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Precise B-Decays Measurement sensitive to BSM Physics at ATLAS

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GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Martin zur Nedden
Humboldt-Universität zu Berlin

For the ATLAS Collaboration

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Outline

- ATLAS B-physics strategy, detector and trigger
- CP violation effects and sensitivity to physics beyond the standard model
- Rare B-decays

It is a pleasure to give this talk in the United Kingdom, which provides both of B-Physics conveners in ATLAS and is deeply involved in many of the studies presented here.

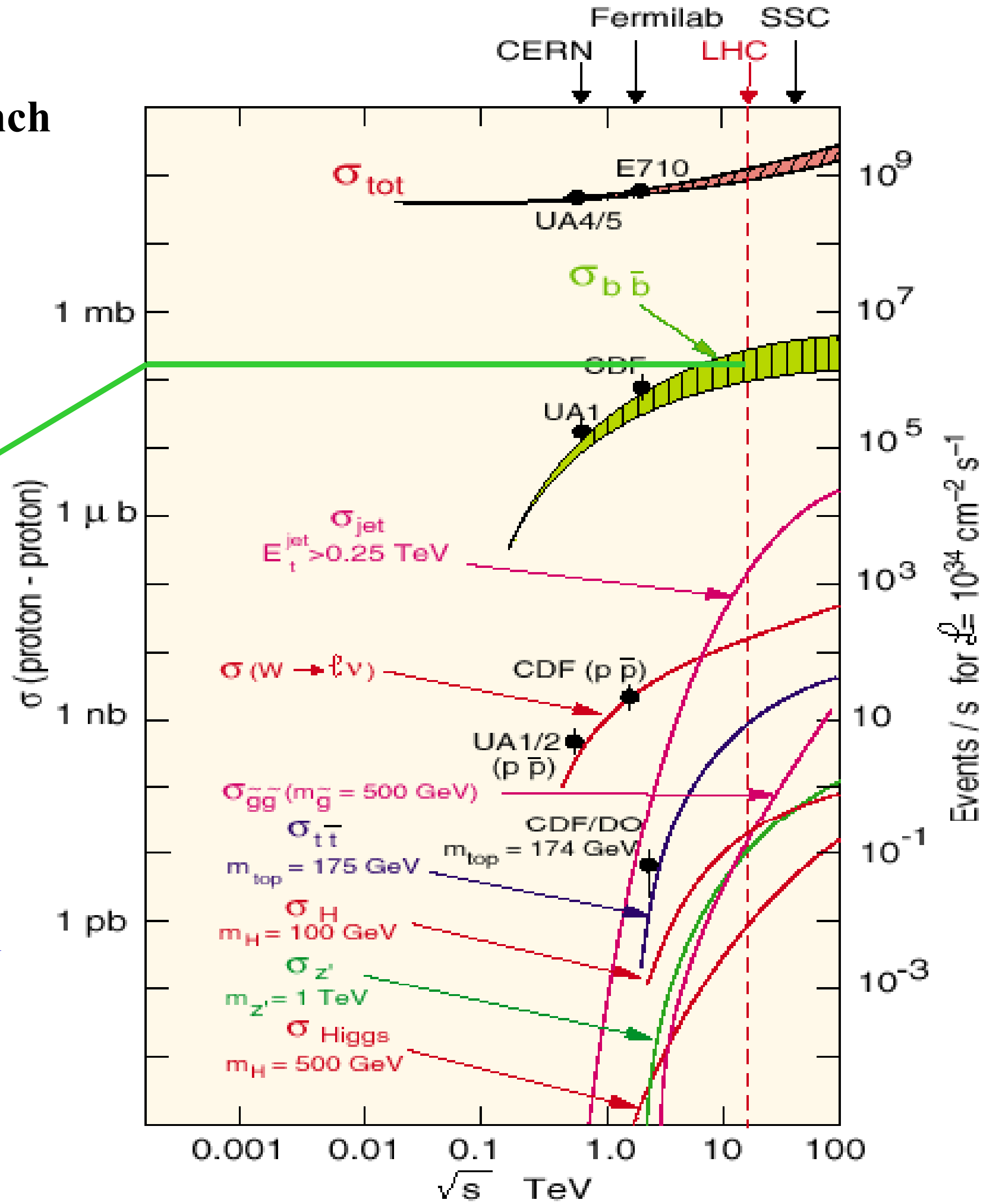
B Physics at LHC

- **LHC at CERN:**
  proton-proton collisions at $\sqrt{s}$ = 14 TeV, bunch crossing rate 40 kHz, circumference 27 km

- **4 experiments at LHC**
  - **ATLAS/CMS:** **general purpose detectors**
  - **LHCb:** **for dedicated B-Physics**
  - **ALICE:** **for heavy ion physics**

- **High $b\bar{b}$ production cross section: ~ 500 μb**
  (~ 1 $b\bar{b}$ pair in 100 p-p collisions).
  Those of interest must be selected by efficient B-trigger.

- **Luminosity operation plans:**
  - **about 100 pb^{-1} in 2008,**
  - **more than 1 fb^{-1} in 2009**
    reaching then luminosity of 10^{33} cm^{-2} s^{-1}
    (~10 fb^{-1} per year)
  - **Design:**
    high-luminosity: 10^{34} cm^{-2}s^{-1}
    (~100 fb^{-1} per year)



General Strategy for B Physics at ATLAS

- ATLAS is a **general-purpose** experiment:
  main emphasis on high-pT physics beyond the Standard Model

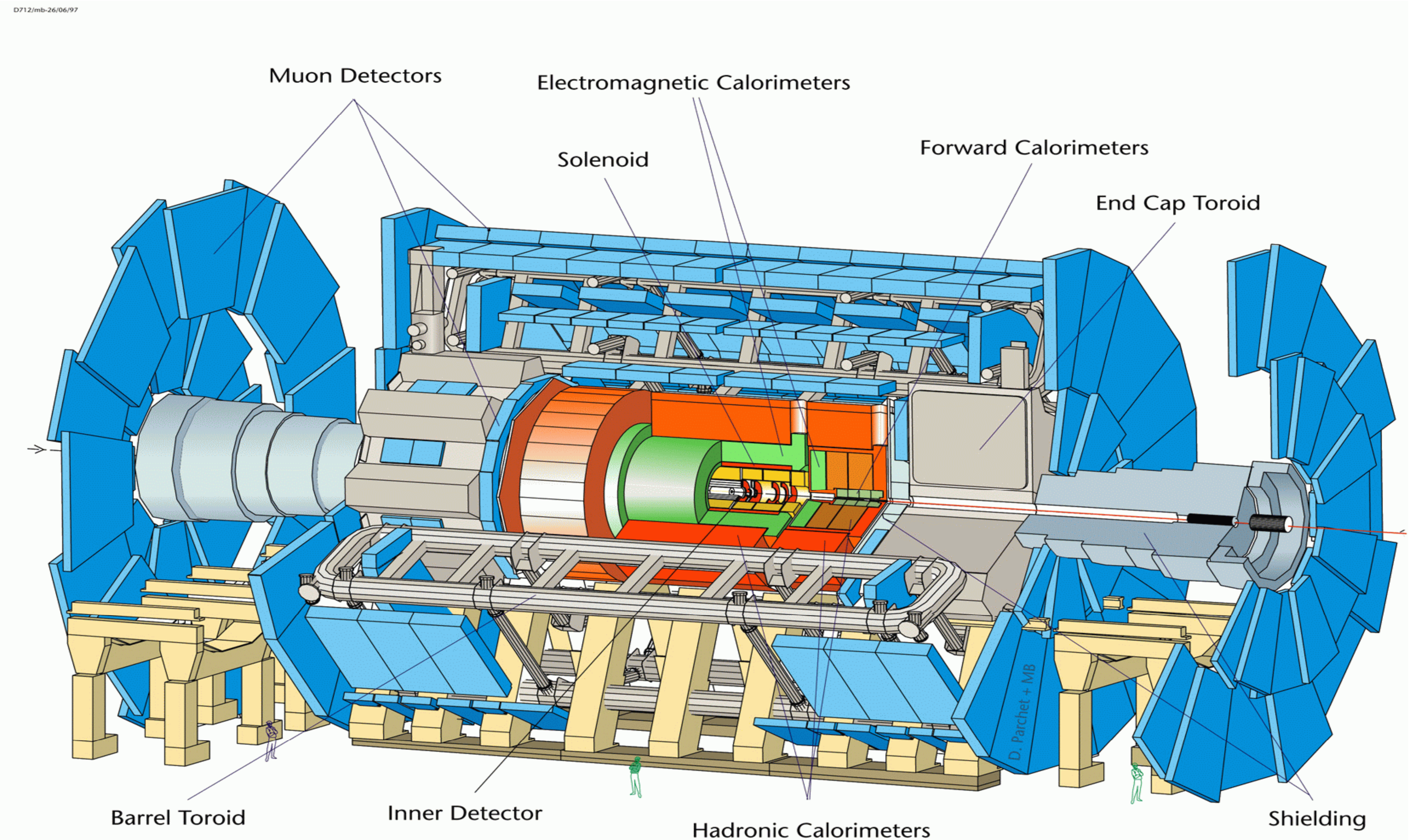
- ATLAS has also **capabilities for a rich B-physics** programme:
  precise **vertexing and tracking**, good **muon identification,** high-resolution calorimetry, dedicated and flexible **B-physics trigger** scheme.

- ATLAS has a **well-defined B-physics programme** for all stages of the LHC operation:
  - Huge b-hadron production statistics allow **precise measurements of their properties**
  - **Theoretical descriptions** of heavy flavoured hadrons need **input from LHC**
  - Precision measurements already achievable **after one year of data taking**

- **Measurements extending the discovery potential for physics beyond SM**
  measurements of **CP violation parameters** that are predicted to be small in the SM
  (e.g in $\mathbf{B_s \to J/\psi\phi(\eta)}$)
  measurements of **rare B-decays**
  ($\mathbf{B_d \to K^*\gamma}$, $\mathbf{B_d \to K^*\mu\mu}$, $\mathbf{B_s \to \phi\gamma}$, $\mathbf{B_s \to \phi\mu\mu}$, $\mathbf{B_s \to \gamma\mu\mu}$, $\mathbf{B \to \mu\mu}$)

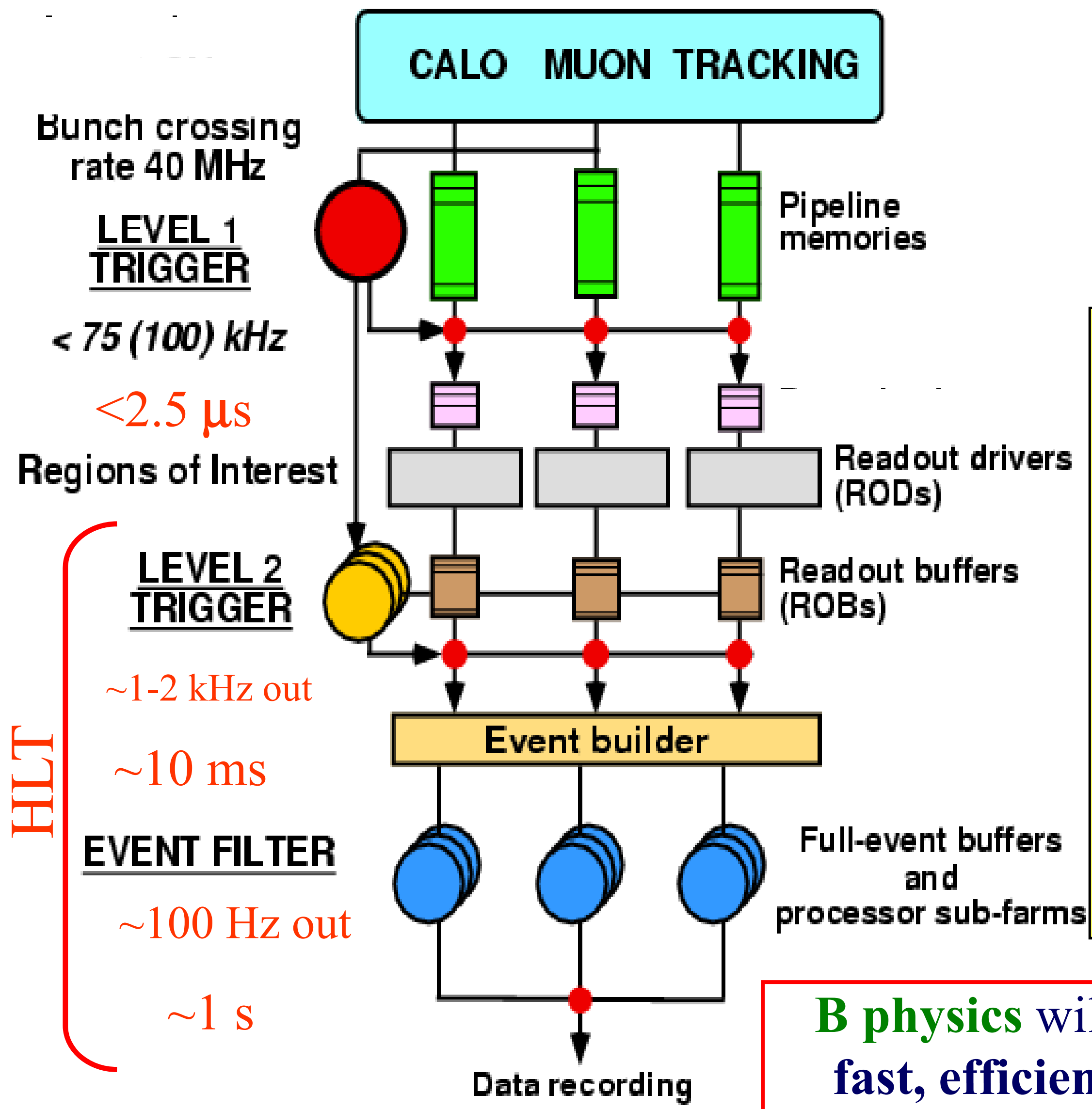
- **Focus on physics topics that will not be accessible for the B-factories**
  mainly B_s, baryon and double heavy flavour hadrons
  ($\mathbf{B_s \to D_s\pi}$, $\mathbf{B_s \to J/\psi\phi(\eta)}$, $\mathbf{\Lambda_b \to J/\psi\Lambda^0}$, **…**)

ATLAS Experiment



46 m long, 22 m diameter, 7'000 t total weight

ATLAS Multi Level Trigger



LEVEL 1 TRIGGER

- Hardware based (FPGAs ASICs)
- Uses coarse granularity calorimeter and muon information
- Identifies **R**egions **of** **I**nterest for further processing

HLT: software based

LEVEL 2 TRIGGER

- Full granularity within **RoI**
- Confirm LVL1 trigger
- Combine info from different detectors in **RoI**s around LVL1

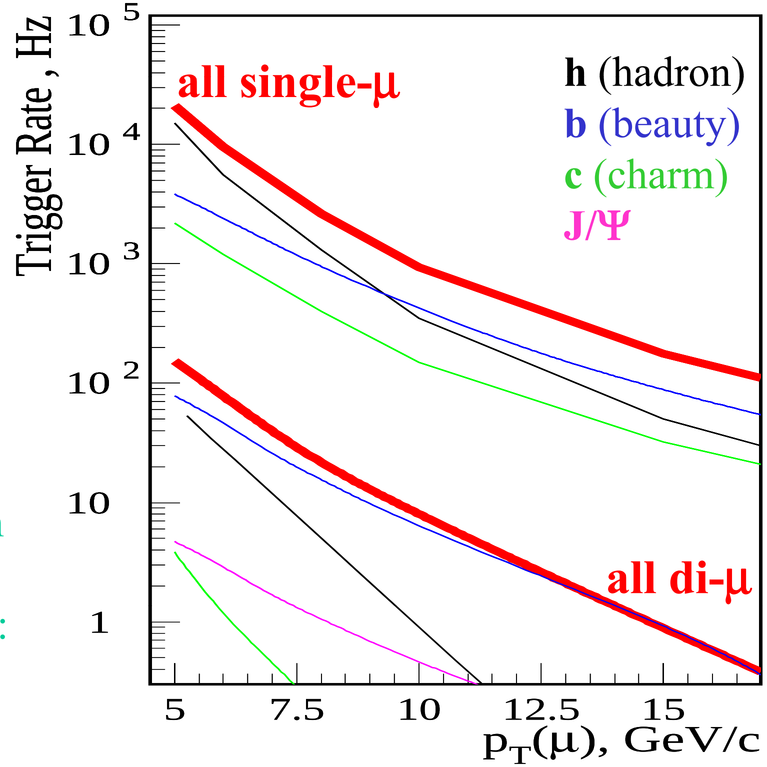
EVENT FILTER

- Refines LVL2 selection using "offline-like" algorithms
- Better alignment and calibration data available

B physics will be using **~10%** of total trigger resources:
fast, efficient and selective trigger strategies needed.

Trigger Strategies for B-Physics

- **limited bandwidth for B-triggers:**
  highly efficient and selective trigger needed.
- **c- and b-events contain mostly low p_T particles:**
  challenge to trigger on those events
- **many b-decays contain J/ψ :**
  useful for **calibration, optimization and understanding** of detector, trigger as well as B-physics
- **B-trigger is based on single- and di-muons in final state**
  BR ~ 10 %, but clean signature at early level in trigger and give flavour tag
- **lower lumi (< $2 \cdot 10^{33}$ cm^{-2}s^{-1})**
  - **LVL1 single μ-trigger** with additional LVL1 signature or a jet in calorimeter at LVL2
  - use LVL1 Regions of Interest (**RoI**) to seed LVL2 reconstruction:
    - **Jet RoI:** for hadronic final states (e.g. $B_s \rightarrow D_s(\phi\pi)\pi$)
    - **EM RoI:** for e/γ final states (e.g. $J/\psi \rightarrow ee$, $K^*\gamma$, $\phi\gamma$)
    - **Muon RoI:** to recover di-muon final-states in which second muon was missed at LVL1
  - LVL1 di-muon trigger



- **high lumi (>2×10^{33} cm^{-2}s^{-1})**
  - **LVL1 di-μ trigger**
  - **$B \rightarrow J/\psi(\mu\mu)$** , rare decays (**$B \rightarrow \mu\mu$, $B \rightarrow K^{0*}\mu\mu$**), double semi leptonic decays
- Developments and studies by **Rutherford, Technion (Haifa) and Tokio**

CP violation in $B_s \to J/\psi\phi$

- $\Phi_s = -2\lambda^2\eta = -2\chi$: **tiny in SM** (-0.036±0.003 from CKM fitter)

Results for 30 fb^{-1} luminosity:		
signal events:		270.000
B_s mass resolution:		16.5 MeV
Background from $J/\Psi K^{0*}$ and $bb \to J/\Psi X$:		15 %
ε(tag) / wrong tag fraction	jet charge	63.0 % / 38 %
	electron	1.2 % / 27 %
	muon	2.5 % / 24 %

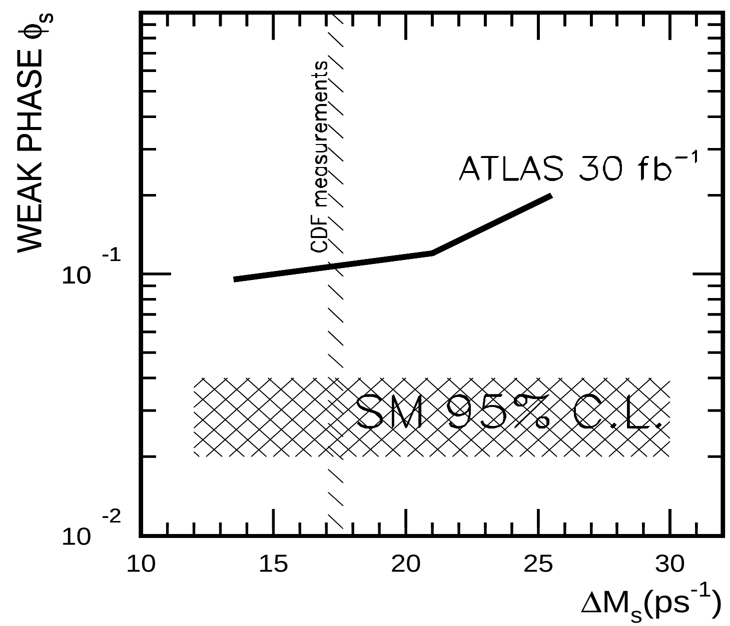
$\sigma(\Phi_s)$ ~ 0.046 (for m_s=20 ps^{-1})
$\sigma(\Delta\Gamma_s)/\Delta\Gamma_s$ = 13%
$\sigma(\Gamma_s)/\Gamma_s$ = 1%
$\sigma(A_{||})/A_{||}$ = 0.9%
$\sigma(A_T)/A_T$ = 3%

- **New Physics could lead to enhanced and measurable CP violation.**
- **7 parameters extracted in maximum likelihood fit to angular distribution of the decay :**

  $A_{||}(t=0)$, $A_T(t=0)$, δ_1, δ_2 (2 ind. magnitudes and phases)

  $\Delta\Gamma_s$, Γ_s, Φ_s (weak decay parameter)

  - despite enormous LHC statistics and well-controlled background – several parameters get highly correlated
  - to avoid failing a fit due to high Δm_s-Φ_s correlation, Δm_s was fixed



Results from **Lancaster University**

Δm_s Measurement

$$B_s^0 / \overline{B_s^0} - \text{system}:$$

Mixing due to weak interaction:

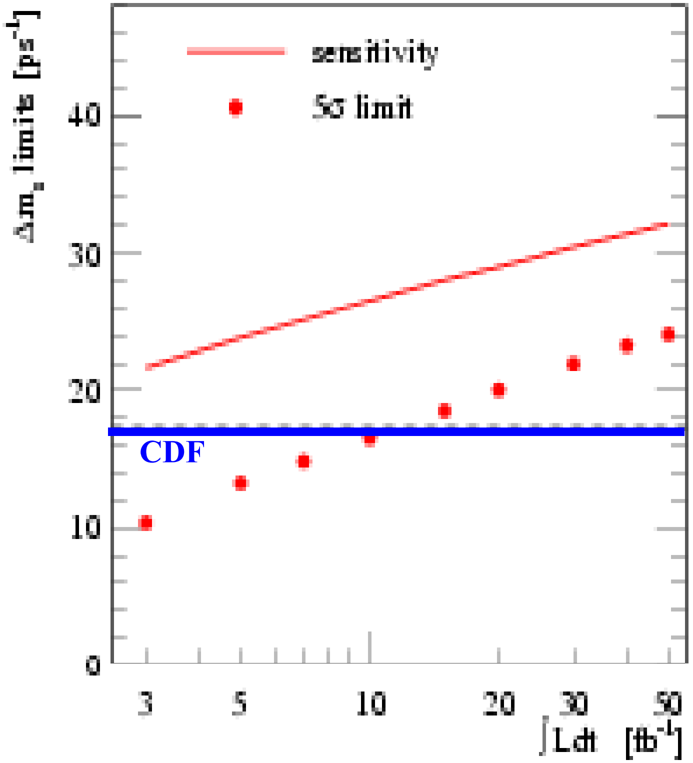
in $B^0_s \to D_s\pi$, $B^0_s \to D_s a_1$ decays:

Probability that initially (t=0) pure B_s^0 is measured As B_s^0 (p_+) or as B_s^0-bar (p_-):

$$p_\pm(t) = e^{-\Gamma t}\left(\cosh(\frac{\Delta\Gamma_s}{2}t) \pm \cos(\Delta m_s t)\right)\frac{\Gamma^2 - \Delta\Gamma_s^2}{2\Gamma}$$

Δm_s derived from:

$$\frac{p_+(t) - p_-(t)}{p_+(t) + p_-(t)} = \frac{\cos(\Delta m_s t)}{\cosh(\frac{\Delta\Gamma_s}{2}t)}$$



ATLAS sensitivity:

Given the low value measured by **CDF**, ATLAS will be able to measure Δm_s with ~10 fb^{-1} (one year).

Luminosity (fb^{-1})	5σ limit (ps^{-1})	95% CL sensitivity (ps^{-1})
10	16.5	26.5
20	20.0	29.0
30	21.9	30.5

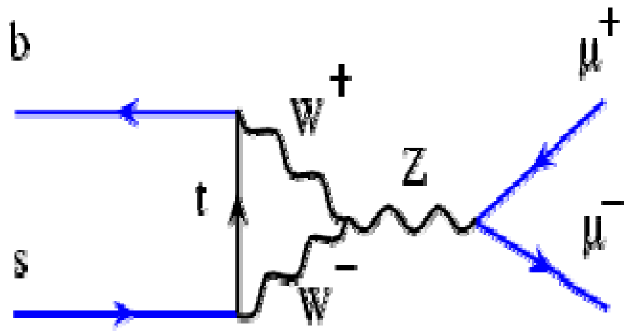
$B^0_s \to D_s\pi$: Univ. Innsbruck
$B^0_s \to D_s a_1$: Univ. Siegen

Rare B-Decays

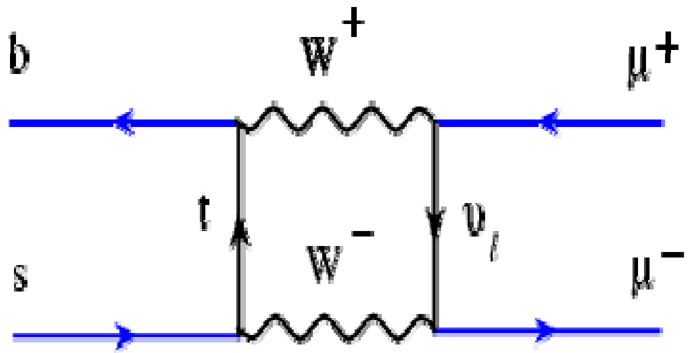
$b \rightarrow d, s$ transitions (FCNC) are forbidden at the tree level in SM and occur at the lowest order through one-loop-diagrams "penguin" and "box"

Main points to study:

- good test of SM and its possible extensions
- information of the long-distance QCD effects
- determination of the $|V_{td}|$ and $|V_{ts}|$
- some of the rare decays as background to other rare decays (for example $B_d \rightarrow \pi^0 \mu^+ \mu^-$ as bkg for $B_{d,s} \rightarrow \mu^+ \mu^-$)



$B_s \rightarrow \mu^+ \mu^-$



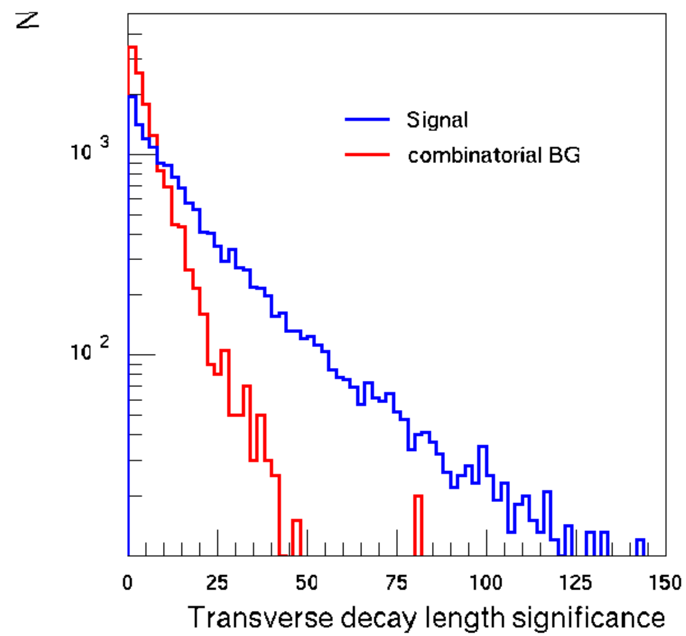
ATLAS offline analysis : $B_s \rightarrow \mu\mu$

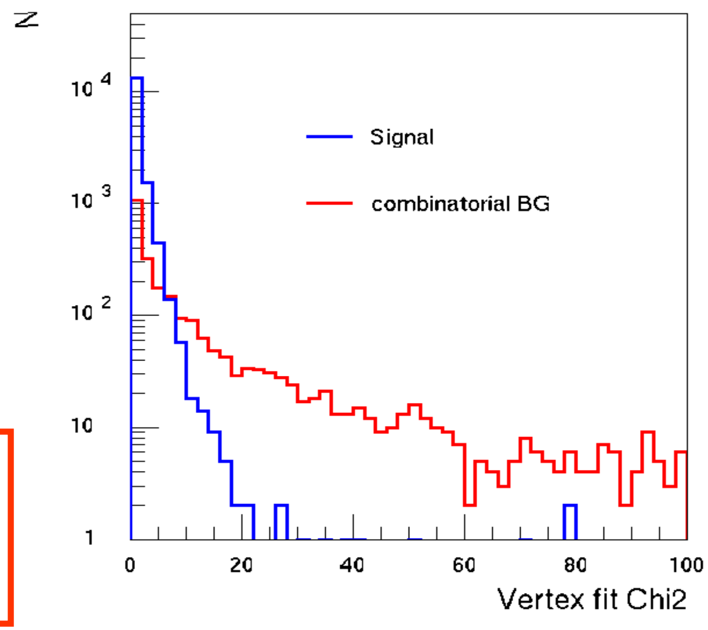
Expected **signal** v.s. inclusive $bb \rightarrow \mu\mu X$ **background**

Cuts	B^0_s signal	BG ($bb \rightarrow \mu\mu X$)
p_T>6 GeV, $\Delta R_{\mu\mu}$<0.9	50 events	6.0×10^6 events
$M_{\mu\mu}$cut ($M_{\mu\mu} = M_{Bs}{}^{+140}{}_{-70}$ MeV)	0.77	2×10^{-2}
Isolation cut: no charged tracks with $p_T > 0.8$ GeV in cone $\theta < 15$ degrees	0.36	5×10^{-2}
$L_{xy}/\sigma(L_{xy})$>11, χ^2<15 (transverse decay length) vertex fit with pointing to primary vertex constraint	0.4	$< 0.7 \times 10^{-4}$
All cuts	**7**	**20 ± 12**

Background:

$$B^0 \rightarrow \pi^- \mu^+ \nu_\mu, B^+ \rightarrow \mu^+ \mu^- l^+ \nu_l, B_c \rightarrow \mu^+ \mu^- l^+ \nu_l$$
$$B^0_d \rightarrow \pi^0 \mu^+ \mu^-, B^0_s \rightarrow \mu^+ \mu^- \gamma, B_d \rightarrow K\pi, B_s \rightarrow KK$$



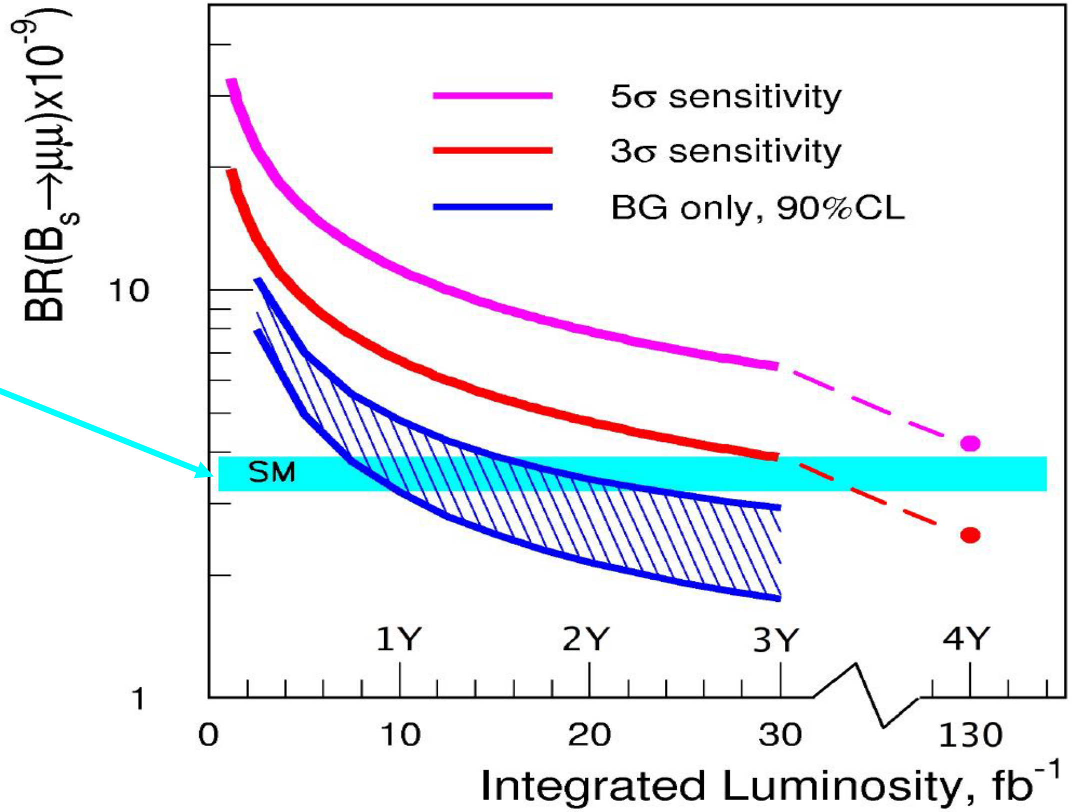


Projected upper limits : $B_s \rightarrow \mu\mu$

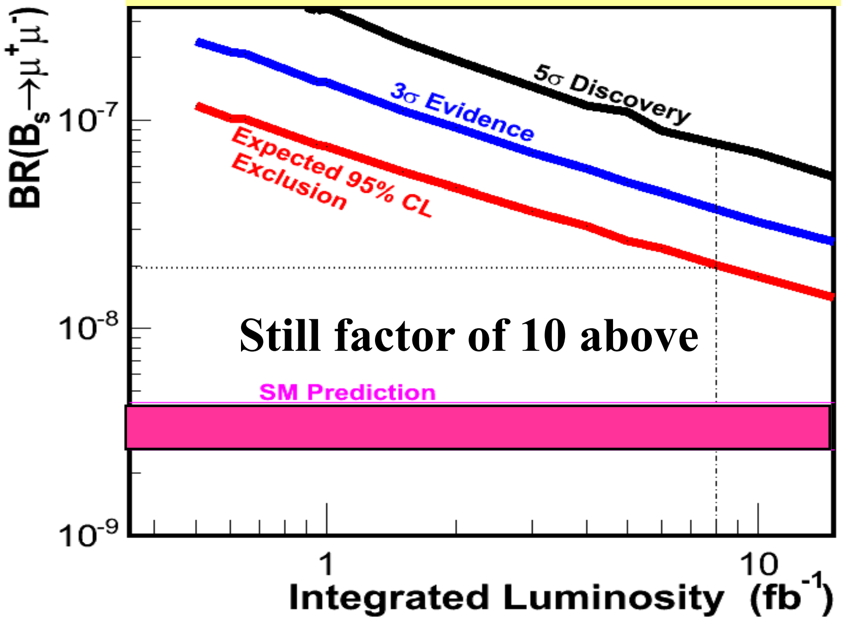
extraction of upper limit on $Br(B_s \rightarrow \mu\mu)$ (from 7 signal and (20 ± 12) background events)

$$Br\left(B_s^0 \rightarrow \mu^+\mu^-\right) \le \frac{N\left(n, n_{bg}\right)}{2\sigma_{Bs} L \alpha \varepsilon_{total}}$$

ATLAS experiment expects to reach the sensitivity of SM prediction



Tevatron projection



ATLAS has proven that the measurement of $B_s \rightarrow \mu\mu$ is still feasible at nominal LHC luminosity $10^{34} cm^{-2} s^{-1}$. This would mean $100\ fb^{-1}$ just in one year.

Analysis by **Univ. of Moscow, Bergen and Lancaster**

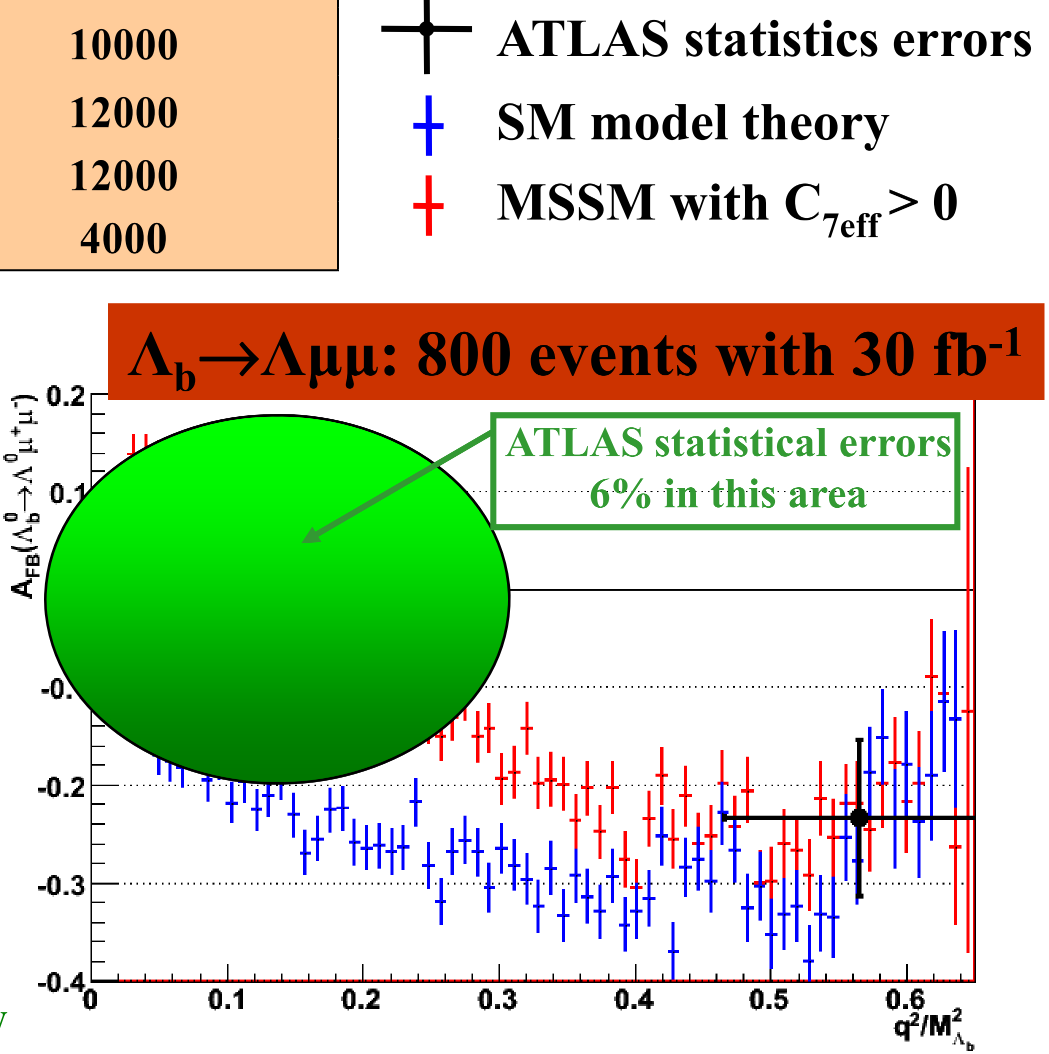
Semi-muonic exclusive rare B-decays in ATLAS

expected statistics of reconstructed events at $L = 30\ fb^{-1}$

BR used in MC	Decay channel	Signal events	Background upper limit
1.3×10^{-6}	$B_d \to K^{0*}\mu\mu$	2500	12000
1.0×10^{-6}	$B_s \to \Phi\mu\mu$	900	10000
3.5×10^{-7}	$B^+ \to K^+\mu\mu$	4000	12000
6.4×10^{-7}	$B^+ \to K^{*+}\mu\mu$	2300	12000
2.0×10^{-6}	$\Lambda_b \to \Lambda\mu\mu$	800	4000

- A_{FB} shape and BR provides strong indirect tests of BSM physics
- shape of distribution sensitive to trigger and offline selection cuts, especially at low q^2 region
  - small μμ opening angle is trigger challenging
  - Λ_b example: detector acceptance and trigger muon: p_T cuts prefers higher q^2 and causes A_{FB} reduction by factor of 0.6 at $q^2/M_b^2 < 0.1$

$\Lambda_b \to \Lambda\mu\mu$: 800 events with 30 fb^{-1}



Analysis by **Univ. Prague, Cosenza and Moscow**

Conclusions

- well-defined B-Physics programme
- different Trigger Strategies for low and high luminosity phases well-prepared
- CP violation studies for B_s
- rare B-decays measurable with ATLAS sensitive to BSM.
- precision B-physics measurements provide an additional method for searches for new physics at LHC