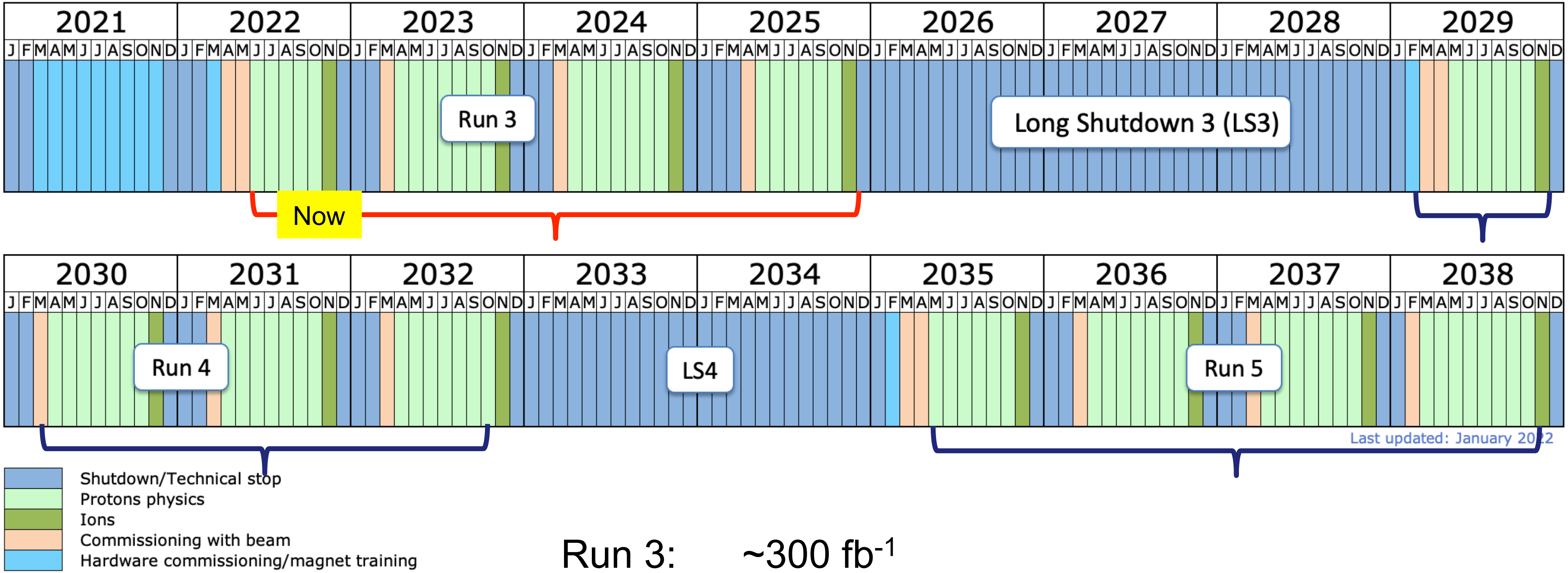
LHC Run-3 expectations and HL-LHC

S. Paganis (NTU Taiwan) on behalf of ATLAS, CMS and LHCb

LHCDays 2022, 3-Oct-2022

LHC long-term plan



Run 3: ~300 fb^{-1}
HL-LHC: ~3000 fb^{-1}

Introduction

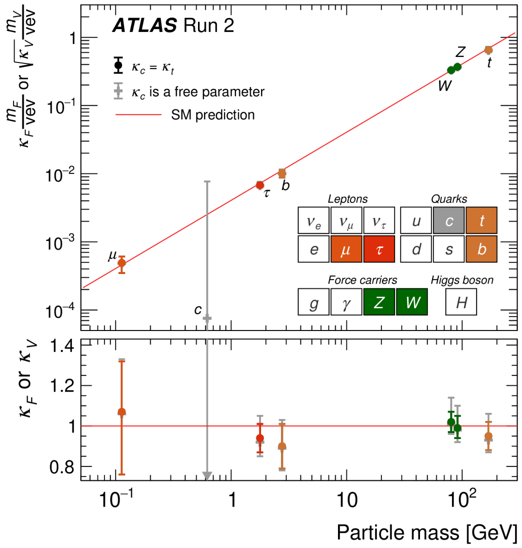
LHC Run 3 just started: 10 years after the discovery!

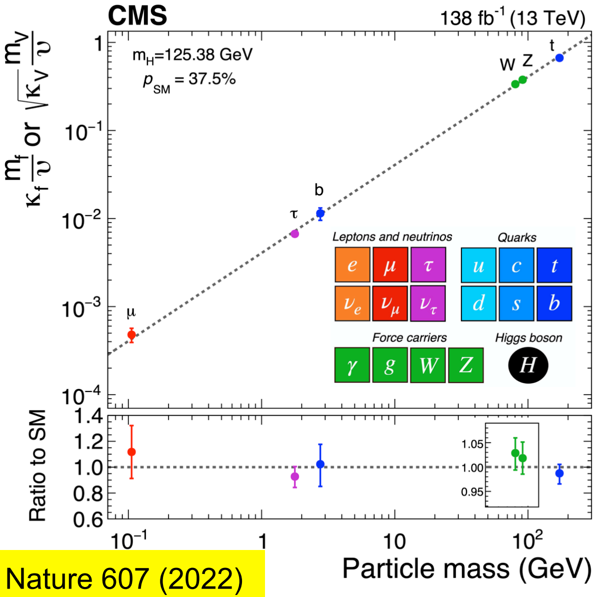
Run-2 data are still being analyzed but a number of flagship analyses have been completed.

All measurements suggest what we have found is the SM Higgs.

- What makes the Higgs?
- What stabilizes the Higgs mass?
- Where is the New Physics?

Run 2: some excesses observed.
Run 3: improved searches, more parameter space covered.
HL-LHC: "Higgs precision"
improve our detectors, exploit the HL





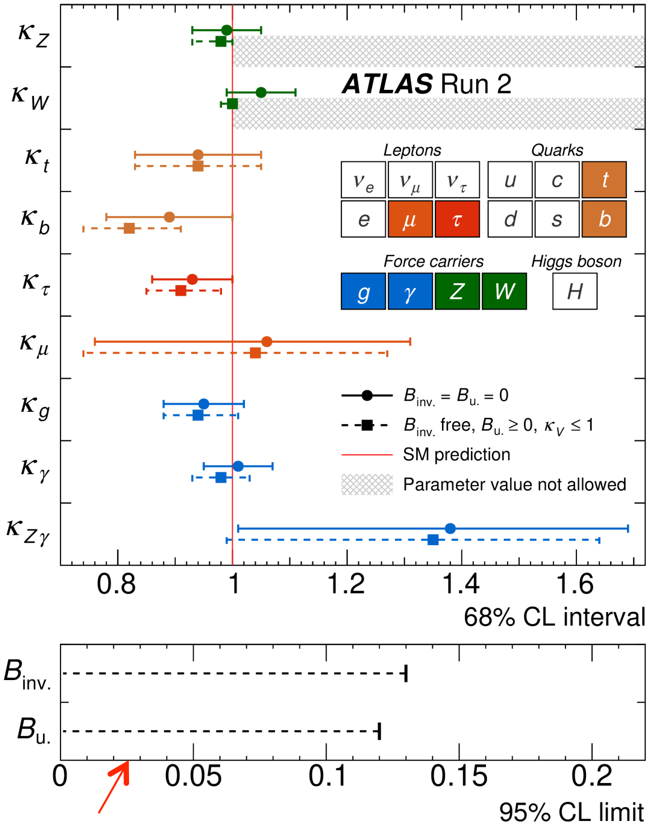
Nature 607 (2022)

Continuing measurements in run 3

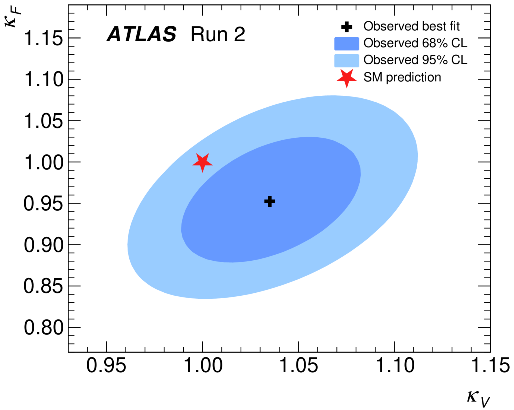
- Higg and EW Precision:
    - Couplings, Mass & Width, Spin Parity, STXS & Differential, **W mass**, …
- New massive particles: new Higgs, new scalars, new vectors, Gravitons, Susy
    - Diphoton, Dilepton, Dijet FS, etc.
- Massive diboson final states: VV, VH, HH
    - Heavy Resonances
- Long-lived particles
- Effective Field Theory (EFT)
- B physics: CPV, CKM measurements, mixing, spectroscopy
- B anomalies related measurements

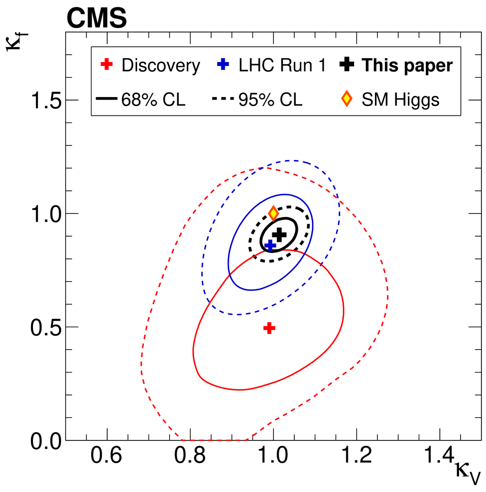
Categories overlap/correlate; classification helps keep track of various observables.

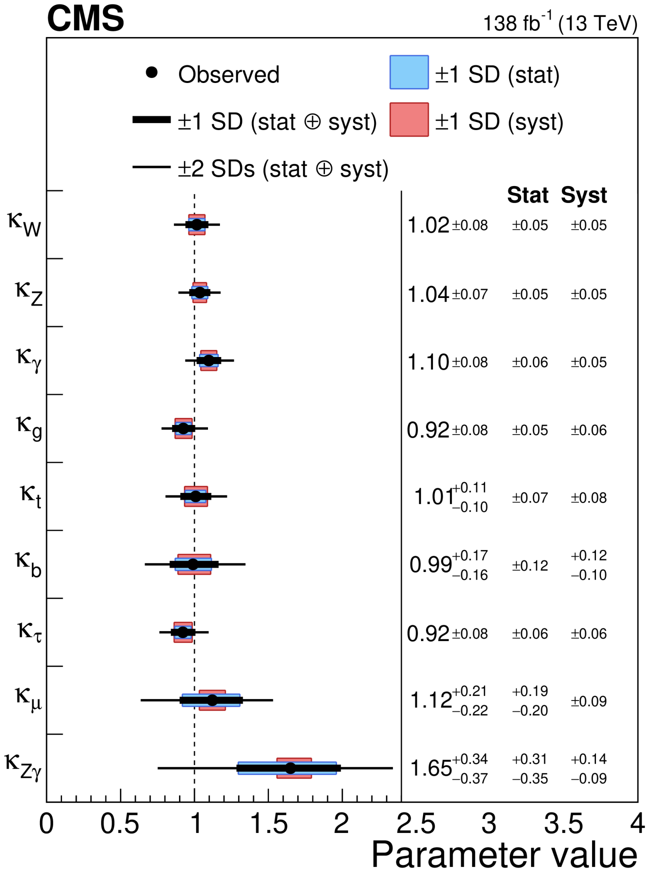
SM Higgs precision in run 2



Invisible and undetected
non-SM Higgs boson decays BR







Nature 607 (2022)

Searches for BSM physics

A sample from run 2

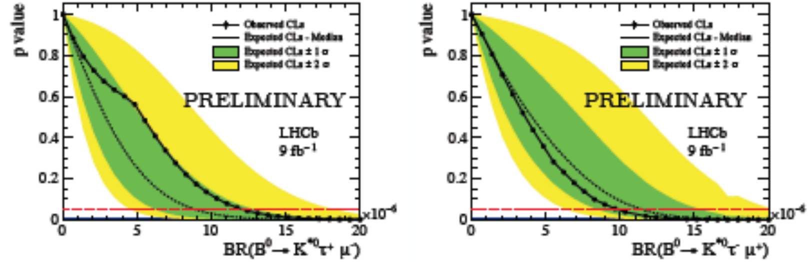
Lepton Flavour number Violation

(F. Blanc ICHEP22)

- Search for $B^0 \to K^{0*}\tau^\pm\mu^\mp$
  - partial $\tau^\pm \to \pi^\pm\pi^+\pi^-(\pi^0)\bar{\nu}_\tau$ reconstruction

$\mathscr{B}(B^0 \to K^{*0}\tau^+\mu^-) < 1.0(1.2) \times 10^{-5}$ @90%(95%) C.L.
$\mathscr{B}(B^0 \to K^{*0}\tau^-\mu^+) < 8.2(9.8) \times 10^{-6}$ @90%(95%) C.L.

LHCb-PAPER-2022-021, 2209.09846

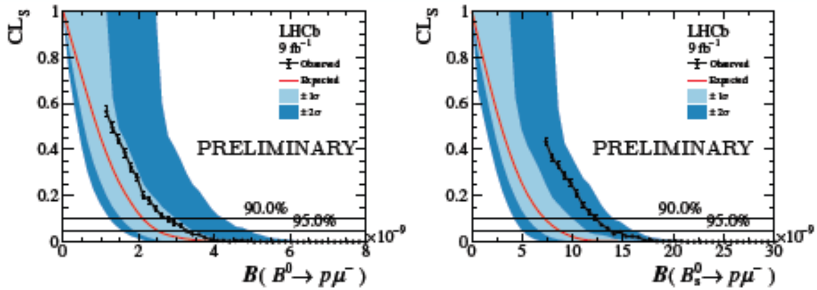


- Search for $B^0_{(s)} \to p\mu^-$

(also Baryon number violating)

$\mathscr{B}(B^0 \to p\mu^-) < 2.6(3.1) \times 10^{-9}$ @90%(95%) C.L.
$\mathscr{B}(B^0_s \to p\mu^-) < 1.2(1.4) \times 10^{-8}$ @90%(95%) C.L.

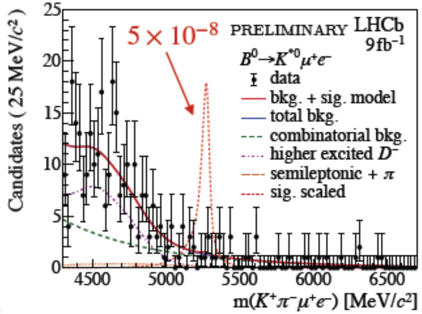
LHCb-PAPER-2022-022 (in preparation)



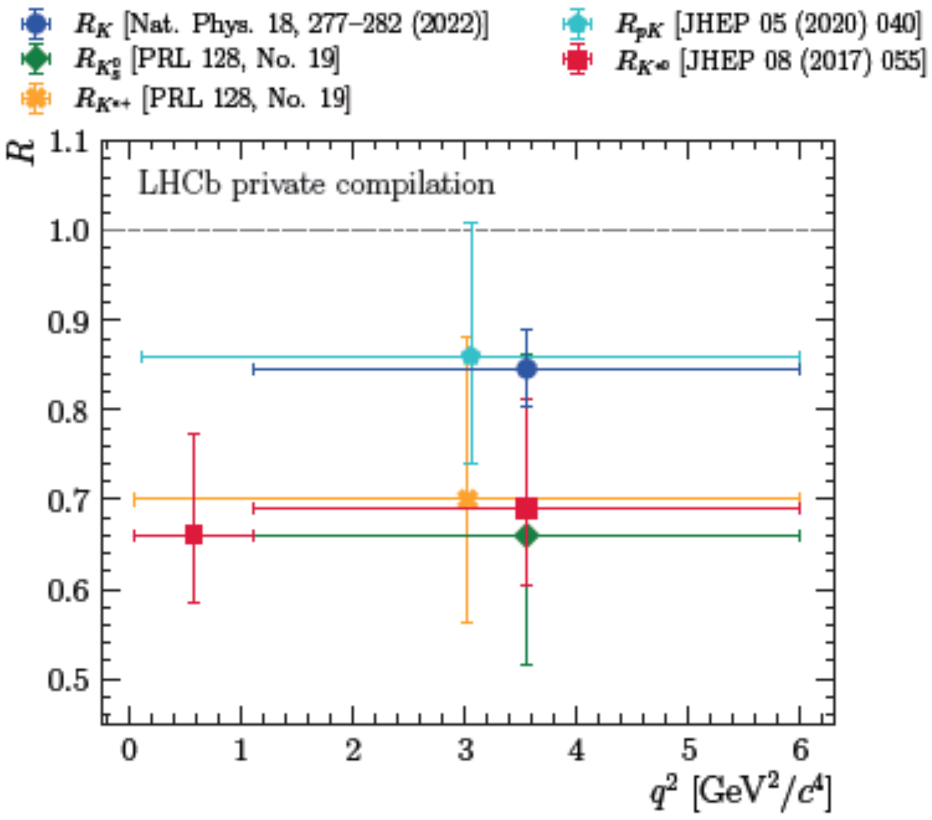
- Search for $B^0 \to K^{0*}\mu^\pm e^\mp$ and $B^0_s \to \phi\mu^\pm e^\mp$

$\mathscr{B}(B^0 \to K^{*0}\mu^+e^-) < 5.7(6.9) \times 10^{-9}$ @90%(95%) C.L.
$\mathscr{B}(B^0 \to K^{*0}\mu^-e^+) < 6.8(7.9) \times 10^{-9}$ @90%(95%) C.L.
$\mathscr{B}(B^0 \to K^{*0}\mu^\pm e^\mp) < 10.1(11.7) \times 10^{-9}$ @90%(95%) C.L.
$\mathscr{B}(B^0_s \to \phi\mu^\pm e^\mp) < 16.0(19.8) \times 10^{-9}$ @90%(95%) C.L.

LHCb-PAPER-2022-008, 2207.04005



Lepton Flavour Universality: b→sℓℓ



Check LFU in b→sℓℓ decays

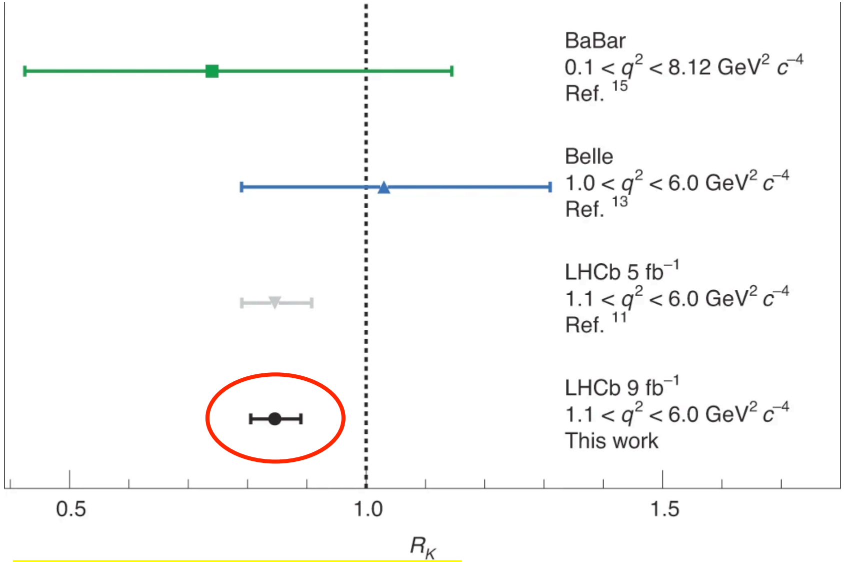
$$R_X = \frac{Br(B \to X\mu^+\mu^-)}{Br(B \to Xe^+e^-)}$$

Run 1 + Run 2 results (9 fb^{-1}) in bins of q^2 for RK (also see next slide)

Updates with full dataset in preparation:

- R_{pK}, R_ϕ, $R_{K\pi\pi}$
- Unified analysis of R_K R_{K^*} with more q^2 bins

Lepton Flavour Universality



Nature 18 (2022) 3, 277-282

3.1σ anomaly

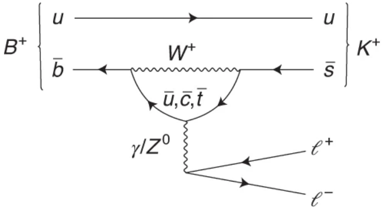
New ↓

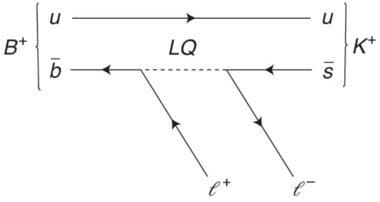
CMS: BR($B_s \rightarrow \mu\mu$) is SM like
CMS-BPH-21-006 (slide 30)

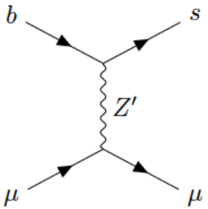
To help overcome the challenge of modeling precisely the different e/μ reconstruction efficiencies, the branching fractions of $B^+ \to K^+\ell^+\ell^-$ decays are measured relative to those of $B^+ \to J/\psi K^+$. Since the $J/\psi \to \ell^+\ell^-$ branching fractions are known to respect lepton universality to within 0.4%, the R_K ratio is determined via the double ratio of BRs

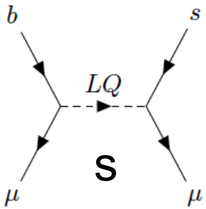
$$R_K = \frac{\mathcal{B}\,(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}\,(B^+ \to J/\psi(\to \mu^+\mu^-)K^+)} \Big/ \frac{\mathcal{B}\,(B^+ \to K^+e^+e^-)}{\mathcal{B}\,(B^+ \to J/\psi(\to e^+e^-)K^+)}$$

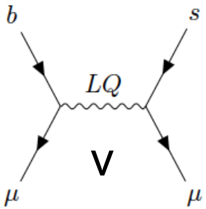
R_K probes the ratio of B-meson decays to muons and electrons.
Testing LFU in such $b \to s\,\ell^+\ell^-$ transitions: SM contributions suppressed, theoretical predictions very precise.







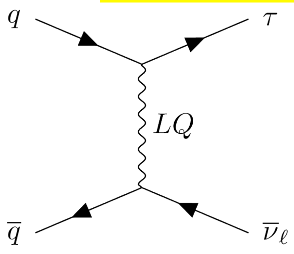




BSM particles can mediate b,s at tree level

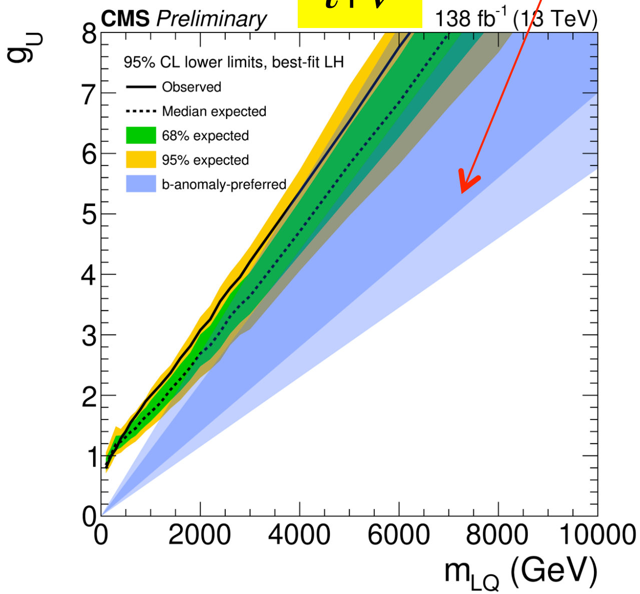
LQ searches related to b-anomalies

ICHEP22: LQ coupling to bτ CMS-PAS-EXO-21-009

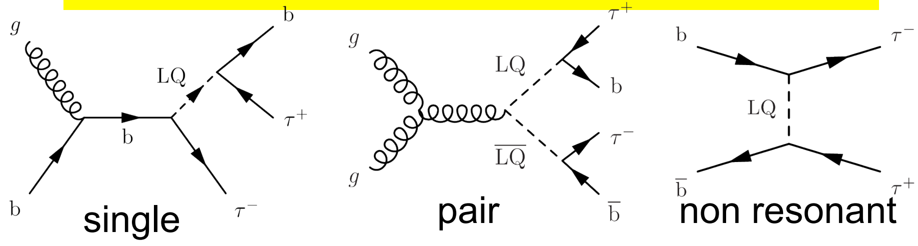


Exclusion limits on the mass and coupling of LQ; the sensitivity of this analysis reaches into the parameter space of LQ models that could explain B-anomalies. Most stringent to date.

$\tau + \nu$



ICHEP22: search for LQ to bτ CMS-PAS-EXO-19-016



$\tau\tau$+b, $\tau\tau$+bb, $\tau\tau$

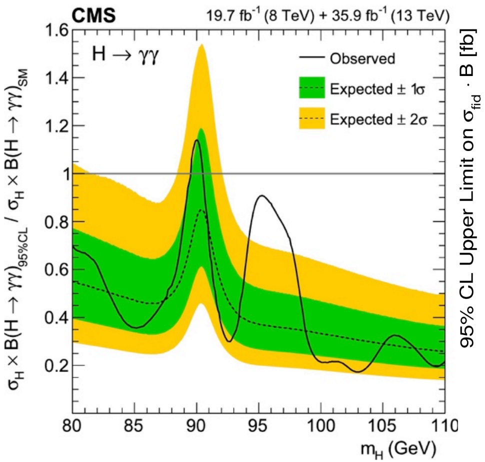
ττ continuum showed an excess:

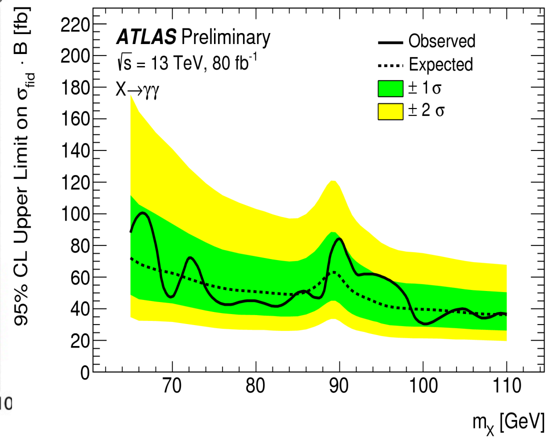
- For a representative LQ **mass of 2 TeV** and a **coupling strength of 2.5**: excess of **3.4σ**

ATLAS similar analysis: ATLAS-CONF-2022-037

From both single and pair LQ production processes, under the assumption of exclusive decays of scalar LQ to $b\tau$, LQ masses below **1.26 TeV, 1.30 TeV and 1.41 TeV are excluded** for a **scalar LQ Yukawa coupling to *b*-quark and *τ*-lepton of 1.0, 1.7 and 2.5, respectively.**

h(95GeV)→γγ





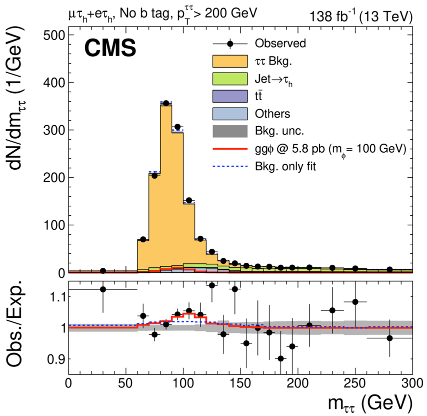
PLB 793 (2019) 320

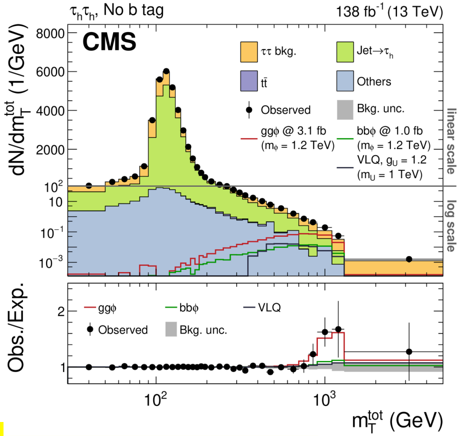
ATLAS-CONF-2018-025

CMS 8TeV and 13TeV(2016) data show an excess
Full run 2 result coming soon.

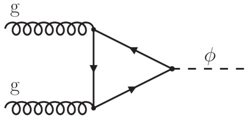
Observed excess with respect to the SM prediction, which is maximal for a mass hypothesis of **95.3 GeV** with a local (global) significance of **2.8 (1.3)** σ.

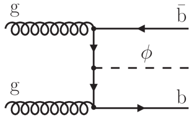
A/H/h→ττ

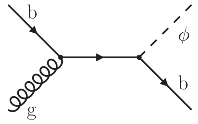




CMS-HIG-21-001 August 2022, reports two excesses.







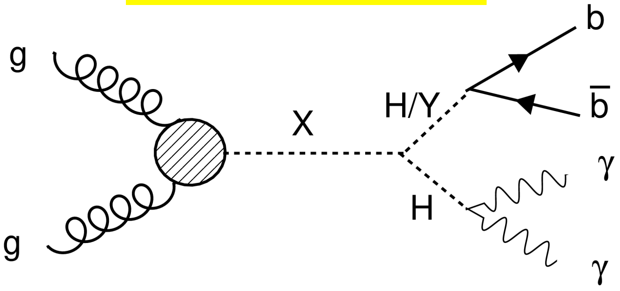
ATLAS: PRL 125 (2020) 051801:
no excess at 1.2TeV, but 100GeV not measured.

Two excesses for ggF with local(global) p-values:

- **3.1σ (2.7σ)** at m_φ = 100 GeV
- **2.8σ (2.4σ)** at m_φ = 1.2 TeV

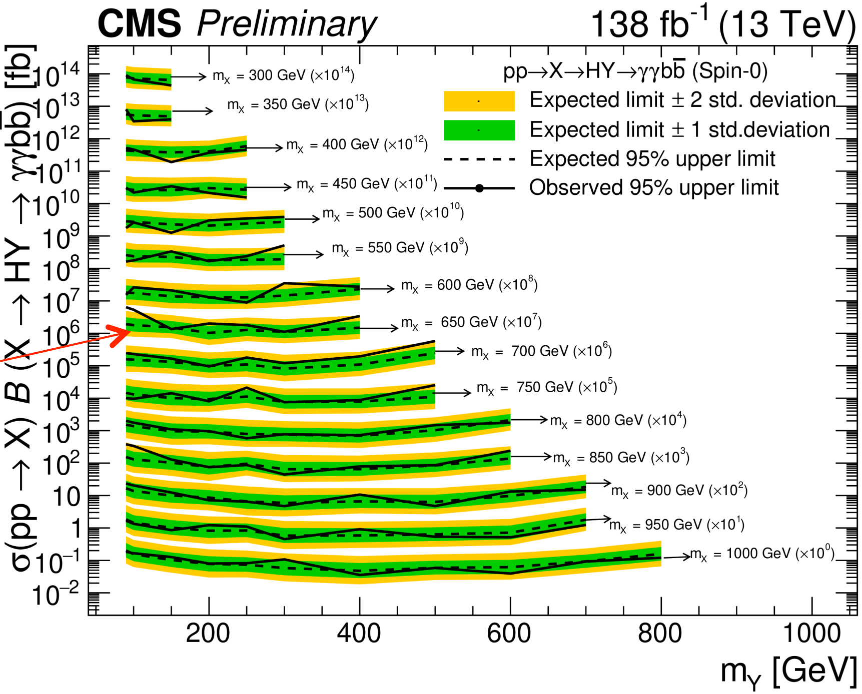
scalar X→Higgs+Y→γγ+bb

CMS-PAS-HIG-21-011



B-only hypothesis: local (global) significance of **3.8 (2.8)** σ is observed for **m_X = 650 GeV** and **m_Y = 90 GeV**.

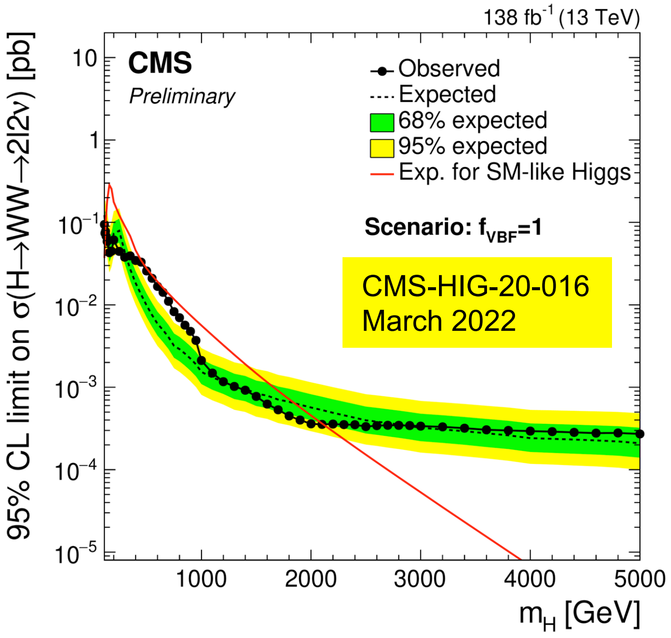
- The HH limits are compared with predictions in the warped extra dimensional model.
- The HY limits are interpreted with the next-to-minimal super-symmetric standard model and the two-real scalar-singlet model.



ATLAS-CONF-2022-045
20-Jul-2022

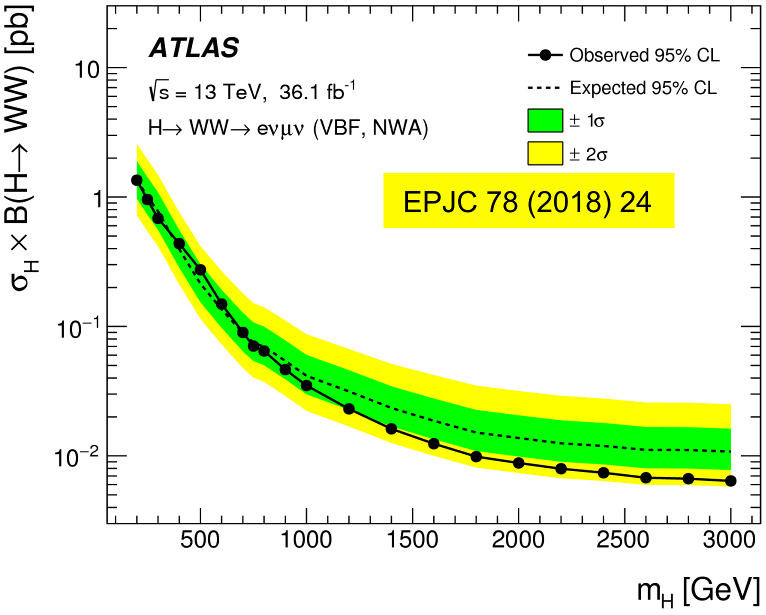
X→Higgs+Y→bb+jj (Higgs to bb)
No excess. Set limits for signals with m_X between 1.5 and 6 TeV and m_Y between 65 and 3000 GeV

h(650 GeV)→WW→2ℓ2ν



Highest global significance **2.6σ** for a resonance mass of 650 GeV in the scenario where only VBF production is considered.

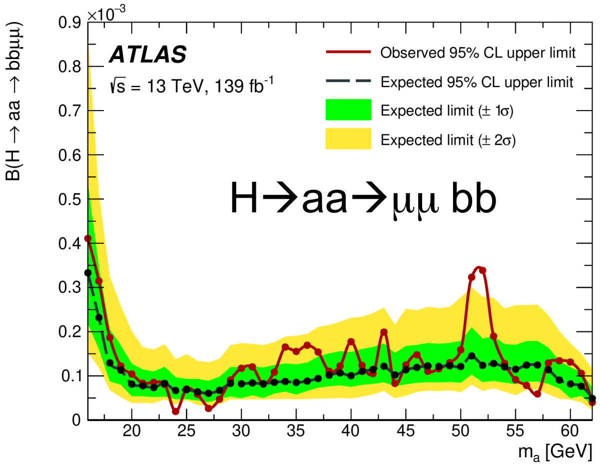
Heavy SM-like Higgs boson excluded at 95% CL up to 2100 GeV, assuming the relative contribution of ggF and VBF production is SM-like and also assuming only VBF production.



ATLAS with 36.1 fb^{-1} shows no excess

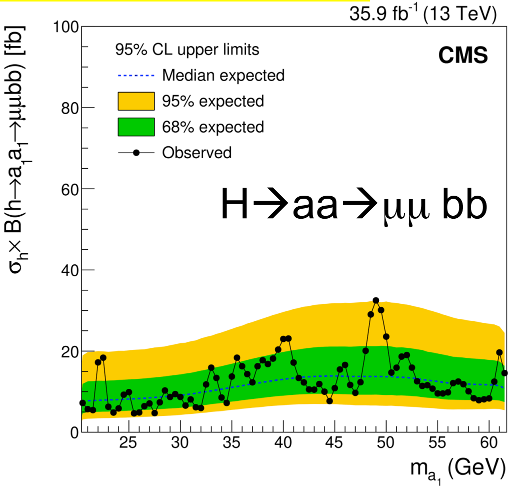
50GeV excess in Higgs→aa

Search for Higgs decays to two light pseudoscalars



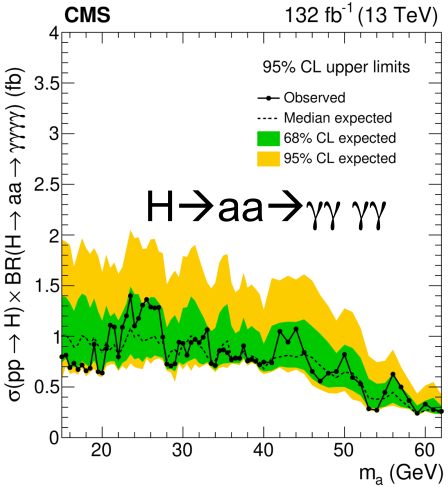
Phys.Rev.D 105 (2022) 012006

Local (global) excess 3.3σ (1.7σ)



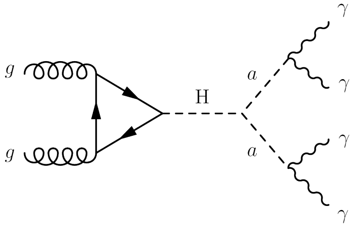
PLB 795 (2019) 398-423

Full run-2 analysis coming soon

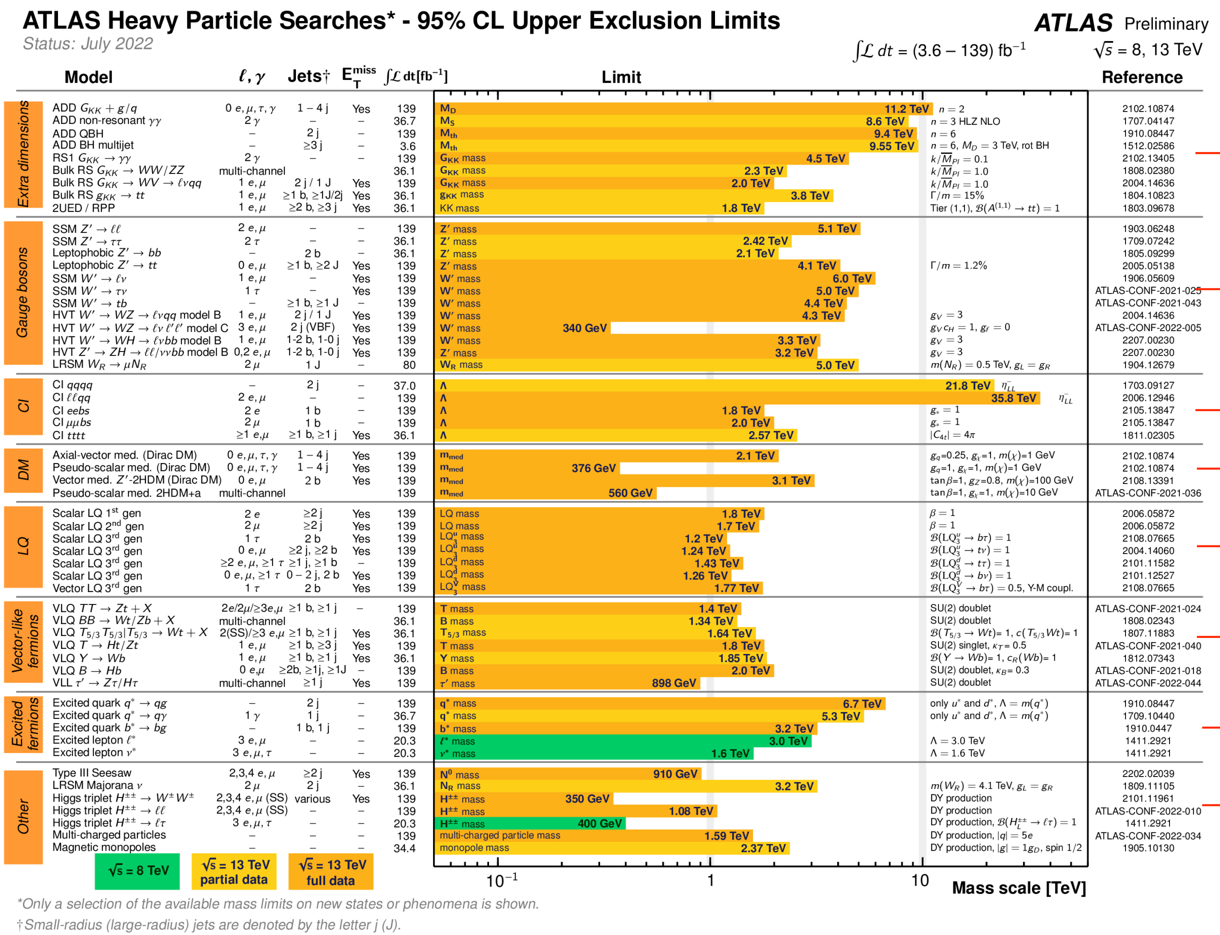


CMS-HIG-21-003 2-Aug-22

No excess in new γγ+γγ result

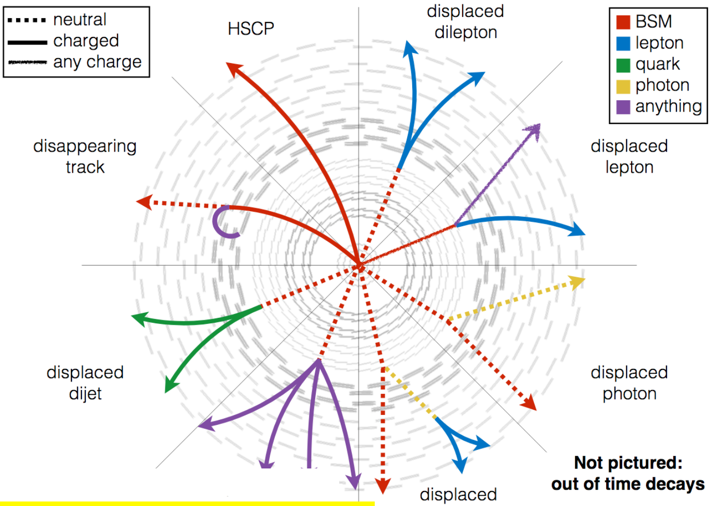


ATLAS: heavy particle searches

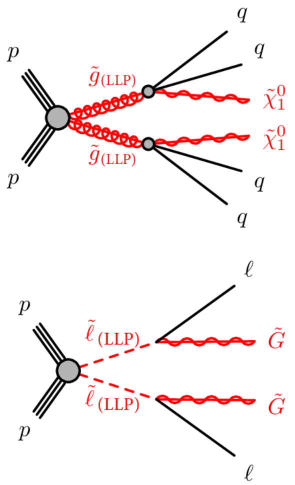


- Extra dimensions
- Gauge bosons
- Contact Interactions
- Dark matter
- Leptoquarks
- Vector-like fermions
- Excited fermions
- Type III seesaw, LRSM Majorana, Higgs triplet, multi-charged particles, monopoles

Long-lived particles

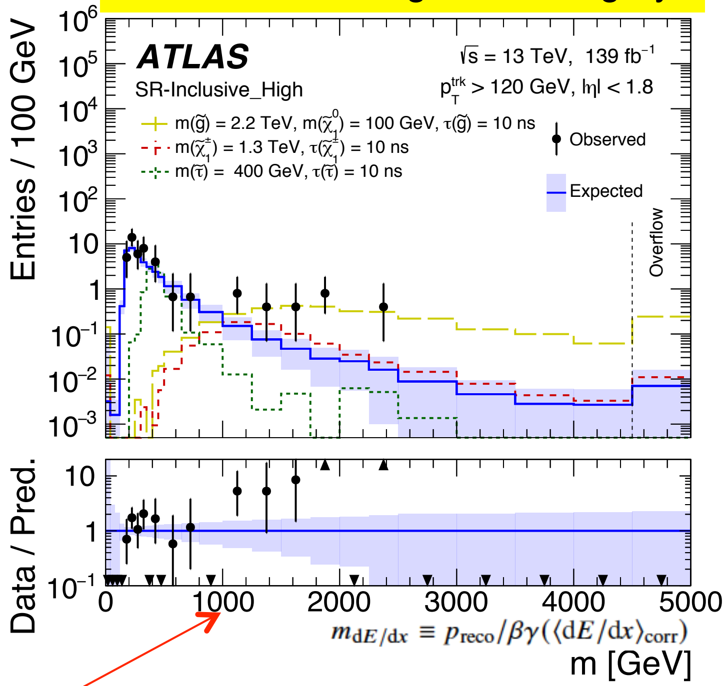


picture from J. Antonelli



ATL-SUSY-2018-42
12-May-2022

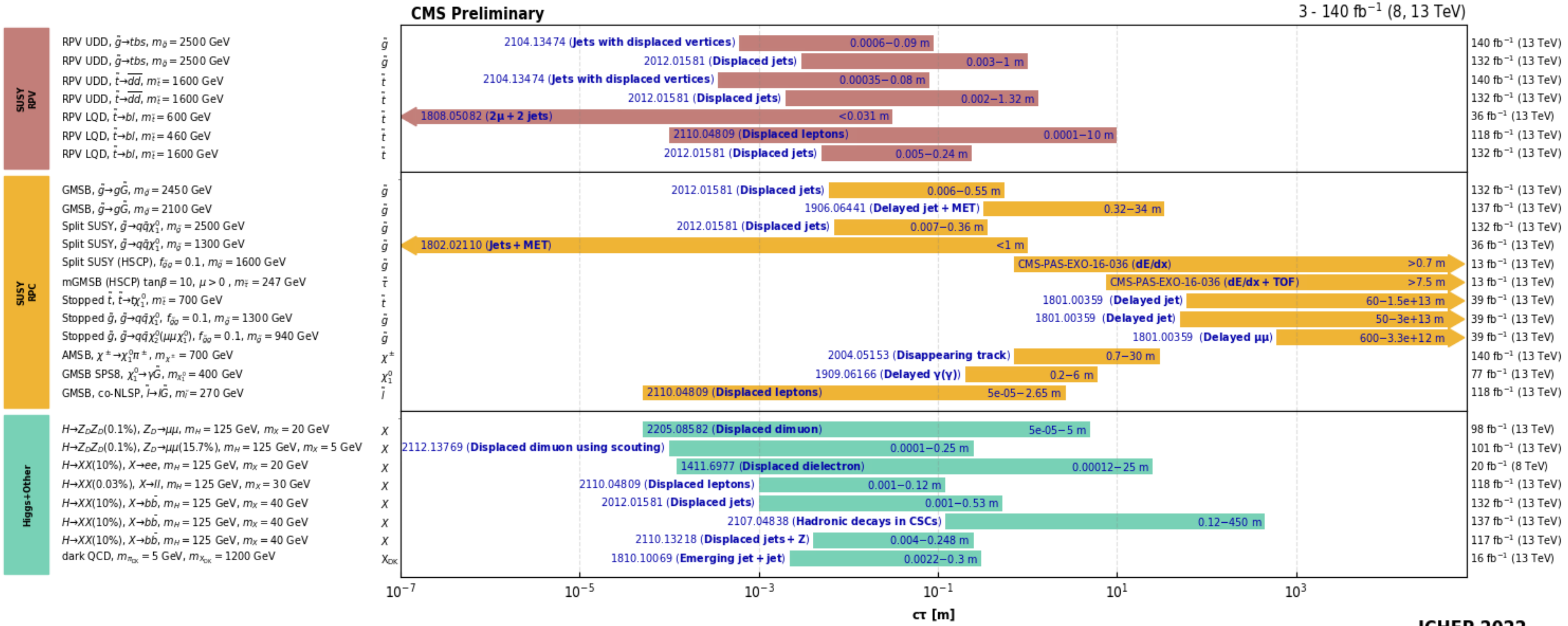
$\mathrm{d}E/\mathrm{d}x$ > 2.4 MeV g^{-1}cm^2 category



Reconstructed mass spectrum for the SM expectation (blue line) and observed data (black dots). Different possible signals that are tested by the search are shown in dashed colours. A small excess of events is observed above 1000 GeV in mass, the local (global) significance of this excess is **3.8 (3.3)** σ.

Long lived particle search status

Overview of CMS long-lived particle searches

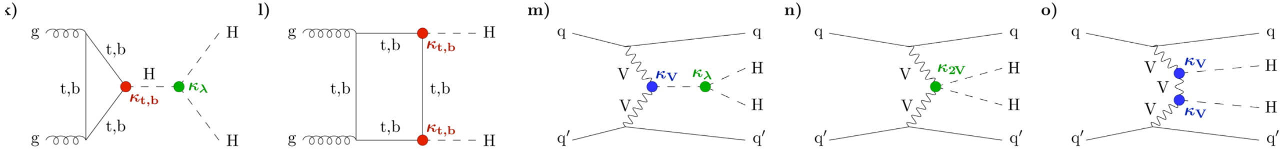


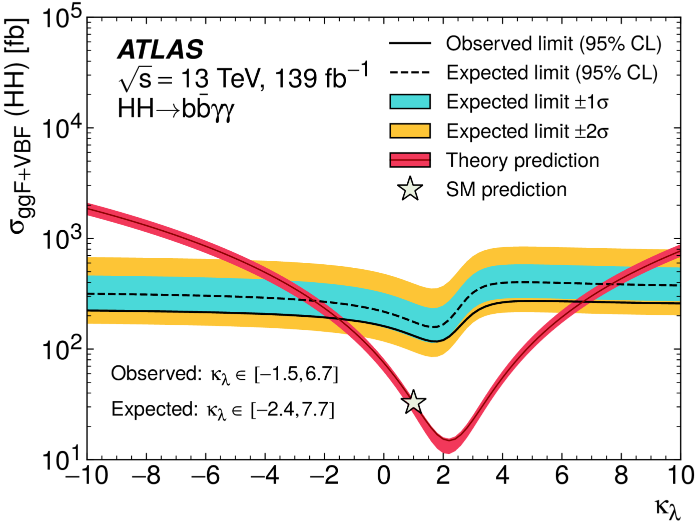
ICHEP 2022

Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). The y-axis tick labels indicate the studied long-lived particle.

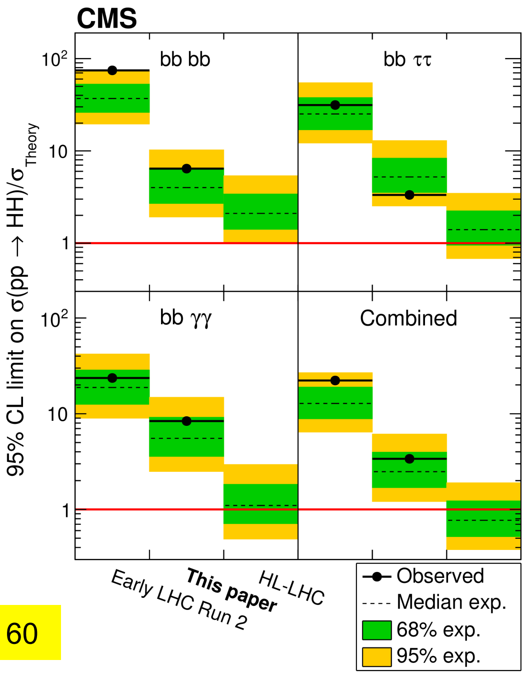
Higgs pair production

Higgs boson pair production





ATLAS-HDBS-2018-34

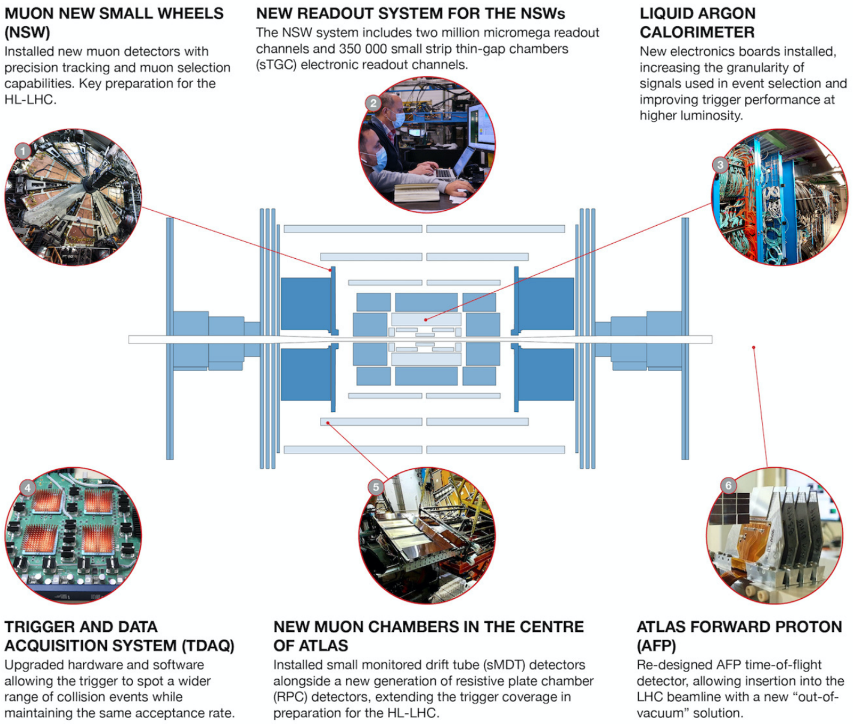


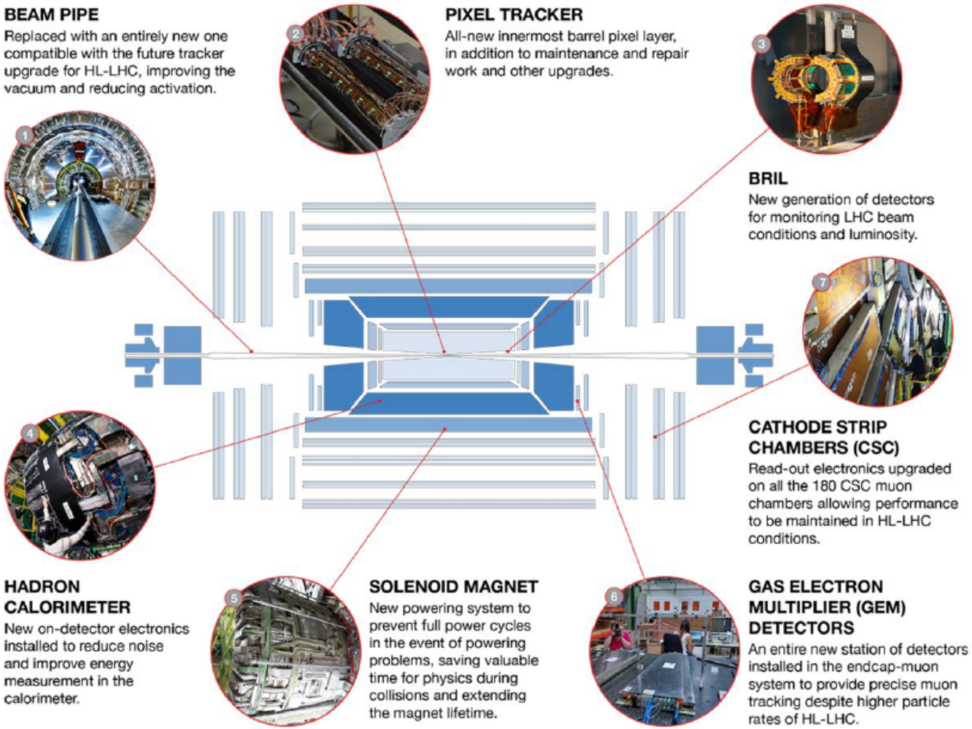
Nature 607 (2022) 60

Observed and expected limits at 95% CL on the cross section of **non-resonant Higgs-boson pair production** as a function of the Higgs-boson self-coupling modifier $\kappa_\lambda = \lambda_{HHH}/\lambda^{SM}_{HHH}$.

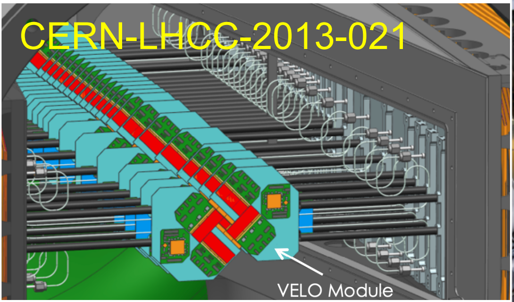
expected and observed limits on HH production in:
- early LHC Run 2 data (35.9 fb^{-1}),
- present using full LHC Run 2 data (138 fb^{-1})
- projections for the HL-LHC (3000 fb^{-1})

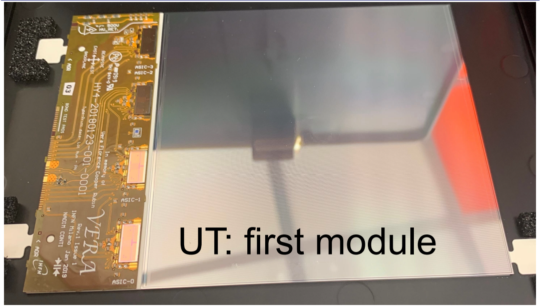
Run-3 ATLAS and CMS upgrades

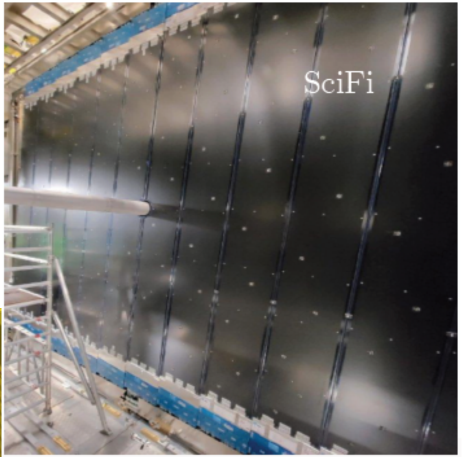


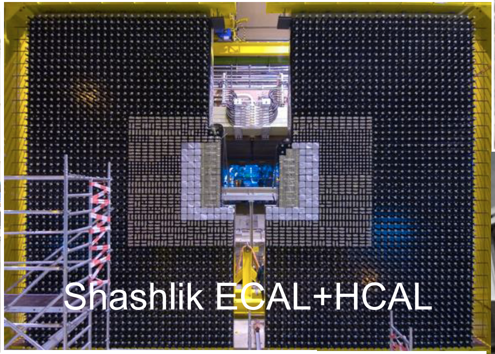


Run-3 LHCb upgrades

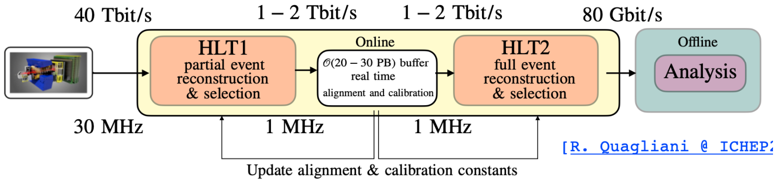




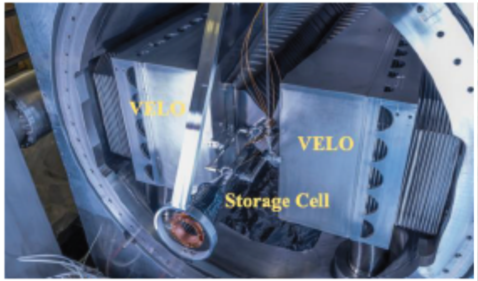


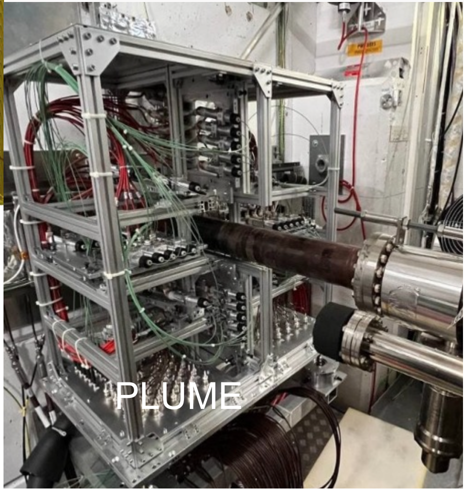


Fully software trigger



[R. Quagliani @ ICHEP2





Run-3 particle searches

Particle	Sample decays	Comment
W', Z' bosons	VV, VH, HH Z'→tt/Tt/TT W'→tb/tB/Tb	30-40% gains in σ depending on mass.
New Higgs bosons	X→HY, HH, …	Gains for heavy Higgs
Vector-like quarks and leptons	gg→pair, qg→single, …	Can be pair-produced due to their coupling to gluons, 1-2TeV ~20% gains. For single production gain depends on mass.
Leptoquarks, diquark scalars	LQ(LQ)+top,LQLQ	Gains similar to VLQ, single/pair LQ large gains.
RS Graviton	tt, VV, VH, HH	For large width 10-20% expect ~30-40% increase in σ.
Dijet resonances	pp→S_{uu}→$\chi\chi$→(jj)(jj)	Gain of factor ~2 (diquark to VLQ quarks)
Susy	Pairs of sparticles, etc.	
Long lived particles	R-hadrons, etc.	
RH neutrinos, excited quarks, colourons, other particles.	t*→tg/ta, b*→tW, X→YZ, Resonances to t/VLQ/W/Z/H	

CMS-PAS-FTR-16-003

CMS-PAS-FTR-16-008

CMS-PAS-FTR-18-009

Data scouting and parking

- **Data scouting**: a paradigm for LHC data analysis based on trigger-level event reconstruction.
  - Events are reconstructed at the HLT using the online PF reconstruction plus other algorithms. Apply a **loose selection** on the reconstructed physics objects. For each event passing the loose selection, save the HLT-reconstructed physics objects to disk.➔ **Explore larger NP parameter space**
  - Discard raw data ➔ significantly increase of the number of physics events stored for analysis.
  - Hadronic activity, electron muon scouting, PF scouting, …

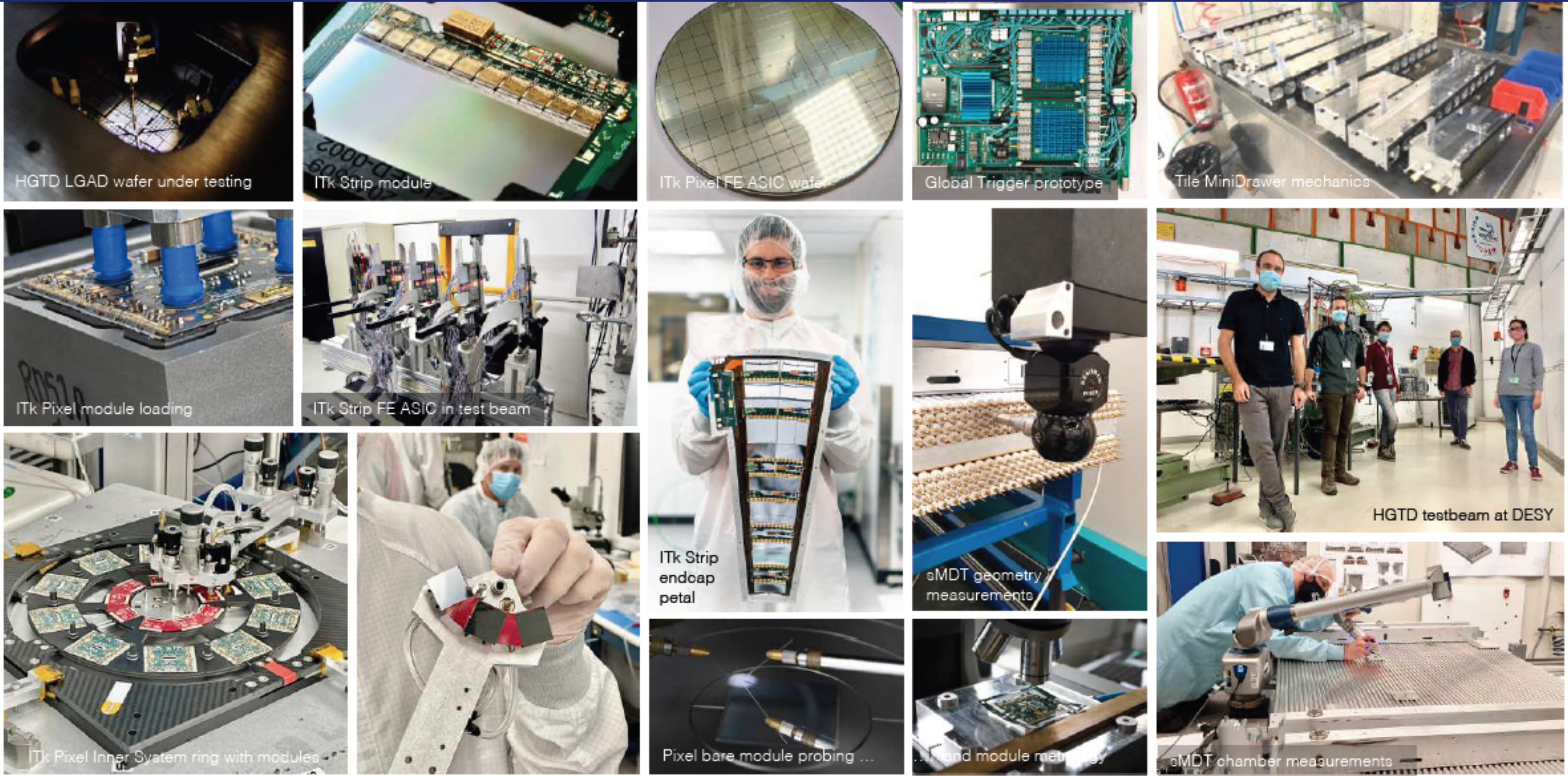
- **Data parking**: select events at the HLT and immediately move them to tape, skipping prompt reconstruction. Events selected in this way remain on tape until there are sufficient free computing resources to reco them.

- **Run 2**: a number of analyses profited, enhancing sensitivity (ATLAS/CMS/LHCb arXiv:1808.00902)
  - Dijet searches, light dimuon resonances, displaced dimuon resonances, …
  - CMS: 0.8 kHz of PF scouting in run 2.

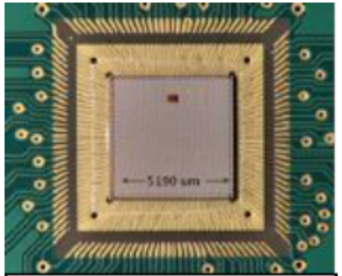
- **Run 3**: enhanced sensitivity in BSM and new searches. Improvements in calo, muon, PF and LLP.
  - Displaced signatures (extend beyond 11cm), Z' searches, Susy search
  - Target rates 30kHz

- **HL-LHC**: gains in displaced vertex analyses.

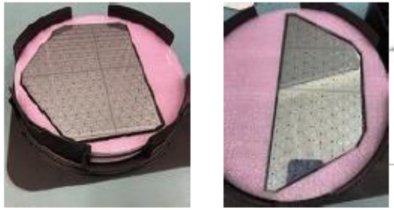
HL-LHC ATLAS upgrades (G.Unal ICHEP22)



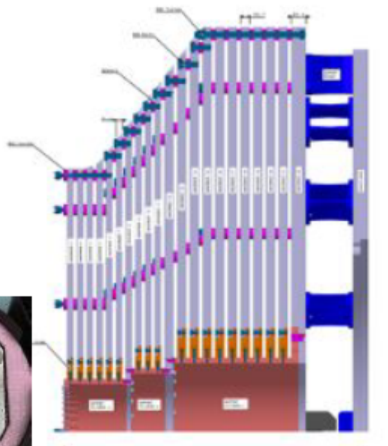
HL-LHC CMS upgrades (A.Rizzi ICHEP22)



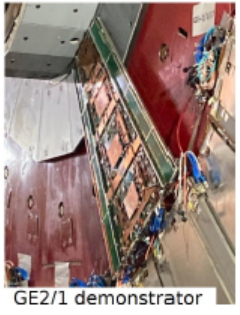
ECON-T-P1 on the test board



HGCAL partial sensors

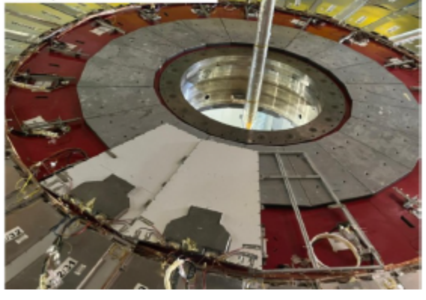


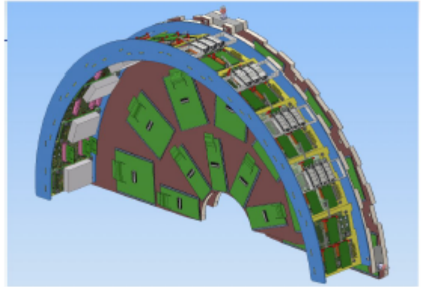
CE-H absorber structure, support wedges, and back-flange



GE2/1 demonstrator

RE3/1 demonstrator

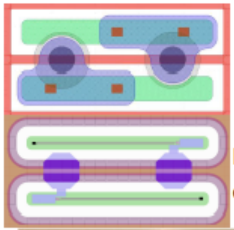


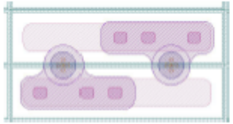


TFPX dee with the 10-portcards revised cartridge

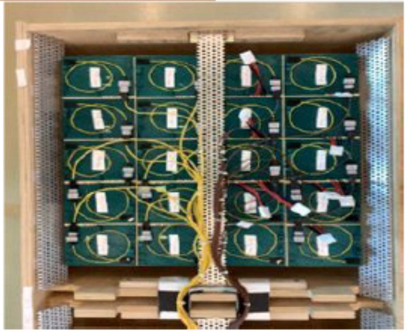
TRACKER INTEGRATION & SERVICES: BTST

Full size 1m long BTST finished prototype at Purdue



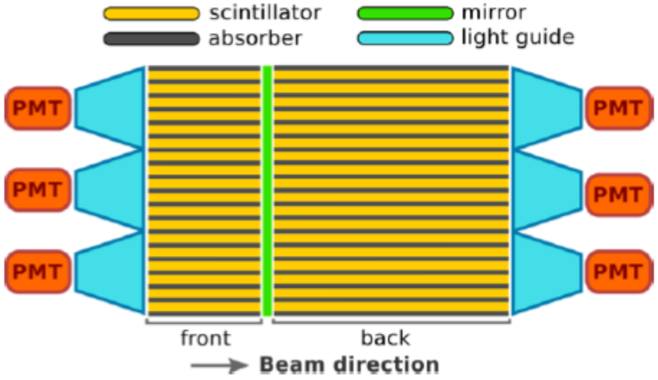


IT; 100x25 µm sensor cells everywhere

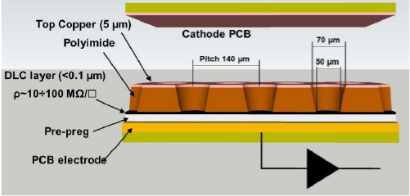


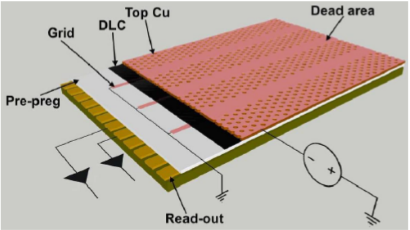
HL-LHC LHCb upgrades

5D Calo with precision timing (High Granularity)

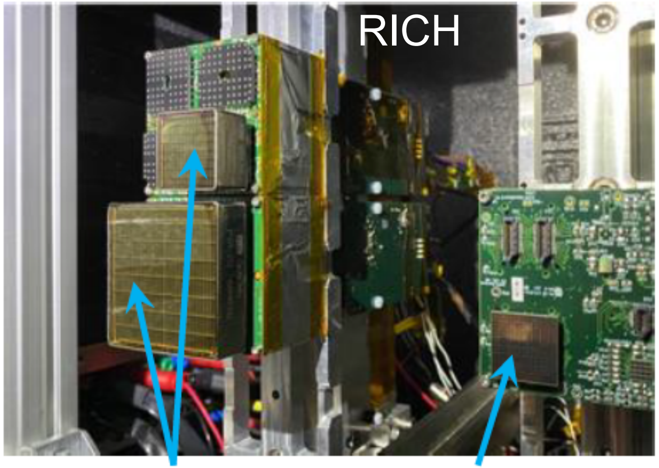


MUON





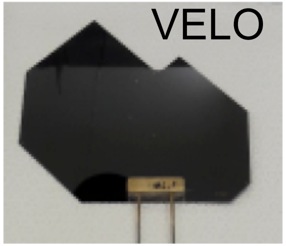
RICH



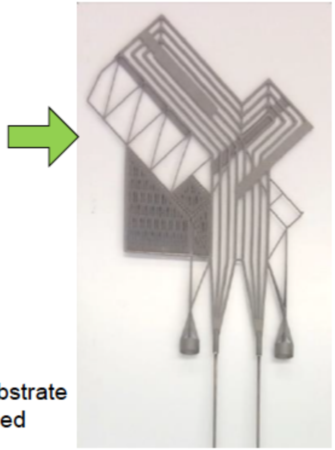
1" & 2" MAPMT

SiPM array

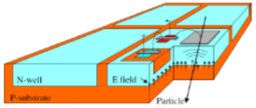
VELO



Microchannel Si substrate for bi-phase CO_2 cooling in Upgrade I

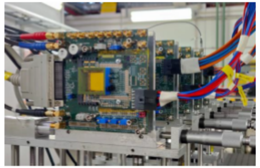


3D printed Ti substrate already prototyped



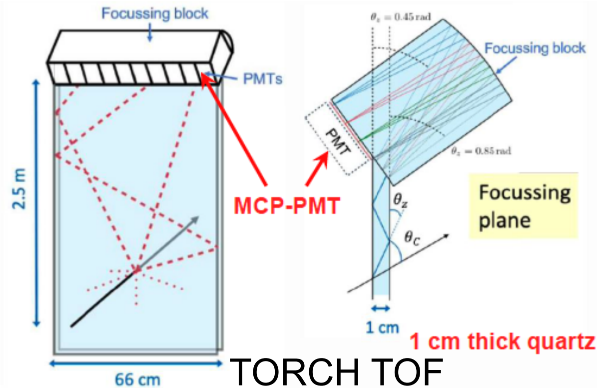
Monolithic Active Pixel Sensor (MAPS)

MightyPix



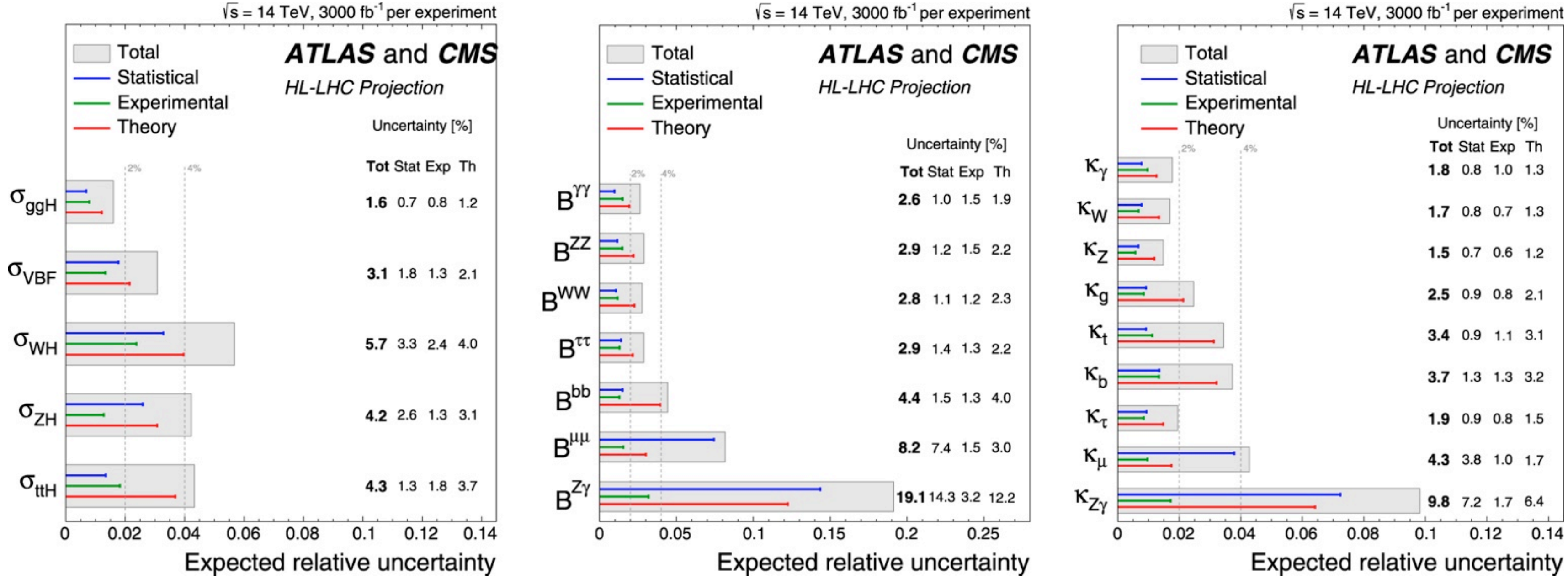
MightyPix1 tested in a beam at DESY

Malta2 bench test at Saclay



TORCH TOF

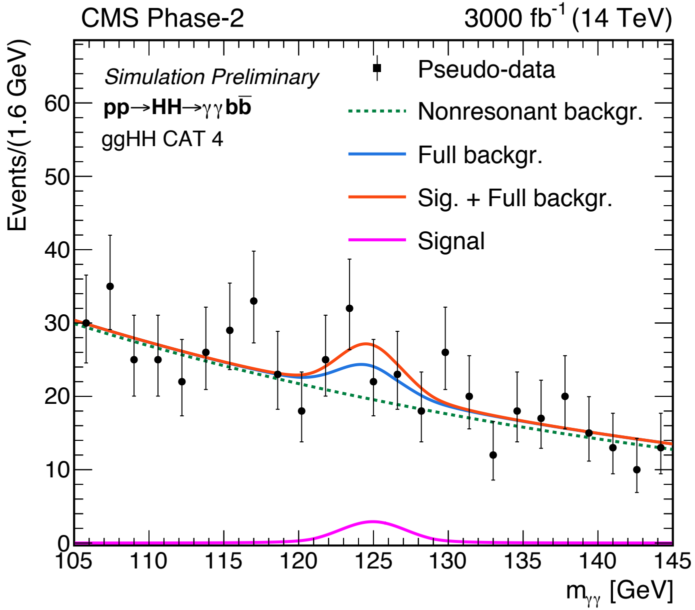
HL-LHC 3ab^{-1}: precision Higgs



CERN Yellow Report CERN-2019-007

HL-LHC 3ab^{-1}: di-Higgs

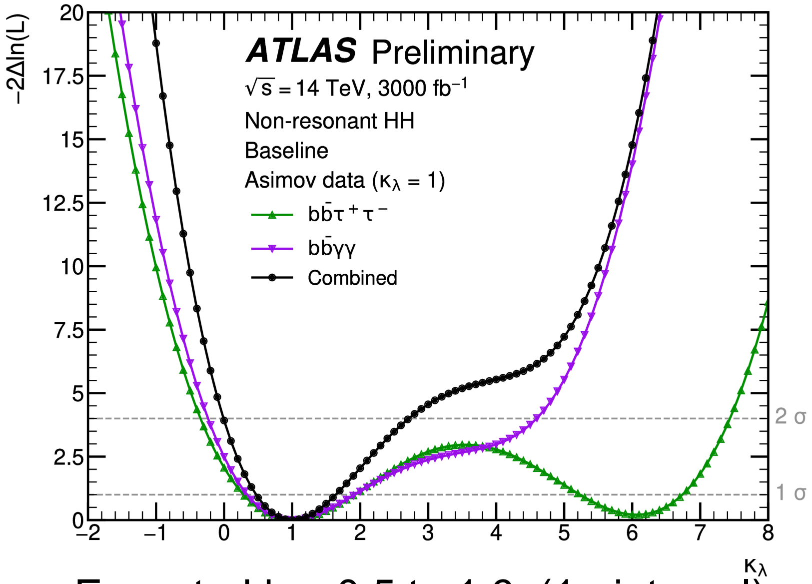
CMS PAS FTR-21-004



2.16σ expected sensitivity from bbγγ

Trilinear Coupling k_λ

ATL-PHYS-PUB-2022-005



Expected k_λ : 0.5 to 1.6, (1σ interval)

bbττ+bbγγ combination: 3.2σ expected

CERN Yellow Report CERN-2019-007

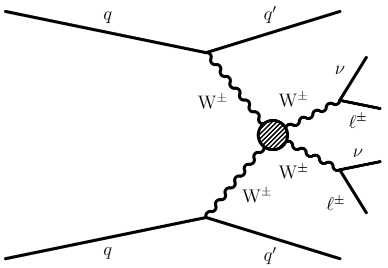
ATLAS+CMS combined: 4σ sensitivity (with older projections)

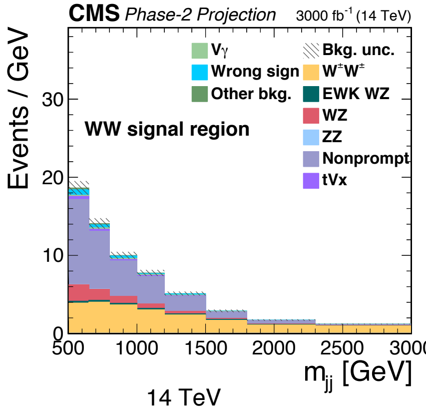
With latest projections, a 5σ combined sensitivity is expected.

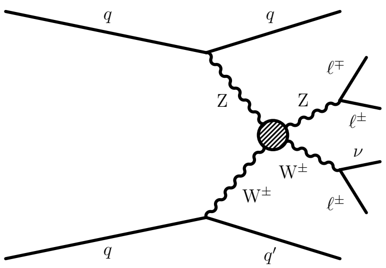
HL-LHC 3ab^{-1}: examples

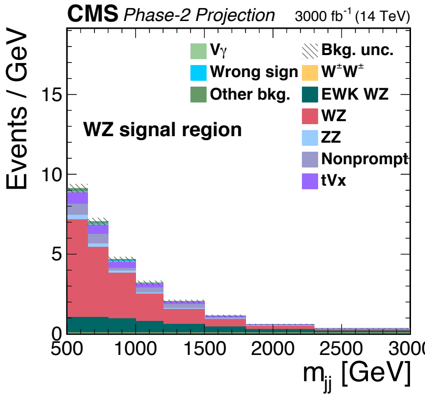
CMS-PAS-FTR-21-001

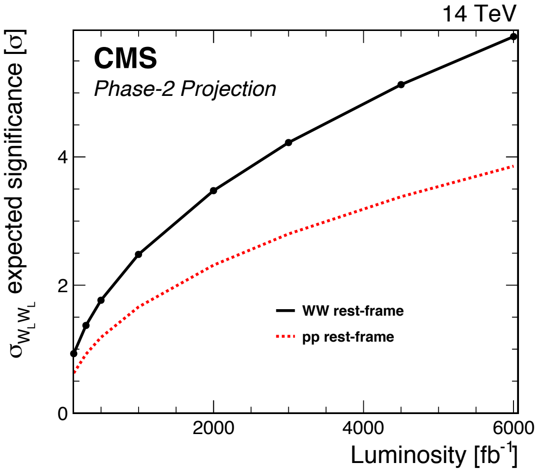
Vector Boson Scattering









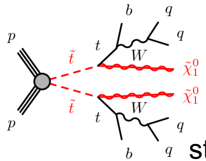


Particle Searches

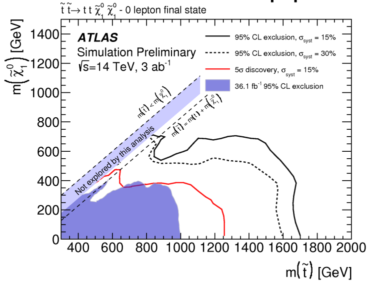
- Z' (W') to leptons reach out to 6TeV (7.5TeV)
- KK excitations to ttbar to 5.7TeV
- Susy particle searches.
- LLPs
  - disappearing tracks
- Dark photons
- Dark Matter
  - mono-Z bosons

HL-LHC $3ab^{-1}$: direct searches

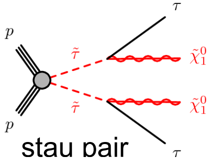
ATL-PHYS-PUB-2018-021



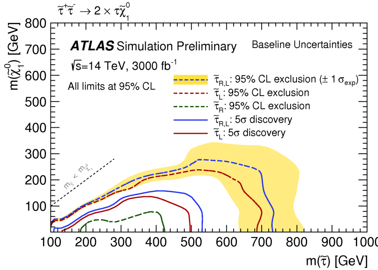
stop pair



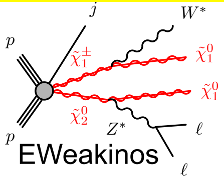
ATL-PHYS-PUB-2018-048



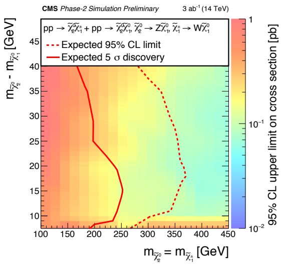
stau pair



CMS-PHYS-FTR-18-001

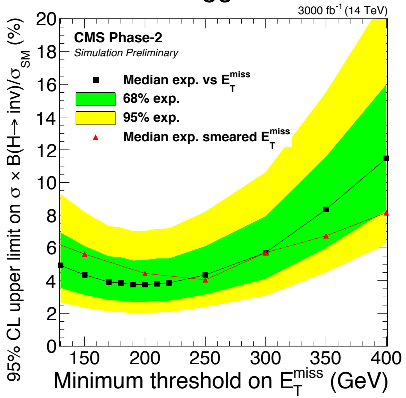


EWeakinos

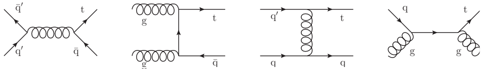


CMS-PHYS-FTR-18-016

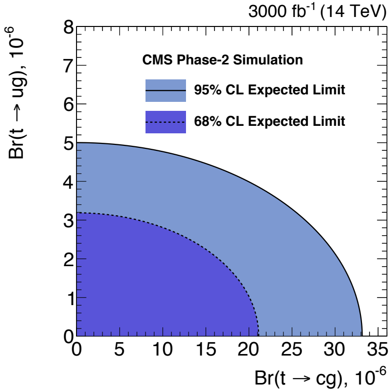
Invisible Higgs



CMS-PHYS-FTR-18-016



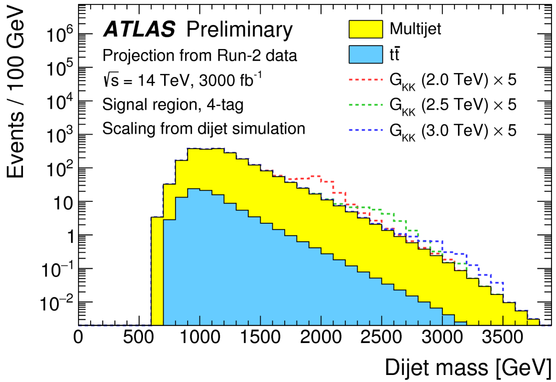
top quark FCNC



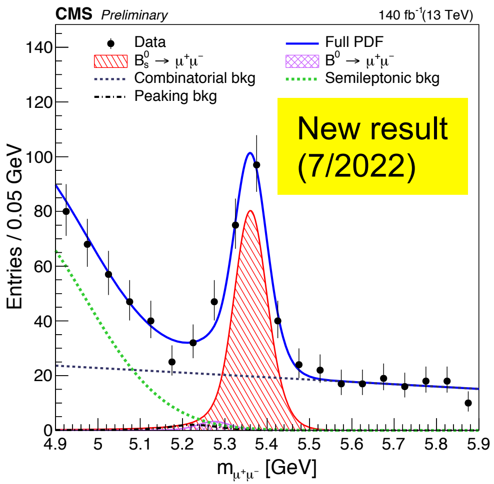
3-Oct-2022

ATL-PHYS-PUB-2018-028

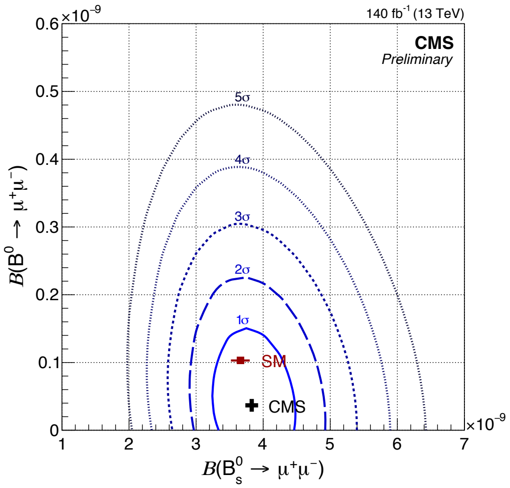
$pp \to G_{KK} \to HH \to 4b$



B-anomalies: B_s decay



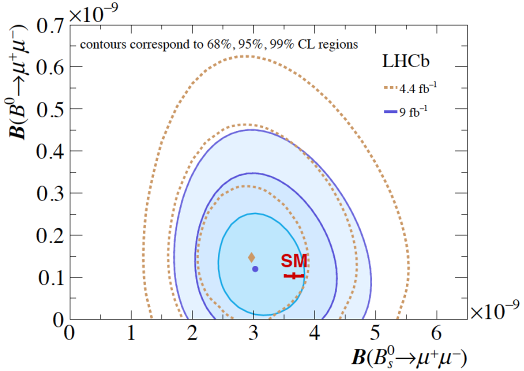
New result (7/2022)



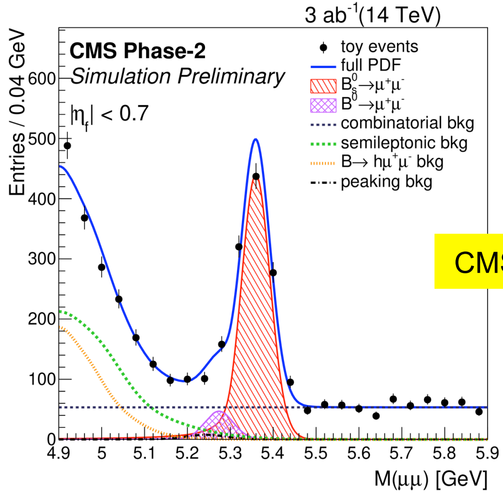
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left[3.83^{+0.38}_{-0.36}\,(\text{stat})\,^{+0.19}_{-0.16}\,(\text{syst})\,^{+0.14}_{-0.13}\,(f_s/f_u)\right] \times 10^{-9}$$

CMS-BPH-21-006

LHCb: PRD 105 (2022) 012010

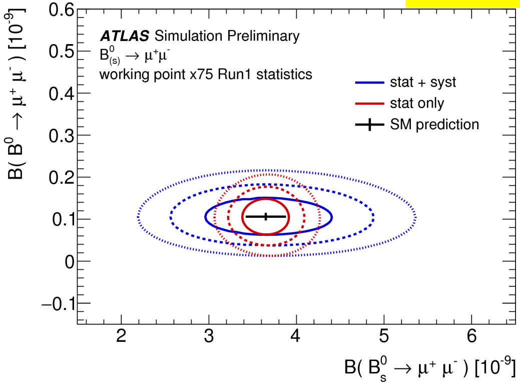


Projections at HL-LHC



CMS-PAS-FTR-18-013

ATL-PHYS-PUB-2018-005

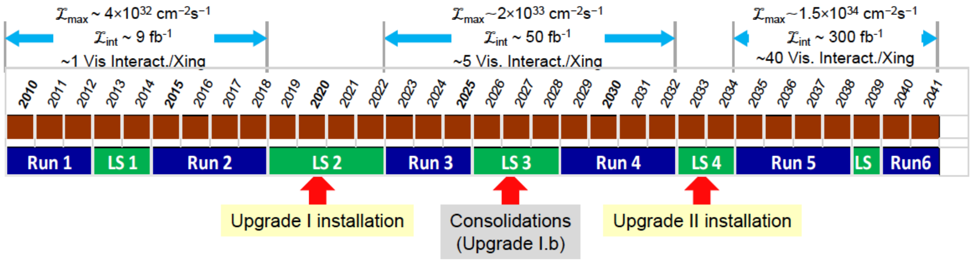


LHCb in HL-LHC

Key observables in flavor physics

Observable	Current LHCb (up to 9 fb^{-1})		Upgrade I (23 fb^{-1})	Upgrade I (50 fb^{-1})	Upgrade II (300 fb^{-1})
CKM tests					
γ ($B \to DK$, *etc.*)	4°	[9,10]	1.5°	1°	0.35°
ϕ_s ($B_s^0 \to J/\psi\phi$)	32 mrad	[8]	14 mrad	10 mrad	4 mrad
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ ($\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu$, *etc.*)	6%	[29, 30]	3%	2%	1%
$a_{\rm sl}^d$ ($B^0 \to D^-\mu^+\nu_\mu$)	36×10^{-4}	[34]	8×10^{-4}	5×10^{-4}	2×10^{-4}
$a_{\rm sl}^s$ ($B_s^0 \to D_s^-\mu^+\nu_\mu$)	33×10^{-4}	[35]	10×10^{-4}	7×10^{-4}	3×10^{-4}
Charm					
ΔA_{CP} ($D^0 \to K^+K^-, \pi^+\pi^-$)	29×10^{-5}	[5]	13×10^{-5}	8×10^{-5}	3.3×10^{-5}
A_Γ ($D^0 \to K^+K^-, \pi^+\pi^-$)	11×10^{-5}	[38]	5×10^{-5}	3.2×10^{-5}	1.2×10^{-5}
Δx ($D^0 \to K_S^0\pi^+\pi^-$)	18×10^{-5}	[37]	6.3×10^{-5}	4.1×10^{-5}	1.6×10^{-5}
Rare Decays					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	69%	[40, 41]	41%	27%	11%
$S_{\mu\mu}$ ($B_s^0 \to \mu^+\mu^-$)	—		—	—	0.2
$A_{\rm T}^{(2)}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
$A_{\rm T}^{\rm Im}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
$\mathcal{A}_{\phi\gamma}^{\Delta\Gamma}$($B_s^0 \to \phi\gamma$)	$^{+0.41}_{-0.44}$	[51]	0.124	0.083	0.033
$S_{\phi\gamma}$($B_s^0 \to \phi\gamma$)	0.32	[51]	0.093	0.062	0.025
α_γ($\Lambda_b^0 \to \Lambda\gamma$)	$^{+0.17}_{-0.29}$	[53]	0.148	0.097	0.038
Lepton Universality Tests					
R_K ($B^+ \to K^+\ell^+\ell^-$)	0.044	[12]	0.025	0.017	0.007
R_{K^*} ($B^0 \to K^{*0}\ell^+\ell^-$)	0.12	[61]	0.034	0.022	0.009
$R(D^*)$ ($B^0 \to D^{*-}\ell^+\nu_\ell$)	0.026	[62, 64]	0.007	0.005	0.002

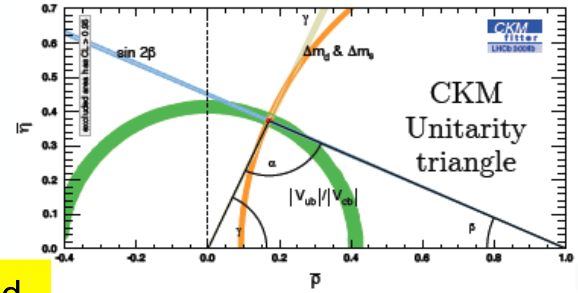
(Ref: LHCC-2021-012 and references therein)

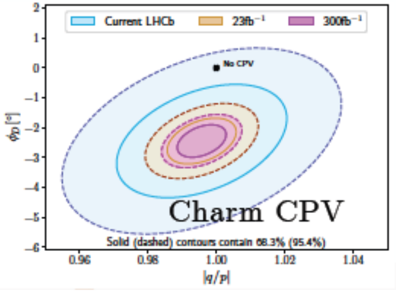


Upgrade II will fully realize the LHCb flavour programme for HL-LHC

Physics Programme at HL-LHC:

- Spectroscopy, High precision EW and Higgs, Dark sectors, Exotic searches, Heavy Ions, Fixed target





Unprecedented precision expected in flavour and beyond

Summary

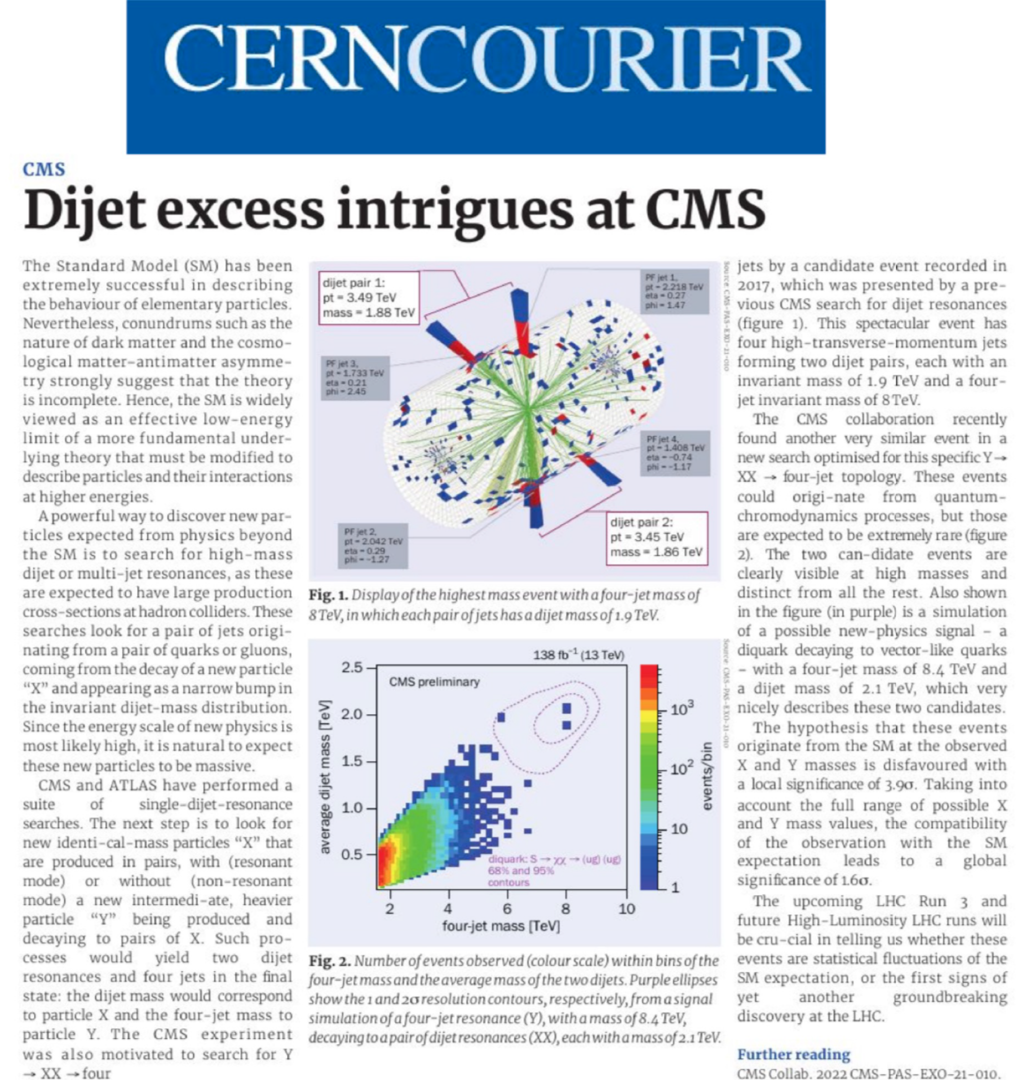
- Several Run-2 analyses and searches with full luminosity are now complete, still a significant number of them in progress
  - Some excesses observed, waiting for more data.

- Run 3 in progress, experiments accumulating luminosity
  - New searches, great prospects
  - Scouting/parking enhance sensitivity, push searches for resonances to lower masses
  - LHCb moving to a software-only trigger – extreme flexibility (e.g. even in strange physics)

- HL-LHC: precise measurements of Higgs couplings and flavour observables.
  - Push sensitivity of searches for new particles

- Exciting times: **we are ready to unlock the secrets of the Higgs field. We are armed with new powerful detector upgrades.**

Extra Slides


CERNCOURIER

CMS

Dijet excess intrigues at CMS

The Standard Model (SM) has been extremely successful in describing the behaviour of elementary particles. Nevertheless, conundrums such as the nature of dark matter and the cosmological matter–antimatter asymmetry strongly suggest that the theory is incomplete. Hence, the SM is widely viewed as an effective low-energy limit of a more fundamental underlying theory that must be modified to describe particles and their interactions at higher energies.

A powerful way to discover new particles expected from physics beyond the SM is to search for high-mass dijet or multi-jet resonances, as these are expected to have large production cross-sections at hadron colliders. These searches look for a pair of jets originating from a pair of quarks or gluons, coming from the decay of a new particle "X" and appearing as a narrow bump in the invariant dijet-mass distribution. Since the energy scale of new physics is most likely high, it is natural to expect these new particles to be massive.

CMS and ATLAS have performed a suite of single-dijet-resonance searches. The next step is to look for new identi-cal-mass particles "X" that are produced in pairs, with (resonant mode) or without (non-resonant mode) a new intermedi-ate, heavier particle "Y" being produced and decaying to pairs of X. Such processes would yield two dijet resonances and four jets in the final state: the dijet mass would correspond to particle X and the four-jet mass to particle Y. The CMS experiment was also motivated to search for Y → XX → four jets by a candidate event recorded in 2017, which was presented by a previous CMS search for dijet resonances (figure 1). This spectacular event has four high-transverse-momentum jets forming two dijet pairs, each with an invariant mass of 1.9 TeV and a four-jet invariant mass of 8 TeV.

Fig. 1. *Display of the highest mass event with a four-jet mass of 8 TeV, in which each pair of jets has a dijet mass of 1.9 TeV.*

Fig. 2. *Number of events observed (colour scale) within bins of the four-jet mass and the average mass of the two dijets. Purple ellipses show the 1 and 2σ resolution contours, respectively, from a signal simulation of a four-jet resonance (Y), with a mass of 8.4 TeV, decaying to a pair of dijet resonances (XX), each with a mass of 2.1 TeV.*

The CMS collaboration recently found another very similar event in a new search optimised for this specific Y → XX → four-jet topology. These events could origi-nate from quantum-chromodynamics processes, but those are expected to be extremely rare (figure 2). The two can-didate events are clearly visible at high masses and distinct from all the rest. Also shown in the figure (in purple) is a simulation of a possible new-physics signal – a diquark decaying to vector-like quarks – with a four-jet mass of 8.4 TeV and a dijet mass of 2.1 TeV, which very nicely describes these two candidates.

The hypothesis that these events originate from the SM at the observed X and Y masses is disfavoured with a local significance of 3.9σ. Taking into account the full range of possible X and Y mass values, the compatibility of the observation with the SM expectation leads to a global significance of 1.6σ.

The upcoming LHC Run 3 and future High-Luminosity LHC runs will be cru-cial in telling us whether these events are statistical fluctuations of the SM expectation, or the first signs of yet another groundbreaking discovery at the LHC.

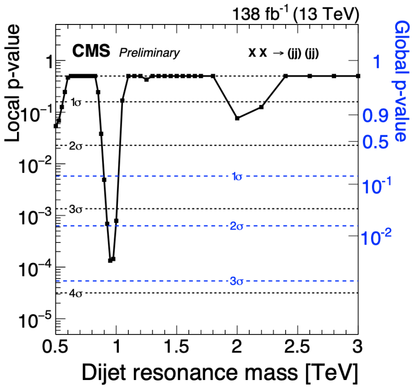
Further reading

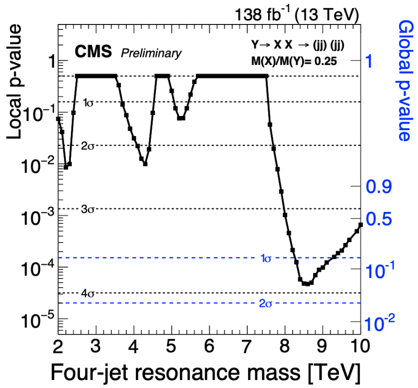
CMS Collab. 2022 CMS-PAS-EXO-21-010.

Search for resonant and non-resonant production of pairs of identical dijet resonances EXO-21-010

Data-driven search for pairs of dijet resonances in final states with at least four jets:

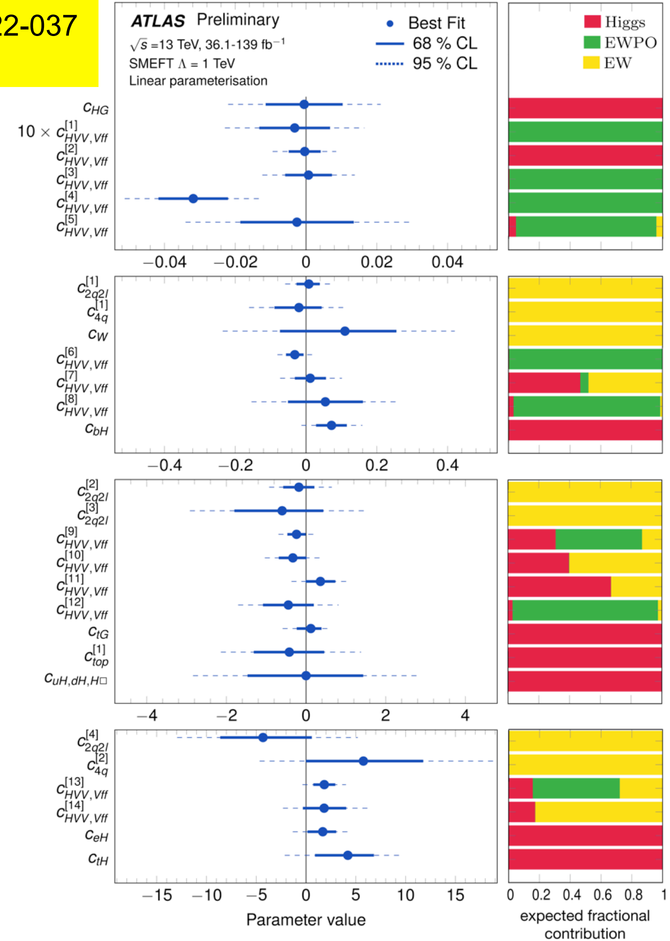
- Resonant: Two events on the tail of the distributions, with a four-jet mass of 8 TeV and an average dijet mass of 2 TeV. **Local (Global) significance: 3.9 σ (1.6 σ)**
- Non-resonant: Excess at average dijet mass of 0.95 TeV, **Local (Global) significance: 3.6 σ (2.5 σ)**





Effective Field Theory

ATL-PHYS-PUB-2022-037
12-July-2022



$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \sum_{d,\text{i}} \frac{c_{\text{i}}^{(d)}}{\Lambda^{d-4}} \mathcal{O}_{\text{i}}^{(d)}$$

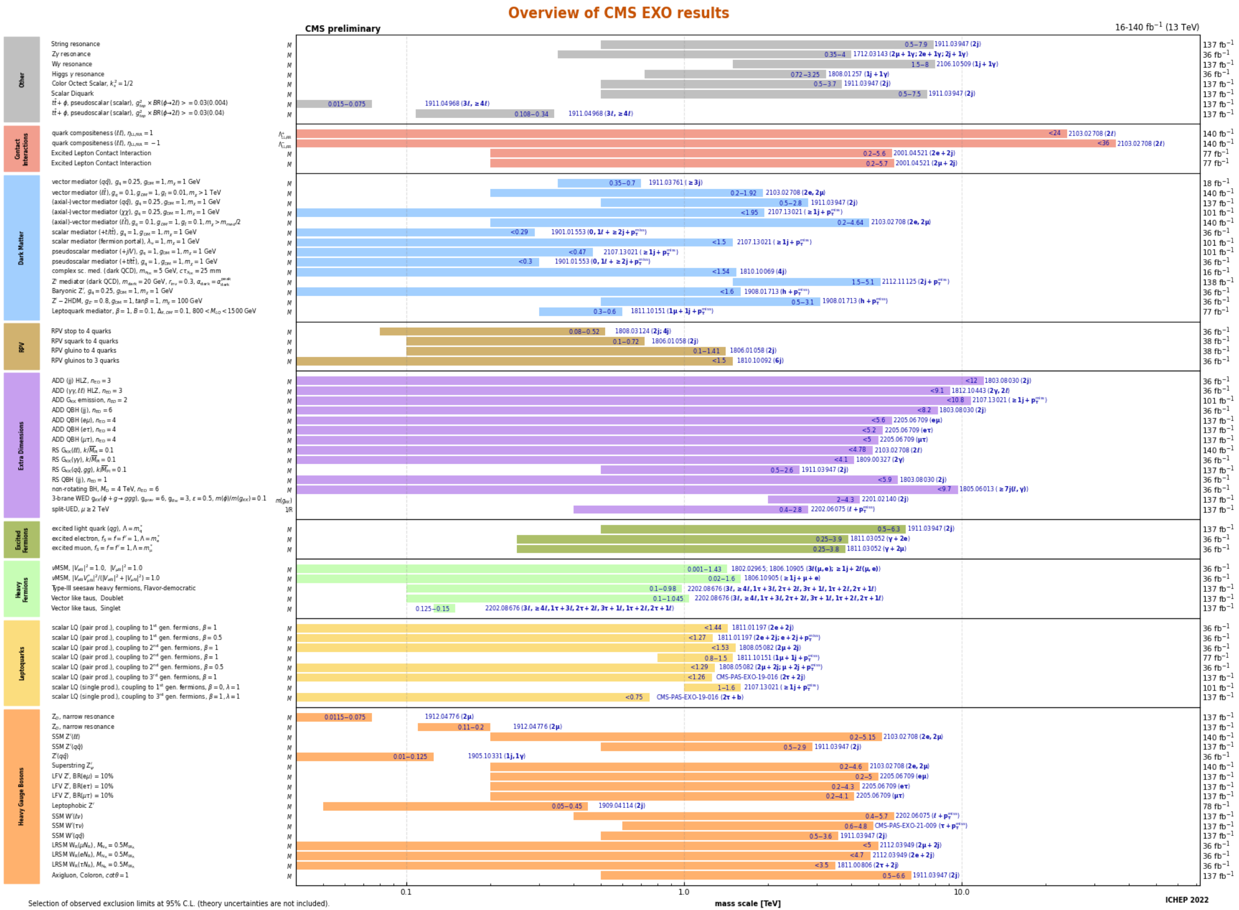
SM is extended by (non-renormalizable) operators with dimension higher than 4.

EFT “valid” until some scale Λ.

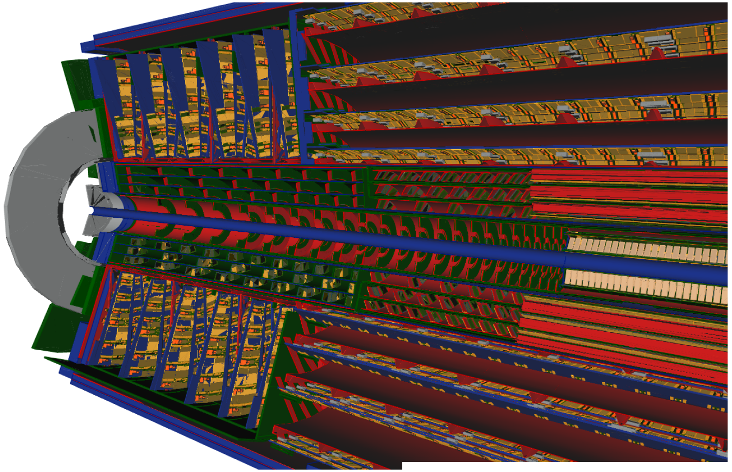
Dim 5 brings in LFV, suppressed by data, so dim 6 operators are the lowest order measured.

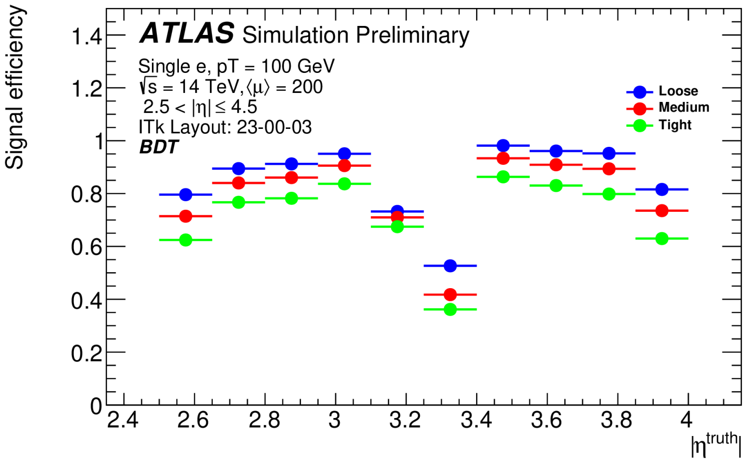
Dimensionless Wilson coefficients can be extracted from ATLAS,CMS, LHCb measurements.

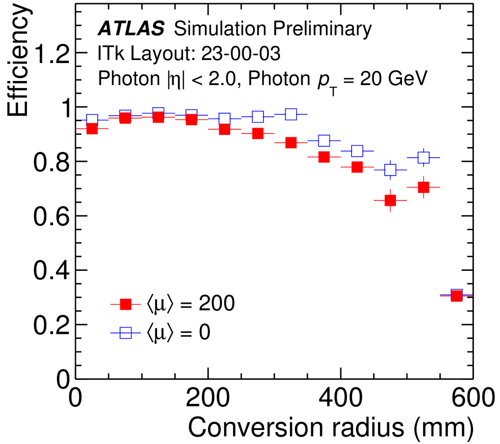
CMS EXO searches summary

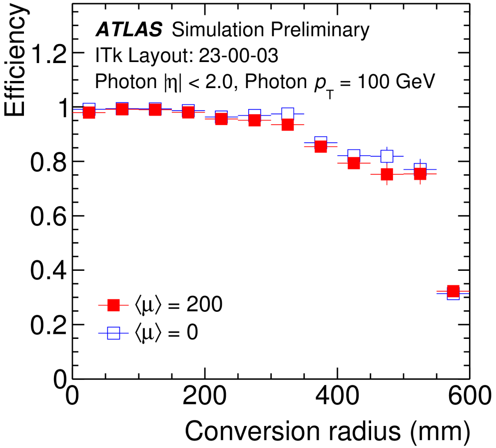


ATLAS ITk performance









Photon efficiency with/without PU