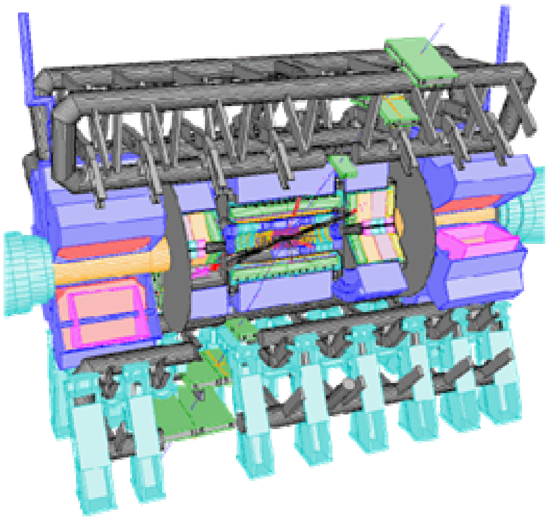
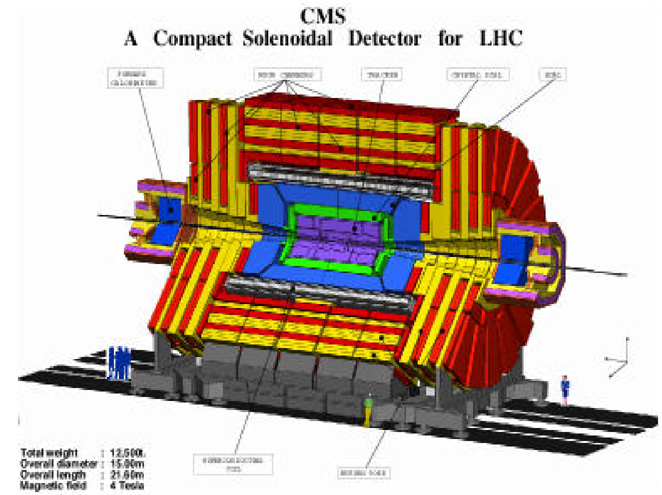
Status and Prospects of ATLAS and CMS for B Physics and CP Violation

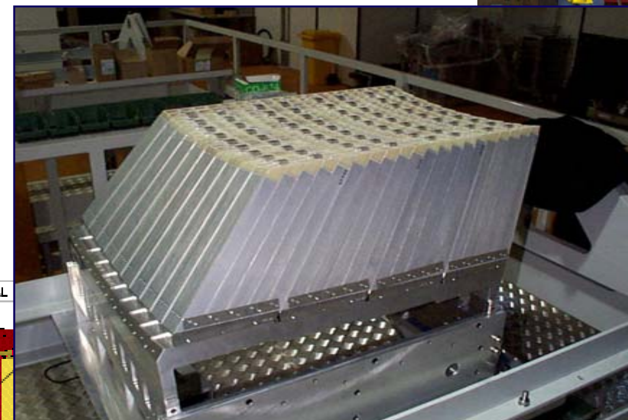




- ☞ Overview of the Detector Status
- ☞ Overview of the physics potential
- ☞ B physics reach:
  - •Trigger,Tagging and off-line strategies
  - •Precision physics
  - •Physics of B_s meson
  - •Potential for rare decays
  - •B hadron production
- ☞ Conclusions

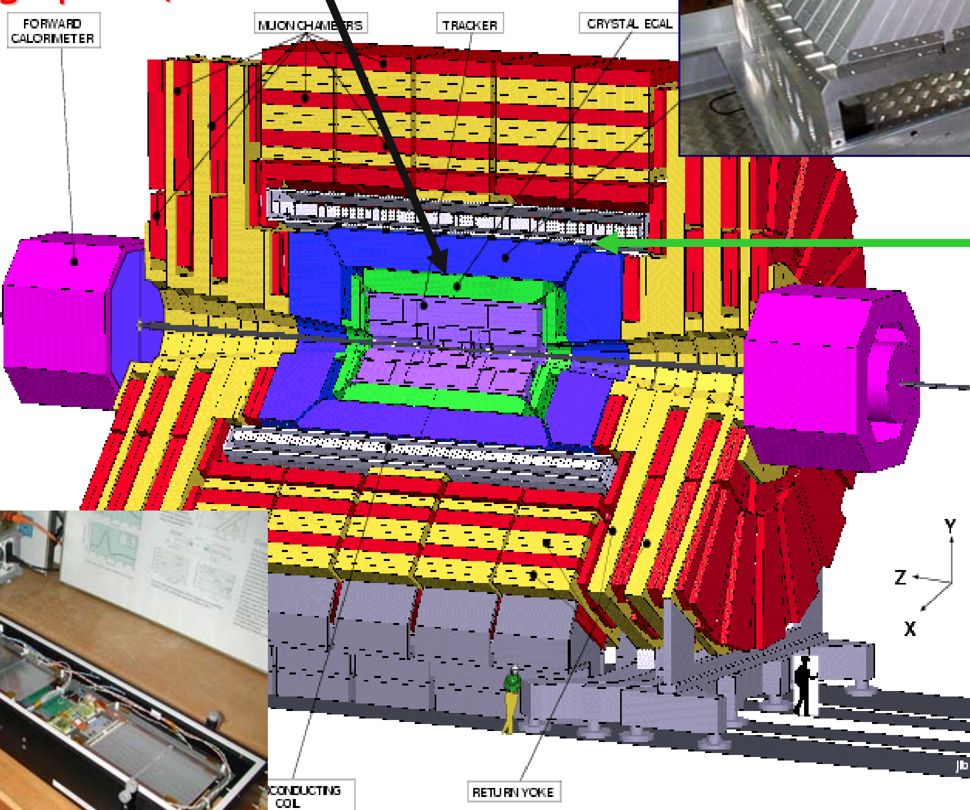
CMS detector

22 m long, 15 m diameter, 14.000 ton



13x6 m Solenoid: 4 Tesla field

➧ tracking up to η ~ 2.4



ECAL & HCAL inside solenoid

Staged Scenario for start-up

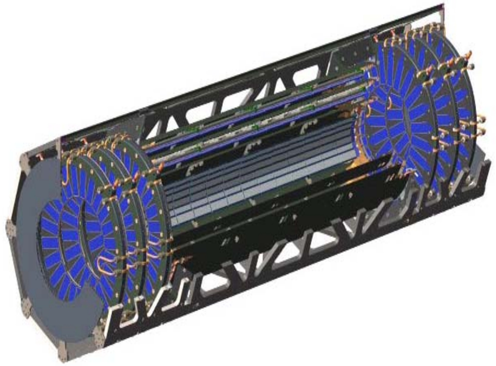
- ME4 staged
- 3rd forward pixel disks missing
- Descoped HCAL (reduced no. of longitudinal samplings)
- Descoped ME1/1a (3 ch in one, muon trigger up to |h| = 2.1)
- Effects on B-physics: limited trigger rate, degraded proper time resolution

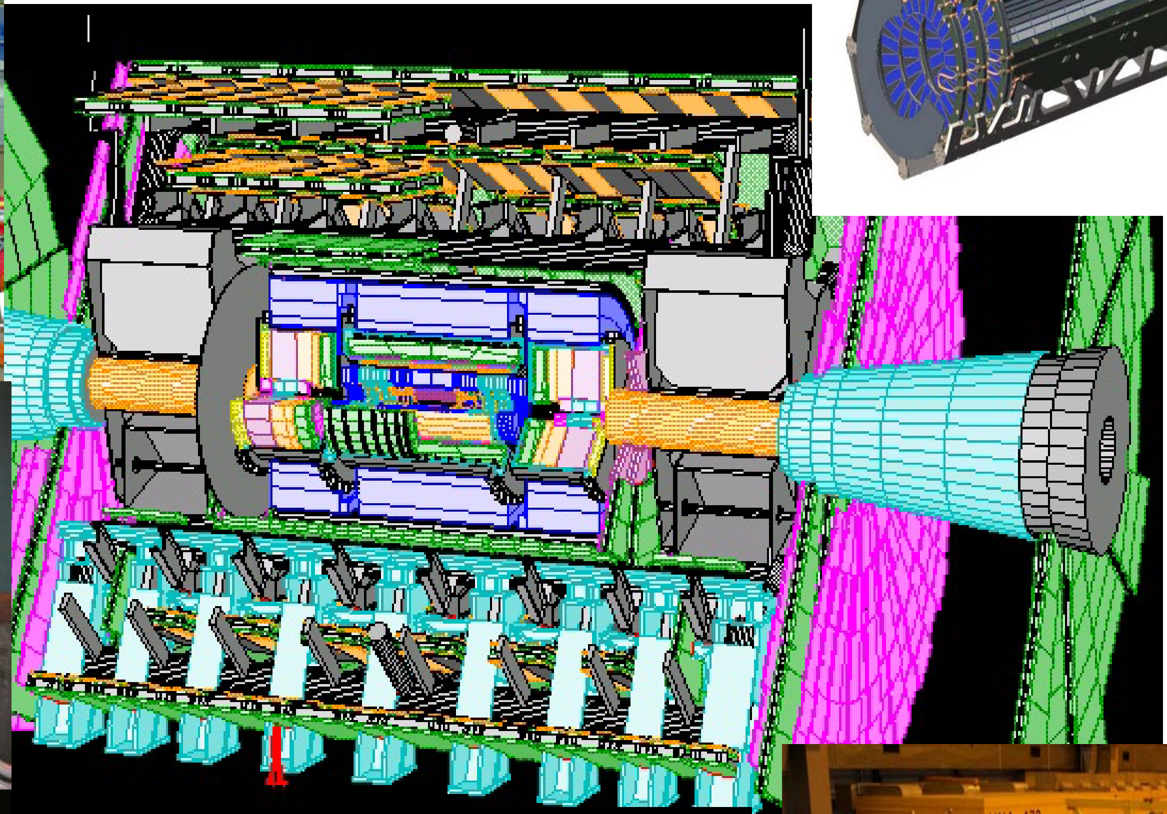
2 Tesla field

tracking up to $\eta \sim 2.4$

ATLAS detector

46 m long, 25 m diameter and ~ 7 10^6 kg



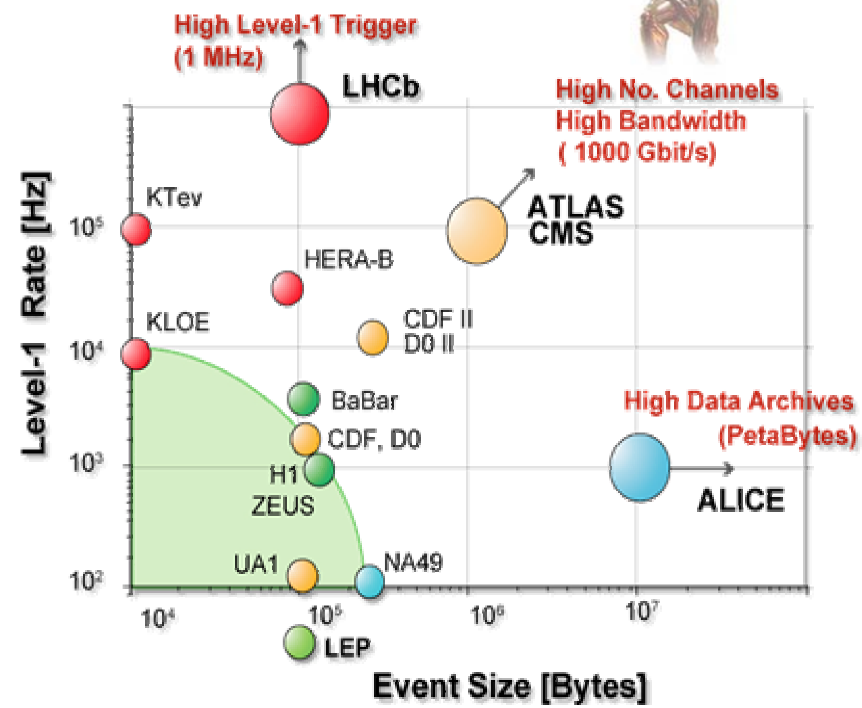


ATLAS initial layout:

- 1 pixel layer, 1 forward pixel disk, TRT wheels C
- A significant fraction of HLT/DAQ processors deferred
- Effects on B-physics: limited trigger rate, degraded proper time resolution

LHC reach

Collision Energy	14 TeV
Design Luminosity	10^{34} cm^{-2} s^{-1}
Interactions per Bunch Crossing	≈ 23
Bunch spacing	25 ns



B-meson decays, precise measurements

- CP violation
- B_s mesons
- Rare decays

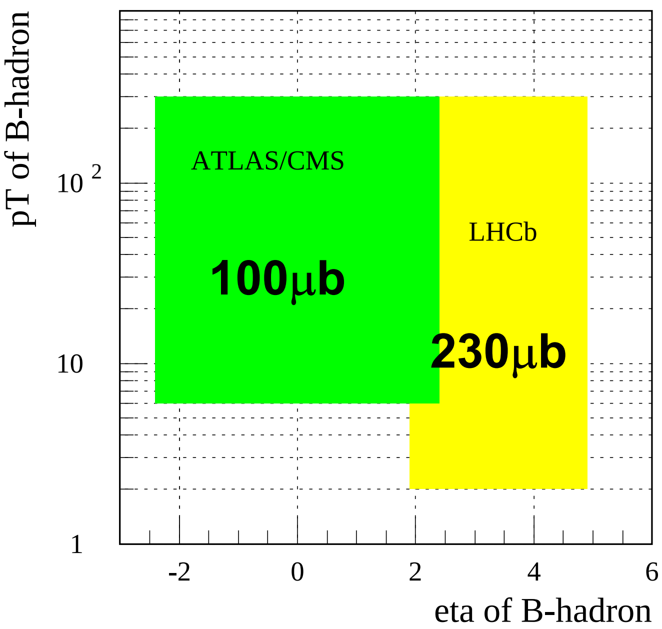
B-hadron production

- Double heavy flavor mesons
- QCD tests of beauty production at LHC central region
- Physics of Beauty baryons, production polarization

- **high detector granularity**
  ⇒ large event size (O(1) MByte)
- **high collision rate (~ 10^8 – 10^9 per sec)**

Overview of the B physics potential

LHC	
σ_{total} = 100 mb $\sigma_{inelastic}$ = 80 mb σ_{bb} = 500 μb	
ATLAS & CMS Central detectors	**LHCb** Forward detector
$\|\eta\| < 2.5$, $p_T > 10$ GeV $\sigma_{B\text{-hadron}} = 100\ \mu b$	$1.9 < \eta < 4.9$, $p_T > 2$ GeV $\sigma_{B\text{-hadron}} = 230\ \mu b$
L = 1-2 x 10^{33} cm^{-2} s^{-1} 10^{34} cm^{-2} s^{-1} for rare decays	L = 2 x 10^{32} cm^{-2} s^{-1}
Exclusive channels ~ 2.8 10^6 Dominated by bb $\rightarrow J/\Psi$ Hadronic channels: < 10^5 (however all with muon tag)	Exclusive channels ~ 3.4 10^6 1.7 10^6 bb $\rightarrow J/\Psi$ Hadronic channels ~ 1.7 10^6



Trigger Strategies

	ATLAS	CMS
Level 1	1μ: p_T> 6 GeV, |η| <2.4 2μ: 3–6 GeV	1μ: p_T> 14 GeV, |η| <2.4 2μ ~ 3 GeV;
Level 2	Lepton reconstruction and Identification Track reconstruction either in full ID volume or in ROI followed by mass cuts on track combinations	
Event Filter	Offline algorithms, Decay vertices cuts ….	

Trigger Strategies

ATLAS as an example

2 μ trigger:
LVL1: 2 μ, **LVL2**: μ track in μ spectrometer+Inner
Bd $\rightarrow$ J/Ψ ($\mu\mu$) Ks, Bs $\rightarrow$ J/Ψ ($\mu\mu$) ϕ, $\Lambda_b \rightarrow$ J/Ψ ($\mu\mu$) Λ,
B $\rightarrow \mu\mu$, B $\rightarrow$ K^{*0} $\mu\mu$, B $\rightarrow \rho\ \mu\mu$

μ-e(γ) trigger:
LVL1: μ + e/γ (E_T> 2 GeV), **LVL2**: tracking in region
Bd $\rightarrow$ J/Ψ (ee) Ks + B $\rightarrow \mu$
$\Lambda_b \rightarrow$ J/Ψ (ee) Λ + B $\rightarrow \mu$
Bd $\rightarrow K^{*0}\gamma$ + B $\rightarrow \mu$ ...

μ-hadron trigger:
LVL1: μ + jet (E_T> 5 GeV), **LVL2** tracking in region
B $\rightarrow \pi\pi$ + B $\rightarrow \mu$, Bs $\rightarrow$ Ds π + B $\rightarrow \mu$, ….

B Tagging strategies

Opposite side lepton tag:

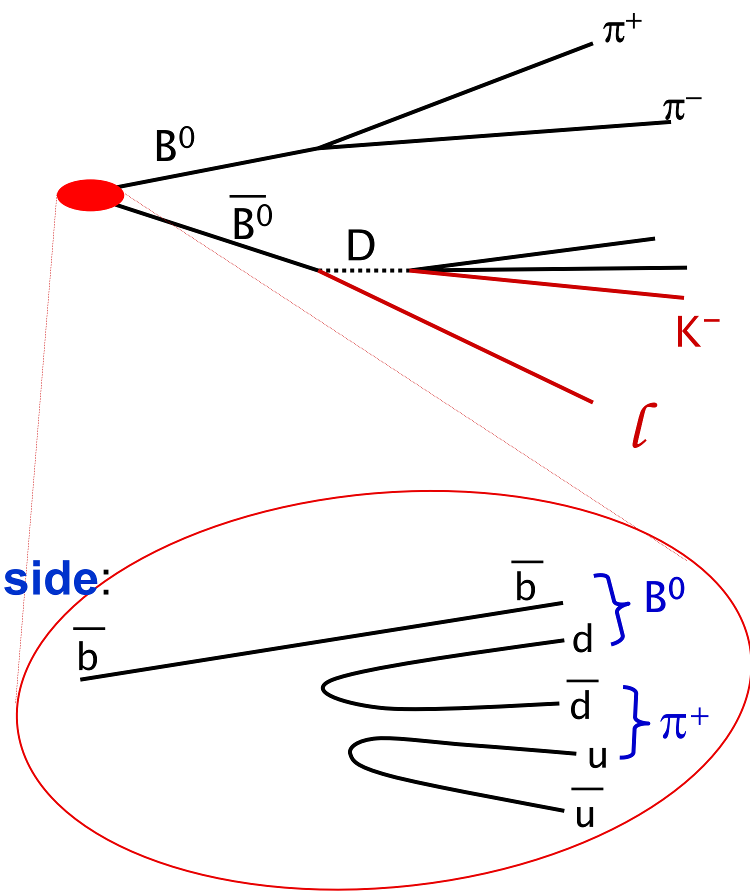
	ATLAS	CMS
Efficiency	4% (e+μ)	4%
D	0.52(μ), 0.46 e	0.44

Same side pion (B + fragmentation)**:

	ATLAS	CMS
Efficiency	82% (μ6,μ3)	21%
D	0.16(μ6, μ3)	0.32

Jet charge – same (ATLAS) and opposite (CMS) side:

	ATLAS	CMS
Efficiency	64% (μ6,μ3)	65%
D	0.17(μ6, μ3)	0.18



Precision measurements

Benchmark channels:

$B_d \to J/\Psi\ K_s \to$ **sin2β**

$B_d \to \pi^+\pi^- \to$ **α sensitivity**

$B_s \to J/\psi\ \phi \to$ **weak phase ϕ_s, $\delta\gamma_s$**

$B_s \to D_s\ \pi(a_1) \to$ **Δm_s**

$B^+ \to K^+\ K^+\ \pi^- \to$ **Br**

Upper limit on Br= 5.3 10^{-7}
for 3 years @ 10^{33} cm^{-2} s^{-1}

Precision measurements
The case of $B_d \to J/\psi\ K_s \to \delta\sin2\beta$

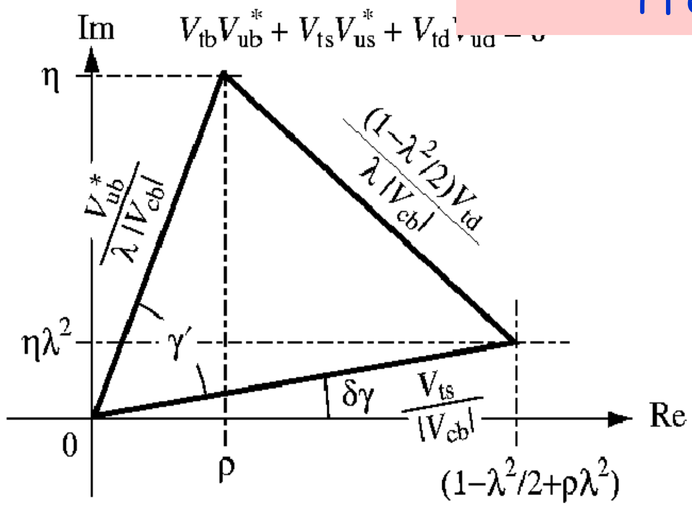
1 year @ 10^{33} cm^{-2} s^{-1}	ATLAS	CMS
N Triggered events N Offline events S/B	800 000 ev 170 000 ev 31	4400 000 ev 430 000 ev 8
$\delta\sin2\beta$ Lepton tags Jet/charge tags Total	 0.039 0.026 0.017	 0.031 0.021 0.015

ATLAS+CMS 3 years @ 10^{33} cm^{-2} s^{-1}	ATLAS+CMS 3 years @ 10^{33} cm^{-2} s^{-1} + LHCb, 5 years @ 10^{32} cm^{-2} s^{-1}
0.007	**0.005**

Systematics can be controlled with very high statistics using control samples such as $B^+ \to J/\Psi\ K^+$

Physics of B_s mesons

CP violation weak phase $\phi_s = 2\delta\gamma = 2\lambda^2\eta$
B_s oscillation parameter Δm_s
Precision on $\Delta\Gamma_s$ ~ 8-12%, Γ_s



Benchmark channels:

$B_s \to J/\psi\ \phi$
$B_s \to D_s\ \pi$
$B_s \to D_s\ a_1$

1 year @ 10^{33} cm^{-2} s^{-1}

	ATLAS	CMS
Proper time resolution	51 fs (60%) 107 fs (40%)	70 fs
Δm_s 5 σ meas. up to	36 ps^{-1}	30 ps^{-1}
Measurable values up to Δm_s	**22.5 ps^{-1}**	**26 ps^{-1}**

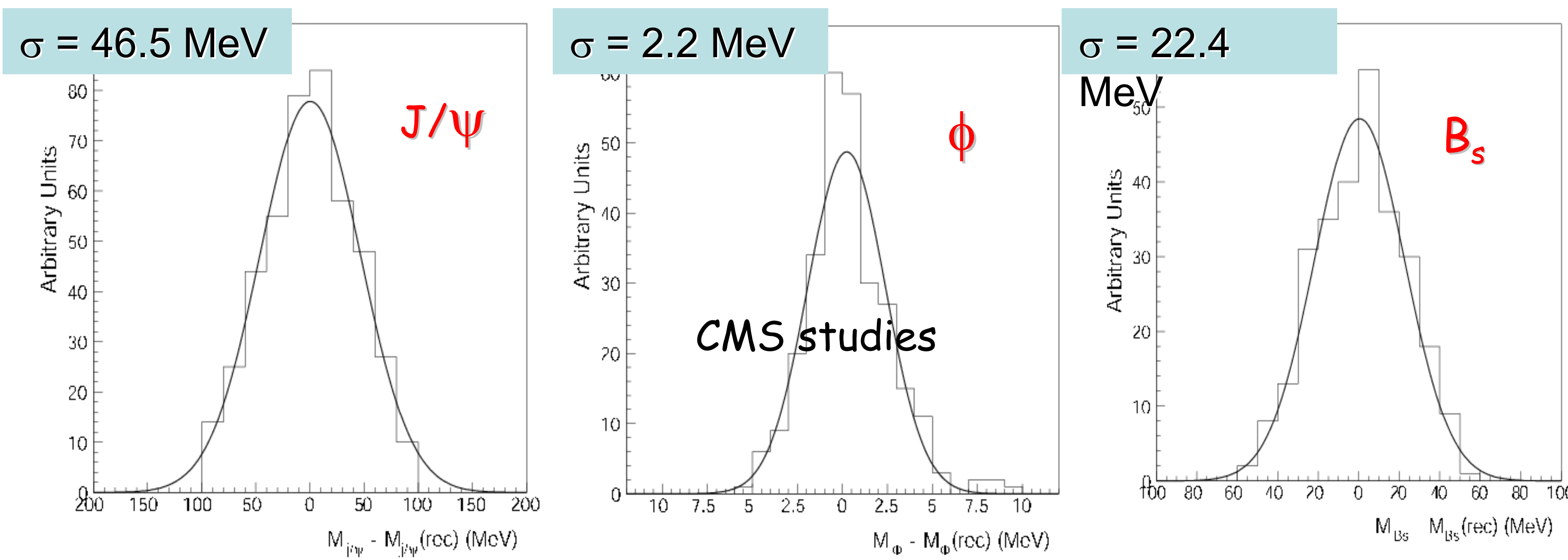
Physics of B_s mesons
$B_s \rightarrow J/\Psi\ \phi$

$BR(B_s \rightarrow J/\psi\ \phi) = (9.3 \pm 3.3) \times 10^{-4}$

$J/\psi \rightarrow \ell^+\ell^-$ ($BR \approx 6\%$), $\phi \rightarrow K^+K$ ($BR \approx 49\%$)

Lvl-1 ε	Lvl-2 ε	Lvl-2 Rate	Lvl-3 ε	Lvl-3 Rate	Events/ $10fb^{-1}$
16.5%	13.7%	14.5 Hz	8.7%	<1.7Hz	83800

HLT mass resolutions

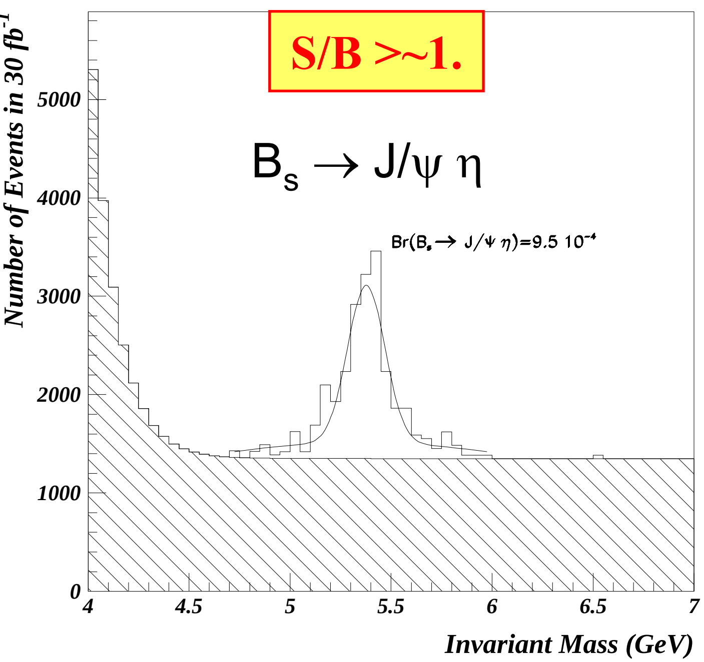


Physics of B_s mesons

$\phi_s = 2\delta\gamma = 2\lambda^2\eta$

SM predicts ϕ_s ~O(0.03) → New Physics

ATLAS studies



Benchmark channels:

$B_s \to J/\psi\ \phi$

$B_s \to J/\psi\ \eta$

$$\delta(\sin\phi_M) = 0.17, x_s = 19.$$
$$\delta(\sin\phi_M) = 0.33, x_s = 30.$$

← **Experimental lower limit**

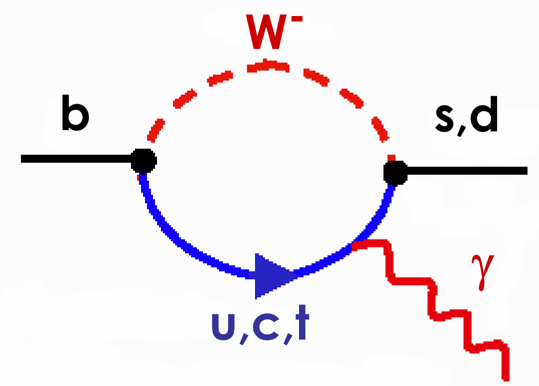
Theory:

$$a_{CP}^{SM} \approx 10\% \text{ and } a_{CP}^{BSM} \text{ up to} \approx 40\% \text{ in some models}$$

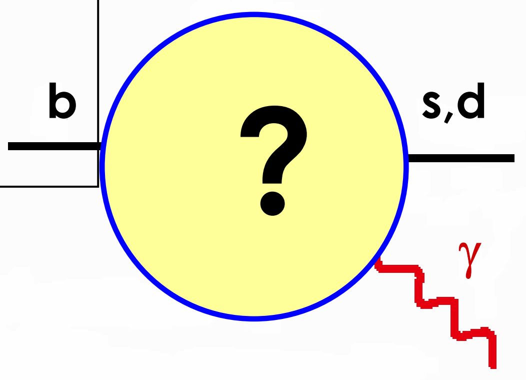
Potential for studying rare decays

$B \to K^* \mu\mu$, $B \to \rho/\phi\ \mu\mu$, $B \to \mu\mu$, $B \to K^* \gamma$, ...

FCNC b→s or b→d only at loop-level in SM
Br < O(10^{-5})



Sensitive to new physics:
New diagrams appearing :*charged Higgs*, *chargino*, *squark* contributions
$|V_{td}|$ $|V_{ts}|$ in SM
Complementary determination from Δm_s



Potential for studying rare decays

The case of $B \to K^* \mu\mu$

$$A_{FB}(S) = \frac{1}{d\Gamma/ds}\int_0^1 \frac{d^2\Gamma}{ds\,d\cos(\theta)}\,d\cos(\theta) - \int_{-1}^0 \frac{d^2\Gamma}{ds\,d\cos(\theta)}\,d\cos(\theta)$$

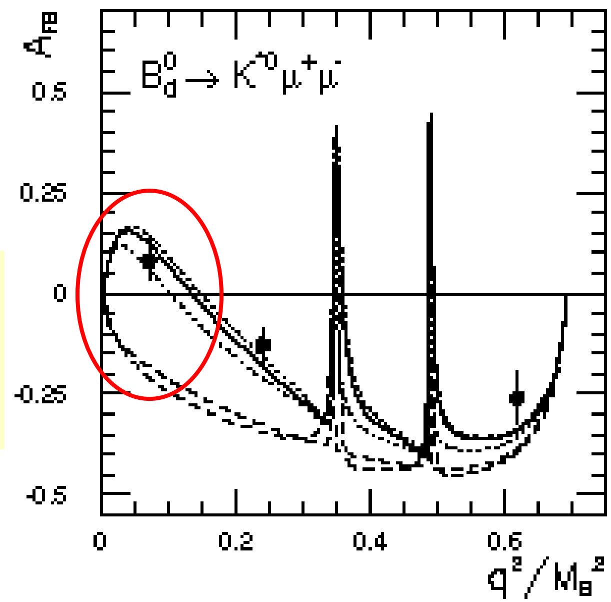
Three points: mean values of A_{FB} in three q^2/M_B^2 experimental regions with error bars

	$B \to K^*\mu\mu$
ATLAS	1995
CMS	4200

—— **SM**

.... **MSSM C7γ >0**

- - - - - - - **MSSM C7γ <0**

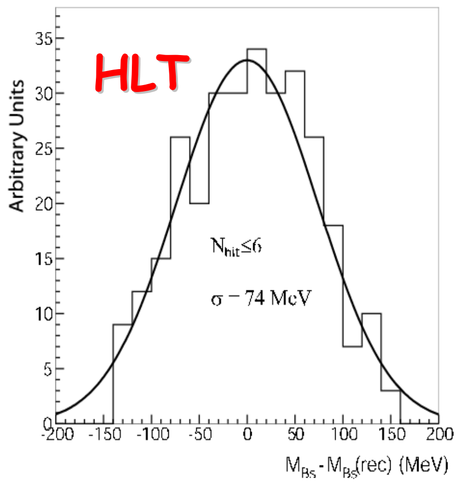


5% precision on A_{FB} after 3 years @ low lumi

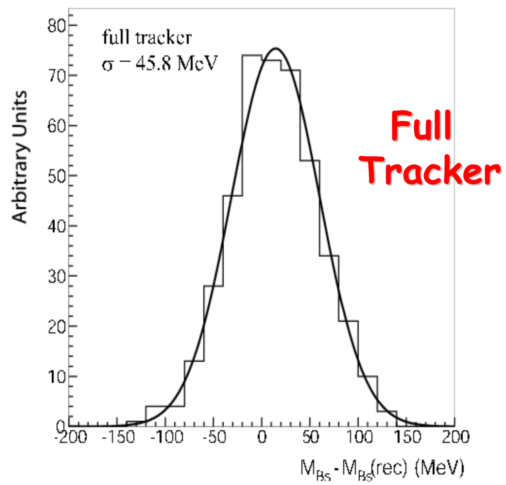
Potential for studying rare decays
The case of B $\rightarrow \mu\mu$

CMS studies for $\mathbf{B_s} \rightarrow \mu\mu$

Mass resolution



σ = 74 MeV



σ = 46 MeV

Offline analysis results (hep-ph/9907256), using SM BR=3.5×10^{-9} (Lvl-1 trigger in $|\eta|<2.4$ instead of $|\eta|<2.1$)
10 fb^{-1} => 7 signal events with <1 background
5σ observation with 30 fb^{-1}
and analysis could be perfomed at high lumi too

	$B_s \rightarrow \mu\mu$	$B_d \rightarrow \mu\mu$	Background
ATLAS	92	14	660
CMS	26	4.1	< 6.4

1 year @10^{34} cm^{-2} s^{-1}

Potential for studying rare decays exploring more difficult modes: $B_d \to K^* \gamma$

ATLAS studies

Level 1: μ6

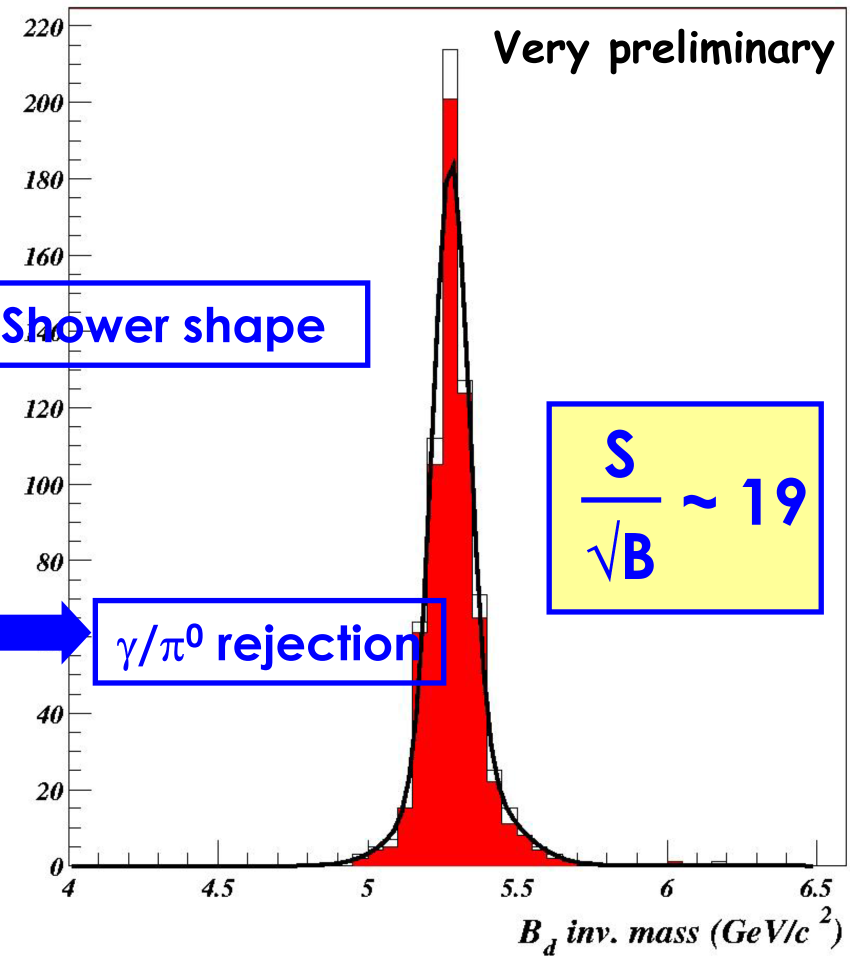
Level 2: γ **cluster candidate is selected if**

- *Cluster Et* **> 4 GeV**
- **0.5 strips** $\leq$ *cluster width* $\leq$ **3.5 strips**
- *Energy leakage in* ϕ *direction* $\leq$ **9 %**
- *Energy leakage in* η *direction* $\leq$ **9 %**

→ **Shower shape**

- *Energy proportion of strips* 2^{nd} *maximum* $\leq$ **6%**
- 2^{nd} *maximum physical meaning* $\leq$ **1.5%**

→ γ/π^0 **rejection**

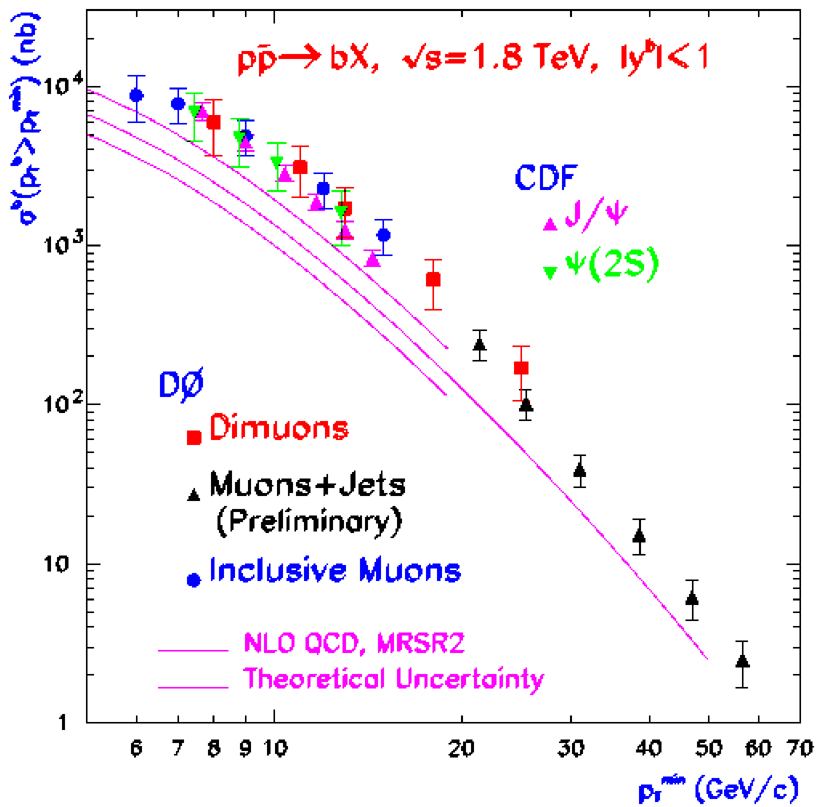


$$\frac{S}{\sqrt{B}} \sim 19$$

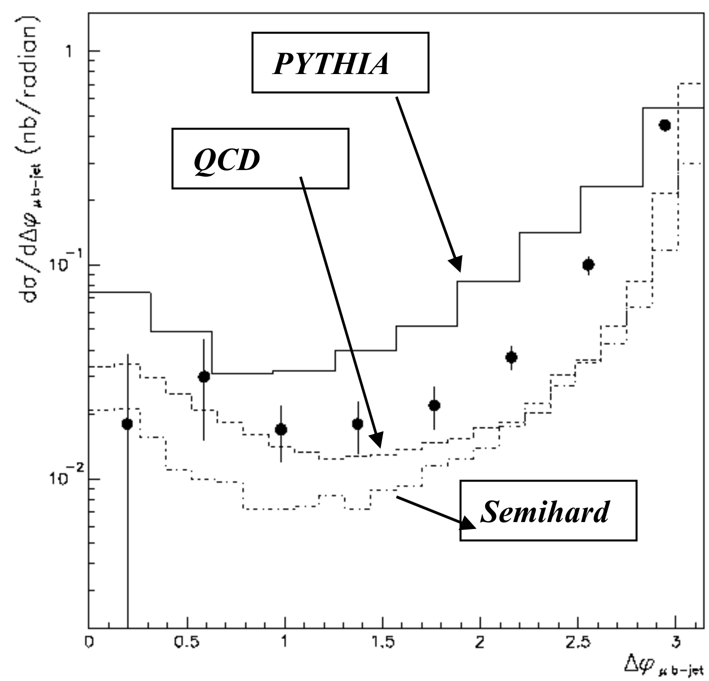
B hadron production at LHC

The case with Fermilab

QCD - NLO describe the shape of differential cross section however underestimates absolute value of cross section by factor ~2.4



CDF measurement of b-b correlation using μ - b-jet data and comparison to models

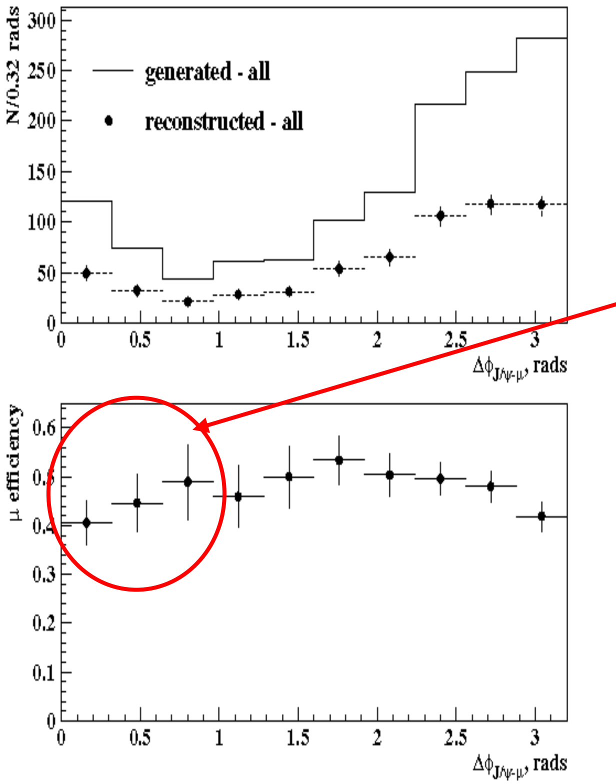


B hadron production at LHC

ATLAS - proposal for measurement of b-b production correlations using exlusive B-decay and semi leptonic decay to muon:

$B \to \mu\ B_d \to J/\psi K_s^0$, $B \to \mu\ B_s \to J/\psi \phi$

$\Delta\phi = \phi_{J/\psi} - \phi_\mu$



No degradation of efficiency as b-b close in space.

Conclusions

General purpose central LHC detectors ATLAS and CMS are well equipped for multi thematic B-physics program - including B-decays and B-production.

1. In CP violation the main emphasis will be on underlying mechanisms and evidence of New physics. ATLAS and CMS are especially precise in measurement of β. LHC 'gold-plated' mode is also $B_s \rightarrow J/\psi\ \phi$
2. B_s mixing studies make clear that there is sensitivity to Δm_s far beyond SM expectations. The width difference $\Delta\Gamma_s$ can be measured best in $B_s \rightarrow J/\psi\ \phi$ with relative precision 8%.
3. Rare decays $B \rightarrow \mu\mu$ have the most favorable experimental signature allowing to measure also at nominal LHC luminosity 10^{34} cm^{-2} s^{-1}. Will measure branching ration of $B_s \rightarrow \mu\mu$ which is in SM of order Br<(10^{-9}). Precision measurements will be done for $B \rightarrow K^*\mu\mu$.
4. Beauty production and correlations at central LHC collisions will be measured for QCD tests. The program includes baryon production polarization
5. ATLAS and CMS beauty trigger strategies will be adapted according to luminosity conditions at initial LHC period.