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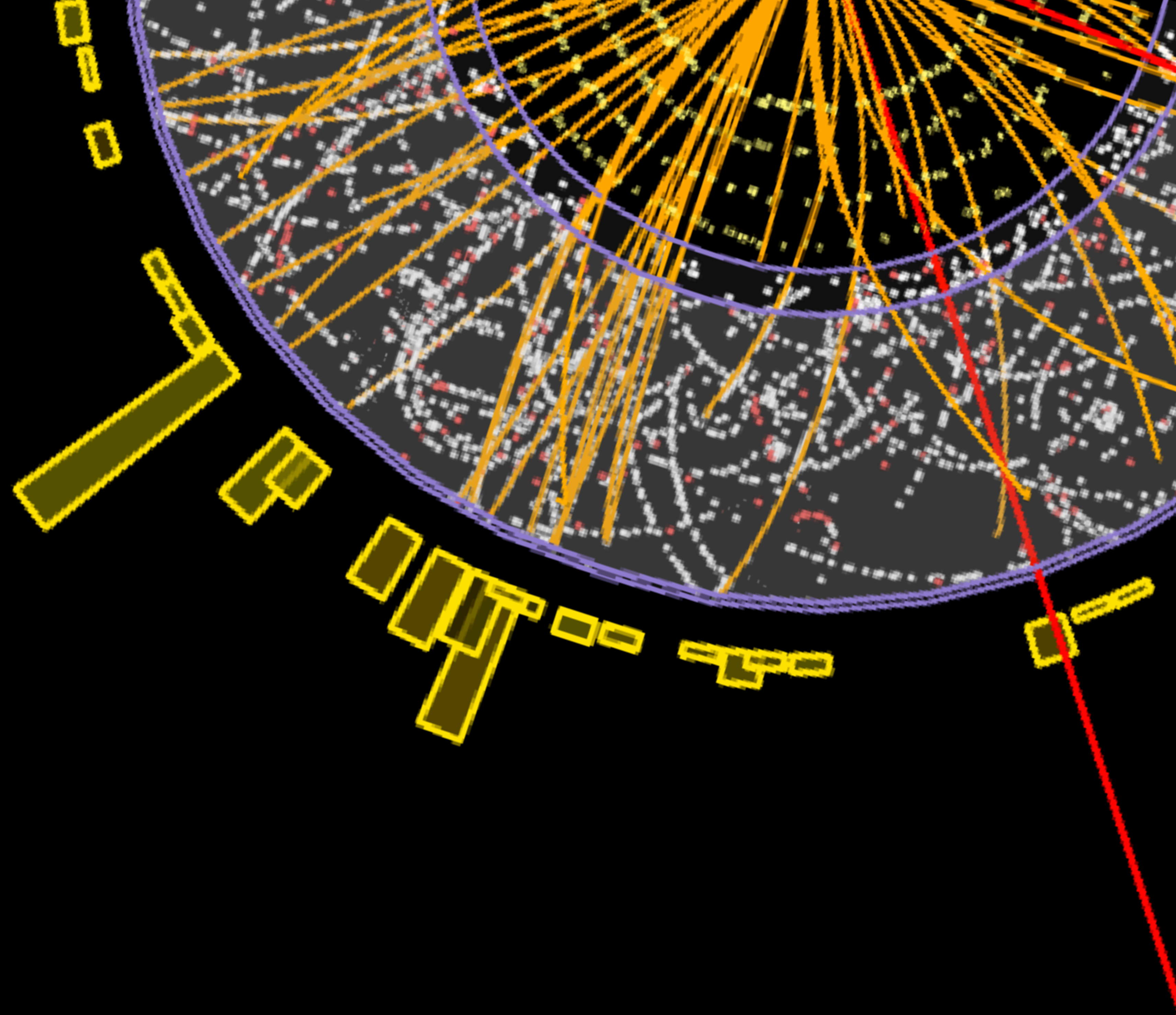

THE J^{PC} AND COUPLINGS AFTERMATH

or at least my personal recollection of how things went (and will go)


apology noun
apol·o·gy | \ ə-ˈpä-lə-jē
plural apologies
old plots!
ATLAS-dominated recollection!
personal views!

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KN Konstantinos Nikolopoulos
resolutions
To: Valerio Ippolito, Cc: Luis Roberto Flores Castill

hi valerio,
sorry probably you have done this already,
but do we have the table and resolution plots for the constraint fit c

thanks,
ksotas

KN Konstantinos Nikolo
Re: resolutions
To: Valerio Ippolito, C

thanks a lot!

sorry, we're pushing too much.
but did you have a chance to prepa

thanks a lot.

Kostas

Found in Sent - CERN Mailbox

Valerio Ippolito 19 June 2012 at 01:02
Re: resolutions
To: Konstantinos Nikolopoulos & 3 more
Details

Hi Kostas,

you can find under

/afs/cern.ch/work/v/vippolit/kostas/candidate_lists

what you asked for. There you have three candidate lists:
- data11
- data12 (the 79 candidates)
- my list for data12 (full dataset available up to yesterday evening

Let me know, particularly for the third one! My biased and tired eye finds interesting the following:

```
4mu    | 204769 |   71902630 |   398 |  124.09 |  86.34 |  31.57 |
125.09 | | bb
4mu    | 204769 |   82599793 |   447 |  123.25 |  84.01 |  34.21 |
123.47 | | bbbb
4e     | 203602 |   82614360 |   429 |  124.49 |  70.63 |  44.66 |
124.61 | | bbbb
4e     | 204910 |   22993546 |   376 |  125.52 |  88.93 |  22.28 |
126.36 | | bbbb
```

(keep in mind that everything beyond run 204668 I accept blindly without GRL, so those three candidates might disappear - but maybe Fabien has hints on these runs/lumiblocks?)

Cheers,
Valerio

See More from Konstantinos Nikolopoulos

Anastopoulos Christos 19 June 2012 at 01:14
Re: resolutions
To: Valerio Ippolito, Cc: Konstantinos Nikolopoulos, Luis Roberto Flores Castillo, Fabien Tarrade
Details

On 06/19/2012 0
4mu | 20
4mu | 20
4e | 20
4e | 20

A ! A ! A! A!
what the heck it

Found in Inbox - CERN Mailbox

Anastopoulos Christos 19 June 2012 at 01:14
Re: resolutions
To: Valerio Ippolito, Cc: Konstantinos Nikolopoulos & 2 more
Details

On 06/19/2012 01:02 AM, Valerio Ippolito wrote:

```
4mu     | 204769 |   71902630 |    398 |  124.09 |  86.34 |  31.57 |
 125.09 | | bb
4mu     | 204769 |   82599793 |    447 |  123.25 |  84.01 |  34.21 |
 123.47 | | bbbb
4e      | 203602 |   82614360 |    429 |  124.49 |  70.63 |  44.66 |
 124.61 | | bbbb
4e      | 204910 |   22993546 |    376 |  125.52 |  88.93 |  22.28 |
 126.36 | | bbbb
```

A ! A ! A! A!
what the heck it was waiting till the last minute ???

cross-checked!
;)

See More from Konstantinos Nikolopoulos

KN

Konstantinos Nikolopoulos 19 June 2012 at 09:46

Re: resolutions

To: Fabien Tarrade, Cc: Valerio Ippolito & 2 more

Details

thanks for the heads up Fab,

i agree with you.
we need to concentrate on the items/checks we need to complete to support our findings.
and if the Higgs is there, it won't be able to hide.

Kostas

See More from Fabien Tarrade

Konstantinos Nikolopoulos
University of Birmingham

contact info at CERN
office : 40-4-C08
phone : +41 22 767 0544

at 09:46
Details
and if the Higgs is there, it won't be able to hide.
Kostas

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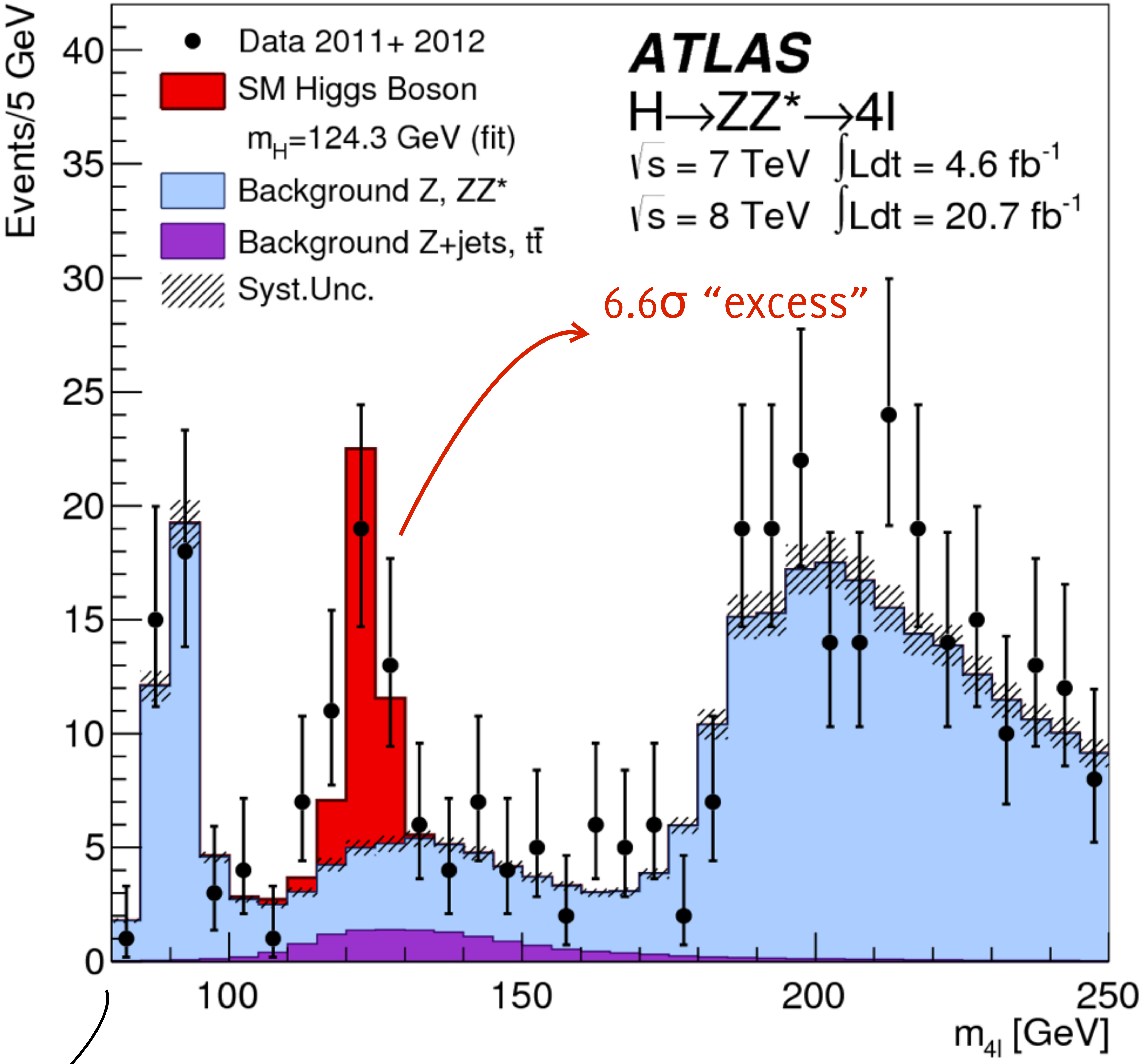
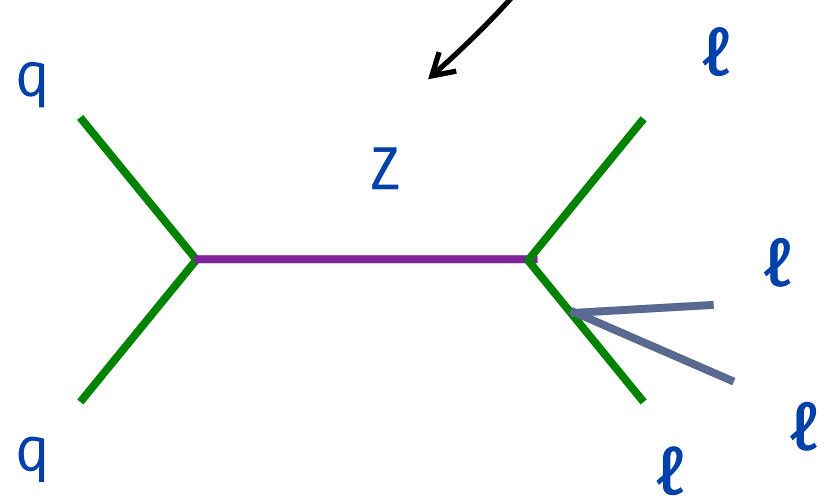
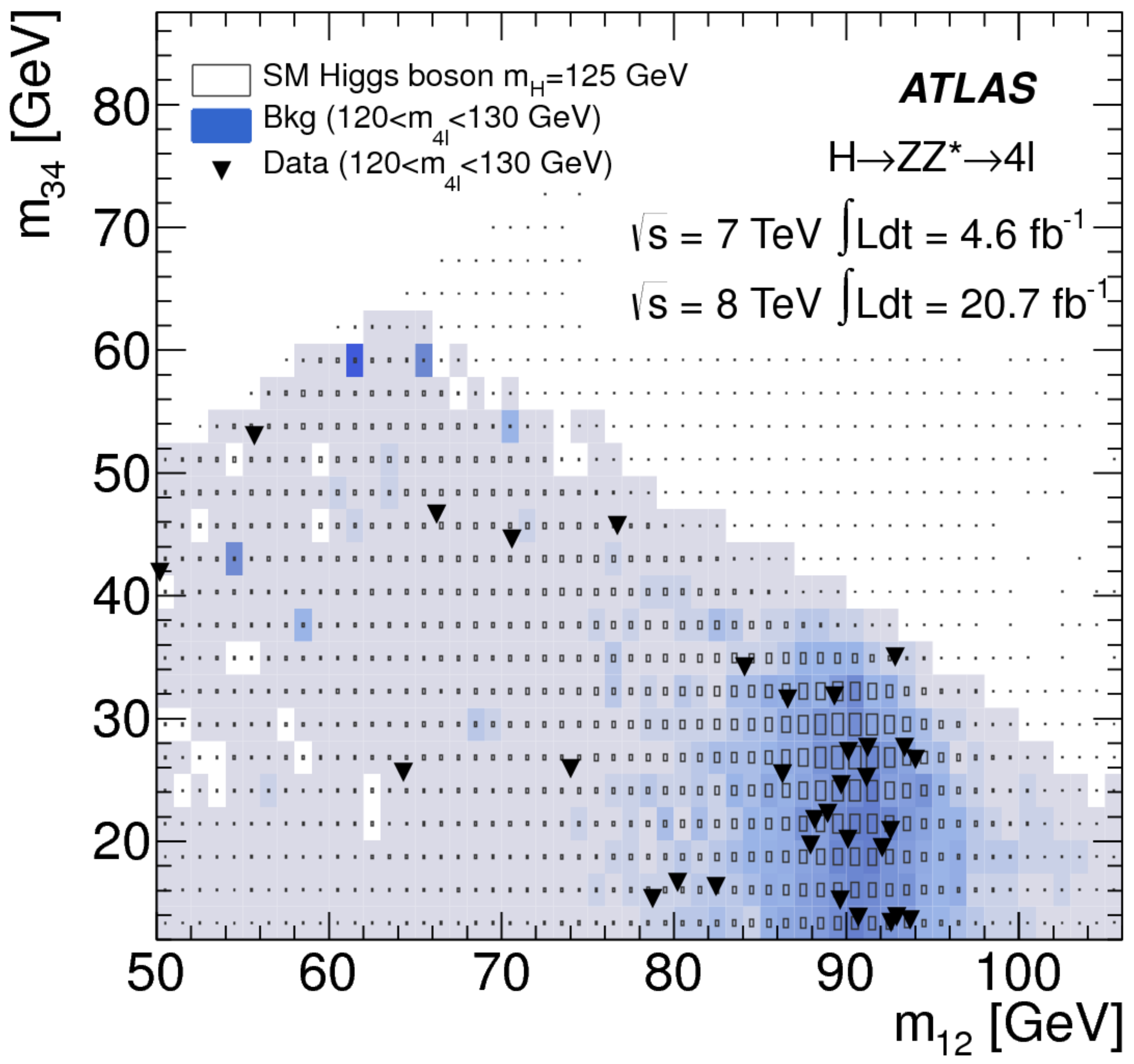
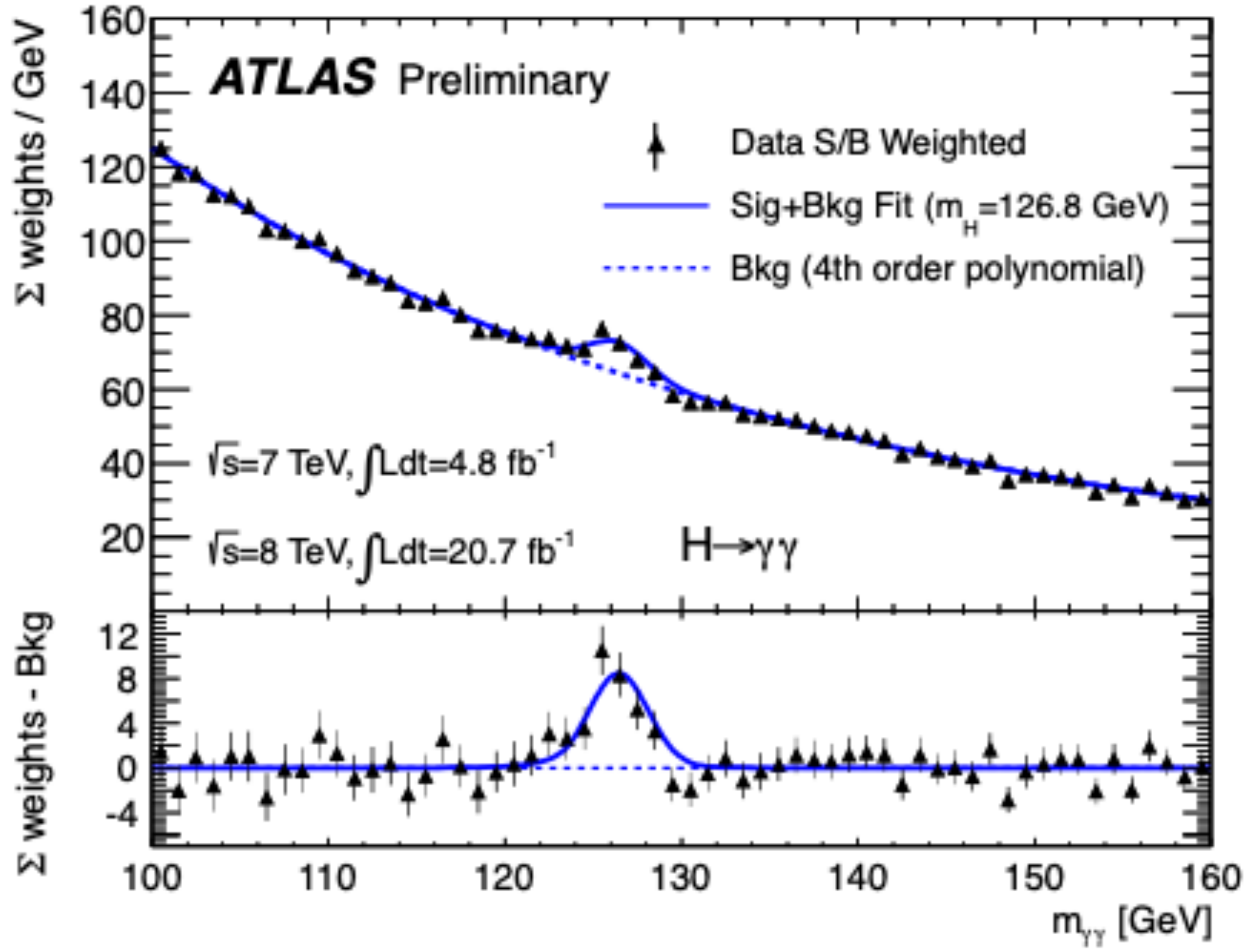
main systematics:
- ZZ production (~5-8%)
- electron ID/reco (~9%)
- luminosity (~4%)
- signal production (~8%)
- momentum scale (<1%)









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HOW DID WE TACKLE J^{PC}

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INFN Sezione di Roma

Spin determination of single-produced resonances at hadron colliders

Yanyan Gao,[1,2] Andrei V. Gritsan,[1] Zijin Guo,[1] Kirill Melnikov,[1] Markus Schulze,[1] and Nhan V. Tran[1]

[1] *Department of Physics and Astronomy, Johns Hopkins University, Baltimore, MD, USA*
[2] *Fermi National Accelerator Laboratory (FNAL), Batavia, IL, USA*

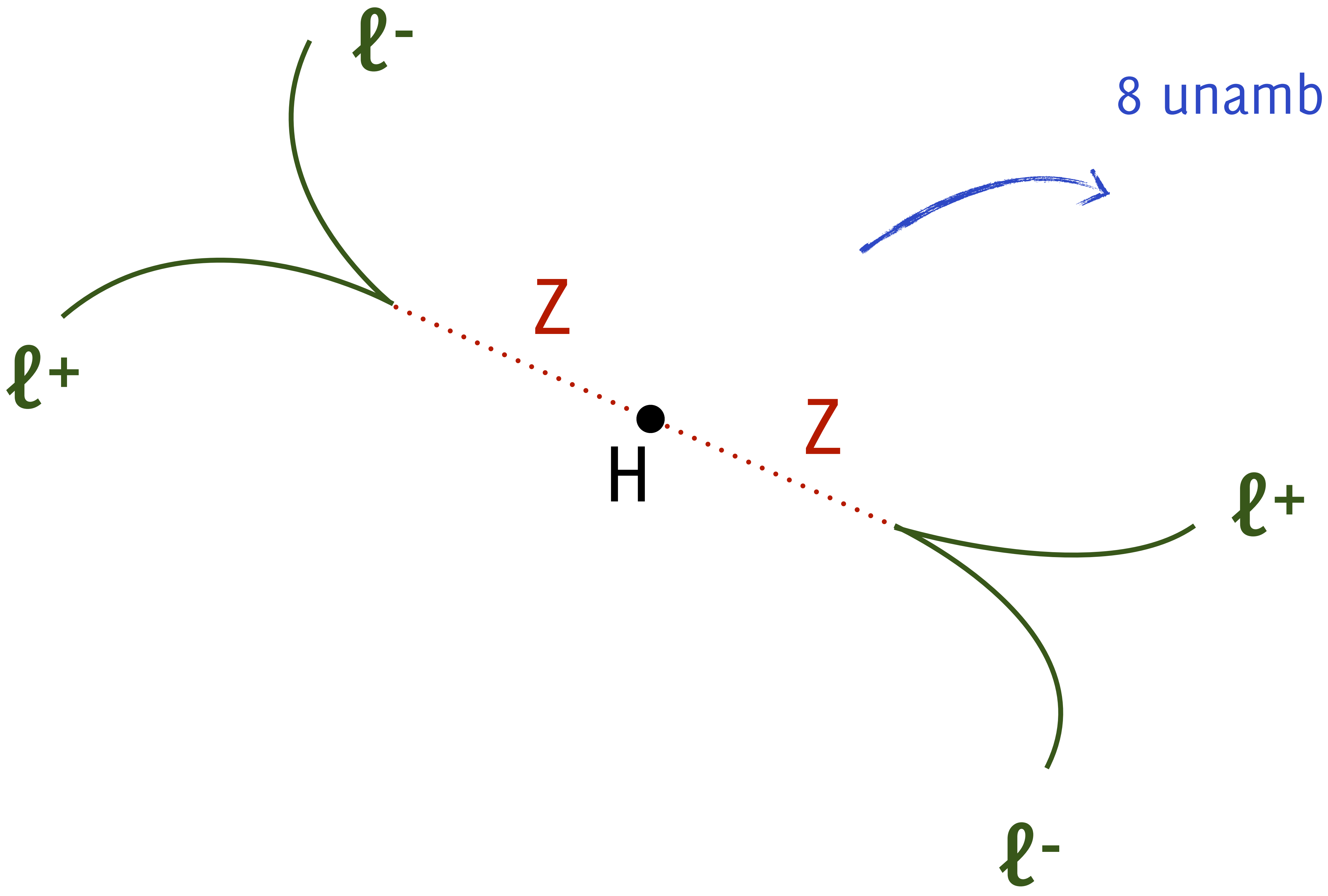
(Dated: submitted on January 19, 2010; revised on March 12, 2010)

We study the production of a single resonance at the LHC and its decay into a pair of Z bosons. We demonstrate how full reconstruction of the final states allows us to determine the spin and parity of the resonance and restricts its coupling to vector gauge bosons. Full angular analysis is illustrated with the simulation of the production and decay chain including all spin correlations and the most general couplings of spin-zero, -one, and -two resonances to Standard Model matter and gauge fields. We note implications for analysis of a resonance decaying to other final states.

PACS numbers: 12.60.-i, 13.88.+e, 14.80.Bn

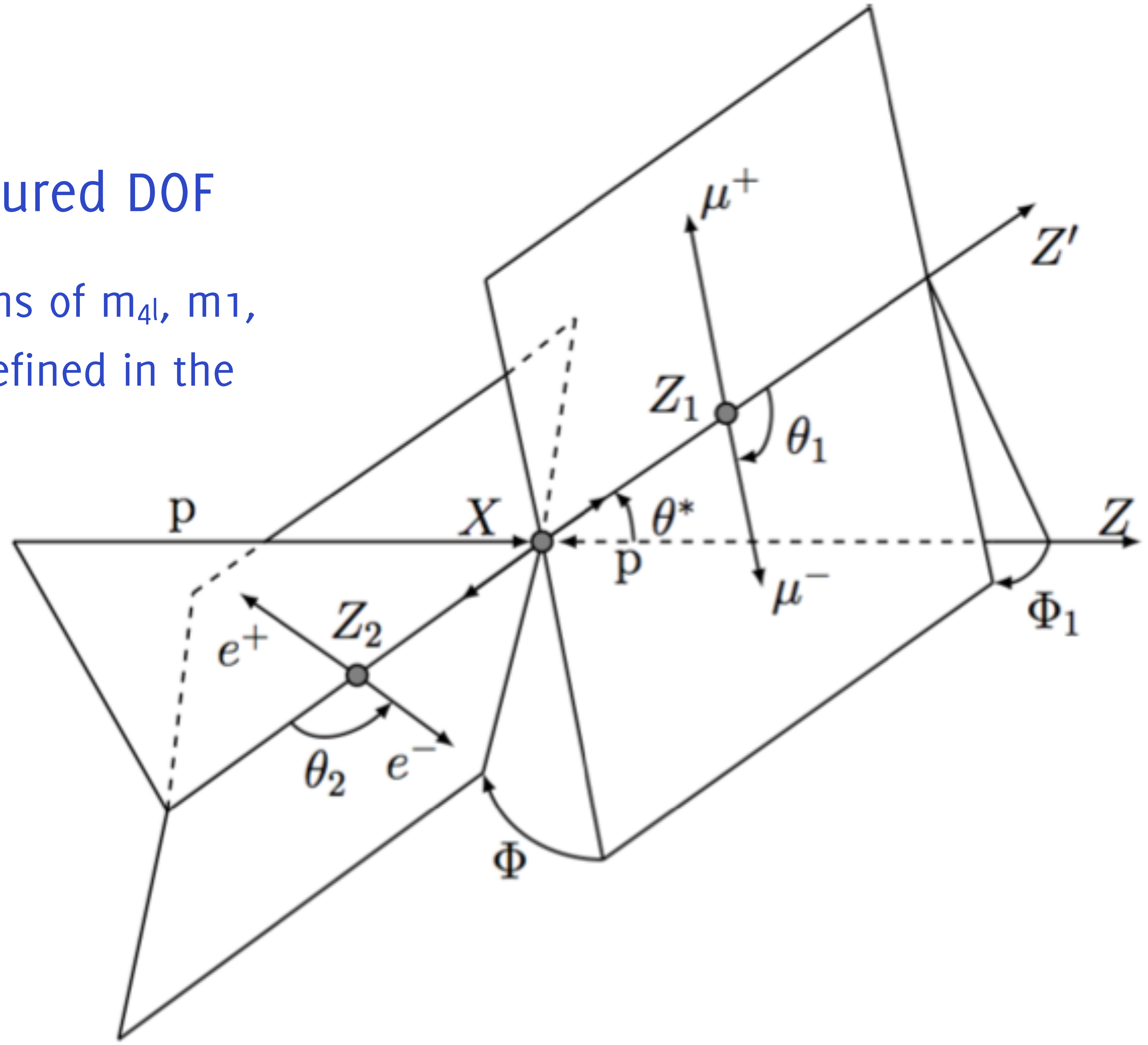
- à la B-physics: https://arxiv.org/pdf/1001.3396.pdf, https://arxiv.org/abs/1001.5300
- m34: https://arxiv.org/pdf/hep-ph/0210077.pdf (and many others)

- in $H \to 4l$, not so different from $B_s \to \phi\phi$ (K^+K^-)



8 unambiguous well-measured DOF

expressed in terms of m_{4l}, m_1, m_2 and angles defined in the final state



relate what you measure and what you want to know
$(p_1,p_2,p_3,p_4) = f\,[A(H \to ZZ)]$

→ ~ 2022 definition of ideal "machine learning task"

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write the most general Lorentz-invariant decay amplitude A(H→ZZ)

e.g.: for J=0

$$A(X \to Z_1 Z_2) = v^{-1}\left(g_1 m_Z^2 \epsilon_1^* \epsilon_2^* + g_2 f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + g_3 f^{*(1),\mu\nu} f_{\mu\alpha}^{*(2)} \frac{q_\nu q^\alpha}{\Lambda^2} + g_4 f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}\right)$$

SM Higgs

pseudoscalar

relate it to the differential mass and angular distribution

phase space + propagator

$$\frac{d\Gamma_J(m_1, m_2, \Omega)}{dm_1 dm_2 d\Omega} \propto P(m_1, m_2) \cdot \sum_i K_i(m_1, m_2) f_i(\Omega)$$

J=0: three helicity combinations (A_{++},A_{--},A_{00})

⇒ K_i = $|A_{++}|^2$, $Re(A_{++}A_{00}^*)$, $Im(A_{++}A_{00}^*)$ ... (9 terms)

$$\mathbf{\Omega} = \{\cos\theta^*, \phi_1, \cos\theta_1, \cos\theta_2, \phi\}$$

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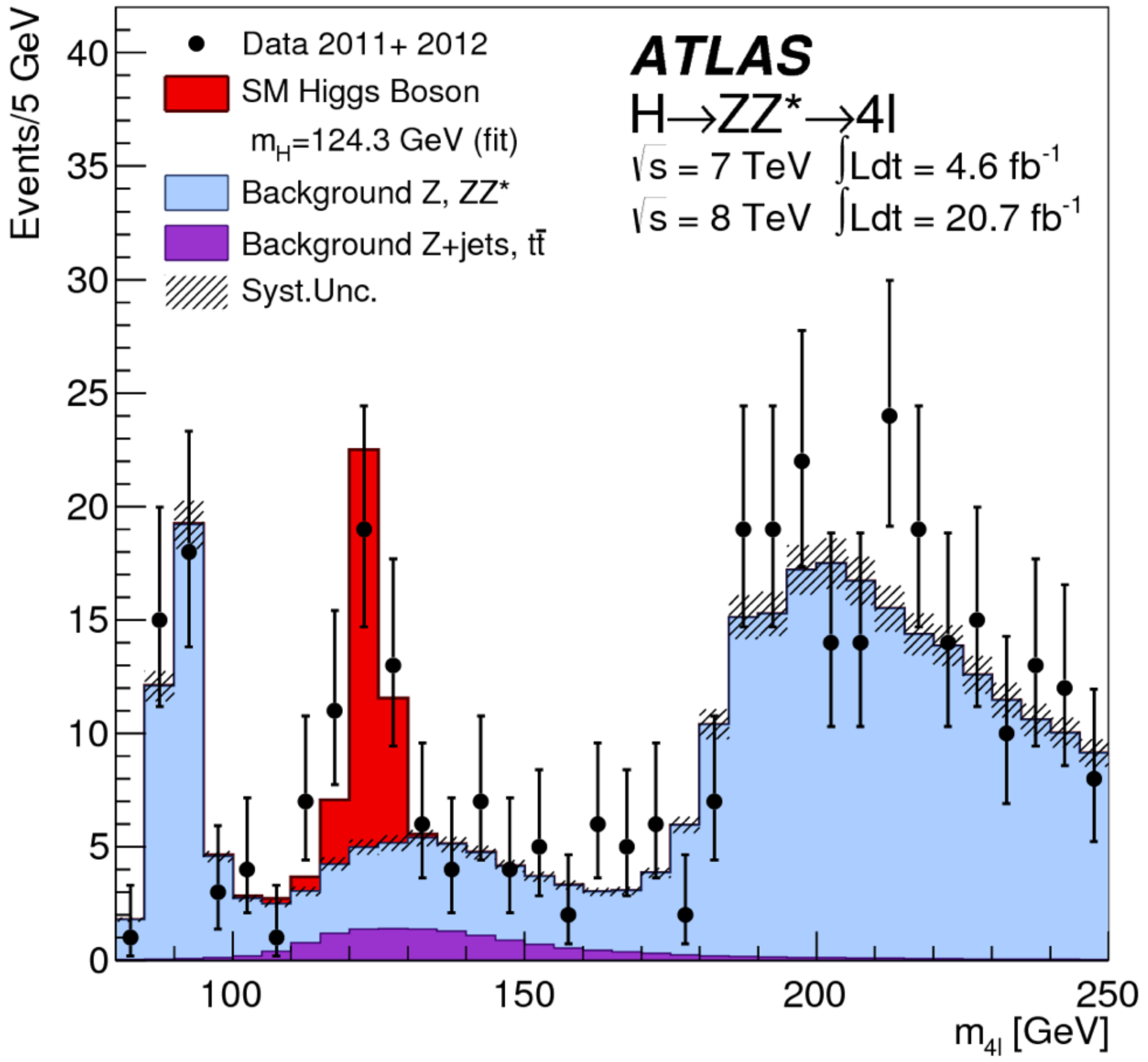
arXiv:1208.4018

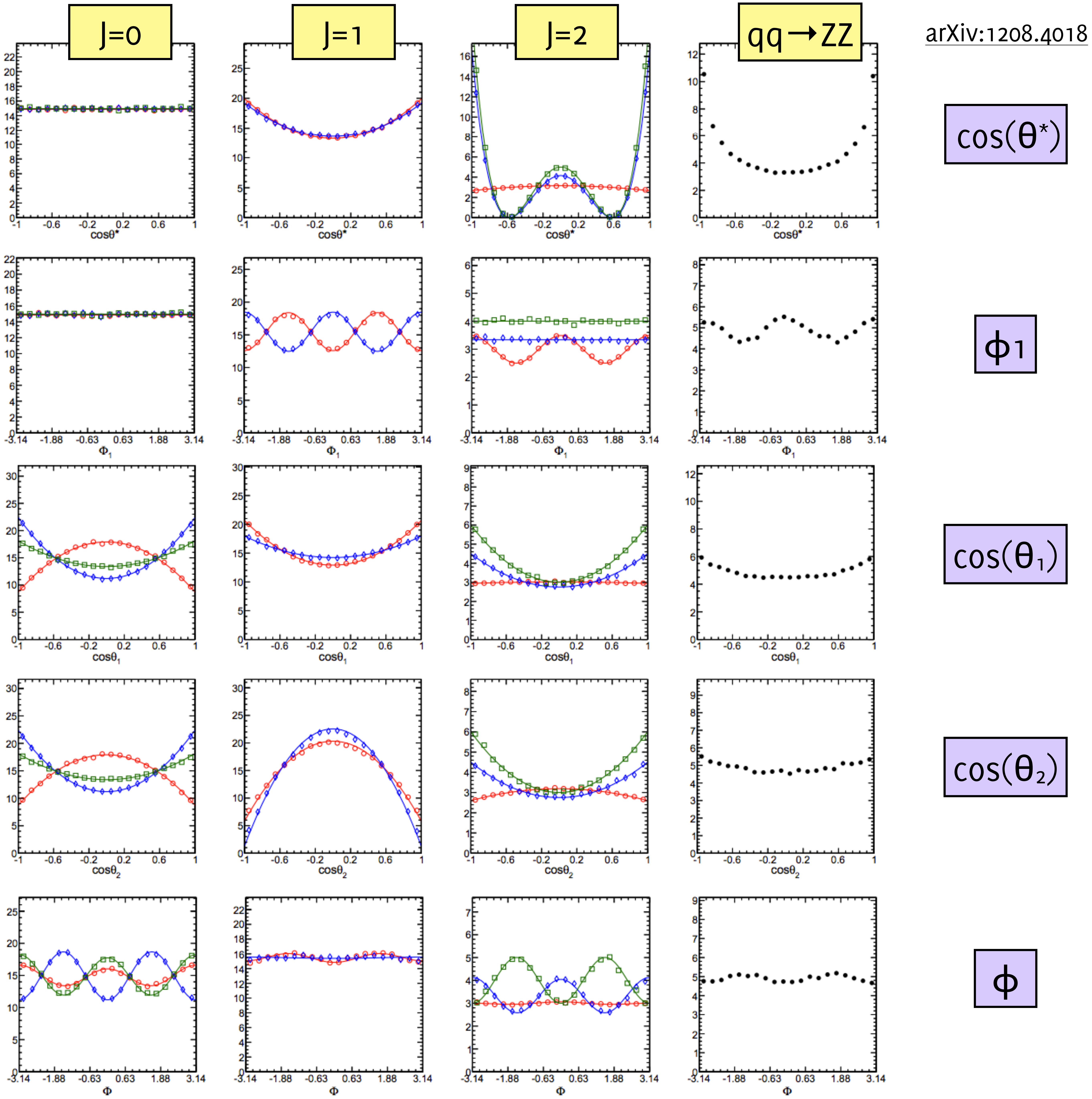


~33 events

J_m^+

J_h^+

J_h^-



LESSONS LEARNED

1. scale reliability of discovery up to property measurements

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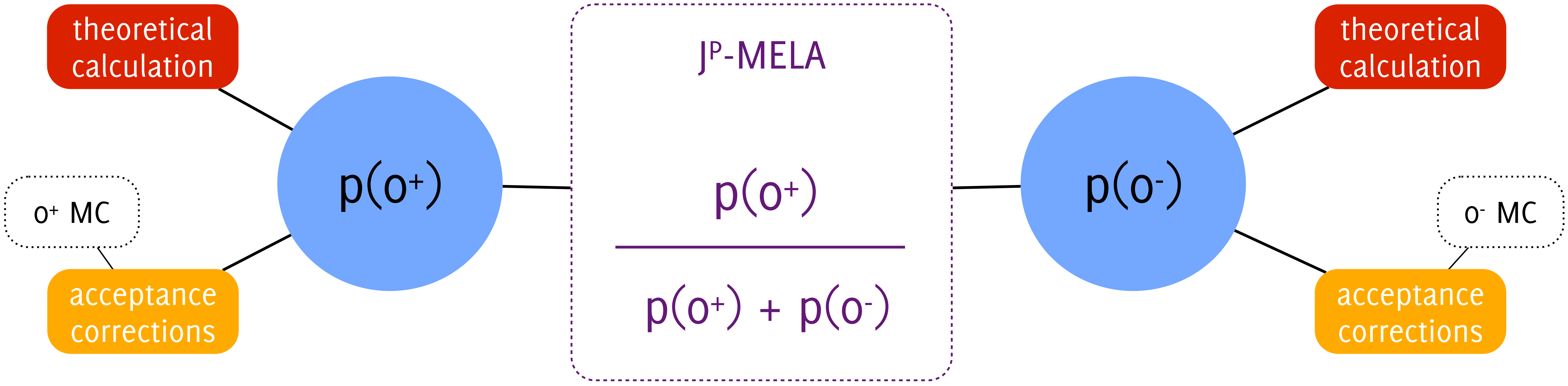

collapse the 7D information on the final state on a single observable

- it is the Bayes discriminant between data likelihood in H_0 and H_1 hypotheses
- mathematically it's the optimal discriminant in the ideal case

the difference between "real" and "ideal" is the effect of reconstruction and selection criteria

☞ $p(m_1, m_2, \Omega)$ is corrected using acceptance functions

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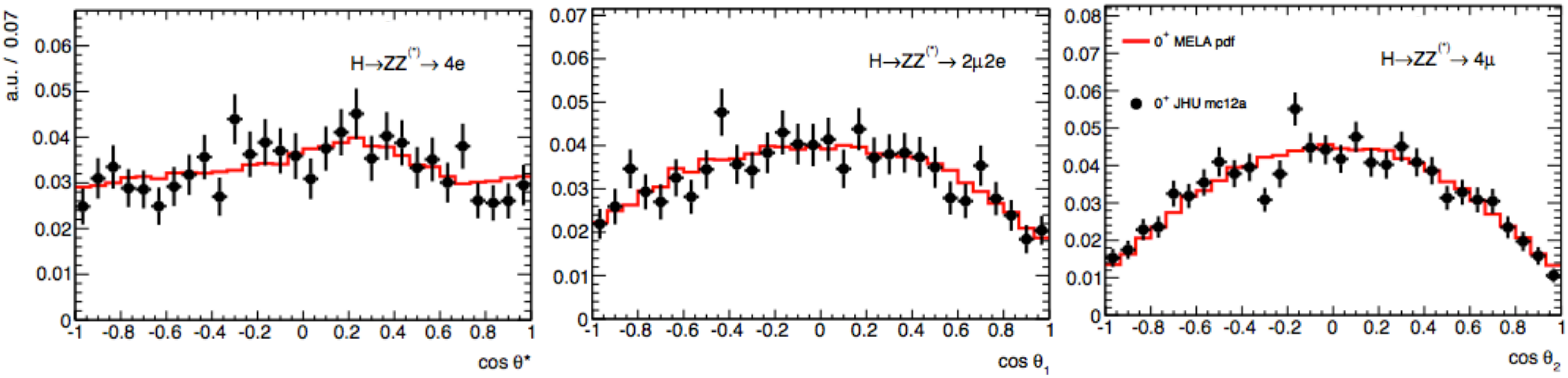

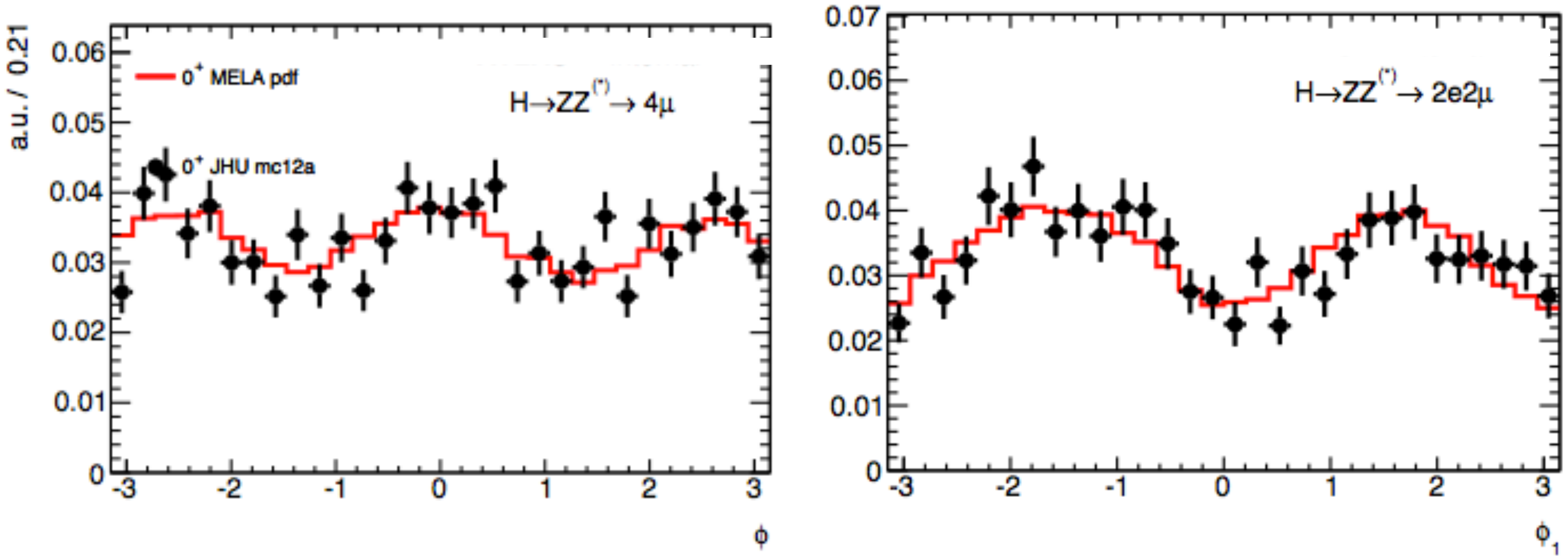

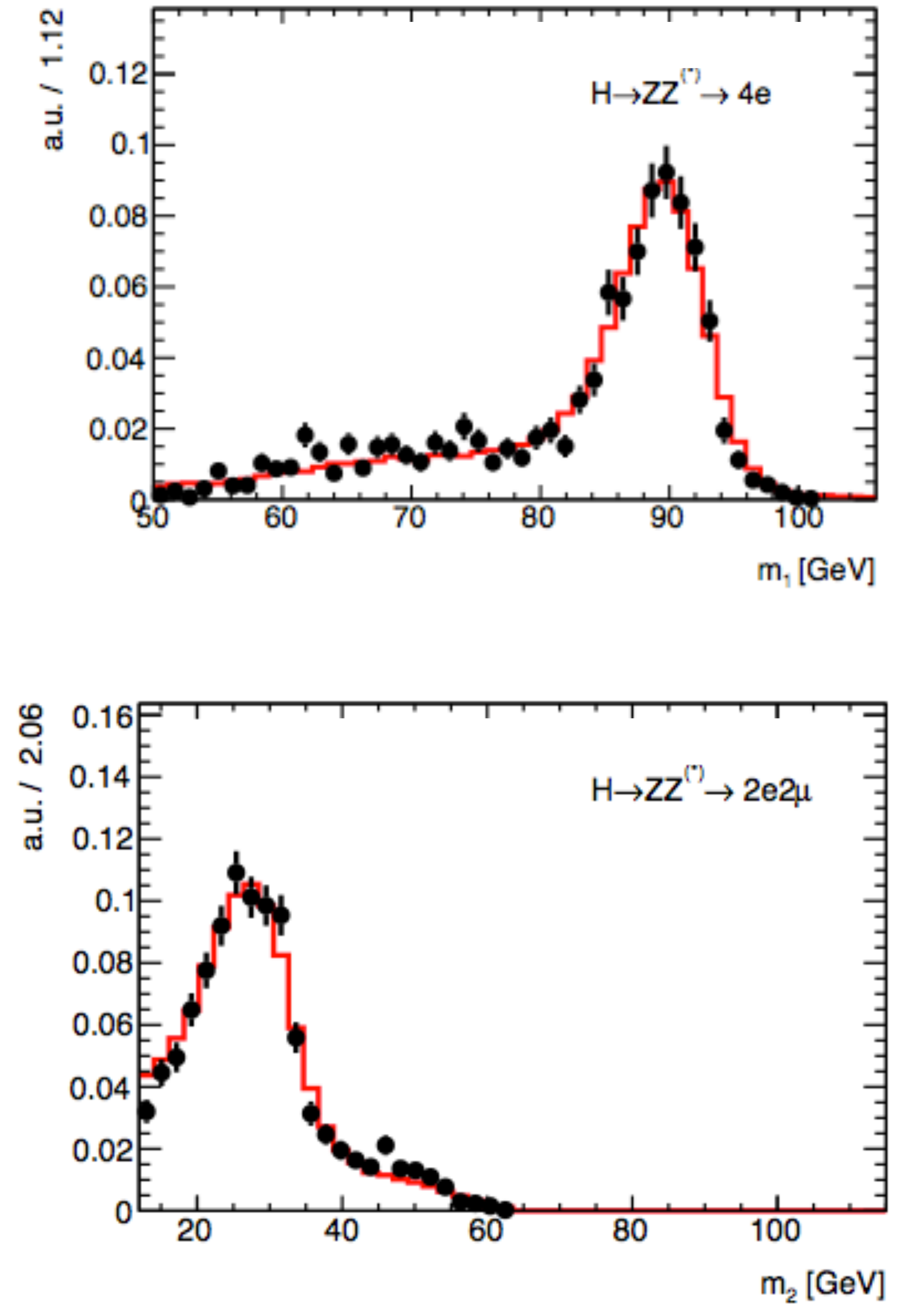

good description of full-sim MC for all tested models

this avoids loss in separation between hypotheses

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LESSONS LEARNED

1. scale reliability of discovery up to property measurements
2. ML needs MC (which needs ML e.g. event weighting, generative networks)

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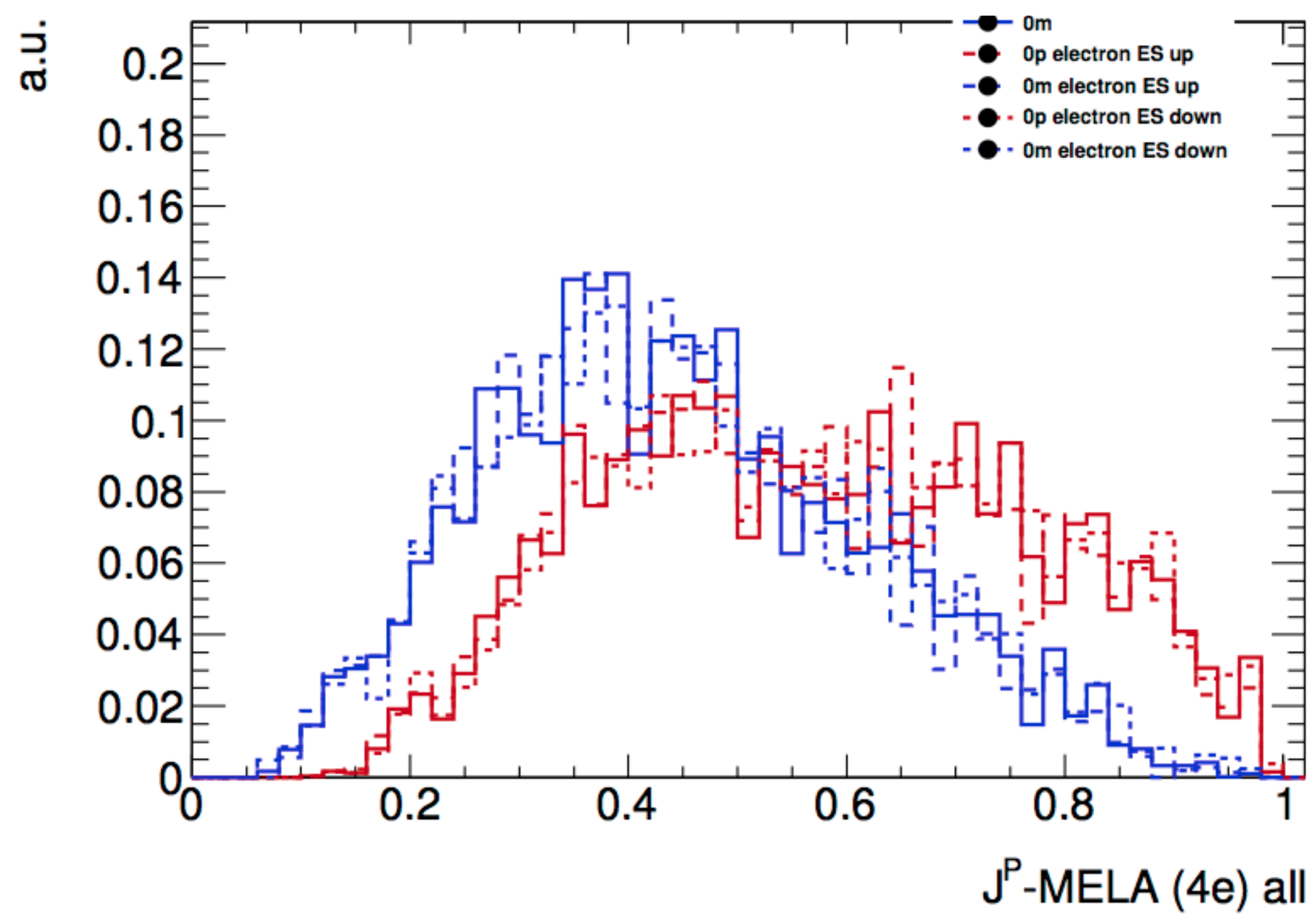
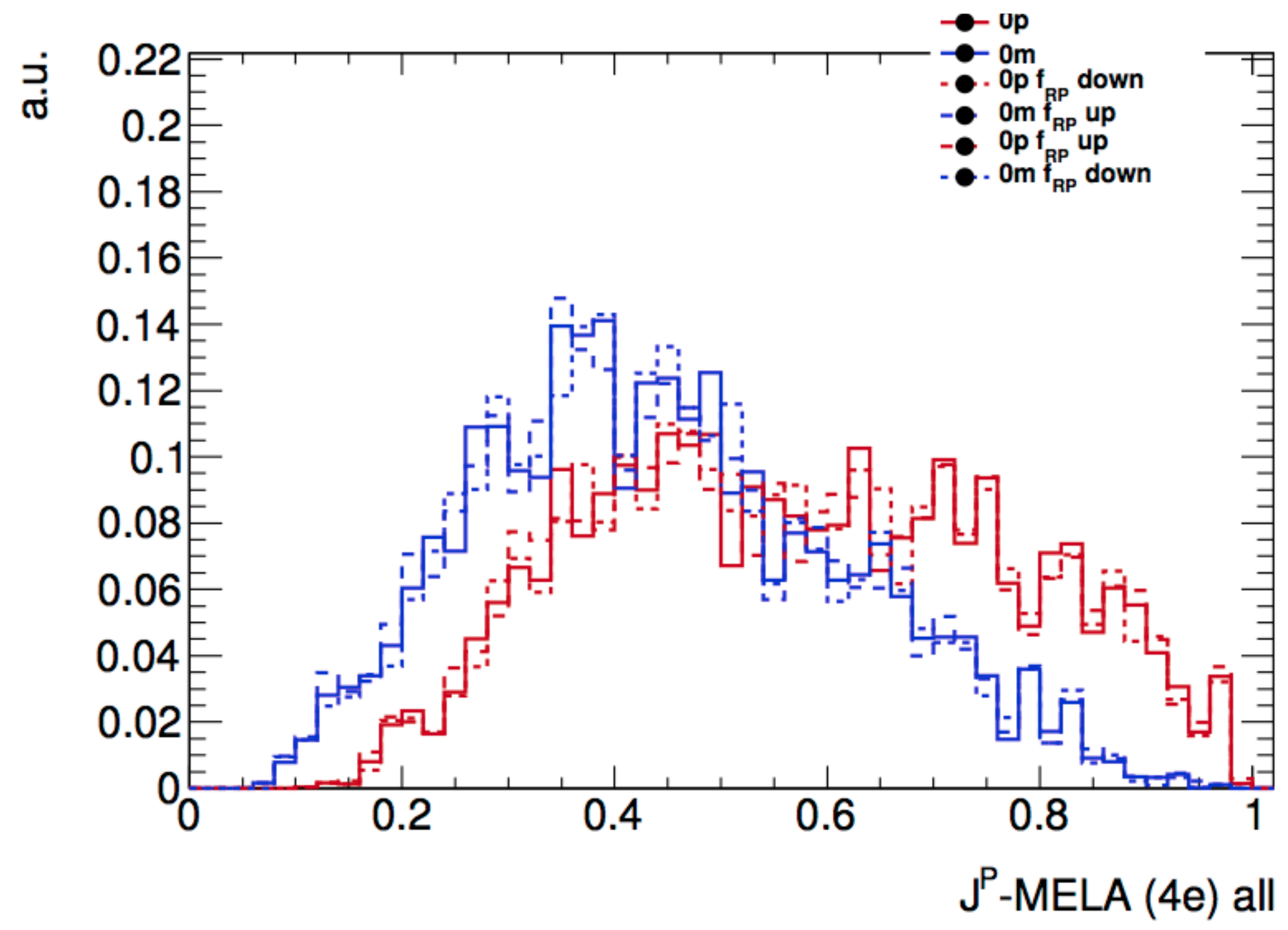
distributions of the discriminant D are calculated on full-sim MC

obtain discriminant shapes for the two signal hypotheses and for backgrounds

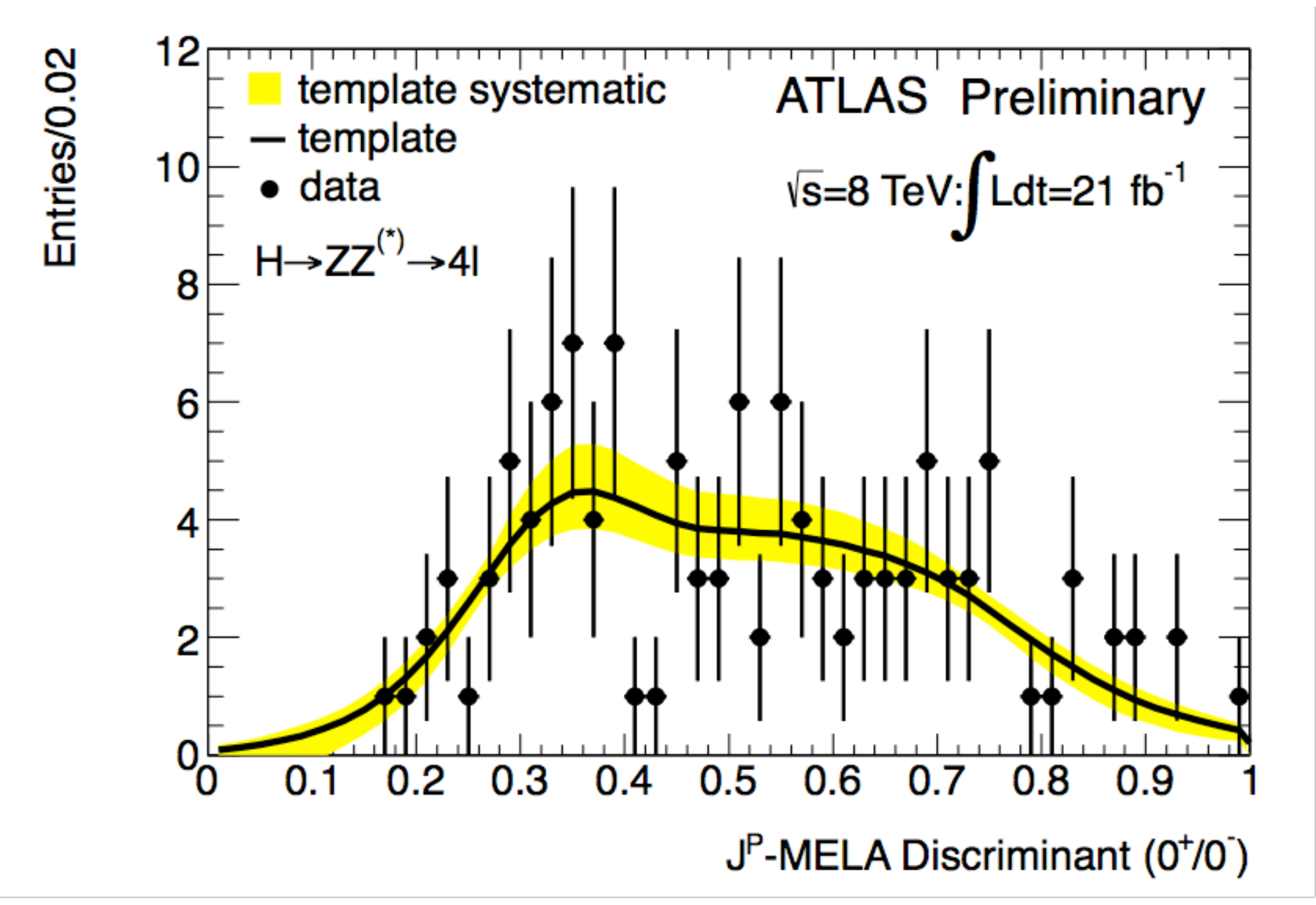
effect of ESS



wrong pairing effects



reducible background



build a likelihood model in the observable D

J^P-MELA discriminant

$$L(\epsilon|\mu) = \text{Pois}(N|\mu N_s + N_b) \cdot \left\{ f_s \left[\epsilon \cdot p(\text{data}|H_0) + (1-\epsilon) \cdot p(\text{data}|H_1)\right] + \sum_{i=ZZ,\text{red}} f_{b_i} p(\text{data}|B_i) \right\}$$

ϵ=0,1

sum across two m4l bins: 4×2×2 channels

([121,127] and [115,130]\[121,127] GeV)

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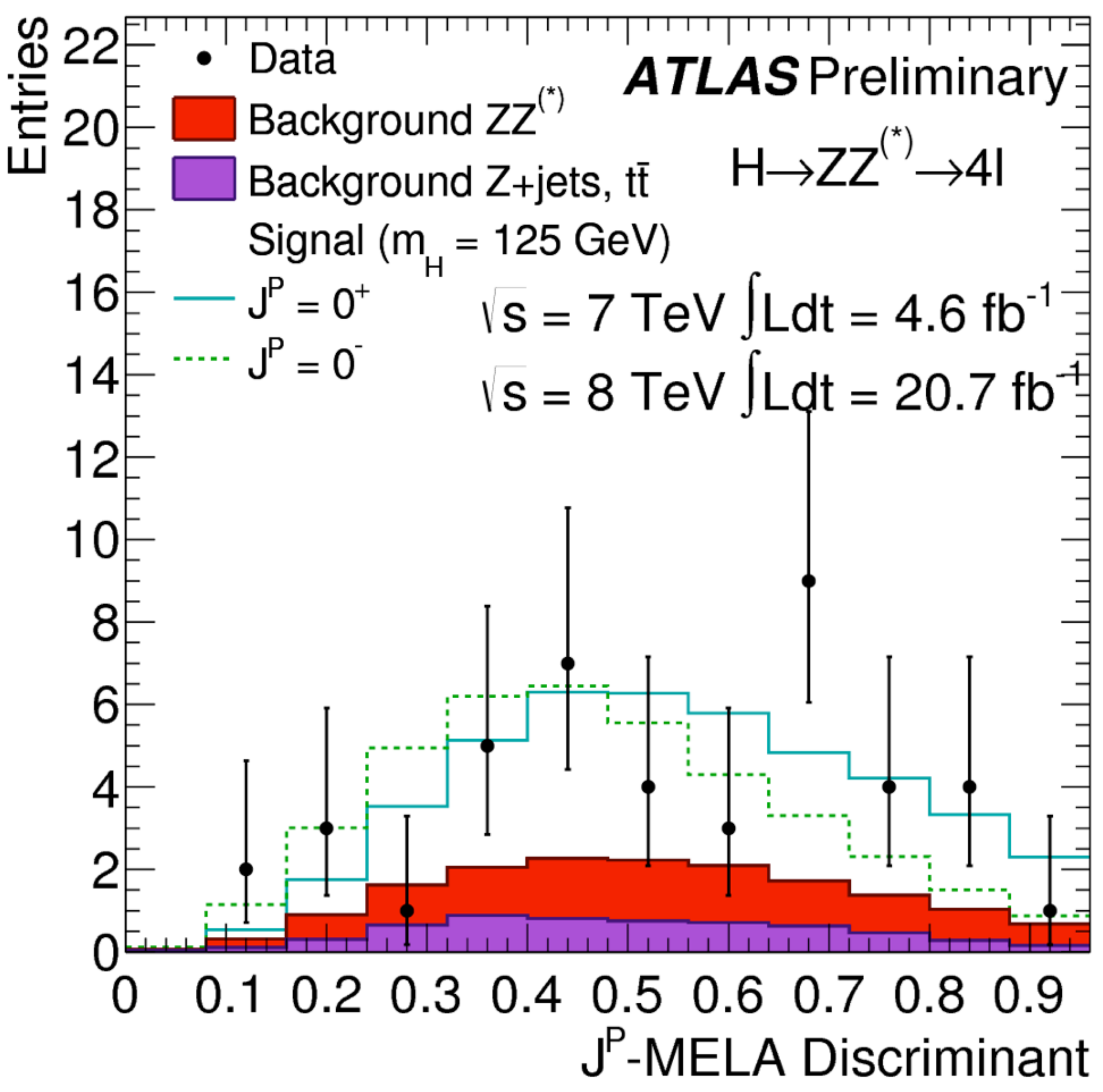
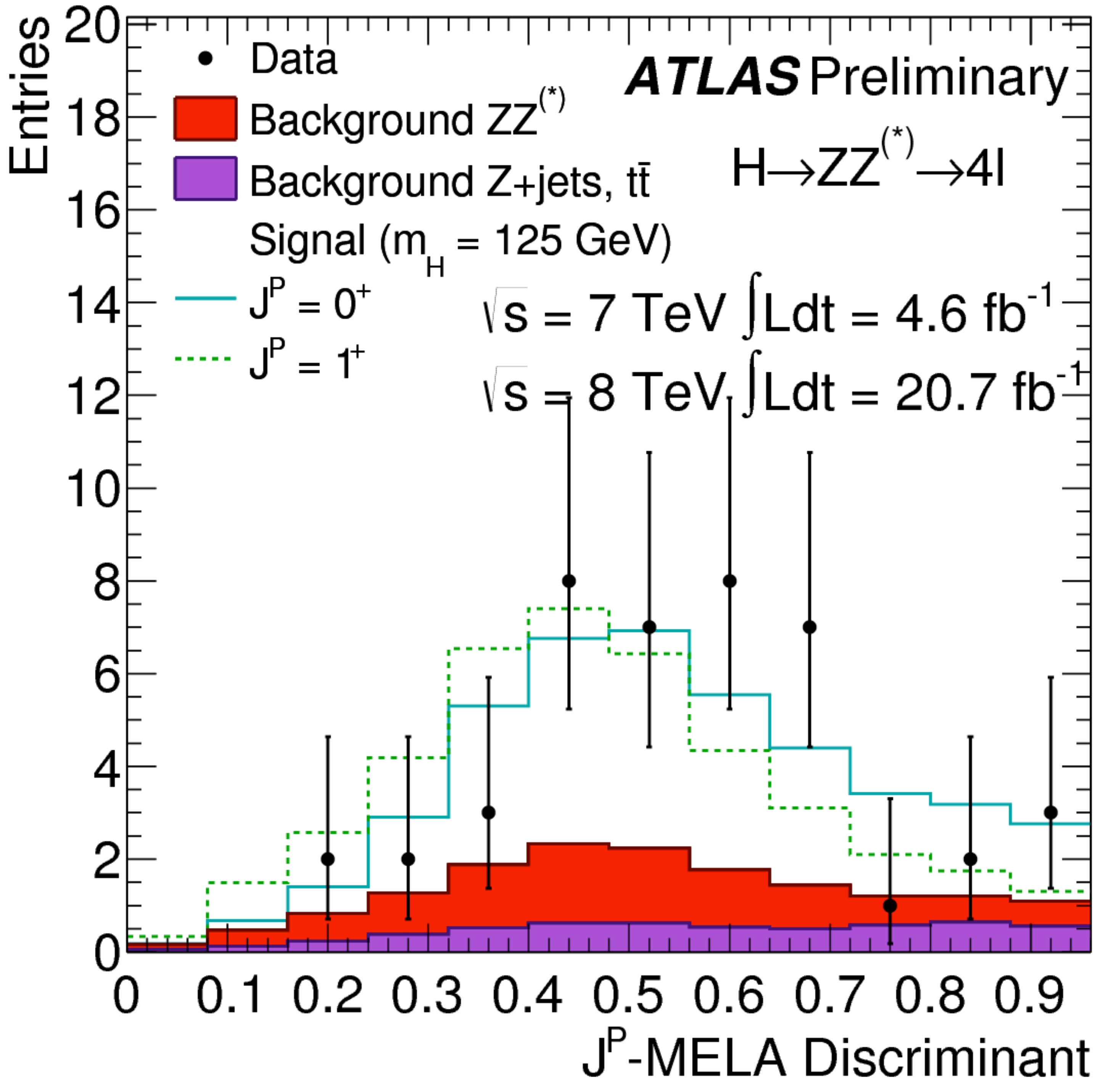
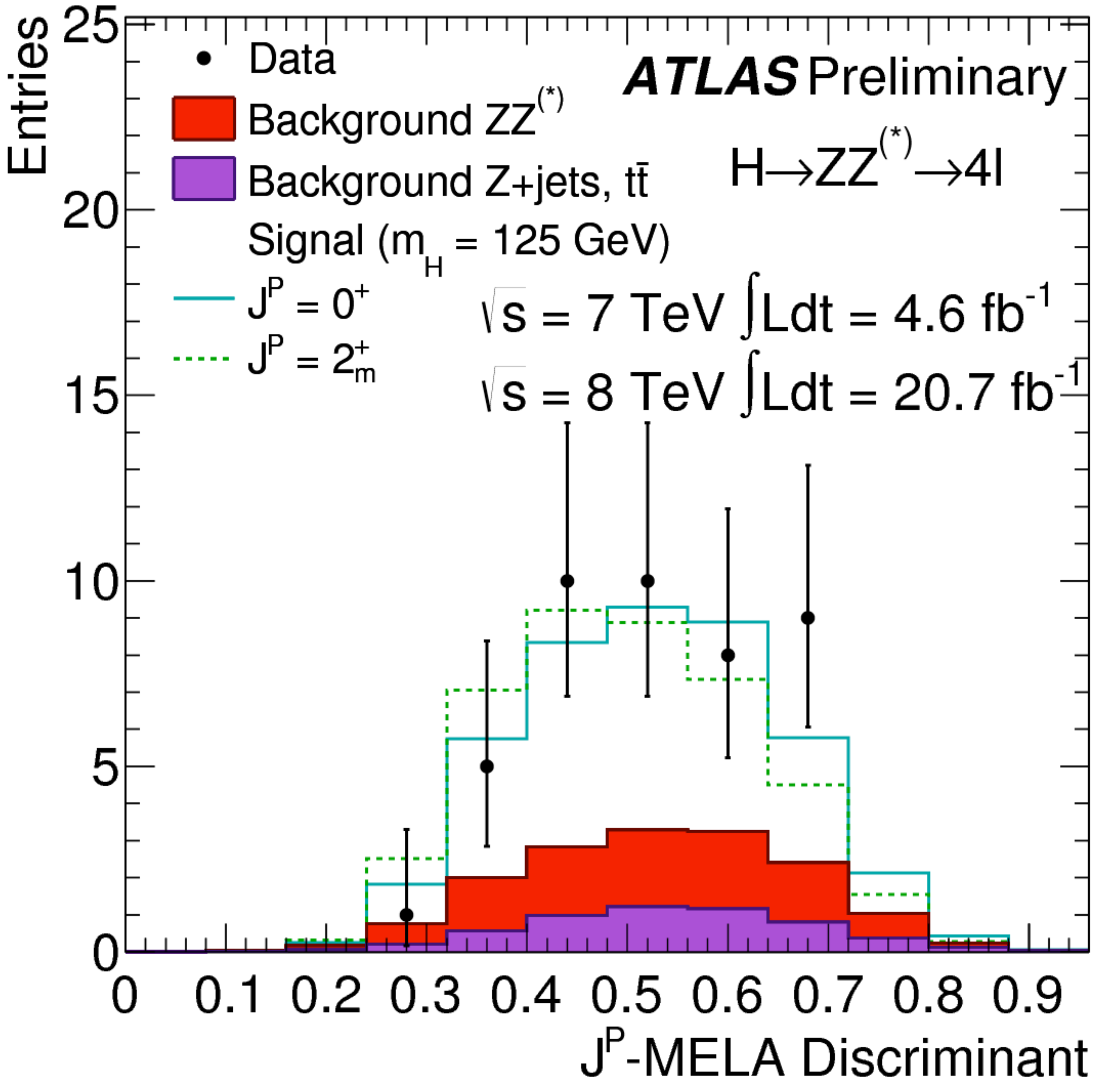
shapes of the discriminant with 7+8 TeV data

J^P-MELA = 0 for alternative hypothesis, 1 for SM Higgs







8 TeV

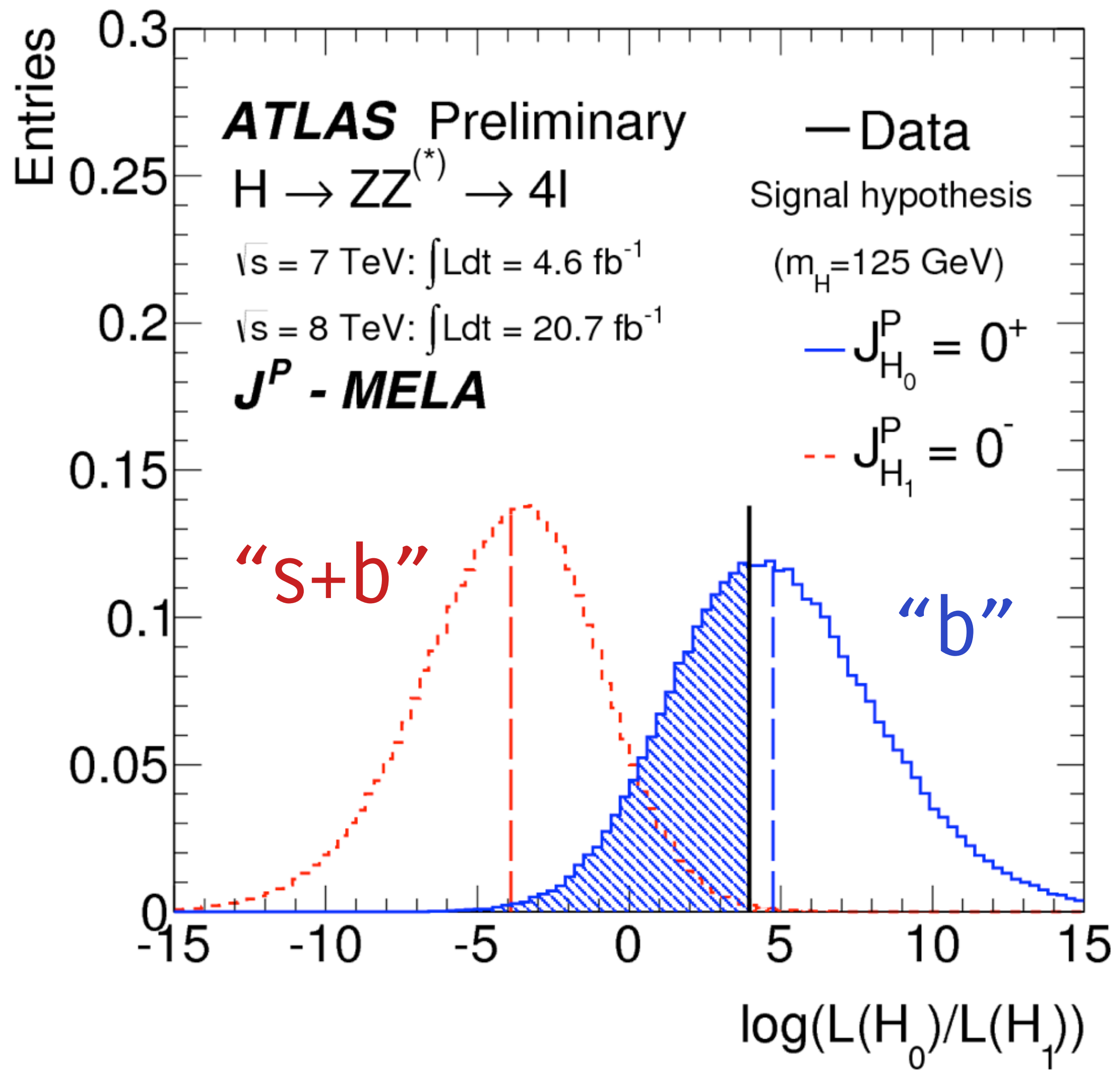
Final State and bin	Signal	ZZ	Reducible
4μ High	4.62	1.42	0.29
4μ Low	0.93	1.92	0.39
$4e$ High	1.95	0.58	0.32
$4e$ Low	0.77	0.83	0.43
$2e2\mu$ High	3.01	1.02	0.31
$2e2\mu$ Low	0.79	1.41	0.42
$2\mu2e$ High	2.22	0.68	0.44
$2\mu2e$ Low	0.65	0.94	0.61

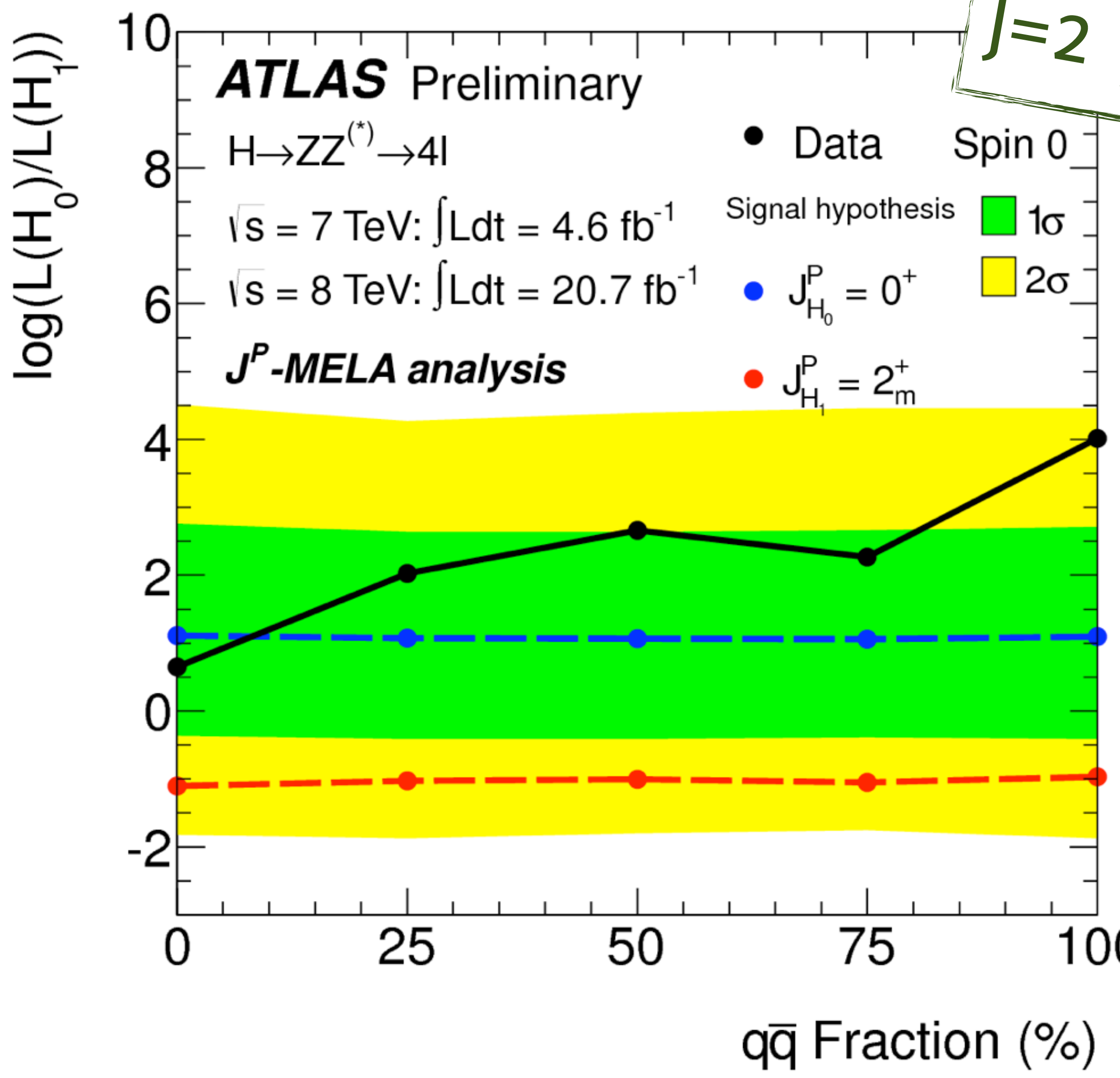
7 TeV

Final State and bin	Signal	ZZ	Reducible
4μ High	0.83	0.27	0.06
4μ Low	0.17	0.40	0.09
$4e$ High	0.24	0.09	0.07
$4e$ Low	0.11	0.12	0.10
$2e2\mu$ High	0.51	0.20	0.07
$2e2\mu$ Low	0.13	0.28	0.09
$2\mu2e$ High	0.33	0.11	0.10
$2\mu2e$ Low	0.09	0.17	0.14

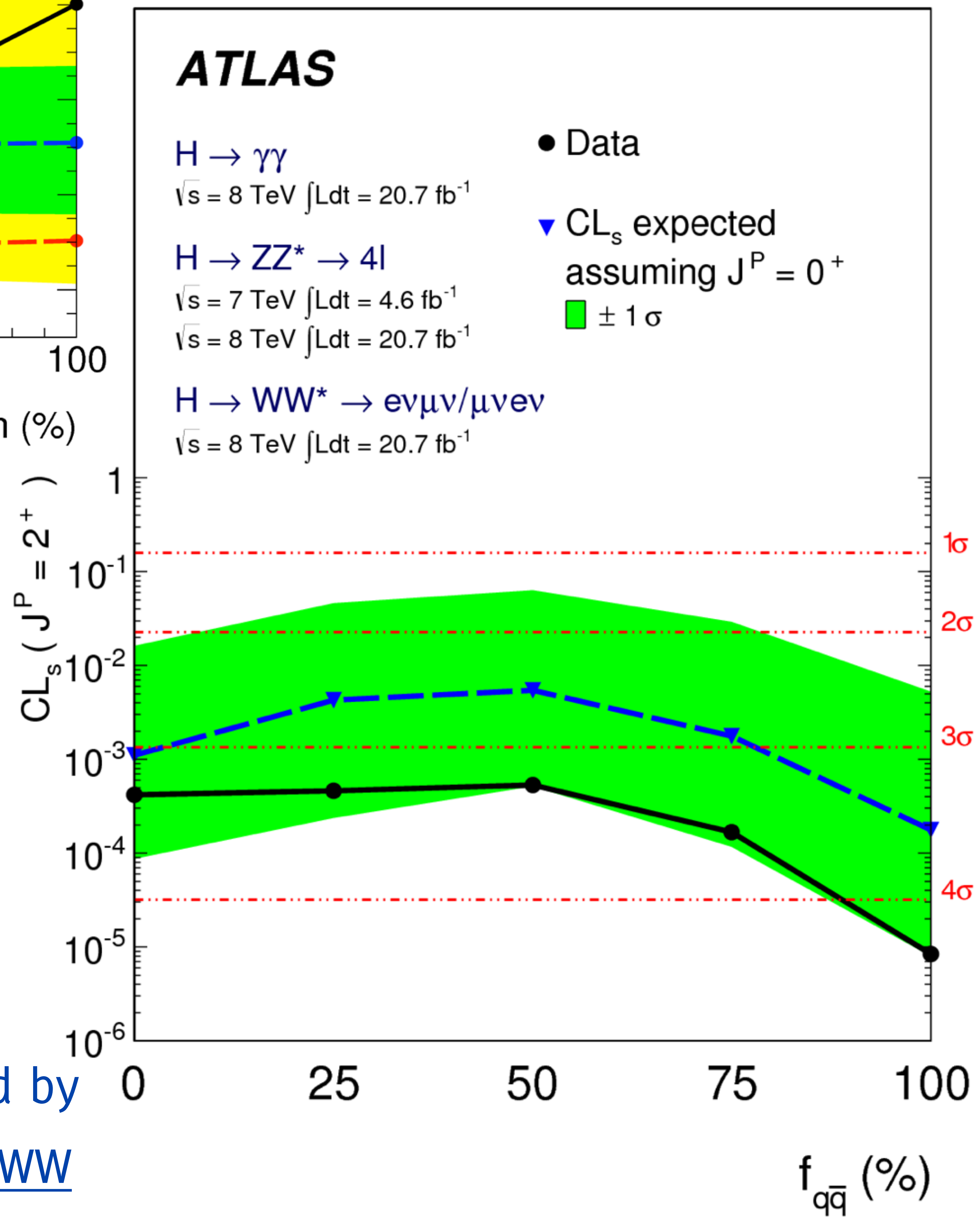
statistical analysis is split in 4 final states, 2 c.o.m. energies, 2 m4l bins ⇒ enhanced H_0/H_1 separation

use distribution of log[L(H₀)/L(H₁)] sampled on pseudo-events to build a test statistics





J=2 production mechanism unknown ⇒ f_{qq}



exclusion given w.r.t. 0+ with $CL_s = CL_{s+b}/CL_b$ method

		J^P-MELA analysis			
		tested J^P for an assumed 0^+		tested 0^+ for an assumed J^P	CL_S
		expected	observed	observed*	
0^-	p_0	0.0011	0.0022	0.40	0.004
1^+	p_0	0.0031	0.0028	0.51	0.006
1^-	p_0	0.0010	0.027	0.11	0.031
2^+_m	p_0	0.064	0.11	0.38	0.182
2^-	p_0	0.0032	0.11	0.08	0.116

>95%

excluded by 4ℓ+γγ+WW

only sensitive to 0+ vs 1+/- (WW), 2+

LESSONS LEARNED

1. scale reliability of discovery up to property measurements
2. ML needs MC (which needs ML)
3. low statistics doesn't mean you shouldn't do complex analyses

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let's take again the most general H→ZZ decay amplitude for spin zero

$$A(X \to Z_1 Z_2) = v^{-1}\left(g_1 m_Z^2 \epsilon_1^* \epsilon_2^* + g_2 f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + g_3 f^{*(1),\mu\nu} f_{\mu\alpha}^{*(2)} \frac{q_\nu q^\alpha}{\Lambda^2} + g_4 f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}\right)$$

in the SM:	2i	O(10^{-2}) (one loop diagrams)	(suppressed by scale² of NP)	≈0 (three-loops diagrams)

non-zero g_2, g_4 affect final state distributions

* CP even/odd admixture present if g_4 and g_1 are both non-zero
  can hint to CP violation (e.g. mixing between multiple Higgs particles à la 2HDM) which might explain matter/antimatter asymmetry
  (excluded) pure pseudoscalar state corresponds to the limit $|g_4/g_1| \to \infty$
* new physics could contribute in loops giving $g_2 \neq 0$

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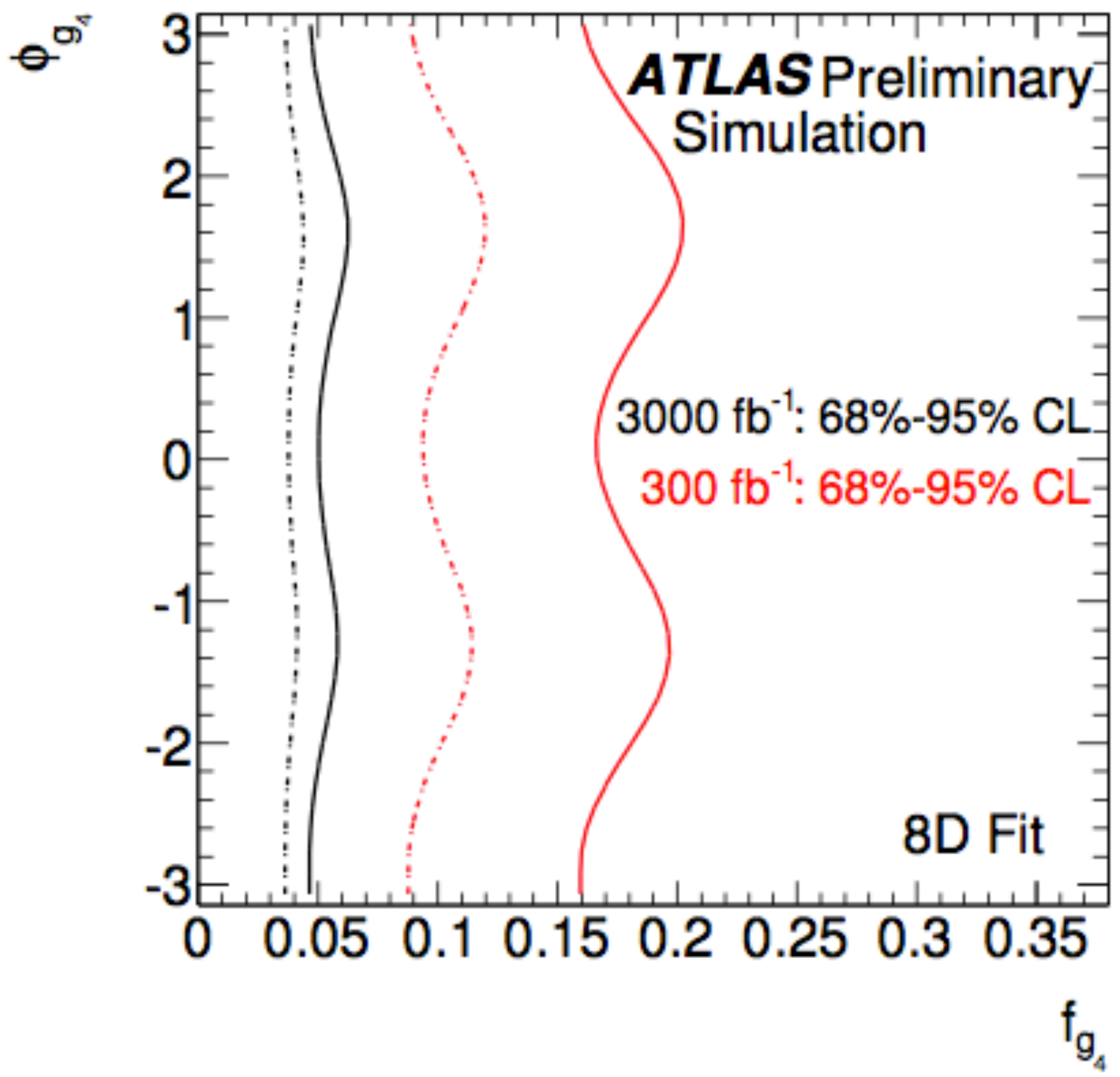
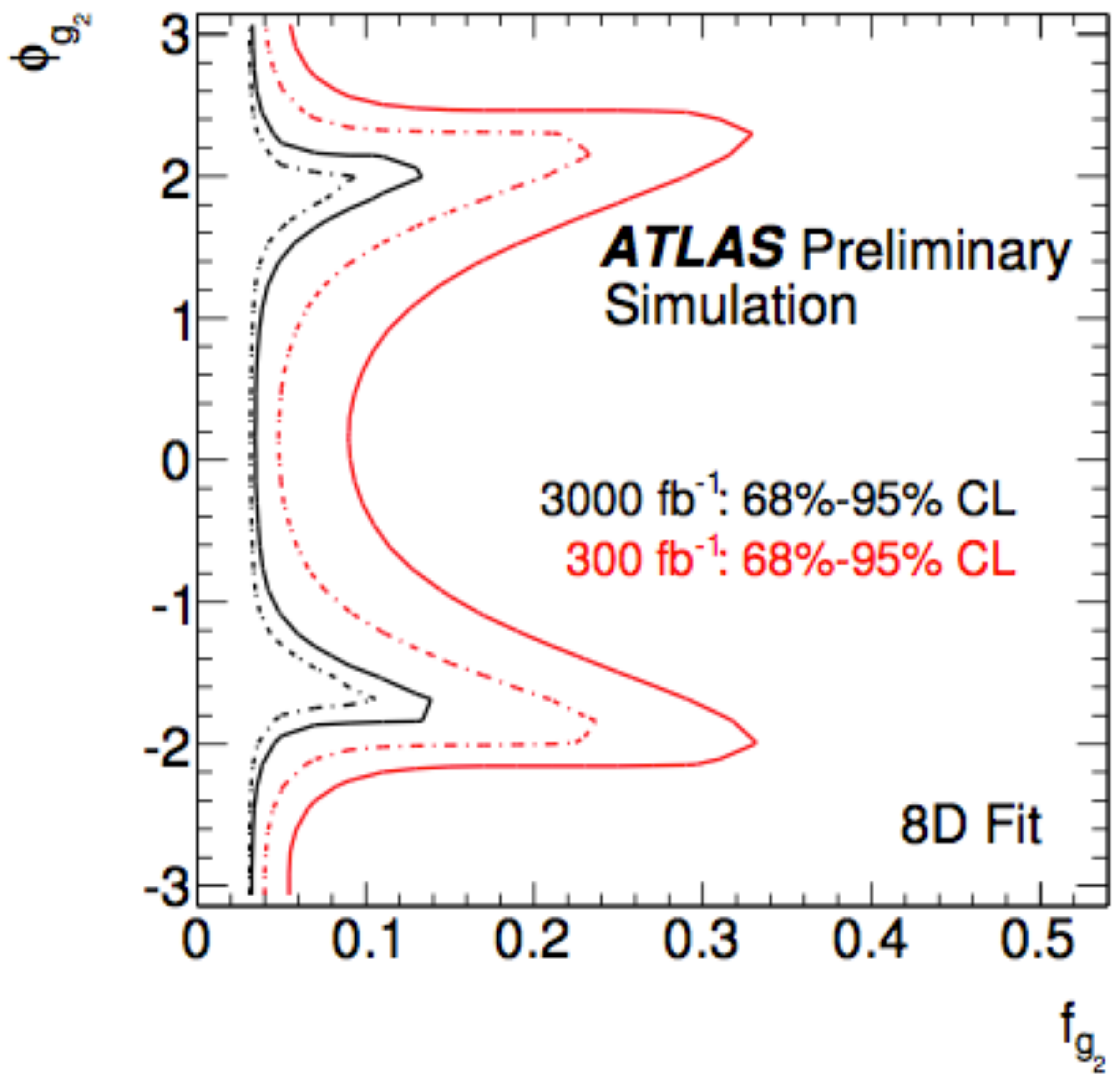
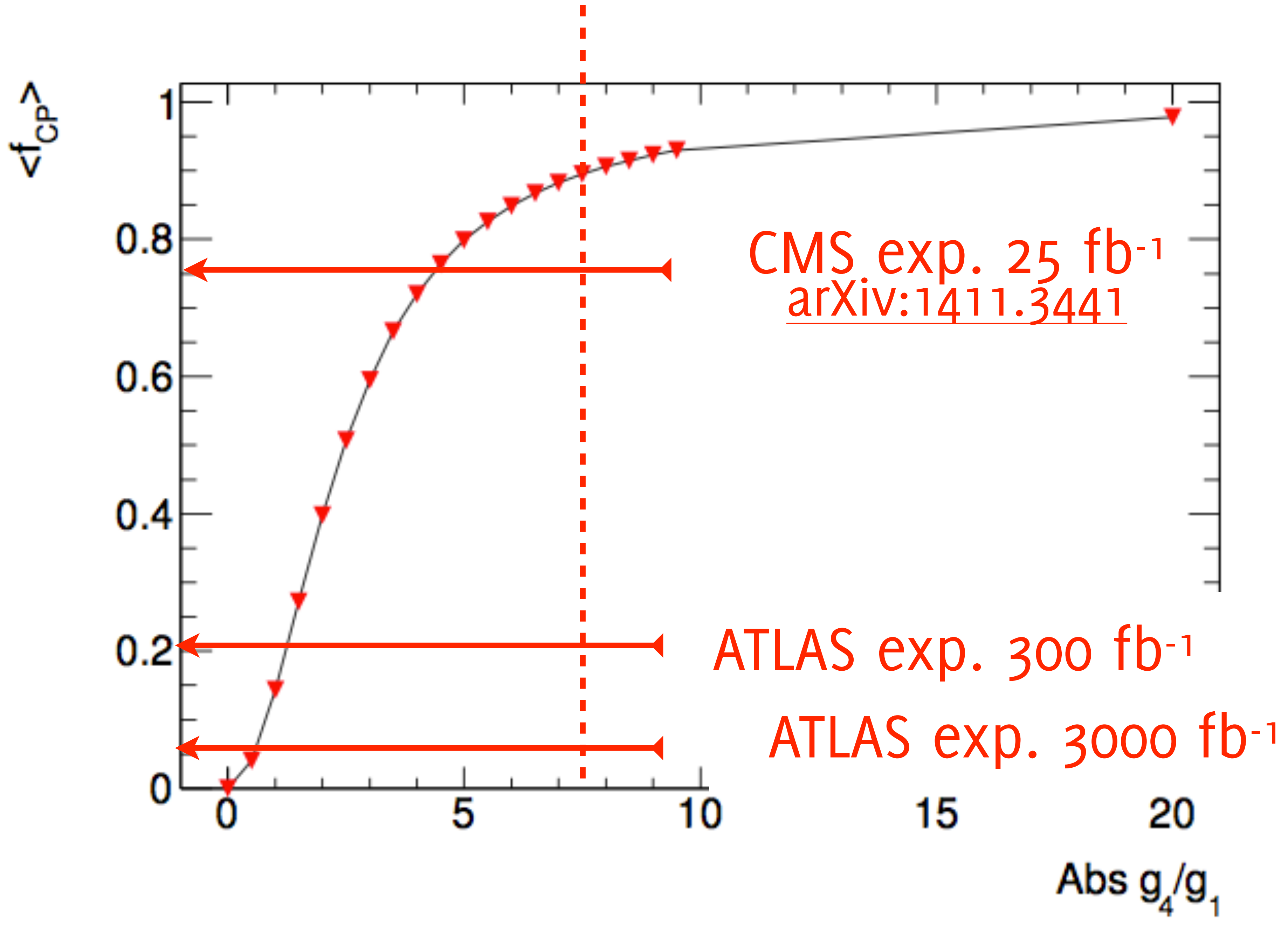
* studied sensitivity on HZZ vertex structure with 300 and 3000 fb^{-1} at 14 TeV

Final State	Signal	ZZ^*	Reducible Backgrounds
4μ	1186	427	214
$2\mu 2e$	867	287	144
$2e2\mu$	1035	383	191
$4e$	871	317	158

* systematics: 3% (lumi) + 5% (lepton reco) + 7-10% (bkg, acc)







Luminosity (fb^{-1})	f_{g_4}	f_{g_2}
300	0.20	0.29
3000	0.06	0.12

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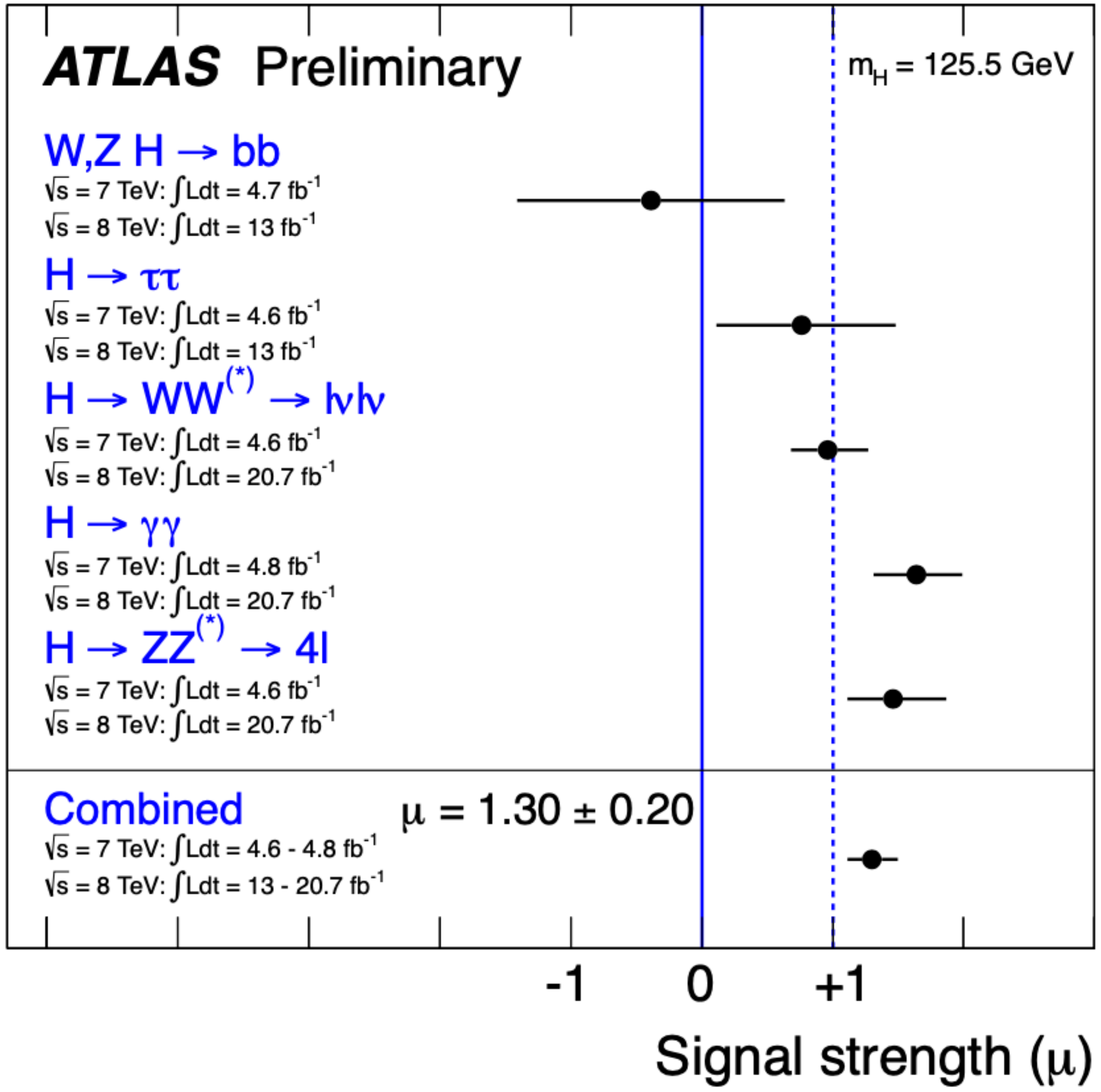
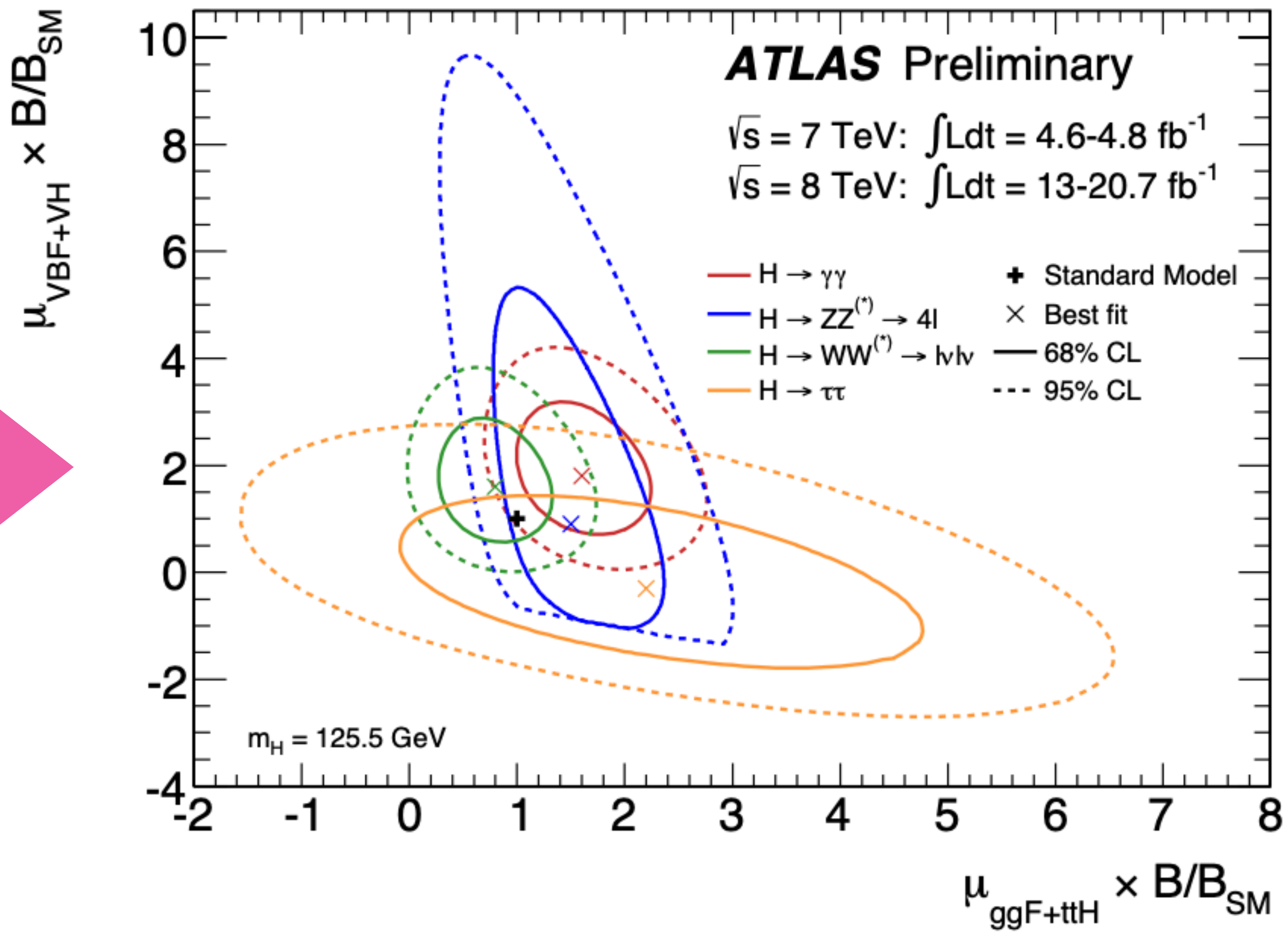


2D likelihood contour



$\mu = 1.30 \pm 0.13(\text{stat}) \pm 0.14(\text{sys})$
9% agreement with SM (μ=1)

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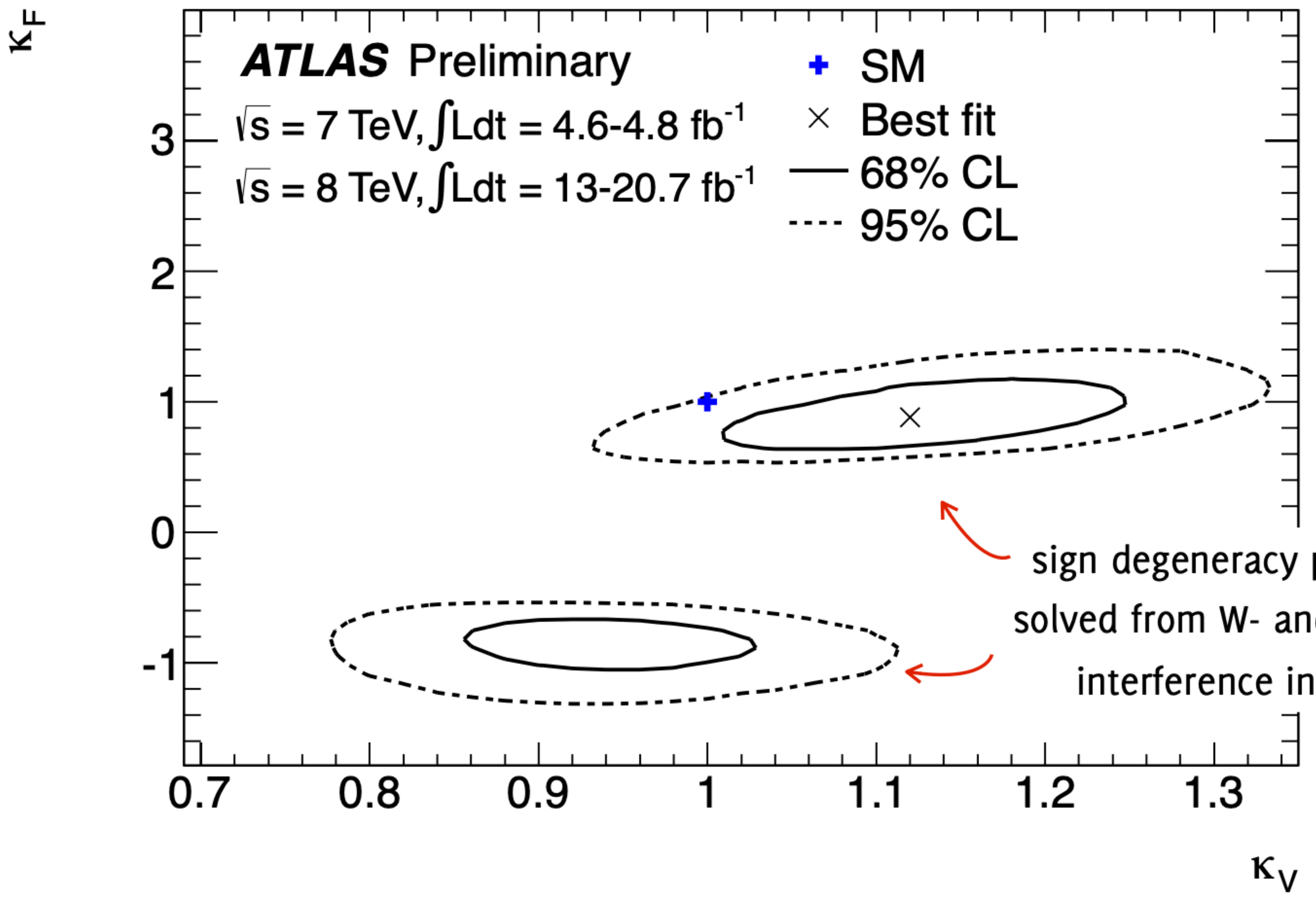
2D likelihood contour



sign degeneracy partially solved from W- and t-loop interference in $H\to\gamma\gamma$

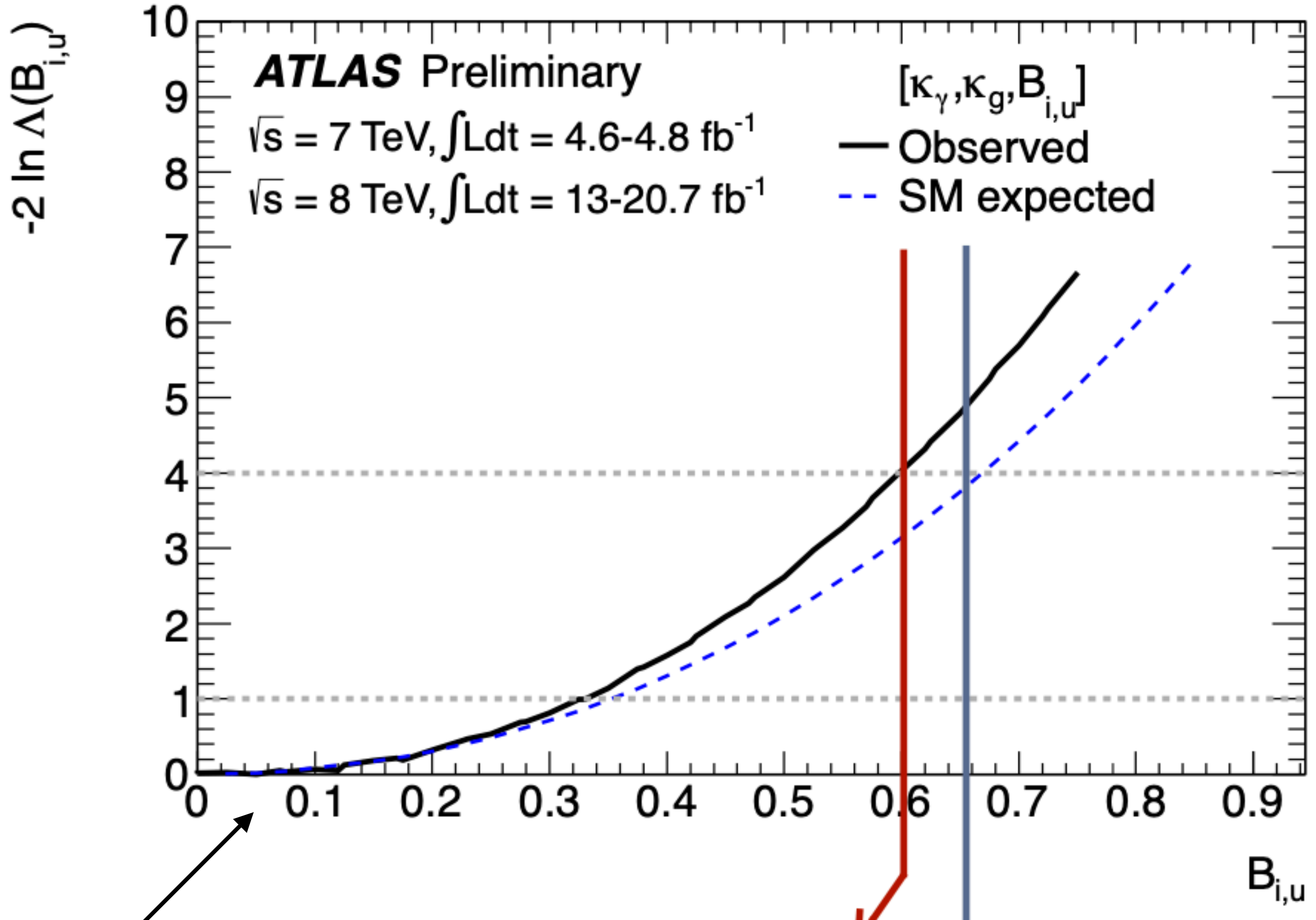
$\kappa_F \in [-0.88, -0.75] \cup [0.73, 1.07]$

$\kappa_V \in [0.91, 0.97] \cup [1.05, 1.21]$

(68% CL intervals)

8% compatibility with SM (1,1)

2. allow for invisible/undetectable final states



2022

$BR_{inv.,undet.} < 0.33$ (< 0.6 @ 95%CL)

$\kappa_g = 1.08^{+0.32}_{-0.14}$

$\kappa_\gamma = 1.24^{+0.16}_{-0.14}$

direct search ZH(→inv): BR<0.65 @ 95%CL

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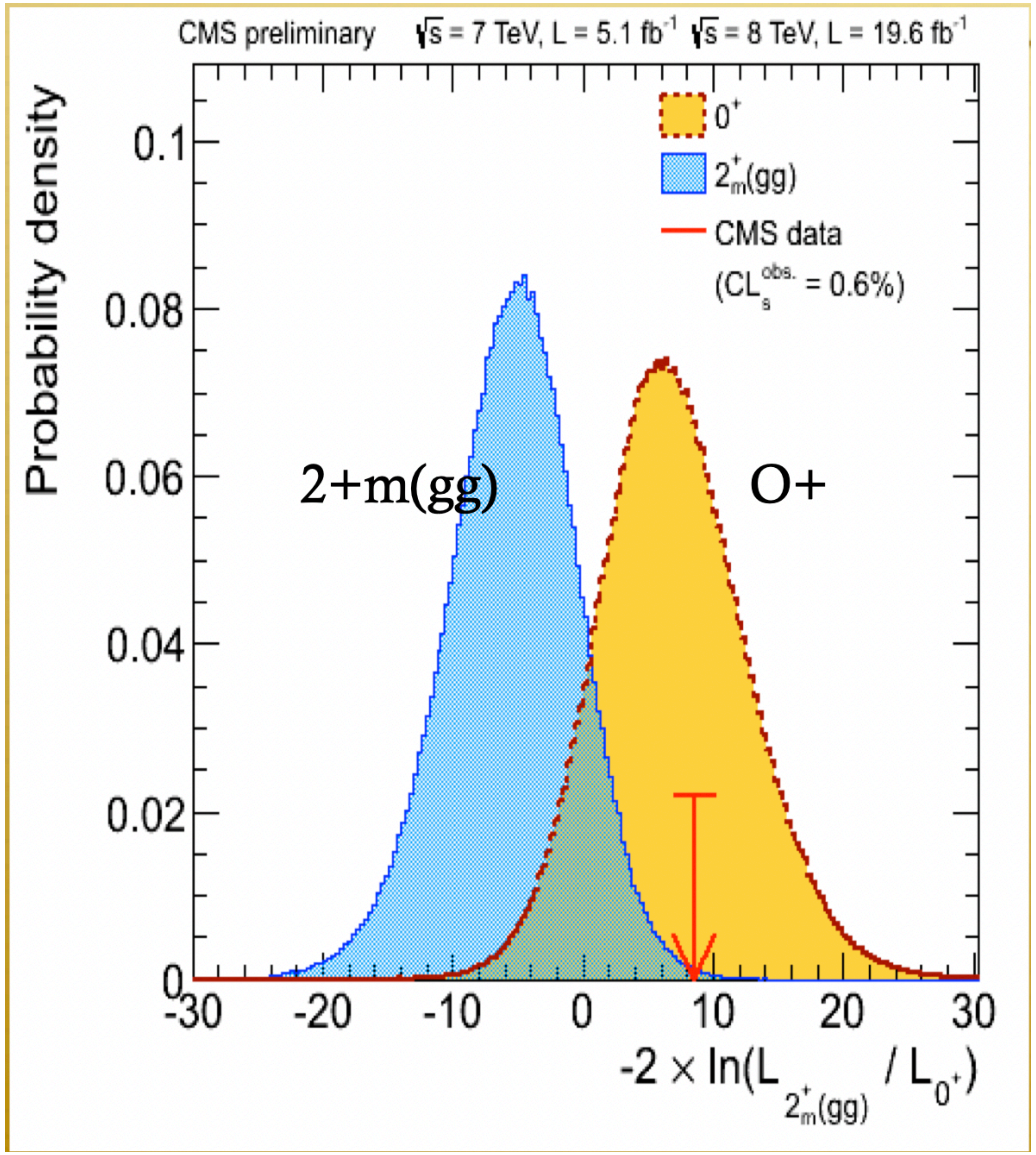

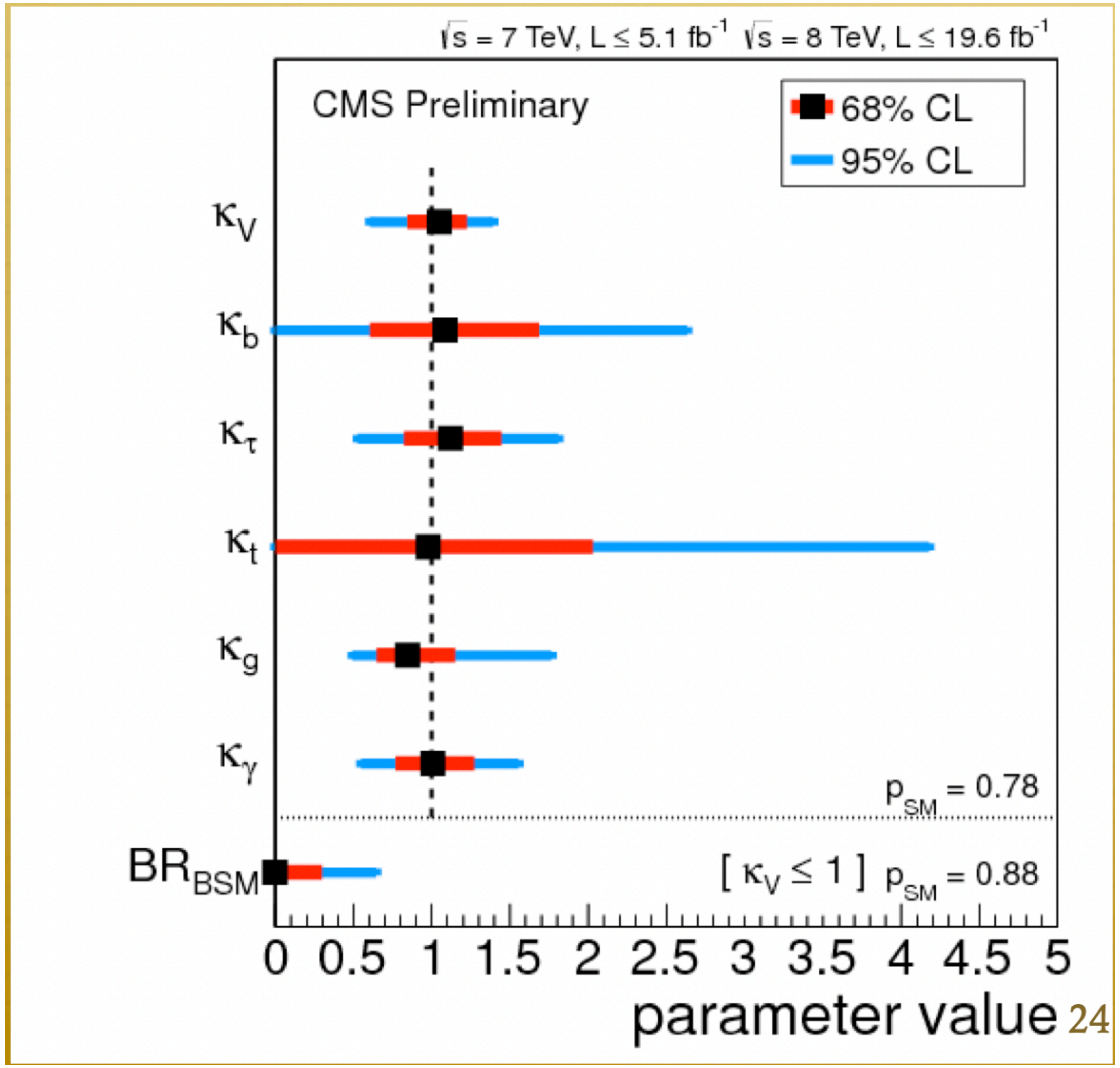

also:

- optimal observables

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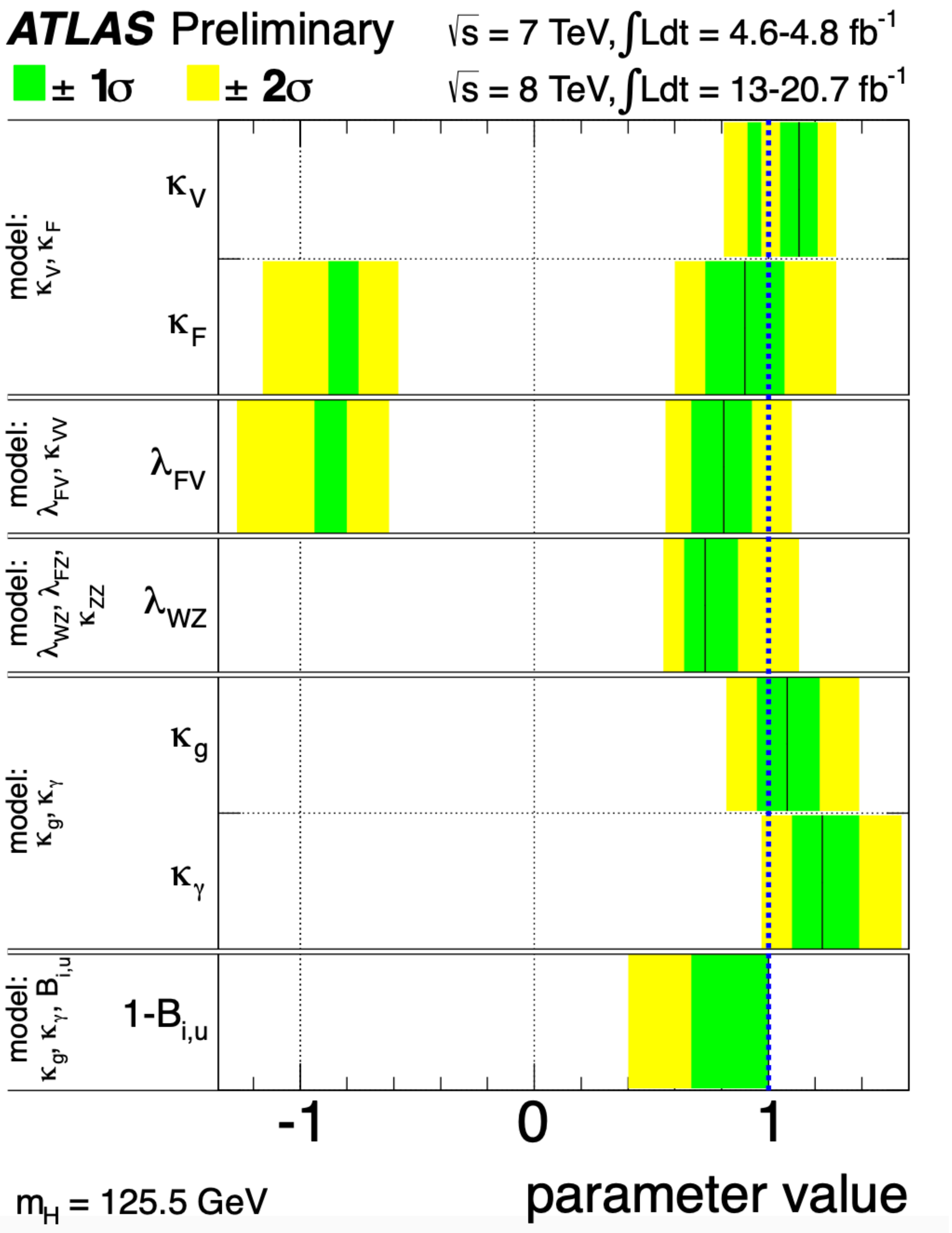
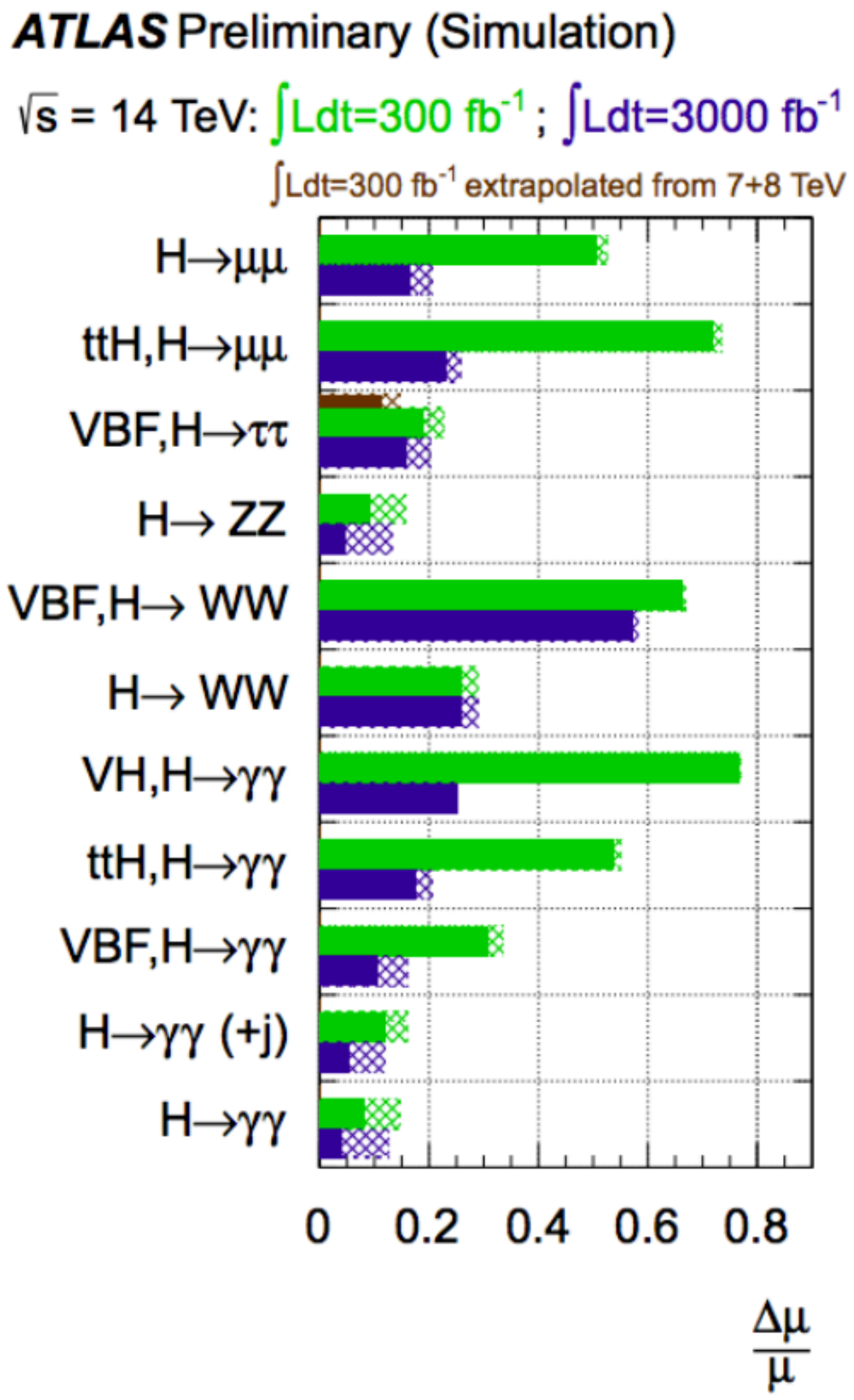
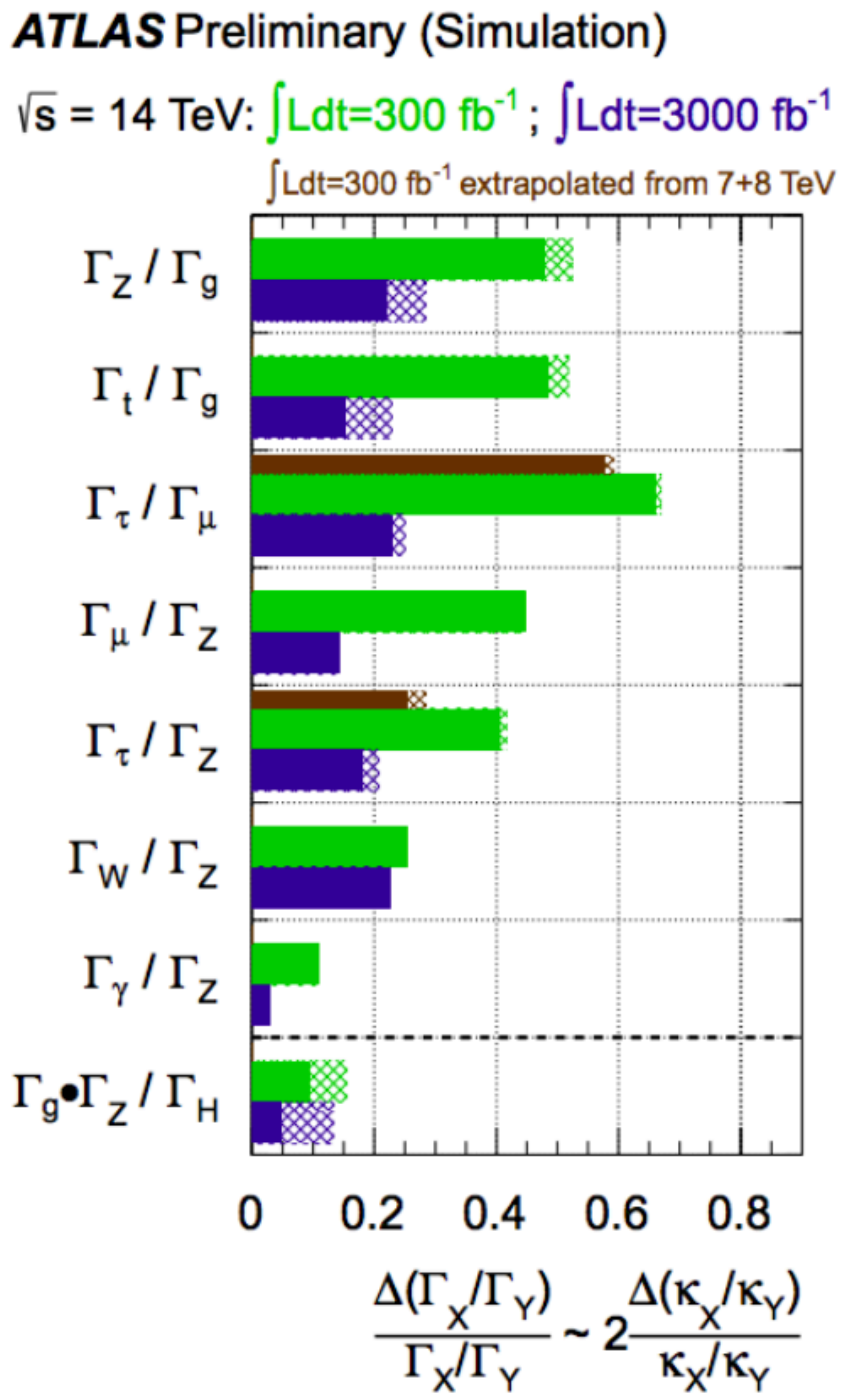
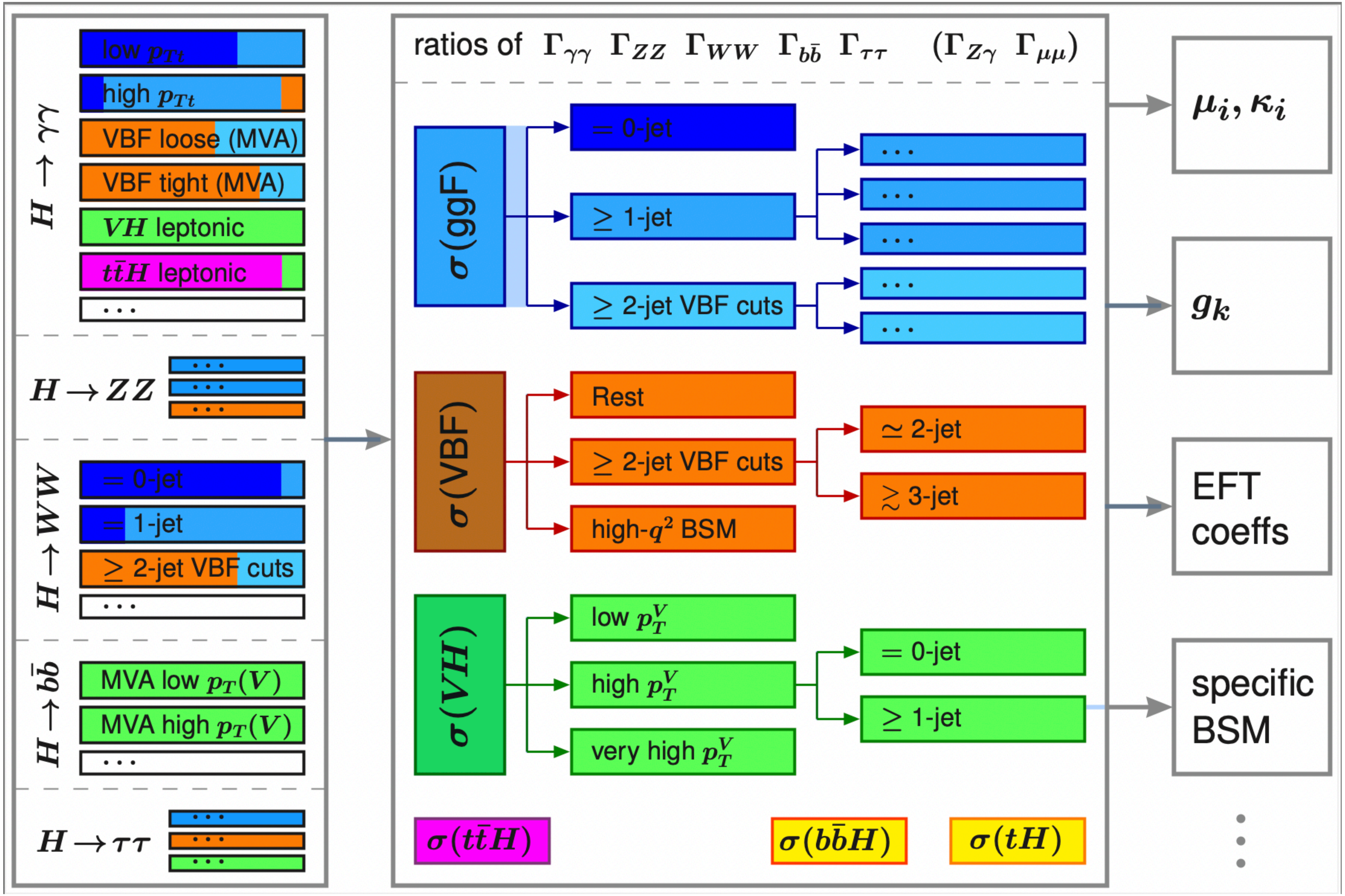






precision in κ_V, κ_F fit

	$300\ \text{fb}^{-1}$	$3000\ \text{fb}^{-1}$
κ_V	3.0% (5.6%)	1.9% (4.5%)
κ_F	8.9% (10%)	3.6% (5.9%)



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LESSONS LEARNED

1. scale reliability of discovery up to property measurements
2. ML needs MC (which needs ML)
3. low statistics doesn't mean you shouldn't do complex analyses
4. effective theories indicate new paths & provide common language

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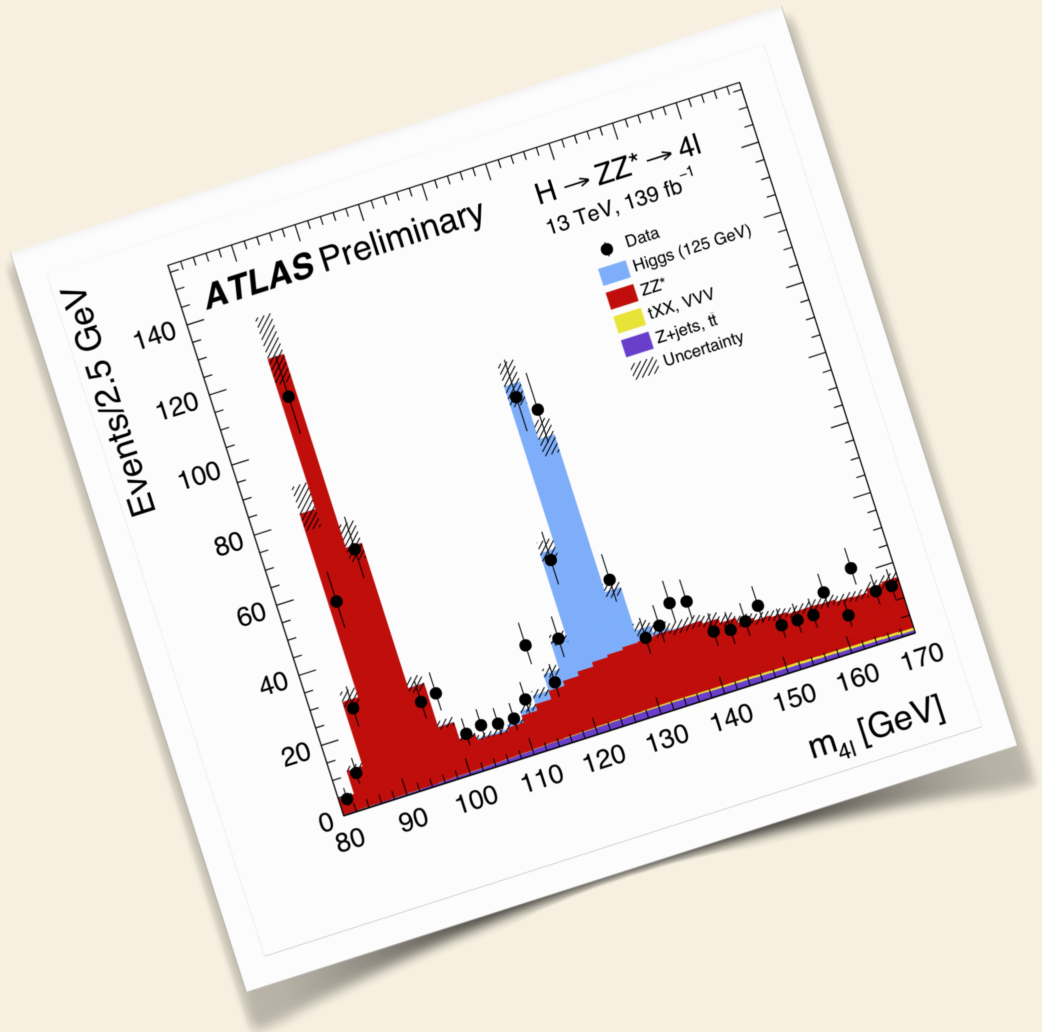
Theory vs. Theory



Effective Field Theory. Supersymmetry. UV-incomplete models. Dark sector. Future colliders. Physics beyond colliders. Underground experiments. Cosmic frontier. Table-top physics. Big bang.

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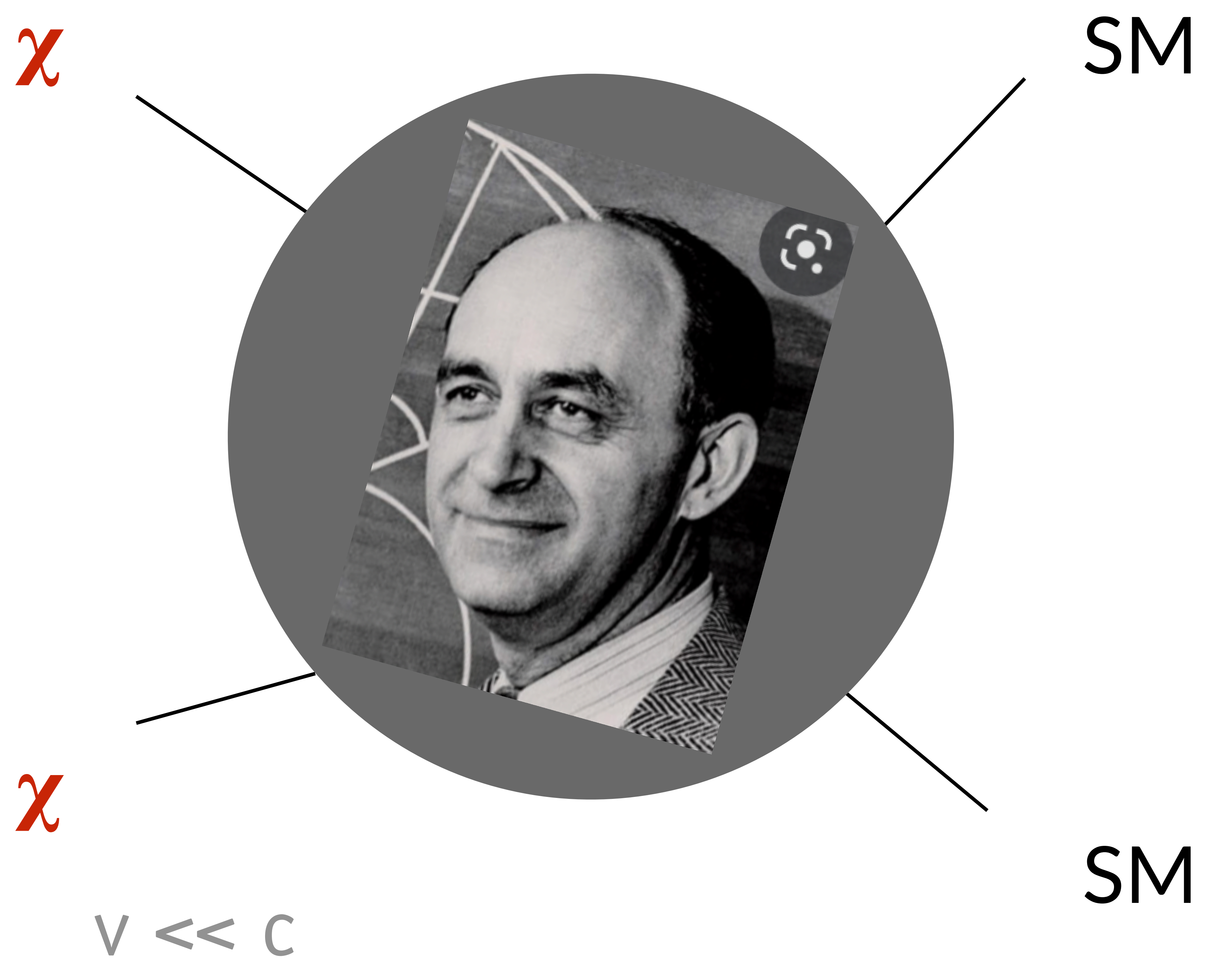

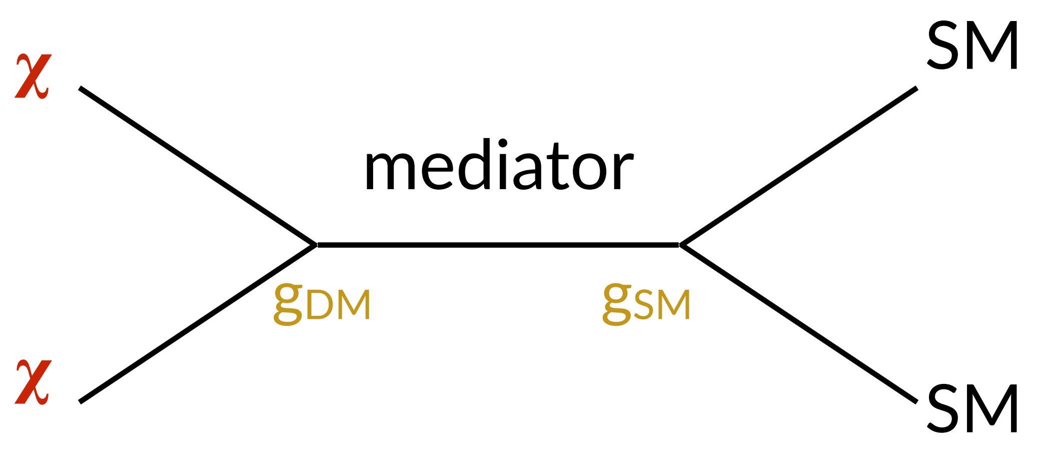

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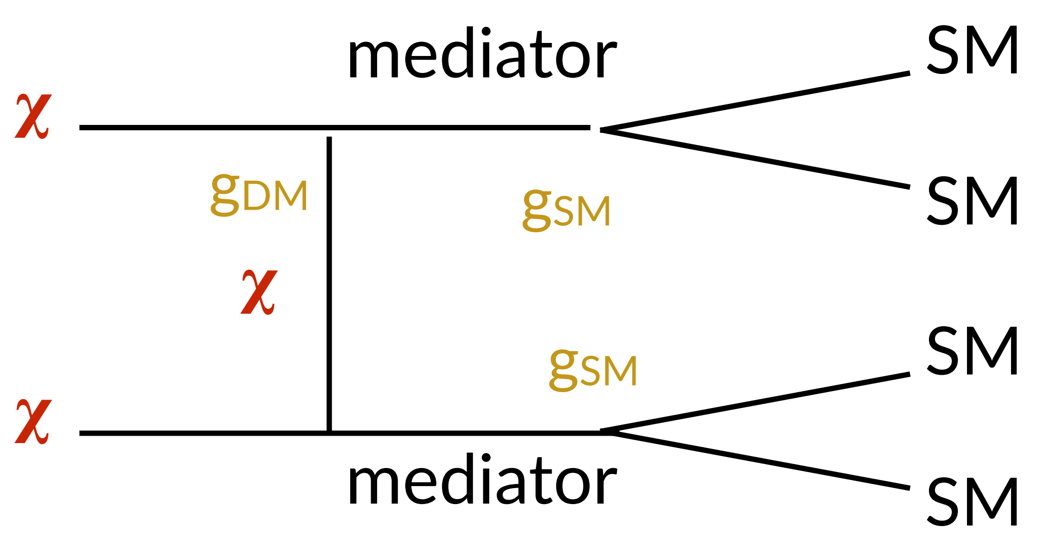

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a small detail can completely change the relic dark matter abundance

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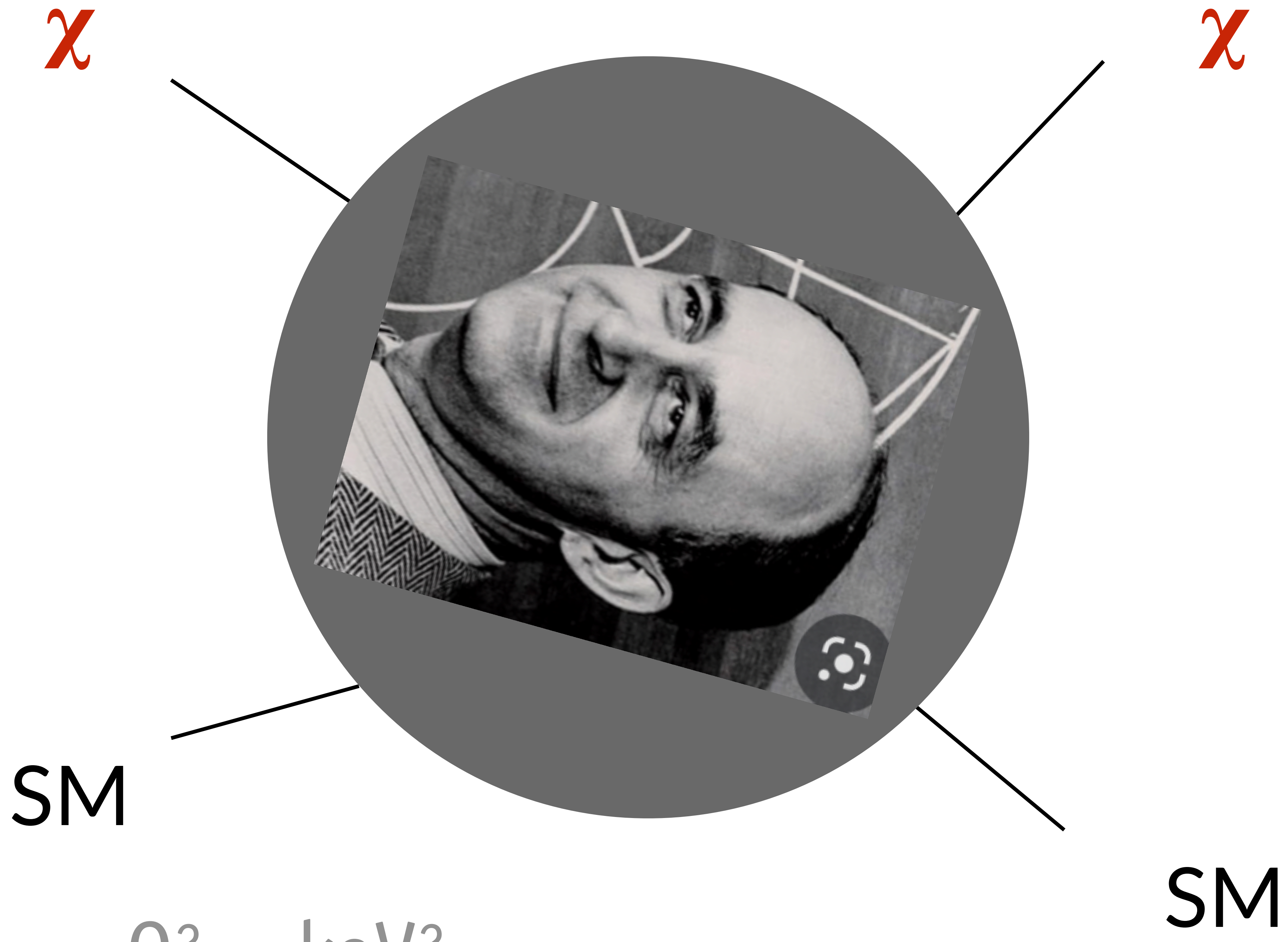
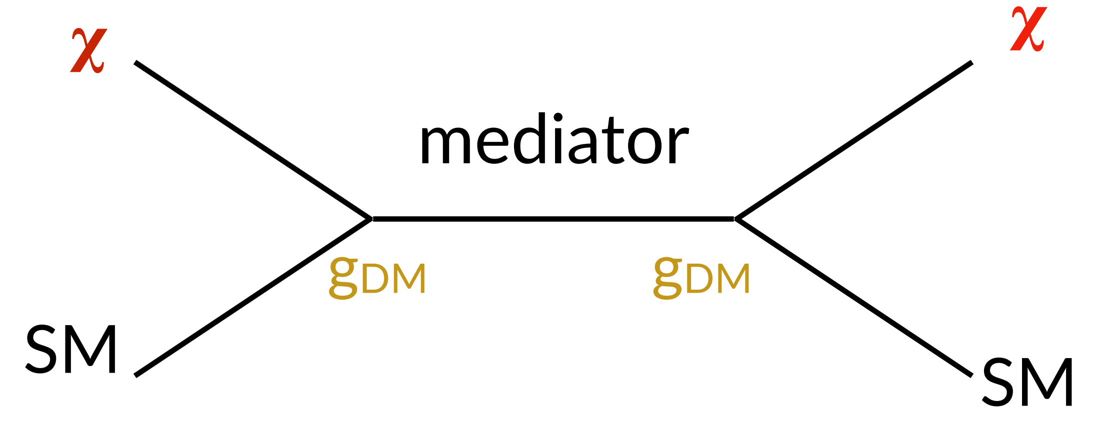


$Q^2 \sim \mathrm{keV}^2$



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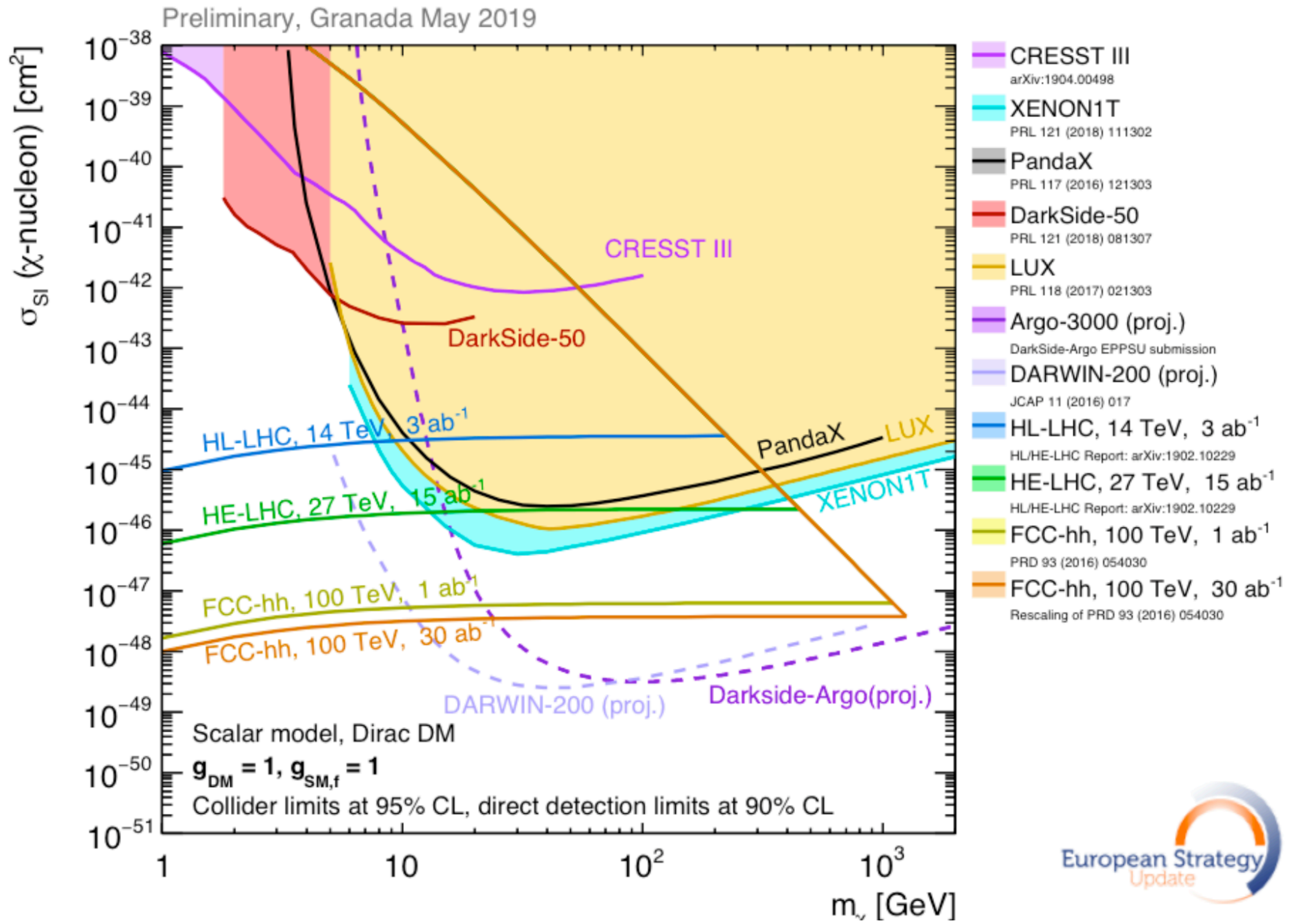

0⁺ $\sigma_{\mathrm{SI}} \approx 1.1 \times 10^{-39}\ \mathrm{cm}^2 \cdot \left(\frac{g_{\mathrm{DM}}\, g_q}{1}\right)^2 \left(\frac{1\ \mathrm{TeV}}{M_{\mathrm{med}}}\right)^4 \left(\frac{\mu_{n\chi}}{1\ \mathrm{GeV}}\right)^2$

0⁻ $\sigma_{\mathrm{SI}} \approx 0$ (suppressed by velocity dependent terms)

1⁺ $\sigma_{\mathrm{SI}} \approx 6.9 \times 10^{-43}\ \mathrm{cm}^2 \cdot \left(\frac{g_{\mathrm{DM}}\, g_q}{1}\right)^2 \left(\frac{125\ \mathrm{GeV}}{M_{\mathrm{med}}}\right)^4 \left(\frac{\mu_{n\chi}}{1\ \mathrm{GeV}}\right)^2$

1⁻ $\sigma^{\mathrm{SD}} \approx 3.8 \times 10^{-41}\ \mathrm{cm}^2 \cdot \left(\frac{g_{\mathrm{DM}}\, g_q}{1}\right)^2 \left(\frac{1\ \mathrm{TeV}}{M_{\mathrm{med}}}\right)^4 \left(\frac{\mu_{n\chi}}{1\ \mathrm{GeV}}\right)^2$

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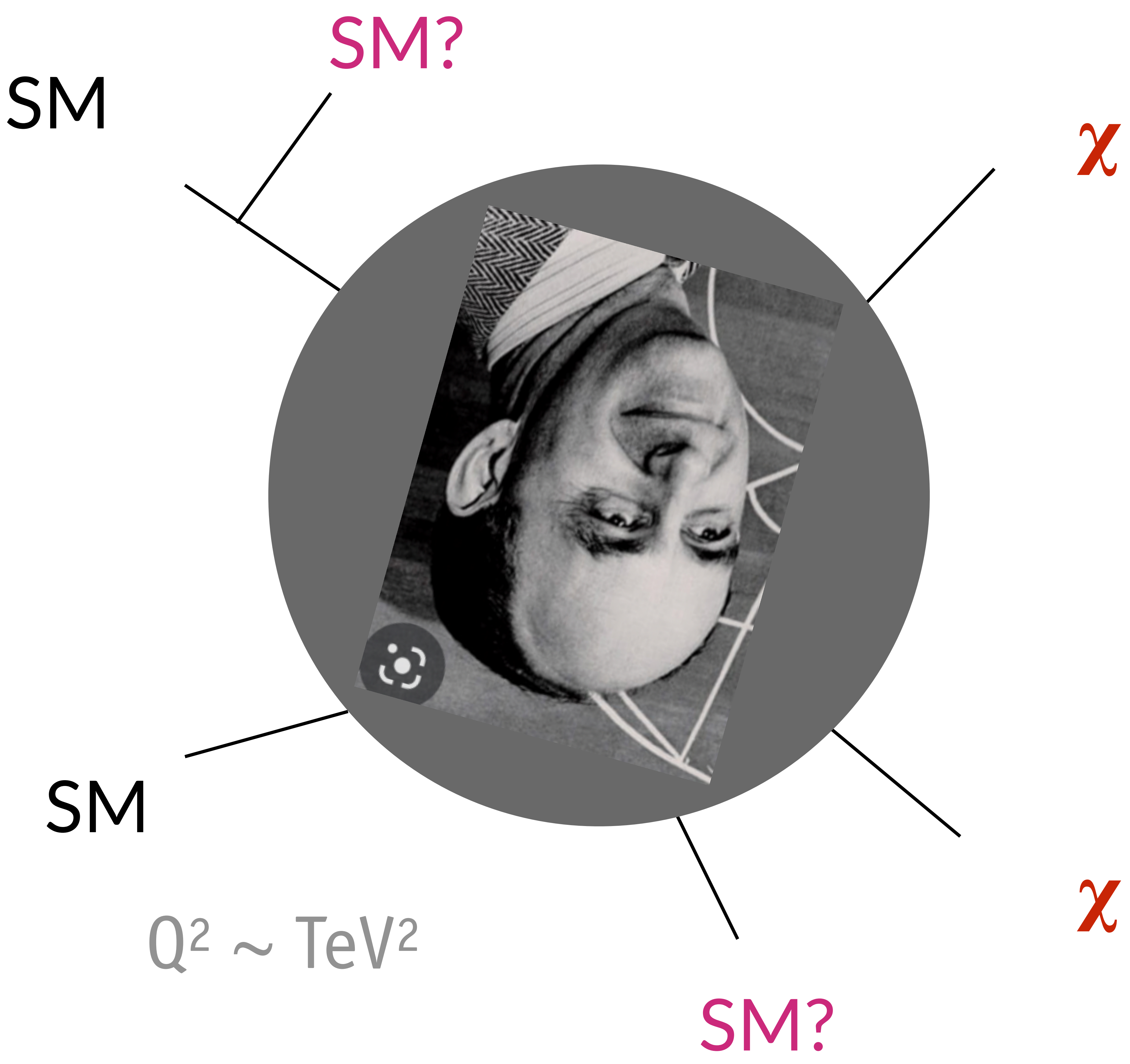
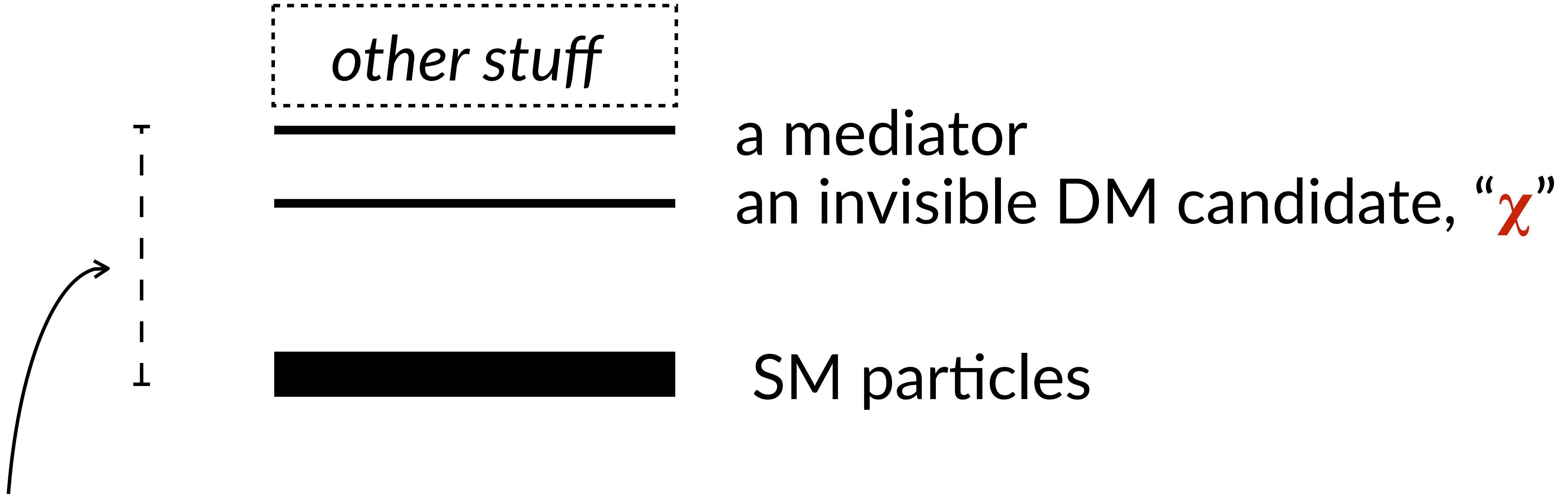
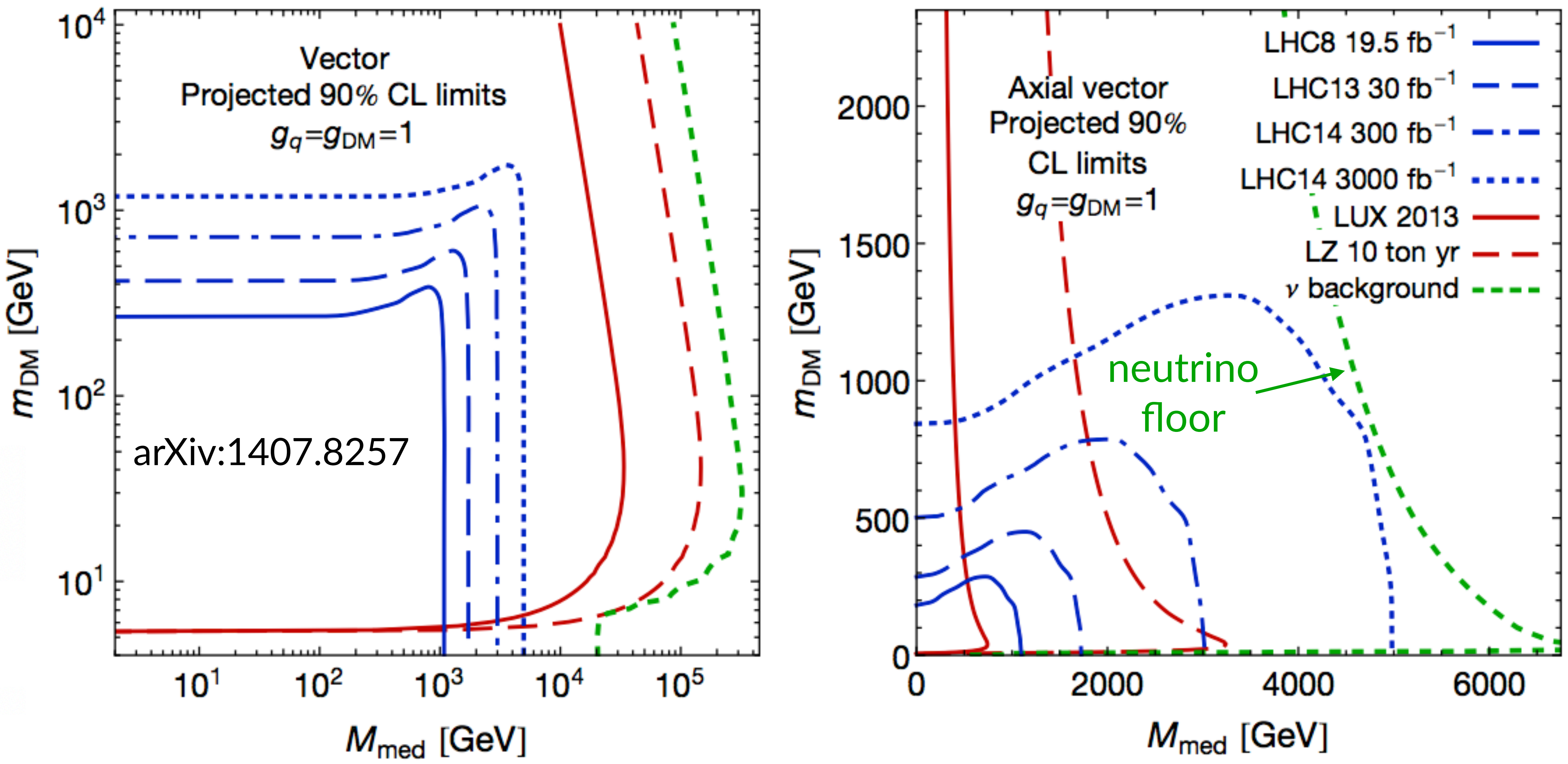




$\Delta m >> q^2$: ***effective field theory*** *(direct detection)*
$\Delta m <\sim q^2$: *use* ***simplified models***

$$\mathcal{L}_{\text{vector}} = -g_{\text{DM}} Z'_\mu \bar{\chi}\gamma^\mu\chi - g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu q$$

$$\mathcal{L}_{\text{axial-vector}} = -g_{\text{DM}} Z'_\mu \bar{\chi}\gamma^\mu\gamma_5\chi - g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu\gamma_5 q$$



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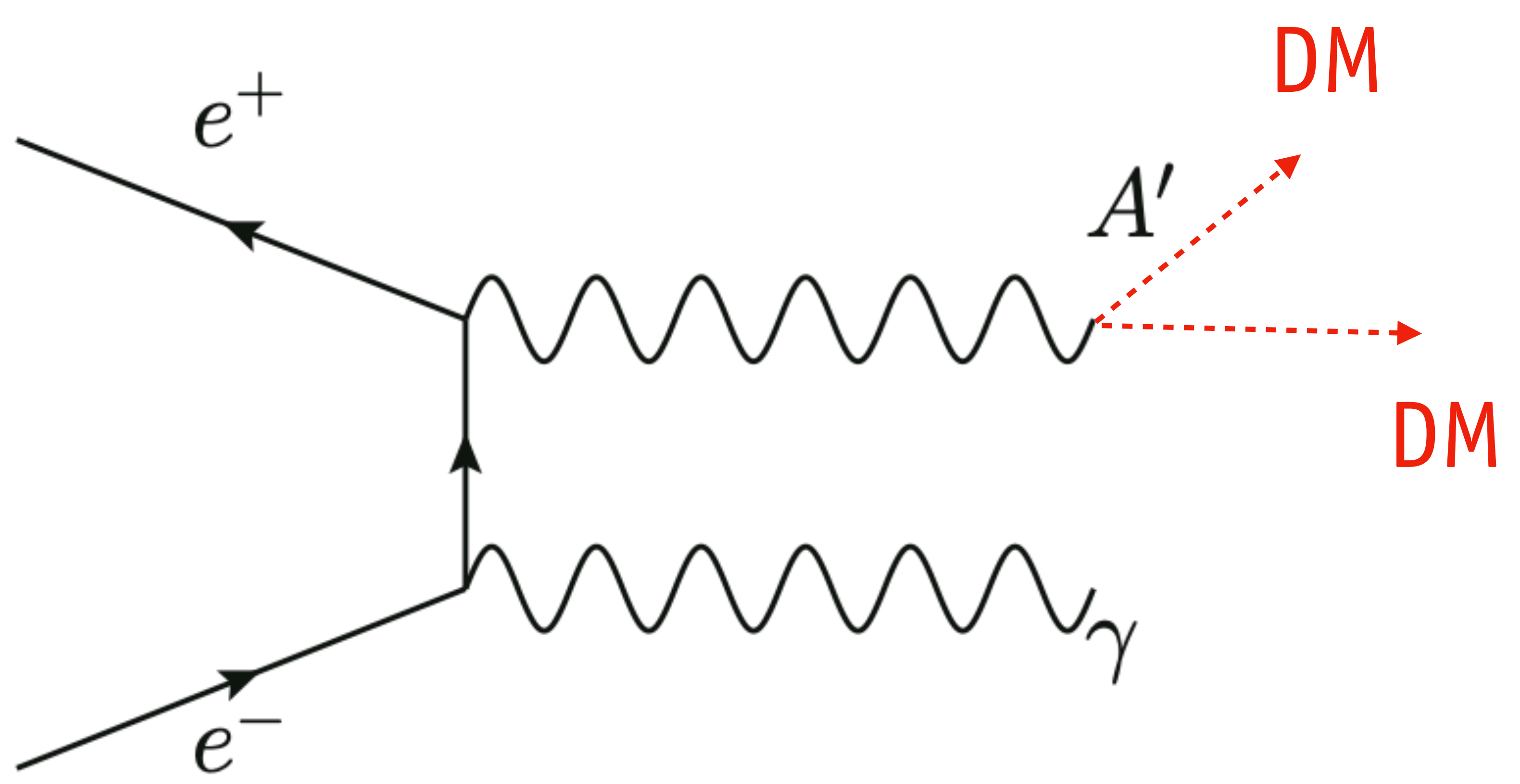
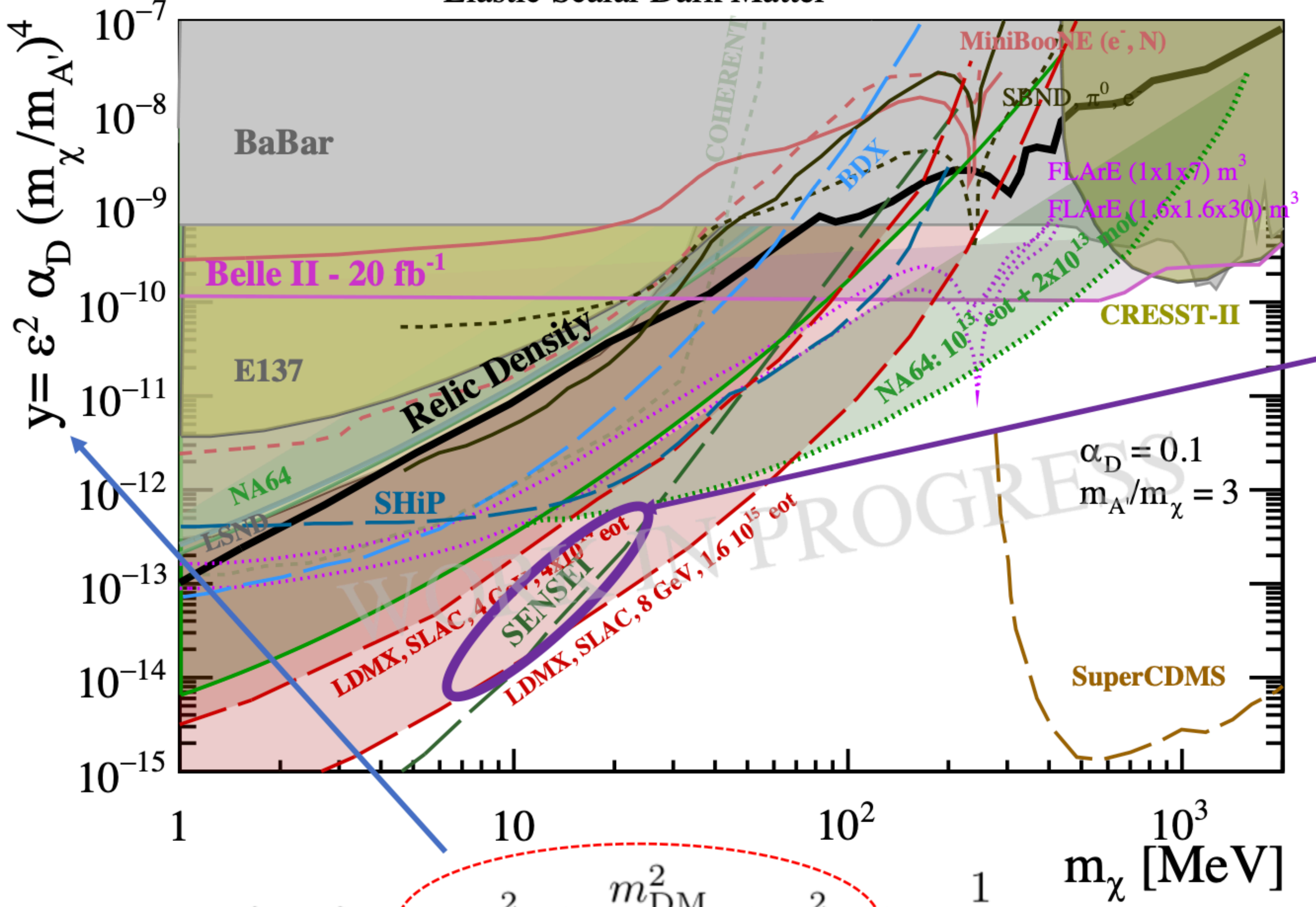


beam on thin-target dark photon searches

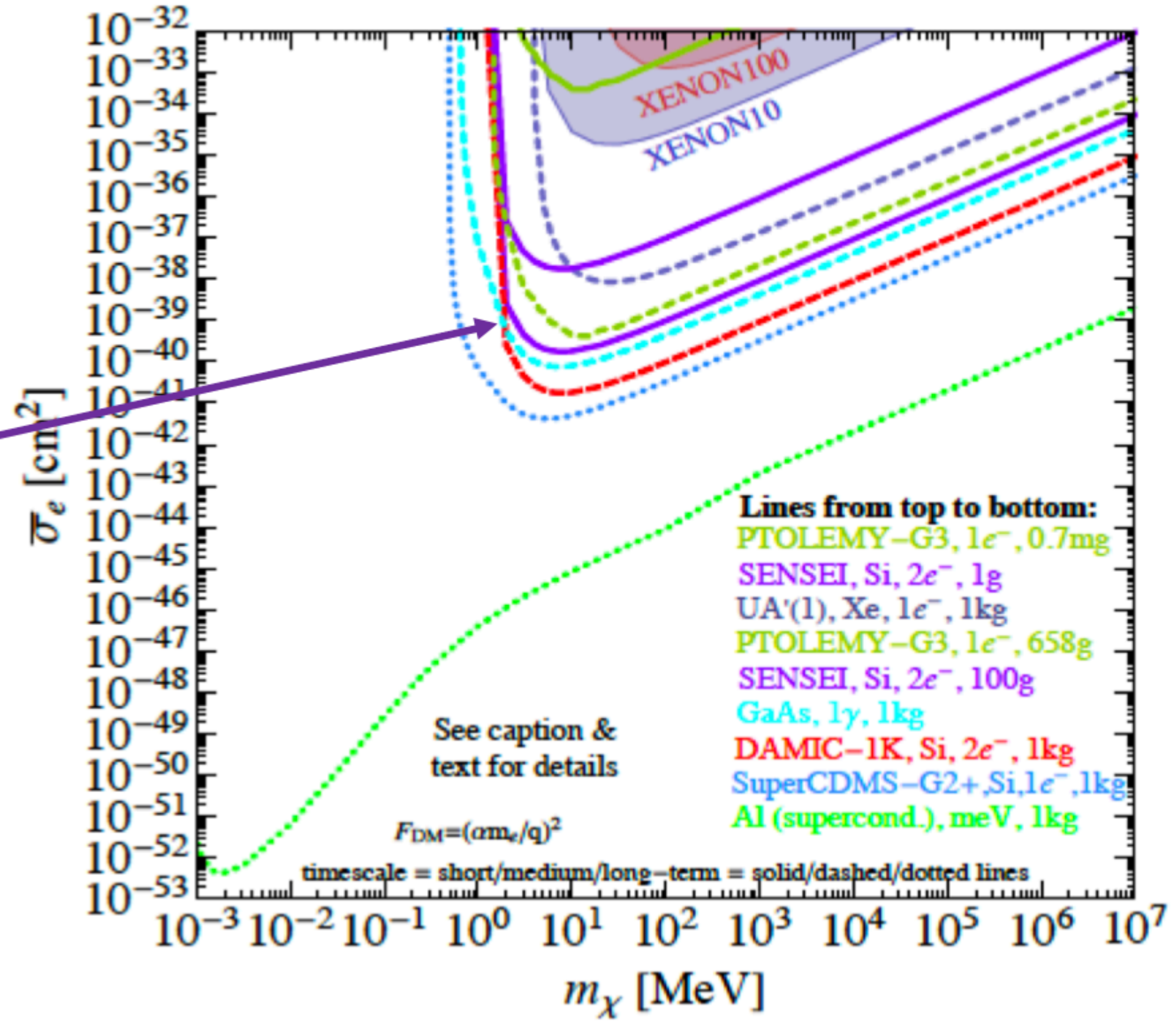
modified-coupling benchmark model vs "LHC" low-Q² extrapolation

Accelerator based:



$$< \sigma v > \sim \alpha_D \varepsilon^2 \alpha \times \frac{m_{DM}^2}{m_{A'}^4} \times m_{DM}^2 \times \frac{1}{m_{DM}^2}$$

Direct detection:



$$\sigma(\chi f \to \chi f) \simeq \frac{16\pi\, \alpha_{em}\, \epsilon^2\, \alpha_D\, \mu_{\chi f}^2}{(q^2 + m_{A'}^2)^2},$$

The definition of a clear theoretical framework allows one to perform a one-to-one comparison between accelerator-based and direct detection DM experiments

G. Lanfranchi @ PBC 2021

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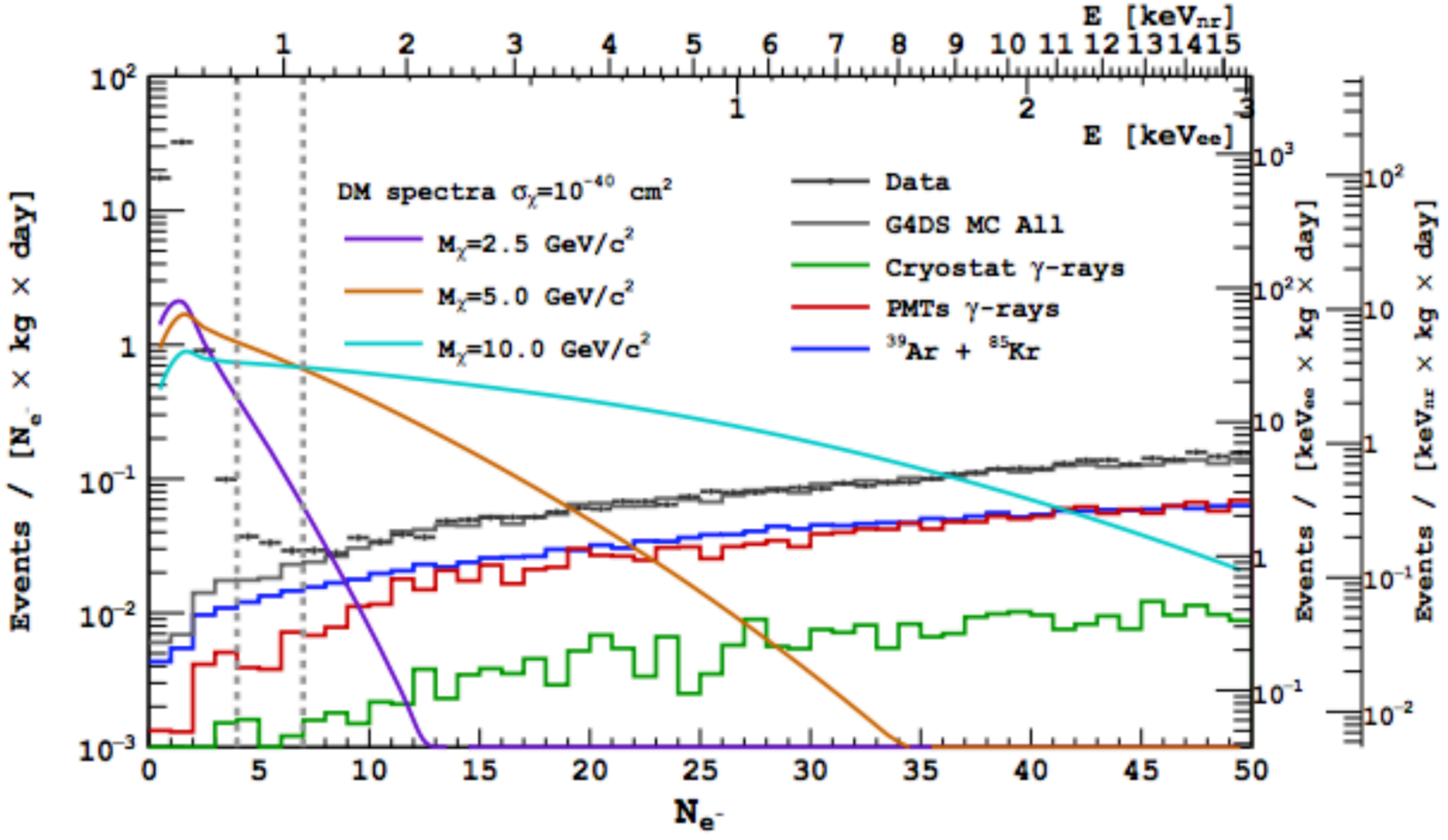
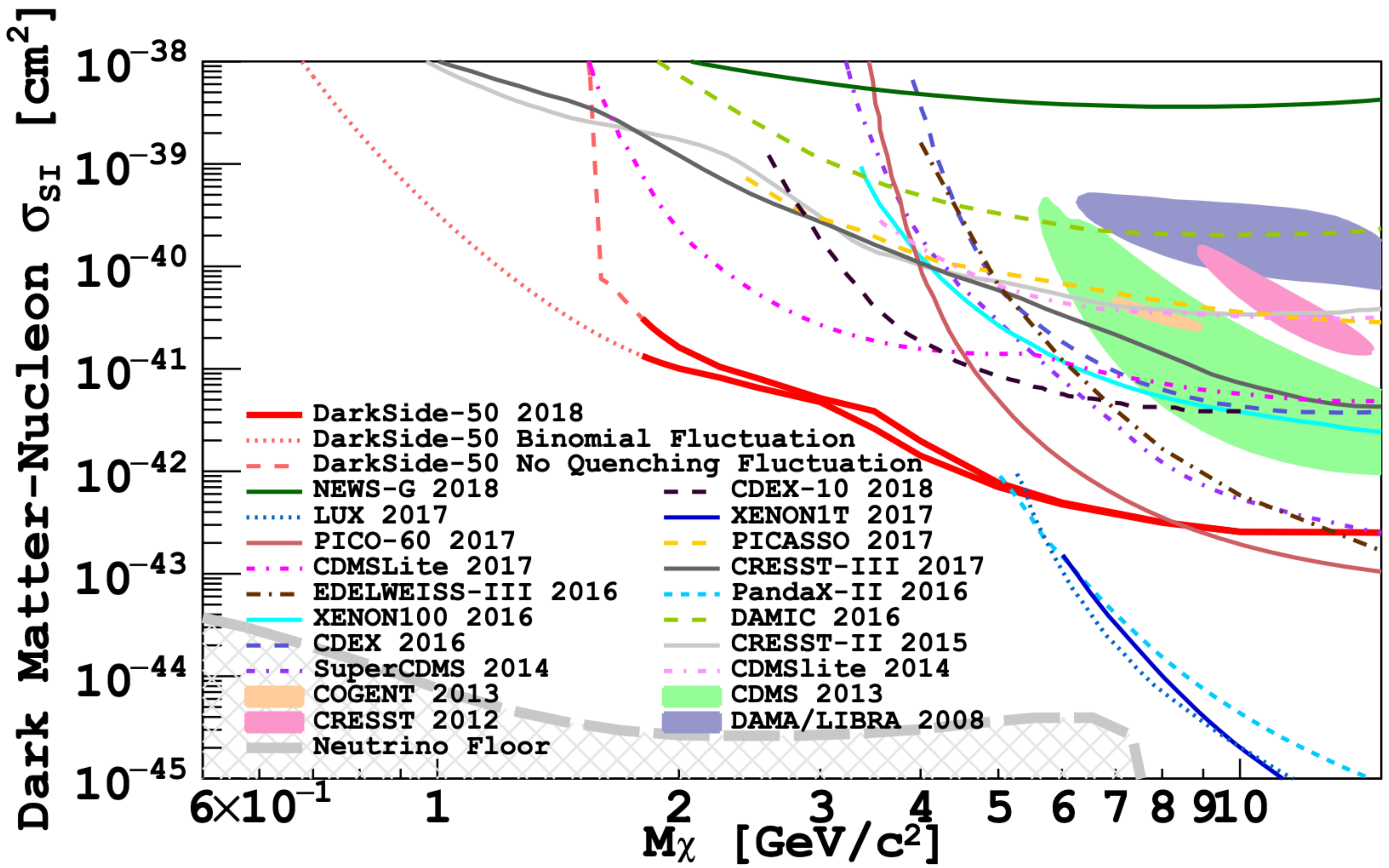


low-Q² extrapolation of benchmark lagrangians



binned ML techniques for DM discovery

(previously, a world of zero-background counting experiments)

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LESSONS LEARNED

1. scale reliability of discovery up to property measurements
2. ML needs MC (which needs ML)
3. low statistics doesn't mean you shouldn't do complex analyses
4. effective theories indicate new paths & provide common language
5. foster continuous cross-contamination of ideas

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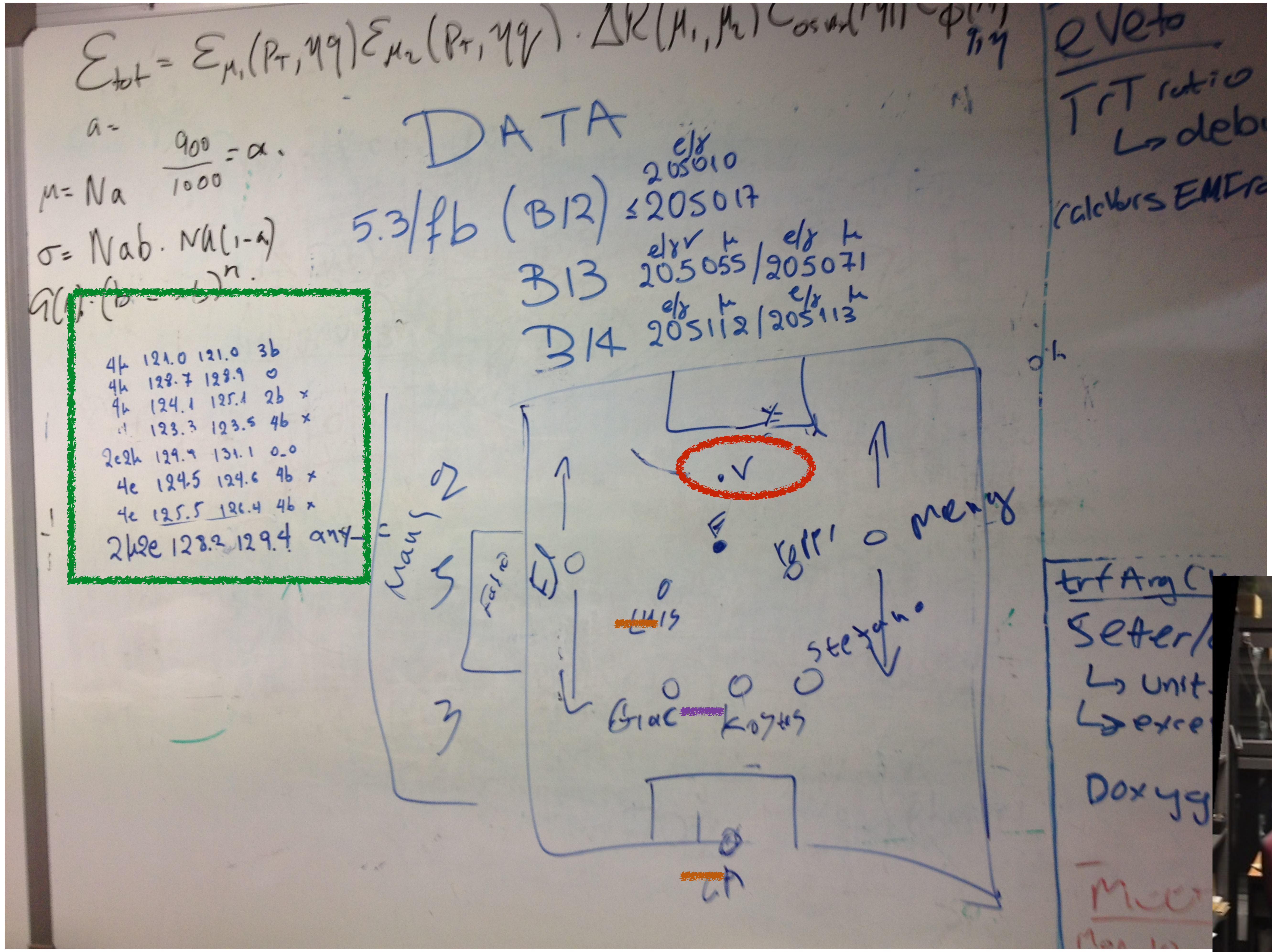
6. have fun!



discovery whiteboard

paper editor

paper editor

convener

Higgs boson

CERN 40/4-C08 - Sunday June 24th, 2012 - ~2 AM


That's all Folks!