“Higgs Impostors at the LHC”

Co-Authors

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If the Vacuum is a substance

Shake it

Its vibrations are QUANTA

The Higgs

τὸ κενὸνον

LHC = MSV

Run the machine

Find something looking like a H


What the
Higgs
is this?

Find a “Higgs” Candidate Particle

$\sigma[\text{Prod}] \times \text{BR(s)} \sim \text{STANDARD}$

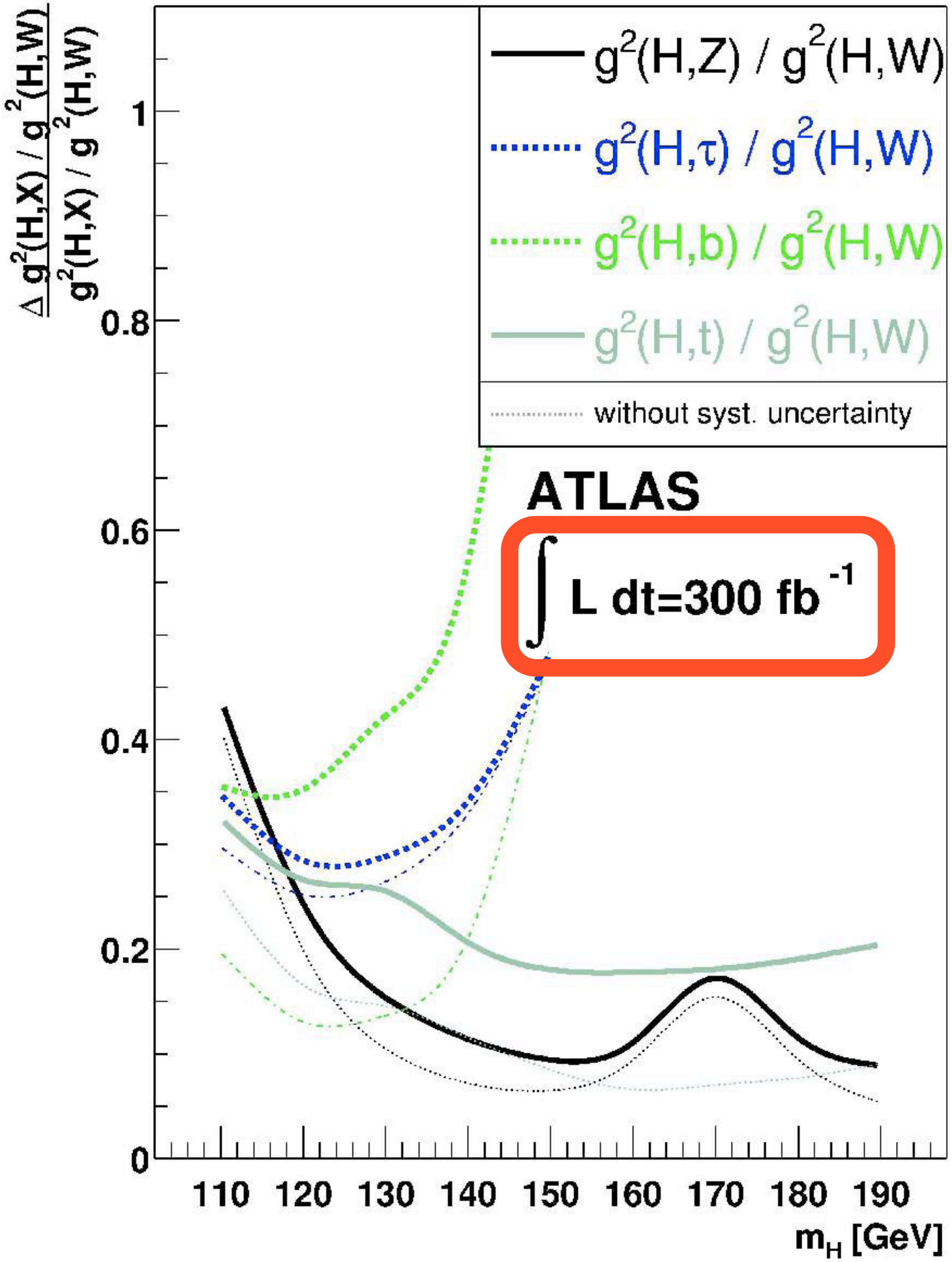
Very L-dt demanding

Is it *the Higgs* or an Impostor ?

What is it’s ***J, P, C*** ???

What is not it’s ***J, P, C*** ???

Is it Pure J^{PC} ? Mixed ? Compo - site ?



Duhrssen, ATL-PHYS-2003-030

$$\sqrt{s} = 14\ \mathrm{TeV}$$

Motivation ?

➖ The currently-available data-analysis “protocols”, are not demonstrably the best one could use

➕ Surely experimentalists are planning to do much better

¡¡It pays TO DO IT RIGHT ... NOW!!

➕ **Some room for improvement :-)**

To be realistic:

A

Competition

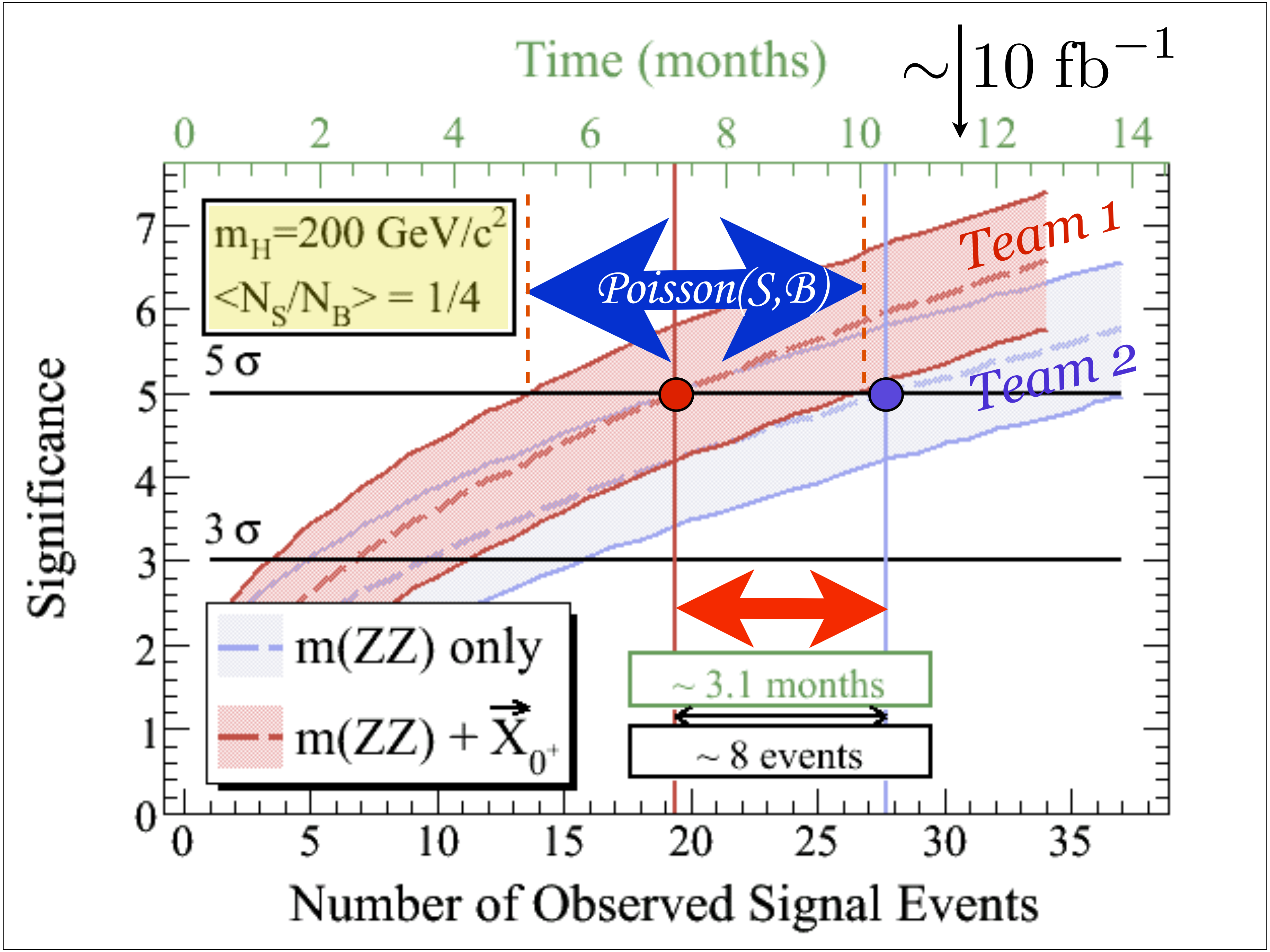
The contest:

- ***Team 1* is doing things *"thoroughly"* *from Starters***
- ***Team 2* is applying *"shortcut"* analysis methods**

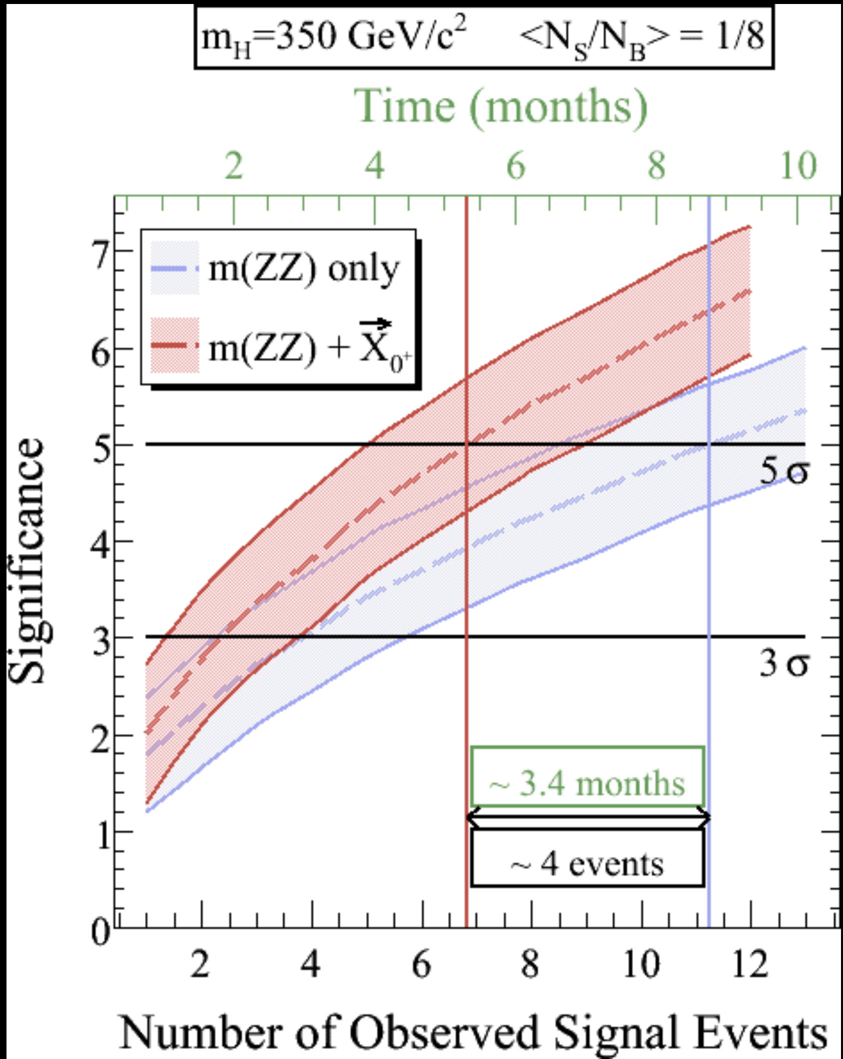
Teams may or may not belong to the same experiment

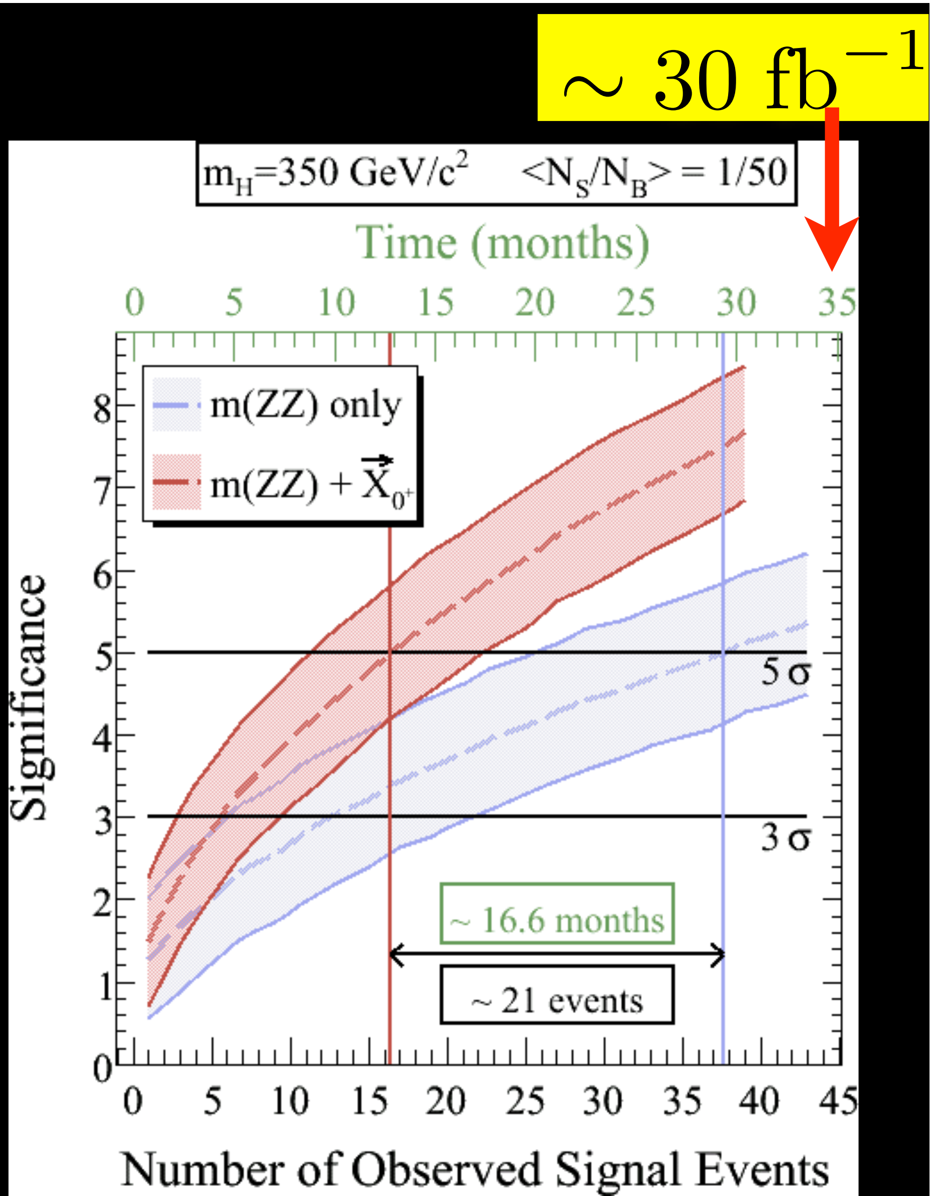
0^+ Discovery-time Plots

- $\sqrt{s} = 10\,\mathrm{TeV}$ ¿ @!!¡¡&** ?
- $\mathrm{L} = 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- *Snowmass factor of 3 (LHC start)*
- *Background: Currently estimated*



Time (months)
~10 fb^{-1}
0 2 4 6 8 10 12 14
m_H=200 GeV/c^2
$\langle N_S/N_B \rangle$ = 1/4
Poisson(S,B)
Team 1
Team 2
5 σ
3 σ
Significance
0 1 2 3 4 5 6 7
m(ZZ) only
m(ZZ) + $\vec{X}_{0^+}$
~ 3.1 months
~ 8 events
0 5 10 15 20 25 30 35
Number of Observed Signal Events



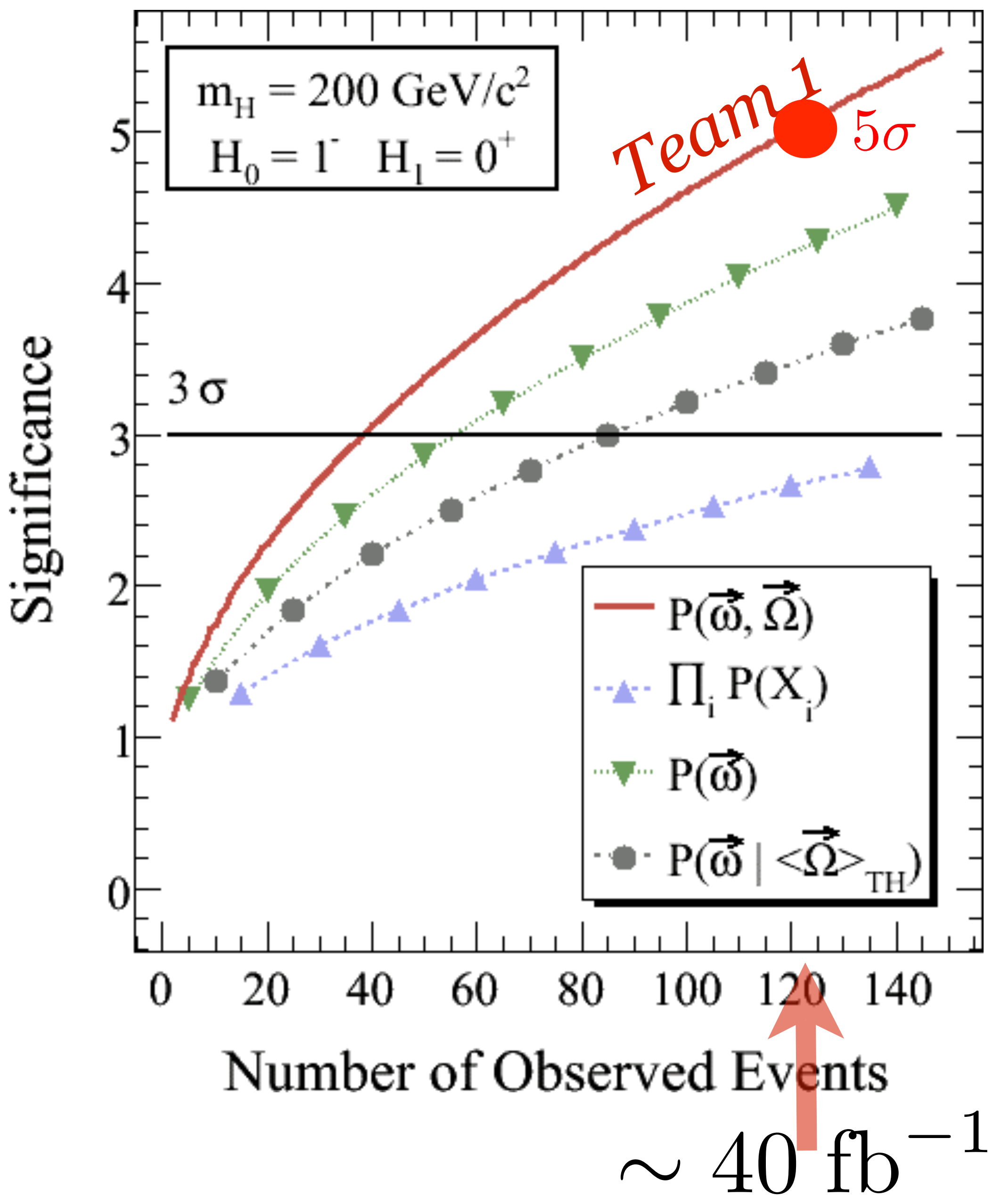


Nominal BackGround

~ 6 times more BG

While gathering significance faster, Team *1* is checking agreement with $J^P = 0^+$

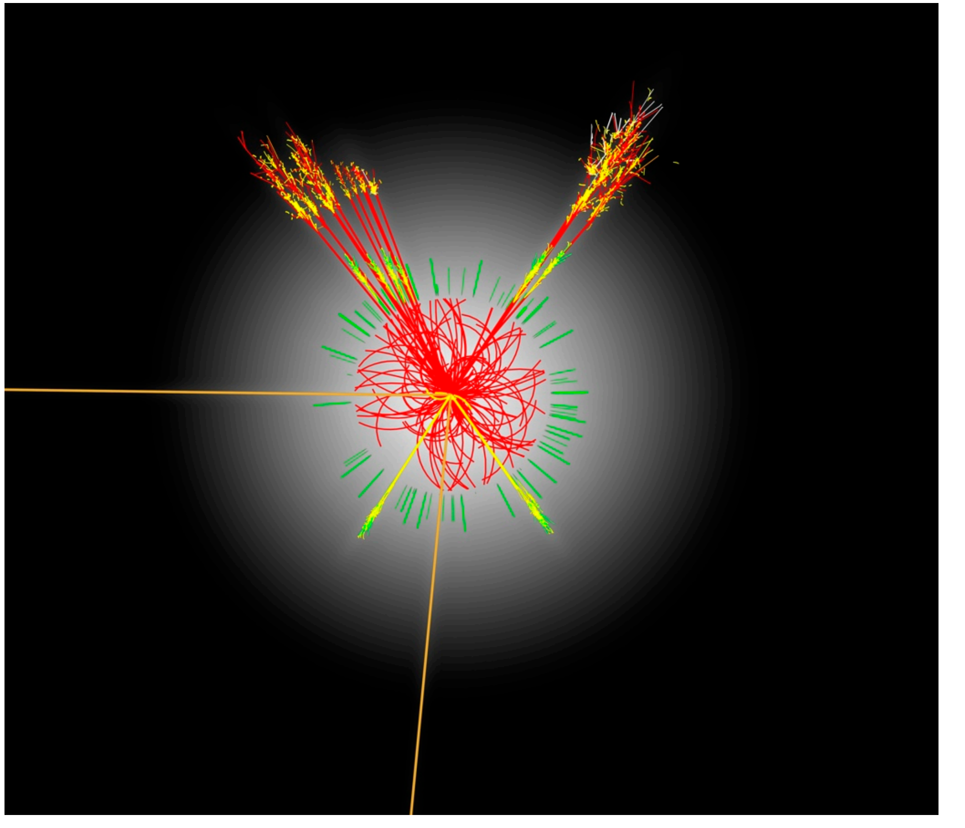
With a few extra lines of code, Team *1* is checking whether the "object" is an impostor, e.g.:



Back to all this in detail

We ARE "translating" to #-standard deviations, but NOT assuming that anything is Gaussian

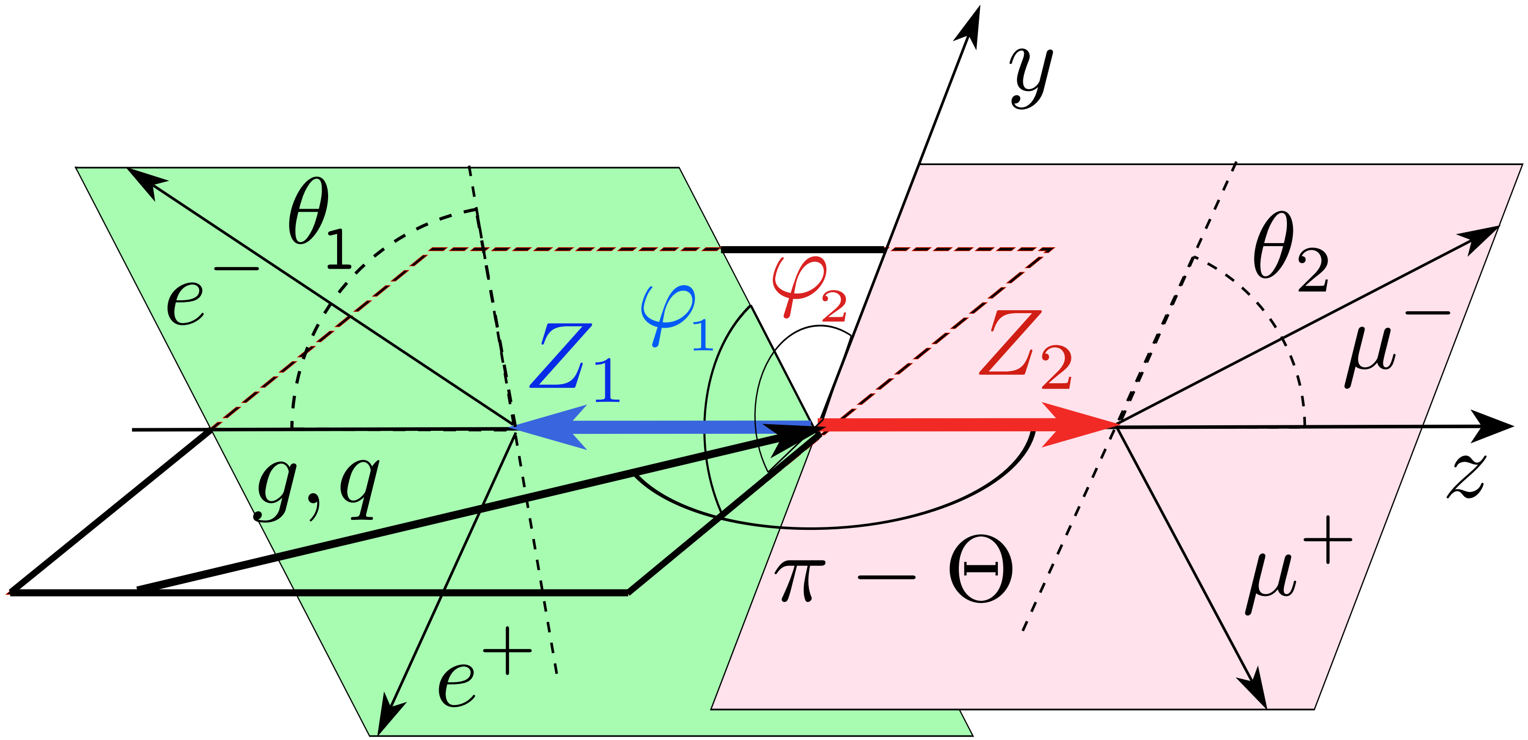
Whaaat am I talking about ?



$$H \text{ or } HI \to ZZ \text{ or } ZZ^*$$

$$Z, Z^{(*)} \to \mu^+ \mu^- \qquad (e^+ e^- \text{ exercise})$$

H (HI) Rest System (undo η and p_T boosts)



M^* in $H(HI) \to ZZ^*$

$\vec{\omega} \equiv \{\cos\theta_1, \cos\theta_2, \varphi \equiv \varphi_2 - \varphi_1\}$ Z-pair decays

$\vec{\Omega} \equiv \{\cos\Theta, \Phi \equiv \varphi_2\}$ Z-pair production

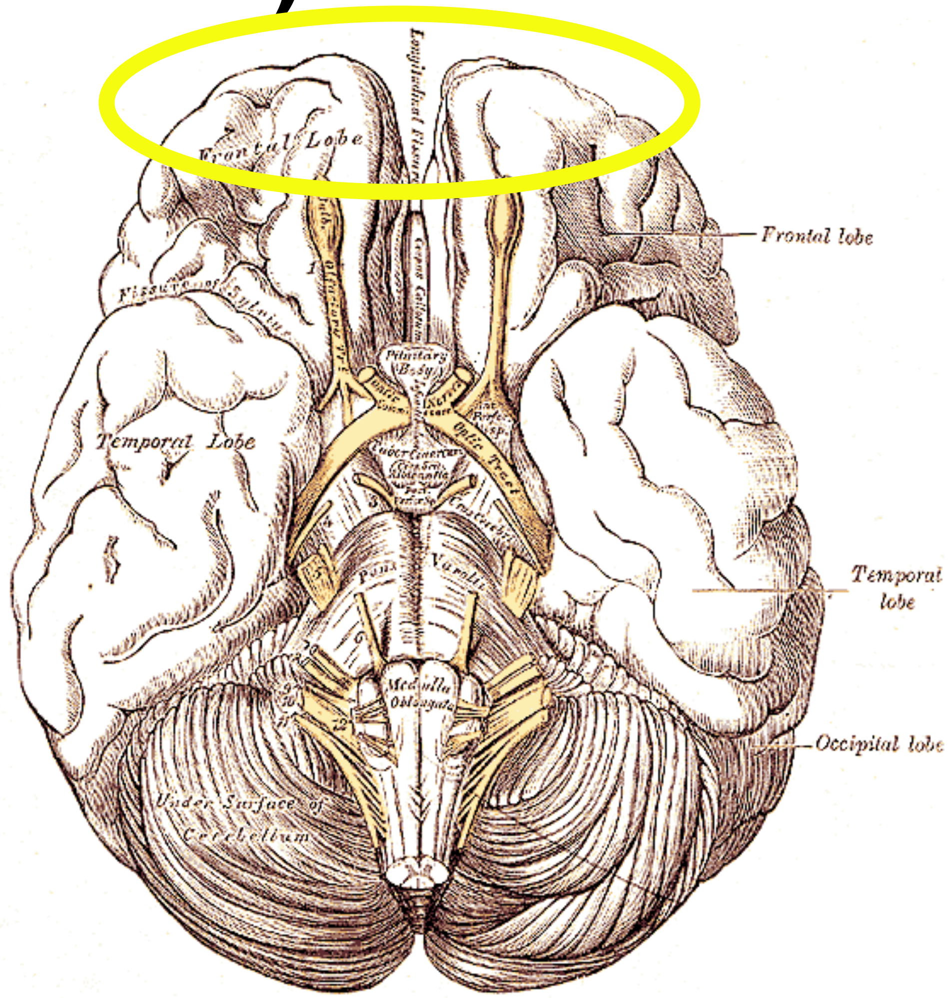
6 "handles" !!!

6 dimensions !!??

Neural Networks (NNWs)

NNWs that know:

- What they are doing
  - How
    - Why



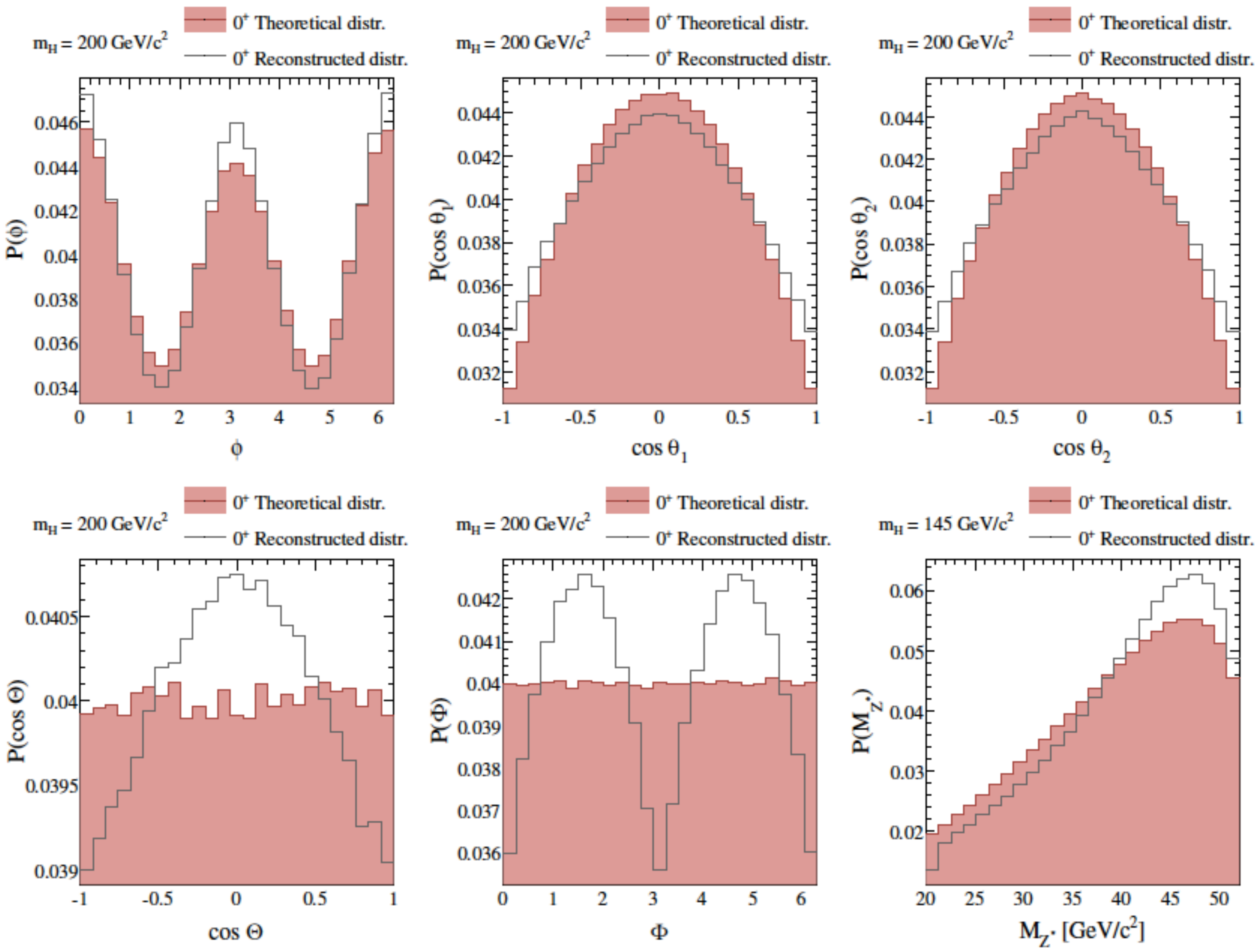


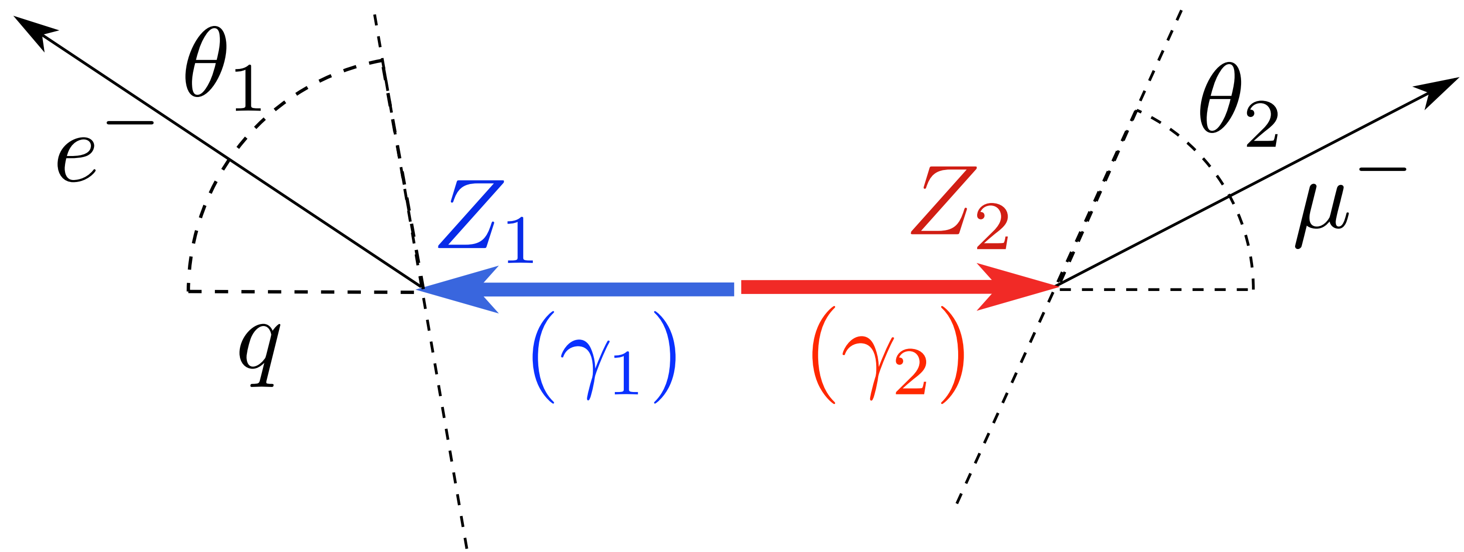
FIG. 24: Kinematic distributions for the variables $\vec{X}$ used in this analysis for a SM Higgs with mass 200 GeV$/c^2$. The filled histograms who the one dimensional projected distributions of each of these variables as described by the analytic matrix element squared PDF's. The unfilled histograms (black lines) show the same one dimensional projections for reconstructed events (muon kinematics are smeared) for events that have passed the signal event selection (introducing acceptance effects). All distributions are normalized to have an integral of 1.

- To OPTIMIZE ⟶ J, P, C properties of the object and its couplings with an absolute MINIMUM of extra assumptions

“Pessimise”:

- WHATEVER the object happens to be:
- Not to use relative BRs (more than one H !)
- Assume η and p_T distributions ~ Standard (actually, roughly expected)

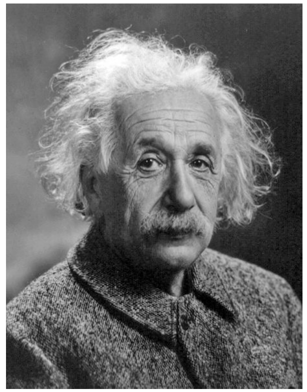
Why is this so deeeeeply interesting?



$$P(\cos\theta_1, \cos\theta_2)$$

$$\hat{P}(\cos\theta_1) \neq P(\cos\theta_1, \cos\bar{\theta}_2)$$

Spooky Action at a distance

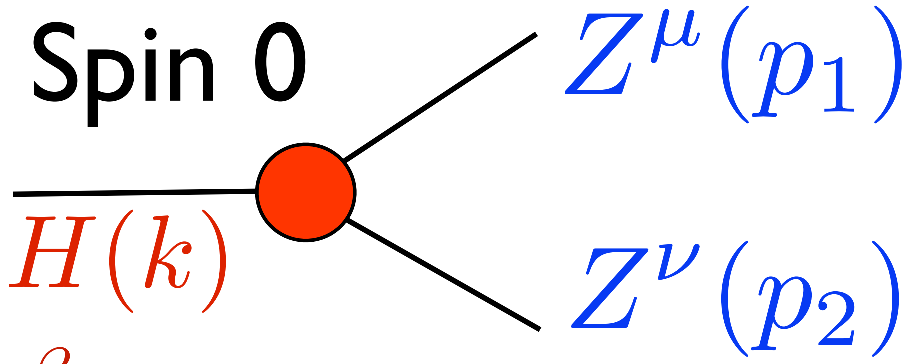


What used to be
paradoxes (*EPR*)

first became the
paradigms of QM

and are now procedures
for FASTER- { SEARCH
and CHARACTERIZATION }

● $\mathcal{L}-inv$ =



$X\, g_{\mu\nu}$ **Standard**

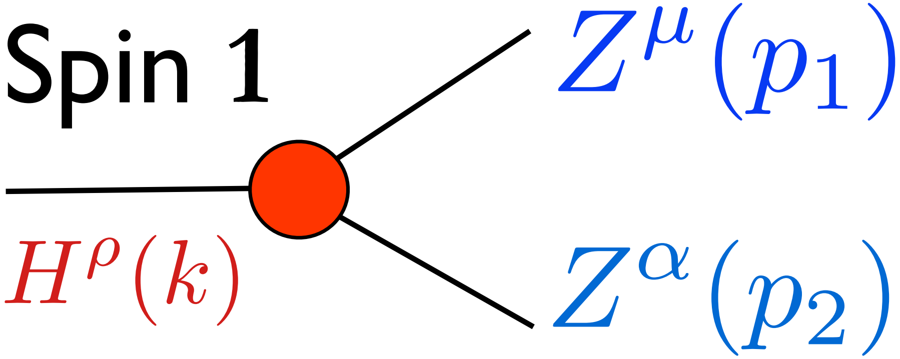
$+(P+i\,Q)\epsilon_{\mu\nu\alpha\beta}\frac{p_1^{\alpha}p_2^{\beta}}{M_Z^2}$ **Pseudoscalar**

$-(Y+i\,Z)\frac{k_{\mu}k_{\nu}}{M_Z^2}$ **Derivative (Composite)**

$$L = \frac{1}{\Lambda} H\,(A_1\,\vec{W}_{\mu\alpha}\cdot\vec{W}^{\mu\alpha} + A_2\,B_{\mu\alpha}B^{\mu\alpha})$$

$$+\frac{1}{\Lambda} H\,i\,\epsilon^{\mu\alpha\sigma\tau}(A_3\vec{W}_{\mu\alpha}\vec{W}_{\sigma\tau} + A_4\,B_{\mu\alpha}B_{\sigma\tau})$$

$\mathcal{L}-inv$ =

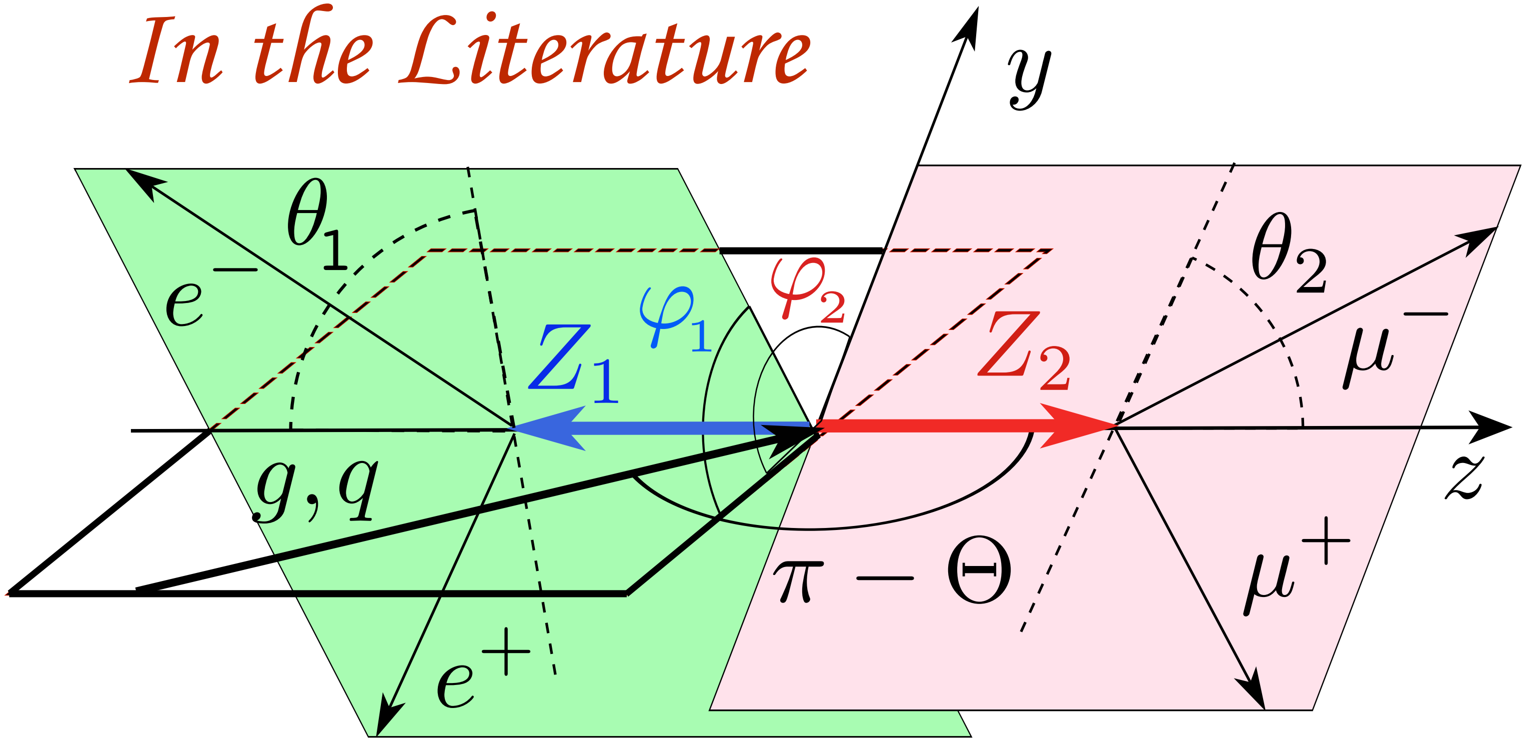


$X\,(g^{\rho\mu}\,p_1^{\alpha} + g^{\rho\alpha}\,p_2^{\mu})$ **Vector**

$+(P + i\,Q)\,\epsilon^{\rho\mu\alpha}(p_1 - p_2)$ ***Axial***

$$L = \frac{1}{\Lambda^2}(\partial^{\mu} H^{\alpha} + \partial^{\alpha} H^{\mu})(A_1\,\vec{W}_{\mu}^{\lambda}\cdot\vec{W}_{\alpha\lambda} + A_2\,B_{\mu}^{\lambda}B_{\alpha\lambda})$$
$$+\frac{1}{\Lambda^2}\epsilon^{\mu\nu\alpha\rho}[A_3(\vec{W}_{\mu}^{\lambda}\overleftrightarrow{D}_{\alpha}\vec{W}_{\nu\lambda})H_{\rho} + A_4(B_{\mu}^{\lambda}\overleftrightarrow{\partial}_{\alpha}B_{\nu\lambda})H_{\rho}]$$

In the Literature



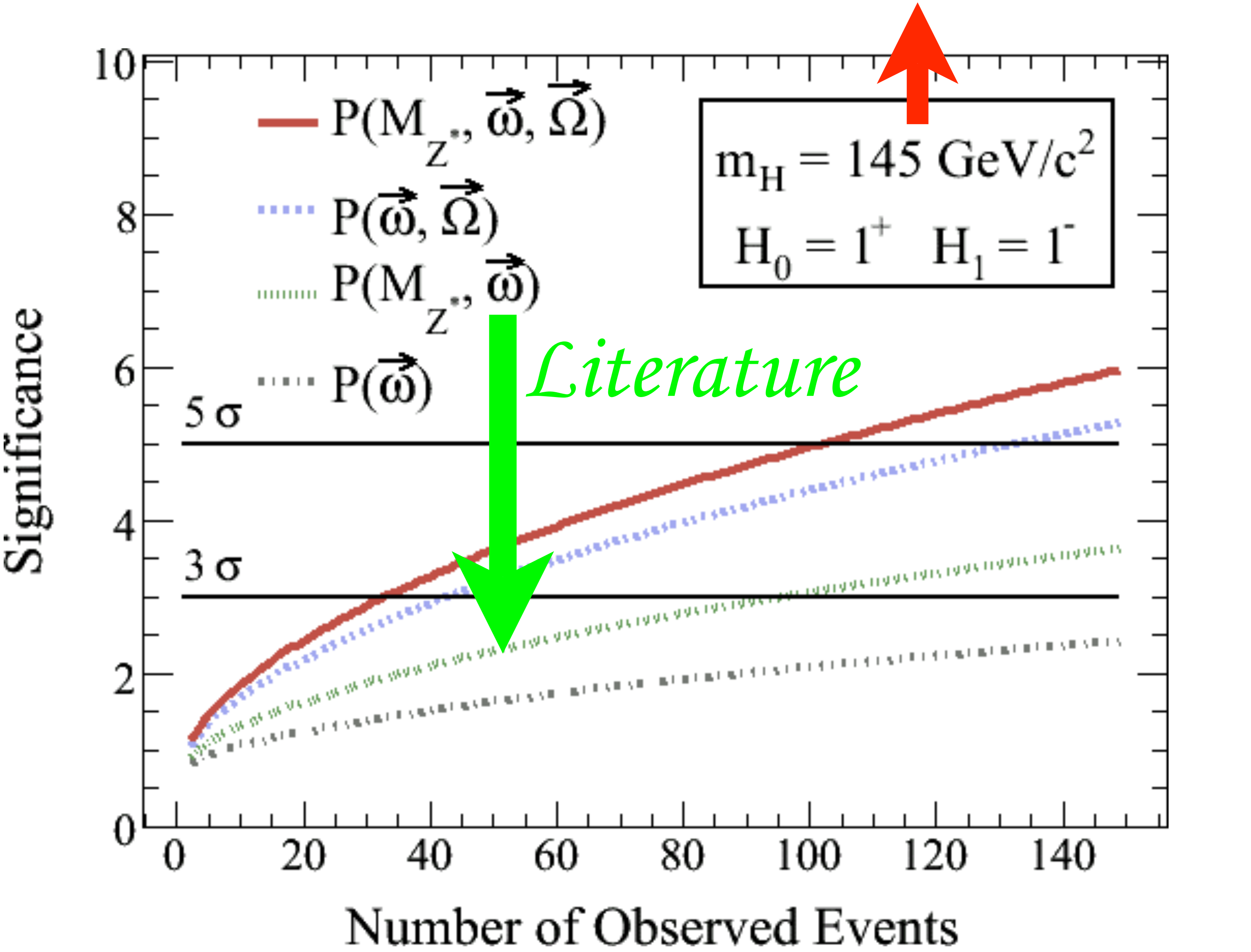
$$\vec{\omega} \equiv \{\cos\theta_1, \cos\theta_2, \varphi \equiv \varphi_2 - \varphi_1\}$$ Lepton-angles: Kept

$$\vec{\Omega} \equiv \{\cos\Theta, \Phi \equiv \varphi_2\}$$ (Z-pair)-angles: Averaged

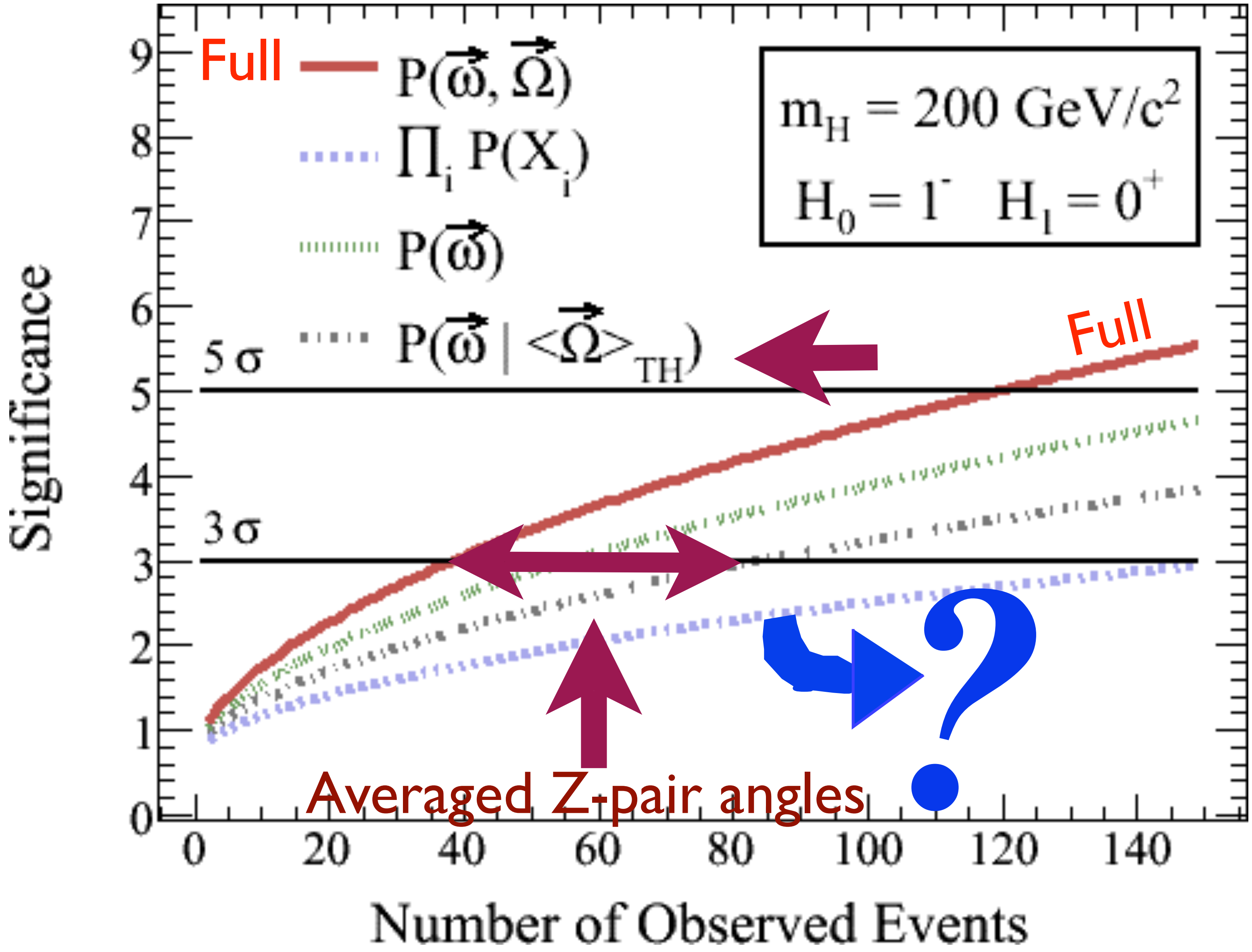
Deletes polarization-memory for spin > 0

Good only for uniform 4π *acceptance*

Median significance curves $H \rightarrow Z Z^*$



DIS-Favouring VECTOR interpretation of SCALAR signal



To handle multi-dimensional PDFs and their likelihoods, occasionally suggested to:

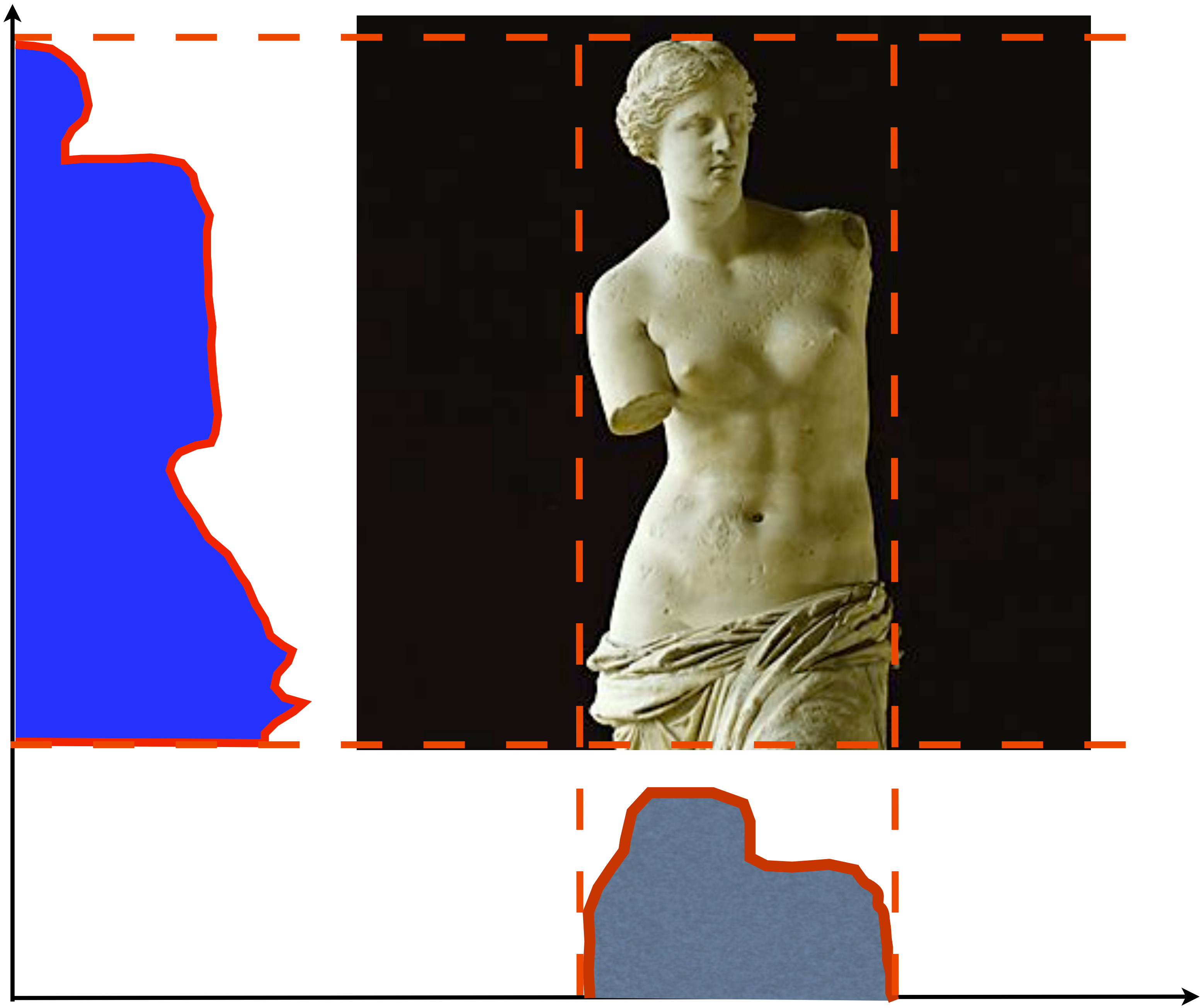
$$P(x_1, ..., x_n)$$

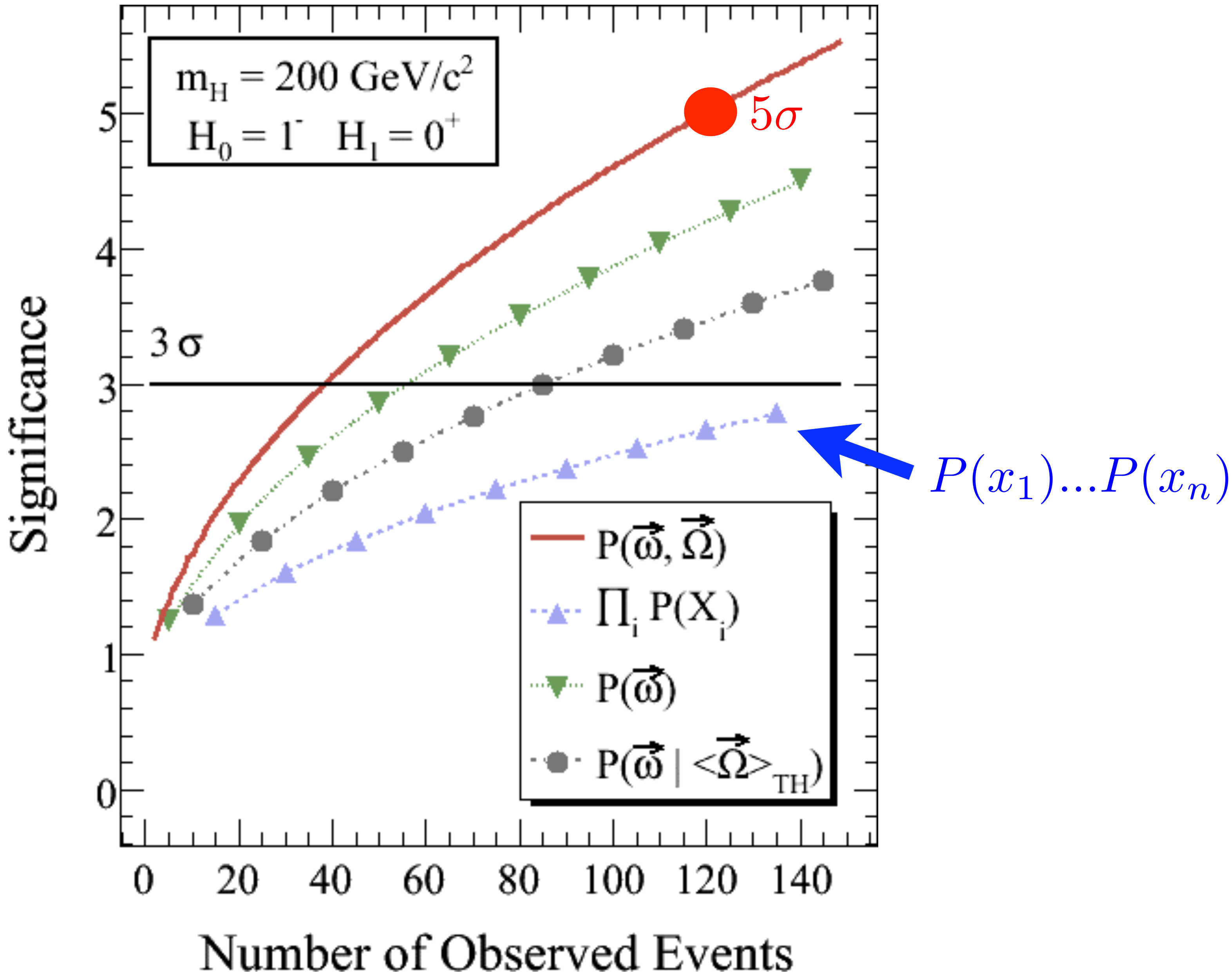
$$P(x_1) = \int P \, dx_2 ... dx_n$$

$$\vdots$$

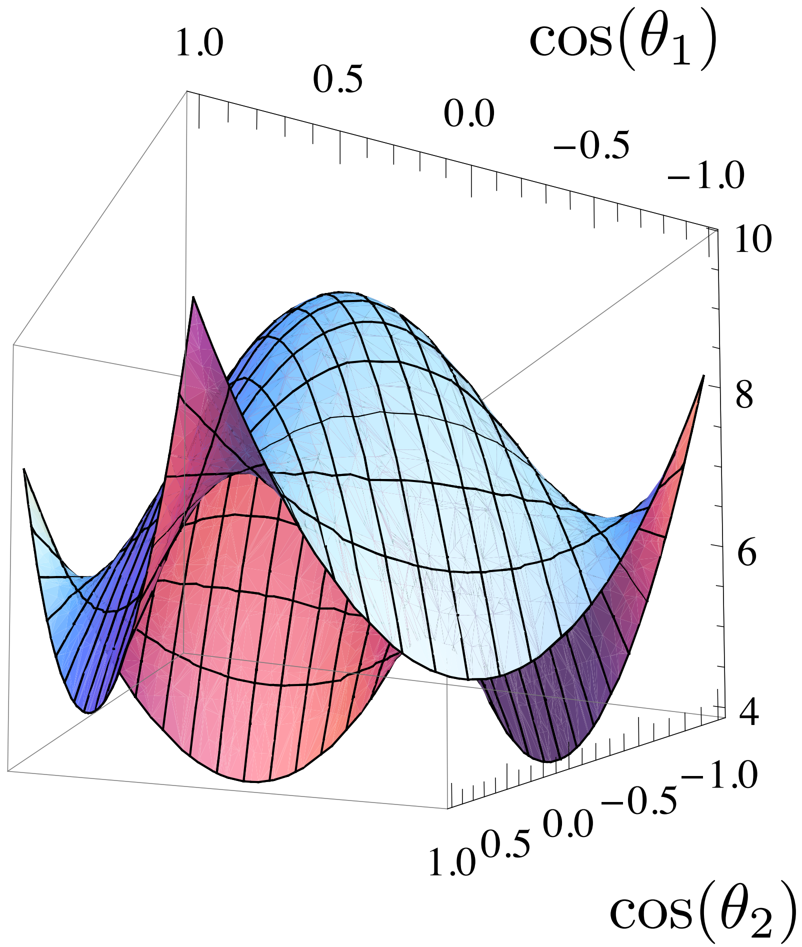
$$P(x_n) = \int P \, dx_1 ... dx_{n-1}$$

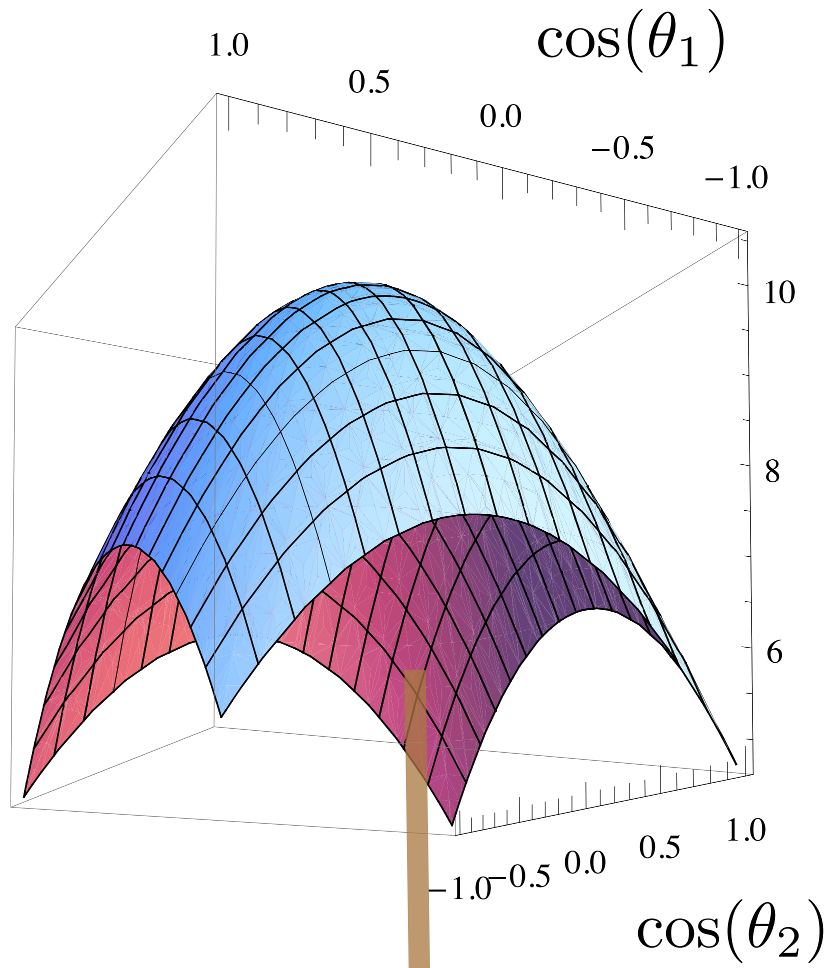
$$P(x_1, ..., x_n) \rightarrow P(x_1) ... P(x_n)$$





m_H = 200 GeV/c^2
$H_0 = 1^-$ $H_1 = 0^+$
5σ
3 σ
Significance
Number of Observed Events
$P(\vec{\omega}, \vec{\Omega})$
$\prod_i P(X_i)$
$P(\vec{\omega})$
$P(\vec{\omega} \mid \langle\vec{\Omega}\rangle_{TH})$
$P(x_1)...P(x_n)$

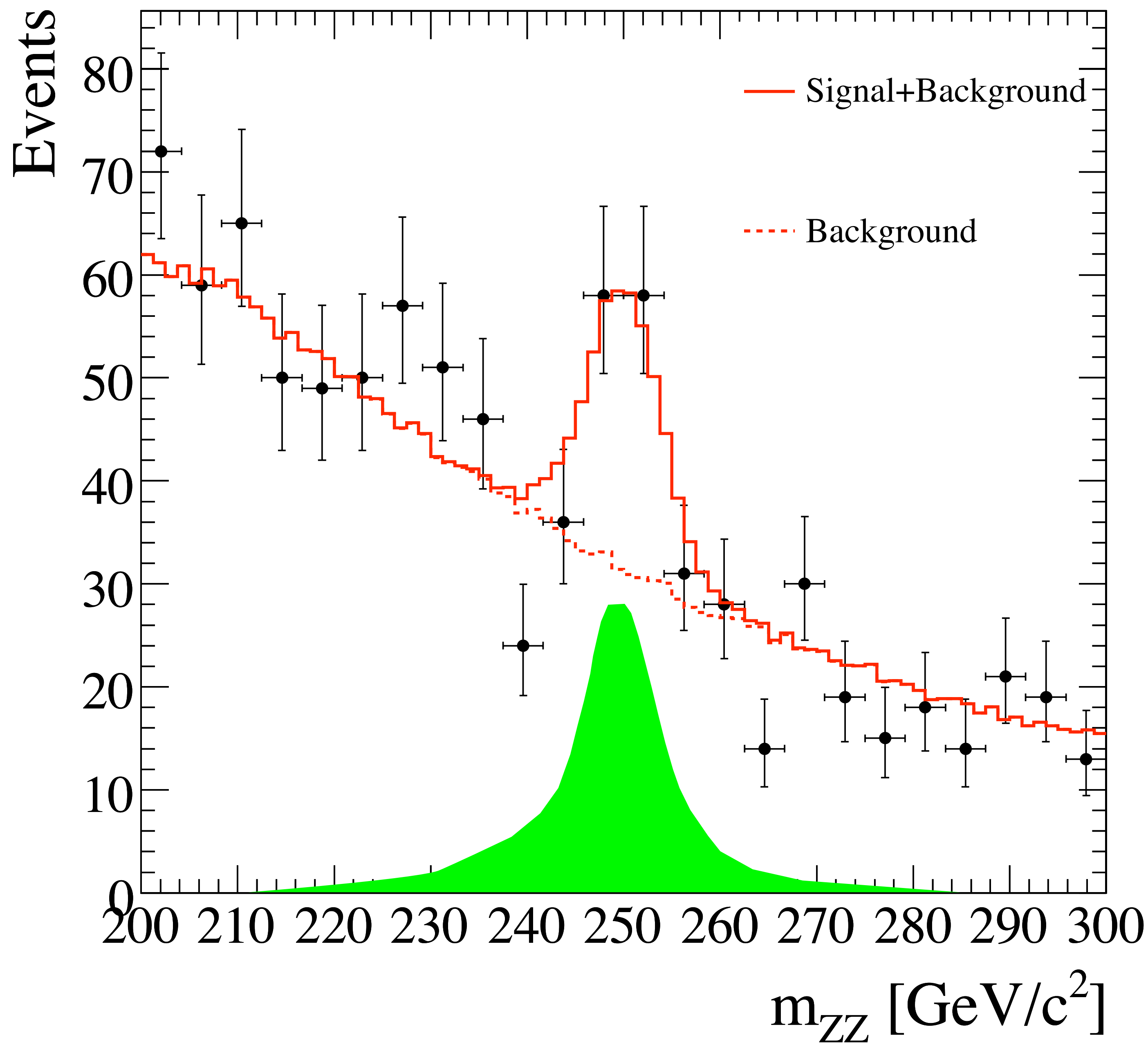




$P[\cos(\theta_1), \cos(\theta_2)]$ $P[\cos(\theta_1)] * P[\cos(\theta_2)]$

A goodness-of-fit test would eventually “disprove”” the right theory


Data Analysis
and
Statistics



Events
80
70
60
50
40
30
20
10
0
200
210
220
230
240
250
260
270
280
290
300
Signal+Background
Background
m_{ZZ} [GeV/c^2]

MC Truth

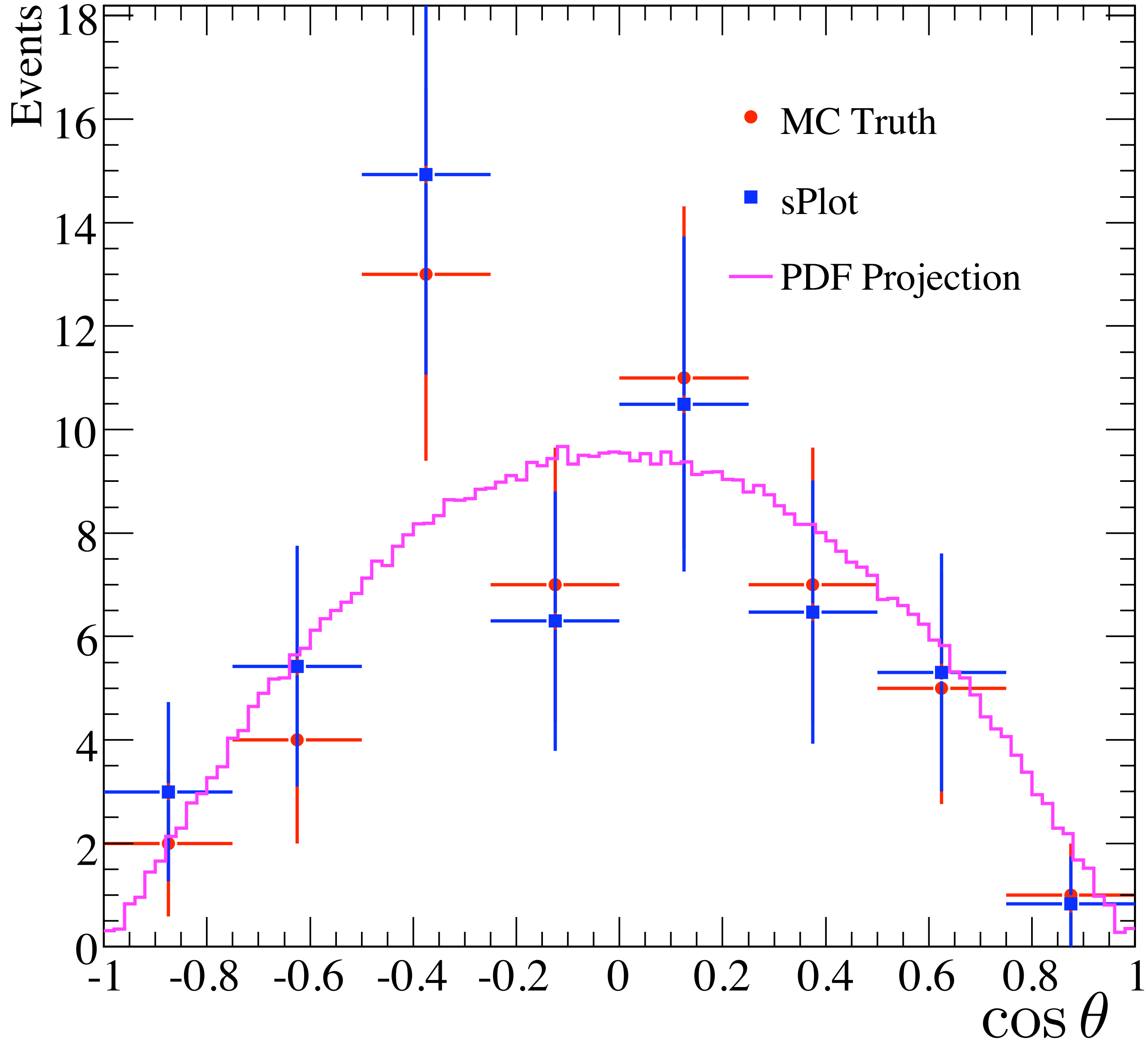
SIGNAL

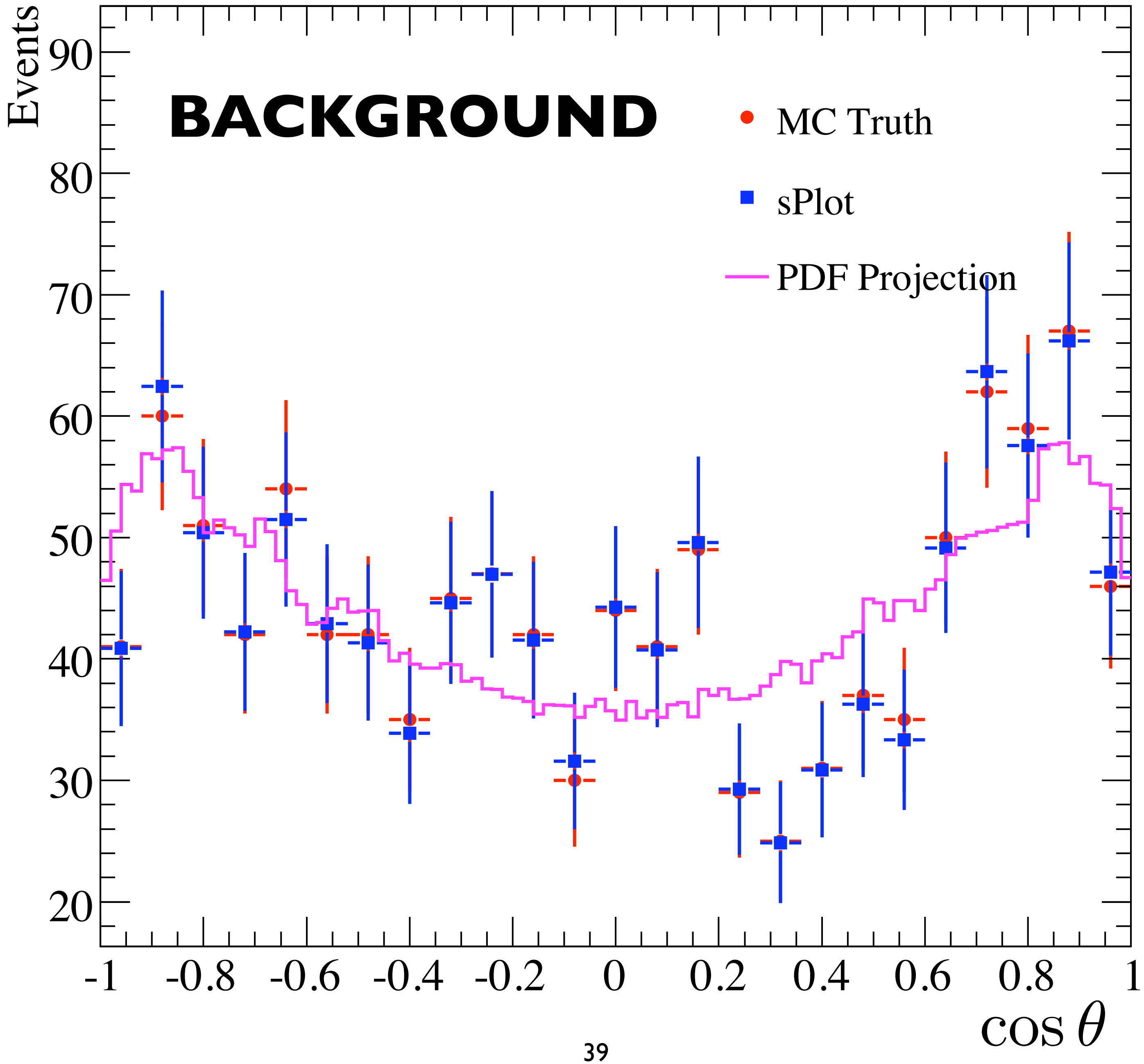
$\cos\theta =$

$\cos\theta_1$

or

$\cos\theta_2$




Events
BACKGROUND
MC Truth
sPlot
PDF Projection
90
80
70
60
50
40
30
20
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
cos θ

s-Separates signal and background

In our case with use of Maximum-Likelihood fit to the M(ZZ) or M(ZZ*) distribution => Ns, Nb

To result in what we need:

a signal-only 5-d (or 6-d) "potato":

The distribution of events in all 5 angles (+ M* in H=>ZZ*).

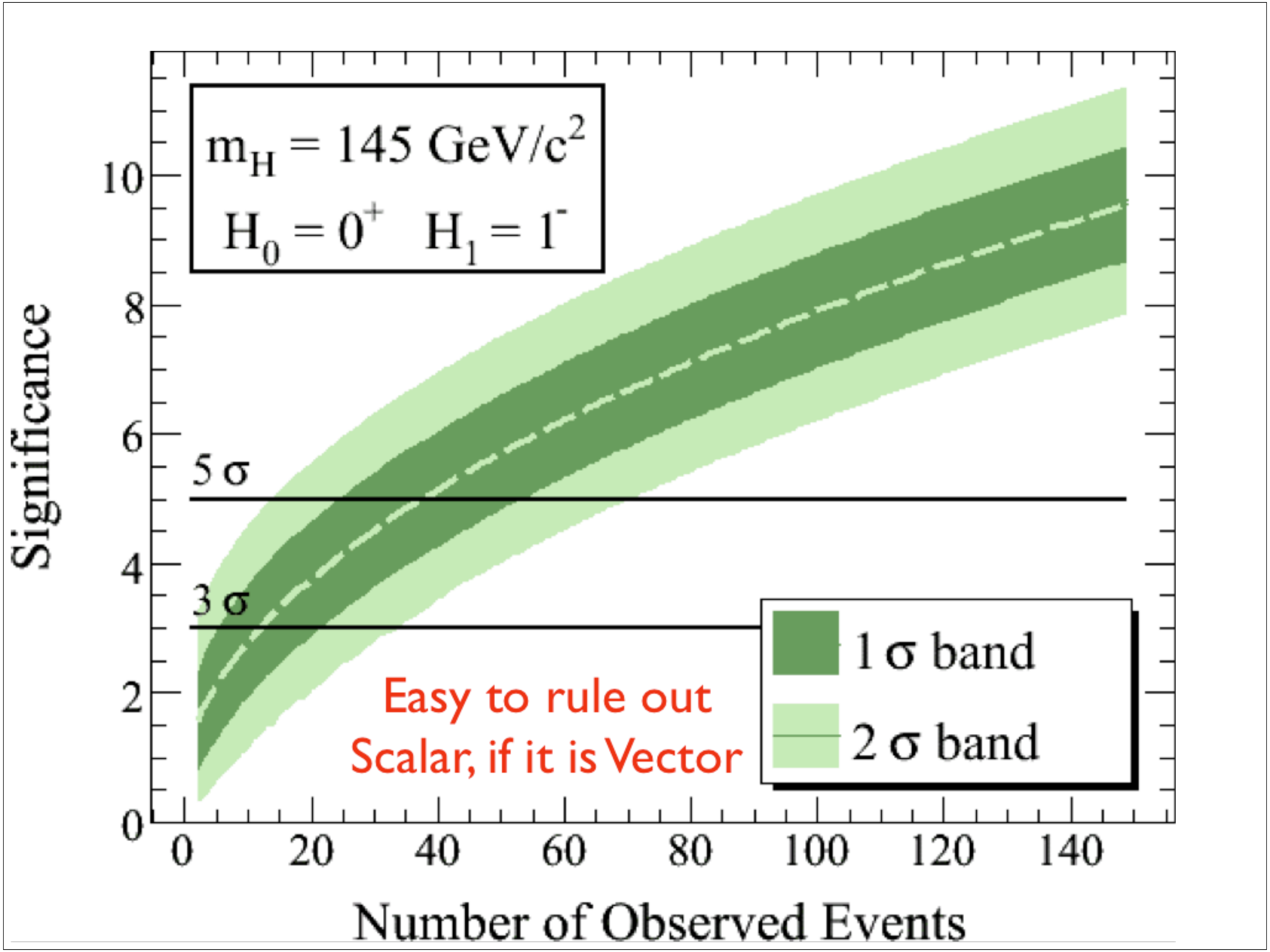
IDEAL FOR TESTING WHAT THE SIGNAL IS... AND IS NOT

Neyman-Pearson test

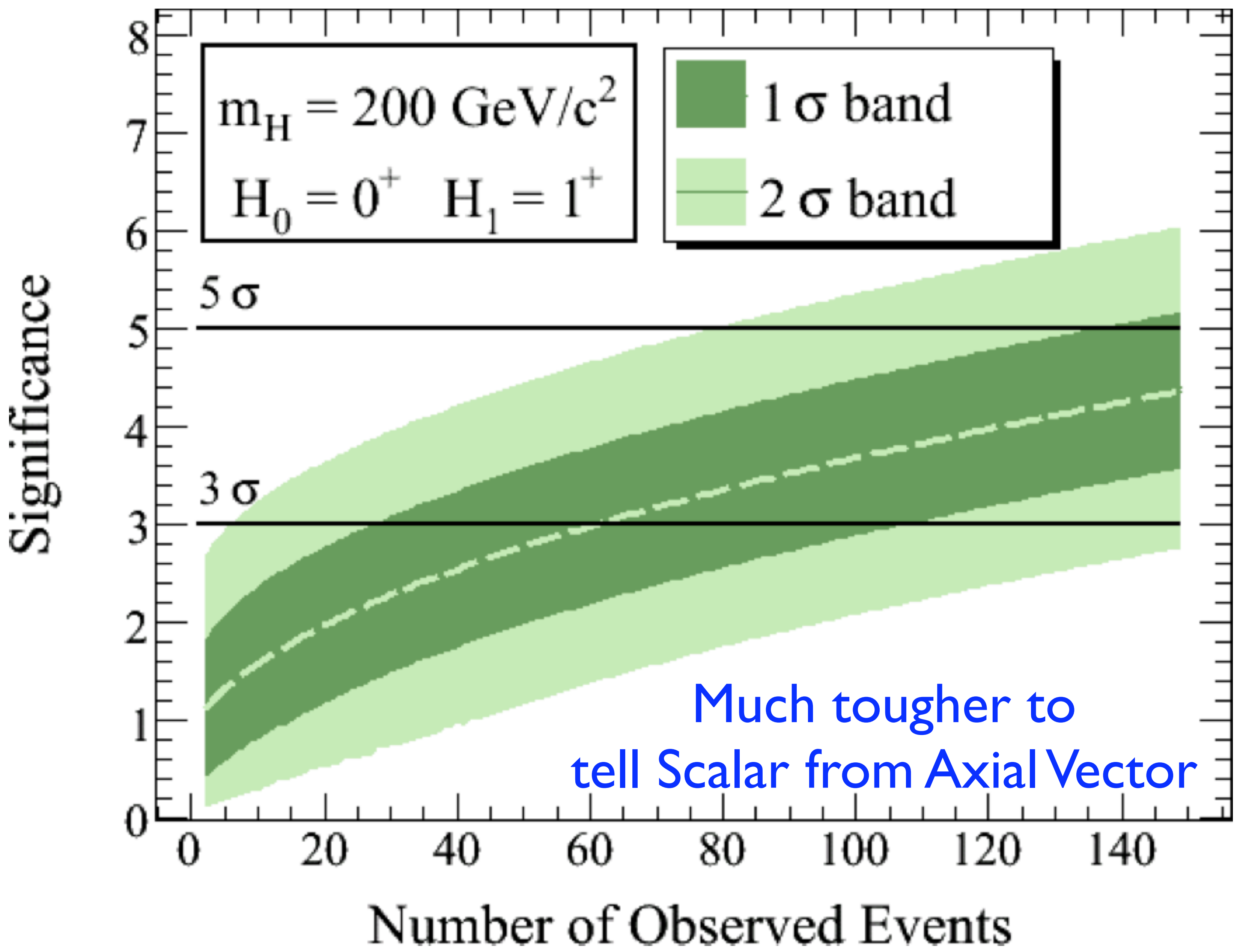
No statistics schpiel

Translate into HEP Language

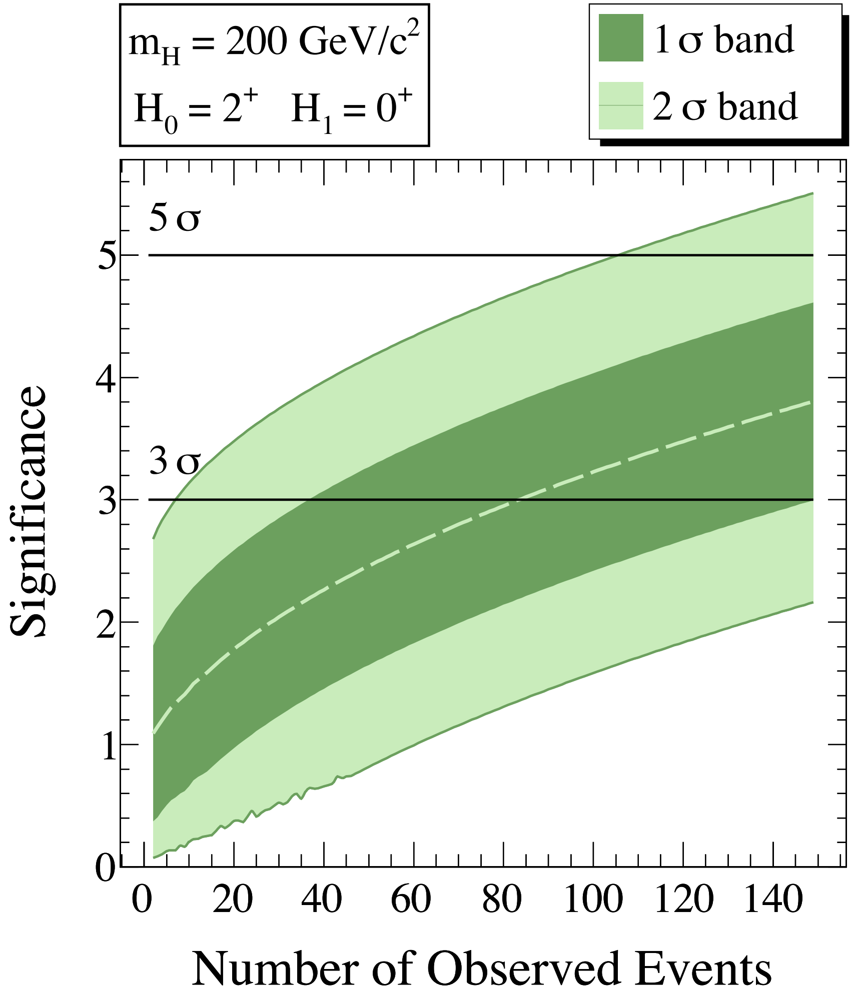
Convert actual probabilities to Gaussian-equivalent # Standard Deviations

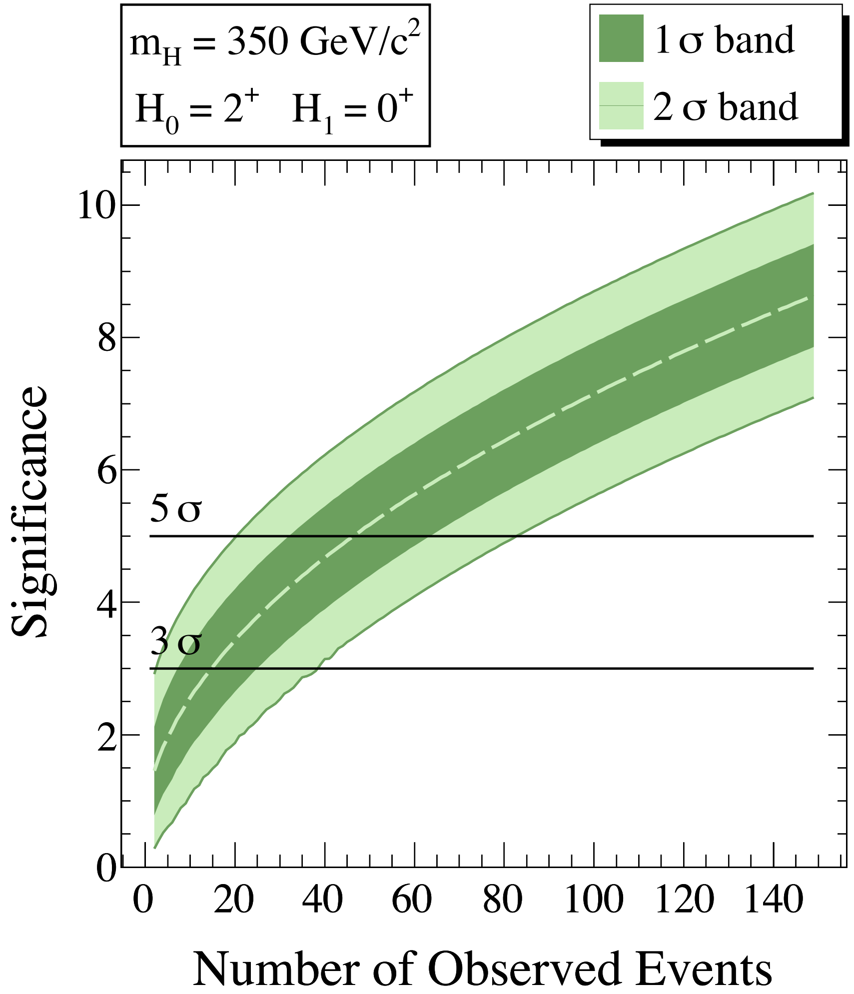


m_H = 145 GeV/c^2
$H_0 = 0^+$ $H_1 = 1^-$
Significance
10
8
6
4
2
0
5 σ
3 σ
1 σ band
2 σ band
Easy to rule out
Scalar, if it is Vector
0
20
40
60
80
100
120
140
Number of Observed Events

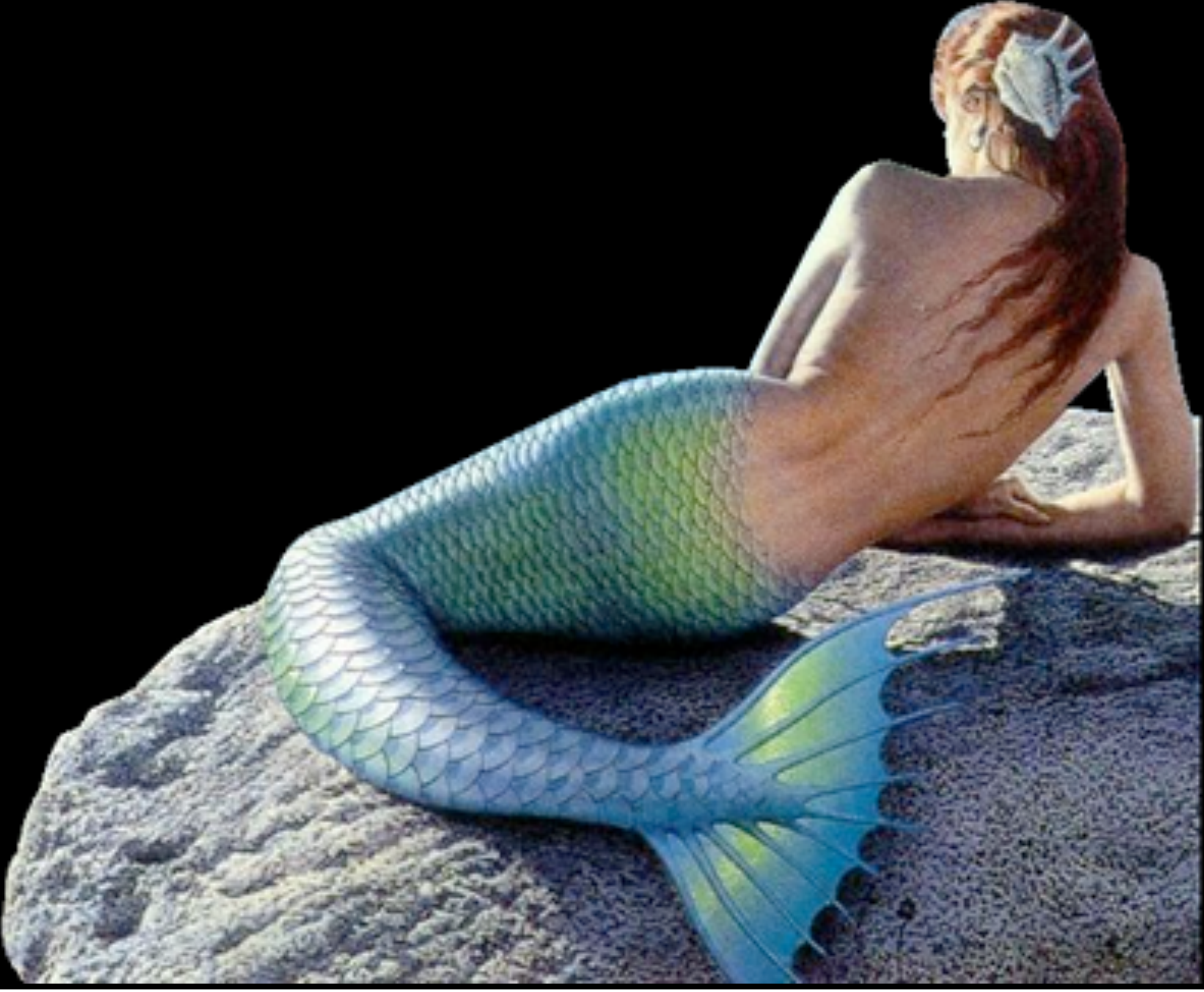

m_H = 200 GeV/c^2
$H_0 = 0^+$ $H_1 = 1^+$
1 σ band
2 σ band
5 σ
3 σ
Significance
Number of Observed Events
Much tougher to
tell Scalar from Axial Vector

Higgs vs Kaluza-Klein (Heavy Graviton)





HZZ "Mixed-(P,C,T)" couplings



“Mixed” hypotheses

e.g.: Standard coupling + Opposite-parity coupling

$$\cos\xi\, L[0^+, ZZ] + \sin\xi\, L[0^-, ZZ]$$

Conventional likelihood approach, as in

$$N_S\, S[M(ZZ)] + N_B\, B[M(ZZ)]$$

Not certifiably optimal, but the alternatives are not significantly different

$\mathcal{L}-inv$ =

$X\ g_{\mu\nu}$ **Standard**

$-(Y + i\,Z)\dfrac{k_\mu k_\nu}{M_Z^2}$

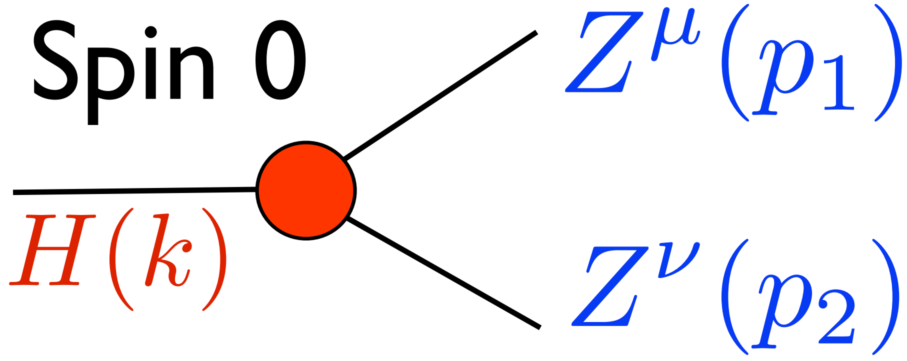
XZ: CP-odd, P-even

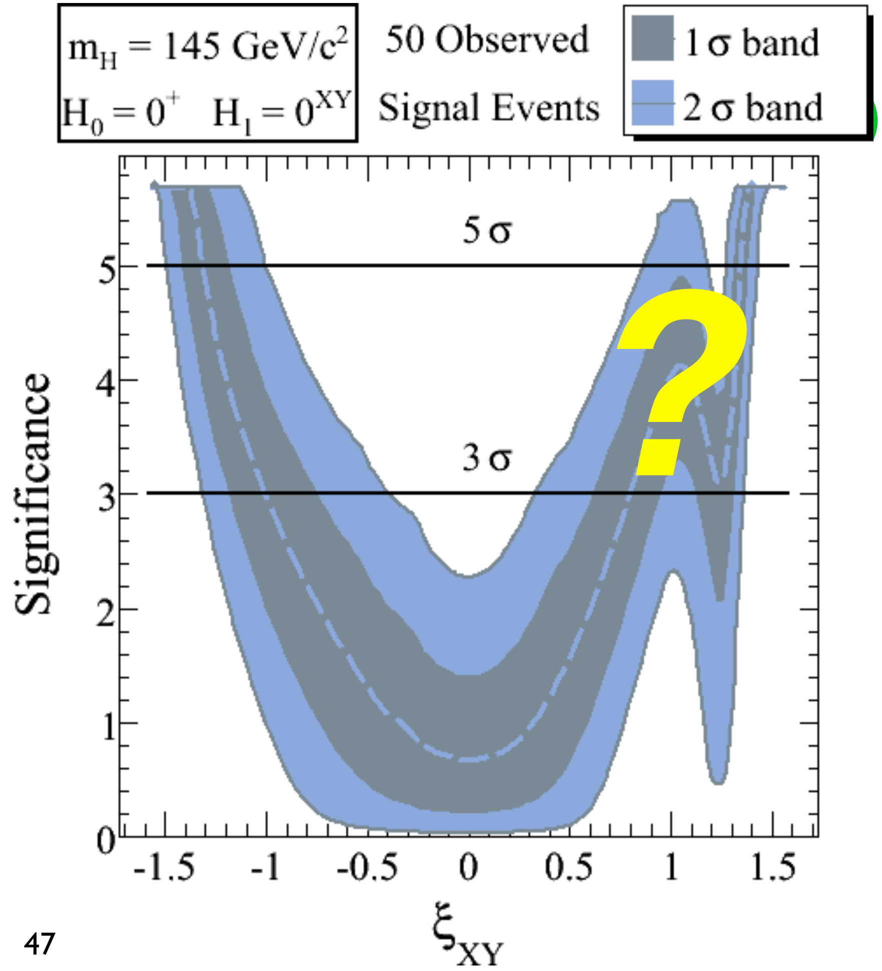
XY: P-even, CP-even

$$\xi \equiv \arctan \frac{Y}{X}$$

$R(H) \sim M^{-1}\ (\leftrightarrow \pi)$

e.g.: observable for some(large) values of ξ

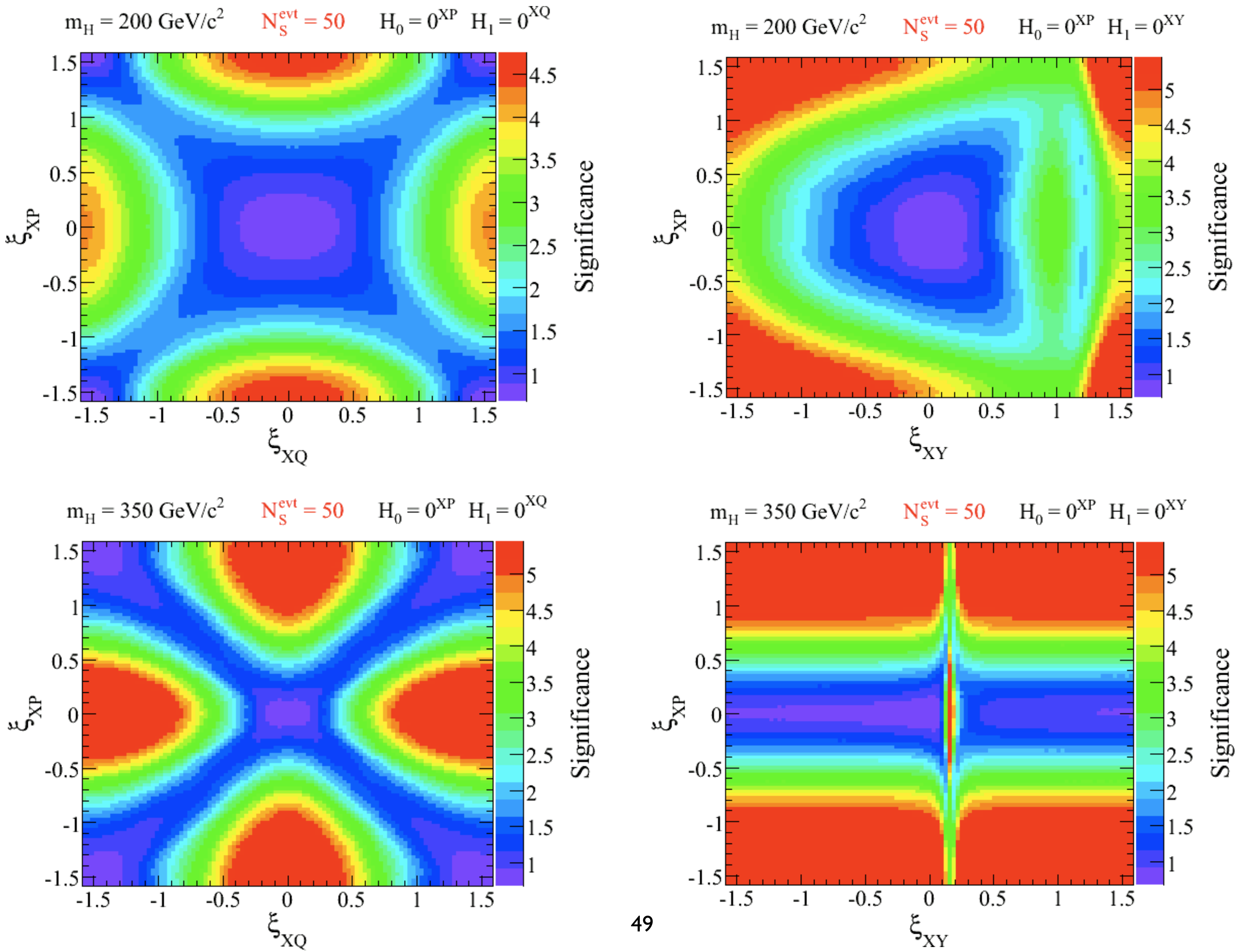




A few examples of ...
Dozens of [fair] questions and their [careful] answers

Some examples of ...
NEXT-TO-LEADING questions and their answers

e.g.: The Higgs-impostor has zero spin, but is non-standard. What is its best description ???

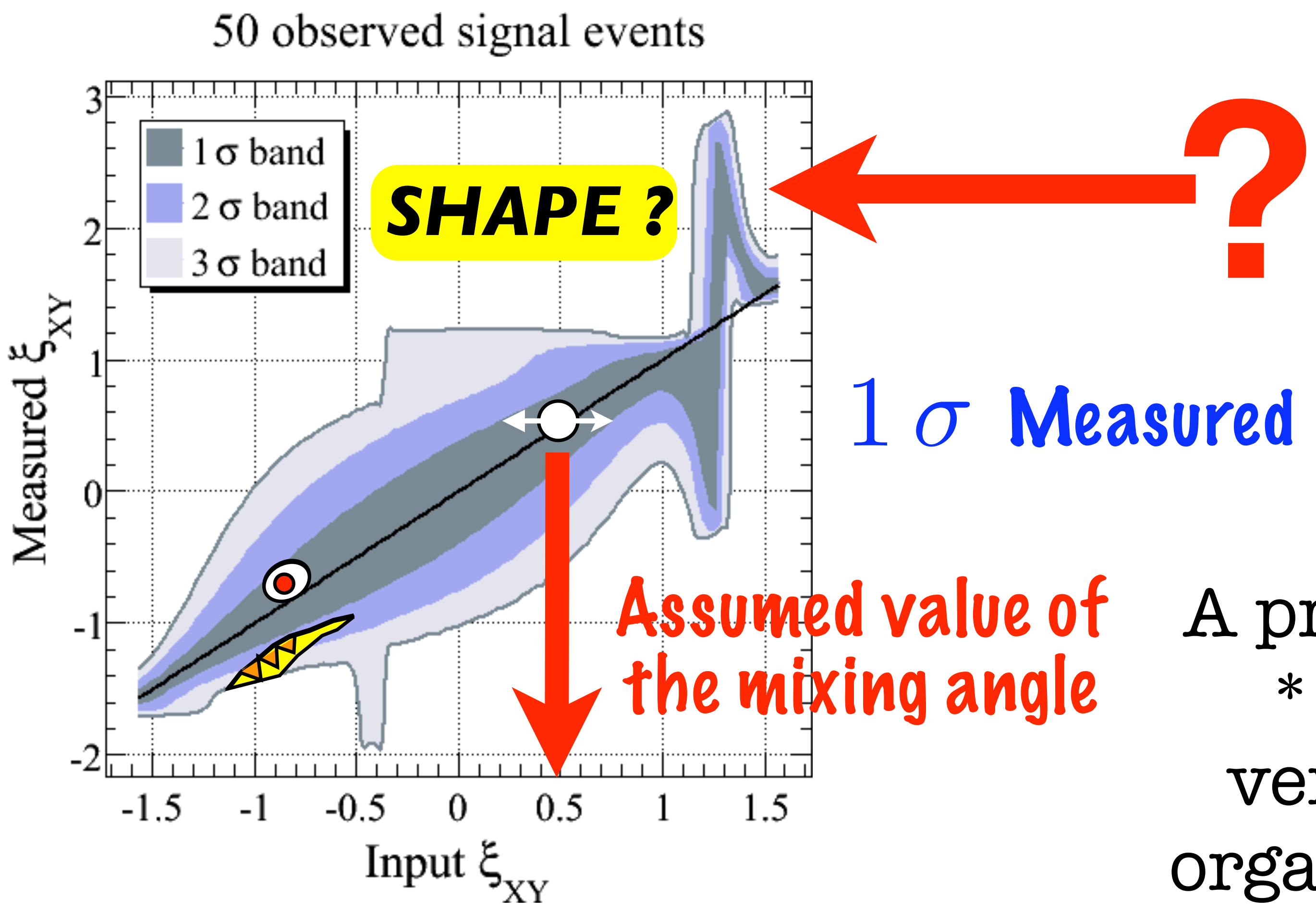

$m_H = 200$ GeV/c^2 $N_S^{evt} = 50$ $H_0 = 0^{XP}$ $H_1 = 0^{XQ}$
ξ_{XP}
ξ_{XQ}
Significance
$m_H = 200$ GeV/c^2 $N_S^{evt} = 50$ $H_0 = 0^{XP}$ $H_1 = 0^{XY}$
ξ_{XP}
ξ_{XY}
Significance
$m_H = 350$ GeV/c^2 $N_S^{evt} = 50$ $H_0 = 0^{XP}$ $H_1 = 0^{XQ}$
ξ_{XP}
ξ_{XQ}
Significance
$m_H = 350$ GeV/c^2 $N_S^{evt} = 50$ $H_0 = 0^{XP}$ $H_1 = 0^{XY}$
ξ_{XP}
ξ_{XY}
Significance

Fairly difficult to tell apart different "mixed" J = 0 HIs

Fairly easy to tell apart any (mixed) J = 0 HI from any (mixed) J = 1 HI

NNLQ (Next to Next to Leading Questions)

e.g.: A "composite Higgs" of M ~ 145 GeV



A problem of *some* very large organisations

$$\cos(\xi)\, g_{\mu\nu} - \sin(\xi)\, k_\mu k_\nu / M_Z^2$$

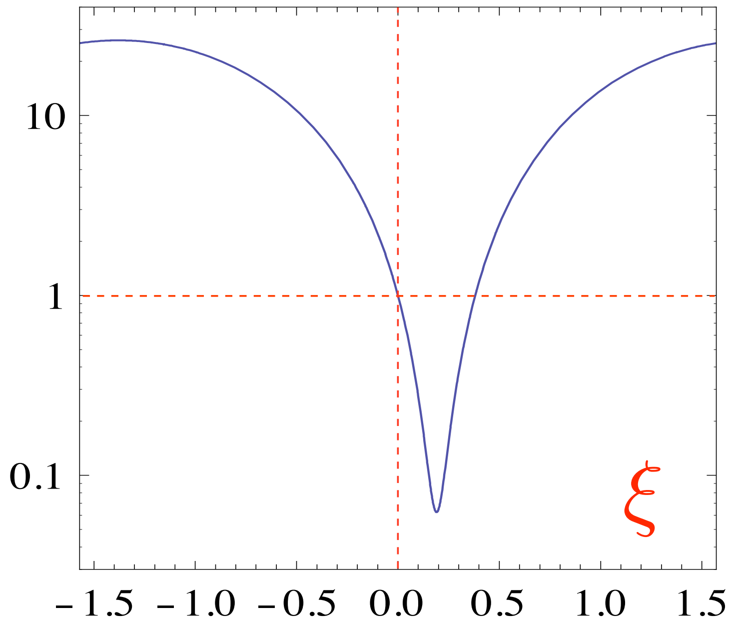
Two terms with the same Quantum Numbers

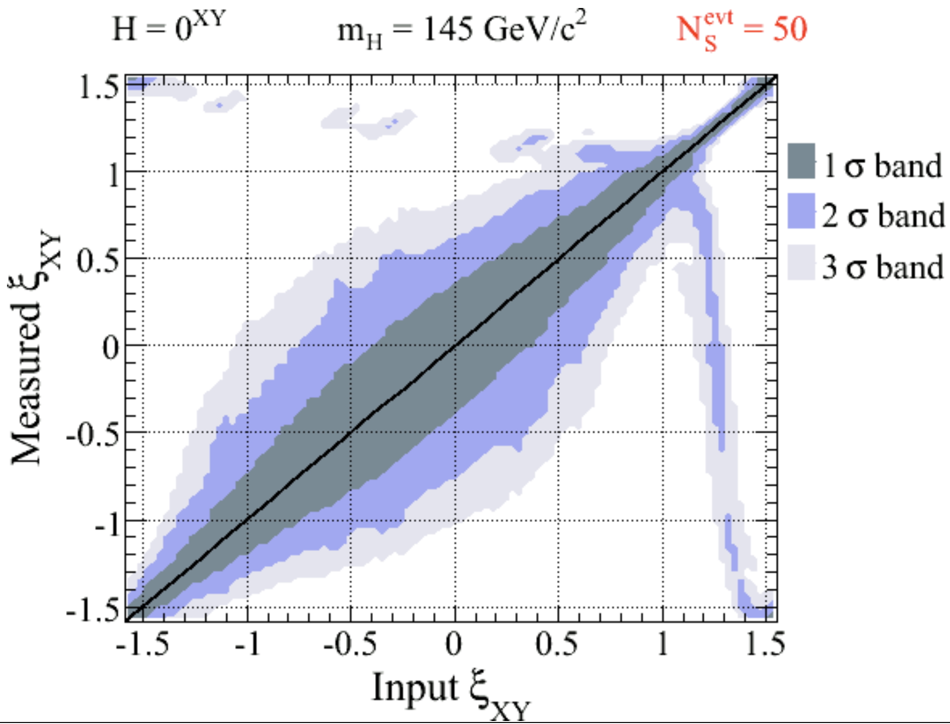
→ *Analogous angular distributions*

→ *Very destructive interferences*

Feldman-Cousins belt construction

$$\frac{|M(\xi)|^2}{|M(0)|^2}$$



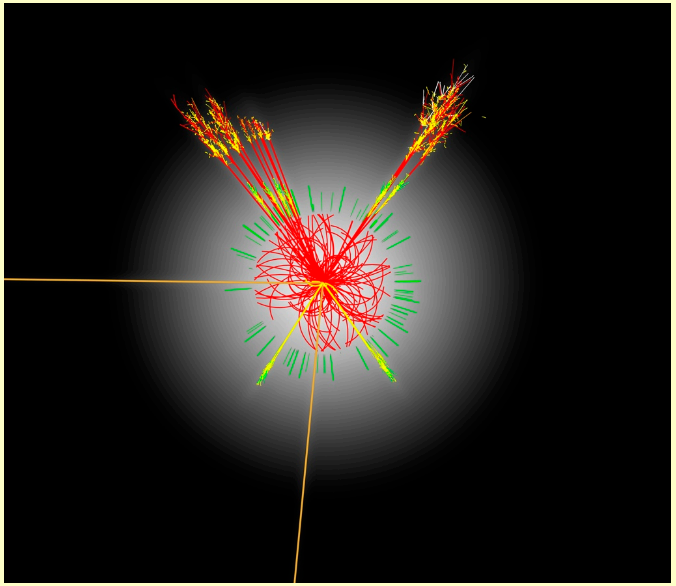


For given

Detector performance

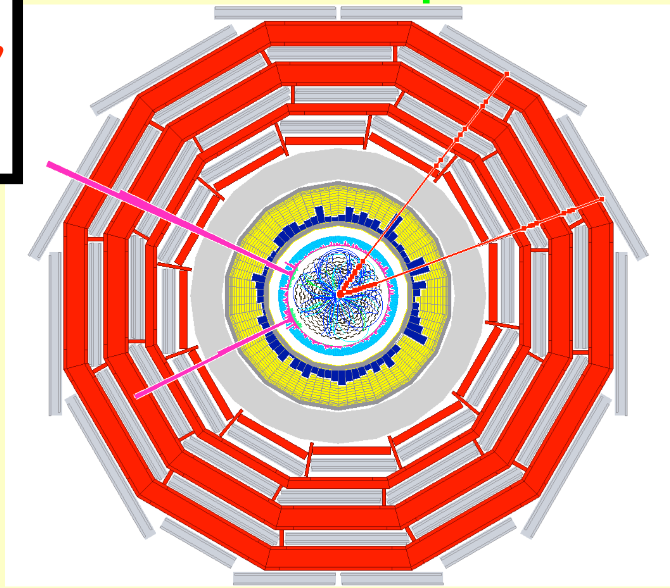
Integrated Luminosity

No extra SF



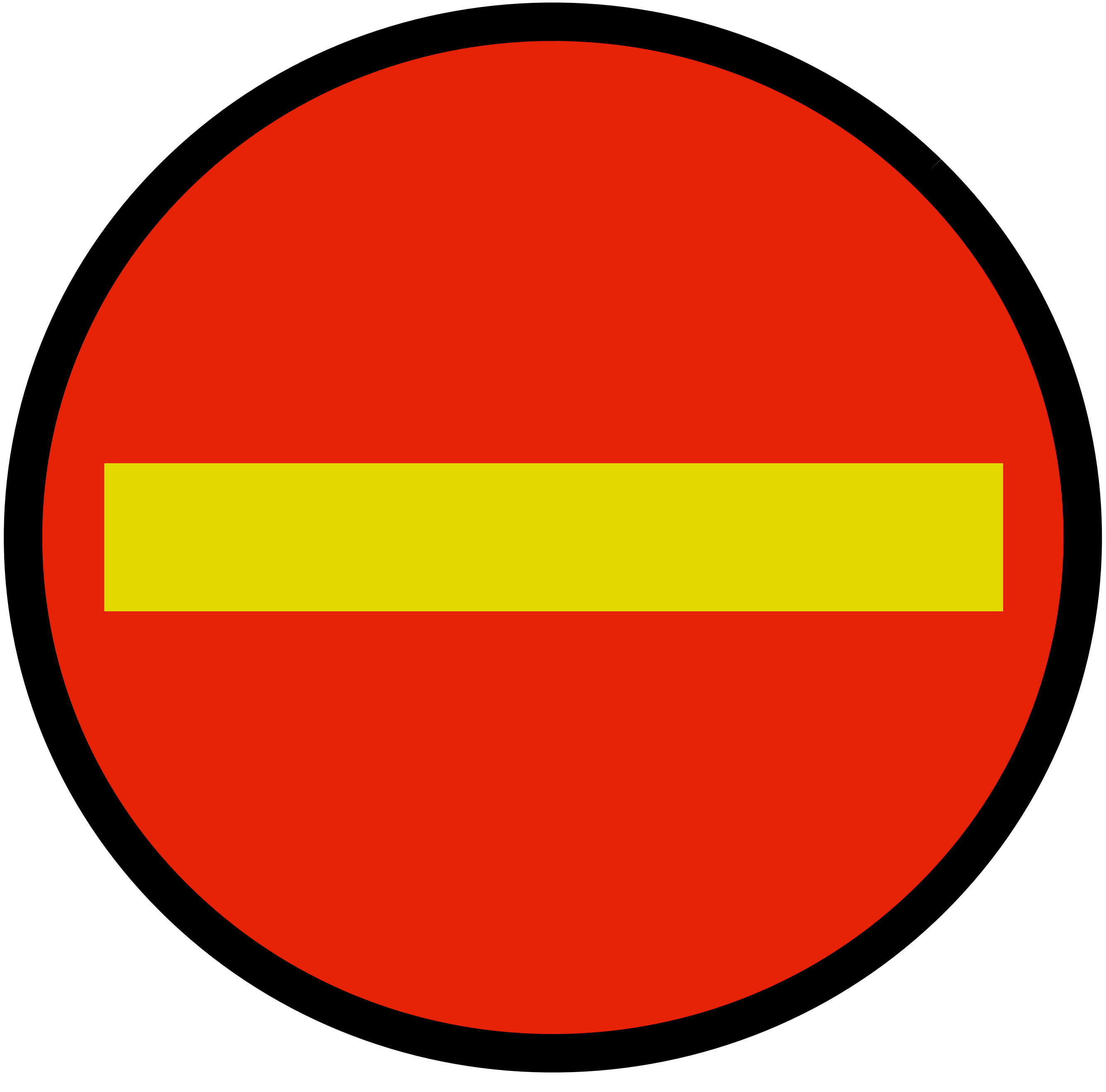
It pays to have ab-initio (!)
an ANALYSIS combining
DISCOVERY & SCRUTINY

Proved by way
of example



Arguably true as well for many other physics items, which... ...

Readily come to mind ...



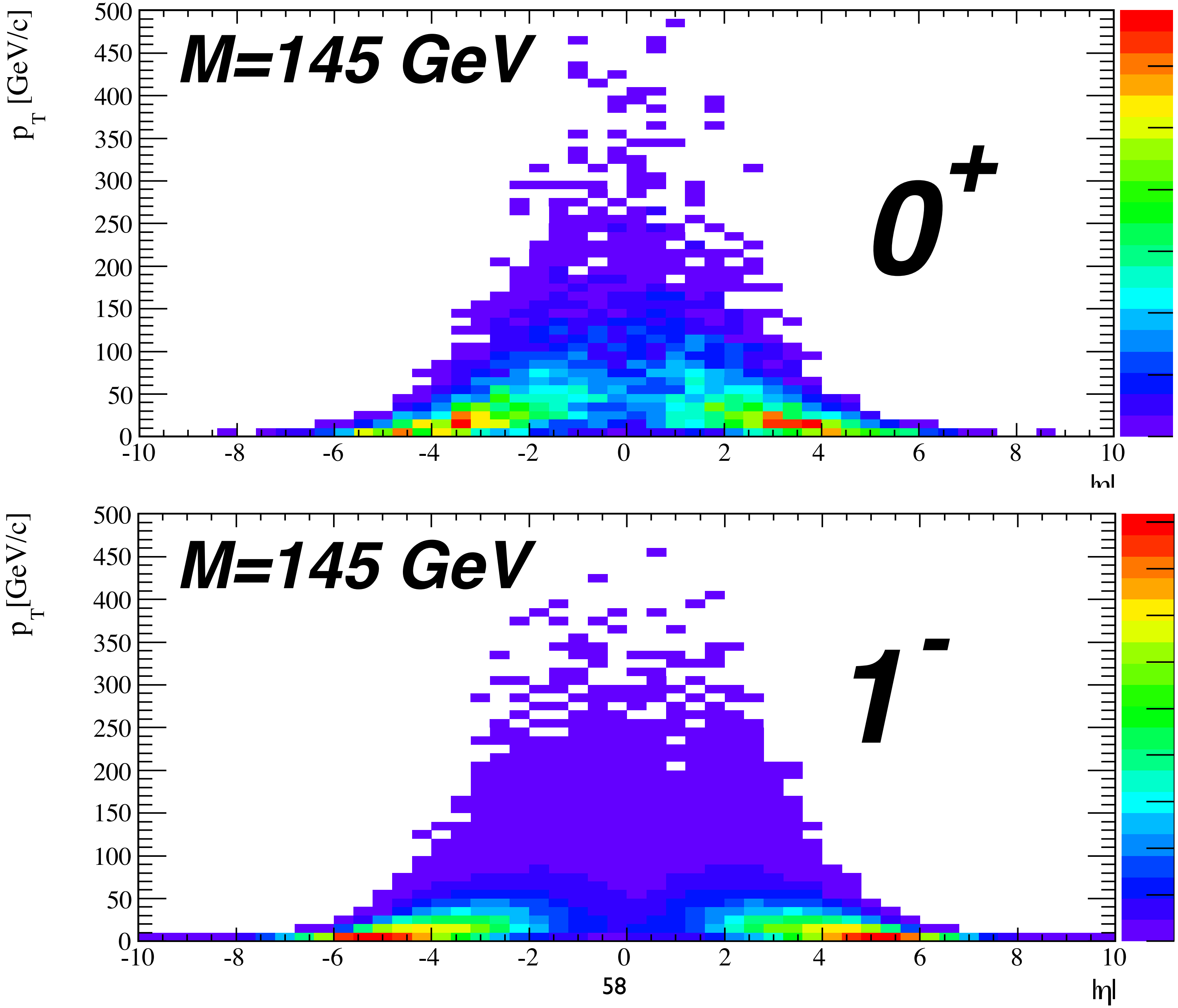
$$\varphi_H(x)$$

at minimum of

$$V(\varphi_H)$$

WARNING

Not a WORD of what I am saying is TRULY ***NOVEL***


M=145 GeV
0+
p_T [GeV/c]
|η|
M=145 GeV
1-
p_T [GeV/c]
|η|

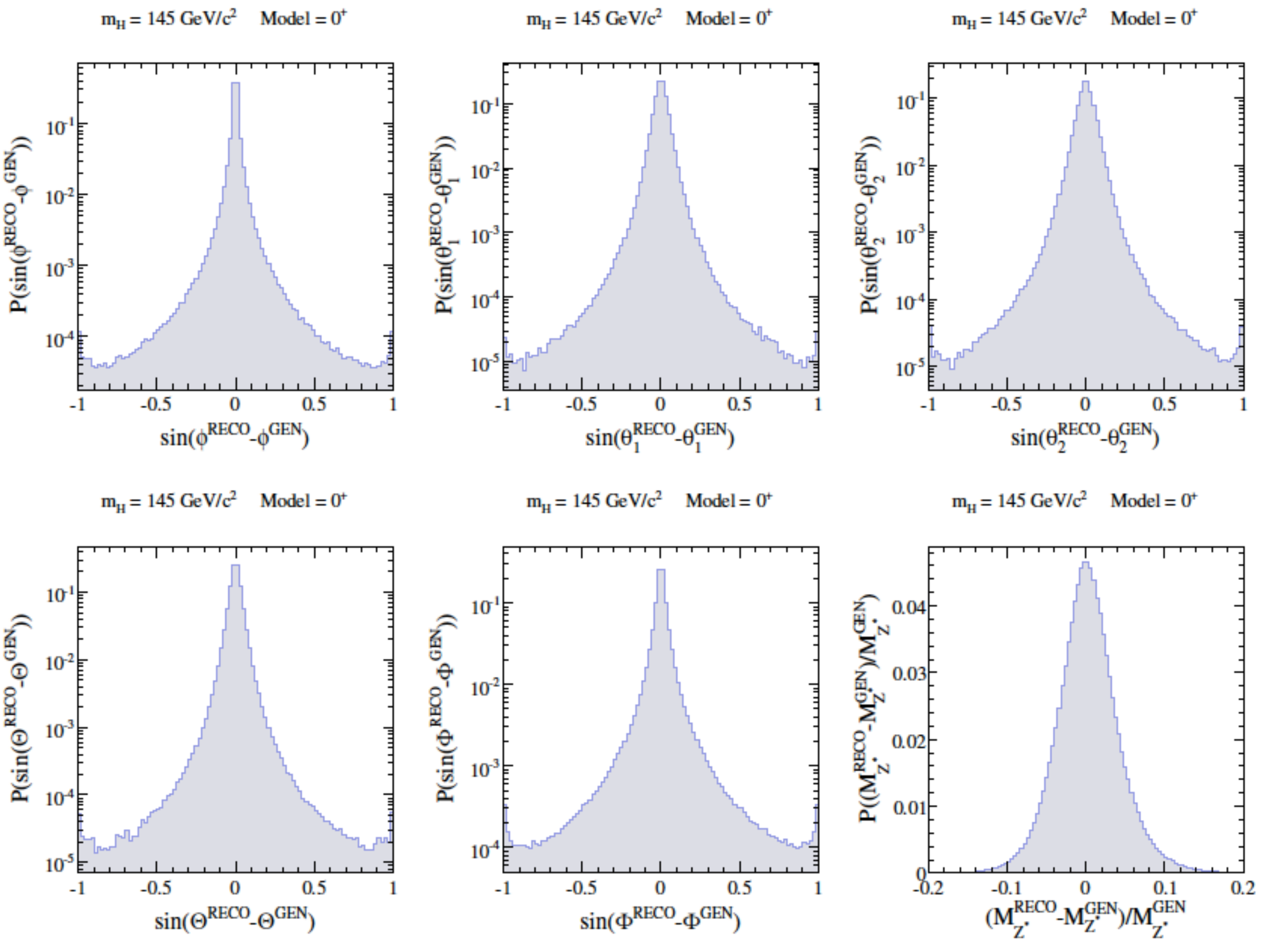


FIG. 25: Distributions indicating the reconstruction resolution for each of the variables $\vec{X}$ for a SM Higgs with mass 145 GeV$/c^2$. Only events which pass the signal selection are included. All distributions are normalized to have an integral of 1.

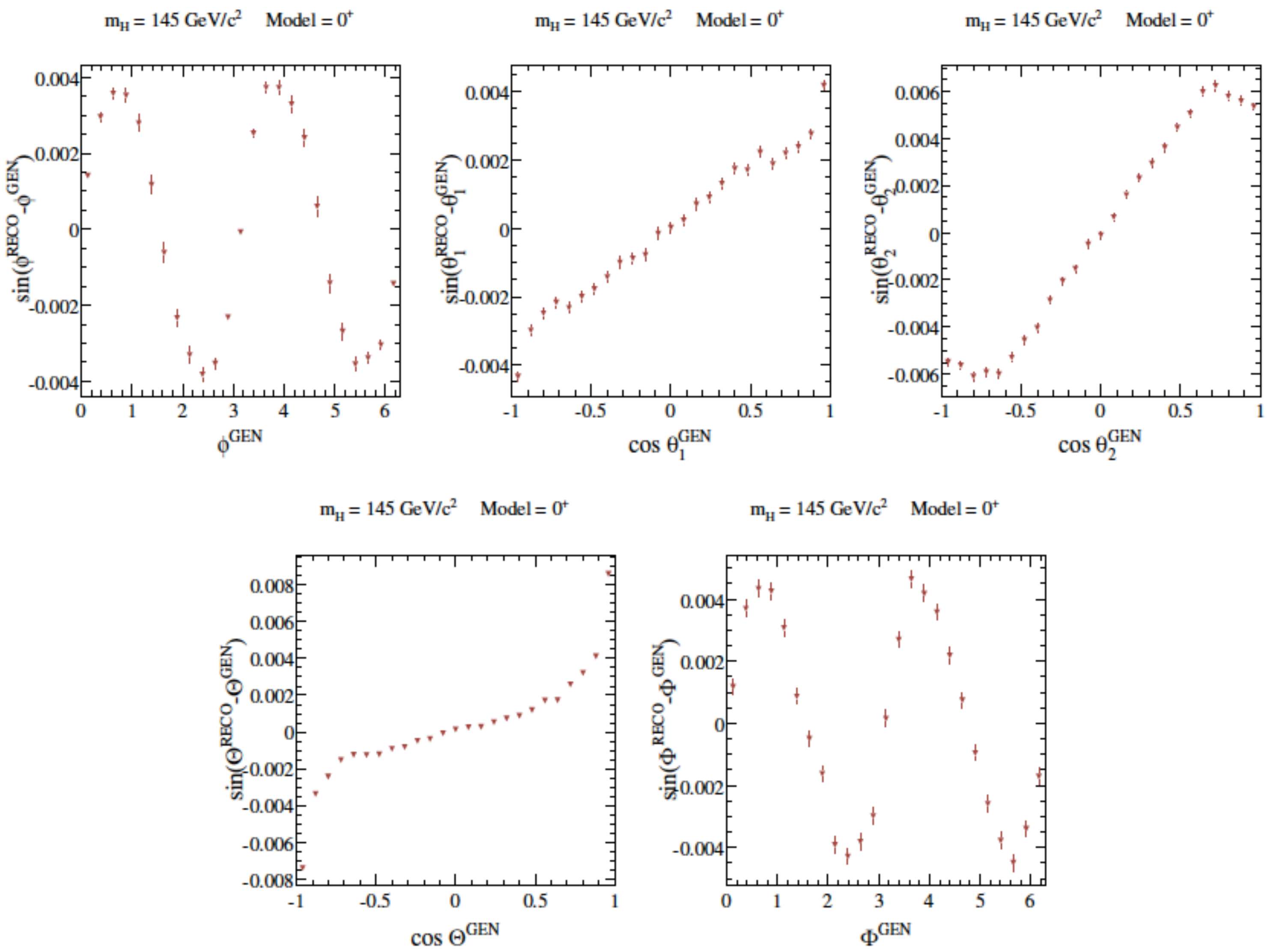


FIG. 26: Distributions showing systematic biases for reconstructed variables $\vec{X}$ for a SM Higgs with mass 145 GeV/c^2. Only events which pass the signal selection are included. All biases are at negligible levels in the context of the numerical representations of the multidimensional PDFs used in this analysis.

Exp. method is not new

- (Para)-Positronium $[J^P = 0^-] \rightarrow$ *QM entangled*
- Helicity can be measured: Thomson scattering
- J.A. Wheeler (Ann .N.Y. Acad.Sci. 48 (1946) 219) got the theory wrong
- Sneyder, Pasternak & Hornbostel (P.R. 73 [1948] 440) and Pryce and Ward (Nat. 160 [1947] 435) got it right
- Bleuler & Bradt's experiment (P.R. 73 [1948] 1398) was not conclusive and Hanna's (Nature 162 [1948] 332) was wrong.
- C.S. Wu & Shaknov (P.R. 77 [1950] 136) did it right !!!

Hopefully history will not fully repeat

$$\bar{\eta} \equiv \frac{2\, c_v\, c_a}{c_v^2 + c_a^2} \qquad Z \to l^+ l^-$$

$$g_1 \equiv \quad \left(c_v^2 + c_a^2\right)^2 \left(g_v^2 + g_a^2\right)$$

$$g_{v,a} \; : \; q\bar{q} \to H\, I$$

$$c \equiv \cos\Theta \;, \qquad s \equiv \sin\Theta$$

$$c_1 \equiv \cos\theta_1 \;, \qquad s_1 \equiv \sin\theta_1$$

$$c_2 \equiv \sin\theta_2 \;, \qquad s_2 \equiv \sin\theta_2$$

$$m_d^2 \equiv m_1^2 - m_2^2 \;,$$

$$M_1^2 \equiv M^2 - 3m_1^2 - m_2^2 \;, \qquad M_2^2 \equiv M^2 - m_1^2 - 3m_2^2 \;,$$

$$M_3^2 \equiv M^2 - 2(m_1^2 + m_2^2) \;, \qquad M_4^2 \equiv M^2 - (m_1^2 + m_2^2)$$

$$\frac{d\mathrm{PDF}[\mathrm{Pure}\, 1^+]}{dm^*\, d\cos\Theta\, d\Phi\, d\cos\theta_1\, d\cos\theta_2\, d\varphi} \propto PS(M, m_1, m_2 = m^*) \times$$

$$P^2 g_1 \Big[M^2 s^2 s_1^2 s_2^2 \left[M_2^4 m_1^2 \cos 2(\phi + \varphi) + M_1^4 m_2^2 \cos 2\phi \right]$$

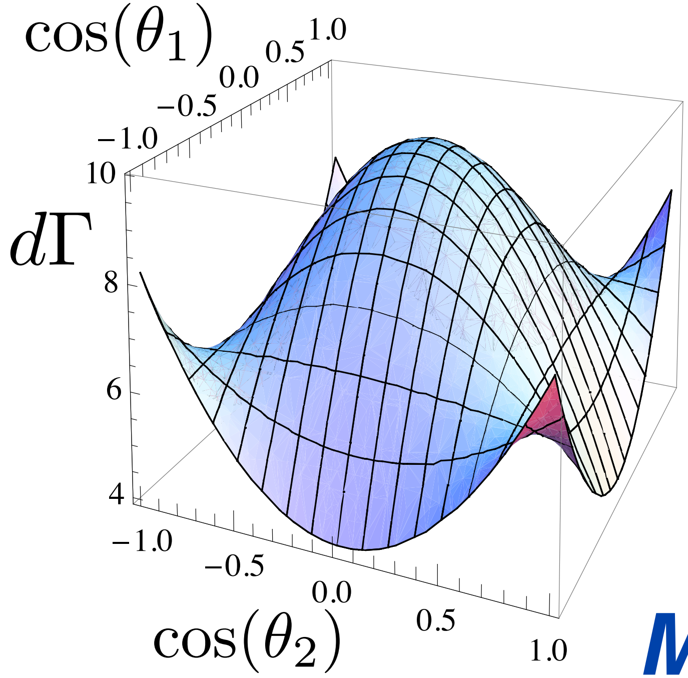
$$+8 m_1^2 m_2^2 m_d^4 s^2 \left[(c_1^2 + c_2^2 + s_1^2 s_2^2 \sin\varphi^2) + 2\bar{\eta}^2 c_1 c_2 \right]$$

$$+(1 + c^2) M^2 \left[2M_1^4 m_2^2 s_1^2 + 2M_2^4 m_1^2 s_2^2 - (M_2^4 m_1^2 + M_1^4 m_2^2) s_1^2 s_2^2 \right]$$

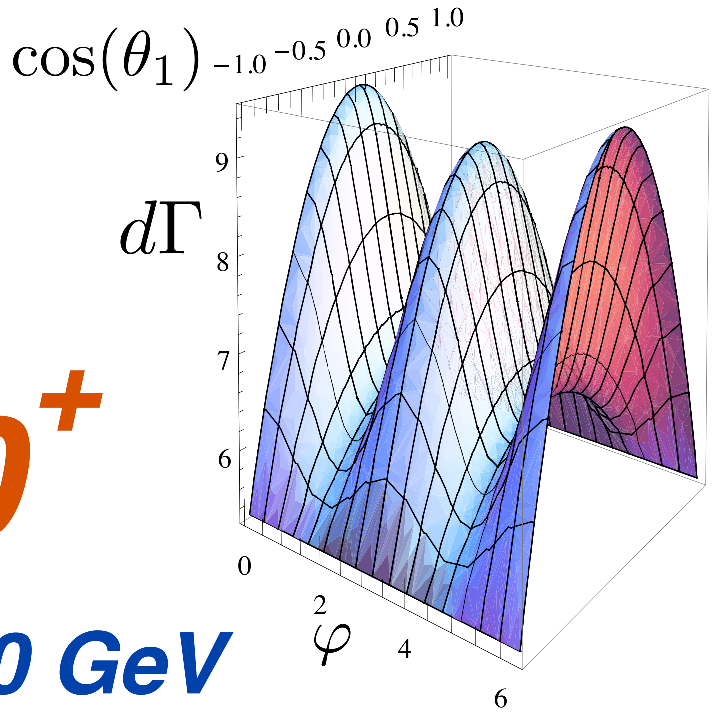
$$-8 M m_d^2 m_1 m_2 c\, s \Big[M_2^2 m_1 s_2 \left(c_2 s_1^2 \sin(\phi + \varphi) \cos\varphi + c_1 (c_1 c_2 + \bar{\eta}^2) \sin\phi \right)$$

$$- M_1^2 m_2 s_1 \left(c_1 s_2^2 \sin\phi \cos\varphi + c_2 (c_1 c_2 + \bar{\eta}^2) \sin(\phi + \varphi) \right) \Big]$$

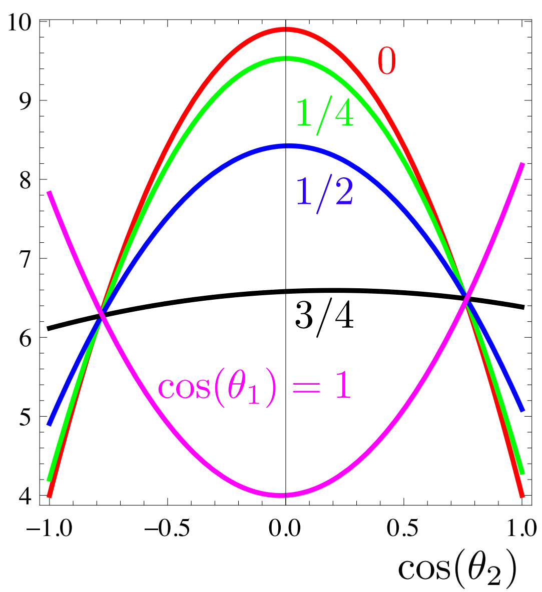
$$+2 M^2 M_1^2 M_2^2 m_1 m_2 s_1 s_2 \left[(1 + c^2)(c_1 c_2 - \bar{\eta}^2) \cos\varphi - s^2 (c_1 c_2 + \bar{\eta}^2) \cos\varphi + 2\phi \right] \Big]$$

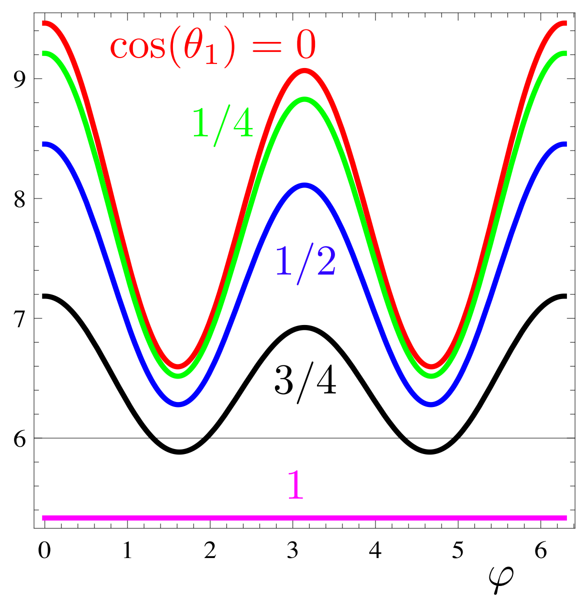

$\cos(\theta_1)$
$d\Gamma$
$\cos(\theta_2)$
-1.0
-0.5
0.0
0.5
1.0
4
6
8
10

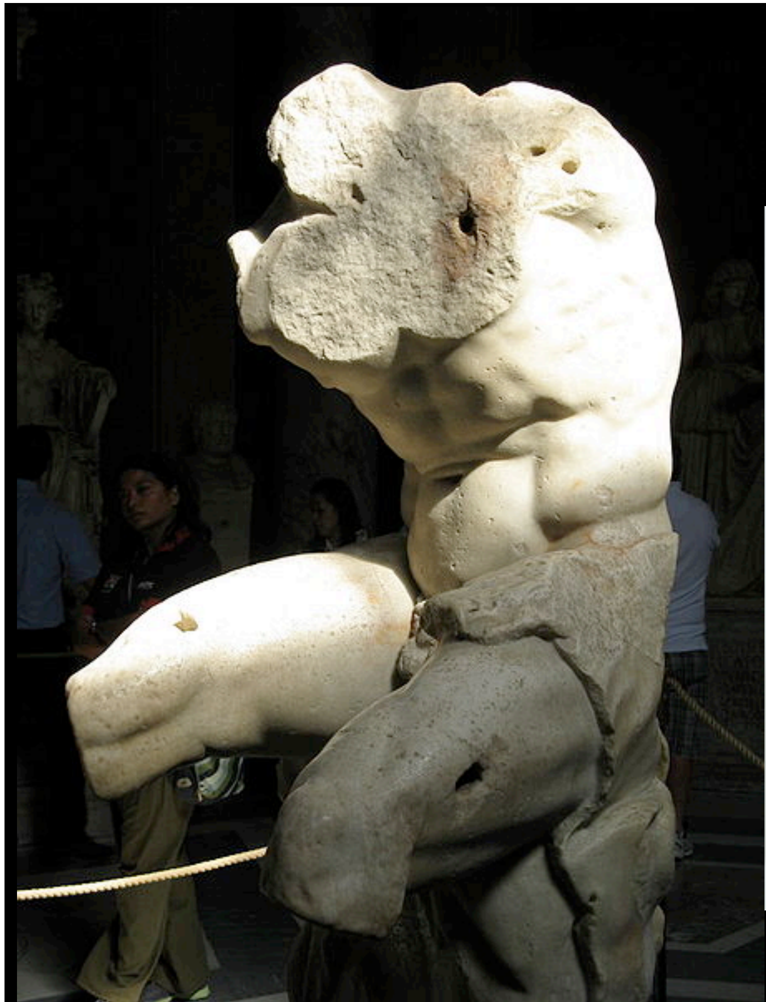
0^+

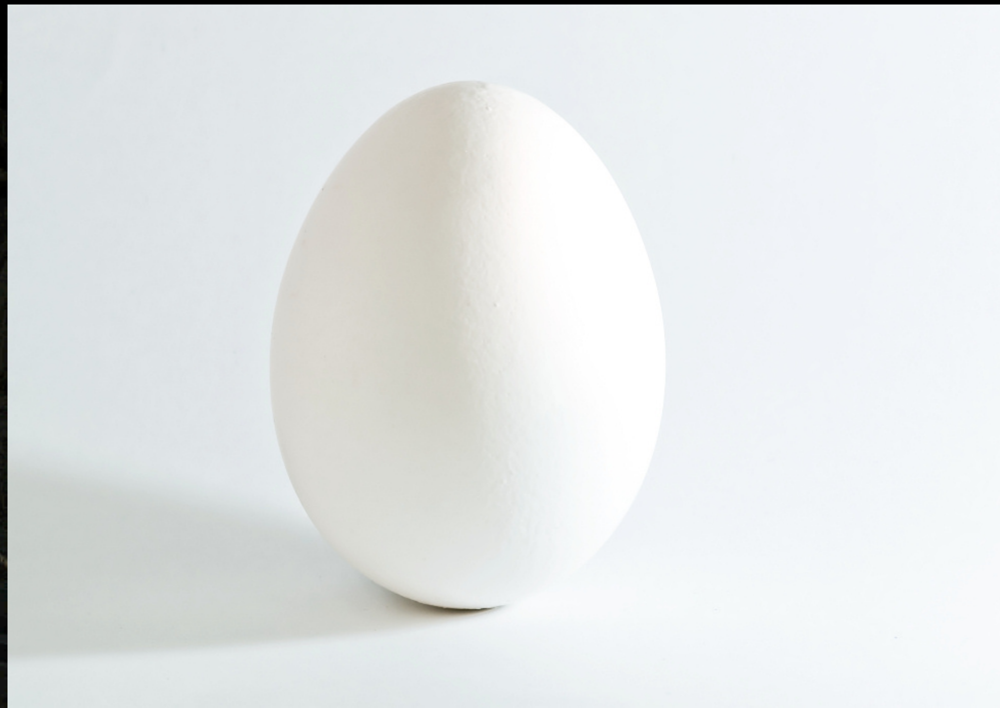

$\cos(\theta_1)$
$d\Gamma$
φ
-1.0
-0.5
0.0
0.5
1.0
6
7
8
9
0
2
4
6

M=200 GeV


0
1/4
1/2
3/4
$\cos(\theta_1) = 1$
$\cos(\theta_2)$
-1.0
-0.5
0.0
0.5
1.0
4
5
6
7
8
9
10


$\cos(\theta_1) = 0$
1/4
1/2
3/4
1
φ
0
1
2
3
4
5
6
7
8
9



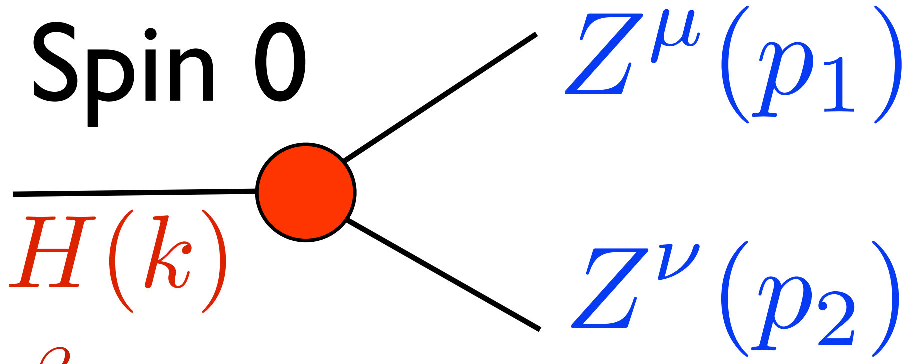


$F(x, y, z) = 0$

$$z = P(x, y)$$

$$z = P(x) * P(y)$$

$\mathcal{L}-inv$ =



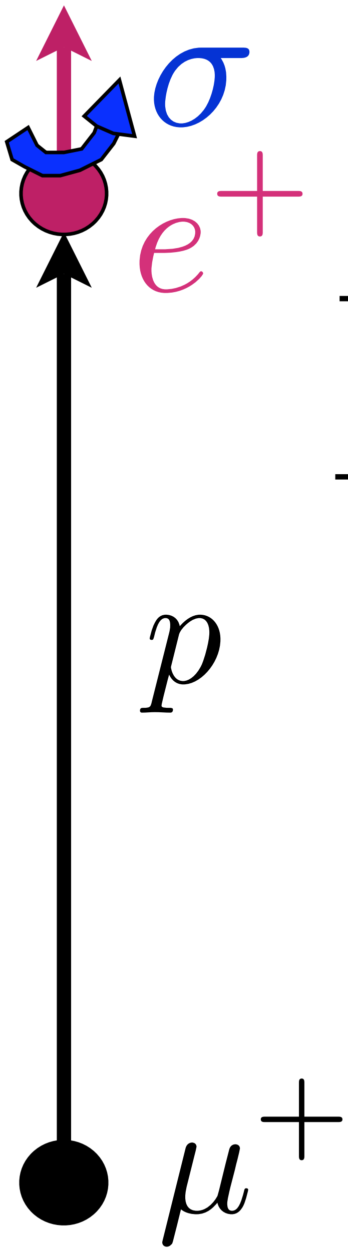
$X\ g_{\mu\nu}$ **Standard**

$$+(P+i\,Q)\epsilon_{\mu\nu\alpha\beta}\frac{p_1^{\alpha}p_2^{\beta}}{M_Z^2}$$ **Pseudoscalar**

$$-(Y+i\,Z)\frac{k_{\mu}k_{\nu}}{M_Z^2}$$ **Derivative (Composite)**

Some Interferences

XP is T-odd
XQ is C-odd
XY is C,CP-even



$$\text{Polarisation} = \frac{v}{c} \simeq 100\%$$

$$e^+ \leftrightarrow e^+_R$$

Demonstrated maximal parity violation in a purely leptonic decay

$$\mathcal{O}_P \equiv \vec{\sigma} \cdot \vec{p}$$ **P-odd**

$$\mathcal{O}_P \rightarrow -\mathcal{O}_P \; \{\vec{x} \rightarrow -\vec{x}\}$$

$$\langle \mathcal{O}_P \rangle \neq 0 \Leftrightarrow (\Gamma \propto A + B\,\mathcal{O}_P)$$

EXP: J. Duclos, J. Heintze, V. Soergel, ADR; Phys. Lett. 9, 62 (1964).

$$\mathcal{O}_T \equiv \vec{p}_{e^+} \cdot \vec{p}_{\mu^+} \times \vec{p}_{\mu^-} \propto \sin\theta_1 \sin\theta_2 \sin\varphi$$

$\mathcal{O}_T \to -\mathcal{O}_T \; \{t \to -t\}$ T-odd (& P-odd)

$\langle \mathcal{O}_T \rangle \neq 0$ ***You HAVE NOT proven that T (↔ CP) is violated***

At the LHC **H => ZZ statistics will be In-Sufficient: You HAVE**

Literature often wrong.

e.g. $\mathcal{O}_T$ *is T-even, C-odd*

$$S \to S_{fi} \qquad |S|^2 = 1 \qquad S \equiv 1 + iT$$

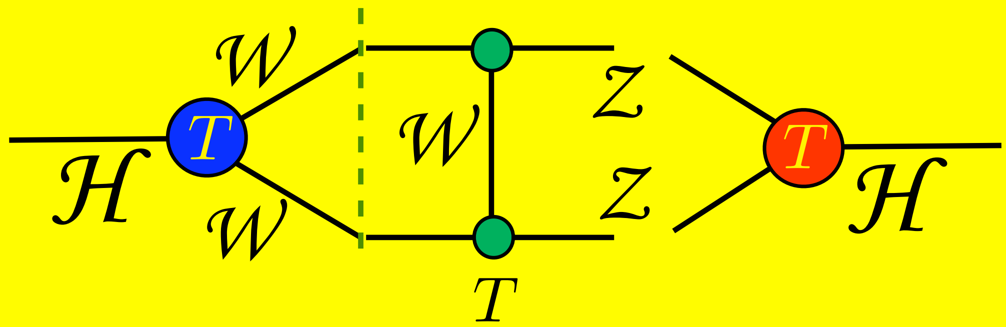
$$T - T^\dagger = i\,T\,T^\dagger \equiv i\,\mathcal{A} \qquad \sum_\Gamma |\Gamma\rangle\langle\Gamma| = 1$$

$$T_{fi} - T^*_{if} = i\,\mathcal{A}_{fi} \equiv \sum_\Gamma T_{f\Gamma}T^*_{i\Gamma}$$

$$|T_{fi}|^2 = |T_{if}|^2 + 2\,Im(\mathcal{A}\,T^*) - |\mathcal{A}|^2$$

Assume T (or CP) -inv $\sim$: $\{\vec{p} \to -\vec{p},\ \vec{\sigma} \to -\vec{\sigma}\}$

$$\underbrace{|T_{fi}|^2 - |T_{\tilde{f}\tilde{i}}|^2}_{\mathcal{O}_T} = \mathcal{O}(T^3) + \mathcal{O}(T^4)$$



$$S \to S_{fi} \qquad |S|^2 = 1 \qquad S \equiv 1 + i\,T$$

$$T - T^\dagger = i\,T\,T^\dagger \equiv i\,\mathcal{A} \qquad \sum_\Gamma |\Gamma\rangle\langle\Gamma| = 1$$

$$T_{fi} - T^*_{if} = i\,\mathcal{A}_{fi} \equiv \sum_\Gamma T_{f\Gamma}T^*_{i\Gamma}$$

$$|T_{fi}|^2 = |T_{if}|^2 + 2\,Im(\mathcal{A}\,T^*) - |\mathcal{A}|^2$$

Assume T (or CP) -inv

$\sim$: $\{\vec{p} \to -\vec{p},\ \vec{\sigma} \to -\vec{\sigma}\}$

$$|T_{fi}|^2 - |T_{\tilde{f}\tilde{i}}|^2 = \sout{\mathcal{O}(T^3) + \mathcal{O}(T^4)}$$

$$\mathcal{O}_T \neq 0 \quad \Rightarrow \quad \sout{\textbf{CP}}$$

${}_sWeights$ and ${}_sPlots$

P. E. Condon & P. L. Cowell, Phys. Rev. D 9 (1974) 2558

F.R. Le Diberder and M. Pivk, BABAR collab.

I can't believe it

Boy! t'is true !!!

So simple and obvious

Why didn't I think of it long ago?

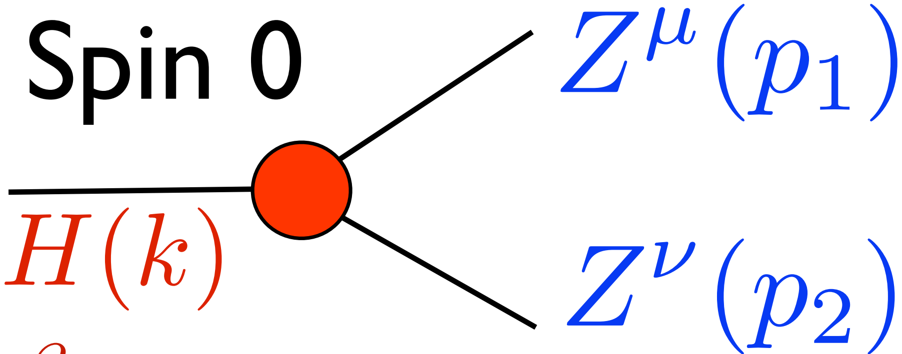
STATISTICALLY *OPTIMAL* FOR A NARROW M(ZZ)

and, WITH A BIT MORE EFFORT, FOR A WIDE ONE

$\mathcal{L}-inv =$

$X\, g_{\mu\nu}$ **Standard**

$+(P + i\,Q)\epsilon_{\mu\nu\alpha\beta}\frac{p_1^\alpha p_2^\beta}{M_Z^2}$ **Pseudoscalar**

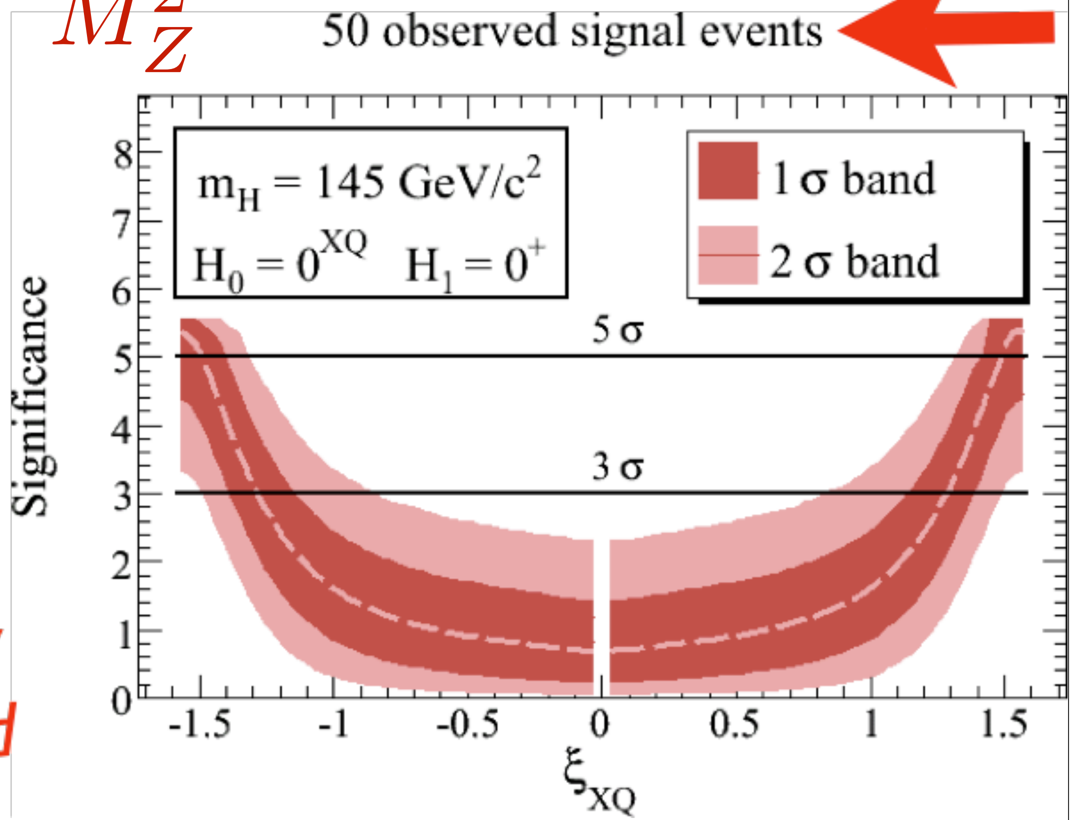


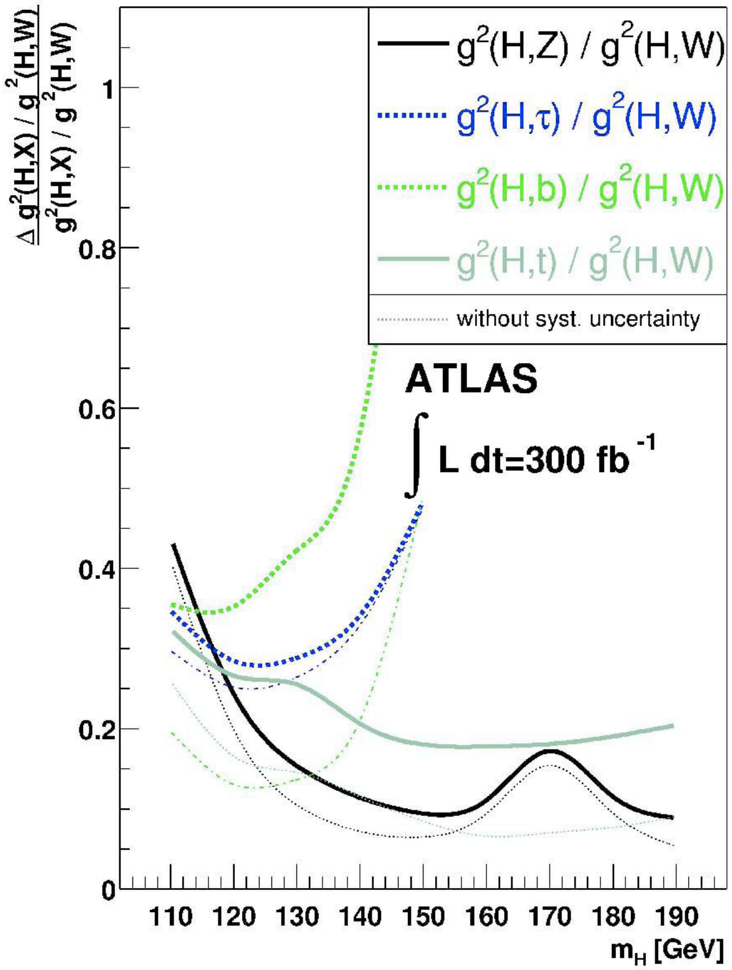
XP: CP-odd, P-even

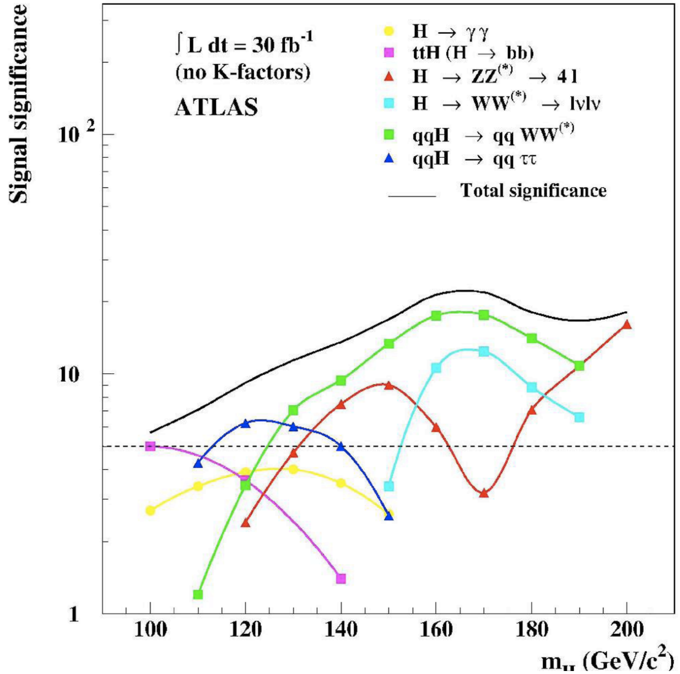
XQ: P-odd, CP-even

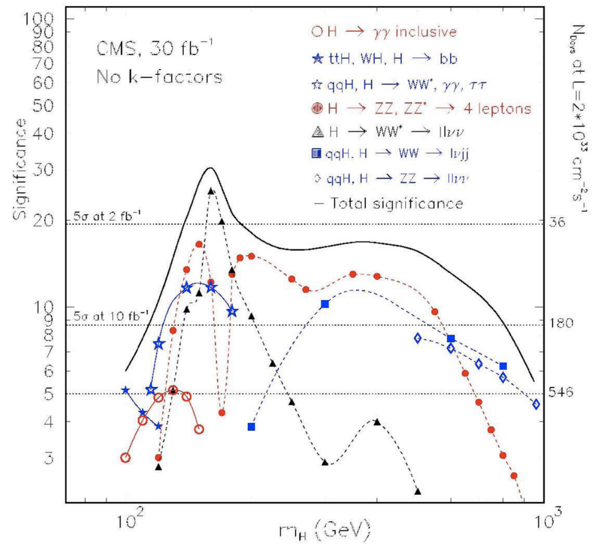
$$\xi \equiv \arctan\frac{Q}{X}$$

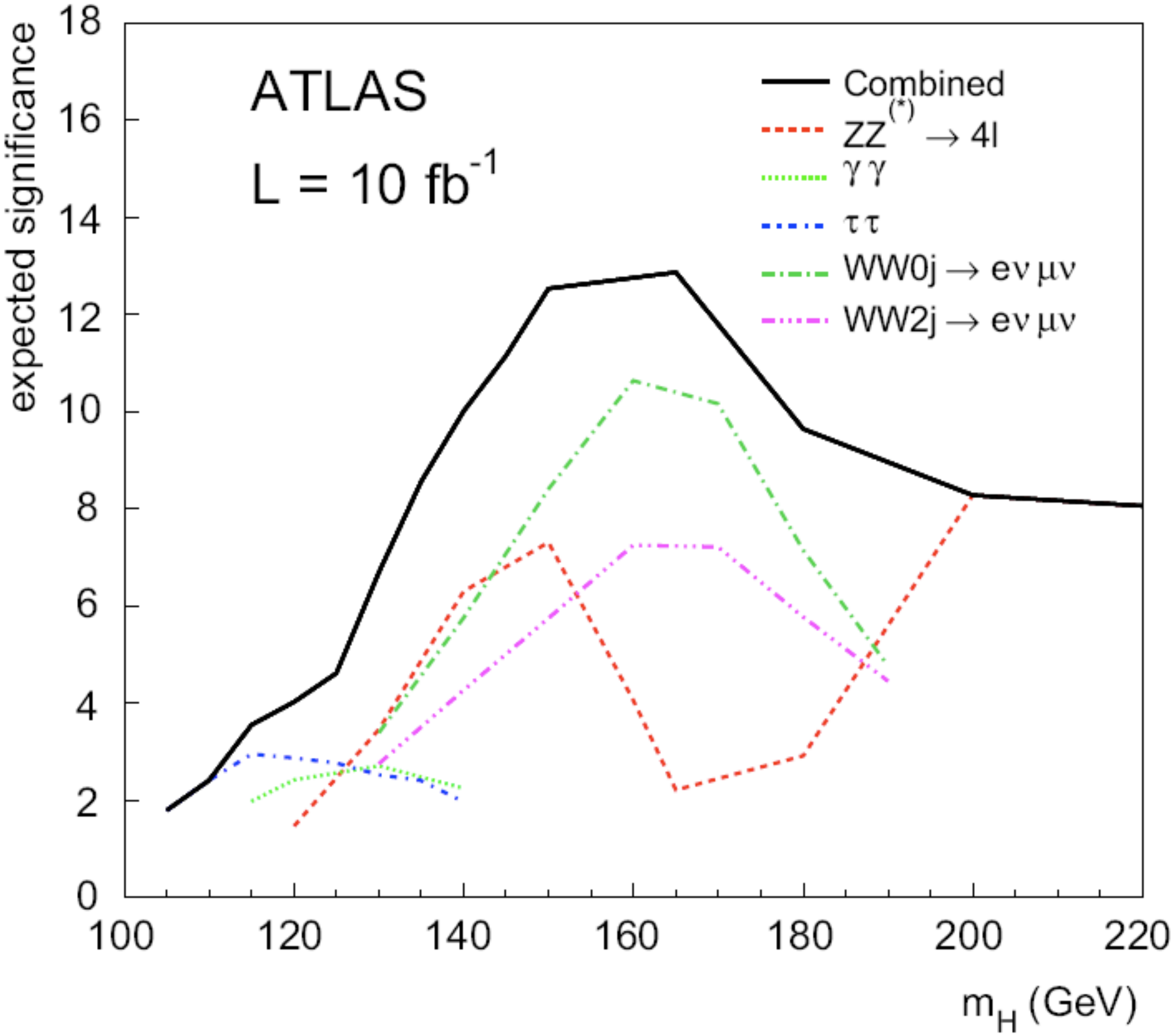
Only large mixings may be disfavoured/Standard




$\Delta g^2(H,X) / g^2(H,W)$ / $g^2(H,X) / g^2(H,W)$
$g^2(H,Z) / g^2(H,W)$
$g^2(H,\tau) / g^2(H,W)$
$g^2(H,b) / g^2(H,W)$
$g^2(H,t) / g^2(H,W)$
without syst. uncertainty
ATLAS
$\int L\,dt = 300\ fb^{-1}$
m_H [GeV]


Signal significance
$\int L\,dt = 30\ fb^{-1}$
(no K-factors)
ATLAS
$H \to \gamma\gamma$
$ttH\ (H \to bb)$
$H \to ZZ^{(*)} \to 4l$
$H \to WW^{(*)} \to l\nu l\nu$
$qqH \to qq\ WW^{(*)}$
$qqH \to qq\ \tau\tau$
Total significance
m_H (GeV/c^2)


CMS, 30 fb^{-1}
No k-factors
$H \to \gamma\gamma$ inclusive
$ttH, WH, H \to bb$
$qqH, H \to WW^*, \gamma\gamma, \tau\tau$
$H \to ZZ, ZZ^* \to$ 4 leptons
$H \to WW^* \to l\nu l\nu$
$qqH, H \to WW \to l\nu jj$
$qqH, H \to ZZ \to ll\nu\nu$
Total significance
Significance
5σ at 2 fb^{-1}
5σ at 10 fb^{-1}
N_{evs} at $L=2*10^{33}\ cm^{-2}s^{-1}$
m_H (GeV)



ATLAS
L = 10 fb-1
Combined
ZZ(*) → 4l
γ γ
τ τ
WW0j → eν μν
WW2j → eν μν
expected significance
0
2
4
6
8
10
12
14
16
18
100
120
140
160
180
200
220
mH (GeV)