Constraining light quark Yukawa couplings from WH charge asymmetry

Omsap Jaroonrak

Supervisors: Cecile Caillol, Andrea Marini

3rd August 2022

EP-CMG-OS

A summer student project

About me

- Name: Omsap Jaroonrak
- Country: Thailand
- Education: Bachelor of Science in Physics, Suranaree university of Technology
- CERN summer studentship: EP-CMG-OS in the CMS collaboration
- After CERN? : applying for M.Sc/Ph.D in Physics
- Email: omsap.jaoonrak@cern.ch or mach2543@gmail.com

Outline

- Introduction and Motivation
- Datacards and Category Modification
- Inclusive Charge Measurement
- Results
- Summary and Outlook

Introduction and motivation

- A **consistency test** for the Standard Model (SM) Higgs
- **First time** measuring **WH charge asymmetry** with Run 2 data (2016-2018)
- Indirectly constraining **Light quark Yukawa couplings**

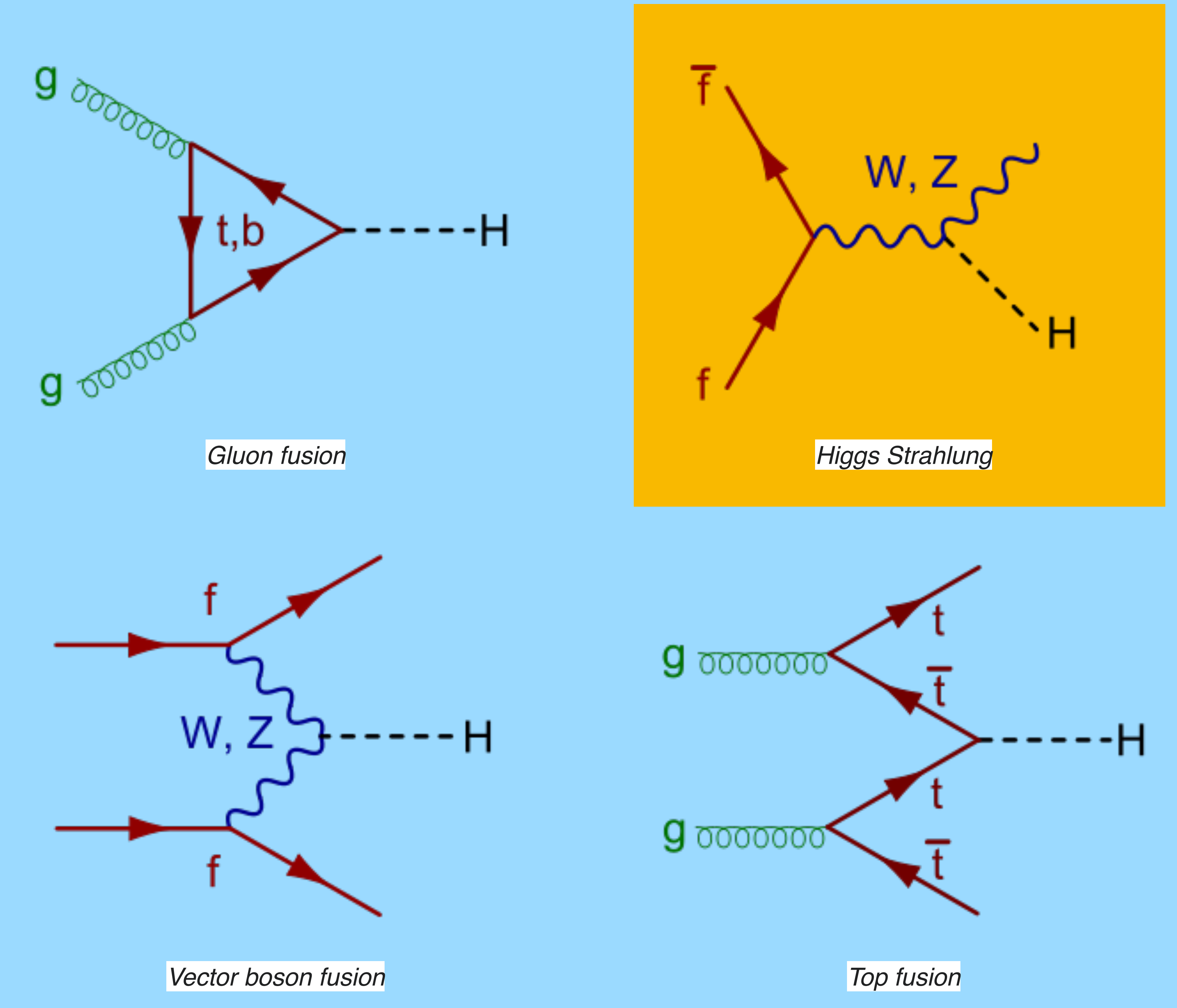
Inclusive charge asymmetry

$$A = \frac{\sigma(W^+h) - \sigma(W^-h)}{\sigma(W^+h) + \sigma(W^-h)}$$

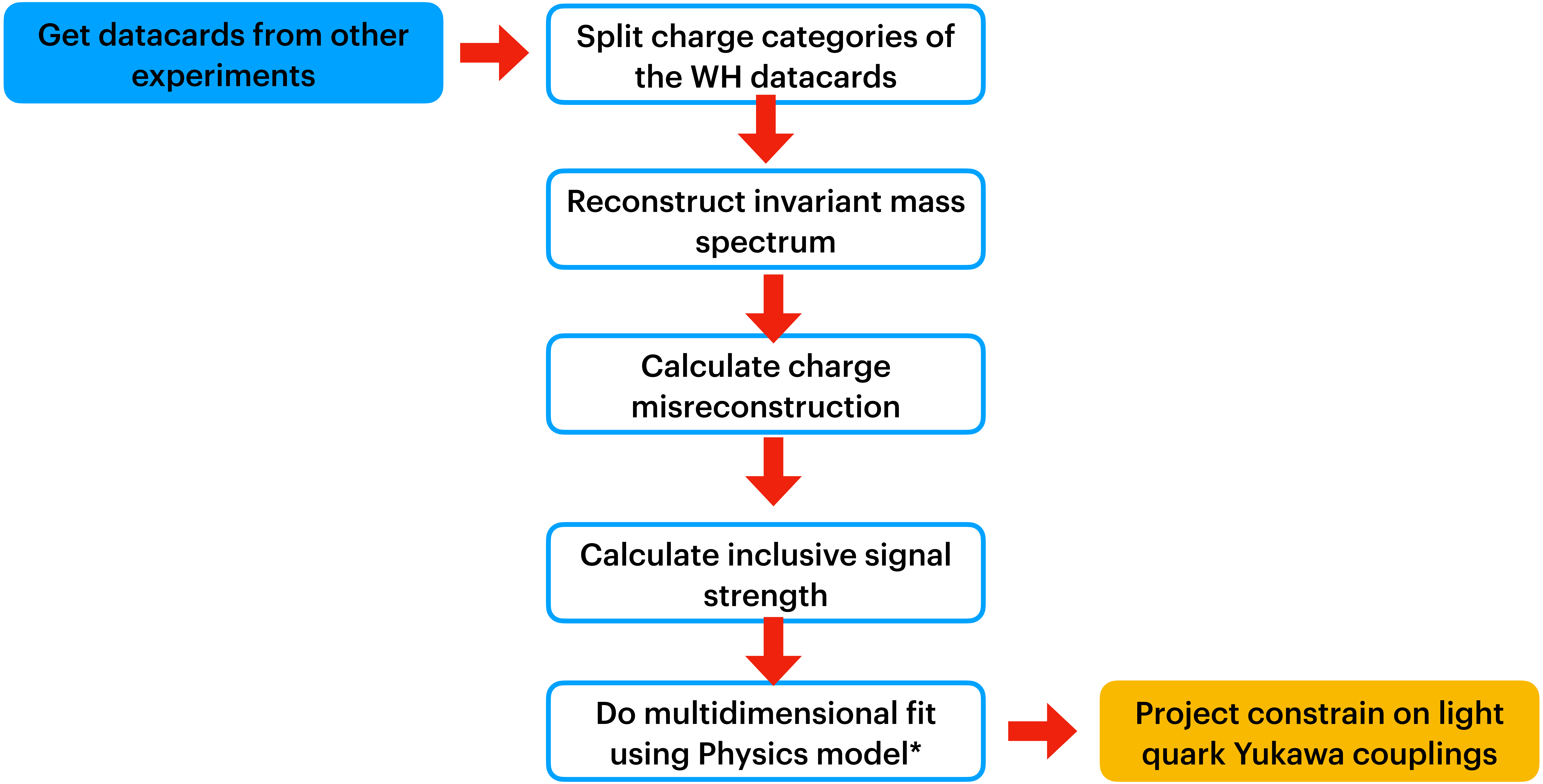
Higgs Boson and WH analysis

- **Associated production** of the Higgs boson
- Higgs coupling to W bosons
- Final states: $e\mu\tau_h$, $e\tau_h\tau_h$, $\mu\mu\tau_h$, and $\mu\tau_h\tau_h$

Production modes of Higgs

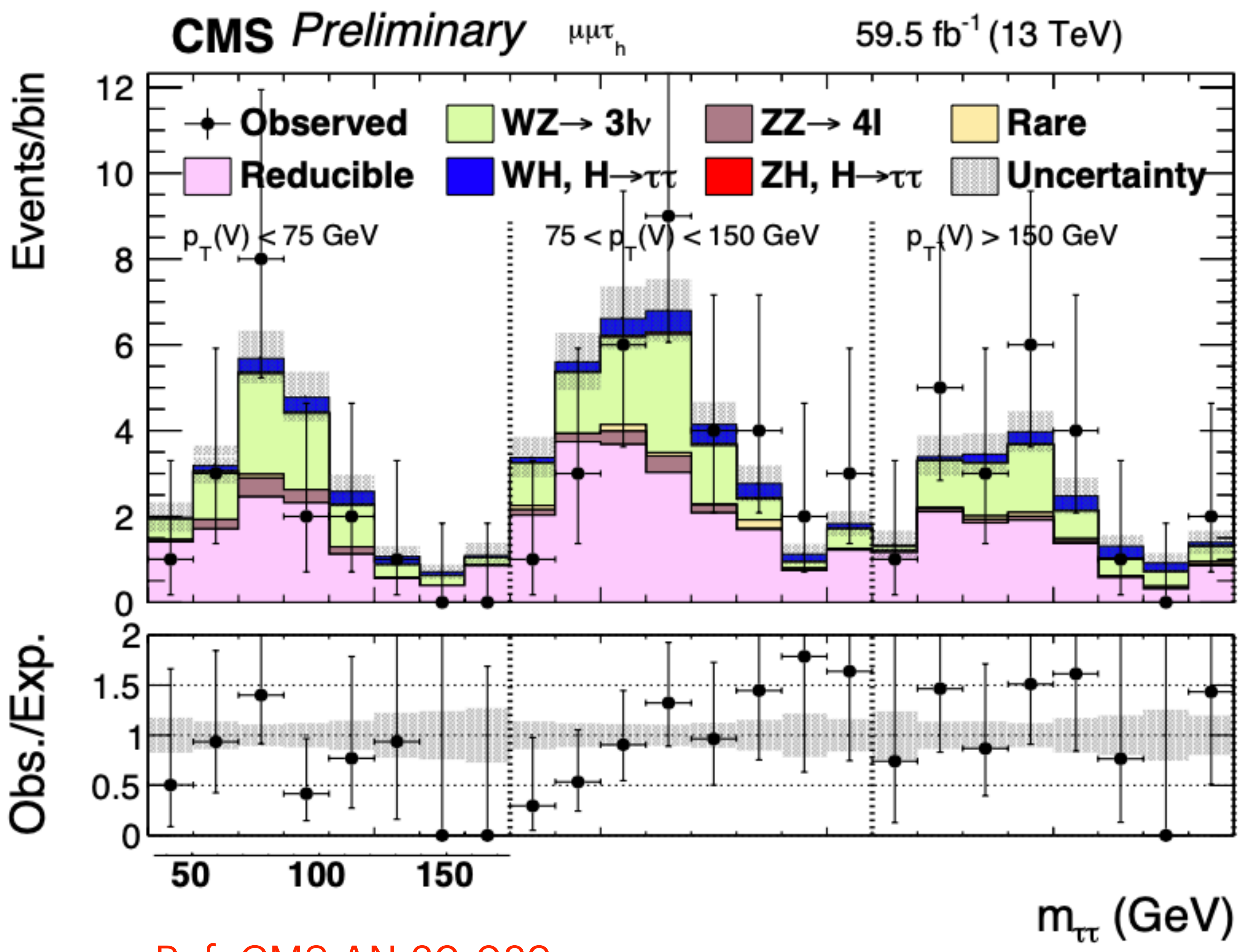


Project workflow

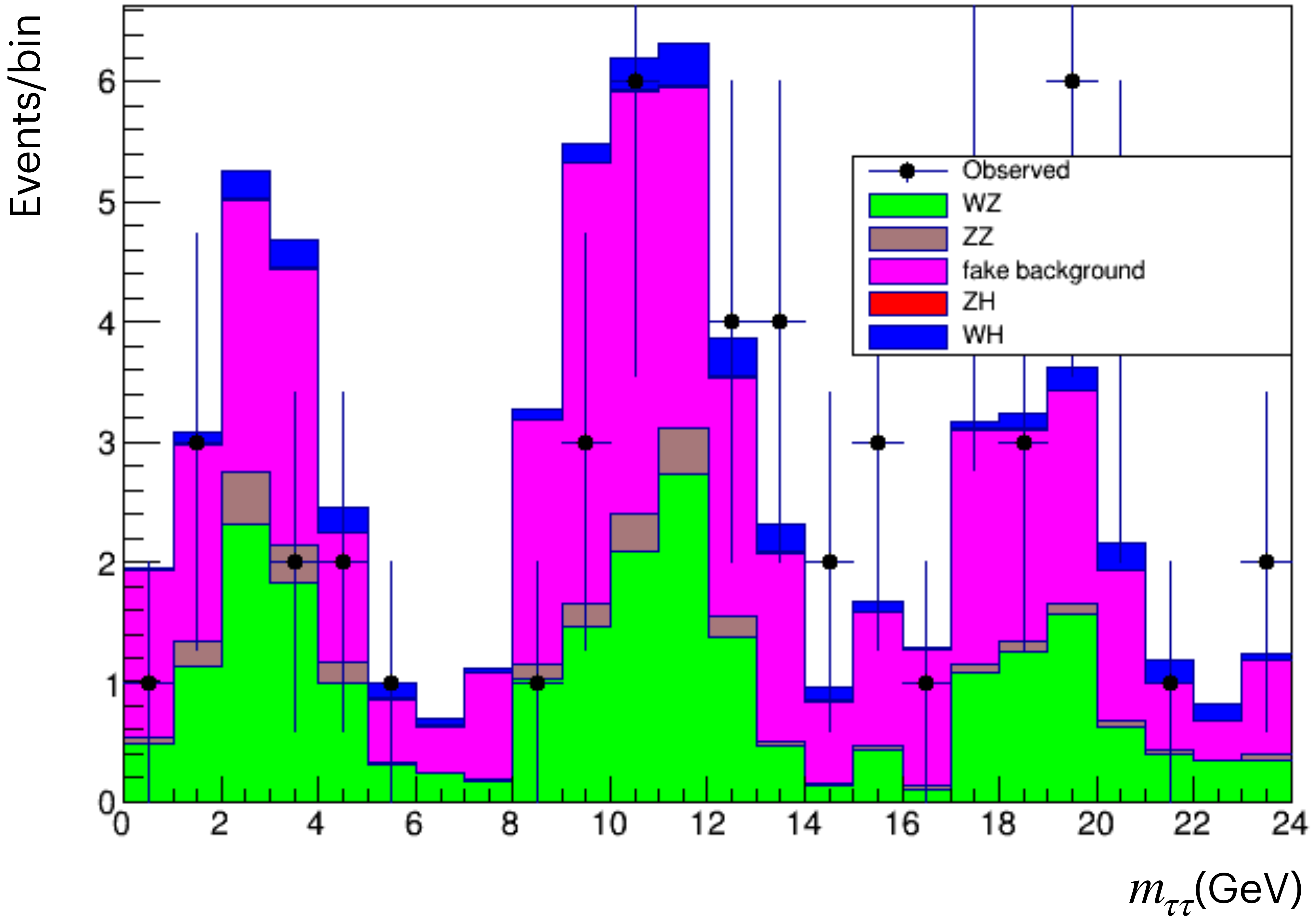


Comparing with the publication

Example: 2018 $\mu\mu\tau_h$



Ref: CMS AN-20-089



We can reproduce the **invariant mass spectrum of Ditau** in the publication with the split charge categories of W bosons.

Inclusive signal strengths for the WH analysis of both charges of W.

Channel	2016	2017	2018	Combined
$e\mu\tau_h$	$4.31^{+2.71}_{-2.37}$	$2.50^{+2.38}_{-2.17}$	$2.18^{+2.15}_{-1.98}$	$3.26^{+1.47}_{-1.39}$
$e\tau_h\tau_h$	$2.56^{+2.85}_{-2.11}$	$1.19^{+2.18}_{-1.63}$	$-1.26^{+1.09}_{-1.26}$	$0.26^{+0.96}_{-0.86}$
$\mu\mu\tau_h$	$3.70^{+2.56}_{-2.10}$	$5.31^{+3.00}_{-2.70}$	$2.25^{+2.44}_{-2.20}$	$3.79^{+1.59}_{-1.45}$
$\mu\tau_h\tau_h$	$0.74^{+1.75}_{-1.43}$	$-0.38^{+1.56}_{-1.26}$	$1.25^{+1.23}_{-1.04}$	$0.82^{+0.83}_{-0.75}$
All WH	$2.59^{+1.21}_{-1.07}$	$1.49^{+1.14}_{-1.02}$	$0.71^{+0.81}_{-0.72}$	$1.48^{+0.60}_{-0.56}$

Ref: CMS AN-20-089

Channel	2016	2017	2018	Combined
$e\mu\tau_h$	$3.31^{+2.65}_{-2.35}$	$3.31^{+2.34}_{-2.11}$	$2.11^{+2.07}_{-1.90}$	$3.11^{+1.44}_{-1.38}$
$e\tau_h\tau_h$	$2.56^{+2.89}_{-2.24}$	$1.6^{+2.35}_{-1.91}$	$-2.12^{+1.22}_{-7.88}$	$-0.05^{+1.09}_{-0.97}$
$\mu\mu\tau_h$	$3.57^{+2.48}_{-2.08}$	$5.30^{+2.97}_{-2.69}$	$2.12^{+2.39}_{-2.20}$	$3.70^{+1.56}_{-1.46}$
$\mu\tau_h\tau_h$	$0.69^{+1.64}_{-1.33}$	$-0.43^{+1.60}_{-1.28}$	$1.38^{+1.25}_{-1.08}$	$0.87^{+0.83}_{-0.75}$
All WH	$2.22^{+1.16}_{-1.03}$	$1.85^{+1.17}_{-1.07}$	$0.67^{+0.81}_{-0.73}$	$1.45^{+0.61}_{-0.57}$

The **inclusive signal strengths for WH** obtained from the split charges are **compatible** with the values obtained from the unspilt charge category.

Physics model

To obtain the **inclusive charge asymmetry**, we can fit the likelihood of the WH with two parameters.

$$L = L(\alpha W^{+} + \beta W^{-} + B)$$

$$A = \frac{\sigma_{(}W^{+}h) - \sigma_{(}W^{-}h)}{\sigma_{(}W^{+}h) + \sigma_{(}W^{-}h)}$$

$$\mu = \frac{signal_{observe}}{signal_{total}}$$

$$\mu = \frac{N_{W+}^{postfit} + N_{W-}^{postfit}}{N_{W+}^{prefit} + N_{W-}^{prefit}}$$

$$\mu = \frac{\alpha N_{W+}^{prefit} + \beta N_{W-}^{prefit}}{N_{W+}^{prefit} + N_{W-}^{prefit}}$$

Scaling factors and inclusive charge asymmetry fit

We parametrize the fitting equation into two **scaling factors** that contain both **A** and μ.

For W^+h:

$$\alpha = \frac{\mu(1 + A)\sigma_{sm}}{2\sigma_{sm}^{W^+h}}$$

For W^-h:

$$\beta = \frac{\mu(1 - A)\sigma_{sm}}{2\sigma_{sm}^{W^-h}}$$

Where :

$$\sigma_{sm} = \sigma_{sm}^{W^-h} + \sigma_{sm}^{W^+h}$$

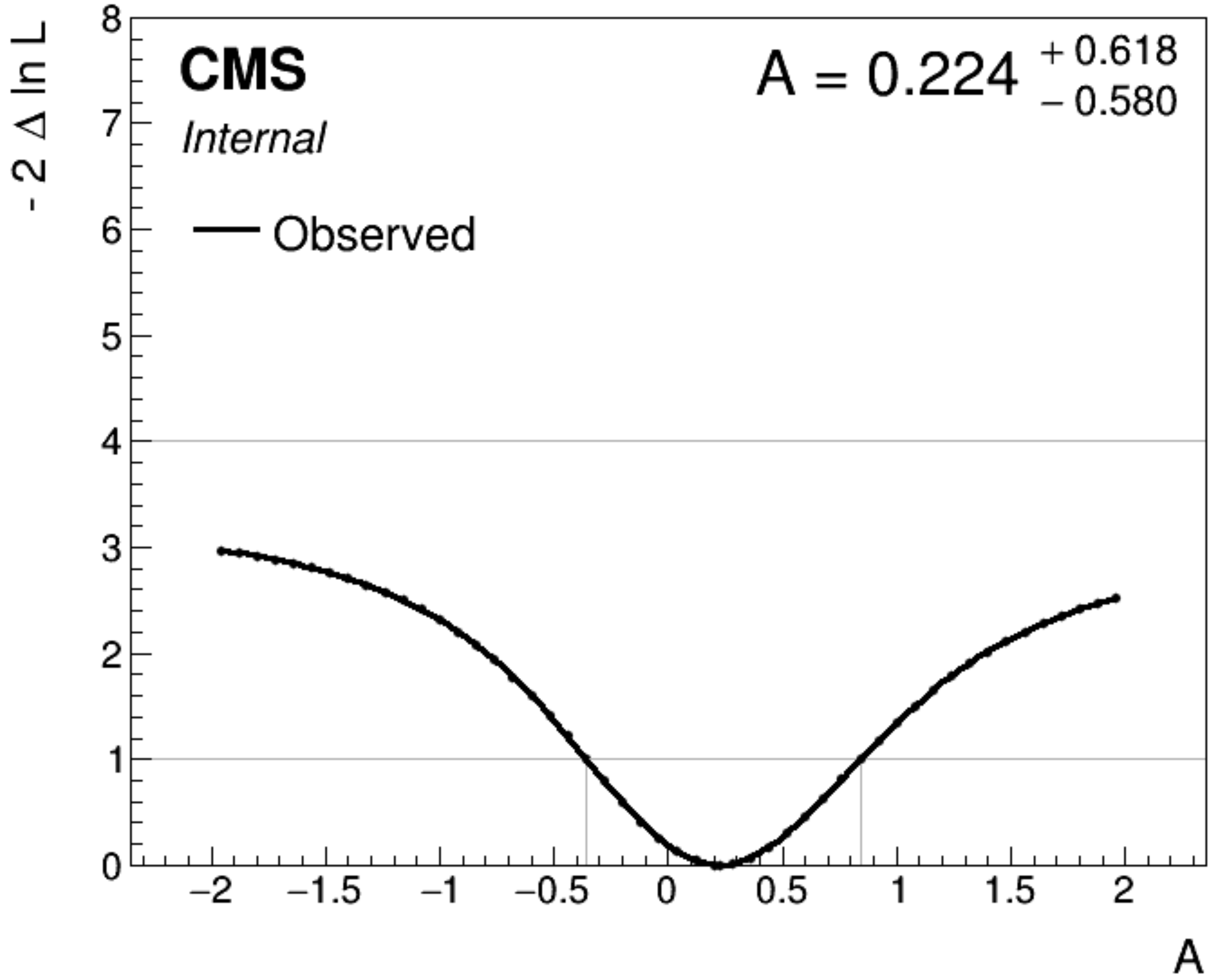
$\sigma_{sm}^{W^+h} = 0.86$ pb

$\sigma_{sm}^{W^-h} = 0.53$ pb

Results

The inclusive charge from Ditau data taken in LHC run 2 (2016-2018)

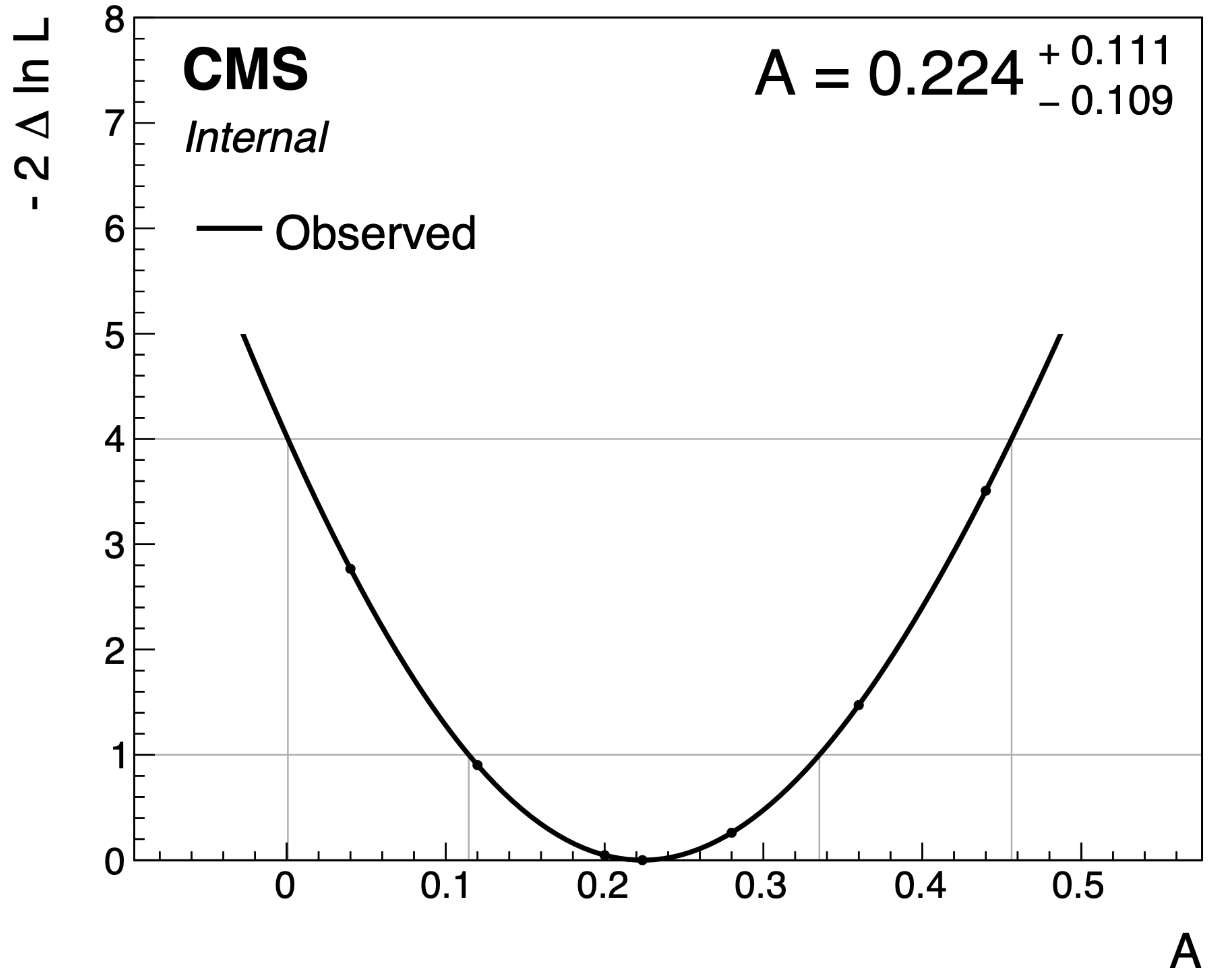
Best fit A : $0.152^{+0.379}_{-0.388}$



Asimov dataset likelihood testing for our Physics Model

Projection

projection based on $\sqrt{s} = 13$ **TeV and** $L = 3\,ab^{-1}$



Asymmetry expected to be similar at $\sqrt{s} = 13.6$ TeV, though cross sections are slighly larger (xs $W^{+}h$ = 0.919 pb, xs $W^{-}h$ = 0.575 pb vh@nnlo+NNPDF31).

Summary and Outlook

- With Ditau Run 2 data (2016 - 2018), we can start to measure the charge asymmetry A, for the moment, limited capability of adding a constraint to the Higgs Yukawa couplings (κ).
- We will study possible systematic that may affect directly the asymmetry.
- Other decay modes — e.g. H -> bb, H -> gg, and H -> WW — may give more information of constraint on light quark Yukawa couplings.

Thank you