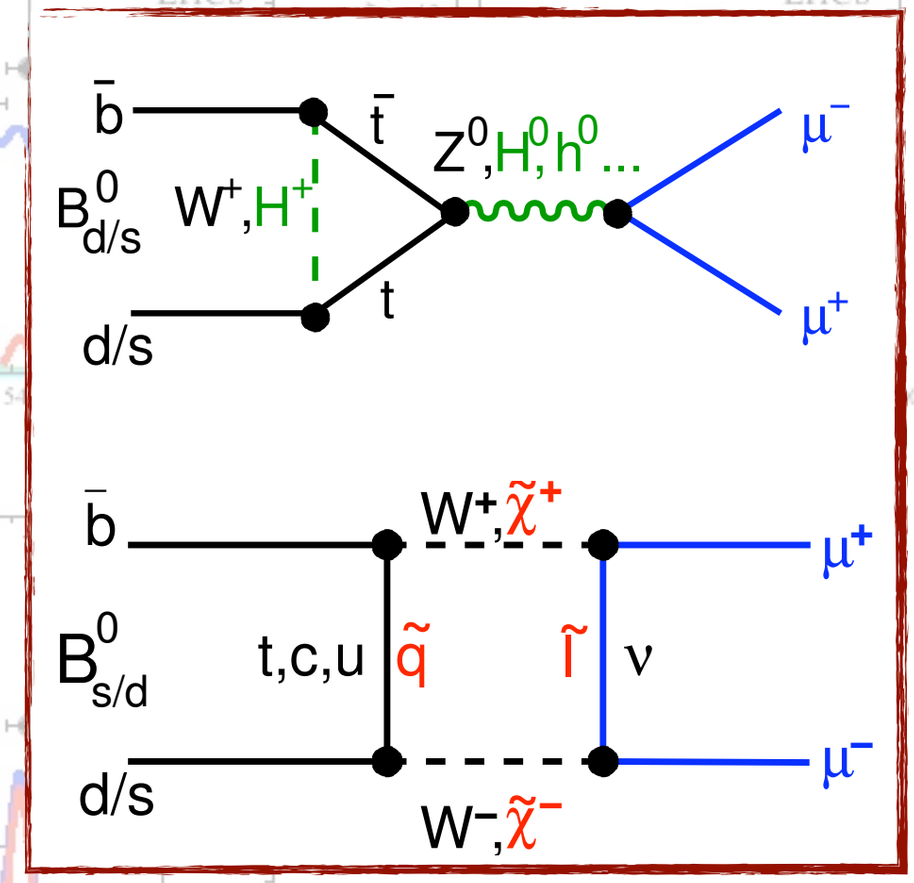


LHCb data + LQCD improvements could really help constrain the UT!

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

The SM predicts the B_s decays into two muons once every 3.4B decays (1/1.6T pp collisions @ LHCb), but this can be enhanced greatly by BSM.

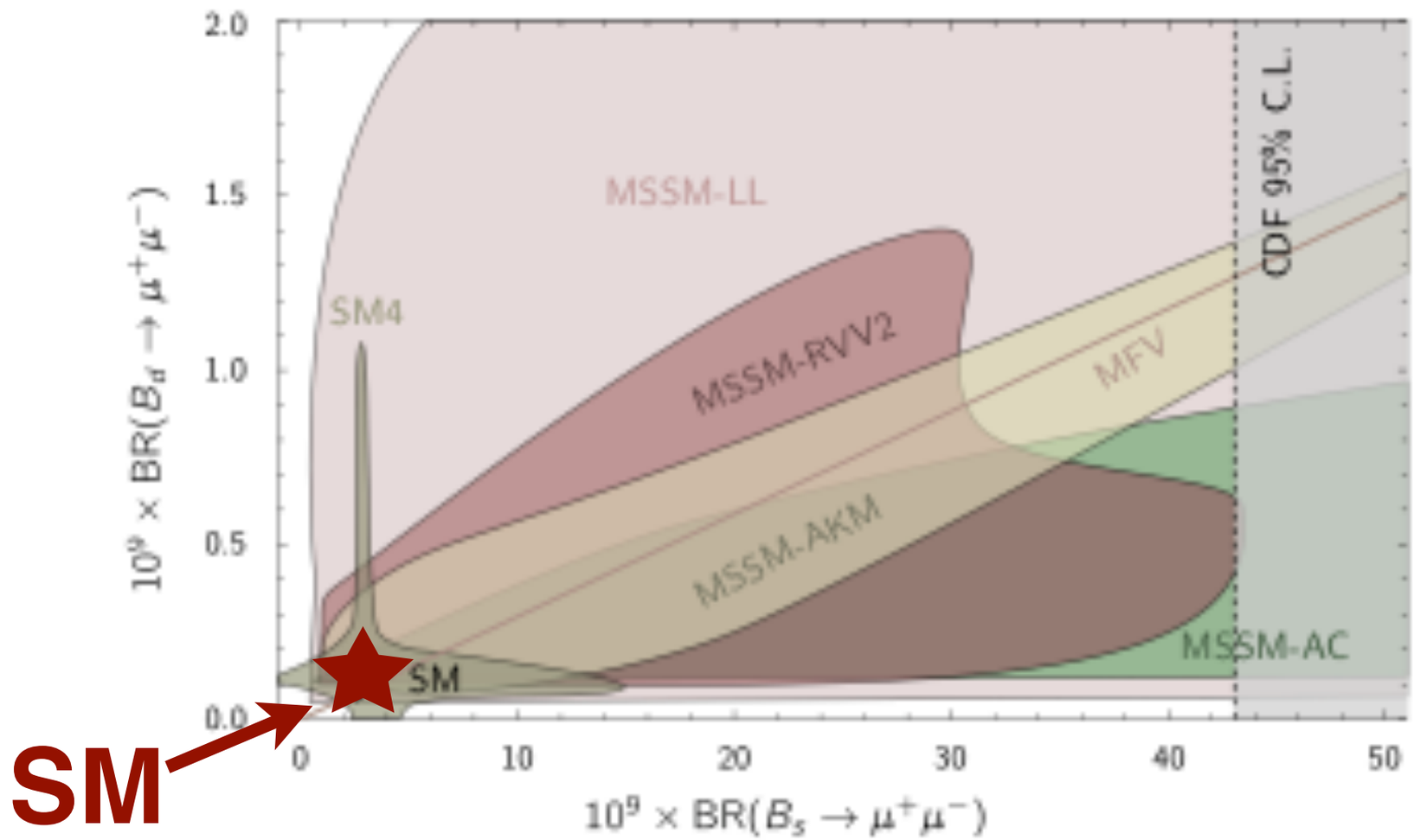




Very interesting channel to explore NP models with extended Higgs sectors. Sensitive to “any” mass scale. Pre-LHC limits not very restrictive.

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

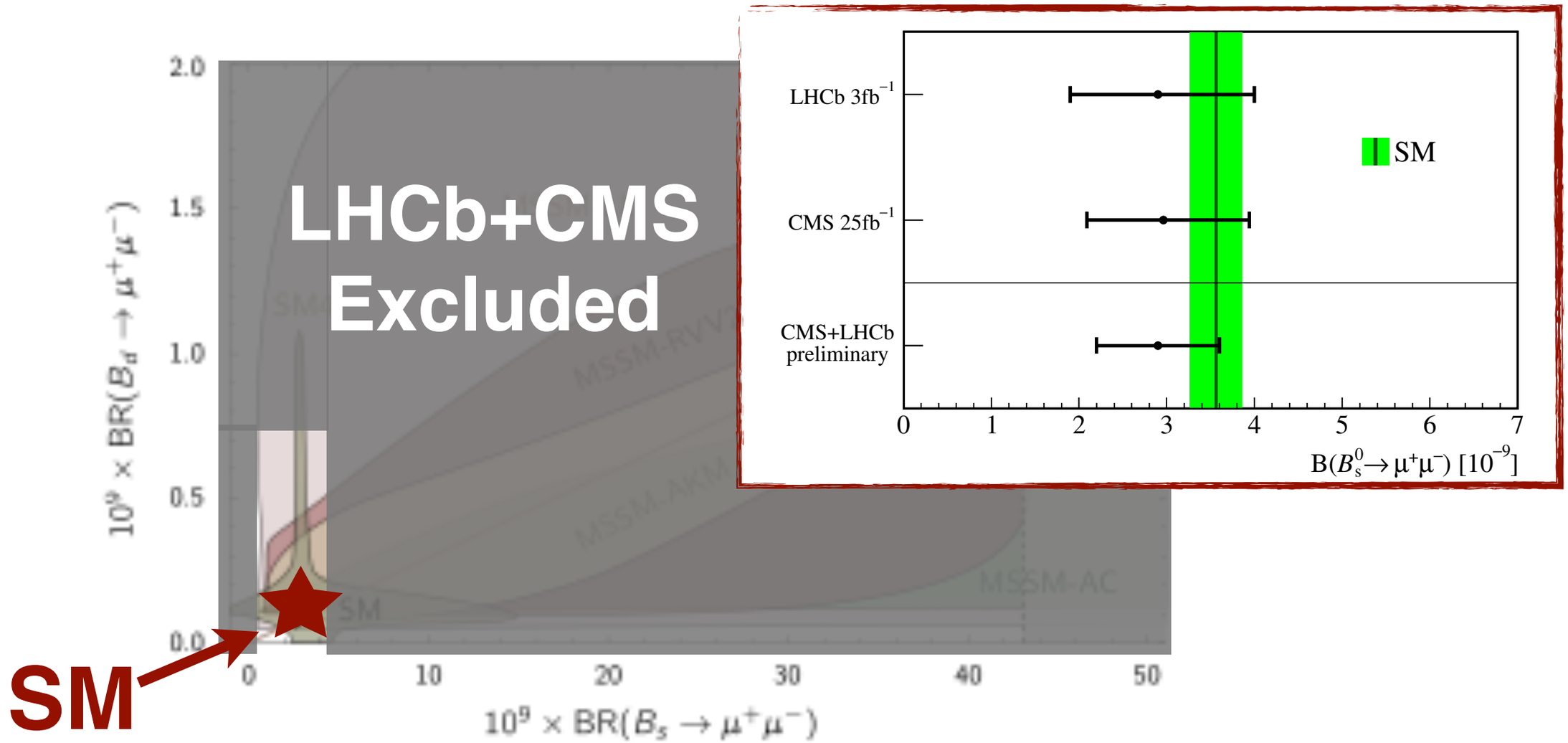
Pre-LHC limits on SUSY not very restrictive.



TH: David Straub

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

Both CMS & LHCb report > 4σ evidence.

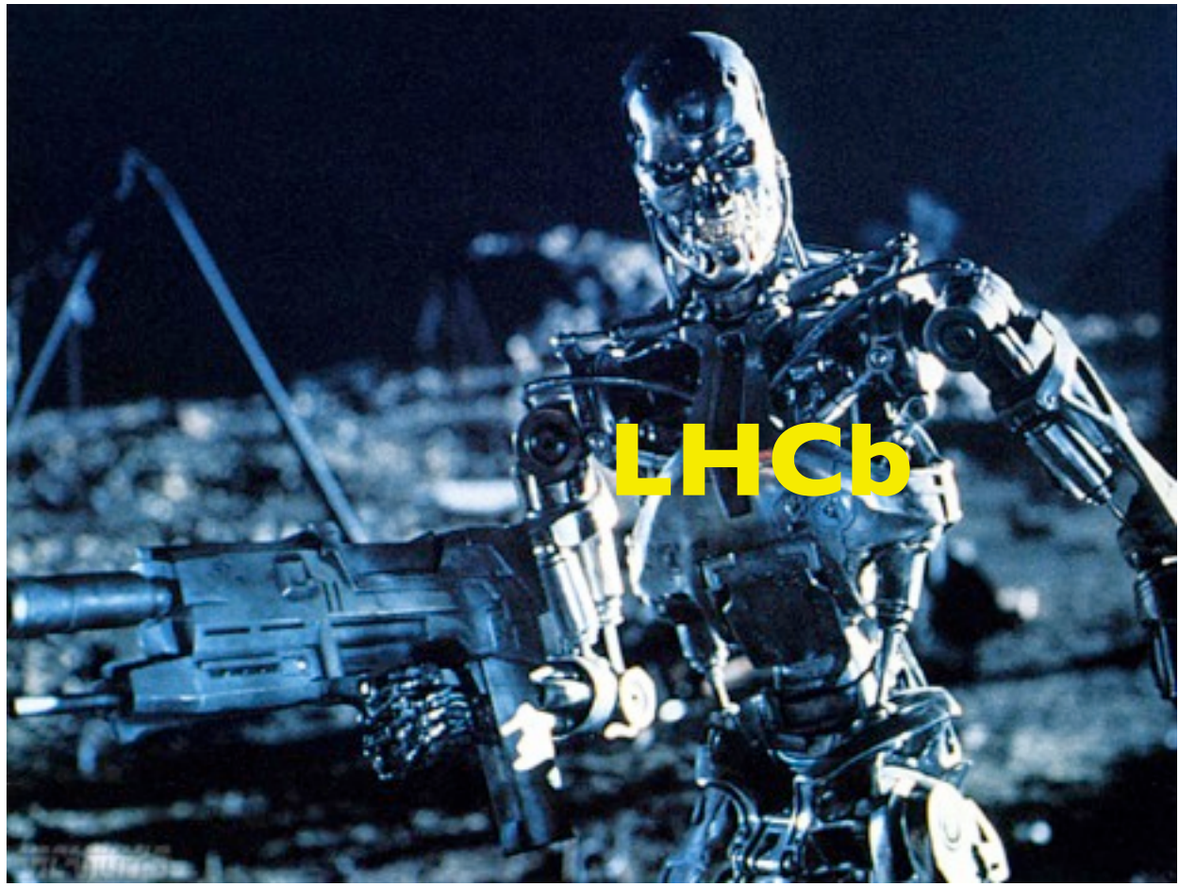


Dominant experimental systematic from fs/fd.
Recent help from MILC [1202.6346]

LHC Run III LHCb+CMS will push experimental error < theory.

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!

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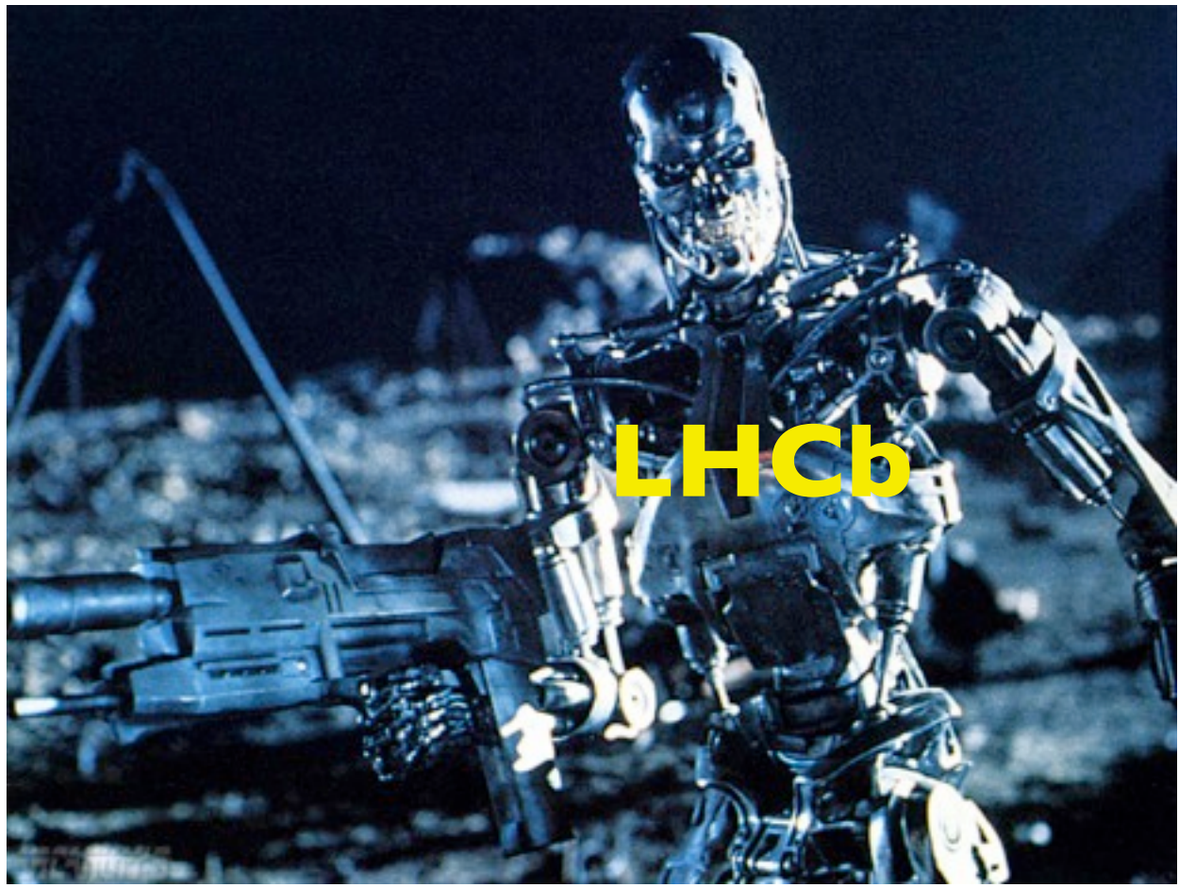

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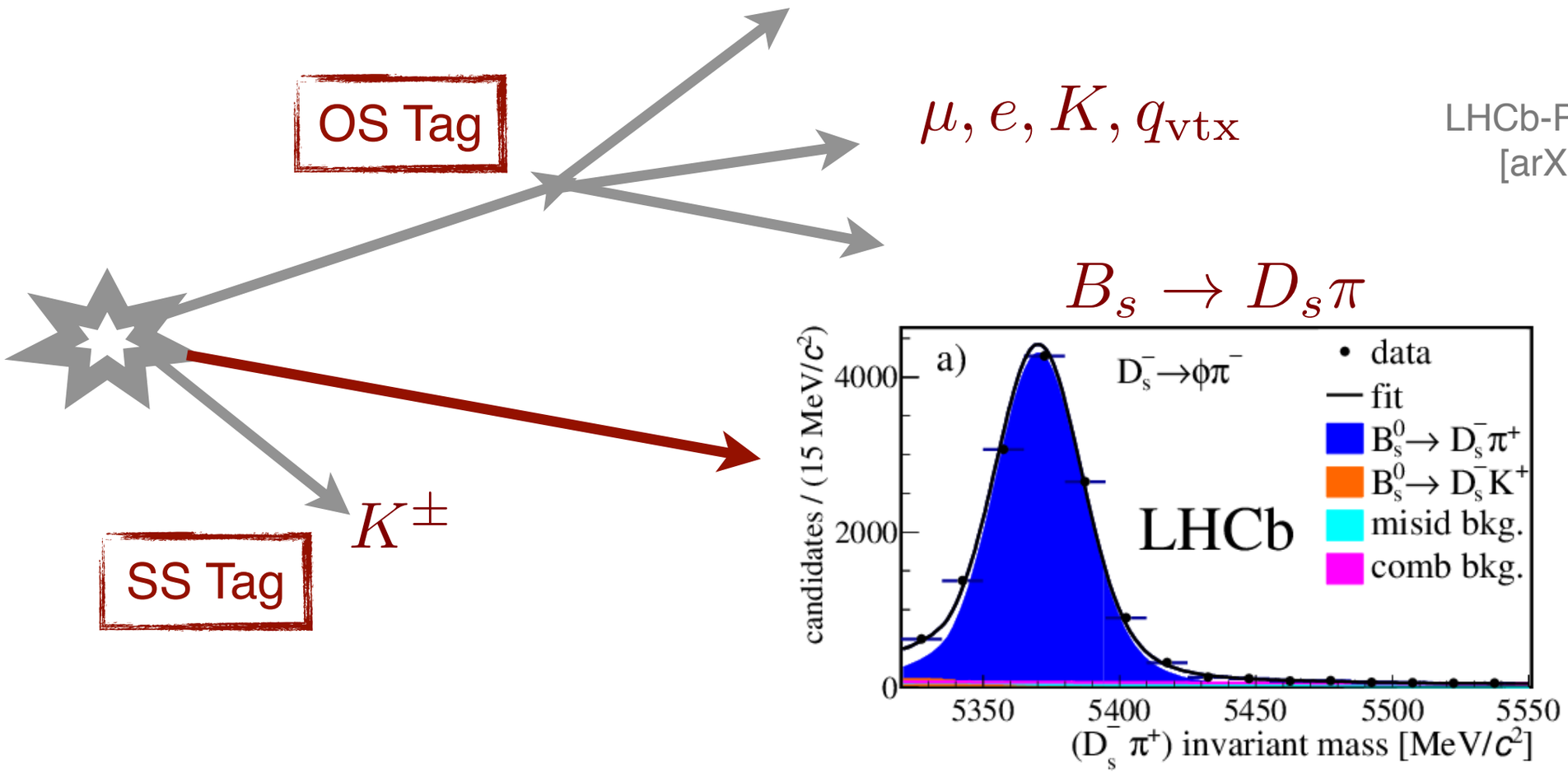
Summary

As our error bars continue to shrink in the coming years as data flows in during LHC Run II (and beyond) ...

... we really need theory support so that our measurements continue to provide relevant physics constraints.

Δm_s

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



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

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.