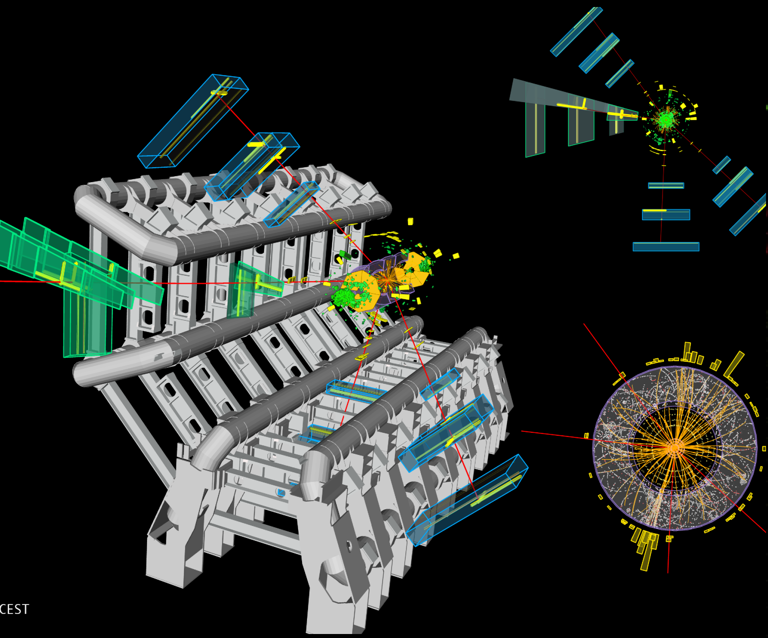
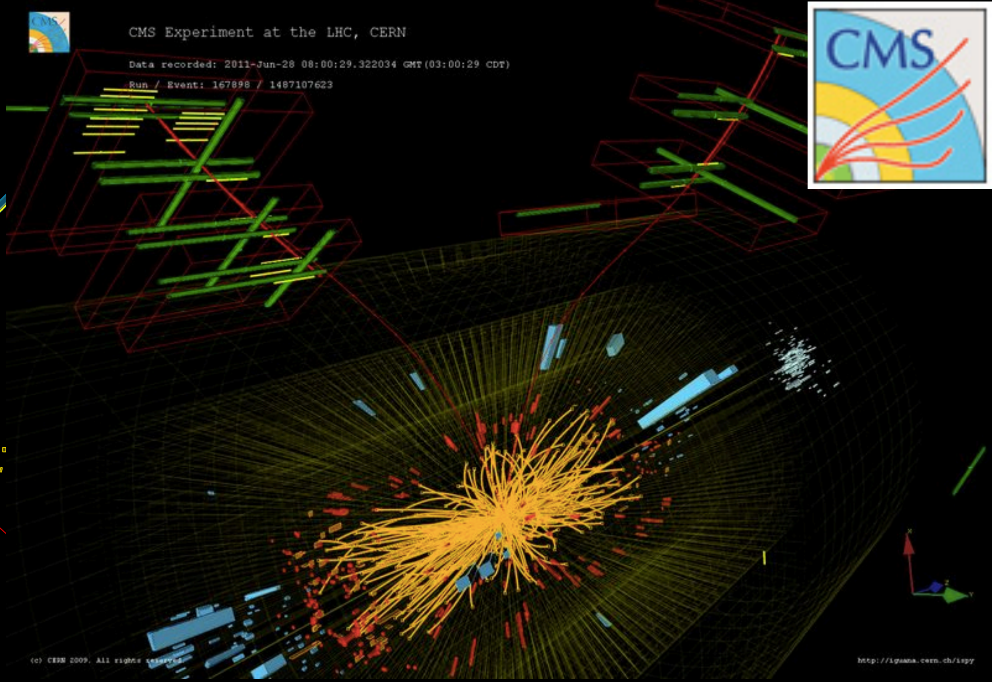
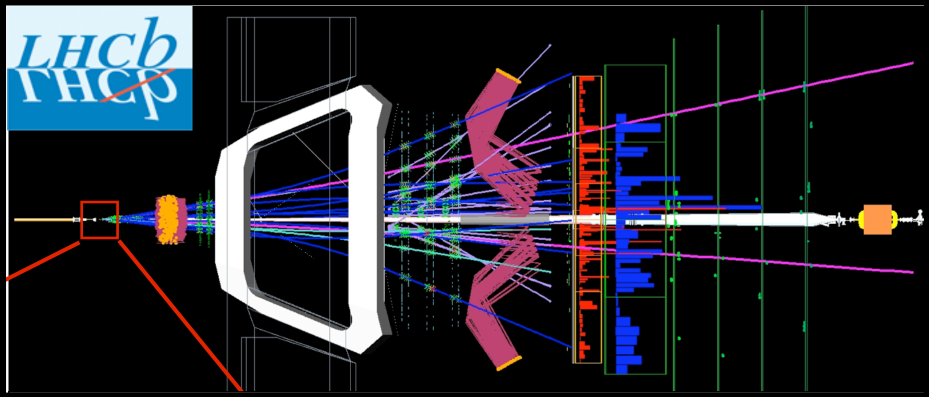
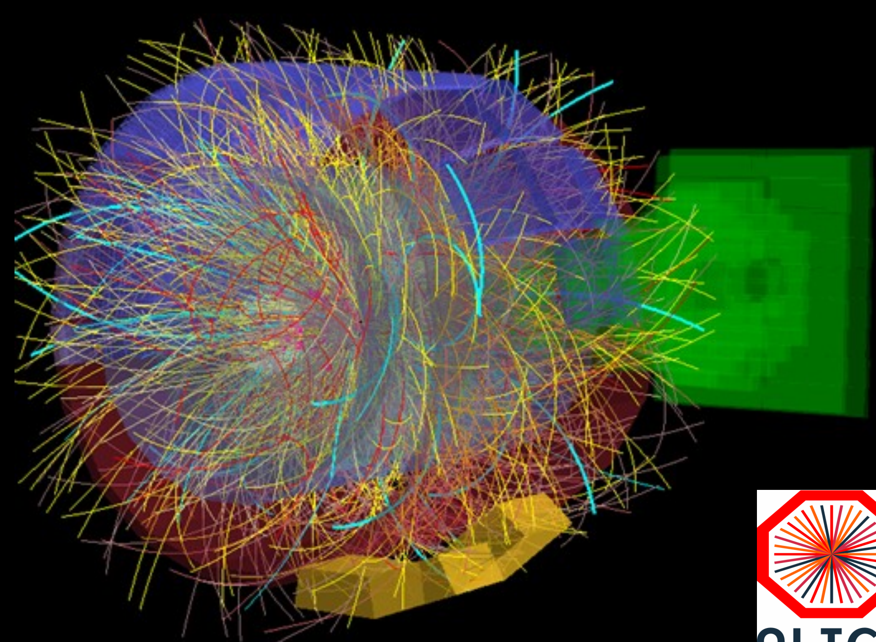




Flavor Physics at LHC





Bruno Touschek Memorial Lectures 2012 - P. Campana (CERN & INFN Frascati)

Flavor Physics at LHC

definition:
study of interactions in b- and c-hadrons produced in pp collisions at LHC

why:
search for new phenomena (New Physics, NP) beyond the Standard Model to explain the ORIGIN OF FLAVOR, one of the unsolved mysteries connected to the origin of fermion generations, the striking hierarchies in the fermion spectrum, the absence of CP violation in strong interactions and the matter antimatter asymmetry (the current level of CP violation being too small by $\sim 10^{10}$)

how:
Heavy Flavor Physics probes large mass scales via virtual quantum "loops" of new particles appearing as corrections to the dominant diagrams ("tree diagram")

where:
looking to very rare decays and searching for unexpected CP violation in b- and c-hadron decays, measuring CKM matrix elements in tree and loops diagrams

Heavy Flavor studies are also important in Pb-Pb collisions (as probes of QGP effects)

LHC : direct vs. indirect searches

The production and detection of new particles at LHC will probe directly the structure of matter and interactions

The goal is to give an answer to the HIERARCHY PROBLEM of Electroweak Symmetry Breaking (stability of SM Higgs under radiative corrections) and to find candidates for the DARK MATTER: the higher the energy available in the collision, the highest the reach in the scale of new masses (DIRECT SEARCHES – ATLAS & CMS)

Any extension of Standard Model must comply with a non-trivial flavor structure (FLAVOR PROBLEM): Flavor is now generally viewed as a key ingredient of any BSM theory, which may help to discover NP and decipher its nature

High precision measurements on "low energy" rare process potentially affected by virtual quantum corrections from new particles may offer alternative insights (INDIRECT SEARCHES - LHCb)

This technique has been used since long time in particle physics with great success

A tiny effect with great consequences

PHYSICAL REVIEW — VOLUME 72, NUMBER 3 — AUGUST 1, 1947

Fine Structure of the Hydrogen Atom by a Microwave Method* **

WILLIS E. LAMB, JR. AND ROBERT C. RETHERFORD
Columbia Radiation Laboratory, Department of Physics, Columbia University, New York, New York

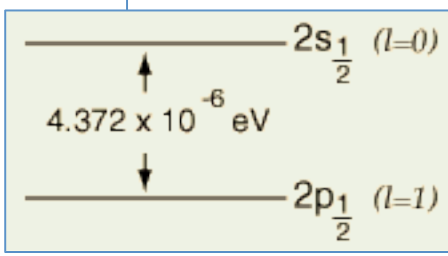
(Received June 18, 1947)

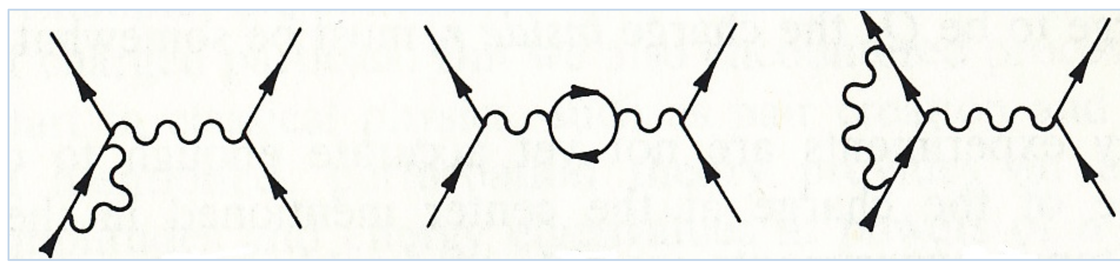
PHYSICAL REVIEW — VOLUME 72, NUMBER 4 — AUGUST 15, 1947

The Electromagnetic Shift of Energy Levels

H. A. BETHE
Cornell University, Ithaca, New York

(Received June 27, 1947)



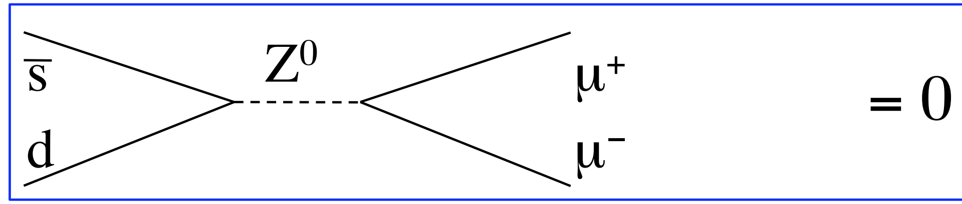


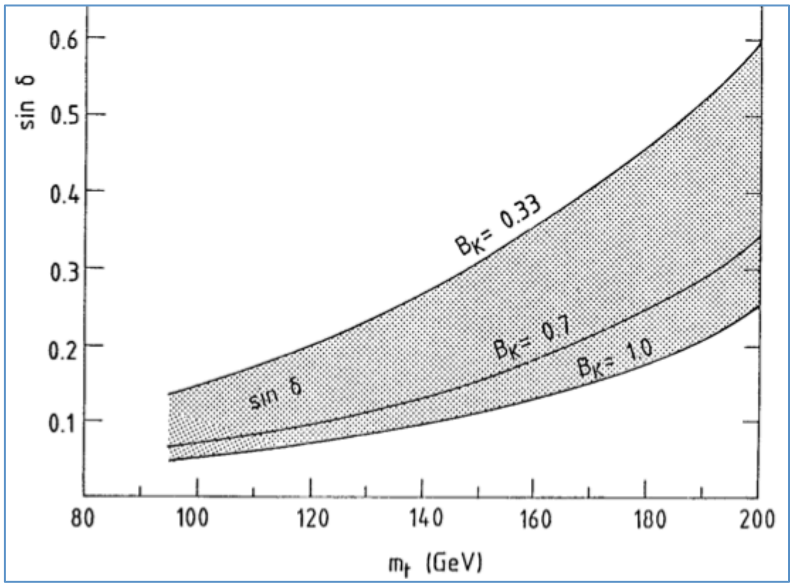
The experimental observation in 1947 of a very small difference in the energy levels of $^2S_{1/2}$ and $^2P_{1/2}$ in H atoms ("Lamb shift") due to quantum virtual effects ("loops") has brought to the development of modern QED (Schwinger, Feynman, Tomonaga - Nobel prize in 1955)

New Physics from (ultra) low energy precise measurements !

Indirect searches: a bright recent past

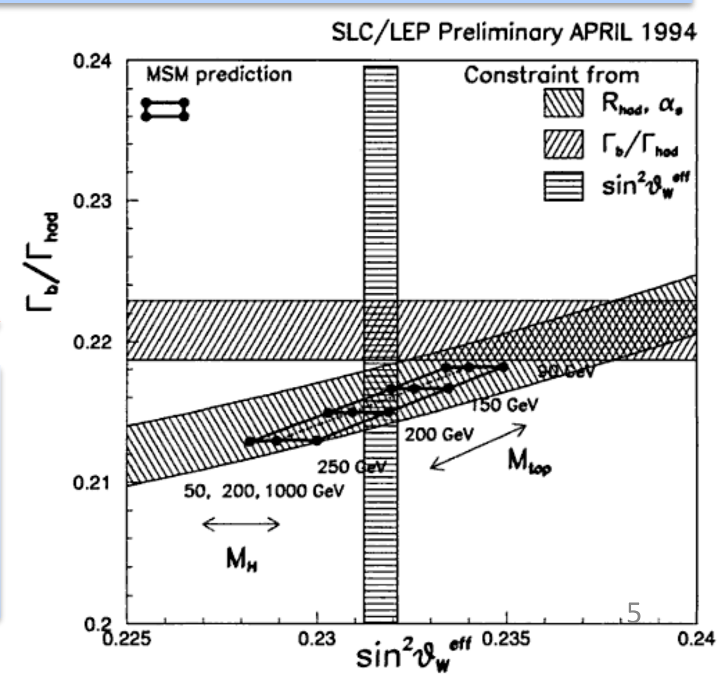
1970: GIM mechanism (hypothesis of c quark) to explain the absence of $K_L \rightarrow \mu\mu$ decay. SU(2) quarks doublets





1987 ARGUS (DESY): the measurement of oscillations frequency of B^0 – anti B^0 system suggested a very high mass of top quark (at least > 50 GeV)

1994 LEP experiments (CERN): the fit to the Γ_b and sin θ_W electroweak parameters imposed strong constraints on M_{top} (found directly in 1995 at Fermilab)



Flavor structure in the SM and beyond

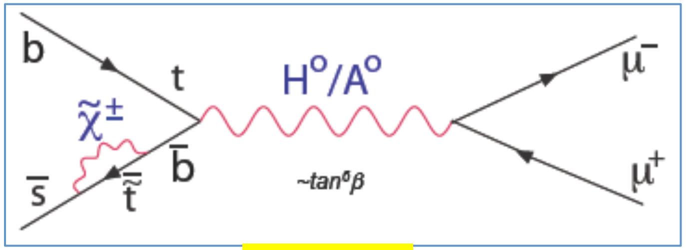
In the extensions of the Standard Model, additional flavor and CP violation can arise from exchange of new scalar (H+, squarks, …), fermionic (gluinos, t', …) or gauge (Z', W', …) degrees of freedom

However new models must respect strong flavor selection rules otherwise they can lead to excessive Flavor Changing Neutral Currents, unless:

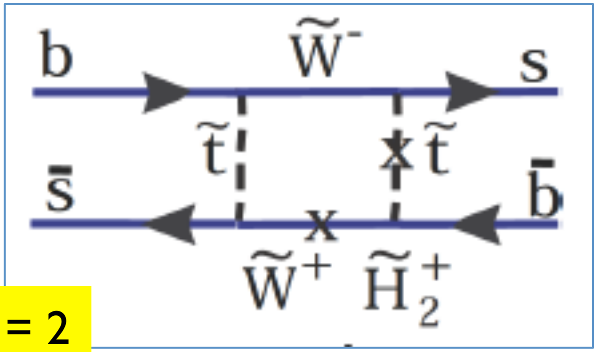
- new particles are very heavy and degenerate: $m_i \gg 1$ TeV ; $\Delta m_{ij} \ll m_i$
- or mixing angles are very small: $U_{ij} \ll 1$

The observed absence of FCNC already now set strong constraints on the TeV-scale physics (higher than those found in direct searches so far , even at LHC)

New Physics could be hidden in quantum corrections to loops in flavor transitions



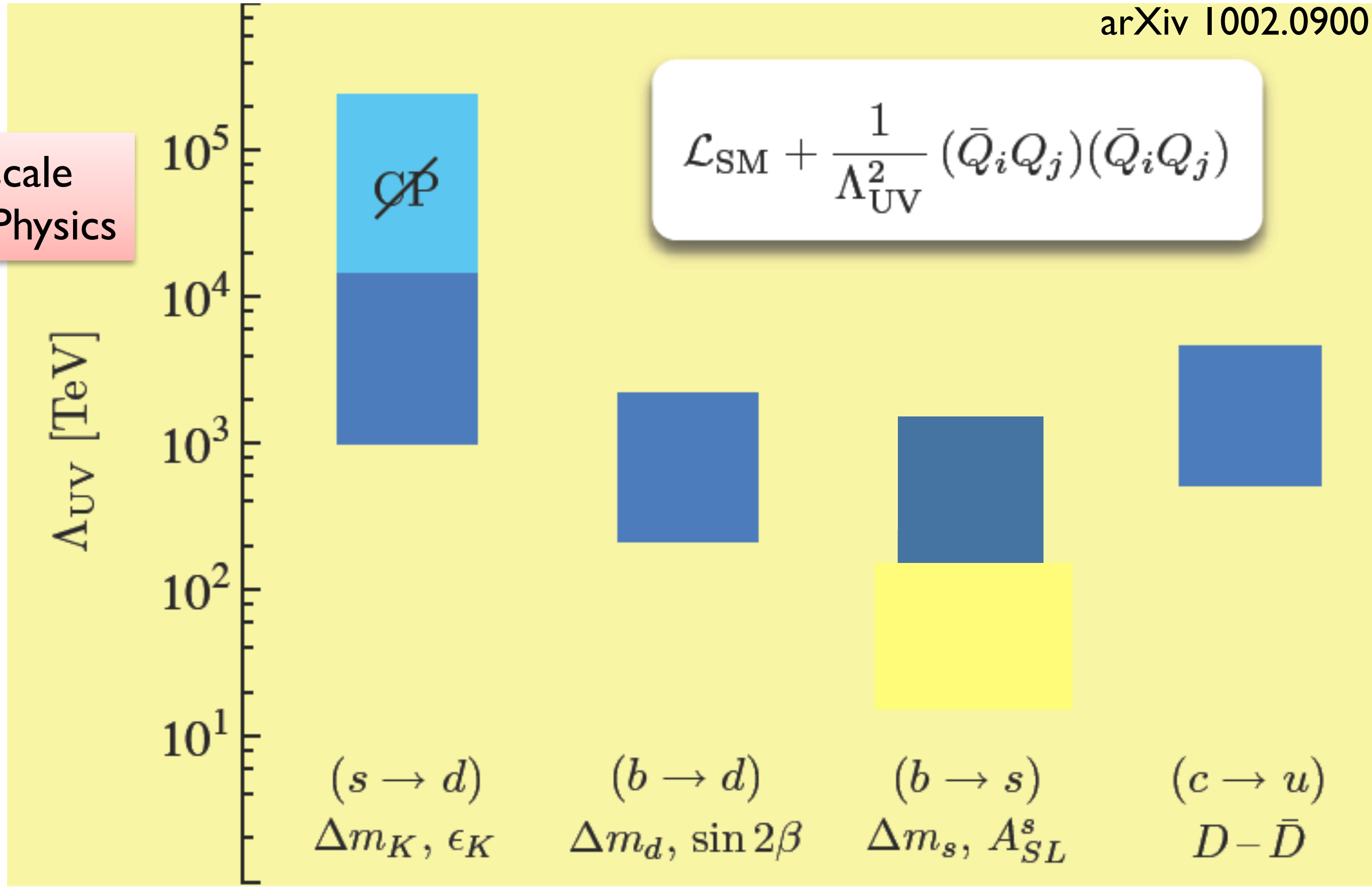
$\Delta F = 1$



$\Delta F = 2$

Present constraints from Flavor Physics

Mass scale of New Physics



CP violation in K system

Oscillations and CPV in B_d system

Oscillations and CPV in B_s system

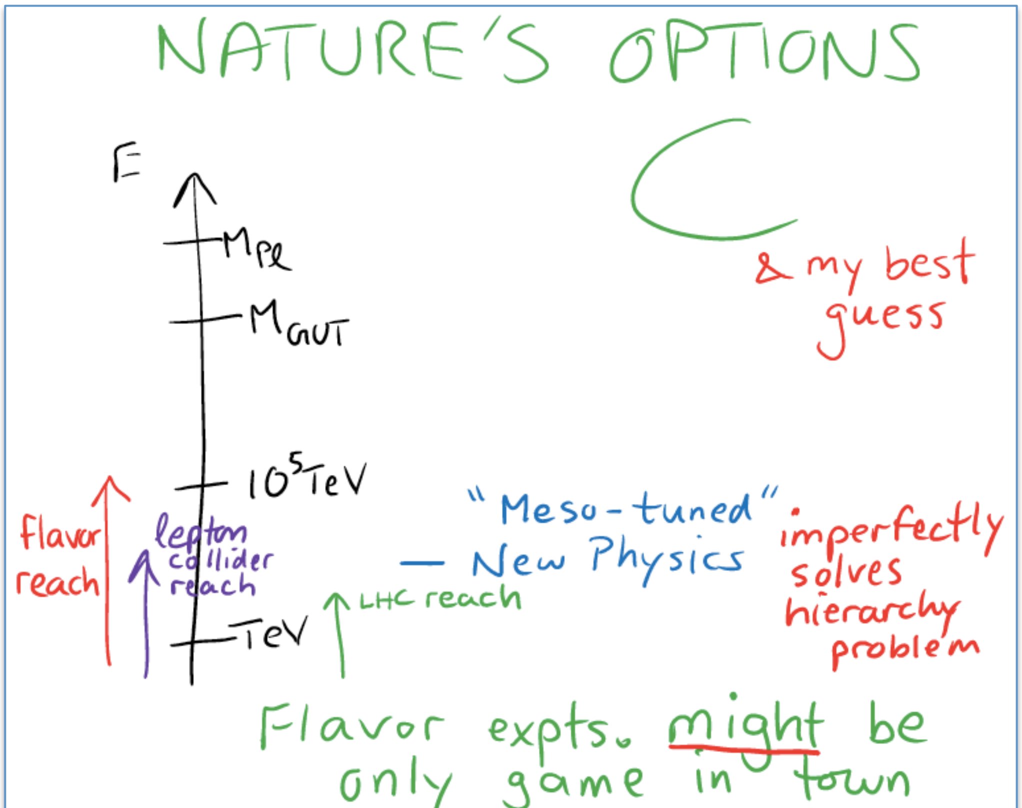
Oscillations in D system

Flavor as a portal to New Physics

Higgs-like particle discovery was a great LHC success, but so far no significant sign of NP in direct searches :

→ energy scale of NP mass scale pushed higher (FLAVOR PROBLEM solved ?)

→ fine tuning needed to protect Higgs mass ? "Naturalness" appears problematic



R. Sundrum CKM2012

Indirect searches have the potential to see NP in flavor phenomena

Precision measurements of FCNC can reveal NP that may be well above the TeV scale (above the LHC reach – one of the possible scenarios)

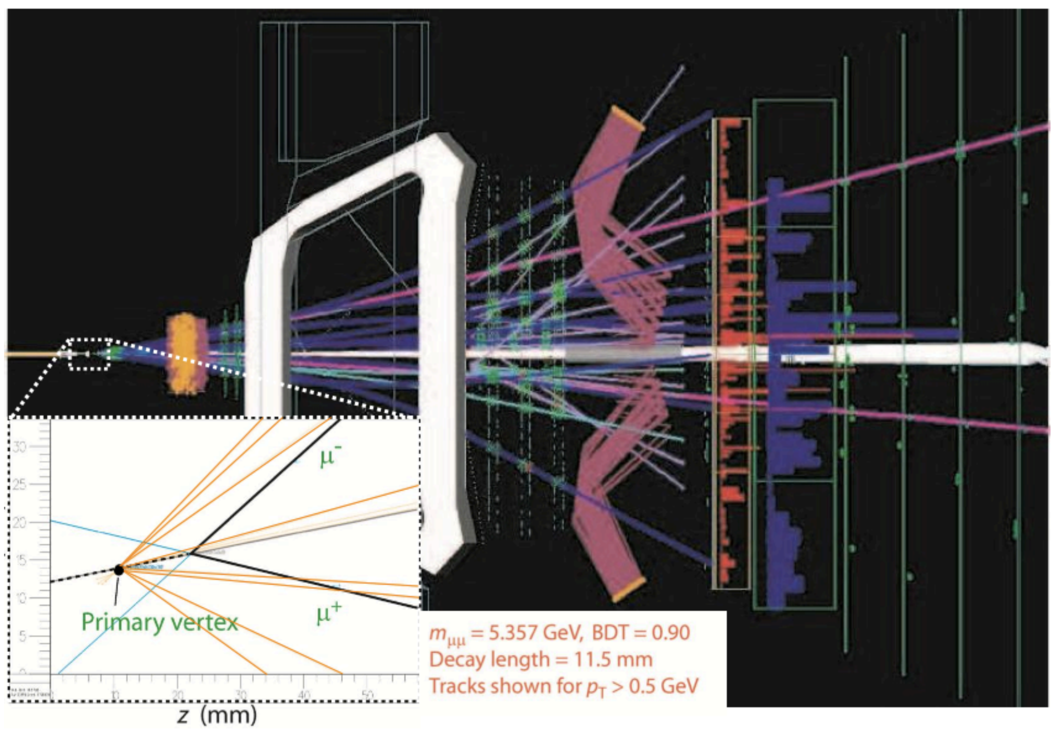
or

can provide key information on the couplings and phases of these new particles if they are visible at the TeV scale.

Why using B mesons ?

In most of the new physics scenarios, large effects are expected in decays of b-quarks (many times new physics effects couple to mass)

B_u , B_d , and B_s mesons are produced abundantly at LHC (together with b baryons)
Long lifetime of b hadrons allow for "easy" experimental detection of decays
Several techniques allow to tag the flavor of the b (b or anti-b)
Large mass of b quark gives phase space to many final states (and daughter particles have high momentum: easier to detect)



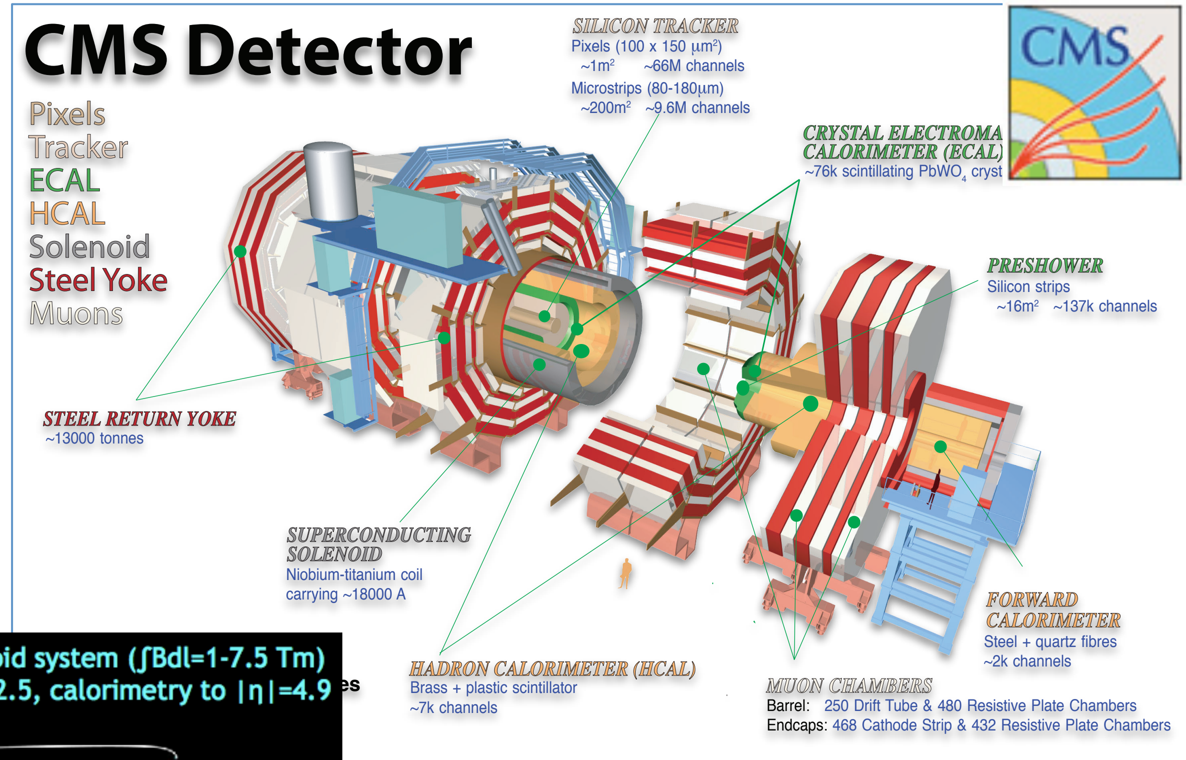
Theoretical predictions in b physics are often accurate (much easier than in lower mass quarks, e.g. charm) and can be compared with experimental observations

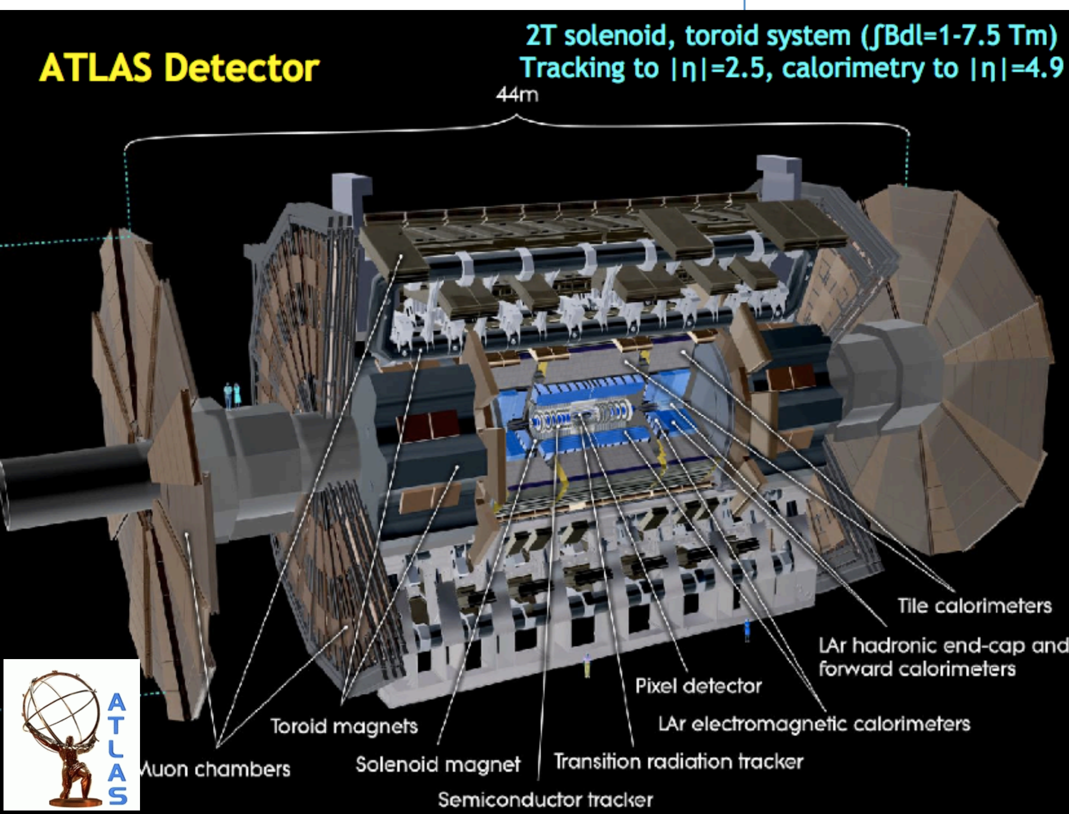
Wealth of data coming from B factories and Fermilab experiments, in a large variety of decay modes

ATLAS and CMS

Main focus on high p_T physics (Higgs and Supersymmetry) but large samples of B events available

Can stand to high luminosity from LHC ~ 7 10^{33} $cm^{-2}s^{-1}$ (now) up to ~ 5 10^{34} $cm^{-2}s^{-1}$ (in future)

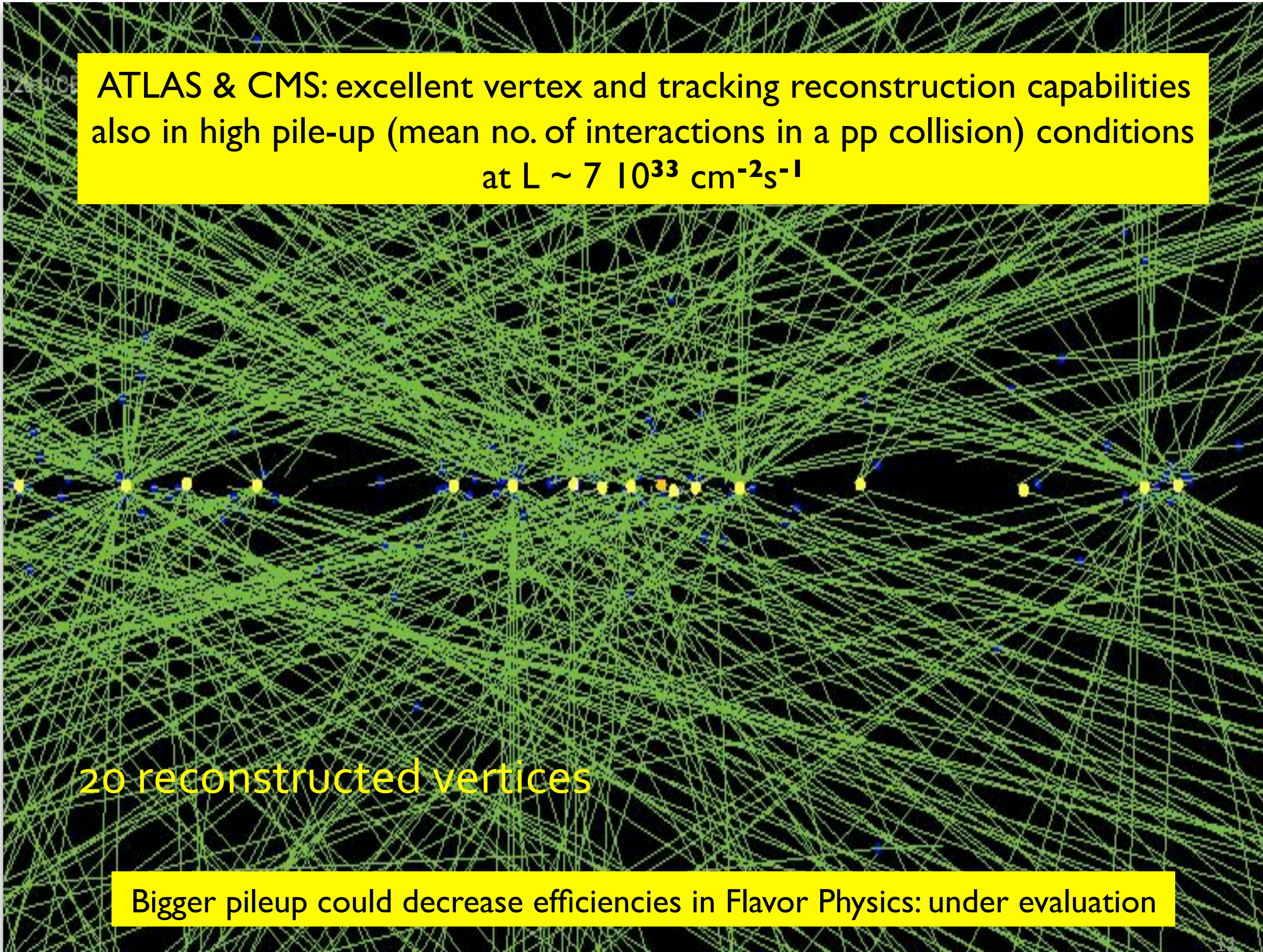




B-hadrons reconstruction mainly exploits excellent vertex detectors (silicon strips and pixels) and muon detectors for precise p measurements

Limited hadron identification, but excellent photon identification

Cuts on medium p_T (4-6 GeV) di-muon final states



ATLAS & CMS: excellent vertex and tracking reconstruction capabilities also in high pile-up (mean no. of interactions in a pp collision) conditions at $L \sim 7\ 10^{33}\ cm^{-2}s^{-1}$

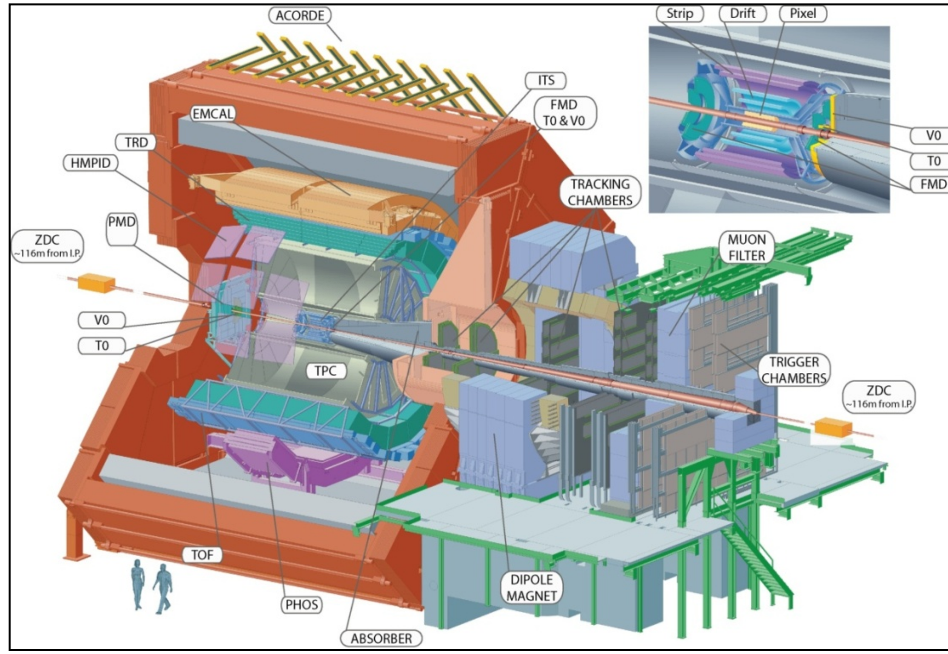
Bigger pileup could decrease efficiencies in Flavor Physics: under evaluation

ALICE (the Little Bang)

Study of QCD phase transition (QGP → hadrons) at t_{Universe} ~10 μs

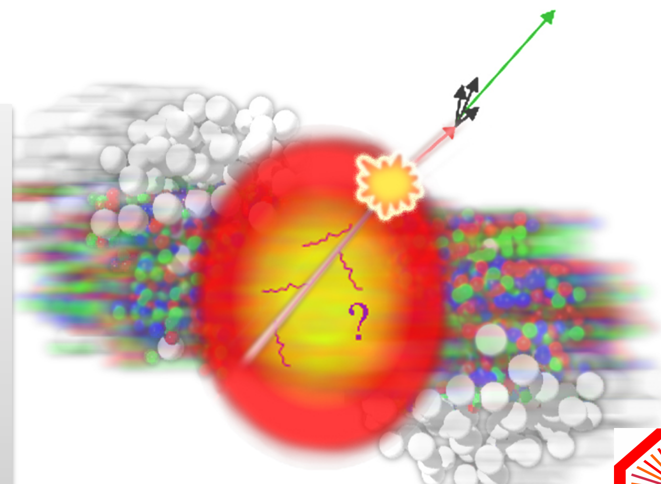
In high-energy Pb-Pb collisions, large energy densities are reached over large volumes (>> 100 fm^3)

Two main parts:
- barrel (|η|<0.9);
- forward μ-spectrometer (-4<η<-2.5)

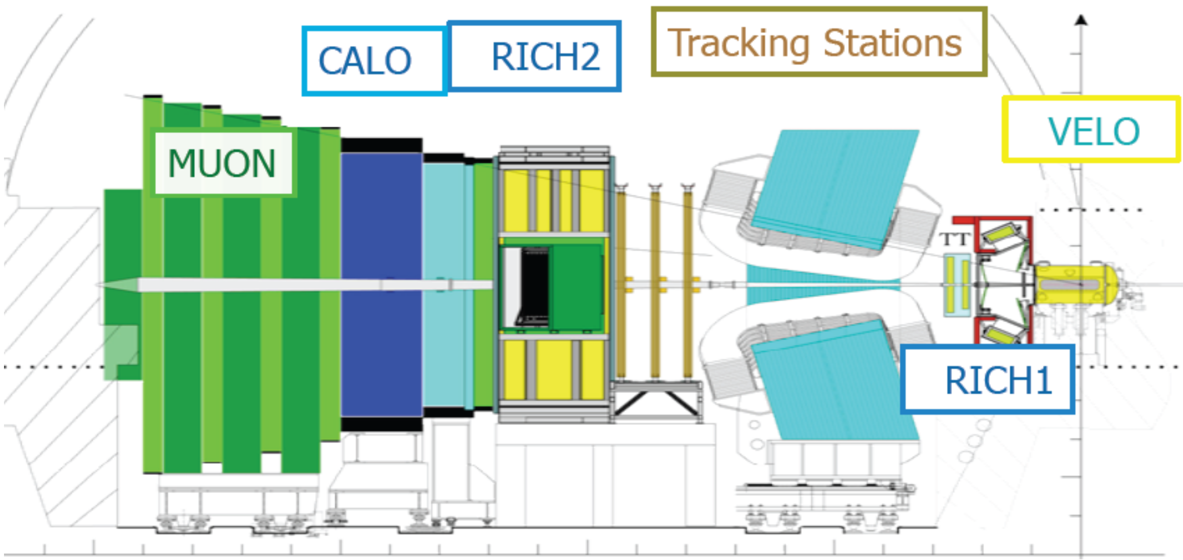


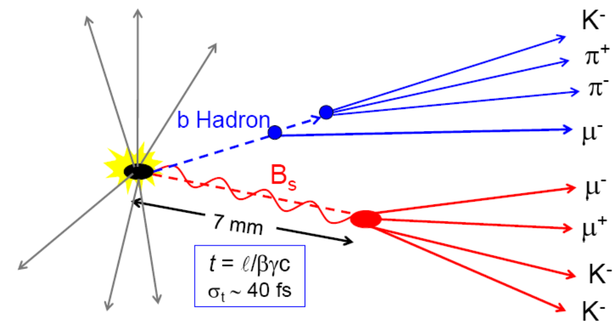
Crucial for heavy flavor: vertexing, tracking, hadron and muon ID, to be performed in harsh conditions (very high particle multiplicities, several 10^3)

Flavor Physics as a "temperature probe" to study behavior of strong interactions in the high density QCD medium of Pb-Pb collisions (e.g. charm production suppression)



LHCb (a dedicated Flavor Physics experiment)





Excellent vertex resolution to resolve fast oscillation of B_s (σ~ 40 fs)

Background rejection (S/B=1/200 at production)

Good particle ID (π, K, p, e, γ, μ) - Precise momentum resolution (~0.5%)

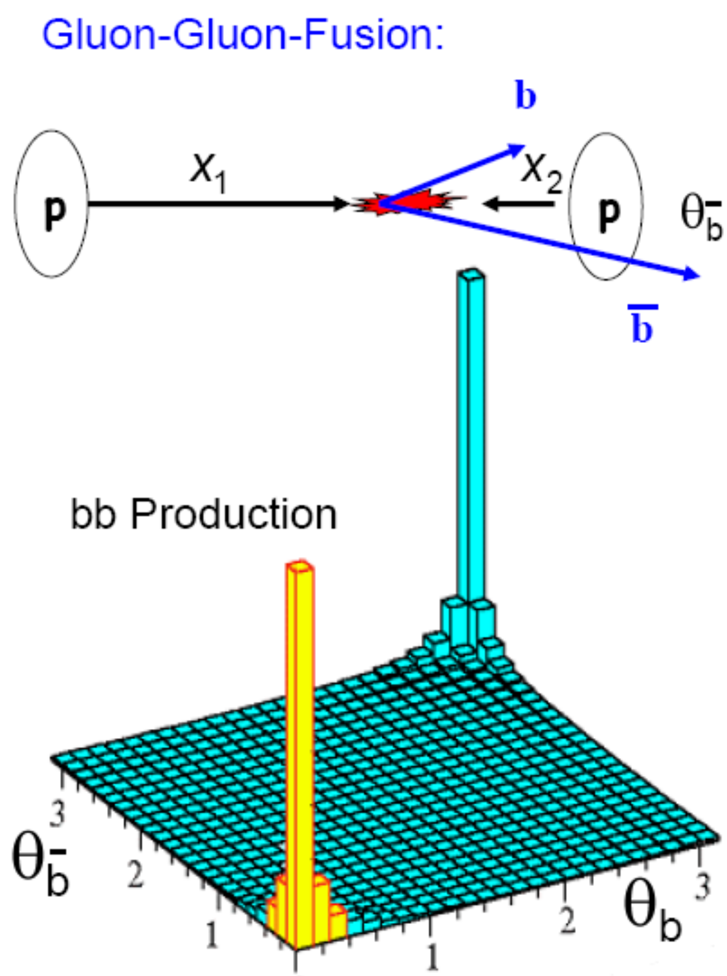
Trigger capability

Efficient selection of hadronic and leptonic final states

Low p_T single μ detection (>1.5 GeV)

Good efficiency also for charm hadronic decays (LHC is a charm factory !)

b and c quark production in the LHCb environment

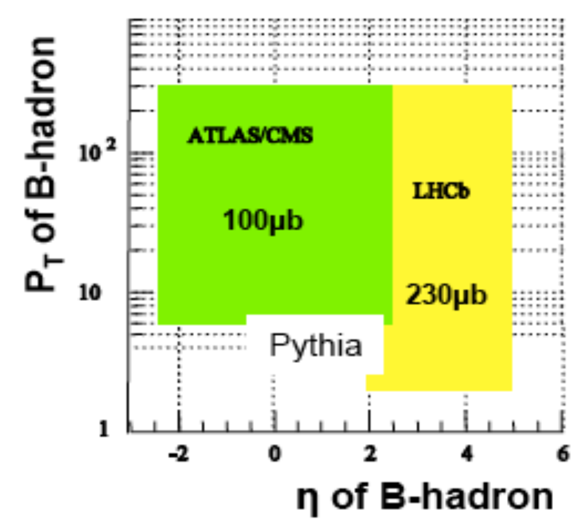


Both b quarks in the forward acceptance of LHCb

- inelastic pp collisions σ ~ 60 mb (7 TeV)
- c quark production σ ~ 6 mb (7 TeV)
- b quark production σ ~ 0.3 mb (7 TeV)

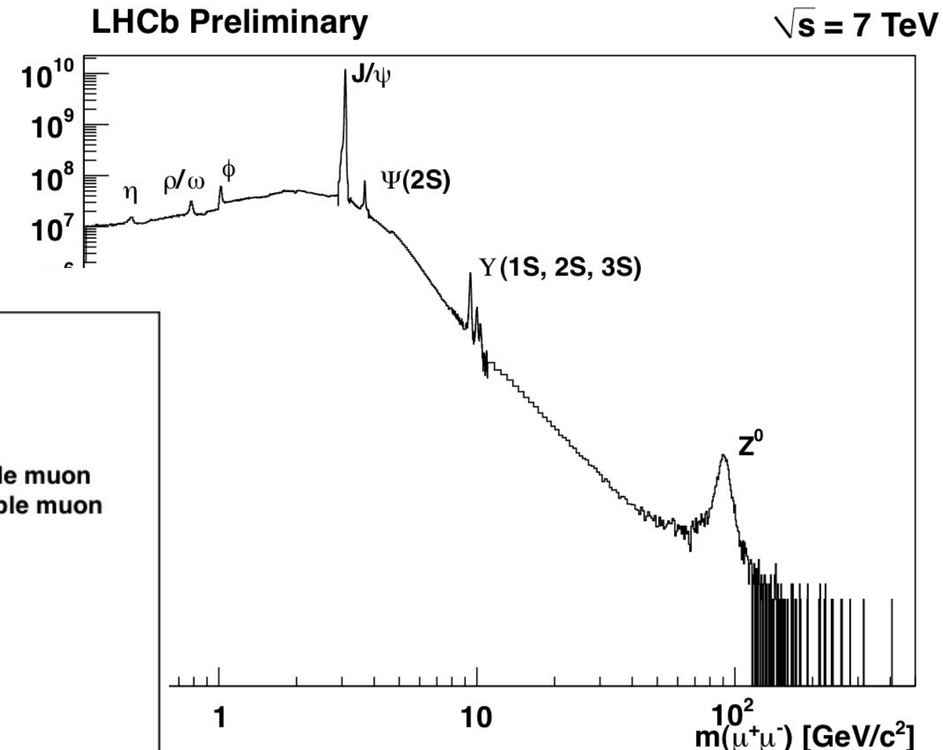
All c- and b- hadrons types produced

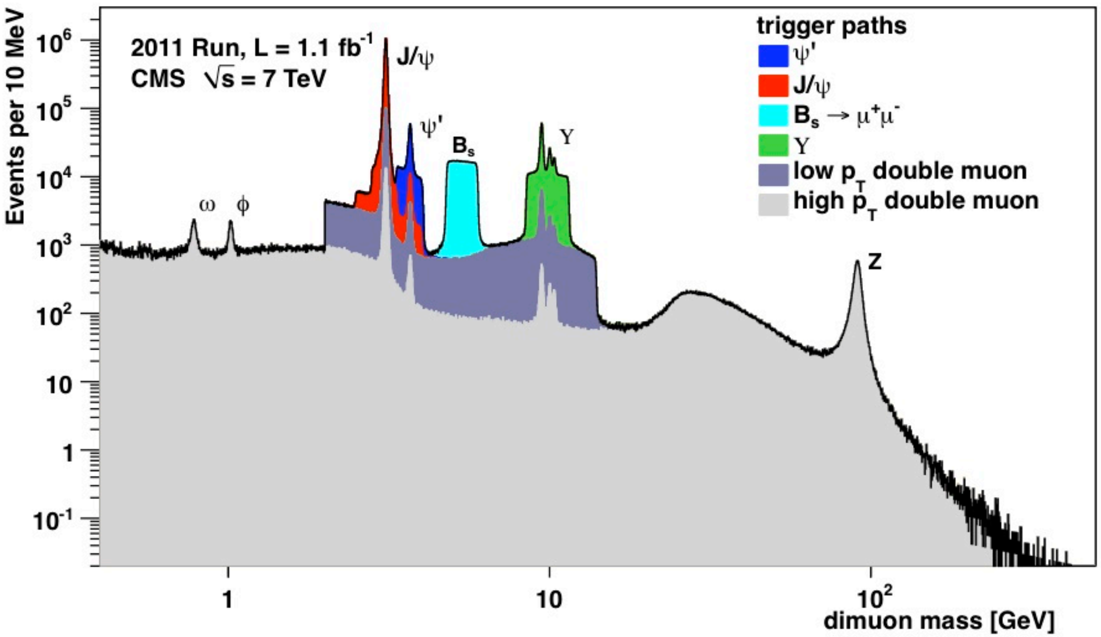
Typical running luminosity (LHCb)
~ 4 10^{32} $cm^{-2}s^{-1}$ (limited by FEE data rate)
~ 15 MHz of pp collisions (few 10 kHz bb)
~ 5 10^{11} b-anti b pairs /y

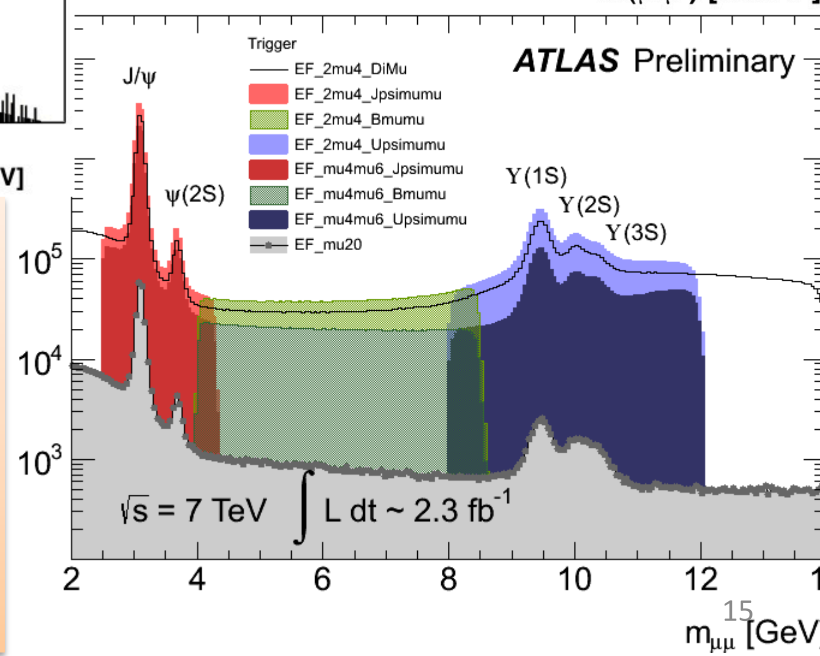


LHCb acceptance : 2 < η < 5 - ATLAS and CMS: |η| < 2.5
ALICE |η| < 0.9 and – 4< η < - 2.5

LHC detectors: precise spectrometers across energy decades





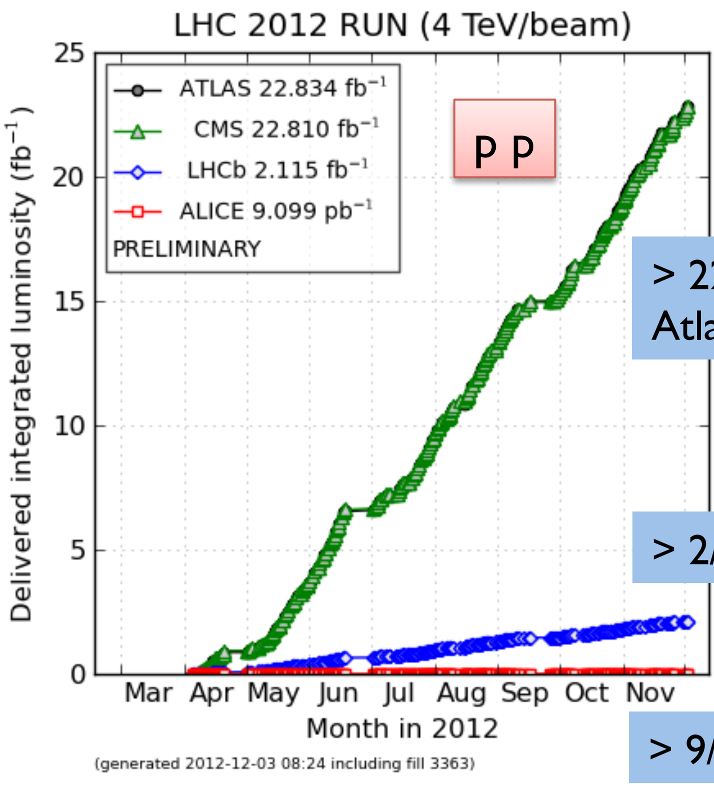


Muon identification plays a key role in reconstruction of heavy mesons with J/ψ in the final state:

- Good acceptance at low p_T
- Error on mass scale ~ 0.1 MeV

→ 30 years of Particle Physics discoveries in one plot (one week of data taking) !

2012 : another "luminous" year at LHC

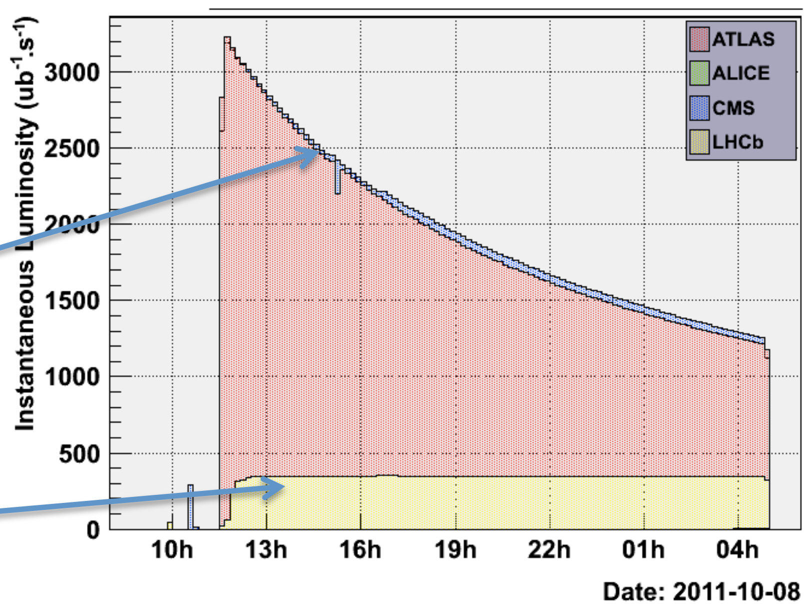


p p

> 22/fb
Atlas, CMS

> 2/fb LHCb

> 9/pb Alice



Pb-Pb runs / ALICE, ATLAS, CMS
p-Pb runs / all the experiments

Luminosity leveling guarantees adequate and stable running and trigger conditions for LHCb even with LHC running at high luminosity (true also for HL-LHC)

Plans for 2015:

- $\sqrt{s}$ = 13 TeV (increased HF cross sections x2)
- Bunch spacing 25 ns (smaller pileup) – L ~ 10^{34} (Atlas & CMS) – L ~ 4 10^{32} (LHCb)

Highlights of Heavy Flavor Physics at LHC

- *Rare B decays (LHCb, Atlas and CMS)*
- *CP violation in B_s system (LHCb, Atlas and CMS)*
- *CKM γ measurement (LHCb)*
- *Charm physics (LHCb)*
- *Heavy Flavor Production & Spectroscopy (All)*
- *Heavy Flavor as probe of QGP (Alice)*

The search for $B_{s\,(d)} \rightarrow \mu\,\mu$

Predicted to be very rare in SM due to GIM & helicity suppression:

Precise predictions in SM:

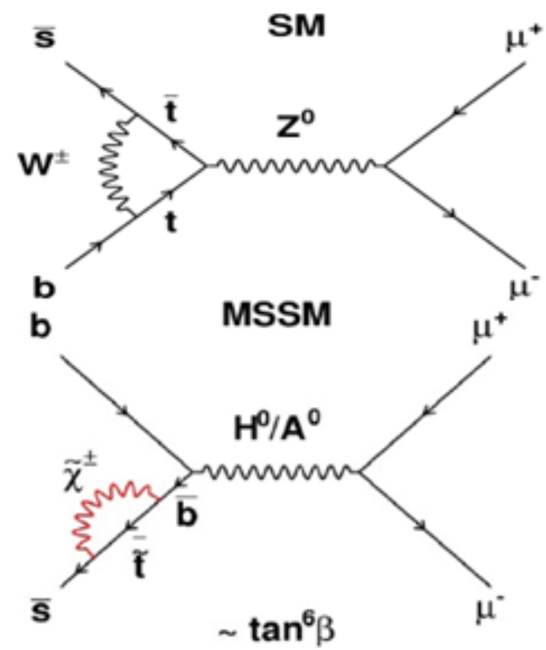
- $BR(B_s \rightarrow \mu\,\mu) = 3.5 \pm 0.2\ 10^{-9}$
- $BR(B_d \rightarrow \mu\,\mu) = 1.1 \pm 0.2\ 10^{-10}$

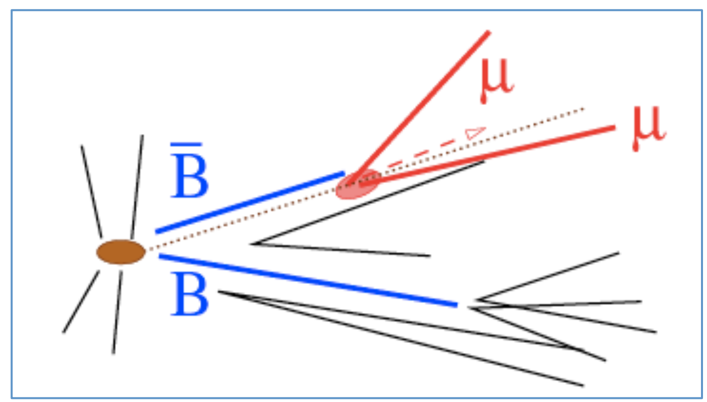
"Golden channel" for New Physics effects
Large sensitivity to NP (e.g. in SUSY)

$$\mathrm{Br}_{\mathrm{MSSM}}(B_q \to \ell^+\ell^-) \propto \frac{M_b^2 M_\ell^2 \tan^6\beta}{M_A^4}$$

Very clean experimental signature

Particularly challenging measurement :
BR ~ few 10^{-9} against a strong peaking background (from $B \rightarrow hh$ and μ mis-id) and a combinatorial one (two random μ faking a B vertex)



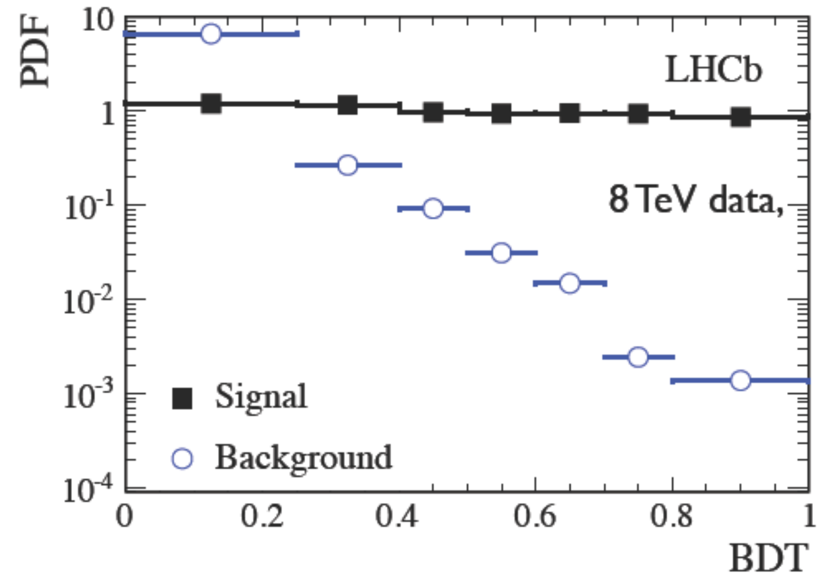


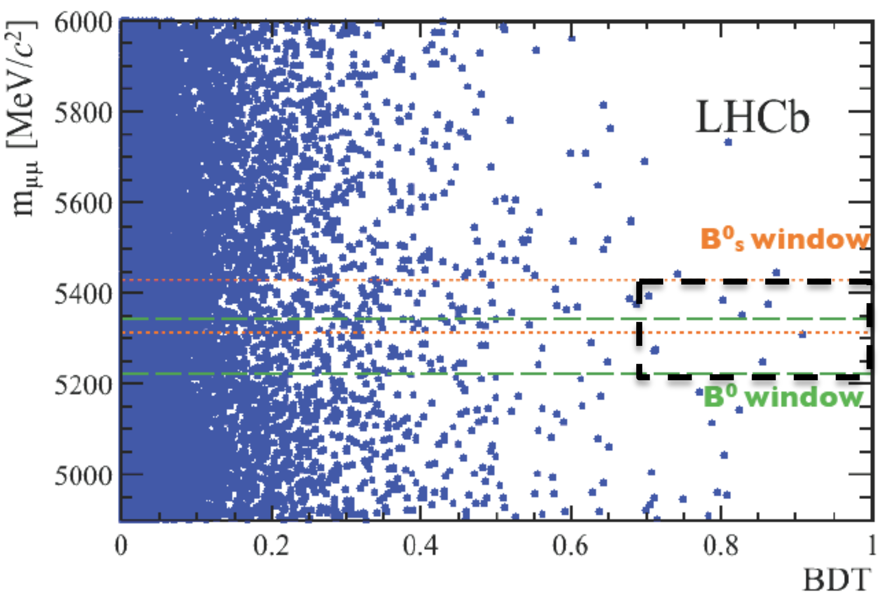
Signal/background separation by invariant mass and multivariate analysis (BDT) including topological and kinematical infos

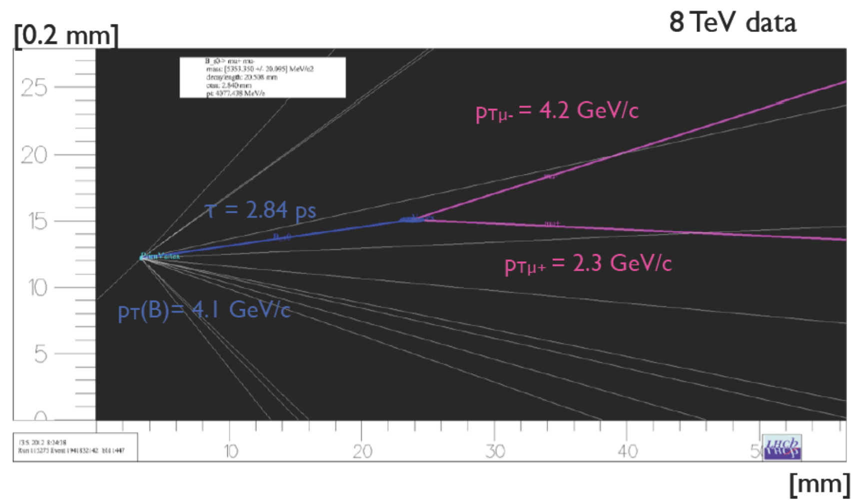
Normalization with B→J/ψK and B→hh

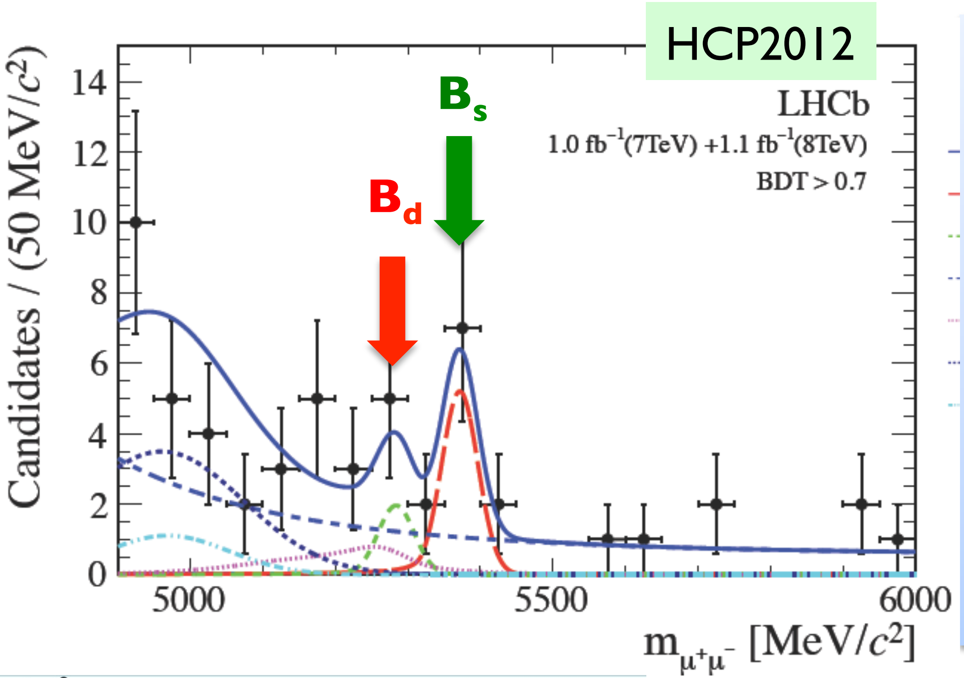
Signal BDT determination with B→hh, background BDT from dimuon sidebands (fully data driven analysis)

Mass peaks and resolution determined from B→hh events









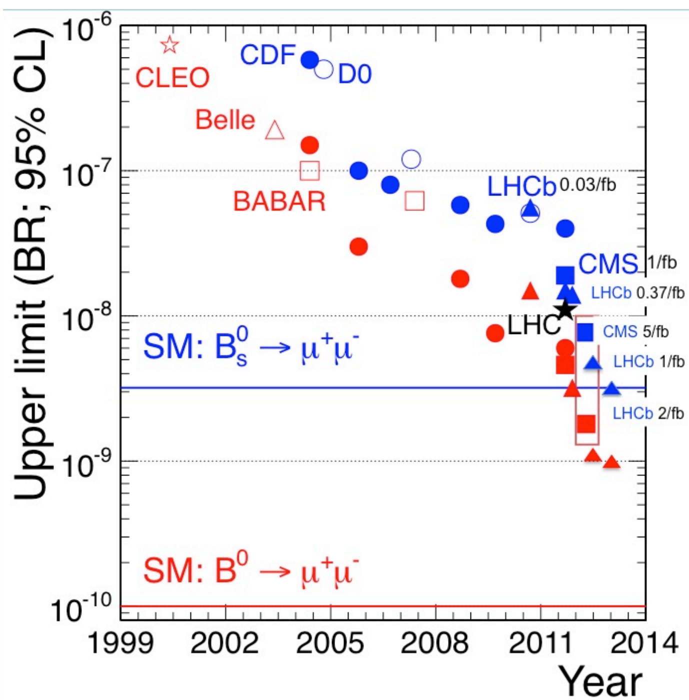
With 2011+2012 data (2.1/fb) LHCb has the first evidence of $B_s \to \mu\,\mu$ decay at ~ 3.5 σ

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.2^{+1.5}_{-1.2})\times 10^{-9}$$

in agreement with SM.
"Background only" p value ~ 5 10^{-4}

Also best limit on $B_d \to \mu\,\mu$

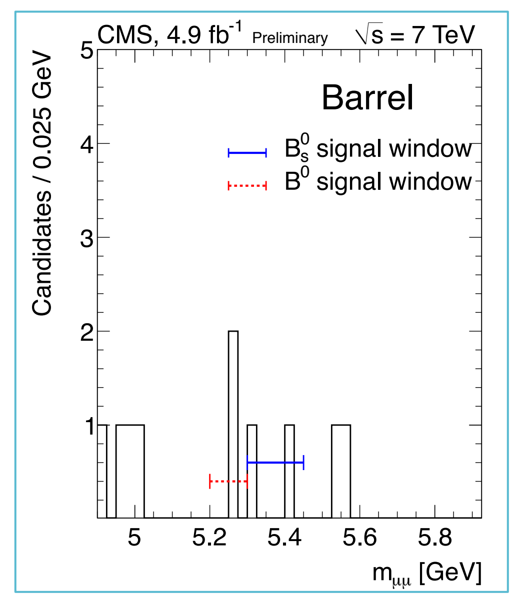
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 9.4\times 10^{-10} \text{ at 95\% CL}$$



Great sensitivity in CMS for $B_{s\,(d)} \to \mu\,\mu$ searches

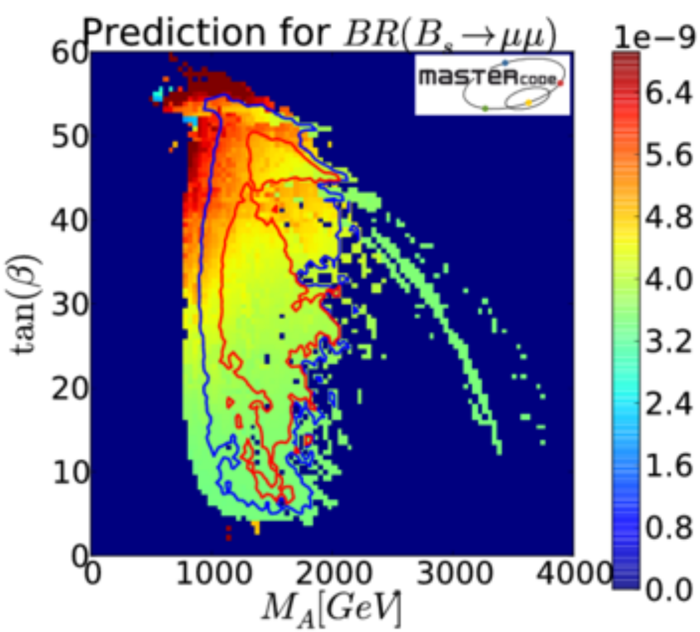
With 5/fb nearly same limit of LHCb (1/fb)

CMS could reach 5σ significance with full 2011-12 data sample (~30/fb)

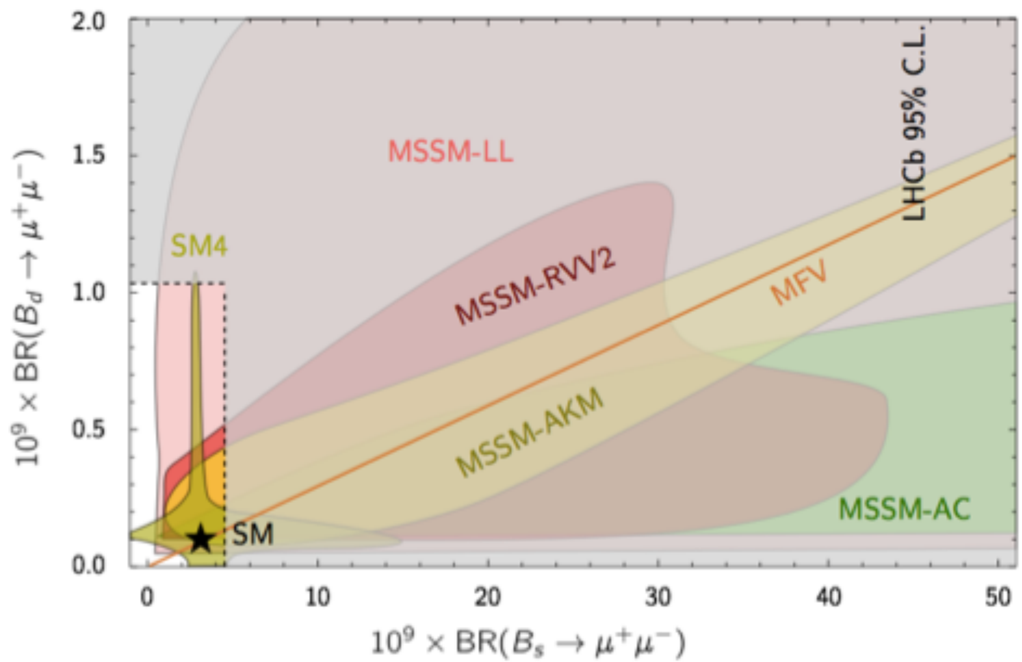


$B_s \rightarrow \mu\mu$ constraining Supersymmetry

$BR(B_s \rightarrow \mu\mu)$ sets strong bounds on *tan β*, at least in CMSSM, and reduces the phase space of Supersymmetry, complementary to direct searches and also removes some of the scenarios for New Physics. However SUSY models are not ruled out.



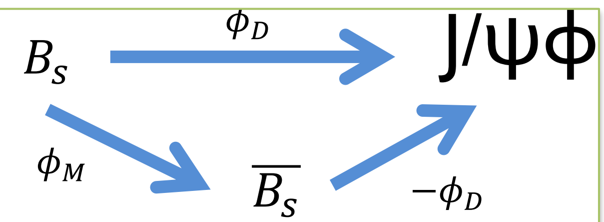
CMSSM



Current double-sided limit : $1.1\times 10^{-9} < \mathcal{B}(B^0_s \rightarrow \mu^+\mu^-) < 6.4\times 10^{-9}$ at 95% CL

CP violation in B_s mixing (ϕ_s and $\Delta\Gamma_s$)

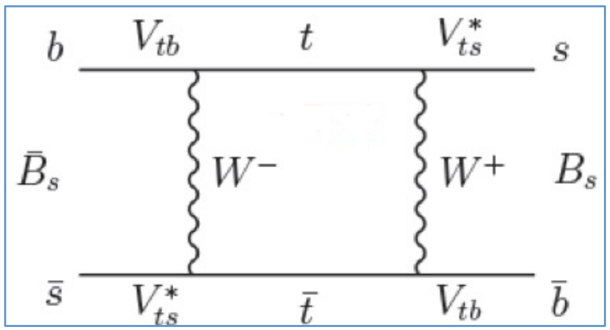
Interference between mixing and decay gives rise to CP violating phase $\phi_s = \phi_M - 2\,\phi_D$



$$\phi_s \overset{\text{SM}}{=} -2\beta_s \equiv -2\arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$$

~ 0 in SM

Requires *time-dependent, flavour tagged, angular* analysis



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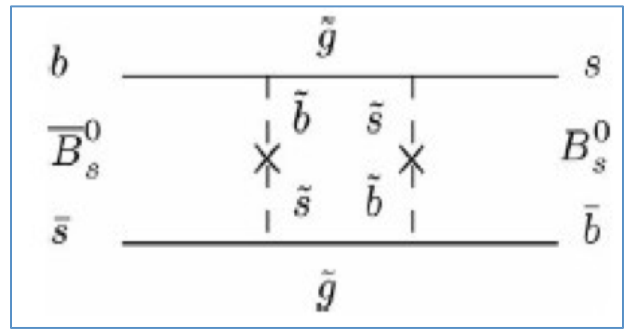


NP ?

Interference effects from New Physics could bring in the amplitude of the process a non zero phase with strong impact on the amount of CP violation

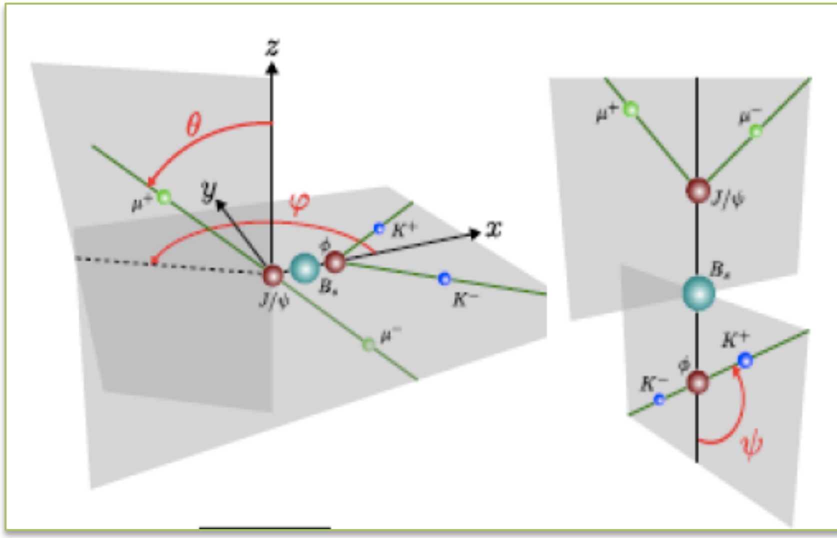
Measuring $\Delta\Gamma_s \neq 0$ allow to disentangle mass and flavor B_s eigenstates (like in B and K systems) → B_{sH} (CP=-1) and B_{sL} (CP=+1) with different lifetimes

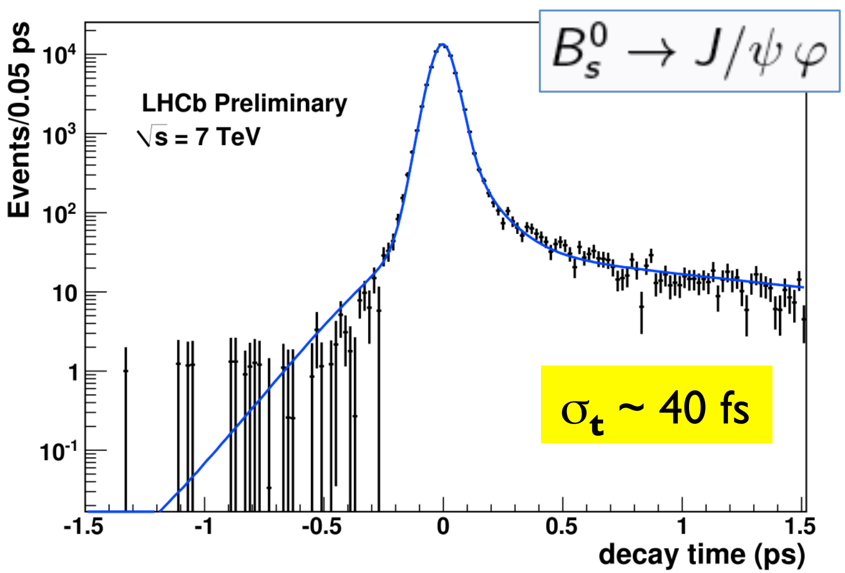
Measuring ϕ_s

Time dependent measurement:
particle ID, flavor tagging, excellent mass and high time resolution needed (to follow the fast oscillations of B_s)

Disentangling CP=1 and CP=-1 final states with angular analysis

Outputs from the fit: ϕ_s , $\Delta\Gamma_s$, Γ_s , …





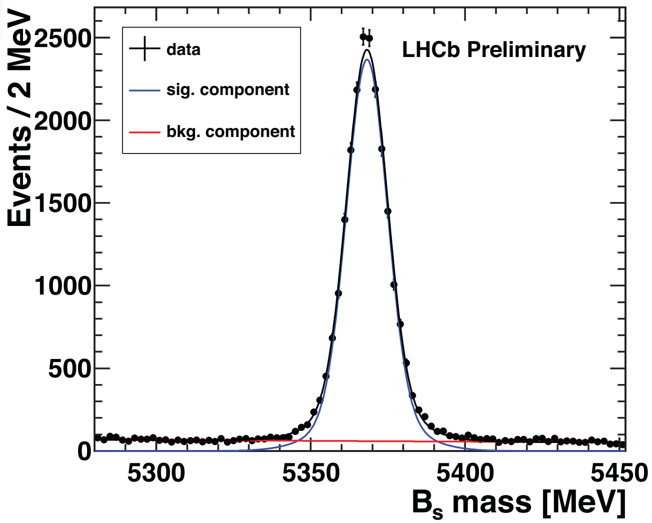
ϕ_s= -0.002 ± 0.083 ± 0.027 rad

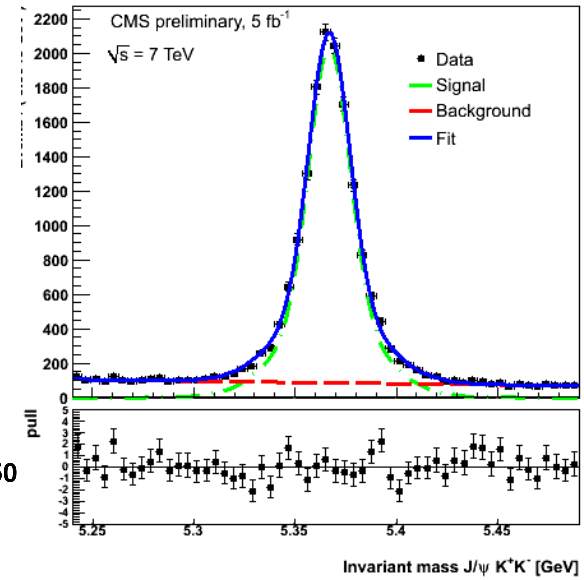
Γ_s = 0.6580 ± 0.0054(stat.) ± 0.0066(syst.) ps^{-1}

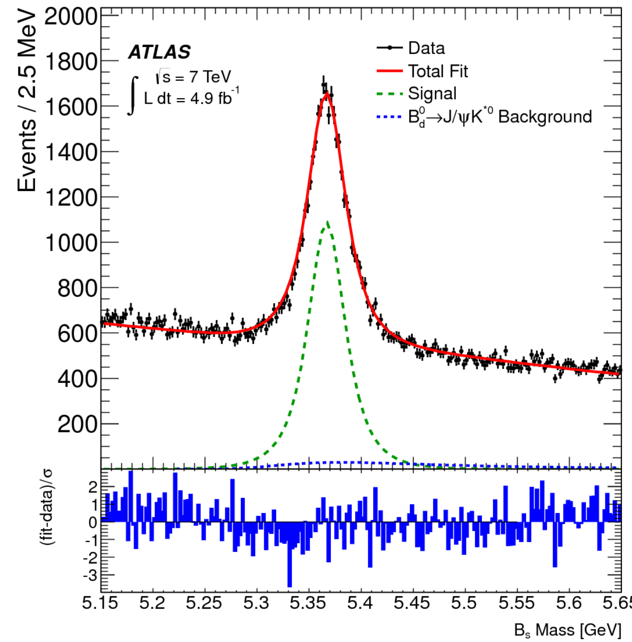
$\Delta\Gamma_s$ = 0.116 ± 0.018(stat.) ± 0.006(syst.) ps^{-1}

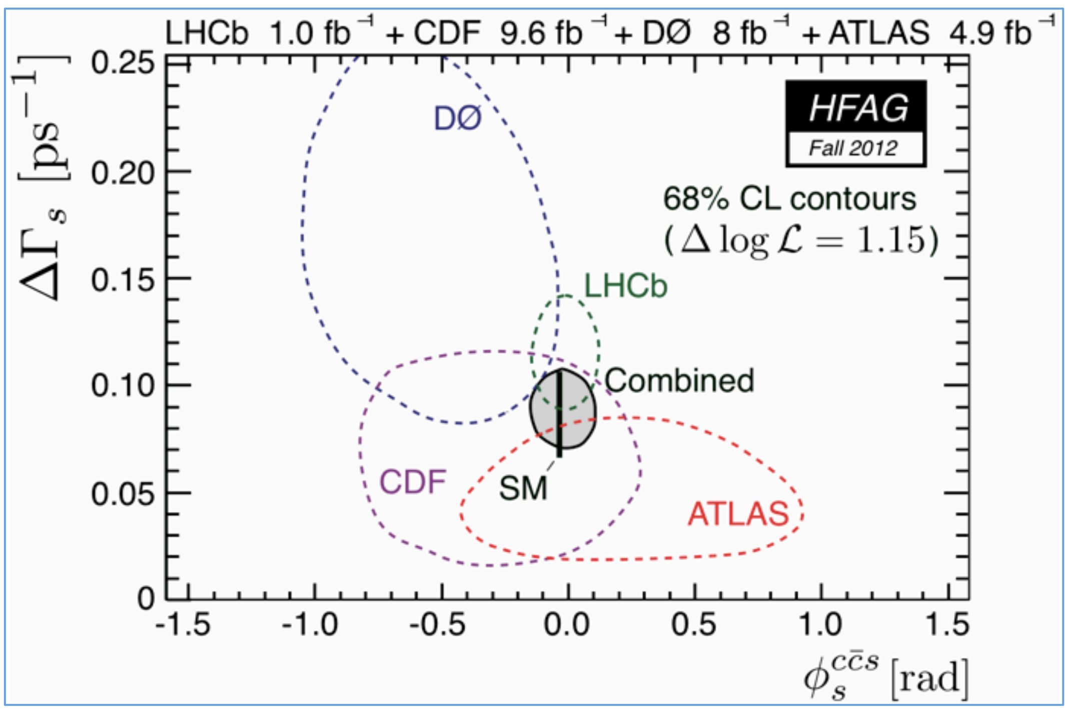
Results obtained combining $B_s \to J/\psi\ \phi$ and $B_s \to J/\psi\ \pi\pi$ (this is CP=+1) channels

Sign ambiguity of $\Delta\Gamma_s$ removed
→ eigenstates of B_s mass states defined









Un-tagged results also from ATLAS

CMS (assuming ϕ_s=0) measures $\Delta\Gamma_s$ = 0.048 ± 0.024 ± 0.003 ps^{-1}

Experimental error on ϕ_s still very far from SM one (0.003)

Study of CPV in B_s mixing

$$a_{sl}^s = \frac{\Gamma(\overline{B}_s^0(t) \to f) - \Gamma(B_s^0(t) \to \overline{f})}{\Gamma(\overline{B}_s^0(t) \to f) + \Gamma(B_s^0(t) \to \overline{f})}$$

Time integrated asymmetry in B_s mixing

Tagged by specific flavor final state (e.g. muons)

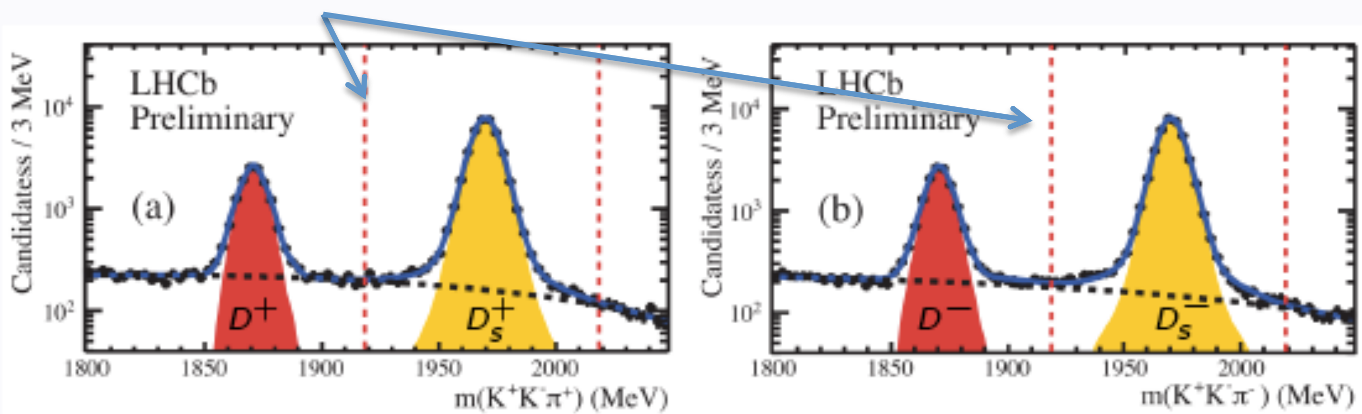
Measured by D0 with semileptonic events (μ and di-μ)

$A_{sl}^{\mu\mu} = (-0.79 \pm 0.20)\%$ (mix of a_{sl}^d and a_{sl}^s)

~ 4 σ tension with SM

Difficult to reconcile with ϕ_s LHCb data

- SM prediction: $a_{sl}^s = (1.9 \pm 0.3) \times 10^{-5}$ *(arXiv: 1205.1444)*
- Use as final state $D_s^{\pm} X \mu^{\mp} \overset{(-)}{\nu}$, $D_s^{\pm} \to \varphi \pi^{\pm}$



- Time-integrated measurement:
  - Effect of small production asymmetry eliminated due to large Δm_s
- Detection asymmetries estimated from calibration samples
- Residual detector asymmetries averaged out using magnet-up and magnet-down data (roughly equal-sized datasets)

LHCb measurement:

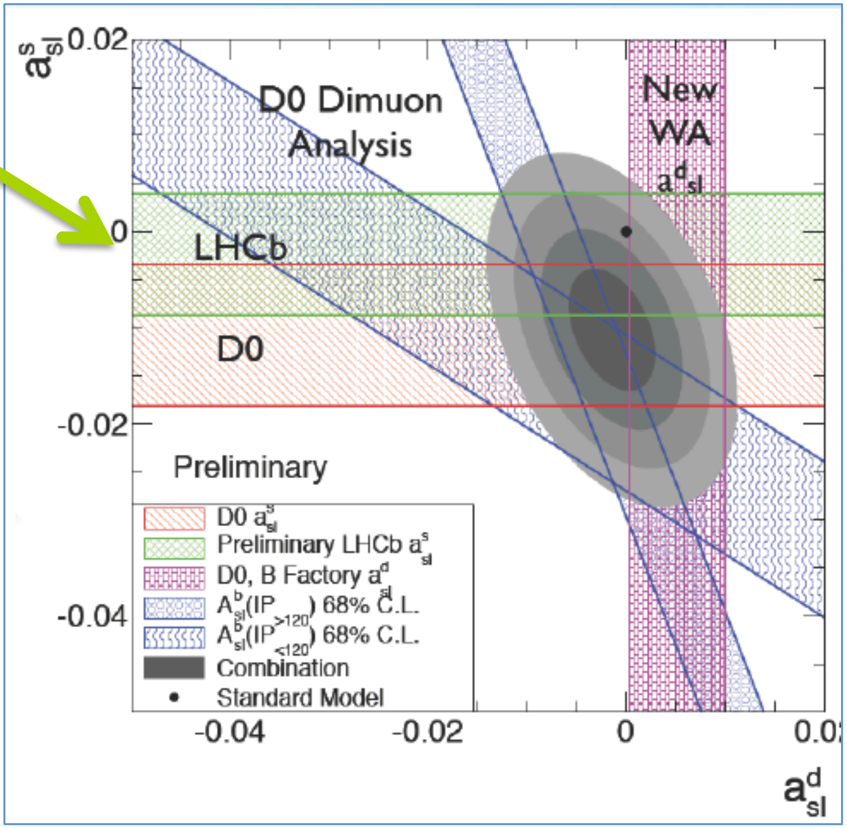
$$a_{sl}^{s} = (-0.24 \pm 0.54 \pm 0.33)\%$$

Combination (using also new values from B-factories)

$a_{SL}(B_d) = (-0.15 \pm 0.29)$ %
$a_{SL}(B_s) = (-1.02 \pm 0.42)$ %

Fitted $a_{SL}(B_s)$: ~ 2.5 σ from SM

More precision from LHCb needed to solve $a_{SL}(B_s)$ issue

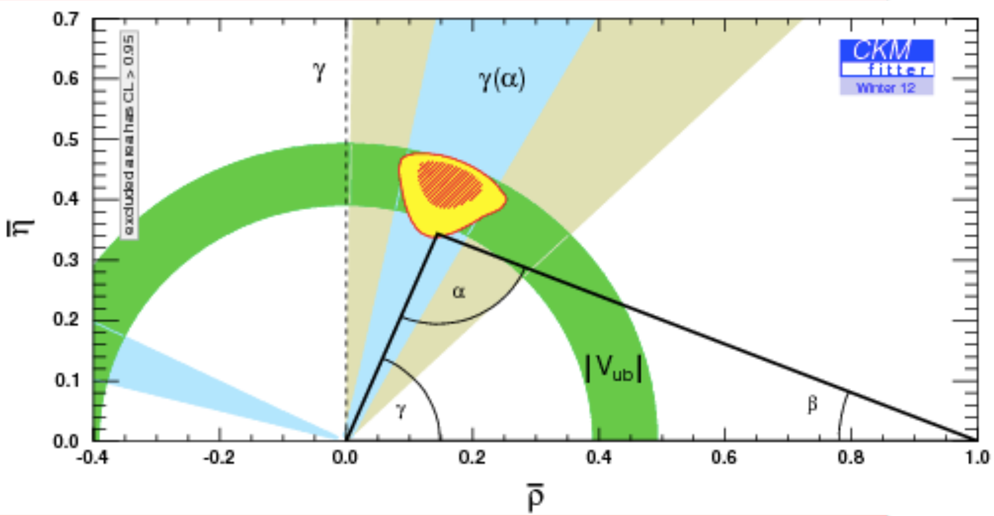


The LHCb measurement of CKM angle γ

The angle γ is still the least known among CKM angles

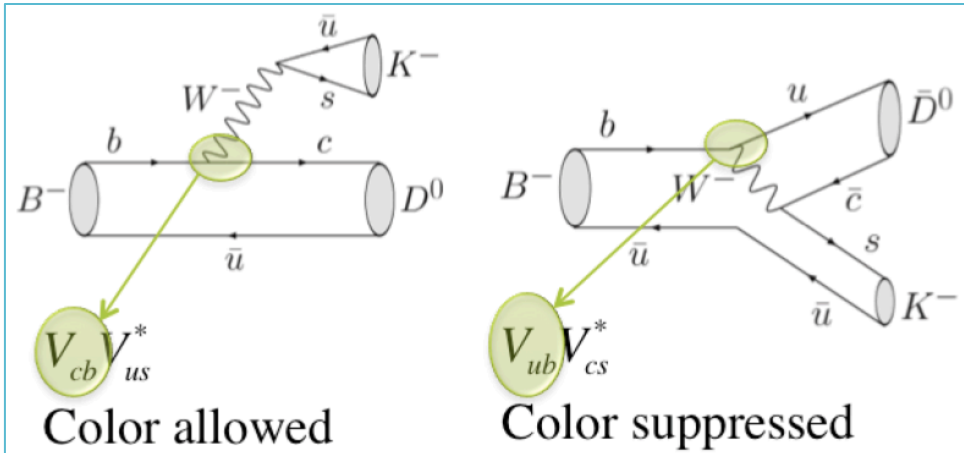
B factories error: ±17°

If NP is hidden in loop diagrams, we have to compare CKM tree measurements (such as γ) with those with loops



LHCb inputs for CKM angle γ:

$B^+ \to DK^+$, $B^+ \to D\pi^+$, $B^+ \to DK^+\pi\pi$, $B^0_{(s)} \to DK^{*0}$, $B^0_{(s)} \to DKK$

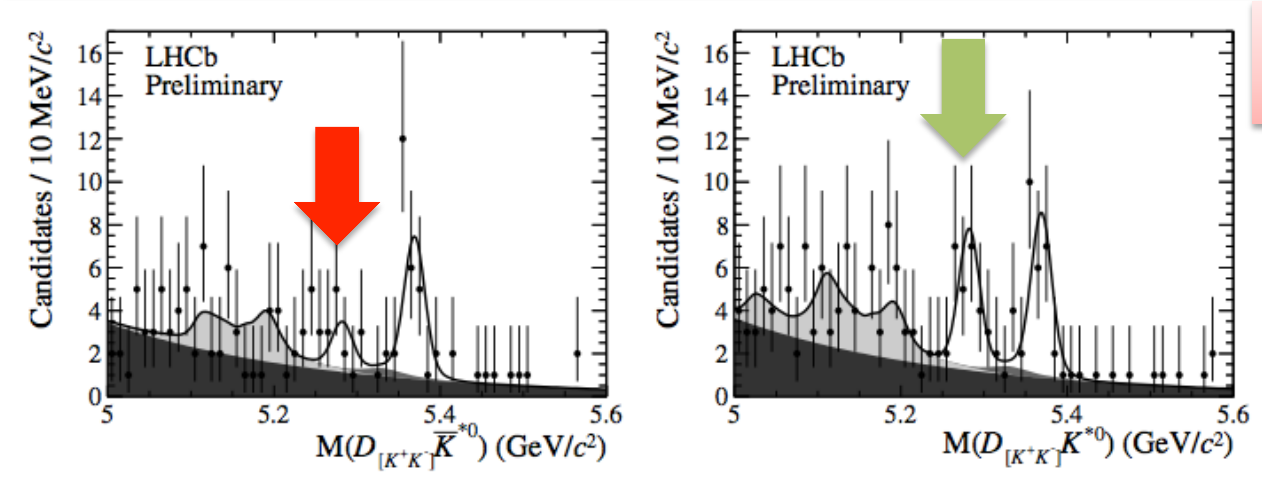


GLW: $D^0 \to K^+K^-, \pi^+\pi^-$

ADS: $D^0 \to \pi^\pm K^\mp$

GGSZ: $D^0 \to K^0_S h^+ h^-$

The statistics of LHCb starts to populate the (very) suppressed hadronic decays in which the interference is used for the determination of γ

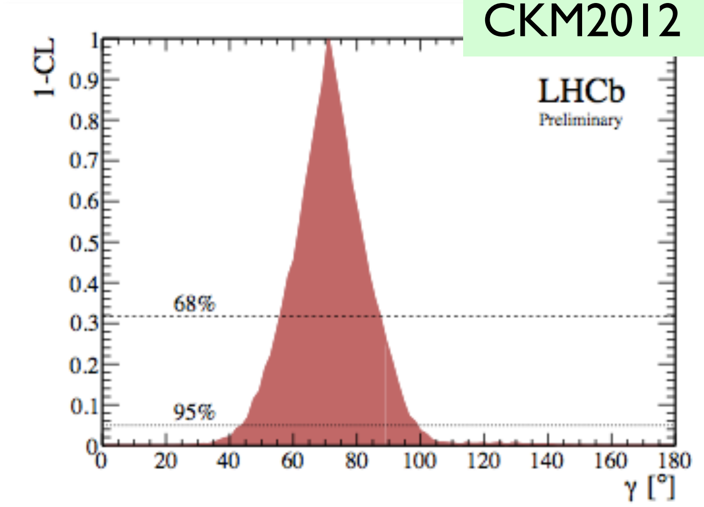


$B^0 \rightarrow DK^{0*},\ D \rightarrow hh$

$B^0 \rightarrow DK^*$ (GLW) – D→KK
B 7 ev. – anti-B 20 ev.

First observation !

CKM2012



Combinations of LHCb $B^+ \rightarrow DK^+$ modes (only) gives

$\gamma = \mathbf{71}^{+17}_{-16}$ deg

LHCb error (with 1/fb) already similar to the one obtained from full sample at B factories. Results from more data and channels to come soon

Charm physics

LHCC is a charm factory ! Charm is the only "up type" quark where we can search for NP

LHCb has the world's largest sample of c-hadron decays in charged modes (x10 current B factories)

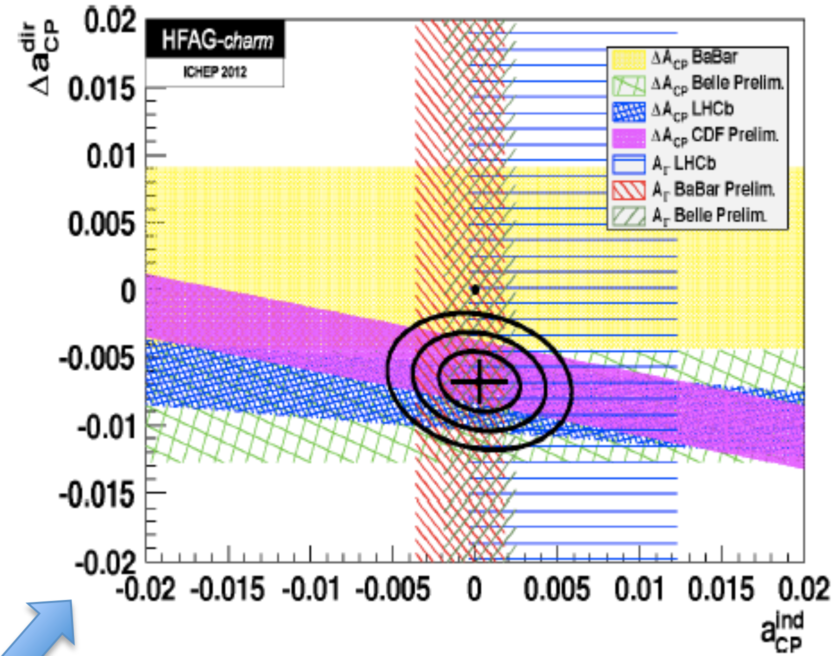
Rich program: mixing , CP asymmetries, branching fractions

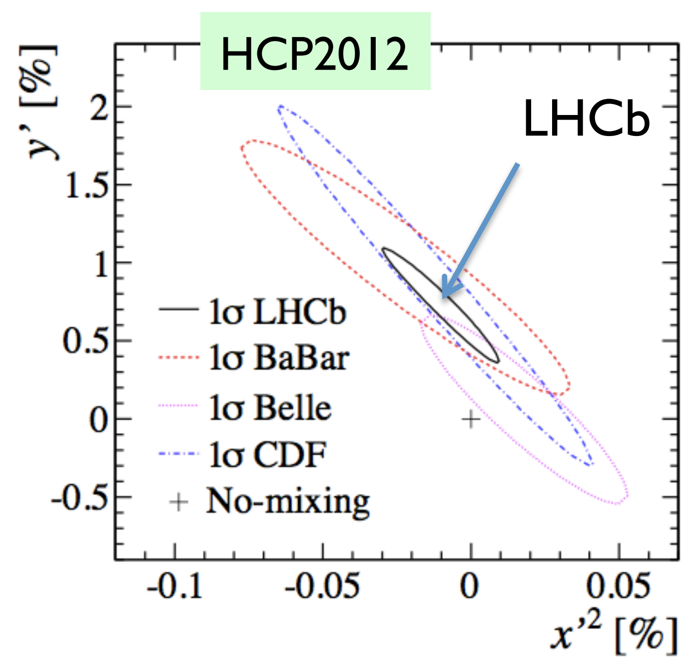
CPV in charm decays ($D^0 \rightarrow KK$ or $\pi\pi$)

Hint of CPV≠0 from LHCb, CDF, Belle
ΔA^{CP}_{dir} = (−0.68 ± 0.15) %

NP or explicable within SM ?
More data & confirmation in other D channels needed

First observation of charm mixing in $D^0 \rightarrow K\pi$ by a single measurement (9σ)





b- , c-hadrons and quarkonium production studies at LHC

- B-mesons and b-baryon properties (cross section, masses, lifetimes, pt spectrum)
- Inclusive muons from Heavy Flavor states
- Production of prompt and non-prompt charmonium (J/ψ , $\psi(2s)$)
- Production of Y(1s),Y(2s),Y(3s)
- Production of χ_b and χ_c (P wave resonances)
- Quarkonium spectroscopy (charmonium and bottomonium)
- Polarization of heavy resonances
- Double charm production (J/ψ J/ψ, J/ψ D, DD)
- Exotic states (X,Y, Z)

…

An impressive amount of information is under collection with unprecedented statistics by the 4 experiments

These studies are vital to setup production models based on perturbative QCD and for Monte Carlo generators, to understand heavy quark spectroscopy, including non standard qq states (exotica)

These measurements provide lots of input for theorists, and plenty of questions, but no clear answers yet

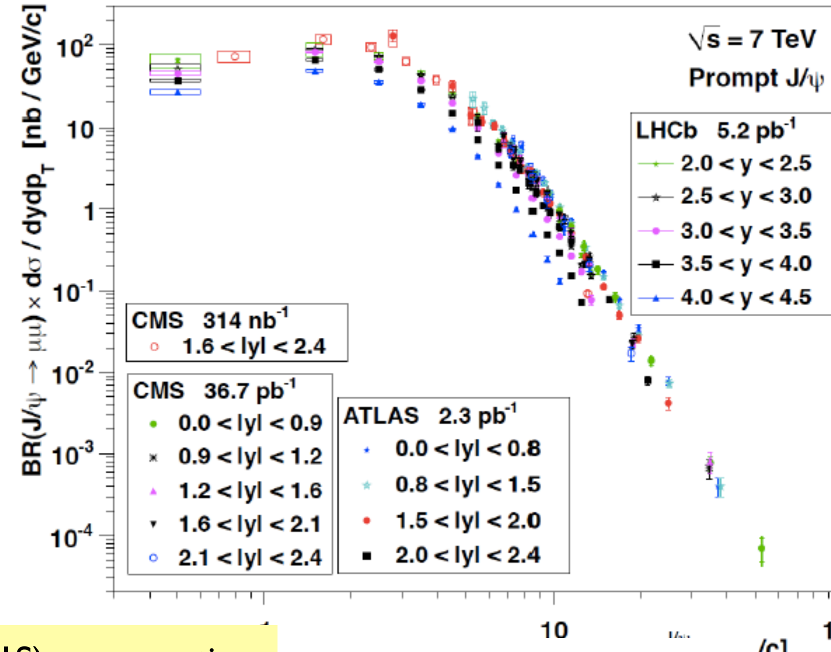
Quarkonia production

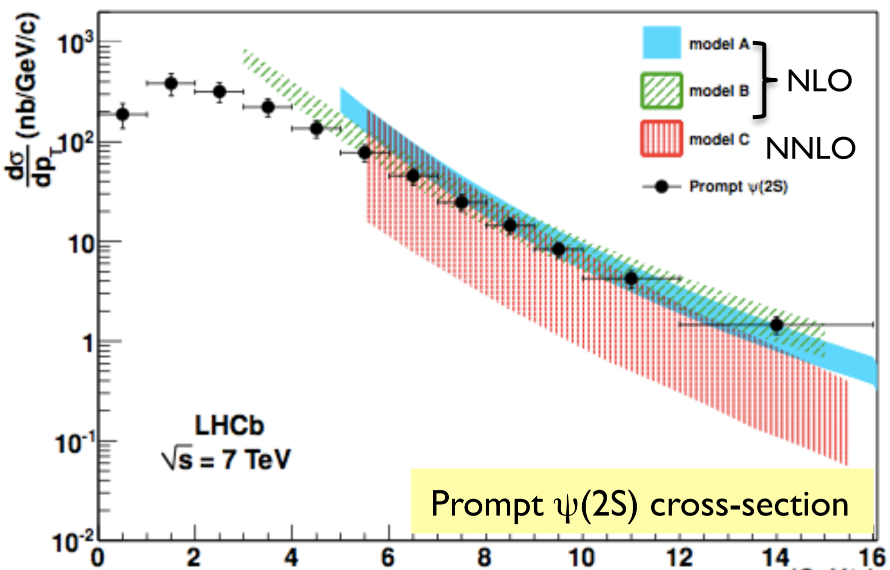
Test perturbative QCD at new energy regime, at higher transverse momentum and in a wider rapidity range than previously (Atlas & CMS: high p_T, low η – LHCb: low p_T, high η − Alice: dense matter)

Production mechanism for heavy quarkonium states not fully understood. Reasonable agreement with models , neither is perfect

p_T spectra alone not enough

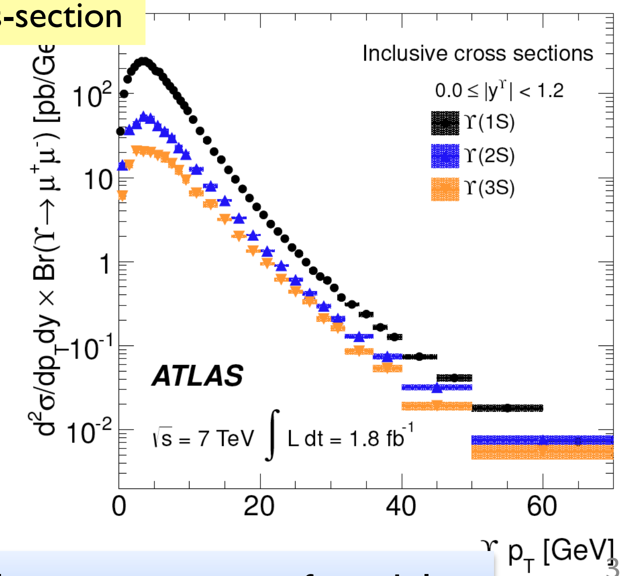
Prompt J/ψ cross-section





Prompt ψ(2S) cross-section

Y(1S) cross-section

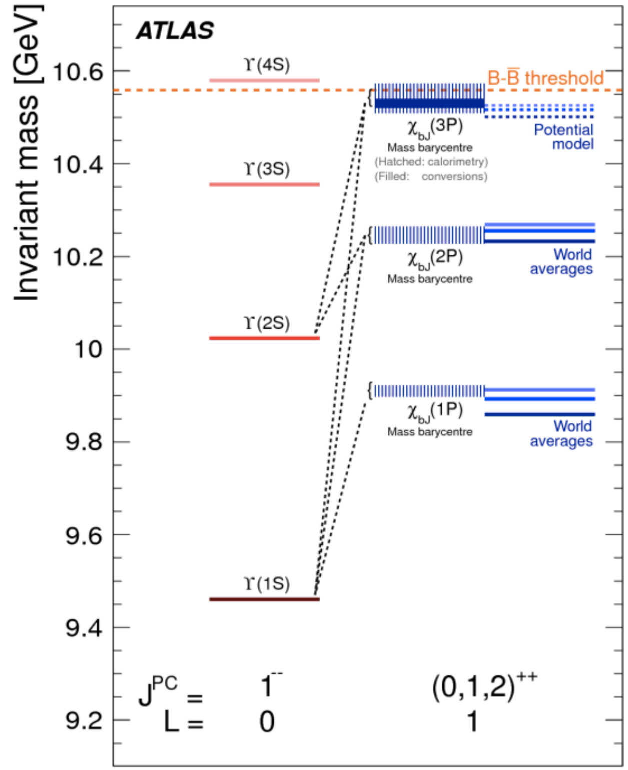


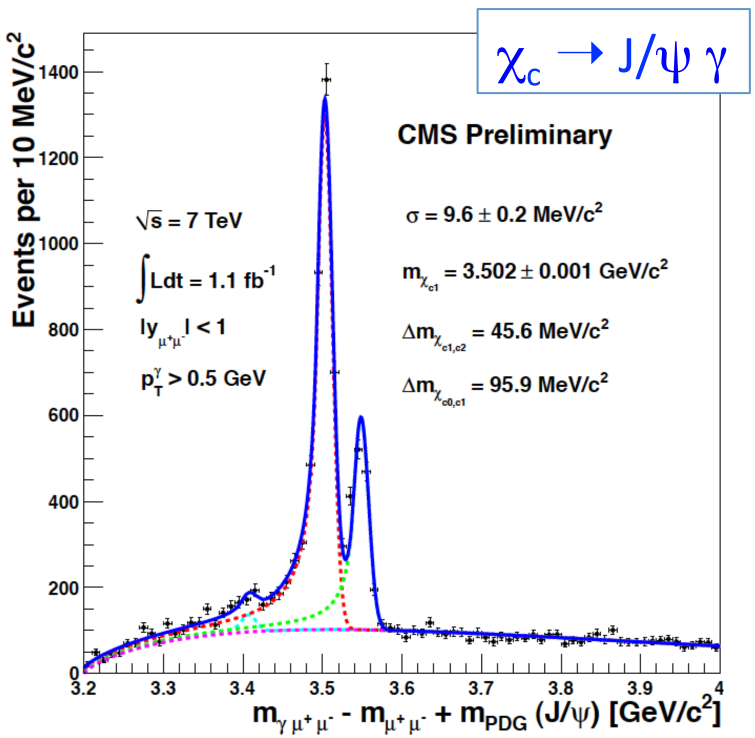
Next challenging measurements: obtain polarization values: strong test of models

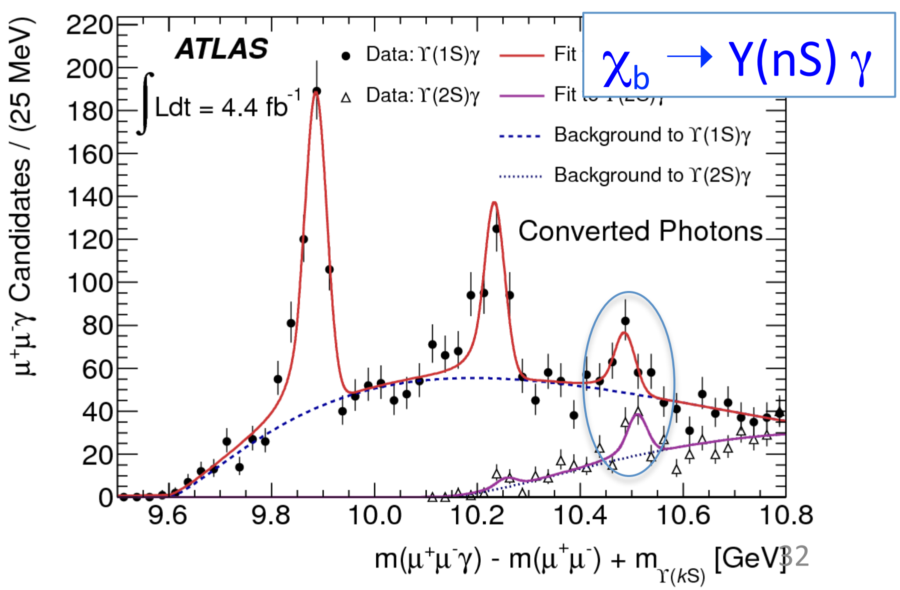
Study of cc and bb P wave resonances

Clarify the mechanisms of hadron production in the fragmentation process. P states are a significant source of J/ψ and Y (S wave states) inclusive production

Key role in identifying and measuring energy of converted photons in final states at LHC (first time at hadron colliders)





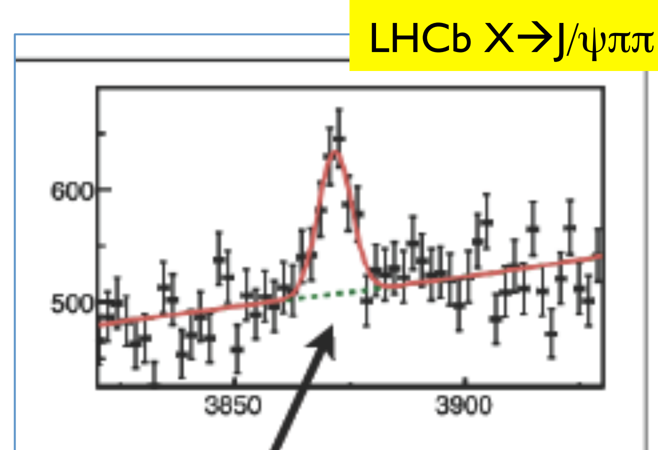


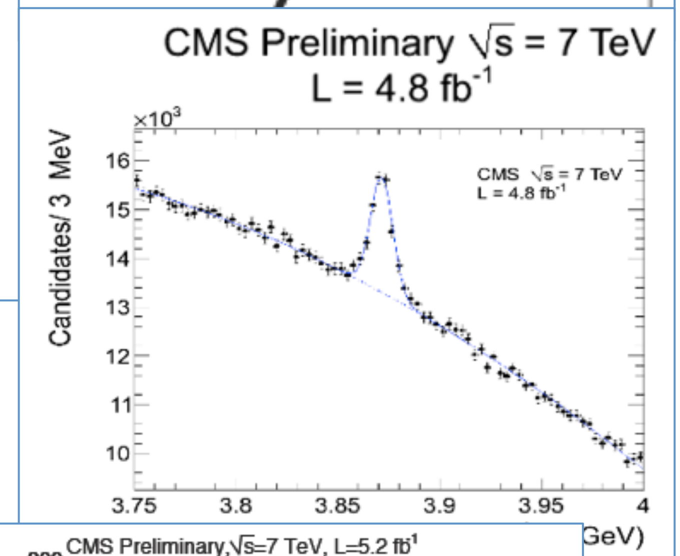
Exotic states in quarkonium

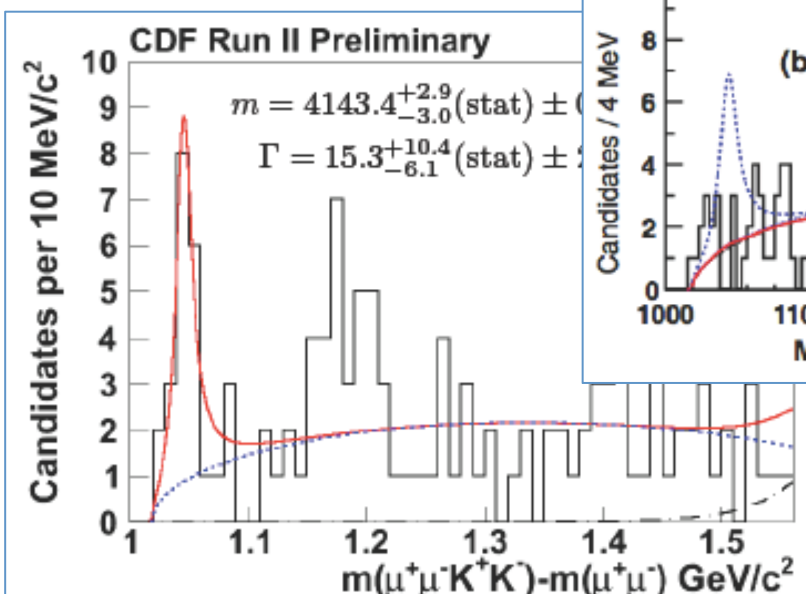
Observation of the new exotic states X(3872), Y(4140), etc… which do not fit into conventional quark models

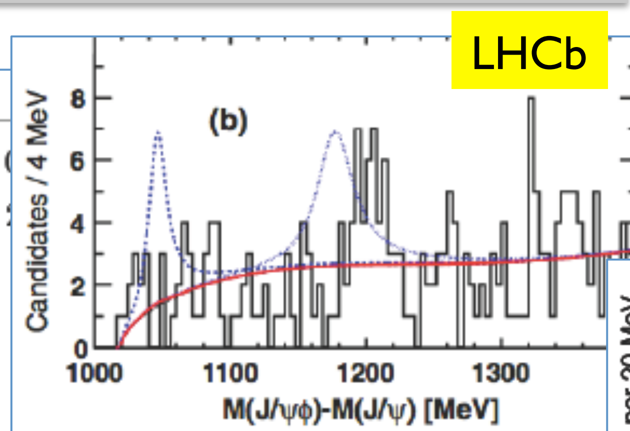
X(3872) has been observed in several decay channels
$J/\psi\ \pi\pi$, DD , $J/\psi\ \gamma$, $\psi(2s)$ and $J/\psi\ \omega$
Motivating interpretation as charmonium, DD molecule, tetra quark state

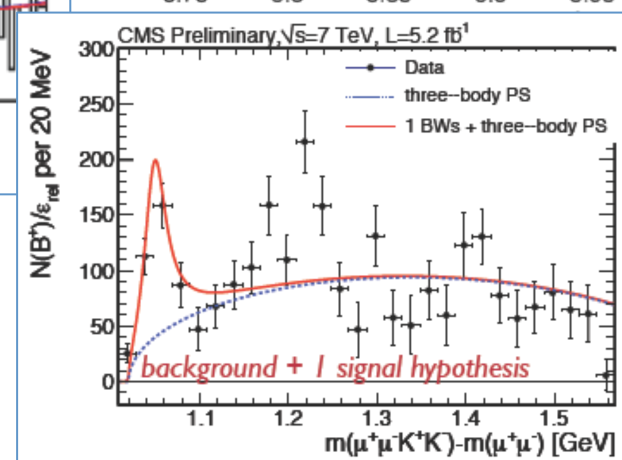
CDF observed a structure in $B^+ \rightarrow J/\psi\ \phi K^+$ [Y(4140)]
LHCb not confirmed it – CMS has some evidence …





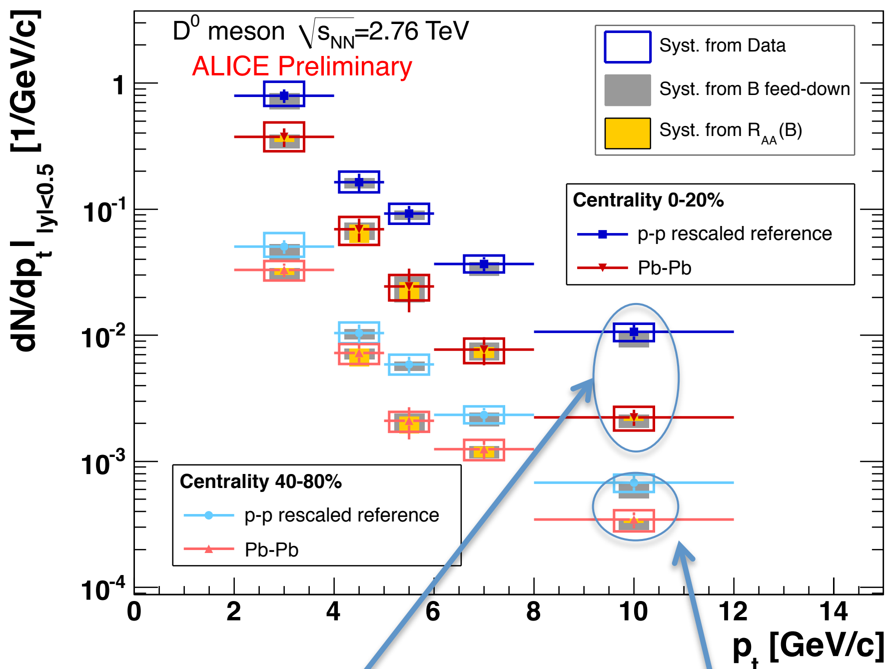


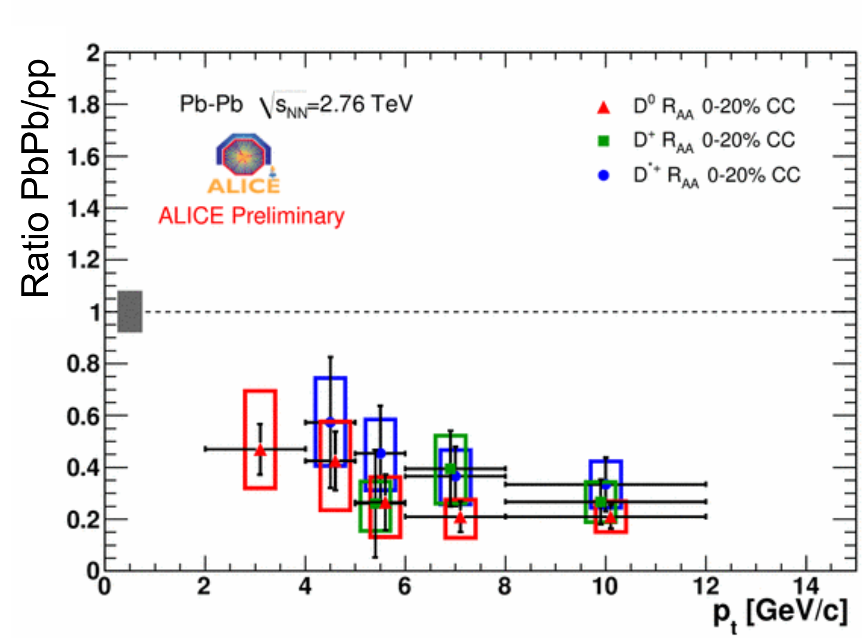




Charm production in dense matter (Alice)

"Centrality" (CC) gives an evaluation of density of matter probed by the heavy meson



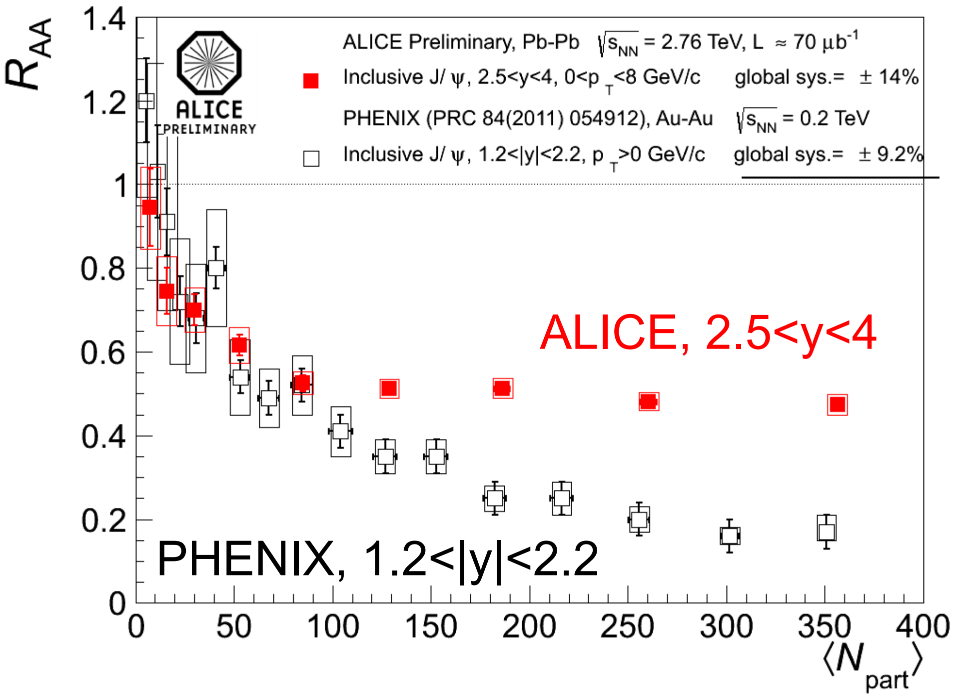


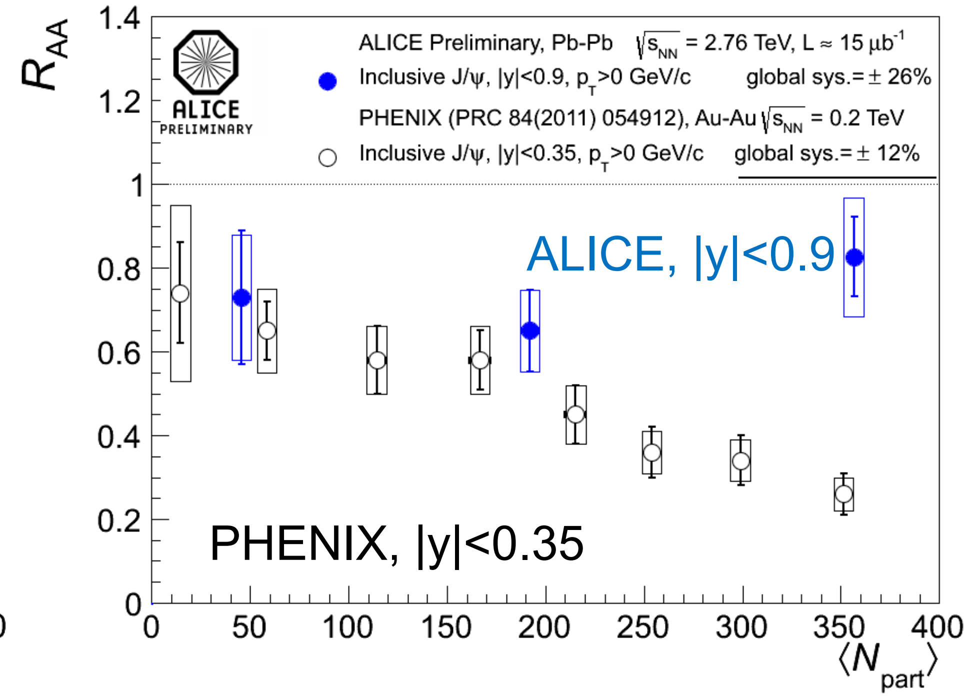
Strong suppression observed in central collisions (0-20%) wrt pp reference

Significant suppression also in semi-peripheral (40-80%) wrt pp reference

Suppression for charm is a factor 3-4 above p_T~5 GeV/c
Indicates strong energy loss of c quarks in the hot and dense QCD medium formed in these collisions

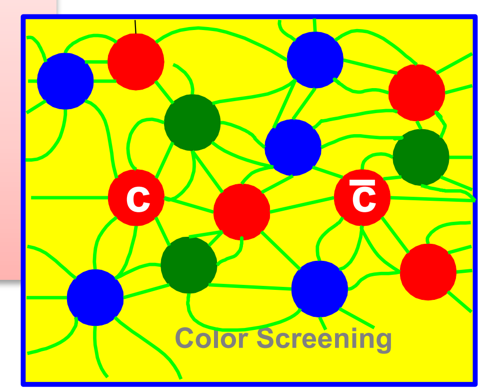
J/ψ suppression in Pb-Pb: results and comparison with RHIC





Smaller J/ψ suppression in spite of the factor 13 in √s (and more evident at small pt)

J/ψ are suppressed in the QGP , as at lower energies, BUT are (re)generated from the large number of freely roaming charm quarks in the QGP (only important at low p_T !) ?



Perspectives: the long way to precision Heavy Flavor Physics with the LHCb upgrade (and some specific contributions from Atlas and CMS)

Type	Observable	Current precision	LHCb 2018	**Upgrade** ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s\ (B_s^0 \to J/\psi\ \phi)$	0.10 [137]	0.025	0.008	~ 0.003
	$2\beta_s\ (B_s^0 \to J/\psi\ f_0(980))$	0.17 [213]	0.045	0.014	~ 0.01
	$a_{\rm sl}^s$	6.4×10^{-3} [43]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{\rm eff}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\rm eff}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\rm eff}(B^0 \to \phi K_S^0)$	0.17 [43]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\rm eff}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\rm eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.08 [67]	0.025	0.008	0.02
	$s_0\,A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [67]	6 %	2 %	7 %
	$A_I(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.25 [76]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [85]	8 %	2.5 %	~ 10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [13]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	~ 100 %	~ 35 %	~ 5 %
Unitarity triangle angles	$\gamma\ (B \to D^{(*)}K^{(*)})$	~ 10–12° [243, 257]	4°	0.9°	negligible
	$\gamma\ (B_s^0 \to D_s K)$	–	11°	2.0°	negligible
	$\beta\ (B^0 \to J/\psi\ K_S^0)$	0.8° [43]	0.6°	0.2°	negligible
Charm CP violation	A_Γ	2.3×10^{-3} [43]	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3} [18]	0.65×10^{-3}	0.12×10^{-3}	–

Final goal : reach theory error

Conclusions

Heavy Flavor can be considered as a portal to the discovery and to understand the flavor structure of New Physics

The excellent performances of LHC and of the experiments has allowed to start producing exciting results in the Heavy Flavor Physics domain (LHCb in particular)

Standard Model is still rock solid but yet there is large room for unexpected phenomena: indirect searches are complementing direct searches for Supersymmetry

A lot of activities and very good perspectives for precise measurements in CP violation in b- and c- hadrons, CKM matrix, very rare decays, and heavy flavor production in p-p and Pb-Pb collisions. LHC has produced already the best measurements in the field

Looking forward to operate at 13 TeV in 2015 to collect more data

LHCb upgrade is planned to increase statistics by more than one order of magnitude to discover New Physics and to pin down theoretical expectations in Flavor Physics within the next decade !