Rare Processes @LHC

PRODUCTION & DECAY
MEASUREMENTS & SEARCHES
WITH HEAVY FLAVOUR

B,Y,Z,H
pp & PbPb

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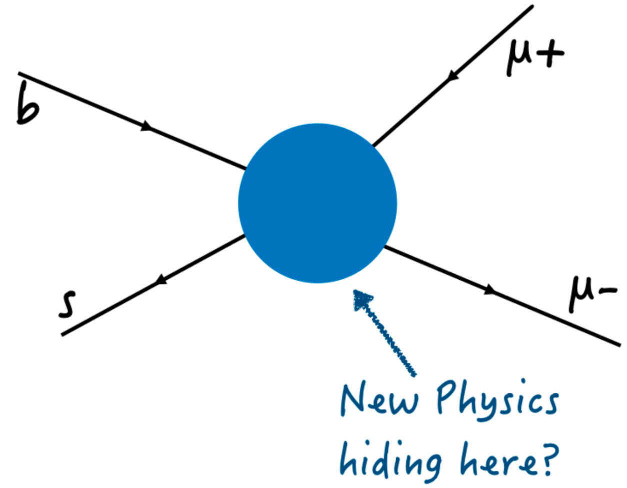
Collaborators: K.-F.Chen (Taiwan), F.Silva, S.Fonseca (UERJ), Z.Shi, Y.-J.Lee (MIT)

for the LIP-CMS Group

JORNADAS CIENTIFICAS LIP
BRAGA, FEB. 15TH, 2020

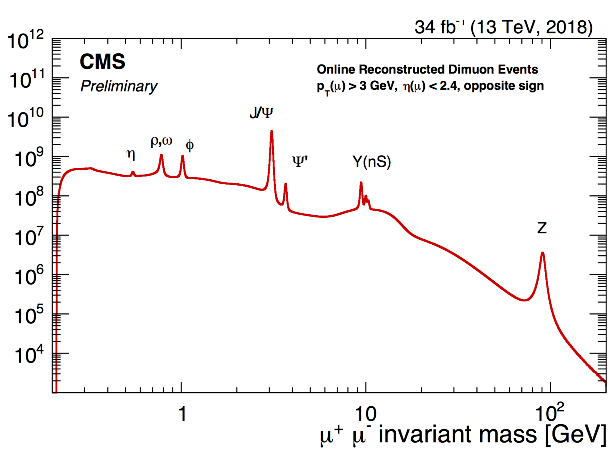
FCT Fundação para a Ciência e a Tecnologia
IF/01454/2013/CP1172/CT0003
CERN/FIS-PAR/0006/2017



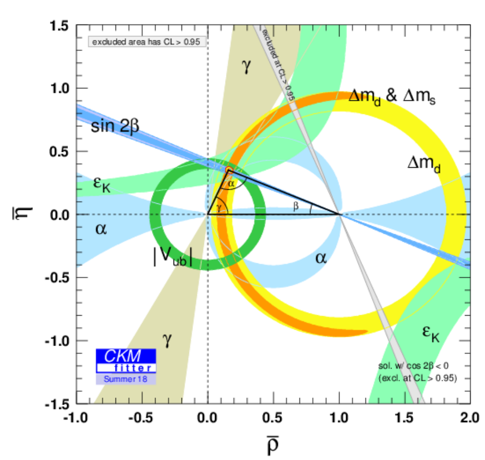
flavour

probing NP beyond TeV

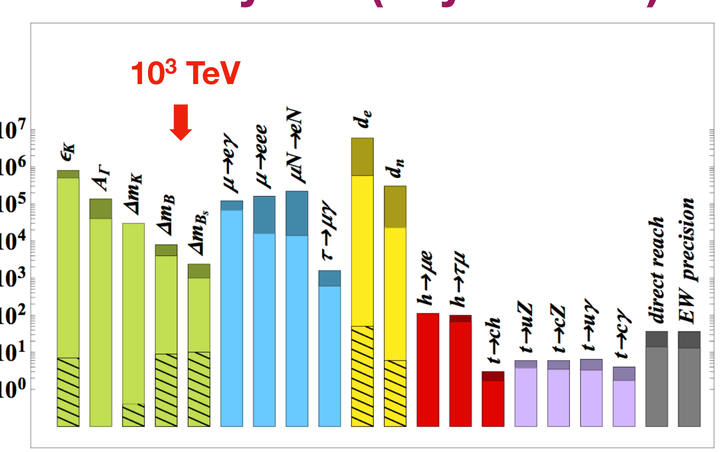
QCD & new hadron states



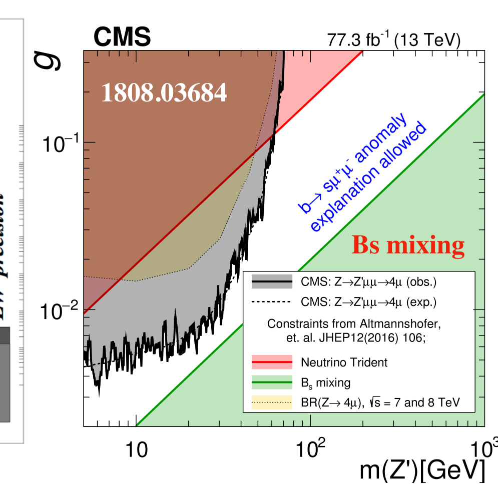
EWK precision (CKM)



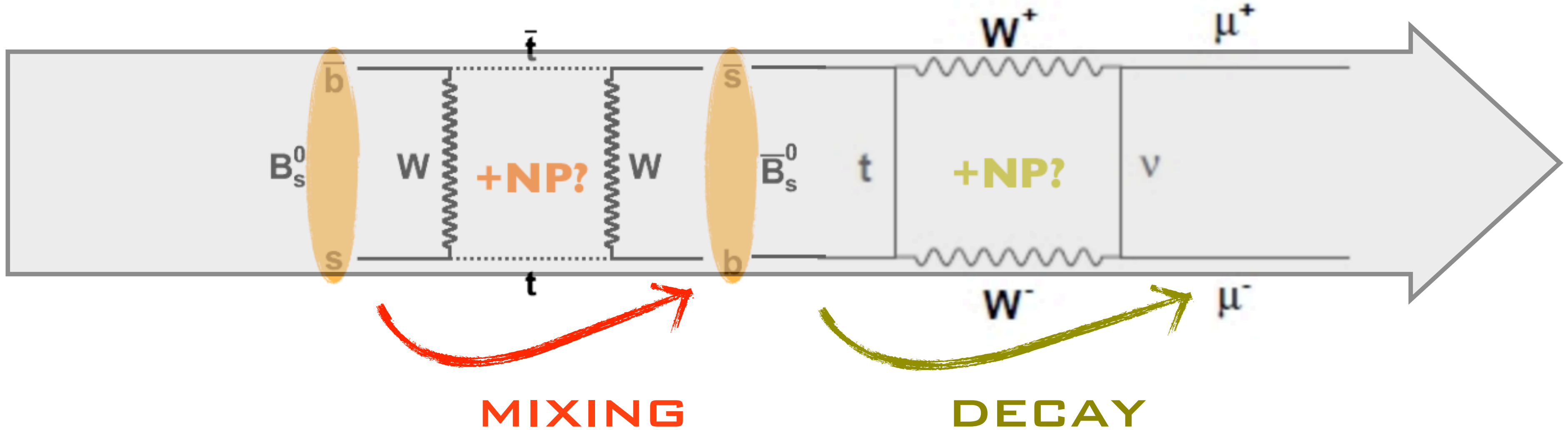
New Physics (beyond TeV)



Flavour Anomalies

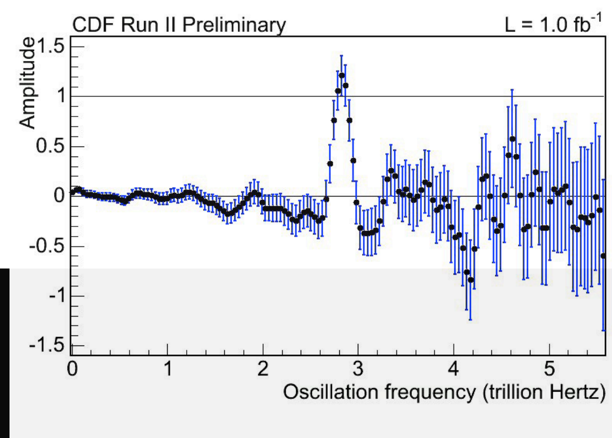


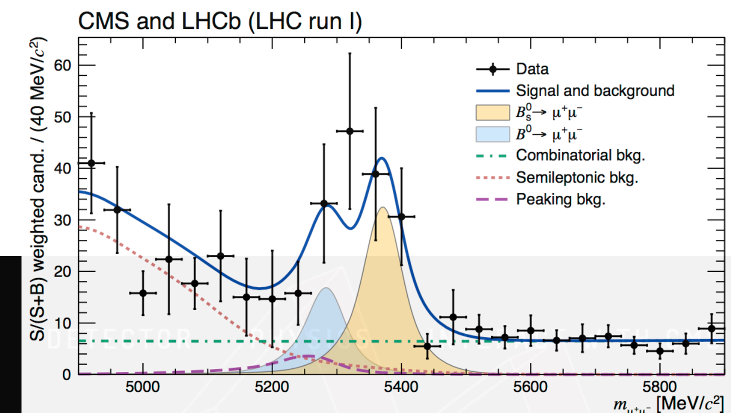
B



μμ

PRL 97 (2006) 242003, NL thesis

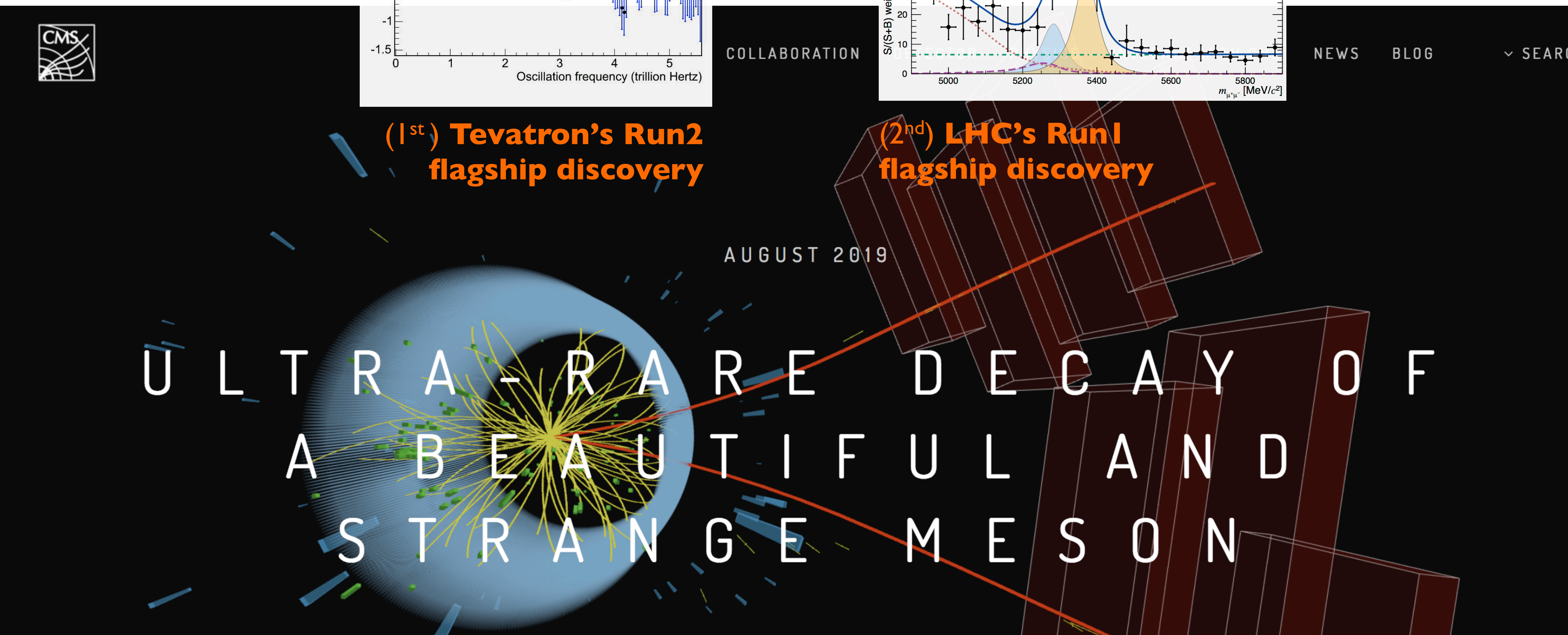




Nature 522 (2015) 68

(1st) Tevatron's Run2 flagship discovery

(2nd) LHC's Run1 flagship discovery

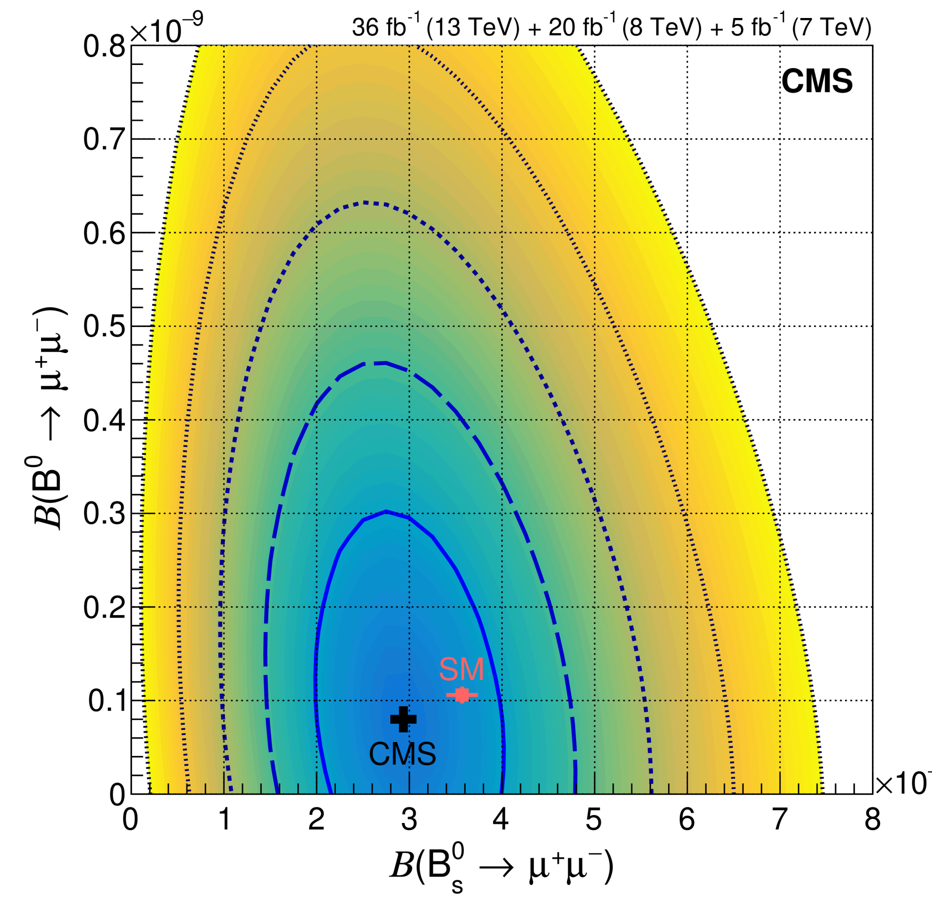


B→μμ | branching fractions

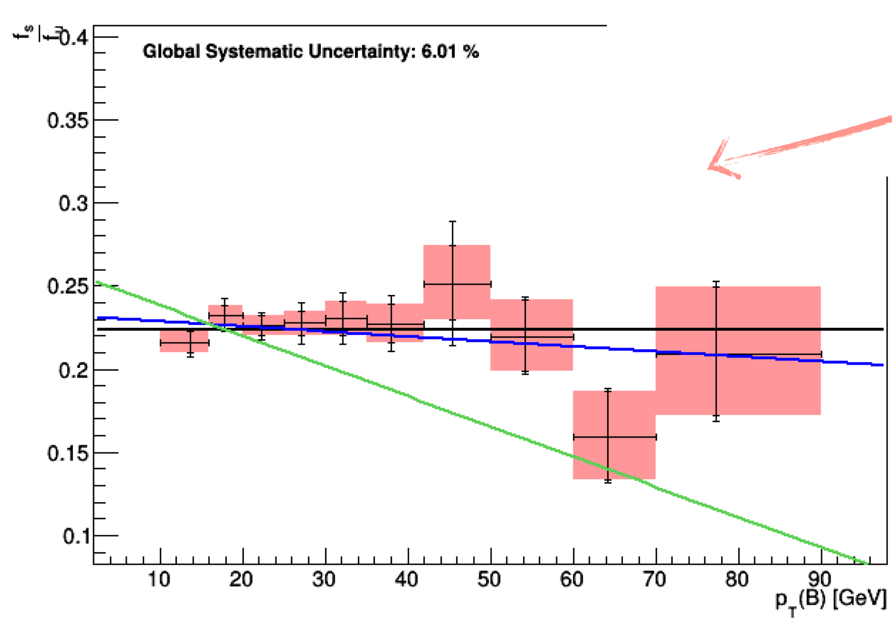
B.Alves, NL

- partial Run2 (2016) + Run1 datasets
  - $B_s \to \mu\mu$: 5.6σ observation (CMS alone)
  - $B^0 \to \mu\mu$: improved upper limit
  - compatible with SM
- fragmentation fraction ratio
  - a dominant systematics
  - studied in Brunos' thesis

arXiv:1910.12127, subm. JHEP
CERN-THESIS-2019-25

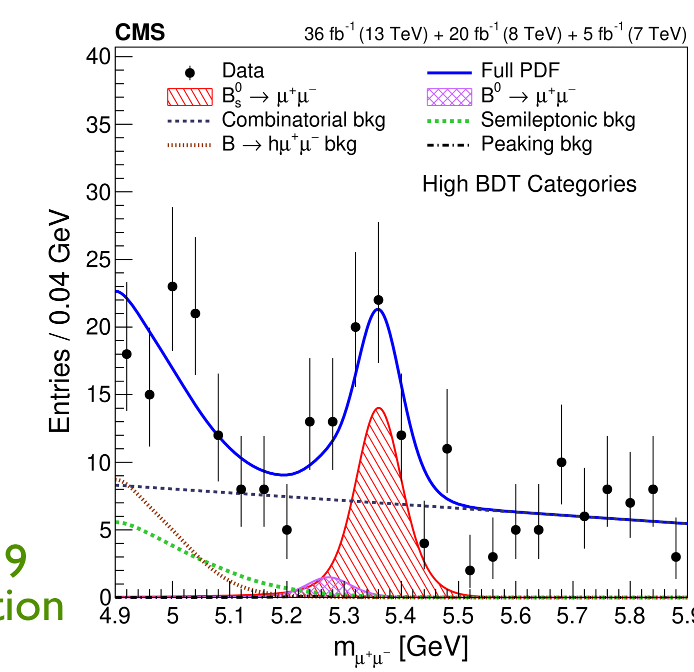


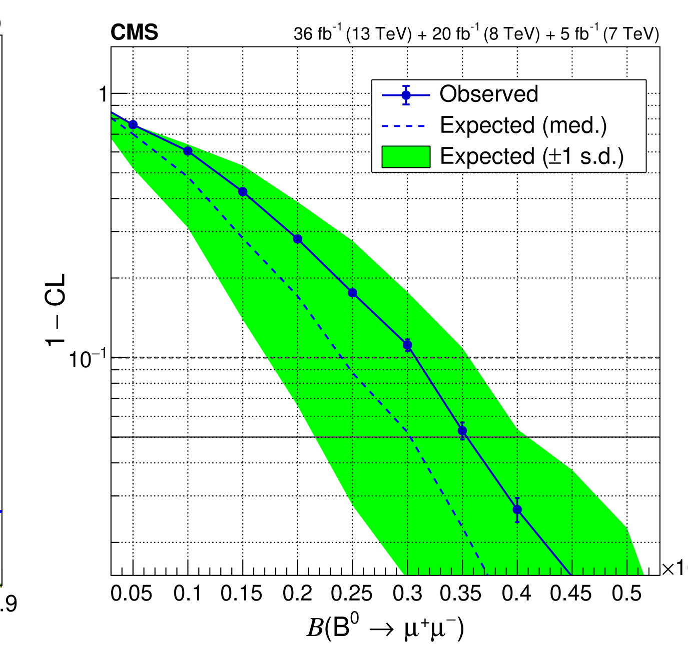
$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = \frac{N_S}{N^{B^+}_{obs}} \frac{f_u}{f_s} \frac{\varepsilon^{B^+}_{tot}}{\varepsilon_{tot}} \mathcal{B}(B^+ \to J/\psi K^+)\, \mathcal{B}(J/\psi \to \mu^+\mu^-)$$



CMS

LHCb'2019 extrapolation

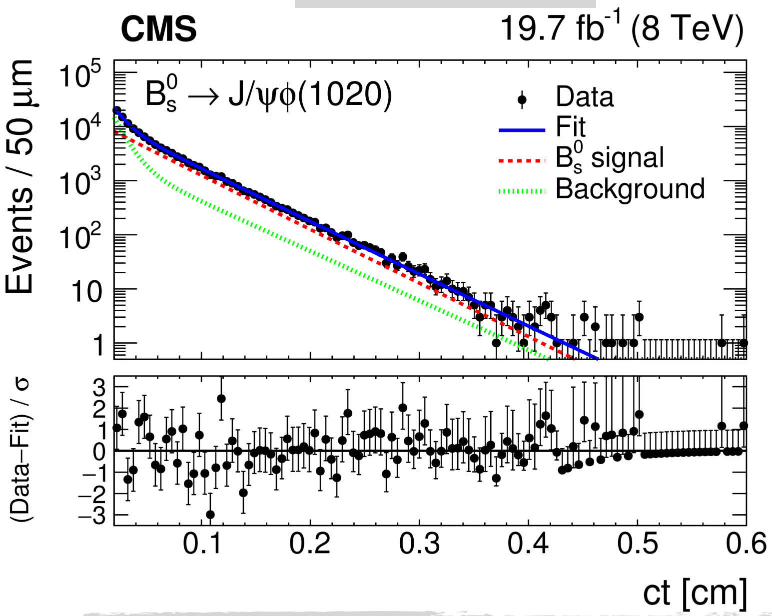




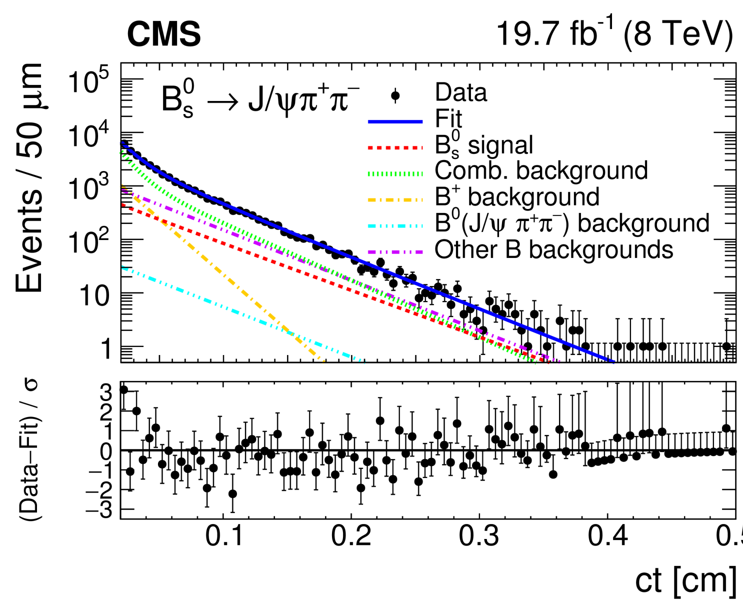
B→μμ | effective lifetime

- effective $B_s \to \mu\mu$ lifetime provides complementary sensitivity for NP
  - in SM only heavy eigenstate decays to lepton pair ➡ not so in NP scenarios
- first measurement of $\tau(B_s \to \mu\mu)$ by CMS
  - methods established in more abundant channels

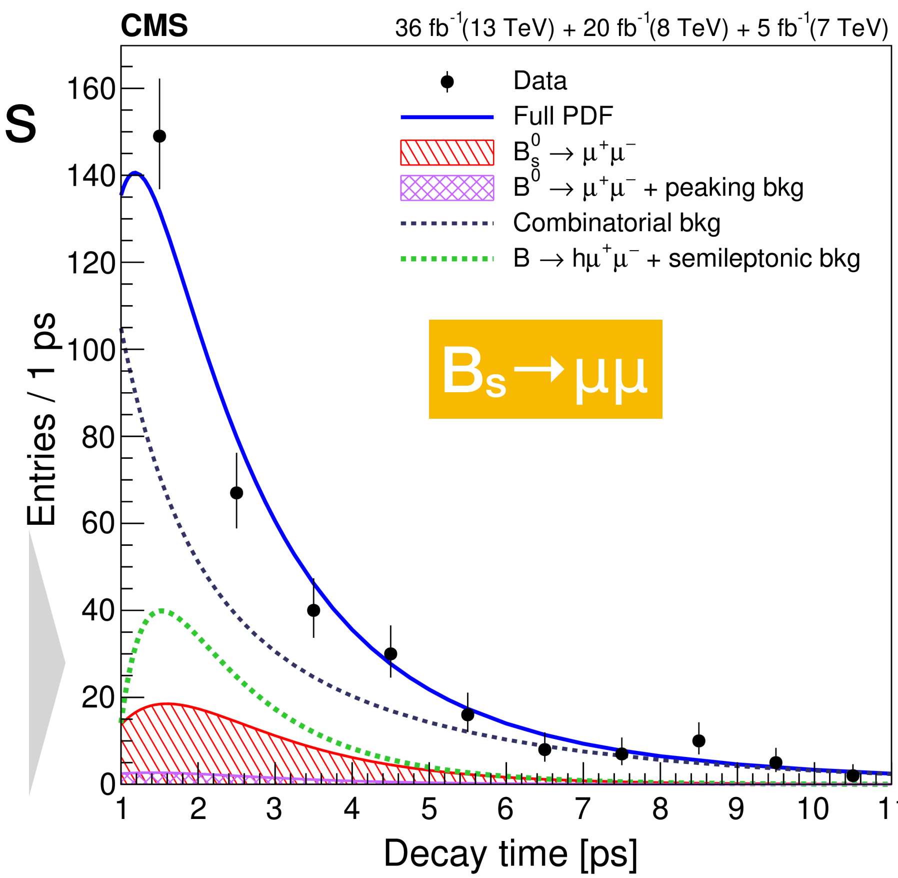
$B_s \to J/\psi\phi$



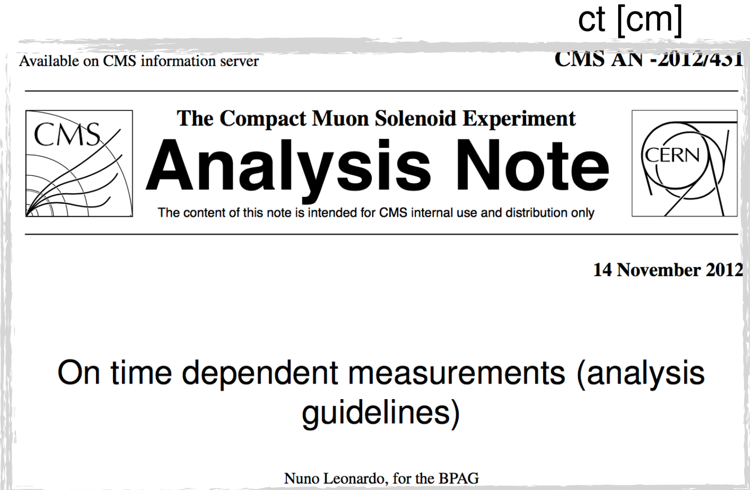
$B_s \to J/\psi\pi\pi$



EPJC 78 (2018) 457



arXiv:1910.12127 (JHEP)


Available on CMS information server CMS AN -2012/431

The Compact Muon Solenoid Experiment

Analysis Note

The content of this note is intended for CMS internal use and distribution only

14 November 2012

On time dependent measurements (analysis guidelines)

Nuno Leonardo, for the BPAG

Competitive precision b-hadron lifetime measurements:

$B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^{*0}$, $B^0 \to J/\psi K_s$, $B_s \to J/\psi\phi$, $B_s \to J/\psi\pi\pi$, $\Lambda_b \to J/\psi\Lambda^0$

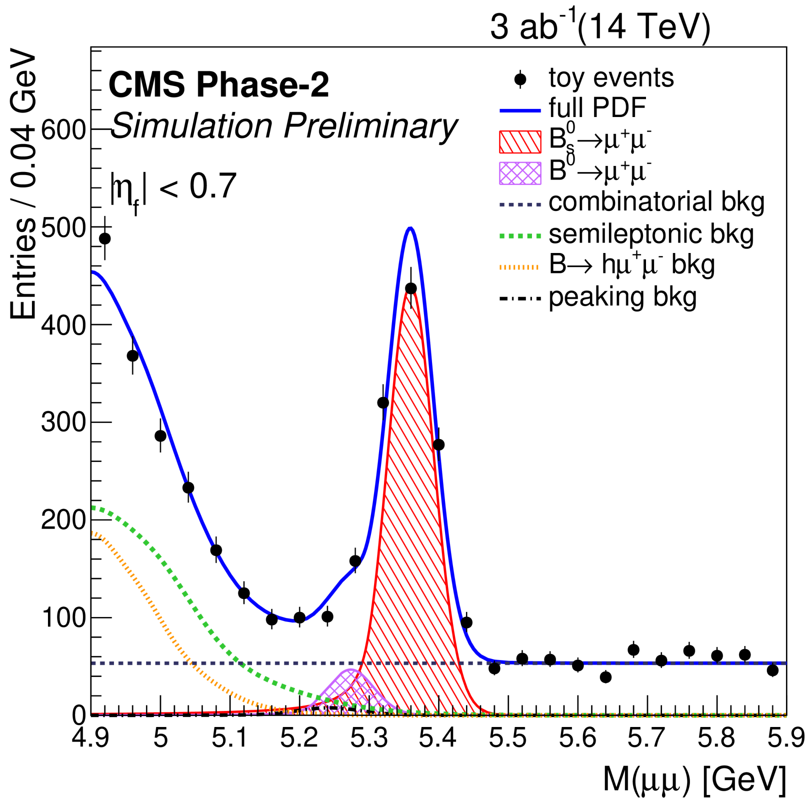
Benchmark for $B_s \to \mu\mu$

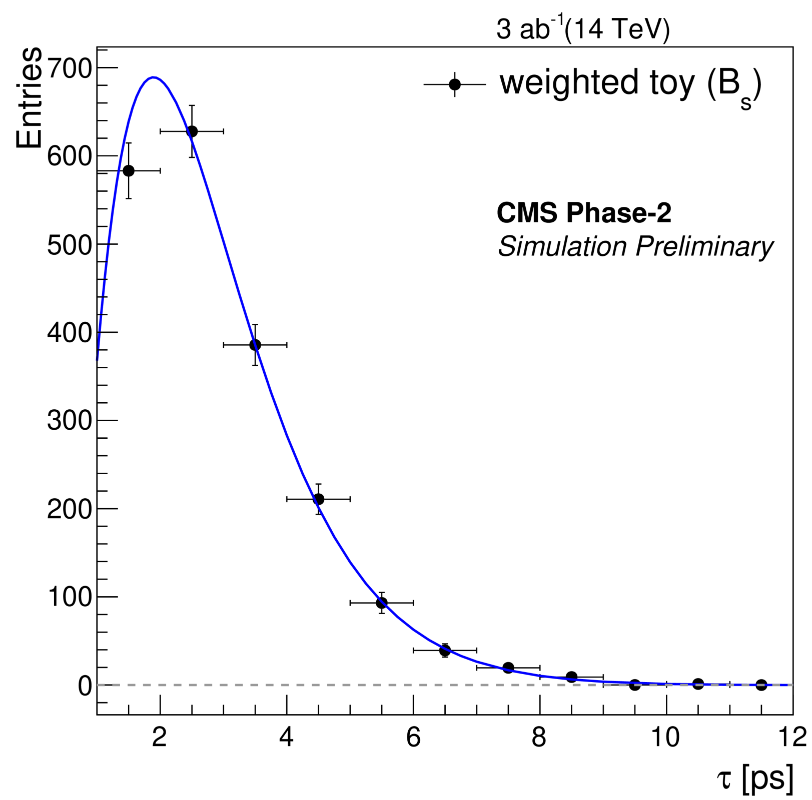
$$\tau_{\mu^+\mu^-} = 1.70\,^{+0.61}_{-0.44}\ \mathrm{ps} \quad \text{[CMS]}$$

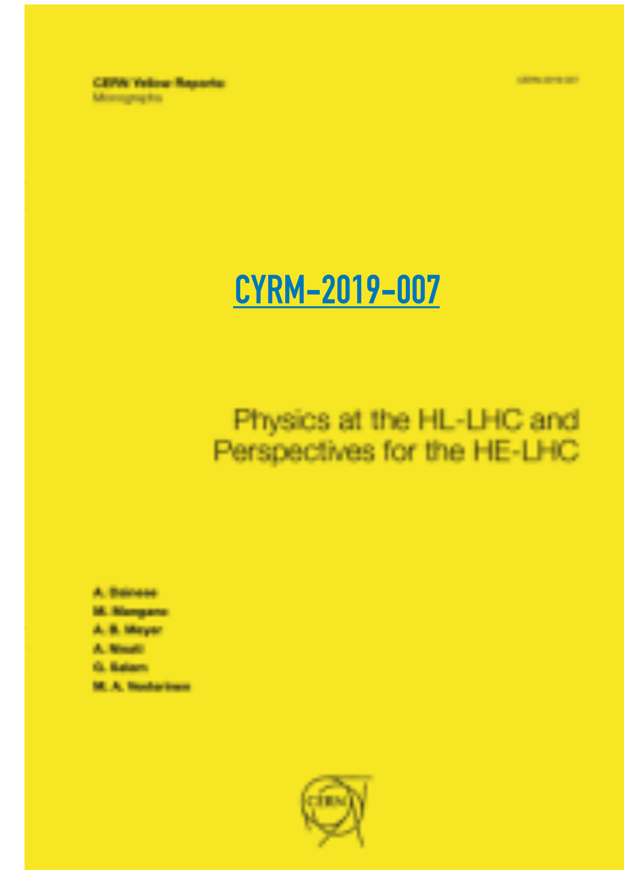
$$\tau_{\mu+\mu-} = 1.615 \pm 0.009\ \mathrm{ps} \quad \text{[SM]}$$

B→μμ | HL-LHC projections

O.Ozcelik, M.Faria, NL







$\mathcal{L}$ (fb^{-1})	$N(B_s)$	$N(B^0)$	$\delta\mathcal{B}(B_s \to \mu\mu)$	$\delta\mathcal{B}(B^0 \to \mu\mu)$	$\sigma(B^0 \to \mu\mu)$	$\delta[\tau(B_s)]$(stat-only)
300	205	21	12%	46%	$1.4 - 3.5\sigma$	0.15 ps
3000	2048	215	7%	16%	$6.3 - 8.3\sigma$	0.05 ps

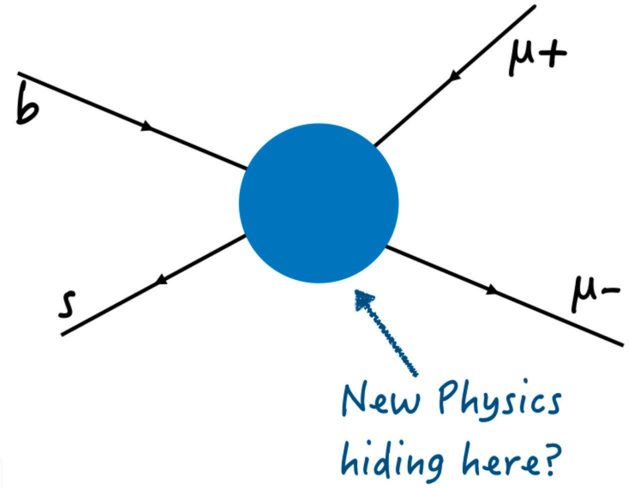
- LIP delivered the CMS B→μμ HL-LHC sensitivity studies
- LIP's contribution to Flavour Physics WG
- Submitted as input to the Update on the European Strategy for Particle Physics

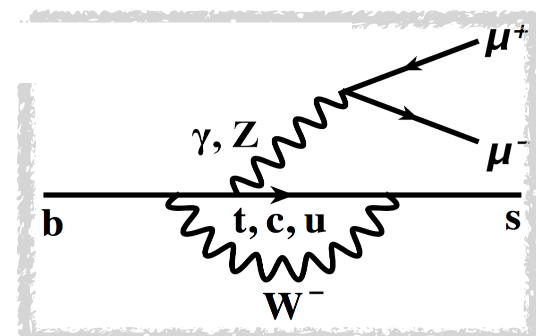
European Strategy Update

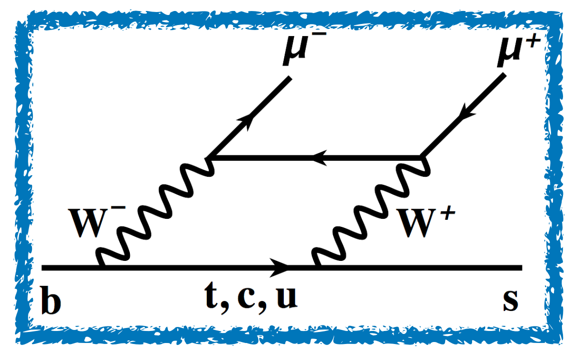
CYRM-2019-007.687
CERN-LPCC-2018-06
February 25, 2019

Opportunities in Flavour Physics at the HL-LHC and HE-LHC

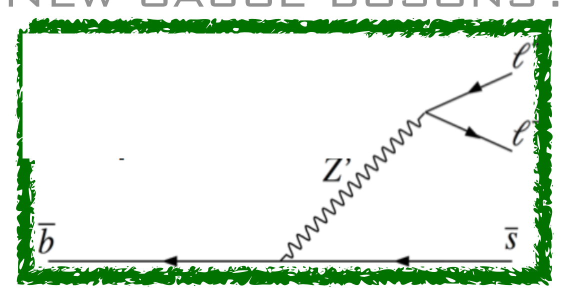
Report from Working Group 4 on the Physics of the HL-LHC, and Perspectives at the HE-LHC



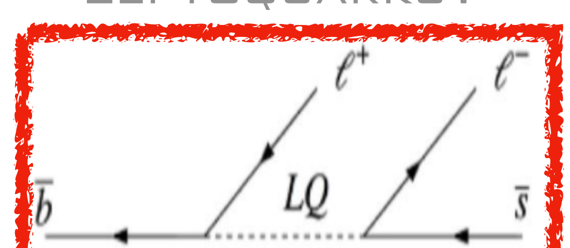




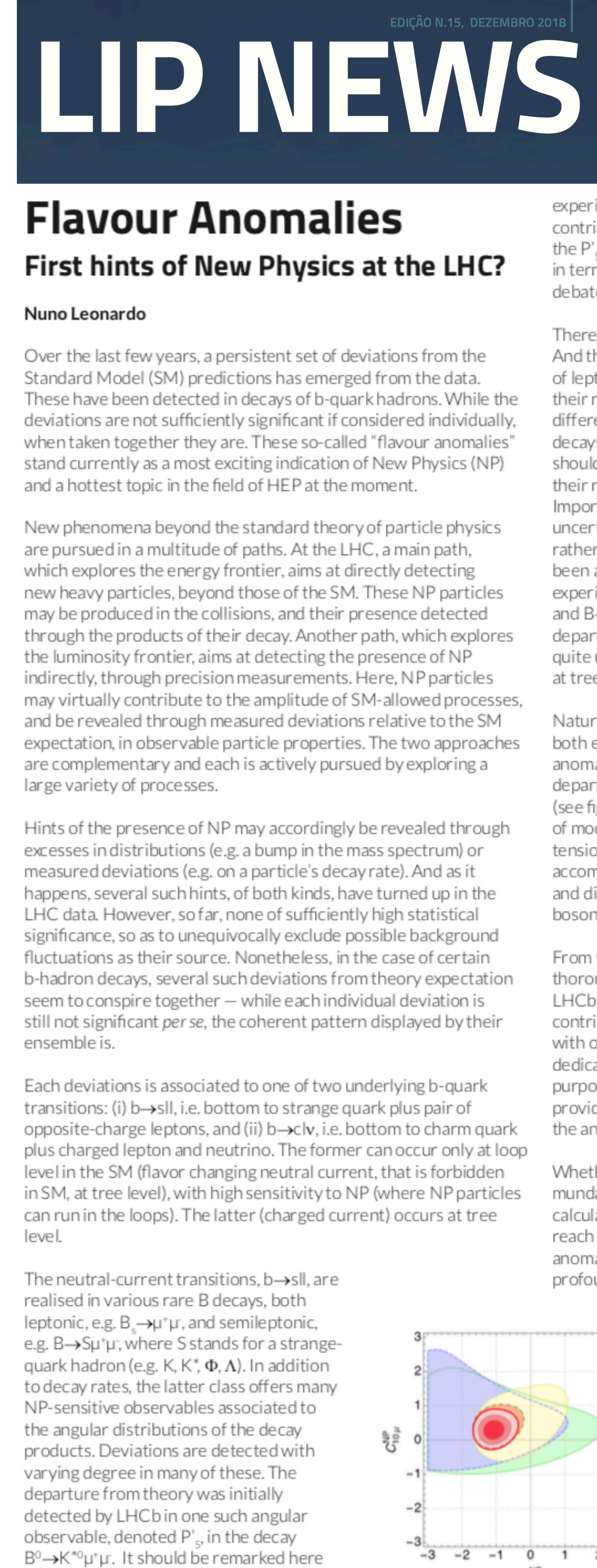
NEW GAUGE BOSONS?



LEPTOQUARKS?



Taken together, the **flavor anomalies** are most significant deviation from SM, and the **strongest indication of NP** in current collider data !


EDIÇÃO N.15, DEZEMBRO 2018
LIP NEWS

Flavour Anomalies

First hints of New Physics at the LHC?

Nuno Leonardo

Over the last few years, a persistent set of deviations from the Standard Model (SM) predictions has emerged from the data. These have been detected in decays of b-quark hadrons. While the deviations are not sufficiently significant if considered individually, when taken together they are. These so-called "flavour anomalies" stand currently as a most exciting indication of New Physics (NP) and a hottest topic in the field of HEP at the moment.

New phenomena beyond the standard theory of particle physics are pursued in a multitude of paths. At the LHC, a main path, which explores the energy frontier, aims at directly detecting new heavy particles, beyond those of the SM. These NP particles may be produced in the collisions, and their presence detected through the products of their decay. Another path, which explores the luminosity frontier, aims at detecting the presence of NP indirectly, through precision measurements. Here, NP particles may virtually contribute to the amplitude of SM-allowed processes, and be revealed through measured deviations relative to the SM expectation, in observable particle properties. The two approaches are complementary and each is actively pursued by exploring a large variety of processes.

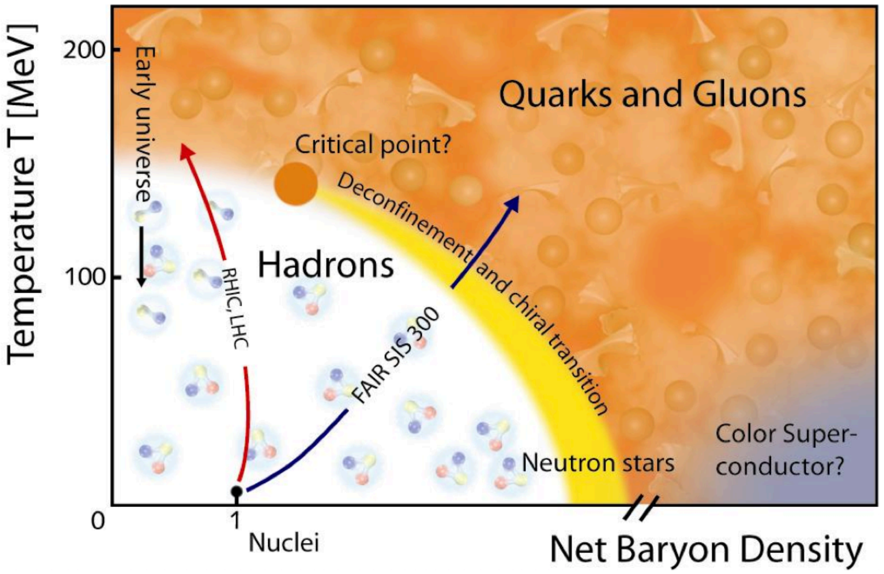
Hints of the presence of NP may accordingly be revealed through excesses in distributions (e.g. a bump in the mass spectrum) or measured deviations (e.g. on a particle's decay rate). And as it happens, several such hints, of both kinds, have turned up in the LHC data. However, so far, none of sufficiently high statistical significance, so as to unequivocally exclude possible background fluctuations as their source. Nonetheless, in the case of certain b-hadron decays, several such deviations from theory expectation seem to conspire together — while each individual deviation is still not significant *per se*, the coherent pattern displayed by their ensemble is.

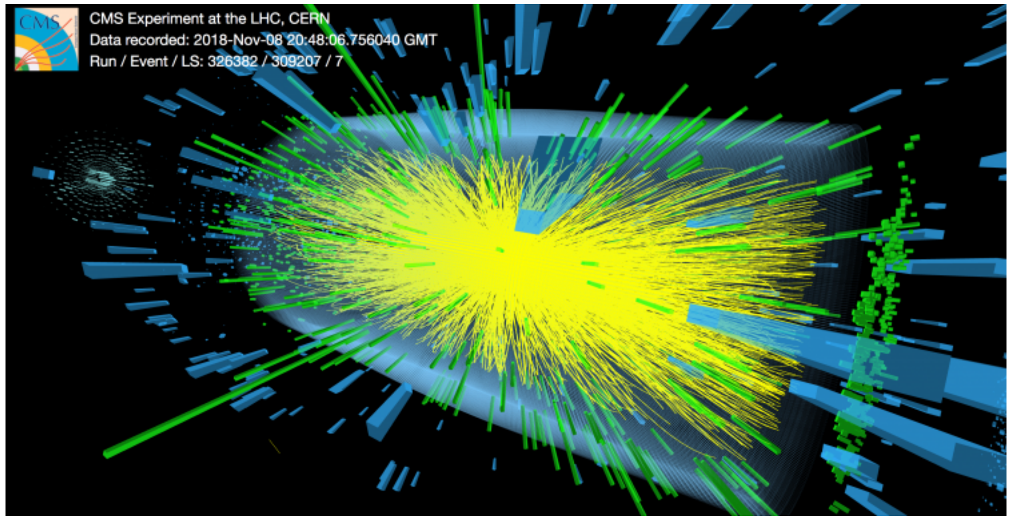
Each deviations is associated to one of two underlying b-quark transitions: (i) b→sll, i.e. bottom to strange quark plus pair of opposite-charge leptons, and (ii) b→clν, i.e. bottom to charm quark plus charged lepton and neutrino. The former can occur only at loop level in the SM (flavor changing neutral current, that is forbidden in SM, at tree level), with high sensitivity to NP (where NP particles can run in the loops). The latter (charged current) occurs at tree level.

The neutral-current transitions, b→sll, are realised in various rare B decays, both leptonic, e.g. $B_s\to\mu^+\mu^-$, and semileptonic, e.g. $B\to S\mu^+\mu^-$, where S stands for a strange-quark hadron (e.g. K, K*, Φ, Λ). In addition to decay rates, the latter class offers many NP-sensitive observables associated to the angular distributions of the decay products. Deviations are detected with varying degree in many of these. The departure from theory was initially detected by LHCb in one such angular observable, denoted P'_5, in the decay $B^0\to K^{*0}\mu^+\mu^-$. It should be remarked here

Heavy ion collisions

probing the QGP with Heavy Flavor

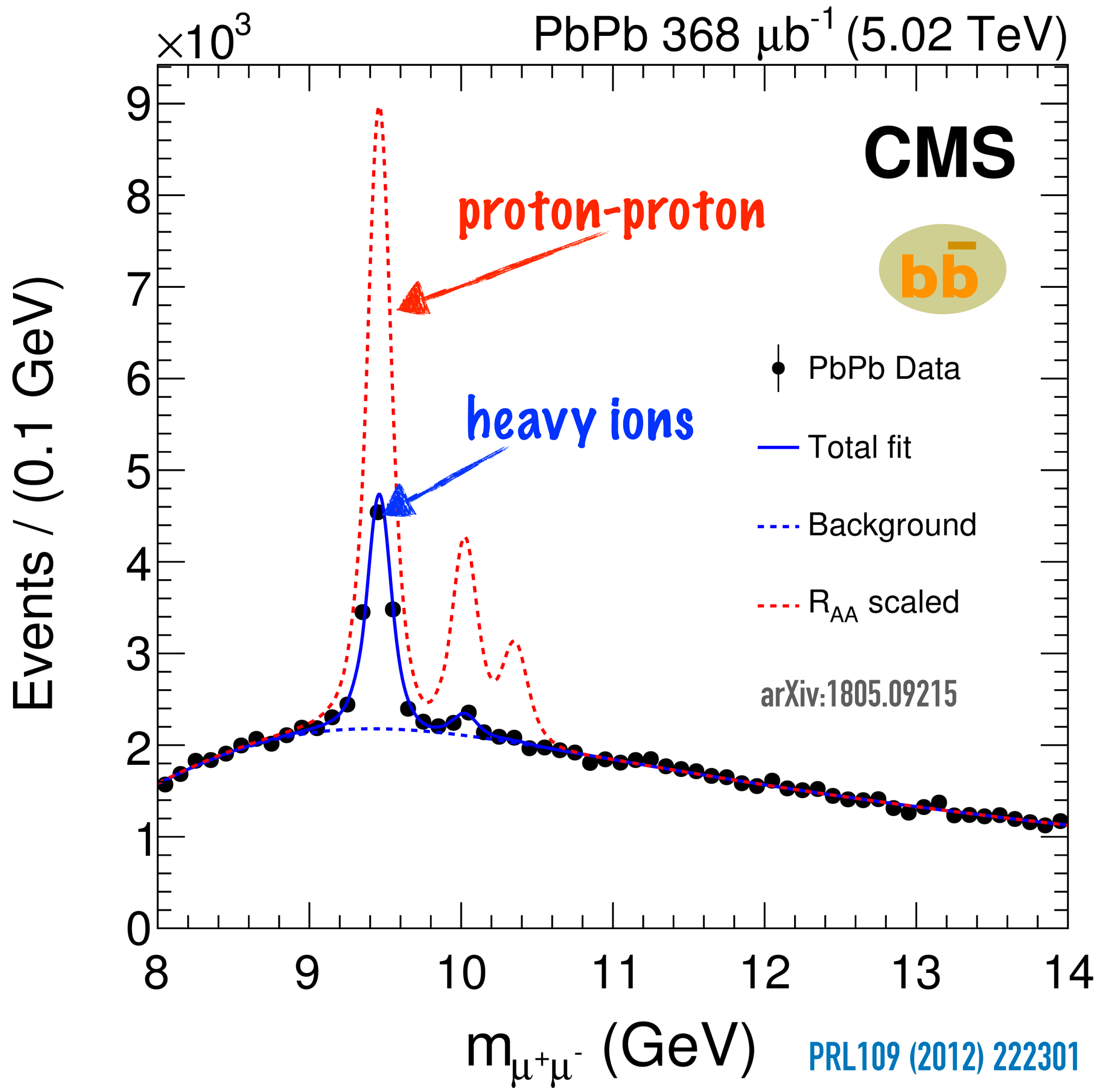




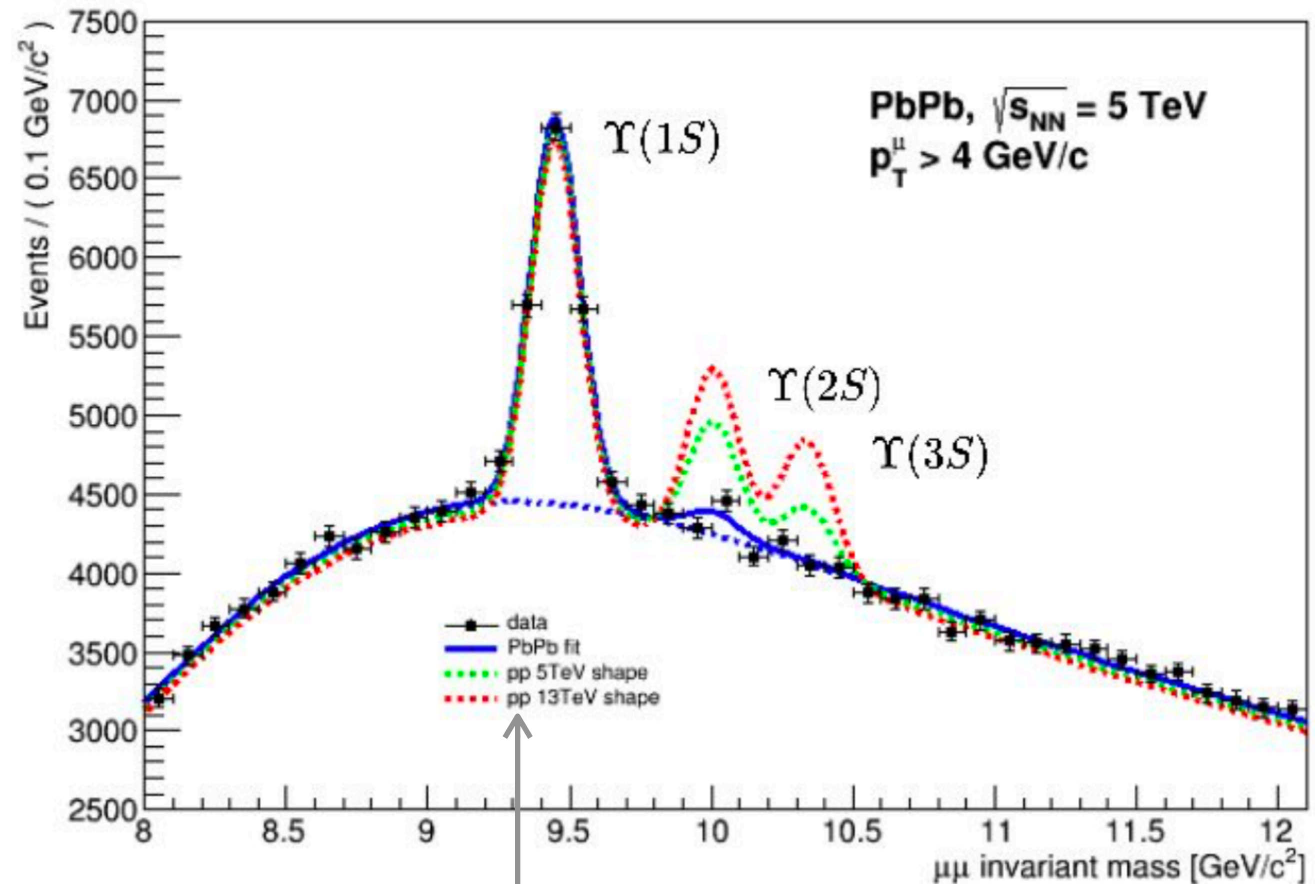
Particles melt in QGP (sequentially!)

J.Lourenço, NL

Run1 observation



Run2 confirmation



Further illustrates the need for reference pp data taken at same collision energy as PbPb

- Flagship observation of **quarkonia** sequential suppression in Run1
- João's summer project confirmation exploring Run2 PbPb vs pp data

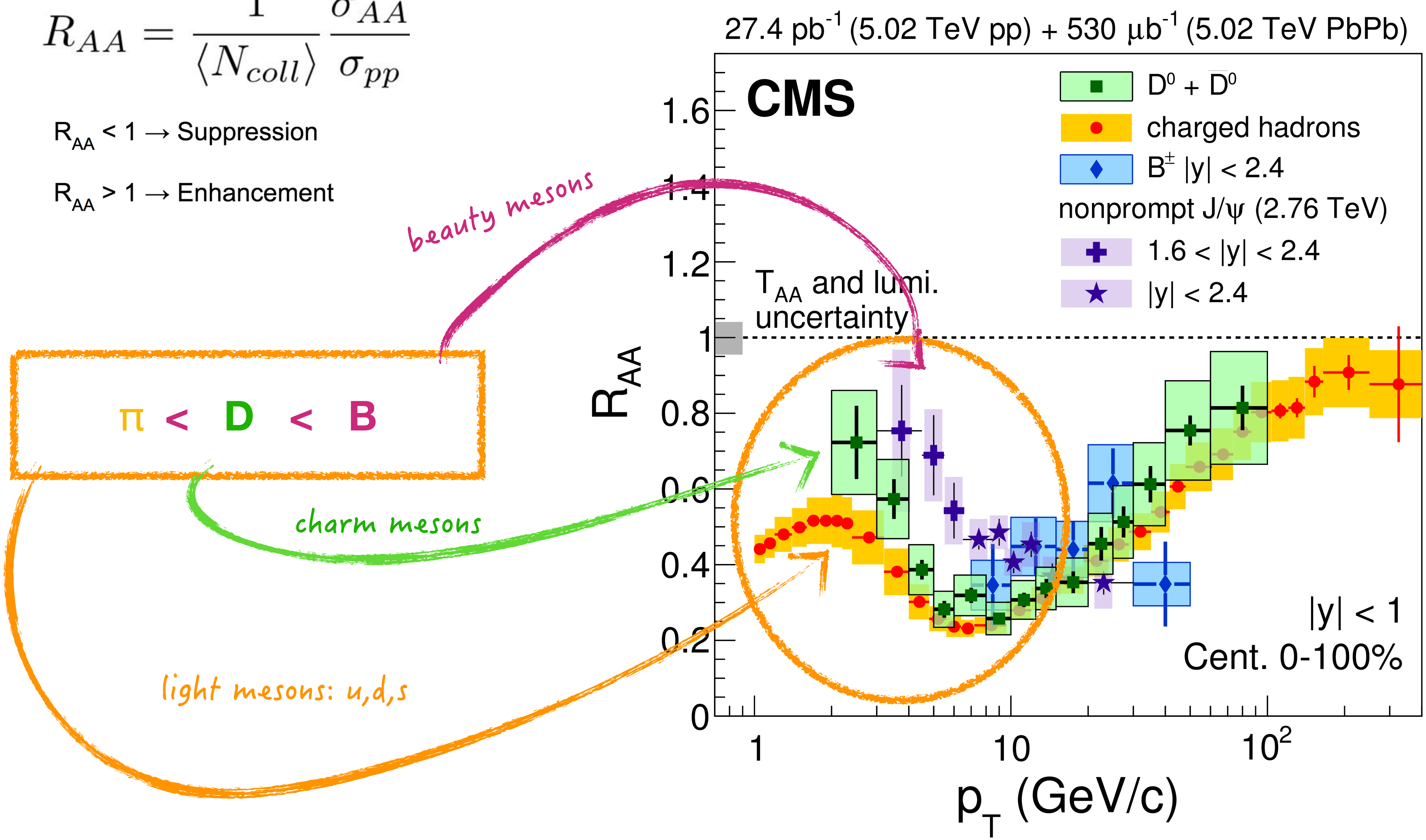
Particles loose energy in QGP (sequentially!)

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{\sigma_{AA}}{\sigma_{pp}}$$

$R_{AA} < 1$ → Suppression

$R_{AA} > 1$ → Enhancement

π < D < B



partons loose energy as they traverse the QGP medium … but heavier quarks loose less!

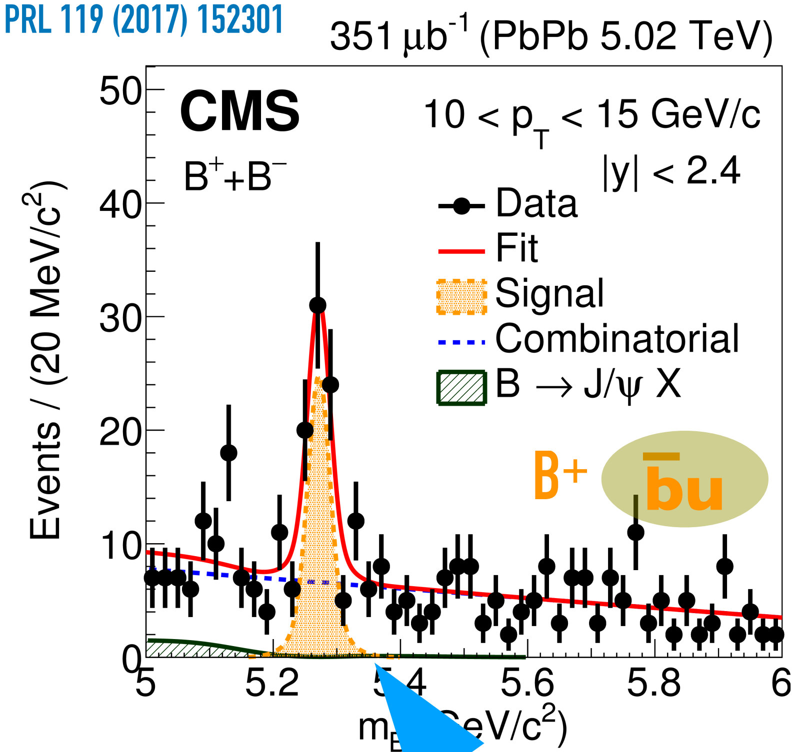
➡ explore fully reconstructed **B hadrons** in heavy ion collisions as **novel probes of QGP**

B mesons observed in nuclear collisions

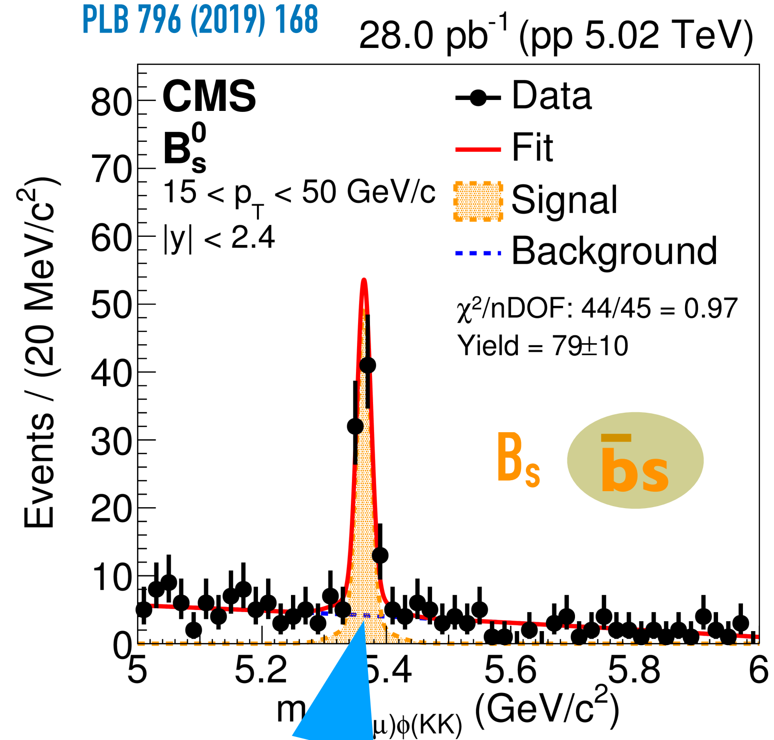
J.Silva (2017), NL

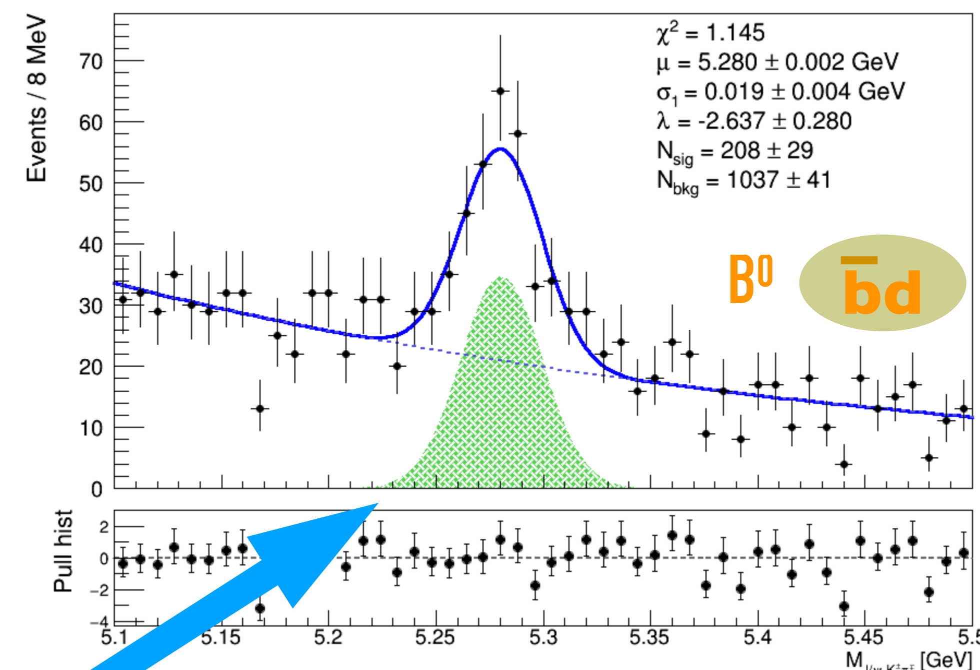
G.Crupi (2019), NL

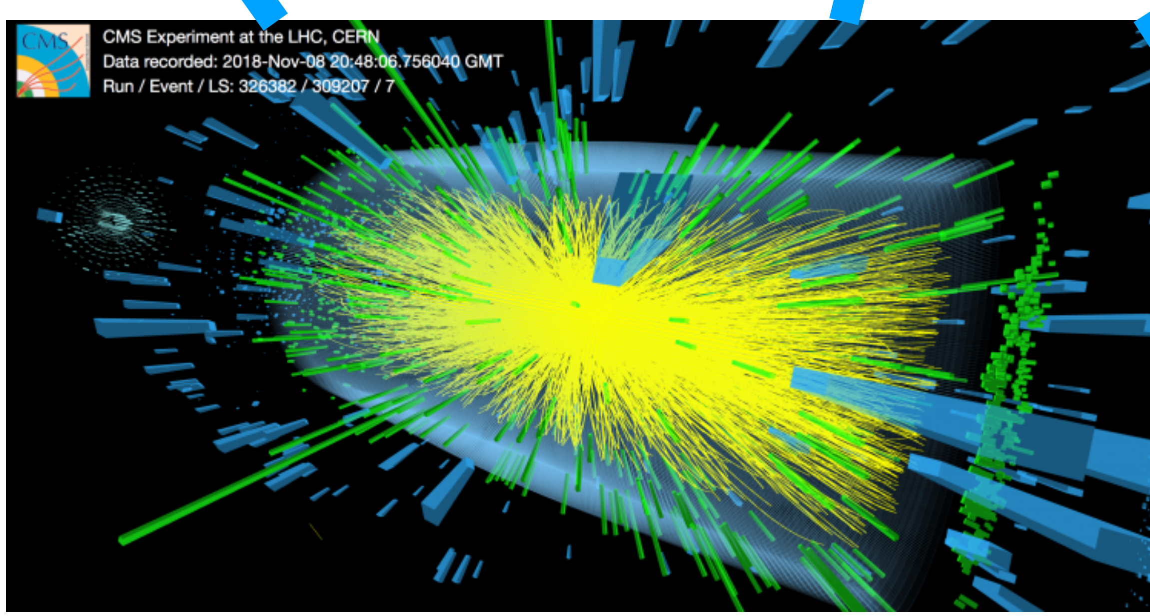
PRL 119 (2017) 152301



PLB 796 (2019) 168





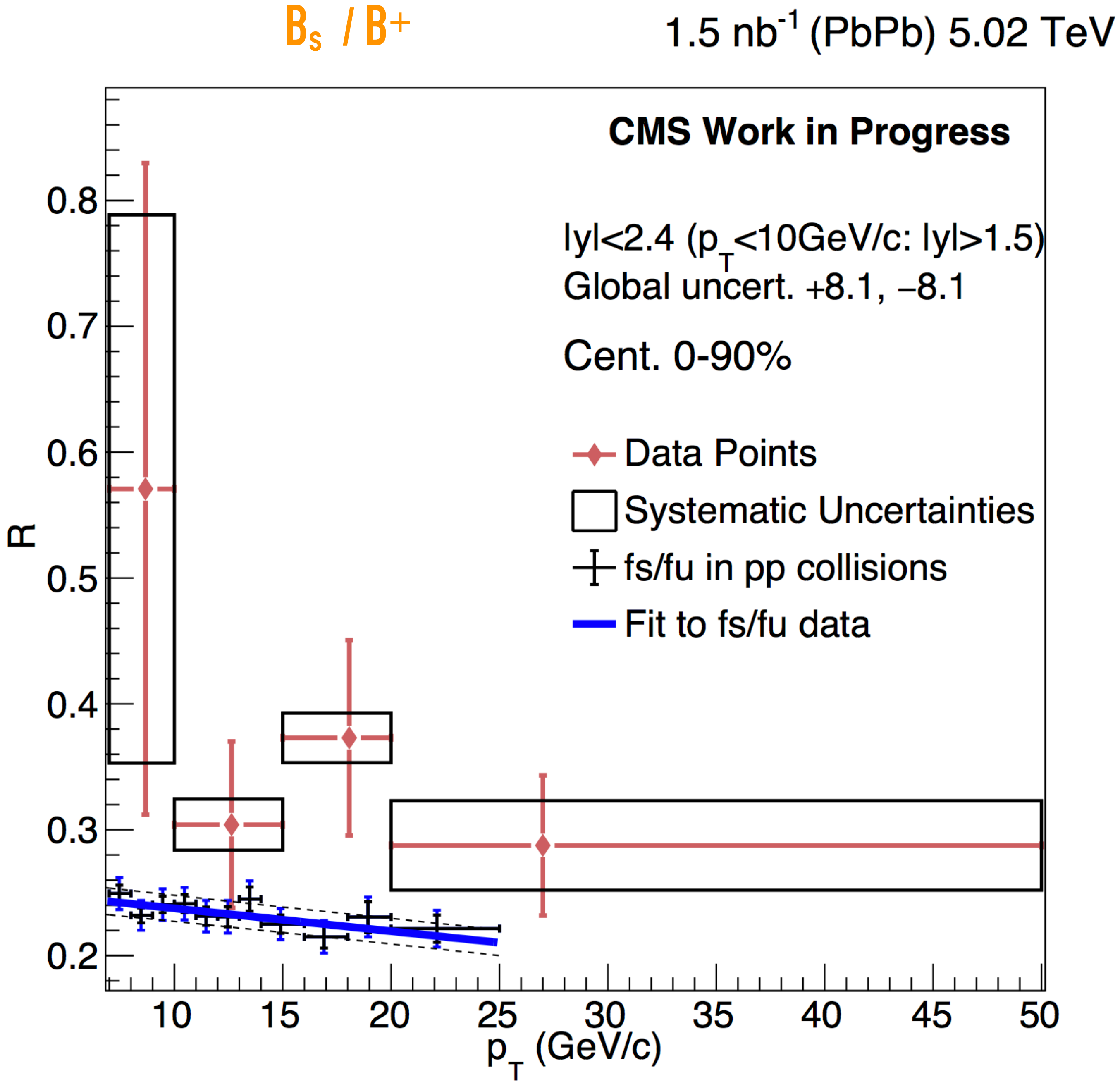


- B(→μμX) decays reconstructed for first time in ion collisions !
- latest is B^0 meson observed (5.2σ) in Giuseppe's internship
- more future PbPb runs / data ➡ probe rarer processes

B_s in QGP: suppressed & enhanced

J.Silva, A.Pardal, J.Gonçalves, NL

B_s / B^+

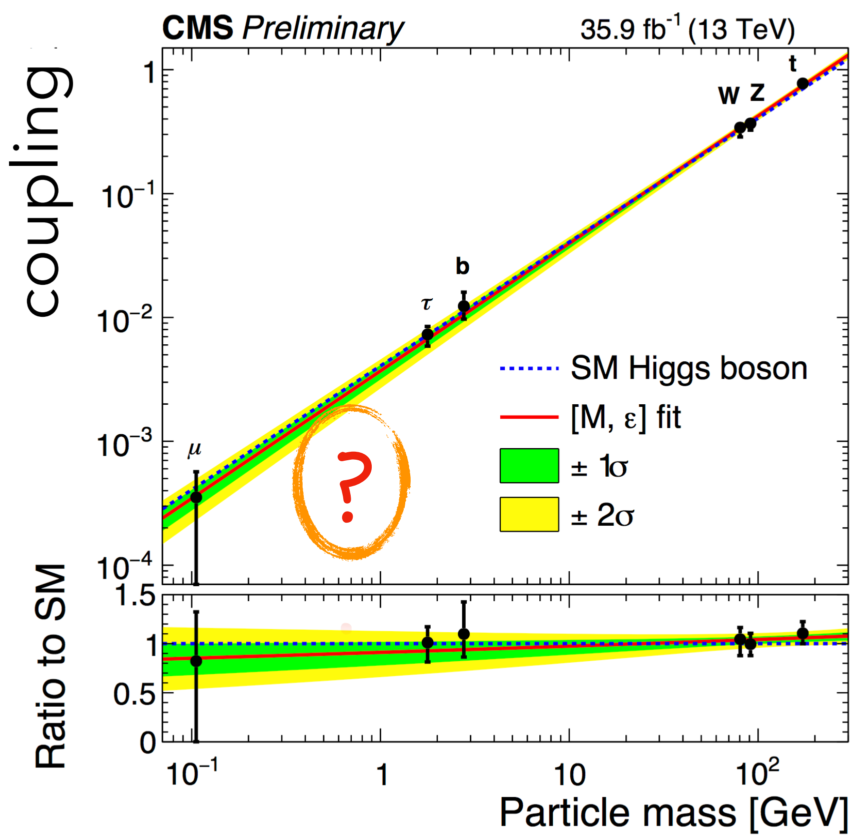


from Júlia's thesis, CERN-THESIS-2018-274

- investigate mass / flavor dependence
- competing effects:
  - energy loss mechanism
  - recombination
- preliminary conclusions
  - B_s and B^+ are suppressed by QGP
    ➡ expected from energy loss
  - B_s production enhanced wrt B^+ in PbPb wrt pp collisions.
    ➡ expected from strangeness enhancement in the QGP
- more PbPb data needed

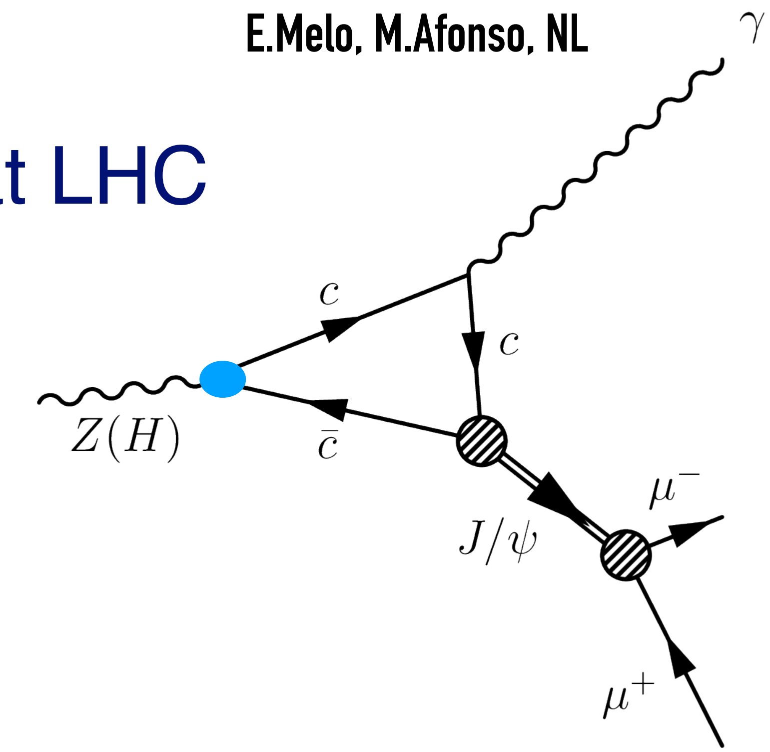
Higgs

& rare Yukawas

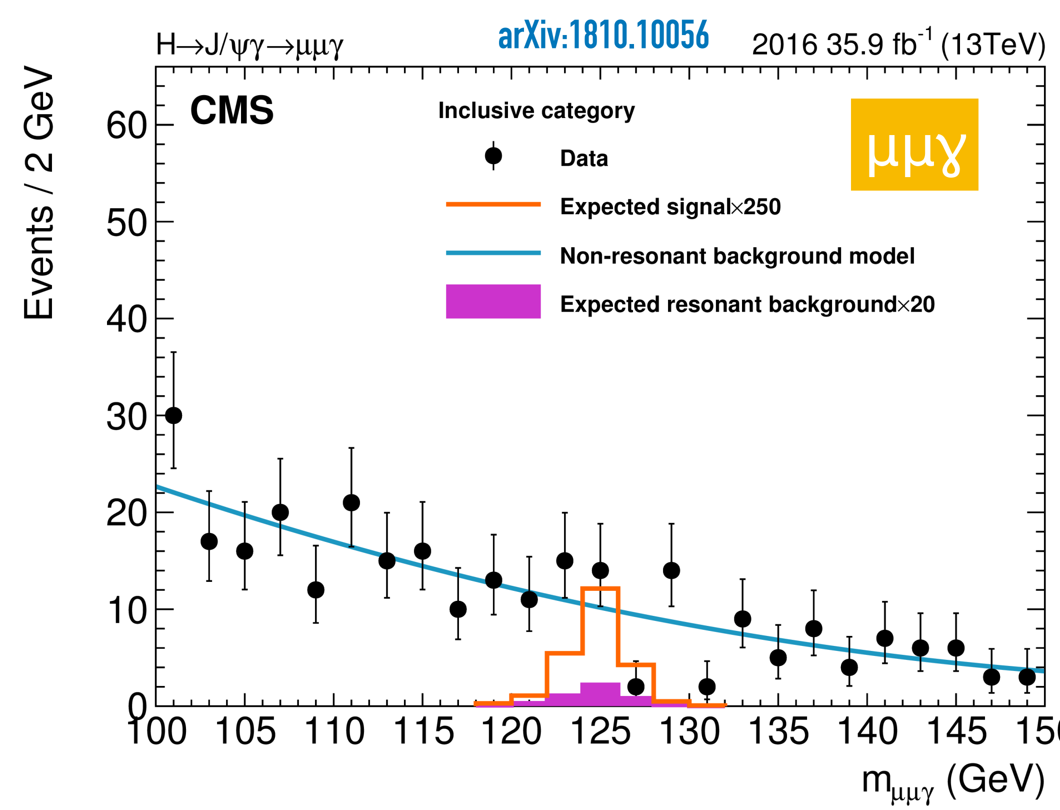


H coupling to beauty & charm?

E.Melo, M.Afonso, NL



- H couplings to light generations challenging at LHC
- inclusive H→qq
  - drawn in overwhelming QCD background
  - requires sophisticated flavour tagging
- exclusive H→Qɣ
  - clean signature, but rare
  - requires dedicated triggers
  - can probe several quarks, H→Υ/ψ/ϕ/ρ+ɣ
- pursuing H→Qɣ and Z→Qɣ
  - 2016 analysis complete
  - targeting full Run2



Currently @CMS
μ(H→cc) < 70 I μ(H→J/ψɣ) < 220