B-Production at ATLAS

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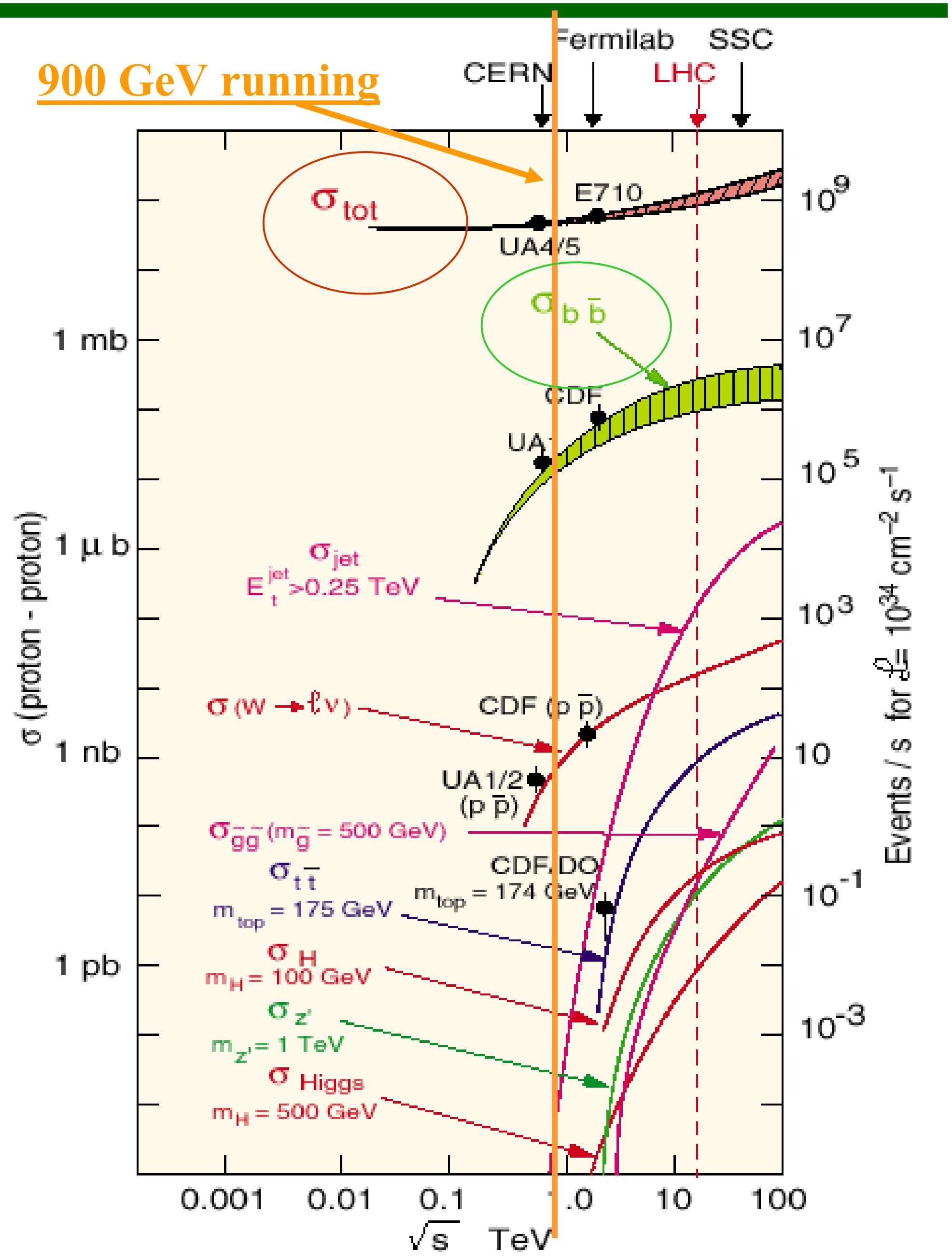
Outline

- B-physics at LHC
- ATLAS B-physics strategy
- ATLAS detector and trigger
- ATLAS B-physics trigger strategy
- Plans for LHC commissioning running
- Plans for data taking at early running (low luminosity)
- Inclusive cross section measurement
- Outlook

B Physics at LHC

- **LHC: proton-proton collisions at $\sqrt{s}$ = 14 TeV, bunch crossing rate 40kHz**
- **High $b\bar{b}$ production cross section: ~ 500 µb (~ 1 in 100 p-p collisions → $b\bar{b}$ pair).**
  Those of interest must be select by B-trigger.
- **Current luminosity plans:**
  - **Pilot-run in 2007, 900 GeV, ~10^{29} cm^{-2}s^{-1}**
  - **low-luminosity: up to 2x10^{33} cm^{-2} s^{-1} (~10 fb^{-1} per year)**
  - **high-luminosity: 10^{34} cm^{-2}s^{-1} (~100 fb^{-1} per year)**

  Beauty cross section dominates at 900 GeV and 14 TeV
- **ATLAS B-physics programme:**
  - **CP violation (e.g. B→J/ψ(X), B→µµ)**
  - **B_s oscillations (e.g. B_s→D_sπ, B_s→$D_s a_1$)**
  - **Rare decays (e.g. B→µµ(X), B→K*γ)**
  - **Inclusive cross section measurement**

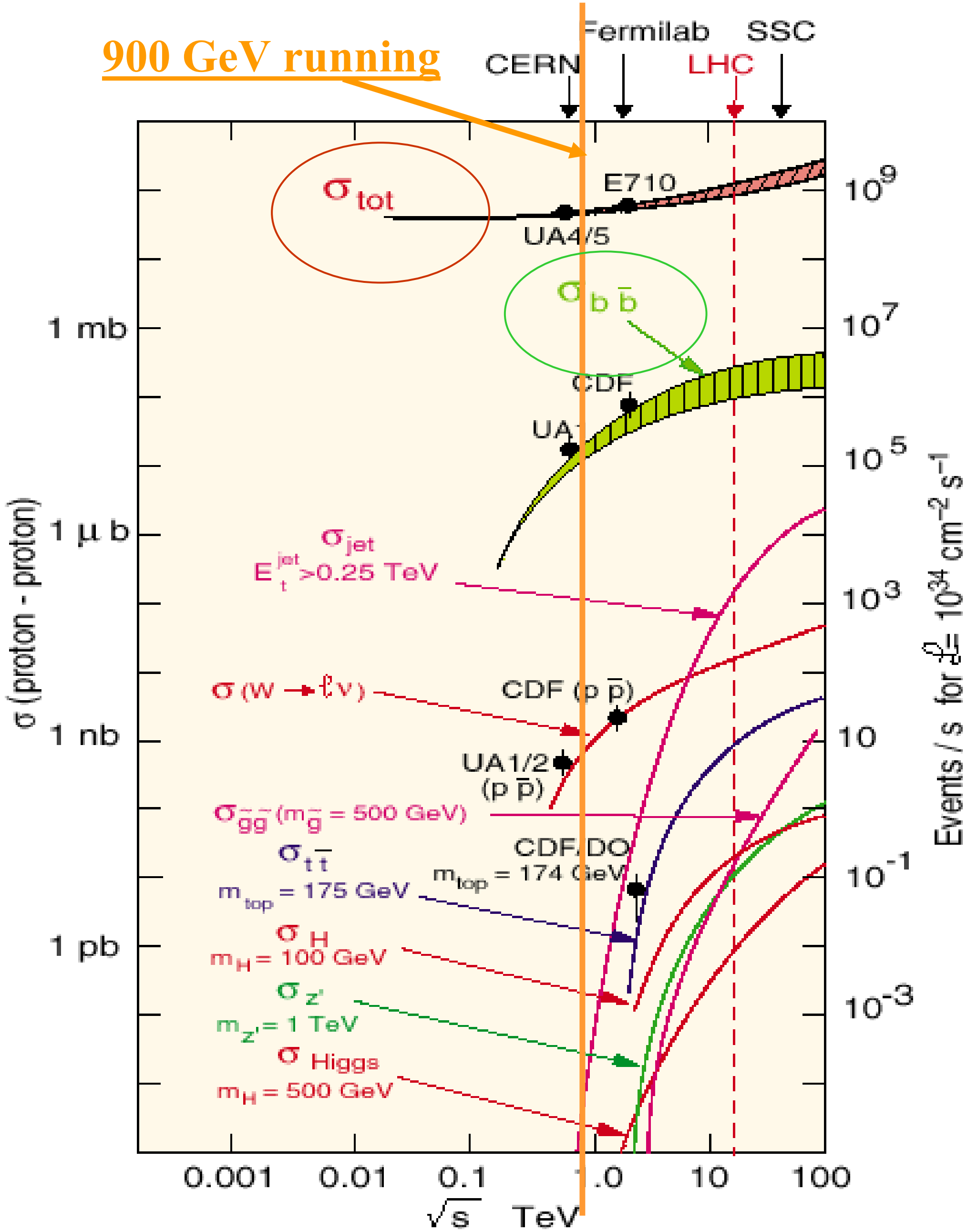


The Commissioning Run 2007

- The run in 2007 will primarily be a **detector and computing commissioning run**, much more than a physics run.

- A few weeks of stable running conditions at the injection energy.

- **At $\sqrt{s}$ = 900 GeV the $b\bar{b}$ fraction of total inelastic events is ~ 10 times smaller than at 14 TeV.**



B-Physics at ATLAS

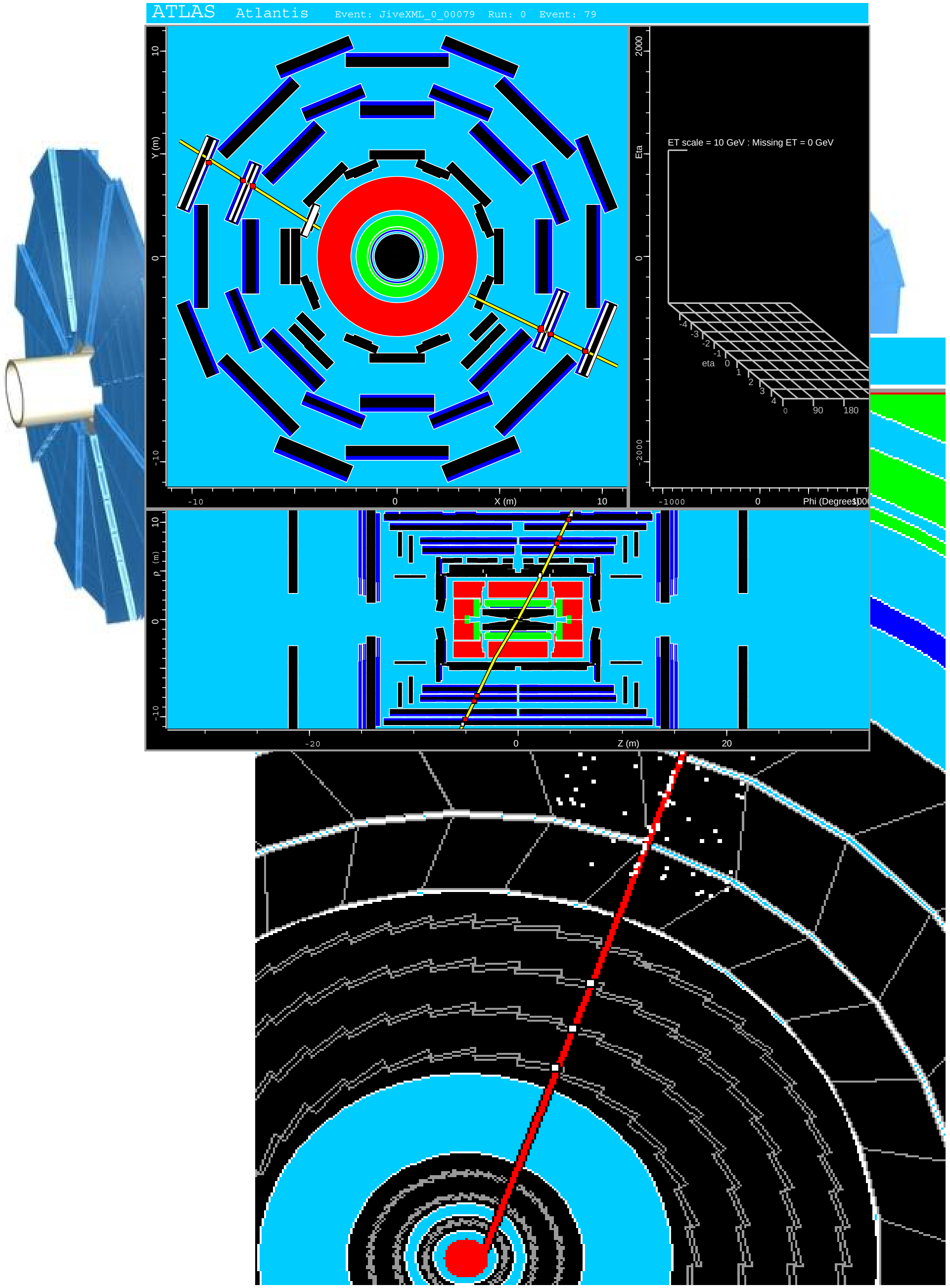
- **ATLAS is a general-purpose experiment:**

  emphasis on high-p_T physics beyond the Standard Model.

- **ATLAS has also capabilities for a rich B-physics programme:**

  precise vertexing and tracking, high-resolution calorimetry, good muon identification, and a dedicated and flexible B-physics trigger scheme.

- **ATLAS has a well-defined B-physics programme for all stages of the LHC operation, from the comissioning run all the way up to the high luminosity running.**



ATLAS Strategy for B-Physics

LHC luminosity periods
early $<10^{33}$ $cm^{-2}s^{-1}$
low 2×10^{33} $cm^{-2}s^{-1}$
nominal 10^{34} $cm^{-2}s^{-1}$

- **Strong points of ATLAS detector :**
  tracking, calorimetry & muon detection
  On the other hand ATLAS has no K/π PID detector
  - centrally produced events in proton-proton collisions at 14 TeV centre of mass energy
  - concentrate on multileptonic and photon decay channels
    - they are possible to trigger on
    - they are sensitive to New Physics

- **Concentrate on measurements that extend the discovery potential of ATLAS for physics beyond the Standard Model**
  - measurements of CP violation parameters that are predicted to be small in the SM (e.g in $B_s \to J/\psi\phi(\eta)$)
  - measurements of rare B-decays ($B_d \to K^*\gamma$, $B_d \to K^*\mu\mu$, $B_s \to \phi\gamma$, $B_s \to \phi\mu\mu$, $B_s \to \gamma\mu\mu$, $B \to \mu\mu$)

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

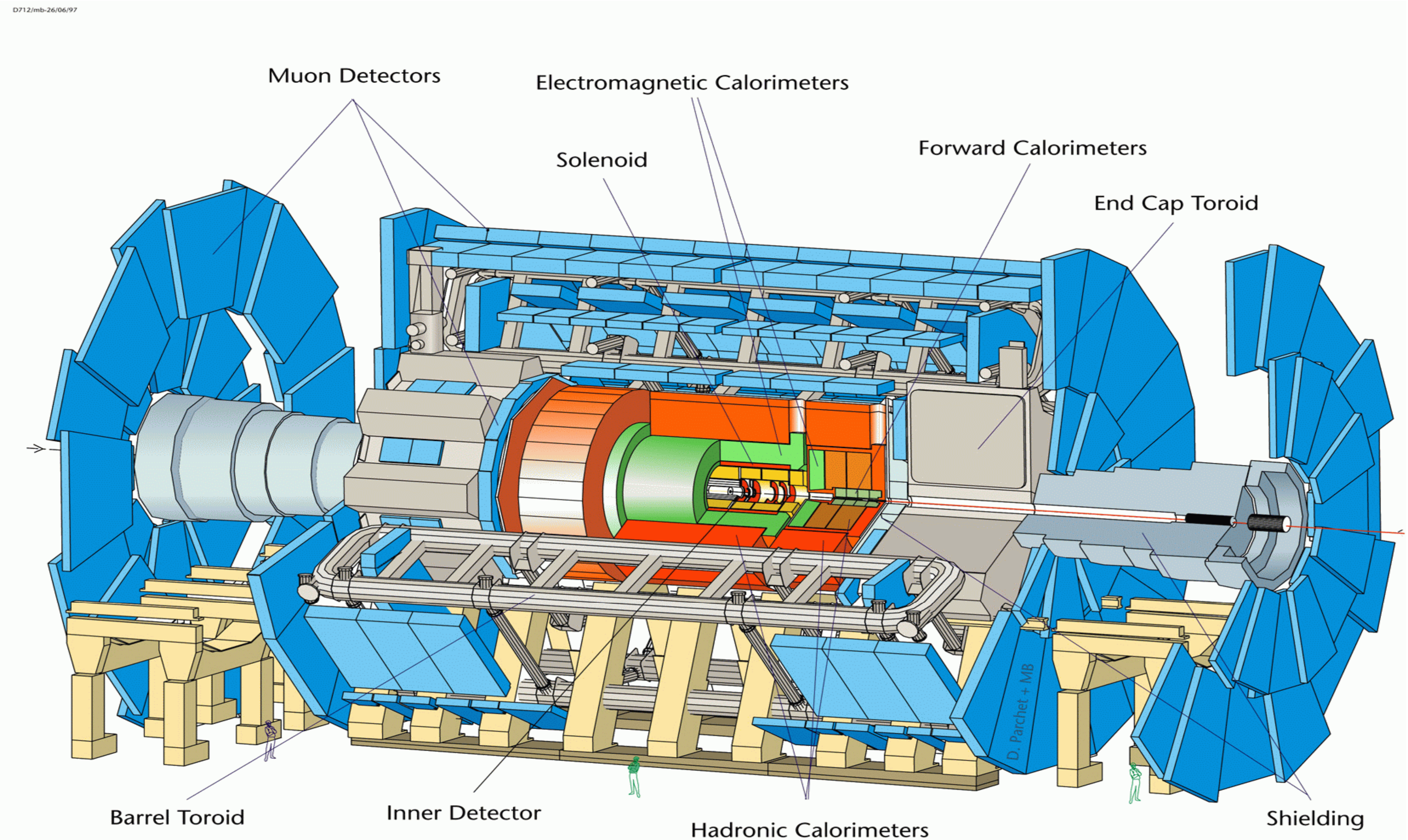
ATLAS B-Physics Program

Aim: precision measurements and new physics

- CP-violation parameters
- B-hadron parameters: masses, lifetimes, widths, oscillation parameters, couplings, b-production, etc.
- Search for New Physics effects: very rare decay modes, forbidden decays/couplings, etc.

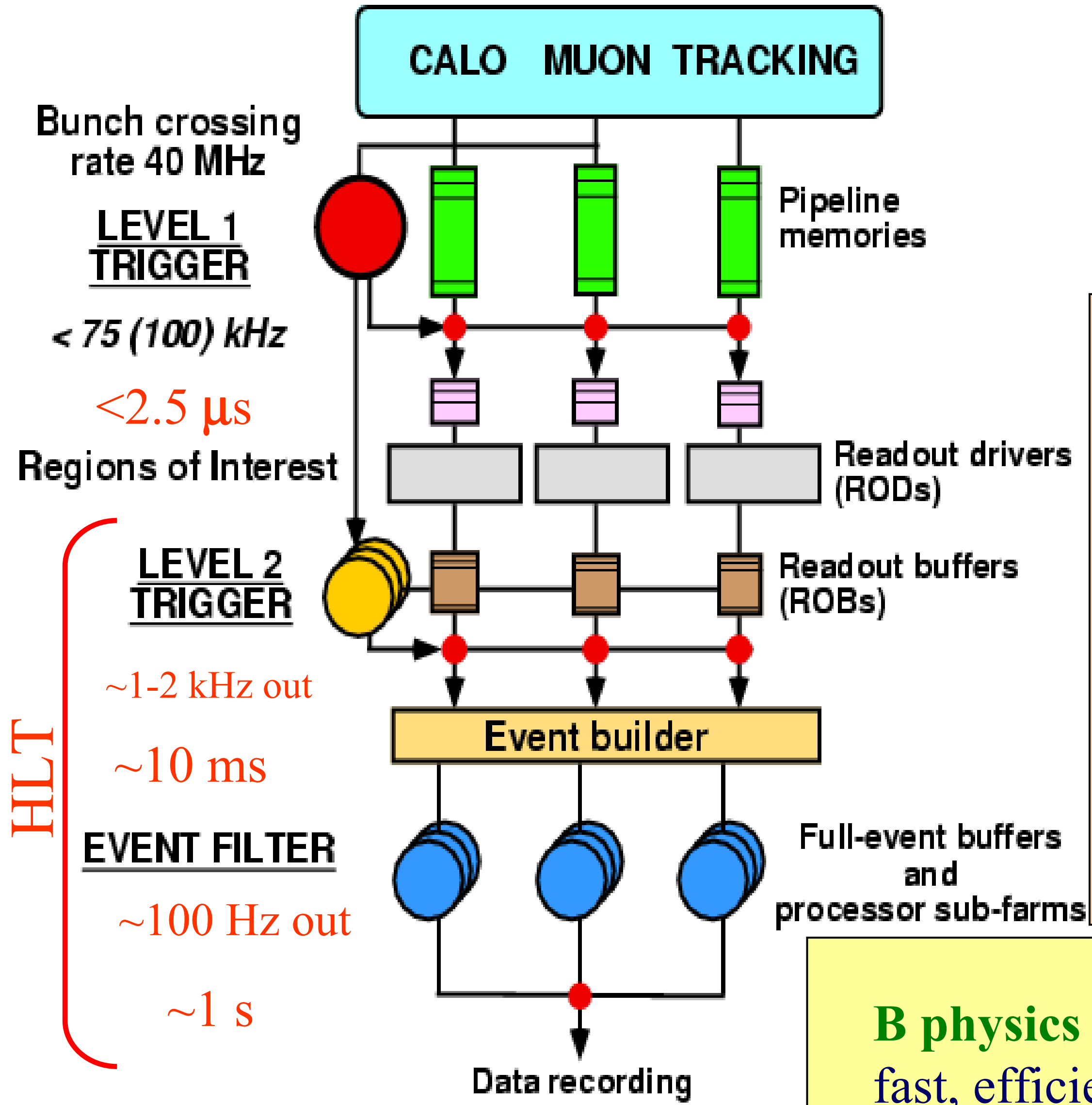
CP violation	$B_d \to J/\psi K_s^0(\pi\pi)$ $J/\psi \to \mu\mu / ee$	$\sin(2\beta) + \Phi_{NP}$
measurement of B_s properties	$B_s \to D_s\pi; B_{s,d} \to D_s a_1$ $B_s \to J/\psi(\mu\mu)\phi(KK)$ $B_{s,d} \to J/\psi(\mu\mu)\eta(\gamma\gamma)$	Δm_s, $\Delta\Gamma_s$, Γ_s, the weak phase ϕ_s
B_c mesons	$B_c \to J/\psi\pi; B_c \to J/\psi\mu\nu$	B_c mass, τ, QCD/EW interplay
Λ_b polarization measurements	$\Lambda_b \to J/\psi(\mu\mu)\Lambda(p\pi)$	asymmetry parameter α_b, P_b, life-time measurements
rare decays	$B_{s,d} \to \mu^+\mu^-; B_d^0 \to K^{*0}\mu\mu$ $\Lambda_b \to \Lambda\mu\mu; B_s^0 \to \phi^0\mu\mu$	precise measurements of the branching ratios and asymmetries

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 **o**f **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

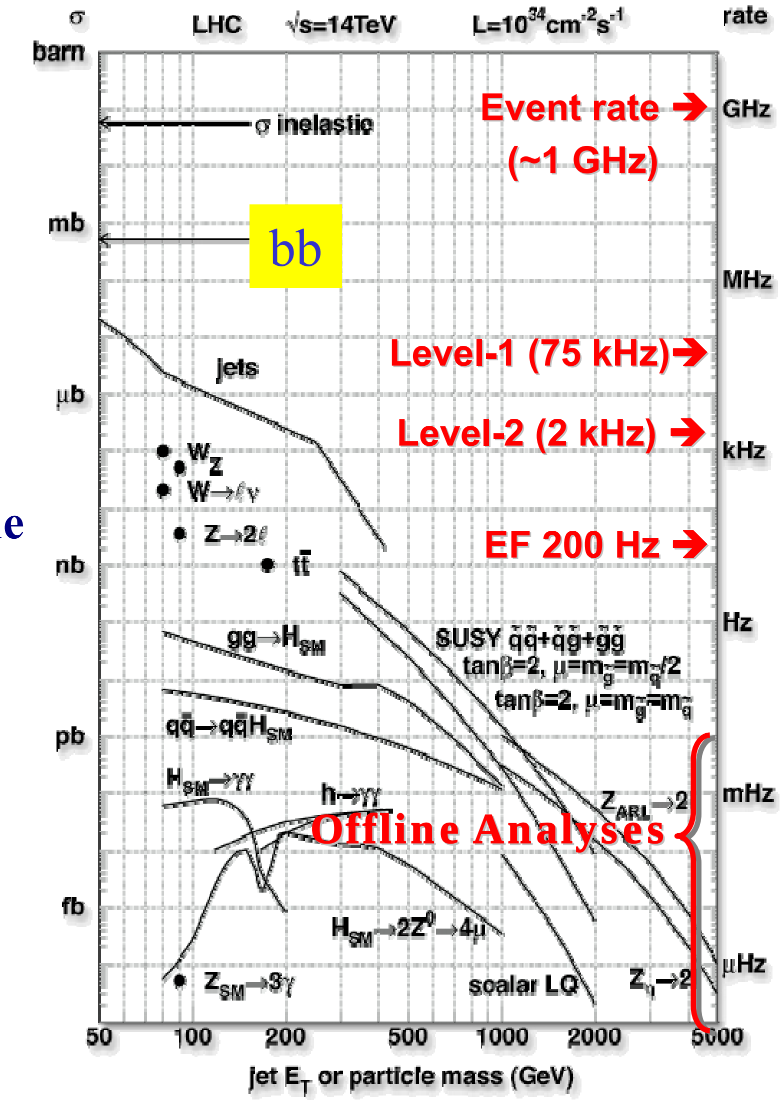
B physics allowed **~ 5-10%** of total trigger resources: fast, efficient and selective trigger strategies needed.

ATLAS general Trigger Strategy

b-production at LHC
σ_{tot} = 100 mb
σ_{bb} = 500 mb
(2×10^{12} bb pairs/year at low lumi)

- **About 1% of collisions produce a $b\bar{b}$ pair**

- In the illustrative trigger menus (described in the HLT/DAQ TDR) **more than 50% of the rate at LVL1** and **almost 40% of the rate at HLT** come from **electron signatures**
  - difficult to decrease the E_T threshold of the selected electrons/photons without additional trigger resources
  - **the key to the B-physics programme are muons based triggers, that can be identified cleanly at early stages of the trigger**.
  - **Muons also give a clean flavour tag**
  - trigger must be more selective than only concentrating in basic signatures (e.g 23 kHz at LVL1 from single muons of p_T>6 GeV)
    - concentrate on **exclusive channels** (reconstruct online the mass of the B hadron)
    - select online on transverse **decay length** (reconstruct primary and secondary vertex)



Trigger Strategies for B-Physics

- **emphasis on high-p_T physics at LHC:**
  limited bandwidth for B-triggers → highly efficient and selective trigger needed.
- **Factor ~2 drop in luminosity during a fill:**
  use of spare bandwith for B-physics triggers
- **Many b-decays contain J/ψ :**
  useful for calibration/understanding detector as well as B-physics
- **B-trigger is based on single and di-muons**
  BR ~ 10 % but clean signature at early level in trigger and give flavour tag (needed in many analyses)

- **Different strategies in different lumi regimes :**
  - High lumi (>2x10^{33} $cm^{-2}s^{-1}$)
    - LVL1 di-muon trigger → events with 2 muons
    - rare decays ($B\to\mu\mu(X)$) & $J/\psi\to\mu\mu$
  - Lower lumi (< 2x10^{33} $cm^{-2}s^{-1}$)
    - Continue di-muon trigger
    - Add triggers using LVL1 single muon trigger. High Level Trigger (HLT) reconstruction in secondary Regions of Interest identified by LVL1.

- **Broad programme of B-physics in initial low luminosity period.**
- Continue with rare-decay searches at high luminosity

ATLAS B-Trigger Strategies

- **High luminosity:**

  di-muon trigger (p_T > 6 GeV)
  - $B \rightarrow J/\psi(\mu\mu)$ X
  - double semi leptonic decyas
  - Rare decays with di-muon , e.g. $B\rightarrow\mu\mu$, $B\rightarrow K^{0*}\mu\mu$

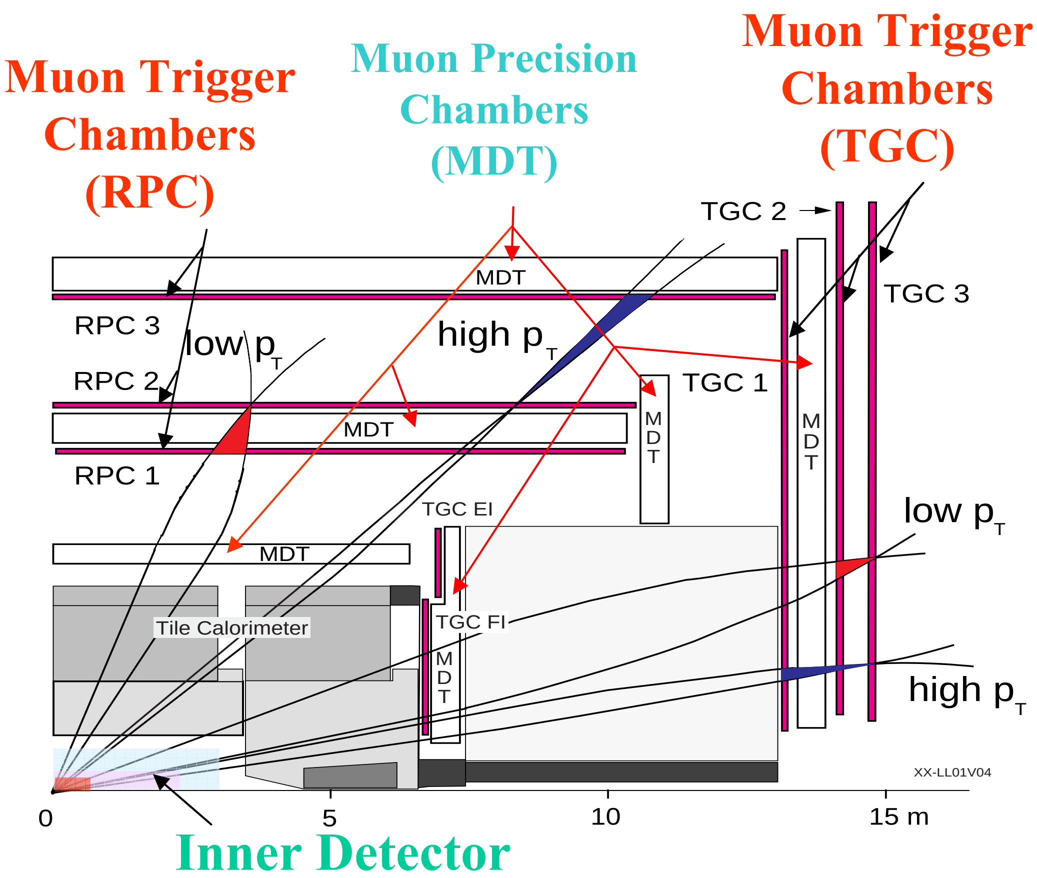
- **Low luminosity**

  – add an other type of trigger:

  single μ-trigger with additional LVL1 signature or a jet in calorimeter

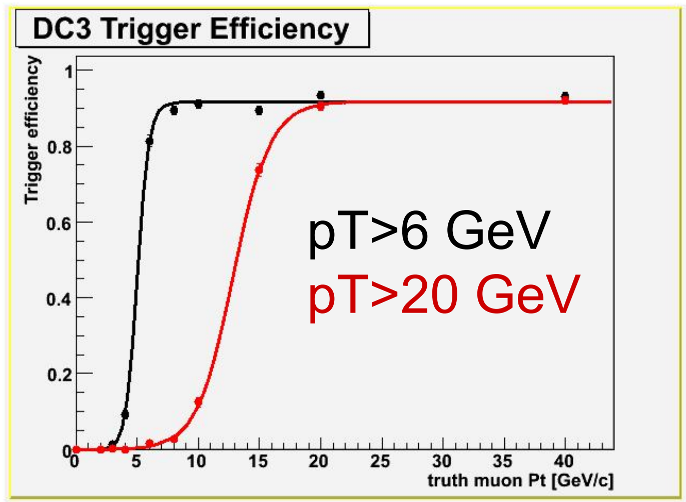
  At LVL2 2 possible approaches:
  - Full reconstruction inside inner detector (time costly)
  - Use LVL1 Regions of Interest (RoI) to seed LVL2 reconstruction:
    - Jet RoI: for hadronic final states (e.g. $B_s\rightarrow D_s(\phi\pi)\pi$)
    - EM RoI: for e/γ final states (e.g. $J/\psi\rightarrow ee$, $K^*\gamma$, $\phi\gamma$)
    - Muon RoI: to recover di-muon final-states in which second muon was missed at LVL1
  - New comparison of the 2 approaches using Jet RoI for $B_s\rightarrow D_s(\phi\pi)\pi$

Example: ATLAS LVL1 Muon Trigger



RPC: Restive Plate Chambers
TGC: Thin Gap Chambers
MDT: Monitored Drift Tubes

- LVL1 muon trigger requires hits in different layers within coincidence window (3/4 hits for low p_T muon).
- Efficiency ~85% (inefficiency mostly due to geometrical reasons (feet and supports))



Cross sections in ATLAS for Muon Channels

Process	Cross-section at $\sqrt{s} = 14$ TeV	Cross-section at $\sqrt{s} = 900$ GeV
Total LHC bb cross section	500 μb	25 μb
Total LHC inelastic σ	70 mb	40 mb
bb → μ6(5) X	4000 nb	60 nb
bb → μ6(5) μ3 X*	200 nb	2 nb
bb → J/ψ (μ6(5) μ3) X*	7 nb	0.1 nb
pp → J/ψ (μ6(5) μ3) X*	28 nb	1 nb
pp → ϒ (μ6(5) μ3)*	9 nb	1.7 nb

*) Dimuon p_T cuts for 14 TeV are (6, 3) GeV, and for 900 GeV (5, 3) GeV
For both muons $|\eta|<2.5$

Triggers for the Commissioning Running

- $\sqrt{s}$ = 0.9 TeV, L = 10^{29}cm^{-2}s^{-1},

  σ_{inel}= 40 mb ↔ 4 kHz interaction rate
- Commissioning run for detector and trigger, but also for offline reconstruction and analysis chains
- Data taking with loose level-1 (LVL1) muon triggers or minimum bias triggers
- The High Level Trigger (HLT) in pass-through mode for testing
- HLT code will run to test the algorithms
- Physics potential limited, but valuable source of commissioning

Expected Rates and Statistics

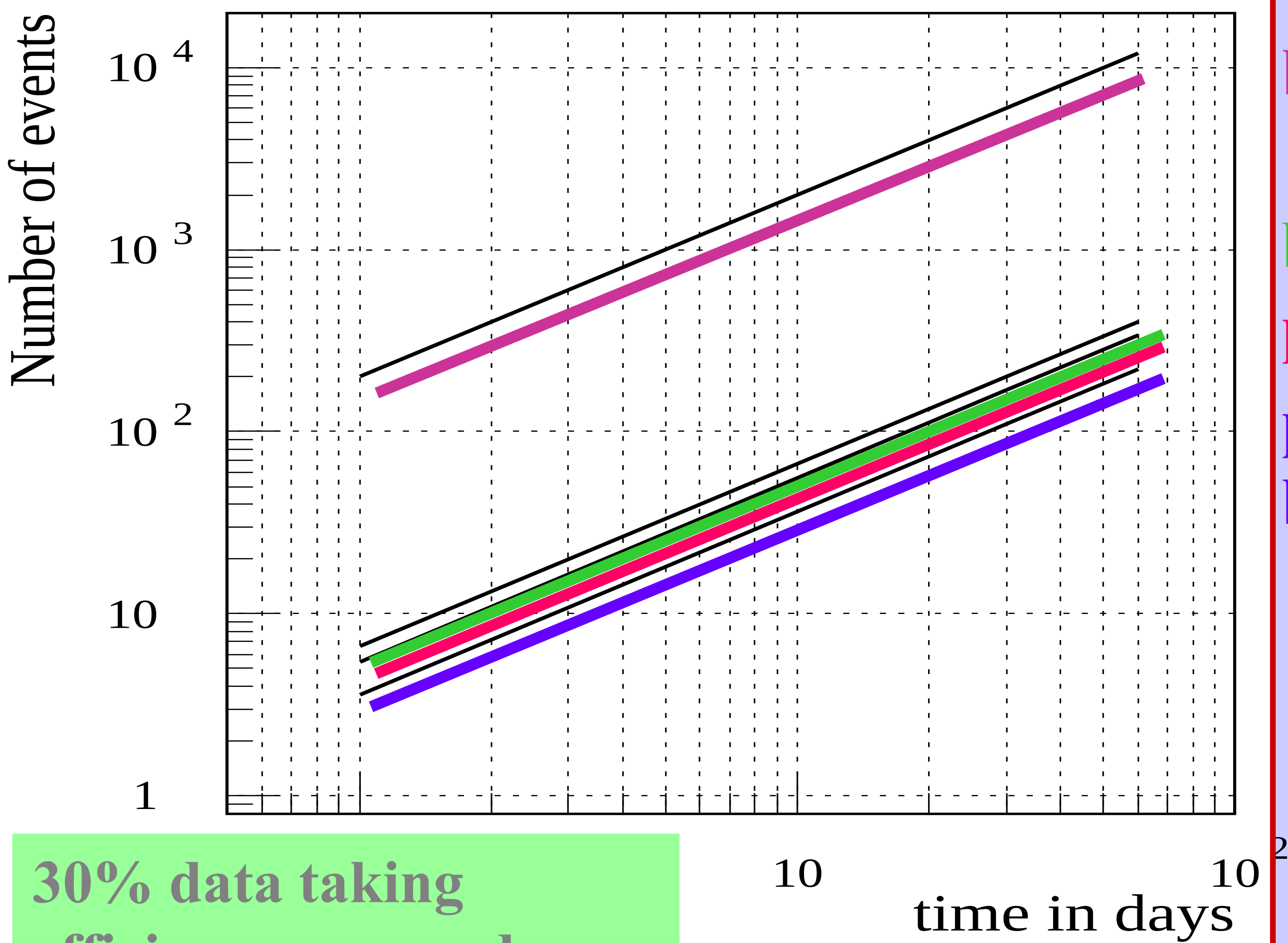
Commisioning Run 2007,
$\sqrt{s}$ =900 GeV, L=10^{29}cm^{-2}s^{-1}

Decay	Rate	N(ev) for 1 d*	N(ev) for 30 d*	N(ev) for 60 d*
bb → m5 X	$60 * 10^{-4}$ Hz	150	4700	9000
bb → m5 m3 X	$2 * 10^{-4}$ Hz	5.2	150	300
bb → J/y (m5 m3) X	$0.1 * 10^{-4}$ Hz	0.3	8	16
pp → J/y (m5 m3) X	$1 * 10^{-4}$ Hz	3	80	160
pp → ϒ (m5 m3)	$1.7 * 10^{-4}$ Hz	4.4	130	260

*) 1 full day is $8.64 * 10^4$ s, 30% data taking efficiency assumed

Event Statistics for B and Quarkonium (Muon Channels)

$\sqrt{s}$ =900 GeV, L=10^{29}cm^{-2}s^{-1}, duration ~ 30 days



30% data taking efficiency assumed

bb → μ5 X

bb → μ5μ3 X

pp → ϒ (μ5μ3) X

pp → J/ψ (μ5μ3) X

bb → J/ψ (μ5μ3) X

Conclusions for 900 GeV Running

- Heavy flavours b and c will be a source of ~ 6000 single-μ and ~500 di-μ in 30 days of beam.
- Muons from decays in flight dominate single muon events at low p_T
- LVL1 muon information will be used to test build of RoI and HLT.
- 100 J/ψ(μ5μ3) and 1700 ϒ(μ5μ3) will be produced – and can serve for first tests of mass reconstruction.
- Any HF physics to be measured?
- Low statistics will not allow to separate direct and indirect J/ψ sources. However first physics measurement may be a ratio of J/ψ and ϒ – events – where muon efficiency corrections (online and offline) cancel.

B-Physics at 14 TeV: Strategies for 100 pb^{-1} to 1 fb^{-1}

Goals for first B-physics measurements:

Serve as a test of understanding detector and trigger:
calibrations, alignment, commissioning, material, field, reconstruction.

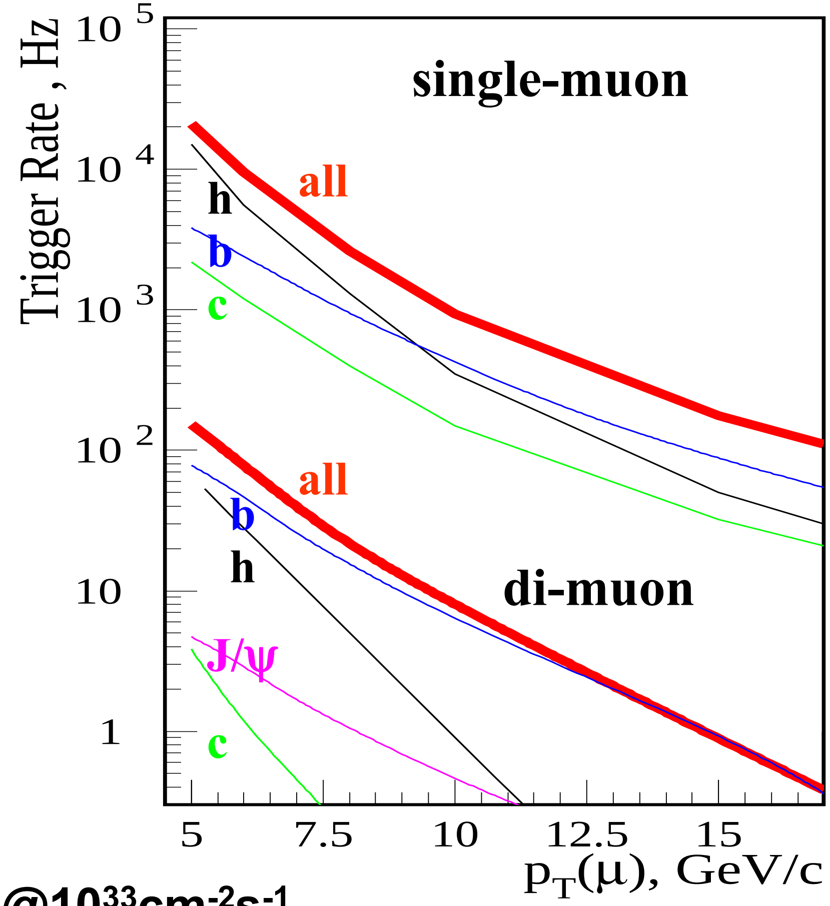
Physics:
cross section measurements at new energy - QCD tests and optimization of B-trigger strategies.

Control B channels:
to verify if we measure correctly well known B-physics quantities, later with increasing integrated luminosity – improve precisions of these.

Control B-measurements:
to prepare further high sensitive and discovery B-measurements: tagging calibrations, production asymmetries, background channels specific for rare decays – some of them new channels themselves.

Sources of low p_T single and double muons

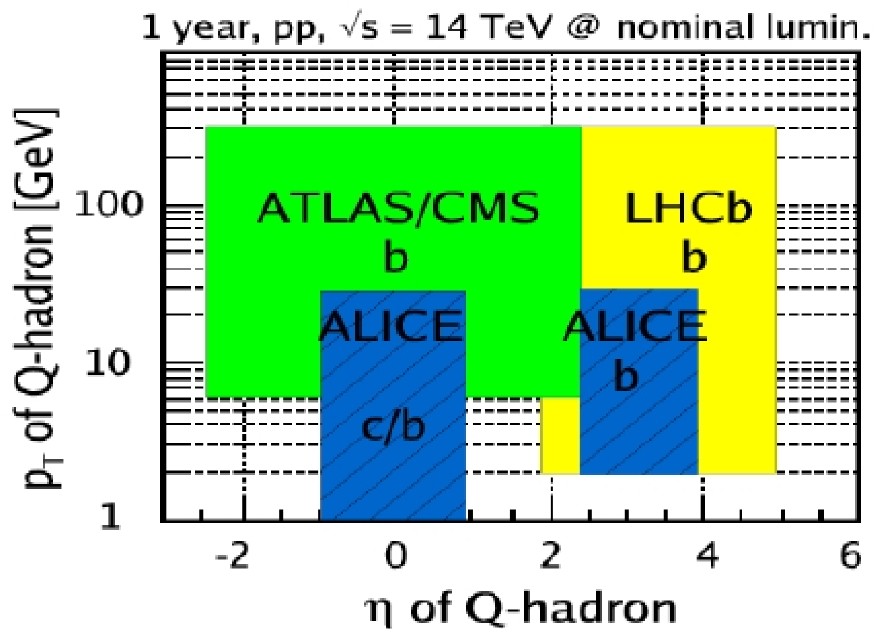
ATLAS muon rates for 14 TeV and $10^{33} cm^{-2}s^{-1}$

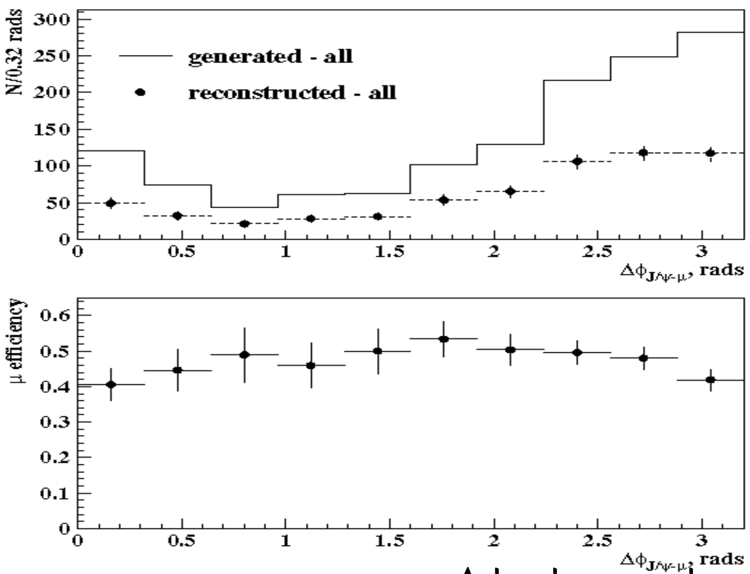


@$10^{33} cm^{-2}s^{-1}$

- **Figure shows all low p_T sources of muons at 14 TeV.**
- **Muons from hadrons decays in flight (denoted as "h" in fig.) dominate in single muon up to $p_T < 8$ GeV**
- **At 900 GeV their contribution may more important - bb fraction of total inelastic cross section ~10 times smaller than at 14TeV.**
- **In di-muon trigger beauty muons dominates in all acepted events over full p_T region**

B-Cross Section Measurements at LHC





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

1. All LHC experiments plan to measure B-cross section in proton-proton collisions.
2. Measurements will cover different phase space – will be complementary.
3. Partial phase space overlaps: LHCb, ATLAS, CMS, Alice - opportunity for cross checks
4. Methods of measurement for low and medium pT events in ATLAS
   - $bb \to \mu6\ X$;
   - $bb \to J/\psi\ X$;
   - Exclusive channels $B^+ \to J/\psi\ K^+$, $B^0 \to J/\psi\ K^{0*}$
   - b-b correlations: $B^+ \to J/\psi\ K^+ + \mu$ (fig. left down)

B-Physics with 100 pb^{-1} (I)

statistics in dominant inclusive, exclusive channels

	10 pb^{-1}	100 pb^{-1}
$pp \to \mu 6\ X$	$60 . 10^{6}$	$600 . 10^{6}$
$bb \to \mu 6\ X$	$40 . 10^{6}$	$400 . 10^{6}$
$cc \to \mu 6\ X$	$20 . 10^{6}$	$200. 10^{6}$
$bb \to \mu 6\ \mu 3\ X$	$2 . 10^{6}$	$20 . 10^{6}$
$pp \to J/\psi(\mu 6 \mu 3)$	$2.8\ 10^{5}$	$2 .8\ 10^{6}$
$\Upsilon\ (\mu 6 \mu 3)$	$0.9 .10^{5}$	$0.9 .10^{6}$
$B^{+} \to J/\psi\ K^{+}$	1700	17 000
$B^{0} \to J/\psi\ K^{0*}$	870	8700

B-Physics with 100 pb^{-1} (II)

measurements in control channels:

Sensitive tests of understanding of detector properties with strong impact on selected B-physics measurements: masses, lifetimes

		Statitics **100 pb-1**	Statistical error on Lifetime	World today (stat + syst)
B^+	$B^+ \to J/\psi K^+$	17000	1.5 %	0.4 %
B^0	$B^0 \to J/\psi K^{0*}$	8700	2.2 %	0.5 %
B_s	$B_s \to J/\psi \phi$	900	6 %	2 %
Λ_b	$\Lambda_b \to J/\psi \Lambda$	260	8 %	5%

ATLAS Sensitivity in Discovery Channel $Br(B^0_s \to \mu^+\mu^-)$

sensitive to SUSY with 100 pb^{-1} and later

Integral LHC Luminosity	Signal ev. after cuts	BG ev. after cuts	ATLAS upper limit at 90% CL	CDF&D0 upper limit at 90% CL
100 pb^{-1}	~ 0	~ 0.2	6.4×10^{-8}	8×10^{-8}
10 fb^{-1}	~ 7	~ 20	1.2×10^{-8}	
30 fb^{-1}	~ 21	~ 60	6.6×10^{-9}	

Conclusions for Initial Running

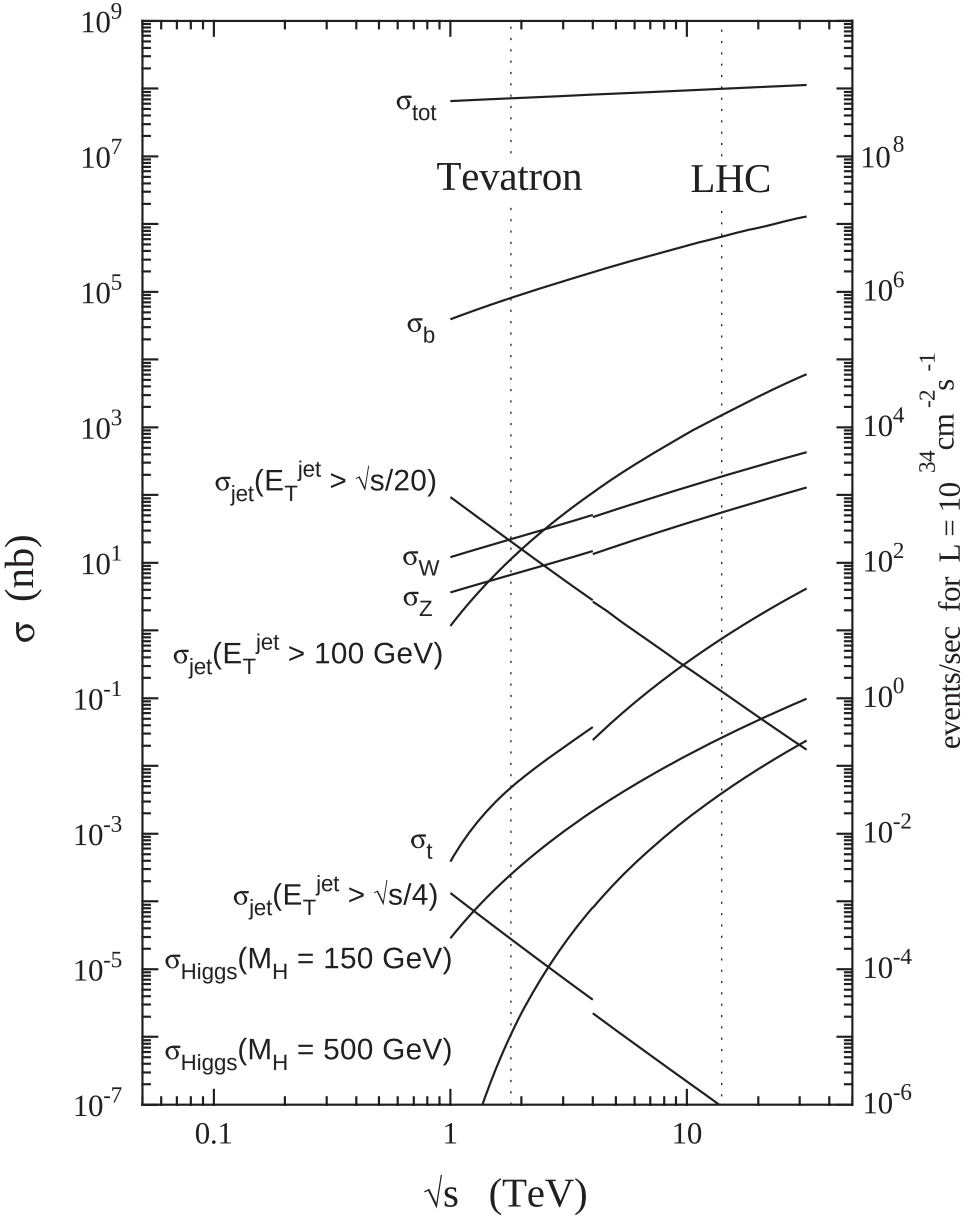
At 900 GeV

- heavy flavours b and c will be a source of ~6000 single-μ and ~500 di-μ in 30 days. These events can be selected by LVL1 muon trigger and serve for first tests of trigger and offline muon reconstruction.
- 100 J/ψ(μ5μ3) and 170 ϒ (μ5μ3) will be produced – can serve for first tests of mass reconstruction

At 14 TeV for 100pb^{-1} up to 1fb^{-1}

- Measurements of B-masses and lifetimes will serve as a sensitive test of understanding detector: alignment, material, field, reconstruction.
- Cross section measurements at new energy - QCD tests and also optimization of B-trigger strategies.
- Control B-measurements to prepare further discovery B-measurements – some control measurements - new physics measurements themselves.
- With 100pb-1 ATLAS can achieve sensitivity **6.4×10^{-8}** in discovery channel $Br(B^0_s \to \mu^+\mu^-)$ which is at the level of today's Tevatron summary.

Inclusive Cross Section Measurement



σ(pp) at design lumi at 14 TeV

inelastic cross section at 70 mb

inclusive b-production at 0.5 mb

ratio σ_b / σ_{inel} = 7.1 x 10^{-3}

rate of **6 MHz** expected

σ(pp) at commisoning run (900 GeV)

inelastic cross section at 40 mb

inclusive b-production at 0.025 mb

ratio σ_b / σ_{inel} = 6.2 x 10^{-4}

rate of **0.3 MHz** expected

Inclusive b-Production Cross Sections

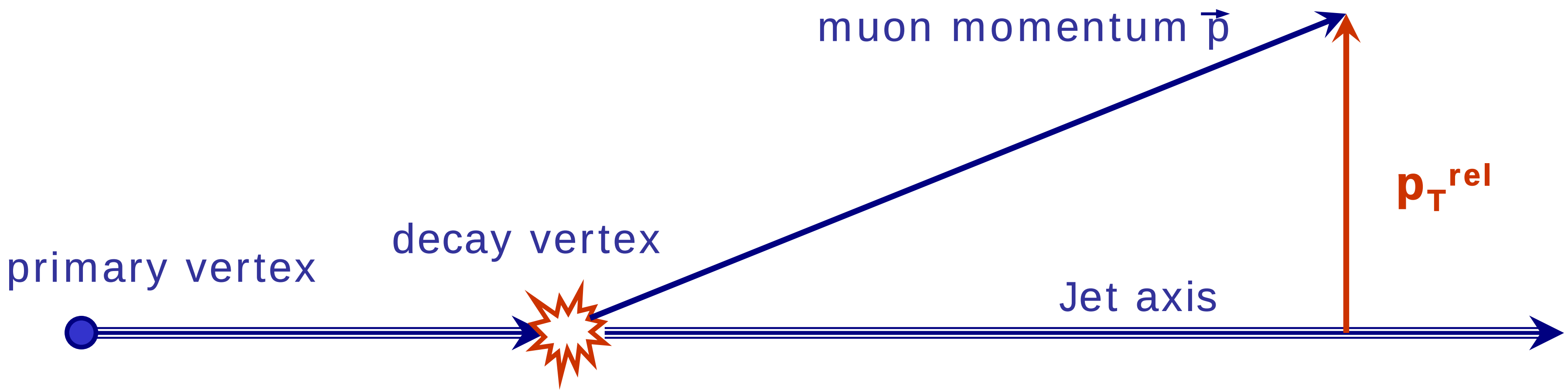
At 900 GeV running

- Well measured cross sections by older experiments (TEVATRON, SppS) below and above 900 GeV
- Monte Carlo descriptions well tuned
- Good opportunity for trigger commissioning and tests
- B-tagging only using CALO and MU-system (p_T^{rel})
- Use **single-μ-trigger**
- To minimize systematics: relative measurement to inclusive μ-production
- Small data sample expected (if any..): no qualified measurement,
- Only a first cross check

At 14 TeV running

- Unknown inclusive b-production cross section: precise measurement needed
- Knowledge of b-production cross section important for trigger commissioning and trigger rate prediction
- First measurement will be inclusive an should combine all available detector information:
  - **Muon** signature and **Jet** in calorimeter should be combined in the so called **p_T^{rel} – methode**
  - Inner detector tracking system: measurement based on **track/vertex information**
- Use **single-μ trigger**, **di-μ trigger** and **μ/e-trigger**

Relative Muon-Jet Transverse Momentum p_T^{rel}

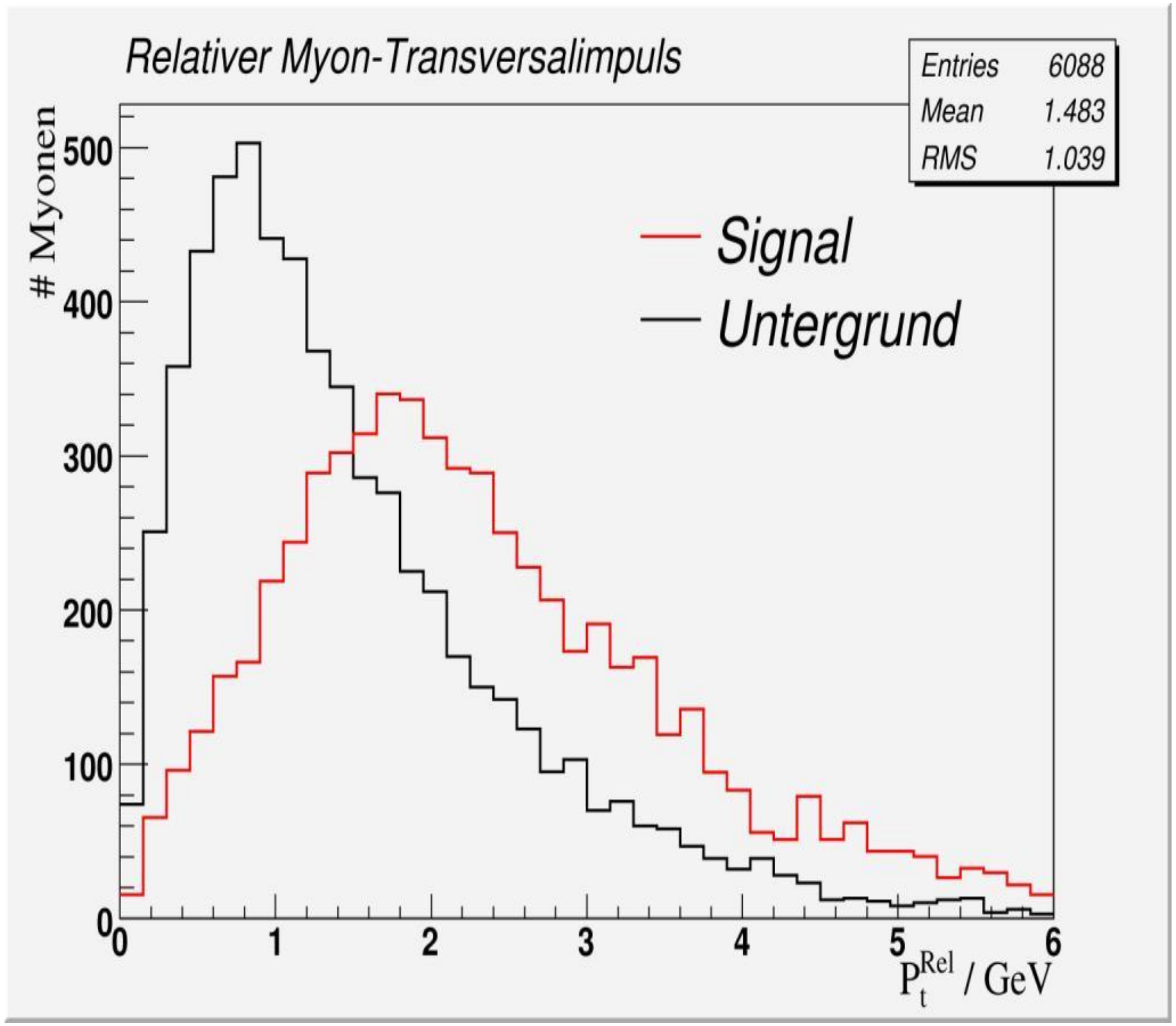


- Maximal $p_T^{rel} \sim \Delta m$ of initial and final states
- Large B-meson mass $\rightarrow$ p_T^{rel} usable for b-flavour tagging
- Main background: leptons from D-mesons ($m_B > 5$ GeV ,$m_D < 2$ GeV)
- Only muon- and calorimeter data neccesary (no innder detector information needed)
  - ideal for fast triggerin on LVL2
- Connection muon $\leftrightarrow$ associated Jet:
  - require exactly one Jet within a cone of **$\Delta^2\varphi + \Delta^2\eta < 0.64$** arround the muon

Relative Myon Transvers Momentum p_T^{rel}

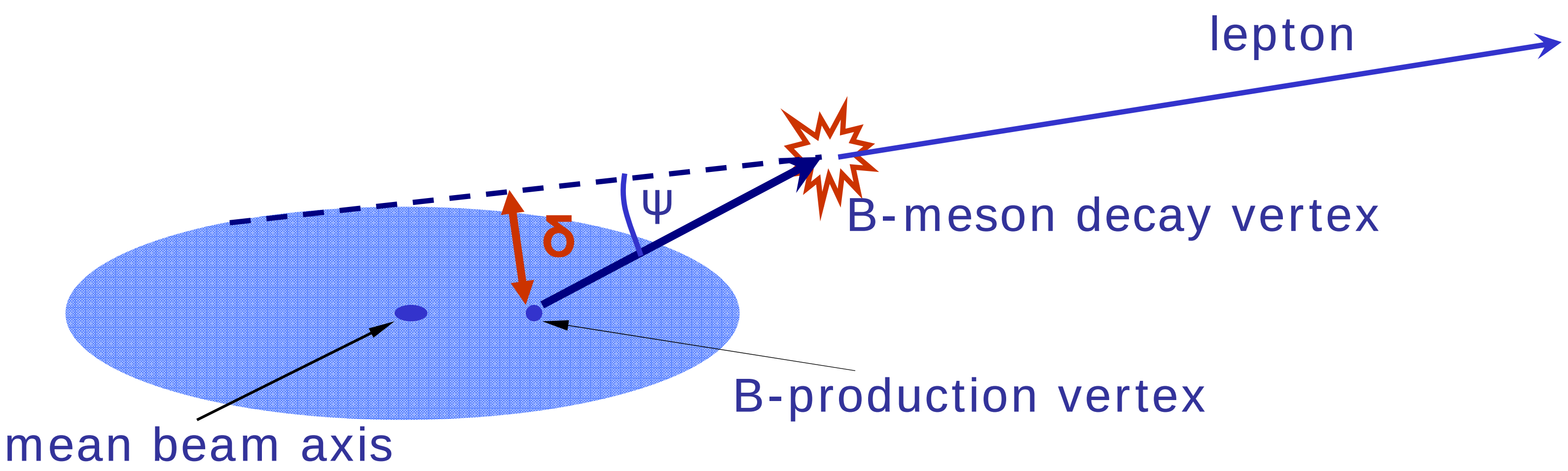
- Maxima of distribution clearly separated
- Suitable for soft seletcion cuts
- Good oportunity for a simple LVL2 trigger b-flavour trigger

Pythia MC (b and light flavour BG)



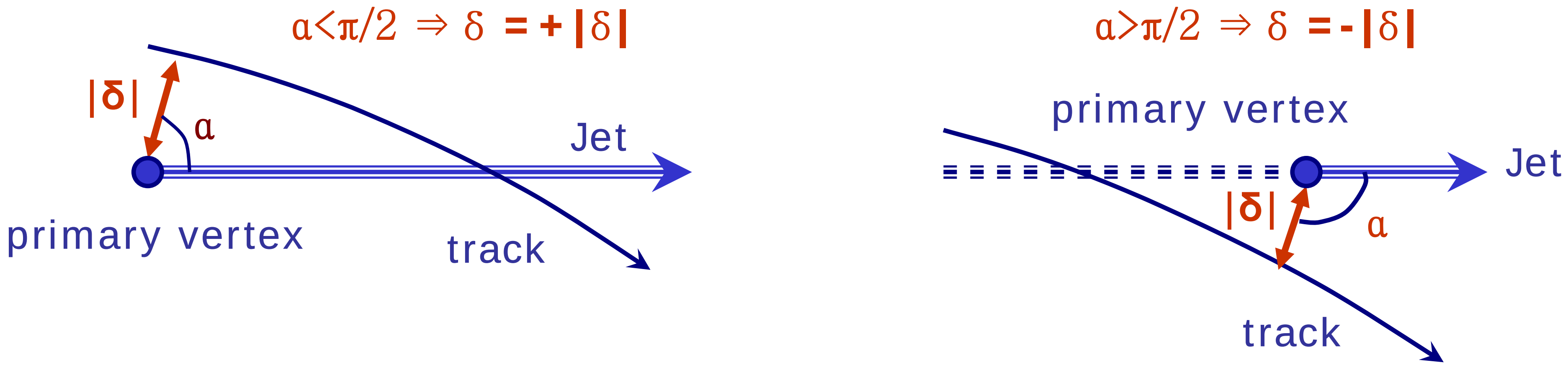
Diploma Thesis from Sören Jetter and Michael Volkmann (HU Berlin)

Impact Parameter δ



- Shortest transversal distance from track to primary vertex
- In relativistic limit (>10 GeV) ~ life time τ
- Long B-meson life time → δ suitable for selection criteria
- Dominant background: leptons from D-mesonen
  - $\tau_D = 1.0$ ps $\Rightarrow \langle\delta_D\rangle \approx 140\mu m$
  - $\tau_B = 1.4$ ps $\Rightarrow \langle\delta_B\rangle \approx 200\mu m$

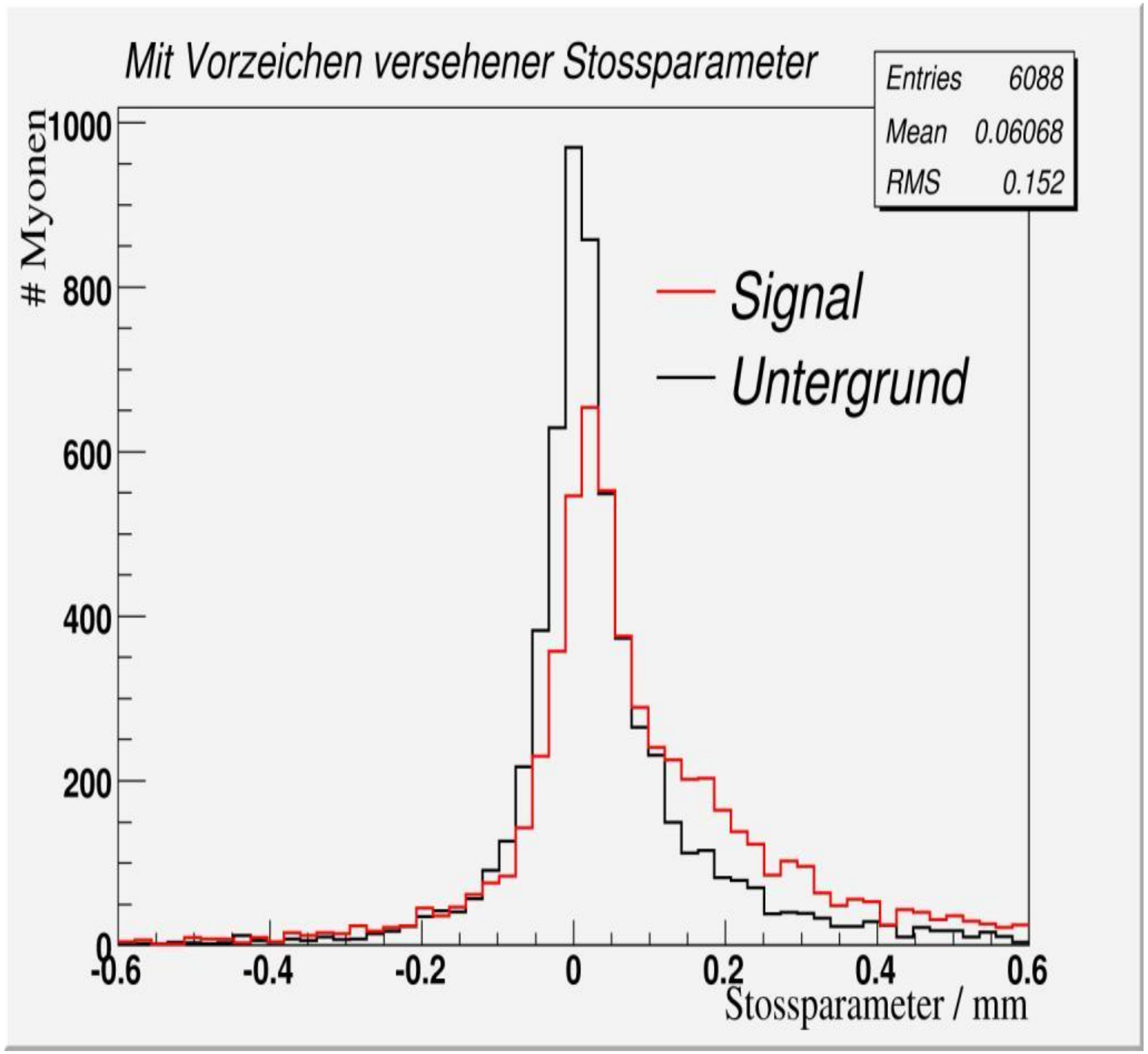
Signed Impact Parameter



- Positive sing correspond to B-physics events
- Negative sing due to
  - detector resolution
  - wrong association of jet – secundary particle
  - wrong reconstructed jet
- Enrichment of b-flavoured events at positive impact parmeters

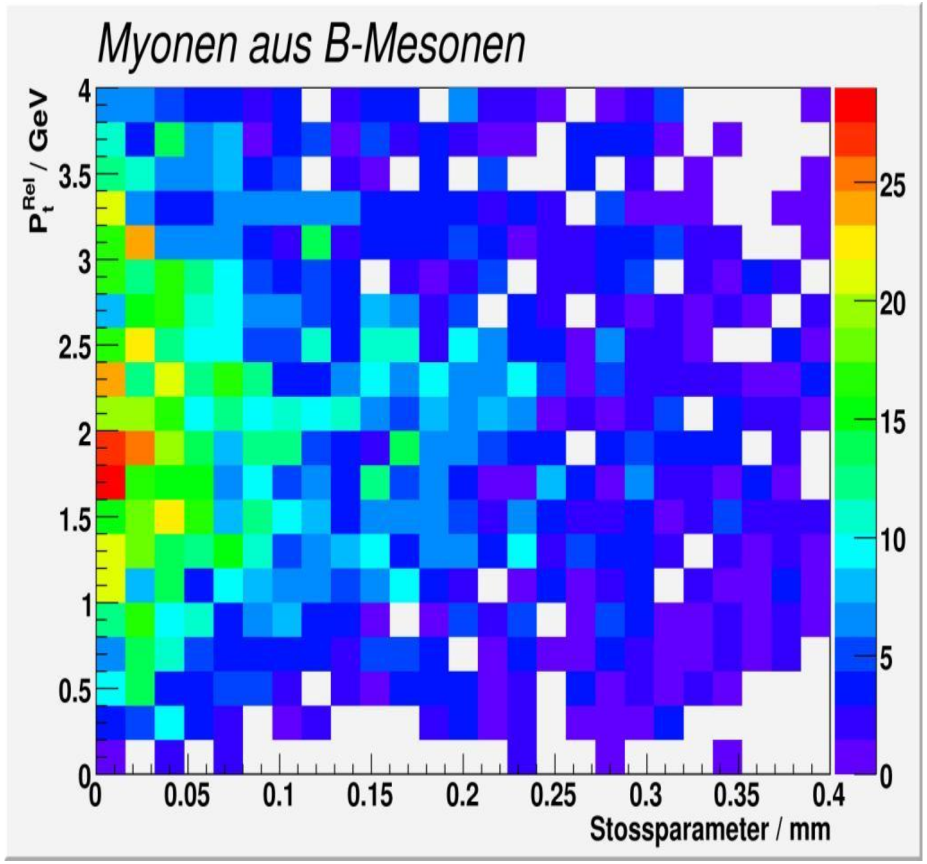
Distribubion of singend Impact Parameters

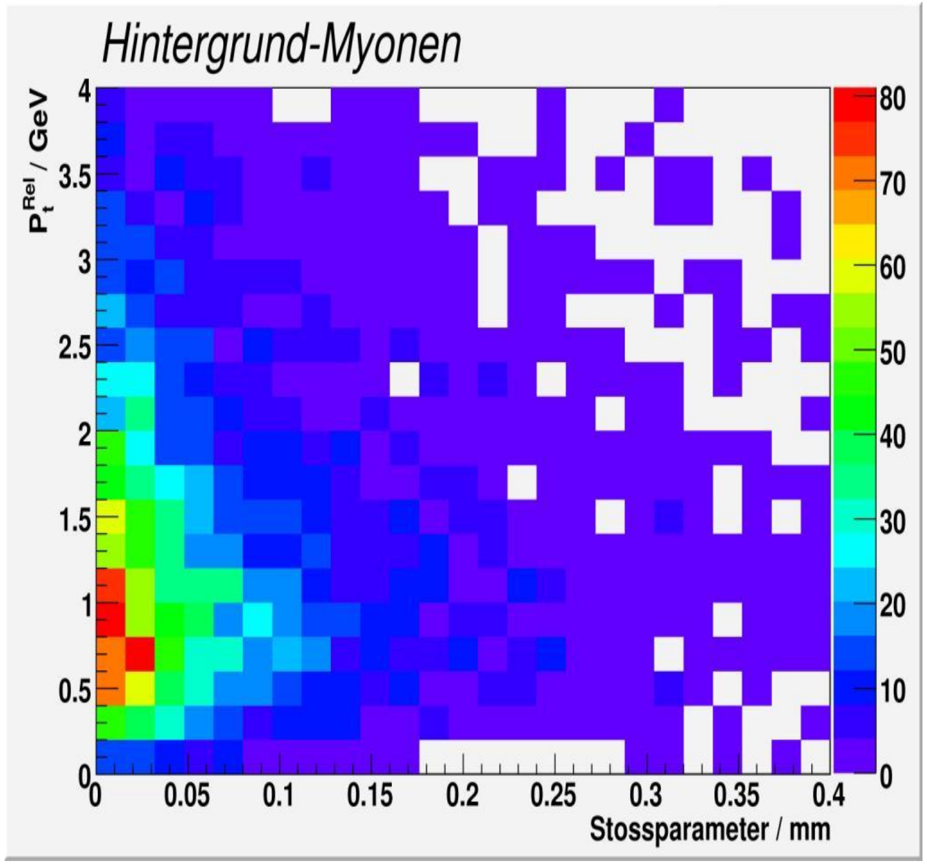
- Gaussian distribution reflects the detector resulution
- negative impact parameter: signal and background are looking identical
- Exponential decay at large impact parameters:
  - signal enrichment



Diploma Thesis from Sören Jetter and Michael Volkmann

Correlation of Impact parameter and p_T^{rel}





Diploma Thesis from Sören Jetter and Michael Volkmann

- relativ transversal momentum and impact parameter of muons are only weakly correlated

→ both can be used for b-flavour tagging

Conclusion

- ATLAS has a well defined B-Physics strategy
  - in analysis
  - in b-tagging and triggering
- 900 GeV run very importand for trigger, detector and analysis tools commissioning
- Physics potential of 900 GeV run limited
- Many B-physics studies can be done with the first data at 14 GeV in the low luminosity phase
- First studies for b-tagging for inclusive cross section measurement