FastTrack: Real Time Silicon Tracking for LHC

Alessandro Cerri

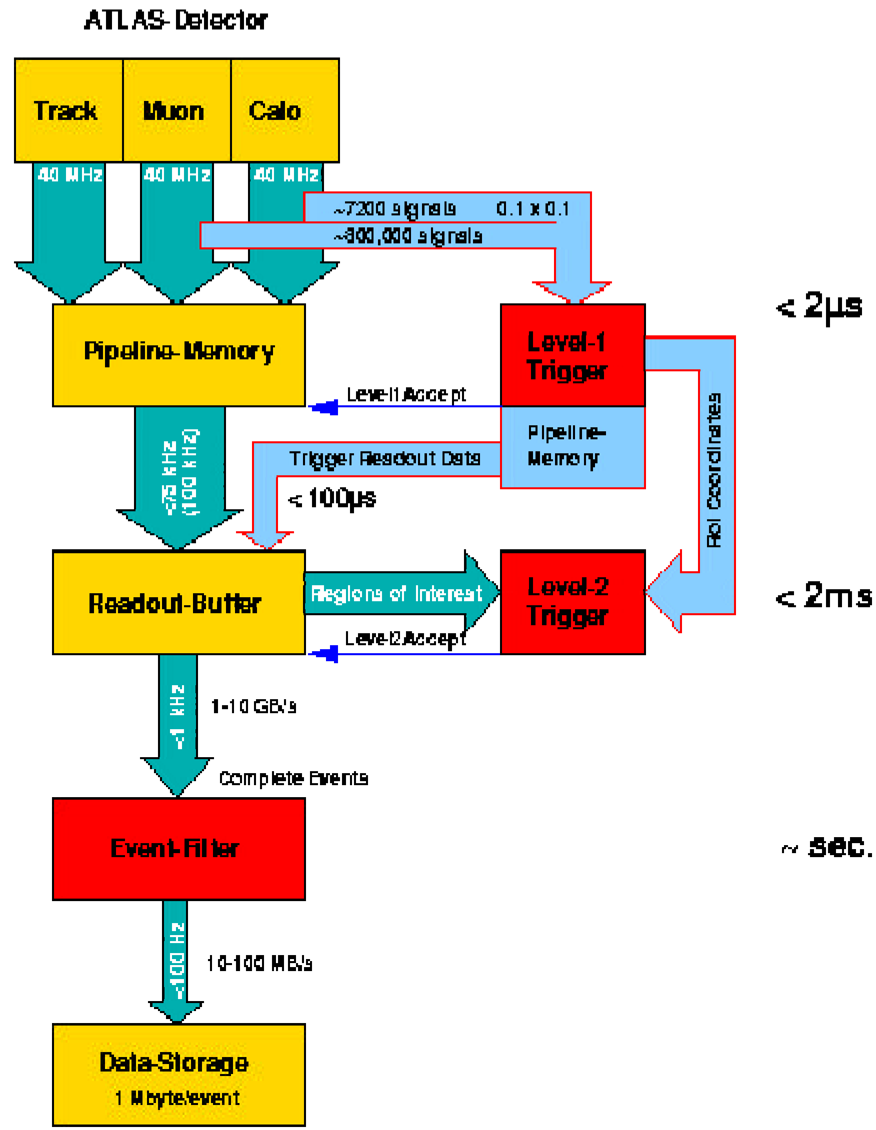
(borrowing from several talks...)

Outline

- What are we talking about?
  - ATLAS trigger (quick!) overview
  - What's missing?
- Does it work? How?
  - CDFII experience
  - Evolving towards LHC
- Why would one want to use it?
  - Selected physics cases
- Think outside the box!

The ATLAS Trigger

- High rate pp collisions force us to throw away events: 40MHz → ~100Hz
- You want to throw away uninteresting* stuff
- How?
- Combine *trigger primitives*: "crude" approximations of analysis objects, like:
  - Jets
  - e/μ
  - Tracks
  - E_t (and lack thereof)
  - EM
- Where is the 3rd generation???



FastTrack

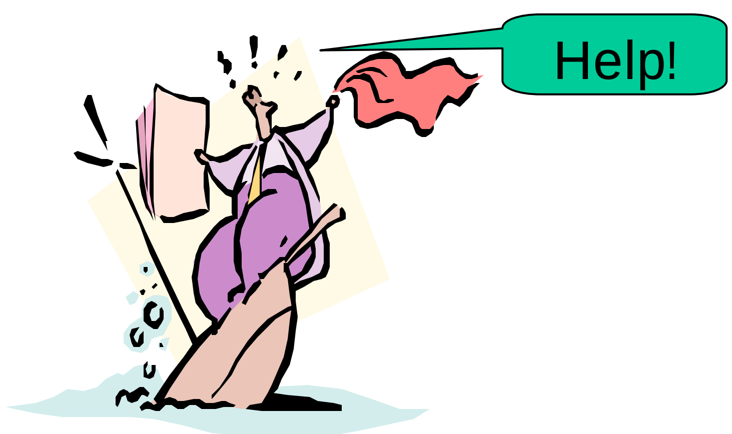
- L2 is designed to be basically a commercial CPU farm
- ...not enough time to reconstruct tracks at full resolution
- Why would I want to do that?
  - b tagging
  - τ

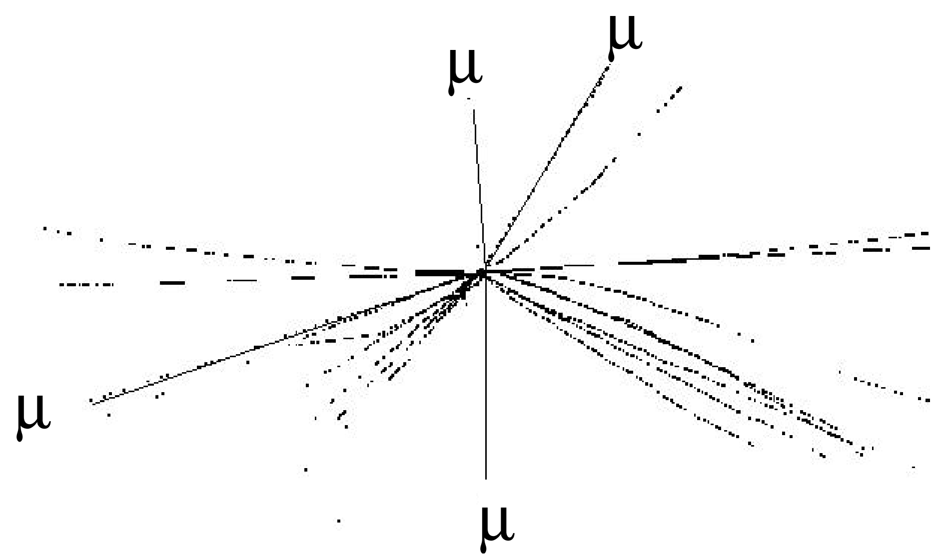
  } 3^{rd} generation is the closest to new physics!
  - ... but keep your mind open: you can do a lot more with a little fantasy!
- Is there money (physics reach) to gain?

FastTrack to the rescue!

30 minimum bias events + $H \to ZZ \to 4\mu$

Where is the Higgs?





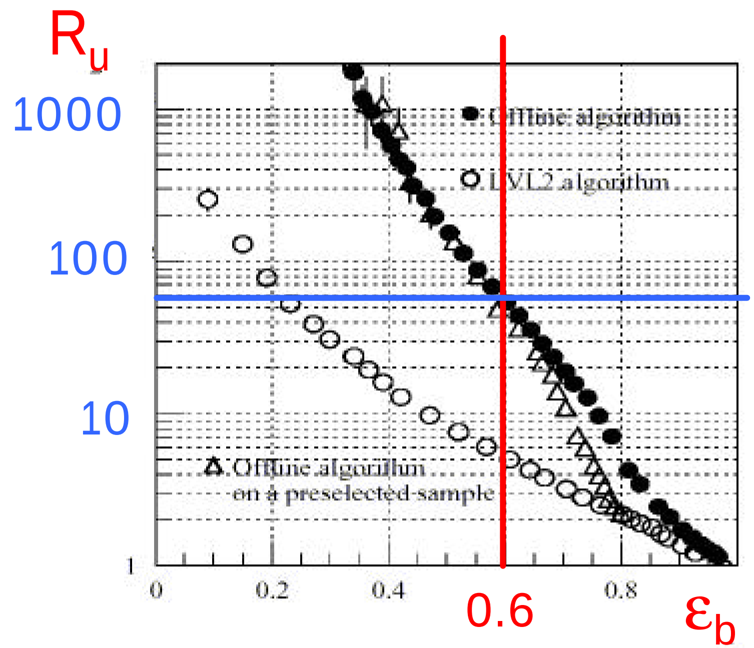
Tracks with P_t>2 GeV

The case for offline-like b-tagging

$Z^0 \longrightarrow b\bar{b}$ Calibration sample

- bbH/A ⟶ bbbb
- tt ⟶ qqqq-bb
- ttH ⟶ qqqq-bbbb
- H/A ⟶ tt ⟶ qqqq-bb
- H ⟶ hh ⟶ bbbb
- H^{+-} ⟶ tb ⟶ qqbb

ATL-DAQ-2000-033



ATLAS TDR-016

with Fast-Track offline b-tag performances early in LVL2. You can do things 1 order of magnitude better

FastTrack/LHC: access to the 3rd generation

Scenario: L= 2 x 10^{33} deferral

	LVL1 selection	LVL1 rate (KHz)	HLT selection	HLT rate (Hz)
ATLAS	μ20 2μ6	0.8 0.2	μ20 2μ10	↓ 40
ATLAS	j200 3j90 4j65	0.2 0.2 0.2	j400 3j165 4j110	↓ 25
ATLAS + FTK	μ6 + j25 + j10 (\|η|<2.5)	2.6	2 b-tags + M_{bb} > 50	160 mini ev.
ATLAS + FTK	"	"	3 b-tags	4
ATLAS + FTK	ΣE_T200 + j70 + j50 + j15 (\|η|<2.5)	4	2 b-jets + M_{bb} > 50	50 mini ev.
ATLAS + FTK	"	"	3b leading	1
CMS	Inclusive b-jet		b-jet 237	5

F. Gianotti, LHCC, 01/07/2002
CMS TDR 6 &

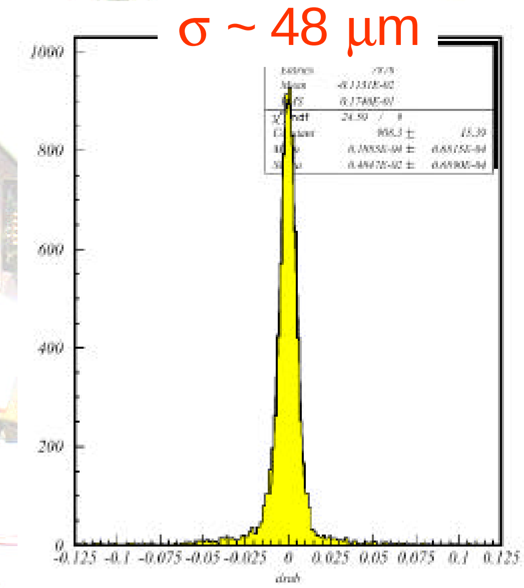
ATL-COM-DAQ-2002-022

Even better strategies: see 'physics cases'

Is it feasible?

- We are talking about something capable of digesting 100000 evts/second and identifying tracks in the silicon
- What on earth would be able to do that?

•... it turns out CDFII has been doing something similar since day 0



•The recipe uses specialized hardware:

1)Clustering

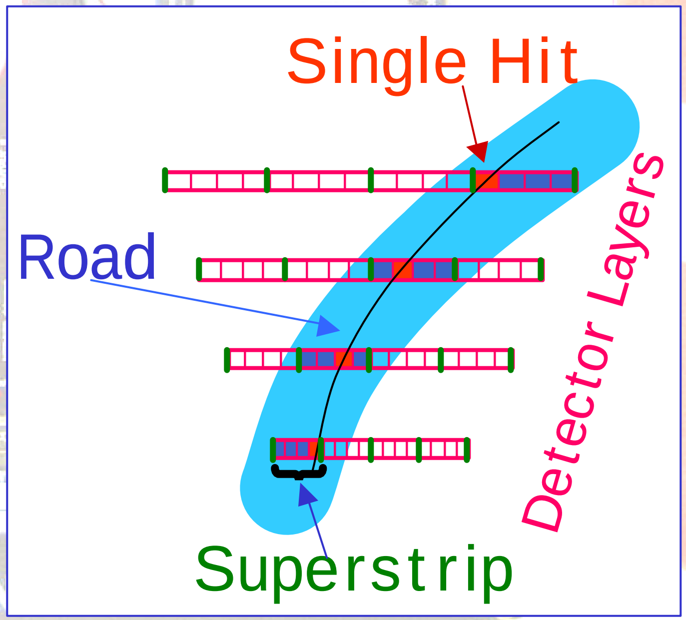
Find clusters (hits) from detector ‘strips’ at full detector resolution

2)Template matching

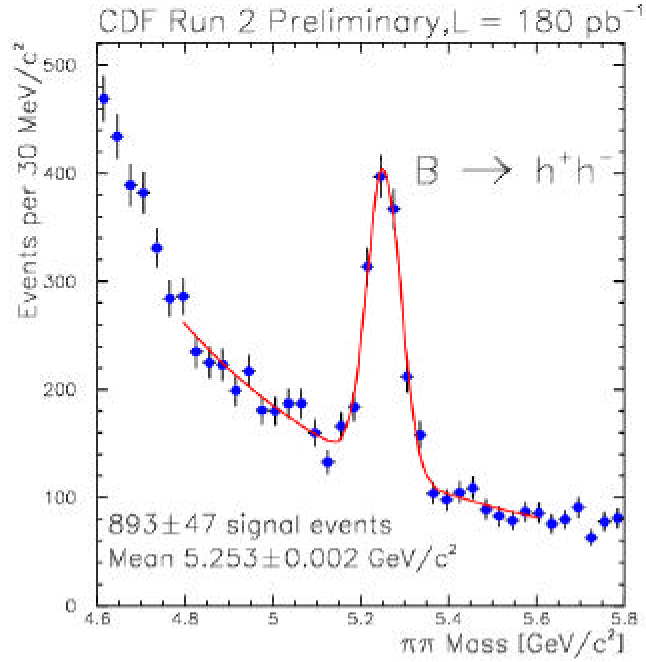
Identify roads: pre-defined track templates with coarser detector bins (superstrips)

3)Linearized track fitting

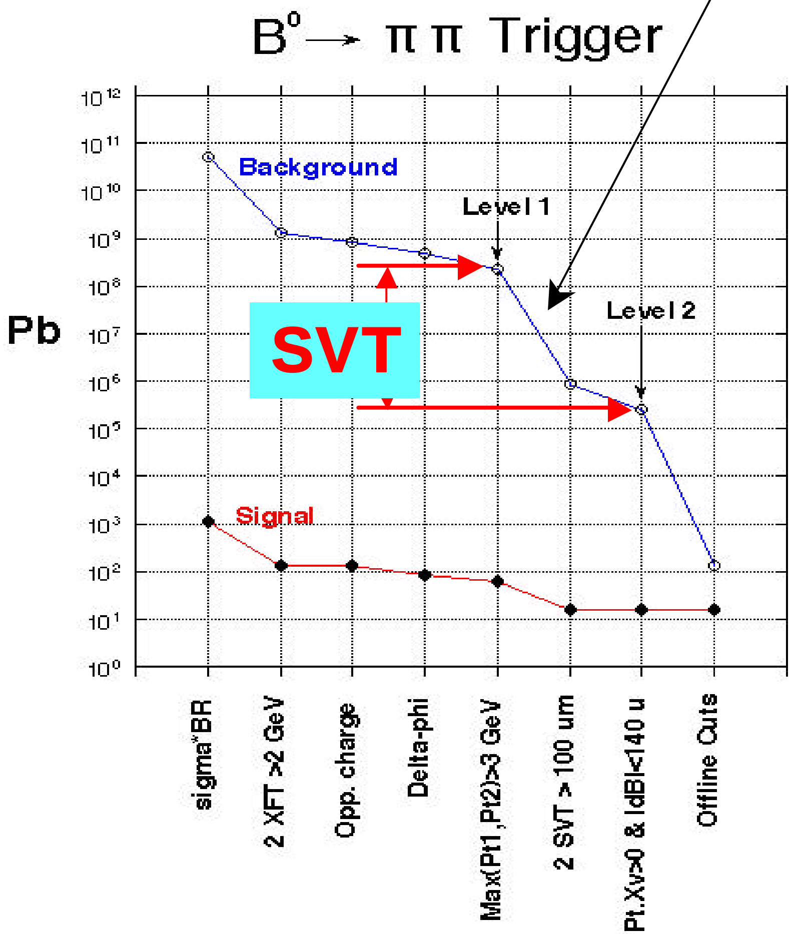
Fit tracks, with combinatorial limited to clusters within roads



Is it effective?



SVT rejection:
3 orders of magnitude



Many high-pt triggers based on SVT are taking data.

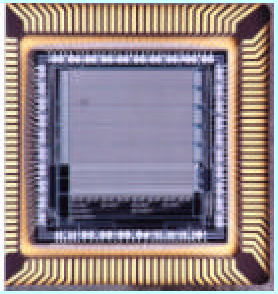
2 b-jets ($Z \rightarrow bb$)
MET + disp. tracks (ZH)
lepton + disp. track (SUSY)
gamma + disp. track (SUSY)

Can we scale to the ATLAS complexity?

- Not easy:
  - 500K channels $\rightarrow$ O(100M)
  - 20μs$\rightarrow$2μs
- But feasible:
  - SVT has been designed in ~1990 with (at the time) state of the art technology
  - We have been thinking a lot on how to improve the technology
  - The SVT 'upgrade' (2005) is in fact partly done with hardware capable of LHC-class performance!

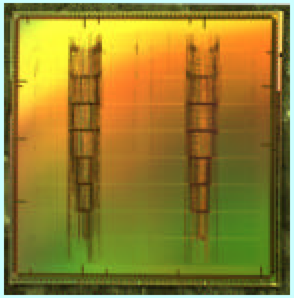
1998: Full custom VLSI "Associative Memory" chip:

128 patterns



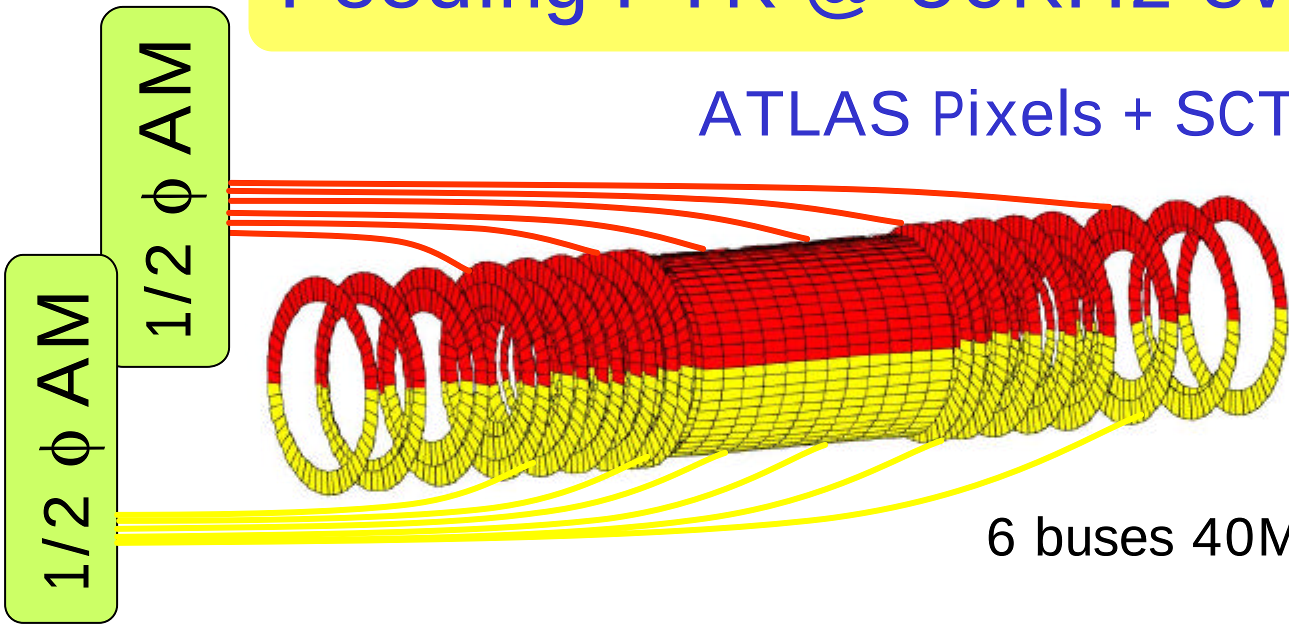
2004: Standard Cell "Associative Memory" chip:

~5000 patterns



Feeding FTK @ 50KHz event rate

ATLAS Pixels + SCT



Divide into ϕ sectors

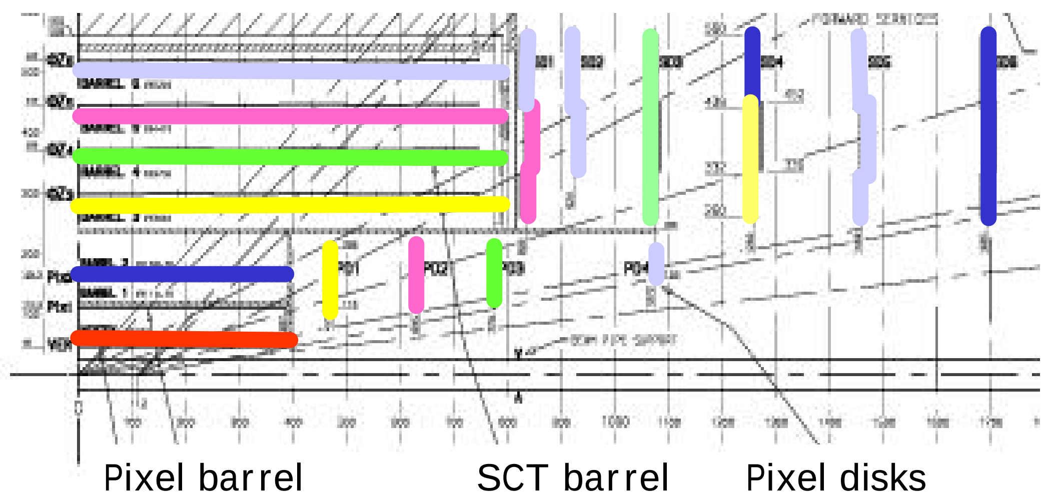
Allow a small overlap for full efficiency

6 buses 40MHz/bus

6 Logical Layers: full η coverage

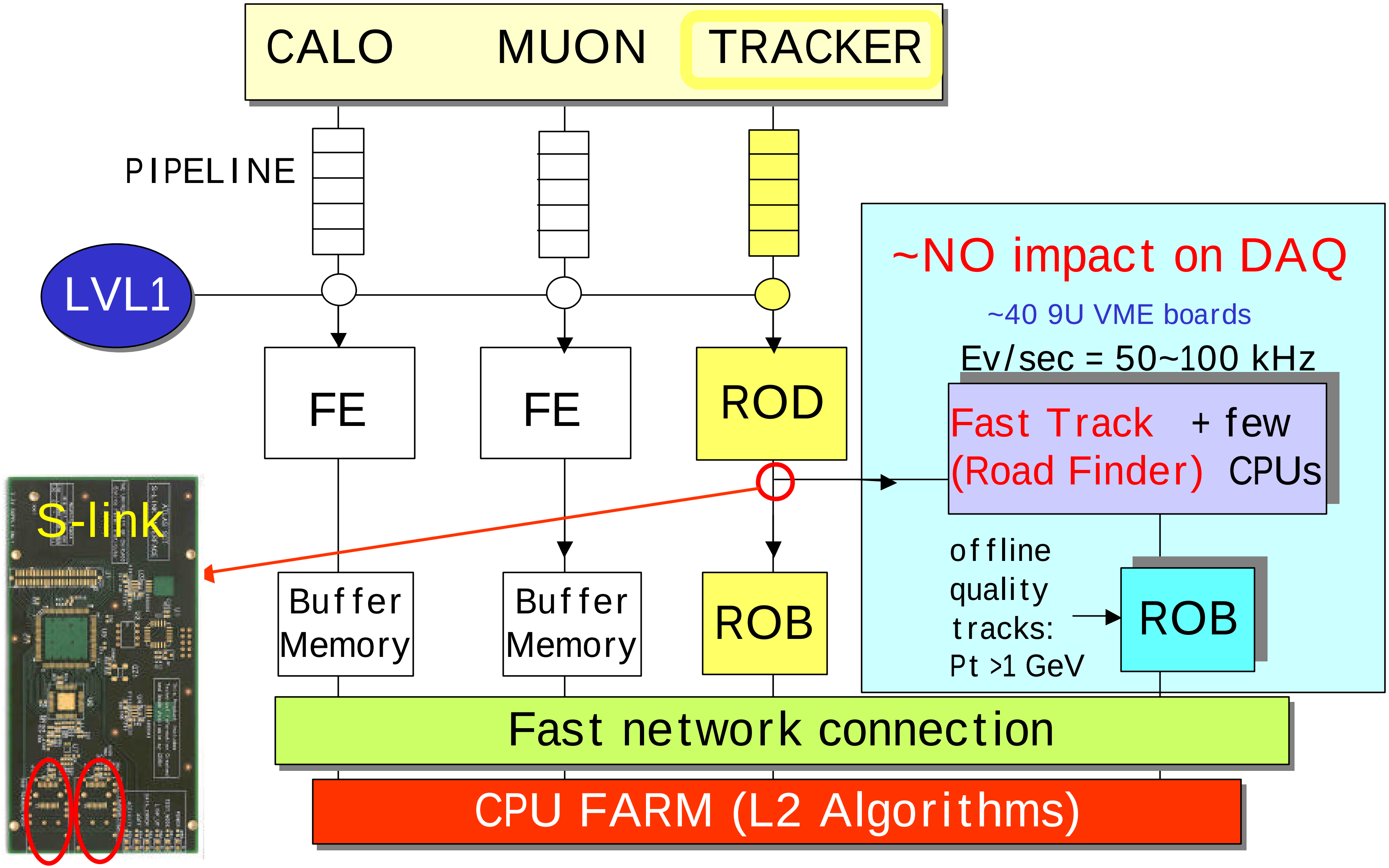
~70MHz cluster/layer
(Low Luminosity, 50KHz ev.)

2 ϕ sectors



ATLAS-TDR-11

How to pick the ATLAS data?



Two outputs!

Selected Physics Cases

Lots of ideas, limited energy:

$Z \to bb$	Better acceptance (calibration samples)
bbH/A $H \to bb, \tau\tau$	Low Pt b-jets
$H \to hh \to bb\ bb$	
$l\tau$	Lower thresholds (calibration sample)
$W \to \tau\nu$	
Multi-prong τ triggers	Improved acceptance
$B \to \mu\mu$	Lower thresholds

Example 1: $Z \rightarrow bb$

- Important calibration tool to measure jet response/resolution (γ-jet and z-jet balance have theo/exp issues)

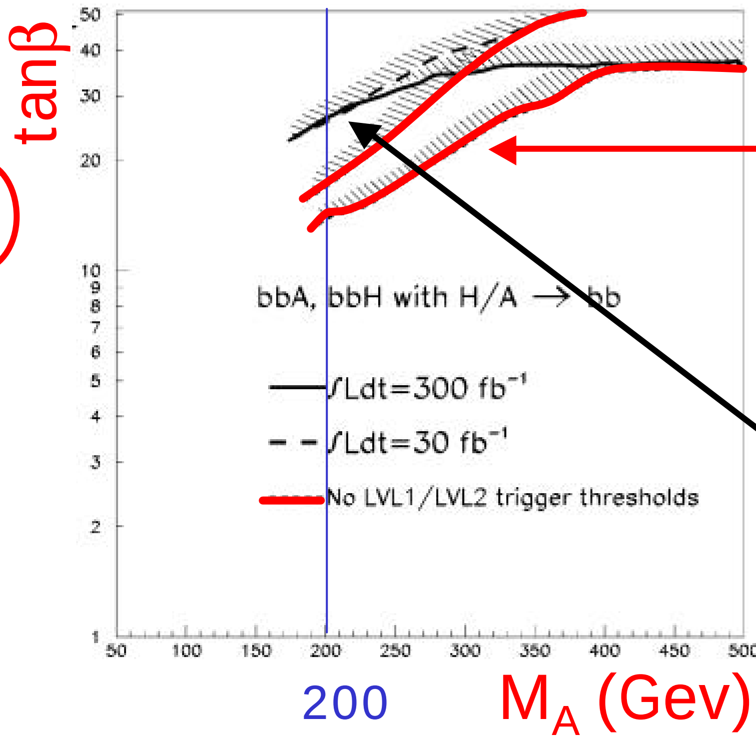
- Standard trigger: Large L1 rate $\Rightarrow$ higher Et threshold $\Rightarrow$ high Mjj turn-on

- With FastTrack: $qg \rightarrow Zq \rightarrow bbq$ (3jet + btag) advantages:
    - Better Mjj acceptance, improved rejection
    - Highest Et jet needs not be tagged!

LVL1		LVL2		$S/\sqrt{B}$
MU6 + 2J	2.6 KHz	$M_{bb} > 50$	160 Hz	$\cong$ 60 (@20 fb^{-1})
3J + SE200	4 KHz	$M_{bb} > 50$	50 Hz	$\cong$ 20 (@20 fb^{-1})
J190	5 KHz	1 non-b, 2b	10 Hz	$\cong$ 21 (@30 fb^{-1})

Example 2: bbH/A ® bbbb

ATLAS-TDR-15 (1999)



Optimized Analysis (not very recent though):
4 b-jets $|\eta^j|<2.5$
P_T^j > 70, 50, 30, 30 GeV
efficiency 10%

Effect of trigger thresholds (70,50,30,30)->4x110 !!!

Standard trigger limits $\tan\beta$ reach at low M_A !!!

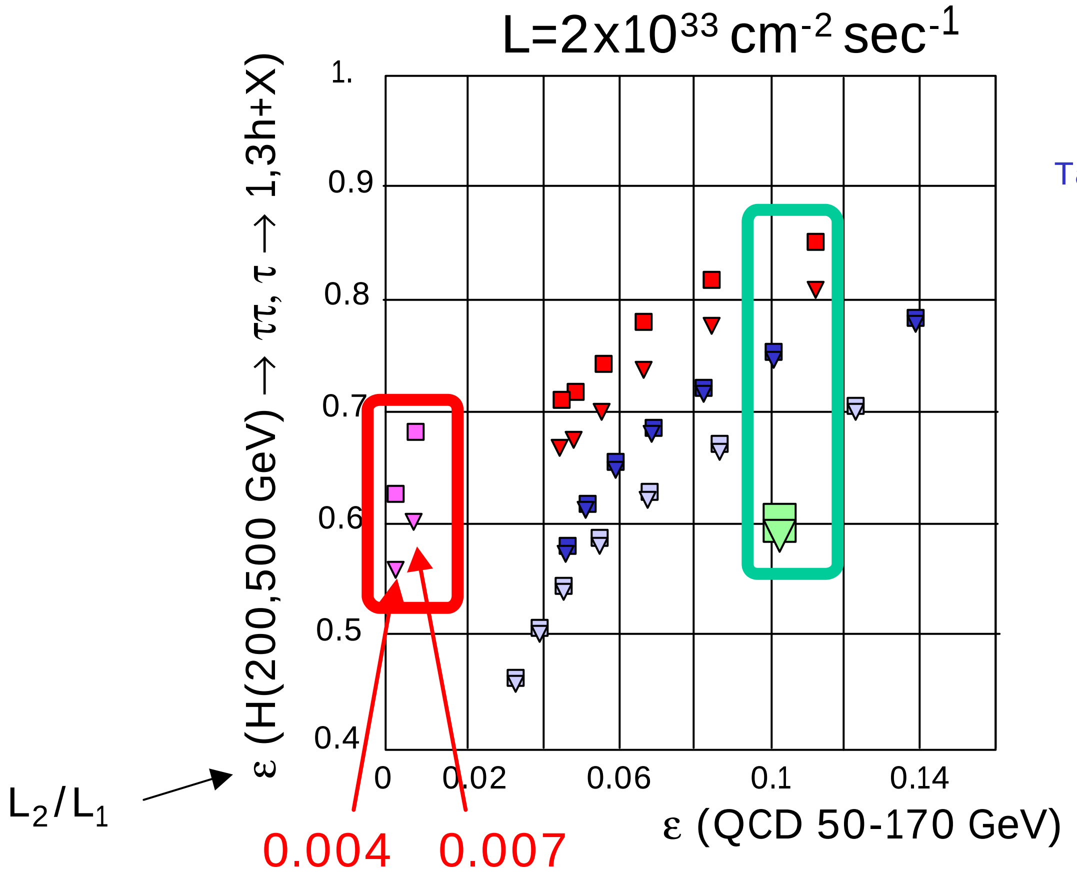
ATL-COM-DAQ-2002-022

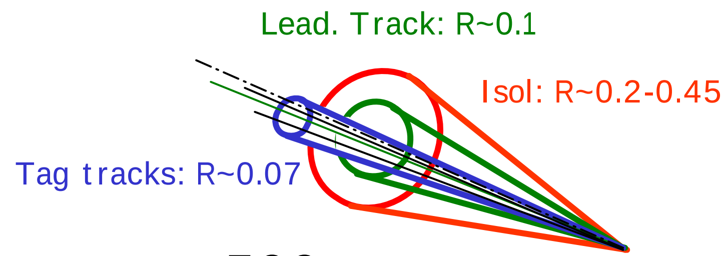
ATLAS + FTK triggers		
LVL1	LVL2	Effic.
Soft$_6$ μ + 2j	3 b-tag	8%
3j + ΣE_T200	3b leading	13%

As efficient as offline selection:
full Higgs sensitivity

Example 3: τ @ CMS

Default algorithm: calorimetric search first, then tracking





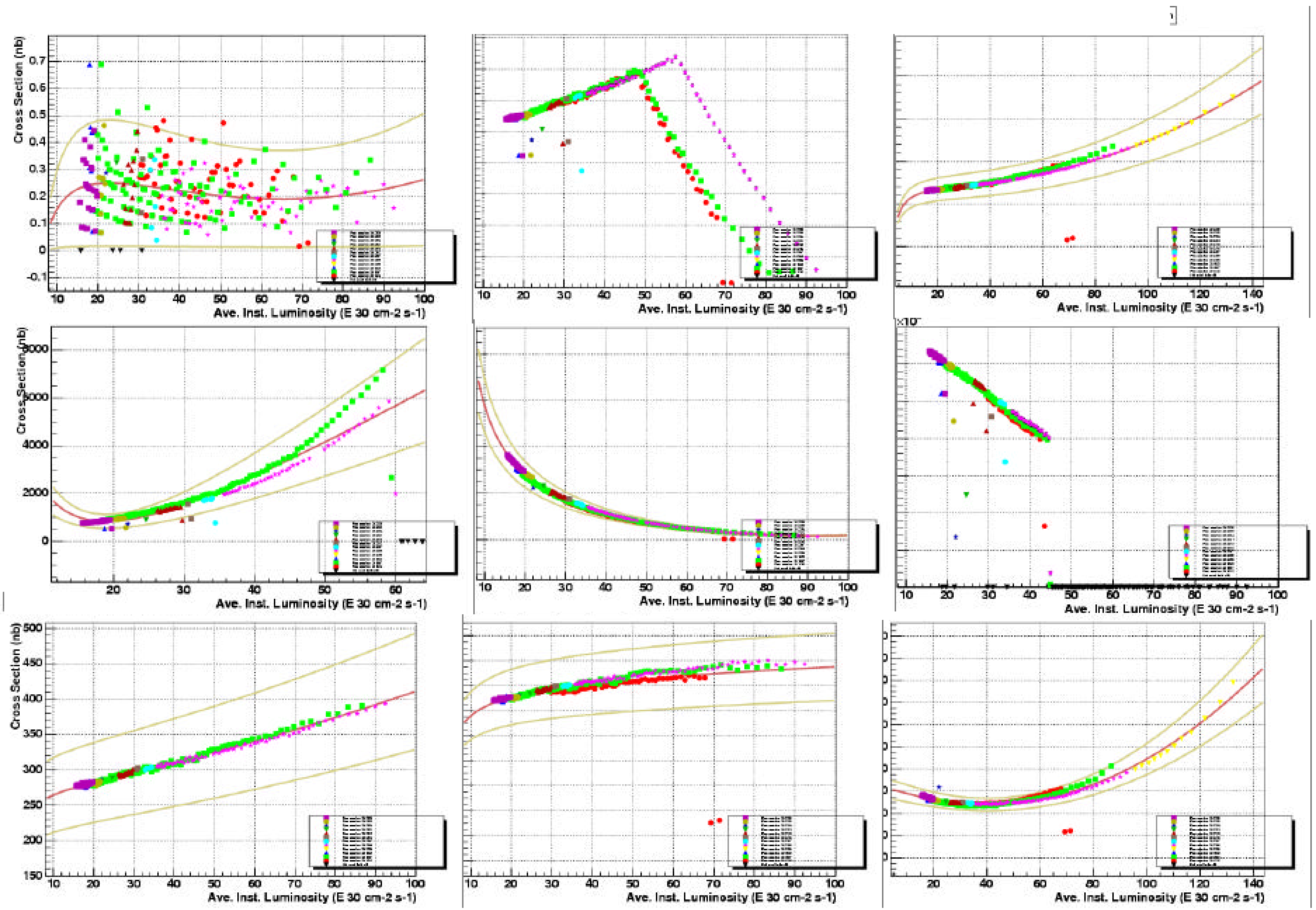
□ m_H=500

▽ m_H=200

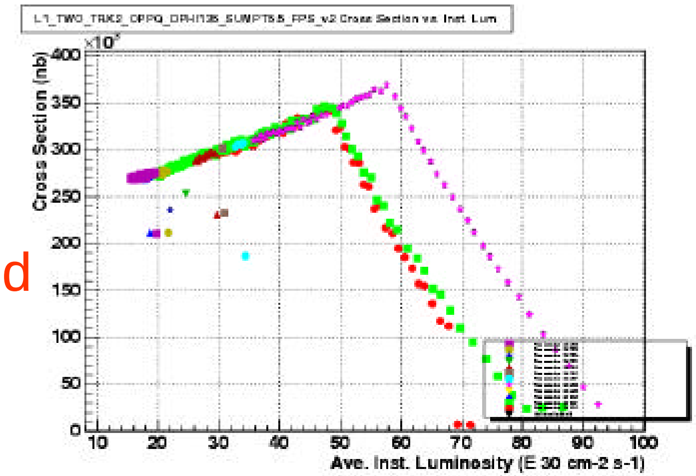
- Staged-Pix tau on first calo jet
- Pix tau on first calo jet
- TRK tau on first calo jets
- TRK tau on both calo jets
- Calo tau on first jet

Efficiency & jet rejection could be enhanced by using tracks before calorimeters.

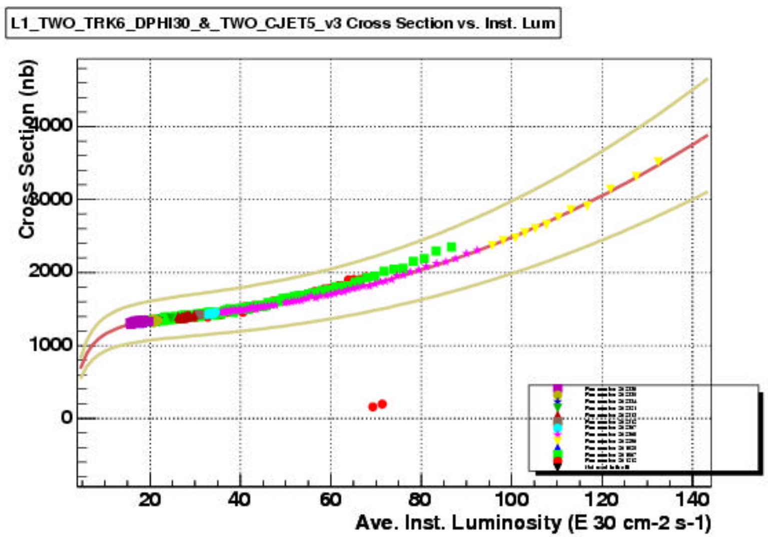
Q: Which of these represents an actual trigger rate vs luminosity?

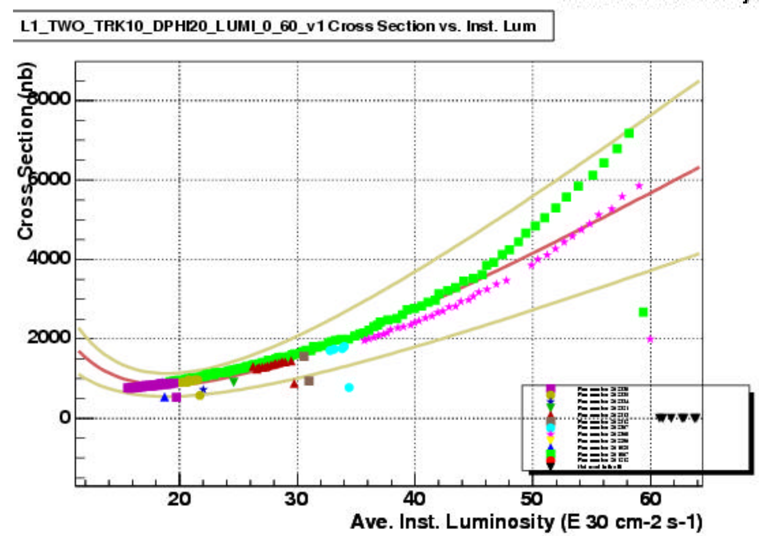


Be careful!



- Rates and rejections must be understood at our best NOW:
  - Anything too loose will be cut out/removed
  - Trigger rates are *not* dominated by physics:





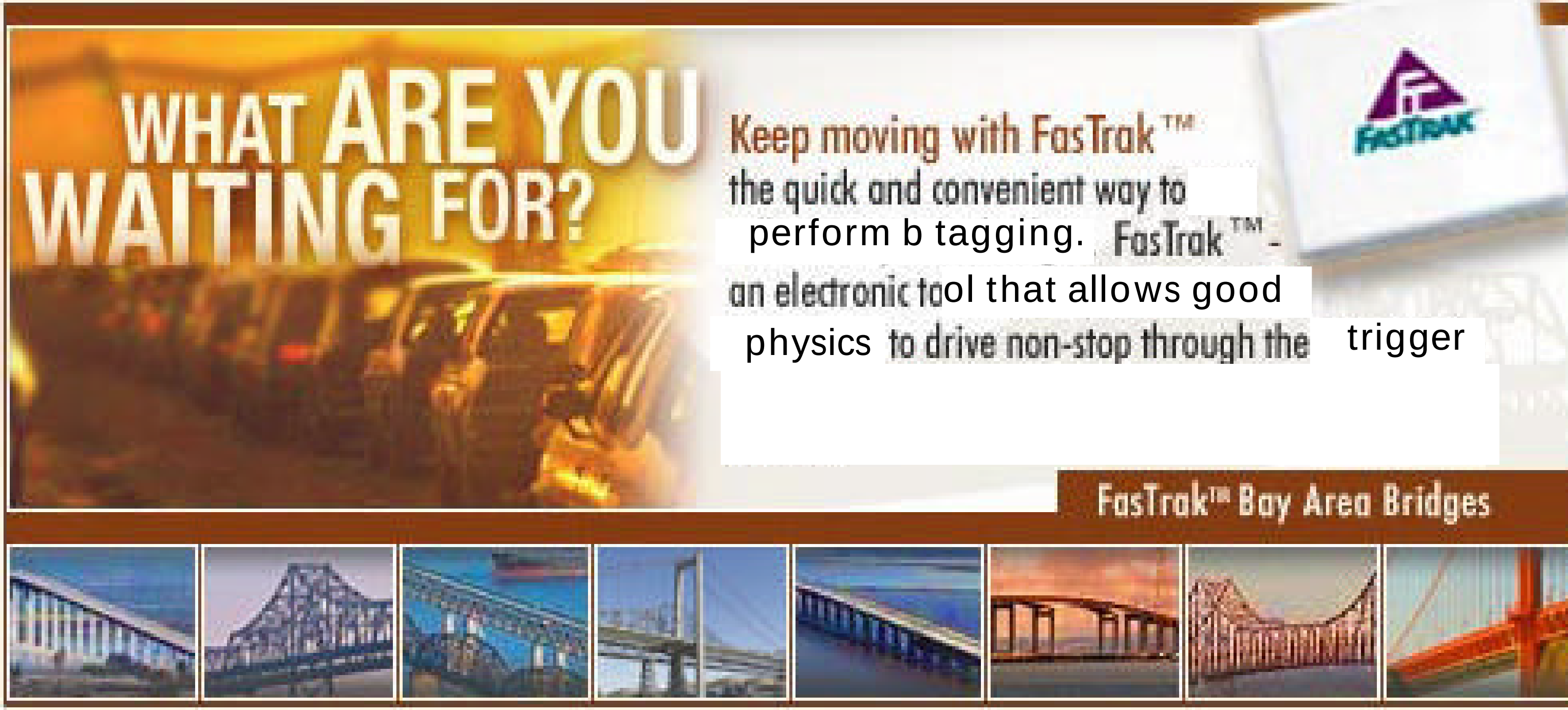
- CDF misunderestimated(©™ GWB) the background rates by large (~2x) factors. Not for ingenuity but for lack of better ways of extrapolating to the High Energy Frontier! Expect something similar!

Where would I put effort

- Simulating background requires HUGE resources: billions of MC events @ 5 minutes/event ?!??
- Revert to fast simulation
    - Calibrate (e.g. jet response and trigger efficiencies) from full simulation
    - Parameterize in AtlFast!
- Need to strengthen the physics case:
    - Ideas
        - Other physics cases
        - Applications
    - Tools
        - Fast simulation is basically there (but still not 100%)
        - There is a substantial setup time: the sooner the better
- Brainstorming!

Beyond b tagging?

- FastTrack is extremely modular
- With little interfacing, any detector can in principle be used as seed for FastTrack objects:
  - Muons
  - Calorimetry
  - TRT
- What would you be able to do with those at trigger level?
- Any other wild dream of yours?
- Mine: FastTrack can do more complicated pattern recognition than just tracks
  - Vertices?
  - Topological triggers?



Some References:

http://www.pi.infn.it/~orso/ftk/

http://www.pi.infn.it/~annovi/

http://hep.uchicago.edu/cdf/shochet/ (under ftkxxx)

http://www-cdfonline.fnal.gov/svt/

IEEE Trans. Nucl. Sci. **51**, 391 (2004)

Hadron Collider Triggers with Offline-Quality Tracking at Very High Event Rates

Alberto Annovi, Antonio Bardi, Mario Campanelli, Roberto Carosi, Pierluigi Catastini, Vincenzo Cavasinni, Alessandro Cerri, Allan Clark, Mauro Dell'Orso, Tarcisio Del Prete, Andrea Dotti, Giampiero Ferri, Stefano Giagu, Paola Giannetti, Giuseppe Iannaccone, Michele La Malfa, Fabio Morsani, Giovanni Punzi, Marco Rescigno, Chiara Roda, Mel Shochet, Franco Spinella, Stefano Torre, Giulio Usai, Laurent Vacavant, Iacopo Vivarelli, Xin Wu, and Lucia Zanello, *Member, IEEE*

Abstract-- **We address the perspectives for precise and fast track reconstruction at hadron collider experiments, in the era opened by SVT, the processor successfully developed for and operated at the CDF experiment. We discuss some applications of offline-quality tracks available to the trigger logic at an early stage, by using the LHC environment as a benchmark. The most interesting application is online selection of b-quarks down to very low Pt providing interesting** hadronic **samples: examples are $Z^0 \rightarrow b\bar{b}$ potentially useful for jet calibration and multi-b final states for supersymmetric Higgs search.**

Then we describe the features of Fast-Track (FTK), a highly parallel processor dedicated to the efficient execution of a fast tracking algorithm. The hardware-dedicated structure optimizes speed and size; these parameters are evaluated for the ATLAS experiment. The paper is generated from outside the ATLAS experiment and has not been discussed by the ATLAS collaboration.

Manuscript received xxx xxxx.

A. Bardi, R. Carosi, T. Del Prete P. Giannetti, F. Morsani, F. Spinella and S. Torre are with Istituto Nazionale di Fisica Nucleare, Pisa, Italy (telephone: +39-050-2214000, e-mail: firstname.lastname @pi.infn.it).

A. Annovi, P. Catastini, V. Cavasinni, M. Dell' Orso, A. Dotti, G. Ferri, M. La Malfa, C. Roda, G. Usai are with Dipartimento di Fisica, Università di

I. Introduction

WE propose the use of a dedicated hardware processor, Fast-Track [1] (FTK), for online pattern recognition of tracker detector data. FTK is an evolution of SVT [2], the tracker now running at the CDF experiment. FTK is a powerful processor that, in combination with a few standard CPUs fully reconstructs events providing offline-quality tracks for all particles of transverse momentum above 1 GeV or even less. This work can be performed at the very high event rates accepted by the level-1 trigger, i.e. up to 50-100 kHz.