B-triggers at ATLAS

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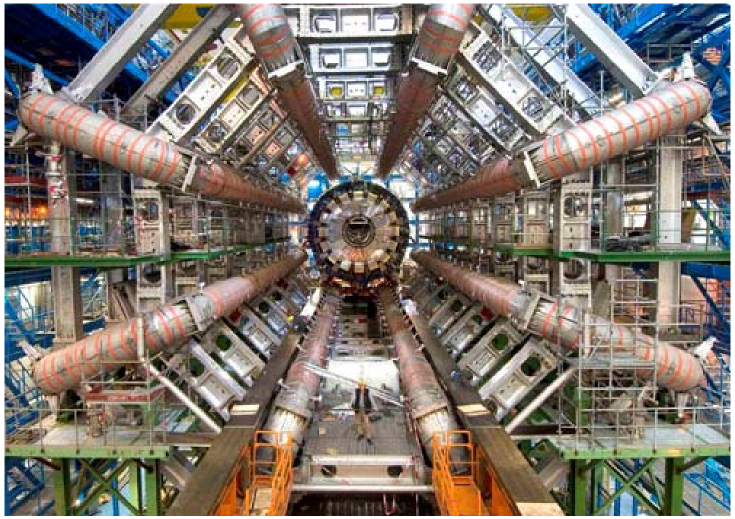


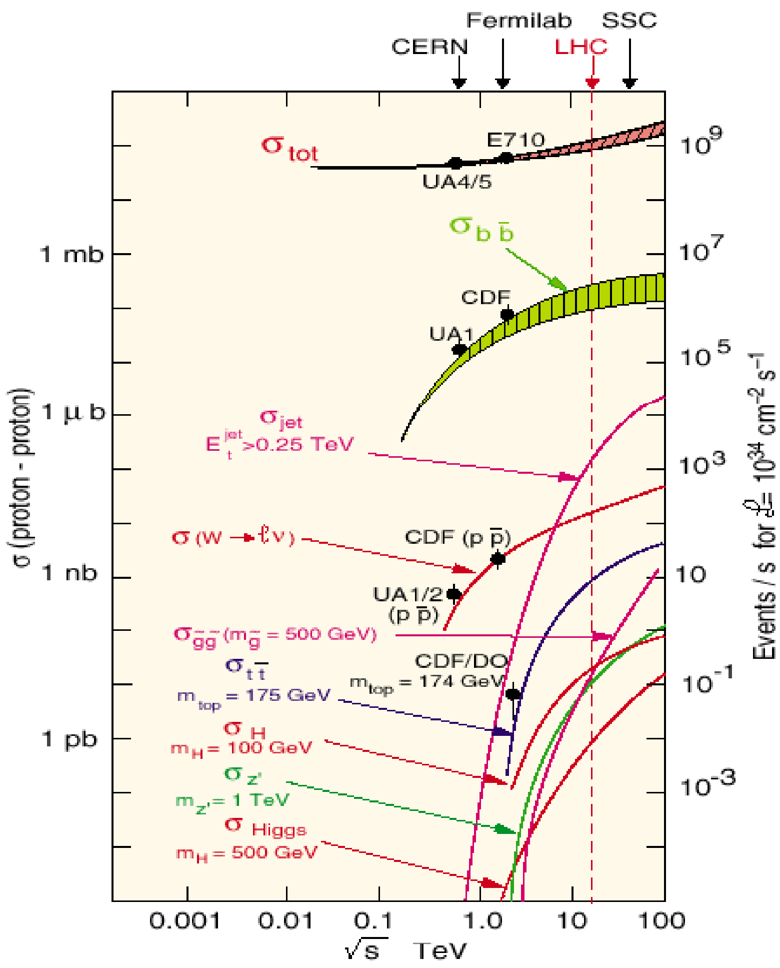
- Introduction
  - B physics at LHC
  - ATLAS and the ATLAS trigger
- B triggers:
  - B-trigger strategy
  - Muon triggers
  - Examples of specific B triggers
  - Menu evolution
  - Efficiency studies
  - Commissioning
- Summary

B physics at LHC

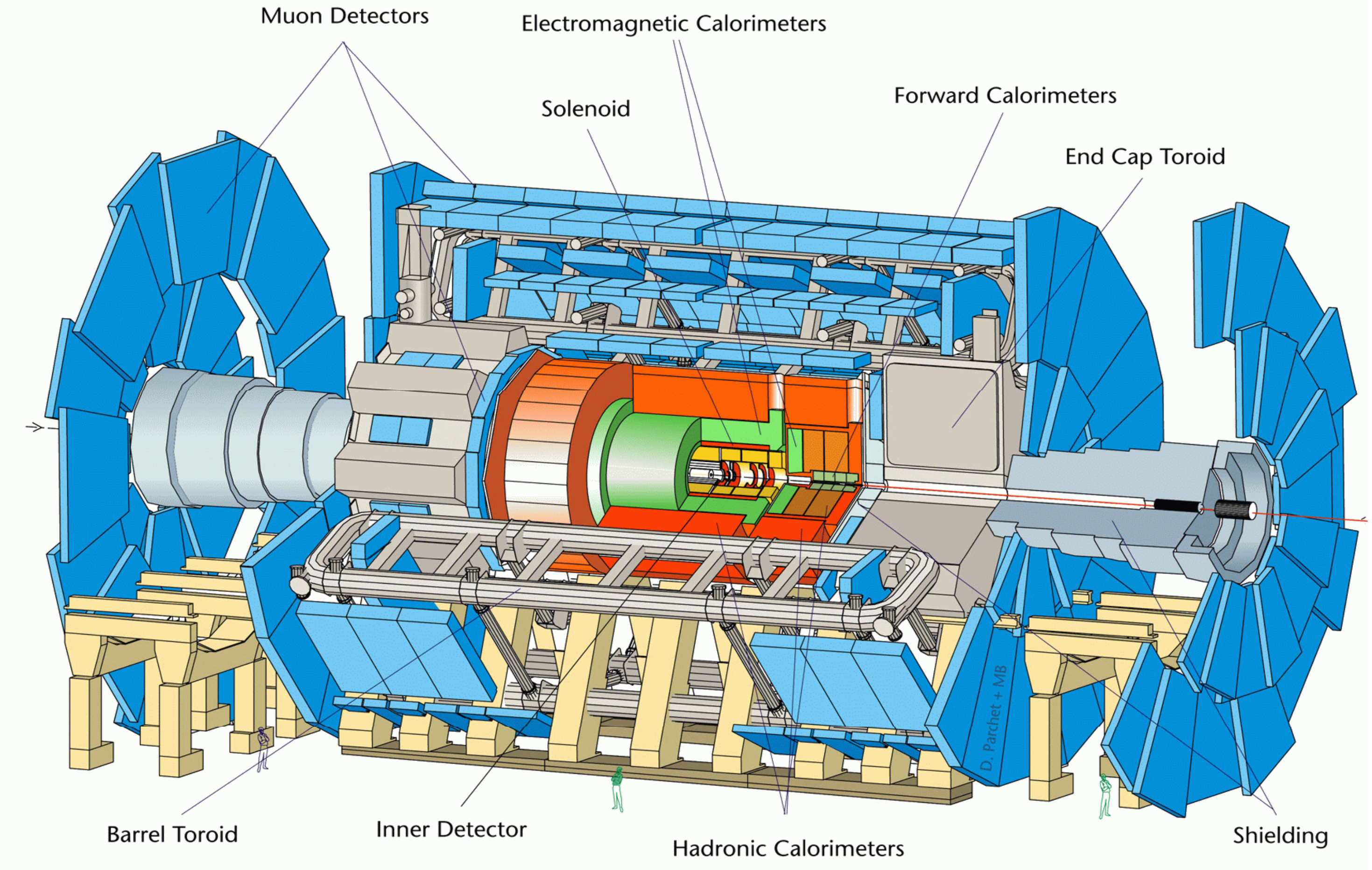
- LHC: proton-proton collisions at $\sqrt{s}$ = 14TeV
  bunch crossing rate 40kHz

- High *bb* production cross section: ~500 μb
  (~ 1 in 100 p-p collisions → *bb* pair). Must select those of interest.

- ATLAS has a wide ranging B-physics programme covering SM and NEW physics:
  - QCD tests (beauty and onia production)
  - CP violation (e.g. $B \to J/\psi(X)$)
  - B_s oscillations (e.g. $B_s \to D_s\pi$, $B_s \to D_s a_1$)
  - Rare decays (e.g. $B \to \mu\mu$, $B \to \mu\mu(X)$, $B \to K^*\gamma$)

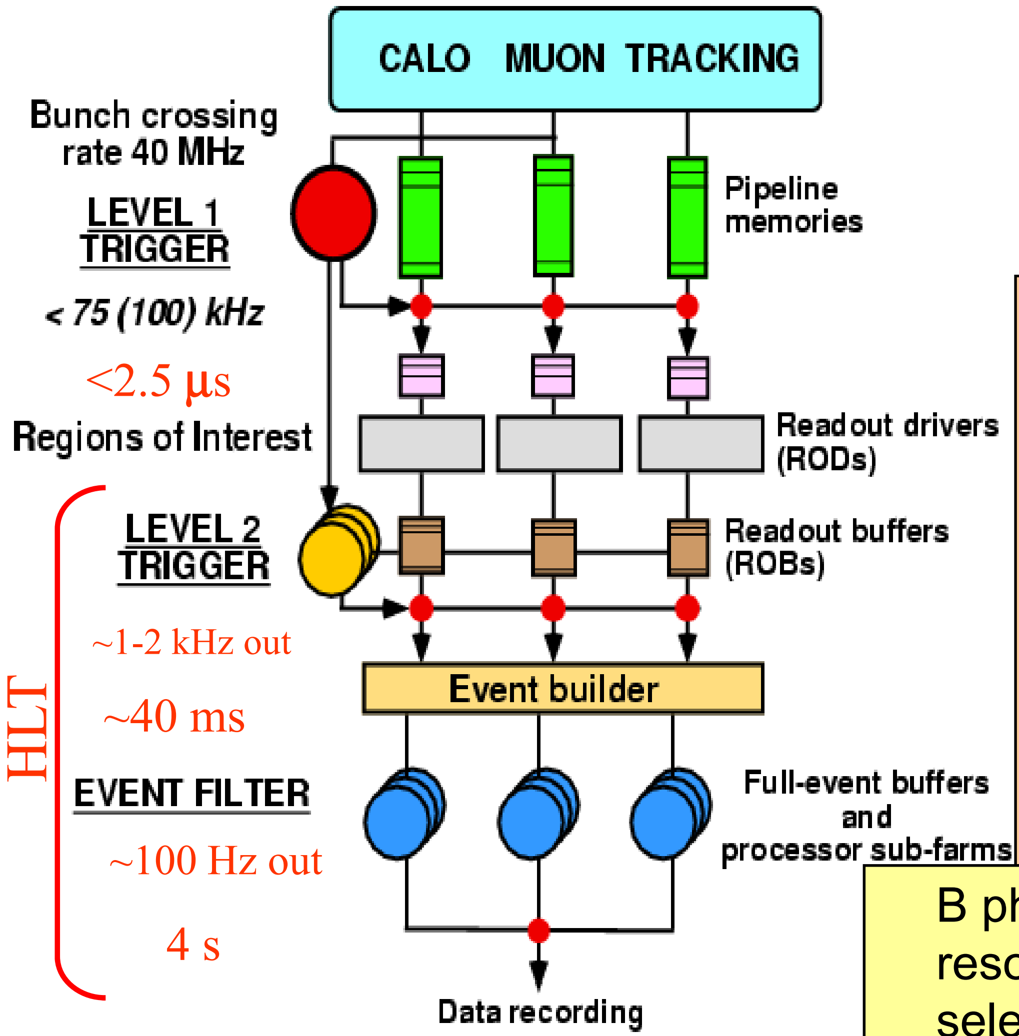


ATLAS detector



➣ 46m Long, 22m Diameter, 7'000 Ton Detector

Overview of ATLAS trigger



LEVEL 1 TRIGGER
- Hardware based (FPGAs ASICs)
- Uses coarse granularity calorimeter and muon information
- Identifies Regions Of Interest for further processing

HLT: software based

LEVEL 2 TRIGGER
- Full granularity
- Confirm LVL1 trigger
- Combine info from different detectors in RoIs 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 => it must be fast, efficient and selective.

B trigger strategies

- Limited bandwidth for B-triggers (ATLAS emphasis on high-p_T physics) – need to be fast, efficient and selective.
- 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)

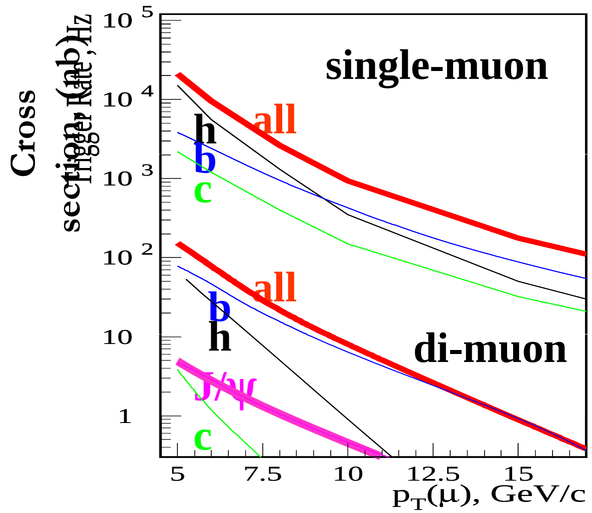
Different strategies in different luminosity regimes :

- High lumi (>~2x10^{33} cm^{-2}s^{-1})

  Need to control the rate, use LVL1 di-muon trigger

- Lower lumi (<~ 2x10^{33} cm^{-2}s^{-1})

  Can use single LVL1 muon trigger in addition.



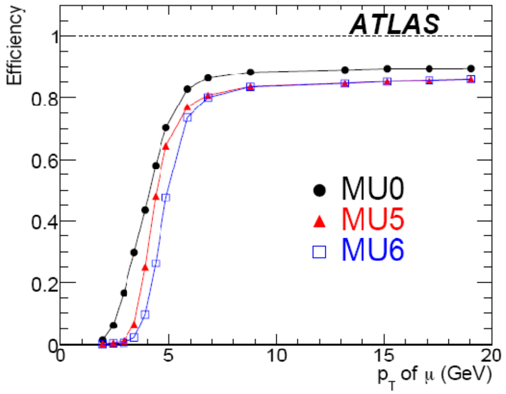
B trigger strategies

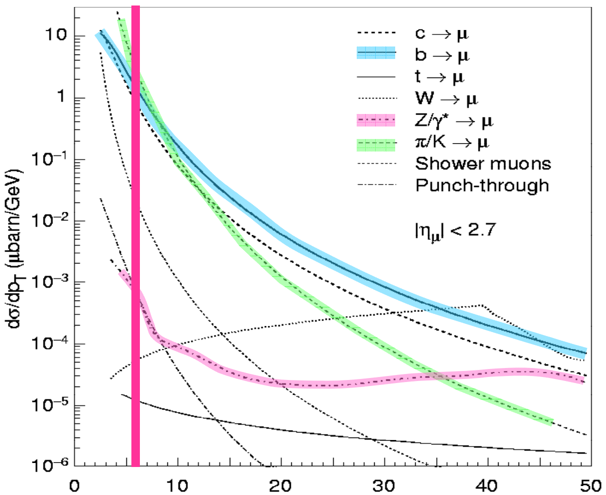
- High lumi (>~2×10^{33} $cm^{-2}s^{-1}$)
  - LVL1 di-muon trigger
  - events with 2 muons:
    - rare decays ($B\rightarrow\mu\mu(X)$), $B \rightarrow J/\psi\ (\mu\mu)\ X$

- Lower lumi (<~ 2×10^{33} $cm^{-2}s^{-1}$)
  - Use single LVL1 muon trigger plus JET/EM signatures at LVL1.
  - Two approaches
    - Full reconstruction in Inner Detector
    - Reconstruction in a Region of Interest (RoI) identified by the LVL1 JET,EM or Muon signature.
  - Possible channels:
    - Jet RoI: hadronic final states, e.g. $B_s\rightarrow D_s(\phi\pi)\pi$
    - EM RoI: em final states such as $J/\psi\rightarrow ee$, $K^*\gamma$, $\phi\gamma$
    - Muon RoI – recover di-muon events where second (low p_T) muon was missed at LVL1

LVL1 muon trigger

Efficiency ~85% (inefficiency mostly due to geometrical reasons (feet and supports))





p_T of muons from different processes

Predict LVL1 rate from convolution of efficiency with predicted cross-section as a function of p_T

Rate ~ 21-30kHz (p_T>6GeV)
(large uncertainty due to changing PYTHIA cross-sections)

>15% due to b events

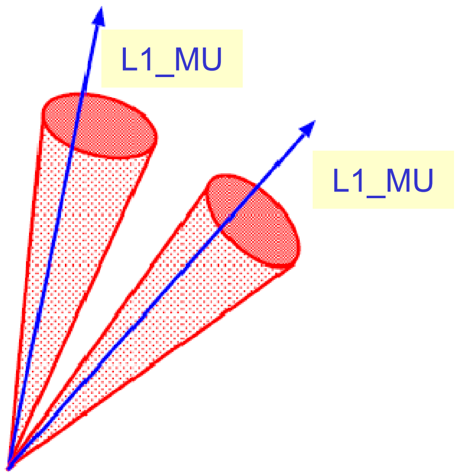
Main background from π/K

Reduce rate at LVL2 by:
- use precision muon chambers
- extrapolate and match to inner detector tracks

Di-muon trigger - two approaches

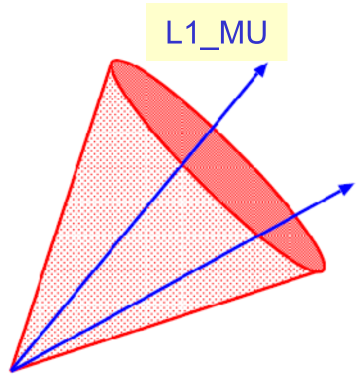
Topological trigger

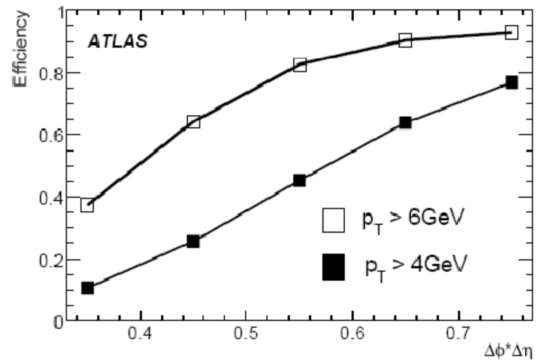
- 2 LVL1 muons
- Confirm at HLT (muons + InnerDetector)
- Make mass, vertex cuts



Single muon LVL1 trigger

- One LVL1 muon
- Confirm at HLT (muons + InnerDetector)
- In large RoI OR entire detector search for the second muon
- Make mass, vertex cuts





Used for $J/\psi \rightarrow \mu\mu$, $\Upsilon \rightarrow \mu\mu$, $B \rightarrow \mu\mu(X)$

Comparison of the two approaches for $J/\psi \to \mu\mu$

Dataset with $J/\psi \to \mu(p_T > 4GeV)\mu(p_T > 2.5GeV)$

Threshold (GeV)	Chain starting from	Single L1 muon		Topological trigger	
		J/ψ ε	**Total rate (Hz)**	J/ψ ε	**Total rate (Hz)**
4 ($L=10^{31}$)	**Level - 1**	73%	**3.5**		
	Level - 2	70%	**2.7**	33%	**0.6**
6 ($L=10^{33}$)	**Level - 1**	75%	**180.5**		
	Level - 2	60%	**126**	15%	**9.3**

Single L1 muon trigger is more efficient but the rate becomes too high at higher luminosities

Seeded by single L1 muon

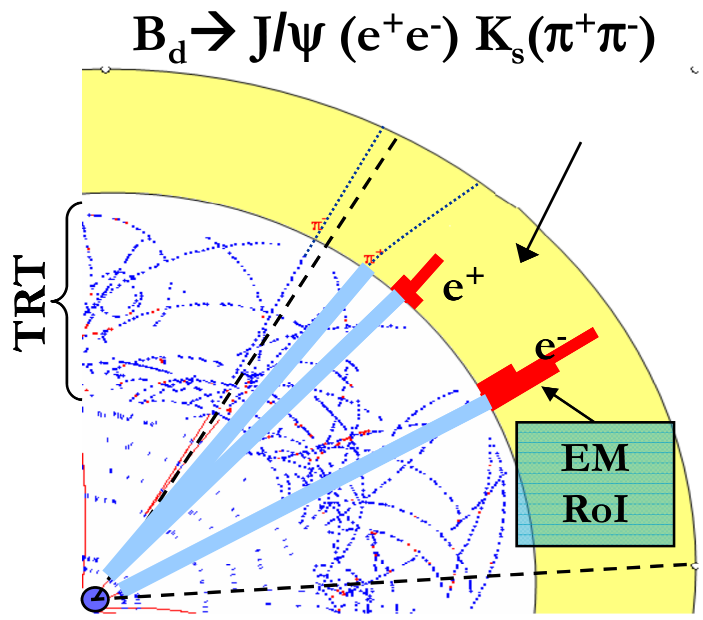
Seeded by L1 di-muon

Full reconstruction versus RoI-guided approach?

- For the triggers using a single L1 muon there are two approaches in the HLT:
  - Track reconstruction in the full Inner Detector (FullScan)
  - Track reconstruction in a Region around the secondary L1 trigger.

- RoI- guided approach retrieves information for smaller region of detector => faster execution times

- Speed depends on RoI size and mean LVL1 RoI multiplicity per event



Example of RoI approach:
Track reconstruction is performed in a region around the L1 EM RoI

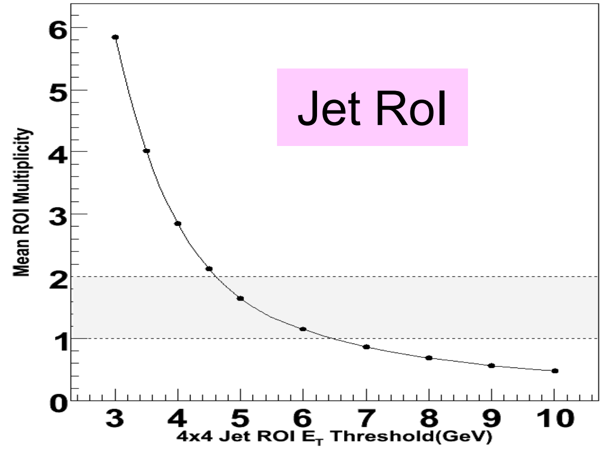
Hadronic and EM B decays
Full reconstruction or RoI guided?

- RoI multiplicity required to be about 1-2 to keep resource needs reasonable => determines thresholds chosen

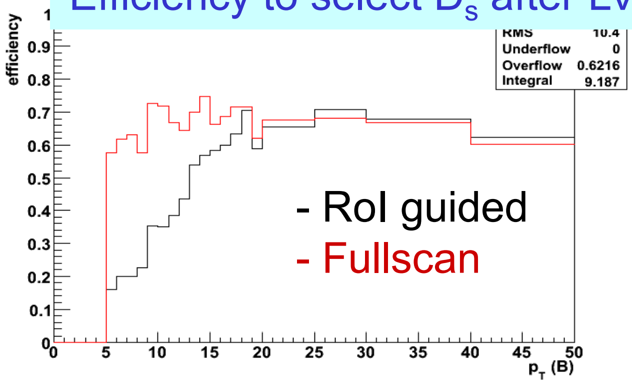
- Higher threshold → less RoIs → lower rate and less resources used but reduced efficiency

- At startup use the FullScan but as luminosity increases move to RoI-guided approach – reduces rate and resources needed.

RoI multiplicity bb→μ(6)X



Efficiency to select D_s after LVL2



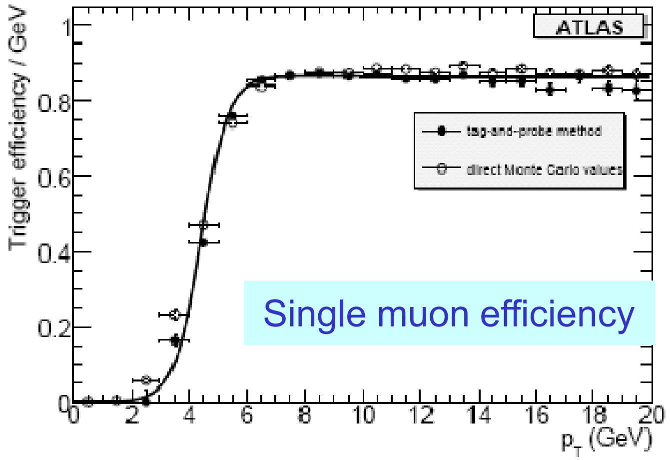
Evolution of trigger menus

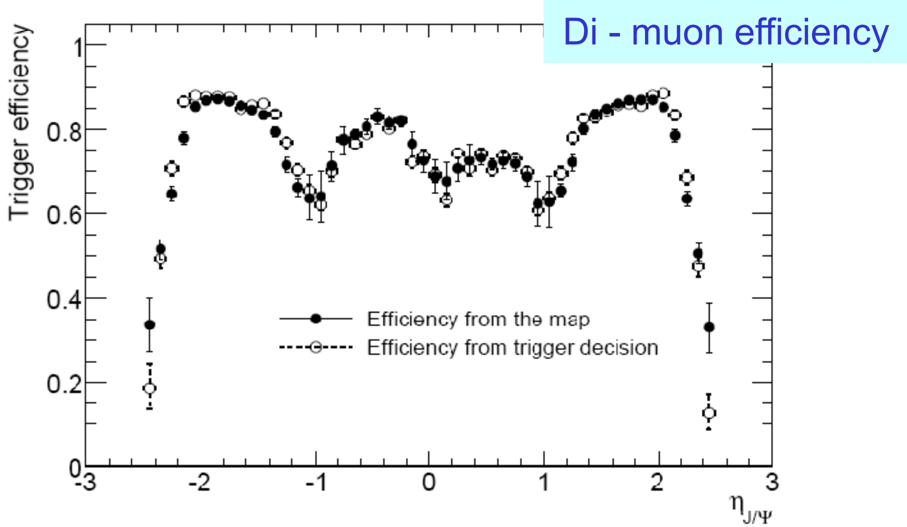
	Example signal	Startup 10^{31}	10^{32}-10^{33}	Above ~ $2x10^{33}$
Topological trigger	Onia($J/\psi\rightarrow\mu\mu$, $\Upsilon\rightarrow\mu\mu$) $B\rightarrow\mu\mu(X)$	2MU4	2MU4	2MU6
Di-muons from single L1 muon	As above (lower threshold for second muon)	MU4 FullScan	MU6 RoI	X
Jet and EM final states	$B_s\rightarrow D_s(\phi\pi)\pi$ $J/\psi\rightarrow ee$, $K^*\gamma$, $\varphi\gamma$	MU4 FullScan	MU6 RoI	X

Extracting di-muon efficiencies from data

- Use tag-and-probe method :
  - Collect events with single muon trigger
  - Reconstruct $J/\psi \rightarrow \mu\mu$ offline. One muon was “trigger” muon
  - The other muon gives an un-biased sample to study trigger efficiency

$$\varepsilon(p_T) = \frac{A}{1+\exp(-a \times (p_T - b))}$$

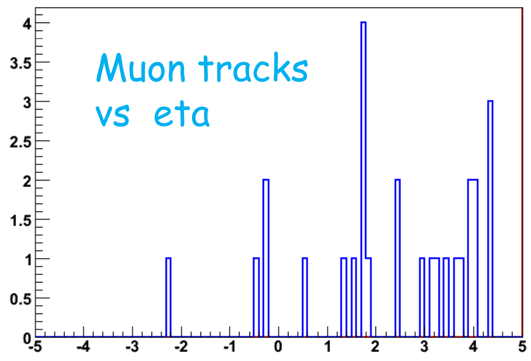




- Fit single muon efficiency curve in bins of η and φ
- Calculate di-muon effiiencies using parent kinematics.
- Understand efficiency to ~1% with 300k events (100pb^{-1})

Commissioning

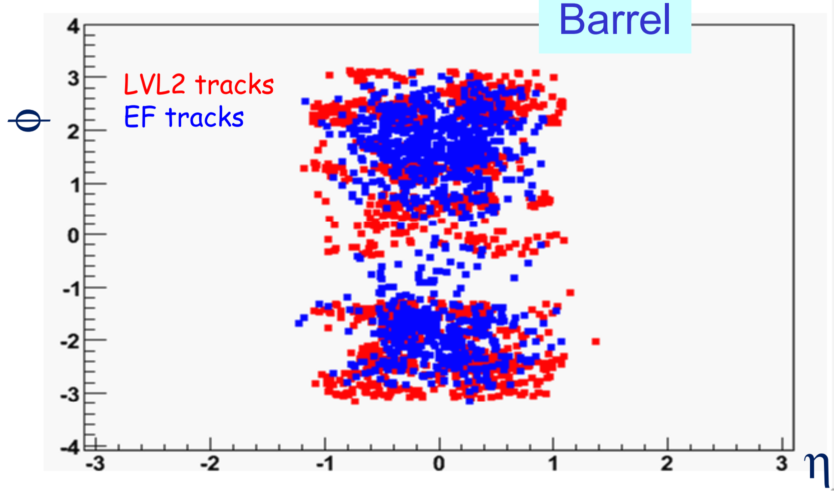
First Beam:

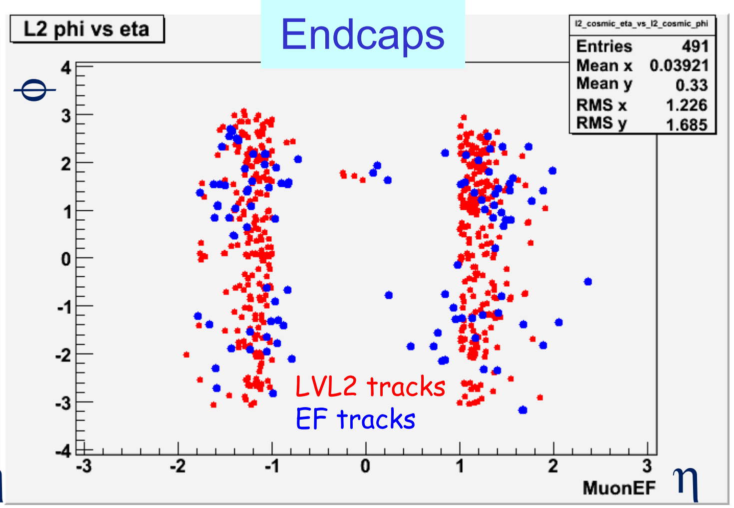


Beam coming from z<0

- Commissioning of muon and tracking triggers with first beams and cosmics is ongoing.
- Await collisions to commission the B physics trigger algorithms.

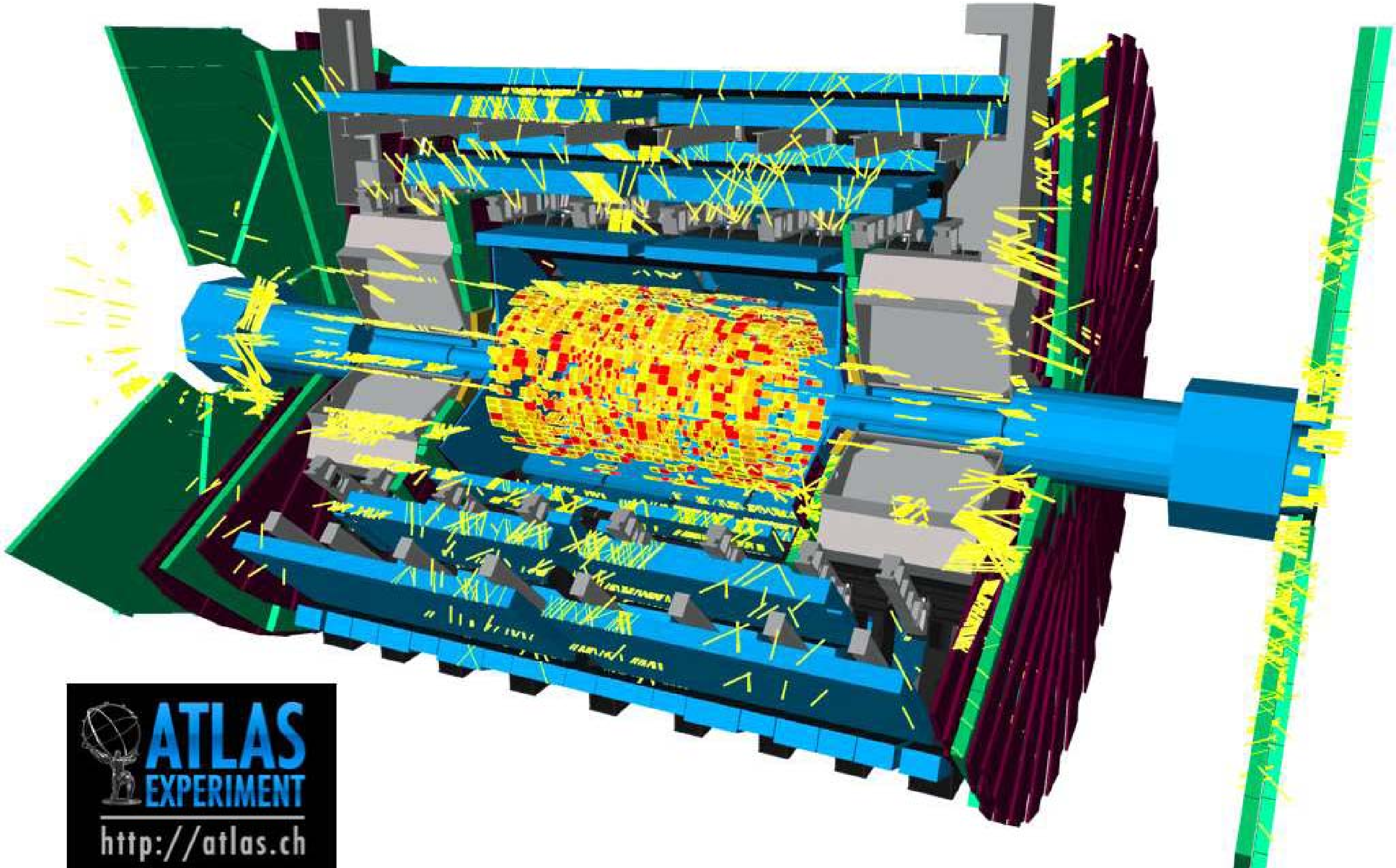
Cosmics:





Summary

- ATLAS plans a full B physics programme from startup to full luminosity.
- Presented a flexible B trigger with the ability to cope with increasing luminosity (FullScan → RoI guided track reconstruction, eventually running only di-muon trigger at design luminosity)
- This will allow a broad programme of B-physics during early running and rare decay searches continue at high luminosity.
- Look forward to first collision data……..



first beam event seen in ATLAS