B Physics: Status & Perspectives @ CMS

Martino Margoni
Universita` di Padova and INFN

- Past: Recent Results
- Present: Ongoing Analyses
- Future: Run II Strategy
  - Trigger & Data Taking
  - Ideas on Physics

Many thanks for contributions to:
R. Covarelli, S. Fiorendi, M. Innocenti,
L. Martini, F. Palla, A. Pompili,
F. Simonetto

BPH Organization: Italian involvement

Conveners: K.-F. Chen, N. Viegas Guerreiro Leonardo, F. Palla

- B Hadrons Production & Decays (R. Covarelli (mandate expires), K. Yi)

  Test of perturbative & non-perturbative QCD models of hadron production and fragmentation. Study dynamics of heavy quarks inside hadrons, decay models & spectroscopy.

- Conventional & Exotic Quarkonia (P. Faccioli (mandate expires), A. Pompili)

  Production cross-sections and polarizations measurements of S- & P-wave states of conventional quarkonium allow to study the hadron formation within the NRQCD framework. Quarkonium spectrum and properties not well understood above the open charm/beauty thresholds: quarkonium-like exotic states with a quark content beyond the ordinary one for hadrons.

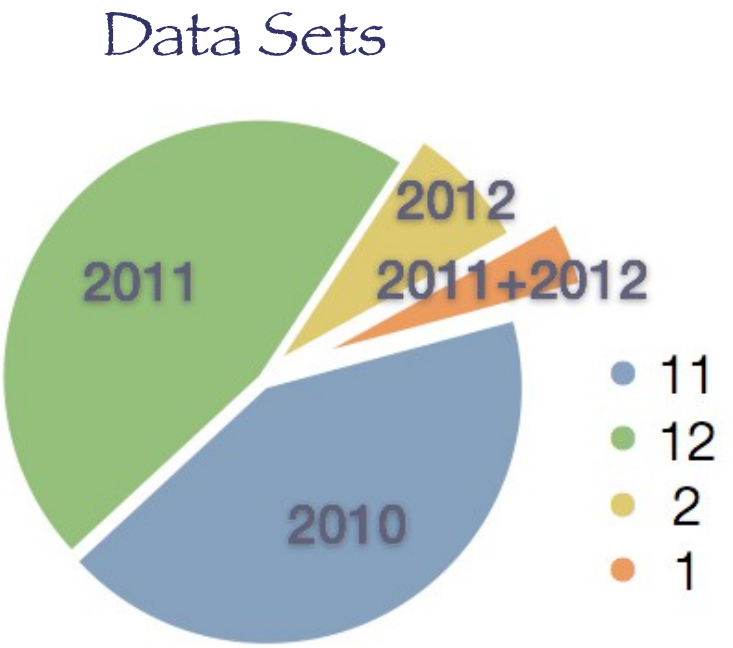
- Rare Decays LFV & CPV (S. Kumar Swain, M. Margoni)

  Search for deviations from SM predictions due to virtual contributions of new particles in loop processes. Most interesting processes are those that are strongly suppressed: Leptonic B decays, FCNC, LFV and CPV in the b, c and τ sectors.

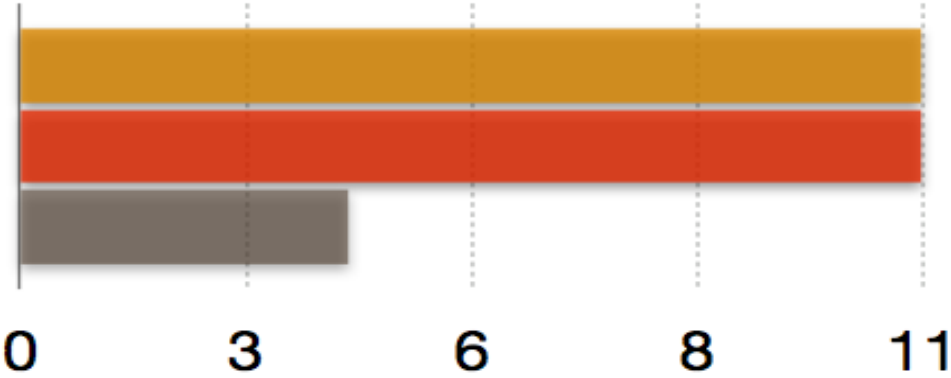
- BPH Trigger (L. Martini)
- BPH Upgrade (M. Galanti moved from Padova to Rochester)

Published Papers

- BPH Group Produced 26 Publications:
  - 3 Paper with > 100 citations
  - 11 Paper with > 50 citations
- First CMS article on B → μμ going to be published on Nature!
- Ongoing Analyses:
  - 8 on 2011 dataset, 11 on 2012 dataset
  - 9 "Mature" results (Approved/Preapproved or almost finalized)
  - 10 at the AWG discussion stage or just started



Quarkonia
B hadron production & decays
CPV & Rare decays



Recent Results

Papers Published/Submitted during 2014

- Observation of a peaking structure in the $J/\psi\,\varphi$ mass spectrum from $B^+ \rightarrow J/\psi\,\varphi\,K^+$ decays (BPH-11-026), PLB 734 261-281 
- Measurement of prompt J/ψ pair production in pp collisions at $\sqrt{s} = 7$ TeV (BPH-11-021), JHEP 09 094
- Measurement of the χ_{b2} and χ_{b1} cross section ratio in pp collisions at $\sqrt{s} = 8$ TeV (BPH-13-005), Submitted to PLB 
- Measurement of the ratios $BR(B_c \rightarrow J/\psi\,3\,\pi)/BR(B_c \rightarrow J/\psi\,\pi)$ and $\sigma(B_c)B_c \rightarrow J/\psi\,\pi\ /\sigma(B^+)B^+ \rightarrow J/\psi\,K$ (BPH-12-011), Subm. JHEP 
- Combination of results on $B \rightarrow \mu\mu$ from the CMS and LHCb experiments (BPH-13-007) Submitted to Nature 

58 Talks given at International Conferences

22 Italian Speakers! (17 from Italian Institutions)

Peaking structures in the $J/\psi\,\phi$ mass spectrum from $B^+ \rightarrow J/\psi\,\phi\,K^+$ decays

PLB 734 261-281

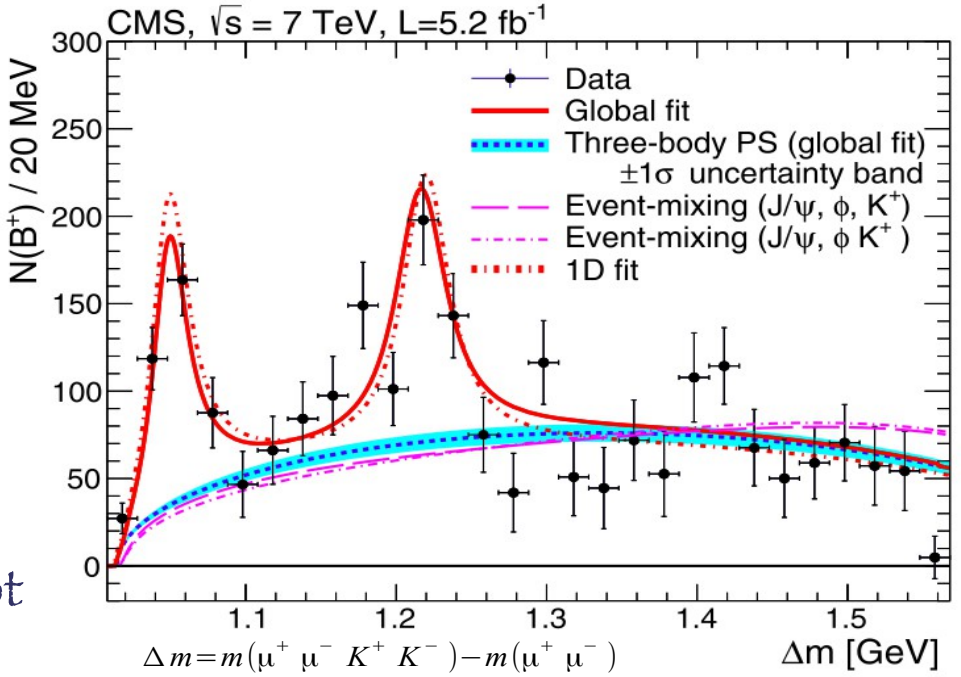
Bari

- Peaking structure observed in $m(J/\psi\,\phi)$ with more than 5 σ:

  $M = 4148.0 \pm 2.4 \pm 6.3$ MeV

  $\Gamma = 28^{+15}_{-11} \pm 19$ MeV

- Consistent with possibly exotic state Y(4140) from CDF (evidence from D0, not confirmed by LHCb)
- $N(\text{"Y"})/N(J/\psi\,\phi\,K) = (10\pm3)\%$ consistent with CDF (and with LHCb's Upper Limit)
- Evidence of additional peak (mass shifted w.r.t CDF) that could be affected by possible ϕK^+ resonances



- Conventional charmonium should decay in open charm with larger width & smaller BR into $J/\psi\,\phi$
- Understanding the nature of both structures need further investigation and requires a full amplitude analysis

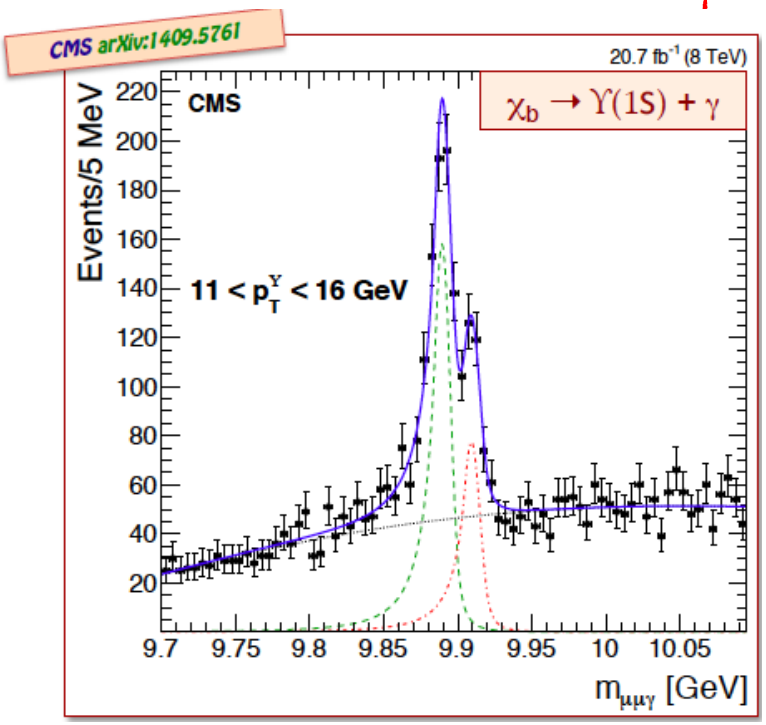
Measurement of $\sigma(\chi_{b2})/\sigma(\chi_{b1})$

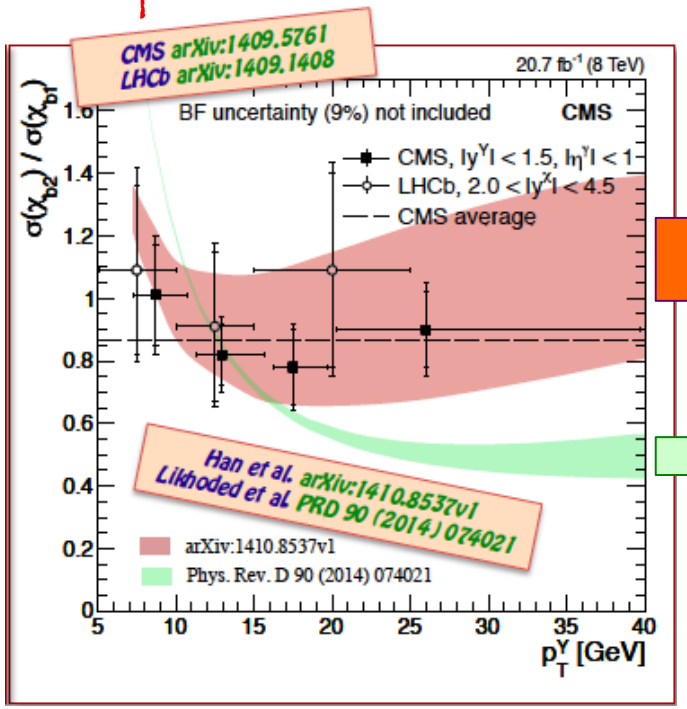
Subm. to PLB

Torino

- P-wave measurements crucial to understand quarkonium production :
  - Study feed-down effects into S-wave states
  - Constrain LDMEs of the χ_c and χ_b states in NRQCD fits to S-wave production data

Reconstruction of converted photons provides mass resolution to resolve the 2 peaks (with 19Mev separation)





CMS & LHCb consistent compared with two different NLO NRQCD calculations (and fits based on different experimental data)

Improve p_T reach and accuracy with Run II !

LHC xsection ratio with smaller uncertainties :

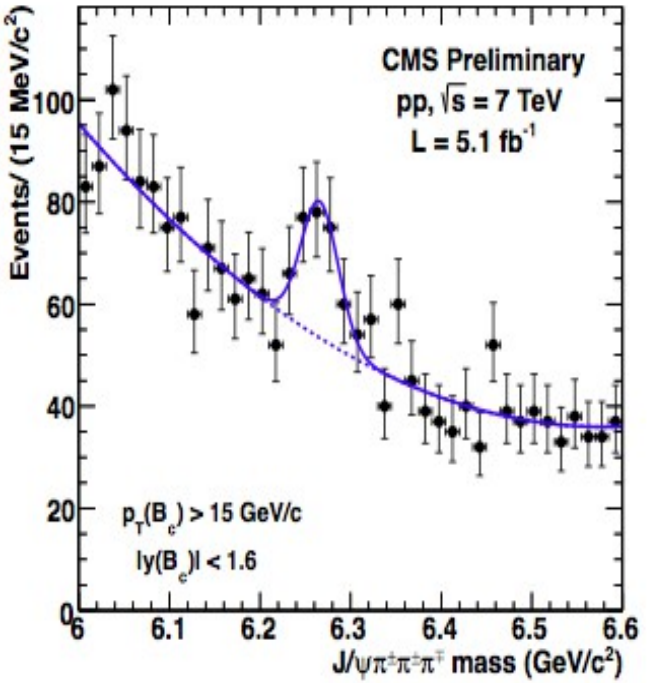
$$< R > \equiv \left\langle \frac{\sigma(pp \to \chi_{b2} + X)}{\sigma(pp \to \chi_{b1} + X)} \right\rangle = 0.85 \pm 0.07(\text{stat+syst}) \pm 0.08\left(BF(\chi_{b1,2} \to \Upsilon(1S) + \gamma)\right)$$

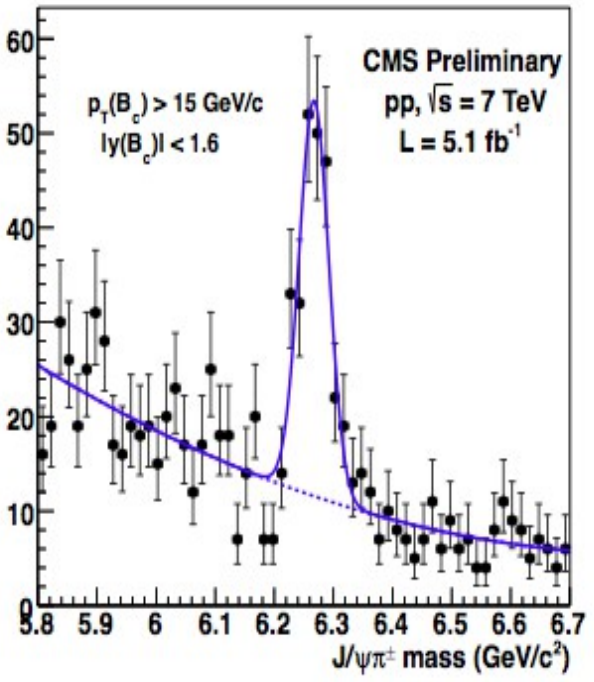
Measurement of $B_c \to J/\psi\, 3\pi / B_c \to J/\psi\, \pi$ and $\sigma(B_c)B_c \to J/\psi\, \pi / \sigma(B^+)B^+ \to J/\psi\, K$

Subm. to JHEP

Milano Bicocca

- B_c mesons carry two different heavy flavors: unique laboratory to study heavy-quark dynamics
- b & c quarks compete via spectator diagram, annihilation process ~10%.





$$\frac{\sigma(B_c)\times BR(B_c\to J/\psi\ \pi)}{\sigma(B^+)\times BR(B^+\to J/\psi\ K)} = (0.48\pm0.05\pm0.04^{+0.05}_{-0.03}(\tau_{B_c}))\times 10^{-2}$$

$$\frac{\sigma(B_c)\times BR(B_c\to J/\psi\ 3\pi)}{\sigma(B_c)\times BR(B_c\to J/\psi\ \pi)} = 2.43\pm0.76^{+0.46}_{-0.44}$$

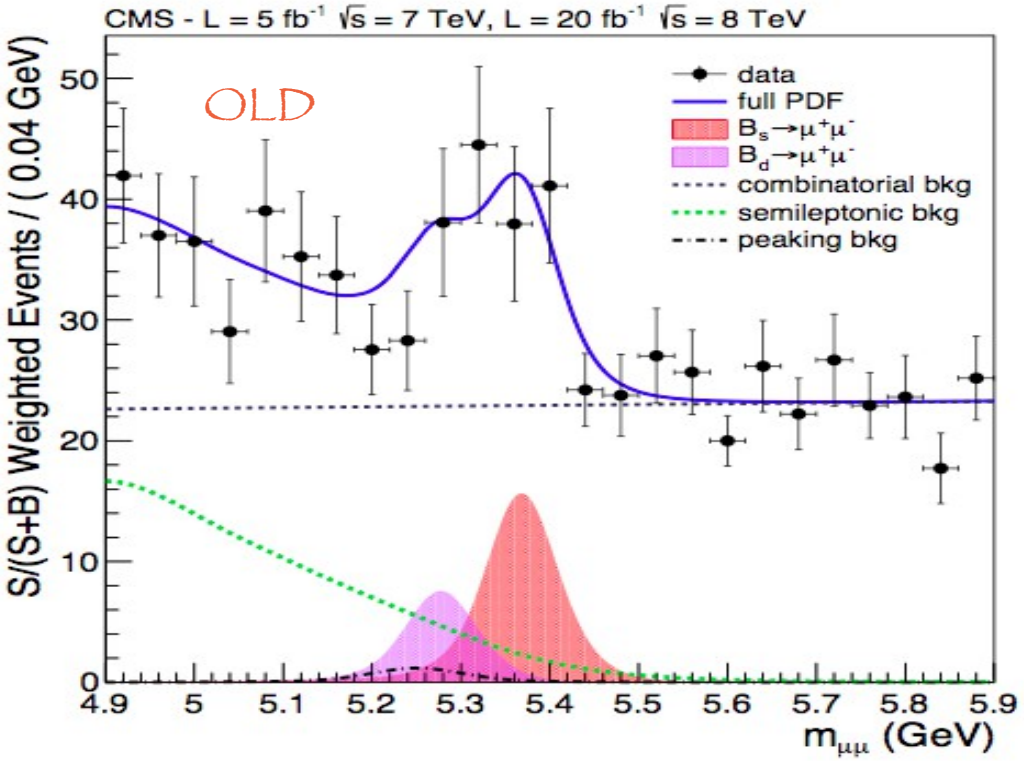
- Results in good agreement with LHCb (in a complementary rapidity region)

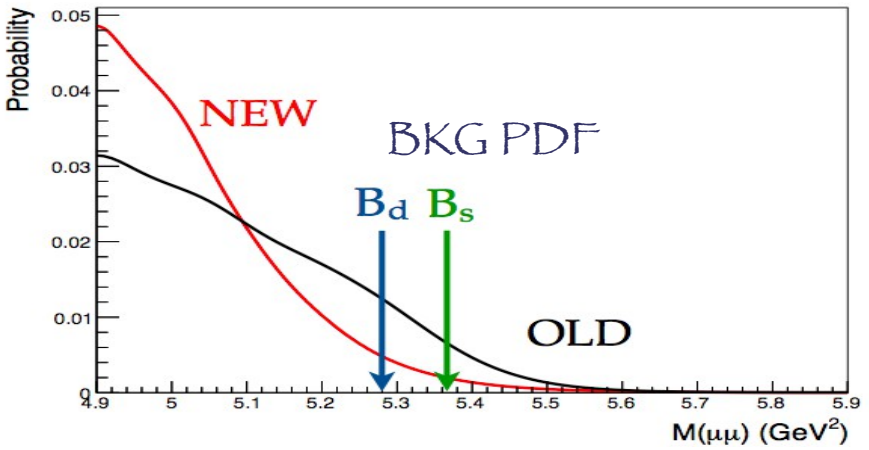
Combination of BR(B → μμ) from the CMS and LHCb experiments

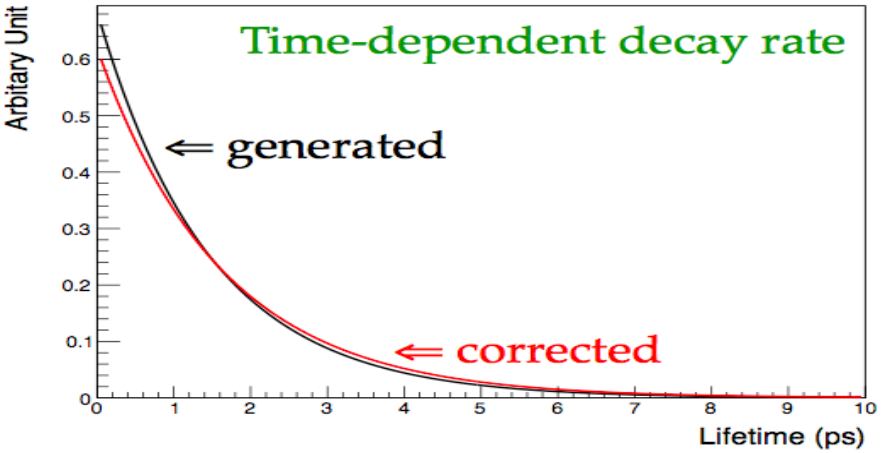
To be Submitted soon

Pisa, Padova (for the CMS Published result)

- CMS Improvements wrt Summer 2013:
  - Input $\tau(B_s)$, f_d/f_s & some BRs from PDG
  - Modeling of the $\Lambda_b \rightarrow p\mu\nu$ Background







$$BR(B_s) = (2.99^{+1.04}_{-0.88}) \times 10^{-9}$$

$$BR(B_d) = (3.48^{+2.13}_{-1.81}) \times 10^{-10}$$

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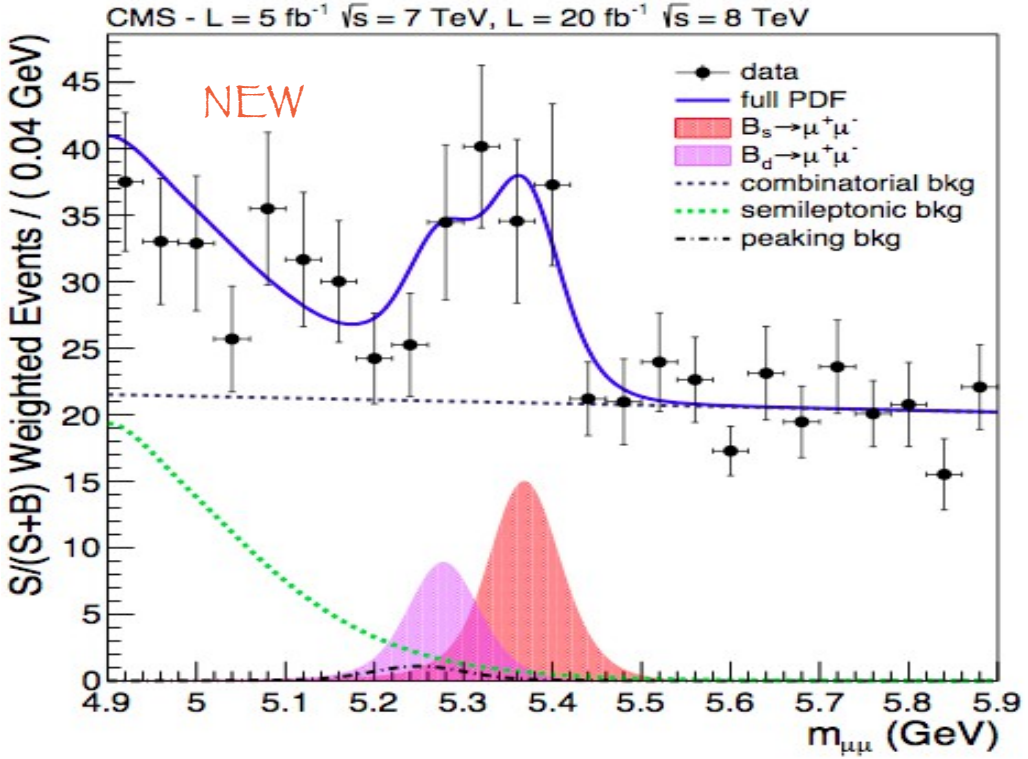

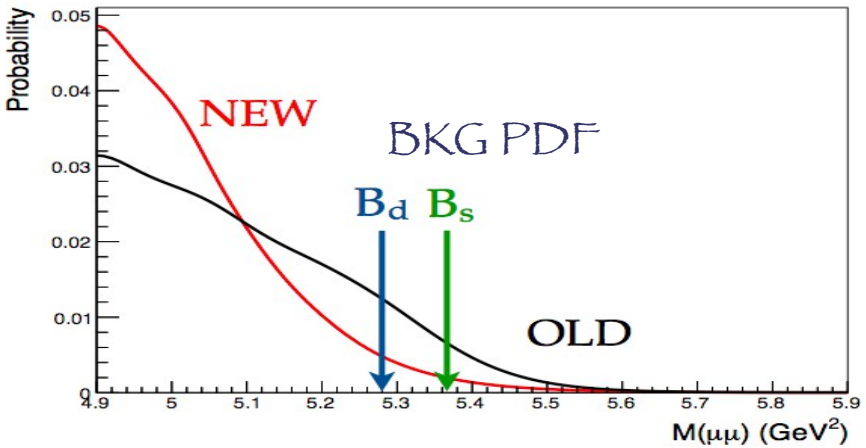

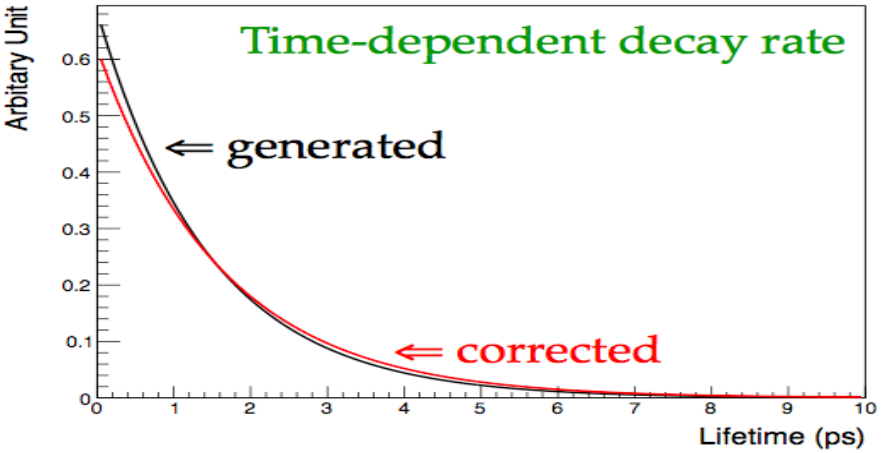

$$BR(B_s) = (2.80^{+0.95}_{-0.81}) \times 10^{-9}$$

$$BR(B_d) = (4.38^{+2.23}_{-1.91}) \times 10^{-10}$$

Combination of BR(B → μμ) from the CMS and LHCb experiments

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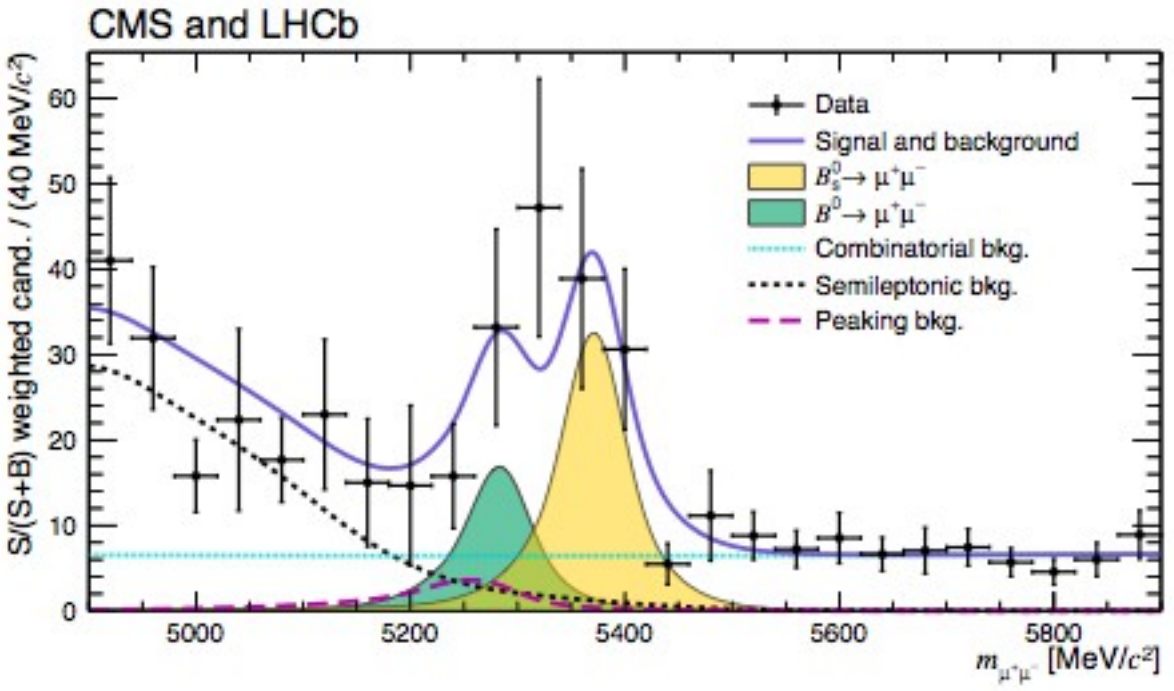
- Full Likelihood combination of CMS & LHCb results
  - Simultaneous unbinned extended maximum likelihood fit to the mass spectra
  - Take into account correlations/estimate significance



$$BR(B_s) = (2.8^{+0.7}_{-0.6}) \times 10^{-9} \quad (6.2\sigma)$$

Expected SM: 7.4

$$BR(B_d) = (3.9^{+1.6}_{-1.4}) \times 10^{-10} \quad (3.0\sigma)$$

Expected SM: 0.8

Standard Model predicts:

$$BR(B_s) = (3.66 \pm 0.23) \times 10^{-9}$$

$$BR(B_s) = (1.06 \pm 0.09) \times 10^{-10}$$

Combination of BR(B → μμ) from the CMS and LHCb experiments

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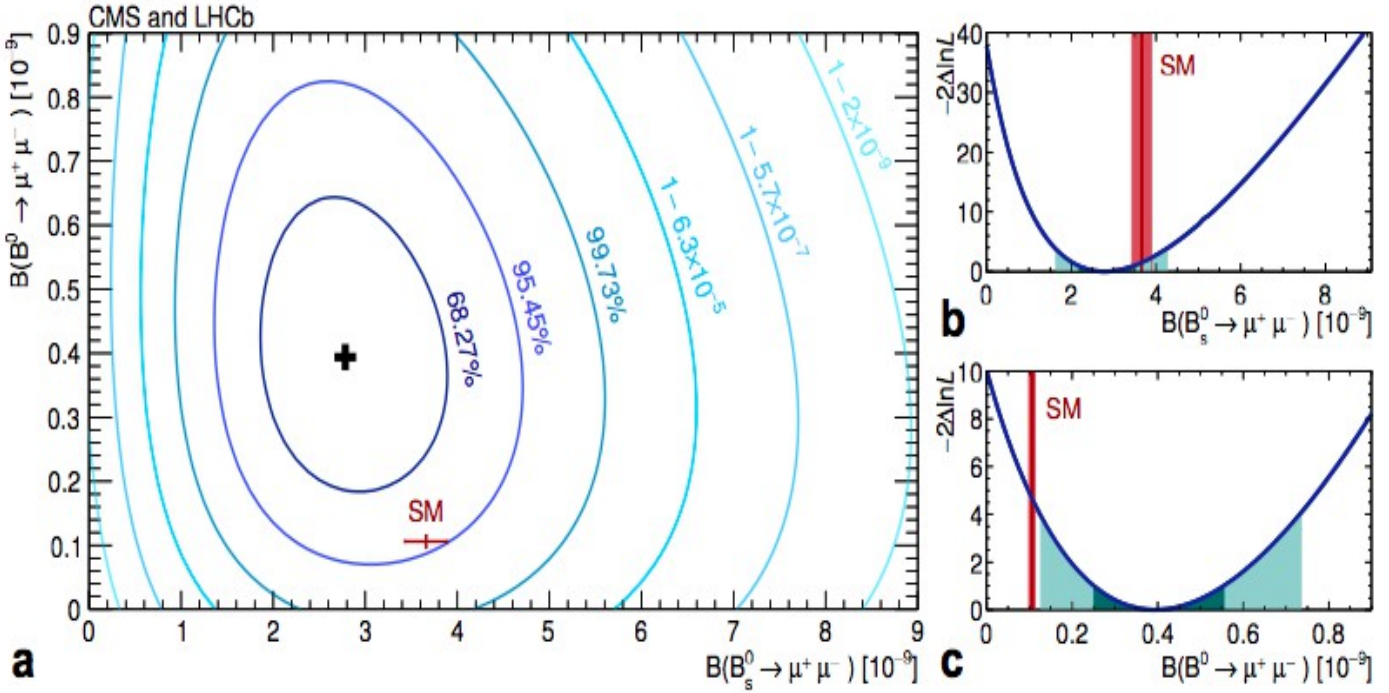

Compatibility vs SM:

1.2 σ for B_s

2.2 σ for B^0

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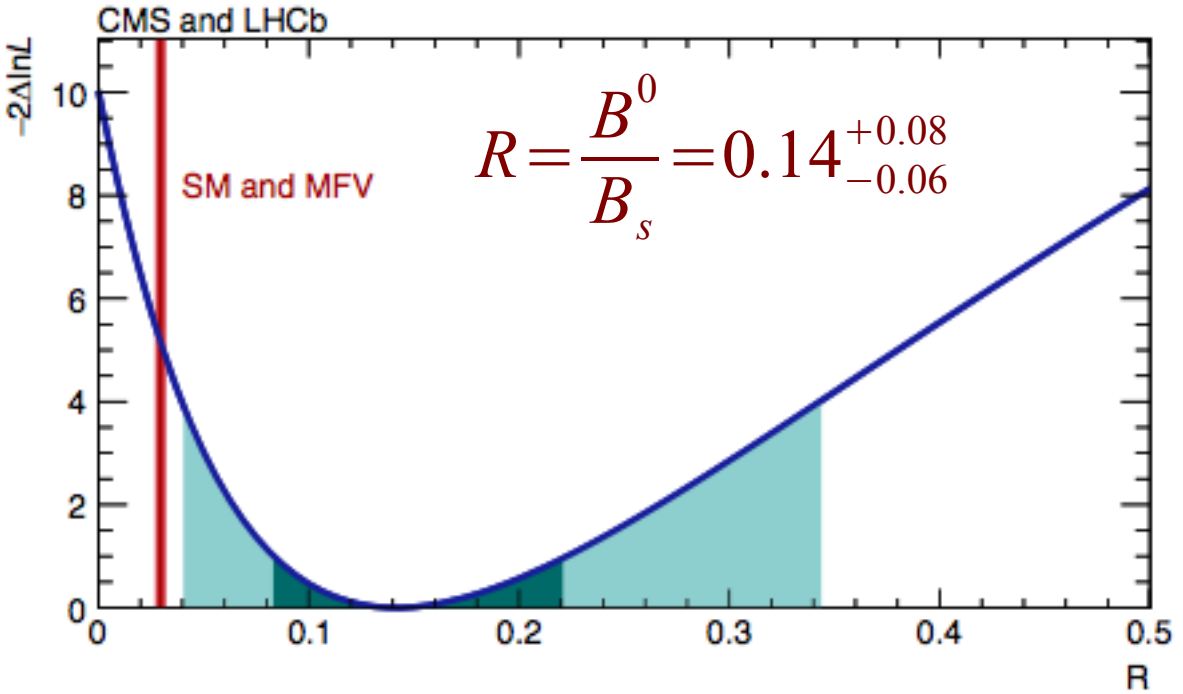


Compatibility vs SM:

1.2 σ for B_s

2.2 σ for B^0

2.3 σ for B^0/B_s

Approved & Ongoing Analyses

CPV & Rare Decays

- Upgrade Performance for the $B \rightarrow \mu\mu$ measurement (Necessity of the new L1 Track Trigger) Approved 
- CP-violating weak phase Φ_s and decay width difference $\Delta\Gamma_s$ using the $B_s \rightarrow J/\psi\varphi$ decay channel (BPH-13-012) Approved Prel. Result 
- Flavor tagging algorithm using Run I data (BPH-14-004) 
- Measurement of the forward-backward asymmetry and other variables in the $B^0 \rightarrow K^{*0} \mu\mu$ decay (BPH-13-010) Pre-Approved 
- B Mixing & dilepton asymmetry A_{ll} using di-muon events (BPH-10-016 & BPH-12-003) 
- B mixing in $\overline{tt}$ events (BPH-14-007) 
- Search for τ lepton decay to 3 muons (BPH 12-004) 

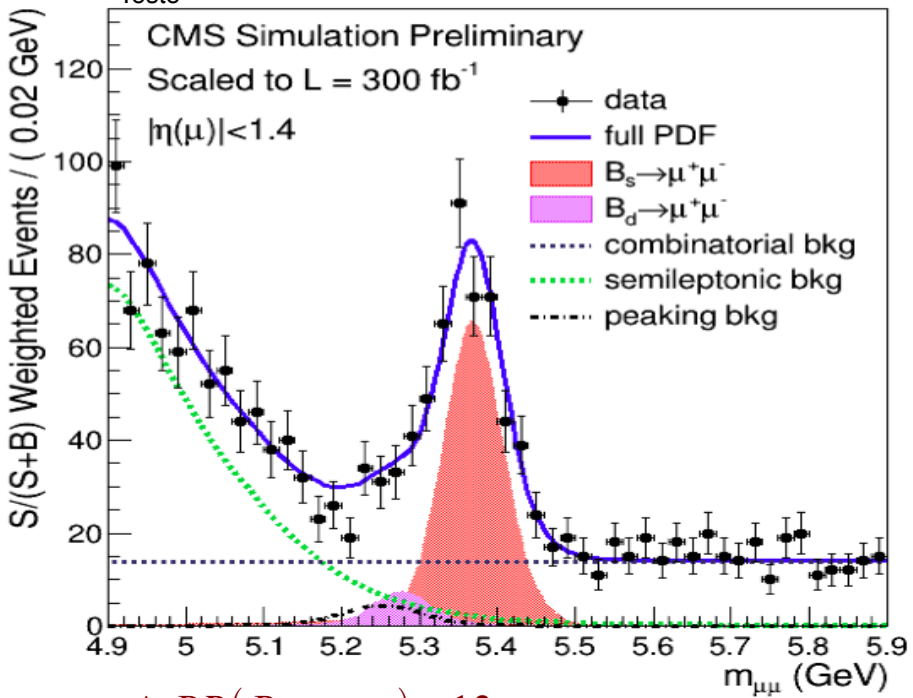
CMS Phase-2 Upgrade performance for $B \rightarrow \mu\mu$

Padova

Pisa

- The focus now is on $BR(B_d)$ and on the ratio $BR(B_s)/BR(B_d)$
- CMS Upgrades more affecting the result:
  - L1 Trigger: new track trigger (necessary to reduce the rate)
  - Tracker: reduced material budget & increased resolution

Testo

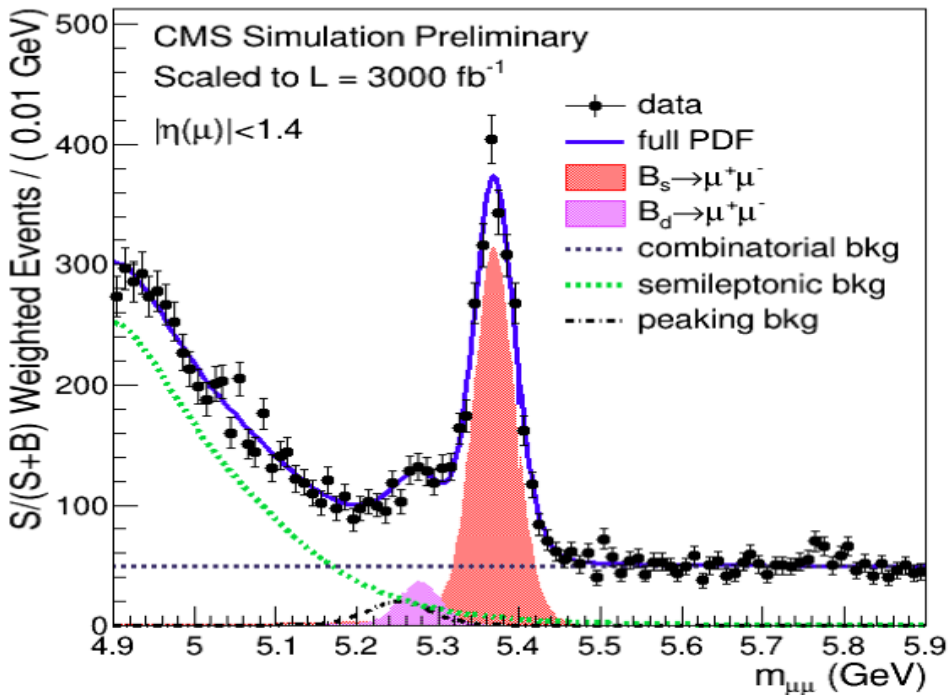


$\Delta BR(B_s \rightarrow \mu\mu) = 13\,\%$

$\Delta BR(B_d \rightarrow \mu\mu) = 48\,\%$

$\Delta(BR(B_d \rightarrow \mu\mu)/BR(B_s \rightarrow \mu\mu)) = 50\,\%$

$B_d \rightarrow \mu\mu$ *significance*: $2.2\,\sigma$



$\Delta BR(B_s \rightarrow \mu\mu) = 11\,\%$

$\Delta BR(B_d \rightarrow \mu\mu) = 18\,\%$

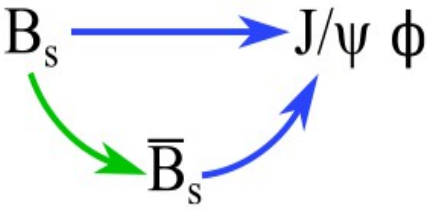
$\Delta(BR(B_d \rightarrow \mu\mu)/BR(B_s \rightarrow \mu\mu)) = 21\%$

$B_d \rightarrow \mu\mu$ *significance*: $6.8\,\sigma$

Measurement of Φ_s and $\Delta\Gamma_s$ with $B_s \to J/\psi\phi$

Pisa

- B_s mesons mix via box diagrams with large $\Delta\Gamma$s between the two mass eigenstates
- CPV phase Φ_s arises for interference between direct and mixing-mediated decays



$$\phi_s \simeq -2\beta_s\,,\ \beta_s = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$$

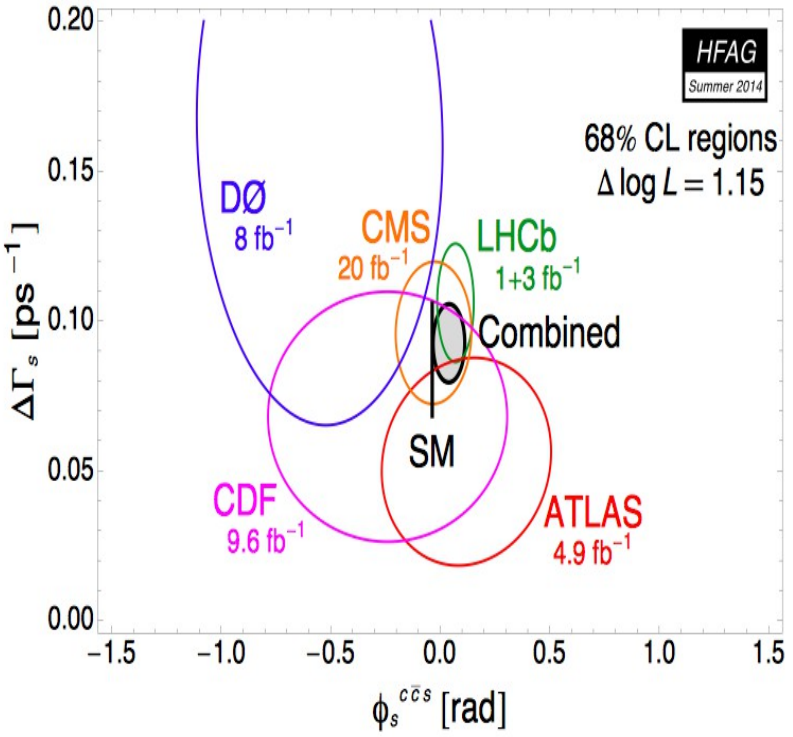
$$2\beta_s = 0.0363^{+0.0016}_{-0.0015}\ \text{rad in the SM}$$

- Mixture of CP-even & CP-odd eigenstates requires angular analysis

$$\Phi_s = -0.03 \pm 0.11 \pm 0.03 \quad rad$$

$$\Delta\Gamma_s = 0.096 \pm 0.014 \pm 0.007 \quad ps^{-1}$$

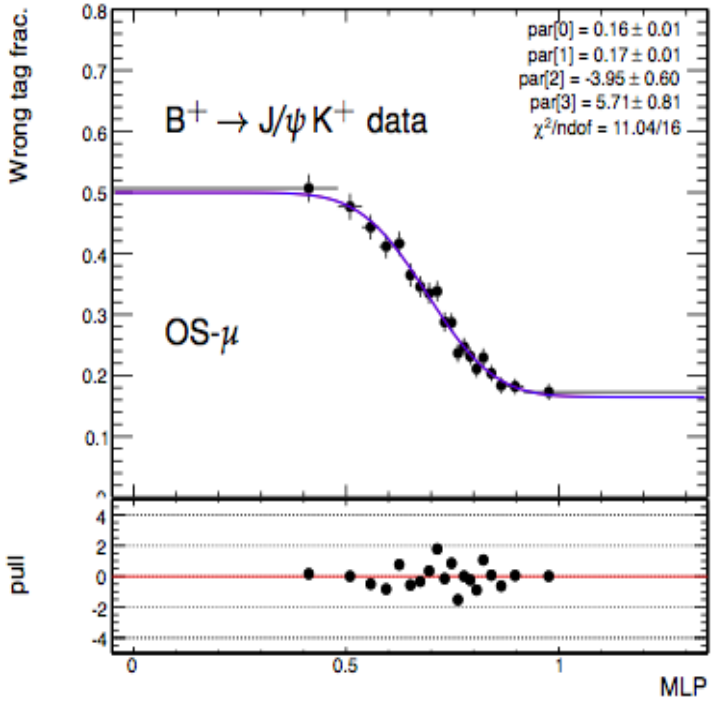
- Competitive with LHCb and consistent with SM predictions



Flavor tagging algorithm

Padova

- CPV measurements using neutral mesons require knowledge of the B flavor @ production time: study Opposite-Side assuming $b\bar{b}$ production
- Flavor obtained from the charge of an OS μ / e
- TMVA analysis to disentangle b ➤l direct decays from b ➤c ➤l cascade & BKG
- Mistag measured on B^+ ➤J/ K^+ real data & corrected for B_s/B^+ difference using MC



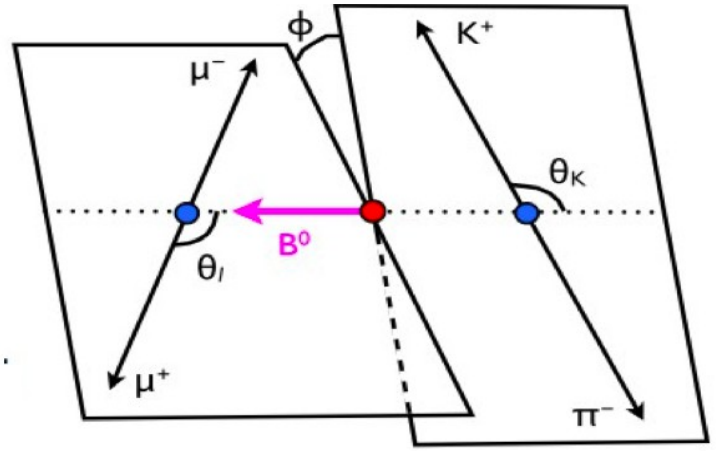
[%]	μ	e	ℓ
ε_{tag}	4.56 ± 0.02	3.92 ± 0.02	8.31 ± 0.03
ω	28.6 ± 0.3	32.5 ± 0.3	30.2 ± 0.2
$\mathcal{P}_{tag}$	0.83 ± 0.02	0.48 ± 0.02	1.31 ± 0.03

- Tagging power improved by ~30% wrt original cut-based strategy

Measurement of the forward-backward asymmetry and other variables in $B^0 \rightarrow K^{*0} \mu\mu$

Milano Bicocca

Pre-Approved



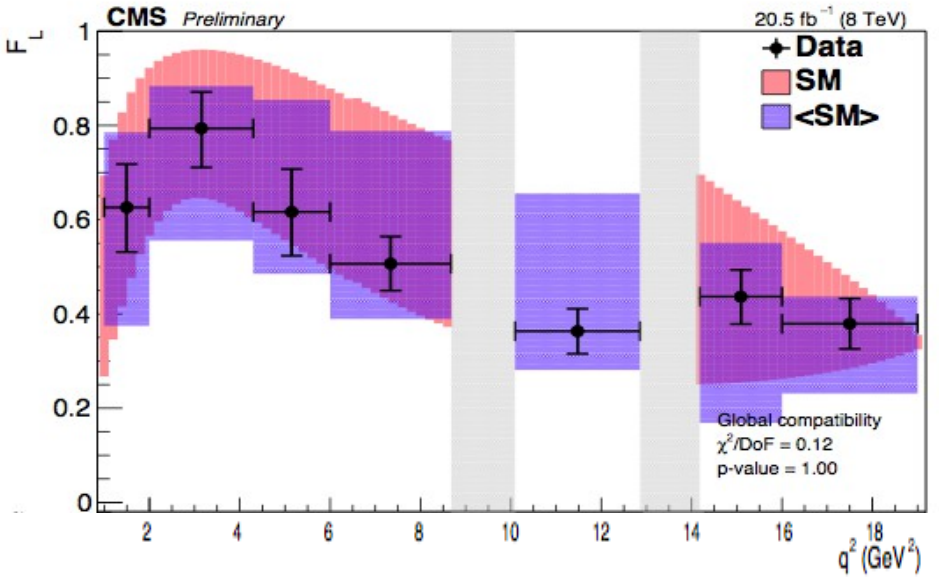
- FCNC process forbidden @ tree level, BR~10^{-6}: Probe the SM
- Sensitive to effects of NP in photon, vector and axial-vector couplings
- Kinematic of the decay determined by three angles

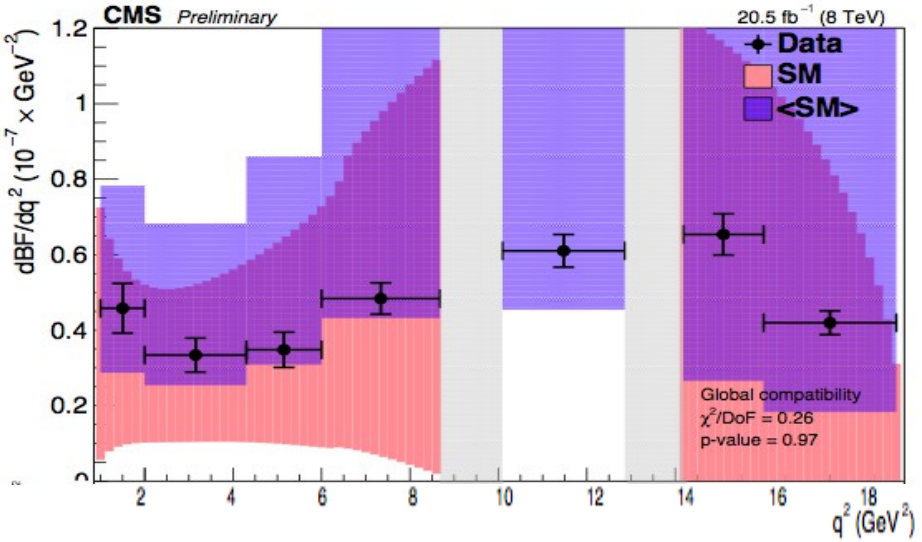
- Events reconstructed in bins of $q^2=m^2(\mu\mu)$
- Observables: dB/dq^2, A_{FB} (forward-backward muon asymmetry), F_L (fraction of longitudinally polarized K*)

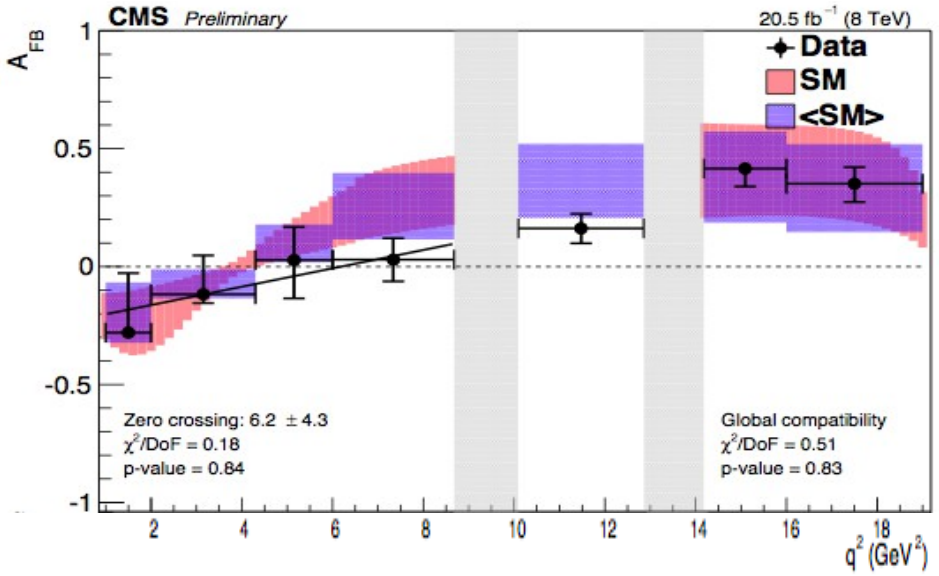
Measurement of the forward-backward asymmetry and other variables in $B^0 \to K^{*0} \mu\mu$

Milano Bicocca

- Improvements wrt 2011 analysis:
  - Mistagged events included in the PDF
  - Measure A_{FB} zero crossing point
  - Variable transformation to take into account their physical domain







B Mixing and SL asymmetry A_{SL} with di-muons

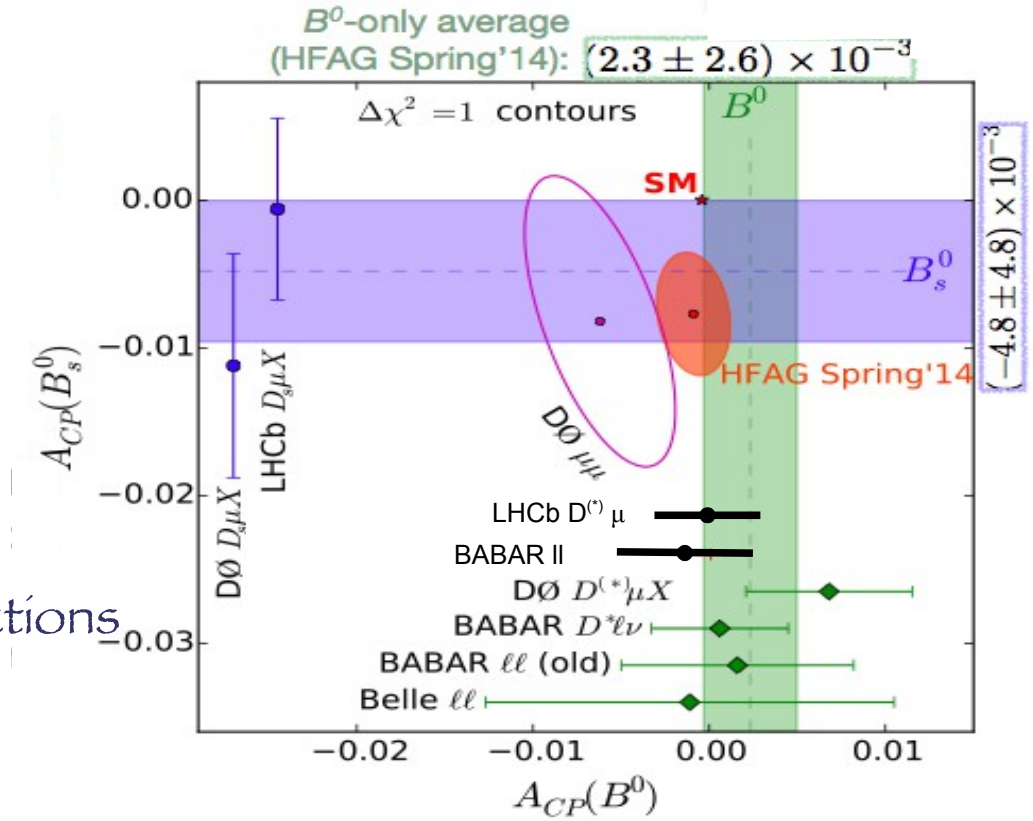
Padova

- Hot topics due to:
  - Discrepancy between LEP & CDF in the integrated mixing rate

$$\bar{\chi} = 0.126 \pm 0.004 \quad (LEP)$$
$$\bar{\chi} = 0.147 \pm 0.011 \, (Tevatron)$$

  - D0 anomaly @ 3.6 σ in A_{SL} from SM predictions

$$A_{sl}^{q} = \frac{N_{B_q^0}(\mu^+\mu^+) - N_{B_q^0}(\mu^-\mu^-)}{N_{B_q^0}(\mu^-\mu^-) + N_{B_q^0}(\mu^-\mu^-)}$$



- Mixing analysis using 3 10^5 non-resonant di-muons (2010 dataset)
  - Fraction of events from B decays from a fit to $P_t(\mu)$ relative to jet direction for different charge correlation samples (SS, OS, SS^{++}, S^{--})

$$\bar{\chi} = 0.126 \pm 0.002 \pm 0.005 \quad (BLIND)$$ (data set 2010, $P_t(\mu)$ >3 GeV no prescaling)

  - Issues: fit convergence, fit/data agreement, BKG composition

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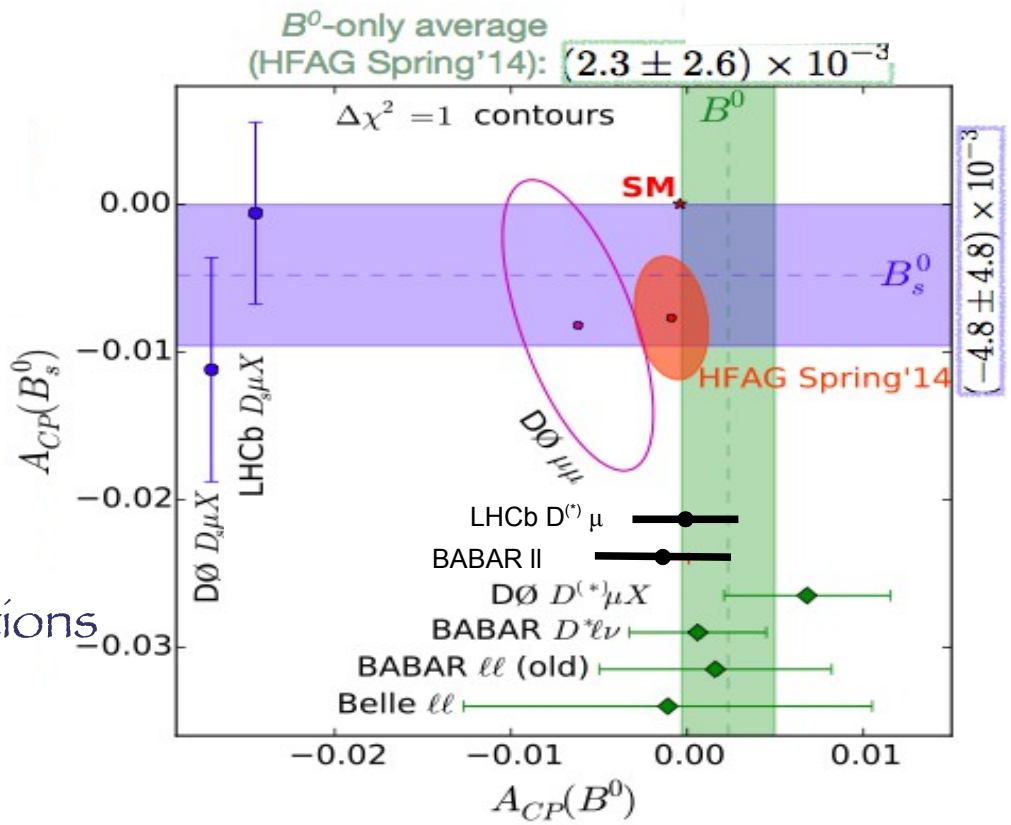


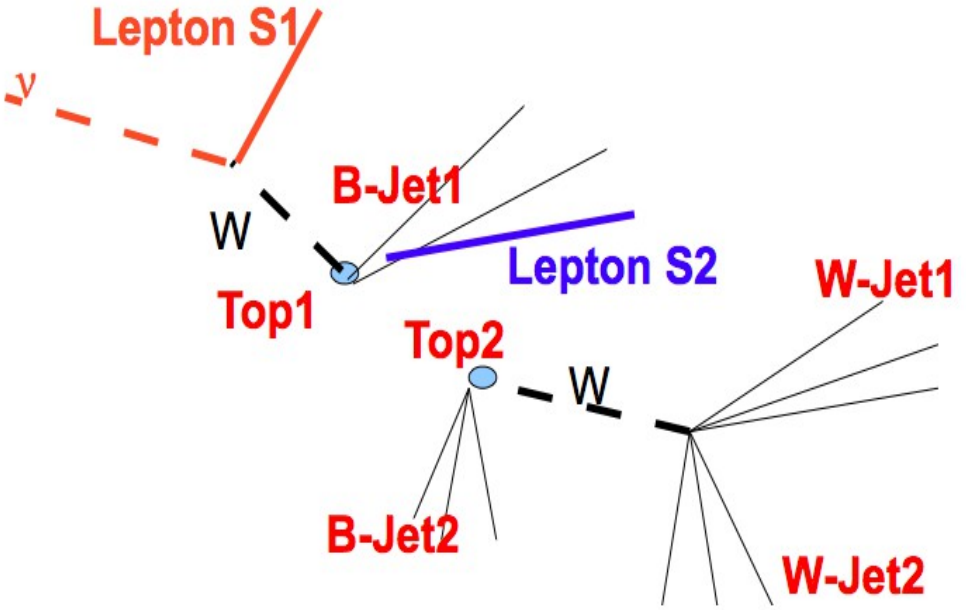
- A_{SL} analysis still to be started will use 3 10^7 same-sign low P_t di-muons (2012 dataset)
  - No need for further data
  - Needs careful treatment of systematics uncertainties (BKG, charge-dependent muon efficiency, B° production asymmetry)

B Mixing and A_{SL} in $t\bar{t}$ events

Padova

- Semileptonic top decays: $t\bar{t}$, $t \rightarrow blv$, $\bar{t} \rightarrow bX$
  - Lepton from top decay tags the flavor of both the B jets at the production time

- Test QCD factorization from comparison of $\chi(mt)$ with $\chi(mZ)$
- Expected statistical error 0.003 (0.002 adding electrons) on 2012 dataset
- Future test of A_{sl} (see Run II strategy)



- Issues:
  - Association of the muon from B decay to the right top
  - Separation between direct $b \rightarrow \mu$ and cascade $b \rightarrow c \rightarrow \mu$ decays
  - Both solved using a MVA

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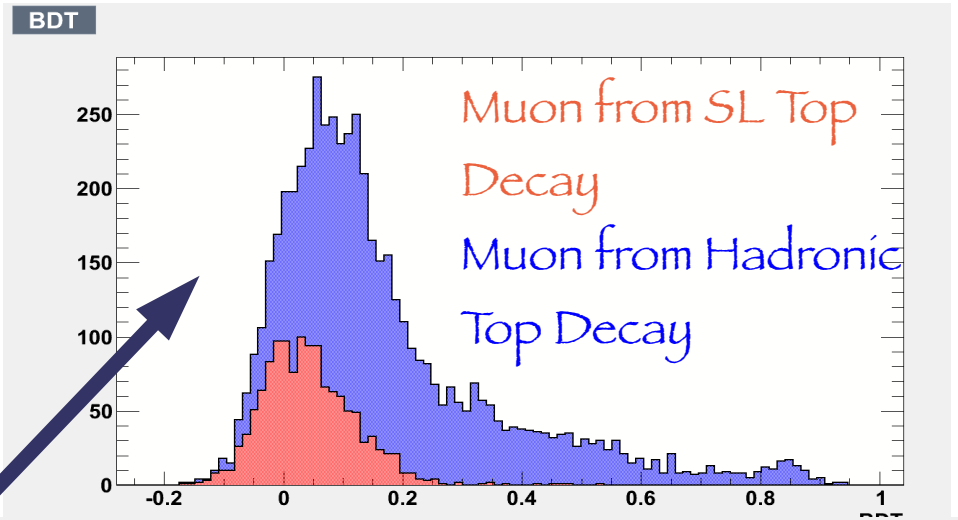
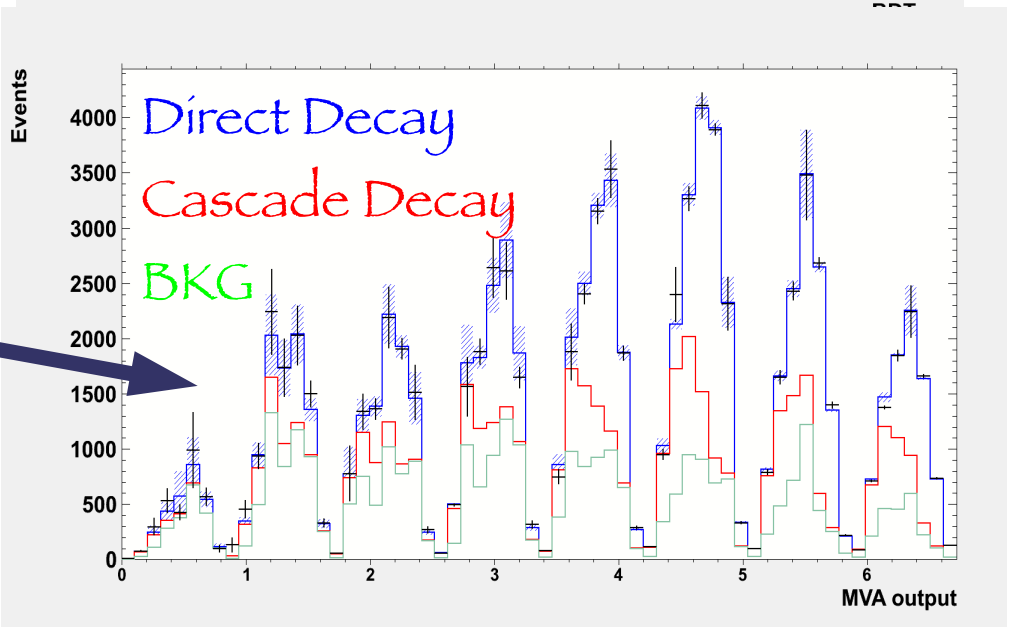
- Future test of A_{sl} (see Run II strategy)

- Issues:
  - Association of the muon from B decay to the right top
  - Separation between direct $b \to \mu$ and cascade $b \to c \to \mu$ decays
  - Both solved using a MVA





Standard & Exotic Quarkonia

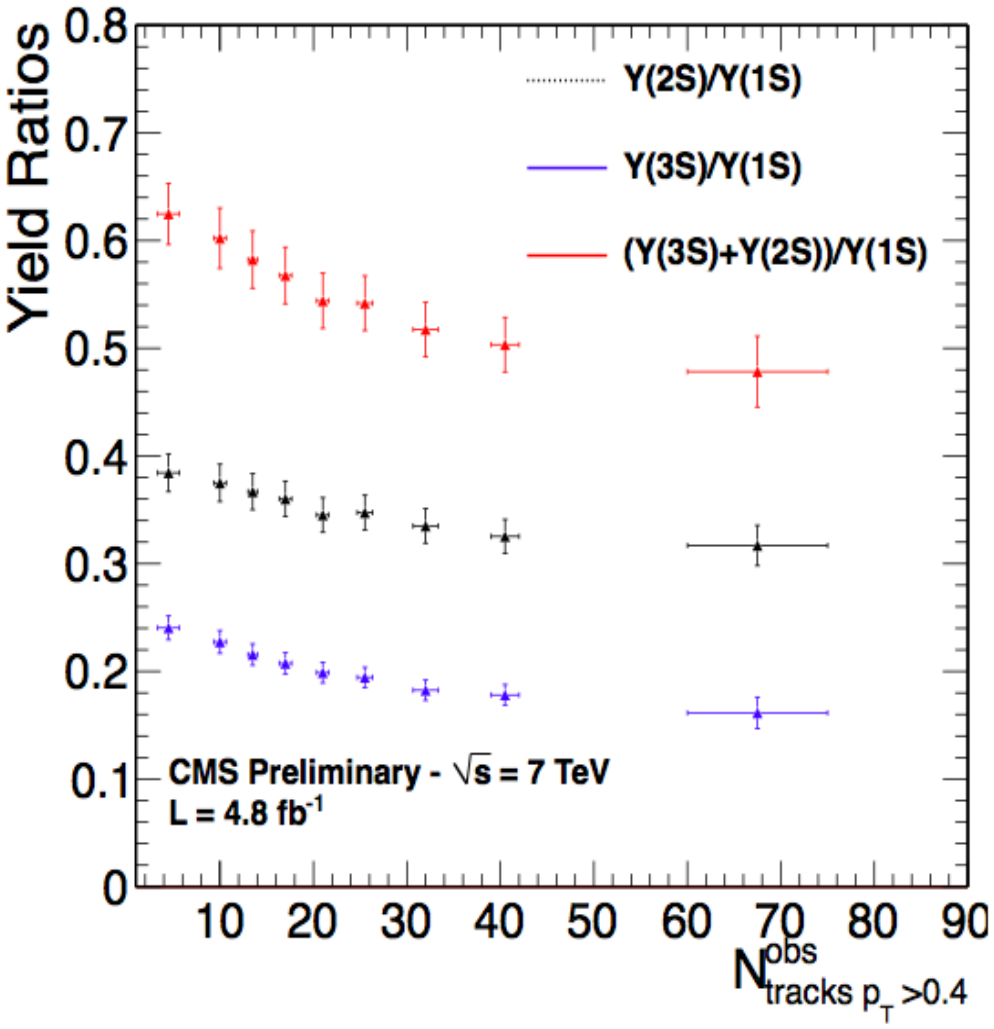
- $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ σ measurements in pp collisions at $\sqrt{s} = 7$ TeV (BPH-12-006) CWR-ended
- Prompt J/ψ and $\psi(2S)$ double-differential production cross sections in pp collisions at 7 TeV (BPH-14-001) Approved
- Υ Production vs charge particle multiplicity (BPH-14-009) 
- Inclusive and exclusive search of $Z^+(4430)$ (BPH-14-003) 

Υ Production vs charge particle multiplicity

Bologna

- Υ(nS) states are standard probes to investigate Quark Gluon Plasma in Heavy Ions collisions (Pb-Pb & p-Pb)
  - Different deconfinement temperature between different states: Study ratio of production vs track multiplicity

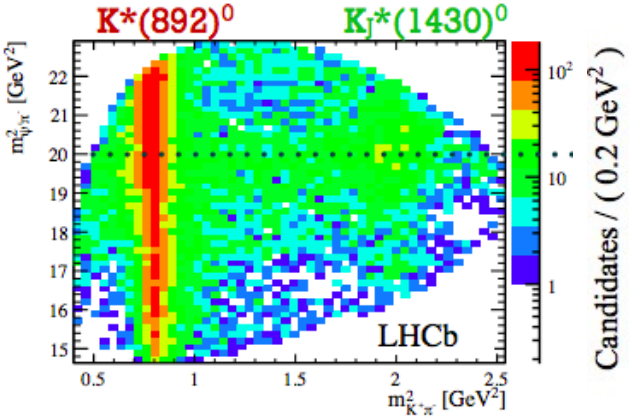
- Preliminary results obtained in pp collisions with larger statistics on 2010+2011 data sets: 1230k Υ(1S), 410k Υ(2S), 230k Υ(3S)

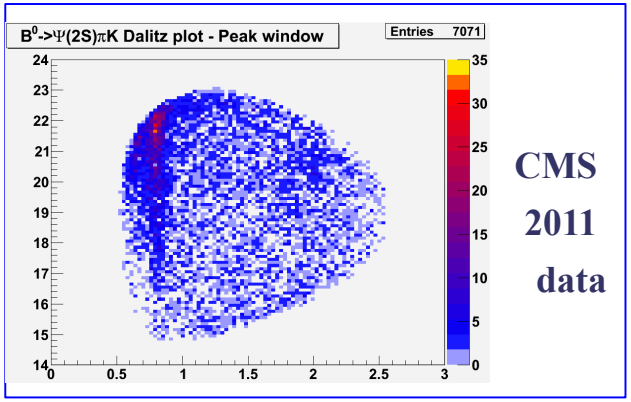


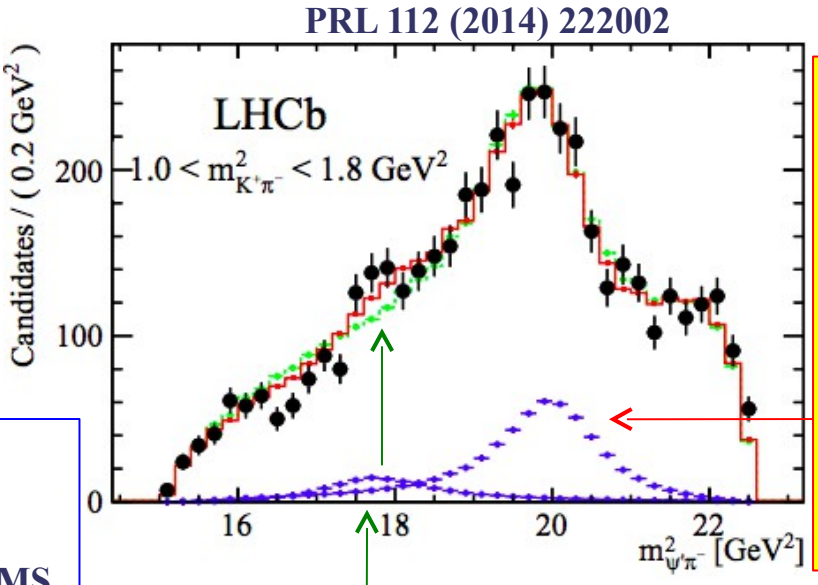
Exclusive & inclusive search of Z(4430)$^+$

Bari

- **Exclusive analysis** (with 4D amplitude analysis of $B^0 \to \psi' K^+ \pi^-$)







$Z(4430)^-$ [$J^P=1^+$ favoured w.r.t. other hypotheses @ 9.7σ signif.] (consistent with Belle). Belle finds its evidence (4σ signif.) also in $B^0 \to J/\psi K^+\pi^-$ decays

2^{nd} exotic $Z'(4240)^-$ $J^P=0^-$ [~6σ signif.]

Amplitude analysis tool being developed together with $B^+ \to J/\psi\, \varphi\, K^+$ analysis

- **Inclusive search** (in $\psi'\pi$ mass spectrum)

  No hints found with 2011+2012 data;

  high backgrounds & Z is a large state (Γ from 107 MeV [Belle2009] to 172 MeV [LHCb2014])

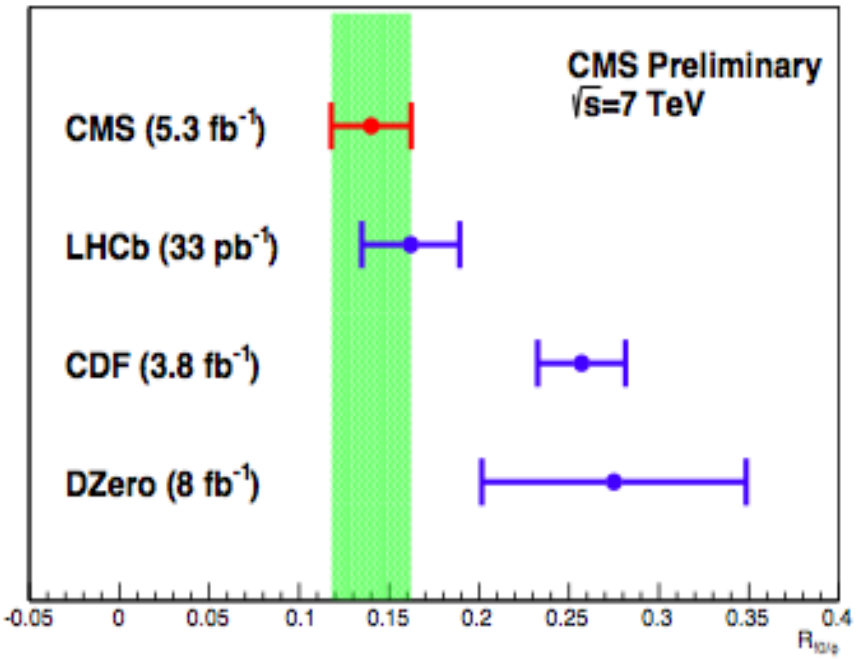
B Production & Spectroscopy

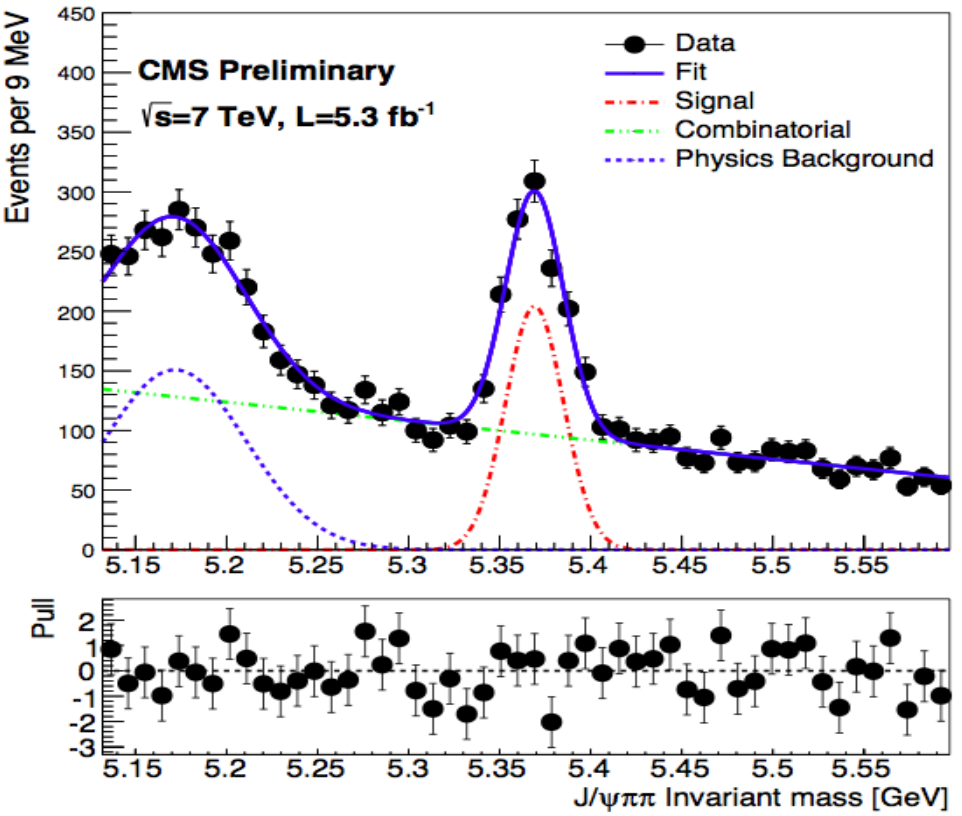
- Measurement of the BR($B_s \rightarrow J/\psi\, f^0$) (BPH-14-002) CWR
- Measurement of the B_c cross-section in pp collisions at 7 TeV (BPH-13-002) Pre-Approved
- Observation of $B^+ \rightarrow \psi(2S)\,\varphi\, K^+$ (BPH-13-009) Mass Plot Approved
- New: Investigation of the 4μ final state (BPH-14-006)
- B_c lifetime with $B_c \rightarrow J/\psi\, \pi$ (BPH-13-011) 
- Search for $B_c(2S)$ state 

Measurement of $BR(B_s \rightarrow J/\psi f^0)$

CWR

- Channel useful to measure mixing-induced CPV Phase Φ_s without angular analysis
- J/ψ f^0 state is a pure CP-odd eigenstate allowing measurement of the CP-odd lifetime
- New Physics could be spotted by BR measurement



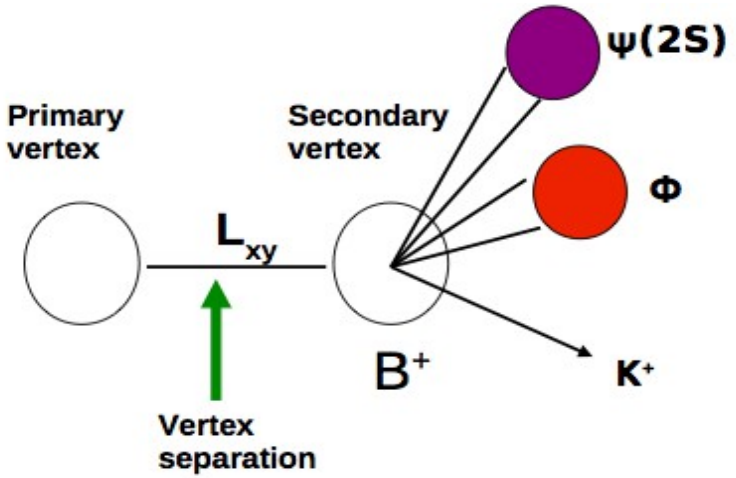


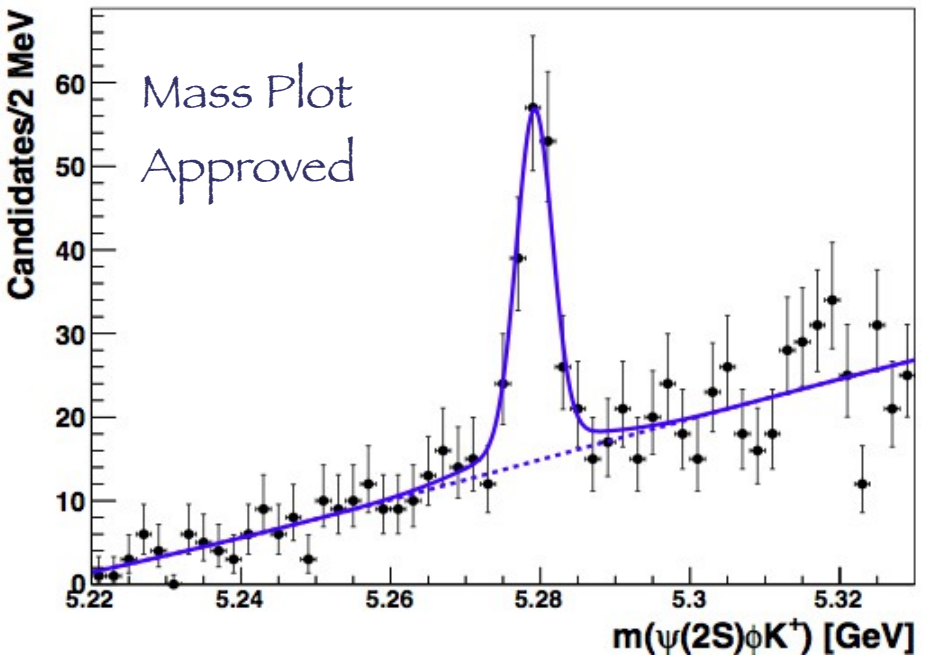
$$\frac{BR(B_s \rightarrow J/\psi f_0; f_0 \rightarrow \pi^+ \pi^-)}{BR(B_s \rightarrow J/\psi \phi; \phi \rightarrow K^+ K^-)} = 0.140 \pm 0.013 \pm 0.018$$

- Consistent with theoretical prediction ~ 20%

First observation of $B^+ \longrightarrow \psi(2S)\,\phi\,K^+$

- Result obtained as part of the investigation of the $J/\psi\ \phi\ K^+$ spectrum





S. Malvezzi & A. Pompili are part of the ARC

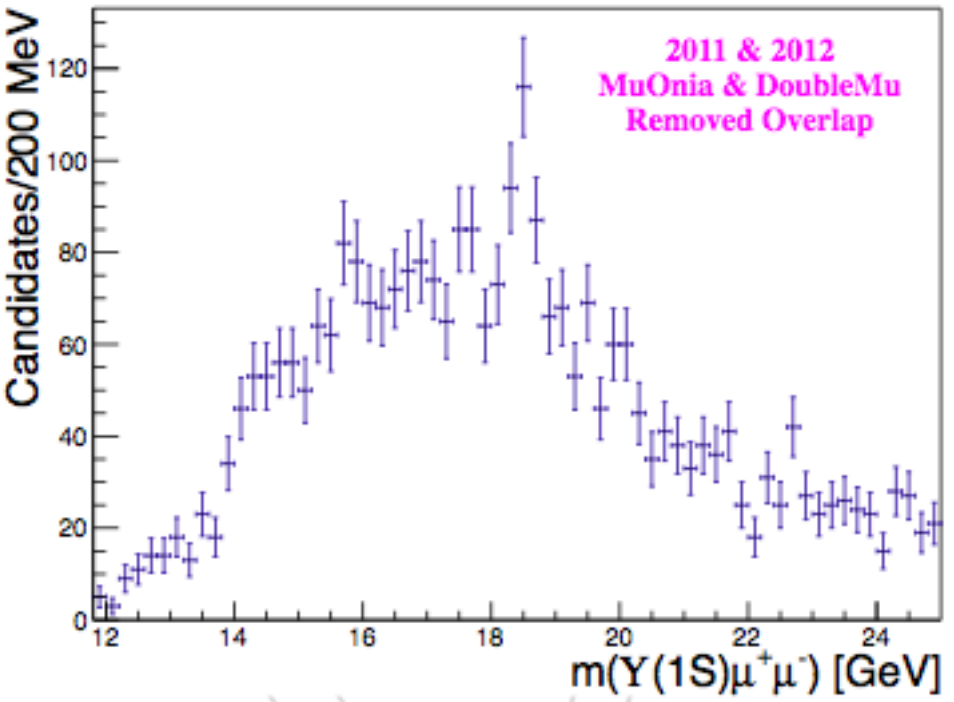
- Observed yield : N = 144 ± 17 events; significance well exceeding 5 σ
- $B^+ \longrightarrow \psi(2S)\ K^+$ used as a normalization channel for the absolute BR measurement (that will go in the paper in preparation);
  very preliminary BR estimate to be approved (systematics still in progress):

$$BR(B^+ \to \psi(2S)\phi K^+) = (4.0 \pm 0.5 \pm 0.5 \pm ?? \times 10^{-6})$$

Investigation of the 4μ final state

- Several new charged quarkonium-like structures discovered recently ($Z^+(4430)$, $Z_c(3900)$): existence of four-quarks states?
- Can be four heavy quarks bound together? Predicted masses mostly below VV threshold
  - Search for VV* states decaying in 4μ with m(V*)<m(V)
- Search for exotic particles, BSM Higgs or DM
- Structure observed in Υ(S1)Υ*(S1)

- Several tests performed:
  - μ selection
  - Cuts on $P_t(\mu)$, $P_t(\mu\mu)$, $P_t(4\mu)$, Υ(1S) mass window
  - Check of unselected combinations



Run II Strategy:

1. Trigger & Data Taking

BPH Trigger Strategy

- BPH trigger focused mainly on muons
- Different features & needs depending on the Physics channel:
  - Rare Decays: almost 100% Background paths ($B_q \rightarrow \mu\mu$)
  - Quarkonia: almost 100% Signal path (J/ψ, Υ)

- Issues:
  - L1: Stay within the old Bandwidth (10 kHz~10 % of the total Bandwidth) despite the increase of a factor 4 in rate
  - Try to reduce the rate without affecting too much the Signal requiring two muons with Opposite Sign @ L1 (first time)

L1 path	Prescale	Rate (kHz)	Pure rate (kHz)
L1_SingleMu20er	1	15.17	2.78
L1_SingleMu25	1	15.83	1.71
L1_DoubleMu0er16_HighQ_WdEta18_OS	1	7.16	5.33
L1_DoubleMu_10_0_HighQ_WdEta18	1	6.06	2.41
L1_QuadMu0_HighQ	1	0.09	0.03
L1_SingleMu5	50000	0.01	0.00
L1_DoubleMu0_HighQ	10000	0.01	0.01
L1_DoubleMu0er16_HighQ_WdEta18	2000	0.02	0.01
L1_TripleMu0_HighQ	100	0.03	0.01
L1_TripleMu_5_5_3_HighQ	1	0.92	0.32

Physics Seeds

Efficiency Seeds

BPH Trigger Strategy

- BPH trigger focused mainly on muons
- Different features & needs depending on the Physics channel:
  - Rare Decays: almost 100% Background paths ($B_q \rightarrow \mu\mu$)
  - Quarkonia: almost 100% Signal path (J/ψ, Υ)

- Issues:
  - HLT: around 100 Hz of Bandwidth @ $L=1.4\ 10^{34}$ without regional reconstruction & Data Parking
    - Quarkonia (50% of rate):
- Take the lowest P_t unprescaled L1 seeds (high P_t quarkonia can emit a low P_t muon)
- Purity~100%; to keep the rate low: increase the P_t cut

HLT path	L1 seed	rate (Hz)	status
Mu25_TkMu0_dEta18_Onia	L1_SingleMu20er OR L1_SingleMu25	7 (pure) 14 (total)	in GRun val. sample
Dimuon20_Jpsi	L1_DoubleMu_10_0_HighQ_WdEta18	20	in GRun val. sample
Dimuon13_PsiPrime	L1_DoubleMu_10_0_HighQ_WdEta18	7	in GRun val. sample
Dimuon13_Upsilon	L1_DoubleMu_10_0_HighQ_WdEta18	14	in GRun val. sample

BPH Trigger Strategy

- BPH trigger focused mainly on muons
- Different features & needs depending on the Physics channel:
  - Rare Decays: almost 100% Background paths ($B_q \rightarrow \mu\mu$)
  - Quarkonia: almost 100% Signal path (J/ψ, Υ)

- Issues:
  - HLT: around 100 Hz of Bandwidth @ $L=1.4\ 10^{34}$ without regional reconstruction & Data Parking
    - Double Quarkonia (5% of rate):
- High Rates & very low-P_t muons: L1 really matters
- 3-muons L1 seeds have too high P_t thresholds or are prescaled
  - 4-muons L1 seed with no P_t requirement

HLT path	L1 seed	rate (Hz)	status
Mu4_Dimuon0_Jpsi	L1_QuadMu0_HighQ	few	in GRun val. sample
Mu4_Dimuon0_Upsilon	L1_QuadMu0_HighQ	few	in GRun val. sample

BPH Trigger Strategy

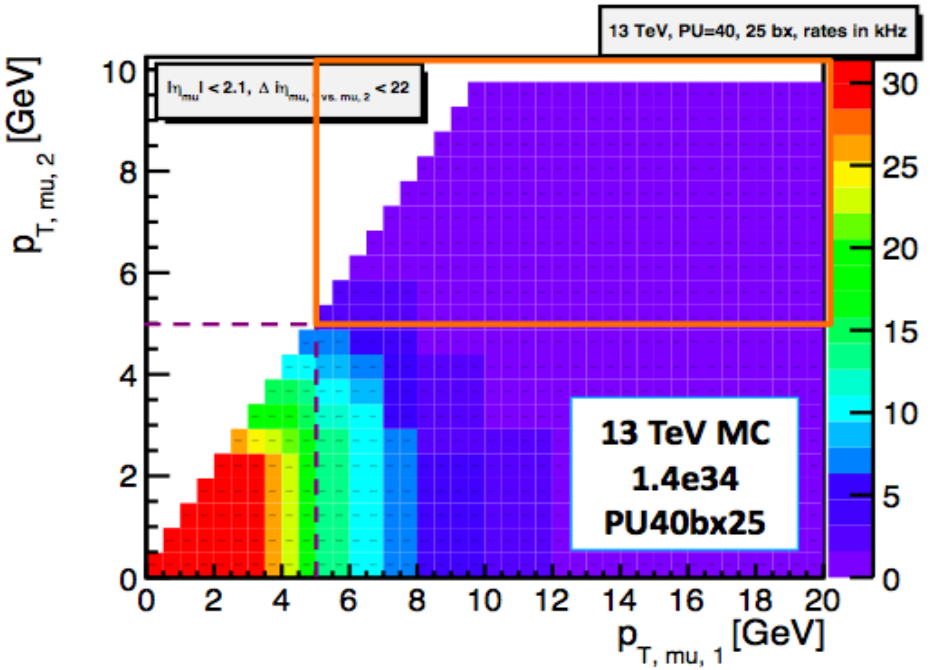
- BPH trigger focused mainly on muons
- Different features & needs depending on the Physics channel:
  - Rare Decays: almost 100% Background paths ($B_q \rightarrow \mu\mu$)
  - Quarkonia: almost 100% Signal path (J/ψ, Υ)

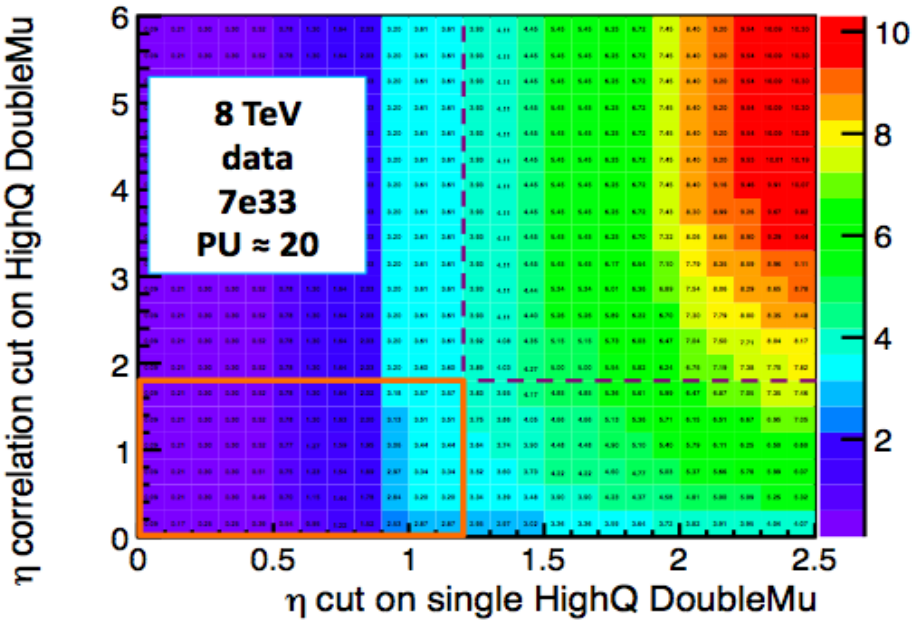
- Issues:
  - HLT: around 100 Hz of Bandwidth @ $L=1.4\ 10^{34}$ without regional reconstruction & Data Parking
    - B Production & Decays (20% of rate):
- Very difficult to limit rate without affecting analyses: paths driven by specific analyses
- Add 1 or 2 high-quality tracks to a dimuon high-quality vertex
  - Benefit from Regional Reconstruction and Data Parking

HLT path	L1 seed	rate (Hz)	status
DoubleMu4_LMNR_Tk_Displaced	L1_DoubleMu0er16_HighQ_WdEta18_OS OR L1_DoubleMu_10_0_HighQ_WdEta18	42	in GRun val. sample
DoubleMu4_Jpsi_Tk_Displaced	L1_DoubleMu0er16_HighQ_WdEta18_OS OR L1_DoubleMu_10_0_HighQ_WdEta18	23	in GRun ✓
DoubleMu4_PsiPrime_Tk_Displaced	L1_DoubleMu0er16_HighQ_WdEta18_OS OR L1_DoubleMu_10_0_HighQ_WdEta18	2	in GRun val. sample

BPH Trigger Strategy

- Rare Decays (B→μμ) (20% of rate):





- Take the lowest P_t unprescaled double-muon L1 seeds, keep thresholds as low as possible, use displaced J/ψ for the normalization channels $J/\psi K^+$, $J/\psi\varphi$ (prescaled)

HLT path	L1 seed	rate (Hz)	status
DoubleMu4_3_Bs	L1_DoubleMu0er16_HighQ_WdEta18_OS OR L1_DoubleMu_10_0_HighQ_WdEta18	12	in GRun val. sample
DoubleMu4_3_Jpsi_Displaced	L1_DoubleMu0er16_HighQ_WdEta18_OS OR L1_DoubleMu_10_0_HighQ_WdEta18	8 ($p = 5$)	in GRun ✓

BPH Trigger Strategy

- Efficiency Paths (5% of rate)
- Aiming at ~ 0.5% Hz per path

HLT path	L1 seed	status
HLT_Mu7p5_L2Mu2_Jpsi	DoubleMu0_HighQ	in GRun ✓
HLT_Mu7p5_L2Mu2_Upsilon	DoubleMu0_HighQ	in GRun val. sample
HLT_Mu7p5_Track2_Jpsi	SingleMu5	in GRun ✓
HLT_Mu7p5_Track3p5_Jpsi	SingleMu5	in GRun ✓
HLT_Mu7p5_Track7_Jpsi	SingleMu5	in GRun ✓
HLT_Mu7p5_Track2_Upsilon	SingleMu5	in GRun val. sample
HLT_Mu7p5_Track3p5_Upsilon	SingleMu5	in GRun val. sample
HLT_Mu7p5_Track7_Upsilon	SingleMu5	in GRun val. sample
HLT_Dimuon6_Jpsi_NoVertexing	DoubleMu0_HighQ	in GRun ✓
HLT_DoubleMu0er16_Jpsi_NoOS_NoVertexing	DoubleMu0_Eta1p6_HighQ_WdEta18	in GRun ✓
HLT_DoubleMu0er16_Jpsi_NoVertexing	DoubleMu0_Eta1p6_HighQ_WdEta18_OS	in GRun ✓
HLT_Dimuon0_Jpsi_Muon	TripleMu0_HighQ	in GRun val. sample

BPH Trigger Strategy

- Total HLT BPH Rate 100 Hz @ L=1.4 10^{34} (Status @ November 10)

HLT path	L1 seed	rate (Hz)	status
Mu25_TkMu0_dEta18_Onia	L1_SingleMu20er OR L1_SingleMu25	7 (pure) 14 (total)	in GRun val. sample
Dimuon20_Jpsi	L1_DoubleMu_10_0_HighQ_WdEta18	20	in GRun val. sample
Dimuon13_PsiPrime	L1_DoubleMu_10_0_HighQ_WdEta18	7	in GRun val. sample
Dimuon13_Upsilon	L1_DoubleMu_10_0_HighQ_WdEta18	14	in GRun val. sample
DoubleMu4_3_Bs	L1_DoubleMu0er16_HighQ_WdEta18_OS OR L1_DoubleMu_10_0_HighQ_WdEta18	12	in GRun val. sample
DoubleMu4_3_Jpsi_Displaced	L1_DoubleMu0er16_HighQ_WdEta18_OS OR L1_DoubleMu_10_0_HighQ_WdEta18	8 ($p = 5$)	in GRun ✓
DoubleMu4_LMNR_Tk_Displaced	L1_DoubleMu0er16_HighQ_WdEta18_OS OR L1_DoubleMu_10_0_HighQ_WdEta18	42	in GRun val. sample
DoubleMu4_Jpsi_Tk_Displaced	L1_DoubleMu0er16_HighQ_WdEta18_OS OR L1_DoubleMu_10_0_HighQ_WdEta18	23	in GRun ✓
DoubleMu4_PsiPrime_Tk_Displaced	L1_DoubleMu0er16_HighQ_WdEta18_OS OR L1_DoubleMu_10_0_HighQ_WdEta18	2	in GRun val. sample
Mu4_Dimuon0_Jpsi	L1_QuadMu0_HighQ	few	in GRun val. sample
Mu4_Dimuon0_Upsilon	L1_QuadMu0_HighQ	few	in GRun val. sample
Efficiency paths	...	few	...

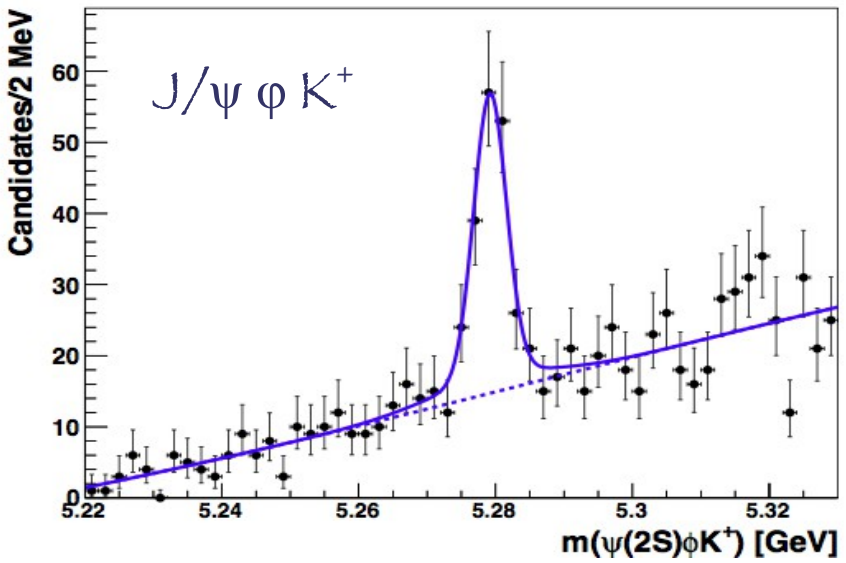
BPH Trigger Strategy

- Help needed from analysts:
  - All the new paths must be studied on expected efficiencies and distributions to check on bugs or unexpected behaviours
  - A first list of samples to be produced in Pythia8:
    - $B^0 \rightarrow J/\psi\ K^*$
    - $B^+ \rightarrow J/\psi\ K^+$
    - $B^0 \rightarrow \mu\mu K^*$
    - $B_s \rightarrow J/\psi\ \varphi$
    - $B^+ \rightarrow \psi(2S)\ K^*$
- Hot studies going on:
  - L1 charge misidentification on data
  - $\mu\mu$ + trk(trk) rate reduction
  - L1 Triple & Quad muon seeds
- Regional reconstruction workshop this week (see next slides)

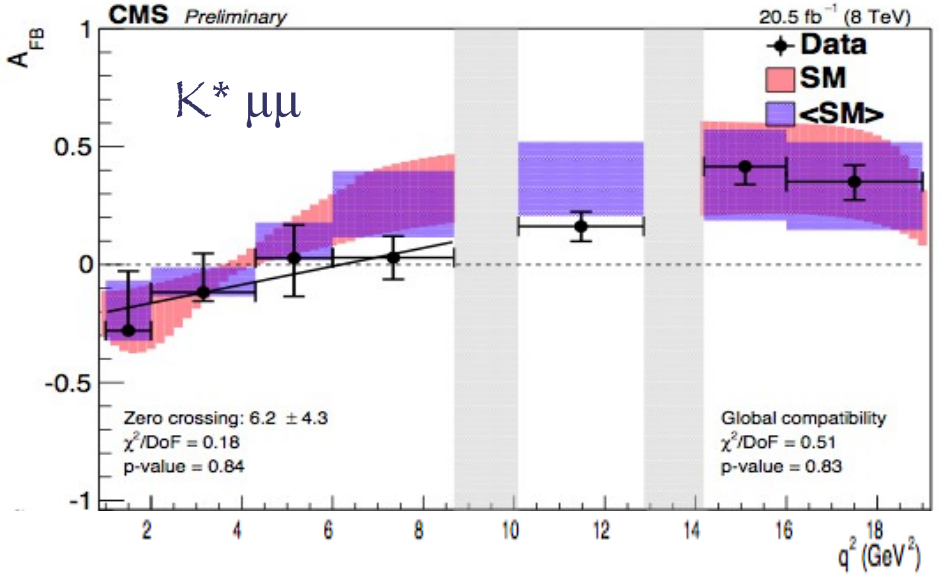
Alternative Data Taking Strategy

- Data Parking
  - In 2012 we had 120 Hz of additional rate on the top of the Stream A 25-30 Hz
  - Important impact on Physics:
    - First observation of $J/\psi\ \varphi\ K^+$ (BPH-13-009)
    - $K^*\ \mu\mu$ Angular analysis (BPH-13-010)

HLT_Dimuon5_PsiPrime



HLT_DoubleMu3p5_LowMass_Displaced



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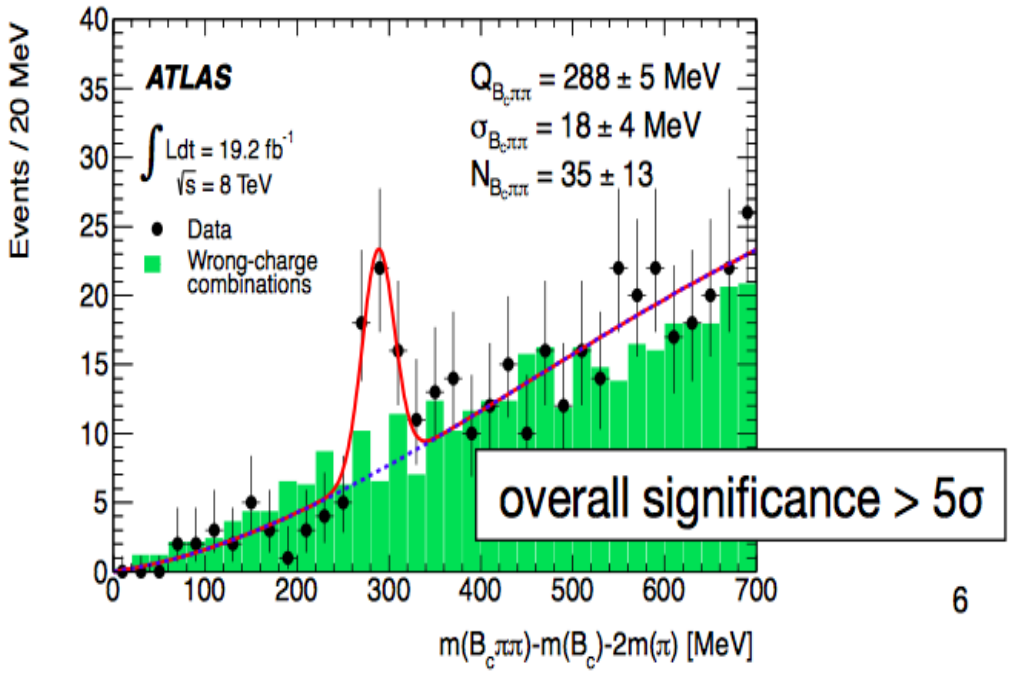
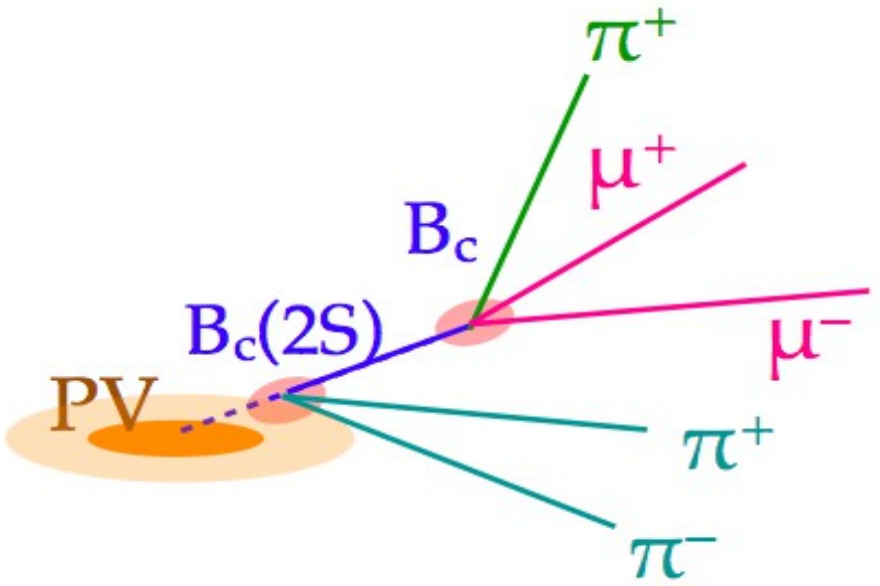
    - Search for $B_c(2S)$ state (no confirmation of Atlas result)





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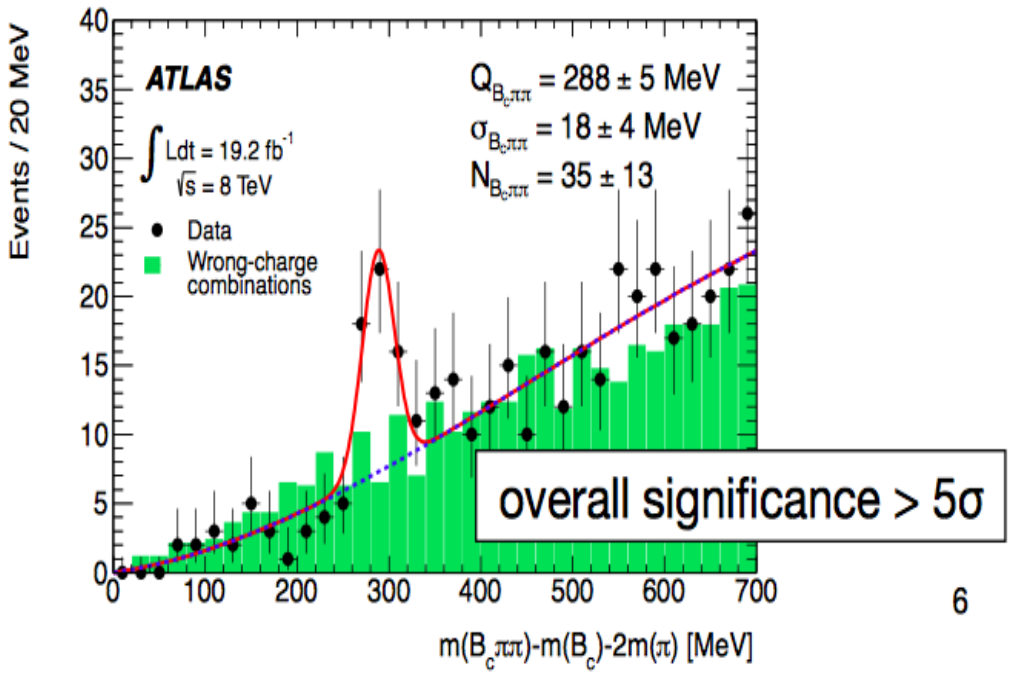

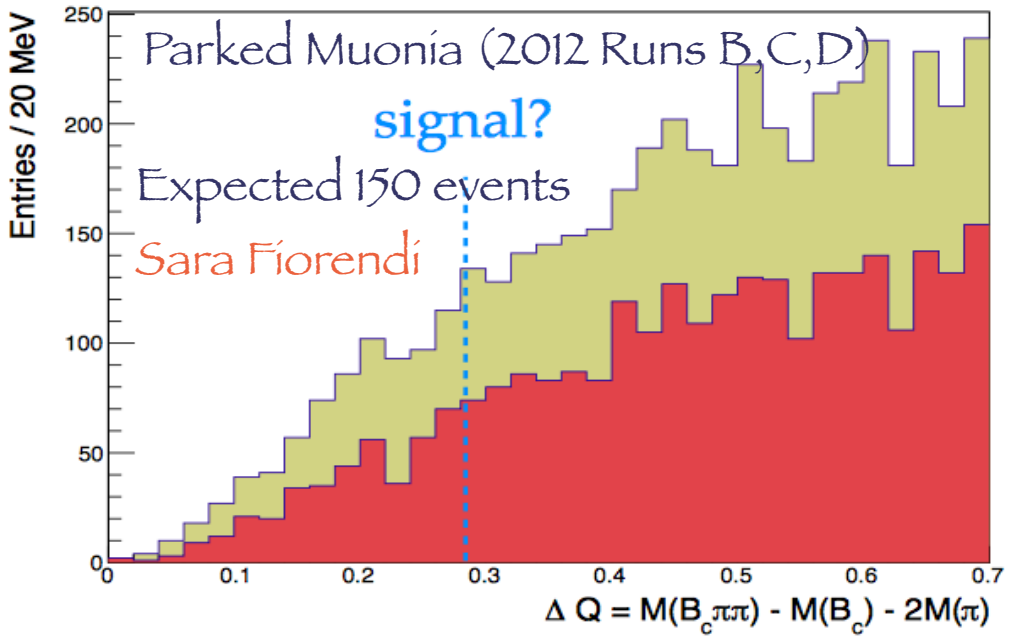

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    - $K^*\ \mu\mu$ Angular analysis (BPH-13-010)
    - Search for $B_c(2S)$ state (no confirmation of Atlas result)

- In Run II it could help in different sectors:
  - Quarkonia/Double Quarkonia: Low-P_t for Polarization (χ_{3b}), $\varphi \rightarrow \mu\mu$, Low-$P_t$ 3-muon Trigger
  - B Production and Decays: J/ψ + additional track(s)
  - CPV, Rare Decays: Displaced vertices, $K_s \rightarrow \mu\mu$, charm $\rightarrow \mu\mu$ (+ $n\pi$)

Alternative Data Taking Strategy

- Regional Reconstruction (Italian Idea)
  - Issue: Large reconstruction time @ Tier0 due to pileup limits HLT Bandwidth
    - Idea: exploit the clear di-muon (+ n tracks & e.m. clusters) signature
    - Seed only the tracks from the same Primary Vertex as the di-muon in a rectangular (θ, φ) region centered in the selected PV (out of 20-40 PVs) taking into account the PV-SV direction of flight
    - Use Reduced P_t thresholds: Increase HLT Physical Rate
- Idea Tested by Po-Hsun Chen, M. Tosi, S. Fiorendi, V. Innocente
  - K* $\mu\mu$ sample with 40 Pileup events
    - Reconstructed average of 36 tracks/event vs 1000 of standard procedure
    - Work going on to check efficiencies, event size, timing
    - Implement it during 2015?
    - Help needed (also) in cfg validation...

Alternative Data Taking Strategy

- 17/18 November:

  Worshop on Scouting, Parking, and Hotline

https://indico.cern.ch/event/345449/

Tuesday, 18 November 2014

10:00 - 12:20 Session on Data Scouting, Hotline & Local reconstruction

Location: 40-S2-B01 - Salle Bohr

- 10:00 **Local reconstruction: BPH** *20'*
  Speakers: Kai-Feng Chen (National Taiwan University (TW)), Po-Hsun Chen (National Taiwan University (TW))
- 10:30 **Discussion on whether local reconstruction could be useful for other groups** *10'*
- 10:40 **Plans from B2G** *15'*
  Speaker: Devdatta Majumder (University of Kansas (KU))
- 11:00 **Plans from EXO** *15'*
- 11:20 **Plans from SUSY** *15'*
  Speaker: Maurizio Pierini (California Institute of Technology (US))
- 11:40 **Inputs and directions from Physics Coordinators** *20'*
  Speakers: Luca Malgeri (CERN), Jim Olsen (Princeton University (US))

Run II Strategy:

2. Physics

(Prospect for Current Analyses & New Ideas):

- Rare Decays, LFV & CPV
- Quarkonia
- B Spectroscopy & Decays
- Flavor Phys. in Heavy Ions Collisions

CPV/Rare Decays: Current Analyses

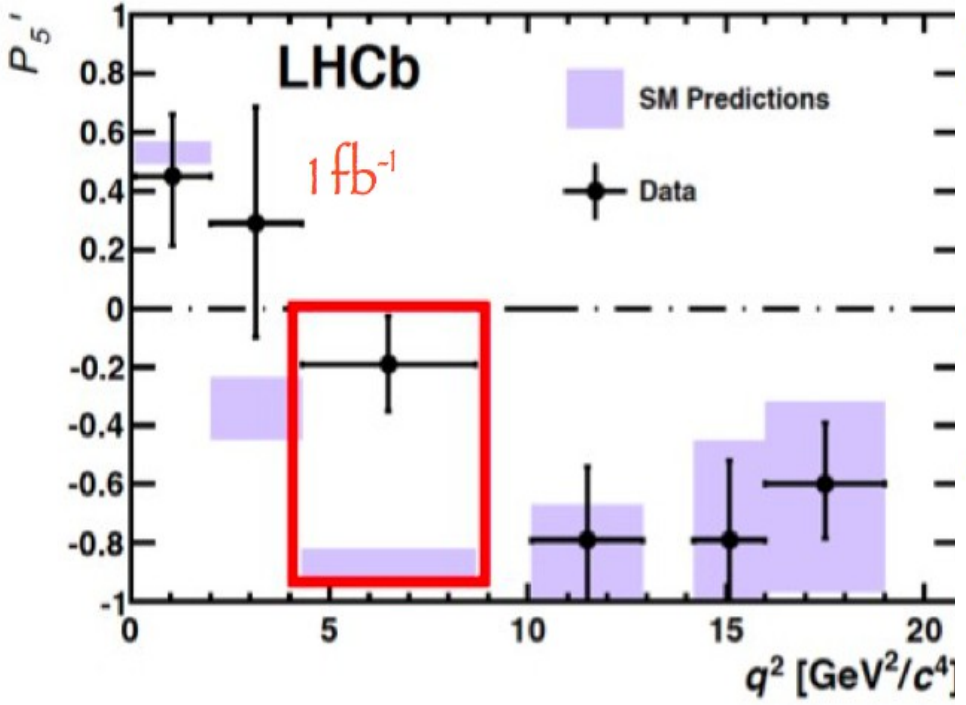
- B → μμ:
  - Improve Muon Misidentification (limiting factor): New MVA binned in η
  - Improve Selection: BDT for isolation, Rare SL BKG study, integrate the Peaking BKG analysis in the mainstream
  - Improve Fit: Include BDT Discriminant, B → hμν & B → hh PDFs

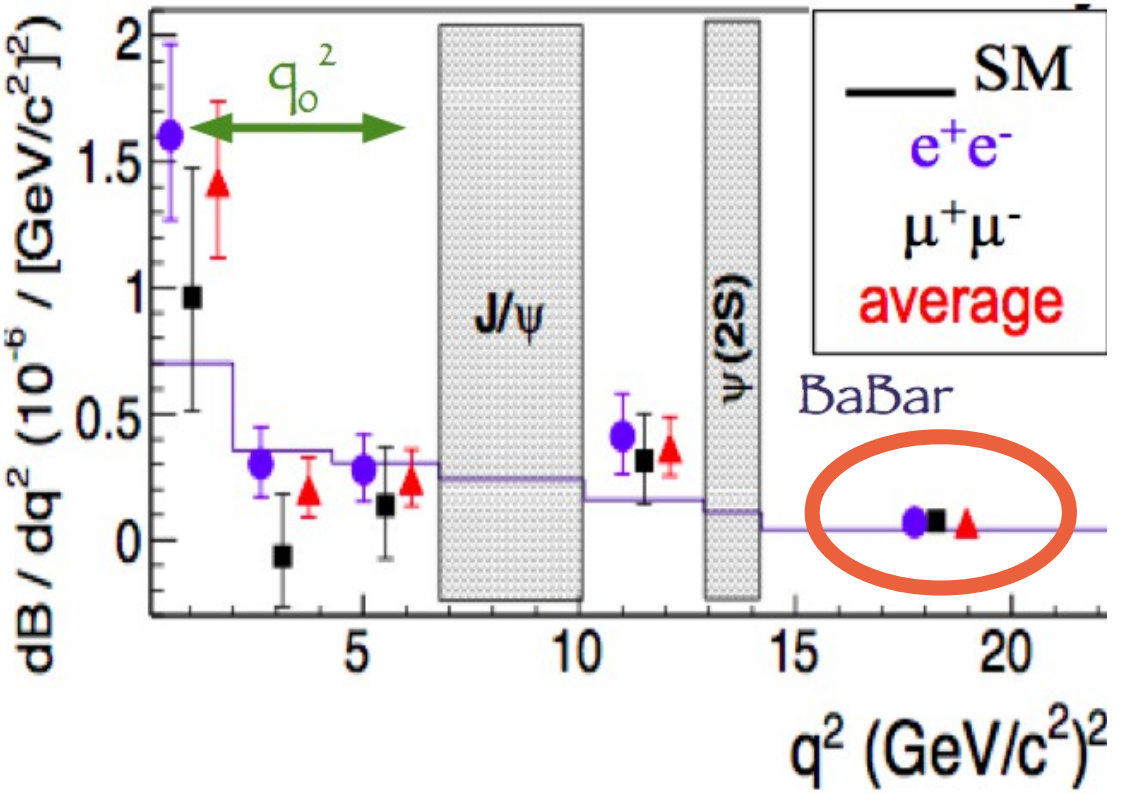
- B → $K^{(*)}$μμ: 
  - Extend the analysis to $B^+ \to K^{*+}\mu\mu$ (35% ε for K_s, 53% BR), $B^+ \to K^+\mu\mu$ (65% BR, one less track, no K* cuts, probe right handed currents), $\Lambda_b \to \Lambda^0\mu\mu$ (right handed couplings)
  - Include measurement of

$$A_I = \frac{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) - \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)}{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) + \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)} \qquad A_{CP} = \frac{\Gamma(\bar{B}^0 \to \bar{K}^{(*)0}\mu^+\mu^-) - \Gamma(B^0 \to K^{(*)0}\mu^+\mu^-)}{\Gamma(\bar{B}^0 \to \bar{K}^{(*)0}\mu^+\mu^-) + \Gamma(B^0 \to K^{(*)0}\mu^+\mu^-)}$$

CPV/Rare Decays: Current Analyses

- $B \rightarrow K^{(*)}\mu\mu$:
  - Use of the angular observables free from Form Factor contributions.
  - LHCb: 3.7 σ discrepancy in P'_5 in $4.3<q^2<8.68$ GeV^2 [PRL 111, 191801(2013)]
  - Possible interpretation as a NP contribution to Wilson coefficient C_9
  - Resulting C^{NP}_9 would imply an inclusive BR($B \rightarrow X_s ll$) suppression of ~25% in $1<q^2<6$ GeV^2 and $q^2>14.4$ GeV^2: not confirmed by BaBar which finds a ~2 σ excess





CPV/Rare Decays: Current Analyses

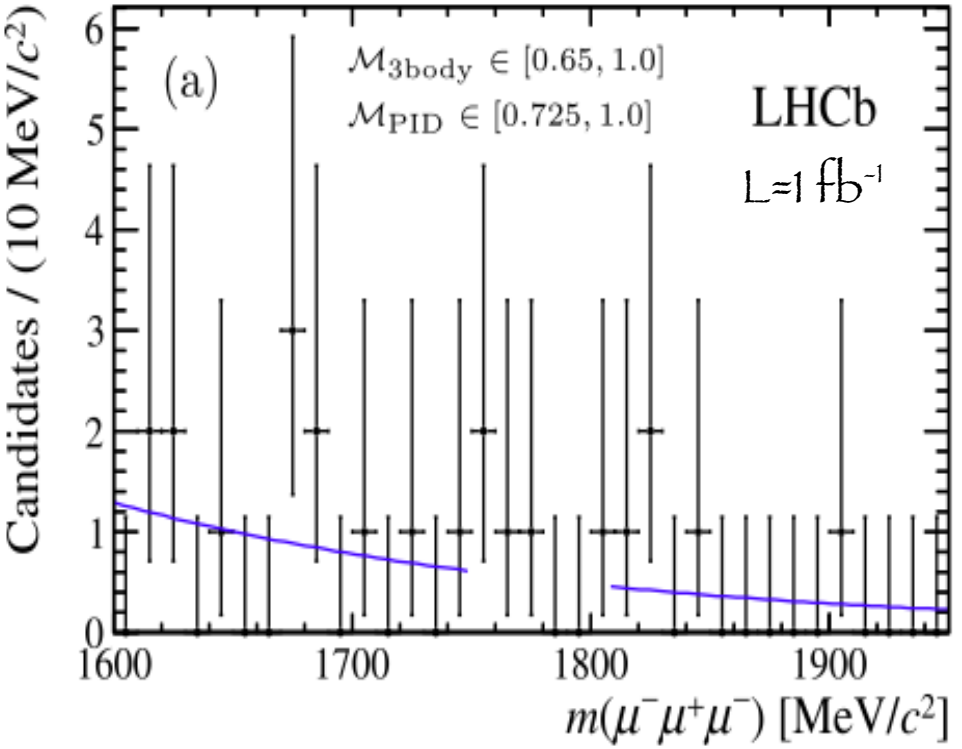
- B Mixing & A_{SL} 
- Using the current tagging strategy in $t\bar{t}$ events:
  - L_{INT}=300 fb^{-1}, σ= 1 nb (5 time the current value) ➡ δA_{SL} (stat) ~0.3%

- Other Possible Analysis: use self-tagging $B^+ \rightarrow J/\psi\ K^+$
  - 2012: 40k events with a μ tag (4 times the top analysis)
  - L_{INT}=300 fb^{-1}, σ = 2 time the current value ➡ δA_{SL} (stat) ~0.2%

- Flavor Tagging : $J/\psi/\varphi$ *et al.* 
  - Include Opposite-Side vertex charge & jet-charge
  - Include the Same-Side cone-charge,...
  - Validate the tagging algorithm with a time-dependent measurement of B^0 mixing

CPV/Rare Decays: Current Analyses

- $\tau \rightarrow 3\mu$
  - Neutrimo mass terms in the SM imply LFV also in the charged sector with BR~10^{-40}
  - NP could significantly enhance LFV in τ decays
- LHCb [PLB 724 36-45 (2013)]:
  - Background rejection exploiting 3-body topology & muon id.
  - Yield normalized to $D_s \rightarrow \varphi(\mu\mu)\,\pi$



LHCb: BR($\tau \rightarrow 3\mu$)<8.0 10^{-8} @ 90% CL

BELLE: BR($\tau \rightarrow 3\mu$)<2.1 10^{-8} @ 90% CL (BEST LIMIT)

CPV/Rare Decays: Current Analyses

- $\tau \rightarrow 3\mu$

Main sources of τ-leptons at LHC

Meson (M)	D_S	D^+	B^0	B_S	B^+
$BR(M \rightarrow \tau + X)$	7.0%	0.2%	2.7%	1.5%	2.7%
$\sigma(M \rightarrow \tau + X)/\sigma(pp \rightarrow \tau + X)$	77%	3%	9%	2%	9%

CMS/NOTE 2002/037

$$\sigma(pp \rightarrow W \rightarrow \tau + \nu_\tau) = 19nb$$
$$\sigma(pp \rightarrow Z^0 \rightarrow \tau\bar{\tau}) = 3nb$$

$$\sigma(pp \rightarrow B_X \rightarrow \tau + \nu_\tau + X) \approx 24\mu b$$

- Expected yields/10 fb^{-1} using current best limit $2.1\,10^{-8}$ from BELLE
  - W: 4 evts
  - Z: 0.7 evts
  - B: 5039 evts

- CMS: New path since 2012: HLT_Tau2Mu_ItTrack (G. Cerminara, F. Fiori, G. Rolandi)
  - Cut on dimuon Invmass, Prob(vertex), Lxy significance; regional tracking (Iterative 4 steps), Dimuon+Tk Vertex
  - Strong interest in the BPH Group: Manpower needed

CPV/Rare Decays: Current Analyses

- $\tau \rightarrow 3\mu$

Main sources of τ-leptons at LHC

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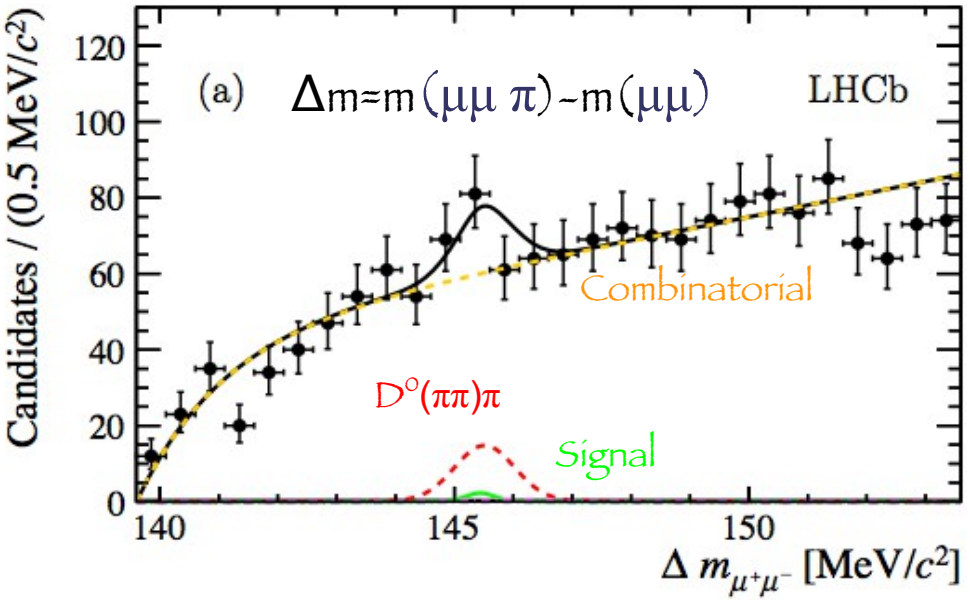
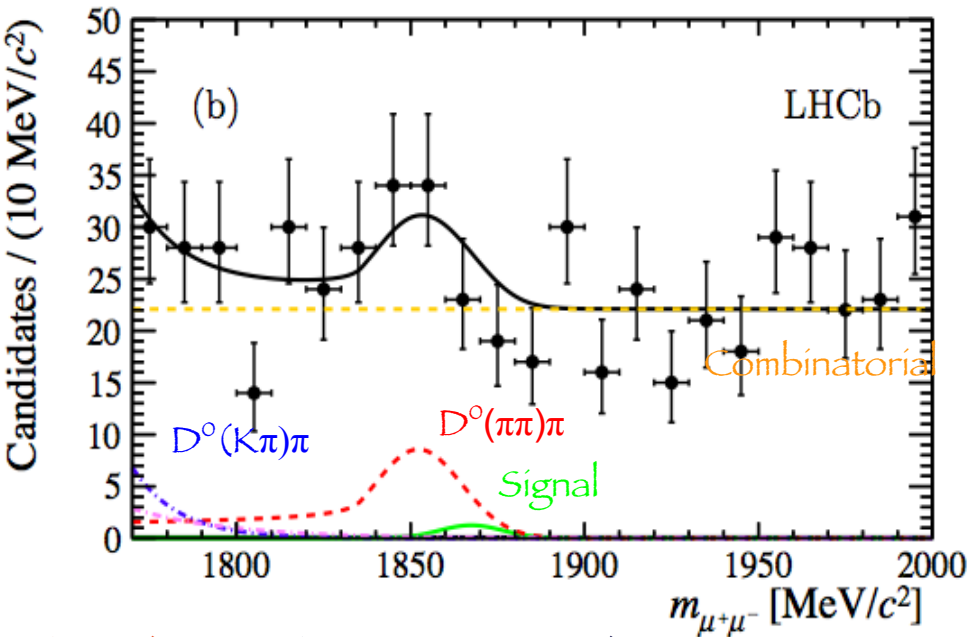
  - W: 4 evts
  - Z: 0.7 evts
  - B: 5039 evts

- Exploit $W \rightarrow \tau\nu$
  - Expect 8 events in Run 1: need $\varepsilon \sim 30\%$ & no BKG to be competitive
  - With L=100 fb^{-1} we might be competitive
  - Need accurate determination of BKG & Efficiency

CPV/Rare Decays: Possible Analyses

- $D^0 \rightarrow \mu\mu$
  - GIM suppression more effective in charm than in b decays. Additional helicity suppression: BR(SM)<6 10^{-11}
- LHCb [PLB 725 15-24 (2013)]:
  - Reconstruct $D^* \rightarrow D^0(\mu\mu)\,\pi$
  - Signal Yield normalized to $D^0 \rightarrow \pi\,\pi$



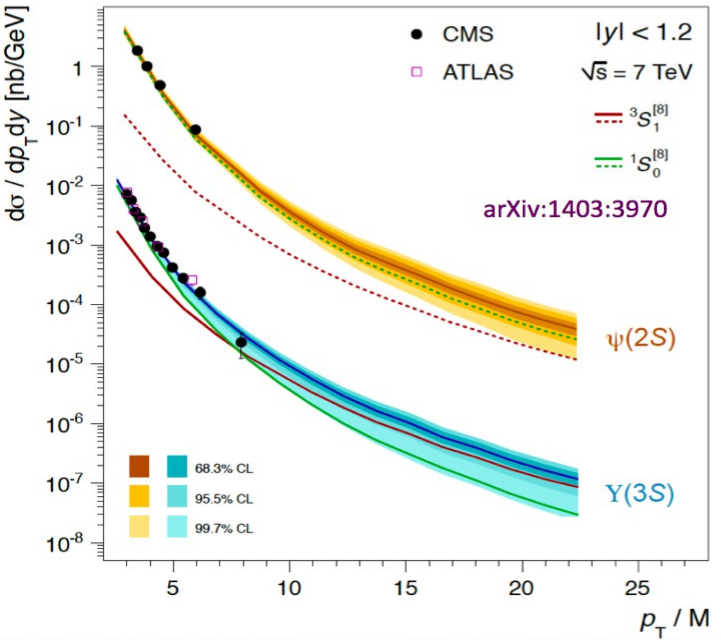


LHCb: BR($D^0 \rightarrow \mu\,\mu$)<6.2(7.6) 10^{-9} @ 90% (95%) CL (BEST LIMIT)

Conventional Quarkonia

- Considering Run II integr. luminosity, a factor 2 in xsections & the improved trigger, we expect a data sample of high-p_T quarkonia few hundreds times larger than in 2011.
- Potential to become a high precision Physics: extend xsection & polarization measurement to the highest p_T attainable (minimizing effects of non-factorizing contributions)
- Measurements of direct xsections & polarizations in order to avoid feed-down contamination (only $\Upsilon(2S)$ can be considered feed-down free)
- Test the dominance of the $^3S_1$ over $^1S_0$ CO terms at high p_T suggested by the differential xsection fits of the S-wave states: higher p_T quarkonia should be transversely polarized.

Perform precision prod. xsection & polarization measurement for χ_c and χ_b and test if this hierarchy among CO contributions holds for P-wave states as well

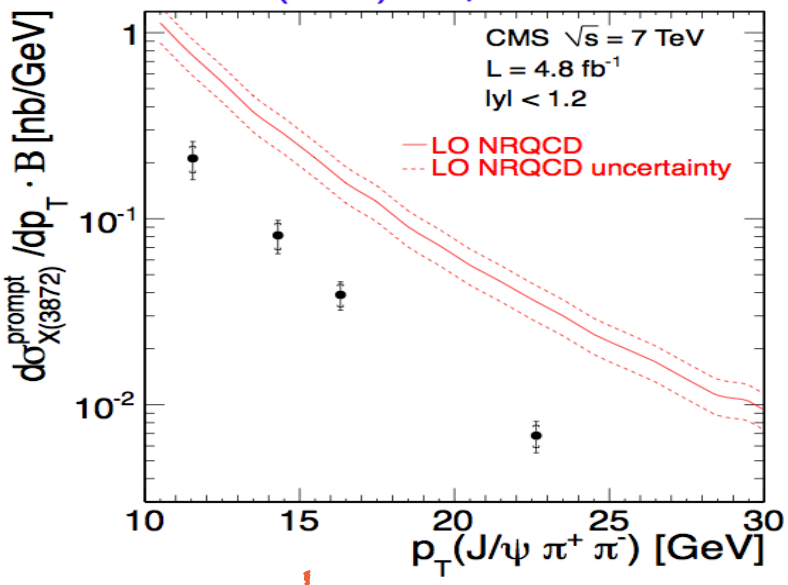


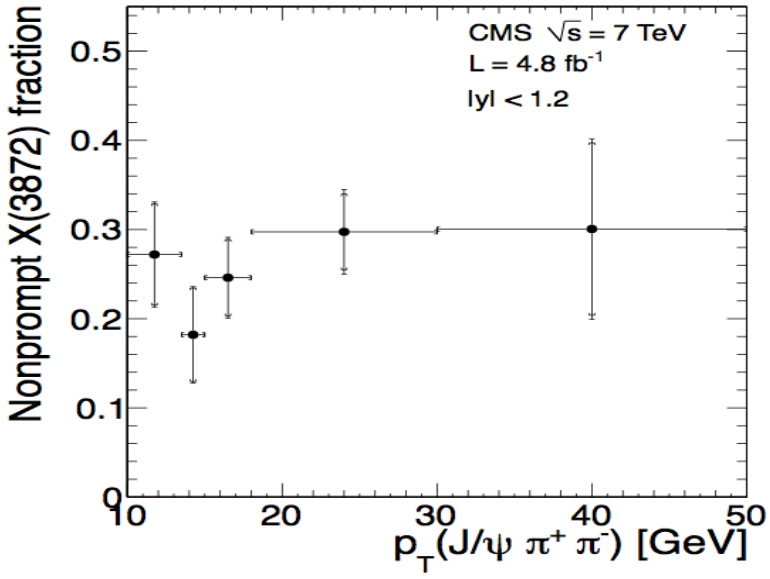
Exotic Quarkonia: X/Y/Z states

- Understand the nature of X(3872)
  - Conventional charmonium hypothesis ruled out by equal amounts of isospin components I=0 & I=1 (maximal isospin violation):

$$\frac{B\left(X \to J/\psi \pi^+ \pi^- \pi^0\right)}{B\left(X \to J/\psi \pi^+ \pi^-\right)} = 1.0 \pm 0.4 \pm 0.3 \qquad \text{(BELLE)}$$

JHEP 1304 (2013) 154, cited 28 times





- CMS Contributions:
  - Differential cross section lower than theoretical prediction
  - Non prompt production ~30%

Exotic Quarkonia: X/Y/Z states

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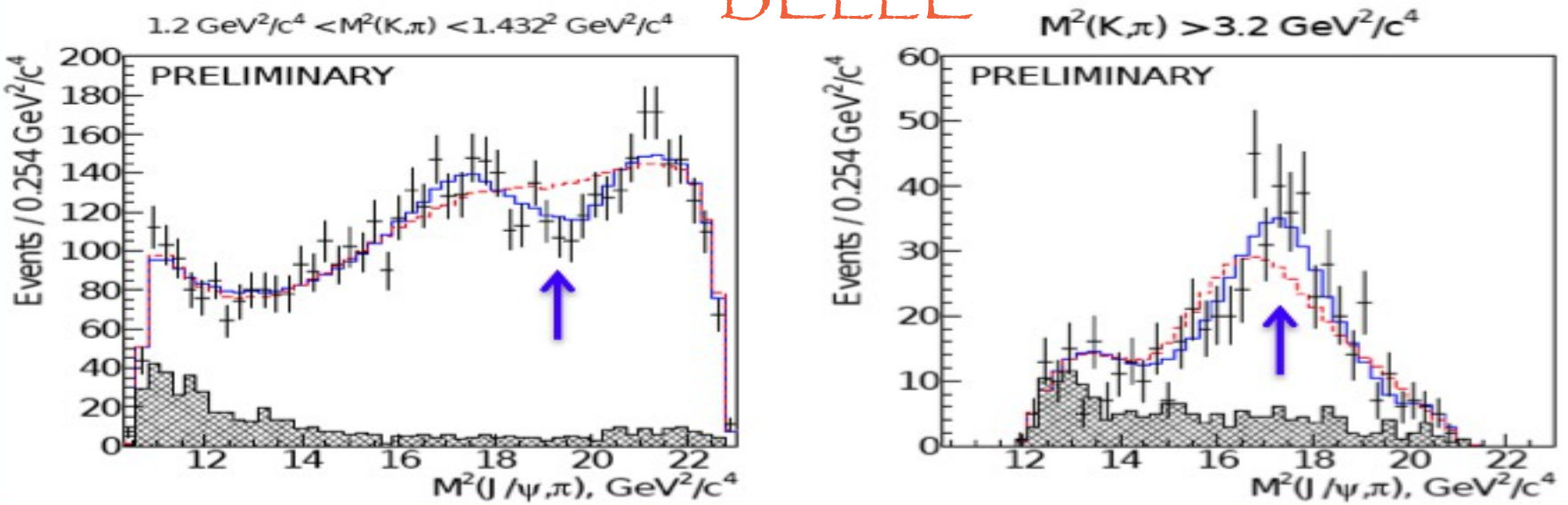
  - Analogously to $B^{0(+)} \to X K^{0(+)} \to (J/\psi\pi^+\pi^-)\, K^{0(+)}$ study also the decays $B^{0(+)} \to \psi'\pi^+\pi^- K^{0(+)}$ (never been studied due to the relatively low yield)
  - Could there be the possibility to find a radial excitation of the X?
  - Selection rules for the radial quantum number? For instance Y(4360)/Y(4660) decay into $\psi'\pi^+\pi^-$ but not into $J/\psi\,\pi^+\pi^-$

Exotic Quarkonia: X/Y/Z states

- Amplitude Analyses 
  - $B^0 \rightarrow J/\psi\varphi K^+$ to understand nature of Y(4140) & Y(4270) [PLB 734 (2014)]
  - $B^0 \rightarrow \psi'\pi^- K^+$ analysis to confirm Z'(4240) will go on in Bari
  - $B^0 \rightarrow J/\psi\,\pi^- K^+$ analysis presented by BELLE @ Moriond QCD 2014:

Comparison of the fit results with $Z_c(4430)^+$ and additional Z_c^+ (blue) and without any Z_c^+ (red).

BELLE



- Observation @ 7.2 σ of new state Z'(4200)
- Something to be checked @ CMS

Exotic Quarkonia: X/Y/Z states

- Prompt production in inclusive searches:

	$Z_b(10610)$	$Z_b(10650)$	$Z_c(3900)$	$Z_c(4020)$
Tevatron	0.26 (0.47)	0.06 (0.17)	11 (13)	1.7 (2.0)
LHC 7	4.8 (8.0)	1.2 (3.0)	187 (211)	29 (31)
LHCb 7	0.76 (1.3)	0.18 (0.47)	33 (39)	5.5 (5.8)
LHC 8	5.9 (9.5)	1.4 (3.5)	220 (240)	34 (36)
LHCb 8	0.9 (1.4)	0.22 (0.56)	40 (48)	6.3 (6.9)
LHC 14	11 (17)	2.6 (6.5)	382 (423)	61 (63)
LHCb 14	1.9 (3.0)	0.52 (1.2)	84 (88)	14 (14)

Signal event yield:
~220x20x10⁶
~4.4x10⁹
but then ...
kinematical cuts &
high backgrounds !

5 x LHCb

more copiously produced !
(look also 2011+2012 data)

[1] Guo, Meissner, Wang, Commun.Theor.Phys, 61 (2014)

Examples of systems to be scanned and states to be searched for :

systems to be scanned	states to be searched for
$J/\psi\ \pi^+\pi^-$	1^{--} states: $Y(4008)$, $Y(4260)$
$\psi'\ \pi^+\pi^-$	1^{--} states: $Y(4360)$, $Y(4660)$
π^0 ~~$J/\psi\ \pi^0$, $J/\psi\ \pi^0\pi^0$, $J/\psi\ \pi^+\pi^0$~~	~~$Z_c^0(3900)$/1^{--} states / $X(3872)$ charged partners~~
$J/\psi\ \pi^\pm$	$Z_c(3900)^\pm$, $Z(4430)^\pm$
$\psi'\ \pi^\pm$	$Z(4430)^\pm$
$\chi_{c1} \to J/\psi\,\gamma$ ~~$\chi_{c1}(1P)\ \pi^\pm$~~	~~$Z_1(4050)^\pm$, $Z_2(4250)^\pm$~~
$h_c(1P) \to J/\psi\,\pi^0$ ~~$h_c(1P)\ \pi^0$~~	~~$Z_c(4020)$~~
$Y(nS)\pi^+\pi^-\ (n=1,2,3)$	$Y_b(10888)$
$Y(nS)\pi^+\ (n=1,2,3)$	$Z_b(10610)^\pm$, $Z_b(10650)^\pm$

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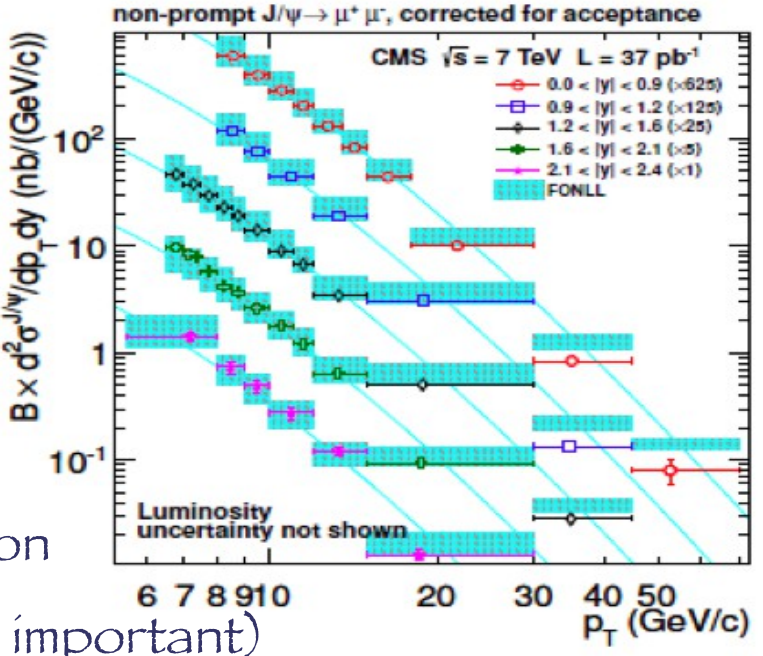
Production & Spectroscopy

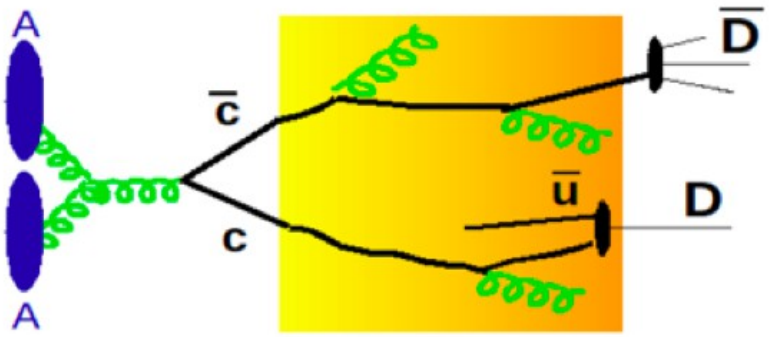
- Charm & bottom production are among the most interesting studies of QCD dynamics @ LHC (σ_c ~ 5 mb, σ_b ~250 μb). Tests of QCD calculations & BKG for NP.
- Good agreement @ 7/8 TeV between Data & "Fixed Order + Next to Leading Log" (FONLL) predictions
- B-hadron cross sections measurements @ 13 TeV will test FONLL at unprecedently √s & P_t
  - Crucial Issue: Efficiency in fine muon bins
- B_c Spectroscopy: enrich the scenario
  - Use J/ψ from $B_c \rightarrow BX \rightarrow J/\psi\, XY$
  - X=D, D_s, τ: improve resonances & τ reconstruction
  - Measure of $\sigma(B_c)/\sigma(B^+)$ at high P_t (theoretically important)



- Beauty Baryons
  - Improve σ (Λ_b) measurement, $\Lambda_b \rightarrow \Lambda\, \mu\mu$
  - Ω_b , Ξ_b ,... new discoveries?

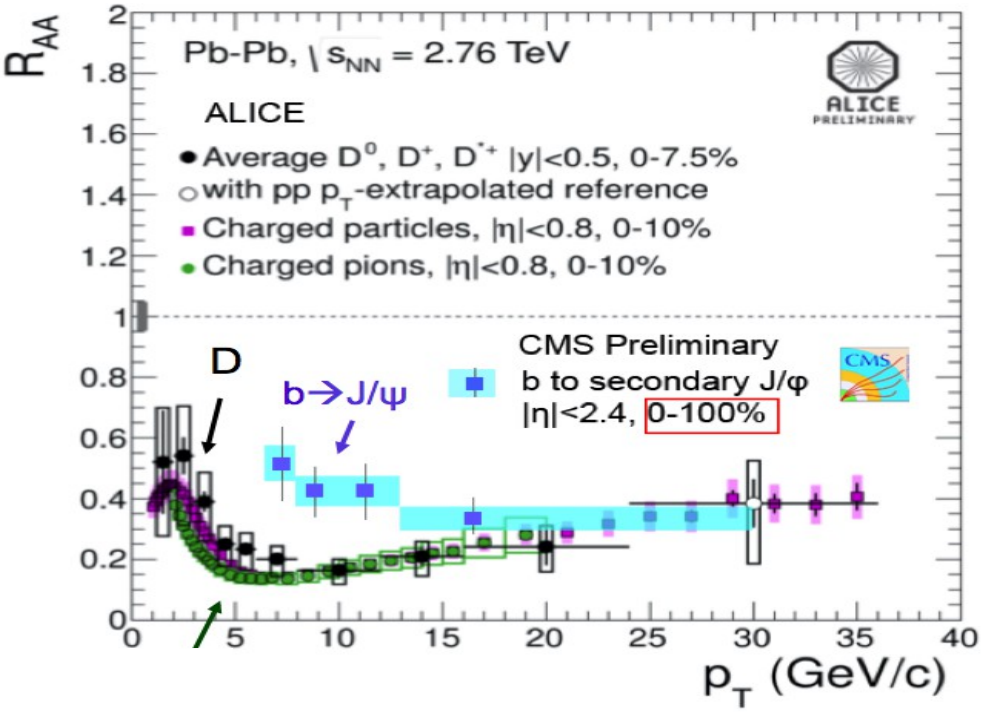
Flavor Physics in Heavy Ions collisions

- Heavy quarks produced in hard scattering in the early stage of the collision
- Initial state effects: modification of the Parton Distribution Functions in nuclei
- Strong interaction with the deconfined medium:
  - Enhanced gluonstrahlung
    - Study in medium energy loss (nuclear modification factor)



$$R_{AA}(p_t) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_t}{dN_{pp}/dp_t}$$

- Predictions:
  - With no medium effects $R_{AA} = 1$
  - With in medium energy loss $R_{AA} < 1$
  - Gluon radiation suppressed at small angles for massive quarks:
    - $R^{B}_{AA} > R^{D}_{AA} > R^{light}_{AA}$



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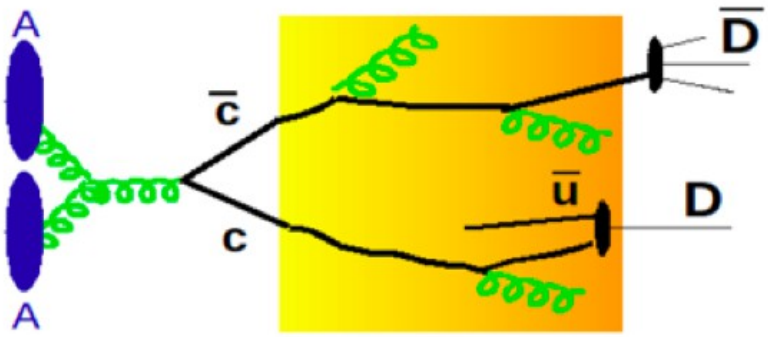

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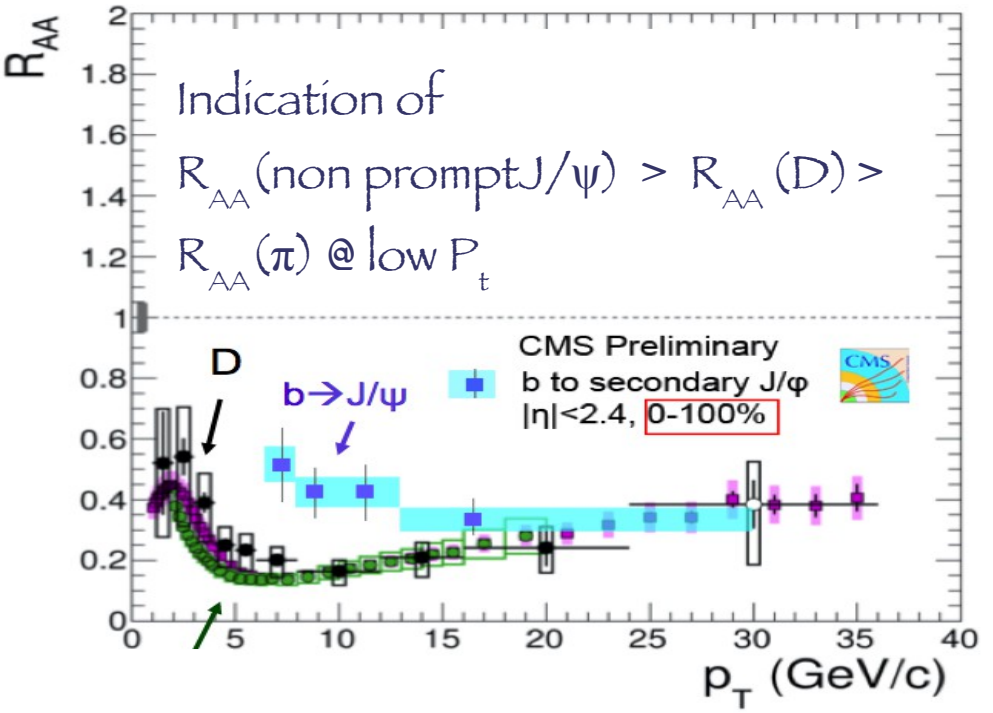

- Analysis will go on @ Run 2
- Together with measurements of D mesons Yields in pPb collisions

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Conclusions

Conclusions

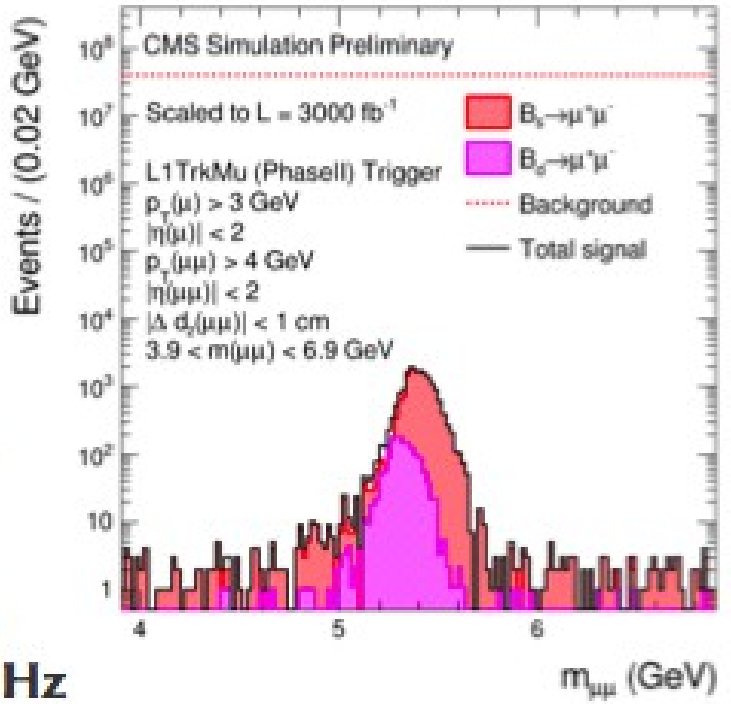
- Impressive amount of results, expecially considering the number of people involved
- Number of Publications will increase by 60% taking into account the current analyses (almost twice as Atlas)
- Important relative weight of Italian Institutions in the PAG (analysts and conveners/subconveners)
- RUN II is approaching:
  - Trigger experts at work with analysts to define the final data taking strategy
  - Many ideas on new possible analyses
- Manpower is needed and very welcome!

Backup

L1 trigger for $B^0_{(s)} \rightarrow \mu\mu$

Mario Galanti

- We simulated a low-p_T di-muon L1 trigger algorithm exploiting the triggering capabilities of the upgraded CMS tracker
  - 2 opposite-charge L1 "Tk muons", reconstructed from a matching of the L1 tracks and L1 standalone muons
  - $p_T(\mu) > 3$ GeV
  - $|\eta(\mu)| < 2$
  - $p_T(\mu\mu) > 4$ GeV
  - $|\eta(\mu\mu)| < 2$
  - $\Delta d_z(\mu\mu) < 1$ cm
  - $3.9 < m(\mu\mu) < 6.9$ GeV
- Mass resolution at L1 is measured to be ≈ 70 MeV using Gaussian fits to the signal peaks
- Trigger rate in the HL-LHC conditions (average of 140 PU events) is estimated to be **a few hundred Hz**
  - It constitutes only a tiny fraction of the total L1 bandwidth

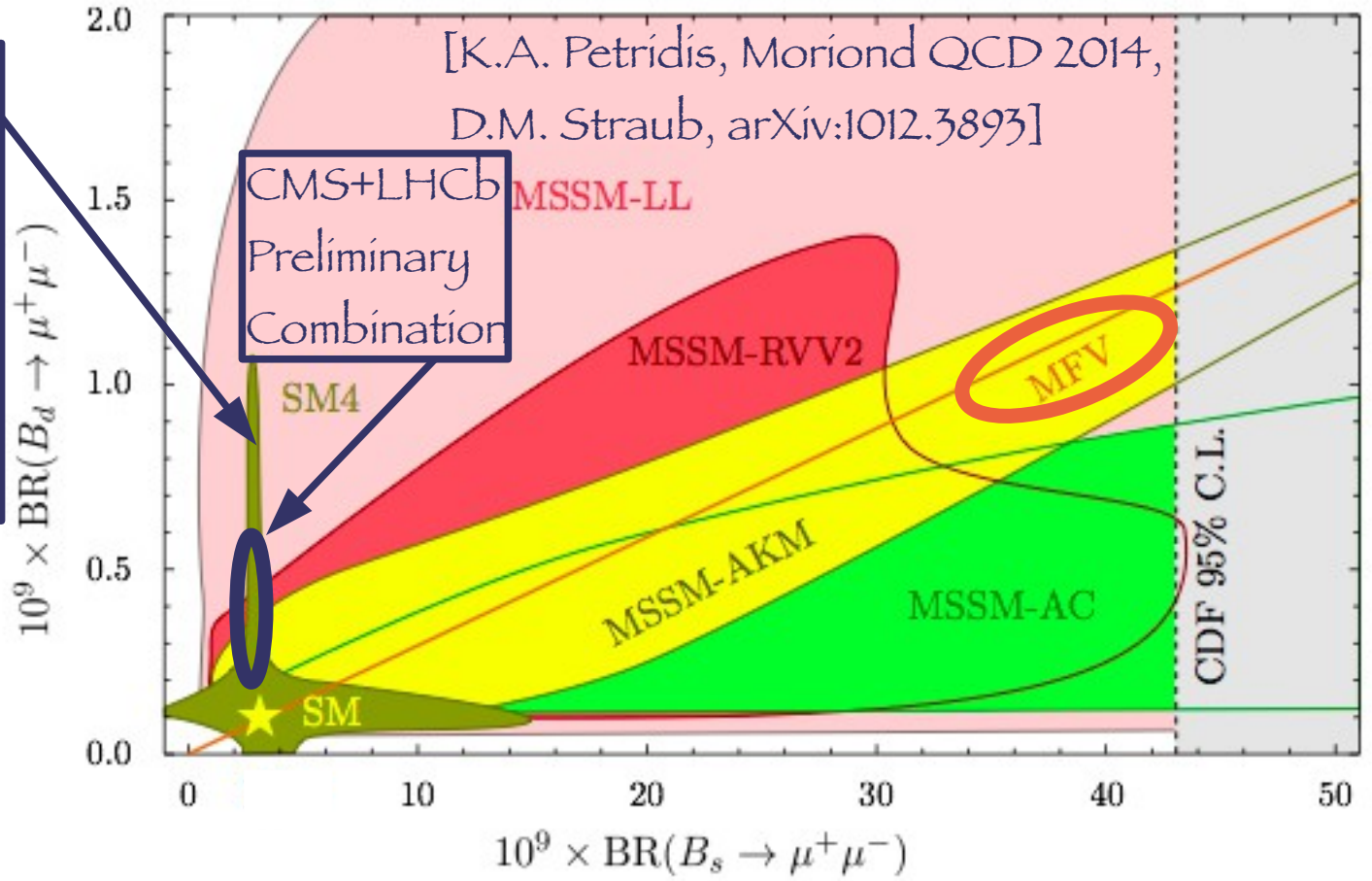


- This study shows that the expected performances of the upgraded CMS L1 trigger are more than sufficient to implement trigger algorithm for $B \rightarrow \mu\mu$ having the same acceptance of the L1 trigger used in LHC Run 1

Constraints from $B \to \mu^+\mu^-$

SM4: SM with a 4th generation

MFV: Flavor Violation governed only by CKM matrix



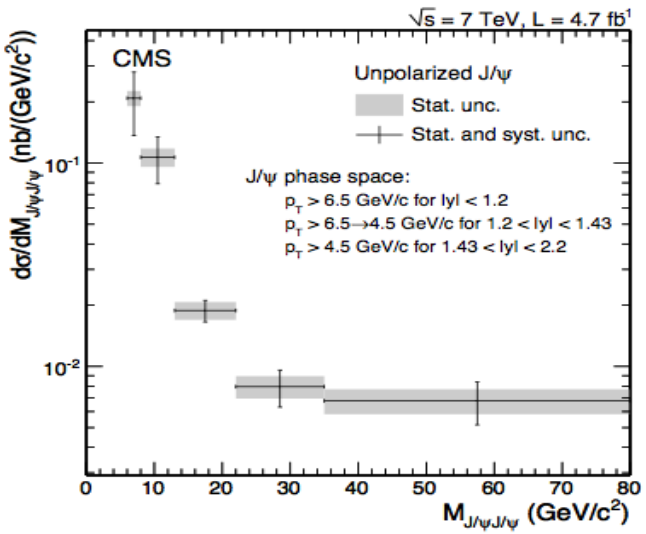
- $BR(B_d)/BR(B_s)$ extremely sensitive probe of NP

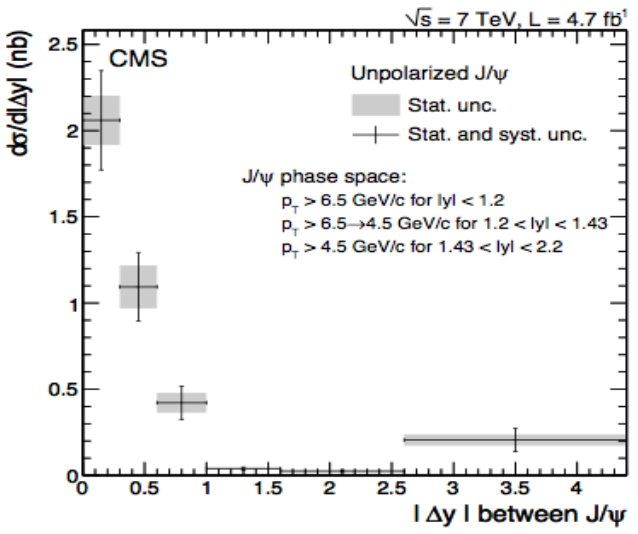
- Result in agreement with SM [0.4 σ for B_s and 1.7 σ for B_d]

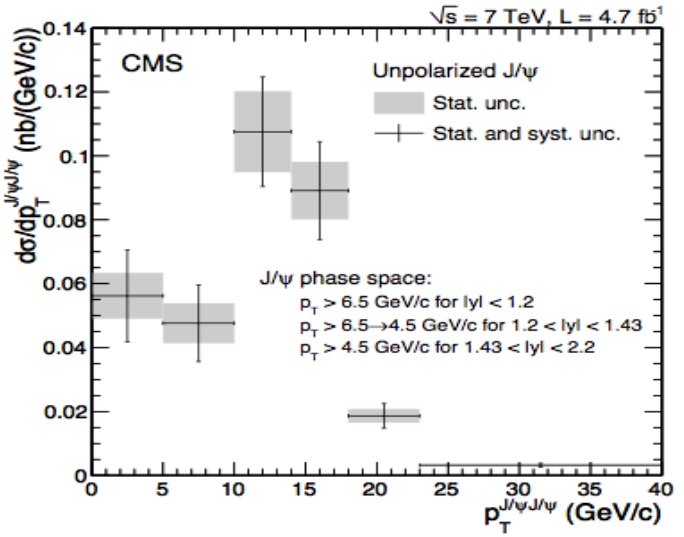
- The focus now is on $BR(B_d)$ and on the ratio $BR(B_s)/BR(B_d)$
- LHCb (after upgrade): measure ratio @ 35% with 50 fb^{-1}

Measurement of prompt J/ψ pair production

- Process sensitive to Multiple-parton scattering populating the large |Δy| region between the two J/ψ — JHEP 09 094
- Production dominated by gluon-gluon fusion. Color-octet contribution negligible @ P_t<15 GeV and low M(J/ψJ/ψ), but increasing with P_t. NLO calculations indicate enhanced color-singlet contribution at higher P_t.
  - First time access to the high P_t (J/ψ) region with no established model predictions. Complementary with LHCb in rapidity.





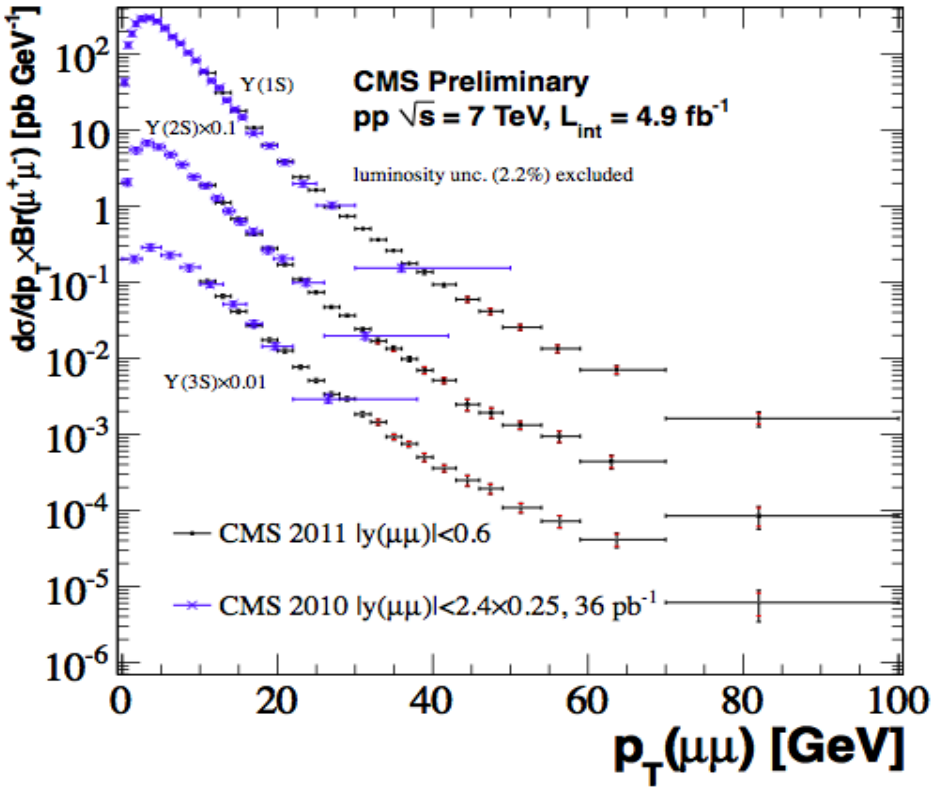


- Assuming unpolarized production:

$\sigma(pp \rightarrow J/\psi J/\psi + X) = 1.49 \pm 0.07 \pm 0.13$ nb

Υ(1S), Υ(2S) and Υ(3S) σ measurements

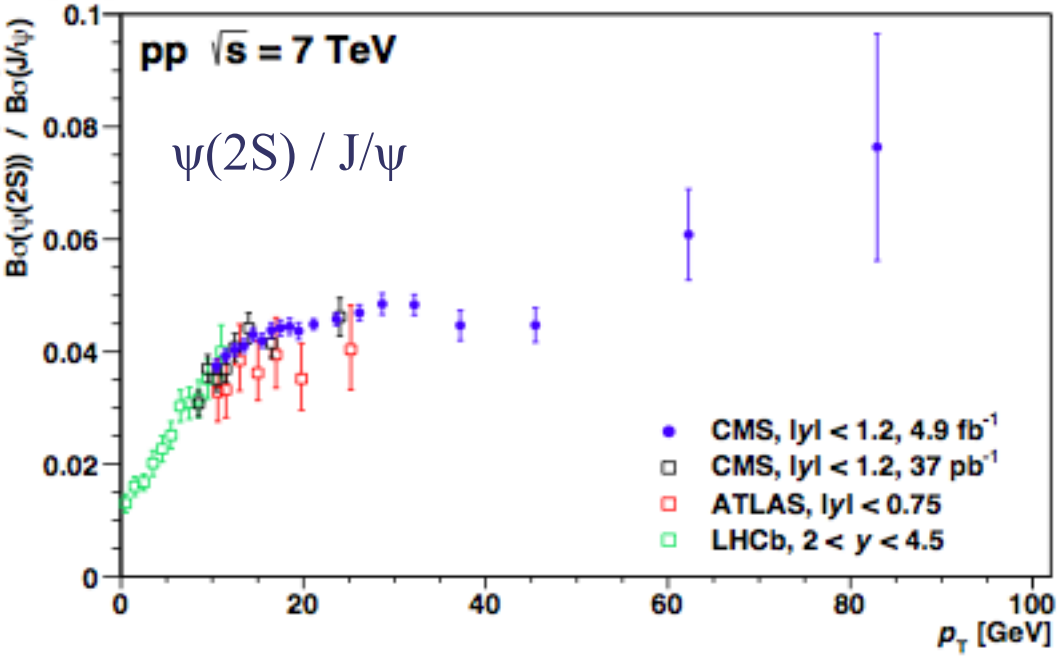
- Different Υ production models predict different $\frac{d\sigma}{dP_t}$ shapes in the high P_t region. NRQCD parameters can be determined by fit on data, which impact the polarization predictions at all P_t.
- Large statistics allow to study the shape up to 100 GeV:
  - $\frac{d\sigma}{dP_t}$ peaks at P_t=4 GeV
  - Exponential behaviour for 10 GeV< P_t < 20 GeV
  - Power-law shape for P_t >20 GeV for all the Υ states
  - Suggestion of a change in the nature of the production process

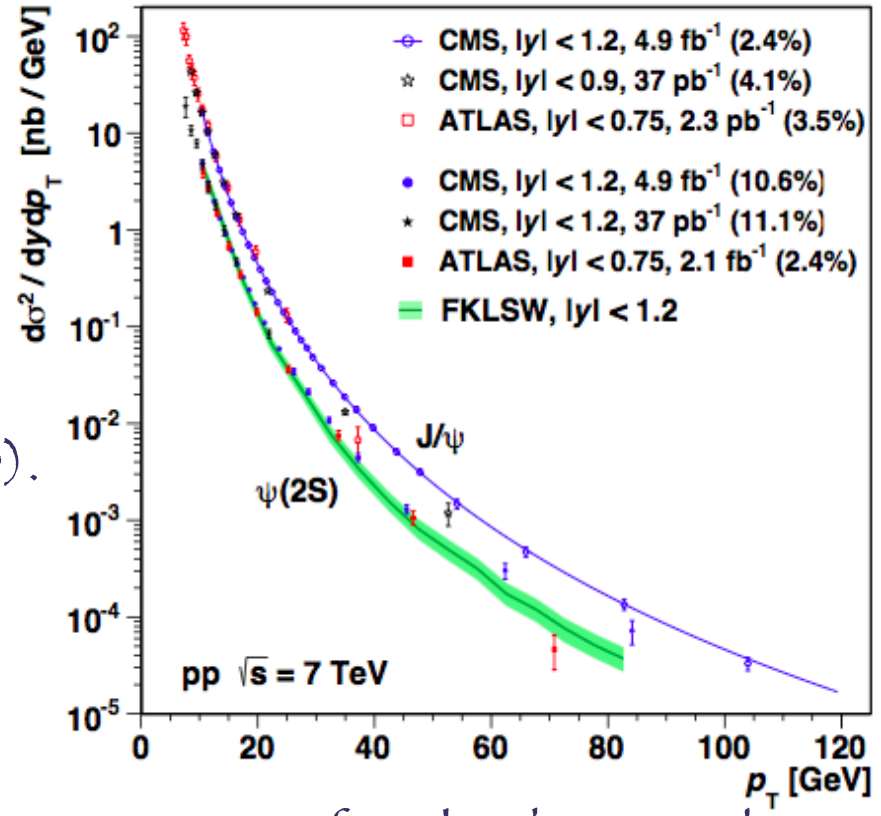


- Need of a model to explain the small polarization and power-law behaviour at high P_t

Prompt J/ψ and ψ(2S) double-differential cross sections in pp collisions at 7 TeV

- LDME parameters not calculable need to be determined by fit to data. Differential cross sections very similar for singlet & octet contributions
- Very important to extend the measurements towards high P_t values (most reliable theory calculations at fixed order in perturbative QCD).





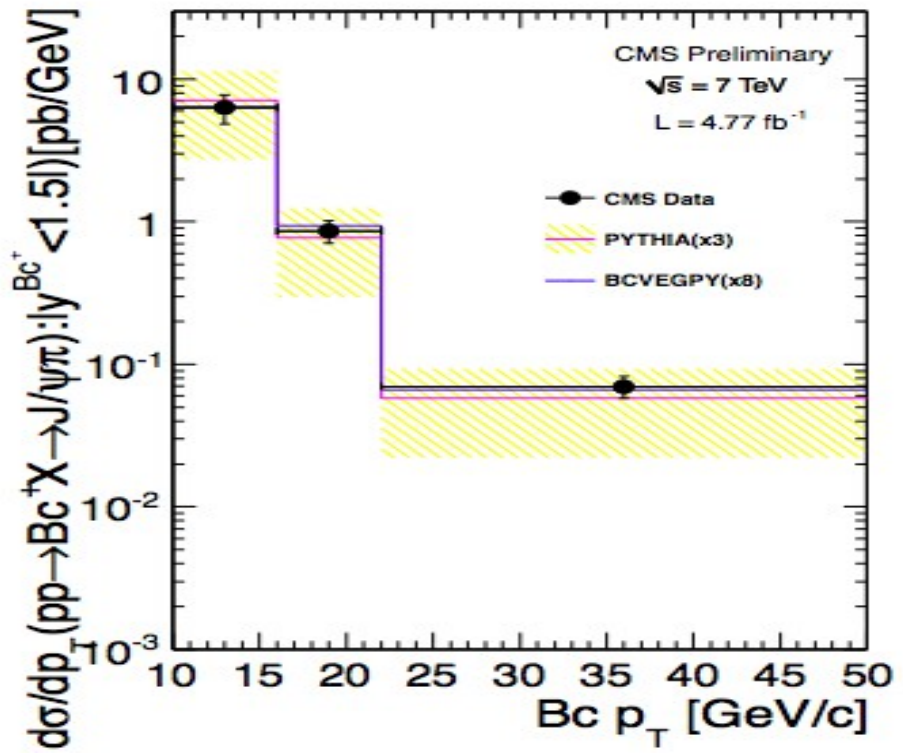
- Cross sections fitted with power-law function

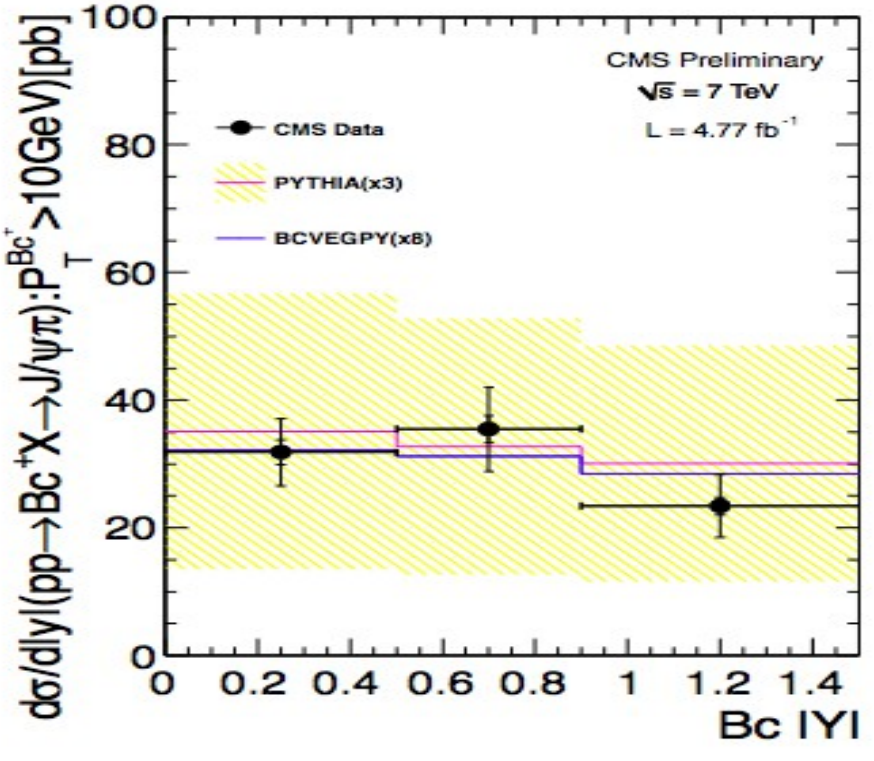
Measurement of the B_c & B^+ cross-sections

Pre-Approved

- B_c mesurements: test for the theoretical predictions on heavy flavor production complementary to quarkonia
- Used decay $B_c \rightarrow J/\psi\,\pi$, $P_t(B_c)>10$ GeV, $|y|<1.5$
- Theoretical predictions are less by a factor 3 (PYTHIA) or 8 (BCEGPY) than data

$$\sigma(B_c) = 45.17 \pm 5.25 \pm 2.85\ pb$$



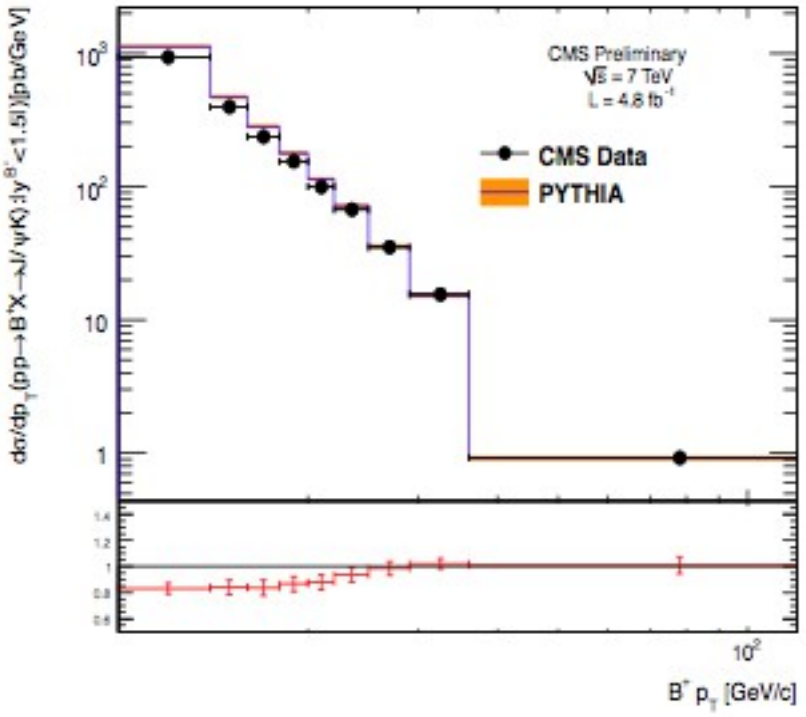


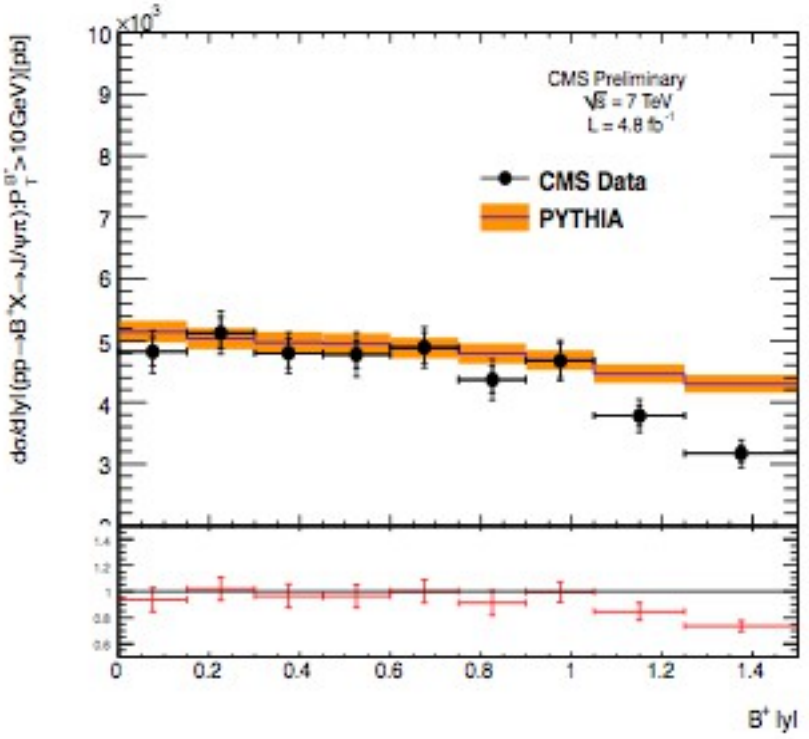
Measurement of the B_c & B^+ cross-sections

Pre-Approved

- Use decay $B^+ \rightarrow J/\psi\, K^+$, $P_t(B^+)>10$ GeV, $|y|<1.5$
- Theoretical predictions for integrated cross section are in agreement with data at 1 σ level

$$\sigma(B^+) = 6503.18 \pm 122.43 \pm 448.72\ pb$$

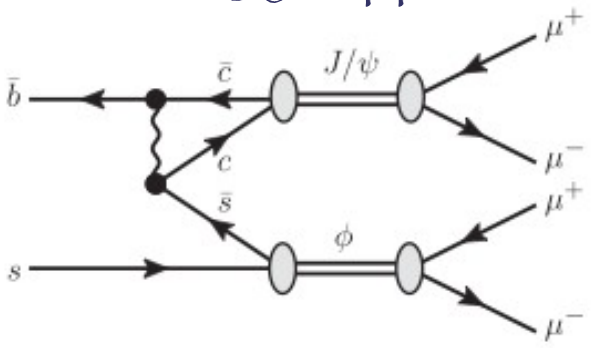


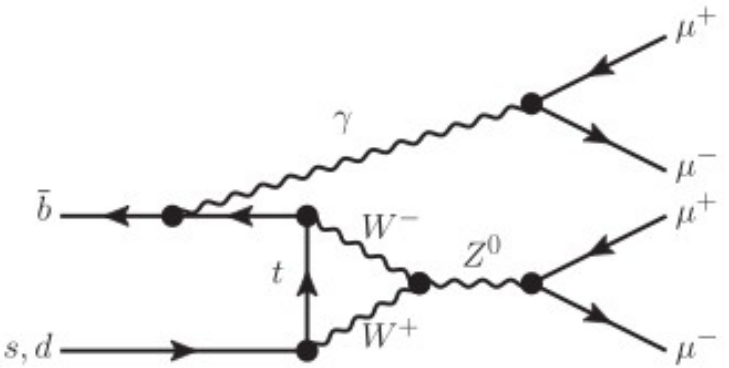


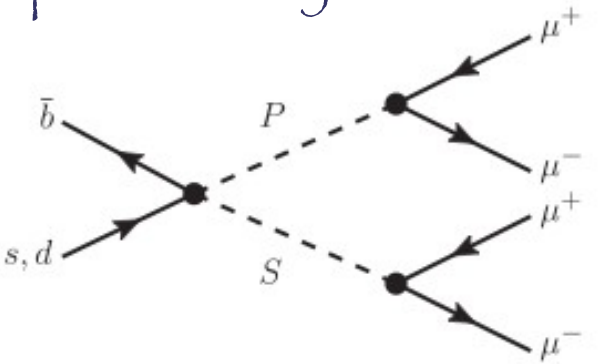
A. Malvezzi, M. Margoni & S. Paoletti are part of the ARC

CPV/Rare Decays: Possible Analyses

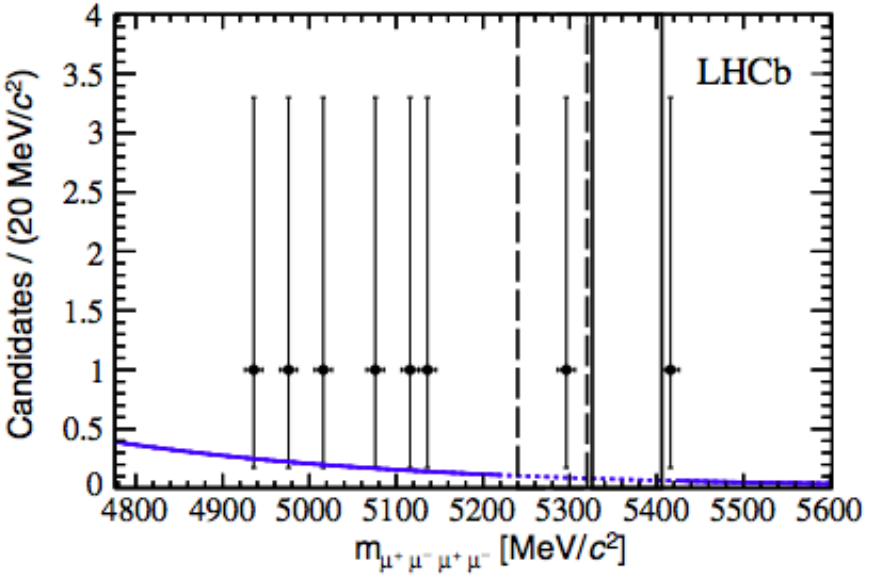
- $B^0 \rightarrow 4\mu$
  - Strongly suppressed in the SM, significant enhancement predicted by MSSM







	Resonant	Non-Resonant	MSSM
BR	$(2.3 \pm 0.9)\ 10^{-8}$	$<10^{-10}$	?



- MSSM: scalar S & pseudo-scalar P sgoldstinos or light Higgs

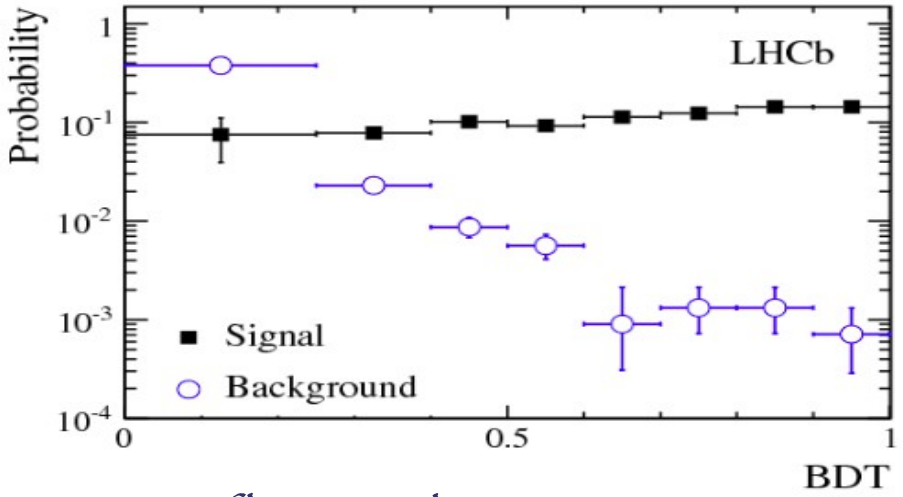
LHCb: [PRL 110, 211801 (2013)]

BR($B^0 \rightarrow 4\mu$) $<6.6\ 10^{-9}$ @ 95% CL

BR($B_s \rightarrow 4\mu$) $<1.6\ 10^{-8}$ @ 95% CL

CPV/Rare Decays: Possible Analyses

- $B^0 \rightarrow e\mu$
- LFV process allowed in NP models via exchange of spin-1 gauge bosons carrying color & lepton quantum numbers (Pati-Salam Leptoquark)
- Current limits from direct search in the range [0.4-0.9] TeV
- Indirect search probe also LQ coupling quarks and leptons of different generations



- BKG dominated by B semileptonic decays & peaking $B^0 \rightarrow hh'$ ($h^{(\prime)}$=K, π) suppressed using a BDT discriminant

Using L=1 fb^{-1} LHCb [PRL 111, 141801 (2013)]

- $BR(B^0 \rightarrow e\mu) < 3.7\ 10^{-9}$ @ 95% CL $M_{LQ} > 126$ TeV @ 95% CL
- $BR(B_s \rightarrow e\mu) < 1.4\ 10^{-8}$ @ 95% CL $M_{LQ} > 101$ TeV @ 95% CL
- Limits 2 orders of magnitude higher than direct searches

BPH Trigger Strategy

- BPH trigger focused mainly on muons
- Different features & needs depending on the Physics channel:
  - Rare Decays: almost 100% Background paths ($B_q \rightarrow \mu\mu$)
  - Quarkonia: almost 100% Signal path (J/ψ, Υ)

- Issues:
  - HLT: around 100 Hz of Bandwidth @ $L=1.4\ 10^{34}$ without regional reconstruction & Data Parking
    - Quarkonia (50% of rate):
- 50% rate is the current goal.
  - It could be in principle reduced in favor of other paths:
    - Reduce the prescaling for $B^+ \rightarrow J/\psi\ K$ (normalization channel for $B \rightarrow \mu\mu$)
    - Increase the rate for dimuon + track triggers (expecially low mass not resonant)