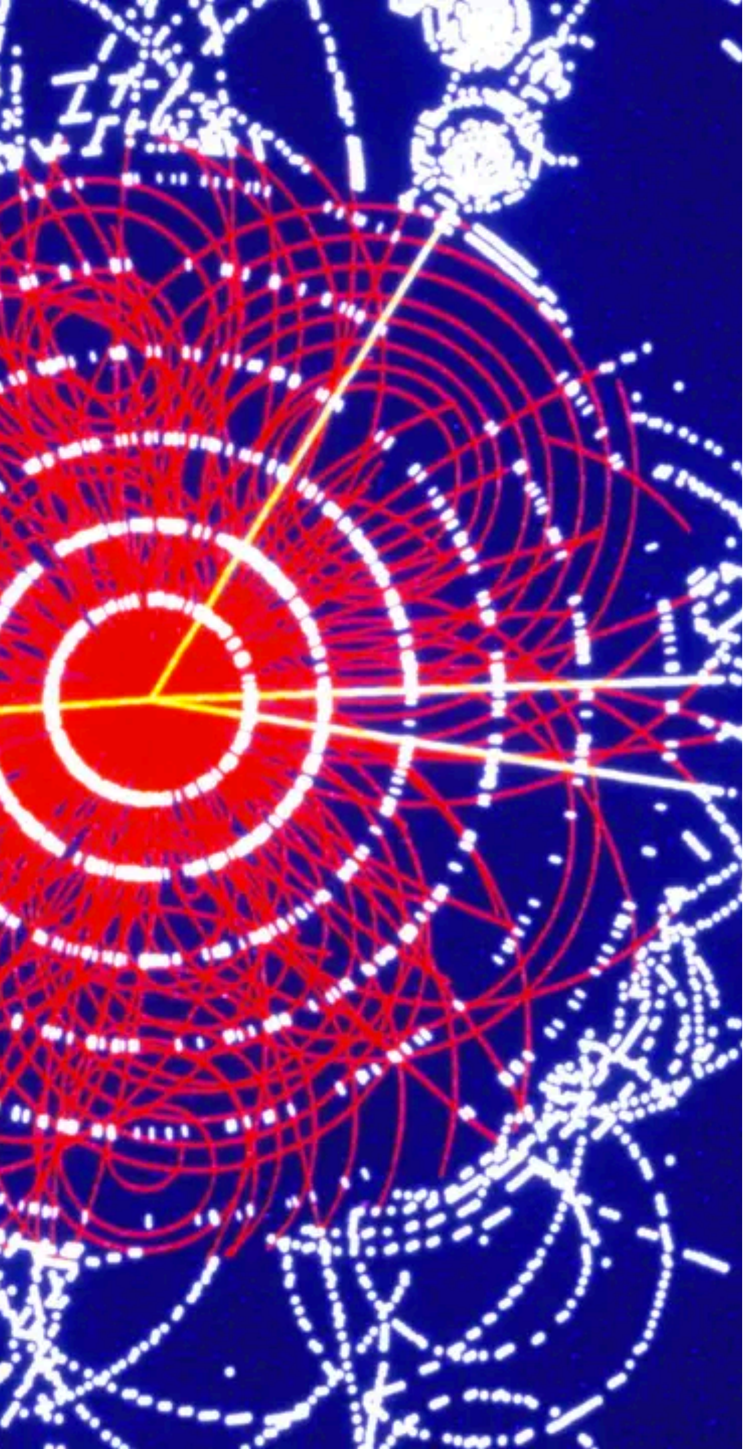


Machine-learning full likelihoods

Rafał Masełek

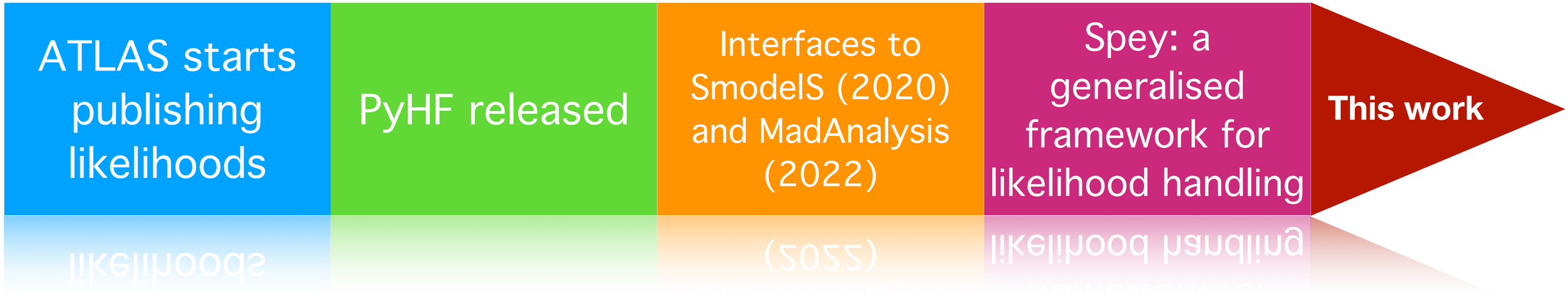
in collaboration with:
S. Kraml, W. Waltenberger, J. Araz, H. Reyes, A. Butter, C. Krause

Reinterpretation & OpenMAPP 18-06-2024

Research supported by IN2P3 theory master project DataMATTER and Polish National Science Centre grant 2021/41/N/ST2/00972.

Full statistical models

Full statistical models (likelihood functions) parametrise the full information about the LHC analyses, both BSM searches and SM measurements [arXiv:2109.04981]



[ATL-PHYS-PUB-2019-029] [arXiv:2211.15838] [arXiv:2009.01809] [arXiv:2206.14870] [arXiv:2307.06996]

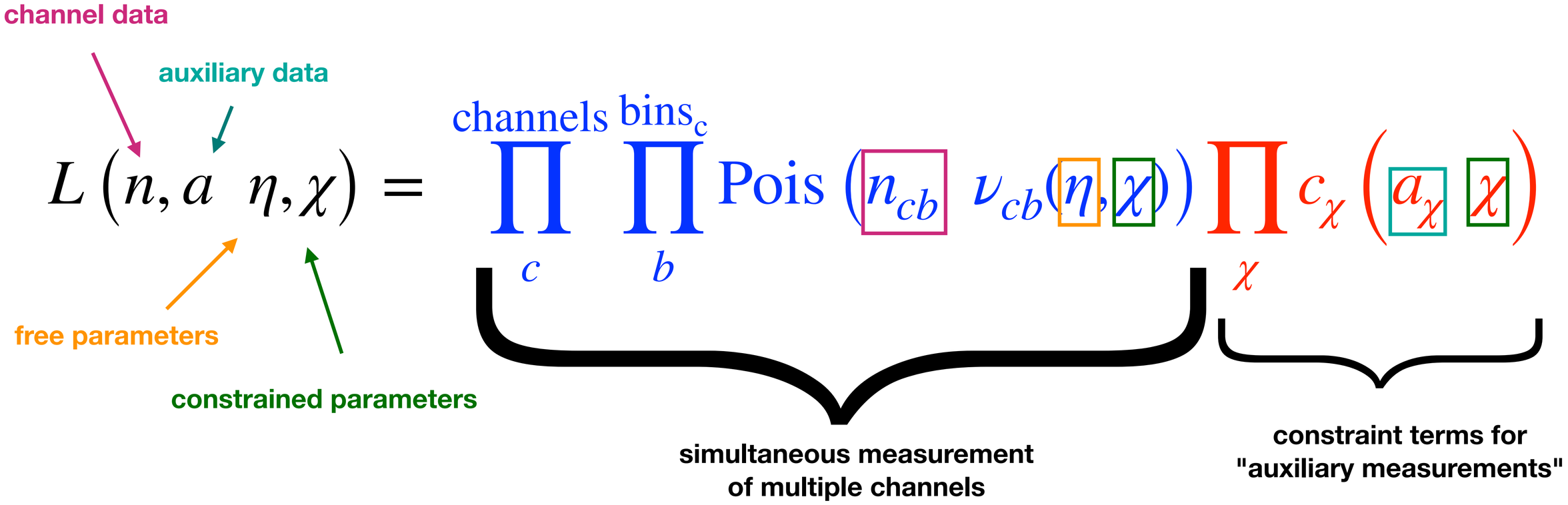
[Based on talk by H. Reyes]

Full statistical model

$$L\left(n, a \;\; \eta, \chi\right) = \prod_{c}^{\text{channels}} \prod_{b}^{\text{bins}_c} \text{Pois}\left(n_{cb} \;\; \nu_{cb}(\eta, \chi)\right) \prod_{\chi} c_{\chi}\left(a_{\chi} \;\; \chi\right)$$

[arXiv:2211.15838]

Full statistical model



[arXiv:2211.15838]

Full statistical model

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$$\nu_{cb}\left(\eta,\chi\right) = \sum_{s}^{\text{samples}} \nu_{scb}\left(\eta,\chi\right) = \sum_{s}^{\text{samples}} \left(\prod_{\kappa} \kappa_{scb}\left(\eta,\chi\right)\right)\left(\nu^{0}_{scb}\left(\eta,\chi\right) + \sum_{\Delta} \Delta_{scb}\left(\eta,\chi\right)\right)$$

multiplicative modifiers **nominal rate** **additive modifiers**

[arXiv:2211.15838]

Hypothesis testing

$$L = L\left(\mu; \theta\right)$$

(unconstrained) parameter(s) of interest

nuissance parameter

Hypothesis testing

$$L = L\left(\mu;\theta\right)$$

$$t(\mu) = 2\log\frac{L\left(\mu;\hat{\theta}(\mu)\right)}{L\left(\hat{\mu};\hat{\theta}(\hat{\mu})\right)} = -2\left[\left(-\log\left(\mu;\hat{\theta}(\mu)\right)\right) - \left(-\log\left(\hat{\mu};\hat{\theta}(\hat{\mu})\right)\right)\right]$$

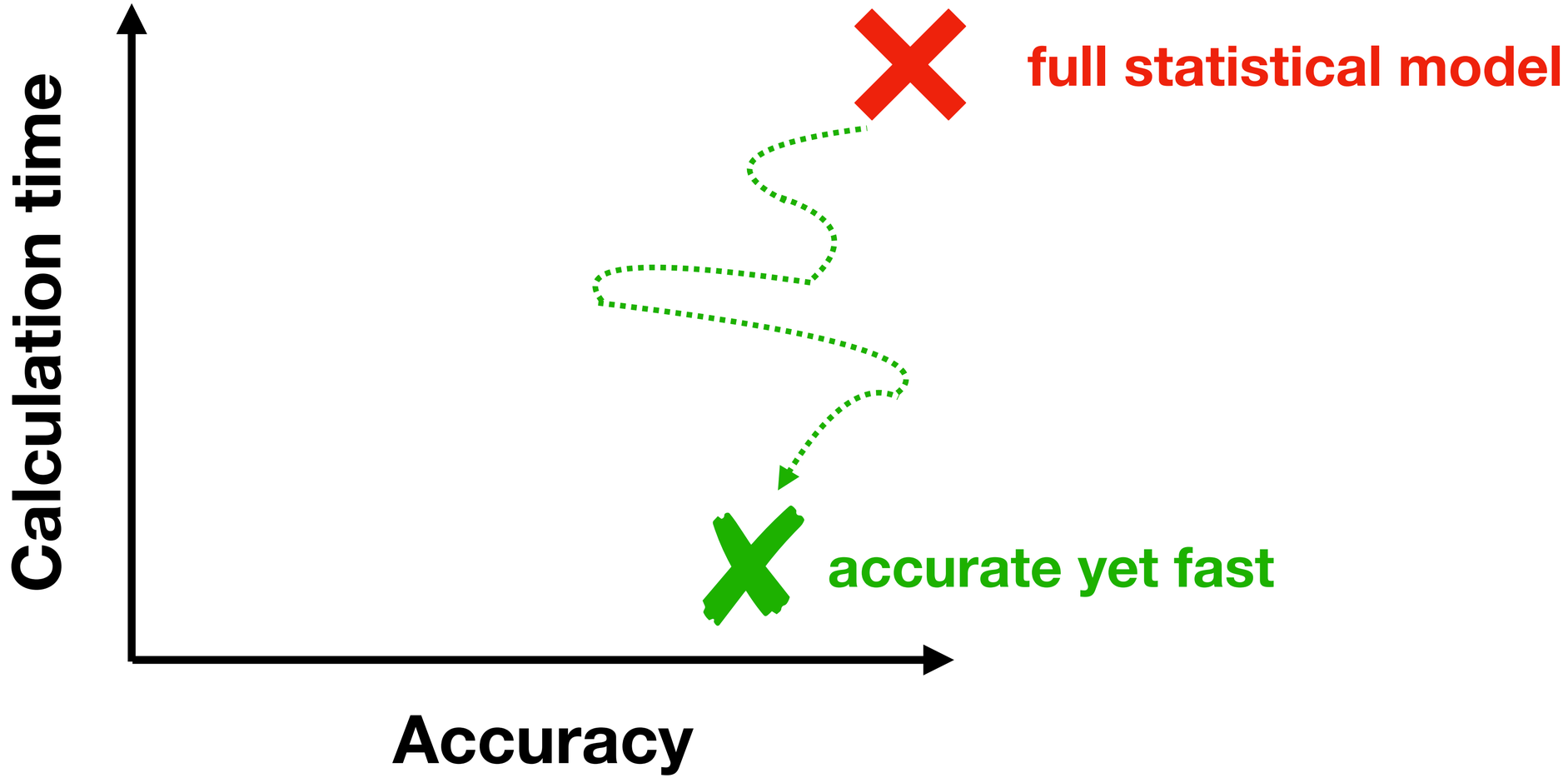
Full statistical model

- Full statistical models are available on HEPData
- They are provided as JSON files
- There are background files and signal patches
- Each patch corresponds to some signal point and contains modifiers to the background files
- There can be hundreds of modifiers
- Spey/PyHF can load and process these files

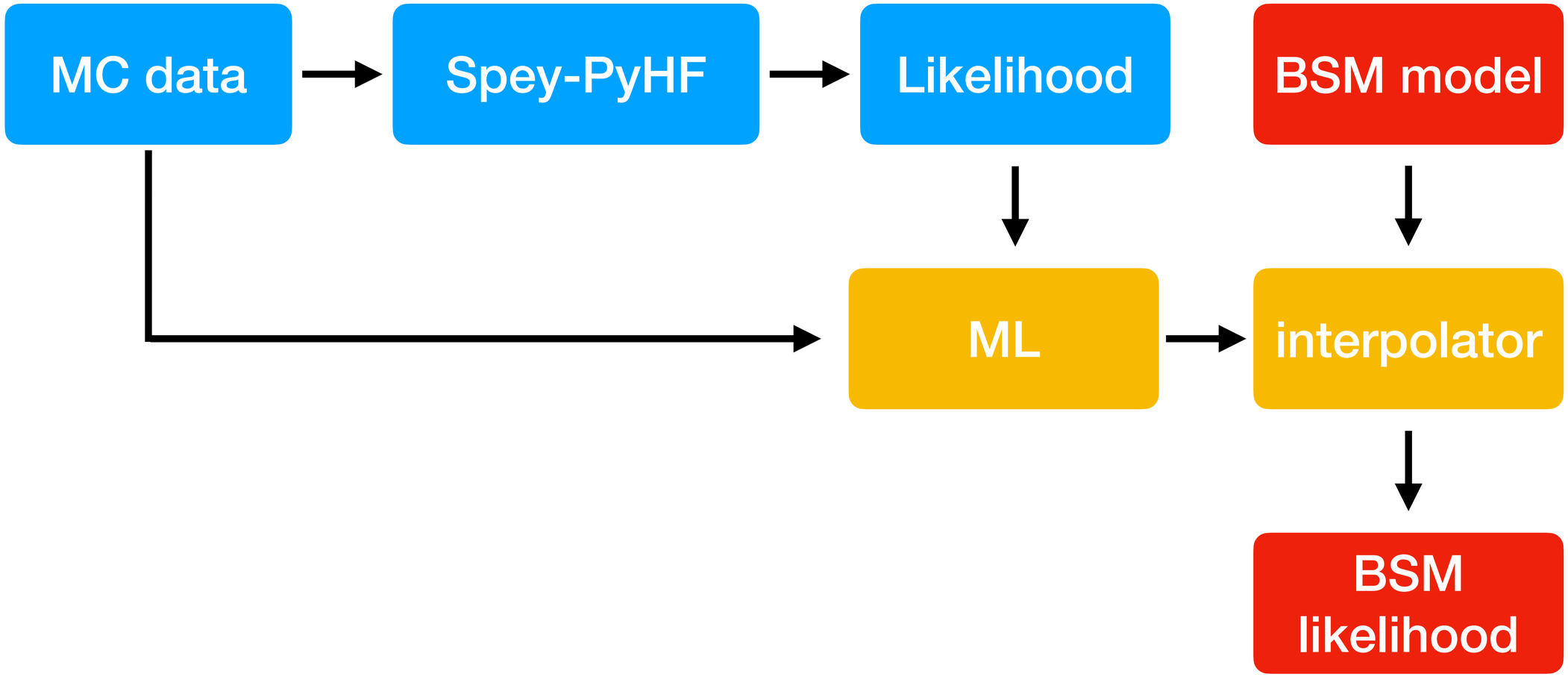

```
"patch": [
    {
        "op": "add",
        "path": "/channels/0/samples/0",
        "value": {
            "data": [
                2.3051342964172363
            ],
            "modifiers": [
                {
                    "data": null,
                    "name": "lumi",
                    "type": "lumi"
                },
                {
                    "data": [
                        0.6571804118166927
                    ],
                    "name": "staterror_QCR1cut_cuts",
                    "type": "staterror"
                },
                {
                    "data": {
                        "hi": 1.06675,
                        "lo": 0.911403
                    },
                    "name": "PRW_DATASF",
                    "type": "normsys"
                },
```


[arXiv:2211.15838]

Accuracy vs. efficiency problem



The idea


MC data
Spey-PyHF
Likelihood
BSM model
ML
interpolator
BSM likelihood

Status of the project

Beach in Dębki, Poland

Project tasks and progress

- **Task I — likelihood scan**
  - MCMC sampling
  - Signal leakage to CRs
  - Parallelization
- **Task II — optimizing and training neural networks**
  - Automatic optimization
  - Training
  - Exporting results to ONNX model with metadata
- **Task III — validation**
  - Compare predictions vs. true values
  - Use SmodelS to calculate limits for the official patches
- **Task IV — publish models and interface to work with them**
  - Provide a complete data base with all published models
  - Ensure FAIRness
  - Maintain and keep updated

Benchmark analyses

- **ATLAS-SUSY-2018-04 [arXiv: 1911.06660]**
  - Search for direct stau production in events with two hadronic τ-leptons in √s=13 TeV pp collisions with the ATLAS detector
  - 2 signal bins, 3 control bins
- **ATLAS-CONF-2019-031 [arXiv: 1909.09226]**
  - Search for direct production of electroweakinos in final states with one lepton, missing transverse momentum and a Higgs boson decaying into two b-jets in pp collisions at √s=13 TeV with the ATLAS detector
  - 9 signal bins, 5 control bins

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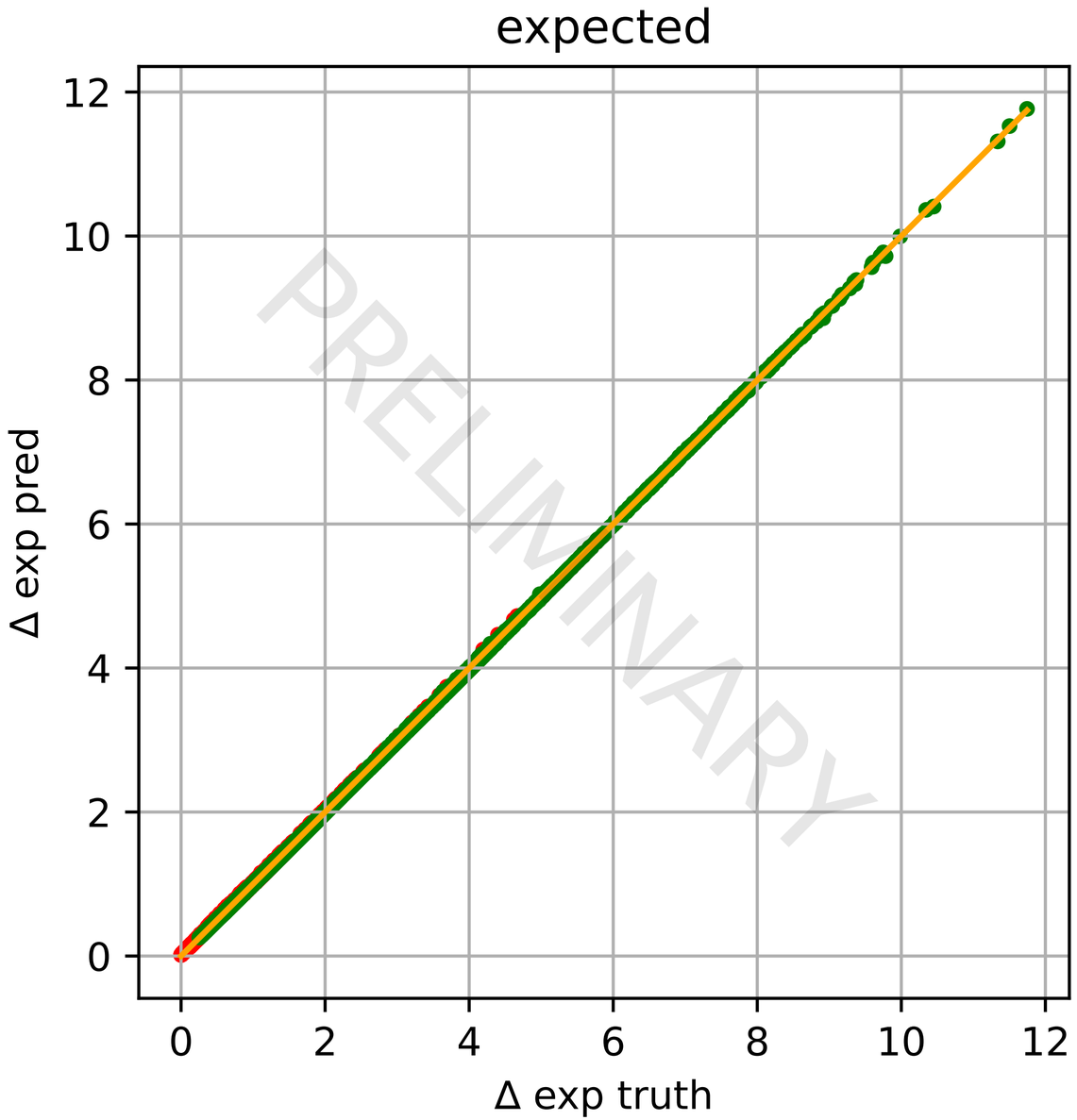
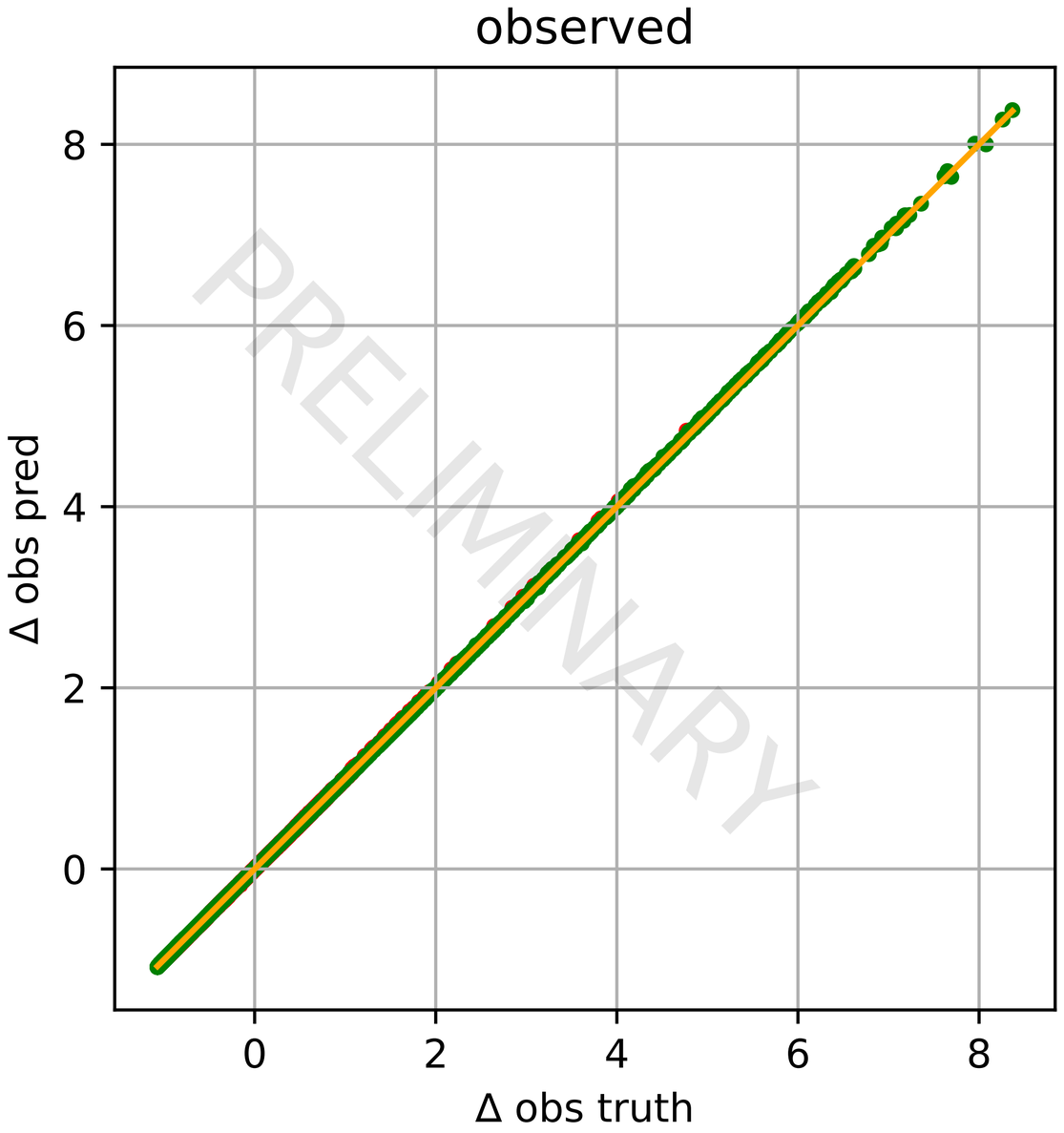
1911.06660

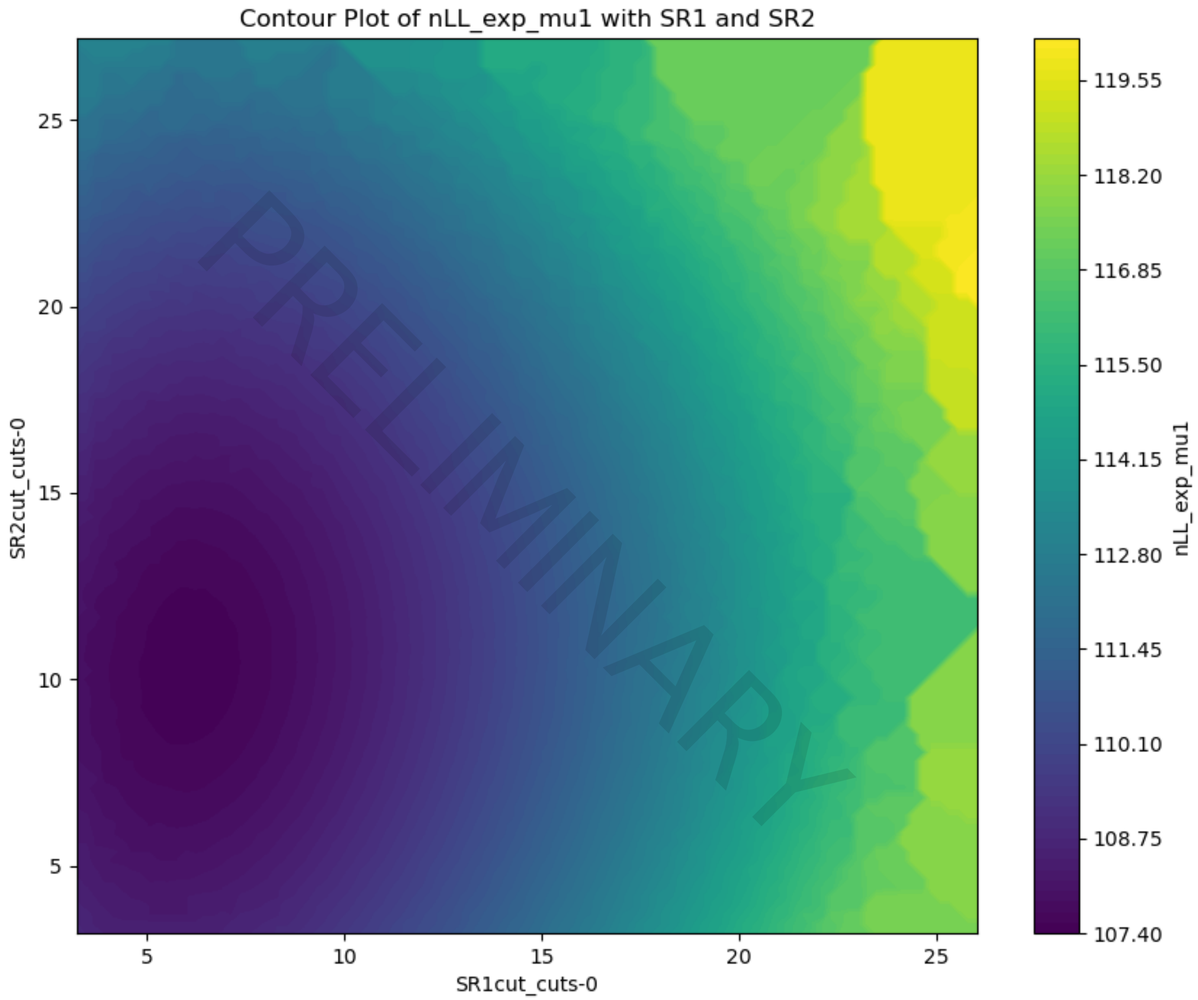
$$\Delta = (-\log L_{\mu=1}) - (-\log L_{\mu=0})$$



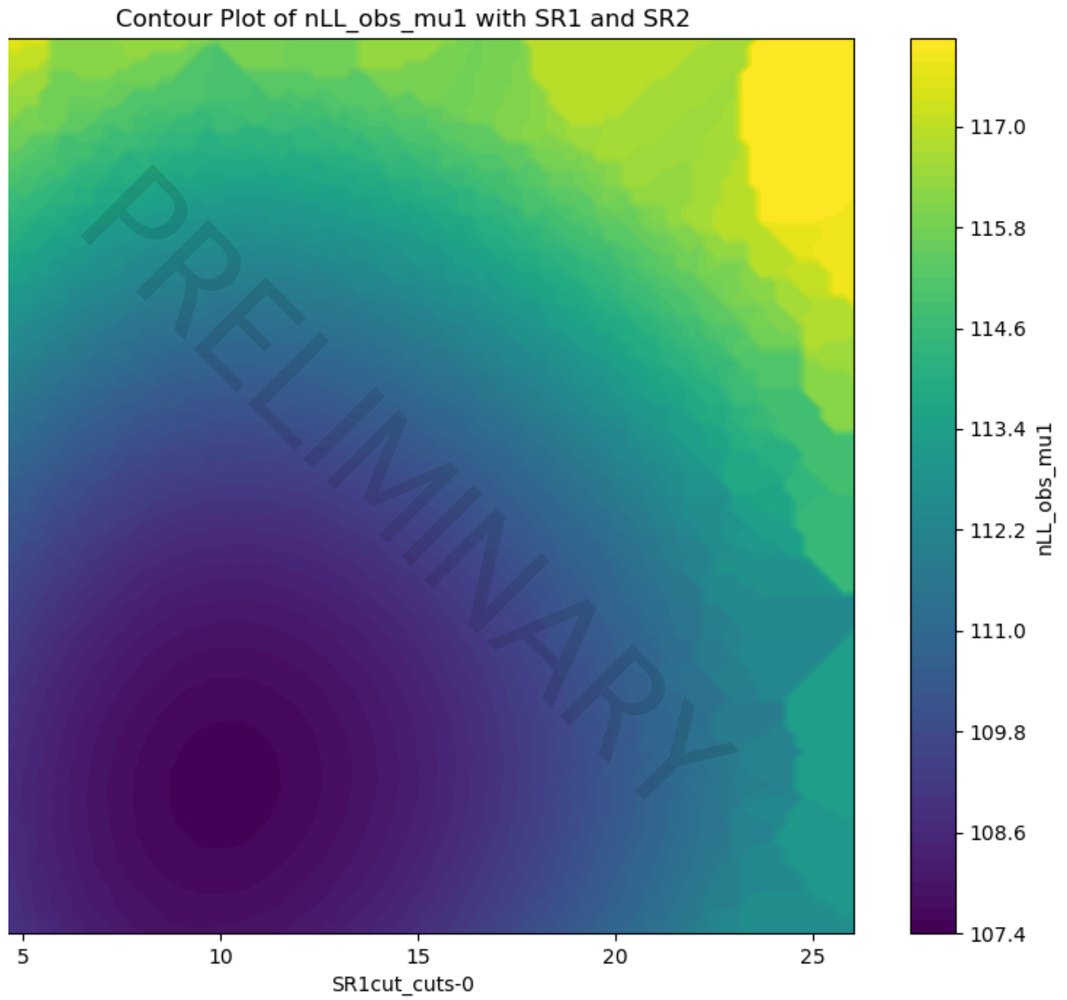


1911.0660

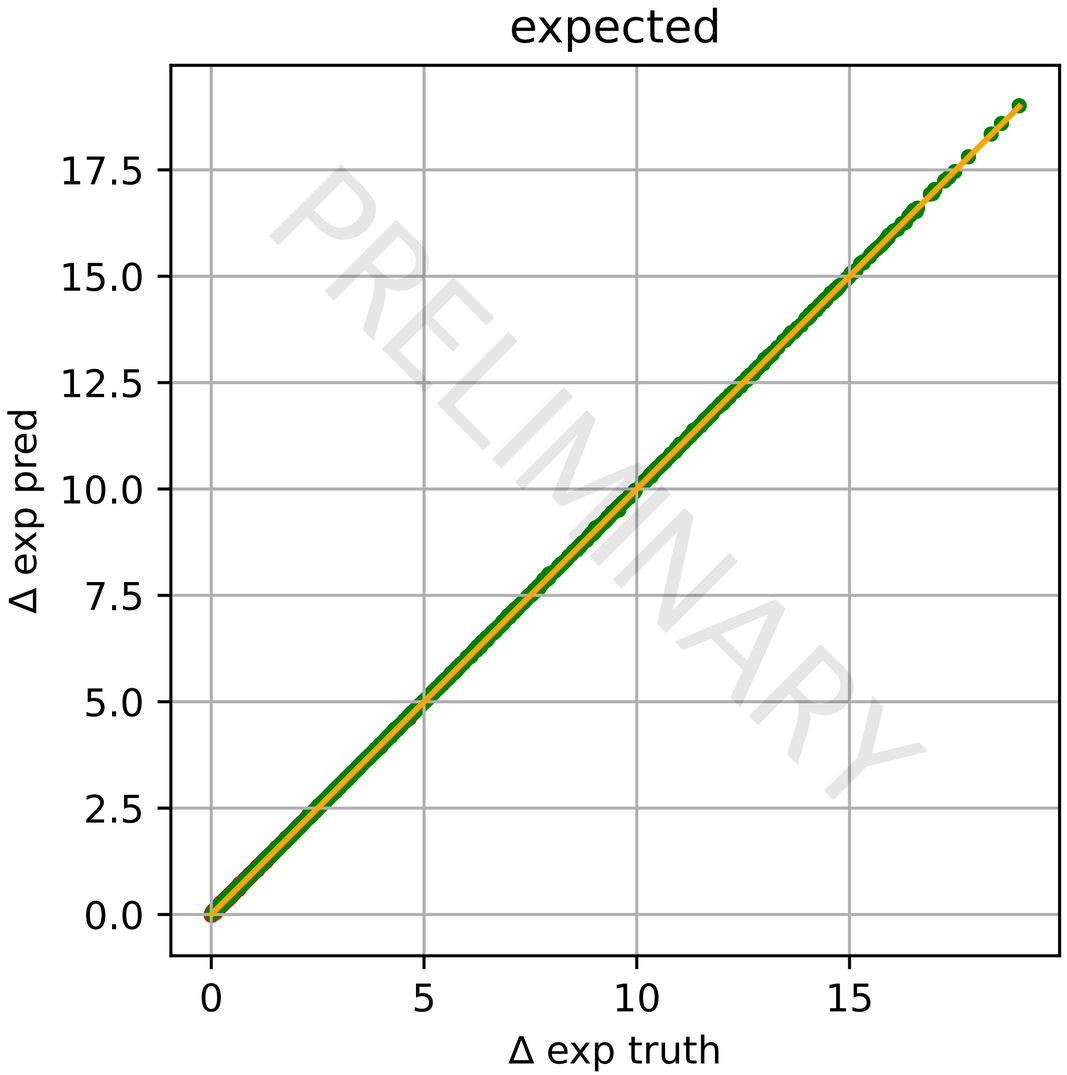
expected

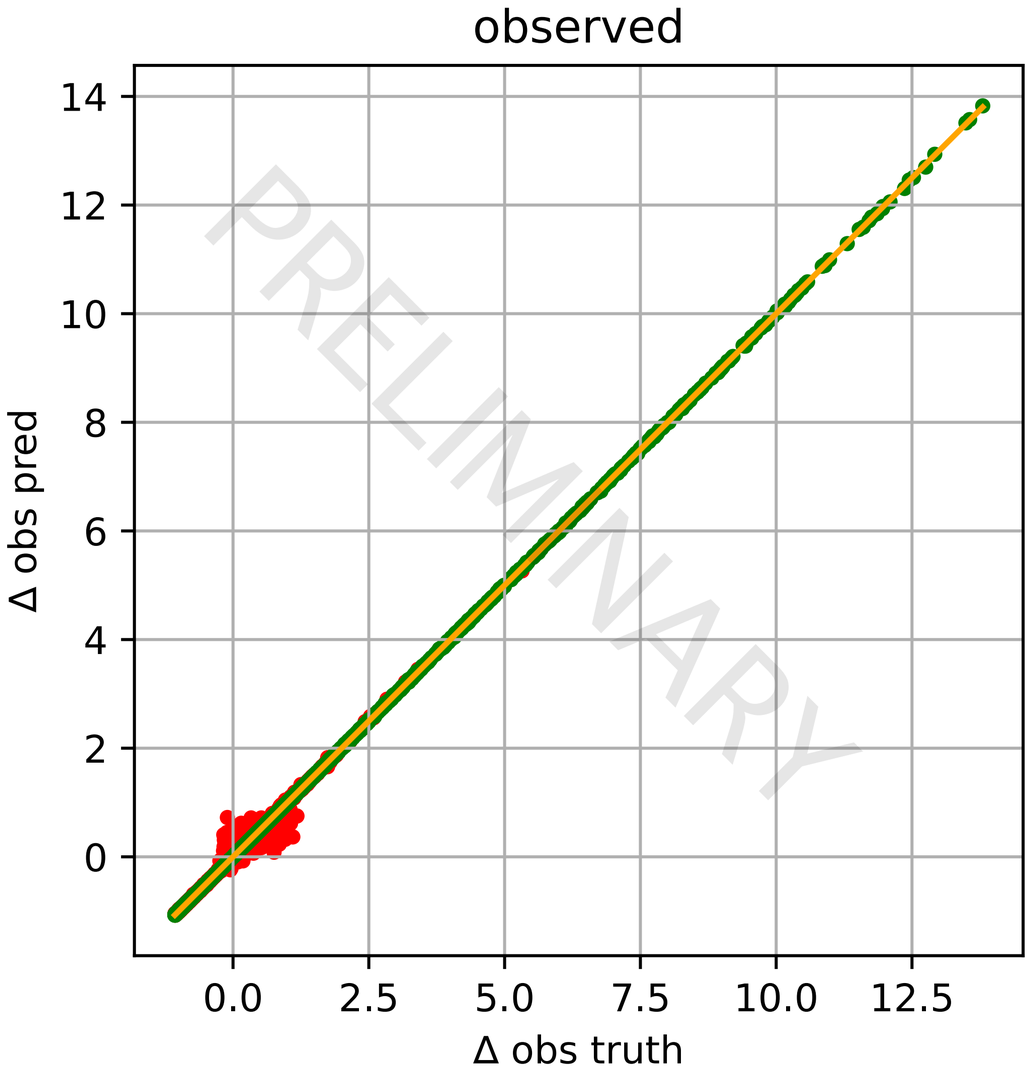


observed



1911.06660 — signal leaking to CRs





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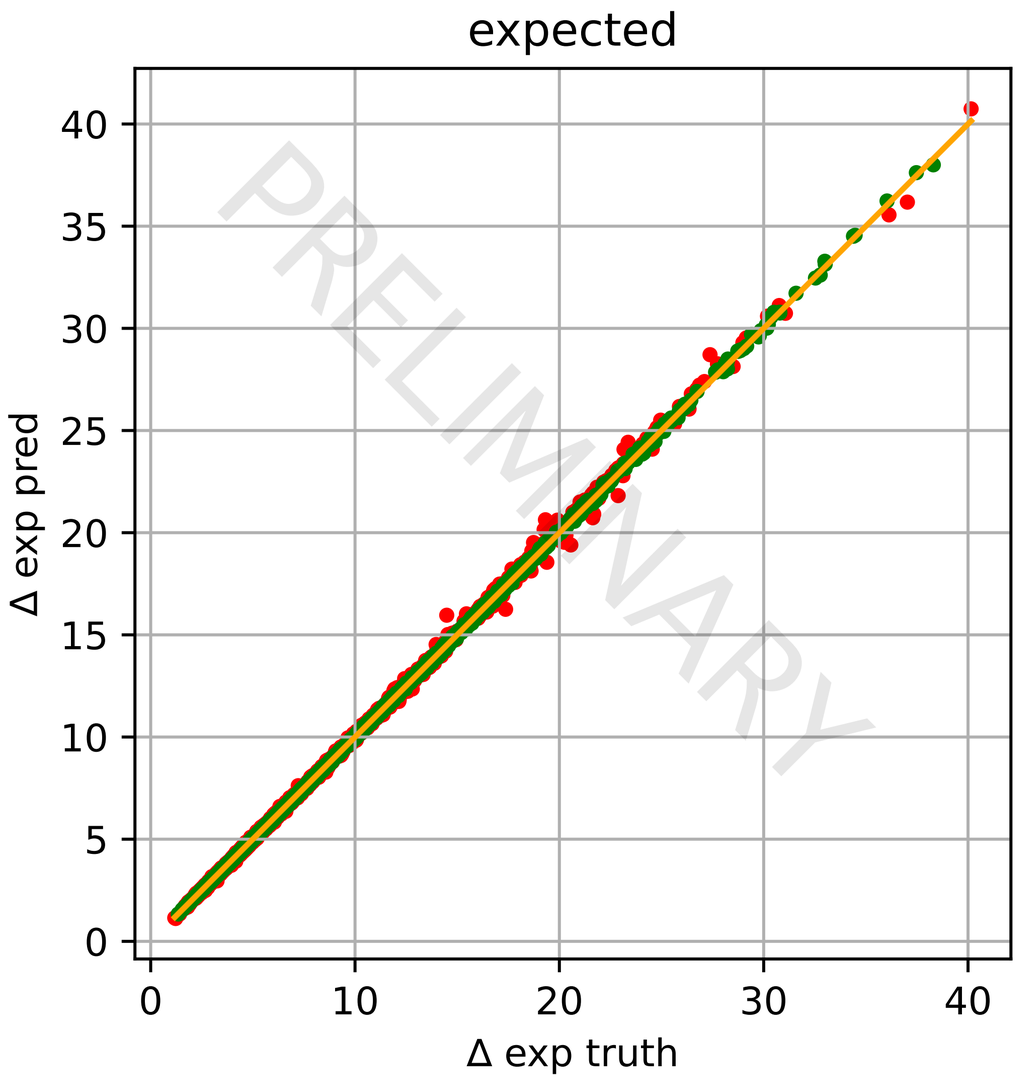
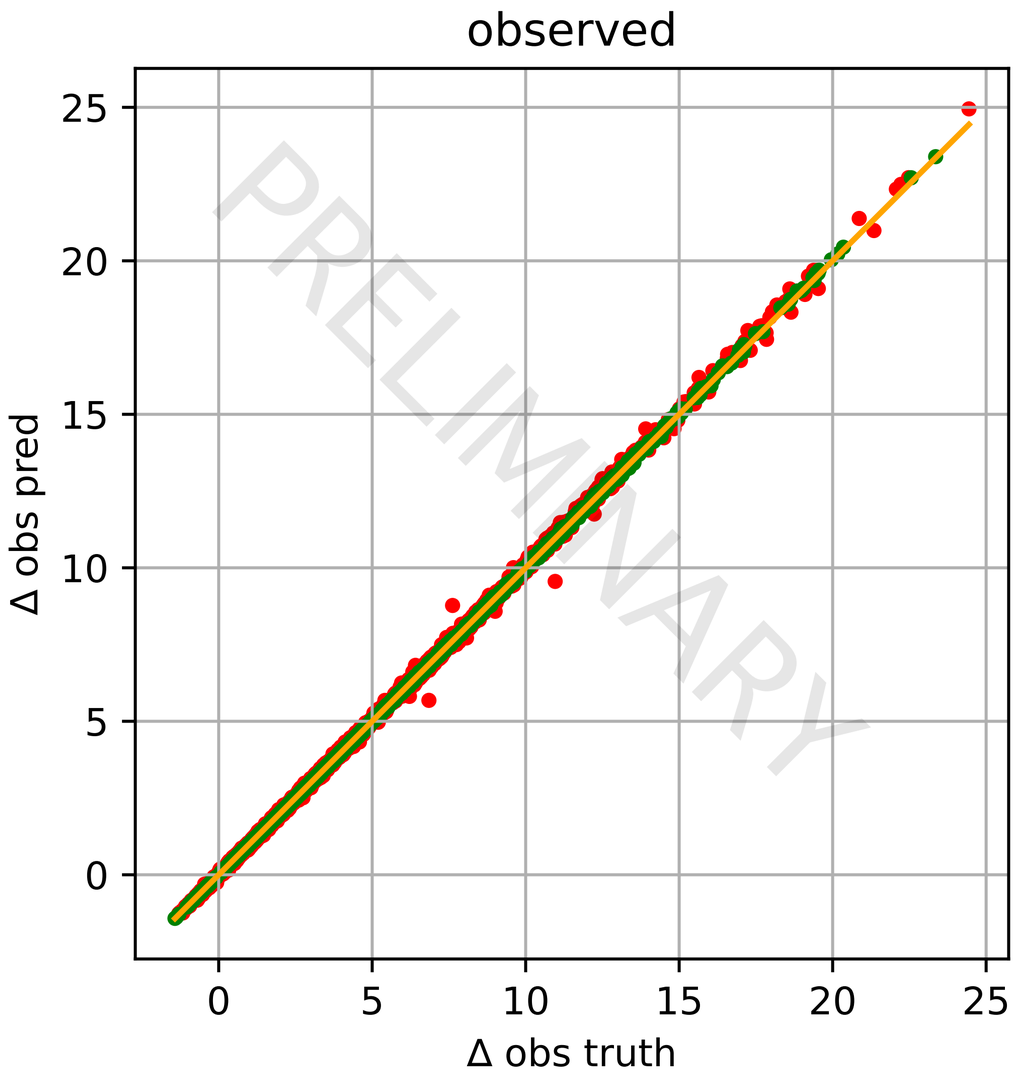
1909.09226


expected
PRELIMINARY
Δ exp pred
Δ exp truth
0
5
10
15
20
25
30
35
40


observed
PRELIMINARY
Δ obs pred
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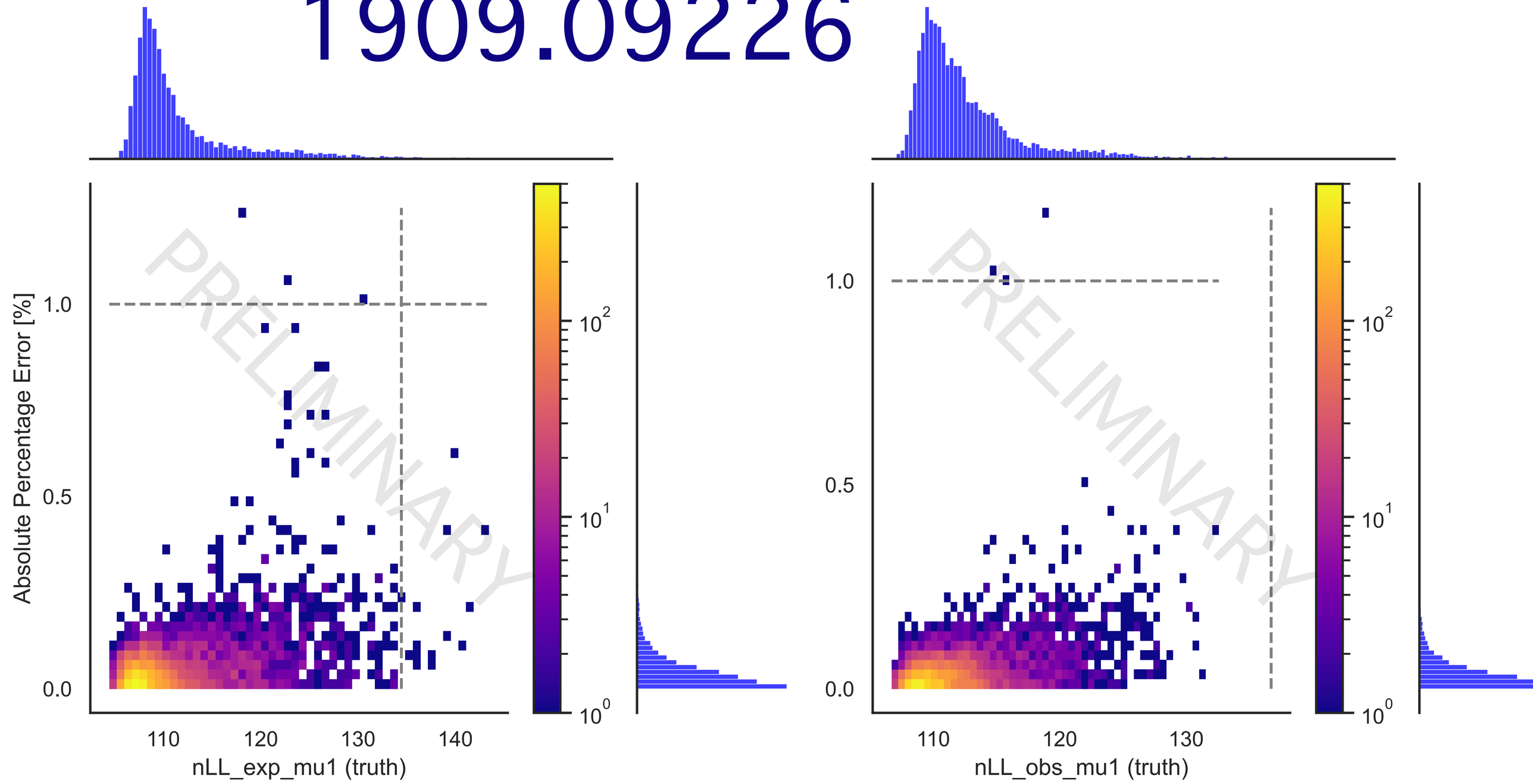
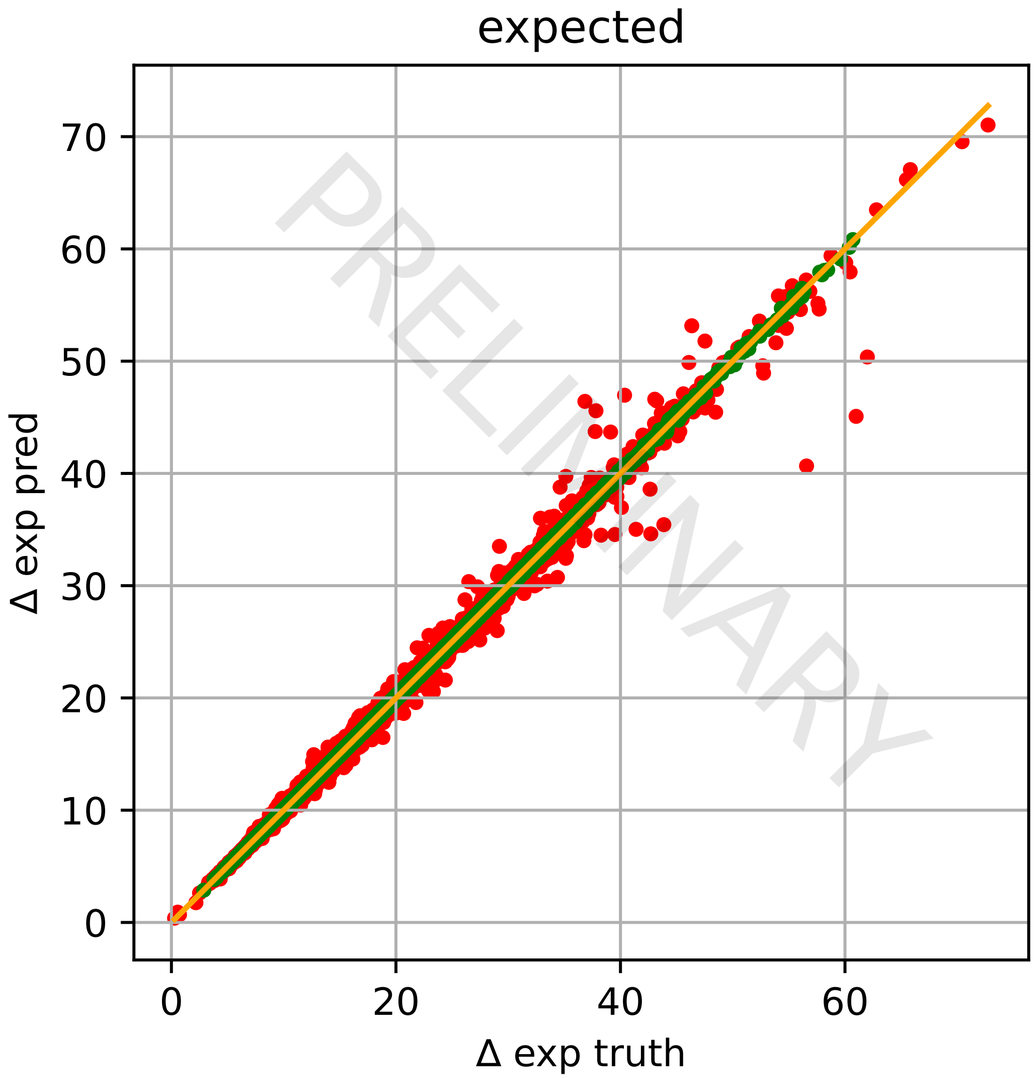
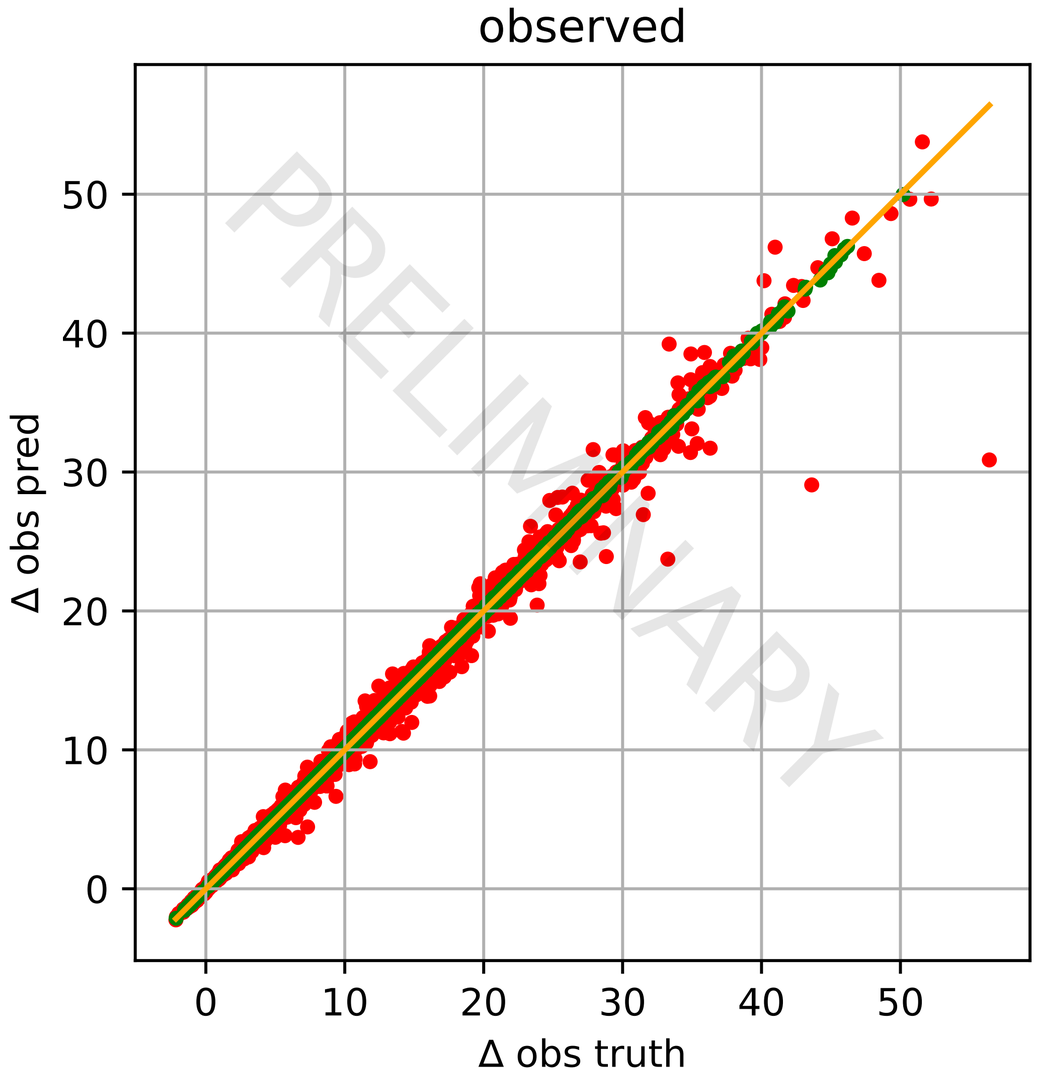
0
5
10
15
20
25

1909.09226


PRELIMINARY
PRELIMINARY
Absolute Percentage Error [%]
1.0
0.5
0.0
110
120
130
140
nLL_exp_mu1 (truth)
10^2
10^1
10^0
1.0
0.5
0.0
110
120
130
nLL_obs_mu1 (truth)
10^2
10^1
10^0

1909.09226— signal leaking to CRs





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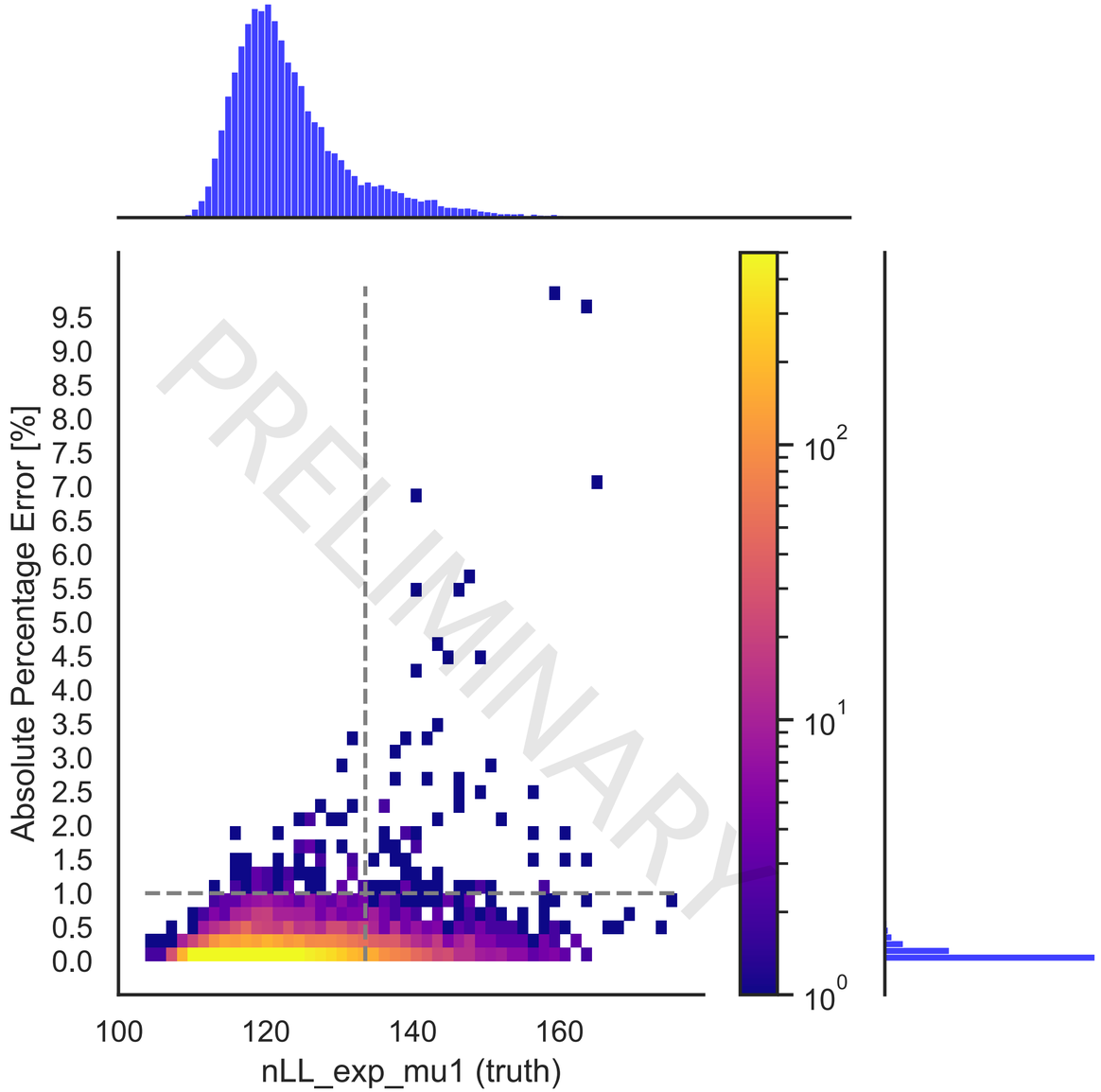

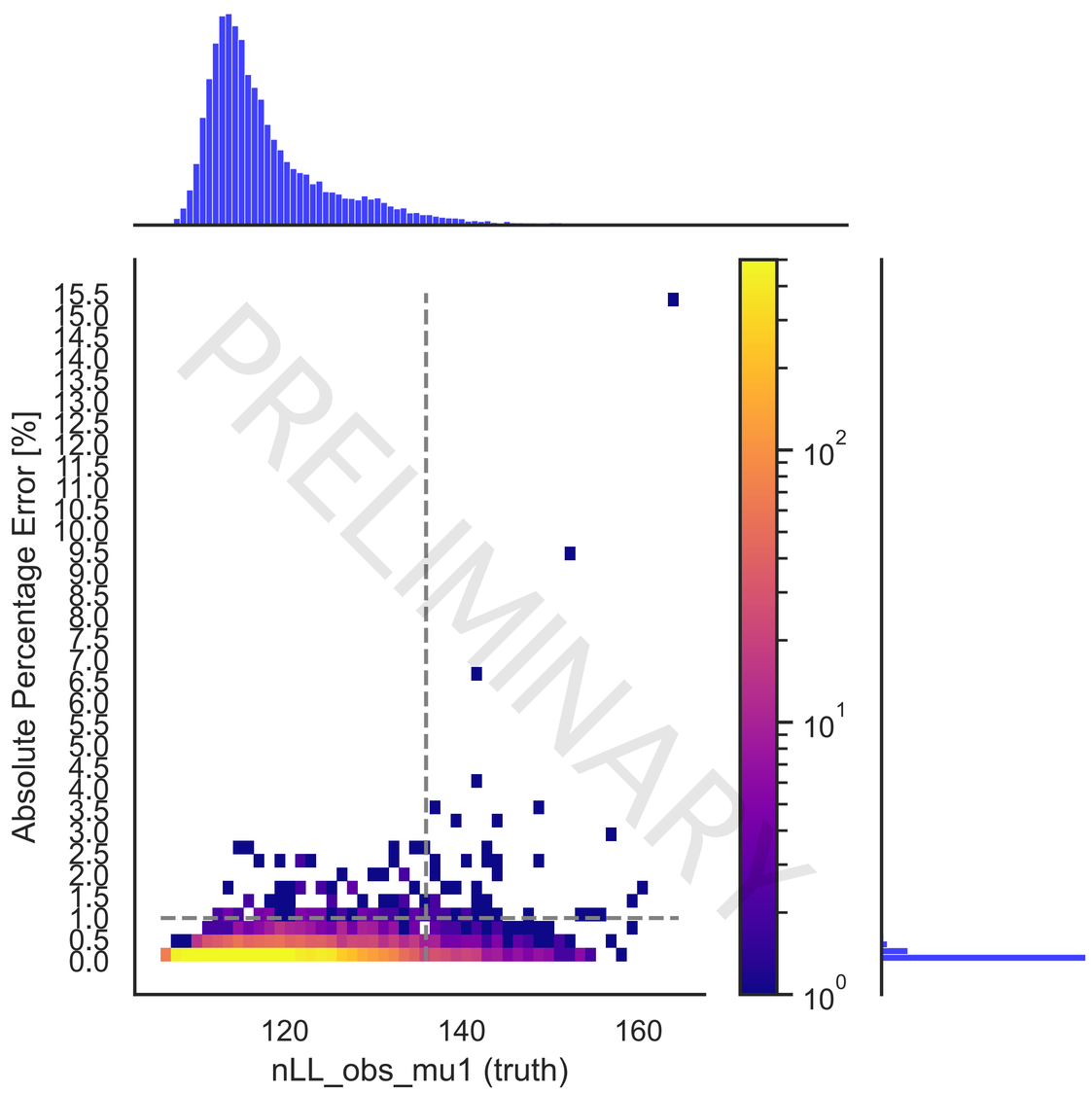

Summary & Outlook

- Full statistical models allow for accurate recasting...
- ... but calculations are time-consuming
- Fast reinterpretation tools, like SmodelS, require new more efficient method
- We propose to use Machine Learning algorithm to interpolate precalculated likelihood tables
- A lot of work has already been put but there are some issues when signal leakage to CRs is included
- More investigation is needed
- Stay tuned!

Thank you for attention!

rafal.maselek@lpsc.in2p3.fr

Dolina Chochołowska, Poland
photo by Piotr Kałuża