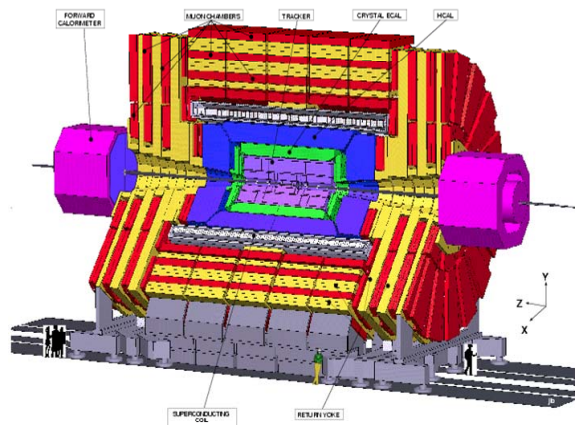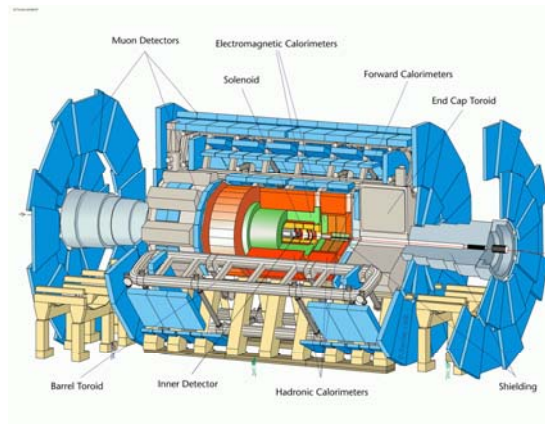# Physics at LHC-2008

Split-CROATIA,
29.9. – 4.10.2008

B-physics with ATLAS and CMS

Brigitte Epp,
Astro- and Particle Physics,
University of Innsbruck, Austria

representing
ATLAS / CMS collaborations

B-physics @ ATLAS/CMS

- p-p collisions at $\sqrt{s}$ = 14 TeV: σ (bb) = 500 µb

  10^5 bb pairs /s @ L=10^{33} cm^{-2}s^{-1}
  huge statistics allows precision
  measurements of B hadron species

- LHC ratio σ_{bb} /σ_{inel} is higher compared to
  earlier accelerators –> µ rate from B-events is
  higher

- ATLAS / CMS are general purpose detectors,
  however B-physics requirements were taken
  into account in detector and trigger building

- robust muon and di-muon triggers –>
  possibility to collect valuable B-physics events
  with LHC data
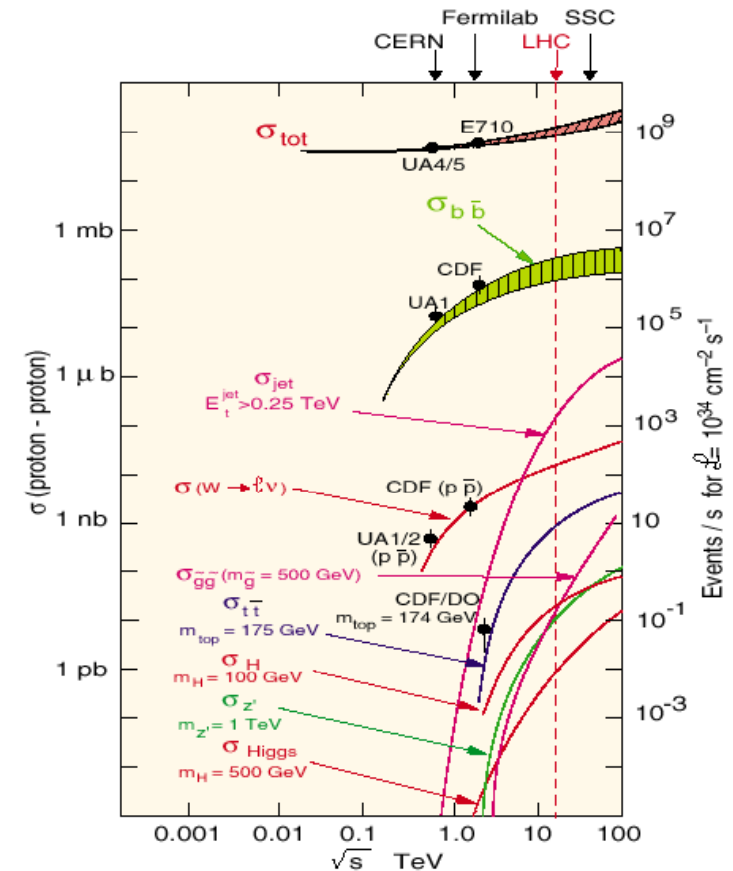
B-physics program @ATLAS/CMS

Early data period:

➢ L_{int} = 10 – 100 pb^{-1}:

- early measurements from J/Ψ and ϒ and b-quark cross-section, QCD tests at new energy
- large b cross-section will allow early extraction of exclusive decays, like B$^+$ → J/Ψ K$^+$, B$_d^0$ → J/Ψ K^{O*}, B$_s$ → J/Ψ Φ
- J/Ψ, ϒ and exclusive B-channels will be a tester for detector calibration (mass, lifetime, etc)

➢ L_{int} = 200 pb^{-1} – 1 fb^{-1}:

- high statistics will allow to improve worlds precision of lifetime measurements
- set new limit for B$_s$ → μμ
- improve measurement on B$_c$ and Λ$_b$

B-physics program @ATLAS/CMS (cont)

Main data period: L_{int} = 10 – 30 fb^{-1} and higher

- rare and semi-rare decays: $B_s \rightarrow \mu\mu$, $b \rightarrow d,s\ \mu\mu$

- CP-violating B_s mixing phase studies: $B_s \rightarrow J/\Psi\ \Phi$, $B_s \rightarrow D_s\pi(a_1)$

- Λ_b polarisation: $\Lambda_b \rightarrow \Lambda\ J/\Psi$

- full potential of B_c and other heavy flavour hadrons

- lepton flavour violating search: $\tau^- \rightarrow \mu^-\mu^+\mu^-$

covers a wide range over the different LHC periods for
SM and New Physics (NP) measurements

Trigger strategy in ATLAS
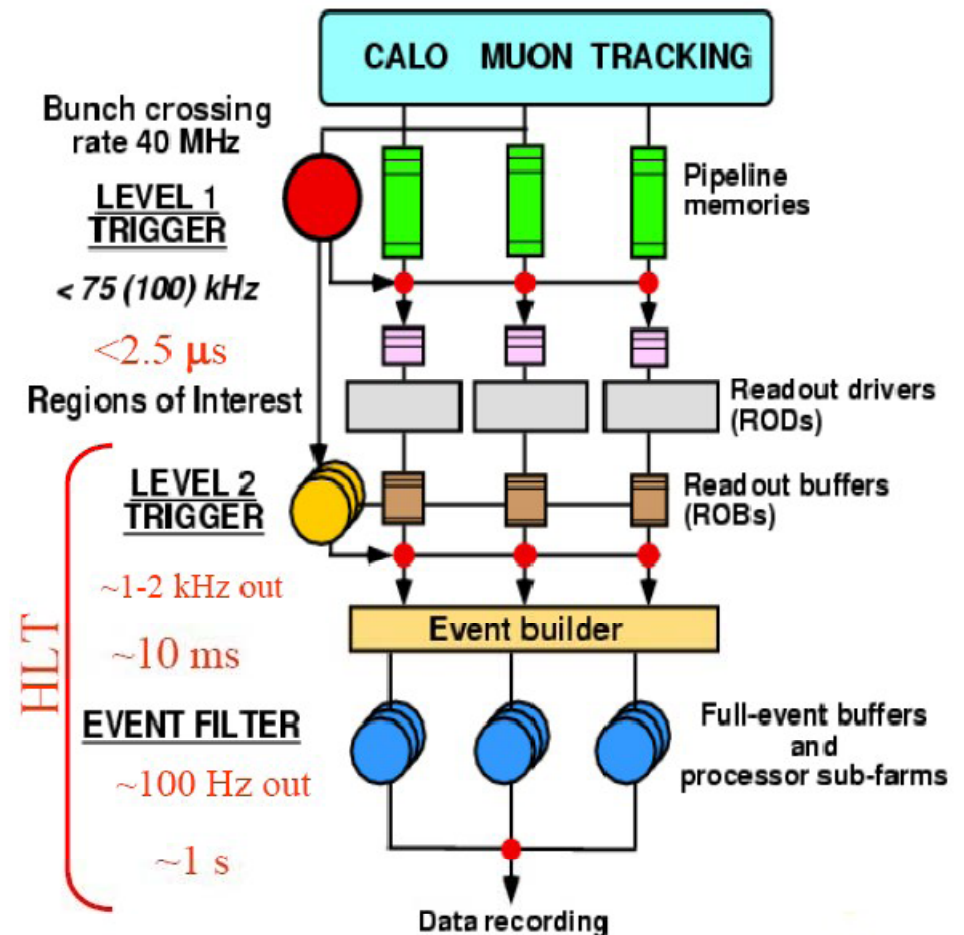
ATLAS trigger schema

- LVL1
  - hardware-based, identifies Regions of Interest (RoI) for further processing

- LVL2
  - confirm LVL1 trigger
  - precision muon chamber and inner detector measurements in LVL1 RoI

- EF
  - refine LVL2 selection using offline-like algorithms
  - full event, alignment and calibration data available

Three level Trigger:
L1   → **hardware**
HLT (L2+EF) → **software**

B-physics Trigger in ATLAS

B-Physics is accounted for 5÷10% of total trigger resources:

it must be fast, efficient and selective

At L = 10^{33} cm^{-2} s^{-1}: (low luminosity)

<u>L1</u>: B-trigger is based on following strategies:
di-muon L1 signature or single muon combined with Jet- or EM-RoI

<u>L2</u>:

- topological di-muon trigger (see high luminosity)
- if only one L1 muon → the second muon is found at the HLT stage
- hadron trigger: tracking in the ID to reconstruct hadrons in RoI, specific for each channel, e.g. $D_s(\Phi\pi)$, rare semi-leptonic channels

μ
μ
enlarged
$RoI_{\mu1}$
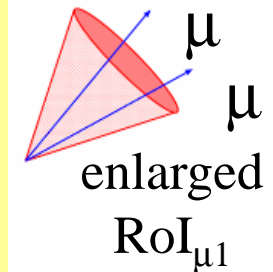
At L = 10^{34} cm^{-2} s^{-1}: (high luminosity)
- topological di-muon trigger: based on two L1 muons confirmed at L2
- optional increase of pt-threshold

μ_1
μ_2
$RoI_{\mu1}$
$RoI_{\mu2}$
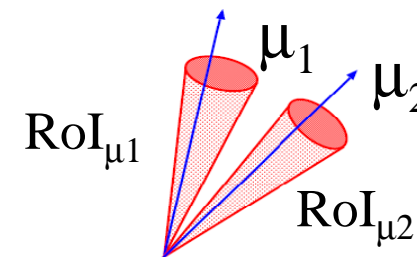
Trigger strategy in CMS

Two Level Trigger: L1   → hardware
                      HLT → software

➢ **Level 1 Trigger** (L1) - hardware
  based on muon detectors and calorimeters
  processing time: 3.2 µs
  40 MHz → 100 kHz

➢ **High Level Trigger** (HLT)
  fast (local) reconstruction similar to offline analysis
  has access to all event data with full precision and granularity
  processing time: ~1s
 100 kHz → 150 Hz

B-physics Trigger in CMS
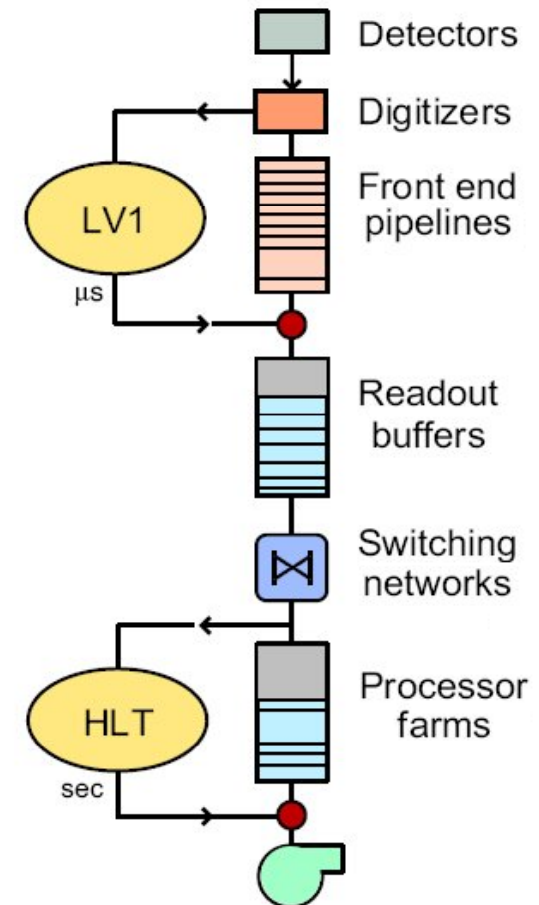
At L1:

Single muon: $p_T > 7$ GeV/c (14 GeV/c for L_{high})
Di- muon: $p_T > 3$ GeV/c (7 GeV/c for L_{high})

At HLT:

Exclusive and inclusive B triggers ~ 5Hz

- reconstruction of three most possible vertices with pixel detector

- regional track reconstruction around L1 μ

- search for (un)like charge track pairs in given mass window

- partial reconstruction combined with p_T-cuts
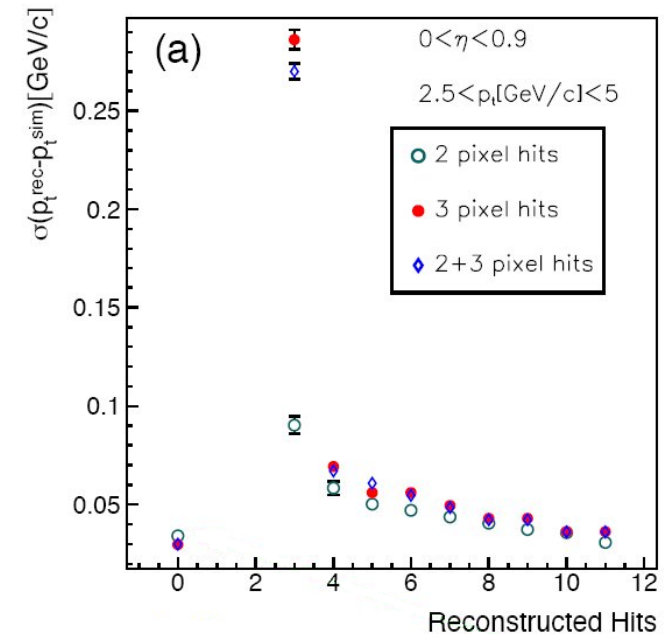
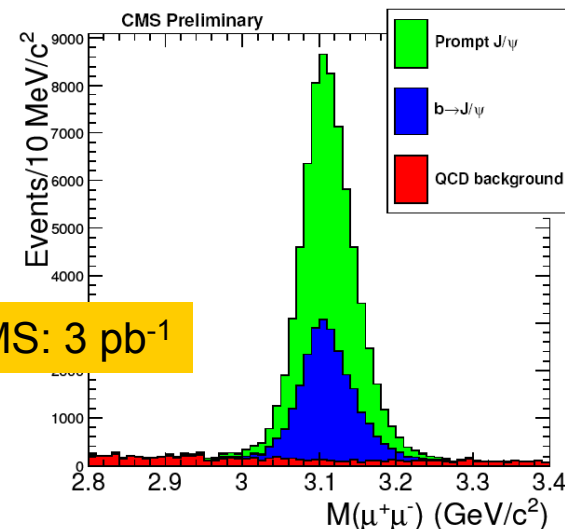# Quarkonia: production

J/ψ −>di-muon
main channel for early data
clear signature −>
      calibration, event monitoring

Already with first LHC
data enough statistics to
probe different
production models

ATLAS
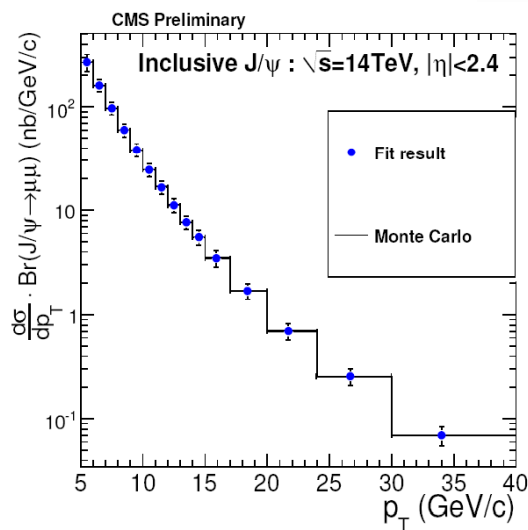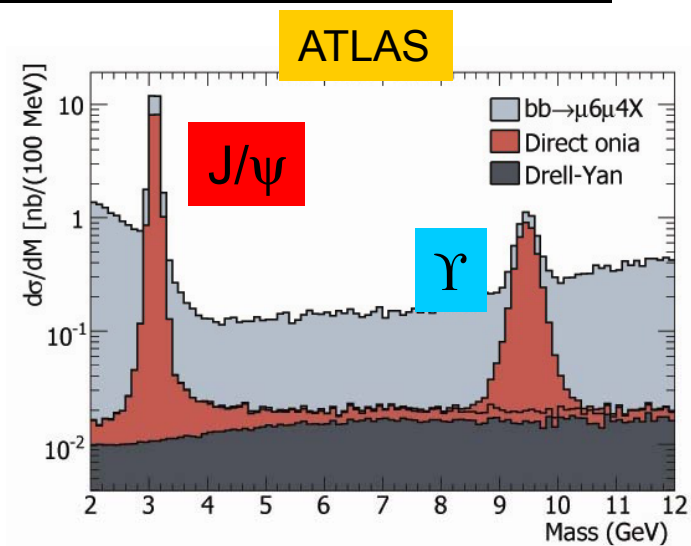
Inclusive J/ψ cross-section

CMS: 3 pb⁻¹

Quarkonia: polarization

Production mechanism of quarkonium unexplained and polarization for J/ψ and Υ not understood   (α .. polarization parameter)

CDF and DØ measurements on J/ψ and Υ are not in agreement with each other and theoretical predictions

Crude superimpose of ATLAS stat uncertainties with 10 pb-1 assuming α=0 :
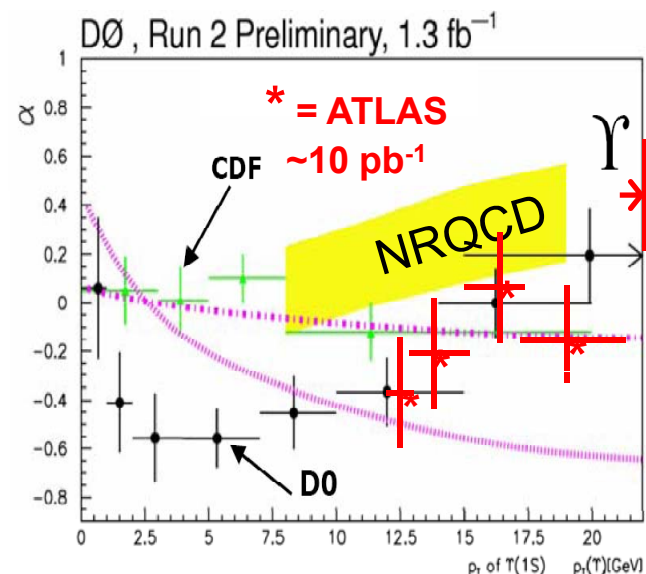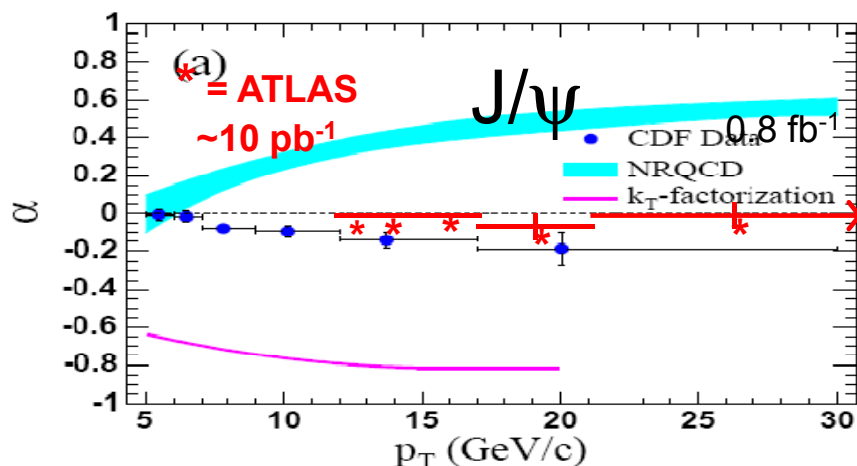
Already with 10 pb^{-1} ATLAS will measure J/ψ polarization to same precision as Tevatron with 1.3 fb^{-1} - but with interesting high p$_T$ data!
Same precision for Υ polarization studies can be reached after ~100 pb^{-1}

Weak phase of B$_s$ mixing

The weak phase of Bs mixing, ϕ_s is very small and precisely predicted within SM

$$\phi_s{}^{SM} = -arg(V_{ts}{}^2) = -2\lambda2\eta = -0.0368 \pm 0.0018$$

some NP- models predict large ϕ_s
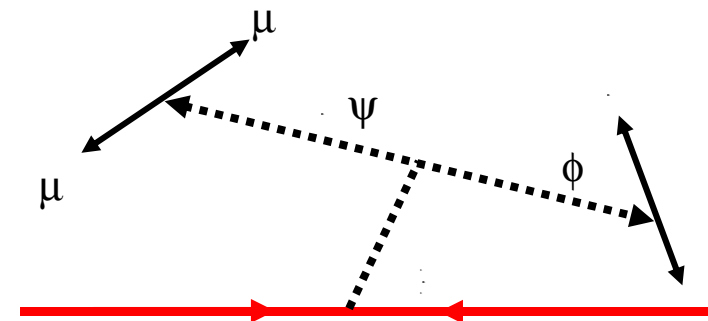
CDF and D0 set confidence level bounds on
ΔΓ$_s$ - ϕ_s
Their conclusion:
➢ assuming SM values ΔΓ$_s$ =0.096 ps^{-1}
and ϕ_s =0.04 the probability of deviation
of these values of as large as the observed
data is 15 % (CDF) and 6.6% (D0)

experimentally most feasible
channel is

B$_s$ → J/Ψ(µµ) Φ(KK):

**Measurement of ϕ_s is challenging
→ could point to NP**

CPV with $B_s \to J/\Psi \, \Phi$ (ATLAS/CMS)

$B_s \to J/\Psi(\mu\mu) \, \Phi(KK)$:

- good to trigger ($\mu\mu$)
- good BG suppression

- Experimental information:
  3 angles, proper time, flavor tag,
  BG–fraction + composition
  Δm_s measurement from $B_s \to D_s\pi(a_1)$

- Independent information of uncertainties
  of experimental values

- huge statistics (~100k per year) →
  multivariable analysis with
  5 parameters + constraint input values

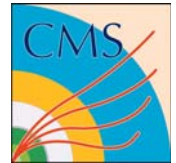ATLAS, CMS after 30 fb^{-1}
→ δ (ϕ_s) = 0.07 each
  (larger through NP?)

	ATLAS	CMS
Luminosity	30 fb^{-1} / 3Y	
Statistics	240000	260000
Background	30%	33%
	dominant B_d-J/y, K* B_d-J/y K$^+\pi^-$	
Time resol	83 fs	77 fs
Mass resol	16.6 MeV	14 MeV
Flav tagging	μ, e, Qjet	μ, e, Qjet
ϕ_s	0.067	0.068
$\Delta\Gamma$s	13%	12%
Γs	1%	0.9%
$A_\parallel$	0.9%	0.8%
$A_\perp$	3%	2.7%
Δm_s (ps^{-1})	17.77 +- 0.12	
$\delta_1\delta_2$	Fixed from B_d-J/y K*	

$B_s \rightarrow \mu\mu$

NP may enhance the BR $(3.42 \pm 0.46) \cdot 10^{-9}$ in SM by several orders of magnitude through new loop diagrams

present best limit: CDF (2007) with 2 fb^{-1} of data

$BR(B^0_s \rightarrow \mu^+\mu^-) < 5.8 \cdot 10^{-8}$ at 95% CL (=17·Br$_{SM}$)

- trigger is di-muon signature $\rightarrow$ search also at nominal LHC L =10^{34} cm^{-2}s^{-1}
- main issue of cuts is background rejection (comb bb$\rightarrow \mu\mu$X , hadron misidentification, rare B-decays)
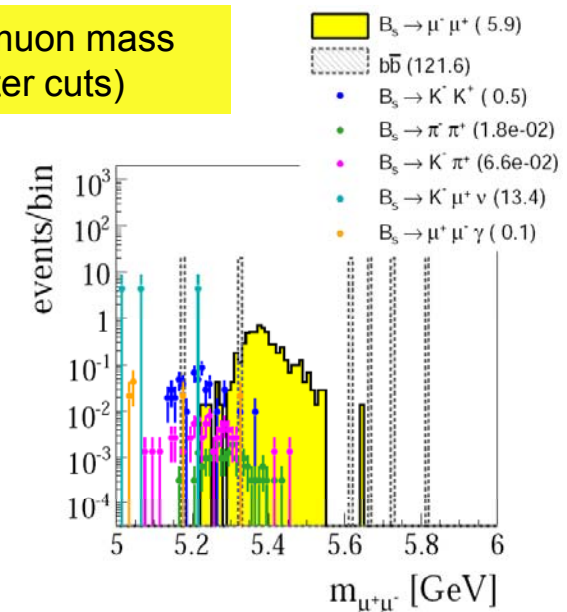
Dimuon mass (after cuts)

ATLAS / CMS have similar discriminating variables with different selection cut values:
- ✓ isolation of the muon pair
- ✓ significance of the decay length
- ✓ angle between di-muon momentum and direction to PV
- ✓ mass window around m(B$_s$)

More details for CMS:
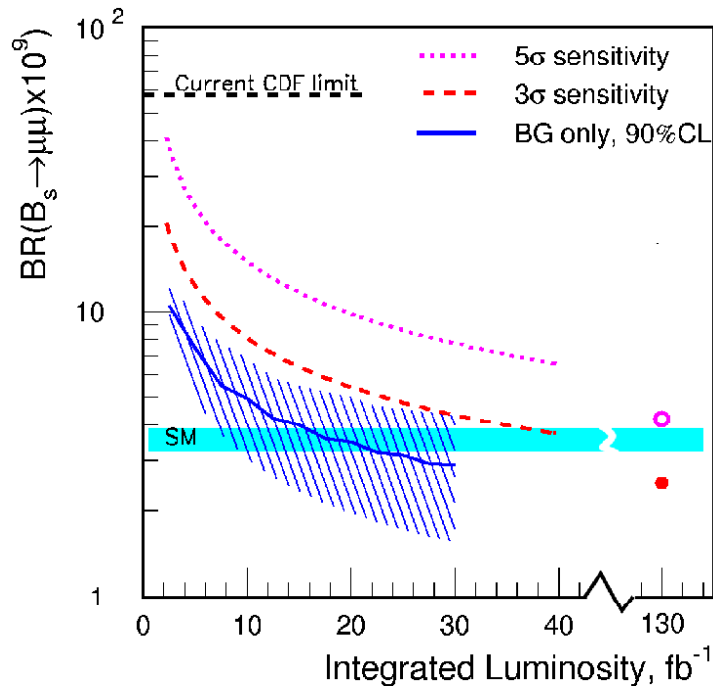see talk in the afternoon B.Caponeri
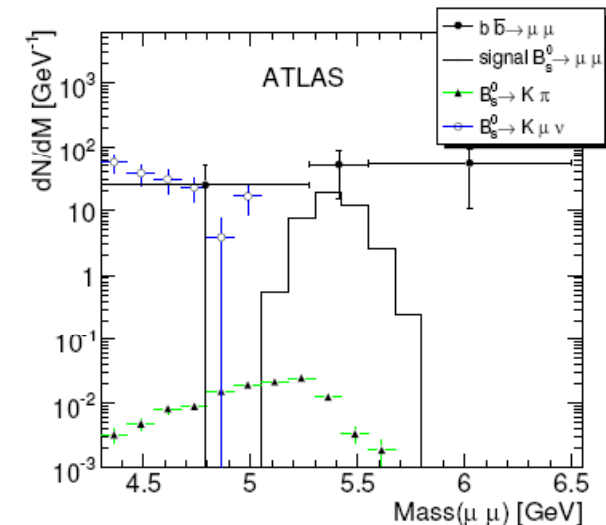
$B_s \rightarrow \mu\mu$: results

For 10 fb^{-1} signal and main backgrounds $\rightarrow$ expected number of events

	$B_s \rightarrow \mu\mu$	$bb \rightarrow \mu\mu X$	$B_s \rightarrow K\pi$	$B_s \rightarrow K\mu\nu$
ATLAS	5.7	14(+13,-10)	0.015	negl.
CMS	6.1	14(+22,-14)	< 0.3	negl.

$B_s \rightarrow \mu\mu$ sensitivity

- with 2 fb^{-1} BR< ~ 2×10^{-8}
- with 10 – 20 fb^{-1} SM prediction region
- 3σ evidence   after 3 years@10^{33}
- 5σ observation after 1 years@10^{34}
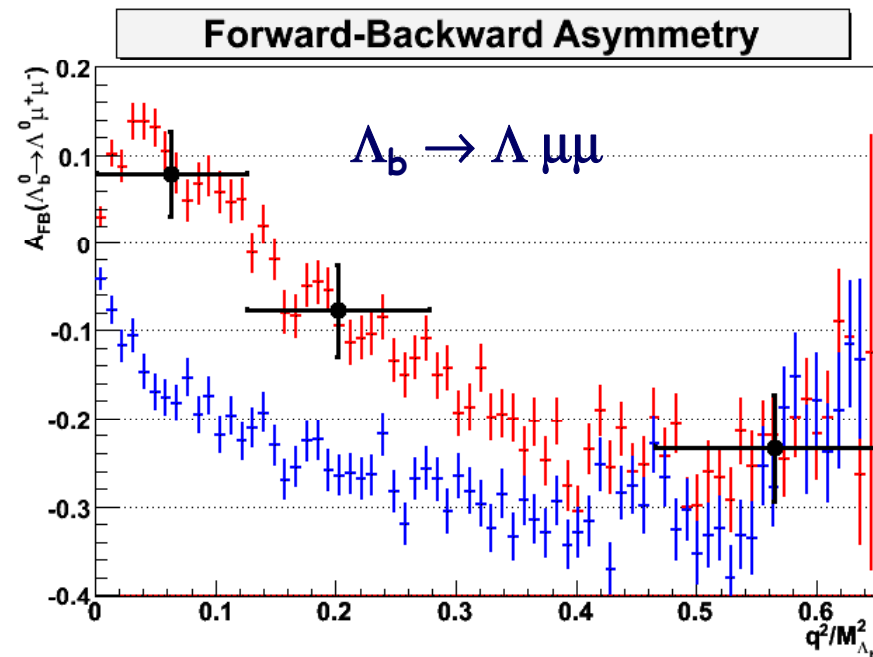
(signal cross section is translated to a BR by the reference process B+ $\rightarrow$ J/Ψ K+)

Exclusive semi-leptonic rare decays b→d,s μμ

b→s(d) $l^+ l^-$ FCNC transitions provide a good test of the SM and indirect search for signals in NP:

- CKM matrix

- differential decay rate sensitive to NP – A_{FB}, dilepton mass spectrum

- information on long-distance
  QCD effects

EXP,   SM
MSSM C7geff>0

Exclusive semi-leptonic rare decays - trigger

L1 di-muon triggers :
study on different trigger cuts

HLT trigger:
specific for each channel
track search for charged hadrons
from Φ, Λ_o, K_o^* decays in the
RoI of ID surrounding the
found di-muon signal

With 30 fb^{-1} ATLAS will achieve a
sensitivity to distinguish between
SM and certain classes of
NP - models.

ATLAS supports semi-rare decays
of all B-hadrons: B^+,B_0, B_s , Λ_b

30 fb^{-1} (3 years)	# of signal events
$B \to K^{0*} \mu\mu$	2500
$B_s \to \phi \; \mu\mu$	900
$B^+ \to K^{+*} \mu\mu$	4000
$B^+ \to K^+ \mu\mu$	2300
$\Lambda_b \to \Lambda \mu\mu$	800

CMS has equivalent potential –
studies are on-going!

LFV in $\tau^- \to 3\mu$ (CMS)

SM lepton flavor violation is negligible, but some NP models allow
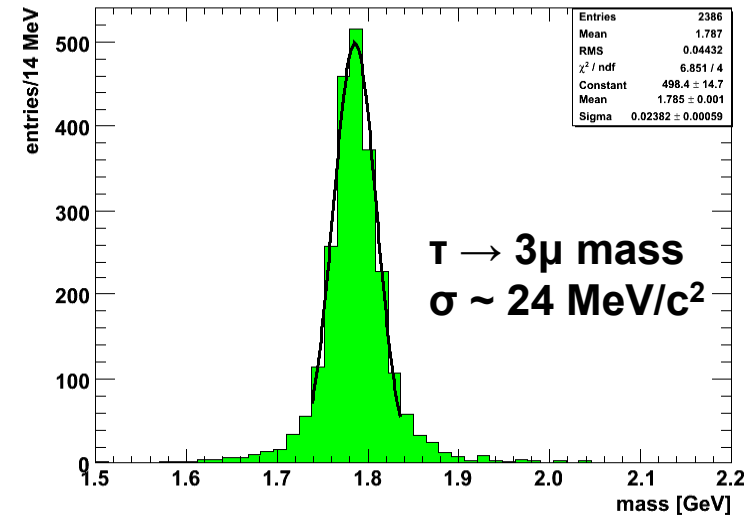BR ~ $O(10^{-10} \div 10^{-7})$

Current exp. limits:
BELLE BR $\leq 3.2 \times 10^{-8}$ (535 fb^{-1})
BaBar BR $\leq 5.3 \times 10^{-8}$ (376 fb^{-1})

$\tau \to 3\mu$ mass
$\sigma \sim 24$ MeV/c^2

τ sources at LHC –

• clean experimental signature
• suitable triggers

Decay	N_τ / 10 fb^{-1}
$W \to \tau \nu_\tau$	1.7×10^8
$Z \to \tau \tau$	3.2×10^7
$B^0 \to \tau X$	4.0×10^{11}
$B^\pm \to \tau X$	3.8×10^{11}
$B_s \to \tau X$	7.9×10^{10}
$D_s \to \tau X$	1.5×10^{12}

CMS L1:   single $\mu \to p_T > 14$ GeV
                di-μ $\to p_T > 3$ GeV
CMS HLT: single $\mu \to p_T > 19$ GeV
                di-μ $\to p_T > 7$ GeV

At L_{high} more stringent trigger (pileup)

Summary

- ATLAS, CMS B-physics program is prepared for all LHC luminosities

- Early period ($<10^{33}$): heavy flavour production measurements provide good ground for QCD tests at the new energy

- 10^{33} period:
  - improve current world's precisions on properties of B-hadron species

  - reach sensitivity to New Physics effects in B_s CP-violation and in semi-rare B-decays

  - reach three sigma effect in $B_s \rightarrow \mu\mu$ (supposing SM)

- Nominal LHC luminosity (10^{34}):
  - thanks to powerful muon triggers ATLAS, CMS will reach $B_s \rightarrow \mu\mu$ five sigma sensitivity already after one year of running

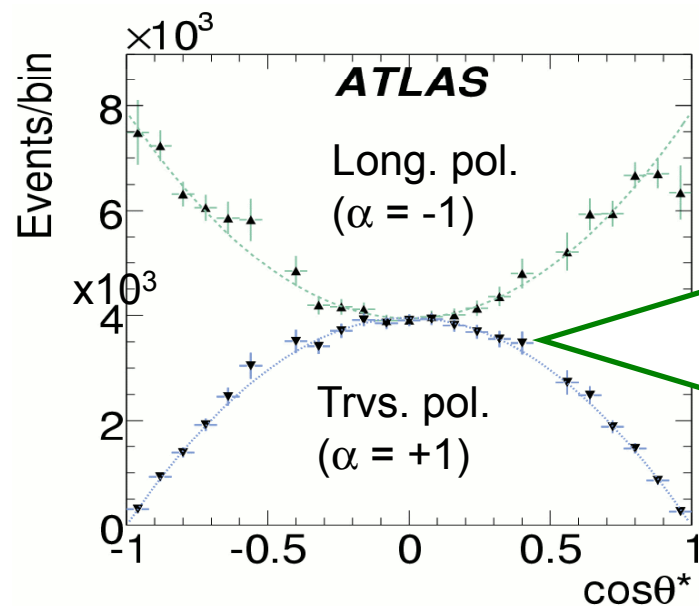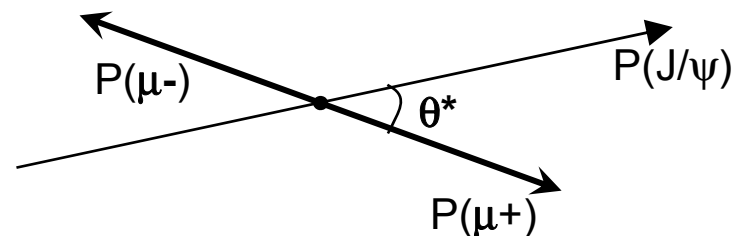- ATLAS, CMS B-physics data are a valuable source for SM and New Physics constraints

Backup

Backup

Polarization - Quarkonia

Measure high-p_T polarization to distinguish production models

$$\frac{dN}{d\cos\theta^*} \propto 1 + \alpha\cos^2\theta^*$$

ATLAS

Long. pol.
($\alpha = -1$)

Trvs. pol.
($\alpha = +1$)

Combine and fit to measured distribution in slices of p_T
Shown: $12 \leq p_T \leq 13$ GeV

- Use software that is also used by CDF
  http://www-cdf.fnal.gov/physics/statistics/statistics_software.html
  - Bayesian method
  - blimit.C returns s_{up} such that $\int_0^{sup} p(s|N_{obs})ds = \beta$
    - s ... signal rate
    - $p(s|N_{obs})$ ... posterior p.d.f. for s, given N_{obs}
    - $s_{up} = blimit(\beta, N_{obs}, \varepsilon, \Delta\varepsilon, N_{bg}, \Delta N_{bg}, \alpha)$
      - β ... CL value (0.9, 0.95)
      - $s^{(\alpha-1)}$ is the prior p.d.f. for the signal s
      - $N_{obs} = \varepsilon \cdot s + N_{bg}$, ε = signal efficiency
  - N_{bg} very large uncertainty due to limited MC statistics
    - will be estimated from sidebands, once data are available
  - Setting $N_{obs} = N_{bg} \pm \Delta N_{bg}$ one gets the upper limit s_{up} on the signal cross section in the absence of signal
   - see blue curve and hatched region on slide 14

Calculating the 3(5)σ discovery sensitivity
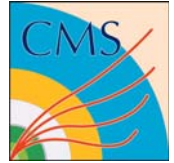
- If $(N_{obs} - N_{bg}) / \sqrt{N_{bg}} \gg 1 \rightarrow$ evident discovery
  - this quantifies the significance of a discovery

- Therefore use the following simple relation
  - $N_{signal} = (N_{\mathbf{obs}} - N_{\mathbf{bg}}) = 3 \cdot \sqrt{N_{bg}}$ and $5 \cdot \sqrt{N_{bg}}$
    - $N_{bg} \propto L_{int}$
    - $N_{signal} = \varepsilon \cdot \sigma(B_S) \cdot Br(B_S \rightarrow \mu\mu) \cdot L_{int}$

  - $Br(B_S \rightarrow \mu\mu)$ for xσ discovery sensitivity scales with $\sqrt{L_{int}}$

Sensitivity for a Δm_s measurement
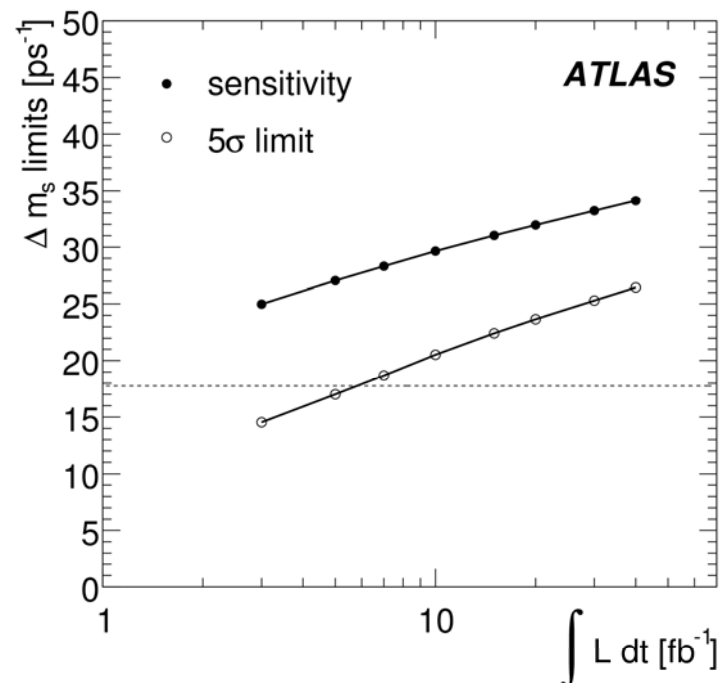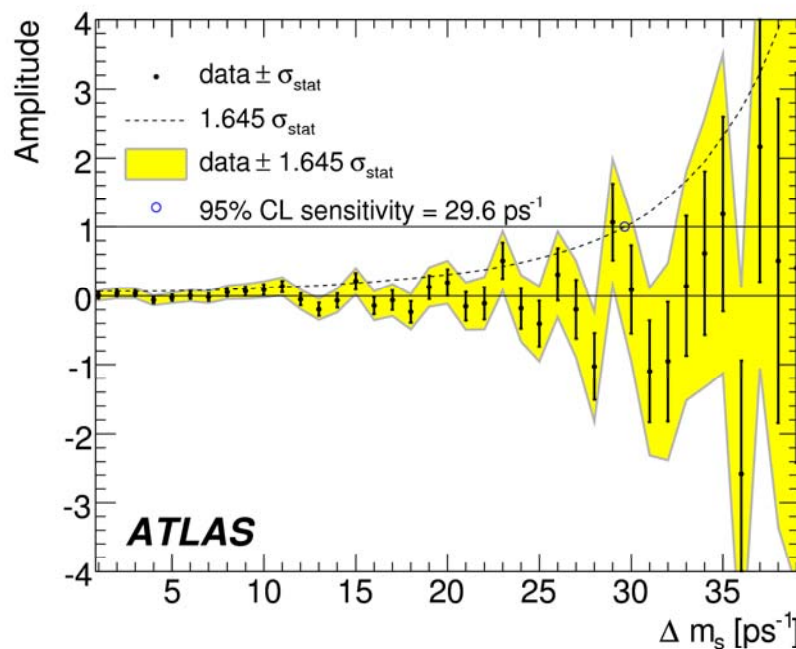
B_s^0 oscillation amplitude as a function of Δm_s for 10 fb^{-1}
using the amplitude fit method

fully hadronic decay channels $B_s^0 \rightarrow D_s^- \pi^+$ and $B_s^0 \rightarrow D_s^- a_1^+$ combined
- 95% CL sensitivity: 29.6 ps^{-1}
- 5 σ measurement limit: 20.5 ps^{-1}