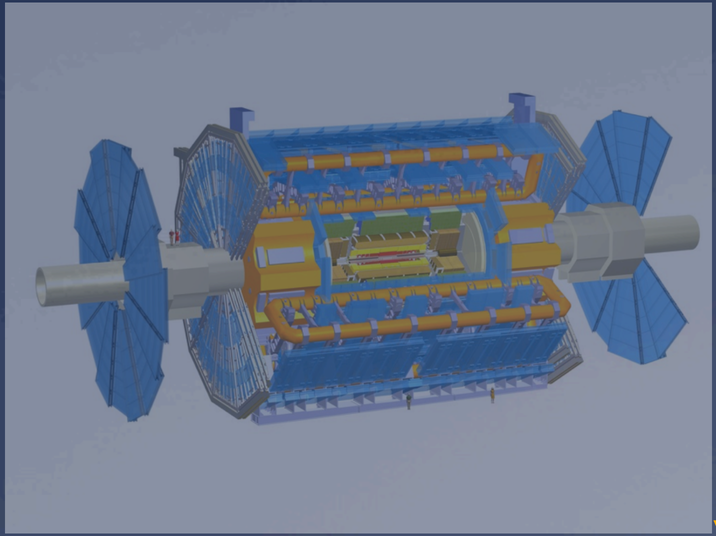
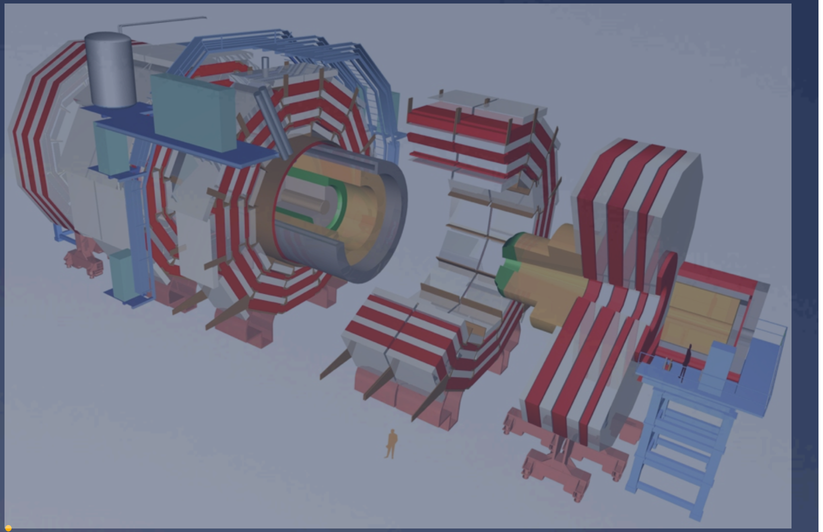
Future measurements and reach with



ATLAS

&

CMS



Vladimir Rekovic

Higgs and Beyond 2013, 5-9 Jun 2013, Tohoku University, Sendai (Japan)

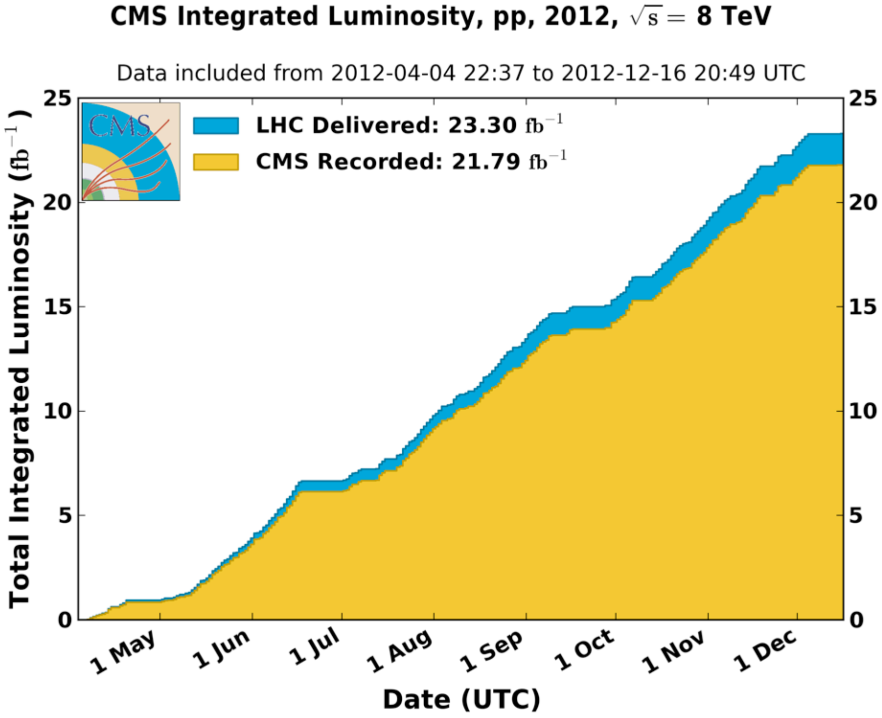
Outline

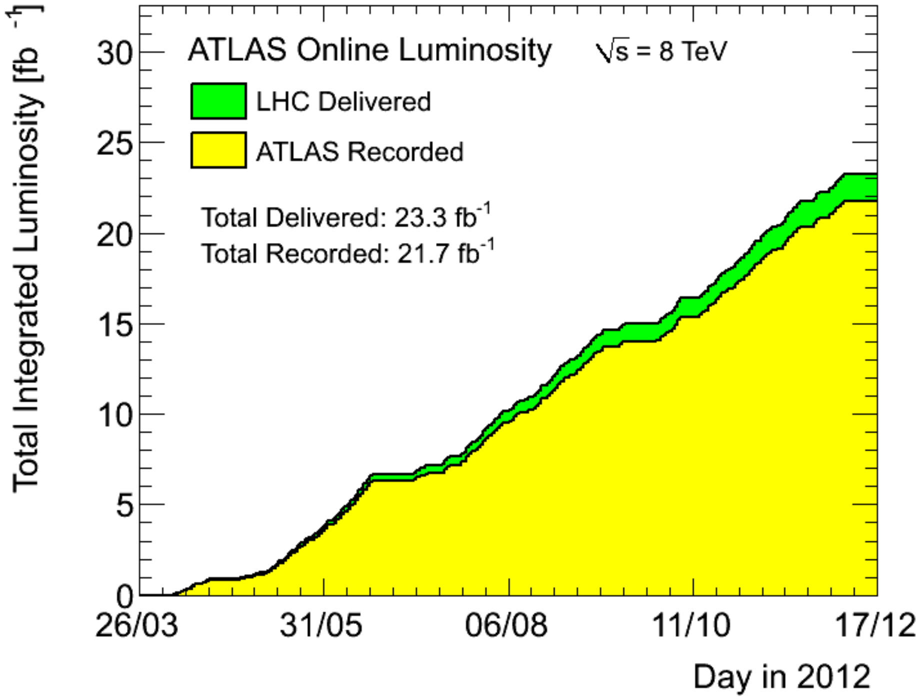
- Results up to now
- Luminosity scenarios for LHC and HL-LHC
- Physics goals
- Upgrade plans for ATLAS & CMS
- Scalar boson physics projections
- Scalar boson rare decays
- Scalar boson self-coupling
- VV scattering
- SUSY prospects
- Exotics projections

Integrated luminosity in 2012

Integrated luminosity recorded in 2012: **~22 fb^{-1}**

2011: L=~6 fb^{-1}





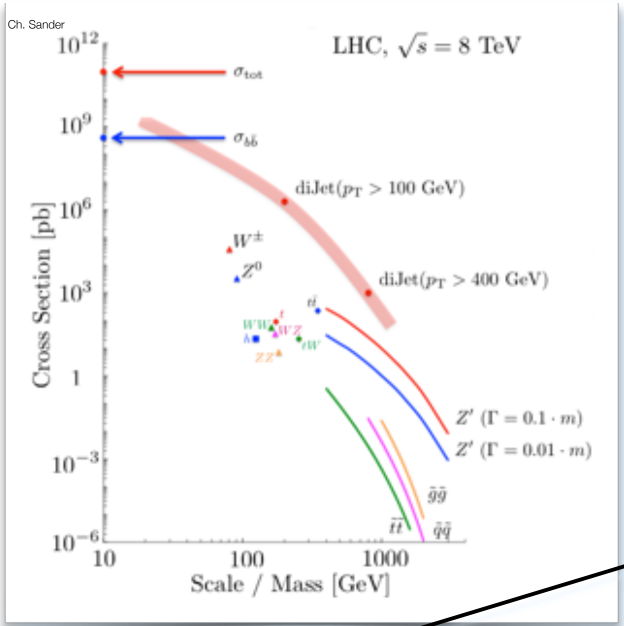
Total delivered luminosity: **~30 fb^{-1}**

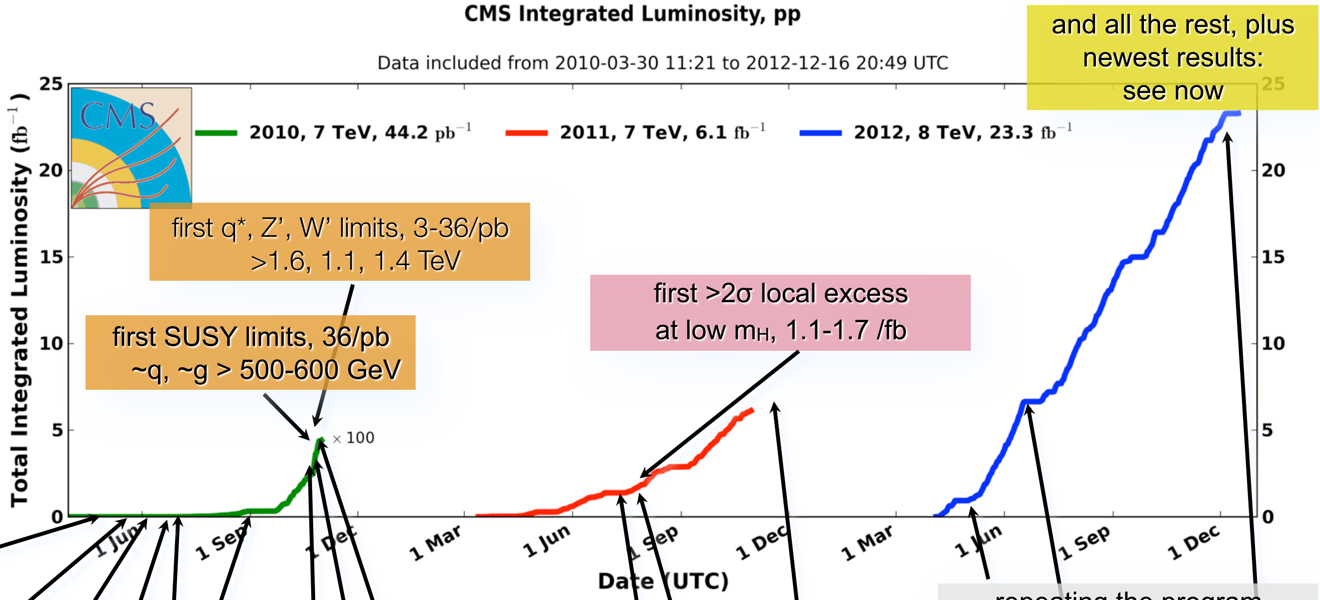
Total recorded luminosity: **~27 fb^{-1}**

Excellent LHC peformance.

Very high data-taking efficiency of the two detectors.

3 years of constant physics results CMS as example ...





and all the rest, plus newest results: see now

first q*, Z', W' limits, 3-36/pb
>1.6, 1.1, 1.4 TeV

first SUSY limits, 36/pb
~q, ~g > 500-600 GeV

first >2σ local excess
at low m_H, 1.1-1.7 /fb

first MinBias / UE
studies, particle multiplicities

first incl. b x-section, 8/nb
δ ~ 15 %

first incl. jet x-section, PF jets
60/nb δ ~ 20-30%

first incl. W/Z x-sections, 200/nb
δ ~ 4-6%, +11% lumi

first incl. J/Ψ x-section, 100/nb
δ ~ 20%

first top xsec, 3/pb
δ ~ 40%

first single top xsec,
t-chan., 36/pb
δ ~ 36%

first m_{top}, 36/pb
Δ ~ 6.5 GeV

first WW xsec, 36/pb
δ ~ 40%
first limit on HWW

first ZZ xsec, 1.1 /fb
δ ~ 40%

going more differential,
e.g. Z/W + j,b,c

first significant limit on
$B_s \rightarrow \mu\mu$, BR<1.9×10^{-8}

first particle discovered
by CMS: Ξ_b

BSM searches continue,
limits pushed

repeating the program
at 8 TeV

a new boson is
announced, 5 /fb

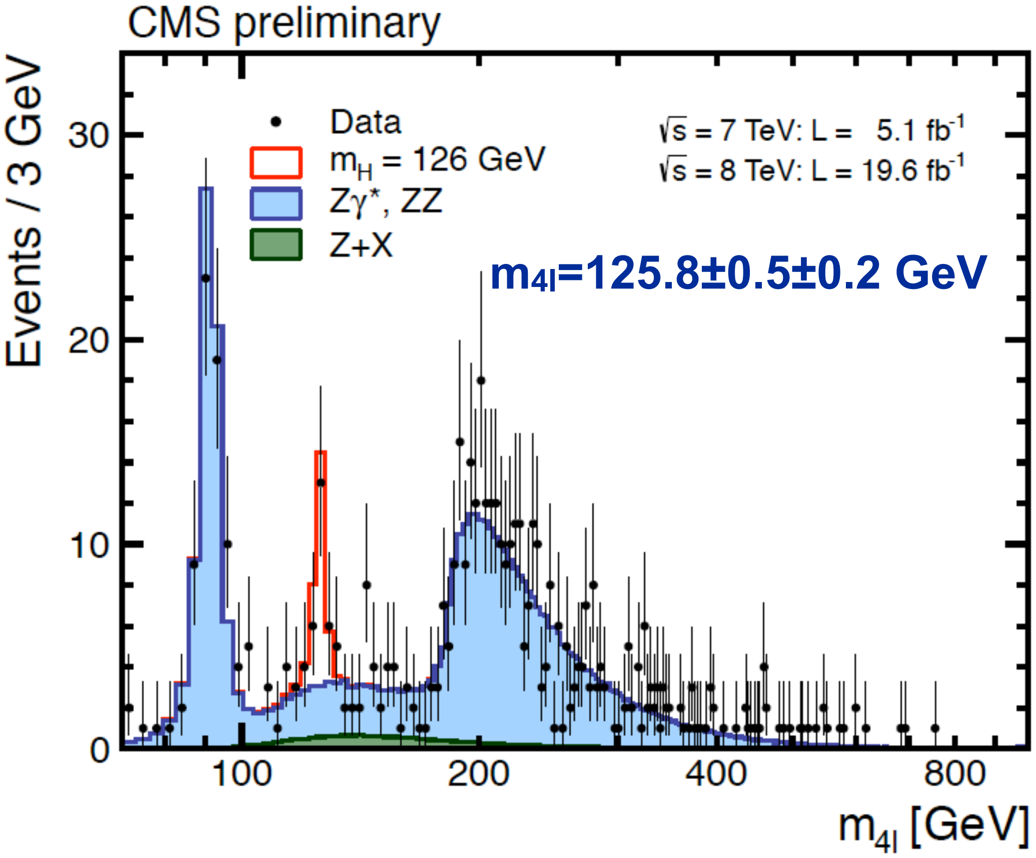
first spin parity analysis
of the boson, 17 /fb

From G. Dissertori (ETH)

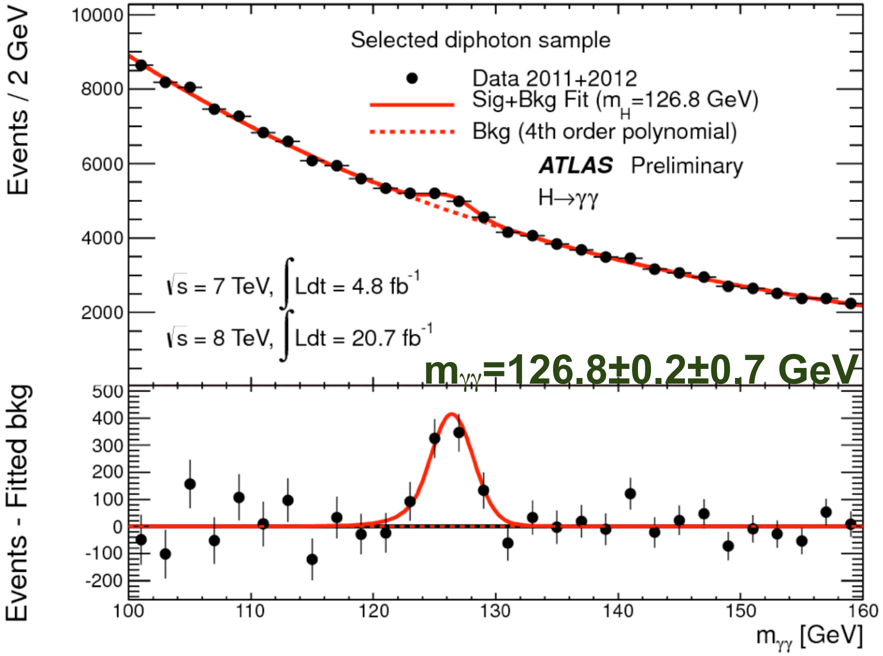
δ .. relative uncert.
Δ .. absolute uncert.

New boson with a mass of ~125 GeV

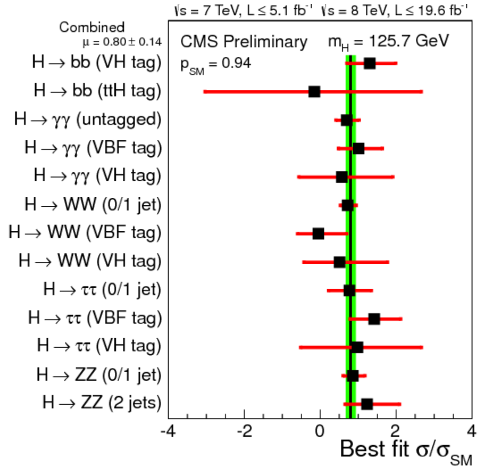
- We have discovered a SM-like scalar boson with a mass of ~125 GeV.
- J^{PC}, consistent with SM scalar boson, couplings will need more data.



m_{4l}=125.8±0.5±0.2 GeV



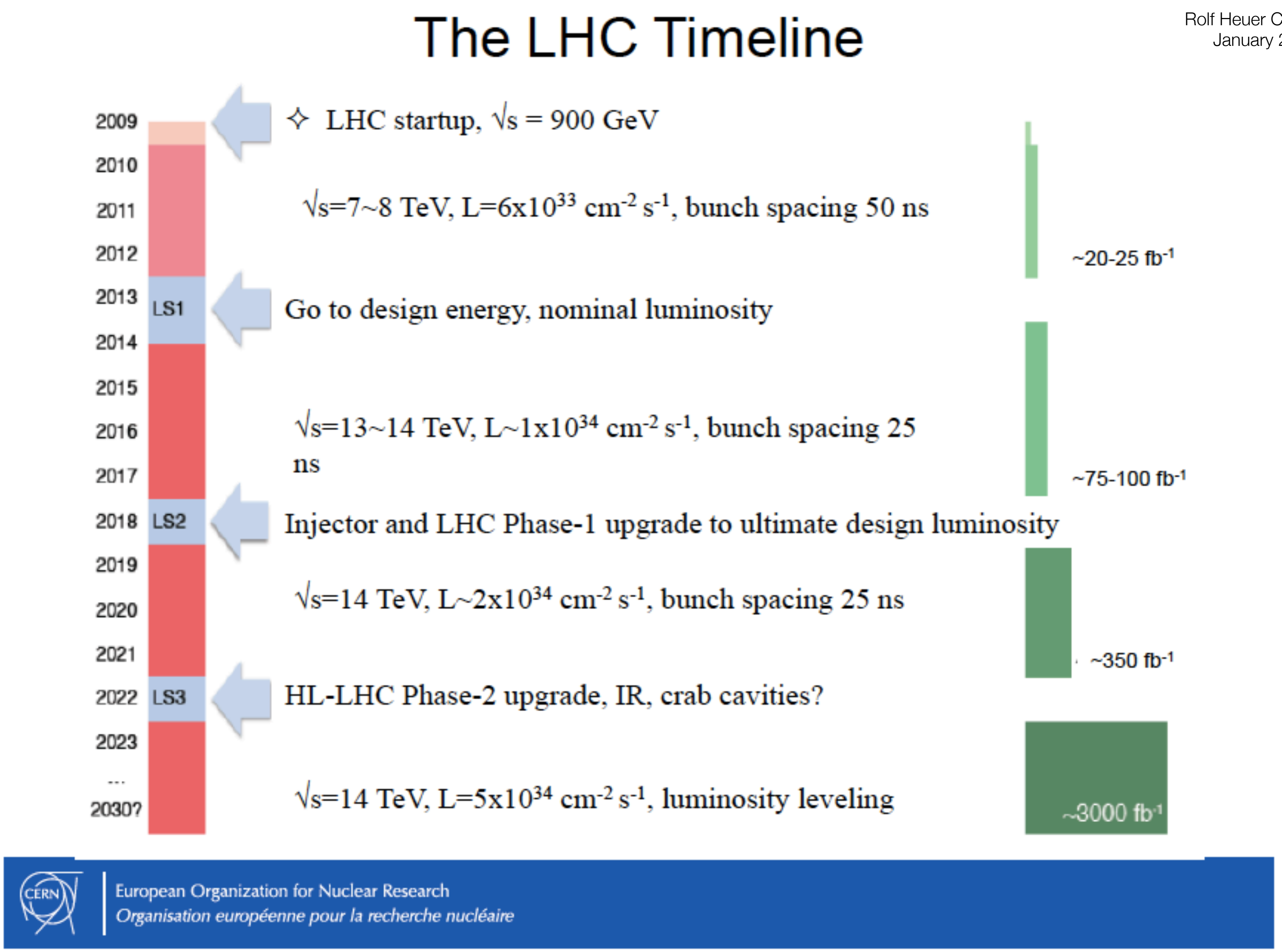
$m_{\gamma\gamma}$=126.8±0.2±0.7 GeV



σ/σ_{SM} = 0.80±0.14

The new boson is consistent with being the SM scalar boson

Plans for HL-LHC



The LHC Timeline

Rolf Heuer CERN-DG
January 2013

✧ LHC startup, √s = 900 GeV

$\sqrt{s}$=7~8 TeV, L=6x10^{33} cm^{-2} s^{-1}, bunch spacing 50 ns

Go to design energy, nominal luminosity

$\sqrt{s}$=13~14 TeV, L~1x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns

Injector and LHC Phase-1 upgrade to ultimate design luminosity

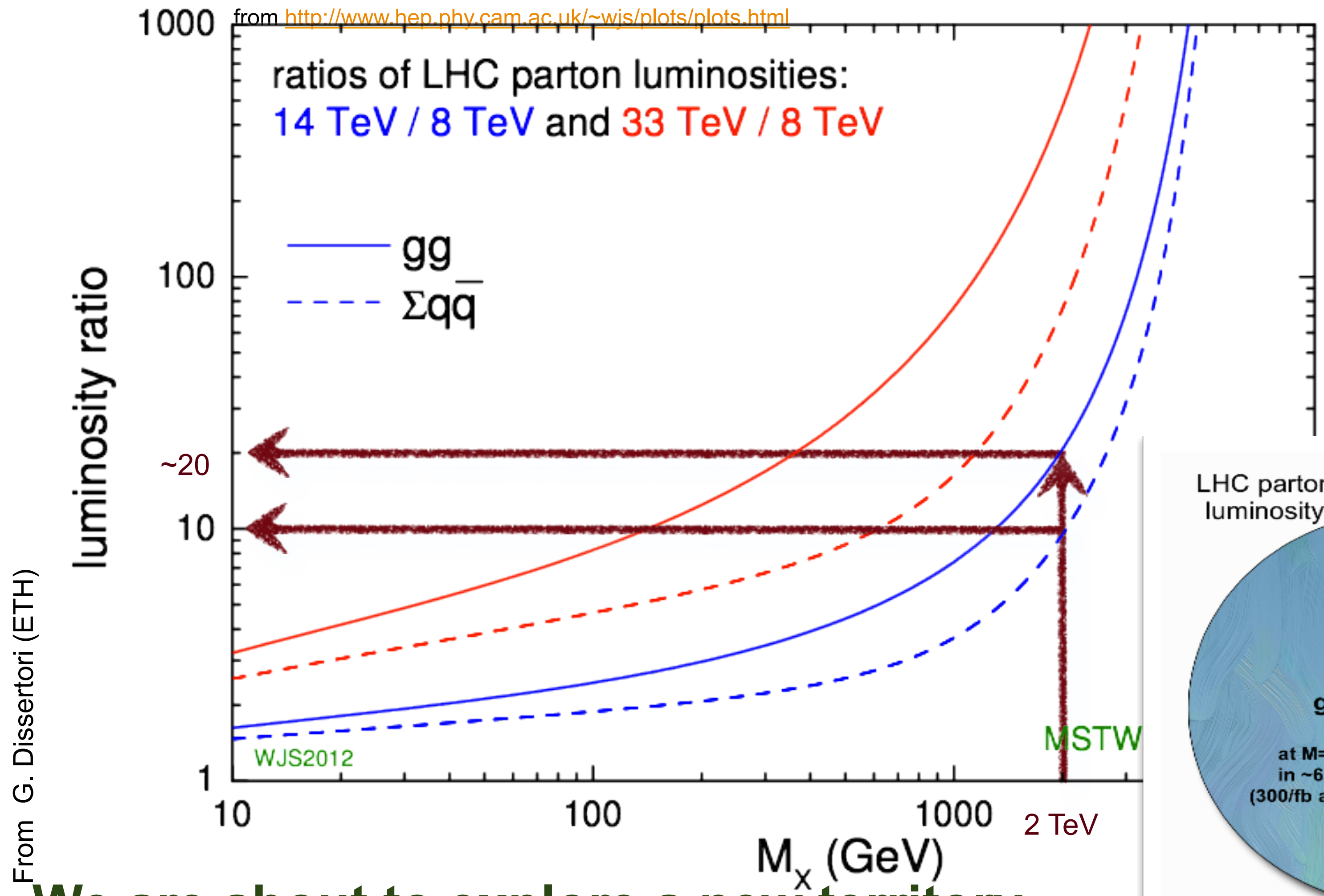
$\sqrt{s}$=14 TeV, L~2x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns

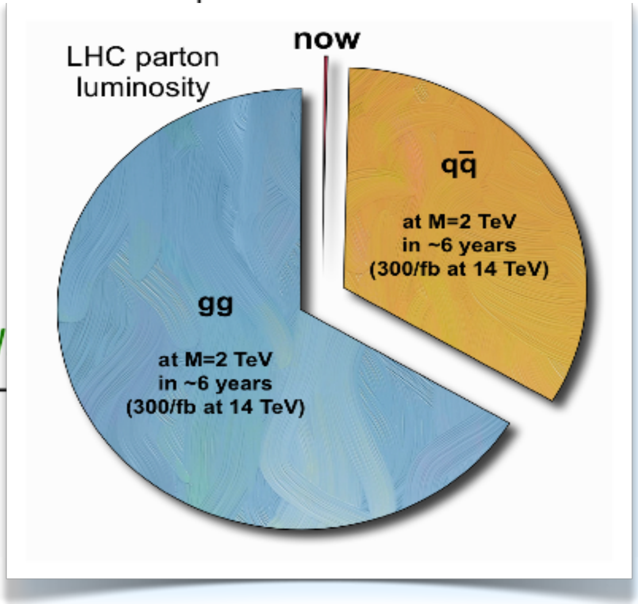
HL-LHC Phase-2 upgrade, IR, crab cavities?

$\sqrt{s}$=14 TeV, L=5x10^{34} cm^{-2} s^{-1}, luminosity leveling

European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

LHC after LS1





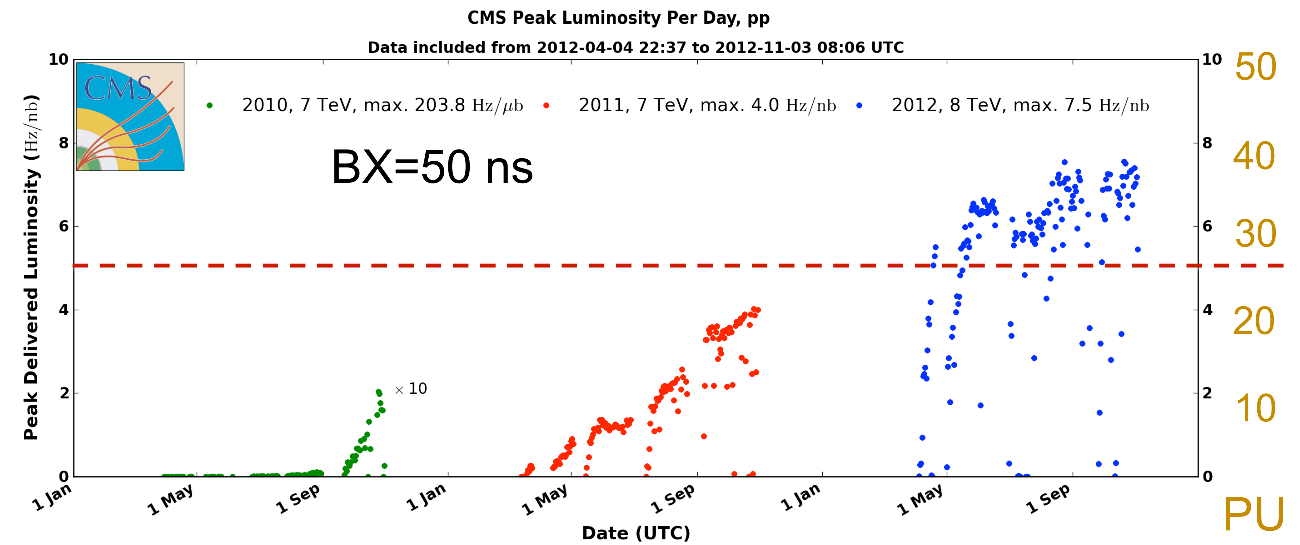
We are about to explore a new territory with significantly improved statistics!

Detector and trigger challenges

- Need detectors and trigger with high performances from low to high energy scales
  - 125 GeV SM-like boson measurements
  - Multi-TeV new physics searches
- Phase 1 Upgrade: twice LHC design luminosity (2018)
  - Event pileup reaches ~50 collisions per beam crossing (@ 25 ns)
  - Factor 5 increase in trigger rates relative to 2012 run
- Phase 2 Upgrade: 5x LHC design luminosity (2021)
  - Event pileup reaches ~140 collisions per beam crossing (@ 25 ns)
  - Need solutions to cope with very high rates (10-15 x 2012), radiation and pileup

ATLAS and CMS were designed to cope with L= 1-2 x10^{34} cm^{-2}s^{-1}

Pileup in 2012

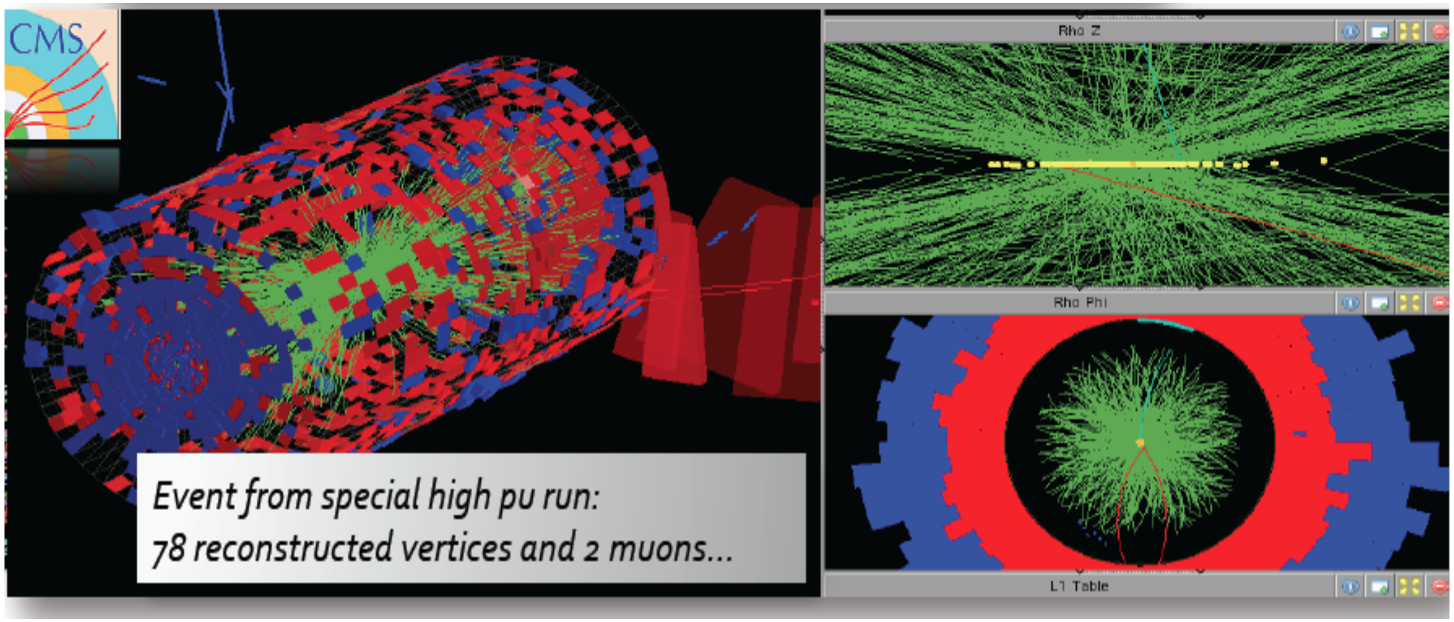


Peak: 37 pileup events

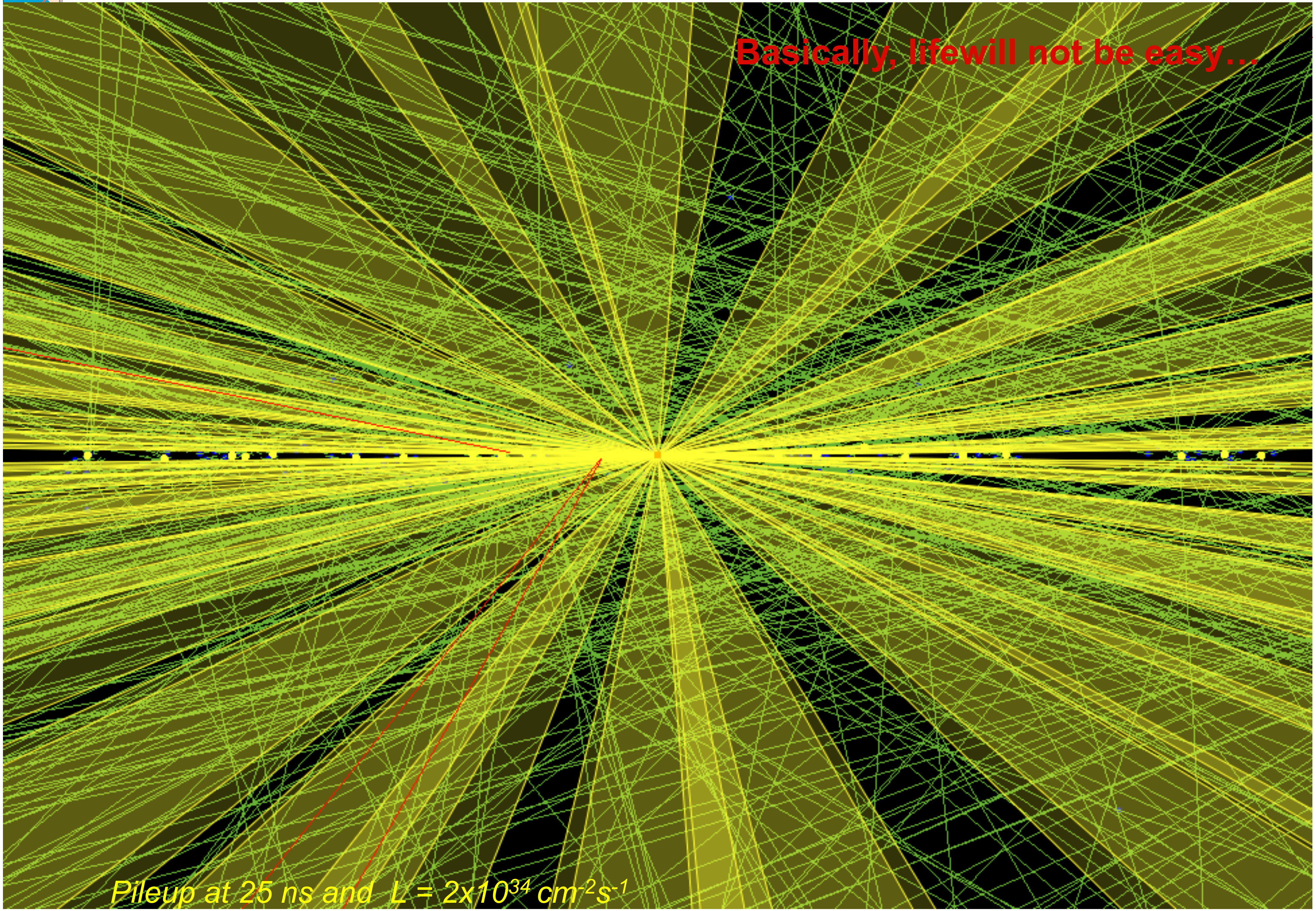
Design value

25 pileup events

(L=10^{34}, BX=25 ns)



Event from special high pu run:
78 reconstructed vertices and 2 muons…

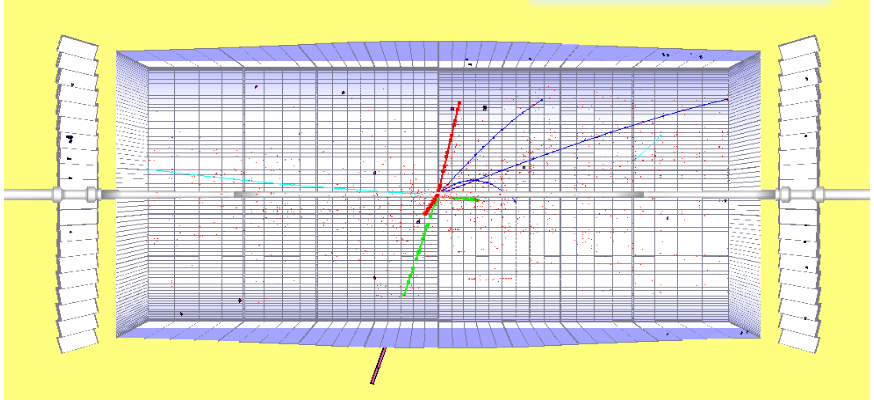


Basically, lifewill not be easy…

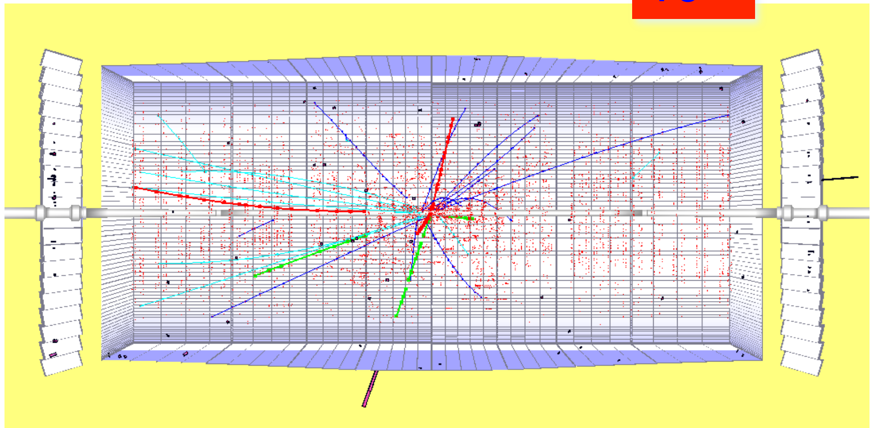
Pileup at 25 ns and $L = 2x10^{34}\ cm^{-2}s^{-1}$

HL-LHC Challenges

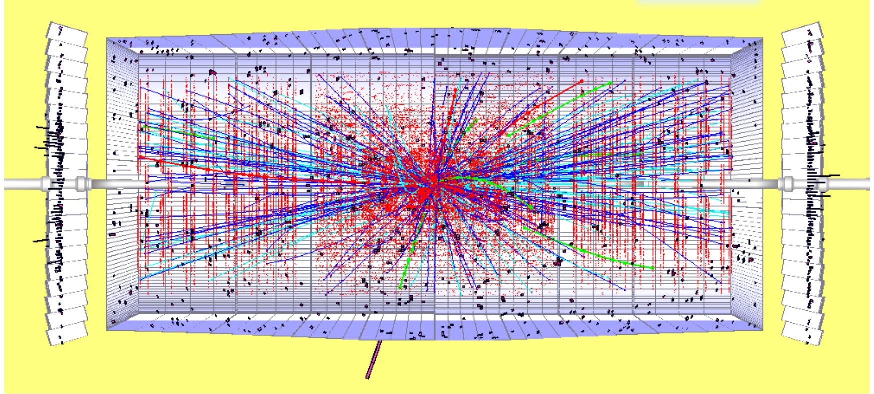
10^{32} cm^{-2} s^{-1}



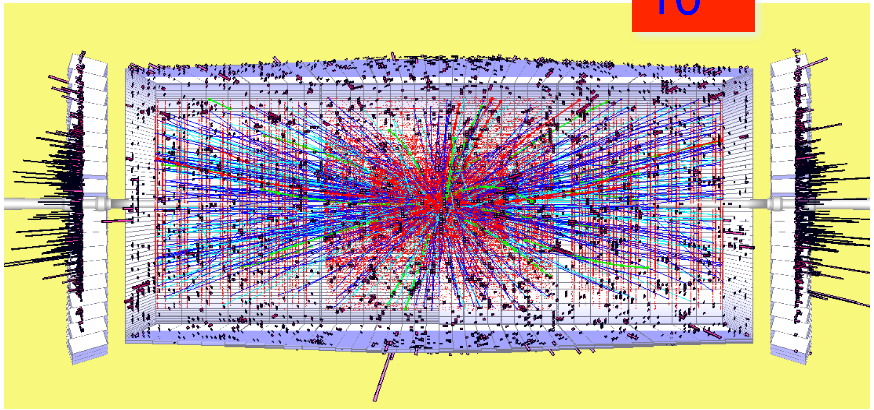
10^{33}



10^{34}



10^{35}



HL-LHC presents increased challenges for Triggering, Tracking and Calorimetry, in particular for low to medium P_T objects

Upgrade challenges and recipe

Maintain low trigger thresholds, efficient particle and physics object reconstruction at high rate and pile-up

Need new technology R&Ds to:

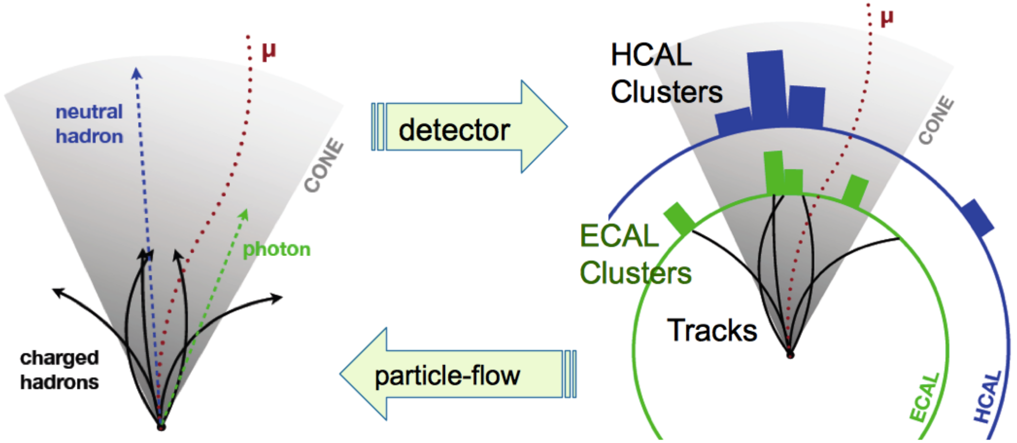
−Increase granularity

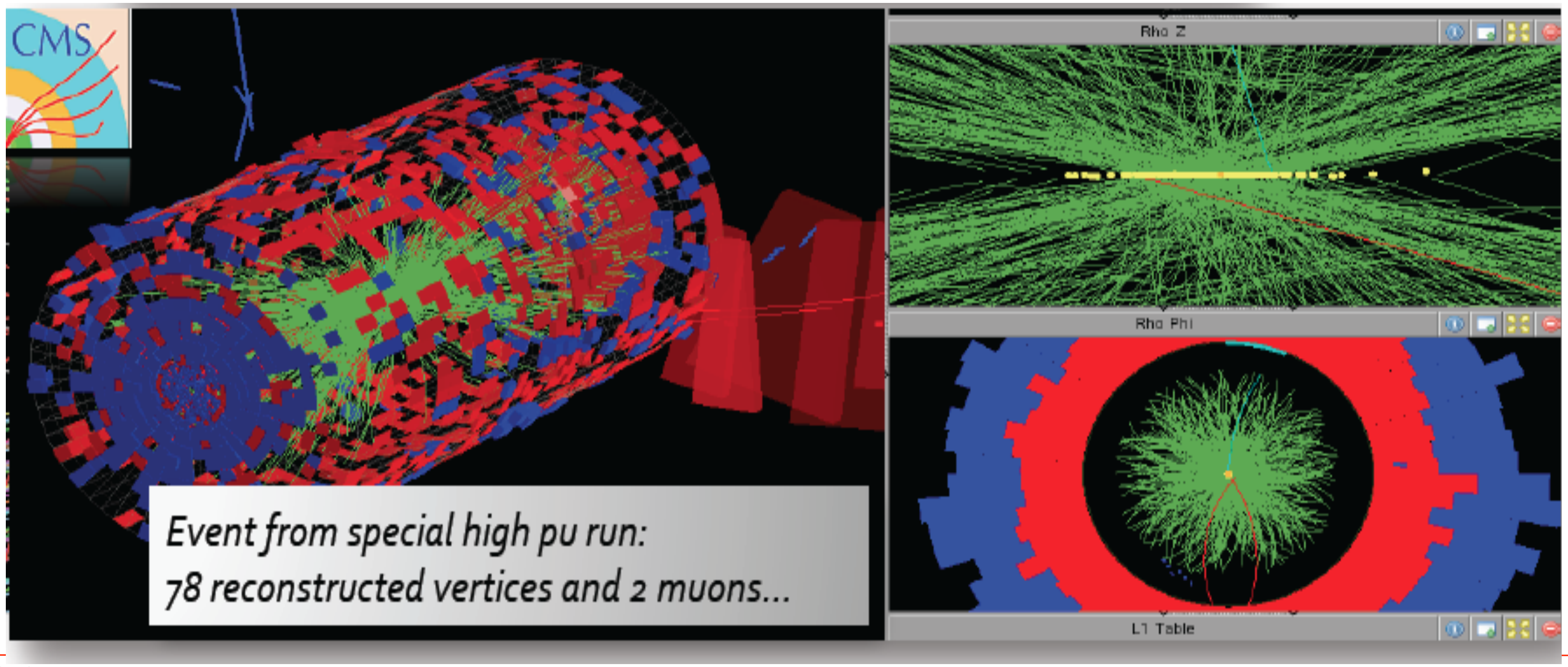
−Increase data bandwidth

−Increase processing power

−Improve radiation hardness

−Minimize material in tracking devices





Event from special high pu run:
78 reconstructed vertices and 2 muons…

Physics program for the future of LHC

The discovery of a Higgs-like boson at m_H~125 GeV suggests the following list of physics priorities and goals

- With LHC 13/14 TeV data until ~2021 (~300 fb^{-1})
  - Measure SM-like scalar boson properties
    - Mass, J^{PC}
    - individual couplings with 5-15% precision
  - Search for new physics at a higher mass scale (new energy region)
    - SUSY
    - Exotics

HL-LHC Physics Drivers

- With HL-LHC 14 TeV data until ~2032 (~3000 fb^{-1})

- Major Focus
  - – High Precision SM scalar boson measurements @ 125GeV
  - – Study scalar boson rare decays and self-coupling
  - – Study VV scattering
  - – Characterize any New Physics discovered during Phase 1 at 14 TeV
  - – Search for new physics in very rare processes

- Experiment strategy: Aim to Maintain (or improve) current physics performance through HL-LHC era
  - – Signal Acceptance, Efficiency & Resolution; S/B ratio
  - – Maintain systematic errors well below statistical

HL-LHC Physics Drivers

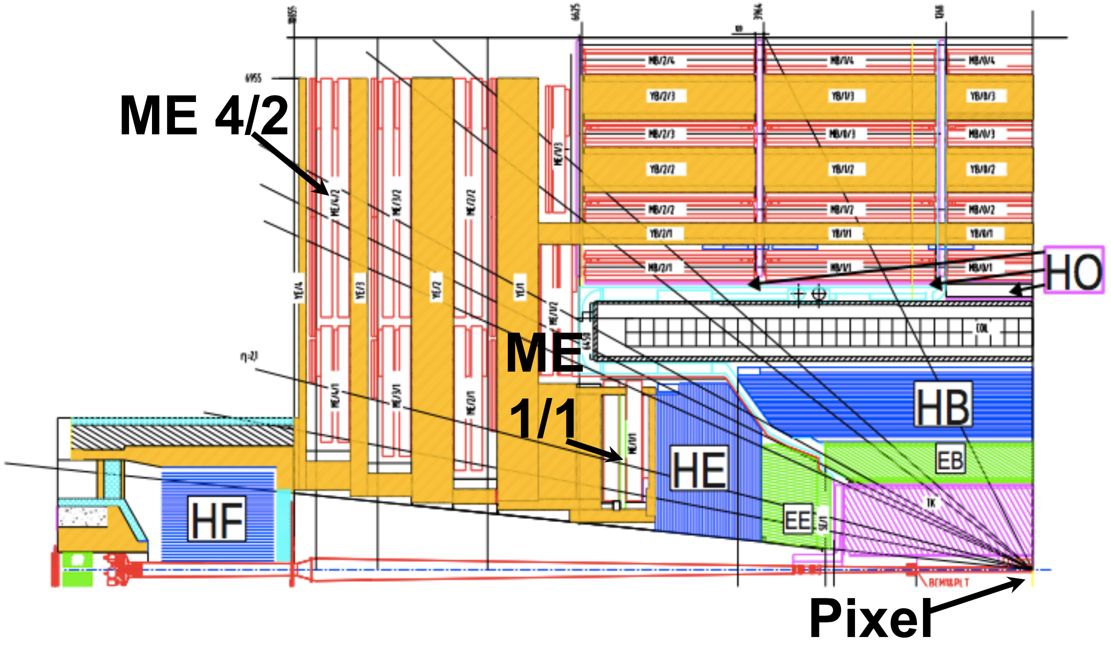
This is Very Challenging: it requires

- Precision measurements of
  - Leptons (e, μ, τ), γ, Jets, b (c) quarks, MET
- Reconstruction of complex event topologies to identify
  - W/Z, top, VBF, etc.
- Over the full range from low to high p_T
  - In a very high rate and high pile-up environment

CMS upgrade program

•LS1 Projects

- Complete Muon coverage (ME4)
- Improve muon operation, DT electronics
- Replace HCAL photo-detectors in Forward (new PMTs) and Outer (HPD→SiPMs)
- DAQ1→DAQ2



Phase 1 Upgrades

- New Pixel detector, HCAL electronics and L1-Trigger upgrade
- GEMs for forward muon det. under review
- Preparatory work during LS1

-New beam pipe for pixel upgrade

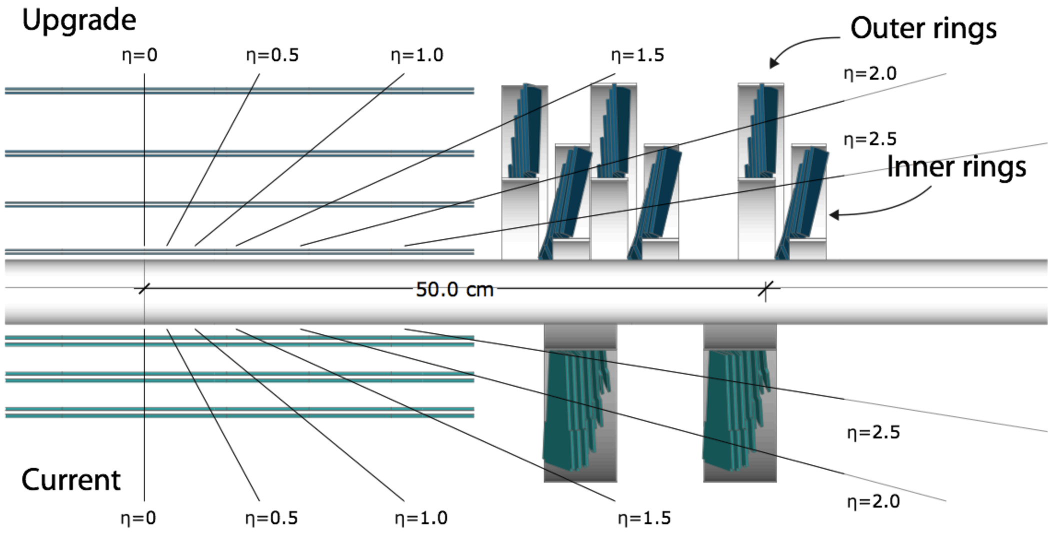
-Install test slices of pixel, HCAL, L1-trigger

-Install ECAL optical splitters for L1-trigger

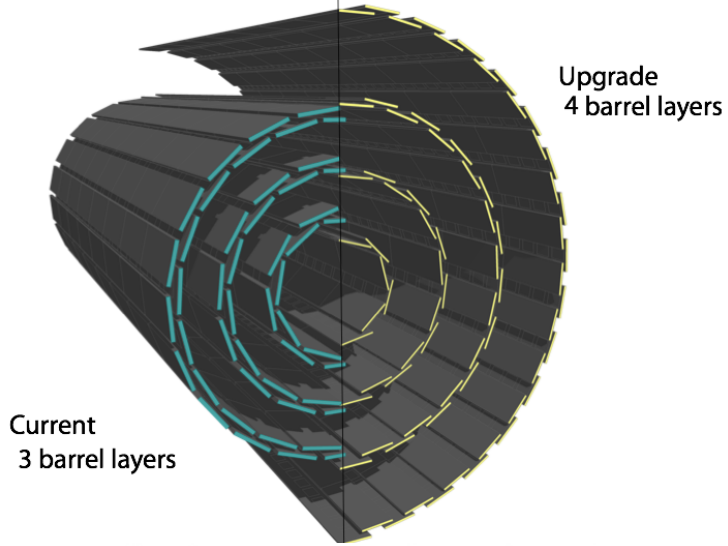
Phase 2: being defined now

- Tracker replacement, L1 Track-Trigger
- Forward: calorimetry, muons and tracking
- High precision timing for PU mitigation
- Further Trigger upgrade
- Further DAQ upgrade

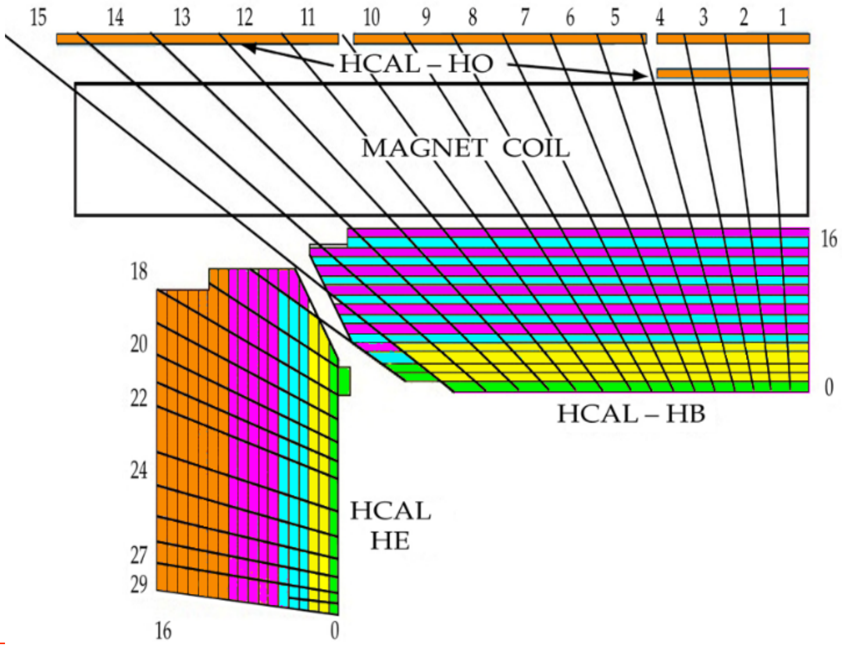
Pixel and HCAL phase 1 upgrades



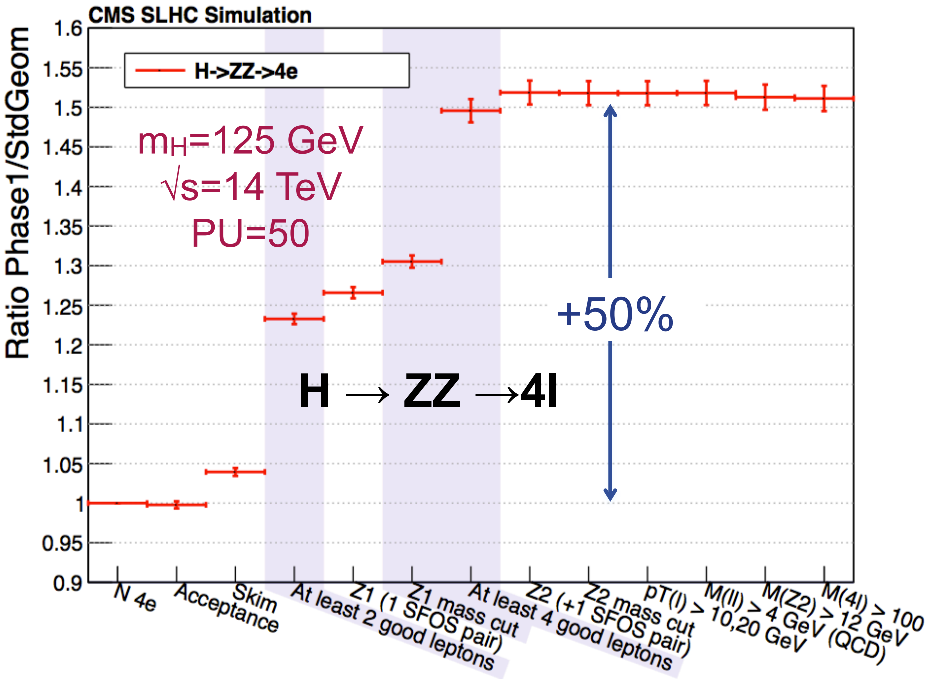
New 4-layer pixel detector Pixel

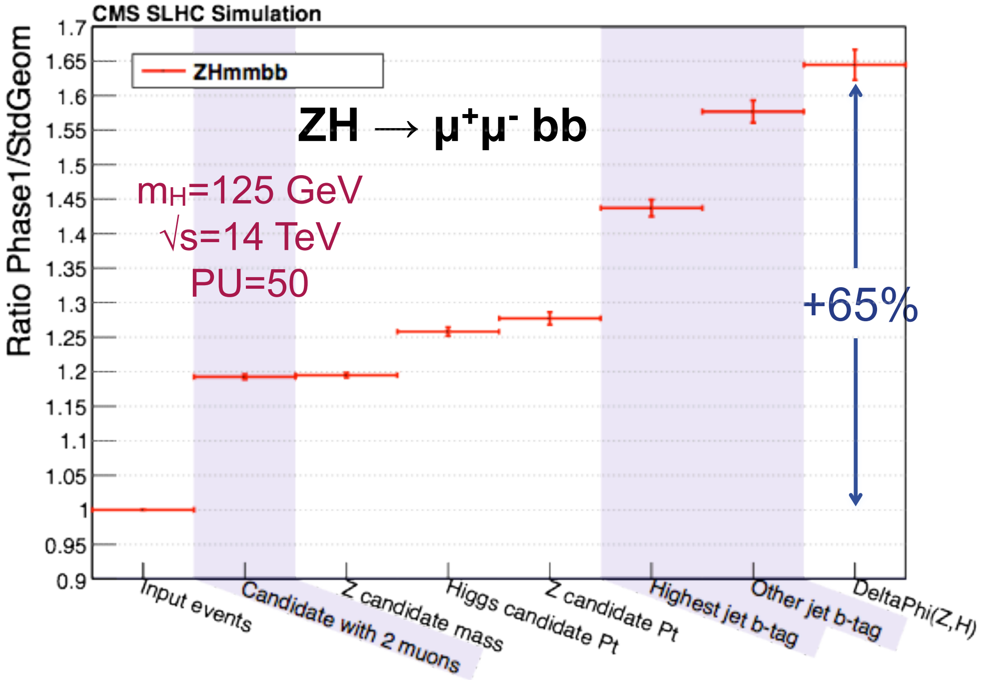


- Upgraded HCAL
  - New photodetectors
  - New electronics (frontend, backend)
  - Improved longitudinal segmentation
  - Improved background rejection, Missing E_T resolution and Particle Flow reconstruction



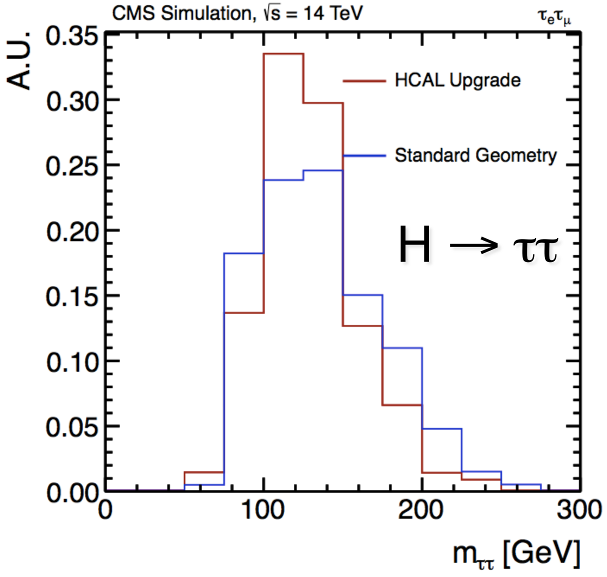
Expected Phase 1 improvements





Significant gain in signal reconstruction efficiency:

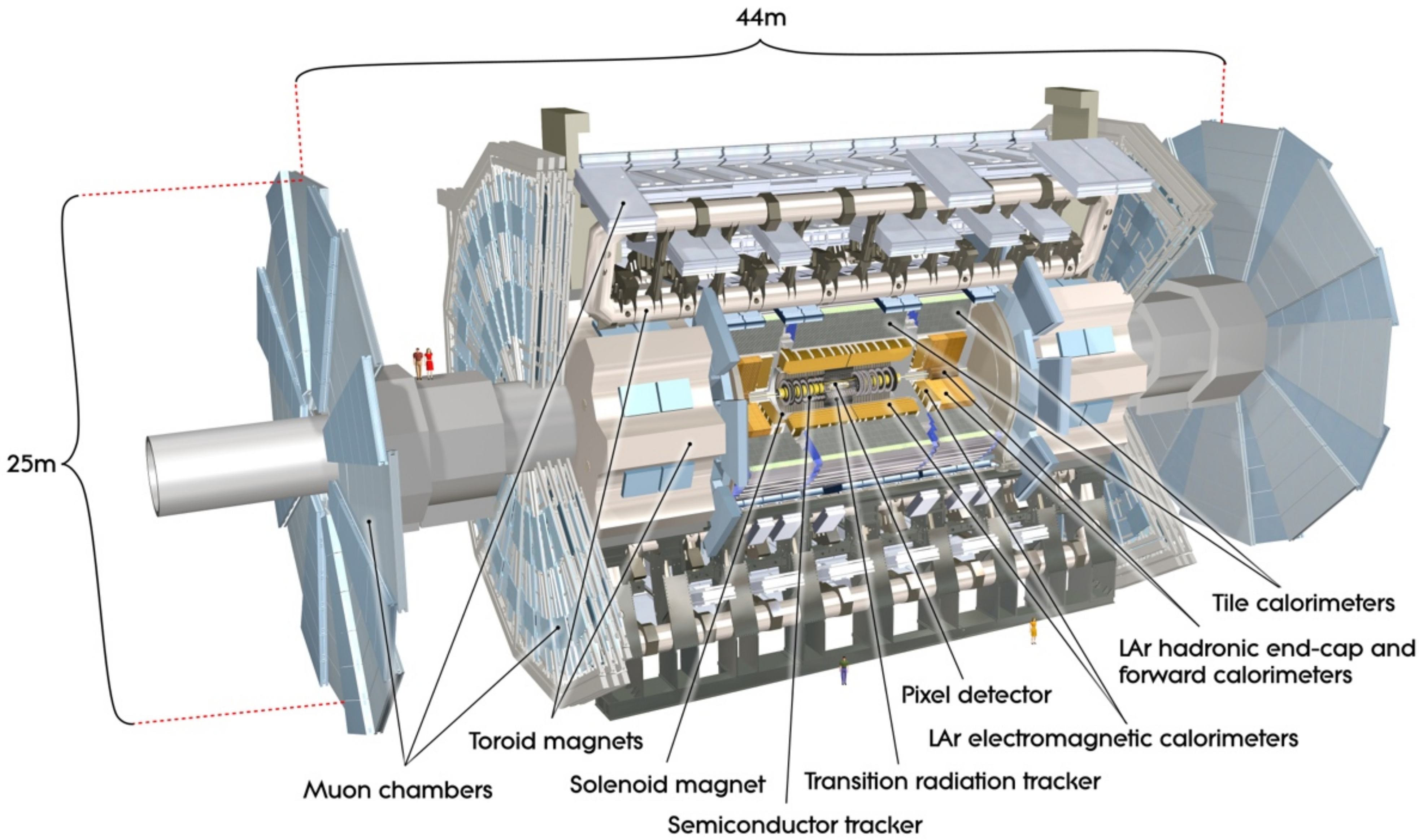
H→ 4μ	+41%
H→ 2μ2e	+48%
H→ 4e	+51%



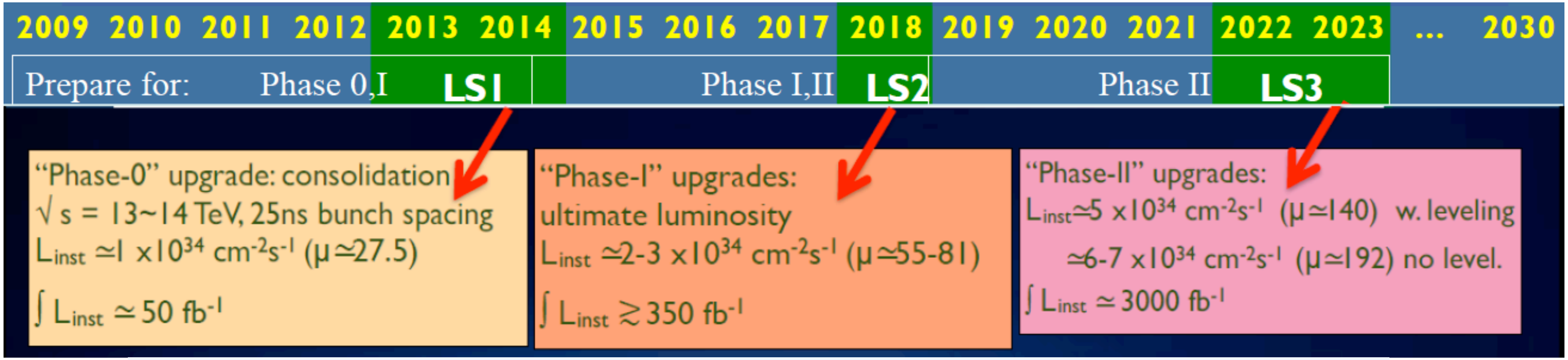
Total efficiency improvement: factor of 2.5 (4.5% → 11%)

Improved jet and MET → 25% improvement in $m_{\tau\tau}$ resolution

ATLAS detector



ATLAS upgrade program



“Phase-0” upgrade: consolidation
$\sqrt{s}$ = 13~14 TeV, 25ns bunch spacing
$L_{inst} \simeq 1 \times 10^{34}$ cm^{-2}s^{-1} ($\mu \simeq 27.5$)
$\int L_{inst} \simeq 50$ fb^{-1}

“Phase-I” upgrades:
ultimate luminosity
$L_{inst} \simeq 2\text{-}3 \times 10^{34}$ cm^{-2}s^{-1} ($\mu \simeq 55\text{-}81$)
$\int L_{inst} \gtrsim 350$ fb^{-1}

“Phase-II” upgrades:
$L_{inst} \simeq 5 \times 10^{34}$ cm^{-2}s^{-1} ($\mu \simeq 140$) w. leveling
$\simeq 6\text{-}7 \times 10^{34}$ cm^{-2}s^{-1} ($\mu \simeq 192$) no level.
$\int L_{inst} \simeq 3000$ fb^{-1}

ATLAS has devised a 3 stage upgrade program

- New insertable pixel b-layer (IBL)
- New Al beam pipe
- New pixel services
- Complete installation of EE muon chambers
- New evaporative cooling plant
- Consolidation of detector services
- Specific neutron shielding
- Upgrade magnet cryogenics

- New Small Wheel (nSW) for the forward muon Spectrometer
- High Precision Calorimeter L1-Trigger
- Fast TracKing (FTK) for L2-trigger
- Topological L1-trigger processors
- New forward diffractive physics detectors (AFP)

- Completely new tracking detector
- Calorimeter electronics upgrades
- Upgrade part of the muon system
- Possible L1-trigger track trigger
- Possible changes to the forward calorimeters

From M. Diemoz

From 2013 to HL-LHC

- From 30 to 3000 fb^{-1}: two orders of magnitude extrapolation in luminosity
    - To calculate physics projections at HL-LHC

Want to have similar trigger and reconstruction peformances as in 2012

Need upgraded detectors to offset the much harsher LHC conditions and radiation damage

ATLAS and CMS have launched a comprehensive upgrade program

Scalar boson projections after LS1

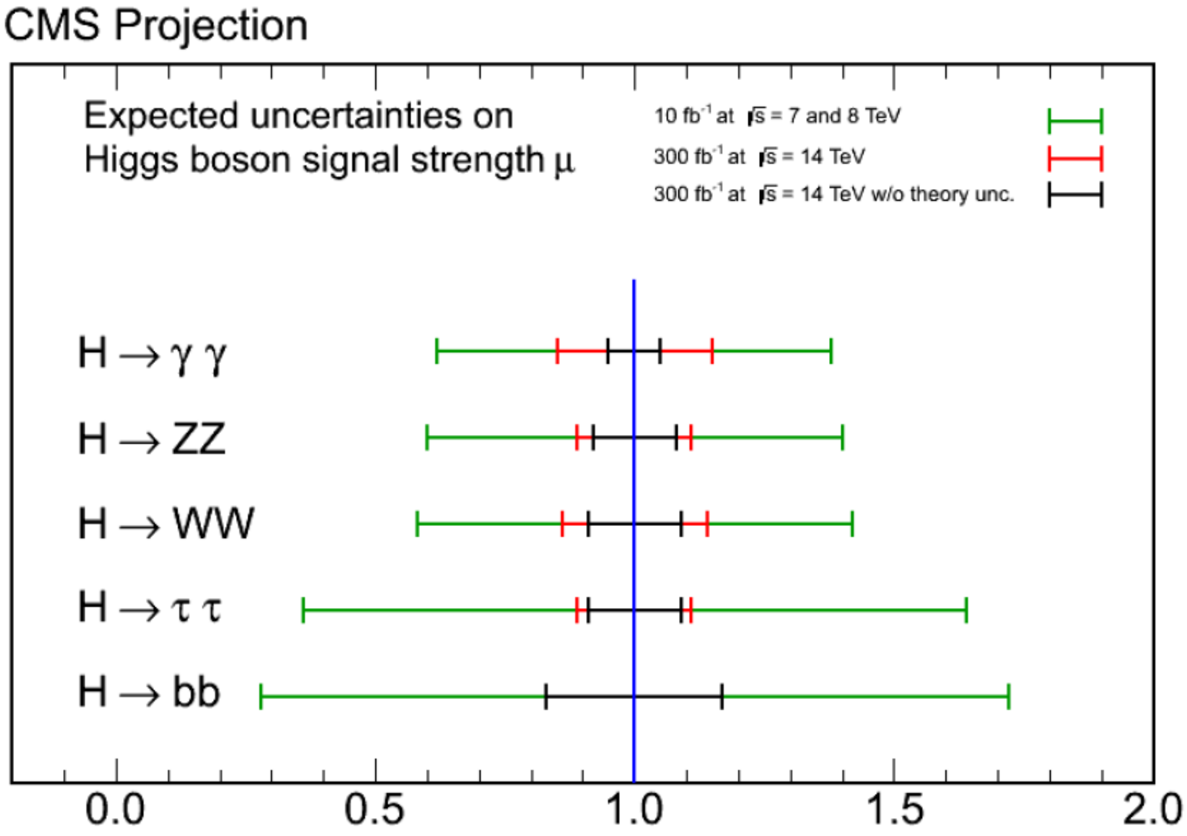
Approaches adopted for physics projections

- **ATLAS**: perform complete physics studies using fast simulation of momentum and energy resolution, acceptance, identification and reconstruction efficiencies, fake rates, etc. Not all channels fully analysed.

- **CMS**: assume that an upgraded detector will compensate the effects of the higher pile-up, using different scenarios of the evolution of systematic errors.

Scalar boson signal with 300 fb^{-1}

- Upgraded detector performances assumed the same as 2012 detector
- Three scenarios for evolvement of systematic errors:
  - Scenario 1: same systematics as in 2012
  - Scenario 2: theory systematics scaled by a factor ½, other systematics scaled by 1/√L
  - Scenario 3: same exp. syst. as in 2012, w/o theory uncertainty

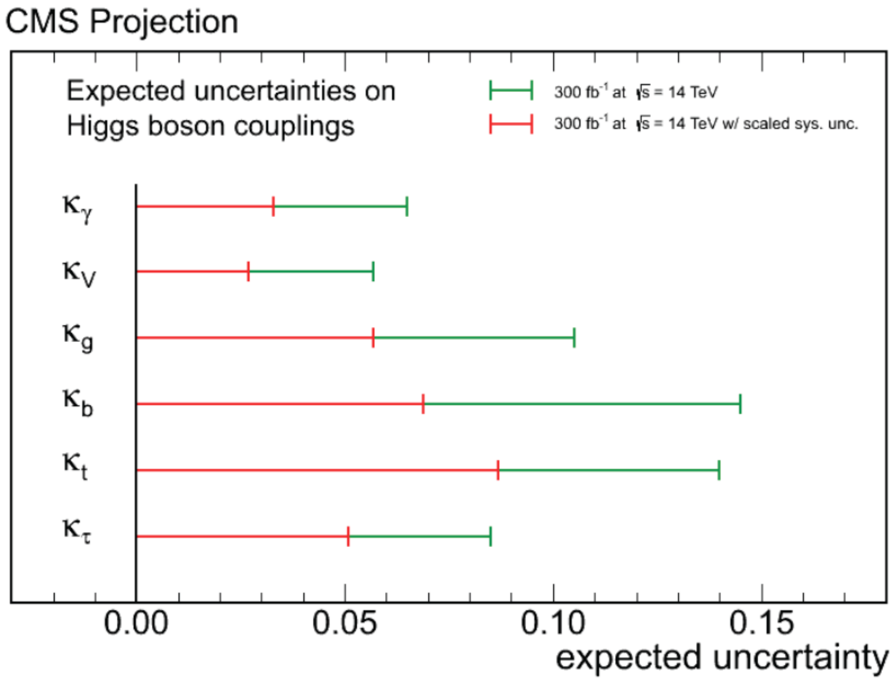


10 fb^{-1}, 7 and 8 TeV (Scenario 1)
300 fb^{-1} , 14TeV (Scenario 1)
300 fb^{-1} , 14TeV (Scenario 3)

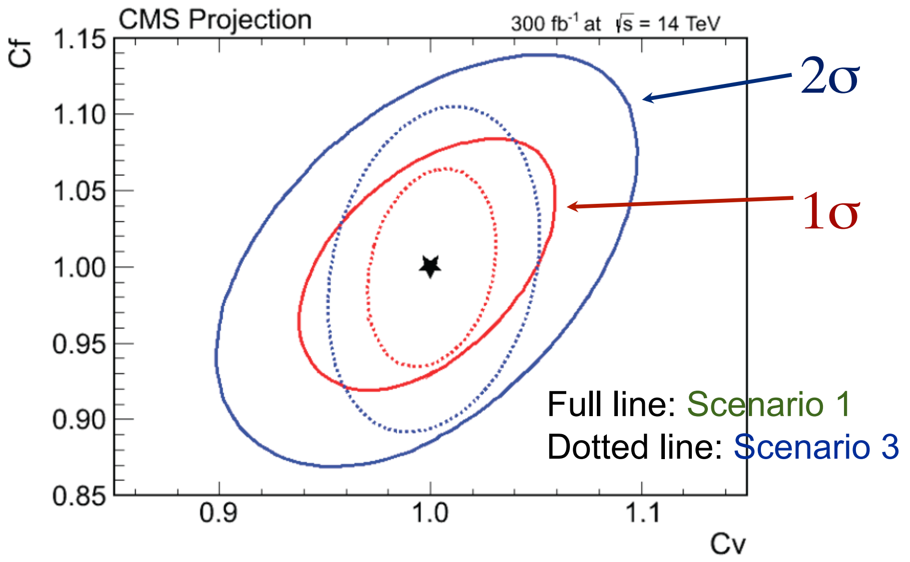
With 300 fb^{-1} the precision on the signal strength is expected to be 10-15% per channel

Scalar boson couplings @300 fb^{-1}

- Three scenarios:
  - Scenario 1: same systematics as in 2012
  - Scenario 2: theory systematics scaled by a factor ½, other systematics scaled by 1/√L
  - Scenario 3: same exp. syst. as in 2012, w/o theory uncertainty



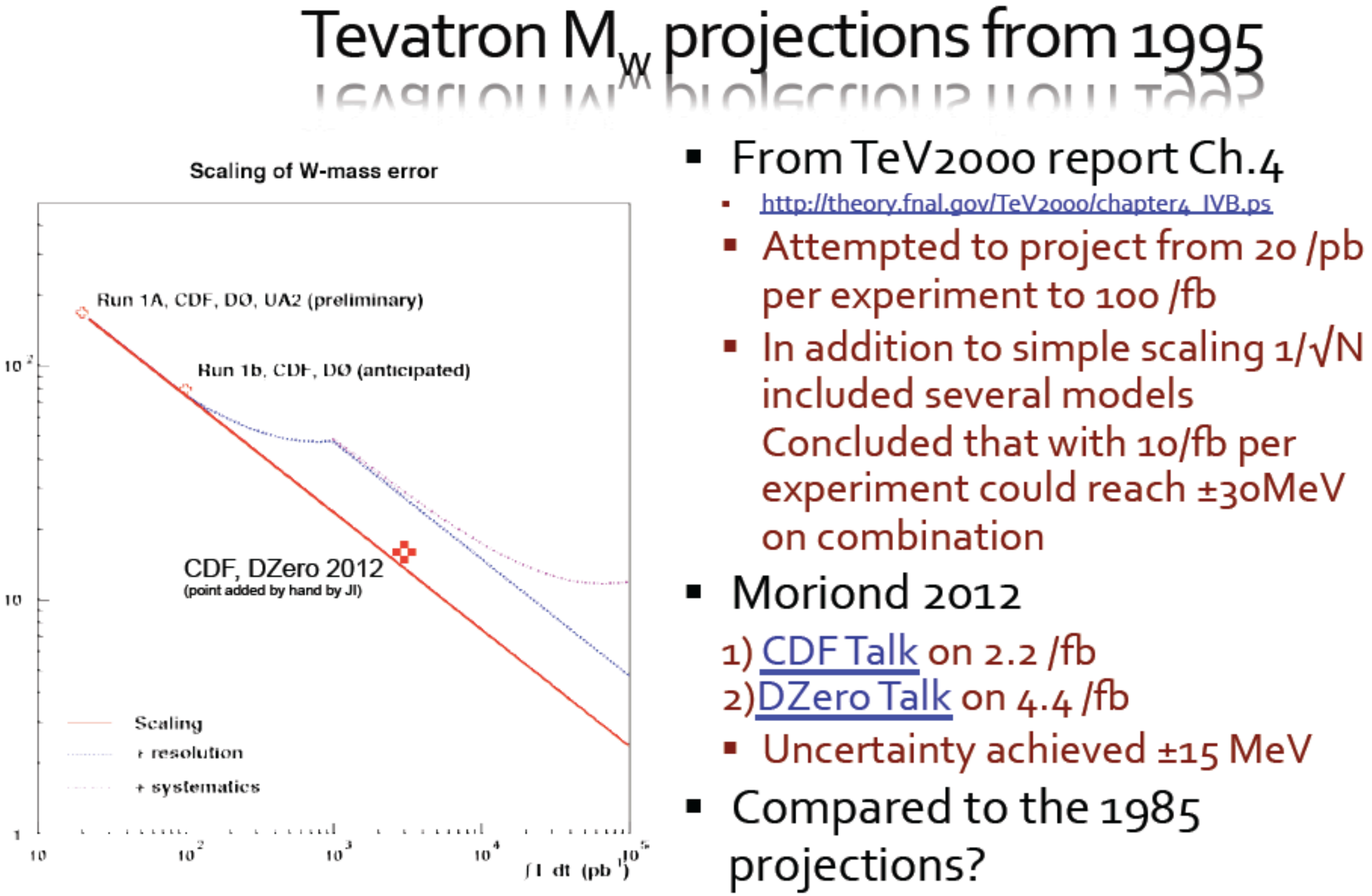
300 fb^{-1} 14 TeV, Scenario 1
300 fb^{-1} 14 TeV, Scenario 2



With 300 fb^{-1} the uncertainties on the Higgs couplings are expected in the range σ (κ_V) ~ 3-6%
σ (κ_f) ~ 5-15%

HL-LHC boson couplings @3000 fb^{-1}

- Extrapolation by two orders of magnitude to higher luminosity
  - is subject to large uncertainties
  - scenarios 1 and 2 provide likely upper and lower bounds
- Experience at LEP and Tevatron indicates that scaling with 1/√L is not unrealistic

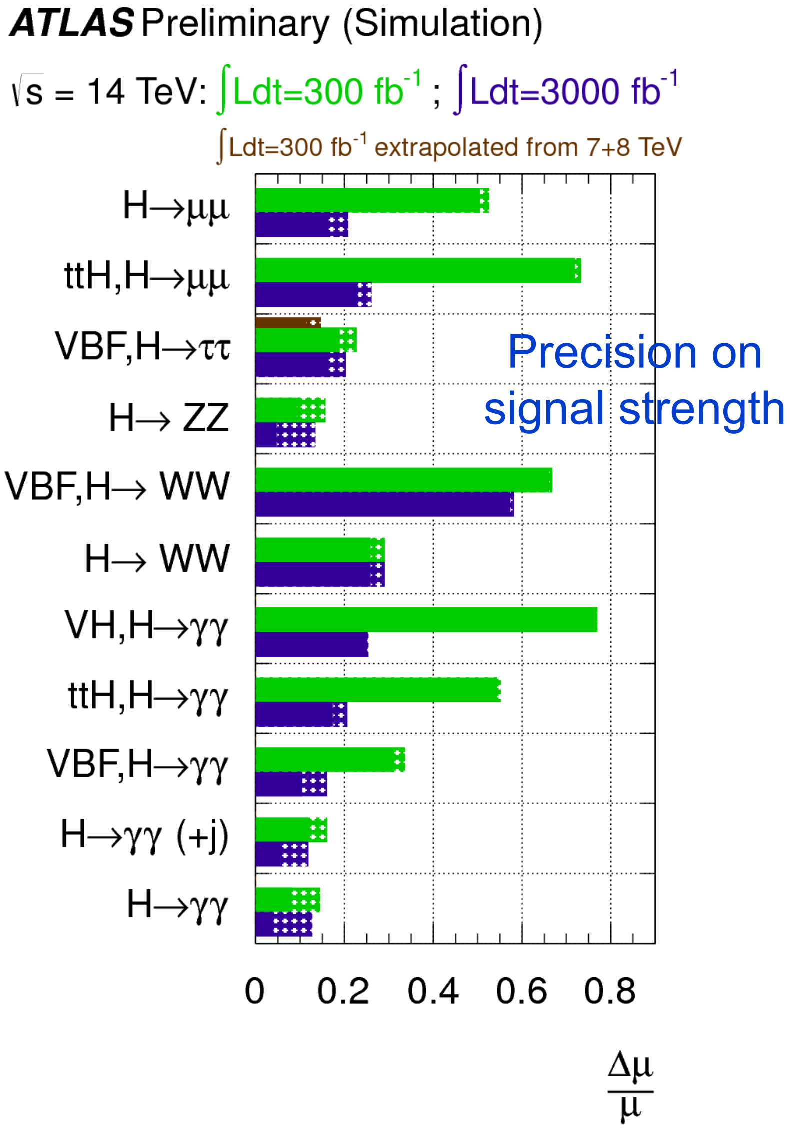


Tevatron M_W projections from 1995

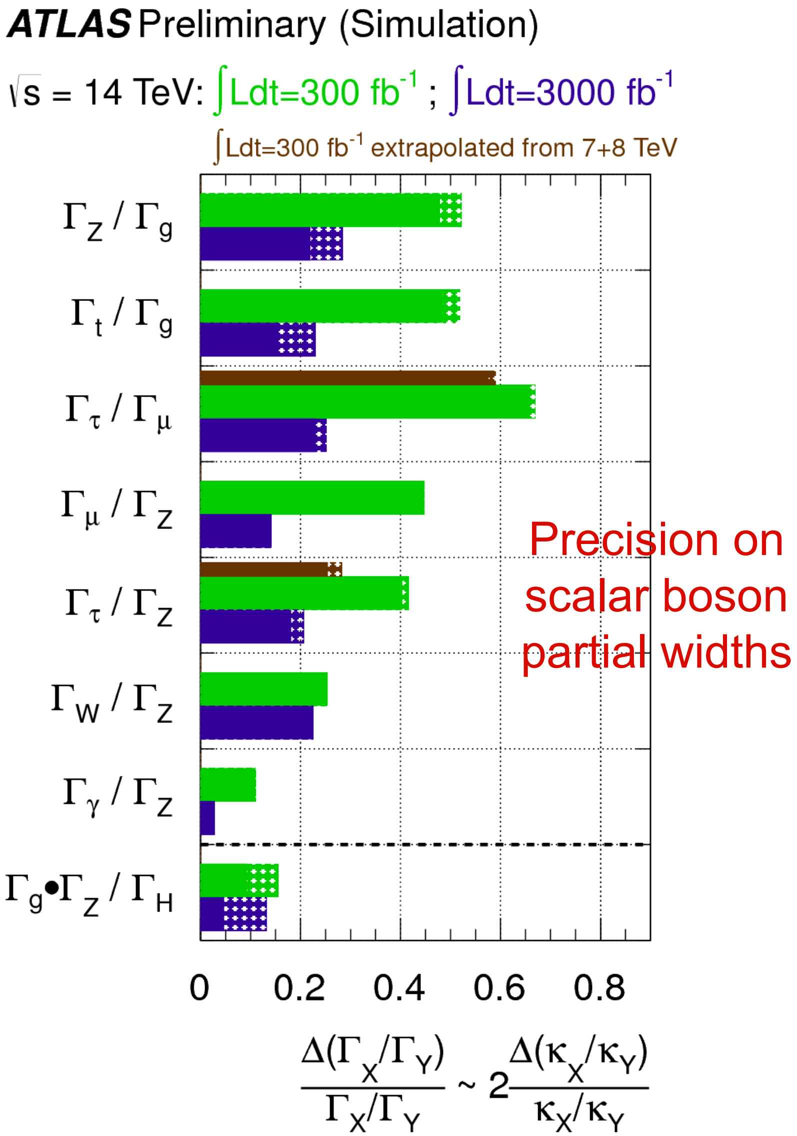
- From TeV2000 report Ch.4
  - http://theory.fnal.gov/TeV2000/chapter4_IVB.ps
  - Attempted to project from 20 /pb per experiment to 100 /fb
  - In addition to simple scaling 1/√N included several models Concluded that with 10/fb per experiment could reach ±30MeV on combination
- Moriond 2012

  1) CDF Talk on 2.2 /fb
  2) DZero Talk on 4.4 /fb
  - Uncertainty achieved ±15 MeV
- Compared to the 1985 projections?

Scalar boson couplings @3000 fb^{-1}



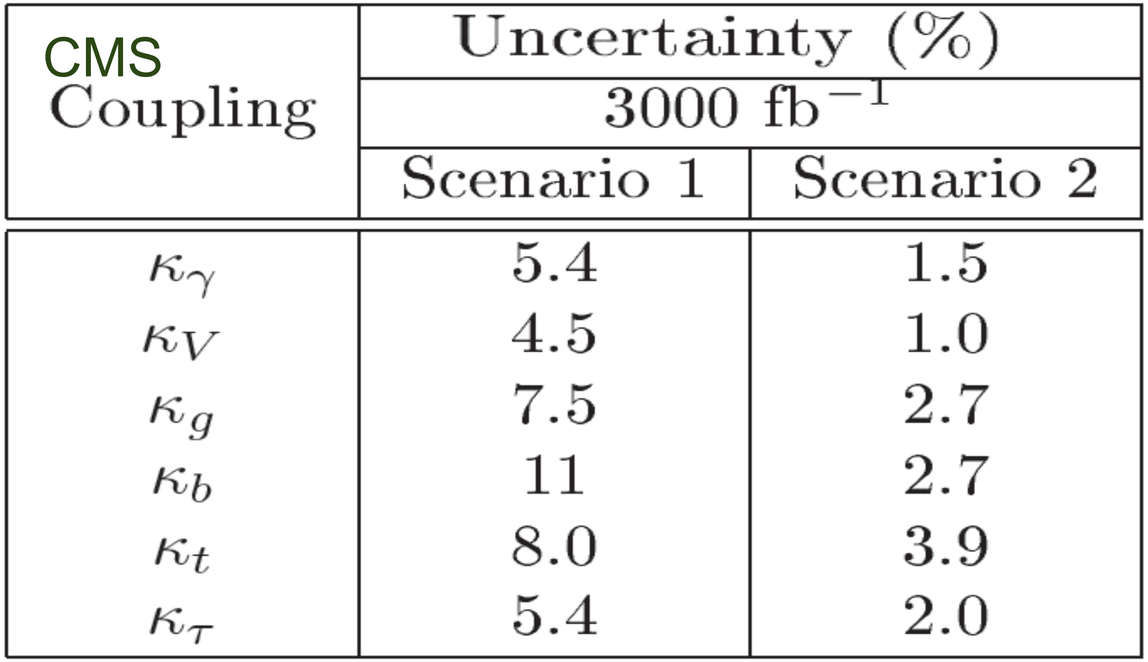
Precision on signal strength



Precision on scalar boson partial widths

- Brown lines made for similar assumptions as for CMS studies.
- With 3000 fb^{-1} the couplings can be determined with high precision (a few %)

HL-LHC Higgs boson couplings @3000 fb^{-1}



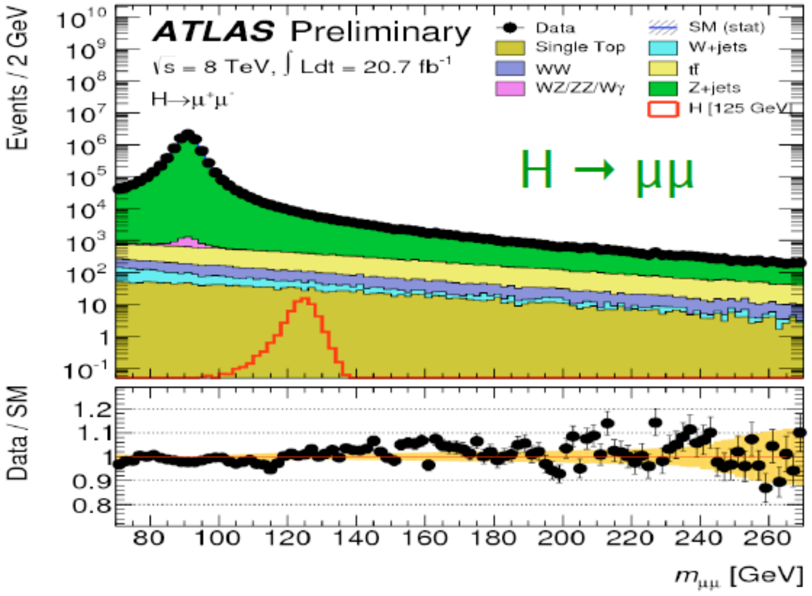
CMS Coupling	Uncertainty (%)	
	3000 fb^{-1}	
	Scenario 1	Scenario 2
κ_γ	5.4	1.5
κ_V	4.5	1.0
κ_g	7.5	2.7
κ_b	11	2.7
κ_t	8.0	3.9
κ_τ	5.4	2.0

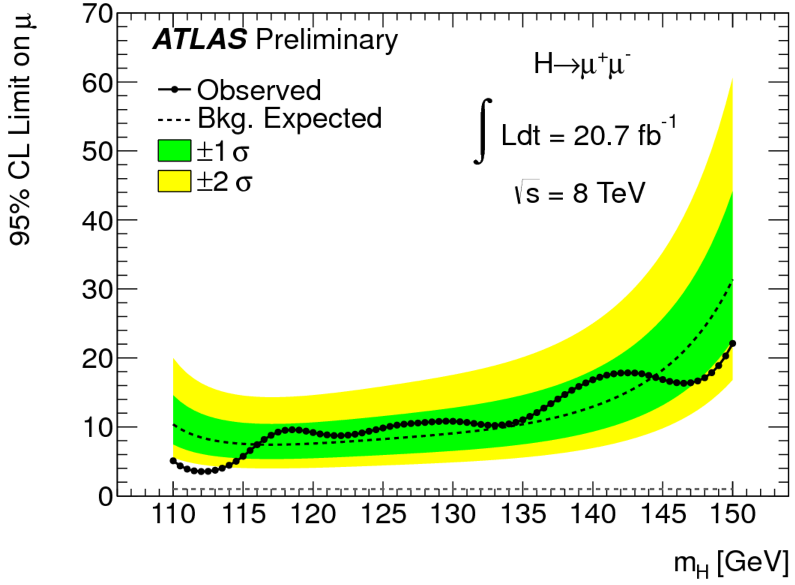
Scenario 1: systematics as in 2012
Scenario 2: theory syst. scaled by a factor ½,
other systematics scaled by 1/√L

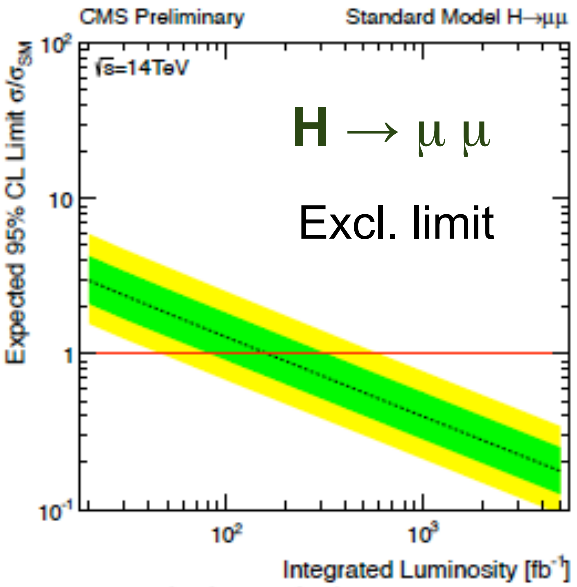
- With 3000 fb^{-1} the Higgs couplings can be determined with high precision (1-4%)

Rare decays: $H\rightarrow\mu\mu$

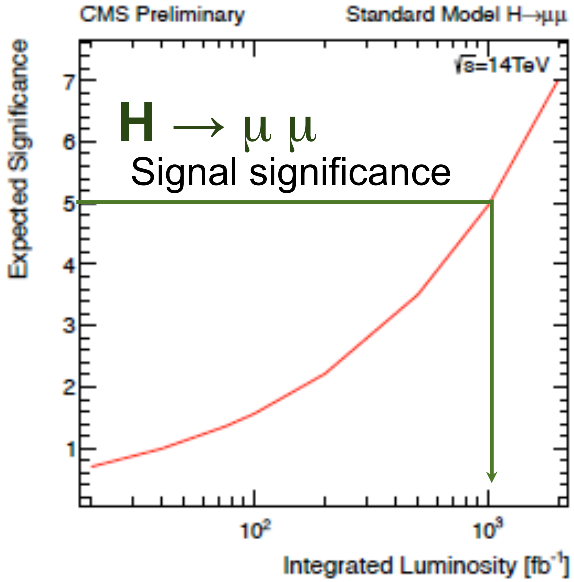
ATLAS-CONF-2013-010







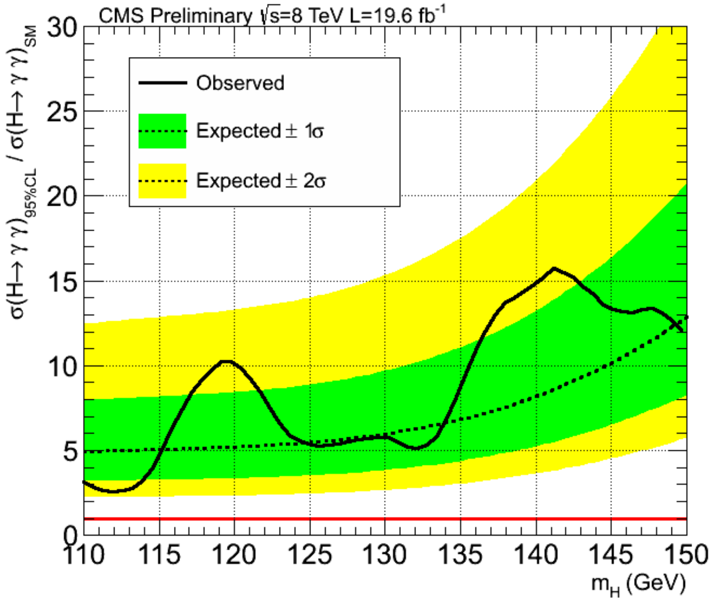
- The decay $H\rightarrow\mu\mu$ can be observed with a significance of 5 sigma
- measurement of the Hμμ coupling with a precision of ~10%



Rare decays: ttH, H→γγ

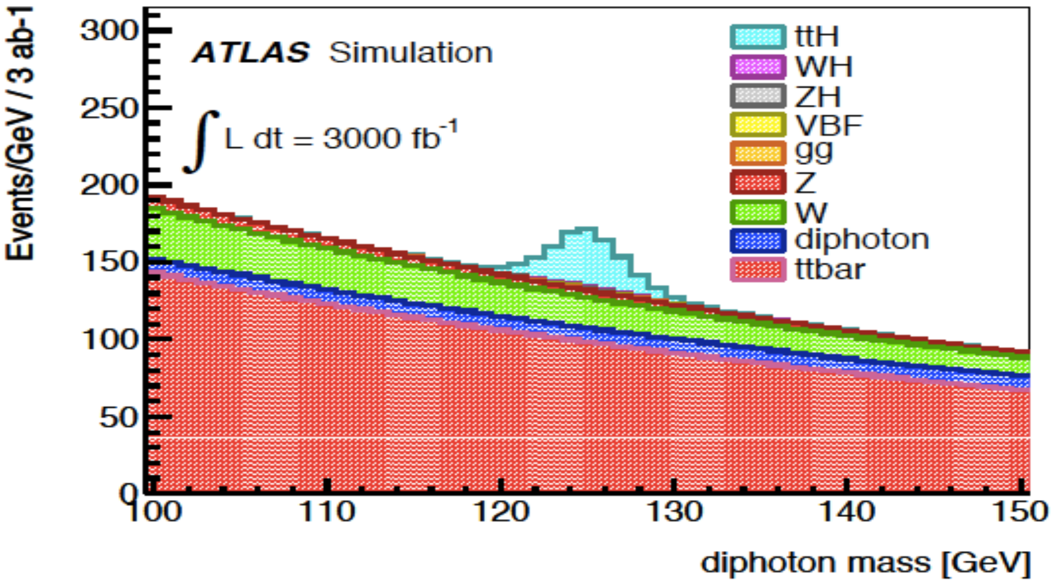
CMS-HIG-13-015 (20/fb @ 8 TeV)

	Observed	Expected	Expected (No Syst.)
Hadronic Channel	6.8	9.2	8.8
Leptonic Channel	10.7	8.0	7.7
Combined	5.4	5.3	5.1



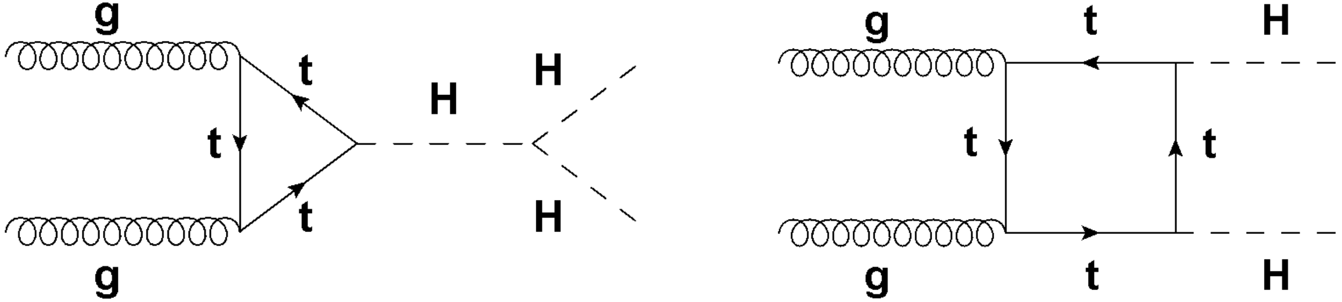
ATLAS projection, 3000 /fb @ 14 TeV

Δμ/μ of 15-20%



Scalar boson self-coupling

Destructive interference between the two diagrams



Many channels to investigate. Most promising ones:

$b\bar{b}W^+W^-$ (large BR but large bkg.)

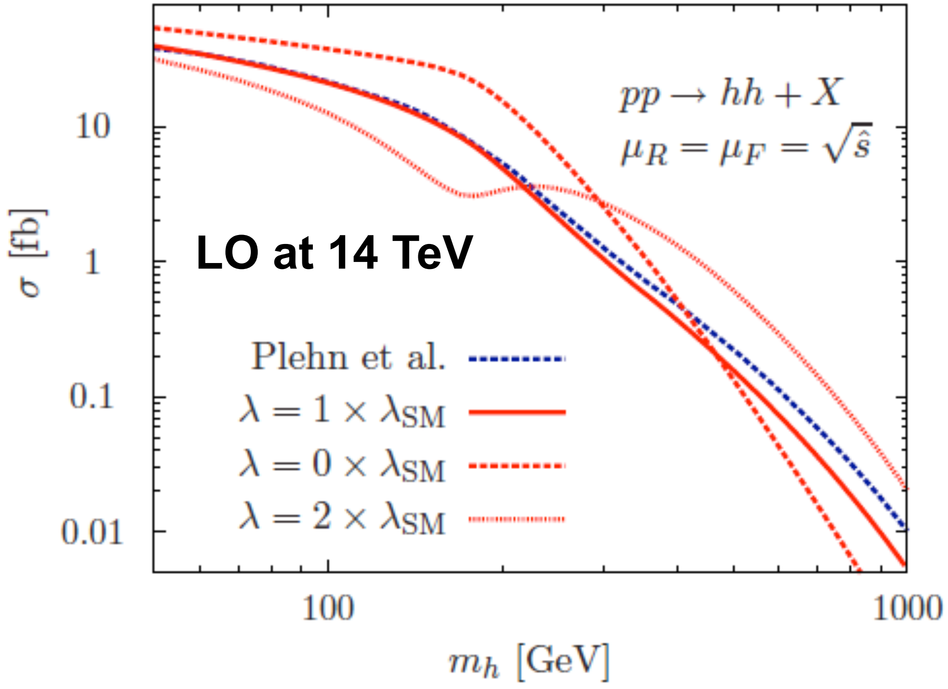
$b\bar{b}\gamma\gamma$ (clean but small BR)

$b\bar{b}\tau^+\tau^-$

$b\bar{b}\mu^+\mu^-$ will do

$b\bar{b}b\bar{b}$

Taken from "Higgs self-coupling measurements at the LHC" by M. J. Dolan, C. Englert and M. Spannowsky, JHEP 10 (2012 112.

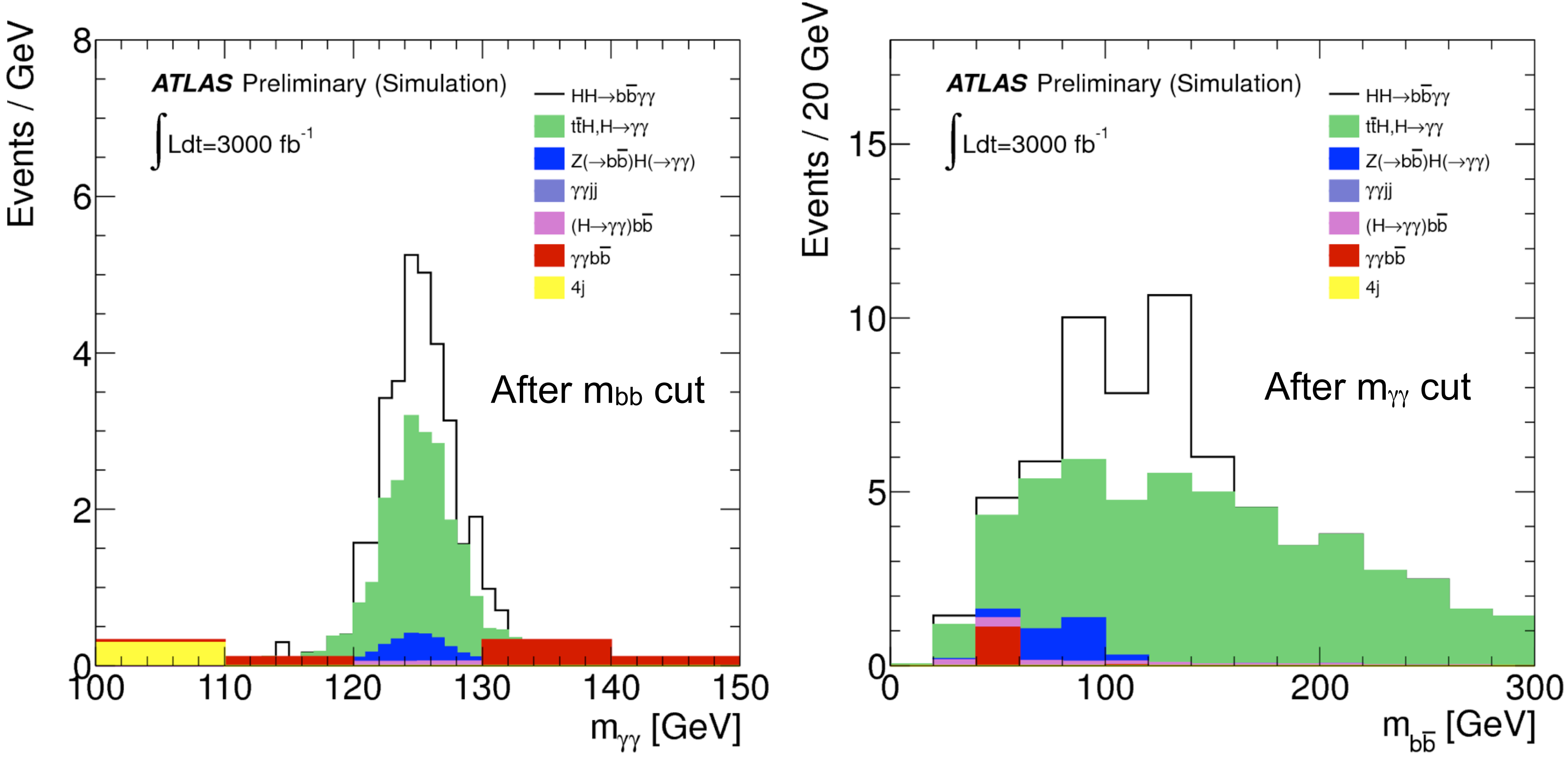


NLO cross-section at m_H=125 GeV:

σ = 34 fb$^{+18\%}_{-15\%}$ (QCD scale) ± 7% (PDF+α_s) ± 10% (EFT)

HH

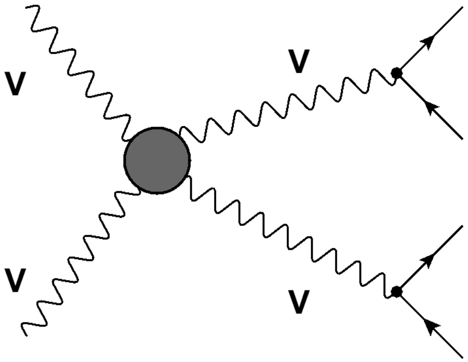
$HH \rightarrow b\bar{b}\gamma\gamma$

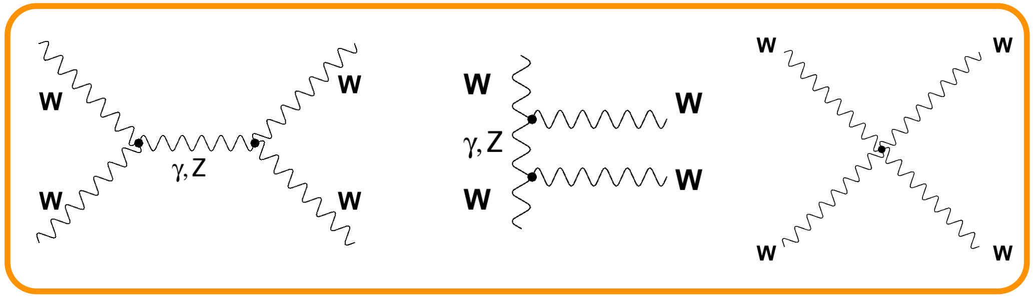


A sensitivity of 3σ per experiment is within reach with $L=3000\ fb^{-1}$

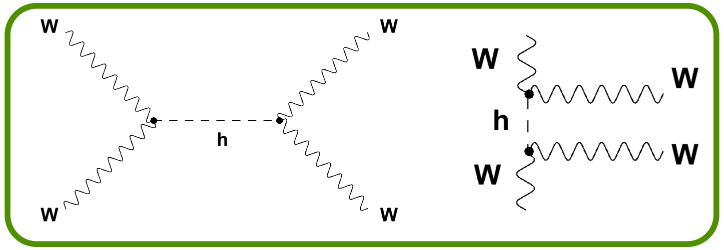
VV scattering: unitarity violation

$VV \rightarrow VV$





S channel **T channel** **QGC**



Without the SM boson, $W^+_LW^-_L \rightarrow W^+_LW^-_L$ violates unitarity at √s ≥ 1.2 TeV

W, Z masses (→ longitudinal degrees of freedom) arise from the BEH mechanism:

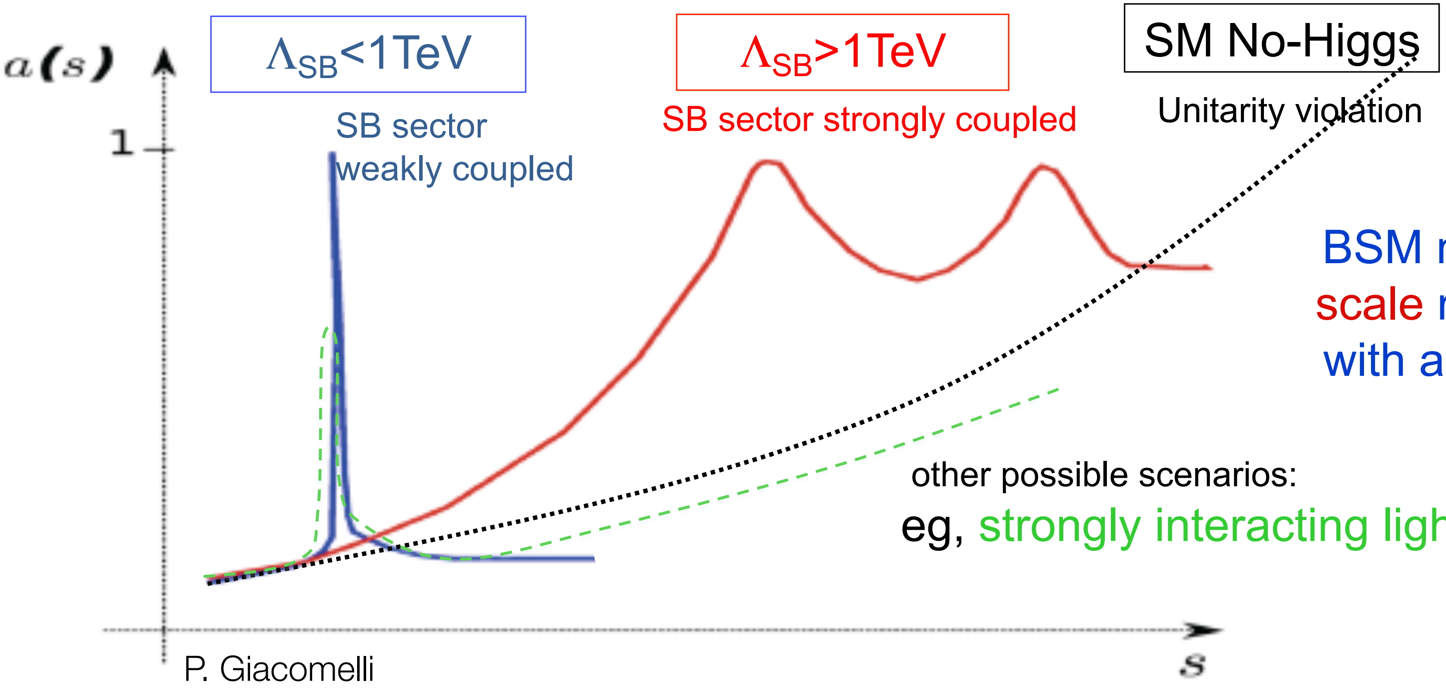
$$A\left(W_L^+W_L^- \rightarrow W_L^+W_L^-\right) \approx \frac{1}{v^2}\left(\boxed{-s-t} + \boxed{\frac{s^2}{s-m_H^2} + \frac{t^2}{t-m_H^2}}\right)$$

VV scattering is the smoking gun for EWSB!

Taken from "Prospects for VV scattering: latest news" by S. Bolognesi (JHU) talk at Implications of LHC results for TeV-Scale physics (March 2012)

VV scattering as a probe for EWSB

VV Scattering spectrum, σ(VV→VV) vs M(VV) is the fundamental probe to test the nature of the BEH boson or to find an alternative EWSB mechanism



BSM models predict TeV-scale resonances “paired” with a light scalar particle

other possible scenarios:

eg, strongly interacting light Higgs (SILH)

Search for possible resonances in VBF spectrum

Adaptation from “Boson Boson scattering analysis” by A.Ballestrero (INFN Torino) talk at First LHC to Terascale Workshop (Sept 2011):

VV scattering: fully leptonic

Only background VV+jets, very low xsec

Number of events for 20 fb^{-1} (fully MC based, no systematics, 14 TeV)

CMS AN 2007-005

CERN-OPEN-2008-020

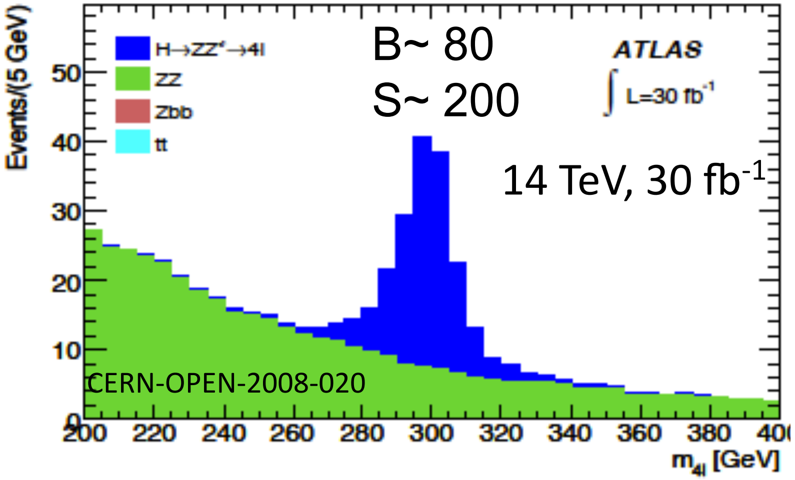
CMS ZZ->4e, 4μ	N signal	N back.
500 GeV	2.2	1.9
>1 TeV	0.1	0.2

CMS ZW->μμμν	N signal	N back.
>1 TeV	0.9	0.8

ATLAS ZZ->2l2ν	N signal	N back.
500 GeV	6.4	3.0

ATLAS ZW->lllν	N signal	N back.
500 GeV	8	5
1.1 TeV	1.4	0.4

Example: ggF Higgs 300 GeV

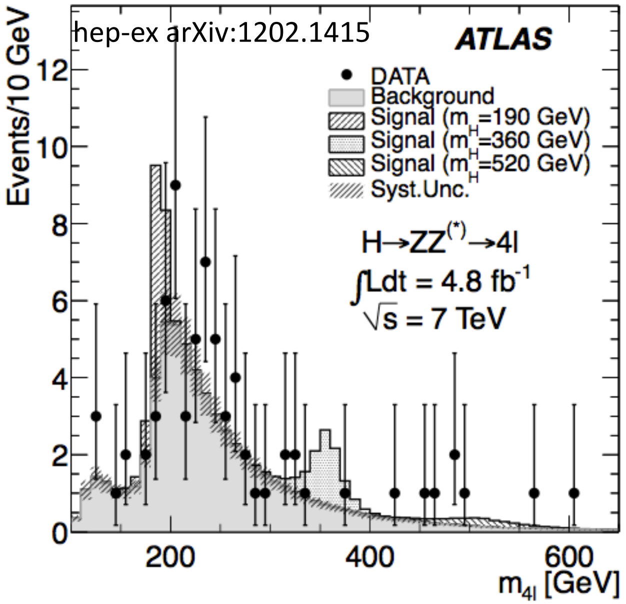


B~ 80

S~ 200

14 TeV, 30 fb^{-1}

CERN-OPEN-2008-020



hep-ex arXiv:1202.1415

Latest results:

B~ 6

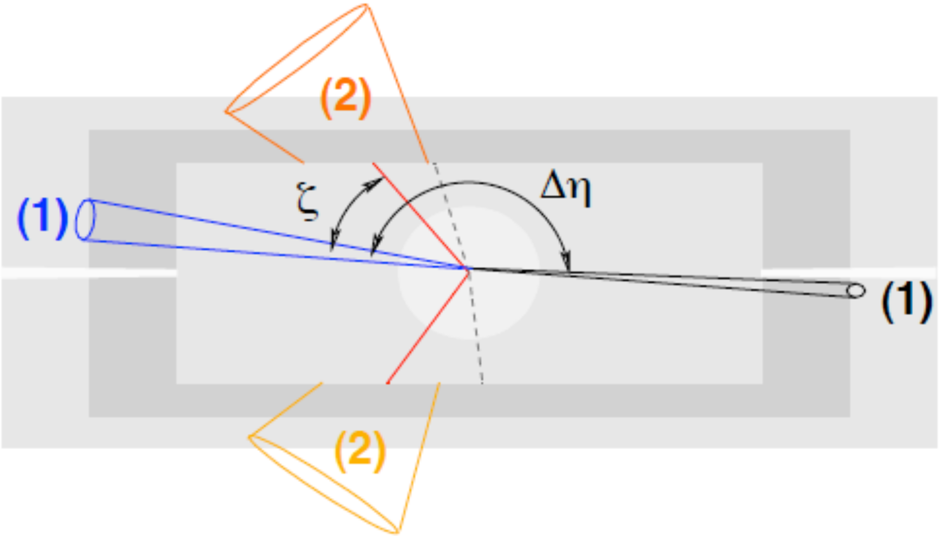
S~ 10

- reso m$_{4l}$ as expected
- improved reco-id efficiencies

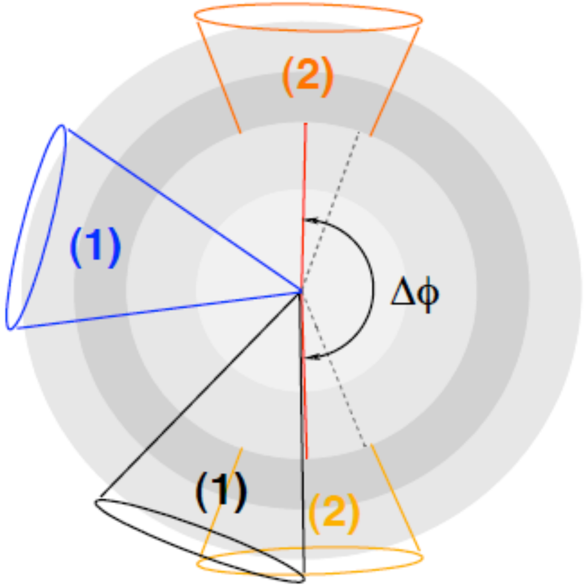
(eg ele ID: TDR time 85-90% -> today 95%)

VBF experimental signature

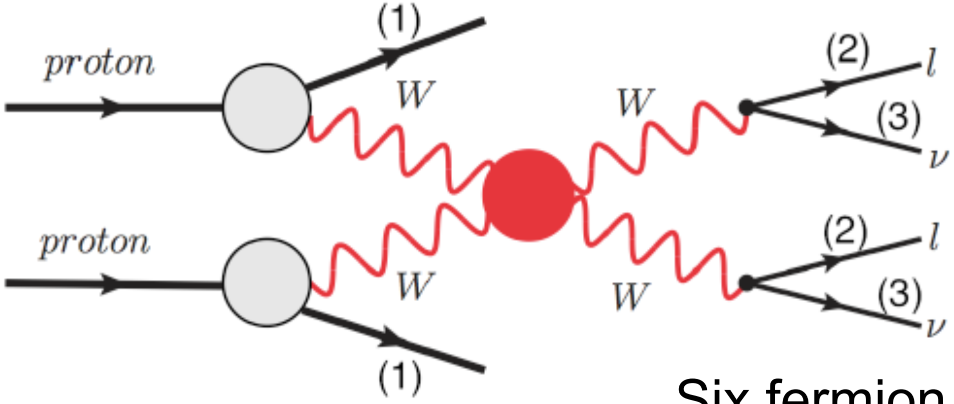
Longitudinal plane



Transverse plane



- *tagging jets* (1): large p_{T}, large $\Delta\eta$
- few jets between tagging jets
- final state $\ell\nu\ell\nu$:
  - *leptons* (2) between tagging jets
  - missing E_{T}(3)



Six fermion final state

From "Study of Vector Boson Scattering including Pile-up with the ATLAS Detector" by P. Anger (TU Dresden), DPG Frühjahrstagung Karlsruhe 2011

VBF final states

- According to the vector bosons' decays we have a multitude of possible final states. We can group them in:

- Fully leptonic
  - pp→qq ℓℓℓℓ (ℓ=μ,e)
  - pp→qq ℓℓℓν
  - pp→qq ℓℓνν

Clean

Can reconstruct m_{VV} (not with 2ν)

Very low yields...

- Semi-leptonic
  - pp→qq jetjet ℓℓ
  - pp→qq jetjet ℓν

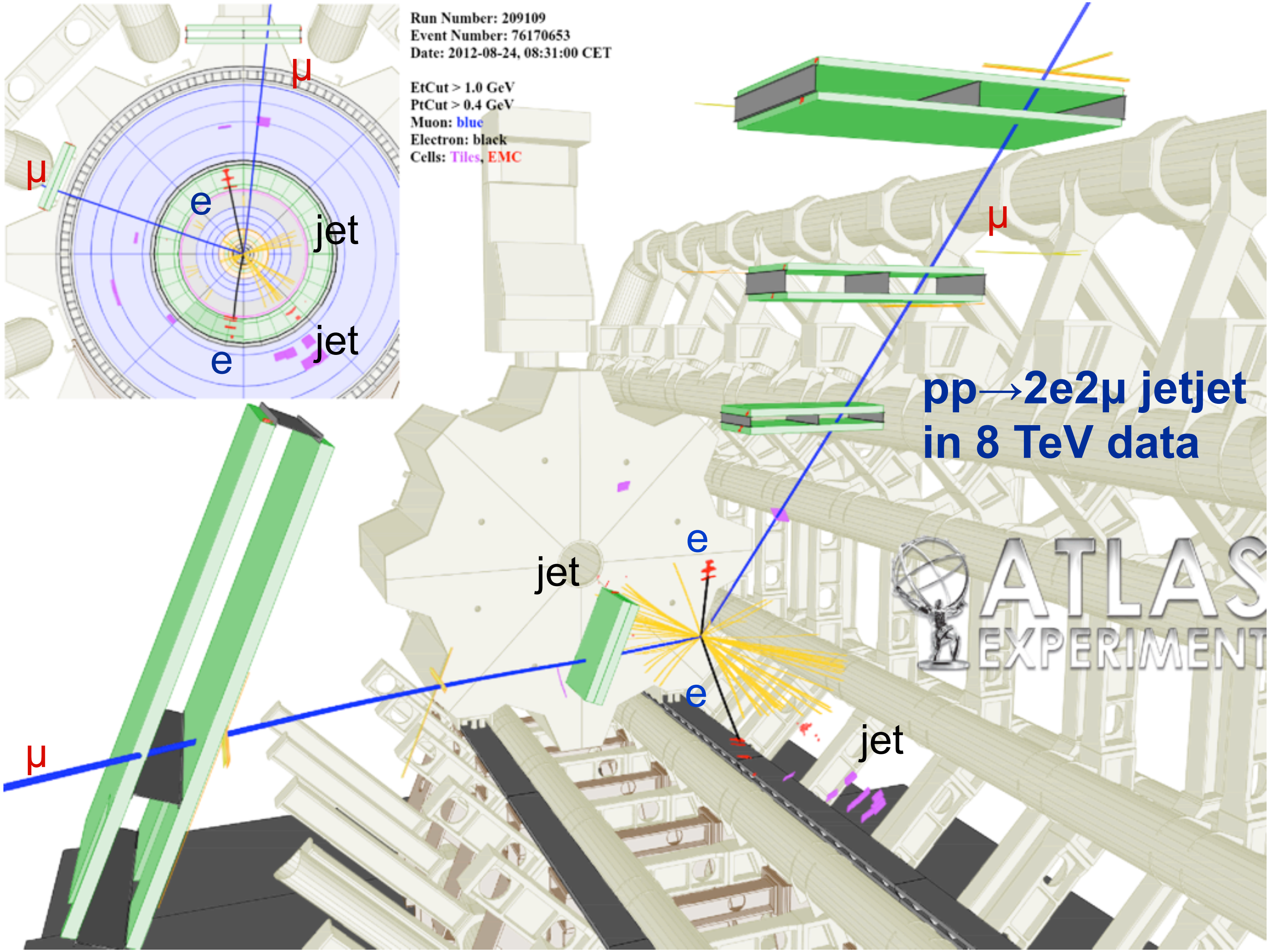
Better yields...

Large backgrounds

Detector needs

Excellent lepton ID, energy resolution, hermeticity, jet tagging at high η

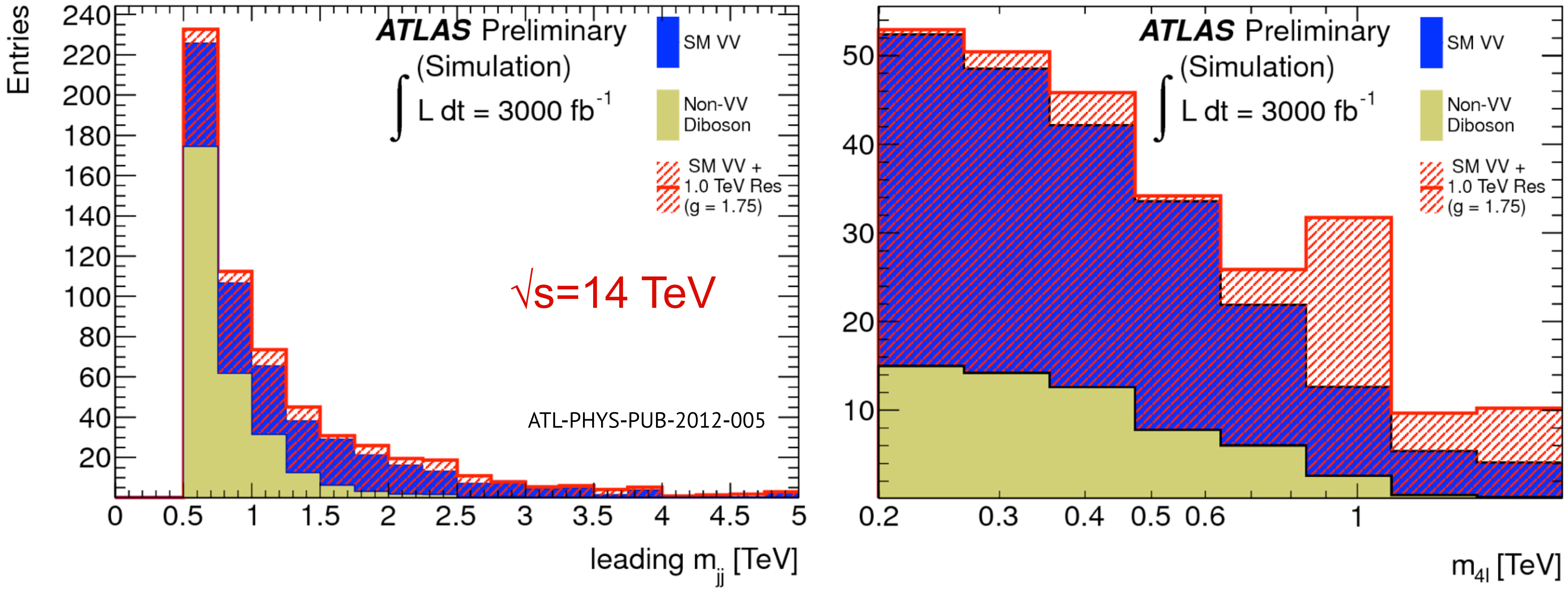
VBF 2e2μ candidate event



pp→2e2μ jetjet in 8 TeV data

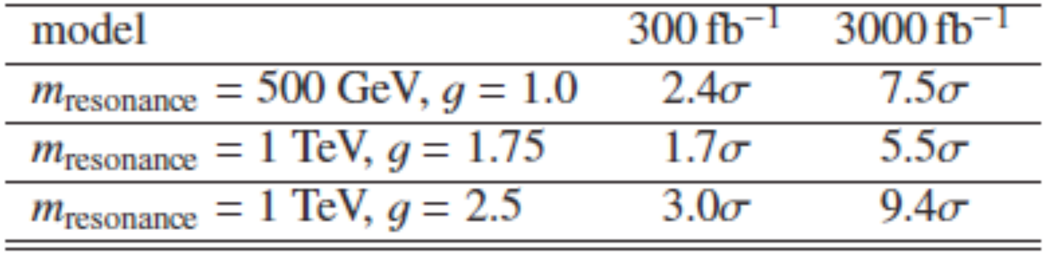
ZZ resonance

pp→ZZ+2j→4ℓ+2j channel



√s=14 TeV

ATL-PHYS-PUB-2012-005



model	$300\ \text{fb}^{-1}$	$3000\ \text{fb}^{-1}$
$m_{\text{resonance}} = 500$ GeV, $g = 1.0$	2.4σ	7.5σ
$m_{\text{resonance}} = 1$ TeV, $g = 1.75$	1.7σ	5.5σ
$m_{\text{resonance}} = 1$ TeV, $g = 2.5$	3.0σ	9.4σ

Sensitivity to anomalous ZZ resonances in Vector boson scattering

VBF SUSY

Direct search for chargino/neutralino production using VBF production to fight otherwise impossible backgrounds.

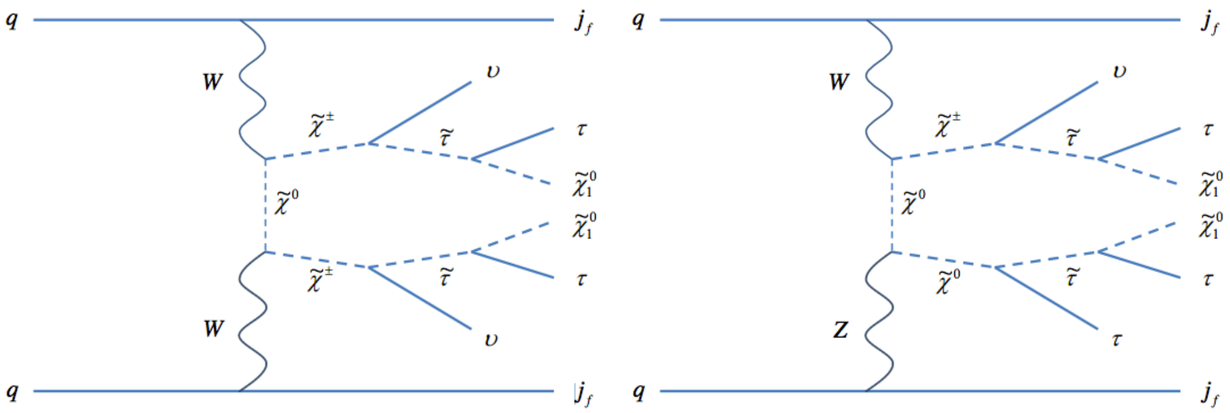
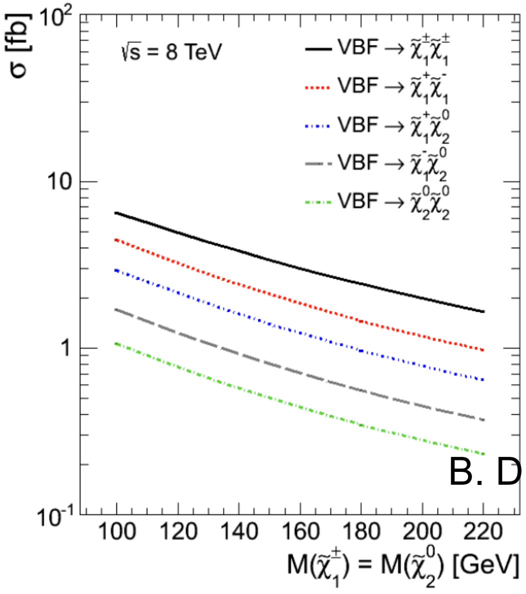


Figure 1: Diagrams of chargino-neutralino pair production through vector boson fusion followed by their decays to leptons and a LSP.

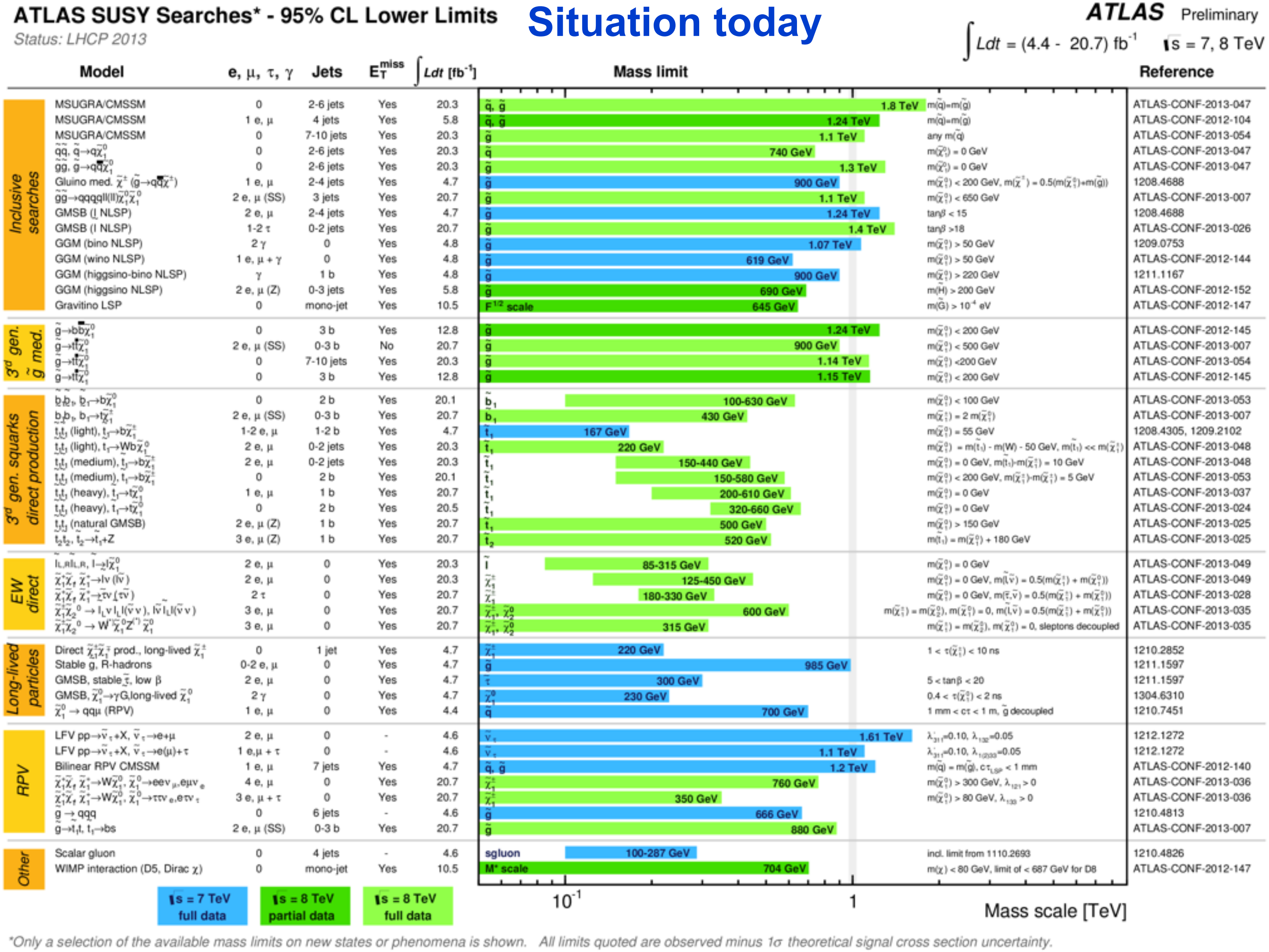


Projections for 14 TeV need to be done. Promising.

B. Dutta, A. Gurrola, W. Johns et al., “Vector Boson Fusion Processes as a Probe of Supersymmetric Electroweak Sectors at the LHC”,. arXiv:1210.0964

SUSY

Situation today



ATLAS SUSY Searches* - 95% CL Lower Limits

Status: LHCP 2013

ATLAS Preliminary

$\int Ldt = (4.4 - 20.7)\ \mathrm{fb}^{-1}$ $\sqrt{s}$ = 7, 8 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int Ldt$ [fb^{-1}]	Mass limit		Reference
Inclusive searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.8 TeV	$m(\tilde{q})=m(\tilde{g})$	ATLAS-CONF-2013-047
	MSUGRA/CMSSM	1 e, μ	4 jets	Yes	5.8	$\tilde{q}, \tilde{g}$ 1.24 TeV	$m(\tilde{q})=m(\tilde{g})$	ATLAS-CONF-2012-104
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	any $m(\tilde{q})$	ATLAS-CONF-2013-054
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 740 GeV	$m(\tilde{\chi}_1^0) = 0$ GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}_1^0) = 0$ GeV	ATLAS-CONF-2013-047
	Gluino med. $\tilde{\chi}^\pm$ ($\tilde{g}\to q\bar{q}\tilde{\chi}^\pm$)	1 e, μ	2-4 jets	Yes	4.7	$\tilde{g}$ 900 GeV	$m(\tilde{\chi}_1^0) < 200$ GeV, $m(\tilde{\chi}^\pm) = 0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	1208.4688
	$\tilde{g}\tilde{g}\to qqqqll(ll)\tilde{\chi}_1^0\tilde{\chi}_1^0$	2 e, μ (SS)	3 jets	Yes	20.7	$\tilde{g}$ 1.1 TeV	$m(\tilde{\chi}_1^0) < 650$ GeV	ATLAS-CONF-2013-007
	GMSB ($\tilde{l}$ NLSP)	2 e, μ	2-4 jets	Yes	4.7	$\tilde{g}$ 1.24 TeV	$\tan\beta < 15$	1208.4688
	GMSB ($\tilde{l}$ NLSP)	1-2 τ	0-2 jets	Yes	20.7	$\tilde{g}$ 1.4 TeV	$\tan\beta > 18$	ATLAS-CONF-2013-026
	GGM (bino NLSP)	2 γ	0	Yes	4.8	$\tilde{g}$ 1.07 TeV	$m(\tilde{\chi}_1^0) > 50$ GeV	1209.0753
	GGM (wino NLSP)	1 e, μ + γ	0	Yes	4.8	$\tilde{g}$ 619 GeV	$m(\tilde{\chi}_1^0) > 50$ GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$ 900 GeV	$m(\tilde{\chi}_1^0) > 220$ GeV	1211.1167
	GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$ 690 GeV	$m(\tilde{H}) > 200$ GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale 645 GeV	$m(\tilde{G}) > 10^{-4}$ eV	ATLAS-CONF-2012-147
3rd gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	12.8	$\tilde{g}$ 1.24 TeV	$m(\tilde{\chi}_1^0) < 200$ GeV	ATLAS-CONF-2012-145
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	2 e, μ (SS)	0-3 b	No	20.7	$\tilde{g}$ 900 GeV	$m(\tilde{\chi}_1^0) < 500$ GeV	ATLAS-CONF-2013-007
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.14 TeV	$m(\tilde{\chi}_1^0) < 200$ GeV	ATLAS-CONF-2013-054
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	3 b	Yes	12.8	$\tilde{g}$ 1.15 TeV	$m(\tilde{\chi}_1^0) < 200$ GeV	ATLAS-CONF-2012-145
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$ 100-630 GeV	$m(\tilde{\chi}_1^0) < 100$ GeV	ATLAS-CONF-2013-053
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e, μ (SS)	0-3 b	Yes	20.7	$\tilde{b}_1$ 430 GeV	$m(\tilde{\chi}_1^\pm) = 2\,m(\tilde{\chi}_1^0)$	ATLAS-CONF-2013-007
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	1-2 e, μ	1-2 b	Yes	4.7	$\tilde{t}_1$ 167 GeV	$m(\tilde{\chi}_1^0) = 55$ GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1\to Wb\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3	$\tilde{t}_1$ 220 GeV	$m(\tilde{\chi}_1^0) = m(\tilde{t}_1) - m(W) - 50$ GeV, $m(\tilde{t}_1) << m(\tilde{\chi}_1^\pm)$	ATLAS-CONF-2013-048
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	2 e, μ	0-2 jets	Yes	20.3	$\tilde{t}_1$ 150-440 GeV	$m(\tilde{\chi}_1^0) = 0$ GeV, $m(\tilde{t}_1)-m(\tilde{\chi}_1^\pm) = 10$ GeV	ATLAS-CONF-2013-048
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0	2 b	Yes	20.1	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}_1^0) < 200$ GeV, $m(\tilde{\chi}_1^\pm)-m(\tilde{\chi}_1^0) = 5$ GeV	ATLAS-CONF-2013-053
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	1 e, μ	1 b	Yes	20.7	$\tilde{t}_1$ 200-610 GeV	$m(\tilde{\chi}_1^0) = 0$ GeV	ATLAS-CONF-2013-037
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	0	2 b	Yes	20.5	$\tilde{t}_1$ 320-660 GeV	$m(\tilde{\chi}_1^0) = 0$ GeV	ATLAS-CONF-2013-024
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e, μ (Z)	1 b	Yes	20.7	$\tilde{t}_1$ 500 GeV	$m(\tilde{\chi}_1^0) > 150$ GeV	ATLAS-CONF-2013-025
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e, μ (Z)	1 b	Yes	20.7	$\tilde{t}_2$ 520 GeV	$m(\tilde{t}_1) = m(\tilde{\chi}_1^0) + 180$ GeV	ATLAS-CONF-2013-025
EW direct	$\tilde{l}_{L,R}\tilde{l}_{L,R}, \tilde{l}\to l\tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{l}$ 85-315 GeV	$m(\tilde{\chi}_1^0) = 0$ GeV	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to \tilde{l}\nu(l\tilde{\nu})$	2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$ 125-450 GeV	$m(\tilde{\chi}_1^0) = 0$ GeV, $m(\tilde{l},\tilde{\nu}) = 0.5(m(\tilde{\chi}_1^\pm) + m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to \tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	0	Yes	20.7	$\tilde{\chi}_1^\pm$ 180-330 GeV	$m(\tilde{\chi}_1^0) = 0$ GeV, $m(\tilde{\tau},\tilde{\nu}) = 0.5(m(\tilde{\chi}_1^\pm) + m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-028
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to \tilde{l}_L\nu\tilde{l}_L l(\tilde{\nu}\nu), l\tilde{\nu}\tilde{l}_L l(\tilde{\nu}\nu)$	3 e, μ	0	Yes	20.7	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 600 GeV	$m(\tilde{\chi}_1^\pm) = m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0) = 0$, $m(\tilde{l},\tilde{\nu}) = 0.5(m(\tilde{\chi}_1^\pm) + m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-035
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to W^{*}\tilde{\chi}_1^0 Z^{(*)}\tilde{\chi}_1^0$	3 e, μ	0	Yes	20.7	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 315 GeV	$m(\tilde{\chi}_1^\pm) = m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0) = 0$, sleptons decoupled	ATLAS-CONF-2013-035
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	0	1 jet	Yes	4.7	$\tilde{\chi}_1^\pm$ 220 GeV	$1 < \tau(\tilde{\chi}_1^\pm) < 10$ ns	1210.2852
	Stable $\tilde{g}$, R-hadrons	0-2 e, μ	0	Yes	4.7	$\tilde{g}$ 985 GeV		1211.1597
	GMSB, stable $\tilde{\tau}$, low β	2 e, μ	0	Yes	4.7	$\tilde{\tau}$ 300 GeV	$5 < \tan\beta < 20$	1211.1597
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	0	Yes	4.7	$\tilde{\chi}_1^0$ 230 GeV	$0.4 < \tau(\tilde{\chi}_1^0) < 2$ ns	1304.6310
	$\tilde{\chi}_1^0 \to qq\mu$ (RPV)	1 e, μ	0	Yes	4.4	$\tilde{q}$ 700 GeV	1 mm < cτ < 1 m, $\tilde{g}$ decoupled	1210.7451
RPV	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e+\mu$	2 e, μ	0	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	$\lambda'_{311}=0.10, \lambda_{132}=0.05$	1212.1272
	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e(\mu)+\tau$	1 e,μ + τ	0	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	$\lambda'_{311}=0.10, \lambda_{1(2)33}=0.05$	1212.1272
	Bilinear RPV CMSSM	1 e, μ	7 jets	Yes	4.7	$\tilde{q}, \tilde{g}$ 1.2 TeV	$m(\tilde{q}) = m(\tilde{g})$, $c\tau_{LSP} < 1$ mm	ATLAS-CONF-2012-140
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e, μ	0	Yes	20.7	$\tilde{\chi}_1^\pm$ 760 GeV	$m(\tilde{\chi}_1^0) > 300$ GeV, $\lambda_{121} > 0$	ATLAS-CONF-2013-036
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to \tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 e, μ + τ	0	Yes	20.7	$\tilde{\chi}_1^\pm$ 350 GeV	$m(\tilde{\chi}_1^0) > 80$ GeV, $\lambda_{133} > 0$	ATLAS-CONF-2013-036
	$\tilde{g} \to qqq$	0	6 jets	-	4.6	$\tilde{g}$ 666 GeV		1210.4813
	$\tilde{g}\to\tilde{t}_1 t, \tilde{t}_1\to bs$	2 e, μ (SS)	0-3 b	Yes	20.7	$\tilde{g}$ 880 GeV		ATLAS-CONF-2013-007
Other	Scalar gluon	0	4 jets	-	4.6	sgluon 100-287 GeV	incl. limit from 1110.2693	1210.4826
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale 704 GeV	$m(\chi) < 80$ GeV, limit of < 687 GeV for D8	ATLAS-CONF-2012-147

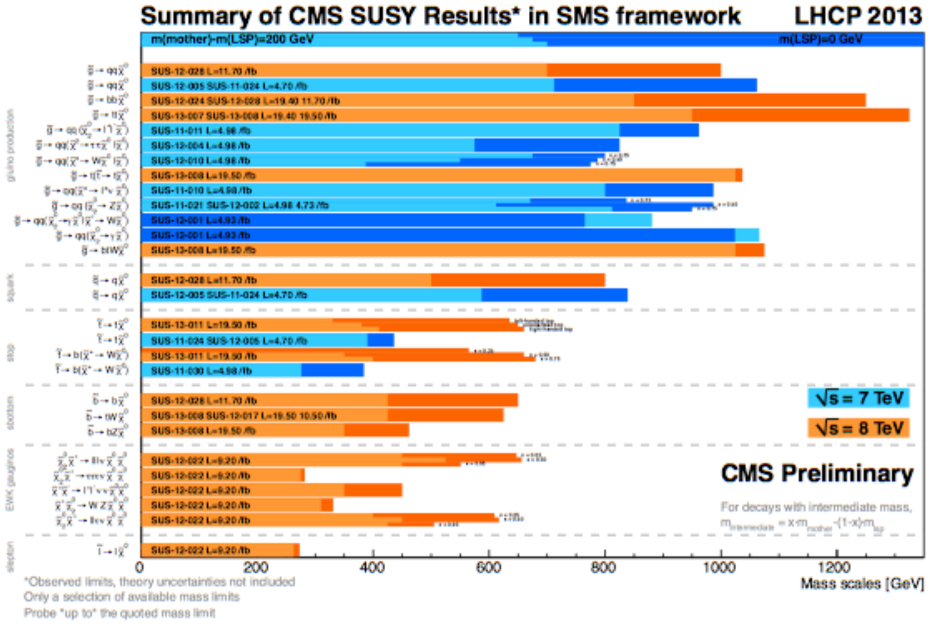
$\sqrt{s}$ = 7 TeV full data

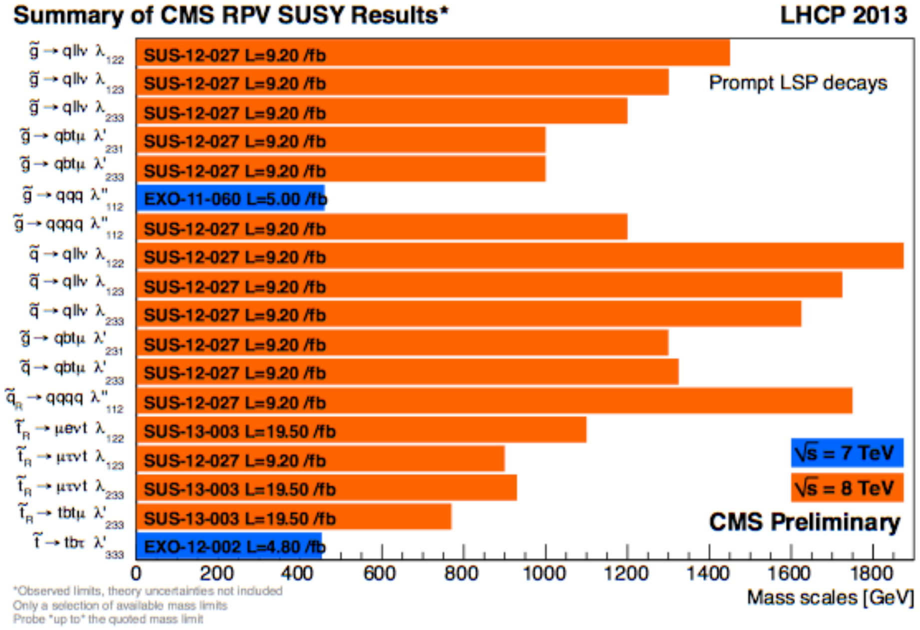
$\sqrt{s}$ = 8 TeV partial data

$\sqrt{s}$ = 8 TeV full data

**Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.*

SUSY





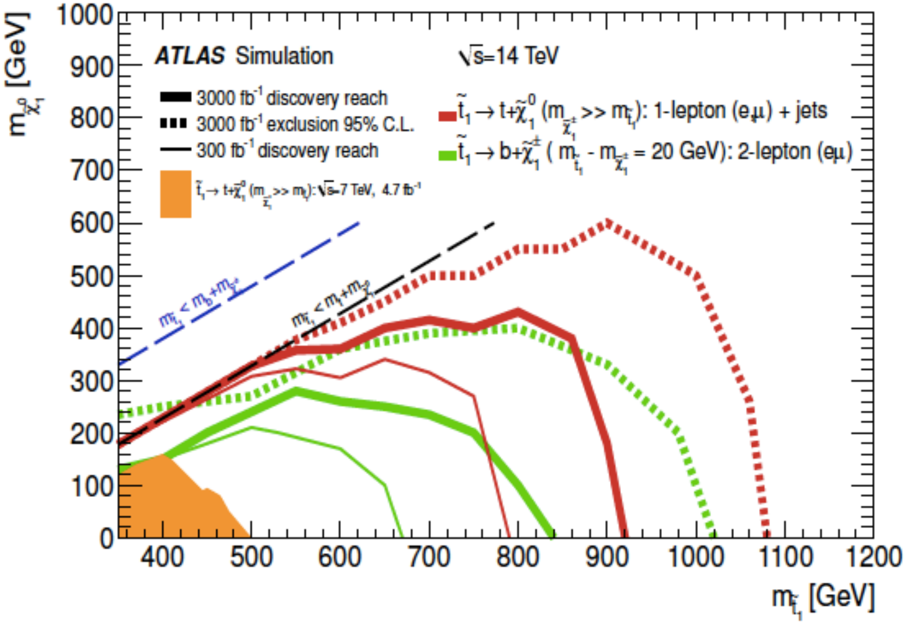
SUSY limits at a glance

EWKinos	~200-400 GeV
Stop, sbottoms	~200-600 GeV
Squarks, gluinos	~600-1300 GeV

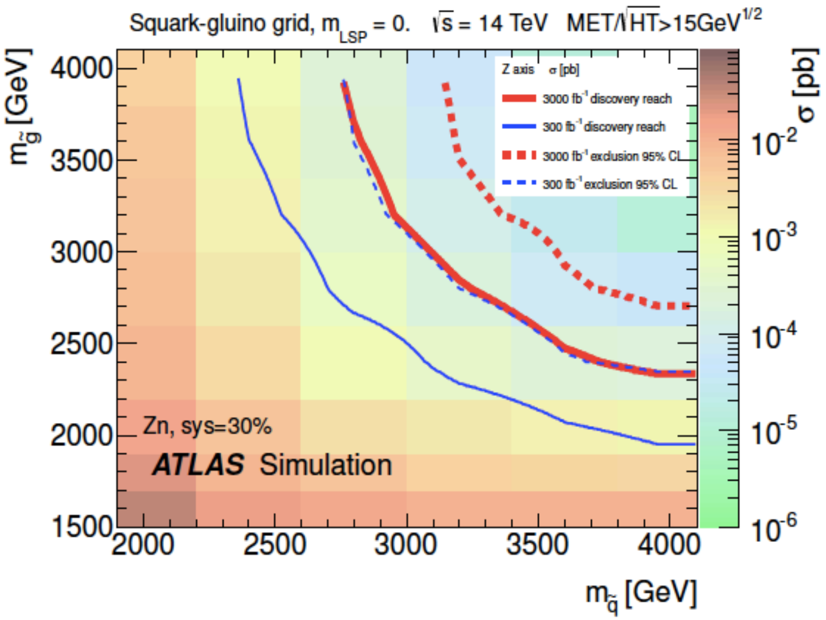
ATLAS SUSY reach at higher luminosity

5s discovery reach (solid lines) and 95% CL exclusion limits (dashed lines)
With 300fb^{-1} (thin lines) and 3000fb^{-1} (thick lines)

Stop-neutralino



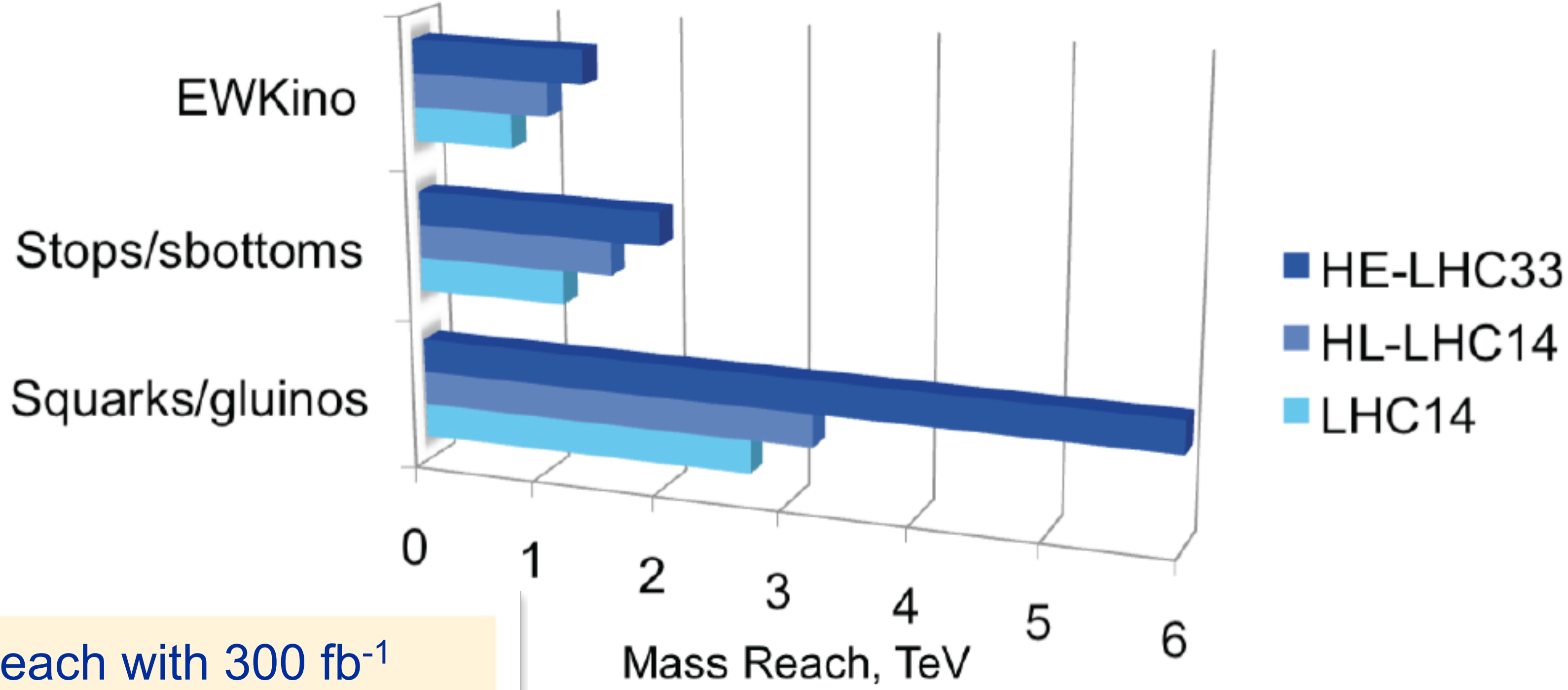
Squark-gluino



Going from L=300 fb^{-1} to L=3000 fb^{-1} the sensitivity to 1st and 2nd gen squarks and gluinos improves by ~400-500 GeV, while to stops by about 200 GeV

CMS SUSY reach at higher luminosity

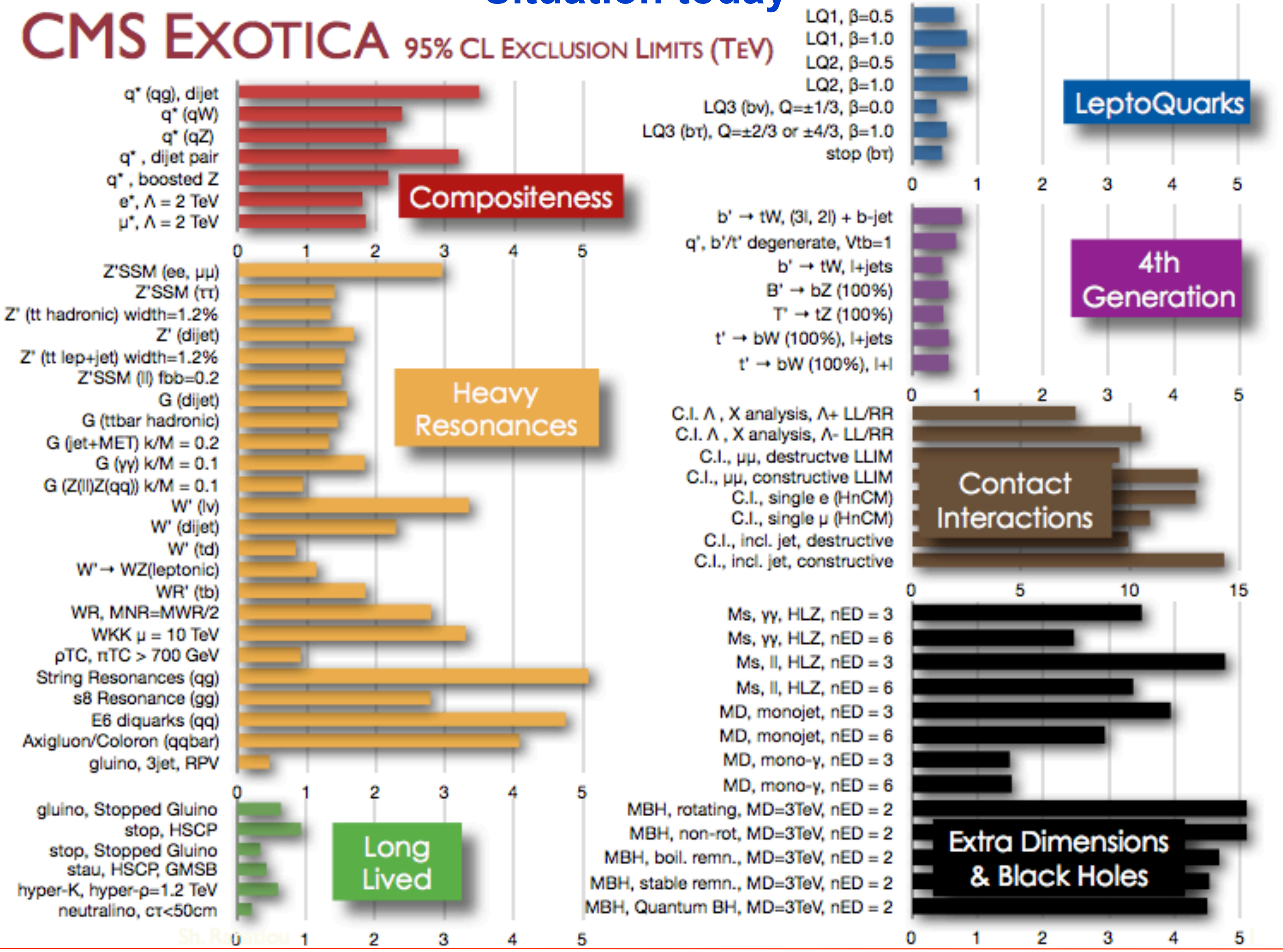
- LHC at 14 TeV expands the reach for SUSY particles to much higher masses. (HE-LHC at 33 TeV does it even more)
- As expected, the gain with HL-LHC is more modest (~25%) in this case.



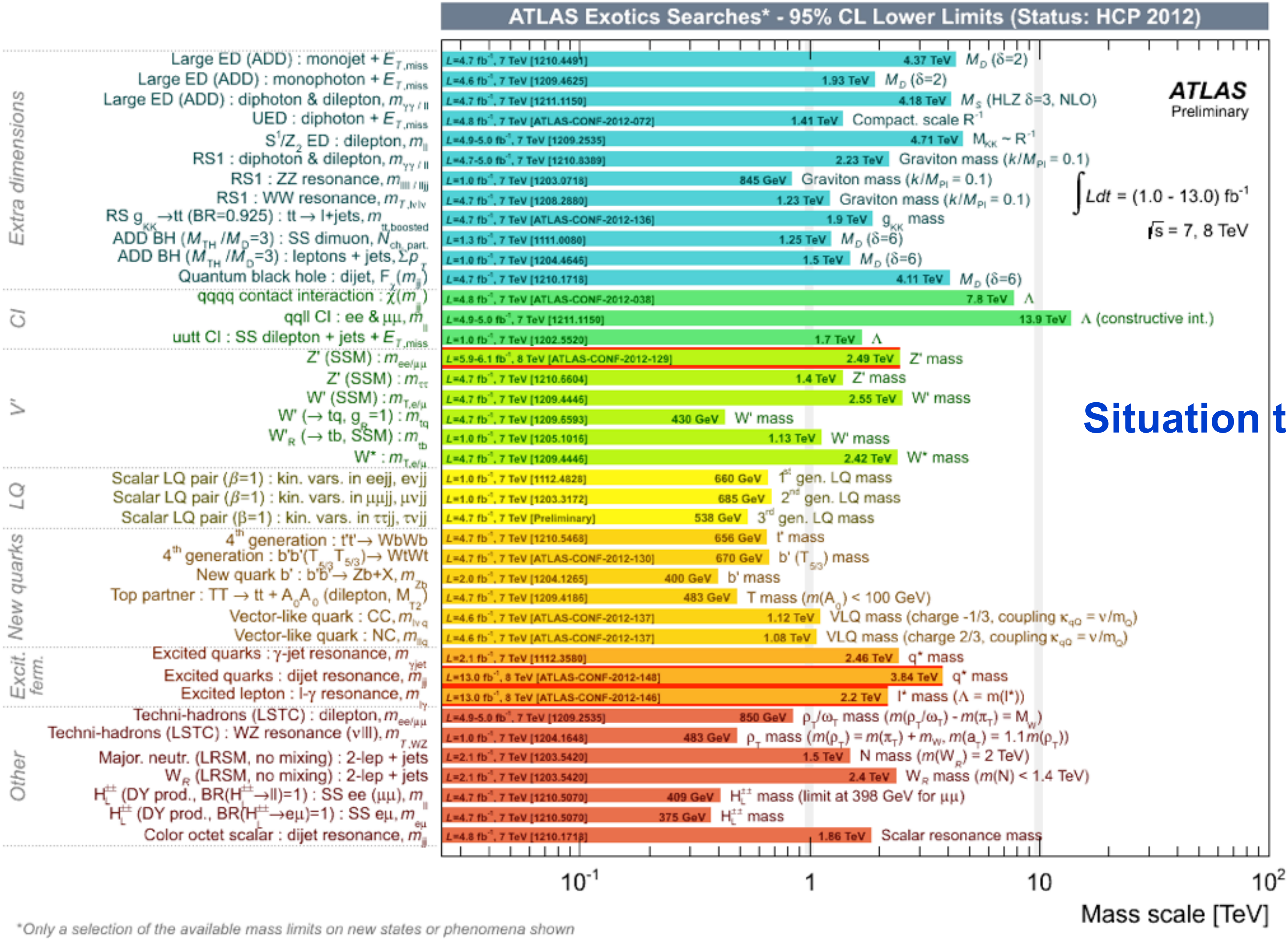
SUSY reach with 300 fb^{-1}
EWKinos up to ~ 800 GeV
Stops,sbottoms up to ~ 1TeV
squarks,gluinos up to ~2.5 TeV

Exotics searches results

Situation today



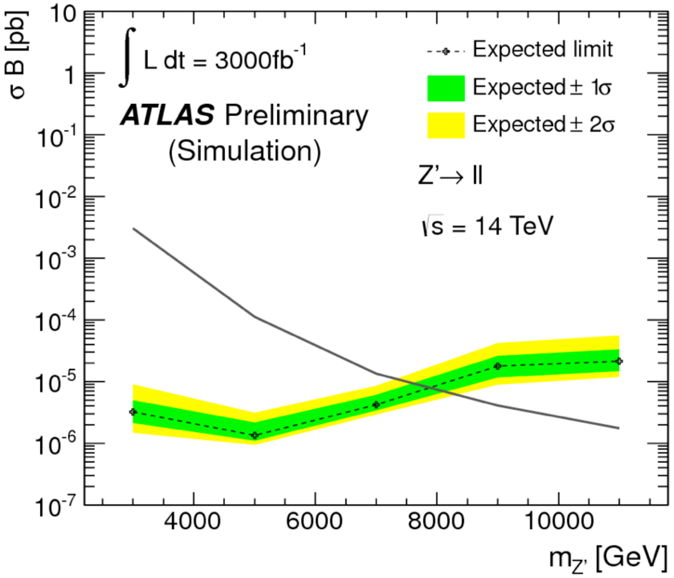
Exotics searches results



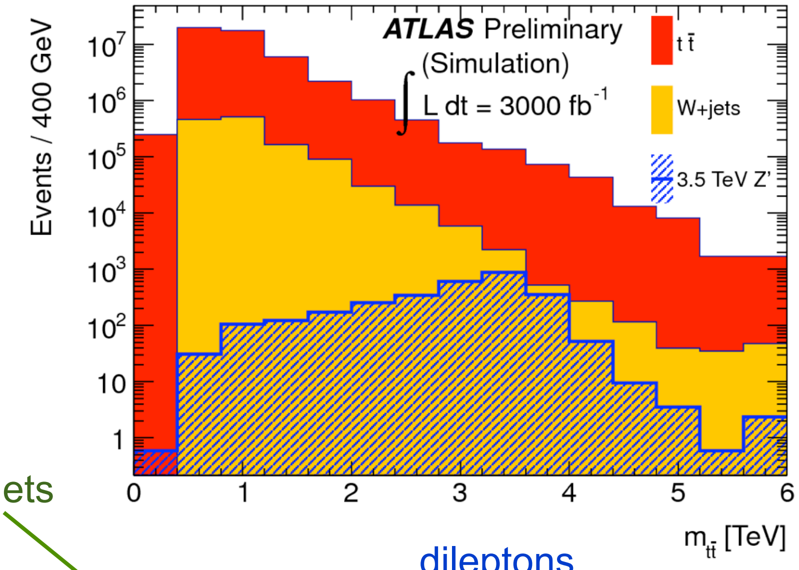
Situation today

*Only a selection of the available mass limits on new states or phenomena shown

ATLAS Exotics searches at HL-LHC



Z'$_{Topcolour}$

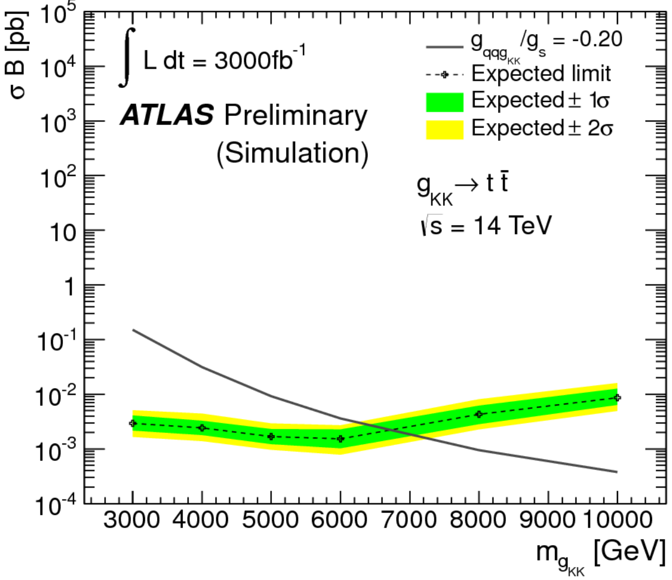


lepton+jets

dileptons

model	300 fb^{-1}	1000 fb^{-1}	3000 fb^{-1}
g_{KK}	4.3 (4.0)	5.6 (4.9)	6.7 (5.6)
$Z'_{\mathrm{Topcolour}}$	3.3 (1.8)	4.5 (2.6)	5.5 (3.2)
$Z'_{SSM} \to ee$	6.5	7.2	7.8
$Z'_{SSM} \to \mu\mu$	6.4	7.1	7.6

Kaluza-Klein gluons in extra-dimensional models



Summary of expected limits for various signatures in the Sequential Standard Model. All mass limits are in TeV.

CMS LQ at HL-LHC

Mass reach (in TeV) for the leptoquark search in the ee jetjet channel

CMS

Scenario	LHC	HL-LHC	HE-LHC
Low S/B	1.6	1.8	2.5
High S/B	1.7	2.3	3.5

Caveat

Many of the projections and studies that I presented are being improved and updated for the ECFA workshop of october 2013, so stay tuned...

Conclusions

- ATLAS and CMS detectors have performed extremely well, took excellent LHC data. SM scalar boson-like particle has been discovered at 125 GeV. Extensive BSM physics program ongoing.
- Operation in a very busy environments (beyond-design) provided valuable experience. Together with a sound upgrades program, the two experiments will advance into Phase I and Phase II towards collecting data of collisions at √s=14 TeV and instantaneous luminosities up to 2x10^{34}cm^{-2}s^{-1}.
  - (Phase I) 300 fb^{-1} in 2015-2018 : A new energy domain (going from √s8 to 14 TeV) opens a large potential for new physics discoveries.
  - (Phase II) 3000 fb^{-1} in 2020-2032 : High luminosity domain (going from 2x10^{34}cm^{-2}s^{-1} to 5x10^{34}cm^{-2}s^{-1}) opens a large potential for high precision measurements.
- Precision SM scalar boson physics at HL-LHC is an attractive future scenario requiring substantial studies and R&D involving major upgrades of full detectors.
  - it is a challenging project
  - scalar boson couplings can be measured with few percent precision
  - rare scalar boson decays, self-coupling studies possible
  - VV scattering will be probed
- LHC has an exciting physics program for the next twenty years.

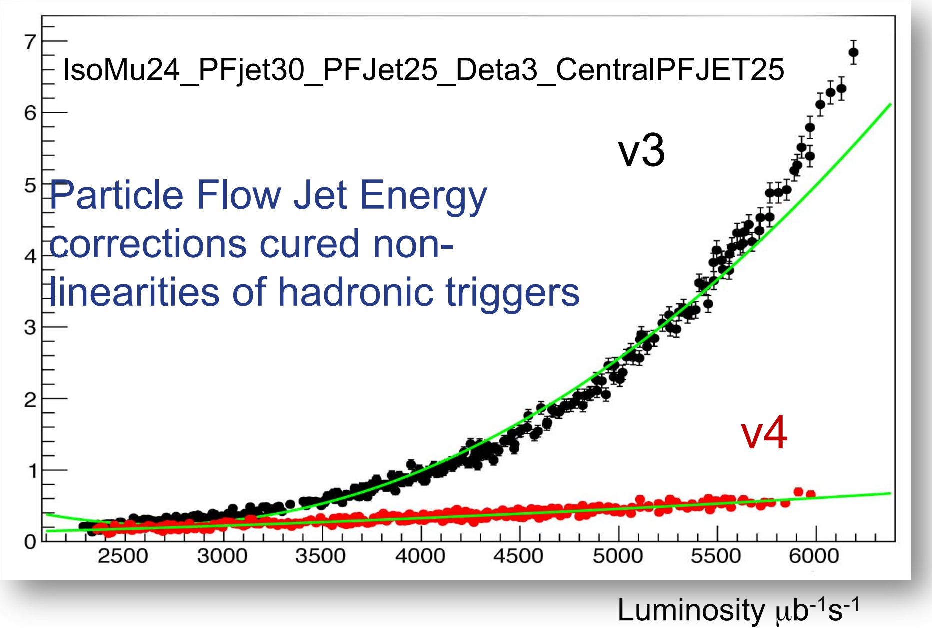
Backup

Trigger challenge in 2012

Maintaining high trigger efficiency while keeping the trigger rate within budget was one of the biggest challenges of the CMS experiment in 2012

The experience obtained in 2012 with peak pileup of ~35 events gives us confidence for high-luminosity running post Long Shutdown 1

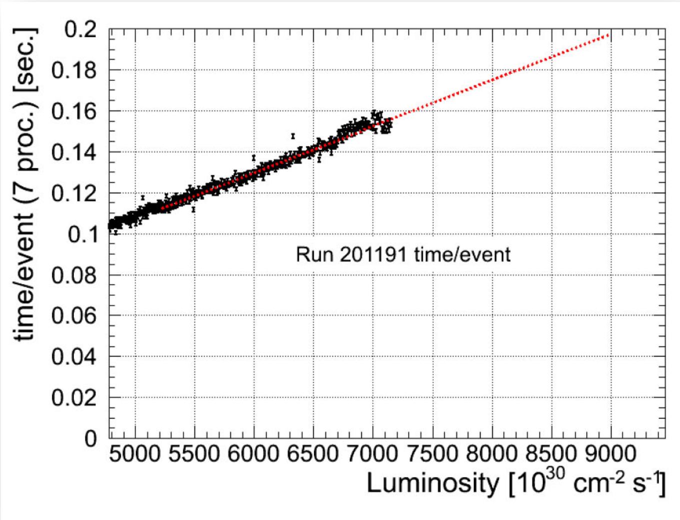
Trigger Cross-sections:



Particle Flow Jet Energy corrections cured non-linearities of hadronic triggers

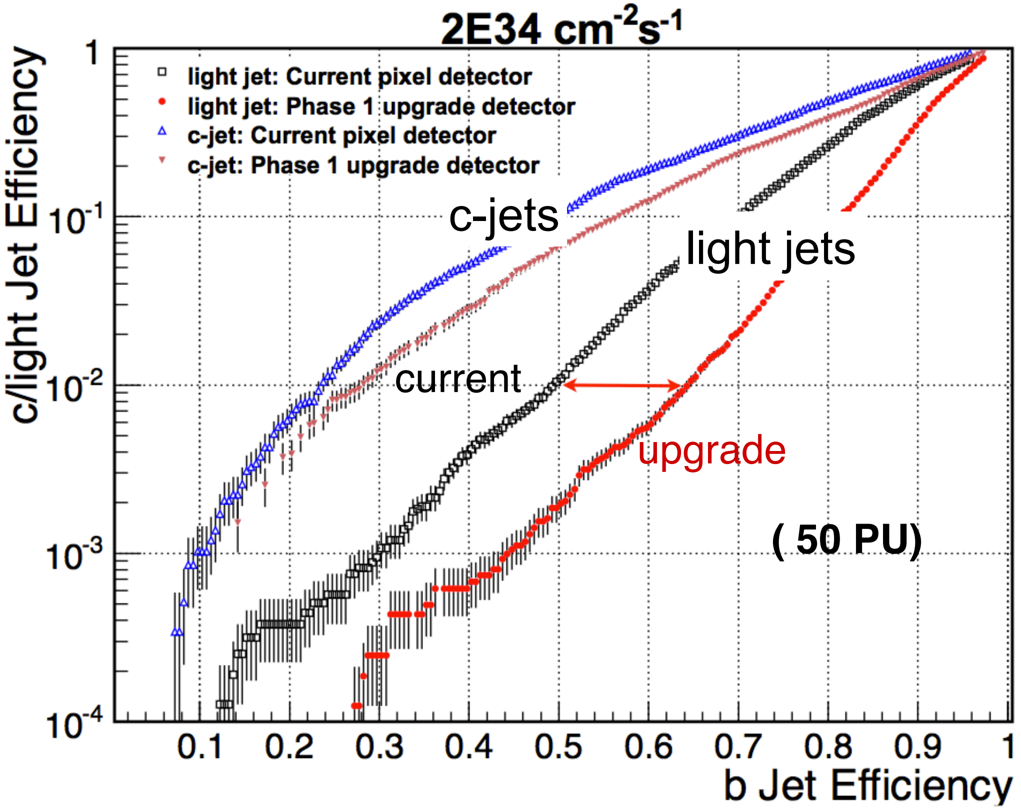
HLT CPU time:

- linear with PU, no signs of runaway

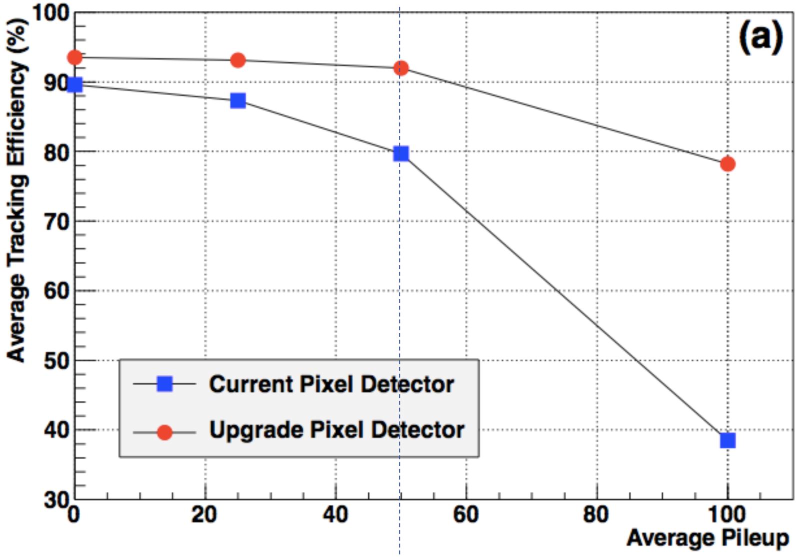


Tracking and b-tagging performance

Improvement of b-tagging efficiency with new pixel detector



Improvement in tracking efficiency w/ new pixel detector, in ttbar events, as a function of pileup



50 pileup

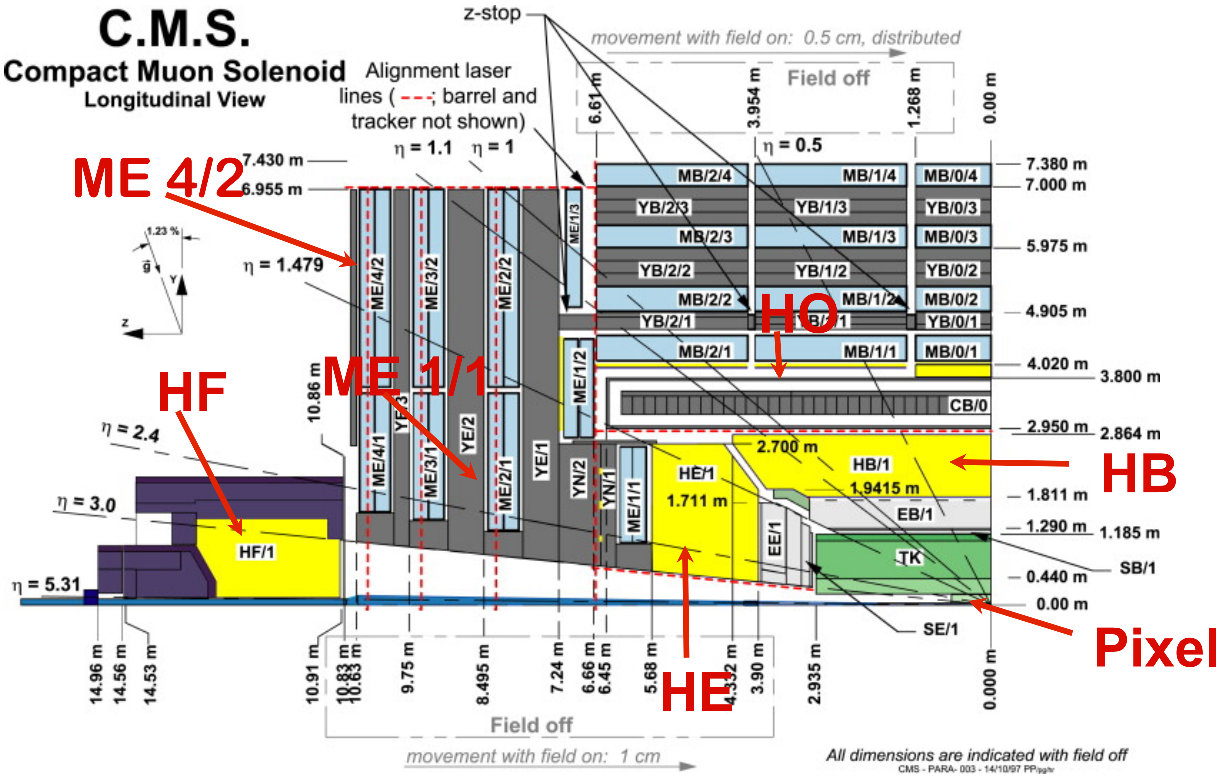
b-tagging efficiency ~ 1.3x better

2 b-jets → (1.3)^2 ~1.69

Primary vertex resolution improved by factor ~1.5 - 2

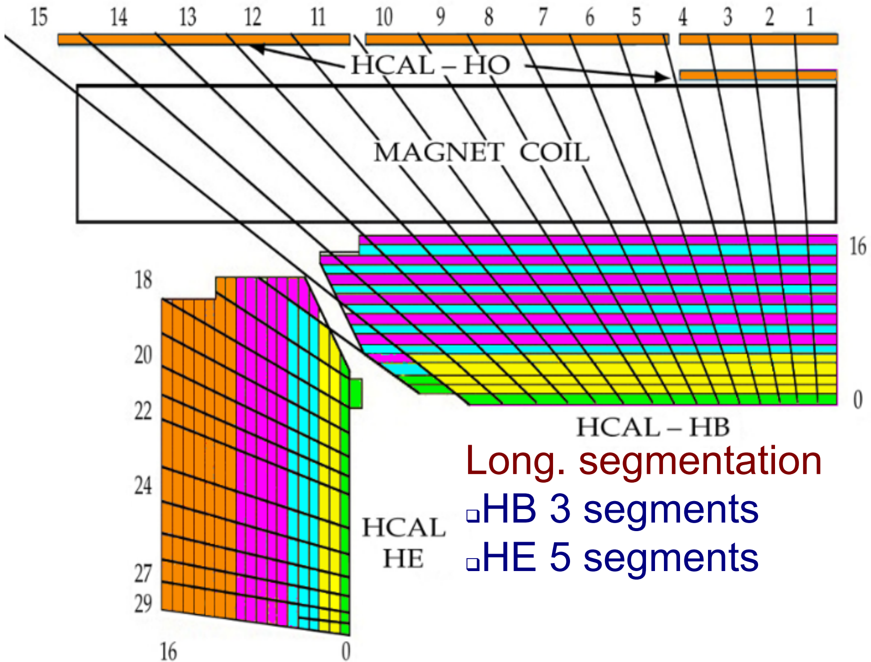
CMS Upgrade program

LS1 and Phase 1



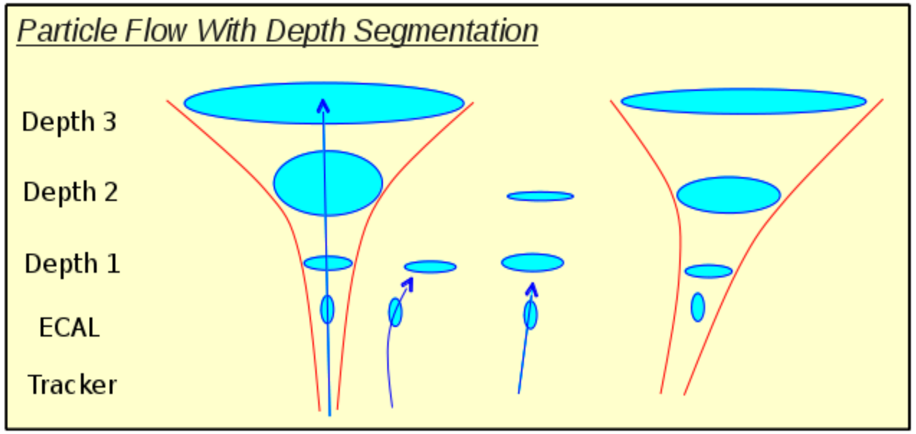
HCAL Upgrade

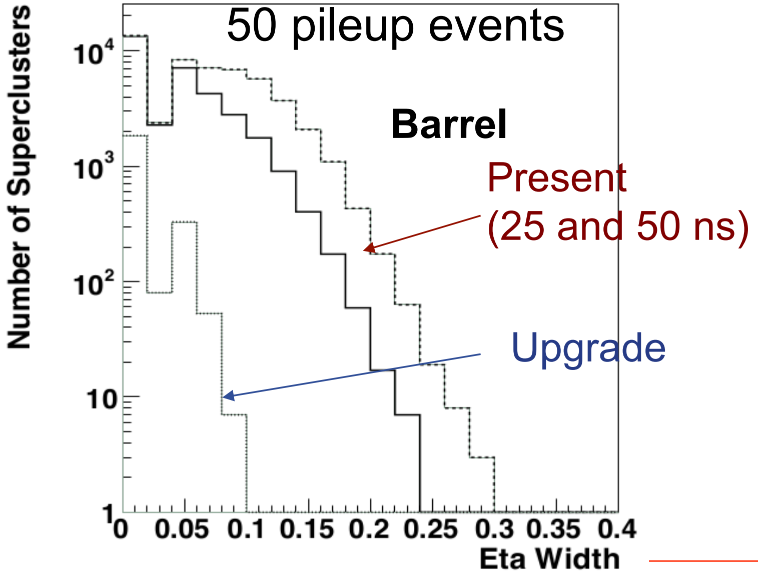
- Upgraded HCAL
  - New photodetectors
  - New electronics (frontend, backend)
  - Improved longitudinal segmentation
  - Improved background rejection, Missing E_T resolution and Particle Flow reconstruction



Long. segmentation
- HB 3 segments
- HE 5 segments

- Hadronic showers spread out with increasing depth


Particle Flow With Depth Segmentation

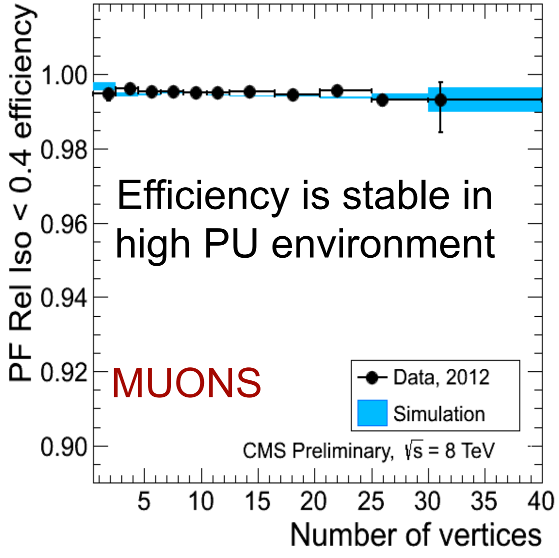

Hadronic cluster width
50 pileup events

Pileup challenges

Reconstruction of hard collisions in high pileup environment requires detectors with very high granularity:

- efficient association of charged tracks to collision vertices
- reconstruction of charged and neutral particles in jets
    - pileup neutrals corrected w/global energy density (ρ)

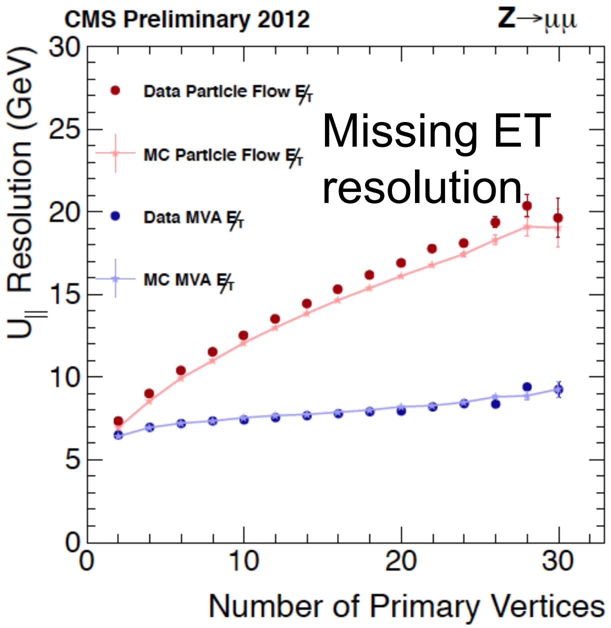
Muon isolation



Efficiency is stable in high PU environment

Physics with high pileup requires full particle flow reconstruction assuring:

- precise jet energy correction
- robust missing energy measurement
- efficient lepton isolation

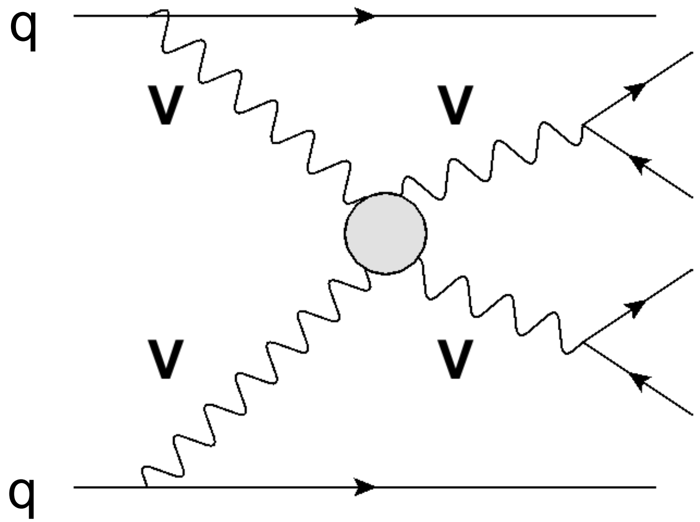


Missing ET resolution

Very efficient reconstruction code is needed to stay within computing budget

Vector Boson Fusion (VBF)

Generic diagram for vector boson fusion (VBF) process



Signature: forward-backward "spectator" jets with very high energy

- Once the vector bosons decay, we have a six-fermion final state
- The full set of qq→6 fermions diagrams has to be considered
- In order to investigate EWSB, one has to isolate VV processes from all other six-fermion final states

➡Apply tight kinematic cuts

Typical kin. cuts

$p_{T,j} > 20$ GeV $|\eta_j|<5$ $p_T^{tag} > 30$ GeV **$|\eta_{j1}-\eta_{j2}|>4.0$**

$\eta_{j1}\cdot\eta_{j2} < 0$ $m_{jj} > 600$ GeV

VV scattering: semileptonic

Semileptonic is most promising: reasonable signal yield

Number of events for 20 fb^{-1} (fully MC based, no systematics, 14 TeV)

WV -> lnjj

ATLAS	N sign.	N back.
500 GeV	6.2	16
800 GeV	13	17
1.1 TeV	4.8	9.2

CMS	N sign.	N back.
500 GeV	337	20759
>1 TeV	45	3281

ZV -> lljj

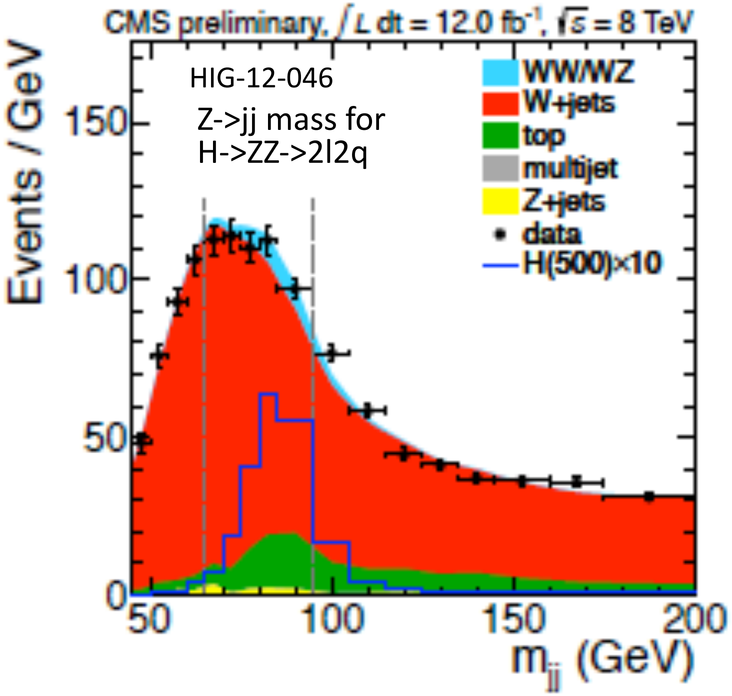
CMS	N sign.	N back.
500 GeV	62	3415
>1 TeV	5	348

For recent inclusive Higgs search:

- more sophisticated analysis developed
(btag categories, angular analyses,
$m_{jj} = m_Z$ kinematic fit)

- data driven background

Improved JES: m_{jj} reso from 20-25% to 10-15%



HIG-12-046

Z->jj mass for
H->ZZ->2l2q

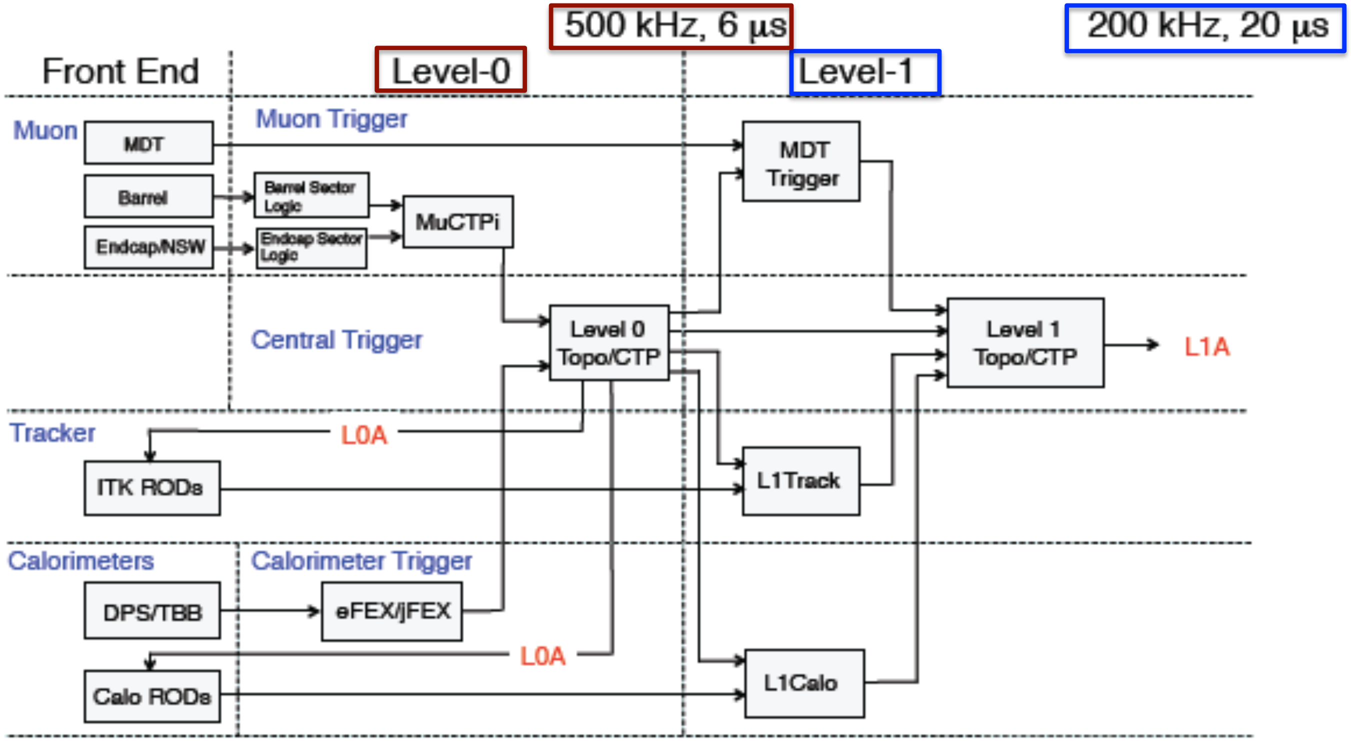
LS3 Phase II Upgrades

HL-LHC Challenges

- The Trigger Systems will require major further upgrades to retain physics acceptance
- The Inner Tracking Detectors will have to be replaced due to radiation damage, and will need higher granularity
- Some End-Cap / FWD Calorimeters may need to be replaced
- Calorimeter Pile-Up will be challenging

Phase II ATLAS Trigger Upgrades

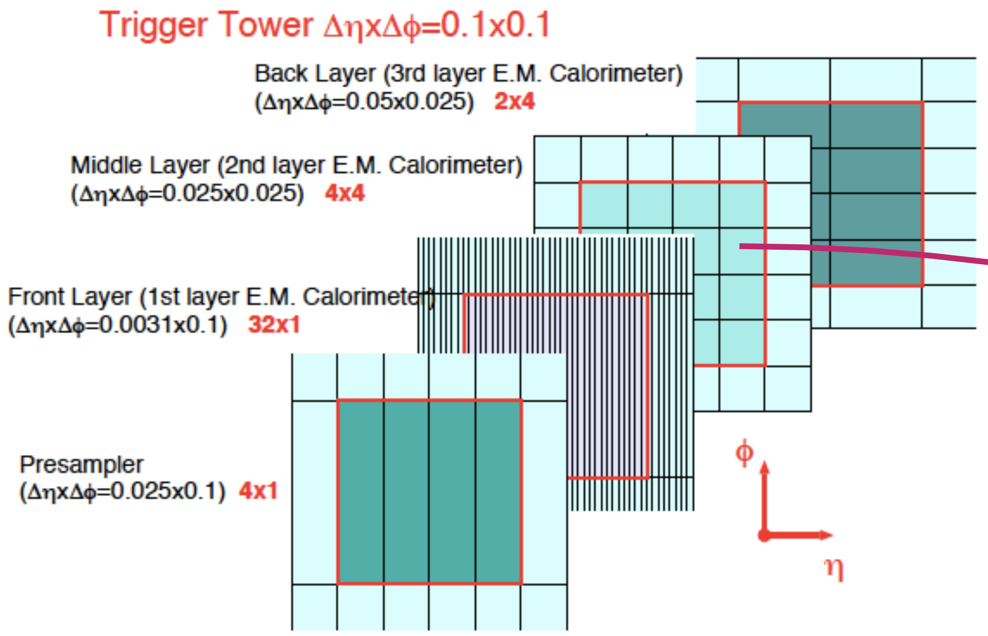
Phase II ATLAS Trigger Architecture



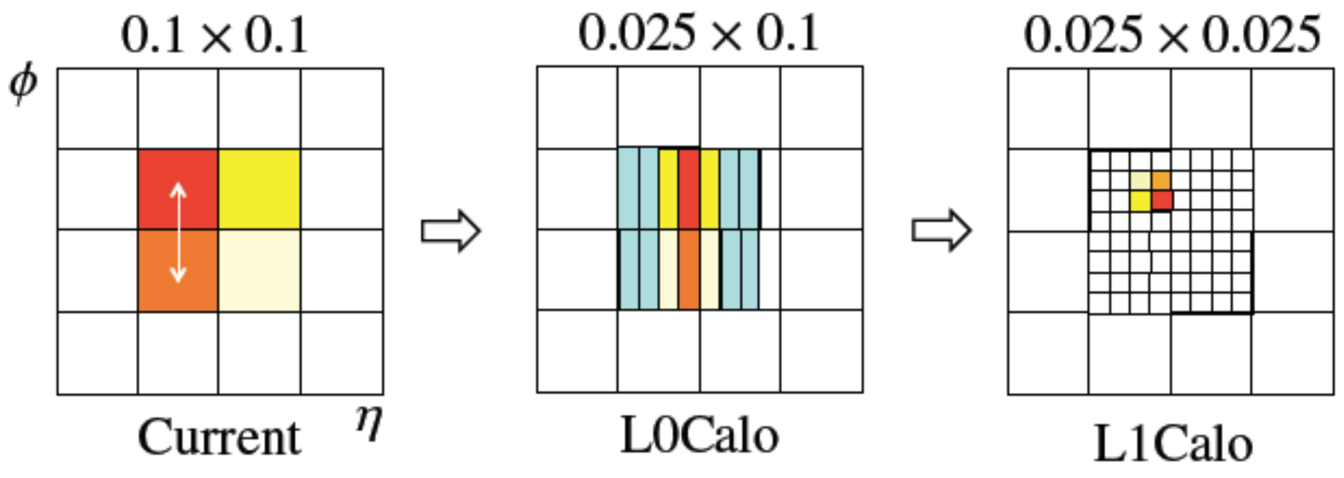
The Level-0 trigger is almost identical to the Phase-I system

The Level-0 accept triggers the full readout of calorimeter ROIs into a new L1Calo system

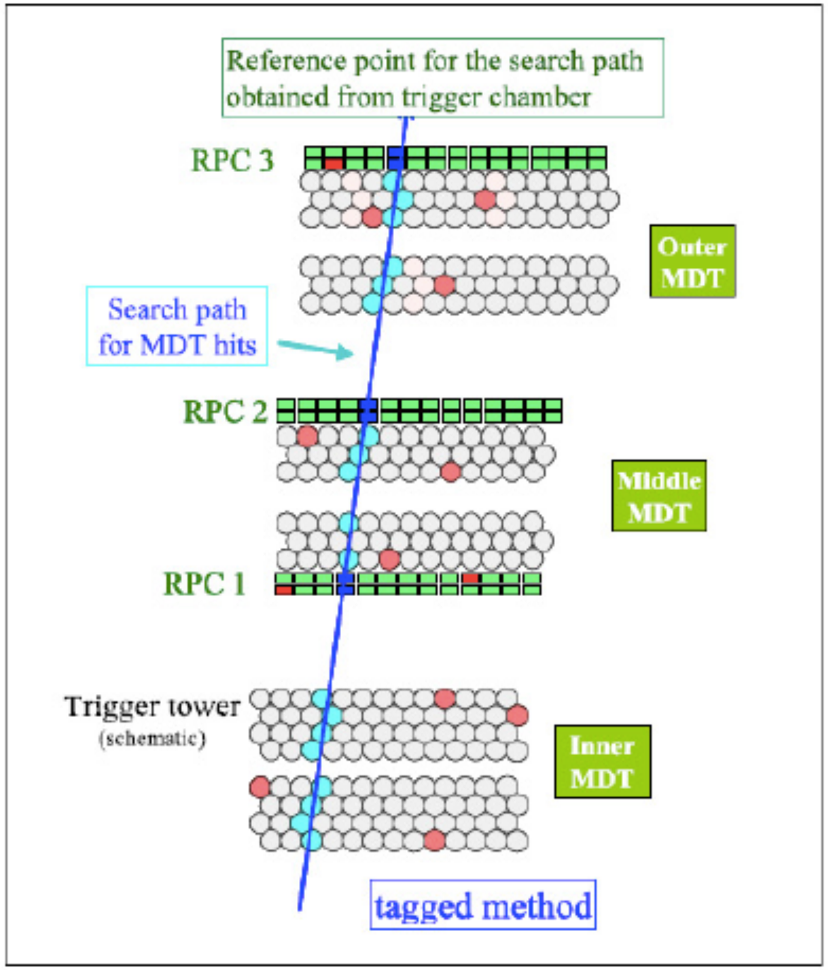
Phase II ATLAS EM CALO Trigger Upgrade



In the new L1 the full ECAL Granularity is available for Trigger purposes



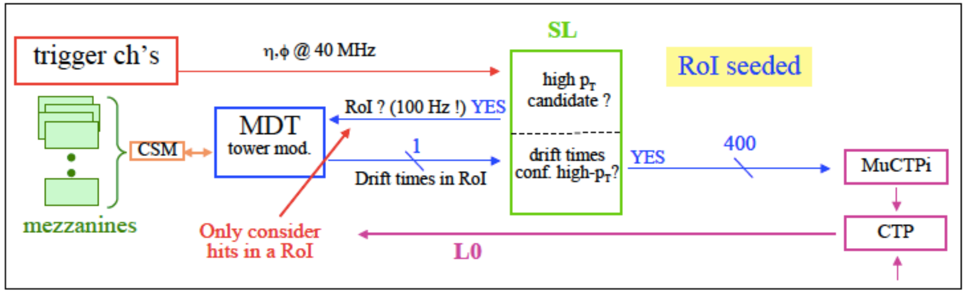
PHASE II ATLAS MDT Trigger Upgrade

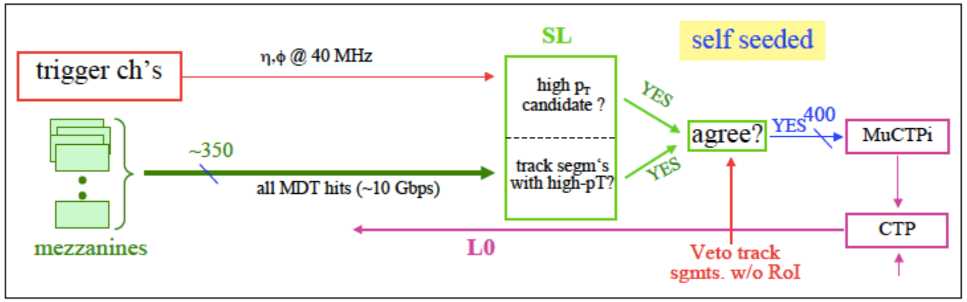


Provide new high speed speed
Data path for MDT, seed by L0 RPC

=> use precision Muon Tracking
at L1 Trigger

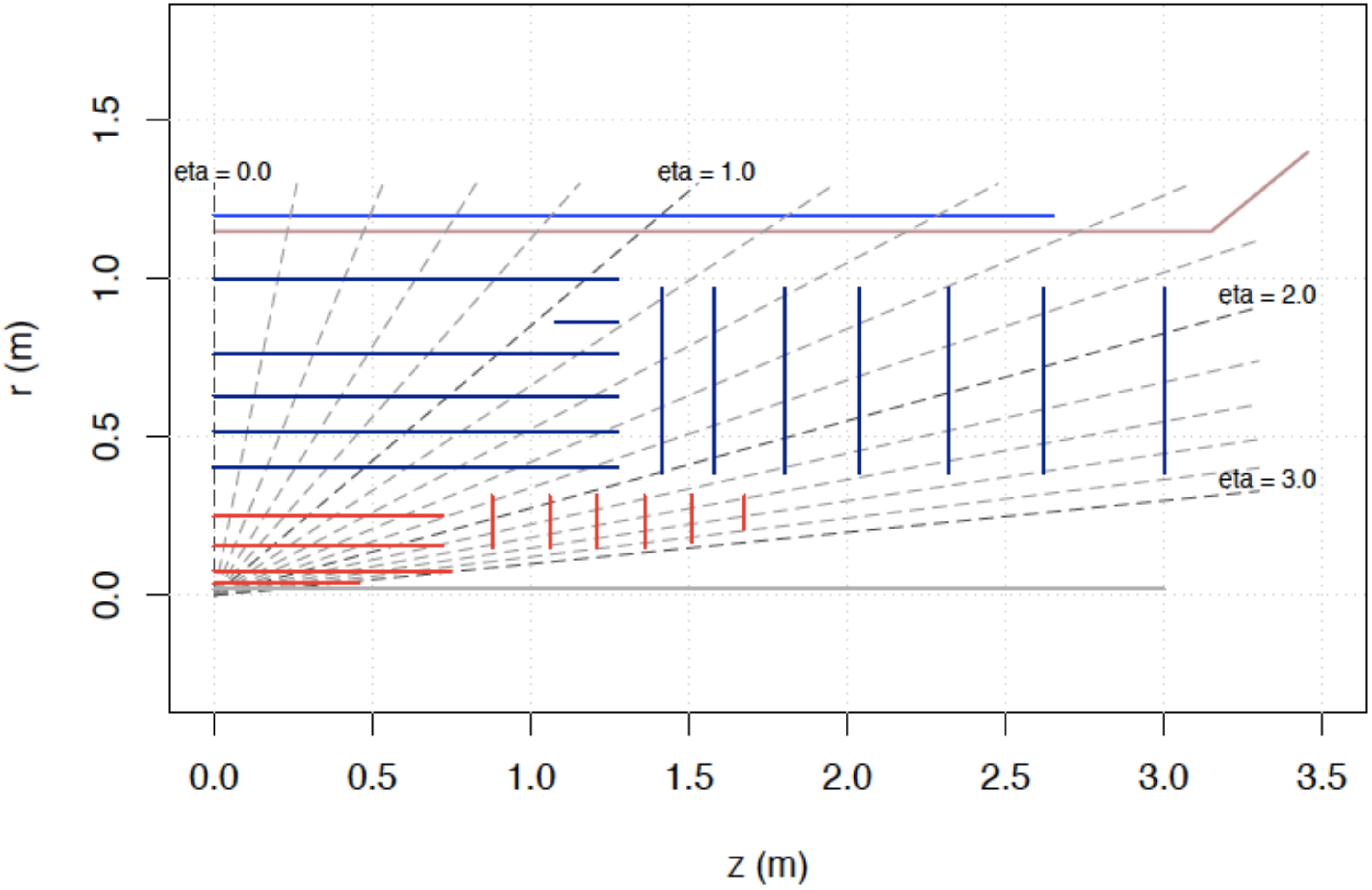
Possible self-seeded L0 option under study





Phase II ATLAS Inner Tracker Upgrades

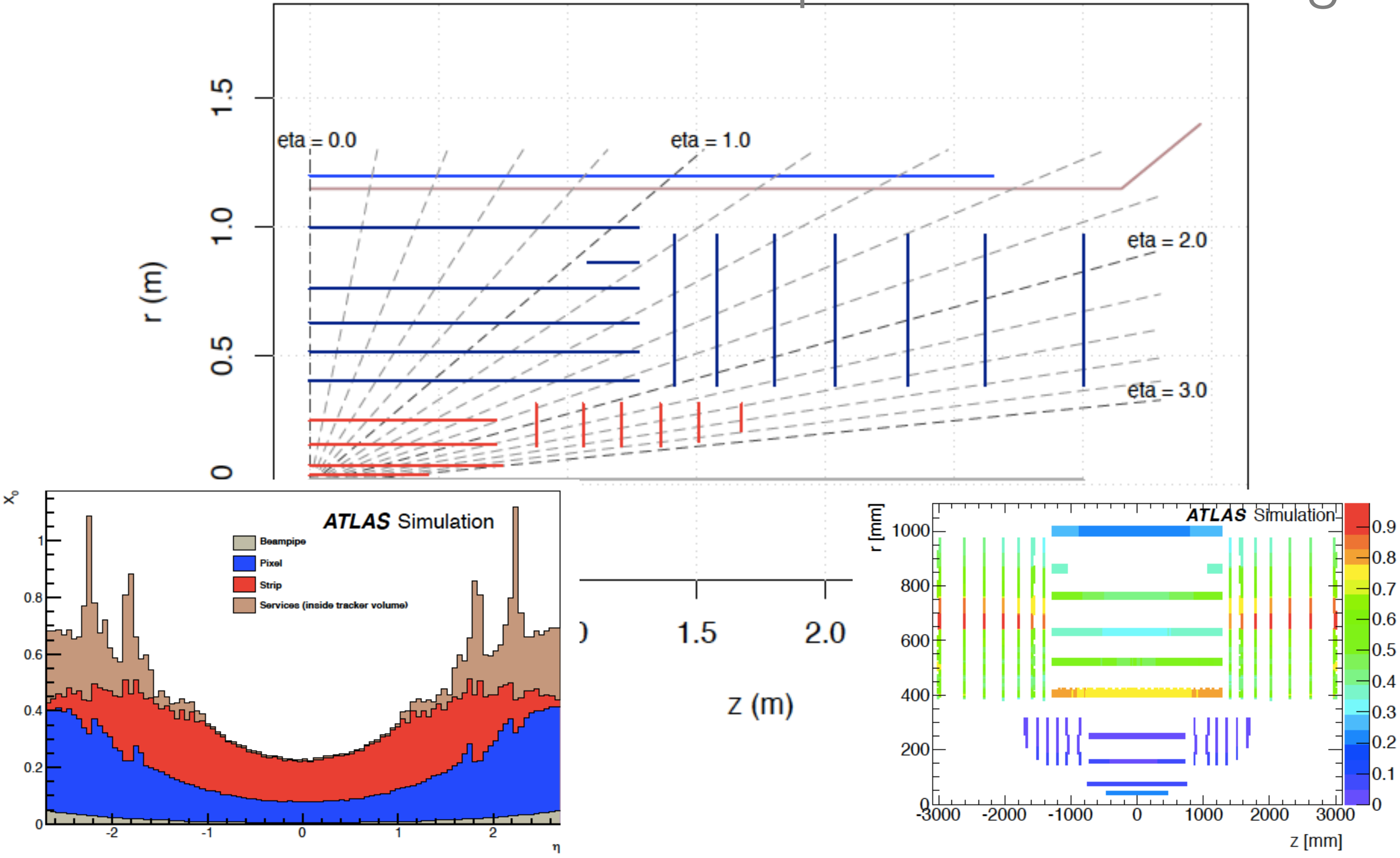
Phase II ATLAS Inner Tracker



Phase II ATLAS Inner Tracker

Increased Granularity => sub % occupancy

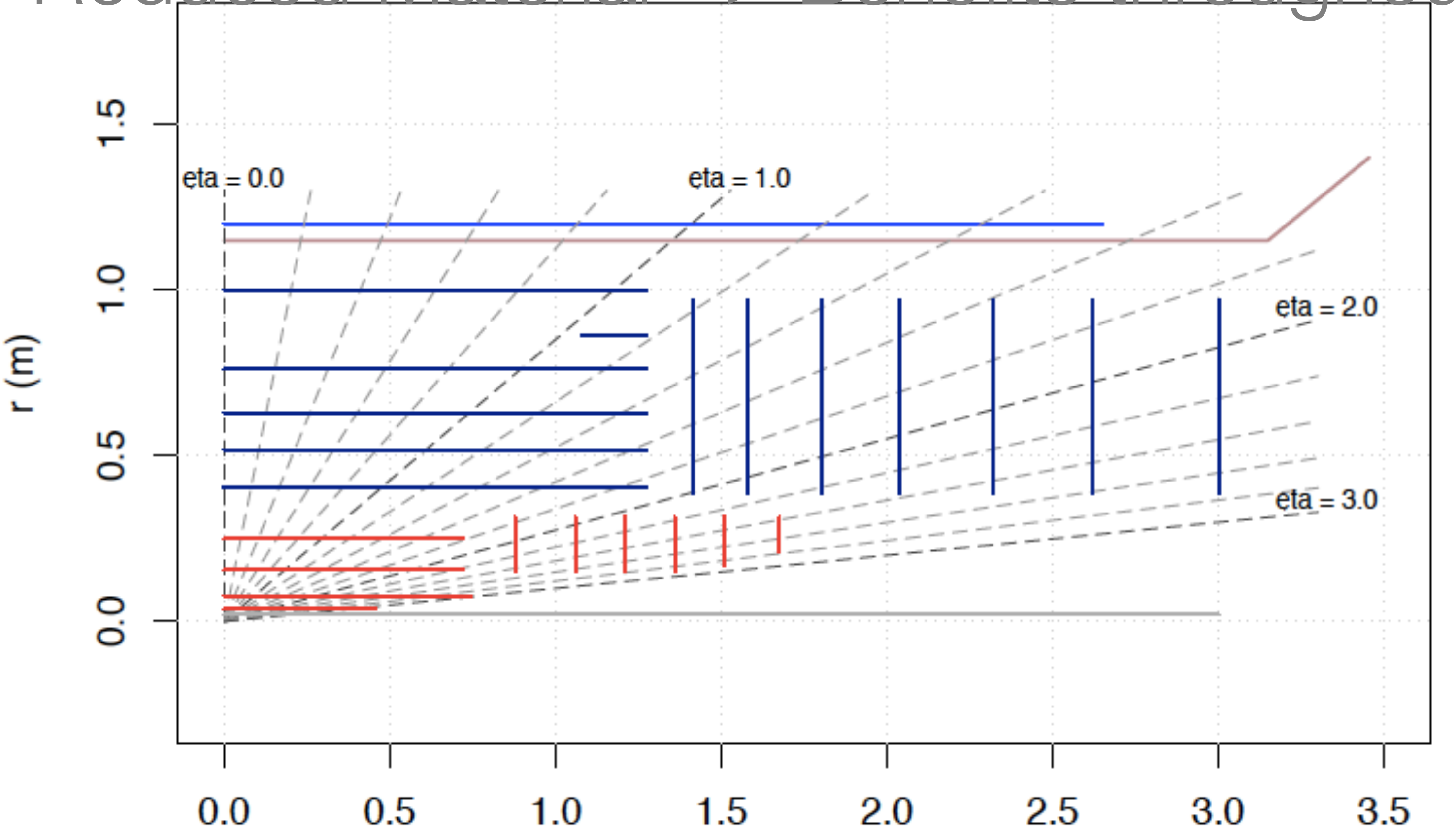
Reduced Material => Benefits performance throughout



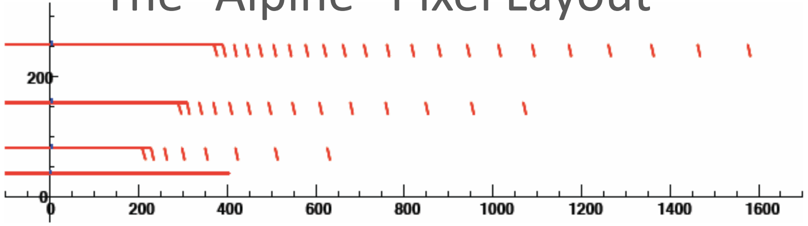
Phase II ATLAS Inner Tracker

Increased Granularity => sub % occupancy

Reduced Material => Benefits throughout



The “Alpine” Pixel Layout



Pixels may provide extende

Tracking Coverage

Different Geometries under study

Phase II CMS Trigger Upgrades

Phase II CMS Trigger Upgrades

- A key goal of the CMS HL-LHC upgrade program is to maintain the acceptances of the key leptonic, photonic, and hadronic trigger objects such that the overall physics acceptance, especially for low-mass scale process like Higgs production, can be kept similar to the one in 2012.

- Two key focus points to accomplish this physics goal
  - The first one is the addition of a L1 Tracking Trigger for identification of tracks associated with calorimeter and muon trigger objects at L1.
  - The second is to study the option of a significant increase of L1 rate (up to 1MHz), L1 latency (up to 20us) and HLT output rate

Phase II CMS Tracking Trigger

- Objective:
  - Reconstruct "all" tracks above 2 ÷ 2.5 GeV
  - Identify origin along beam axis with ~ 1 mm precision
- Tracker modules provide both 40MHz "Level-1 data" and 100kHz "readout data"
  - The whole tracker sends out data at each BX
- Level-1 data require local rejection of low-pT tracks
  - Reduce bandwidth, and simplify track finding @ Level-1
  - Threshold of ~ 1÷2 GeV ⇒ data reduction of one order of magnitude or more

Phase II CMS Tracking Trigger

- Design modules with p_T discrimination: p_T modules
  - Correlate hits in two closely-spaced sensors to provide vector (stub) in transverse plane: angle is a measure of p_t
  - Exploit the strong magnetic field of CMS

- Level-1 “stubs” are processed in the back-end
  - Form Level-1 tracks, p_T above 2÷2.5 GeV
  - To be used to improve different trigger channels

Phase II End-Cap & Forward Upgrades

Long Term Performance Concerns

- End-Cap & FWD Calorimeters will all suffer substantial performance degradation, due to radiation damage
    - In each subsystem this has a strong η dependence, and is most pronounced toward the inner edge of the coverage

- Take as input Dose Maps for $3ab^{-1}$ target integrated luminosity to estimate expected detector performance degradation

- Convolute with target sustained luminosity & pile-up to estimate physics performance
    - Does it meet the physics requirements?

Long Term Performance Concerns

- ATLAS is considering installation of new Mini-FCAL in front of current Lar FCAL, if needed

- For CMS the present understanding is that replacement of EE, HE and FE will likely be required
  - Scope of Upgrade to be defined
  - Various Options under Study

ATLAS Mini-FCAL

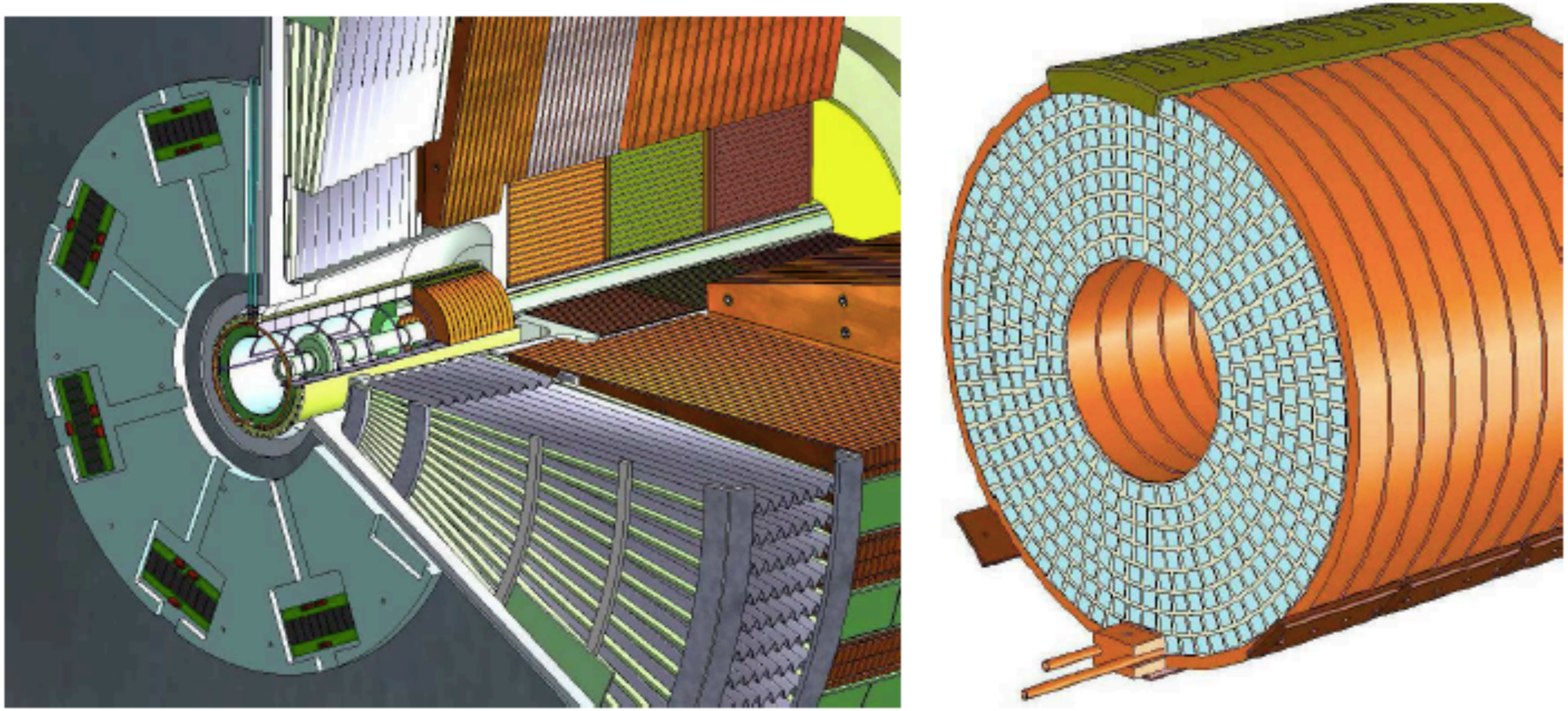
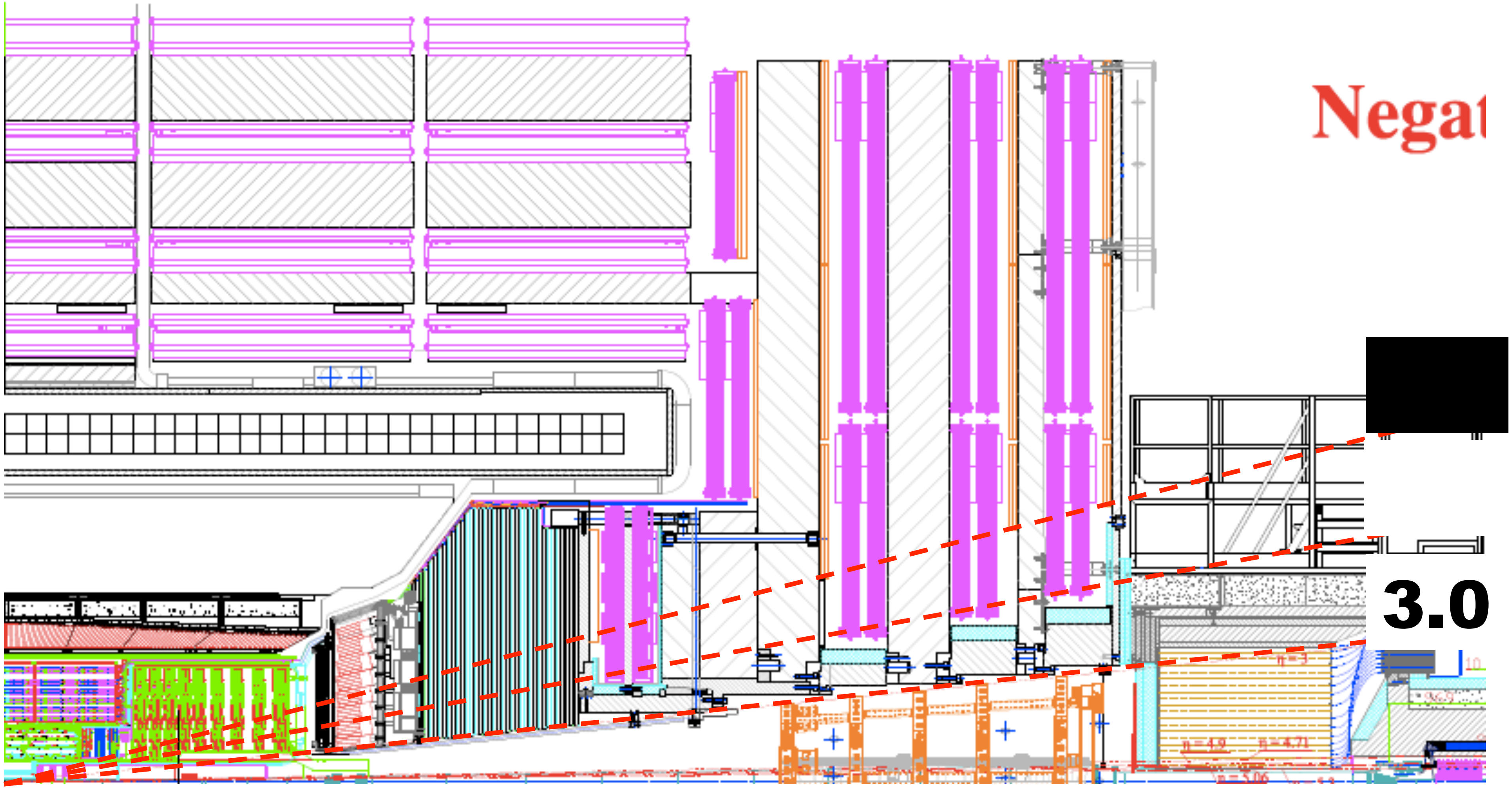


Figure 10.2. Baseline layout of Mini-FCal. The left hand illustration is an overview of the Mini-FCal showing the surrounding detectors and cryostat with part of the beam pipe still in place. Five of the preamplifier boards can be seen on the front face of the LAr cryostat. The right hand diagram shows the Mini-FCal in detail with the first absorber removed so that the diamond detector layer can be seen. The cooling pipes are visible at the bottom.

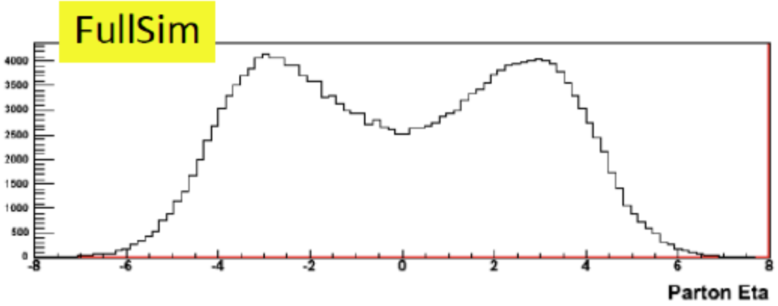
Phase II CMS Options for End-Cap & Forward Upgrades

CMS ¼ View



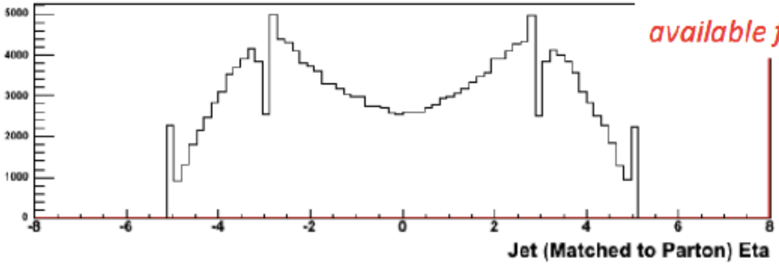
[redacted]

Taking a Fresh Look at the FWD Region



VBF Higgs production with H→γγ (no PU)

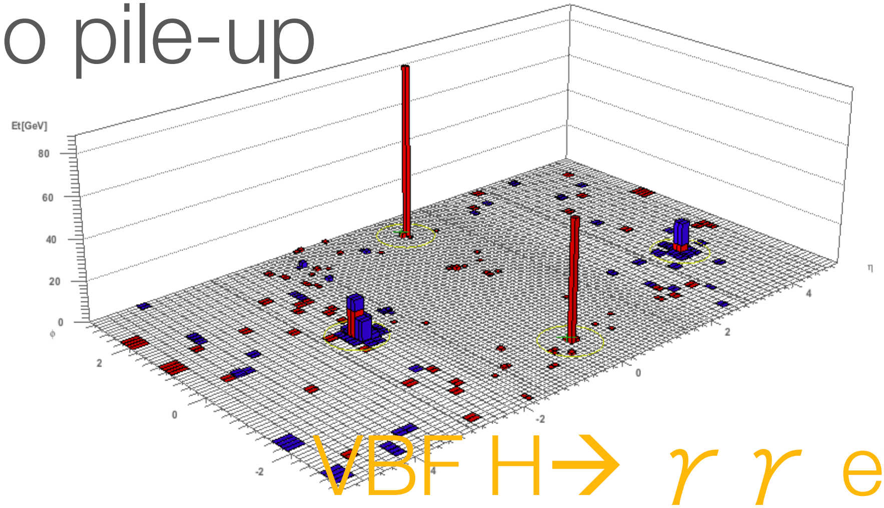
Looked at PFlow jets that were matched to the parton

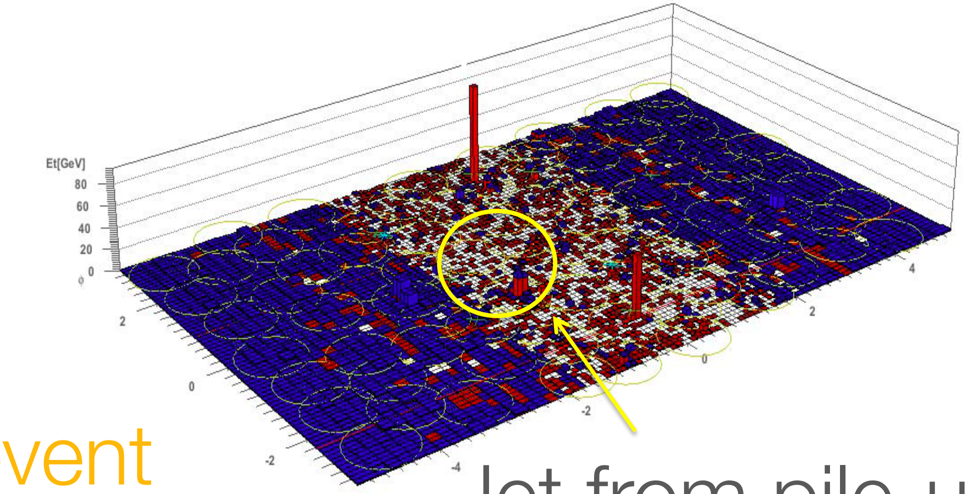


No tracking information available for forward jets

Clearly see the effect of the transition between the Endcap and HF

No pile-up





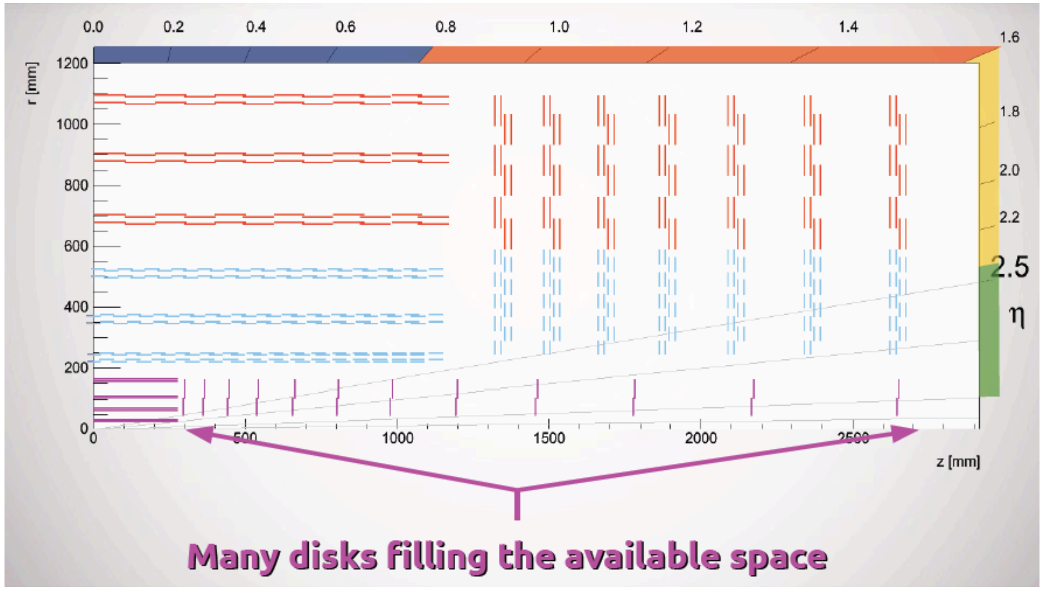
VBF H→ γγ event

Jet from pile-up

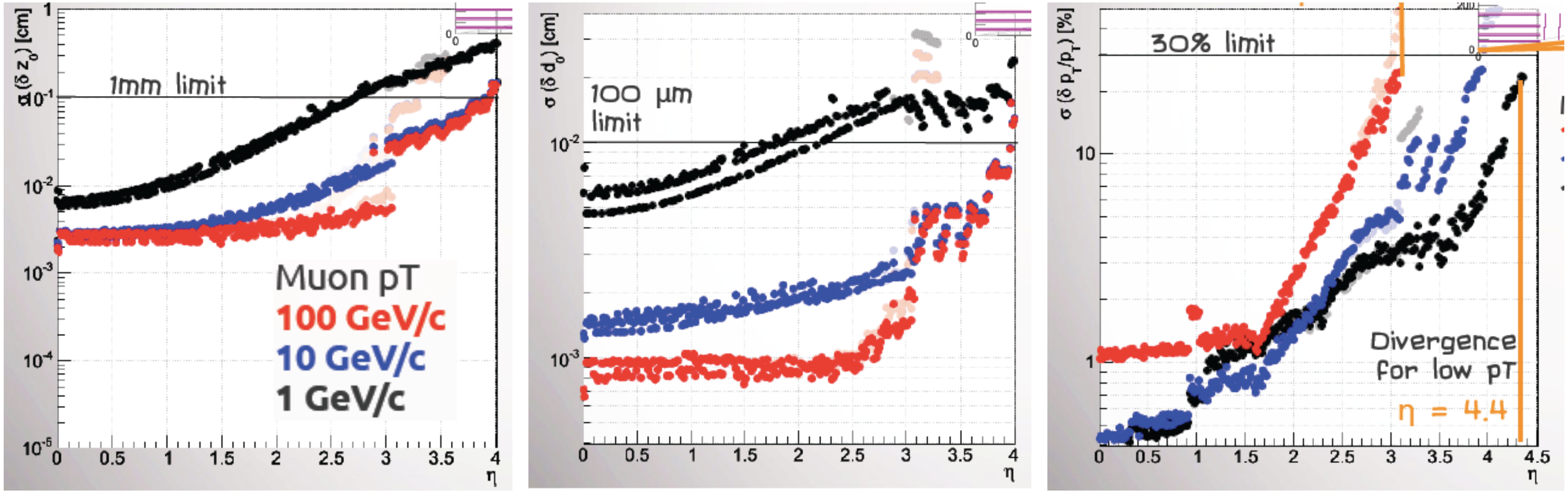
Taking a Fresh Look at the FWD Region

- Consider extension of Tracking coverage to higher values of η
  - Mainly motivated by FWD Jet Tagging for VBF & $W_L W_L$ scattering, which peak a η~3
    - Provide Particle Flow reconstruction / pile-up mitigation for VBF Jets
  - May be done “adiabatically”, mainly by extending Forward Pixel Discs
  - May allow extension of e, γ and μ coverage
    - consider this from Calo & Muon system stand-point

Extended Tracker Coverage



Many disks filling the available space



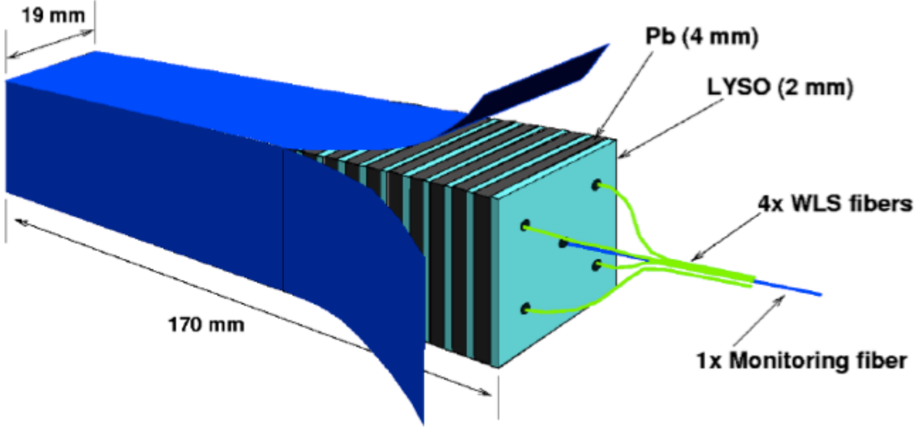
End-Cap & FWD Calorimeters

Options for Possible Calorimeter Replacements

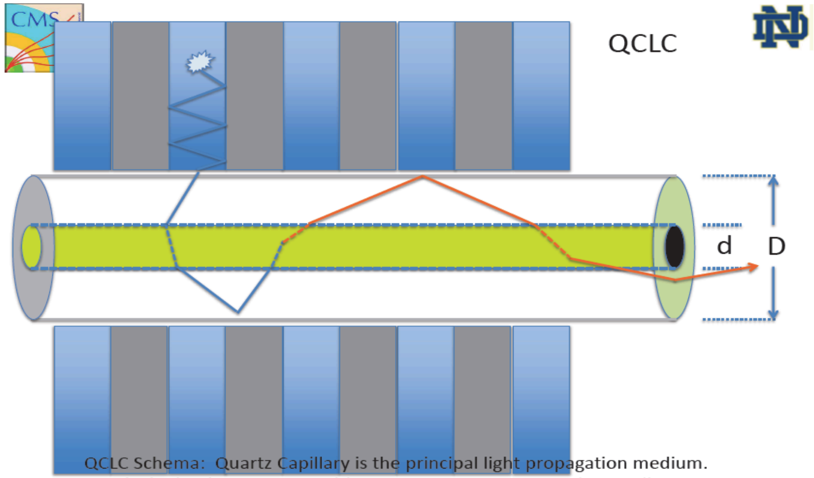
- **EE:** Study Resolution Requirements, evaluate Shashlik option + others
- **HE:** Keep existing absorber, replace scintillator plates with higher granularity ones
- **HF:** Replace with similar or more compact detector inside plug
- Other options include:
  - An integrated EE/HE calorimeter?
  - Extending End-Cap Calorimeters from present $\eta = 3$ to $\eta = 4$?

CMS End-Cap Calorimeter

Lyso plates - tungsten absorber - WLS in quartz tube



EE Shashlik Strawman & Simulation



QCLC Schema: Quartz Capillary is the principal light propagation medium.
Core is the luminous source with some transparency over shorter distance.

Rad Hard by Design: minimize light path in Scintillator & WLS

Quartz Fiber is Rad Hard

- Major R&D effort, radiation and test beam studies
  - Sensitive material of the calorimeter: quartz, LYSO, ceramics, …
  - Fiber optics to transport the light: extruded rad hard crystals, liquids and quartz capillaries, ceramics

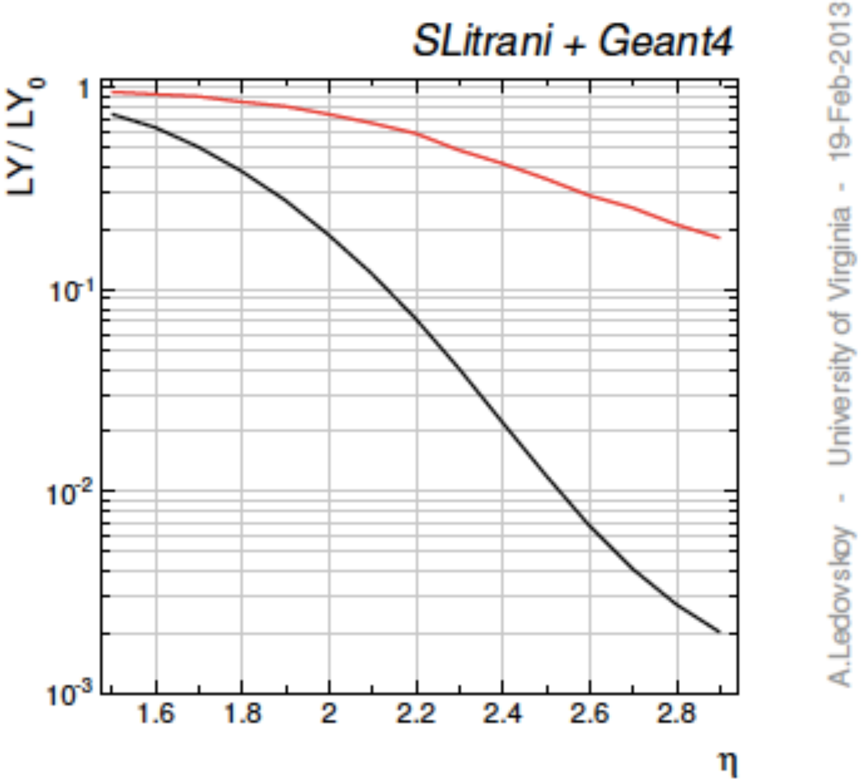
CMS End-Cap Calorimeter

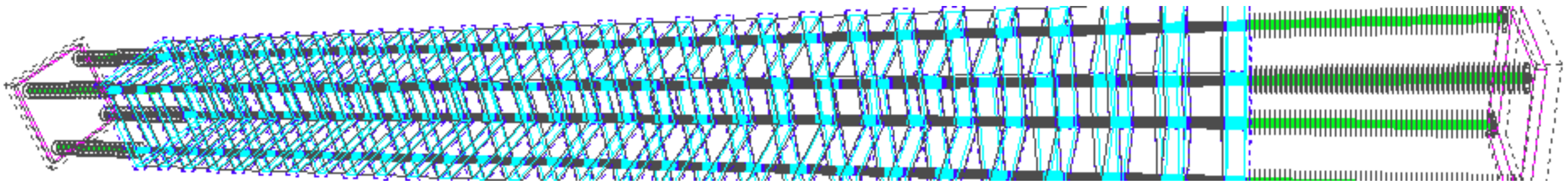
STRAWMAN ECAL = SHASHLIK

Advantage is in radiation resistance

Degradation in light output from
EM showers reaching
 VPT in current EE (black)
 Quartz fiber in Strawman (red)
after 3000 /fb

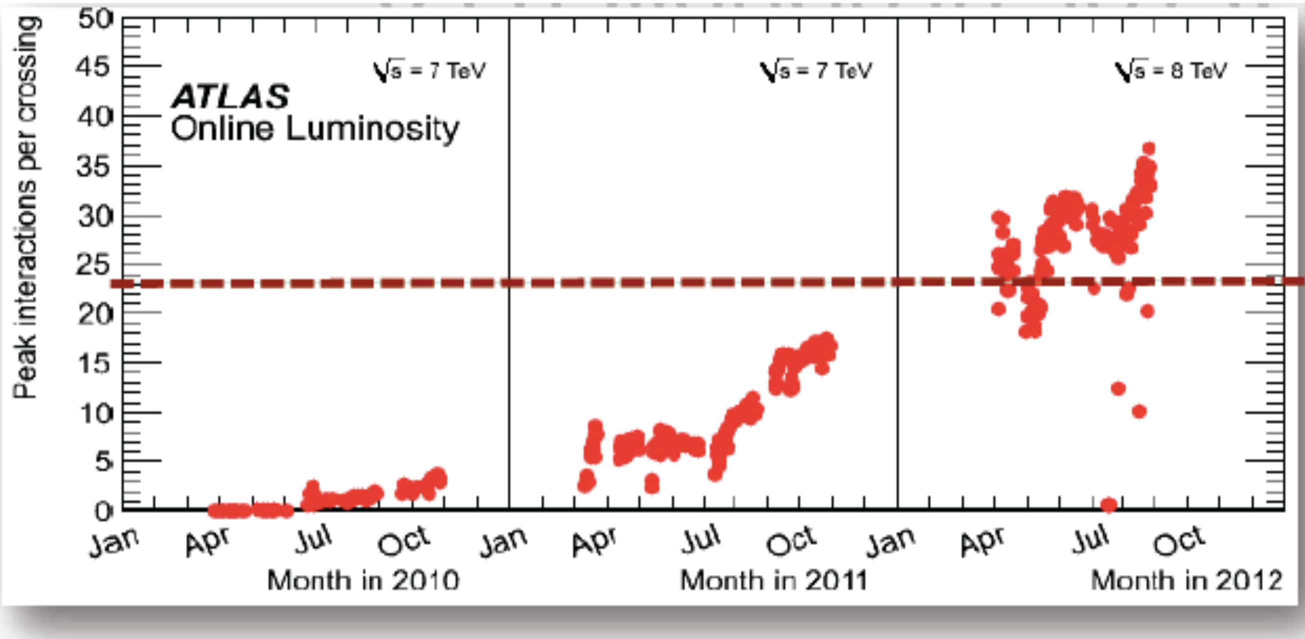
Additional loss of transparency in quartz fibers is not taken into accout for red line





Calorimeter TOF Pile-Up Mitigation

A Z->μμ event with 25 reconstructed PU Vtx



~Design value (L=10^{34}, 25ns)

Z→ μμ event from 2012 data with 25 reconstructed vertices

A Z->μμ event with 25 reconstructed PU Vtx

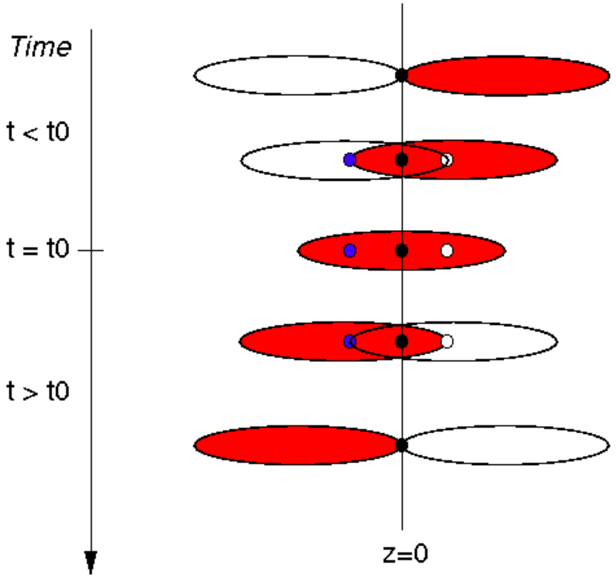
The Tracker can mitigate the effect of pile-up interactions for charged particles, but cannot help with neutrals

Will precision Calorimetry continue to be possible with 140~200 pile-up interactions?

Is there a useful way to mitigate Calorimeter pile-up?

Calorimeter TOF Pile-Up Mitigation

- Consider 10ps~20ps TOF calorimeter resolution for MIP's and γ, together with Tracker coverage



Collisions are distributed over
Several cm in Z, and a few 100ps in time

Calorimeter TOF Pile-Up Mitigation

- Consider 10ps~20ps TOF calorimeter resolution for MIP's and γ, together with Tracker coverage
  - Tracking identifies location Z_0 of interesting collision vertex
  - TOF of charged particles from that collision identifies time t_0 of interesting collision
  - Use Z location and time to select calorimeter clusters associated to Z_0 & t_0 of interesting collision
  - For H -> γγ use timing of γ's to produce reduced list of possibly compatible vertices, then select best match with similar criteria as for present analysis
- Could result in similar effective pile-up conditions as in 2011~2012
  - Neutral hadrons will need special attention

Calorimeter TOF Pile-Up Mitigation

- An EM Pre-shower detector is (one) possible Straw-Man for Calorimeter TOF

- An EM pre-shower could be deployed in the Barrel, in front of the existing EB
  - Where it may be required to reduce number H->$\gamma\gamma$ candidate vertices
- As well as in the End-Cap and FWD regions
  - Where it may be most useful for filtering out pile-up clusters

  - In addition to pile-up mitigation, an EM pre-shower might also give improved π^0 rejection, as well as pointing (resolution in the barrel), which may reduce backgrounds and further aid H -> $\gamma\gamma$ vertex reconstruction: to be verified…