b-Jet Triggering in ATLAS: from conception to commissioning and first analyses

Seminar at CPPM, Marseille - Feb 16th, 2012

Andrea Coccaro

Outline

Outline

CERN Associate

Jr visiting scientist

Research associate

INFN
Università di Genova

2006 2007 2008 2009 2010 2011 2012

Master

Ph.D.

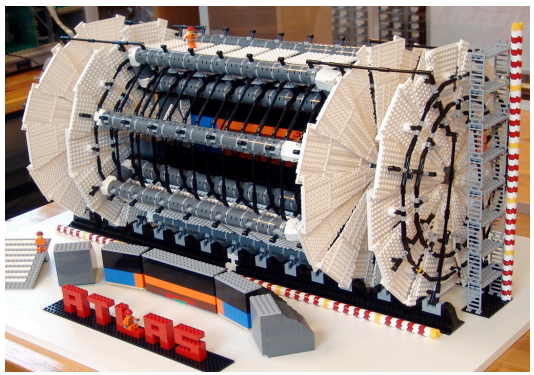
ATLAS member

b-jet trigger deputy convener

b-jet trigger convener

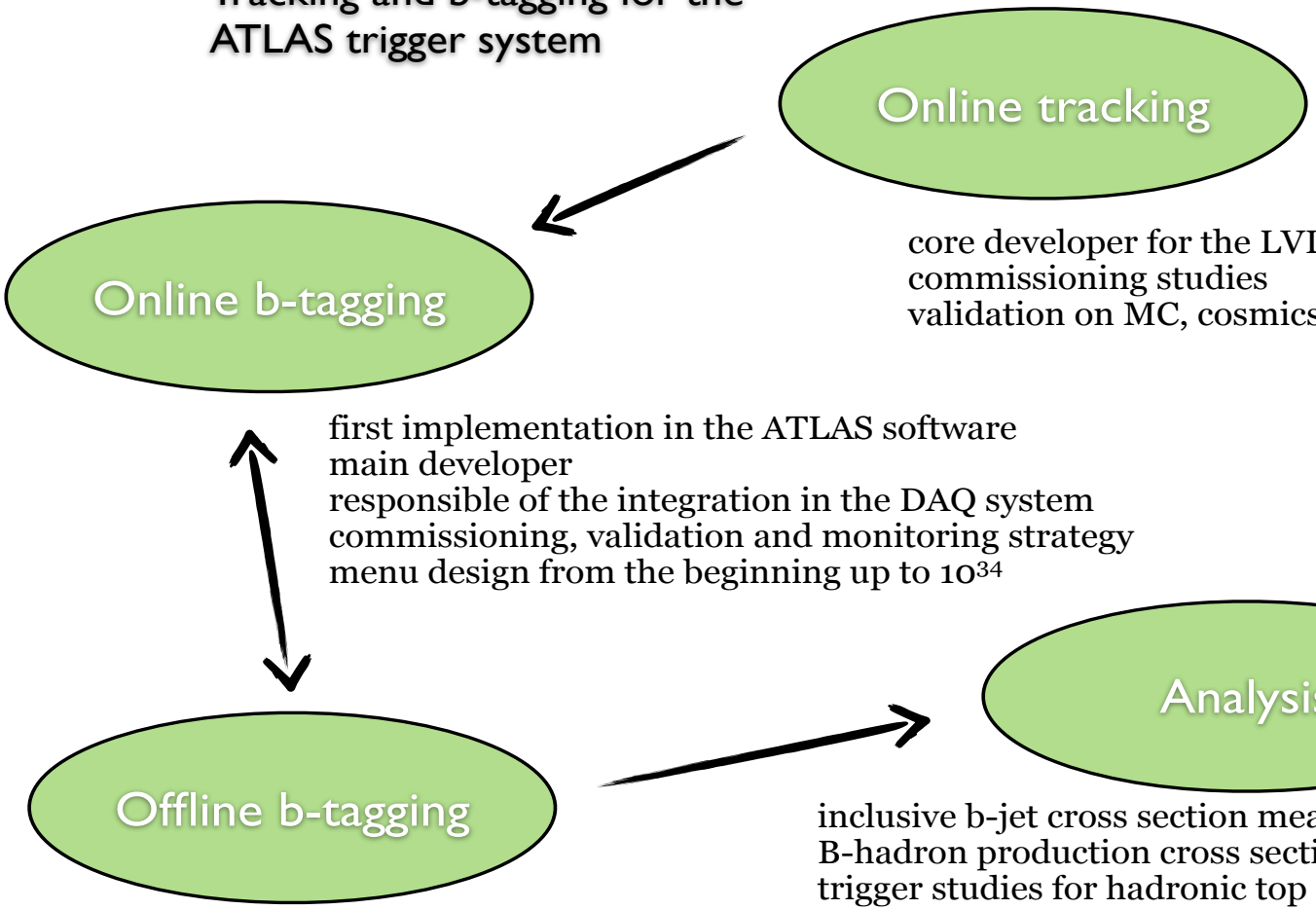
member of the Trigger Menu Coordination Group

member of the ID trigger taskforce



boom cosmics 0.9 Tev 7 TeV 10E33 5/fb

Ph.D. Thesis
Tracking and b-tagging for the ATLAS trigger system



What's next? Exploit b-jet triggers for
- hadronic top (ongoing in ATLAS)
- $H \rightarrow bb$ (ongoing in ATLAS)
- searches beyond the Standard Model

Outline

The ATLAS Trigger

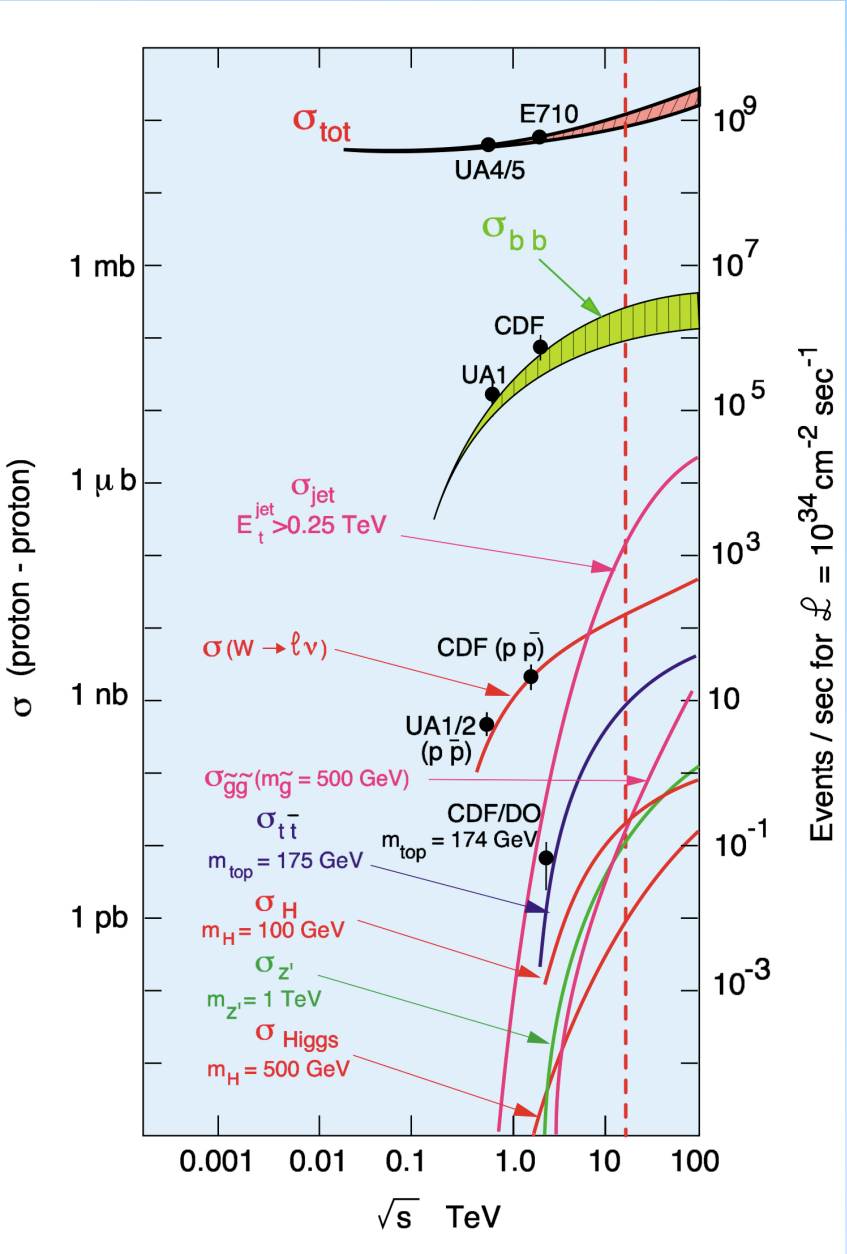
Task

Inspect detector information and provide a first and fast decision on whether to keep or not the event

At LHC energies:

- inelastic pp cross section $\sim 60\,\text{mb}$;
- $t\bar{t}$ cross section $\sim 170\,\text{pb}$;
- $t\bar{t}H(\rightarrow b\bar{b})$ cross section $\sim 0.3\,\text{pb}$.

Selection of about one event to be stored out of 10^6, while keeping the potentially interesting events with good efficiency.

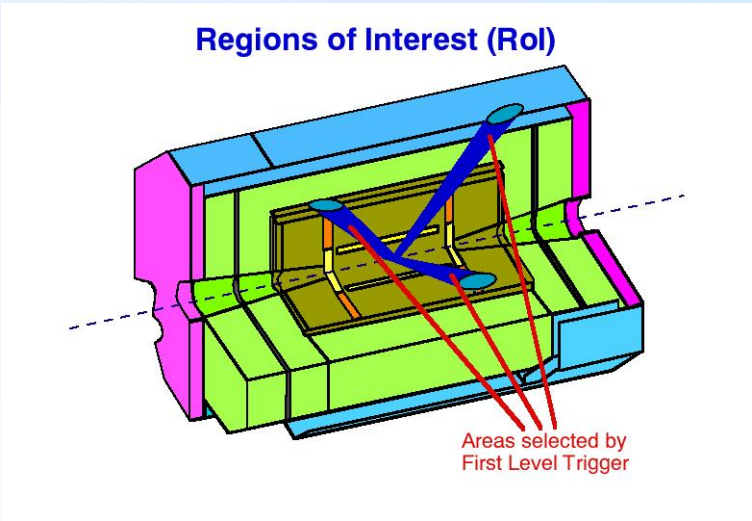


The ATLAS Trigger

LHC interaction rate is reduced through three subsequent selection steps:

Level1 Trigger (LVL1):

- hardware based;
- latency 2 μs;
- input/output rate: from 40 MHz to 75 KHz;
- regions of interest (RoIs) to minimize processing time and network traffic.



High Level Trigger (LVL2+EF):

- software based;
- full granularity for all subdetectors

Level2 Trigger (LVL2):

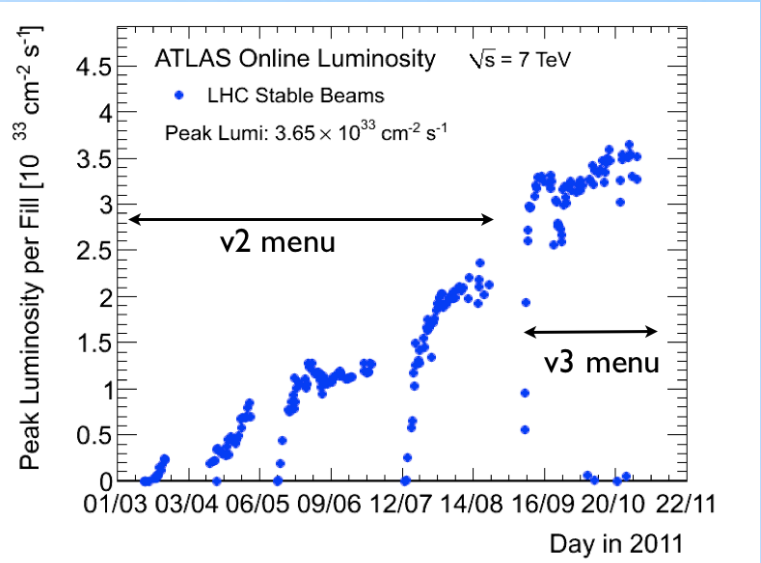
- average execution time $\sim$ 40 ms
- input/output rate: from 75 KHz to 3 KHz;
- RoI driven from LVL1;

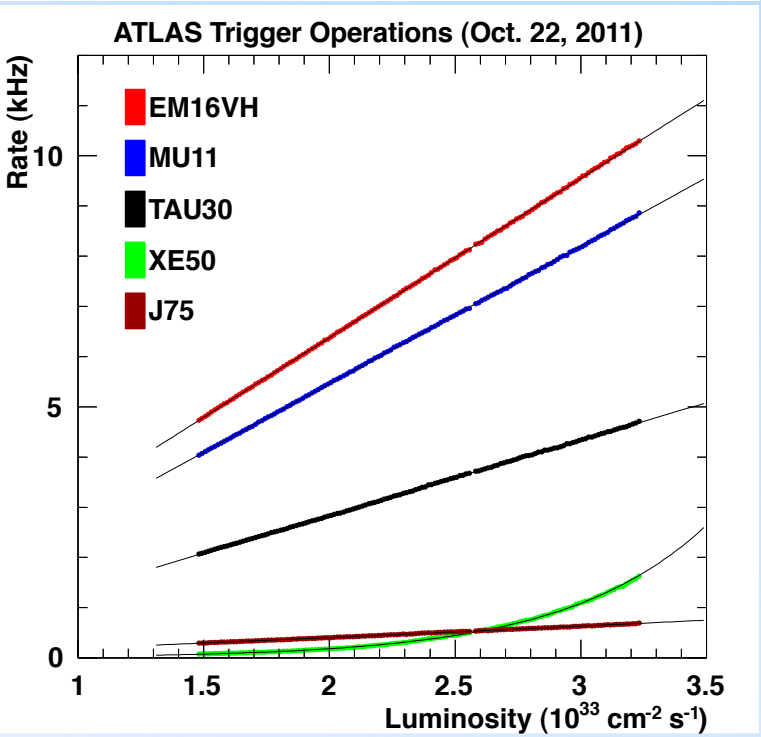
Event Filter (EF):

- average execution time $\sim$ 4 s
- input/output rate: from 3 KHz to $\sim$ 300 Hz
- off-line quality algorithms;
- data storage: $\sim$ 300 MB/s.

Trigger Operations in 2011

- LHC performance better than initially foreseen and design values for several machine parameters were surpassed
- keep operations as much stable as possible (but a second menu deployed with different LVL1 items for the latest periods)
- HLT trigger output scaled to 350 Hz and mostly kept there





Outline

1. Who Am I?
2. The ATLAS Trigger
3. Online Tracking
4. *b*-Jet and μ-Jet Triggers
5. *b*-Tagging Calibration Analyses using μ-Jet Triggers
6. Analysis using μ-Jet Triggers
7. Which Analyses for *b*-Jet Triggers?
8. Conclusions

Track Reconstruction at the HLT

Task

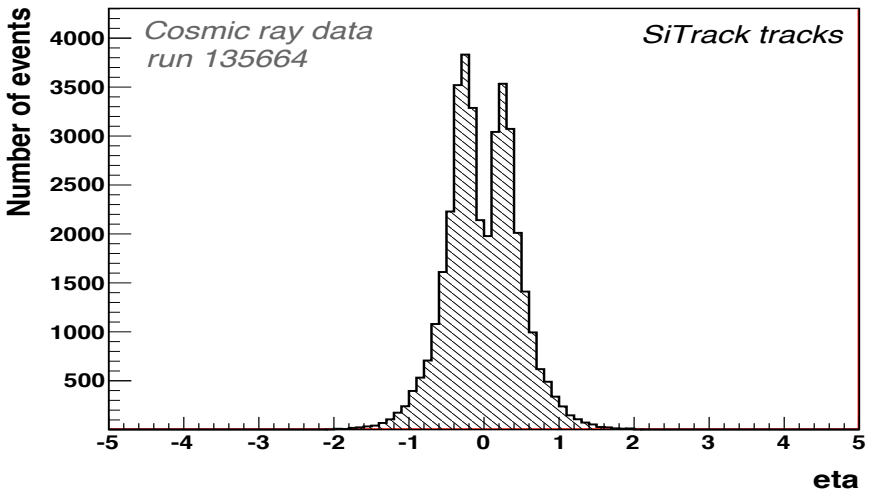
Reconstruct trajectories of charged particles for the online selection

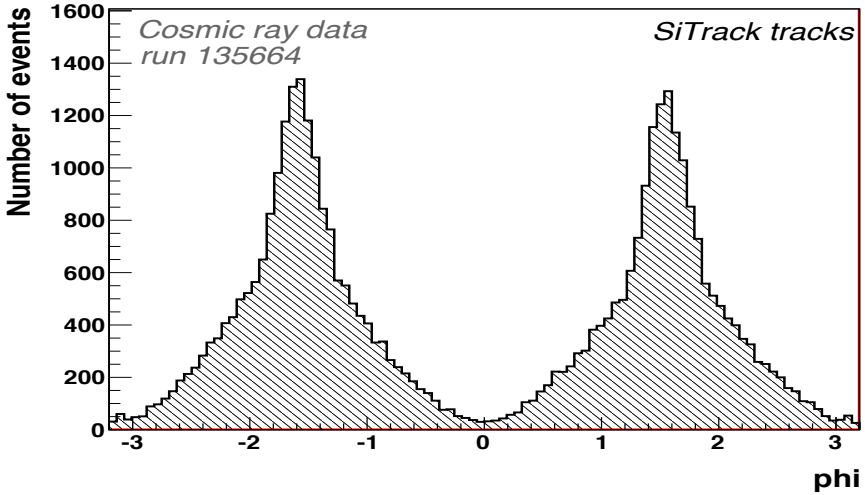
Online tracking is used for the definition of the following trigger items:

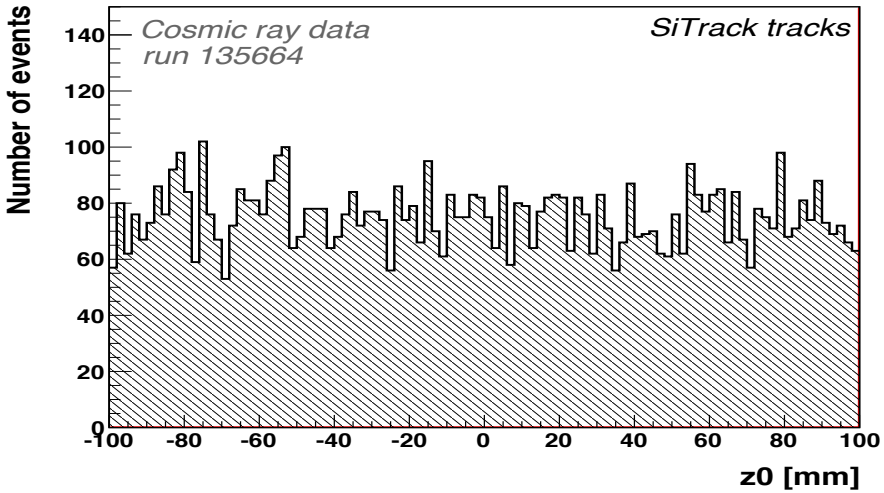
- selection of high-p_T electrons and muons: tracks reconstructed in the ID are used to match information from the calorimeters and the muon detectors
- reconstruction of tracks from tau decays: tracks are used for both matching information from outer detectors and to apply cuts on track multiplicity
- *b*-jet tagging: the impact parameters of the reconstructed tracks are used to evaluate the discriminant variables for identifying jet flavor
- *B* physics: identifying specific B-physics decay channels by using decay vertex reconstruction, mass cuts etc
- beam spot determination: tracks are used to estimate the beam spot in the transverse plane

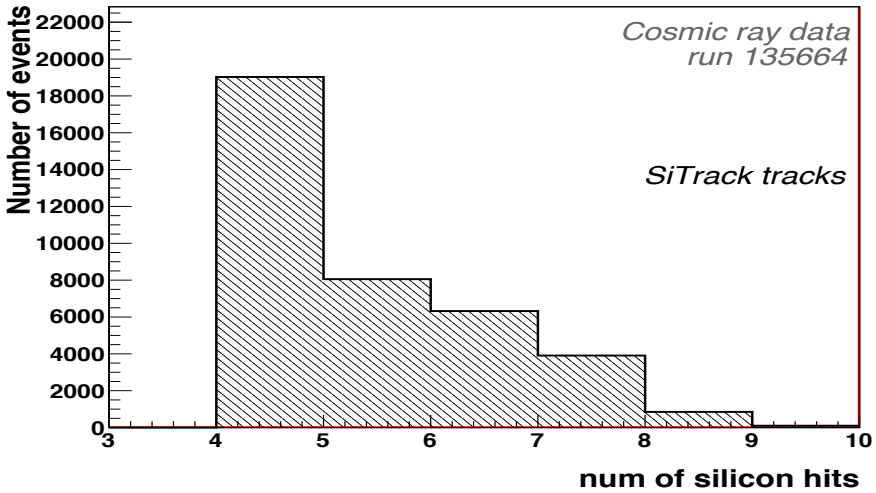
The tight constraint on the mean execution time forces algorithm development to a very delicate balance between time consumption and performance

Back to Cosmics: LVL2 Tracking









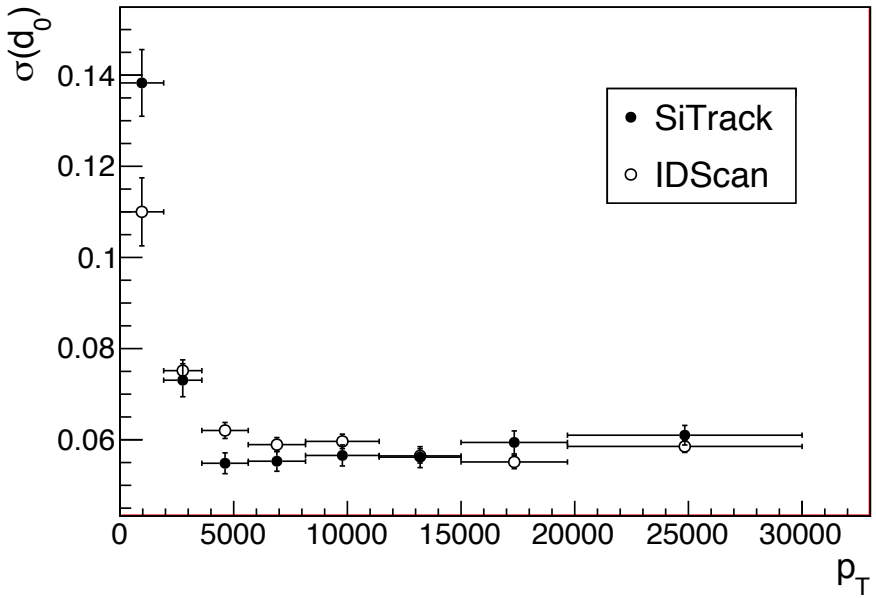
Back to Cosmics: Impact Parameter Studies

For each cosmic muon, reconstruct two tracks at LVL2 in the two halves of the detector.
That's two trajectories of the same particle!

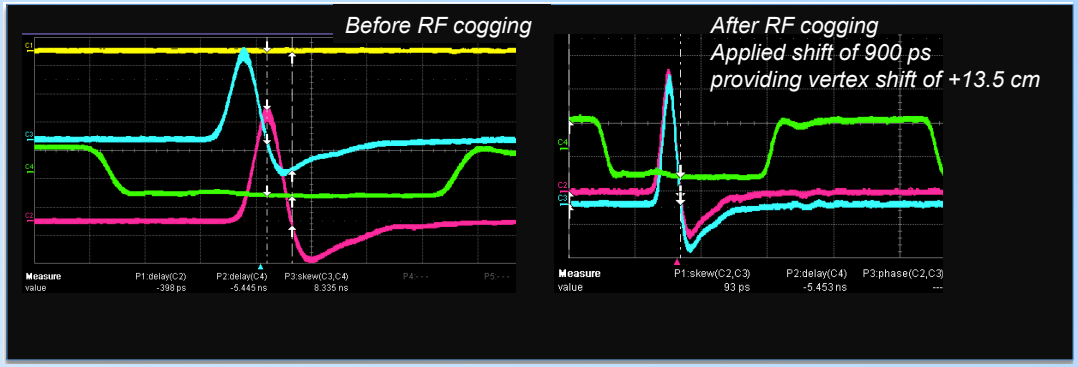
Self-resolution for SiTrack and IDScan with the upper and lower track:

$$\sigma(d_0) = (d_0^{upper} - d_0^{lower})/\sqrt{2}$$

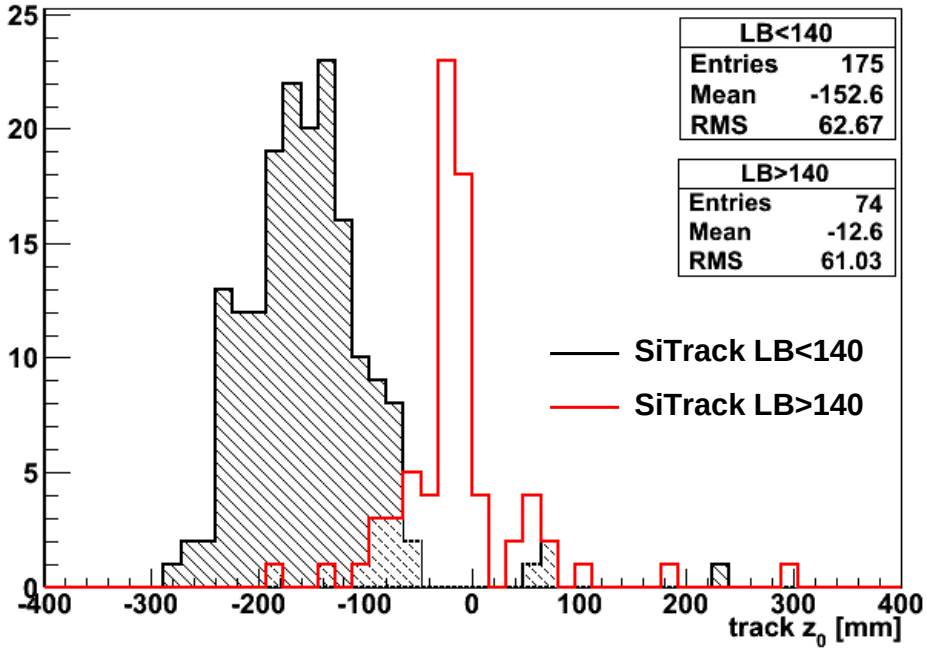
SiTrack	$\sigma(d_0)$ [μm]
before any alignment	390
after first alignment	60
MC	25



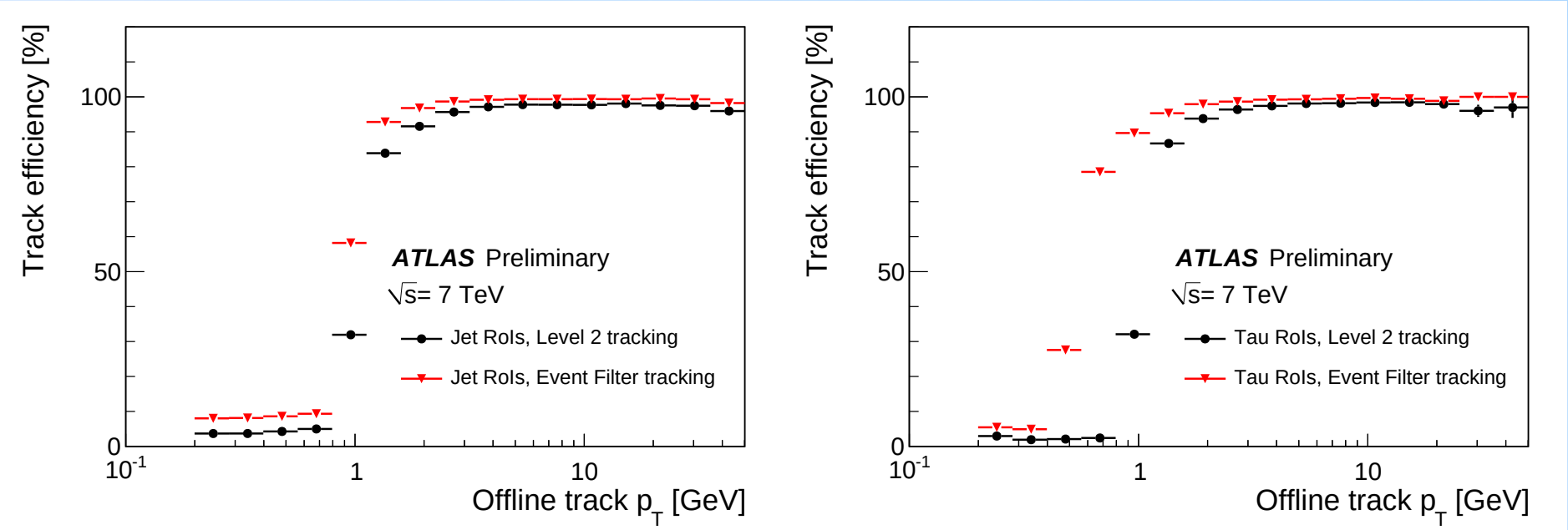
Back to 0.9 TeV: First Collisions Ever



- impact parameter distributions of reconstructed SiTrack tracks in first ATLAS run with proton collisions
- phase adjustment between proton beams detected by the LVL2 tracking algorithm



Making Short a Very Long Story



- algorithms tuned to be efficient starting at 1 GeV to limit the execution time without compromising the signal efficiency
- plots included in the ATLAS paper "Performance of the ATLAS Trigger System in 2010" [Inspire record]

Outline

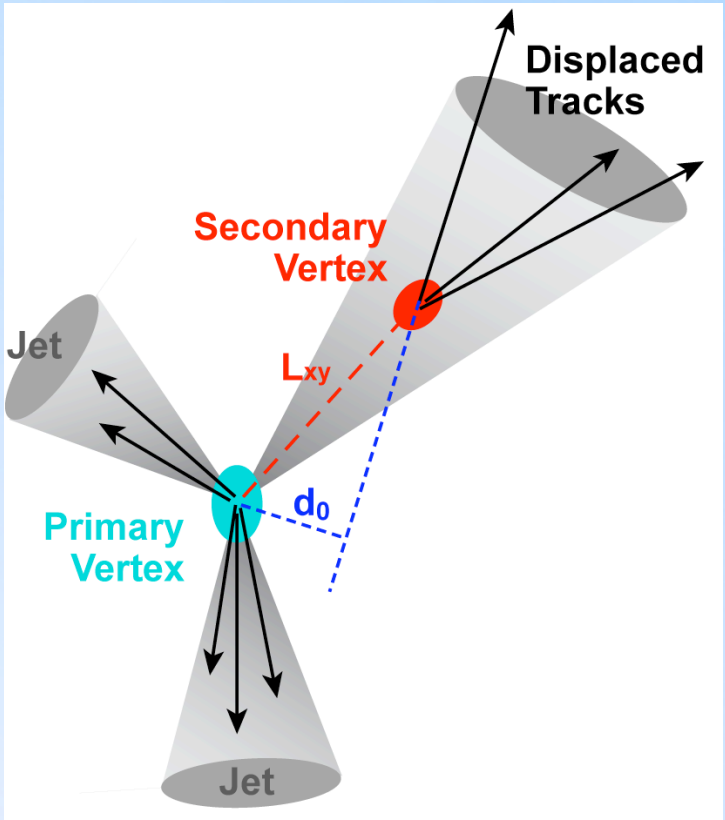
1. Who Am I?
2. The ATLAS Trigger
3. Online Tracking
4. *b*-Jet and μ-Jet Triggers
5. *b*-Tagging Calibration Analyses using μ-Jet Triggers
6. Analysis using μ-Jet Triggers
7. Which analyses for *b*-Jet Triggers?
8. Conclusions

b-Tagging

Task

Identify jets stemming from the hadronization of beauty quarks exploiting physical properties to distinguish them from jets which contain only lighter quarks

1. semi-leptonic decays of B-hadrons ($BR(b \to \mu\nu X) \approx 11\%$) and its relatively larger transverse momentum distribution with respect to the jet axis
   $\Longrightarrow$ soft lepton tagging
2. lifetime of B-hadrons relatively long ($\tau_b \approx 1.6$ ps, $c\tau_b \approx 450\mu$m and flight path lenght $\langle l \rangle = \beta\gamma c\tau \approx 5$ mm)
   $\Longrightarrow$ spatial tagging, based on
   - impact parameters
   - secondary vertices



Online *b*-tagging

Why?

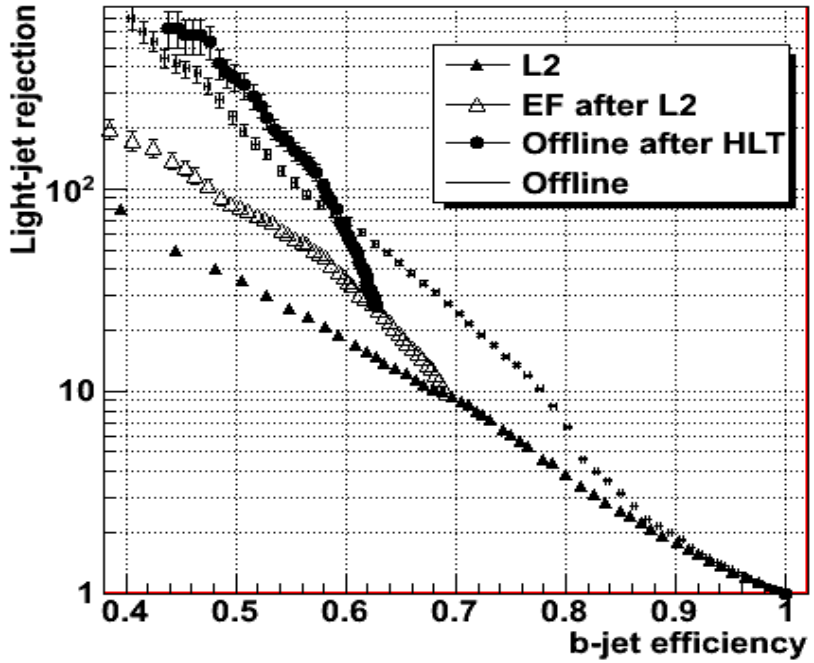
- to improve the flexibility of the trigger scheme
- to extend the ATLAS physics potential in case of no leptons in the event

How?

- lowering the jet trigger thresholds and enabling the *b*-tagging selection
- reconstructing tracks only in RoIs to limit the execution time

Different channels may benefit from requesting this kind of trigger firing:

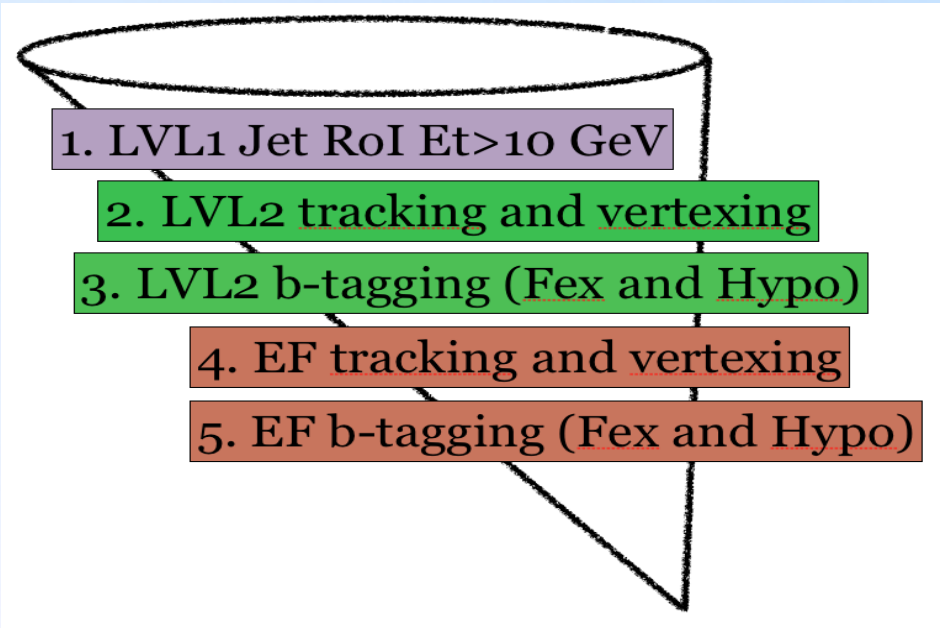
- top quark decays
- SM Higgs boson searches
- supersymmetric Higgs boson searches
- new physics



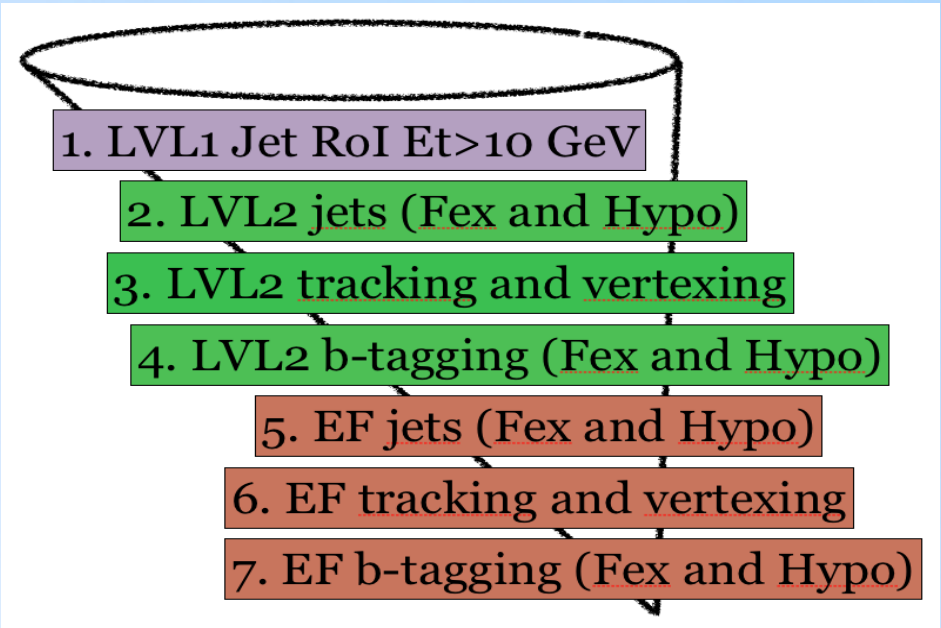
b-Jet Triggers in 2011

Two basic configurations adopted in 2011

mainly for $\mathcal{L} < 10^{33}$

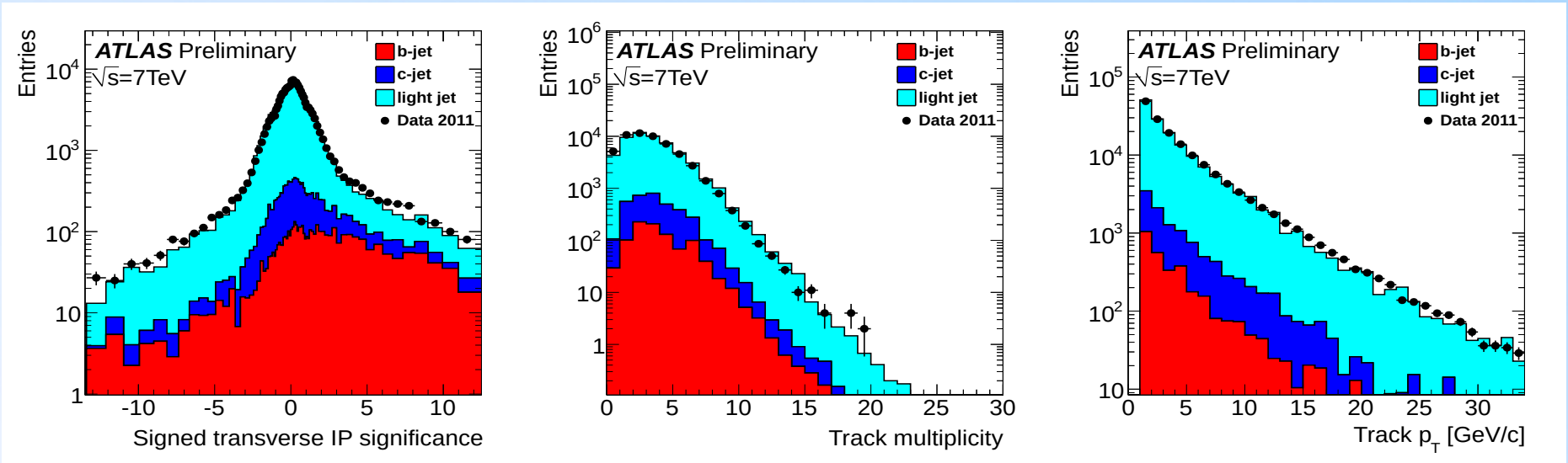


mainly for $\mathcal{L} > 10^{33}$



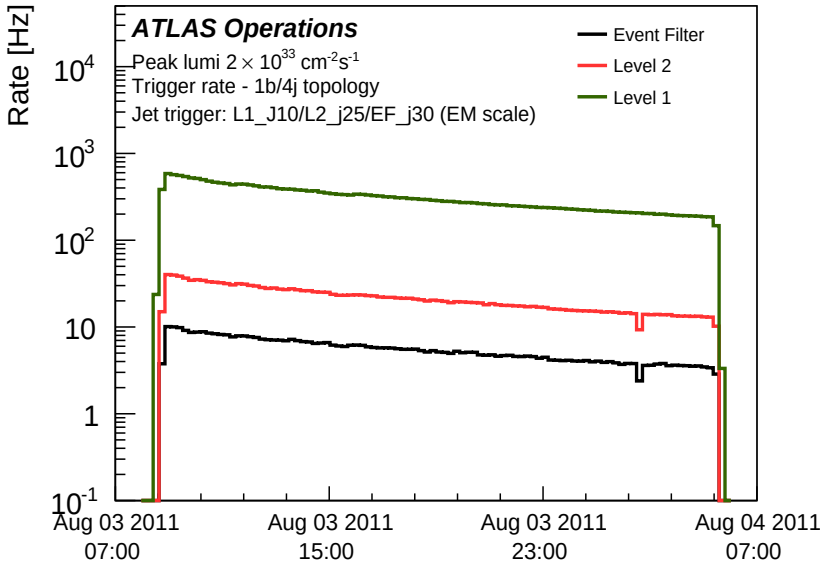
Why? LVL1 jet turn-on curve is not steep and HLT jets can efficiently reduce the rate keeping unchanged the plateau region

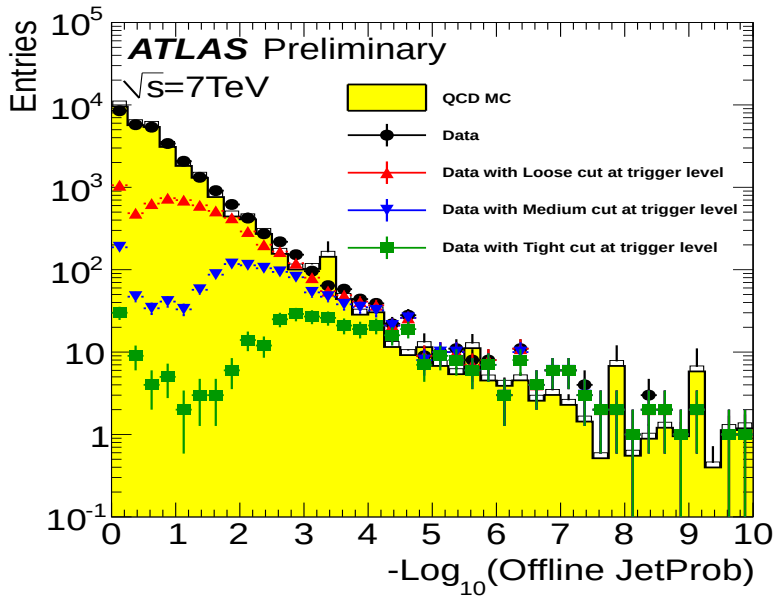
b-Jet Trigger Performance in 2011



- tracking details notoriously hard to estimate in simulation but anyway very good data/MC agreement of most relevant quantities
- the residual data/MC discrepancy of tagging rates is corrected using scale factors derived with ad-hoc measurements

b-Jet Trigger Performance in 2011





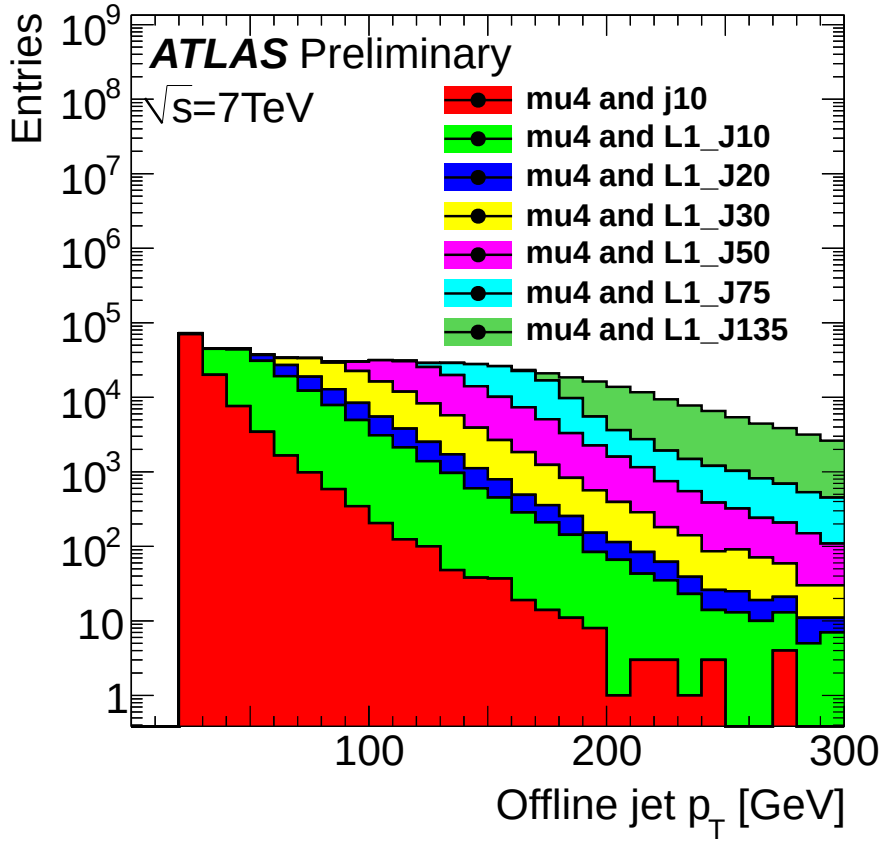
- operating points induced by rate considerations to avoid prescale
- offline *b*-tagging is biased by the online selection
- the exact correlation depends on the *b*-tagging algorithm

b-Jet Trigger News for 2012?

1. Secondary vertex reconstruction at HLT
2. Per-event primary vertex computation
3. New likelihood tuning with track categories
4. full-scan jet reconstruction before the LVL2 jets
5. b-tag HLT jets and not LVL1 RoIs
6. More combined triggers

μ-Jet Triggers

- set of triggers requiring a geometrical matching between a μ and a jet
- with different jet thresholds to cover the entire jet p_T spectrum while keeping the total bandwidth fixed and limited to few Hz
- online *b*-tagging sequence inserted in μ-jet triggers to always have the corresponding *b*-tagging weight available
- triggers extensively used in ATLAS for *b*-tagging calibration



Outline

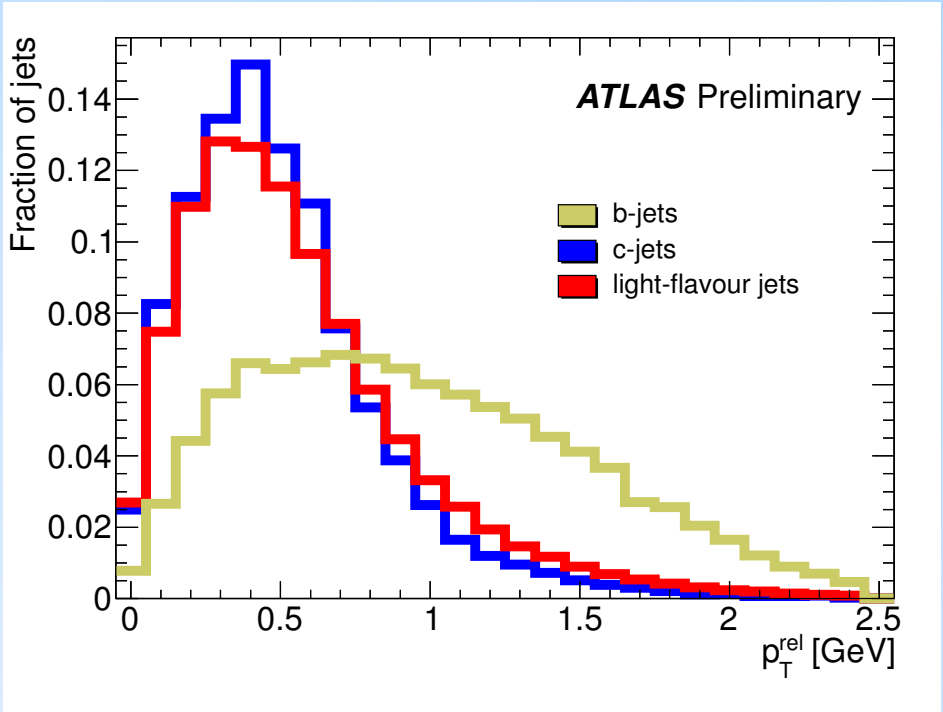
1. Who Am I?
2. The ATLAS Trigger
3. Online Tracking
4. b-Jet and μ-Jet Triggers
5. b-Tagging Calibration Analyses using μ-Jet Triggers
6. Analysis using μ-Jet Triggers
7. Which Analyses for b-Jet Triggers?
8. Conclusions

b-Tagging Calibration Using p_T^{rel}

Simple idea:

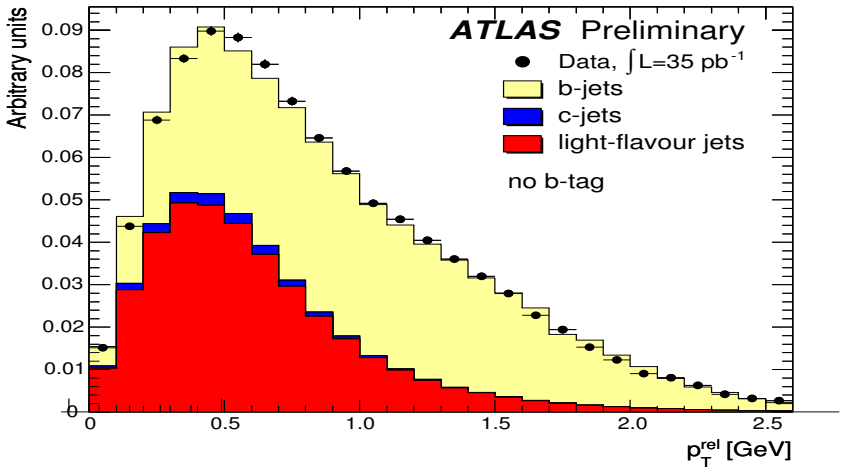
1. use p_T^{rel} (momentum of the muon transverse to the combined muon plus jet axis) templates for *b*- *c*- and light-flavour jets
2. fit the p_T^{rel} distribution on data
3. obtain the fraction of *b*-jets before and after a *b*-tag requirement
4. the *b*-tag efficiency is then defined as

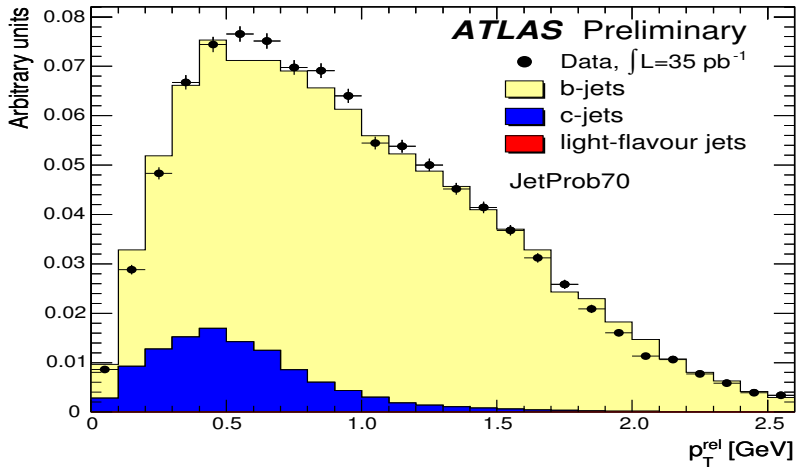
$$\epsilon_b^{data} = \frac{f_b^{tag} \cdot N^{tag}}{f_b \cdot N} \cdot C$$

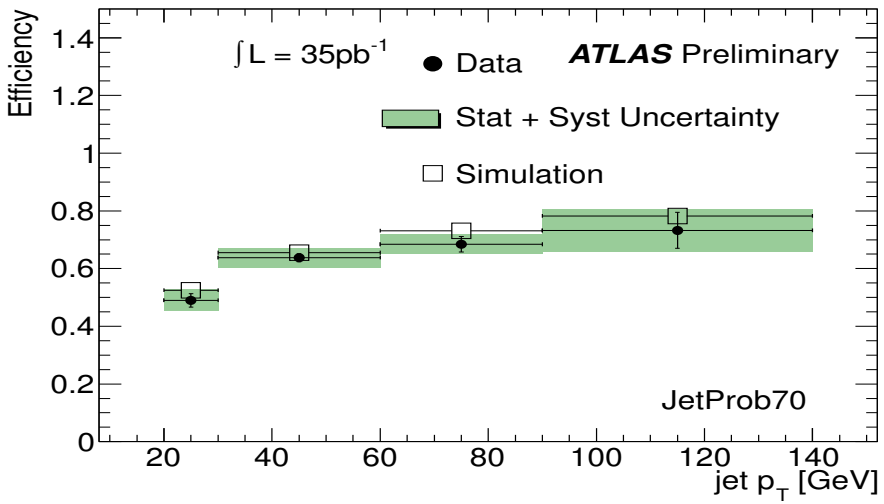


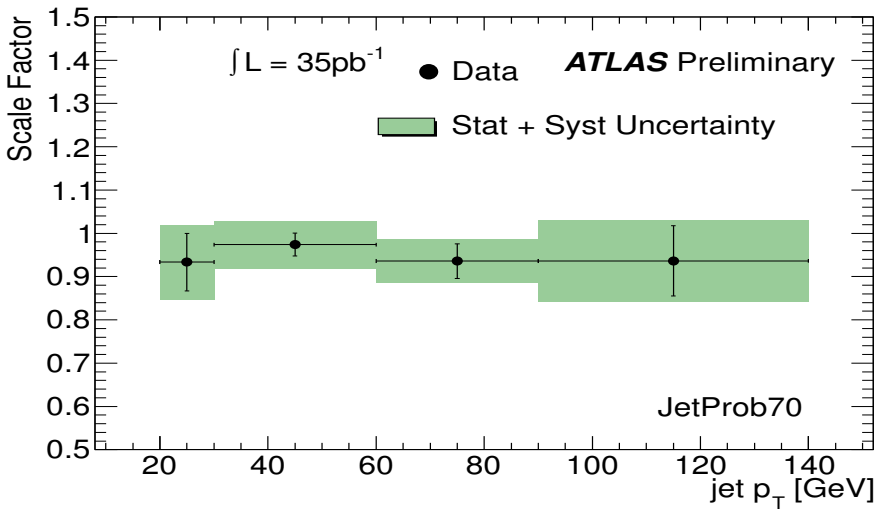
The method has been successfully applied to calibrate online, offline and online plus offline *b*-tagging. Nowadays only offline results are public

b-Tagging Calibration Using p_T^{rel}







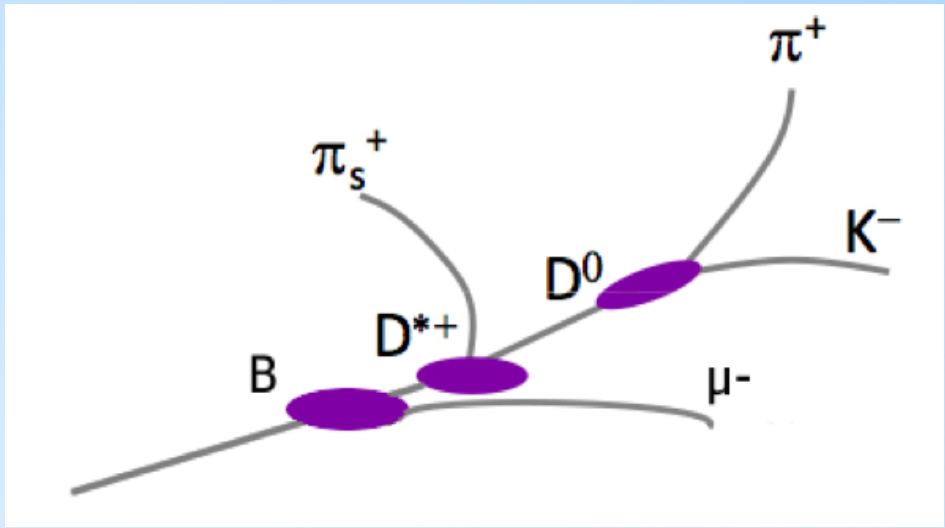


b-Tagging Calibration Using $D^*\mu$

- selection of a very clean b-jet sample explicitly reconstructing the $b \to D^*\mu X \to D^0\mu X(\to K\pi)\pi$ chain
- $\mathcal{BR}(b \to D^*\mu X) \approx 2.75\%$
- extract the b-tag efficiency from the $D^*\mu$ sample inverting

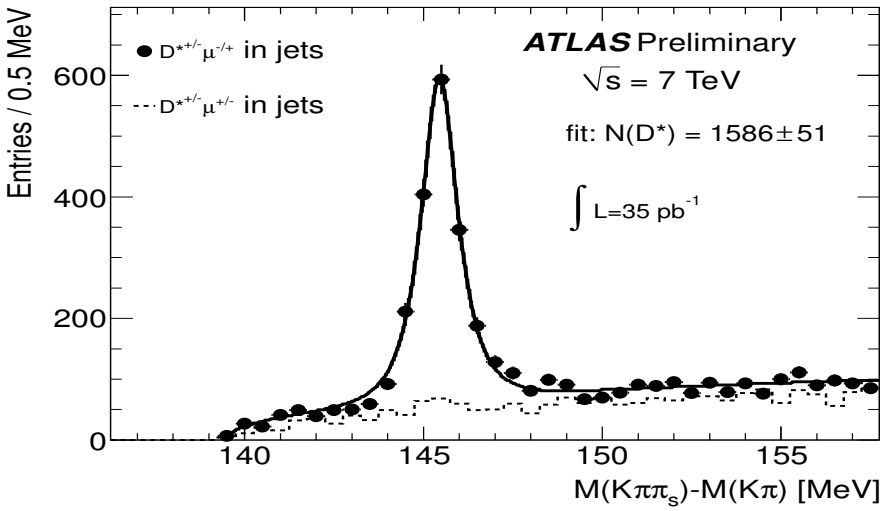
$$\epsilon_{D^*\mu} = \frac{n_b\epsilon_b + n_{c\overline{c}}\epsilon_{c\overline{c}} + n_{b'\overline{b'}}\epsilon_{b'\overline{b'}}}{n_b + n_{c\overline{c}} + n_{b'}}$$

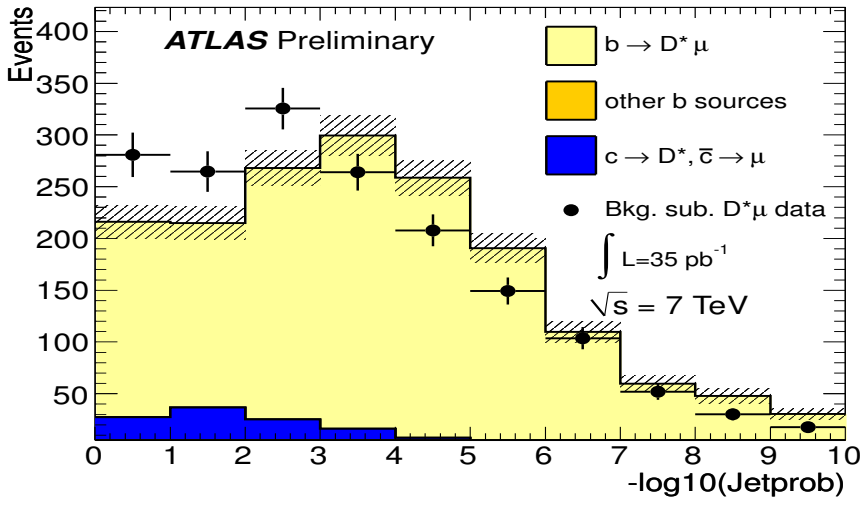
b: direct semileptonic B-hadron decays
$c\overline{c}$: from $c \to D^*$ and $\overline{c} \to \mu$
b': from other B-hadron decays

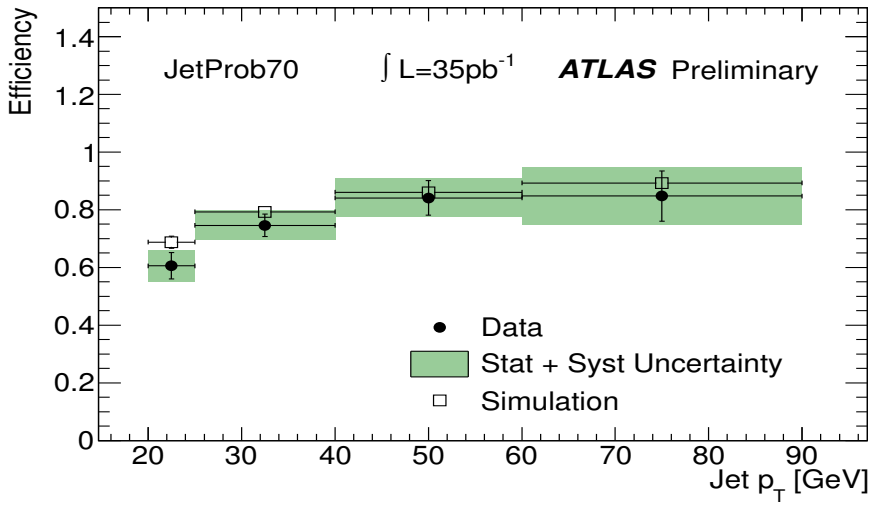


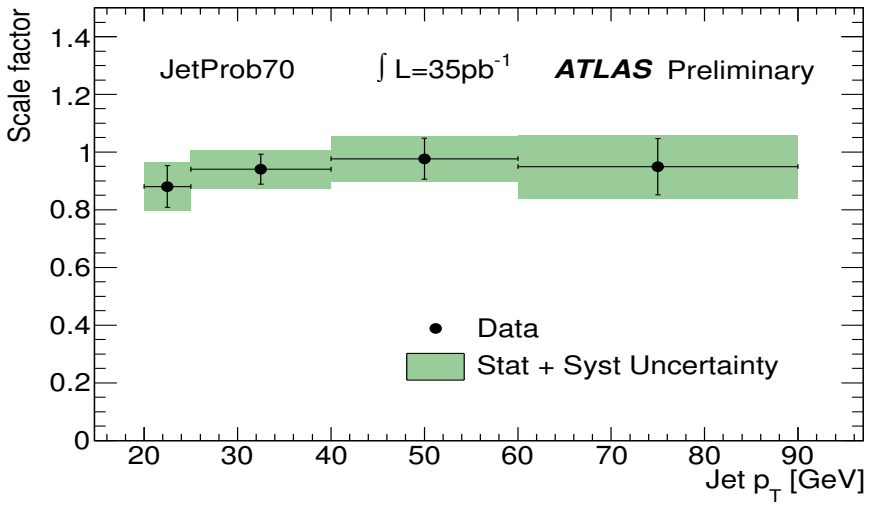
The method has been successfully applied to calibrate offline b-tagging and work is now ongoing for the online and online plus offline calibration

b-Tagging Calibration Using $D^*\mu$









Outline

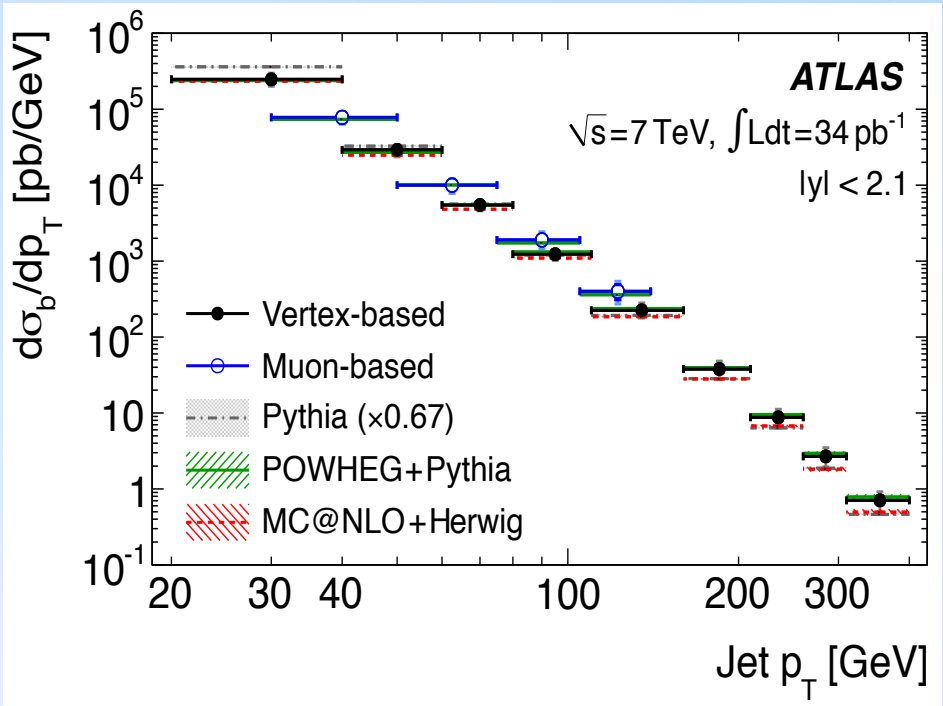
Muon-based *b*-jet cross section

Differential *b*-jet cross section measurement using the 2010 data and the sample collected by μ-jet triggers and comparison with different next-to-leading order QCD predictions.

$$\frac{d\sigma}{dp_T^{bjet}} = \frac{F_b(p_T^{bjet})N^{jets}}{2\mathcal{L}\epsilon(p_T^{\mu}, p_T^{bjet})}\frac{1}{\Delta p_T^{bjet}}$$

- F_b: b fraction in the sample
- N^{jets}: total number of jets per p_T bin
- 2: charge correction to take into account both positive and negative muons
- ϵ: overall efficiency
- Δp_T^{bjet}: p_T bin width

In collaboration with *CPPM*



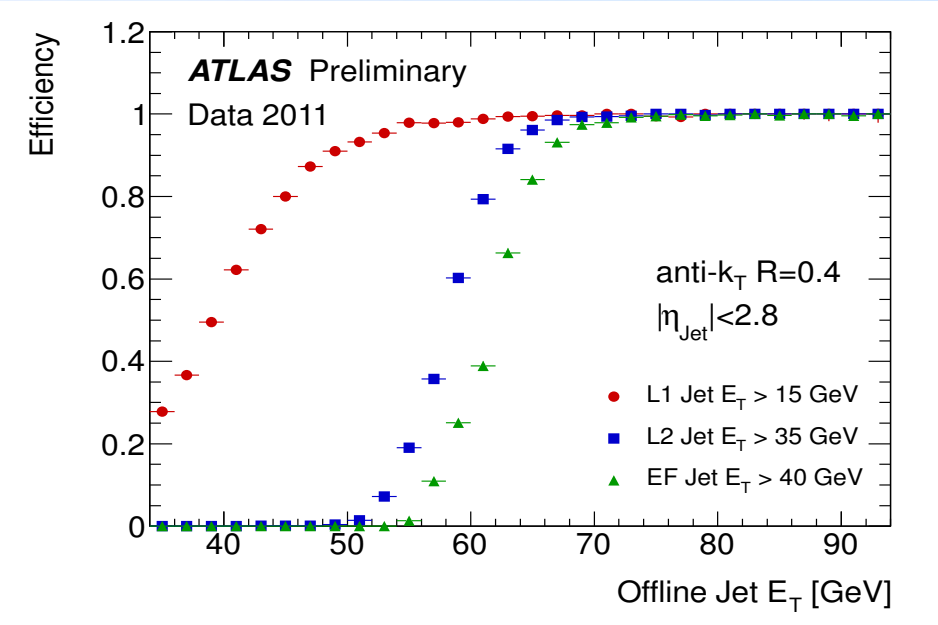
EPJC 71 (2011) 1846 [Inspire record]

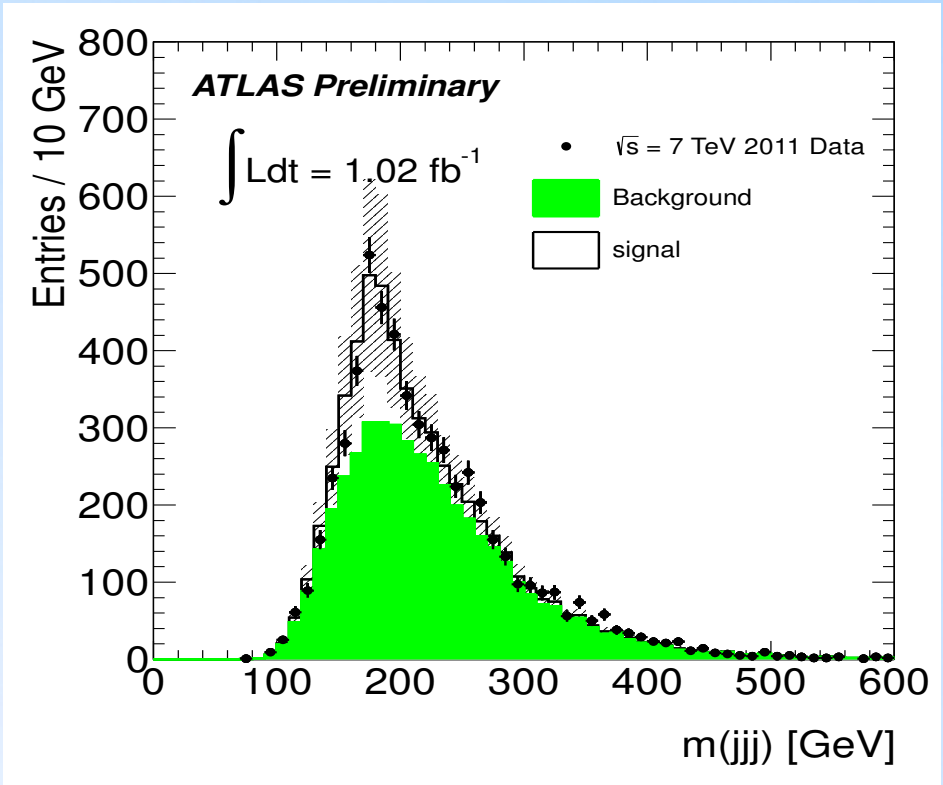
Outline

Hadronic Top Cross Section

- the huge QCD background is the main challenge, already at the trigger level
- ATLAS publication with a 5-jet trigger, ongoing effort to repeat the analysis with a 4-jet trigger and a 1 *b*-tag requirement
- increase in acceptance thanks to the online *b*-tagging

In contact with *CPPM*, *LPC*

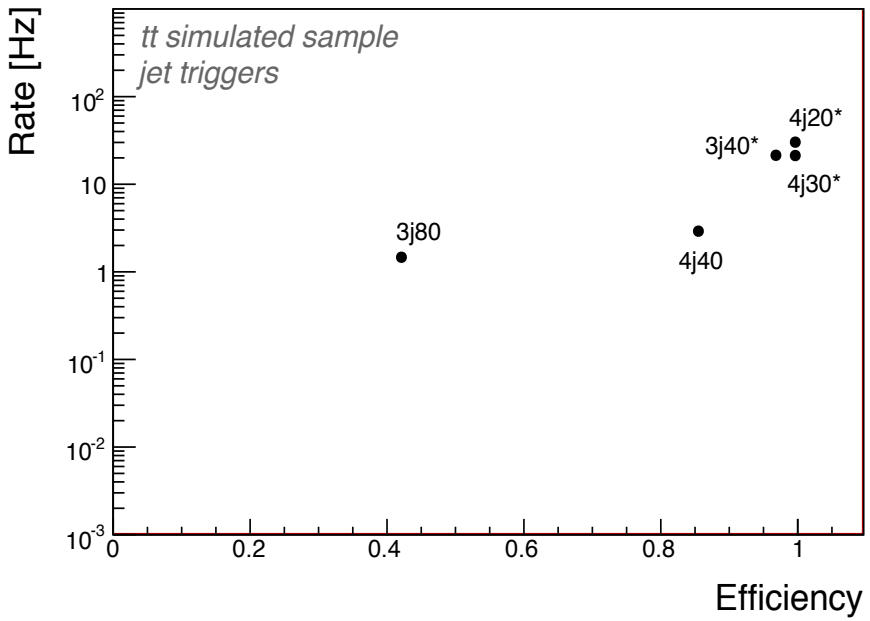


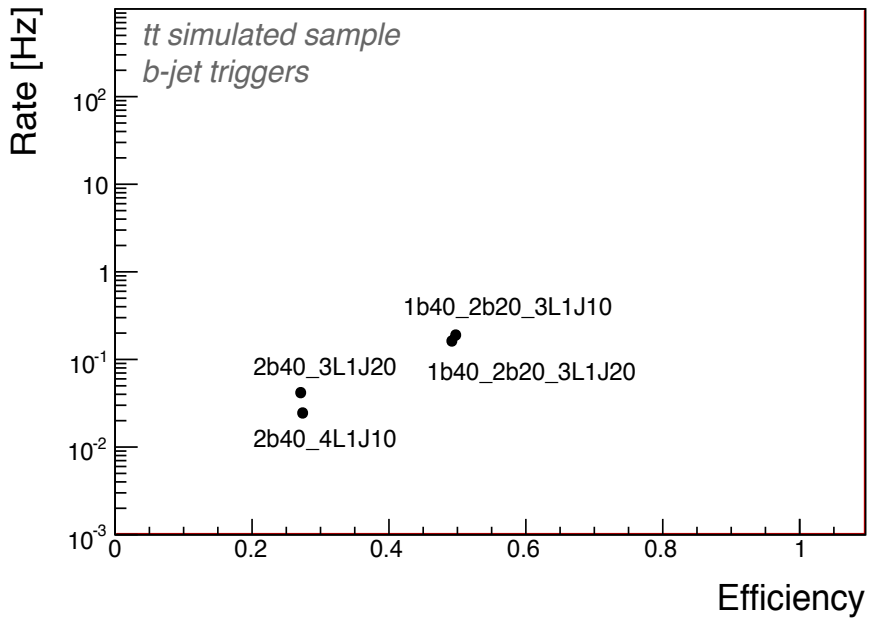


ATLAS-CONF-2011-140

An Old Exercise: Impact of *b*-Jet Triggers

An outdated example for the $t\bar{t}$ hadronic channel - Rate for $\mathcal{L} = 10^{31}$ cm^{-2} s^{-1}

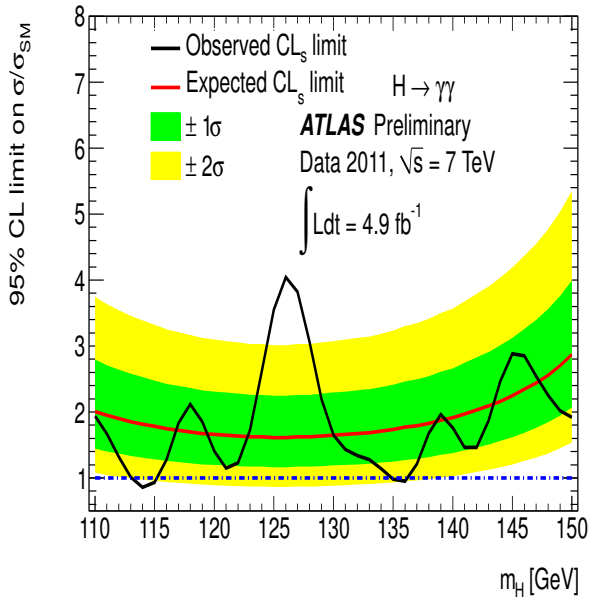


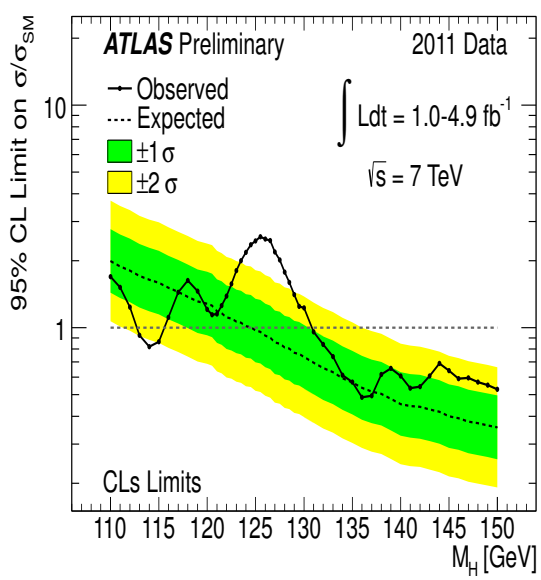


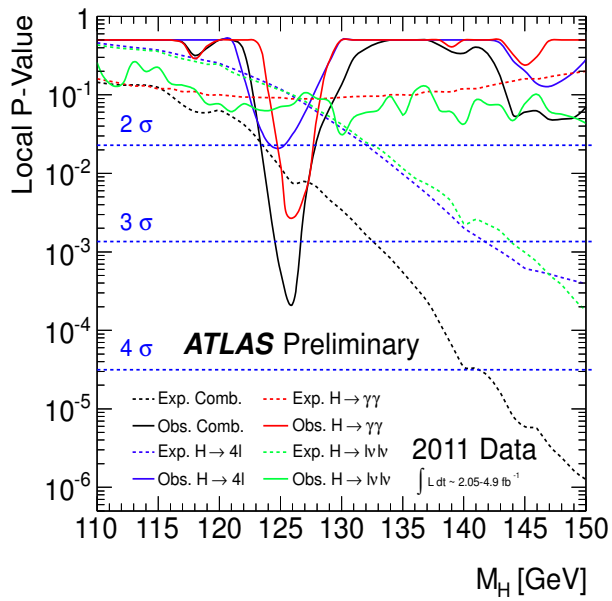
Signature	LVL1 item	Efficiency	Rate at LVL1	Rate at EF
3j80	L1_3J40	0.42 ± 0.02	2.7 ± 0.1	1.5 ± 0.2
4j40	L1_4J20	0.85 ± 0.02	3.3 ± 0.1	2.9 ± 0.1
1b40_2b20_3L1J10	L1_3J10	0.50 ± 0.02	191 ± 2	0.19 ± 0.03
1b40_2b20_3L1J20	L1_3J20	0.49 ± 0.02	25.2 ± 0.4	0.16 ± 0.02

Higgs Searches

2012 might be the year for particle physics!



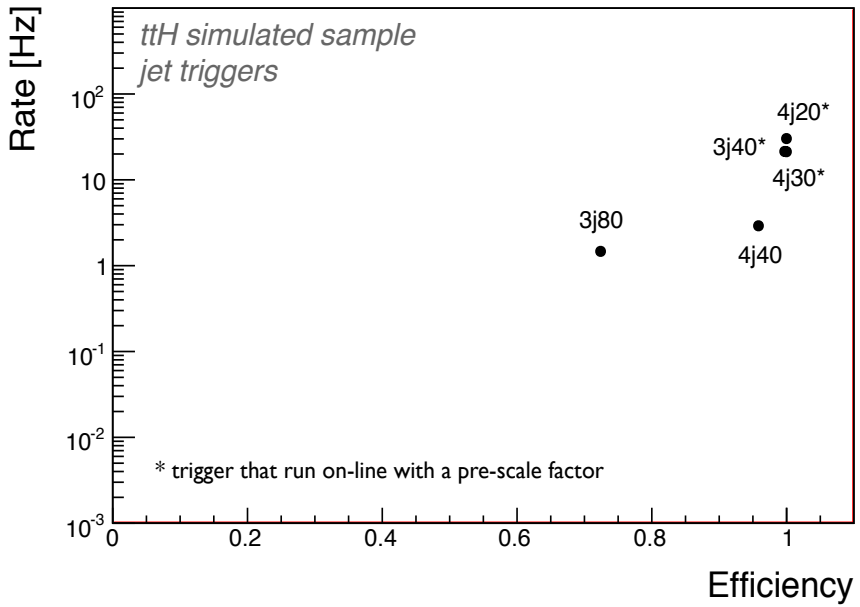


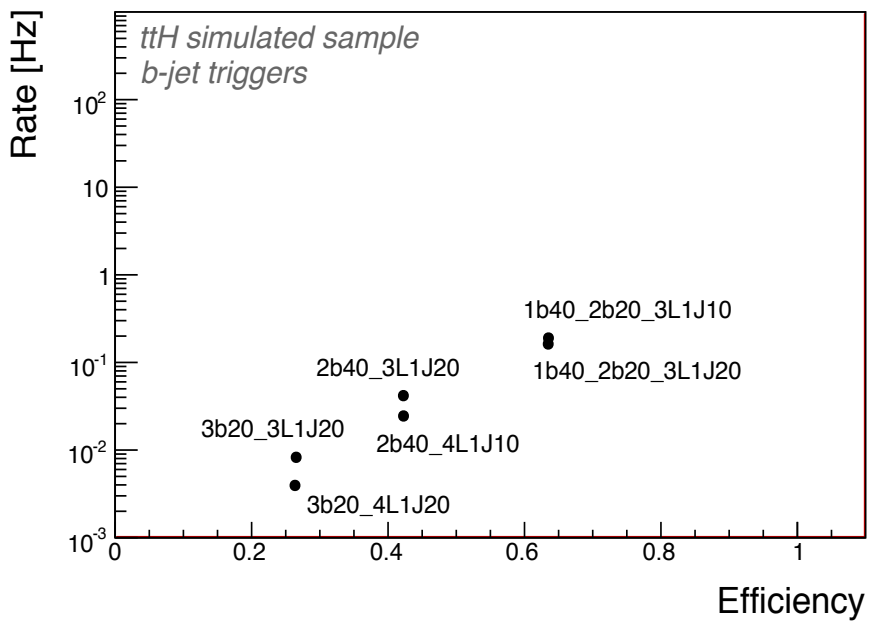


- $\mathcal{BR}(H \to b\bar{b}) \simeq 58\%$ at $m_H = 125\,\text{GeV}$
- if the Higgs boson is in this mass region, $H \to b\bar{b}$ channel is crucial to verify the Higgs coupling to fermions

Again An Old Exercise: Impact of *b*-Jet Triggers

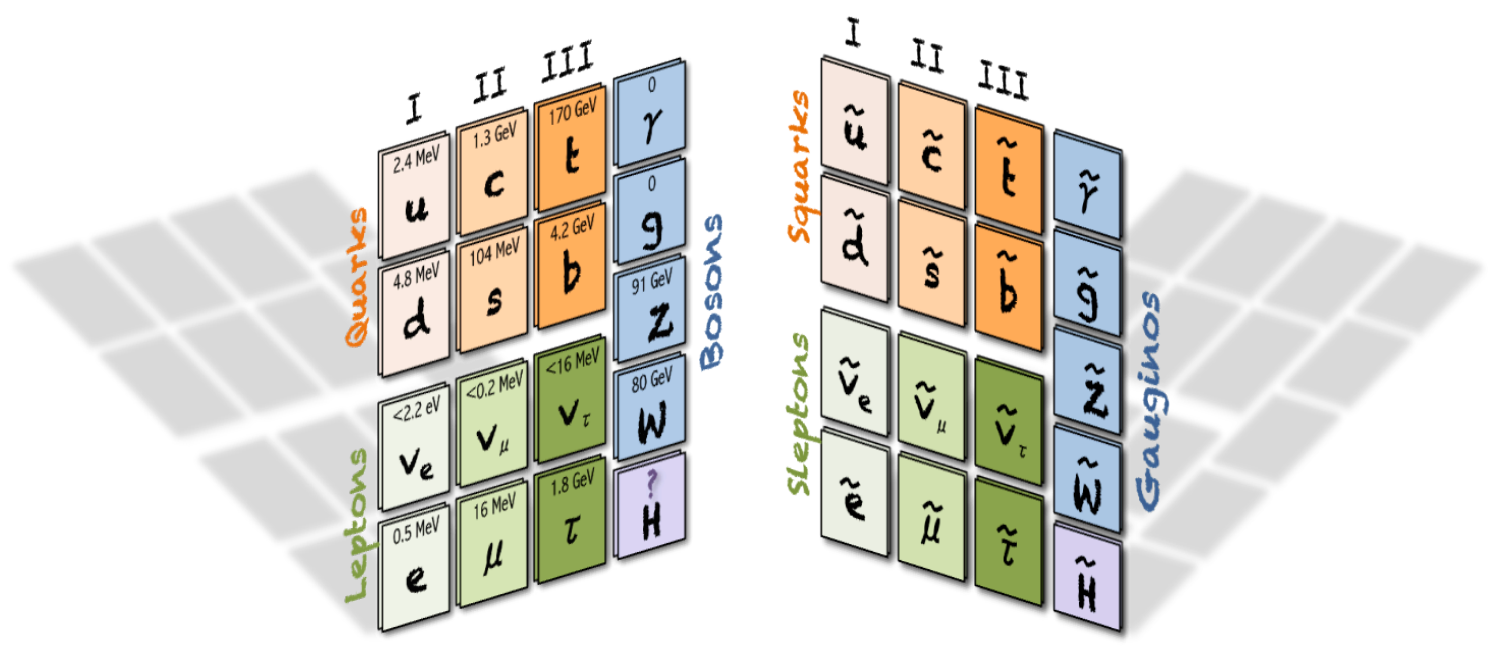
An outdated example for the $t\bar{t}H$ hadronic channel - Rate for $\mathcal{L} = 10^{31}$ cm^{-2} s^{-1}





Signature	LVL1 item	Efficiency	Rate at LVL1	Rate at EF
3j80	L1_3J40	0.72 ± 0.01	2.7 ± 0.1	1.5 ± 0.2
4j40	L1_4J20	0.95 ± 0.01	3.3 ± 0.1	2.9 ± 0.1
1b40_2b20_3L1J10	L1_3J10	0.63 ± 0.01	191 ± 2	0.19 ± 0.03
1b40_2b20_3L1J20	L1_3J20	0.63 ± 0.01	25.2 ± 0.4	0.16 ± 0.02

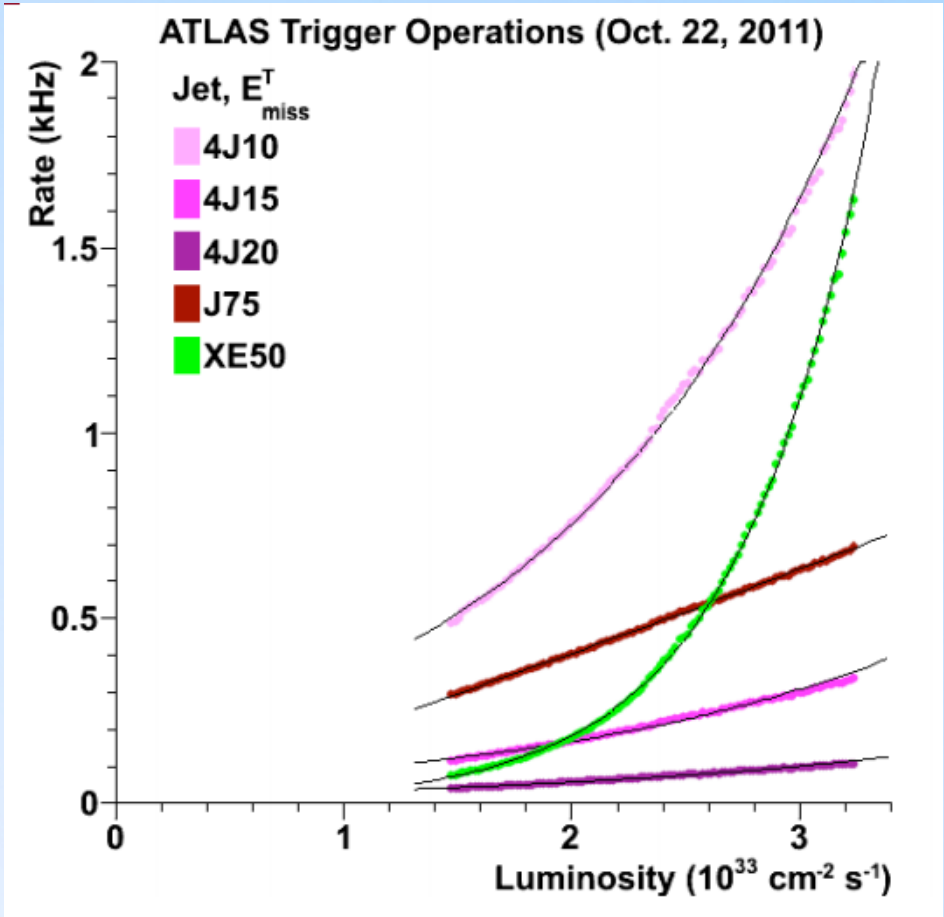
And beyond the SM?



- SUSY is the most popular extension of the Standard Model
- many models and possible final states, typical signature jet plus missing energy
- but region of the phase space of the parameters where missing energy is not large and a *b*-tag requirement makes the difference in terms of trigger acceptance!
- many studies for the 2012 trigger menu ongoing in ATLAS right now

Trigger Menu in 2012

- emphasis on combined triggers, possibility to *b*-tag jets without using the LVL1 jet information
- missing energy trigger strongly dependent on pile-up
  $\Rightarrow$ a *b*-jet plus missing energy trigger will be in place for $ZH \rightarrow \nu\nu b\bar{b}$
- additional triggers are being studied right now to combine
  1. *b*-jet and lepton requirement
  2. *b*-jet and total transverse energy requirements
  3. *b*-jet and photon requirement
  4. multiple *b*-jet requirement



Outline

Conclusions

- I had the privilege to perform a coherent work in ATLAS with emphasis in trigger and physics performance activities
- I actively participated in all the exciting phases of the LHC turn-on especially from the tracking perspective
- core developer of the online tracking and extensive work in the *b*-tagging community: at the trigger level, from the first implementation to the convenorship in 2011
- after my Ph.D. thesis main focus on menu design for high luminosity, *b*-tagging calibration and also contributions for analyses

It's time to ...

... turn all my experience into physics analyses!
... and this matches well with the LHC physics program!
b-jet triggers are useful for certain analyses in 2011 and will be fundamental for a wide class of measurements and searches in 2012!