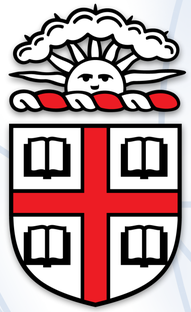
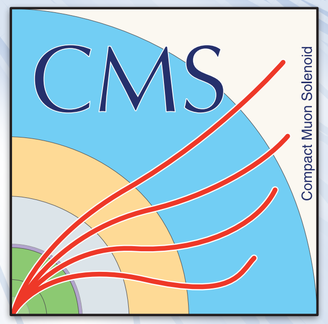
Beyond the standard model physics at the HL-LHC with CMS

Emanuele Usai on behalf of CMS Collaboration



BROWN

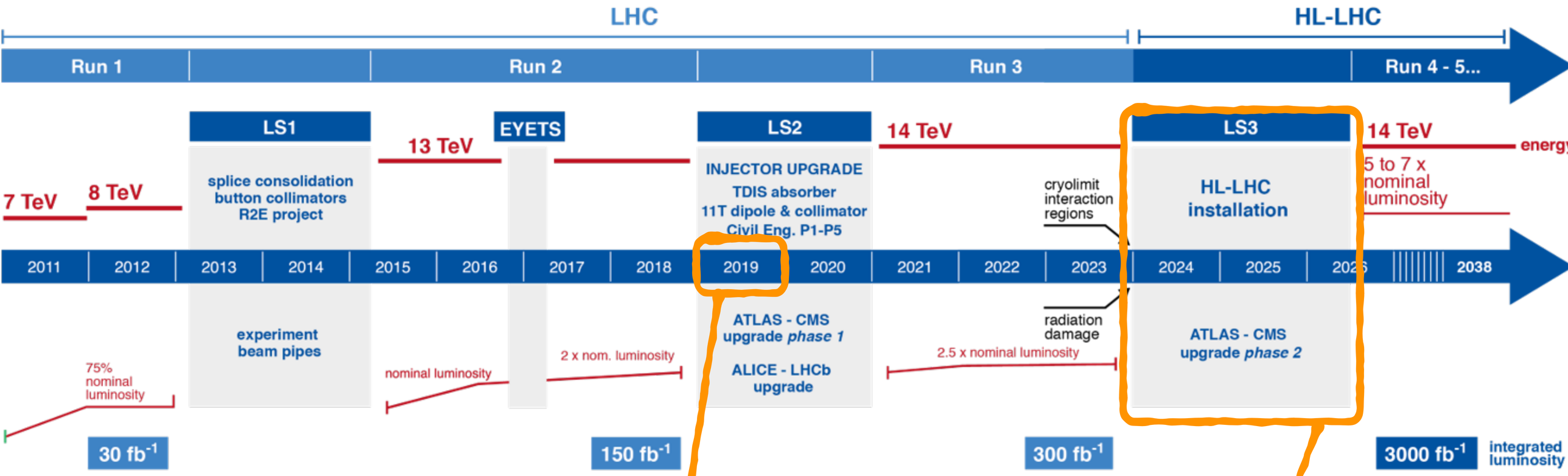


SUSY 2019 — 23 May 2019

outline

- CMS Phase 2 upgrade and the HL-LHC
- dark matter & dark sector
- exotic leptons
- high-mass resonances
- summary

Plan



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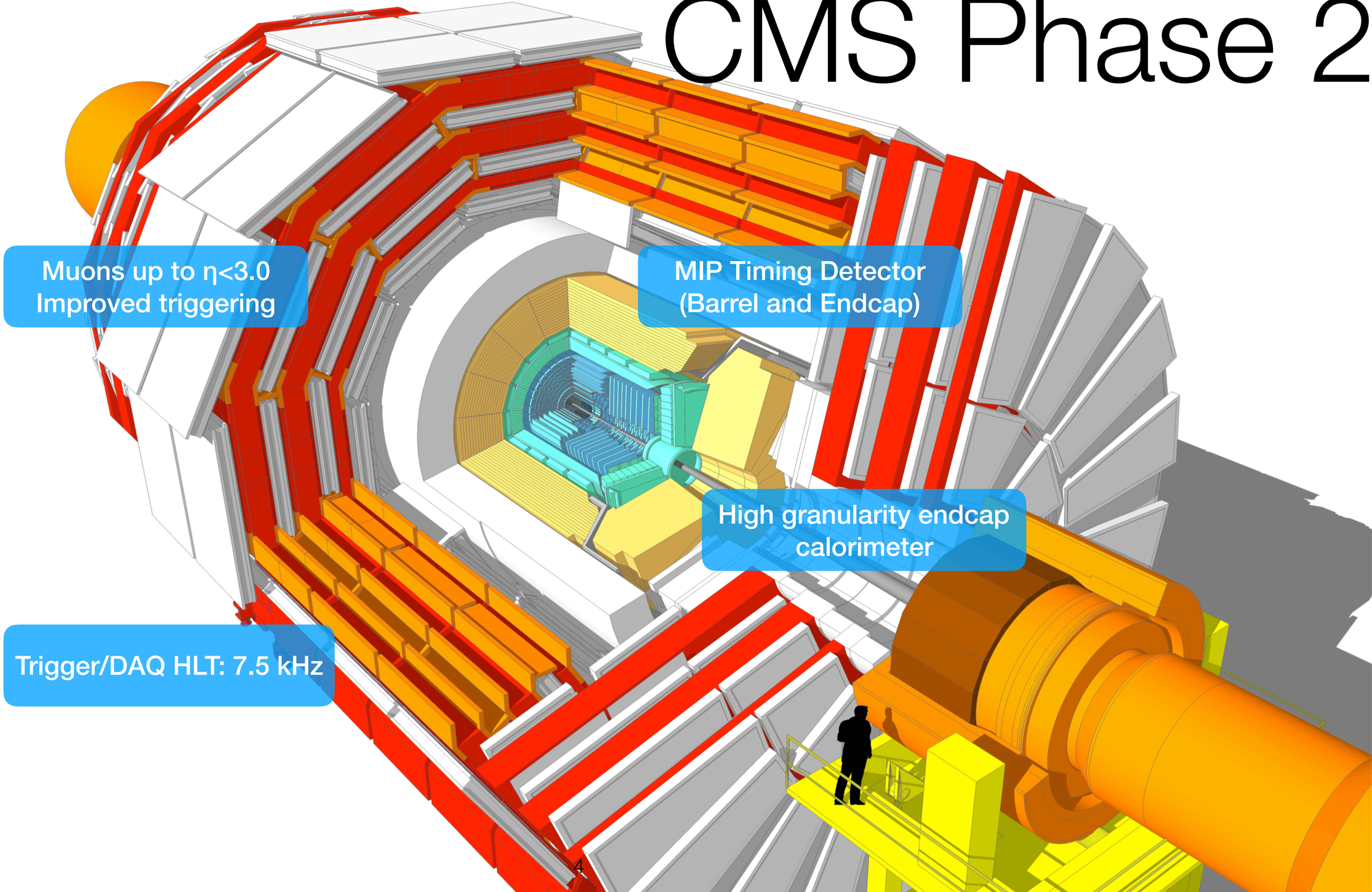
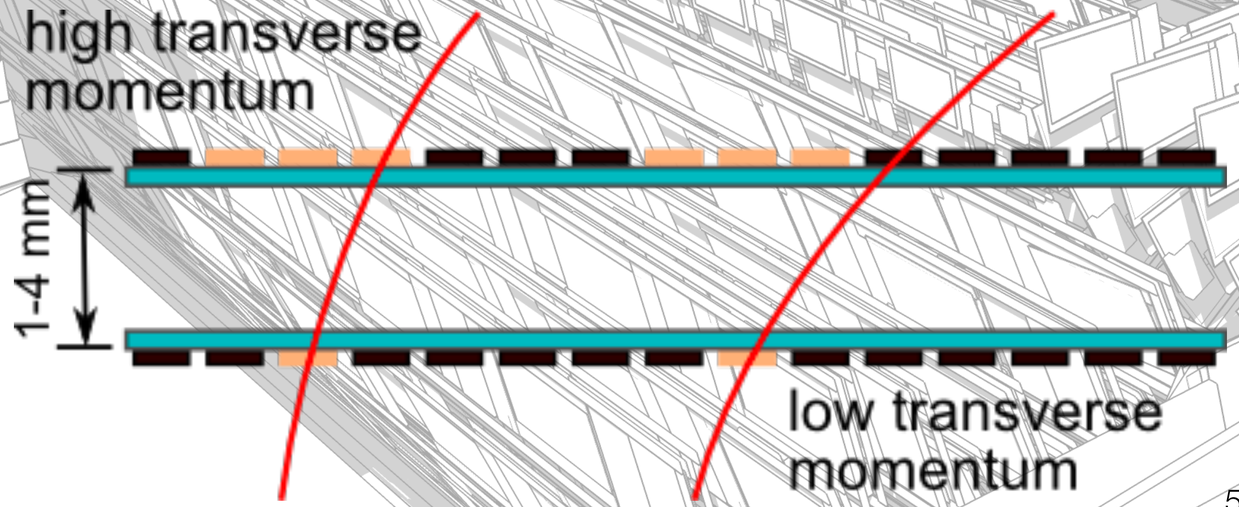
CMS Phase 2 installation

CMS Phase 2

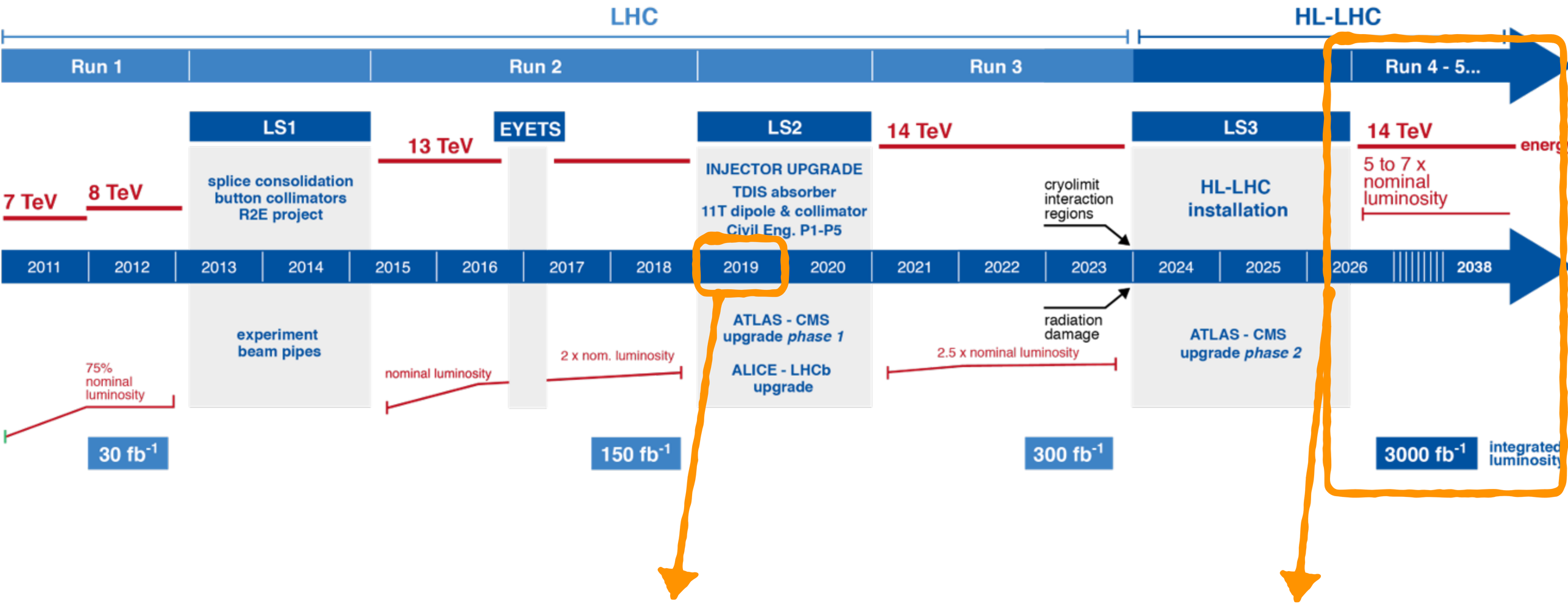

Muons up to η<3.0
Improved triggering
MIP Timing Detector
(Barrel and Endcap)
High granularity endcap
calorimeter
Trigger/DAQ HLT: 7.5 kHz

Tracker



- New tracker up to |eta|<4
- Fast system to reject low pT track
- Enables readout at HW trigger
- Radiation hard

HL-LHC



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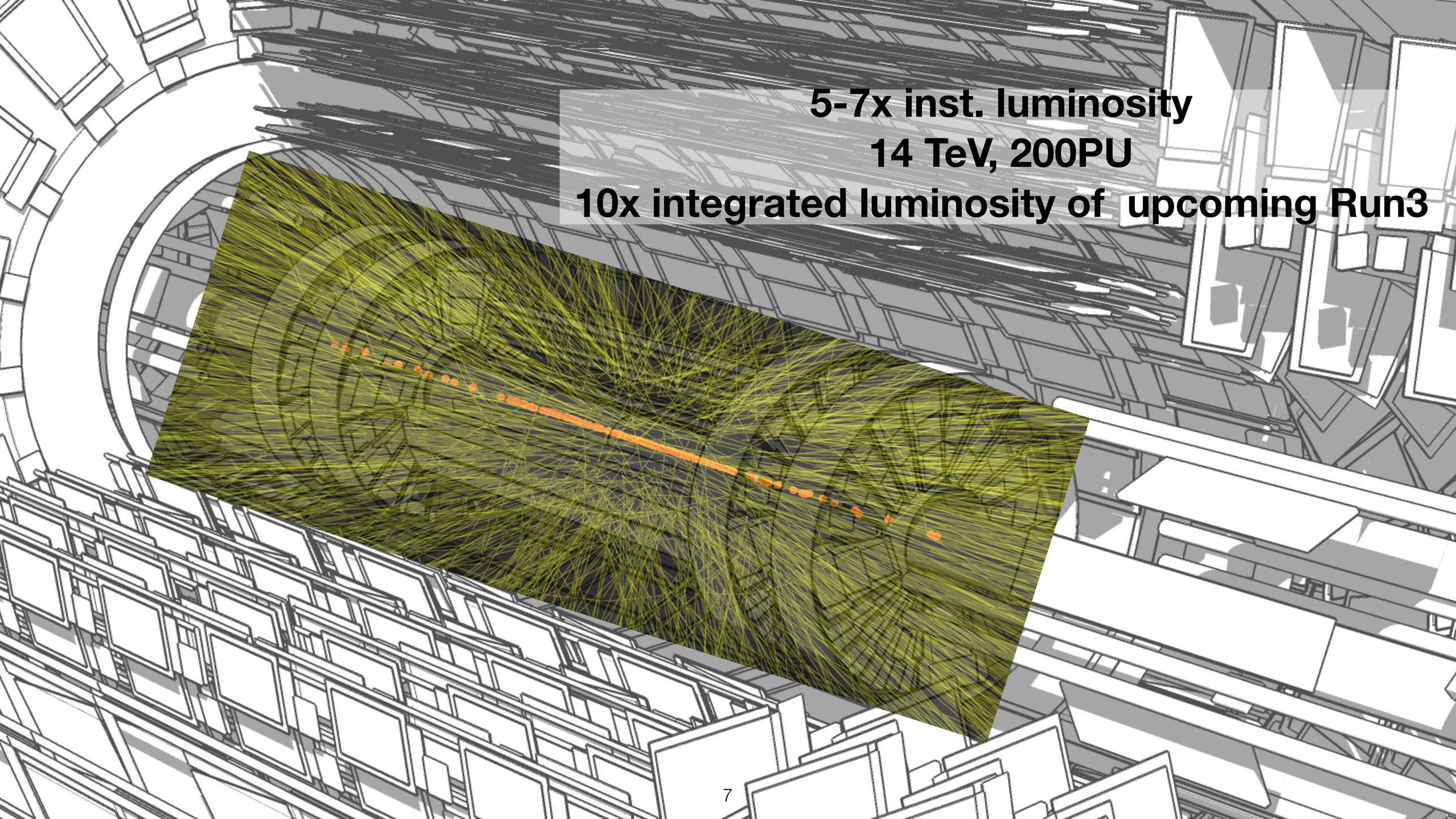
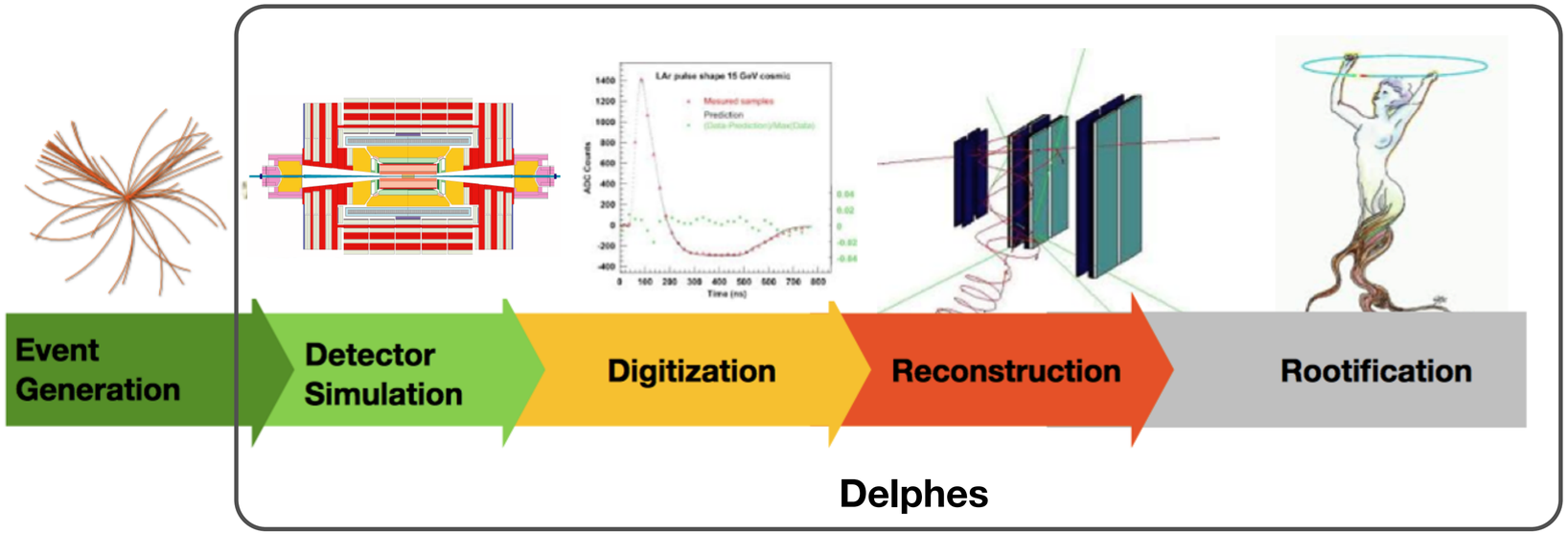
This talk


5-7x inst. luminosity
14 TeV, 200PU
10x integrated luminosity of upcoming Run3

Delphes simulations

HL-LHC simulations need large statistics!

Courtesy of A. Salzburger



parametrize detector response

efficiency | track res. | calo obj.

reconstruct high-level objects

P Flow | jets | MET

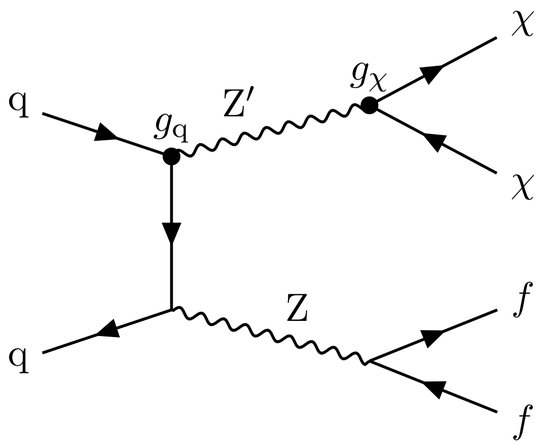
tune performance against FULLSIM

Systematic scenarios:
Same as Run2
HLLHC estimation from 1812.07831 (many systematics reduced ~50%)
No systematics (limit case)

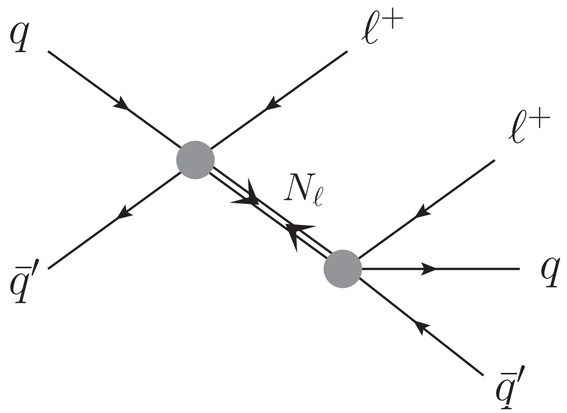
Luminosity scenario:
300/fb (~same as Run3)
3000/fb

dark matter & dark sector

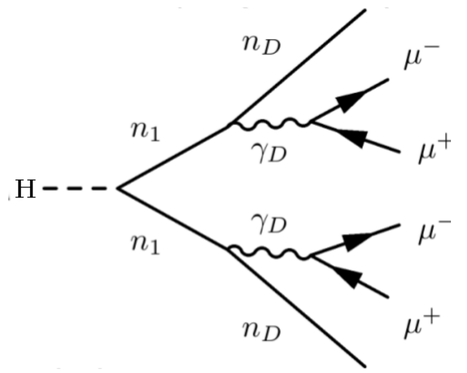
Mono-Z DM



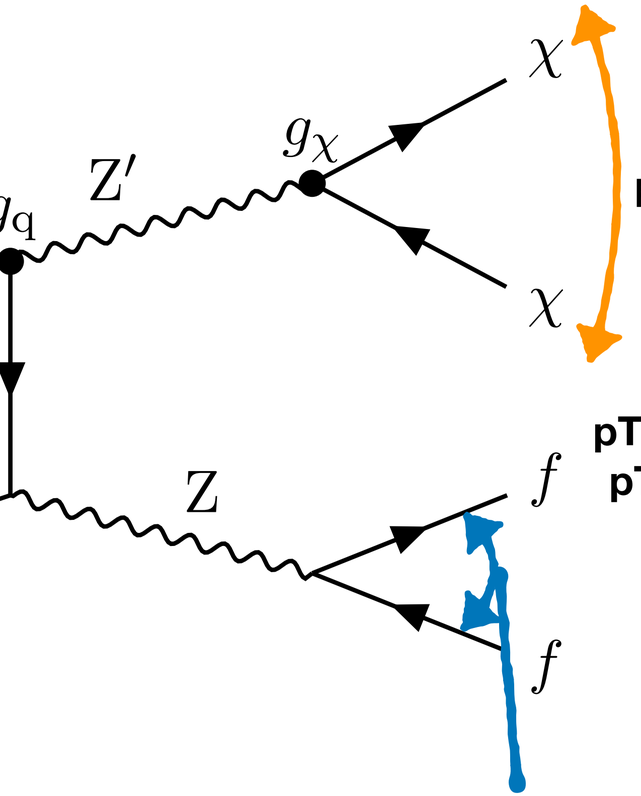
Majorana nu → l + qq



Dark photon with displ. mu



Mono-Z DM



$|M(\ell\ell) - m_Z| < 15\,\text{GeV}$

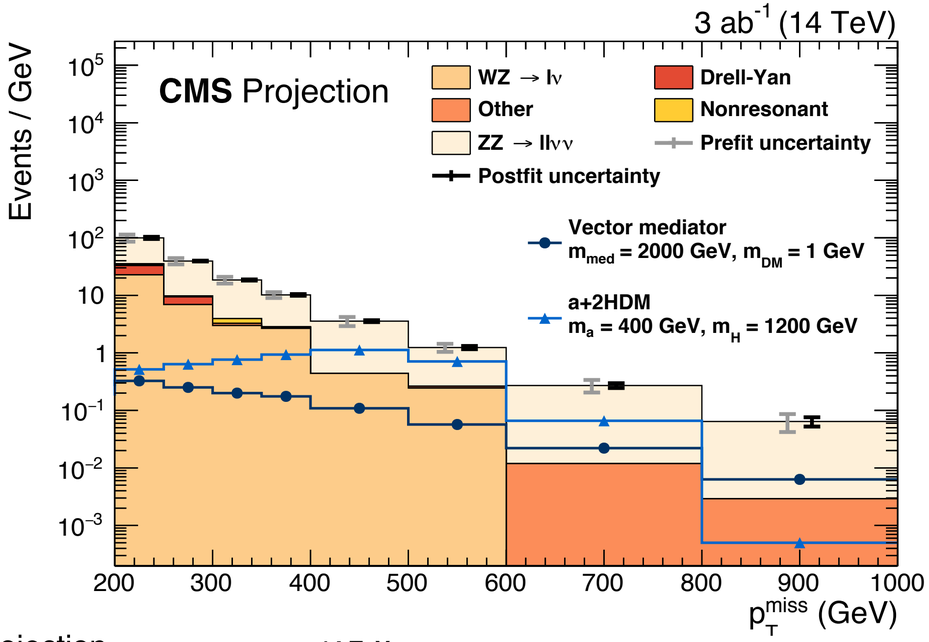
pT $> 60\,\text{GeV}$

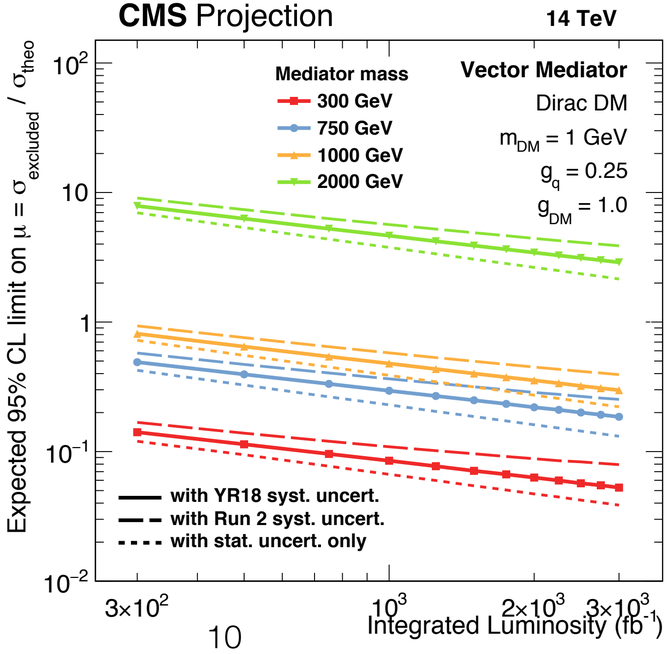
dR < 1.8

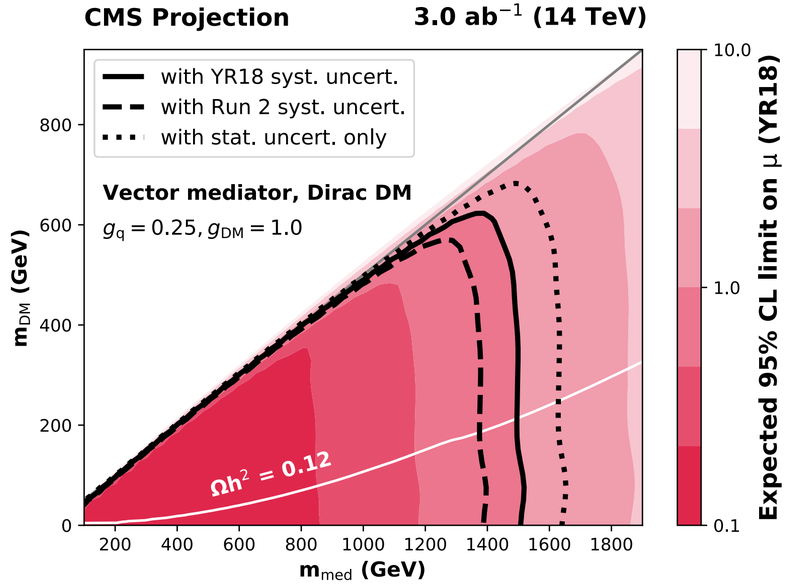
Other selections

$\Delta\phi(\vec{p_T}^{\ell\ell}, \vec{p_T}^{\text{miss}})$	> 2.6
$\lvert p_T^{\text{miss}} - p_T^{\ell\ell}\rvert / p_T^{\ell\ell}$	< 0.4
$\Delta\phi(\vec{p_T}^{j}, \vec{p_T}^{\text{miss}})$	> 0.5 rad

FTR-18-007 and arxiv:1812.07831

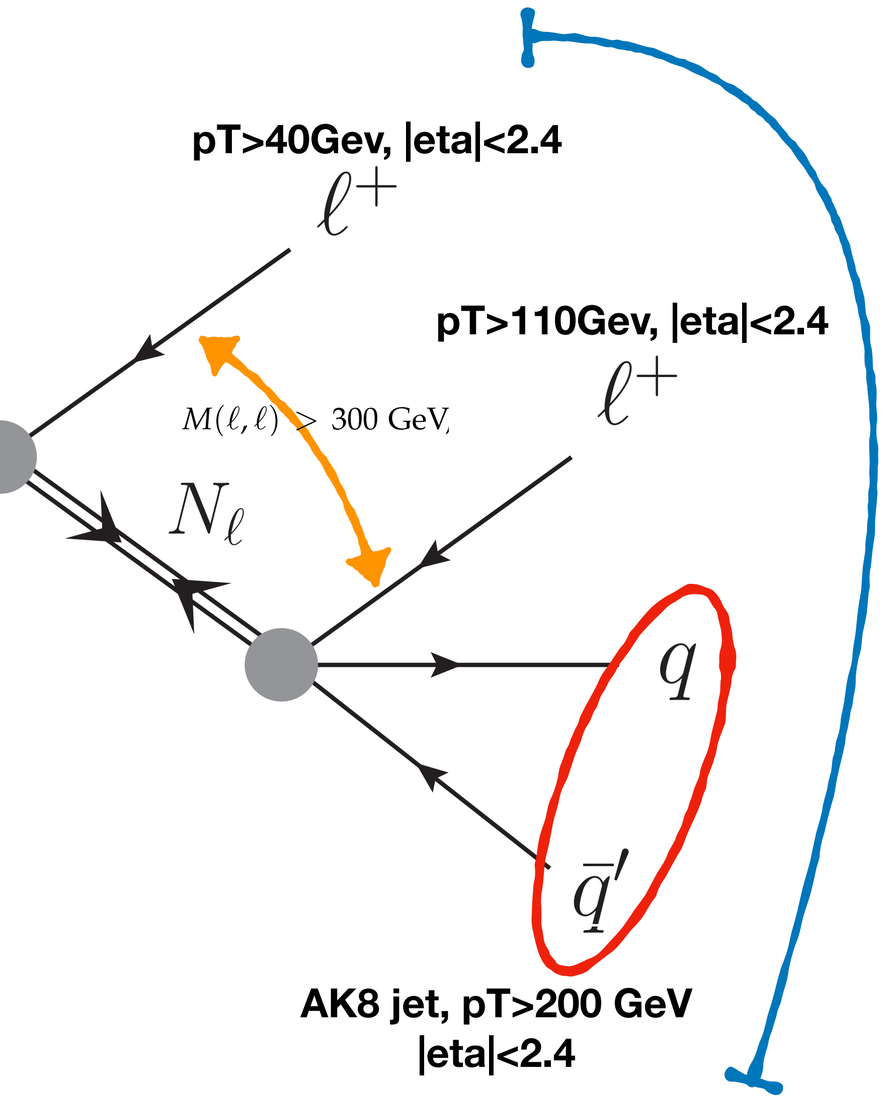




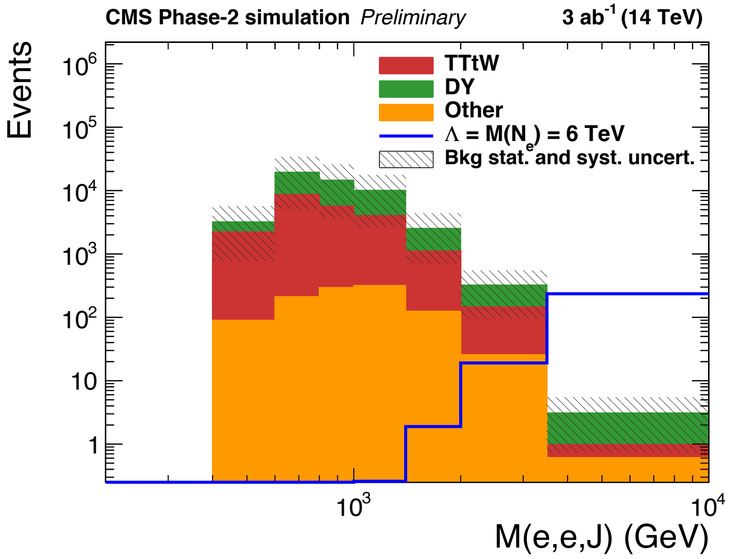


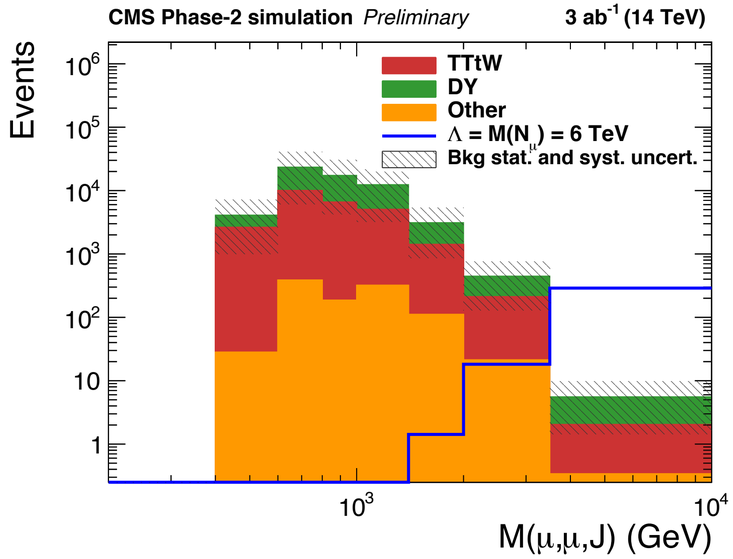
Majorana nu → l + qq

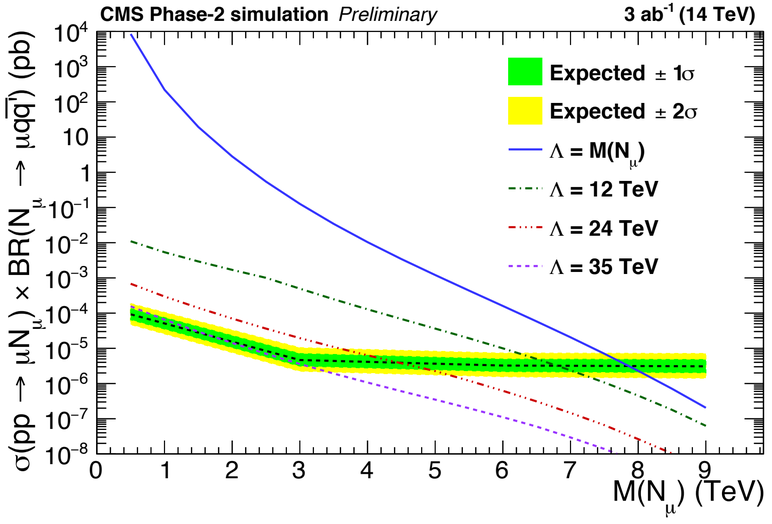
FTR-18-006 and arxiv:1812.07831



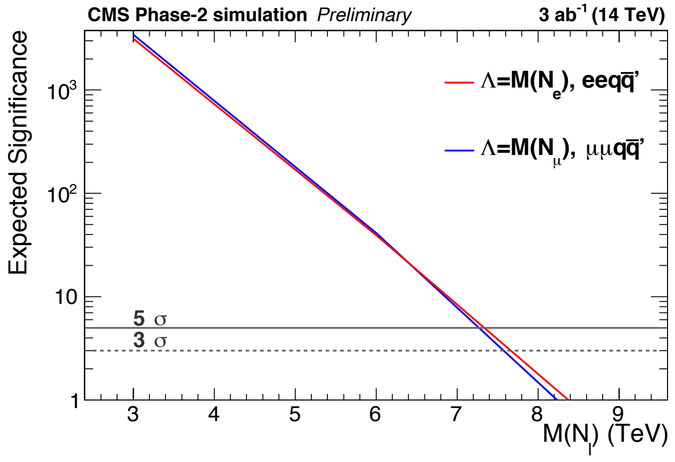
m(l,l,jet)
discriminating variable







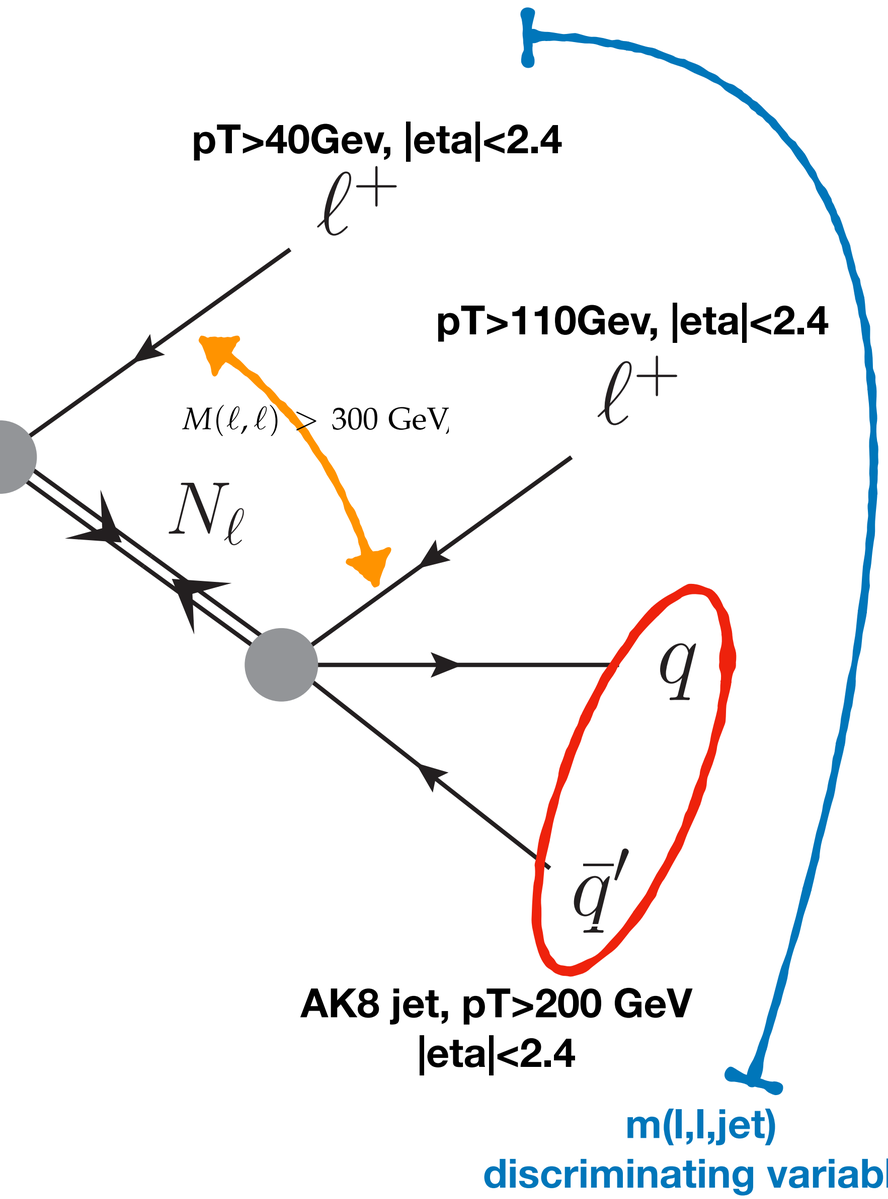
Mass limit 8 TeV

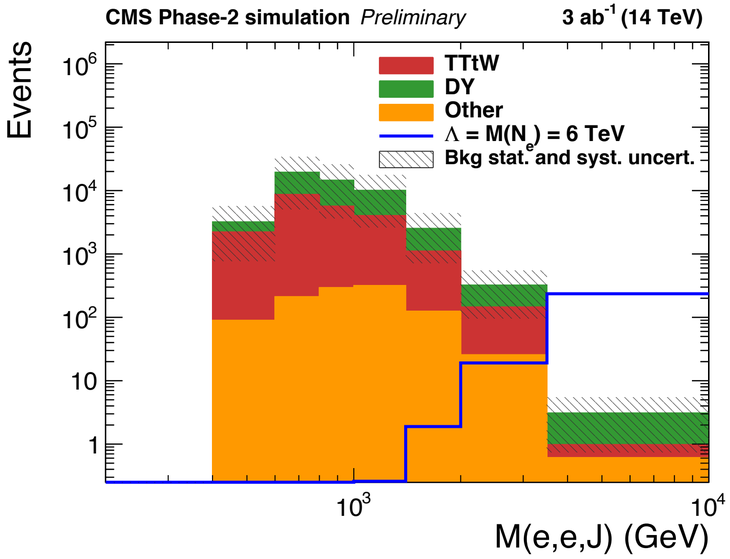


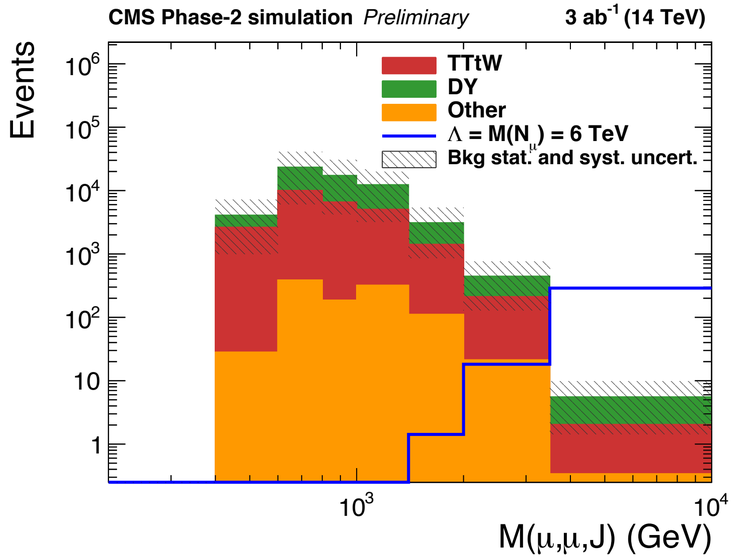
5sigma discovery reach: 7.2 TeV

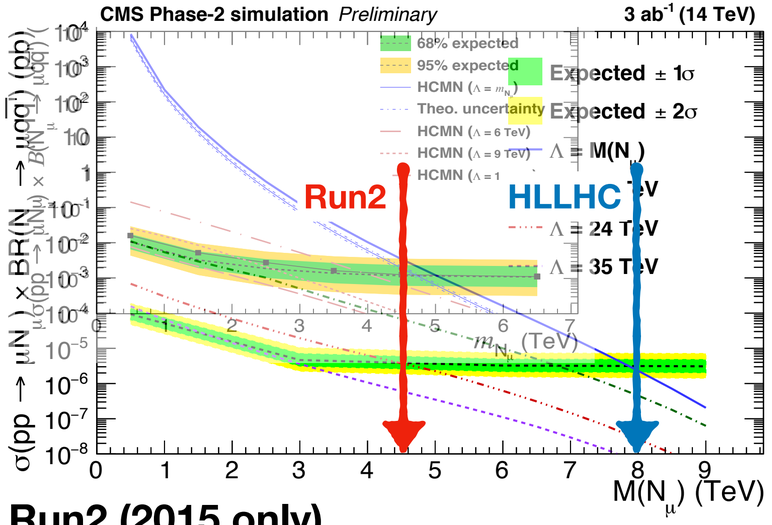
Majorana nu → l + qq

FTR-18-006 and arxiv:1812.07831



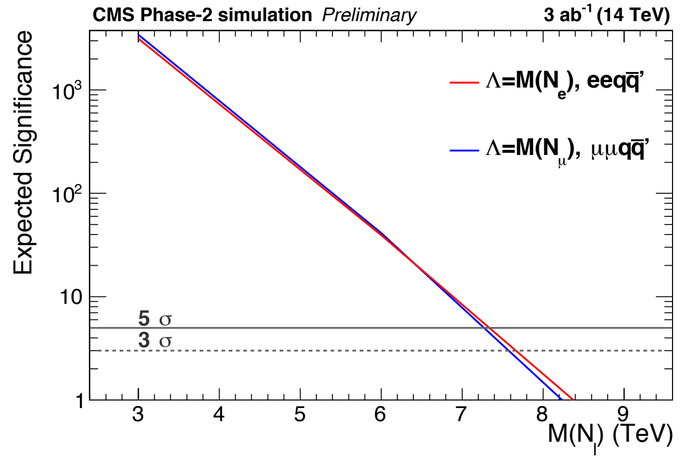






Run2 (2015 only)

arXiv:1706.08578



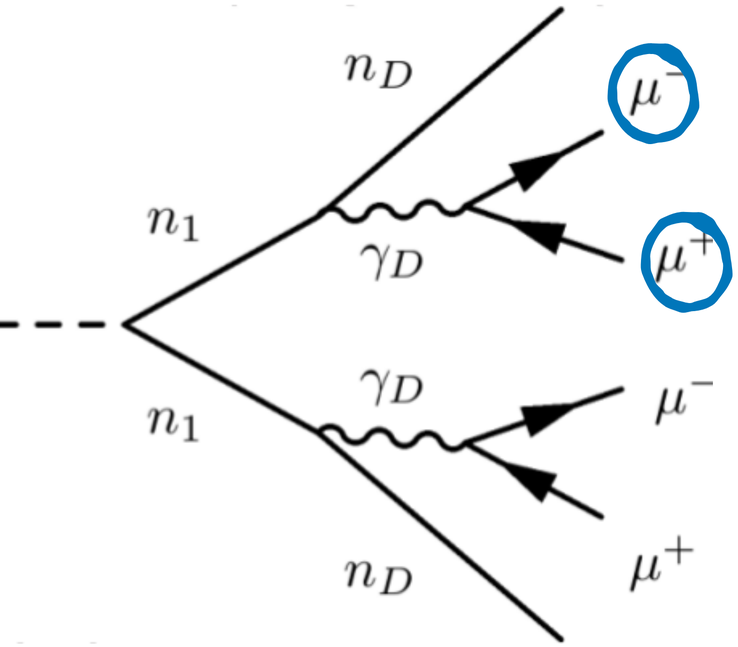
Mass limit 8 TeV

5sigma discovery reach: 7.2 TeV

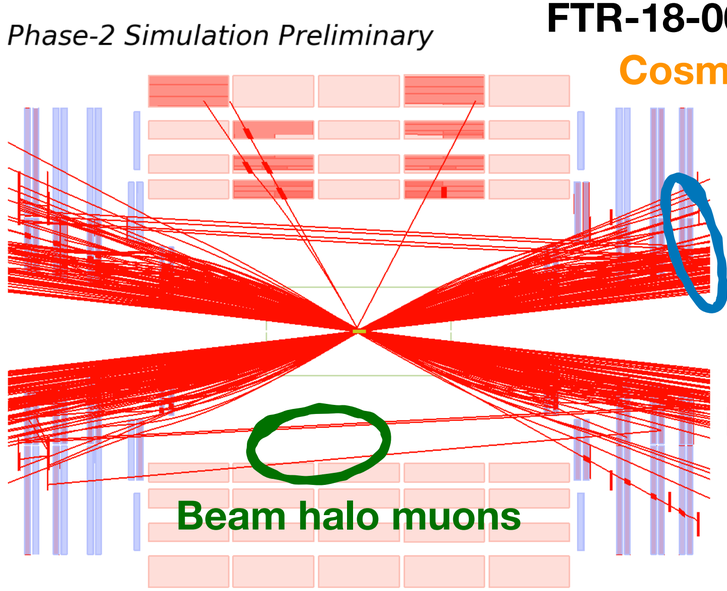
Dark photon with displaced muons

FTR-18-002 and arxiv:1812.07831

Analysis needs dedicated displaced muon trigger
Depending on muon upgrade performance

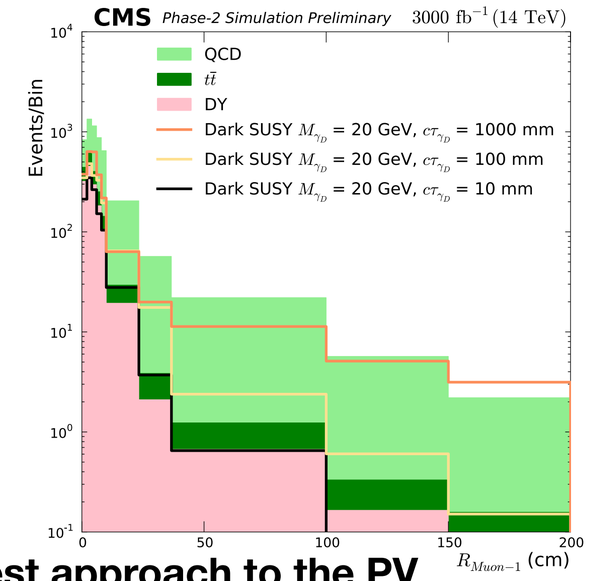


$p_T \geq 15$ GeV and $|\eta| \leq 2.8$
$\chi^2/\text{ndof} \leq 2.0$
$|d_0|/\sigma(d_0) \geq 5.0$
Nhit requirement

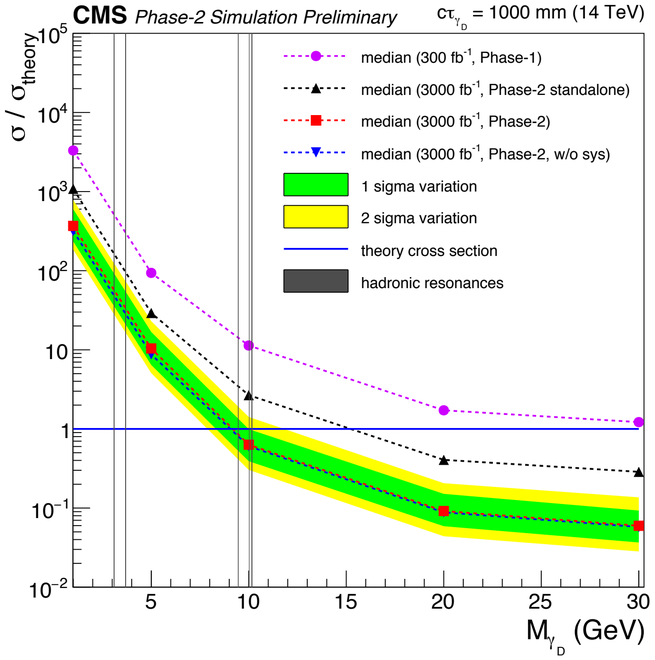


Rejected by muon pT cut and back to back

Dedicated displaced standalone algorithm (DSA)
Designed for highly displaced muons
Leaving hits only in muon detector

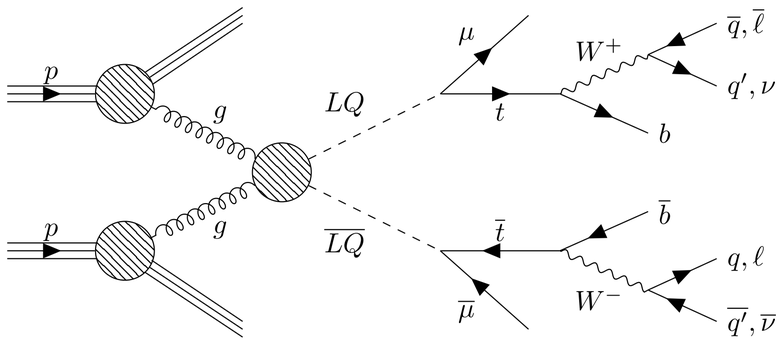


3D Distance of closest approach to the PV

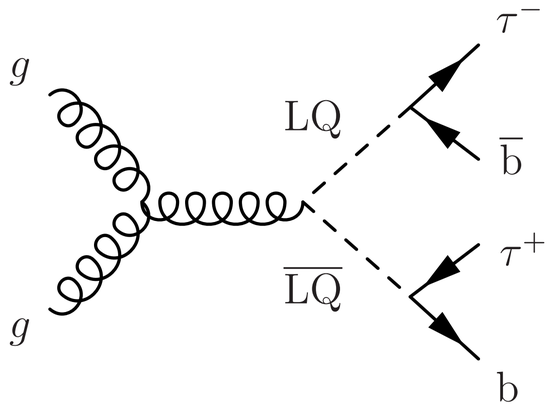


exotic leptons

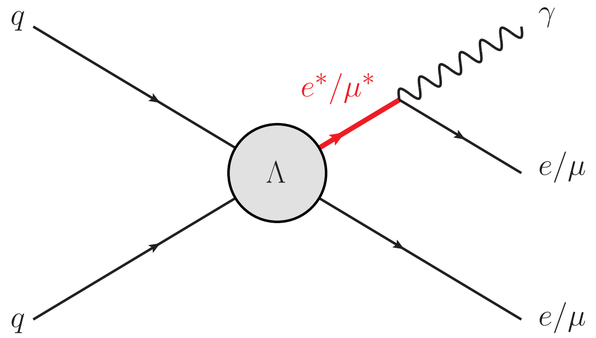
Leptoquarks pair → t + lept



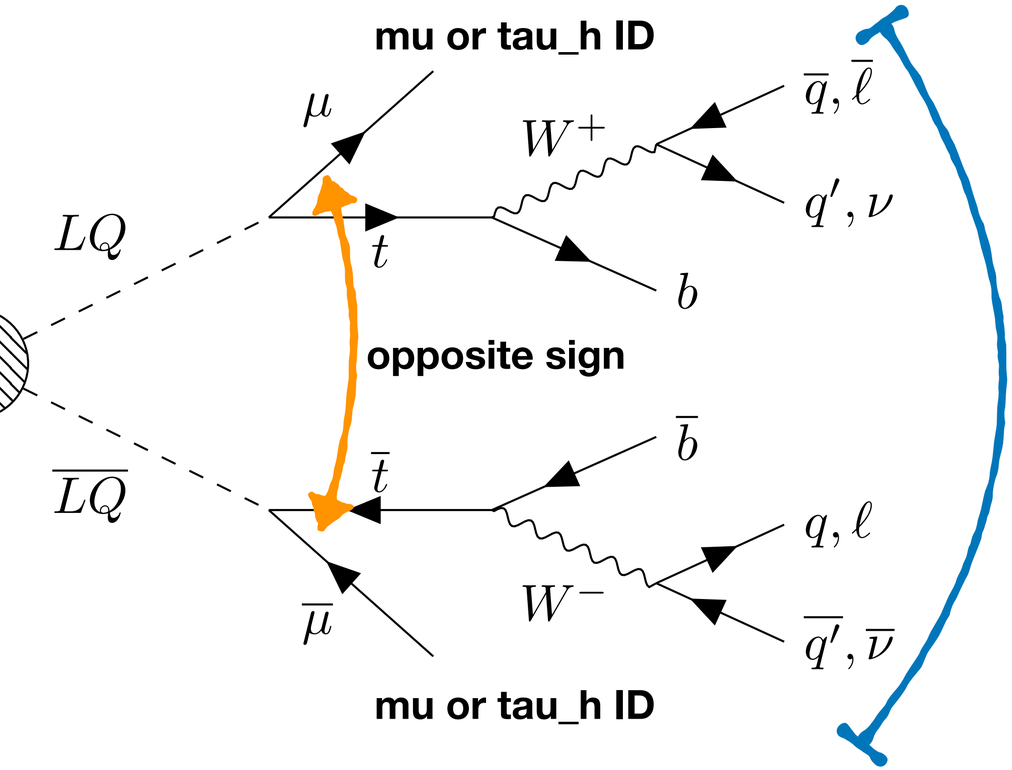
Leptoquark→ b + tau



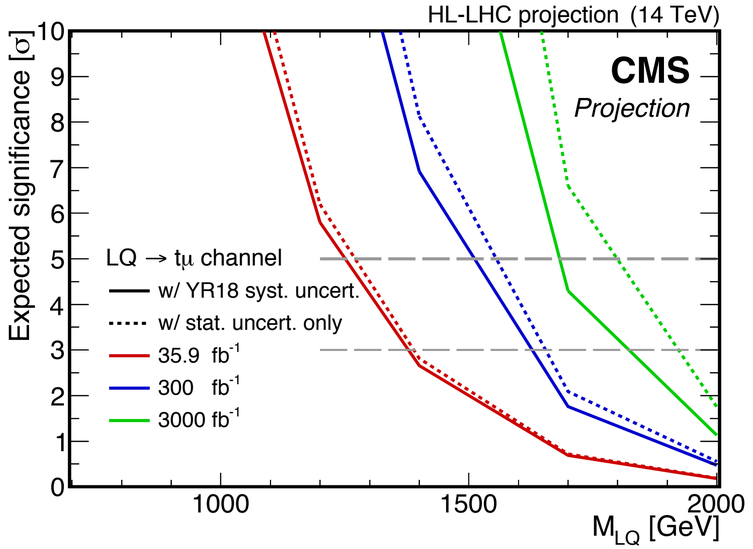
e*, mu* → ll+gamma

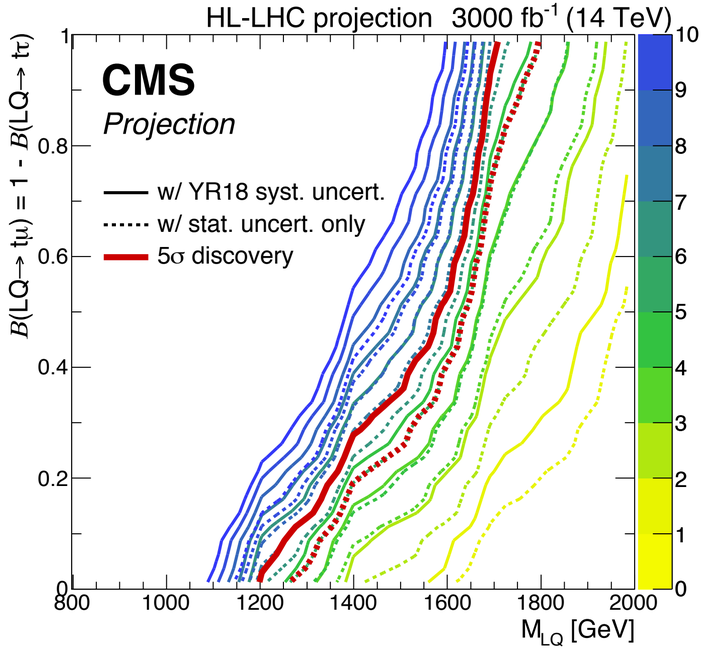


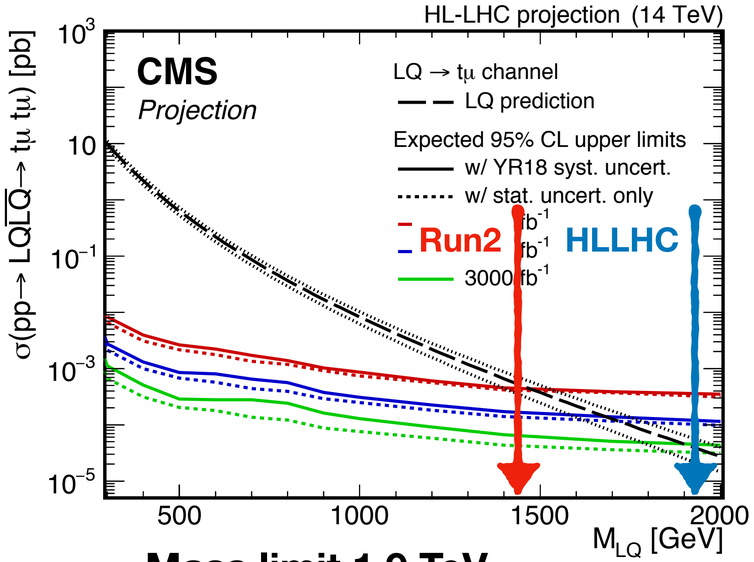
Leptoquarks pair → t + lept



Probe all combinations of jets, lepton, pTmiss
Choose combination that minimizes chi2-like variable





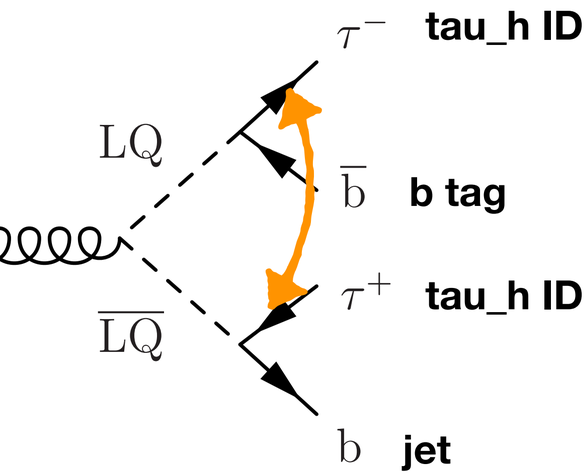


Mass limit 1.9 TeV

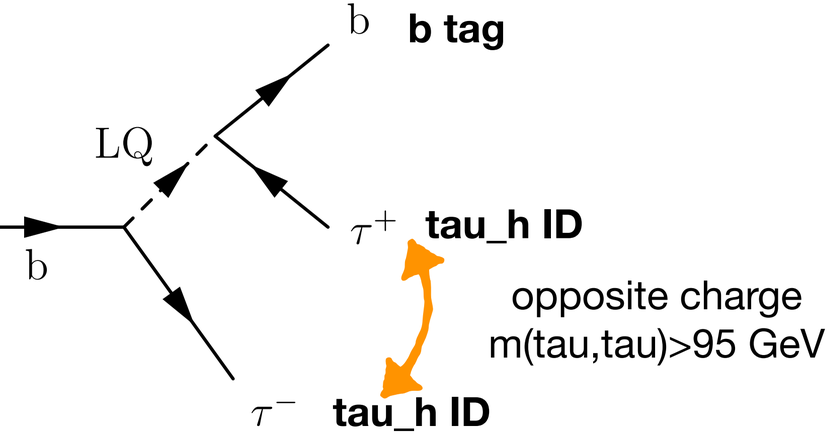
FTR-18-008 and arxiv:1812.07831

Leptoquark→ b + tau.

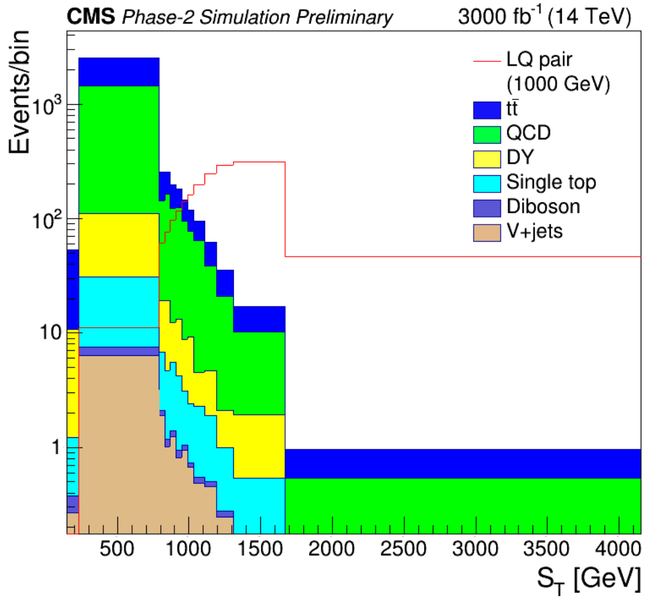
FTR-18-028 and arxiv:1812.07831

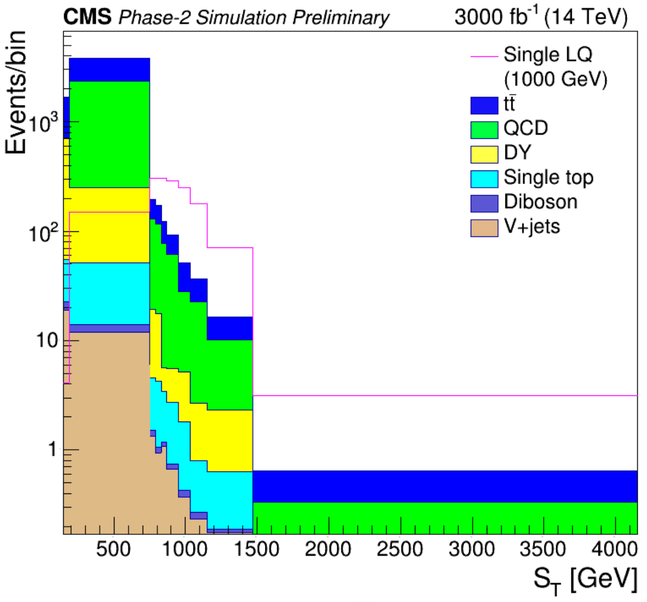


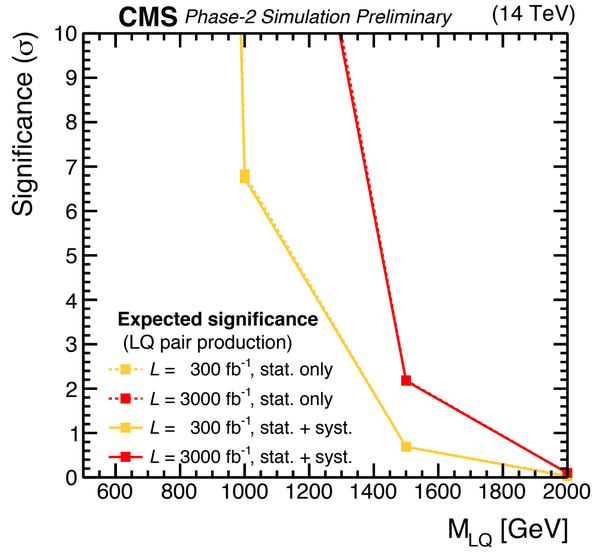
AK4 jet $p_{T,jet} > 50$ GeV and $|\eta_{jet}| < 2.4$

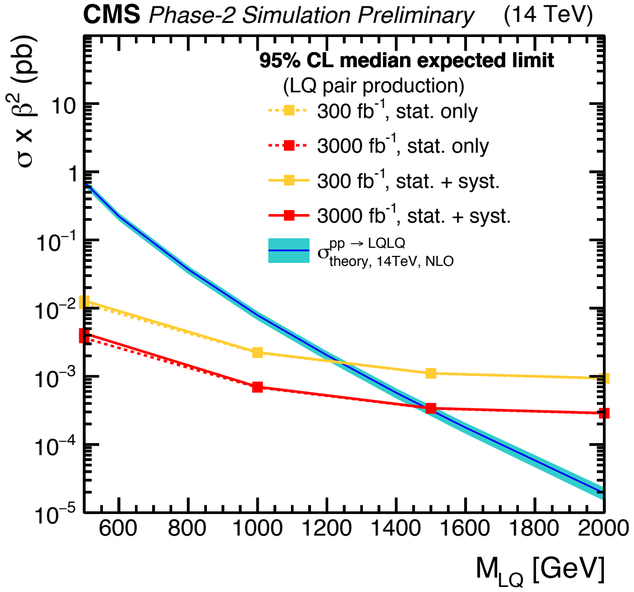


Isolated electron, muon veto





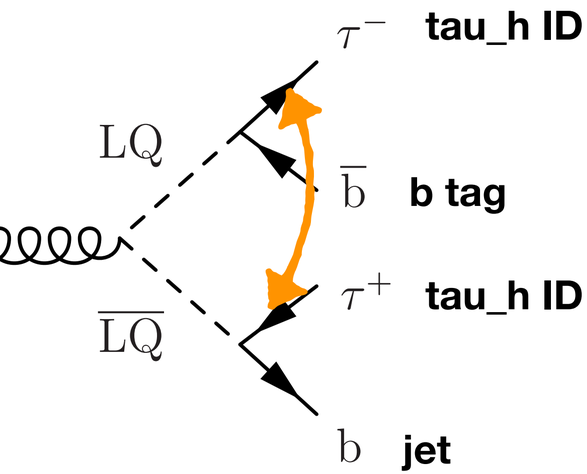




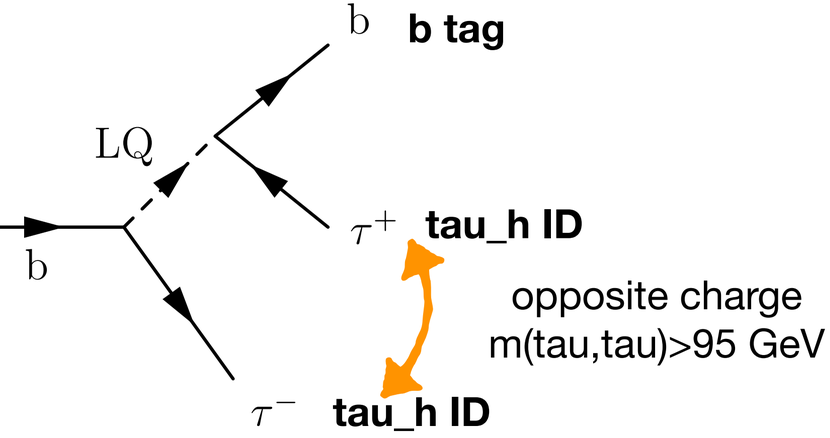
Mass limit: 1.5 TeV

Leptoquark→ b + tau

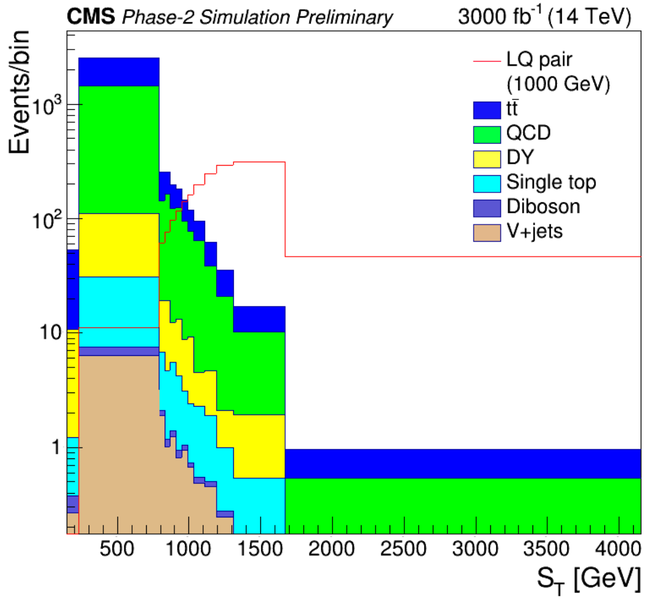
FTR-18-028 and arxiv:1812.07831

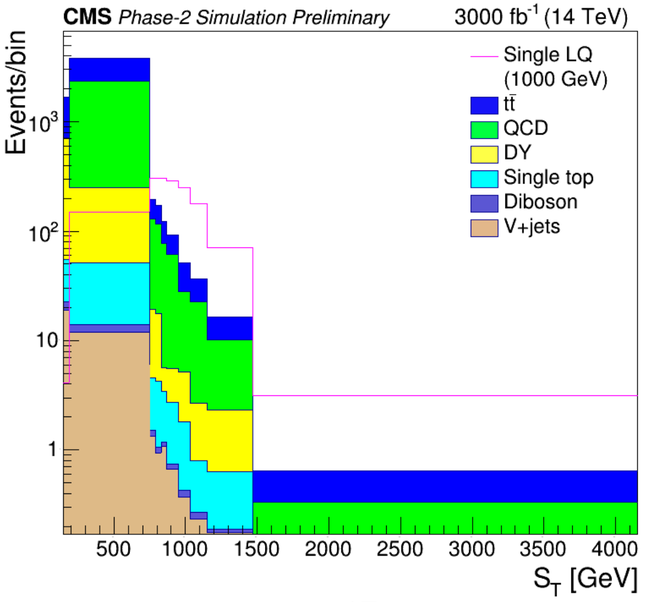


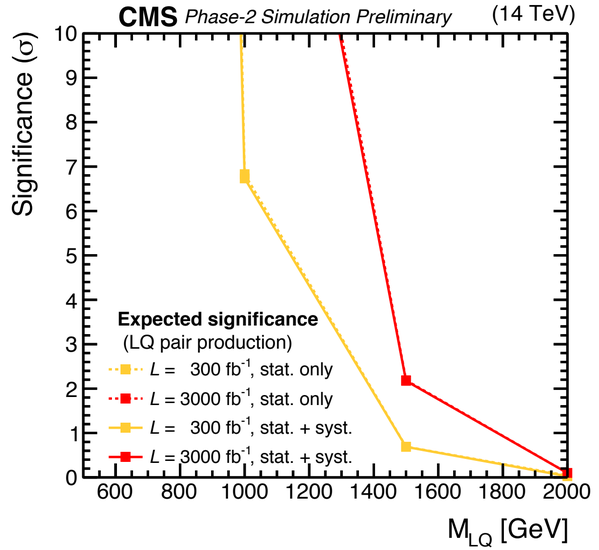
AK4 jet $p_{T,jet} > 50$ GeV and $|\eta_{jet}| < 2.4$

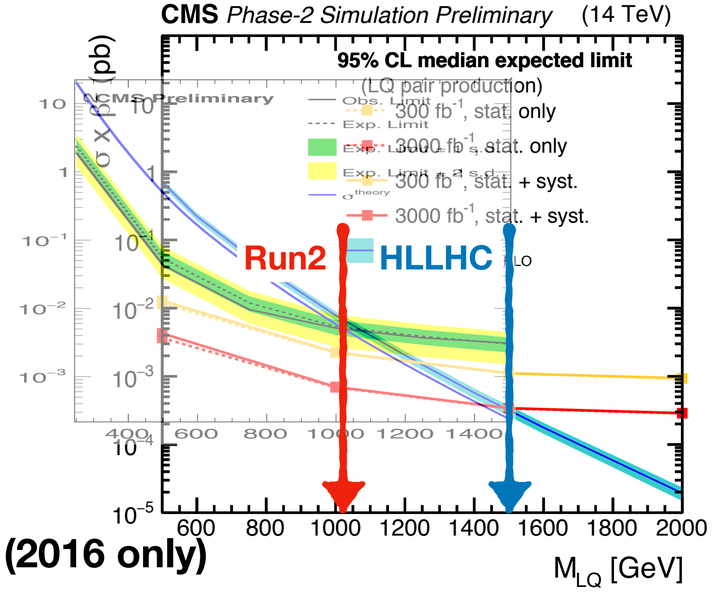


Isolated electron, muon veto







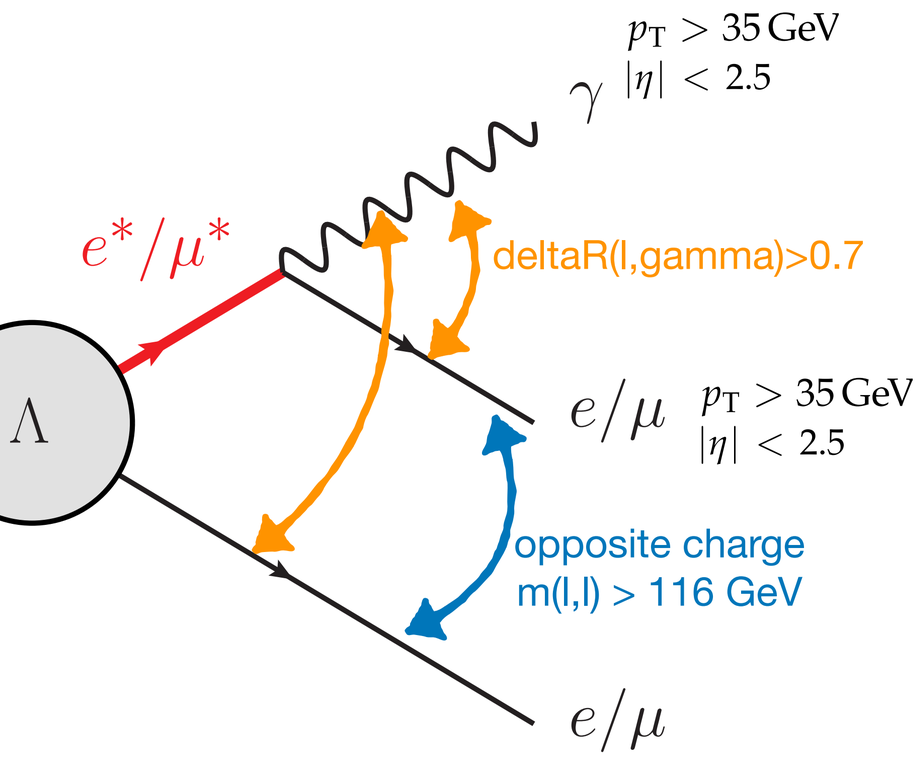


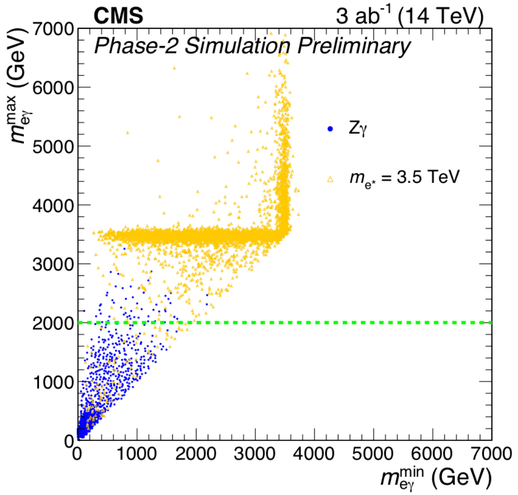
Run2 (2016 only)
EXO-17-016

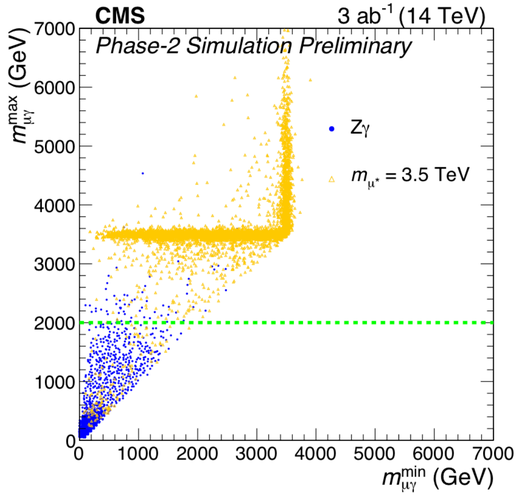
Mass limit: 1.5 TeV

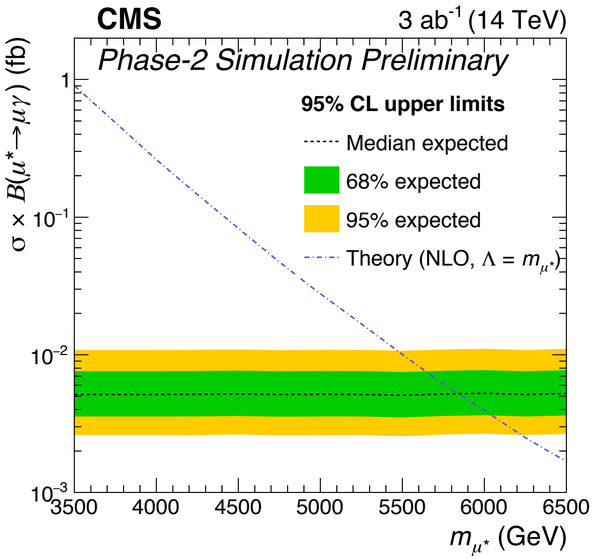
e*, mu* → ll+gamma

FTR-18-029 and arxiv:1812.07831

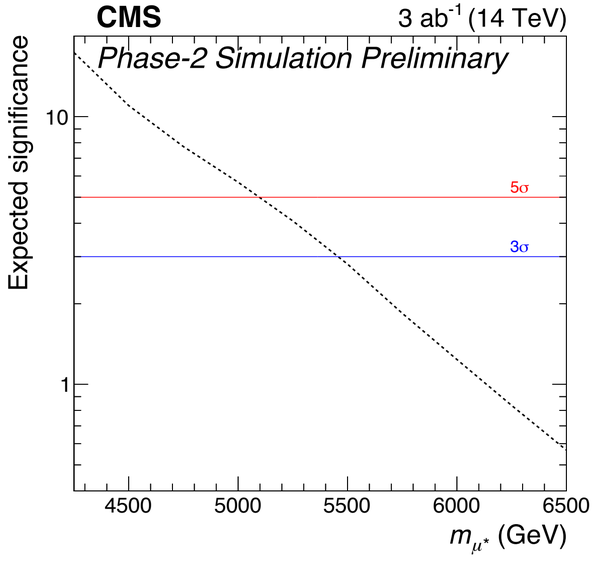








Mass limit 5.1 TeV

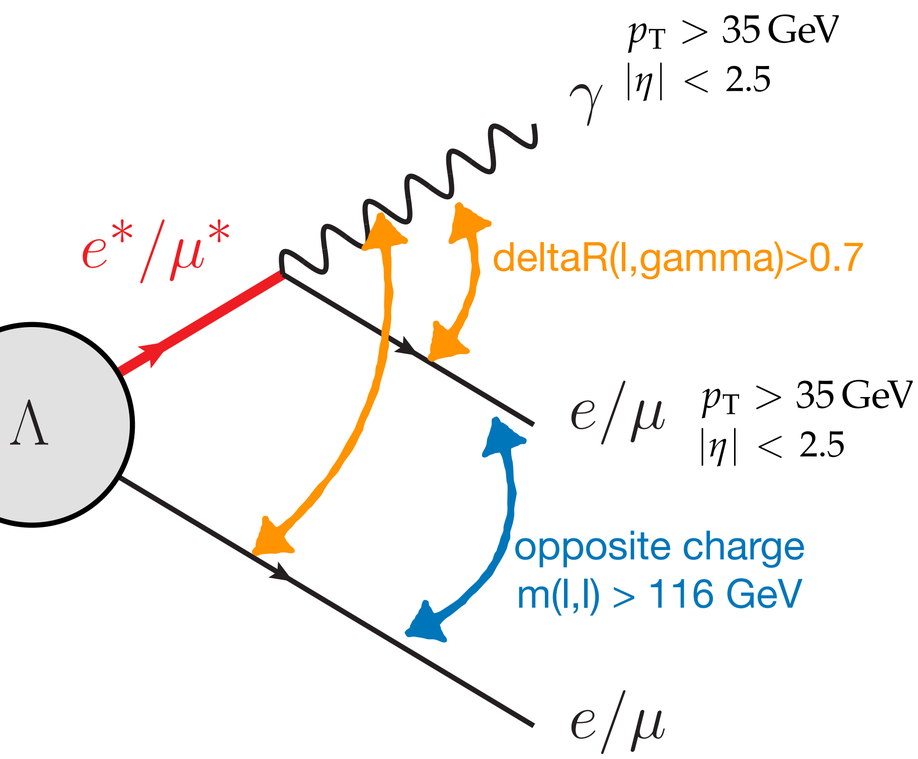


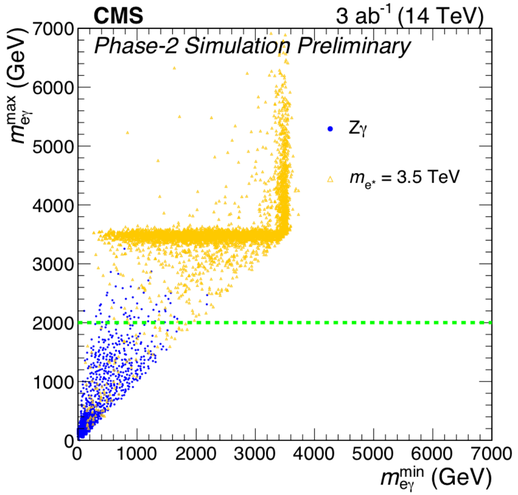
5sigma discovery reach: 5.1 TeV

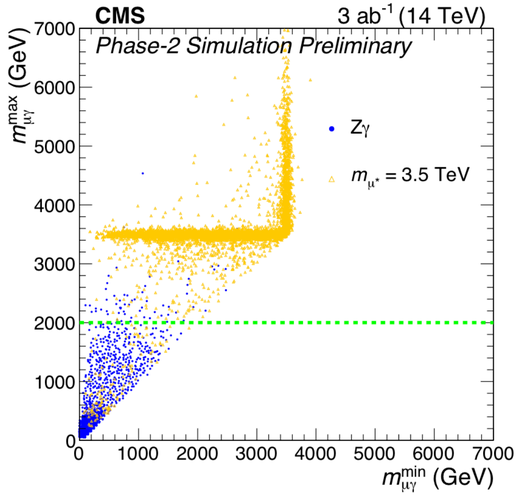
Composite excited lepton

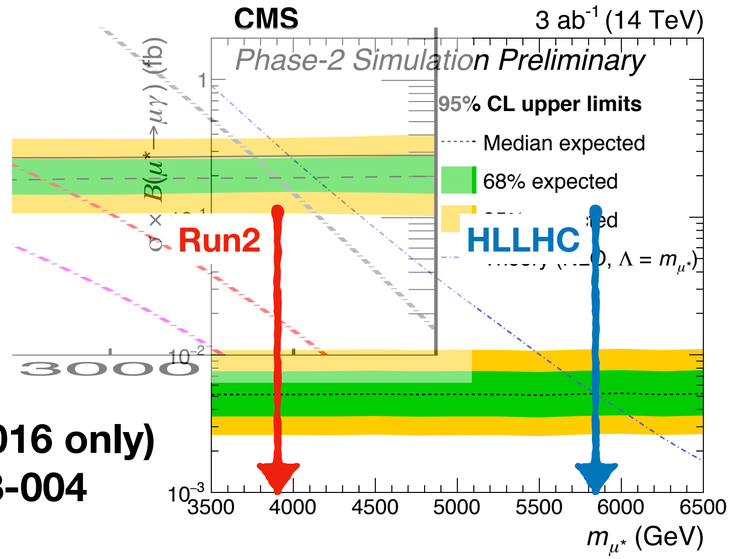
e*, mu* → ll+gamma

FTR-18-029 and arxiv:1812.07831



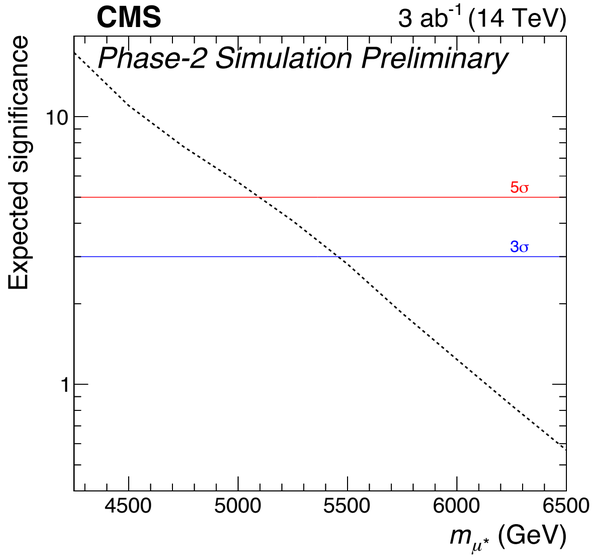






Run2 (2016 only)
EXO-18-004

Mass limit 5.1 TeV

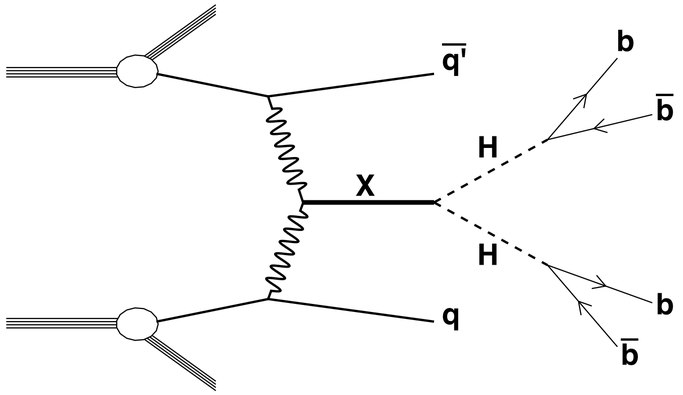


5sigma discovery reach: 5.1 TeV

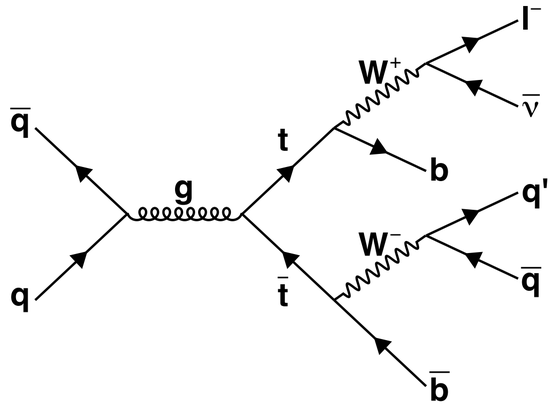
Composite excited lepton

high-mass resonances

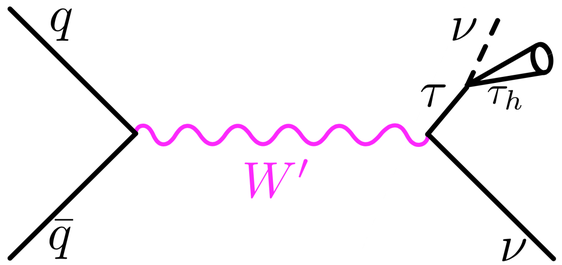
VBF X → HH → bbbb



RS gluon → tt



W’ → tau nu



VBF X → HH → bbbb

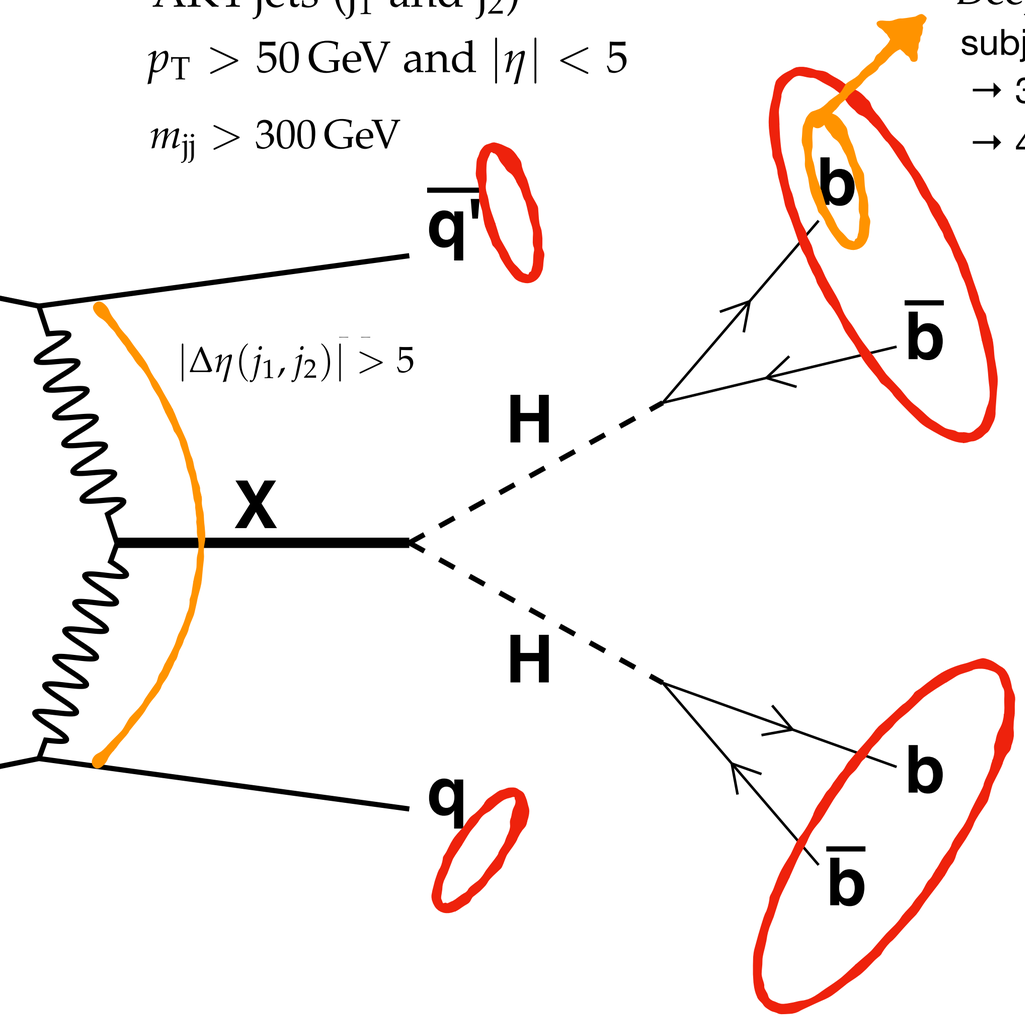
FTR-18-003 and arxiv:1812.07831

AK4 jets (j_1 and j_2)

$p_T > 50\,\text{GeV}$ and $|\eta| < 5$

$m_{jj} > 300\,\text{GeV}$

$|\Delta\eta(j_1, j_2)| > 5$



DeepCSV subjet b tag

→ 3 b tag category

→ 4 b tag category

Higgs tags

AK8 jets, J_1 and J_2

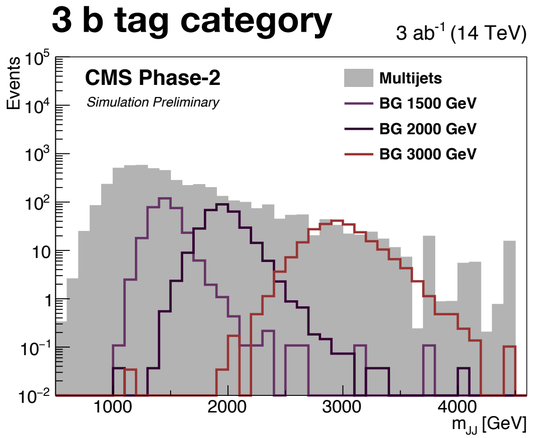
$p_T > 300\,\text{GeV}$

$|\eta| < 3.0$

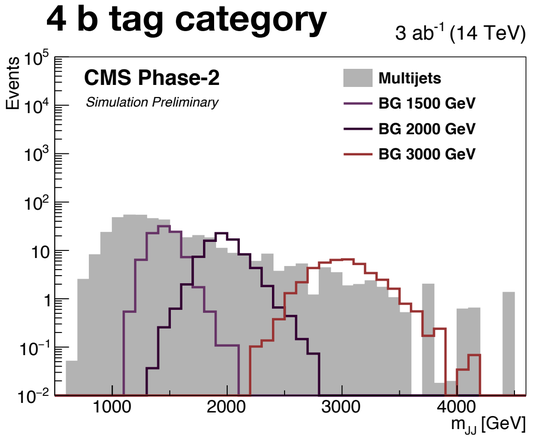
$\tau_{21} < 0.6$

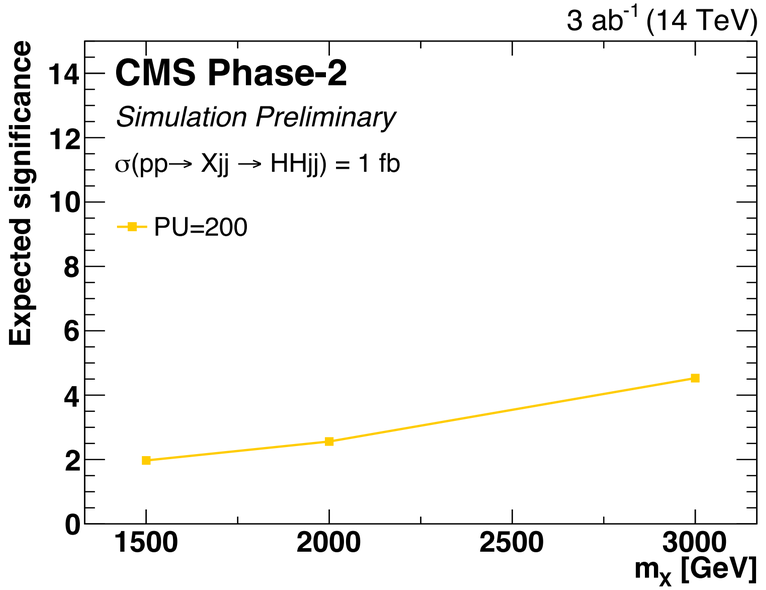
SoftDrop mass 90–140 GeV

3 b tag category



4 b tag category





Bulk graviton

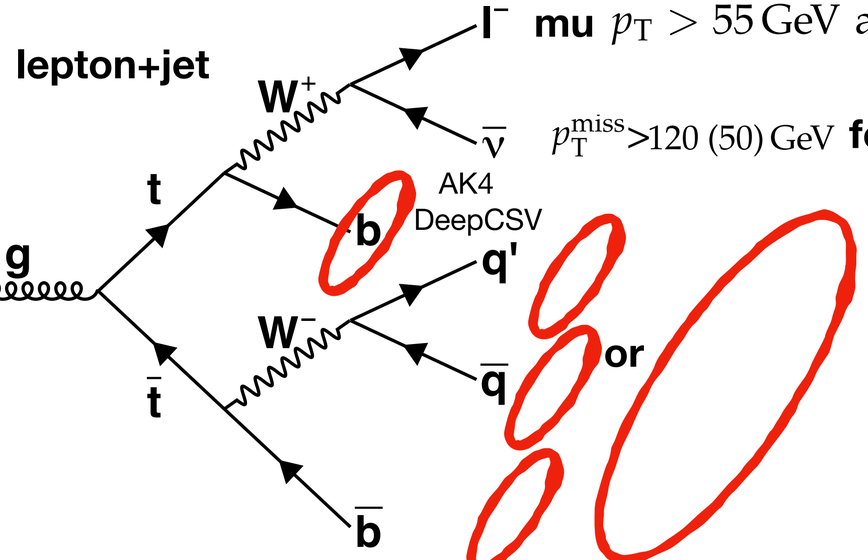
RS gluon → tt

FTR-18-009 and arxiv:1812.07831

e $p_T > 80\,\text{GeV}$ and $|\eta| < 3$

mu $p_T > 55\,\text{GeV}$ and $|\eta| < 3$

lepton+jet

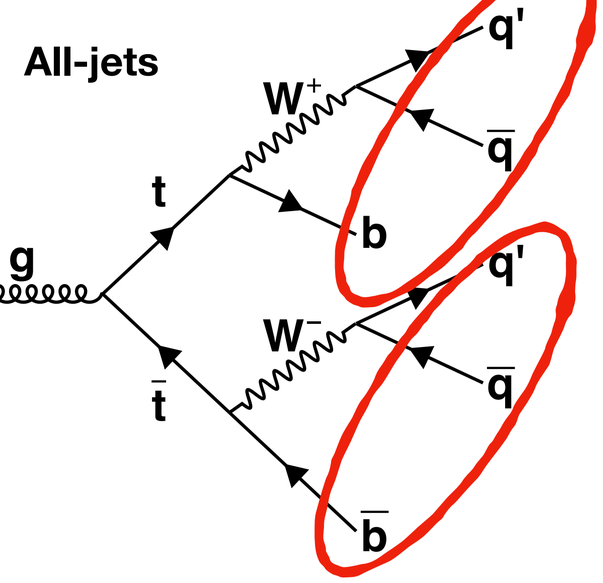


p_T^{miss}>120 (50) GeV **for mu (e)**

AK4 DeepCSV

or

All-jets



Top tagging

AK8 SoftDrop

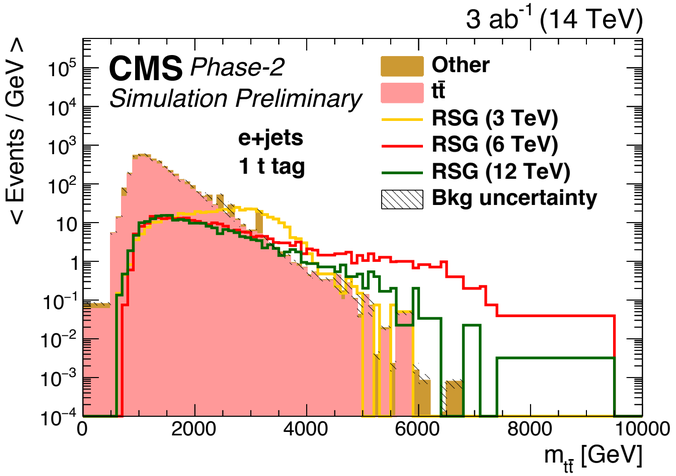
$p_T > 400\,\text{GeV}, |\eta| < 4$

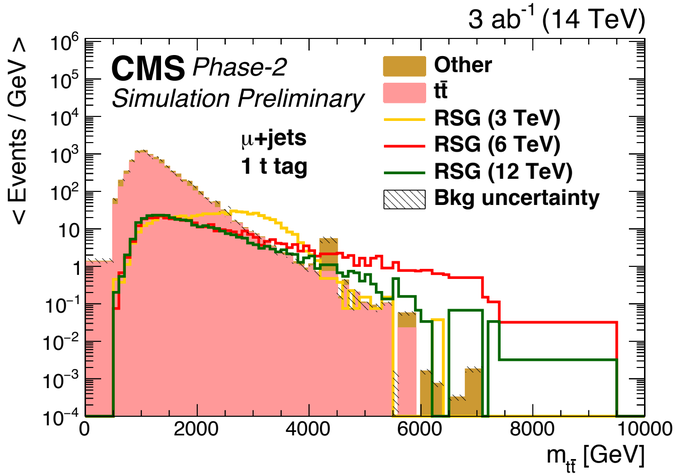
$105 < m_{SD} < 210\,\text{GeV}$

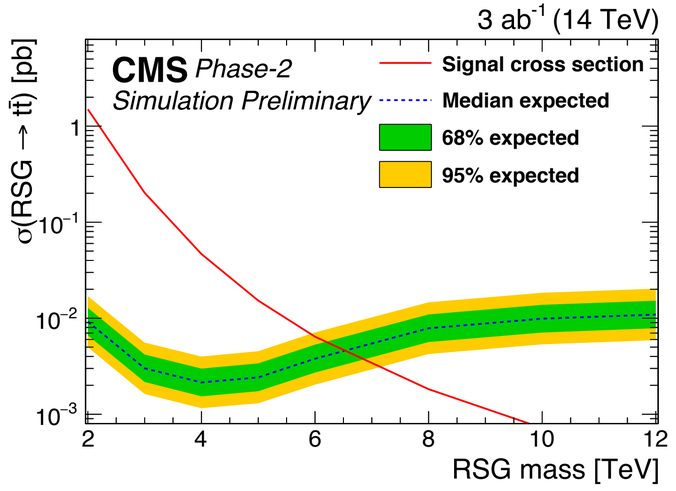
$\tau_3/\tau_2 < 0.65$

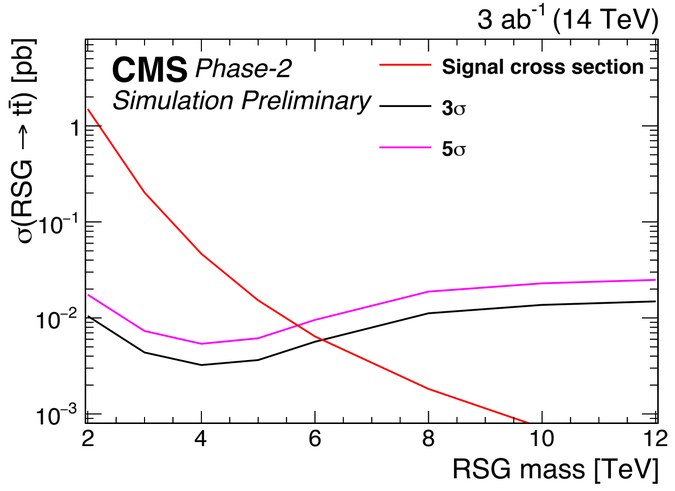
DeepCSV (subjet)

Single lepton









Mass limit 6.5 TeV

5sigma discovery reach 5.5 TeV

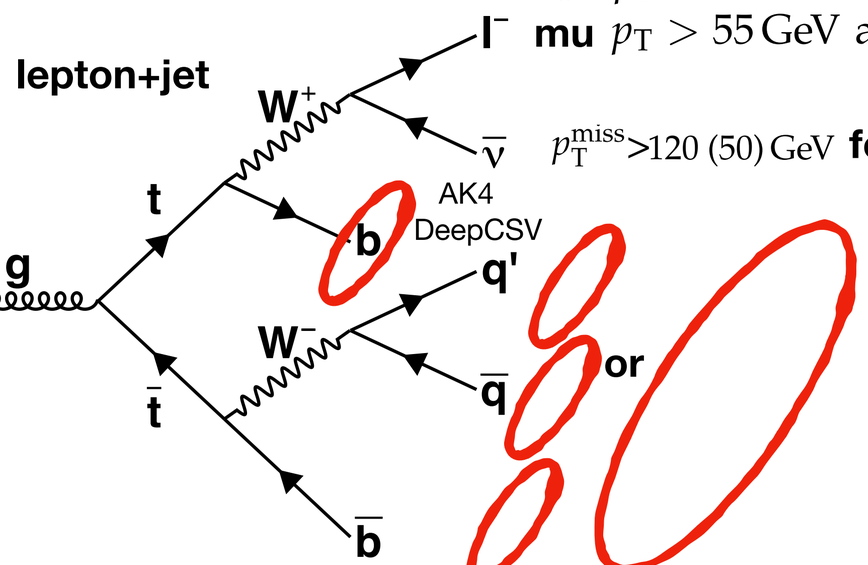
RS gluon → tt

FTR-18-009 and arxiv:1812.07831

e $p_T > 80\,\text{GeV}$ and $|\eta| < 3$

mu $p_T > 55\,\text{GeV}$ and $|\eta| < 3$

lepton+jet

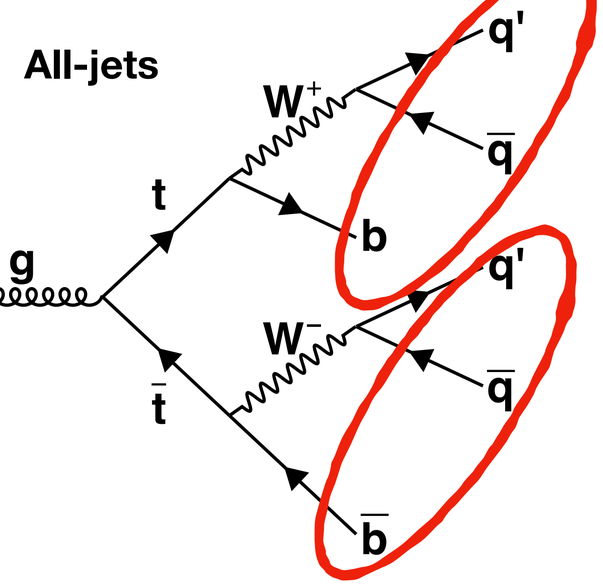


p_T^{miss}>120 (50) GeV **for mu (e)**

AK4 DeepCSV

or

All-jets



Top tagging
AK8 SoftDrop

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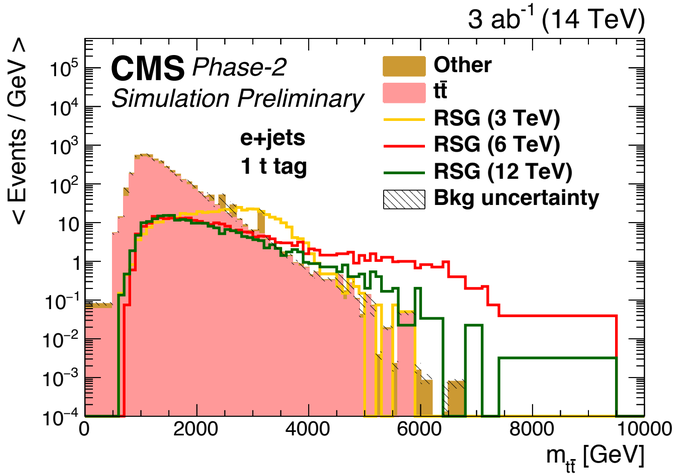
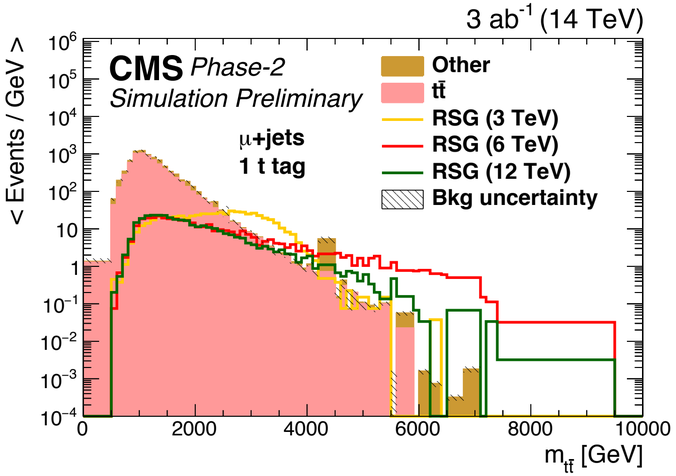
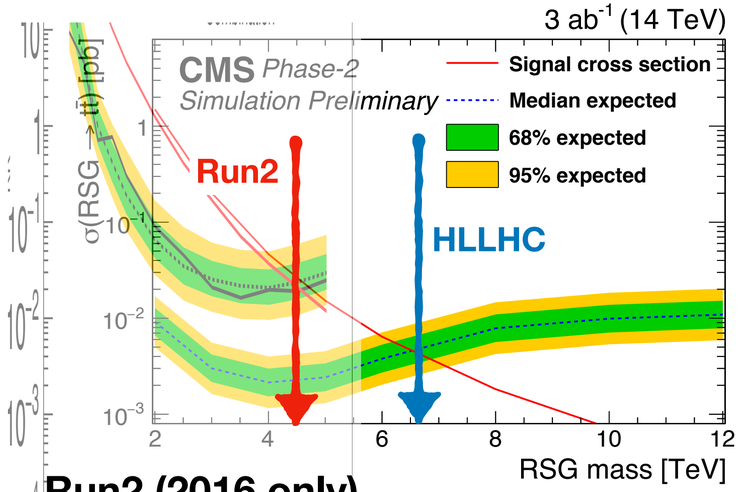
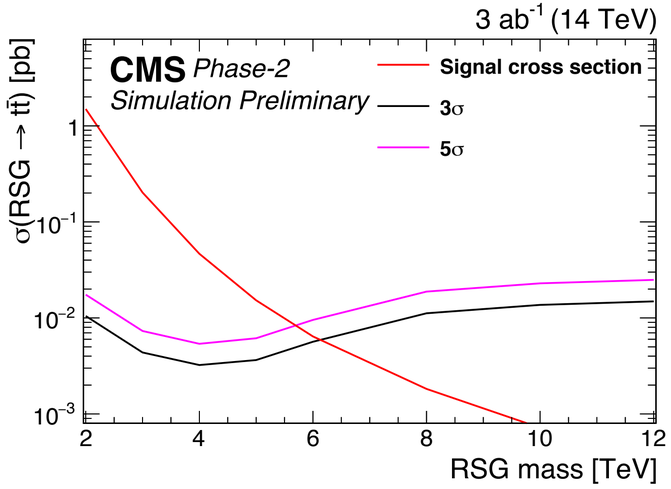
DeepCSV (subjet)

Single lepton









Run2 (2016 only)

arXiv:1810.05905v2

Mass limit 6.5 TeV

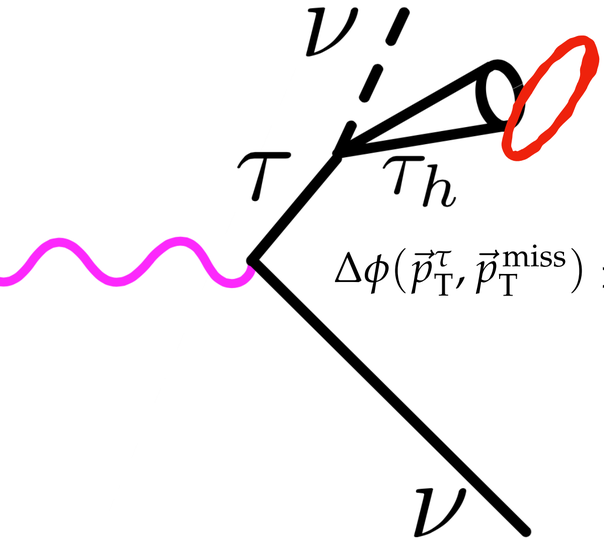
5sigma discovery reach 5.5 TeV

W' → tau nu

AK4 jet

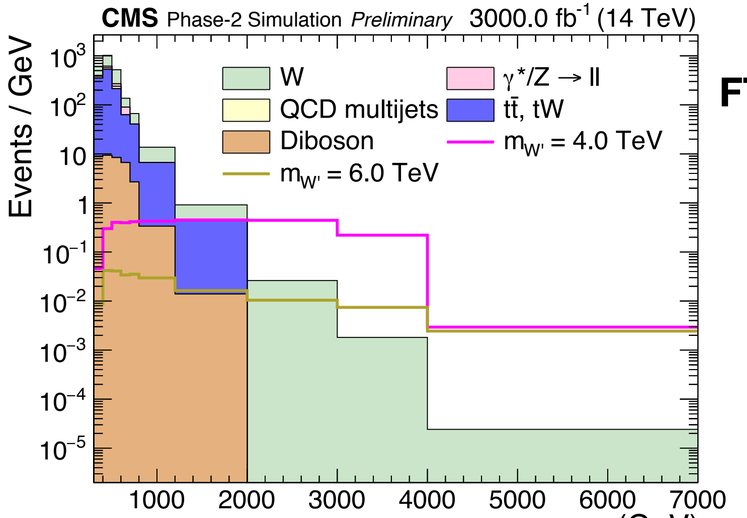
$p_{\mathrm{T}} > 30\,\mathrm{GeV}$ and $|\eta| < 2.7$

tau_h ID



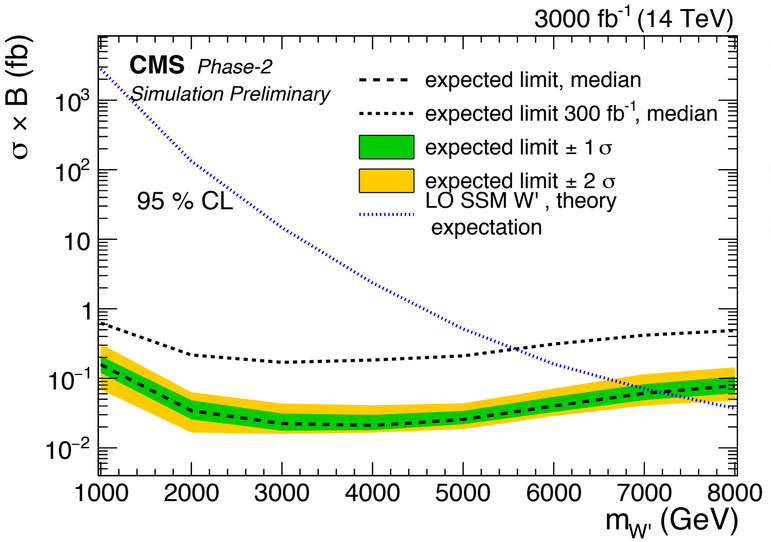
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\,\tau}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}) > 2.4$

$p_{\mathrm{T}}^{\mathrm{miss}}$ satisfies $0.7 < p_{\mathrm{T}}^{\tau}/p_{\mathrm{T}}^{\mathrm{miss}} < 1.3$

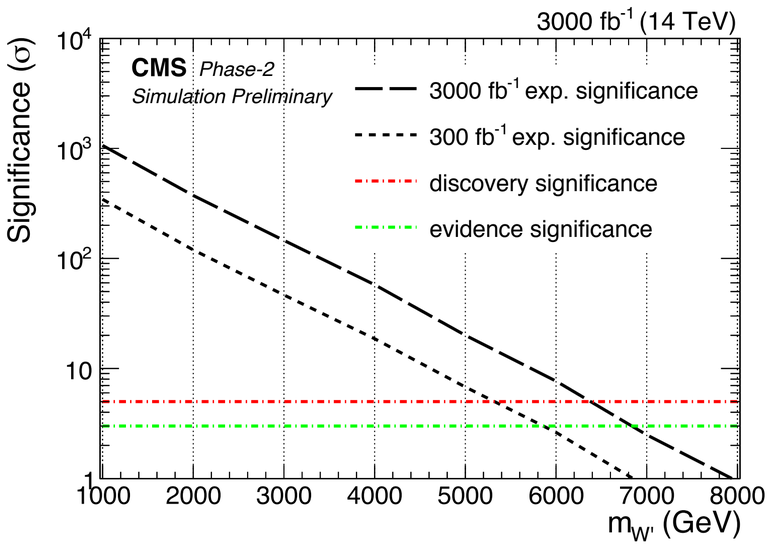


FTR-18-030 and arxiv:1812.07831

$$m_{\mathrm{T}}\,(\mathrm{GeV}) = \sqrt{2 p_T^{\tau} p_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos\Delta\phi(\vec{p}_{\mathrm{T}}^{\,\tau}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}))}$$



Mass limit 7 TeV



5sigma discovery reach 6.3 TeV

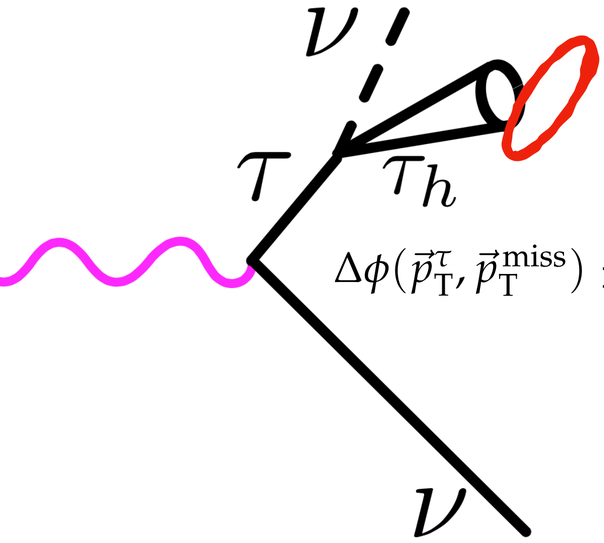
SSM W'

W' → tau nu

AK4 jet

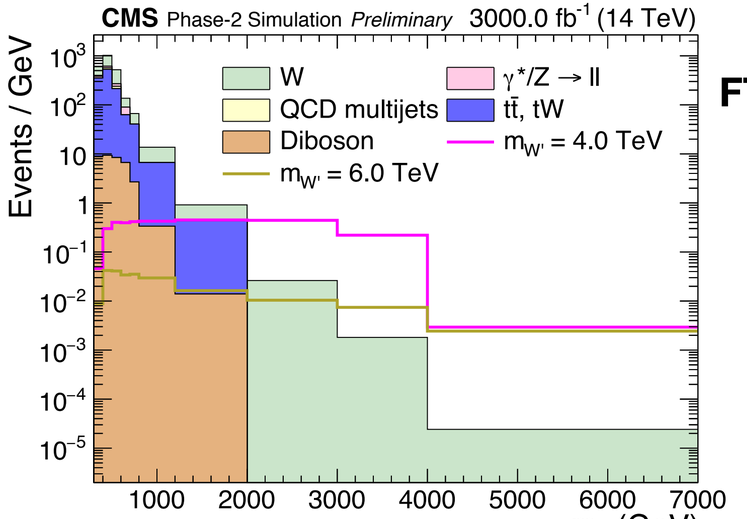
$p_{\mathrm{T}} > 30\,\mathrm{GeV}$ and $|\eta| < 2.7$

tau_h ID



$\Delta\phi(\vec{p}_{\mathrm{T}}^{\,\tau}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}) > 2.4$

$p_{\mathrm{T}}^{\mathrm{miss}}$ satisfies $0.7 < p_{\mathrm{T}}^{\tau}/p_{\mathrm{T}}^{\mathrm{miss}} < 1.3$

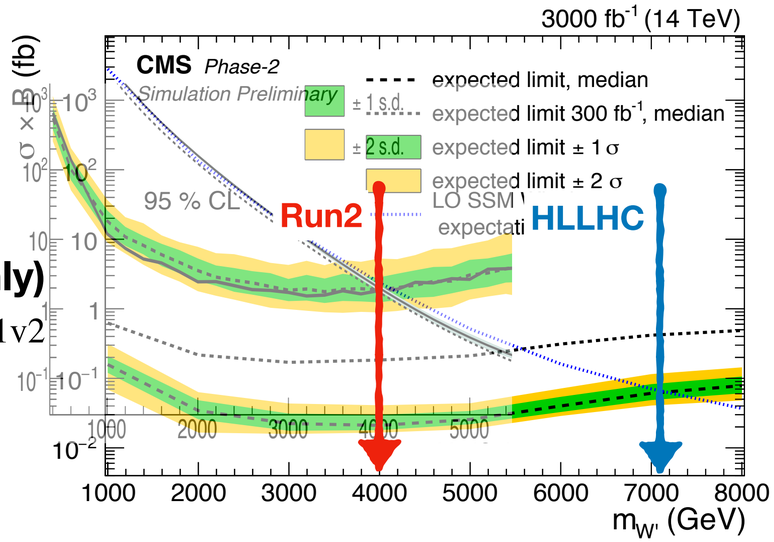


FTR-18-030 and arxiv:1812.07831

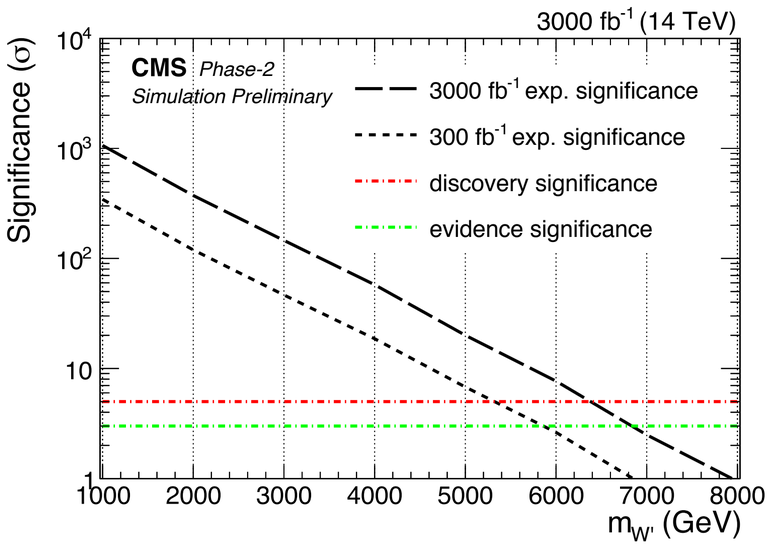
$$m_{\mathrm{T}}\,(\mathrm{GeV}) = \sqrt{2 p_T^{\tau} p_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos\Delta\phi(\vec{p}_{\mathrm{T}}^{\,\tau}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}))}$$

Run2 (2016 only)

arXiv:1807.11421v2



Mass limit 7 TeV



5sigma discovery reach 6.3 TeV

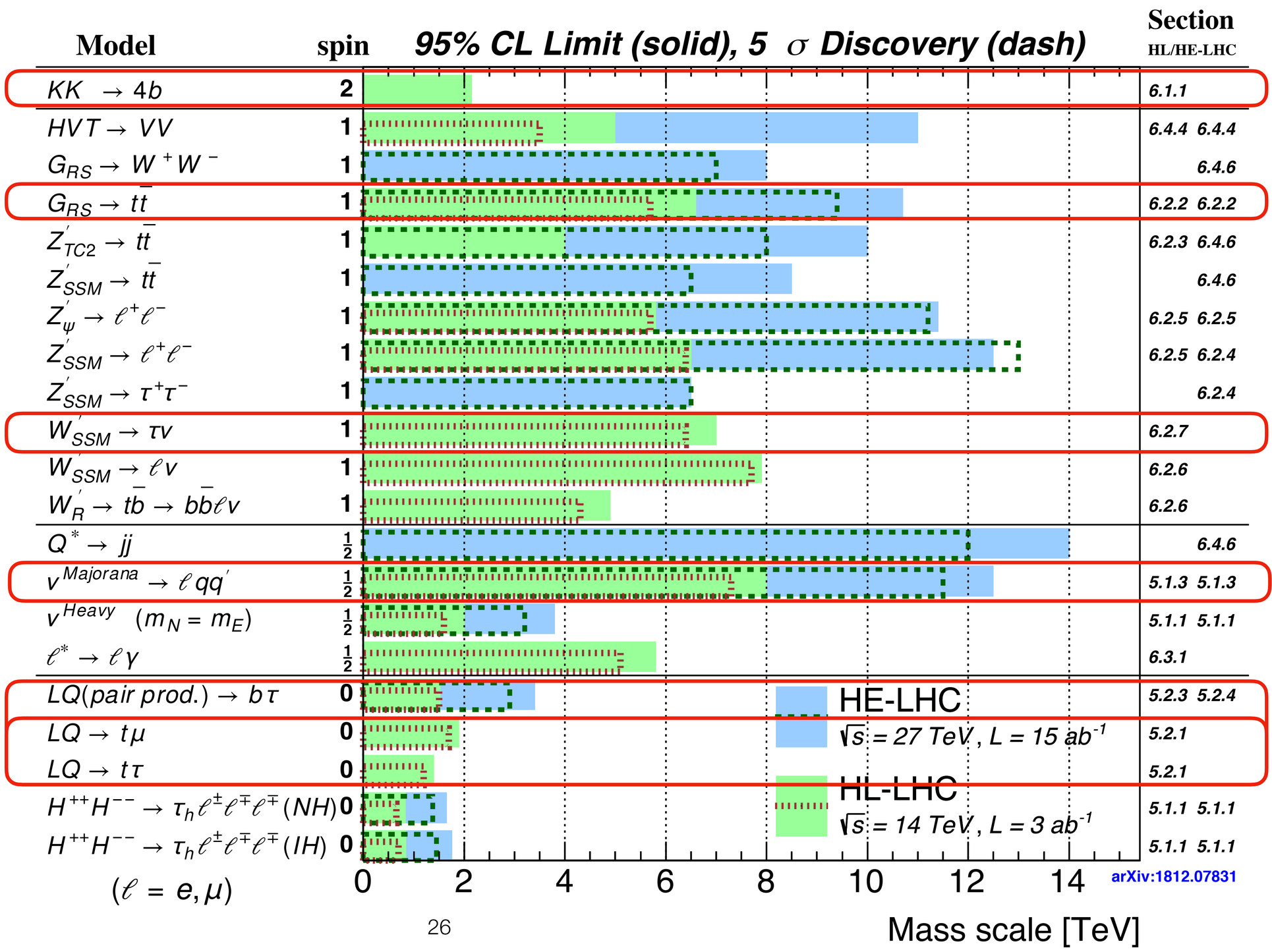
SSM W'

These results collected in the Yellow Report:

Beyond the Standard Model Physics at the HL-LHC and HE-LHC

CMS+ATLAS+LHCb+ALICE +theory

arXiv:1812.07831



summary

- HL-LHC: push the limits of the LHC program
  5-7x inst. luminosity
  14 TeV, 200PU
  10x integrated luminosity of upcoming Run3

- CMS Phase 2: ambitious hardware upgrade
  necessary to cope with radiation damage and 200PU
  new tracker up to eta=4, track trigger
  high granularity forward calorimeter

- Most searches will greatly benefit the increased luminosity and the improved detector.
  5sigma discovery achievable for multi-TeV resonances
  Some resonance searches reaching the limits of the phase space

Backup