ICNFP2016

BROOKHAVEN NATIONAL LABORATORY

ATLAS EXPERIMENT

ATLAS physics prospect at the HL-LHC

Stefania Stucci (Brookhaven National Laboratory, BNL)
on behalf of the ATLAS experiment

4-15 July 2016

Chania, Greece

Outline

Higgs Sector and SM Physics

1

Higgs couplings, rare Higgs decay, VBS, HH

Supersymmetry

2

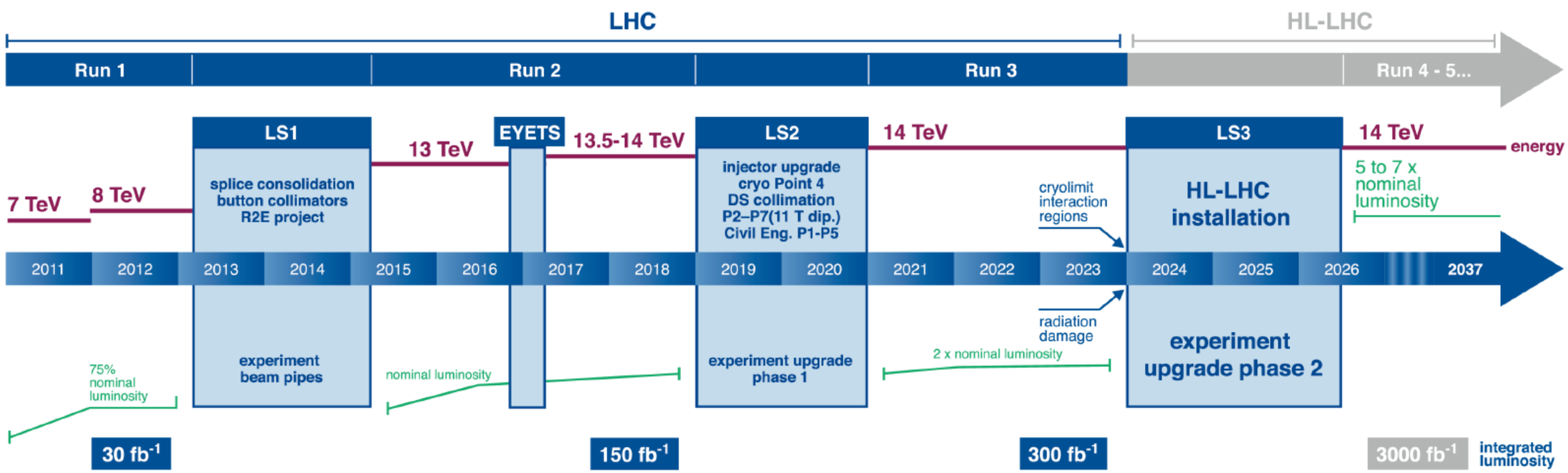
Electroweak channels

Exotics

3

Dark matter, EFT

High Luminosity LHC

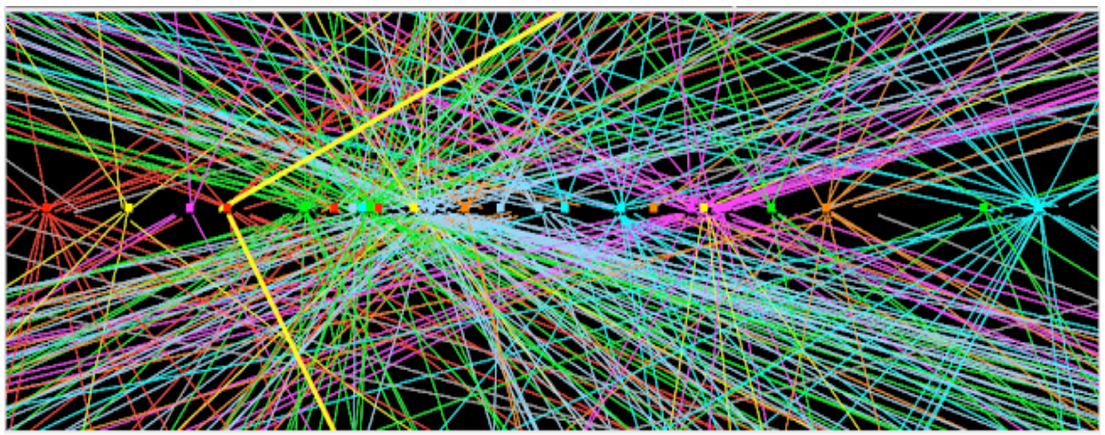


HL-LHC: 3000 fb^{-1} at a center-of-mass energy equal to 14 TeV

$\langle\mu_{PU}\rangle \approx 140$ → $5 \times 10^{34}\ cm^{-2}s^{-1}$

$\langle\mu_{PU}\rangle \approx 200$ → $7.5 \times 10^{34}\ cm^{-2}s^{-1}$

multiple interaction in the same bunch crossing

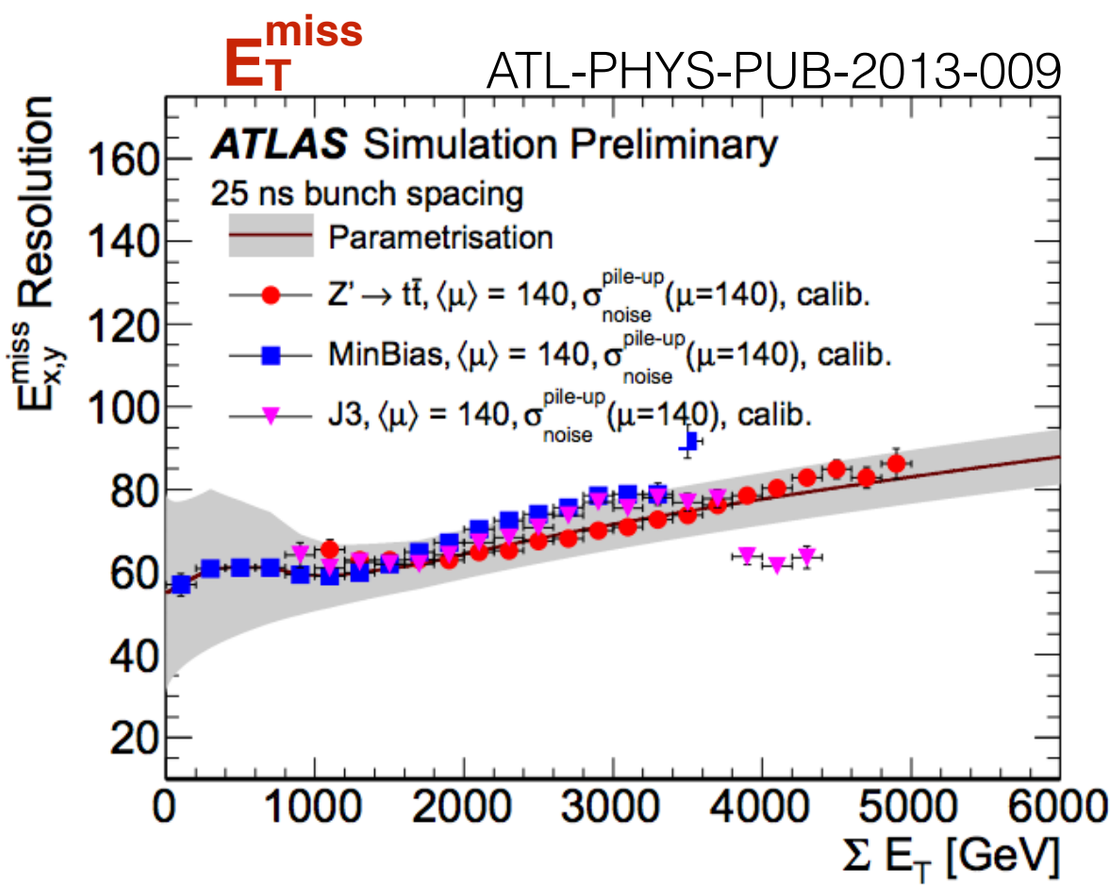


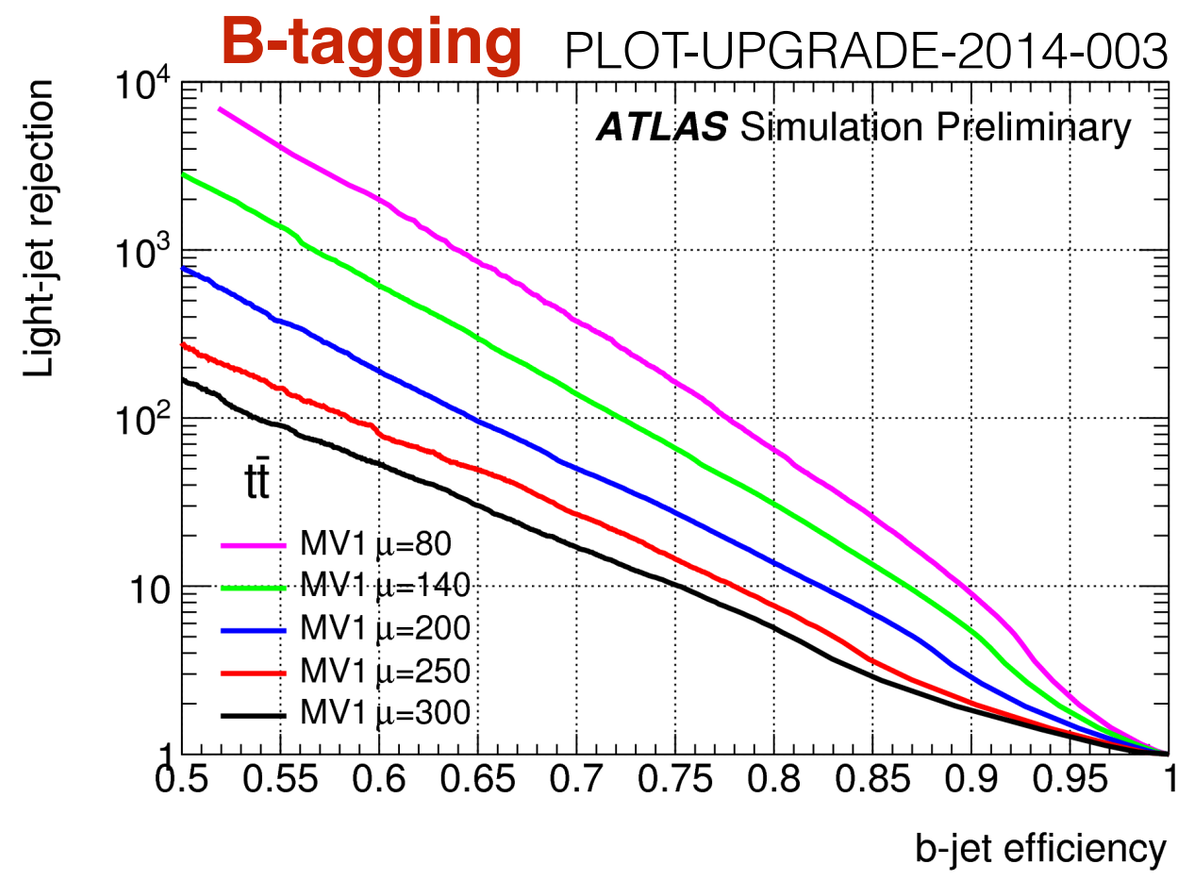
Detector upgrade

- **Planned system upgrades to cope with the increase of luminosity**
  - Radiation damage on some subsystems of the present detector
  - Replacement of the Inner Detector (ITK)
  - Trigger redesign
  - Muon upgrade: increase coverage, trigger improvement
  - Considering new high-granularity forward calorimeter + timing detector
- **Guide line: achieve same or better performances as in Run 1**
- **Pile-up mitigation essential element for the design**
  - Tracking information in L1 trigger
  - Tracking coverage up to $|\eta| \approx 4$
    - **Reference scenario**: $|\eta| < 4.0$
    - **Middle scenario**: $|\eta| < 3.2$
    - **Low scenario**: $|\eta| < 2.7$

Upgrade studies

- Complete understanding of the challenges of operation at $\langle\mu_{PU}\rangle \sim 140-200$
  - The performance of physics objects has been studied with full simulation MC events in the pile up conditions of HL-LHC
  - Results have been parametrized with ***smearing functions***
  - MC samples with generator level information have been processed applying these smearing functions
- Unless specified, the analysis presented are made with $\langle\mu_{PU}\rangle = 140$





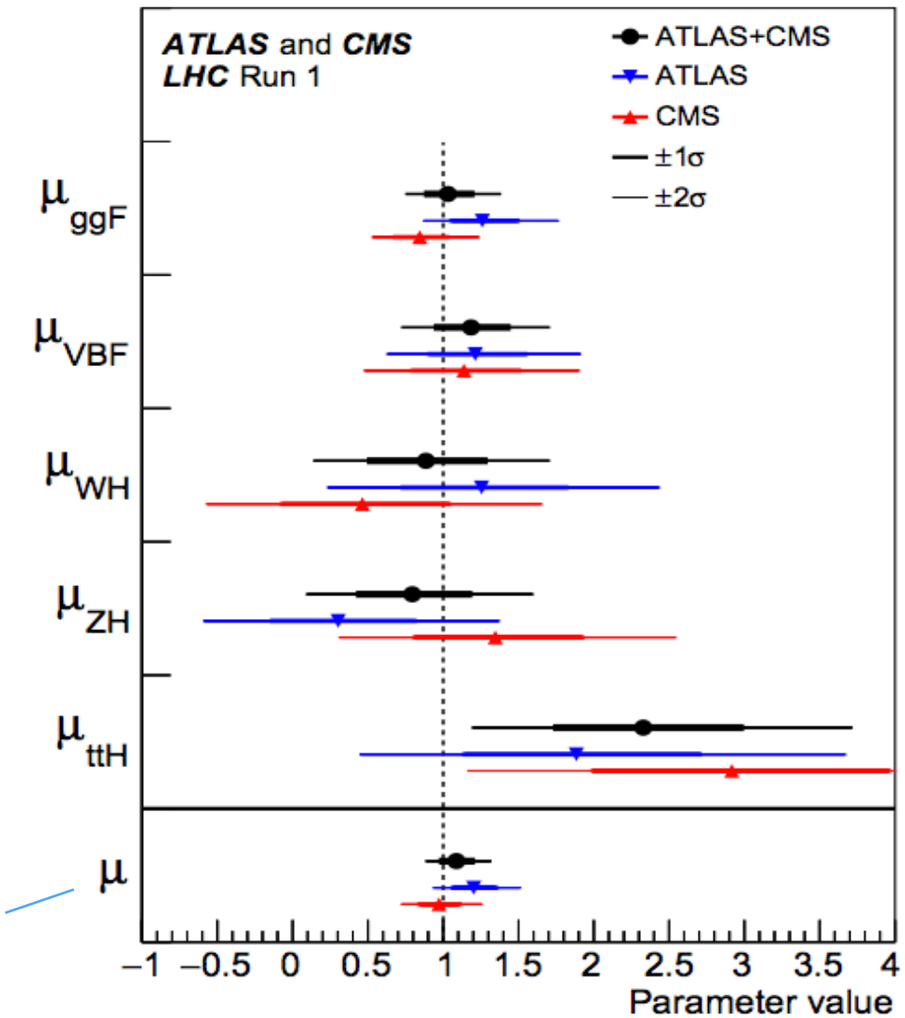
Higgs Sector and SM Physics

What's Next?

Higgs Sector and SM Physics

- Mass: 125.09 ± 0.21(stat.) ± 0.11(syst.) GeV
- Signal strength μ: $1.09^{+0.11}_{-0.10}$
- J^P consistent with 0^+
- Precision measurement Higgs couplings need more statistics
- Rare decays

arXiv:1606.02266



ratio of the measured Higgs boson rate to its SM prediction

Precision tests are needed in order to confirm that the Higgs mechanism is the responsible of the EWKSB and discover possible deviations from SM theory

Higgs coupling studies

ATL-PHYS-PUB-2014-016

- **Production and decay mode considered in the study:**

	$H\to\gamma\gamma$	$H\to ZZ$	$H\to WW$	$H\to\tau\tau$	$H\to bb$	$H\to Z\gamma$	$H\to\mu\mu$
$gg\to H$	X	X	X			inclusive	X
VBF	X	X	X	X			X
VH	X	X			X		
ttH	X	X					X

→ $H\to\gamma\gamma$ and $H\to ZZ^*\to 4l$ Higgs decays from ttH production mode, particularly important for probing top-quark Yukawa coupling

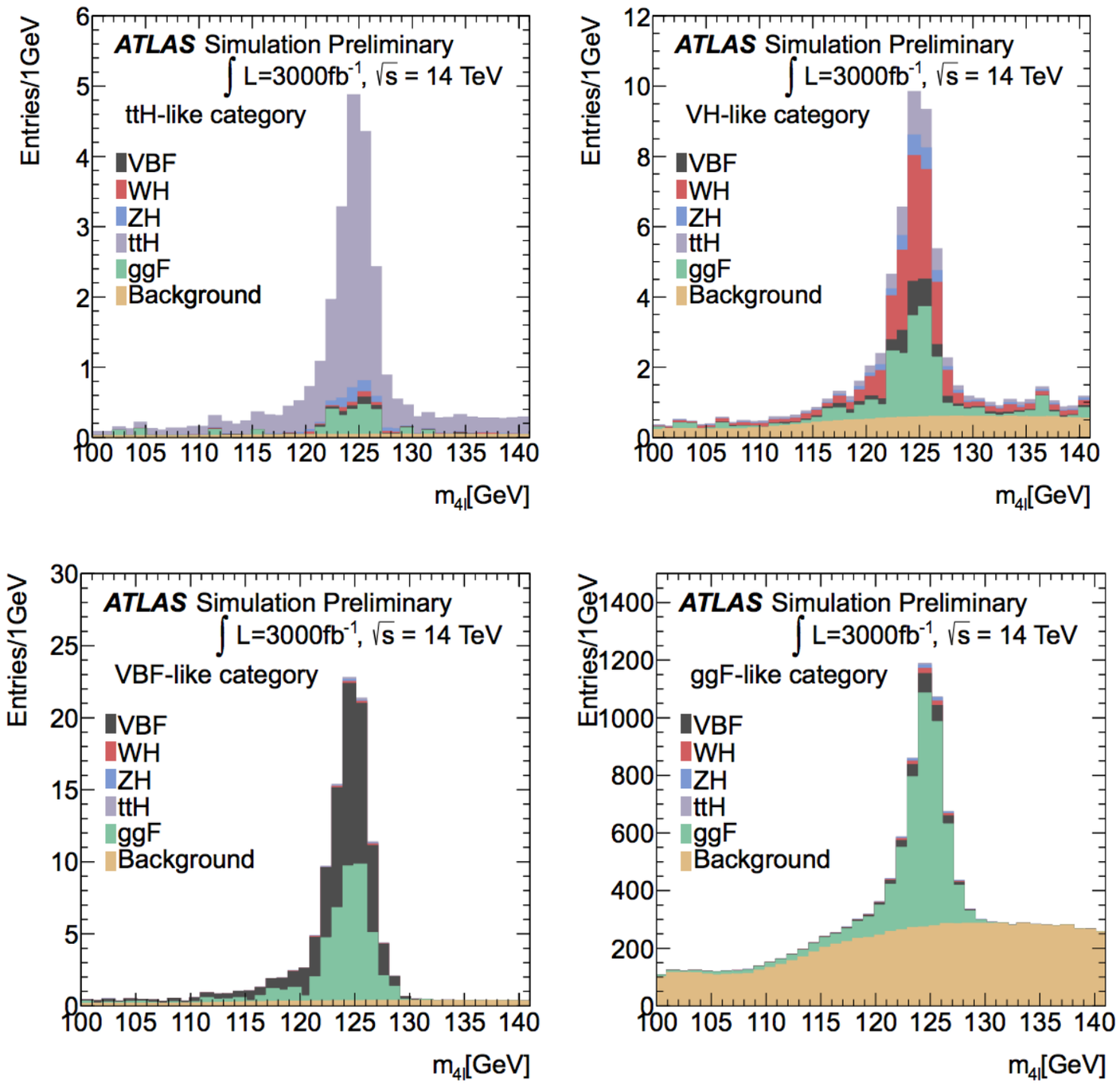
→ $H\to\mu\mu$ second generation charged lepton coupling

Example: H → ZZ* →4l

ATL-PHYS-PUB-2013-014

- High purity signal
- Analysis presented here do not account for tracker extension
  - preliminary study: main improvement comes from the trigger upgrade

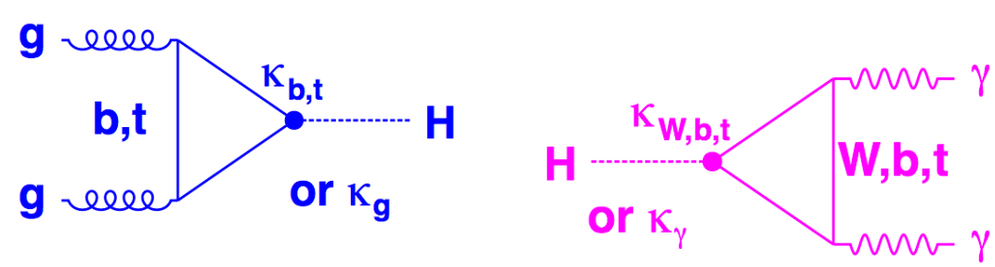
Production modes	
ggF	3800
VBF	97
WH	67
ttH	35
ZH	5.7



Coupling fit framework

k-framework

- Framework to look for deviations from the SM: disentangle deviations in production and decay with explicit modeling of Higgs width
- Introduce one scalar factor **k** per SM particle with 'observable' Higgs coupling



- Assumptions:
  - Only one Higgs
  - Width of the Higgs boson is narrow

decay width into final state ff

rate for a given channel

$$(\sigma \cdot BR)(i \to H \to ff) = \frac{\sigma_i \cdot \Gamma_{ff}}{\Gamma_{\mathrm{H}}}$$

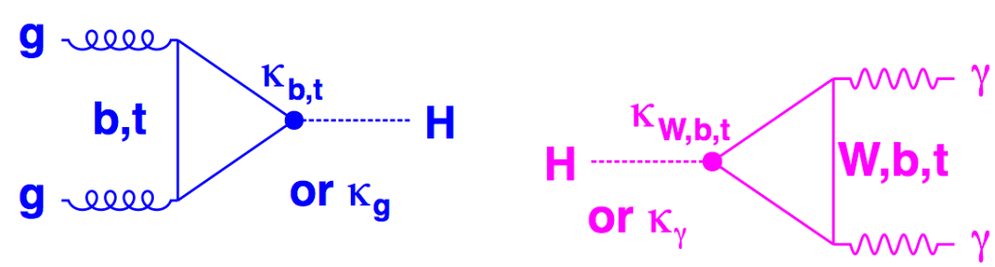
Higgs total width

production x-sec via initial state i

Coupling fit framework

k-framework

- Framework to look for deviations from the SM: disentangle deviations in production and decay with explicit modeling of Higgs width
- Introduce one scalar factor **k** per SM particle with 'observable' Higgs coupling



- Assumptions:
  - Only one Higgs
  - Width of the Higgs boson is narrow

decay width into final state ff

rate for a given channel

$$(\sigma \cdot BR)(i \to H \to ff) = \frac{\sigma_i \cdot \Gamma_{ff}}{\Gamma_{\mathrm{H}}}$$

Higgs total width

production x-sec via initial state i

absolute

ratios

Higgs coupling studies

- Assumption on the total width allows **absolute** coupling scale factors to be extracted
  - No BSM Higgs decay modes assumed

$$\left.\begin{array}{l}\Gamma_i \sim \kappa_i^2\, \Gamma_i^{SM} \\ \sigma_i \sim \kappa_i^2\, \sigma_i^{SM} \\ \Gamma_H = \Sigma_i\, \kappa_i^2\, \Gamma_i^{SM}\end{array}\right\} \quad \frac{\sigma \cdot \mathrm{B}\,(gg \to H \to \gamma\gamma)}{\sigma_{\mathrm{SM}}(gg \to H) \cdot \mathrm{B}_{\mathrm{SM}}(H \to \gamma\gamma)} = \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

- Combined fit to determine the Higgs boson scale factors

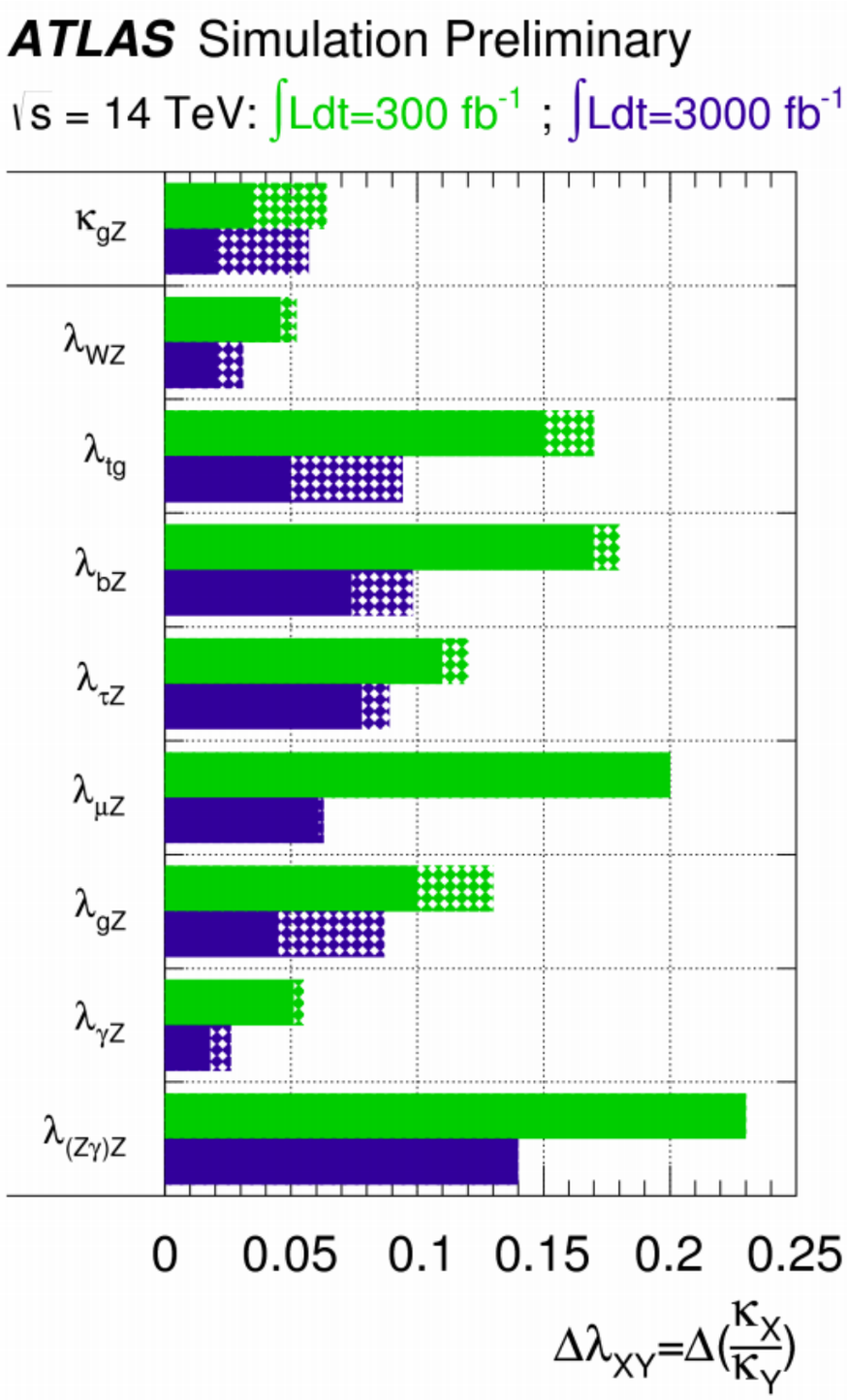
[no theor. uncert., full theor. uncert.] (%)

κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	$\kappa_{\mu\mu}$
[4, 5]	[4, 5]	[4, 4]	[5, 9]	[10, 12]	[8, 11]	[9, 10]	[14, 14]	[7, 8]

At HL-LHC, couplings can be determined with ATLAS with 4-14% precision

Higgs coupling ratio

ATL-PHYS-PUB-2014-016



- Most generic model:
  - **No assumption on the total width: only coupling ratios can be measured**

$$\lambda_{XY} = \kappa_X/\kappa_Y$$

coupling scale factors ratios for initial and final state

$$\sigma \cdot B\,(i \to H \to f) \sim \lambda_{iY}^2 \cdot \kappa_{YY'}^2 \cdot \lambda_{fY}^2$$

$$\kappa_{YY'} = \kappa_Y \cdot \kappa_{Y'}/\kappa_H$$

  - Systematic uncertainties partly cancel in ratios

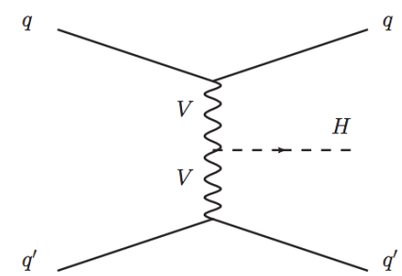
- 2~3% precision reachable in some channel if syst. unc. controlled
- HL-LHC yields a factor 2~3 improvement in coupling ratio determination

(VBF) H → ZZ* →4l

NEW

ATL-PHYS-PUB-2016-008

- Study of the potential improvement due to extend tracking:
  - **Reference scenario**: |η| < 4.0
  - **Middle scenario**: |η| < 3.2
  - **Low scenario**: |η| < 2.7



Distinctive - two high energetic jets in the final state

Statistical uncertainty only					
Scoping scenario	VBF + 2j events	ggF + 2j events	$qqZZ$ + 2j events	Z_0	$\Delta\mu/\mu$
Reference	192 (168)	287 (140)	39 (16)	10.2	0.152
Middle	218 (167)	454 (155)	69 (15)	9.5	0.157
Low	259 (159)	803 (182)	124 (21)	8.6	0.165

- Improvement in both discrimination between VBF and ggF (MVA) and in pile up rejection thanks to tracking extension
  - Expected significance Z_0 reduced by 4% (14%) from Reference to Middle (Low) scenario
  - Rel. uncertainty on the signal strength increases by 3% (9%) from Reference to Middle (Low) scenario

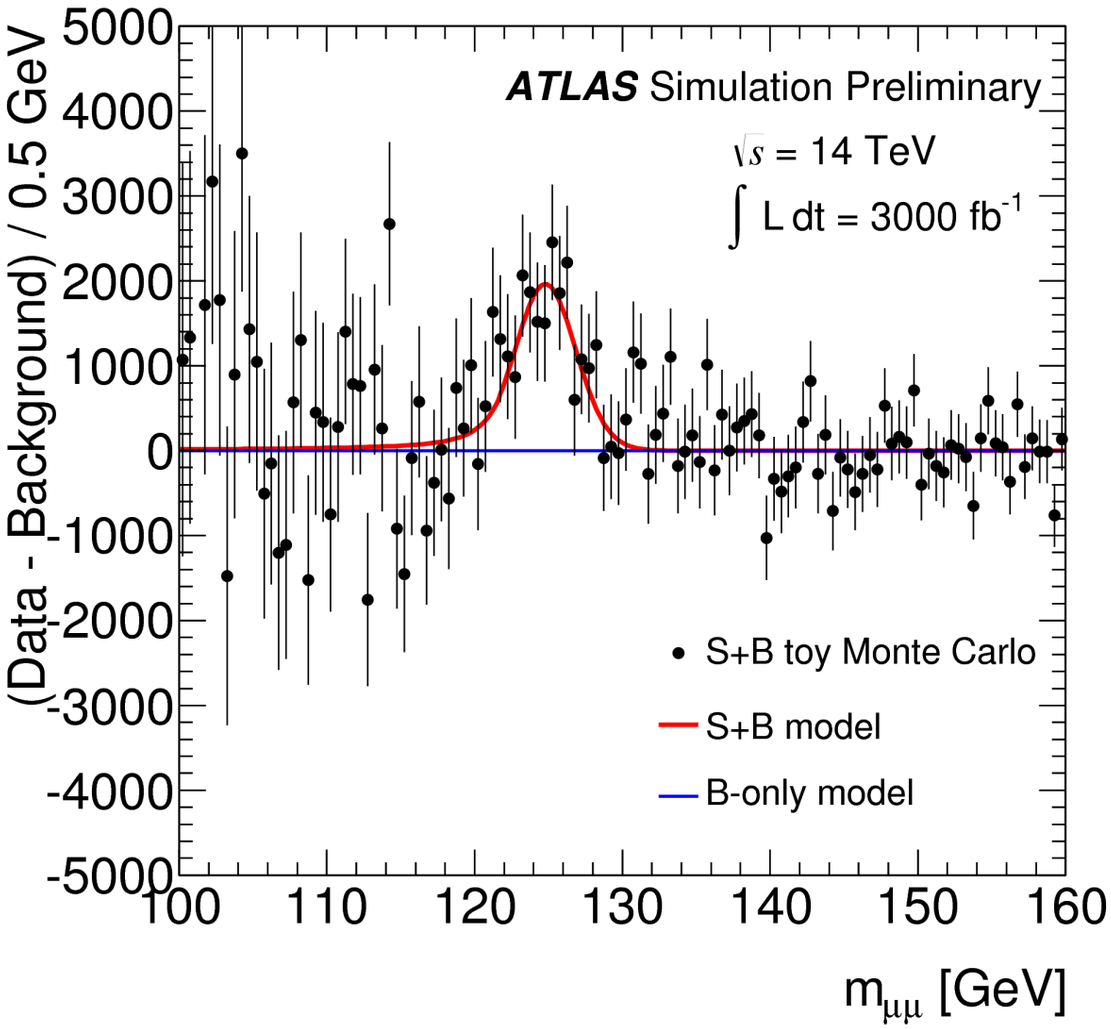
Rare Higgs decay: H→μμ

ATL-PHYS-PUB-2013-014

One of the strongest point of the HL-LHC physics program

H→μμ

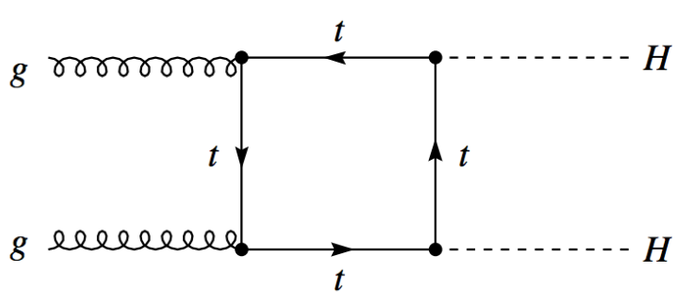
- **Direct study of the coupling to second generation leptons**
- **Test lepton non-universality in the Higgs boson sector**
- **~20% accuracy in signal strength measurement**
- **7σ significance expectation**
- **Can improve with tracker extension - not yet studied**

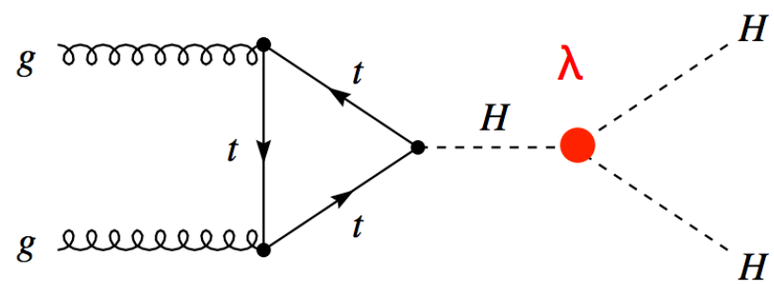


Higgs pair production

- Higgs trilinear self-coupling λ_{HHH} probe
- Several **BSM** processes expect much larger rate than the SM predictions

SM = destructive interference





NNLO σ^{SM} = 40.8 fb

Decay Channel	Branching Ratio	Total Yield (3000 fb^{-1})
$b\bar{b} + b\bar{b}$	33%	4.1×10^4
$b\bar{b} + W^+W^-$	25%	3.1×10^4
$b\bar{b} + \tau^+\tau^-$	7.4%	9.0×10^3
$W^+W^- + \tau^+\tau^-$	5.4%	6.6×10^3
$ZZ + b\bar{b}$	3.1%	3.8×10^3
$ZZ + W^+W^-$	1.2%	1.4×10^3
$\gamma\gamma + b\bar{b}$	0.3%	3.3×10^2
$\gamma\gamma + \gamma\gamma$	0.0010%	1

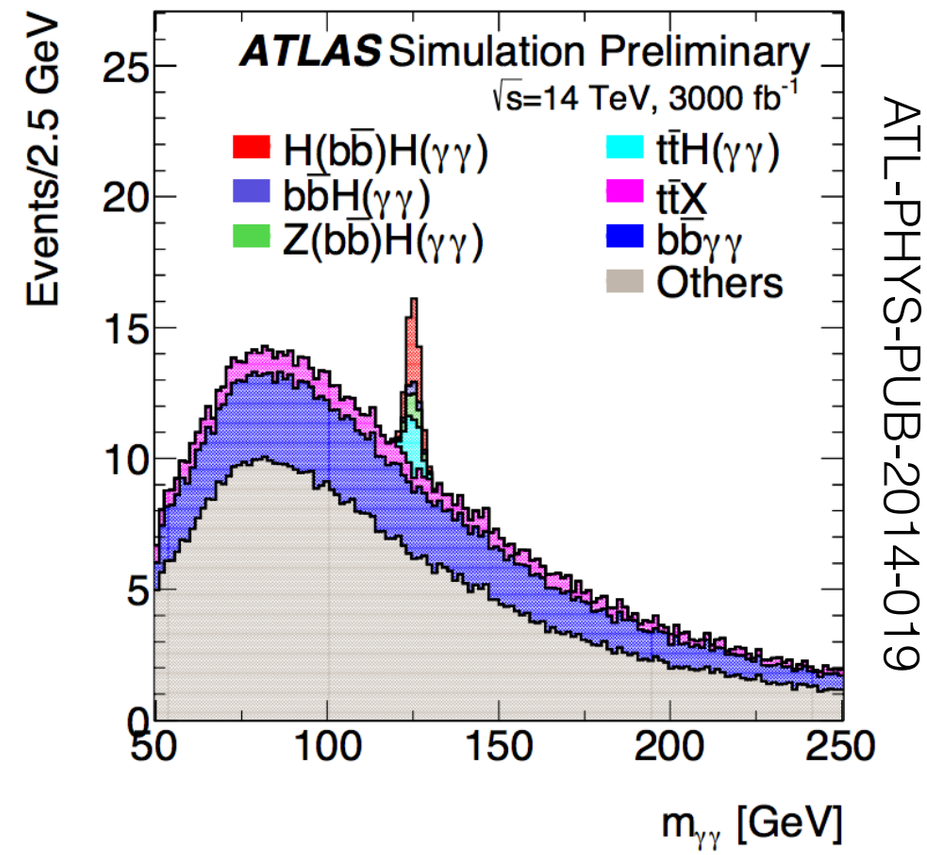
- **Results can be improved by combining as many other channels as possible**

Higgs pair production

H→bb , H→$\gamma\gamma$

- Expected significance: 1.3σ
- Exclusion regions

$$\lambda_{HHH} / \lambda_{HHH}^{SM} \leq -1.3 \text{ or } \geq 8.7$$

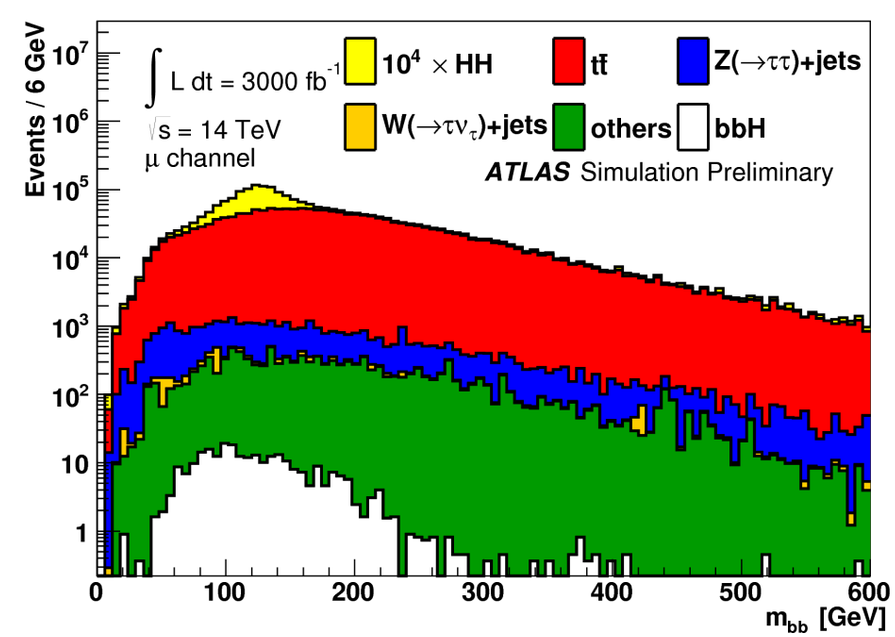


ATL-PHYS-PUB-2014-019

H→bb , H→$\tau\tau$ NEW

- Expected significance: 0.6σ
- Exclusion regions

$$\lambda_{HHH} / \lambda_{HHH}^{SM} \leq -4 \text{ or } \geq 12$$

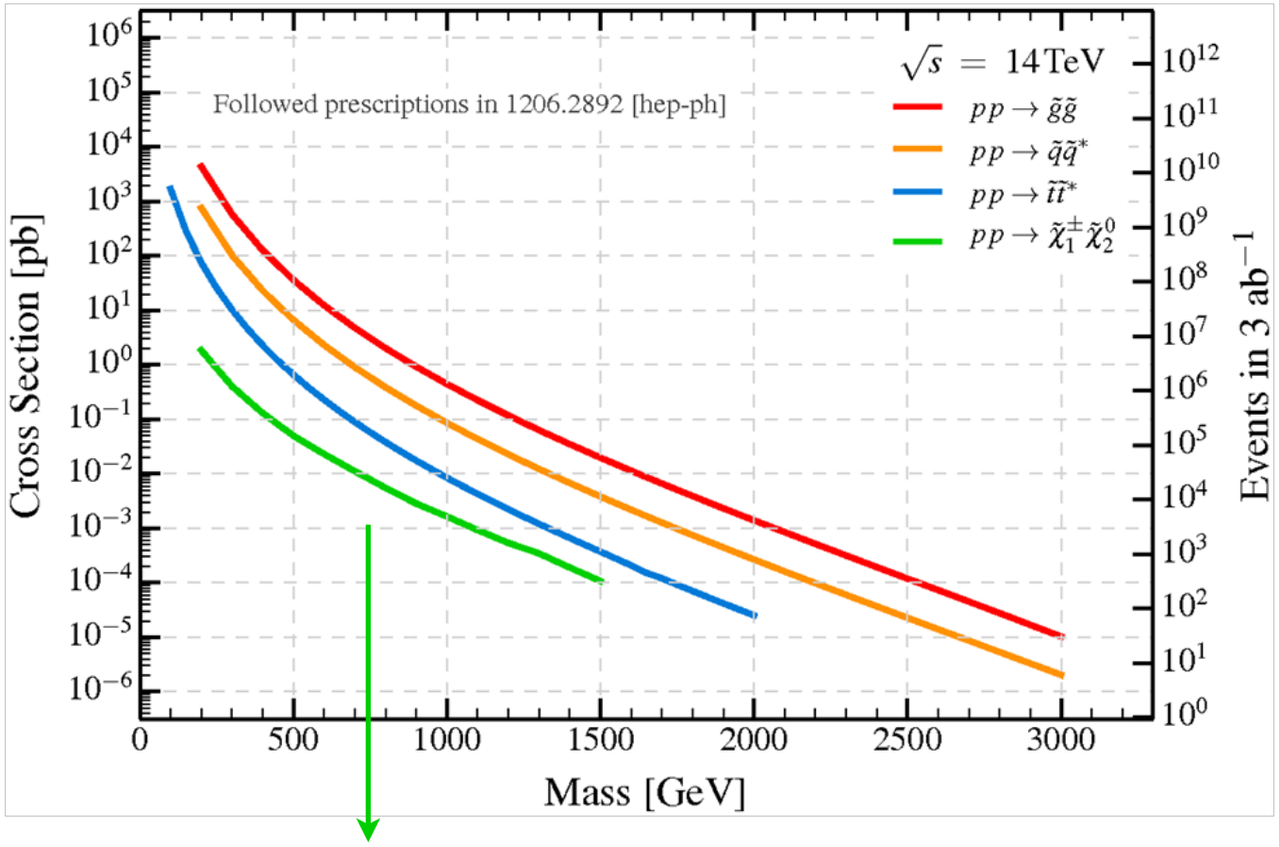


ATL-PHYS-PUB-2015-046

Supersymmetry

Models and interpretations

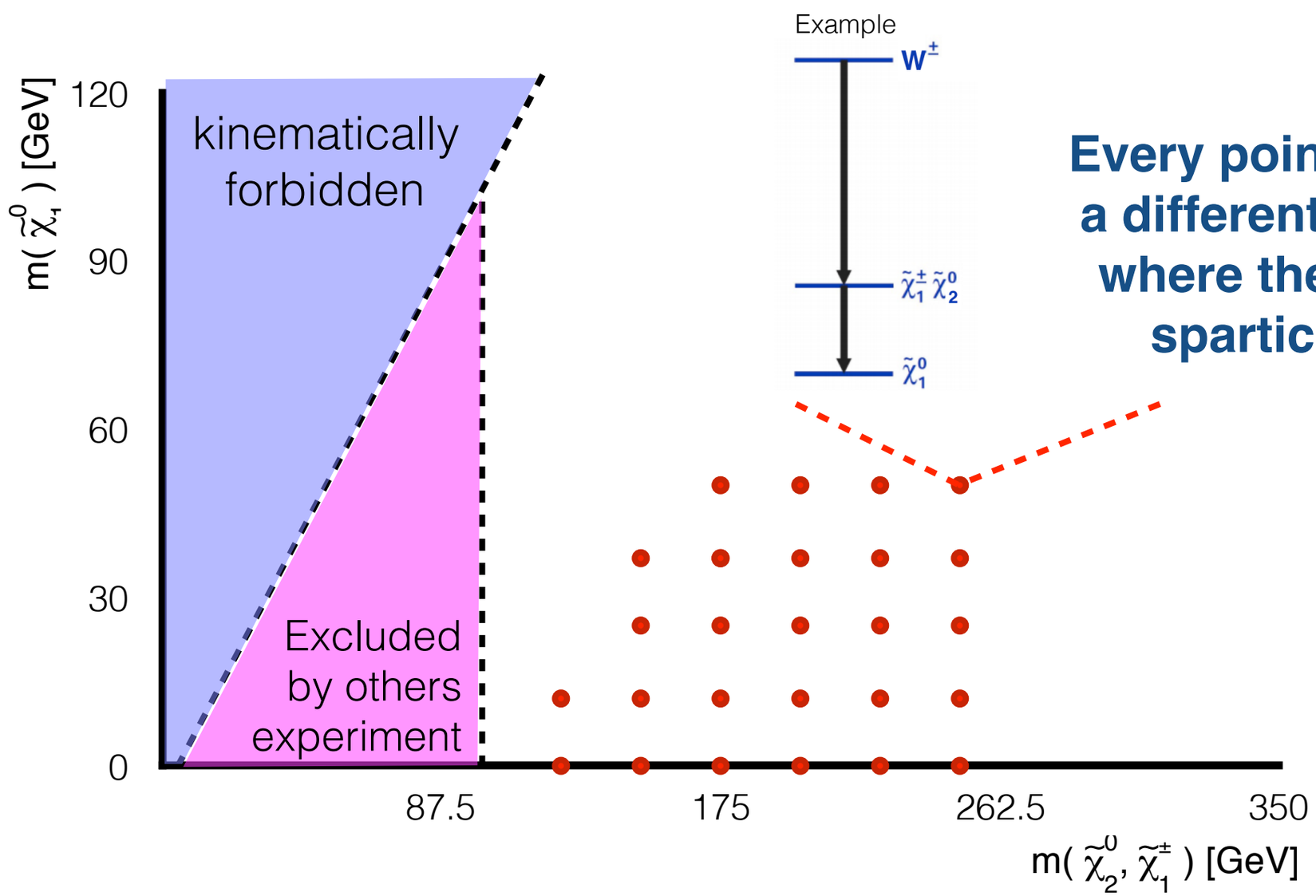
- Still one of the most attractive framework
- Stop, sbottom, gluino and higgsinos are light in natural models
- EWK production benefits from the high luminosity
- All the upgrade analyses presented here assume:
  - R-parity conserving
  - Simplified model (next slide)



May dominate the SUSY production at LHC if the masses of the gluinos and squarks are large

Simplified model

- **Small number of sparticles, assumed BR - usually 100%**
- **Described by masses and cross sections**
- **Simple and broad approach for designing SUSY searches**

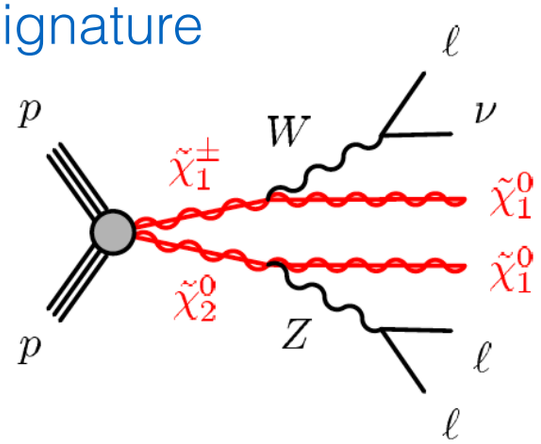


Every point in the grid is a different signal model where the mass of the sparticles change

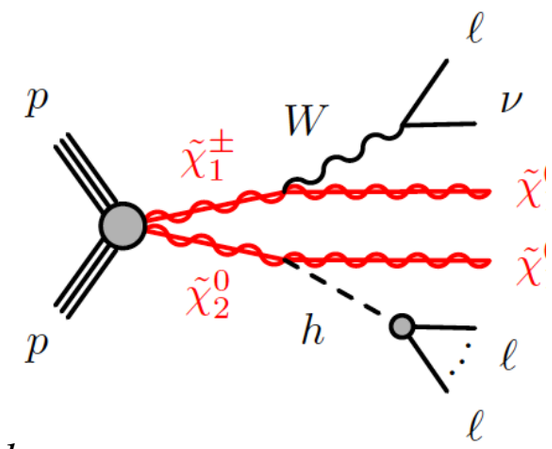
$\tilde{\chi}_1^{\pm}\,\tilde{\chi}_2^0$ production

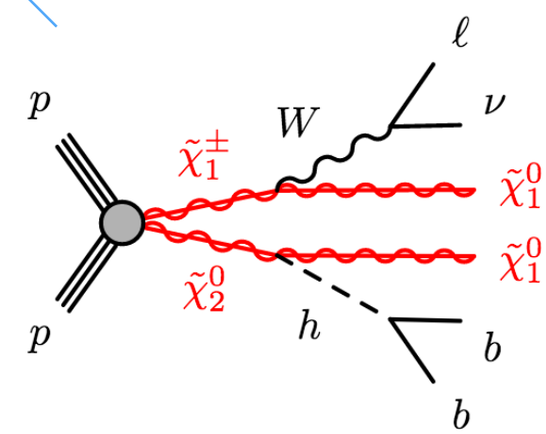
WZ / Wh mediated

clean signature

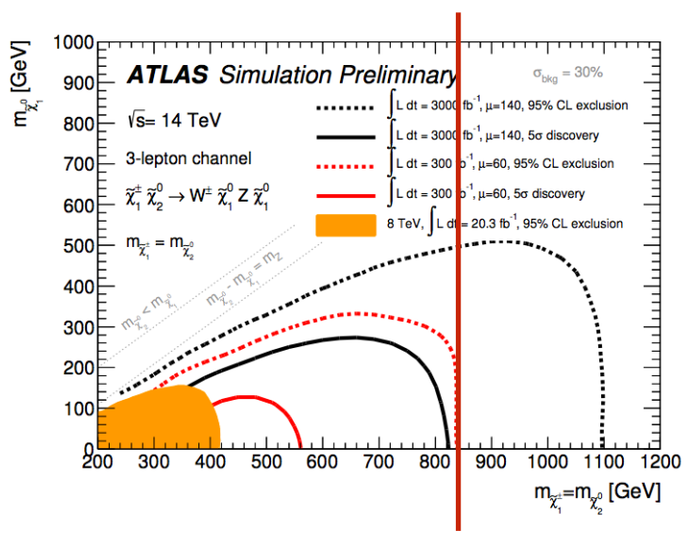


higgs in signature

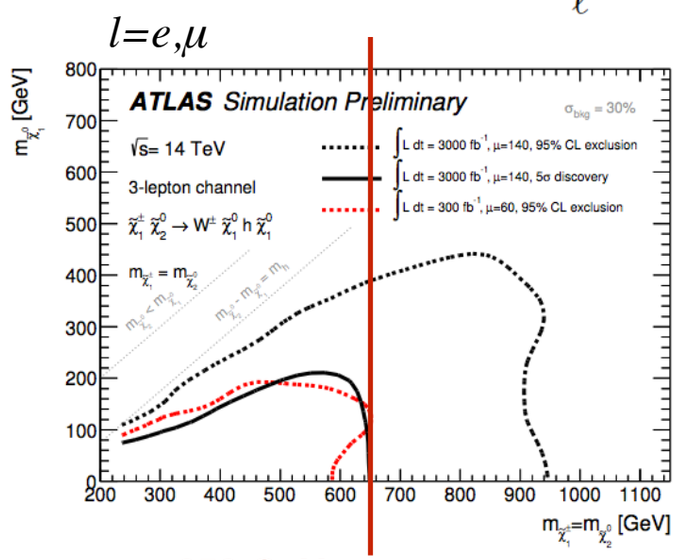




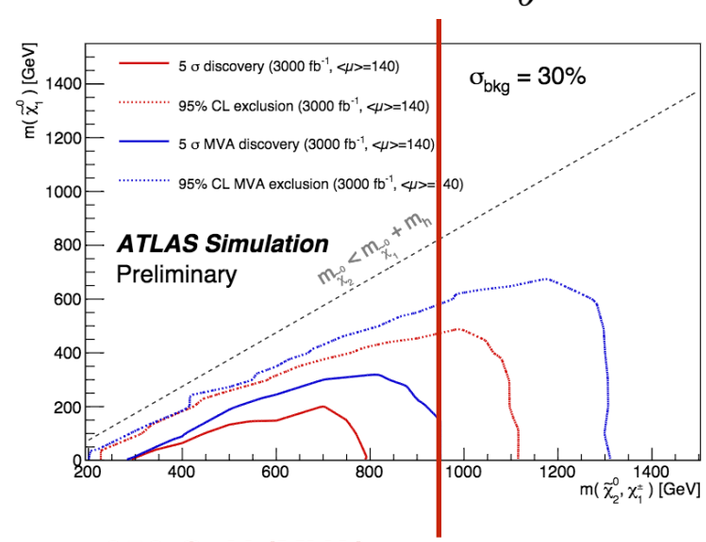
ATL-PHYS-PUB-2014-010



820 GeV
discovery sensitivity



650 GeV



ATL-PHYS-PUB-2015-032

950 GeV (MVA)

MVA technique improves discovery sensitivity by 150 GeV

The current searches have yielded sensitivity in few hundreds GeV mass range: their reach at HL-LHC is expected to significantly extend beyond these limits

Exotics

Mono jet search for dark matter

ATL-PHYS-PUB-2014-007

- DM produced in association with a jet → E_T^{miss} + jet
- Physics described as a **point coupling** in Effective Field Theory (**EFT**) if the mass M_{med} of the quark-DM interaction mediator is much larger than the typical momentum transfer

  - Allow comparison with direct measurement experiments
  - Strength of point couple determined by

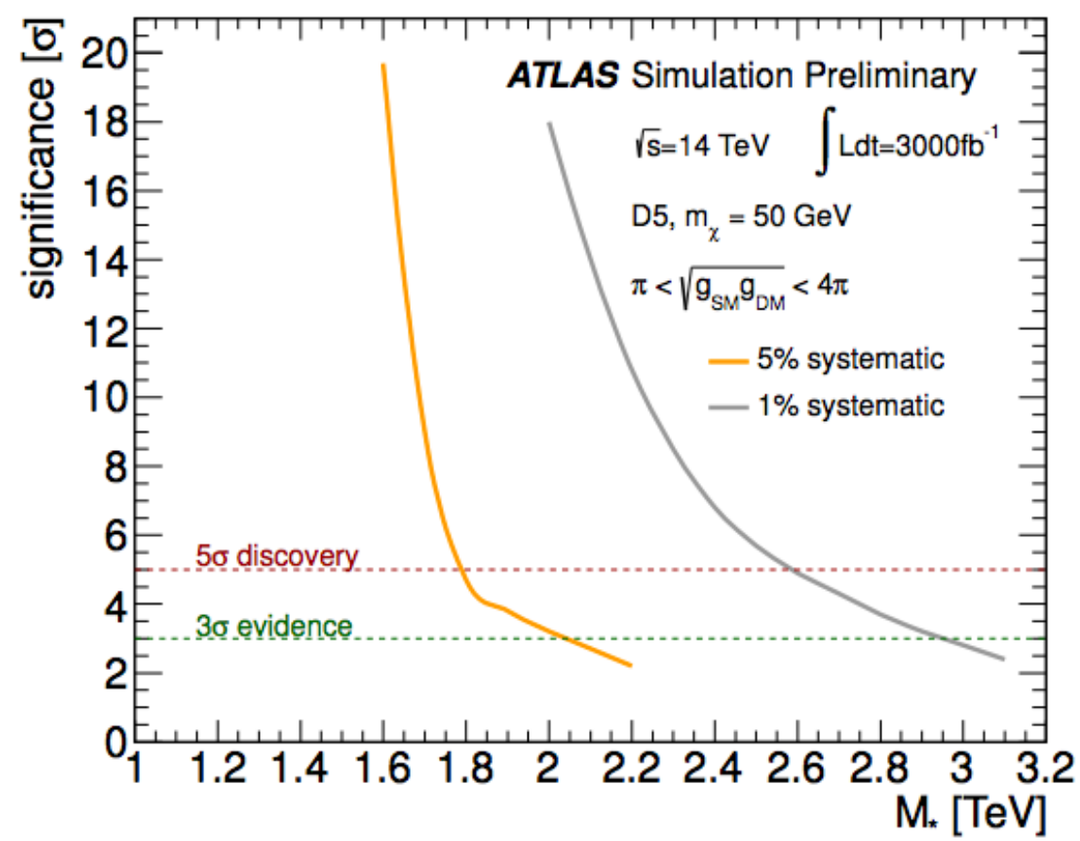
$$M^* = M_{med} / \sqrt{g_{SM} g_{DM}}$$

coupling to SM and DM

  - Validity of EFT in discussion

$$Q_{tr} < M_{med}$$

typical scale of interaction

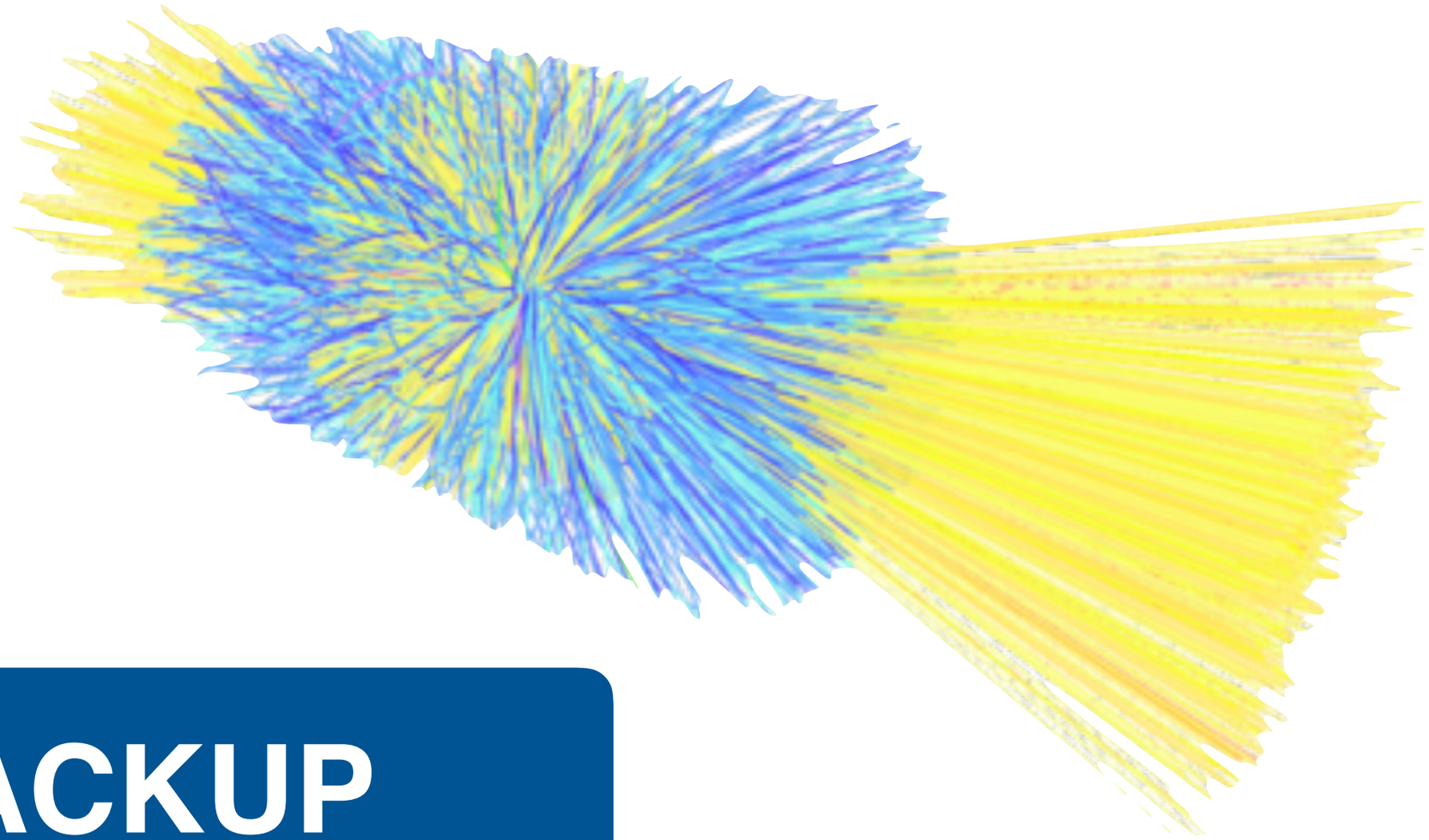


The discovery of the Higgs boson opens a new era in the LHC physics within and beyond the Standard Model

Precision test requiring high luminosity are needed in order to discover possible deviations from the SM theory

HL-LHC allow to measure Higgs coupling to a few percent precision and rare processes

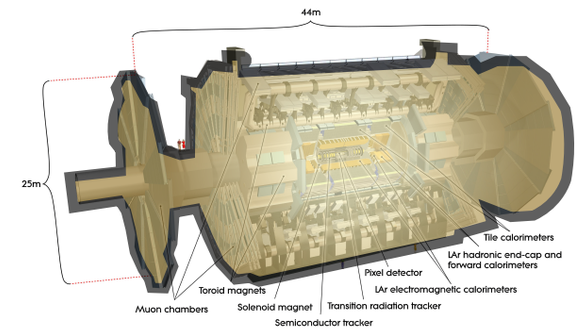
If new physics is found at the LHC, ATLAS at HL-LHC can measure its properties. If not, it will significantly increase the discovery reach in many signatures with small production cross section



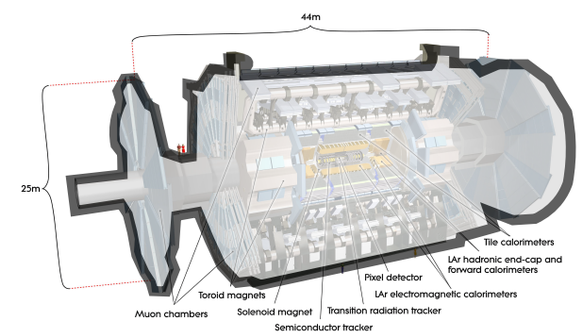
BACKUP

Upgrade studies

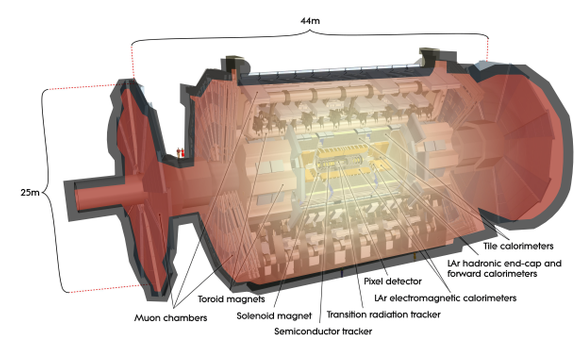
- Sensitivity studies are carried out with 14 TeV Monte Carlo samples and by applying detector response corrections to generator level particles



- Three detector layouts (Reference, Middle and Low) which correspond to three costing scenario and differs in both acceptance and performances



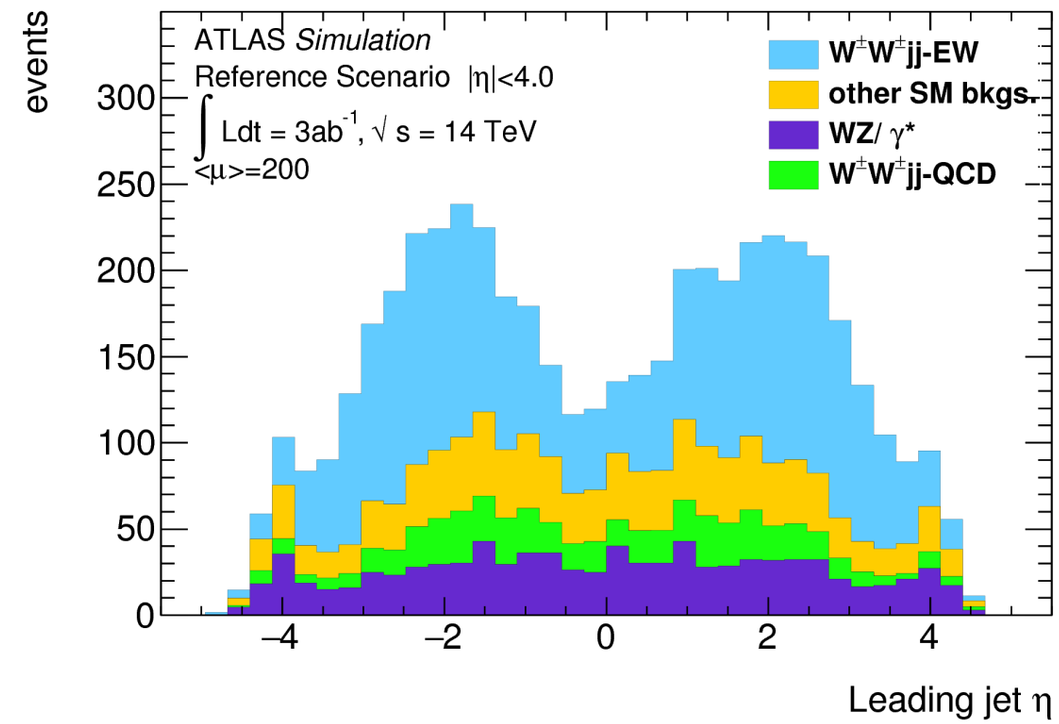
- Discovery reach critically relies on the performance of the lepton trigger, lepton reconstruction, b-jet identification and missing transverse momentum reconstruction



Vector Boson Scattering

LHCC-G-166

- Unique window into the nature of the EWKSB
  - VBS amplitude unitarized by the Higgs boson
  - Many physics scenarios predict enhancement



- WW-ewk offers clear signature of two same-sign leptons with two forward jets
  - Final state comparable to QCD-induced processes
  - Tracker extension increases the precision of the measurement

scoping document

Scenario	Z_{σ_B}	$\Delta\sigma/\sigma$
Reference scenario	11.3 ± 0.6	5.9%
Middle scenario	6.06 ± 0.3	11%
Low scenario	5.02 ± 0.2	13%

Dilepton/Ditop resonances search

ATL-PHYS-PUB-2013-003

- Many extensions of the SM predict new resonances

Benchmark models

- Extradimension: Kaluza Klein (KK) gluons decaying to a pair of top-antitop

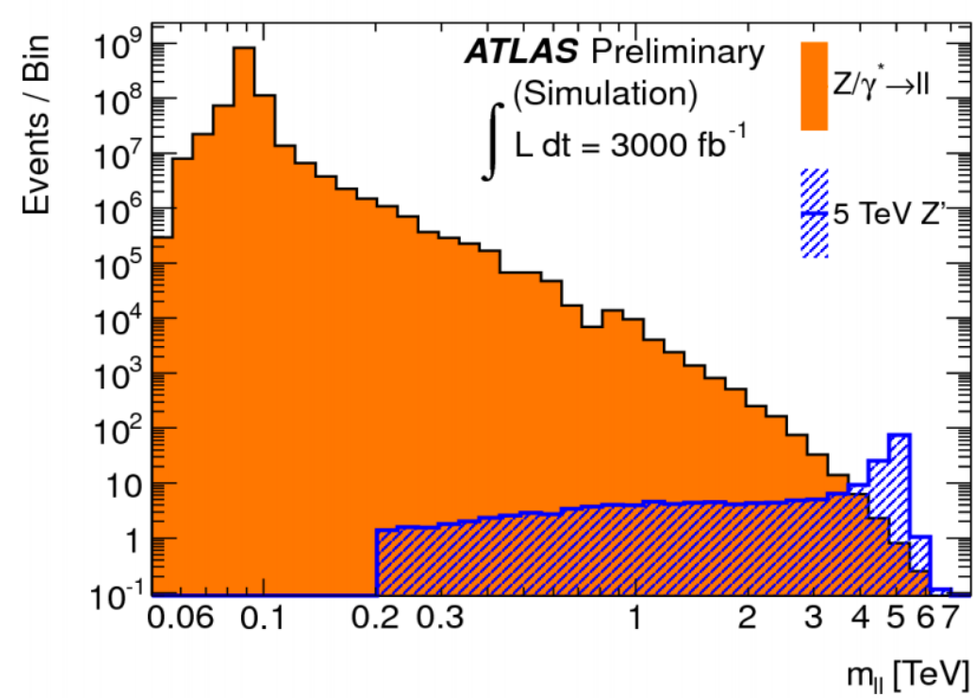
- Top color: Z' bosons decaying to top-antitop pairs

- Z'→ ee, Z'→μμ offer clear signatures

mass reach [TeV]

model	3000 fb^{-1}
g_{KK}	6.7 (5.6)
Z'_{topcolor}	5.5 (3.2)

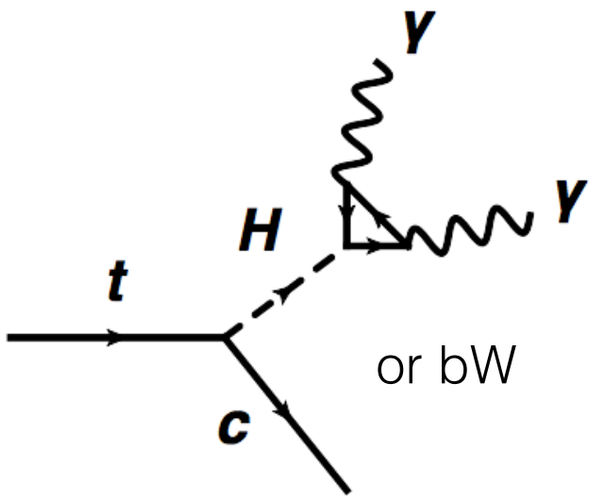
1lep 2lep



BSM rare decays: t→cH

ATL-PHYS-PUB-2013-012

- **Flavour changing neutral current (FCNC) — sign of new physics**
  - GIM suppression relaxed → coupling larger than SM (QS, FC-2HDM, MSSM)

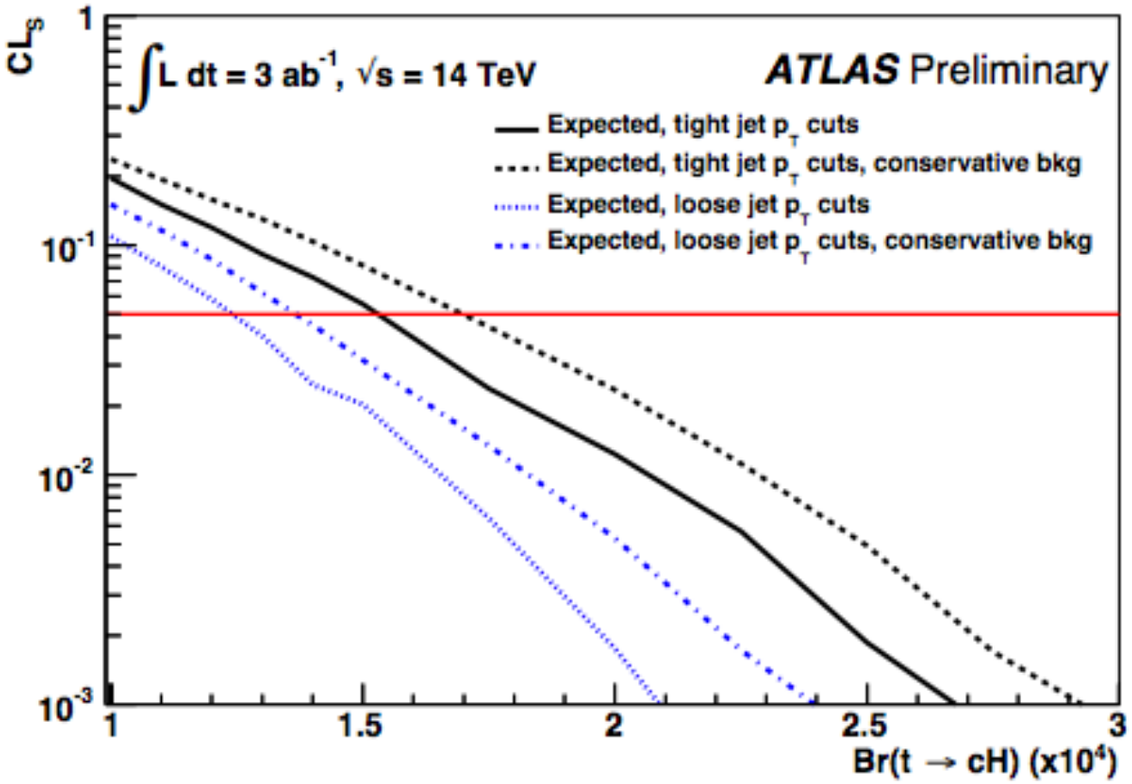


SM $BR(t \to cH) = 3\times10^{-15}$

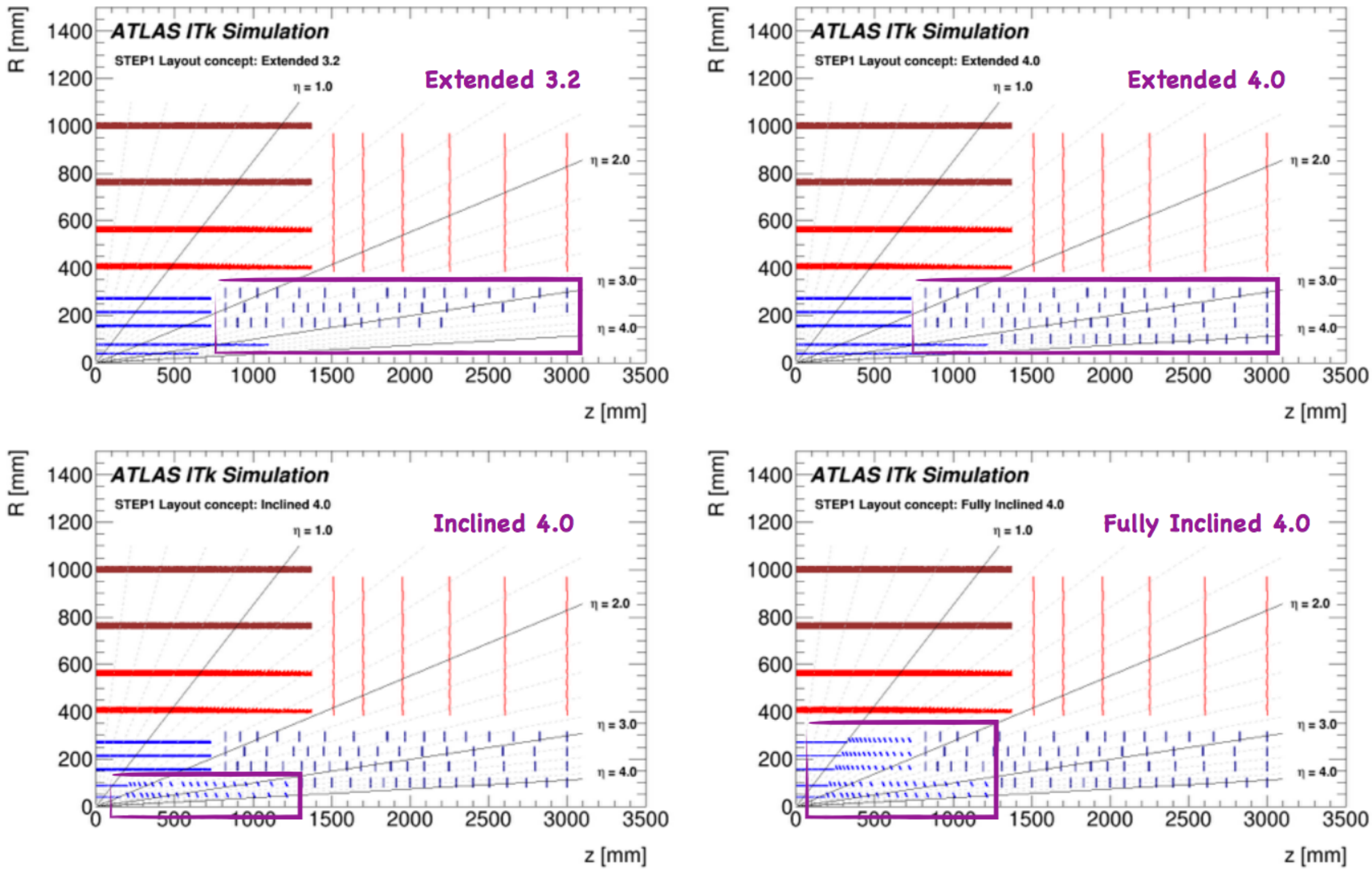
BSM $BR(t \to cH) \sim 10^{-5}–10^{-3}$

- **Expected limit**

$BR(t \to cH) = 1.5\times10^{-4}$



ITK layouts


ATLAS ITk Simulation
STEP1 Layout concept: Extended 3.2
Extended 3.2
ATLAS ITk Simulation
STEP1 Layout concept: Extended 4.0
Extended 4.0
ATLAS ITk Simulation
STEP1 Layout concept: Inclined 4.0
Inclined 4.0
ATLAS ITk Simulation
STEP1 Layout concept: Fully Inclined 4.0
Fully Inclined 4.0
η = 1.0
η = 2.0
η = 3.0
η = 4.0
R [mm]
z [mm]

light jet rejection

Efficiency to tag a jet of flavor **q** *ad* **b-jet***:*

$$\varepsilon_q = \frac{\text{Number of jets of real flavor q tagged as b}}{\text{Number of jets of real flavor q}}$$

ε_{udsc} = mistagging rate

$r_{udsc} = 1/\varepsilon_{udsc}$: light jet rejection