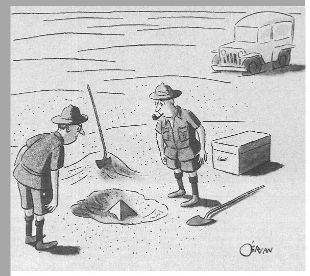
Towards discovery of a light Higgs boson

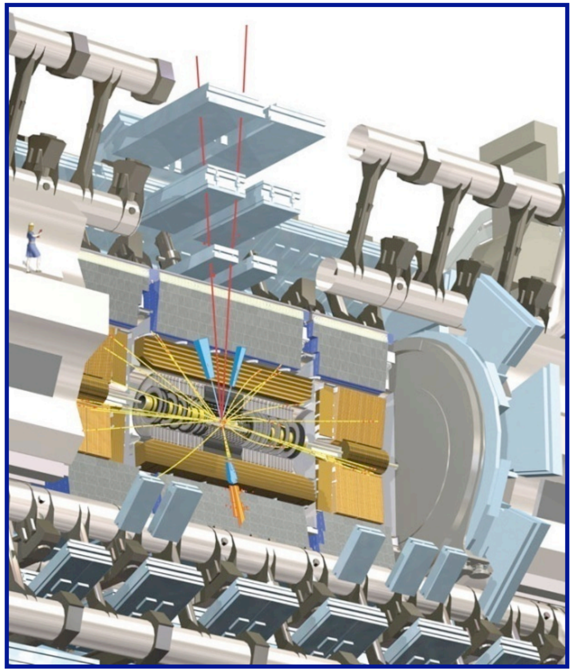
-

From detector design to final analysis



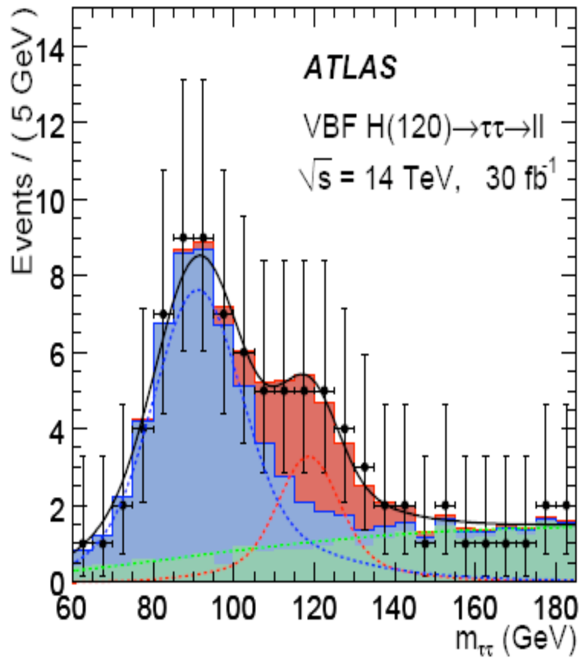
"This could be the discovery of the century. Depending, of course, on how far down it goes."

Markus Schumacher, Universität Freiburg, 24.11. 2009

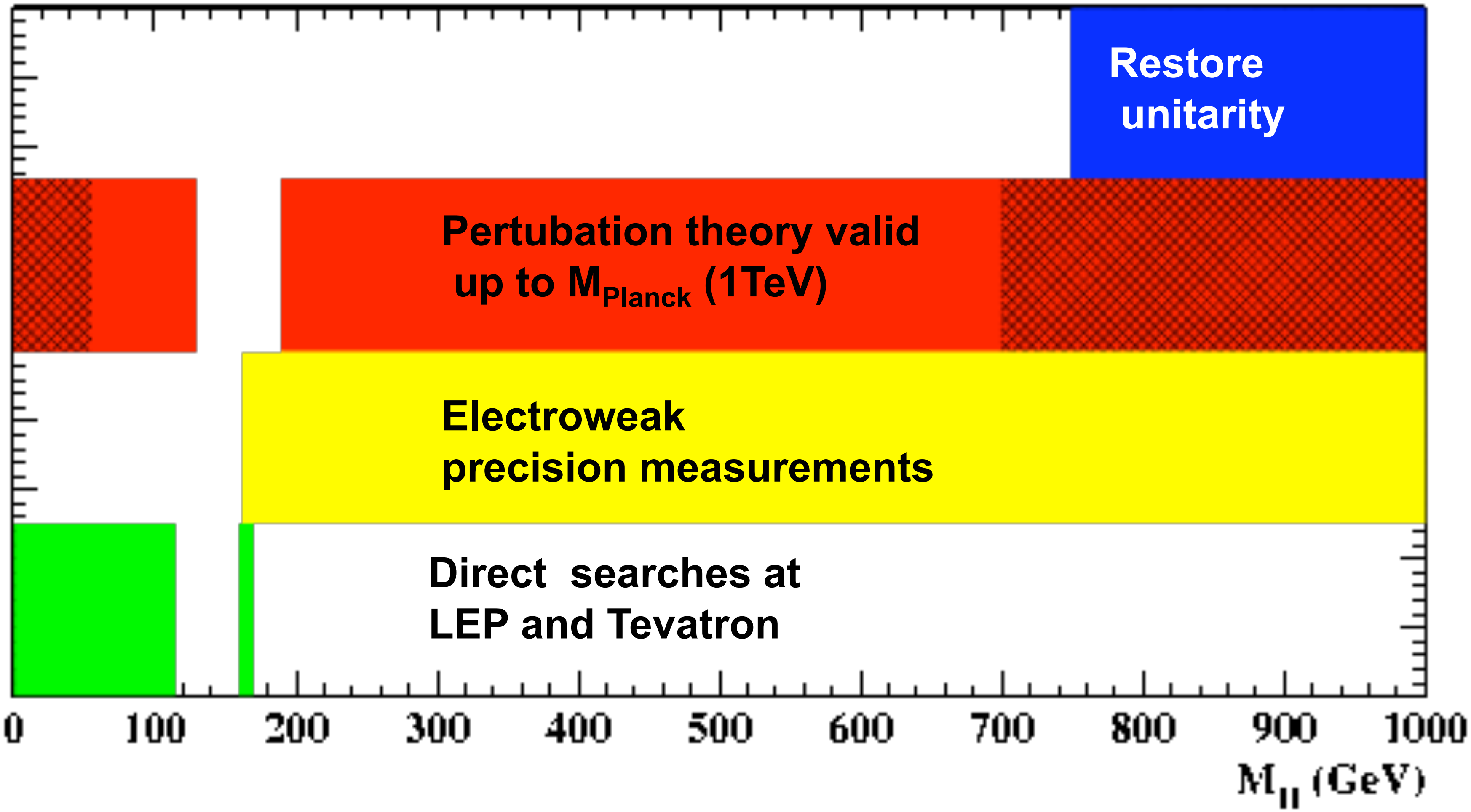


- Some general remarks
- Which topologies?
- Ex.1: H→ 2 photons incl.
- Ex.2: H→ 2 taus in VBF
- Conclusion

- other examples by Y. Sirois
- no detailled comparison btw. CMS and ATLAS



Current knowledge about the Higgs Boson Mass

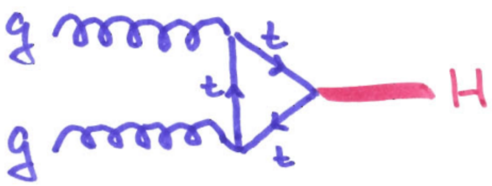


Standard Model prefers a light Higgs boson

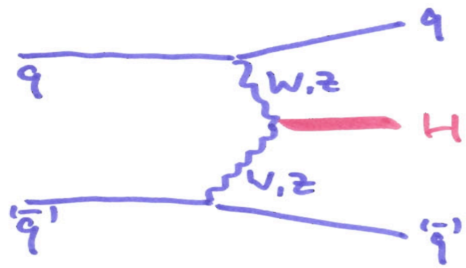
Theoretically allowed range up to 750 GeV

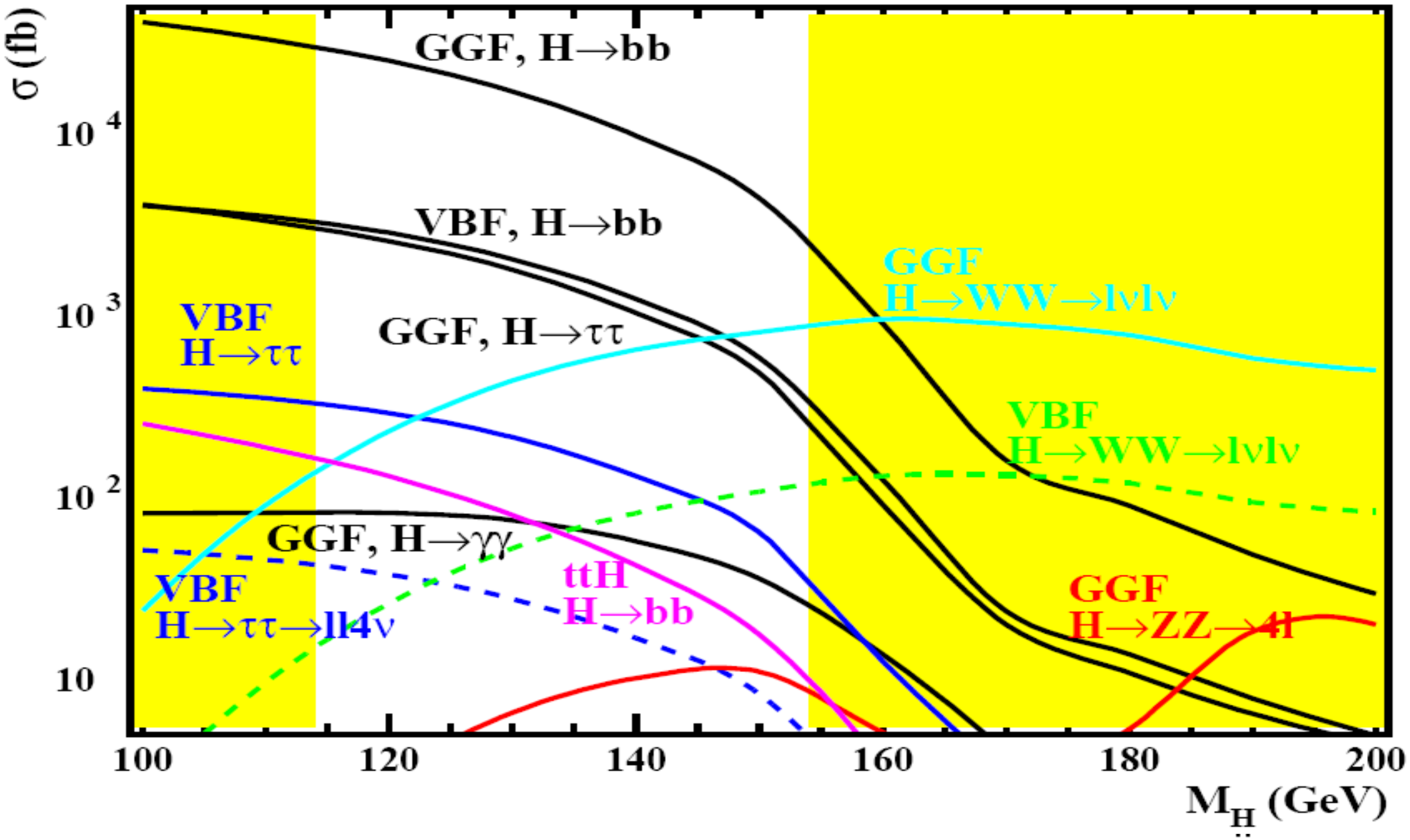
Signalrates for Higgs boson production

Gluonfusion (GGF)

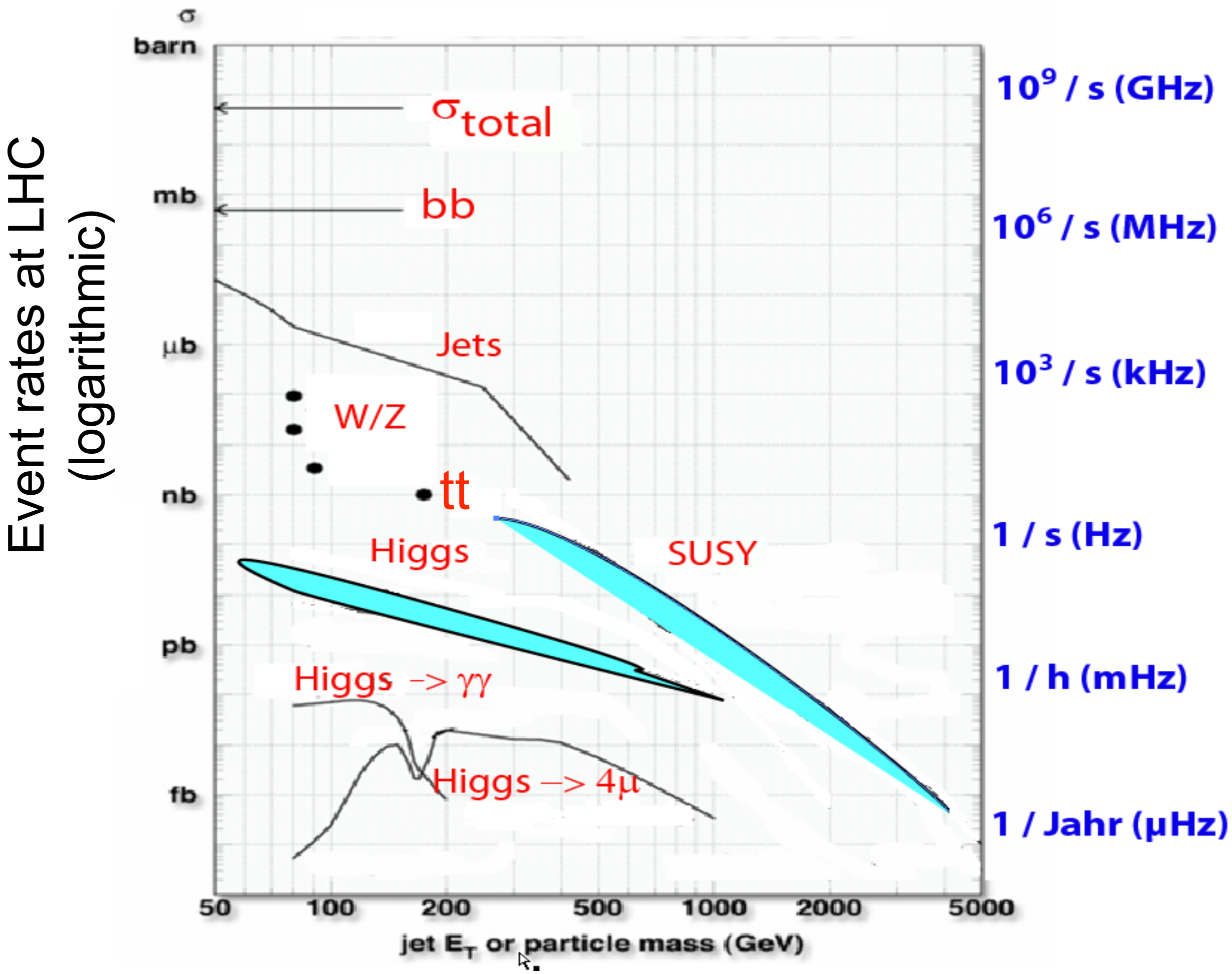


Vektorbosonfusion (VBF)





The challenge



all collisions
→ **not interesting**

data volume
1 Million Gigabyte/s
„Trigger“

recording
→ **maybe interesestings (0.0005%)**

Data volume:
1 Audio-CD/s
clever selection

possible discoveries
→ **only 0.000000001%**

only 1 Higgs particle on per 1 000 000 000 000 proton collisions

only 1 Higgs particle per 1 000 000 recorded events

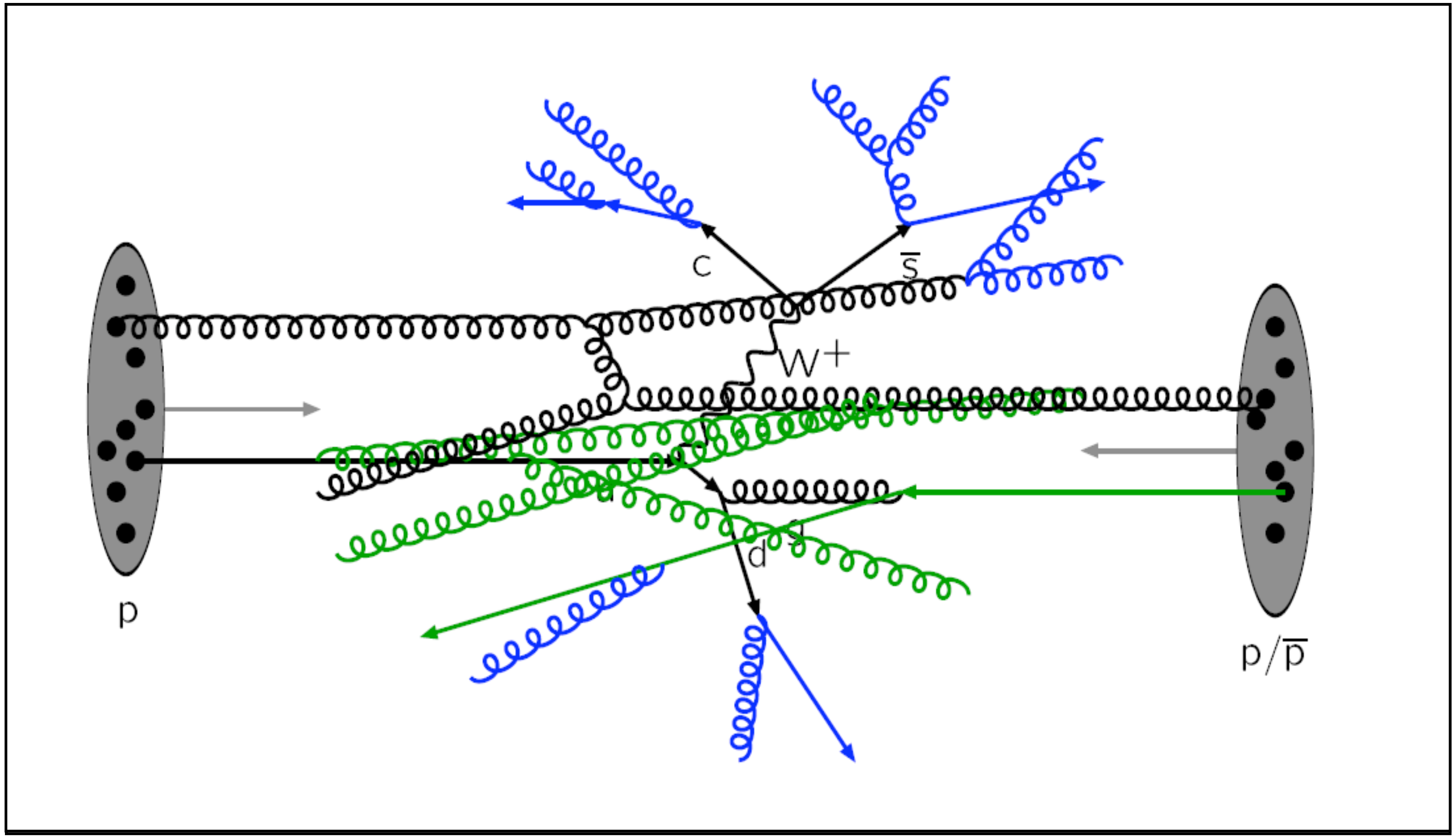
will not discuss trigger issues in this talk: >~90% for electron, myons and photons

A „complete“ event at LHC

„hard“ collision

+ ISR,FSR

+ „underlying event“



+ ~23 overlayed pp-interactions/bunch crossing at design luminosity

→ 10^9 pp-collisions / seconds

→ ~1600 charged particles in detektor per „event“

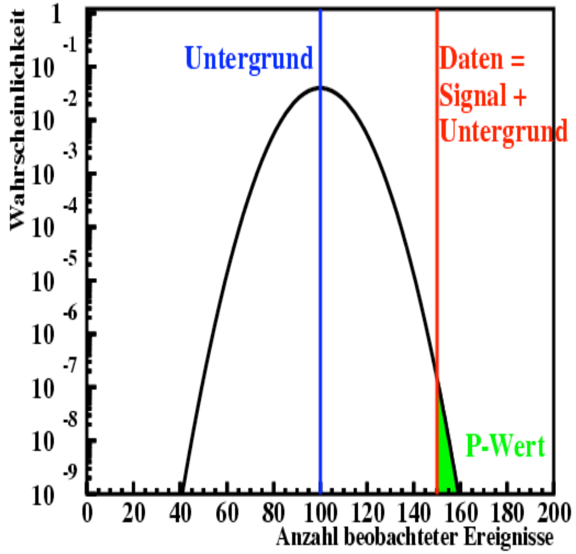
+ impact from „pile up“: readout time > Δt = 25 ns btw. bunch crossings

→severe requirements for radiation hardness, granularity, readout speed

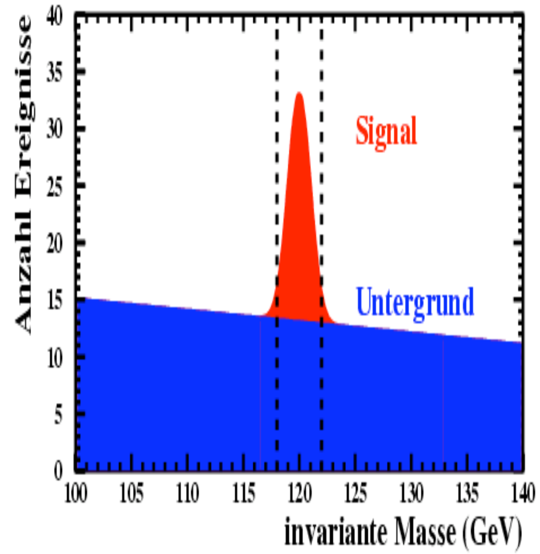
(not further discussed in this lecture, ECAL: 10^{15}n/cm^2 and 200 kGy/10yrs)

Discovery = significant deviation from SM expectation

- significant: probability of background fluctuation $<2.9 \times 10^{-7}$ equivalent to „5 sigma" for Gauss. distribution
- deviation: - new peak in mass distribution
  - excess in kinematic distribution



- for discovery (event counting or more information):
  - only need knowledge of background
  - wrong modelling of signal (rate and shape)
    → non optimal search strategy → more data needed
- for exclusion (and discovery potential)
  - need signal efficiency (and shape) in addition



- determination of background:

  (i) from data itself with little theory and MC input
  via auxilary measurement from same data set

  (ii) prediction from theory + MC + detector performance
  background=lumi*cross section*acceptance*efficiency

Which combination of production and decay?

	Gluon fusion	VBF	WH/ZH	ttH
$H \rightarrow \gamma\gamma$				
$H \rightarrow ZZ \rightarrow 4\,l$				
$H \rightarrow WW \rightarrow 2l2\nu$				
$H \rightarrow \tau\tau$				
$H \rightarrow bb$				

- sufficient production rate? σ_{prod}xBR large enough
- efficient trigger? electrons, photons, myons, taus+missing energy
- background reducible? mass reconstructable, good signal/background
- background controllable? determination from data possible

Mass resolution and signal-to-background ratio

- mass resolution:

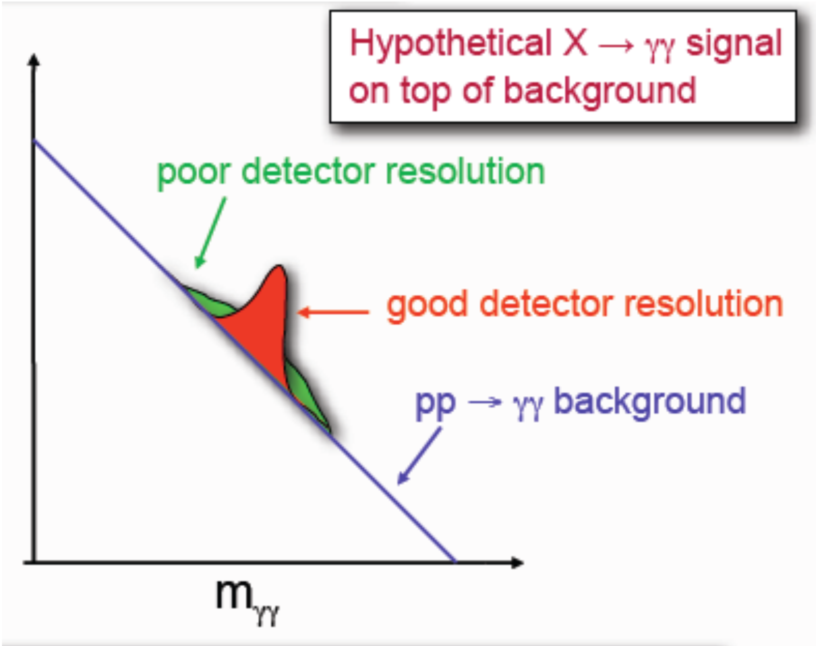
  propagates approx. linearly in significance

  resolution worse by factor 2

  mass window increased by factor 2

  larger background by factor 2

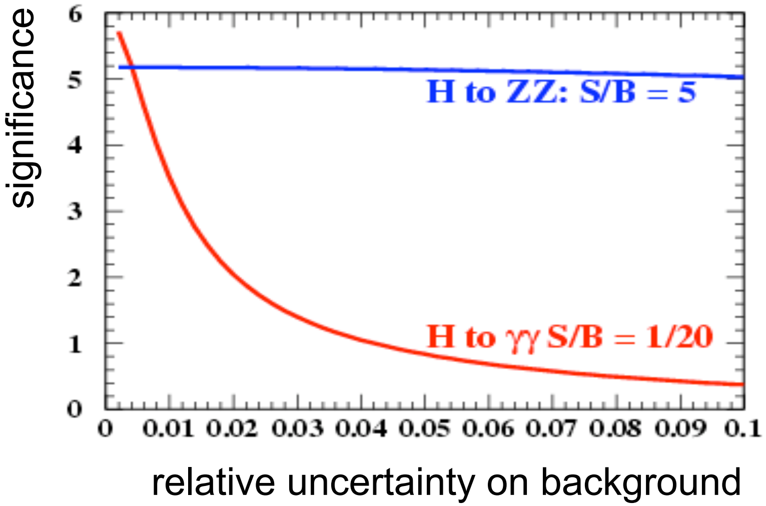
  worse signal-to-background ratio



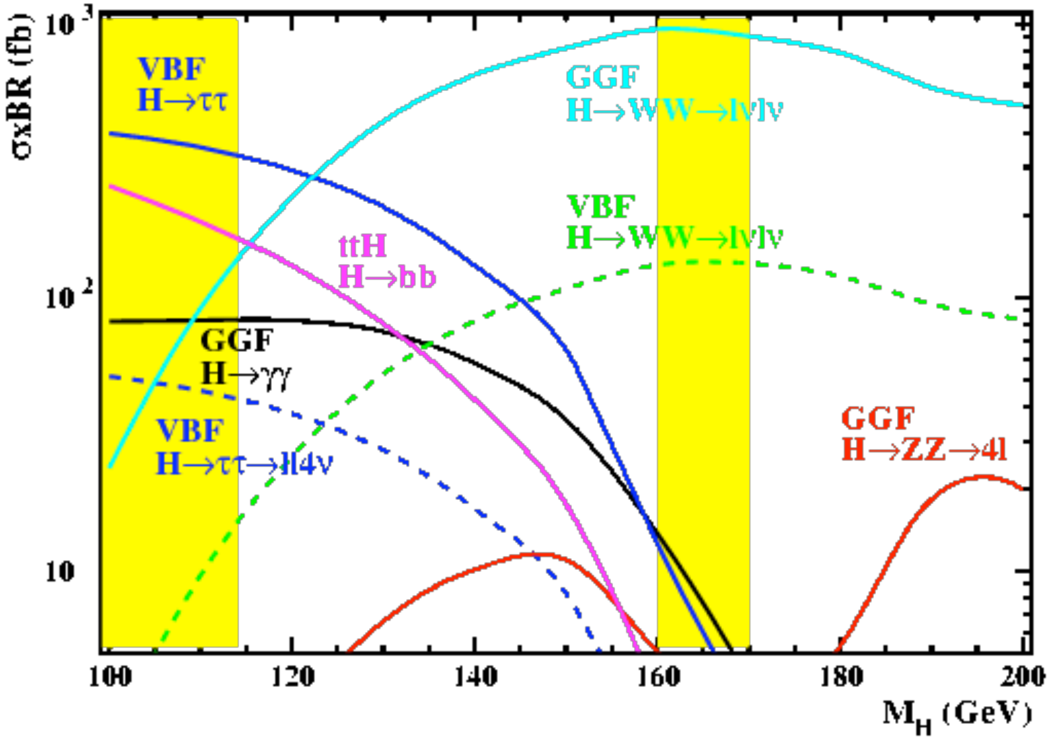
- signal-to-background-ratio:

  crucially influences impact

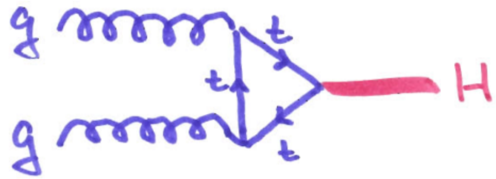
  of systematic uncertainties



Important channels for discovery of a light Higgs boson

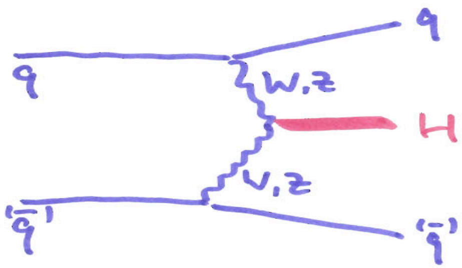


- inclusive search for H→2 photons
  only use Higgs decay products in analysis

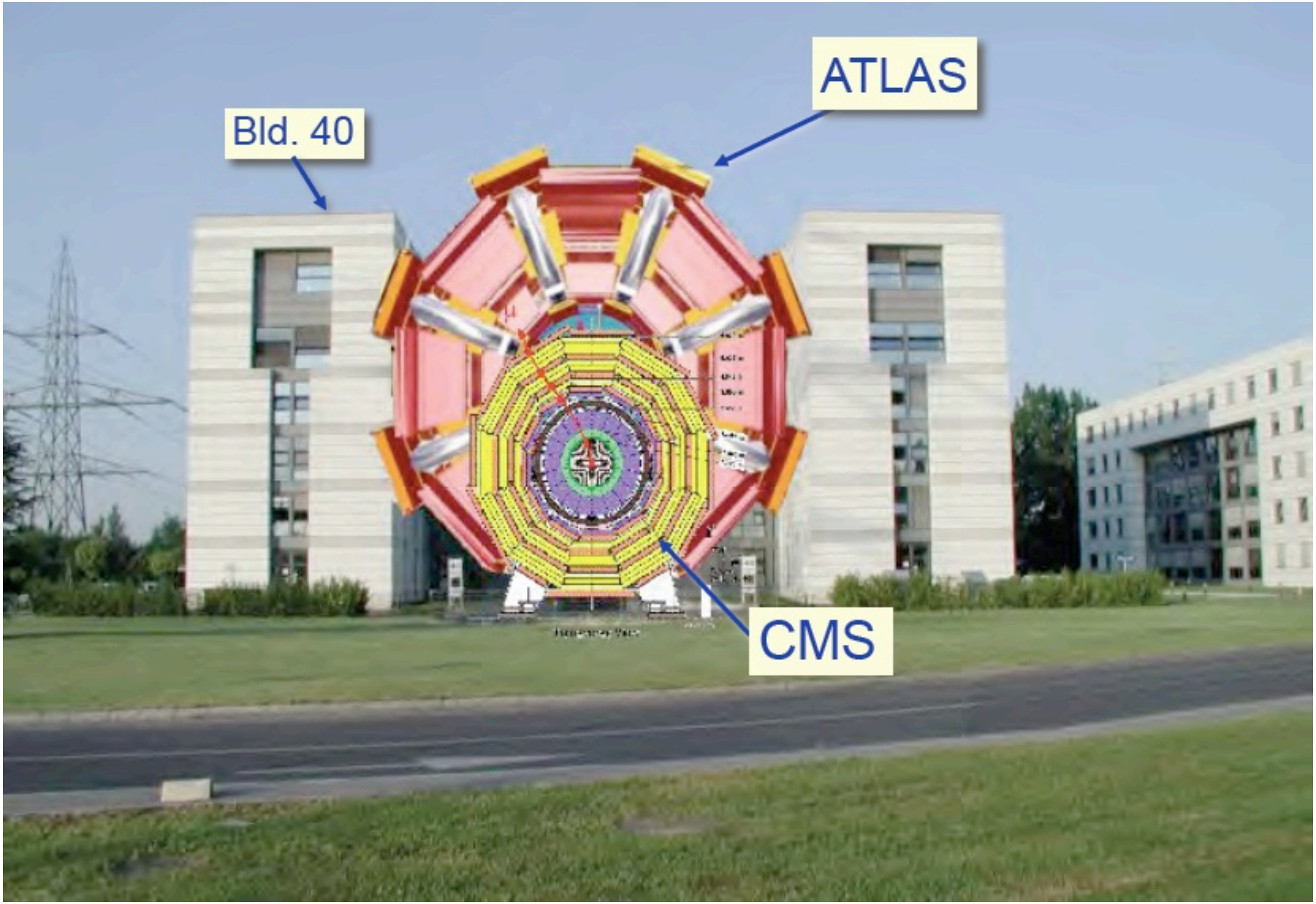


- exclusive search for H→ 2 τ in vector boson fusion
  exploit additional signature (forward jets, rapidty gap)

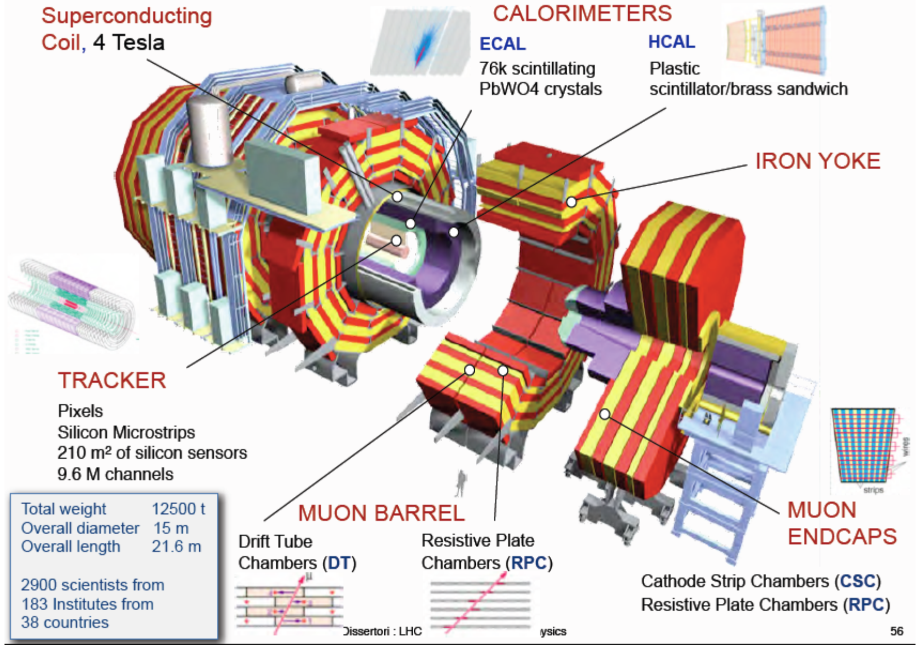
- additional channels: H→ZZ→ 4l, H→WW→ 2(l+ν)
  → see lecture by Yves Sirois



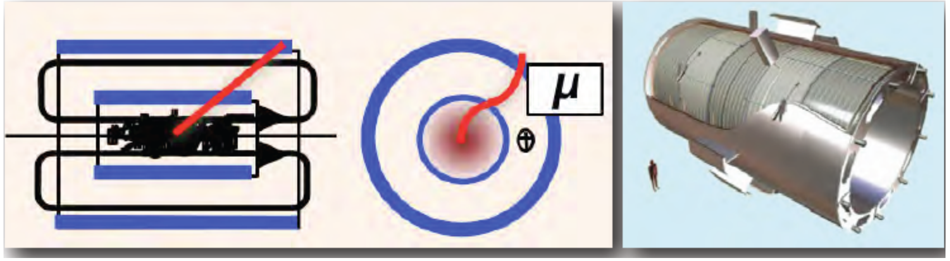
CMS and ATLAS: size comparison



Choice of magnet system

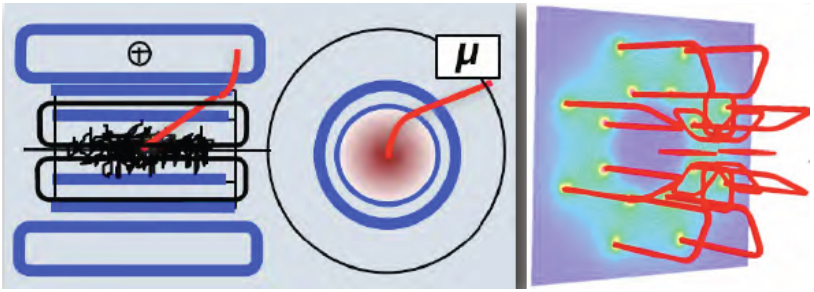


CMS: solenoid 4T

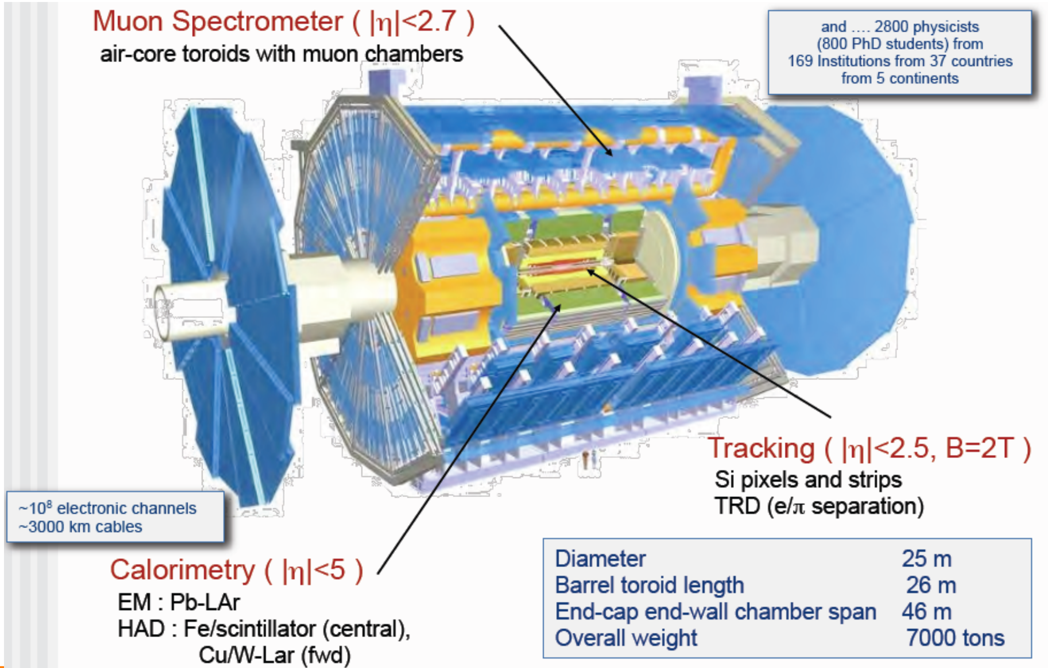


- excellent momentum resolution
- compact design: use B-field return yoke for μ-measurements
- calorimetry inside solenoid

ATLAS: solenoid 2T + toroid

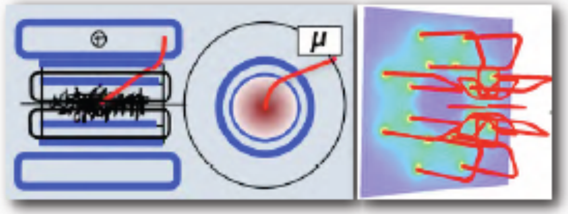


- standalone muon spectrometer up to small angles (air coil toroid)
- „deep“ and fine segmentedcalorimetry



Magent choice and influence on detector design

- Only one magnet system
  - simple and compact overall design
  - excellent momentum resolution using inner tracker
- R_{sol} determines cost, R=3m was doable
- B=4 T was realizable, 3.5 T would still deliver good physics
- Needs (instrumented) return yoke
  - limits momentum resolution at low p because of multiple scattering
  - might be problem for standalone muon triggering at high rate running (SLHC)
  - understanding of stray field
- Tracking limited at large rapidities
- All calorimeters inside coil
  - good for resolution, but puts size constraints on Tracker+Calos
  - eg. with R_{sol}=3m, $R_{Tracker}$=1.2-1.3m, <2m left for ECAL+HCAL !



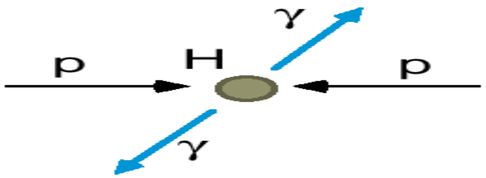
- Two magnet systems, because need smaller solenoid for inner tracking near IP
  - determines very large size, complex structure
- Large toroids determine cost
  - less coils (12->8): cheaper, but less uniform field
  - Thus need very precise field map !
- No return yoke needed
  - closed flux in air -> much less multiple scatt.
  - better standalone muon triggering/tracking at high rates
  - keeps calorimeters field free
  - a "lot of space" for calorimeters
- Good tracking at large rapidities
- Calorimeters outside small solenoid
  - material affects resolution of calorimeters

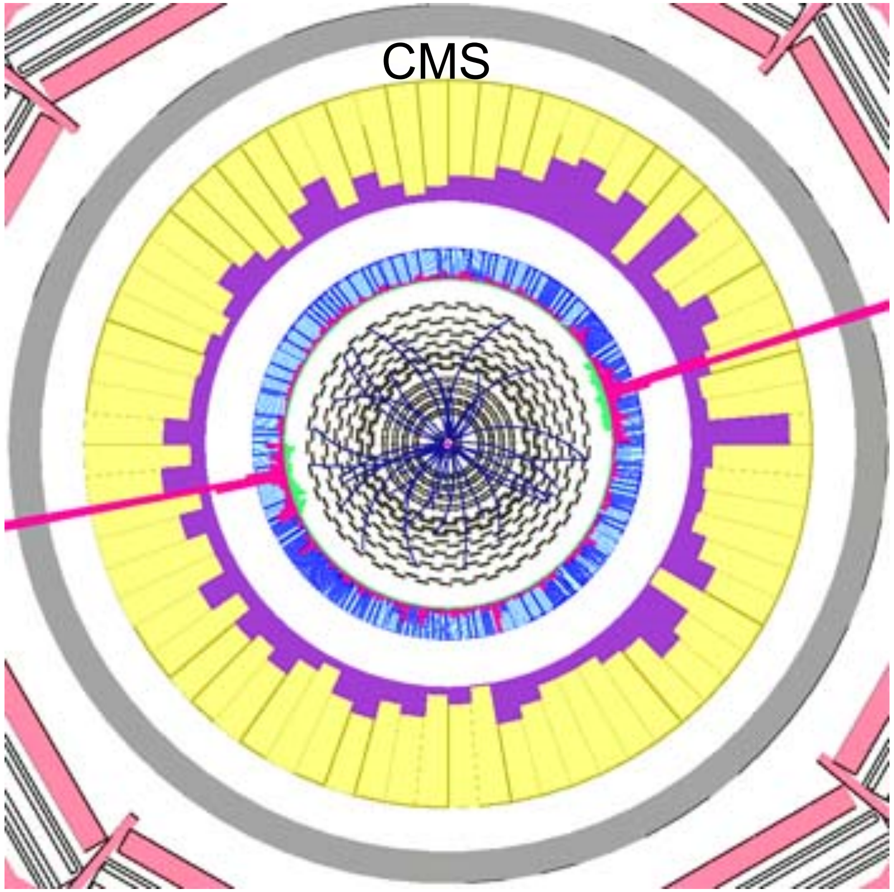
Overview of magnet systems

TABLE 3 Main parameters of the CMS and ATLAS magnet systems

	CMS	ATLAS		
Parameter	**Solenoid**	**Solenoid**	**Barrel toroid**	**End-cap toroids**
Inner diameter	5.9 m	2.4 m	9.4 m	1.7 m
Outer diameter	6.5 m	2.6 m	20.1 m	10.7 m
Axial length	12.9 m	5.3 m	25.3 m	5.0 m
Number of coils	1	1	8	8
Number of turns per coil	2168	1173	120	116
Conductor size (mm^2)	64×22	30×4.25	57×12	41×12
Bending power	$4\ T \cdot m$	$2\ T \cdot m$	$3\ T \cdot m$	$6\ T \cdot m$
Current	19.5 kA	7.7 kA	20.5 kA	20.0 kA
Stored energy	2700 MJ	38 MJ	1080 MJ	206 MJ

Inclusive search in H→ 2 photons

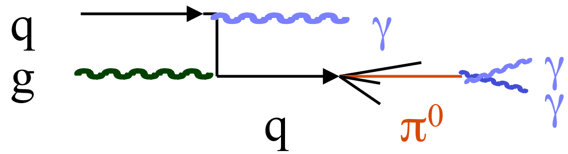




- signature: two high pt photons

  production rate: 83 fb
- backgrounds

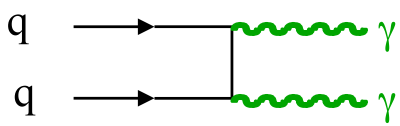
reducible: γ -jet 180 nb + jet-jet 480 μb



→discriminate photon + jet

goal: jet rejection of several 1000 @ ε~80%

irreducible: γγ 29pb



→excellent reconstruction of $M_{\gamma\gamma}$

goal: ΔM/M~O(1%)

Diphoton mass resolution

$M_{\gamma\gamma} = E_1 E_2 (1 - \cos\theta_{12})$ → excellent energy resolution + direction determination

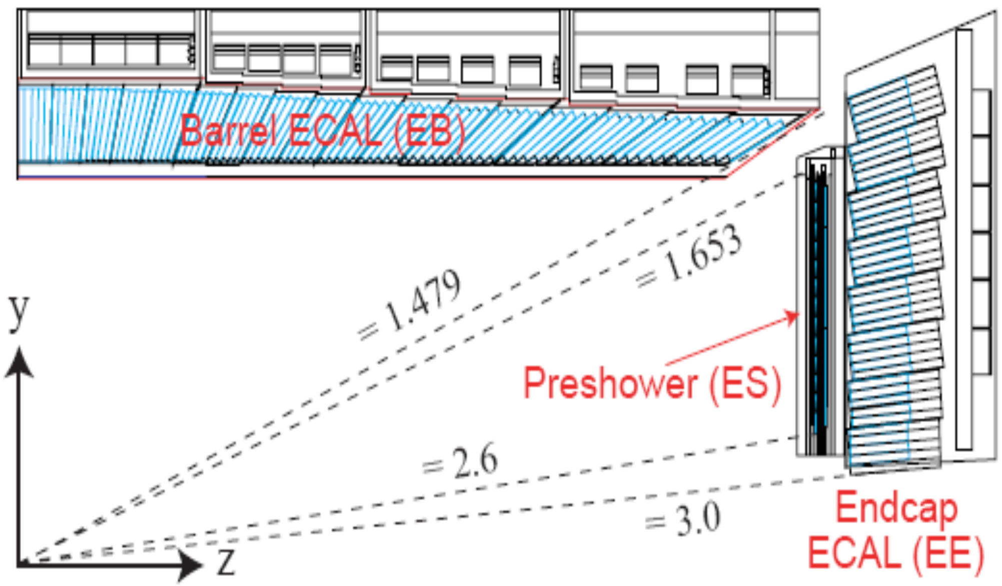
$\Delta M/M = \mathrm{sqrt}((\Delta E_1/E_1)^2 + (\Delta E_2/E_2)^2 + (\Delta\theta_{12}\sin\theta_{12}/(1-\cos\theta_{12}))^2)$

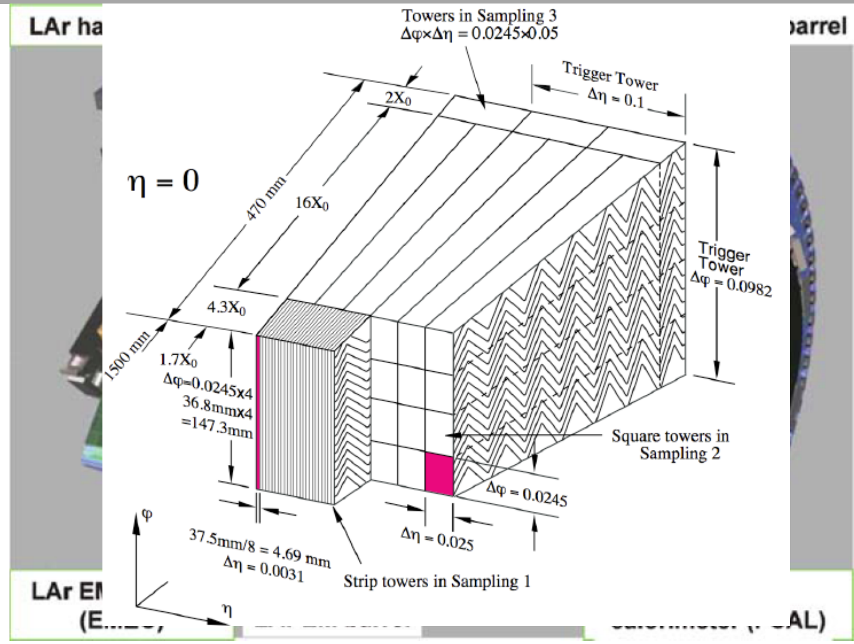
- parametrisation of relative energy resolution in electromagnetic calorimeters (ECAL)

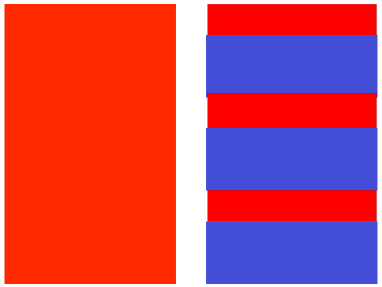
$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{S}{\sqrt{E}}\right)^2 + \left(\frac{N}{E}\right)^2 + C^2$$

- S stochastic term: statistic of shower particles, shower containment, shower fluctuations,…
- N noise term: from digitisation, pileup, ….
- C constant term: calibration, uniformity, stability of signal yield

Technology choices in CMS and ATLAS

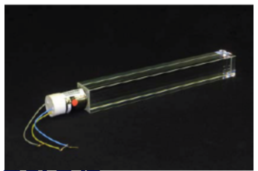






- CMS: homogenous

  $PbWO_4$ crystals $22x22mm^2$
  R_M=22mm, X_0=8.9 mm
  → excellent s-term
  - inside solenoid
  - no longitudinal segmentation
  + preshower in endcap



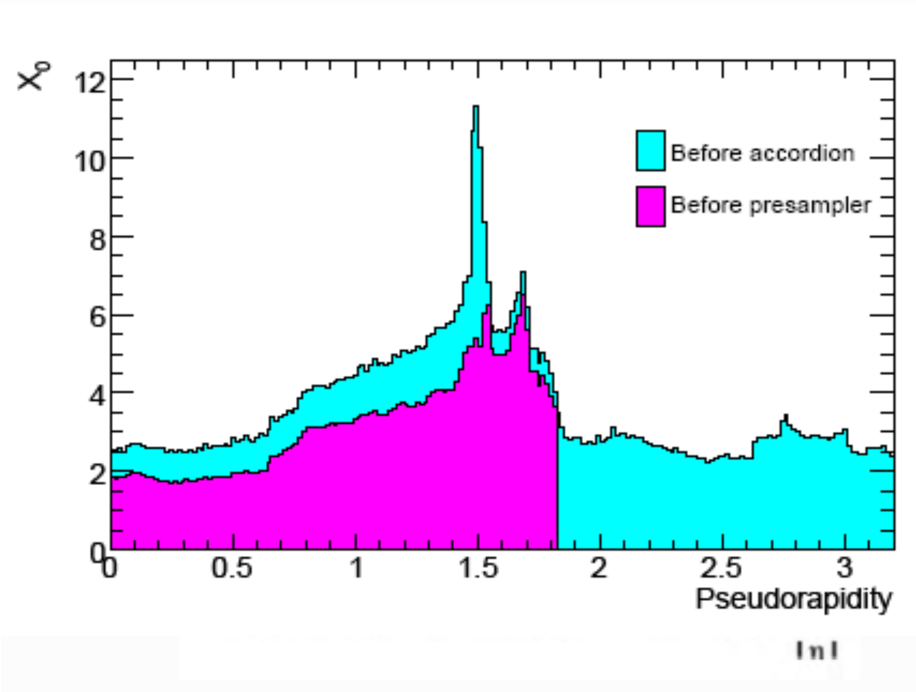
- ATLAS: sampling calorimeter

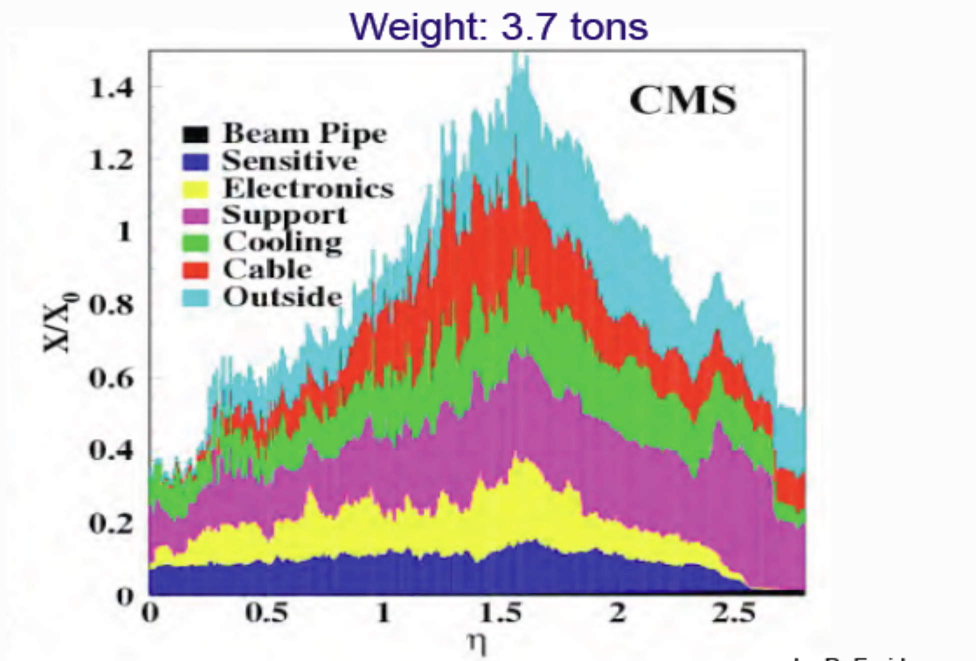
  lead/liquid Argon accordion

  - outside solenoid (2 to 4 X_0)
  - 3(4) longitudinal segments

  + preshower detector in barrel

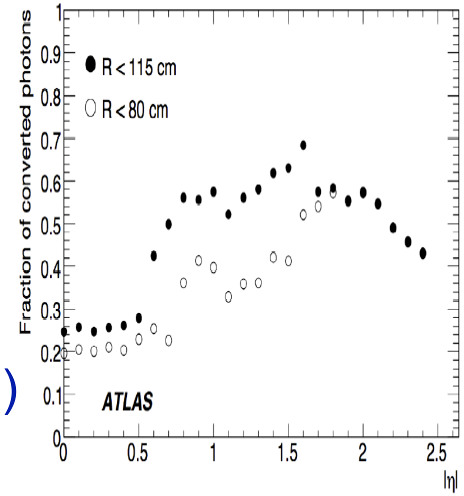
Significant amount of material in front of ECALS

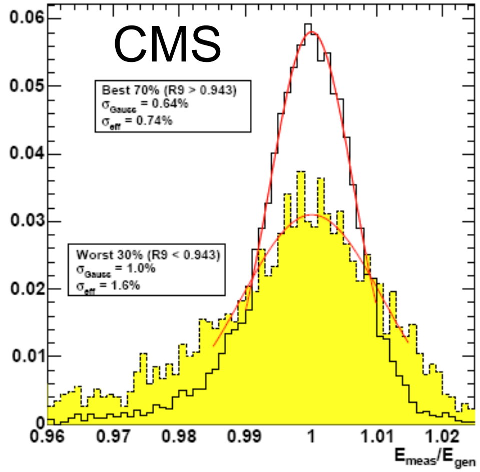




by D. Froidevaux

- large fraction of converted photons:
  ATLAS: ~60% of all events at least one converted photon (r<80cm)
  → special treatment of conversions
  (broader clusters, reconstruction of tracks)





Comparison of ATLAS and CMS ECALS

TABLE 8 Main parameters of the ATLAS and CMS electromagnetic calorimeters

	ATLAS		CMS	
Technology	Lead/LAr accordion		$PbWO_4$ scintillating crystals	
Channels	Barrel	End caps	Barrel	End caps
	110,208	63,744	61,200	14,648
Granularity	$\Delta\eta \times \Delta\phi$		$\Delta\eta \times \Delta\phi$	
Presampler	0.025×0.1	0.025×0.1		
Strips/ Si-preshower	0.003×0.1	0.003×0.1 to 0.006×0.1		32×32 Si-strips per 4 crystals
Main sampling	0.025×0.025	0.025×0.025	0.017×0.017	0.018×0.003 to 0.088×0.015
Back	0.05×0.025	0.05×0.025		
Depth	Barrel	End caps	Barrel	End caps
Presampler (LAr)	10 mm	2×2 mm		
Strips/ Si-preshower	$\approx 4.3\ X_0$	$\approx 4.0\ X_0$		$3\ X_0$
Main sampling	$\approx 16\ X_0$	$\approx 20\ X_0$	$26\ X_0$	$25\ X_0$
Back	$\approx 2\ X_0$	$\approx 2\ X_0$		
Noise per cluster	250 MeV	250 MeV	200 MeV	600 MeV
Intrinsic resolution	Barrel	End caps	Barrel	End caps
Stochastic term *a*	10%	10 to 12%	3%	5.5%
Local constant term *b*	0.2%	0.35%	0.5%	0.5%

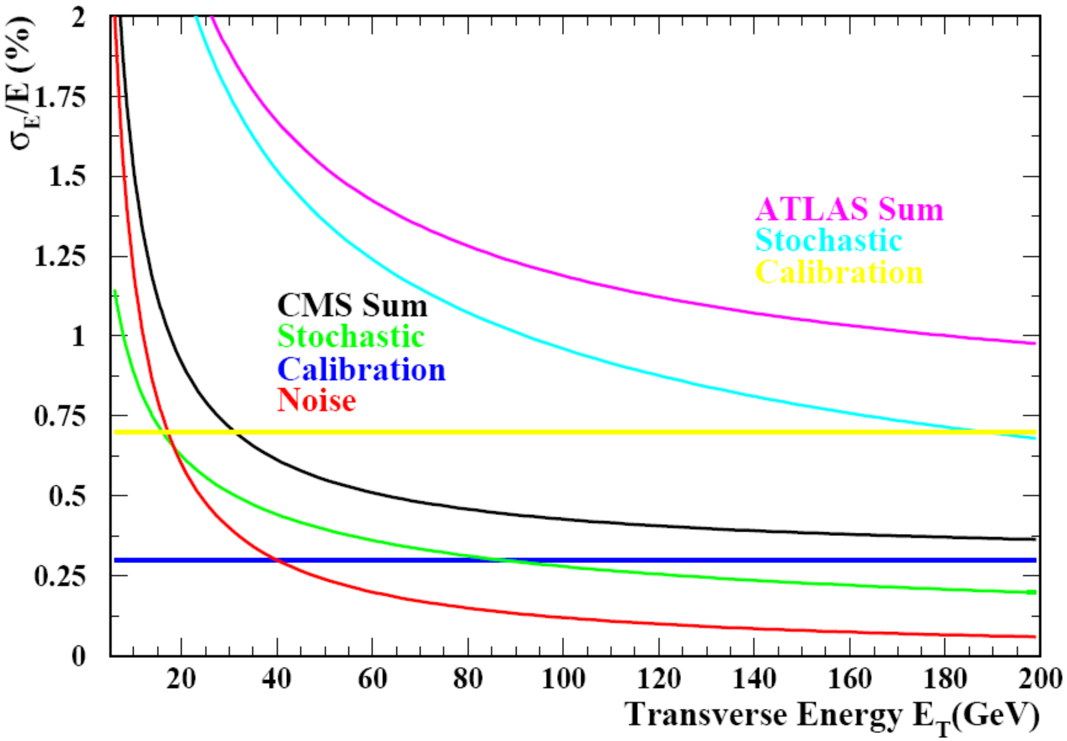
Note the presence of the silicon preshower detector in front of the CMS end-cap crystals, which have a variable granularity because of their fixed geometrical size of $29 \times 29\ mm^2$. The intrinsic energy resolutions are quoted as parametrizations of the type $\sigma(E)/E = a/\sqrt{E} \oplus b$. For the ATLAS EM barrel and end-cap calorimeters and for the CMS barrel crystals, the numbers quoted are based on stand-alone test-beam measurements.

Froidevaux, Sphicas

- depth in X_0 comparable
- lateral segmentation comparable
- noise per cluster comparable
- stochastic term ~ 3 to 2 better

  in CMS compared to ATLAS

Comparison of expected energy resolution



- CMS versus ATLAS
  - stochastic term factor 3 smaller
  - constant term factor 2 smaller
- s+c cross over

  ATLAS: ~180 GeV

  CMS: ~ 20 GeV

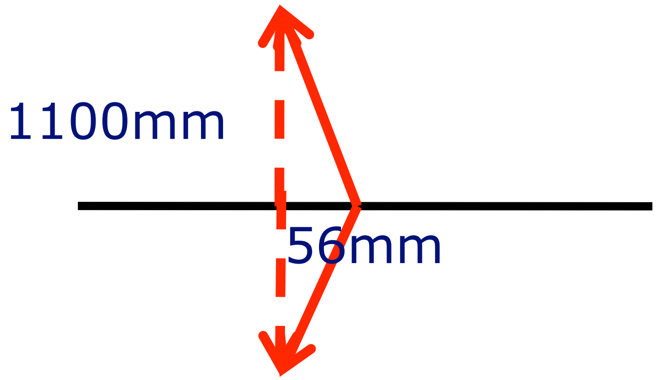
  compare: typical photon energy cuts 25 to 40 GeV

- the issue of calibration: example CMS
  - temperature stability: Δlight yield = -1.9% /1K → ΔT=0.05K
  - voltage stability: Δ gain=3% / V → ΔV = 60mV
  - knowledge of dead material, monitoring of crystal intransparancy from radiation
  - production+test beam+cosmic rays: 3%
  - in situ: W→eν events: match p from tracker to E from calo
  - Z→ee events: match to known Z mass
  - π^0,η→ 2 photons Z→$\mu\mu\gamma$

→ goal 0.3%

Influence of direction measurement

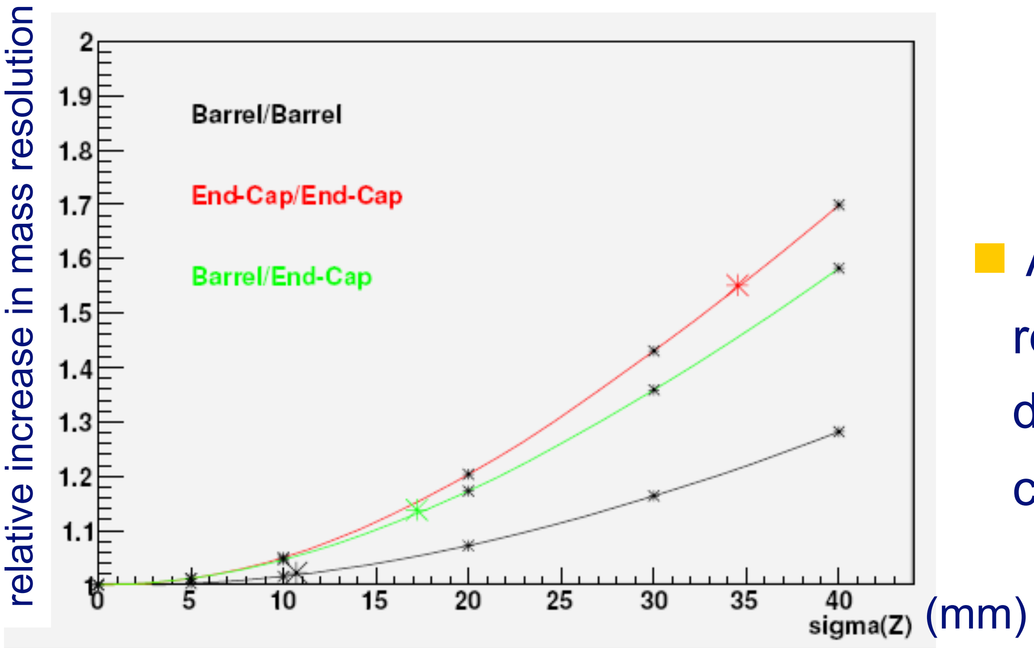
- beam spread: x,y 14 μ m, z 56mm: constraint to (0,0,0)
  → ATLAS and CMS: contribution ~ 1.5 GeV to mass measurement



- tan θ =1100/56=19.6 → 3 degree
  → 6 degree = 0.1 rad difference in θ_{12}

$$\Delta M/M = \Delta\theta_{12}\sin\theta_{12}/(1-\cos\theta_{12})$$

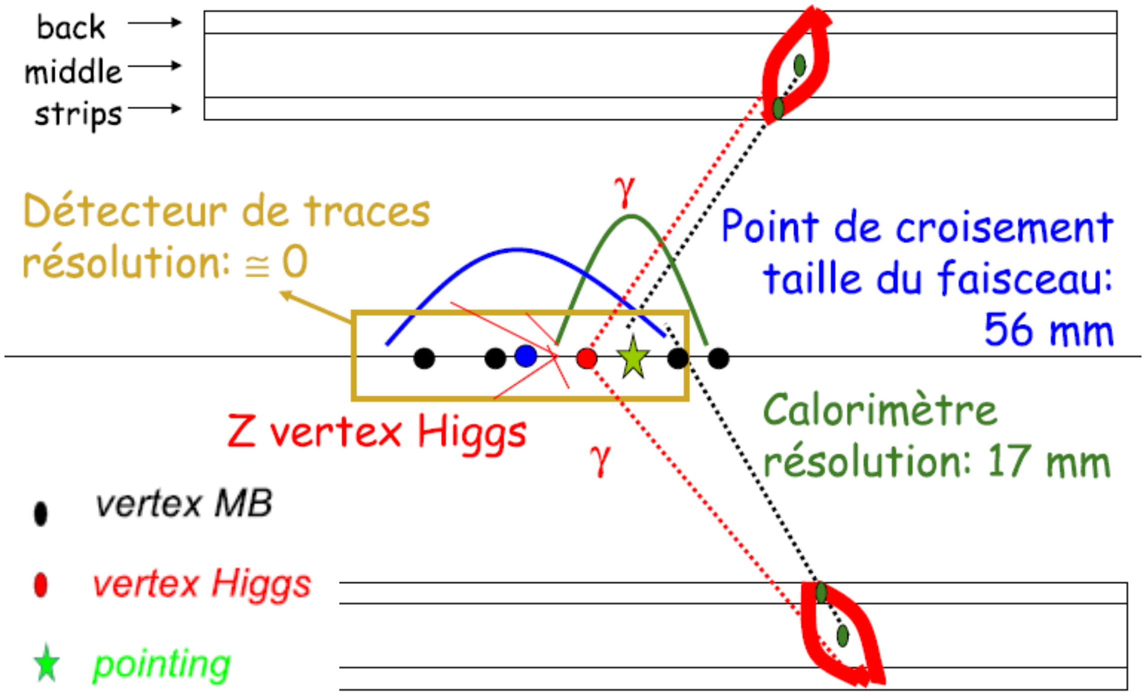
θ_{12} = 170: 0.1 → 1%



- ATLAS toy MC:
  relative increase in mass resolution depending on knowledge of Z component of photon vertex

Influence of direction measurment

- direction mass resolution determined by knowledge of z photon vertex
  - use (0,0,0) „beam spot“
  - identify Higgs production vertex from underlying event tracks (CMS+ATLAS)
  - using pointing information from calo (ATLAS $\sigma(\theta) = 55mrad/\sqrt{E}$)



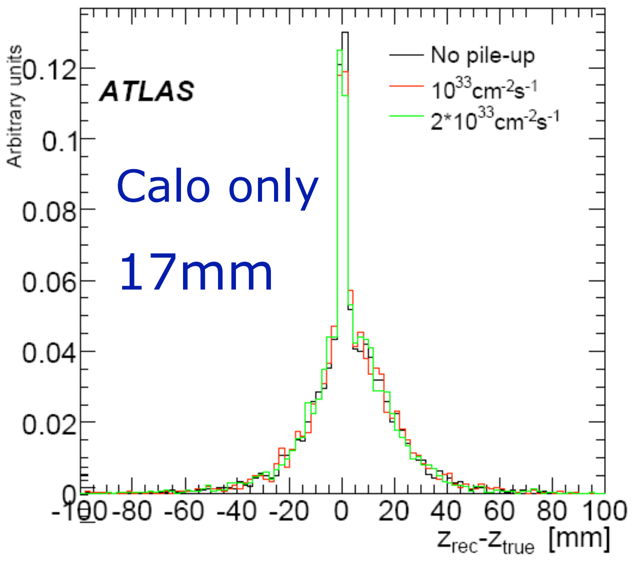
z definition	σ_z mm	σ_m(GeV)
Beam “spot”	56	2.04
calorimeter	17	1.34
UE for PV	0.1	1.22

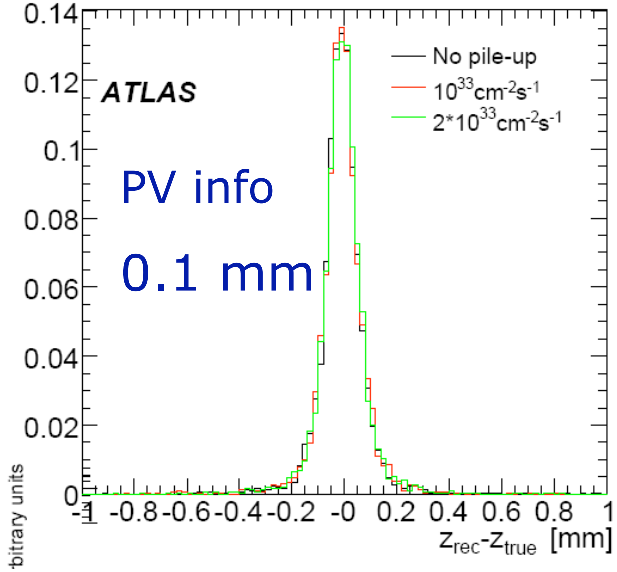
ATLAS toy MC

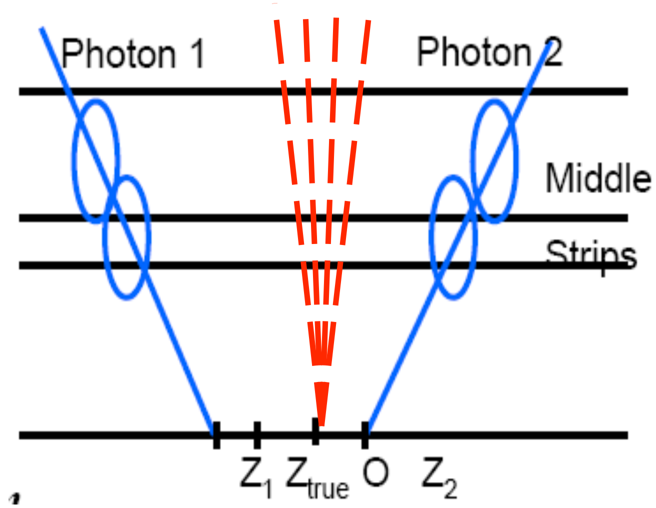
- both experiments claim to find correct vertex with efficiency of 80% at L=2x10^{33}/cm/s

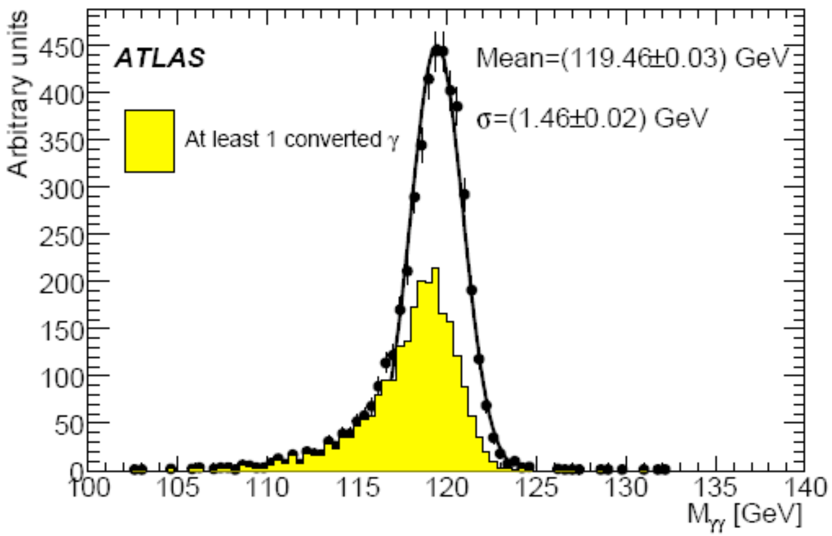
Mass resolution: origin of photons in z

Photon vertex: - photon direction from calo (+ conversion)
- primary vertex from underlying event









excellent mass resolution

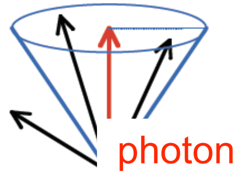
needs good knowledge of:

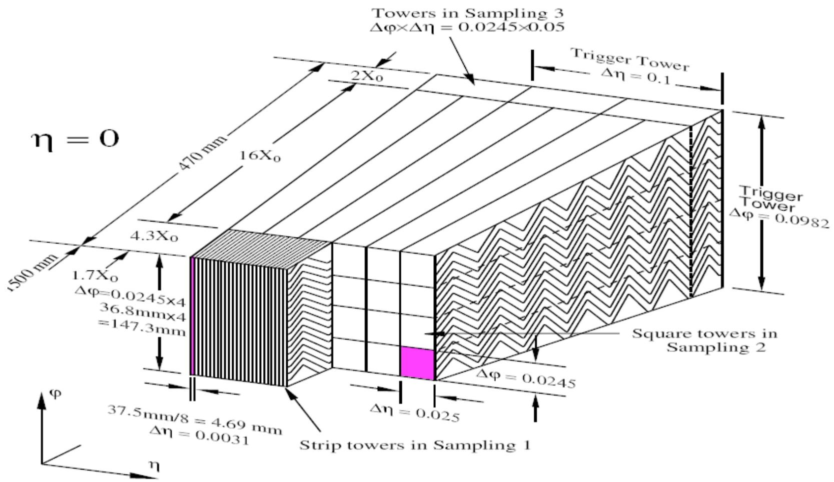
- energy scale: few per mille

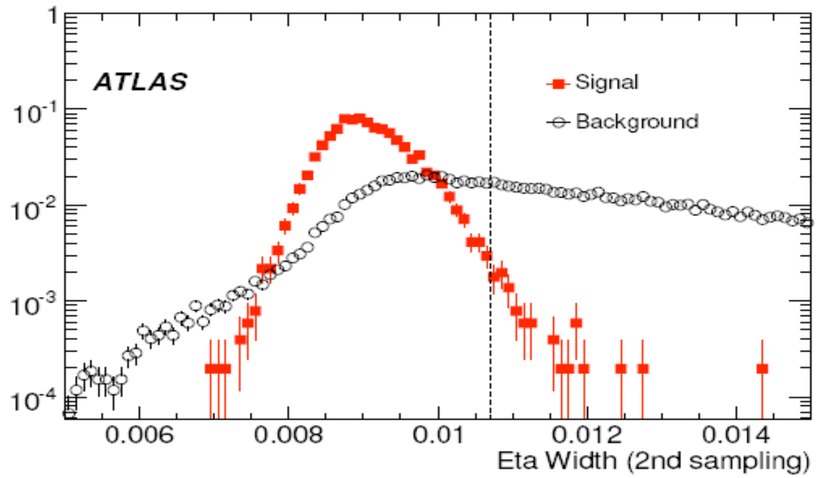
- incl. conversions + dead material

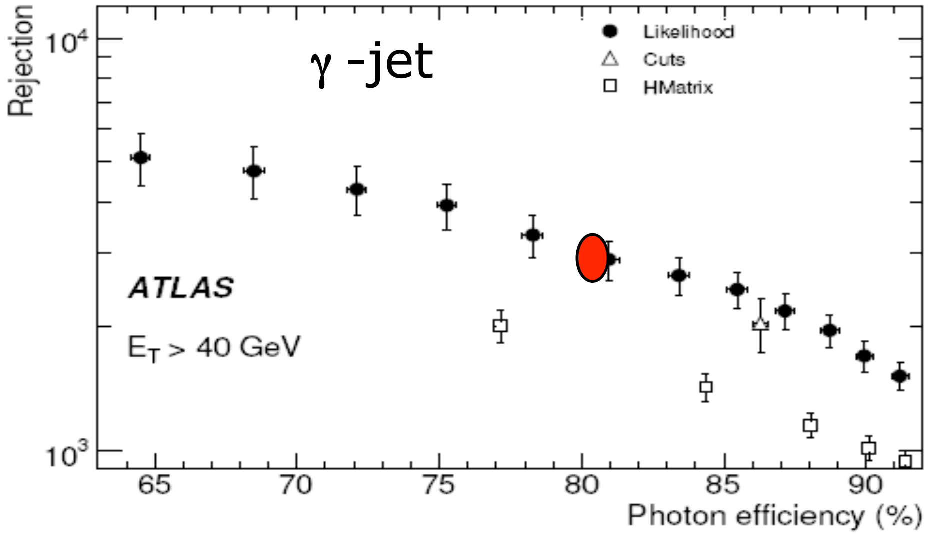
Discrimination between photons, π^0 and jets

- exploit high granularity of ATLAS ECAL e.g. cluster width in 2nd sampling + other shower shapes + HCAL info + isolation in tracking detector







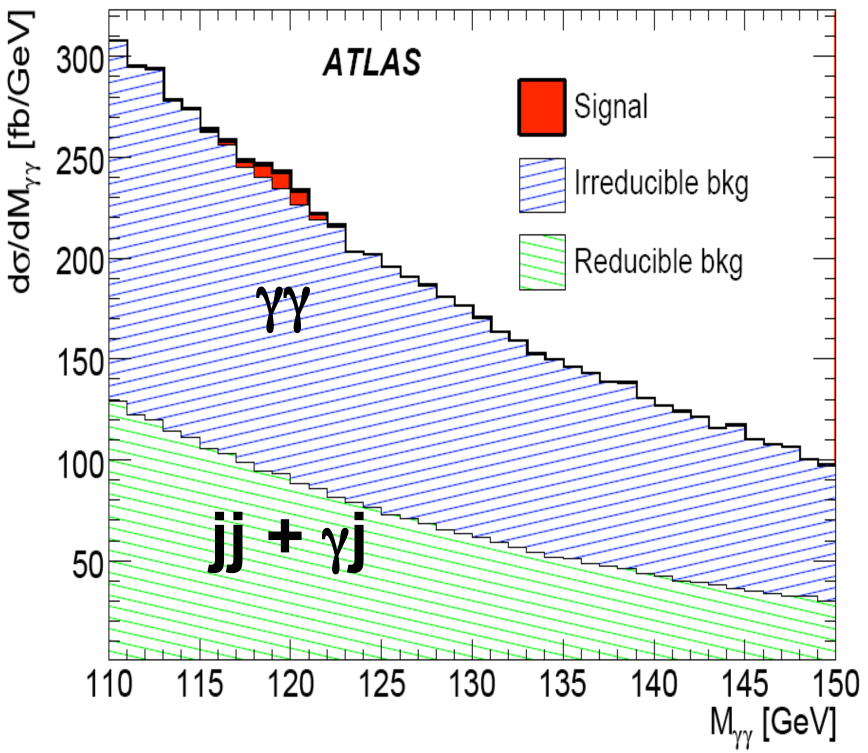


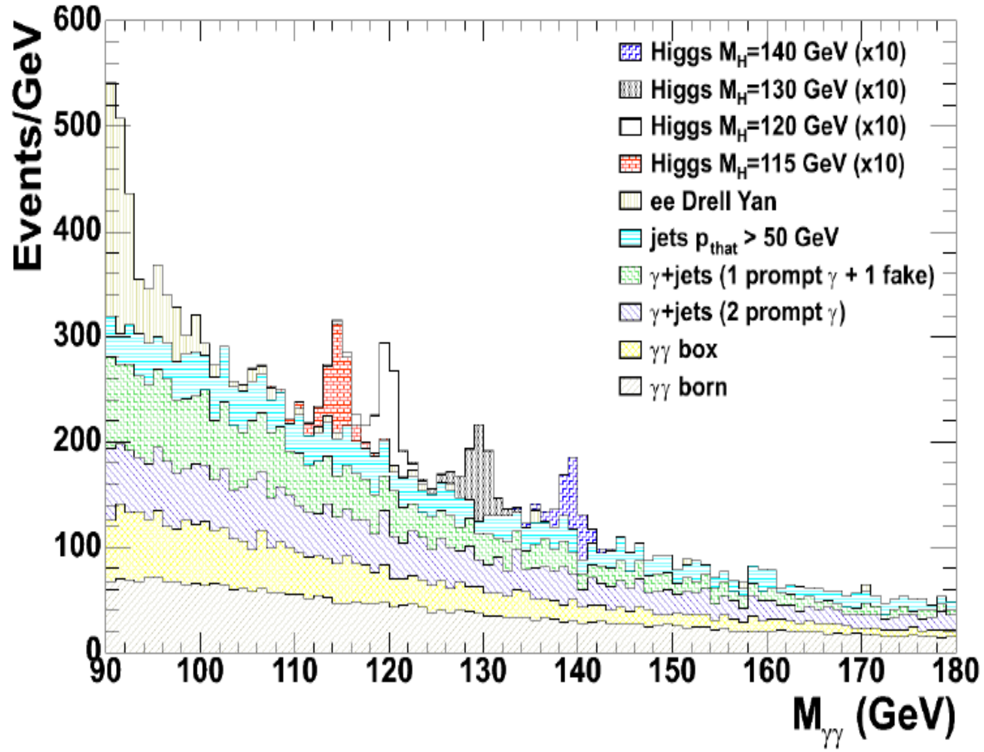
	All	quark-jet	gluon-jet
	before isolation cut		
Rejection	5070±120	1770±50	15000±700
	after isolation cut		
Rejection	8160± 250	2760±100	27500±2000

better rejection for broader gluon jets

efficieny for photons > 25 GeV: 80%

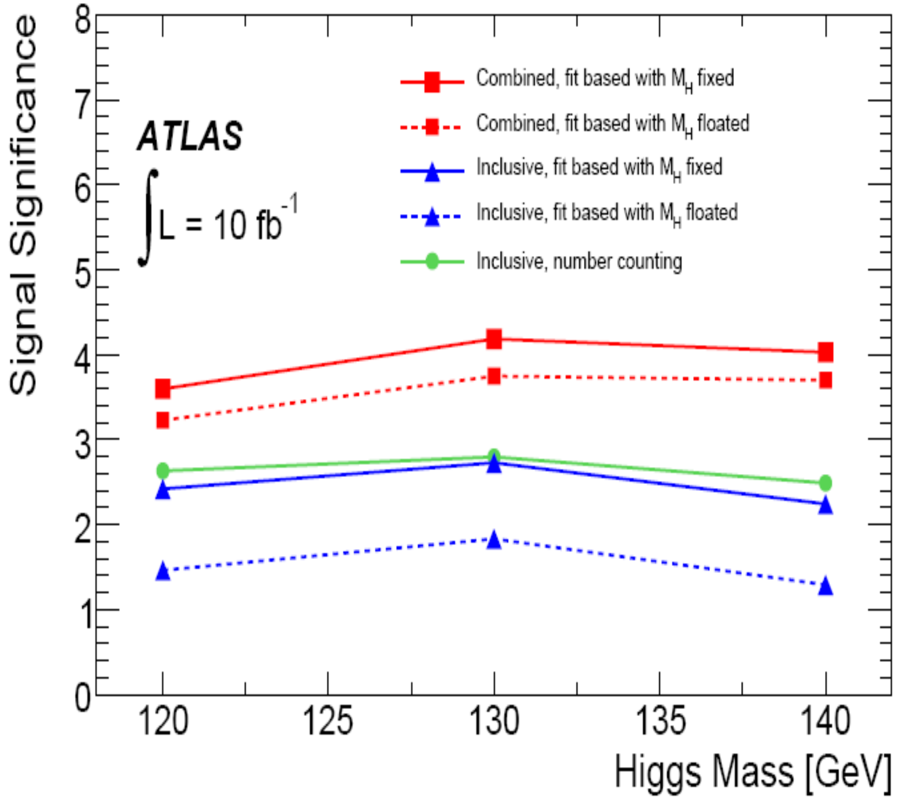
Mass distributions

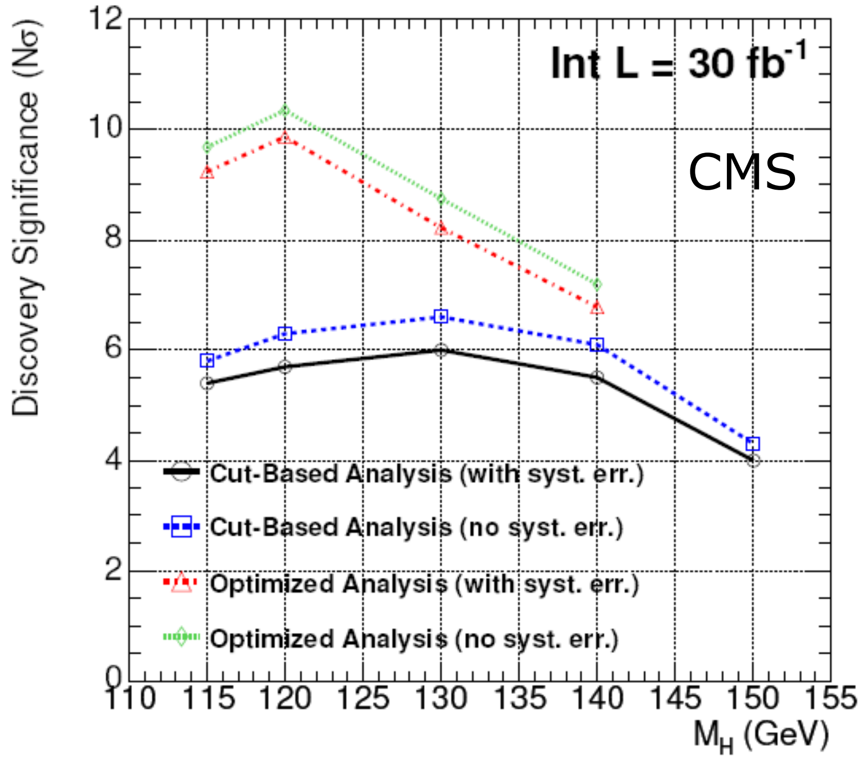




- signal efficiency ~25%, mass speak significantly smaller at CMS
- S/B~1/40 in ATLAS , ~1/x in CMS?
- background estimate from sideband: 0.65% (0.4%stat., 0.5% BG shape, 20 fb^{-1}) CMS
- improved analysis developed in both experiments based on
  - (i) categories: (non) converted photons and pseudorapidtdy →mass resolution
  - (ii) additional information (pt of Higgs, ….) + multivariate techniques
  - (iii) exclusive analysis for VBF, WH, ttH production

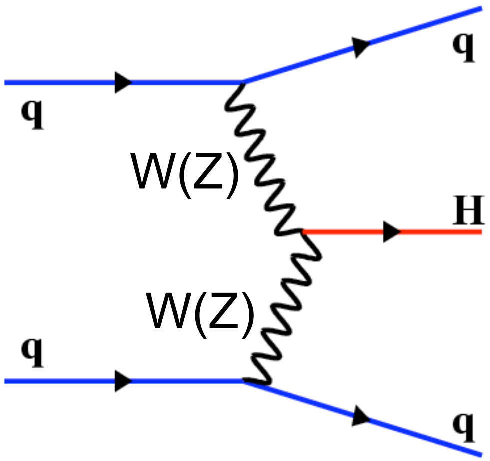
H→ 2 photons: significance





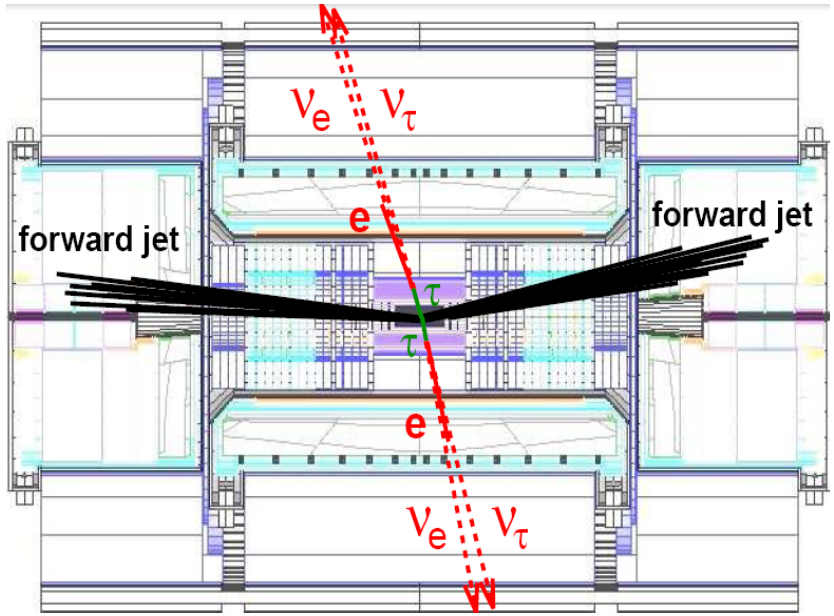
- depends crucially on mass resolution and hence on ECAL calibration
- ATLAS: 1% worse E resolution ~10% loss in significance
- CMS: estimate of signal systematics ~20% (15% theory, 5% lumi, 3% exp.)
- comparison difficult: different cross sections and MC generators used
  numbers for mass resolution, jet rejections not fully available

Weak vector boson fusion $H \rightarrow \tau\tau$

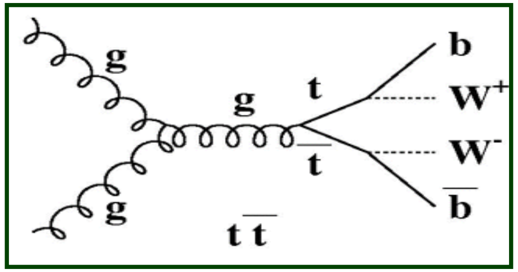


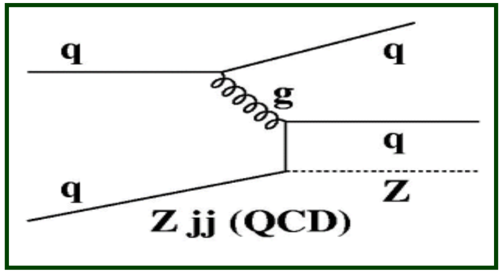
$\tau\tau \rightarrow ll$ ($l=e,\mu$): 40fb
$\tau\tau \rightarrow l$ had: 140 fb

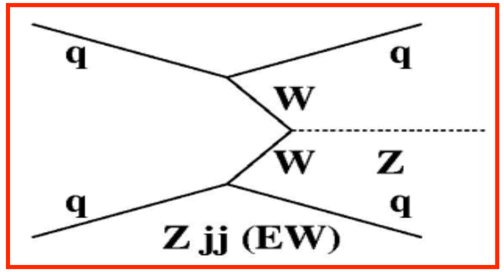
- signature:
  - 2 forward jets with rapidity gap
  - Higgs decay products in central detector
  - missing energy from neutrinos



- background: reducible --→ irreducible





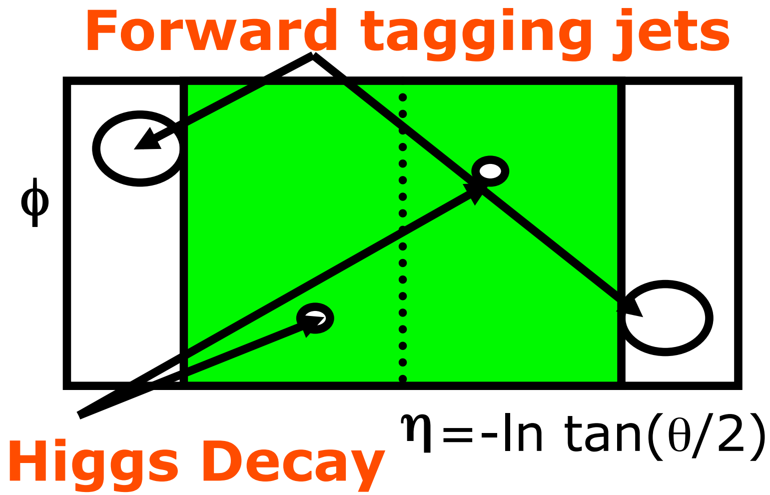


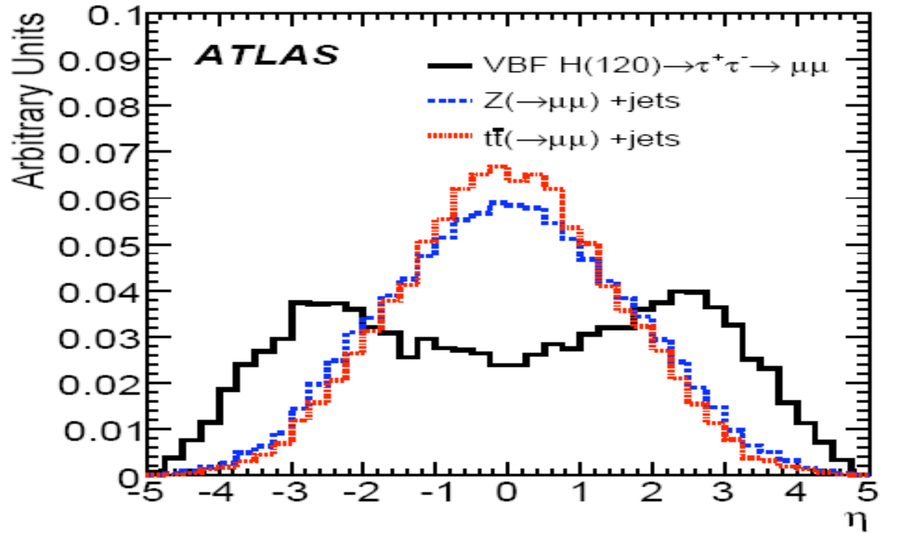
833 pb | 770(ll)+170($\tau\tau$)pb | 1.7pb ($\tau\tau$)

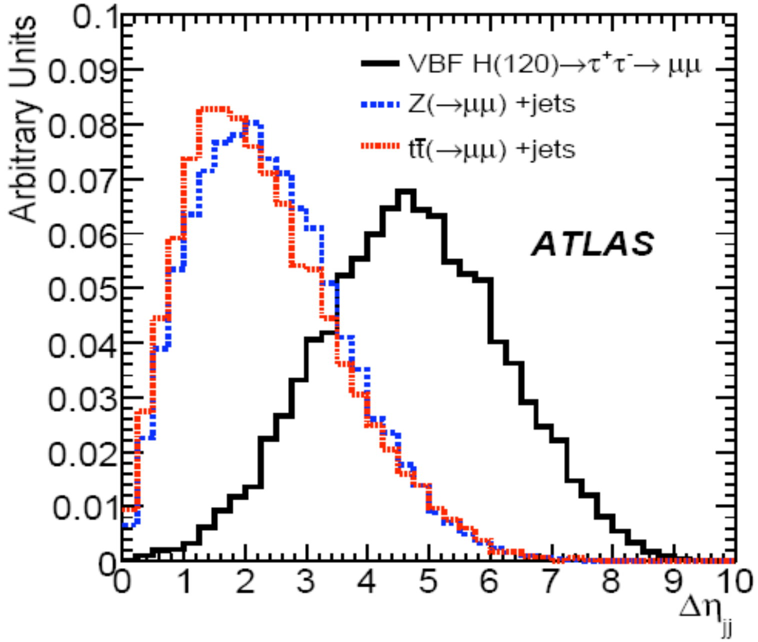
kinematics, colour flow, …

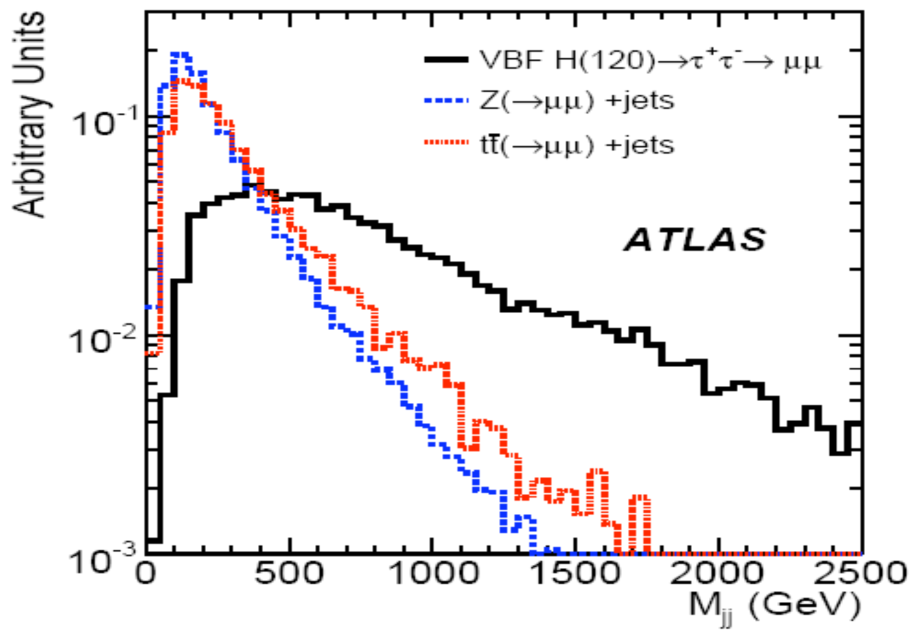
mass reconstruction

Vector boson fusion: kinematic differences

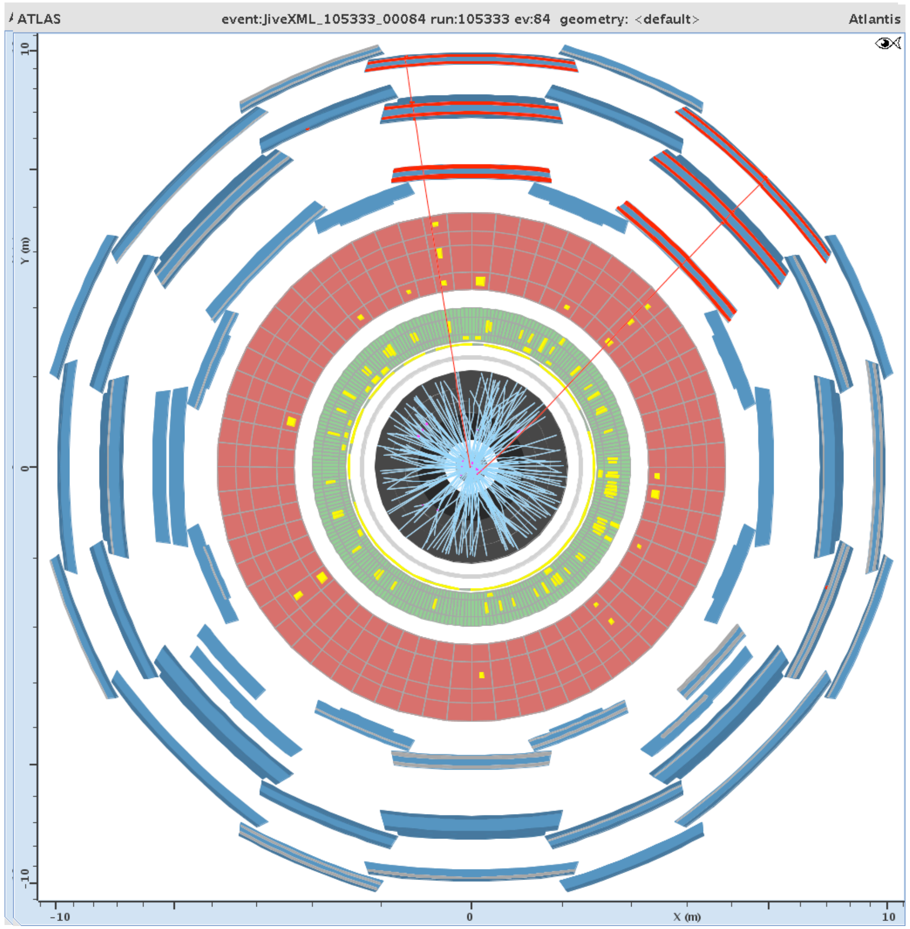


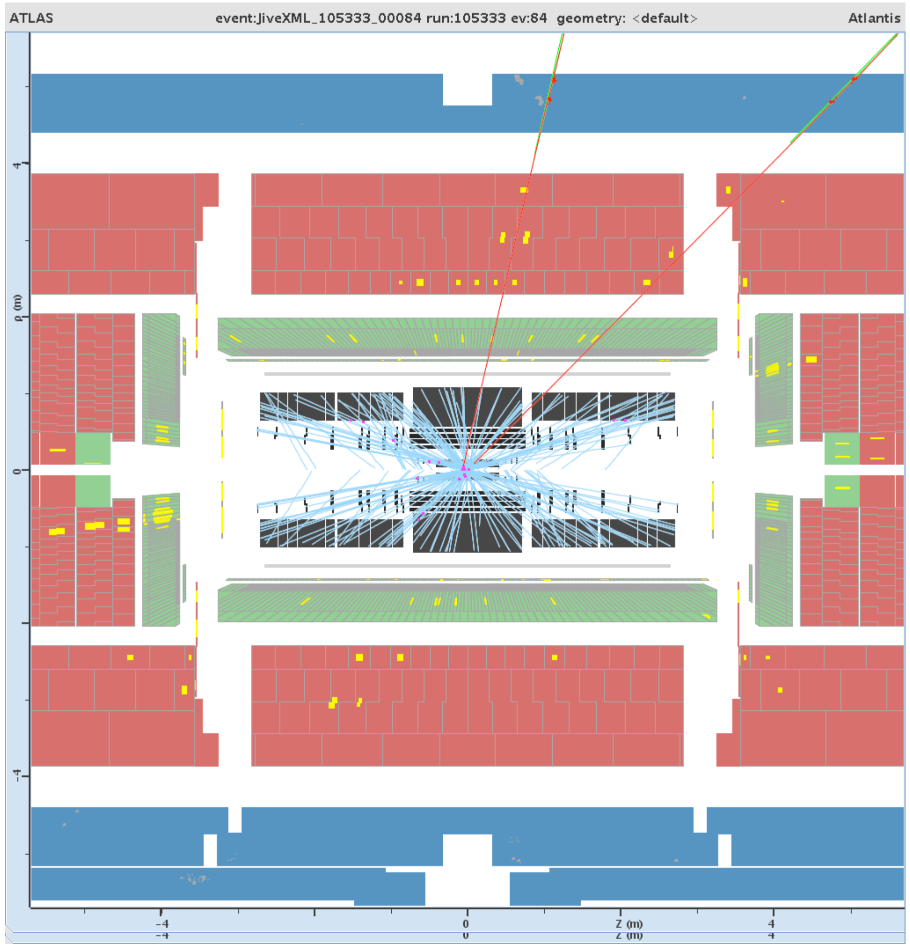






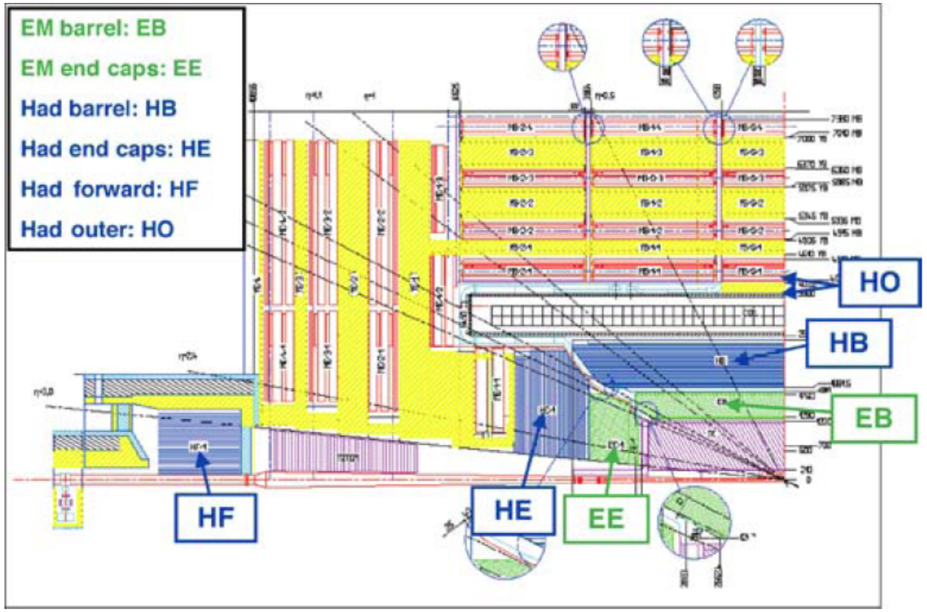
VBF: Challenges

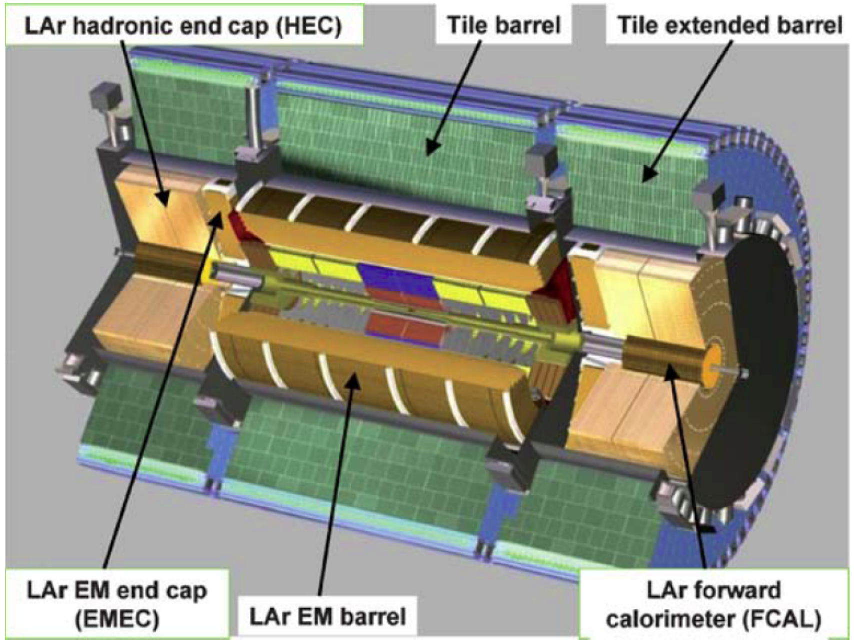




- reconstruction of tagging jets down to 1 degree to beam line
- application of jet veto exploiting rapidity gap
- reconstruction of invariant di-tau mass in collinear approximation
- background estimation from data

Technology choices for hadronic calorimetry





both use non compensating sampling technology

→ different response to electons/photons and hadrons: e/h~1.4

- CMS:

  steel/brass+scintillator(quartz)

  space restriction from bore of solenoid

  → only 6 hadronic interaction length @90^{o}

  + tailcatcher (HO) outside solenoid

- ATLAS:

  - steel+scintillating tiles in barrel
  - Cu(W)/Liquid Argon in endcap+forward

  all outside solenoid

Comparison of ATLAS and CMS HCALS

- containment of jet at 1 TeV requires ~ 11 hadronic interaction length
- sampling fraction in CMS ~ factor 2 to 3 smaller than ATLAS
- tailcatcher in CMS completes „small“ primary HCAL

TABLE 9 Main parameters of the ATLAS and CMS hadronic calorimeters

	ATLAS	CMS
Technology		
Barrel/Ext. barrel	14 mm iron/3 mm scint.	50 mm brass/3.7 mm scint.
End caps	25–50 mm copper/8.5 mm LAr	78 mm brass/3.7 mm scint.
Forward	Copper (front) - Tungsten (back)/0.25–0.50 mm LAr	Steel/0.6 mm quartz
Channels		
Barrel/Ext. barrel	9852	2592
End caps	5632	2592
Forward	3524	1728
Granularity ($\Delta\eta \times \Delta\phi$)		
Barrel/Ext. barrel	0.1×0.1 to 0.2×0.1	0.087×0.087
End caps	0.1×0.1 to 0.2×0.2	0.087×0.087 to 0.18×0.175
Forward	0.2×0.2	0.175×0.175
Samplings ($\Delta\eta \times \Delta\phi$)		
Barrel/Ext. barrel	3	1
End caps	4	2
Forward	3	2
Abs. lengths (min.-max.)		
Barrel/Ext. barrel	9.7–13.0	7.2–11.0 10–14 (with coil/HO)
End caps	9.7–12.5	9.0–10.0
Forward	9.5–10.5	9.8

Note that the CMS barrel calorimeter (HB) is complemented by a tail catcher behind the coil (HO) to minimize problems with longitudinal leakage of high-energy particles in jets.

TABLE 10 Main performance parameters of the different hadronic calorimeter components of the ATLAS and CMS detectors, as measured in test beams using charged pions in both stand-alone and combined mode with the ECAL

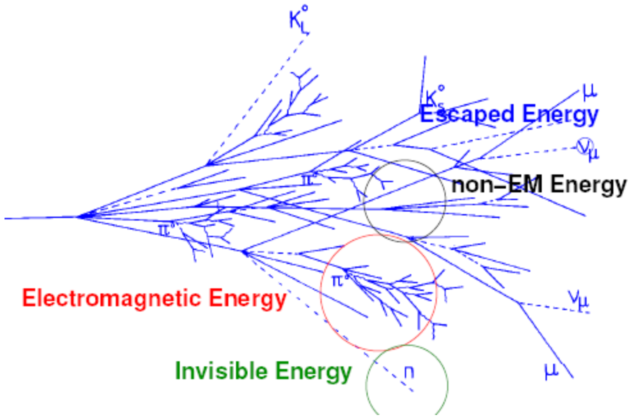
	ATLAS				CMS	
	Barrel LAr/Tile		End-cap LAr			
	Tile	Combined	HEC	Combined	Had. barrel	Combined
Electron/hadron ratio	1.36	1.37	1.49			
Stochastic term	$45\%/\sqrt{E}$	$55\%/\sqrt{E}$	$75\%/\sqrt{E}$	$85\%/\sqrt{E}$	$100\%/\sqrt{E}$	$70\%/\sqrt{E}$
Constant term	1.3%	2.3%	5.8%	$< 1\%$		8.0%
Noise	Small	3.2 GeV		1.2 GeV	Small	1 GeV

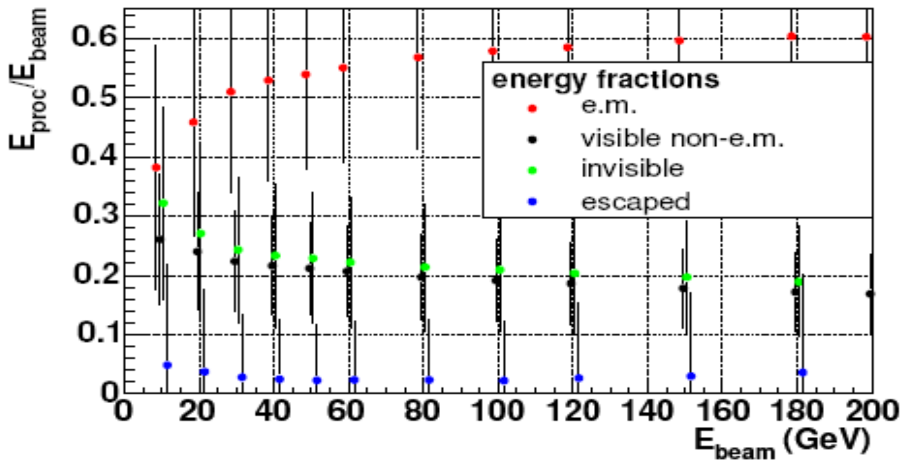
The measured electron/hadron ratios are given separately for the hadronic stand-alone and combined calorimeters when available, and the contributions (added quadratically except for the stand-alone ATLAS tile calorimeter) to the pion energy resolution from the stochastic term, the local constant term, and the noise are also shown, when available from published data.

Froidevaux, Sphicas

Challenges in jet energy reconstruction

- different response to photons/electrons and hadrons depending on particle energy





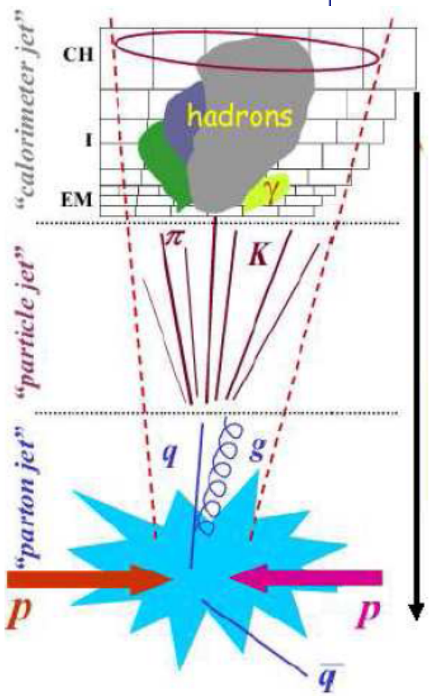
→non uniformity → software compensation

i) based on cell energy/density+shape of cluster (ATLAS)
(to be cecked with tau→π^+ decays)

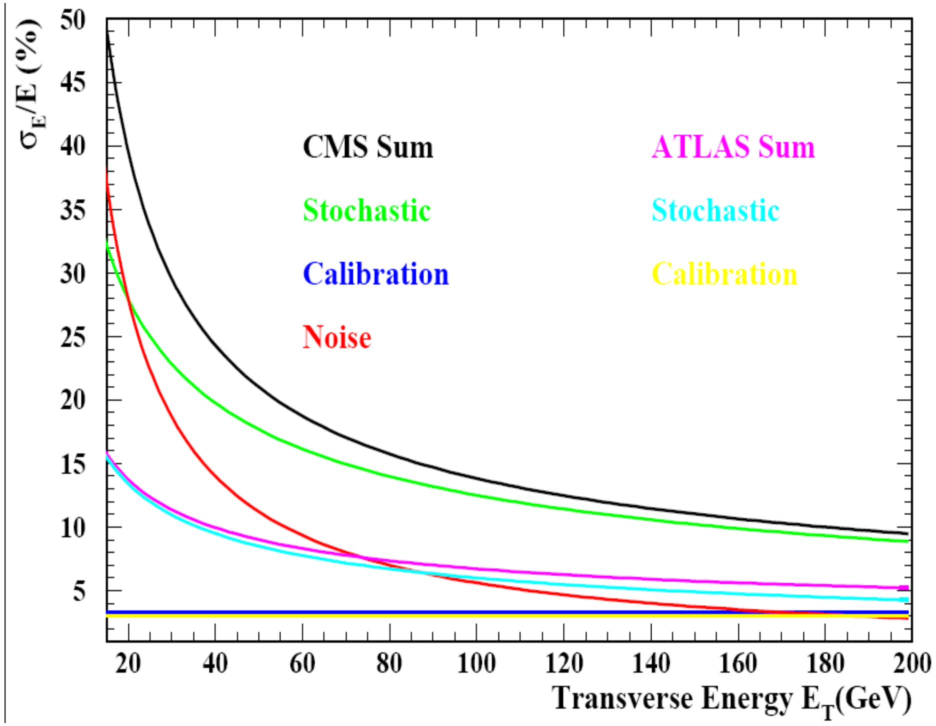
ii) „global“ correction depending on η,E_T (CMS+ATLAS)
jet algorithm and „jet size“

1) reconstruction level to particle level
(non compensation, dead material, cracks)

2) particle level to parton level
(out of cone, underlying event, pile up, ….)



Jet energy resolutions



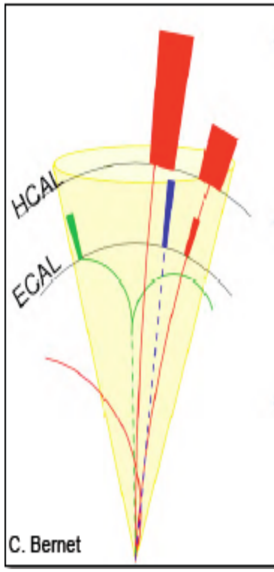
- jet energy resolution
  ~ factor 2 better in ATLAS
- improvements from using tracks
  „energy flow" algorithms
  investigated in both experiments
  10% relative for E_T<100GeV

- „in situ" calibration:
  - dijet for uniformity (ET balance)
  - photon + jet, Z+jet (ET balance) for absolute energy scale
  - t→bW, W→jj W mass constraint for absolute energy scale

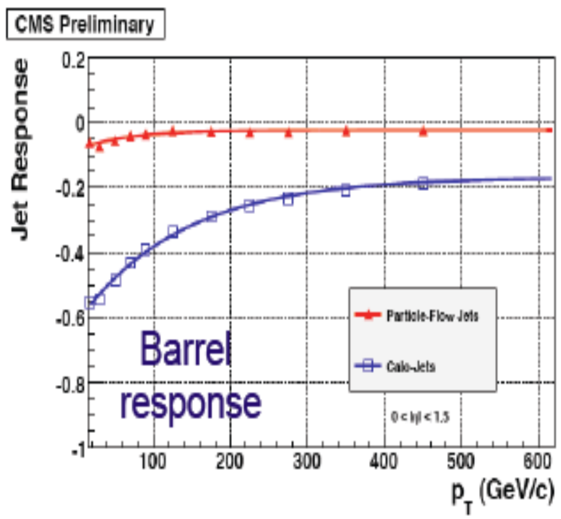
Goal for constant term: 3% ATLAS 6%CMS

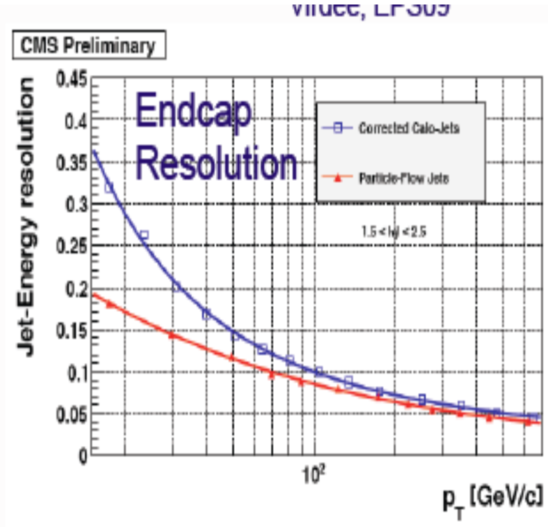
for absolute energy scale and uniformity ~ 1%

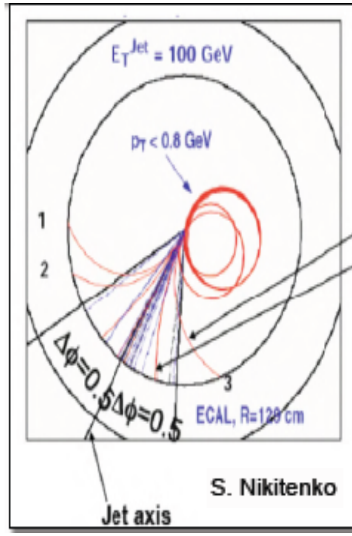
Energy/Particle flow idea and performance



- Reconstruct/identify all stable particles in the event:
  - Photons, charged and neutral hadrons, electrons, muons
- By combining all subdetectors in the best possible way
  - Tracker, preshower, ECAL, HCAL, muon chambers
- The resulting list of particles is the input of
  - Jet clustering
  - Tau and b ID
  - MET reconstruction







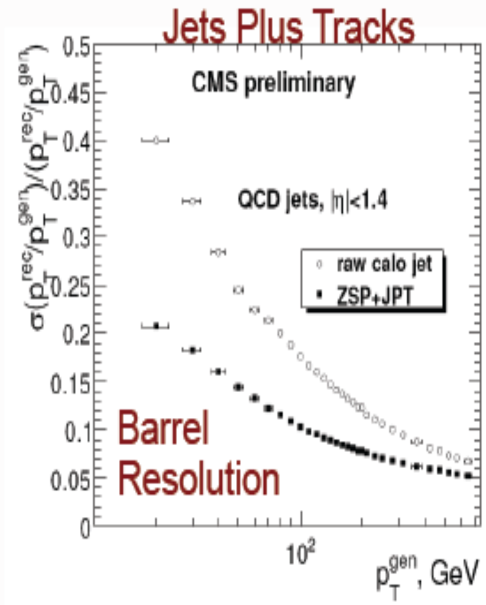
The goal of algorithm: correct calorimeter jet energy to the energy of particles at vertex.

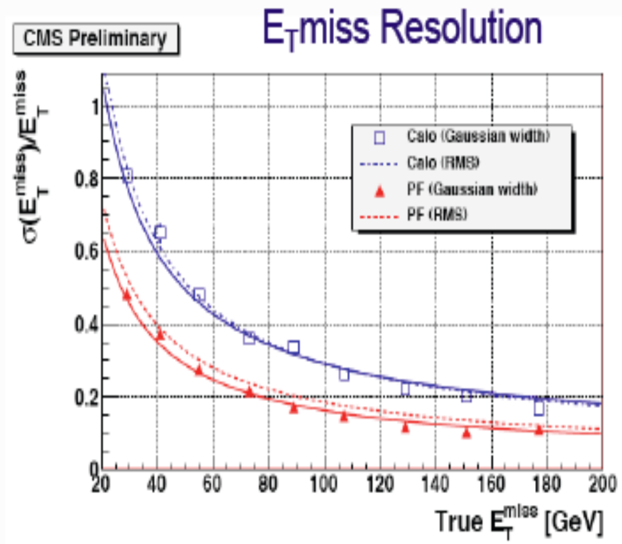
out-of-calo-cone track

in-calo-cone track

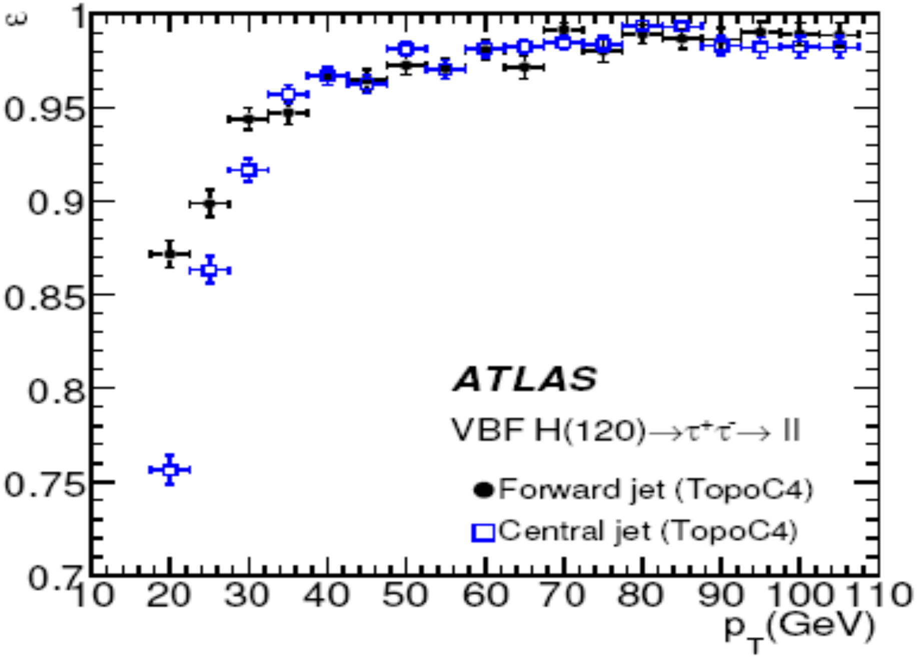
Basic algorithm steps:

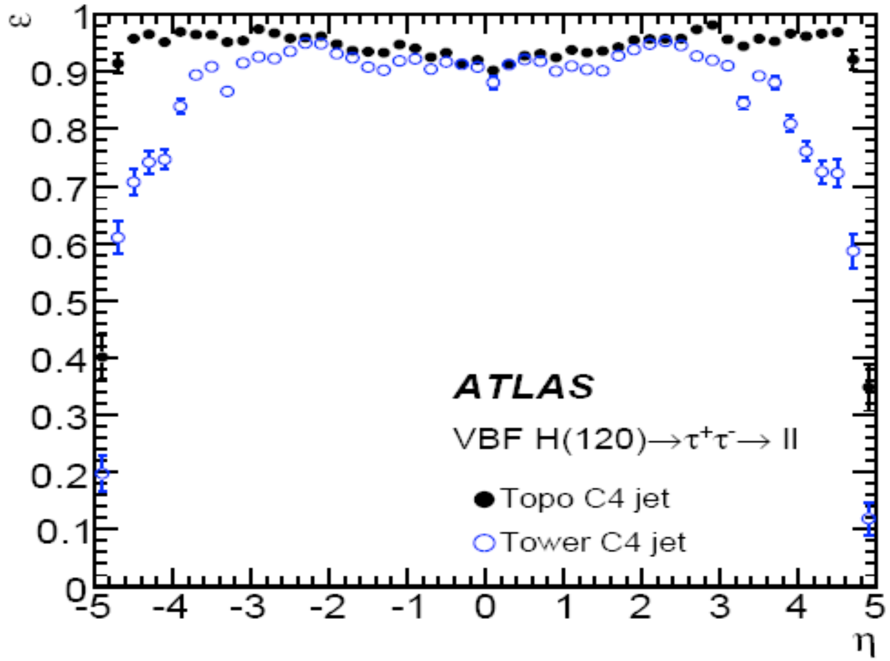
1. Subtract average expected response of "in-calo-cone" tracks from calo jet energy and add track momentum
2. Add momentum of "out-of-cone" tracks





Tagging of forward jets in VBF



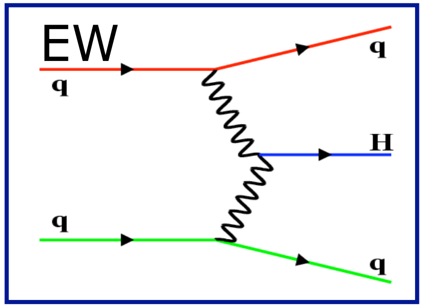


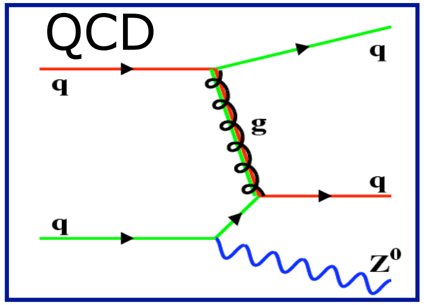
jet reconstruction:

- high efficiency for tagging jets up to pseudorapidty of 4.8 (1 degree)
- fake rate only few %
- currently moderate sensitivity to pileup observed
  (depending on noise suppression tool, cluster and jet algo used)

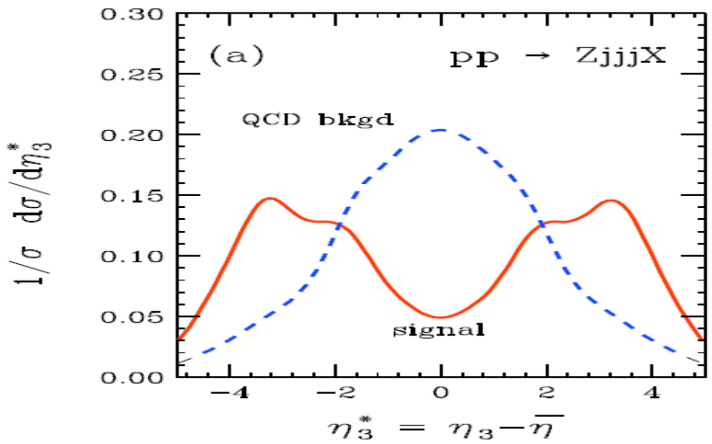
Central Jet Veto

- different color flow in EW and QCD processes





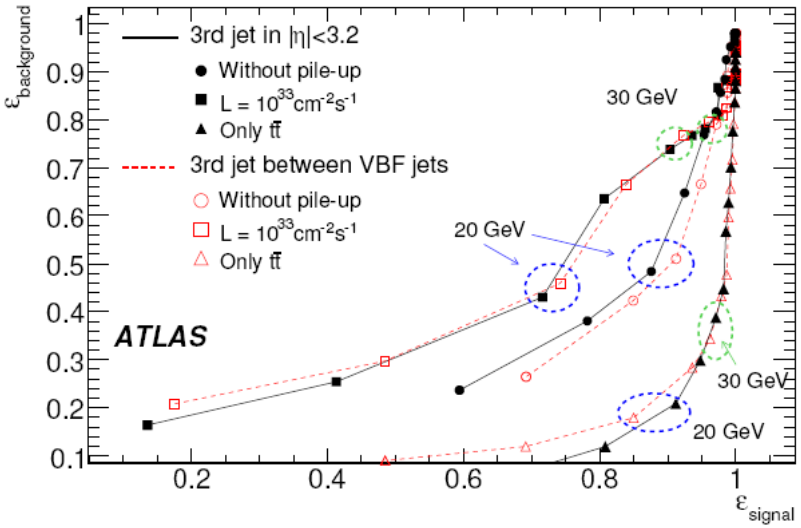
D. Zeppenfeld et al., Phys.Rev.D54 (1996)6680

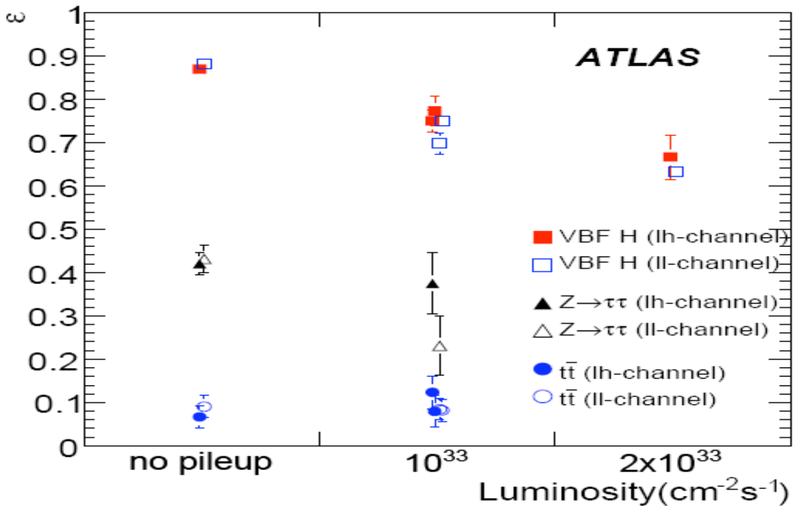


- radiation in signal close to tagging jets → rapidity gap

QCD background (Z+jets,tt): additional central jets likely

→ veto on additional jet with P_t>20 GeV and |η| <3.2 (ATLAS)

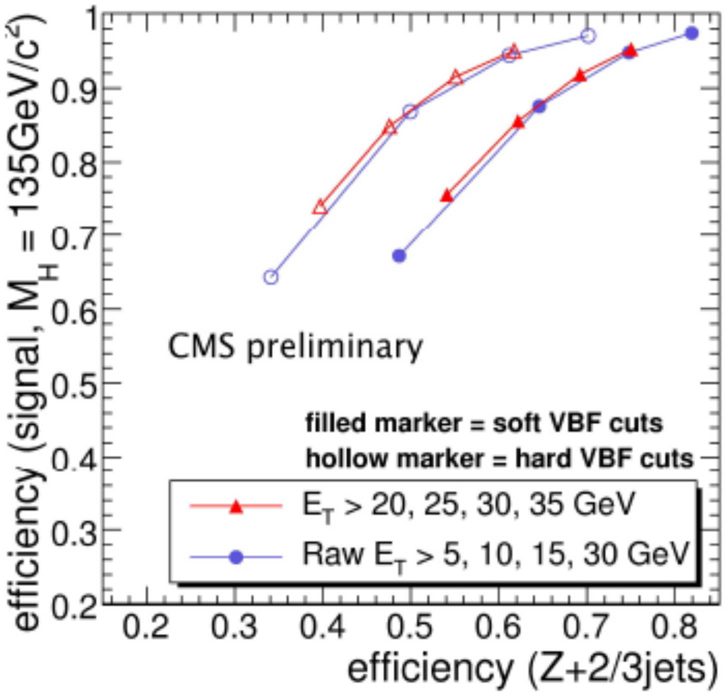


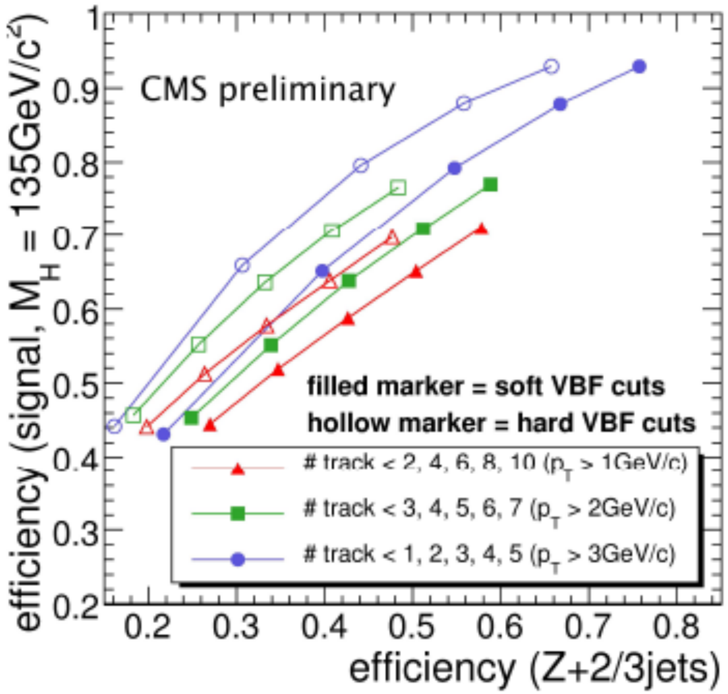


influence of pile up significant use of tracking information under investigation

Central Jet Veto (II)

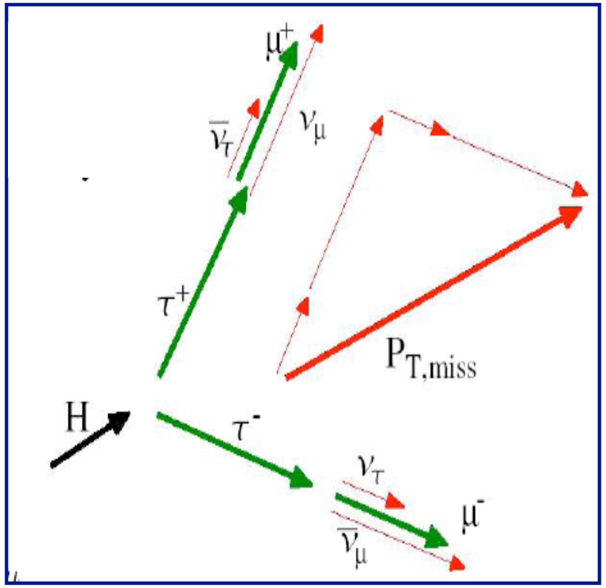
CMS: comparison of track counting with calorimeter jet veto



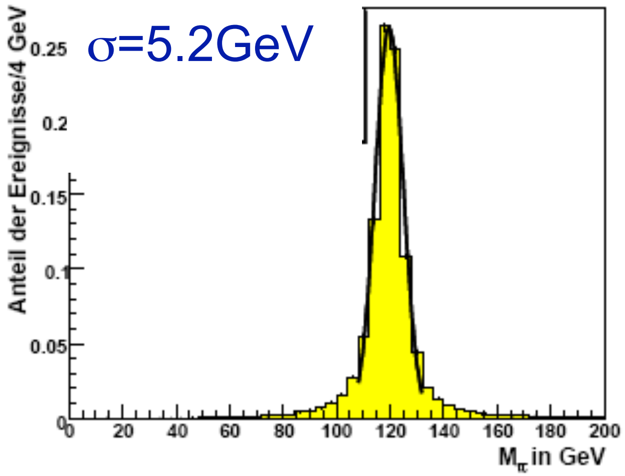


- open issues:
  - how to estimate veto efficiency for signal process from data? (needed for exclusion)
    some ideas around, but not validation to satifactory level
  - theory prediction: NLO for H+3jets stable at few percent
    but large differnece from parton shower and underlying event

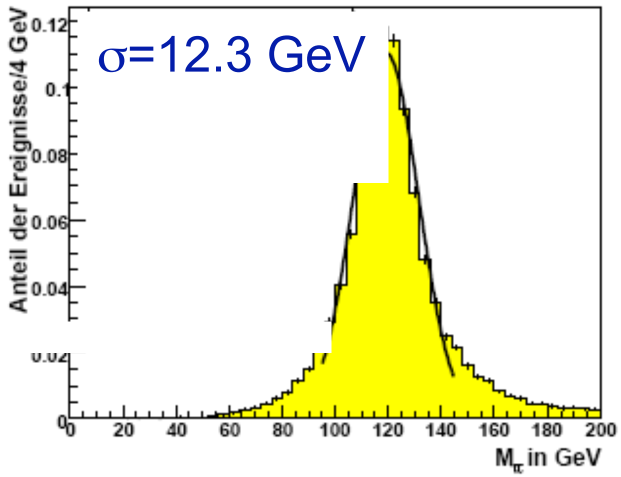
Mass reconstruction in collinear approximation



true neutrinos

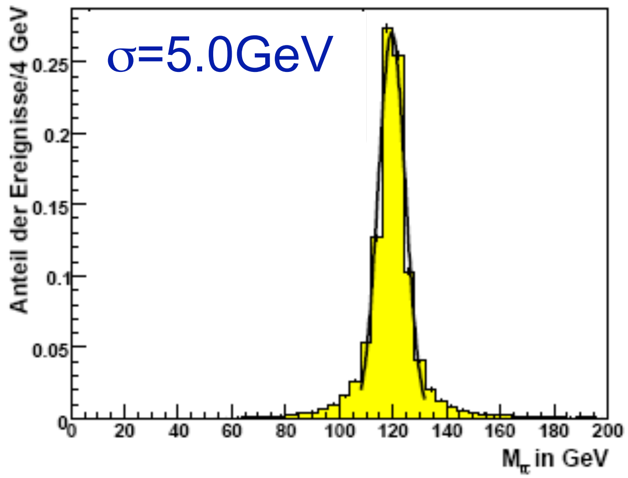


true myons

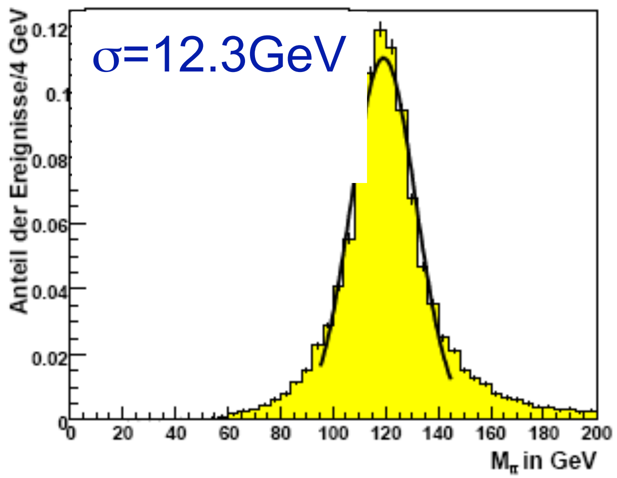


needs lepton 4-momenta and ETMISS vector

mass resolution completly determined by ETMISS resolution



true neutrinos and myons

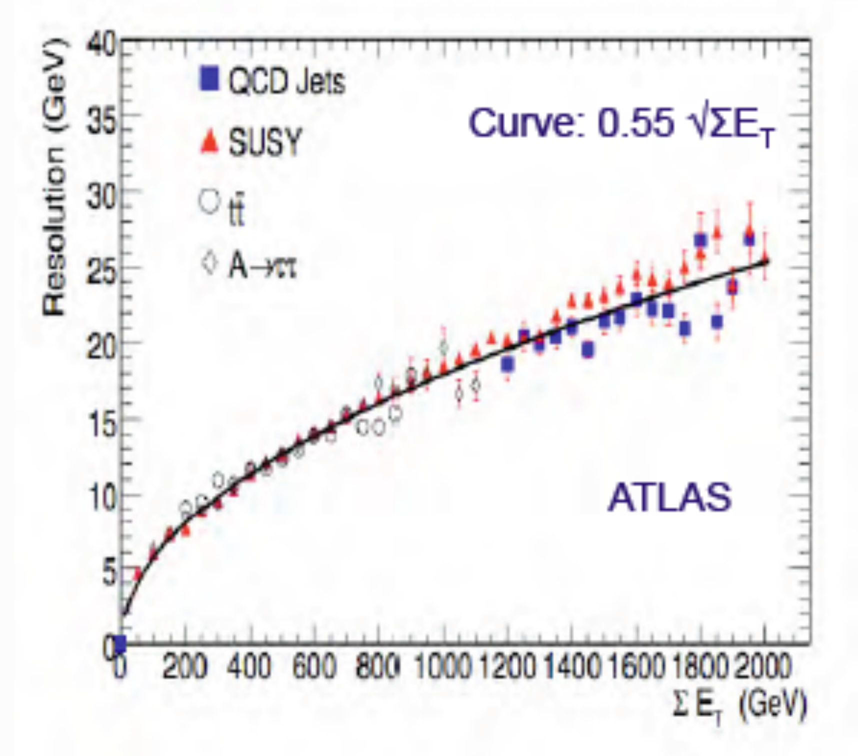


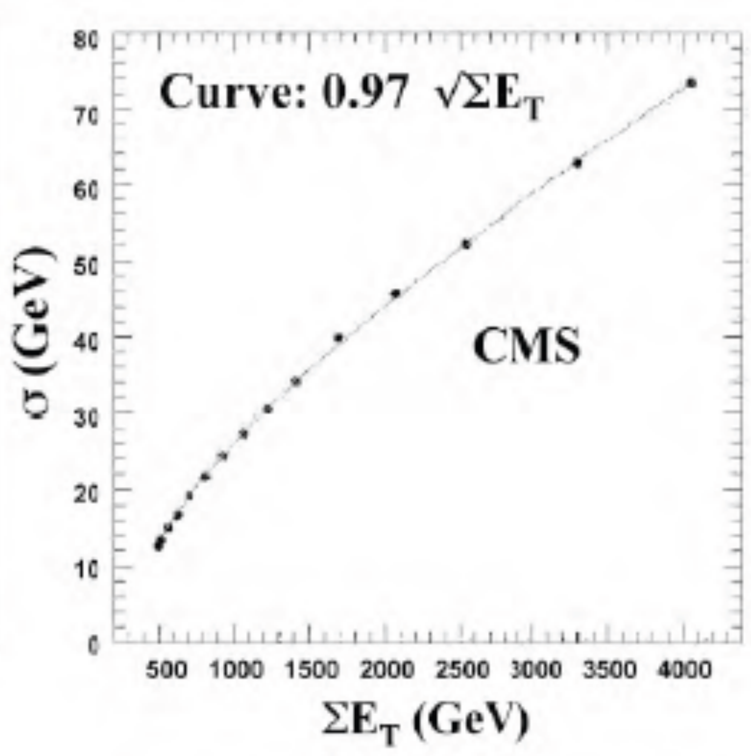
all reconstructed

Missing transverse energy resolution

- missing energy resolution: dominated by jets and unclustered energy
- 1) noise suppression 2) calibration of hadronic actitivity (cells, towers)

  3) correction for muons 4) apply correction for identified obejcts (e,τ)
- σ(ETMiss)=C*sqrt(Σ ET)

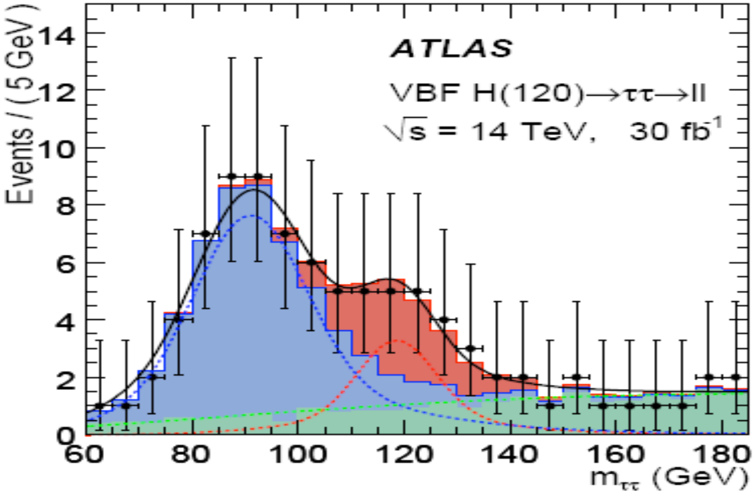




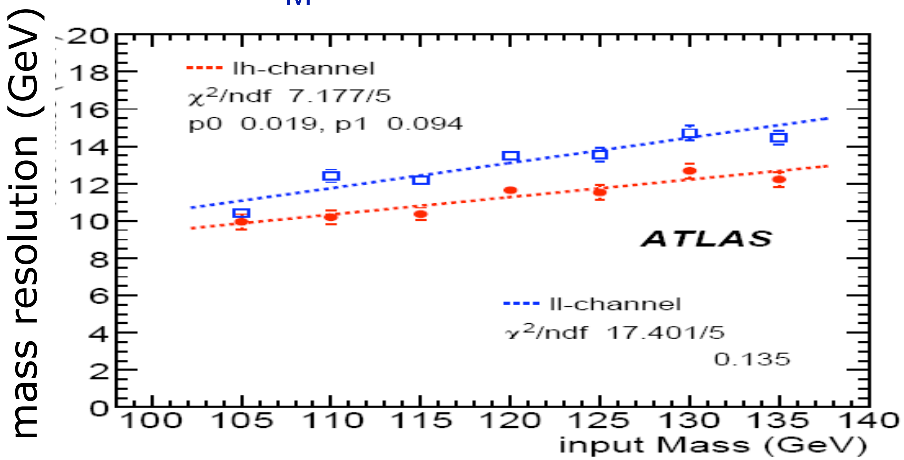
- further improvements possible using tracker information (CMS)

Final mass distributions and resolutions

- mass distributions after all cuts

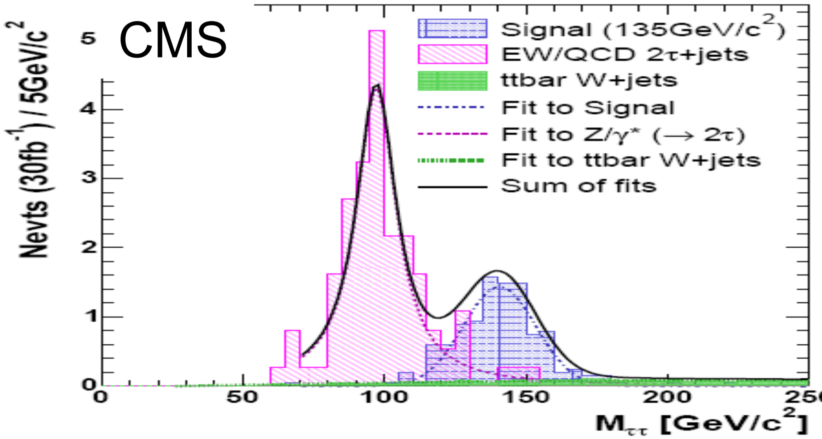


- ATLAS: σ_M /M~10%



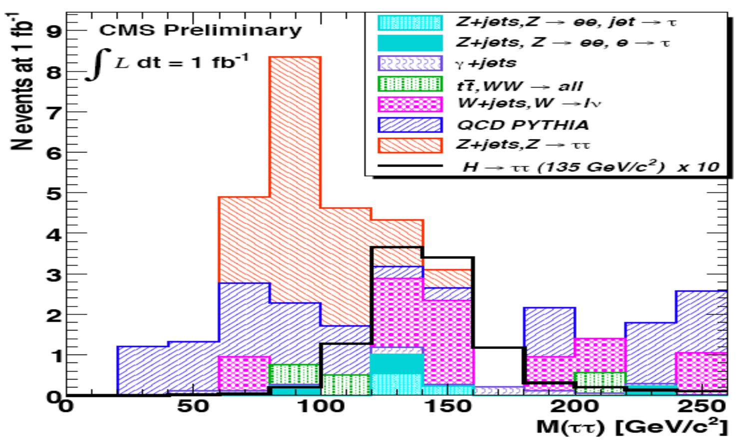
pile-up: resolution worse by 20% (relative)

- CMS: PhysicsTDR σ_M/M~9%



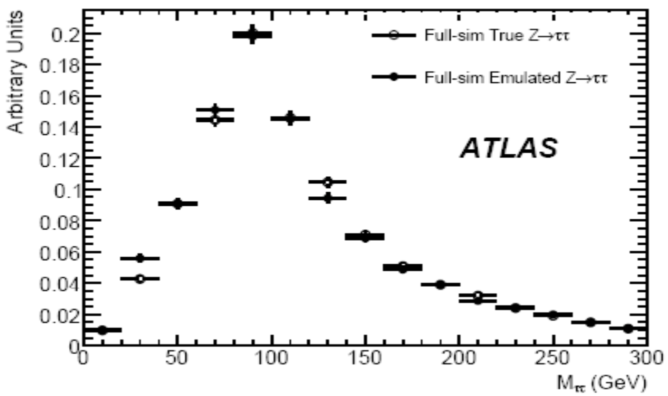
- CMS: prel. new study σ_M/M~15%?

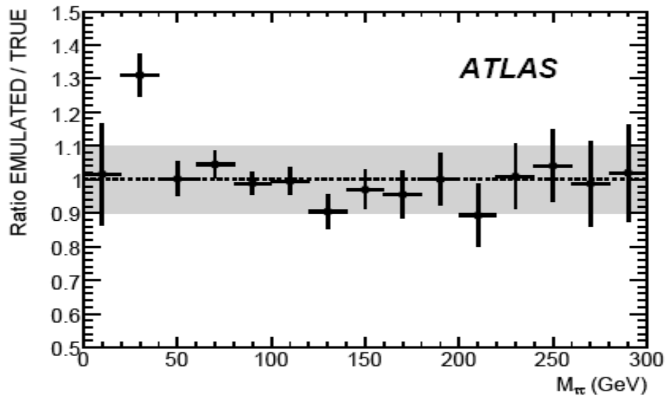
CMS PAS HIG-08-008

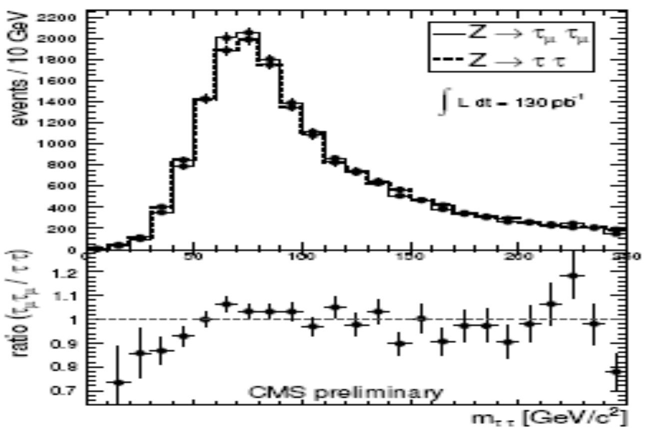


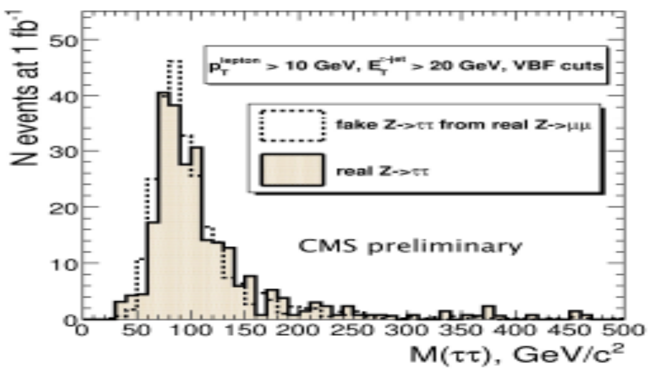
Background estimation from data: example Z+jets

- signal sits on shoulder of dominant background → do not trust simulation
- select jjZ→μμ in data, remove muons and replace by Z→ττ◊αβ simulated decay
  - signal free control sample - use pileup noise, kinematics etc, from data









- similar methods for other backgrounds developed e.g. OS vs SS for W+jets

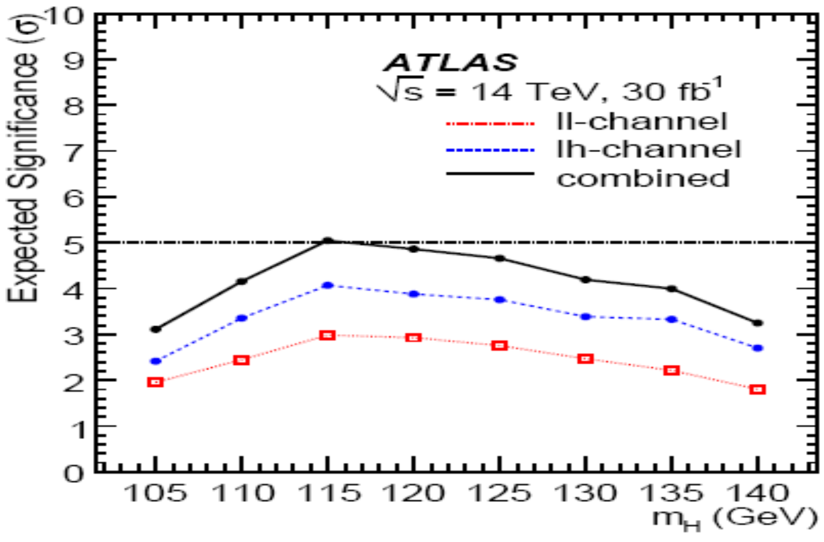
Uncertainty on signal efficiency (ATLAS)

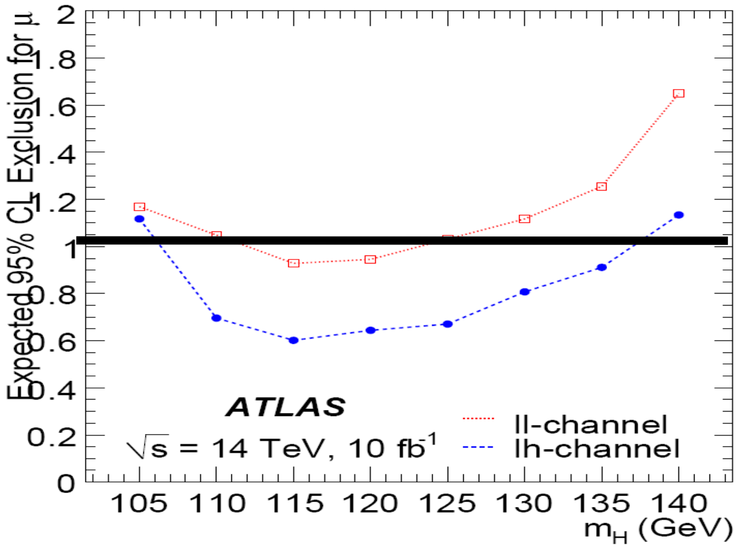
Source	Relative uncertainty	Effect on signal efficiency
luminosity	$\pm 3\%$	$\pm$ 3%
muon energy scale	$\pm$ 1%	$\pm$ 1%
muon energy resolution	$\sigma(p_T) \oplus 0.011 p_T \oplus 1.7\ 10^{-4} p_T^2$	$\pm$ 0.5%
muon ID efficiency	± 1 %	$\pm$ 2%
electron energy scale	$\pm$ 0.5%	$\pm$ 0.4 %
electron energy resolution	$\sigma(E_T) \oplus 7.3\ 10^{-3} E_T$	$\pm$ 0.3 %
electron ID efficiency	$\pm$ 0.2%	$\pm$ 0.4%
tau energy scale	$\pm$ 5%	$\pm$ 4.9%
tau energy resolution	$\sigma(E) \oplus 0.45\sqrt{E}$	$\pm$ 1.5%
tau ID efficiency	$\pm$ 5%	$\pm$ 5%
jet energy scale[†]	$\pm$ 7% ($\|\eta\| \leq 3.2$) $\pm$ 15% ($\|\eta\| \geq 3.2$) $\pm$ 5% (on E_T^{miss})	$^{+16\%}/_{-20\%}$
jet energy resolution	$\sigma(E) \oplus 0.45\sqrt{E}$ ($\|\eta\| \leq 3.2$) $\sigma(E) \oplus 0.67\sqrt{E}$ ($\|\eta\| \geq 3.2$)	$\pm$ 1%
b-tagging efficiency	$\pm$ 5%	$\pm$ 5%
forward tagging efficiency	$\pm$ 2 %	$\pm$ 2%
central jet reconstruction efficiency	$\pm$ 2 %	$\pm$ 2%
total summed in quadrature		$\pm 20\%$

Source	Relative uncertainty	Effect on signal efficiency
PDF uncertanties	$\pm 3.5\%$	$\pm 3.5\%$
scale dependence on cross-section	$\pm 3\%$	$\pm$ 3%
scale dependence CJV efficiency	$\pm$ 1%	$\pm$ 1%
parton-shower and underlying event	$\pm \leq 10\%$	$\pm < 10\%$
total summed in quadrature		$\pm < 10\%$

Discovery and exclusion potential: VBF,H→ττ

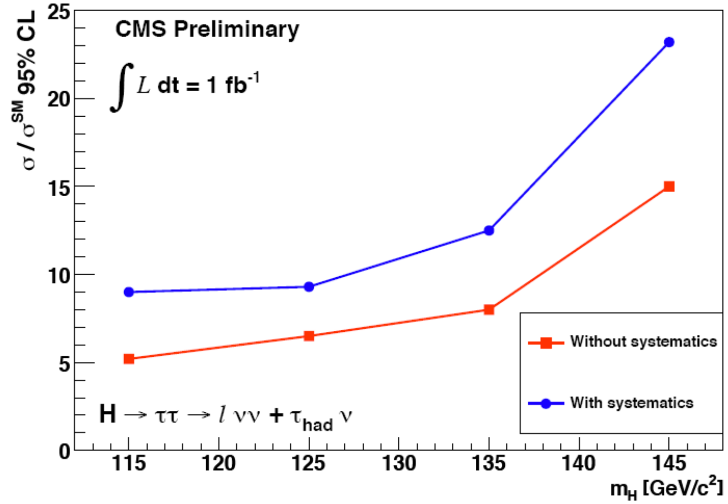
- ATLAS



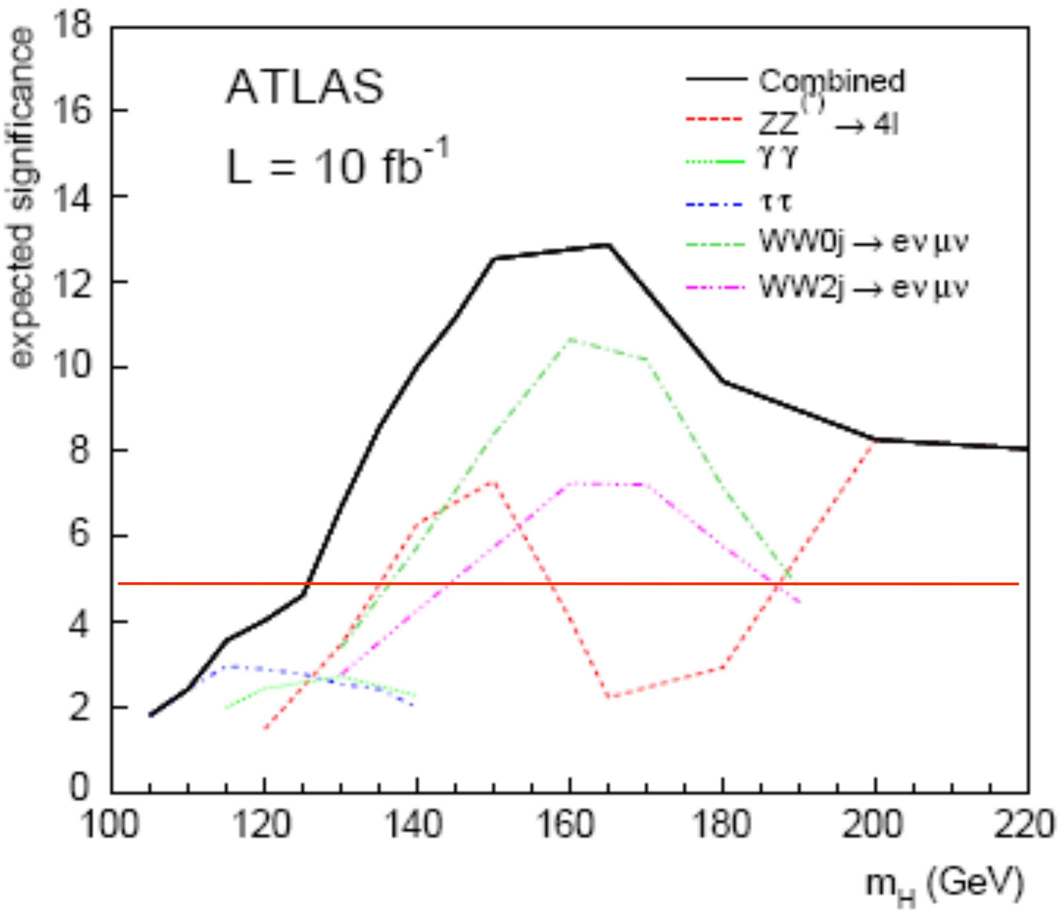


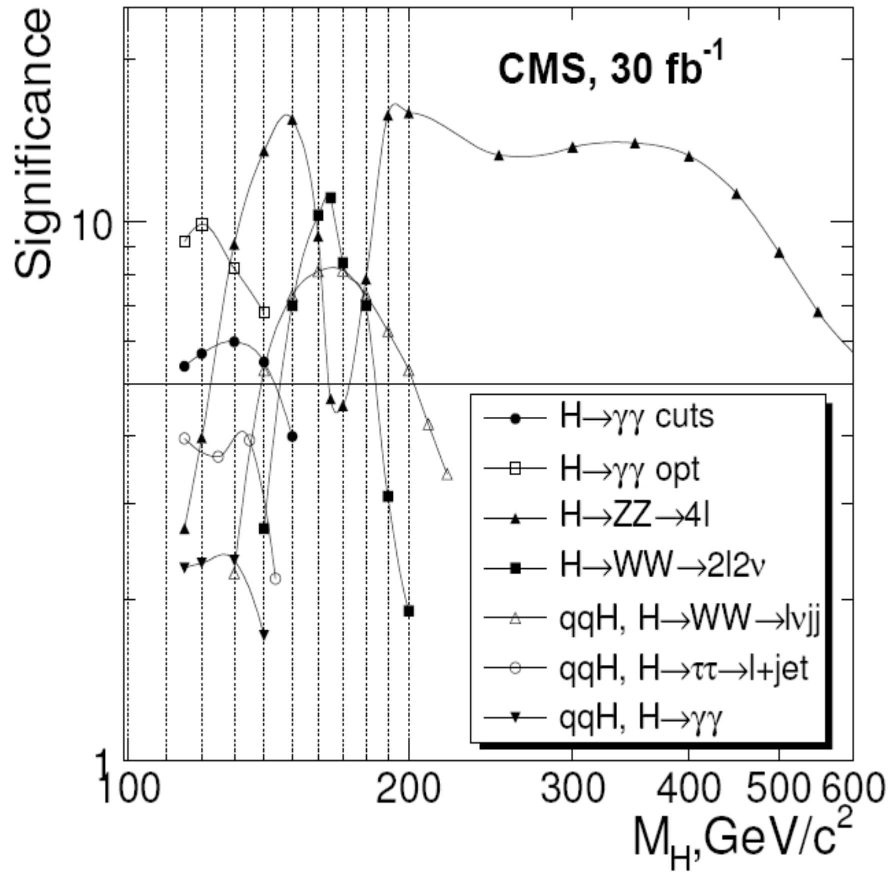
- CMS (only lep had final state)

M_H [GeV]	115	125	135	145
Production σ [fb]	4.65×10^3	4.30×10^3	3.98×10^3	3.70×10^3
$\sigma\times BR(H\rightarrow\tau\tau\rightarrow lj)$ [fb]	157.3	112.9	82.38	45.37
N_S at 30 fb^{-1}	10.5	7.8	7.9	3.6
N_B at 30 fb^{-1}	3.7	2.2	1.8	1.4
Significance at 30 fb^{-1} ($\sigma_B = 7.8\%$)	3.97	3.67	3.94	2.18
Significance at 60 fb^{-1} ($\sigma_B = 5.9\%$)	5.67	5.26	5.64	3.19



Potential for discovery





no comment on comparsion of sensitivity of different channels in two experiment

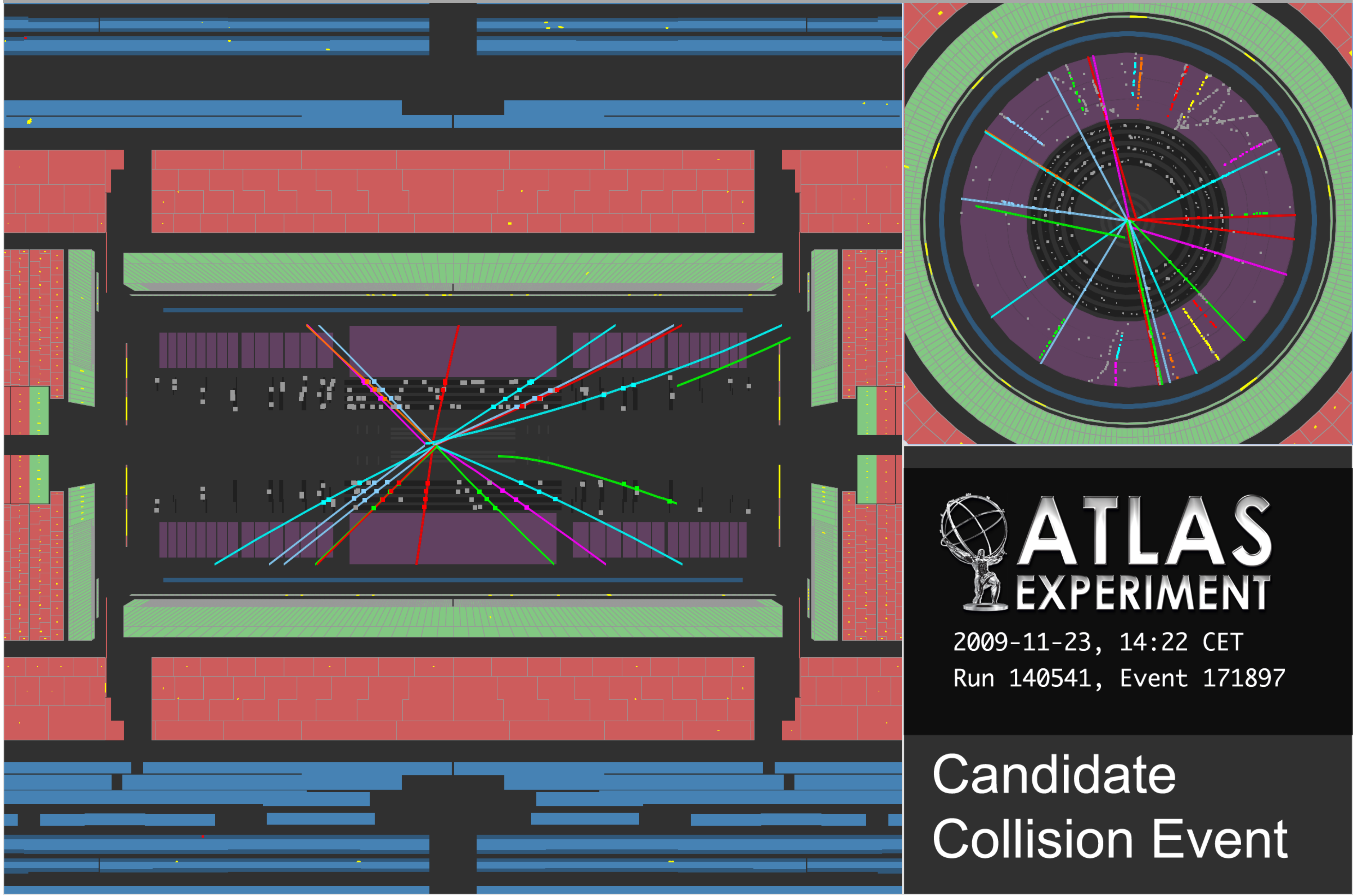
CERN press release: first collisions in LHC

Geneva, 23 November 2009. Today the LHC circulated two beams simultaneously for the first time, allowing the operators to test the synchronization of the beams and giving the experiments their first chance to look for proton-proton collisions. With just one bunch of particles circulating in each direction, the beams can be made to cross in up to two places in the ring. From early in the afternoon, the beams were made to cross at points 1 and 5, home to the ATLAS and CMS detectors, both of which were on the look out for collisions. Later, beams crossed at points 2 and 8, ALICE and LHCb.

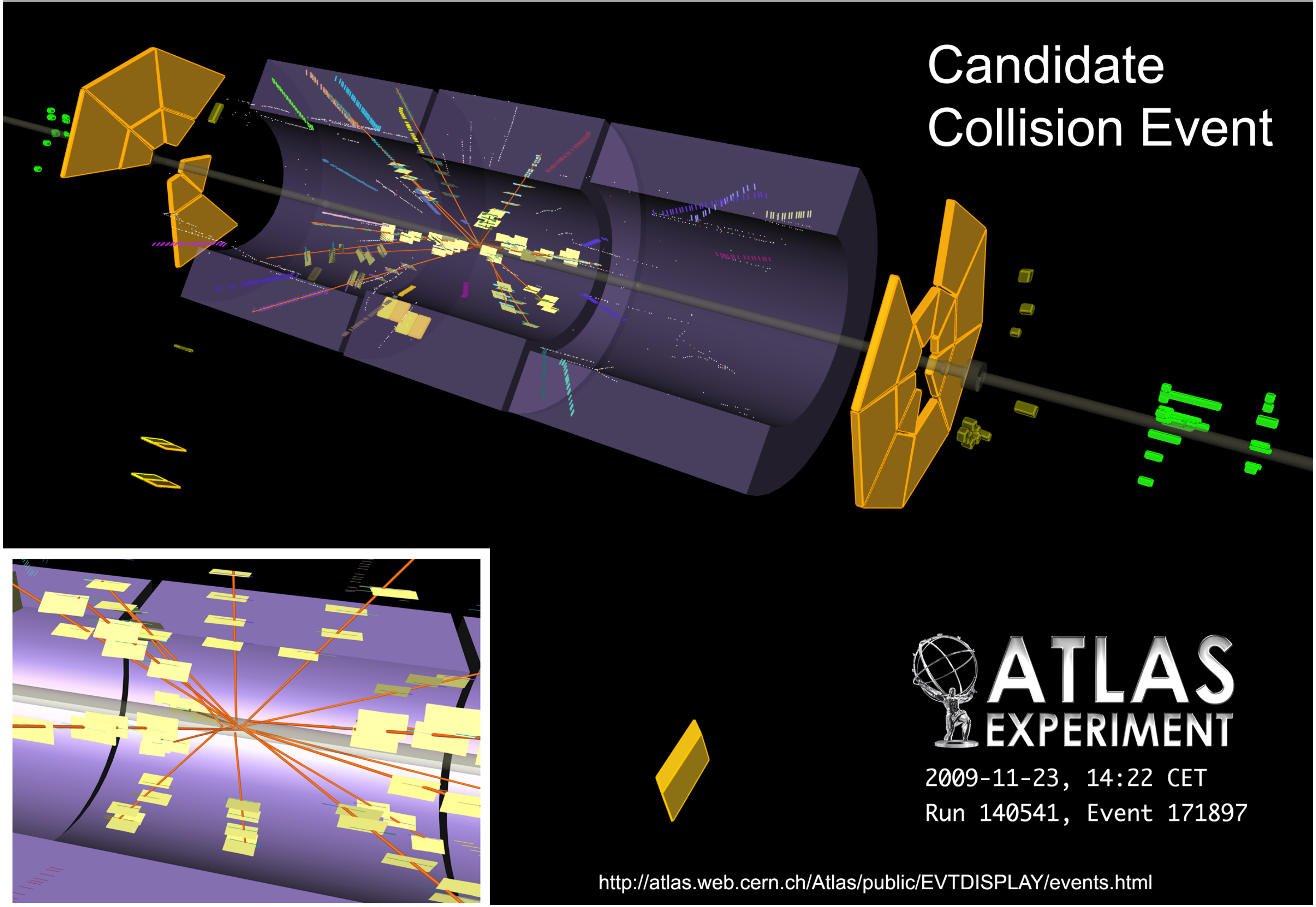
"It's a great achievement to have come this far in so short a time," said CERN1Director General Rolf Heuer. "But we need to keep a sense of perspective – there's still much to do before we can start the LHC physics programme."

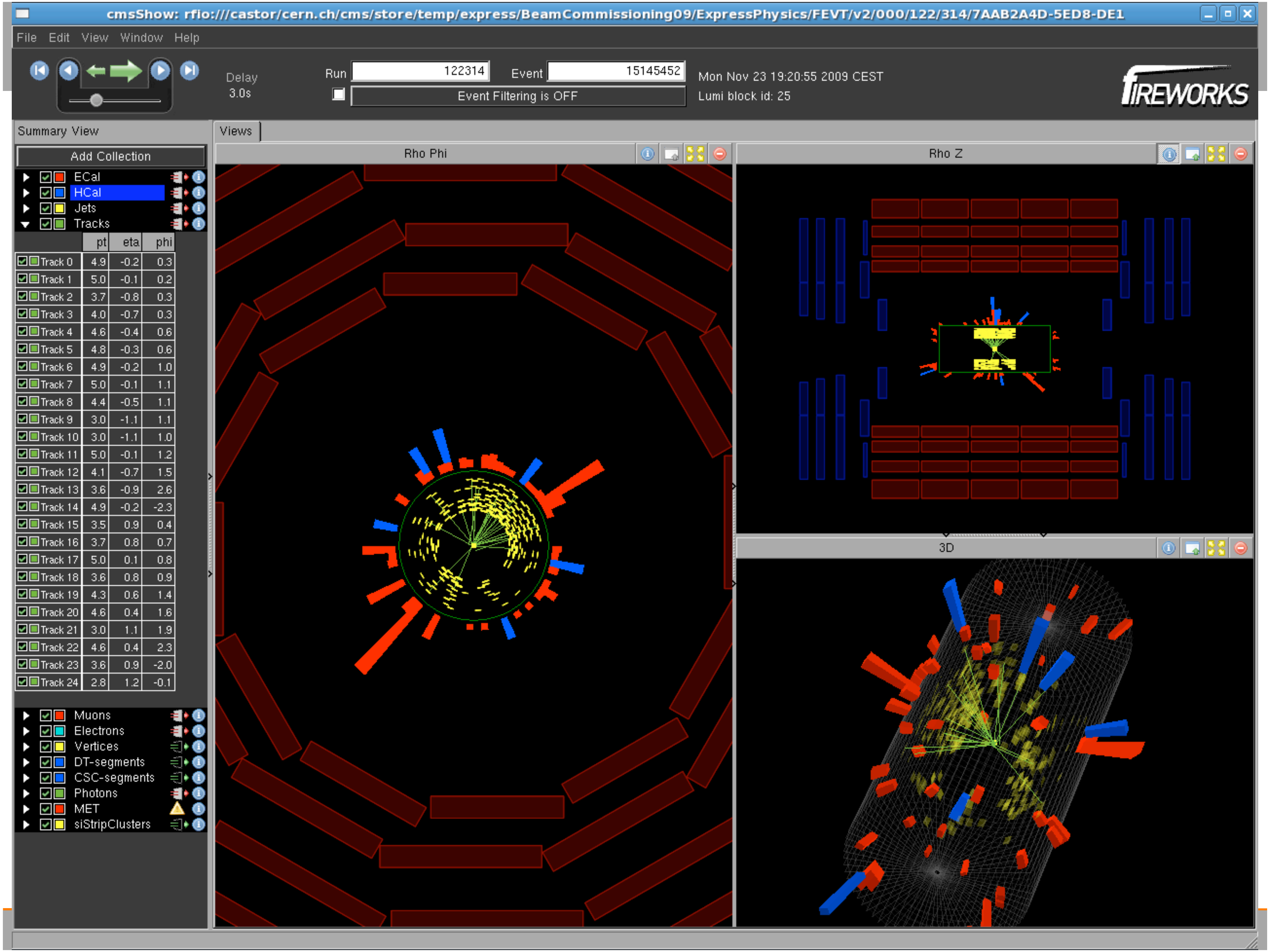
Beams were first tuned to produce collisions in the ATLAS detector, which recorded its first candidate for collisions at 14:22 this afternoon. Later, the beams were optimised for CMS. In the evening, ALICE had the first optimization, followed by LHCb. …

These developments come just three days after the LHC restart, demonstrating the excellent performance of the beam control system. Since the start-up, the operators have been circulating beams around the ring alternately in one direction and then the other at the injection energy of 450 GeV. The beam lifetime has gradually been increased to 10 hours, and today beams have been circulating simultaneously in both directions, still at the injection energy.
Next on the schedule is an intense commissioning phase aimed at increasing the beam intensity and accelerating the beams. All being well, by Christmas, the LHC should reach 1.2 TeV per beam, and have provided good quantities of collision data for the experiments' calibrations.



http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html


Candidate
Collision Event
ATLAS
EXPERIMENT
2009-11-23, 14:22 CET
Run 140541, Event 171897
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html


cmsShow: rfio:///castor/cern.ch/cms/store/temp/express/BeamCommissioning09/ExpressPhysics/FEVT/v2/000/122/314/7AAB2A4D-5ED8-DE1
File Edit View Window Help
Delay
3.0s
Run 122314
Event 15145452
Event Filtering is OFF
Mon Nov 23 19:20:55 2009 CEST
Lumi block id: 25
FIREWORKS
Summary View
Add Collection
ECal
HCal
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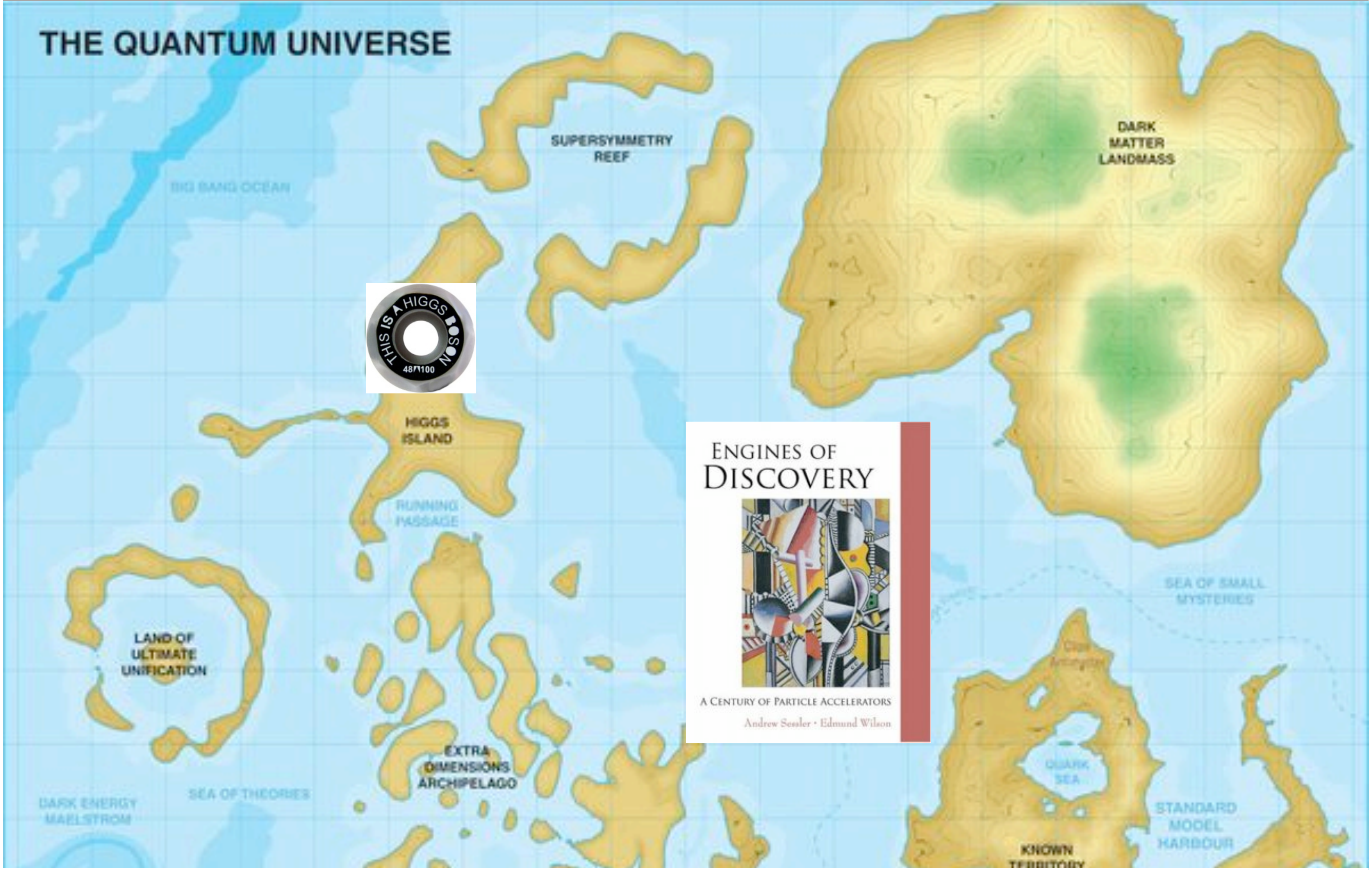
Tracks
pt eta phi
Track 0 4.9 -0.2 0.3
Track 1 5.0 -0.1 0.2
Track 2 3.7 -0.8 0.3
Track 3 4.0 -0.7 0.3
Track 4 4.6 -0.4 0.6
Track 5 4.8 -0.3 0.6
Track 6 4.9 -0.2 1.0
Track 7 5.0 -0.1 1.1
Track 8 4.4 -0.5 1.1
Track 9 3.0 -1.1 1.1
Track 10 3.0 -1.1 1.0
Track 11 5.0 -0.1 1.2
Track 12 4.1 -0.7 1.5
Track 13 3.6 -0.9 2.6
Track 14 4.9 -0.2 -2.3
Track 15 3.5 0.9 0.4
Track 16 3.7 0.8 0.7
Track 17 5.0 0.1 0.8
Track 18 3.6 0.8 0.9
Track 19 4.3 0.6 1.4
Track 20 4.6 0.4 1.6
Track 21 3.0 1.1 1.9
Track 22 4.6 0.4 2.3
Track 23 3.6 0.9 -2.0
Track 24 2.8 1.2 -0.1
Muons
Electrons
Vertices
DT-segments
CSC-segments
Photons
MET
siStripClusters
Views
Rho Phi
Rho Z
3D

The LHC will enter a new territory



Detector design driven by physics goals often from Higgs physics

Whether LHC will add a chapter depends on detailed understanding of detectors

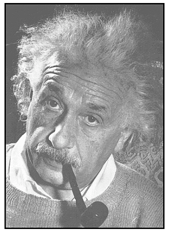
The origin of mass

$F = m\,a$

„Inertia"

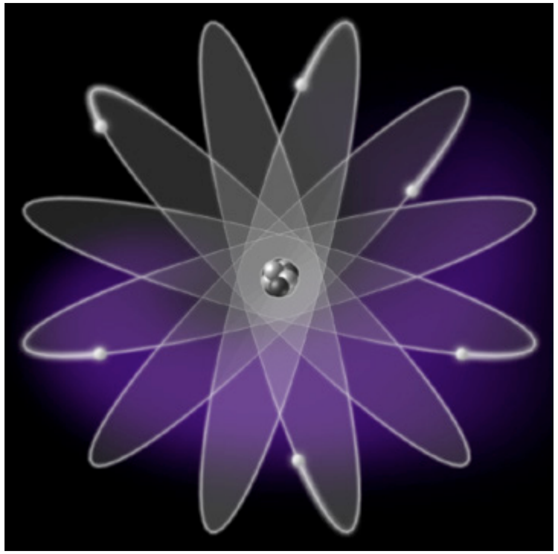
$F = mg$

„Gravitation"



$m = E/c^2$

„Energy"

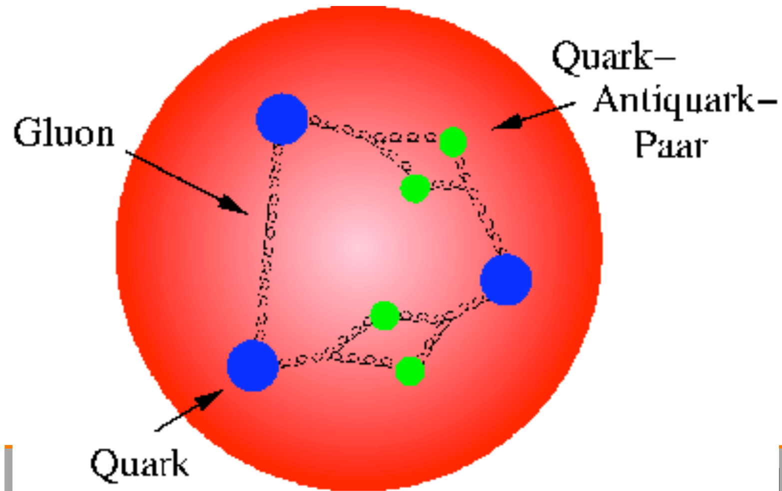


atom = elementary electrons +

nucleons (p,n) in nucleus

m_N =938(9) MeV m_e= 0.5 MeV

atom and nucleus „lighter" than sum of constituents → negative bindung energy

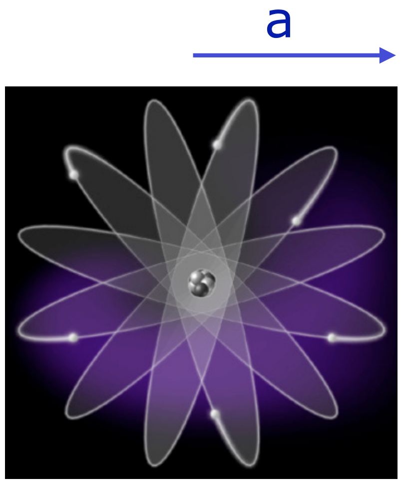


proton and neutron mass ~ 1 GeV:

M_u = O(5 MeV) M_d=O(10 MeV)

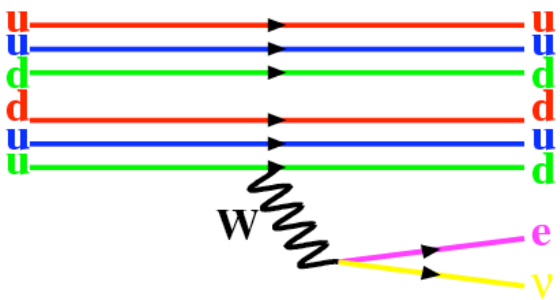
rest: $M=E/c^2$ „energy" of strong interaction (g,q, QCD vacuum)

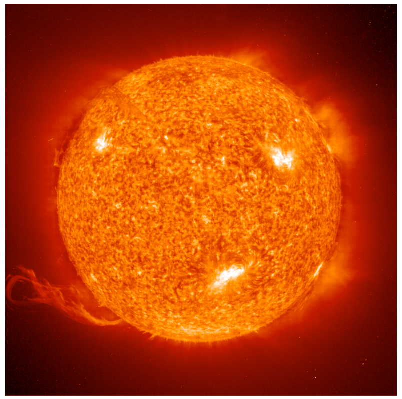
Elementary Particle Masses and their Meaning



- electron mass m_e=0.5 MeV:
  def. length scale of our world, Bohr radius $a=1/\mathbf{a}_{em}\, m_e$
  m_e = 0 no atomic binding
  m_e = 0.02MeV human giants 45 m,
  visible light in infrared
  m_e = 105 MeV K-capture pe→nν possible
  → only Helium, n + ν → different universe

- no/small W boson mass (M_W = 81 GeV):
  fusion in stars:
  p+p→D e+n $G_F \sim M_W^{-2}$
  shorter burning of sun
  at lower temperature
  → no humans on earth

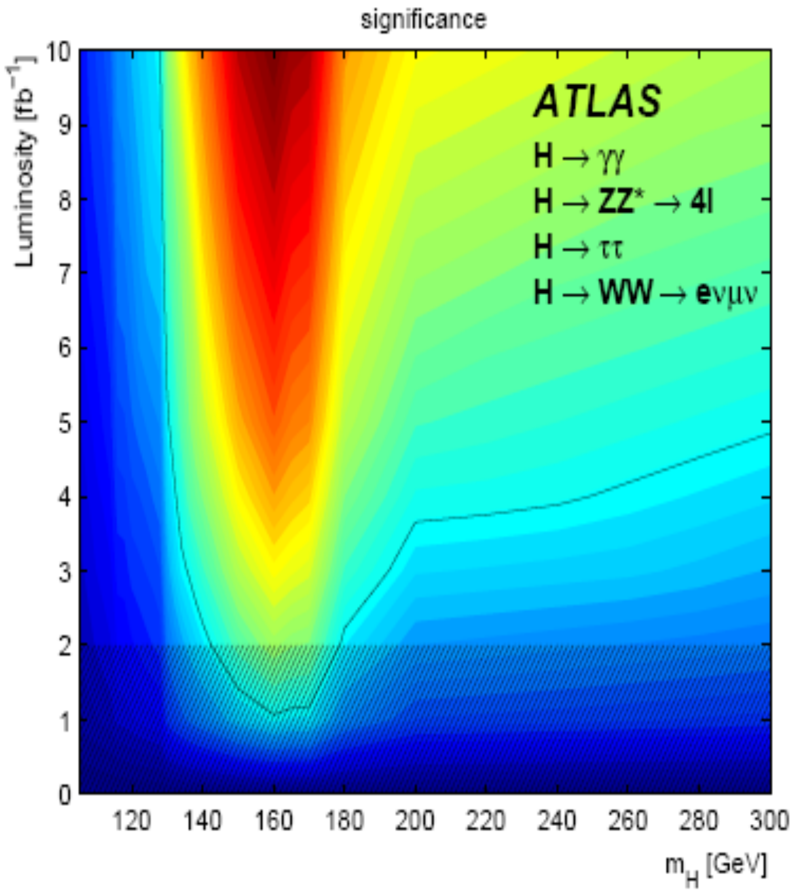




mass values of e, u, d, W and their fine tuning mandatory
for existence and developement of our universe

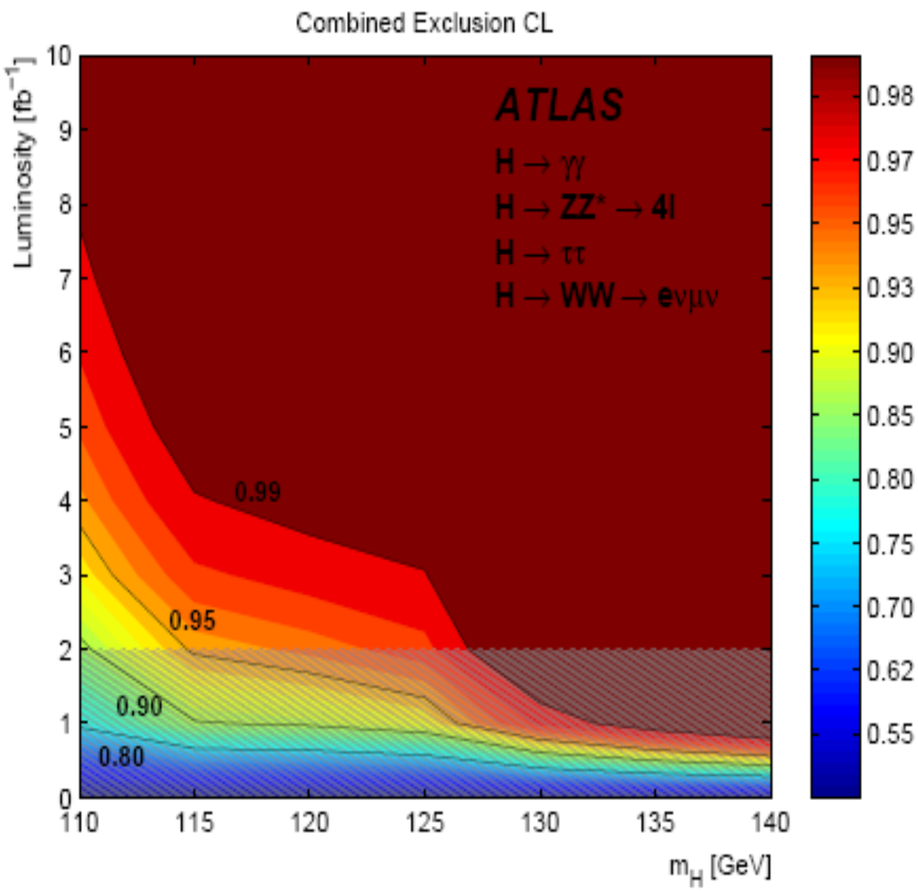
Needd integrated luminosity

Discovery



Sensitivity starts with 1 fb^{-1}

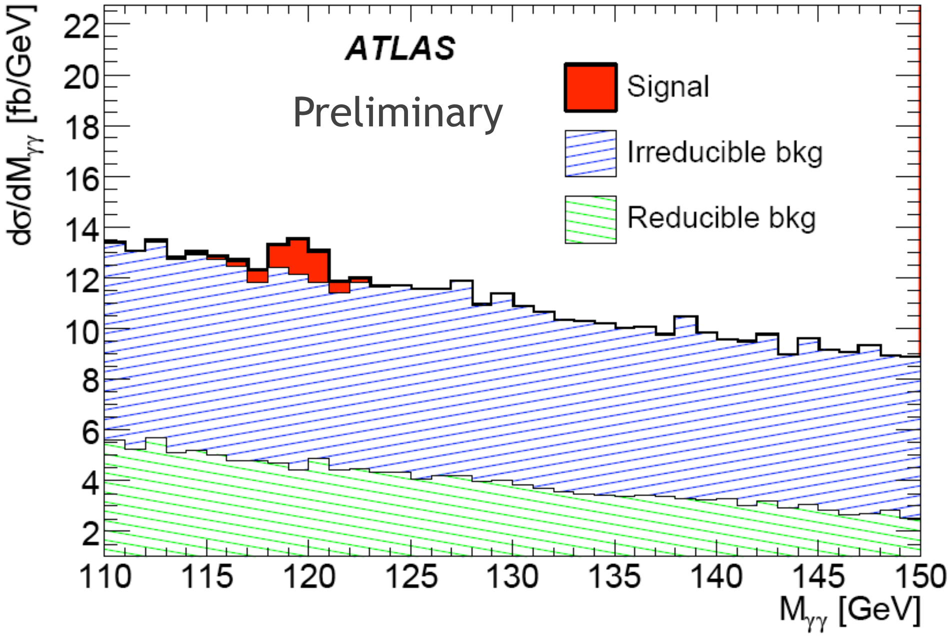
Exclusion



With $2fb^{-1}$: exclusion from M_H of 115 to 460 GeV

Backup

H + 1,2 jet analysis: improving S/B ratio



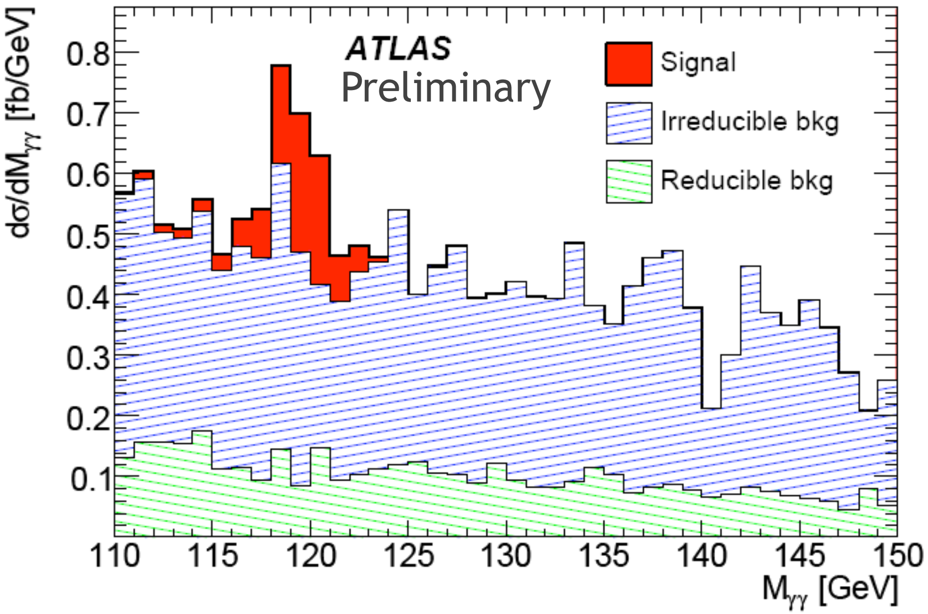
- one jet:

  P_T(jet) >20 GeV ; $M_{j\gamma\gamma}$>350 GeV

  S/B = 1/12

  accepted signal = 4fb

  50% of signal from gluon fusion



- two jets (VBF analysis):

  S/B = 1/2

  accepted signal = 1fb

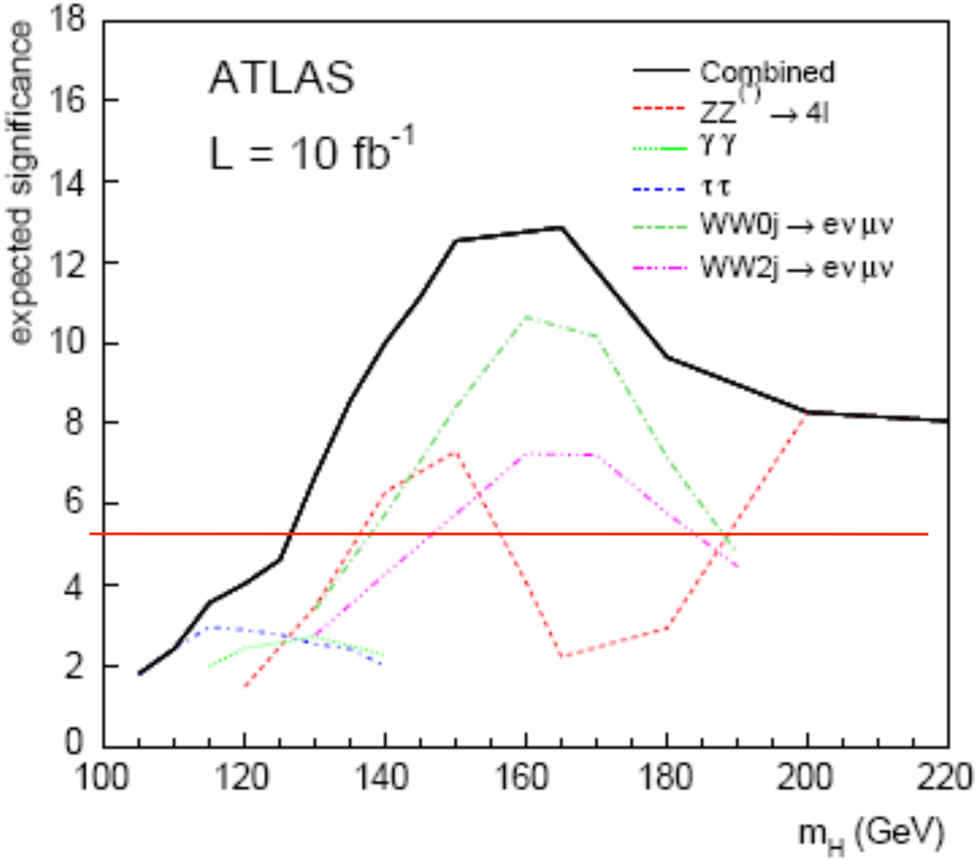
  80% of signal from VBF production

Comparion of expected performance

	ATLAS ≡ A Toroidal LHC ApparatuS	CMS ≡ Compact Muon Solenoid
MAGNET (S)	Air-core toroids + solenoid in inner cavity 4 magnets Calorimeters in field-free region	Solenoid Only 1 magnet Calorimeters inside field
TRACKER	Si pixels+ strips TRT → particle identification B=2T $\sigma/p_T \sim 5 \times 10^{-4}\, p_T \oplus 0.01$	Si pixels + strips No particle identification B=4T $\sigma/p_T \sim 1.5 \times 10^{-4}\, p_T \oplus 0.005$
EM CALO	Pb-liquid argon $\sigma/E \sim 10\%/\sqrt{E} + 0.007$ longitudinal segmentation	$PbWO_4$ crystals $\sigma/E \sim 3\%/\sqrt{E} + 0.003$ no longitudinal segm.
HAD CALO	Fe-scint. + Cu-liquid argon (10 λ) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Brass-scint. (~7 λ +catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	Air → $\sigma/p_T \sim 2\%$(@50GeV) to 10% (@1 TeV) standalone	Fe → $\sigma/p_T \sim 1\%$ (@50 GeV) to 10% (@1 TeV) combining with tracker

Entdeckungspotential bei ATLAS

- Erwartung für 10 fb^{-1}

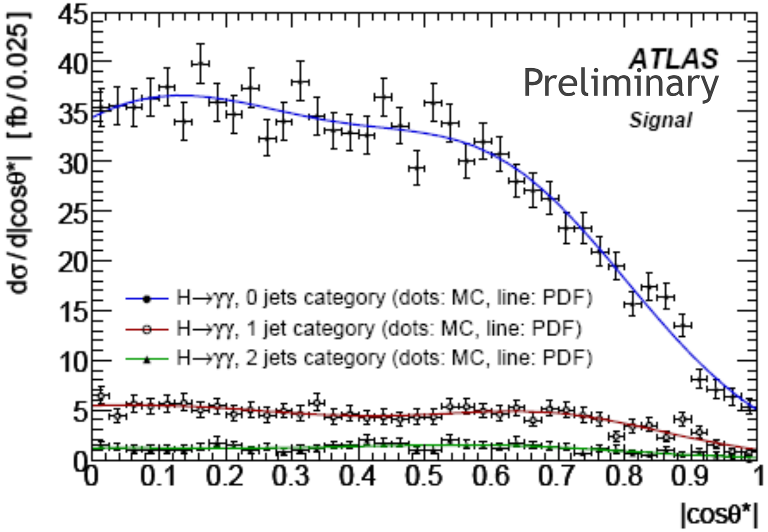


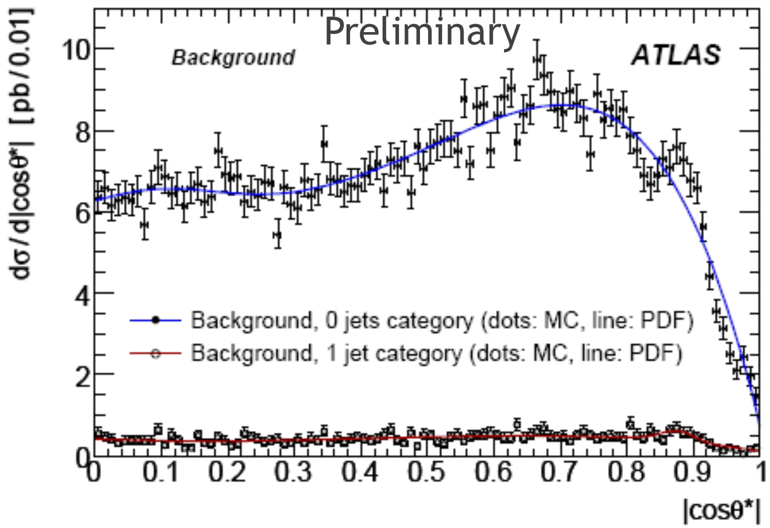
- Entdeckung von 124 to 440 GeV
- kleine Massen am schwierigsten

- H→γγ und ττ jeweils alleine keine Entdeckung bis 30 fb^{-1}

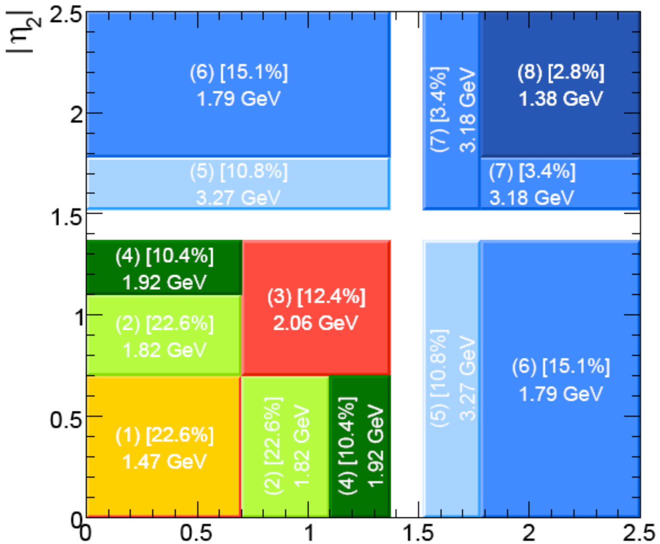
H → 2 photons: optimising the analysis

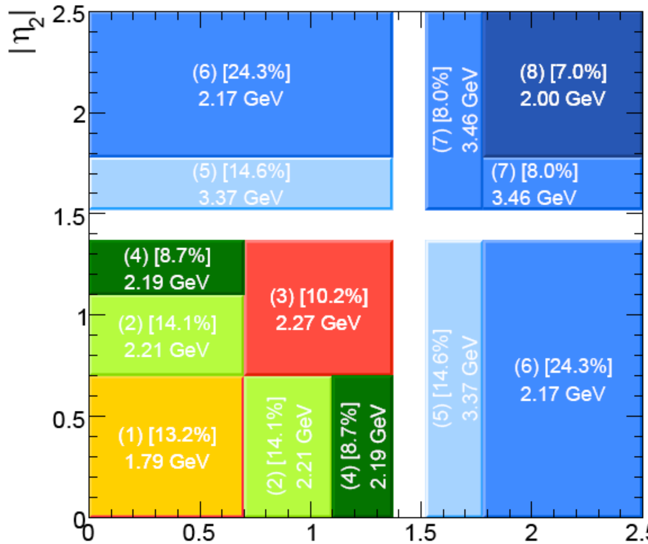
- exploiting more info: $M_{\gamma\gamma}$ + cosθ* + PT_{Higgs}





- event categories due to mass resolution: pseudorapidity of 2 photons

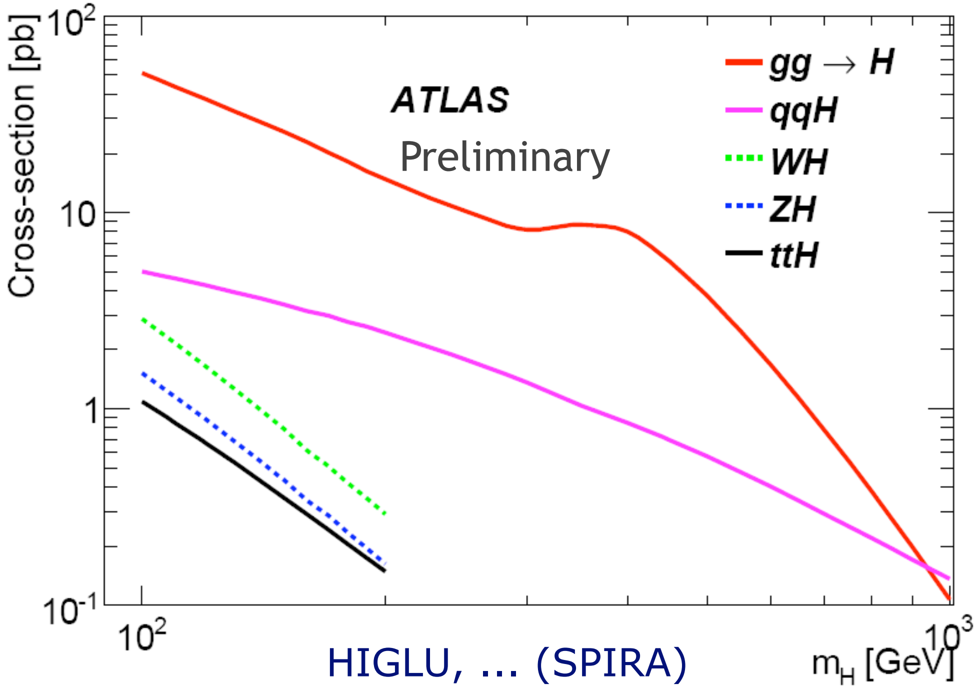


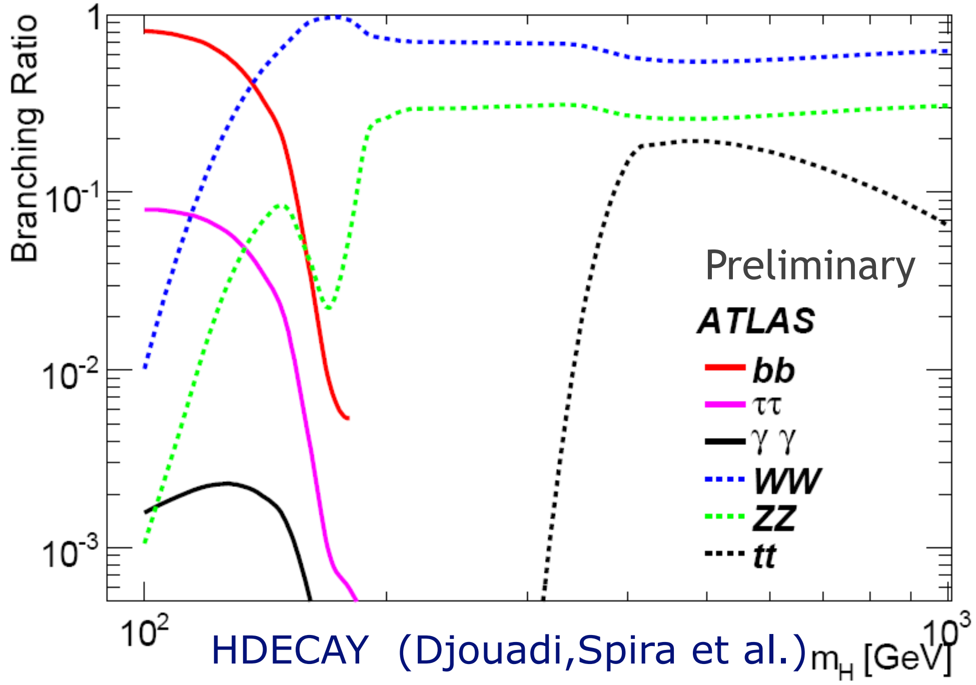


left: 0 conversions

right: >0 conv.

Signal rates for SM Higgs boson production





- NLO (in QCD) cross section section used (except ttH, H→bb analysis)

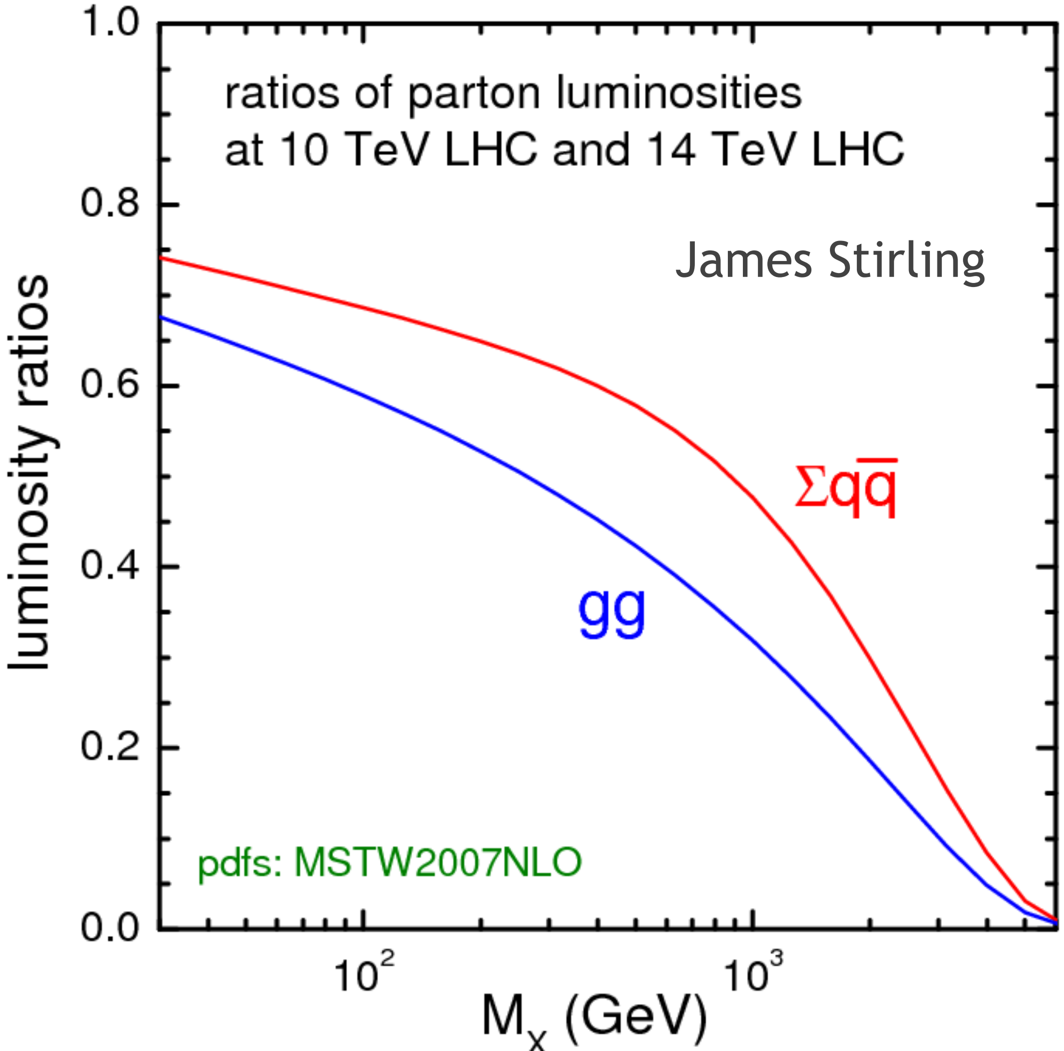
- NNLO (in QCD) and NLO (in EW) result often available and sizable
  but for overall consistency and consistency with background not used

- programs: HIGLU, PP2H, … HDECAY by M. Spira et al. + CTEQ6M(L1) pdfs

- topologies for "early discovery":
  inclusive: H→ZZ→4 leptons, H→WW→lν lν, H → 2 γγ
  exclusive: qqH (VBF) with H→ττ (→WW, →γγ) ttH with H→bb

10 vs 14 TeV?

- probably start with collision at 10 TeV due to dipole commisioning



at 10 TeV, lower cross-section for high mass objects
d
u
e to lower parton luminosities...

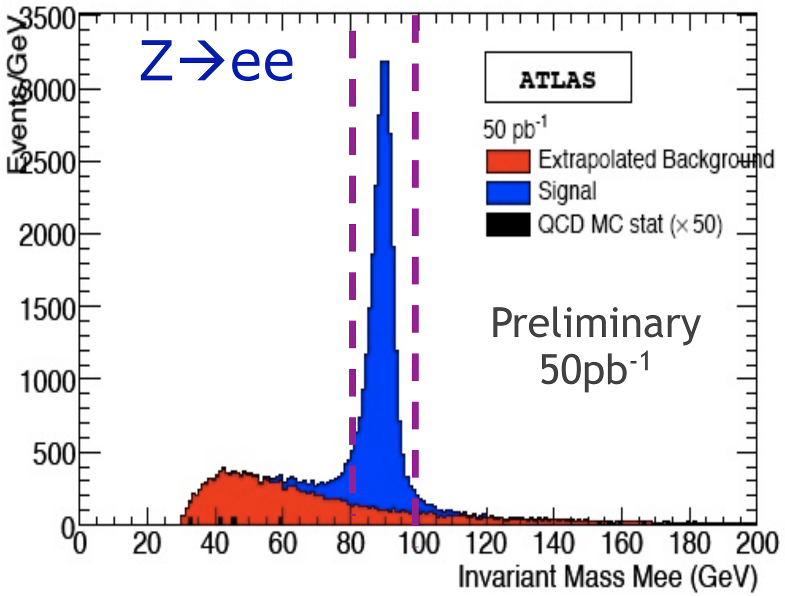
below ~
20
0 GeV, the suppression is <50% (process dependent)

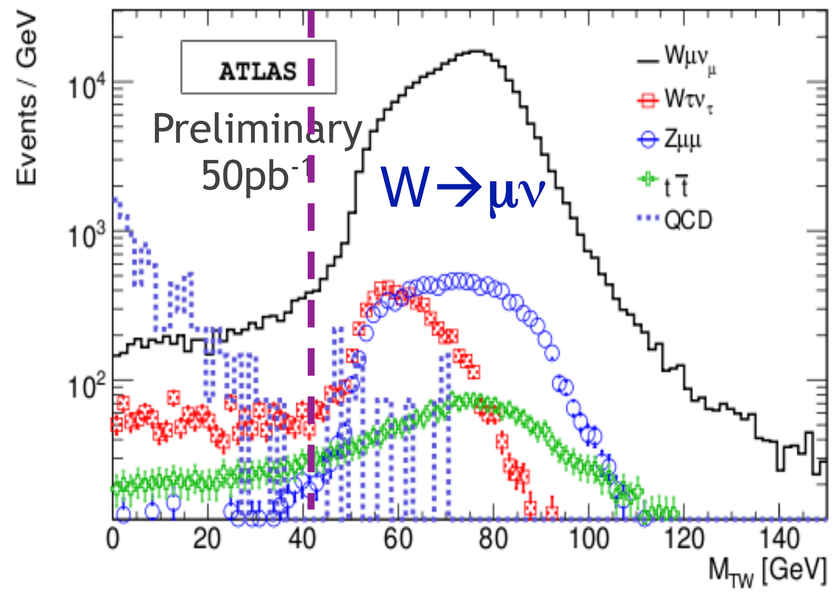
e.g. tt ~ factor 2 lower cross-section (still 50x Tevatron)

above ~2-3 TeV the effect is more marked

Rediscovery of the SM: W and Z production

with 50 pb^{-1}: cross-section measurements limited by systematics





$$\sigma = \frac{N - B}{\mathscr{L}\, A\, \varepsilon}$$

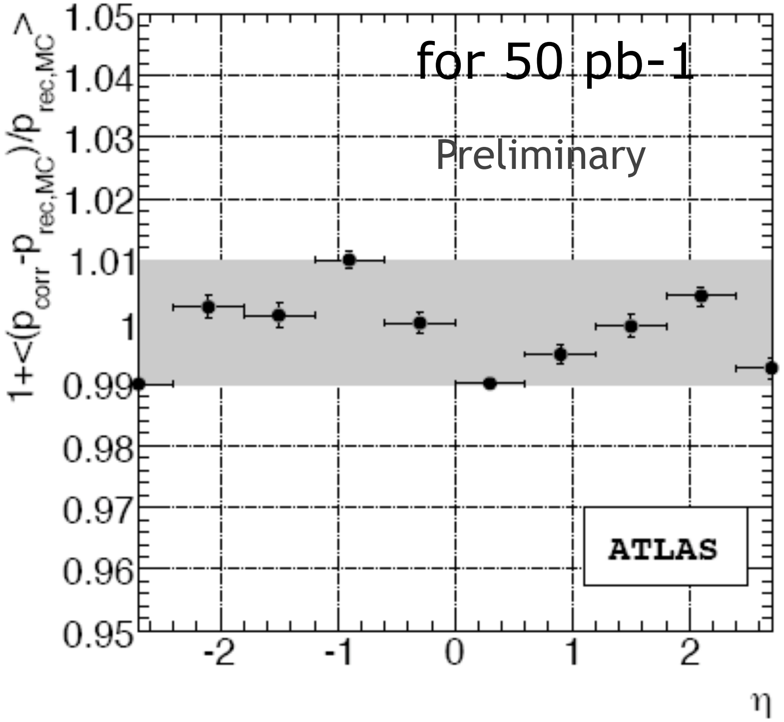
Process	$N(\times 10^4)$	$B(\times 10^4)$	$A \times \varepsilon$	$\delta A/A$	$\delta\varepsilon/\varepsilon$	σ (pb)
$W \to e\nu$	22.67 ± 0.04	0.61 ± 0.92	0.215	0.023	0.02	$20520 \pm 40 \pm 1060$
$W \to \mu\nu$	30.04 ± 0.05	2.01 ± 0.12	0.273	0.023	0.02	$20530 \pm 40 \pm 630$
$Z \to ee$	2.71 ± 0.02	0.23 ± 0.04	0.246	0.023	0.03	$2016 \pm 16 \pm 83$
$Z \to \mu\mu$	2.57 ± 0.02	0.010 ± 0.002	0.254	0.023	0.03	$2016 \pm 16 \pm 76$

- Background: ΔB from control samples
- Acceptance: ΔA from variation MC model (UE, PDF,...)
- Efficiency: Δε from "tag + probe" method
- Lumi error: initially 20% not considered here

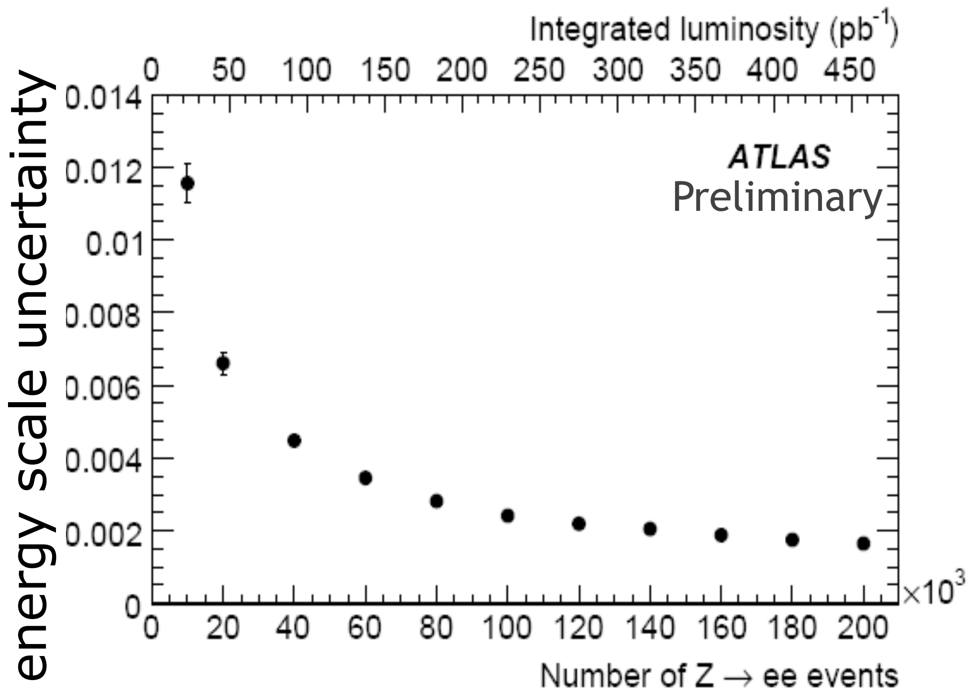
Lepton E/P_T scale and resolution

- compare: M_Z line shape in data with different scales and resolutions in MC

muons



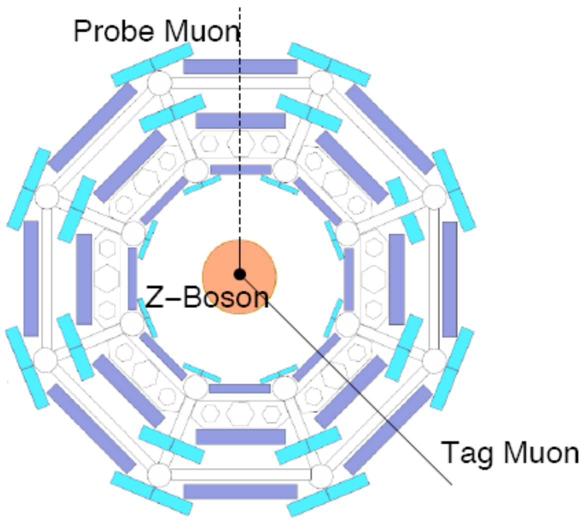
electrons



- muons: scale and resolution with 0.5 GeV for p_t =50GeV for 50 pb^{-1}
- electrons: scale 0.2% at Z mass with 100 pb^{-1},

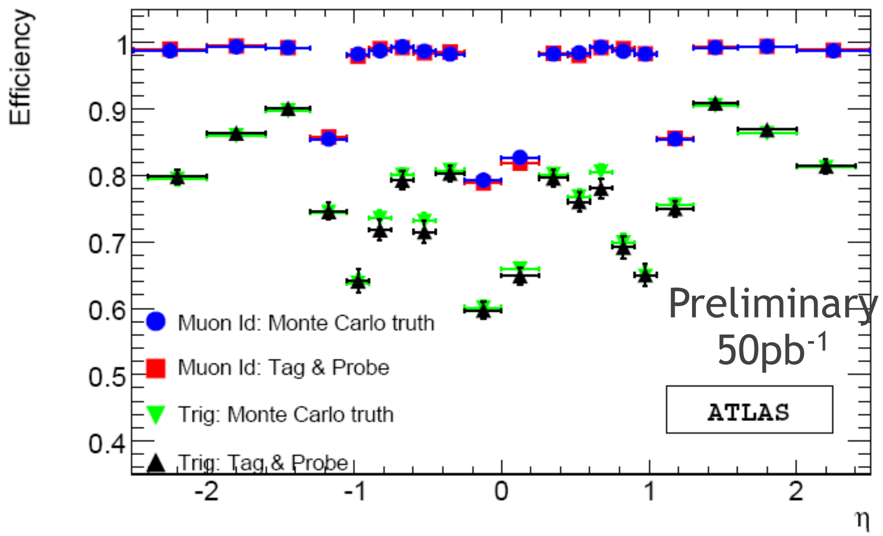
  0.5% for central at other energies, else 1 to 2% initially

Tag and Probe Method

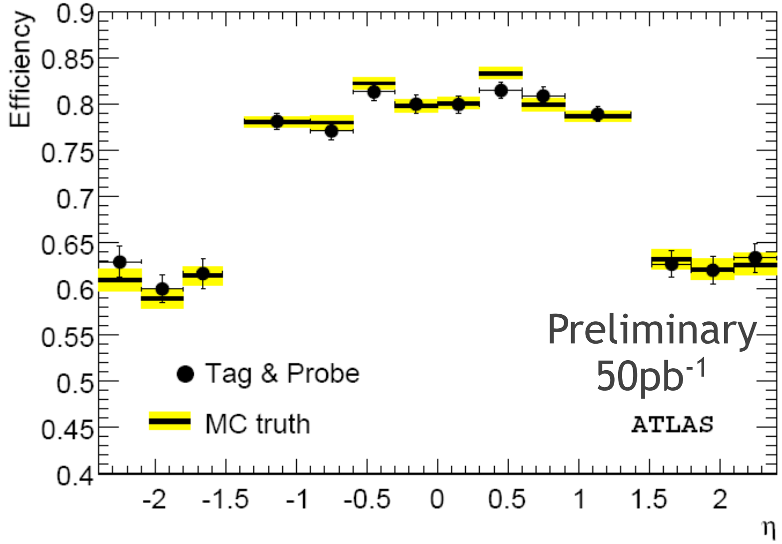


- select on tight lepton and unbiased „e/μ candidate" consistent with M_Z
- get efficiency from ratio of „passed/all"

muons



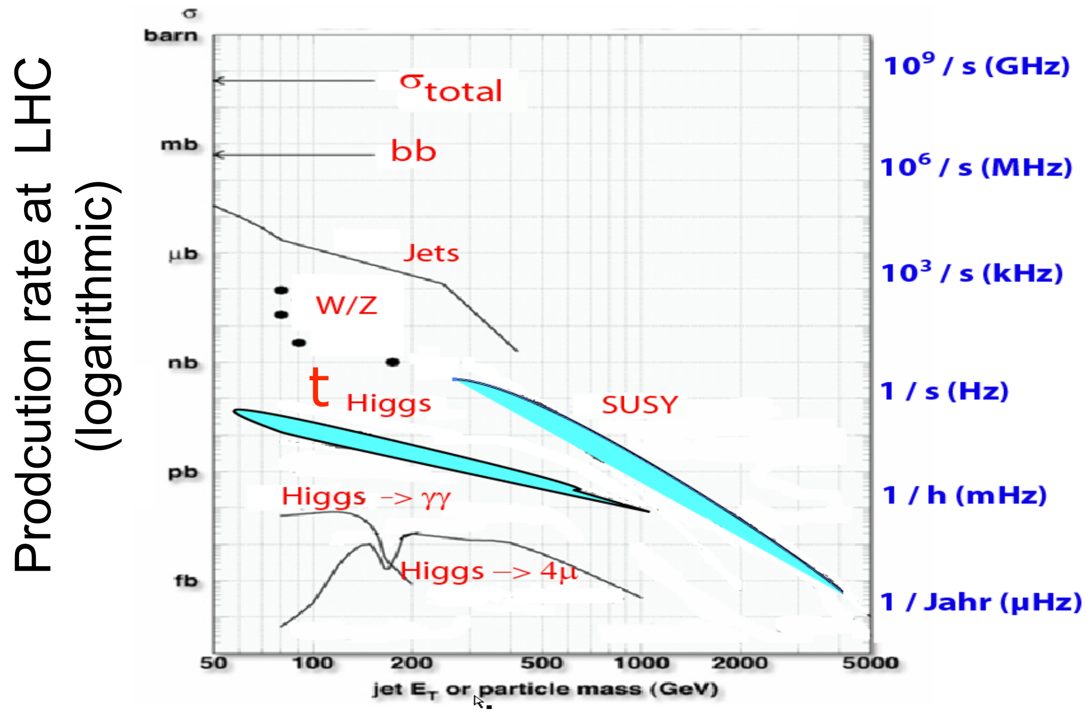
electrons



efficiency determined with accuracy of ~ 2% with $50pb^{-1}$

Event rates and roadmap

at design lumi



Process	Events (10 pb^{-1})
minumum bias	~ ∞
W→eν	10^5
Z→ee	10^4
tt→qqbeνb	10^3
Higgs (130 GeV)	10
Gluinos (1 TeV)	1

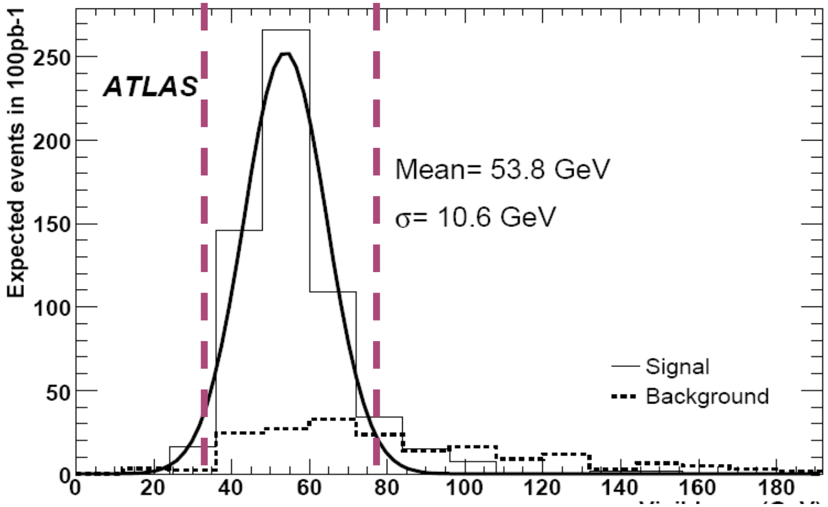
~10pb: - establish and measure SM standard candles (Z,W,t) and use them for detector calibration („tag and probe") for e,μ
- look for spectacular and/or simple signature of new physics

~100pb: - improve understanding of detetecor (ETMISS, JETS) and of SM process relevant for Higgs/SUSY/... searches
- first sensitivity for SUSY at low mass,...

~1fb: - first sensitivity to SM Higgs

In Situ Determination of Tau Performance

- selection of Z→tau tau→ lep had:



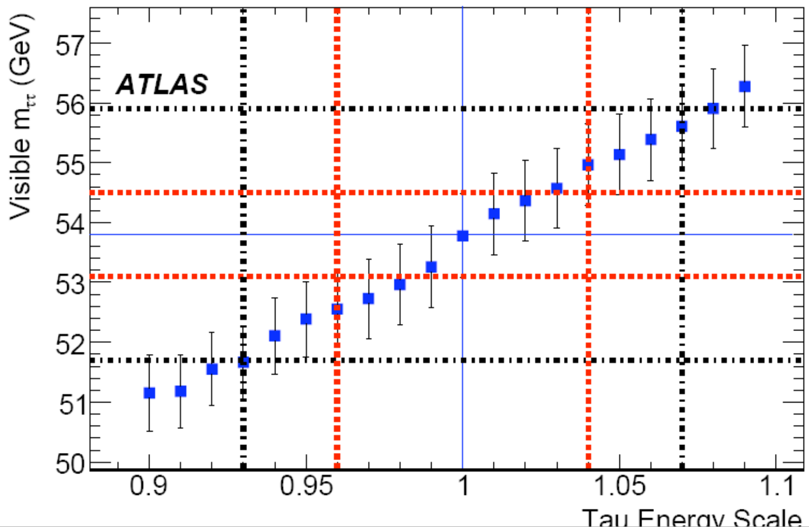
visible $m_{\tau\tau}$ (GeV)

QCD BG = same sign leptons

signal =same sign – opposite sign

- efficiency: compare measurements of $\sigma(Z\rightarrow\tau\tau)$ with one of $\sigma(Z\rightarrow\mu\mu/ee)$
- fake rate: select dijet samples apply tag+probe: Δ_{stat}<0.1% ($100pb^{-1}$)

- tau energy scale:



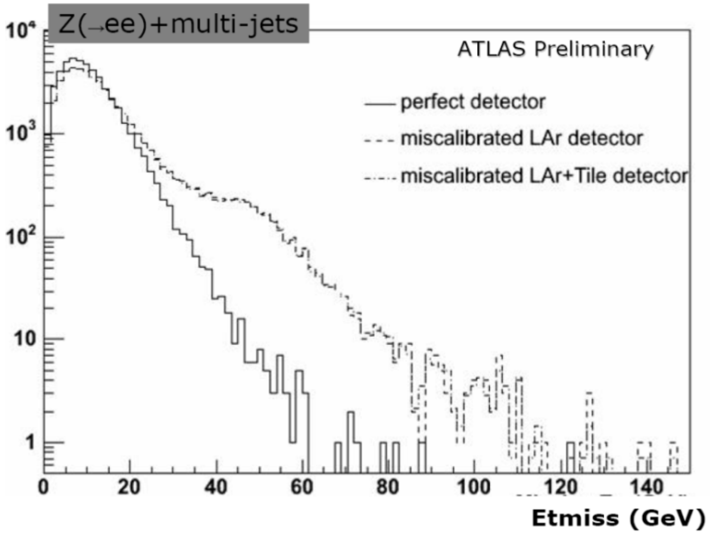
compare visible $m_{\tau\tau}$ distributions:

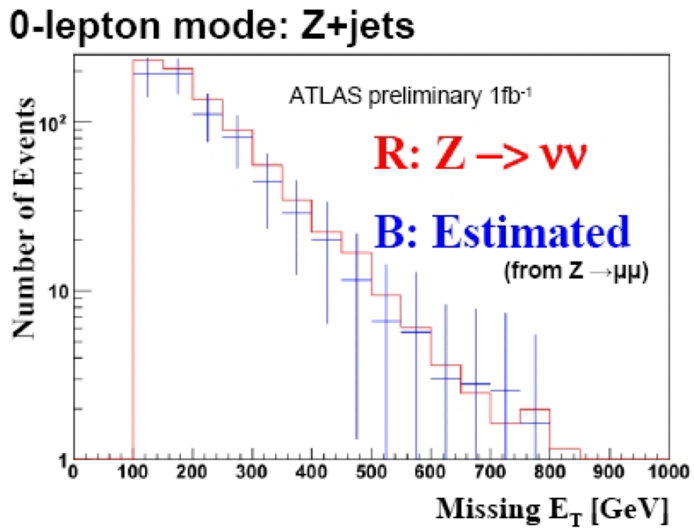
MC with different tau energy scale

and data ($100pb^{-1}$)

Red (black) 1 3 sigma lines

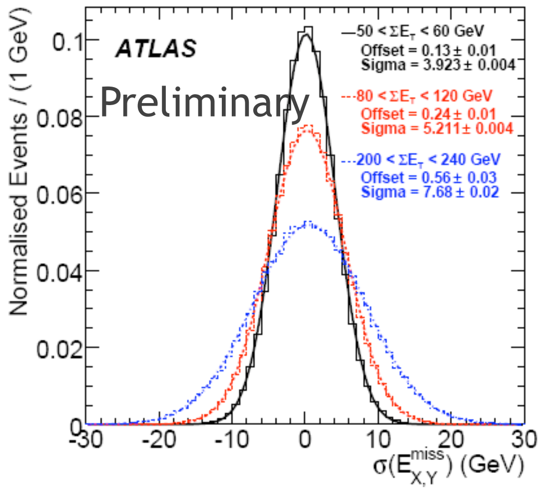
- E_T^{miss} is one of the hardest quantities to measure
- Understanding of all detector components required
- Strategy: "calibrate" E_T^{miss} with known SM processes from data
- Example: DY-Production of $Z \rightarrow \mu\mu$
  1. Tune $Z \rightarrow \mu\mu$ MC with data
  2. Remove muons and compare with $Z \rightarrow \nu\nu$
  3. Tune E_T^{miss} from observed differences

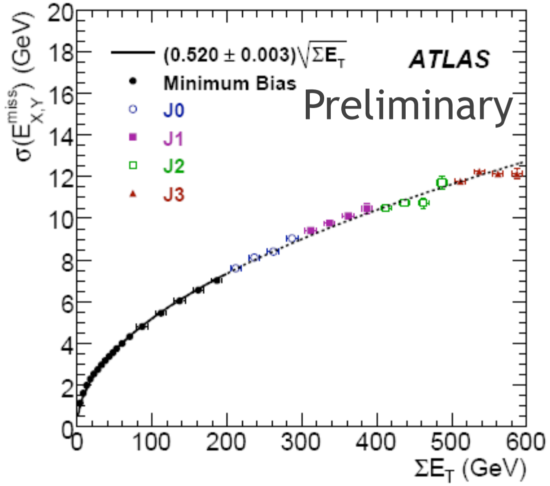




In Situ Determination of Missing Energy Performance

- expected performance: $\sigma = a \cdot \sqrt{\Sigma E_T}$ a: 0.53 and 0.57
- minimum bias (10^{-5} pb): no true missing ET

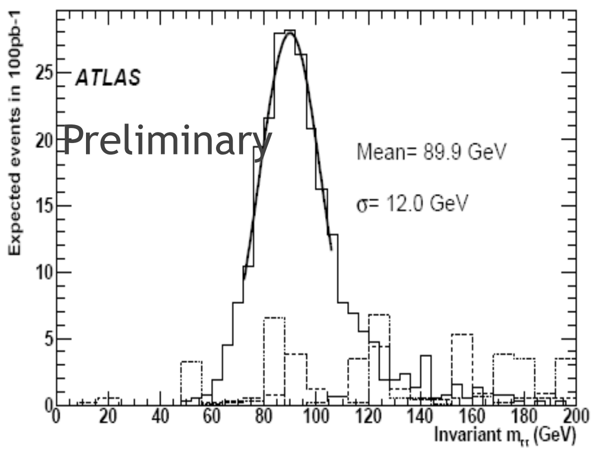


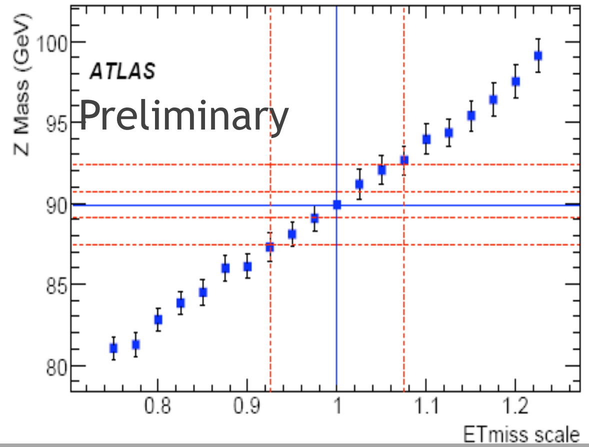


$\Delta a/a$ ~ 6%

for low sum ΣE_T

- Z→tautau→lep had: missing energy scale from known M_Z

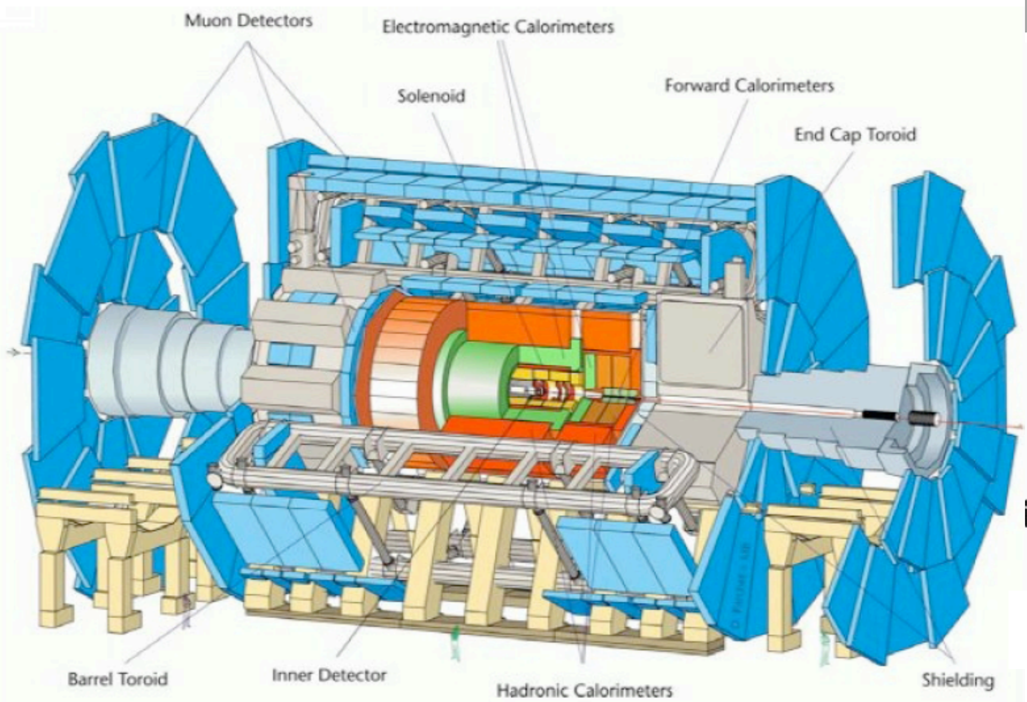


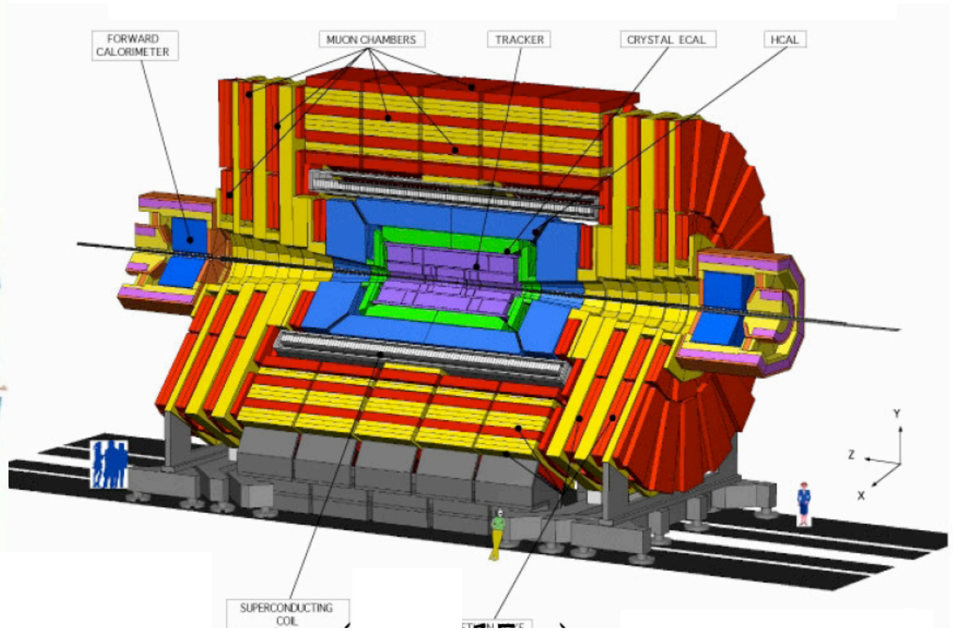


determination accuracy of 8%

=3 σ deviation from true M_Z

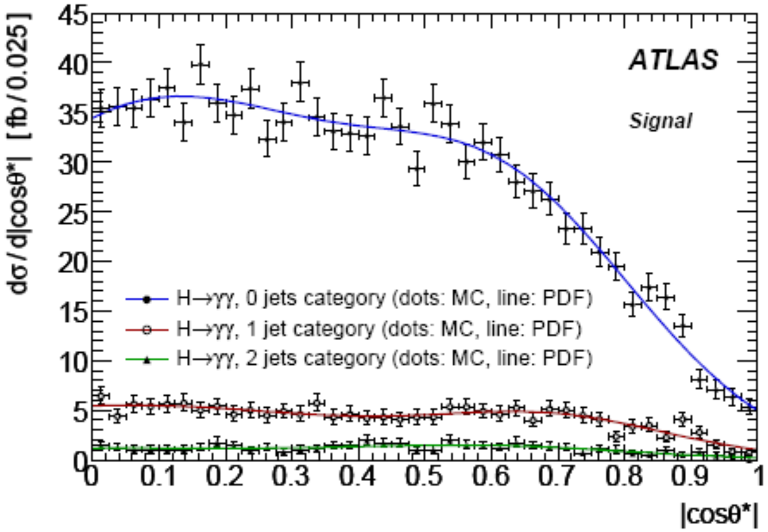
ATLAS and CMS

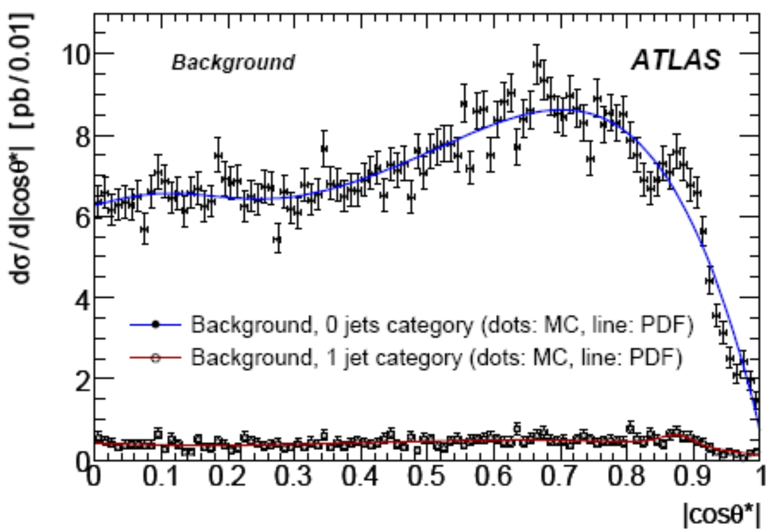




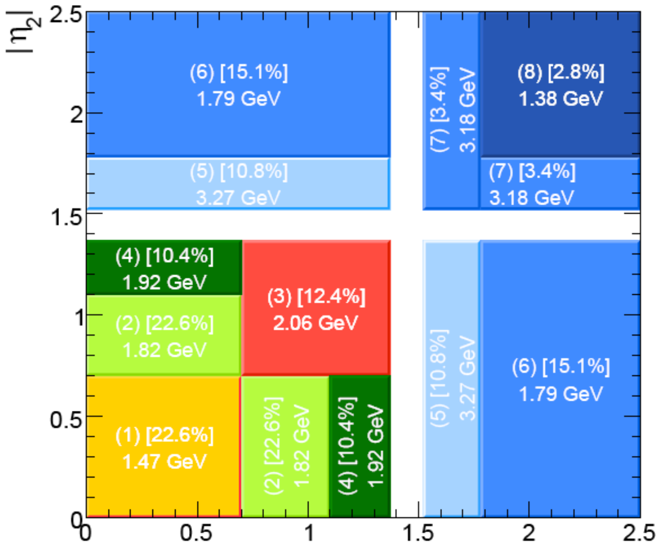
	ATLAS	CMS
TRACKER	B=2T $\sigma/p_T \sim 5\times10^{-4}\, p_T \oplus 0.01$	B=4T $\sigma/p_T \sim 1.5\times10^{-4}\, p_T \oplus 0.005$
EM CALO	$\sigma/E \sim 10\%/\sqrt{E}$ uniform longitudinal segmentation	$\sigma/E \sim 2\text{-}5\%/\sqrt{E}$ no longitudinal segm.
HAD CALO	$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	$\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	Air $\rightarrow$ $\sigma/p_T \sim 7$ % at 1 TeV	Fe $\rightarrow$ $\sigma/p_T \sim 5\%$ at 1 TeV

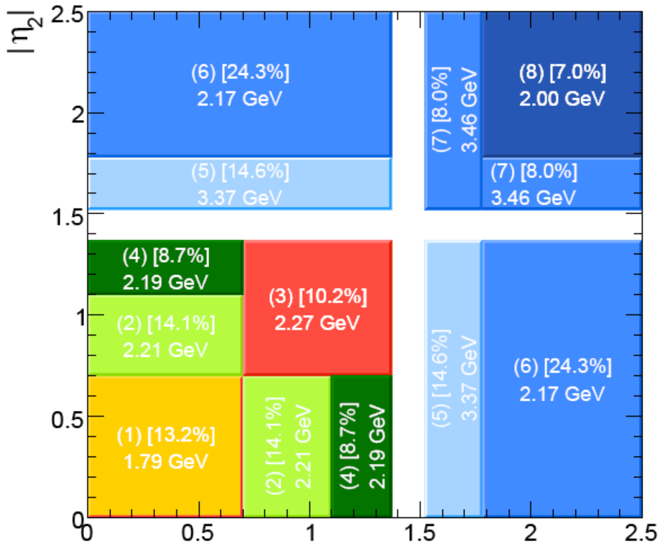
- exploiting more info: $M_{\gamma\gamma}$ + cosθ* + PT_{Higgs}





- event categories due to mass resolution: pseudorapidity of 2 photons

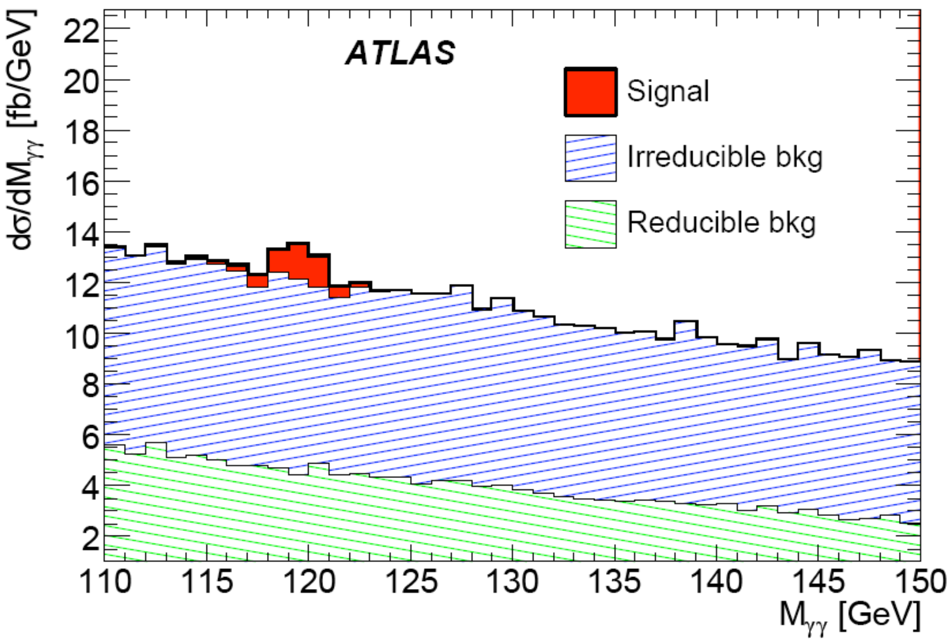




Left: 0 conversion

Right: >0 conv.

H+0,1,2 jet analysis: improving S/B ratio



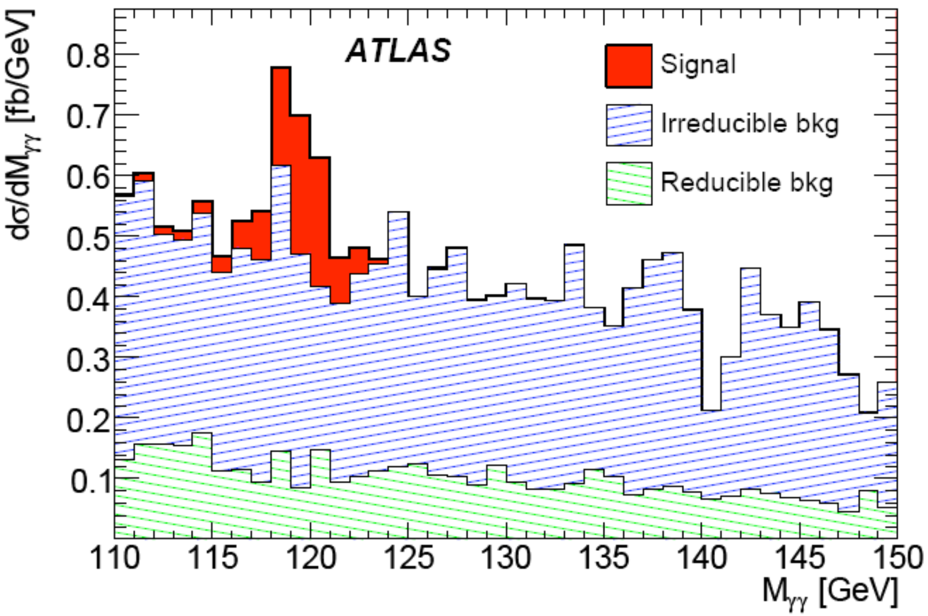
- One Jet:

PT(jet) >20 GeV ; $M_{j\gamma\gamma}$>350 GeV

S/B=1/12

Signal = 4fb

50% of signal from gluon fusion



- Two Jet (VBF analysis):

S/B= 1/2

Signal = 1fb

80% of signal from VBF production