Looking into the Future with the LHC

Physics Prospects at the upgraded Large Hadron Collider

The 2nd China LHC Physics (CLHCP) workshop

16-19 December 2016

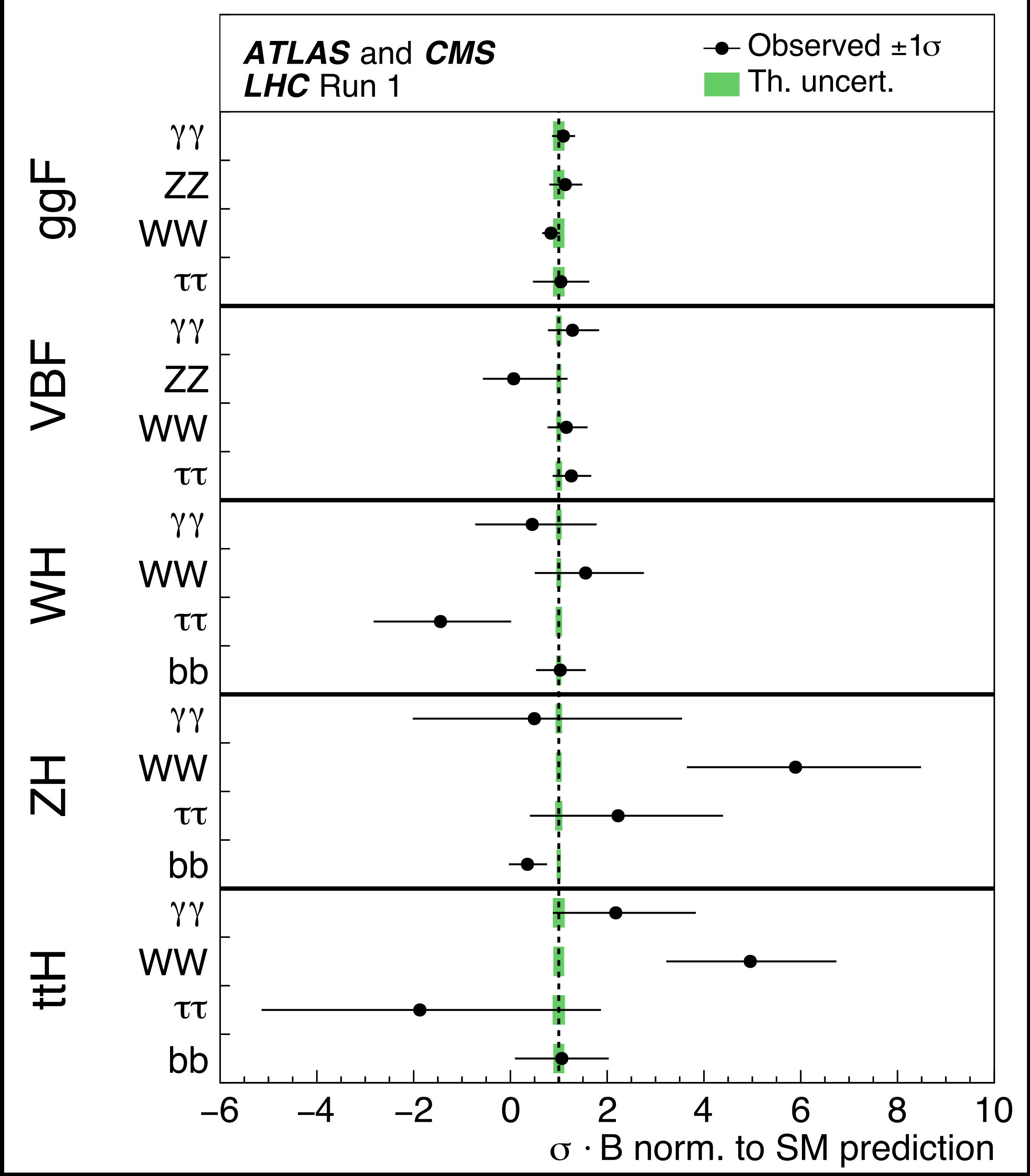
João Guimarães da Costa

The Highlight of the LHC Program

The Higgs Boson

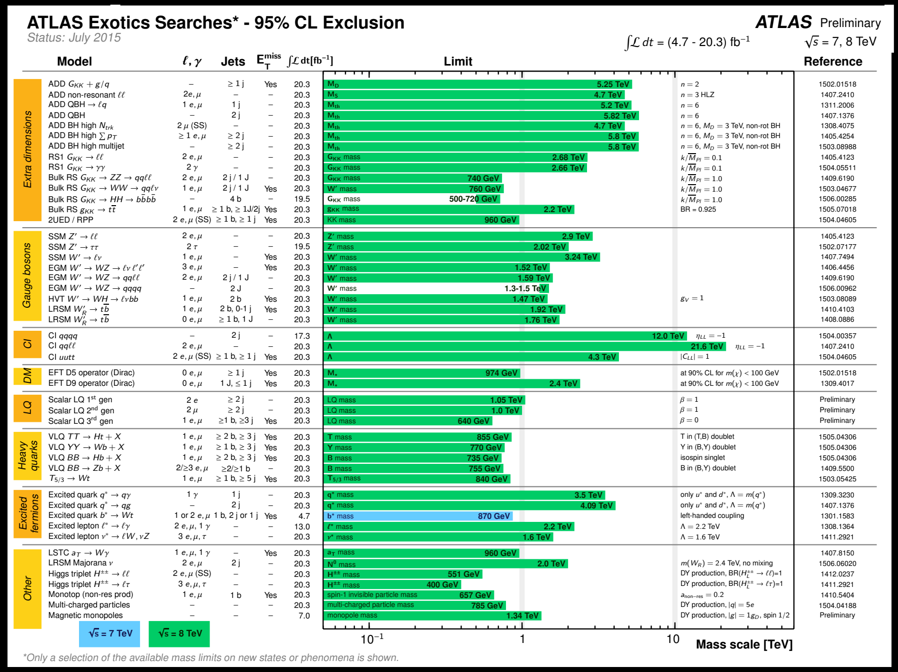
arXiv: 1606.02266

- Measurements of properties in progress @13 TeV
- So far, appears consistent with SM predictions
- Precision measurements are required to understand electroweak symmetry breaking
- Higgs could also be a portal to BSM physics



Major motivation for HL-LHC

The HL-LHC Physics Program



LHC is a discovery machine

Many ongoing searches…

Indications here and there but no conclusive sign of new physics yet

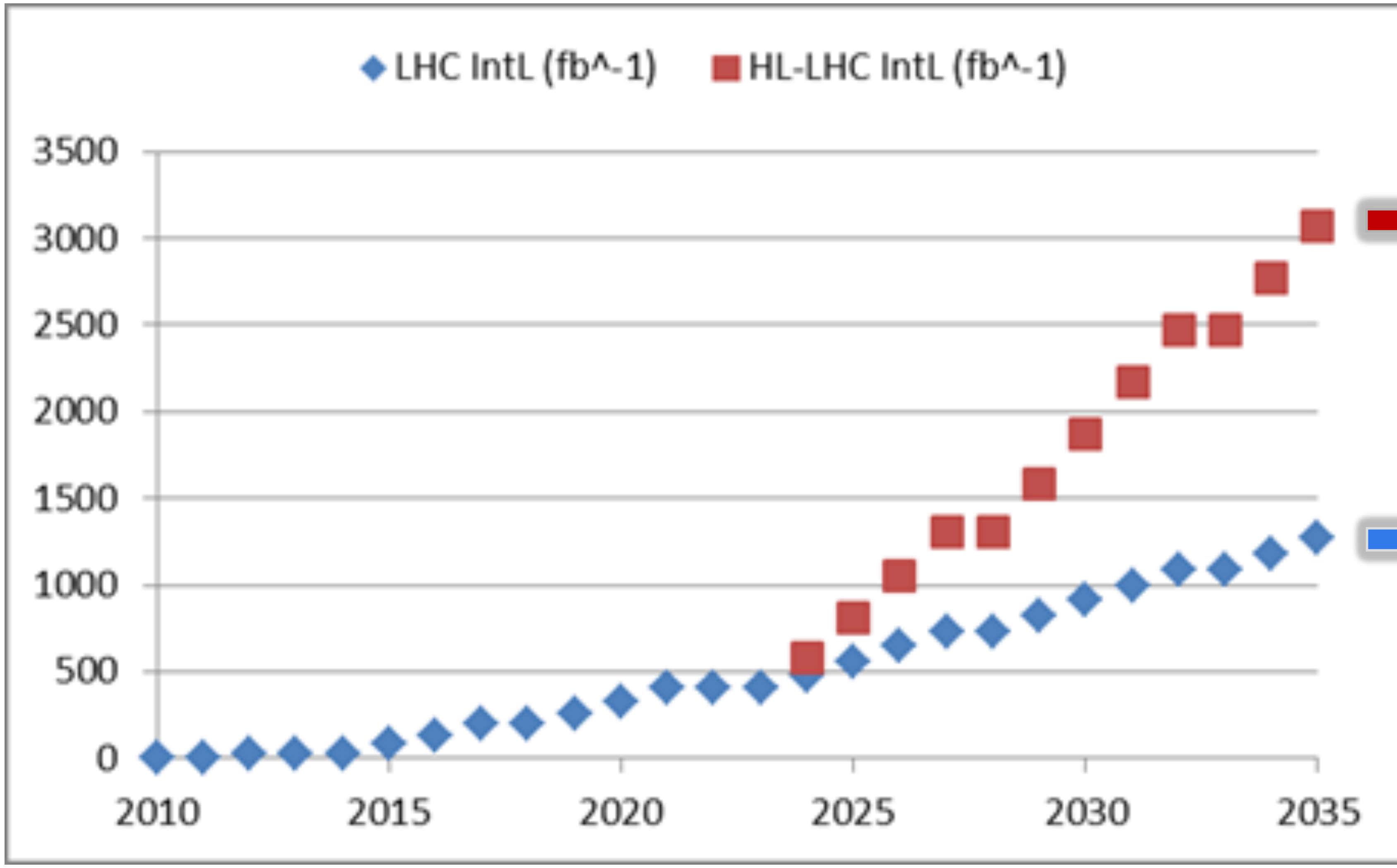
HL-LHC has the potential for major discoveries

Today

- Higgs Physics
- Exotics Bump Hunting
- Dark Matter Searches
- Search for Long Lived Particles
- Supersymmetry

} **HL-LHC**

Why the High-Luminosity LHC?



High Luminosity LHC

By implementing HL-LHC

Almost a factor 3

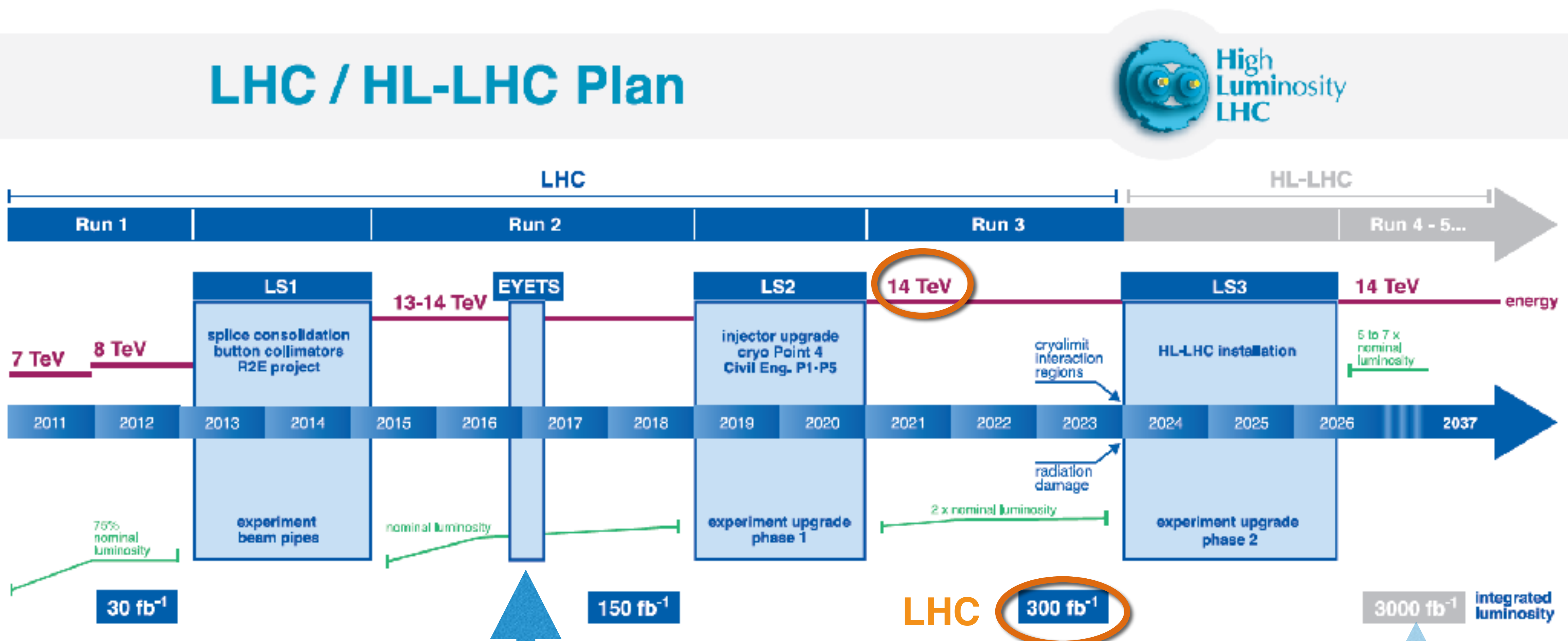
By continuous performance improvement and consolidation

Around 300 fb^{-1} the present Inner Triplet magnets reach the end of their useful life (due to radiation damage) and must be replaced.

Goal of HL-LHC project:

- 250 – 300 fb^{-1} per year
- **3000 fb^{-1} in about 10 years**

High-Luminosity LHC Plan



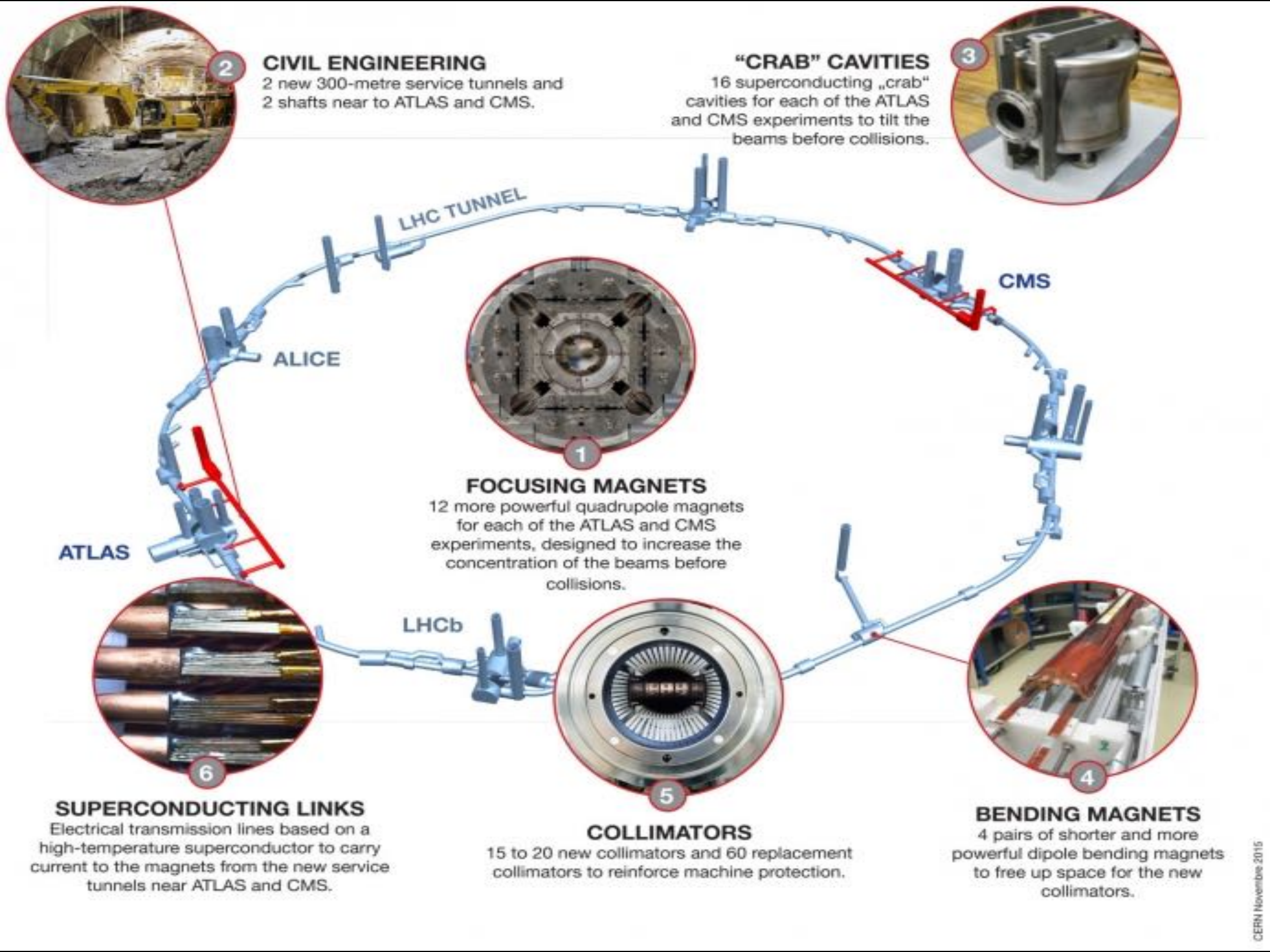
We are here!
~35 fb-1 collected in Run 2

CEPC startup?

HL-LHC goal is deliver 3000 fb^{-1} in 10 years

- Implies integrated luminosity of 250-300 fb^{-1} per year
- Requires peak luminosities of 5-7x10^{34} $cm^{-2}s^{-1}$ while using luminosity leveling (3-5 hours at peak luminosity)

Design for "ultimate" performance 7.5x10^{34} $cm^{-2}s^{-1}$ and 4000 fb^{-1}


2
CIVIL ENGINEERING
2 new 300-metre service tunnels and
2 shafts near to ATLAS and CMS.
"CRAB" CAVITIES
16 superconducting „crab"
cavities for each of the ATLAS
and CMS experiments to tilt the
beams before collisions.
3
LHC TUNNEL
CMS
ALICE
1
FOCUSING MAGNETS
12 more powerful quadrupole magnets
for each of the ATLAS and CMS
experiments, designed to increase the
concentration of the beams before
collisions.
ATLAS
LHCb
6
SUPERCONDUCTING LINKS
Electrical transmission lines based on a
high-temperature superconductor to carry
current to the magnets from the new service
tunnels near ATLAS and CMS.
5
COLLIMATORS
15 to 20 new collimators and 60 replacement
collimators to reinforce machine protection.
4
BENDING MAGNETS
4 pairs of shorter and more
powerful dipole bending magnets
to free up space for the new
collimators.
CERN Novembre 2015

Focusing magnets

Beam more focused before the collision

12 more powerful quadruplet magnets for ATLAS and CMS experiments

Magnetic field:

8 Tesla (LHC)

↓

12 Tesla (HL-LHC)

Superconducting material:

Niobium-Titanium alloy (LHC)

↓

Niobium-tin (Nb_3Sn) compound (HL-LHC)

Squeezing the beam at IP

Quads for the inner triplet

Decision 2012 for low-β quads

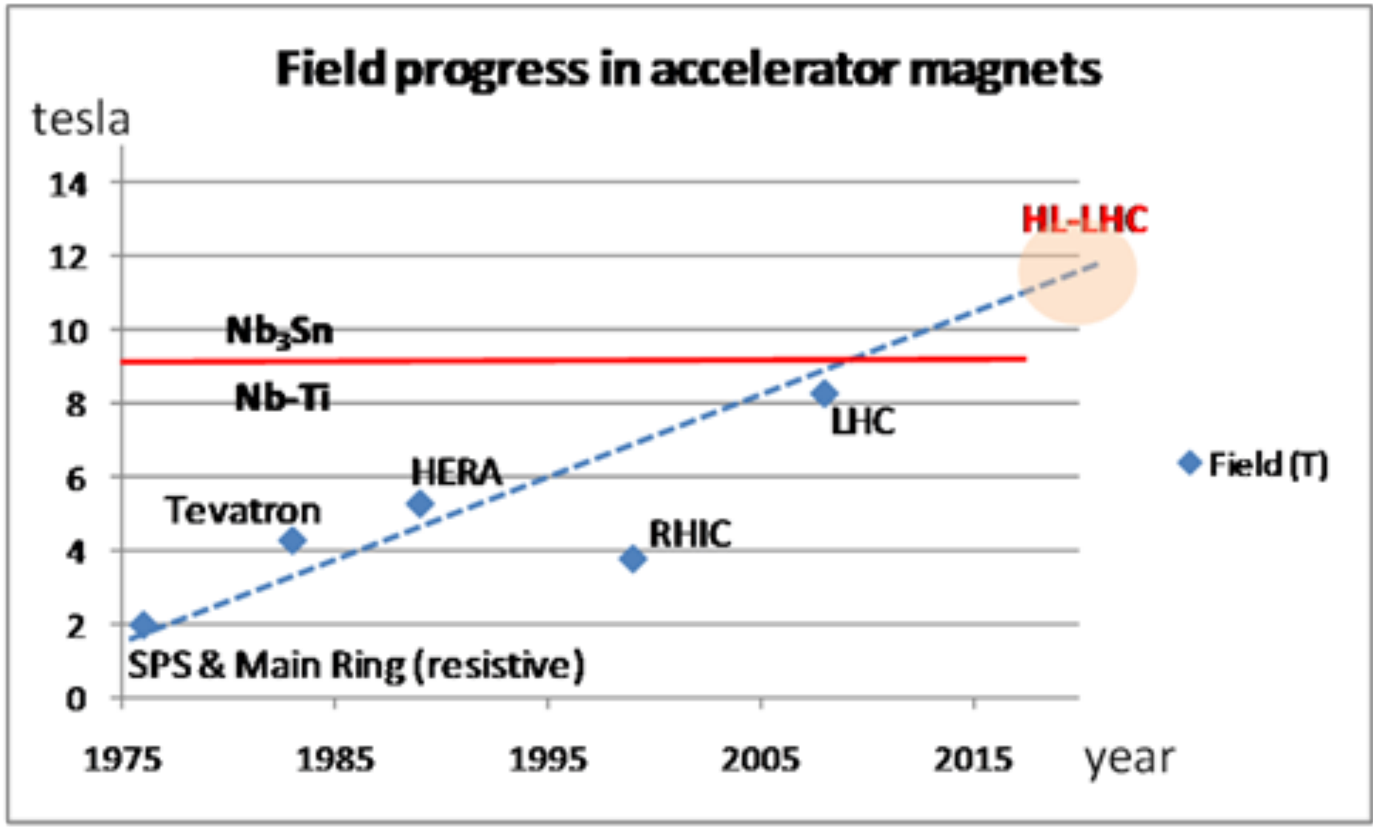
Aperture ∅ 150 mm – 140 T/m

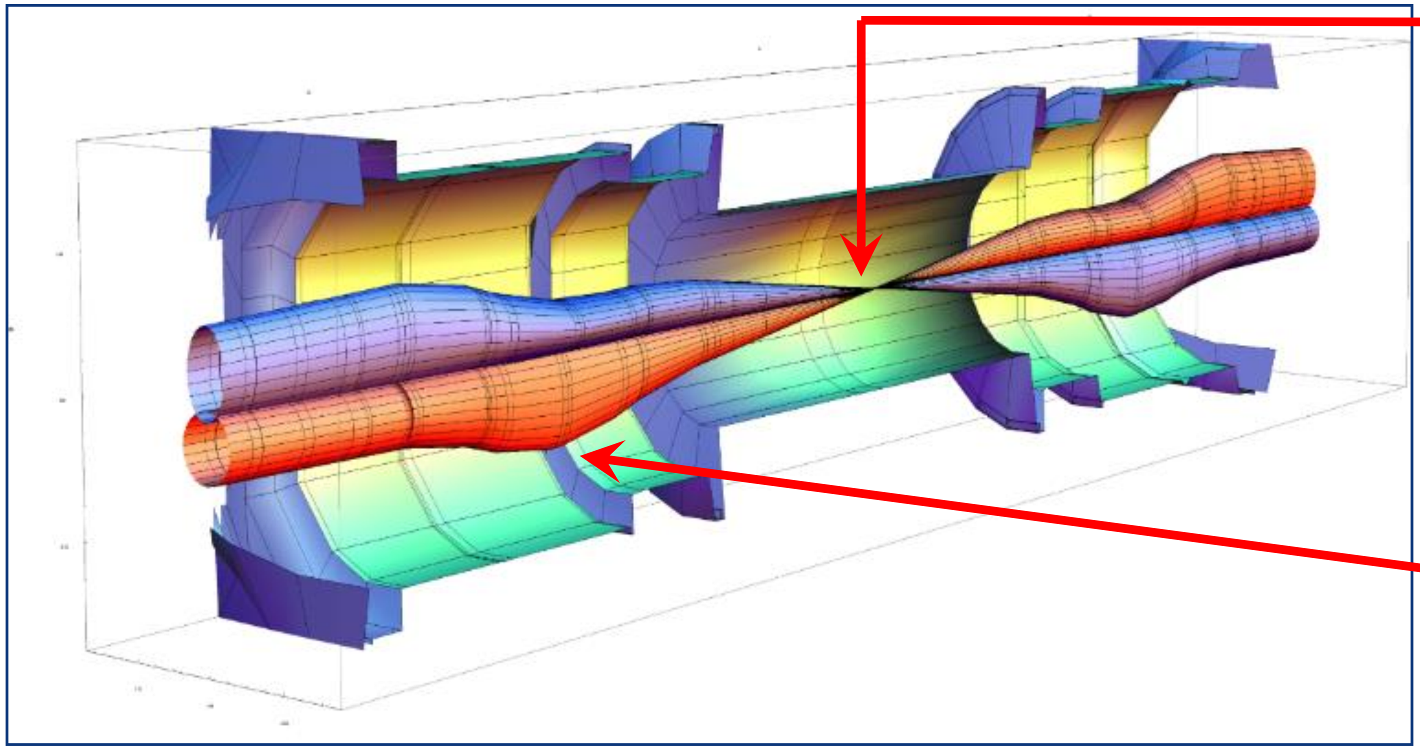
(B_{peak} ≈12.3 T)

operational field, designed for 13.5 T

=> Nb_3Sn technology

(LHC: 8 T, 70 mm)

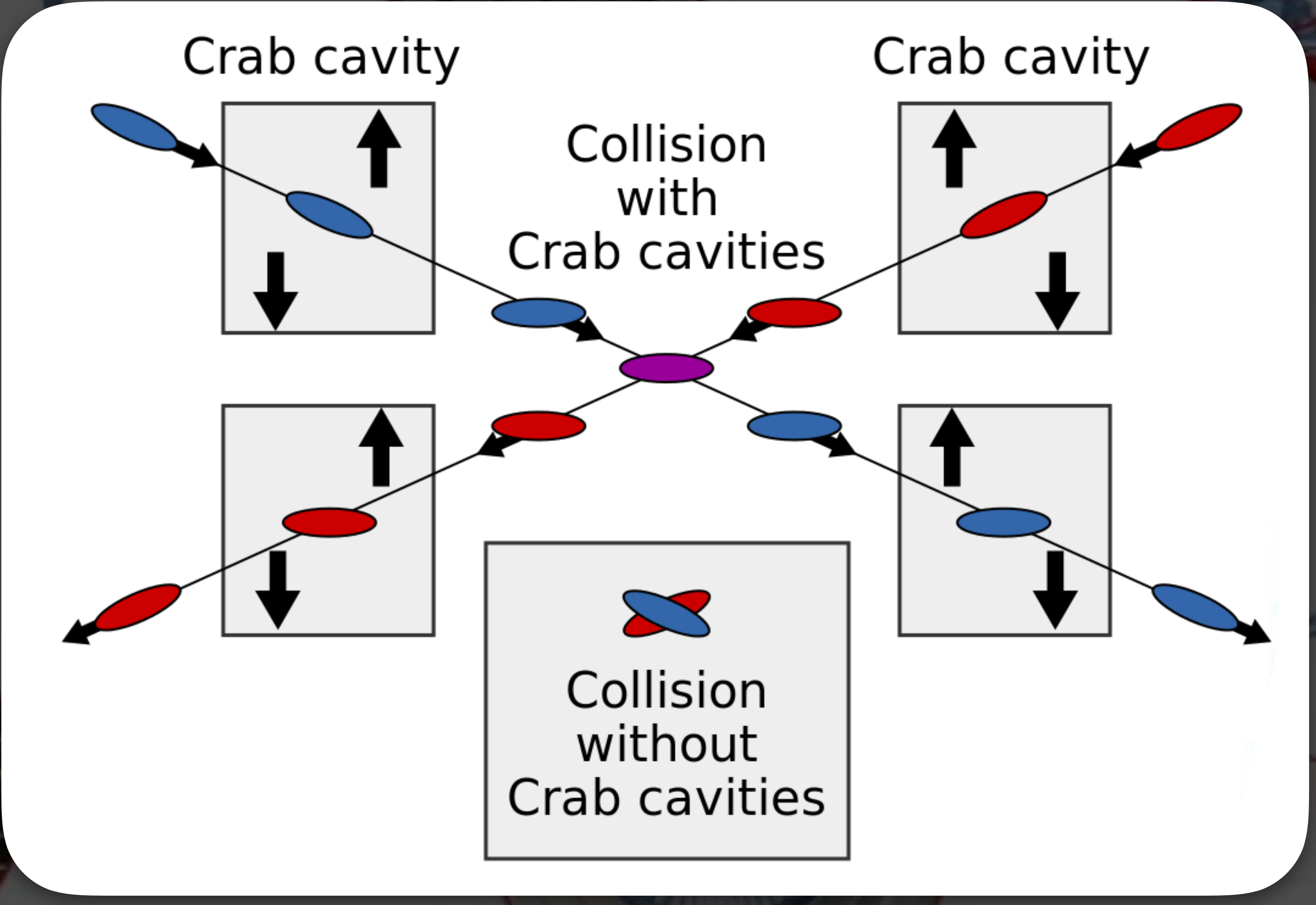




	$\beta_{triplet}$	Sigma triplet	β*	Sigma*
Nominal	~4.5 km	1.5 mm	55 cm	17 um
HL-LHC	~20 km	2.6 mm	15 cm	7 um

Crab cavities

Tilt the particle bunches before collision in order to increase the area where they meet

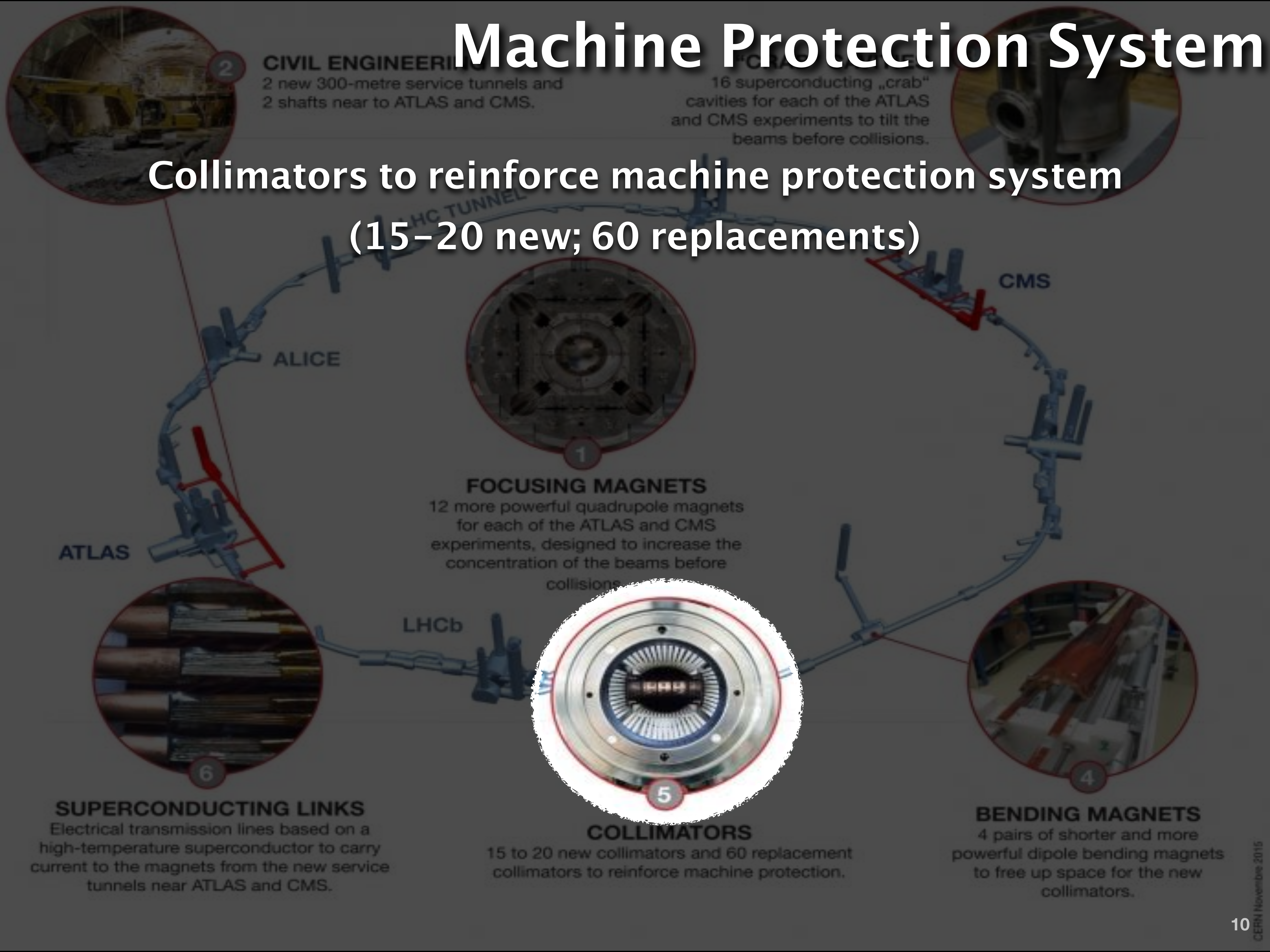


4 crab cavities to be installed close to each ATLAS and CMS experiments

(Installation LS3)

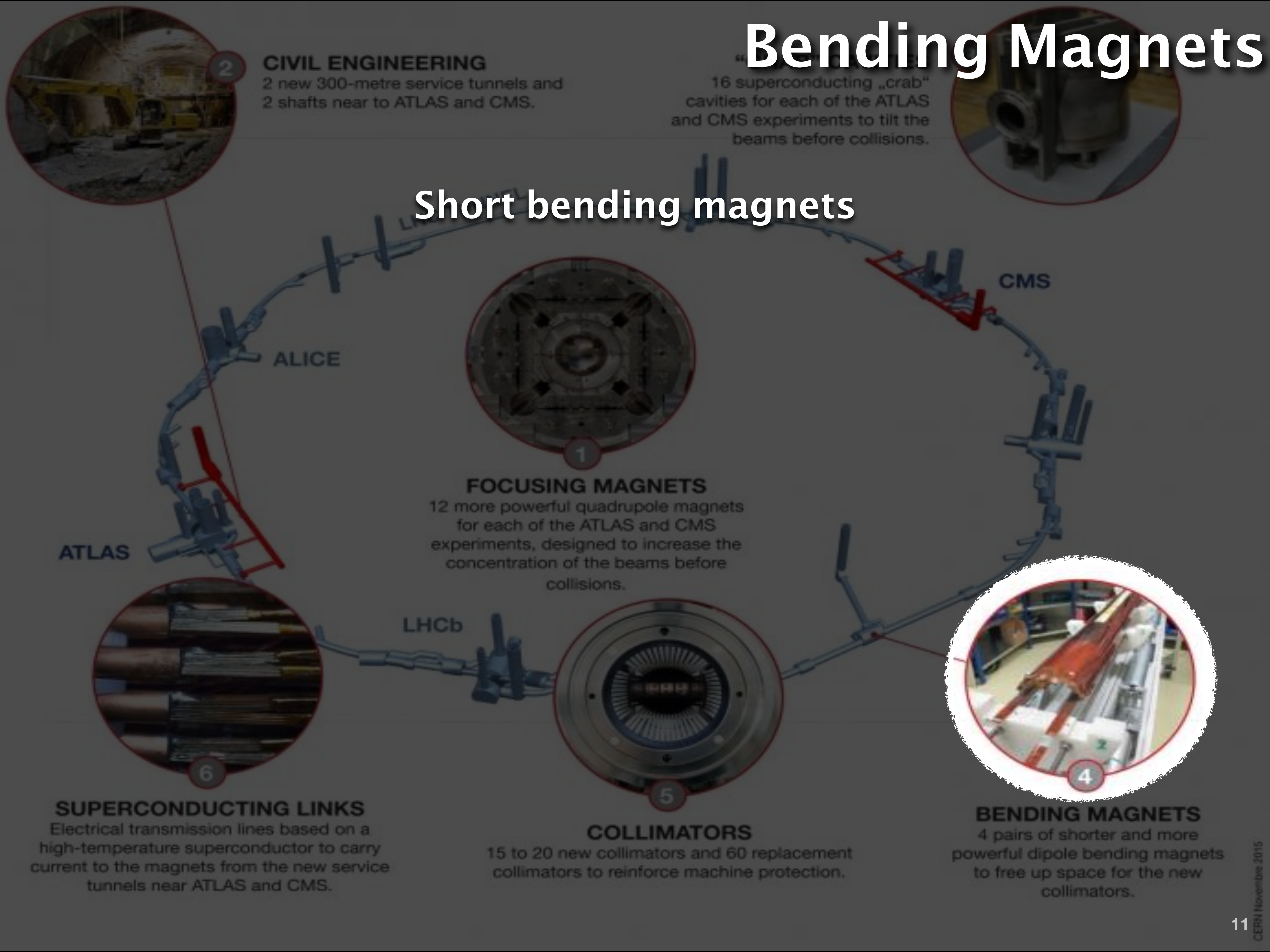
Machine Protection System

Collimators to reinforce machine protection system (15–20 new; 60 replacements)



Bending Magnets

Short bending magnets

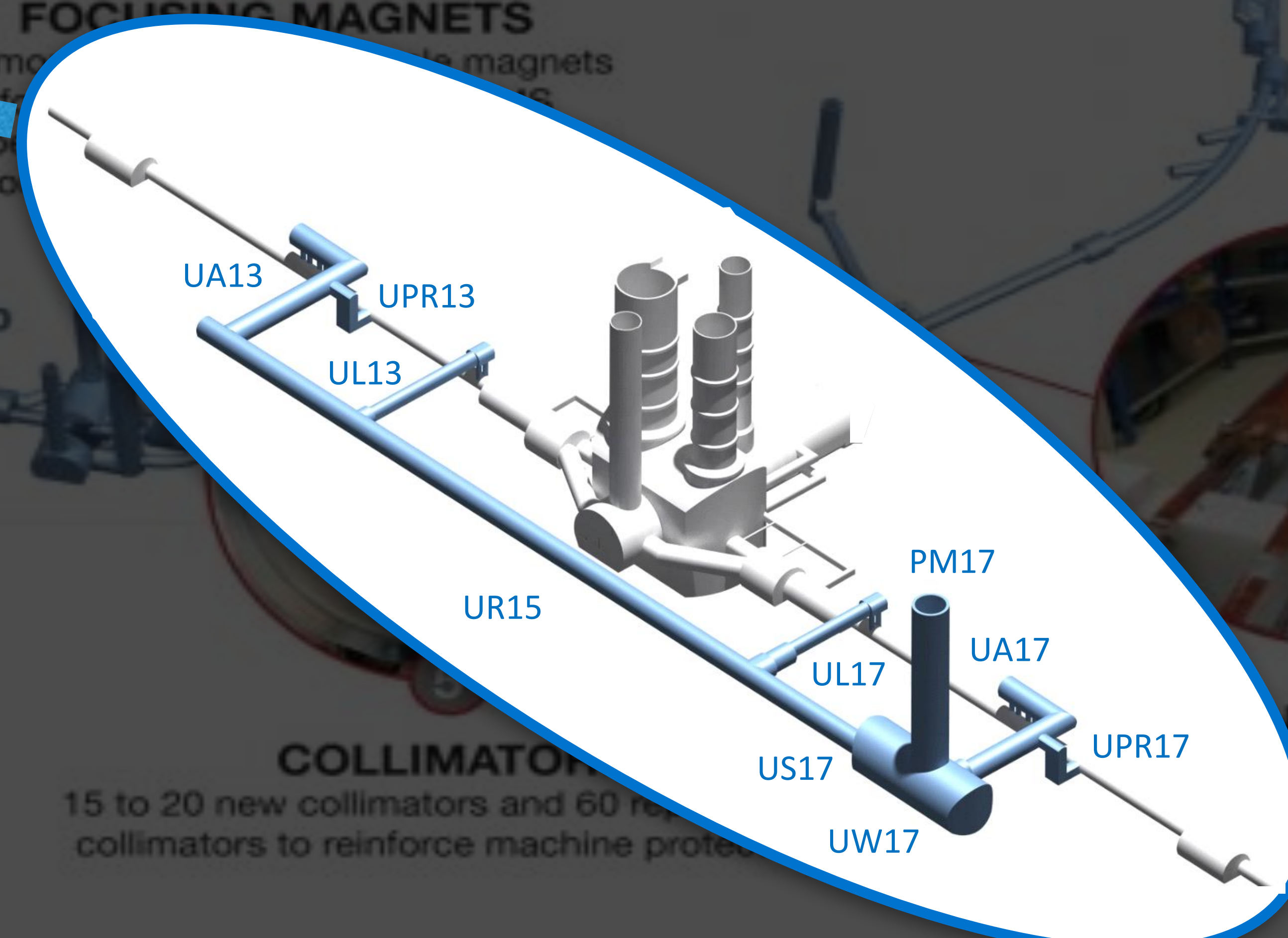


Civil-engineering work

2 new ~300-meter long service tunnels to be excavated near ATLAS and CMS

House equipment sensitive to radiation

e.g. Power converters (AC from network to high-intensity DC for magnets)



New Superconducting Transmission Lines

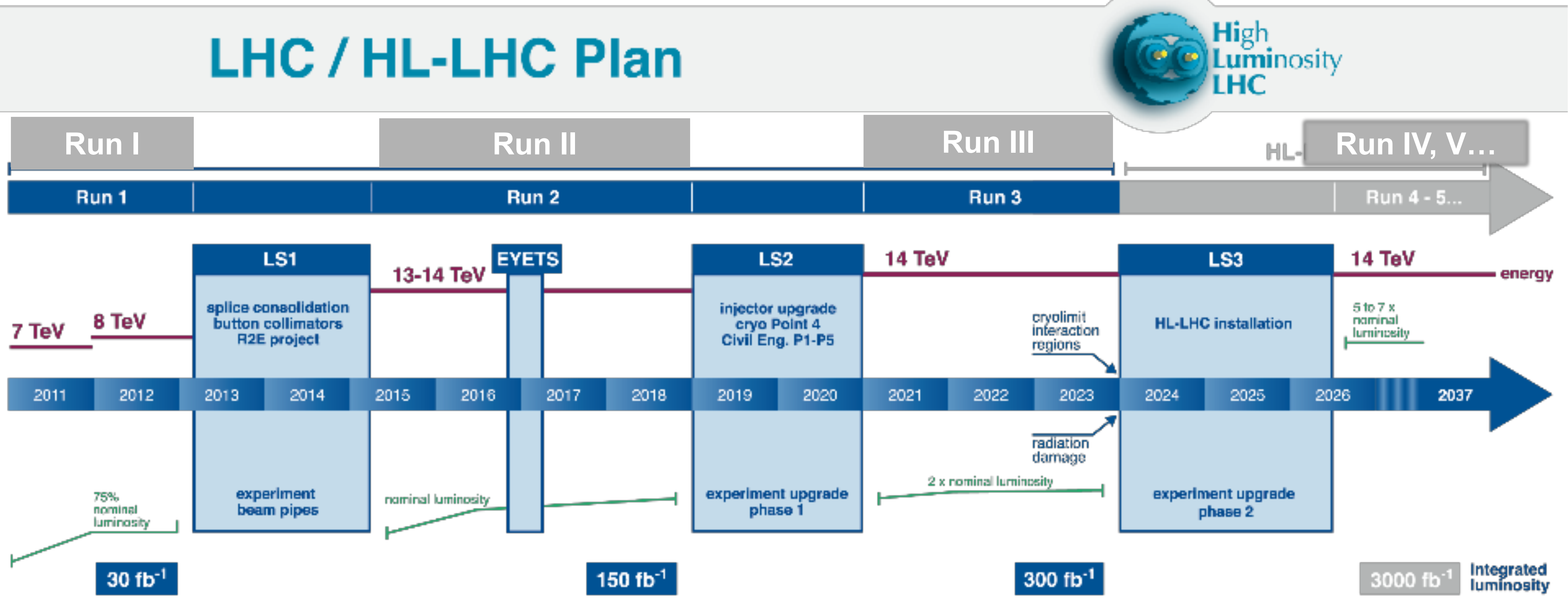
New electrical transmission lines will connect power converters to accelerator magnets

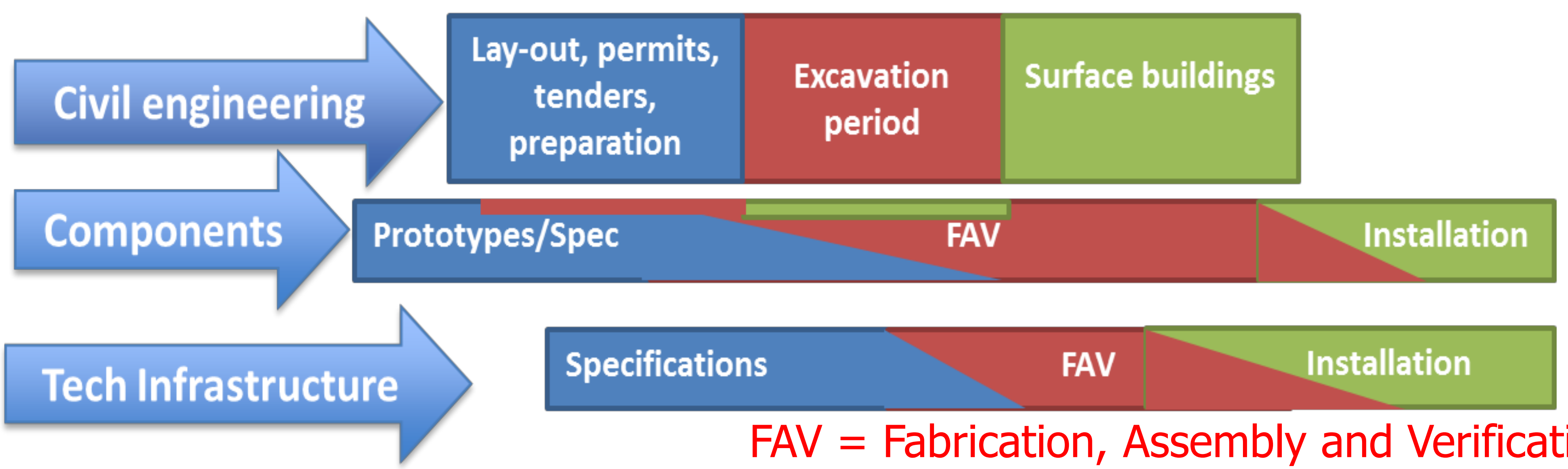
Cables made of high-temperature superconducting material (Magnesium diboride)

- Operate at 20 Kelvin
- Record current intensities: < 100,000 Amps

HL-LHC Schedule

Construction project has been approved

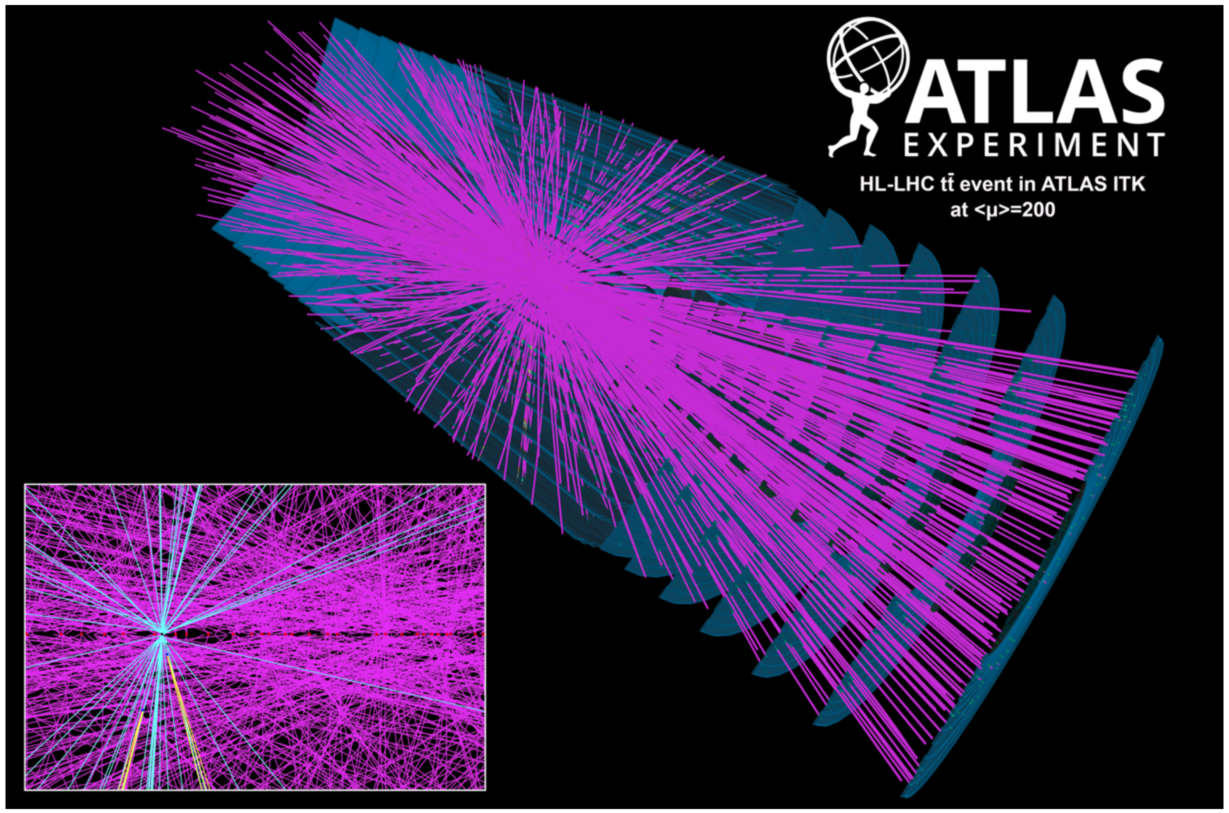




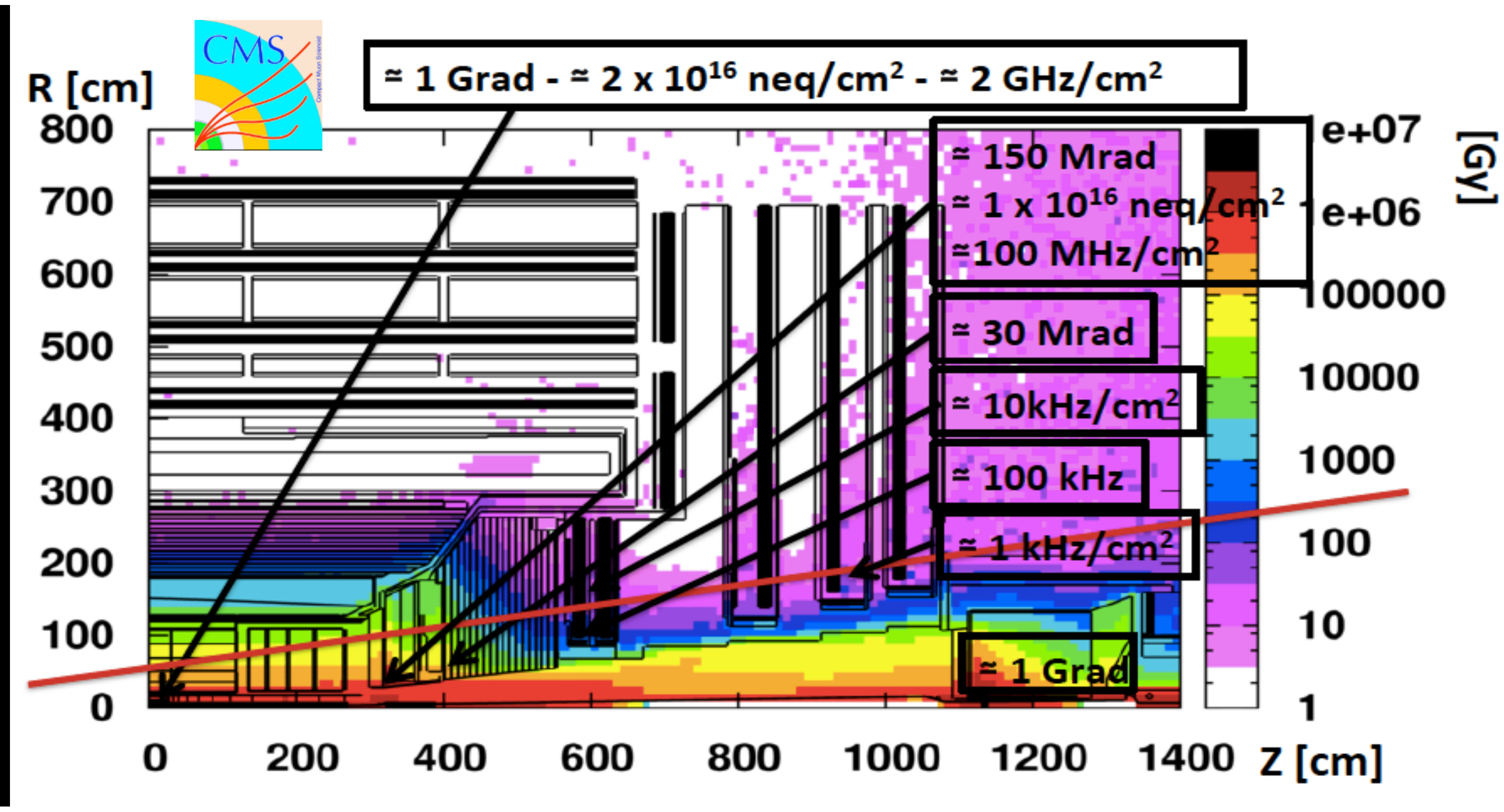
FAV = Fabrication, Assembly and Verification

The High-Luminosity Challenge

Very high pile-up



Very intense radiation



Major experiment upgrades needed to:

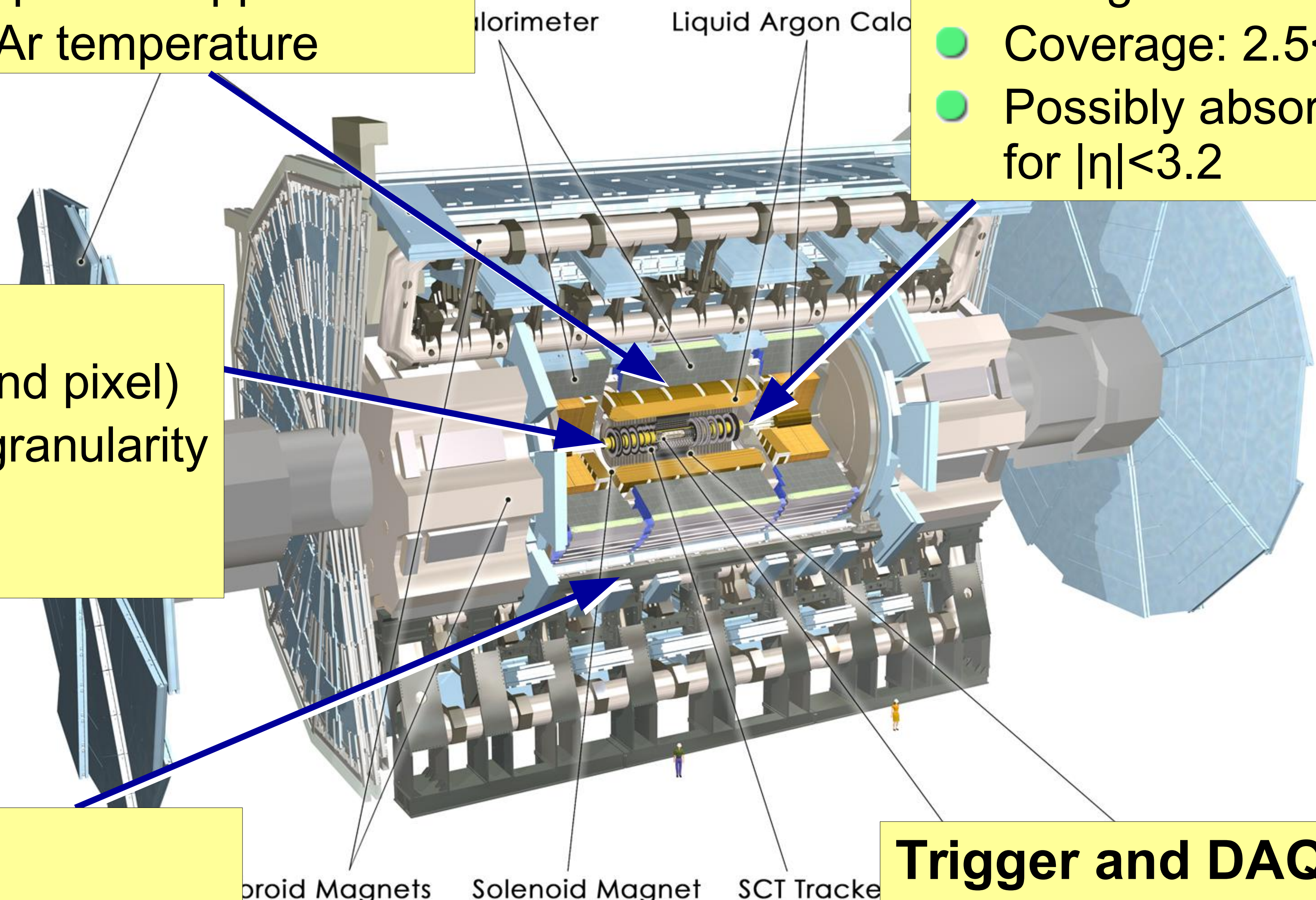
- **Improve radiation hardness** and replace detectors at end-of-life
- **Mitigate pile-up (high granularity, fast timing)**
- **Allow higher event rates to maintain trigger capabilities**

Goal is to maintain or improve current physics performance

ATLAS Detector Upgrades

Calorimeters
- New BE/FE electronics
- New HV power supplies
- Lower LAr temperature

(Timing detector)
- High granularity timing detector
- Coverage: 2.5<|η|<4.2
- Possibly absorber for |η|<3.2



Tracker
- All silicon tracker (strip and pixel)
- Radiation tolerant, high granularity
- Low material budget
- Coverage up to |η|=4

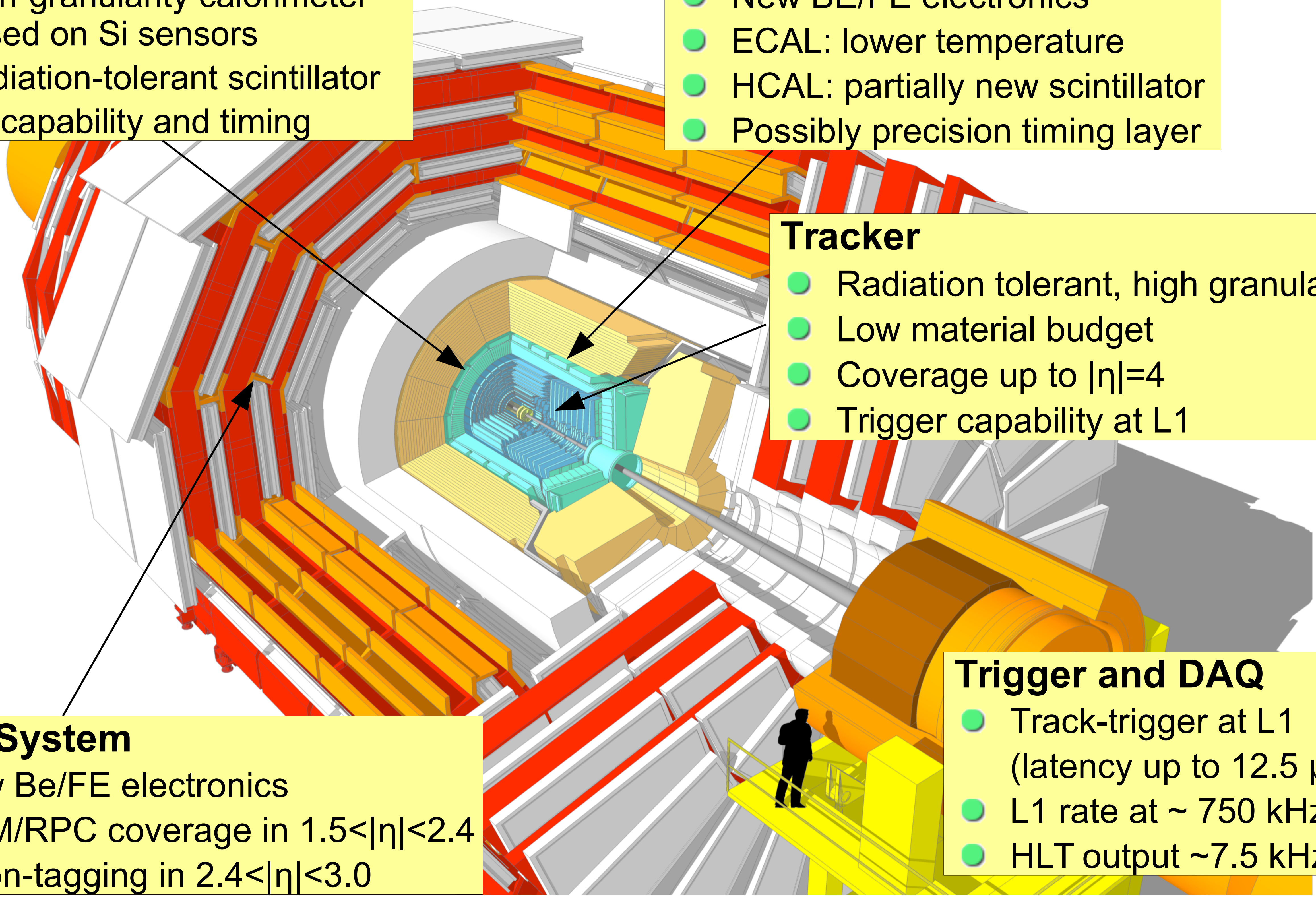
Muon System
- New BE/FE electronics
- New RPC layer in inner barrel
- Muon-tagging in 2.7<|η|<4.0 (under study)

Trigger and DAQ
- L0 rate at ~ 1 MHz (latency up to 10 μs)
- Possible hardware L1 track trigger
- HLT output ~10 kHz

CMS Detector Upgrades

Endcap Calorimeter
- High-granularity calorimeter based on Si sensors
- Radiation-tolerant scintillator
- 3D capability and timing

Barrel Calorimeter
- New BE/FE electronics
- ECAL: lower temperature
- HCAL: partially new scintillator
- Possibly precision timing layer



Tracker
- Radiation tolerant, high granularity
- Low material budget
- Coverage up to $|\eta|=4$
- Trigger capability at L1

Muon System
- New Be/FE electronics
- GEM/RPC coverage in $1.5<|\eta|<2.4$
- Muon-tagging in $2.4<|\eta|<3.0$

Trigger and DAQ
- Track-trigger at L1 (latency up to 12.5 μs)
- L1 rate at ~ 750 kHz
- HLT output ~7.5 kHz

Higgs Physics at the HL-LHC

A natural benchmark for detector design

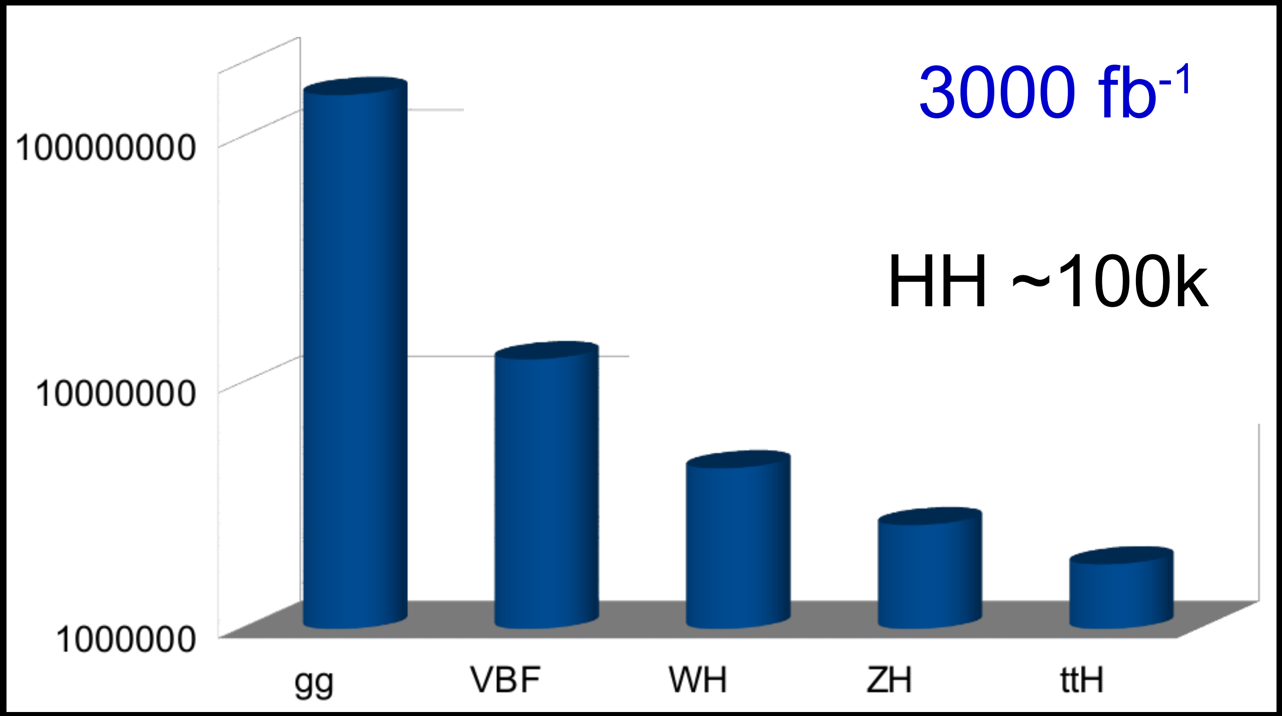
Higgs program at the HL-LHC

Major component of the HL-LHC physics program

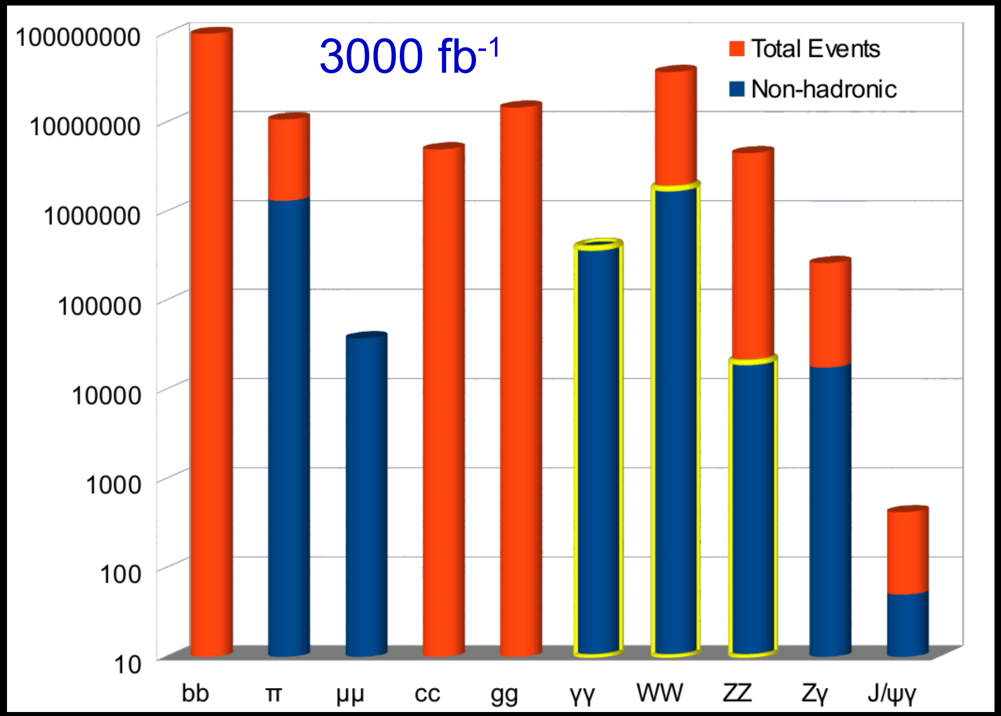
Main Higgs measurements at HL-LHC:

- **Higgs couplings**
- **Higgs self-coupling**
- **Rare Higgs decays**
- **Higgs differential distributions**
- **Heavy Higgs searches**

Higgs Production @ HL-LHC



Higgs Decay Channels



LHC: the first Higgs factory

Observable number of Higgs events per LHC experiment				
	2013	~2018	~2023	~2035
$H \to ZZ \to 4l$	20	120	4,000	40,000
$H \to \gamma\gamma$	570	6,500	25,000	240,000
VBF $H \to \tau\tau$	50	700	2,600	20,000

Analysis Strategy for HL-LHC Projections

HL-LHC analysis projections done in two ways

- **Parameterized detector performance**
  - Generator-level particles smeared with detector performance parameterized from full simulation and reconstruction of upgraded HL-LHC detectors
  - Effects of pile-up included for either:
    - $L = 5 \times 10^{34}$ $cm^{-2}s^{-1}$ (140 pile-up events)
    - $L = 7 \times 10^{34}$ $cm^{-2}s^{-1}$ (200 pile-up events)
  - Analyses based on existing Run 1 analyses with simple re-optimization for higher luminosity
- **Extrapolation of Run-1 or Run-2 results**
  - Scale signal and background to higher luminosities
  - Correct for different center of mass energy
  - Analyses not re-optimized for higher luminosity
  - Assume same detector performance as in Run-1/2 (some use corrections based on studies from first approach)

Systematic uncertainties considerations

- Large HL-LHC statistics ➜ often systematics become dominating in precision measurements
  - Difficult to predict how they will evolve with luminosity/time
- Both experiments start from current systematics with slightly different approaches:

ATLAS

- Experimental systematics scaled to best guess for HL-LHC
- Results provided with current theory systematics and without theory systematics

CMS

Provides results in two scenarios:

- S1: Current experimental and theory systematics
- S2: Experimental scaled with luminosity ($1/\sqrt{L}$) until a certain best achievable uncertainty level. The current theory systematics is halved

- Both approaches aim to bracket the achievable precision

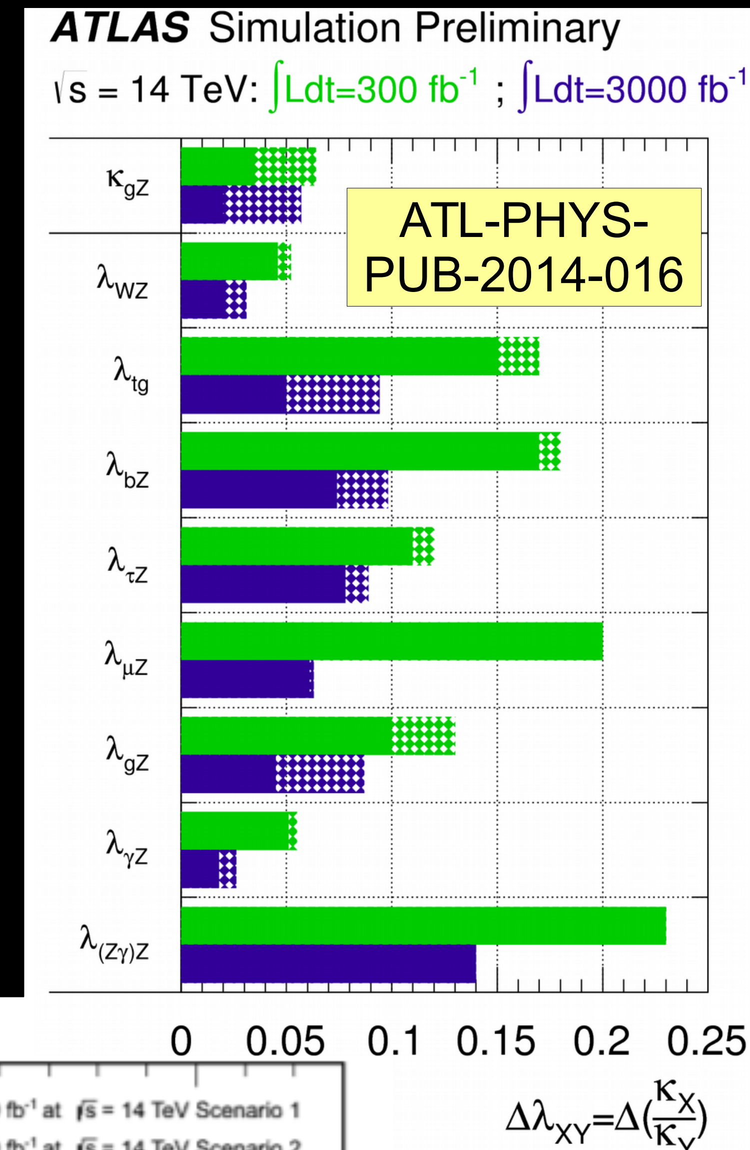
Projections for Higgs Couplings

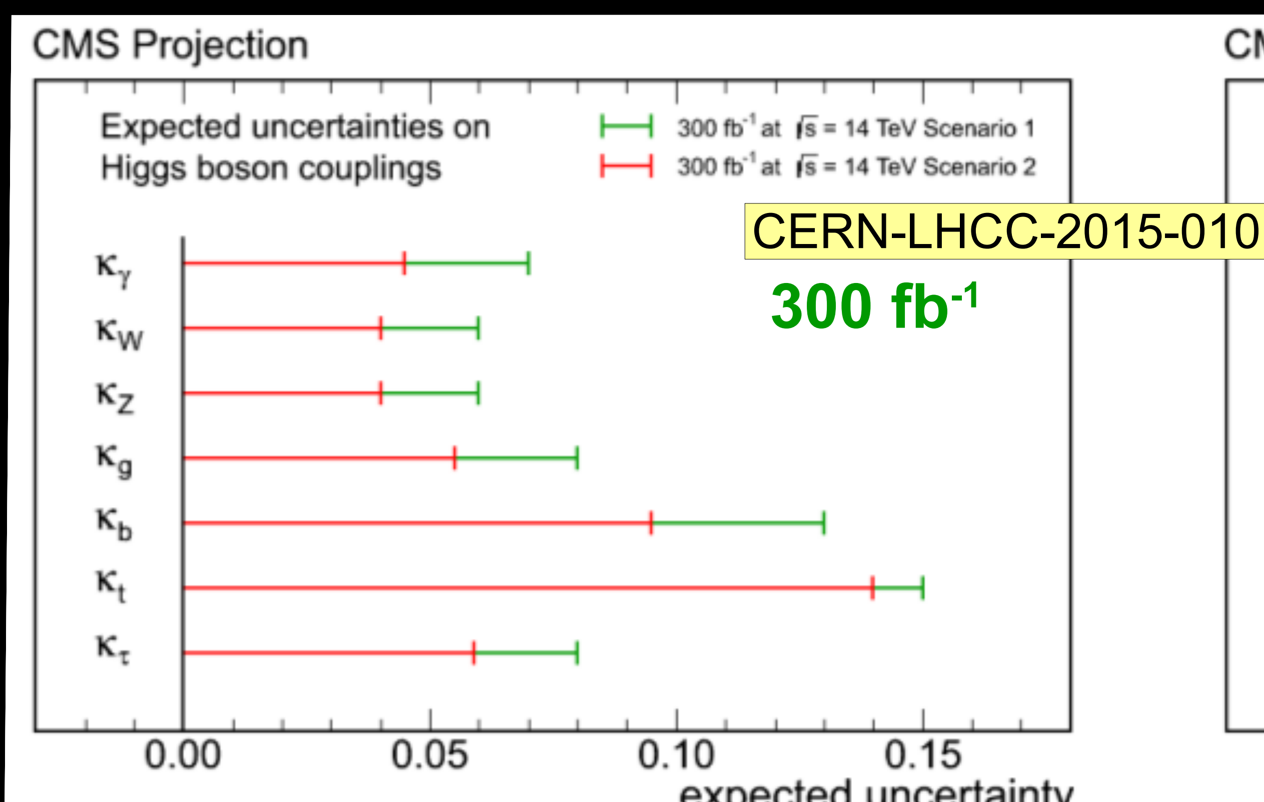
Full set of HL-LHC coupling projections are based on Run-1 analyses

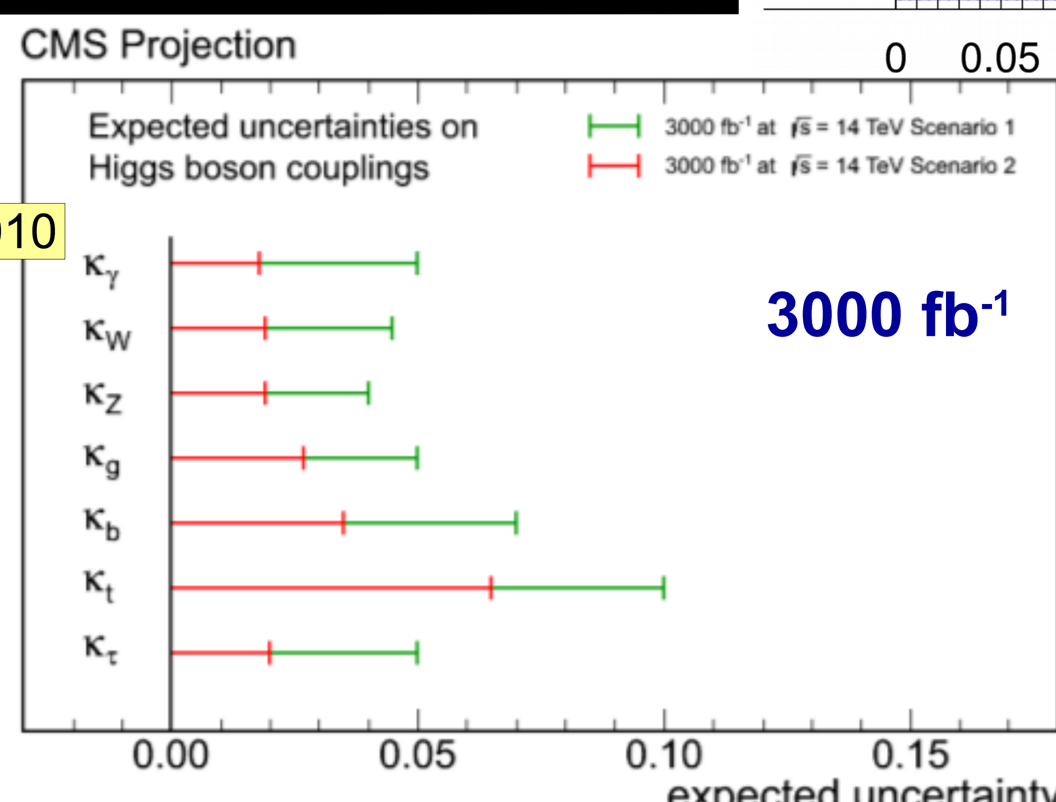
ATLAS: used μ=140
CMS: same as Run-1 performance

Higgs coupling precision (per experiment):
- **W, Z and γ: 3-5%**
- **μ: ~7%**
- **t, b and τ: 5-10%**

Do not include improved detector designs or improvements in analysis techniques



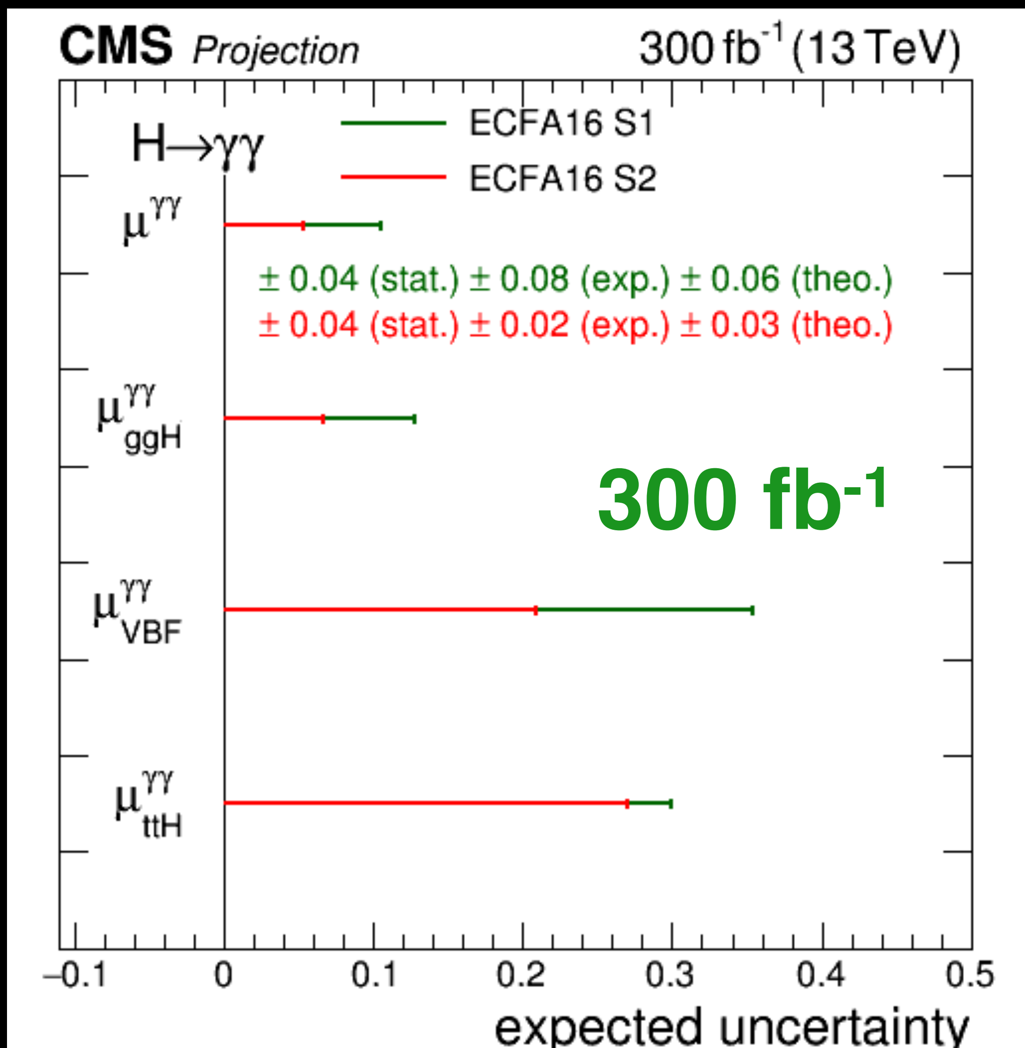


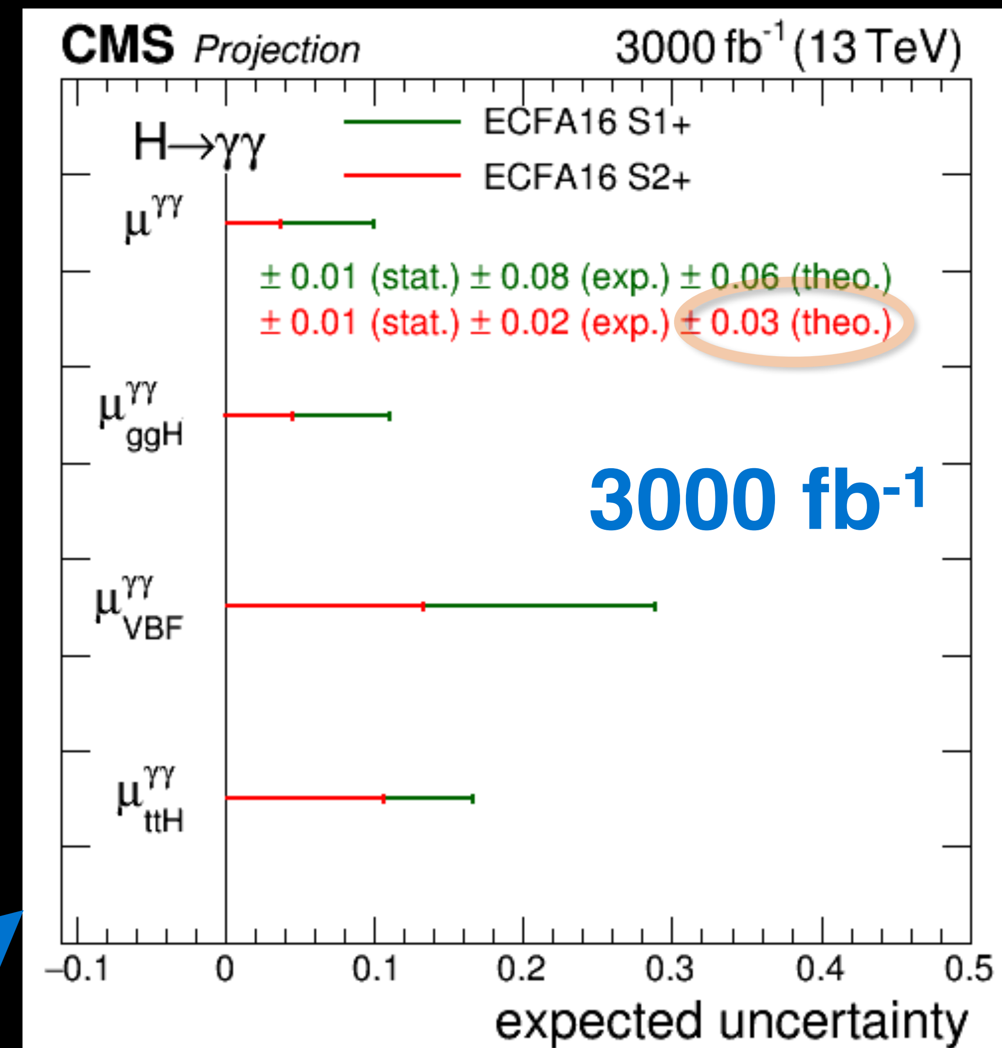


Projections based on Run 2 analysis

CMS-DP-2016-064

H→ γγ projections updated based on 13 TeV (12.9 fb^{-1}) analyses



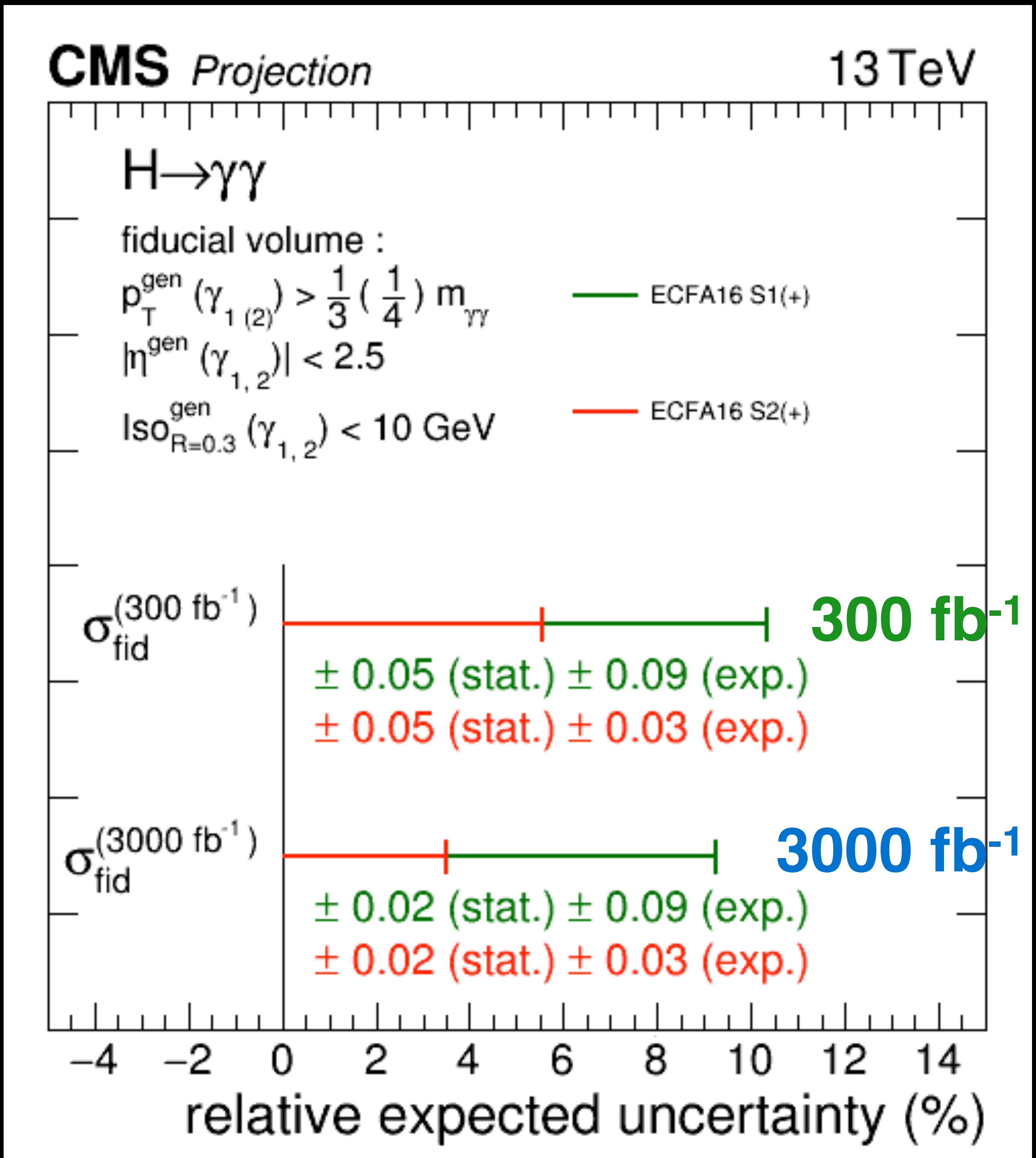


Added expected degradation at μ = 200
Beamspot ~5cm
Vertex identification reduced from 80% to 40%
Photon ID efficiency decreased by 2.3% (10%) in EB (EE)

Projections based on Run 2 analysis

CMS-DP-2016-064

H→ γγ projections updated based on 13 TeV (12.9 fb^{-1}) analyses



Theoretical uncertainties become dominant at HL-LHC

Measure

Fiducial cross sections

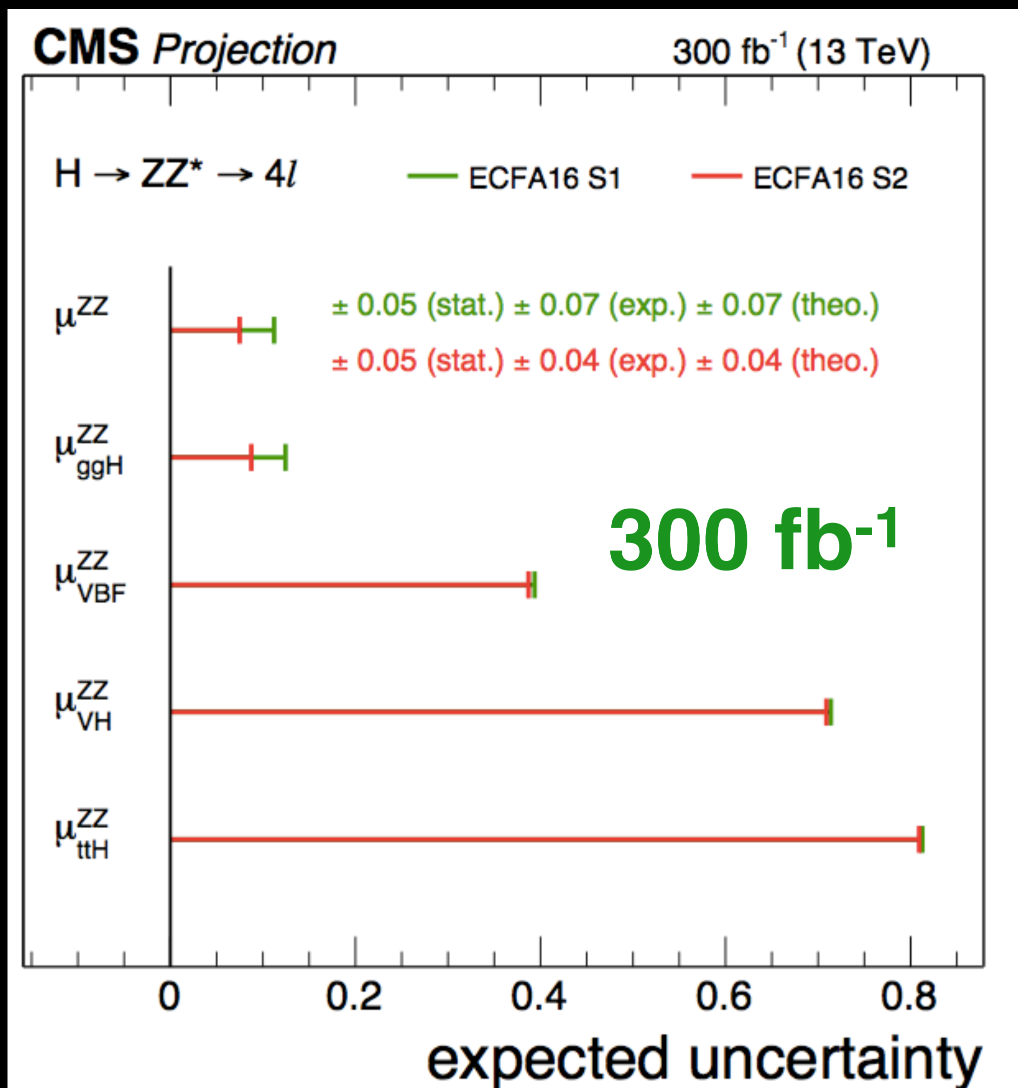
Decouple theoretical uncertainties

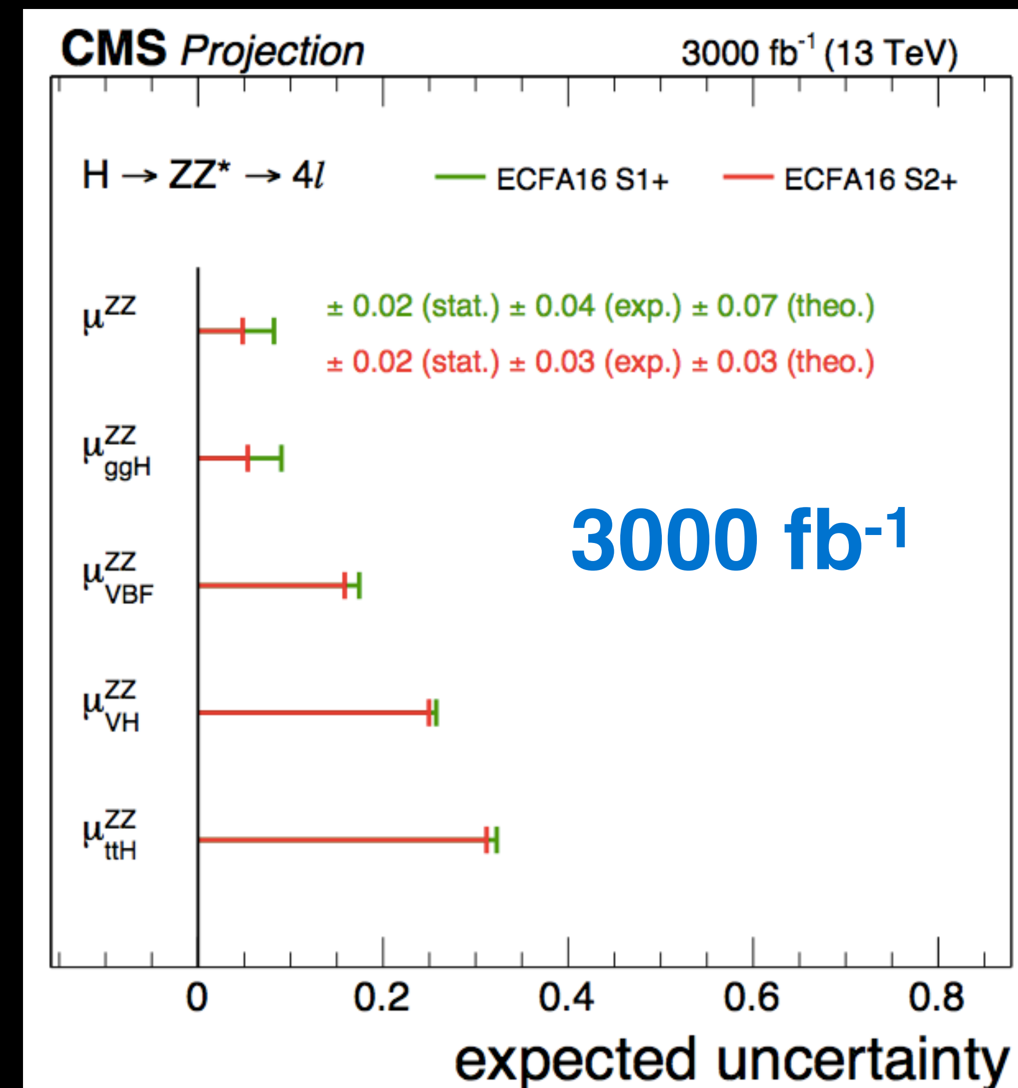
Can achieve ~4% uncertainty

Projections based on Run 2 analysis

CMS-DP-2016-064

H→ ZZ projections updated based on 13 TeV (12.9 fb^{-1}) analyses

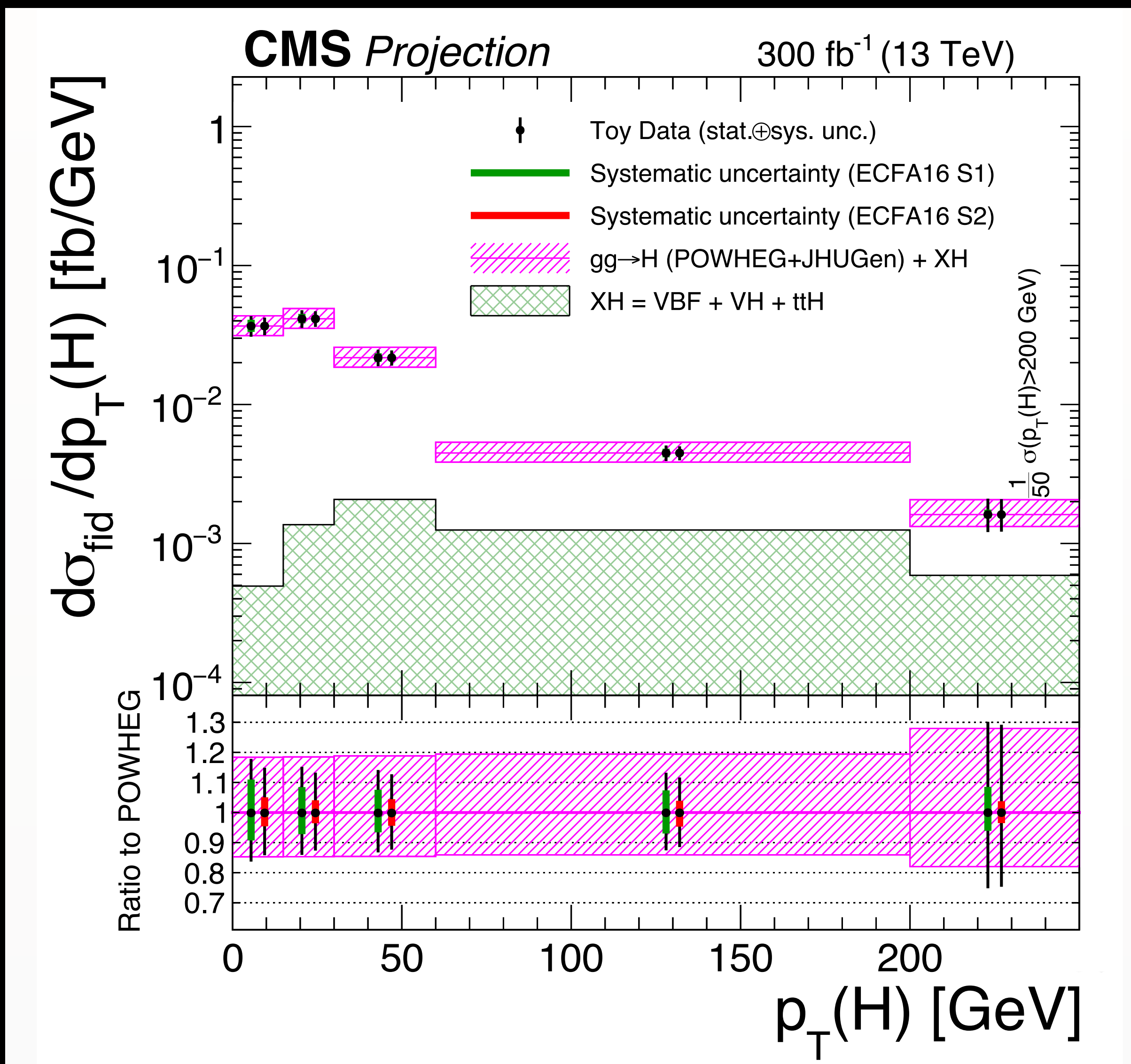


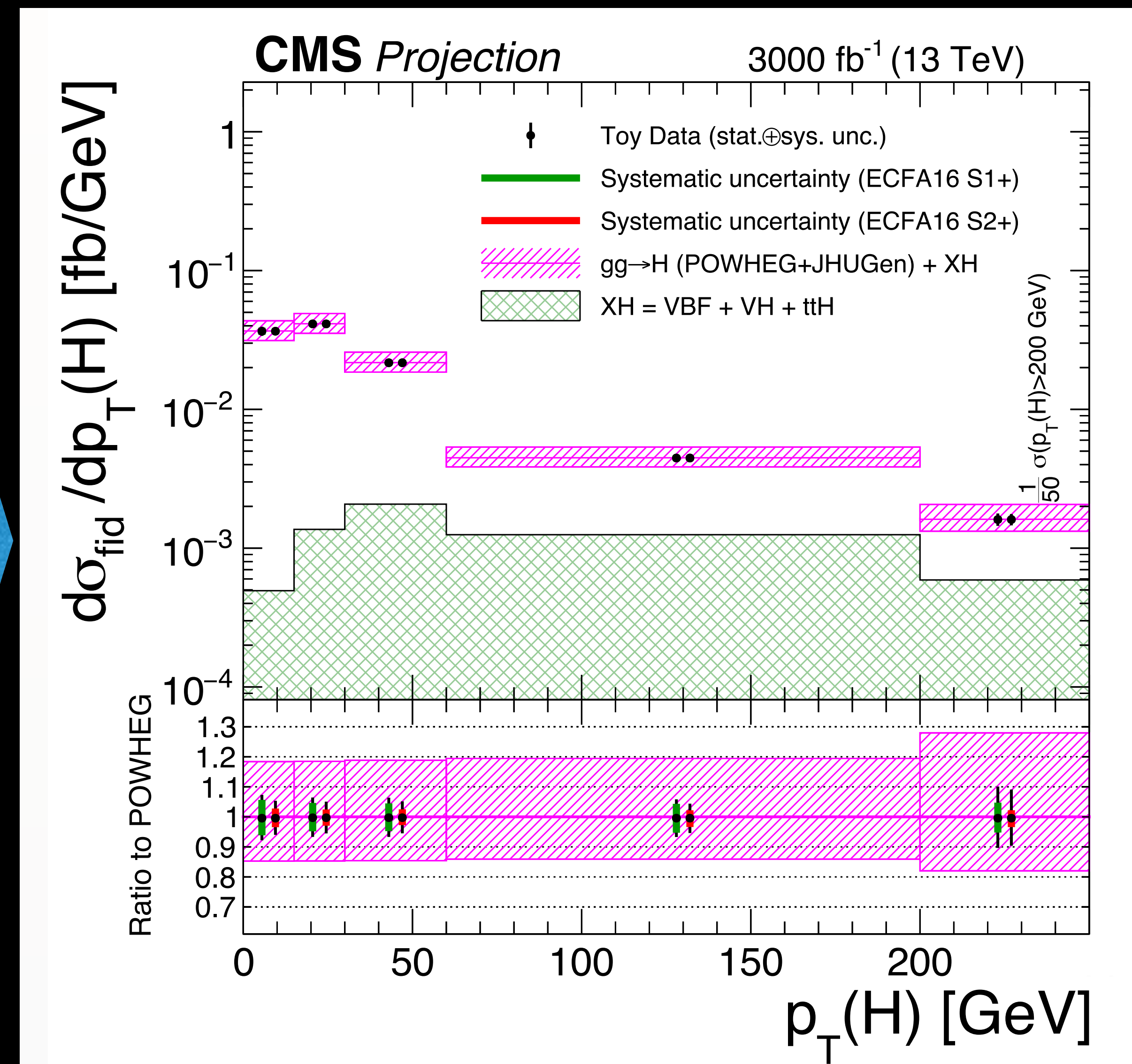


Added expected degradation at μ = 200
Reduced lepton efficiency
Increased misidentification

H→ ZZ – Differential $p_T(H)$ Cross Section

CMS-DP-2016-064

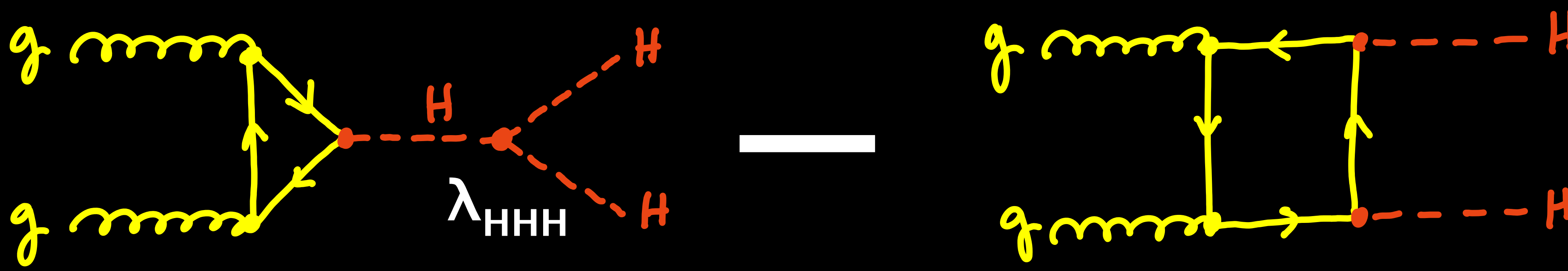




Can make precise differential $p_T(H)$ cross section measurements

Higgs Self Coupling – λ_{HHH}

A major goal of HL-LHC: Measurements of Higgs pairs production



Extremely small cross section: σ ~ 41 fb ± 11%

HH	Branching ratio	Total yield (3000 fb^{-1})
bb + bb	33%	40,000
bb+WW	25%	31,000
bb + ττ	7.3%	8,900
ZZ + bb	3.1%	3,800
WW + ττ	2.7%	3,300
ZZ+WW	1.1%	1,300
γγ + bb	0.26%	320
γγ + γγ	0.0010%	1.2

Requires full HL-LHC luminosity to reach SM sensitivity

Need to combine all channels

Higgs Self Coupling Projections

CMS extrapolation from Run-2 analyses

CMS-DP-2016-064

Channel	Median expected limits in μ_r ECFA16 S1	Median expected limits in μ_r ECFA16 S2	Median expected limits in μ_r Stat. Only	Z-value ECFA16 S1	Z-value ECFA16 S2	Z-value Stat. Only	Uncertainty as fraction of $\mu_r = 1$ ECFA16 S1	Uncertainty as fraction of $\mu_r = 1$ ECFA16 S2	Uncertainty as fraction of $\mu_r = 1$ Stat. Only
$gg \to HH \to \gamma\gamma bb$ (S1+/S2+)	1.3	1.3	1.3	1.6	1.6	1.6	0.64	0.64	0.64
$gg \to HH \to \tau\tau bb$	7.4	5.2	3.9	0.28	0.39	0.53	3.7	2.6	1.9
$gg \to HH \to VVbb$		4.8	4.6		0.45	0.47		2.4	2.3
$gg \to HH \to bbbb$		7.0	2.9		0.39	0.67		2.5	1.5

ATLAS simulations (HH→bbbb is Run-2 extrapolations)

Channel		Expected limit in μ Full Syst.	Expected limit in μ Stat. only	Significance Full Syst.	Significance Stat. only	Limits on λ/λ_{SM} at 95% CL Full Syst.	Limits on λ/λ_{SM} at 95% CL Stat. only
$gg \to HH \to \gamma\gamma bb$	ATL-PHYS-PUB-2014-019			1.3σ		$-1.3 < \lambda/\lambda_{SM} < 8.7$	
$gg \to HH \to \tau\tau bb$	ATL-PHYS-PUB-2015-046	4.3		0.6σ		$-4 < \lambda/\lambda_{SM} < 12$	
$gg \to HH \to bbbb$	ATL-PHYS-PUB-2016-024	5.2	1.5			$-3.5 < \lambda/\lambda_{SM} < 11$	$0.2 < \lambda/\lambda_{SM} < 7$
$ttHH \to t_{had} t_{lep} bbbb$	ATL-PHYS-PUB-2016-023				0.35σ		

Higgs: A natural benchmark for detector design

The design of the upgraded HL-LHC detectors is a complex process:

Want ultimate performance, but limited by cost and time for upgrade during long shutdown

Higgs measurements are corner stone of the HL-LHC physics program

Provide prime motivation for many upgrades beyond current detector capabilities

Will provide some examples

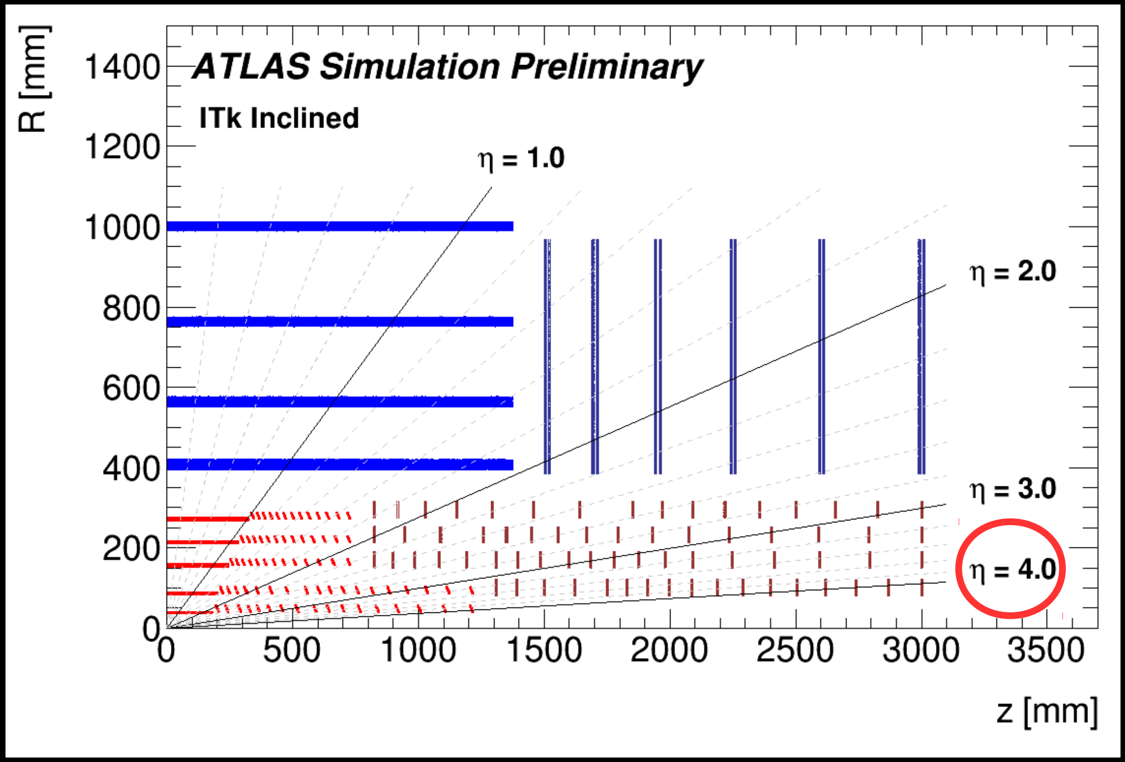
Extended Trackers at ATLAS and CMS

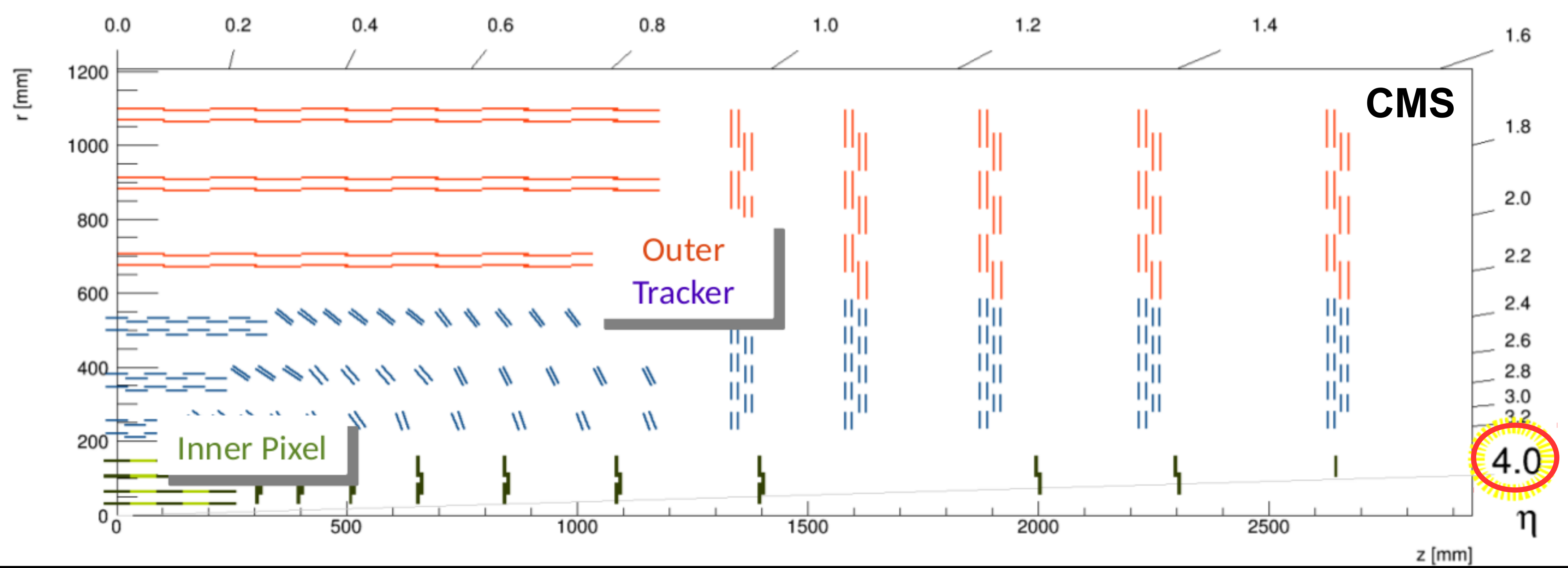
ATLAS and CMS plan to extend tracker coverage to η~4 with pixel extension

Multiple benefits:

- Extended lepton coverage (with forward muon tagger)
- Forward b-tagging
- Improved vertexing

Primary benefit is pile-up suppression

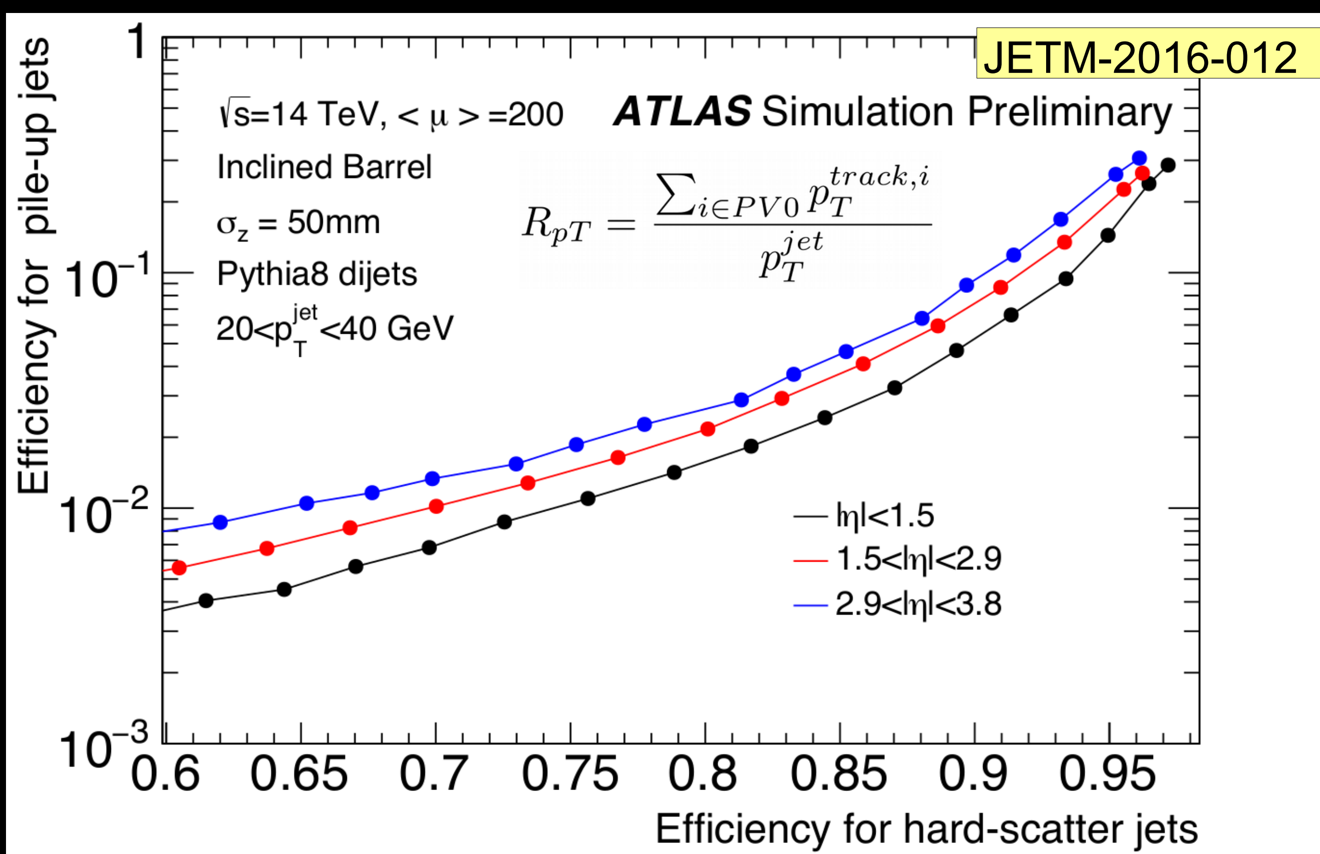




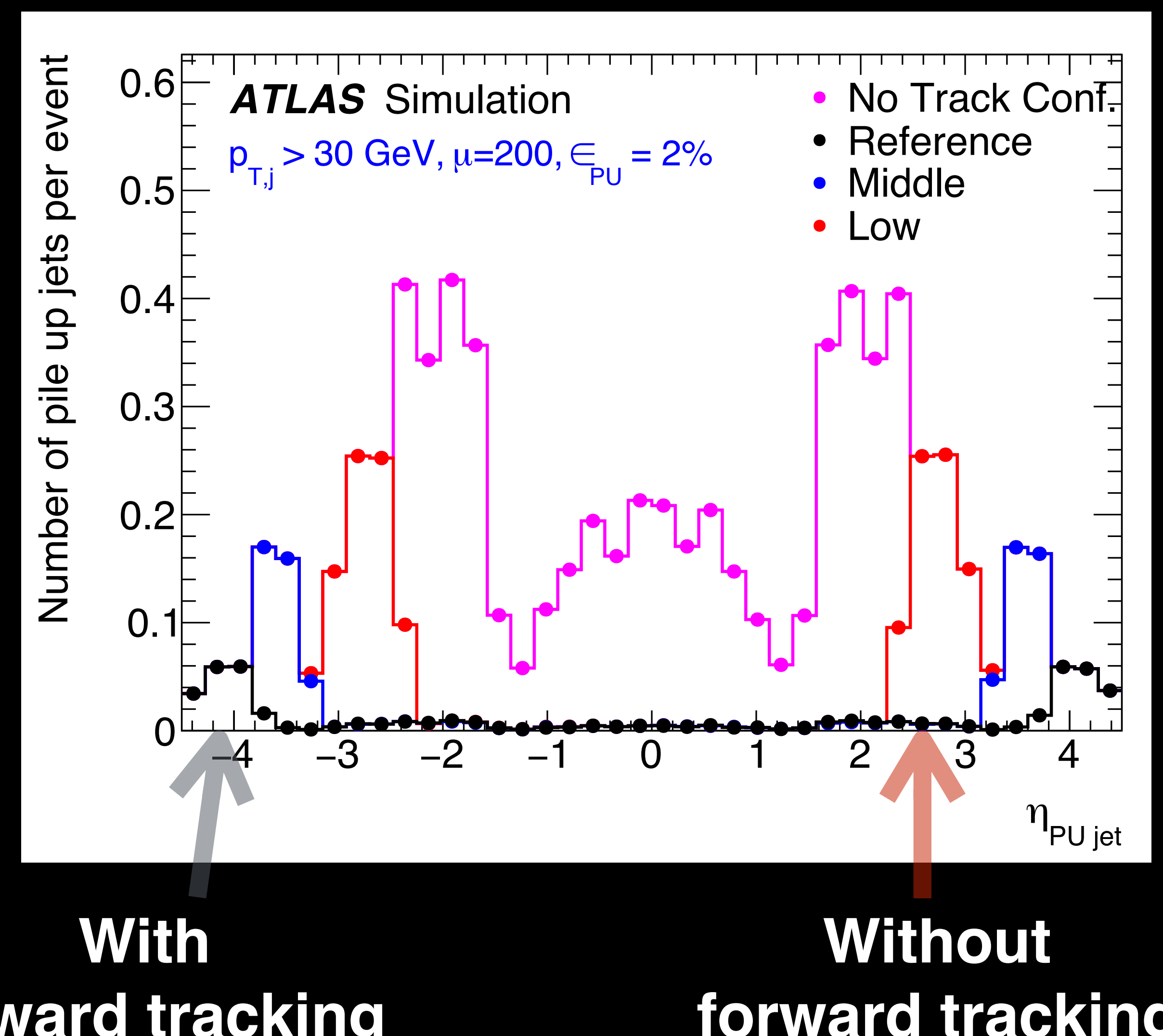
Suppression of pile-up jets

At μ=200, every events has ~5 pile-up jets (p_T>30 GeV)

Can suppress these by using tracking to associate them to either pile-up or hard-scatter vtx



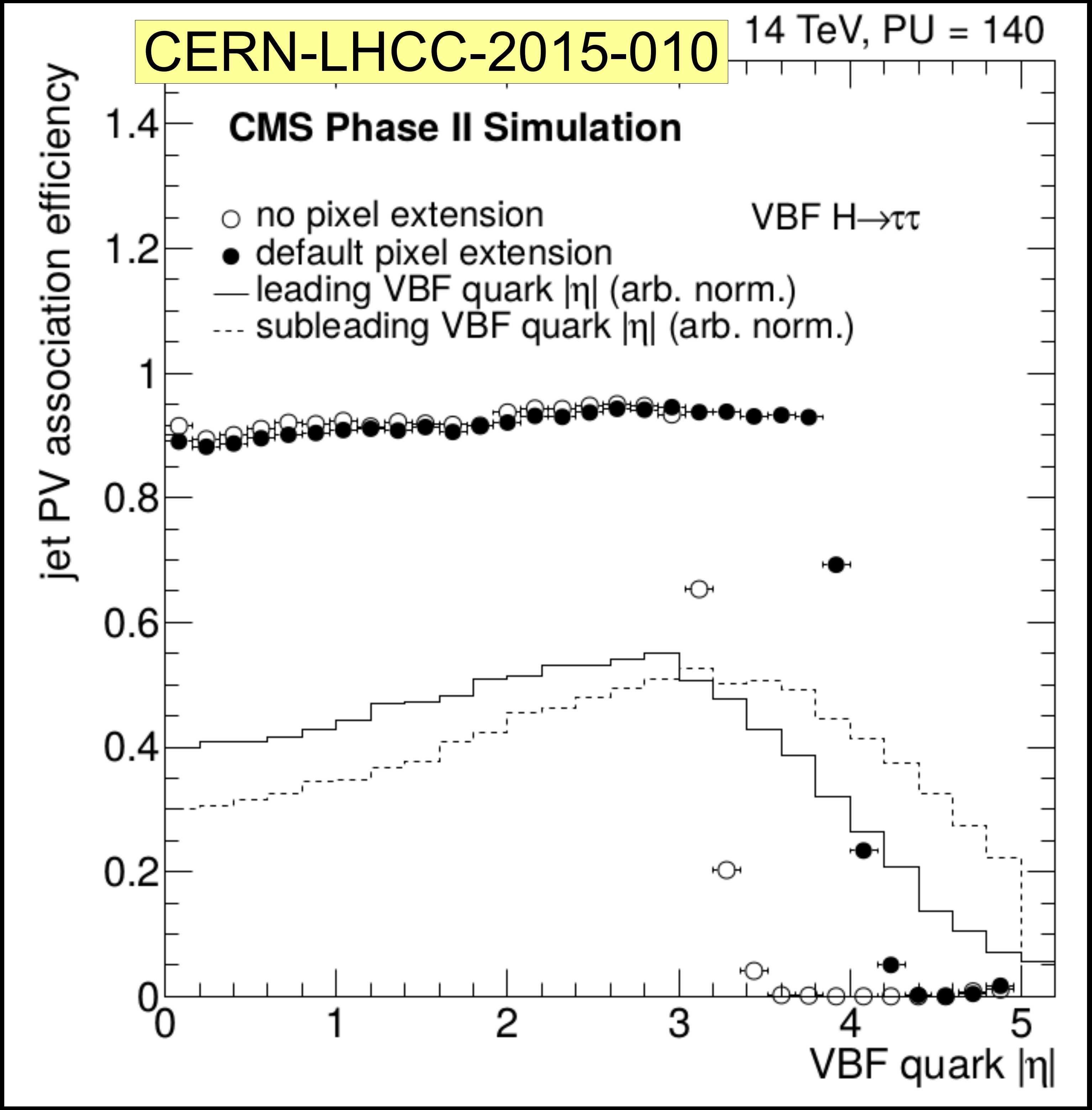
Pile-up jets per event versus η



Most important for VBF processes

Jet-PV association in VBF events

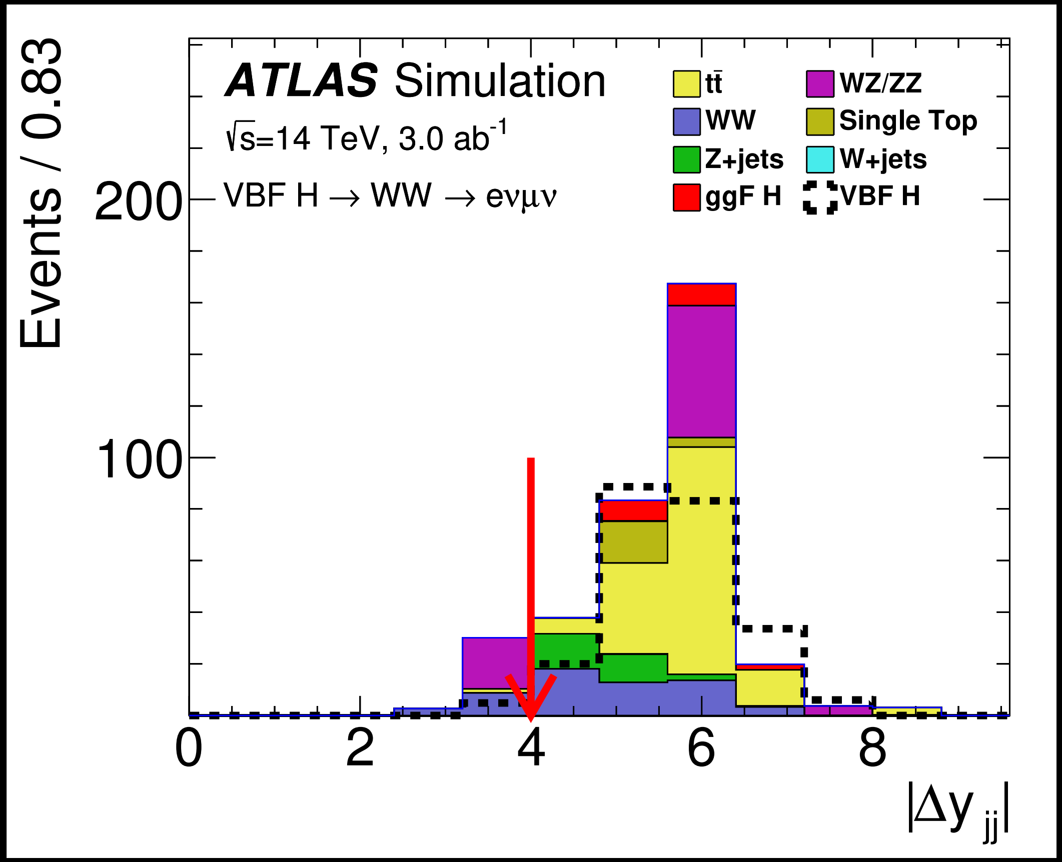
For VBF Higgs production needs to use jets out to η~4



Higgs VBF → WW → eν μν Analysis

ATL-PHYS-PUB-2016-018

Physics gain of forward tracker studied in H→WW analysis



Simple cut based analysis:

- **2 forward jets** (|η|>2) in opposite hemispheres
- **No other jet above 30 GeV** in between jets
- e/μ in between forward jets
- Missing E_T>20 GeV

Events after selection:

- **~ 200 signal** events
- **~ 400 background** events from tt and non-VBF Higgs

Tracker coverage	Δ_μ precision			Significance (σ)		
	Full	1/2	None	Full	1/2	None
|η|<4.0	0.20	0.16	0.14	5.7	7.1	8.0
|η|<3.2	0.25	0.21	0.20	4.4	5.2	5.4
|η|<2.7	0.39	0.32	0.30	2.7	3.3	3.5

Different levels of theoretical uncertainties on Higgs production

Factor two gain in precision from extended tracker coverage

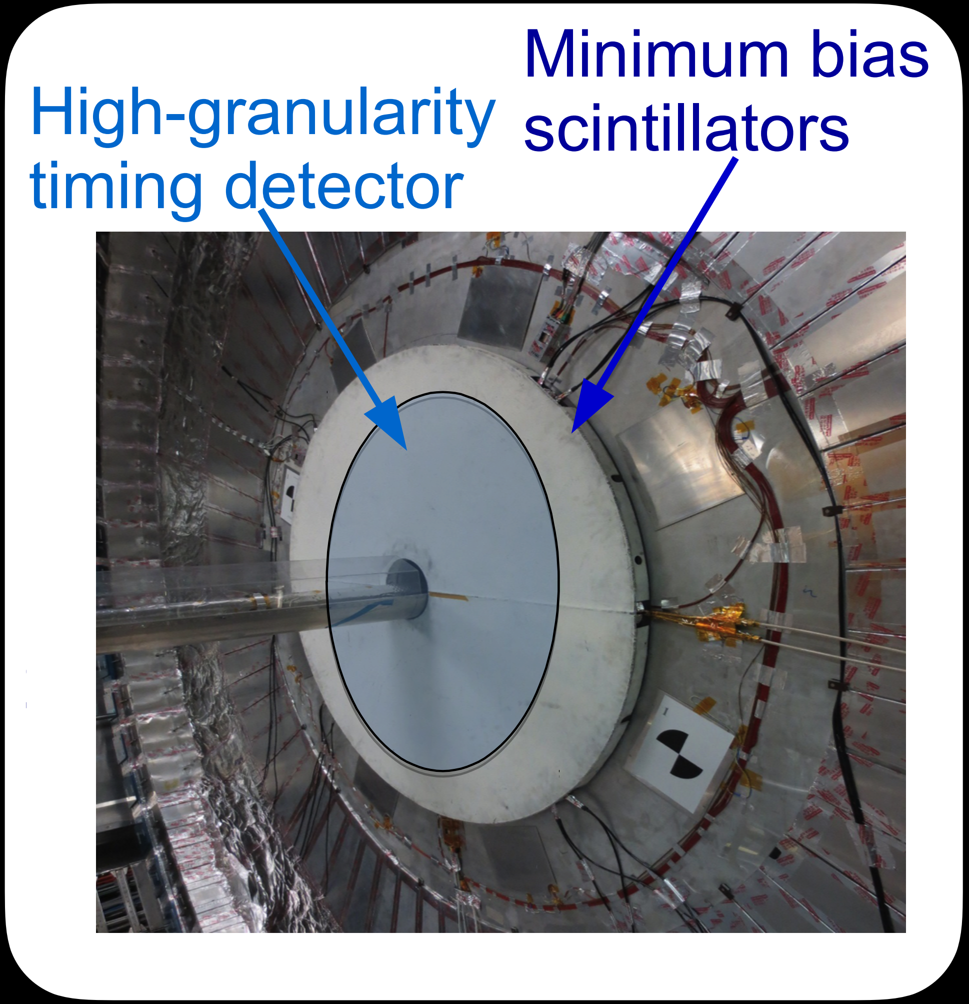
High-granularity timing detector

Additional pile-up rejection can be achieved using precise timing

Different time of flight and different collisions times in event

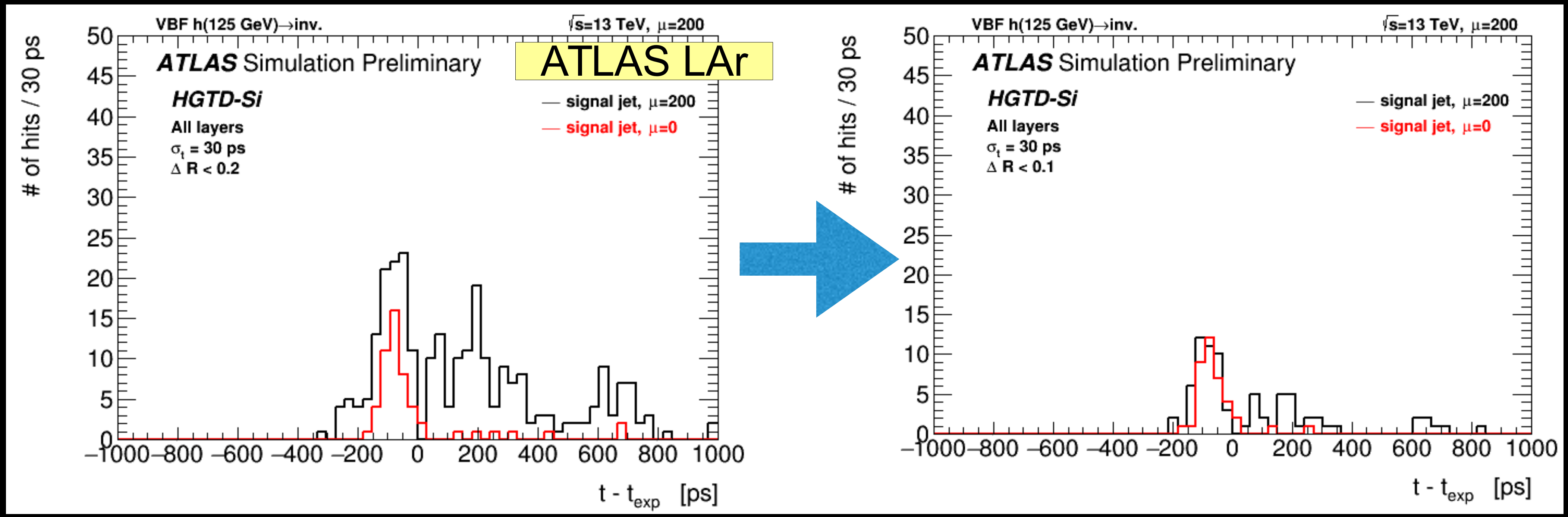
ATLAS considering thin timing device

- Four layers silicon sensors
- Coverage for 2.4<|η|<4.2
- Possible Tungsten absorber for |η|<3.2
- Timing target: 30-50 ps per MIP

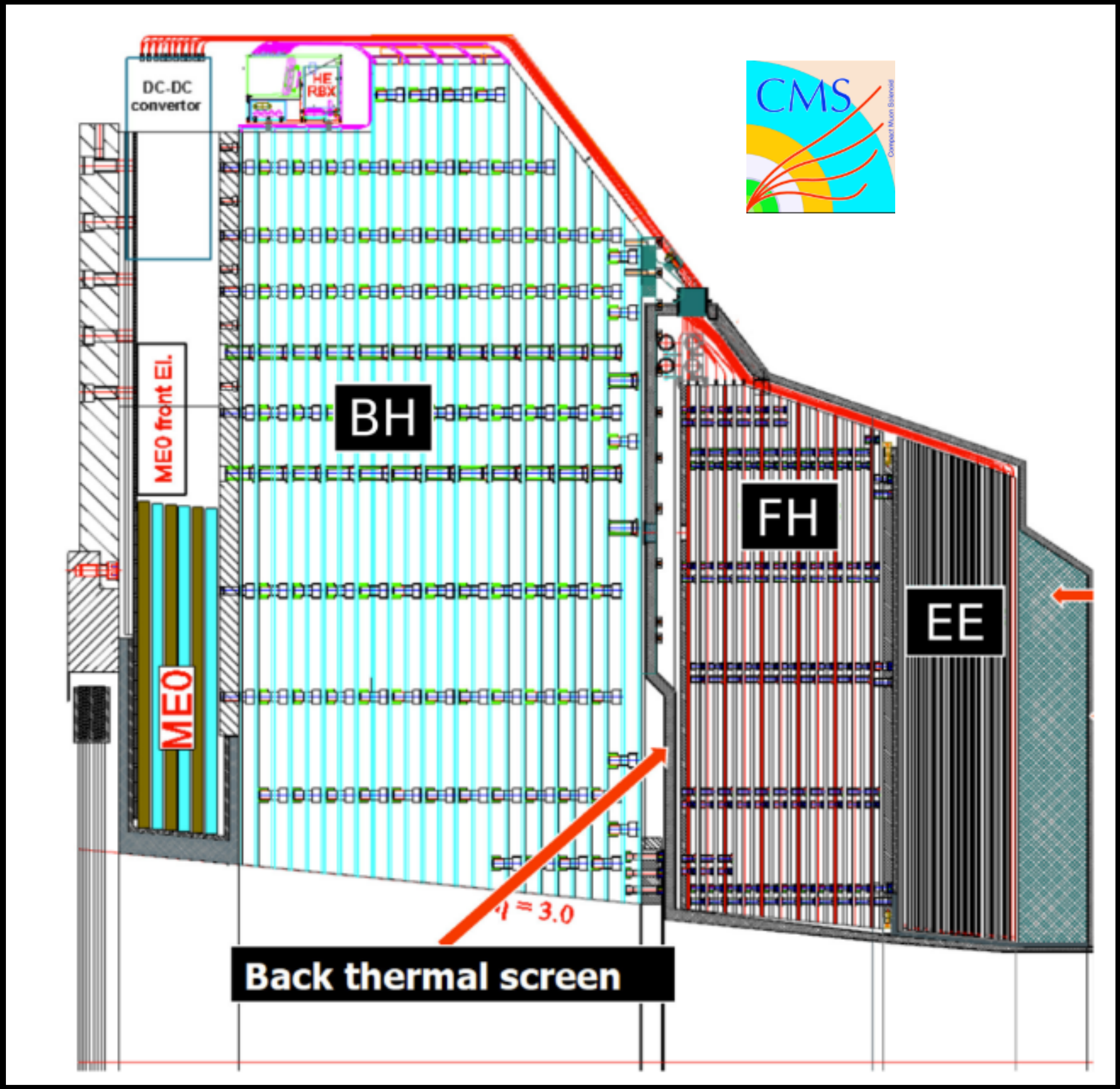


Provide extra sensitivity for VBF

- Possible to also enhance jet trigger



Timing detectors in CMS



Endcap calorimeter (1.5<|η|<3) replaced by multi-layer silicon-based calorimeter

Current calorimeter not rad-hard enough

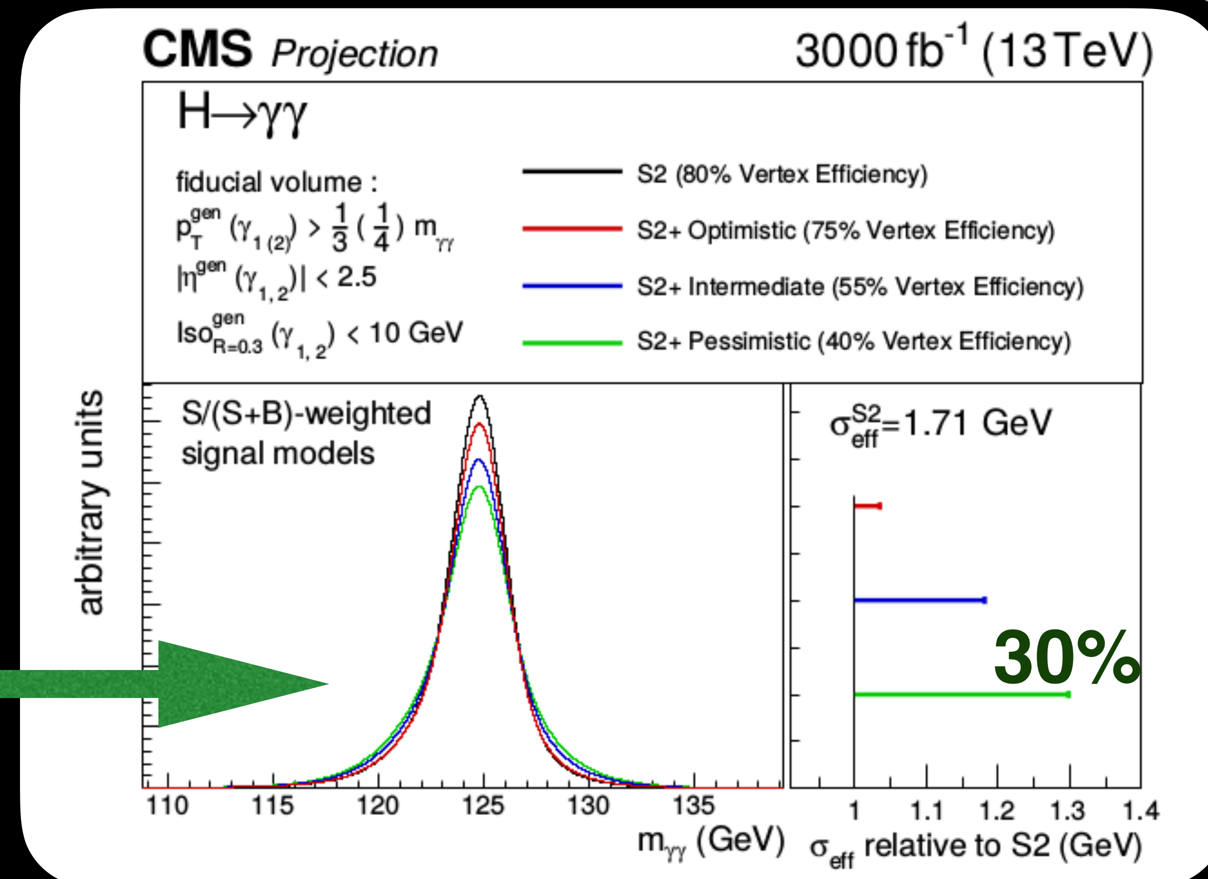
- Use of silicon allows intrinsic time resolution down to 50 ps for large signal
- **Barrel calorimeter electronics upgraded to also provide precision timing (30 ps)**
- Additional timing layer for charged particles in front of calorimeter under consideration

H→ γ γ with Timing Detector

Vertex selection efficiency drops with increase in pileup

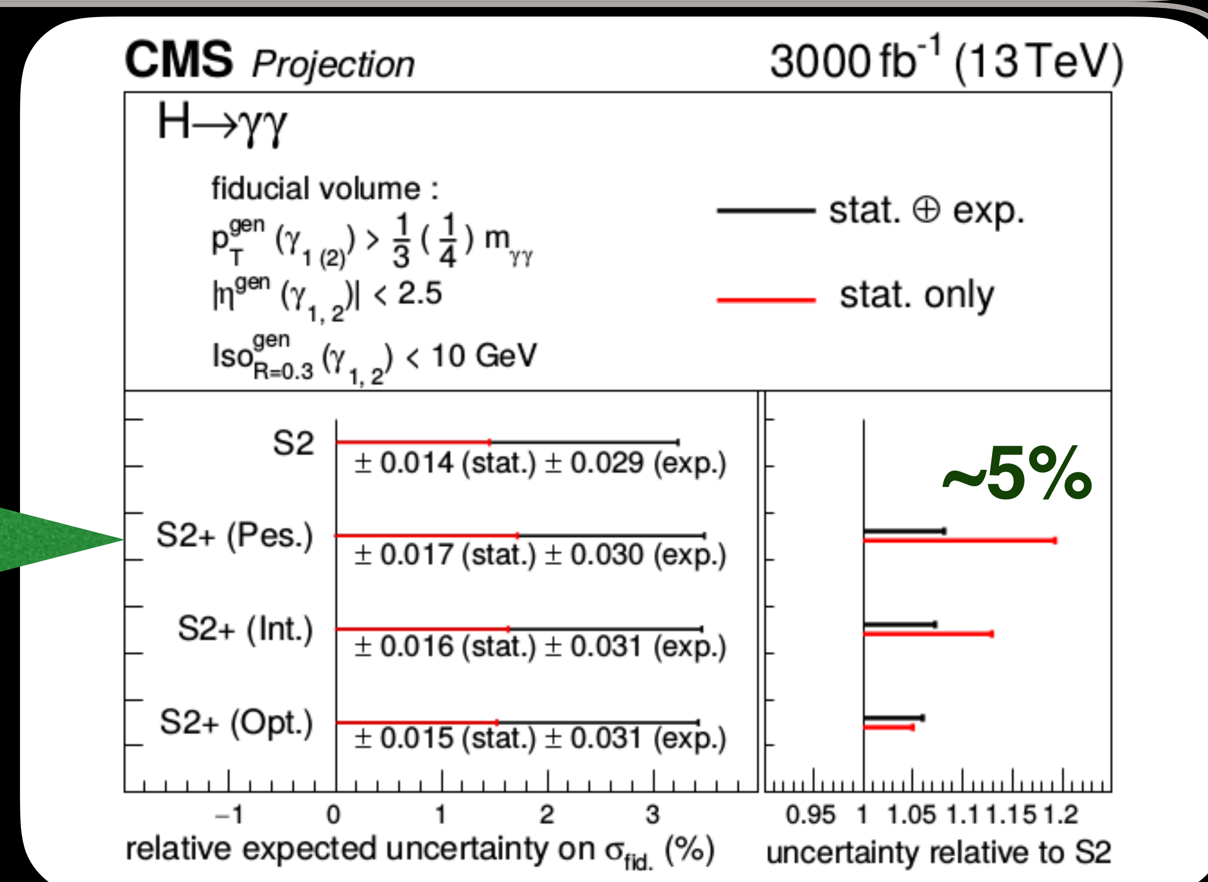
~80% now → ~40% at μ = 200 pileup

- **Results in large degradation of mass resolution**
- **Impact on fiducial cross section measurement**



With full use of calorimeter and charged particle timing information vertexing efficiency can be almost full recovered

Corresponds to effectively 30% more luminosity



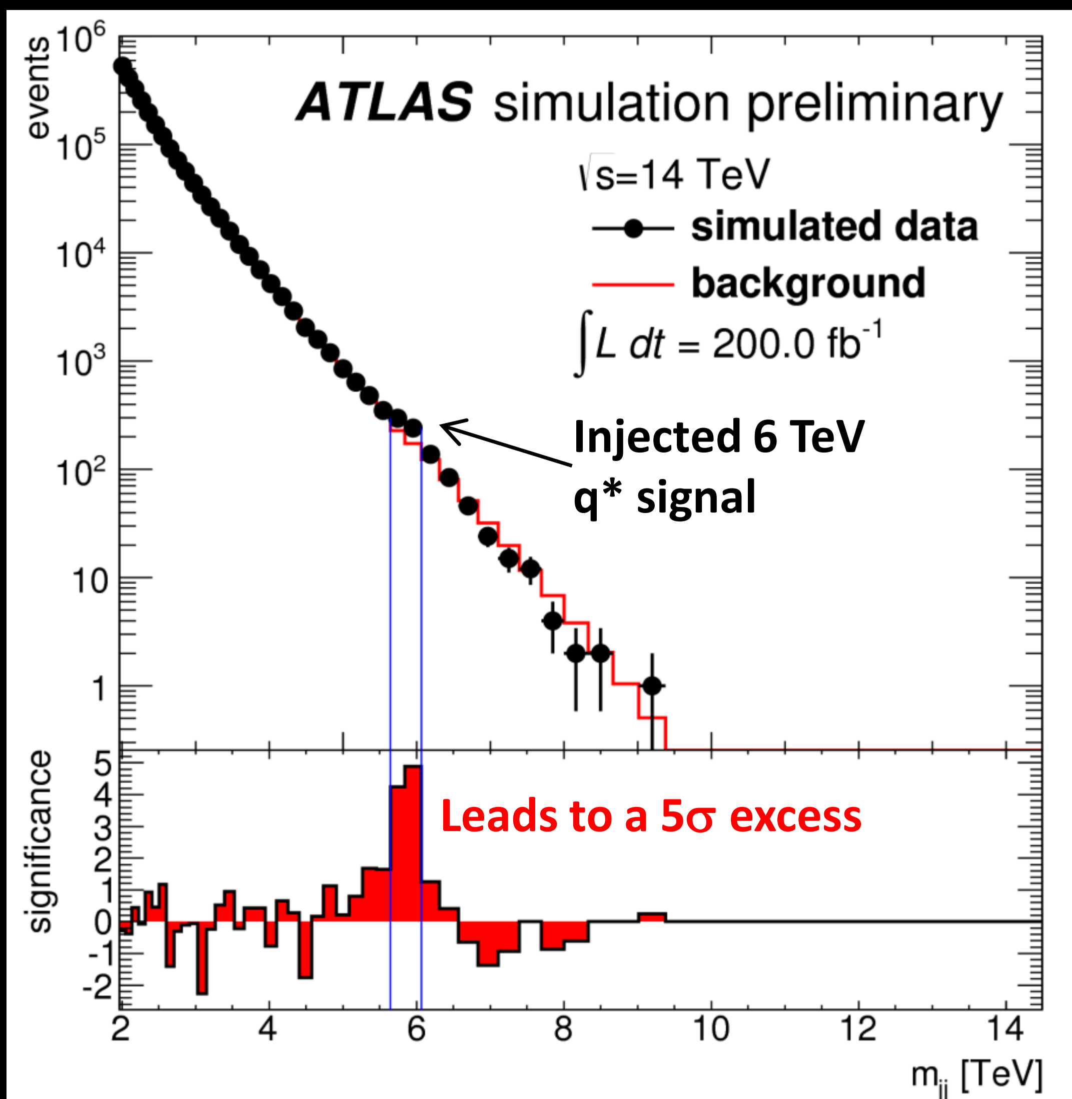
Exotics Bump Hunting

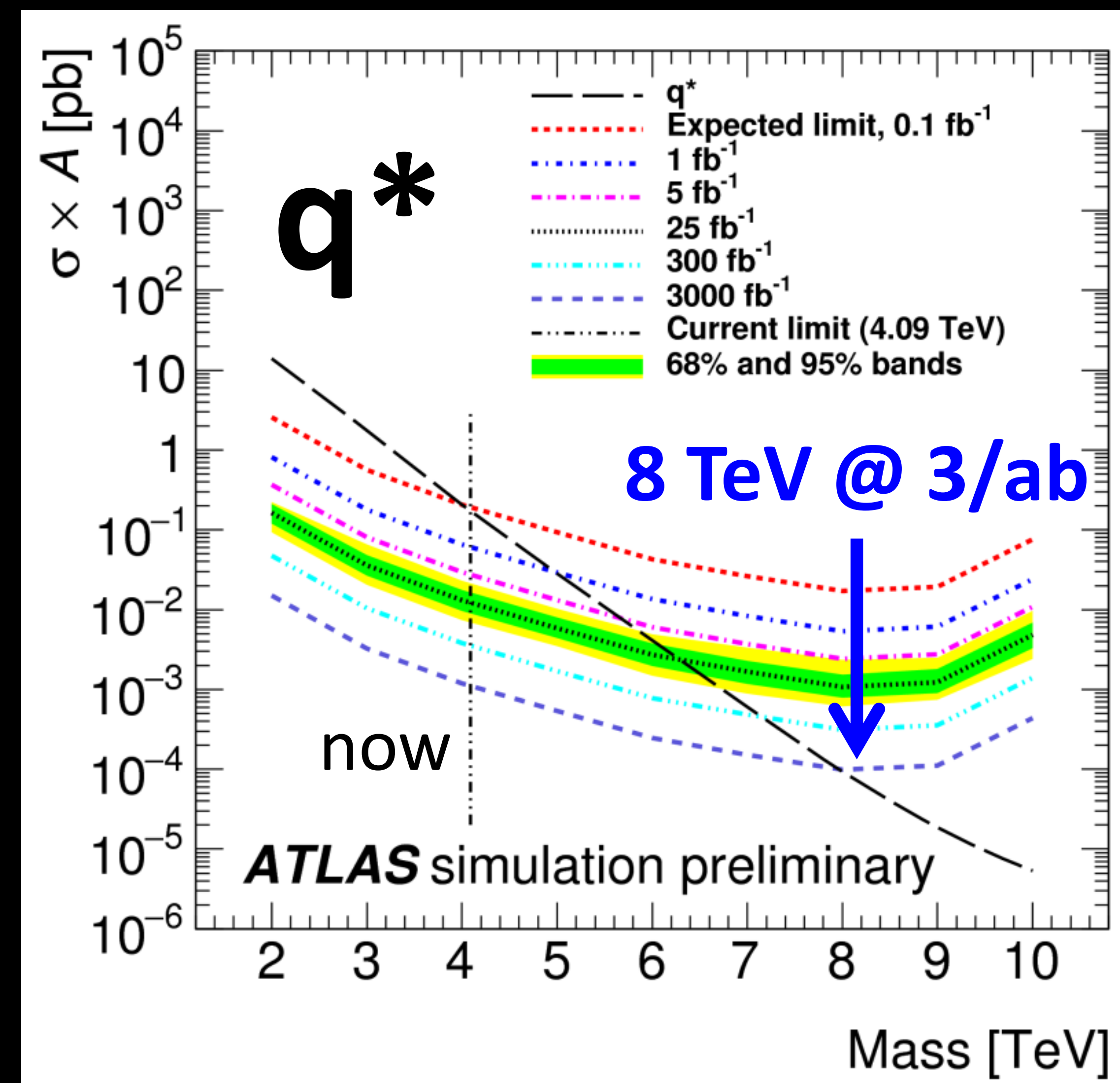
ATLAS Dijet (bump hunt)

ATL-PHYS-PUB-2015-004

Powerful search technique for new physics, model-independent as long as a sharp resonance
Many interpretations possible

Discovery reach for excited quarks (q*)



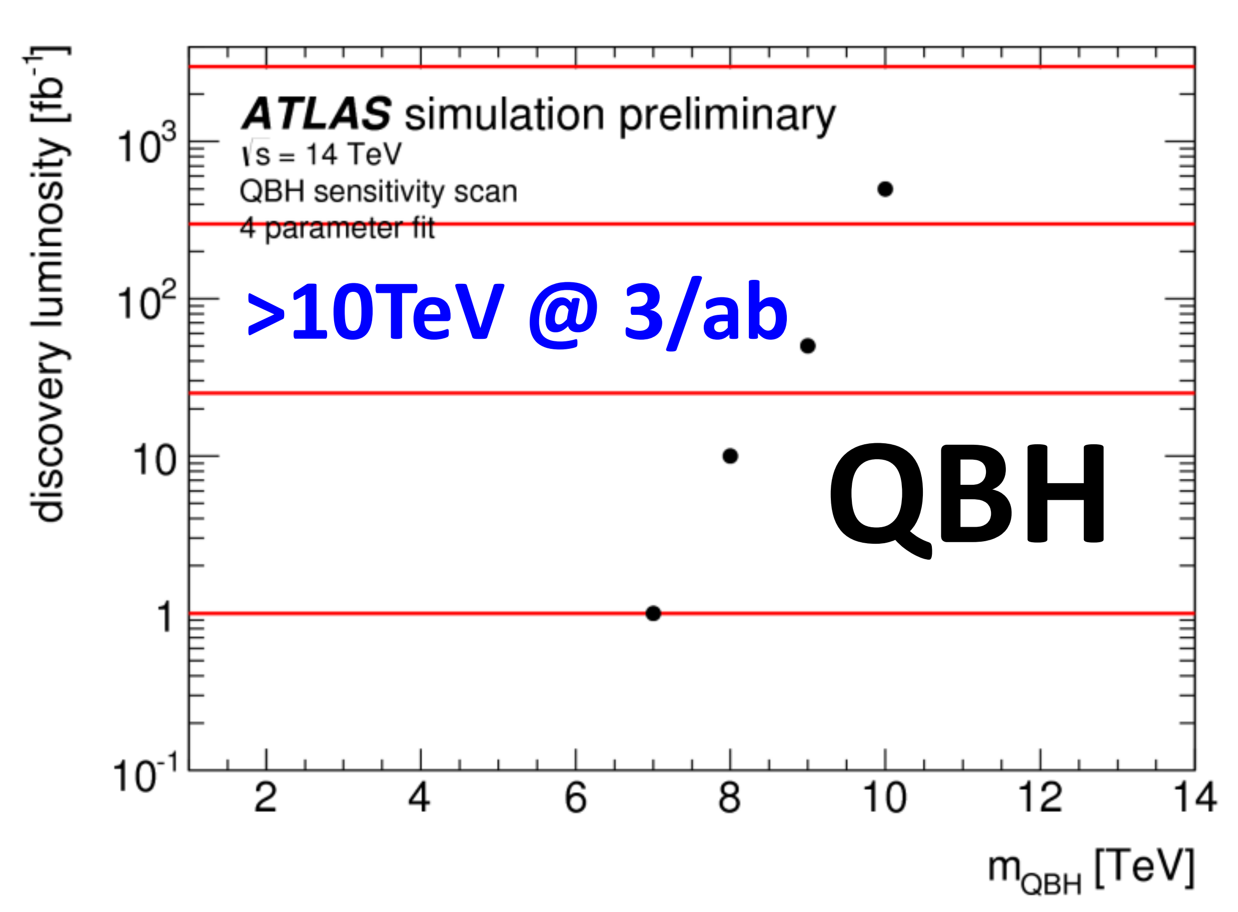


ATLAS Dijet (bump hunt)

ATL-PHYS-PUB-2015-004

Powerful search technique for new physics, model-independent as long as a sharp resonance Many interpretations possible

Discovery reach for Quantum Black Holes



CMS Projections @ 3/ab

Discovery of SSM W´ masses up to 7 TeV

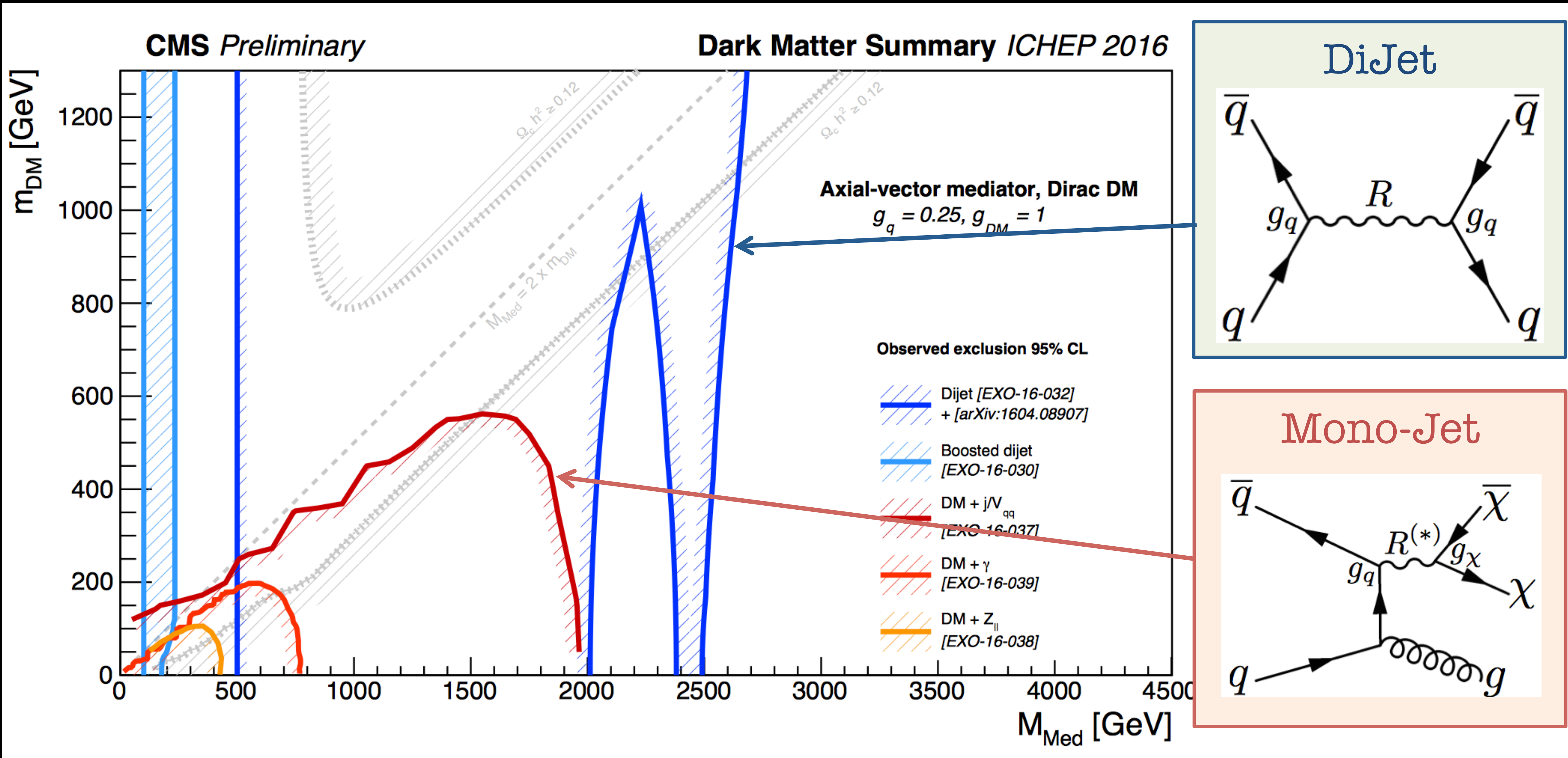
Exclusion limit m(W´ ->tb) > 4 TeV @95% CL

Exclusion limit m(Z´) > O(4 TeV) @95% CL
(depending on resonance width and systematics)

Dark Matter

LHC searches complement direct detection experiments

Summary of CMS Dark Matter Results



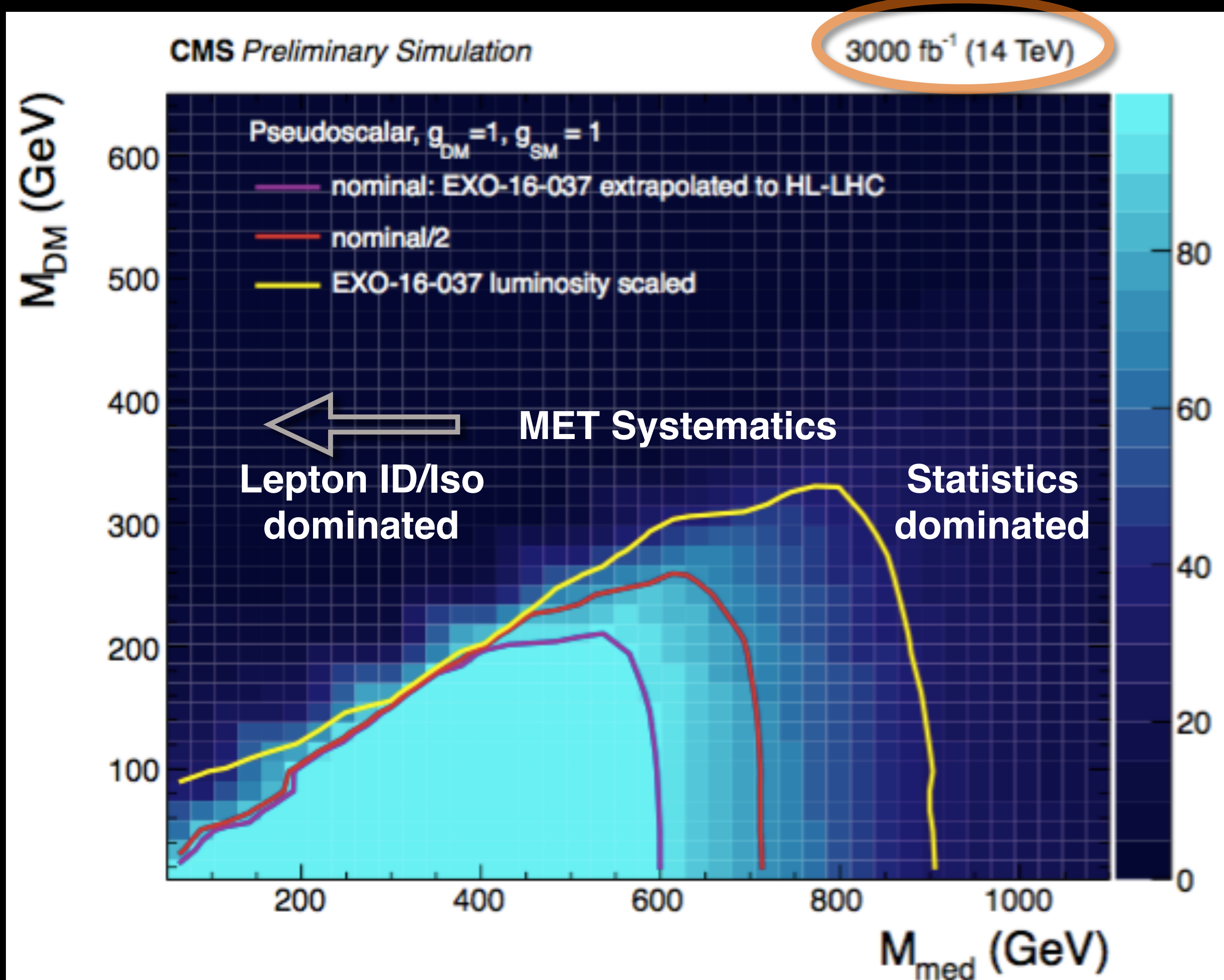
4 parameters (M_{med}, m_{DM}, g_{SM}, g_{DM})

2D exclusion limit

Dark Matter at the HL-LHC: MET+monojet

CMS-DP-2016-064

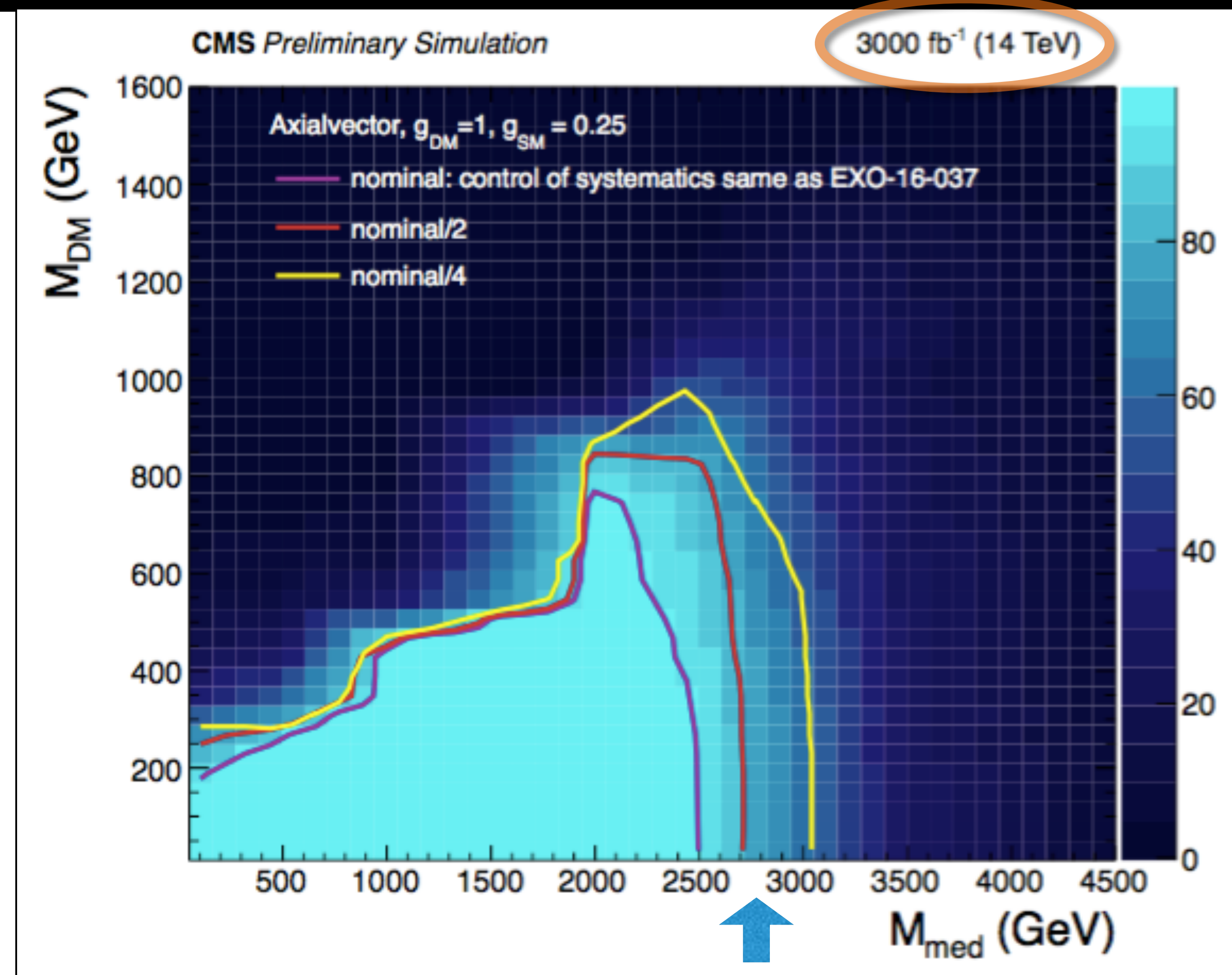
Pseudoscalar spin-0 mediator



Not accessible to direct detection

Only LHC provides sensitivity

Axialvector spin-1 mediator



Suppressed in direct detection

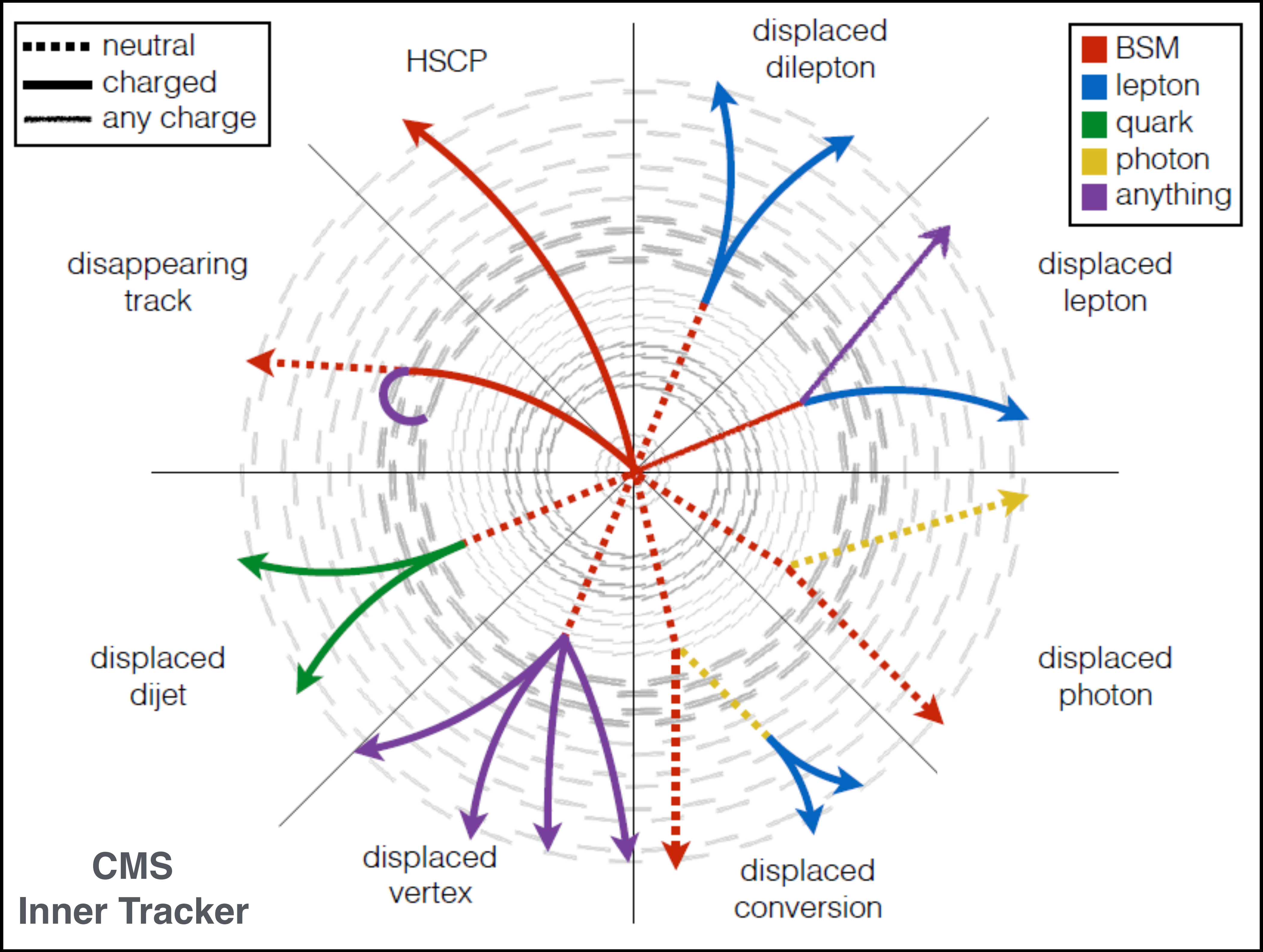
LHC provides complementary sensitivity

'nominal' : scale the uncertainties at low MET dominated by the systematic uncertainties on lepton ID/Iso to HL-LHC recommendation, scale the systematics at high MET by luminosity

Long Lived Particles (LLP)

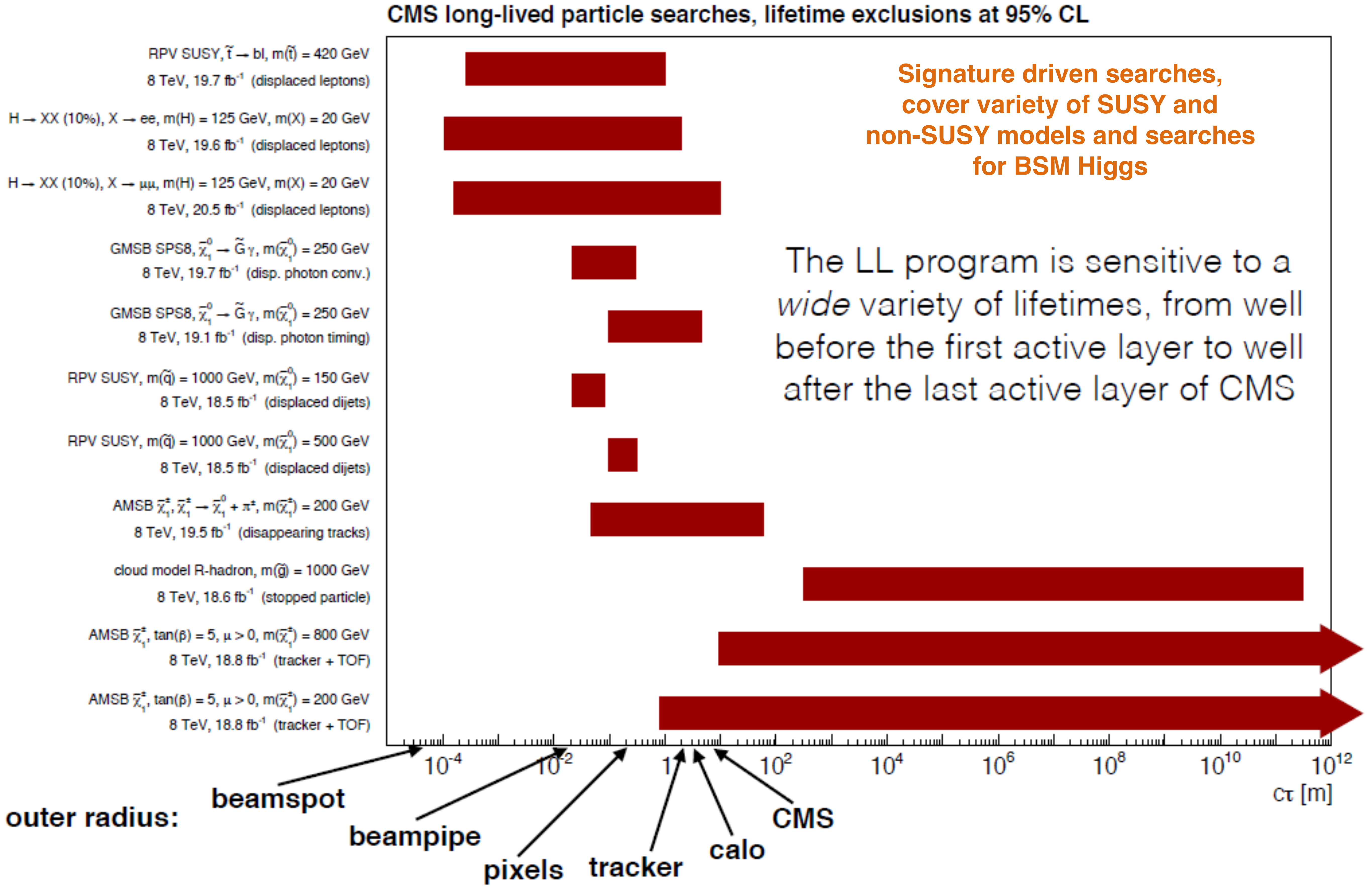
A new focus at the LHC

Special Signatures from LLP



- **Non-standard objects, custom trigger/reconstruction/simulation**
- **Need to maintain dedicated detector capabilities**

Special Signatures from LLP

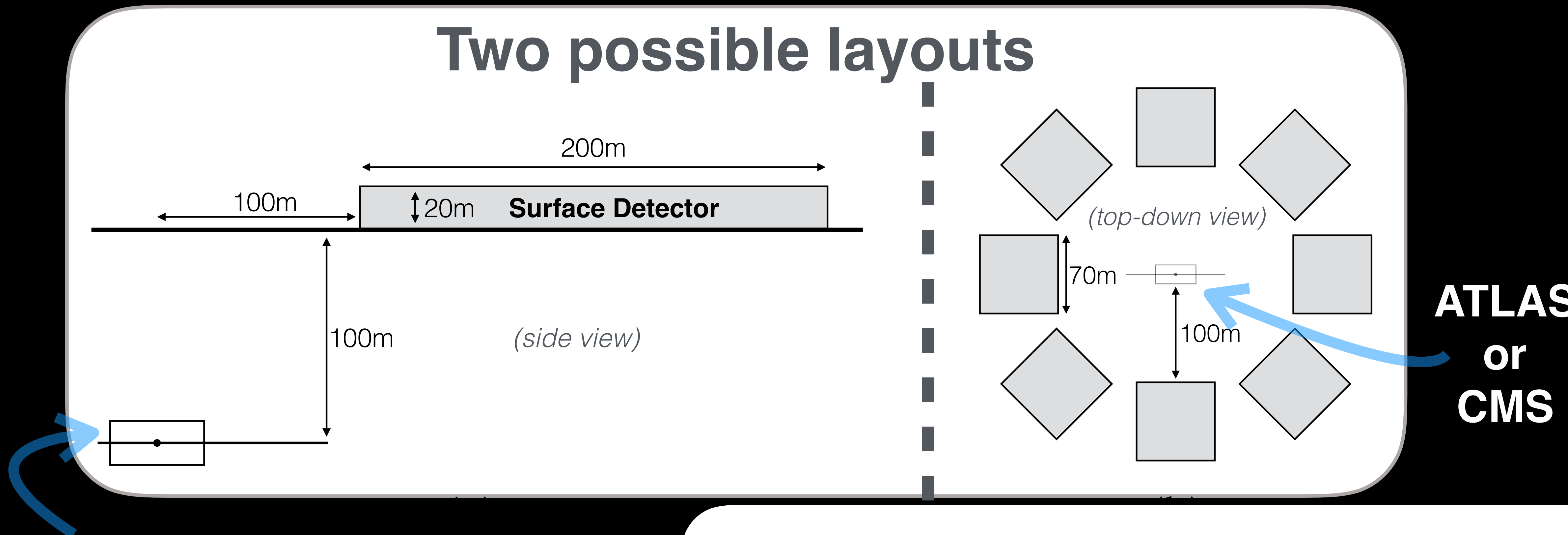


New Detectors to Explore the Lifetime Frontier

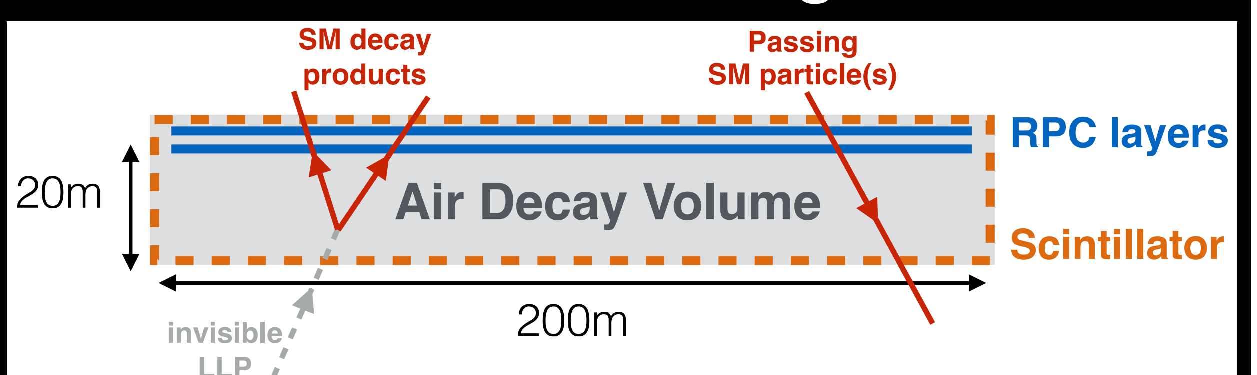
ArXiv:1606.06298

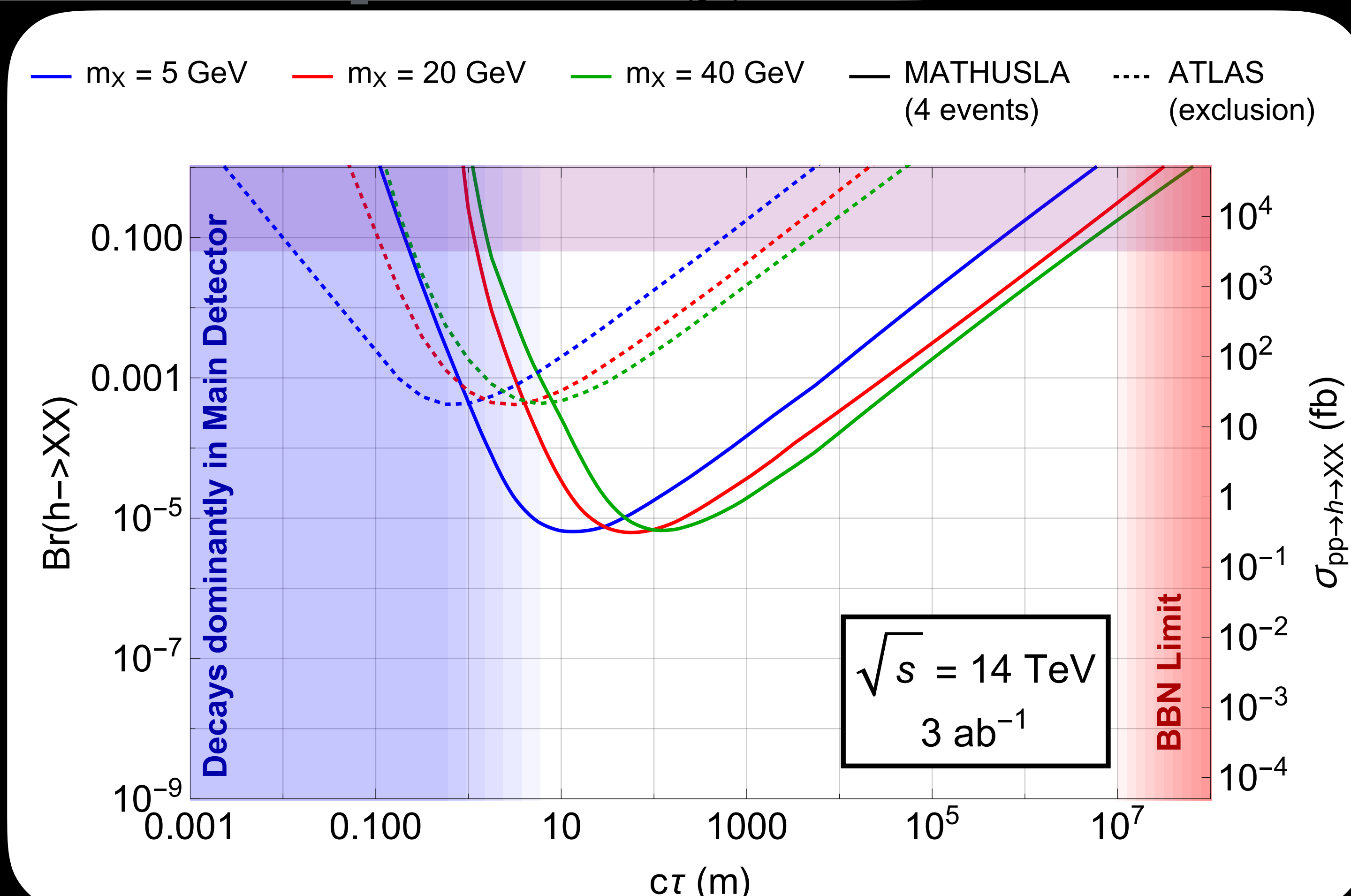
MATHUSLA: MAssive Timing Hodoscope for Ultra Stable neutraL pArticles!!

Two possible layouts



Possible design





Supersymmetry

Focus on scenarios previously not accessible

Low cross sections and compressed mass spectra

Direct Production of stau Pairs

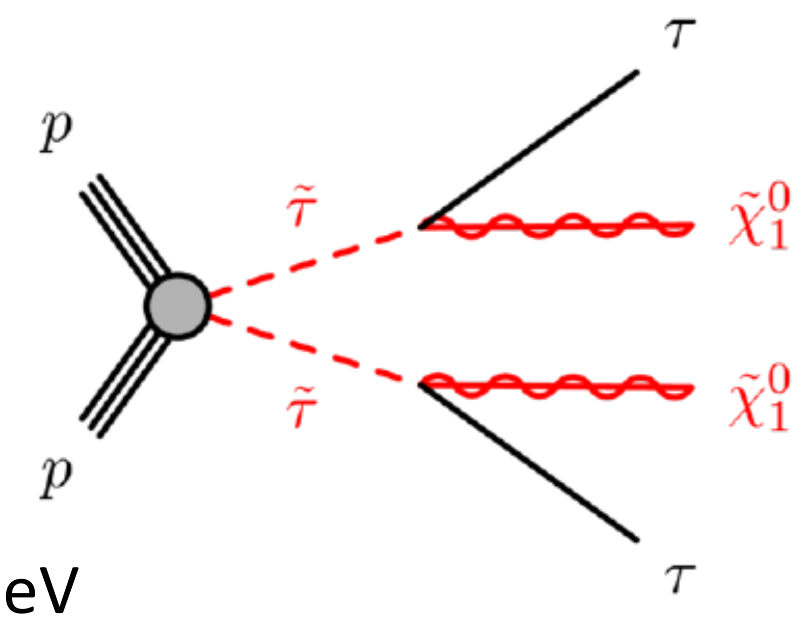
ATL-PHYS-PUB-2016-021

Assume 100% BR to SM tau and LSP.

Signature:

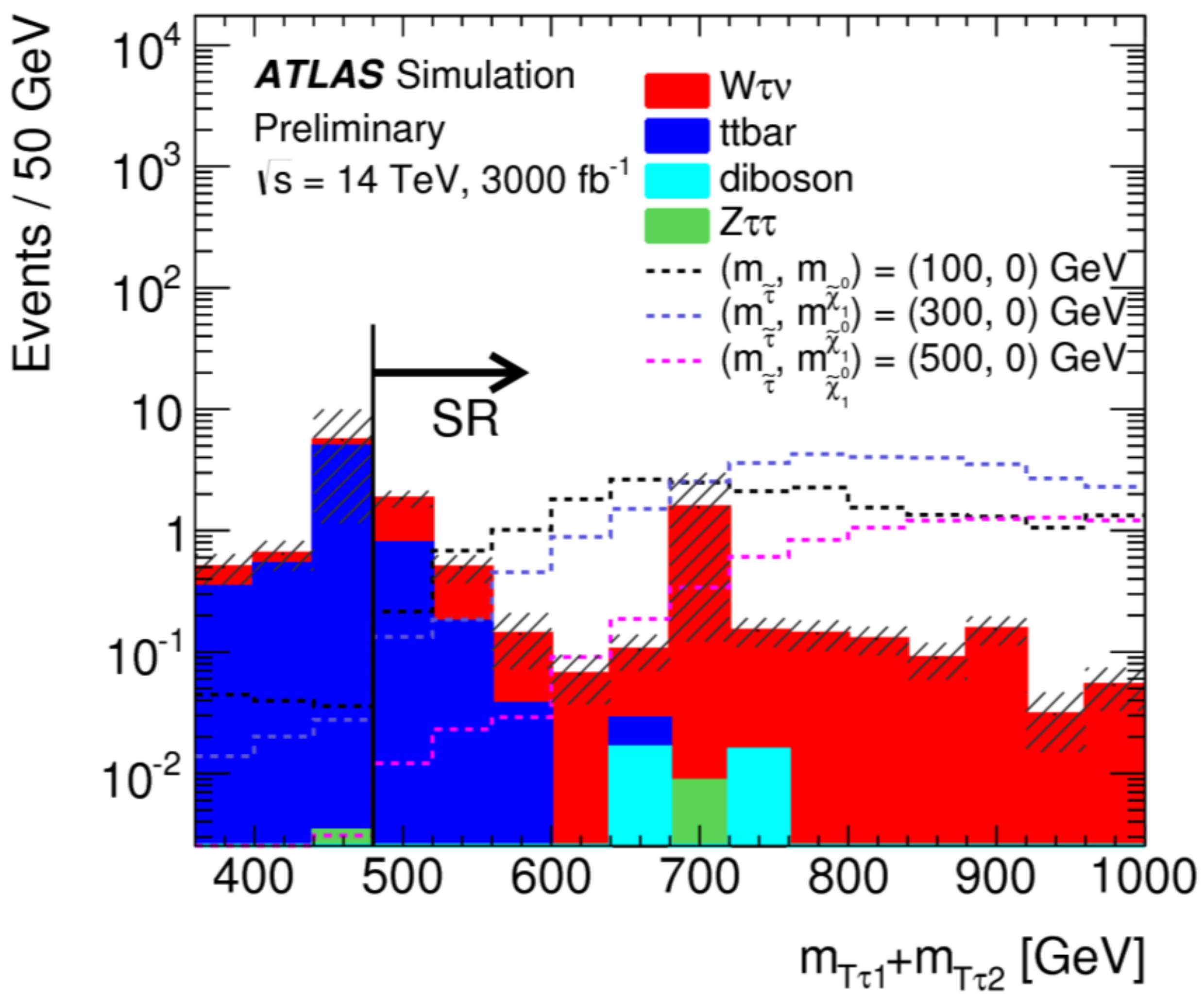
- 2 tau jets (hadronically decaying tau)
- Large MET (from $\tilde{\chi}_1^0$)

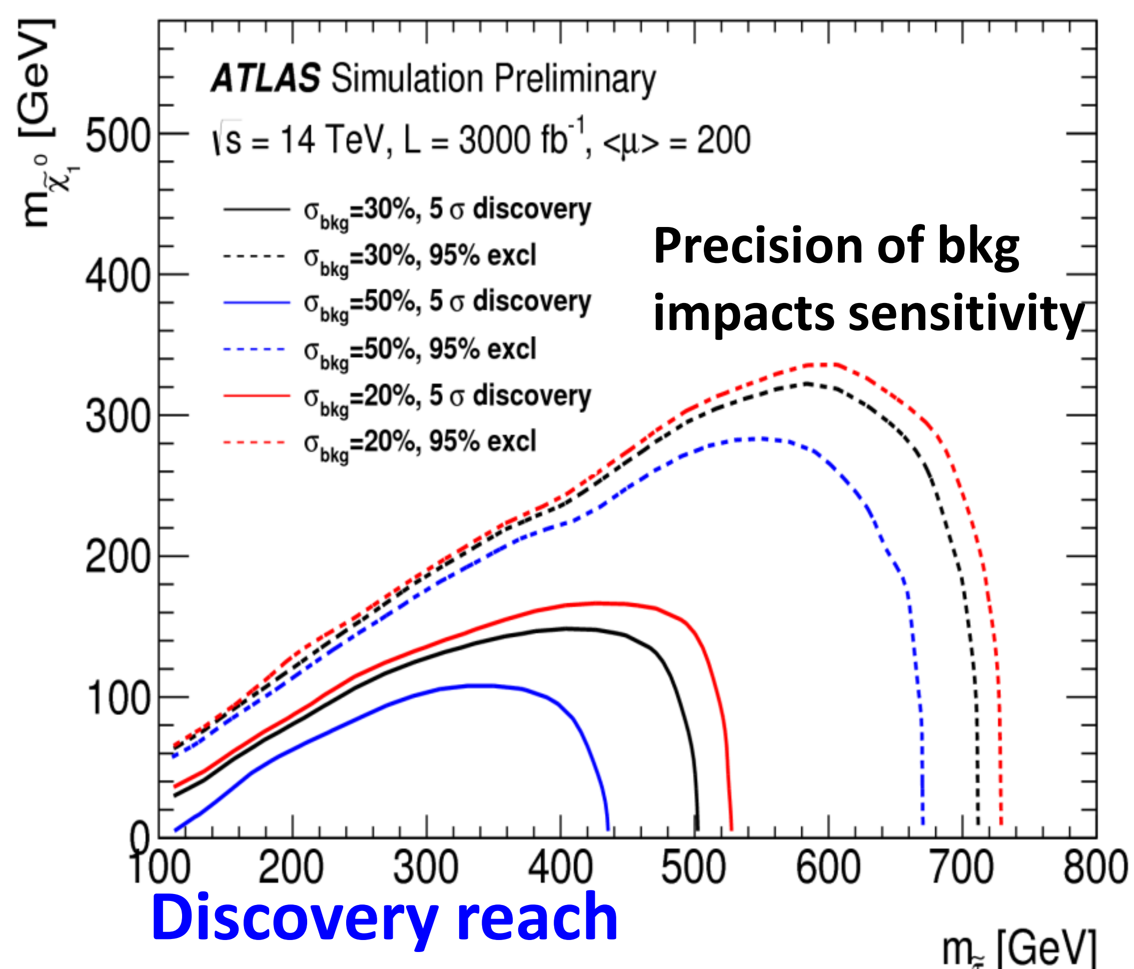
Main background: W+jets, ttbar



Selection: 2 OS taus, loose jet and Z-veto, MET>280 GeV

Define signal region (SR) in $m_T(\tau 1) + m_T(\tau 2)$





Discovery reach

430-520 GeV @ 3/ab depending on bkg

Direct stop pair production with compressed mass spectra

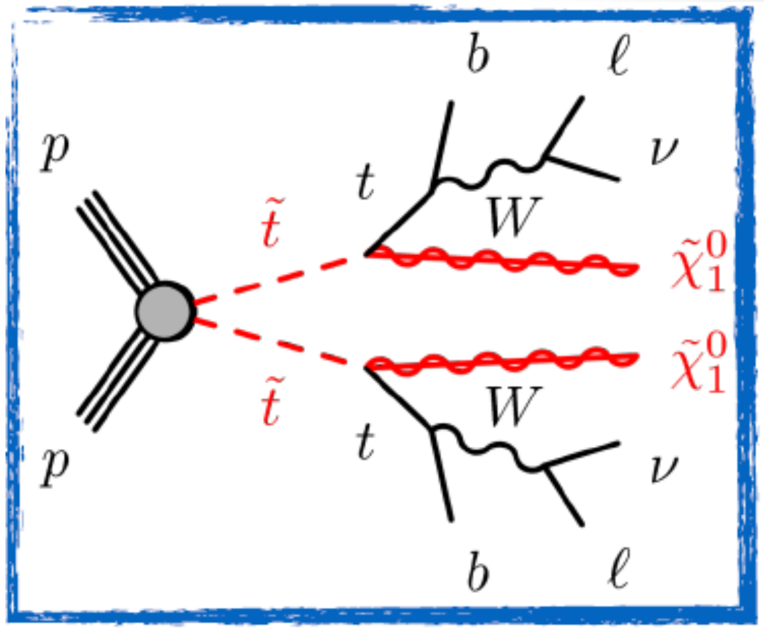
ATL-PHYS-PUB-2016-022

Compressed mass spectra

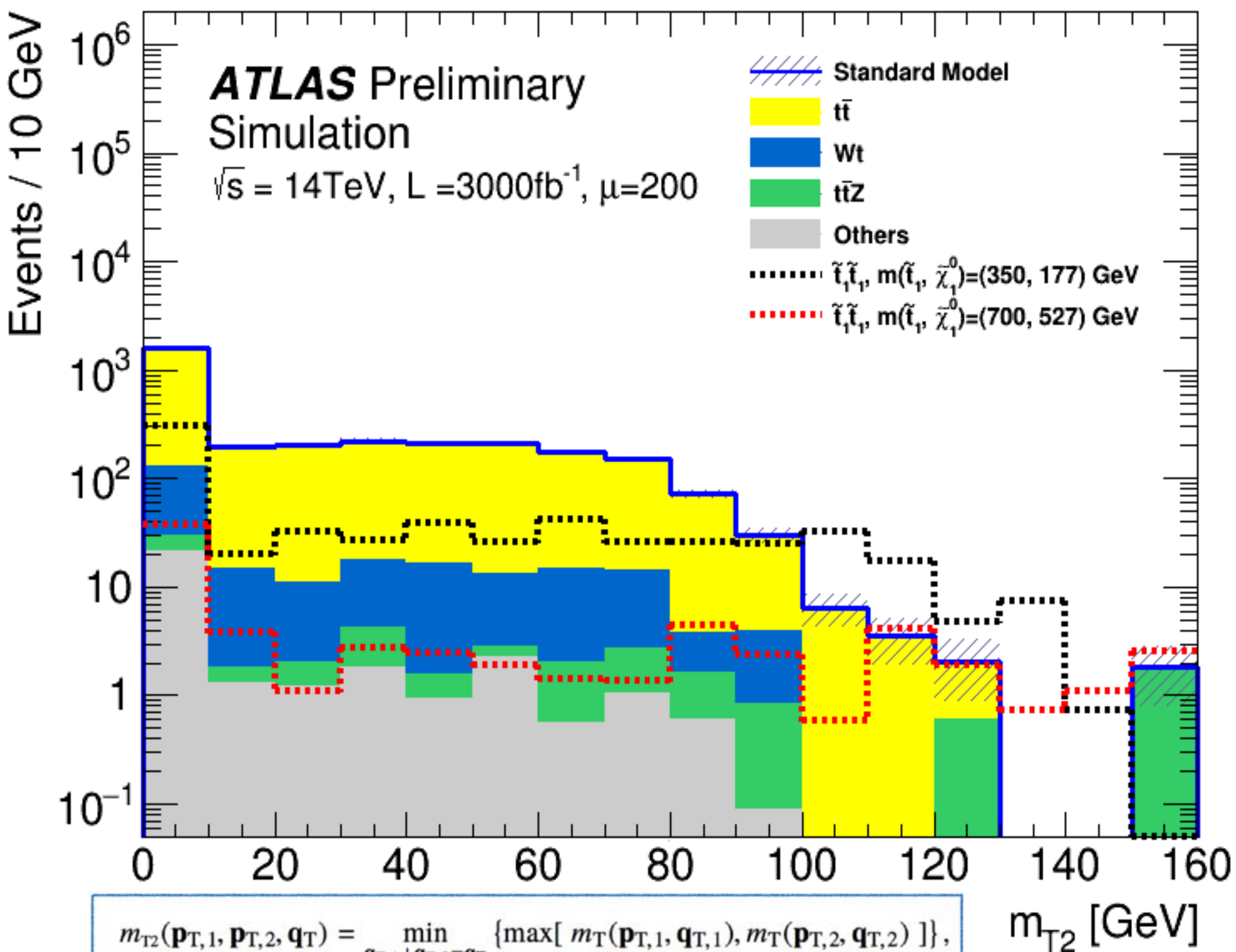
Scenario with low stop-neutralino mass difference

$$(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}) \cong m_t$$

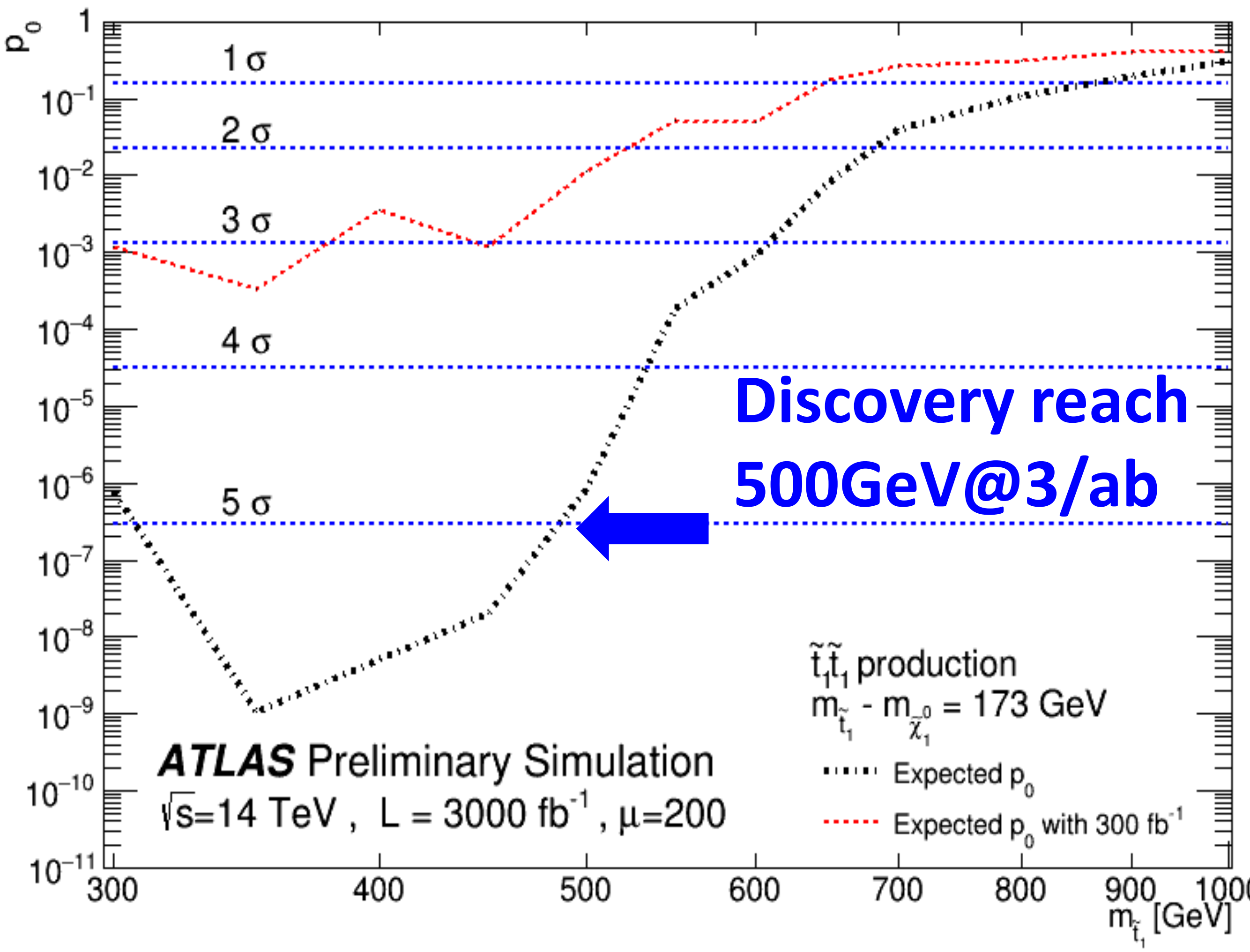
Project sensitivity of 2-lepton channel (needs luminosity), **key to study stop properties** (e.g. spin).



Signature: 2 leptons + 2 b-jets + MET



$$m_{T2}(\mathbf{p}_{T,1}, \mathbf{p}_{T,2}, \mathbf{q}_T) = \min_{\mathbf{q}_{T,1}+\mathbf{q}_{T,2}=\mathbf{q}_T} \{\max[\, m_T(\mathbf{p}_{T,1}, \mathbf{q}_{T,1}), m_T(\mathbf{p}_{T,2}, \mathbf{q}_{T,2})\,]\},$$



Final remarks and outlook

High-Luminosity LHC is now a construction project

High-Luminosity LHC very challenging environment

→ Major detector upgrades being planned to cope with it

→ Higgs precision measurements are a main physics driver for detector upgrades

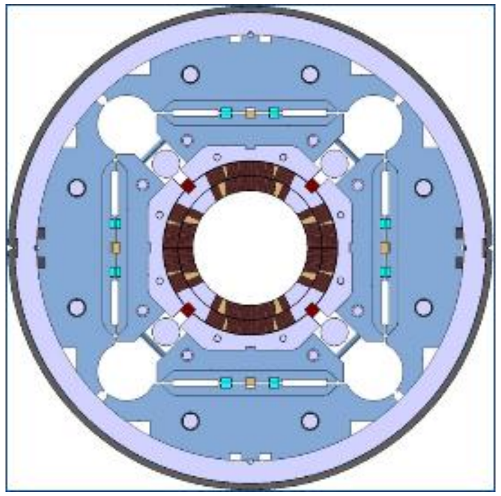
→ Expect upgraded detectors to match current performance in most areas even at highest pile-up levels

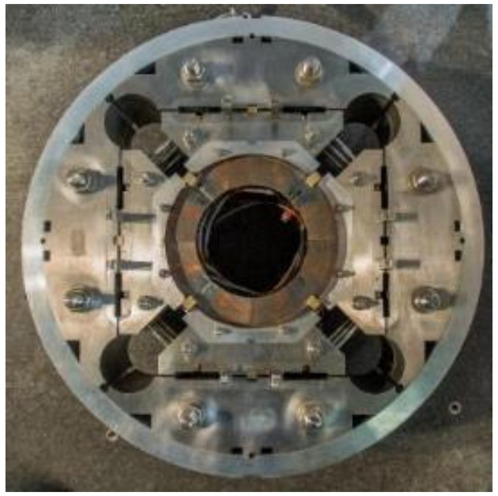
Rich BSM physics potential for HL-LHC

Several projections and full analyses for a variety of existing benchmark channels (heavy bosons, DM) reaching O(5-10 TeV)

Backup Slides

First short model focusing magnet

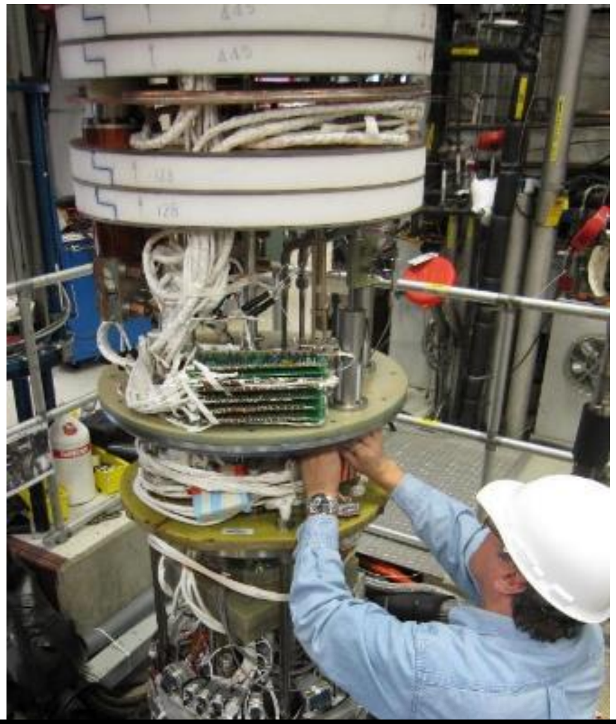




CERN - US LARP collaboration

Design and Nb_3Sn coils by CERN and LARP together (50%-50%)

Full collider characteristics.
Final length will be 3 to 5 times more



First short model magnet MQXFS1 (1.5 m)
Inner triplet Quad final cross section diameter(150 mm)

Extrapolation strategy for ECFA16 projections

Public results are extrapolated to larger data sets 300 and 3000 fb^{-1}. In order to summarize the future physics potential of the CMS detector at the HL-LHC, extrapolations are presented under different uncertainty scenarios:

S1 All systematic uncertainties are kept constant with integrated luminosity. The performance of the CMS detector is assumed to be unchanged with respect to the reference analysis.

S1+ All systematic uncertainties are kept constant with integrated luminosity. The effects of higher pileup conditions and detector upgrades on the future performance of CMS are taken into account.

S2 Theoretical uncertainties scaled down by a factor 1/2, while experimental systematic uncertainties are scaled down by the square root of the integrated luminosity until they reach a defined lower limit based on estimates of the achievable accuracy with the upgraded detector. The performance of the CMS detector is assumed to be unchanged with respect to the reference analysis.

S2+ Theoretical uncertainties scaled down by a factor 1/2, while experimental systematic uncertainties are scaled down by the square root of the integrated luminosity until they reach a defined lower limit based on estimates of the achievable accuracy with the upgraded detector. The effects of higher pileup conditions and detector upgrades on the future performance of CMS are taken into account.

Theoretical uncertainties follow the prescriptions of the LHC Yellow Report 4 (in preparation).

Extrapolation strategy for ECFA16 projections

Public results are extrapolated to larger data sets 300 and 3000 fb^{-1}. In order to summarize the future physics potential of the CMS detector at the HL-LHC, extrapolations are presented under different uncertainty scenarios:

	systematics unchanged	exp. sys. scaled* $1/\sqrt{L}$	theo. sys. scaled 1/2	high PU effects
ECFA16 S1	✓	✗	✗	✗
ECFA16 S1+	✓	✗	✗	✓
ECFA16 S2	✗	✓	✓	✗
ECFA16 S2+	✗	✓	✓	✓

(*) until they reach a defined lower limit based on estimates of the achievable accuracy with the upgraded detector.

ALICE Detector Upgrades

New Inner Tracking System (ITS)

- improved pointing precision
- less material → thinnest tracker at the LHC

Muon Forward Tracker (MFT)

- new Si tracker
- Improved μ pointing precision

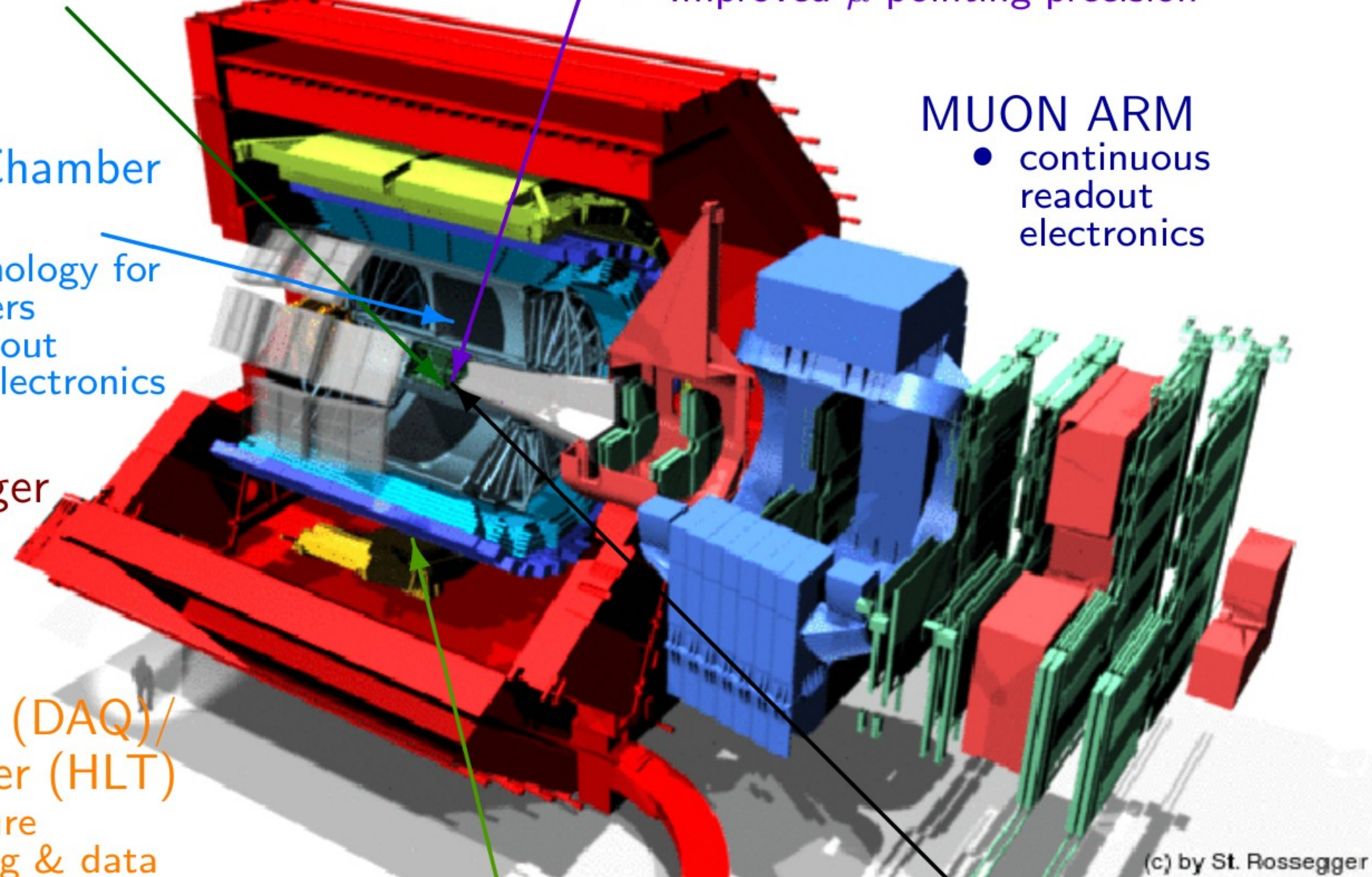
MUON ARM

- continuous readout electronics

Time Projection Chamber (TPC)

- new GEM technology for readout chambers
- continuous readout
- faster readout electronics

New Central Trigger Processor (CTP)



Data Acquisition (DAQ)/ High Level Trigger (HLT)

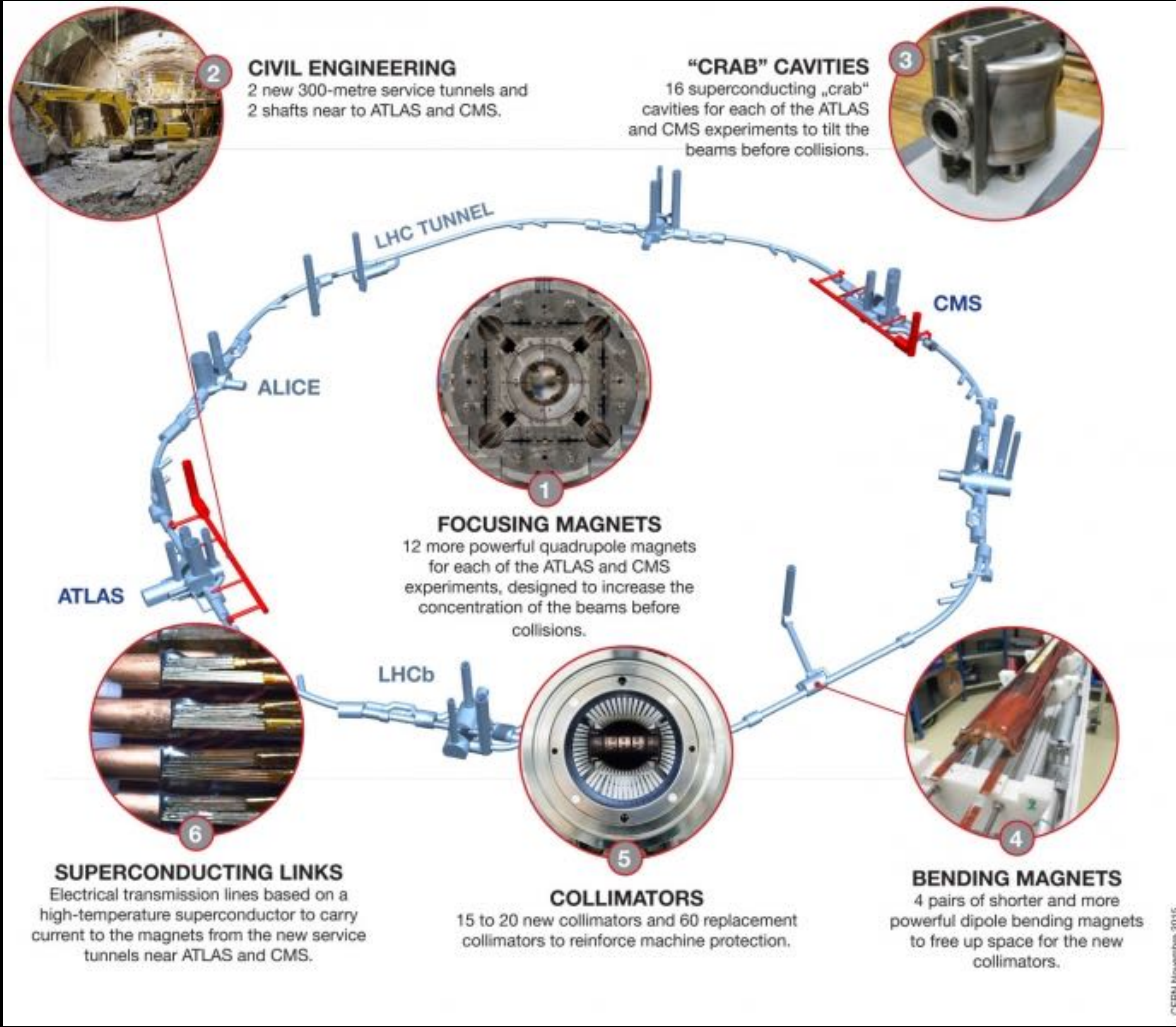
- new architecture
- on line tracking & data compression
- 50kHz Pbb event rate

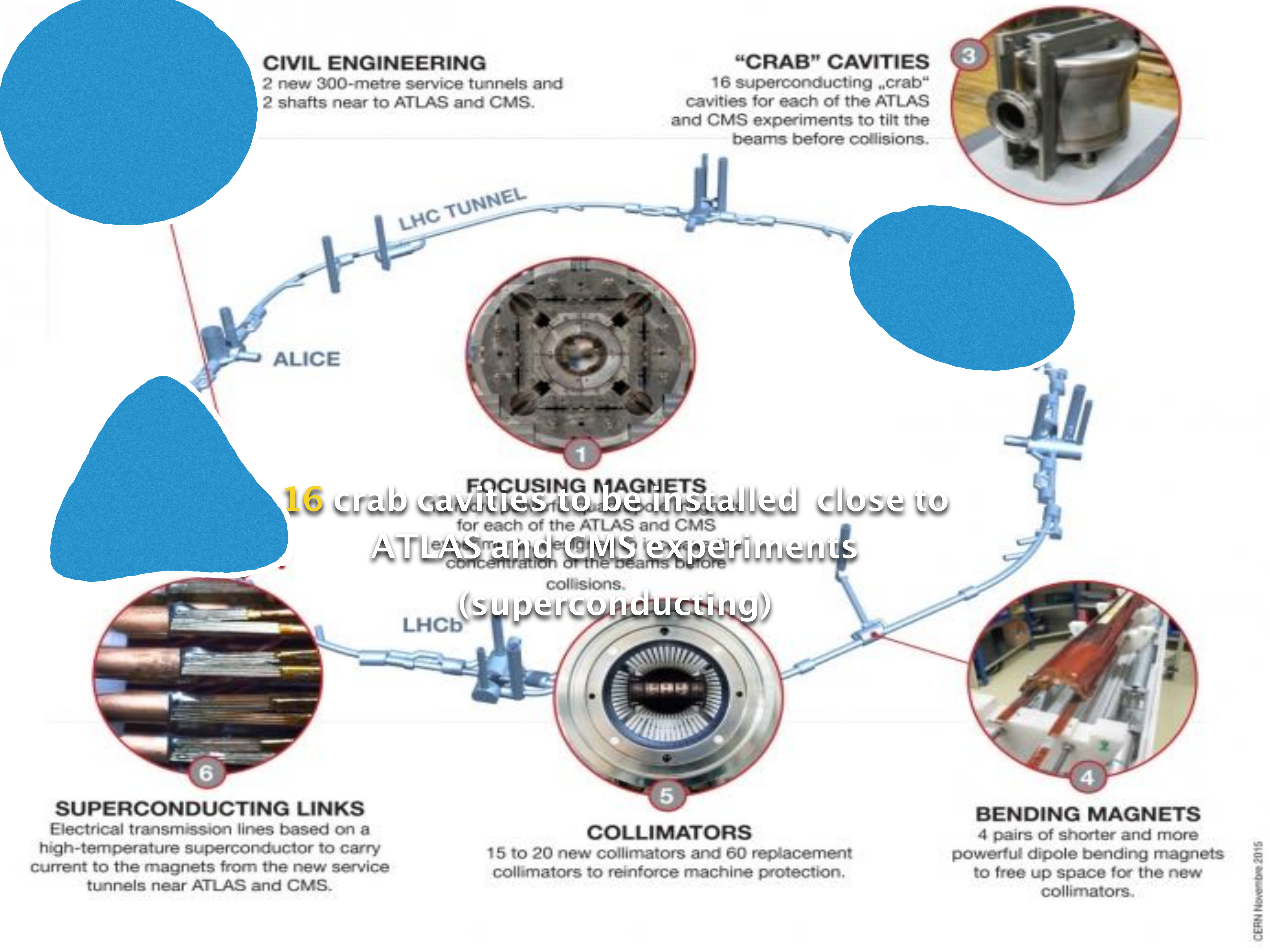
TOF, TRD, ZDC

- Faster readout

New Trigger Detectors (FIT)

→ technical design reports in CDS


2
CIVIL ENGINEERING
2 new 300-metre service tunnels and
2 shafts near to ATLAS and CMS.
"CRAB" CAVITIES
16 superconducting „crab"
cavities for each of the ATLAS
and CMS experiments to tilt the
beams before collisions.
3
LHC TUNNEL
CMS
ALICE
ATLAS
1
FOCUSING MAGNETS
12 more powerful quadrupole magnets
for each of the ATLAS and CMS
experiments, designed to increase the
concentration of the beams before
collisions.
LHCb
6
SUPERCONDUCTING LINKS
Electrical transmission lines based on a
high-temperature superconductor to carry
current to the magnets from the new service
tunnels near ATLAS and CMS.
5
COLLIMATORS
15 to 20 new collimators and 60 replacement
collimators to reinforce machine protection.
4
BENDING MAGNETS
4 pairs of shorter and more
powerful dipole bending magnets
to free up space for the new
collimators.
CERN Novembre 2015



16 crab cavities to be installed close to ATLAS and CMS experiments (superconducting)

The LHC future

Upgrade Plans

Physics restarts in June 2015

$\sqrt{s} \sim 13$ TeV   Bunch spacing: 50 —> 25 ns

2014 LS1

2015

2016

2017

Peak luminosity
1.6×10^{34} cm^{-2} s^{-1} , ~50 events per crossing

L ≥ 100 fb^{-1}

2018 LS2

2019

2020

2021

Peak luminosity
2.4×10^{34} cm^{-2} s^{-1} , ~60 events per crossing

L ≥ 300 fb^{-1}

2022 LS3

2023

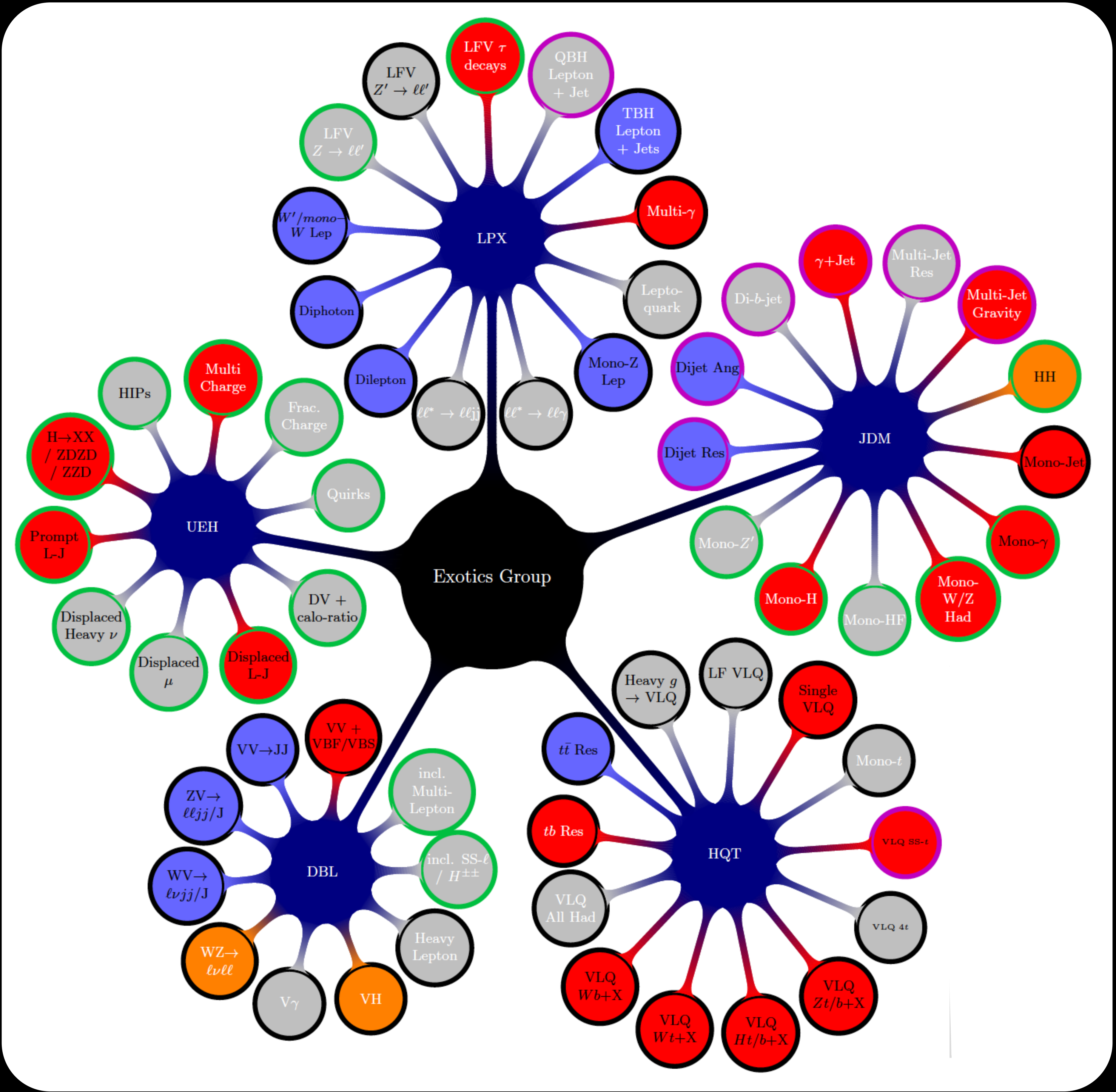
⋮

2030? HL-LHC

Peak luminosity
5×10^{34} cm^{-2} s^{-1} , ~140 events per crossing

L ≥ 3000 fb^{-1}

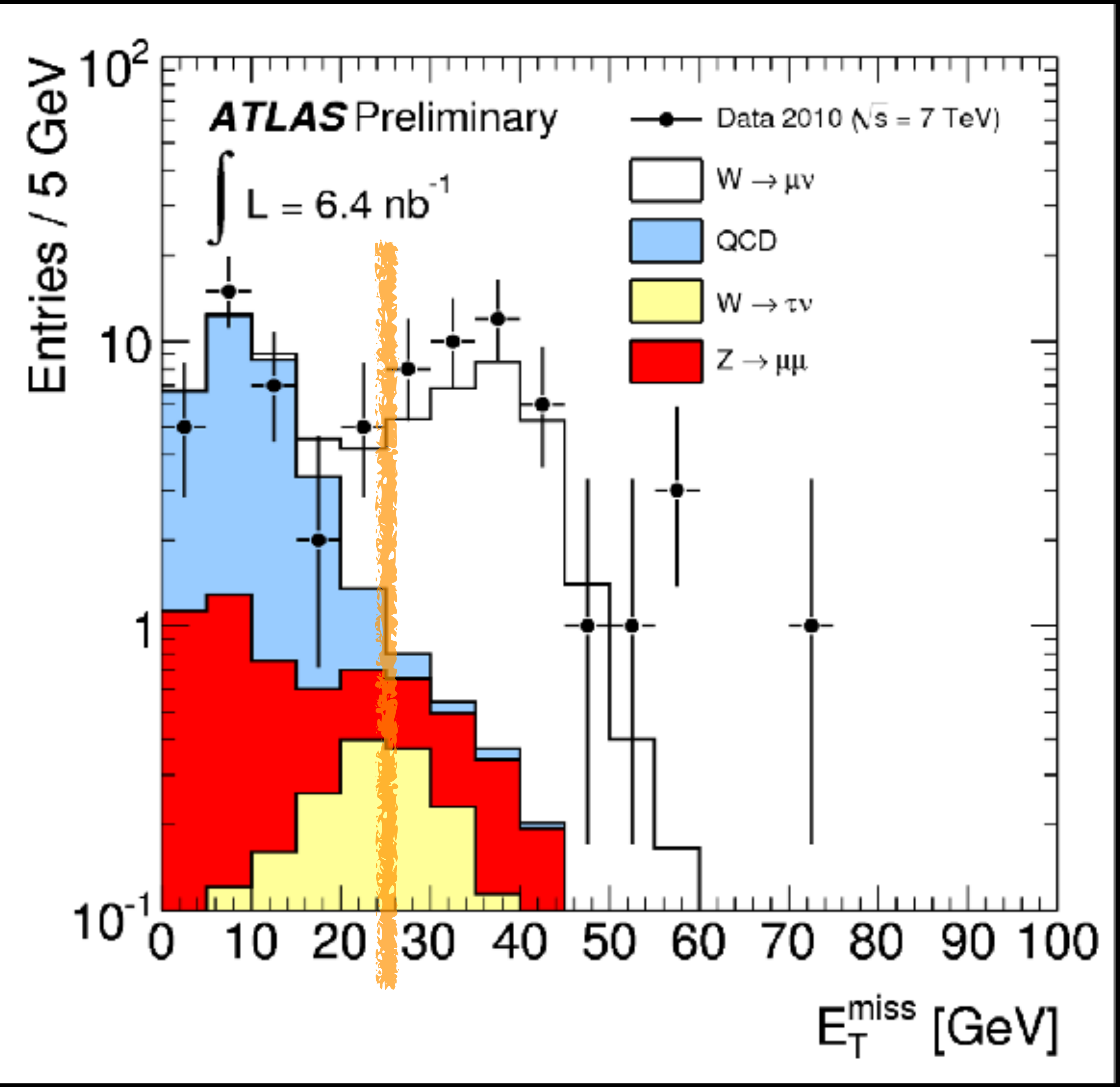
A plethora of physics being explored for Run II



The W Boson Observation in 2010

This goes better when I am discussing what can be done in 2015

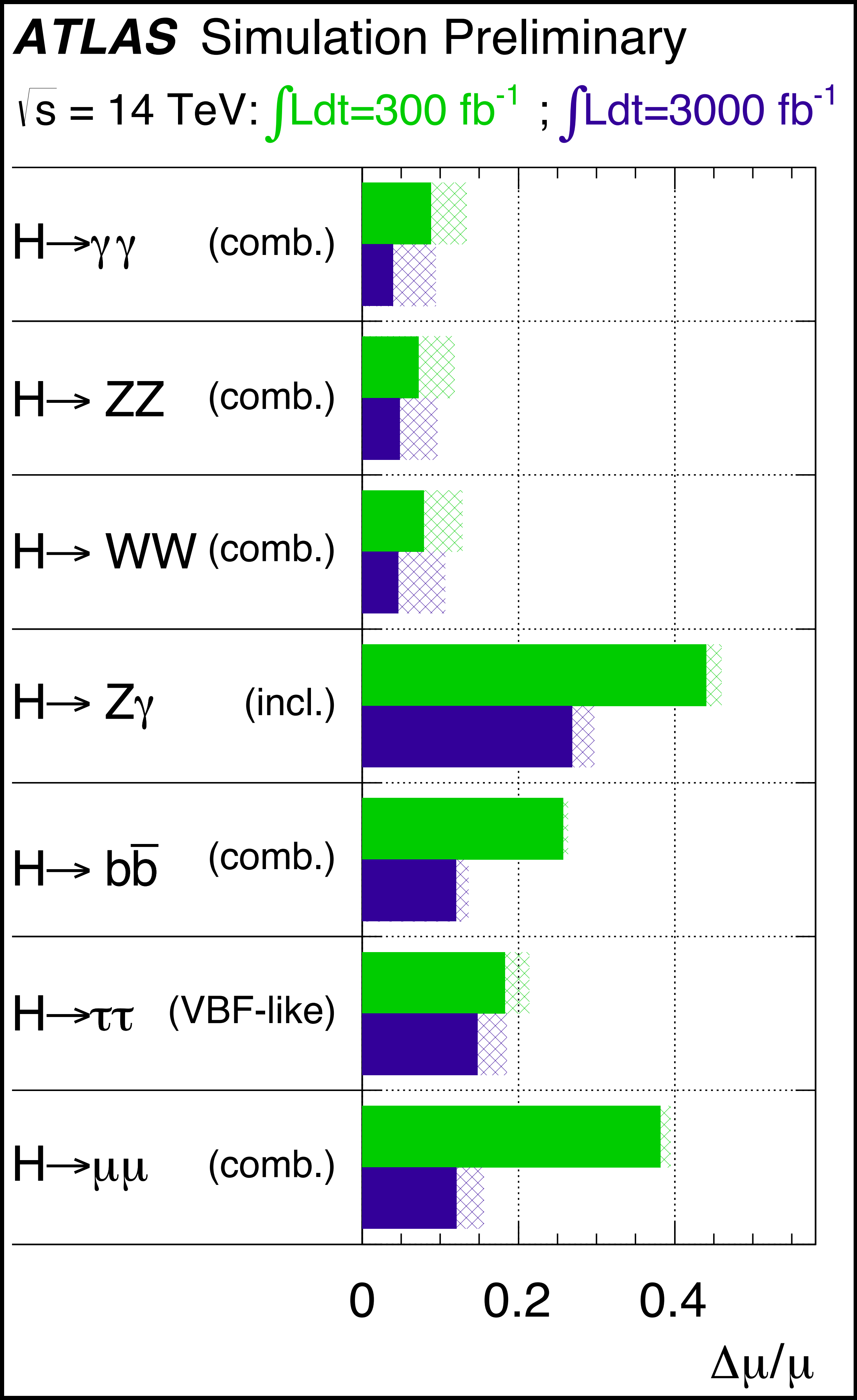
PLHC 2010: March-May 2010 da



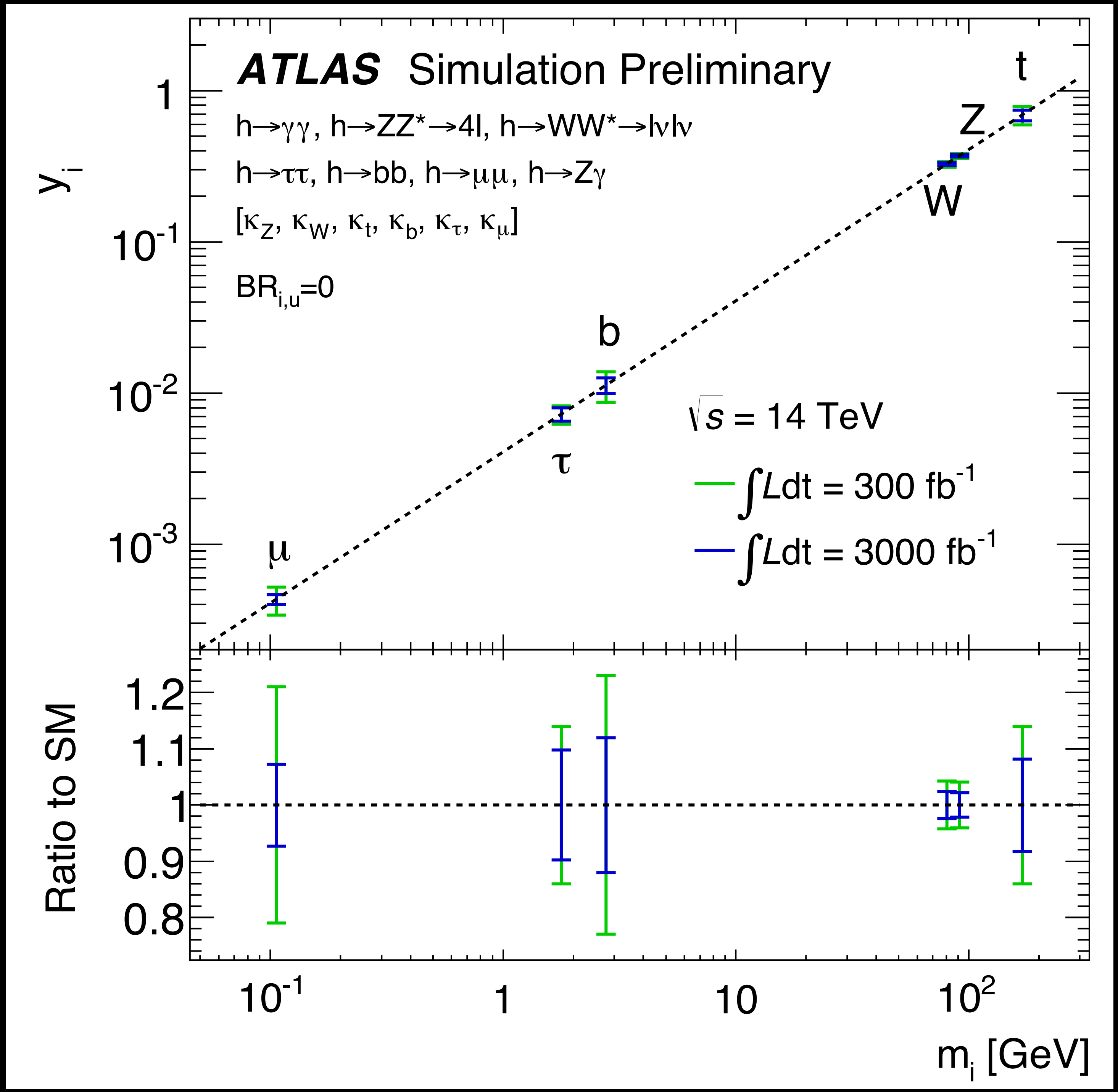
	$W \to \mu\, \nu$ (events)
Signal	25.9
Bkg	2.8
Expected	28.7
Observed	40

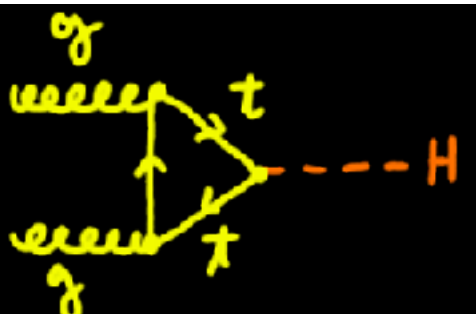
Or, the discovery of Supersymmetry?

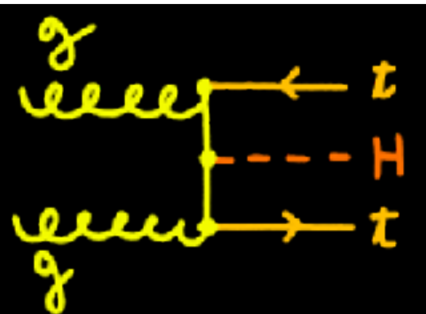
Higgs Production Strength Uncertainty Prospects



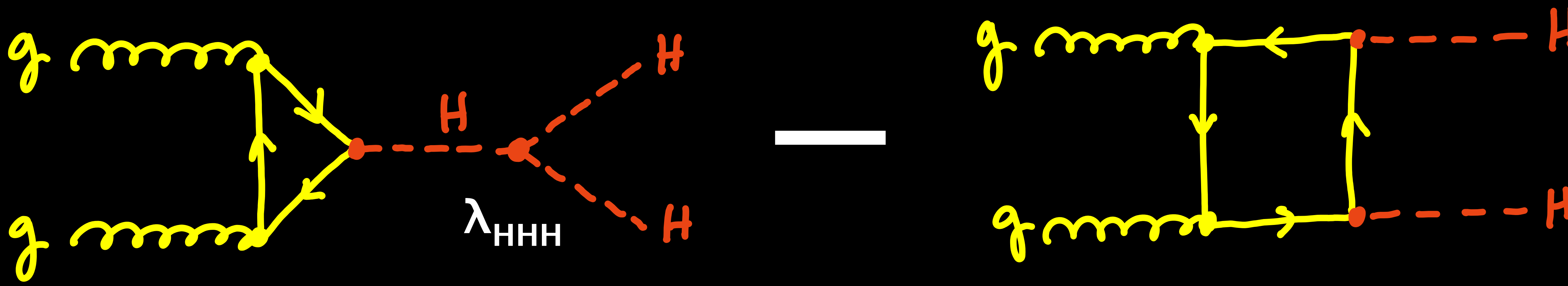
Reduced couplings scale factors



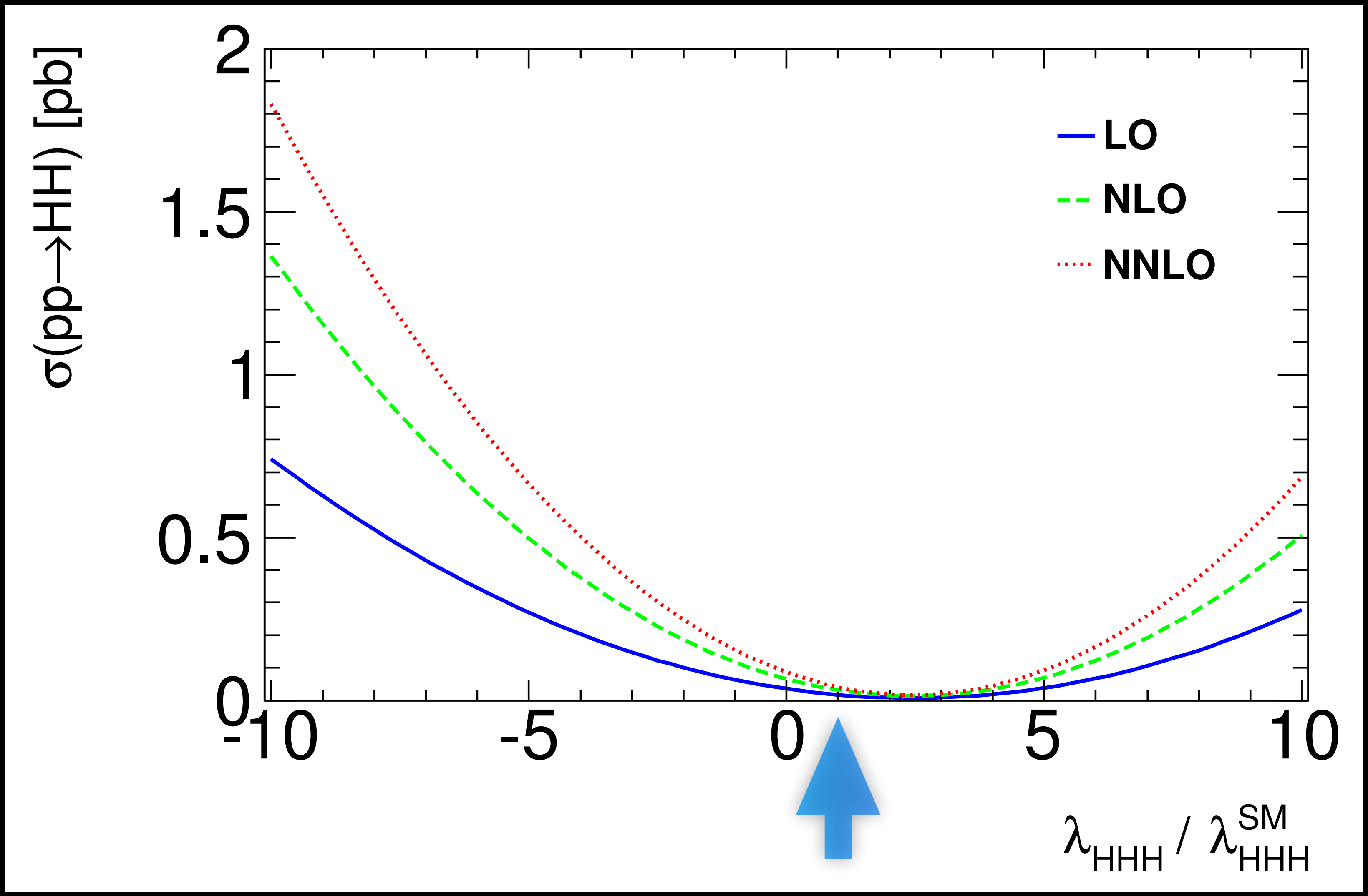




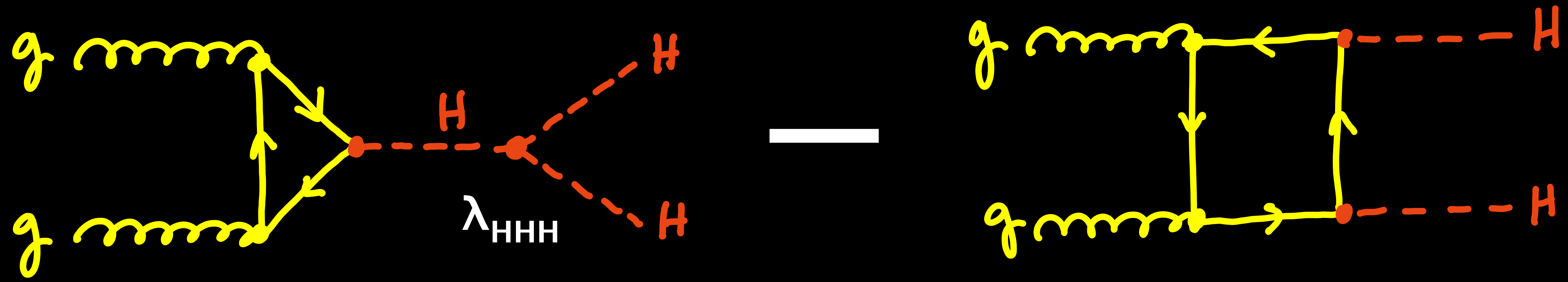
Higgs Self Coupling – λ_{HHH}



σ ~ 41 fb ± 11%



Higgs Self Coupling – λ_{HHH}



$\sigma \sim$ 41 fb ± 11%

HH	Total yield (3000 fb^{-1})	Significance
bb + bb	40,000	ongoing
bb + ττ	8,900	ongoing
ZZ + bb	3,800	—
WW + ττ	3,300	< 1σ
γγ + bb	320	1.3 σ

8 events expected after selection

Need to combine all channels

Upgrade Plans

Collisions restarted in Spring 2015

$\sqrt{s} \sim 13$ TeV — Bunch spacing: 50 —> 25 ns

2014 — **LS1**

2015

- New inner pixel layer
  (improve vertexing resolution by 10-30%)

2016

2017

Peak luminosity
1.6×10^{34} cm^{-2} s^{-1} , ~50 events per crossing

$L \geq 100$ fb^{-1}

2018 — **LS2**

2019

- New muon small wheel
- Improve L1 trigger capabilities

2020

2021

Peak luminosity
2.4×10^{34} cm^{-2} s^{-1} , ~60 events per crossing

$L \geq 300$ fb^{-1}

2022 — **LS3**

2023

- Replace inner tracker
- New trigger electronics scheme
  (Upgrade Muon/calorimeter electronics)

:

:

2030? — **HL-LHC**

Peak luminosity
5×10^{34} cm^{-2} s^{-1} , ~140 events per crossing

$L \geq 3000$ fb^{-1}

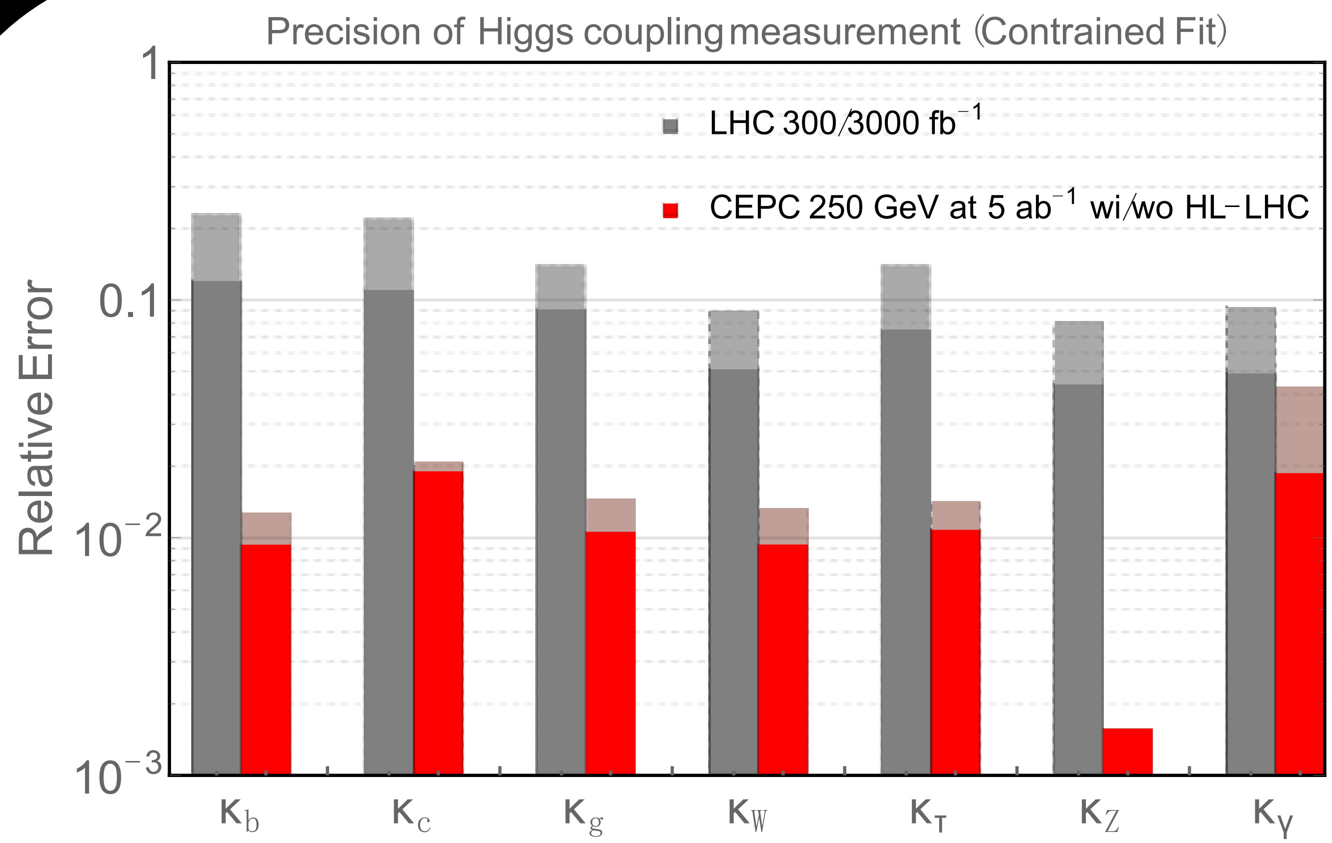
New Collider(s)

Colliders under discussion

Name	Location	Type	Particles	Energy
CEPC	China	Circular	ee	90->240 GeV
SppC	China	Circular	pp	70-100 TeV
FCC-hh	CERN	Circular	pp	100 TeV
FCC-ee	CERN	Circular	ee	90->350 GeV
ILC	Japan	Linear	ee	250-500 GeV
CEPC/SPPC	China	Circular	ep	< 4.2 TeV
FCC-ep	CERN	Circular	ep	3.5 TeV

Higgs couplings at new colliders

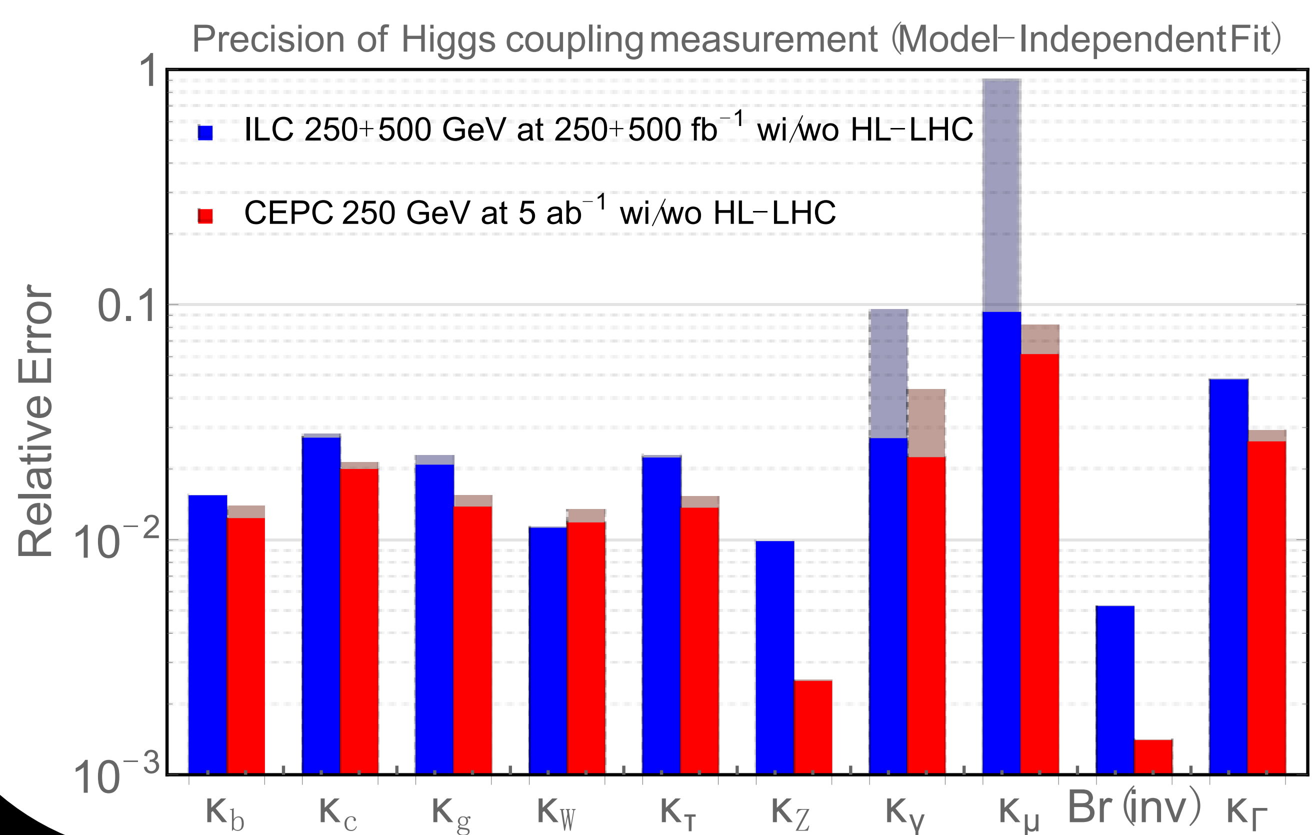
CEPC
vs
LHC



1%

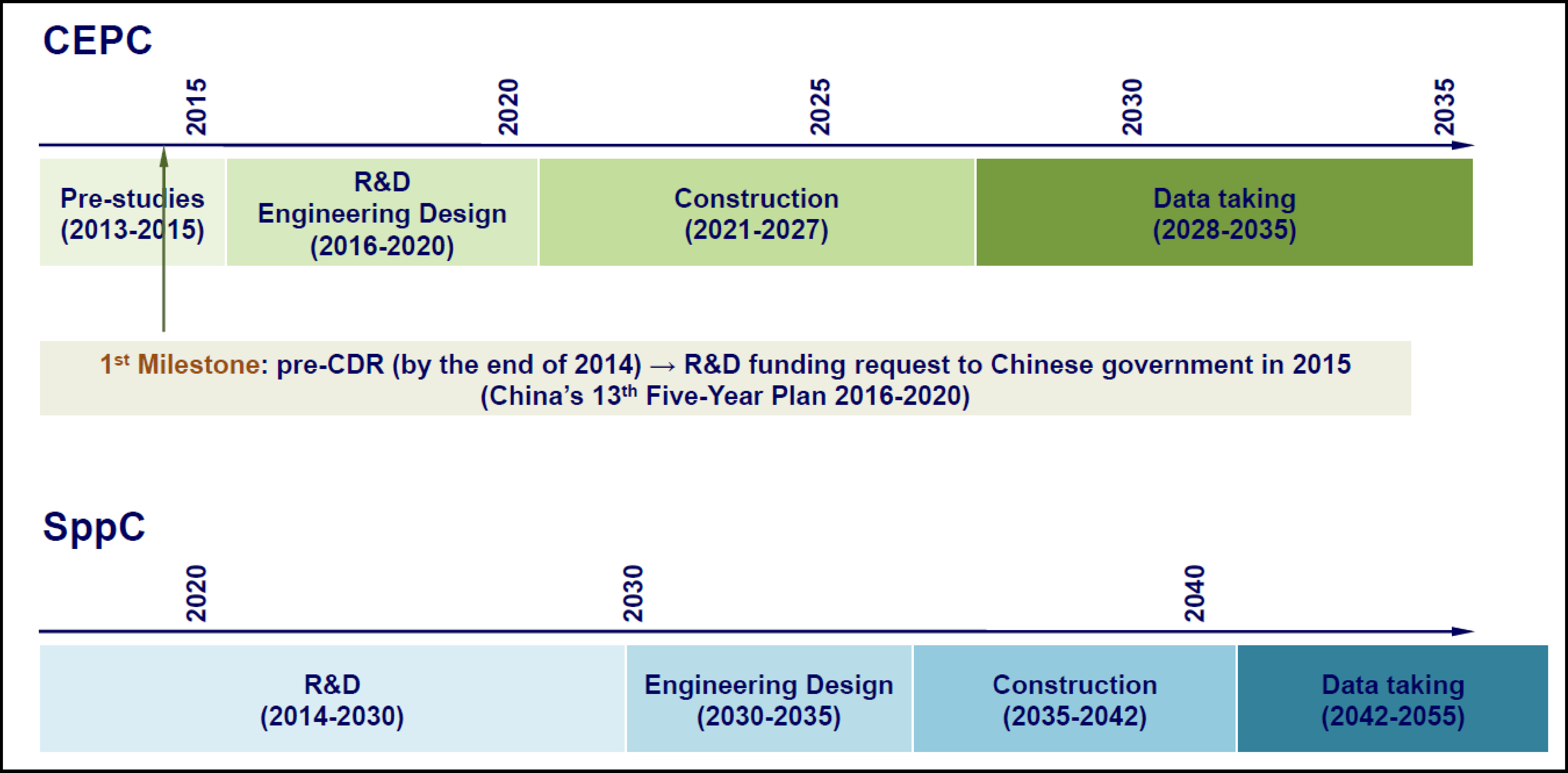
Self-coupling
FCC-hh/SppC
10-15%

CEPC
vs
ILC

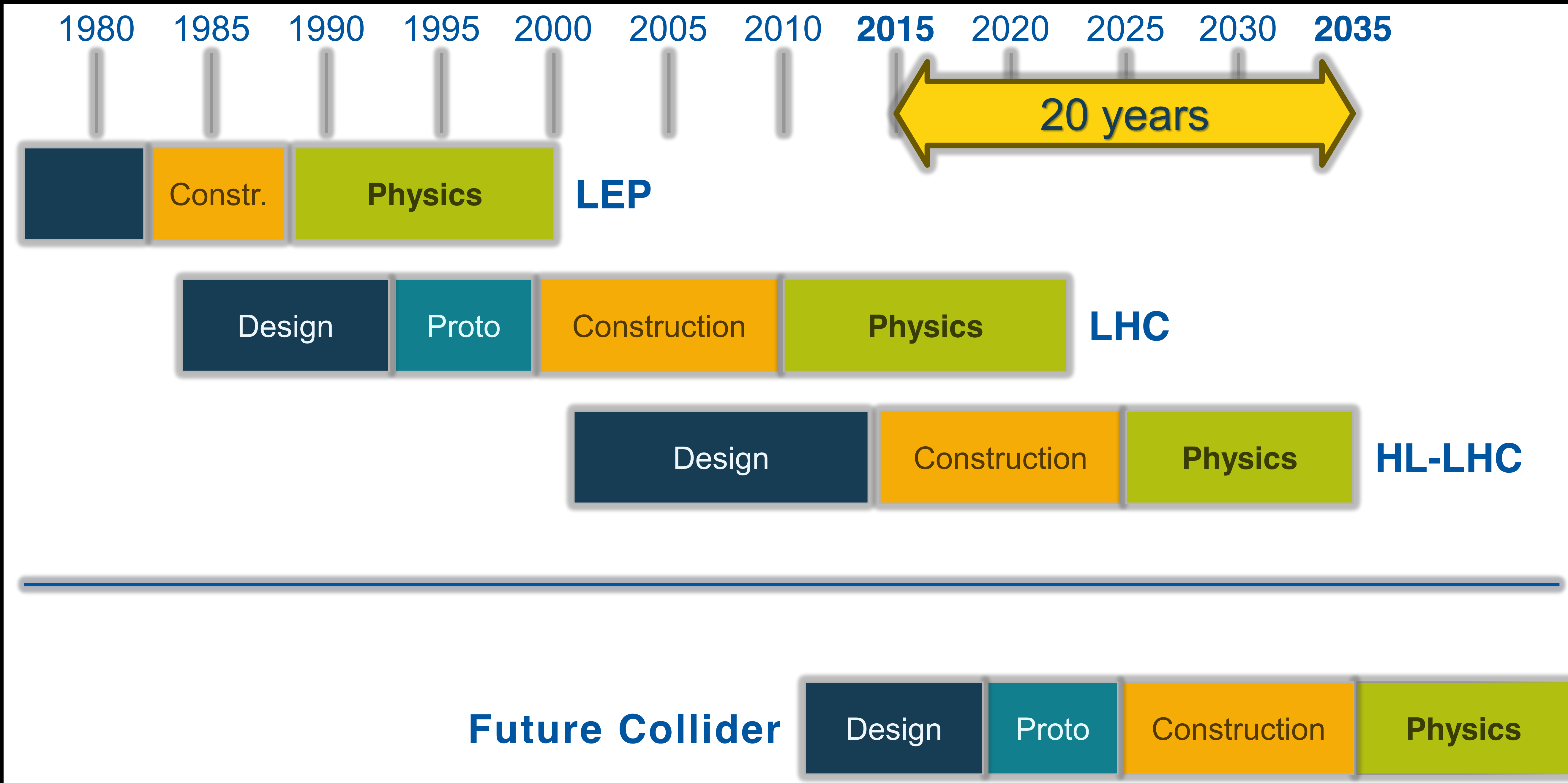


1%

CEPC/SppC Timeline



CERN FCC-hh/FCC-ee timeline



New accelerators

W and Z bosons ==> LEP

top quark ==> Tevatron, run II; LHC

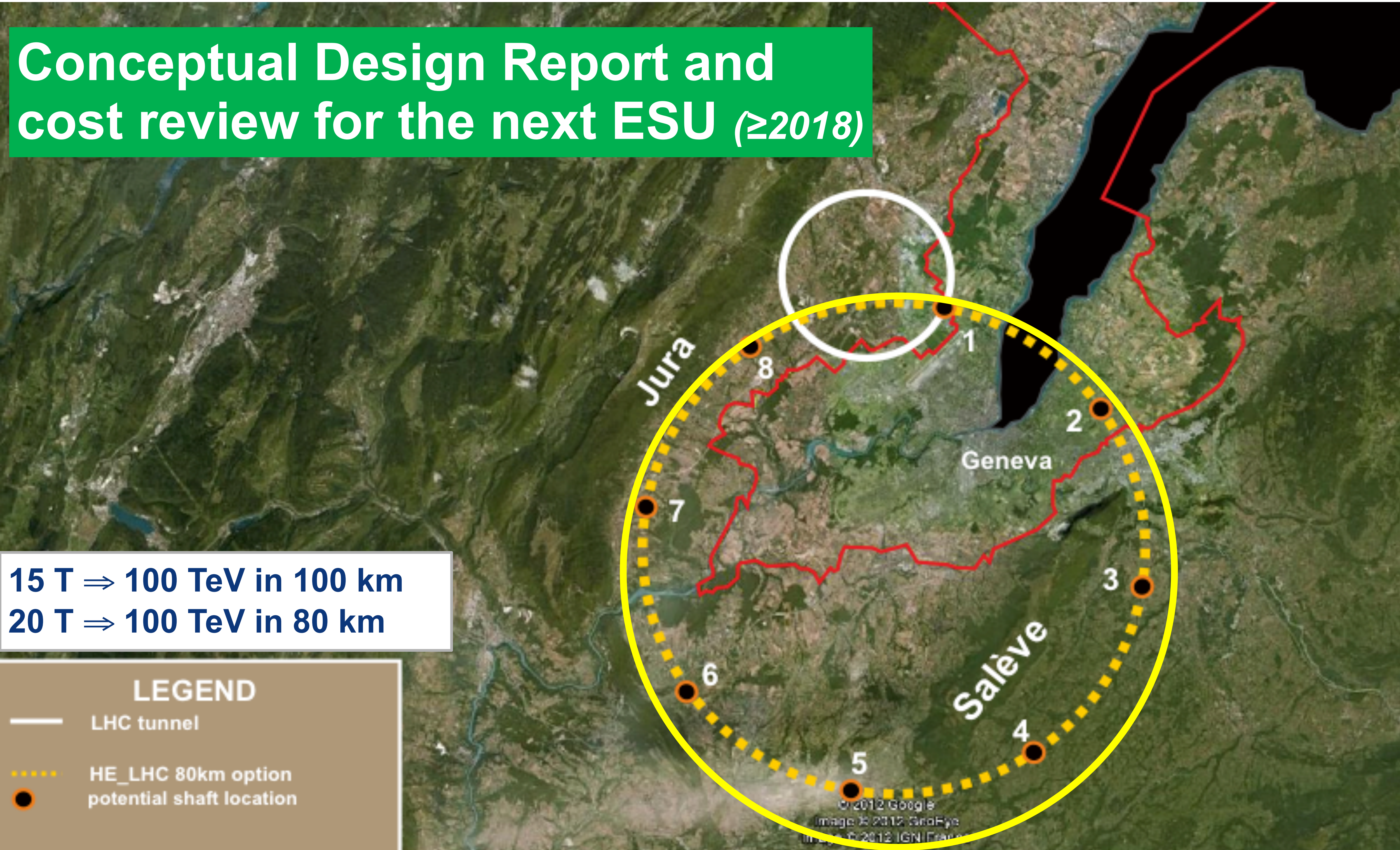
Higgs ==> HL-LHC, new accelerator

Schedules

80-100 km tunnel infrastructure in Geneva area – design driven by pp-collider requirements
with possibility of e+-e- (TLEP) and p-e (VLHeC)

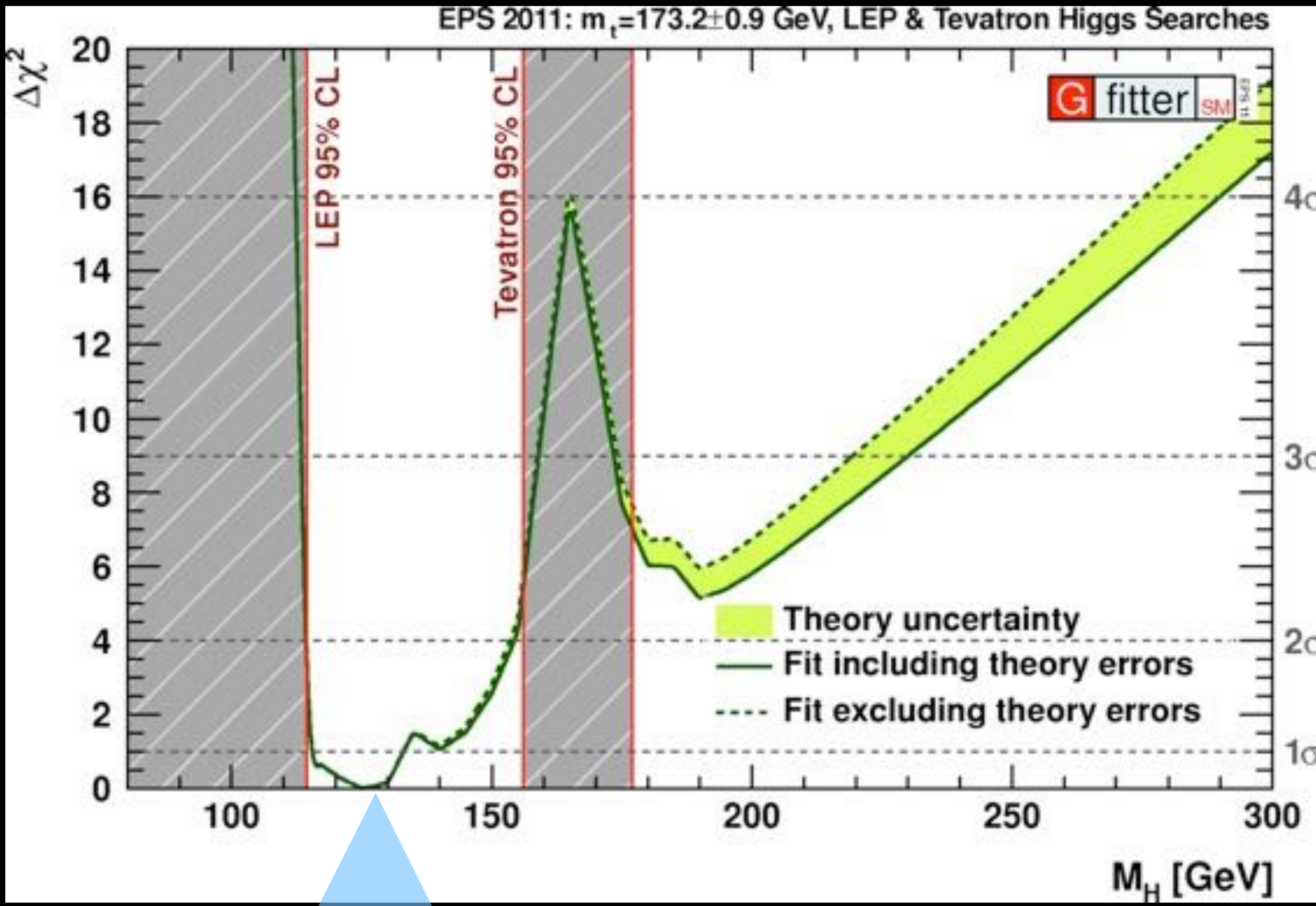
Conceptual Design Report and cost review for the next ESU *(≥2018)*

15 T ⇒ 100 TeV in 100 km
20 T ⇒ 100 TeV in 80 km



Electroweak Fit Status (July 2011)

Excludes LHC data and direct Higgs searches from ATLAS and CMS



Complete Fit
(including direct limits on Higgs from LEP and Tevatron)

m_H = 125.2 GeV (most likely value)
Range: [116,133]

First presented at PANIC ‘11