Trigger Strategies and Early Physics at CMS

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Berkeley Workshop on Physics Opportunities with Early LHC Data
Berkeley, May 6-8, 2009

Outline

Introduction of experimental setup

- accelerator: LHC
- detector: CMS
- starting up

Trigger Strategies

- general architecture
- trigger primitives
- basic and more elaborated trigger tables

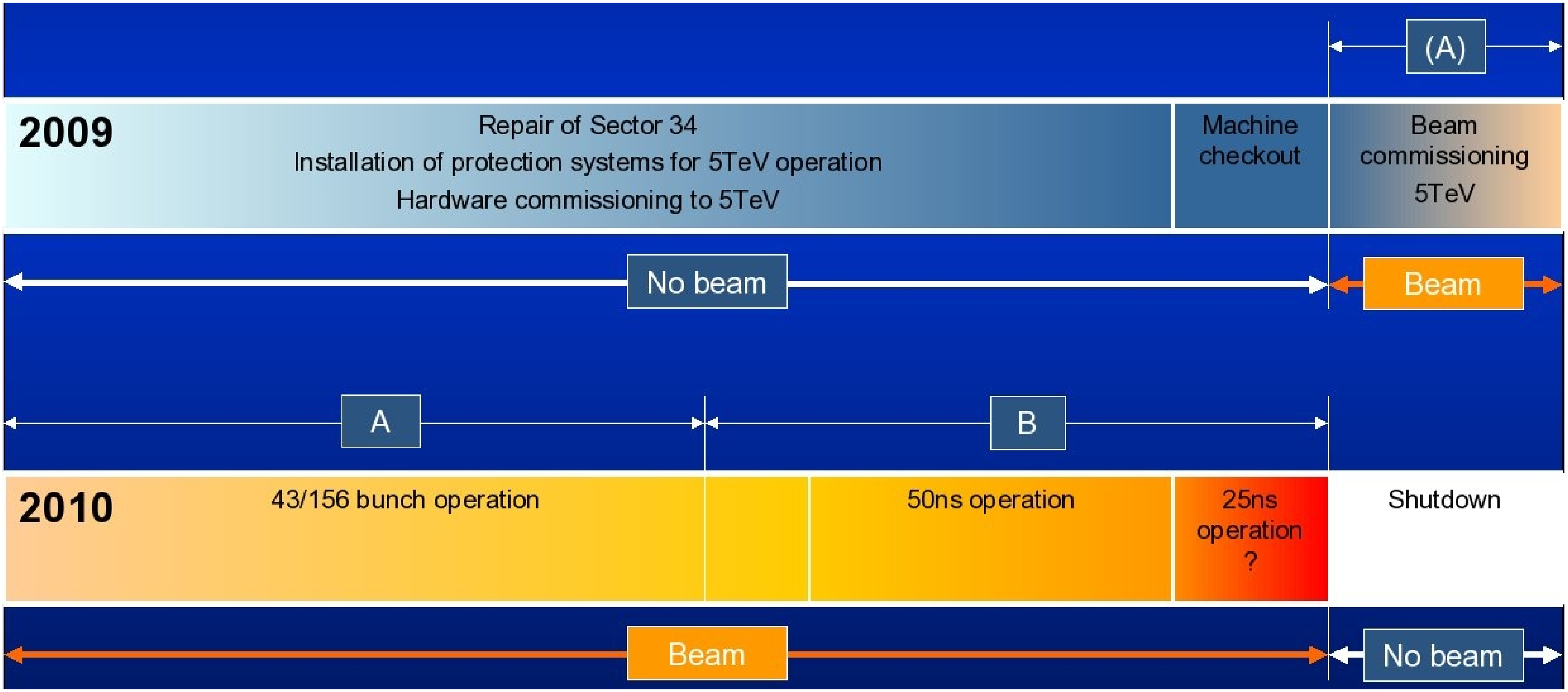
Early physics opportunities

- electroweak, top
- Higgs
- non Standard Model stuff

LHC Startup Schedule

Overview

- first beam in September, first collisions end of September
- 450 GeV beam energy *'runlet'* very likely
- moving up soon to beam energies as high as 5 TeV
- plan to deliver ~200 pb^{-1} of integrated luminosity
- within roughly 9-10 month (follows 9 month break)



From R.Bailey, April 2009 Oxford IoP

LHC Run Plan 2009/10

Luminosity profile (gu)estimations

- determine relevance of pile up events: mild pileup
- prepare tuning of trigger setups

Month	No. Bunches	Protons per bunch	β* [m]	% Nom	Peak luminosity cm-2s-1	Integrated luminosity
1	Beam Commissioning					
2	43	3×10^{10}	4	0.4	1.2×10^{30}	100 – 200 nb^{-1}
3	43	5×10^{10}	4	0.7	3.4×10^{30}	~2 pb^{-1}
4	156	5×10^{10}	2	2.5	2.5×10^{31}	~13 pb^{-1}
5	156	7×10^{10}	2	3.3	4.9×10^{31}	~25 pb^{-1}
6	720	3×10^{10}	2	6.7	4.0×10^{31}	~21 pb^{-1}
7	720	5×10^{10}	2	11.2	1.1×10^{32}	~60 pb^{-1}
8	720	5×10^{10}	2	11.2	1.1×10^{32}	~60 pb^{-1}
9	720	5×10^{10}	2	11.2	1.1×10^{32}	~60 pb^{-1}
10	Ions					
Total						**200 – 300 pb^{-1}**

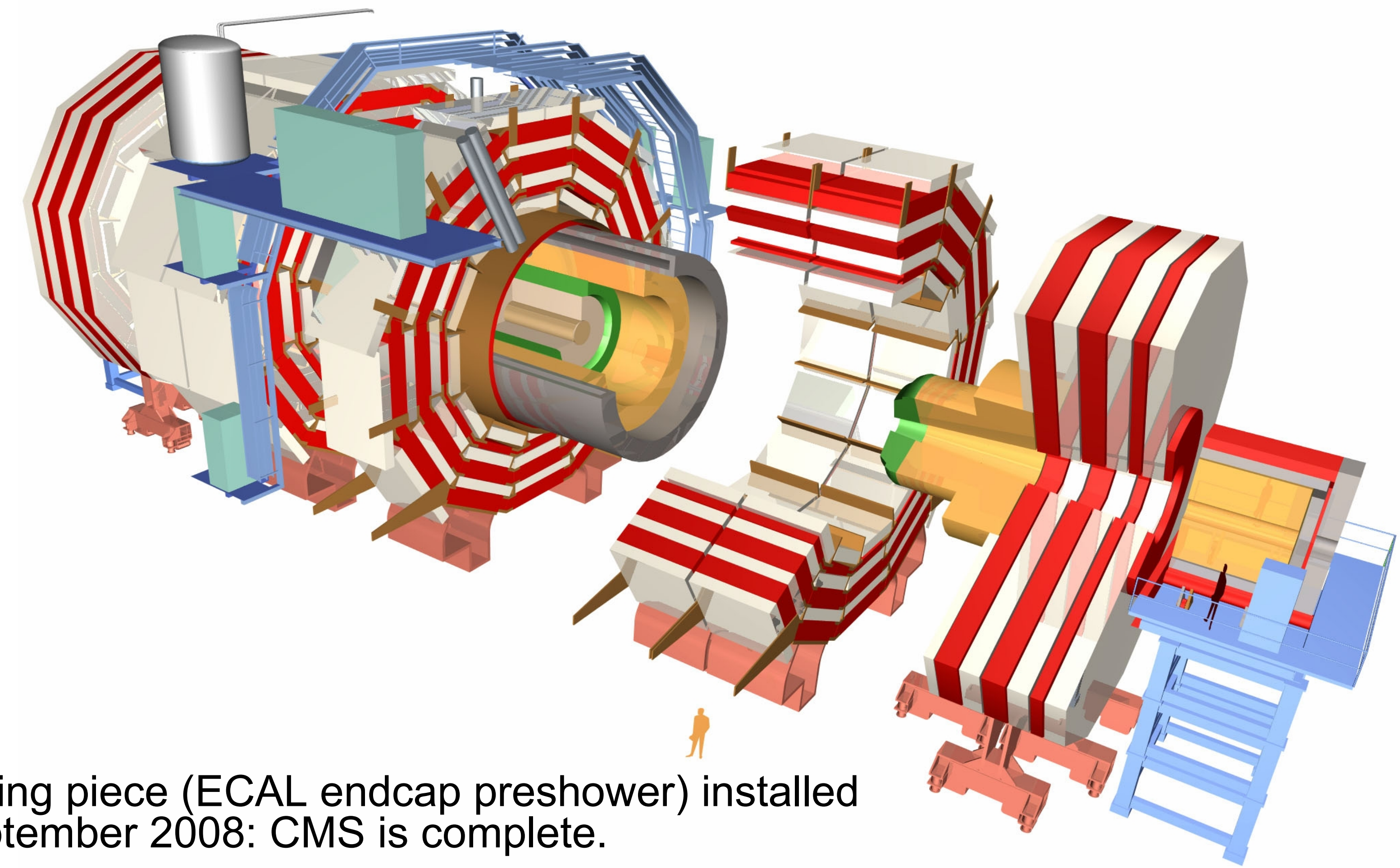
From R.Bailey, April 2009 Oxford IoP

careful: delivered lumi != lumi usable for physics

CMS – Compact Muon Solenoid

General overview

- detector was ready to take data in September 2008
- … and it still will be for September 2009
- *see N.Bacchetta yesterday: 'CMS Detector Performance for 09/10'*



Last missing piece (ECAL endcap preshower) installed since September 2008: CMS is complete.

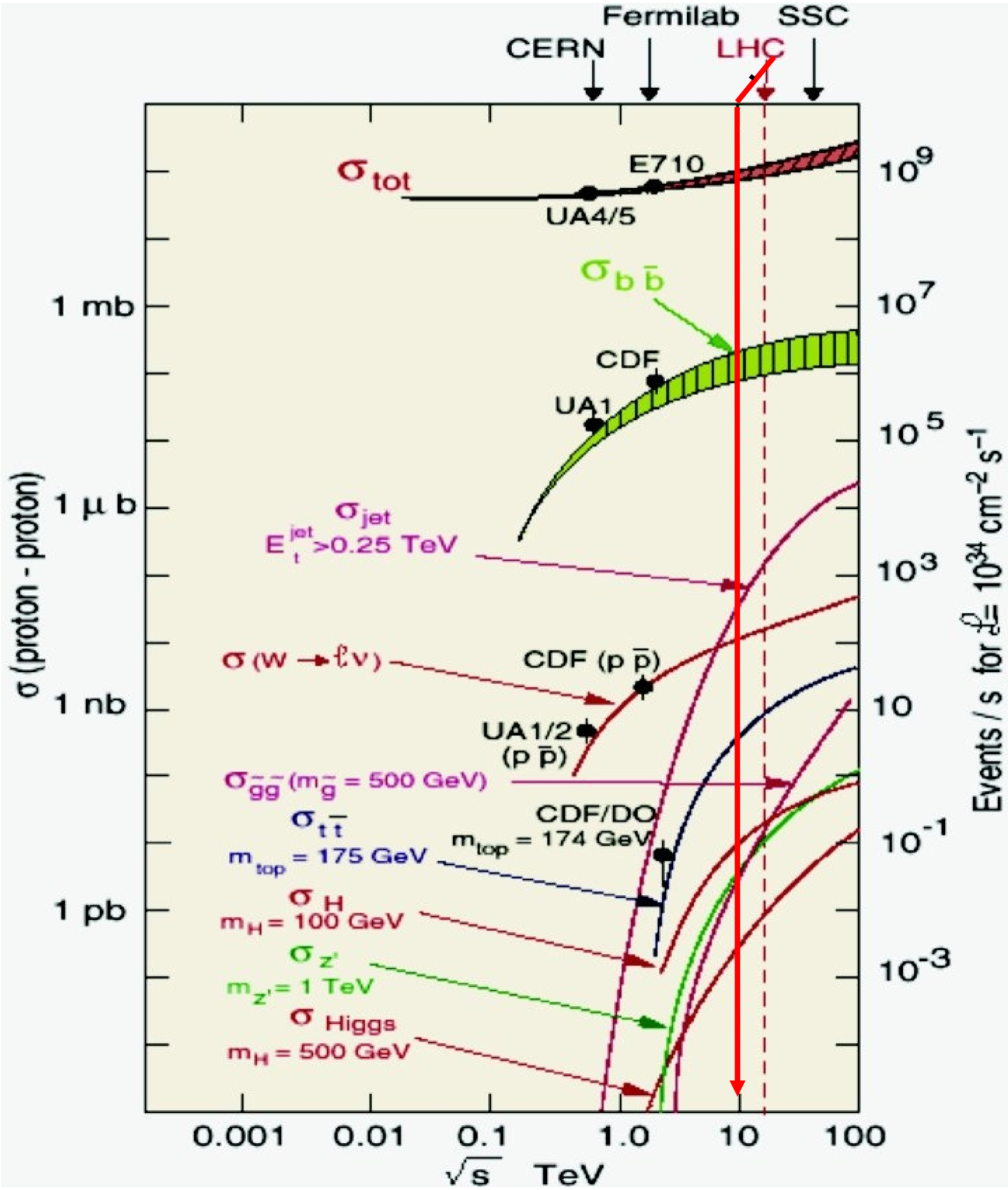
Physics Overview

Physics processes

- production relative to σ_{tot}:
  bb at 10^{-3}, $W \to \ell\nu$ at 10^{-6} and *Higgs*(m=100 GeV) at ~10^{-11}
- 32 MHz beam crossing, only about 300 Hz tape writing: $1/10^5$
- fast and sophisticated selection process essential: trigger

Trigger

- complete trigger has to work: otherwise no useful data registered
- already in first data taking: rate enormous and trigger important
- core trigger organization: use electron, muon, jet and energy signatures



14 TeV → 10 TeV: need 2 times the events for same sensitivity

CMS Trigger - Overview

Traditional HEP trigger systems

- organized in levels: level-1, level-2, level-3
- increasing amount of data and time to analyze
- level-1: custom boards, level-2: programmable logic chips, level-3: computing farm running fast reconstruction
- CMS follows pattern generally but level-2 and level-3 merged into High Level Trigger (HLT)

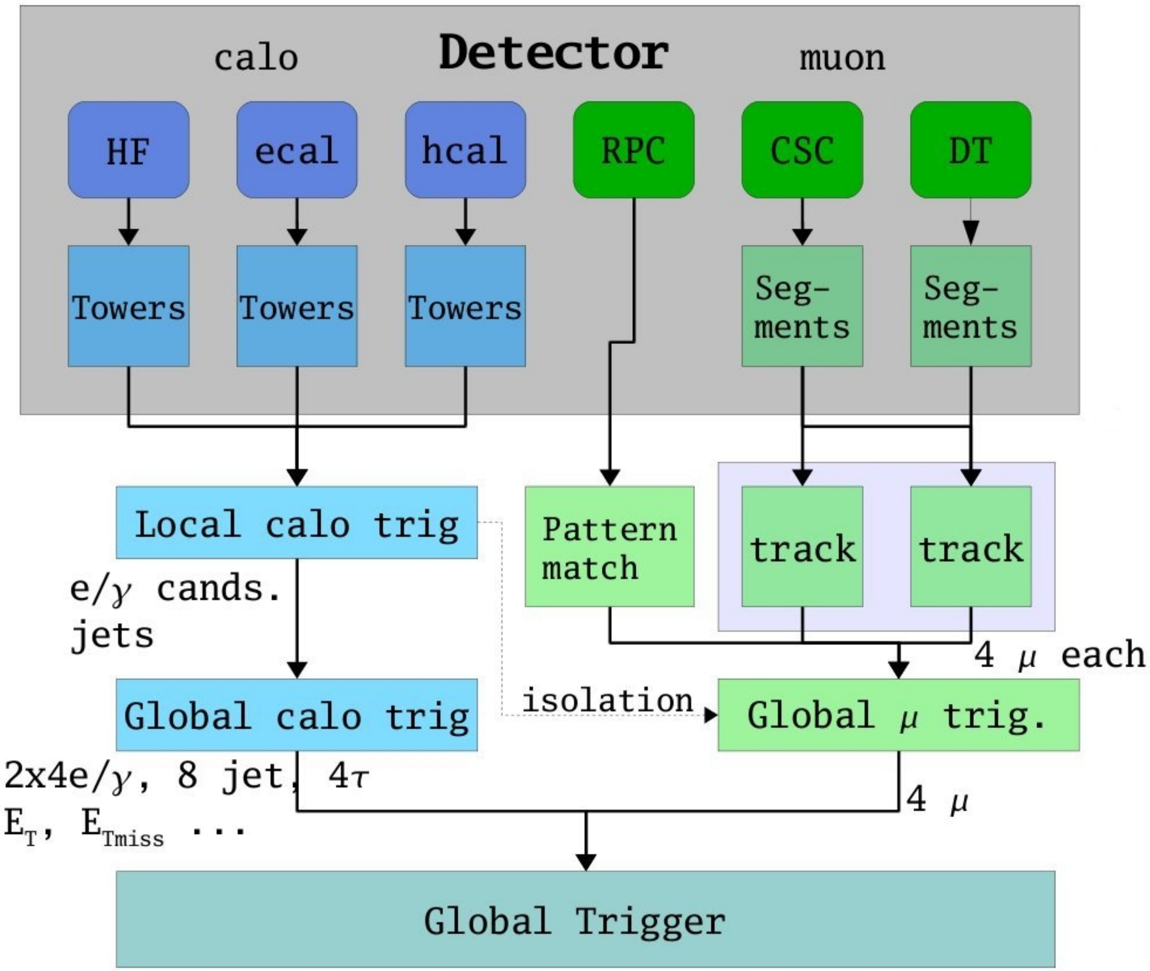
Trigger concepts

- level-1 primitives: muons, electrons, calorimeter energies
- confirm, refine, combine and extend in HLT
- exactly defined trigger path: level-1 + HLT (exact path)
- avoid volunteers
  - facilitates analysis: efficiency for defined path only
  - eases trigger table design and adaptation to data taking conditions

Level-1 Data Flow

Calorimeters and muon detector based

- enough for electron, muon, jets and missing E_T



Tracker not included

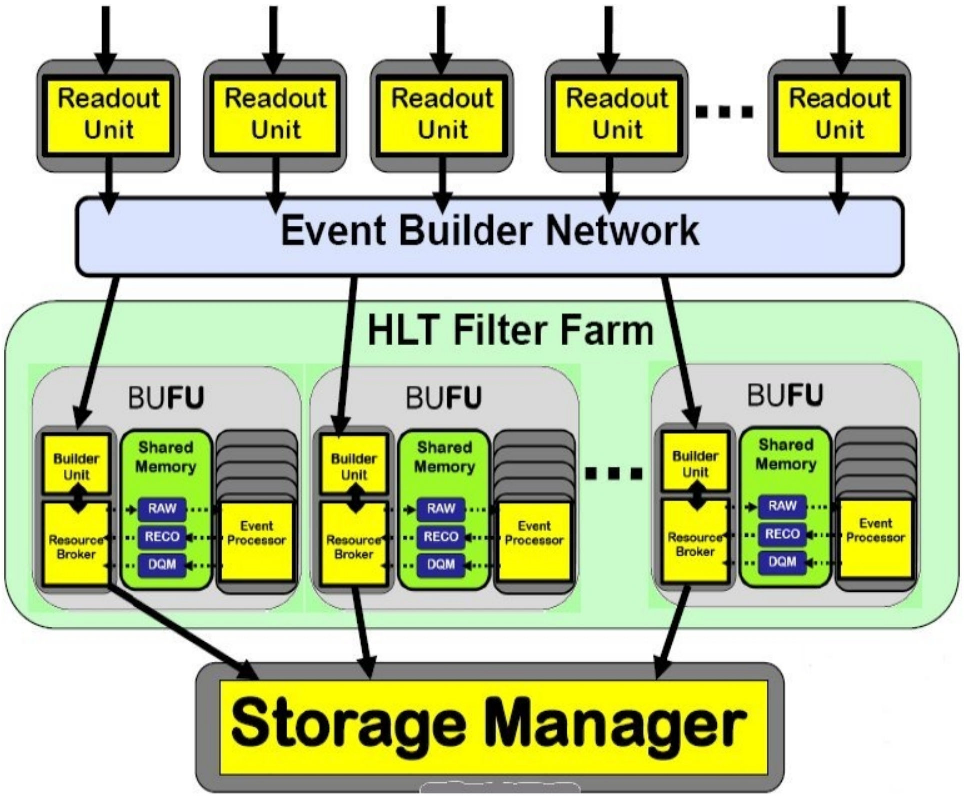
- no level-1 possibility of displaced track trigger
- limits purely hadronic c/b hadron decays
- and enrichment of hadronically decaying heavy flavor jets

Track trigger planned for upgrade

HLT Data Flow

HLT internal structure

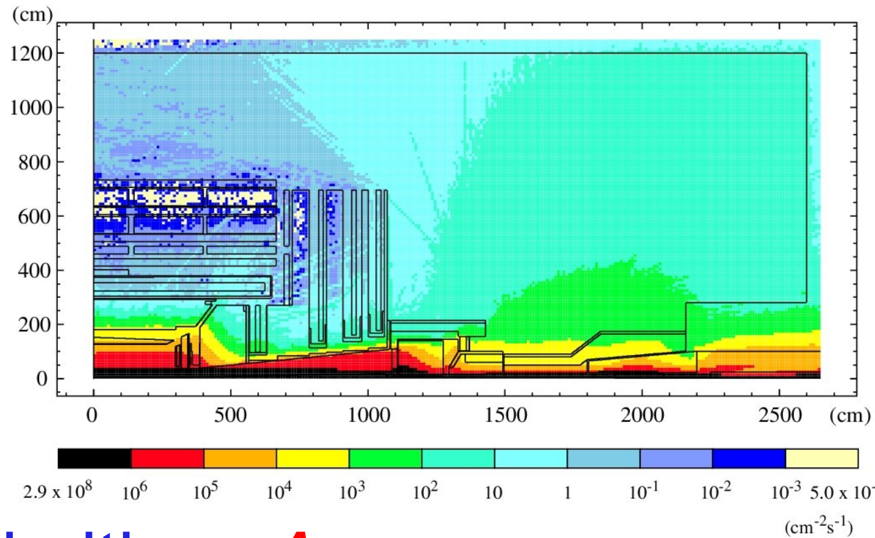
- level-2
  - unpack muon, ecal, hcal data
  - based on level1 seeds perform local reconstruction
  - apply level-2 algorithms and filter
- level-3
  - unpack tracker locally (*mostly* pixel)
  - perform local reconstruction based on level-2 results
  - apply level-3 algorithms and filter
- send accepted events to storage



Event Builder/HLT Primitives

- RU – Readout Unit
- BU – Builder Unit
- FU – Filter Unit
- SM – Storage Manager

Trigger – Practical Considerations 1



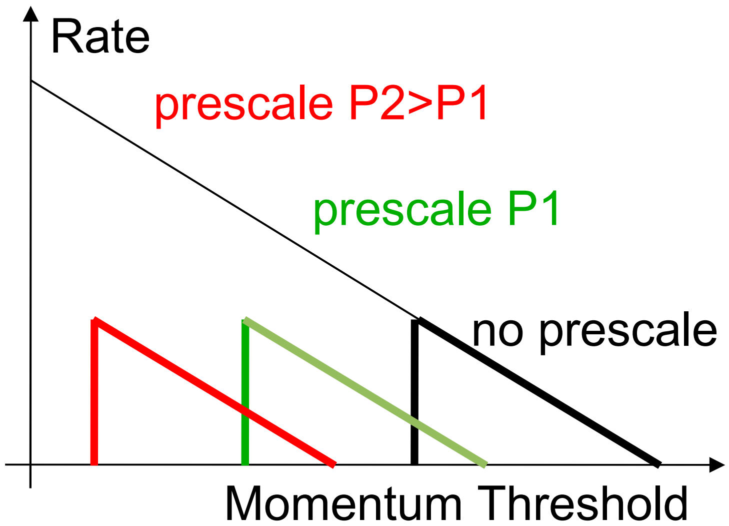
Triggering 101

- clean, simple and robust pattern
- muons are best: *A+*
  - rely on muon detectors
  - there are just very few of them
  - and there is little background
- electrons/photons are not so bad either: *A-*
  - rely on ECAL: fast and precise energy
  - EM shower contained, no HCAL deposition
  - though there are many calorimeter towers
- general large energy triggers: *B*
  - there are tons of events, but adjusting threshold should work
- missing energy: *C*
  - ideally there are few, but ....
  - measuring to little or too much can get you in trouble quickly
  - needs lots of work until properly working

Trigger – Practical Considerations 2

Trigger table design

- inclusive triggers
  - for a wide variety of applications
  - typically single trigger primitive: isolated muon, loose electron, ...
  - usually have high rate, control rates:
    - request minimum momentum (threshold)
    - pre-scale trigger (loosing good events)
    - use two objects of same type, *ex.* two isolated muons (less general of course)
  - efficiencies: backup triggers, auto accept events



- exclusive triggers
  - more specific for a particular type of physics
  - typically more complex combinations of primitives: non isolated muon and 4 jets
  - usually have low rate

Understanding the Detector

Commissioning detector

- cosmic data taking with magnet on (3.8 T)
- running with special trigger and readout conditions
- but no beam or collisions
- excellent results → expect well functioning CMS detector

Adding beams and collisions

- high detector read out rate
- dense particle presence from collisions
- beam related particle spray
- various new challenges
  - occupancy as expected?
  - do reconstruction algorithms work as advertised?
  - is trigger rate manageable? is data size manageable?
  - find calibration samples before relying too much on Monte Carlo!

Understanding the Detector

Carefully design program to understand detector

- trigger has to work – otherwise no events to study
- any triggered data useful: even at 450 GeV beam energy
  - low energies take out pressure to discover new physics
  - focus on detector: *where did that large MET come from?*
- use of standard candles essential: large samples
  - pi0, conversions, *J/psi*, *Upsilon*, *W*, *Z* ....
  - sideband subtraction allows very clean studies:
    muons, electrons and photons – our analysis primitives
- measure standard candles and publish: ultimate detector understanding is achieved through publication
- what makes CMS different from Tevatron detectors?
  - tracker – 10 x more material, innermost pixel, less hits per track
  - ECAL crystal calorimeter – excellent resolution
  - HCAL depth – should be fine
  - muon system – well protected by calorimeters, excellent resolution

Early Physics

Something to keep in mind

- new physics channel already open at Tevatron will need to wait: Tevatron has no signal but has sufficient data
- physics channels just opening beyond the Tevatron are a possibility, little data == first LHC year could be enough
- be ready for the obvious candidates, but do not be disappointed when we do not see anything right away

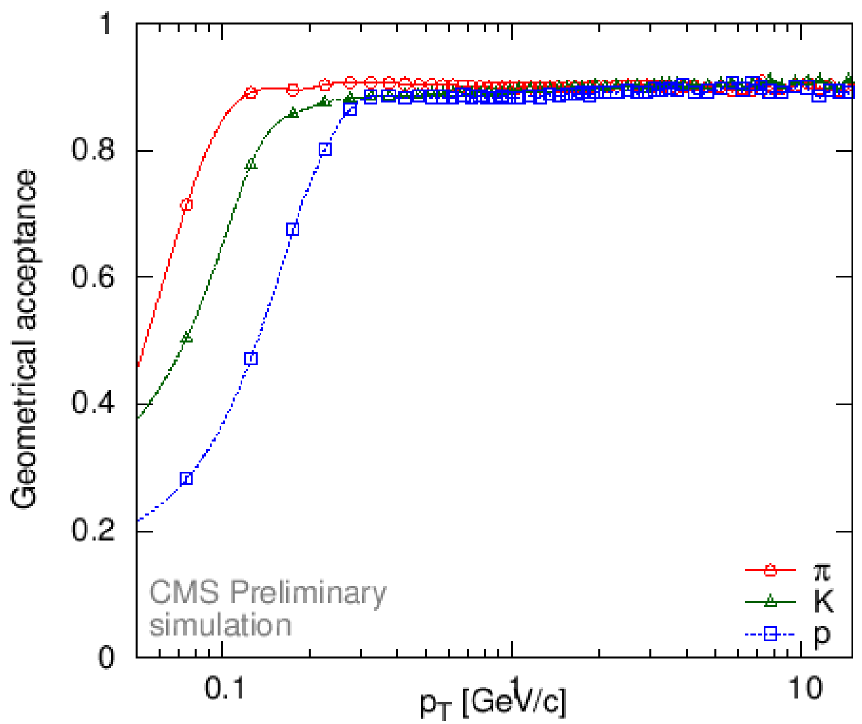
My personal bet of what will happen

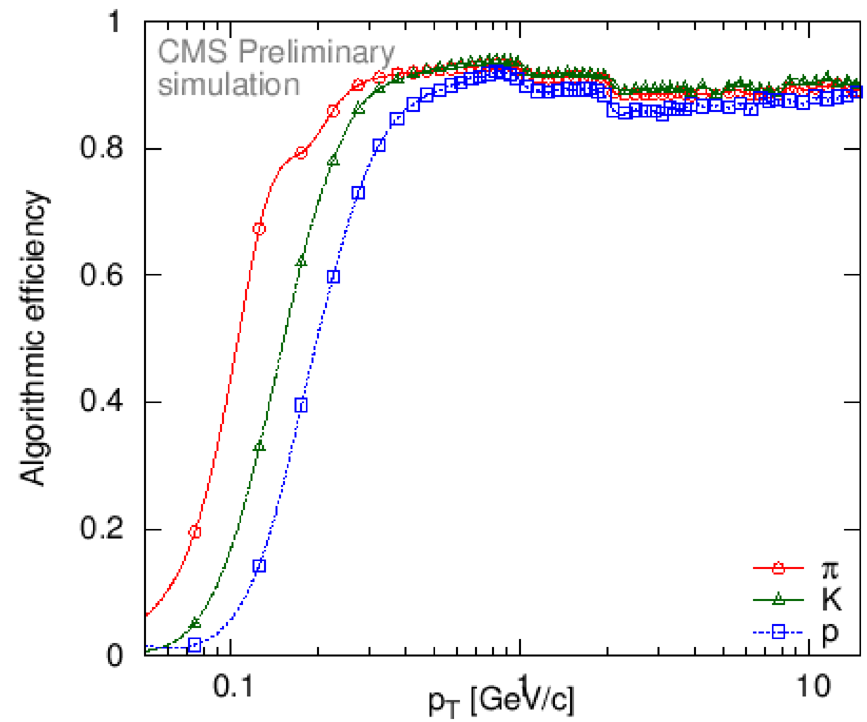
- first year dedicated to understanding detector/trigger
- .. and publishing bread and butter measurements

Early Physics

MinBias events come first and in large quantities

- measure charge multiplicity and track p_T spectrum
- one of the first measurements, probably
- provides normalization for Heavy Ion collisions
- low momentum tracking needed: tracks curve a lot at ~ 4T





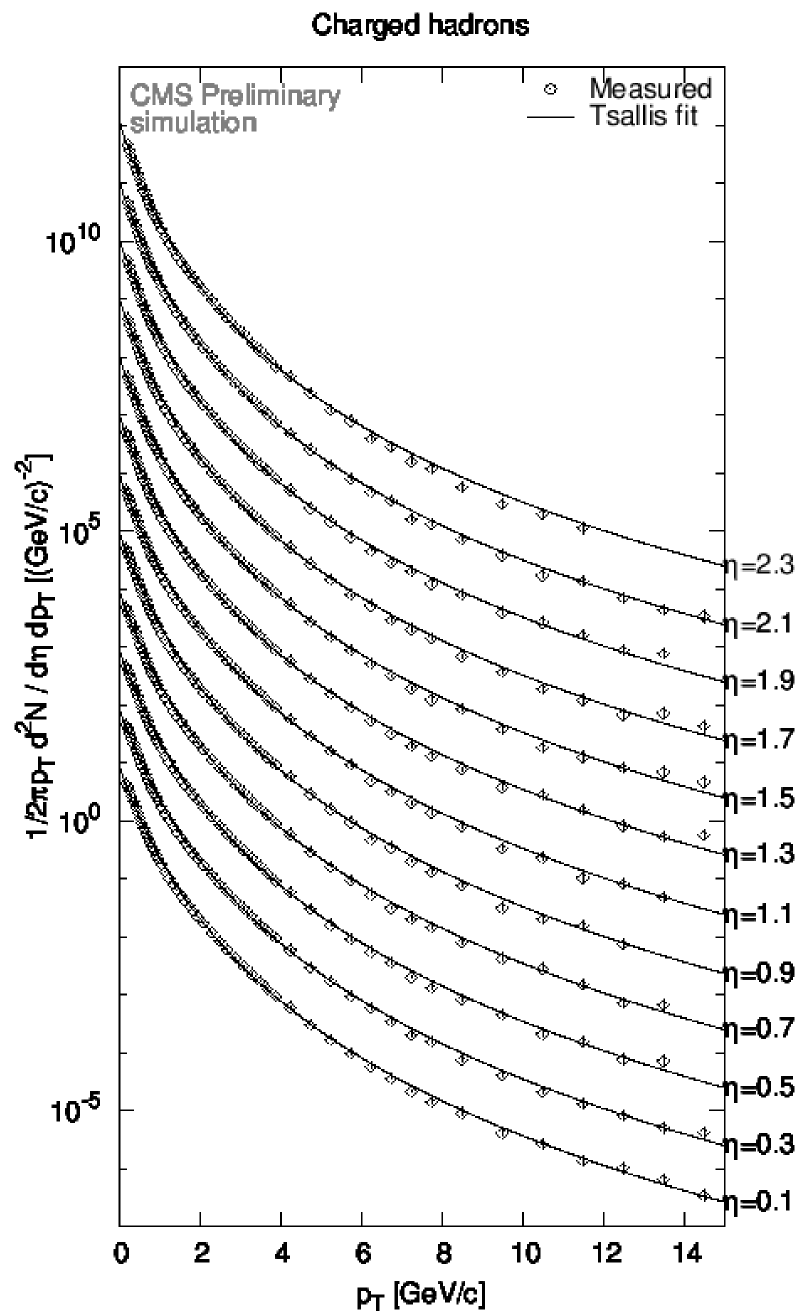
Early Physics

MinBias events *continued*

- p_T spectrum covers a good range for |eta| up to 2.3
- measurement quickly systematics limited
- low momentum better covered than initially anticipated

For the high p_T aficionados

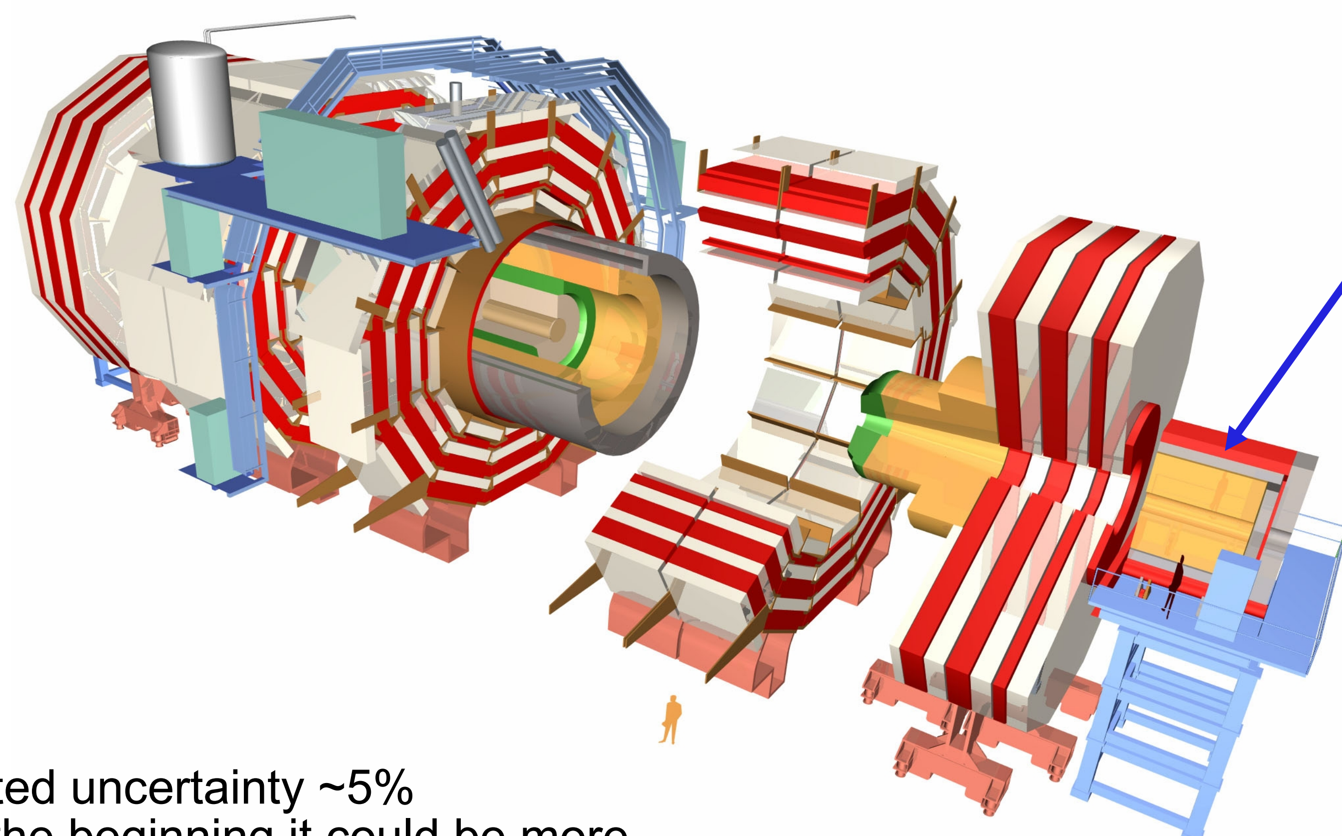
- MinimumBias events make up the pileup
- precise understanding will help all of us



Early Physics

Luminosity measurement

- relative luminosity measured in HF (3.0<|eta|<5.0)
- overall normalization through various possibilities
  - using LHC measurements or Totem
  - two-photon to di-muons, W/Z production *etc.*

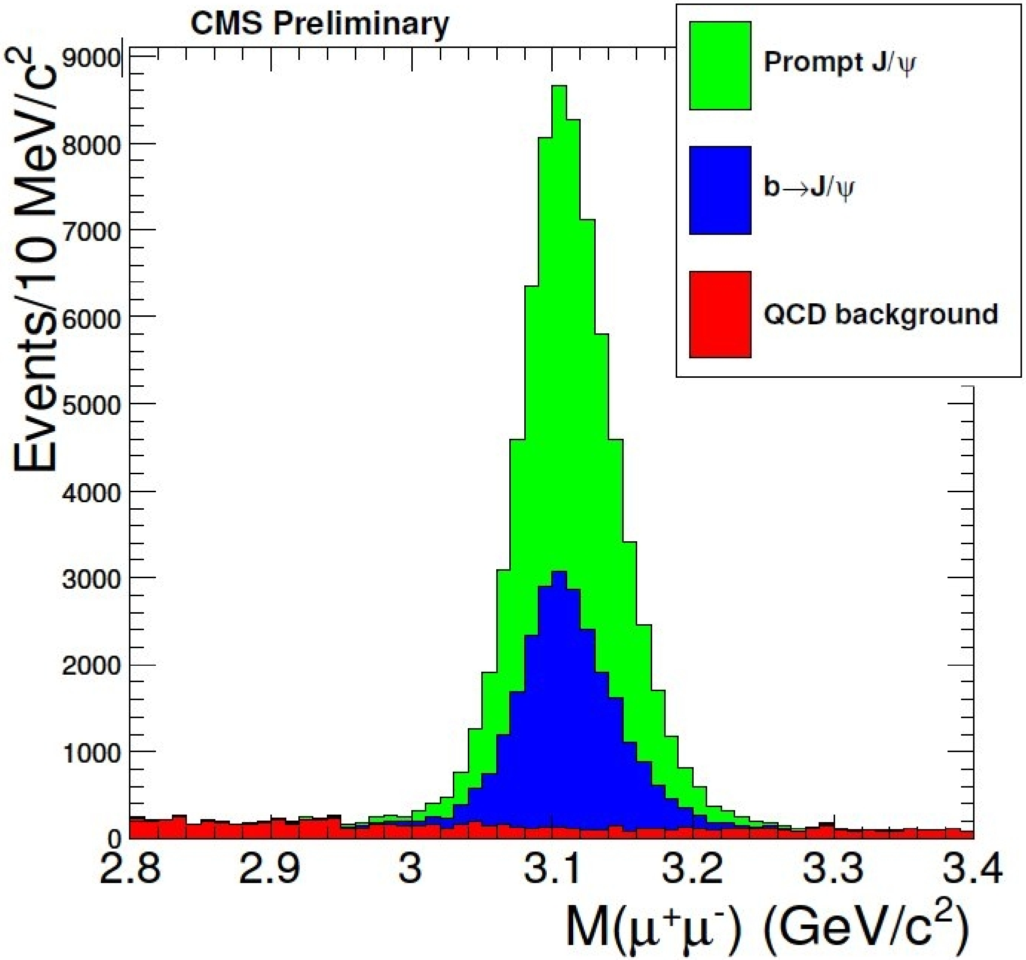


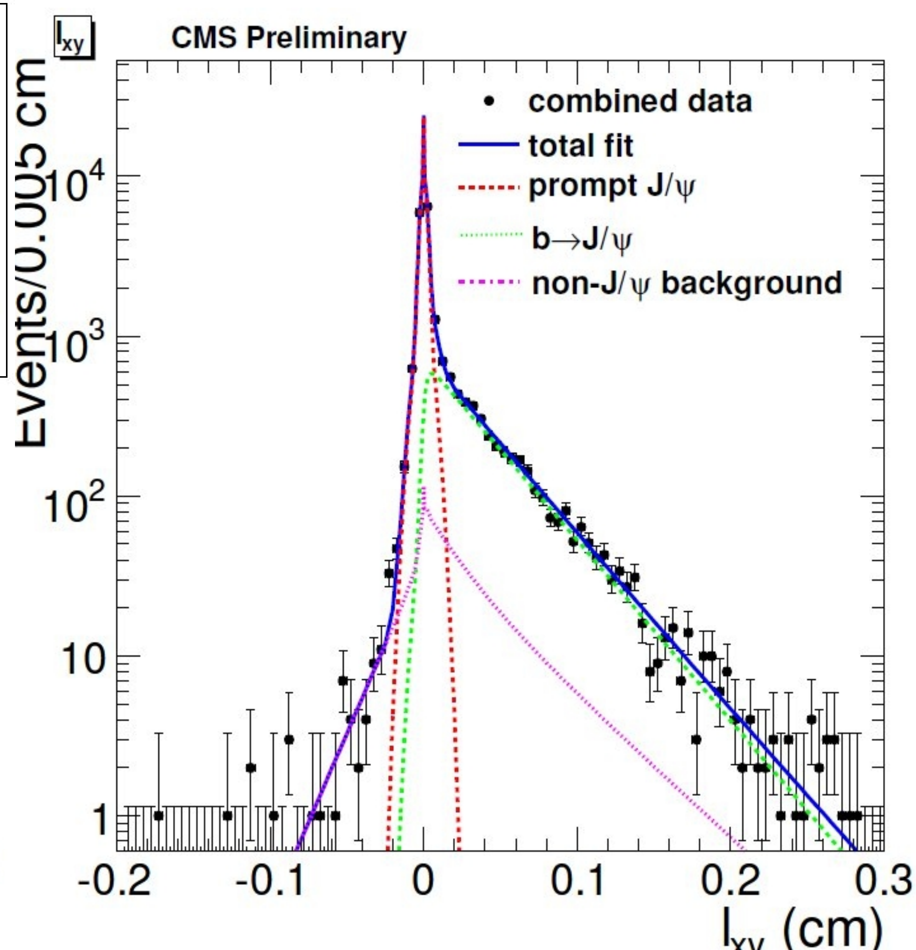
Expected uncertainty ~5%
but in the beginning it could be more

Early Physics – B Physics

Heavy flavor physics: J/psi as tool

- prompt production: charmonium cross section
  - Upsilon production similarly interesting
- analysis at 14 TeV predicts 70k events for only 3 pb^{-1}



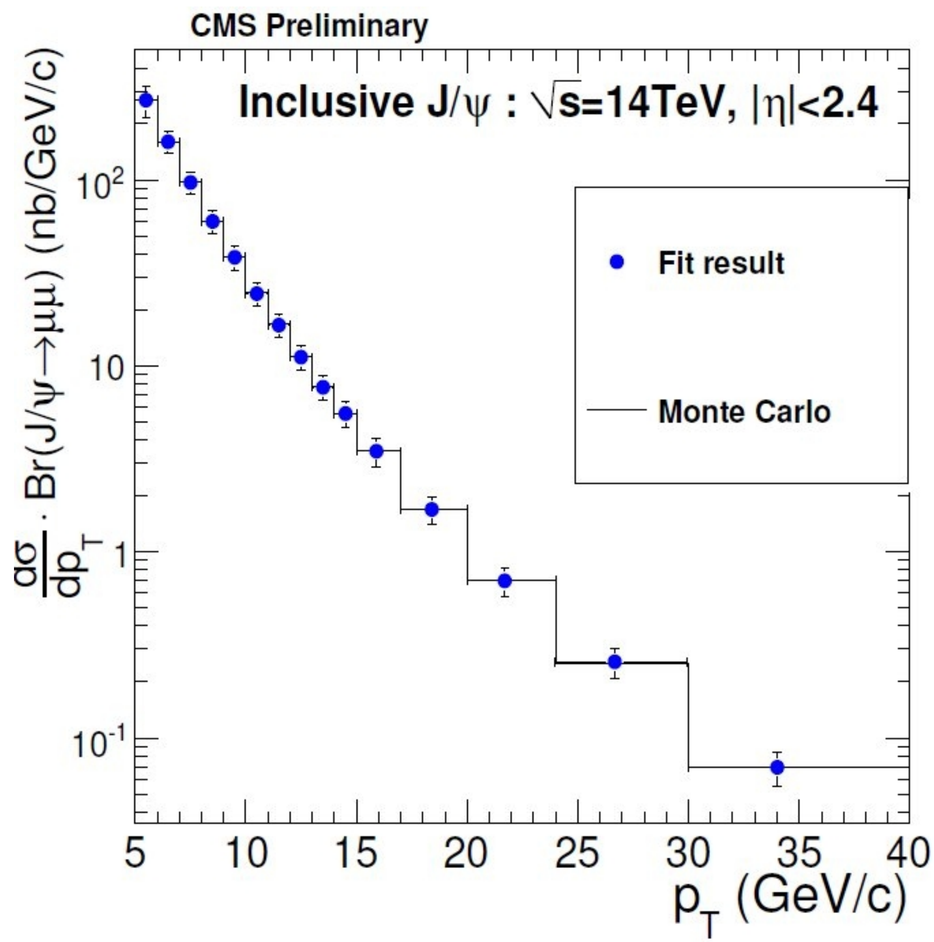


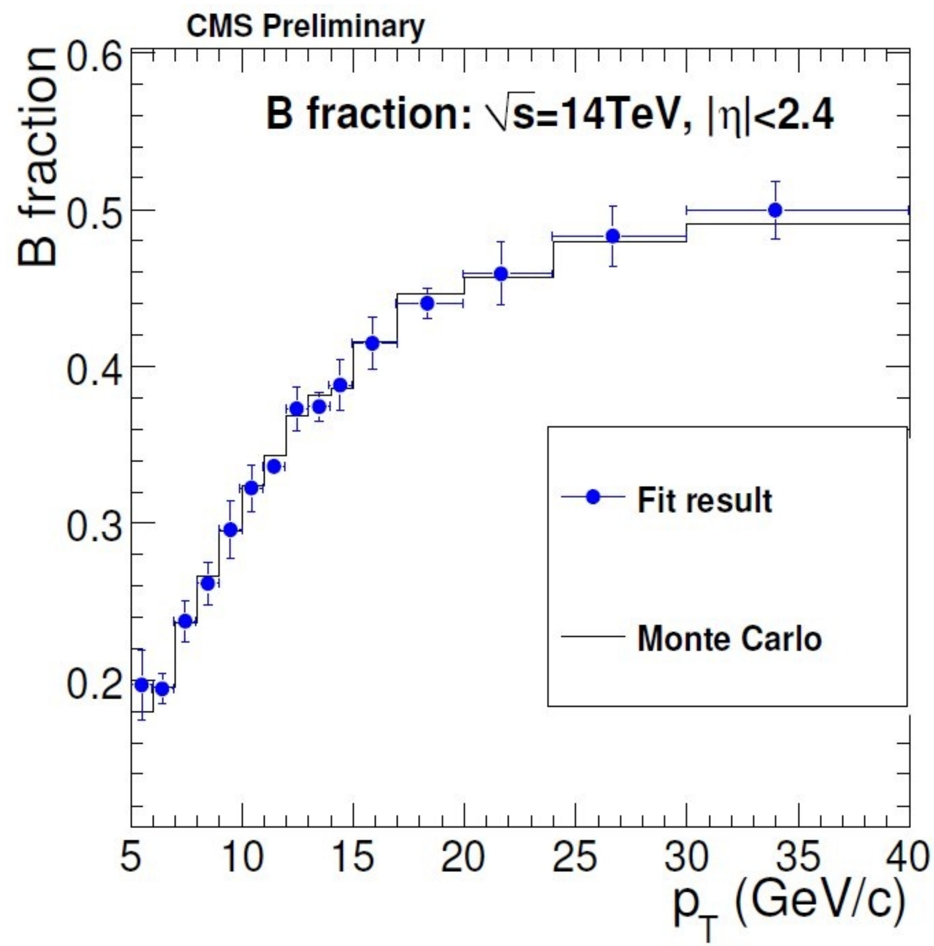
see talk by Zoltan Gecse, yesterday

Early Physics – B Physics

Heavy flavor physics: J/psi as tool

- background for prompt production is another signal
- secondary production
  - measure inclusive *b* production cross section
  - measure $b\bar{b}$ correlations





Early Physics - Electroweak

How many single boson events per 200 pb^{-1}?

- ℓ = electron, muon
- $W \rightarrow \ell\nu$: 4M events
- $Z \rightarrow \ell\ell$: 0.4M events
- precise cross section possible and study of *W/Z* + jets
- of course luminosity needs to be provided

Diboson processes will be marginal with 200 pb^{-1}

- *WW* enough to observe it
- *WZ* might be just visible
- *ZZ* needs more luminosity

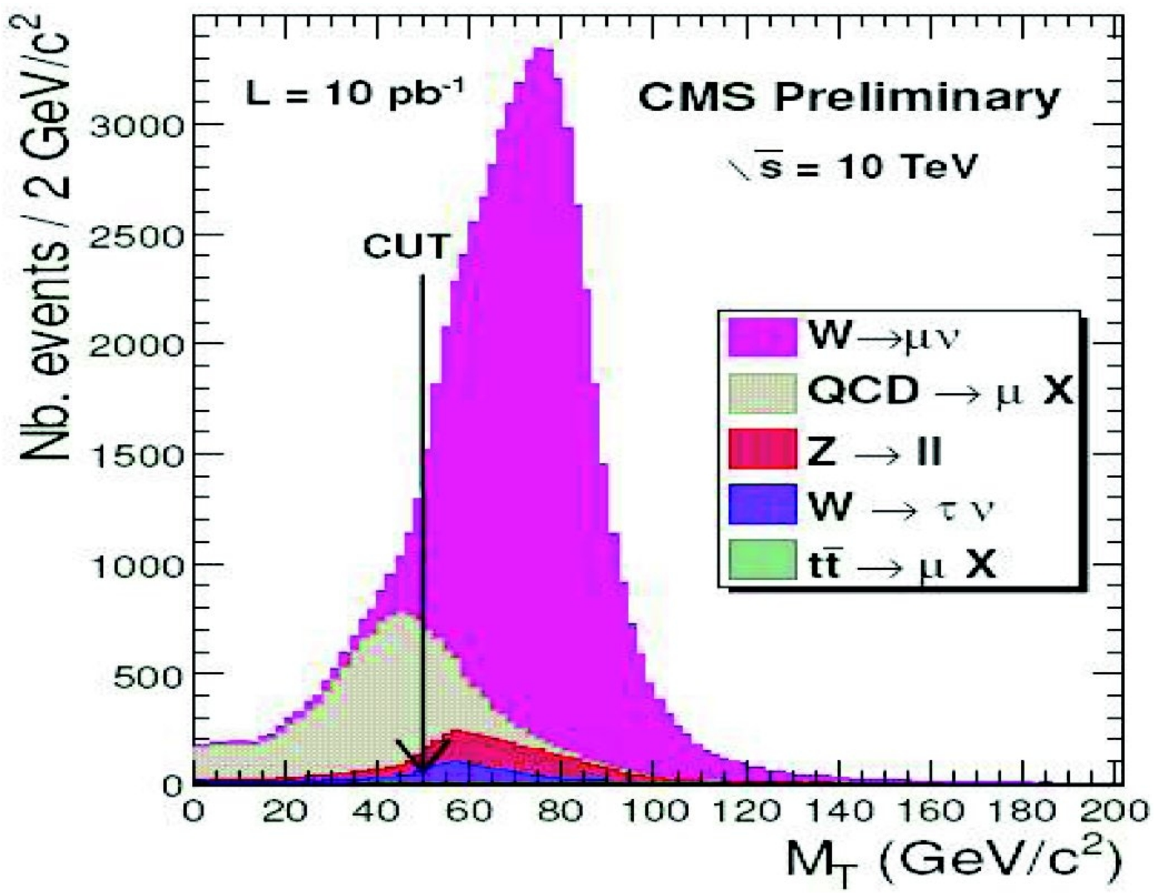
Early Physics - Electroweak

$Z \to \ell\ell$ analysis

- relies purely on leptons → straight forward
- study ground for $W \to \ell\nu$

$W \to \ell\nu$ analysis

- complication: missing energy from neutrino
- large sample allow detailed studies to commission missing E_T and lepton Id
- understand fake leptons



see also talk by Phil Harris, later today

Early Physics - Top

Top quark

- a new and rare particle at the Tevatron
- … a clean standard candle at the LHC

Ken Bloom (Nebraska) calls it a 'candelabra', but that is just another story.

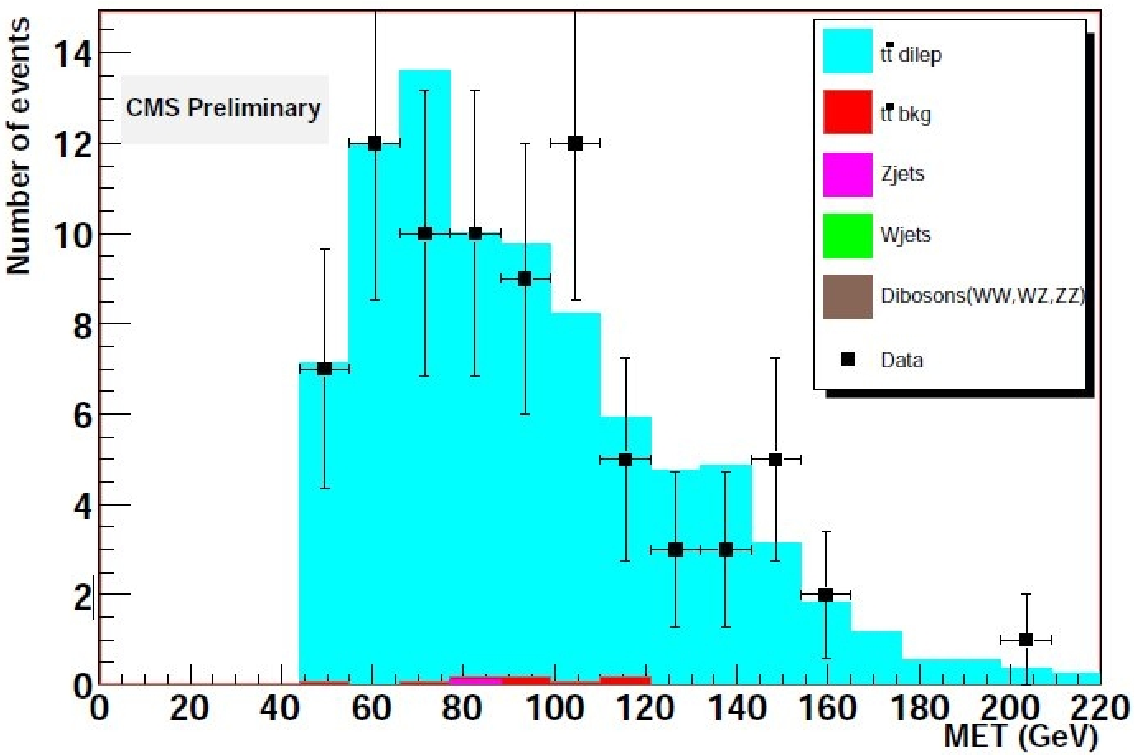
What has changed?

- production 90% through gluon-gluon
- larger boost

Includes basic objects

- leptons
- *b* quarks
- missing energy
- jets

see talk by Julien Caudron, later today



100 pb^{-1} at 14 TeV in electron-muon channel

Early Physics - Higgs

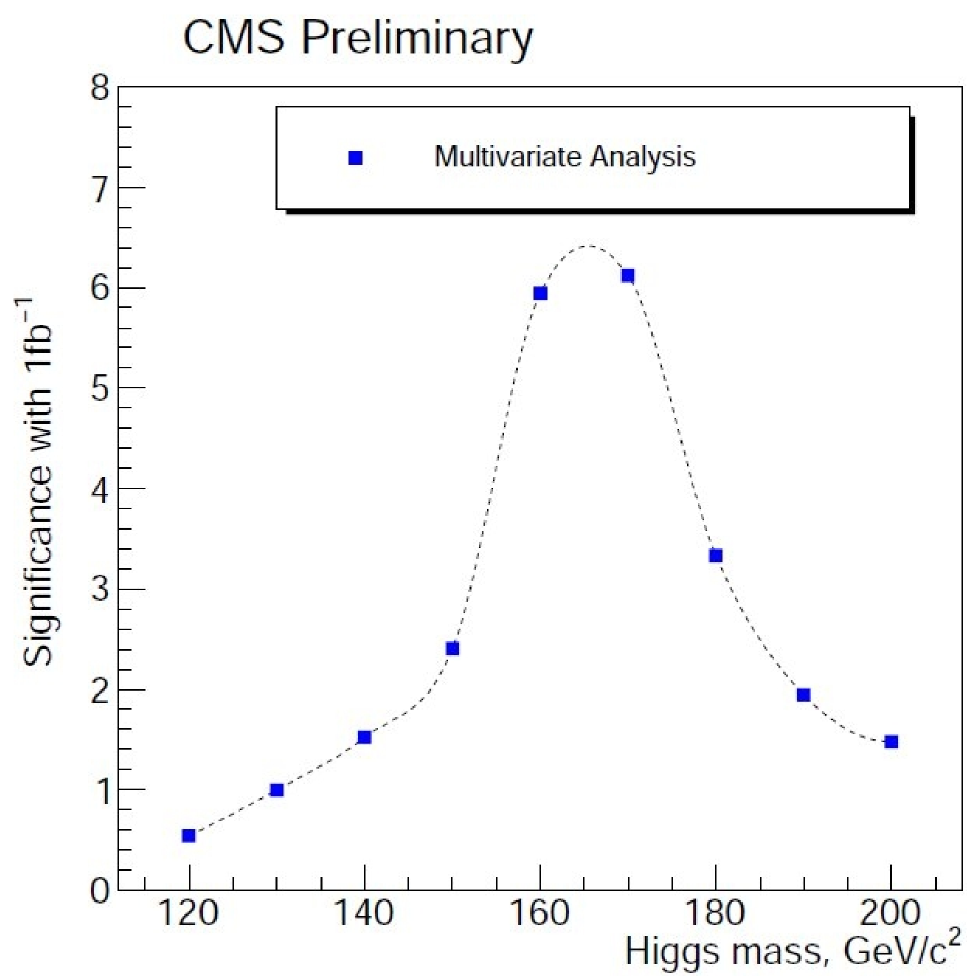
Clearly, not enough events to see a SM Higgs signal

General comments

- *H*→*WW* at *WW* threshold equivalent with Tevatron reach
- analysis complex and unlikely matured in such short time
- picture: 14 TeV, 1 fb^{-1}
- please scale accordingly....

First 95% CL exclusion?

- maybe we get lucky



see also talk by Joanna Weng, later today

Early Physics - BSM

Most promising new physics

- search will follow our understanding of the various quantities: starting from leptons and photons
- SUSY
  - has of course exciting and very large signal channels visible even with 200 pb^{-1}
  - CMS will cover the phase space (leptons/photons first)
- next generation bosons
  - once *Z* and *W* analyses are done, just open the mass window: check for *Z'*, *W'*
  - some work needed because background changes for very high momentum leptons, as well as the lepton Id itself
- of course more signatures are interesting including missing energy, taus, jets .....

Conclusion

CMS Trigger strategies

- high priority: bad trigger leads to no or too few good data
- two stage system: Level-1 and High Level Trigger
- robust trigger primitives, very flexible to combine them
- inclusive triggers combined with specific exclusive ones
- pre-scaling possible to adjust rates to luminosity

Early physics with CMS

- intense phase of detector and trigger commissioning results in a large number of *bread and butter* publications
  - track multiplicity, jet cross section, *W/Z* production, top...
- of course all possible new physics channels are being carefully monitored.... we all hope for an exciting start
- keep a watch also for the unexpected!