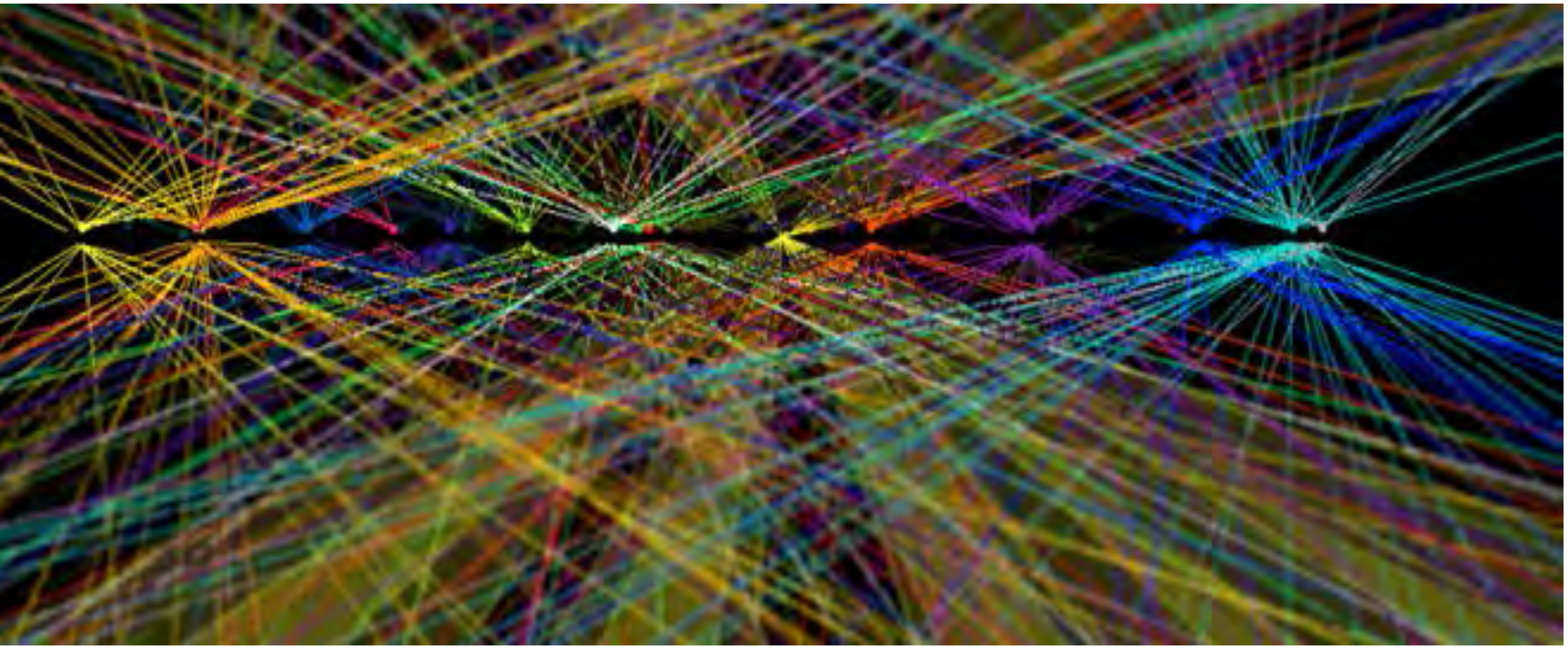
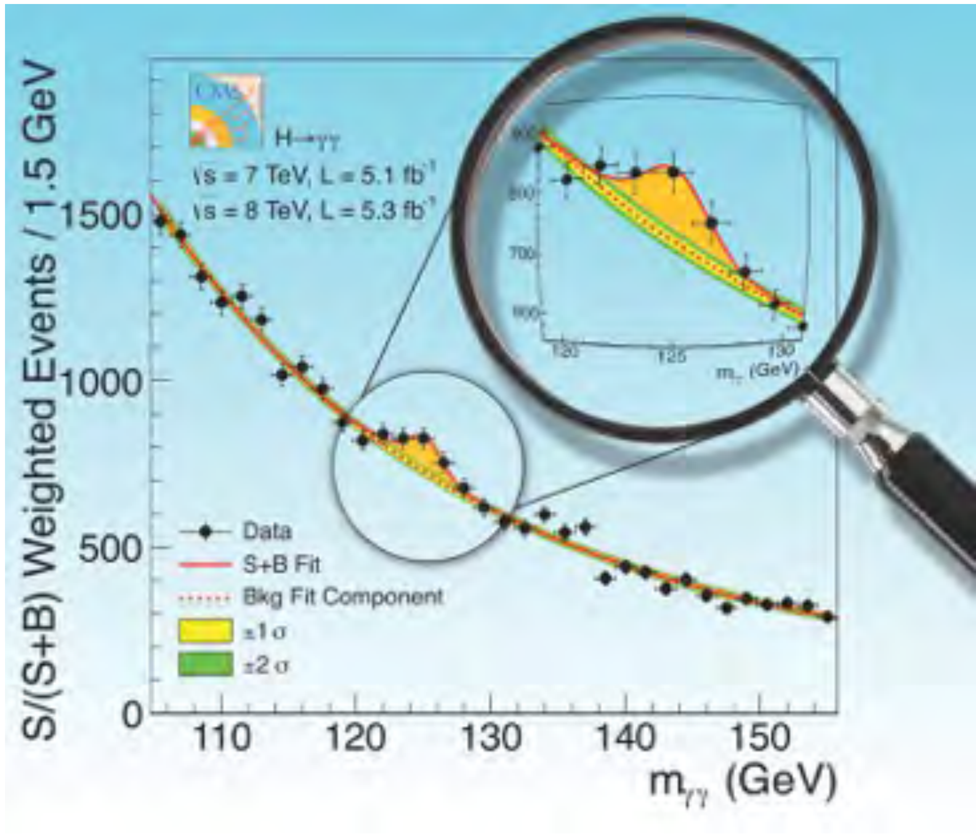
# Status of CMS & ATLAS

Aaron Dominguez, University of Nebraska
HEPAP, December 8-9, 2014





# LHC Program

- The first run of the LHC has been a tremendous success for ATLAS and CMS
- The USA is a crucial partner in both experiments
- This great success of the LHC program has also brought very good public attention to our field
- These new discoveries have shed some light, but we’re in a fertile era of questions:
    - Why is the Higgs light? Where is dark matter? Does the Higgs have anything to do with dark energy? Where is SUSY? What can rare b-decays tell us? Are there more exotic things? (Gravity?) More structure in quark-gluon plasma?
- USCMS and USATLAS are well positioned to face these questions, now and in the future — this is the excitement and centrality of the LHC program

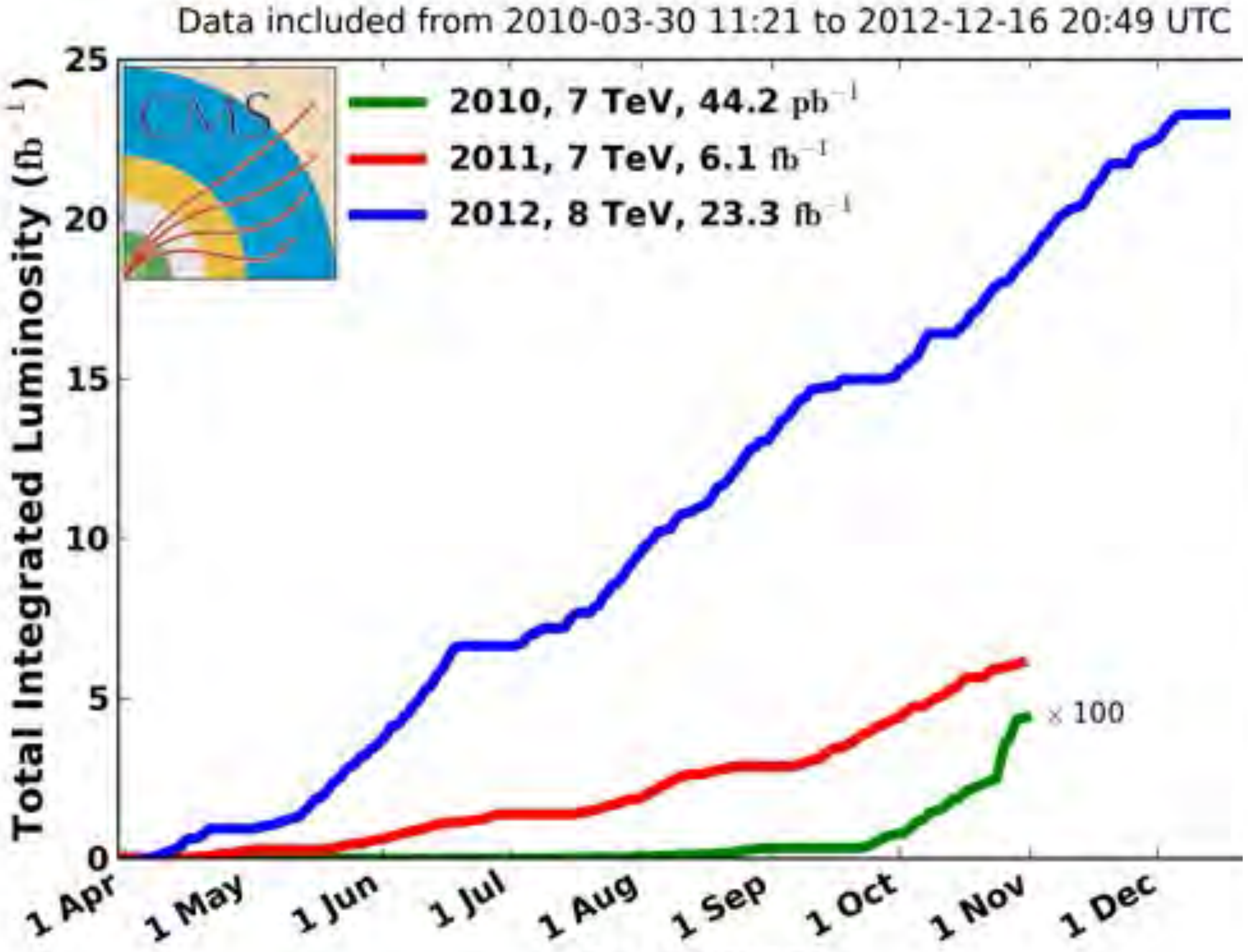
# USCMS & USATLAS

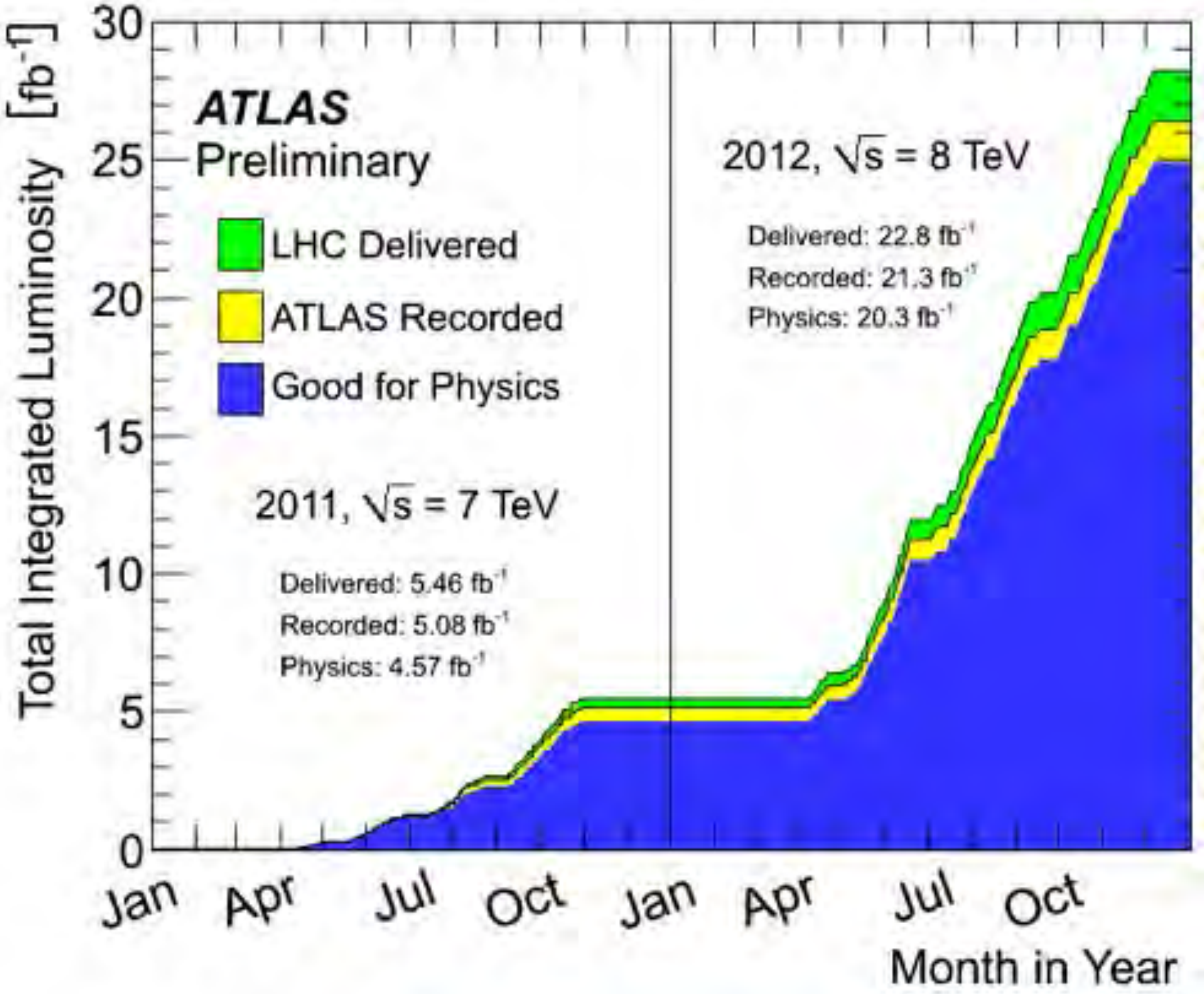
| | | |
|---|---|---|
| 🟥 | CMS | 49 universities, national 1 lab |
| 🟦 | ATLAS | 31 universities, national 3 labs |

# RUN 1

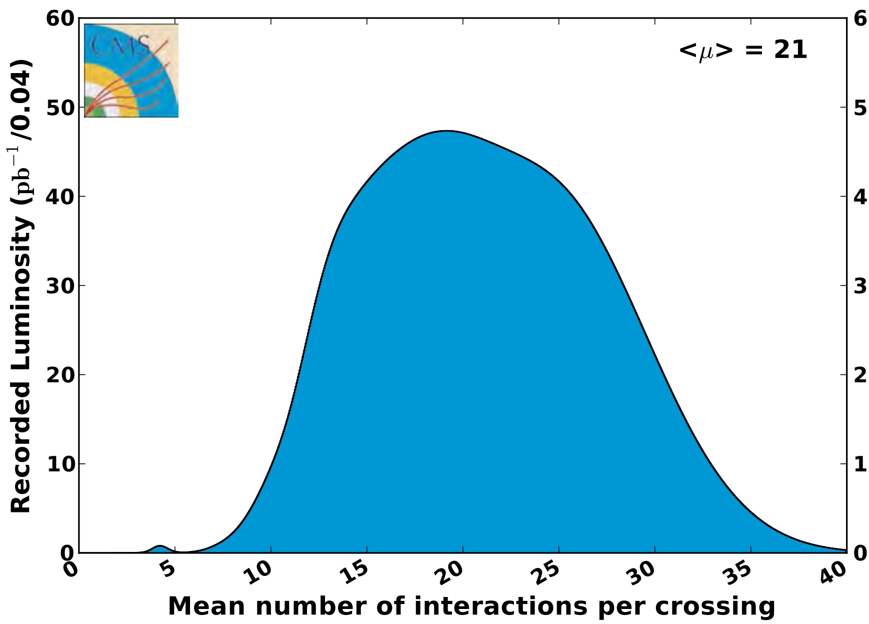
# Proton-Proton Program

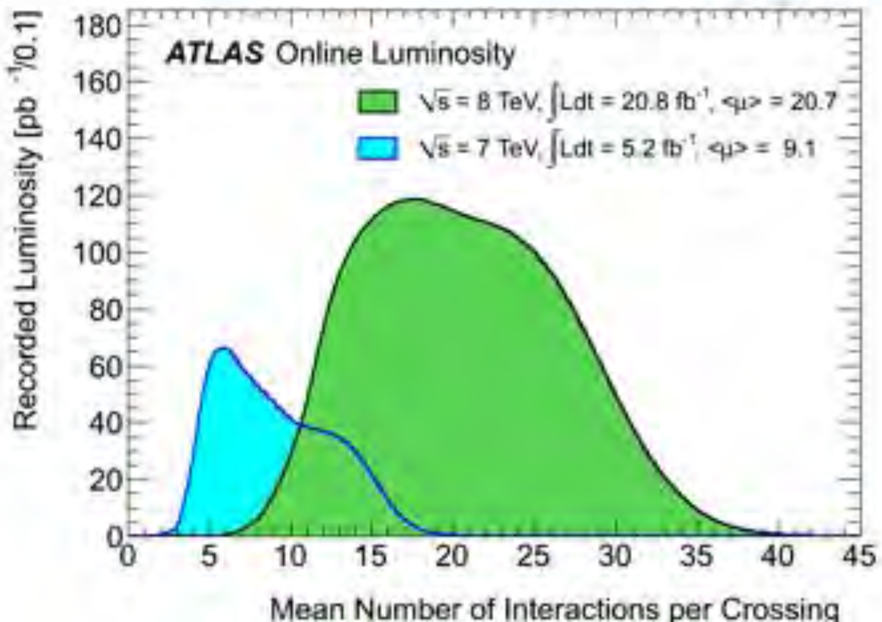
CMS Integrated Luminosity, pp



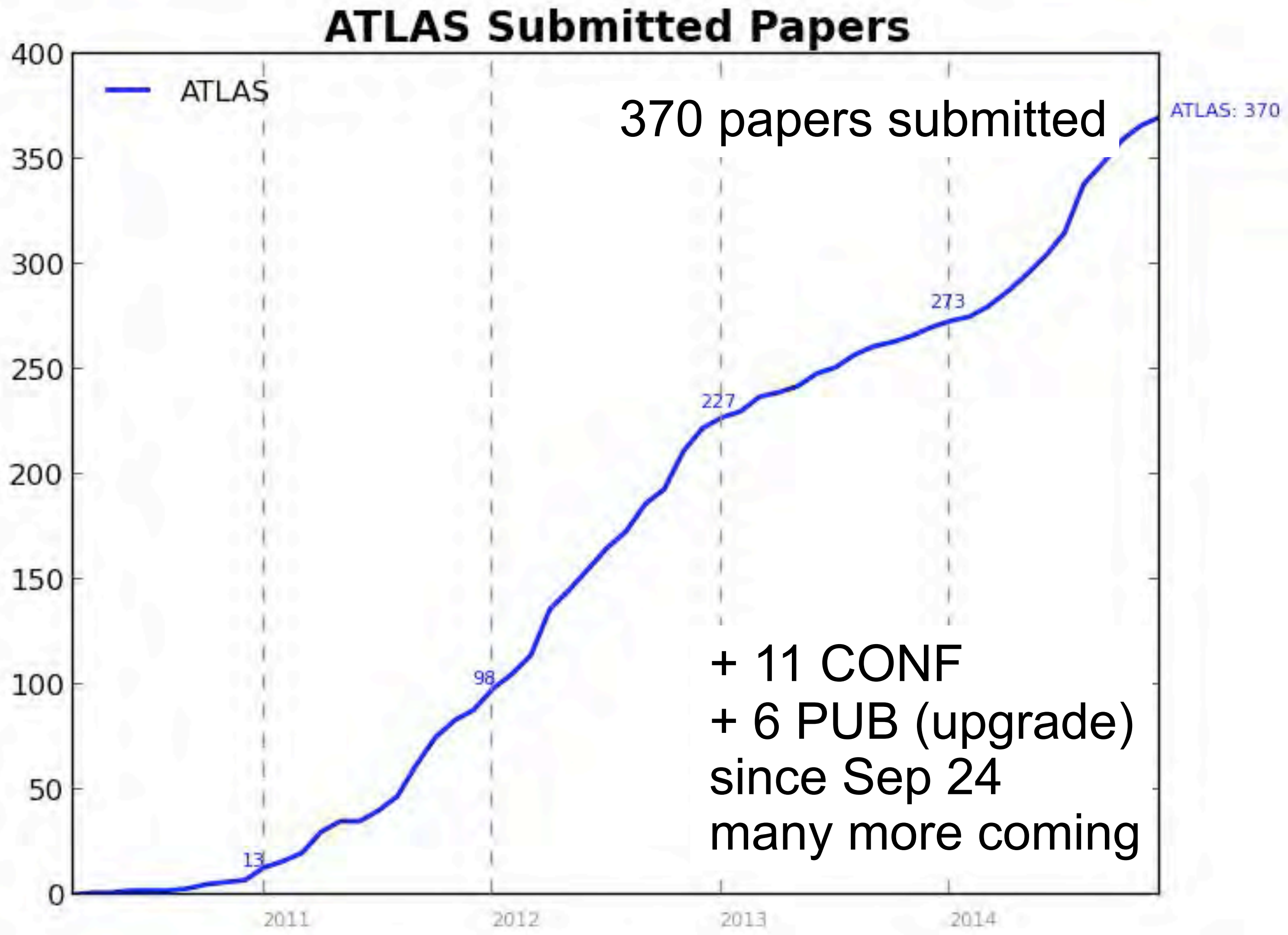


CMS Average Pileup, pp, 2012, $\sqrt{s} = 8$ TeV



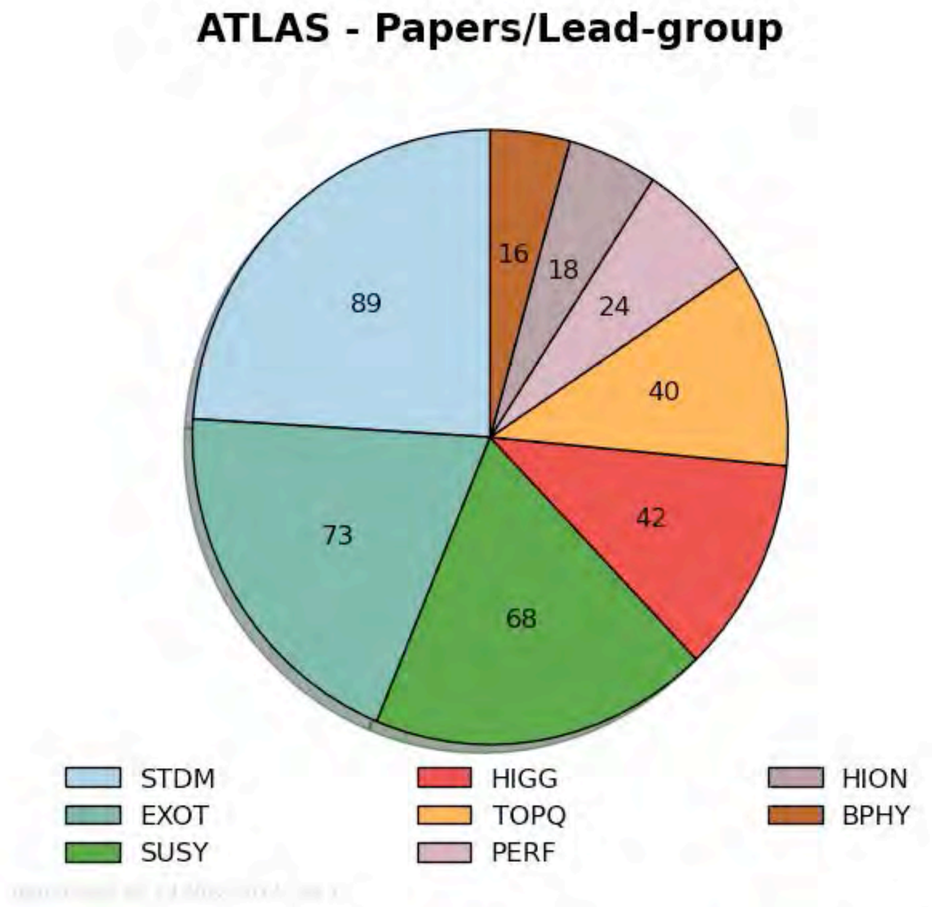


# Publication status



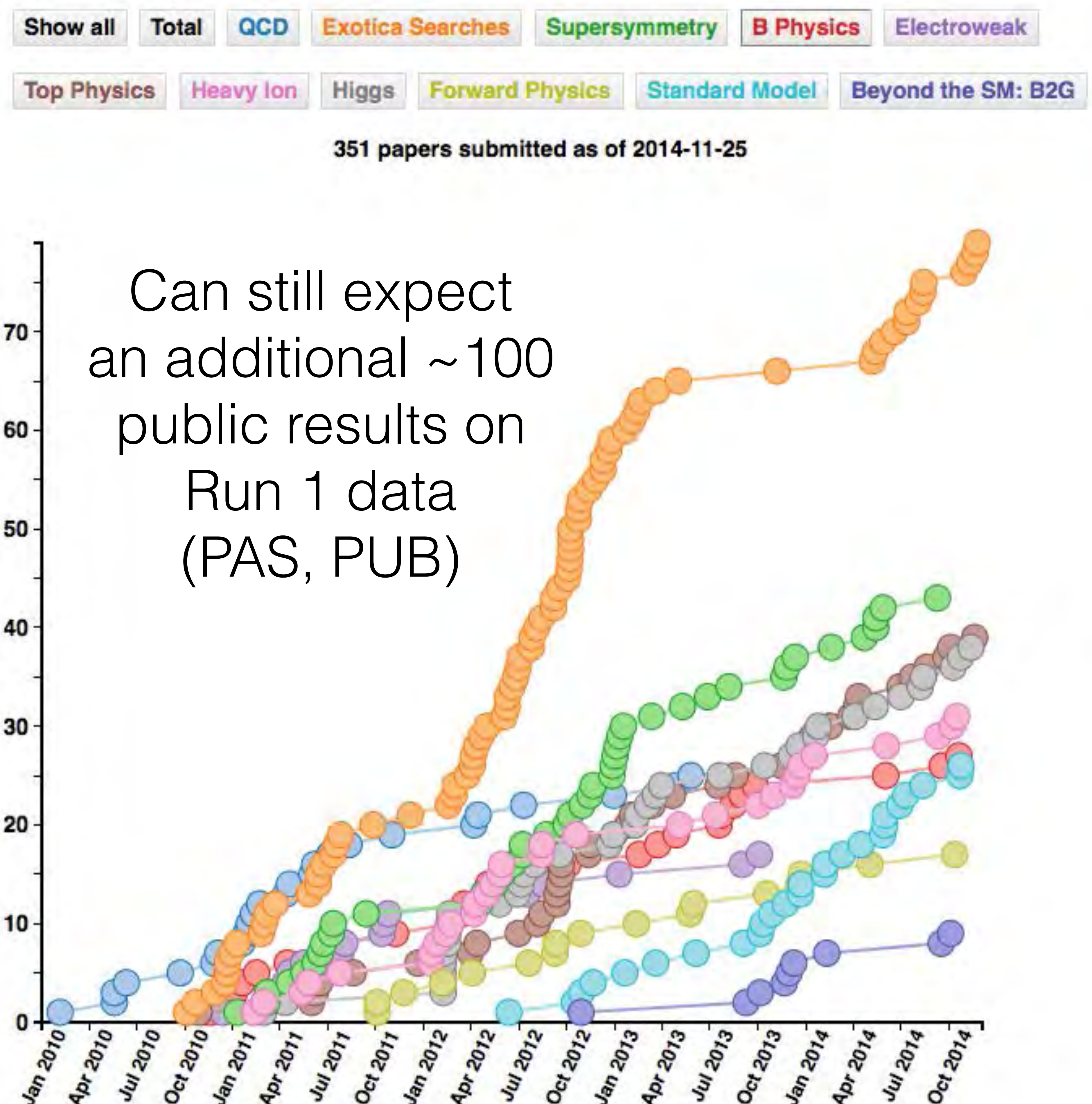
370 papers submitted

+ 11 CONF
+ 6 PUB (upgrade)
since Sep 24
many more coming



Few highlights on next slides

# CMS Publications



351 papers submitted as of 2014-11-25

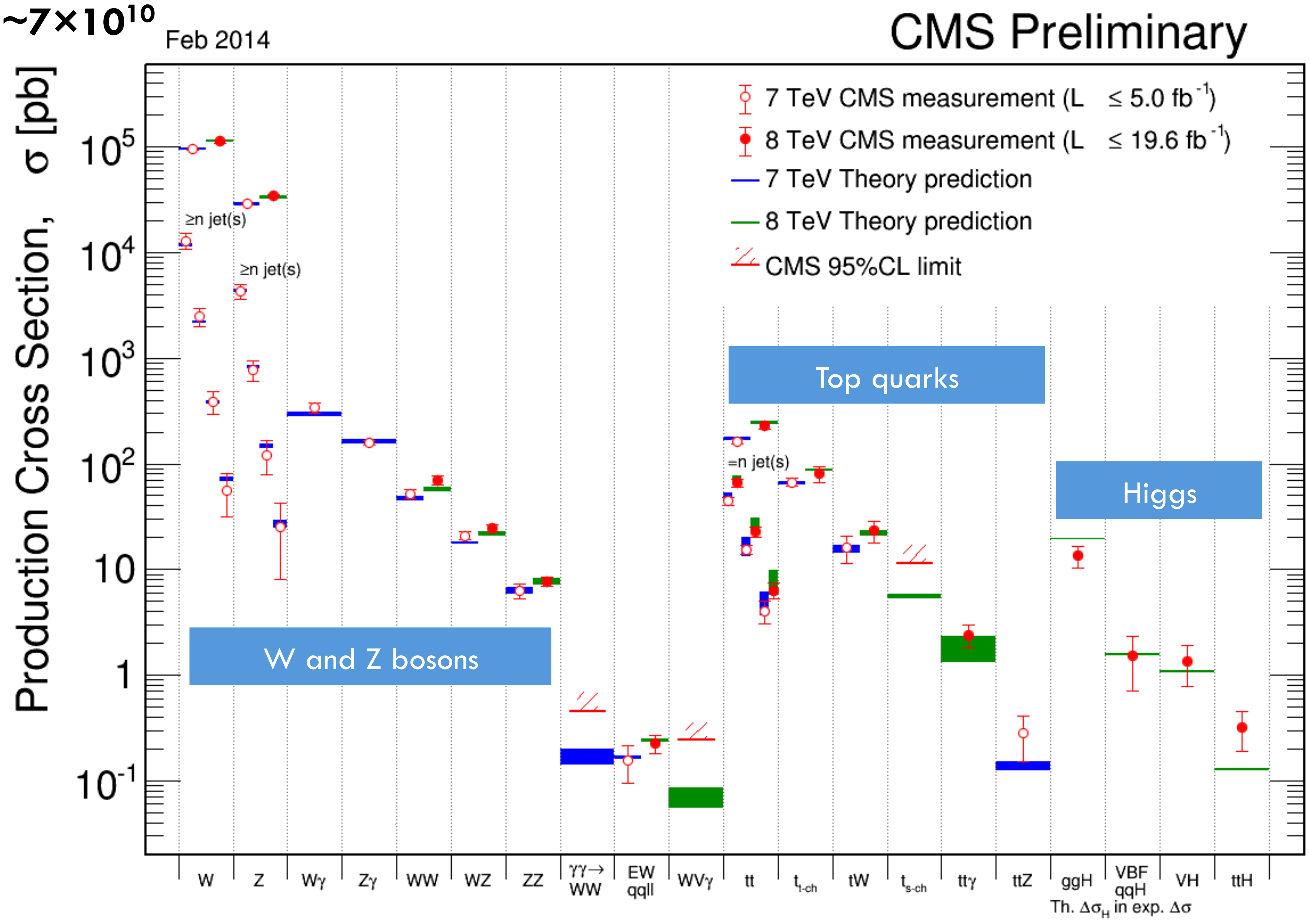
Can still expect
an additional ~100
public results on
Run 1 data
(PAS, PUB)

# On the shoulders of giants: detector makers & theory calculators

**"Yesterday's discovery is today's calibration, and tomorrow's background." – V. L. Telegdi** [http://cern.ch/go/If9C] [http://cern.ch/go/KD8D]

***Inelastic collisions: ~7×$10^{10}$***

**Six orders of magnitude** of EWK, top, and Higgs Physics



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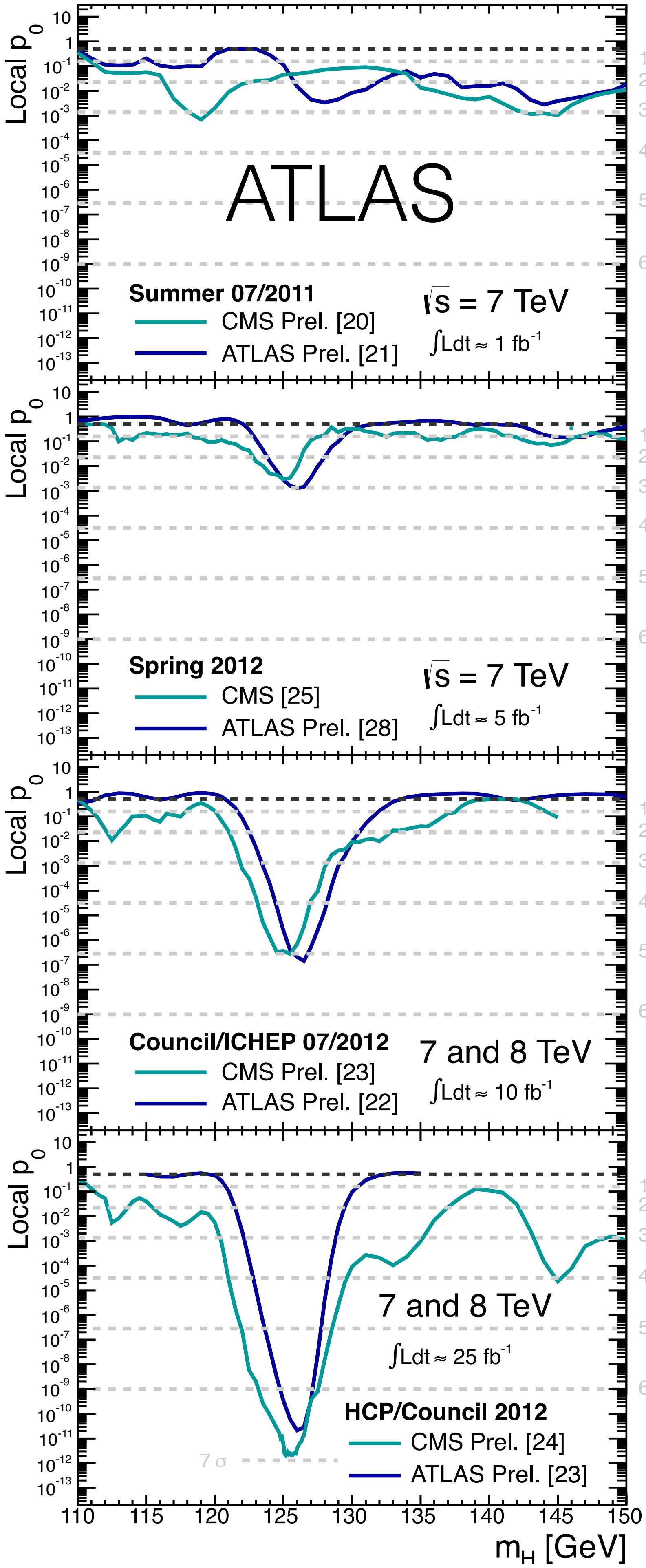
PDG, review of Particle Physics



# A Textbook and Timely Discovery

- Summer 2011: EPS and Lepton-Photon

  First (and last) focus on limits (scrutiny of the $p_0$)

- December 2011: CERN Council

  First hints

- Summer 2012: CERN Council and ICHEP

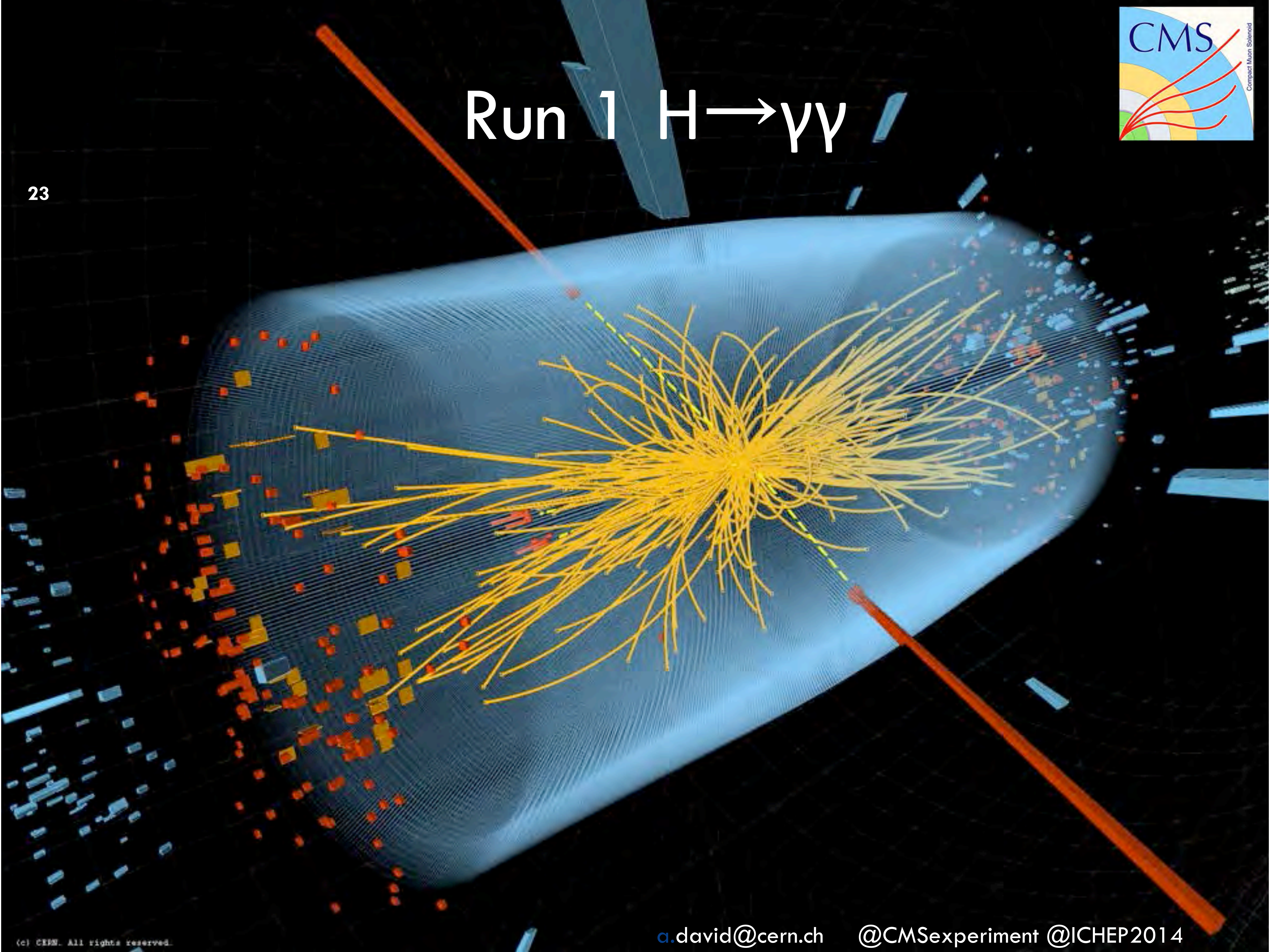
  Discovery!

- December 2012: CERN Council

  Begining of a new era

(Marumi Kado, ICHEP14)

# Run 1 H→γγ



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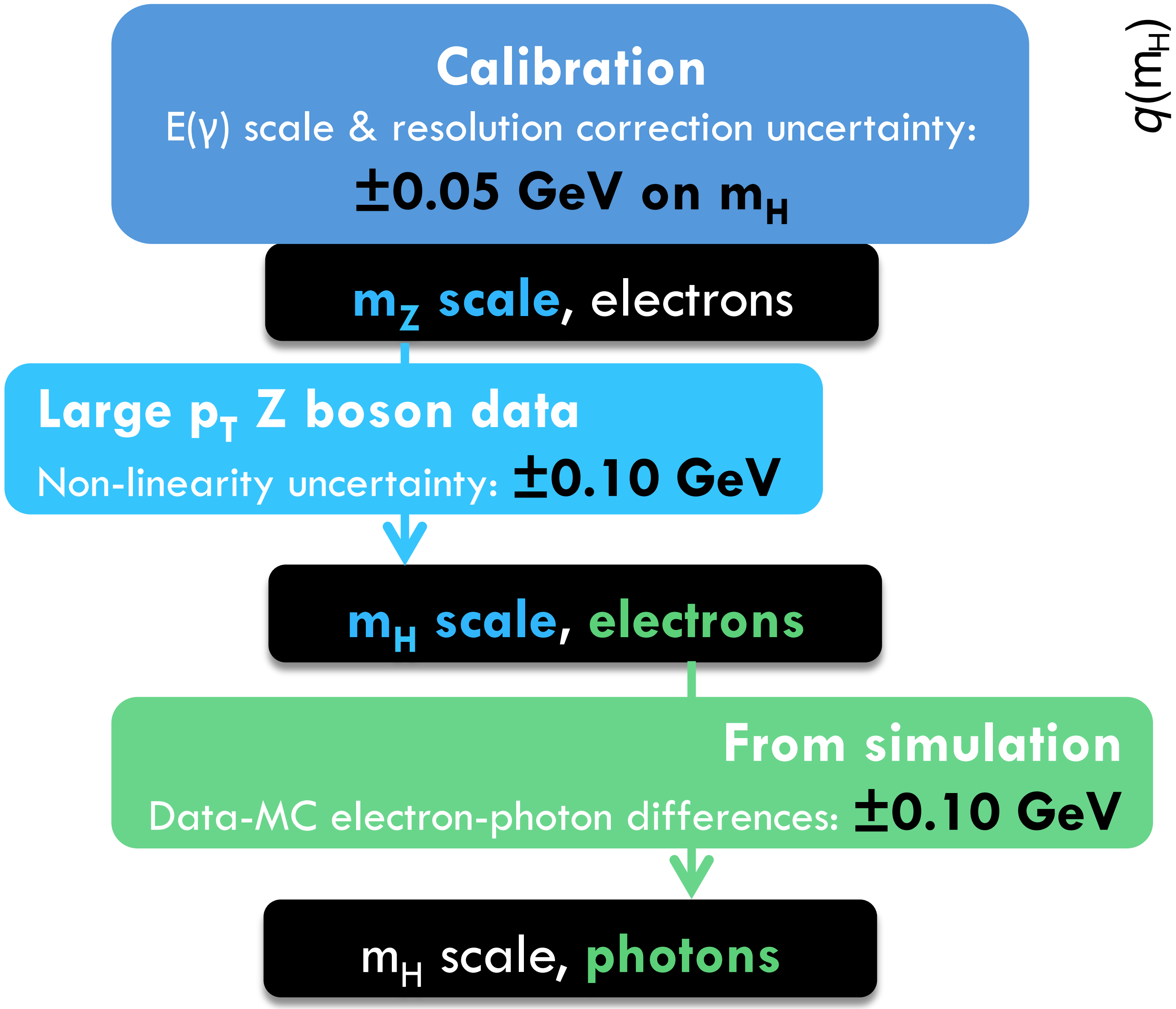
# H⟶ γγ mass measurement

[arXiv:1407.0558, submitted to EPJC]

$$\mathrm{m_H} = 124.70^{+0.35}_{-0.34}\ [\pm 0.31(\mathrm{stat.}) \pm 0.15(\mathrm{syst.})]\ \mathrm{GeV}$$



**Calibration**

E(γ) scale & resolution correction uncertainty:

**±0.05 GeV on $m_H$**

**$m_Z$ scale**, electrons

**Large $p_T$ Z boson data**

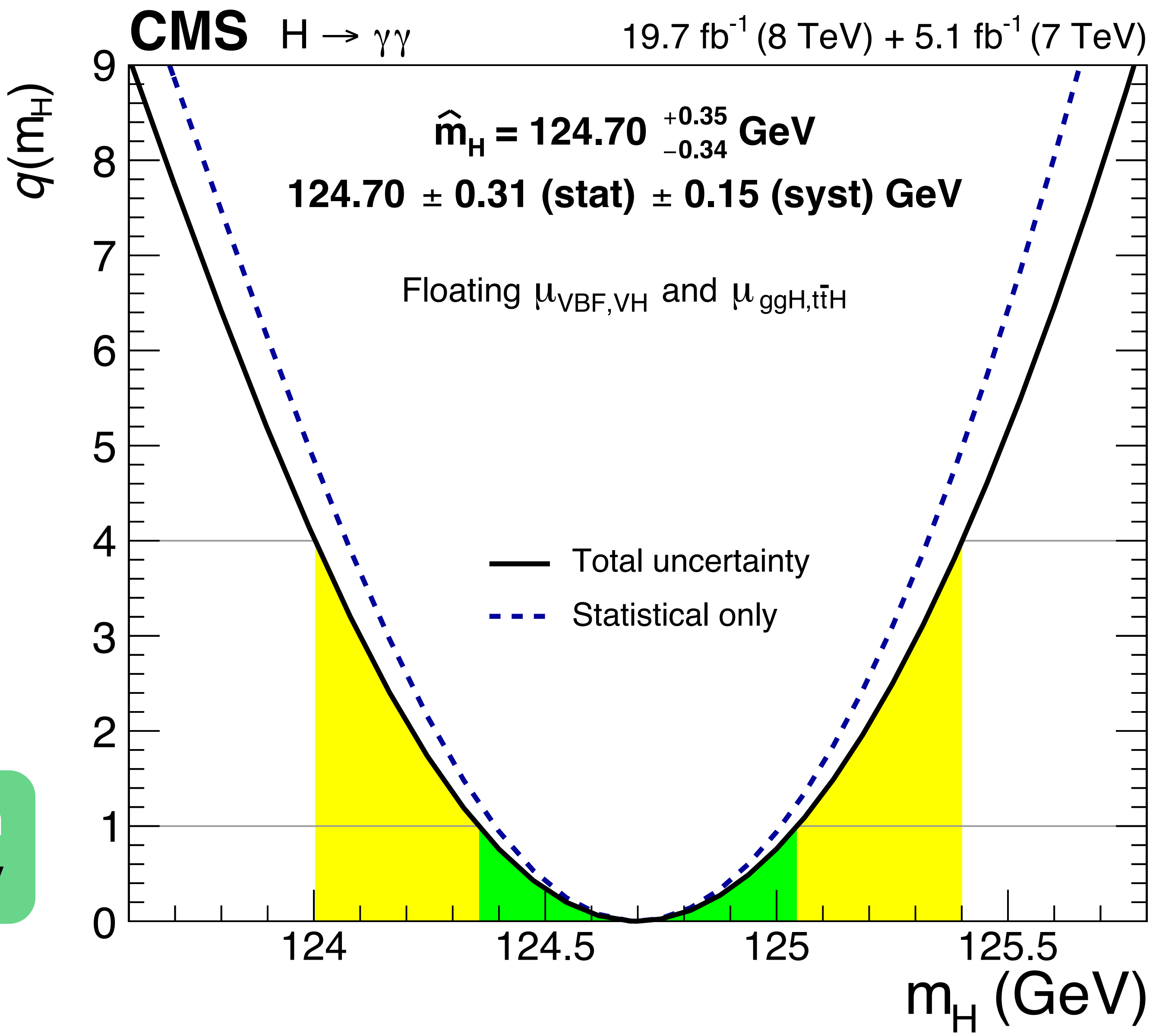
Non-linearity uncertainty: **±0.10 GeV**

**$m_H$ scale, electrons**

**From simulation**

Data-MC electron-photon differences: **±0.10 GeV**

$m_H$ scale, **photons**

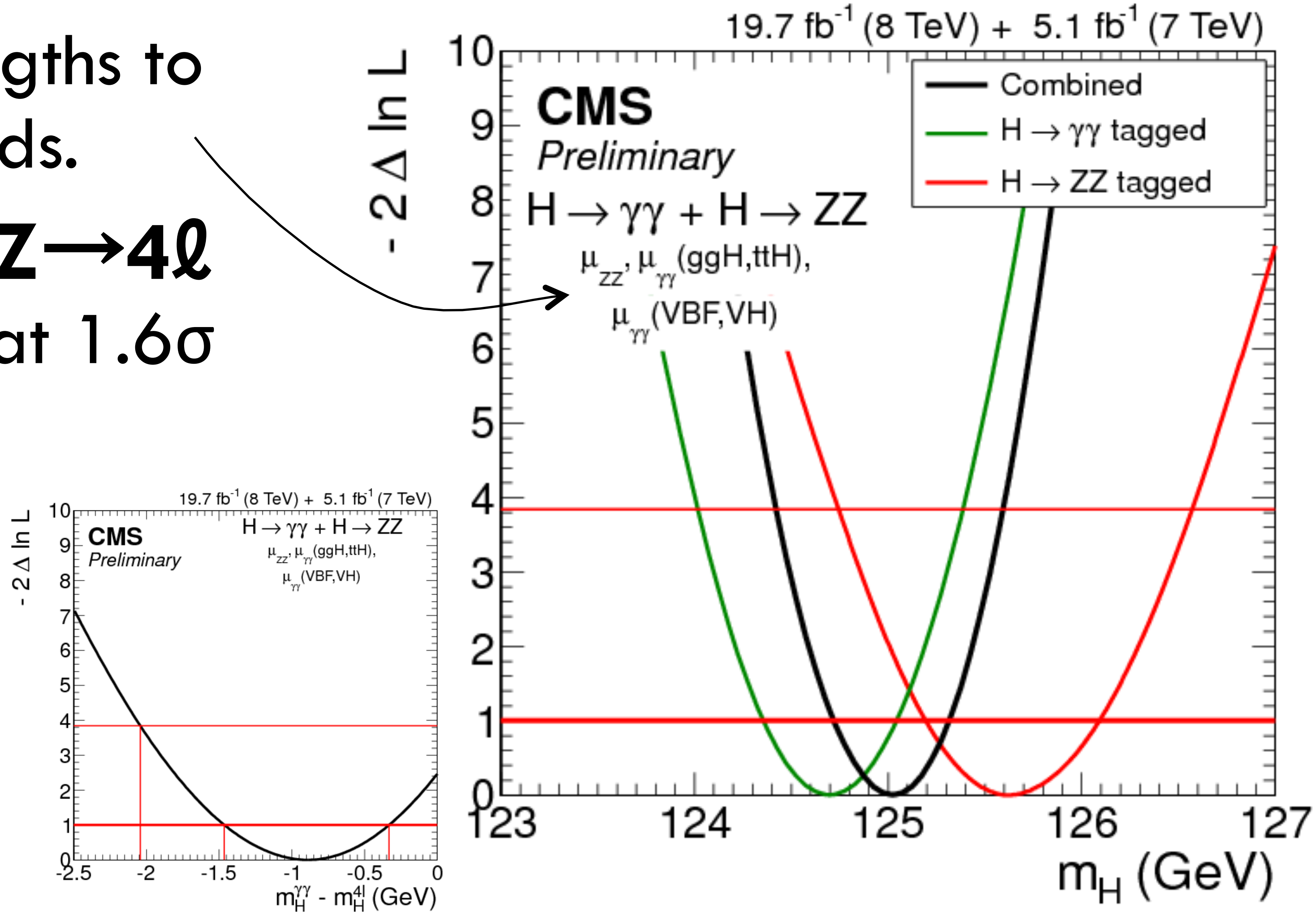


# Combined mass measurement

[CMS-PAS-HIG-14-009]

$$m_H = 125.03 \pm 0.30 \left[ {}^{+0.26}_{-0.27}(\text{stat.}) {}^{+0.13}_{-0.15}(\text{syst.}) \right] \text{GeV}$$

- ☐ Float 3 signal strengths to not depend on yields.
- ☐ **H→γγ and H→ZZ→4ℓ** results compatible at 1.6σ level.

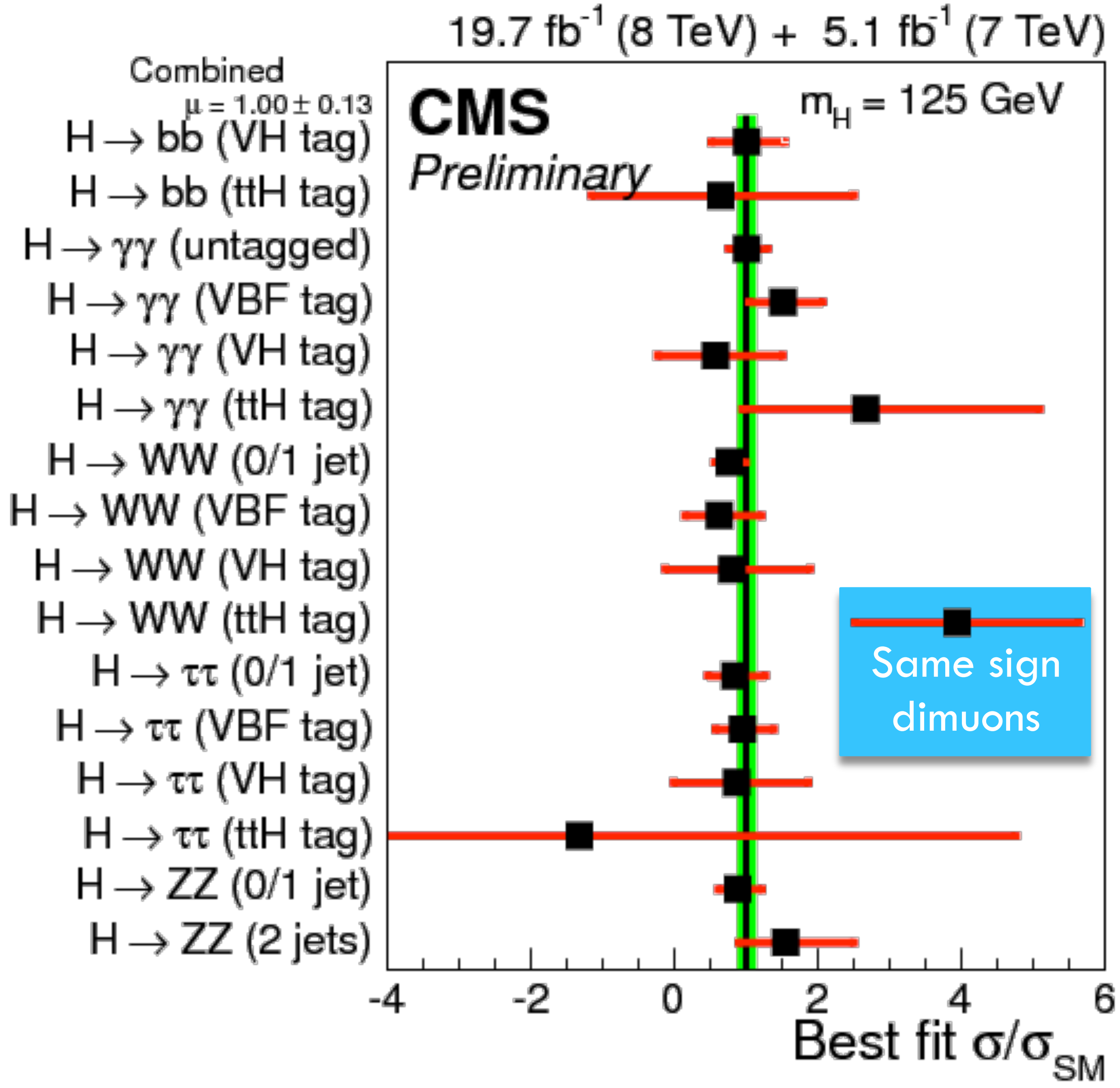


# Signal strength

[CMS-PAS-HIG-14-009]

$$\sigma/\sigma_{\rm SM} = 1.00 \pm 0.13 \ \left[\pm 0.09({\rm stat.})^{+0.08}_{-0.07}({\rm theo.}) \pm 0.07({\rm syst.})\right]$$

- Grouped by production tag and dominant decay:
  - $\chi^2/\text{dof} = 10.5/16$
  - p-value = 0.84 (asymptotic)
- ttH-tagged 2.0σ above SM.
  - **Driven by one channel.**



Same sign dimuons

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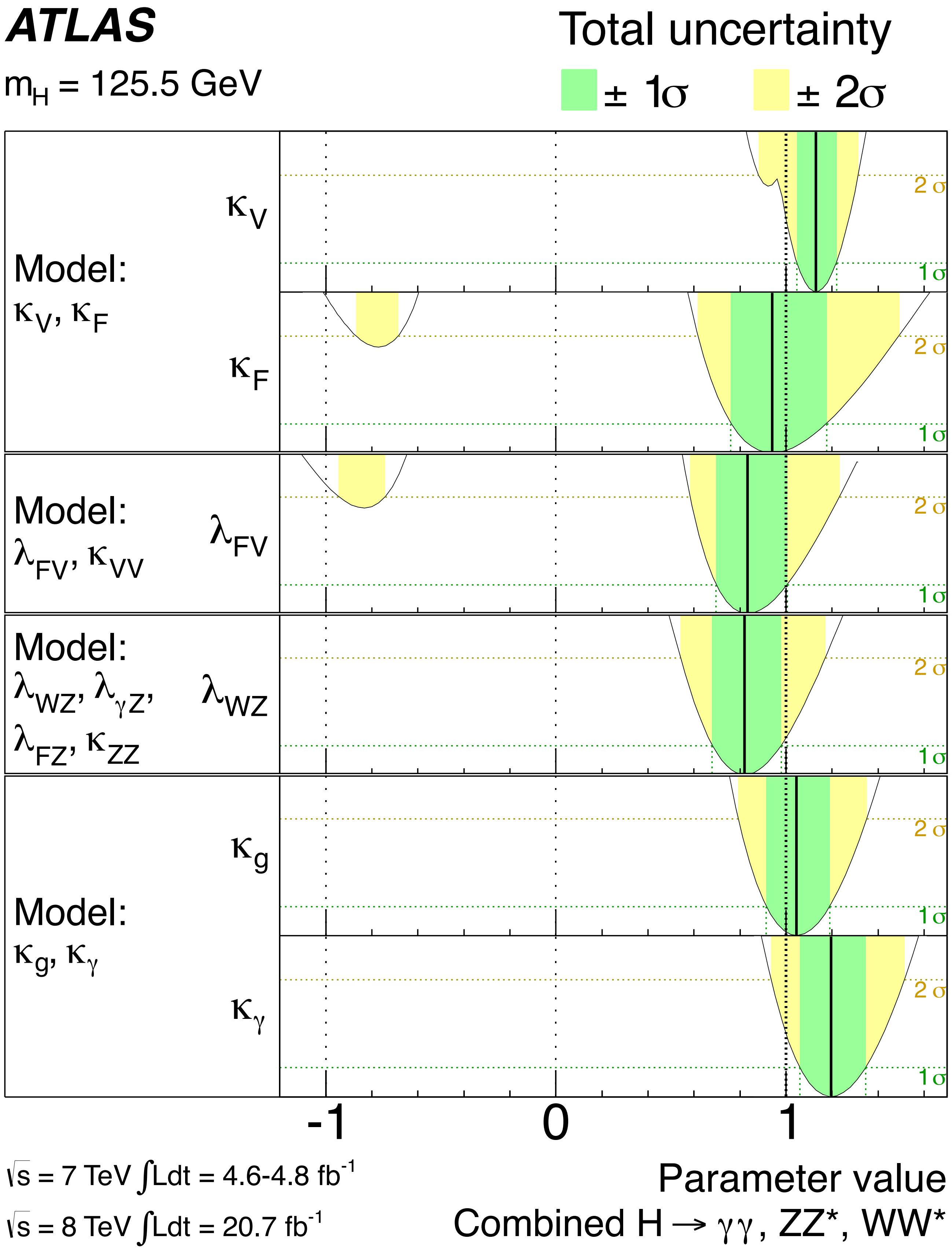


Summary of the measurements of the coupling scale fac- tors for a Higgs boson with mass mH =125.5 GeV. The best fit values are represented by the solid vertical lines, with the ±1σ and ±2σ uncertainties given by the dark- and light-shaded band, respectively. For a more complete illustration, the distributions of the likelihood ratios from which the total uncertainties are extracted are overlaid. The measurements in the various benchmark models, separated by double horizontal lines, are strongly correlated. Phys. Lett. B 726 (2013), pp. 88-119

# Landscape Redefined

## Expansion of the Higgs Physics Program!

### Precision

- Mass and width
- Coupling properties
- Quantum numbers (Spin, CP)
- Differential cross sections
- Off Shell couplings and width
- Interferometry

### Rare decays

- $Z\gamma$
- Muons $\mu\mu$
- LFV $\mu\tau$, $e\tau$
- $J/\Psi\gamma$, $Z\Upsilon$, etc…

$$H^0$$

### Tool for discovery

- Portal to DM (invisible Higgs)
- Portal to hidden sectors
- Portal to BSM physics with $H^0$ in the final state ($ZH^0$, $WH^0$, $H^0H^0$)

### Is the SM minimal?

- 2 HDM searches
- MSSM, NMSSM searches
- Doubly charged Higgs bosons

### …and More!

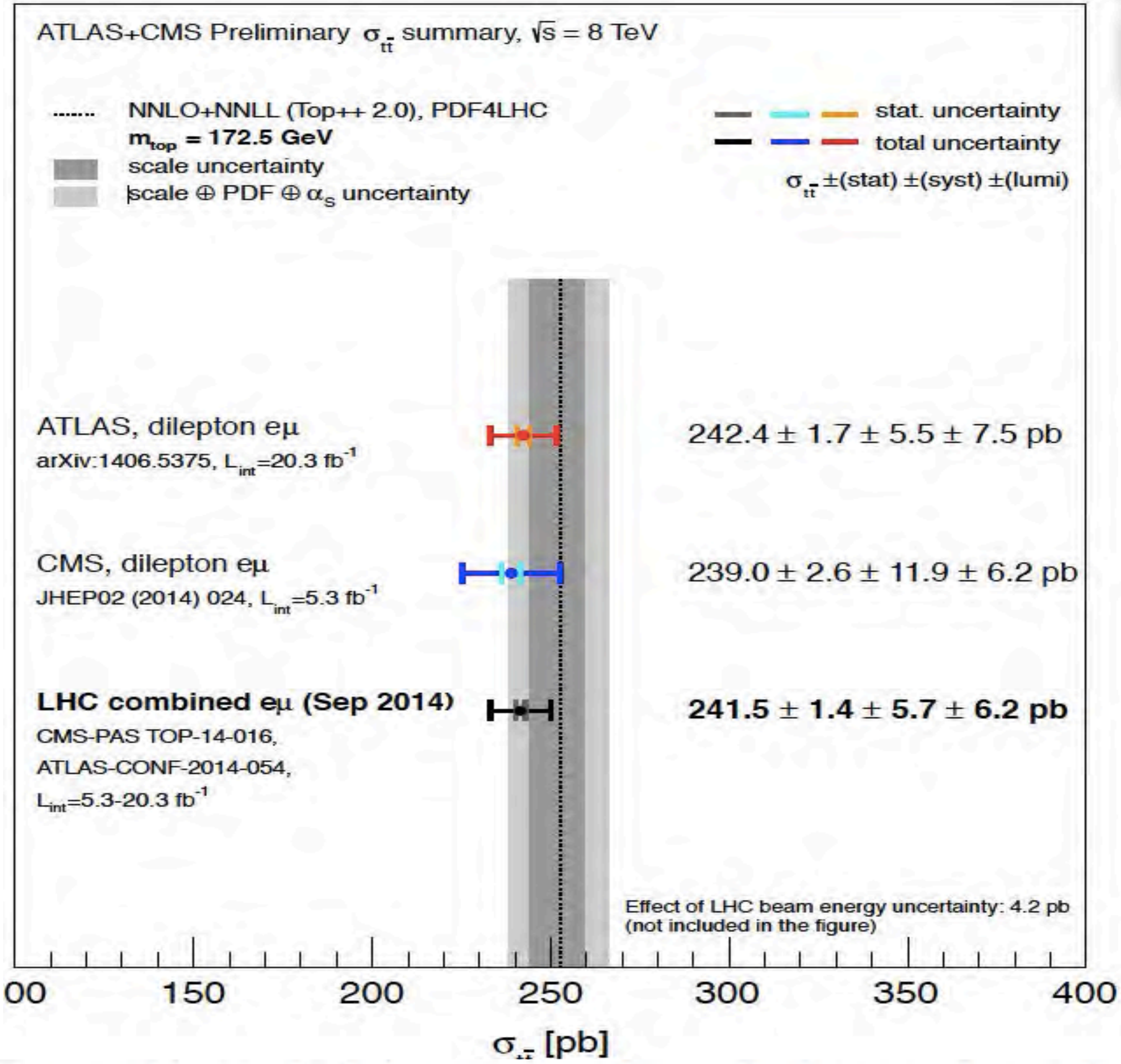
- FCNC top decays
- Di-Higgs production
- Trilinear couplings prospects
- Etc…

*(Marumi Kado, ICHEP14)

# ATLAS-CMS ttbar cross-section combination

(S. Goy)

- Study dilepton decay channel with exactly one electron and one muon in the final state
- Precision now at the level of 3.5% (most precise measurement of $\sigma_{t\bar{t}}$ so far)
  - An additional uncertainty due to the calibration of the LHC beam energy is 4.2 pb



Best fitted valued

$$\sigma_{t\bar{t}} = 241.5 \pm 1.4\ (\text{stat.}) \pm 5.7\ (\text{syst.}) \pm 6.2\ (\text{lumi.})\ \text{pb} = 241.5 \pm 8.5\ \text{pb}$$

for a top mass of 172.5 GeV $1/\sigma_{t\bar{t}} d\sigma_{t\bar{t}}/dm_t = -0.46\%/\text{GeV}$

CMS PAS TOP-14-016
ATLAS- CONF-2014-054

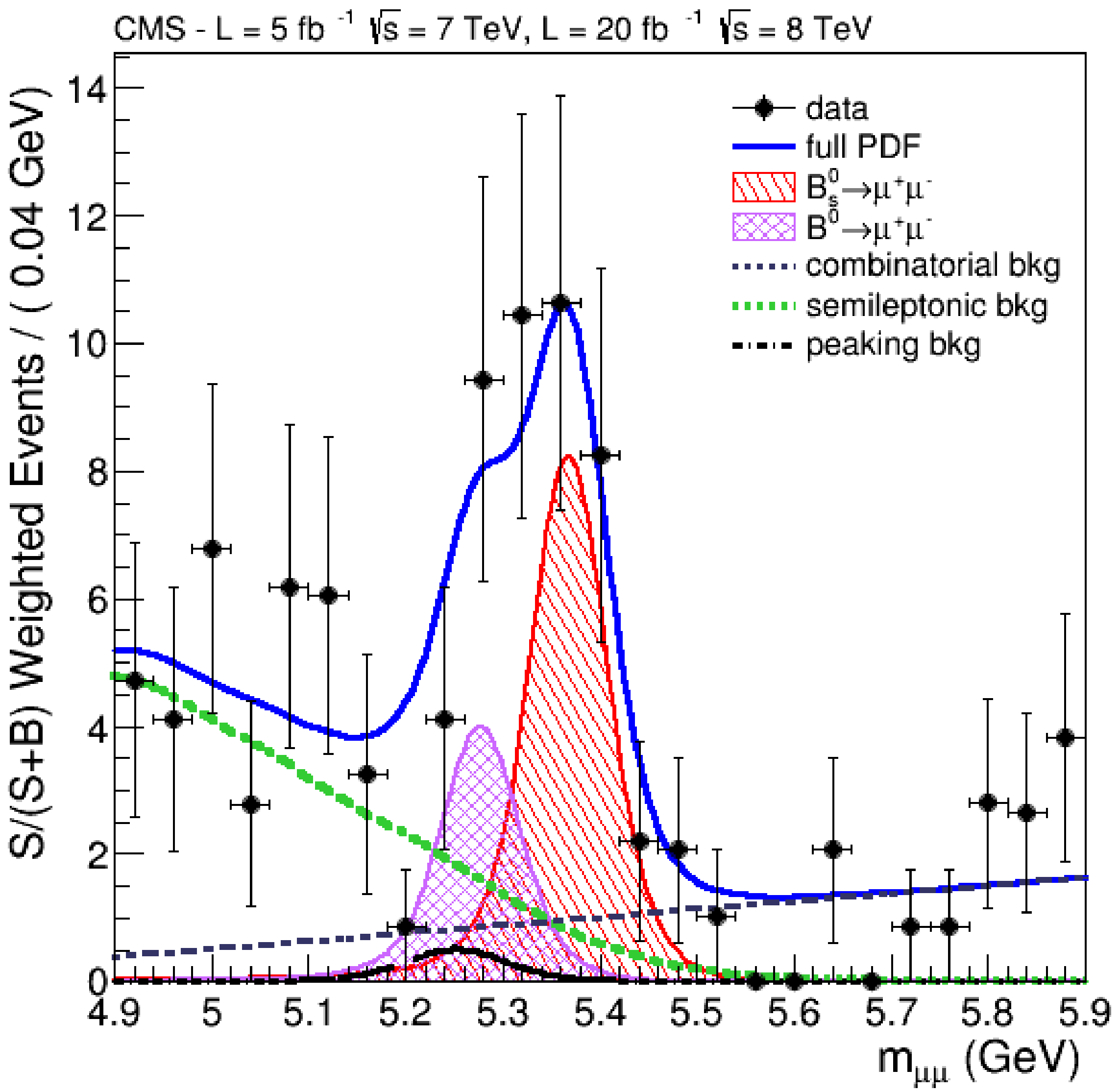
Observation of Bs to mumu

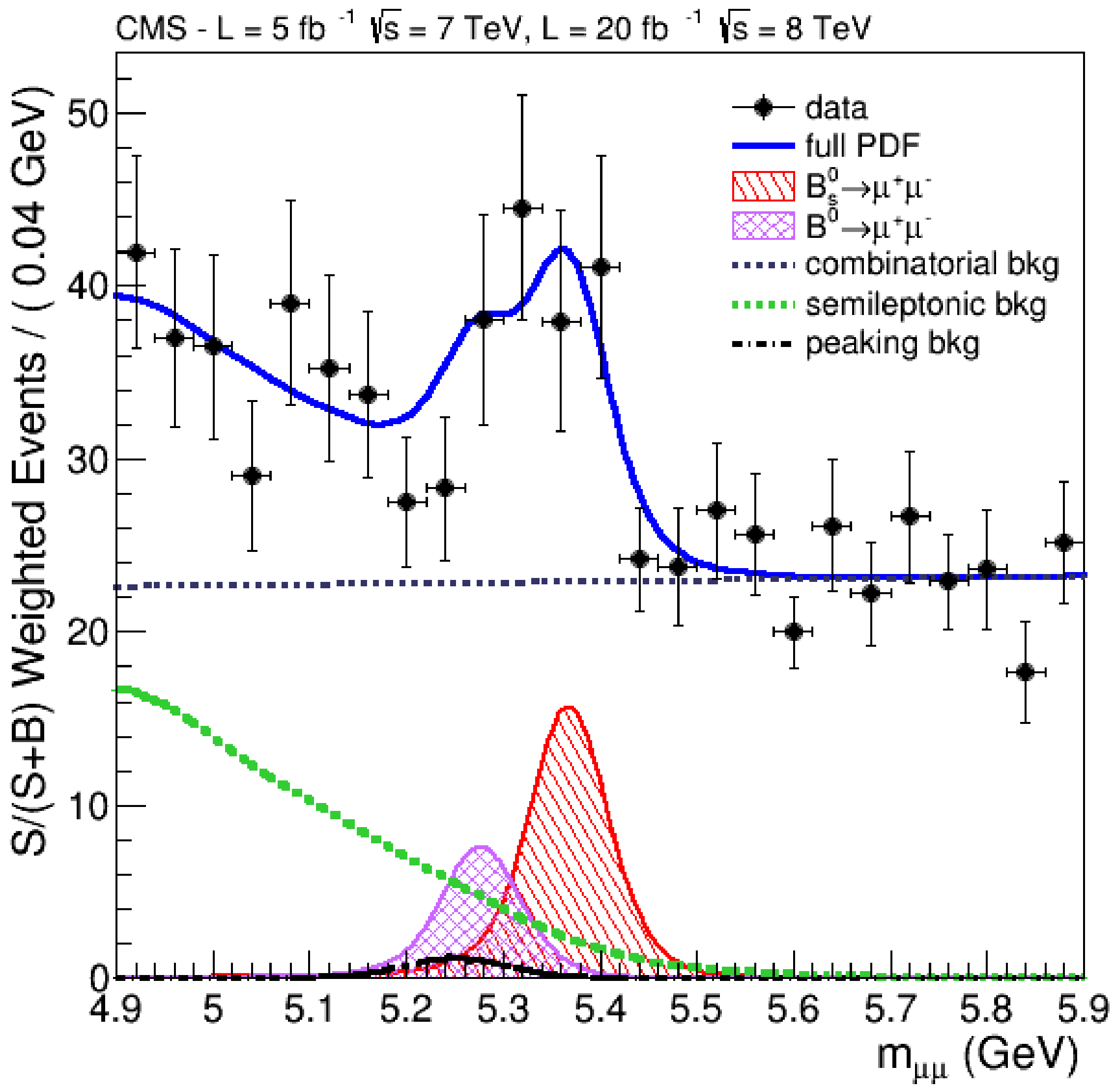
# Weighted invariant mass distributions

**Illustrative only! Not used to extract results**

## 1D BDT cut

## BDT categories





# Bs and Bd to mu mu

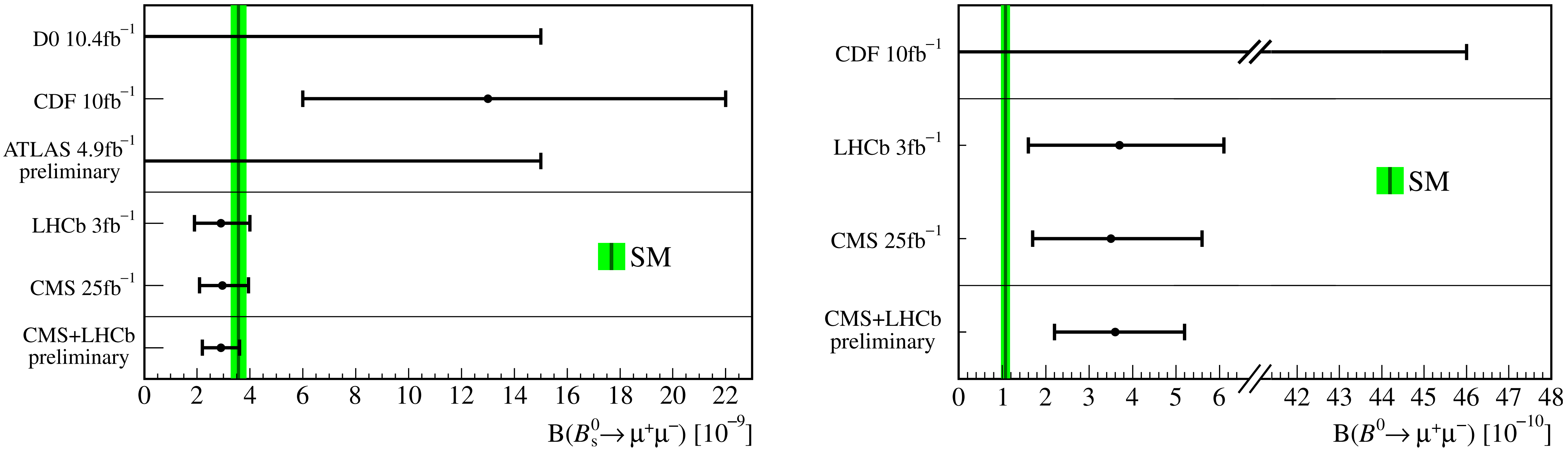


Figure 2: Comparison of previous results [7–9], the latest CMS and LHCb results [11, 12], the combined value, and the SM prediction (vertical line) for (left) the time-integrated branching fraction $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ and (right) $\mathcal{B}(B^0 \to \mu^+\mu^-)$. Upper limits at 95 % CL are shown as bars starting at zero, while other measurements are shown as data points with $\pm 1\sigma$ combined statistical and systematic uncertainties. The width of the vertical band represents the uncertainty in the SM prediction.

**CMS PAS BPH-13-007**
**LHCb-CONF-2013-012**

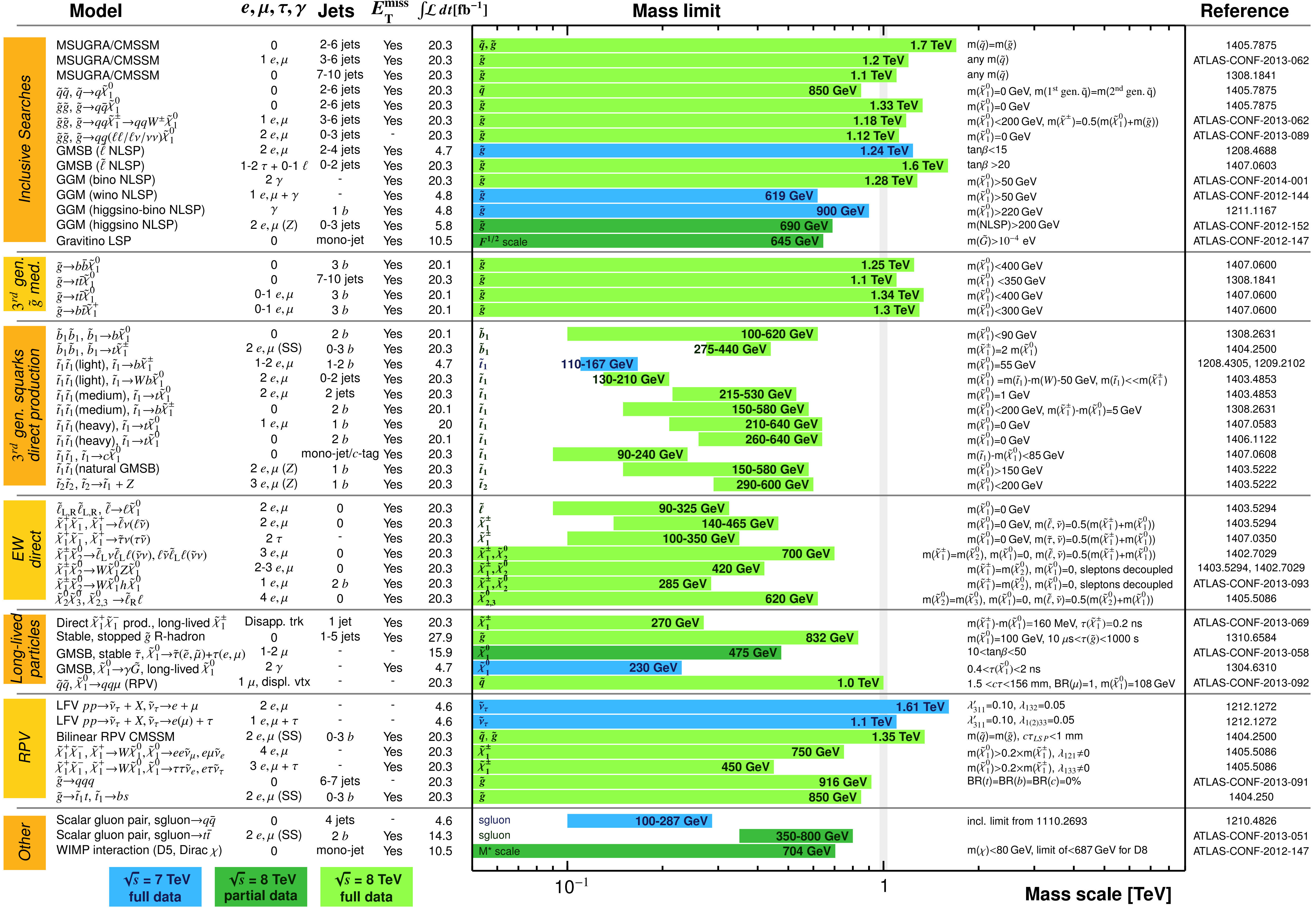
# ATLAS SUSY Searches* - 95% CL Lower Limits

*Status: ICHEP 2014*

(F. Wuerthwein)

***ATLAS*** Preliminary

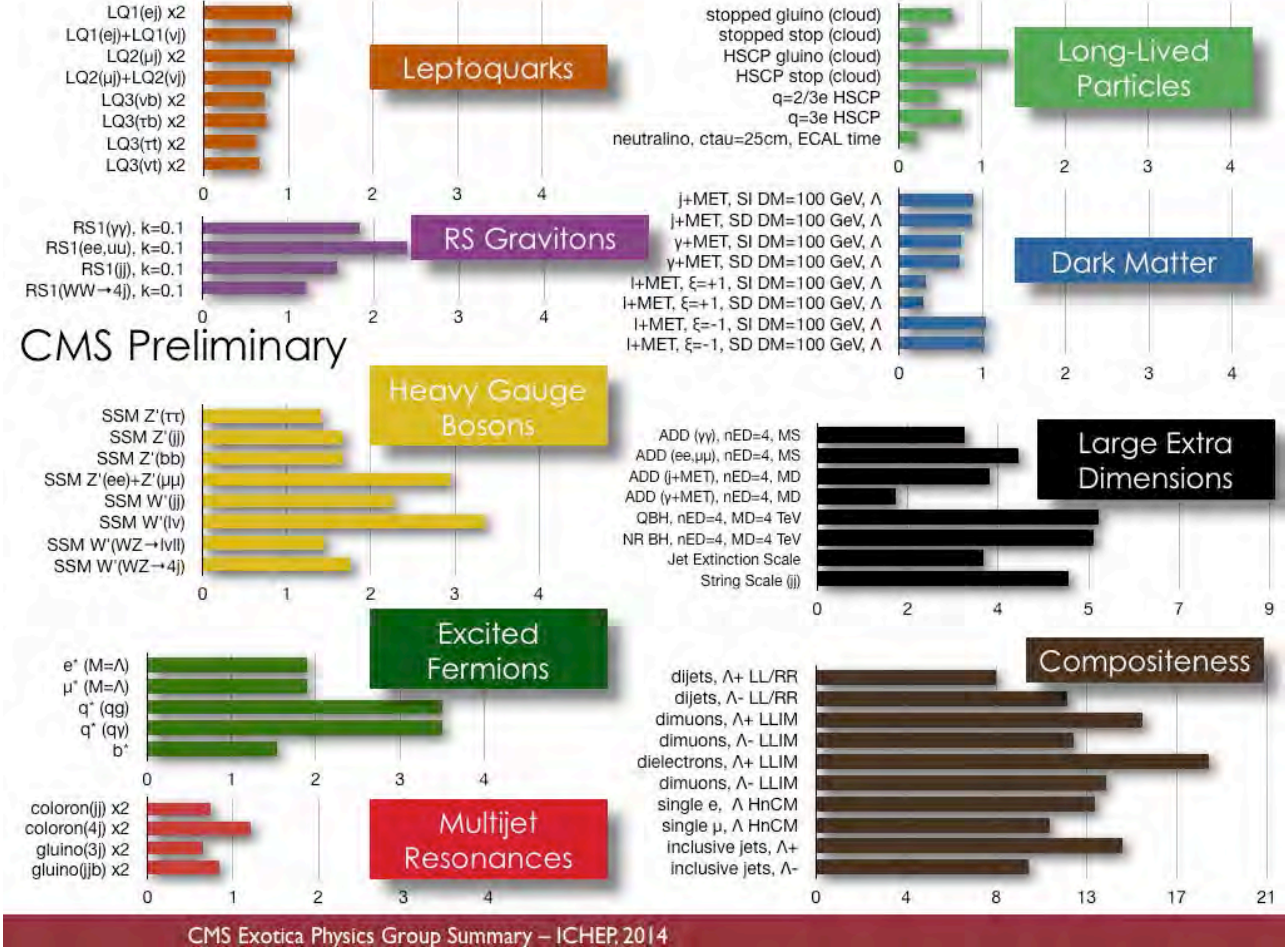
$\sqrt{s}$ = 7, 8 TeV



| | Model | $e,\mu,\tau,\gamma$ | Jets | $E_T^{miss}$ | $\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$ | Mass limit | | | Reference |
|---|---|---|---|---|---|---|---|---|---|
| Inclusive Searches | MSUGRA/CMSSM | 0 | 2-6 jets | Yes | 20.3 | $\tilde{q},\tilde{g}$ | 1.7 TeV | m($\tilde{q}$)=m($\tilde{g}$) | 1405.7875 |
| | MSUGRA/CMSSM | 1 $e,\mu$ | 3-6 jets | Yes | 20.3 | $\tilde{g}$ | 1.2 TeV | any m($\tilde{q}$) | ATLAS-CONF-2013-062 |
| | MSUGRA/CMSSM | 0 | 7-10 jets | Yes | 20.3 | $\tilde{g}$ | 1.1 TeV | any m($\tilde{q}$) | 1308.1841 |
| | $\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}^0_1$ | 0 | 2-6 jets | Yes | 20.3 | $\tilde{q}$ | 850 GeV | m($\tilde{\chi}^0_1$)=0 GeV, m(1$^{st}$ gen. q̃)=m(2$^{nd}$ gen. q̃) | 1405.7875 |
| | $\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}^0_1$ | 0 | 2-6 jets | Yes | 20.3 | $\tilde{g}$ | 1.33 TeV | m($\tilde{\chi}^0_1$)=0 GeV | 1405.7875 |
| | $\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}^\pm_1\to qqW^\pm\tilde{\chi}^0_1$ | 1 $e,\mu$ | 3-6 jets | Yes | 20.3 | $\tilde{g}$ | 1.18 TeV | m($\tilde{\chi}^0_1$)<200 GeV, m($\tilde{\chi}^\pm$)=0.5(m($\tilde{\chi}^0_1$)+m($\tilde{g}$)) | ATLAS-CONF-2013-062 |
| | $\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}^0_1$ | 2 $e,\mu$ | 0-3 jets | - | 20.3 | $\tilde{g}$ | 1.12 TeV | m($\tilde{\chi}^0_1$)=0 GeV | ATLAS-CONF-2013-089 |
| | GMSB ($\tilde{\ell}$ NLSP) | 2 $e,\mu$ | 2-4 jets | Yes | 4.7 | $\tilde{g}$ | 1.24 TeV | tan$\beta$<15 | 1208.4688 |
| | GMSB ($\tilde{\ell}$ NLSP) | 1-2 $\tau$ + 0-1 $\ell$ | 0-2 jets | Yes | 20.3 | $\tilde{g}$ | 1.6 TeV | tan$\beta$ >20 | 1407.0603 |
| | GGM (bino NLSP) | 2 $\gamma$ | - | Yes | 20.3 | $\tilde{g}$ | 1.28 TeV | m($\tilde{\chi}^0_1$)>50 GeV | ATLAS-CONF-2014-001 |
| | GGM (wino NLSP) | 1 $e,\mu+\gamma$ | - | Yes | 4.8 | $\tilde{g}$ | 619 GeV | m($\tilde{\chi}^0_1$)>50 GeV | ATLAS-CONF-2012-144 |
| | GGM (higgsino-bino NLSP) | $\gamma$ | 1 $b$ | Yes | 4.8 | $\tilde{g}$ | 900 GeV | m($\tilde{\chi}^0_1$)>220 GeV | 1211.1167 |
| | GGM (higgsino NLSP) | 2 $e,\mu$ ($Z$) | 0-3 jets | Yes | 5.8 | $\tilde{g}$ | 690 GeV | m(NLSP)>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 |
| $3^{rd}$ gen. $\tilde{g}$ med. | $\tilde{g}\to b\bar{b}\tilde{\chi}^0_1$ | 0 | 3 $b$ | Yes | 20.1 | $\tilde{g}$ | 1.25 TeV | m($\tilde{\chi}^0_1$)<400 GeV | 1407.0600 |
| | $\tilde{g}\to t\bar{t}\tilde{\chi}^0_1$ | 0 | 7-10 jets | Yes | 20.3 | $\tilde{g}$ | 1.1 TeV | m($\tilde{\chi}^0_1$) <350 GeV | 1308.1841 |
| | $\tilde{g}\to t\bar{t}\tilde{\chi}^0_1$ | 0-1 $e,\mu$ | 3 $b$ | Yes | 20.1 | $\tilde{g}$ | 1.34 TeV | m($\tilde{\chi}^0_1$)<400 GeV | 1407.0600 |
| | $\tilde{g}\to b\bar{t}\tilde{\chi}^+_1$ | 0-1 $e,\mu$ | 3 $b$ | Yes | 20.1 | $\tilde{g}$ | 1.3 TeV | m($\tilde{\chi}^0_1$)<300 GeV | 1407.0600 |
| $3^{rd}$ gen. squarks direct production | $\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}^0_1$ | 0 | 2 $b$ | Yes | 20.1 | $\tilde{b}_1$ | 100-620 GeV | m($\tilde{\chi}^0_1$)<90 GeV | 1308.2631 |
| | $\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}^\pm_1$ | 2 $e,\mu$ (SS) | 0-3 $b$ | Yes | 20.3 | $\tilde{b}_1$ | 275-440 GeV | m($\tilde{\chi}^\pm_1$)=2 m($\tilde{\chi}^0_1$) | 1404.2500 |
| | $\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1\to b\tilde{\chi}^\pm_1$ | 1-2 $e,\mu$ | 1-2 $b$ | Yes | 4.7 | $\tilde{t}_1$ | 110-167 GeV | m($\tilde{\chi}^0_1$)=55 GeV | 1208.4305, 1209.2102 |
| | $\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1\to Wb\tilde{\chi}^0_1$ | 2 $e,\mu$ | 0-2 jets | Yes | 20.3 | $\tilde{t}_1$ | 130-210 GeV | m($\tilde{\chi}^0_1$) =m($\tilde{t}_1$)-m($W$)-50 GeV, m($\tilde{t}_1$)<<m($\tilde{\chi}^\pm_1$) | 1403.4853 |
| | $\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1\to t\tilde{\chi}^0_1$ | 2 $e,\mu$ | 2 jets | Yes | 20.3 | $\tilde{t}_1$ | 215-530 GeV | m($\tilde{\chi}^0_1$)=1 GeV | 1403.4853 |
| | $\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1\to b\tilde{\chi}^\pm_1$ | 0 | 2 $b$ | Yes | 20.1 | $\tilde{t}_1$ | 150-580 GeV | m($\tilde{\chi}^0_1$)<200 GeV, m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=5 GeV | 1308.2631 |
| | $\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1\to t\tilde{\chi}^0_1$ | 1 $e,\mu$ | 1 $b$ | Yes | 20 | $\tilde{t}_1$ | 210-640 GeV | m($\tilde{\chi}^0_1$)=0 GeV | 1407.0583 |
| | $\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1\to t\tilde{\chi}^0_1$ | 0 | 2 $b$ | Yes | 20.1 | $\tilde{t}_1$ | 260-640 GeV | m($\tilde{\chi}^0_1$)=0 GeV | 1406.1122 |
| | $\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}^0_1$ | 0 | mono-jet/$c$-tag | Yes | 20.3 | $\tilde{t}_1$ | 90-240 GeV | m($\tilde{t}_1$)-m($\tilde{\chi}^0_1$)<85 GeV | 1407.0608 |
| | $\tilde{t}_1\tilde{t}_1$ (natural GMSB) | 2 $e,\mu$ ($Z$) | 1 $b$ | Yes | 20.3 | $\tilde{t}_1$ | 150-580 GeV | m($\tilde{\chi}^0_1$)>150 GeV | 1403.5222 |
| | $\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$ | 3 $e,\mu$ ($Z$) | 1 $b$ | Yes | 20.3 | $\tilde{t}_2$ | 290-600 GeV | m($\tilde{\chi}^0_1$)<200 GeV | 1403.5222 |
| EW direct | $\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}^0_1$ | 2 $e,\mu$ | 0 | Yes | 20.3 | $\tilde{\ell}$ | 90-325 GeV | m($\tilde{\chi}^0_1$)=0 GeV | 1403.5294 |
| | $\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to\tilde{\ell}\nu(\ell\tilde{\nu})$ | 2 $e,\mu$ | 0 | Yes | 20.3 | $\tilde{\chi}^\pm_1$ | 140-465 GeV | m($\tilde{\chi}^0_1$)=0 GeV, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}^\pm_1$)+m($\tilde{\chi}^0_1$)) | 1403.5294 |
| | $\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to\tilde{\tau}\nu(\tau\tilde{\nu})$ | 2 $\tau$ | - | Yes | 20.3 | $\tilde{\chi}^\pm_1$ | 100-350 GeV | m($\tilde{\chi}^0_1$)=0 GeV, m($\tilde{\tau},\tilde{\nu}$)=0.5(m($\tilde{\chi}^\pm_1$)+m($\tilde{\chi}^0_1$)) | 1407.0350 |
| | $\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$ | 3 $e,\mu$ | 0 | Yes | 20.3 | $\tilde{\chi}^\pm_1,\tilde{\chi}^0_2$ | 700 GeV | m($\tilde{\chi}^\pm_1$)=m($\tilde{\chi}^0_2$), m($\tilde{\chi}^0_1$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}^\pm_1$)+m($\tilde{\chi}^0_1$)) | 1402.7029 |
| | $\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to W\tilde{\chi}^0_1Z\tilde{\chi}^0_1$ | 2-3 $e,\mu$ | 0 | Yes | 20.3 | $\tilde{\chi}^\pm_1,\tilde{\chi}^0_2$ | 420 GeV | m($\tilde{\chi}^\pm_1$)=m($\tilde{\chi}^0_2$), m($\tilde{\chi}^0_1$)=0, sleptons decoupled | 1403.5294, 1402.7029 |
| | $\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to W\tilde{\chi}^0_1h\tilde{\chi}^0_1$ | 1 $e,\mu$ | 2 $b$ | Yes | 20.3 | $\tilde{\chi}^\pm_1,\tilde{\chi}^0_2$ | 285 GeV | m($\tilde{\chi}^\pm_1$)=m($\tilde{\chi}^0_2$), m($\tilde{\chi}^0_1$)=0, sleptons decoupled | ATLAS-CONF-2013-093 |
| | $\tilde{\chi}^0_2\tilde{\chi}^0_3$, $\tilde{\chi}^0_{2,3}\to\tilde{\ell}_R\ell$ | 4 $e,\mu$ | 0 | Yes | 20.3 | $\tilde{\chi}^0_{2,3}$ | 620 GeV | m($\tilde{\chi}^0_2$)=m($\tilde{\chi}^0_3$), m($\tilde{\chi}^0_1$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}^0_2$)+m($\tilde{\chi}^0_1$)) | 1405.5086 |
| Long-lived particles | Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$ | Disapp. trk | 1 jet | Yes | 20.3 | $\tilde{\chi}^\pm_1$ | 270 GeV | m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=160 MeV, $\tau$($\tilde{\chi}^\pm_1$)=0.2 ns | ATLAS-CONF-2013-069 |
| | Stable, stopped $\tilde{g}$ R-hadron | 0 | 1-5 jets | Yes | 27.9 | $\tilde{g}$ | 832 GeV | m($\tilde{\chi}^0_1$)=100 GeV, 10 $\mu$s<$\tau$($\tilde{g}$)<1000 s | 1310.6584 |
| | GMSB, stable $\tilde{\tau}$, $\tilde{\chi}^0_1\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$ | 1-2 $\mu$ | - | - | 15.9 | $\tilde{\chi}^0_1$ | 475 GeV | 10<tan$\beta$<50 | ATLAS-CONF-2013-058 |
| | GMSB, $\tilde{\chi}^0_1\to\gamma\tilde{G}$, long-lived $\tilde{\chi}^0_1$ | 2 $\gamma$ | - | Yes | 4.7 | $\tilde{\chi}^0_1$ | 230 GeV | 0.4<$\tau$($\tilde{\chi}^0_1$)<2 ns | 1304.6310 |
| | $\tilde{q}\tilde{q}$, $\tilde{\chi}^0_1\to qq\mu$ (RPV) | 1 $\mu$, displ. vtx | - | - | 20.3 | $\tilde{q}$ | 1.0 TeV | 1.5 <$c\tau$<156 mm, BR($\mu$)=1, m($\tilde{\chi}^0_1$)=108 GeV | ATLAS-CONF-2013-092 |
| RPV | LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e+\mu$ | 2 $e,\mu$ | - | - | 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 $e,\mu+\tau$ | - | - | 4.6 | $\tilde{\nu}_\tau$ | 1.1 TeV | $\lambda'_{311}$=0.10, $\lambda_{1(2)33}$=0.05 | 1212.1272 |
| | Bilinear RPV CMSSM | 2 $e,\mu$ (SS) | 0-3 $b$ | Yes | 20.3 | $\tilde{q},\tilde{g}$ | 1.35 TeV | m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm | 1404.2500 |
| | $\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to W\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$ | 4 $e,\mu$ | - | Yes | 20.3 | $\tilde{\chi}^\pm_1$ | 750 GeV | m($\tilde{\chi}^0_1$)>0.2×m($\tilde{\chi}^\pm_1$), $\lambda_{121}\neq0$ | 1405.5086 |
| | $\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to W\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$ | 3 $e,\mu+\tau$ | - | Yes | 20.3 | $\tilde{\chi}^\pm_1$ | 450 GeV | m($\tilde{\chi}^0_1$)>0.2×m($\tilde{\chi}^\pm_1$), $\lambda_{133}\neq0$ | 1405.5086 |
| | $\tilde{g}\to qqq$ | 0 | 6-7 jets | - | 20.3 | $\tilde{g}$ | 916 GeV | BR($t$)=BR($b$)=BR($c$)=0% | ATLAS-CONF-2013-091 |
| | $\tilde{g}\to\tilde{t}_1t$, $\tilde{t}_1\to bs$ | 2 $e,\mu$ (SS) | 0-3 $b$ | Yes | 20.3 | $\tilde{g}$ | 850 GeV | | 1404.250 |
| Other | Scalar gluon pair, sgluon$\to q\bar{q}$ | 0 | 4 jets | - | 4.6 | sgluon | 100-287 GeV | incl. limit from 1110.2693 | 1210.4826 |
| | Scalar gluon pair, sgluon$\to t\bar{t}$ | 2 $e,\mu$ (SS) | 2 $b$ | Yes | 14.3 | sgluon | 350-800 GeV | | ATLAS-CONF-2013-051 |
| | WIMP interaction (D5, Dirac $\chi$) | 0 | mono-jet | Yes | 10.5 | M* scale | 704 GeV | m($\chi$)<80 GeV, limit of<687 GeV for D8 | ATLAS-CONF-2012-147 |

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

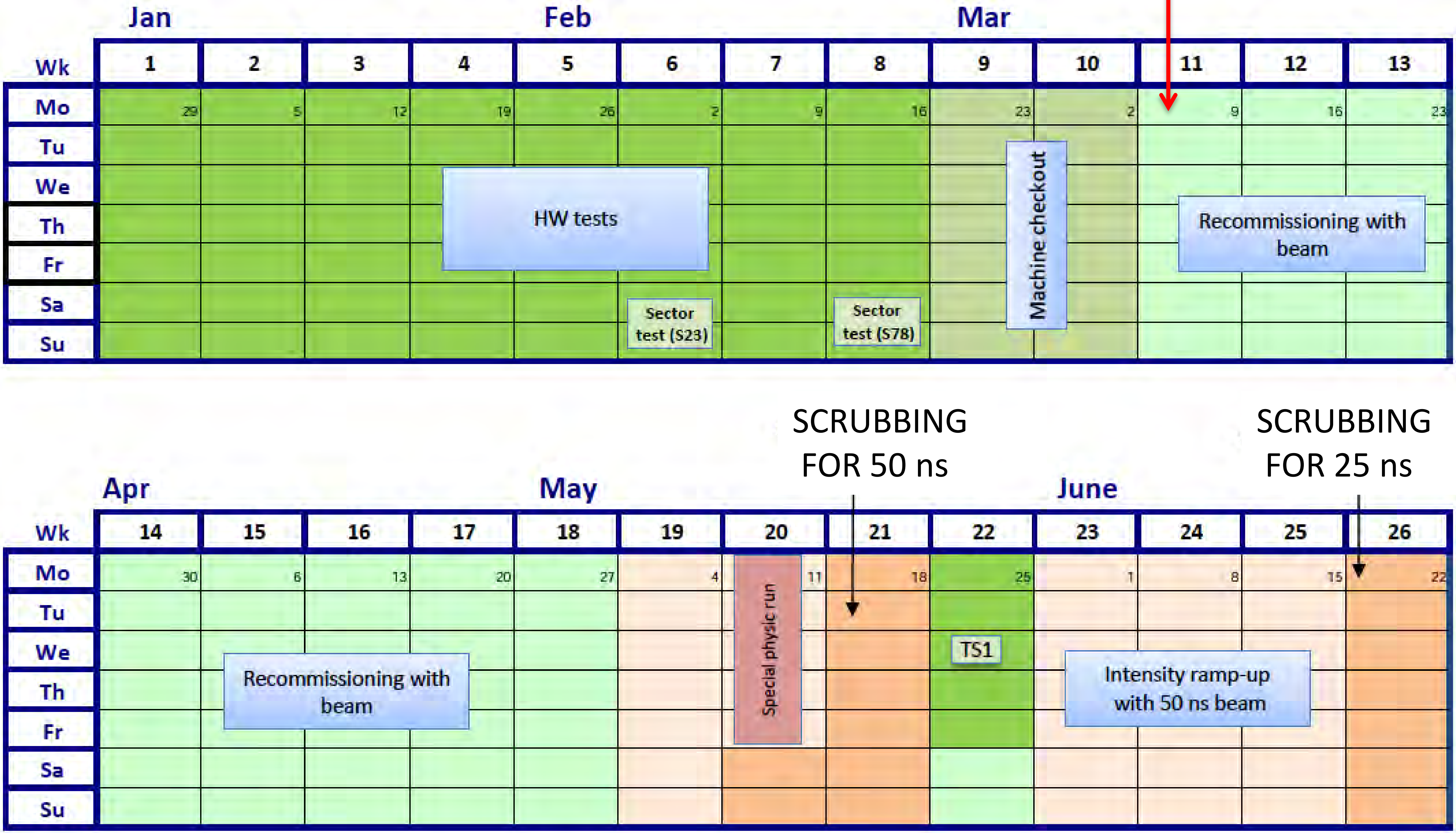
(F. Wuerthwein)



Run 1 has set the stage
for…
RUN 2

# 2015 Q1/Q2

FIRST BEAM
9th MARCH



| | Jan | | | | Feb | | | | Mar | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wk | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Mo | 29 | 5 | 12 | 19 | 26 | 2 | 9 | 16 | 23 | 2 | 9 | 16 | 23 |
| Tu | | | | | | | | | | | | | |
| We | | | | | | | | | | | | | |
| Th | | | | | | | | | | | | | |
| Fr | | | | | | | | | | | | | |
| Sa | | | | | | | | | | | | | |
| Su | | | | | | | | | | | | | |

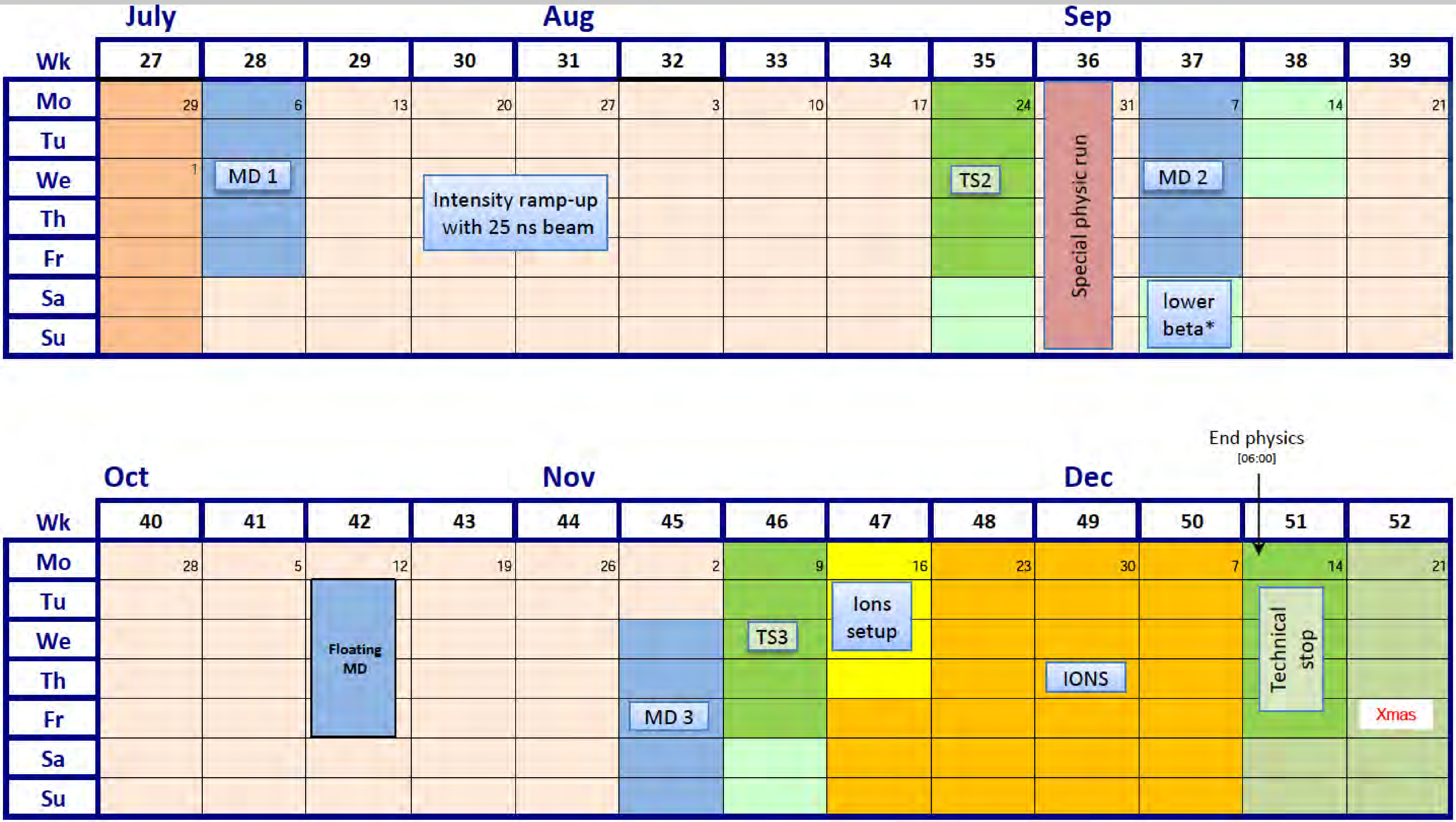
SCRUBBING
FOR 50 ns

SCRUBBING
FOR 25 ns

| | Apr | | | | May | | | | | June | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wk | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| Mo | 30 | 6 | 13 | 20 | 27 | 4 | 11 | 18 | 25 | 1 | 8 | 15 | 22 |
| Tu | | | | | | | | | | | | | |
| We | | | | | | | | | | | | | |
| Th | | | | | | | | | | | | | |
| Fr | | | | | | | | | | | | | |
| Sa | | | | | | | | | | | | | |
| Su | | | | | | | | | | | | | |

(M. Lamont, LHCC Nov 2014)

# 2015 Q3/Q4



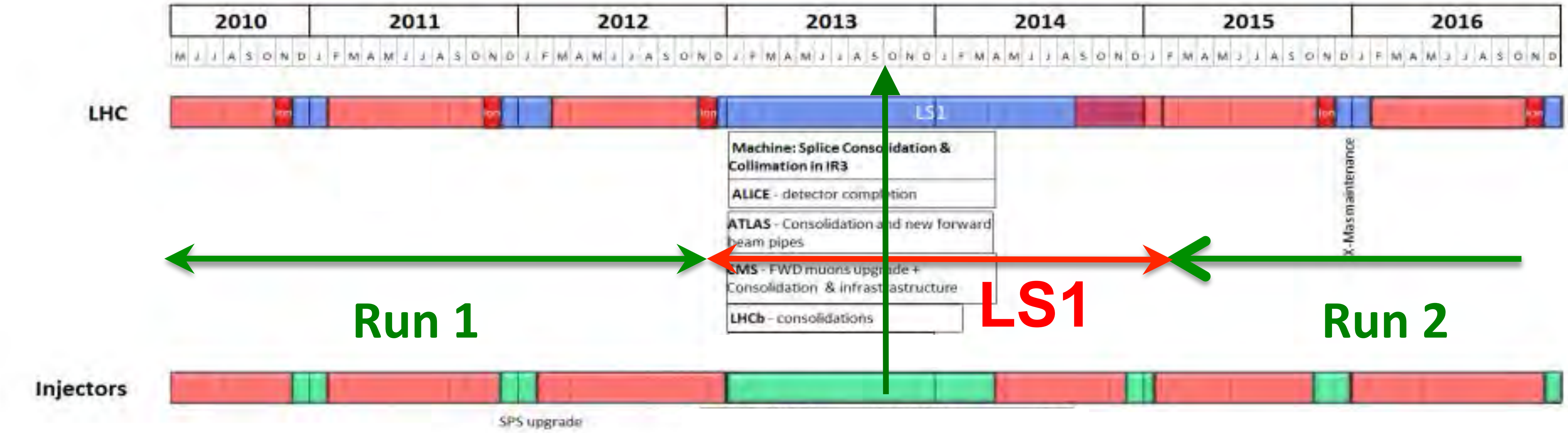
| | July | | | | Aug | | | | | Sep | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Wk** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** | **36** | **37** | **38** | **39** |
| **Mo** | 29 | 6 | 13 | 20 | 27 | 3 | 10 | 17 | 24 | Special physic run<br>31 | 7 | 14 | 21 |
| **Tu** | | | | | | | | | | | | | |
| **We** | 1 | MD 1 | | Intensity ramp-up with 25 ns beam | | | | | TS2 | | MD 2 | | |
| **Th** | | | | | | | | | | | | | |
| **Fr** | | | | | | | | | | | | | |
| **Sa** | | | | | | | | | | | lower beta* | | |
| **Su** | | | | | | | | | | | | | |

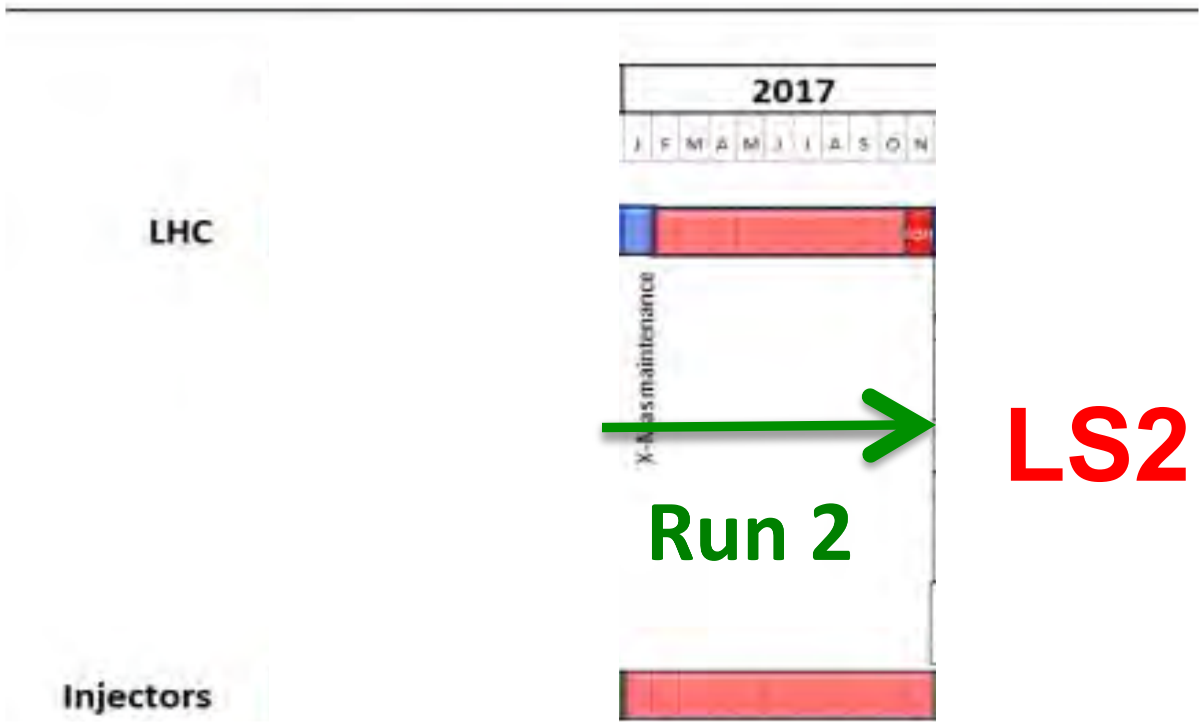
End physics
[06:00]

| | Oct | | | | Nov | | | | | Dec | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Wk** | **40** | **41** | **42** | **43** | **44** | **45** | **46** | **47** | **48** | **49** | **50** | **51** | **52** |
| **Mo** | 28 | 5 | 12 | 19 | 26 | 2 | 9 | 16 | 23 | 30 | 7 | 14 | 21 |
| **Tu** | | | Floating MD | | | | | Ions setup | | | | Technical stop | |
| **We** | | | | | | | TS3 | | | | | | |
| **Th** | | | | | | | | | | IONS | | | |
| **Fr** | | | | | | MD 3 | | | | | | | Xmas |
| **Sa** | | | | | | | | | | | | | |
| **Su** | | | | | | | | | | | | | |

(M. Lamont, LHCC Nov 2014)

# LHC Roadmap Run 2
# 3 years Operation Run after LS1





(J. Hansen, WLCG13)

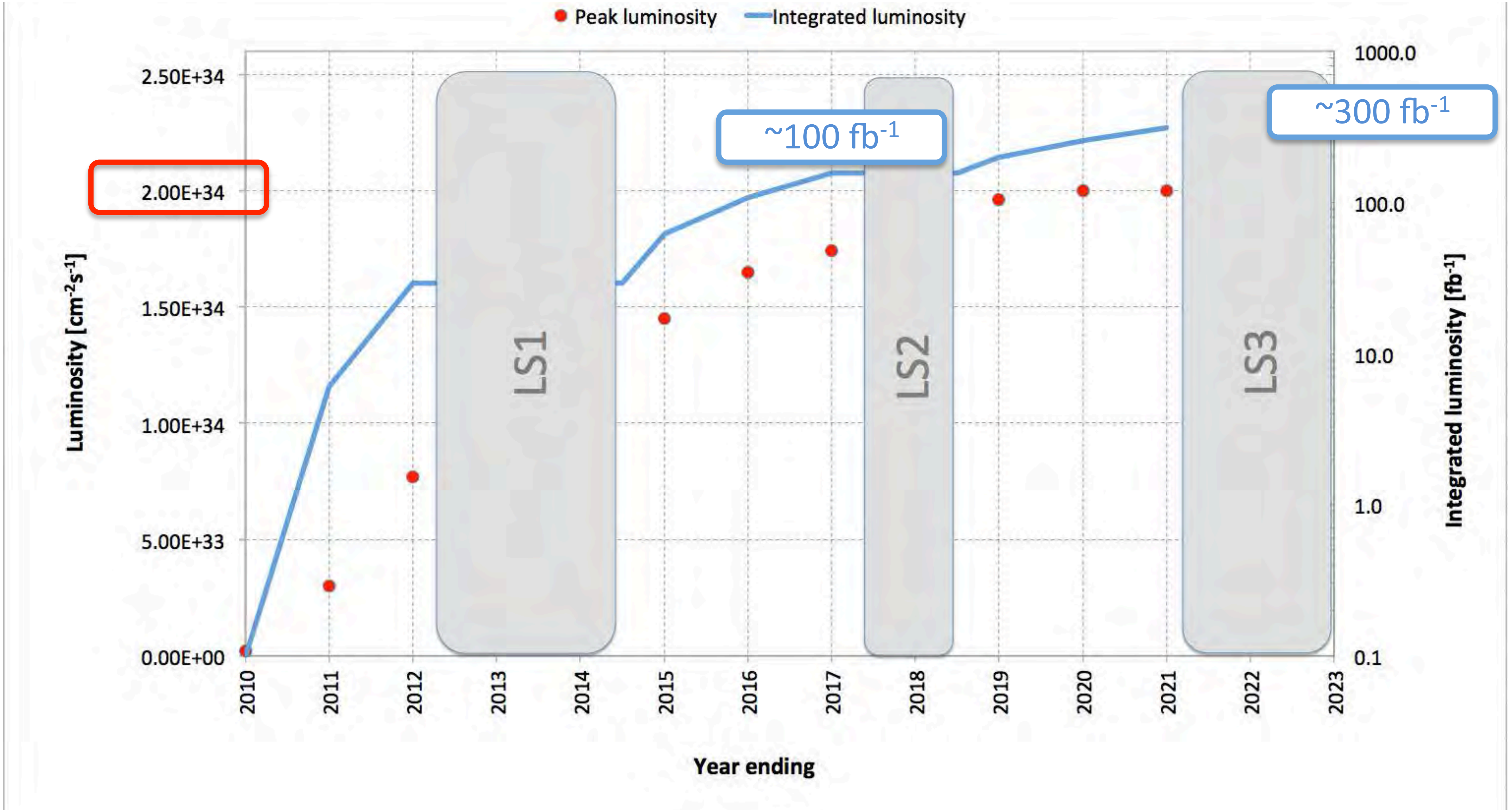
## LHC Roadmap Run 2

- Energy: 6.5 TeV
- Bunch spacing: 25 ns
  - pile-up considerations
- Injectors potentially able to offer nominal intensity with even lower emittance

**Run 2:**
**Start with 6.5 TeV and later decision towards 7 TeV according to magnet training**

| | Number of bunches | Ib LHC FT [1e11] | Emit LHC [um] | Peak Lumi [$cm^{-2}s^{-1}$] | ~Pile-u | Int. Lumi per year [$fb^{-1}$] |
|---|---|---|---|---|---|---|
| 25 ns BCMS | 2590 | 1.15 | 1.9 | 1.7e34 | 49 | ~45 |

# Luminosity evolution

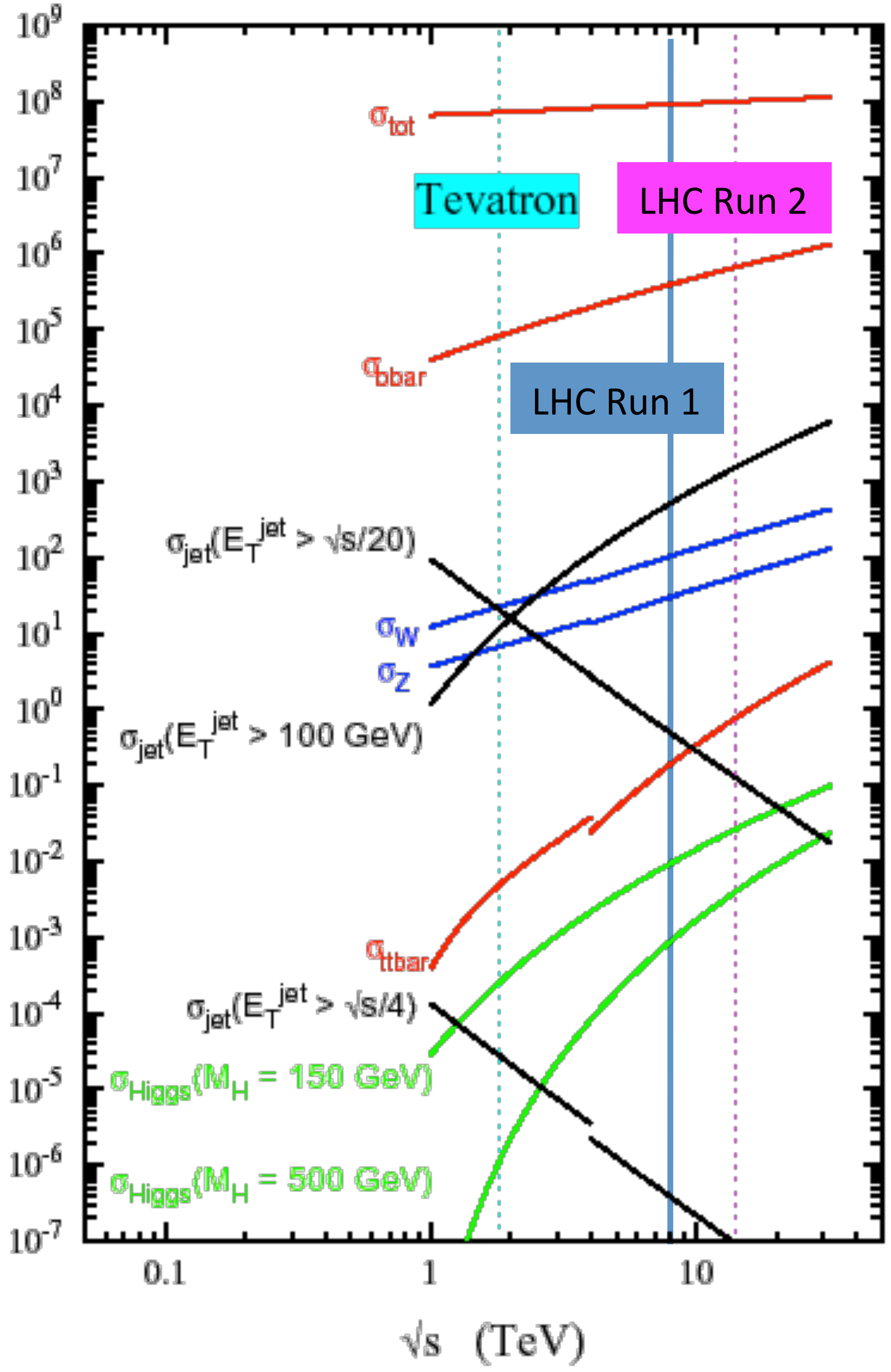


Still uncertainty on length of end-of-year breaks Usual caveats apply

(J. Hansen, WLCG13)

# Physics prospects at Run 2

- Increase of cross sections from LHC8 to LHC14
  - Improved discovery potential at LHC
- **A Higgs factory**:
  - 5.5M Higgs events produced
  - 100K event useful for precision measurements
- Note: today ATLAS+CMS have 1400 Higgs events



Physics subjects

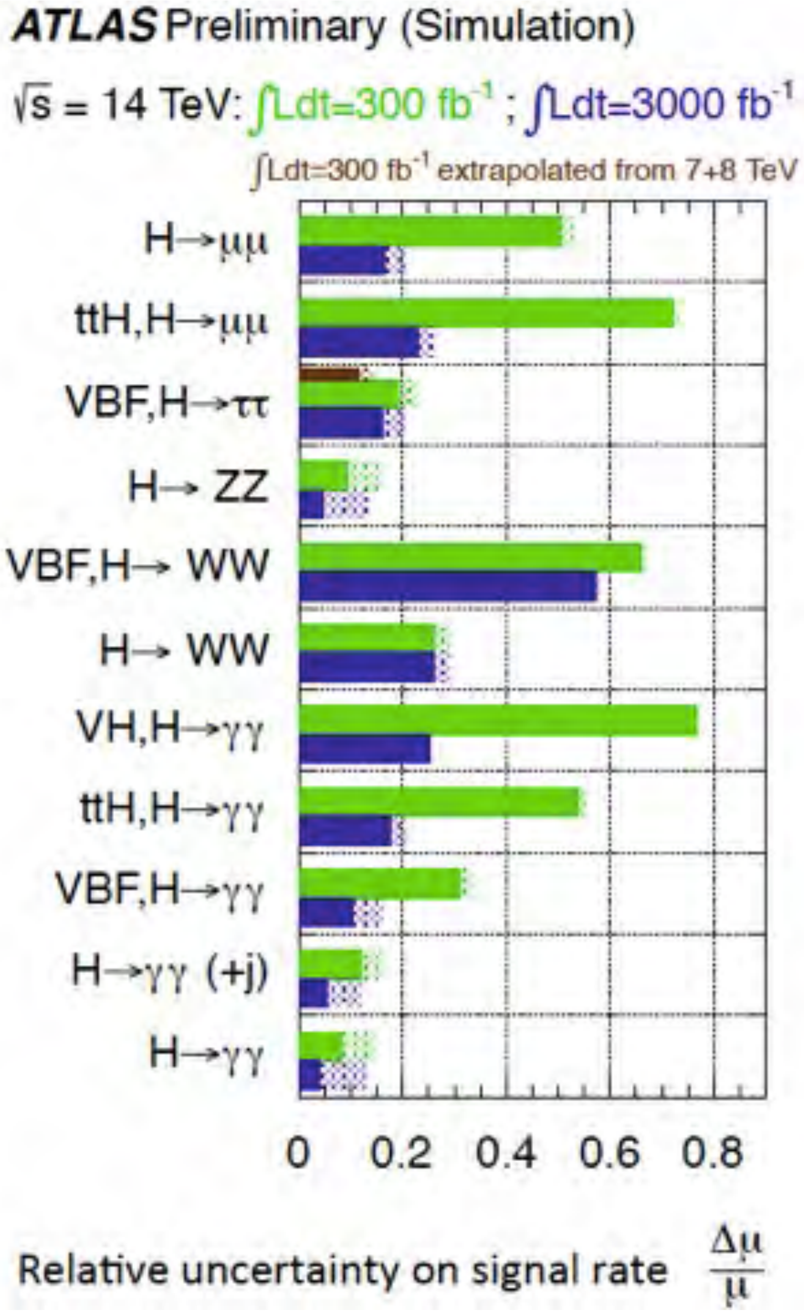
- Higgs precision measurement
  - Mass
  - Cross-sections
- Measure as many Higgs couplings to fermions and bosons as precisely as possible
- Very weak possibility to observe that the Higgs boson fixes the SM problems with $W_L W_L$ scattering at high E
- Extend limits for searches

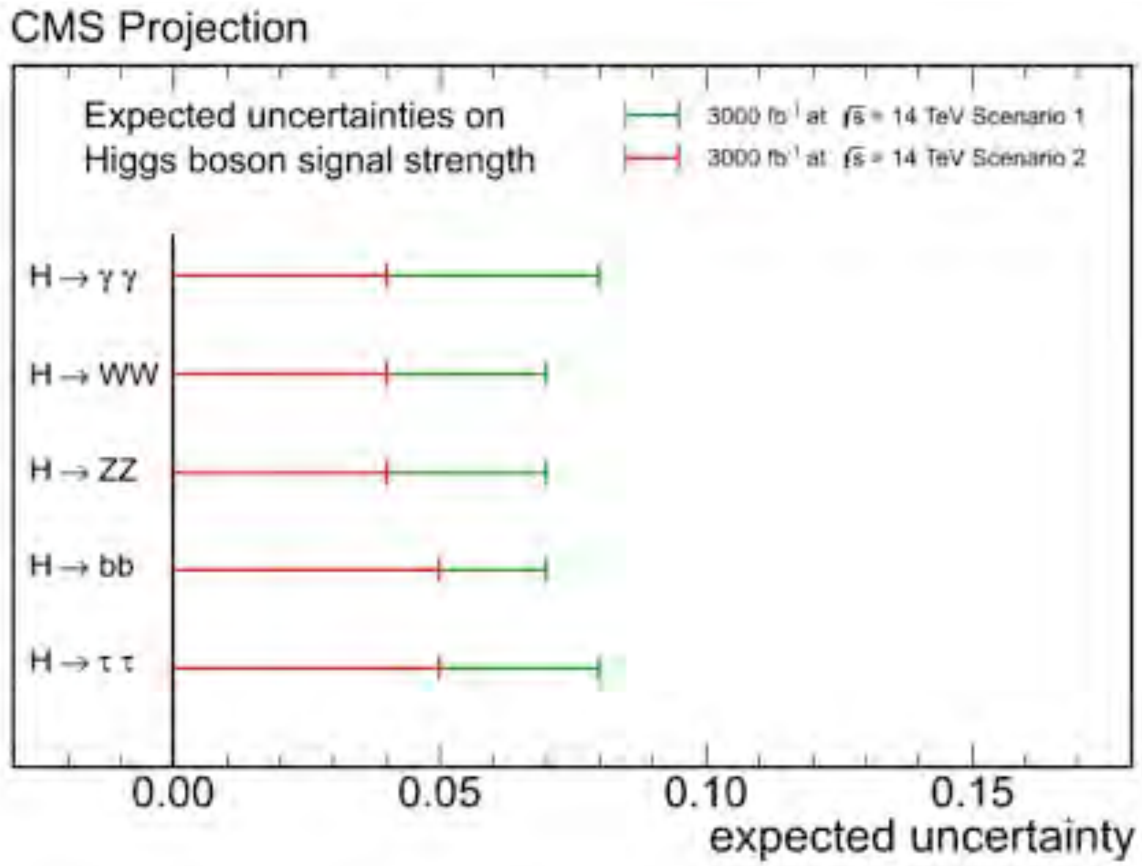
CMS and ATLAS white papers:
arXiv:1307.7135 and 1307.7292

(J. Hansen, WLCG13)

# Uncertainty on signal strength

- 100 fb-1 is a factor 1.5 larger!





| L (fb$^{-1}$) | $H \to \gamma\gamma$ | $H \to WW$ | $H \to ZZ$ | $H \to bb$ | $H \to \tau\tau$ | $H \to Z\gamma$ | $H \to$ inv. |
|---|---|---|---|---|---|---|---|
| 300 | [6, 12] | [6, 11] | [7, 11] | [11, 14] | [8, 14] | [62, 62] | [17, 28] |
| 3000 | [4, 8] | [4, 7] | [4, 7] | [5, 7] | [5, 8] | [20, 24] | [6, 17] |

Assumptions on systematic uncertainties
Scenario 1: no change
Scenario 2: Δ theory / 2, rest ∝ 1/√L

Based on parametric simulation

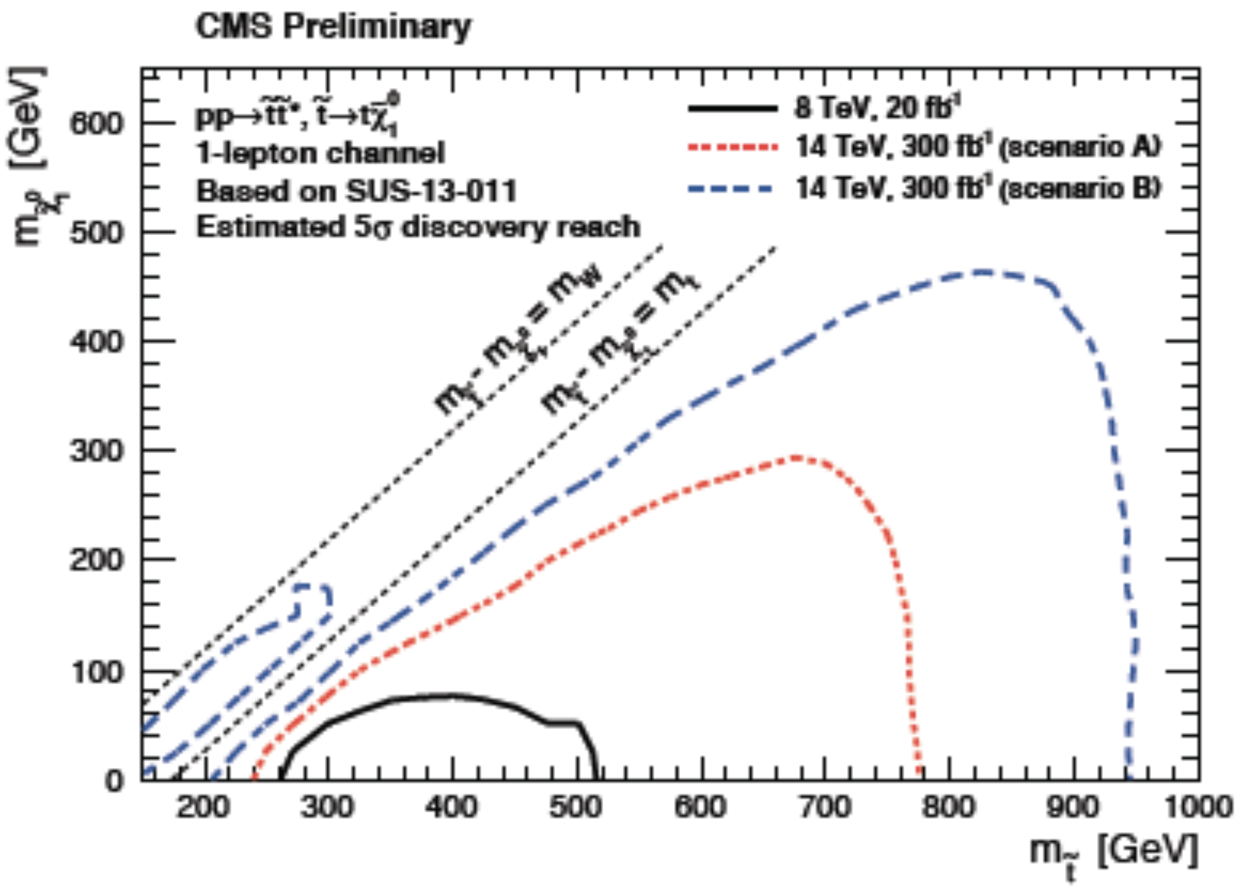
Extrapolated from 2011/12 results

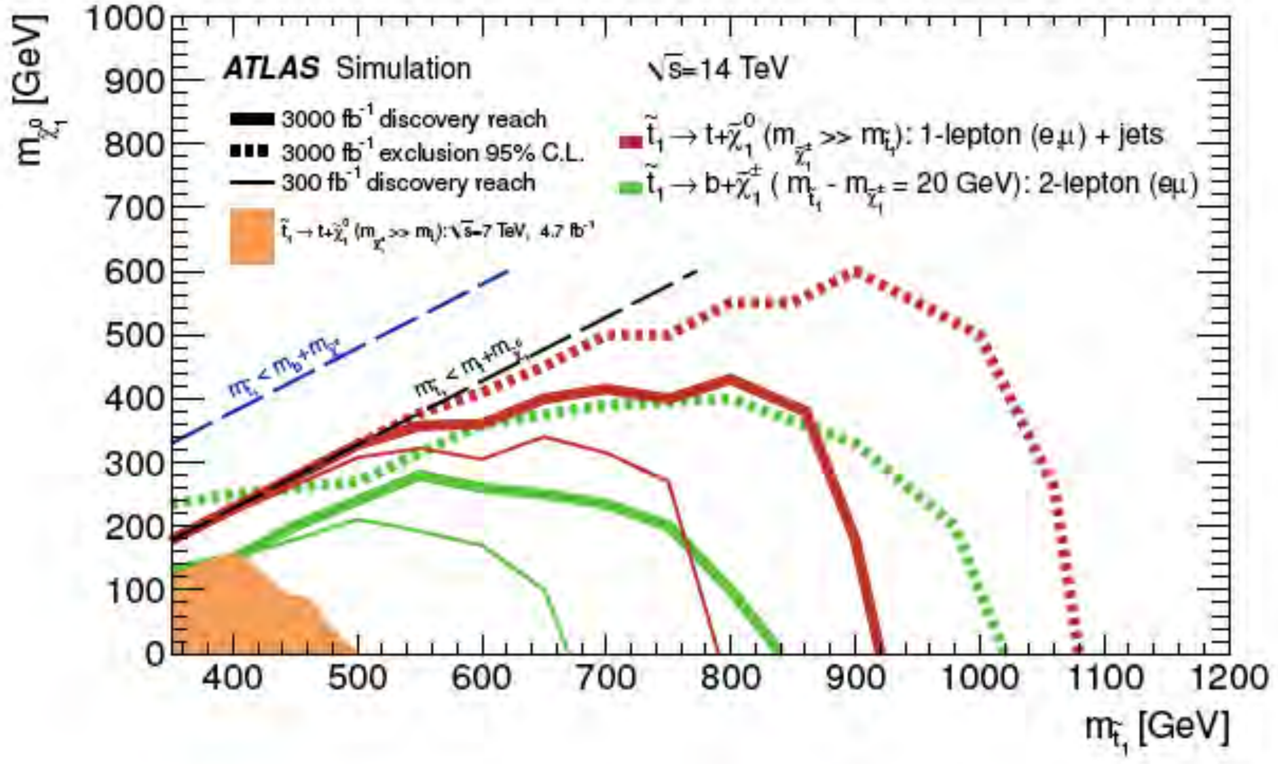
(J. Hansen, WLCG13)

# Stop discovery potential

- Challenging analysis due to large top background
- Systematic uncertainties important
- 300 fb$^{-1}$:
  - Discovery up to 700 GeV in direct production
- Further improvements may be possible with reoptimization

(J. Hansen, WLCG13)



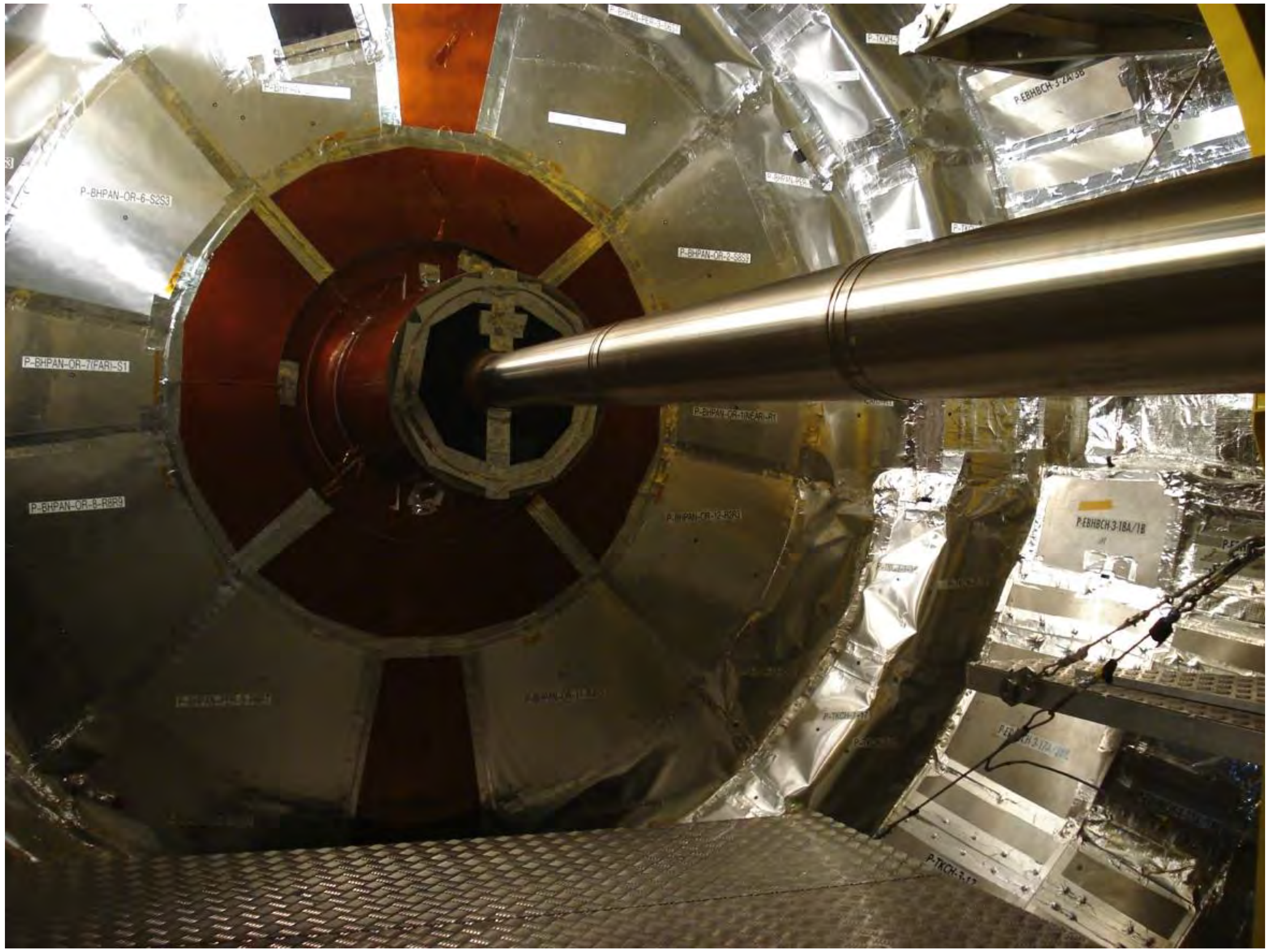


Technical Coordination

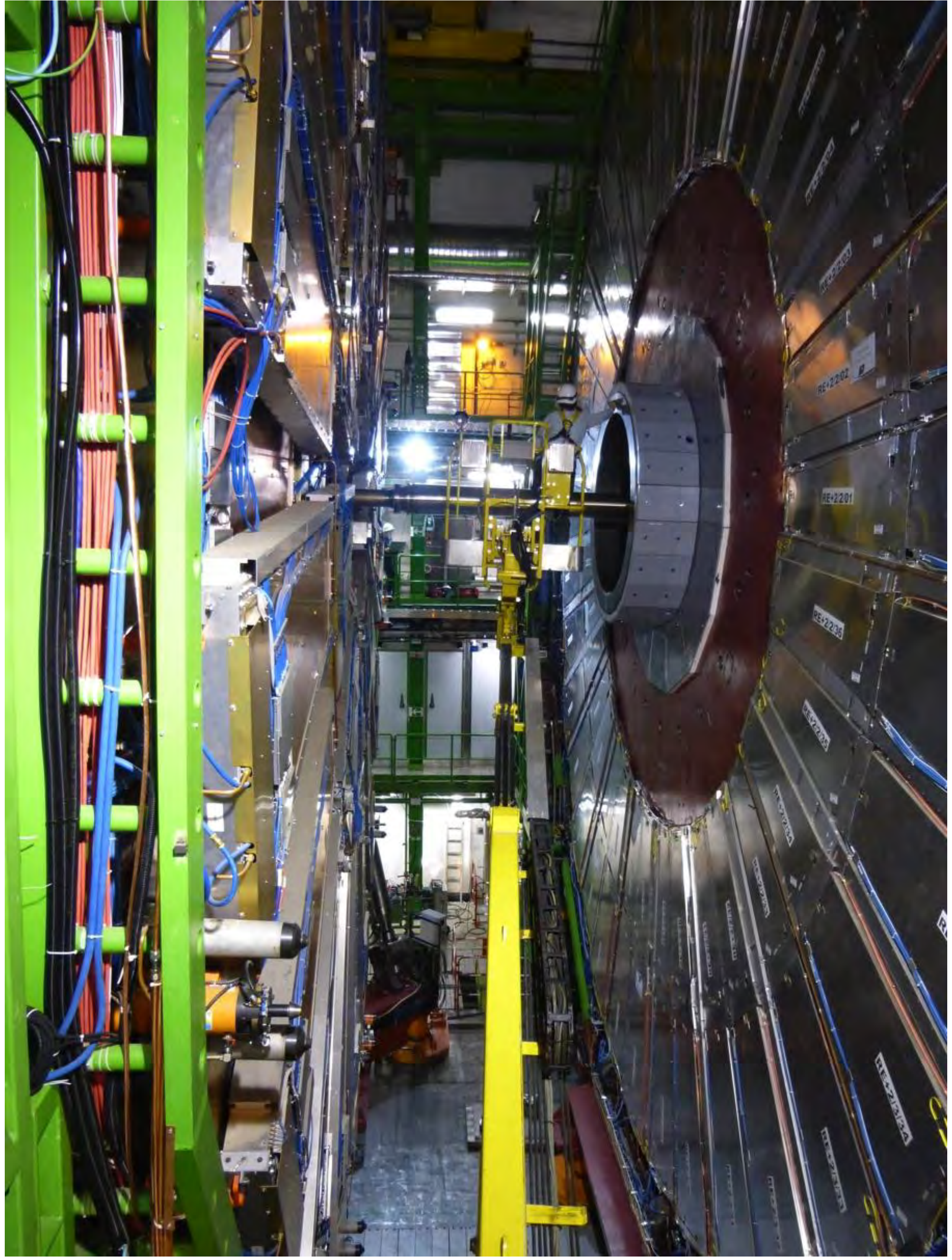
# Experiments Getting Ready for Run 2!

LHCC refs Nov 2014 AB/WZ

## Closing endcap disks



Tracker bulkhead & nose sealed.
Protoype camera system fitted



Closing….

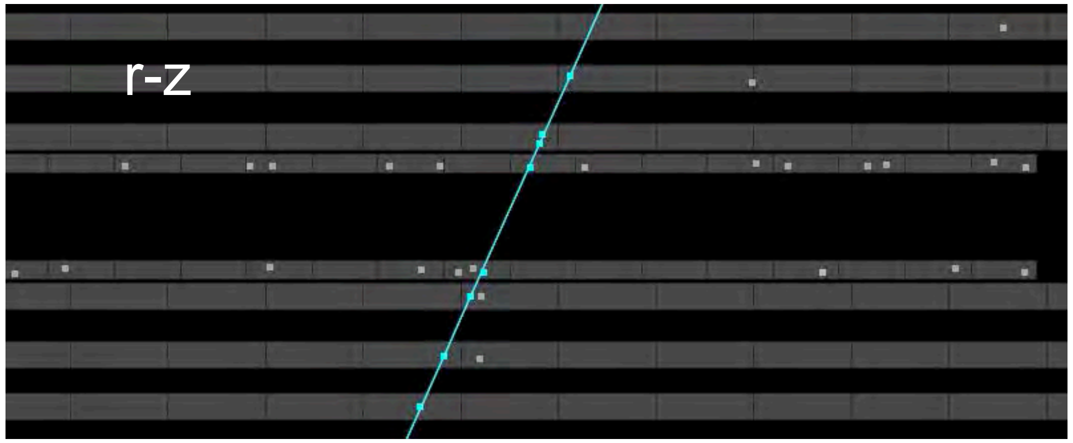
(A. Ball)

# Pixel detector

- **BPIX half-shell fully repaired and back to CERN**
- Reminder: failure was localized in one quadrant only– all others fine
  - Failure: shorts between wire-bonding pads on the high density interconnect
  - Isolated failure during a test with power and most probable high local humidity
- 40 new modules
- 19 repaired modules
- This half-shell works now 100%!
- Connection to supply tube done ✔
- Initial checkout done ✔
- Ready for installation by end of November

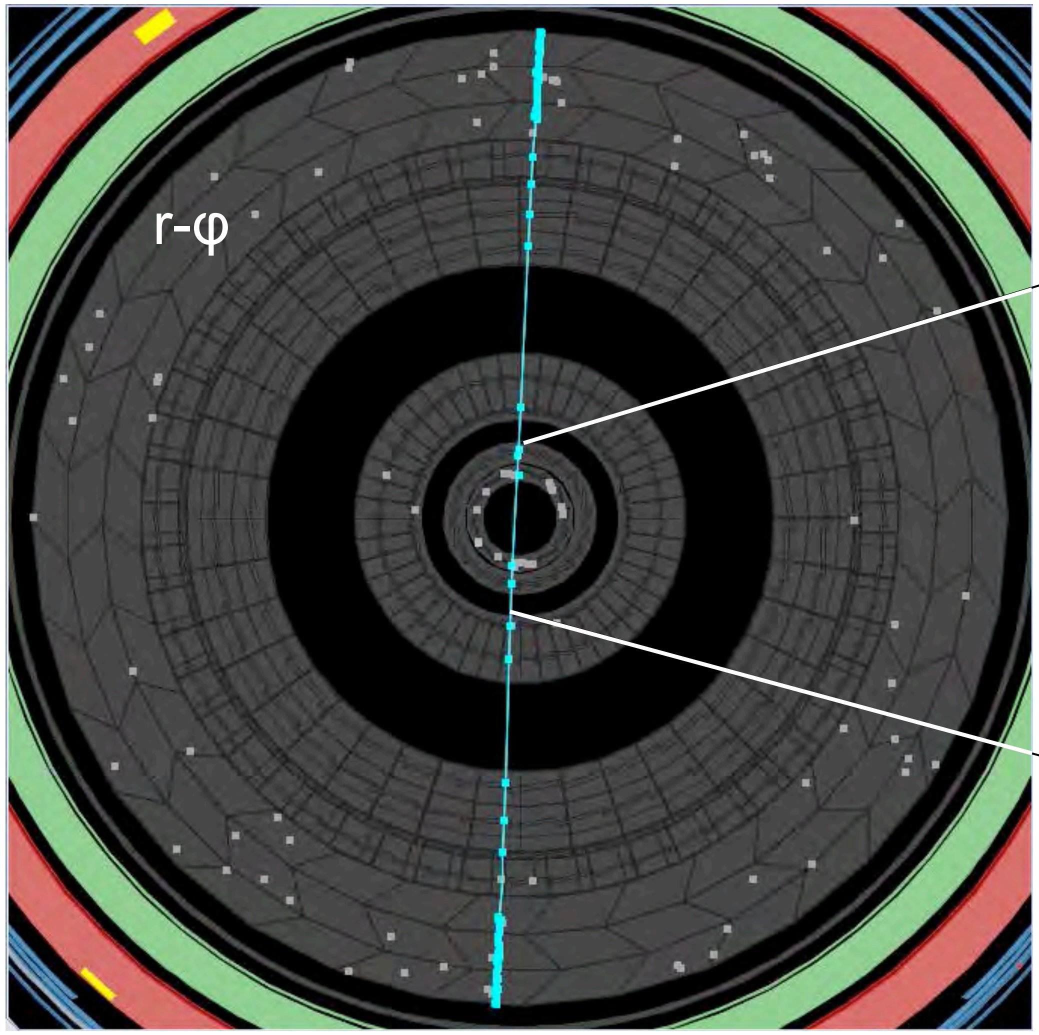
(Sylvia Goy, LHCC Nov 2014)

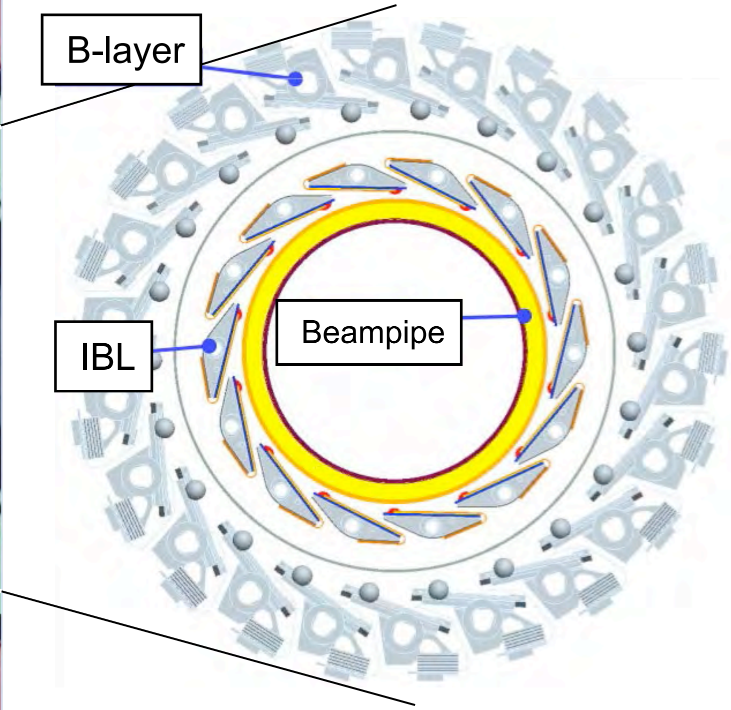
# IBL integration in Cosmic run

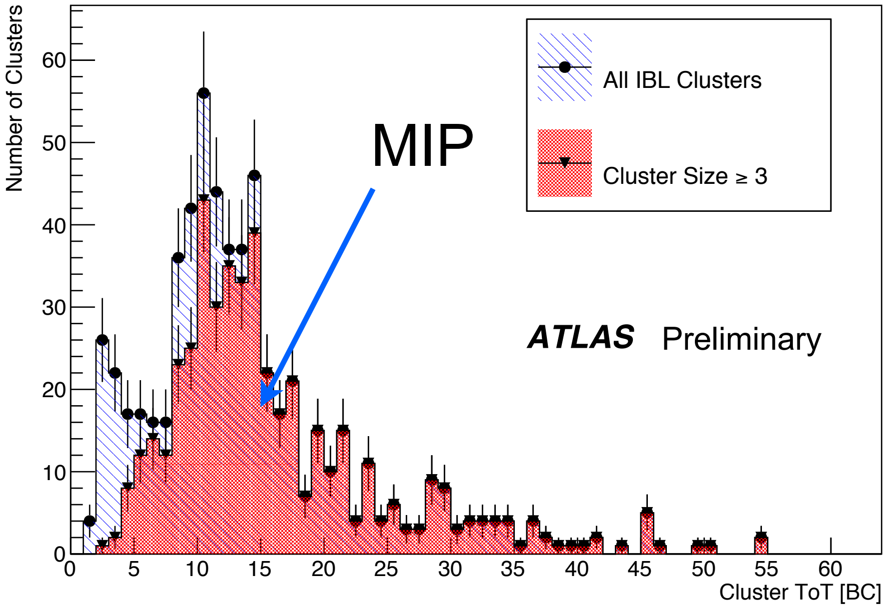


IBL and Pixel data taking with ATLAS :
Successful track reconstruction in all ID parts

DAQ, calibration, DCS, online/offline are integrated and are under the test
DCS integrated; Cooling/PS operating stably





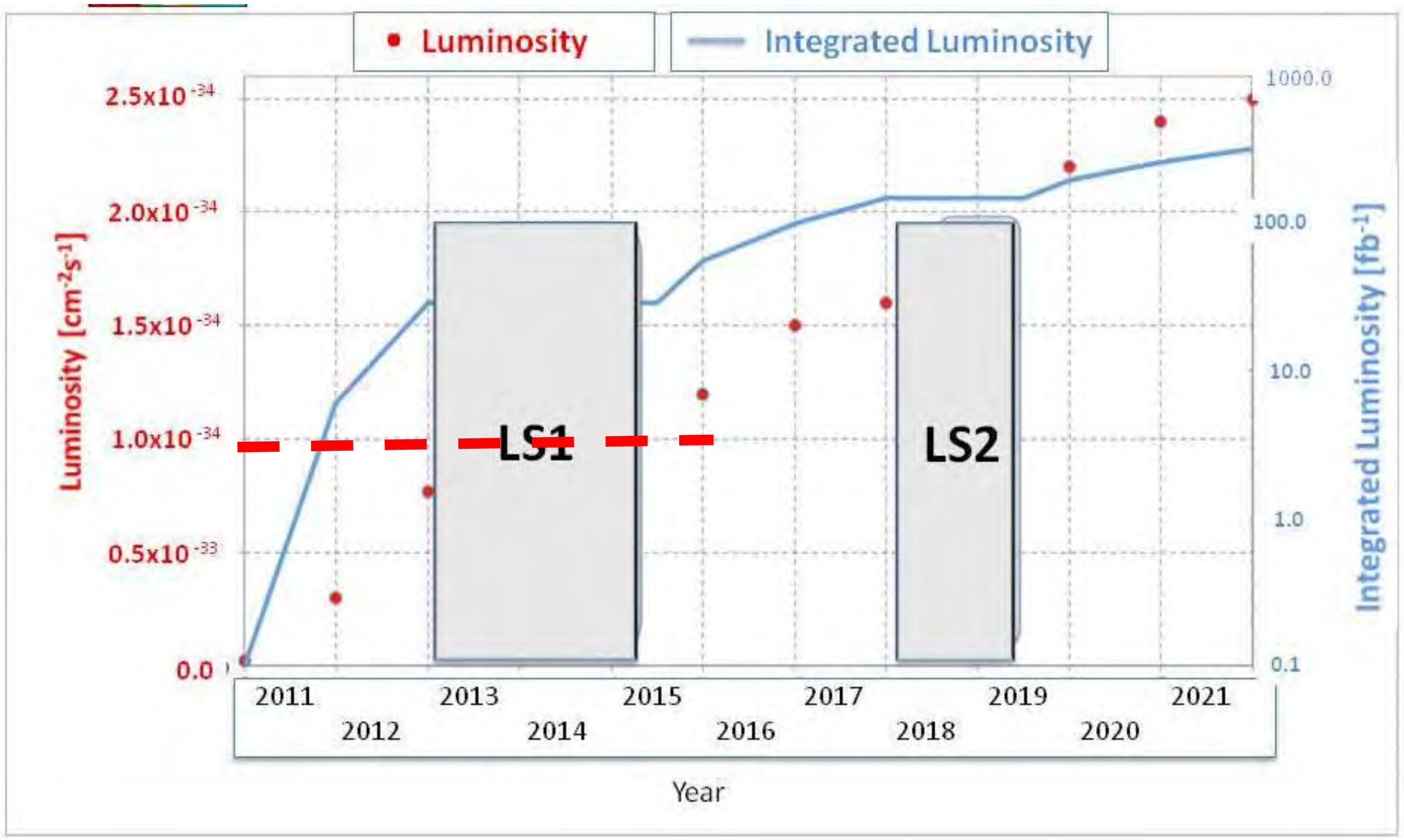


Time over Threshold

# ATLAS & CMS Closing Up and Commissioning for Run 2 and…

# Preparing Phase-1 Upgrades

# LHC Performance & Schedules



Conditions
- ~ $2x10^{34}$ by LS2, higher after LS2
- ~ $200fb^{-1}$ by LS2, ~ $500fb^{-1}$ by LS3
- 25ns is the plan, but … easier and more reliable at 50ns?
- Integrated luminosity is the goal

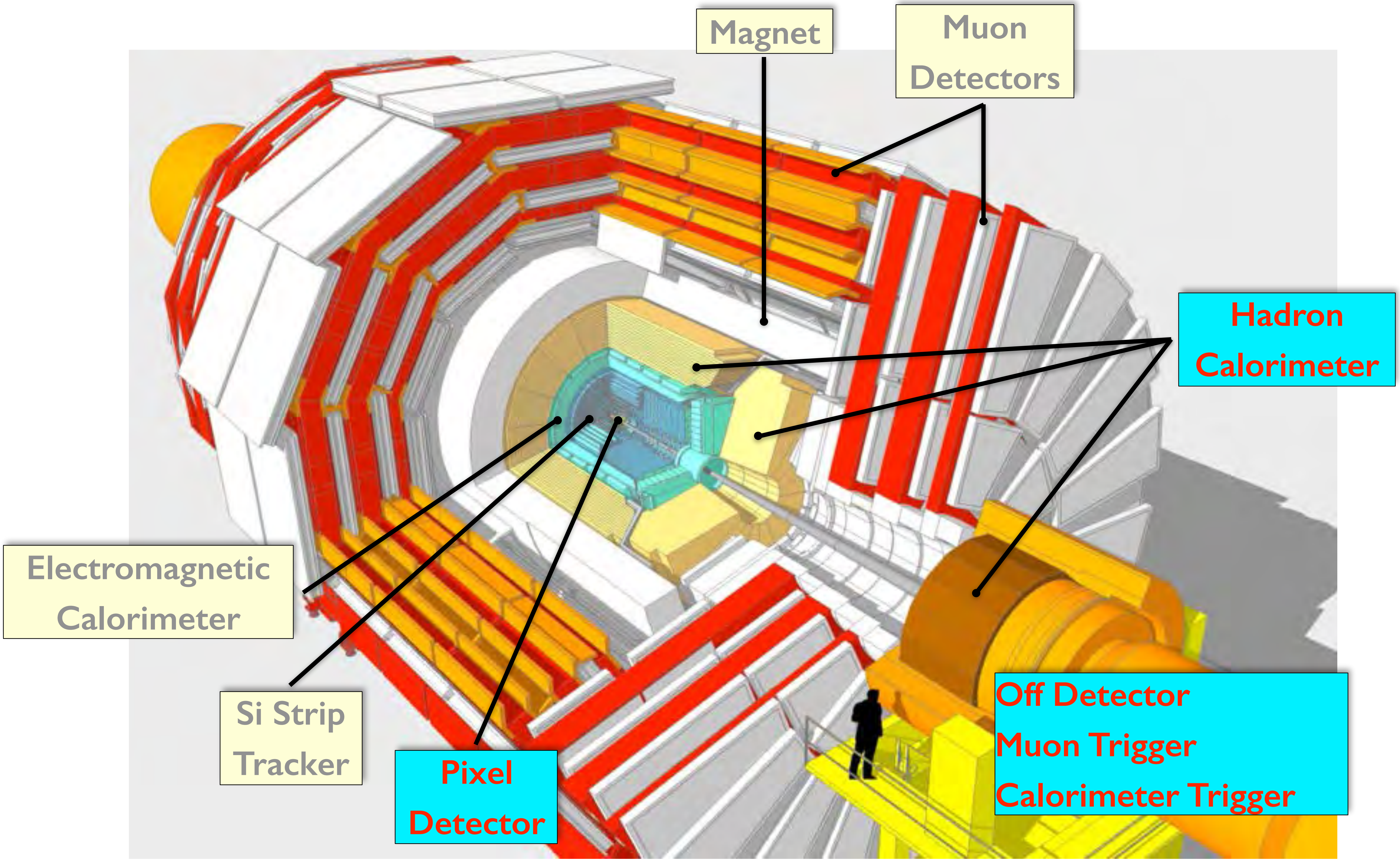
For the Upgrades
- “Baseline” PU~50, study ~100
- Lumi-leveling will come into play

| | Number of bunches | β* [m] | Half X-angle [μrad] | Ib SPS | Emit SPS [um] | Peak Lumi [$cm^{-2}s^{-1}$] | ~Pile-up | Int. Lumi [$fb^{-1}$] |
|---|---|---|---|---|---|---|---|---|
| 25 ns | 2800 | 0.50 | 190 | 1.2e11 | 2.8 | 1.1e34 | 23 | ~30 |
| 50 ns | 1380 | 0.40 | 140 | 1.7e11 | 2.1 | 1.8e34<br>β* level | 81<br>β* level | ? |
| 25 ns low emit | 2600 | 0.40 | 150 | 1.15e11 | 1.4 | 2.0e34 | 48 | 52 |
| 50 ns low emit | 1200 | 0.40 | 120 | 1.71e11 | 1.5 | 2.2e34 | 113 | ? |

# Basic Goal of the CMS Phase-1 Upgrade

- Preserve the ability to reconstruct all the Standard Model objects and Missing Energy at higher luminosity than the original design
  - Achieve the same or better efficiency, resolution, trigger thresholds, and background rejection at 14 TeV with 50+ pile-up than at 8 TeV with less than 20 pile-up
- Evolutionary upgrades to existing detectors when access is possible:
  - Hadron Calorimeter
  - Pixel Detector
  - Level 1 Trigger

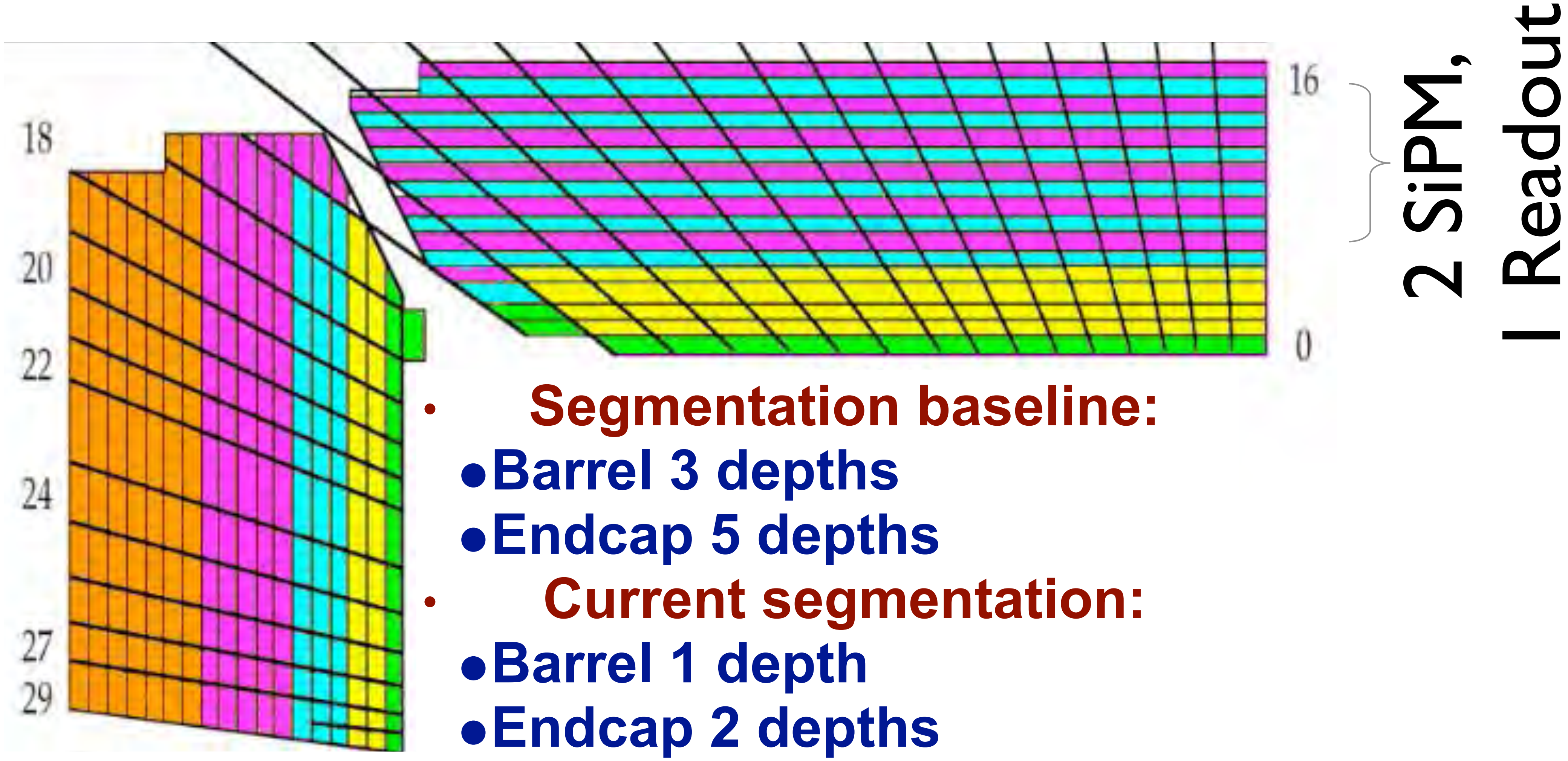
# Scope of CMS Phase-1 Upgrade



# Brief Description of the Phase-1Project

- Hadron Calorimeter (HCAL):
  - New "frontend" photosensors with higher gain allows longitudinal granularity and includes timing information to deal with the higher pileup.
  - Accompanying "backend" electronics, provides increased bandwidth to handle the resulting larger volume of information
- Pixel Tracker (PIX):
  - New 3 layer endcap detector, replacing current 2 layer one, new 4 layer barrel detector, replacing current 3 layer one, which improves tracking and vertexing, and decreases multiple scattering and conversion due to less mass in the tracking volume and mitigates data loss due to modern readout chip electronics. **INSTALL IN 2016/2017**
- Level 1 Trigger (TRIG):
  - Conversion to modern electronics system ($\mu$TCA) with high bandwidth optical links and large FPGAs allowing more sophisticated algorithms to run on the expanded amount of data available the calorimeter and muon system.

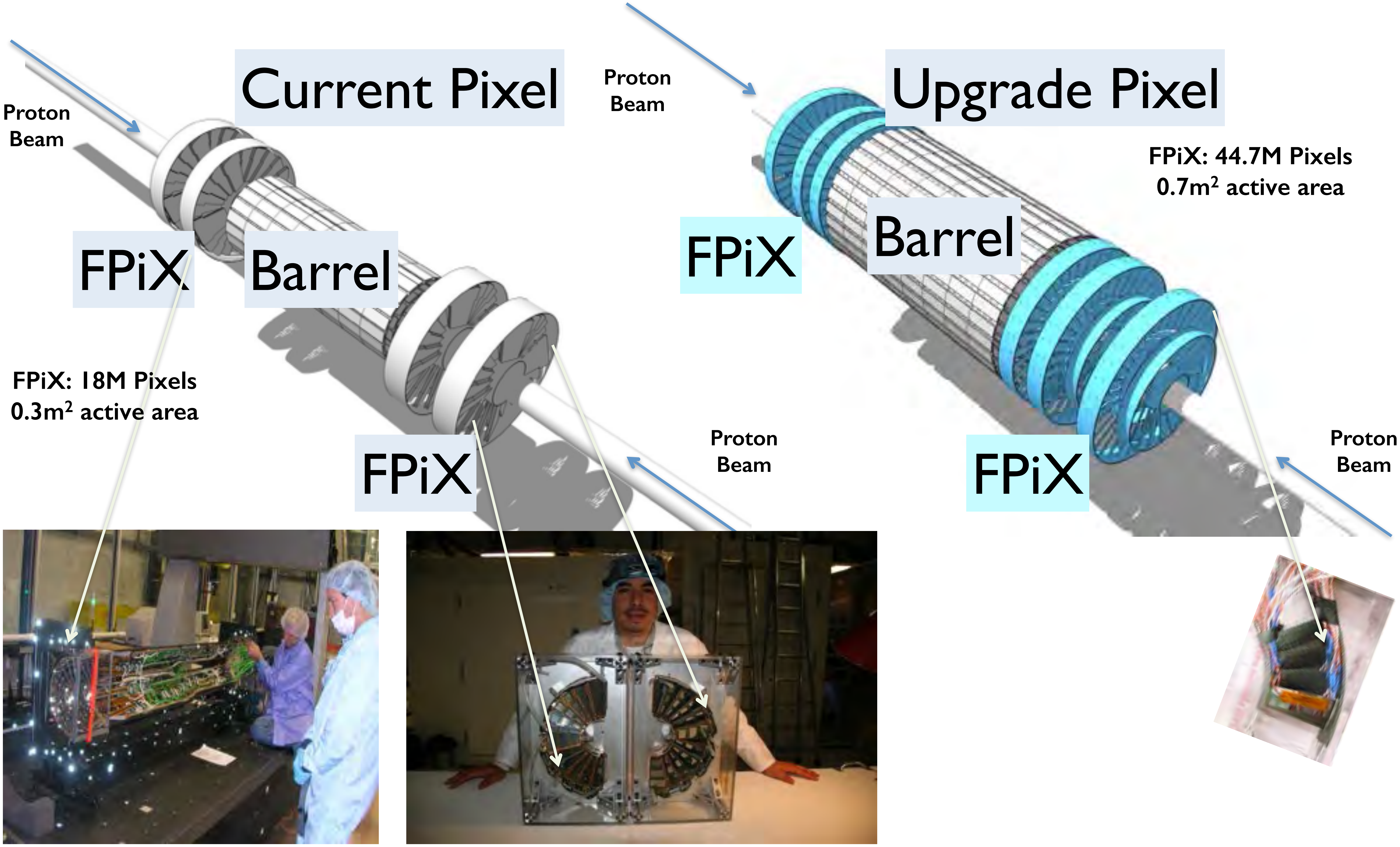
# HCAL Phase-1 Upgrade



- **Segmentation baseline:**
  - **Barrel 3 depths**
  - **Endcap 5 depths**
- **Current segmentation:**
  - **Barrel 1 depth**
  - **Endcap 2 depths**

- Increased gain of SiPMs and high data link volumes allow for increased depth segmentation of the calorimeter
  - Amount of segmentation limited by power/ cooling/volume
- Radiation damage is strongly depth-dependent, requiring depth segmentation for correction without introducing large constant term

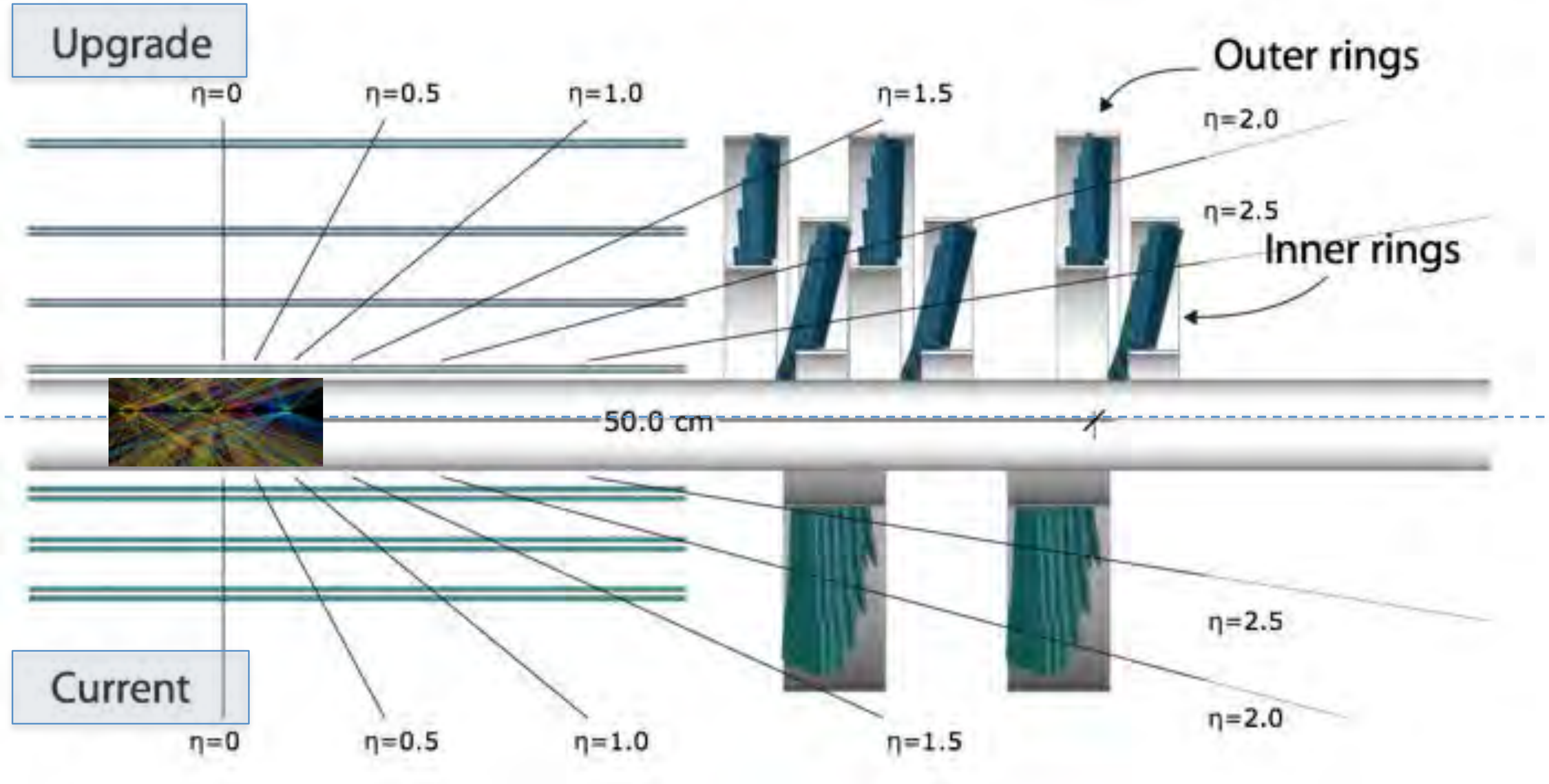
# Phase-1 Upgrade Pixels



FPiX: 18M Pixels
0.3m$^2$ active area

FPiX: 44.7M Pixels
0.7m$^2$ active area

# Requirements



*__Pixel Upgrade:__*

- Baseline L = $2x10^{34}$ cm$^{-2}$sec$^{-1}$ & 25ns → 50 pileup **(50PU)**
- Tolerate L = $2x10^{34}$ cm$^{-2}$sec$^{-1}$ & **50ns** → 100 pileup **(100PU)**
- **Survive Integrated Luminosity of 500fb$^{-1}$**
- (Evolutionary upgrade with) **minimal disruption of data taking**
- **Same detector concept**: higher rate readout, data link & DAQ w/ less material forward
- **Robustify tracking** : 4 hit coverage;)

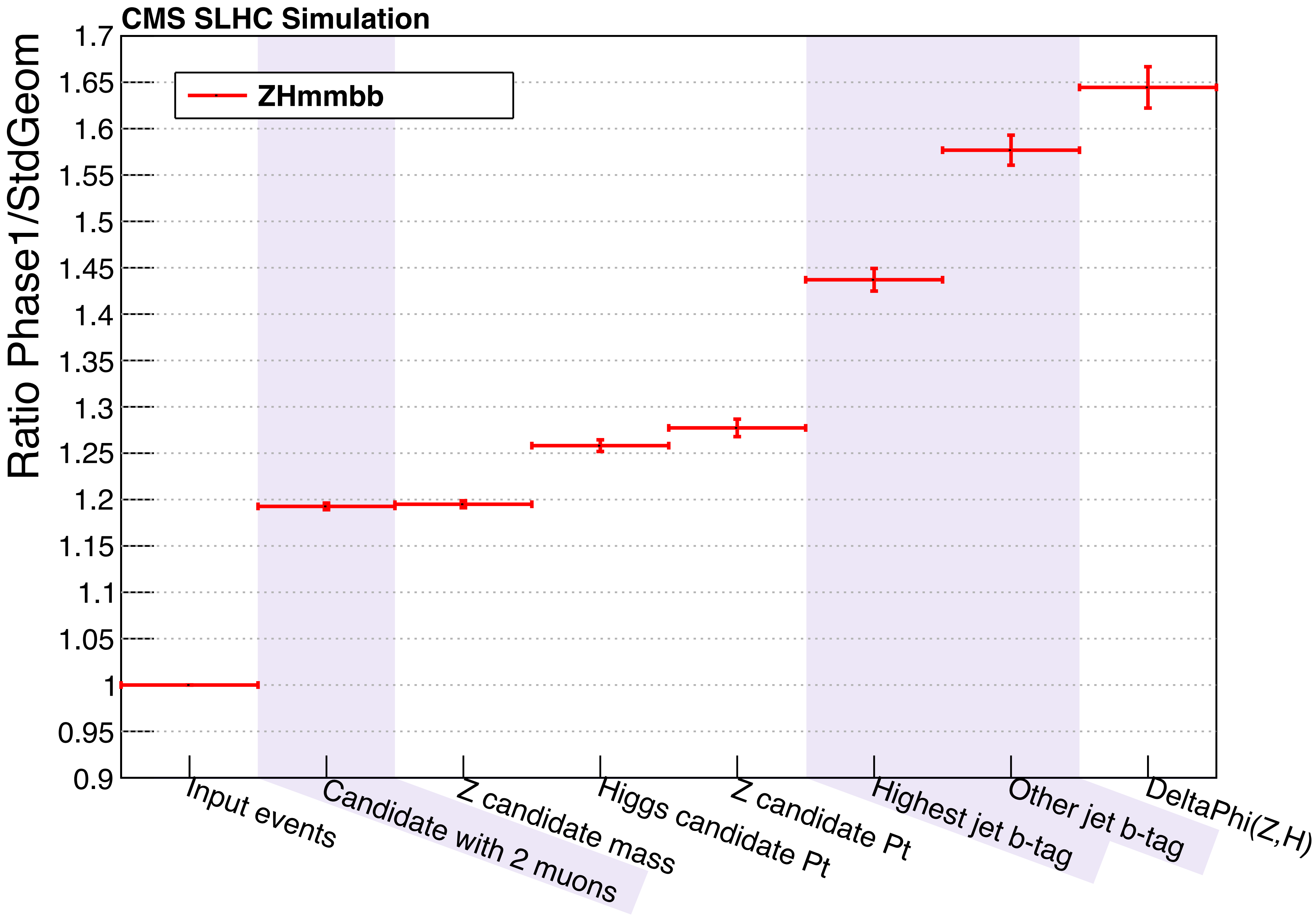
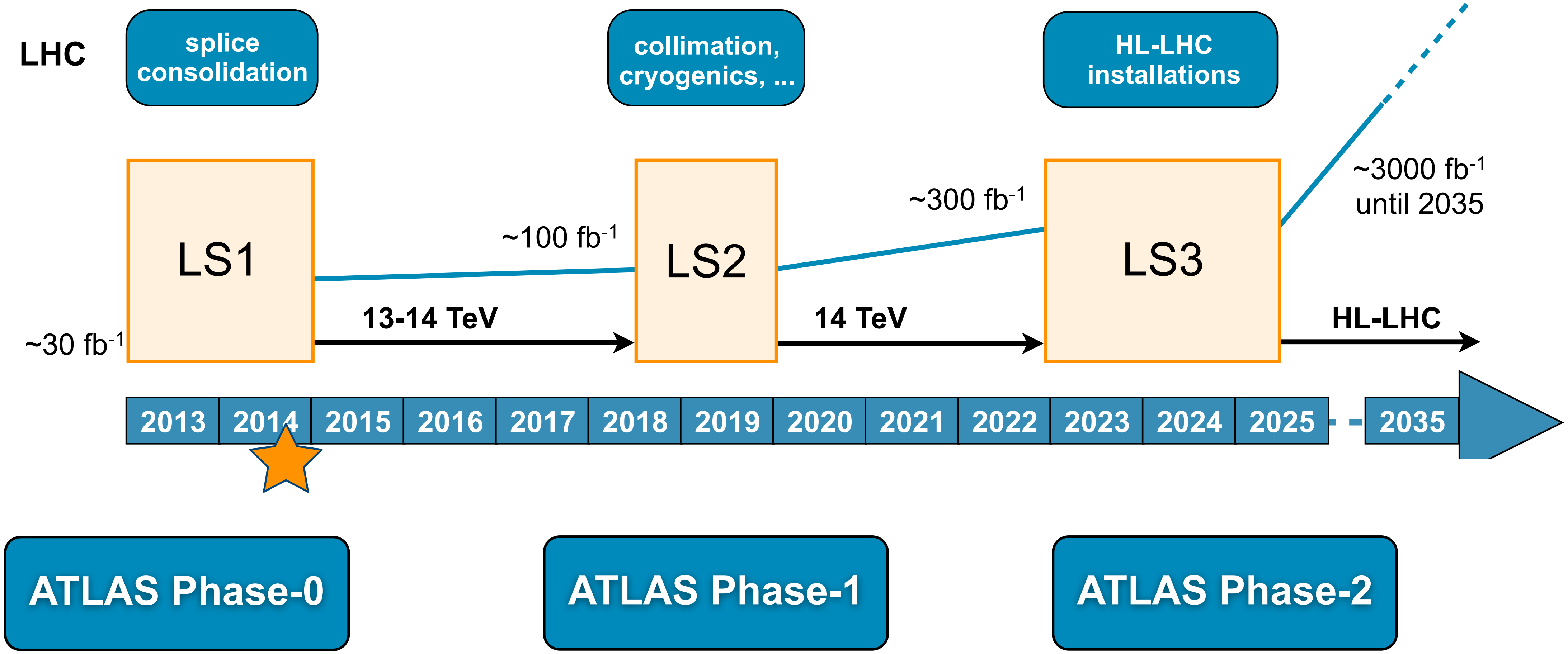


Figure 14: The ratio of the number of events each sequential cut for the upgraded detector relative to the current detector. The cuts where the largest improvement from the upgraded detector are expected are highlighted.

# THE ATLAS ROADMAP



LHC

splice consolidation

collimation, cryogenics, ...

HL-LHC installations

LS1

LS2

LS3

~30 fb$^{-1}$

~100 fb$^{-1}$

~300 fb$^{-1}$

~3000 fb$^{-1}$ until 2035

13-14 TeV

14 TeV

HL-LHC

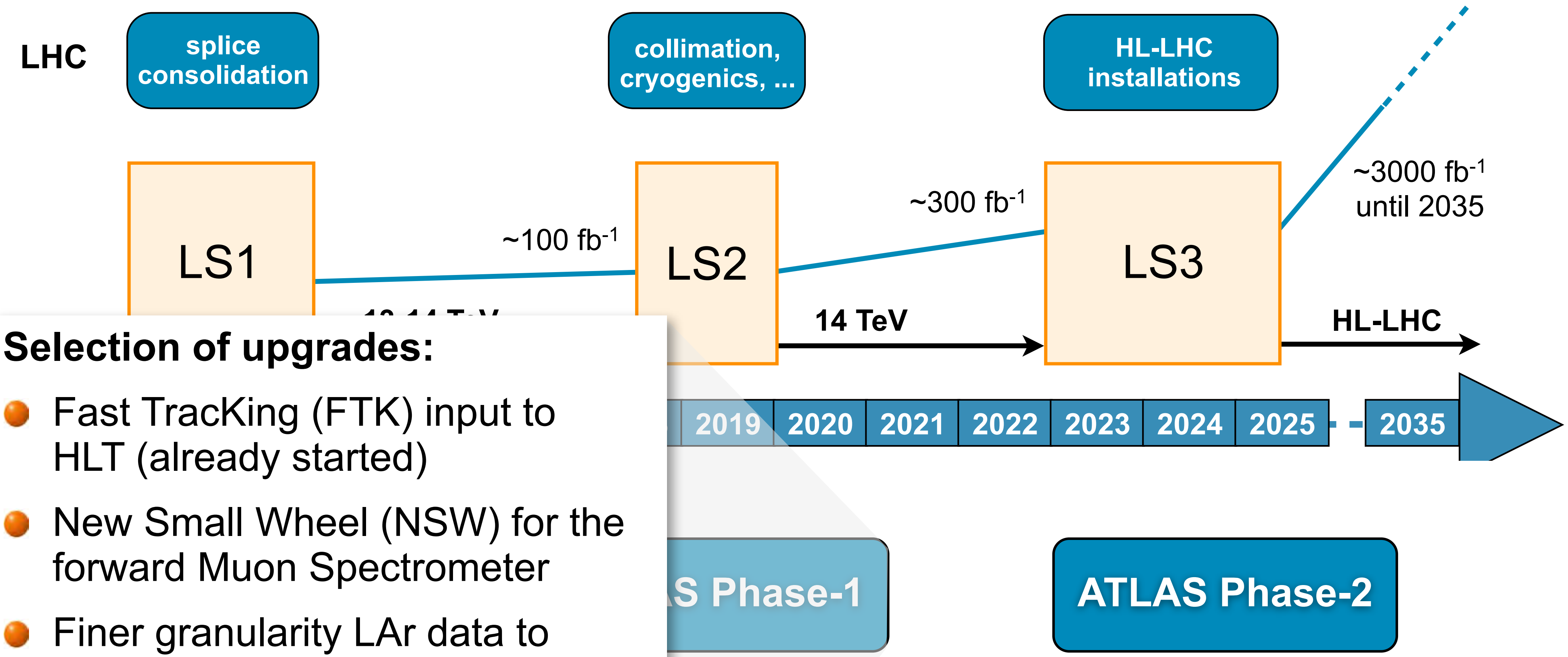
2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2035

ATLAS Phase-0

ATLAS Phase-1

ATLAS Phase-2

# THE ATLAS ROADMAP



**Selection of upgrades:**

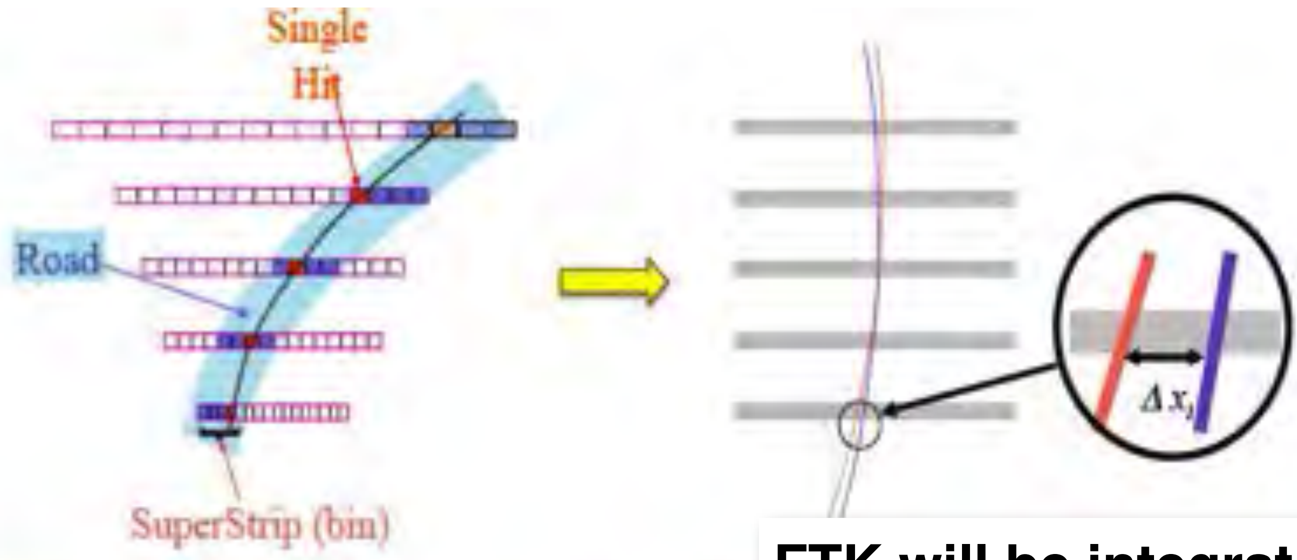
- Fast TracKing (FTK) input to HLT (already started)
- New Small Wheel (NSW) for the forward Muon Spectrometer
- Finer granularity LAr data to Level-1
- TDAQ Upgrades to Level-1/HLT
- Additional forward proton system (AFP)

# FAST TRACK TRIGGER (FTK)

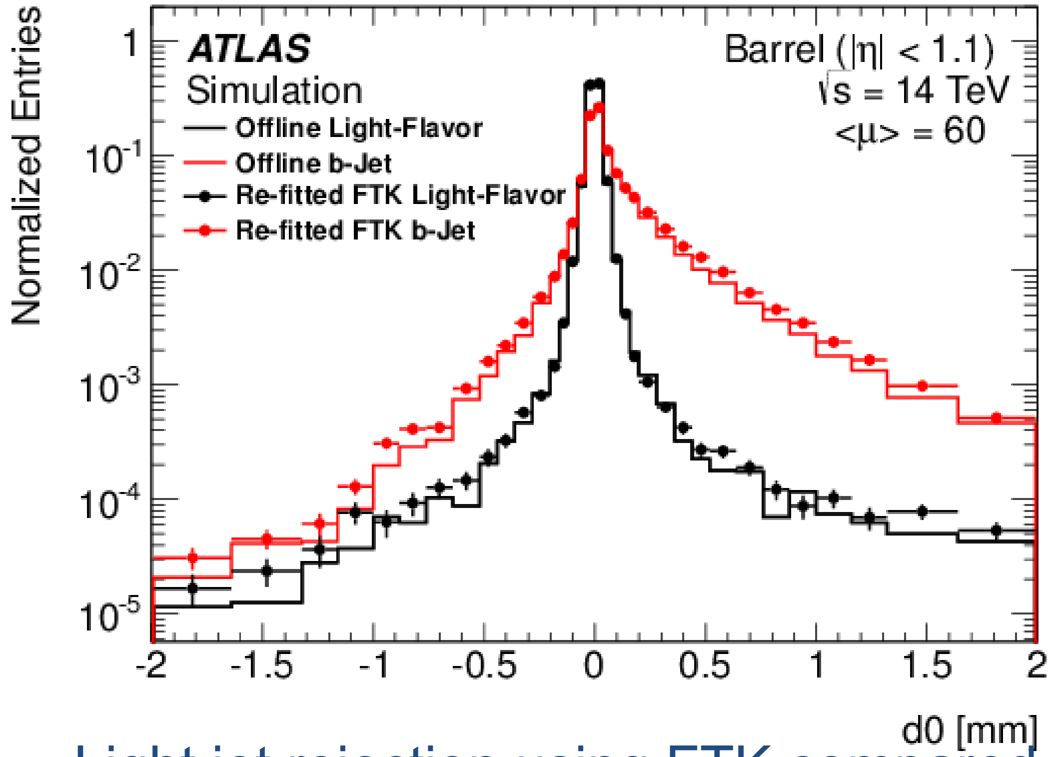
- Dedicated, hardware-based track finder (based on CDF Silicon Vertex Triggering development)
  - Runs after the first level trigger on duplicated Si-detector read-out links.
  - Provides tracking input to the HLT for the full event at 100kHz.
  - Finds and fits tracks (~ 25 μs) in the ID silicon layers at nearly offline precision.
- Processing performed in two steps

hit pattern matching to pre-stored patterns (coarse)

subsequent linear fitting in FPGAs (precise)



Associative memory ASIC

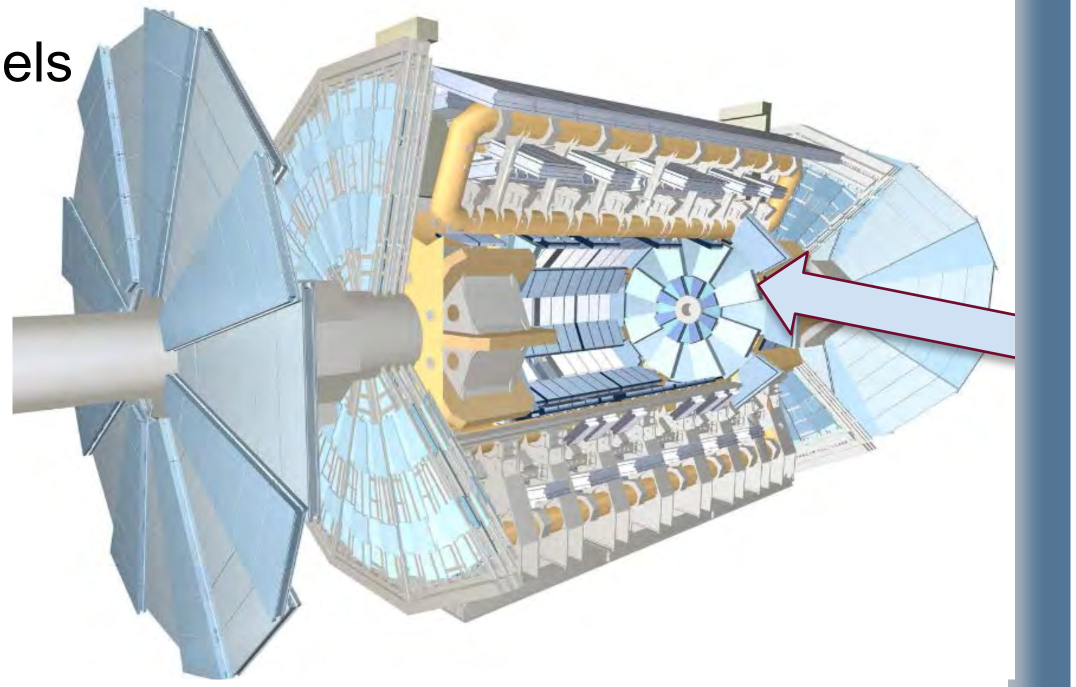


Light jet rejection using FTK compared to offline reconstruction

**FTK will be integrated in run 2 with complete coverage by 2016**

# MUONS: NEW SMALL WHEEL

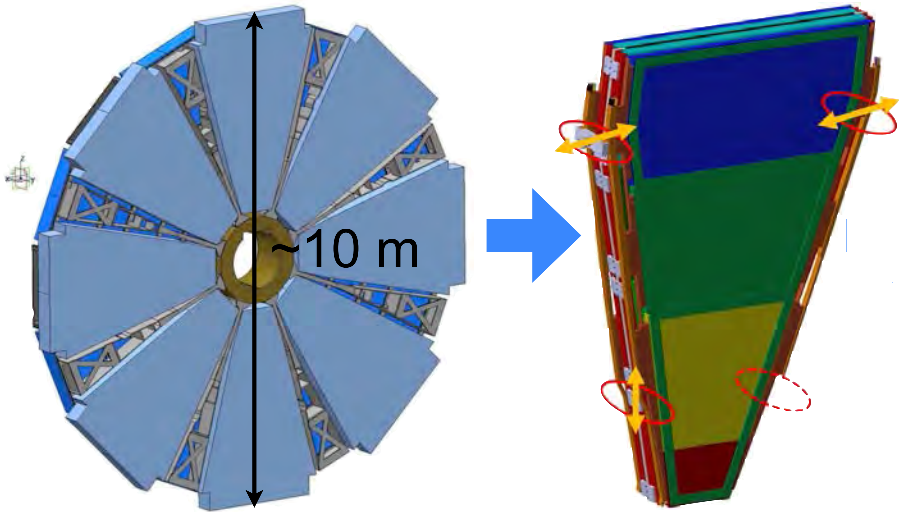
- Consequences of luminosity rising beyond design values for forward muon wheels
  - Degradation of the tracking performance (efficiency / resolution)
  - L1 muon trigger available bandwidth exceeded unless thresholds are raised



- Replace Muon Small Wheels with **N**ew Muon **S**mall **W**heels
  - Improved tracking and trigger capabilities
  - Meets Phase-2 requirements
    - compatible with <μ>=200, up to L~$7 \times 10^{34}$ $cm^{-2}s^{-1}$

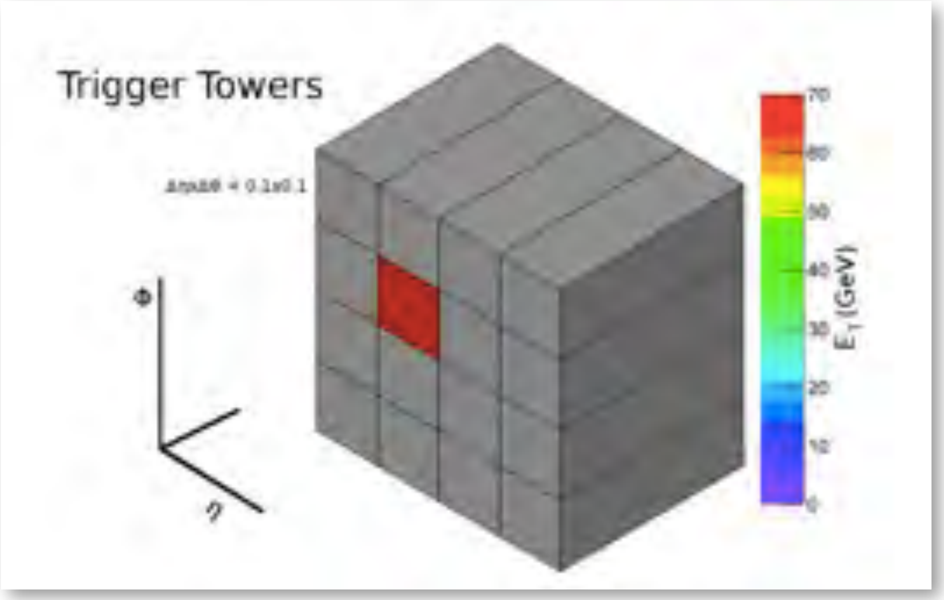
- MicroMegas (area of 1200 $m^2$)
  - Space resolution < 100 μm independent of incidence angle
  - High granularity -> good track separation
  - High rate capability due to small gas amplification region and small space charge effect

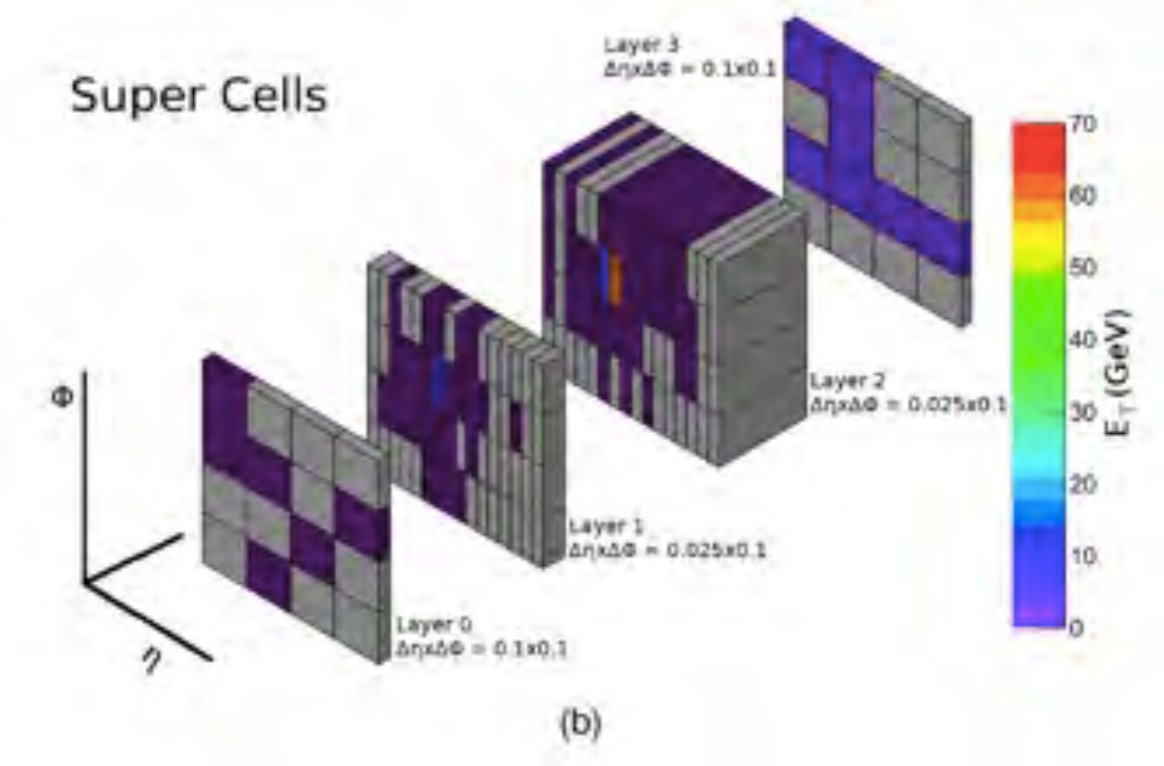
- Small strip Thin Gap Chambers (sTGC) (area of 1200 $m^2$)
  - Space resolution < 100 μm independent of incidence angle
  - Bunch ID with good timing resolution to suppress fakes
  - Track vectors with < 1 mrad angular resolution
  - Based on proven TGC technology



# LEVEL 1 CALORIMETER TRIGGER UPGRADE

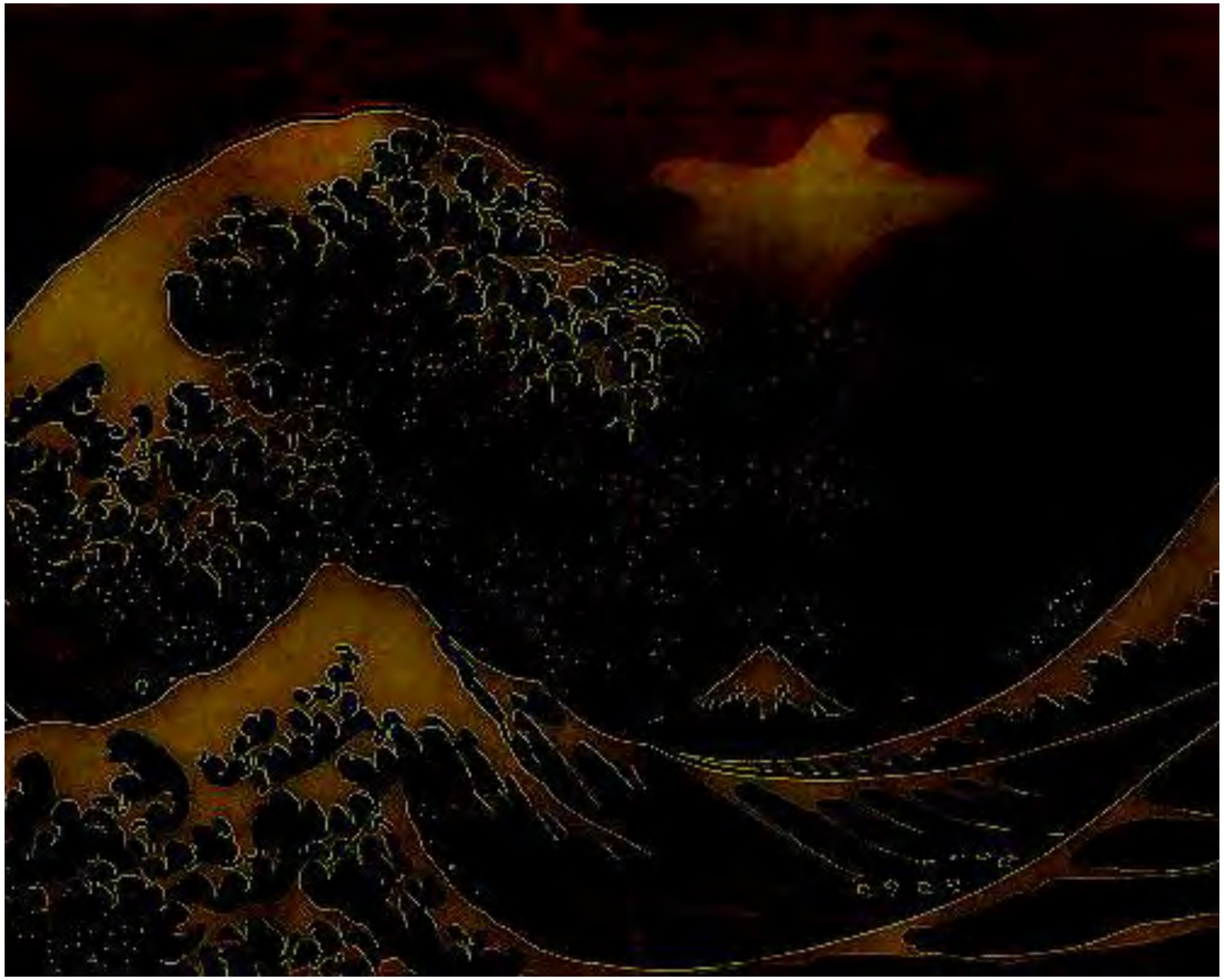
- Upgrade of LAr Level-1 trigger electronics, to provide finer granularity for Level-1 trigger decision
  - e.g. 10 super-cells instead of 1 trigger tower (in the barrel)
  - introduction of Feature Extraction Modules (FEX) in trigger path.
- Maintain high efficiency for Level-1 triggering on low $p_T$ electrons and photons.
- Retain transverse energy in each layer instead of summing → longitudinal shower information.
- Improvement in Level-1 trigger electron reconstruction, isolation, energy resolution.
- Forward compatible with Phase-2 Upgrade.





# Phase-2 Upgrades

*The LHC has allowed us to glimpse the outlines of some remarkable physics, but we don't see the detail clearly…*



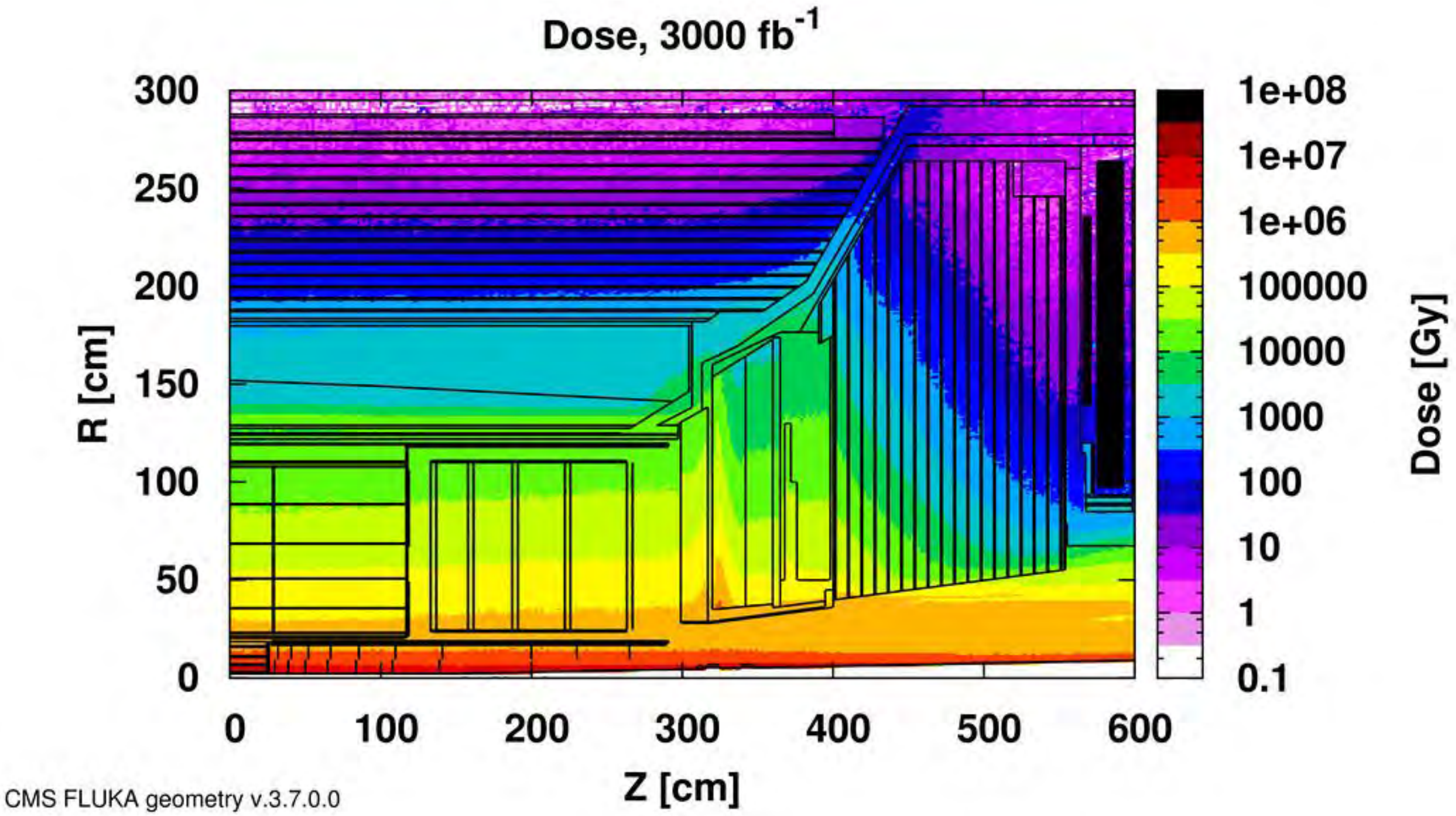
*The HL-LHC is a much brighter light to shine on the situation…*

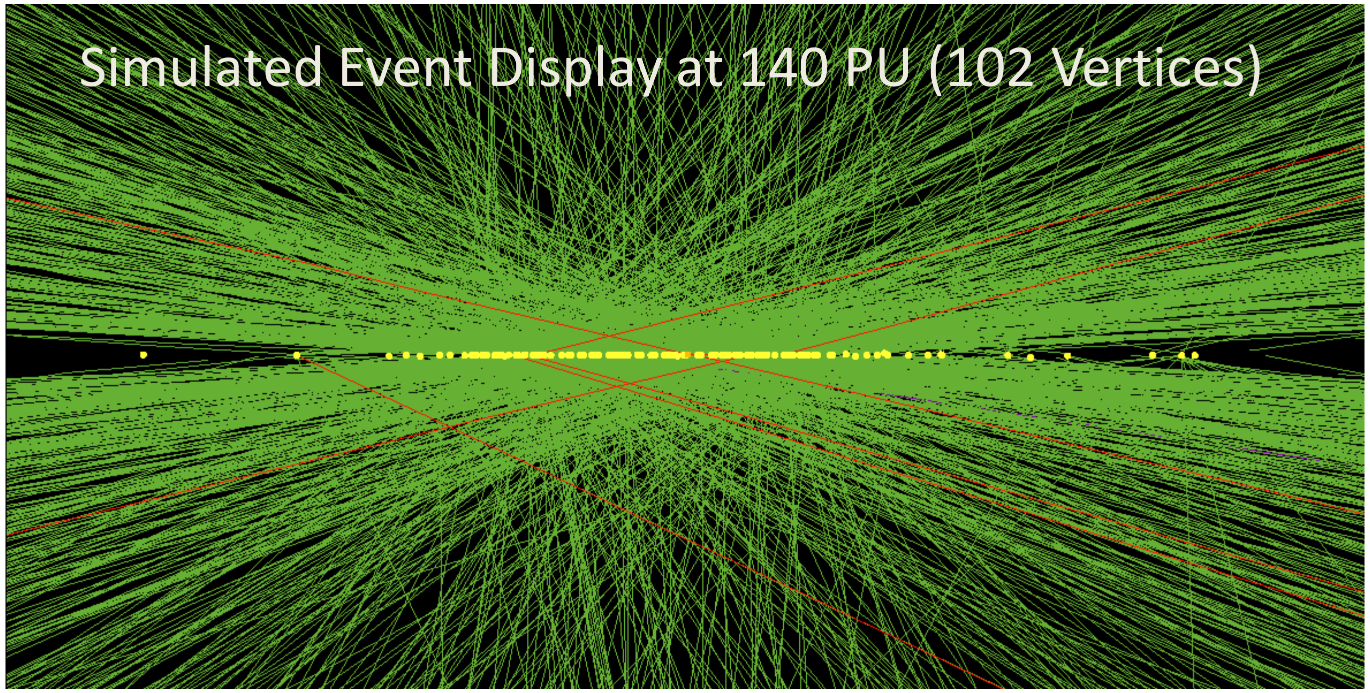
(J. Mans)

# The HL-LHC is a very bright lamp to see physics details, which makes it a challenging environment for detectors and reconstruction

- Radiation
  - Ionizing dose
  - Neutron fluences up to $2 \times 10^{16}$ n/cm$^2$ in pixels

- Pileup
  - 140 average simultaneous interactions (many events with > 180)



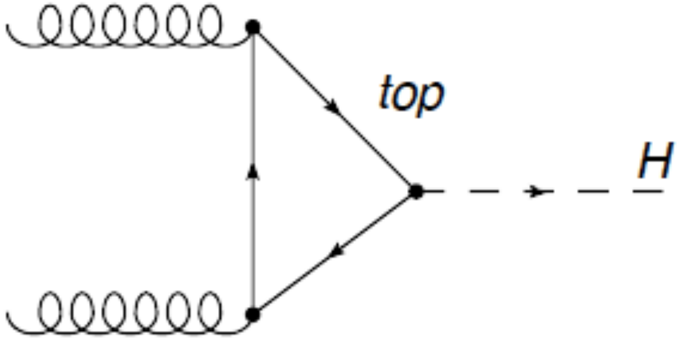


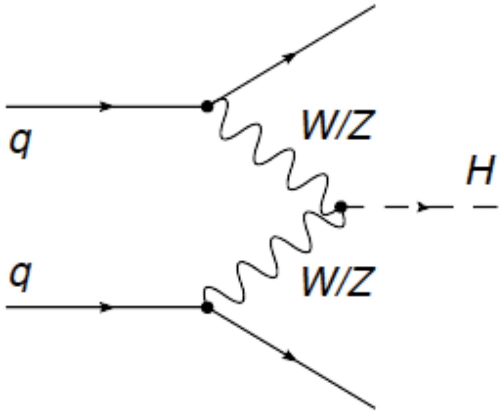
(J. Mans)

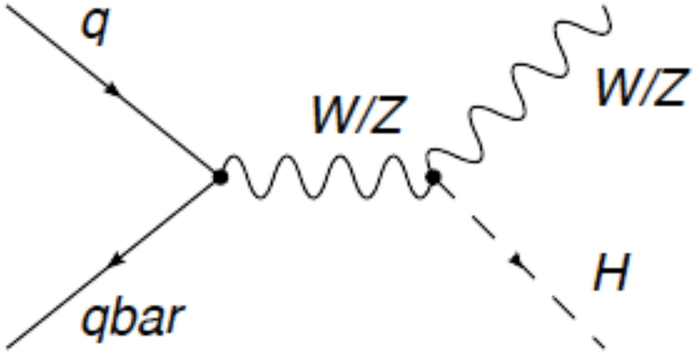
(J. Mans)

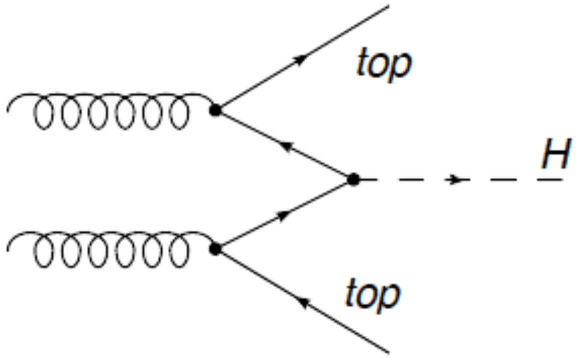
# Higgs factory: HL-LHC

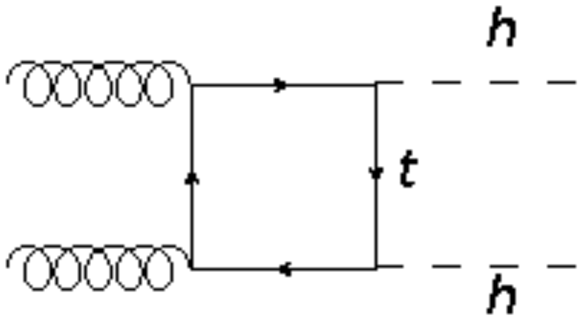
| | Higgs bosons at √s=14TeV |
|---|---|
| HL-LHC, 3000fb$^{-1}$ | 170M |
| VBF (all decays) | 13M |
| ttH (all decays) | 1.8M |
| H->Zγ | 230k |
| H->μμ | 37k |
| HH (all) | 121k |

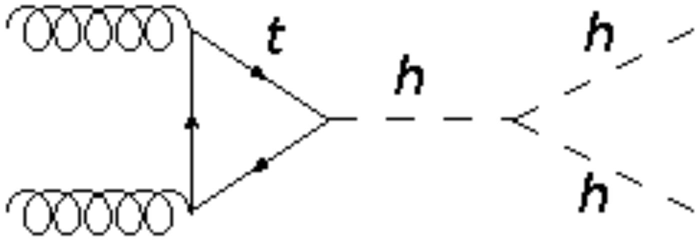








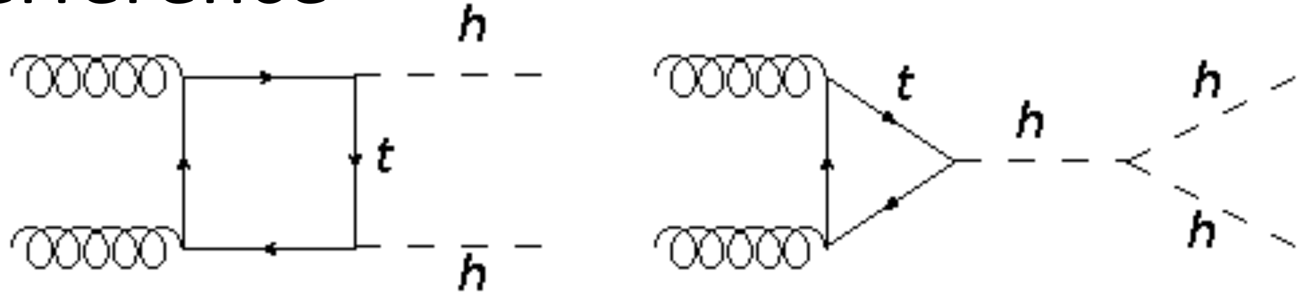




(A. Apyan, ECFA 2014)

# Di-Higgs Production

- One of the exciting prospects of HL-LHC
  - Cross section at √s=14 TeV is 40.2 fb [NNLO]
  - Challenging measurement
    - New preliminary results from ATLAS and CMS
- Destructive interference

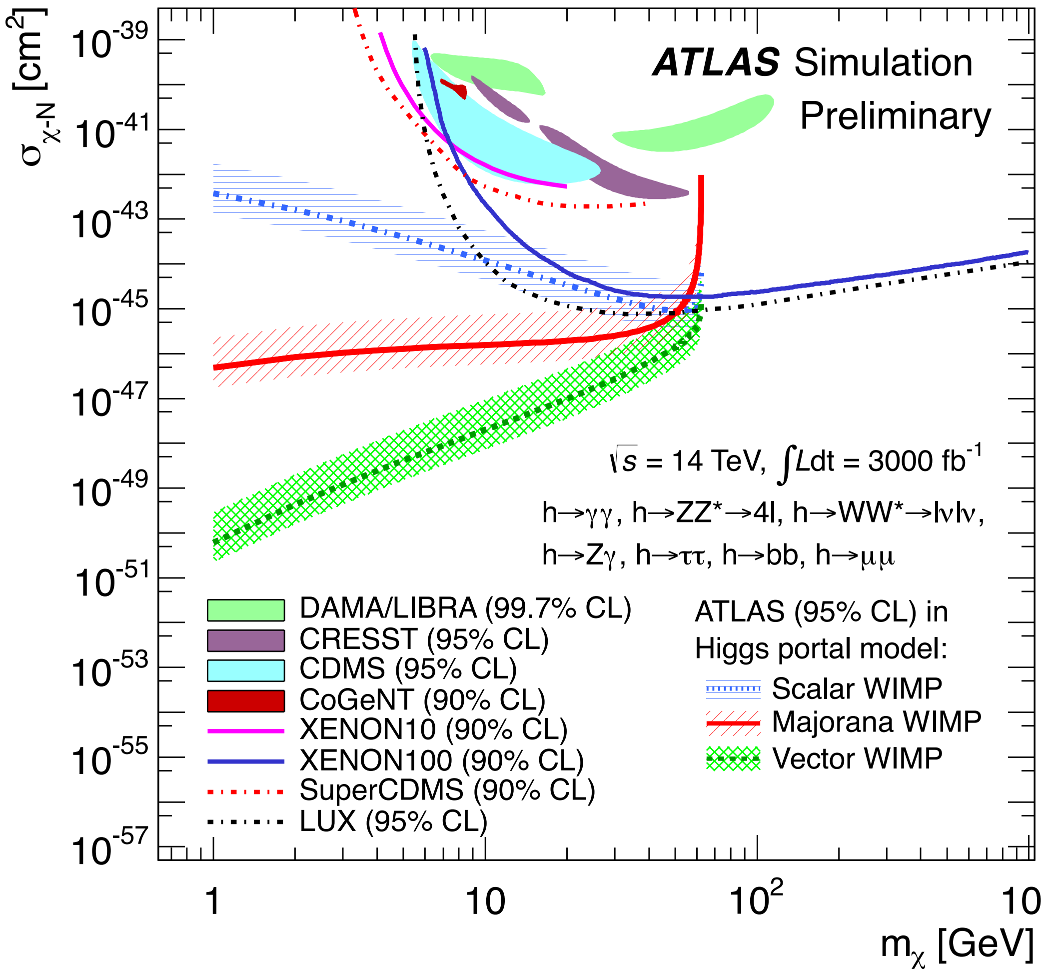


- Final states shown today
  - bbγγ [320 expected events at HL-LHC, 3000fb$^{-1}$]
    - But relatively clean signature
  - bbWW [30000 expected events at HL-LHC, 3000fb$^{-1}$]
    - But large backgrounds
- bbbb and bbττ final states under consideration

(A. Apyan, ECFA 2014)

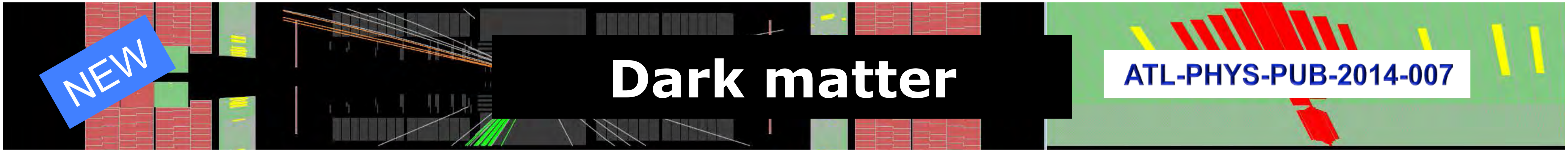
# Higgs portal to Dark Matter

- BR of Higgs decays to invisible final states
  - ATLAS: $BR_{inv} < 0.13$ (0.09 w/out theory uncertainties) at $3000 fb^{-1}$
  - CMS: $BR_{inv} < 0.11$ (0.07 in Scenario 2) at $3000 fb^{-1}$
- The coupling of WIMP to SM Higgs taken as the free parameter
- Translate limit on BR to the coupling of Higgs to WIMP



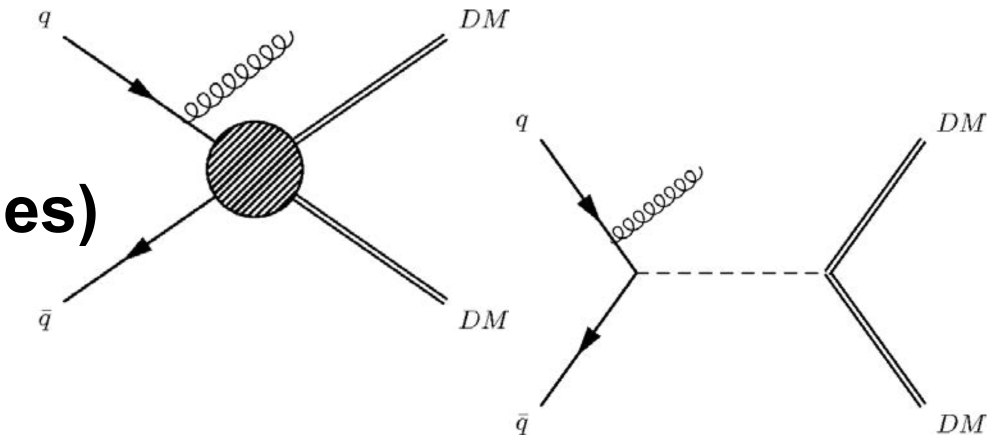
ATL-PHYS-PUB-2014-017

(A. Apyan, ECFA 2014)

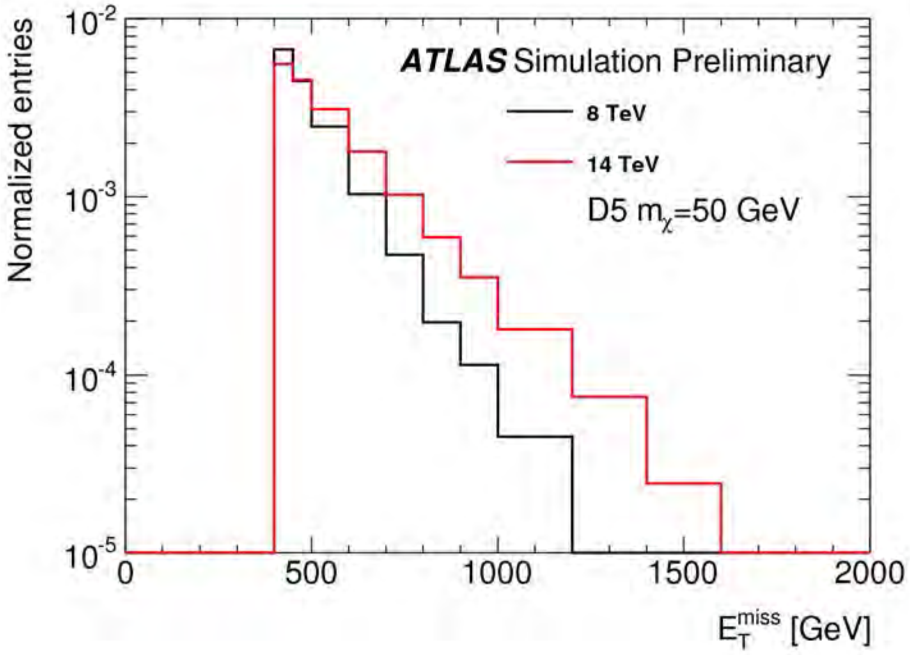


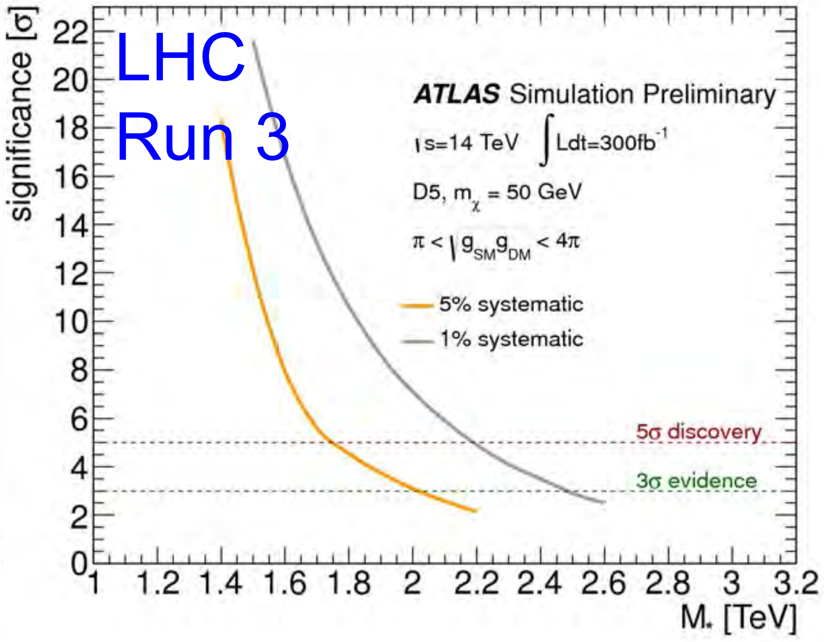
# Dark matter

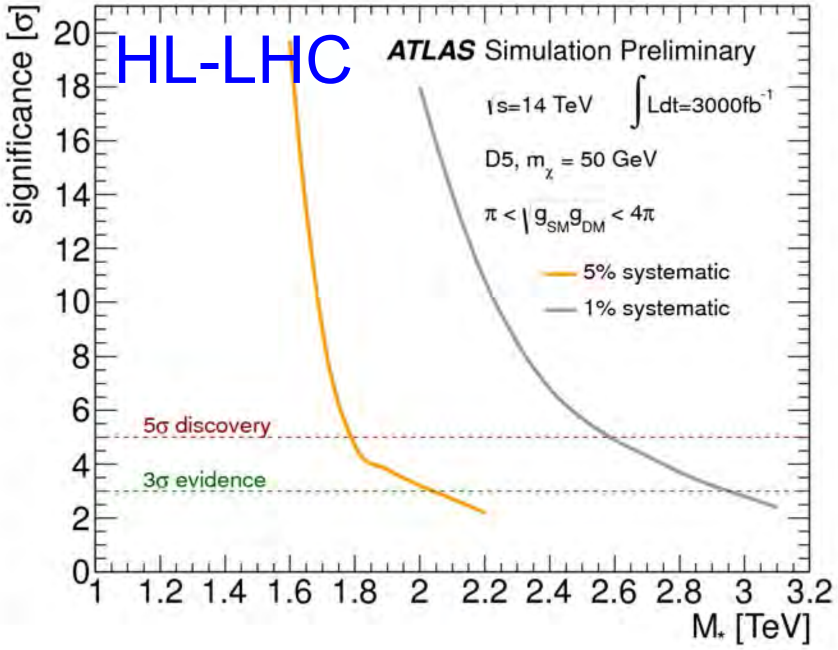
ATL-PHYS-PUB-2014-007



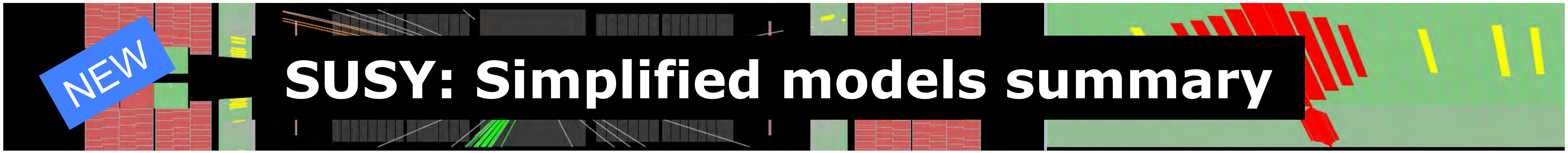
- **Models**
  - **Effective Field Theory (contact interaction btw SM and DM particles)**
  - **Simplified models with explicit mediator**
- **Signature (“mono-X”)**
  - **Initial state radiation or direct coupling via mediator particle**
  - **Mono-jet: high-$p_T$ leading jet (≤ 2 jets), large $E_T^{miss}$, e/μ veto**





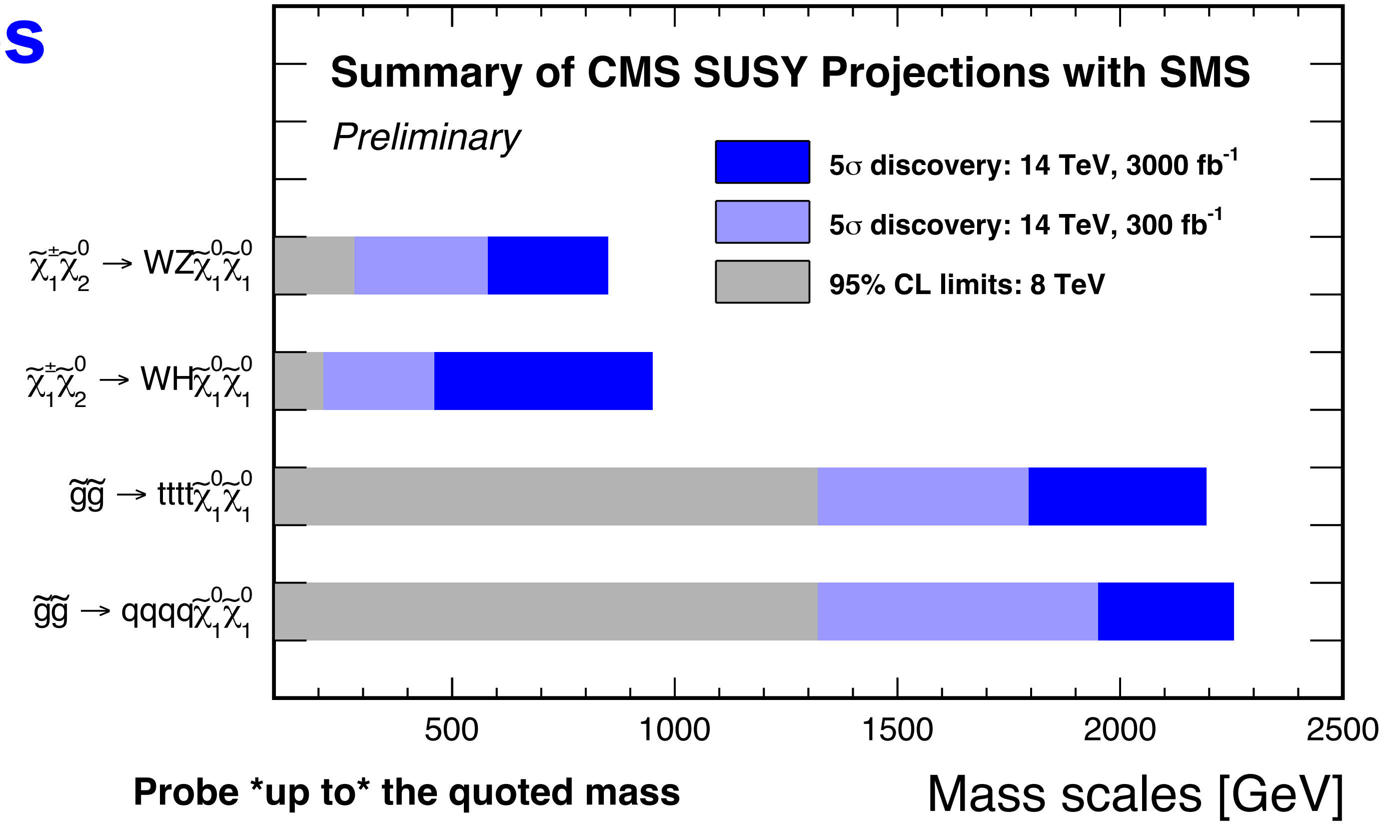


- **5σ discovery up to suppression scale M* of 2.2 (2.6) TeV for 300 (3000) fb$^{-1}$ (assuming 1% systematic uncertainty)**



# SUSY: Simplified models summary

- Focus on production of a reduced set of sparticles
  - Assume decoupled spectrum
  - Decay BR generally assumed to be 100%
- Discovery potential increases by ~20% in terms of gluino, squark and stop masses
- More substantial gains for $\chi_1^+\chi_2^0$ EW production
  - At least 50% increase in mass reach
    DOUBLES in case of WH final state

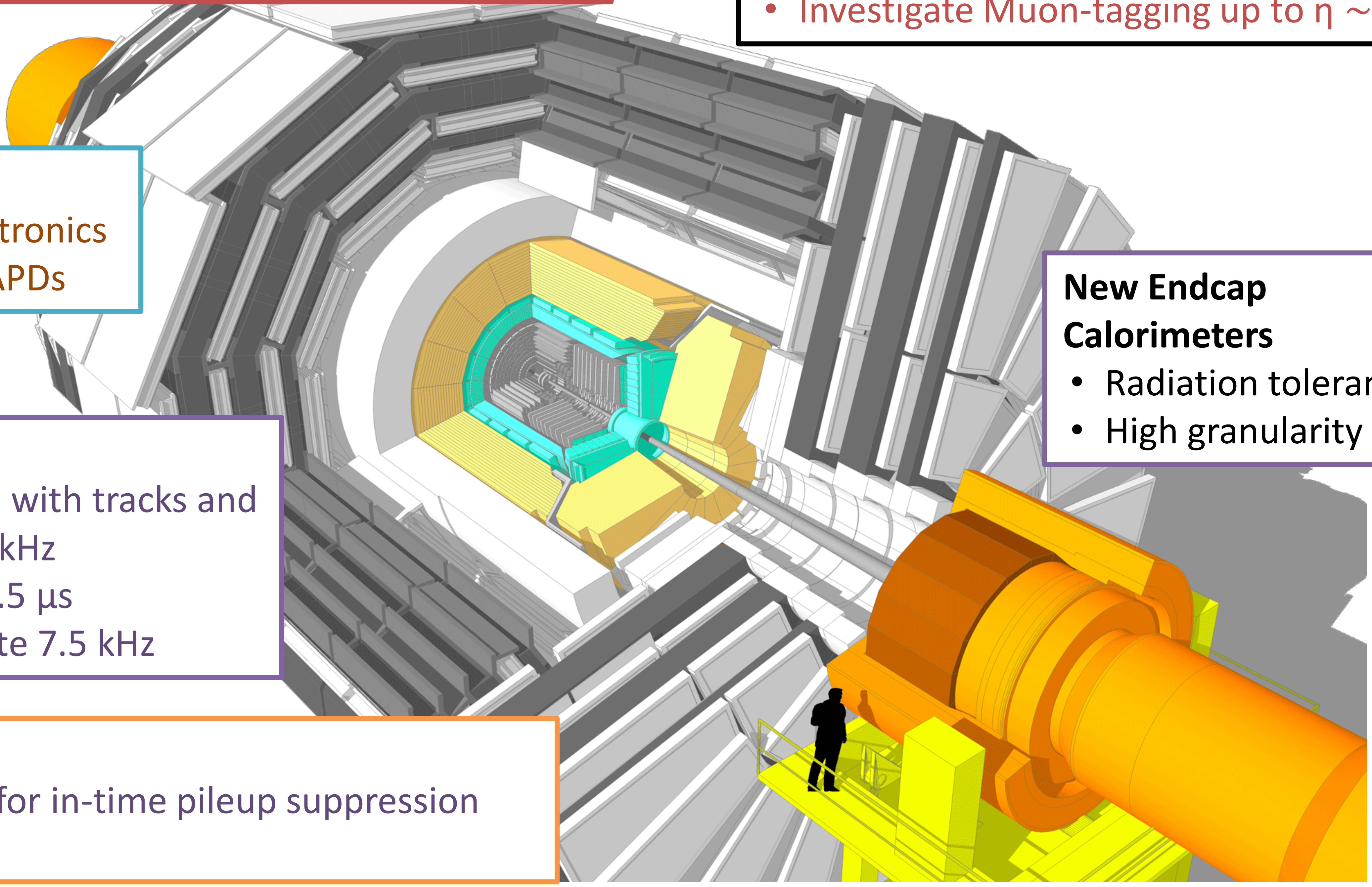


Probe *up to* the quoted mass

| **ATLAS** projection | gluino mass | squark mass | stop mass | sbottom mass | $\chi_1^+$ mass WZ mode | $\chi_1^+$ mass WH mode |
|---|---|---|---|---|---|---|
| Run 3<br>300 fb$^{-1}$ | 2.0 TeV | 2.6 TeV | 1.0 TeV | 1.1 TeV | 560 GeV | None |
| HL-LHC<br>3000 fb$^{-1}$ | 2.4 TeV | 3.1 TeV | 1.2 TeV | 1.3 TeV | 820 GeV | 650 GeV |

5σ discovery up to quoted mass

# CMS has a comprehensive plan for adjusting detector, where necessary, to cope with these challenges.



**New Tracker**

- Radiation tolerant - high granularity - less material
- Tracks in hardware trigger (L1)
- Coverage up to η ~ 4

**Muons**

- Replace DT FE electronics
- Complete RPC coverage in forward region (new GEM/RPC technology)
- Investigate Muon-tagging up to η ~ 3

**Barrel ECAL**

- Replace FE electronics
- Cool detector/APDs

**New Endcap Calorimeters**

- Radiation tolerant
- High granularity

**Trigger/DAQ**

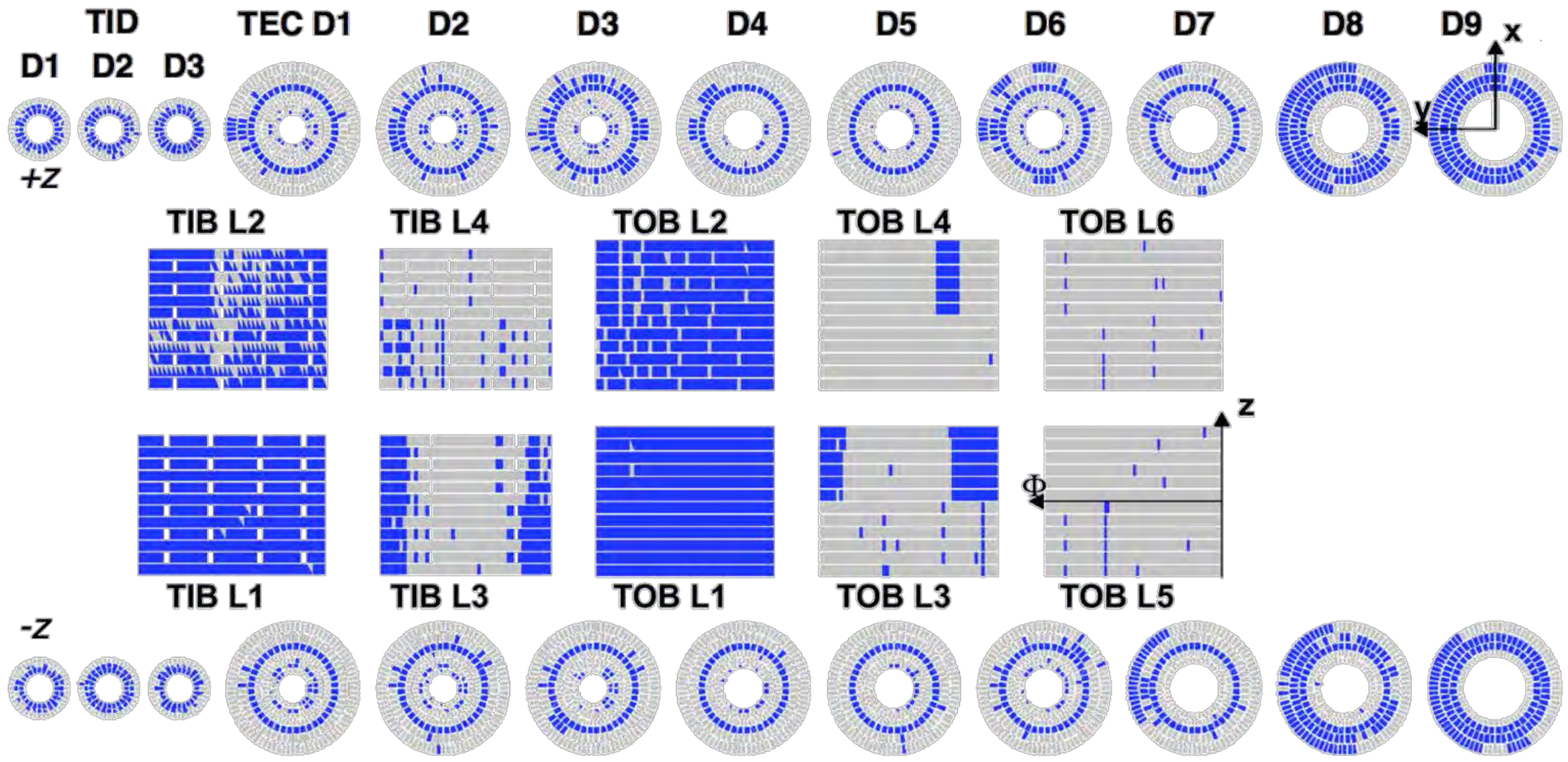
- L1 (hardware) with tracks and rate up ~ 750 kHz
- L1 Latency 12.5 μs
- HLT output rate 7.5 kHz

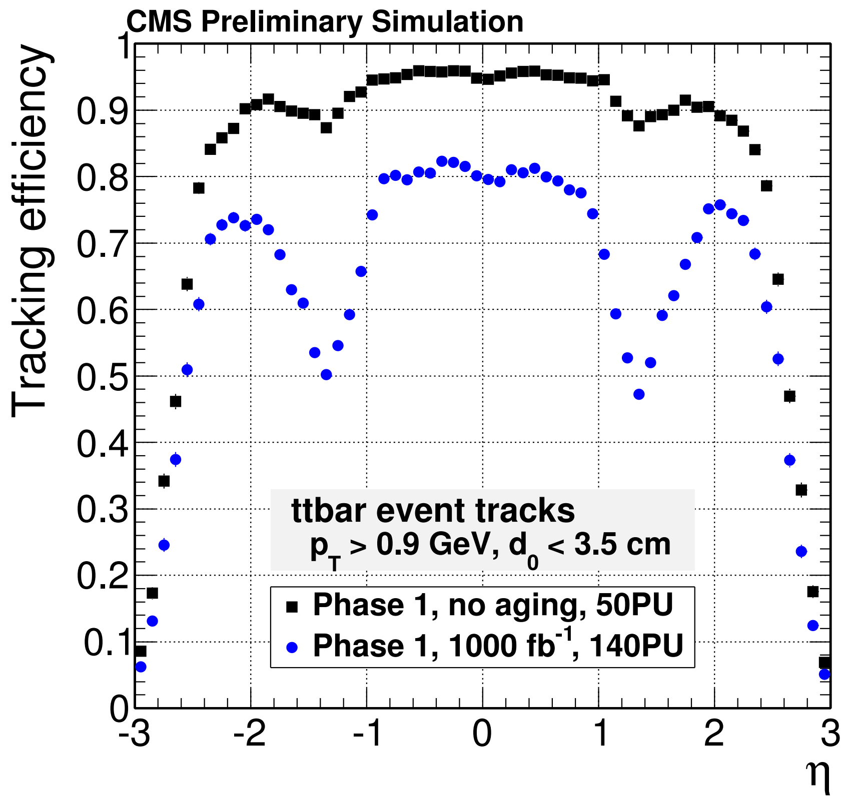
**Other R&D**

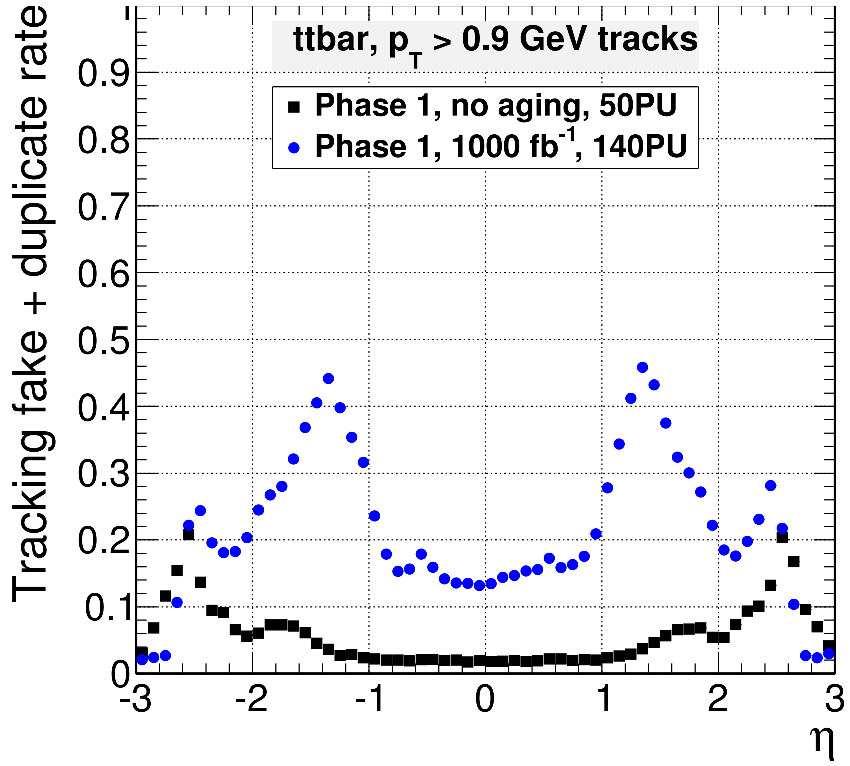
- Fast-timing for in-time pileup suppression
- Pixel trigger

(J. Mans)

# Tracker replacement is necessary due to efficiency loss and fake rate increase





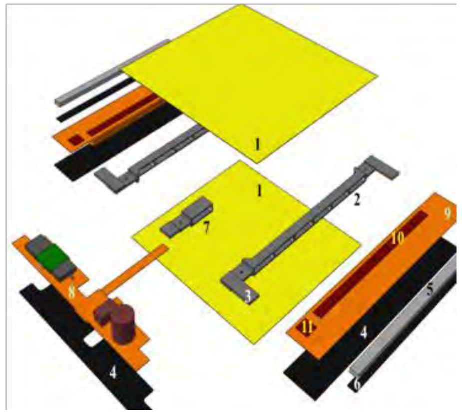


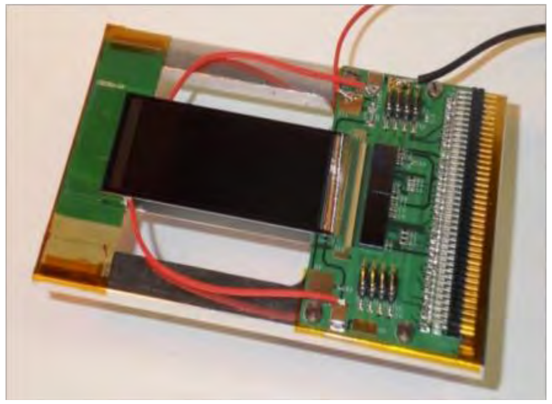
Blue tracker modules are inactive after 1000 $fb^{-1}$ due to very high leakage currents induced by neutron fluence.

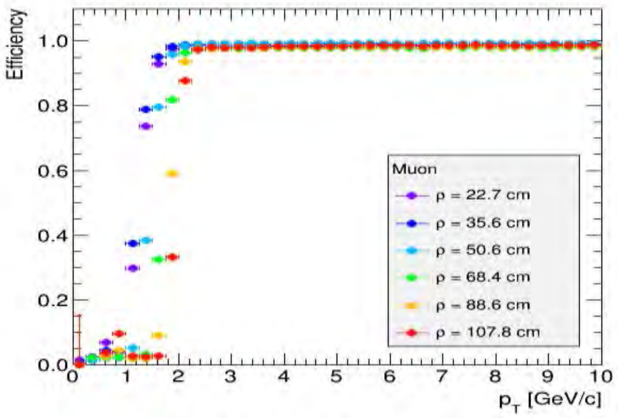
(J. Mans)

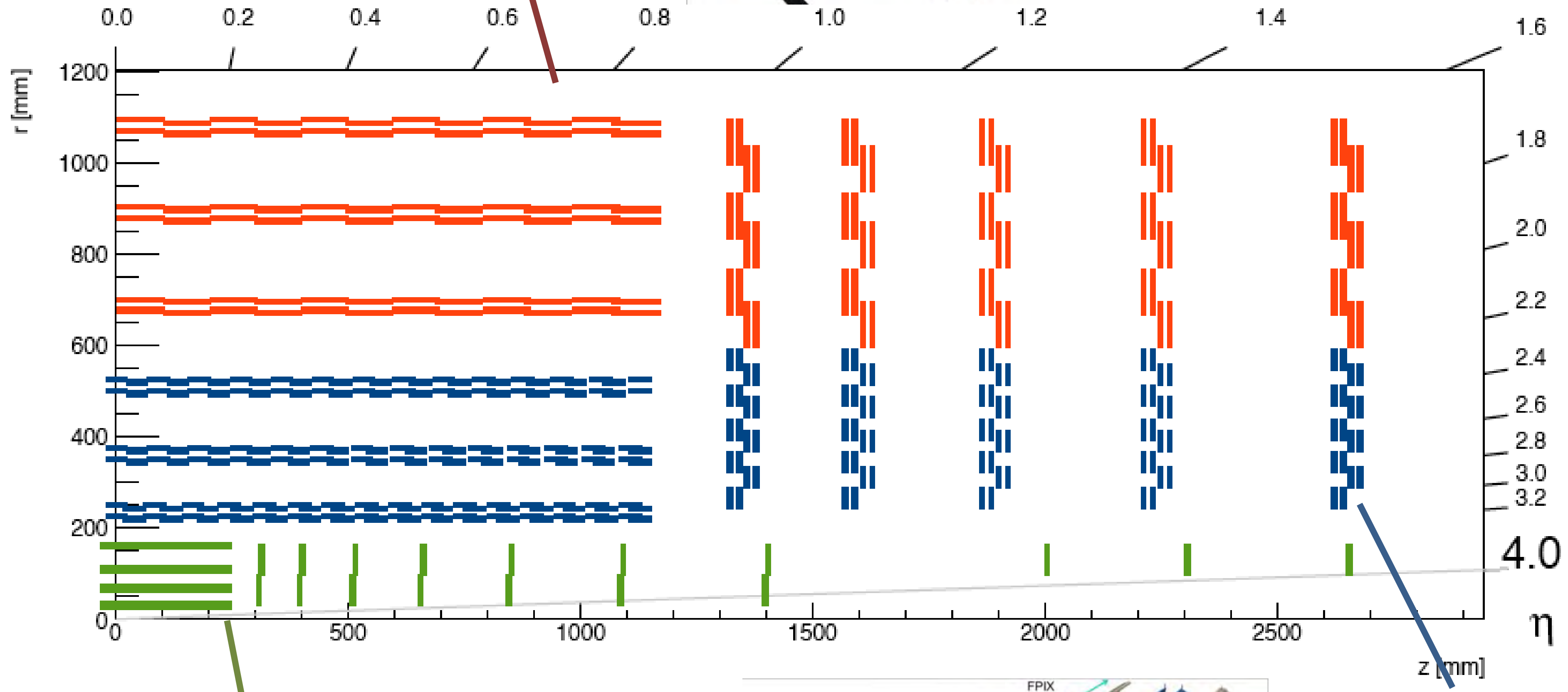
# Detailed conceptual design for all-silicon tracker with three section and trigger-stub capability

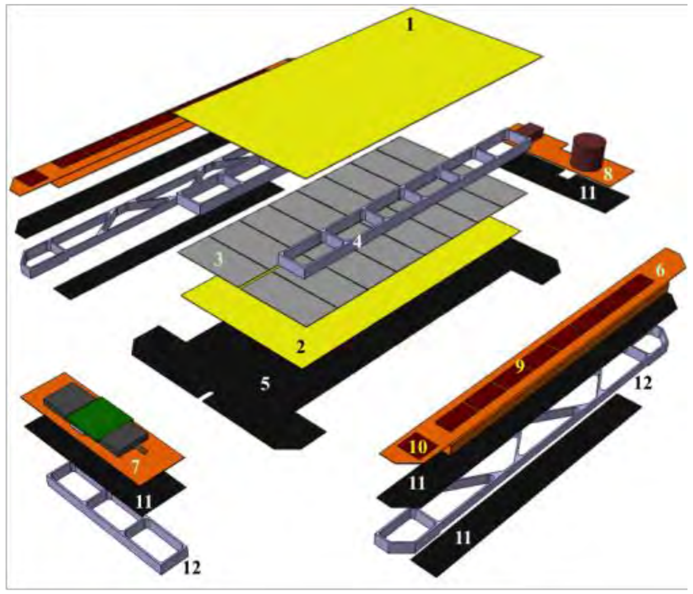
**Strip/Strip Modules**
90 µm pitch/5 cm length

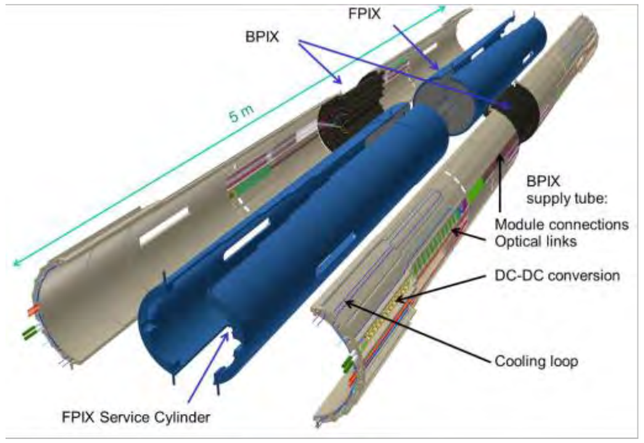










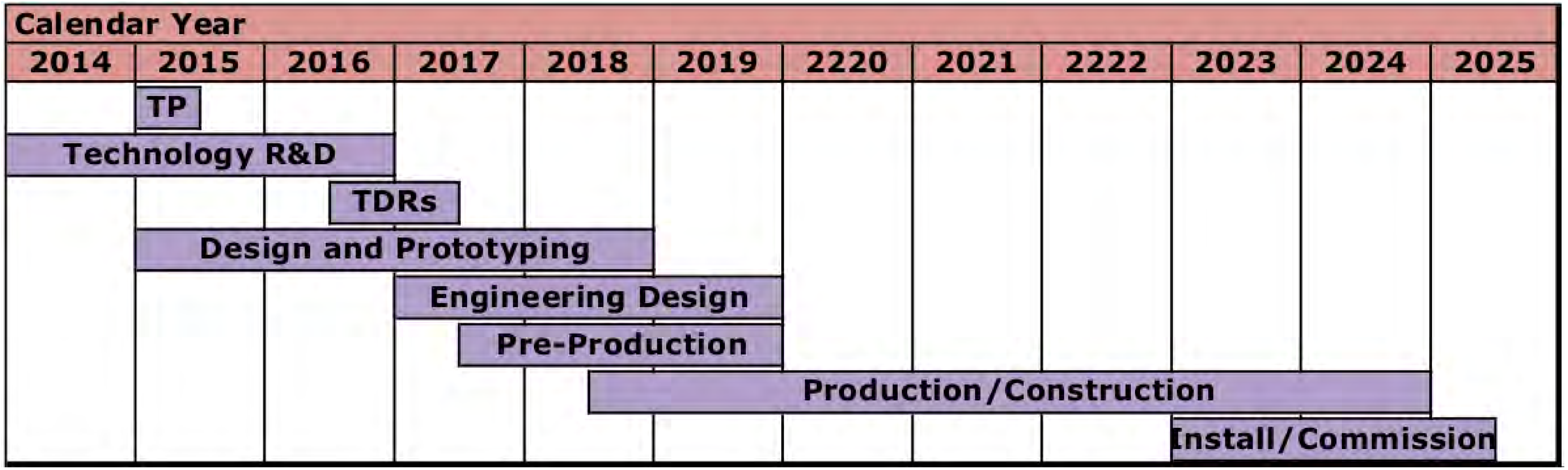


**Strip/Pixel Modules**
100 µm pitch/2.5 cm length
100 µm x 1.5 mm “macropixels”

**Inner Pixel**
Covers up to η=4.0

(J. Mans)

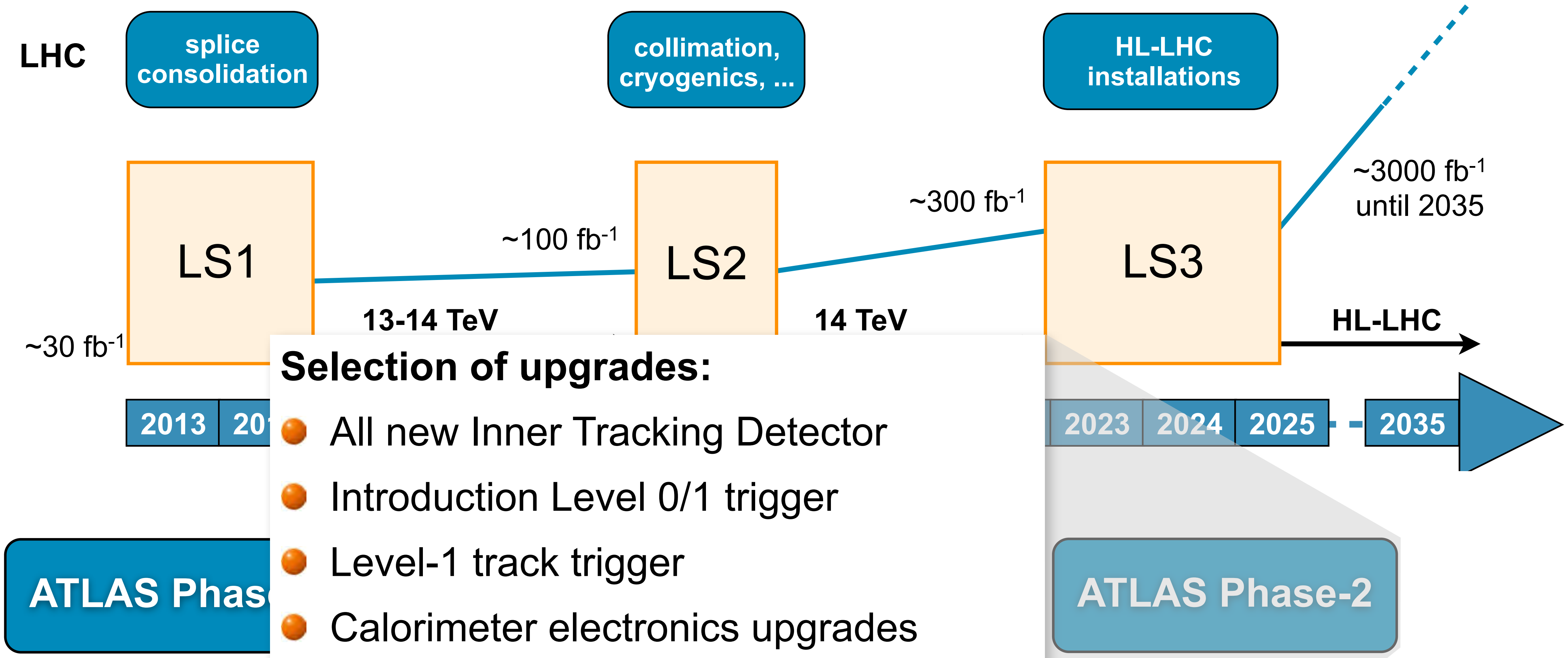
# The next two years are important ones for technology R&D leading up to the technical design reports for major subsystems



- CMS HL-LHC Technical Proposal is being completed now with full-simulation physics studies
  - Decision on endcap calorimeter technology planned for early 2015
- CMS will complete Technical Design Reports on the key upgrades in 2016/17
  - Next two years are very important for final R&D leading up to the TDRs

(J. Mans)

# The ATLAS Roadmap

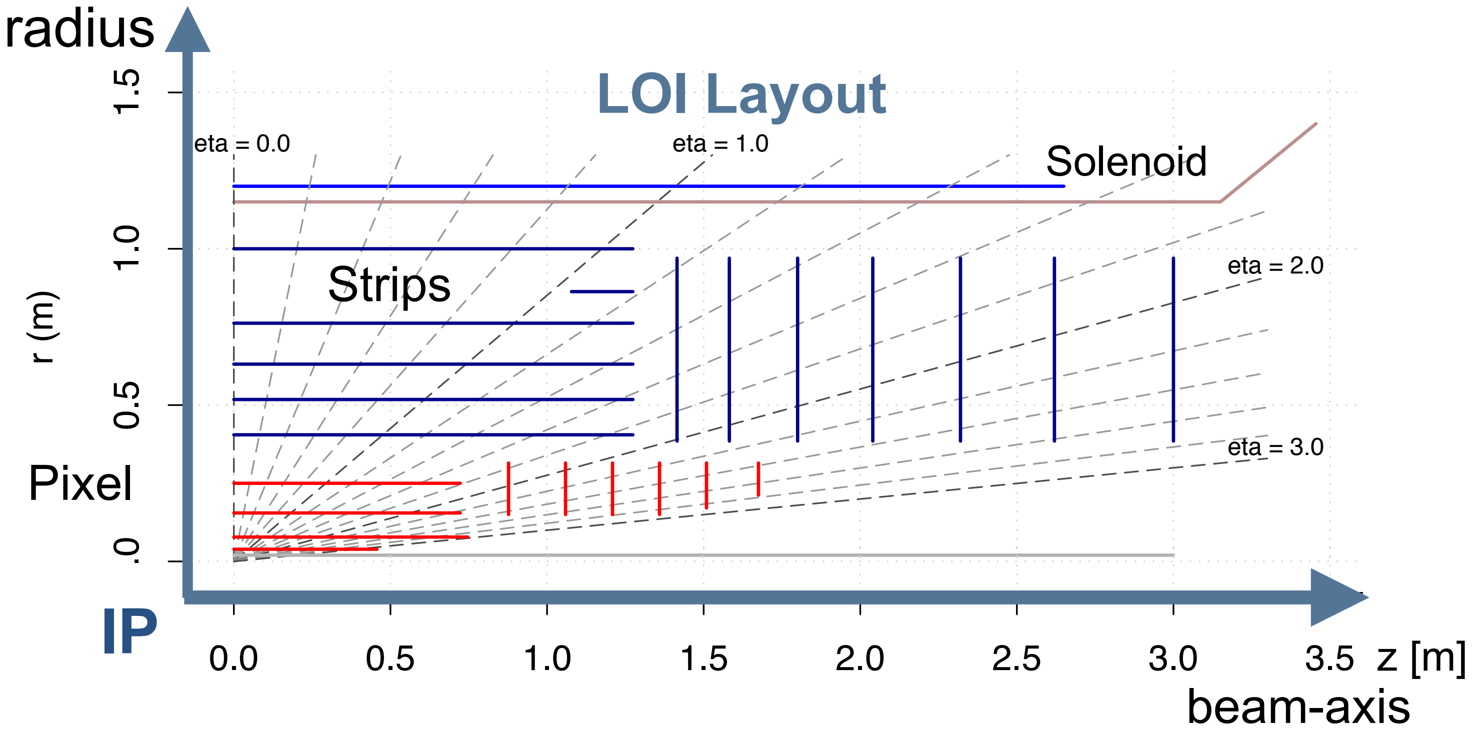


**Selection of upgrades:**

- All new Inner Tracking Detector
- Introduction Level 0/1 trigger
- Level-1 track trigger
- Calorimeter electronics upgrades
- Upgrade muon trigger system and electronics
- DAQ upgrade
- Enhancements to high-eta region

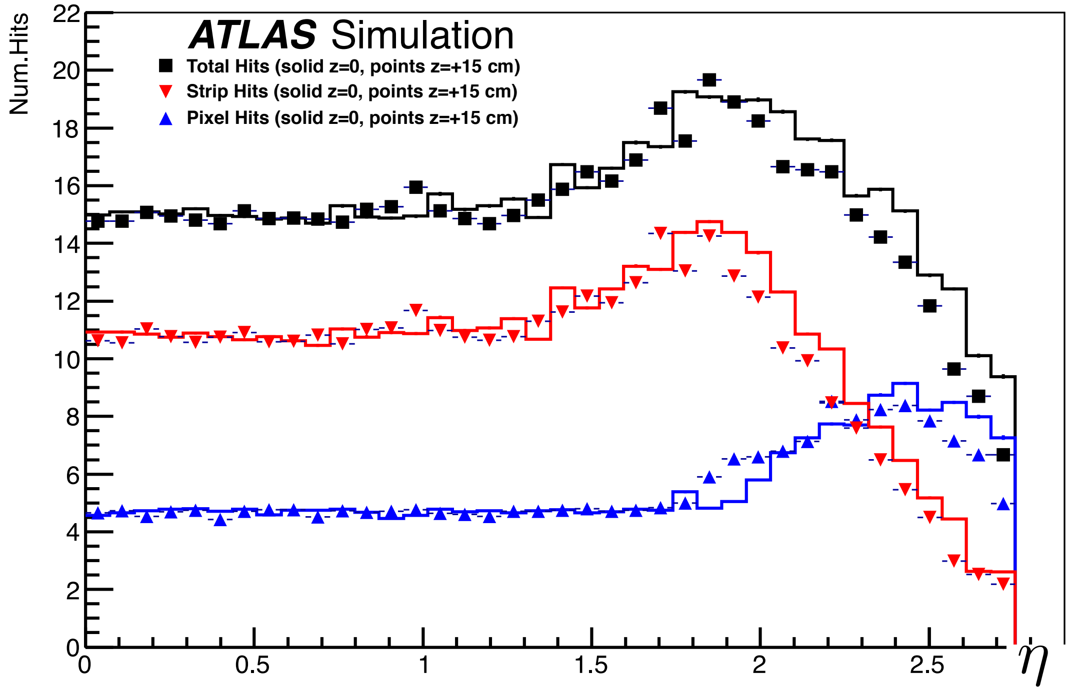
# ATLAS TRACKER UPGRADE

|  | **Silicon Area** | **Channels [$10^6$]** |
|---|---|---|
| **Pixel** | 8.2$m^2$ | 638 |
| **Strip** | 190$m^2$ | 71 |



- Remove Transition Radiation Tracker (TRT) as occupancy is too high during HL-LHC
- Install new all-Silicon tracker with much higher readout bandwidth
- Granularity increase by factor > 4

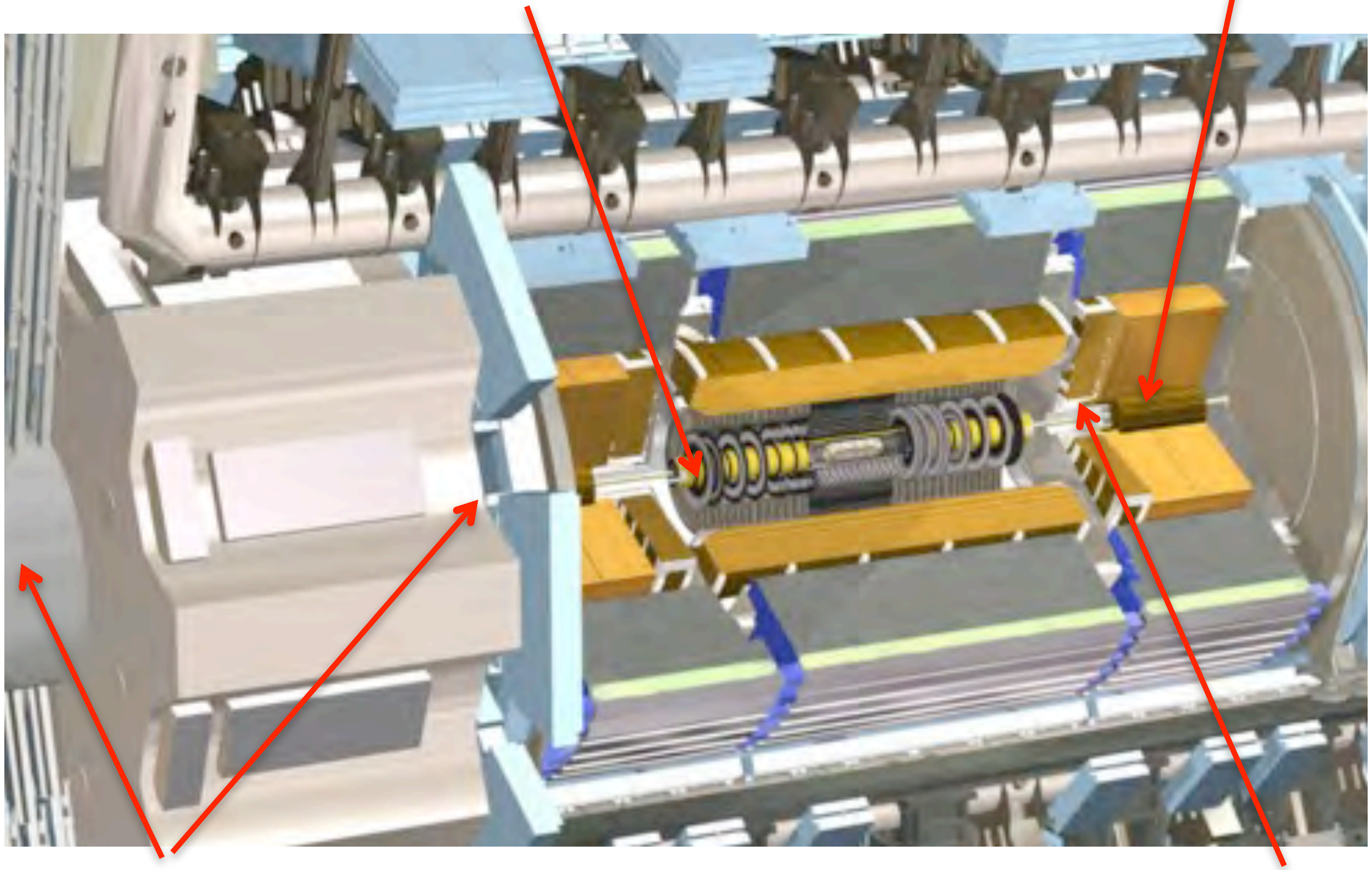
- LOI layout optimised for tracking performance
- Biggest changes compared to current tracker:
  - pixels system extends out to larger radii
  - more pixel hits in forward direction to improve tracking
  - smaller pixels and short inner strips to increase granularity
- Currently design studies ongoing to optimize various sub-detectors.



# POSSIBLE EXTENSIONS AT LARGE $\eta$

Extend ITK tracker to $\eta$ = 4.0: different pixel layouts/performance (extended IBL, disks, rings, pixel granularity,…)

sFCal with improved segmentation and reduced pulse length in $3.1<\eta<4.9$



Trigger w/ fwd tracking:
- L0/L1 capabilities
- vertex information

Recommendation in spring 2015 !

Muon spectrometer options for $2.7<\eta<4.0$:
- 1 pixelated tag chamber before EC toroid
- 2 chambers (before/after EC toroid)
- 2 chambers +1.5T warm toroid

Segmented timing detectors in front of EMEC/FCAL in $2.5<\eta<4$ (MBTS location): (~100$\mu$m;~10ps)

# Summary

- CMS and ATLAS have enjoyed an excellent Run 1 of the LHC and are finishing up analyses from this era

- My apologies for not covering heavy ion physics

- Phase-1 upgrades are approved (thank you!) and underway to take advantage of increasing luminosity of the LHC

- Phase-2 upgrades are being seriously considered at the technical proposal stage right now

- We are very much looking forward to the next run and the fun that follows