Search for a low-mass resonance in diphotons with CMS

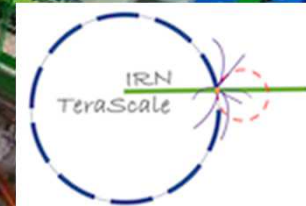## Based on CMS-PAS-HIG-20-002

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IP2I Lyon (IN2P3-CNRS)/Université Claude Bernard Lyon 1
on behalf of the CMS Collaboration

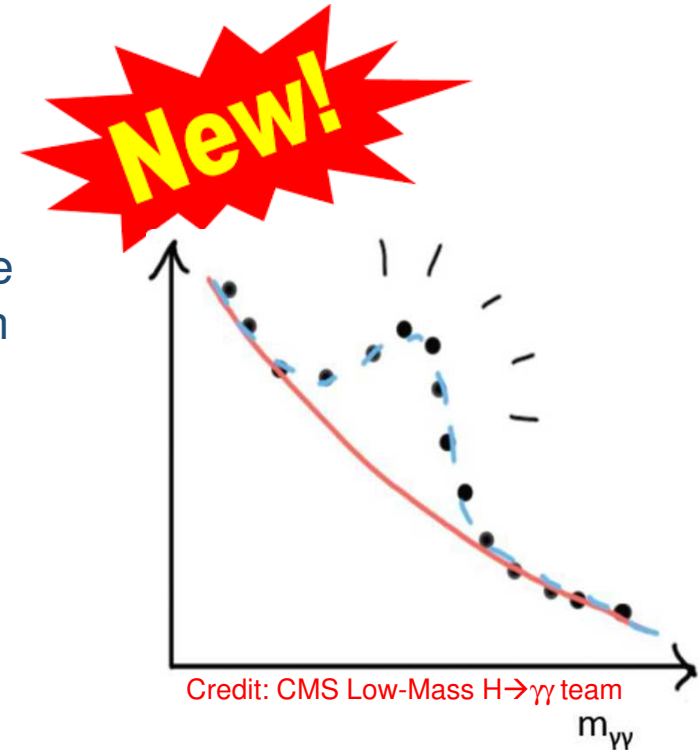IRN Terascale@LPSC Grenoble (FR)

April 25, 2023

Outline

New!

- "Search for a standard model-like Higgs boson in the mass range between 70 and 110 GeV in the diphoton final state in proton-proton collisions at $\sqrt{s}= 13$ TeV" **Full LHC Run 2 data!**

- CMS-PAS-HIG-20-002 http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-20-002/

- Presented for the **first time last month** at EW
- Motivation
- Analysis strategy, event selection, changes wrt previous publication
- Signal and background modeling
- Results
- Comparison with ATLAS results
- First theoretical interpretations
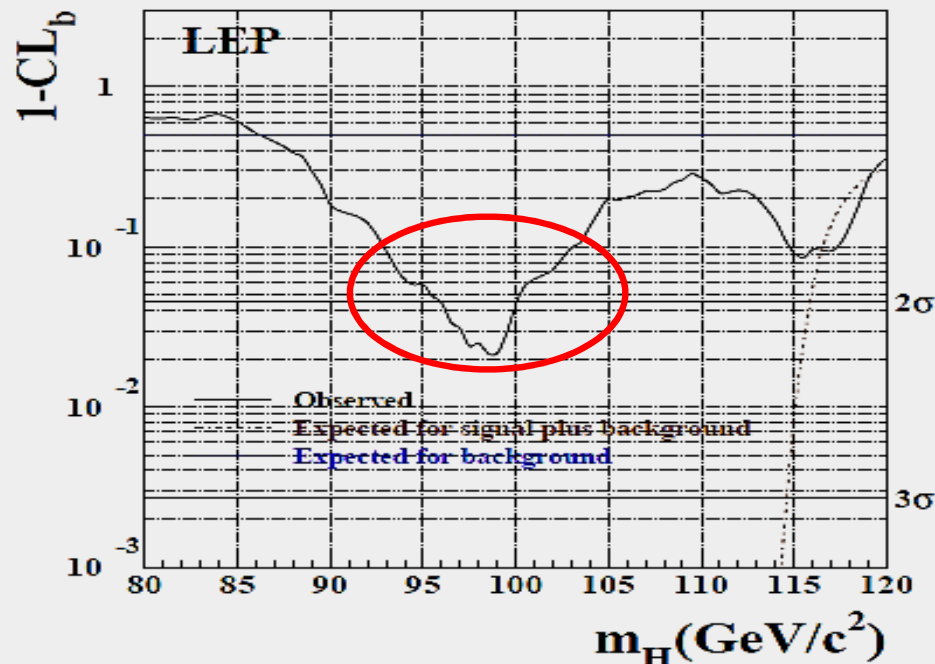- Conclusions and perspectives
- Acknowledgements

Credit: CMS Low-Mass H→γγ team

$m_{\gamma\gamma}$

Motivation for low-mass diphoton searches

Final LEP SM Higgs boson search results: >2σ excess at mH= 98 GeV. Has contributed to sustained interest by both theorests and experimentalists in the possibility of additional low-mass (pseudo-) scalars

Much theoretical activity since then: Numerous BSM models allow a resonance with m<125 GeV coexisting with the Higgs boson discovered in 2012 GeV (generalized 2HDM, NMSSM, Higgs triplet….)

LEPHWG, Phys. Lett. B565:61-75,2003
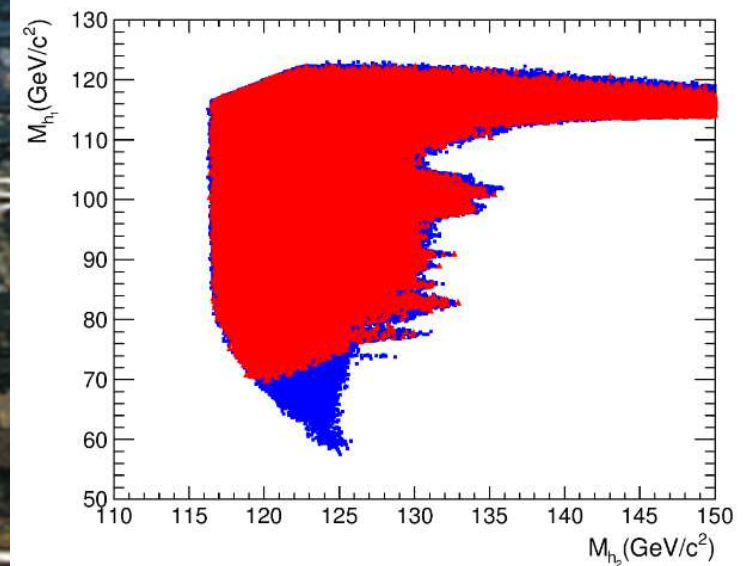
J. Fan et al., Chinese Phys. C 38 073101

Fig. 1. The NMSSM Higgs boson mass spectrum in the M_{h_1} vs. M_{h_2} plane. Points for case I are represented by blue squares and case II by red triangles.
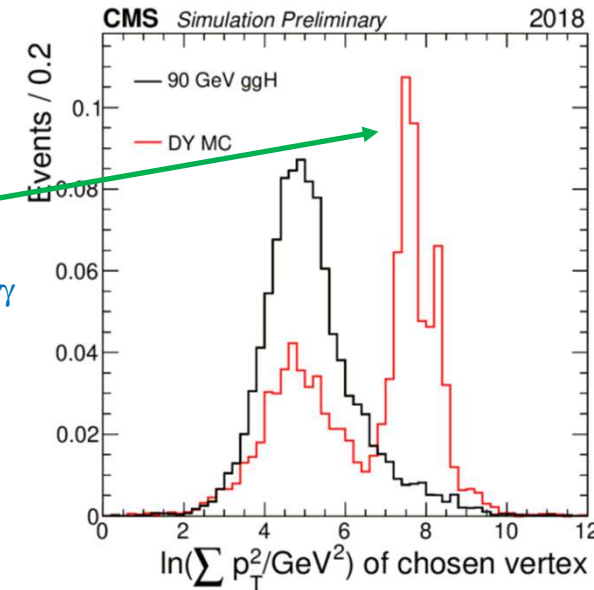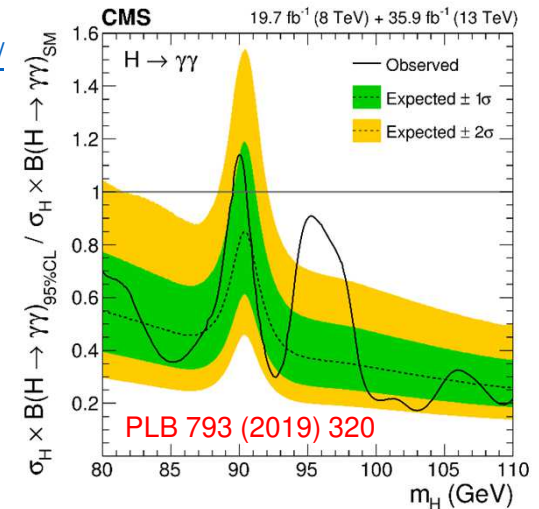
SM-like H→γγ (70 GeV<m_H<110 GeV)

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-20-002/

- Search for narrow signal peak over smoothly-falling background (direct γγ, reducible γ + jet, jet+jet processes) except for relic Z→ee
- Event reconstruction/selection, γ ID techniques (BDTs), signal and data-driven background modeling with discrete profiling method inherited from SM H→γγ analysis
- Major changes wrt prior version (PLB 793 (2019) 320) (2012+2016 data):

  - Kinematic event selection BDT ($p_T/m_{\gamma\gamma}$, η, $\cos(\phi_1 - \phi_2)$, both PhotonID BDT outputs, mass resolution wrt correct and incorrect vertices, vertex probability) reoptimized and events categorized for low-mass case

  - Electron/relic Z→ee veto (based on pixel detector hits) reinforced with:

    - Rejection of photon candidates also reconstructed as electrons

    - Maximum value of $\ln(\Sigma p_T^2/GeV^2)$[tracks in chosen vertex] as function of $p_{T\gamma\gamma}$

  - 2017/18: Events with additional jets selected for class targeting VBF process

  - 2016: data reanalyzed with improved calibration

- Major systematic uncertainties: per-photon energy resolution <20%, renormalization and factorization scales<14%, UE modeling <27%, PS<16%, JES corrections (VBF class) <16%.
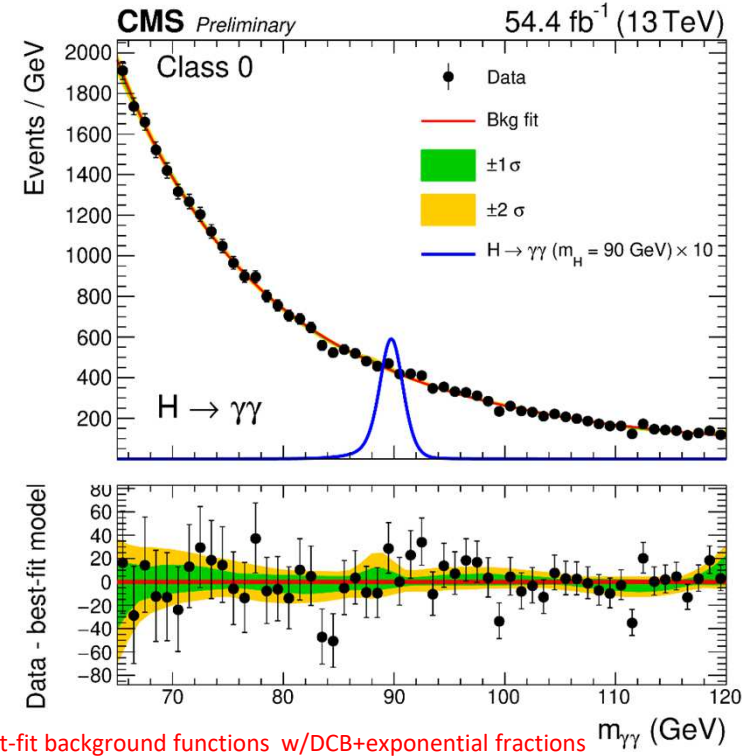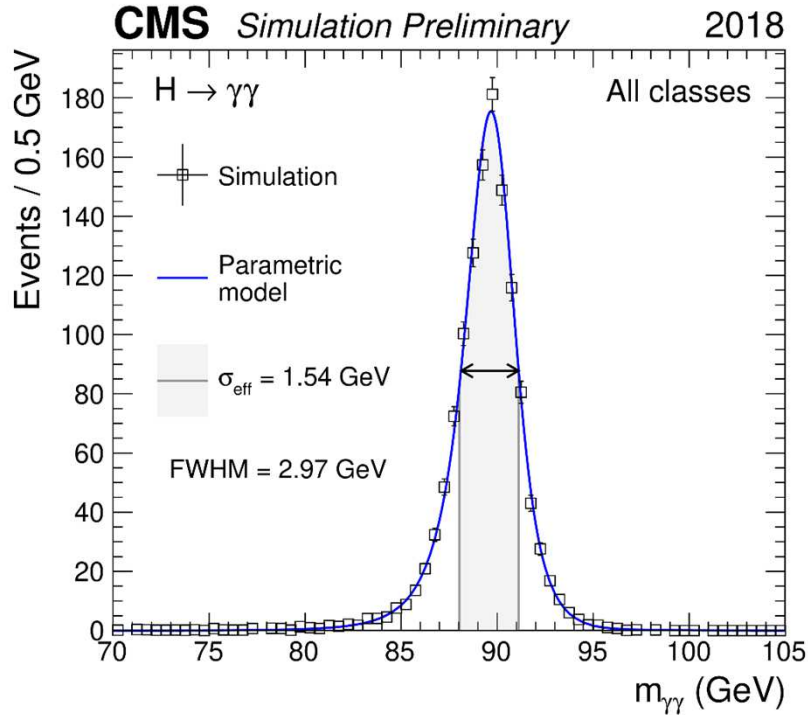
CMS 19.7 fb^{-1} (8 TeV) + 35.9 fb^{-1} (13 TeV)

H → γγ

— Observed
Expected ± 1σ
Expected ± 2σ

$\sigma_H \times B(H \to \gamma\gamma)_{95\%CL} / \sigma_H \times B(H \to \gamma\gamma)_{SM}$

PLB 793 (2019) 320

m_H (GeV)

CMS Simulation Preliminary 2018

Events / 0.2

— 90 GeV ggH
— DY MC

$\ln(\Sigma p_T^2/GeV^2)$ of chosen vertex

SM-like H→γγ (70 GeV<m_H<110 GeV)

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-20-002/

- Signal modeling (sum of Gaussian functions): ggH, ttbarH, VBF, VH production processes present in SM proportions, 'SM-like' σ from LHC Higgs WG

- Background model fit, stat.uncertainties only, 2018

- Background modeling (discrete profiling): Sums of continuous functions (different families/orders) with DCB+exponential (normalization floating)
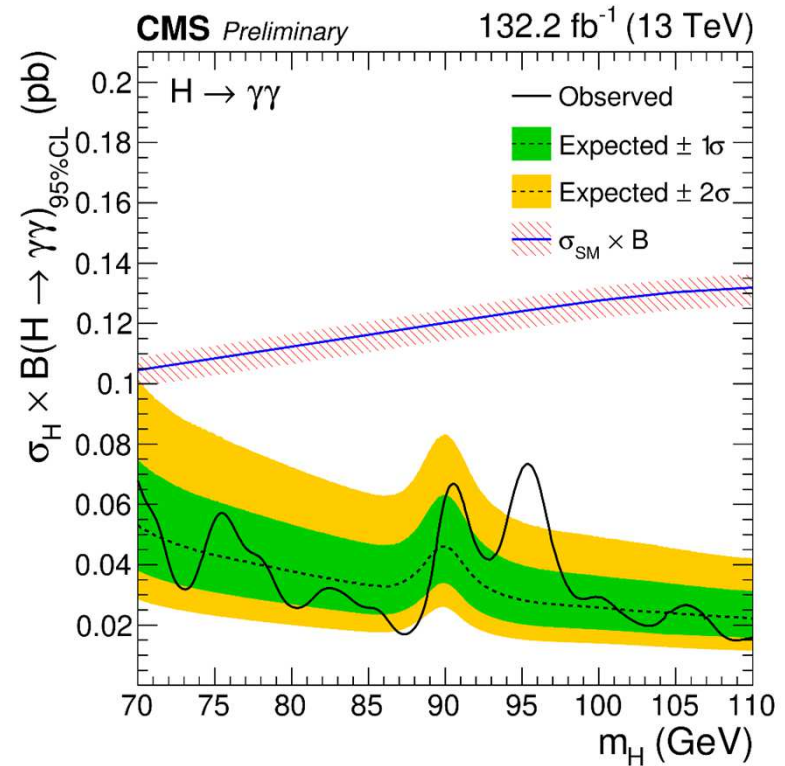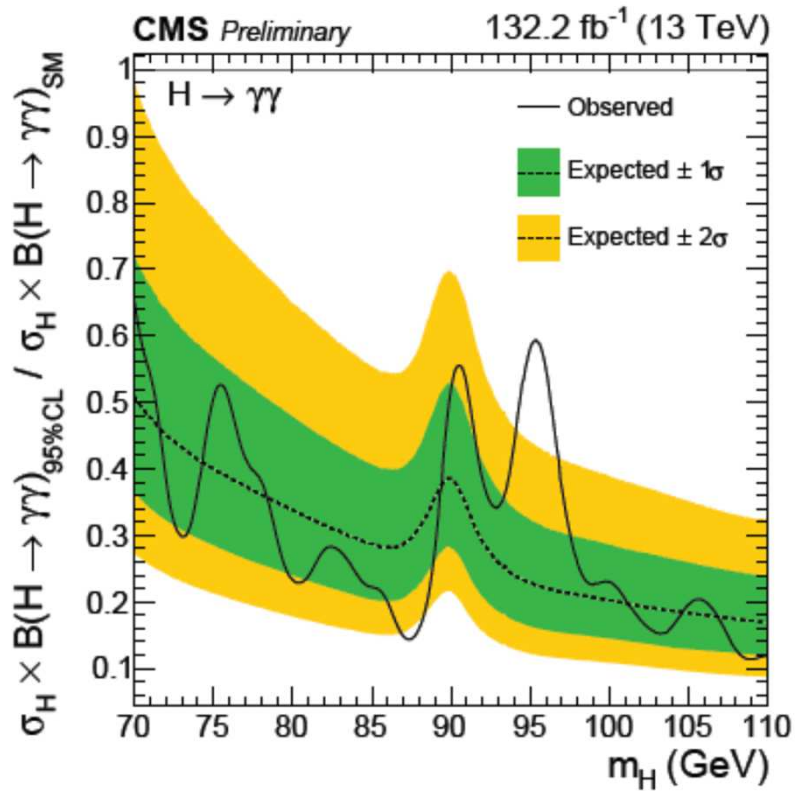
Best-fit background functions w/DCB+exponential fractions

Event class		0	1	2	VBF
2016	Family/Order	Power Law 1	Bernstein 4	Exponential 3	
	DCB + Exp. Fraction (%)	3.0	3.1	3.3	
2017	Family/Order	Bernstein 3	Exponential 3	Bernstein 4	Bernstein 3
	DCB + Exp. Fraction (%)	2.7	1.4	1.9	2.6
2018	Family/Order	Laurent 1	Bernstein 4	Exponential 3	Bernstein 2
	DCB + Exp. Fraction (%)	0.5	4.1	4.8	0.8

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SM-like H→γγ (70 GeV<m_H<110 GeV)

New!

- Observed and expected 95% CL UL on σ X B relative to SM-like expectation (production processes assumed in SM proportions)
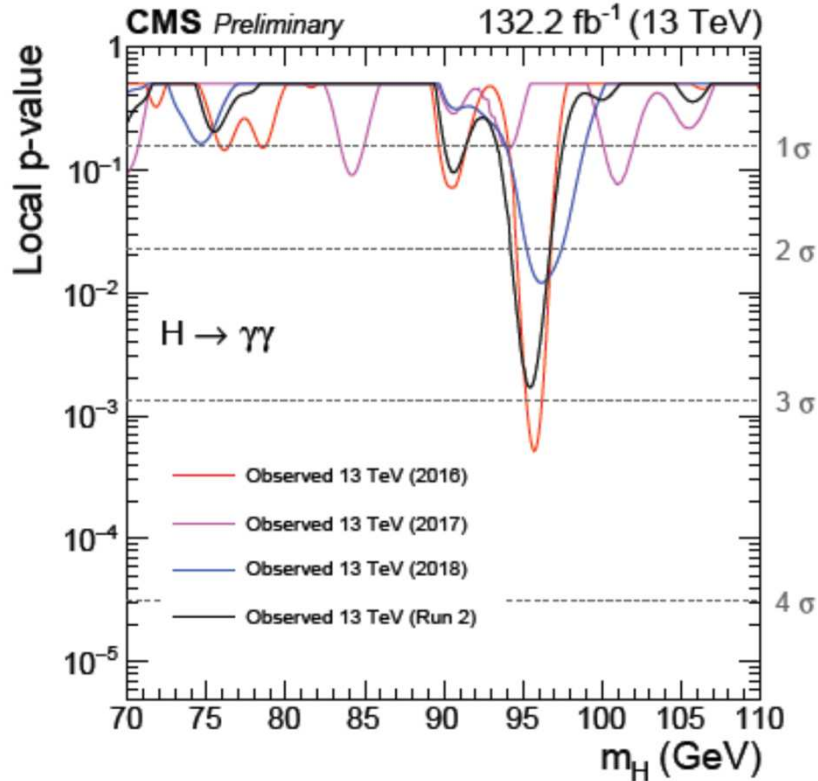
- Observed absolute 95% CL UL on σ X B between 15-73 fb

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SM-like H→γγ (70 GeV<m_H<110 GeV)

- Observed local p-values for 2016, 2017, 2018 and combination

- S/(S+B)-weighted $m_{\gamma\gamma}$ distribution with S+B fit for m_H =95.4 GeV

- Modest excess with ~2.9σ local (1.3σ global) significance at $m_{\gamma\gamma}$=95.4 GeV, more data needed to conclude!
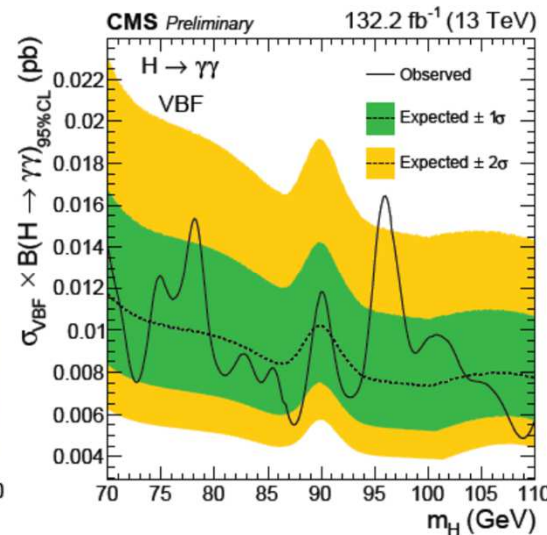
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SM-like H→γγ (70 GeV<m_H<110 GeV)

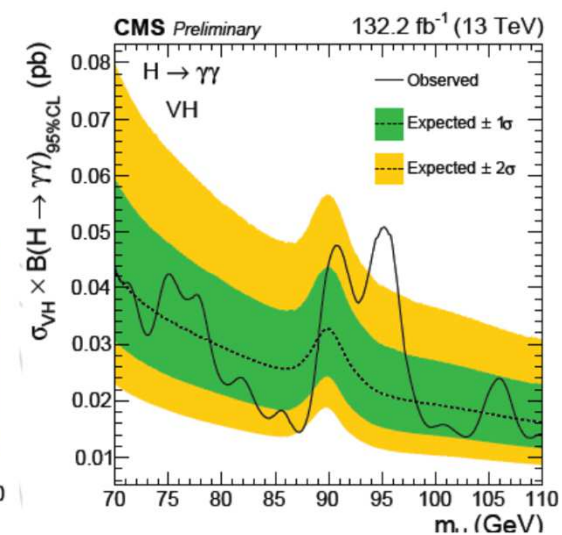- Observed and expected 95% CL limits on σ X B by production process (integrated over all event classes)

- 100% production via gluon-induced processes (ggH, ttbarH in SM proportions)

- 100% production via fermion-induced processes (VBF, VH in SM proportions)
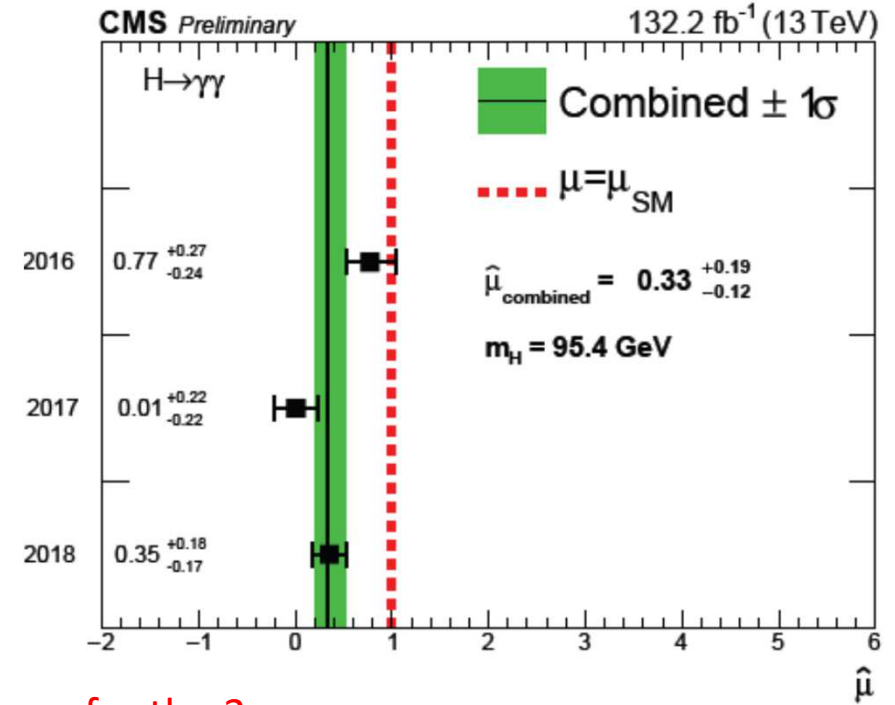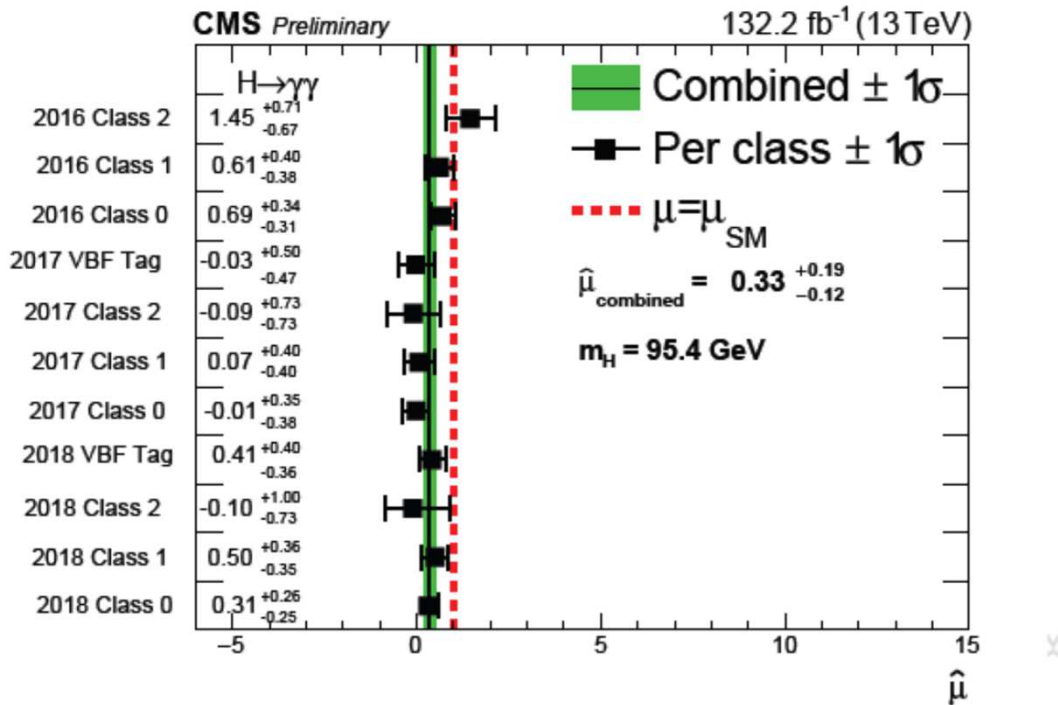
- 100% production via VBF

- 100% production via VH

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SM-like H→γγ (70 GeV<m_H<110 GeV)

New!

CMS-PAS-HIG-20-002

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-20-002/

- 'Signal' strengths μ fixing m_H=95.4 GeV

- for the 11 event classes :
  χ^2 compatibility probability: 68%

- for the 3 years
  χ^2 compatibility probability: 6%

- First search for new diphoton resonances in this mass range with full LHC Run 2 data!
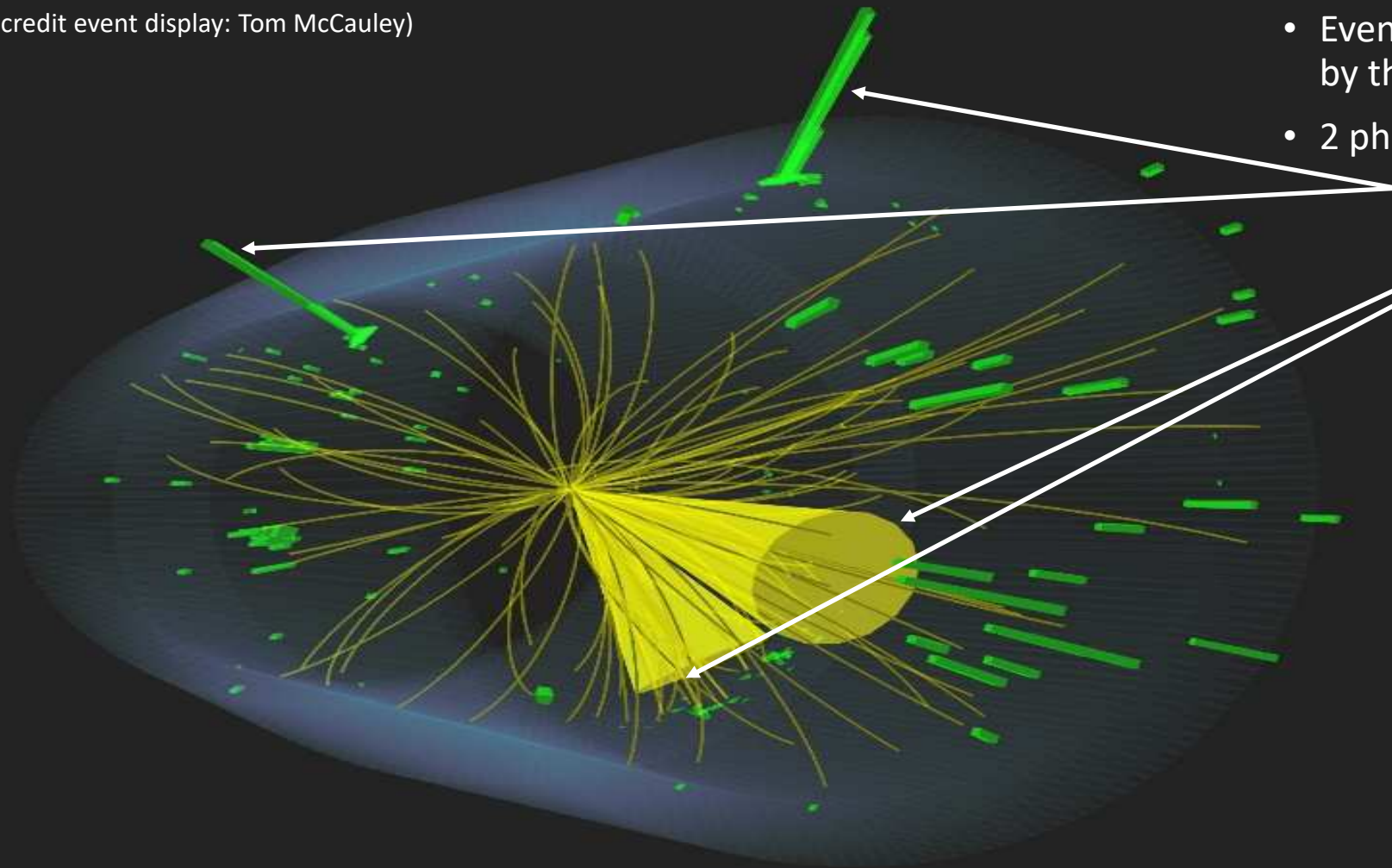
CMS Experiment at the LHC, CERN
Data recorded: 2018-Oct-03 11:26:05.236800 GMT
Run / Event / LS: 323954 / 100651384 / 51

(credit event display: Tom McCauley)

- Event recorded in 2018 selected by the analysis
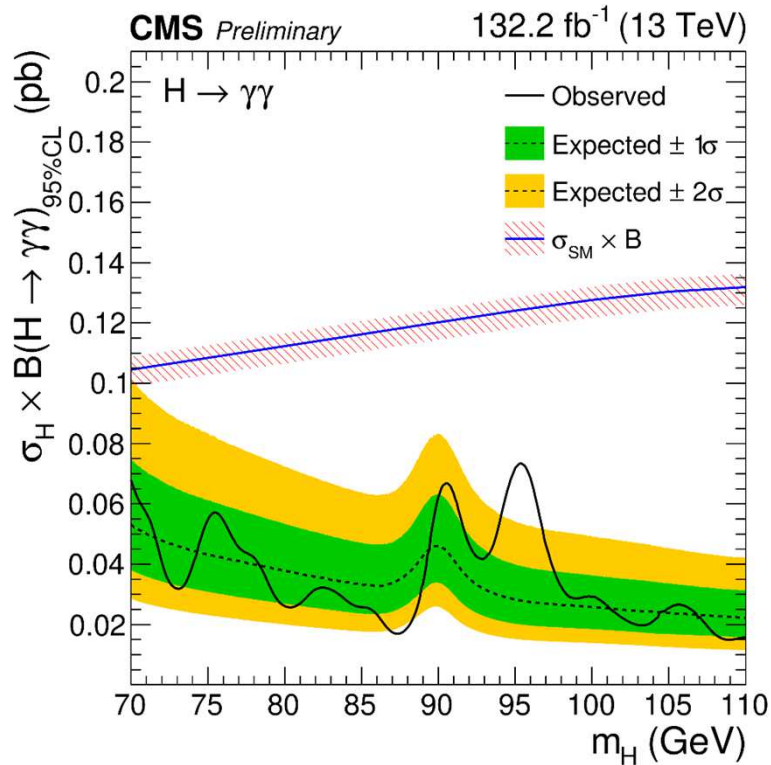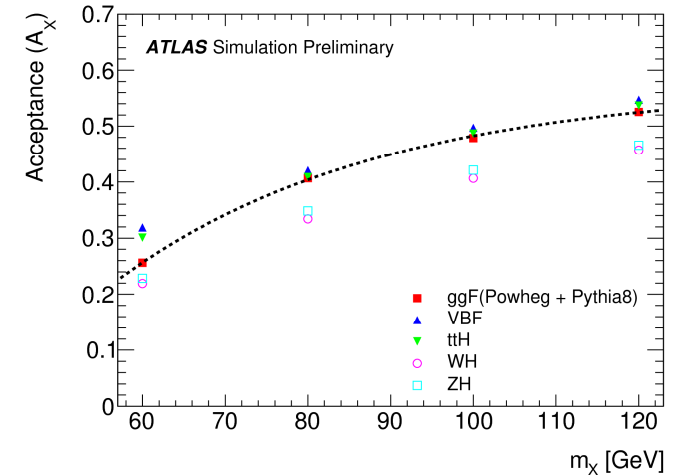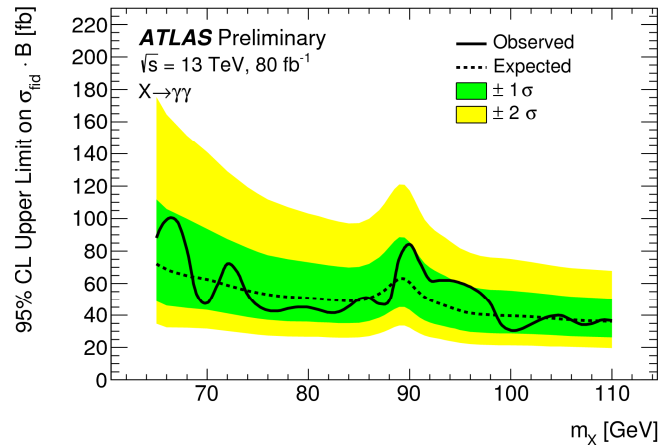- 2 photons and 2 jets

SM-like H→γγ (70 GeV<m_H<110 GeV)

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-20-002/

- These results

- Most recent ATLAS results: ATLAS-CONF-2018-025 (2016+2017)

- Limit on **fiducial** σXB

$$\sigma_{\text{fid}} = A_X \sigma$$

$$A_X(m_X) = 0.57 - 2.07\, e^{-3.13\, m_X/100},$$

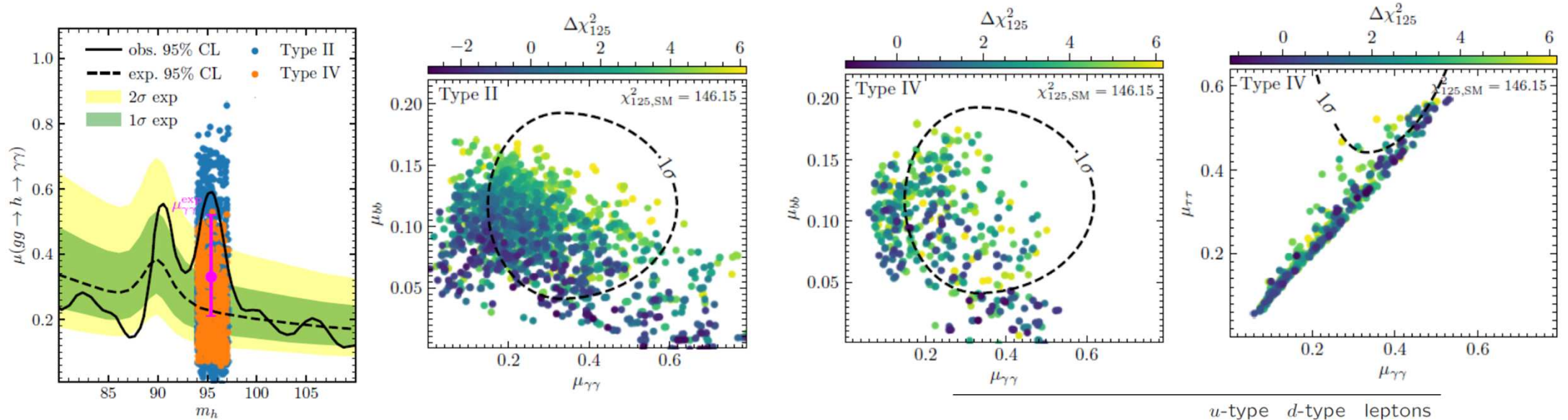- Observed absolute 95% CL UL on **total** σ X B between 15-73 fb

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http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-20-002/

- First theoretical interpretation of these results: arXiv 2303.12018 (Biekoetter, Heinemeyer, Weiglein): 2HDM + complex singlet model (S2HDM) compatible with excesses at ~95 GeV for $m_{\gamma\gamma}$ (this analysis) and m_{bb} (LEP) for Types II and IV, also with $m_{\tau\tau}$ (CMS, arXiv:2208.02717, subm. JHEP) for Type IV (points in agreement with all experimental and theoretical bounds)

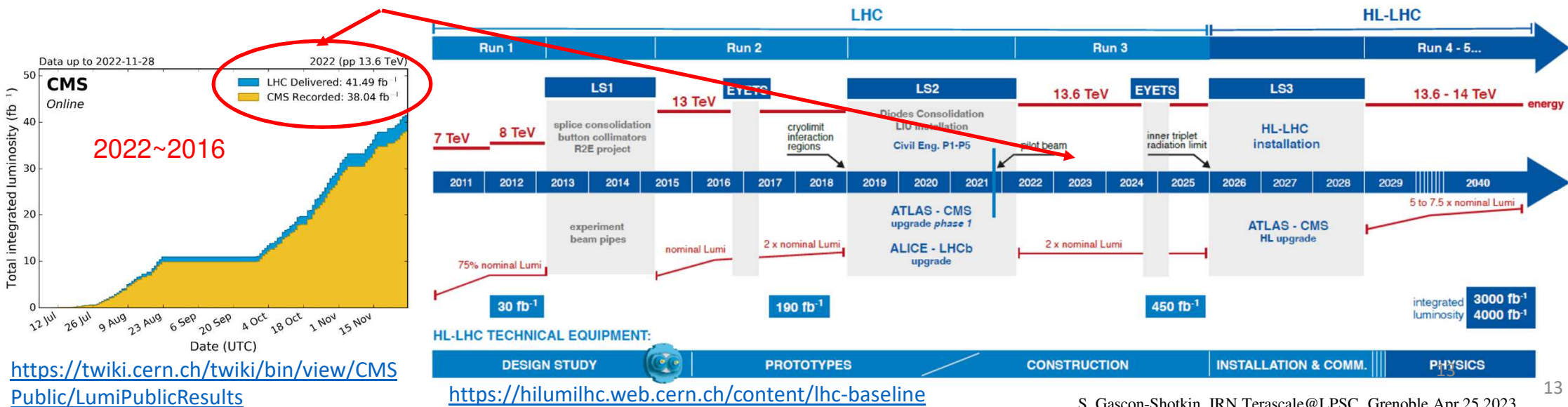- Model contains 3 CP-even (h_1, h_2, h_3), 1 CP-odd (A) neutral, 2 charged (H^{+-}) and 1 DM (χ) scalars

- Model types similar to those in 2HDM

	u-type	d-type	leptons
type I	Φ_2	Φ_2	Φ_2
type II	Φ_2	Φ_1	Φ_1
type III (lepton-specific)	Φ_2	Φ_2	Φ_1
type IV (flipped)	Φ_2	Φ_1	Φ_2

Conclusions and Perspectives

🔶 Presented new CMS search for additional low-mass SM-like H→γγ (70 GeV<mH<110 GeV) using full LHC Run 2 data: No evidence for the existence of extra Higgs bosons found so far

🔶 Modest excess at $m_{\gamma\gamma}$=95.4 GeV with 2.9σ local (1.3σ global) significance.

🔶 First diphoton resonance search in this mass range with full LHC Run 2 data

🔶 More (Run 3) data is needed to conclude on the nature of this excess….and it's on it's way! (250fb^{-1})

2022~2016

https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults

https://hilumilhc.web.cern.ch/content/lhc-baseline

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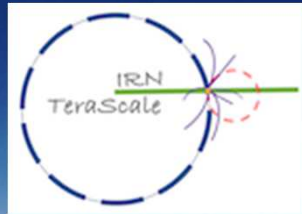
Acknowledgements

Th. Biekoetter, F. Canelli, A. DeWit, L. Finco, S. Heinemeyer, M. Lethuillier, H. Mei, M. Pierini, M. A. Shahzad, J. Steggemann, J. Tao, G. Weiglein...

Thanks to the Terascale@LPSC organization!

Backup