Physics Prospect at the High Luminosity LHC

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On behalf of CMS collaboration at the LHC

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What has been achieved by CMS experiment at LHC so far

- **Observation of a Higgs boson with a mass of 125 GeV consistent with Standard Model (SM) expectation.**

✓ Observation or evidence of the major decay modes to vector bosons as well as 3rd generation fermions of SM (t, b, τ) at 3 to 5 σ significance level ➔ couplings follow the pattern as depicted.

✓ Strong evidence for 0^+ spin-parity assignment of the Higgs boson.

- **Confirmation of SM predictions in perturbative framework for the electroweak and QCD sectors to a precision level of about few per mille.**

- **Measurement of rare decays such as $B_s \rightarrow \mu^+ \mu^-$: consistent with the SM.**
- **Observation of other new particles, eg., new excited beauty baryon Ξ_b , mass splitting in χ_b**

- **Exclusion of wide areas of parameter space for beyond standard model scenarios** ➔ no hint of exotic heavy objects, with sufficiently strong couplings to quarks and gluons as well as with sufficiently distinctive signatures up to several TeV.

Need for high luminosity operation of LHC

a la M.Mangano in 2015

The "no-matter-what-the-LHC-finds" scenario:

- ✓ Tests of SM properties of Higgs in terms of couplings to vector bosons & fermions
- ✓ Measure rare decays of Higgs (eg., H→ $\mu\mu$, H→ $Z\gamma$)
- ✓ Measure self-coupling of Higgs
- ✓ Explore SM dynamics, from flavour physics in B decays at GeV scale to TeV scale scattering of W boson pairs

The"LHC-makes-a-discovery" scenario:

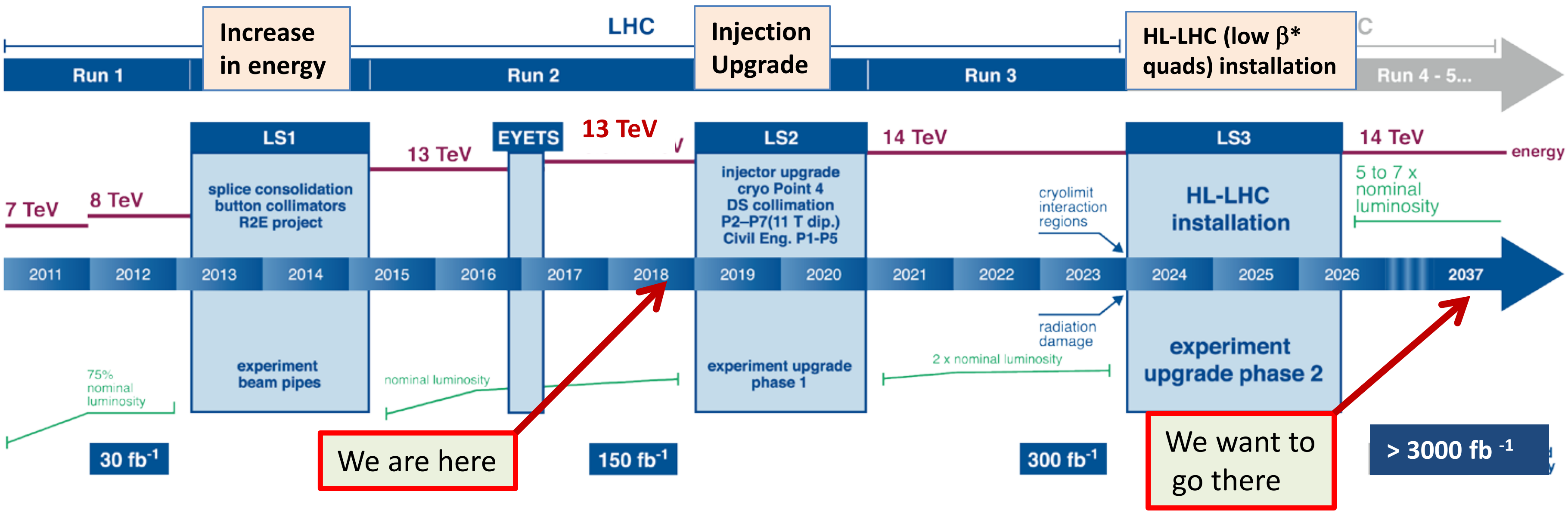
- ✓ Find the detailed characteristics → 300 /fb is not enough!

The "still-don't-know-what's-next" scenario:

- ✓ High Lumi LHC (HL-LHC) is the only guaranteed facility for exploration of physics beyond SM
- ✓ Extend the searches for beyond standard model physics to new corners

With HEP knocking at the heaven's door, we have miles to go before we sleep!

Roadmap of the LHC



Run2 (2015 - 2018) : √s = 13 TeV

- Instantaneous luminosity: L ~ $2.2*10^{34}/cm^2/s$
- Pile Up (PU) ~ 50 on average
- Integrated lumi: $\mathcal{L}$ ~ 140 /fb by end 2018

Phase-1 upgrade of CMS: 2013-2020

Run3 (2021 - 2023) : √s = 14 TeV

- L = $2.5*10^{34}/cm^2/s$, PU > 50
- $\mathcal{L}$ ~ 300 /fb by end 2023

Run4 (2026 – 203X): √s = 14 TeV

→ **More data!**

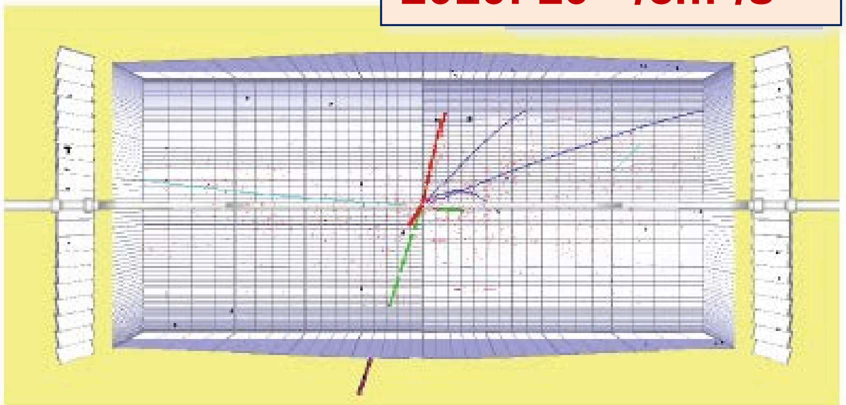
HL-LHC (2026 --): approved project

- Lumi-level > **5x design**, L= $(5 – 7.5)*10^{34}/cm^2/s$
- PU = 140 - 200
- $\mathcal{L}$ = 3000 - 5000 /fb

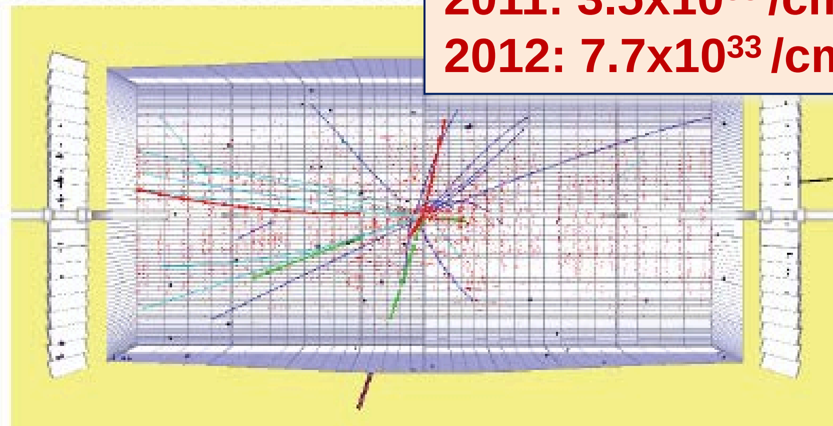
➔ **Phase-2 upgrade of CMS during 2024-2026**

Experimental Challenge at High Luminosity LHC

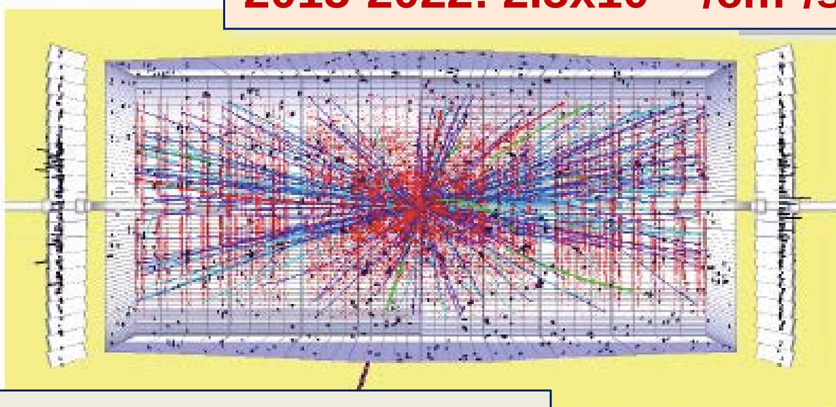
2010: 10^{32} /cm^2/s



2011: 3.5×10^{33} /cm^2/s
2012: 7.7×10^{33} /cm^2/s

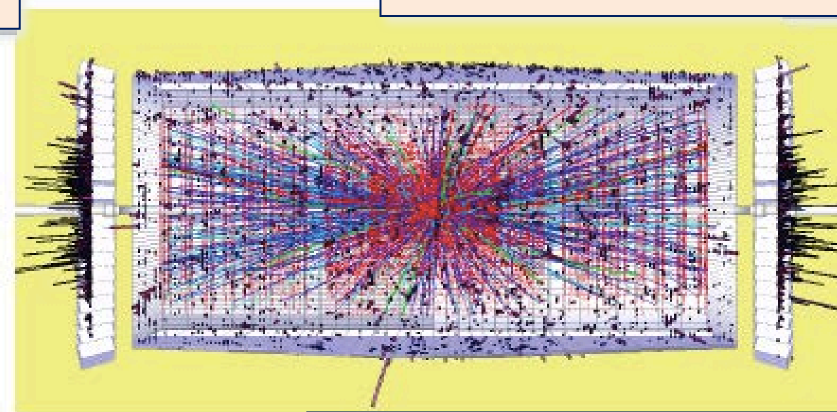


2015-2022: 2.5×10^{34} /cm^2/s



~1 billion pp interactions/s

> 2026: 0.5-1×10^{35} /cm^2/s



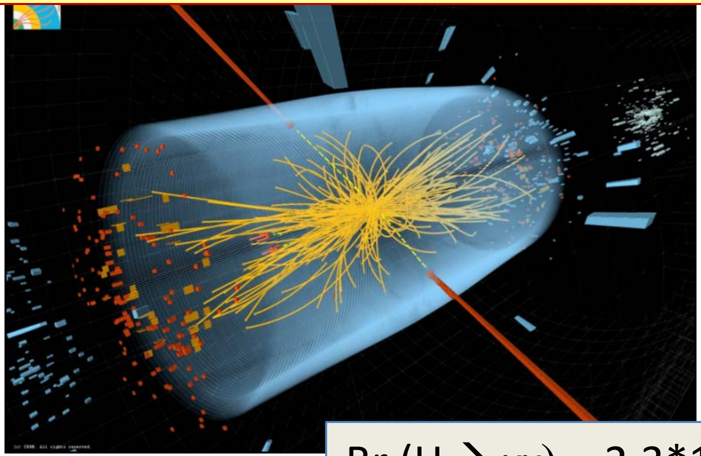
~10 billion pp interactions/s

Tracking, Calorimetry and Triggering, in particular for low to medium p_T objects, need fine granular and radiation hard detectors, new strategies in DAQ and Software.

Expectation from experiments

- LHC is an exploratory machine for enhancing discovery potential at TeV scale
- Quality and capability of instrument highly detrimental

Discovery of Higgs boson: July, 2012



Br (H→ $\gamma\gamma$) = $2.3*10^{-3}$

- HL-LHC necessarily offers a very harsh and challenging experimental environment → very high demand on detector to deliver physics benefitting from high luminosity

Present detector is built with 15-20 years old technologies

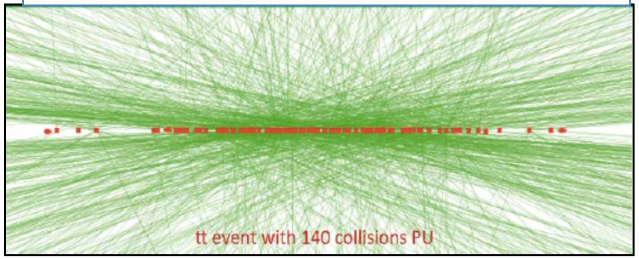
→ will not suffice at HL-LHC

Main considerations for detector design

- Electroweak scale (100 GeV) → does not change with luminosity!

- Trigger threshold cannot change much if we want to explore precision physics
  → Problem: single object identification challenged by numerous particles from 8 times higher PU than design!
  → Solution: development of higher trigger rate capability, bandwidth, as well as higher storage buffer
  → trigger decision with more latency

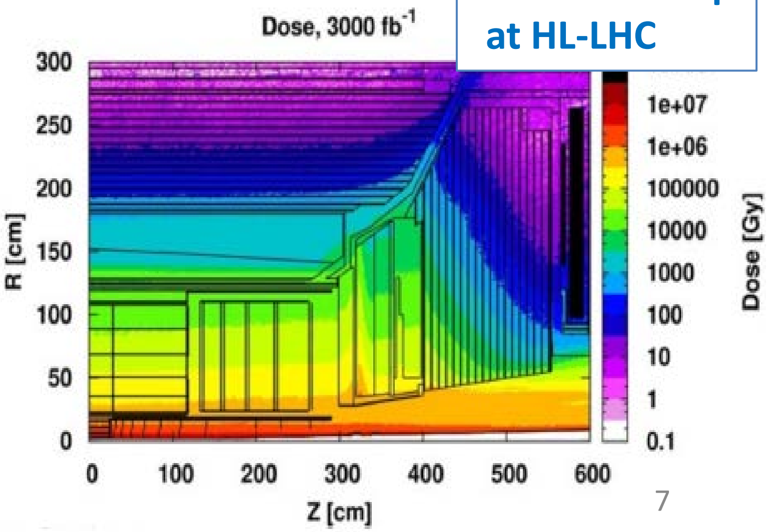
Vertex reconstruction at HL-LHC



- Radiation 6 times higher than nominal design!
→ Need detectors with radiation-hard material
→ High granularity of detector is essential.

- **Exploit evolution in technology for detector and electronics during last 2 decades.**

Radiation map at HL-LHC



Strategy to deal with HL-LHC environment

- Essential to maintain or improve upon the performance of detector in terms of → reconstruction, identification, and rejection of background
- Increased use of silicon sensors (radiation tolerant)
- More granularity in silicon provides possibility to deal with high pileup
- Precision timing with resolution of ~50 ps to separate collisions in space & time
- Sustain large event rate by faster processing of data in real time for trigger by using modern high speed electronics

Examples for physics drivers towards detector design:

i) Vector boson scattering, Vector Boson Fusion production of single and double Higgs ➔ **need enhanced acceptance for VBF jets in mid-rapidity region AND discrimination against PU jets.**

ii) EW physics, H→ ZZ* → 4ℓ ➔ **requires acceptance of leptons in forward direction.**

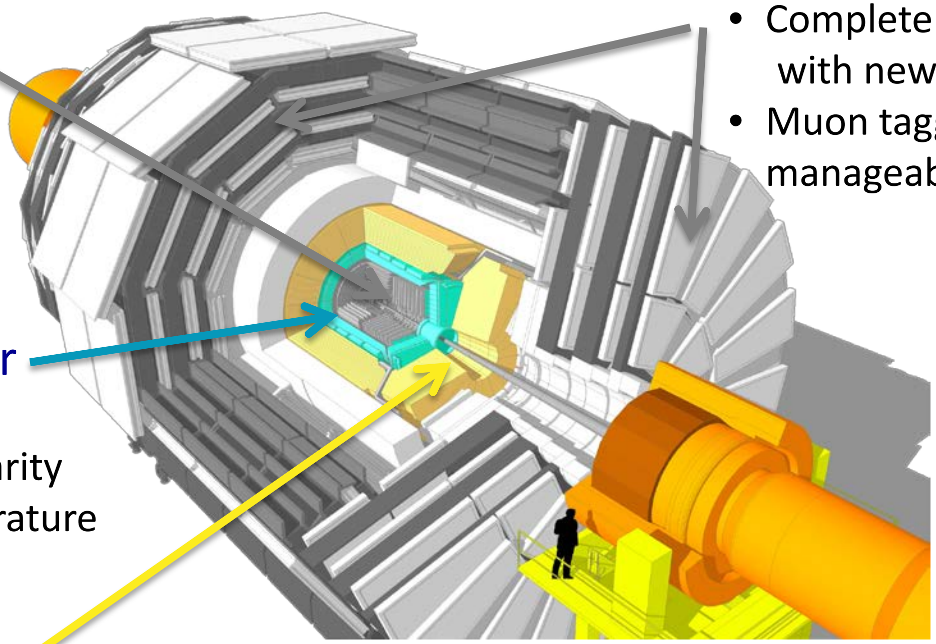
CMS upgrades for Phase-2

New Tracker

- Rad. tolerant , increased granularity , lighter and less material
- Trigger with tracks for $P_T \geq 2$ GeV in Outer Tracker region
- Extended coverage to $|\eta| \simeq 3.8$

Muon systems

- New DT & CSC FE/BE electronics
- Complete RPC coverage $1.5 < |\eta| < 2.4$ with new GEM/RPC technology
- Muon tagging $2.4 < |\eta| < 3$, with manageable rate reduction.



Barrel EM calorimeter

- New FE/BE electronics
- Spatial and time granularity
- Lower operating temperature

- Beam radiation & luminosity monitors
- Common systems & infrastructure

Trigger/HLT/DAQ

- Track information in Trigger hardware
- High speed optical links & GHz FPGAs
- L1 Trigger latency: 12.5 µs
- Reduce rate from 1 GHz to 750 kHz
- HLT output 7.5 kHz

New Endcap Calorimeters

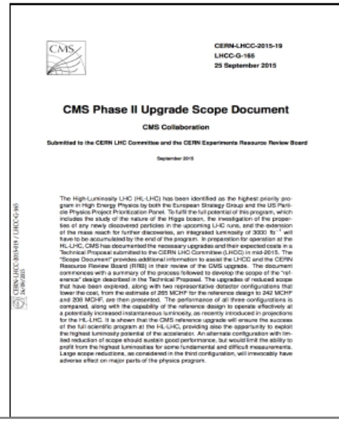
- Large area of silicon,
- radiation tolerant
- increased transverse & longitudinal segmentation
- intrinsic precise timing capability

Documents to LHCC

Technical proposal

CERN-LHCC-2015-010

Scope document

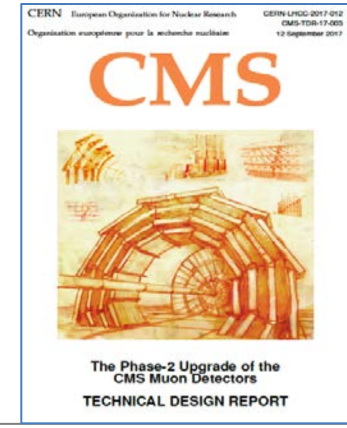


CERN-LHCC-2015-019

Tracker TDR

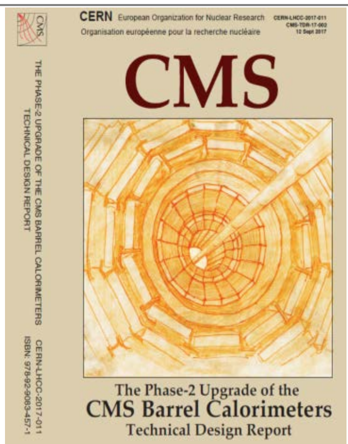
CERN-LHCC-2015-019

Muon TDR



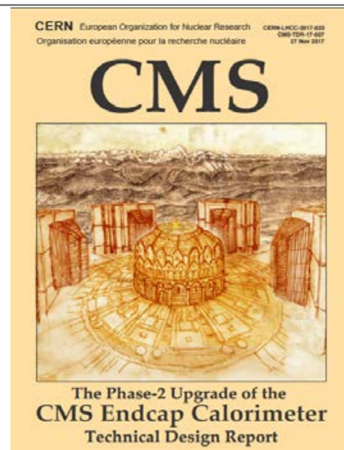
CERN-LHCC-2015-012

Barrel calorimeter TDR



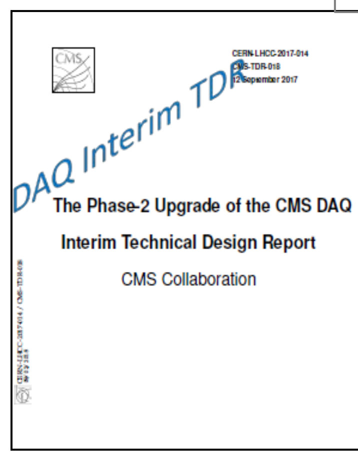
CERN-LHCC-2015-011

Endcap calorimeter TDR

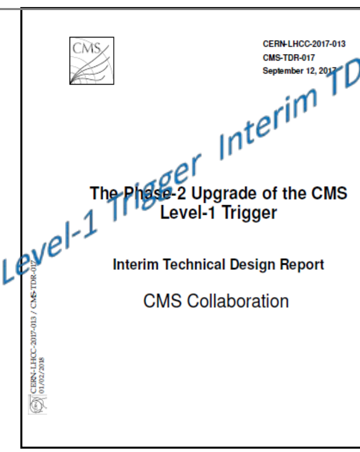


CERN-LHCC-2017-023

Trigger TDR due in 2020



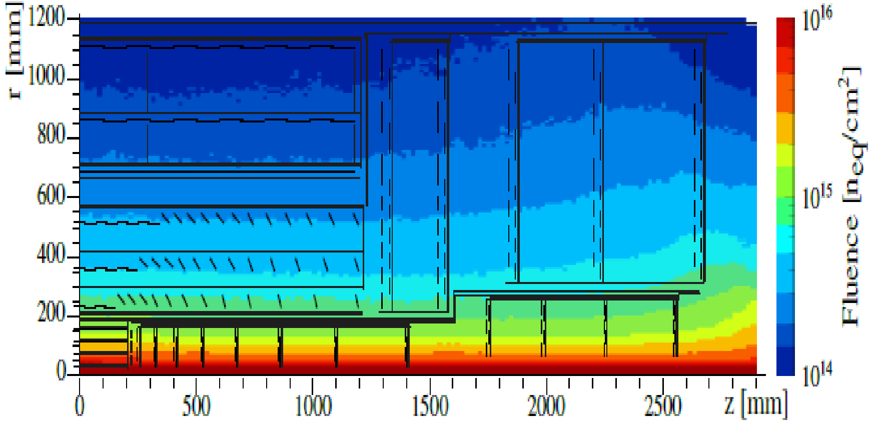
CERN-LHCC-2017-014

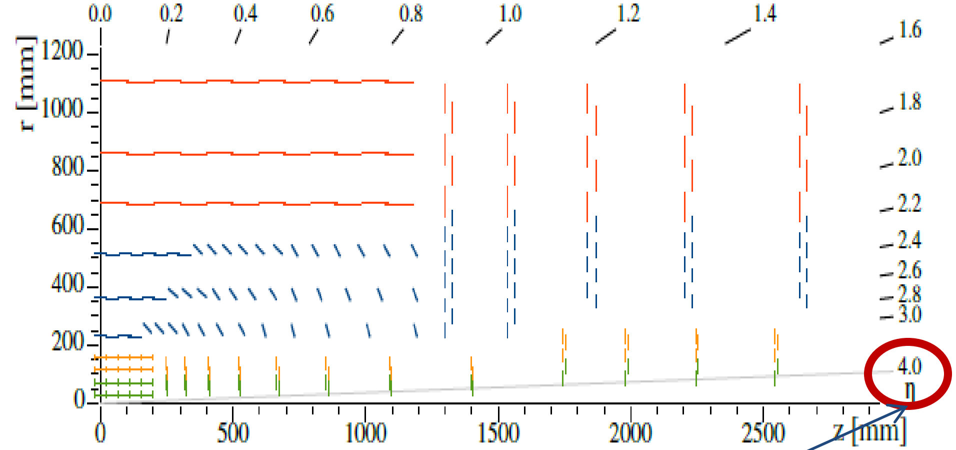


CERN-LHCC-2017-013

Upgraded Tracker: main features

Fluence @ 3/ab of 1 MeV *neq*





Extended acceptance

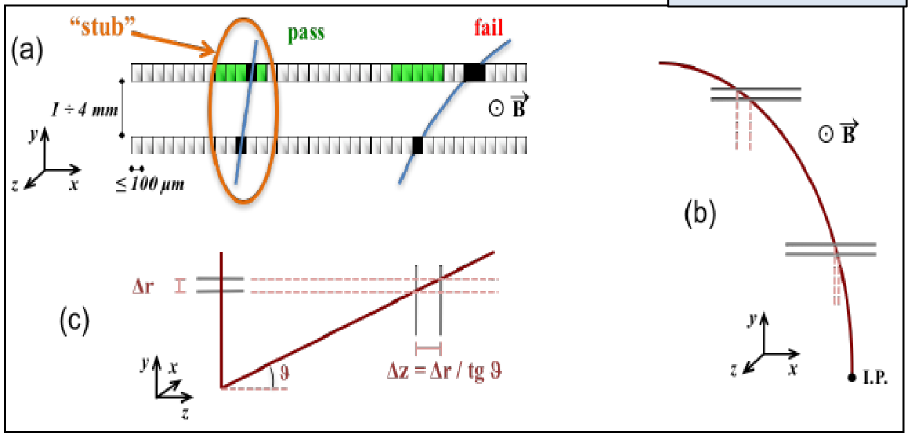
- Increased granularity
- Thinner sensors

➔ Reduced hit merging

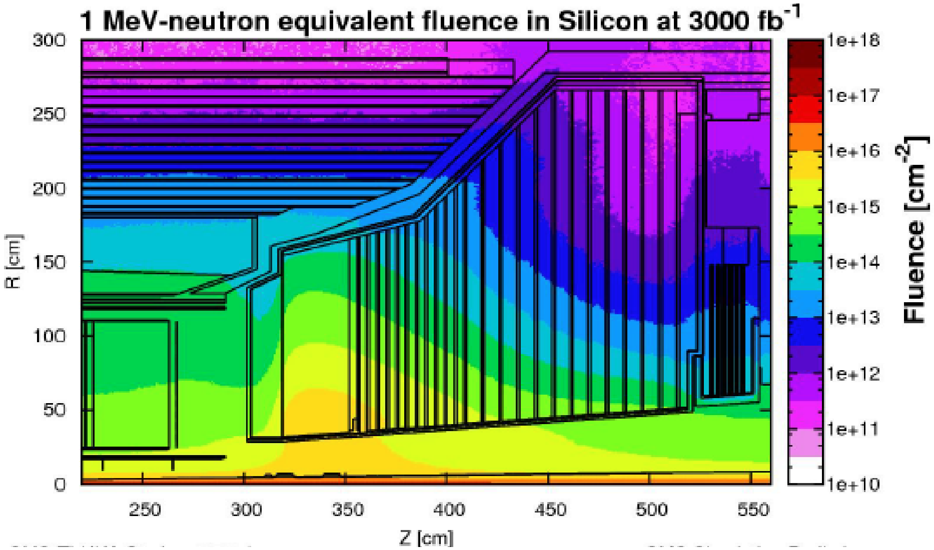
- Long pixel modules to measure z-coord.
- 2 sensor modules/layer in outer barrel
- Barrel/endcap: 6/5 layers/disks

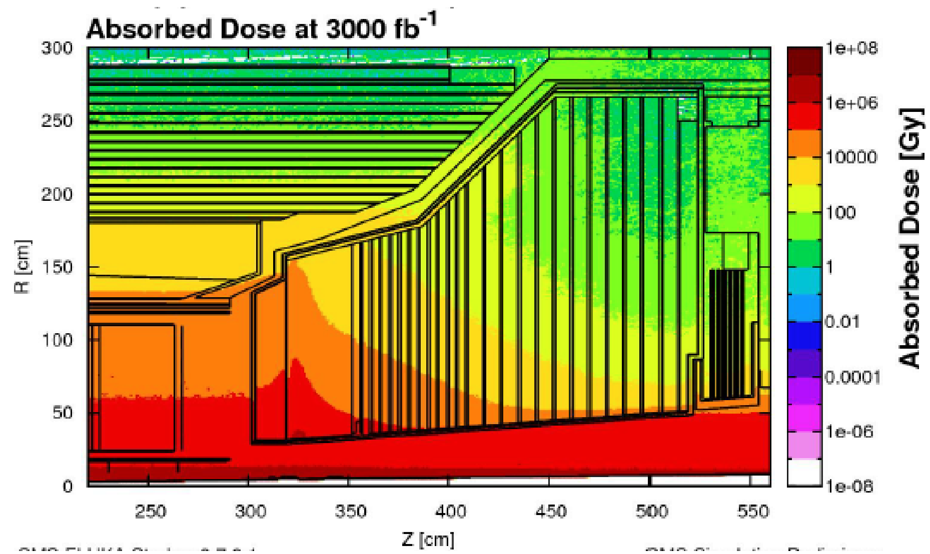
- Data readout at 750 kHz
- Maintainable during winter shutdown

p_T module



Calorimeter Endcap (CE): main features



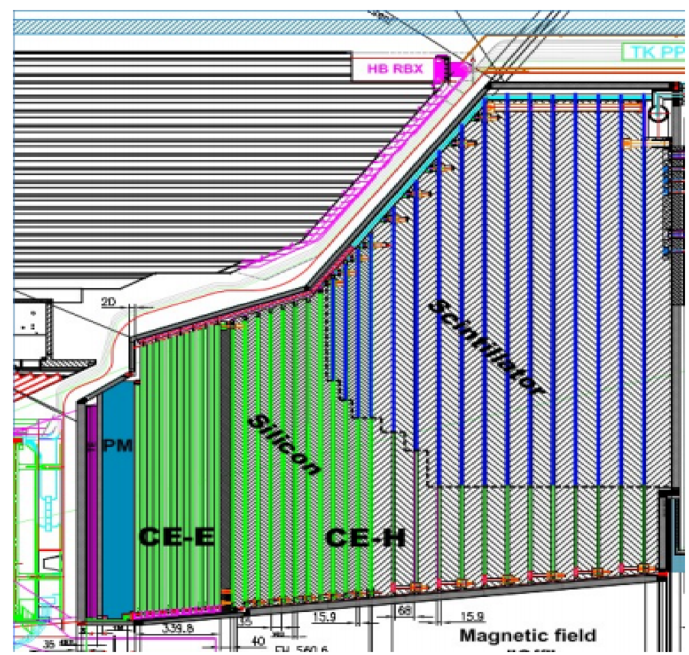


Endcap coverage: $1.5 < |\eta| < 3.0$		
Total	Silicon sensors	Scintillator
Area	600 m^2	500 m^2
Number of modules	27 000	4 000
Cell size	0.5 – 1 cm^2	4 – 30 cm^2
N of channels	6 000 000	400 000
Power	Total at end of HL-LHC: ~180 kW @ -30°C	

28 layers of CE-E
→ 25 X_0 (1.3 λ)

24 layers of CE-H
→ 8.5 λ

>6M channels
readout 40 MHz



- High transverse & longitudinal granularity + timing info
- Enhanced capability for particle flow reconstruction

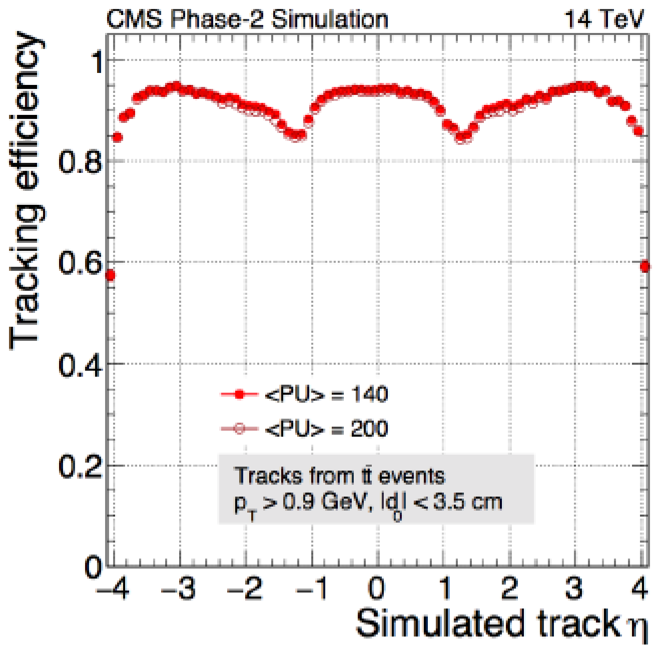
Performance of upgraded detector: Tracking

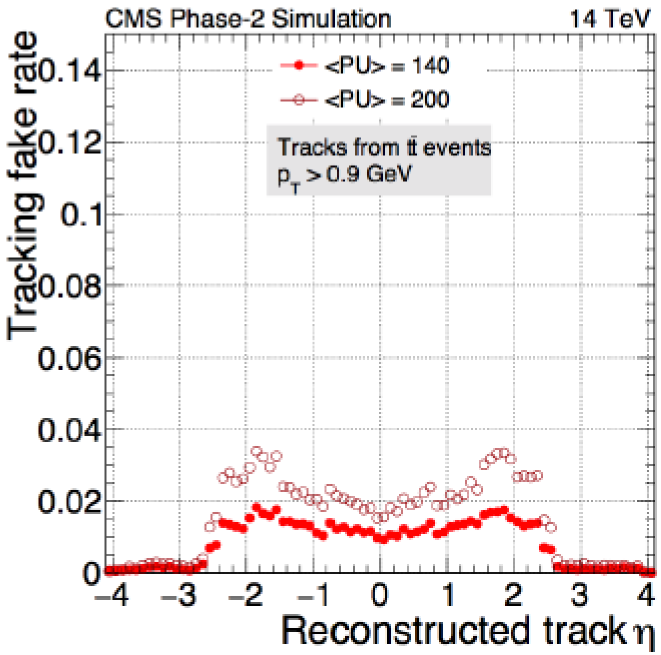
- Consideration of tracks in Level1 trigger decision is crucial and detrimental

→ Keeps low threshold

→ Enables pile up mitigation using particle-flow like algorithms for trigger decision

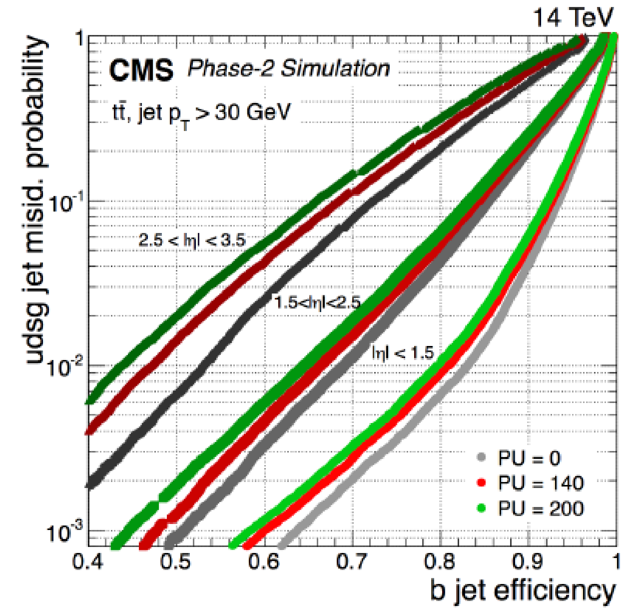
- Improved coverage in $|\eta|$ and reduced material budget allows to preserve & enhance basic tracking performance.

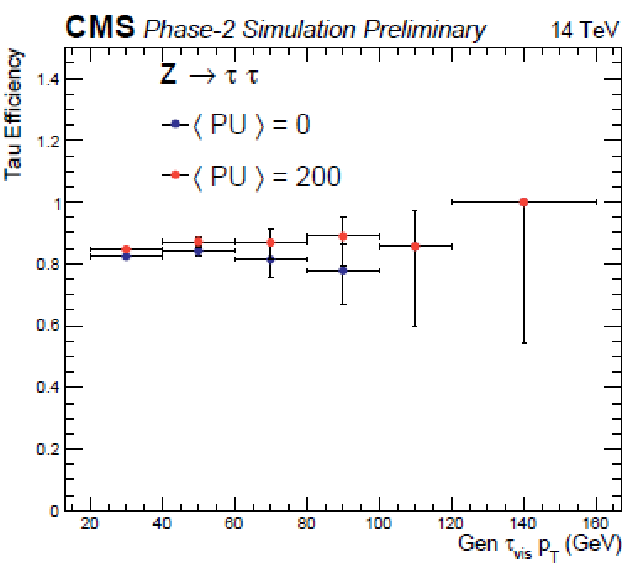


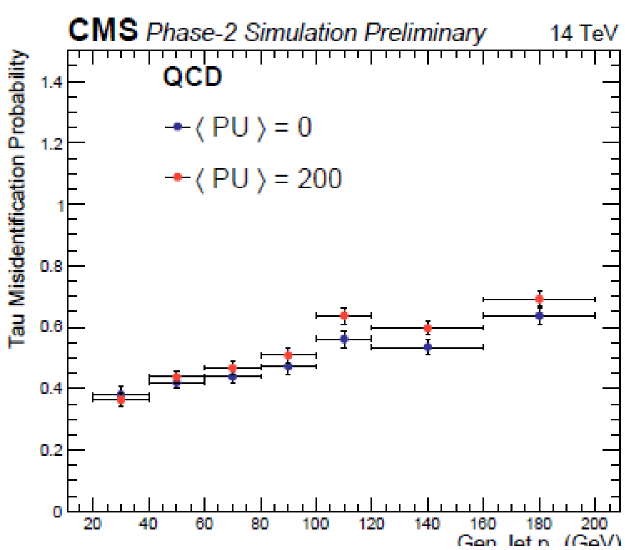


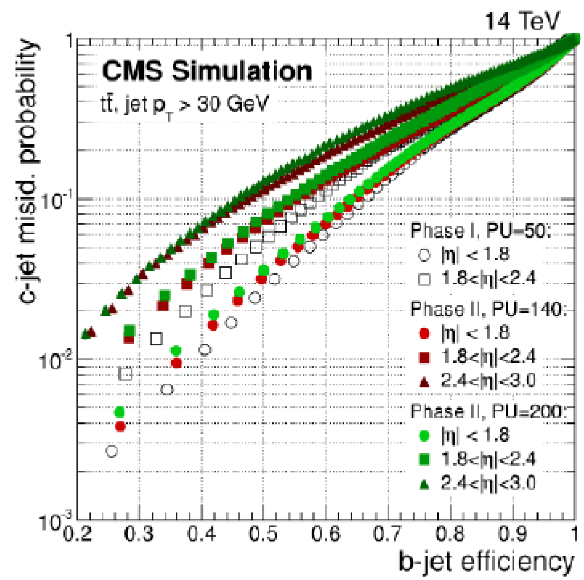
Performance of upgraded detector: b- and τ- tagging

- Uniform performance as a function of # of PU
- b-tagging capability enhanced in forward region
- Tau-tagging performance is also preserved and enabled in forward region









Performance of CE-Calo: electrons

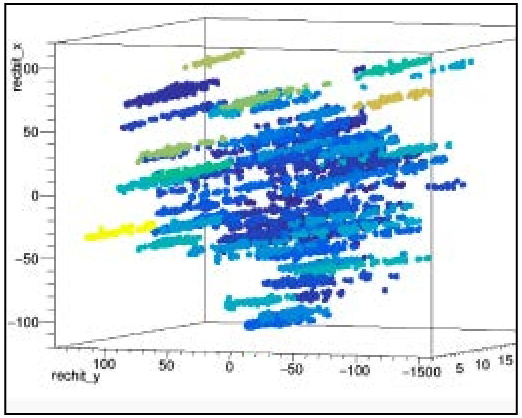
- 5D imaging (energy, position, timing) is a big advantage for particle flow
- EM showers for electron compact (R_{Molier} ~ 3 cm), known shape, associated with track
- Clustering of hits in steps:

-- 2D clustering in every layer based on energy density based imaging algo

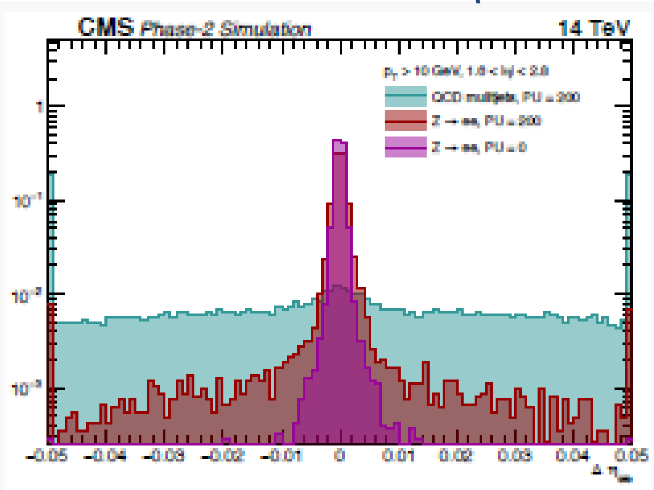
-- 3D clustering to reconstruct IP-pointing cylinder

- Axis pointing improves rejection of PU photon vis-à-vis bremsstrahlung

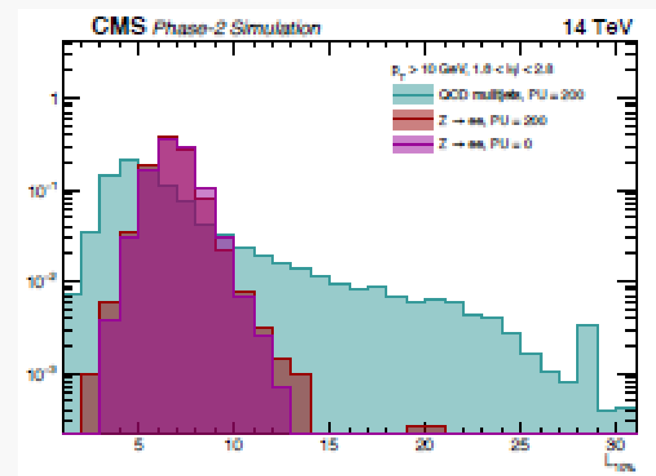
Clusters with pT >1 GeV



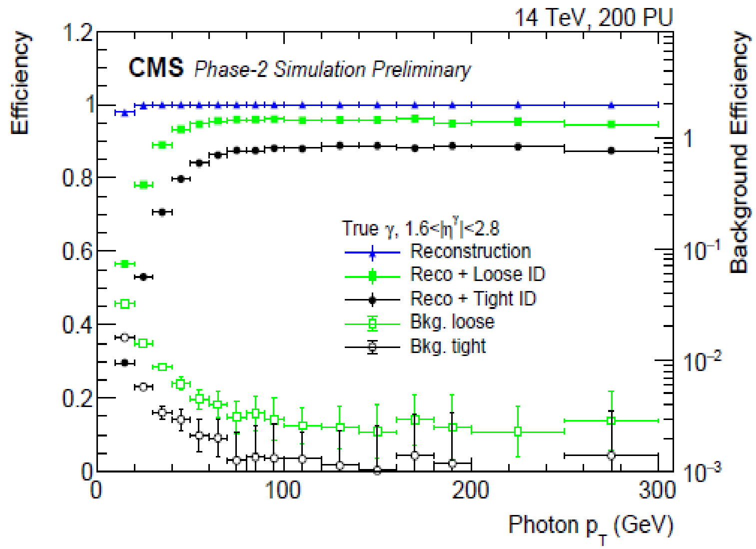
Track-cluster Δη

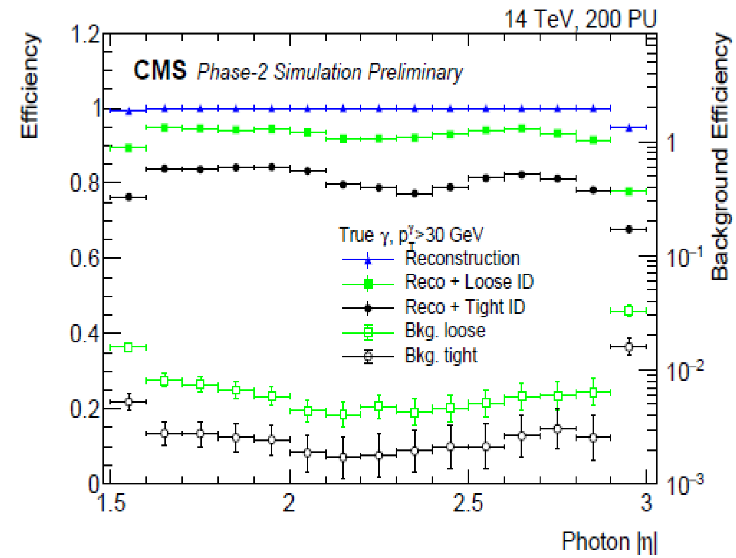


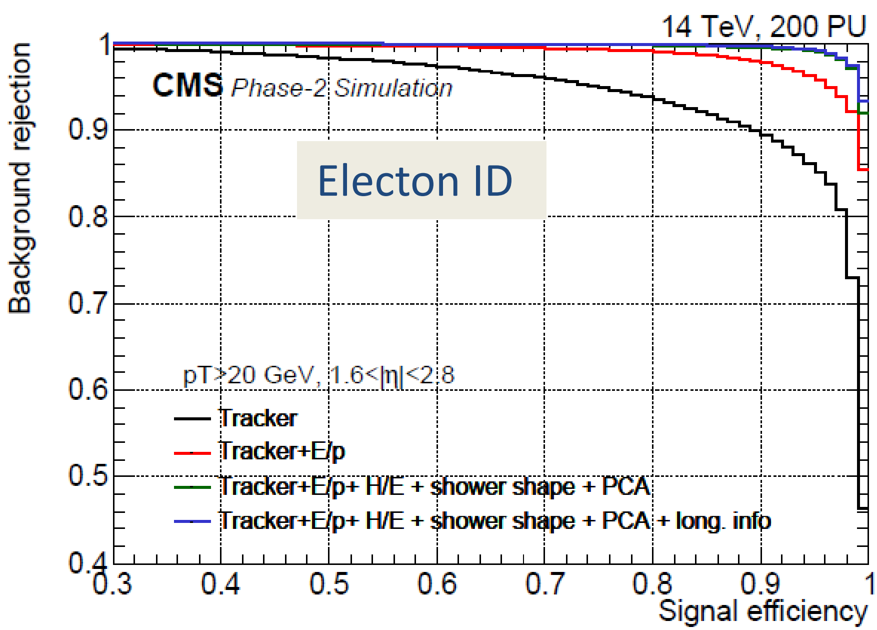
First cluster with 10% energy fraction

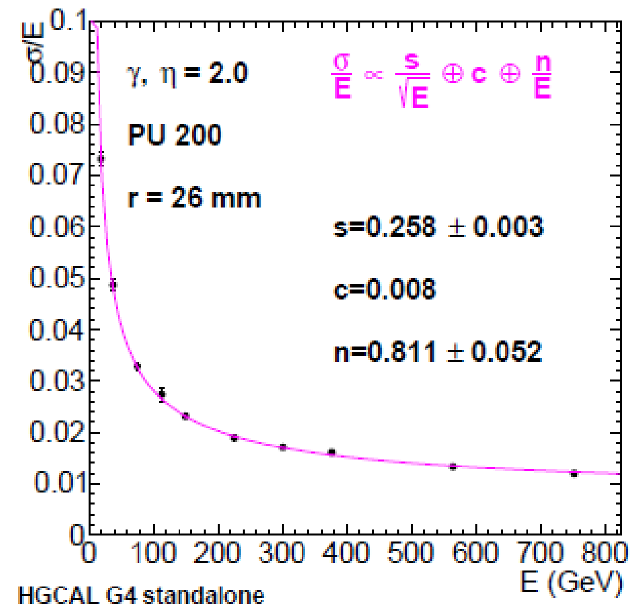


Photon & electron performance





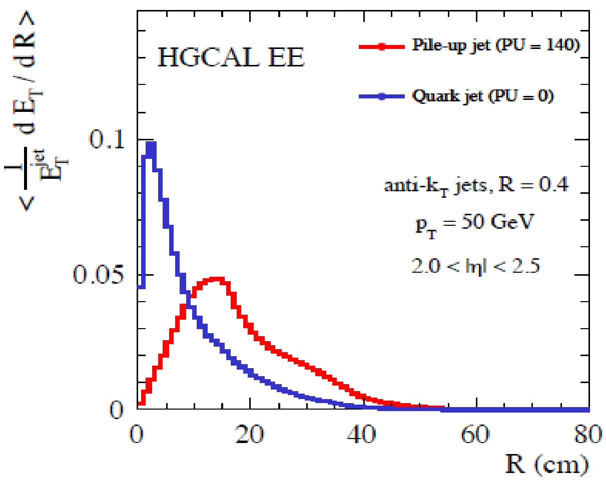




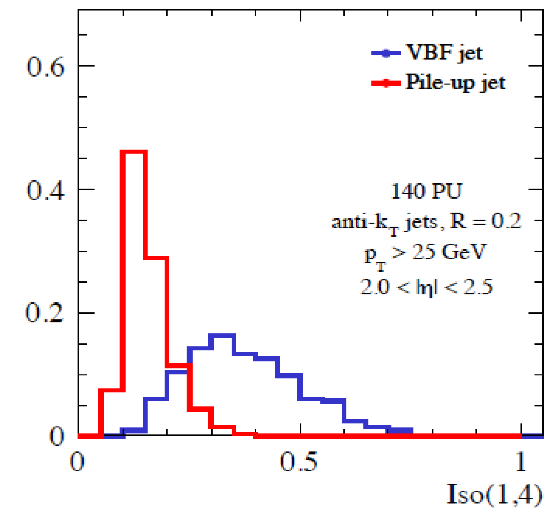
Performance of CE-Calo: jets

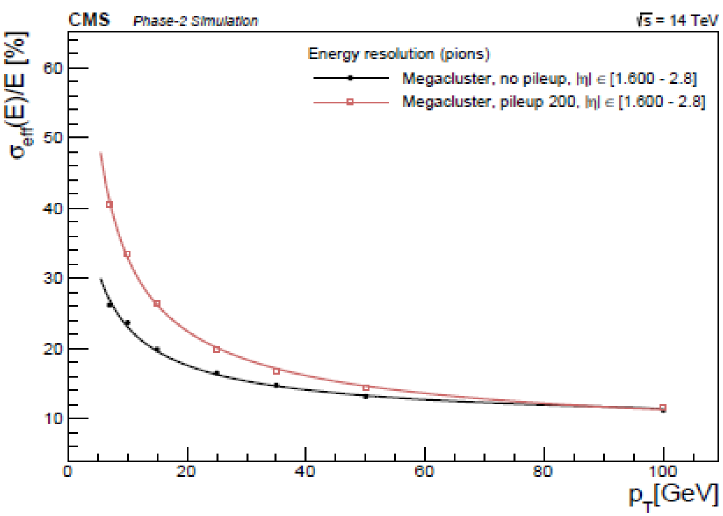
Use shape variables to discriminate against PU jets (wider and develops earlier)
➔ useful to resolve boosted topologies like VBF jets, top tagging

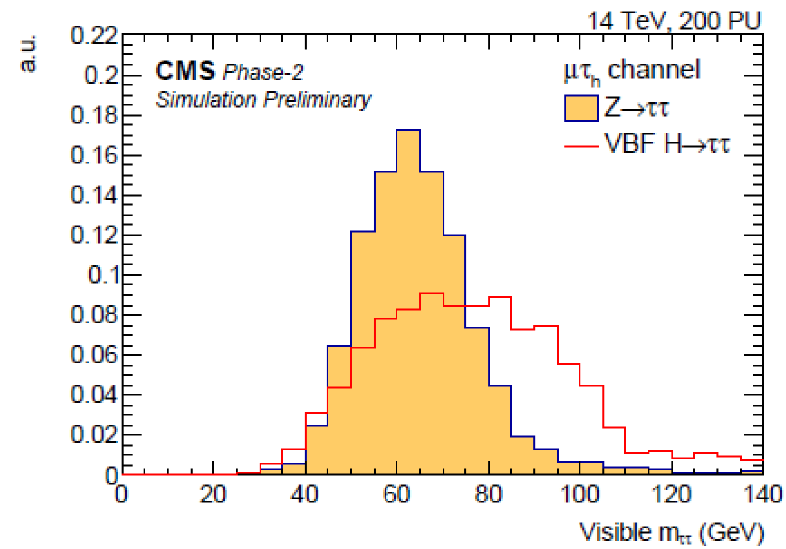
Radial jet profile in CE-E



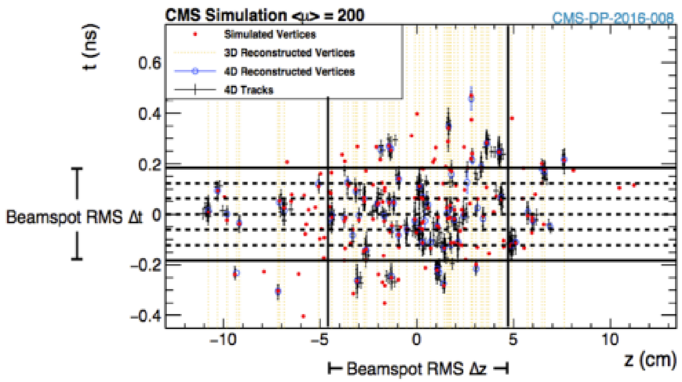
VBF vs. PU jet isolation



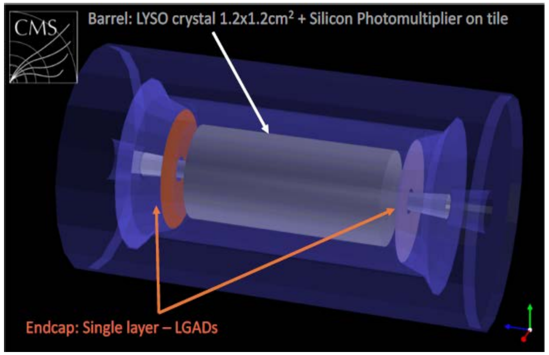




Precision timing layer



Collision vertices with 200 PU spread around IP with
$\Delta z \sim 5$ cm, $\Delta t \sim 200$ ps



- Since neutral particles cannot be associated directly with interaction vertices, primary vertex selection (using info from calorimeter) for H→ $\gamma\gamma$ gets worsened from 80% to 30% at HL-LHC

➔ soln.: upgraded electronics of barrel calorimeter and HGCAL hybrid readout

- Precision timing with resolution of 20 to 30 ps allows separation of PU vertices

→ useful for 4-d reconstruction of charged particles.

➔ dedicated timing layer (LYSO +SiPM above Outer Tracker Barrel) for charged tracks (+ modification of readout for barrel calorimeter)

→ Crucially helps in isolation of leptons.

Electroweak physics at HL-LHC

1. Test the SM theory of EWSB via a comprehensive portfolio of (multi) boson production measurements : rich sector, always!

Most significant motivations:

(i) Check the role of Higgs in restoring the unitarity of gauge boson interactions
➔ measure **W_L W_L scattering in $W^{\pm} W^{\pm}$ production** via vector boson fusion

(ii) Test electroweak gauge invariant effective field theory
➔ measure **triple and quartic gauge interactions in V_1V_2 scattering**, $V_{1,2}$ = W, Z

Caveat: all the processes have very small rate, interesting physics lies at the high tail of transverse momentum, invariant mass, etc. .

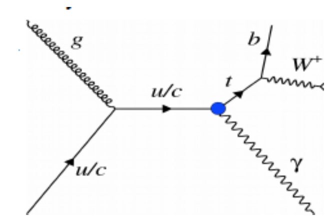
2. Improve the precision of EW observables, eg., M_W , $\sin^2 \vartheta_W$

3. Produce precision constraints on PDFs (eg. lepton charge asymmetry in W events)

4. Test predictions of perturbative QCD
→ differential distributions reveal the effect of higher order quantum corrections.

Top physics at HL-LHC

- Large rate allows to investigate new phase-space corners using boosted tops
- Precise test of perturbative QCD
- Background for many searches of Higgs and new physics
- May be associated with new physics : top as portal to BSM!
- FCNC processes, eg., Br.($t \rightarrow c\gamma$) =1.5* 10^{-4} can be studied
- Top coupling via single t production estimated accurately
- **Top mass crucial input for electroweak fit**
  → must be measured precisely



σ_{tt}	~ 1 nb	→ 3B top pairs
$\sigma_{t\text{-channel}}$	~ 200 pb	→ 600M tops
$\sigma_{s\text{-channel}}$	~ 10 pb	→ 30M tops
$\sigma_{tt\gamma/V/H}$	~ 1 pb	→ 3M top pairs
σ_{tH}	~ 10 fb	→ 30k tops

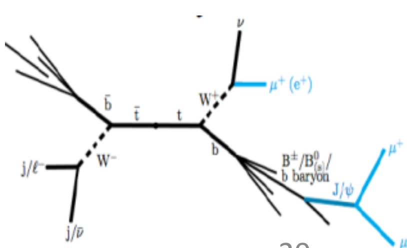
i) Traditional method systematics dominated →
reconstruct invariant mass of top decay products

For 300/fb & 3/ab , Δm_t = 0.44 & 0.2 GeV

→ mainly due to theory uncertainty related to "pole" mass of top

ii) Measure decay length of b-hadrons in tt decays to achieve Δm_t = 0.6 & 0.4 GeV

iii) Use $t \rightarrow Wb \rightarrow \ell\,\nu$ + (J/ψ +X) to achieve Δm_t = 0.8 & 0.6 GeV



HL-LHC as Higgs factory

- # Higgs produced in 3/ab : ~160M

~ 0.5M useful for precision measurements →

→ Δm_H within 100 MeV, likely to be systematics limited

~ 400k $H \to \gamma\gamma$
~ 20K $H \to ZZ^* \to 4l$
~ 38K $H \to \mu\mu$
~ 800 VBF $H \to \tau\tau$
~ 17k $H \to Z\gamma$

→ **measure cross section, couplings precisely**
Branching ratio uncertainty ~ 5% on main channels

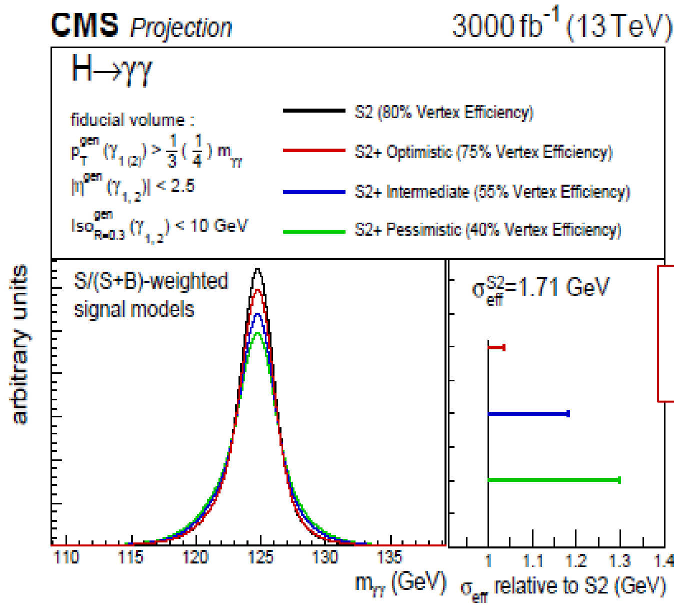
→ **Estimate deviations from SM in terms of coupling modifiers**

Scenarios to account for systematic uncertainties:

- **S1:** all sys. uncertainties same as in Run2 or in reference analysis (~2016)
- **S2**: Theoretical uncertainty down by X 0.5,
  Experimental uncertainty ~ $1/\sqrt{L}$, up to a limit
  ΔL = 1.5%, Jet Energy Scale uncert. = 1%
  b-tag efficiency uncert. = 1% for p_T > 30 GeV
- **S1+, S2+ :** Consider detector upgrades & degradation of performance over time
  eg., identification of γ worsens, resolution remains same

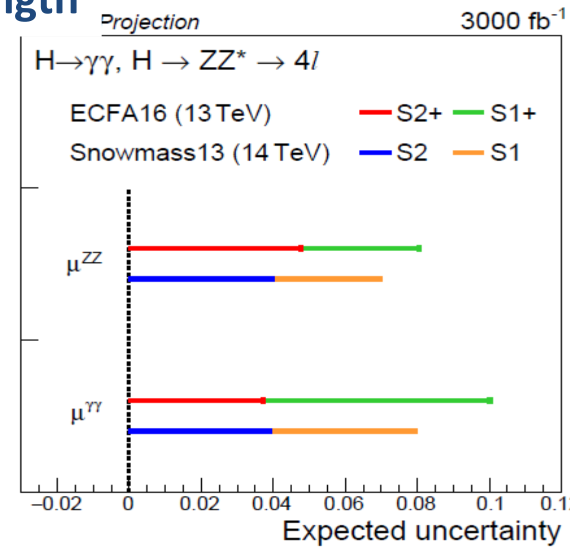
Expectations in Higgs physics

Mass resolution

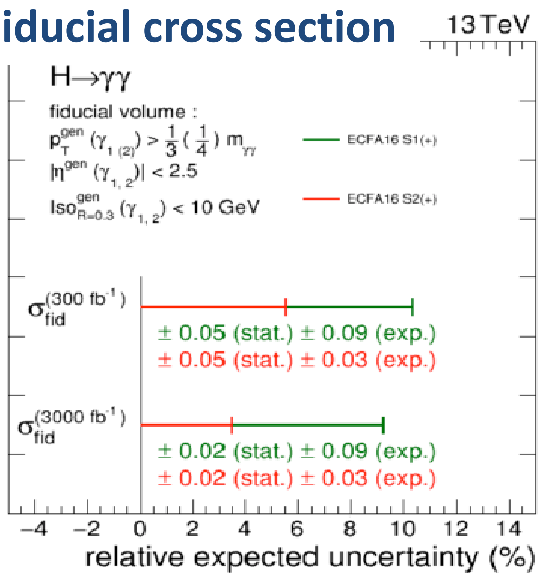


Effective gain in luminosity by 20%

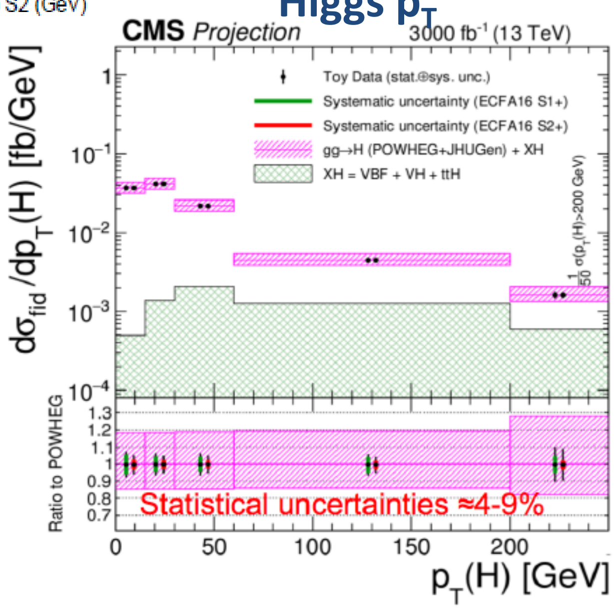
Signal strength



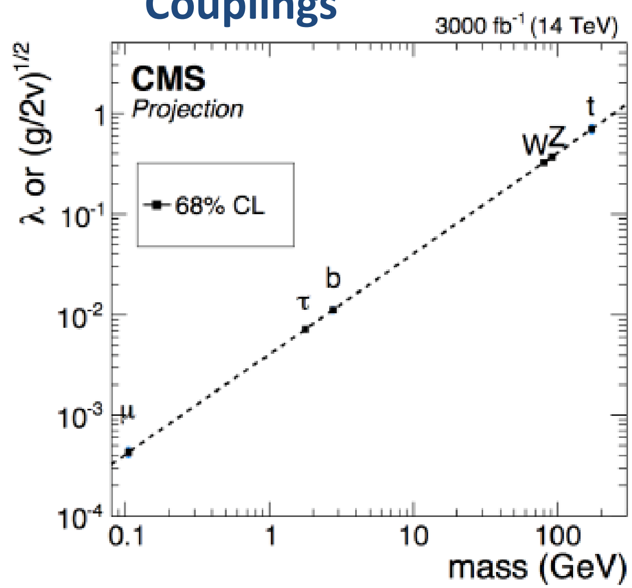
Fiducial cross section



Higgs p_T

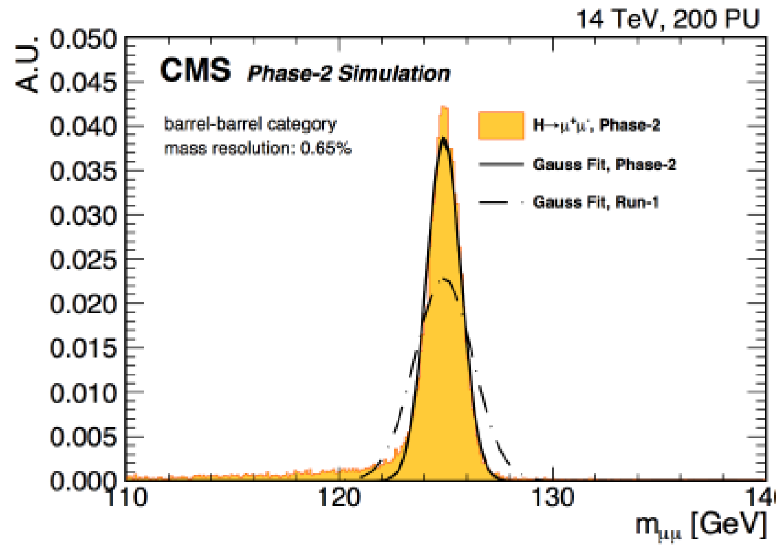


Couplings



Improvement in performance: rare decays

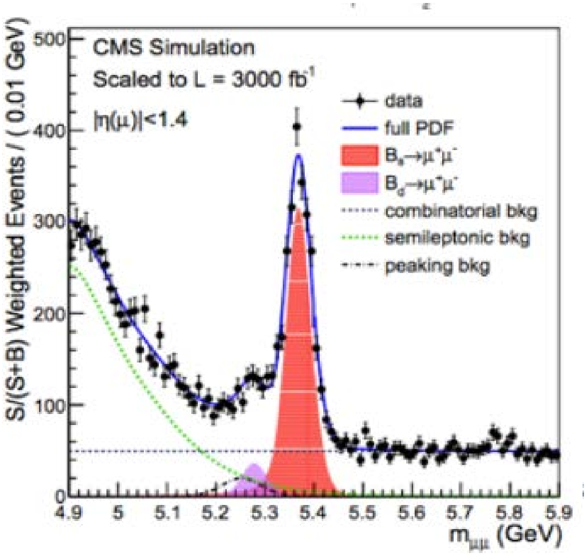
- Study of Higgs Yukawa coupling to 2nd generation lepton in H→ μμ, Br. =2*10^{-4}

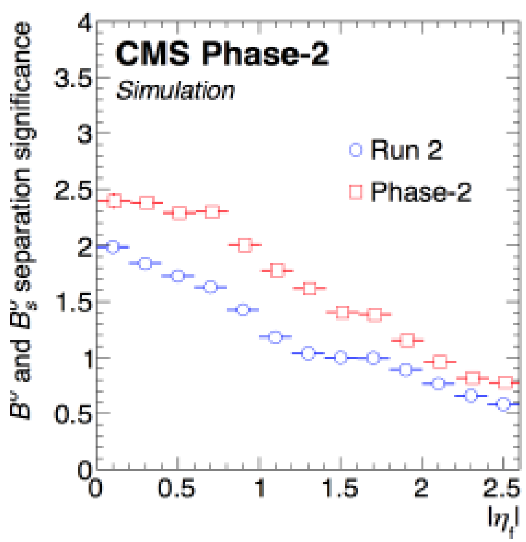


- Dimuon mass resolution crucial for observation above large background due to Drell-Yan

➔ Expect 5 - 10% uncertainty in Br. for 3/ab

- For B→ μμ decays, separation of B_d and B_s peaks in $m_{\mu\mu}$ ➔ mass resolution crucial





- Significance of B_d = 2.2 (6.8)σ with 300 (3000) /fb

- Increase in lepton acceptance does not particularly help here.

HL-LHC: Era of di-Higgs!

- Higgs potential in SM: $V = \frac{1}{2}m_H^2\Phi_H^2 + \lambda v \Phi_H^3 + \frac{\tilde{\lambda}}{4}\Phi_H^4$

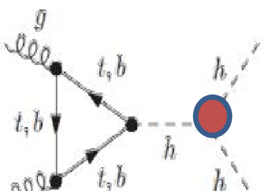
Trilinear coupling

Quartic coupling

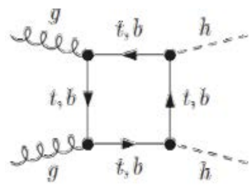
- Higgs self-coupling: crucial feature of EWSB
  → **measurement is THE most challenging at LHC**

In SM both couplings equal to 0.13, given m_H

- Tri-linear coupling (λ_{HHH}) accessible via di-Higgs production



λ_{HHH}



Destructive interference
➔ σ(HH): ~ 40 fb

	bb	WW	ττ	ZZ	γγ
bb	33%				
WW	25%	4.6%			
ττ	7.4%	2.5%	0.39%		
ZZ	3.1%	1.2%	0.34%	0.076%	
γγ	0.26%	0.10%	0.029%	0.013%	0.0053%

- box diagram dominates for boosted events

- Current data not sufficient for accessing SM process
  → rate can be large due to anomalous couplings AND resonant production

- Final states considered for analysis till now: bbγγ, bbW(lν)W(jj), bbττ, 4b

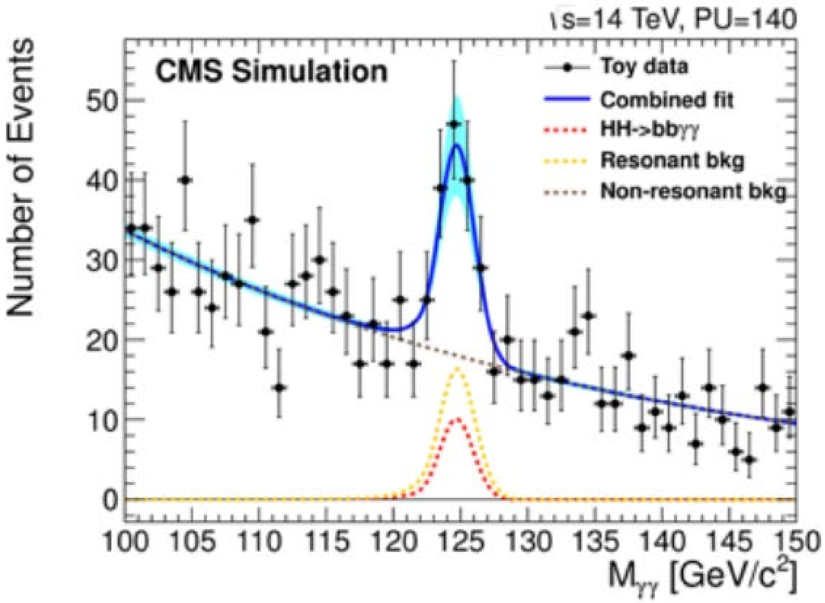
- **Combination of measurements by ATLAS & CMS may produce 3σ significance measurement at HL-LHC.**

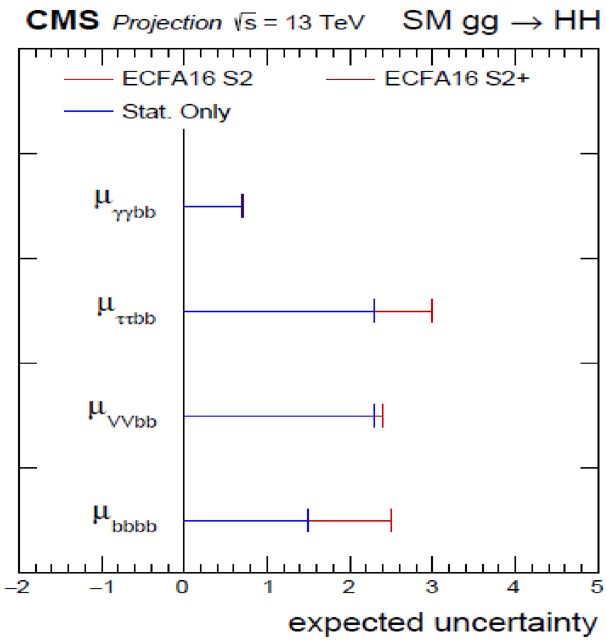
HH → bbγγ

- 320 events of bbγγ final state in 3000/fb
- Backgrounds: ZH, ttH, bbH
- Best sensitivity

- 90% of photons are in barrel region

➔ less issues with worsening of γ energy resolution and identification

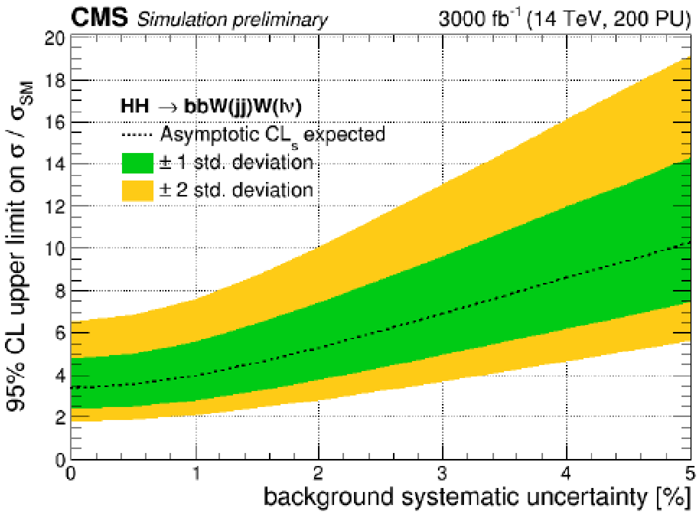




Projection based on 13 TeV preliminary analysis of 2015 data

HH → bbW(jj)W(ℓν)

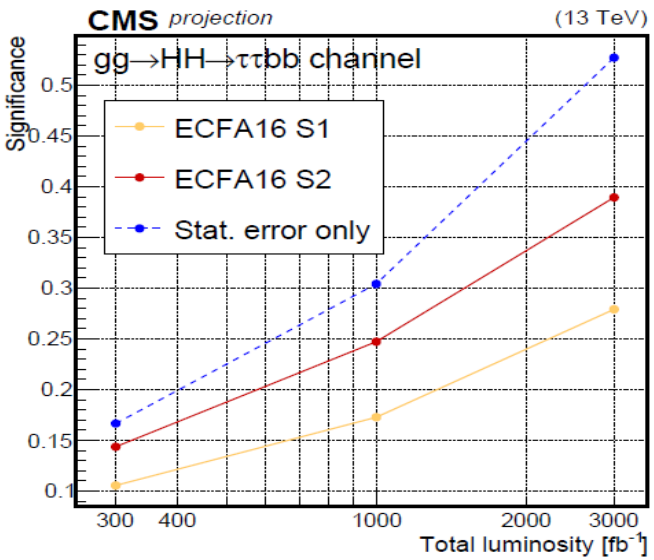
- 8640 events of bbW(→jj)W(→lν) final state in 3000/fb
- Main backgrounds: tt, Drell-Yan



HH→ττbb

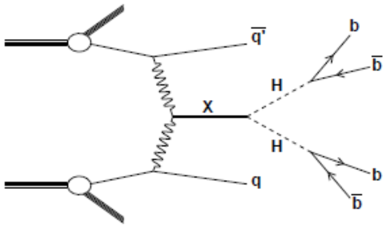
Projection of reach in pp→ HH →**ττbb** *channel based on 13 TeV preliminary analysis of 2015 data*

- p_T^{τ} > 45 GeV
- Large background from multijets



VBF production of resonance X → HH → 4b

- BSM search, eg., warped extra dimension
  → spin-0 radion or spin-2 KK excitation of graviton
  → the resonance could also be also a SUSY Higgs



- Current limit on mass of X ~ 3 TeV for s-channel production & $\sigma < 1.4$ fb

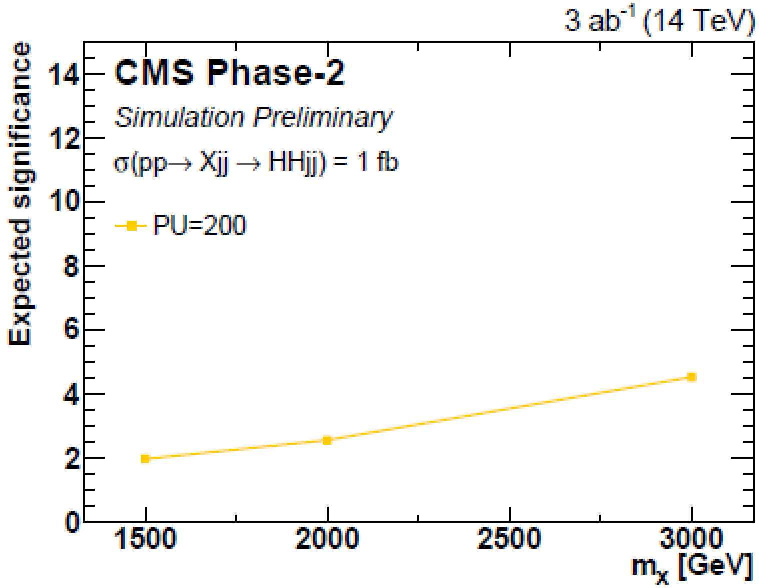
- VBF production process dominates if X has phobia for quarks and gluons!

- Boosted Higgs → fat jet with substructure

- Gain due to CE-Calo & extended b-tagging

- Currently main uncertainty in sub-jet identification: 13%

- Analysis will gain further in future due to improvement in event reconstruction and better identification of objects.

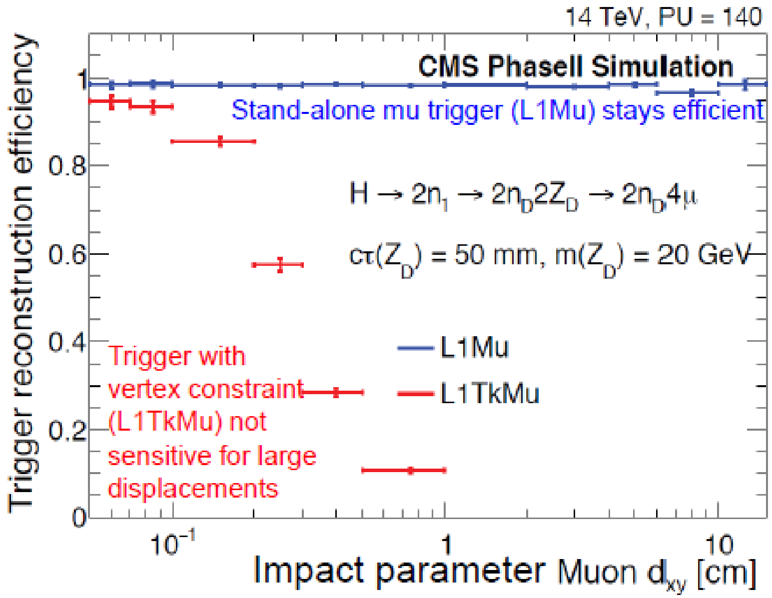


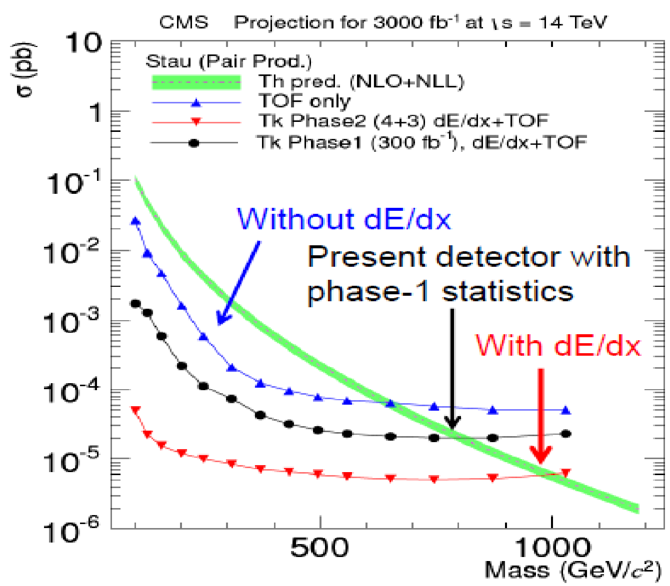
Long-Lived particles

- Displaced muons from decays of long-lived particles have large impact parameter d_{xy} ➔ need efficient muon trigger without vertex constraint.

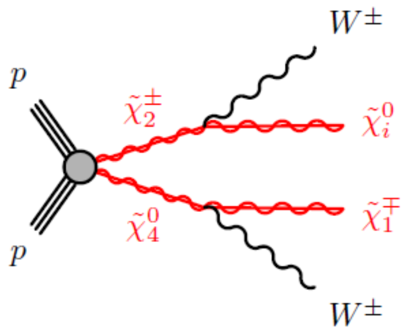
- Slow moving particle (HSCP) will deposit anomalous dE/dx in silicon tracker . ➔signature allows separation from background (MIP).

- If dE/dx capability is not maintained, no sensitivity gain in Phase-2 for this class of models. ➔ Timing info significantly enhances discovery potential for massive long-lived particles by measuring the decay time.



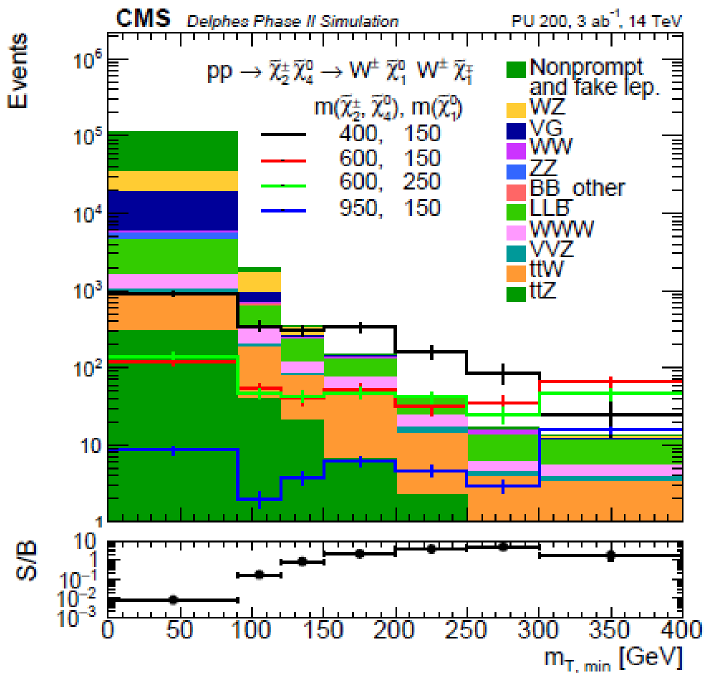


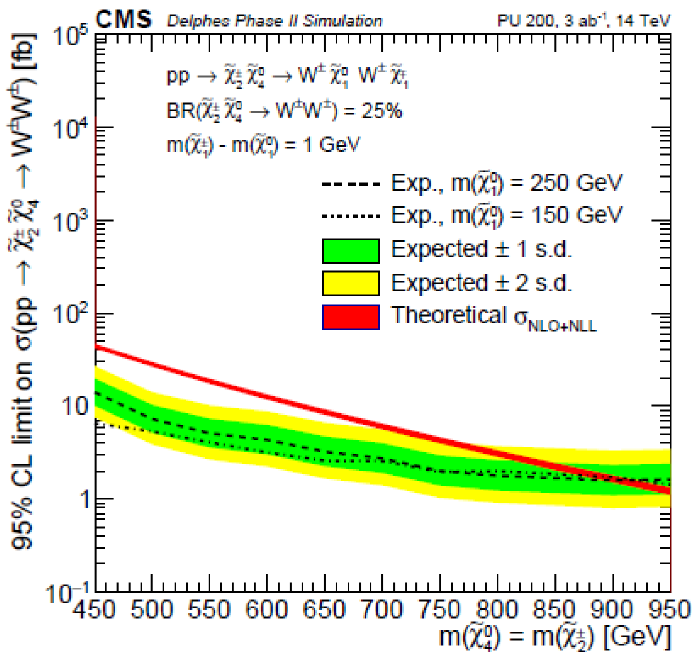
Electroweakino production with same sign leptons



- Mass spectra characterised by higgsino like low mass particles with $\mu \sim m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_2^0}, m_{\tilde{\chi}_1^0}$

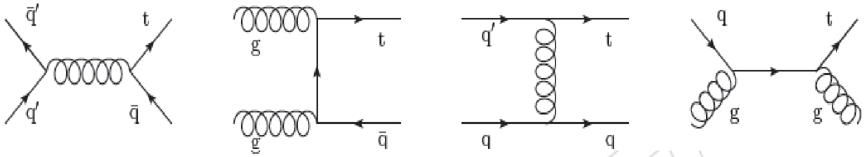
Potential to probe most of parameter space of natural SUSY with electroweakino mass of $\tilde{\chi}_1^0$ ~ 150 GeV





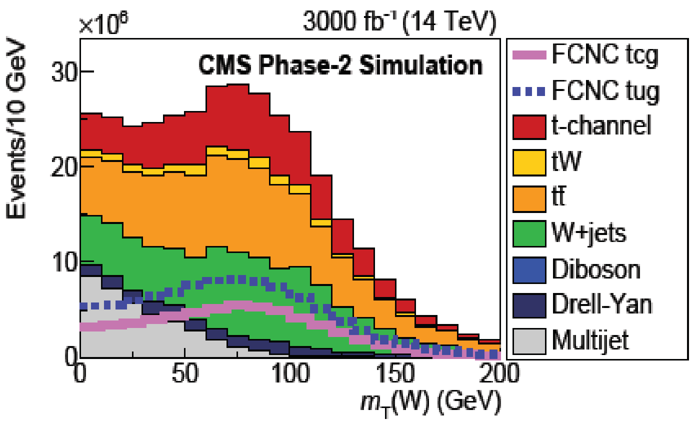
$$m_{T,min} = \min[m_{T(lep_1,p_T^{miss})}, m_{T(lep_2,p_T^{miss})}].$$

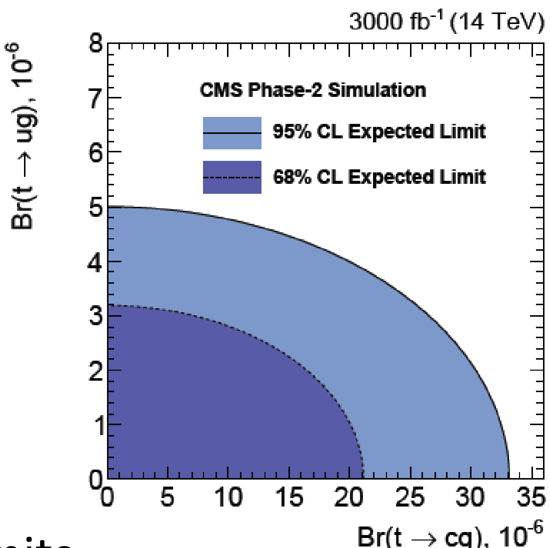
FCNC in top production

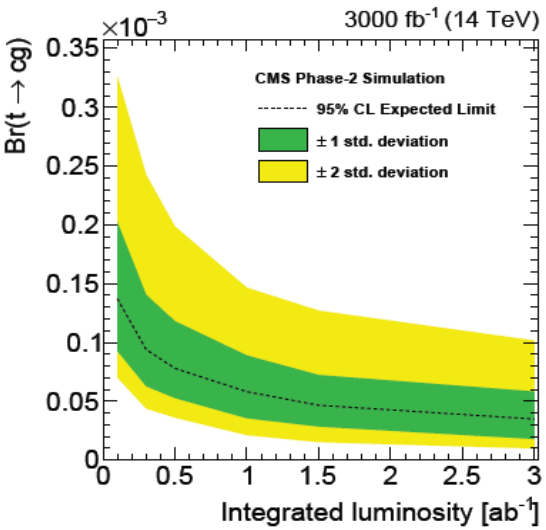


- FCNC involving top is less constrained
- Can be studied better in inclusive single top production processes

- Use model-independent effective Lagrangian: $\mathfrak{L} = \frac{\kappa_{tqg}}{\Lambda} g_s \bar{q} \sigma^{\mu\nu} \frac{\lambda^a}{2} t G^a_{\mu\nu}.$







95% CL upper limit on effective coupling: better by order of magnitude compared to current limits

$$|\kappa_{tcg}|/\Lambda < 5.2 \times 10^{-3} \; (9.1 \times 10^{-3}) \;\; \mathrm{TeV}^{-1}$$

Conclusion

- Very rich prospect of physics at the HL-LHC provides the motivation for significant upgrade programme of LHC machine and the experiments during ~ next decade.

  Eg.,: extended reach of BSM searches, precision measurements in Higgs sector

- However, experiments are challenged by the harsh environment to be handled with Phase-2 upgraded CMS detector which is based on harnessing new technologies in novel ways.

- With detector upgrade design almost finalised, detailed studies are being made to estimate the performance.

  Few results of detector performance and physics reach has been presented highlighting the justification of massive investment and efforts for Phase-2 upgrade of CMS.

- New results based on advanced experimental techniques and better simulations are always streaming in . ***Stay tuned!***

Backup

Level-1 Trigger/ High-level Trigger /DAQ

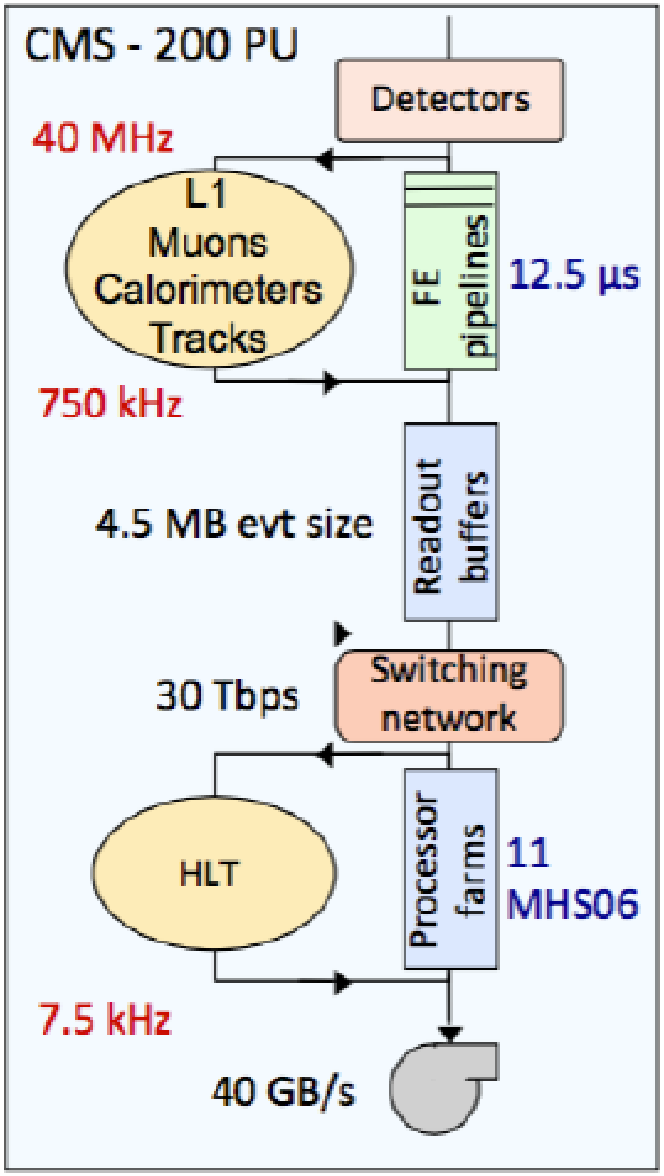
- L1 trigger

High bandwidth and processing power boards
First layer to match detector information
Second layer to produce trigger objects

Trigger timing, throttling and control
High bandwidth bi-directional link allowing trigger I nformation to steer readout

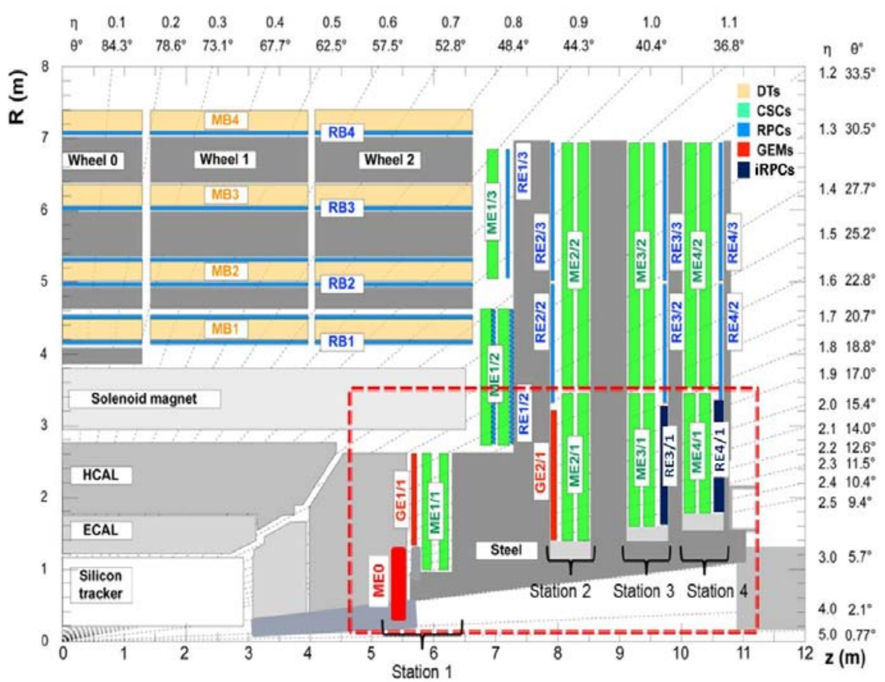
DAQ
Similar event builder, HLT, storage as present
Increase band width: 800 links X 100 Gbps with 30% occupancy to provide 30 Tbps evenet builiding throughput

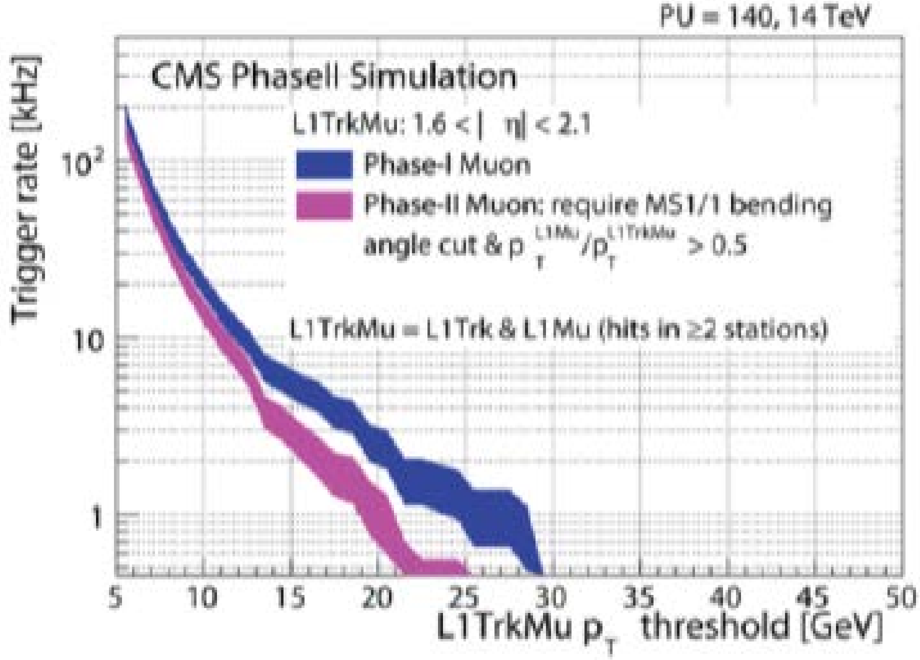
HLT
Processing power scales as PU X L1 rate → need increase by a factor of about 50 wrt Run2 at 200 PU



Muon system upgrade

- Good standalone trigger capability at L1 up to |η| < 2.45
- Improved rate reduction combined with track trigger
- Trigger on displaced vertices
- Better resolution for offline reconstruction
- Efficient muon identification with reasonable background rate up to |η| < 3





Search for new resonance: forward backward asymmetry (e+e- final state)

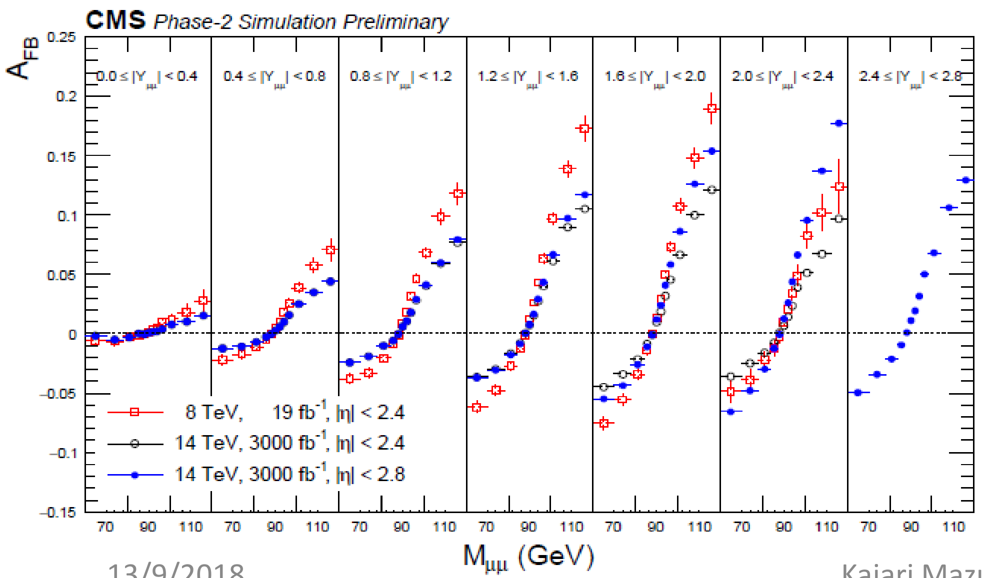
- Asymmetry arises due to vector and axial vector couplings of leptons to weak, neutral gauge boson $A_{\mathrm{FB}} = \frac{\sigma_{\mathrm{F}} - \sigma_{\mathrm{B}}}{\sigma_{\mathrm{F}} + \sigma_{\mathrm{B}}}$

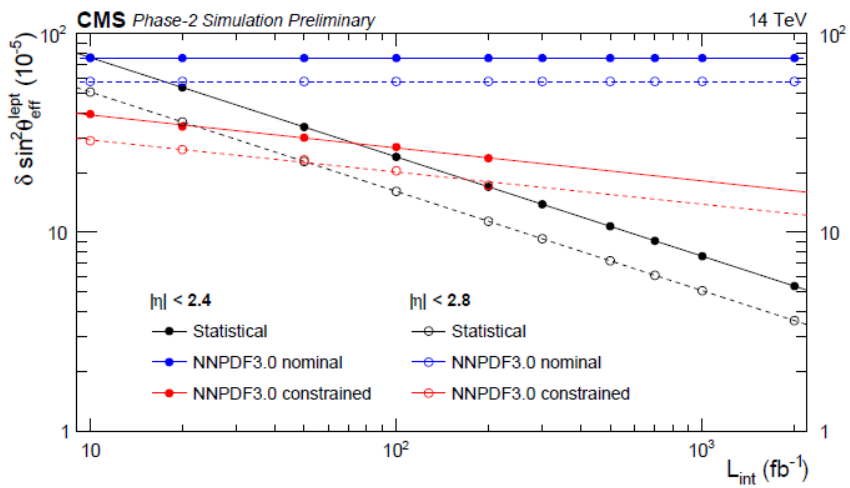
$$\cos\theta^* = \frac{2(p_1^+ p_2^- - p_1^- p_2^+)}{\sqrt{M^2(M^2 + P_{\mathrm{T}}^2)}} \times \frac{P_z}{|P_z|}$$

- Defined in terms of angle ϑ^* measured in Collins-Soper frame
- Effective weak mixing angle sensitive to additional gauge bosons → mass & rapidity dependence of A_{FB} used to extract $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$

FTR-17-001

- Accurate measurement of $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$ can be used to constrain PDFs





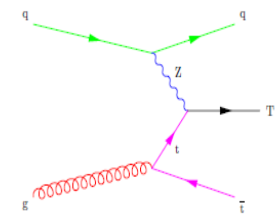
Systematic uncertainties for new particle searches

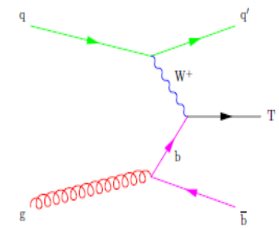
Table 1: Systematic uncertainties in two scenarios used for extrapolating from results using 12.9 fb^{-1} of data collected at $\sqrt{s} = 13$ TeV [9]. The "current systematic" scenario assumes no change in systematics from their nominal values in the 12.9 fb^{-1} dataset used for projection. The "reduced systematic" scenario assumes a realistic reduction in the magnitude of systematic uncertainties from their nominal values, based on improvements in dataset size, detector performance, and theoretical accuracy among others. For systematics which affect the shape of the invariant mass distribution, the value quoted for the rate uncertainty is approximate.

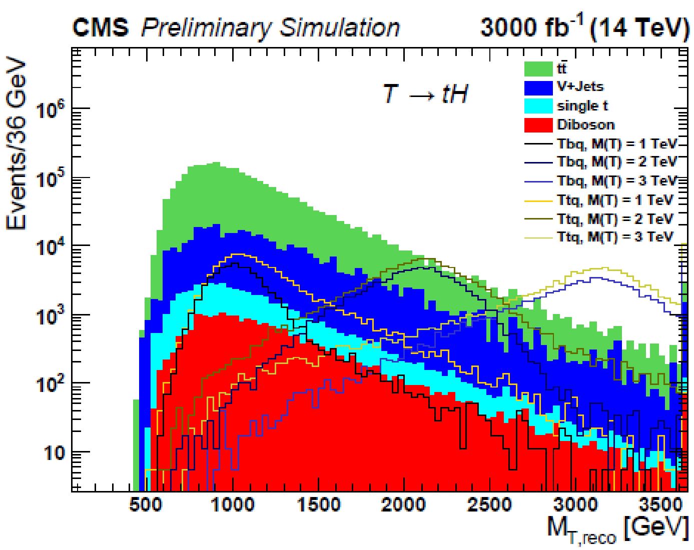
Source	Current systematics	Reduced systematics	Shape?
Luminosity	6.2%	1.5%	No
Trigger Efficiency (e/μ)	2%/5%	1%/1%	No
Lepton ID Efficiency (e/μ)	5%/2%	1%/1%	No
Jet Energy Scale	3.8%	1%	Yes
Jet Energy Resolution	1%	0.07%	Yes
b/c-tagging	2.7%	1%	Yes
light quark mis-tagging	1.2%	1.2%	Yes
W+jets Heavy Flavor Fraction	2.3%	1.1%	Yes
Top p_T Reweighting	18%	6%	Yes
Pileup	1.3%	0.09%	Yes
PDF	6.1%	3%	Yes
Matrix element Q^2 scale	18.9%	9.5%	Yes
$t\bar{t}$ Parton matching Q^2 scale	1.7%	0.9%	Yes
Theoretical top cross section	15%	7.5%	No
Theoretical bosonic cross section	10%	5%	No

Vector-like quark: single production of T, decay via tH

- Left-/right-handed coupling ($c_L^{\ bW}$ / $c_R^{\ tZ}$) for singlet/doublet
- Produced in pp→ Tbq/Ttq process via charged or neutral current
- Charge: +2/3, narrow width (10 GeV), H→ bb

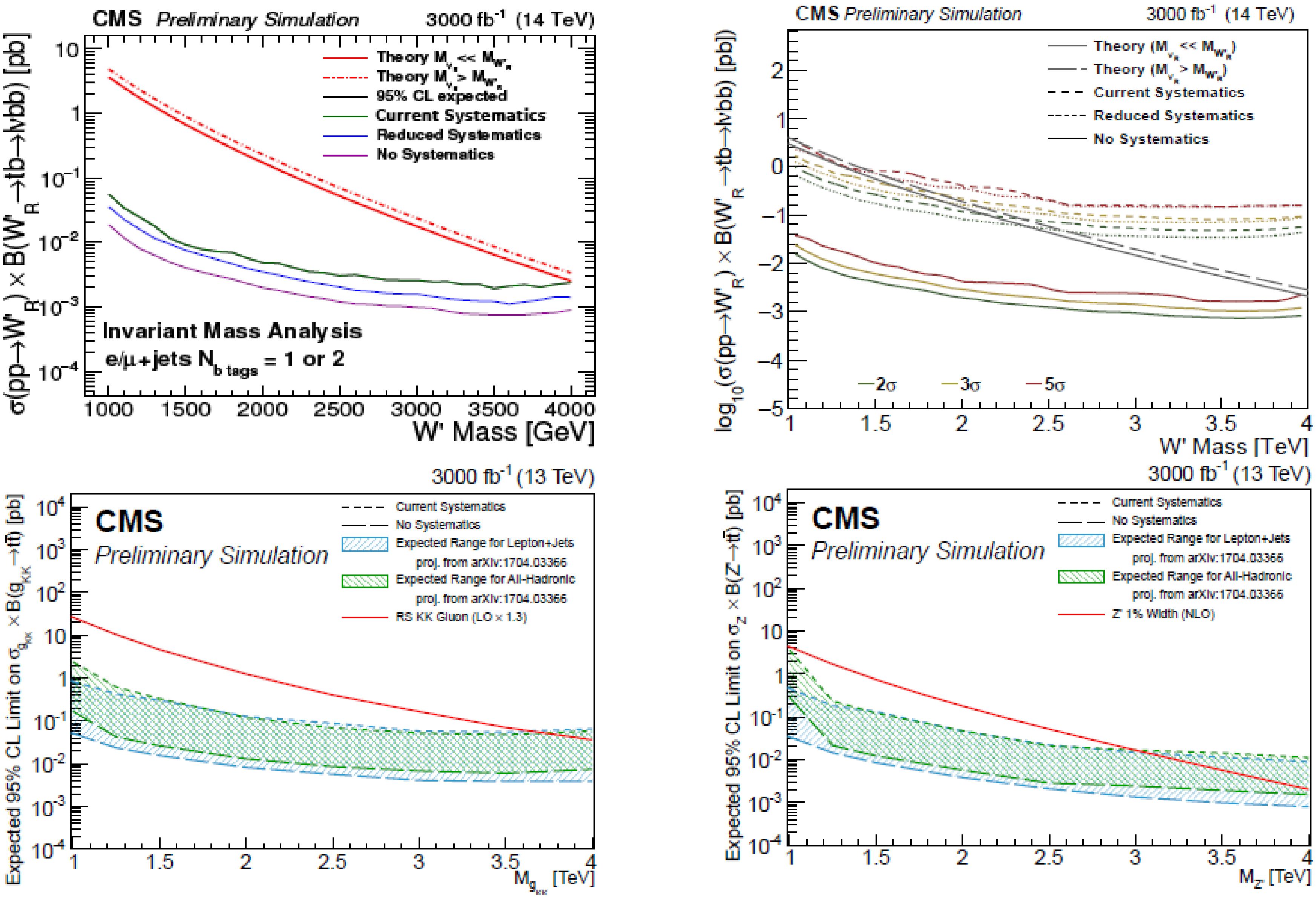






Mass (GeV)	Expected cross section upper limit (fb)	
	Tbq (LH)	Ttq (RH)
1000	85.9	54.7
1500	28.4	20.3
2000	12.8	9.06
2500	7.20	4.64
3000	4.69	4.10

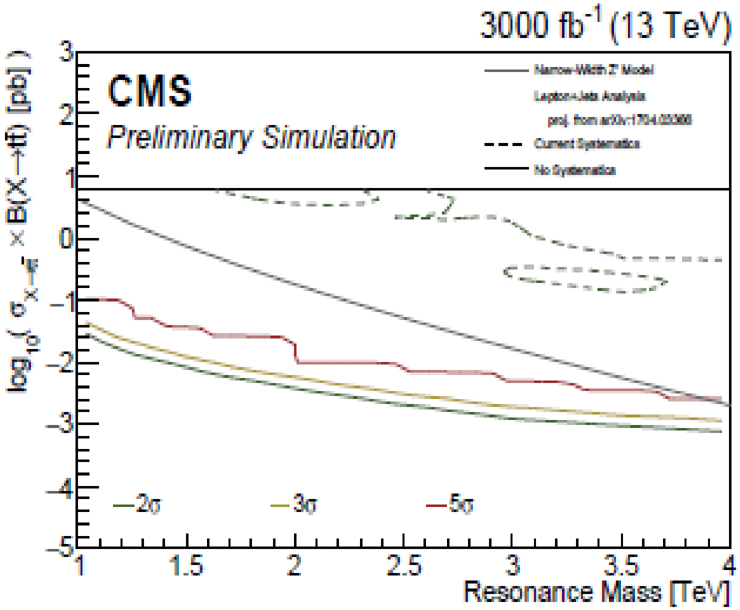
Potential for new searches with 3/ab

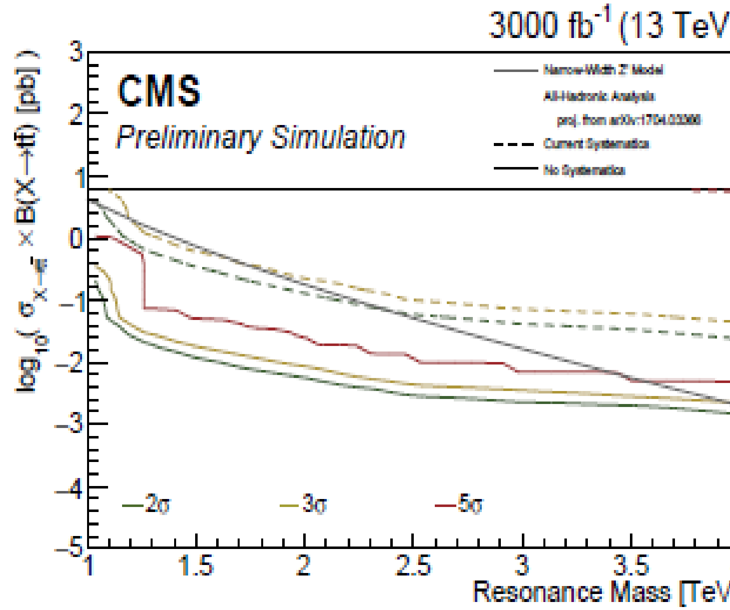


Leptonic final state

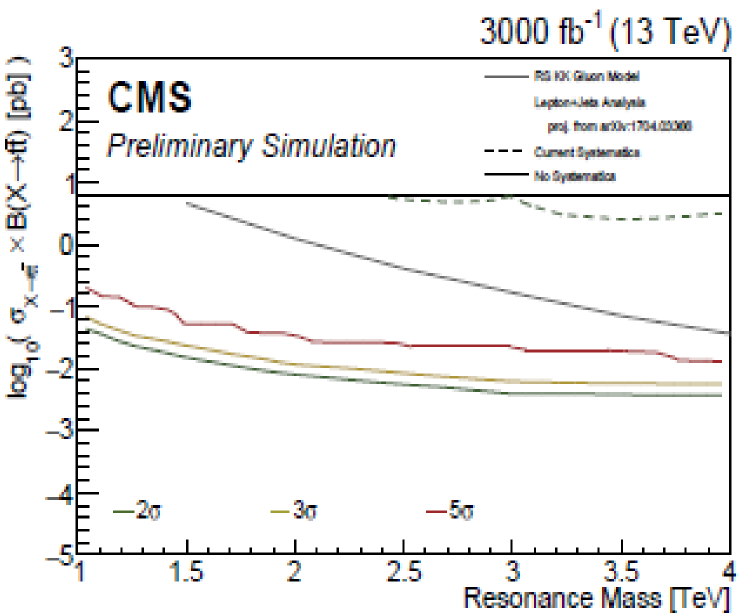
Hadronic

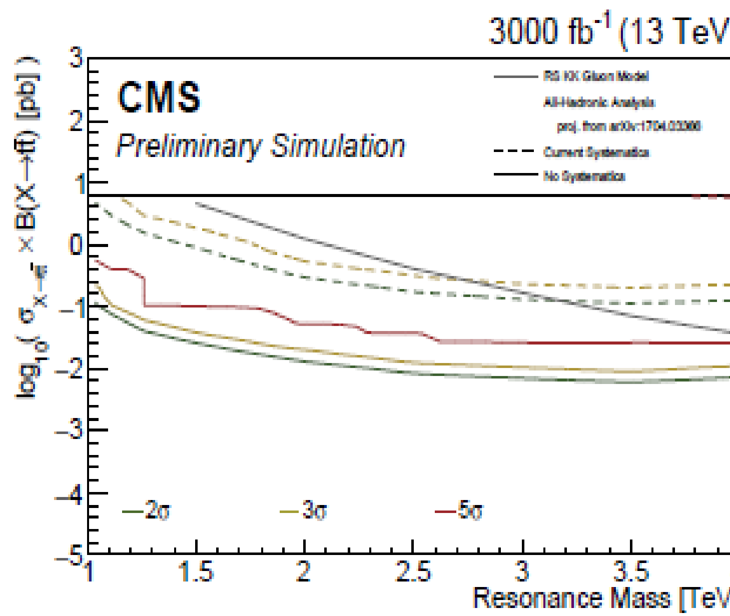
Narrow width Z’



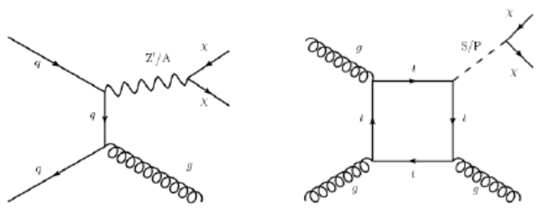


RS KK gluon

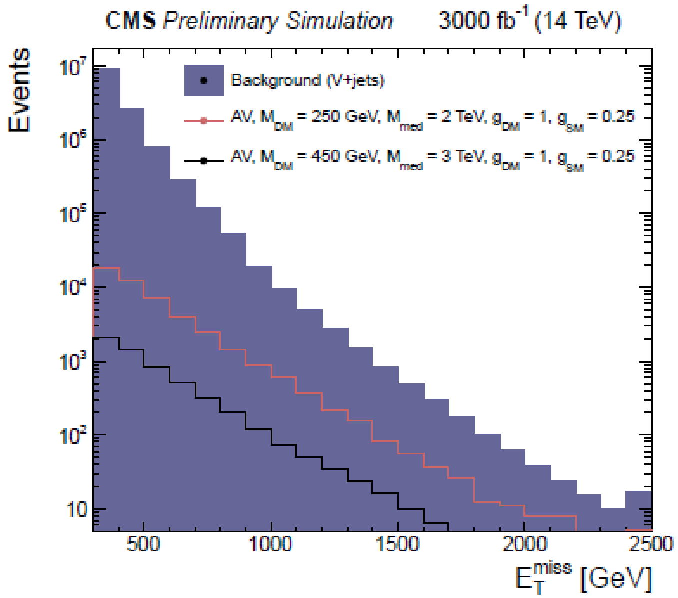




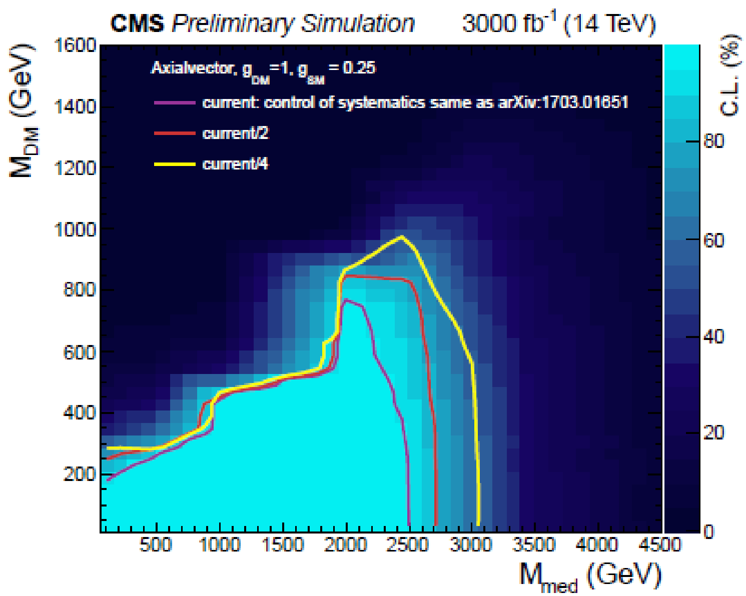
Search for dark matter

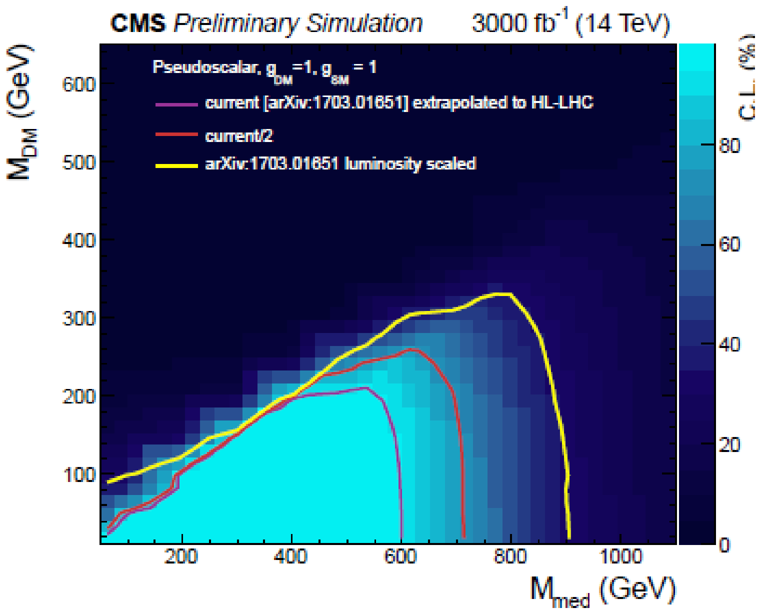


Production via axial-vector or pseudoscalar mediator



- Need an object to trigger the event ➔ DM must be produced in association with an identifiable object





Jet performance