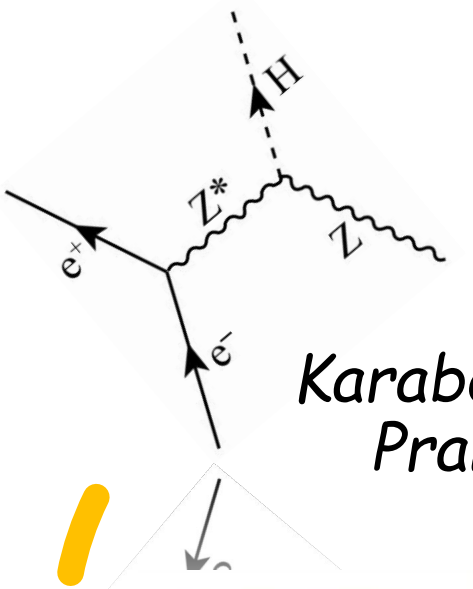
Observation of a ~95 GeV Scalar at CEPC



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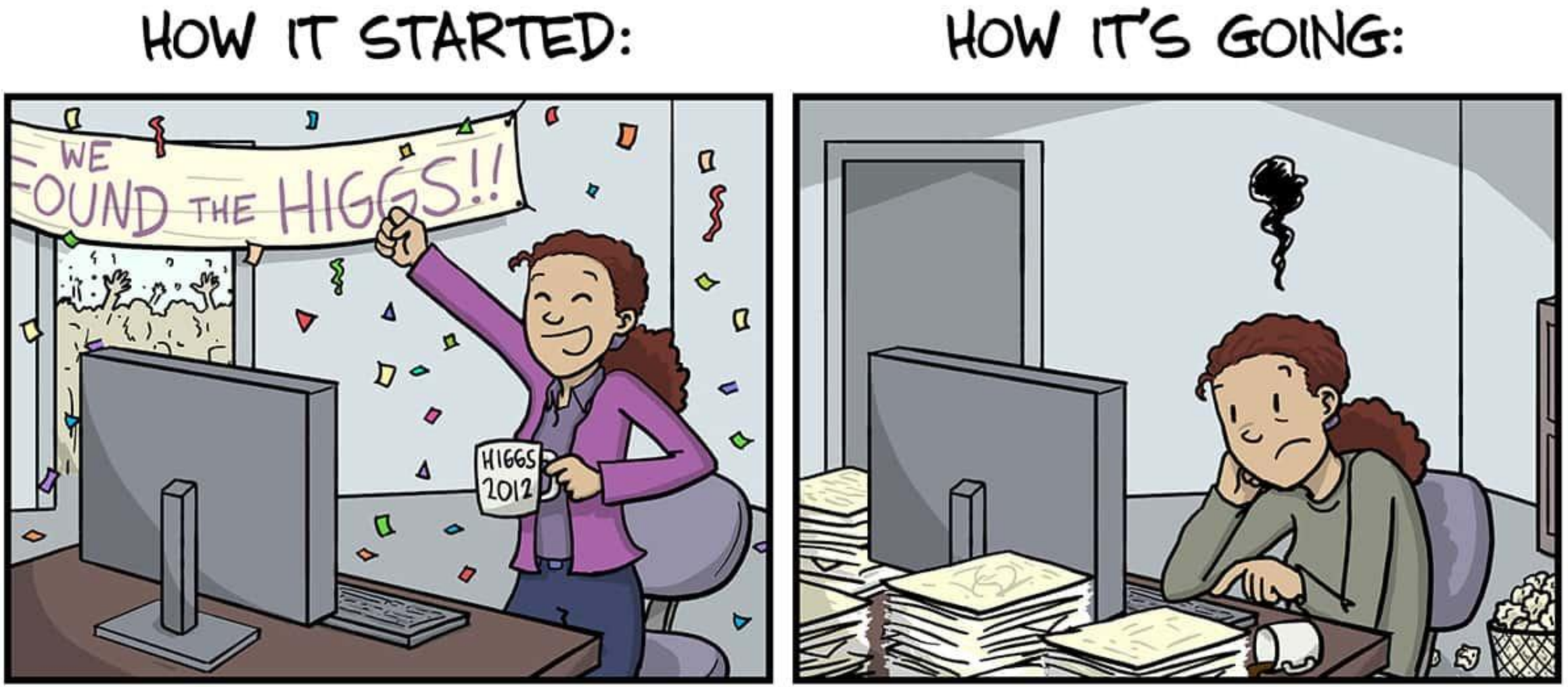
NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

International Workshop on the High Energy Circular Electron Positron Collider


HOW IT STARTED:
HOW IT'S GOING:
WE FOUND THE HIGGS!!
HIGGS 2012

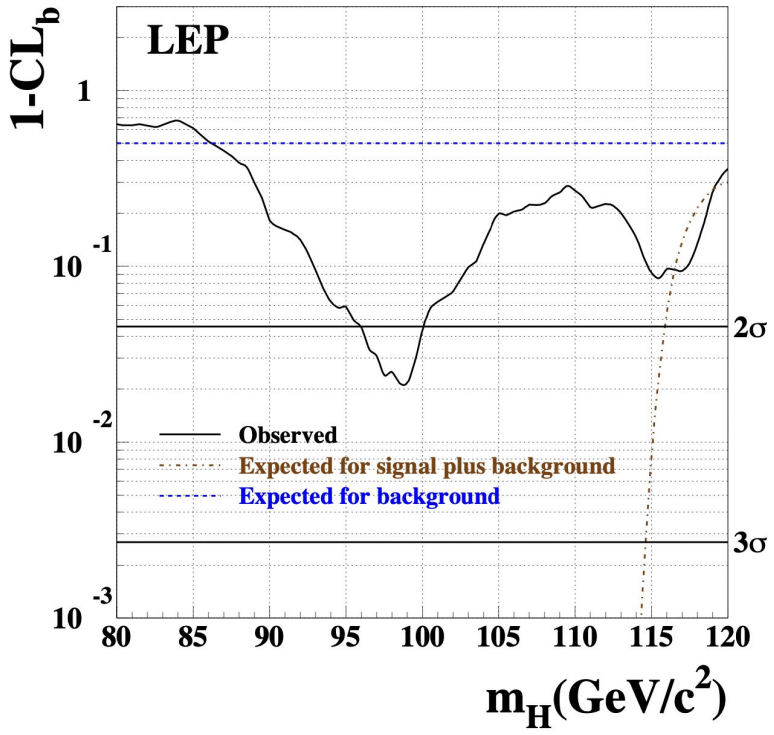
Overview

- The 95 GeV Candidate
- 2HDM+S Model Framework
- Statistical Analysis and Parameter Scans
- Discovery Potential of CEPC
- Event Discrimination: Deep Neural Network
- Conclusion

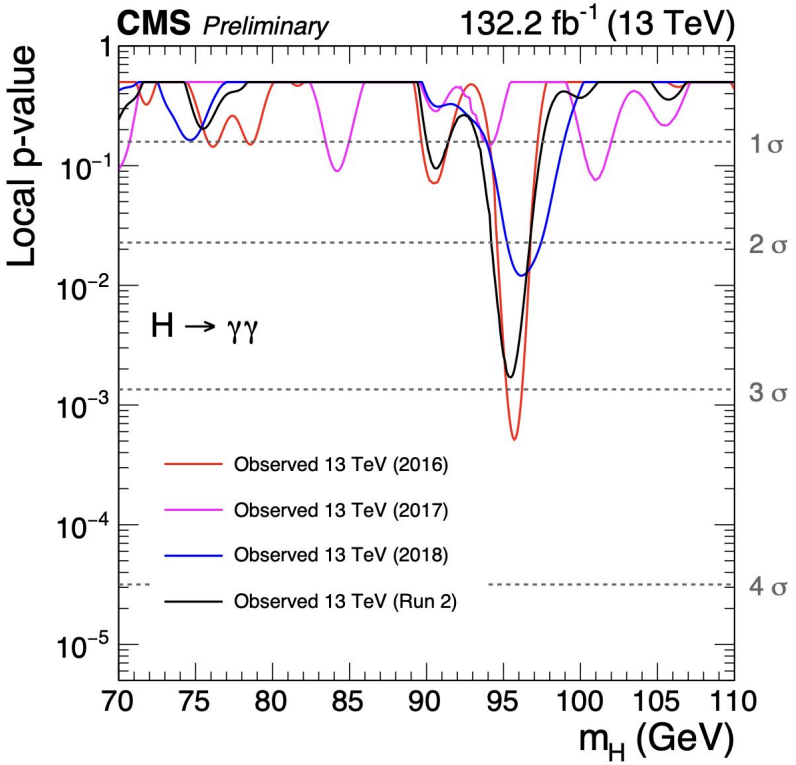
The 95 GeV Candidate

➢ **Results around 96 GeV from LEP (> 2 σ) and CMS (2. 9σ). Further motivates asymmetric searches H→ SS'…**

LEP, Phys. Lett. B 565 (2003) 61–75



CMS PAS HIG-20-002



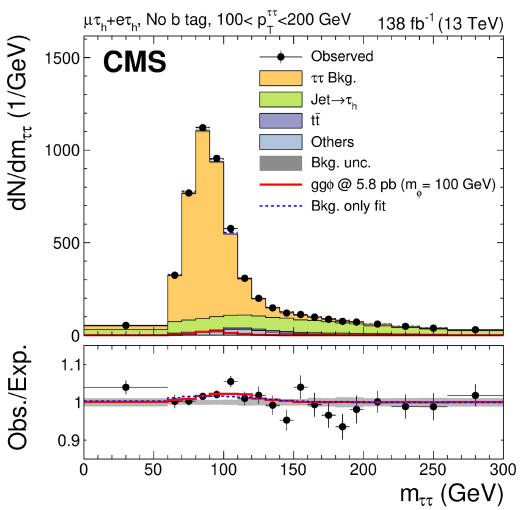
The 95 GeV Candidate

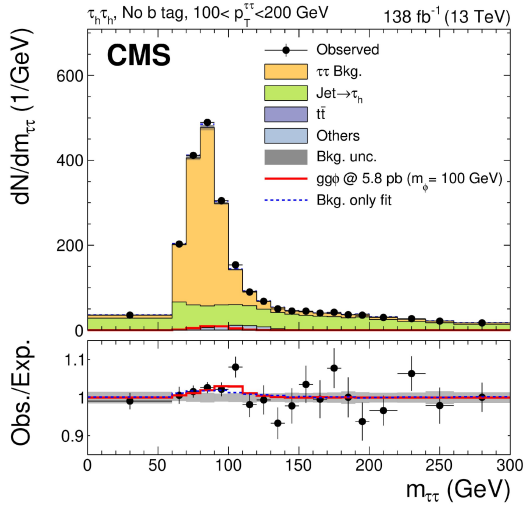
CMS, arXiv:2208.02717

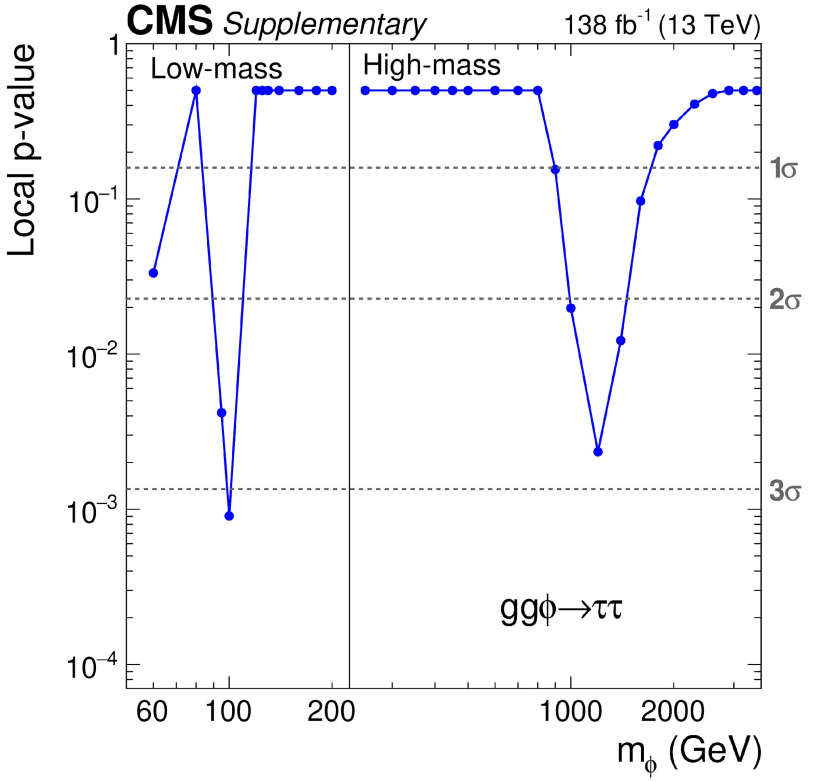
Dedicated search for scalar decaying into tau pairs. CMS observes a local (global) excess of 3.1 (2.7)σ at ~100 GeV.

$$H \rightarrow \tau\tau$$

Phys.Rev.D 108 (2023) 3, 035026



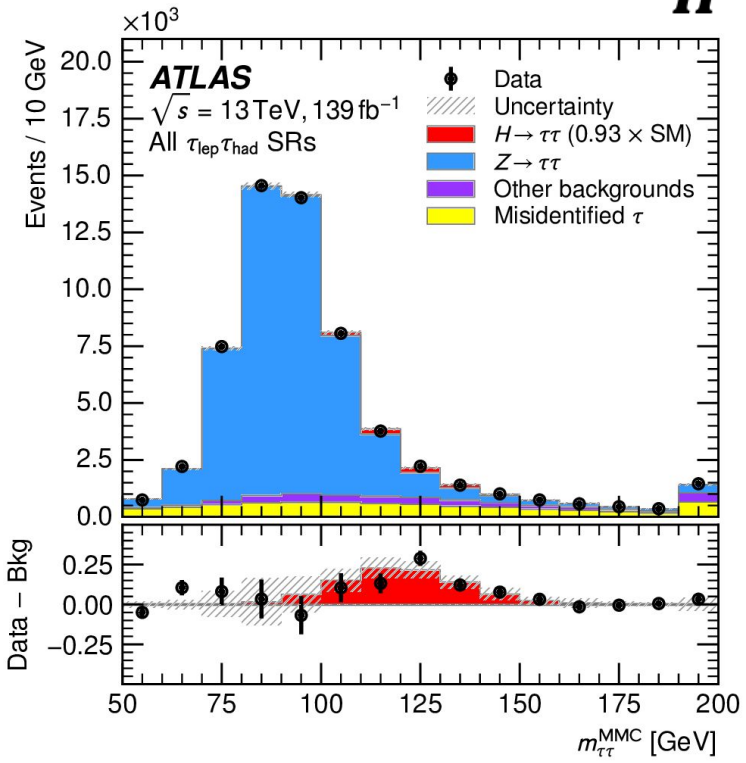


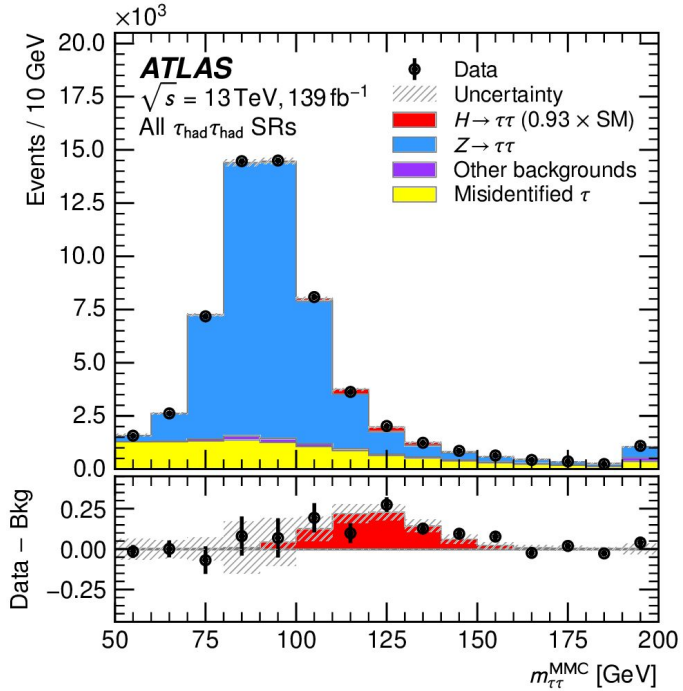


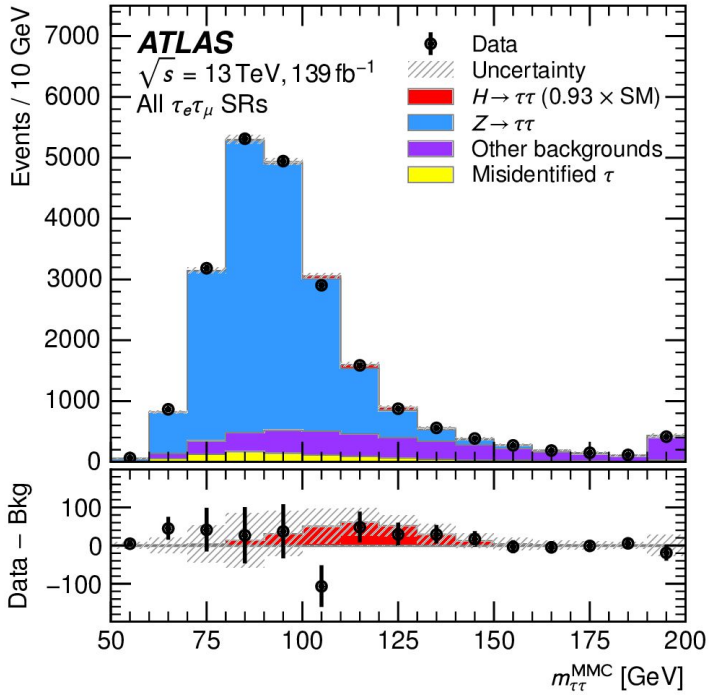
The 95 GeV Candidate

ATLAS, arXiv:2201.08269

$H \to \tau\tau$

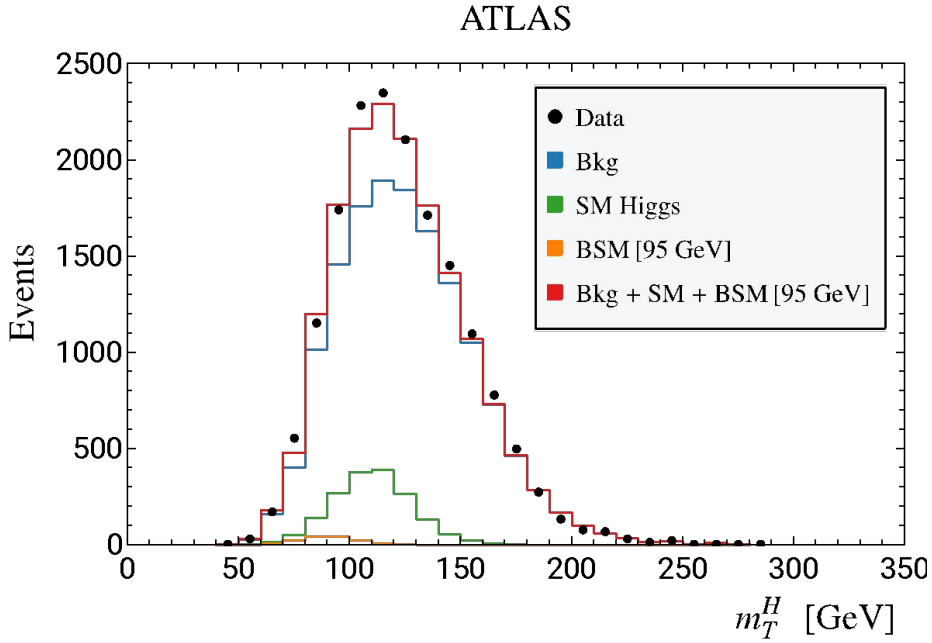


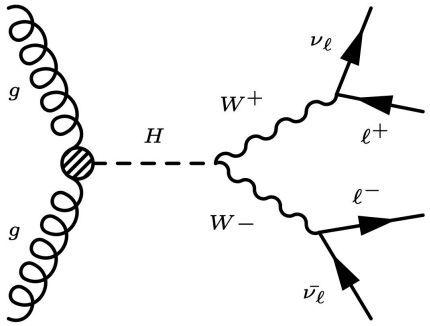


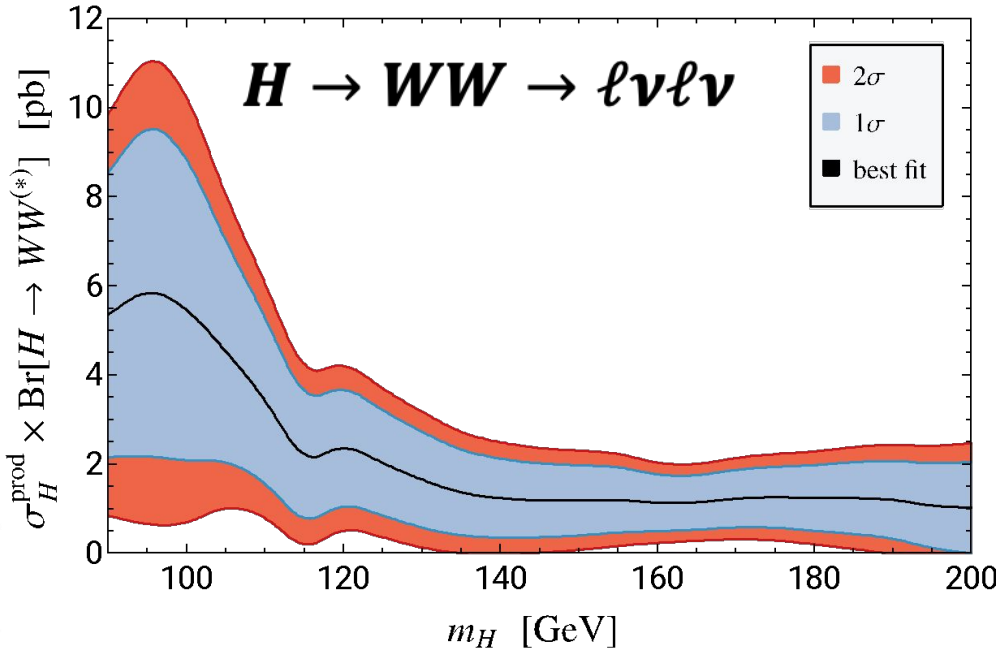


ATLAS has not performed a dedicated search for low mass scalar. That said, we do not seem to see a clear excess around 95 GeV in the sideband. Is the CMS excess an upward fluctuation?

The 95 GeV Candidate

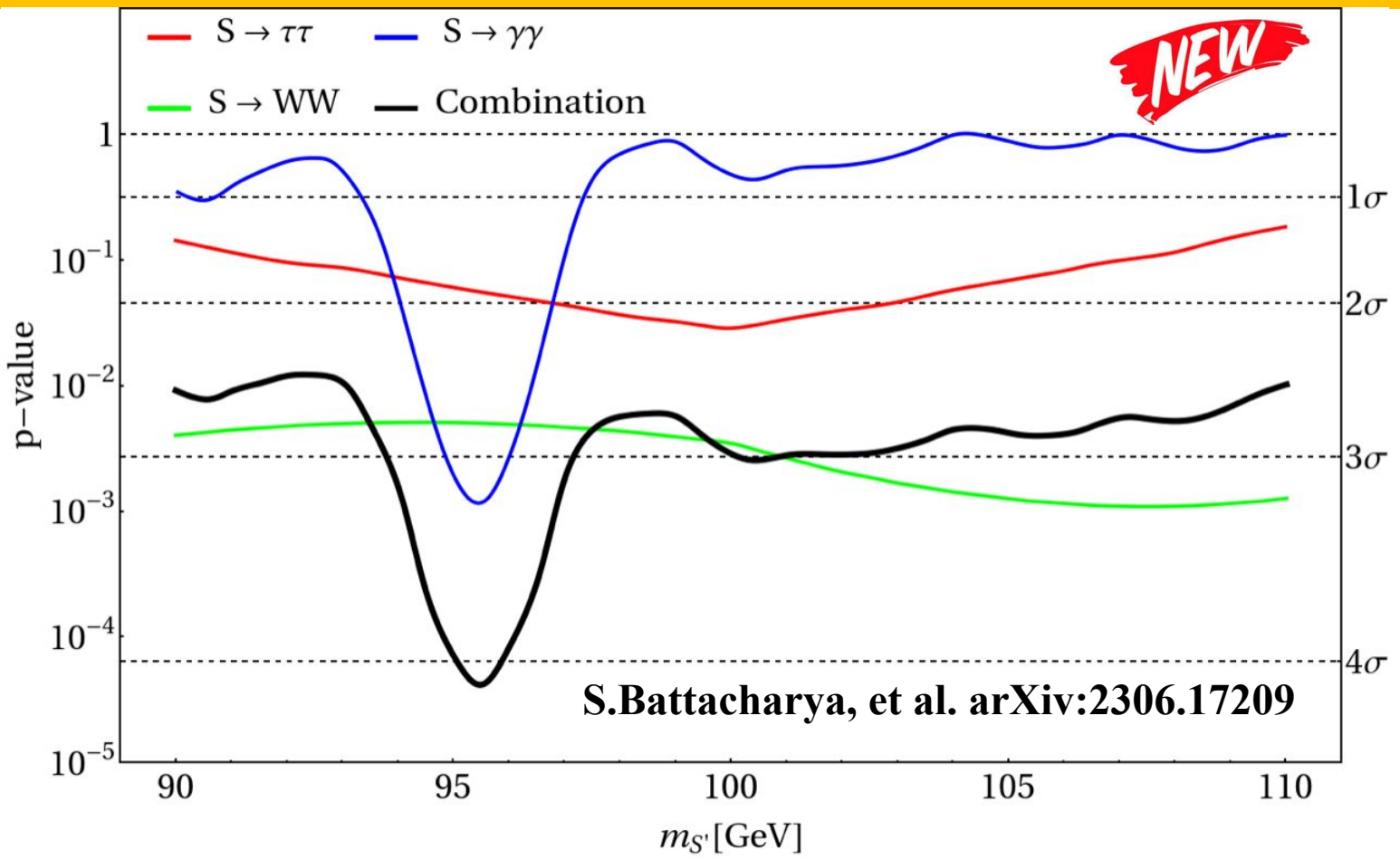






SM Higgs hypothesis alone. alone is having difficulty describing the ll+MET transverse mass spectra, giving room to other Higgs-like signals. Compatibility with other signals under study.

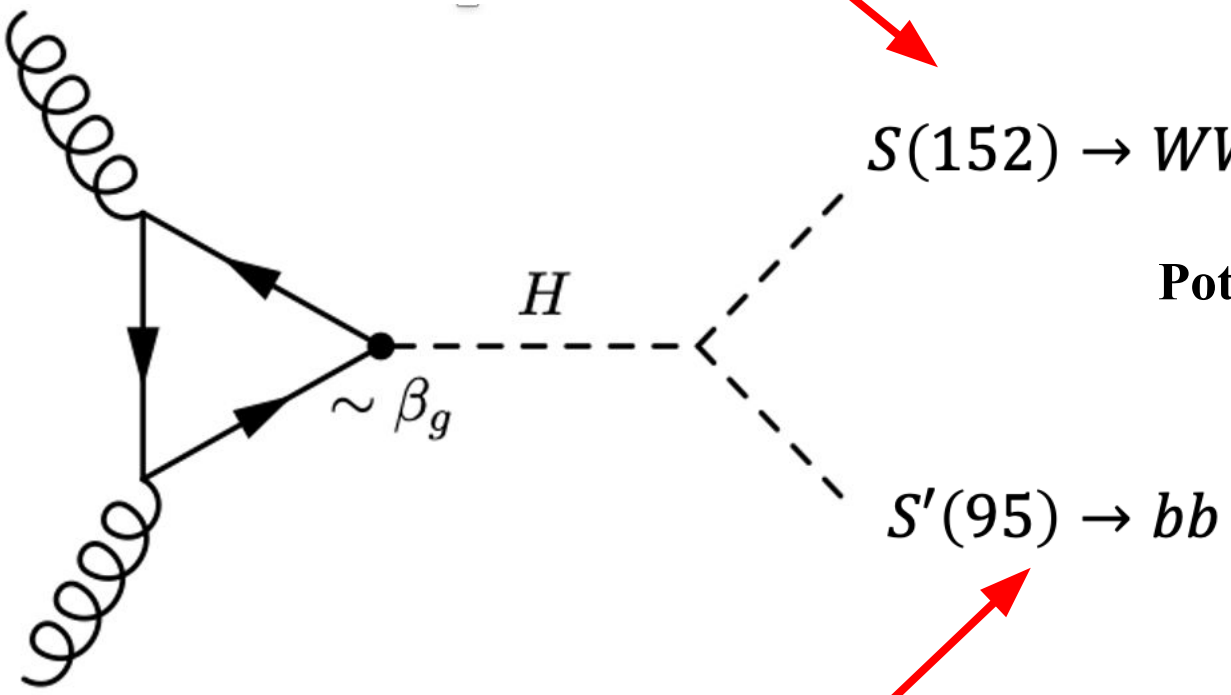
The 95 GeV Candidate



Recent results reported by the ATLAS experiment with significance of narrow resonance at 95 GeV has reached 3.8σ global significance.

➔ **Multi-lepton Anomalies reaches 8σ !!**

The 95 GeV Candidate



Potential contributor to multi-lepton anomalies at the LHC

2HDM+S Model Framework

Fields:

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \frac{1}{\sqrt{2}}(v_1 + \rho_1 + i\eta_1) \end{pmatrix}, \quad \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \frac{1}{\sqrt{2}}(v_2 + \rho_2 + i\eta_2) \end{pmatrix}, \quad \Phi_S = v_S + \rho_S$$

Potential:

$$\begin{aligned} V \;=\; & m_{11}^2|\Phi_1|^2 + m_{22}^2|\Phi_2|^2 - m_{12}^2(\Phi_1^\dagger\Phi_2 + h.c.) + \frac{\lambda_1}{2}(\Phi_1^\dagger\Phi_1)^2 + \frac{\lambda_2}{2}(\Phi_2^\dagger\Phi_2)^2 \\ & + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) + \frac{\lambda_5}{2}[(\Phi_1^\dagger\Phi_2)^2 + h.c.] \\ & + \frac{1}{2}m_S^2\Phi_S^2 + \frac{\lambda_6}{8}\Phi_S^4 + \frac{\lambda_7}{2}(\Phi_1^\dagger\Phi_1)\Phi_S^2 + \frac{\lambda_8}{2}(\Phi_2^\dagger\Phi_2)\Phi_S^2 \end{aligned}$$

Z_2 Symmetry: $\Phi_1 \to \Phi_1$, $\Phi_2 \to -\Phi_2$, $\Phi_S \to \Phi_S$

Z_2' Symmetry: $\Phi_1 \to \Phi_1$, $\Phi_2 \to \Phi_2$, $\Phi_S \to -\Phi_S$ (broken by $v_S \Rightarrow$ no DM)

Physical States: h_1, h_2, h_3 ($\mathcal{CP}$-even), A ($\mathcal{CP}$-odd), $H^\pm$ (charged)

2HDM+S Model Framework

Three Neutral CP-even Higgses :

$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix} = R \begin{pmatrix} \rho_1 \\ \rho_2 \\ \rho_S \end{pmatrix}, \quad R = \begin{pmatrix} c_{\alpha_1} c_{\alpha_2} & s_{\alpha_1} c_{\alpha_2} & s_{\alpha_2} \\ -(c_{\alpha_1} s_{\alpha_2} s_{\alpha_3} + s_{\alpha_1} c_{\alpha_3}) & c_{\alpha_1} c_{\alpha_3} - s_{\alpha_1} s_{\alpha_2} s_{\alpha_3} & c_{\alpha_2} s_{\alpha_3} \\ -c_{\alpha_1} s_{\alpha_2} c_{\alpha_3} + s_{\alpha_1} s_{\alpha_3} & -(c_{\alpha_1} s_{\alpha_3} + s_{\alpha_1} s_{\alpha_2} c_{\alpha_3}) & c_{\alpha_2} c_{\alpha_3} \end{pmatrix}$$

Coupling to massive gauge bosons : (Identical to all four types)

	$c_{h_i VV} = c_\beta R_{i1} + s_\beta R_{i2}$
h_1	$c_{\alpha_2} c_{\beta-\alpha_1}$
h_2	$-c_{\beta-\alpha_1} s_{\alpha_2} s_{\alpha_3} + c_{\alpha_3} s_{\beta-\alpha_1}$
h_3	$-c_{\alpha_3} c_{\beta-\alpha_1} s_{\alpha_2} - s_{\alpha_3} s_{\beta-\alpha_1}$

2HDM+S Model Framework

Coupling to fermions:

	u-type ($c_{h_i tt}$)	d-type ($c_{h_i bb}$)	leptons ($c_{h_i \tau\tau}$)
type I	$\frac{R_{i2}}{s_\beta}$	$\frac{R_{i2}}{s_\beta}$	$\frac{R_{i2}}{s_\beta}$
type II	$\frac{R_{i2}}{s_\beta}$	$\frac{R_{i1}}{c_\beta}$	$\frac{R_{i1}}{c_\beta}$
type III (lepton-specific)	$\frac{R_{i2}}{s_\beta}$	$\frac{R_{i2}}{s_\beta}$	$\frac{R_{i1}}{c_\beta}$
type IV (flipped)	$\frac{R_{i2}}{s_\beta}$	$\frac{R_{i1}}{c_\beta}$	$\frac{R_{i2}}{s_\beta}$

2HDM+S Model Framework

Coupling to fermions:

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type III (lepton-specific)	$\frac{R_{i2}}{s_\beta}$	$\frac{R_{i2}}{s_\beta}$	$\frac{R_{i1}}{c_\beta}$
type IV (flipped)	$\frac{R_{i2}}{s_\beta}$	$\frac{R_{i1}}{c_\beta}$	$\frac{R_{i2}}{s_\beta}$

"Physical" input parameters:

$$\alpha_{1,2,3}\,, \quad \tan\beta\,, \quad v\,, \quad v_S\,, \quad m_{h_{1,2,3}}\,, \quad m_A\,, \quad M_{H^\pm}\,, \quad m^2_{12}$$

Statistical Analysis and Parameter Scans

$$\chi^2_{\gamma\gamma,\tau^+\tau^-,b\bar{b},WW} = \frac{(\mu_{\gamma\gamma,\tau^+\tau^-,b\bar{b},WW} - \mu^{exp}_{\gamma\gamma,\tau^+\tau^-,b\bar{b},WW})^2}{(\Delta\mu^{exp}_{\mu\ \gamma\gamma,\tau^+\tau^-,b\bar{b},WW})^2}$$

$$\mu_{XX} = \frac{\sigma^{BSM}(gg\rightarrow S)\cdot BR^{BSM}(S\rightarrow XX)}{\sigma^{BSM}(gg\rightarrow S(m=m_{SM}))\cdot BR^{SM}(S(m=m_{BSM})\rightarrow XX)}$$

$\mu^{exp}_{WW} = 14.6 \pm 6.8$

$\mu^{exp}_{\gamma\gamma} = 0.27 \pm 0.095$

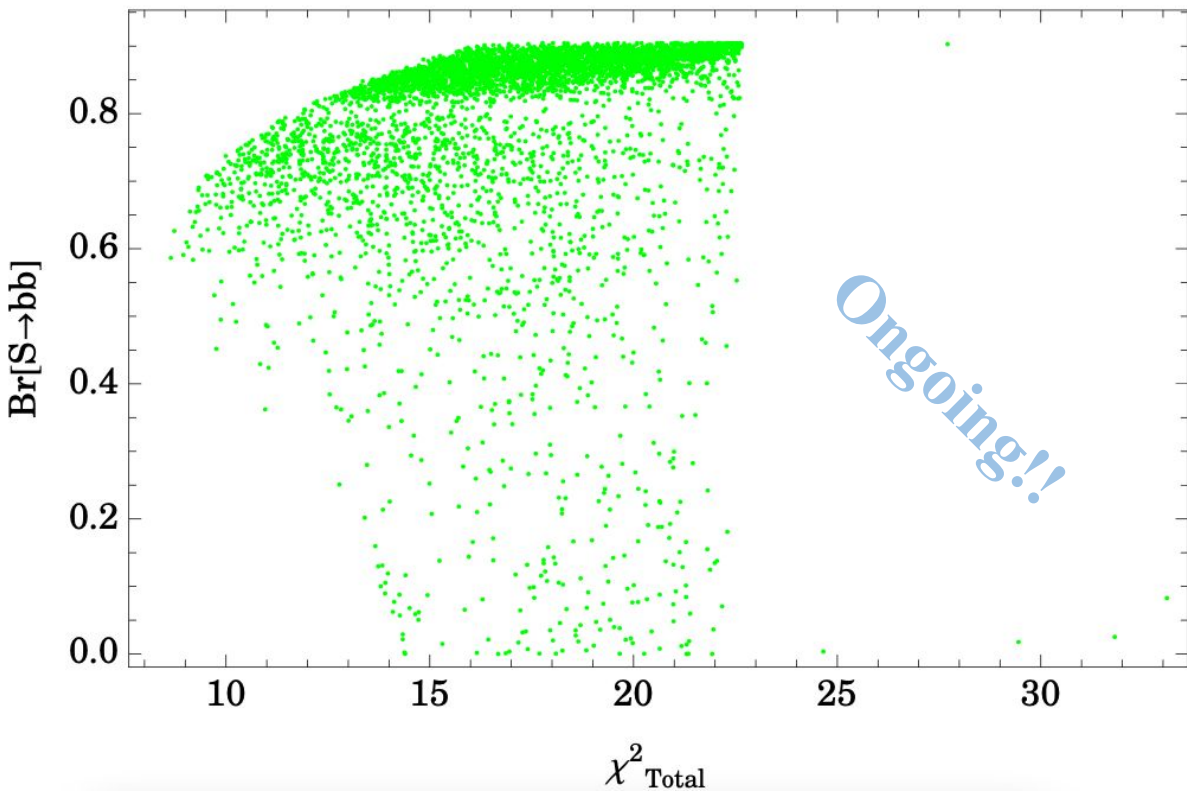
$\mu^{exp}_{b\bar{b}} = 0.117 \pm 0.057$

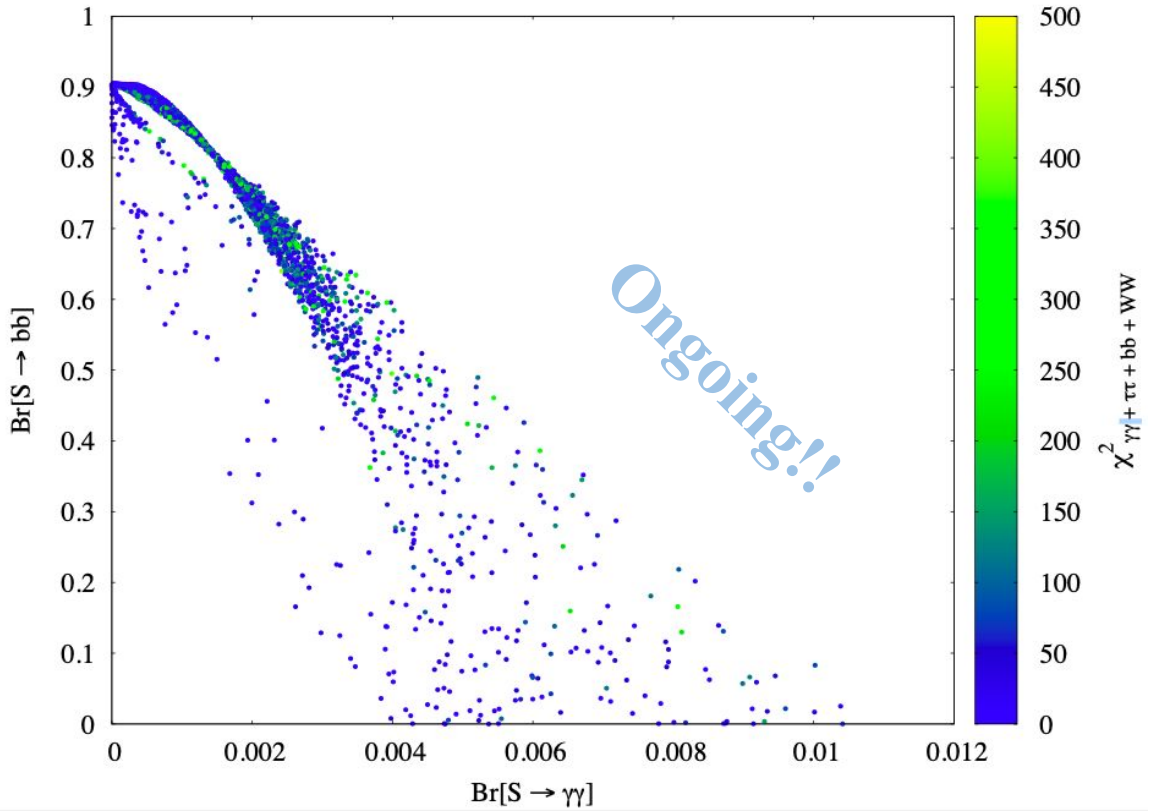
$\mu^{exp}_{\tau\tau} = 0.6 \pm 0.25$

Cross section :

$S(95) = 76.3$ pb

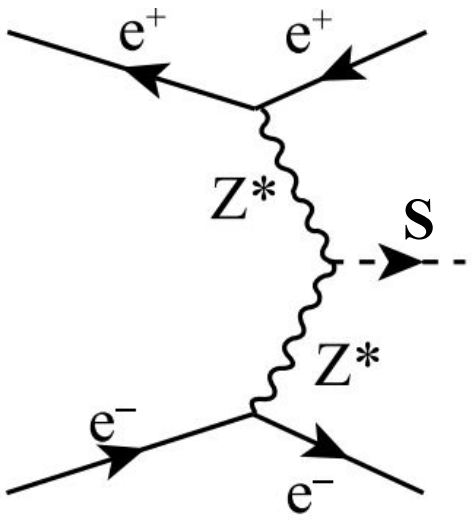
Statistical Analysis and Parameter Scans



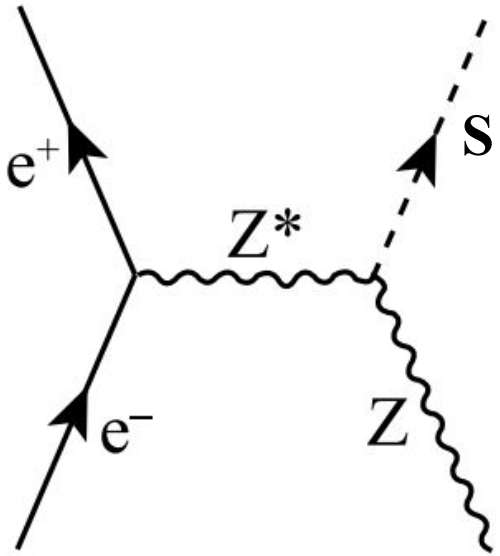


➔ **Further validates the choice for BSM signal as 10% of SM background for the allowed parameter space within 2HDM+S framework**

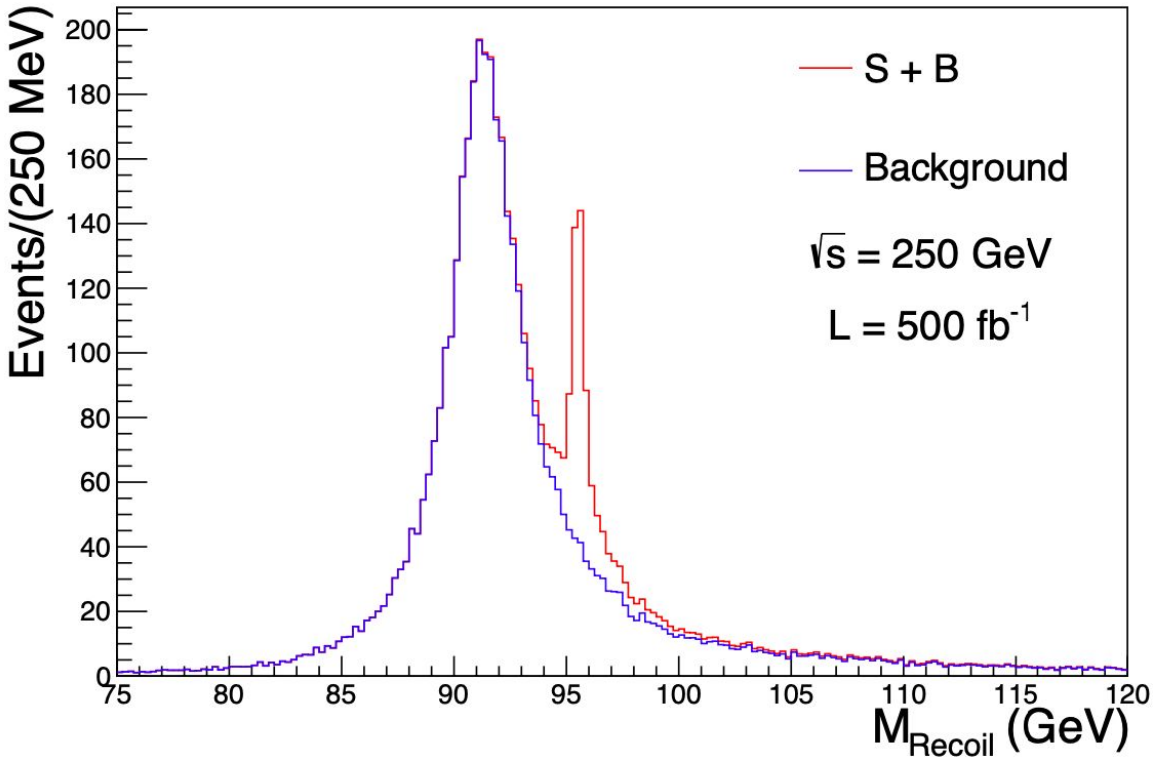
Discovery Potential of CEPC

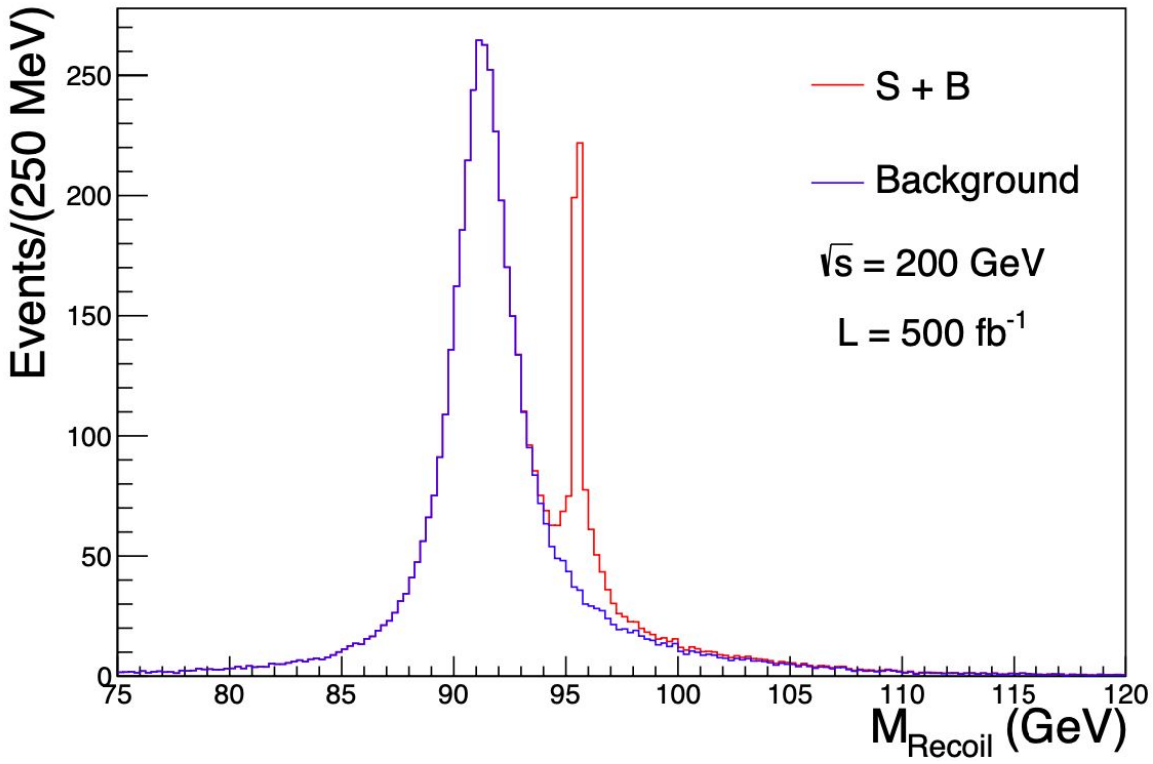


$$M_{recoil} = \sqrt{s + M^2_{\mu^+\mu^-} - 2(E_{\mu^+} + E_{\mu^-})\sqrt{s}}$$



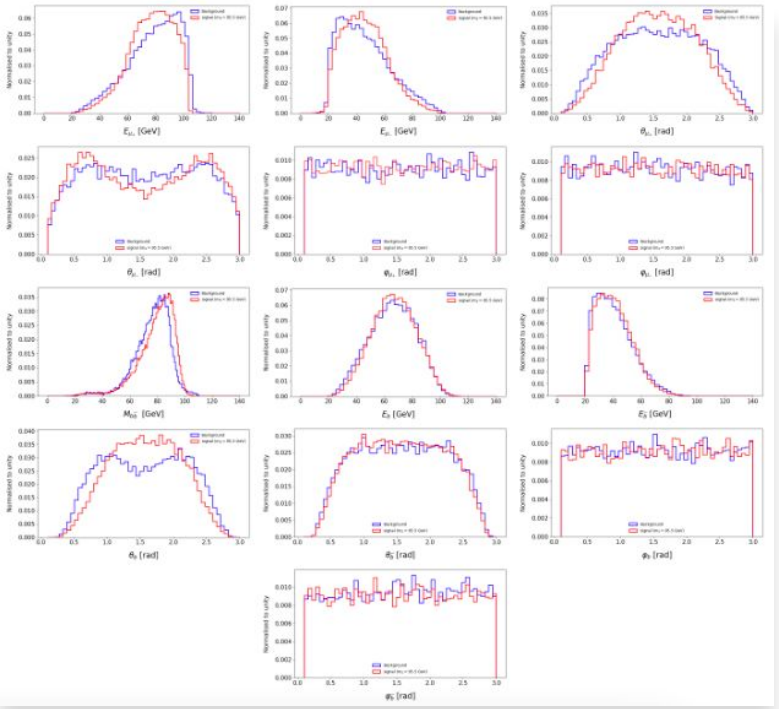
Discovery Potential of CEPC

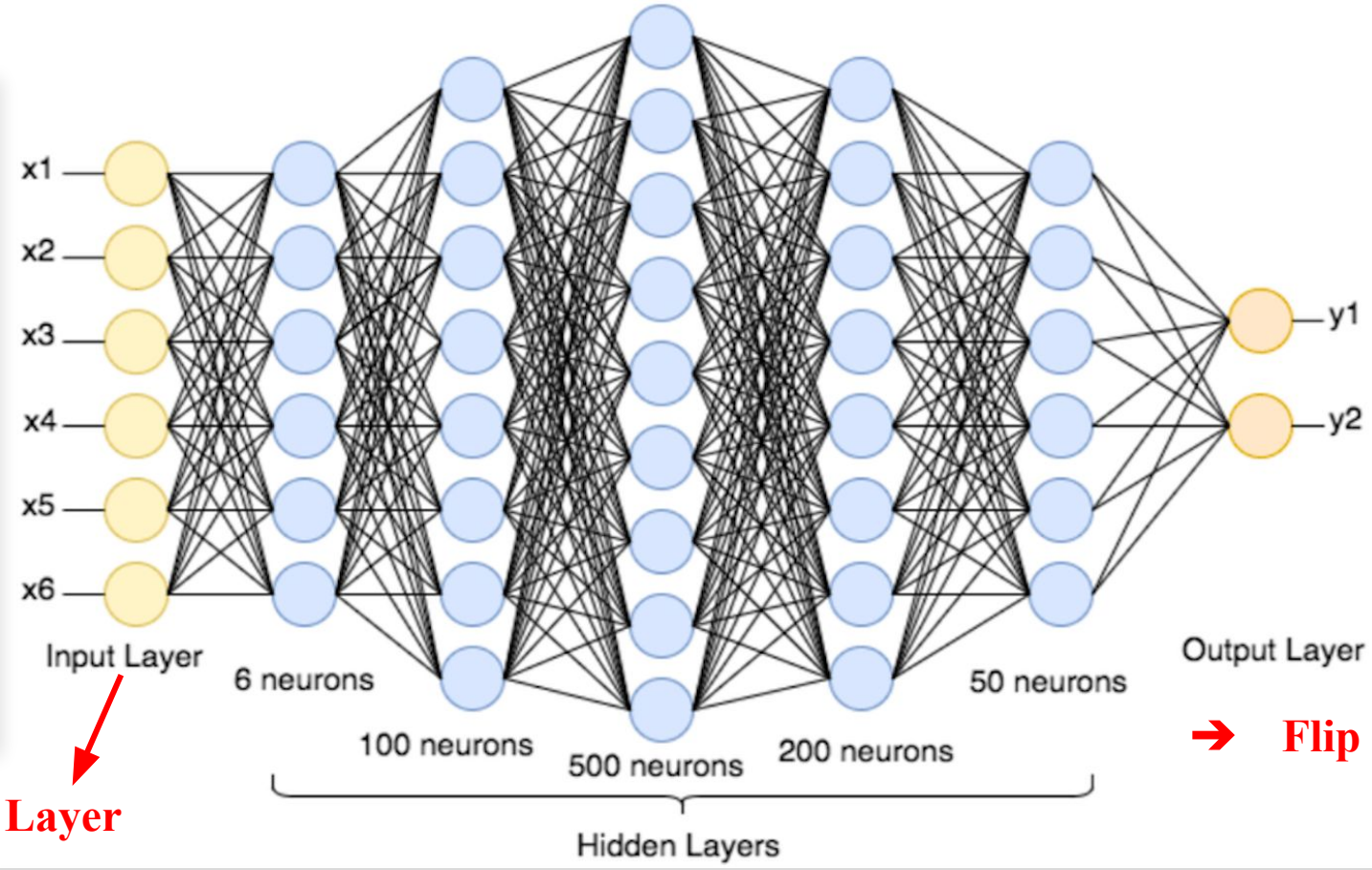




➔ **Even at √s = 200 GeV, we can expect to make an observation**

Event Discrimination: Deep Neural Network

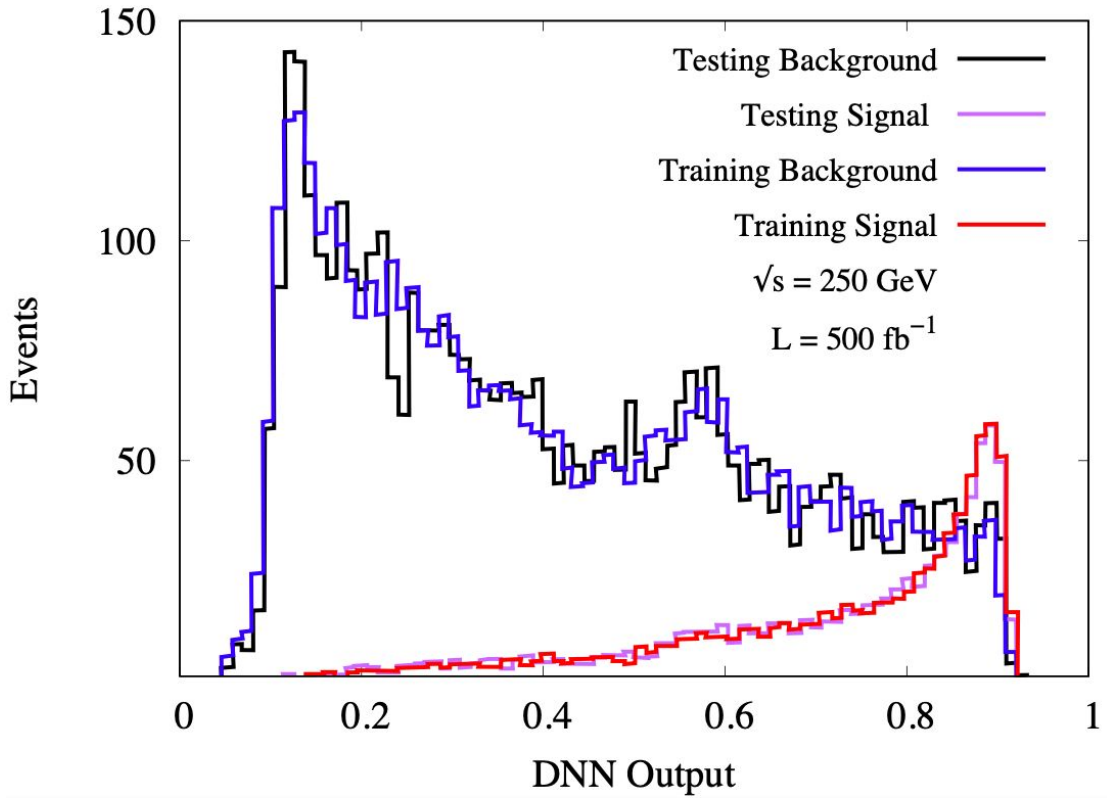




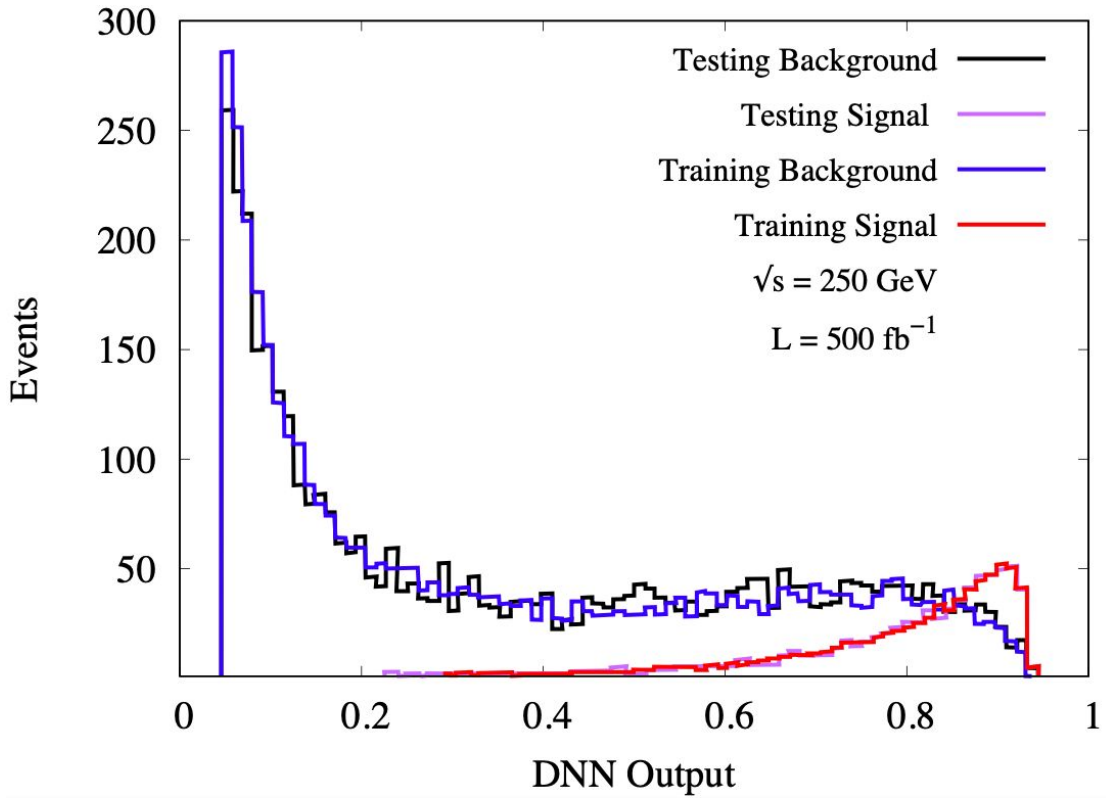
➔ 14 Input Variables in the Input Layer

➔ Flip Coin

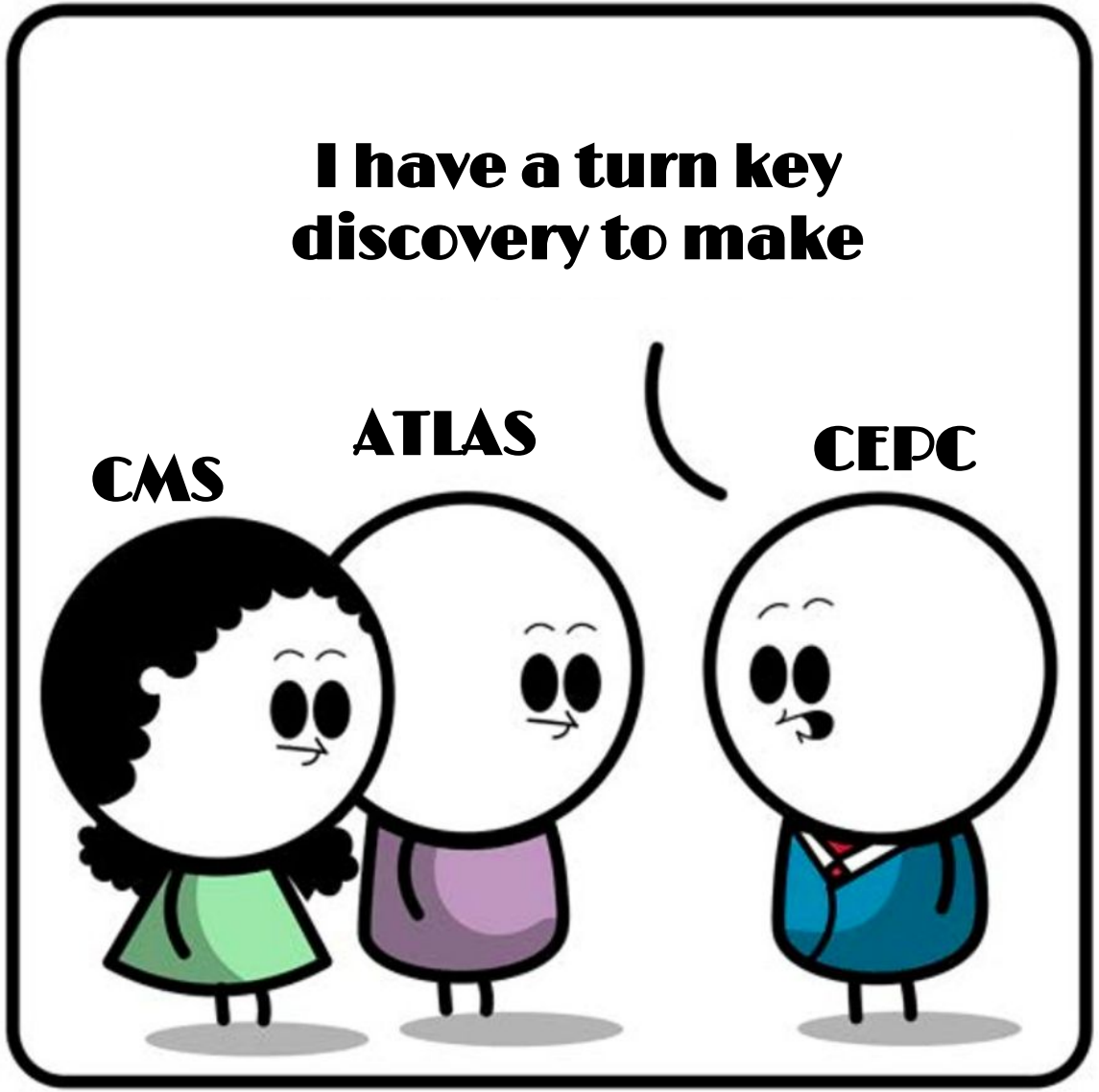
Event Discrimination: Deep Neural Network



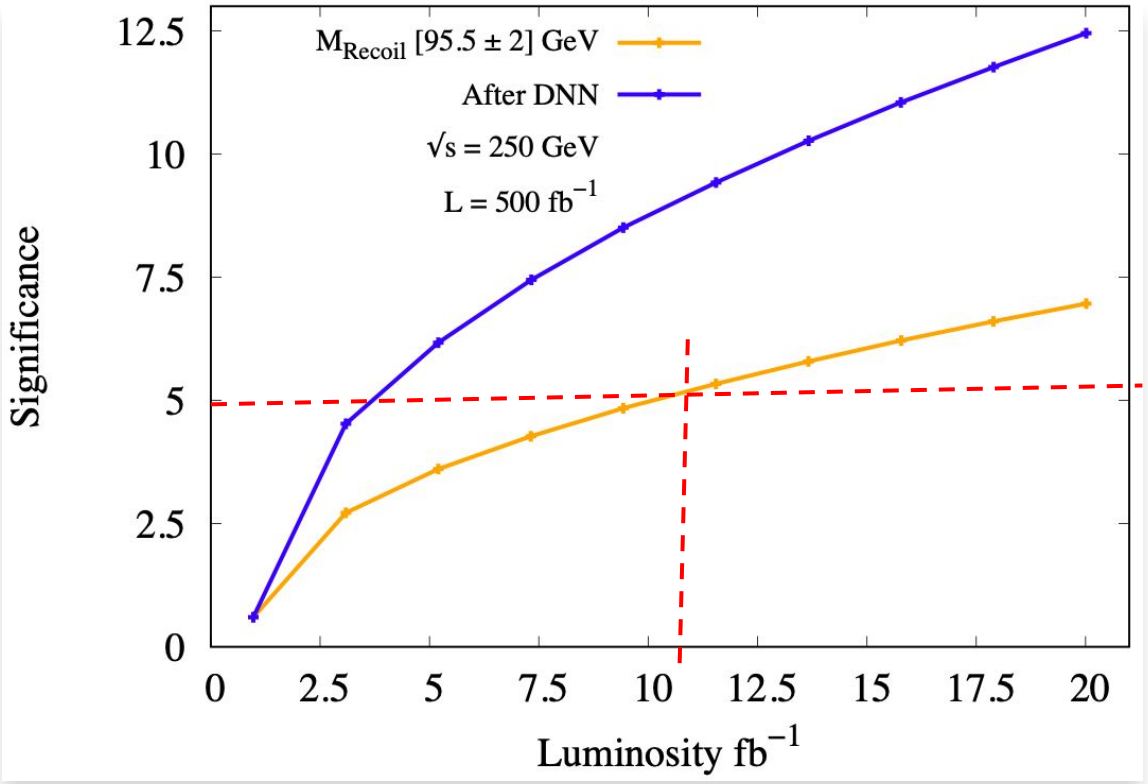
➔ **Excluding Recoil mass**



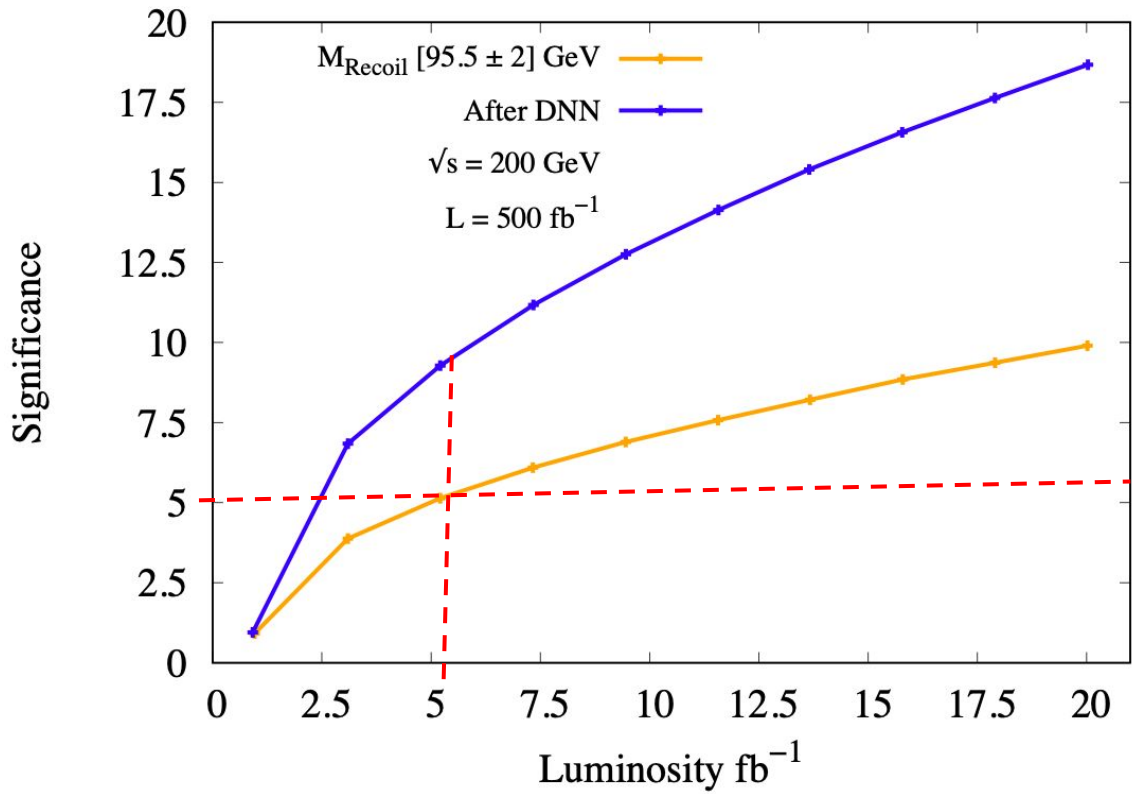
➔ **Including Recoil mass**


I have a turn key discovery to make
CMS
ATLAS
CEPC

Discovery Potential of CEPC (Again)

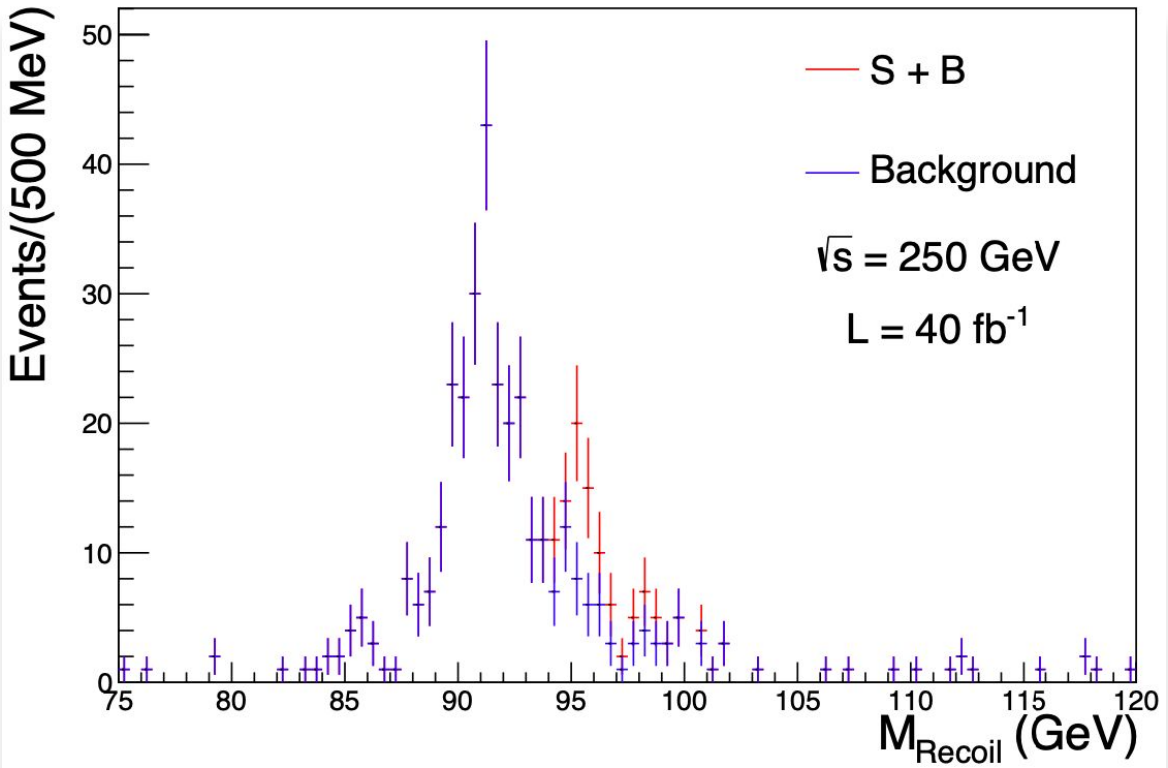


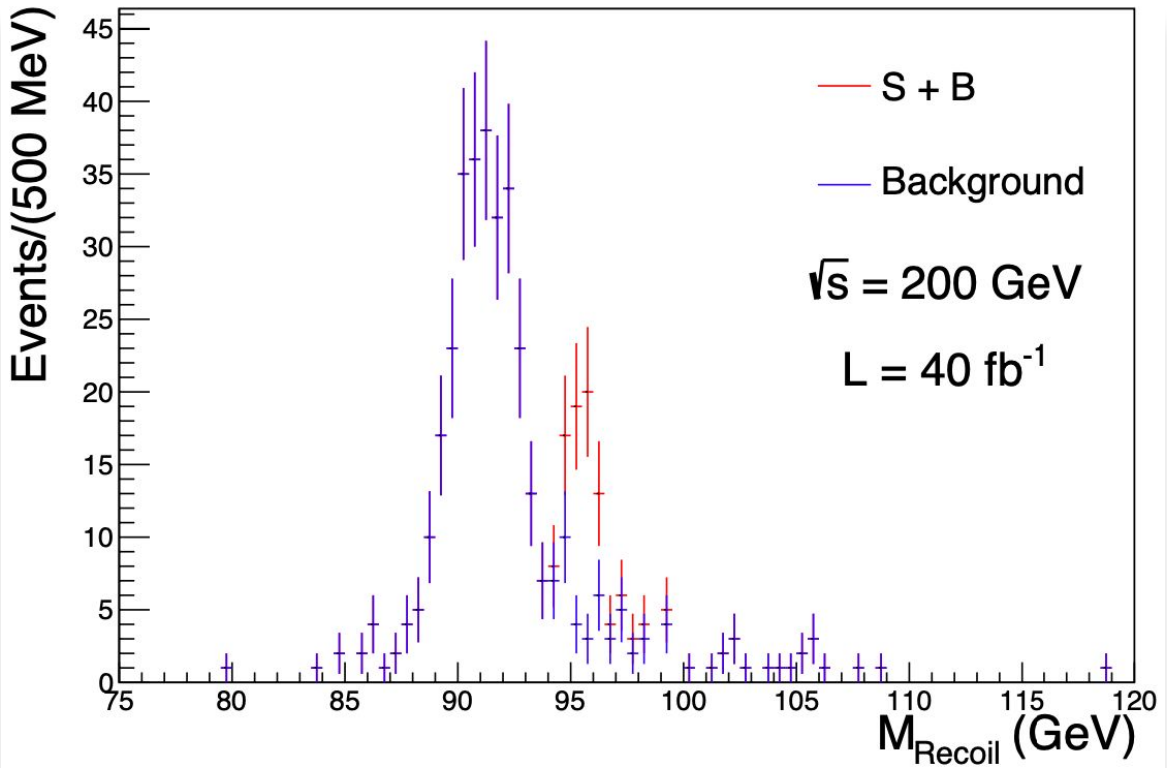
➔ **Expected 5σ in 8 Days**



➔ **Expected 5σ in 4 Days**

Discovery Potential of CEPC (Again)





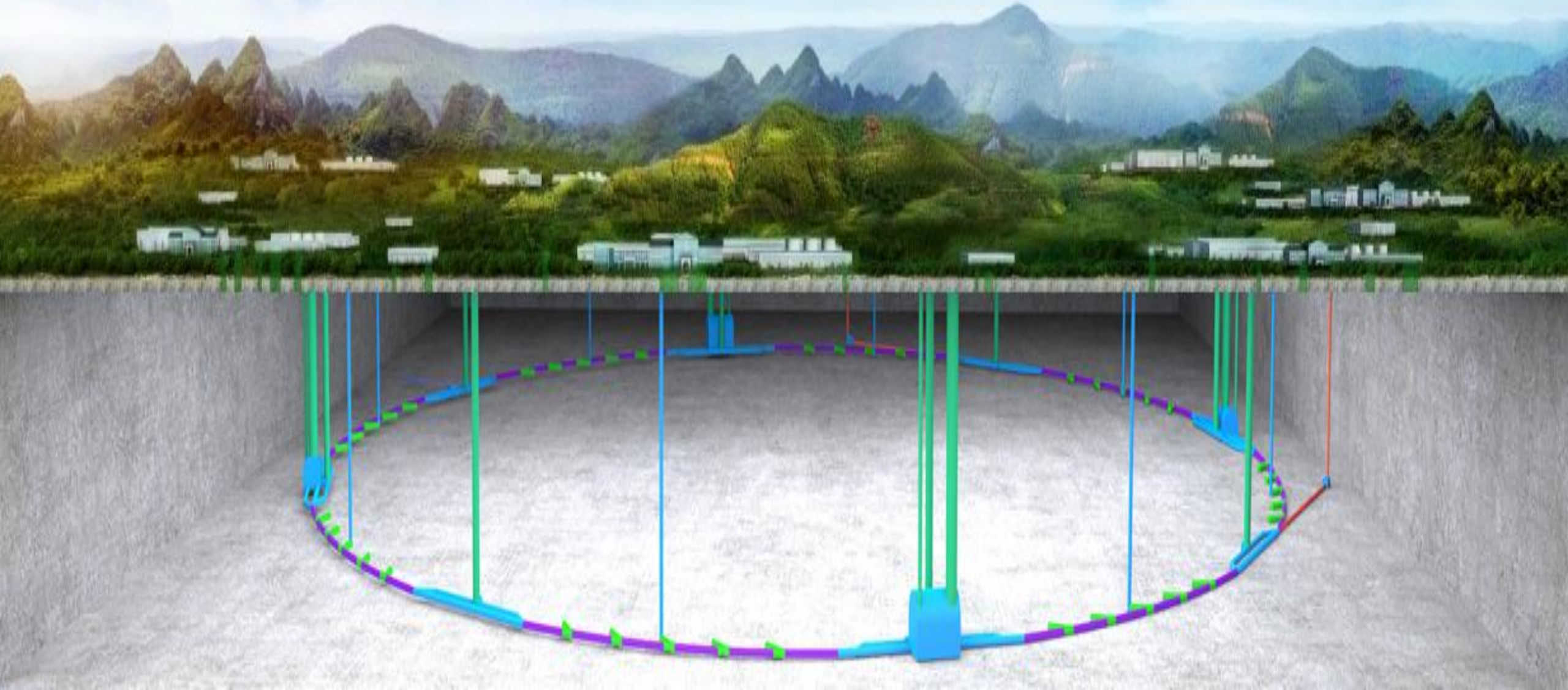
➔ **Expected Initial CEPC Measurements**

Summary and Conclusion

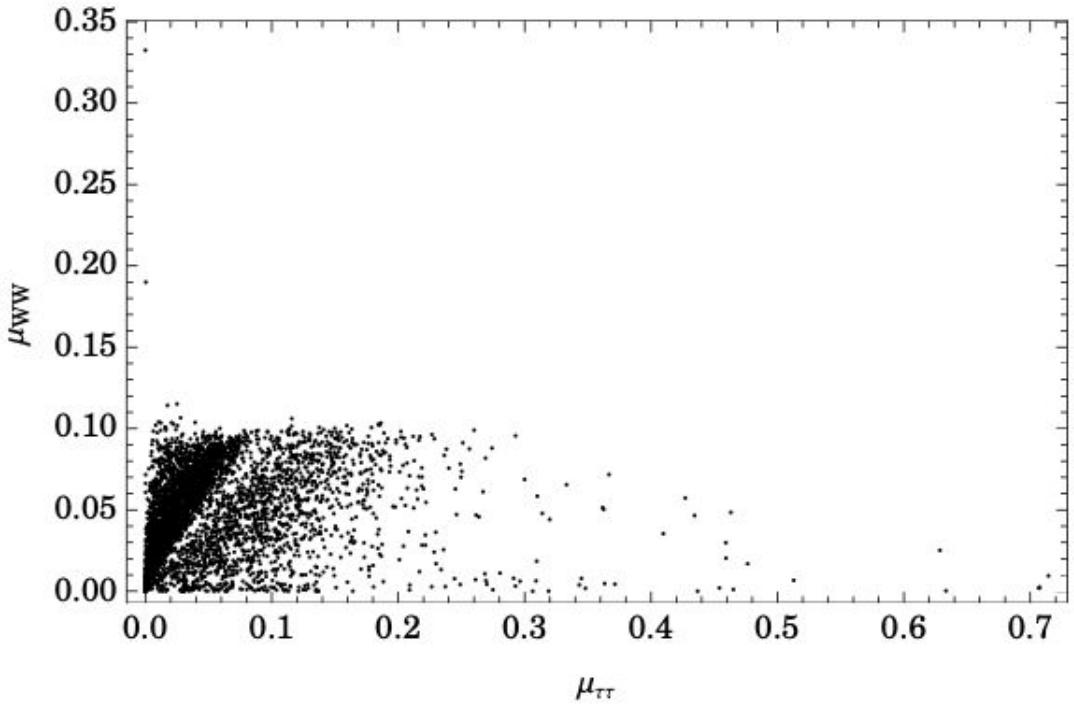
- **Reported 95 GeV excesses: LEP = 2 σ, CMS = 2.9 σ, CMS: 2.4 σ, ATLAS = 1.7 σ**
- **The Observation reaches 5σ significance with 15 (10) fb^{-1} for $\sqrt{s}$ = 250 (200) GeV at CEPC**
- **Turn key discovery ("8 days")**
- **Signifies multi-lepton anomalies reaches 8σ (with excesses at 152 GeV ~ 4.8 σ)**
- **This observation could set up the existence of Beyond the Standard Model Physics.**

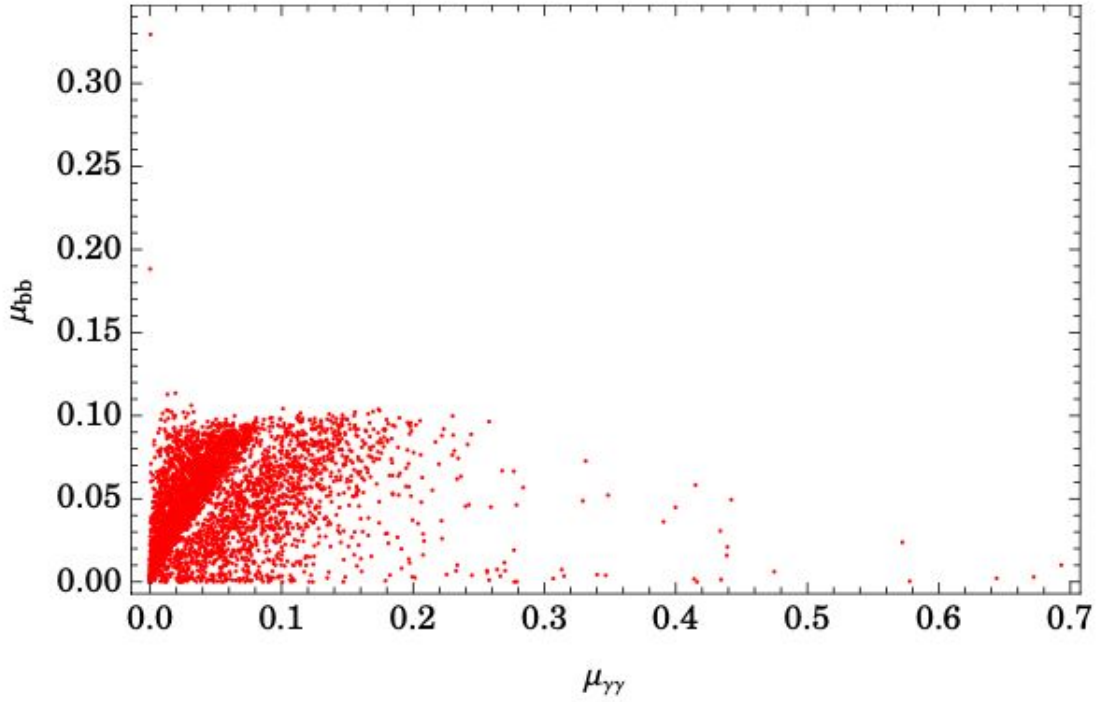
Further Questions?

Additional Slides



Parameter Scans





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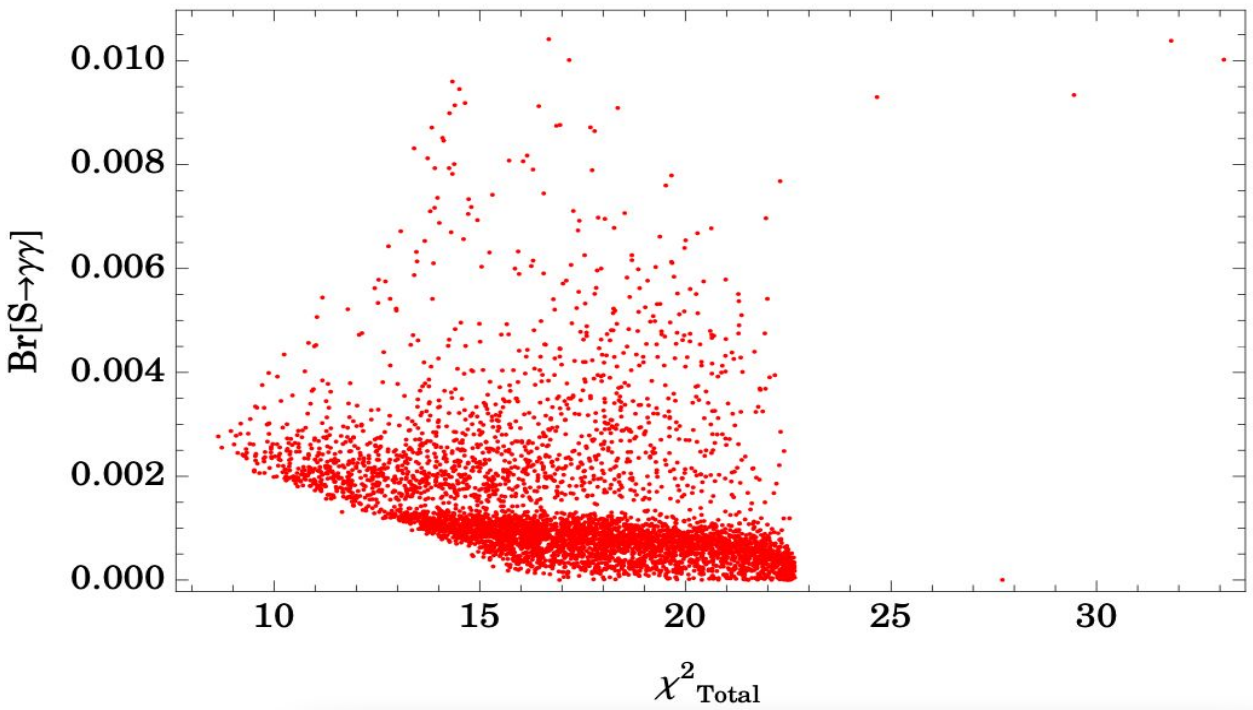
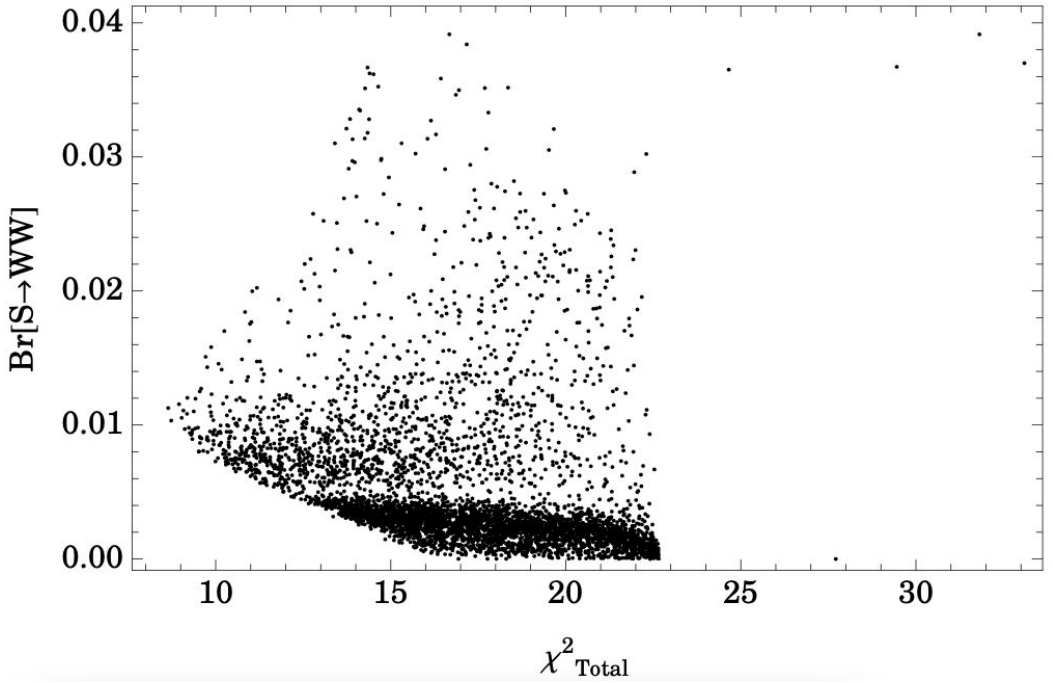
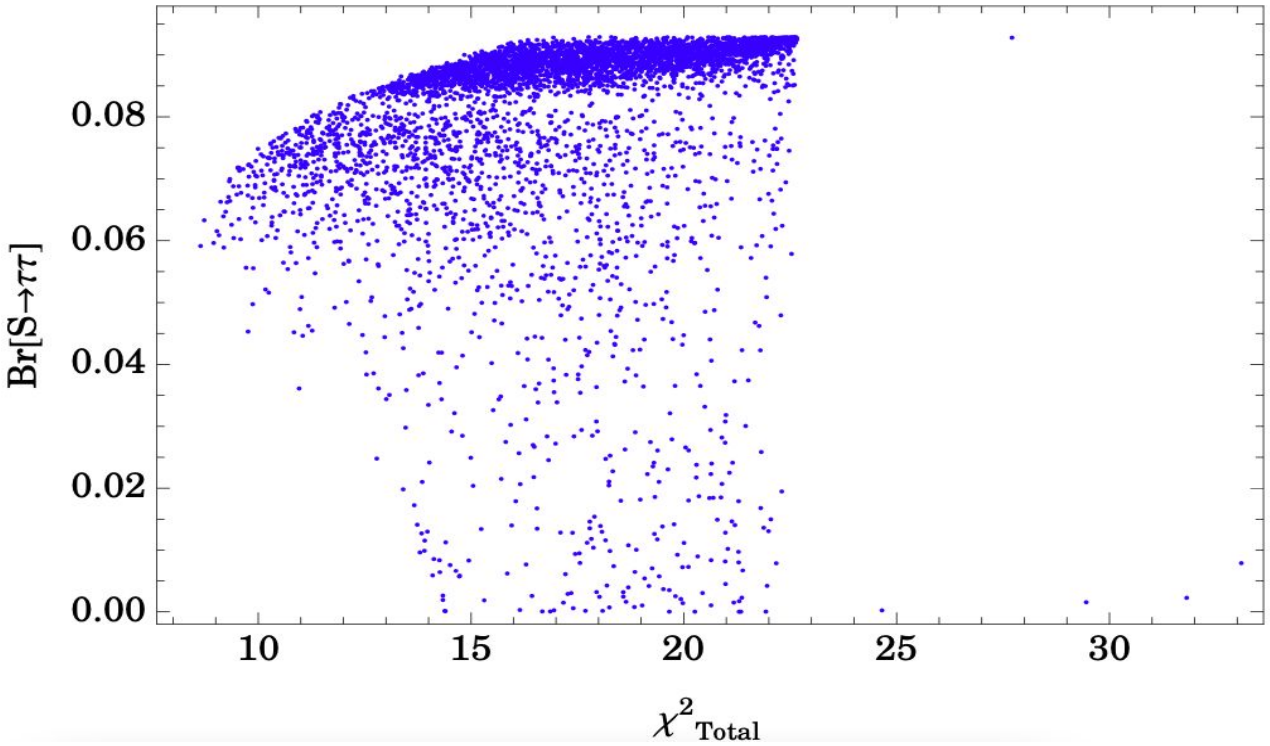




Parameter Scans



Parameter Scans