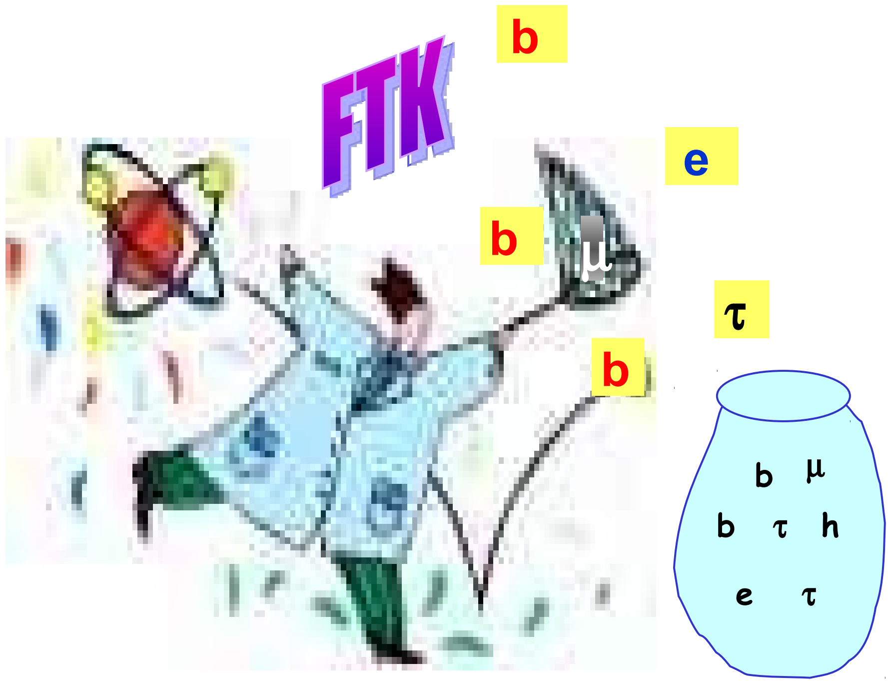
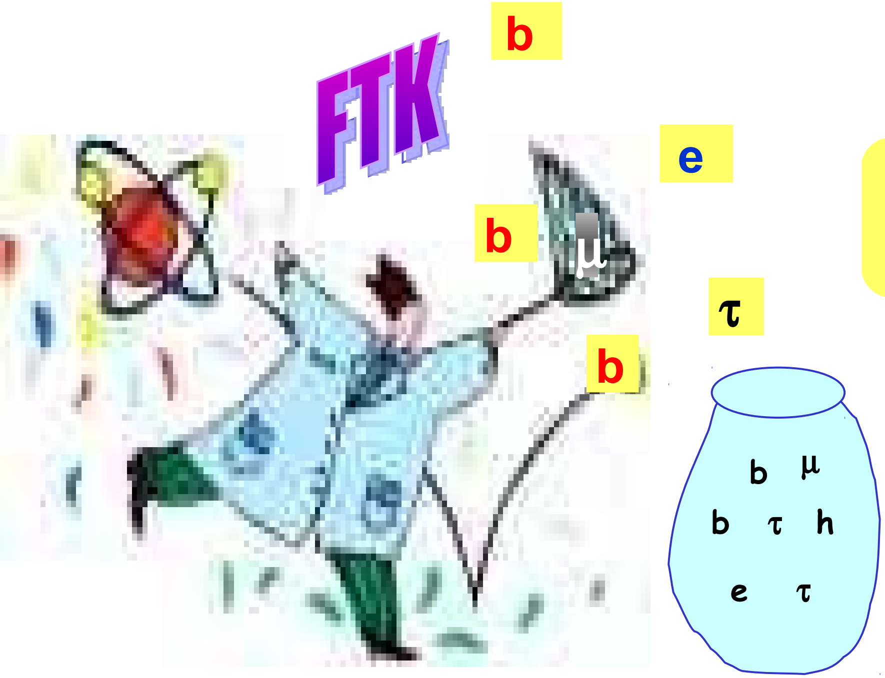
The Fast Tracker real time processor and its impact on the muon isolation, tau & b jet online selections at Atlas

ATL-DAQ-SLIDE-2010-098
01 June 2010



F. Crescioli for the FTK Collaboration



Outline

Efficient selection of b, τ, μ, e:
to be efficient on "light" particles
(W, Z, H….) in terrific pileup

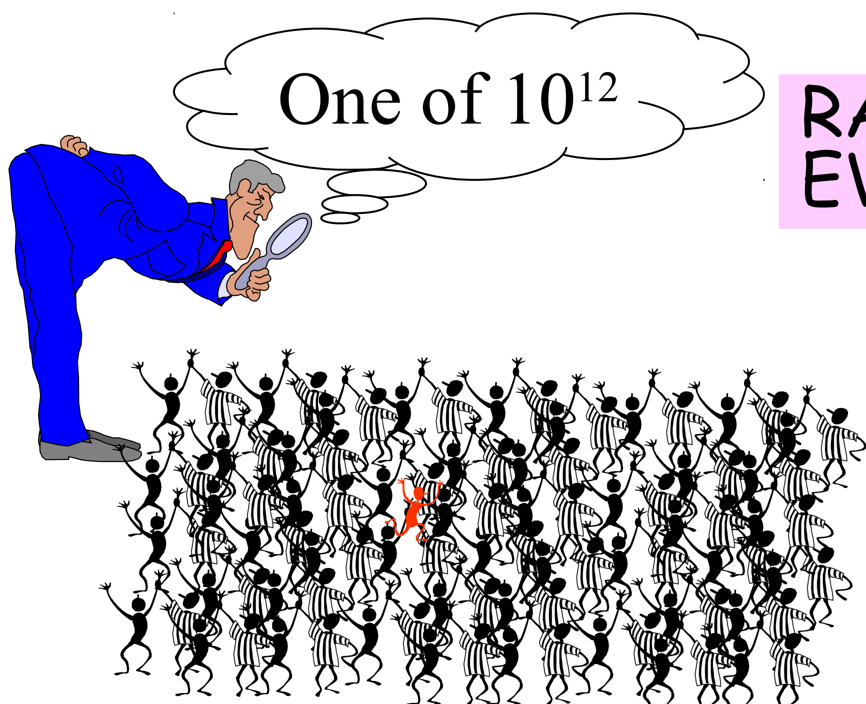
- Why FTK? Timing and Event complexity @High Luminosity
- Physics case: stiff-leptons, b-jets, tau-jets
- FTK architecture

Why FAST TRACKING is IMPORTANT for TRIGGER @ HADRON COLLIDERS WITH HIGH PILE-UP

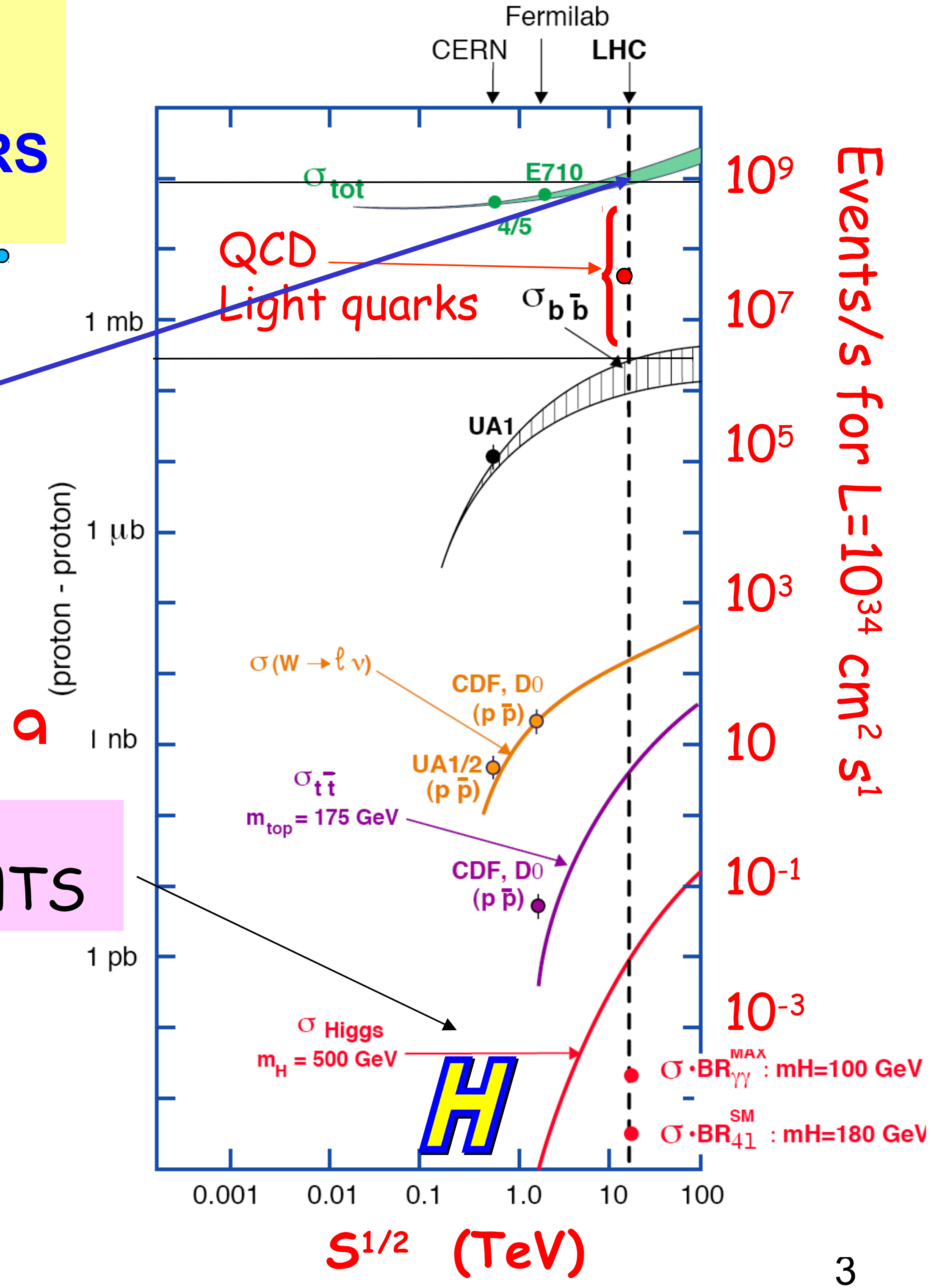
Pile-up: Hard Life!

25 events @10^{34} $cm^{-2}s^{-1}$
40 MHz coll. Rate

75 events @$3x10^{34}$ $cm^{-2}s^{-1}$
40 MHz coll. Rate SLHC



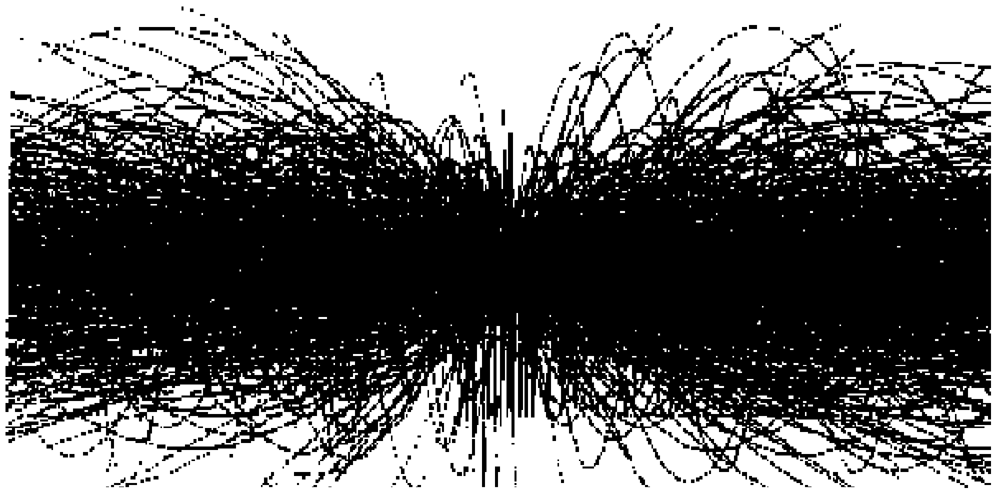
RARE EVENTS



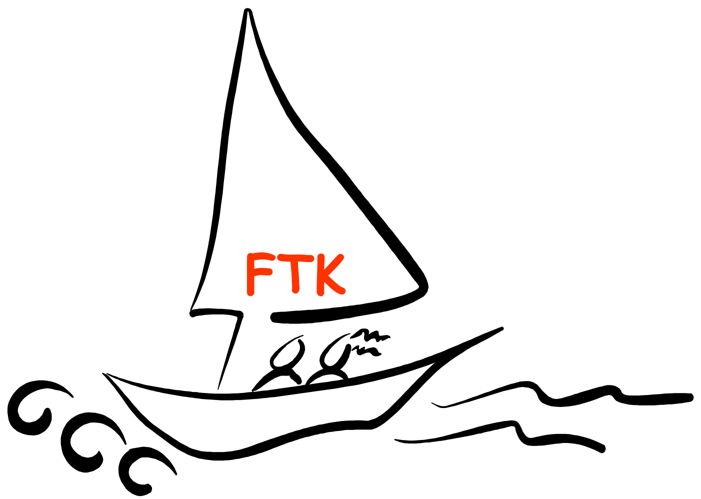
L1-L2 early tracking: a tough problem

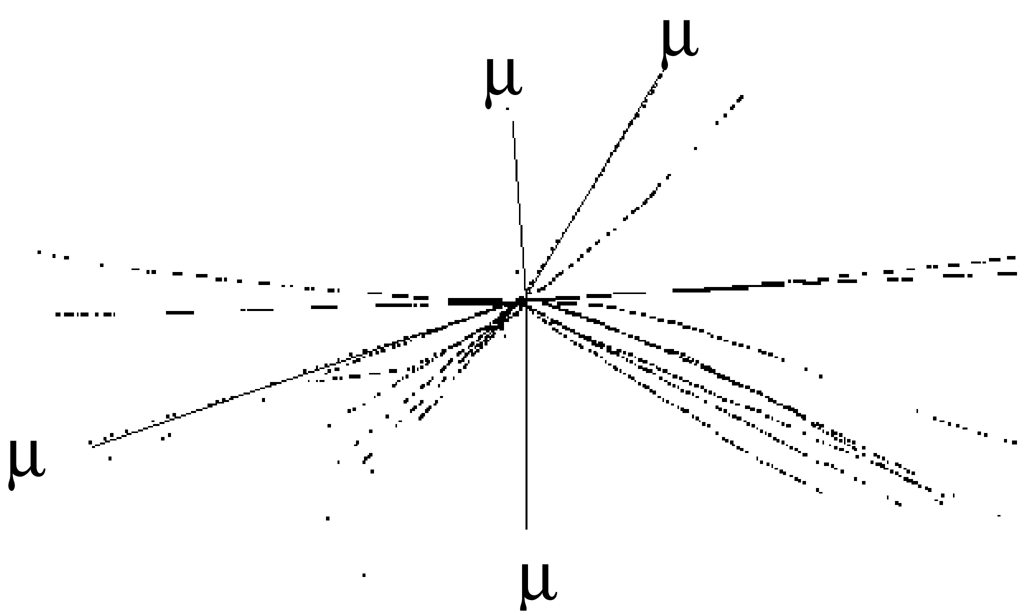
30 minimum bias events + H->ZZ->4μ

@LHC (both CMS & Atlas) tracking is missing @L1 and late @L2



Where is the Higgs?

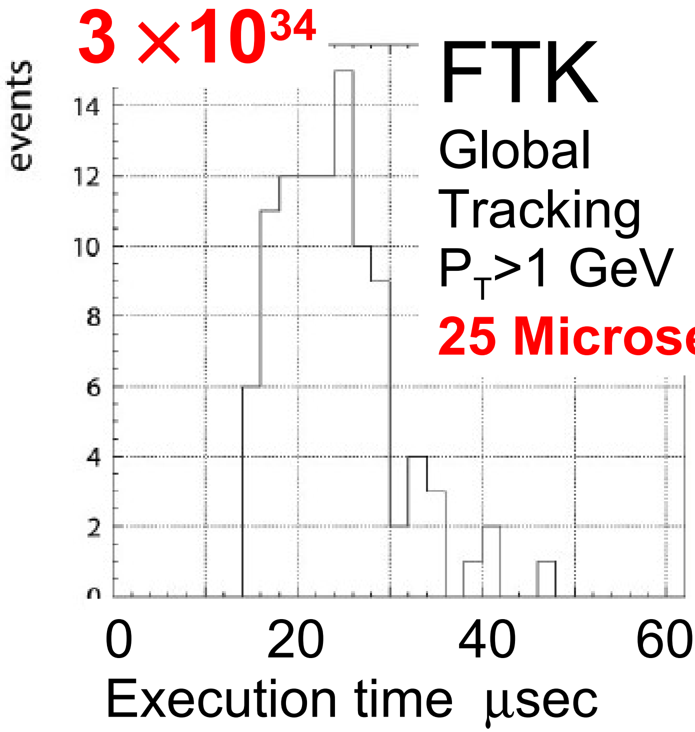


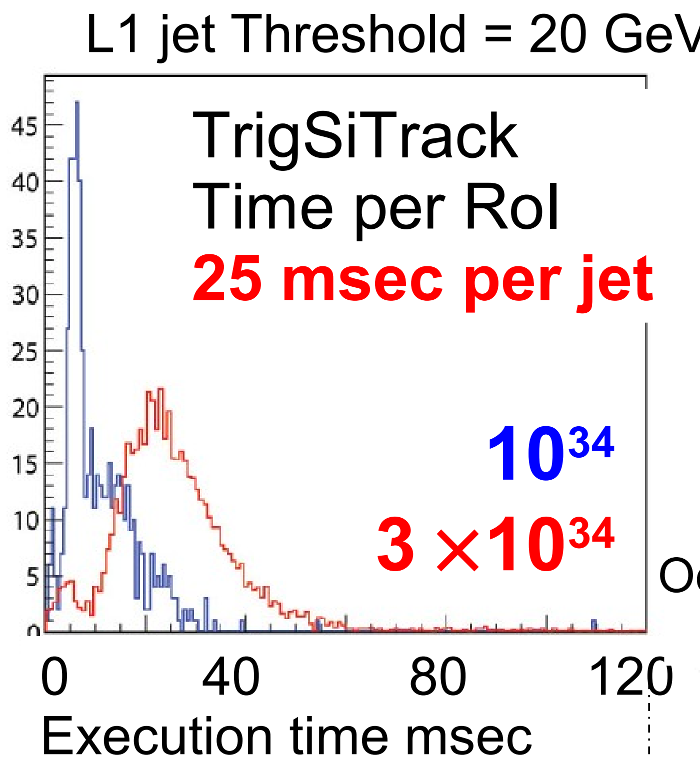


Tracks with P_t>2 GeV

FTK extremely important @ High Luminosity

Timing

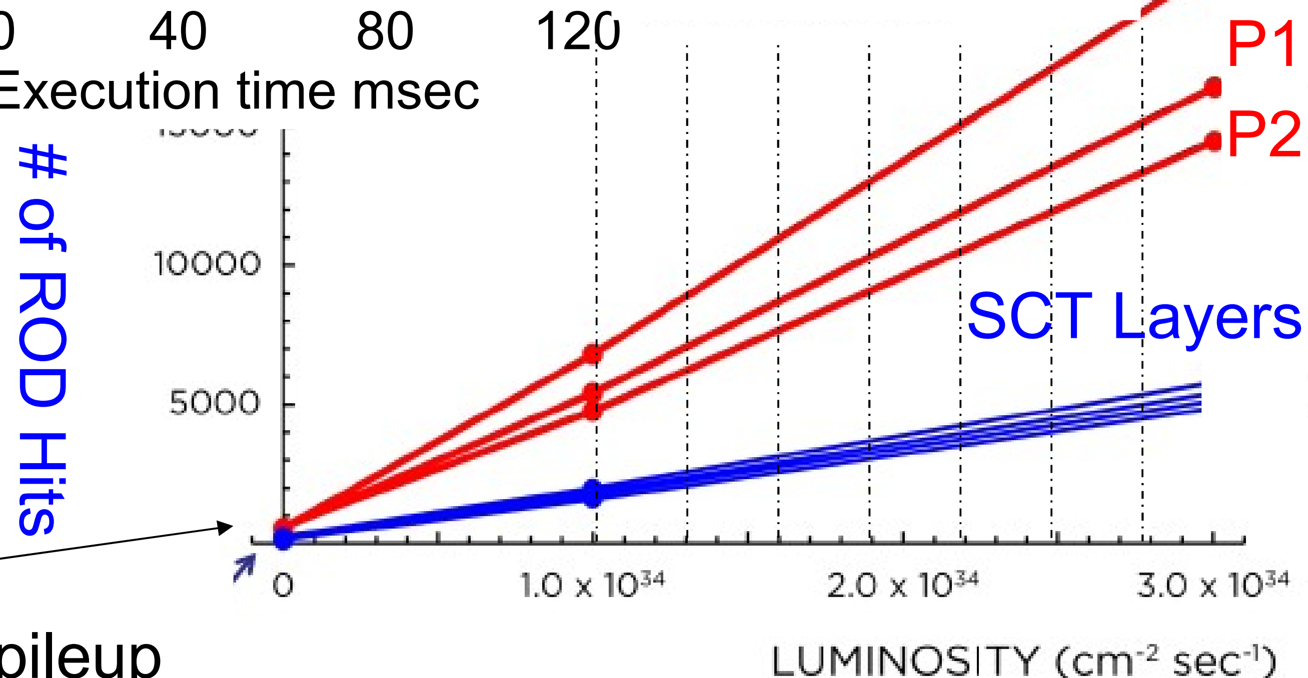




WH events@3×10^34 average of 40 jet > 70 Gev per event

(not yet optimized for high luminosity)

Occupancy vs Luminosity



Y intercept:
Hard scattering!
negligible compared to pileup

Why L1-L2 early TRACKING is IMPORTANT?

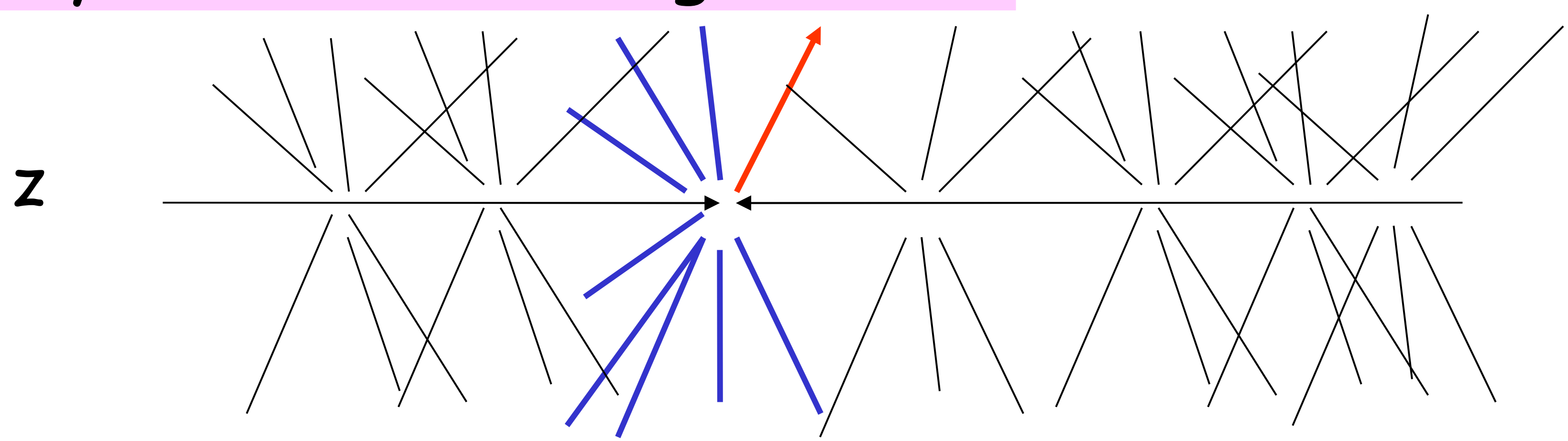
The most **STANDARD STIFF LEPTON TRIGGERS** based on **ISOLATION** have problems at very high pile-up

The calorimeter tower integrates energy from **all the particles**, also from **Pileup**!
We want **ISOLATION** from **HARD SCATTERING** not from **Pileup**!

Lepton identification: primary vertices fast identification
→ Isolation with tracks of Pt>Th and from right vertex

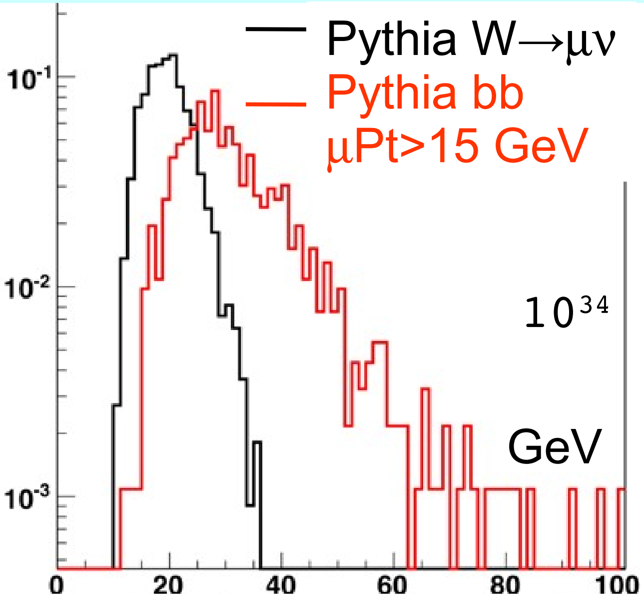
Only 7 vertices: imagine 100!

10 cm/100=1 mm

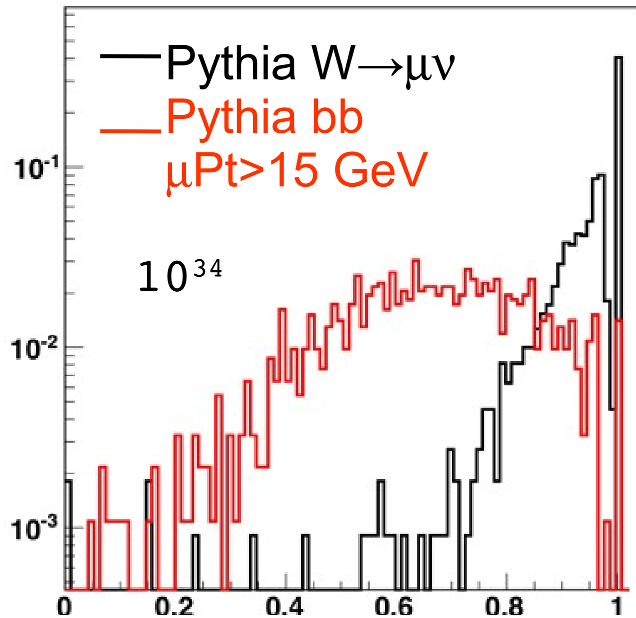


Tracking more stable than calorimetric isolation against pile-up!

Why FTK is IMPORTANT? Stiff Muon isolation

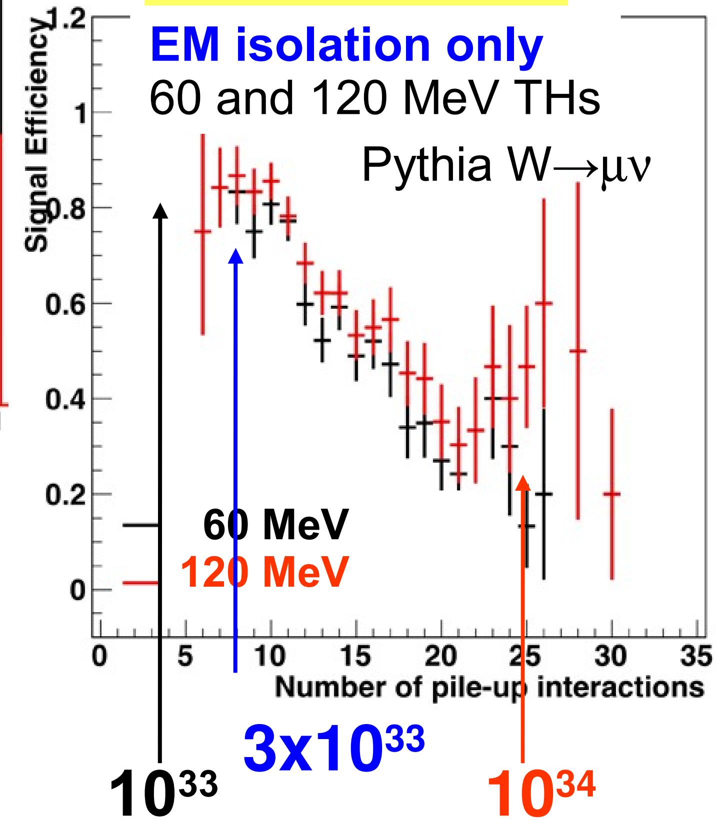


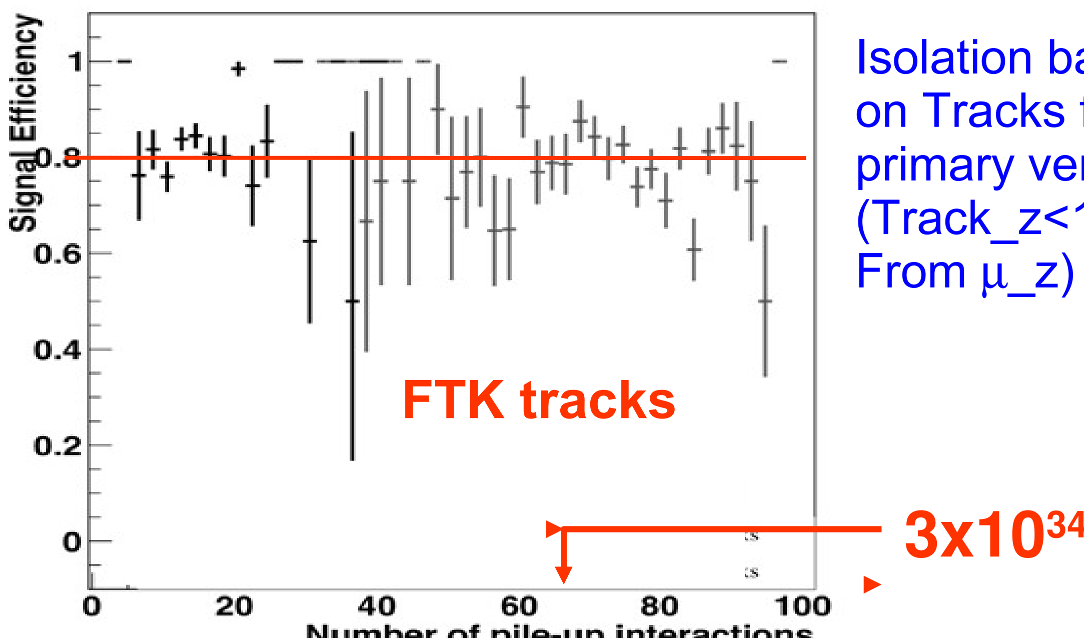
EM calorimeter isolation: energy above 60 MeV in 0,07 <ΔR< 0.4



Tracking isolation:
μ *PT/(PT* sum tracks in ΔR<0.2)

cuts set so that rejection factor for *bb* events is **10**.

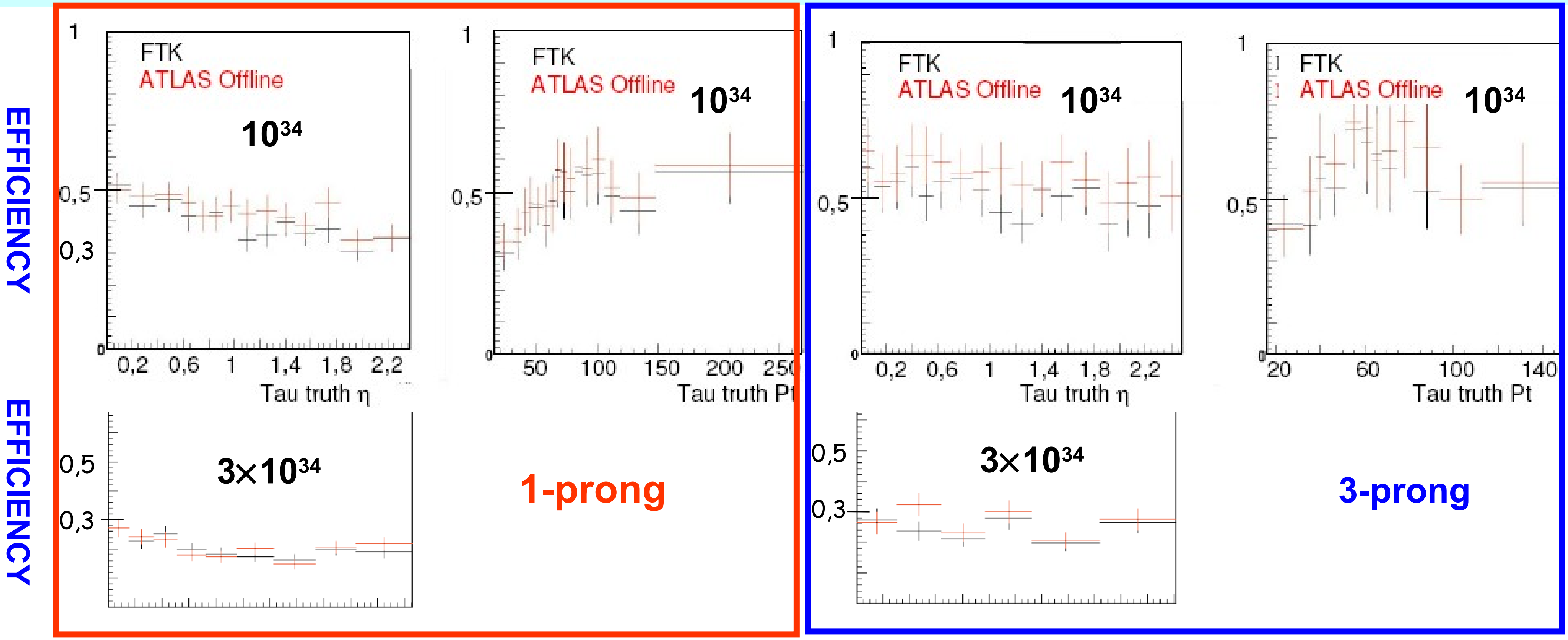


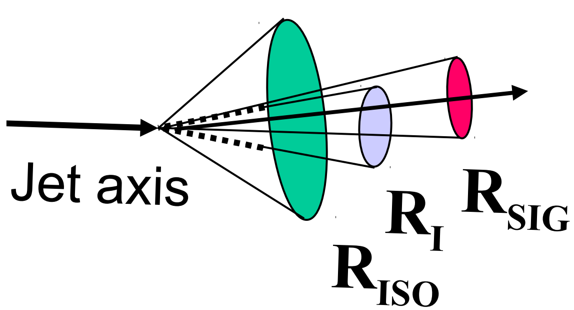


Isolation based on Tracks from primary vertex (Track_z<10 mm From μ_z)

EFFICIENCY from **20%** to **80%**
It is better than a factor 4 Luminosity increase!
Today CDF HIGGS SEARCH POSSIBLE just BECAUSE of CDF TRIGGER UPGRADES

Why Online Tracking is IMPORTANT? Hadronic Taus





leading P_T track in Ri (Ri=0,35 around jet axis)

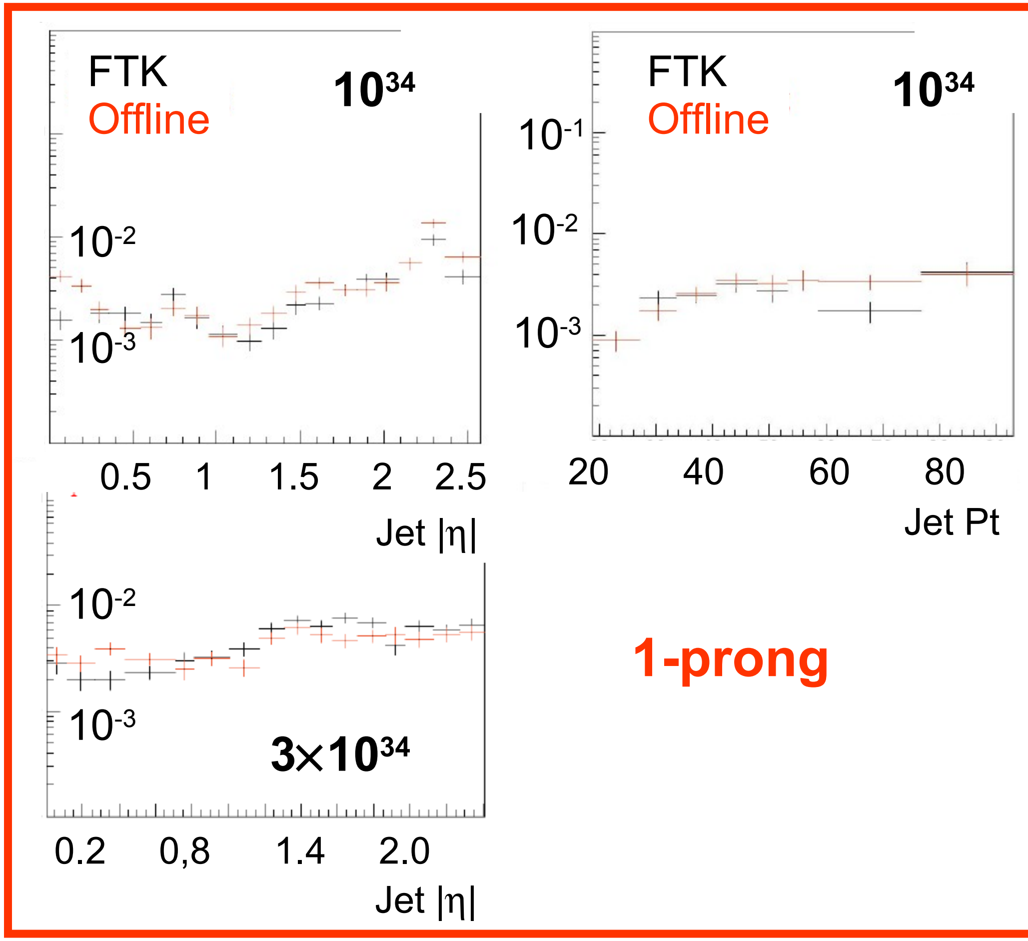
P_T> 6 GeV

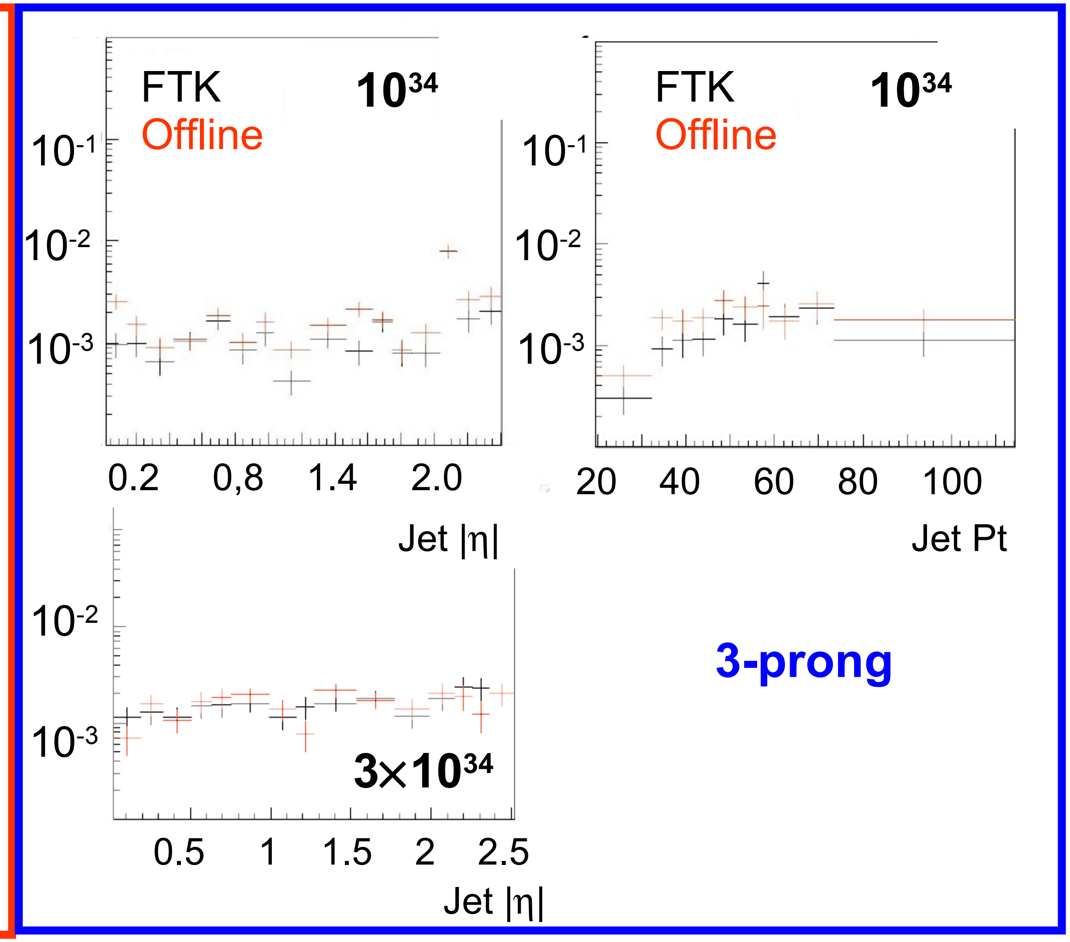
Rsig = 0,13 & Riso=0,26 around leading track;

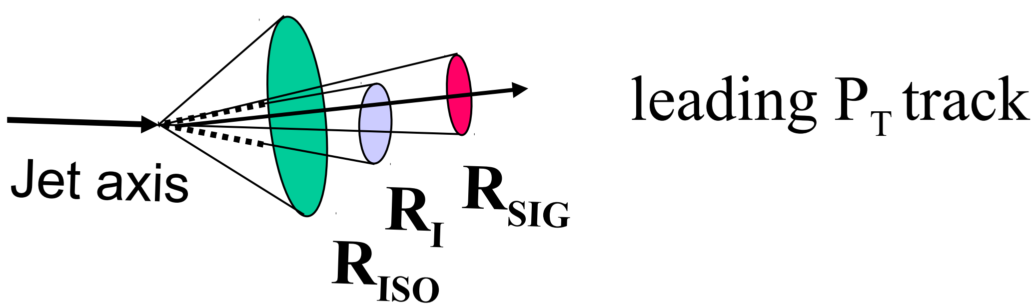
1 (1-prong) or 2-3 (3-prong) tracks in Rsig;

no tracks with Pt above 1.5 GeV in Riso.

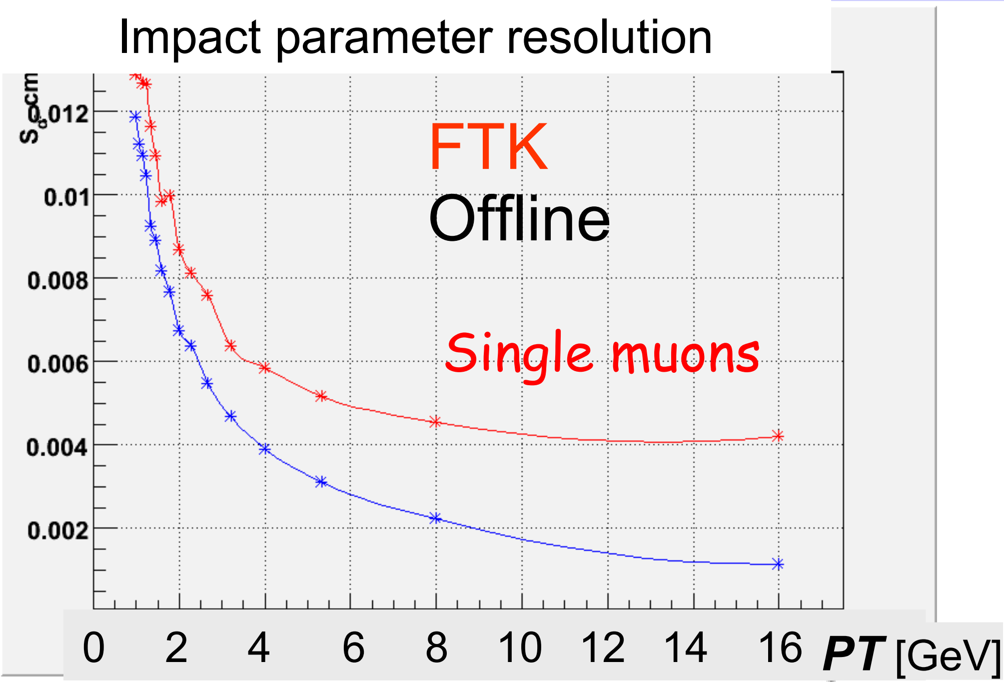
Efficiency on Jets: FAKES for Had Tau selection

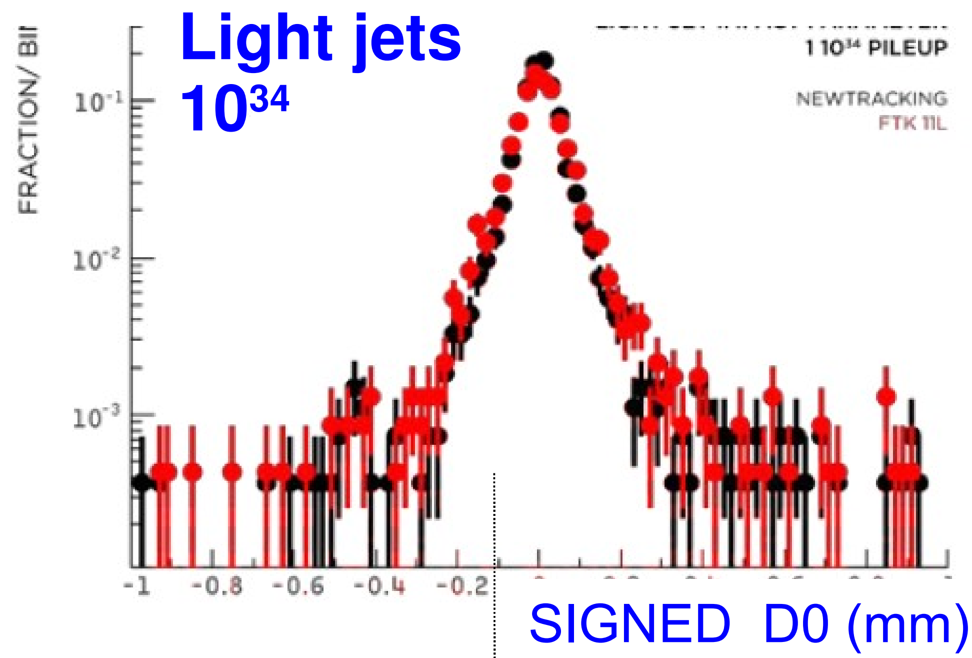


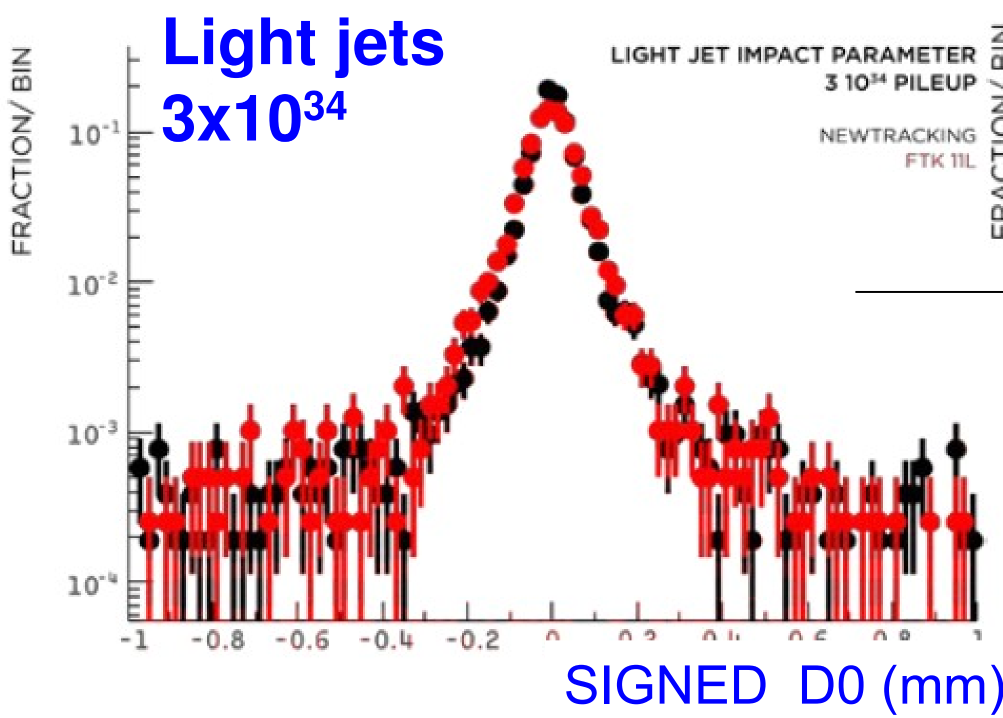


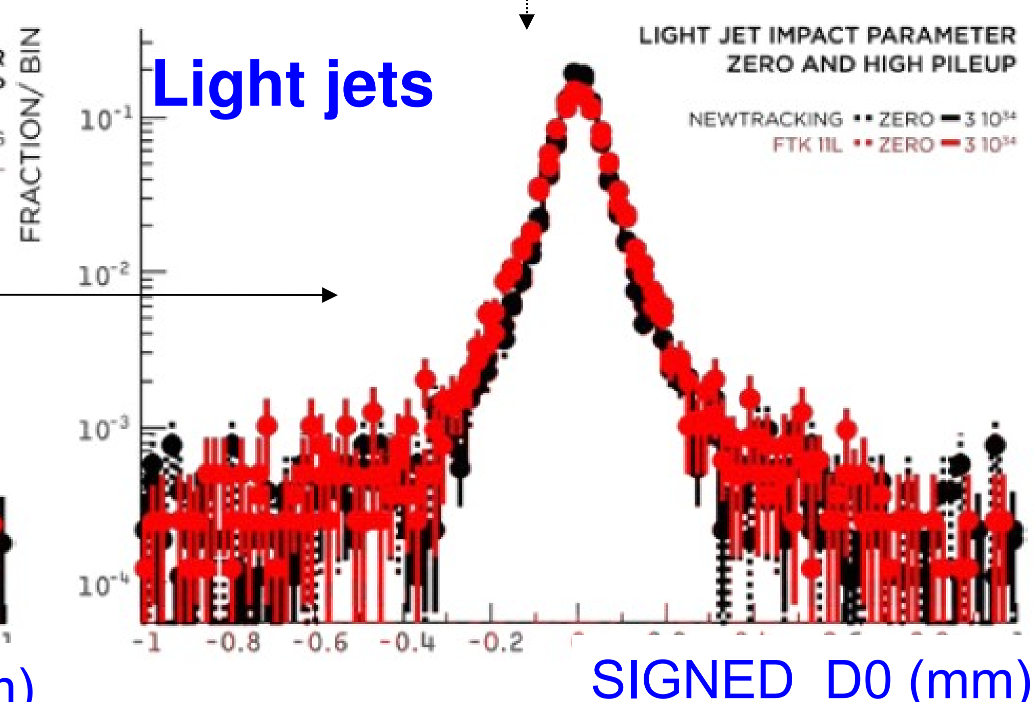


Why FTK is IMPORTANT? Online b-tag @ATLAS

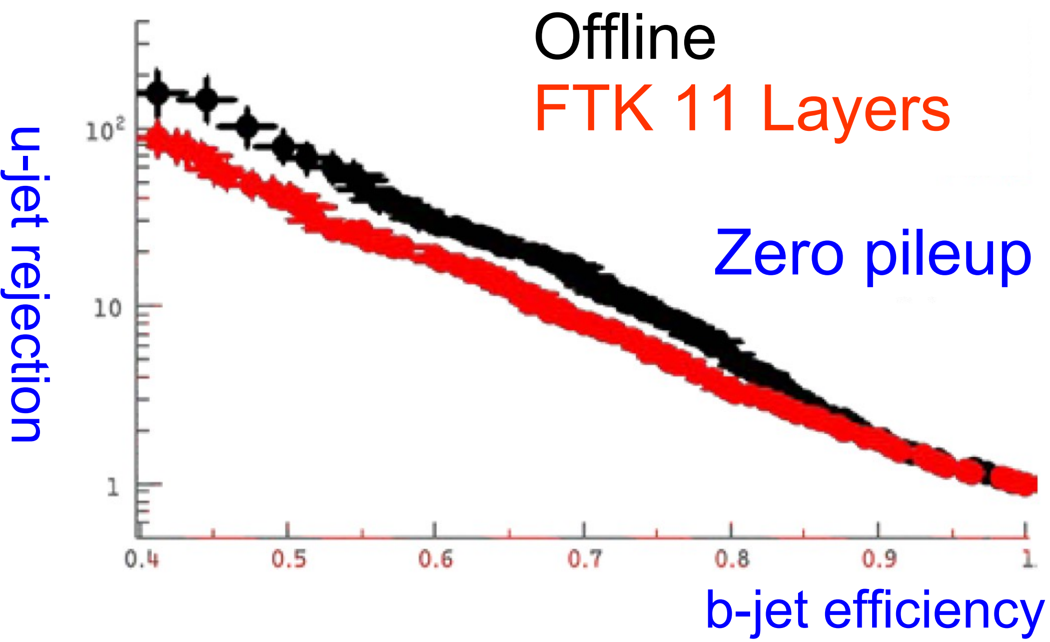


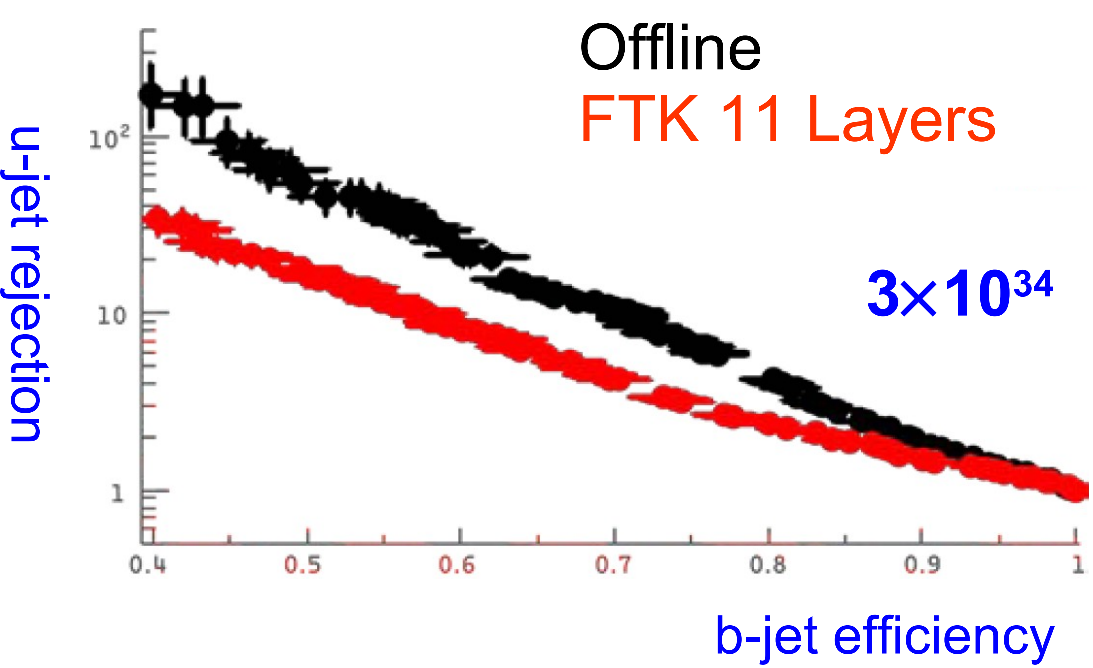






Signed D0 significance Likelihood tagging performance



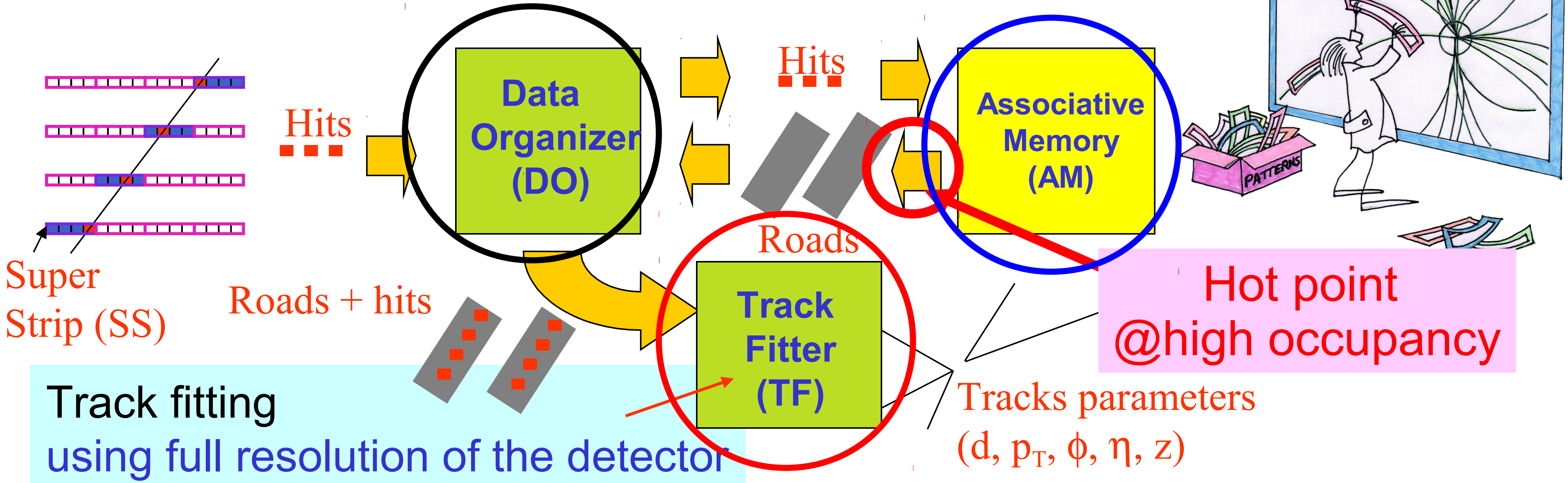


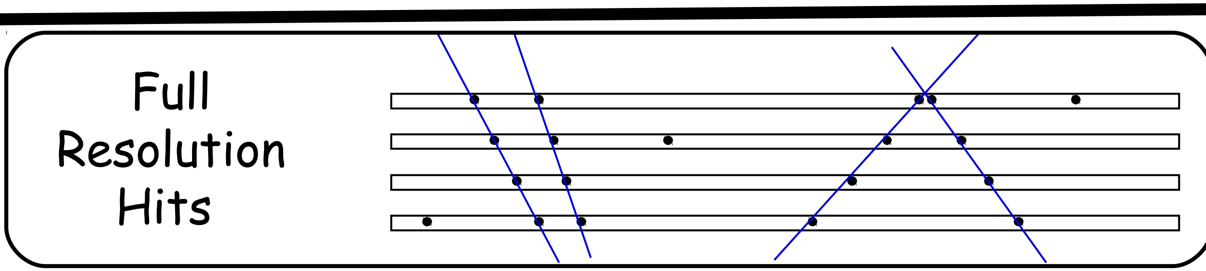
Offline is more stable than FTK when luminosity increases but FTK results are interesting

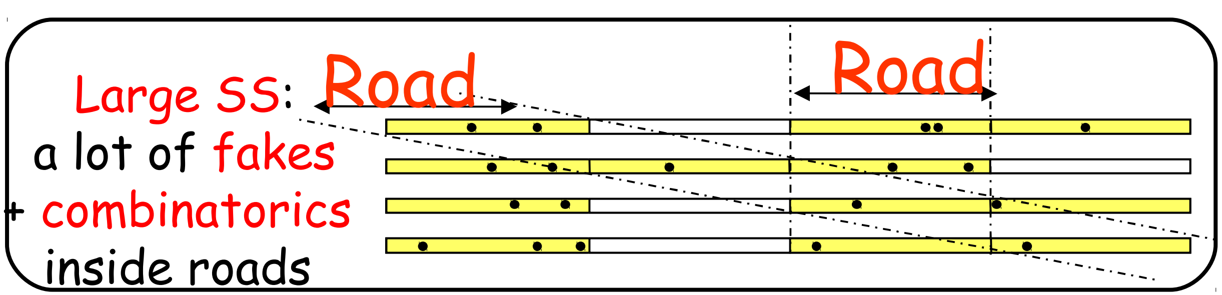
The CPU time freed for the tracking can be used to implement more complex algorithms like secondary-vertexing

FTK Architecture

Tracking in 2 steps: find Roads first (*Pattern Matching* with *Associative Memory*, AM) then find Tracks inside Road (Fit by TF)

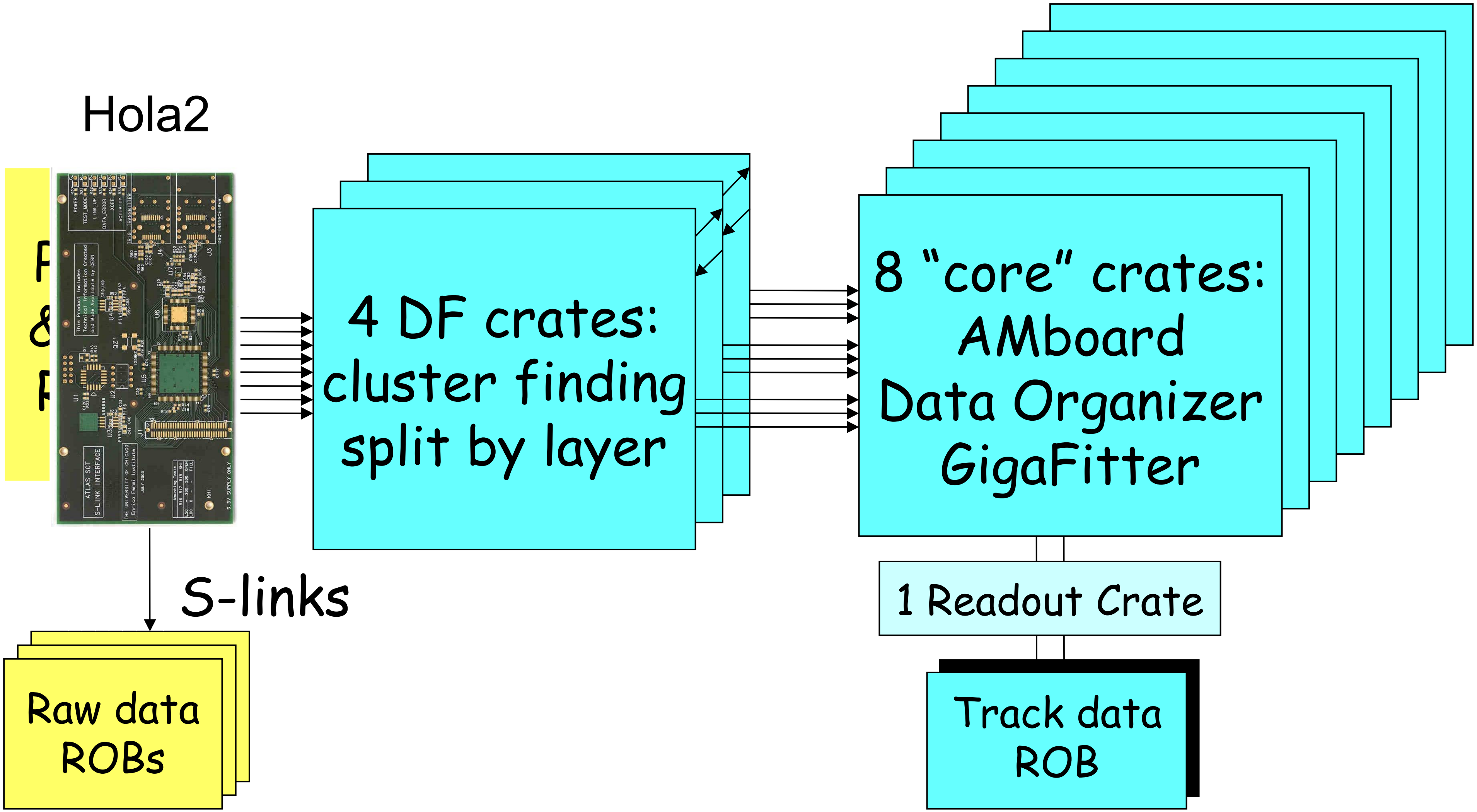






Road size: a parameter to balance the AM size & the DO-TF workload

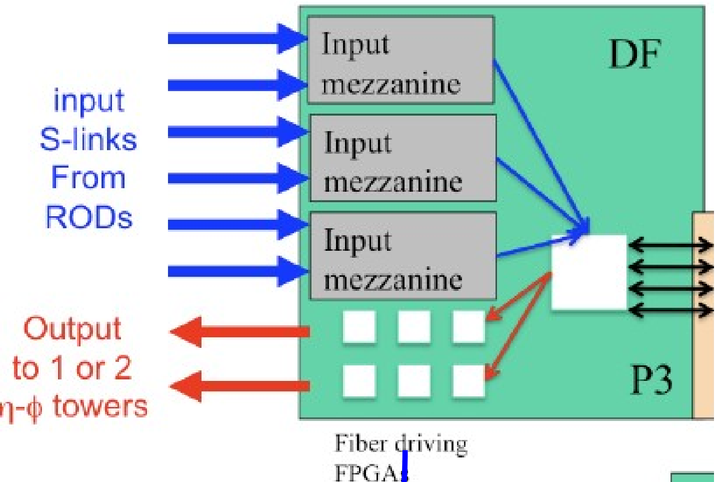
FTK: Architecture

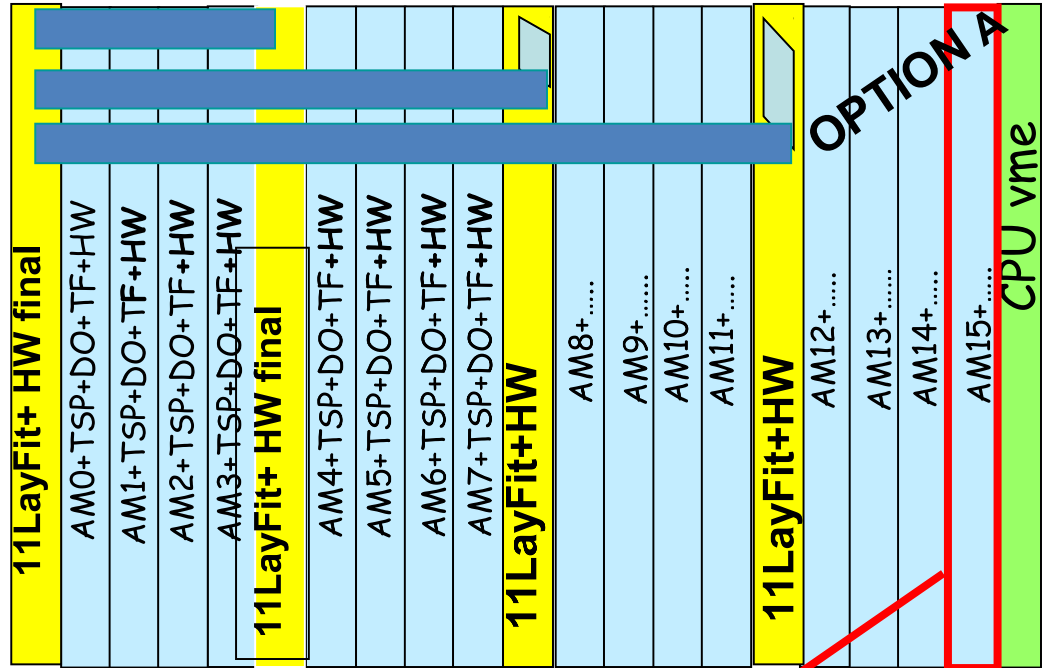


8x core crates

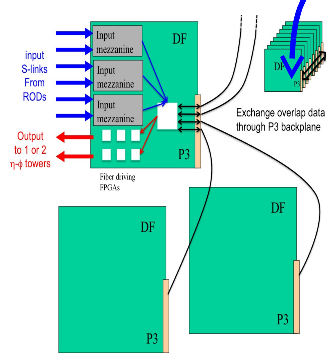
Data Formatter (DF)

Receives silicon hits.
Does pixel cluster finding.
Distributes data to η-φ towers.



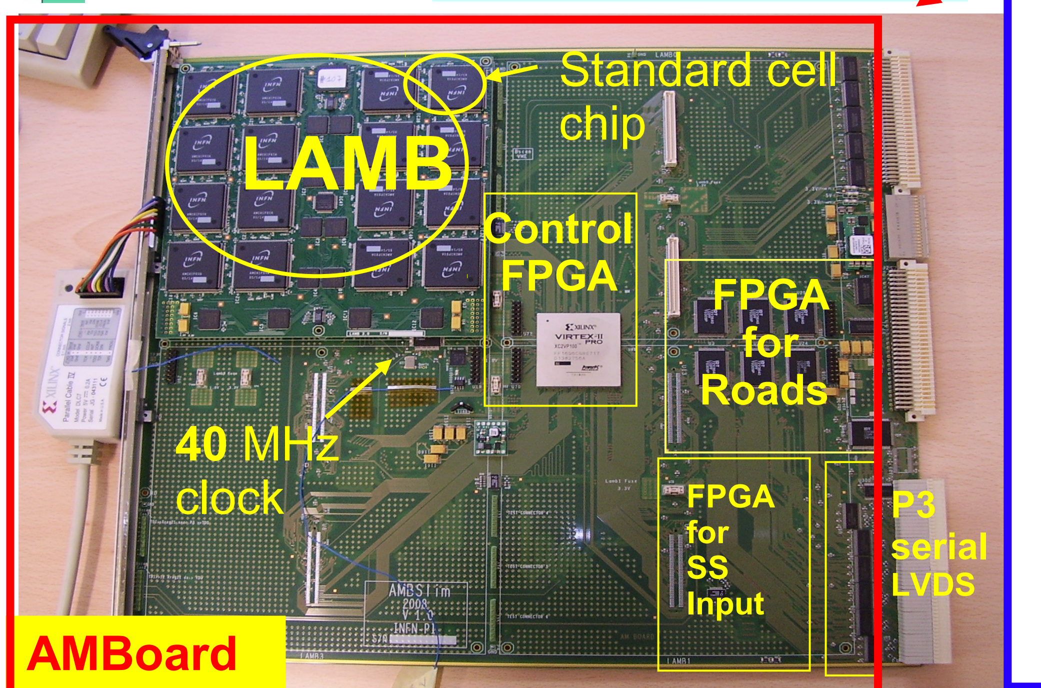


4x DF crates

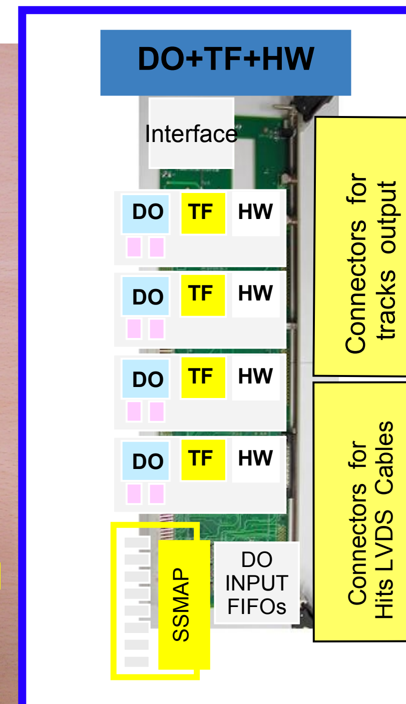


Exchange overlap data over P3 backplane

Processing Unit



AUX card



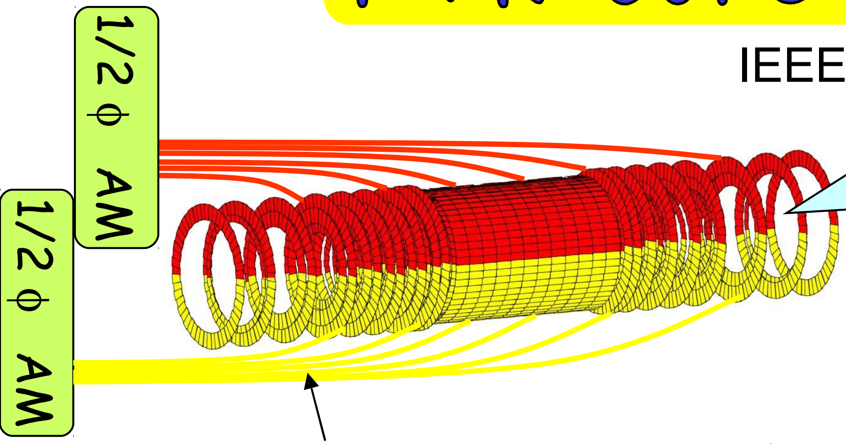
Conclusions

- **Having high-quality global tracking at the start of level-2 processing can make a significant contribution to the trigger expecially at 3×10^{34}**
- **We have a preliminary design that can handle the data flow at that luminosity, will take less than 100 μs/event, gives excellent physics performance, and is affordable.**
- **There is an implementation plan that can start to help ATLAS early.**

BACKUP

FTK-core Basic Architecture 1

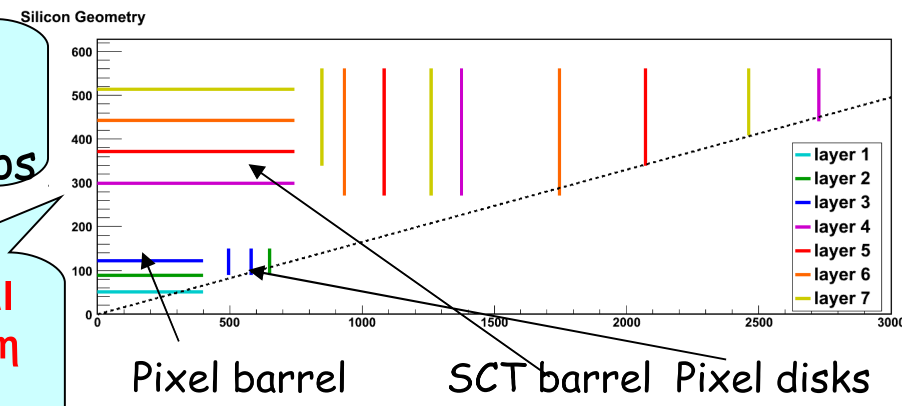
IEEE Trans. Nucl. Sci. **51**, 391 (2004)



6 18-bit buses, hit rate: 40MHz/bus
input bandwidth of 4 Gbit/s

Divide into φ sectors with overlaps

6-12 Logical Layers: full η coverage

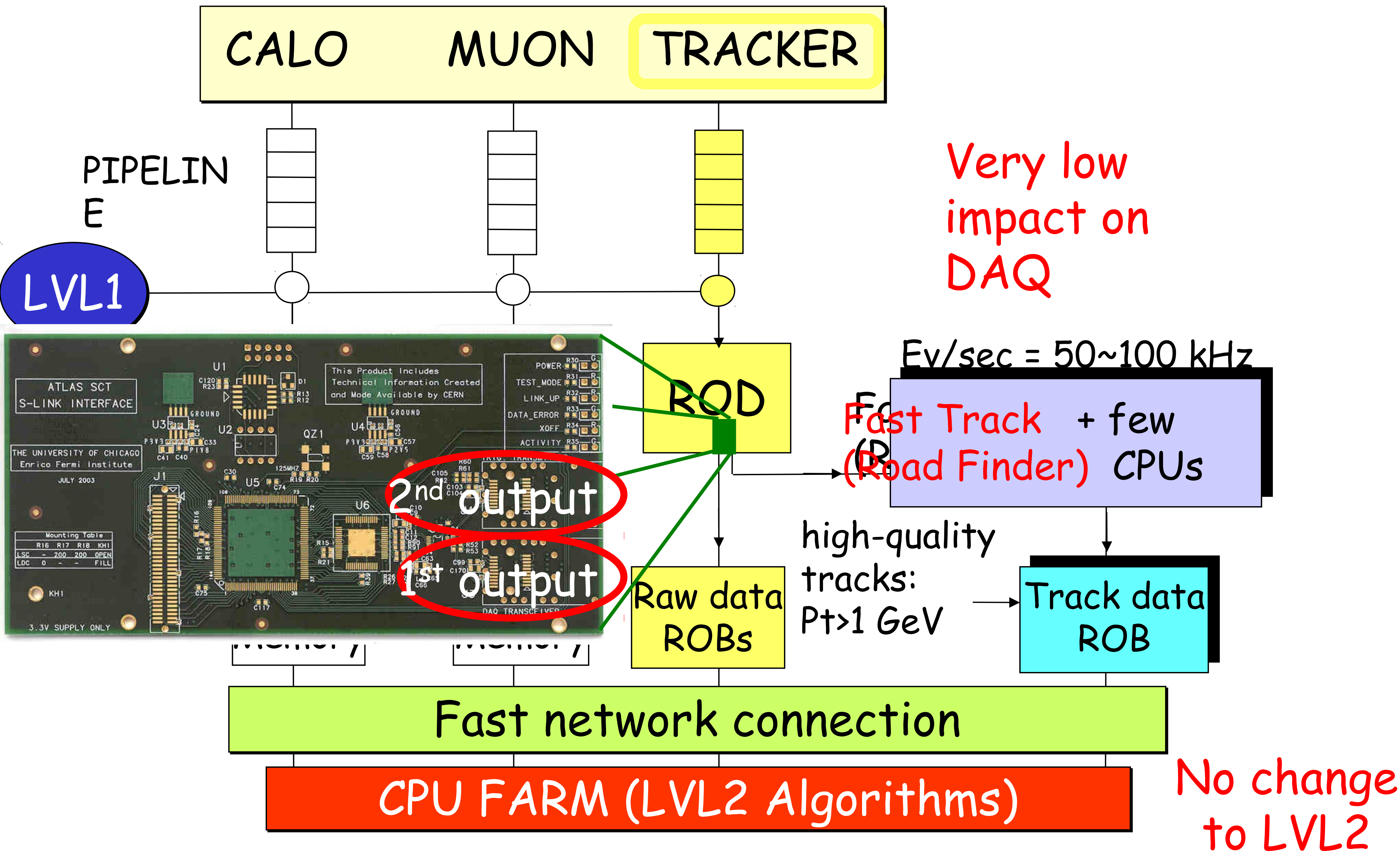


Goal: High Lum 8 ϕ sectors ⟶ 8 9U VME crates for the FTK core

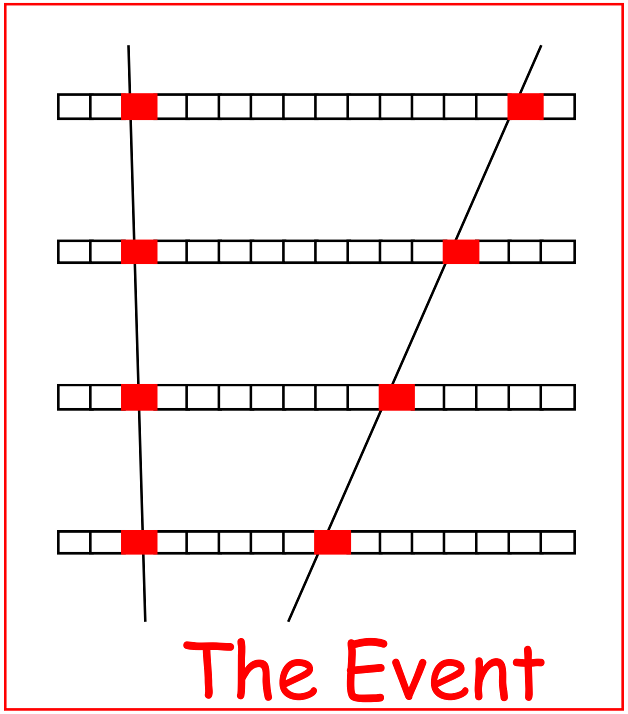
NOTE: The "core FTK" crates do not include the DATA Formatter boards, receiving and Formatting the detector hits

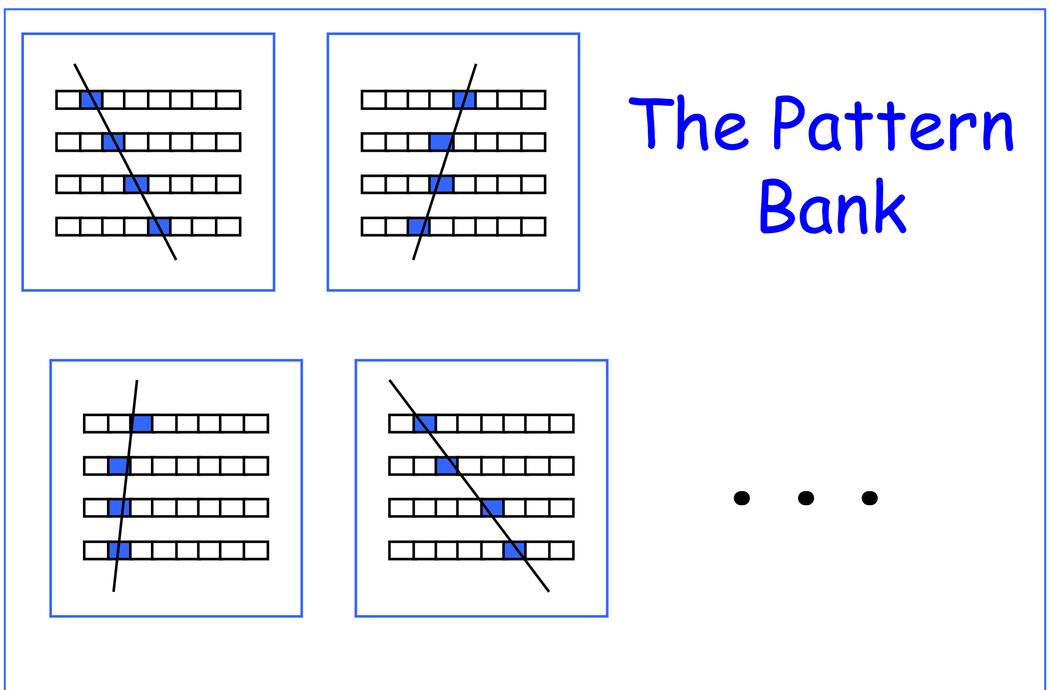
- All 11 silicon layers are necessary to reduce fakes at 10^{34} cm^{-1} s^{-1} & more
- Overlaps require hits in a small region to be sent to two neighboring AMs
- Capability of the system to increase the computing power for increasing instant Luminosity or unpredicted background:
  1. Possible increase of phi sector number → more overlaps, more crates
  2. Introduction of new algorithms – better tuning of existing system
  3. Technology advancement: denser AM chips, more powerful FPGAs, links….

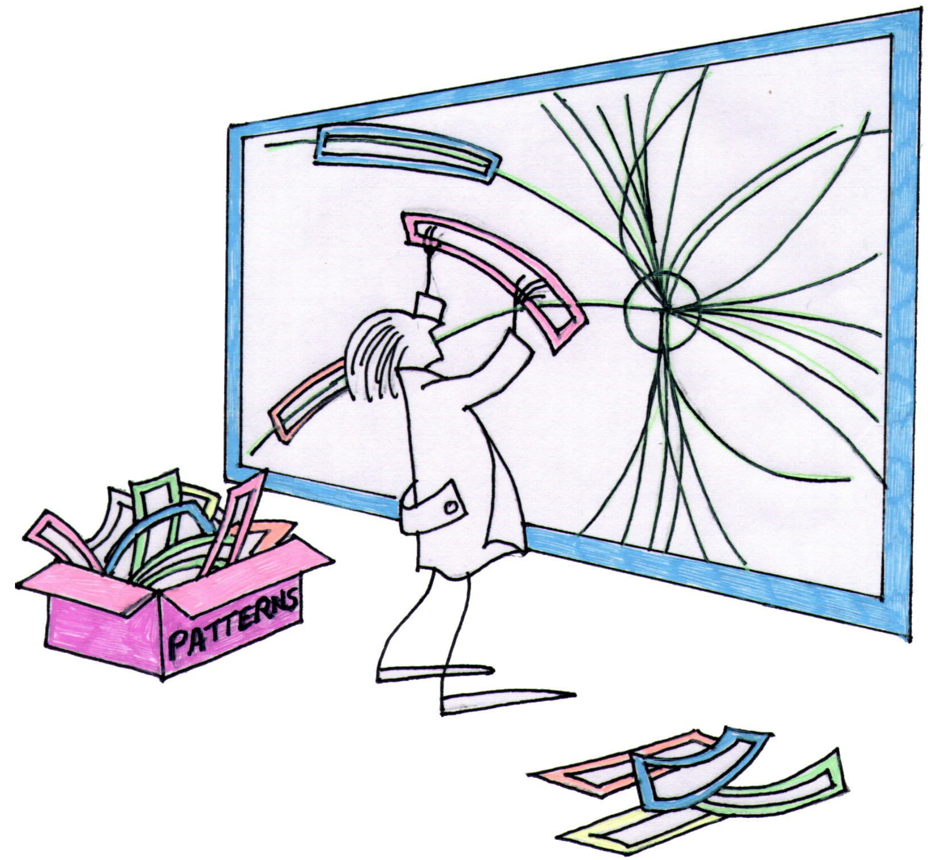
Where could we insert FTK?



TRACKING WITH PATTERN MATCHING



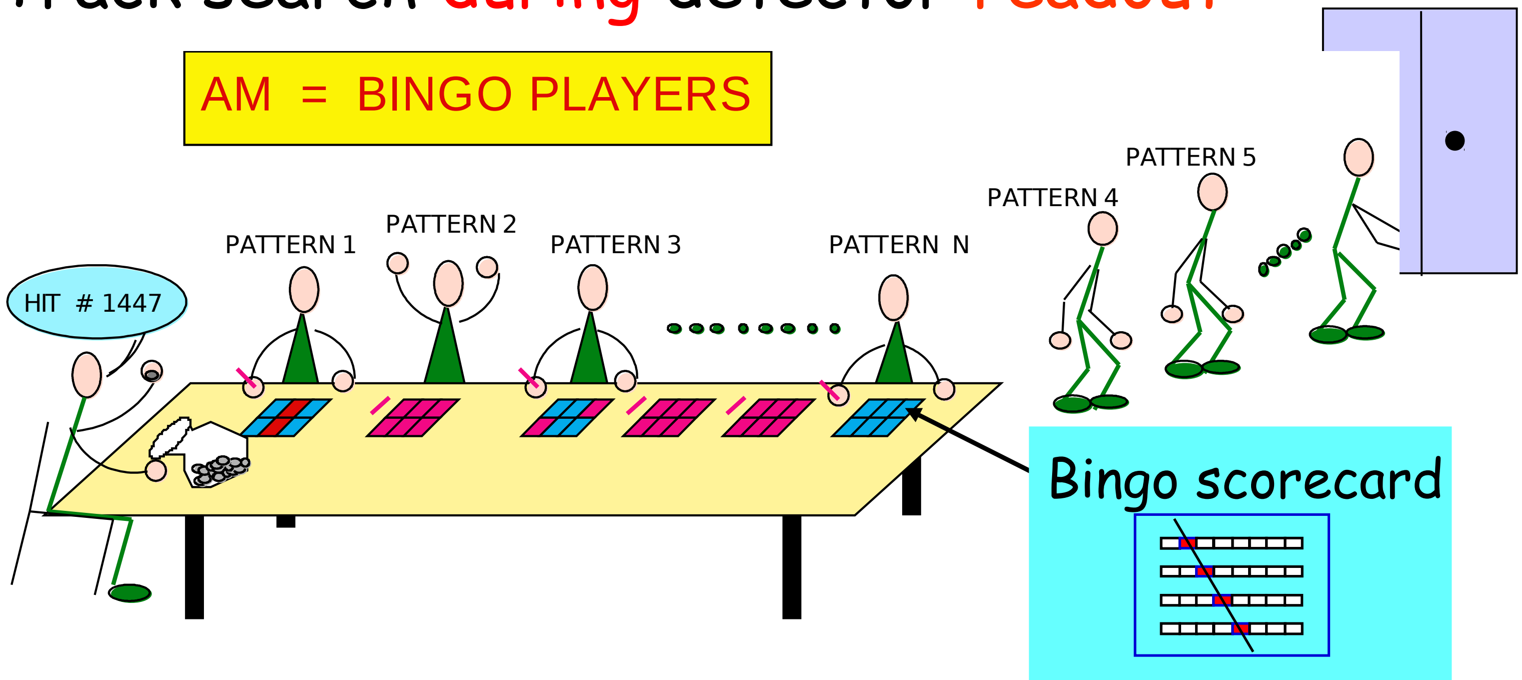


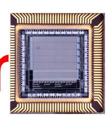
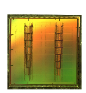


The *Associative Memory - AM*

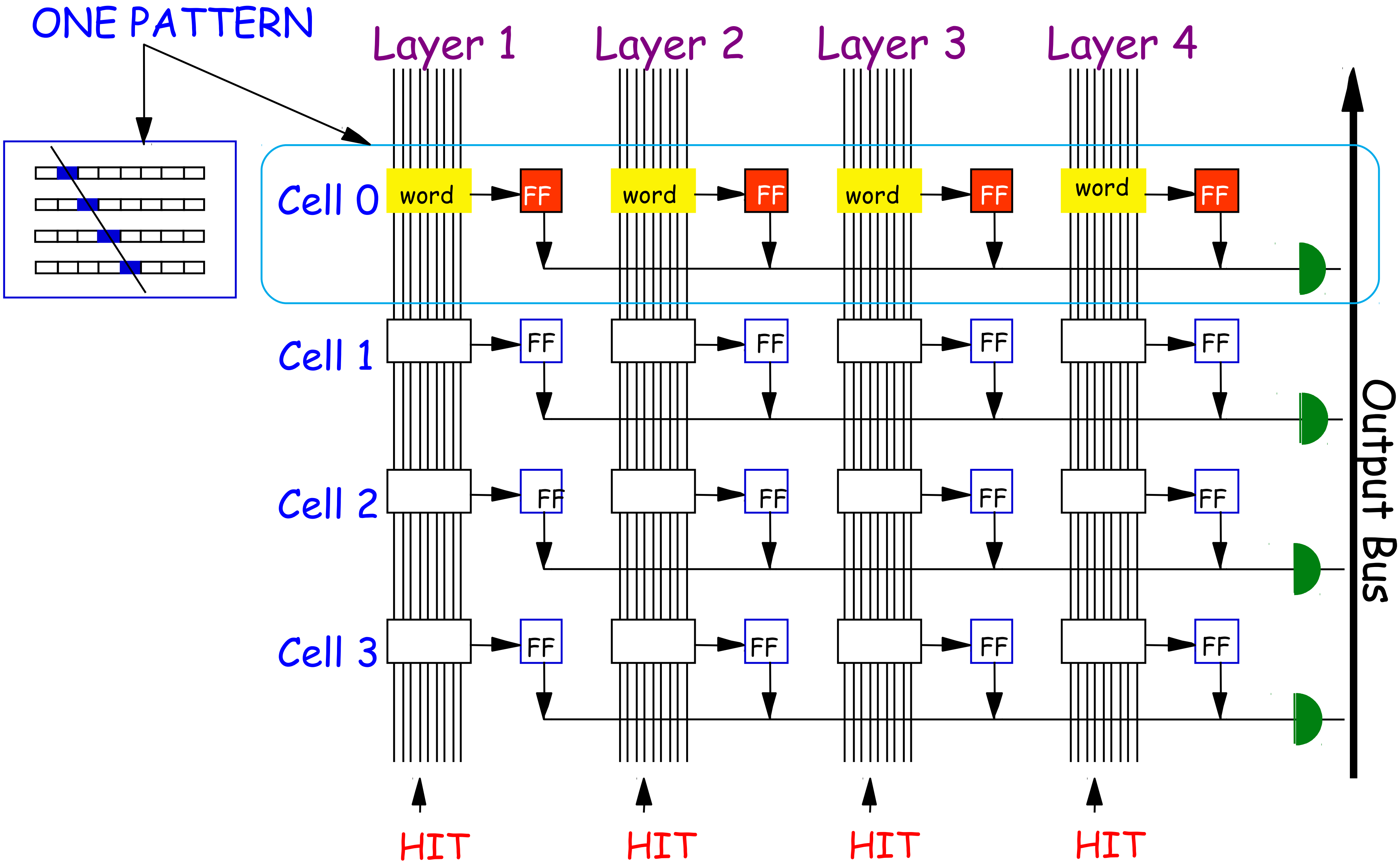
Dedicated device - maximum parallelism:

- Each pattern with private comparator
- Track search during detector readout

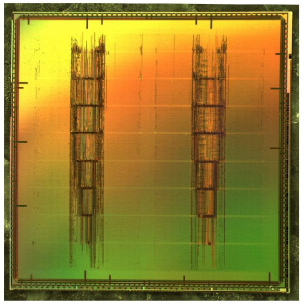


- **Full custon**  **700 nm: 0,128 6L kpattern/chip**
- **FPGA 350 nm: 0,128 6L kpattern/chip**
- **standard ce**  **180 nm: 5,0 6L kpattern/chip**
- **new for FTK 90 nm: ~25 8L kpattern/chip**
- **90 nm 2,5 D: 50 8L kpattern/chip**

A schematic drawing of the AM



Which banks we would like to have



What we have now: **Standard Cell 180** µm

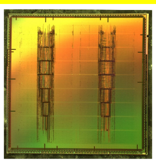
1 pattern/chip for 6-layer patterns,

2500 pattern/chip for 12-layer patterns

"A VLSI Processor for Fast Track Finding Based on Content Addressable Memories",
IEEE Transactions on Nuclear Science, Volume 53, Issue 4, Part 2, Aug. **2006** Page(s):2428 - 2433

90 nm technology provides a factor 4 → 10000 patterns/chip

Full custom cell provides at least a factor 2 → 20000 patterns/chip



NEXT: NEW VERSION For both L1 & L2

8 layers instead of 12 provides a factor 1,5 → 30000 patterns/chip

1,5 x 1,5 cm**2 2D chip = 2 Tiers 1x1 cm**2 → 60000 patterns/chip

With a **2 D chip** we gain a factor **25**!

1 AMboard: 128 chips → ~8 Mpatterns per board

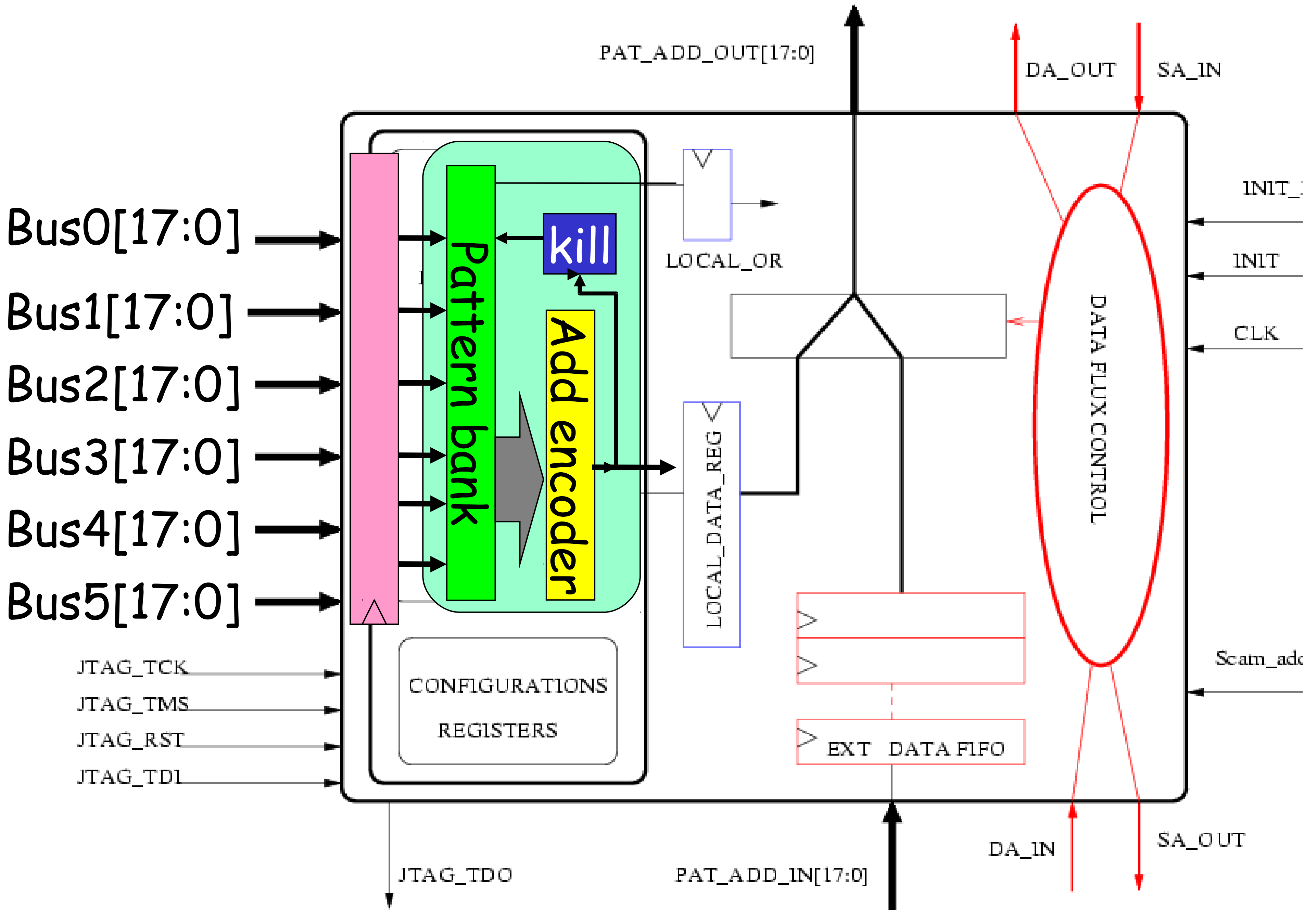
1 Crate: 16 AMboard → 128 Mpatterns per crate

If 2 Tiers of 1,5x1,5 or 4 Tiers 1x1 → 256 Mpatterns per crate

With a 2 Tier - **2.5 D chip** we gain a **factor 50!**

100 MHz running clock

The CDF final AMchip architecture



AMCHIP

We are working (L.Sartori, Pisa+ M.Beretta, E. Bossini, Frascati) at the 2010 mini-asic prototype provided of full custom cell **(M. Beretta Frascati) with 2 main goals:**

1. **Area reduction to obtain higher pattern densities**
2. **Power consumption reduction to be able to use large silicon areas**

Pattern Density/power with respect the CDF chip:

- 90 nm against 180 nm → factor ~4 for area and power consumption reduction (V_{90}/V_{180})**2
- Full custom cell: a factor 2 gain for both area and consumption.

Future collaboration with Fermilab to stack 2 or 4 tiers with 2.5 D technology

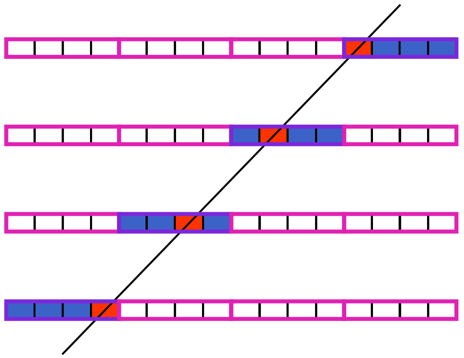
FTK @ Low - Intermediate Luminosity?

- It is a very important **Hardware & Physics** test before 10^{34} & $3x10^{34}$; test on **real conditions** of the detector; **large impact** on the whole trigger. Study of "minimum bias" **b-tag** and **tau-tag** trigger ($Z0 \rightarrow bb$, tau-tau+QCD backg). Level-2 and Event Filter algorithms in CPUs have to take into account new track availability at L2 start.

- **Level-1** has to be re-studied also for **Phase 1**. **Global Level-1** is going to be designed for **Phase 1**. **Influence** of FTK experience on real data.

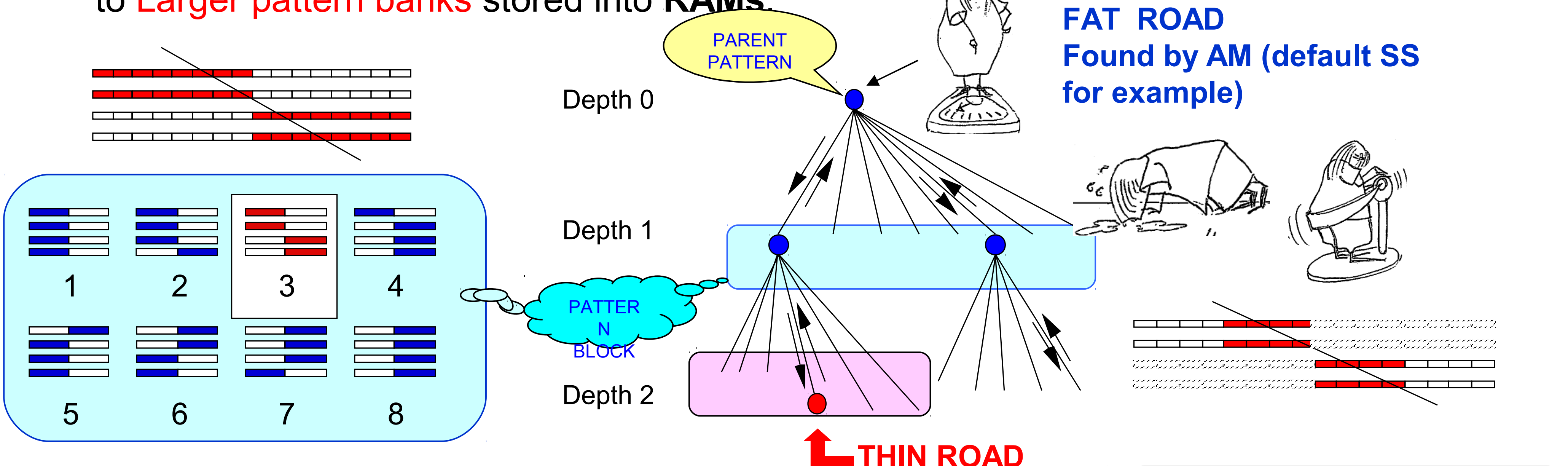
- Availability of **new phase space regions,** like enlargement of phase space for "**Hadronic Channels**". This is not included in the **LHC baseline trigger**, neither in **CMS** neither in **Atlas**.
  There could be a new **interest in Atlas in this area**.

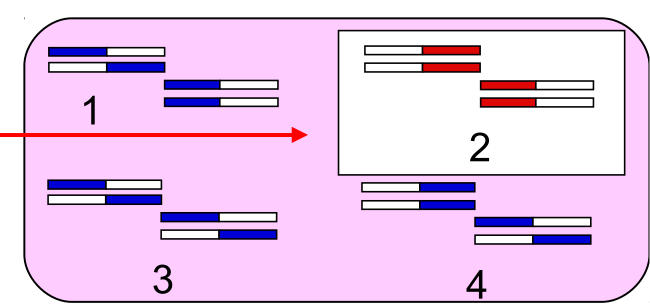
Binary search to go down to better SS resolutions



The **AM chip** for each found road should provide:

1) The Road IDentifier (address)
2) The Bitmap : one bit per layer, saying which SSs are empty & which are full (11 bits: 11101111111 eg.)
3) 4 more bits for each layer, Sub-SS, saying which of the 4 SS subdivisions are empty and which are full (4 bits × 11 Layers). The **TSP** will search **THIN** roads comparing Sub-SS to Larger pattern banks stored into **RAMs**.





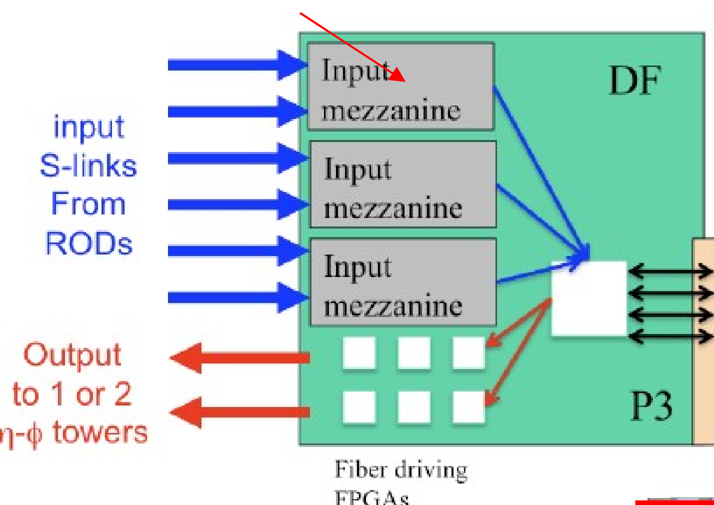
Algorithm: NIM A287 (1990) 436-438
http://www.pi.infn.it/~paola/Tree_search_algorithm.pdf

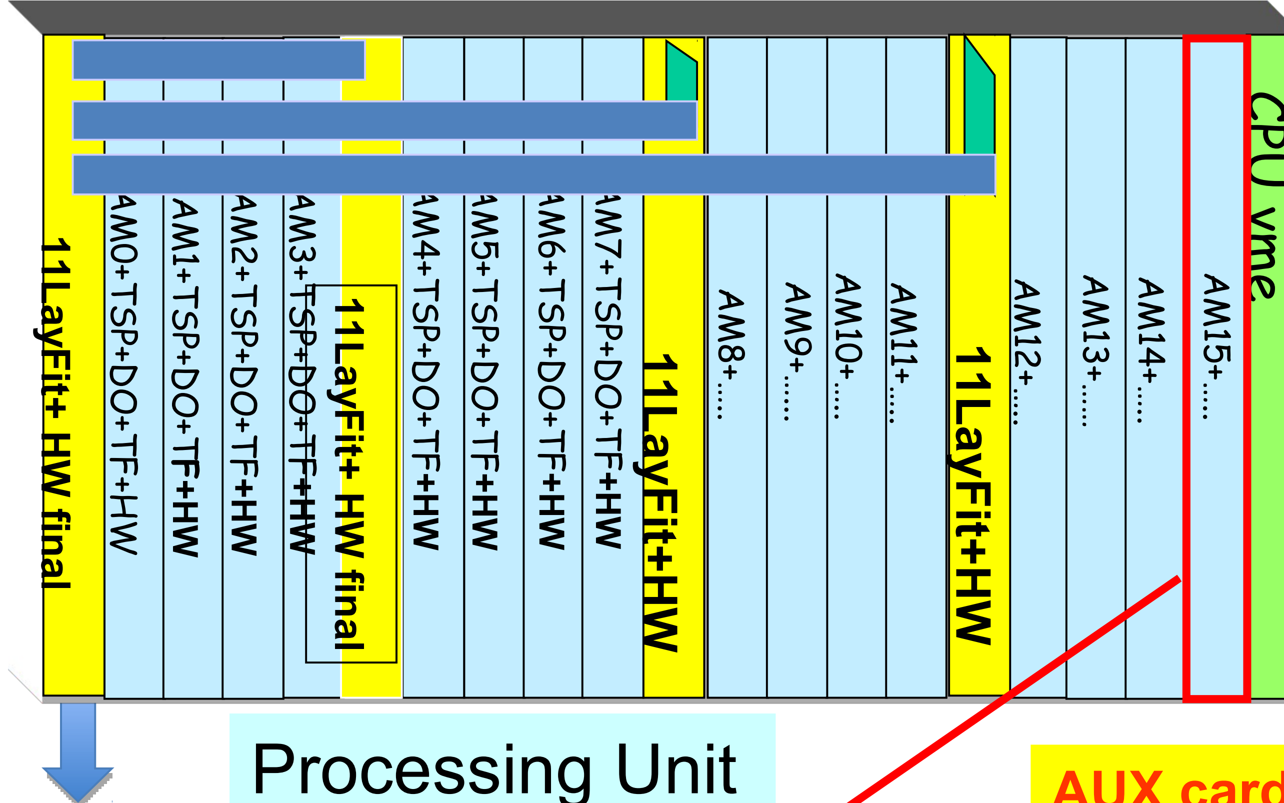
Tree Search Processor: NIM A **287**, 431 (1990),
http://www.pi.infn.it/~orso/ftk/NIMA287_431.pdf
IEEE Toronto, Canada, November 8-14 1998 http://www.pi.infn.it/~paola/TSP_v14.pdf

Staging

- Start late this year to assemble a vertical slice in a test stand:
  - Use existing boards (EDRO board from SLIM5 & AM board)
  - Cover a small projective wedge in the detector
  - Develop the code needed for interaction with ATLAS TDAQ
  - Test new prototype boards as they are produced
  - Connect to the detector when test stand works & dual-output HOLAs are available.
- Install all dual-output HOLAs during 2012 shutdown
- Assemble a system using the existing AM chip adequate for a few $\times 10^{33}$.
- Expand the system for 1×10^{34}.
- Replace AM chips (& LAMBs) for 3×10^{34}.

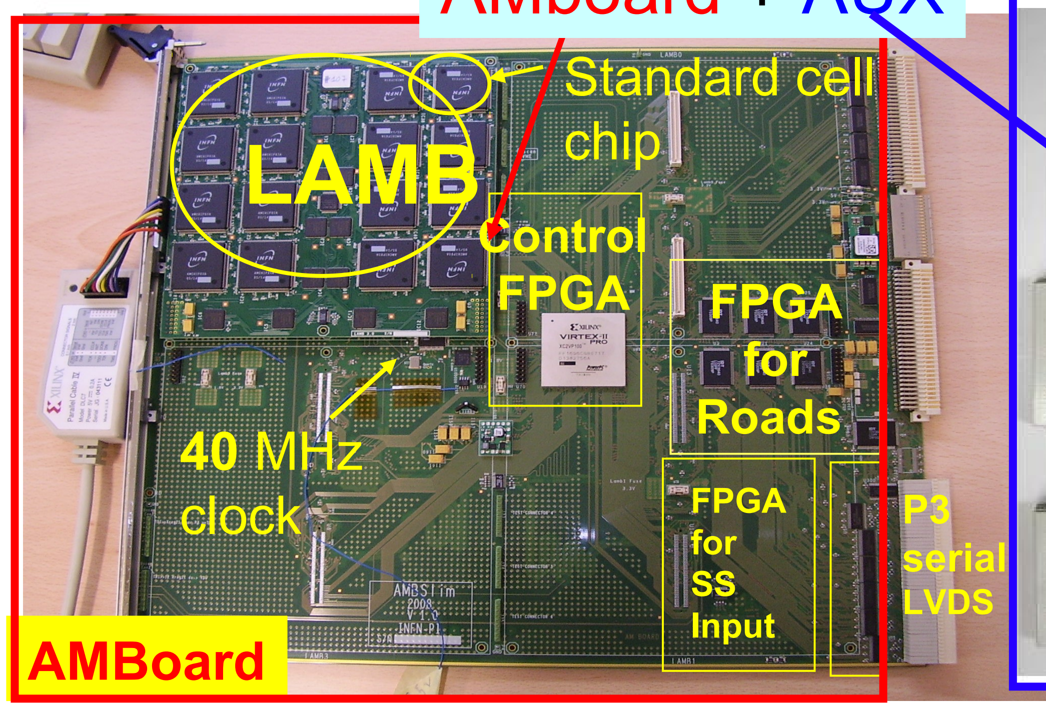
DATA FORMATTER



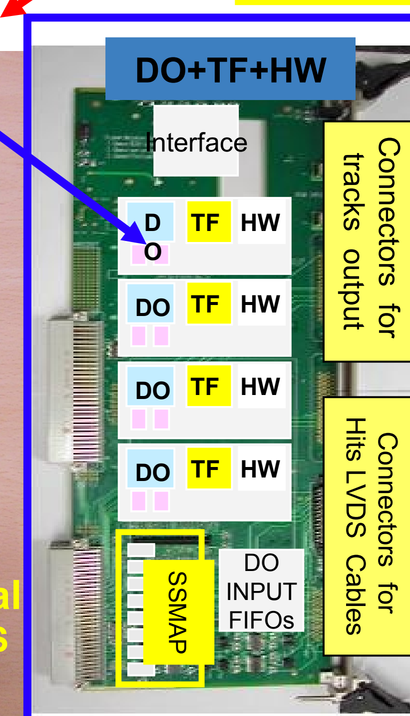


Processing Unit

AMboard + AUX



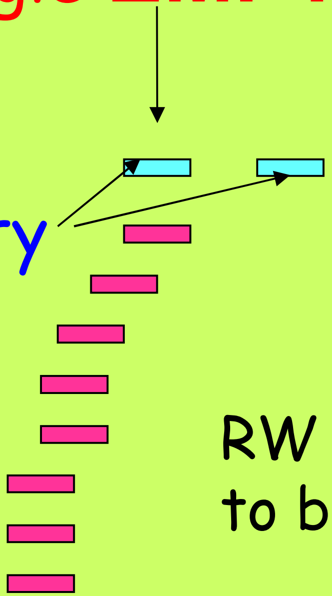
AUX card



New cleanup functions against Ghosts RoadWarriors - HitWarrior

Nuclear Science, IEEE Transactions on: **The "Road Warrior" for the CDF online silicon vertex tracker** Volume 53, Issue 2, April 2006 Page(s):648 - 652

RW works on **SS** before knowing the fit chi**2
It deletes ghosts acting on roads that differ **ONLY** for a single **EMPTY** SS

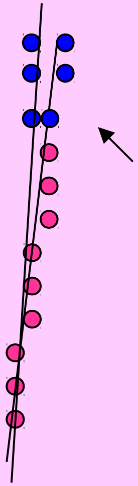


RW reduces fits to be done

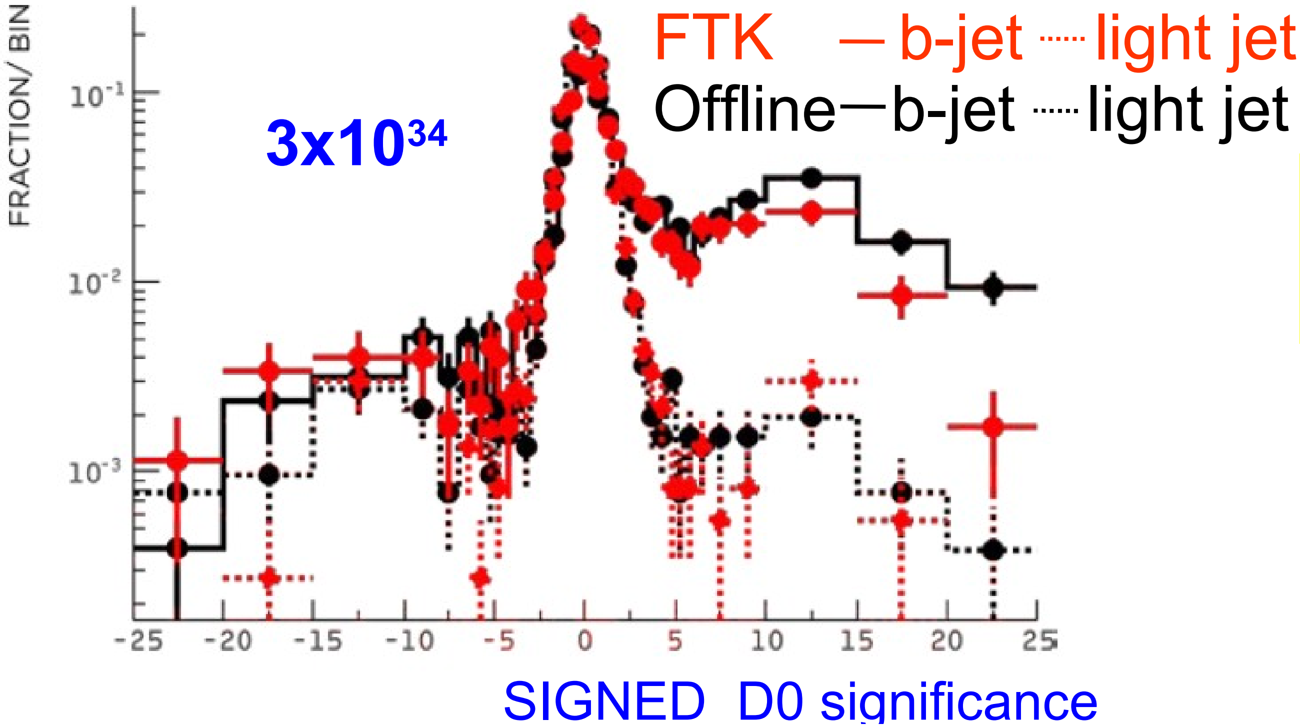
HW works on hits after the fits so can choose the best combination!

DUPLICATE tracks if they share **N** Hits

HW is very efficient deleting ghosts



The fit chi**2 or more complex criteria can discriminates



Impact parameter Significance inside jets

level-2 *d*0 likelihood tagger

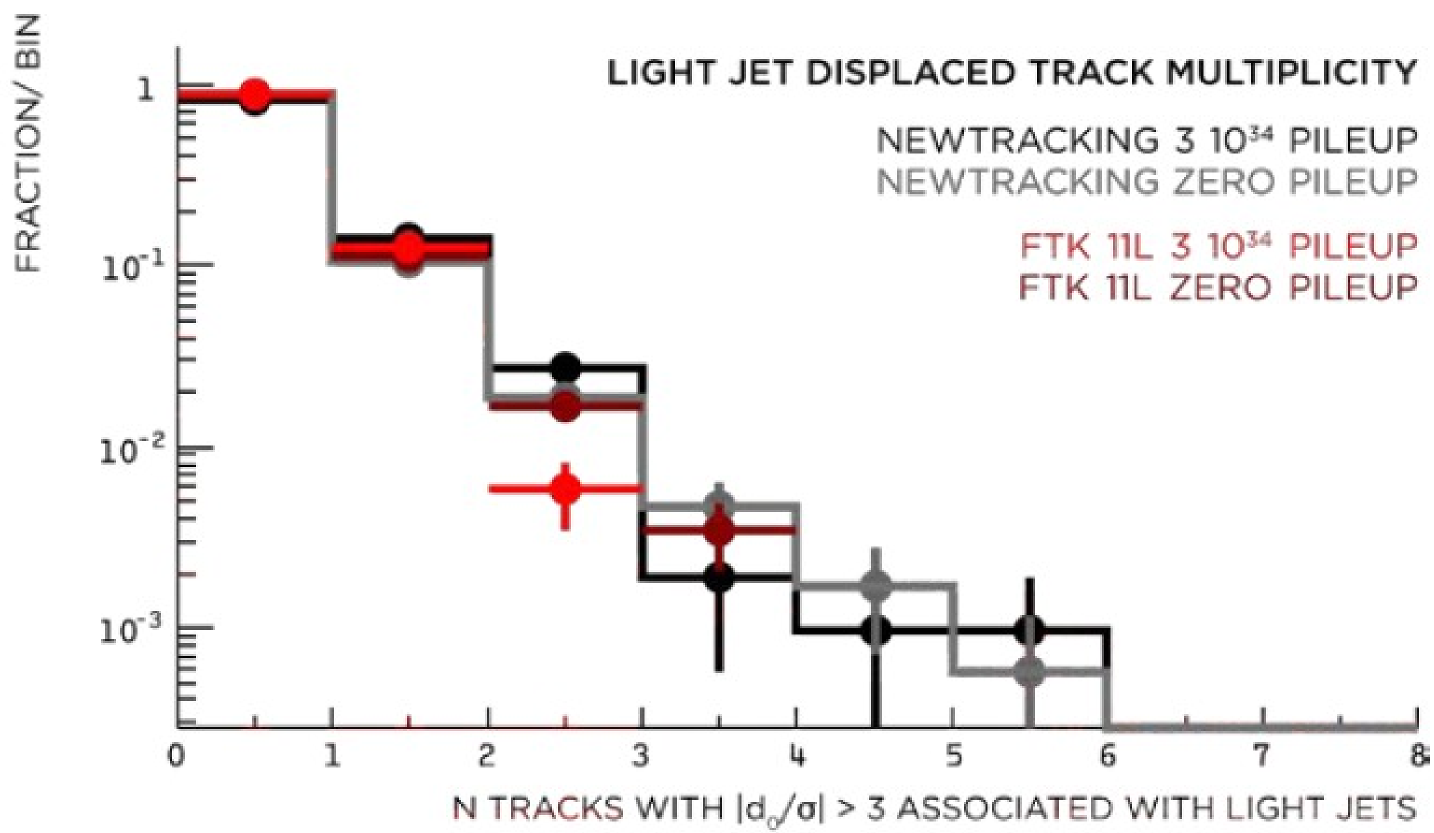
offline IP2D algorithm.

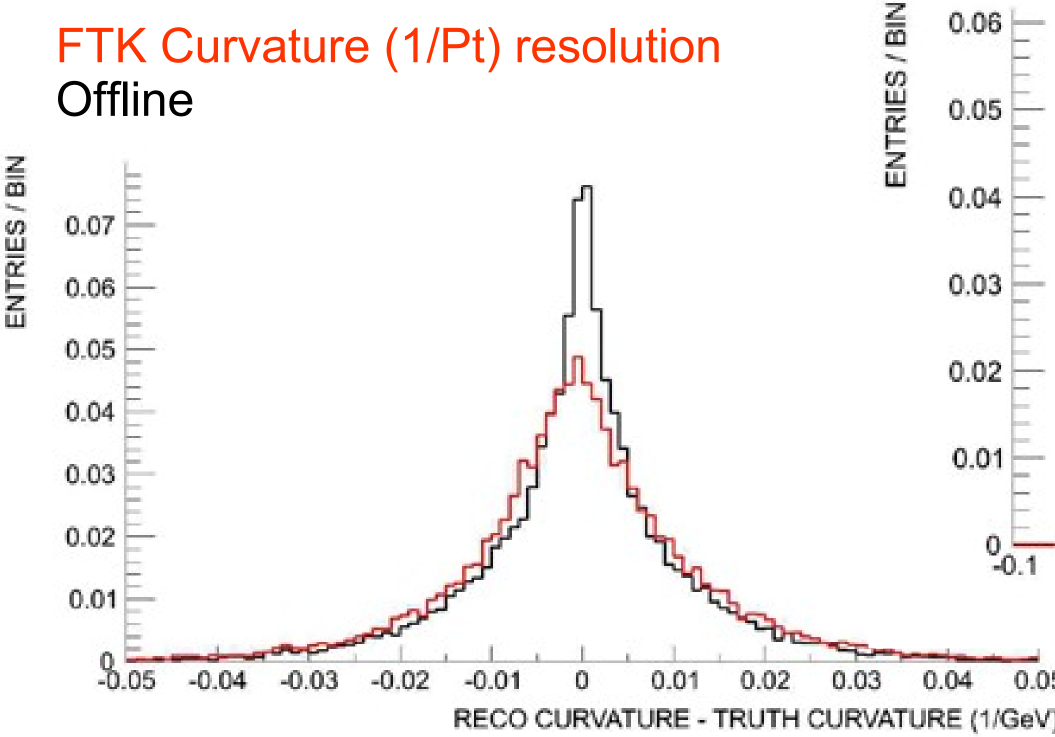
likelihood functions: signed *d*0 significance distributions of tracks in *b* and light jets

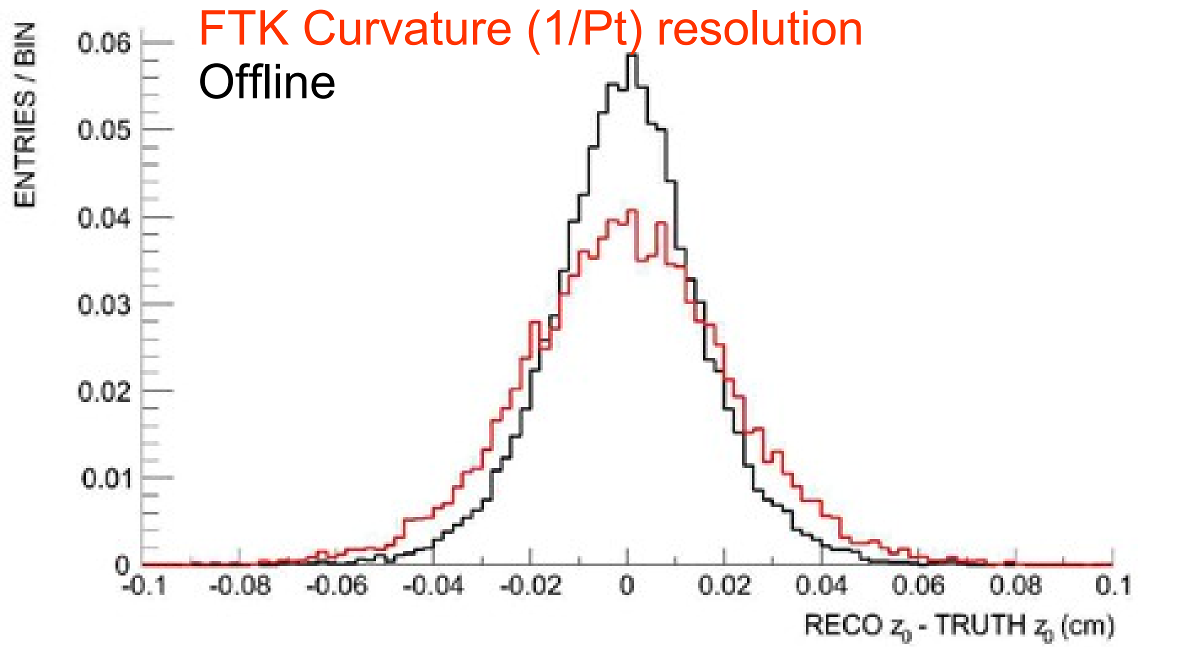
Lb & Lu for jet: calculated as product of L of tracks inside jet:

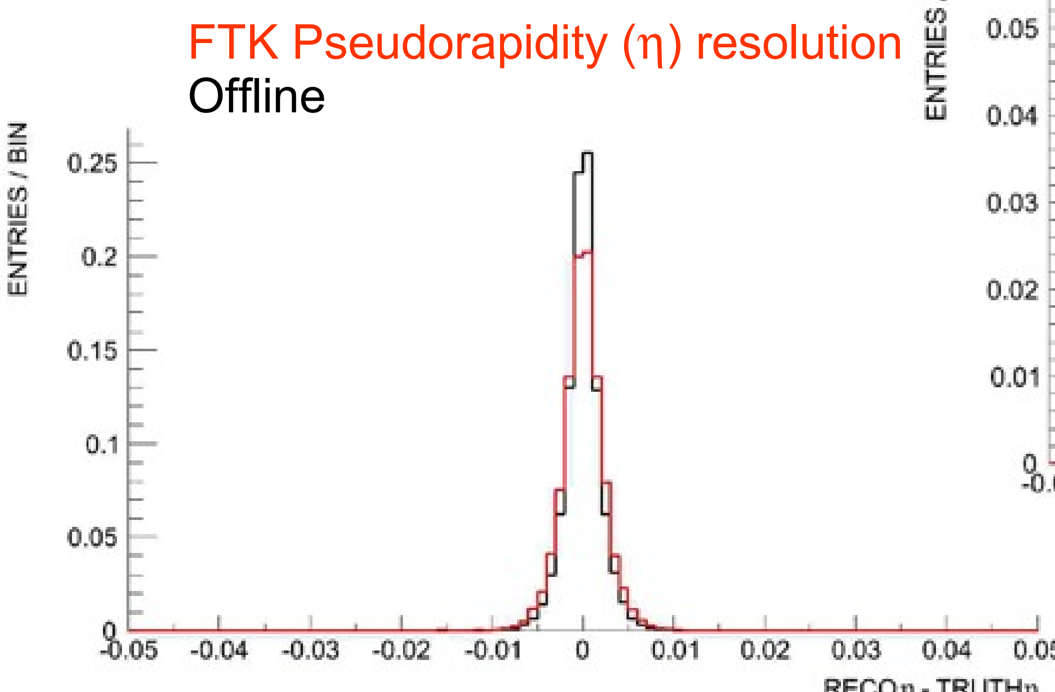
Lb/*Lu* of jet finally used

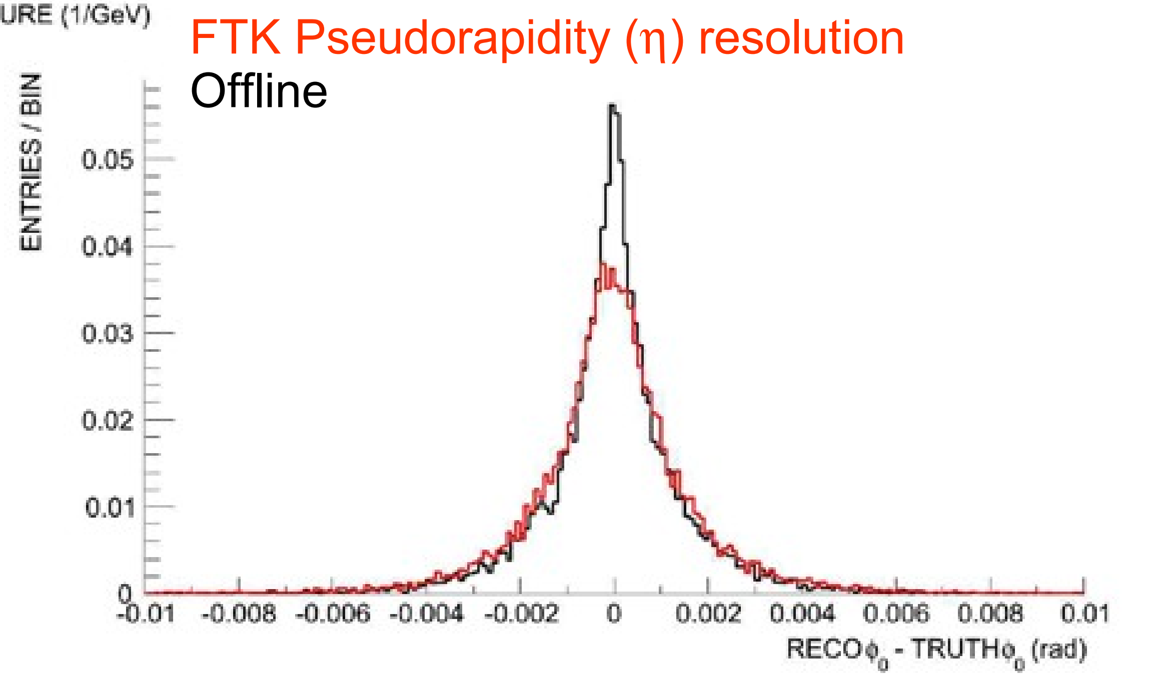
Next: **secondary vertexing**




FTK Curvature (1/Pt) resolution
Offline
ENTRIES / BIN
RECO CURVATURE - TRUTH CURVATURE (1/GeV)


FTK Curvature (1/Pt) resolution
Offline
ENTRIES / BIN
RECO z_0 - TRUTH z_0 (cm)

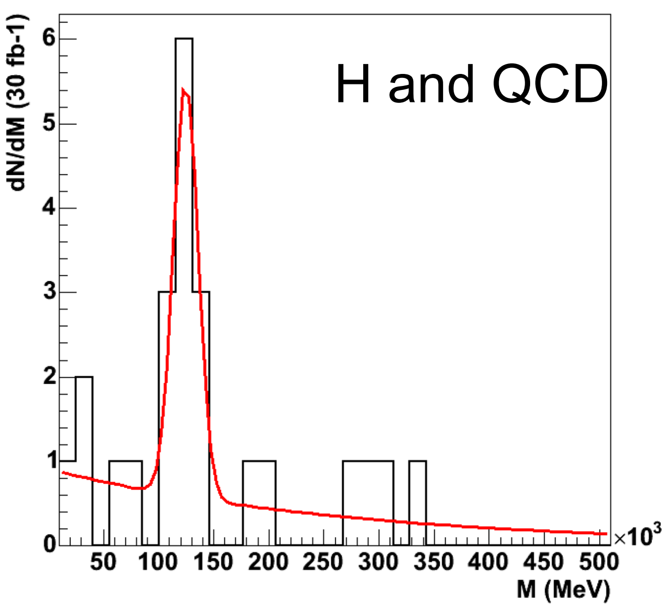

FTK Pseudorapidity (η) resolution
Offline
ENTRIES / BIN
RECOη - TRUTHη

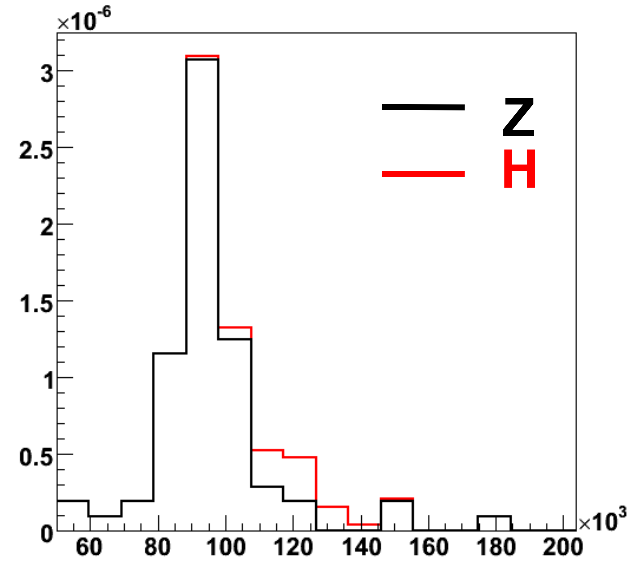

FTK Pseudorapidity (η) resolution
Offline
ENTRIES / BIN
RECOϕ_0 - TRUTHϕ_0 (rad)

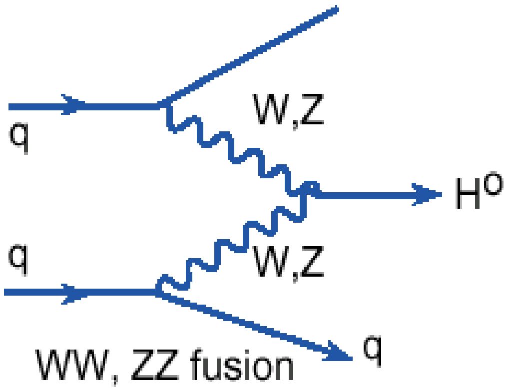
Physics case for τ-jet samples: one example is VBF Hqq $\rightarrow \tau_h \tau_h qq$

ATLFAST (9.0.4) 6 signal events and 4 bg events in 30 fb^{-1} (bg : Z+jets,ttbar,QCD dijets) with baseline trigger menu tau35i+XE45 foreseen for a luminosity of 2*10^33 $cm^{-2}s^{-1}$

F. Sarri e V. Cavasinni

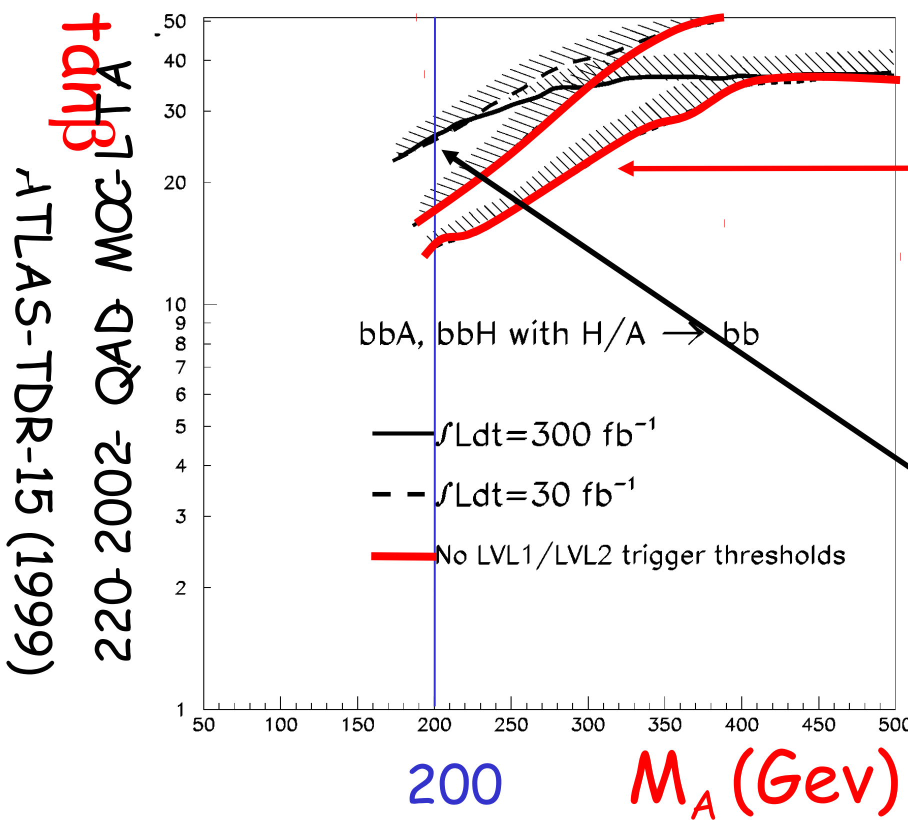






Promising channel that will profit a lot of a L2 fast track recontruction to keep low the trigger thresholds (35 GeV taus)

bbH/A → bbbb



Analysis:
4 b-jets $|\eta^j|<2.5$
$P_T^j >$ 70, 50, 30, 30 GeV
efficiency 10%

Effect of trigger thresholds before deferrals

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

As efficient as offline selection:
full Higgs sensitivity

PHYSICS for b-tagged samples (No-pile-up): some examples

Higgs Trigger ε	qqH	WH	ttH	Z^0H
Efficiency %	~25	~25	>90	~35

ATLFast

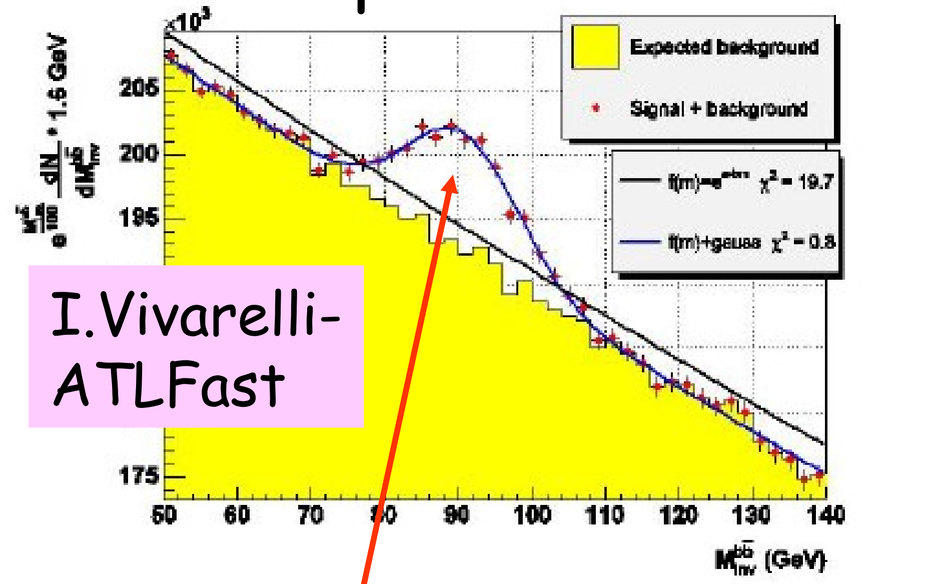
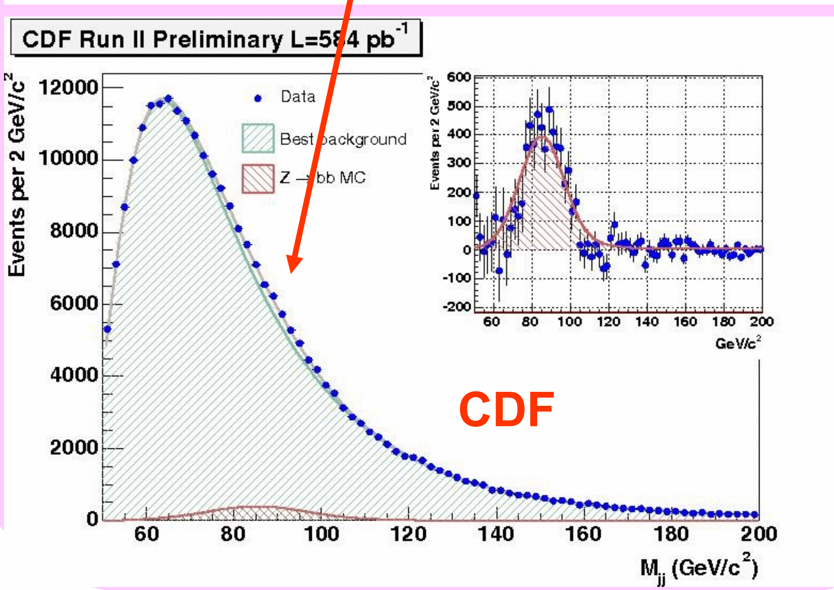
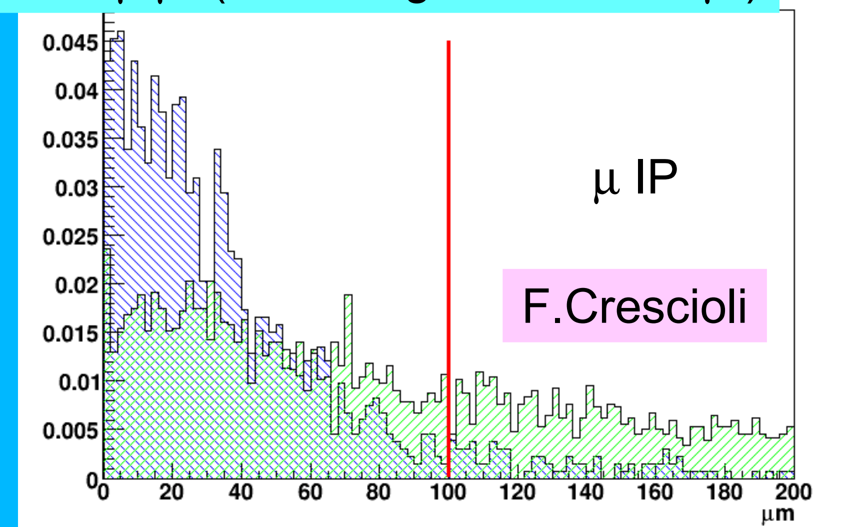
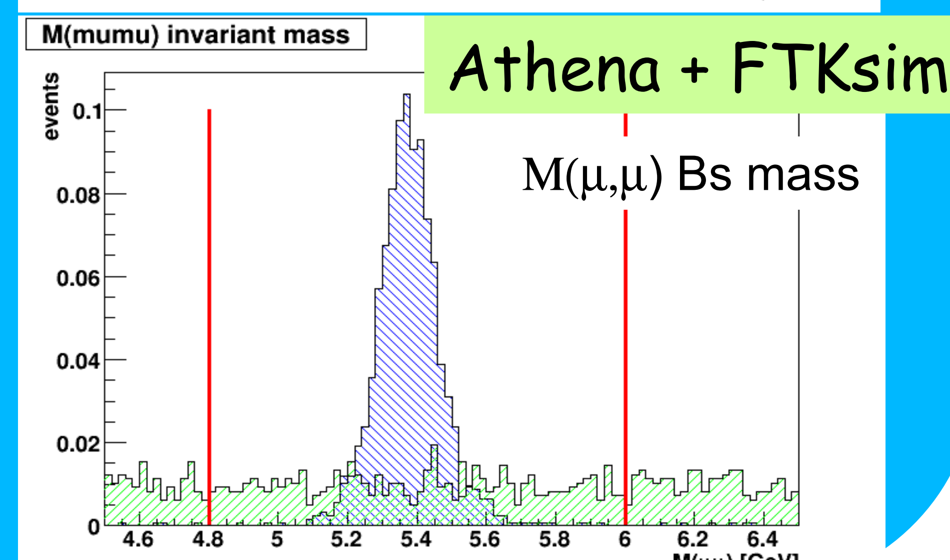


Figure 6: The $Z \rightarrow b\bar{b}$ signal after 30 fb^{-1}.

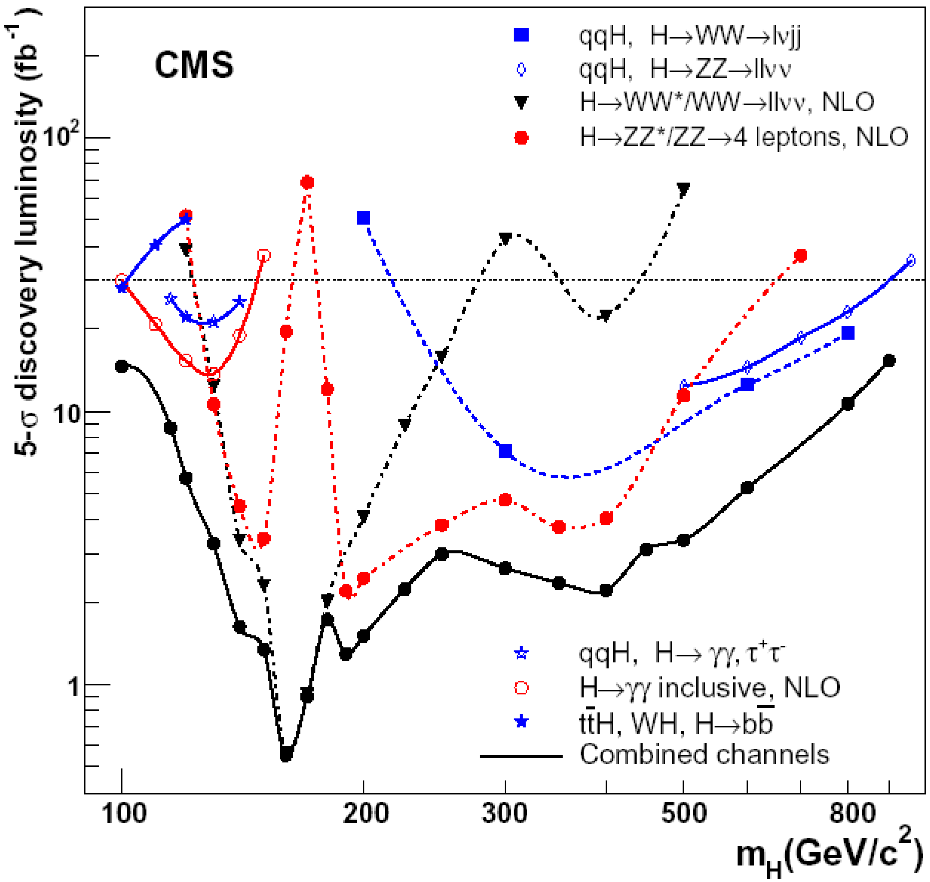


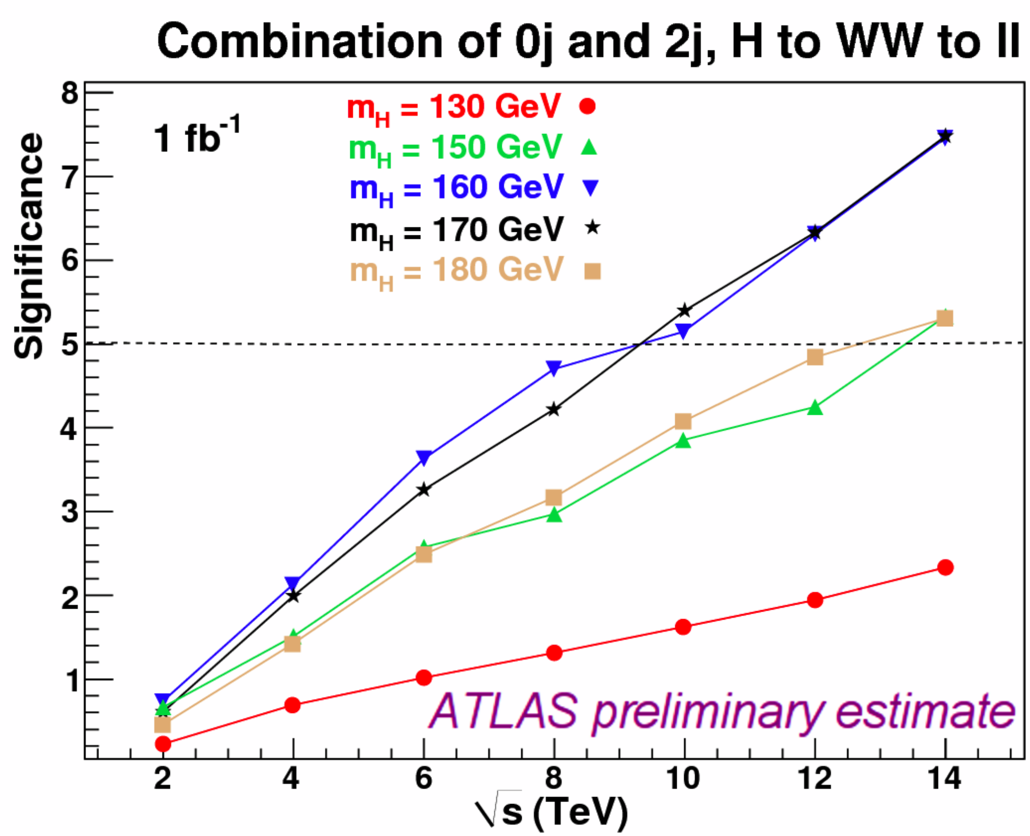
Bs -> μ μ (x3 using soft second μ)





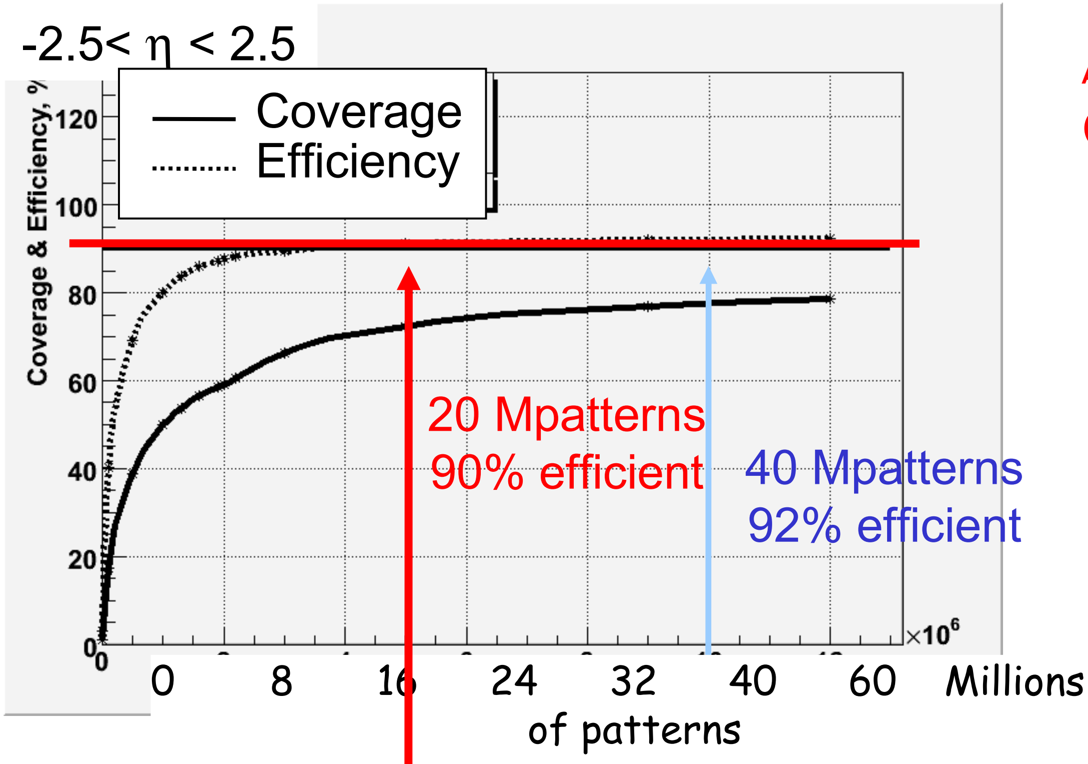
LHC SM Higgs Discovery Potential





- Sensitivity best at m_H=160 GeV/c^2:
  - Observation possible with ~1 fb^{-1} (or improvement of Tevatron limits)
- Much more difficult at low mass (preferred region)
  - Need at least 10 fb^{-1} to cover full mass range

Bank generated with Athena fully simulated single muons



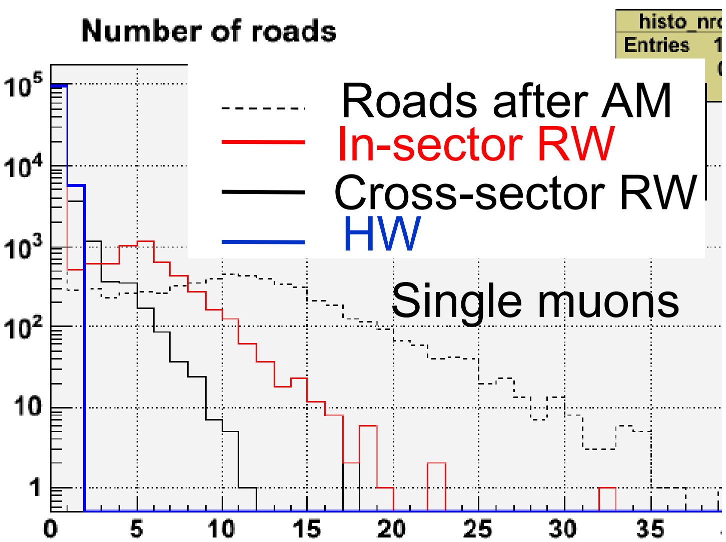
A. Kapliy (Chicago)
G. Volpi (Pisa)

SS sizes: in z → as long as the whole module (144 pixels);
in phi → 50 pixels and 64 SCT strips
– Default SS size: can be optimized –

Coverage = # evts with (11 hits/11 layers) / # evts
Efficiency = # evts with (11/11) OR (10/11) / # evts
.
EFFICIENCY allows for a missing LAYER (majority). Blue arrow shows a bank using less majority

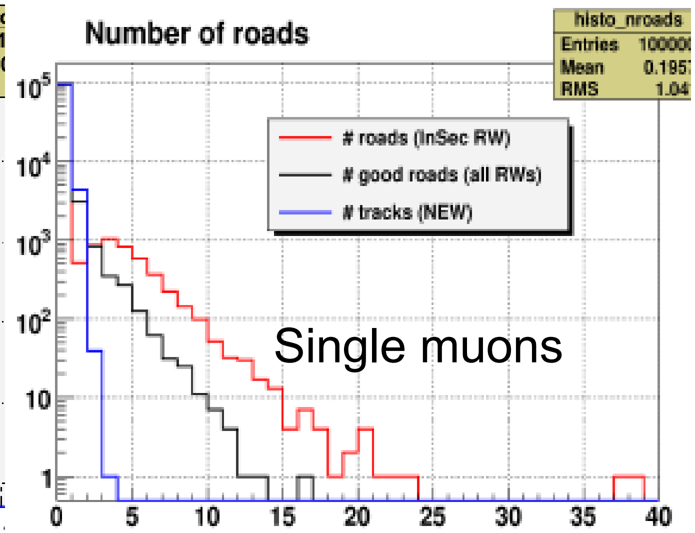
The effect of cleanup for banks of different coverage

BARREL ONLY- Default SS size
7 L – 5,6 M patterns / region
with efficiency ~98%



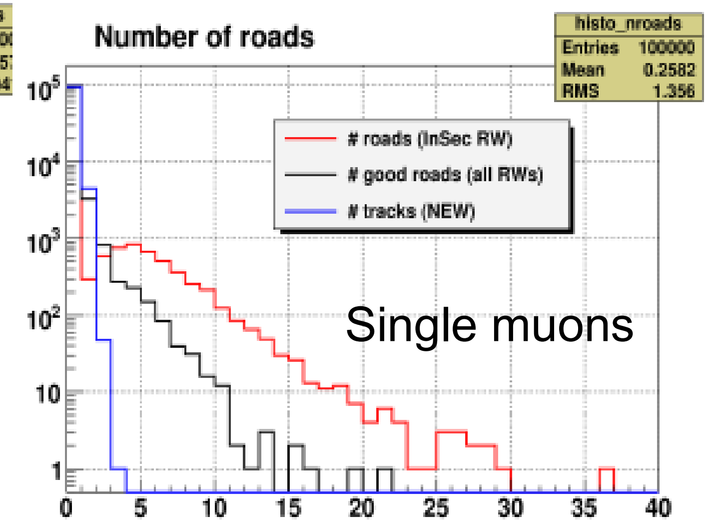
<#roads>=10.6
<roads>=2.15 (-80%)
<nfits>= 2.2

11 L – 8,4 M patterns / region
with efficiency ~85%
Coverage ~60%



<In-sec>=4.54
<Cross-sec>=2.27 (-50%)
<tracks>=1.51

11 L – 68 M patterns / region
with efficiency > 90 %
Coverage > 80 %



<In-sec>=5.72
<Cross-sec>=2.29 (-60%)
<tracks>=1.51

Richer banks produce much more ghosts

G. Volpi (Pisa)