$\sqrt{s}$ =1.96 TeV physics input to $\sqrt{s}$=14 TeV detector and triggering start-up

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thanks to organizers, "Landscape" group conveners and Dan Green.

Sources

- Jim Virdee, Fabiola Gianotti, Paris Sphicas, Albert de Roeck, Sasha Nikitenko, Patrick Le Dû

The homework

[...]We suggest the following tentative title

"Staging of Detectors and Triggers in Light of Tevatron Results"

The point of this workshop is to show how experience and results from the Tevatron could help the start-up of the LHC. We do not know yet what the final outcome of searches and measurements at the Tevatron will be, but we can anticipate that there will be difficulties with the start-up of the LHC. We would like you to consider how the leadership of ATLAS and CMS might choose to prioritize triggers and the staging of subdetectors considering results from the Tevatron.[...]

Tough!

How can we use Tevatron data to help commissioning the ATLAS/CMS trigger/detectors ahead of time? Contingency/prioritization flexibility is embedded.

The High Energy Data We Have

- Tevatron
  - $p\bar{p}$, ∼120 pb$^{-}1$ at $\sqrt{s} = 1.8$ TeV
  - $< 300\ pb^{-1}$ at $\sqrt{s} = 1.96$ TeV
- HERA
  - ep at $\sqrt{s} = 320$ GeV $\sim 120\ pb^{-1}$ (2001)
- LEP
  - ee at $\sqrt{s}$ up to 209 GeV $\sim$ 1 fb$^{-}1$

Q: How to best use these data to steer the LHC start-up

Our High Energy Delinquencies Today

- Tevatron
  - top quark mass and $t\bar{t}$ cross section
  - "superjet" events vis à vis b-tagging
- HERA
  - H1 vs ZEUS - events with large missing E_T and a lepton
- LEP
  - A_{fb}^{0b}

other: neutrino masses, [cosmological constant & not yet Higgs]

Q: How to best inform the LHC start-up

a current list of pheno BSM, Beyond SUSY

J.Lykken LHC Physics Vienna 2004

- U(1)′
- little higgs
- EWSB or SUSY breaking from extra dimensional boundary effects
- KK modes
- black holes, string balls
- flavor and EDs
- leptoquarks

Q: How to best guide the LHC start-up

Initial Remarks

- **most all can be motivated from one kind or another of Extra Dimensions and/or SUSY**

- **there is loose or strict dualities between the BSM models $\rightarrow$ the final states/data signatures can be the same $\rightarrow$ the characterization of an excess or a deviation could be in the fine details $\rightarrow$ dig out all the information out of an event (there is millions of channels in the modern detectors giving you kinematics, topology, everything)**

- **From the "analysing the data" point of view, i think one needs to know the qualitative and quantitative differences in**

the predictions of the models and not exactly the models $\rightarrow$ this leads to the disentangling efforts today (is it UED or is it SUSY, is it a Z' or is it an RS graviton mode? is it a monopole or a light gluino? etc)

- **all data that we have today point to the fact that there is something more but that it is rather tricky to say what.**

- **in HEP today when we talk about Beyond the Standard Model (including SUSY) we talk about data at the edge or tails of the standard model (e.g large invariant masses, tails of distributions)**

- **the accurate and precise determination of the standard model physics is crucial: (i) as a background to direct exotic searches (ii) as an indirect probe of other physics**

example list of "Very Exotic" searches (CDF's)

- Dilepton Resonances
  - searching for Z', RS Extra Dimensions, Technicolor
  - using $ee,\ \mu\mu,\ \tau\tau$
- Same-Sign Dilepton Resonances
  - searching for H^{++}
  - using $ee, \mu\mu, e\mu, \tau\tau$
- Dilepton+Photon
  - searching for heavy leptons
  - using $ee\gamma, \mu\mu\gamma, \tau\tau\gamma$

- Dilepton+Di-jet
  - searching for leptoquarks
  - using $eejj, \mu\mu jj, \tau\tau jj, e\nu jj, \mu\nu jj, \tau\nu jj, \nu\nu jj$
- Photon+missing E_T
  - searching for ADD Graviton
  - using $\gamma + \mathrm{missing\ E_T}$
- Photon+jet
  - searching for b'
  - using $\gamma + \mathrm{missing\ E_T}$
- Highly-ionizing (slow) track
  - searching for H^{++}, H^{--}, monopoles, UEDs stops and staus

example LHC list of "Very Exotic" Searches (ATLAS's)

- Jets and Missing ET :
  - L. Vacavant and I. Hinchliffe: Signals of Models with Large Extra Dimensions in ATLAS
  - P-H Beauchemin, G. Azuelos and C. Burgess Graviscalars in ATLAS
- Narrow Graviton Resonances
  - B.C. Allanach, K. Odagiri, M.A. Parker and B.R. Webber :Narrow Graviton Resonances with the ATLAS Detector at the Large Hadron Collider
- Virtual Graviton Exchange
  - V. Kabachenko, A. Miagkov, A. Zenin: di-photon and di-lepton, $t\bar{t}$ production from virtual graviton exchange graviton exchange on dijet production
- Radion and other scalars
  - G. Azuelos, D. Cavalli, H. Przysiezniak and L. Vacavant: Search for the Randall Sundrum Radion using the ATLAS detector
  - PH Beauchemin, G. Azuelos, C. Burgess: Graviscalar in ATLAS

- Gauge Excitations
  - G. Polesello and G. Azuelos : Gauge excitations in TeV-1 scale extra dimensions
  - M. Petra and G. Polesello : KK excitation of the W boson
  - S. Ferrag and G. Polesello : KK excitations of gluons
- Black Holes
  - A. Parker: Black hole production and Decay
  - A. Sabetfakhri: Search for Black Holes at the LHC
  - T. Yamamura and J. Tanaka: Search for Black Holes
  - J. Grain: Search for Gauss-Bonnet Black Holes
- TransPlanckian Elastic Collisions
  - G. Azuelos: First look at TransPlanckian elastic collisions in ATLAS, Oct. 2002 meeting
- Singlet Neutrino
  - K. Assamagan and A. Deandrea: The hadronic tau decay of a heavy charged Higgs in models with sin glet neutrino in large extra dimensions
- Dark energy
  - K. Baker Dark Energy Signals Cosmological Constant Signatures in ATLAS
- Universal Extra Dimensions
  - PH Beauchemin: Dijets in a scenario of Universal Extra Dimensions

Historical

- example of discovery in one machine/detector that informed strategy/methods amendment or change in another.
  - UAx $\longrightarrow$ Tevatron's CDF and D0 strategies for the top (the information was the non-discovery of the top for masses up to 100 GeV/c^2).
  - CDF's evidence for the top (using b-tagging/silicon) $\longrightarrow$ D0's clean dilepton channel at a mass of ~ 175 GeV/c^2.
  - BELLE's X(3872) $\longrightarrow$ CDF/D0 digging in J/Ψ datasets
  - more (homework)

Questions

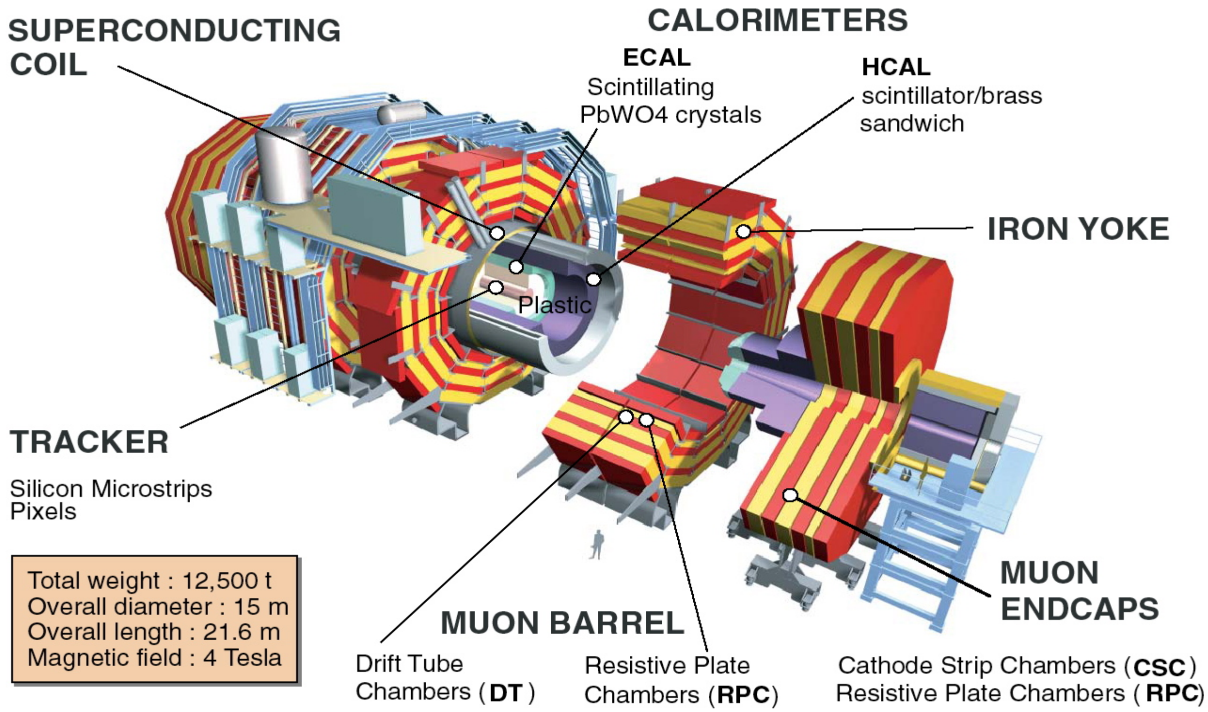
- lepton $\longrightarrow$ hadron
- $\sqrt{s} \longrightarrow \sqrt{s'}$
- detector technology $\longrightarrow$ (detector technology)$'$
- DAQ/trigger $\longrightarrow$ (DAQ/trigger)$'$

As Late As Possible but ahead of time

- " you cannot improvise a drama (thriller) while you are filming it. You must have it on paper ahead of time. Otherwise it is like a composer real-time composing with the orchestra (*flute give me a G-minor*, and he writes it down– doesn't work)." – Alfred Hitchcock

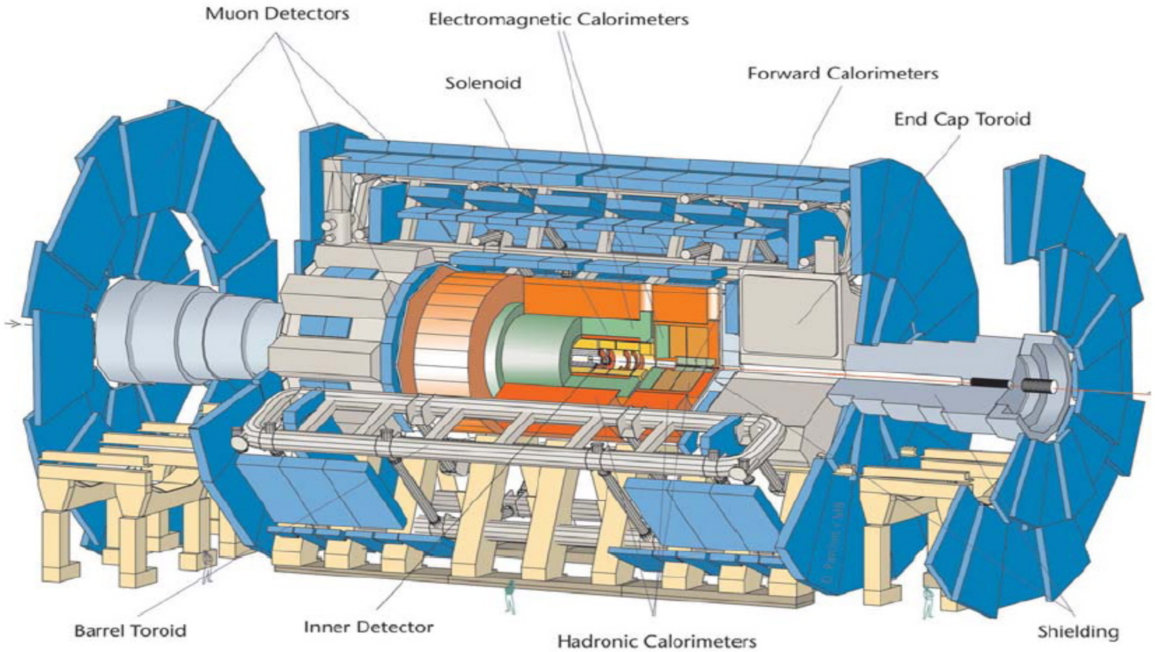
- We are 2.5 years before the LHC official start-up. The "script" is in production (detectors/TDAQ). The staging is money/physics scope/(available now and projected)-technologies driven. "As late as possible" is the aim in many aspects of TDAQ, but ALAP is rapidly becoming now.

Detectors+Triggers



• installed by April 2007 • staged parts: 3^{rd} forward pixel disks, ME4, PRCs in $|\eta| > 1.6$ • 2-3 months shutdown after pilot run to install pixel, fix problems picked up at the run • start-up: pile-up interactions/crossing = 2, 50% of DAQ.

Detectors+Triggers

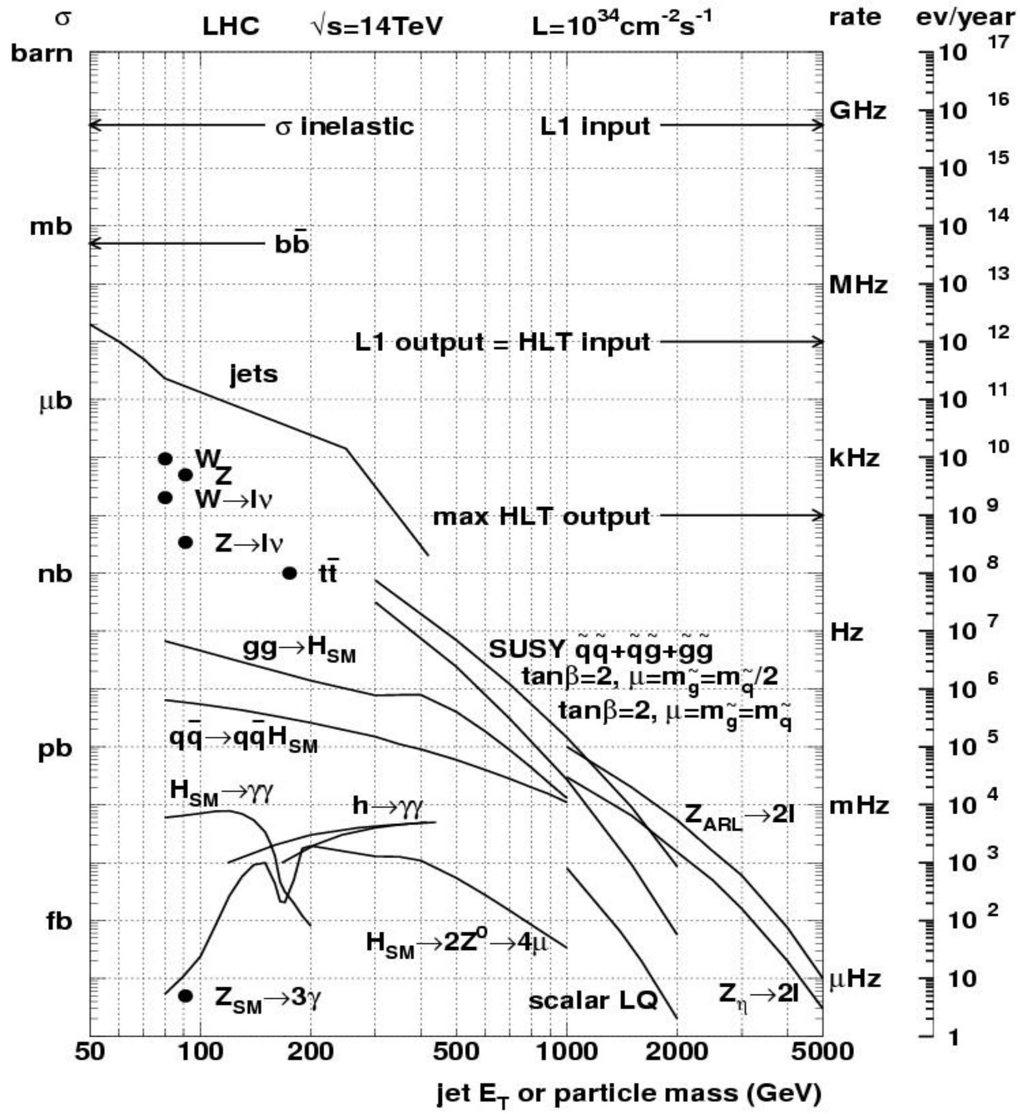


• installed by April 2007 • staged parts : tracker-1 pixel layer, outermost TRT wheels, muons:EES & EEL MDTs, half of CSCs, LAr: partof ROD system, tile gap scint. forward shielding. • no shutdown in base plan. • start-up: pile-up interactions/crossing = 2, 25-50% of DAQ.

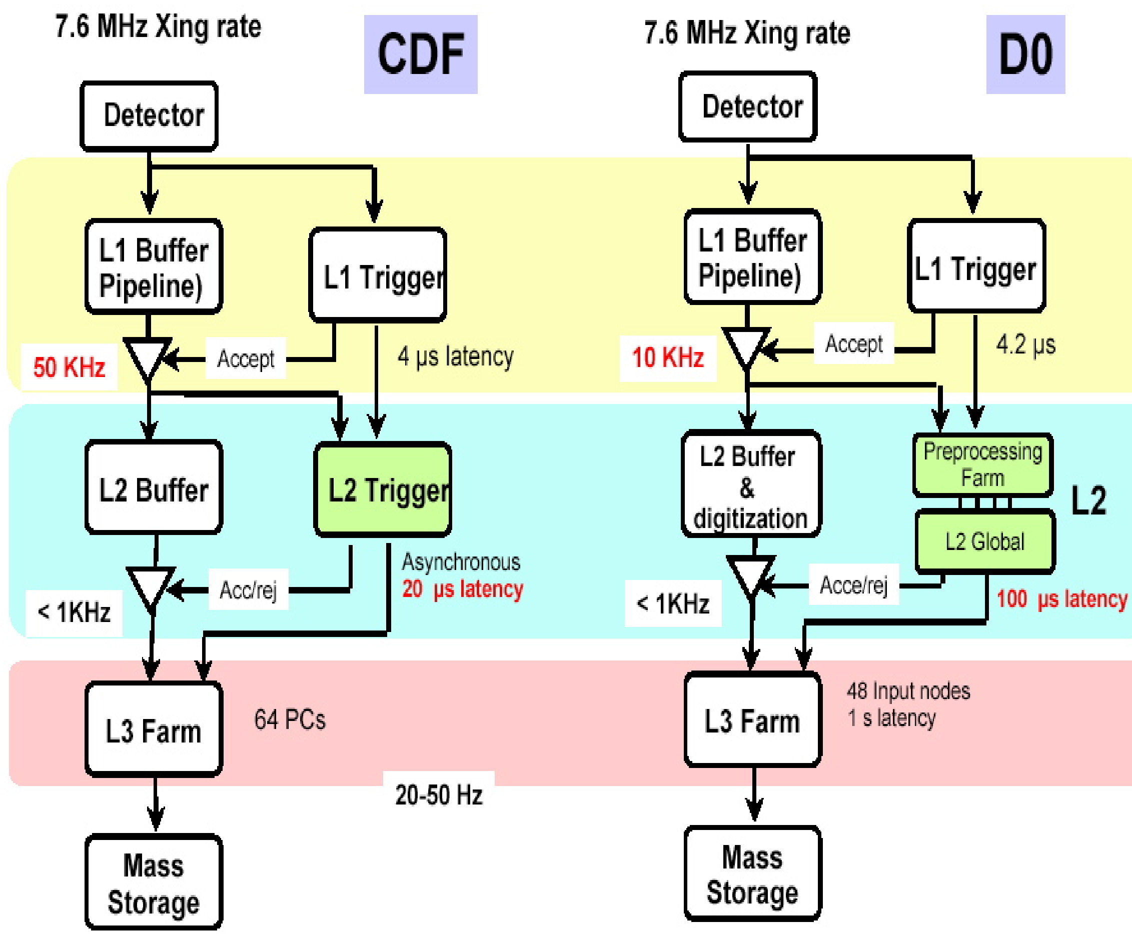
e.g. Event Rates

at $\mathcal{L} = 2 \times 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$

Process	Events/s	Events/year
$W \to e\nu$	30	$2 \cdot 10^8$
$Z \to ee$	3	$2 \cdot 10^7$
$t\bar{t}$	1.6	10^7
$b\bar{b}$	$2 \cdot 10^5$	10^{12}
$\tilde{g}\tilde{g}$ (m = 1 TeV)	0.002	10^4
Higgs (m= 120 GeV)		
Higgs (m= 800 GeV)	0.002	10^4
QCD jets $p_T > 200$ GeV	10^2	10^9


σ
barn
LHC √s=14TeV L=10^34cm^-2s^-1
rate
ev/year
σ inelastic
L1 input
GHz
mb
bb̄
MHz
L1 output = HLT input
jets
μb
kHz
W
Z
W→lν
Z→lν
max HLT output
nb
tt̄
Hz
gg→H_SM
SUSY q̃q̃+q̃g̃+g̃g̃
tanβ=2, μ=m_g̃=m_q̃/2
tanβ=2, μ=m_g̃=m_q̃
qq̄→qq̄H_SM
pb
H_SM→γγ
h→γγ
mHz
Z_ARL→2l
fb
H_SM→2Z^0→4μ
Z_SM→3γ
scalar LQ
Z_η→2l
μHz
50
100
200
500
1000
2000
5000
jet E_T or particle mass (GeV)

TeV trigger architecture



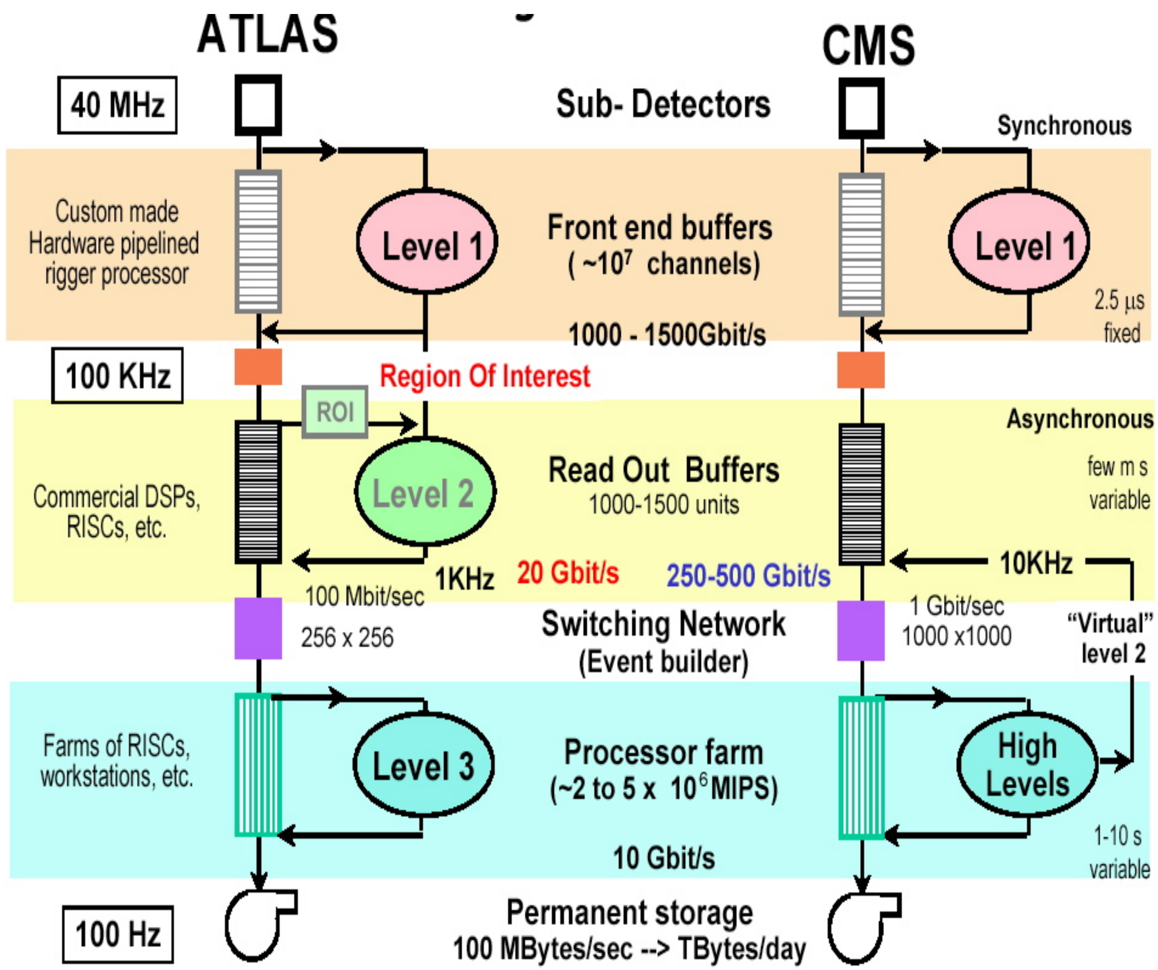
TeV trigger architecture

- Level 1 is hardware - operates on reduced/coarse data using crude signatures (hits, local energy deposits over threshold)
- Level 2 is composite - hardware for data preprocessing (muon,silicon) and software for matching, clustering etc
- Level 3 is a farm - general purpose CPUs

Selection Strategies LHC

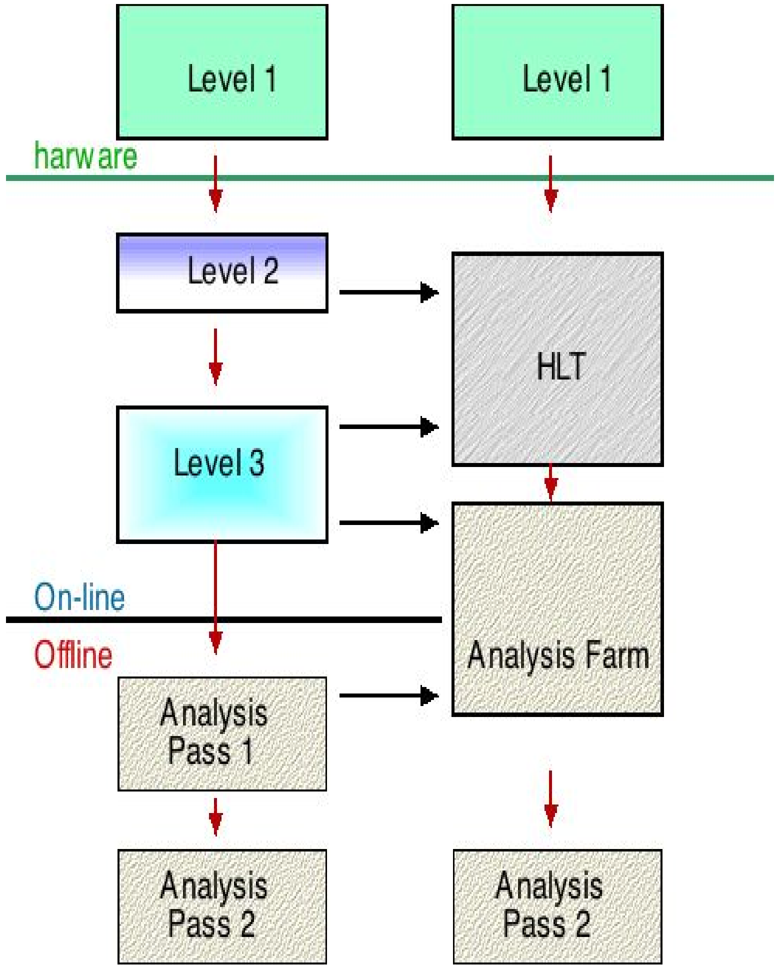
- Level-1. Input 40 MHz, Output 100 kHz.
  - Regional ID of high p_T objects. Using coarse dedicated data: energy clusters, track segments, missing E_T.
- Level-2. Input 100 kHz, Output 1 kHz.
  - Particle ID and Global topology. Using digitized data: fine granularity, track reconstruction, matching between sub-detectors, using decays, multplicities and refining thresholds.
  - **Physics Process ID.** Partial event reconstruction: vertices, masses &tc.
- Level-3. Input 1 kHz, Output 100 Hz.
  - **Physics Analysis**. "Off-line" type analysis of classified events.

Trigger Path



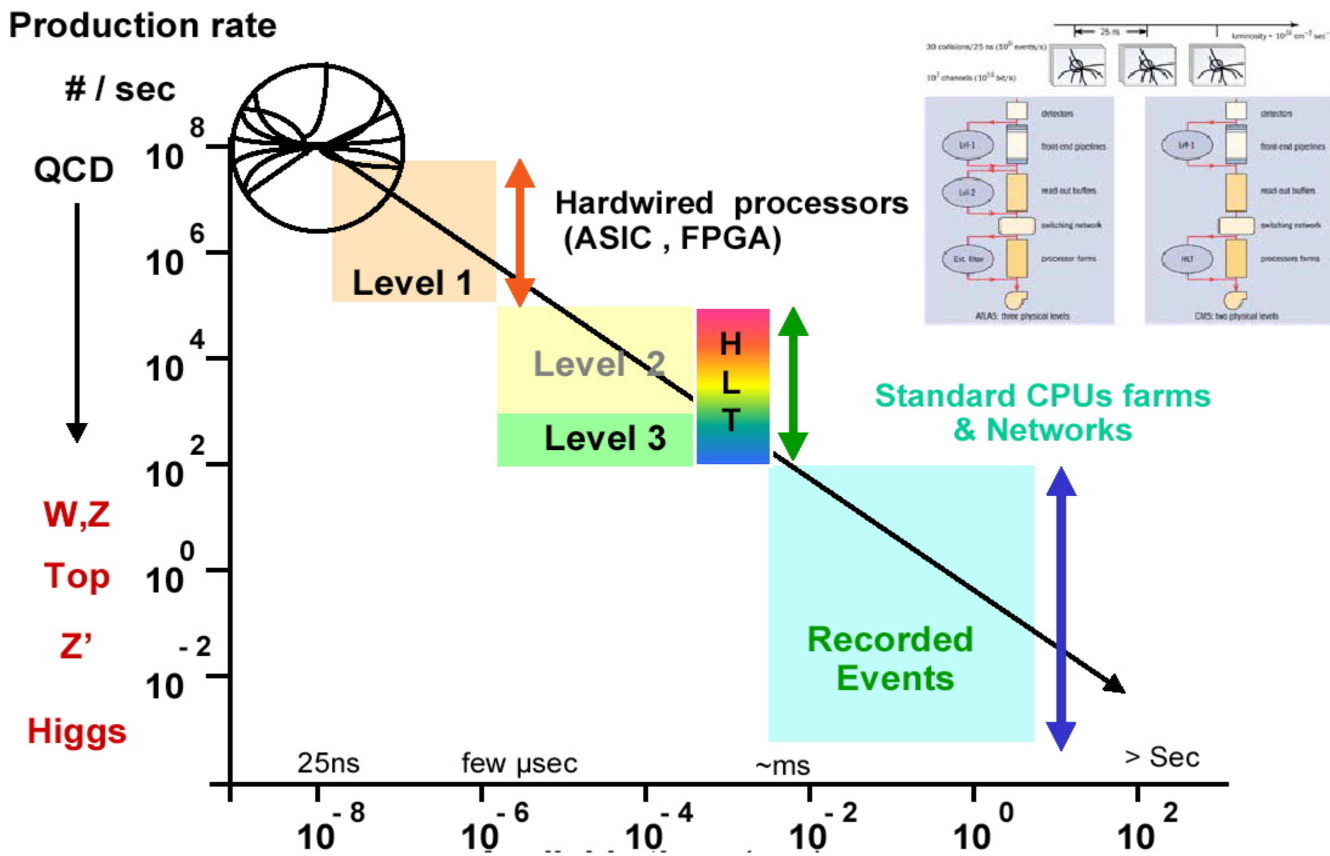
Trigger Path Evolution

- Two Trigger Stages:
  - Hardware/quasi-hardwired Level 1 for low level physics objects.
  - Software **HLT**=L2+L3 for high level particle and physics process ID.
- Complex algorithms move down. e.g.
  - Level-1 calorimeter jet and τ triggers!
  - Level-2 vertex triggers.
- Comodity products:
  - VME, PCI ...
  - off the shelf technology- PC farms, network switches.
  - high level computing languages.



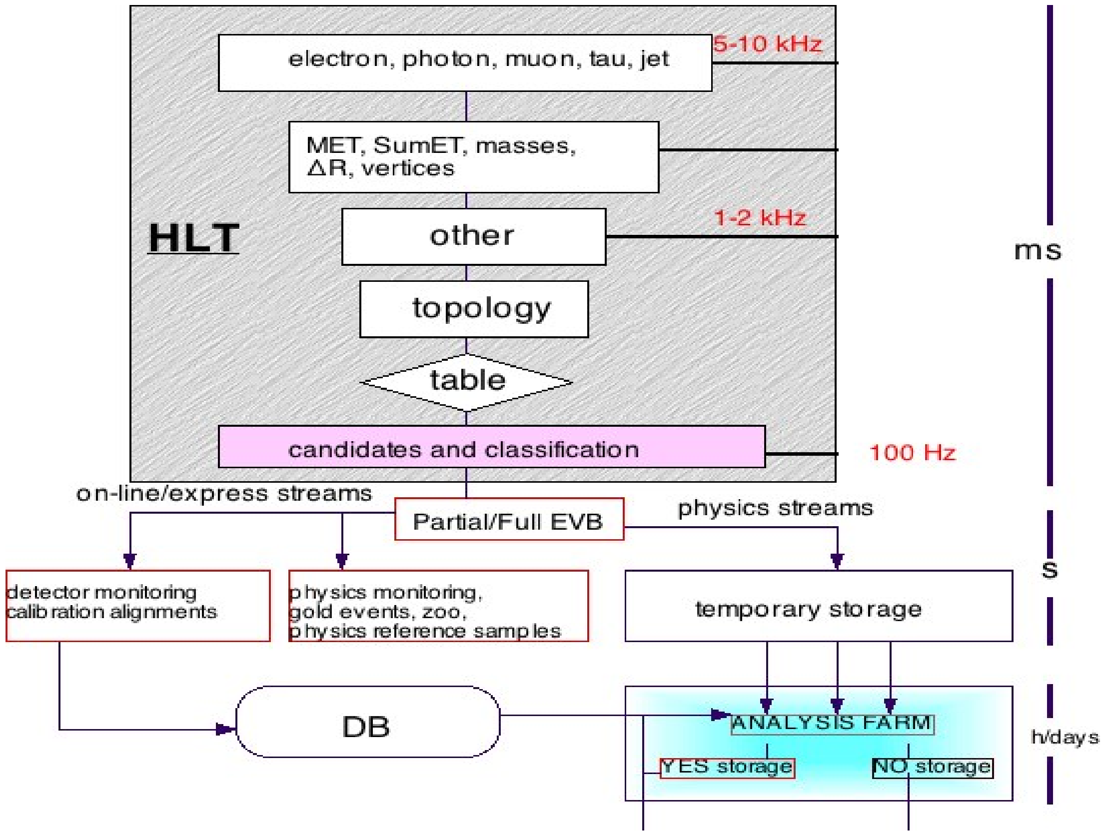
- merged data and control networks, processing at L2 (HLT), on-line complex selection algorithms (offline-on-line no strict boundaries).

Multilevel Data Selection



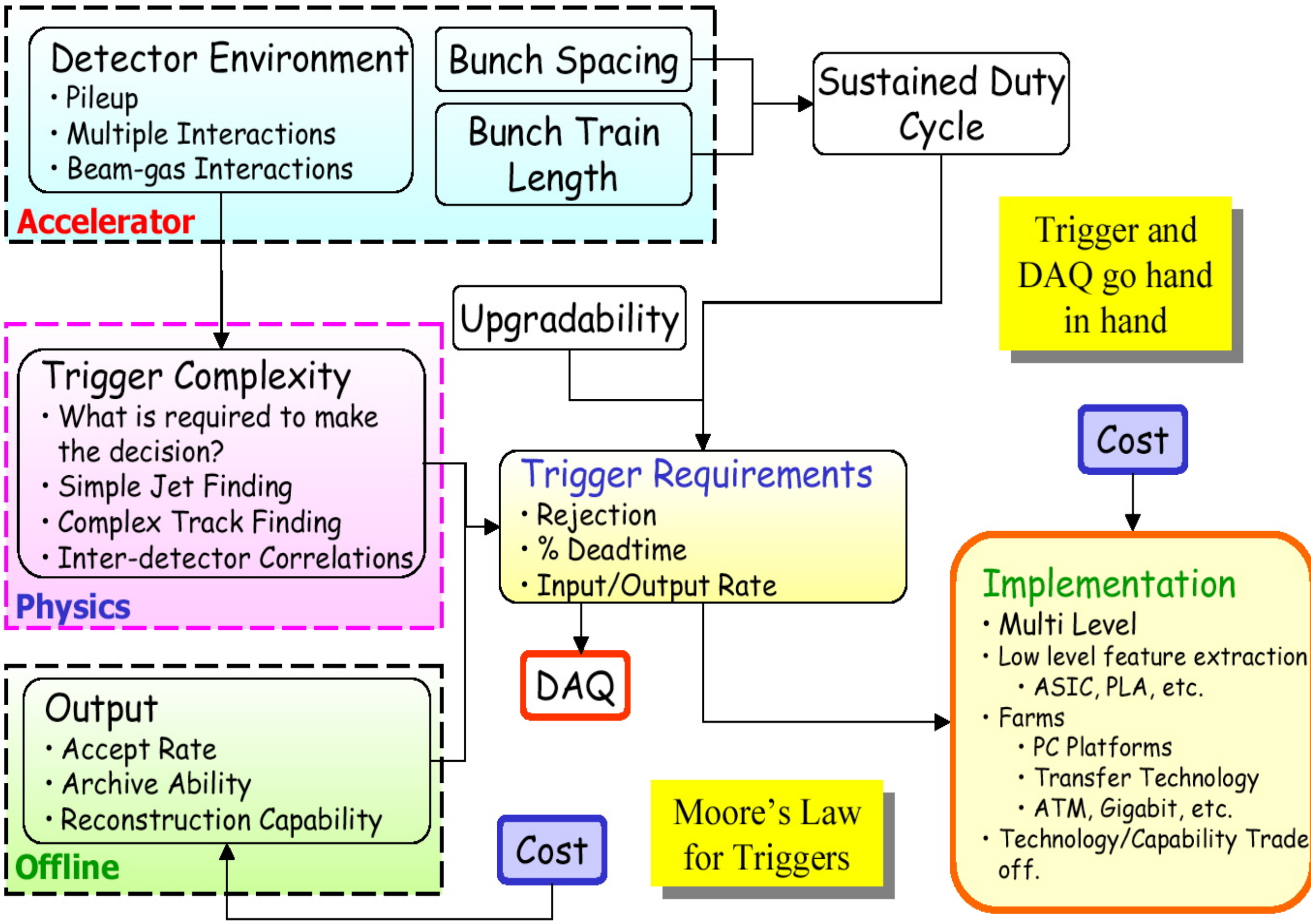
- Avalaible time (sec) versus Production rate (Events/sec)

Trigger/Analysis Flow



- HLT is flexible/fully programmable

TDAQ parameters, dependencies



example physics objects (ATLAS)

[Eur Phys J C 34,s01, s173b (2004)]

Objects	Physics	Naming
electron	higgs, W'/Z', ED, SUSY, W, top	e25i,2e15i
photon	higgs, ED, SUSY	γ60i,2γ20i
muon	higgs,W'/Z',ED,SUSY,W,top	μ20i, 2μ10
jet	SUSY, compositeness, resonances	j400,3j165,4j110
jet+$\not{E}_T$	SUSY, leptoquarks	j70+xE70
tau+$\not{E}_T$	MSSM higgs, SUSY	τ35+xE45

ATLAS L1 example $\mathcal{L} = 2 \times 10^{33}$ cm^{-2}s^{-1}

[Eur Phys J C 34,s01, s173b (2004)]

Trigger	Rate
MU20	0.8
2MU6	0.2
EM25I	12.0
2EM25I	4.0
J200	0.2
3J90	0.2
4J65	0.2
J60+xE60	0.4
TAU25I+xE30	2.0
MU10+EM15I	0.1
pre-scaled+calibration	5.0
Total	∼25

ATLAS HLT example $\mathcal{L} = 2 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Trigger	Rate (Hz)
e25i	40
2e15i	< 1
γ60i	25
2γ20i	2
μ20i	40
2μ10	10
j400	10
3j165	10
4j110	10
j70+xE70	20
τ35i+xE45	5
2μ6 with vrtx,decay length and mass cuts (m$_B$, m$_{J/\Psi}$)	10
Others (pre-scaled, exclusive, monitor, calibration)	20
Total	$\sim$ 200

CMS L1 example $\mathcal{L} = 2 \times 10^{33}\,\mathbf{cm}^{-2}\mathbf{s}^{-1}$

Trigger	Threshold (GeV or GeV/c)	Rate (kHz)	Cumulative Rate (kHz)
Inclusive isolated electron/photon	29	3.3	3.3
Di-electrons/di-photons	17	1.3	4.3
Inclusive isolated muon	14	2.7	7.0
Di-muons	3	0.9	7.9
Single tau-jet trigger	86	2.2	10.1
Two tau-jets	59	1.0	10.9
1-jet, 3-jets, 4-jets	177, 86, 70	3.0	12.5
Jet * E_T^{miss}	88 * 46	2.3	14.3
Electron * Jet	19 * 45	0.8	15.1
Minimum-bias (calibration)		0.9	16.0
TOTAL			16.0

[CMS, The TriDAS Project, Technical Design Report, Volume II: Data Acquisition & High-Level Trigger CERN/LHCC 2002-26]

CMS HLT example $\mathcal{L} = 2 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Trigger	Threshold (GeV or GeV/c)	Rate (Hz)	Cumulative Rate (Hz)
Inclusive electron	29	33	33
Di-electrons	17	1	34
Inclusive photons	80	4	38
Di-photons	40, 25	5	43
Inclusive muon	19	25	68
Di-muons	7	4	72
τ-jet * $\not{E}_T$	86 * 65	1	73
Di-τ-jets	59	3	76
1-jet * $\not{E}_T$	180 * 123	5	81
1-jet OR 3-jets OR 4-jets	657, 247, 113	9	89
Electron * Jet	19 * 45	0.4	89.4
Muon * Jet	15 * 40	0.2	89.6
Inclusive b-jets	237	5	94.6
Calibration and other events (10%)		$\sim$10	105
TOTAL			**105**

Some Questions

- Give an example of the flexibility at L1.

L1 accepts events on the basis of menu items. Up to 160 bits of input data in up to 256 menu items (example from ATLAS CTP). Menu items are enablable/disablable for certain bunches of the LHC (i.e during gaps you can enable the calibration menu). There is an individually programmable pre-scale factor for each menu item. The information of why an event was flagged (as passing through any menu item) is kept (for eg efficiency calculation at offline). There is low-priority and high-priority triggers based on the complexity of the algorithm and the deadtime they introduce. An example from calorimetry: 8 electron/photon 3-bit multiplicity values corresponding to different sets of cluster, isolation and hadron-veto thresholds. 8 additional 3-bit multiplicity values that can be programmed for use either as electron/photon or as tau/hadron clusters corresponding to different sets of cluster and isolation thresholds. 8 jet 3-bit multiplicity values corresponding to different thresholds. 8 forward-jet 2-bit multiplicity values (4 per end) corresponding to different thresholds.

⋆⋆⋆

•Jets and in particular τ-jets at L1 ??

Yes. The τ-id (isolation) is used to trigger on QCD **with lower** p_T **thresholds** (look eg at the CMS L1 table) and **acceptable rates**. Estimated using PYTHIA. If PYTHIA works for CDF/D0 we know that the estimates will not be orders of magnitude off.

⋆⋆⋆

• What sort of information from the Tevatron can directly benefit the tables?

• The % of calibration and prescaled data- Probably under-allocated bandwidth in the LHC tables. • Tunning of MC with real data for pile-up (see e.g. Rick Field Pythia tuneX). This might have an impact on uncertainties for rates and efficiencies. • Clean-up offline methods at the Tevatron that could be incorporated at the HLT algorithms. • ...

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- Are these tables close-to-final?

No. The tables are examples for studies and showcasing the TDAQ architecture abilities. The real HLT tables will be formed after commissioning and first data. There are many more example triggers incorporated in the simulations but are not studied in detail yet. (e.g. H_T triggers at CMS.)

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- What is the current staging and the safety margin?

Example CMS: 50% of the Level 1 design bandwidth= 50 kHz. 1/3 safety margin for the table is ∼16 kHz shown in the Level 1 example table.

⋆ ⋆ ⋆

- The tables are Higgs oriented. What about the “landscape”?

Commissioning with benchmark processes

fill-in the arrows excercise

- Minimum Bias
- Dijets
- $W \rightarrow e, \mu$
- $Z \rightarrow ee, \mu\mu$
- Z recoil
- Z+jets
- ...

- EM scale
- Muon Scale
- Jet/hadron scale
- Intercalibration
- UE, pile-up
- pdfs

TeV and multiTeV

- compare: Number of interactions per crossing.
- compare: σ(EWK)/σ(QCD).
- think: QCD.
- extrapolate(?): machine and detector/trigger reliability.
- condider: technology inputs.
- consider: other physics results inputs.
- ask: how much calibration data is neccessary and sufficent?

- ask: where is deadtime in data-taking coming from?

TeV4LHC

- the top quark mass and $t\bar{t}$ cross section - accurate and precise
  - the multiple power of the top
  - recent example (A de Roeck): the EGRET results favored a particular mSUGRA point. Try running it with 175, 178 and with 180 GeV/c^2 top mass (http://cmsdoc.cern.ch/ smaria/cmspub/exo/maria-exotics.html)
- the W mass : in looking for the Higgs.
- the W/Z+jets cross sections : in normalizing backgrounds for SUSY (for example).
- the dibosons, single top.

- QCD QCD QCD : from tuning the minimum bias MC (cfp PYTHIA/R. Field) to jet cross sections

The Tevatron can guide the LHC with precise SM results and methods. At start-up the LHC will have no other but $\sqrt{s}$ =1.96 TeV references.

TeV4LHC- the fear factor

There is room for thought in this area for this workshop

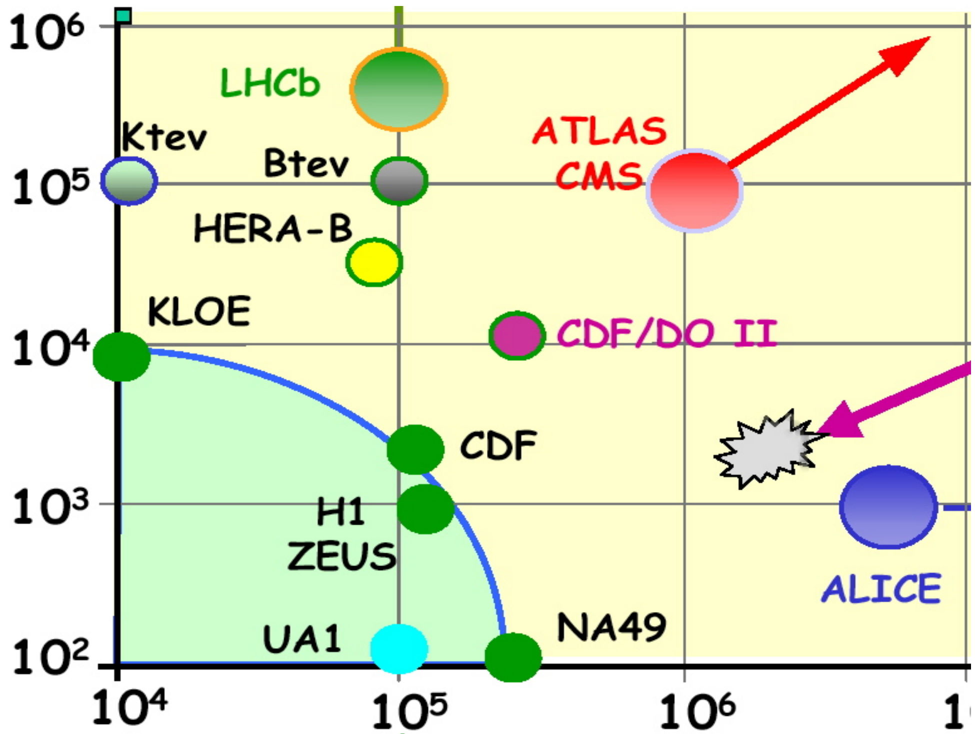
(examples from A. de Roeck LC/LHC complimentarity studies)

- If the Tevatron discovers a (meta)stable massive charged particle (stau) in a model with gravitino LSP: ATLAS and CMS would adapt the trigger (and perhaps their TOF) to catch these more efficiently.

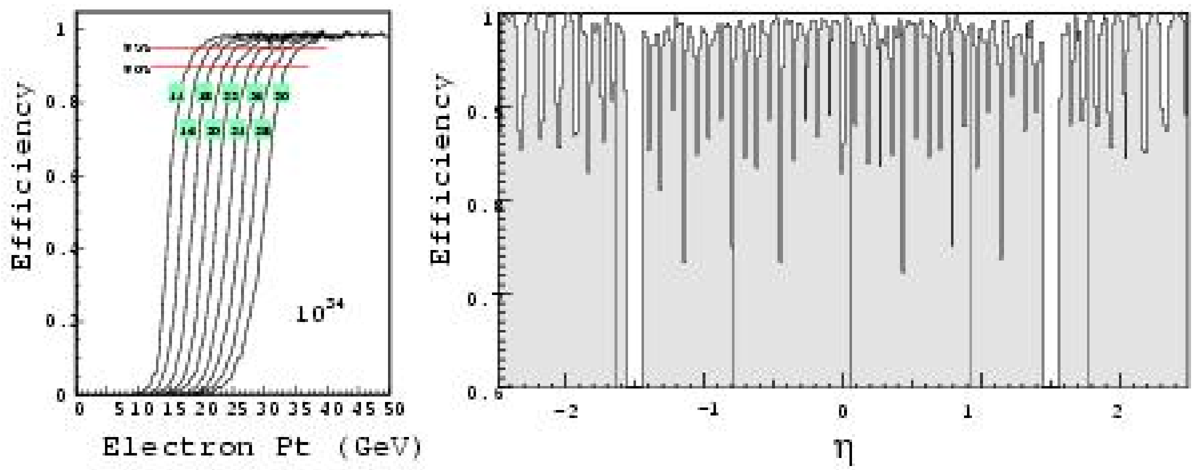
- the coannihilation region: Imagine that a heavy charged particle is discovered at the Tevatron, that decays into a neutral with a small mass splitting. The LHC experiments would adapt the lepton p_T triggers to collect these more efficiently.

• also other weird/tricky signals – such as recently from high scale susy.

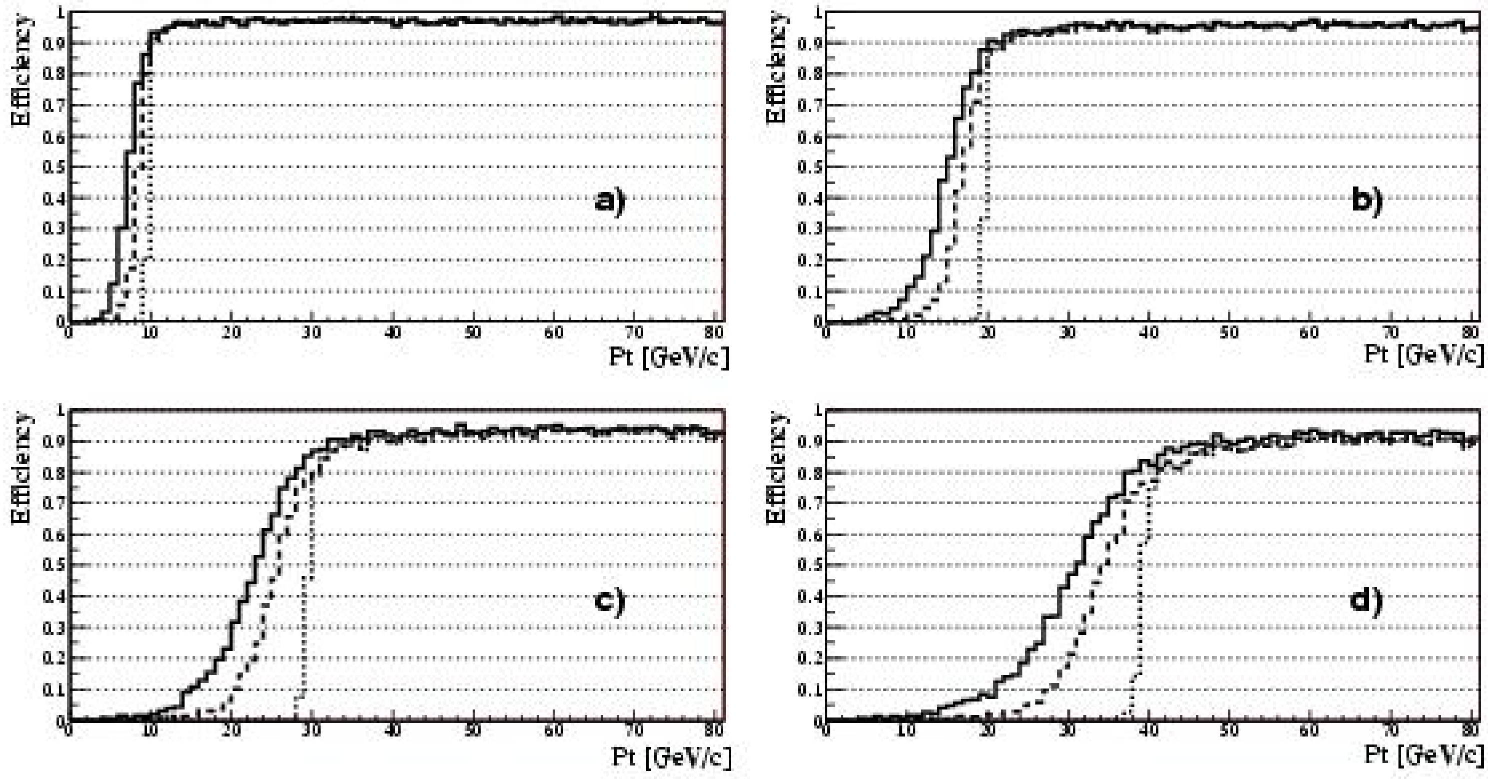
back-up



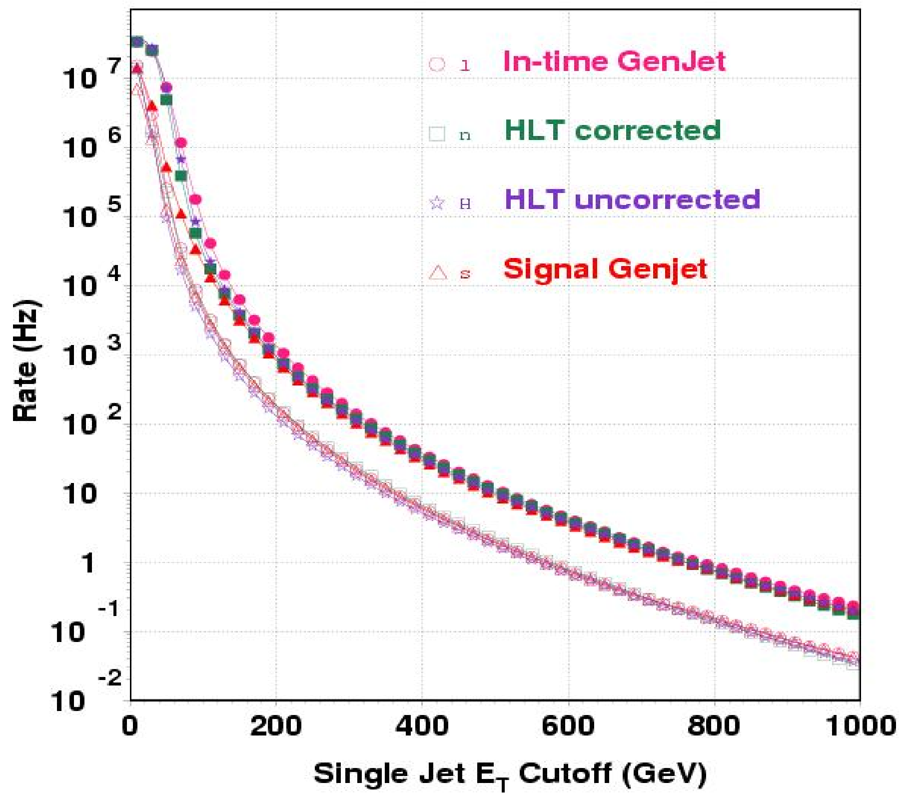
• Event size (bytes) versus Level-1 Trigger Rate (Hz). • ATLAS/CMS High number of channels/bandwidth (500 Gbit/s). • LHCB High Level-1 trigger. • ALICE Highest event size/data archive.



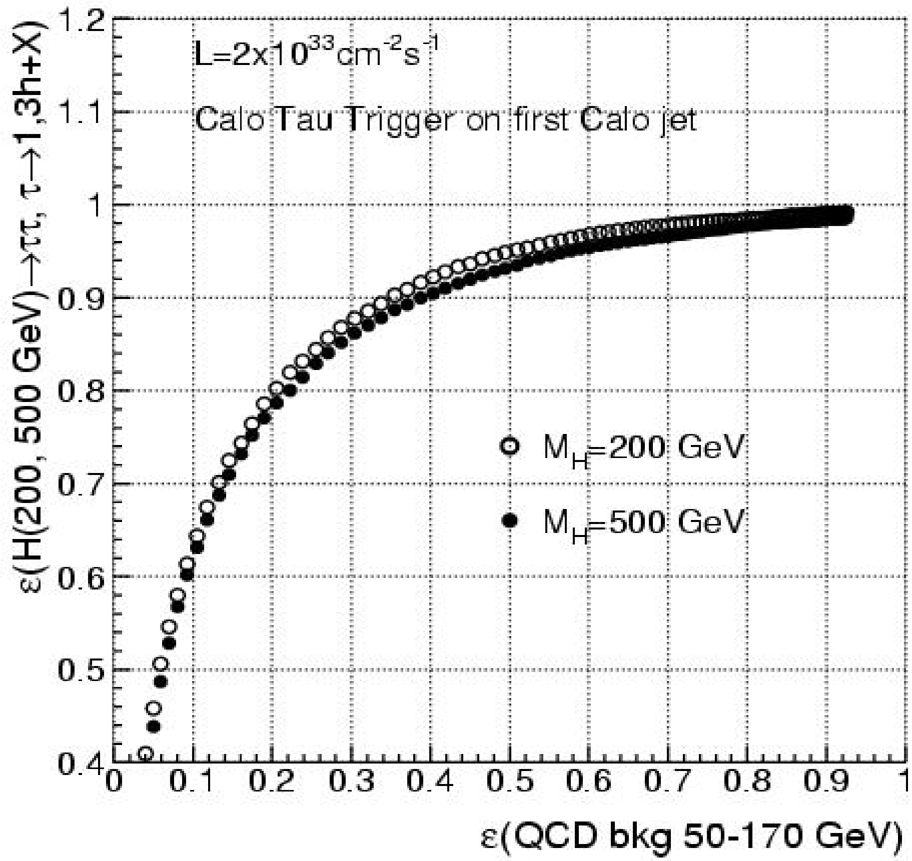
The efficiency of the Level-1 trigger for single electrons as a function of the electron p_T. On the right, the efficiency, as function of η, for electrons with p_T=35 GeV/c.



Cumulative efficiency for single muons to pass the Level-1 (solid), Level-2 (dashed), and Level-3 (dotted) triggers as a function of the generated p_T for several trigger thresholds: a) $p_T > 10$ GeV/c, b) > 20 GeV/c, c) > 30 GeV/c, and d) $>$ 40 GeV/c.



Rates for a single- jet trigger at the generator-level using only particles from the hard scattering to make the jets and also using all particles, including those from the pileup interactions, at both low and high luminosity. Also shown are the HLT single-jet trigger rates both before and after jet energy scale corrections at low and high luminosity. The open (filled) symbols show the low (high) luminosity rate.



Efficiency of the *Calorimeter Tau* trigger when applied to the first calorimeter jet in $A^0/H^0 \to \tau\tau \to 2\tau$-jet and QCD di-jet events. M_H= 200 and 500 GeV/c^2 for $\mathcal{L} = 2 \times 10^{33}$ cm^{-2}s^{-1}. $P_{isol} = \sum_{\Delta R<0.4} E_T - \sum_{\Delta R<0.13} E_T$ is varied between 1 GeV and 20 GeV in 0.2 GeV steps.