Top Mass at CDF and Preparation for ATLAS

Jean-François Arguin
Lawrence Berkeley Laboratory

Institute of Particle Physics
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Outline:

Standard Model
- achievements and limitations

Hadron colliders
- Discovery and precision machines

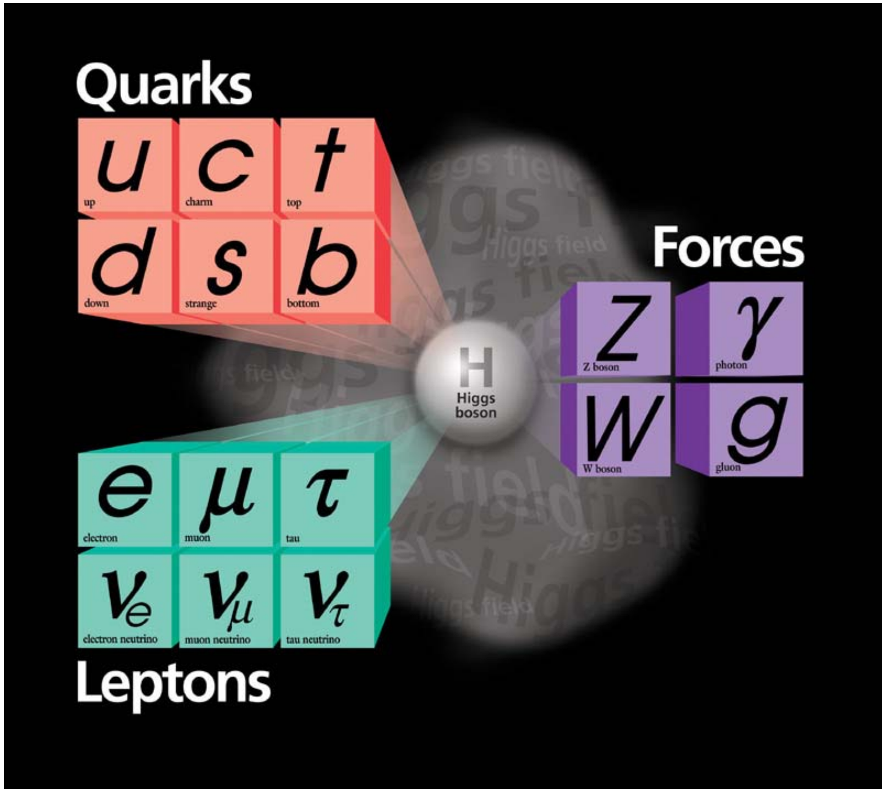
Experiments of the present and future
- Tevatron and LHC
- CDF and ATLAS

The Top quark
- Measurement of M_{top} at CDF

Preparation for first data at ATLAS
- Search for Supersymmetry at ATLAS
- Preparing the pixel detector and computing model

The Standard Model

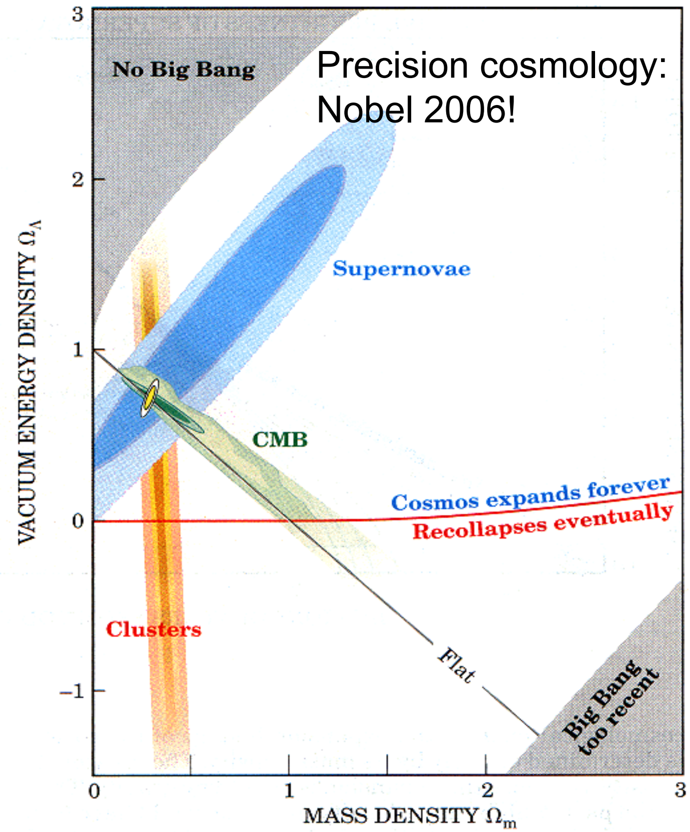
- The Standard Model (SM) provides a fundamental description of nature
- Essential ingredients:
  - Matter particles: fermions
  - Forces mediated by bosons
  - One boson providing mass
- The Higgs boson is the last SM particle yet to be discovered

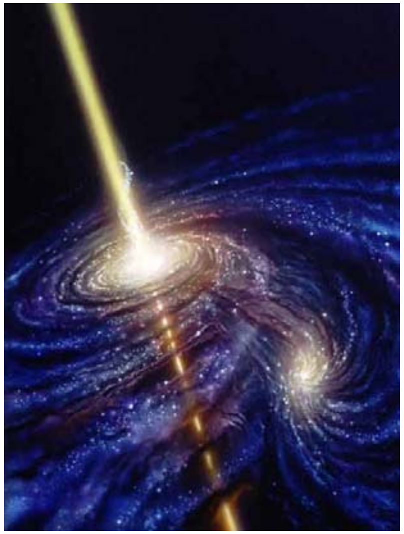


Superb agreement data-theory for the last 20 years!!

Standard Model: an effective theory

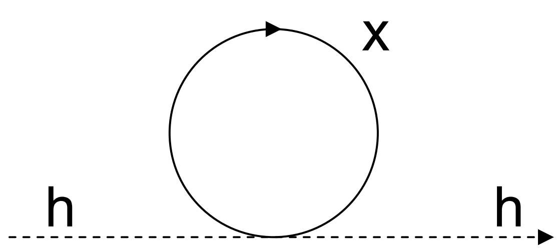
- SM is incomplete:
  - Dark matter and energy → SM=5% of Universe!!
  - Many unexplained features:
    - 3 generations of fermions
    - Many free parameters
    - Spectrum of particle masses
    - Why fermion=matter and boson=force?
  - Provides only a description of the infinitesimally small
    - Ex: no good theory for black holes





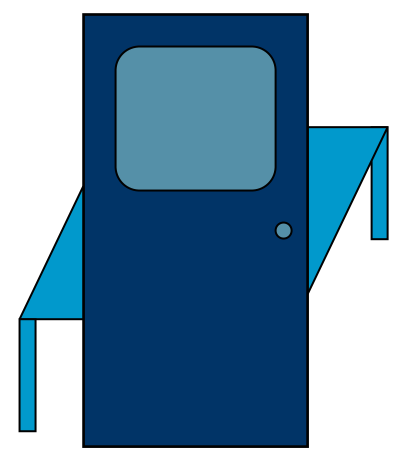
Problem… the Higgs is unstable

- A complete theory is expected at a higher energy
  - 10^{16} GeV? 10^{19} GeV?
- The Higgs boson is sensitive to higher scale physics
  - Through higher order perturbative corrections



- Problems: Data indicates M_H~O(1TeV)

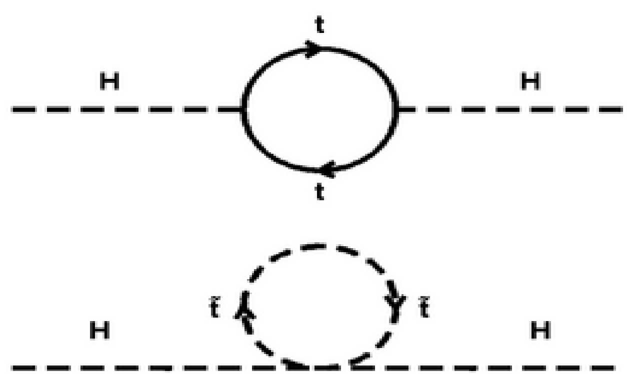
→ Fine-tuning of the Higgs



→ Focus of theorists for the last two decades

Example of Solution: Supersymmetry

- Symmetry relating bosons and fermions
  - Each fermion has a partner boson (and vice-versa)
- SUSY provides a beautiful solution to fine-tuning:



- SUSY has other benefits!
  - Symmetry between bosons and fermions
  - Dark matter candidate
  - Coupling constant unification
  - Predicted by string theory

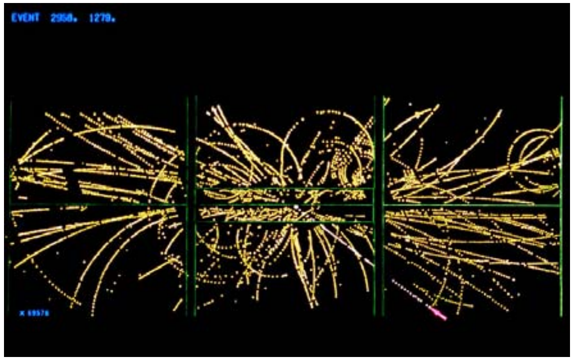
→ SUSY is often regarded as the most attractive extension of SM

- Discovery of superpartners would be a major achievement

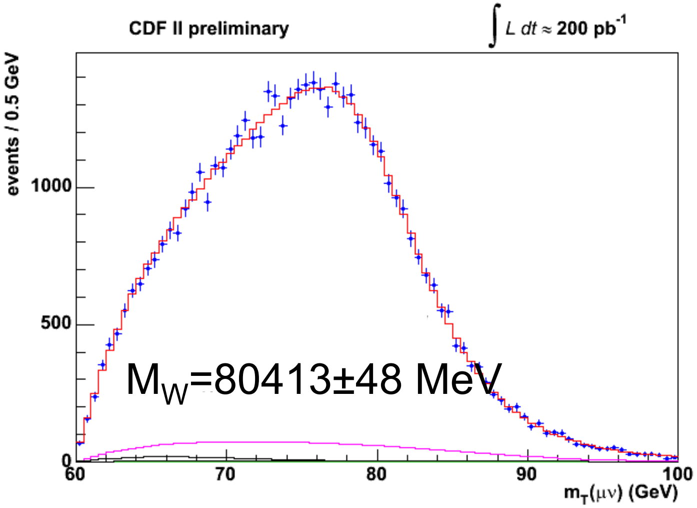
Hadron Colliders

- Hadron collider (pp, ppbar) experiments have greatly contributed to establishing the SM:
  - W/Z boson discovery
  - Top quark discovery
- Hadron colliders not only discovery machine…
- … but also precision ones (large statistics)

Hadron colliders not only discovered the W boson…

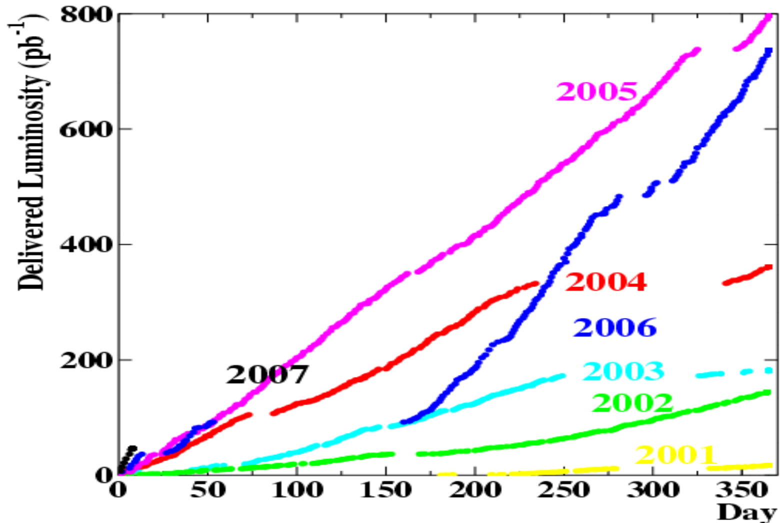


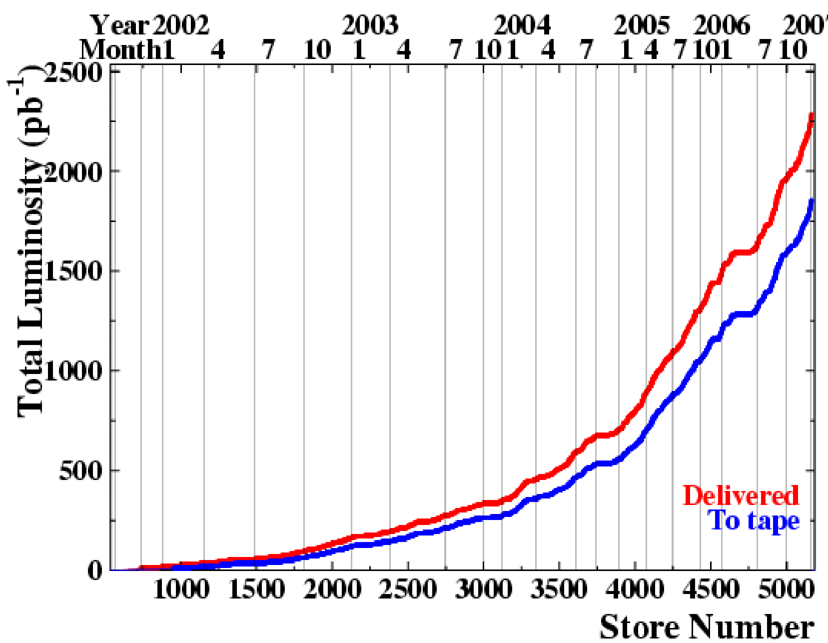
but have the best meas. of M_W (CDF 2007)!



The Present: Tevatron

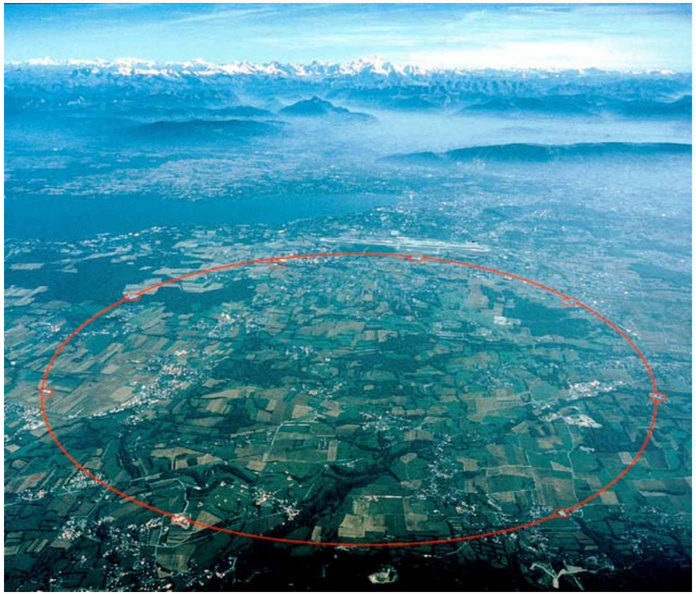
- ppbar collisions at 1.96 TeV
- Initial lumi. typically excess $2\text{x}10^{32}\text{cm}^{-2}\text{s}^{-1}$
- Run I (1992-1995)
- Run II (2001-)



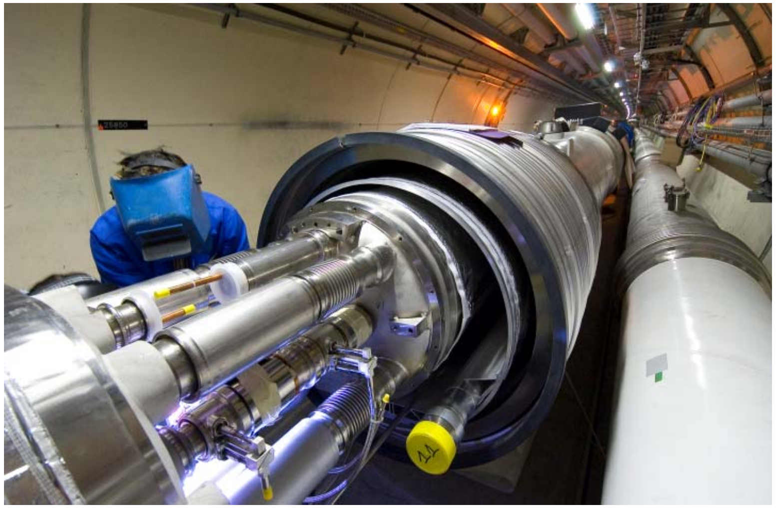


The Future: Large Hadron Collider

Beam Parameters	Tevatron	LHC
Colliding particles	ppbar	pp
Beam energy (TeV)	0.98	7
Design Luminosity ($cm^{-2}s^{-1}$)	$2x10^{32}$	$1x10^{34}$
Bunch separation (ns)	396	25
Average #interactions per crossing	6	20



- **LHC is nearing completion:**
  - Last dipole magnet: Mar. 07
  - First 900 GeV Run: Nov. 07
  - First 14 TeV Run: Spring 08



Designing hadron collider experiments

- Very large total x-section of 10^8 nb…
- …But signal x-section much smaller (e.g.ttbar ~1 nb)

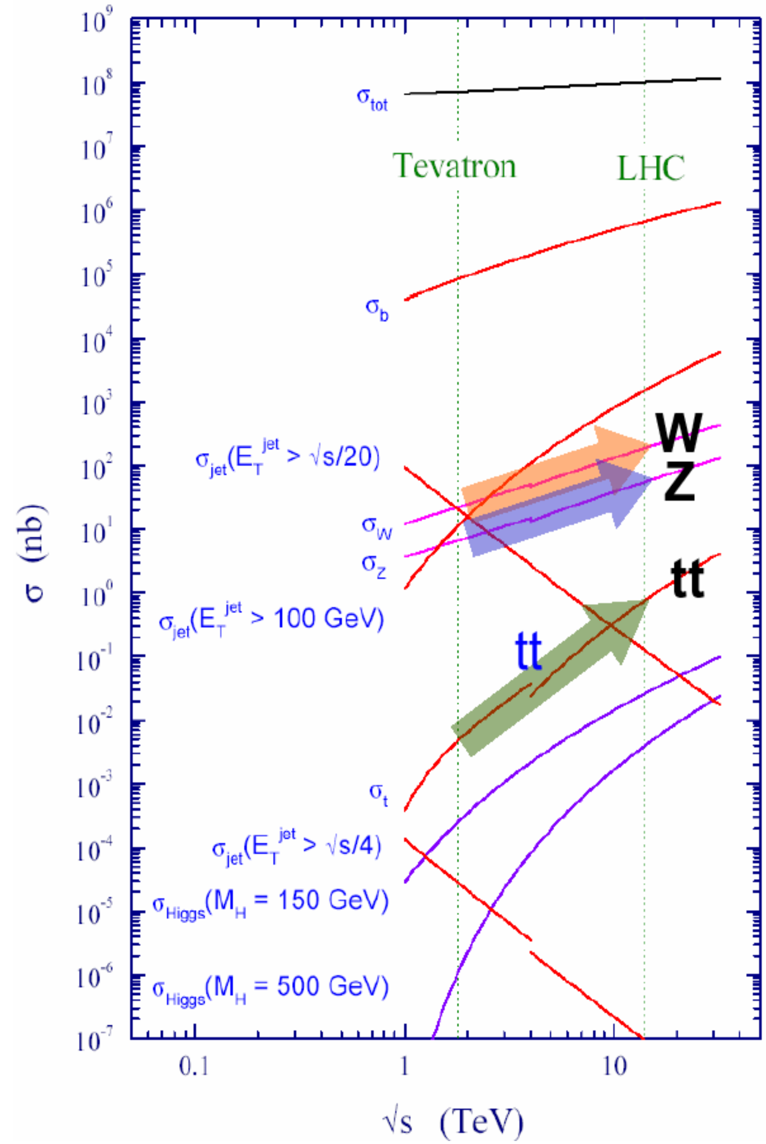
→ *fast pipelined triggers*

- Crowded events (underlying event, pile-up)

→ *high granularity detectors*

→ *Rad-hard detectors*

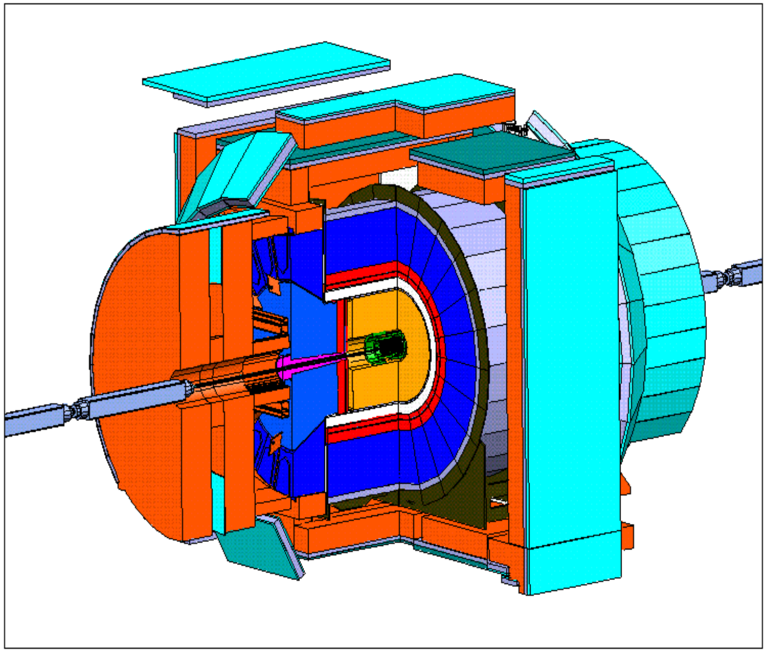
- *Note increased x-section of massive particles at LHC → discovery machine!*



The CDF Detector

CDF II: general purpose solenoidal detector

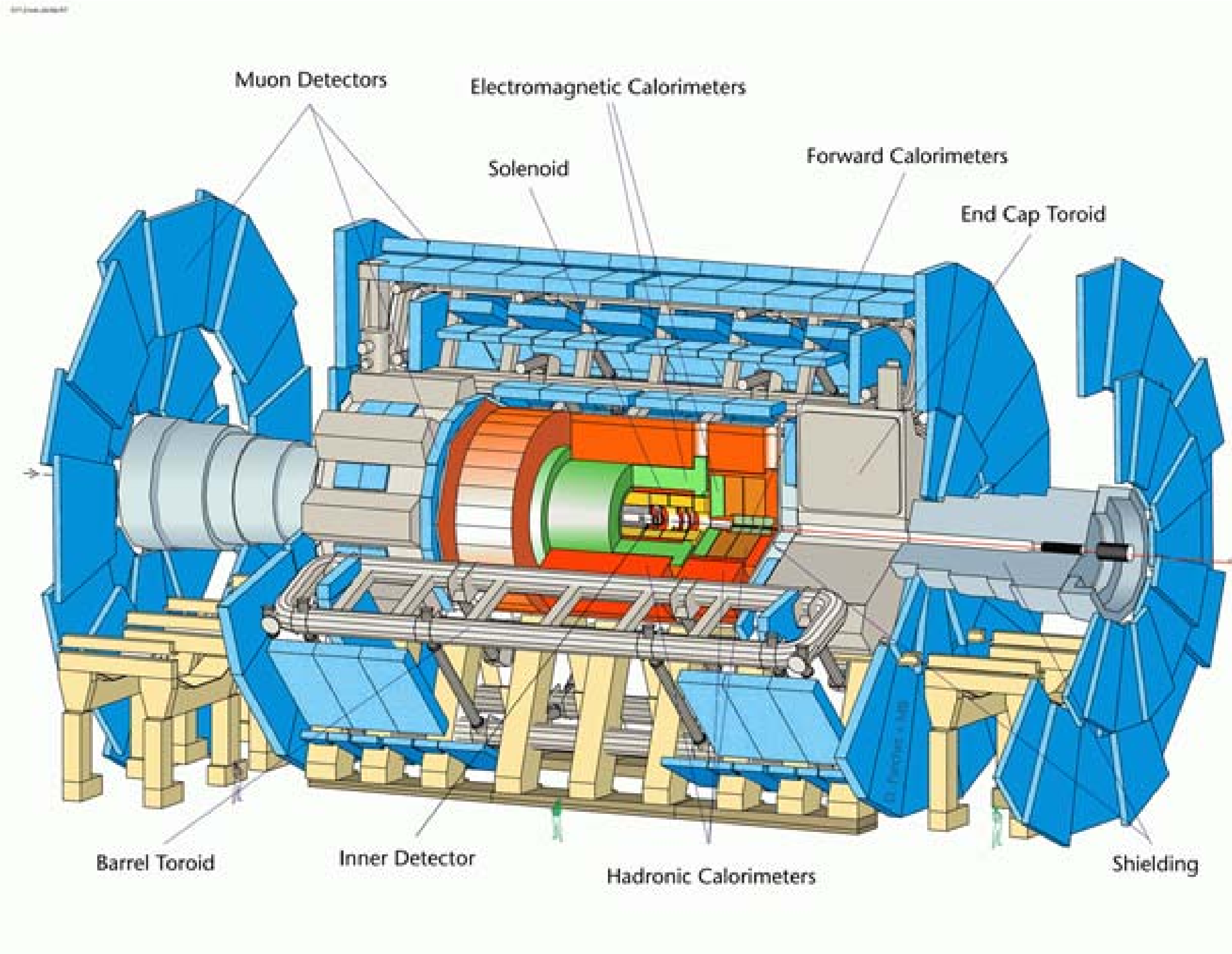
- 7 layers of silicon tracking
  - B-tagging eff. ~40%
- COT: drift chamber
  - coverage $|\eta|<1$
  - Resolution: $\sigma_{p_T}/p_T^2=0.1\%$
- Muon chambers
  - Scintillator, proportional chamber interspersed with absorber
  - Provide muon ID up-to $|\eta|\approx 1.5$
- Calorimeters
  - Coverage $|\eta|<3.6$
  - EM reso.: $\sigma_E/E\approx 14\%/\sqrt{E}$
  - HAD reso.: $\sigma_E/E\approx 80\%/\sqrt{E}$



The ATLAS Detector

One of the two general purpose detector around LHC

- Tracking ($|\eta|<2.5$, B=2T) :
  - Si pixels and strips
  - Transition Radiation Tracking
  - Inside solenoid field
- Calorimetry ($|\eta|<5$) :
  - EM : LAr with Accordion shape
  - HAD: tile scintillator (central), LAr (fwd)
- Muon Spectrometer ($|\eta|<2.7$) :
  - air-core toroids with muon chambers



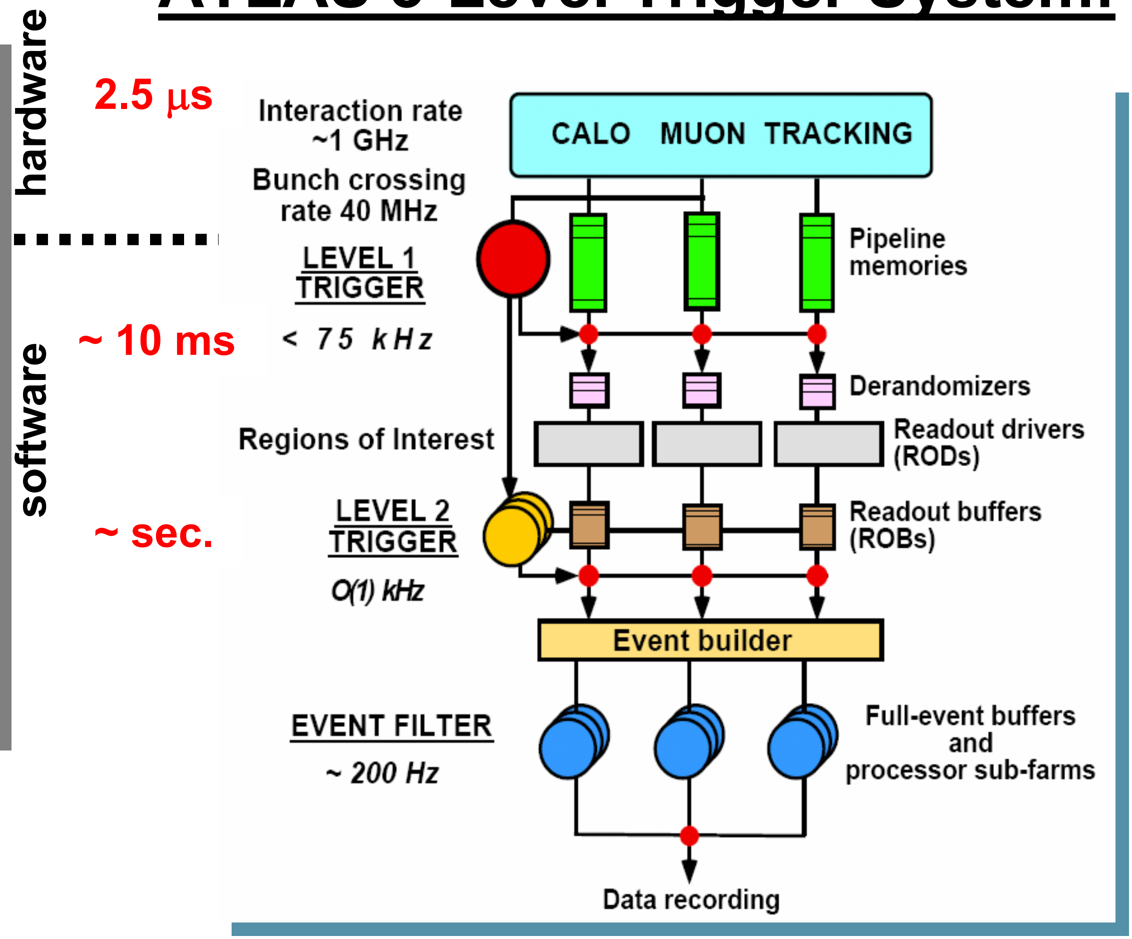
Example of Trigger System: ATLAS

1) **LVL1** decision based on data from calorimeters and muon trigger chambers;

2) **LVL2** uses Regions of Interest (identified by LVL1) with full granularity from all detectors

3) **Event Filter** has access to full event and can perform more refined event reconstruction. Rate of 200 Hz independent of lumi.

ATLAS 3-Level Trigger System:



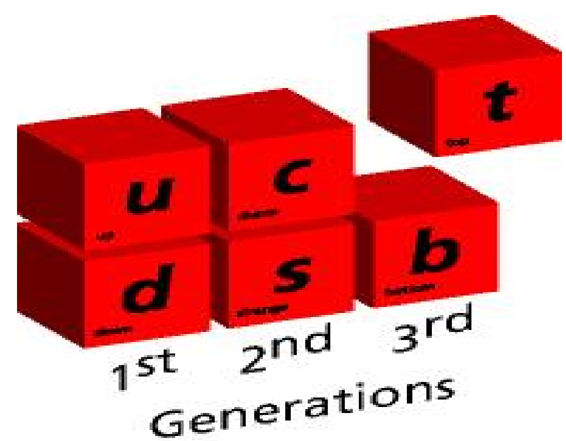
Flagship hadron collider measurement: M_{top}

- The most striking characteristic of the top quark → huge mass!

$$M_{top} \approx 170 GeV / c^2$$

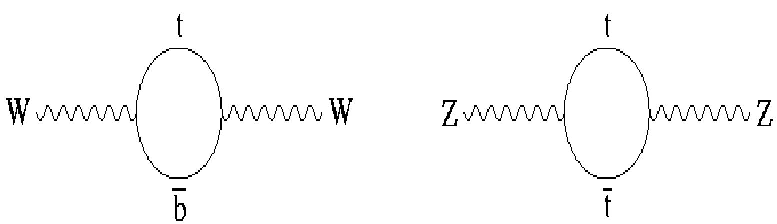
  - 40 times the mass of closest fermion (b quark)
  - Comparable to a gold nucleus…
- Maybe the top is special?
  - Coupling to Higgs λ~1…
  - … is that a hint?

  → Precise M_{top} can constrain new physics



M_{top} to Constrain the Higgs

- Loop involving top quarks: dominant corrections to predictions of many SM observables

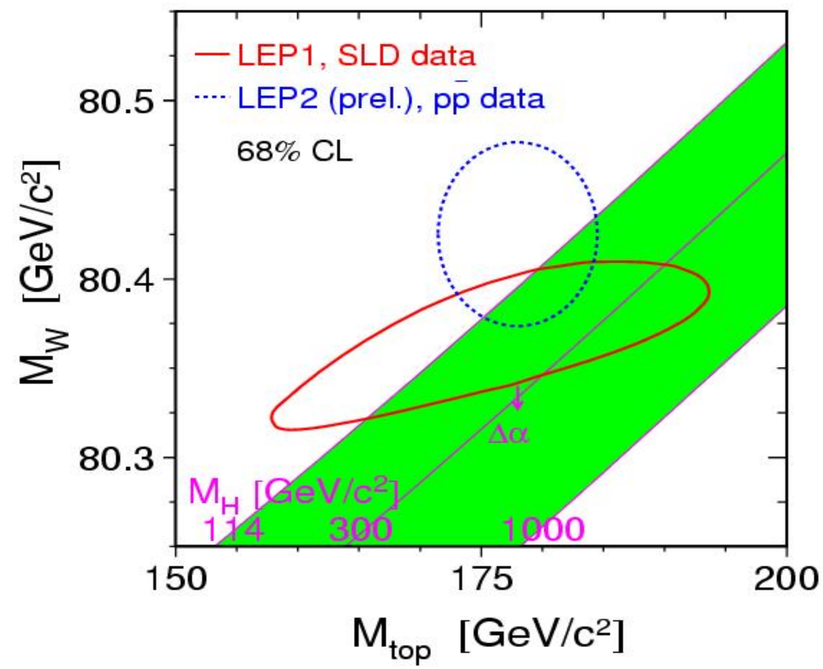


- Correction factor from top loops:

$$\Delta\rho = \frac{G_F N_c M_t^2}{8\sqrt{2}\pi^2}$$

- Constraints from Tevatron Run I (2000):

$$M_{top} = 178.0 \pm 4.3 GeV/c^2$$



$$M_{Higgs} = 126^{+73}_{-48} GeV/c^2$$

Topology of Top Events

- **Pair production dominates (6 pb at Tevatron)**
- **Half-life of top: $\sim 10^{-25}s$** $\rightarrow$ Top decays before hadronizing!
- **Decay** in SM:

  $$Br(t \rightarrow Wb) \approx 100\%$$

- W decays define channel (dilepton, lepton+jets, all-hadronic)

Challenge I for M_{top}

Statistical limitations:

1) **Small statistics**: ~30 identified lepton+jets ev. / 100 pb^{-1}
2) **Complicated final state to reconstruct**

Especially jet combinatorics:

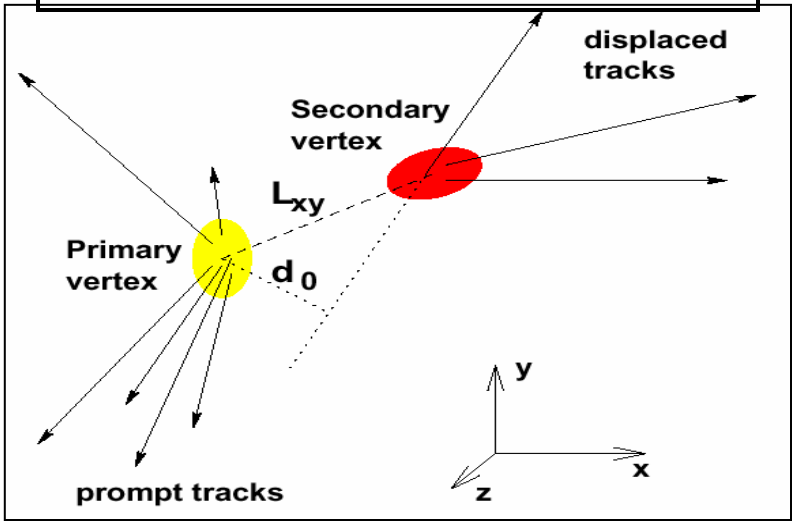
- 12 possible jet-parton assignments (if ==4-jets)\

→ **B-tagging helps a lot!**

Also important to reduce background

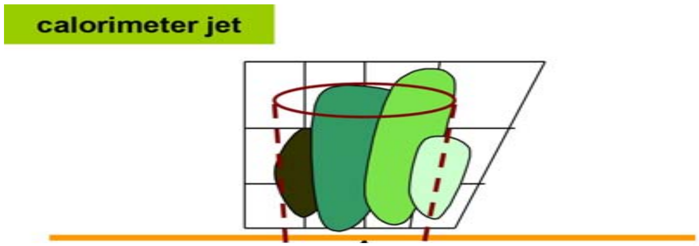
B-tagging:

- Most often based on secondary vertex technique
- Pixel and silicon detector are crucial
  - Good track impact parameter resolution
  - Close to interaction point



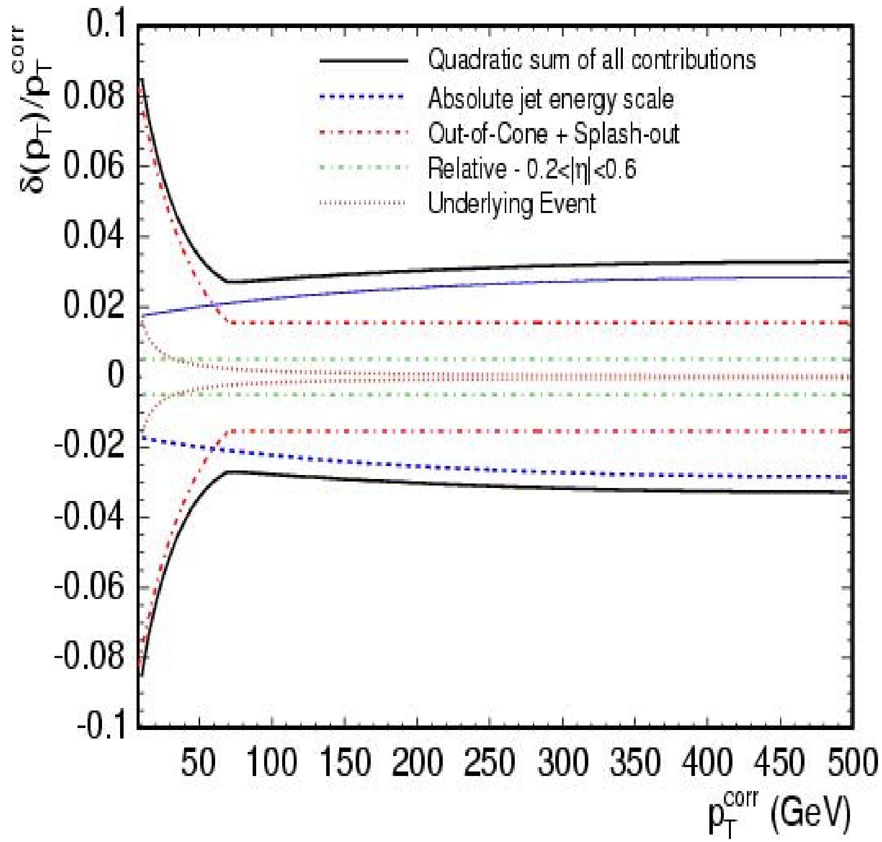
Challenges II for M_{top}

- World average uncertainty of 4.3 GeV/c^2 (~100pb^{-1}) has two major contributors:
  - Statistics: 2.7 GeV/c^2
  - Jet energy scale (JES): 2.6 GeV/c^2
- Run II: goal of 8 fb^{-1}
  - Thus stat. uncertainty will become naturally small
- → Particular attention should be brought to JES uncertainty in Run II
- JES uncertainty due to complexity of jet fragmentation and detection:



Jet Energy Scale at CDF-II

- Jet energy response calibrated in MC to be compatible with data (dijet, gamma+jets, etc)
- Uncertainty on calibration is $\pm 1\sigma_c$
  - Corresponds to ~3 GeV/c^2 in M_{top}



Novel approach: further reduce JES uncert. using W→jj decays

Selecting top-antitop Events

- Selecting events in the lepton+jets channel:

$$t\bar{t} \rightarrow l\nu q\bar{q}'b\bar{b}$$

- Event selections:
  - High-p_T e or μ
  - Large missing E_T
  - ≥4 large E_T jets
- Background: W+jets, QCD multijets, etc.
- Separation in four subsamples

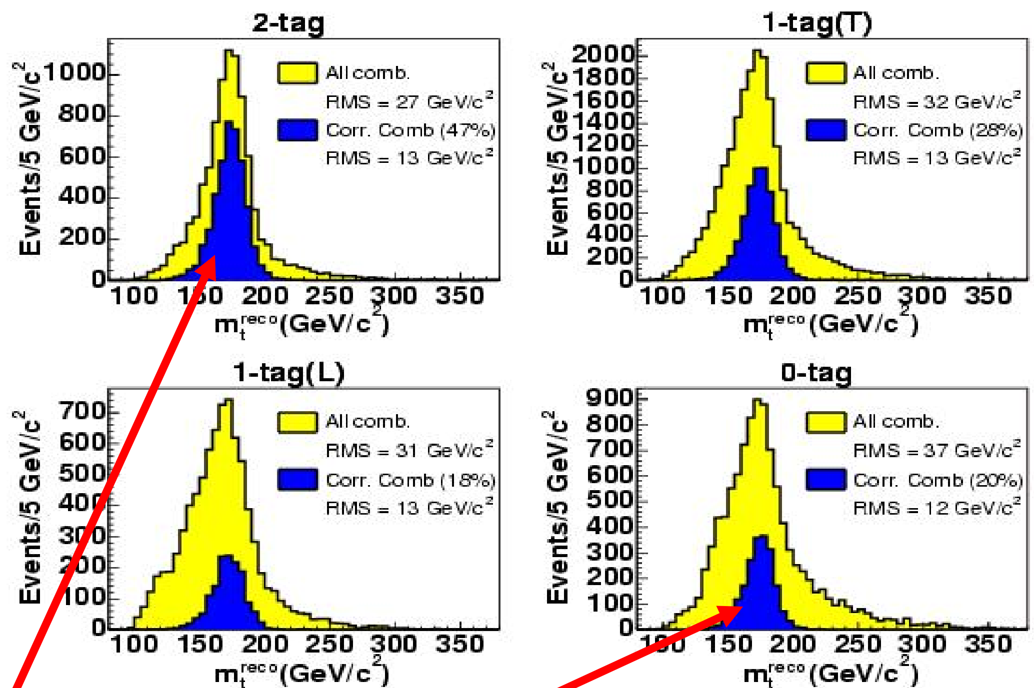
↓

Four events category:

Category	**2-tag**	**1-tag(T)**	**1-tag(L)**	**0-tag**
j1-j3	E_T>15	E_T>15	E_T>15	E_T>21
j4	E_T>8	E_T>15	15>E_T>8	E_T>21
S:B	10.6:1	3.7:1	1.1:1	0.9:1

Top Quark Mass Reconstruction

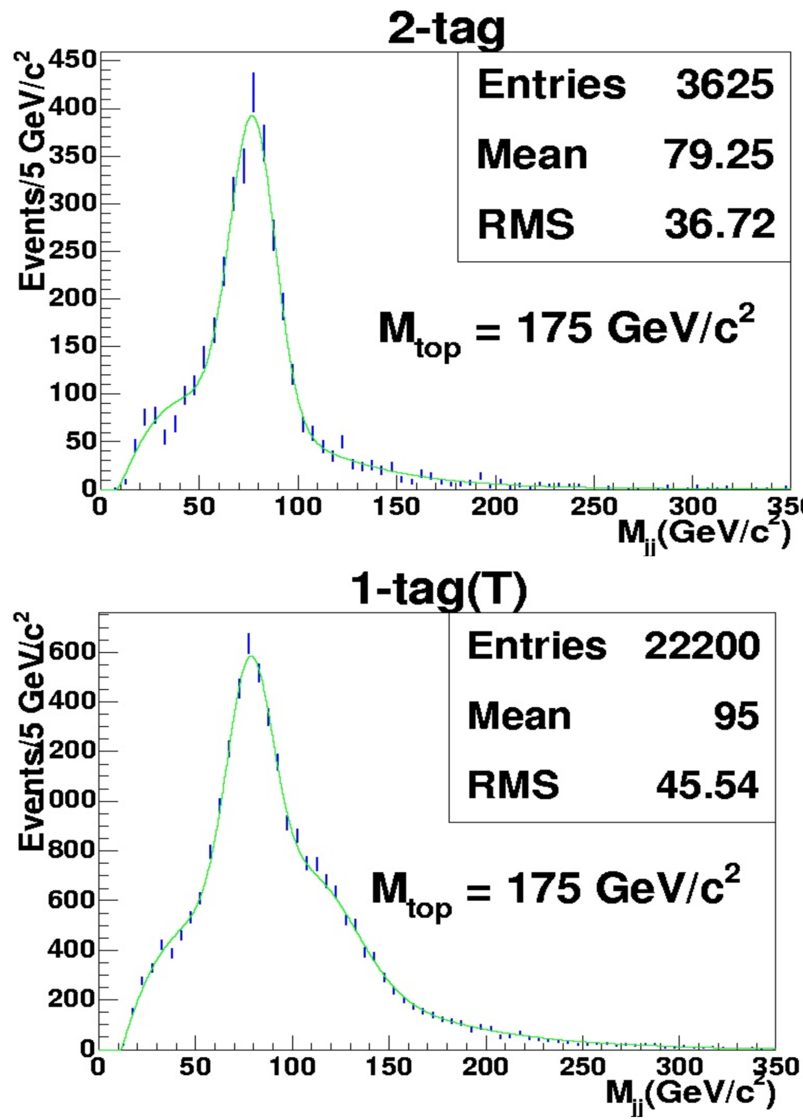
- Event-by-event mass m_t^{reco} from kinematic fit
- Try all jet-parton assignments: use mass yielding best chi-square
- Assign b-tag jets to b-quarks



More correct combinations with b-tags!

Hadronic W Boson Mass

- Novelty: monitor simultaneously W →jj invariant mass to reduce JES uncert.
- Principle:
  - Reconstruct m_{jj} using all jet-parton assignments
  - m_{jj} sensitive to JES but mostly independent on M_{top}



Application of W→jj to M_{top} Measurement?

1) Can we use W→jj to calibrate b-jets?

B-Jet Systematic Source	Uncertainty (GeV/c²)
HQ Fragmentation and color flow	0.5
Semileptonic decay	0.4
Total	**0.6**

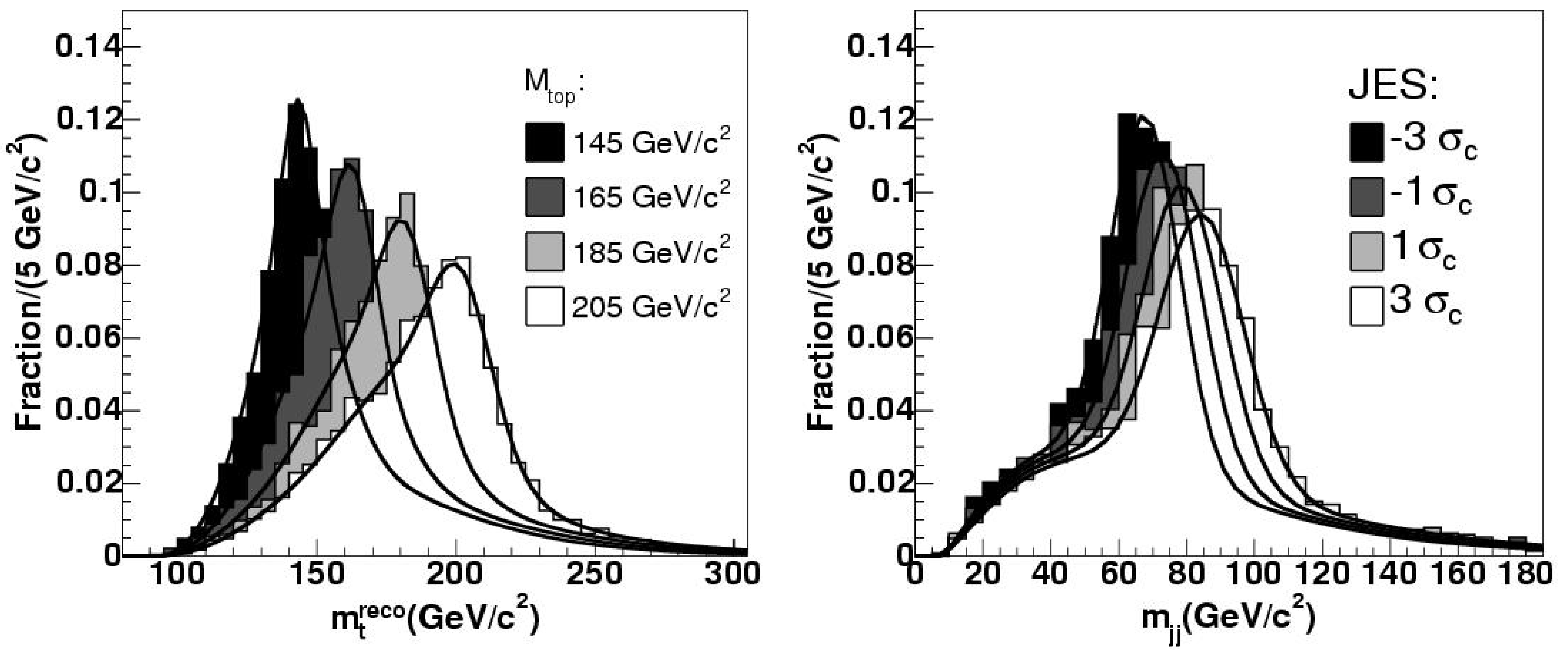
→ b-jets energy scale can be mostly set using W→jj

2) How to take into account correlations M_{top}-JES?

- m_{jj} displays some dependence on M_{top}
- Therefore, fitted JES is correlated to true top mass
- **Solution: simultaneous fit of M_{top} and JES**

Mass Templates

- Templates of m_t^{reco} and m_{jj} created as a function of M_{top} and JES:

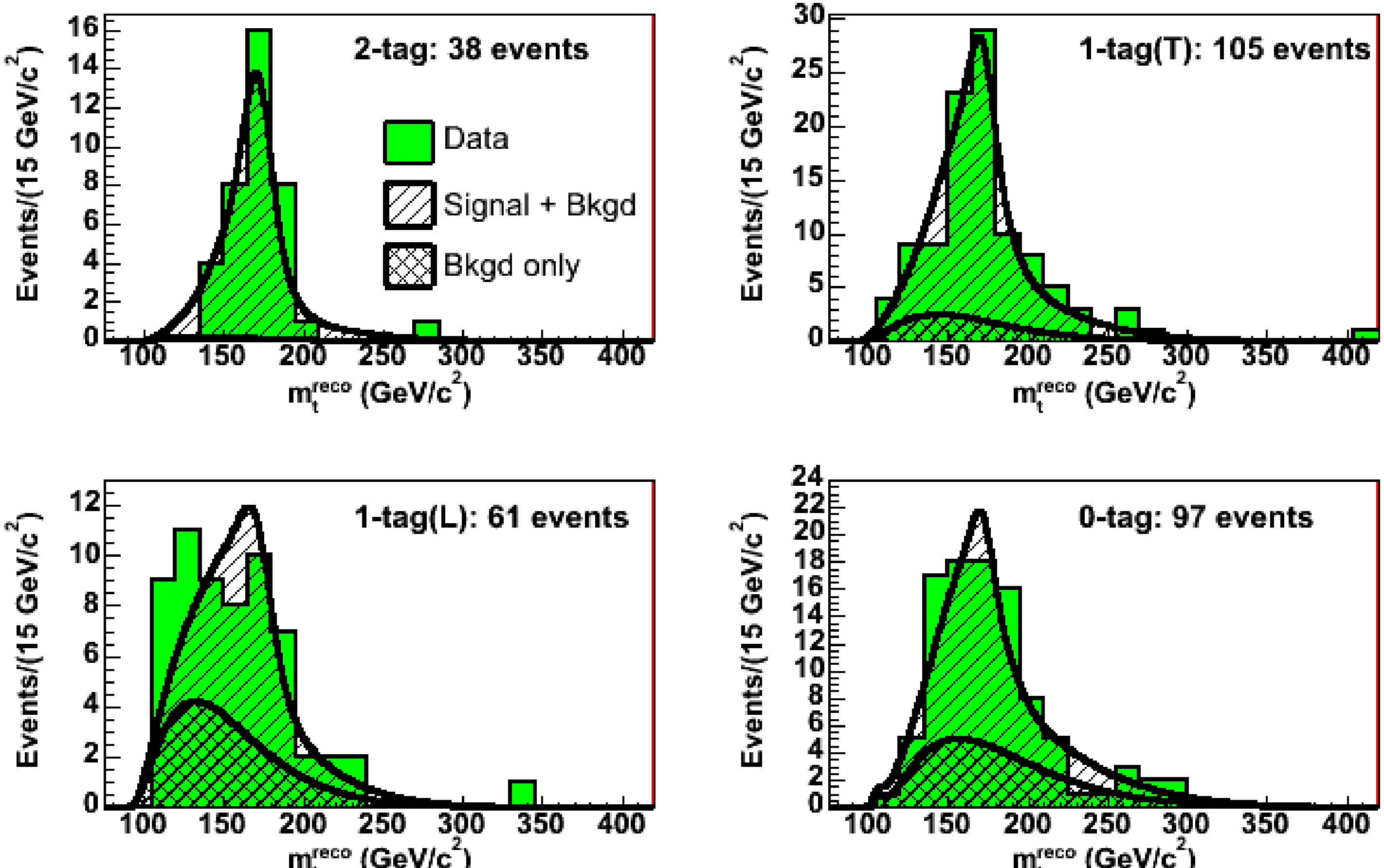


- Likelihood fit employed to extract M_{top} and JES
- Additional constraint on JES: use information from traditional CDF calibration

Results on Data I

$$M_{top} = 173.4 \pm 2.5(stat. + JES)GeV/c^2$$

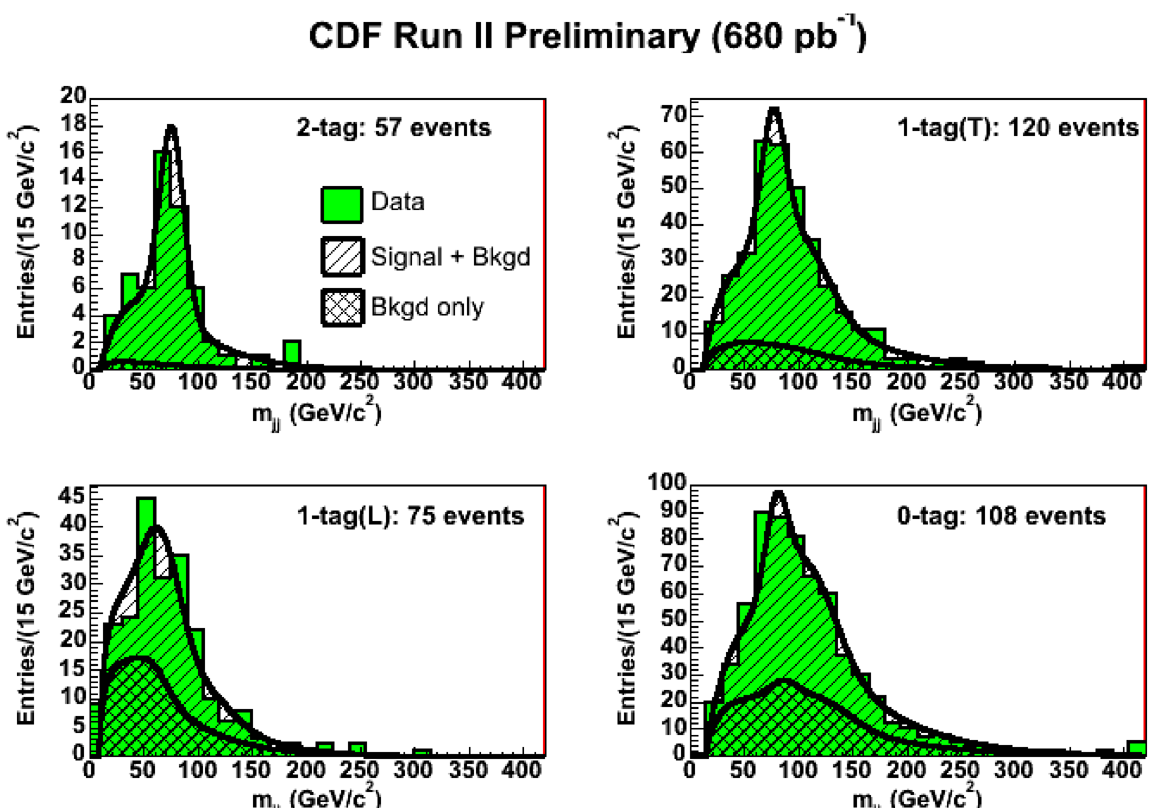
CDF Run II Preliminary (680 pb^{-1})



Results on Data II

$$JES = -0.3 \pm 0.6\sigma_c$$

- Very good agreement data-MC JES
- W→jj + traditional calibration yield **40% better JES uncert.**



Systematic Uncertainties

- Systematic uncertainties apart from JES (included in the fit) are small
- Novelty: introduce b-jets modeling uncertainty
- Total: 1.3 GeV/c^2

Source	ΔM_{top}(GeV/c^2)
b-jets modeling	0.6
Residual JES	0.7
ISR	0.5
FSR	0.2
Background shape	0.6
PDF	0.3
Other MC modeling	0.3
Total	1.3

Final result (680pb^{-1}) :

$$M_{top} = 173.4 \pm 2.8 GeV / c^2$$

Impact of Measurement

- Currently most precise measurements uses a matrix-element method (updated for 1 fb^{-1}, same $W \rightarrow jj$ technique, similar sensitivity):

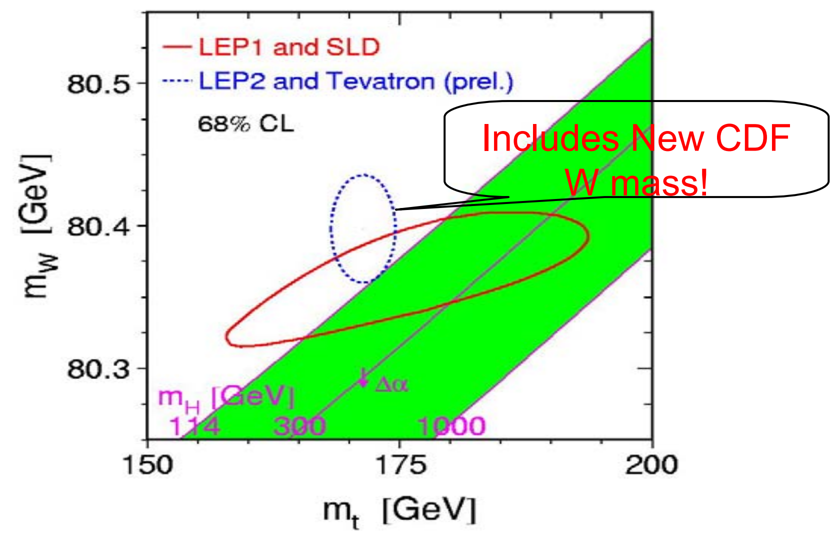
$$M_{top} = 170.9 \pm 2.6 GeV / c^2$$ (Luminosity ~1 fb^{-1})

- New world average:

$$M_{top} = 171.4 \pm 2.1 GeV / c^2$$

- Indirect constraints:

$$M_{Higgs} = 80^{+36}_{-26} GeV / c^2$$

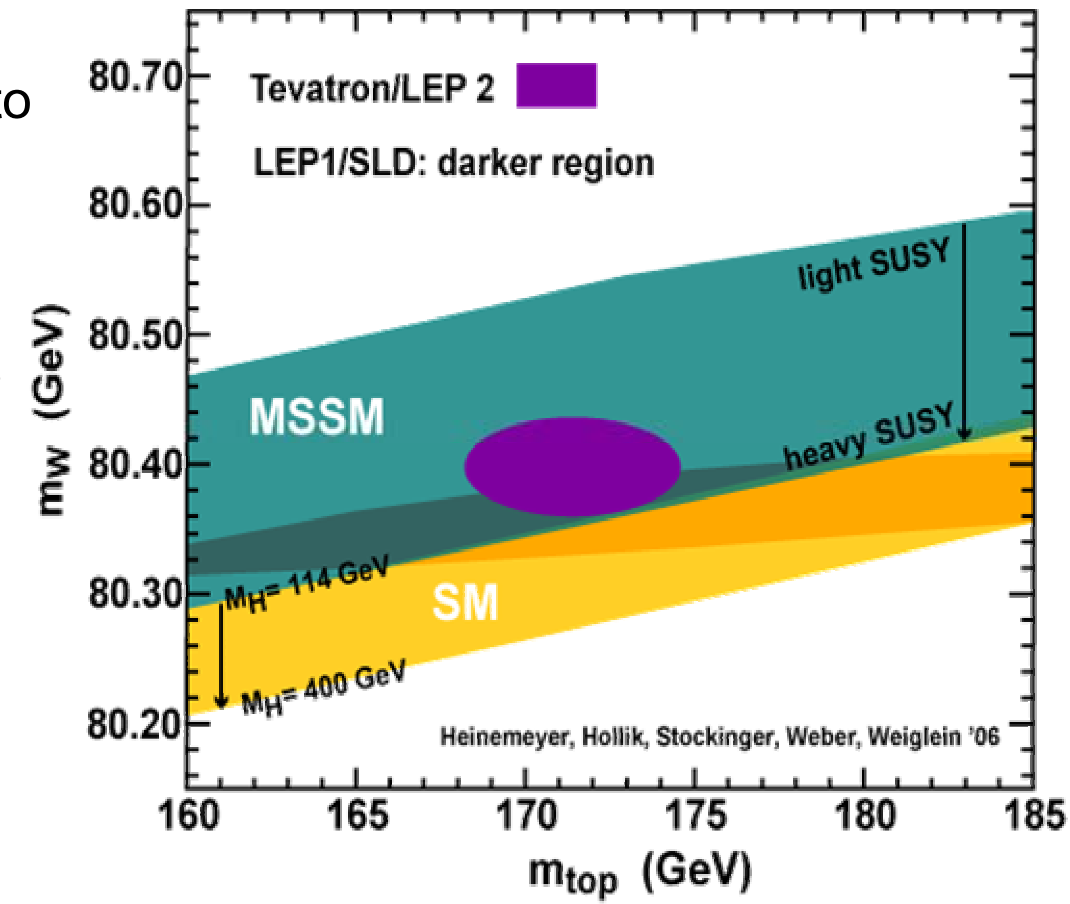


Including LEP searches:

SM is squeezed! → 114 < M_H < 153 @ 95% C.L.!

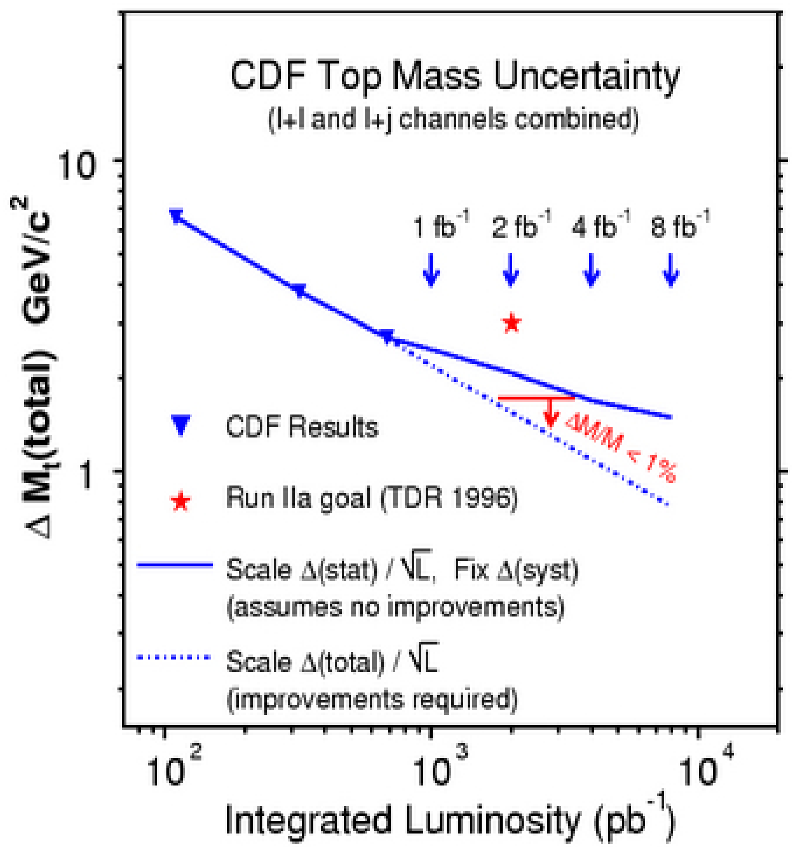
M_{top} constraints on SUSY

- In supersymmetric models, corrections to Higgs sector dominated by top quarks
- Data currently favors MSSM over SM (not conclusive yet)



Future of Analysis with W→jj

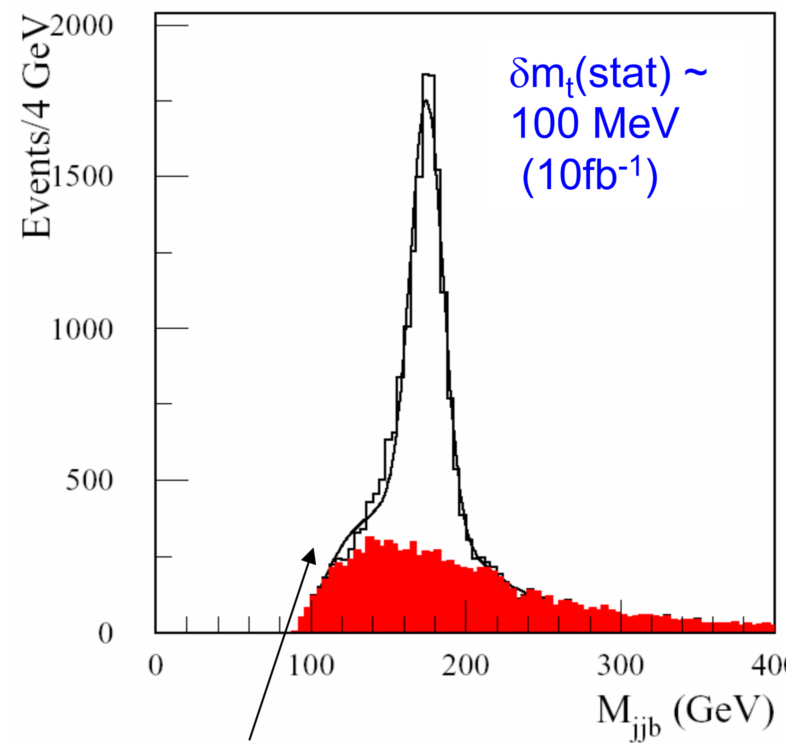
- Using W→jj: JES uncertainty becomes essentially statistical
- Will reach JES uncert. below 1 GeV/c^2 in Run II
- Total M_{top} uncertainty between 1-2 GeV/c^2 by the end of Run II



Top Physics at the LHC

- LHC is a top factory:
  - 10 ttbar per day at Tevatron
  - 1 ttbar per second at LHC!!
- Measurement of M_{top} become systematically limited
  - Prospects hard to estimate, but ~1 GeV/c^2 after lots of work!
- Large top sample extends list of measurements:
  - m_{ttbar}, charged Higgs, charge, W helicity, Yukawa coupling, etc…

Golden channel: 2 b-tag

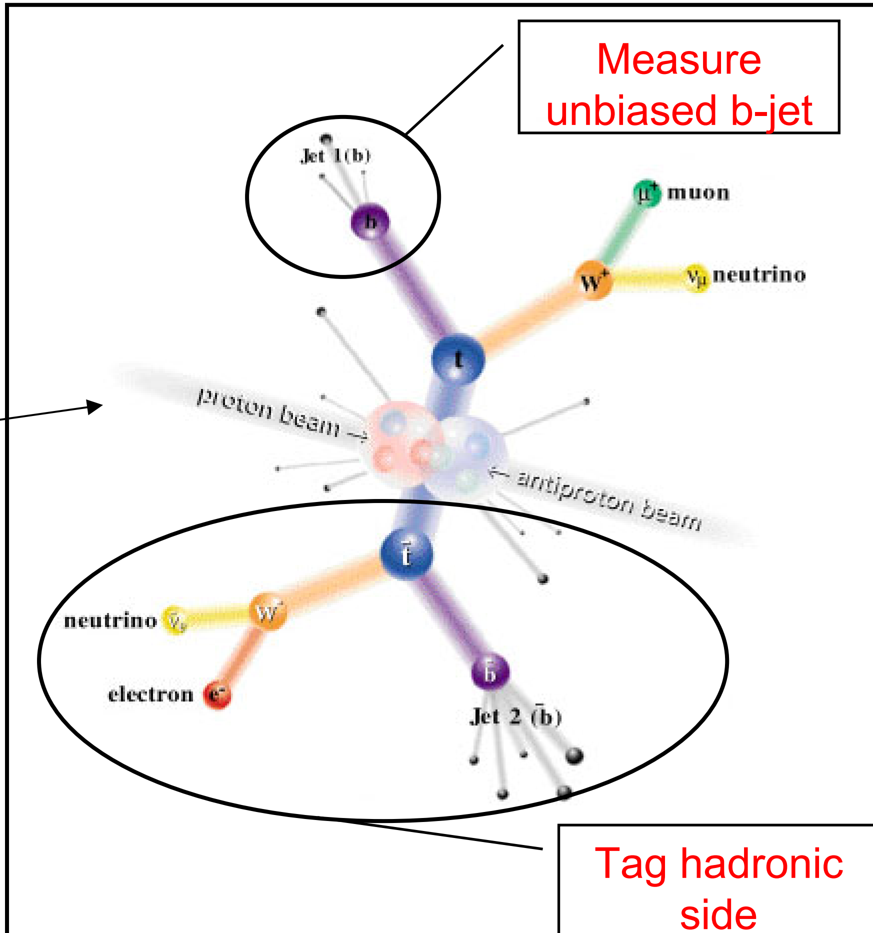


Top boosted at LHC: Jet pairing performed using angle with lepton

Top as an Experimental Tool at LHC

Samples are so large at LHC that top can be used for calibration!!:

- W→jj technique again
- Calibrate B-tagging
  - Important e.g. to extract H→bb efficiency
- ttbar: background to new physics
  - E.g. supersymmetry

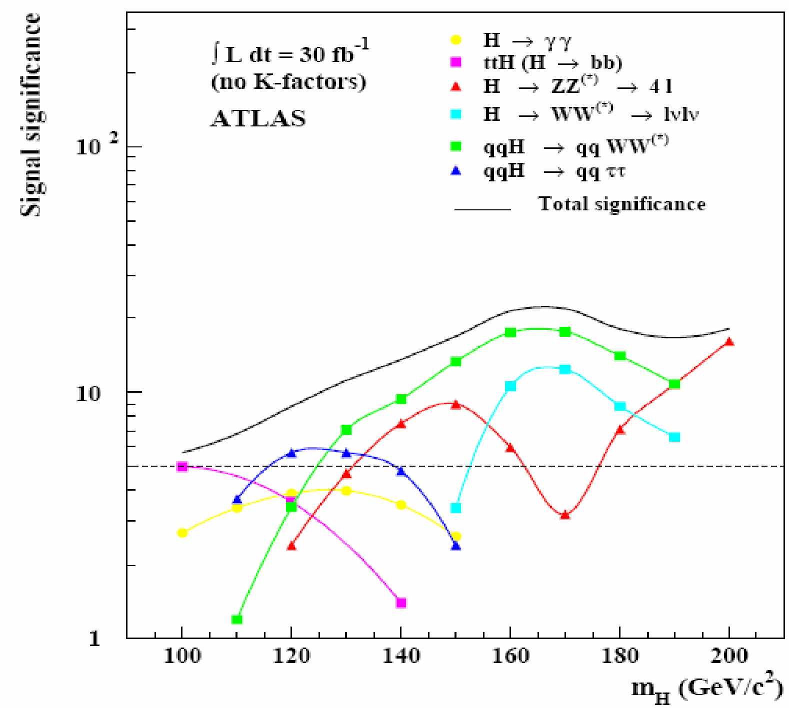


Preliminary studies:
$\sigma(\varepsilon)$ ~2% after 10 fb^{-1}

LHC: A Discovery Machine

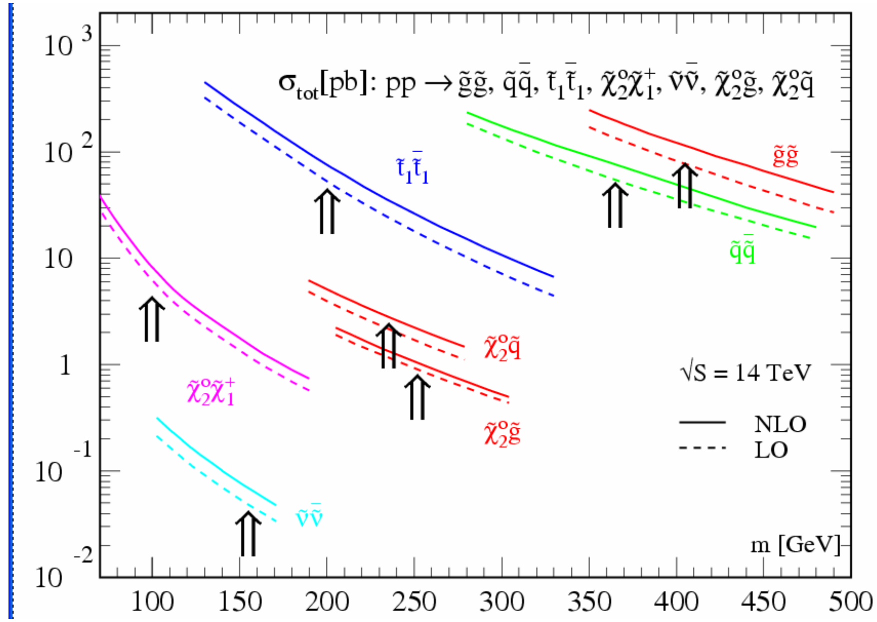
- **Large center-of-mass energy should be exploited to search for new phenomenon**
- C.M. energy not chosen arbitrarily
  - Can discover Higgs for every mass
  - <u>In principle, should discover canceling physics!</u>

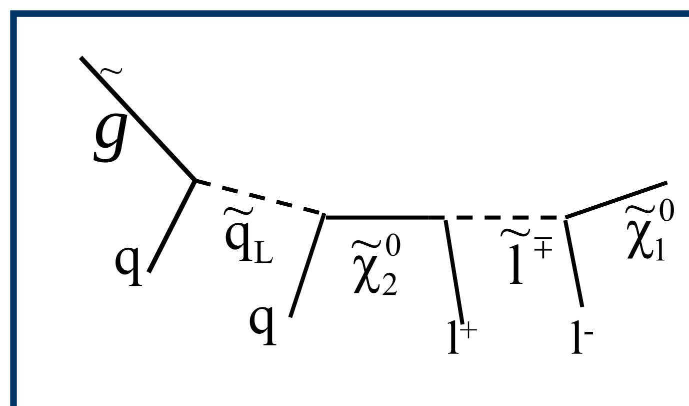
  → theories solving fine-tuning introduce new phenomena at the TeV scales



SUSY at the LHC

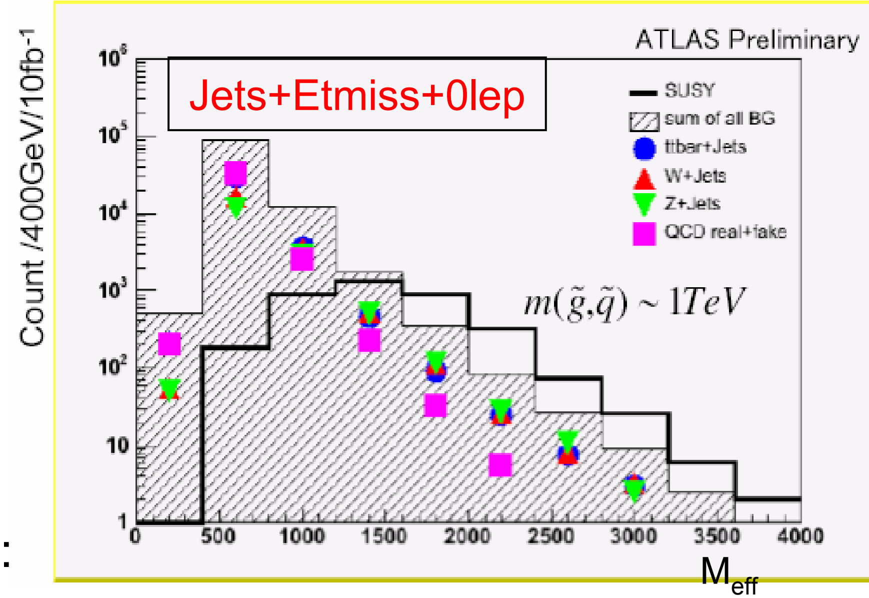
- If SUSY solves Higgs fine-tuning → superpartners expected at O(100 GeV-1 TeV)
- Cross-sections can be large (σ_{SUSY}~1-100pb^{-1})
  - Good candidate for early discovery!!
- SUSY general pheno (R-parity conserved):
  - Cascade decay: many jets, leptons, …
  - LSP is stable → Etmiss

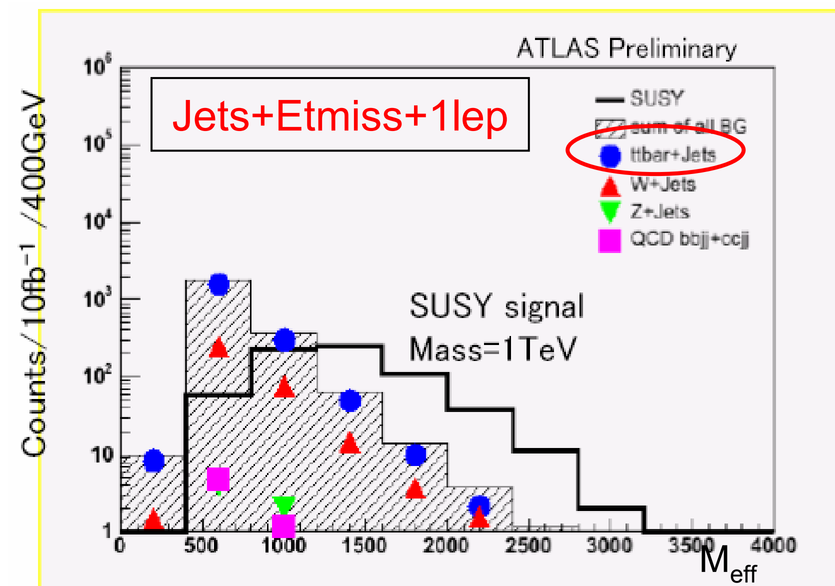




SUSY Searches

- Search channel:
  - Classic: Jets+Etmiss
  - Cleaner: Jets+Etmiss+leptons
- Typical SUSY cut
  - NJet>=4 (PT1st>100GeV, pT4th>50GeV)
  - MET>100 GeV
- M_{eff}: distinguish SUSY from SM:
  - $M_{eff} = \Sigma|p_T^i| + E_T^{miss}$
- LHC can cover up-to M_{SUSY}~2 TeV with 10 fb^{-1}
- *Note: Much more SUSY at LHC*
  - E.g. Measurement SUSY parameters, SUSY Higgs, R-parity violating, split-SUSY, etc.

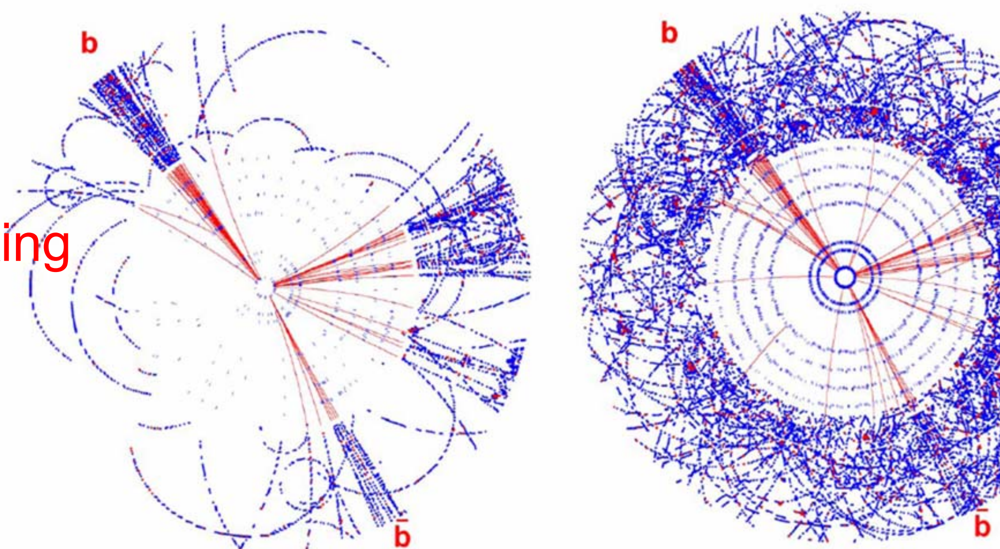




The ATLAS Pixel Detector

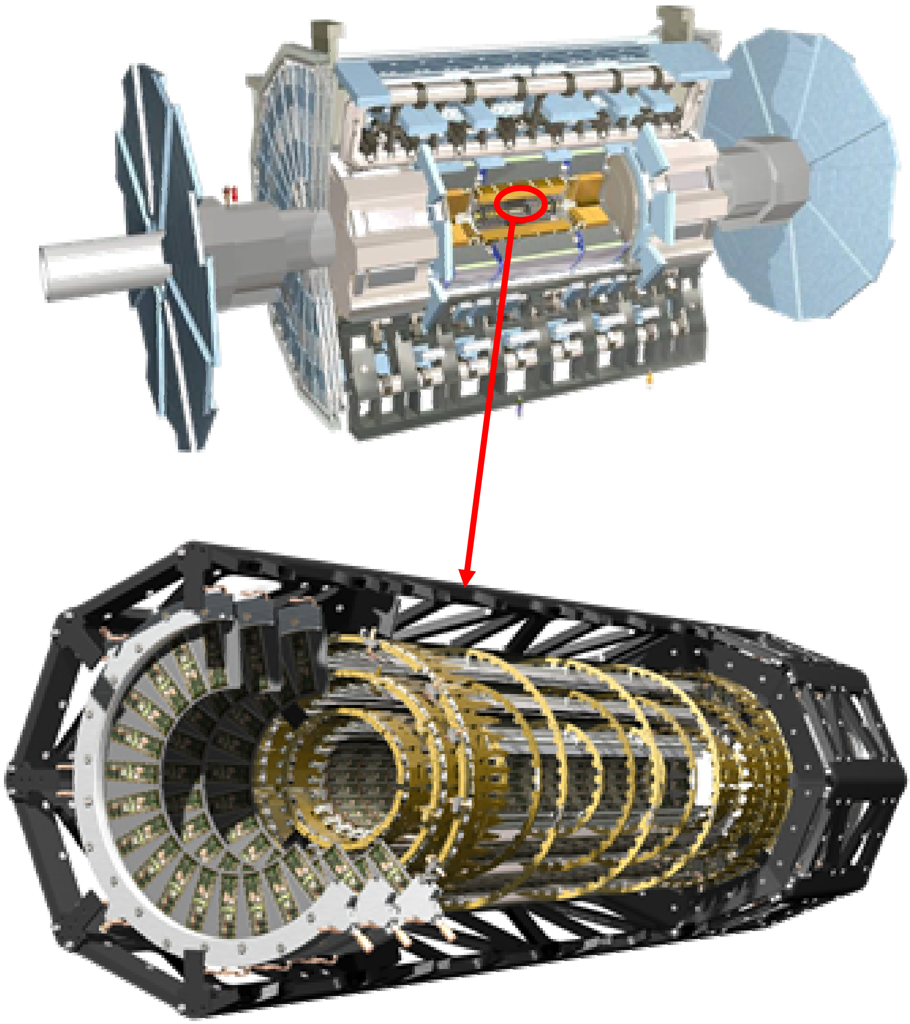
- The pixel detector is crucial for ATLAS physics program:
  - Pattern recognition in high multiplicity events
    Occupancy at $10^{34} cm^{-2} s^{-1}$:
    - *Pixel ~10^{-4}*
    - *SCT ~ 1%*
    - *TRT~ few %*
  - Great d_0 and z_0 resolution *(12μm and 70μm)* and close to IP → Required for B-tagging *(ε(b)=60%, mistag(udsg)<1%)*
- Pixel largely determines ability of ATLAS for tracking and vertexing!

- LHC environment requirements:
  - 25 ns bunch crossing → fast FE electronics, on-detector buffering
  - Lifetime dose of 10^{15} neq/cm2 → low T operation, rad-hard



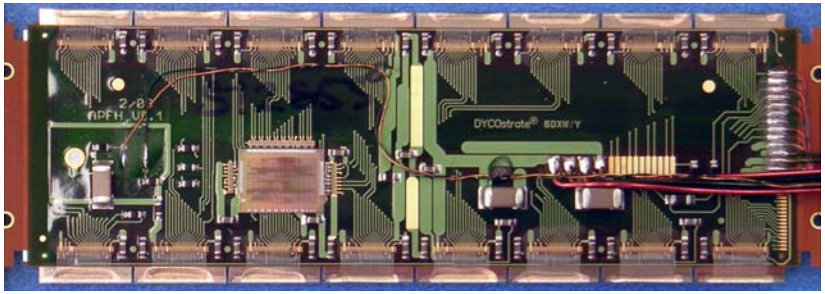
Pixel Detector Description

- 3 barrel layers ($|\eta|<1.9$) + 3 disks ($1.9 <|\eta|<2.5$)
- Tracking volume: 1.6 m long, 0.2 m radius
- 80 millions channels!
- 10% X_0 material at $\eta=0$

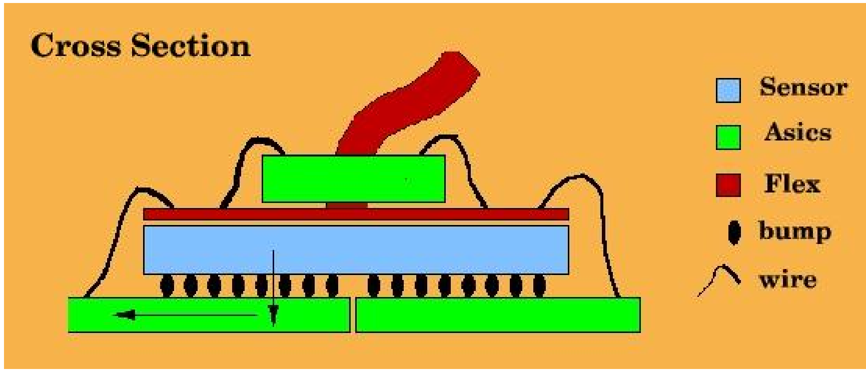


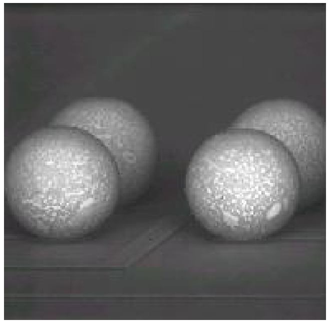
Pixel Module and Readout

- 1744 hybrid pixel modules with:
  - 46080 pixels with analog and digital readout
  - 16 FE chips for primitive event building and buffering while waiting for L1 signal
  - 1 Controller chip for communication, event building, formatting
  - Events are then sent off-detector for further event building and maybe used by Level2 trigger



Area ~2x6 cm



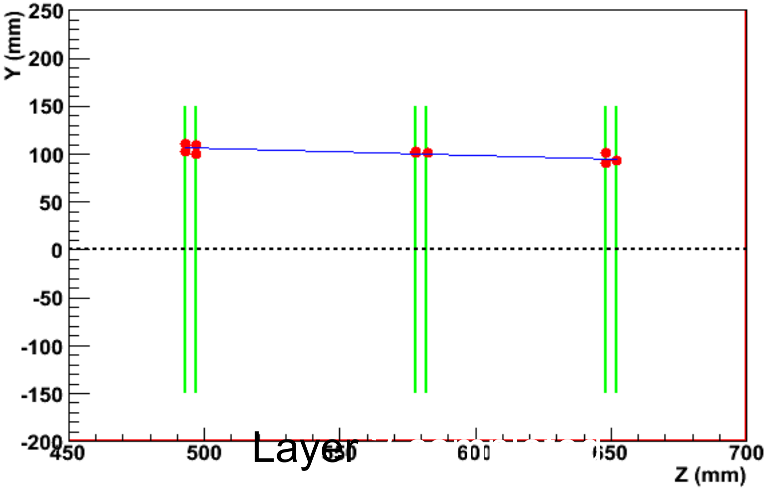


Solder bumps ~50 μm

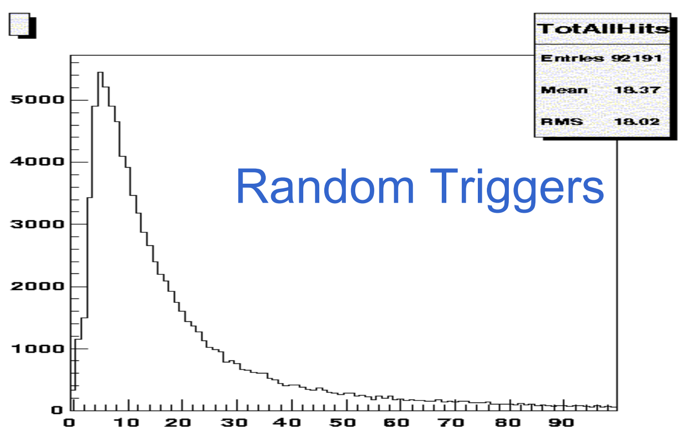
Pixel: Recent Achievements

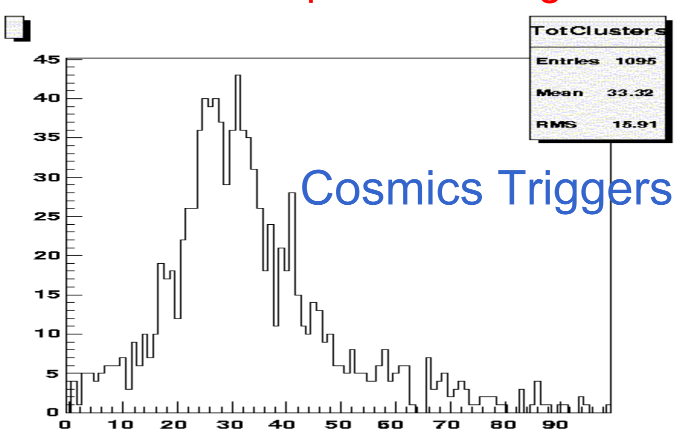
- Barrel layers and end-caps assemblies are completed
- Production and integration very efficient
  - Bad pixels <<1%
- Performed cosmic data taking using one end-cap

Cosmic track through the end-cap

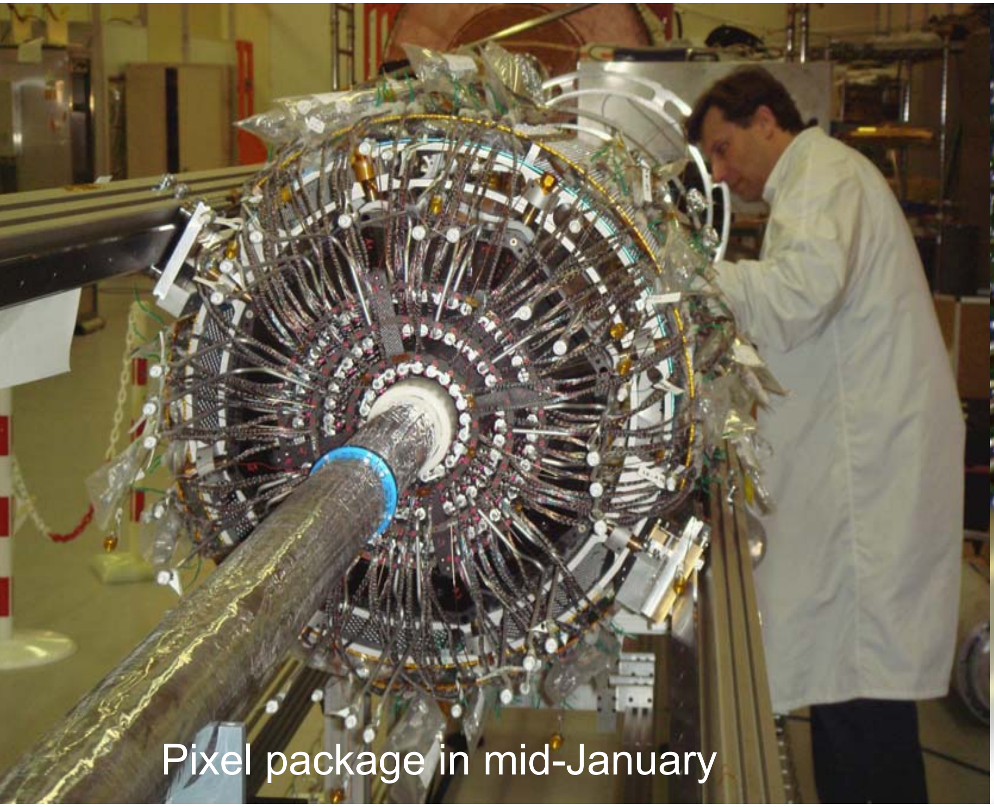


Proof of cosmics: deposited charge

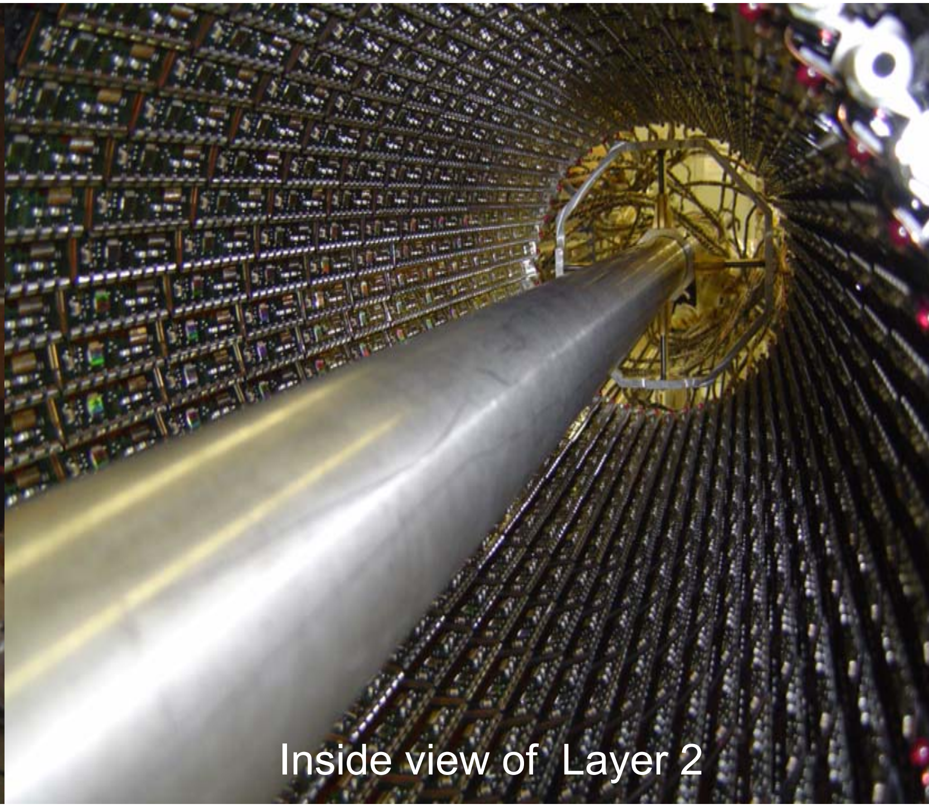




Next step: integration of pixel package



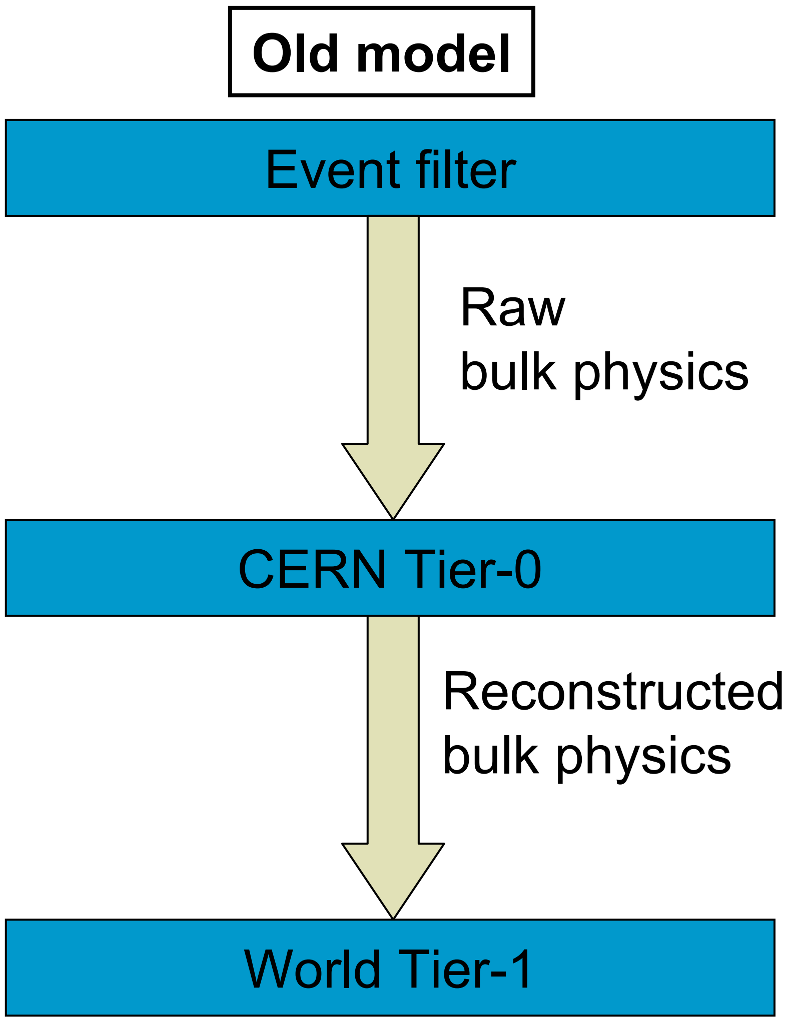
Pixel package in mid-January



Inside view of Layer 2

- Package: detector, beam pipe, services, support structure
- Integration starting now until the end of March
  - My responsibility: Testing modules and services during integration
- Installation in the ATLAS detector early this summer!

Improving Data Access: Streaming Model

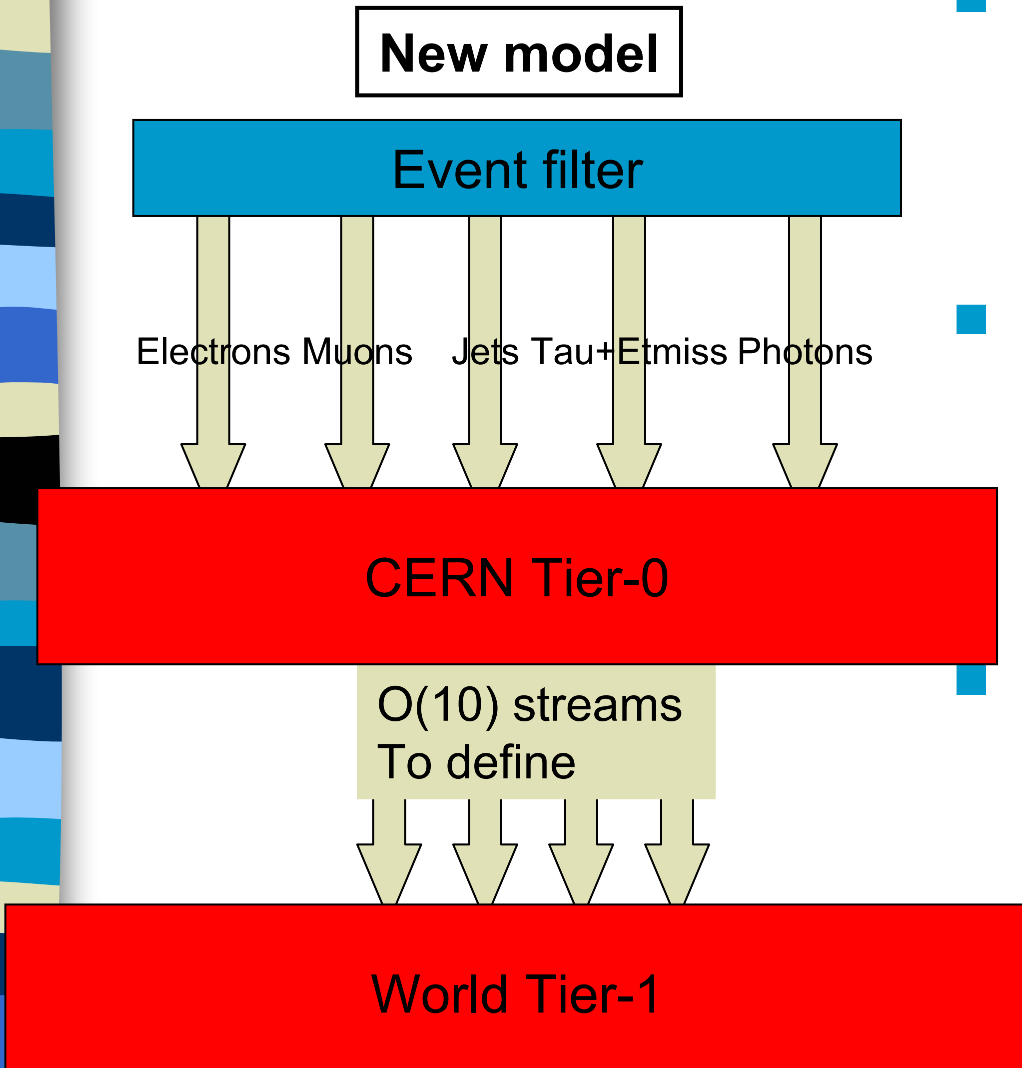


- **Old model (1 year ago)**: all events written to same file for permanent storage

  → **Not optimized**
- Data access can make the difference in the success of an experiment!!

→ Could determine which experiment makes discovery first!

Improving Data Access: Streaming Model



- **New model:** write events in “streams” based on common features
- E…

Q: can we afford streaming?

process it at Tier-0/1 first!

(about 5% increase in storage is OK But 20% is too much…)

- Issue: treatment of events passing one or more stream?
  - Streaming= more data storage

Calculation of Overlaps

- Complex task:
  - Simulate all processes with large cross-sections:
    - Jets, W/Z, ttbar, etc
  - Estimate rates of all ATLAS trigger for all processes…

Result: overlap rate ~3% at $10^{33}cm^{-2}s^{-1}$

- Reason of small overlaps: rate dominated by fakes

Event rates (Hz) for electron stream

Processes	Stream A e25i	Stream A 2e15i	Stream A e15imu10
Dijet (17-35 GeV)	23±13	0±0	0±0
Dijet (35-70 GeV)	18±3.8	0±0	0.79±0.79
Dijet (70-140 GeV)	0.57±0.28	0.14±0.14	0.14±0.14
Dijet (140-280 GeV)	0.062±0.036	0±0	0.021±0.021
Dijet (280-560 GeV)	0.00013±0.00013	0±0	0±0
Dijet (560-1120 GeV)	0±0	0±0	0±0
Dijet (1120-2240 GeV)	0±0	0±0	0±0
Dijet (>2240 GeV)	5.6e-08±5.6e-08	0±0	0±0
γ+jet	0.68±0.051	0.0038±0.0038	0±0
$W\to e\nu$	13±0.11	0.0082±0.0041	0±0
$W\to \mu\nu$	0.00077±0.00077	0±0	0.0023±0.0013
$Z\to ee$	1.6±0.0043	0.8±0.0053	0.00012±8.3e-05
$Z\to \mu\mu$	3.2e-05±3.2e-05	0±0	6.4e-05±4.5e-05
$Z\to \tau\tau$ (loose)	0.063±0.0012	0.006±0.00039	0.0081±0.00046
γ/Z (30<M<81 GeV)	0.16±0.0019	0.11±0.0016	0.00042±9.9e-05
γ/Z (M>100 GeV)	0.094±0.00038	0.033±0.00025	0.00066±3.6e-05
$\gamma\gamma$	0.0016±5.9e-05	8.9e-06±4.4e-06	0±0
$ZZ\to 4l$	4.1e-05±1.5e-07	2.7e-05±1.5e-07	1.5e-05±1.3e-07
ttbar ($\geq$ 1l)	0.21±0.0009	0.01±0.00023	0.017±0.00029
Single-top (Wg fusion)	0.033±0.00044	9.3e-05±2.7e-05	0.00058±6.7e-05
Single-top (Wt)	0.0078±7.3e-05	2.2e-05±4.5e-06	0.00012±1e-05
Total	57±14	1.1±0.14	0.98±0.8
Predictions	~ 40		–

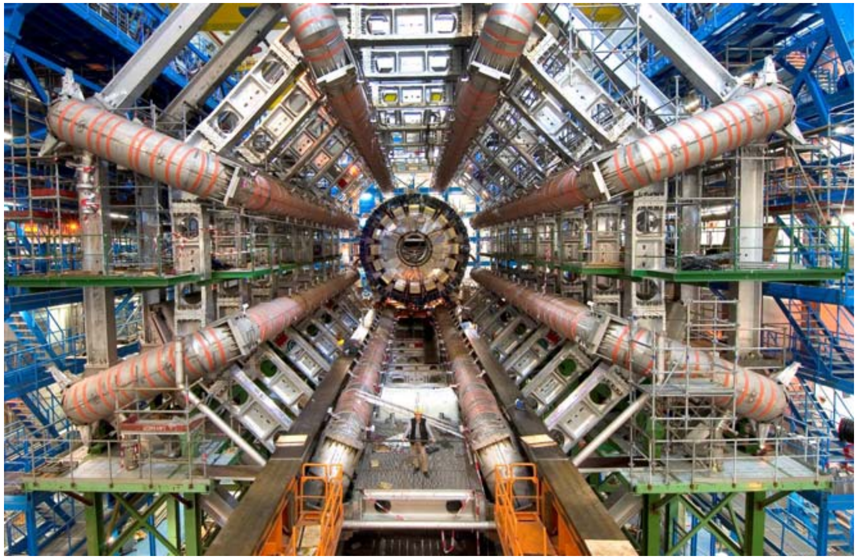
Conclusion of Streaming Studies

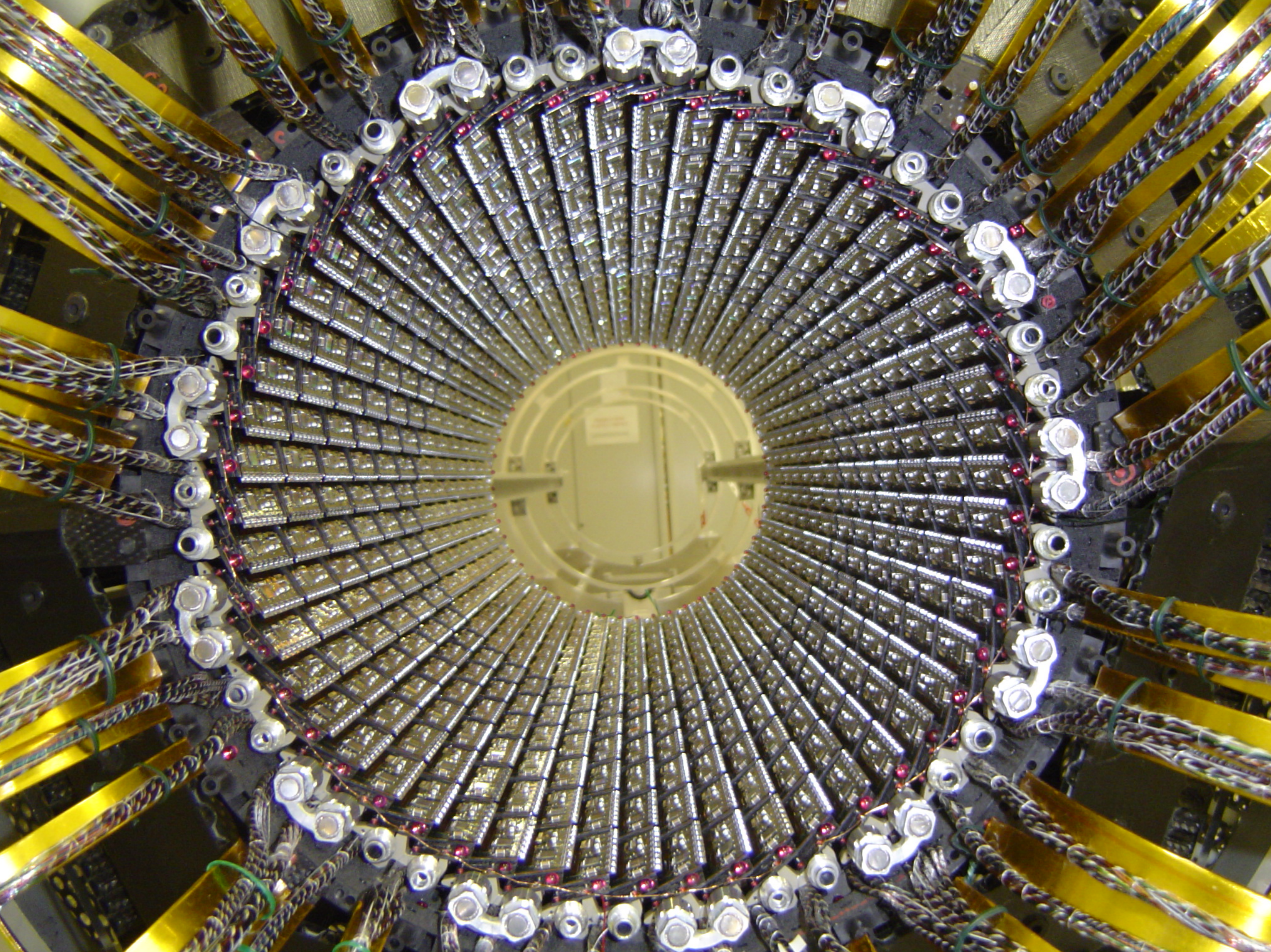
- Conclusion of overlap studies: <u>ATLAS can afford streaming</u>
- Implement the raw streams (electrons, muons, jets, photons, tau and Etmiss)
- A streaming test is currently studying the details of implementation

Conclusions

- Hadron colliders very powerful machine:
  - Precision measurements: M_{top} at CDF with 1% accuracy!
  - Discovery: great potential for Higgs and Supersymmetry at the LHC

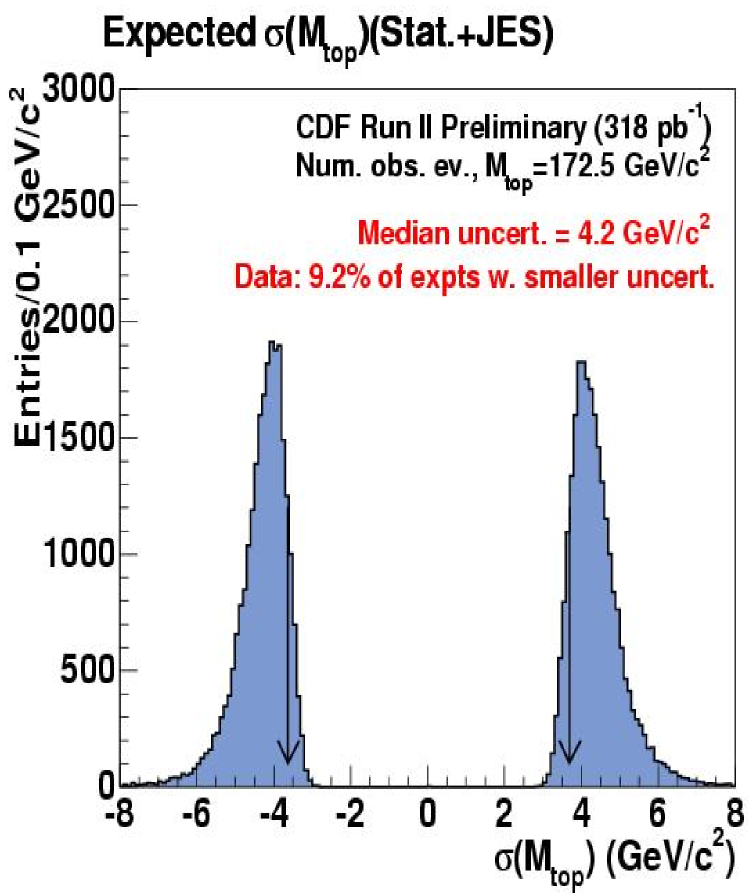
The great tradition of hadron collider physics will be perpetuated at the ATLAS!

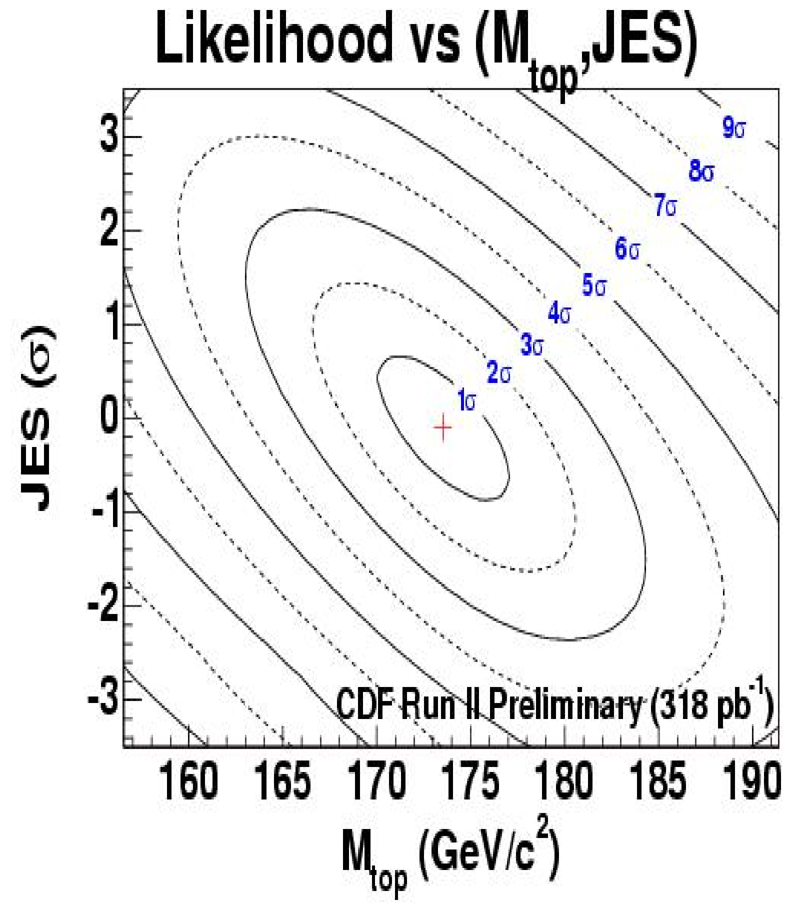




Additional material

Results on Data III

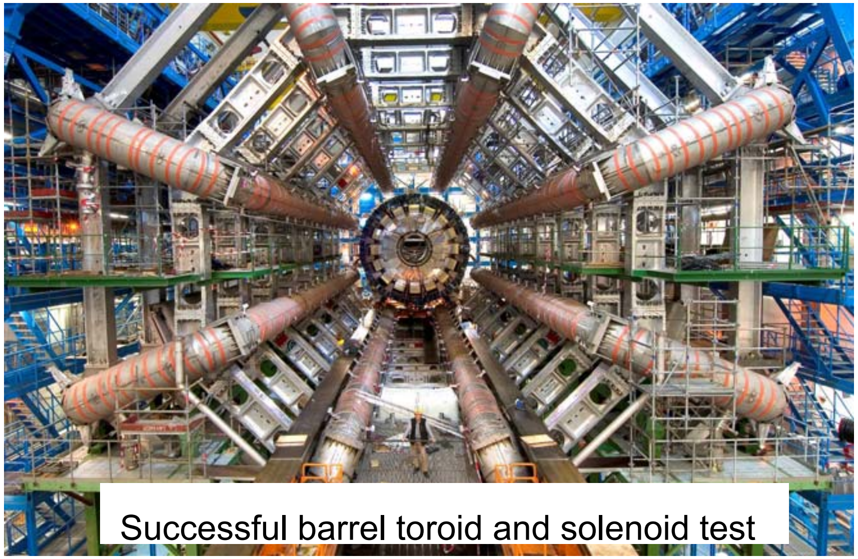




Status of ATLAS

- Lots of work still to be done, e.g.:
  - Complete muon wheel installations
  - Installation of pixel
  - Complete installation of services and cabling
  - In-situ commissioning and cosmics

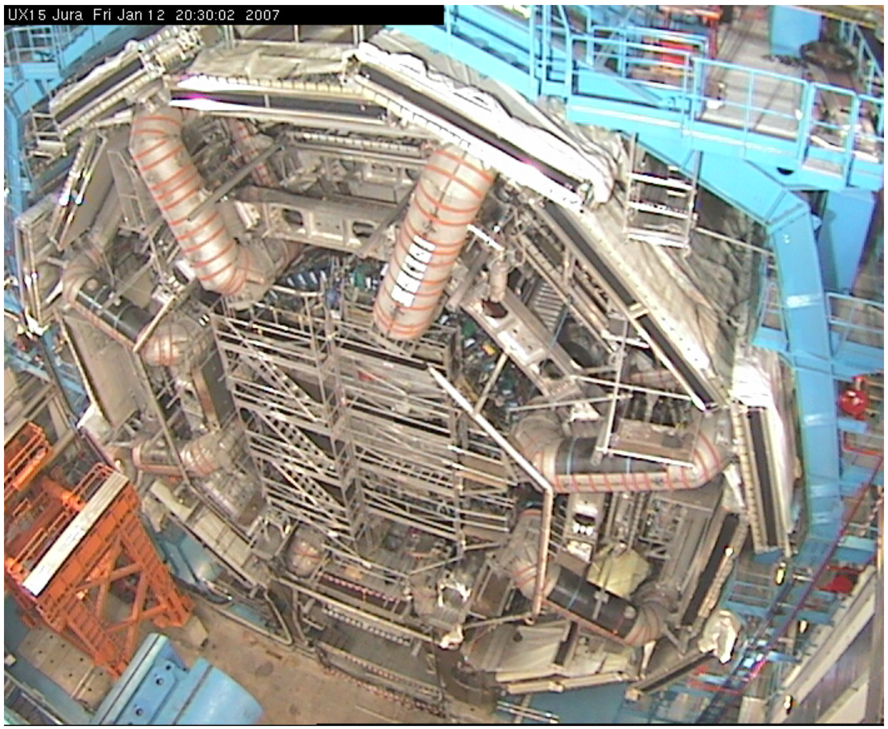
SCT+TRT installed



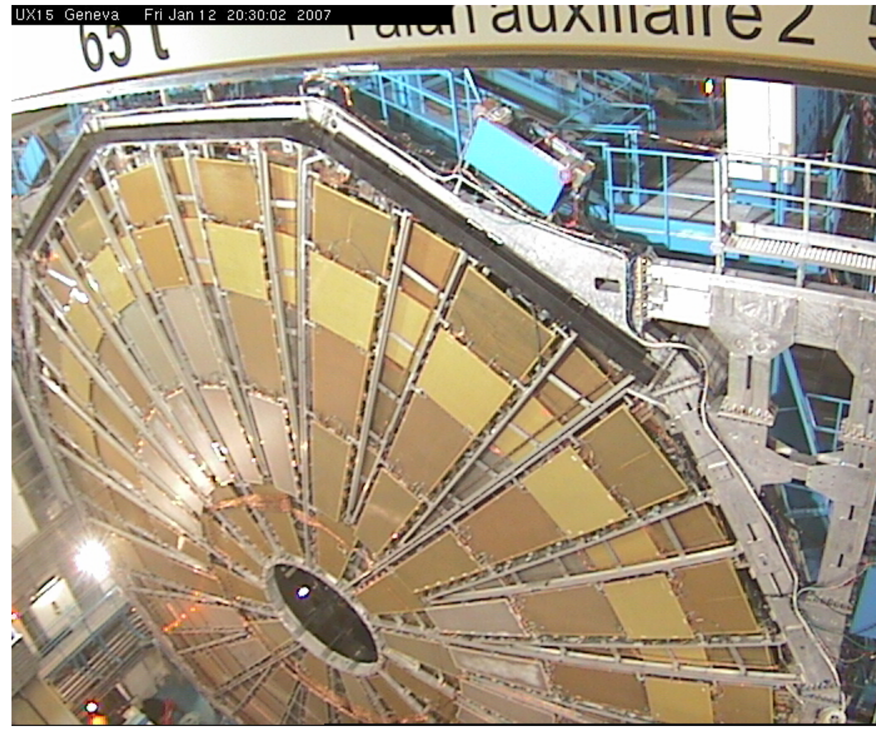
Successful barrel toroid and solenoid test

TGC1 big wheel installed

ATLAS pit ~8 months before closing



Geneva side (A)

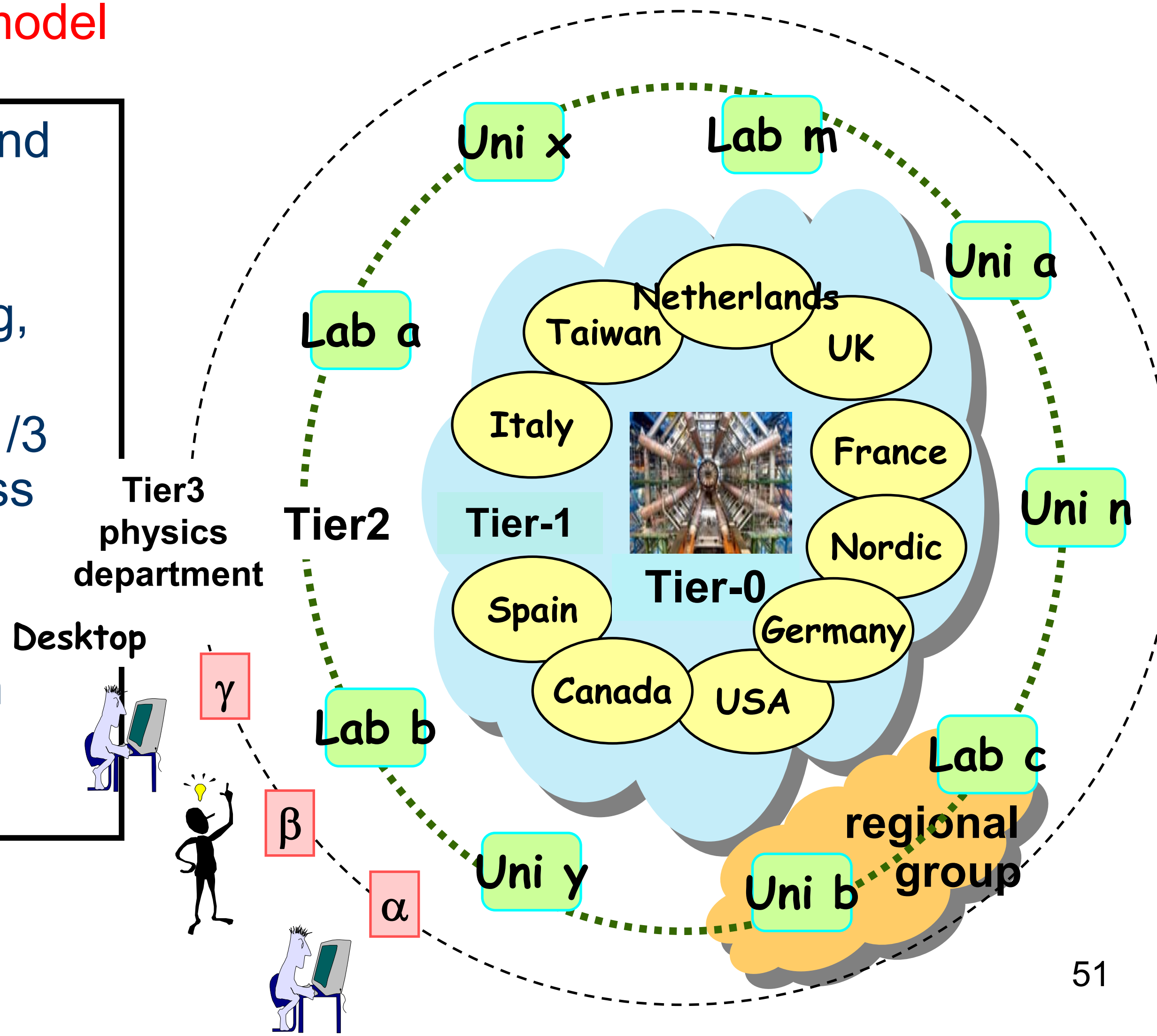


Jura side (C)

The ATLAS Computing Model

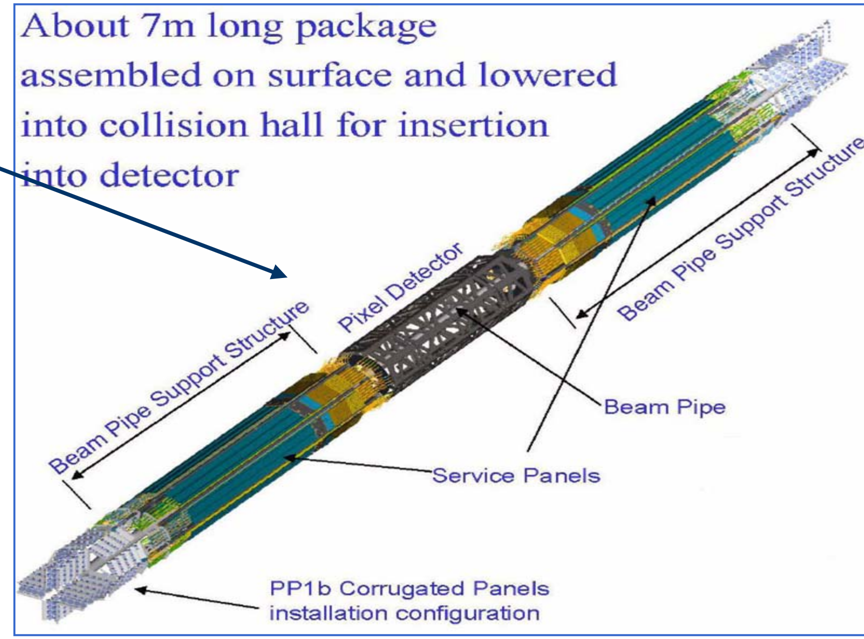
Large event size results in ~3 Pb of raw data per year
→ distributed computing model

- Tier-0: first processing and host of raw data
- Tier-1: host full copy of ESD/AOD, re-processing, scheduled data access
- Tier-2: simulation, host 1/3 AOD, chaotic data access
- Tier-3: local clusters
  for user analysis
- Inter-site communication provided by the GRID



Next step: pixel package integration

- The pixel package integrated at the surface (until end of March)
- During this procedure, it will be crucial to test the modules and services: → Connectivity Test
  - Last chance before lowering the pixel detector in the pit!



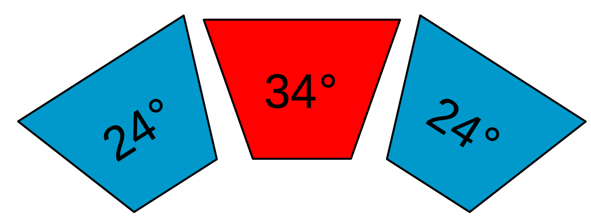
- Design constraints for CT:
  - Uses full readout chain → module permanently connected to Service Panel
  - Must run fast → test full detector in 6-8 weeks
  - Must run warm → no cooling available and max T= 40°C!

Designing the Connectivity Test

- Need to design DAQ code that:
  1) Check electrical services
  2) Check optical links
  3) Check permanent module connections to Service Panel
  4) Check module functionality
- Estimated time: ~4h per Service Panel

- Designing a warm CT:
  – How many modules can be powered, run at a time?
  – T measurements performed using cosmic test end-cap

Power 6 modules per sector at a time



Overlaps results

Overlapping events

Final Overlap Table (rate in Hz)

Streams	electrons (A)	muons (B)	jets (C)	photons (D)	xE and taus (E)	B physics (F)
electrons (A)	31±7.9	0.0056±0.00058	0.00053±6.2e-05	1.2±0.4	1.4±0.035	1.3e-05±1.3e-05
muons (B)	–	34±8.7	0.021±0.015	0.0028±0.002	0.22±0.022	0.076±0.0043
jets (C)	–	–	38±5.9	0.48±0.4	0.71±0.4	0±0
photons (D)	–	–	–	22±5.7	0.22±0.073	0±0
xE and taus (E)	–	–	–	–	32±7.9	1.5e-05±6.4e-06
B physics (F)	–	–	–	–	–	9.5±5.5

Note: table contains only events passing 1 or 2 streams
Rate for passing 3 or more streams is 0.62 ± 0.023 Hz

Total overlap = 3.3 ± 0.9%

Events passing only one stream

- Results: overlap only ~3% → manageable!
- Reason of modest overlap:
  - Rates are dominated by fakes → tend to pass only 1 trigger
  - E.g. rates for dijet and ttbar are <1% and ~45%, respectively
- Overlaps dominated by e, photon and taus (EM-like objects)