CMS Experiment at the LHC, CERN
Data recorded: 2012-Nov-30 07:19:44.547430 GMT(08:19:44 CEST)
Run / Event: 208307 / 997510994

μ-

μ+

Heavy flavor physics with the CMS experiment

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25-26 September 2013

GSI-Darmstadt/Frankfurt

Why heavy flavor physics?

- **Physics of beauty and charm quarks in p-p collisions**
- **Research area with rich of phenomenology:**
  - **Heavy flavor production measurements**
    - Tests of QCD (hard scattering, fragmentation, NRQCD, etc.)
  - **Spectroscopy and particle properties**
    - Spectrum of standard and exotic quarkonium states
    - Heavy baryon spectroscopy
    - Particle lifetimes, masses, etc.
  - **Rare beauty decays**
    - Complementary to direct searches: can access multi-TeV energy scales through loop contributions

Recent results!

CMS published 23 journal articles in the heavy flavor domain
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH

The Large Hadron Collider

LHC performance - pp run

Parameter/Effects	Limitations	Now
Beam energy limited by maximum dipole field. Industrially available technology.	7 TeV	3.5 -> 4 TeV
Bunch and total beam intensity beam-beam effect (tune spread), small allowed space in Q-space, collimators (impedance, collective instabilities), electron cloud, radiation	$N < 1.7\ 10^{11}$ $N_{nom} = 1.15\ 10^{11}$ $I < 0.85$ A	**$N \sim 1.5\ 10^{11}$**
Normalized emittance Limited by injectors and main dipole aperture	$\varepsilon_n < 3.75\ \mu m$	**1.9 - 2.4 μm**
Beam size at IP (β^*) Limited by (triplet) quadrupole aperture	$0.55\ m < \beta^* < 1\ m$ $\sigma \sim 17\ \mu m$	0.6 m $\sigma \sim 20\ \mu m$
Crossing angle Limited by (triplet) quadrupole aperture	300 μrad	290 μrad
Number of (colliding) bunches Limited by stored beam energy, electron cloud eff.	2808	1368
Luminosity	$1\ 10^{34}$	7.5×10^{33}

Legend:

N : particles/bunch

n : nr. of bunches

I : current / beam

$\varepsilon_n = \varepsilon\gamma$, ε : emittance

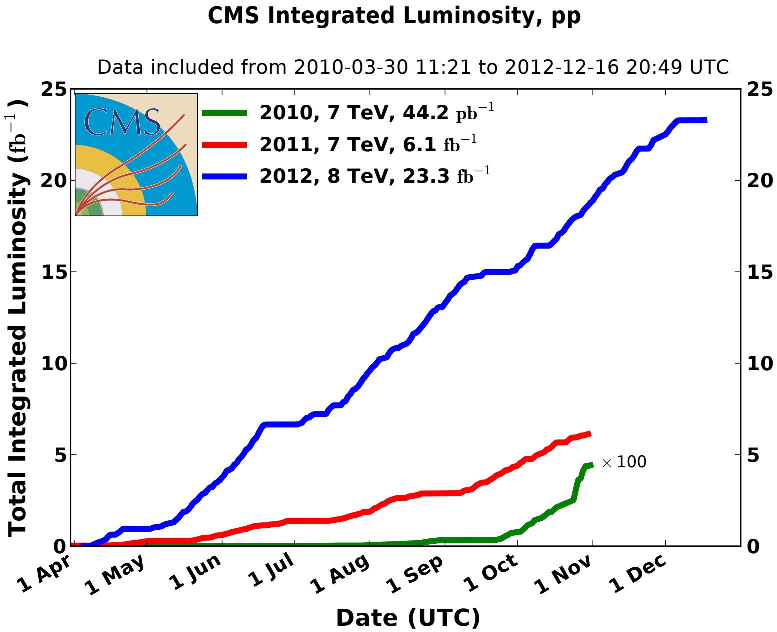
β^* : β at IP

Beam size $\sigma^2 = \beta\varepsilon$

Q : tune (number of trans. oscil./turn)

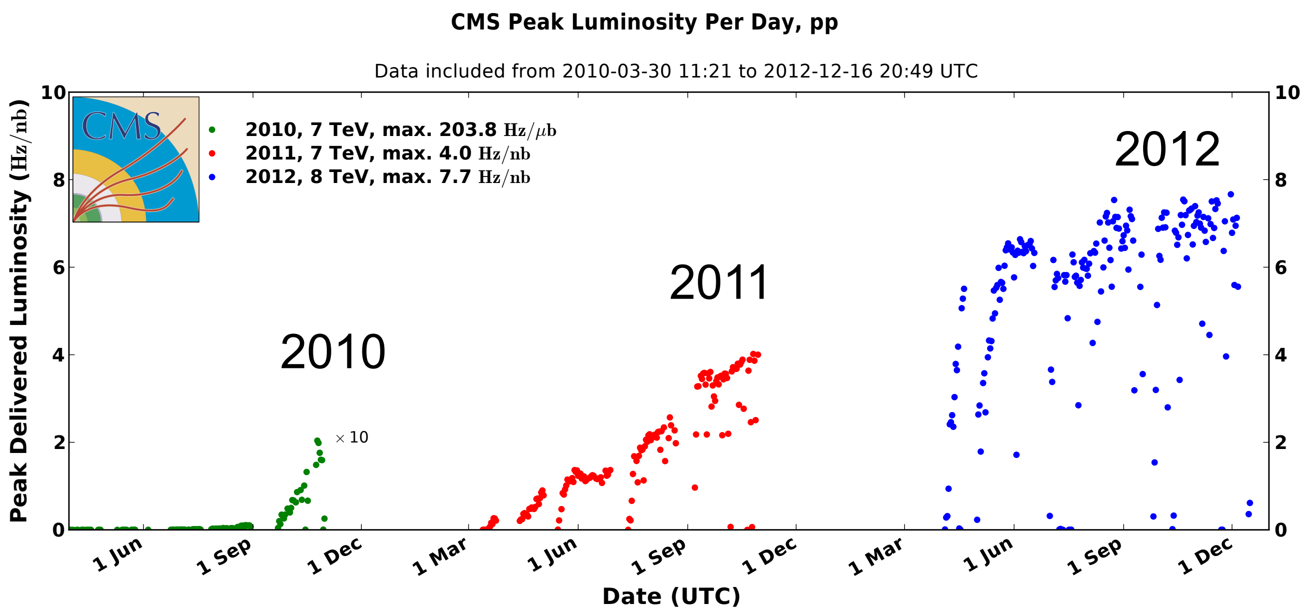
Courtesy: G.Tonelli

Datasets and luminosity



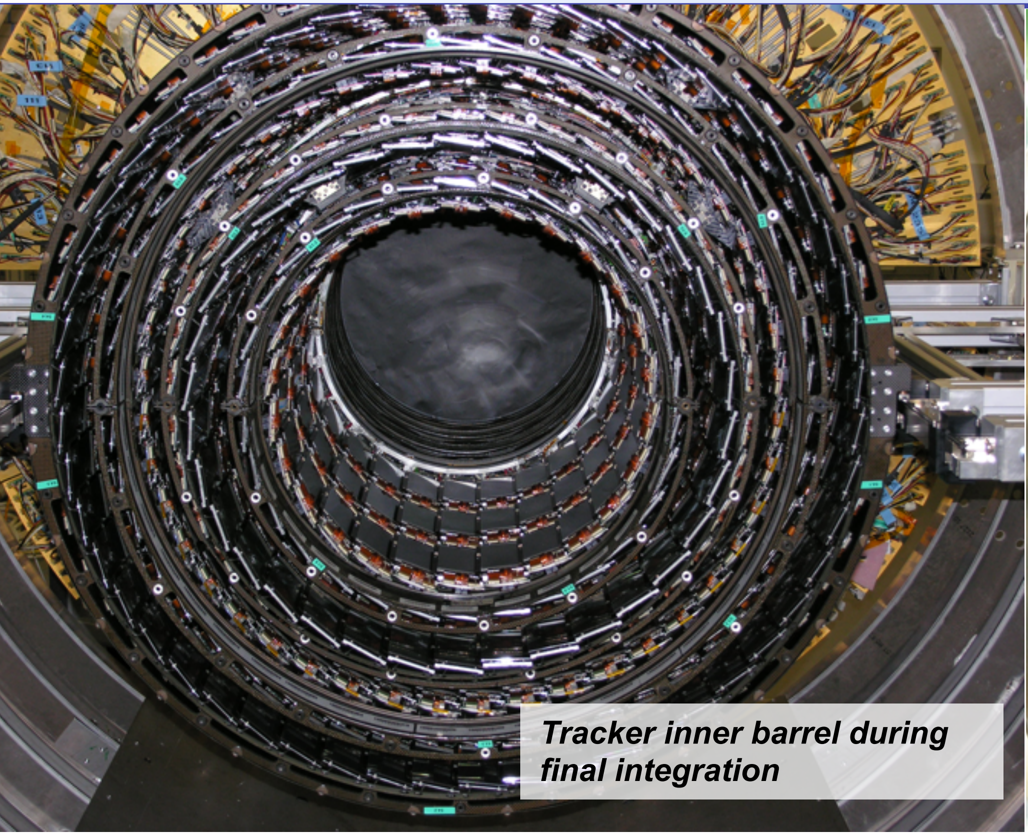
2010: ~40/pb at L_{inst}~10^{32} $cm^{-2}s^{-1}$
2011: ~6/fb at L_{inst}<$4x10^{33}$ $cm^{-2}s^{-1}$
2012: ~23/fb at L_{inst}<$7.5x10^{33}$ $cm^{-2}s^{-1}$

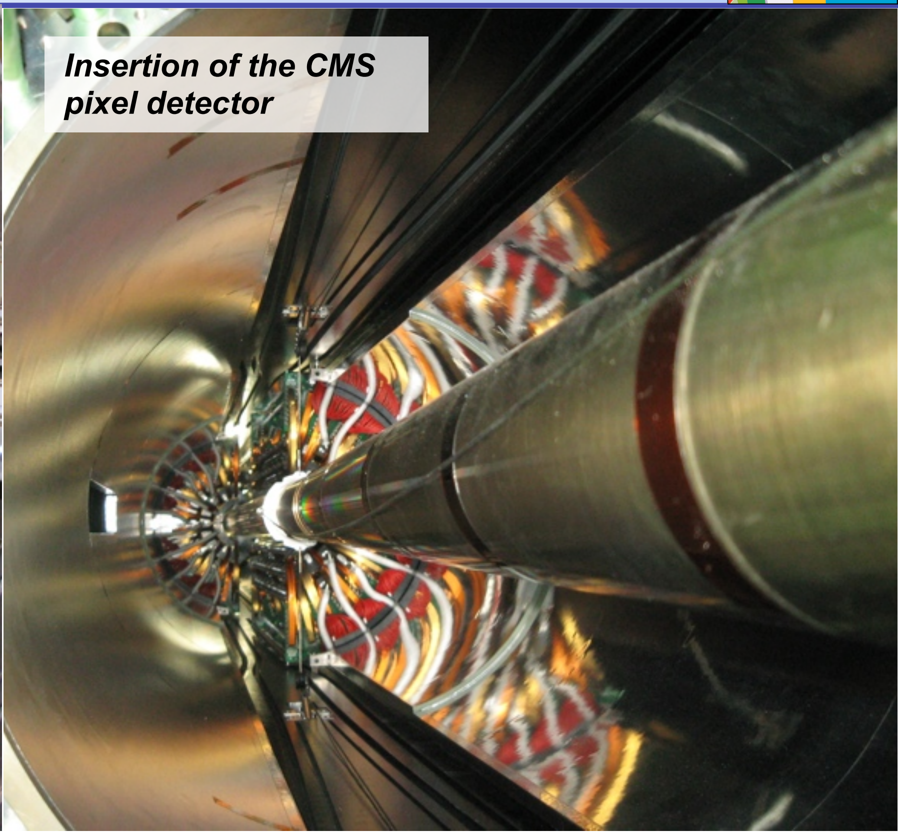
Steady increase of L_{inst} in 2011
2012 at rather stable L_{inst}



The CMS detector

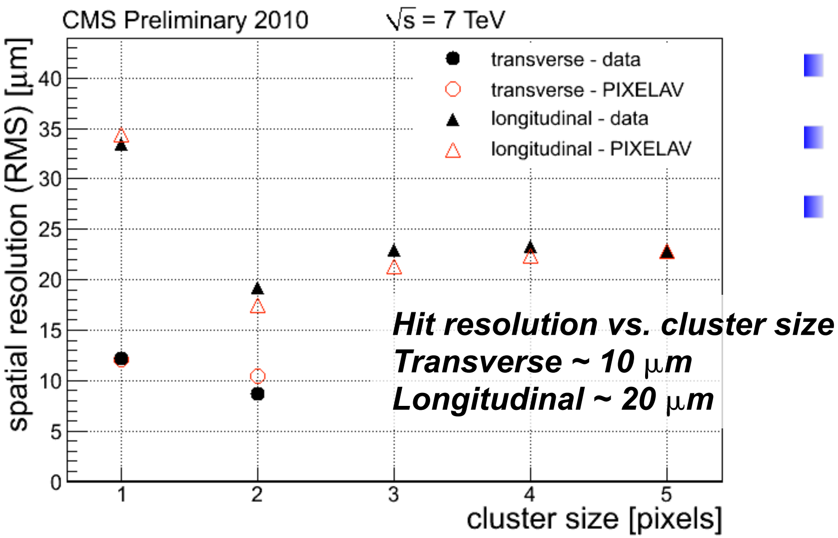
CMS: Tracker



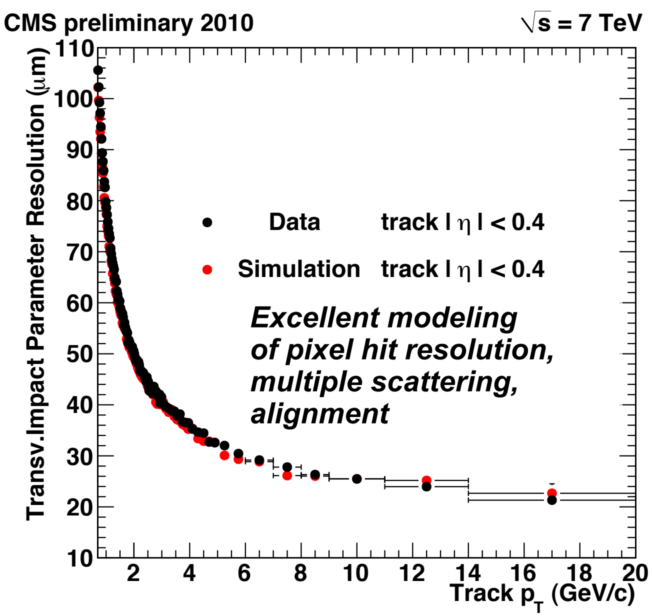


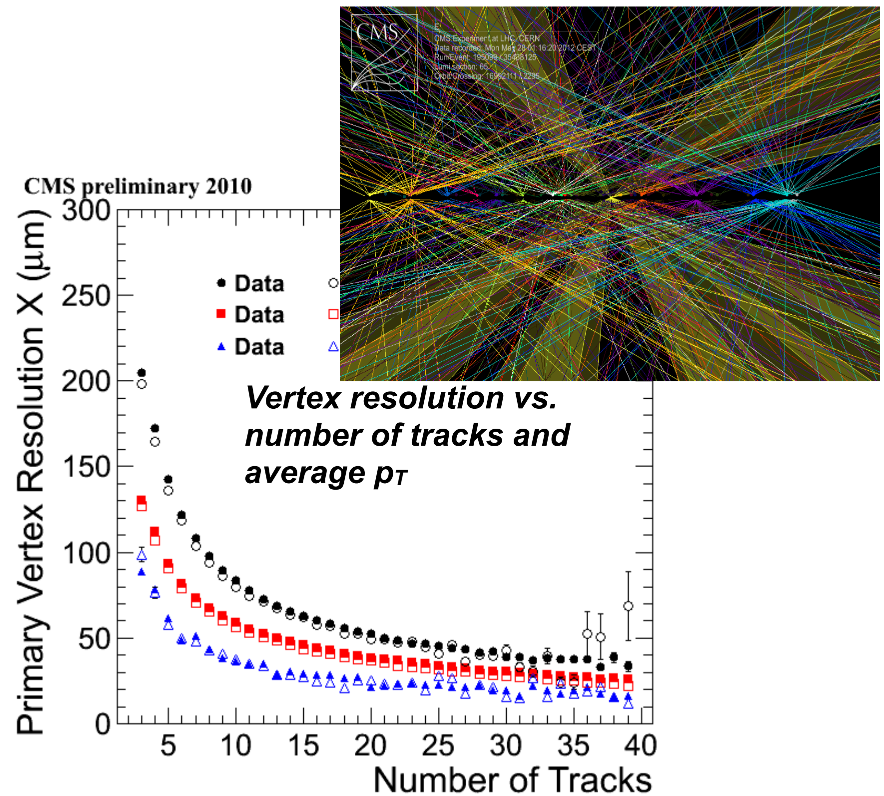
- **CMS is equipped with a full-silicon tracking detector**
  - Three layers and two disks of **pixel sensors** (~66M channels)
  - Ten barrel layers and 3+9 endcap wheels of **strip sensors** (~10M channels)
  - Pseudorapidity coverage up to **2.4**. Transverse momentum resolution 2-3%.

CMS: Pixel detector



- ~98% operational during data taking
- Hit efficiency >99%
- Excellent understanding of detector resolution:
  - Hit position, impact parameter, vertices

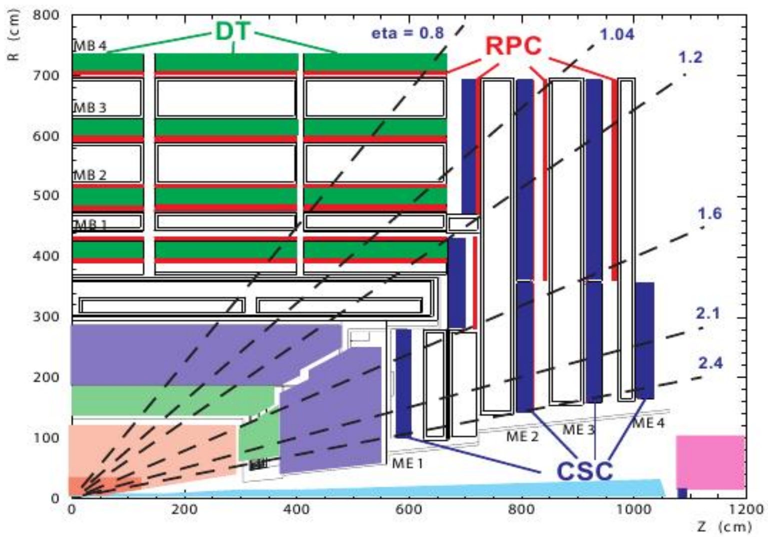




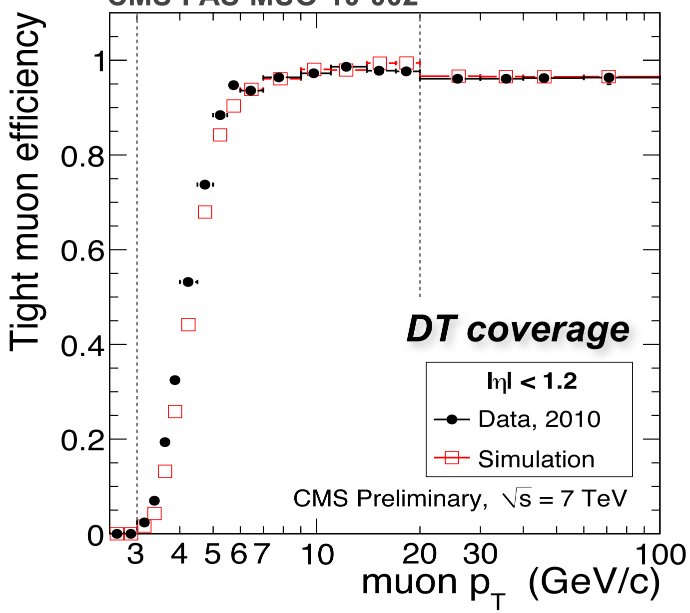
CMS-PAS-TRK-10-005
Eur.Phys.J. C70 (2010) p.1165

CMS: Muon system

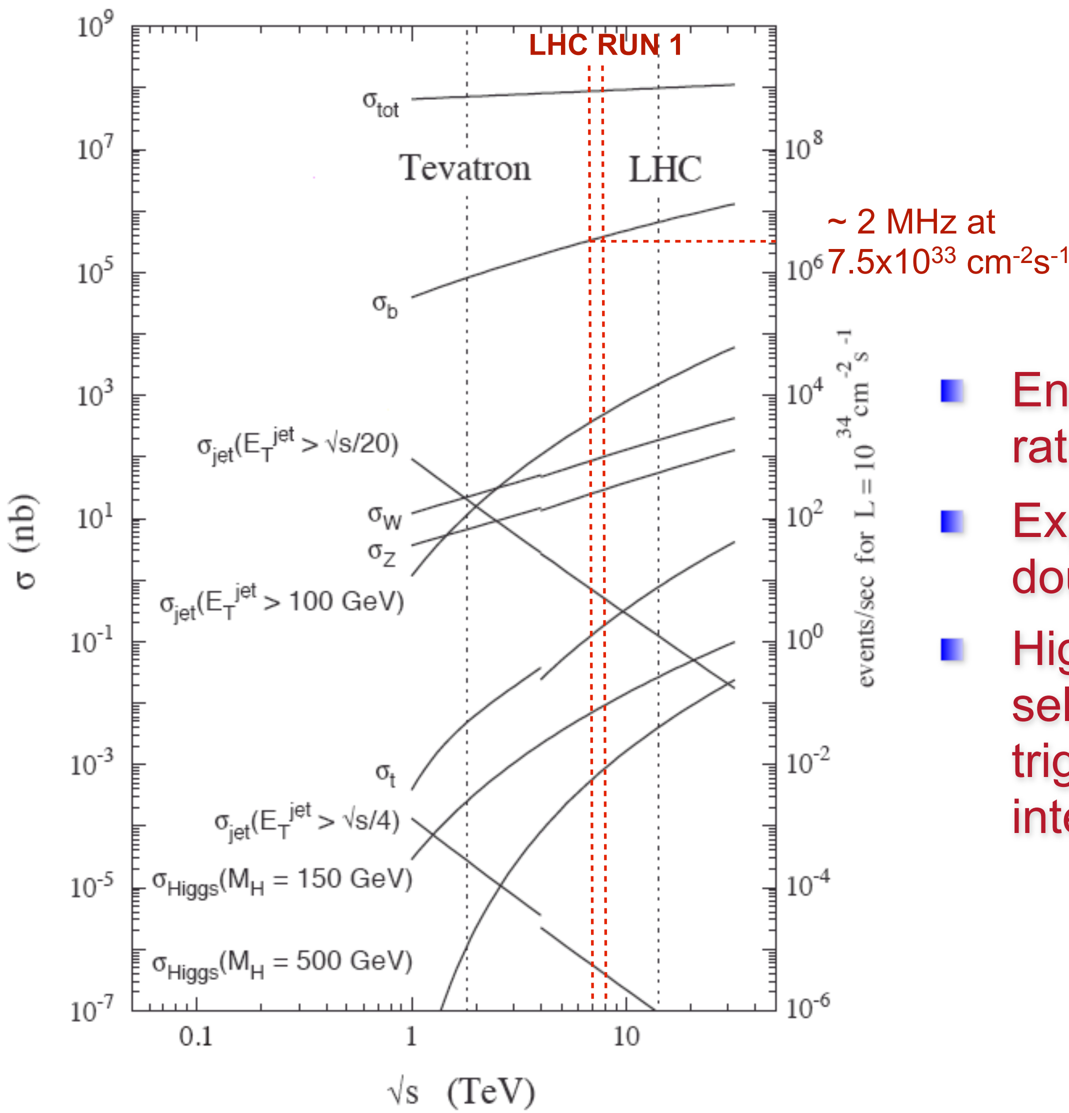
- Tracks:
  - Excellent p_T resolution ≈ 2-3%
  - Efficiency above 99% for central muons
  - Impact parameter resolution ~15 μm
- Muon candidates:
  - Match between muon segments and a silicon track
- Large pseudorapidity coverage: $|\eta| < 2.4$
- Muon efficiencies evaluated with
  - MC methods
  - Data-driven methods: Tag & Probe
- Muon misidentification rates from data:
  - $D^* \to D^0\pi$, $D^0 \to K\pi$
  - $K_S \to \pi\pi$
  - $\Lambda \to p\pi$



CMS-PAS-MUO-10-002

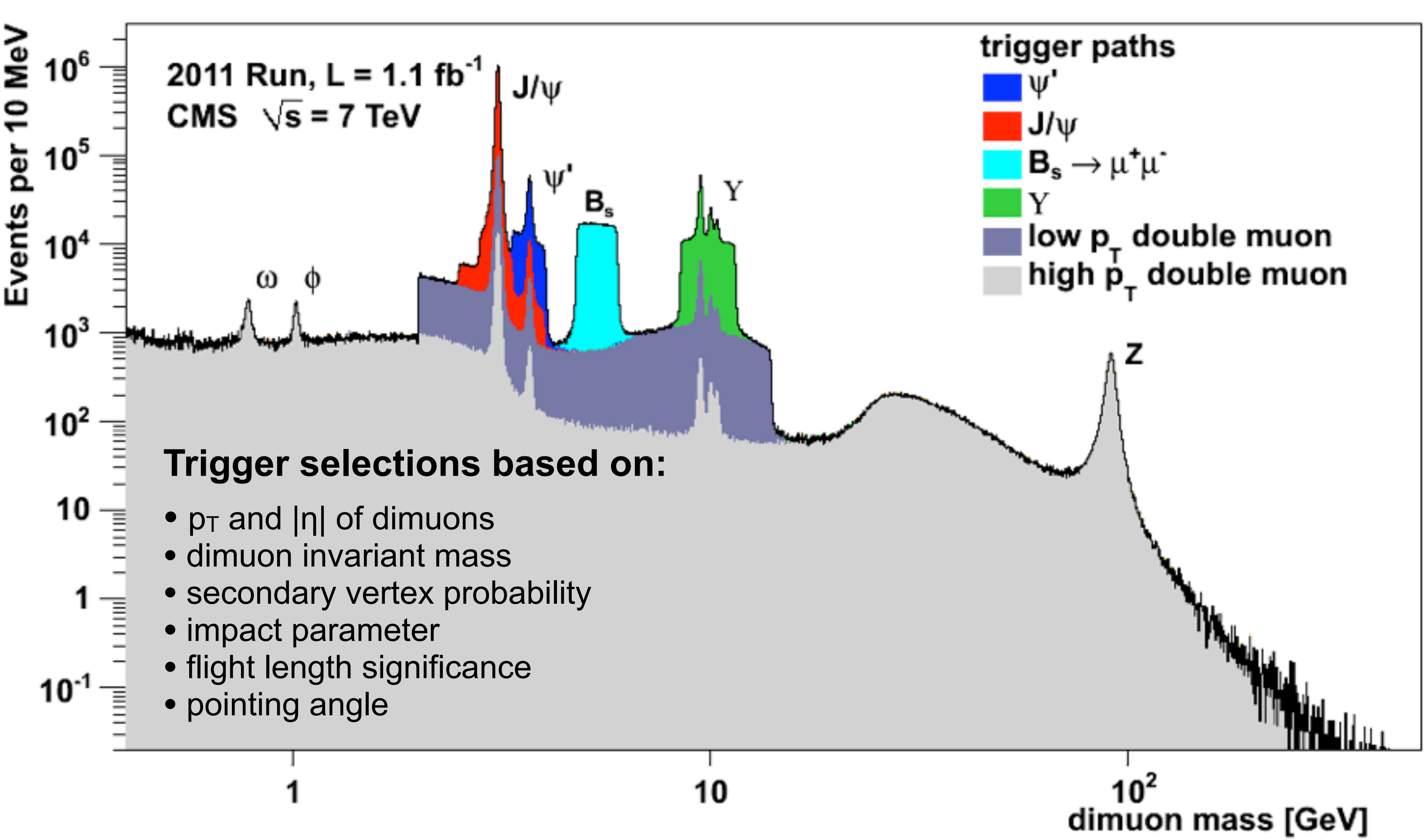


b quark production at the LHC



- Enormous b quark production rate at the LHC Run 1
- Expected to more than double in Run 2
- High rates implies very selective requirements at trigger level to store interesting b decays

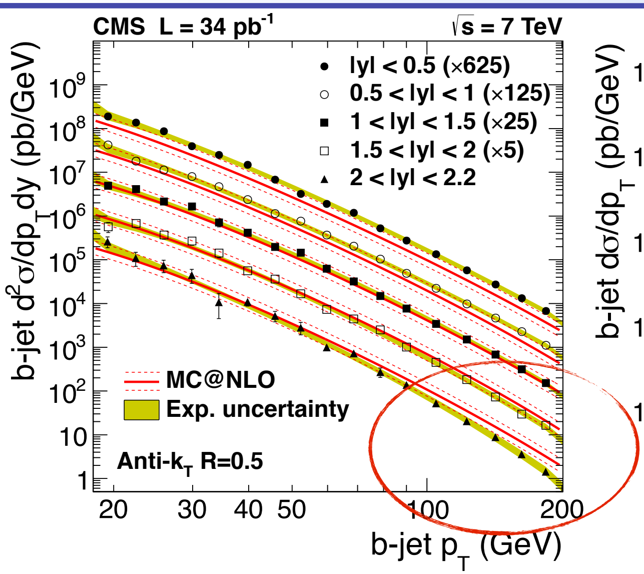
Triggers for heavy flavor physics

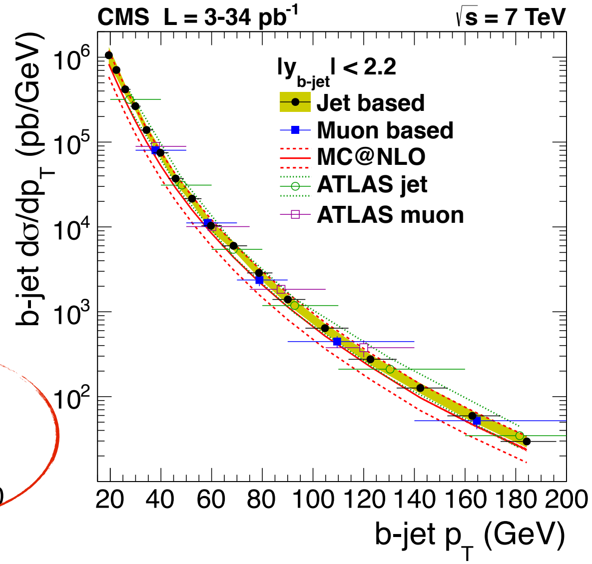


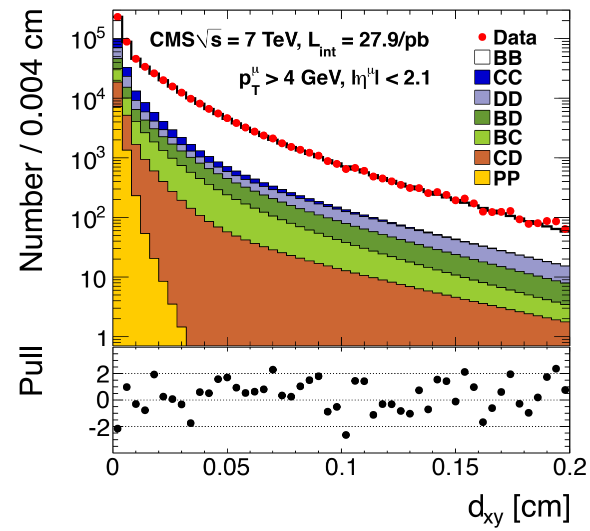
- Trigger requirements tightened following the increase in instantaneous luminosity.
- About 10% of CMS bandwidth assigned to heavy flavor physics
- Single muon trigger efficiencies measured from data (tag&probe), dimuon correlations from MC

Understanding the rates: Production measurements

Inclusive B production







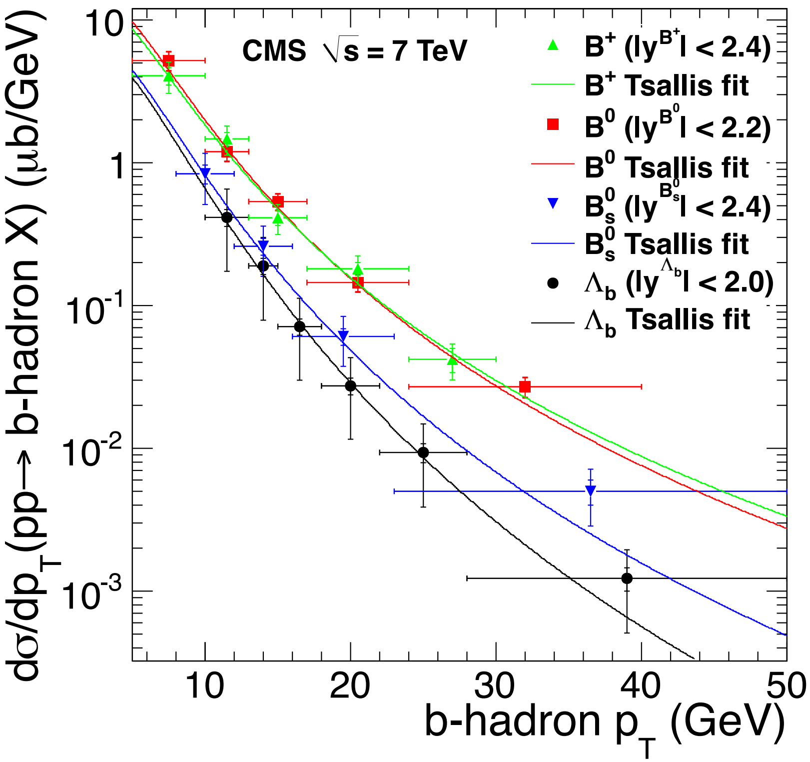
- **Inclusive B cross sections using tagged jets and events with two semileptonic muons**
  - NLO in agreement with data but systematically below
  - Further measurements needed to pin down **high-pt and rapidity** regions
    - MC@NLO and POWHEG giving somewhat different predictions

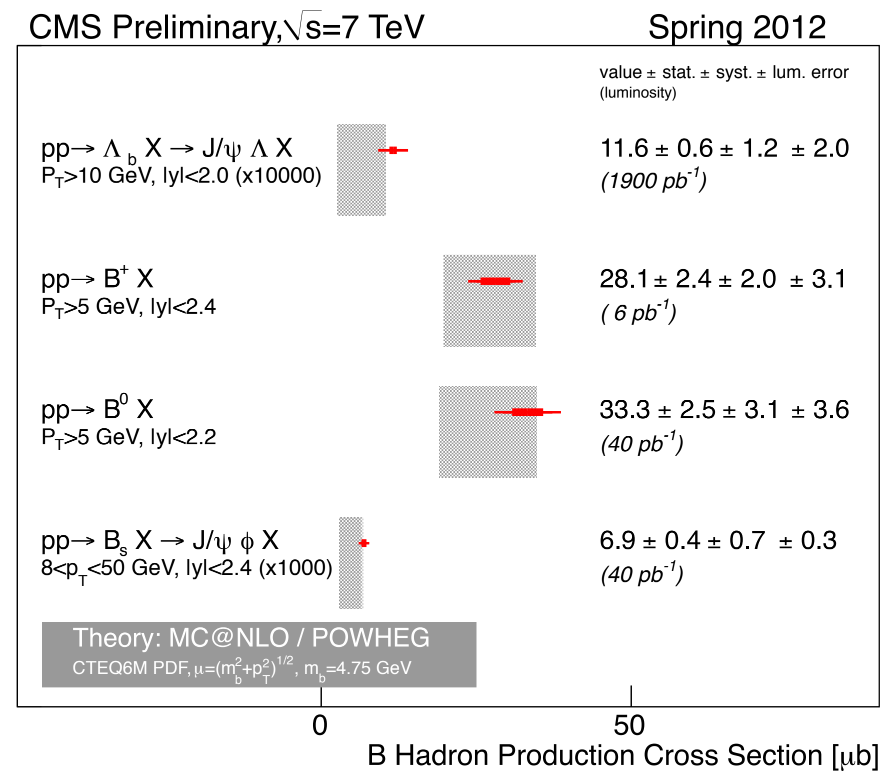
Process	p_T range [GeV/c]	(Pseudo)-rapidity range	Cross section [μb]	NLO QCD [μb]	Ref.
$pp \to bX \to \mu X$	$6-\infty$	$\lvert\eta\rvert < 2.1$	$1.32 \pm 0.01 \pm 0.30 \pm 0.15$	$0.95^{+0.41}_{-0.21}$	[1]
$pp \to b\bar{b}X \to \mu\mu X$	$4-\infty$	$\lvert\eta\rvert < 2.1$	$(26.18 \pm 0.14 \pm 2.82 \pm 1.05) \times 10^{-3}$	$(19.95^{+4.68}_{-4.33}) \times 10^{-3}$	[4]
$pp \to$ b jet X	$30-\infty$	$\lvert y\rvert < 2.4$	$2.14 \pm 0.01 \pm 0.41 \pm 0.09$	$1.83^{+0.64}_{-0.42}$	[5]
$pp \to B^+X$	$5-\infty$	$\lvert y\rvert < 2.4$	$28.3 \pm 2.4 \pm 2.0 \pm 1.1$	$25.5^{+8.8}_{-5.4}$	[9]
$pp \to B^0X$	$5-\infty$	$\lvert y\rvert < 2.2$	$33.2 \pm 2.5 \pm 3.1 \pm 1.3$	$25.2^{+9.6}_{-6.2}$	[10]
$pp \to B_sX \to J/\psi\phi X$	$8-50$	$\lvert y\rvert < 2.4$	$(6.9 \pm 0.6 \pm 0.5 \pm 0.3) \times 10^{-3}$	$(4.9^{+1.9}_{-1.7}) \times 10^{-3}$	[11]

Source: http://arxiv.org/abs/1201.6677

JHEP 04 (2012) 084
JHEP 06 (2012) 110

B hadron production





$$\frac{1}{N}\frac{dN}{dp_T} = C\,p_T\left[1+\frac{\sqrt{p_T^2+m^2}-m}{nT}\right]^{-n}$$

Power low behavior from Tsallis fit

$n(B^+,B^0) = 5.7\pm0.3$

$n(\Lambda_b) = 7.6\pm0.4$ (4.7σ tension)

NLO predictions compatible with data but tendency to be below data

P_T dependence of $\frac{\text{baryon}}{\text{meson}}$ fragmentation?

Phys. Lett. B714, 136
Phys. Rev. Lett. **106** (2011) 112001
Phys. Rev. Lett. **106** (2011) 252001
Phys. Rev. D84 (2011) 052008

Spectroscopy:
A new baryon found

On the media

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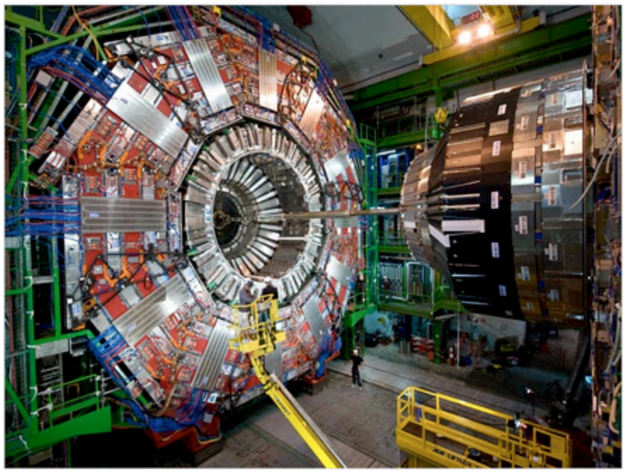
"Beautiful" New Particle Found at LHC

Xi(b)* a "brick in the wall" for solving how matter's made, expert says.



The CMS detector inside the Large Hadron Collider captured evidence of the new particle (file picture).

Photograph courtesy Maximilien Brice, CERN

Ker Than
for National Geographic News
Published May 1, 2012

An atom-smashing experiment at the Large Hadron Collider (LHC) has detected a new subatomic particle—and it's a beauty.

Known as Xi(b)* (pronounced "csai bee-star"), the new particle is a baryon, a type of matter made up of three even smaller pieces called quarks. Protons and neutrons, which make up the nuclei of atoms, are also baryons.

(Related: "Proton Smaller Than Thought—May Rewrite Laws of Physics.")

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First particle discovery at CMS!

May 1st, 2012

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New "Beauty Baryon" Particle Discovered at Large Hadron Collider

It's just the second new particle to be discovered at the atom smasher where physicists also seek the elusive Higgs boson particle

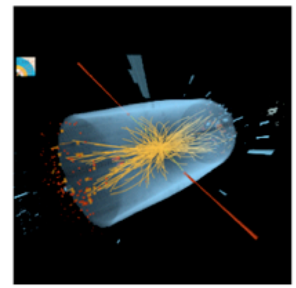
By Clara Moskowitz and LiveScience | May 1, 2012 | 20

A never-before-seen subatomic particle has popped into existence inside the world's largest atom smasher, bringing physicists a step closer to unraveling the mystery of how matter is put together in the universe.

After crashing particles together about 530 trillion times, scientists working on the CMS experiment at Switzerland's Large Hadron Collider (LHC) saw unmistakable evidence for a new type of "beauty baryon."

Baryons are particles made of three quarks (the building blocks of the protons and neutrons that populate the nuclei of atoms). Beauty baryons are baryons that contain at least one beauty quark (also known as a bottom quark). The new specimen is a particular type of excited beauty baryon called Xi(b)*, pronounced "csai–bee-star."

The discovery was announced Friday (April 27) in a paper released by the CMS collaboration (CMS stands for Compact Muon Solenoid, one of a handful of detectors built into the 17-mile, or 27-kilometer, underground loop of the LHC machine).



A typical candidate event at the Large Hadron Collider (LHC), including two high-energy photons whose energy (depicted by red towers) is measured in the CMS electromagnetic calorimeter. The yellow lines are the measured tracks of other particles produced in the collision. The pale blue volume shows the CMS crystal calorimeter barrel. *Image: CERN/CMS*

"It's very rewarding," Vincenzo Chiochia, a University of Zurich physicist working on the CMS experiment, told LiveScience. "We work for projects that run for several years — from conception to data taking, it can take more than 10 years — so when you actually come up with a discovery, and you know this particle collider is among the few that can produce it, it's extremely exciting."

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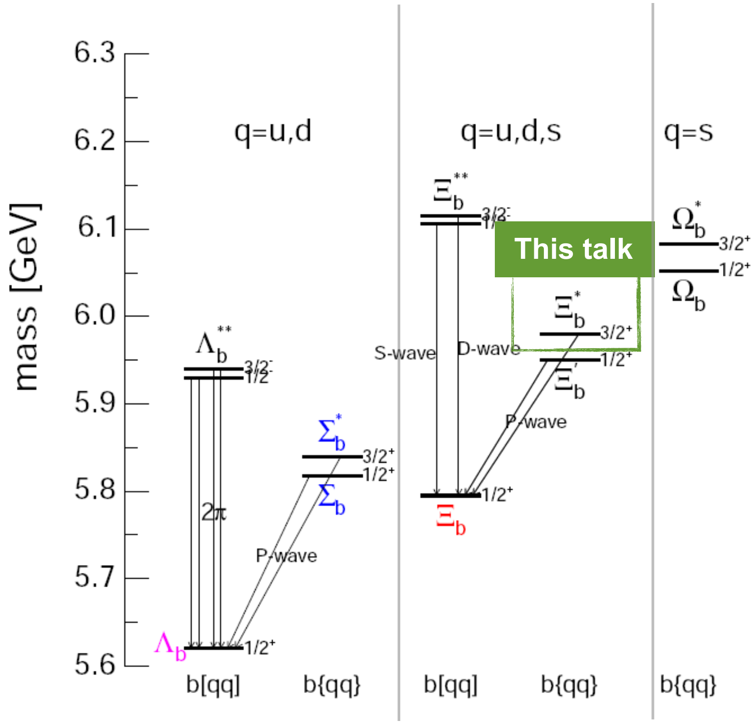
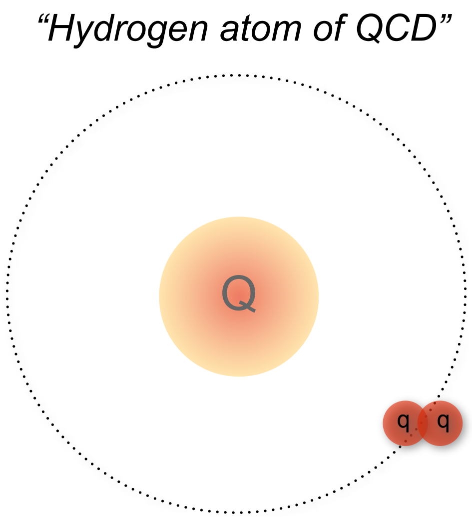
Heavy baryons with beauty

- In **heavy quark effective theory** an heavy baryon is made of
  - Static color field from **heavy quark**
  - Cloud corresponding to the **light di-quark** system



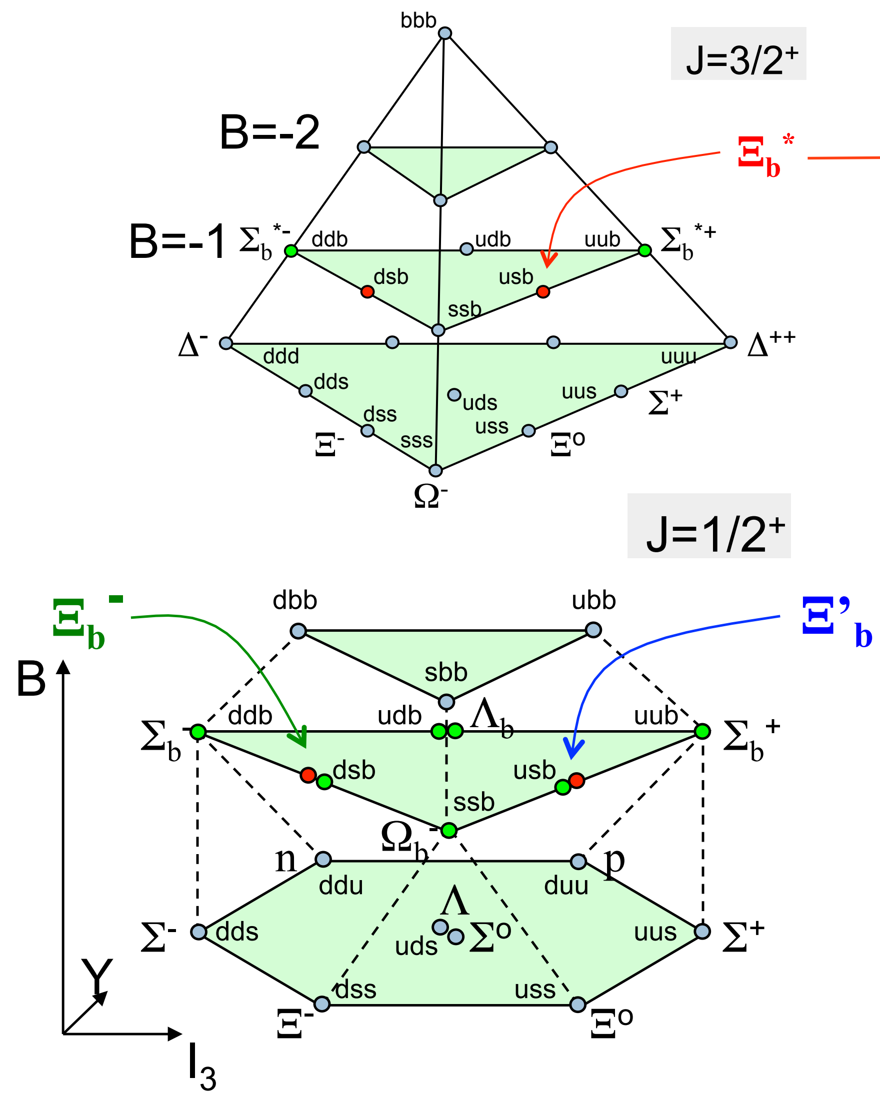


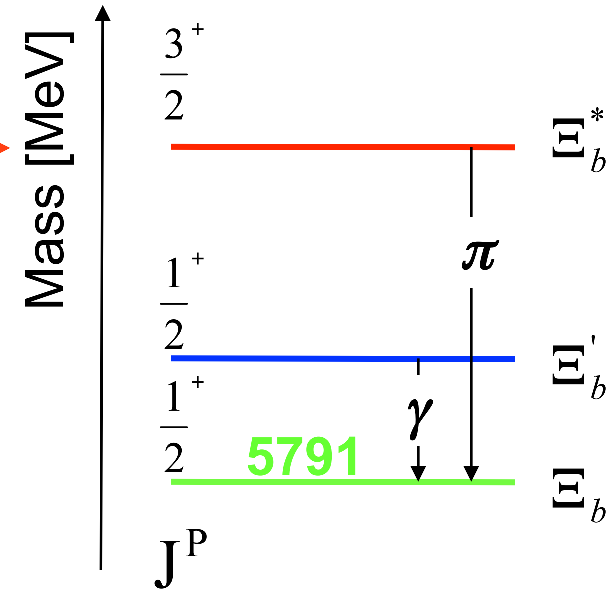
Antisymmetric flavor configuration [q_1,q_2]: **Λ-type** baryons Λ_b^0=|bdu>

Symmetric flavor configuration {q_1,q_2}: **Σ-type** baryons Σ_b=|buu>

q_i is a **strange** quark: Ξ_b family - **both** q_i are **strange** quarks: Ω_b^-

The Ξ_b baryon family





Analog to charmed baryon spectrum

$$\Xi_c(2645)^0 \rightarrow \Xi_c^+ \pi^-$$

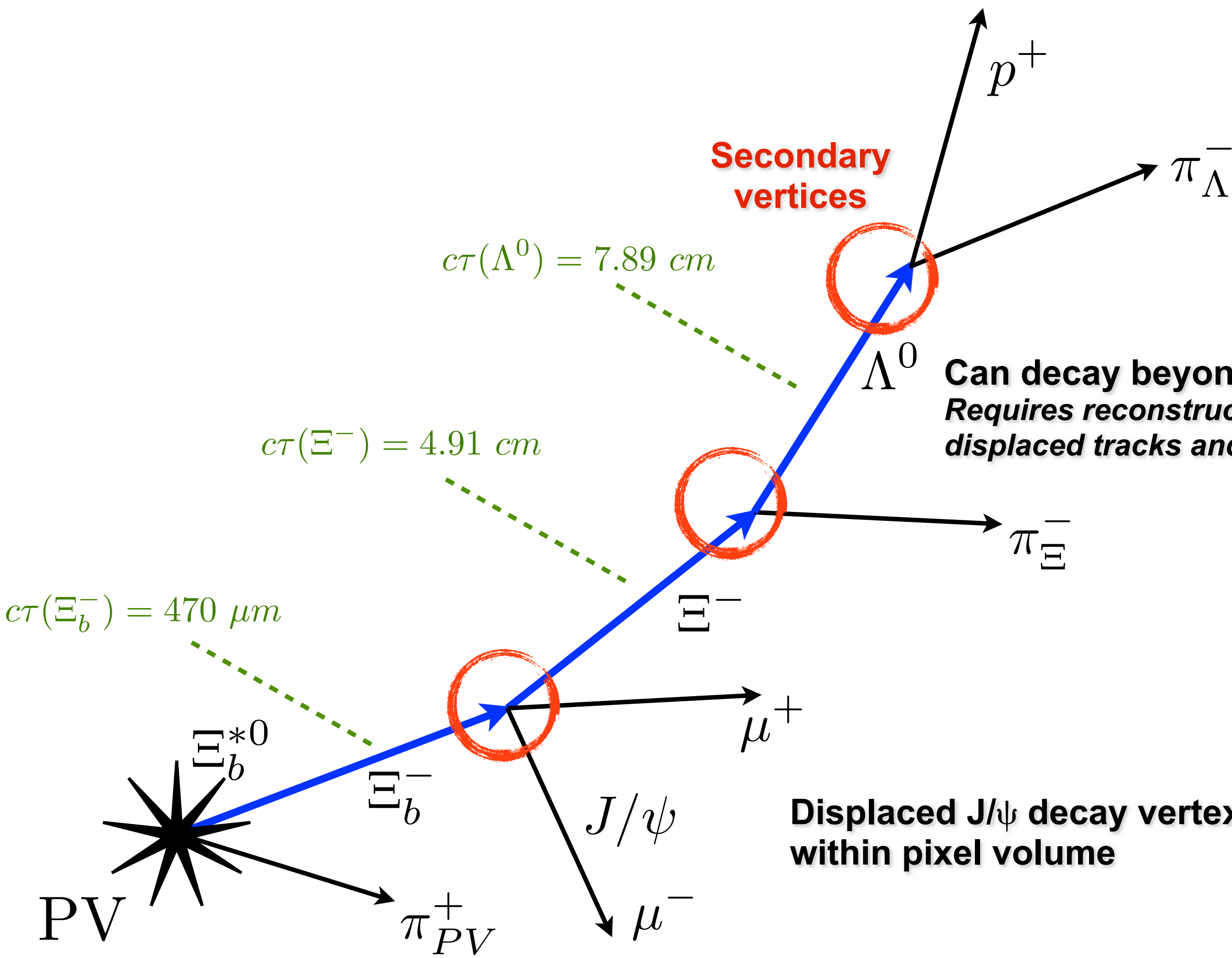
Q value: $M(\Xi_b^{*0})-M(\Xi_b^-)-M(\pi^+)\approx 11\text{-}29$ MeV

Width < 1MeV

"Heavy neutron" with u-s-b quarks

Phys. Rev. D **66**, 014502 (2002)
Phys. Rev. D **77**, 034012 (2008)
Phys. Rev. D **79**, 014502 (2009)
Phys. Rev. D **84**, 014025 (2011)
arXiv:1203.3378v1 [hep-lat]

Ξ_b^{*0} decay chain

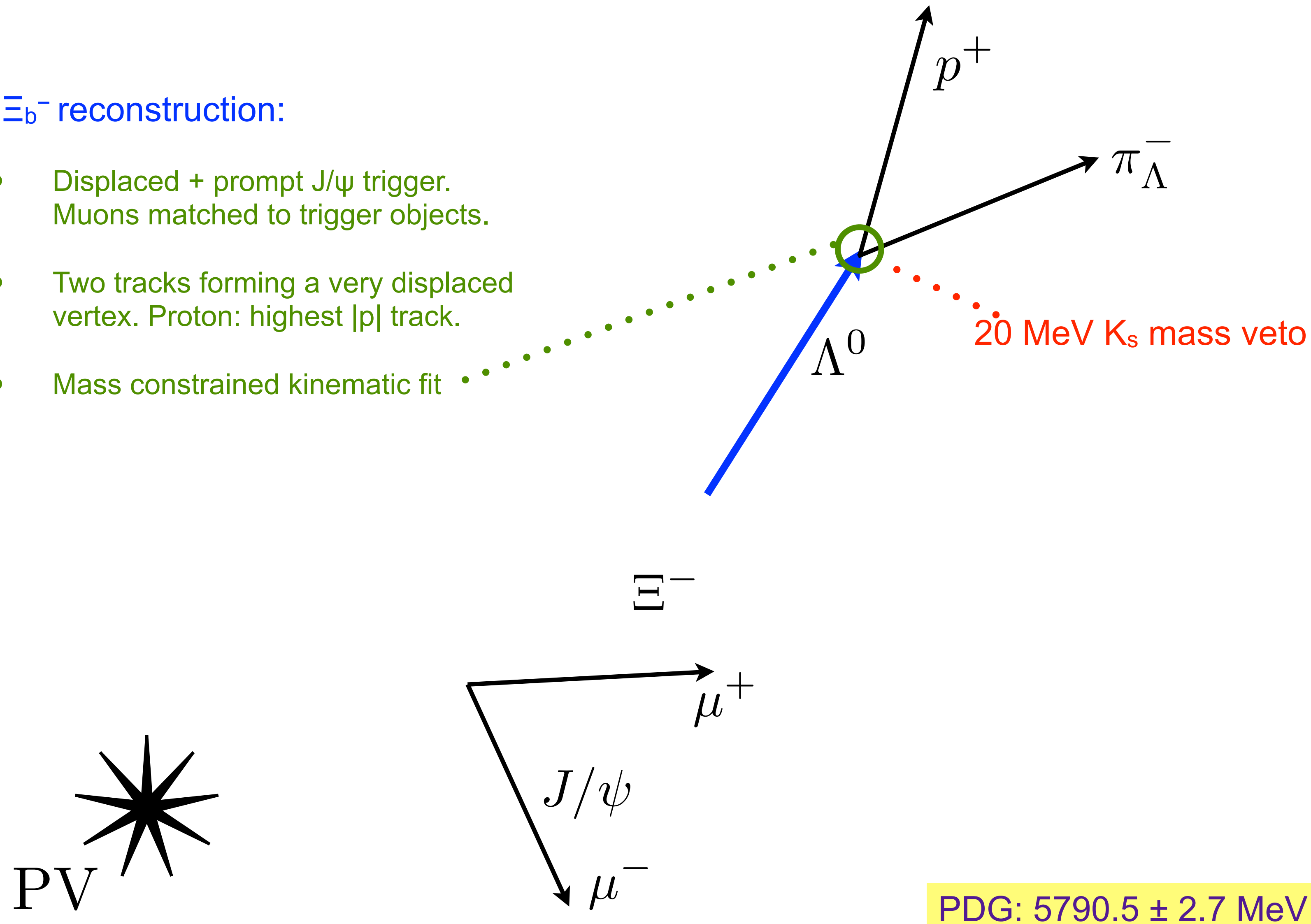


Can decay beyond pixel volume
Requires reconstruction of very displaced tracks and vertices

Displaced J/ψ decay vertex within pixel volume

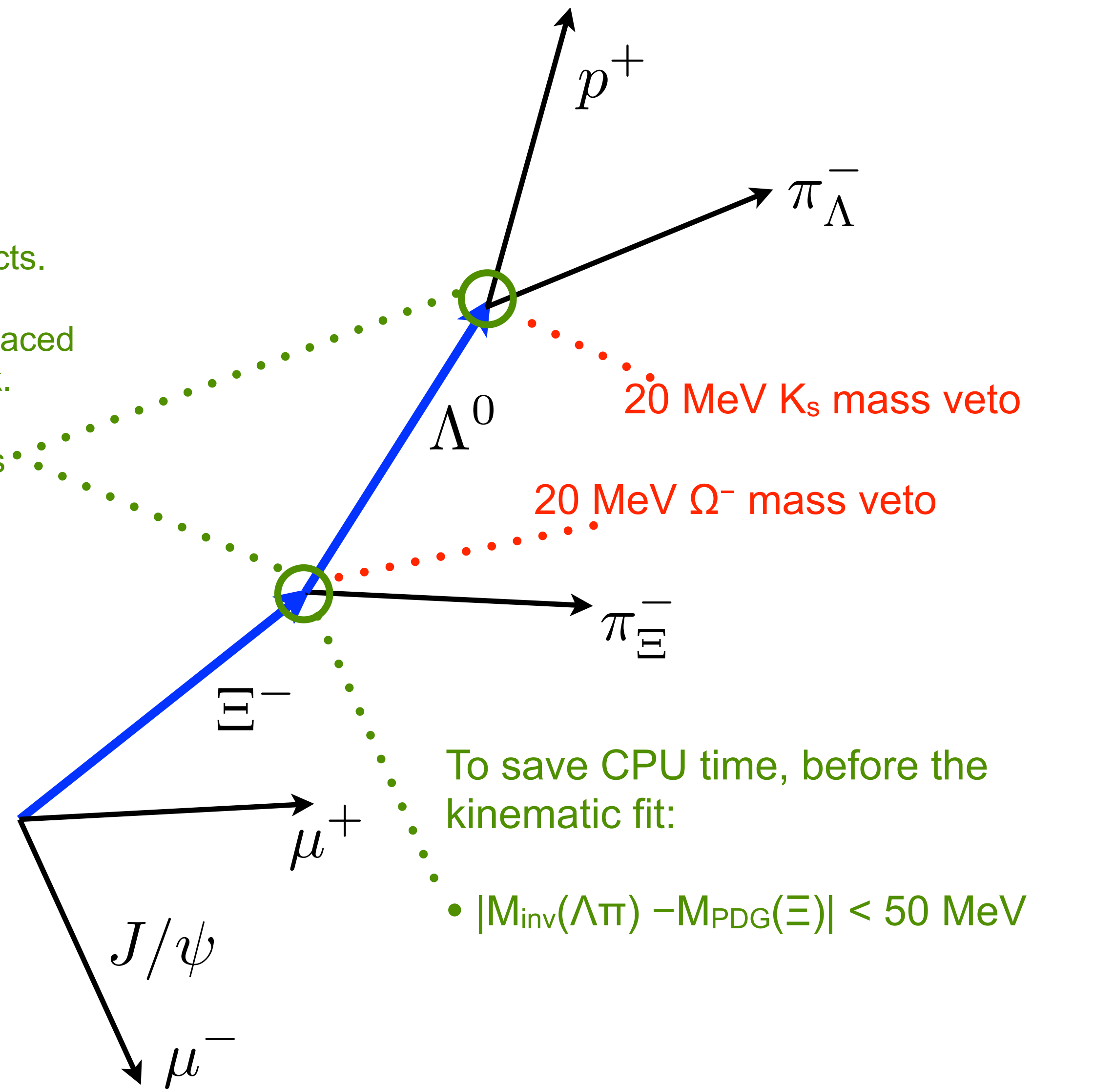
Ξ_b^- selection

- Ξ_b^- reconstruction:
  - Displaced + prompt J/ψ trigger. Muons matched to trigger objects.
  - Two tracks forming a very displaced vertex. Proton: highest |p| track.
  - Mass constrained kinematic fit



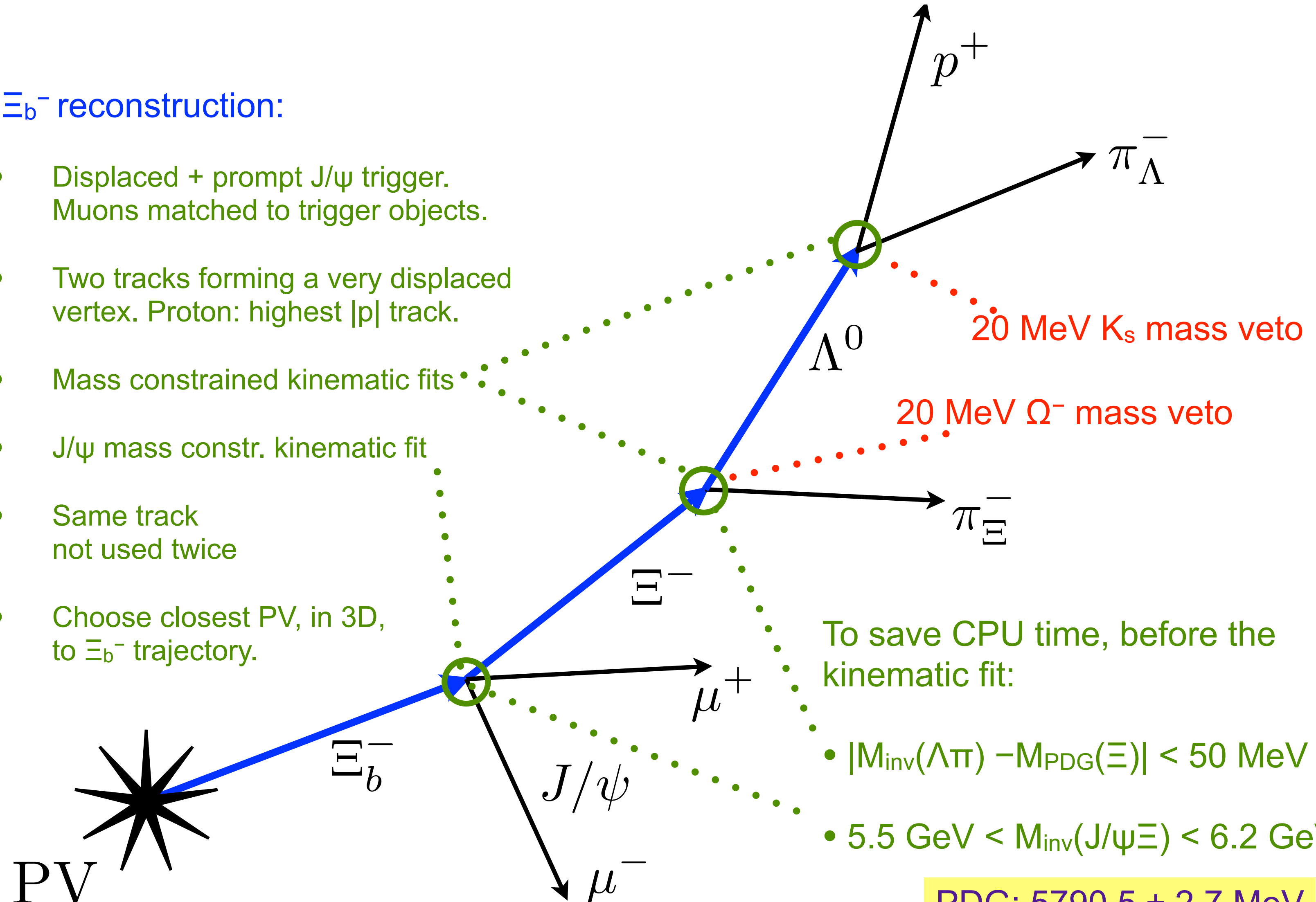
PDG: 5790.5 ± 2.7 MeV

- Ξ_b^- reconstruction:
  - Displaced + prompt J/ψ trigger. Muons matched to trigger objects.
  - Two tracks forming a very displaced vertex. Proton: highest |p| track.
  - Mass constrained kinematic fits



Ξ_b^- selection

- Ξ_b^- reconstruction:
  - Displaced + prompt J/ψ trigger. Muons matched to trigger objects.
  - Two tracks forming a very displaced vertex. Proton: highest |p| track.
  - Mass constrained kinematic fits
  - J/ψ mass constr. kinematic fit
  - Same track not used twice
  - Choose closest PV, in 3D, to Ξ_b^- trajectory.



To save CPU time, before the kinematic fit:

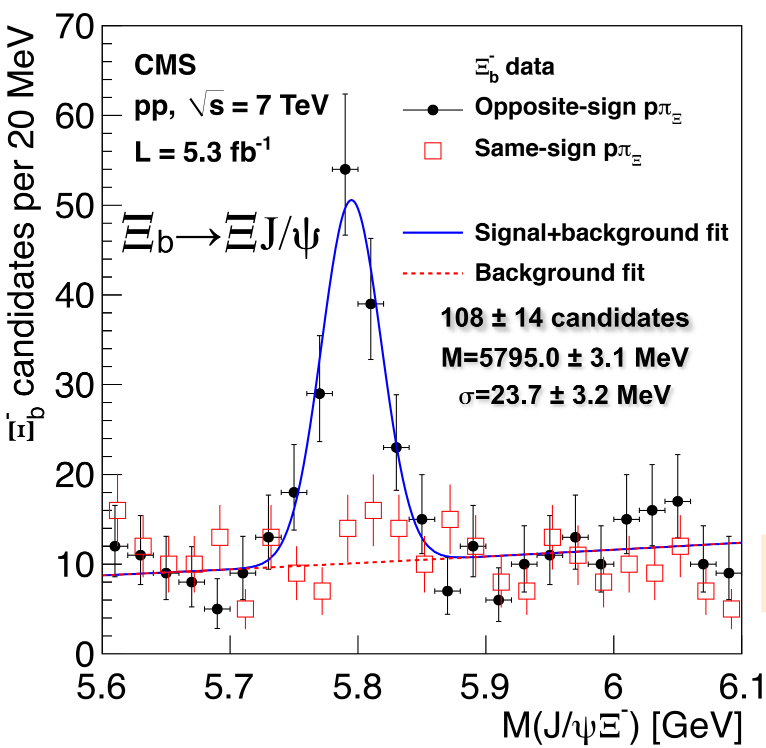
- $|M_{inv}(\Lambda\pi) - M_{PDG}(\Xi)| < 50$ MeV
- $5.5 \text{ GeV} < M_{inv}(J/\psi\Xi) < 6.2$ GeV

PDG: 5790.5 ± 2.7 MeV

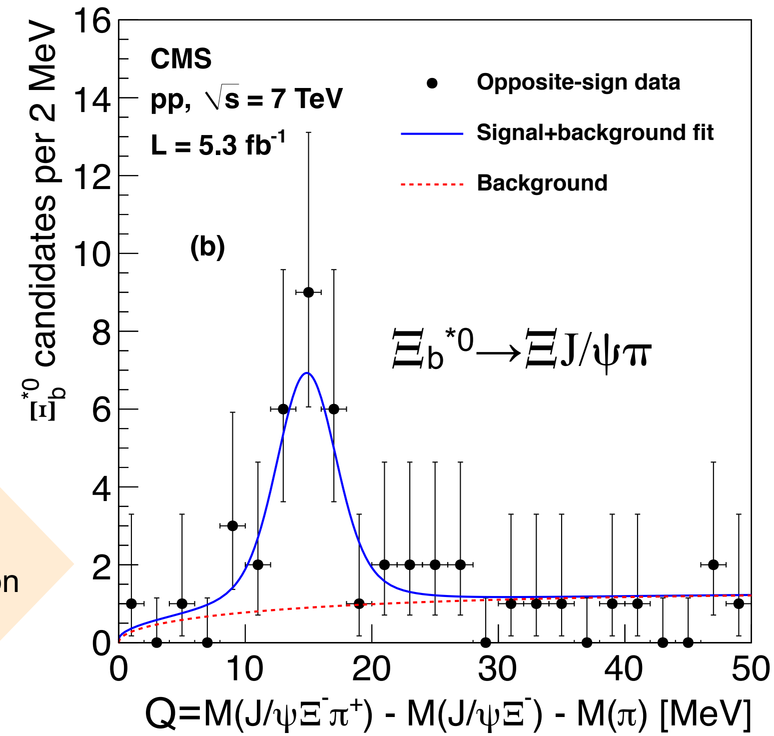
Observation of the Ξ_b^{*0} baryon

21 events observed, 3.0±1.4 background expected

Resolution from MC: σ_{MC}**=1.9±0.1 MeV**



Additional prompt pion



Q = 14.8 ± 0.7 ± 0.3 MeV

M(Ξ_b) = 5945.0 ± 0.7(stat.) ± 0.3(syst.) ± 2.7(PDG) MeV

Γ_{BW}=2.1±1.7 MeV (Theory: 0.93 MeV)

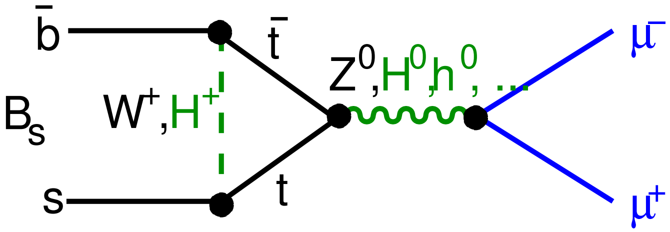
Significance from **ln(L_{s+b}/L_b)=6.9**

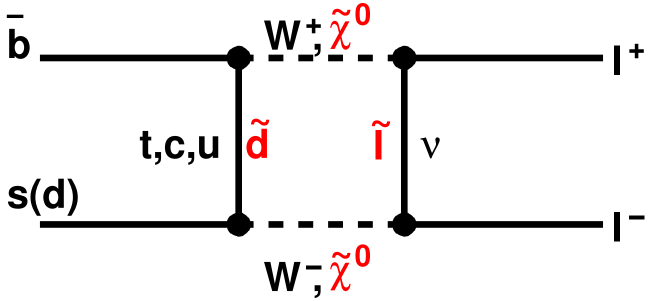
Phys. Rev. Lett. 108, 252002 (2012)

Looking outside the box: Rare B decays

Why searching for $B_{s,d}\to\mu^+\mu^-$?

- **Decays highly suppressed in SM**
  - Forbidden at tree level
  - b →s(d) FCNC transitions only through *Penguin* or *Box* diagrams
  - Cabibbo ($|V_{td}|<|V_{ts}|$) and helicity suppressed
- **Standard Model predictions**
  - $\mathcal{B}(B_s\to\mu\mu)=(3.56\pm0.18)\times10^{-9}$ [1]
    - ~10% corrections from B_s mixing when comparing to experiments included [1,2]
    - CKM best fit: $(3.6^{+0.2}_{-0.3})\times10^{-9}$ [3]
  - $\mathcal{B}(B^0\to\mu\mu)=(1.07\pm0.10)\times10^{-10}$ [1]
- **Sensitivity to new physics, e.g. extended Higgs sector and SUSY particles:**
  - 2HDM branching ~$(\tan\beta)^4$ and $m(H^+)$
  - MSSM branching ~$(\tan\beta)^6$
  - Leptoquarks
  - 4th generation top





[1] JHEP 1307 (2013) 77
[2] PRL 109, 041801 (2012), arXiv:1208.0934
[3] Phys. Rev. D85: 033005, 2011

A 30-years quest!

Two-body decays of B mesons

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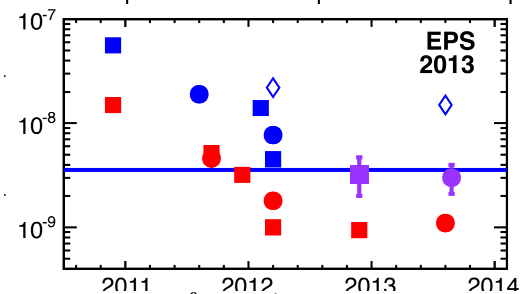
(Received 8 June 1984; revised manuscript received 10 September 1984)

Various exclusive and inclusive decays of B mesons have been studied using data taken with the CLEO detector at the Cornell Electron Storage Ring. The exclusive modes examined are mostly decays into two hadrons. The branching ratio for a B meson to decay into a charmed meson and a charged pion is found to be about 2%. Upper limits are quoted for other final states ψK^-, $\pi^+\pi^-$, $\rho^0\pi^-$, $\mu^+\mu^-$, e^+e^-, and $\mu^\pm e^\mp$. We also give an upper limit on inclusive ψ production and improved charged multiplicity measurements.

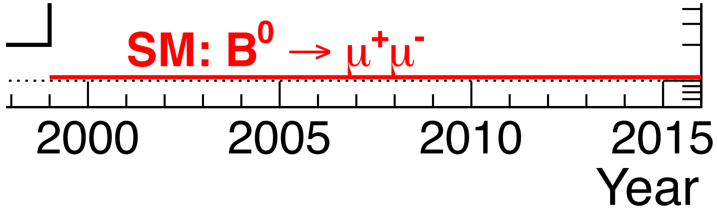


Measurement of the $B_s^0 \to \mu^+\mu^-$ Branching Fraction and Search for $B^0 \to \mu^+\mu^-$ with the CMS Experiment

S. Chatrchyan *et al.**
(CMS Collaboration)

(Received 18 July 2013; published 5 September 2013)

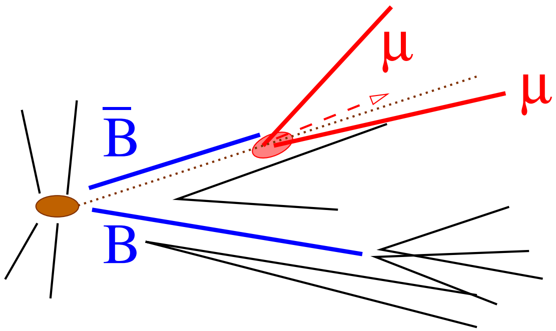
Results are presented from a search for the rare decays $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ in pp collisions at $\sqrt{s} = 7$ and 8 TeV, with data samples corresponding to integrated luminosities of 5 and 20 fb^{-1}, respectively, collected by the CMS experiment at the LHC. An unbinned maximum-likelihood fit to the dimuon invariant mass distribution gives a branching fraction $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.0^{+1.0}_{-0.9}) \times 10^{-9}$, where the uncertainty includes both statistical and systematic contributions. An excess of $B_s^0 \to \mu^+\mu^-$ events with respect to background is observed with a significance of 4.3 standard deviations. For the decay $B^0 \to \mu^+\mu^-$ an upper limit of $\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.1 \times 10^{-9}$ at the 95% confidence level is determined. Both results are in agreement with the expectations from the standard model.



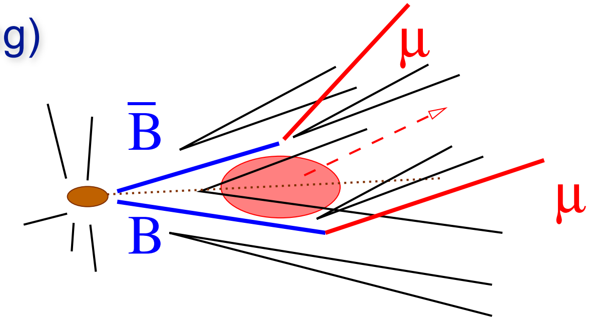
Event characteristics

Key ingredients:
Good dimuon vertex, correct B mass assignment, isolation, momentum pointing to interaction point

- **Signal characteristics:**
  - Two muons from a well reconstructed decay vertex
  - Mass compatible with B_s (or B^0)
  - Dimuon momentum aligned with B flight direction

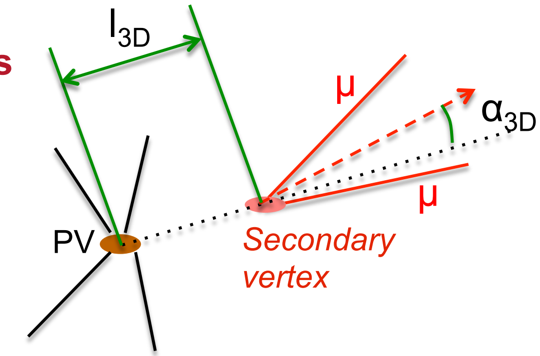


- **Background sources:**
  - Two semi-leptonic B decays (e.g. from gluon splitting)
  - One semi-leptonic B decay + misidentified hadron
  - Hadronic B decays
    - Peaking: $B_s \rightarrow K^- K^+$
      - More problematic within the B^0 mass window
    - Rare semileptonic: $B_s \rightarrow K^- \mu^+ \nu$, $\Lambda_b \rightarrow p \mu \nu$

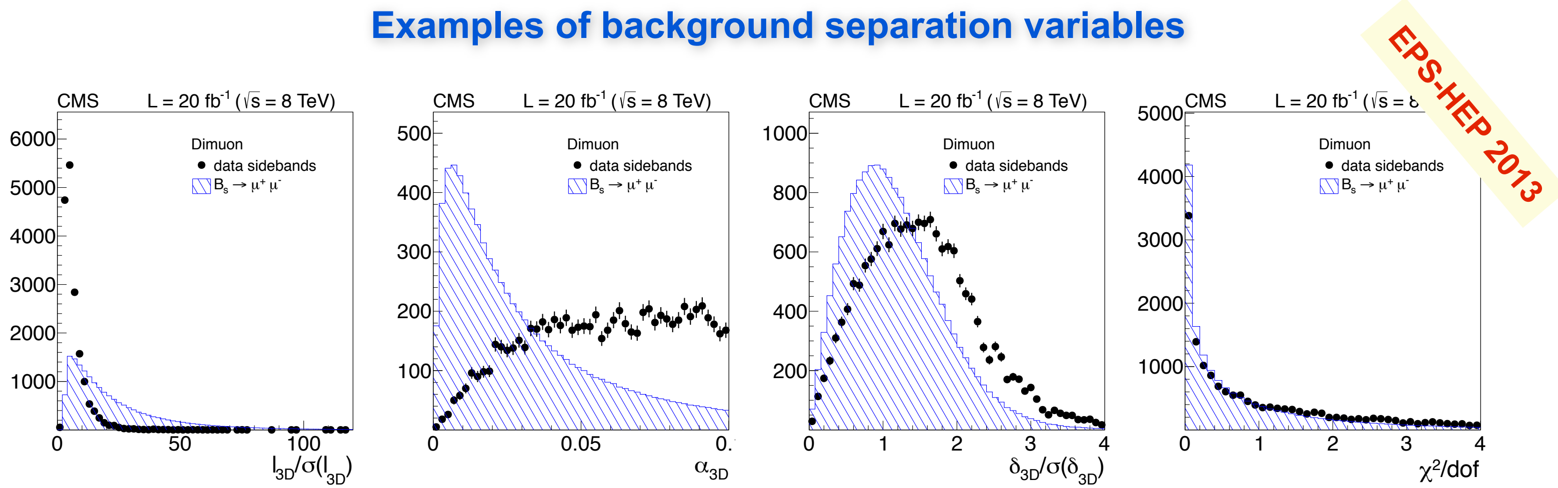


Discriminating variables

- **Boosted decision tree (BDT) selection**
  - 12 input variables: kinematic, Tracker only, Muon only,Tracker+Muon variables
  - Trained on signal MC sample and dimuon data sidebands
- **Same BDT for normalization ($B^+ \to J/\psi K$) and control ($B_s \to J/\psi \phi$) channels**
- **Robustness studies**
  - Insensitive to invariant mass using MC signal events with shifted mass
  - Output independent on high- or low-mass sideband
  - Insensitive to multiple collisions (pileup)



Examples of background separation variables

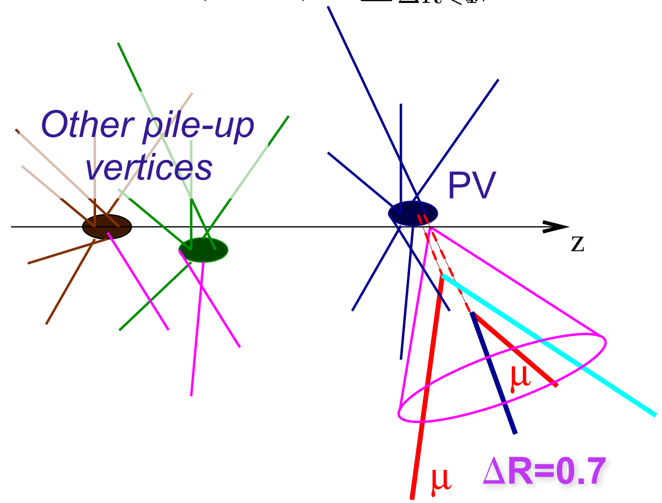


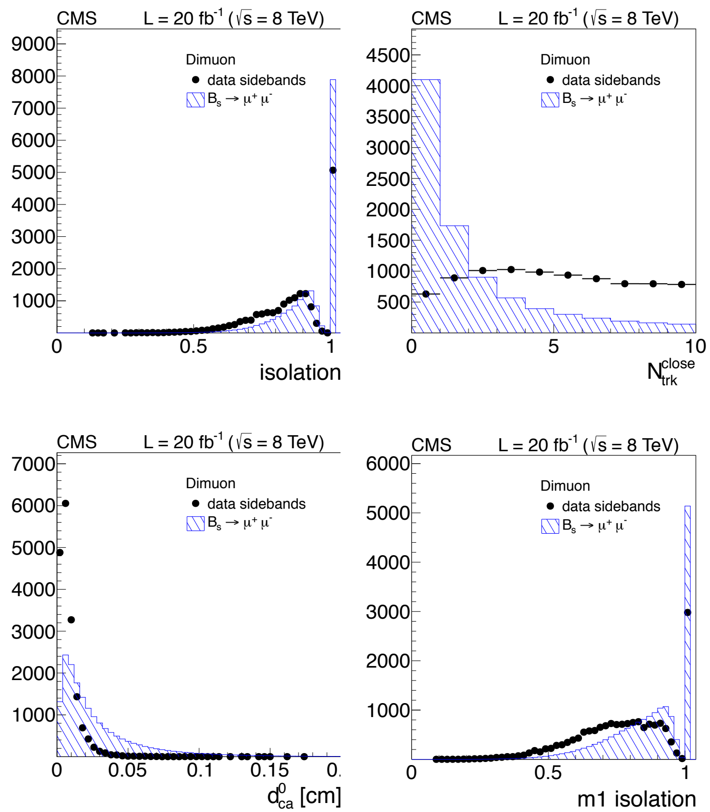
Flight length significance ***Pointing angle*** ***Impact parameter significance*** ***B-vertex reduced chi²***

Isolation variables

- **Relative isolation of muon pairs**
  - Cone with ΔR=0.7 around di-muon momentum
  - Include all tracks with p_T>0.9 GeV from same PV or d_{CA}<500 μm from B vertex
  - Dip at ~0.97 from minimum track p_T requirement

$$\text{Isolation} = \frac{p_T(\mu^+\mu^-)}{p_T(\mu^+\mu^-) + \sum_{\Delta R<0.7} p_T}$$





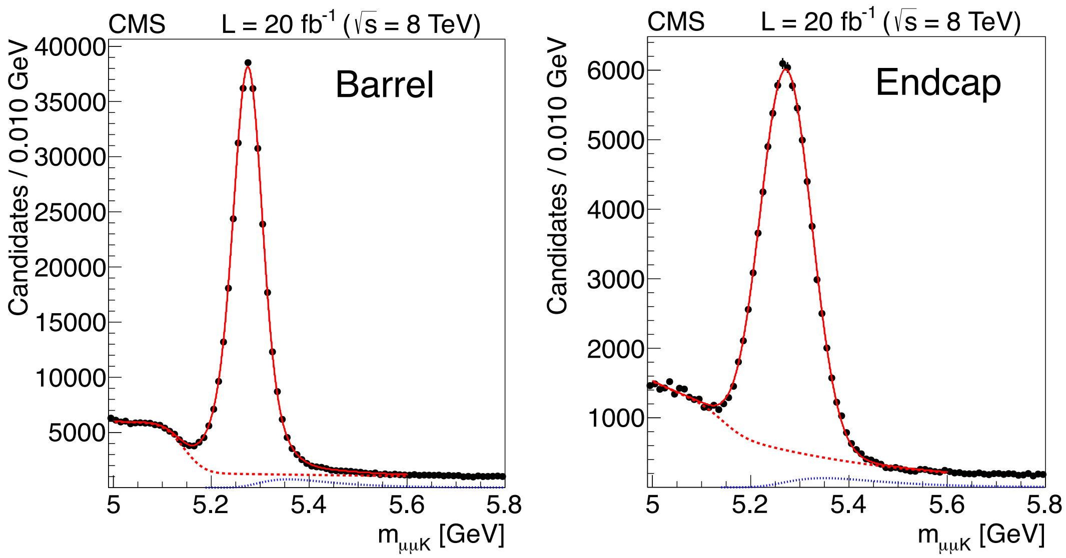
- **B-vertex isolation**
  - either tracks not associated to any primary vertex or tracks associated to the same B candidate
  - Distance of the closest track to SV (d_{ca})
  - Number of close tracks in d_{ca}<300 μm and p_T>0.5 GeV
- **Muon isolation**
  - tracks in muon cone with ΔR=0.5

Signal normalization

- **Branching ratios calculated w.r.t. normalization channel $B^+ \to J/\psi(\mu^+\mu^-)K^+$**
  - Many systematic uncertainties cancel in ratio
  - No need for absolute luminosity and b-quark cross section
  - Large B^+ yield and well known branching ratio to $J/\psi K^+$ (3% uncertainty)
  - Ratio of b-quark fragmentation fractions to B_s/B^+: $f_s/f_u = (256 \pm 20) \times 10^{-3}$ [JHEP 04 (2013) 001]

From LHCb

$$\mathrm{Br}(\mathrm{B_s} \to \mu^+\mu^-) = \frac{\mathrm{N}(\mathrm{B_s} \to \mu^+\mu^-)}{\mathrm{N}(\mathrm{B}^+ \to \mathrm{J}/\psi \mathrm{K}^+)} \frac{\mathrm{f_u}}{\mathrm{f_s}} \frac{\epsilon_{\mathrm{tot}}^{\mathrm{B}^+}}{\epsilon_{\mathrm{tot}}^{\mathrm{B_s}}} \mathrm{Br}(\mathrm{B}^+ \to \mathrm{J}/\psi \mathrm{K}^+)$$



2011-12
B^+ Candidates:
380×10^3 barrel
90×10^3 endcap

Branching ratio measurement

- **BDT output divided into 4 (2) bins for 2012 (2011) data and barrel/endcap categories**
- **Simultaneous UML fit of B_s and B^0 candidates:**
  - **B^s and B^0 decays signal**
  - **Peaking backgrounds (e.g. $B^0 \to K\pi$, $B_s \to KK$)**
  - **Rare s-l backgrounds (e.g. $\Lambda_b \to p\mu\nu$)**
  - **Combinatorial background**
- **Event-per-event mass resolution included**

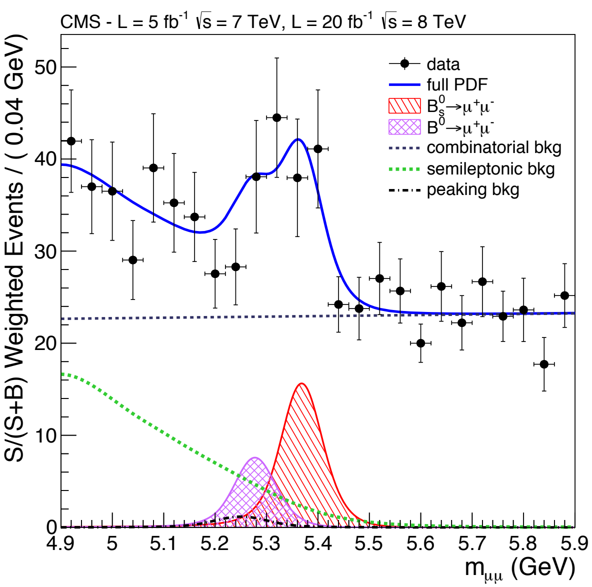
$$BR(B_S \to \mu\mu) = \left(3.0^{+0.9}_{-0.8}\ (\text{stat})^{+0.6}_{-0.4}\ (\text{syst})\right) \times 10^{-9}$$

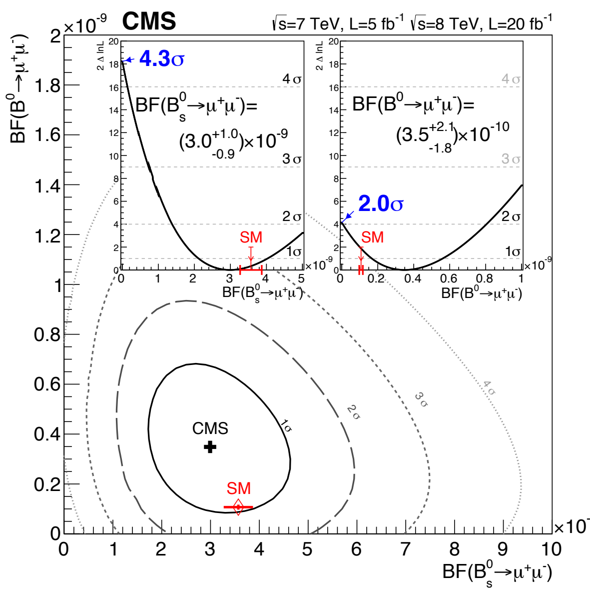
$$BR(B_d \to \mu\mu) = \left(3.5^{+2.1}_{-1.8}\ (\text{stat+syst})\right) \times 10^{-10}$$

Significances

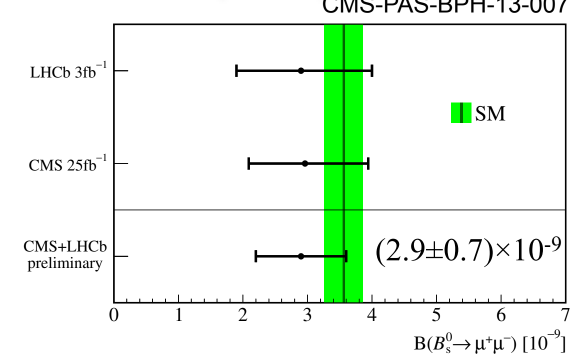
$B_s \to \mu\mu$: 4.3 σ (exp. median 4.8 σ)

$B^0 \to \mu\mu$: 2.0 σ





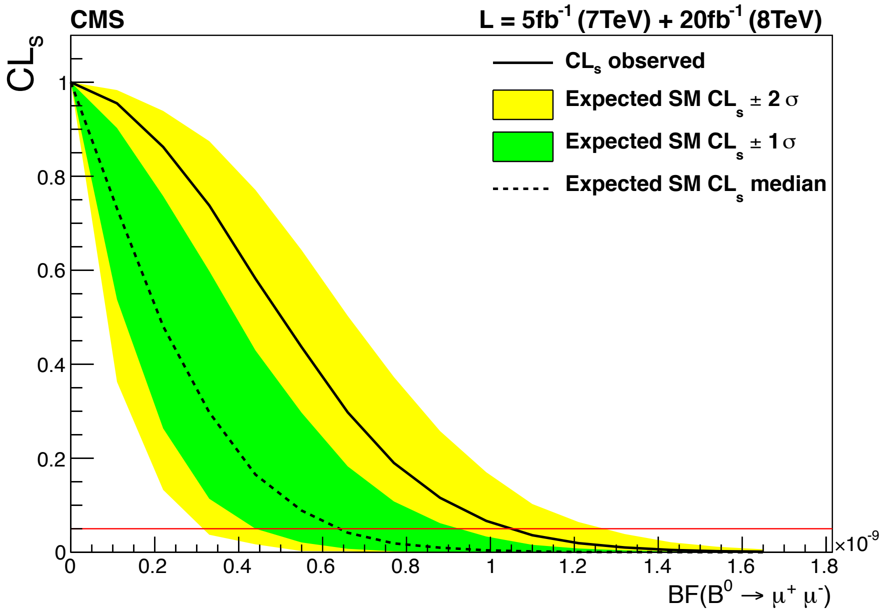
CMS+LHCb combination
(~24% precision)



CMS: Phys.Rev.Lett. 111 (2013) 101804
LHCb: Phys. Rev. Lett. 08 (2013) 117

Exclusion limits on $B^0 \rightarrow \mu^+\mu^-$

- **No significant excess observed in the B0 mass window**
  - Upper limit on BR computed using CL_s method



$$BR(B_d \rightarrow \mu\mu) < 1.1 \times 10^{-9}\ @95\%\ CL$$

(expected 6.3×10^{-10} in presence of SM+background)

$$BR(B_d \rightarrow \mu\mu) < 9.2 \times 10^{-10}\ @90\%\ CL$$

The quest goes on!!

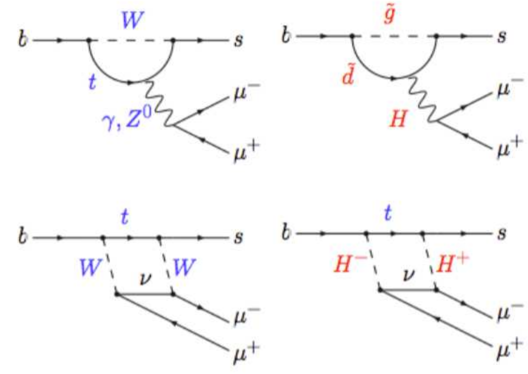
My call: use Run2 data to increase the precision on B_s branching (SM precision ~5%), keep on hunting the B^0 decay, measure ratio of the two decays
Perhaps surprises are still around the corner?

New physics in b→s transitions?

- Described by effective hamiltonian in operator product expansion
  - b→s transitions sensitive to $O^{(')}_{7,9,10}$

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[\underbrace{\sum_{i=1}^{6} \mathcal{C}(\mu)\mathcal{O}(\mu)}_{\text{LH}} + \sum_{i=7,...,10,P,S} \left(\underbrace{\mathcal{C}(\mu)\mathcal{O}(\mu)}_{\text{LH}} + \underbrace{\mathcal{C}'(\mu)\mathcal{O}'(\mu)}_{\text{RH}} \right) \right]$$

i=1,2 Tree
i-3-6,8 Gluon penguin
i=7 Photon penguin
i=9,10 Electroweak penguin
i=S Higgs (scalar) penguin
i=P Pseudoscalar penguin



SM **BSM**

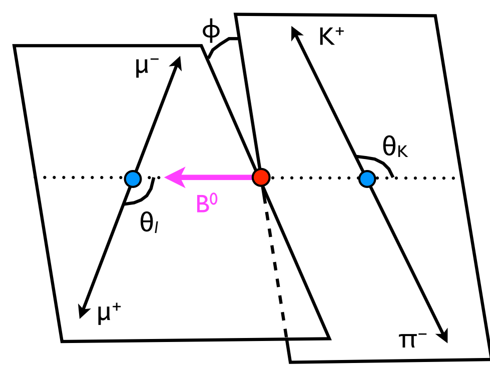
Decay $B^0 \to K^* l^- l^+$ provides samples sufficiently large to measure observables sensitive to effective coefficients. E.g:

$$A_{FB} \propto -Re[(2C_7^{eff} + \frac{q^2}{m_b^2} C_9^{eff}) C_{10}]$$

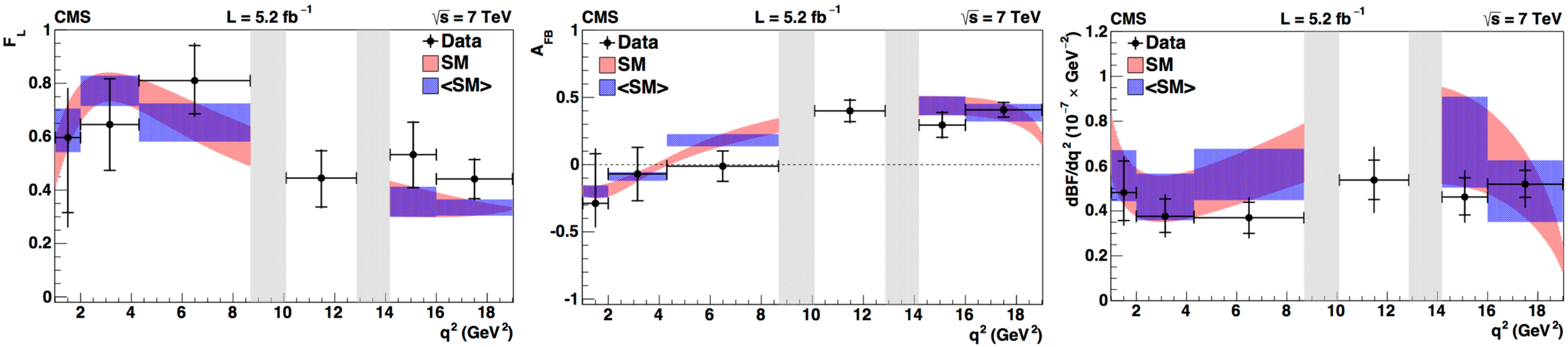
C_i^{eff} are linear combinations of $C(\mu)$

ϕ-integrated angular distribution

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_K\, d\cos\theta_l\, dq^2} = \frac{9}{16}\left\{ \left[\frac{2}{3}F_S + \frac{4}{3}A_S\cos\theta_K\right](1-\cos^2\theta_l) + (1-F_S)\left[2F_L\cos^2\theta_K(1-\cos^2\theta_l) + \frac{1}{2}(1-F_L)(1-\cos^2\theta_K)(1+\cos^2\theta_l) + \frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_l\right]\right\}.$$

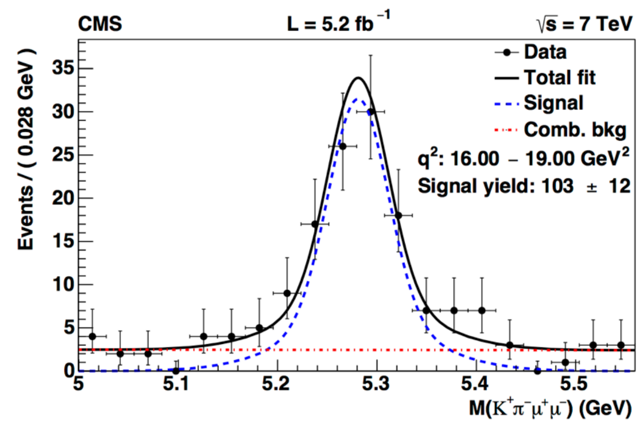


q^2 = dimuon invariant mass



CMS data: arXiv:1308.3409
SM: Phys. Rev. D 87 (2013) 034016

- Angular fit of the $K\pi\mu\mu$ system in bins of dimuon invariant mass q^2
- Signal yields ranging from 23 to 103 events in each bin
- Vertical shaded bands correspond to J/ψ and $\psi(2S)$ resonances
- **Results consistent with SM predictions and previous measurements**
- **World's most precise measurement of A_{FB} and F_L at high q^2**

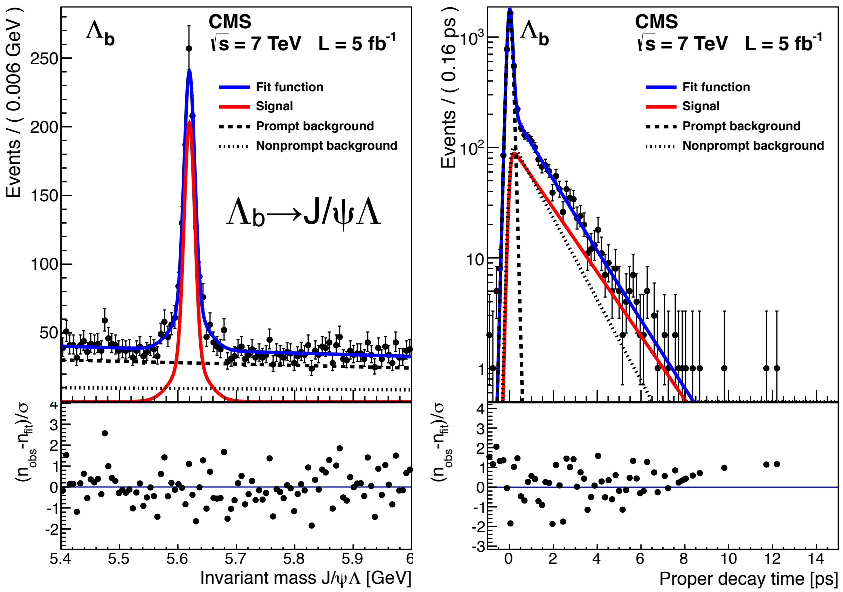


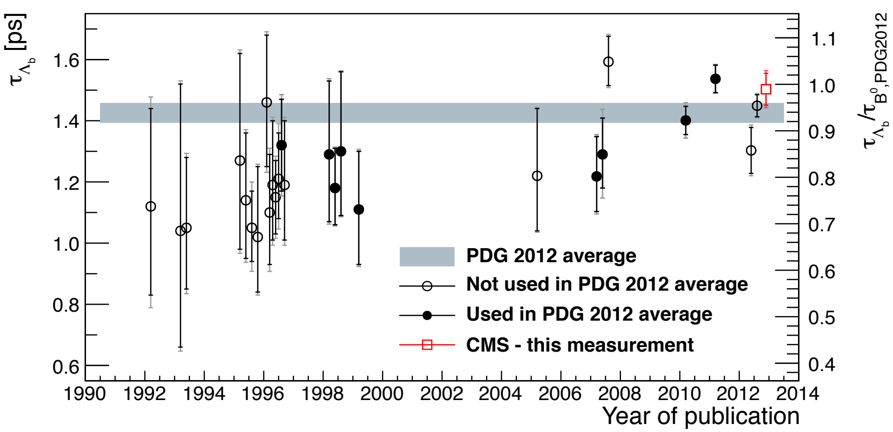
Next: analyze 2012 samples and measure more angular variables

see the localized excesses observed by LHCb [arXiv:1308.1707] and interpretations [e.g.: arXiv:1308.1501, arXiv:1309.2466, ...]

Lifetime measurements

Λ_b lifetime





- Λ_b baryon lifetime in $J/\psi\Lambda$ decays
- Theoretical predictions in tension with earlier measurements
- Use dimuon trigger without lifetime significance cut.
- Lifetime from combined maximum-likelihood mass and proper decay time fit
  - **About 1000 signal events**
  - **$\tau(\Lambda_b)$=1.503 ± 0.052(stat.) ± 0.031(syst.) ps**
  - **World average: 1.425 ± 0.032 ps**
- B^0 lifetime determined in $J/\psi K_s$ decays as cross check compatible with PDG
- Dominant systematic uncertainty from proper decay time efficiency
- Compatible with ATLAS determination and world average

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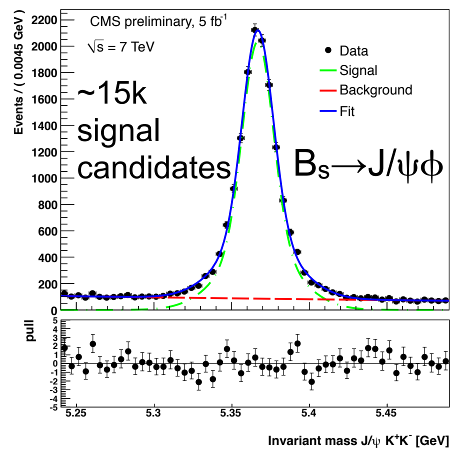
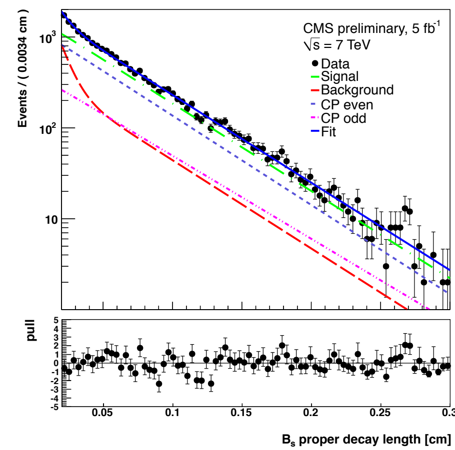
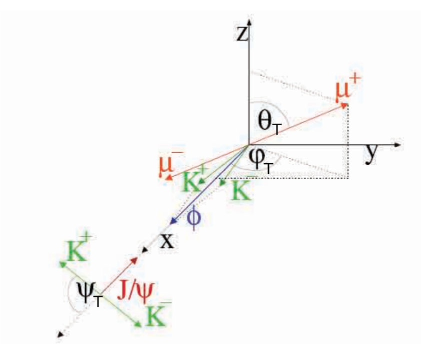
B_s lifetime difference

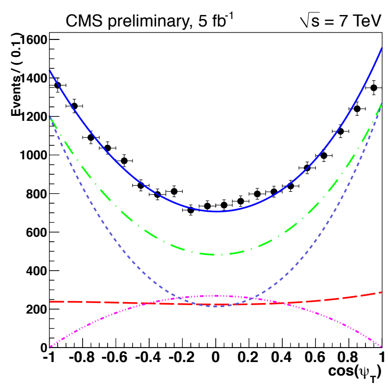
- B_s lifetime difference $\Delta\Gamma_s=\Gamma_H-\Gamma_L$
  - SM expectation $\Delta\Gamma_s/\Gamma_s$= 0.12±0.06
- Selecting decays to $J/\psi\phi$ candidates, with $J/\psi\rightarrow\mu\mu$ and $\phi\rightarrow KK$.
- 5D fit of mass, proper decay time and 3 angular variables to separate CP states
  - **0.048 ± 0.024 (stat.) ± 0.003 (syst.) ps^{-1}**
- Compatible with world average

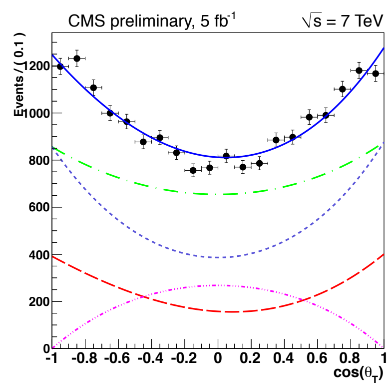
CMS PAS BPH-11-006

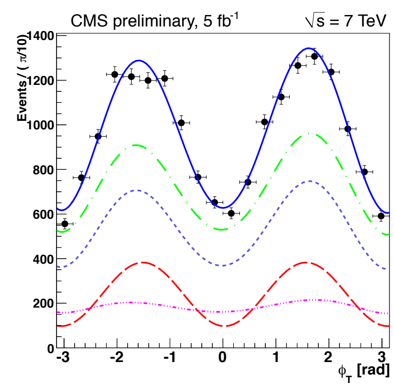






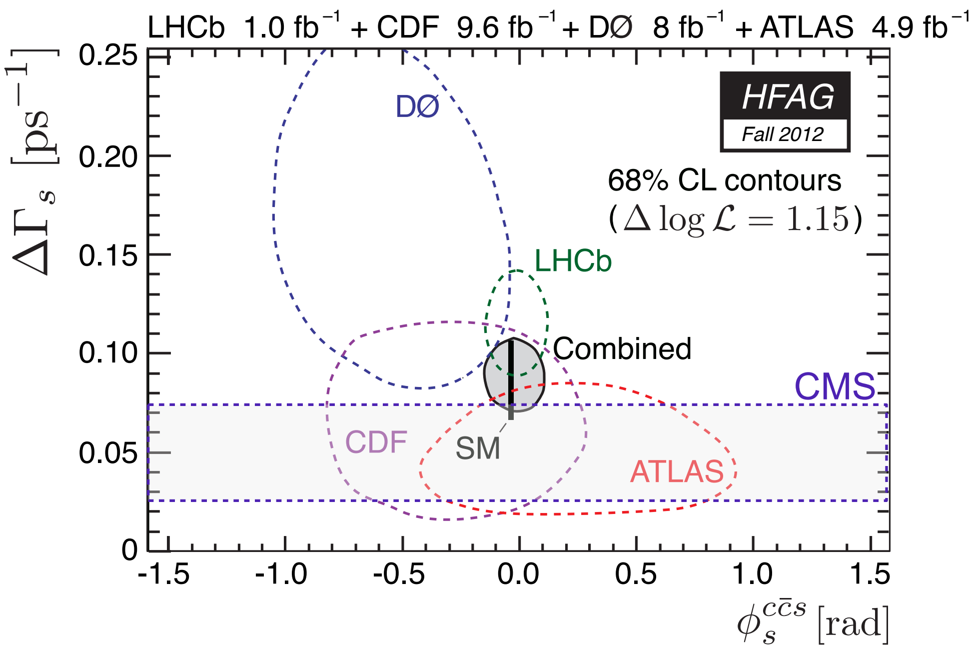






Summary of CPV in B_s decays

- Rather consistent picture from Tevatron and LHC experiments
- Closing on the SM value also in this case
- CMS currently working on the determination of the CP violating phase ϕ_s



Summary

- The excellent performance of the CMS detector and LHC have allowed key contributions to the field heavy flavor physics
- Wide range of topics covered: **Standard Model physics** and the **great beyond**
- Several aspects of heavy flavor production are not yet well understood and spectroscopy is not a closed chapter!
- No sign of physics beyond the Standard Model yet, but we keep on searching!
- Analysis of the large datasets collected in 2012 is in progress. Expect new results (and perhaps surprises?) at the forthcoming conferences!

Future upgrades

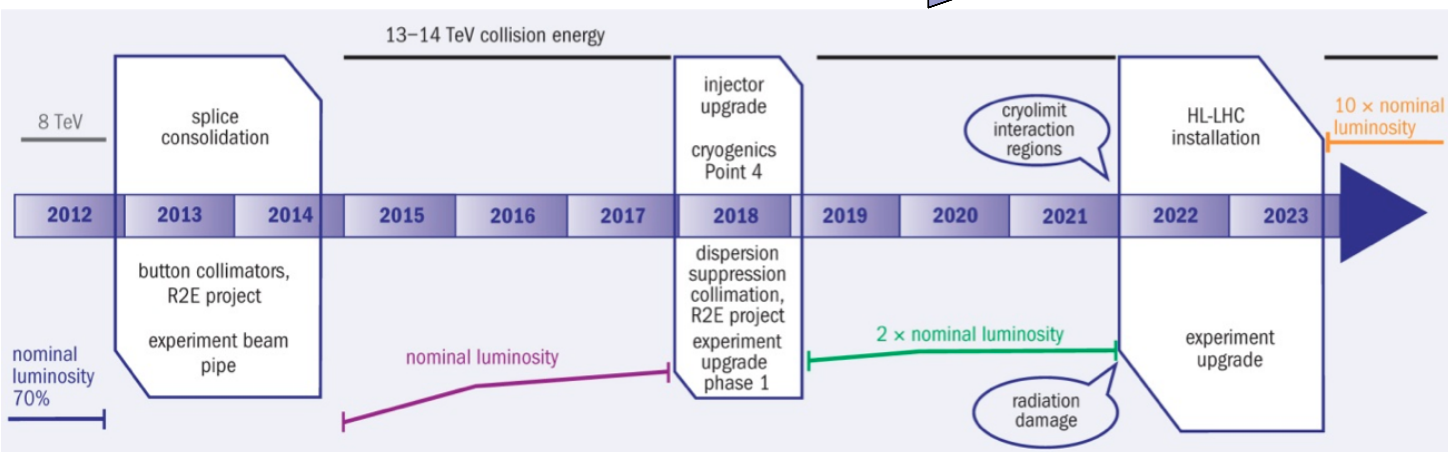
40 fb^{-1}/year
13/14 TeV

>50 fb^{-1}/year
13/14 TeV

End of Phase 1
300-500 fb^{-1}

PHASE 1

PHASE 2

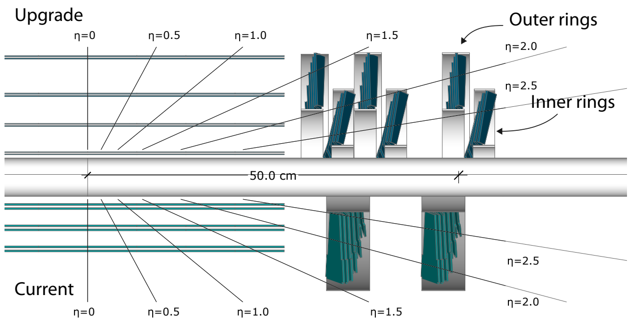


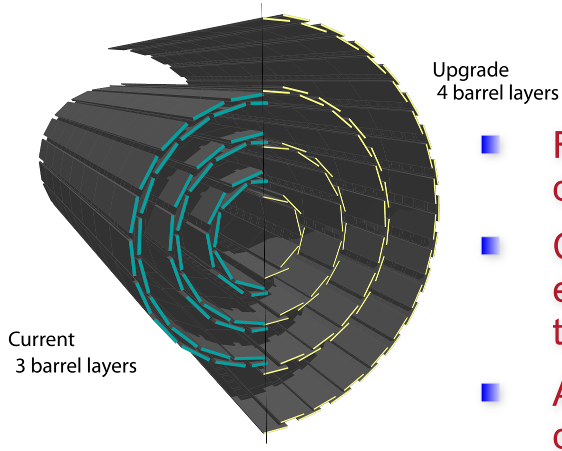
HL-LHC
14 TeV
>250 fb-1/year

LHCb Upgrade
ATLAS/CMS Upgrades phase 1

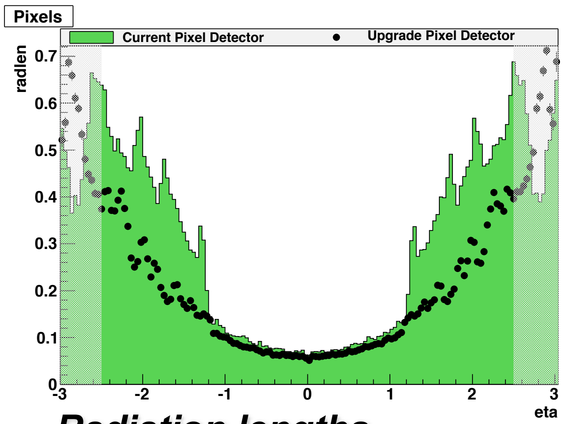
ATLAS/CMS
Upgrades phase 2

~3000 fb^{-1} expected in 10 years running

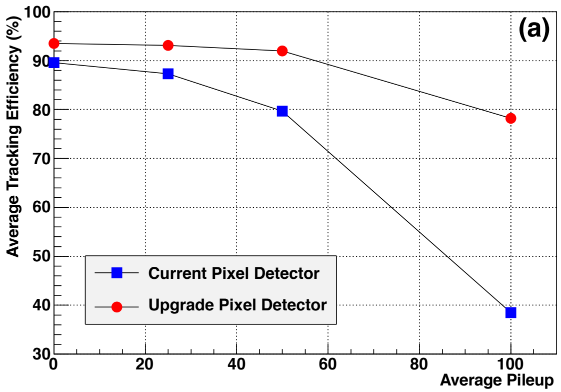




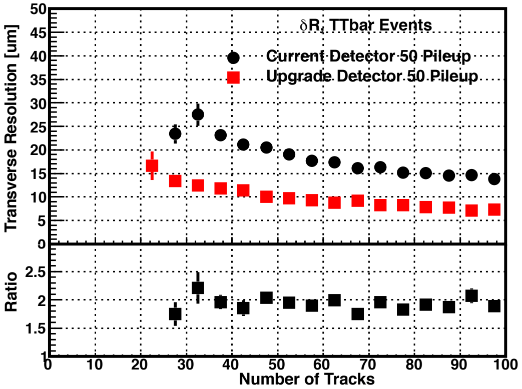
- Four barrel layers and three endcap disks on each side
- Carbon fibre structure, CO_2 evaporative cooling, first layer closer to interaction point (2.9 cm)
- Analog readout with on-chip digitization
- New (Old): 79 (48) million pixel cells distributed over 1184 (768) detector modules



Radiation lengths



Tracking efficiency



Primary vertex resolution

BACKUP SLIDES

- Use differences between data and MC for systematics
  - $B^{\pm} \rightarrow J/\psi\, K^{\pm}$ 3% ; $B_s \rightarrow J/\psi\, \phi$ 9.5% (2011) and 3.5% (2012)