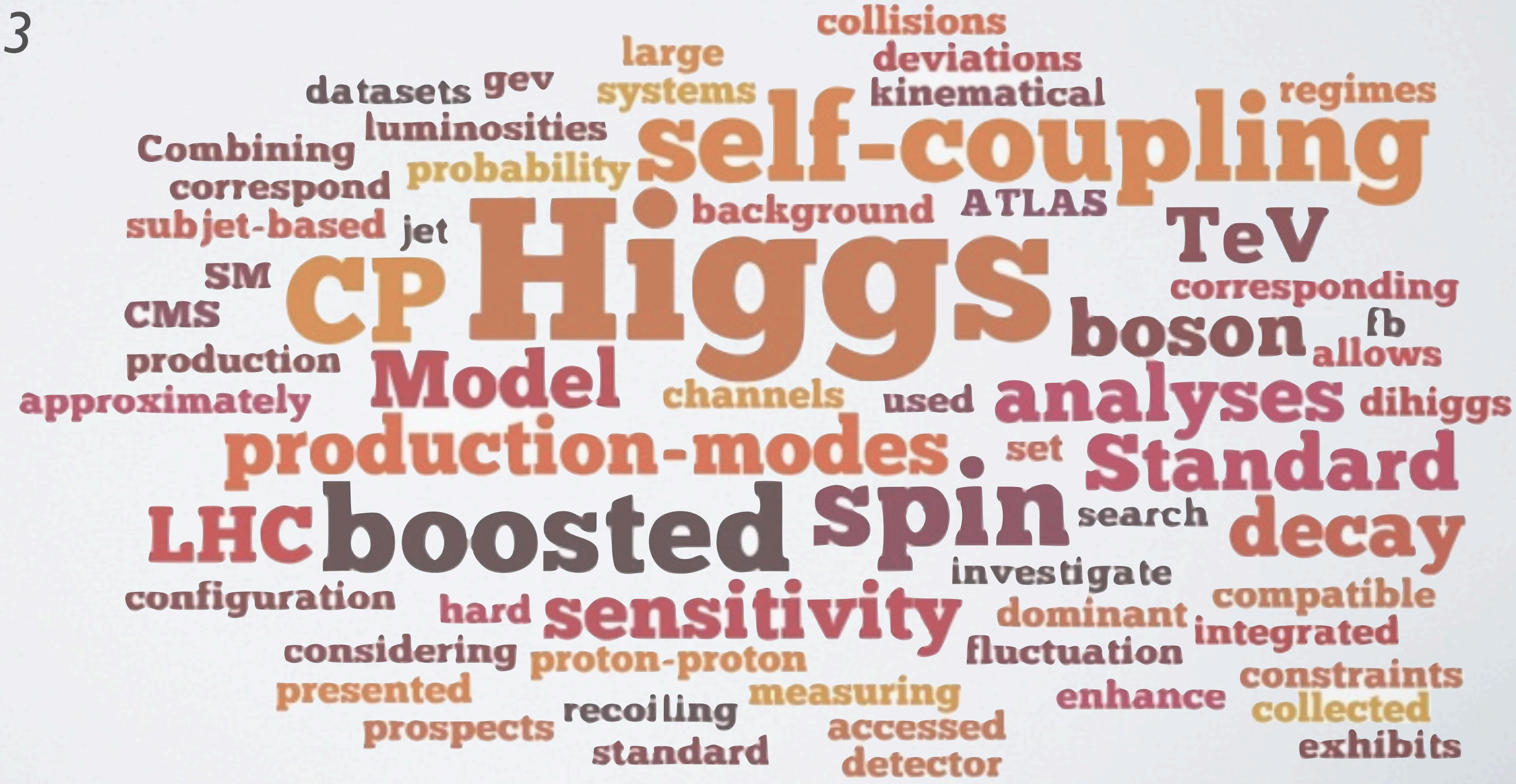
THEORY CHALLENGES AND TOOLS FOR HIGGS PHYSICS

CHRISTOPH ENGLERT

Durham, 07.01.2013



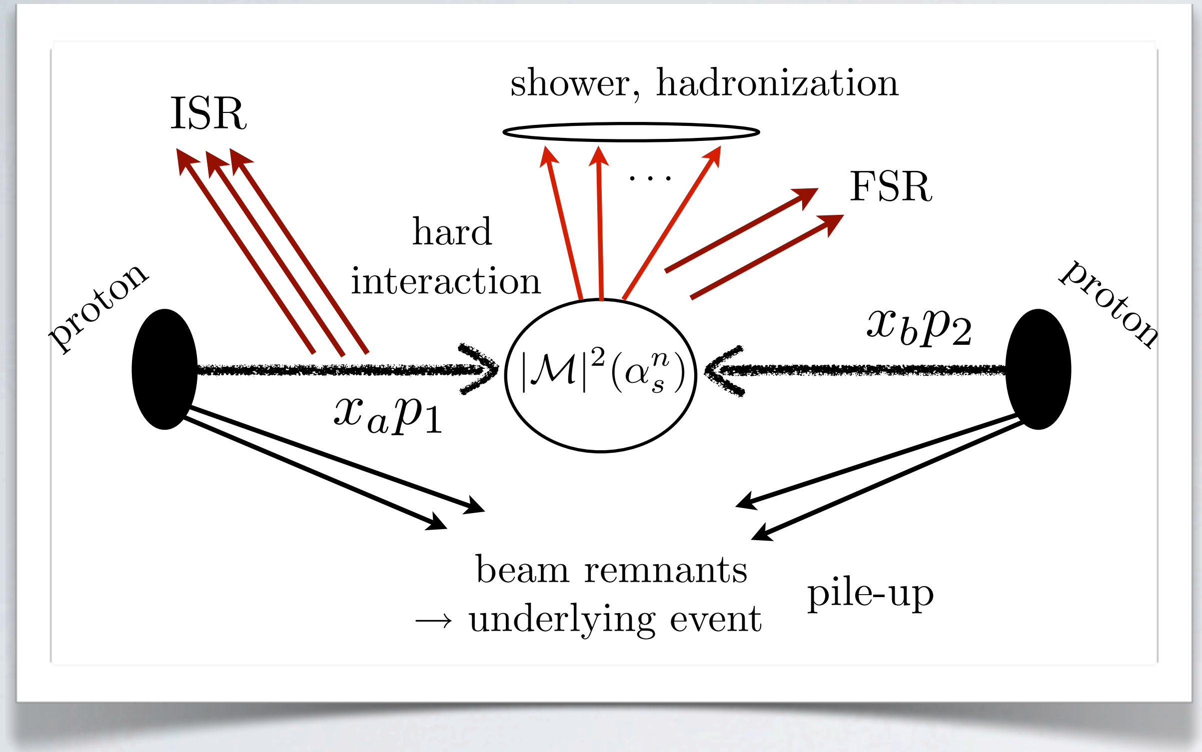
WHAT (NOT) TO EXPECT...

- I will review "classical" challenges (i.e. perturbative **uncertainties**, **precision calculations**, ...) in the context of jet-based analyses
- I will also review new jet substructure-based analysis **strategies**
- I will mention a (biased) list of **tools** on the way. Some of them you may already know, some you won't. The hands-on session allows you to dig deeper.
- It's one hour. Therefore no details.
- Higgs physics as a phenomenological example, but all what I say is also true in wider context.
- **INTERRUPT ME AT ANY TIME IF SOMETHING REQUIRES MORE EXPLANATION***

---

* or meet me for a beer at the bar

How we model hadron collider measurements ...

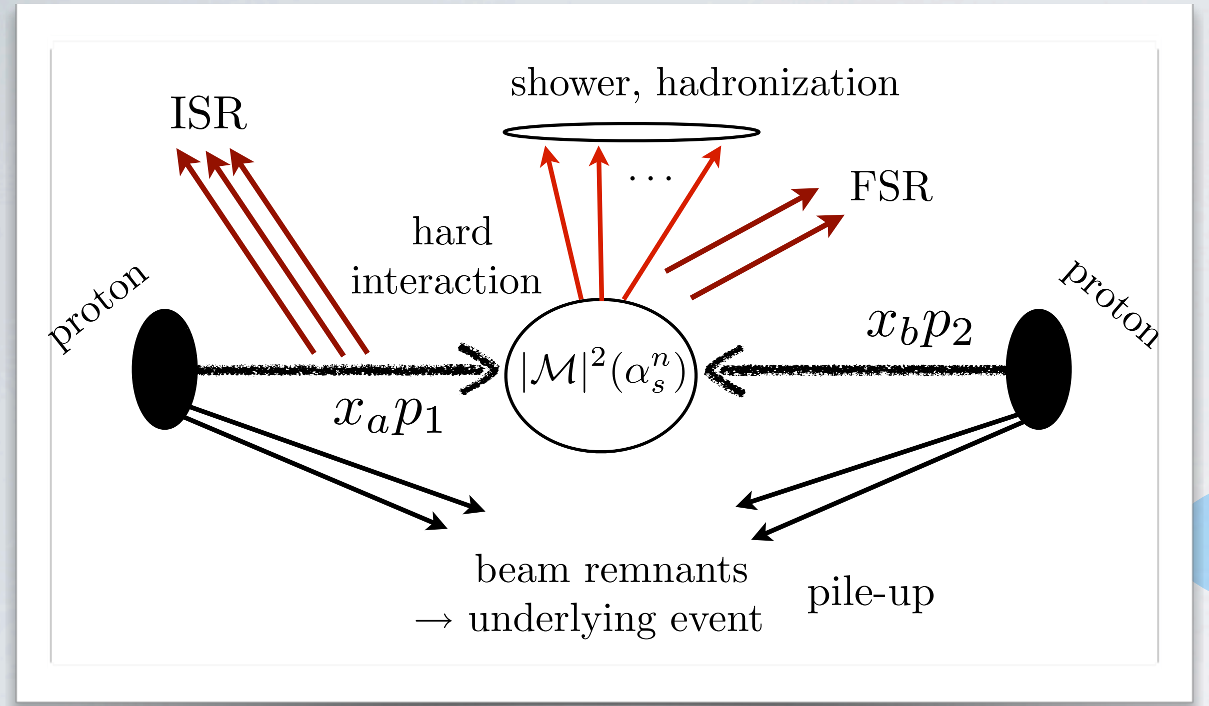


$$\mathrm{d}\sigma(P(p_1)P(p_2) \to X)$$

$$= \sum_{a,b} \iint_0^1 \mathrm{d}x_a \, \mathrm{d}x_b \, f_{a/P}(x_a, \mu_F^2) \, f_{b/P}(x_b, \mu_F^2)$$

$$\mathrm{d}\sigma(a(x_a p_1) b(x_b p_2) \to Y) \; \Theta[\mathcal{C}(X)] \; \mathcal{F}(X, Y)$$

How we model hadron collider measurements ...

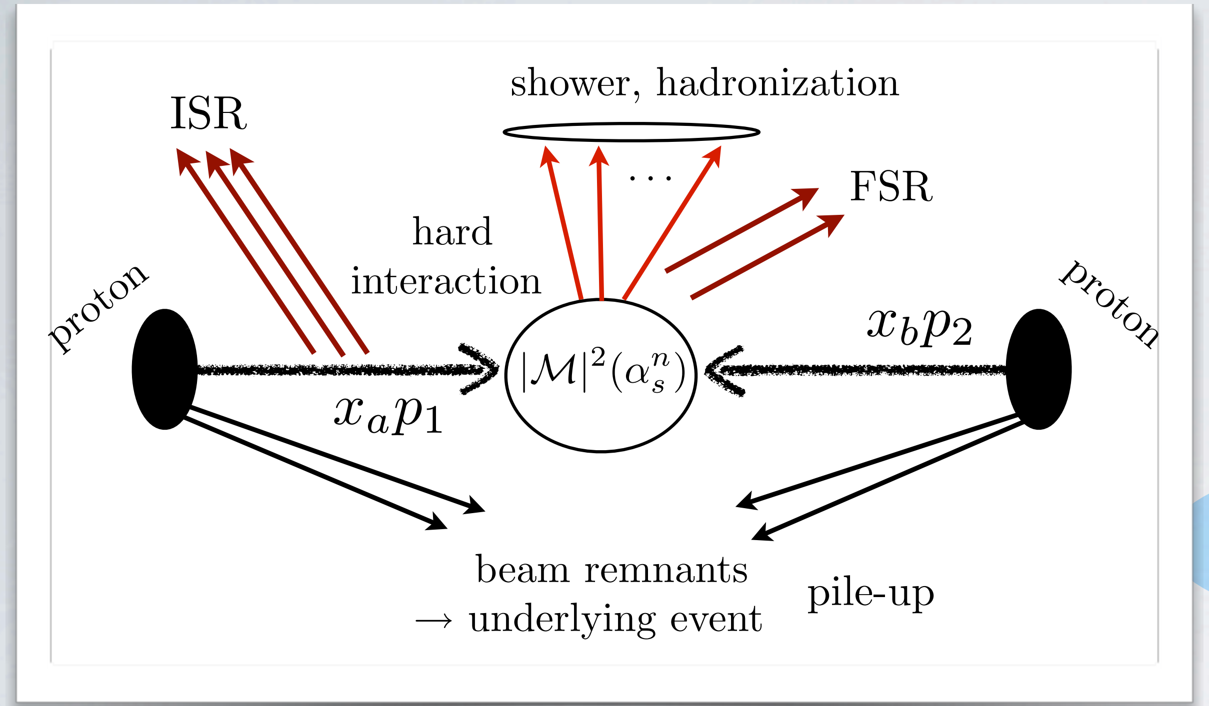


$$\mathrm{d}\sigma(P(p_1)P(p_2) \to X)$$
$$= \sum_{a,b} \iint_0^1 \mathrm{d}x_a \, \mathrm{d}x_b \, f_{a/P}(x_a, \mu_F^2) \, f_{b/P}(x_b, \mu_F^2)$$
$$\mathrm{d}\sigma(a(x_a p_1) b(x_b p_2) \to Y) \; \Theta[\mathcal{C}(X)] \; \mathcal{F}(X, Y)$$

hard partonic (fixed-order) cross section (matched with parton shower, LL resum.)

[Corcella et al. HERWIG]
[Bähr et al. HERWIG++]
[Frixione et al. MC@NLO]
[Alioli et al. POWHEG Box]
[Hoeche et al. SHERPA]

How we model hadron collider measurements ...



$$\mathrm{d}\sigma(P(p_1)P(p_2)\to X)$$

$$=\sum_{a,b}\iint_0^1 \mathrm{d}x_a\,\mathrm{d}x_b\, f_{a/P}(x_a,\mu_F^2)\, f_{b/P}(x_b,\mu_F^2)$$

$$\mathrm{d}\sigma(a(x_a p_1)b(x_b p_2)\to Y)\,\Theta[\mathcal{C}(X)]\,\mathcal{F}(X,Y)$$

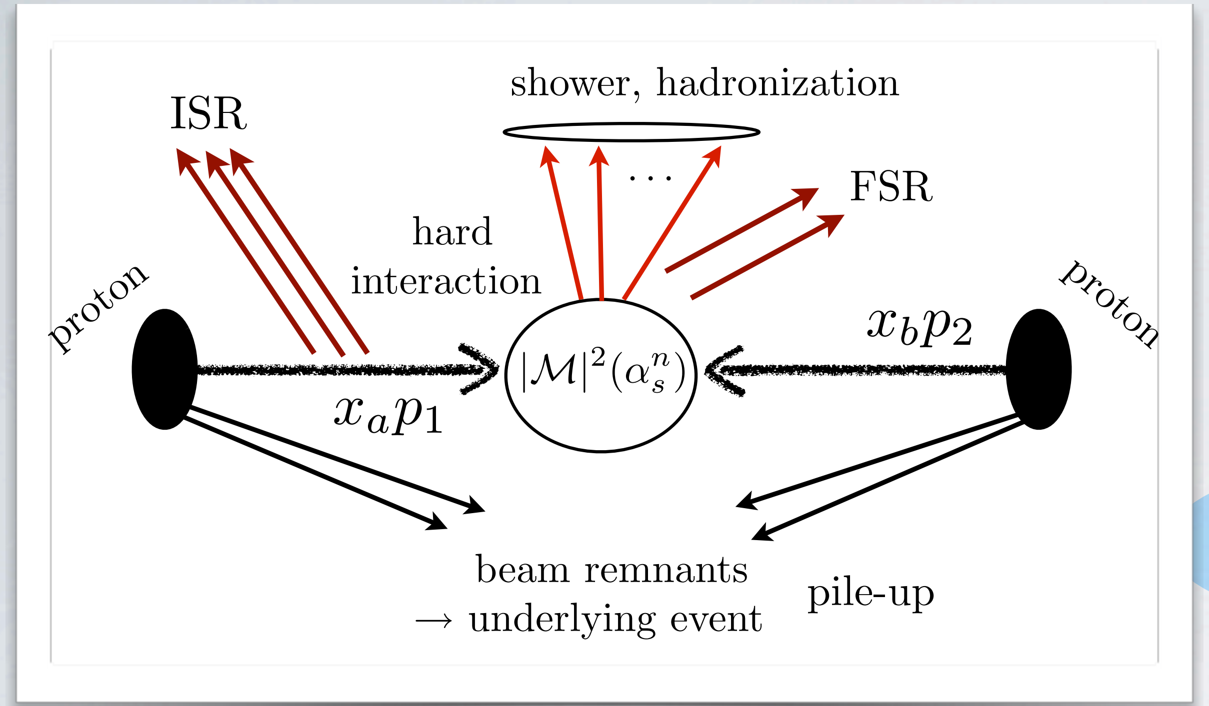
hard partonic (fixed-order) cross section (matched with parton shower, LL resum.)

[Corcella et al. HERWIG]
[Bähr et al. HERWIG++]
[Frixione et al. MC@NLO]
[Alioli et al. POWHEG Box]
[Hoeche et al. SHERPA]

acceptance cuts

- S/B
- detector geometry

How we model hadron collider measurements ...



$$\mathrm{d}\sigma(P(p_1)P(p_2)\to X) = \sum_{a,b}\iint_0^1 \mathrm{d}x_a\,\mathrm{d}x_b\, f_{a/P}(x_a,\mu_F^2)\, f_{b/P}(x_b,\mu_F^2)\, \mathrm{d}\sigma(a(x_a p_1)b(x_b p_2)\to Y)\,\Theta[\mathcal{C}(X)]\,\mathcal{F}(X,Y)$$

hard partonic (fixed-order) cross section (matched with parton shower, LL resum.)

[Corcella et al. HERWIG]
[Bähr et al. HERWIG++]
[Frixione et al. MC@NLO]
[Alioli et al. POWHEG Box]
[Hoeche et al. SHERPA]

acceptance cuts

- S/B
- detector geometry

IR safe hadronic observable

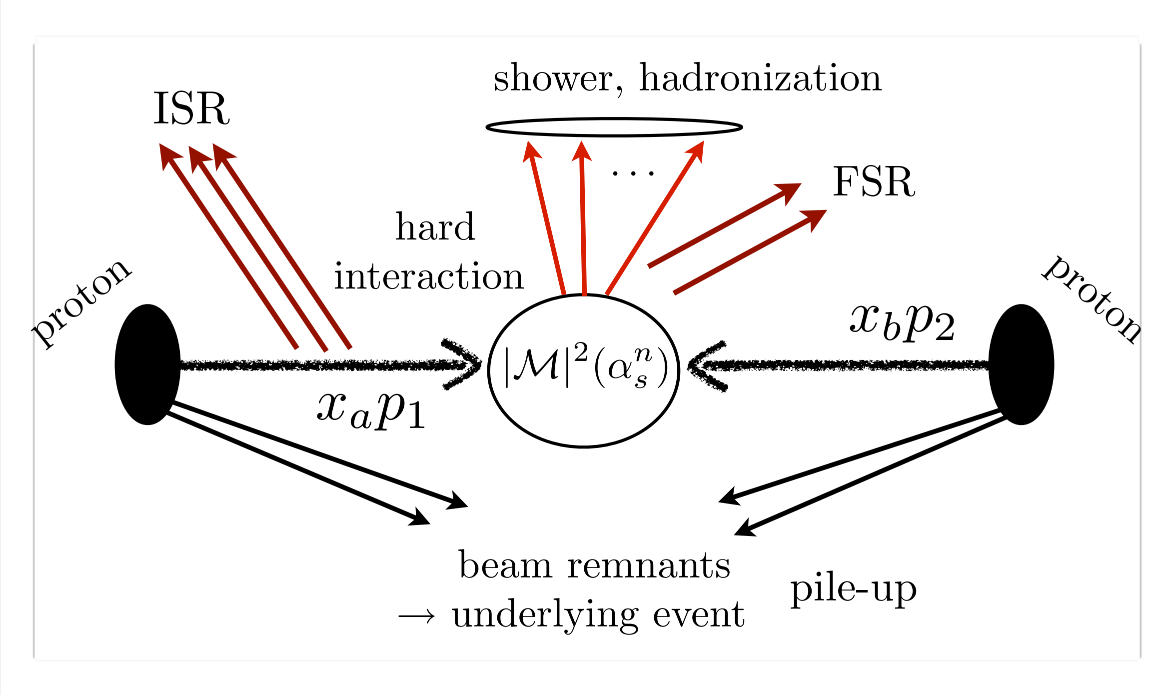
- translate theoretical objects into physical quantities (i.e. **jets**,...)

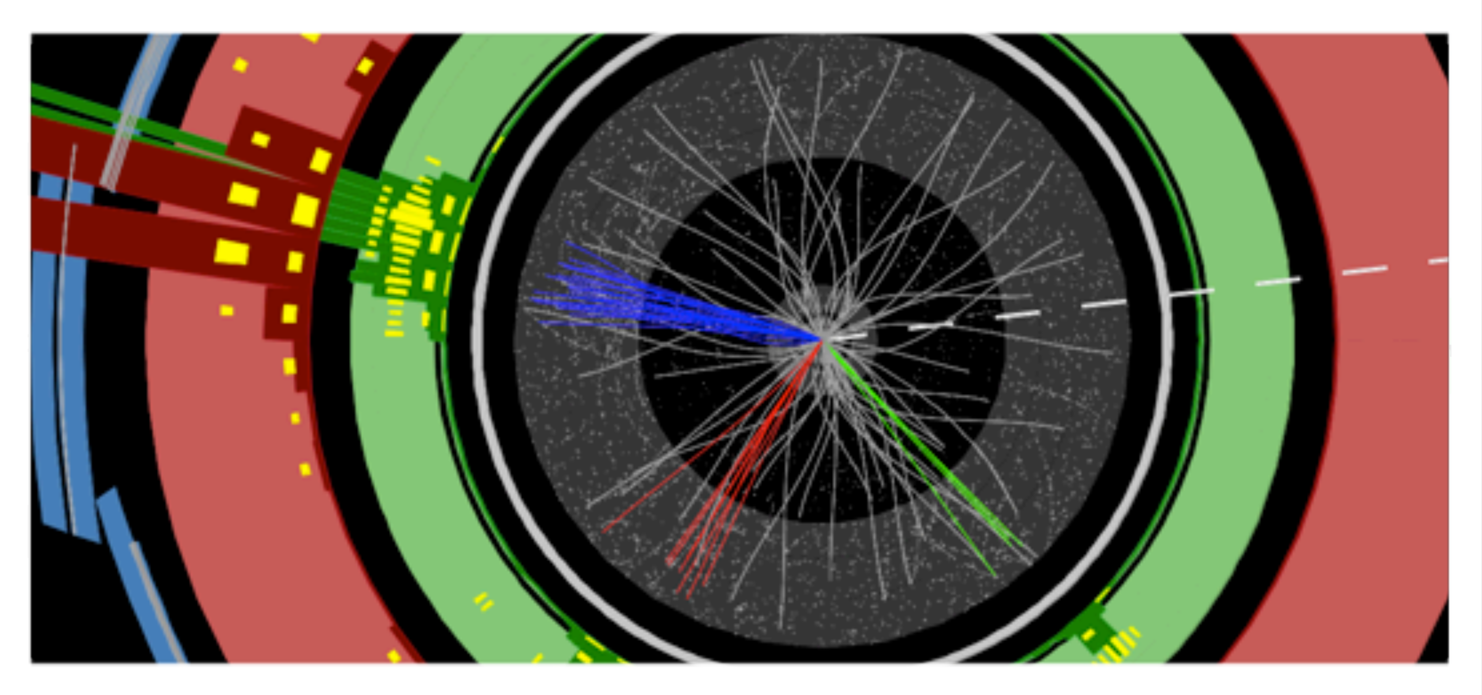
  [Catani, Dokshitzer, Webber '92] [Ellis, Soper '93]

- form invariance of the perturbative series expansion, factorization

  [Kinoshita, Lee, Nauenberg \`64, \`66]
  [Collins, Soper, Sterman \`88]
  ....

How we model hadron collider measurements ...





[ATLAS '11]

hard partonic (fixed-order) cross section (matched with parton shower, LL resum.)

[Corcella et al. HERWIG]
[Bähr et al. HERWIG++]
[Frixione et al. MC@NLO]
[Alioli et al. POWHEG Box]
[Hoeche et al. SHERPA]

acceptance cuts

- S/B
- detector geometry

IR safe hadronic observable

- translate theoretical objects into physical quantities (i.e. **jets**,...)

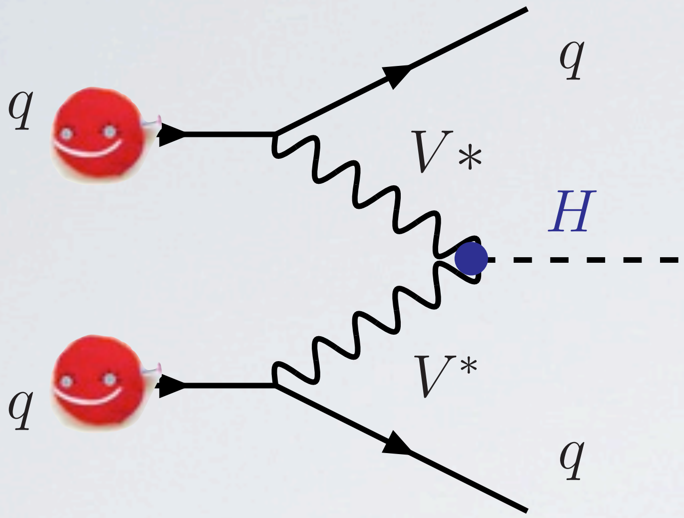
  [Catani, Dokshitzer, Webber '92] [Ellis, Soper '93]

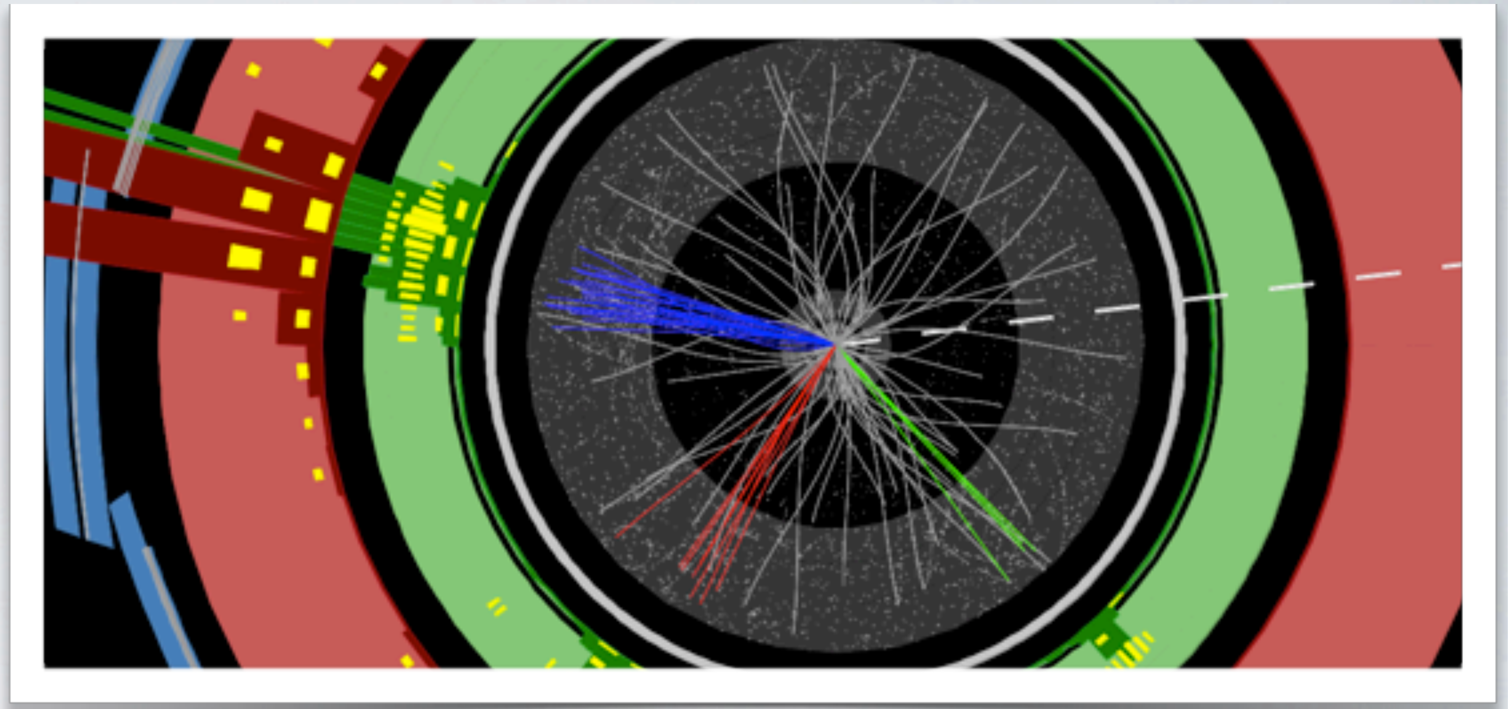
- form invariance of the perturbative series expansion, factorization

  [Kinoshita, Lee, Nauenberg \`64, \`66]
  [Collins, Soper, Sterman \`88]
  ....

Why jets ??

$\mathcal{M} \sim$

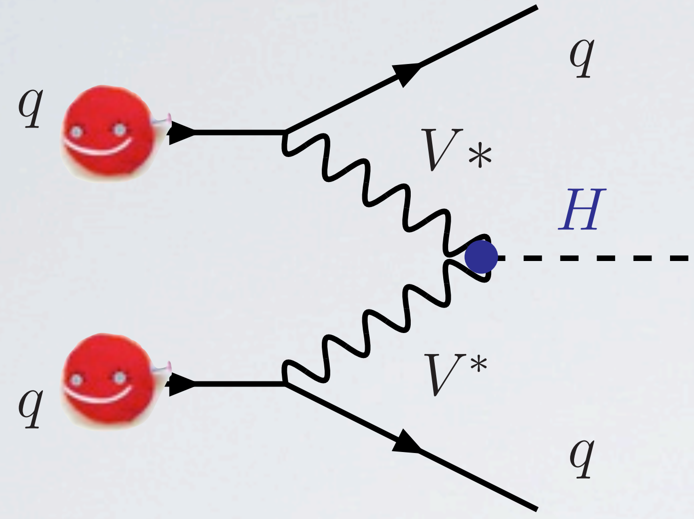


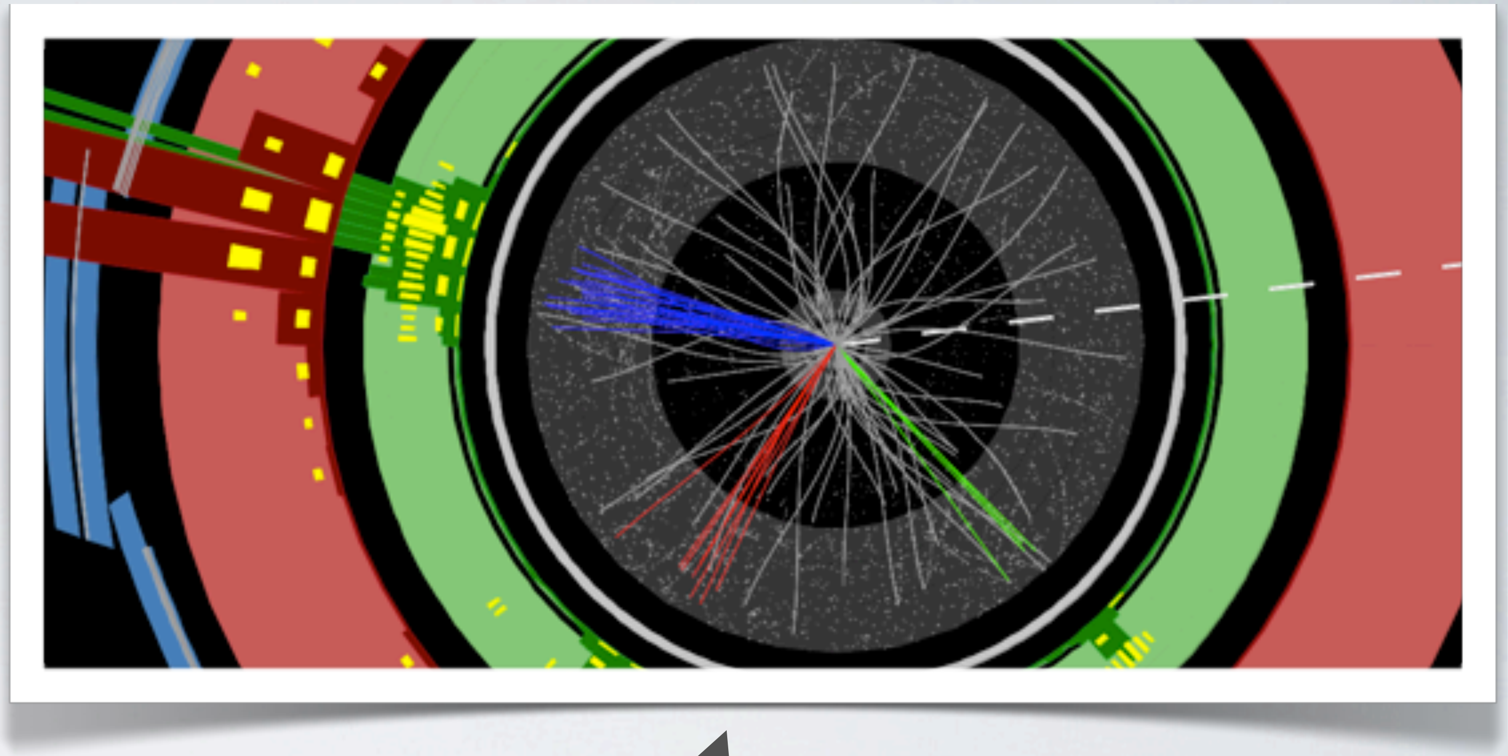


phenomenological interface
of theory and experiment

Why jets ??

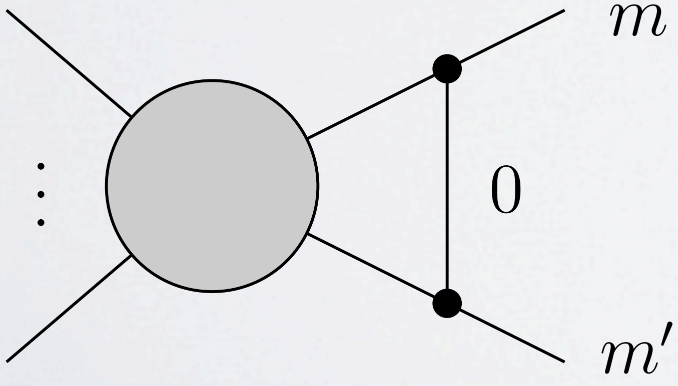
$\mathcal{M} \sim$



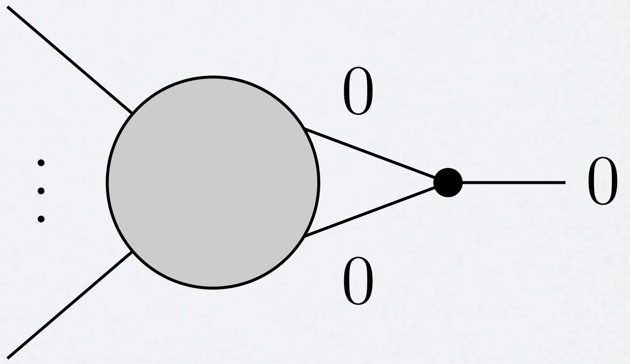


phenomenological interface of theory and experiment

IR issues with pQCD (in the chiral limit): DIVERGENCIES



soft singularities



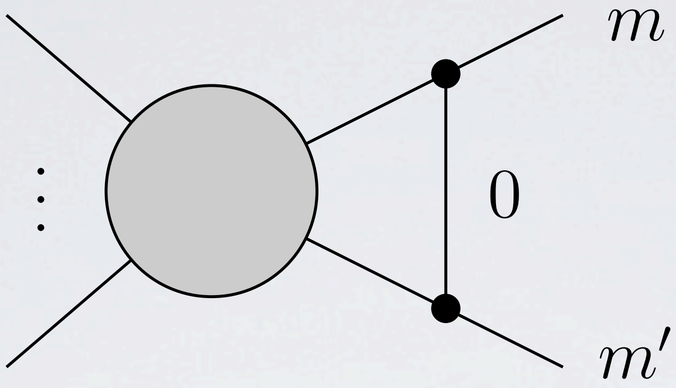
$$\sim \log \frac{0}{m^2}$$

collinear mass singularities

Why jets ??

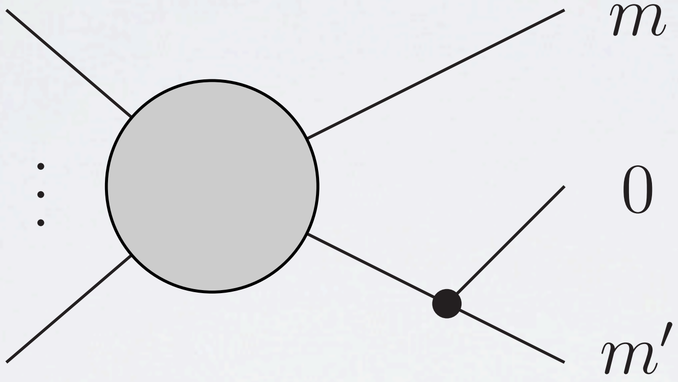
IR issues with pQCD (in the chiral limit): DIVERGENCIES

n-to-2 particle phase space



$$\sim \log \frac{0}{m^2}$$

n-to-2+1 particle phase space



$$\sim \log \frac{m^2}{0}$$

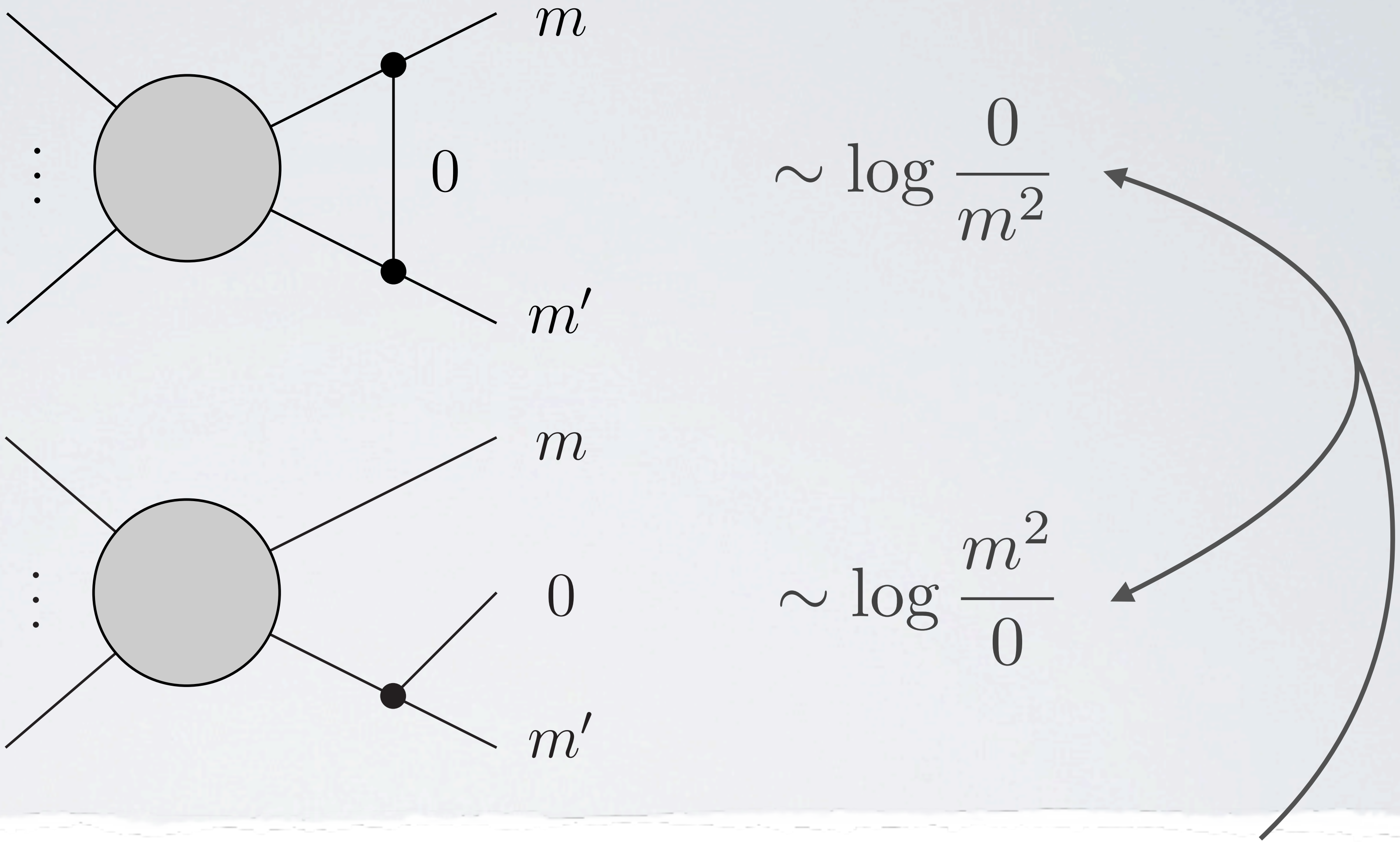
[Kinoshita `62] [Lee, Naunberg `64]

Why jets ??

IR issues with pQCD (in the chiral limit): DIVERGENCIES

n-to-2 particle phase space

n-to-2+1 particle phase space



$$\sim \log \frac{0}{m^2}$$

$$\sim \log \frac{m^2}{0}$$

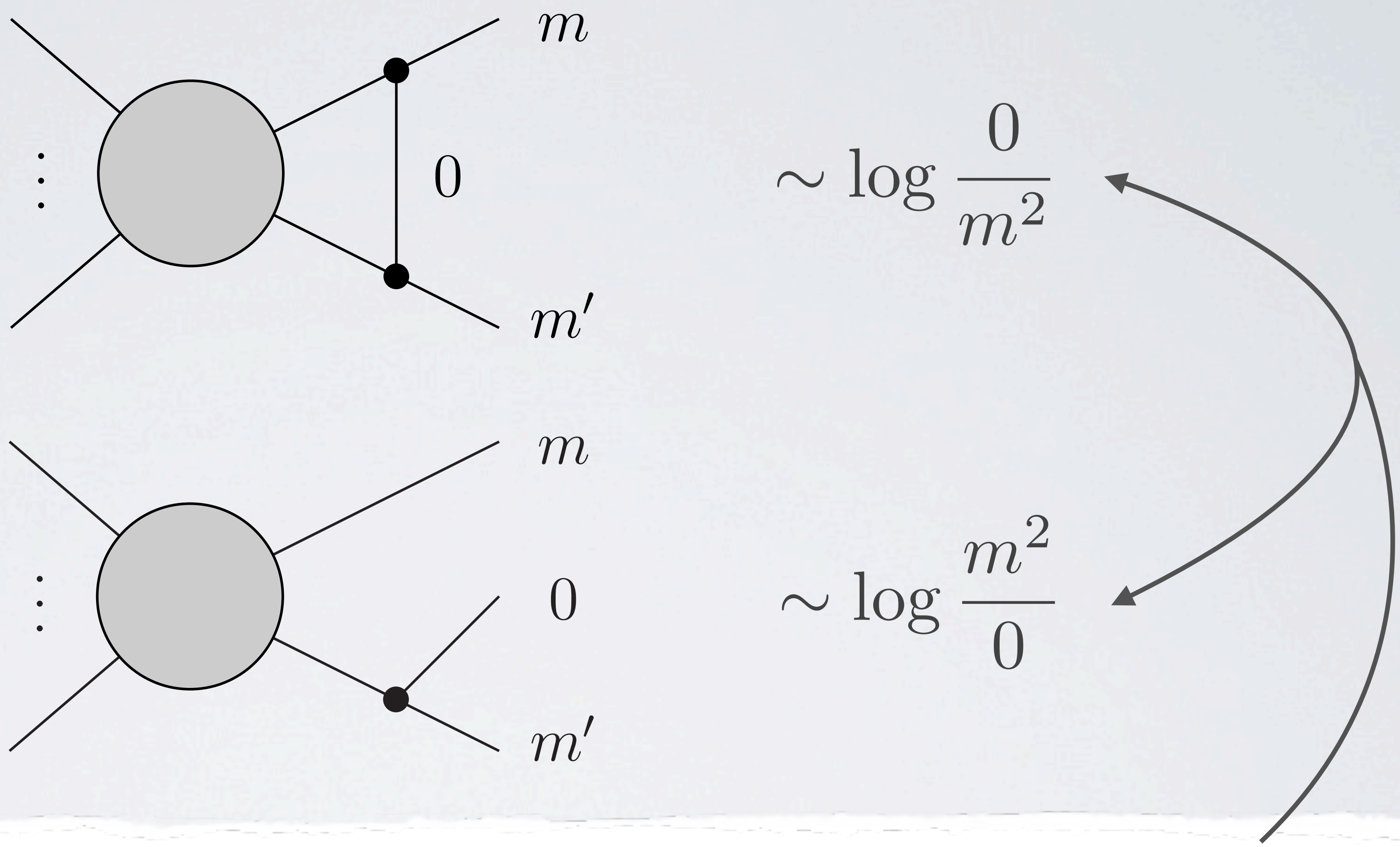
[Kinoshita `62] [Lee, Naunberg `64]

$$\mathcal{F}\left(p_f^{(1)},\ldots,p_f^{(i-1)},p_f^{(i)},p_f^{(i+1)},\ldots\right) \longrightarrow \mathcal{F}\left(p_f^{(1)},\ldots,p_f^{(i-1)},p_f^{(i+1)},\ldots\right)$$

$$\text{if } p_f^{(i)} \cdot p_f^{(j)} \to 0 \text{ for all } j \text{ with } i \text{ fixed but arbitrary}$$

Why jets ??

IR issues with pQCD (in the chiral limit): ~~DIVERGENCIES~~



n-to-2 particle phase space

$$\sim \log \frac{0}{m^2}$$

n-to-2+1 particle phase space

$$\sim \log \frac{m^2}{0}$$

[Kinoshita `62] [Lee, Naunberg `64]

$$\mathcal{F}\left(p_f^{(1)},\dots,p_f^{(i-1)},p_f^{(i)},p_f^{(i+1)},\dots\right) \longrightarrow \mathcal{F}\left(p_f^{(1)},\dots,p_f^{(i-1)},p_f^{(i+1)},\dots\right)$$

$$\text{if } p_f^{(i)} \cdot p_f^{(j)} \to 0 \text{ for all } j \text{ with } i \text{ fixed but arbitrary}$$

final state hadron observables must not be sensitive to collinear and soft radiation

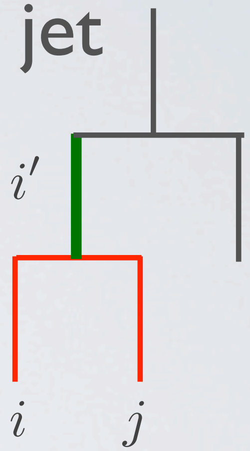
Contemporary jet algorithms (infrared safe)

1. for each of the final state tracks/calorimeter hits/partons compute

$$d_{ij} = \min(p_{T,i}^{2k}, p_{T,j}^{2k}) \frac{\Delta R_{ij}^2}{R^2} \qquad \Delta R_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$

$$d_{iB} = p_{T,i}^{2k}$$

2. find the minimum of $\{d_{ij}, d_{iB}\}$
3. if the minimum is d_{ij} recombine $ij \to i'$ and return 1
4. if the minimum is d_{iB} remove i from the list and define it a final state jet and return to 1
5. stop when no candidates are left



angular ordering!

cluster history

$k = 0$ Cambridge/Aachen: small ... large distances

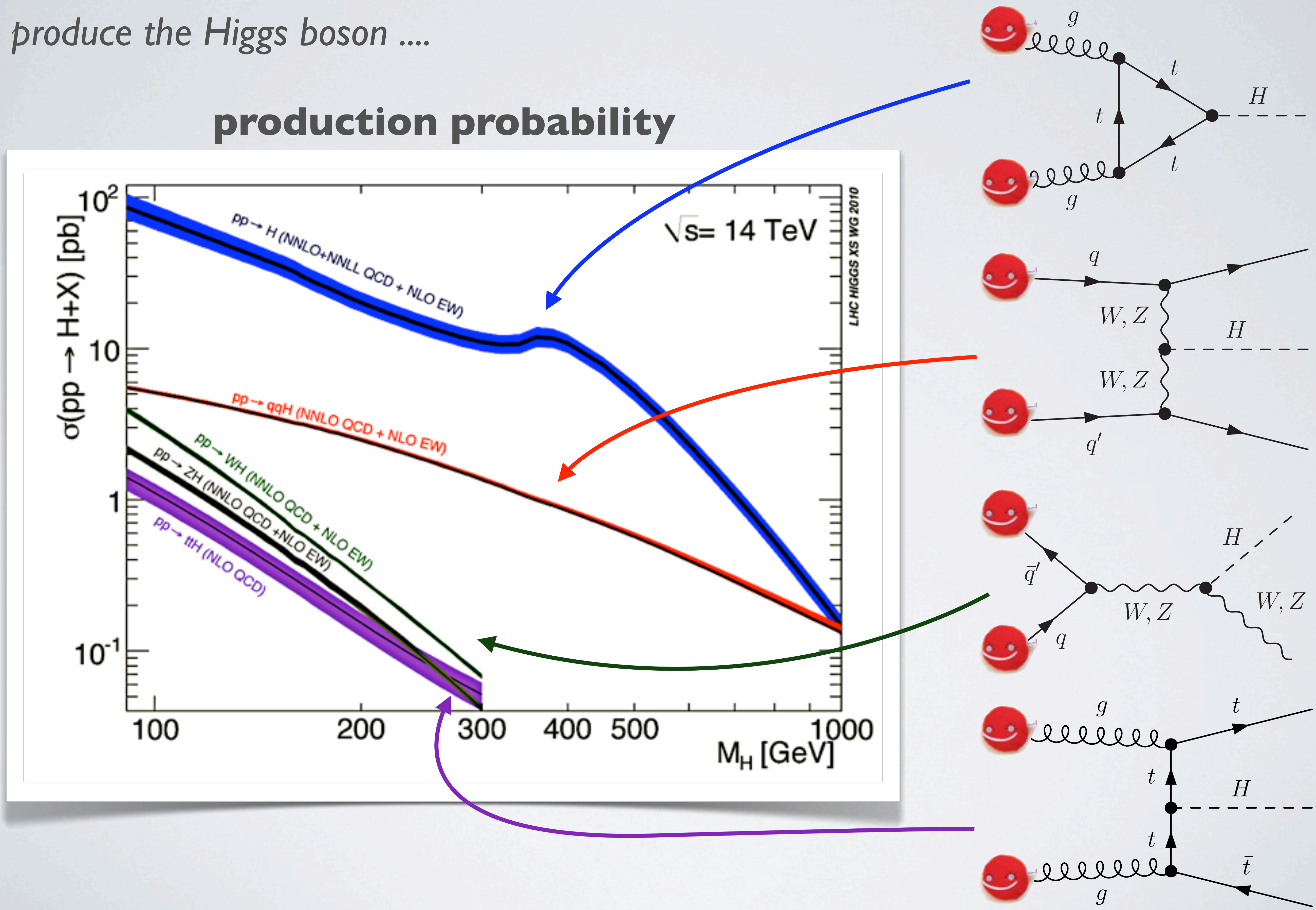
$k = 1$ inclusive kT: soft, small .... hard, large

$k = -1$ anti-kT: hard, small .... soft, large

This is what the LHC is designed to do ...

produce the Higgs boson ....

production probability

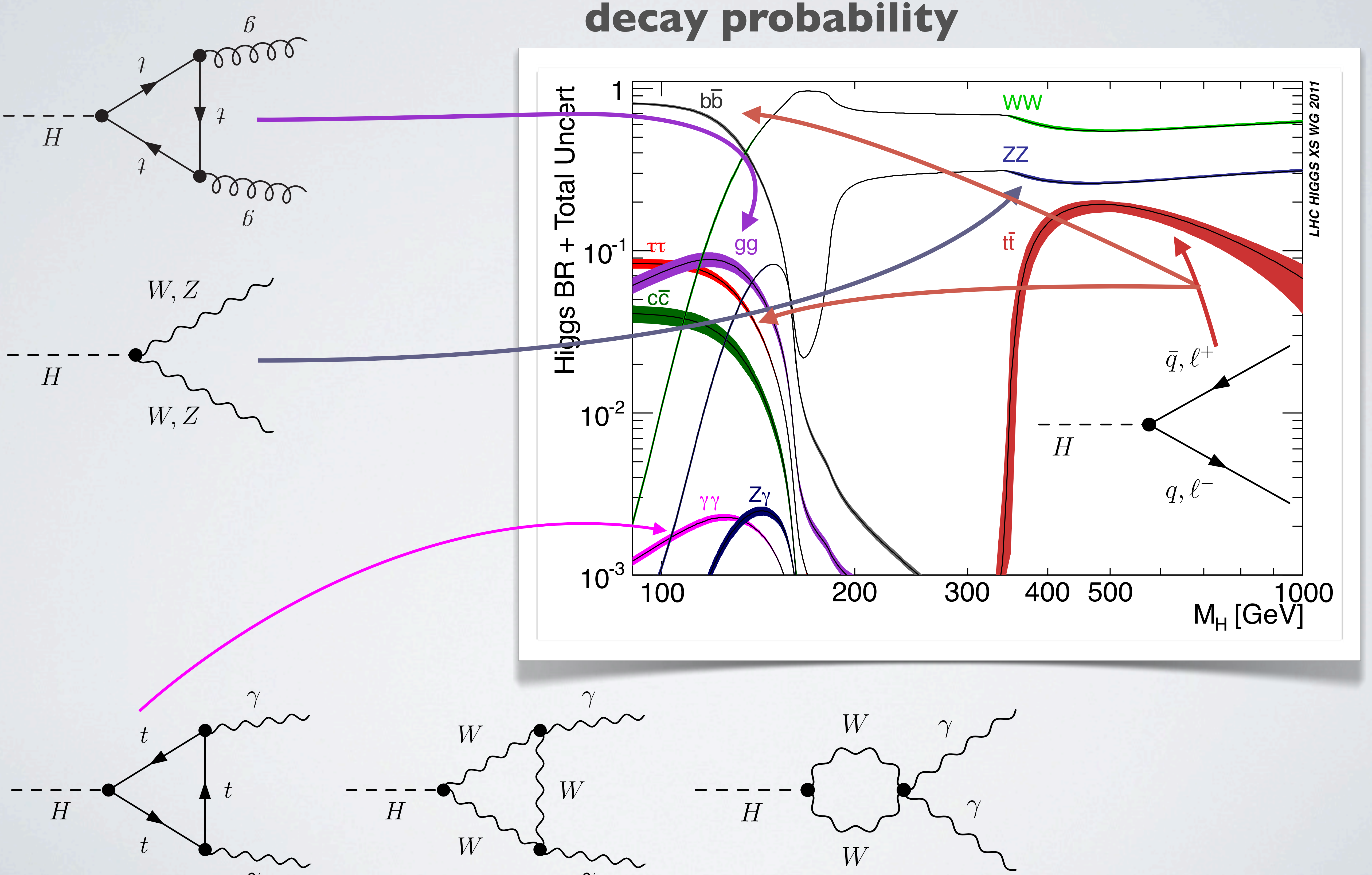


This is what the LHC is designed to do ...

... and measure its decay products...

[Prophecy4f, HDecay]

decay probability



This is what the LHC is designed to do ...

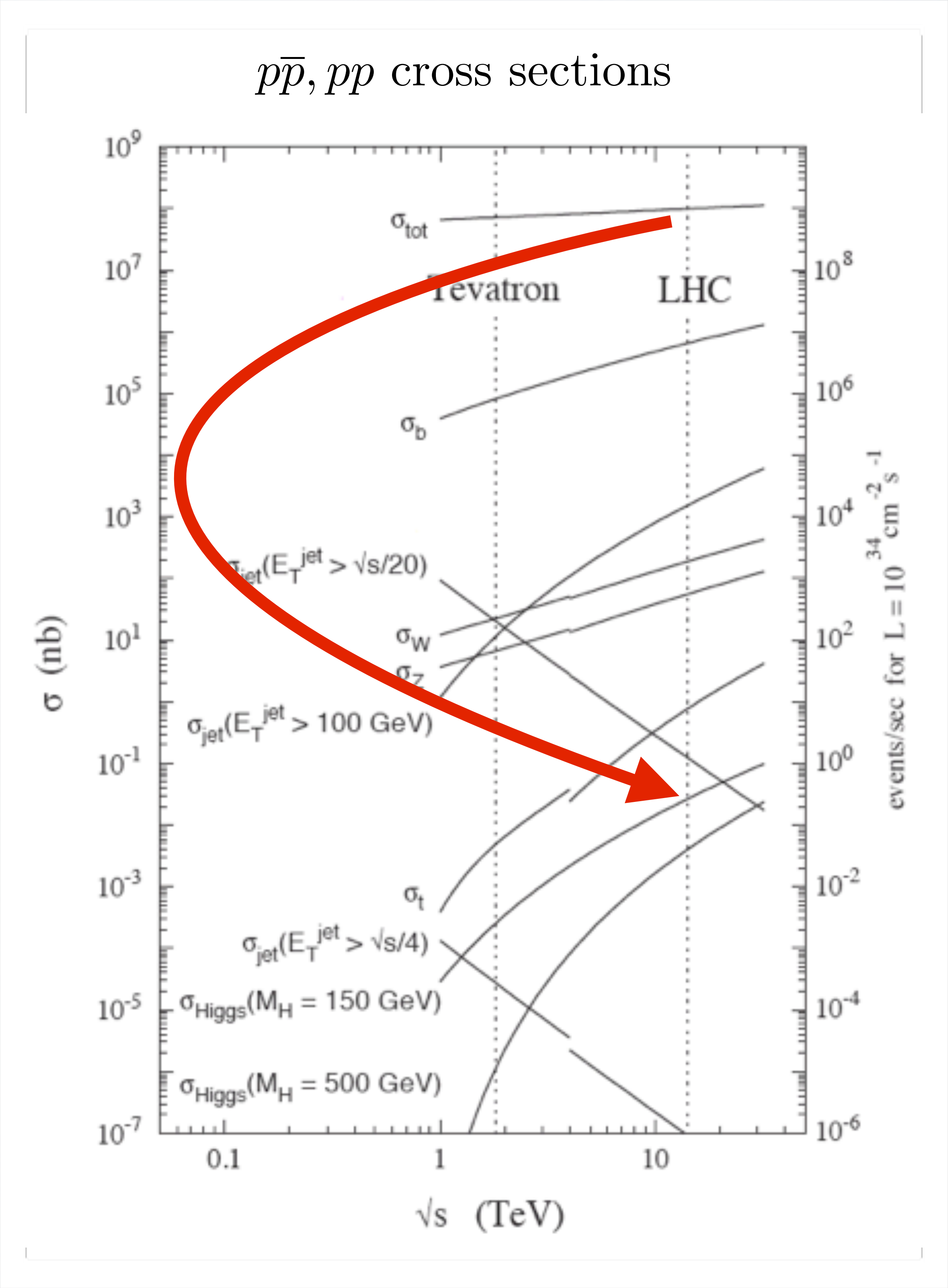
... in an extremely busy hadronic environment!

$<10^{-10}$ of the events are interesting

"find 1 person in 1000 world populations"

To get a hold on the Higgs boson and its properties we have to

- devise dedicated search strategies
- apply advanced statistical methods
- assess & improve simulation uncertainties (higher orders, parton densities, ...)



July 04, 2012

July 04, 2012

I'm alright': Katie stocks up for BBQ ans Tom

ATTHEW LYSIAK, NANCY DILLON

Vednesday, July 04, 2012

A smiling Katie Holmes uttered her first public words Wednesday after declaring her independence from stranged hubby Tom Cruise. "I'm all right," the 33-year-ld actress told the Daily News as she pushed a shopping art carrying the couple's adorable daughter Suri. "Thank ou," she said graciously. Holmes flashed a grin as she strolled the aisles of a Whole Foods grocery store in helsea and picked up the ingredients for a Fourth of July feast: ground beef, hamburger rolls, strawberries and bananas.

Im alright, the 33-year-old actress told the Daily News. >

RELATED: KATIE AND SURI GO FOR ICE CREAM, TOM TURNS 50 ALONE

July 04, 2012

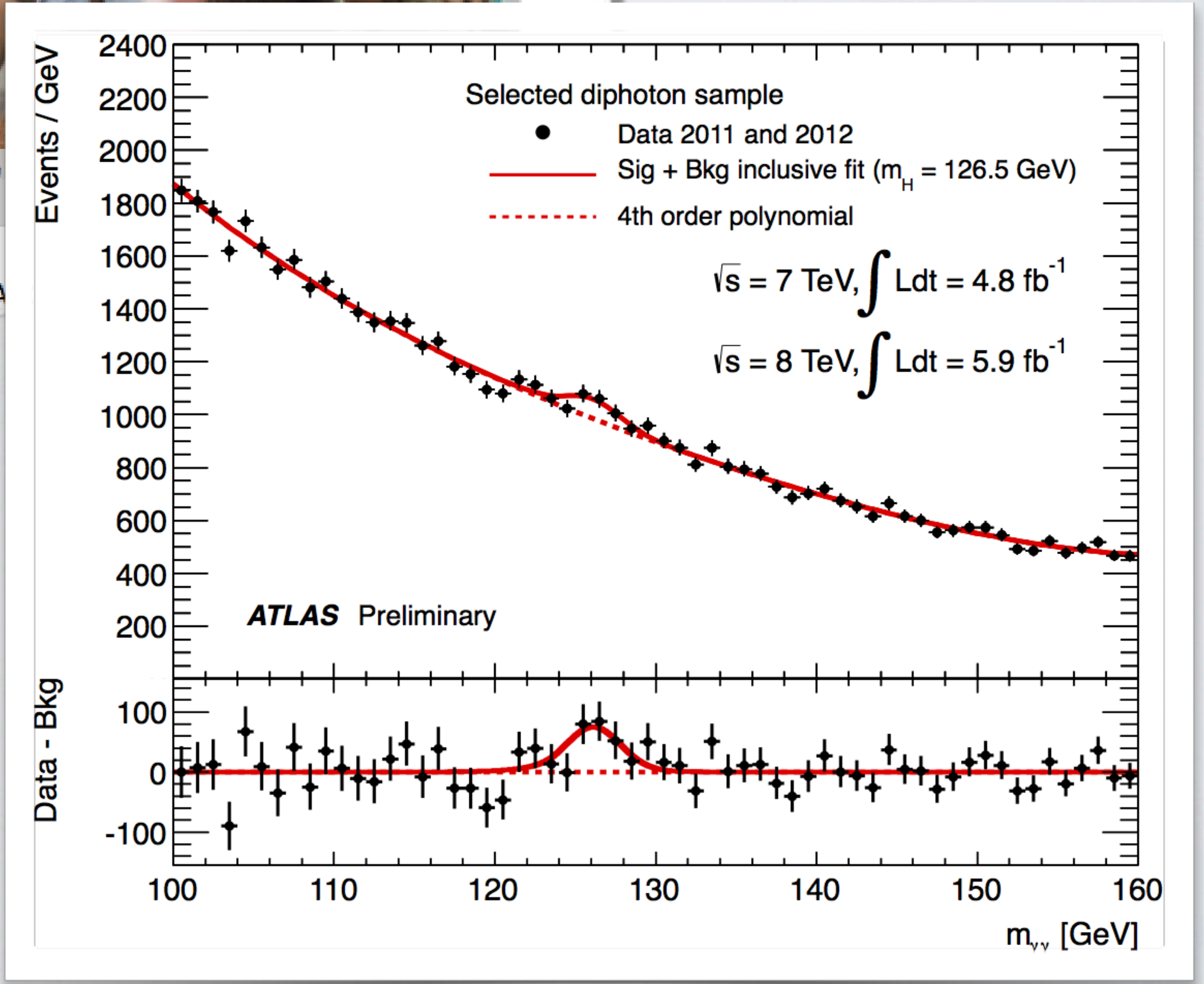
I'm alright': Katie stocks up for BBQ sans Tom

MATTHEW LYSIAK, NANCY DILLON

Wednesday, July 04, 2012

A smiling Katie Holmes uttered her first public words Wednesday after declaring her independence from estranged hubby Tom Cruise. "I'm all right," the 33-year-old actress told the Daily News as she pushed a shopping cart carrying the couple's adorable daughter Suri. "Thank you," she said graciously. Holmes flashed a grin as she strolled the aisles of a Whole Foods grocery store in Chelsea and picked up the ingredients for a Fourth of July feast: ground beef, hamburger rolls, strawberries and bananas.

RELATED: KATIE AND SURI GO FOR ICE CREAM, TOM TURNS 50 A

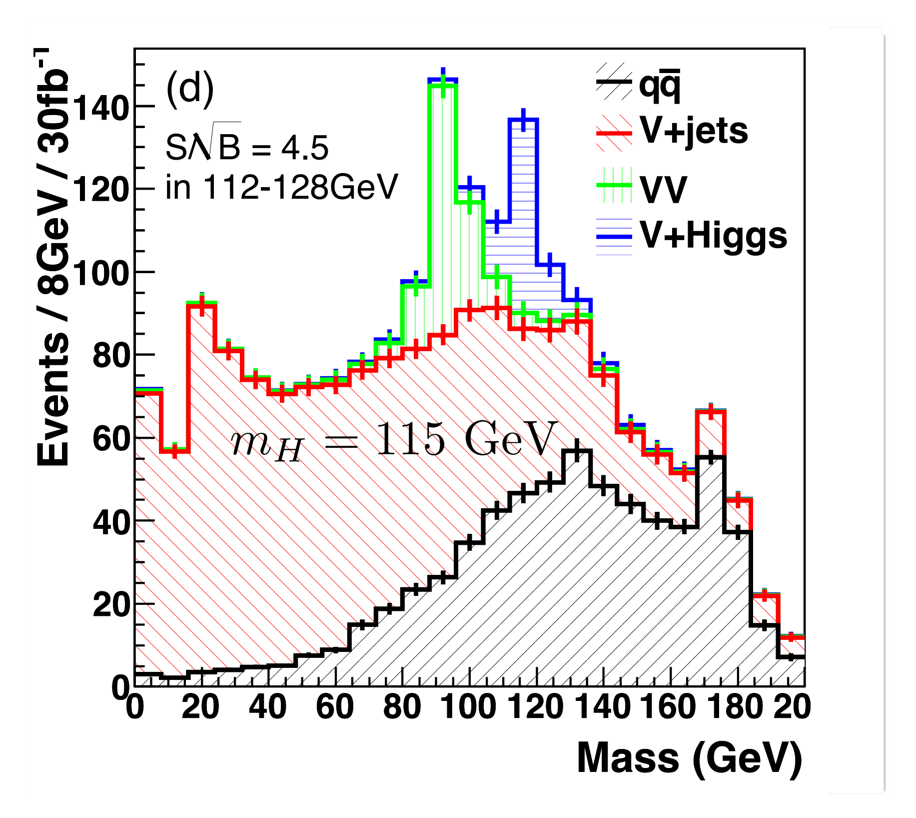


"I think we have it."

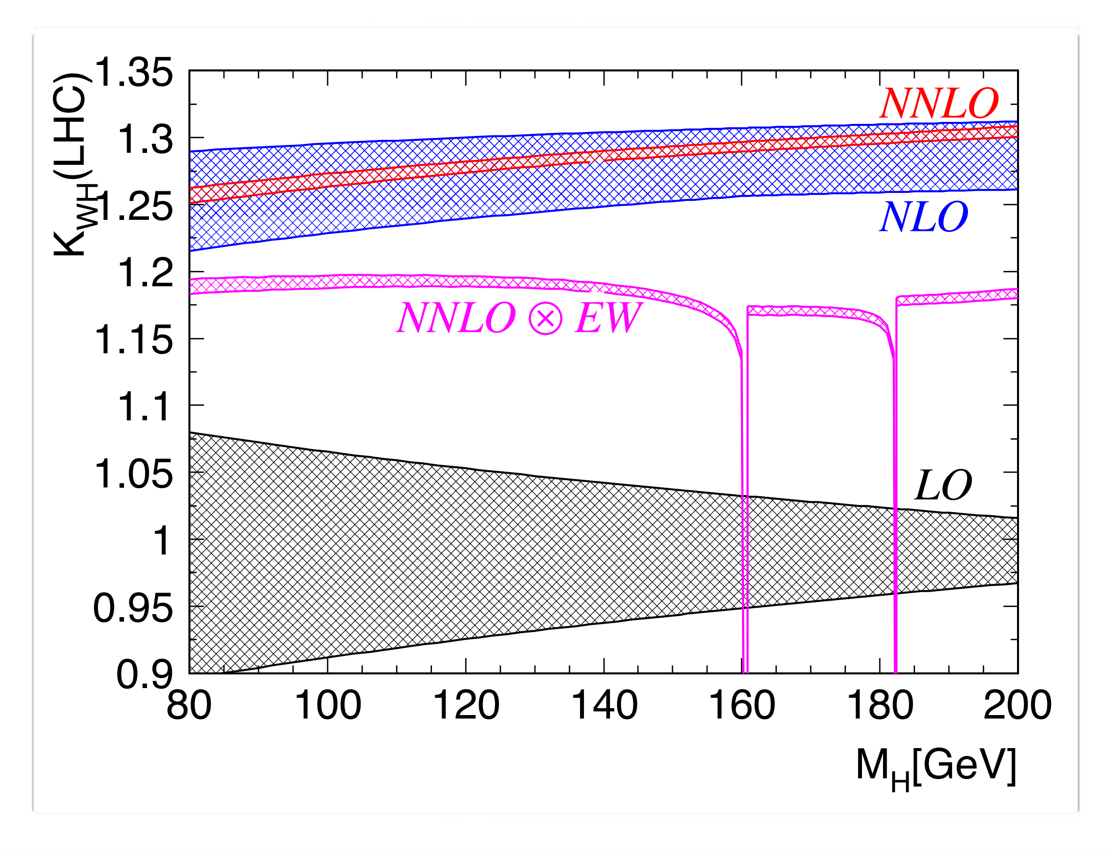
- R. Heuer

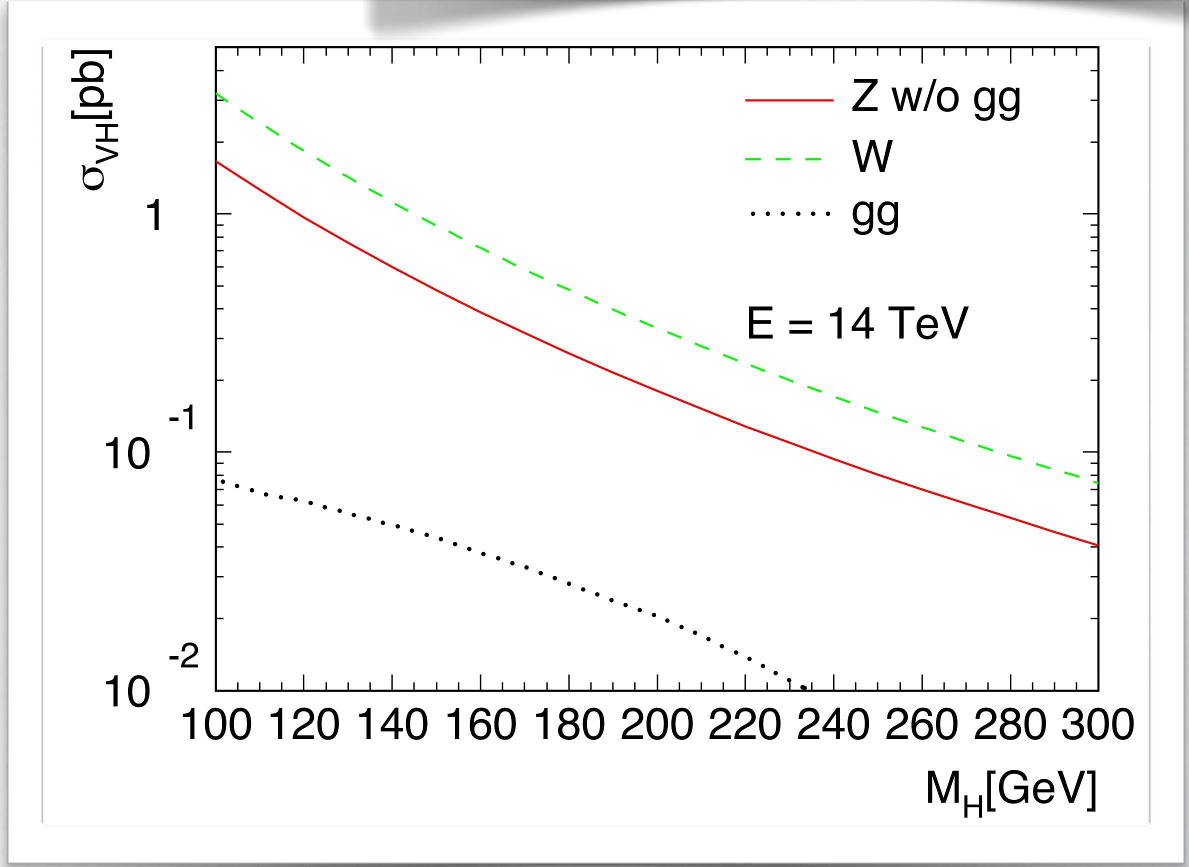
Higgs strahlung

- main production channel at the Tevatron, small production cross section at the LHC due to pdfs (large vs small x)
- moderate NLO corrections K=1.2 ... 1.3
- one of the main search channels for a light Higgs using boosted final states and subjet analyses, $H \to b\bar{b}$



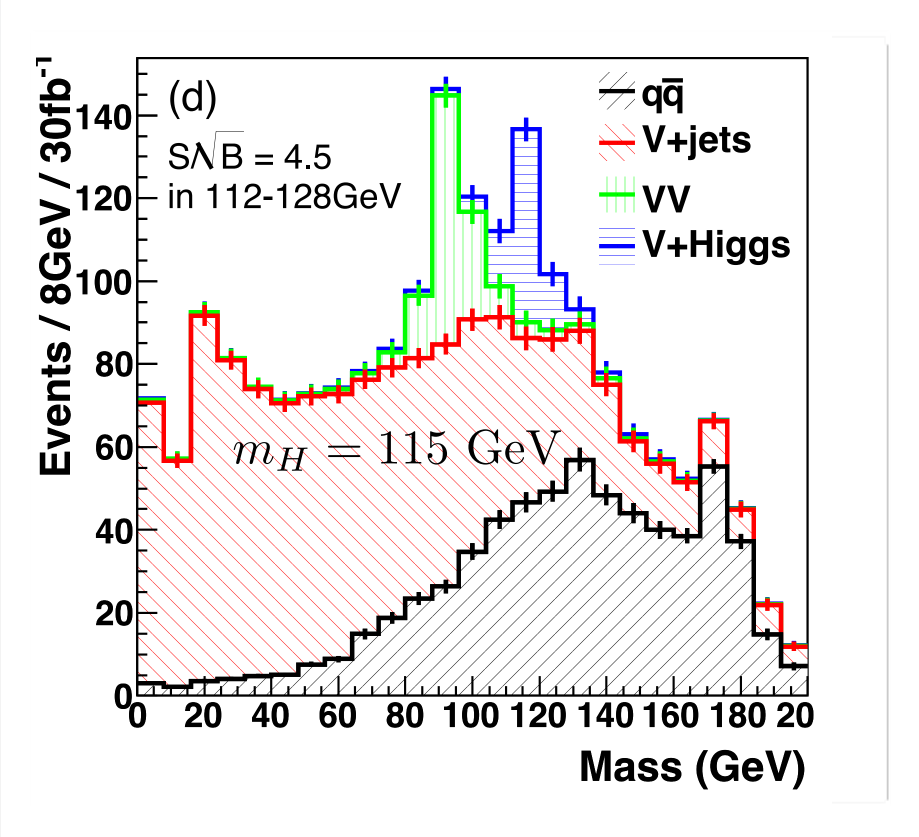
[Butterworth, Davison, Rubin, Salam `08]



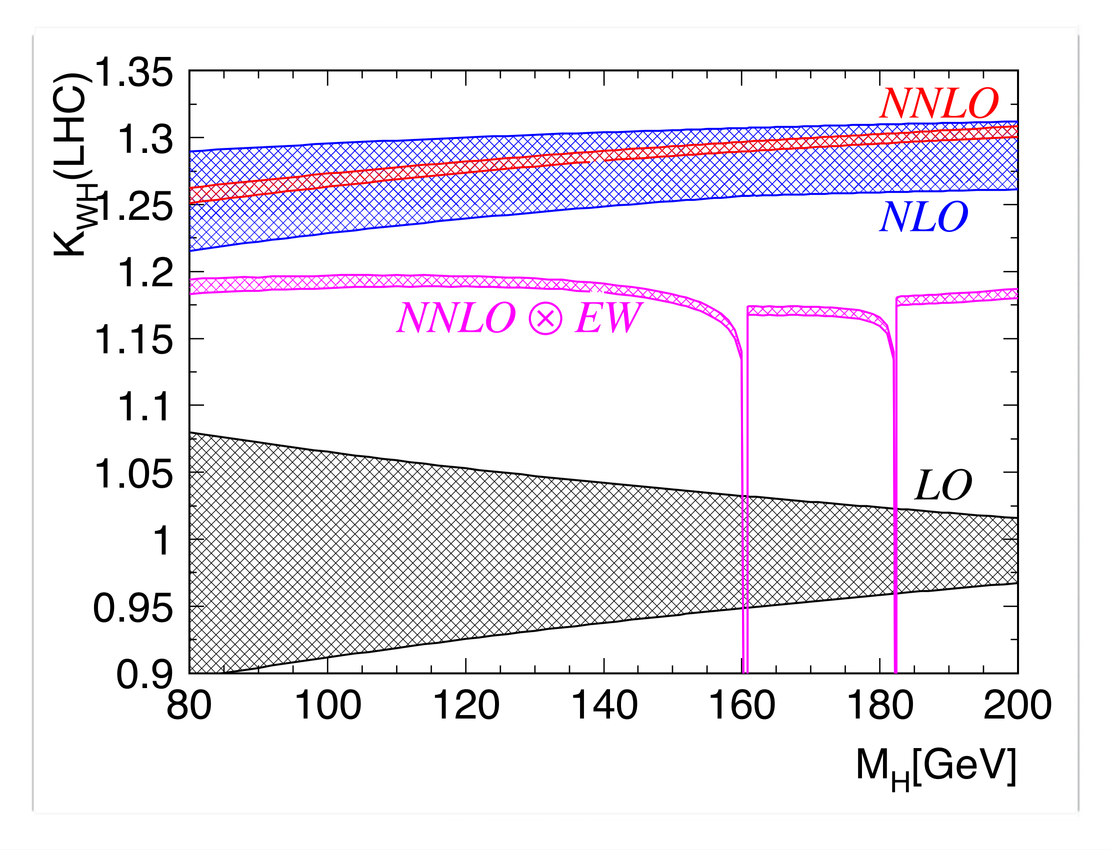


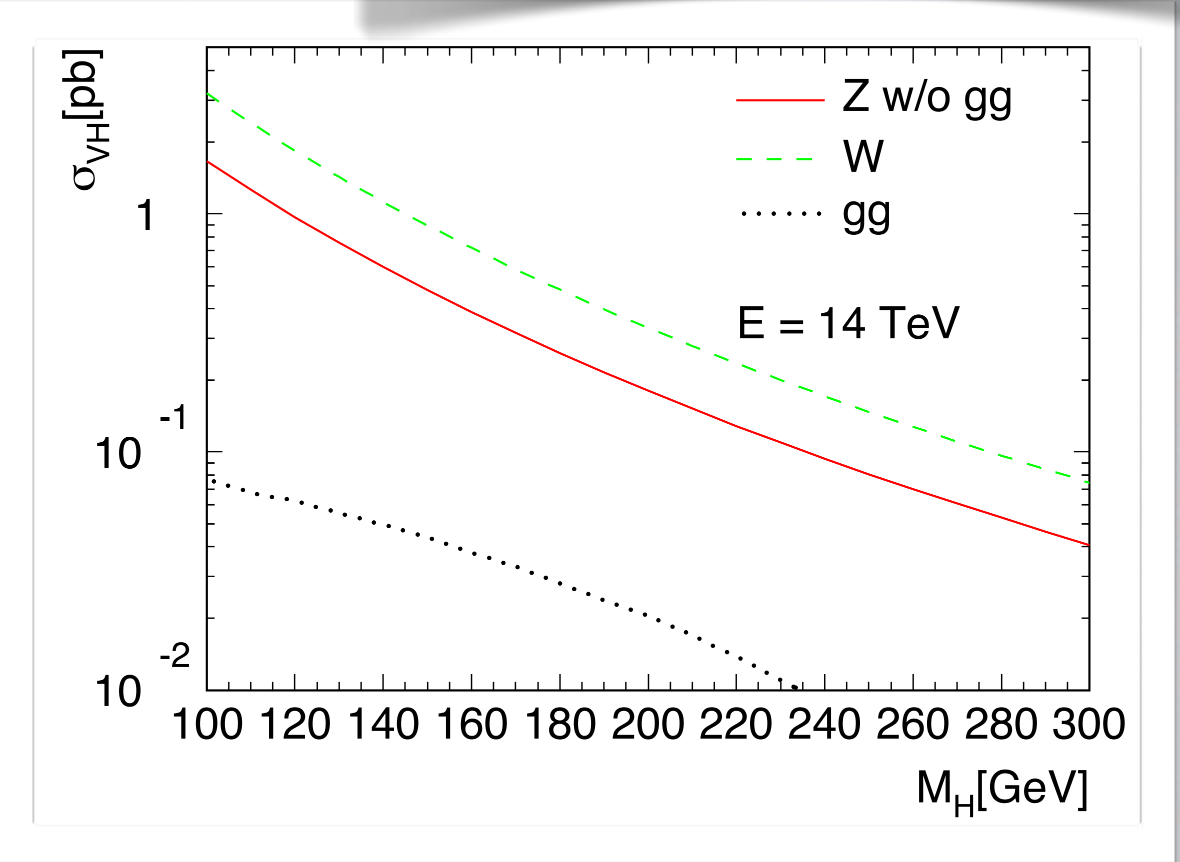
Higgs strahlung

- main production channel at the Tevatron, small production cross section at the LHC due to pdfs (large vs small x)
- moderate NLO corrections K=1.2 ... 1.3
- one of the main search channels for a light Higgs using boosted final states and subjet analyses, $H \to b\bar{b}$



[Butterworth, Davison, Rubin, Salam `08]





[Han, Willenbrock `90], [Ciccolini, Dittmaier, Krämer `03], [Brein, Djouadi, Harlander `03]

Boosted techniques: Higgs subjet taggers in a nutshell

boosted decays of massive particles can end up in the same jet: $\Delta R_{bb} \sim m_h/p_{T,H}$

[Butterworth, Davison, Rubin, Salam `08]

1. mass drop $m_{j_1} < 0.66 m_j$

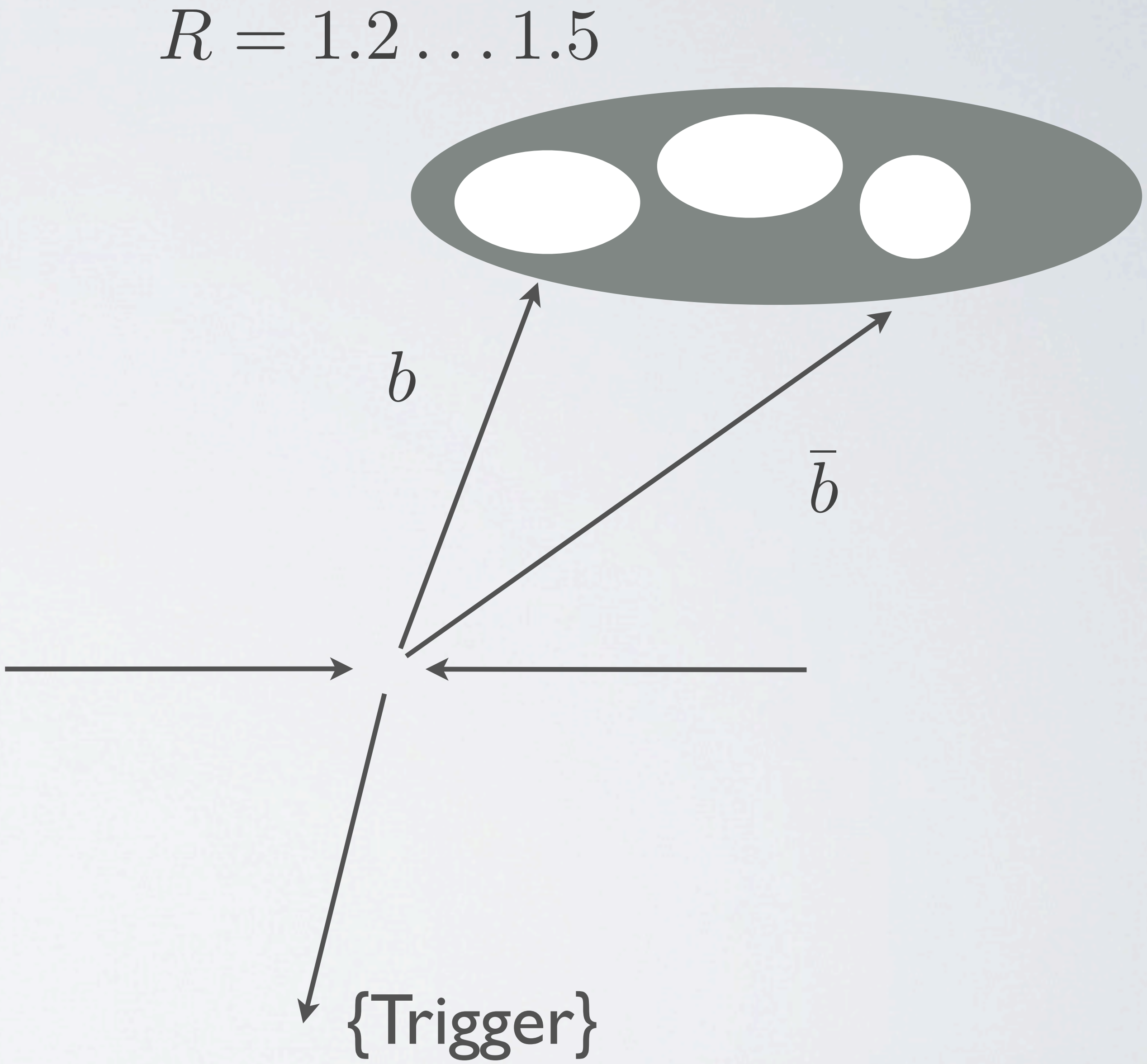
2. check asymmetry

$$\frac{\min(p_{T,j1}^2, p_{T,j2}^2)}{m_j^2} \Delta R_{j1,j2}^2 > y_{\mathrm{cut}}$$

3. apply "filtering" to clean up UEV

4. take 3 hardest subjets

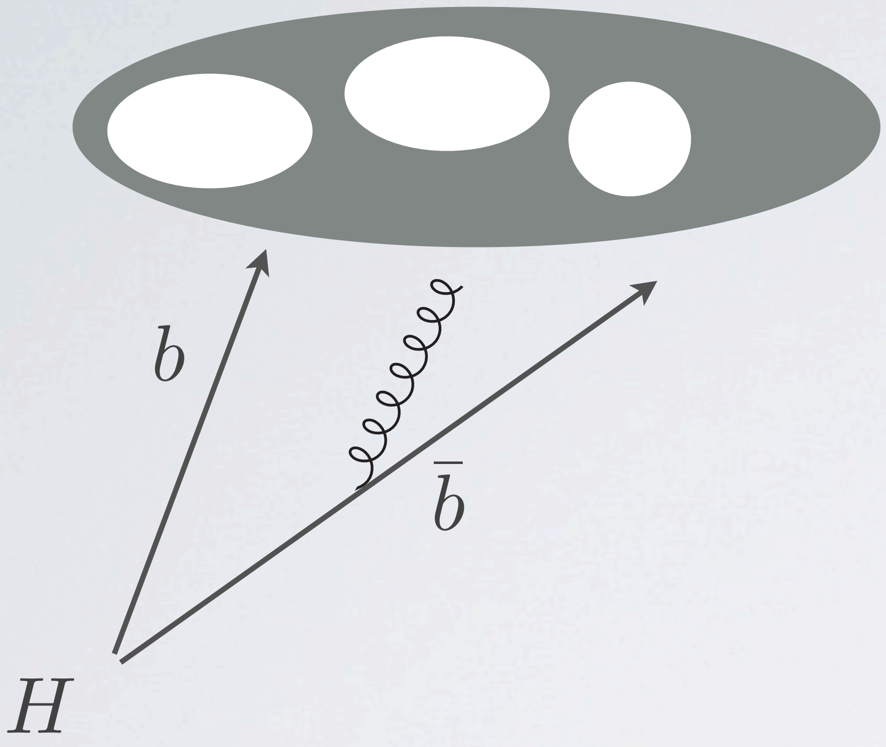
5. b tagging on the two hardest ones



Jet “grooming”...

FILTERING

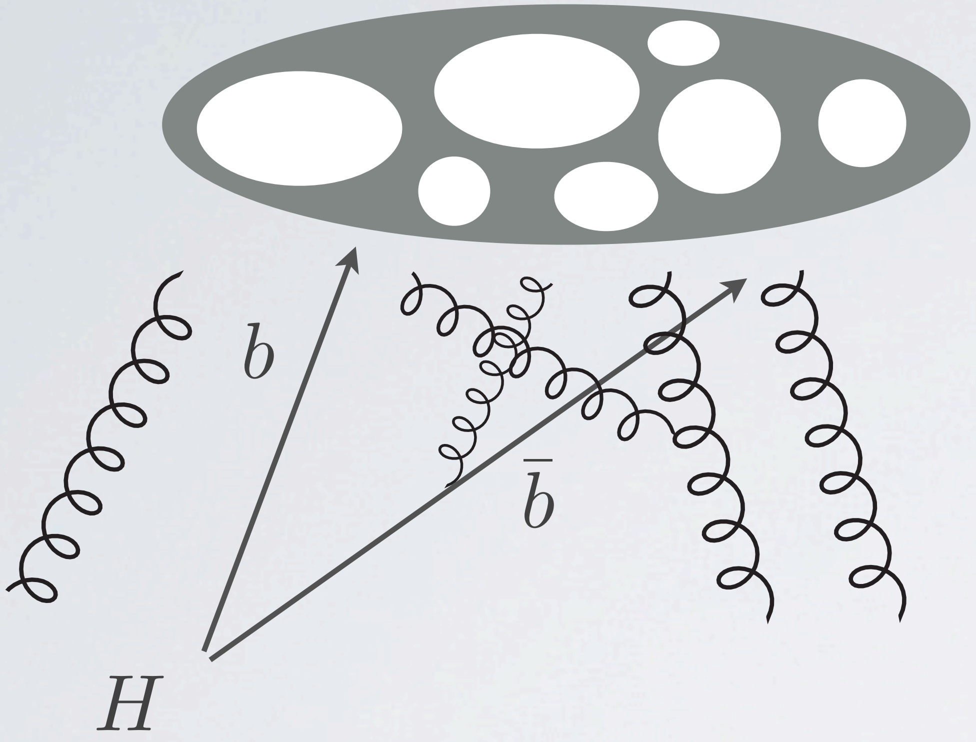
[Butterworth, Davison, Rubin, Salam `08]



Jet “grooming”...

FILTERING

[Butterworth, Davison, Rubin, Salam `08]



underlying event

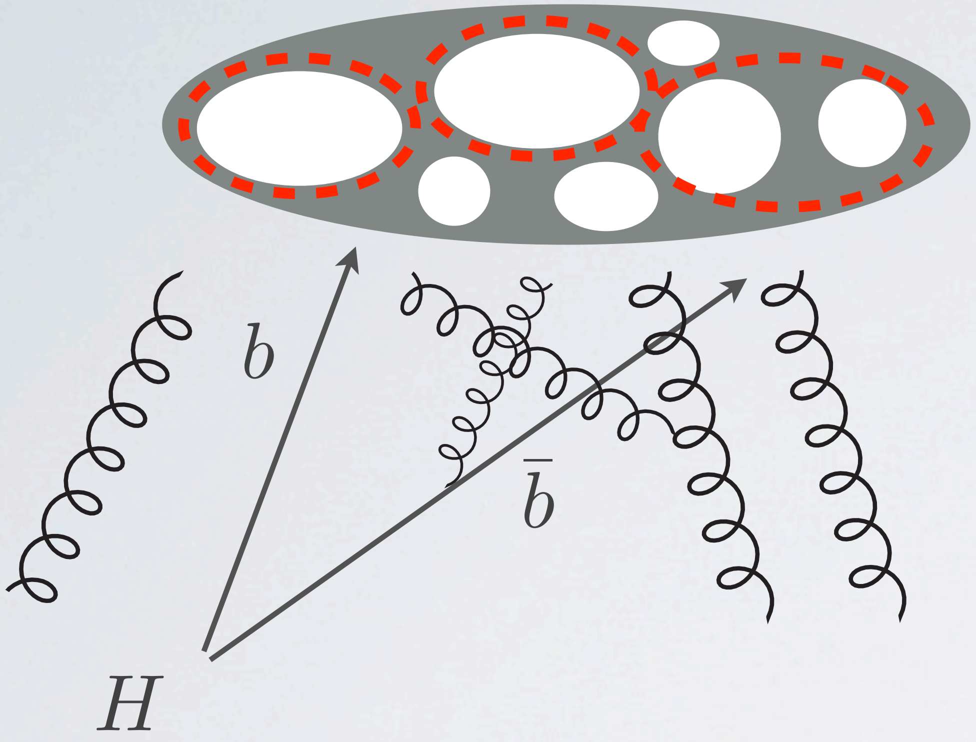
$\delta p_T \sim R^2 - R^4/8$

but sum from soft tracks

Jet “grooming”...

FILTERING

[Butterworth, Davison, Rubin, Salam `08]



recluster jet with finer resolution

$$R_{\text{filt}} = \min(0.3, R_{b\bar{b}})$$

underlying event

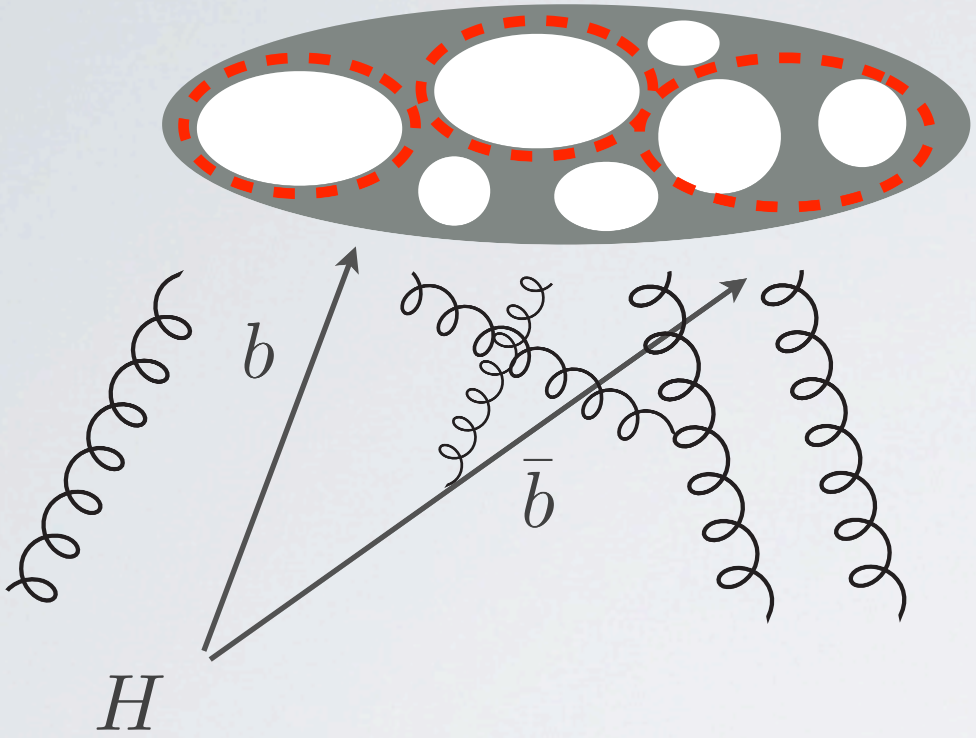
$\delta p_T \sim R^2 - R^4/8$

but sum from soft tracks

Jet "grooming"...

FILTERING

[Butterworth, Davison, Rubin, Salam `08]



recluster jet with finer resolution

$$R_{\text{filt}} = \min(0.3, R_{b\bar{b}})$$

underlying event

$\delta p_T \sim R^2 - R^4/8$

but sum from soft tracks

TRIMMING

[Krohn, Thaler, Wang `09]

- do normal jet clustering with big cone size $R \simeq 1.5$
- recluster with a finer resolution *and* a different jet algorithm (i.e. anti-kT)
- reject each subjet's contribution if $p_{T,i} \leq f_{\text{cut}} \Lambda_{\text{hard}}$
- combine leftover subjets to the "trimmed" jet

get rid of soft radiation and focus on "lighthouse" tracks

more jet "grooming" and substructure

PRUNING

[Ellis, Vermillion, Walsh `09]

- do normal jet clustering with big cone size
- rerun clustering with the following modification

1. for each recombination $i, j \to i'$ compute

$$z = \frac{\min(p_{T,i}, p_{T,j})}{p_{T,i} + p_{T,j}} \quad \text{and} \quad R_{ij}$$

2. if $z \leq z_{\text{cut}}$ and $R_{ij} \geq R_{\text{cut}}$ *do not merge* candidates but *discard* the softer candidate and continue with the algorithm

more jet “grooming” and substructure

PRUNING

[Ellis, Vermillion, Walsh `09]

- do normal jet clustering with big cone size
- rerun clustering with the following modification

1. for each recombination $i, j \rightarrow i'$ compute

$$z = \frac{\min(p_{T,i}, p_{T,j})}{p_{T,i} + p_{T,j}} \quad \text{and} \quad R_{ij}$$

2. if $z \leq z_{\mathrm{cut}}$ and $R_{ij} \geq R_{\mathrm{cut}}$ *do not merge* candidates but *discard* the softer candidate and continue with the algorithm

subtract soft wide-angle emission from the jet

more jet "grooming" and substructure

PRUNING

[Ellis, Vermillion, Walsh `09]

- do normal jet clustering with big cone size
- rerun clustering with the following modification

1. for each recombination $i, j \to i'$ compute

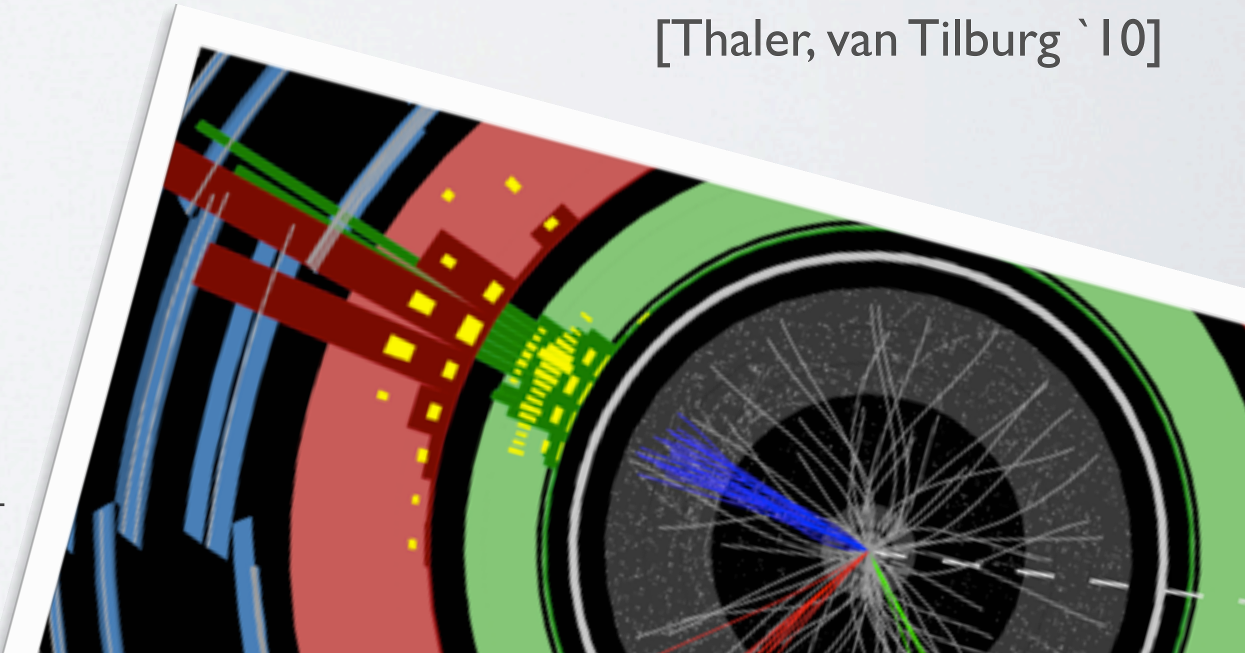
$$z = \frac{\min(p_{T,i}, p_{T,j})}{p_{T,i} + p_{T,j}} \qquad \text{and} \qquad R_{ij}$$

2. if $z \leq z_{\rm cut}$ and $R_{ij} \geq R_{\rm cut}$ *do not merge* candidates but *discard* the softer candidate and continue with the algorithm

subtract soft wide-angle emission from the jet

N-subjettiness

[Thaler, van Tilburg `10]



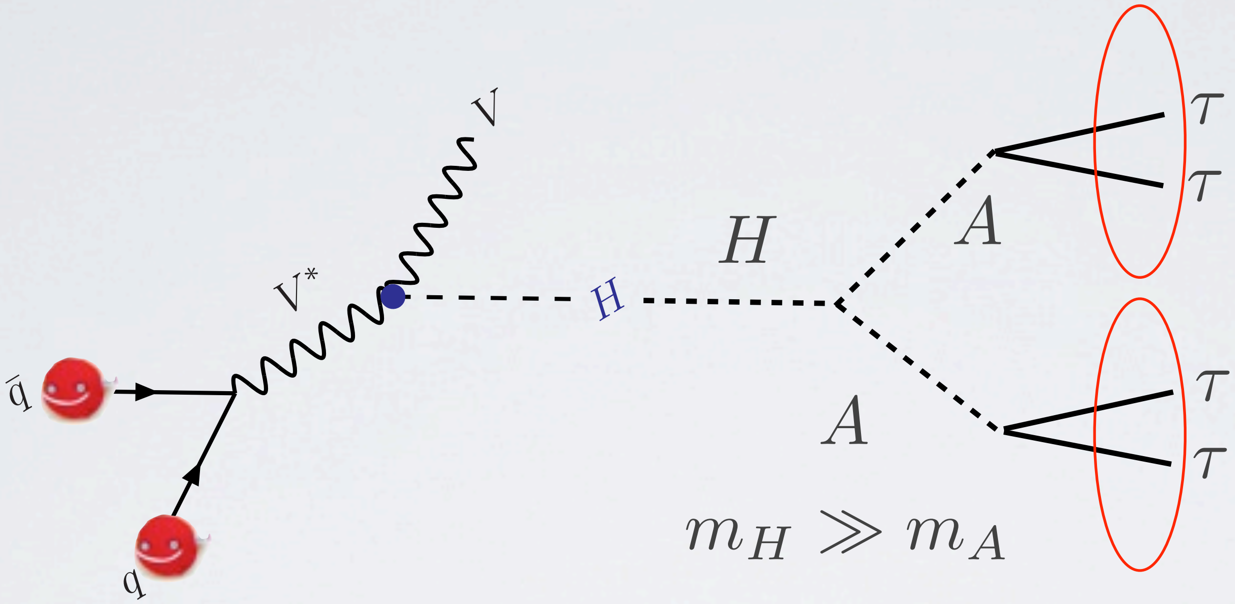
how N-"clumpy" is the jet substructure ?

$$\tau_N = \frac{\sum_k p_{T,k} \min\left(\Delta R(1,k), \ldots, \Delta R(N,k)\right)}{\sum_j p_{T,j} \, R}$$

some phenomenological applications...

"Buried" Higgs bosons show up in many models with extended electroweak sectors. Currently $\mathrm{BR}(H \to \text{non-standard}) \lesssim 0.5$.

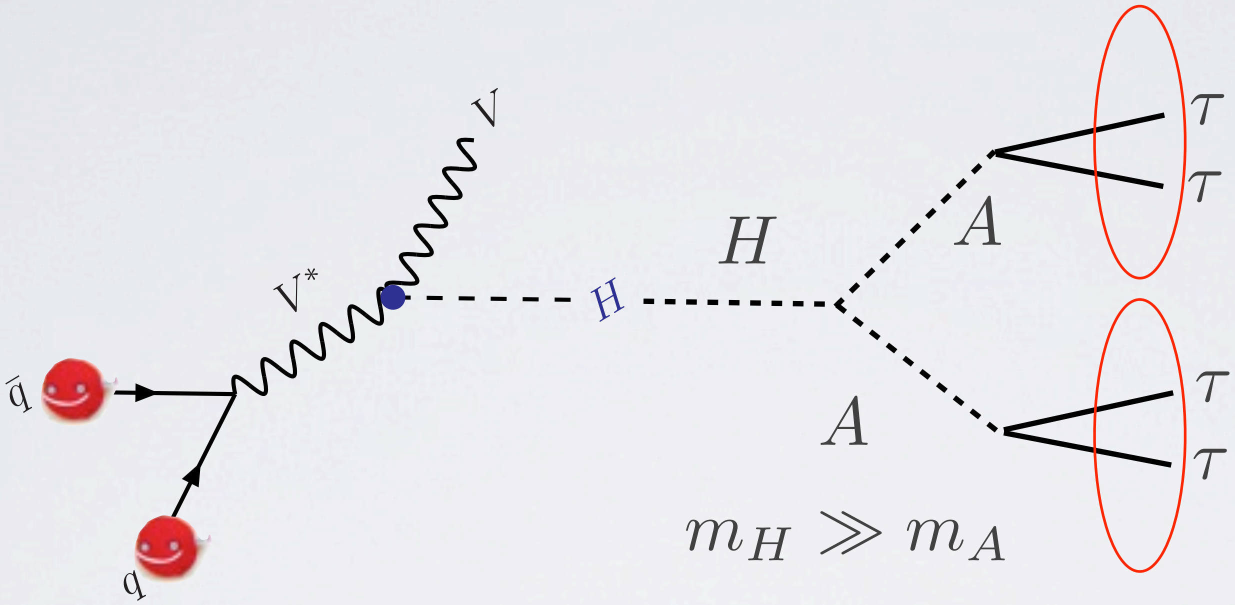
A known example is the NMSSM for $\tan\beta \simeq 5,\ m_A \simeq 10\ \mathrm{GeV}$

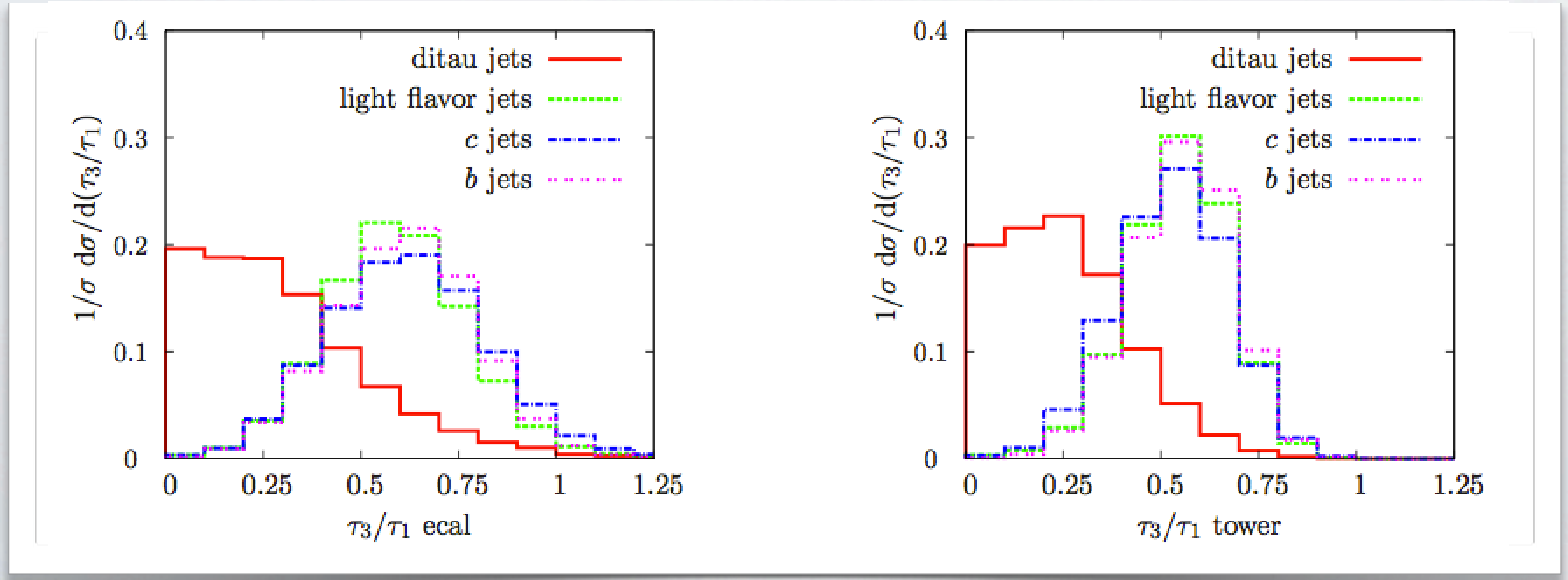


some phenomenological applications...

“Buried” Higgs bosons show up in many models with extended electroweak sectors. Currently $\mathrm{BR}(H \to \text{non-standard}) \lesssim 0.5$.

A known example is the NMSSM for $\tan\beta \simeq 5,\ m_A \simeq 10\ \mathrm{GeV}$

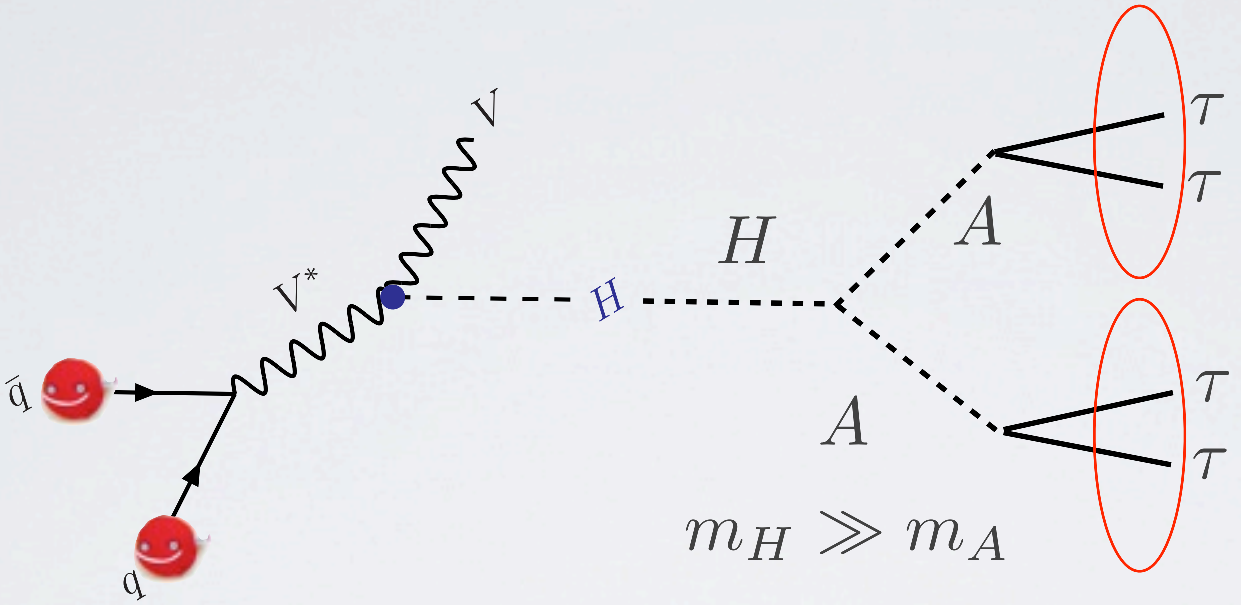




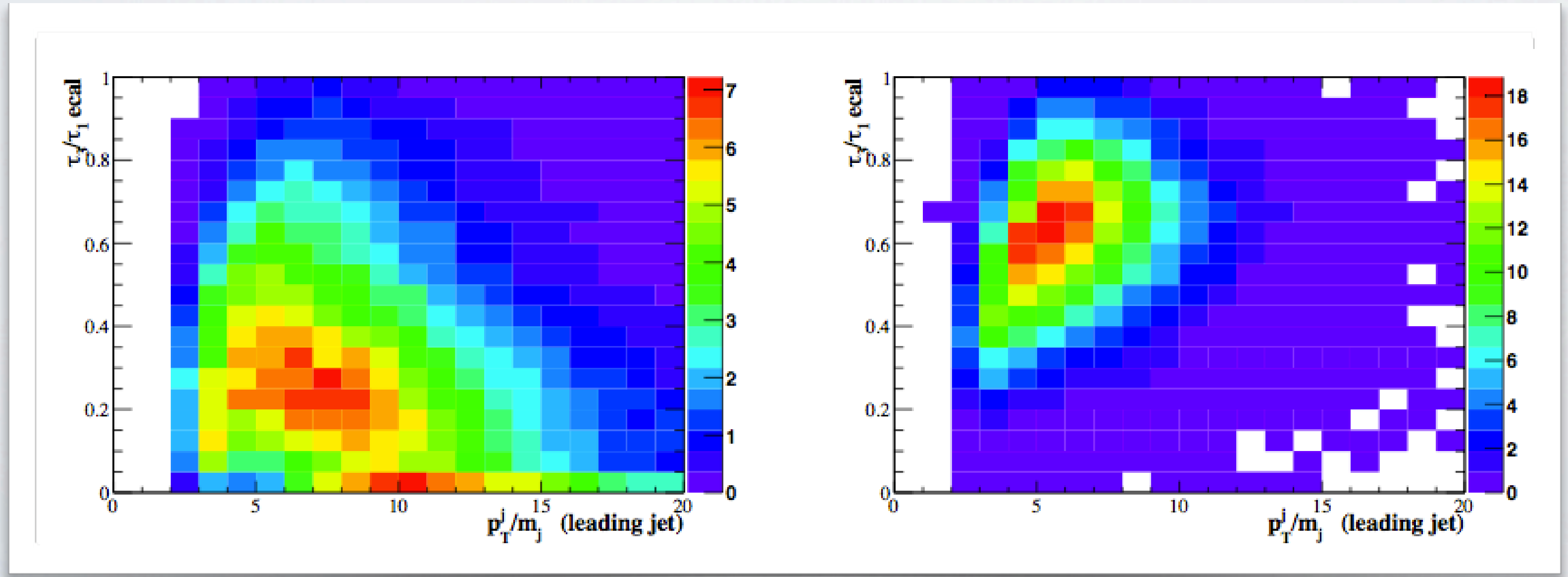
some phenomenological applications...

“Buried” Higgs bosons show up in many models with extended electroweak sectors. Currently $\mathrm{BR}(H \to \text{non-standard}) \lesssim 0.5$.

A known example is the NMSSM for $\tan\beta \simeq 5,\ m_A \simeq 10\ \mathrm{GeV}$



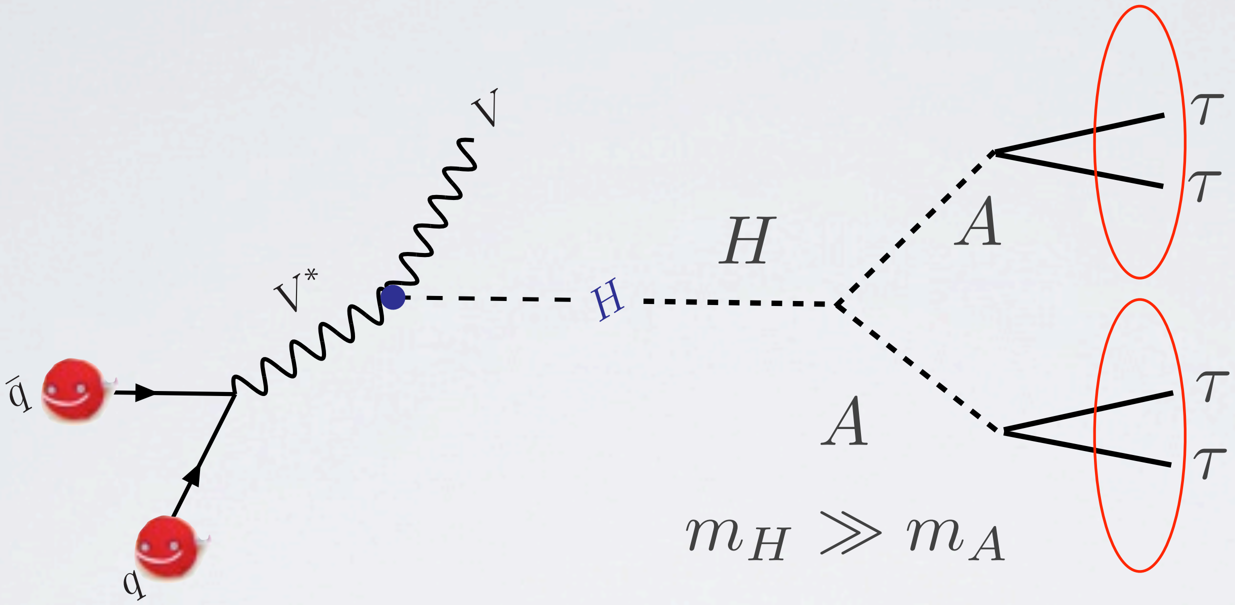
$$m_H \gg m_A$$

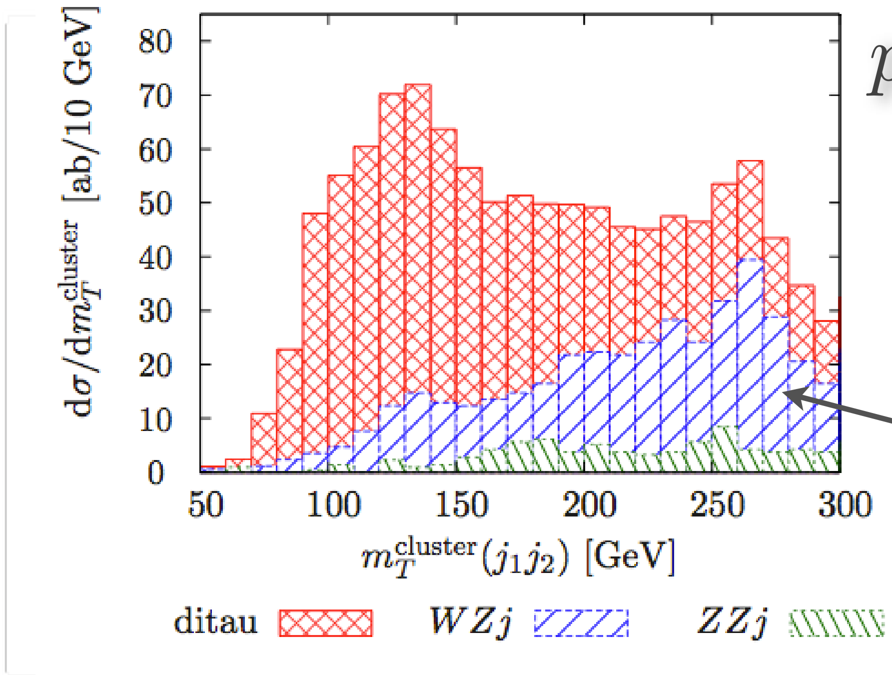


some phenomenological applications...

"Buried" Higgs bosons show up in many models with extended electroweak sectors. Currently $\mathrm{BR}(H \to \text{non-standard}) \lesssim 0.5$.

A known example is the NMSSM for $\tan\beta \simeq 5,\ m_A \simeq 10\ \mathrm{GeV}$





$$pp \to (Z \to 2\ell) + \not{E}_T + 2j + X$$

sensitivity $S/\sqrt{B} = 5$ for

$\mathcal{L} = 12\ \mathrm{fb}^{-1}\ (\sqrt{s} = 14\ \mathrm{TeV})$

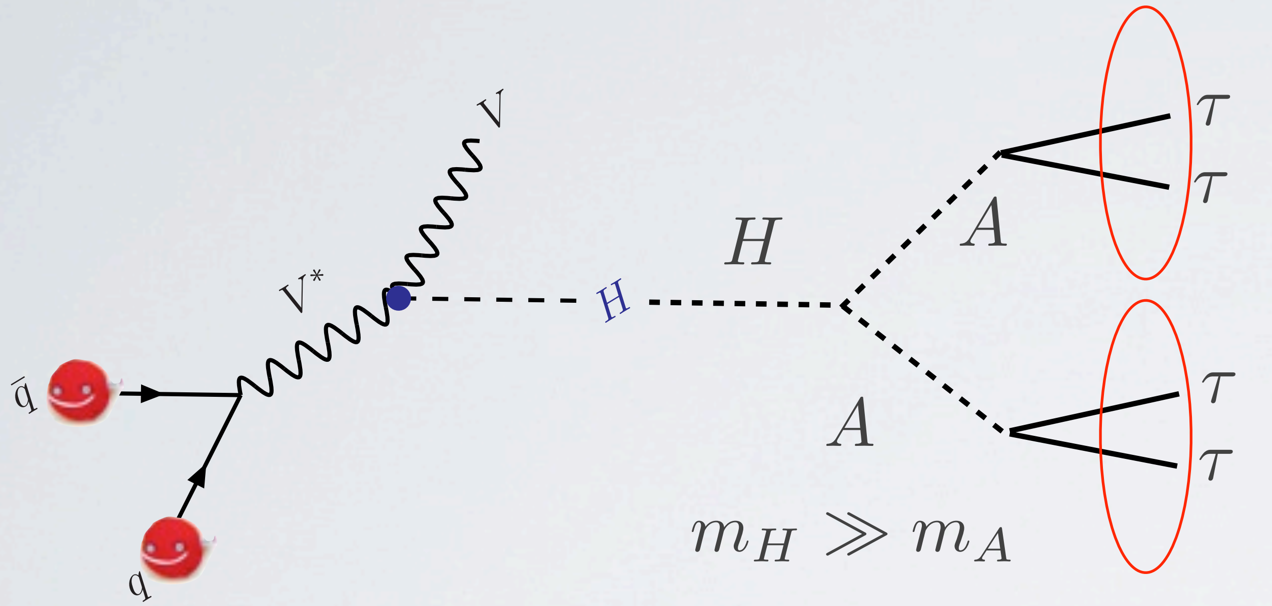
NLO QCD $K = 0.86$

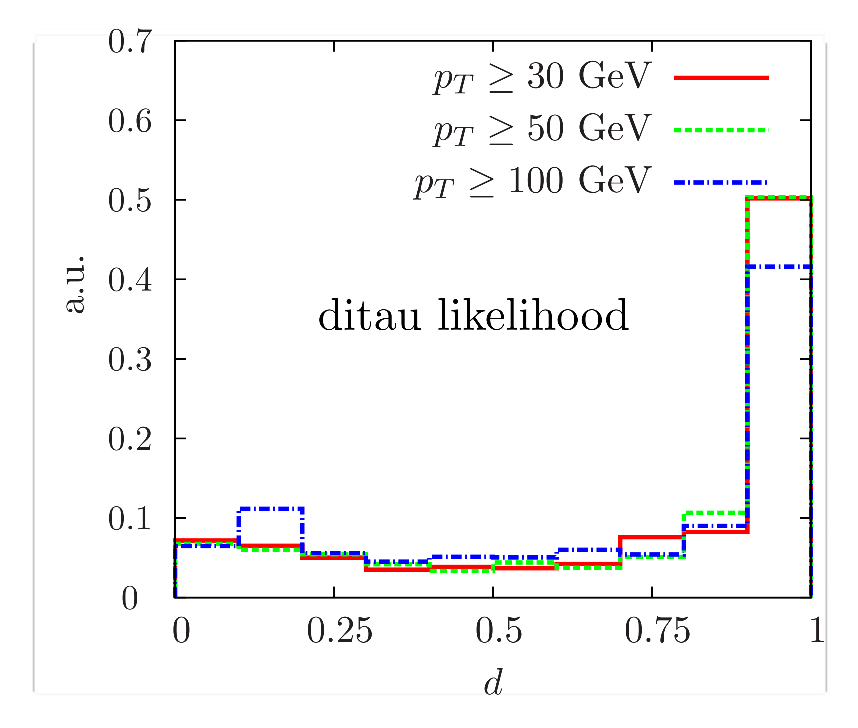
[Campanario, CE, Spannowsky `10]
[Campanario, CE, Kallweit et al. `10]

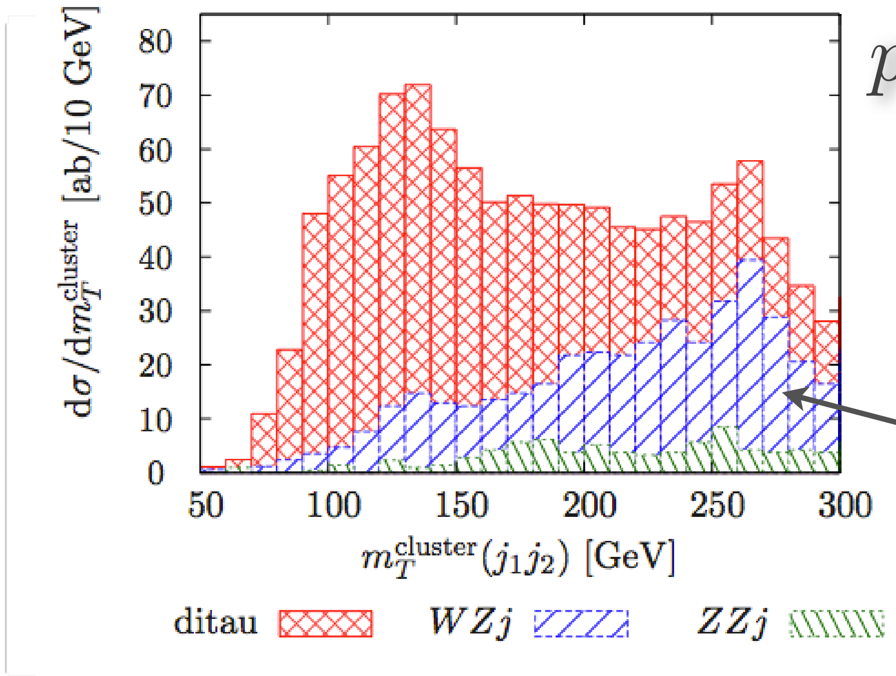
some phenomenological applications...

“Buried” Higgs bosons show up in many models with extended electroweak sectors. Currently $\mathrm{BR}(H \to \text{non-standard}) \lesssim 0.5$.

A known example is the NMSSM for $\tan\beta \simeq 5, \;\; m_A \simeq 10\ \mathrm{GeV}$







$$pp \to (Z \to 2\ell) + \not{E}_T + 2j + X$$

sensitivity $S/\sqrt{B} = 5$ for

$$\mathcal{L} = 12\ \mathrm{fb}^{-1} \;\; (\sqrt{s} = 14\ \mathrm{TeV})$$

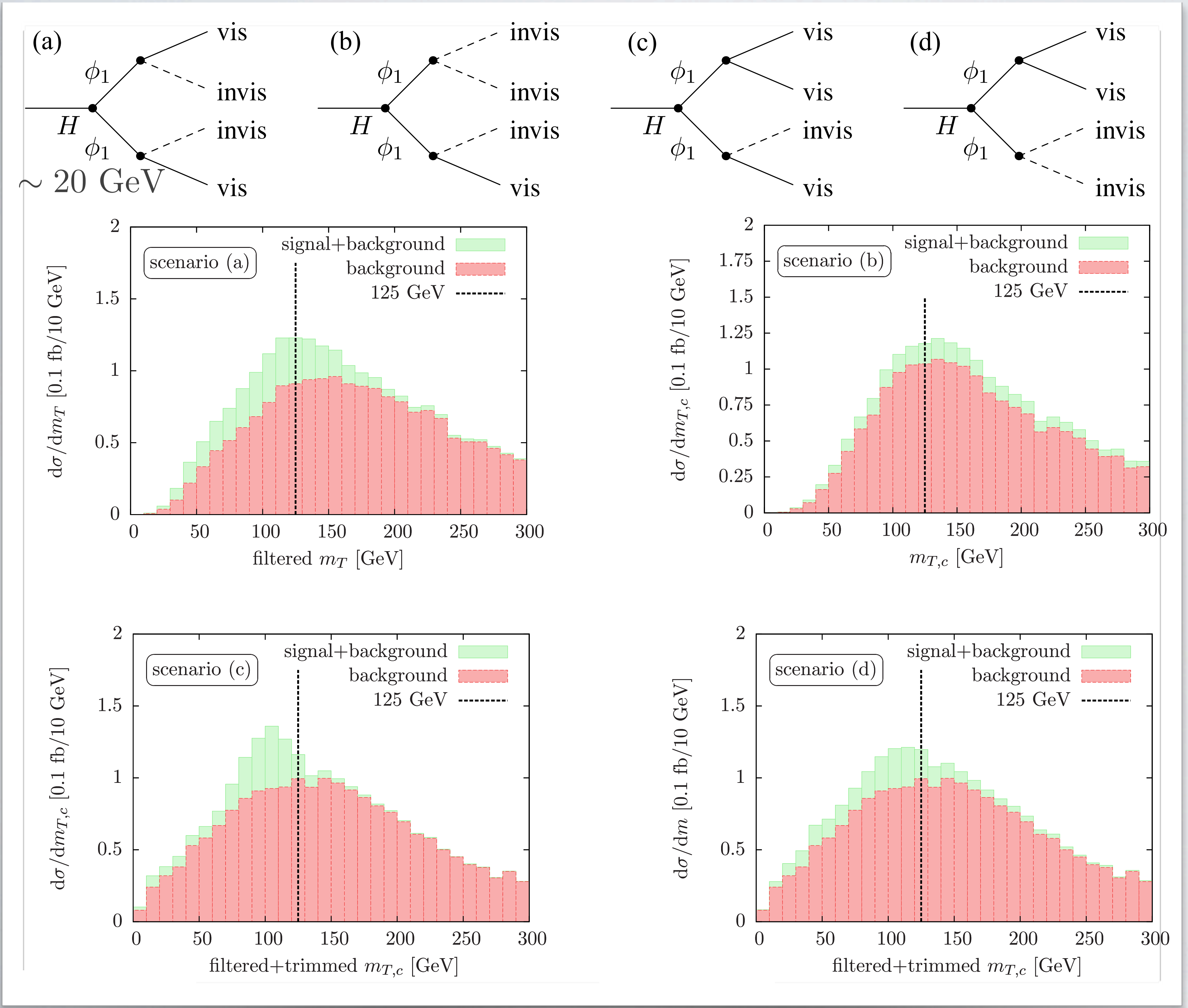
NLO QCD $K = 0.86$

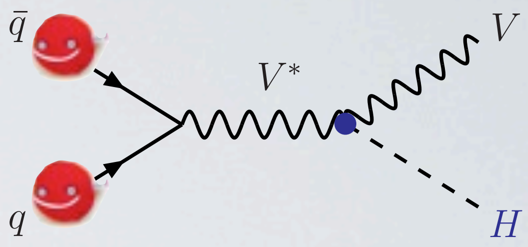
[Campanario, CE, Spannowsky `10]
[Campanario, CE, Kallweit et al. `10]

(in)visible non-standard branching ratios

[CE, Spannowsky, Wymant `12]

$$\mathcal{L}_{\text{new}} \overset{???}{\not\supset} \eta|\phi_{\text{SM}}|^2|\phi_{\text{hid}}|^2$$ (allowed by gauge invariance & renormalizability)



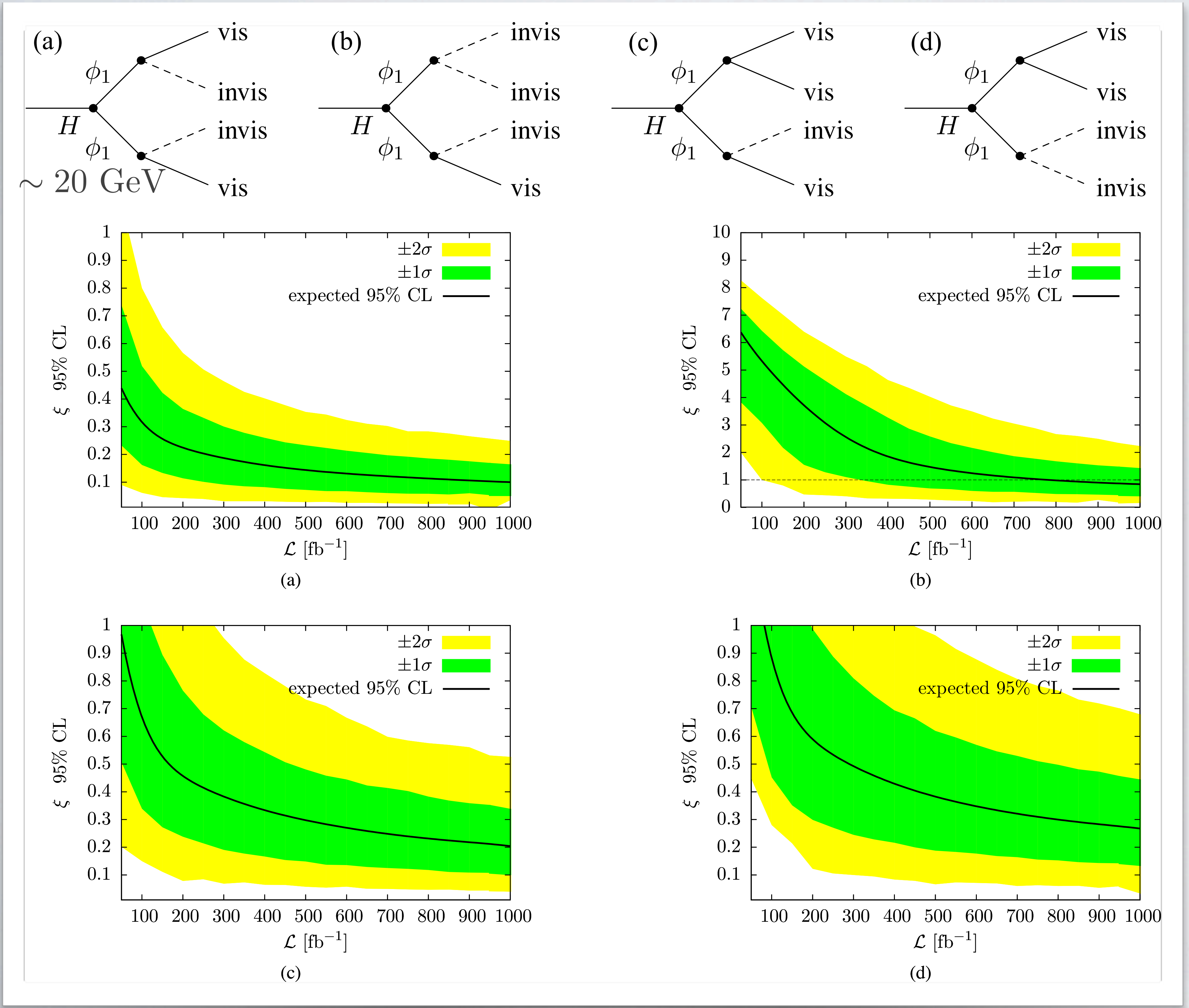


- boosted kinematics
- triggers
- subjet algorithms
  - mass drop
  - filtering
  - trimming
- b tagging
- “particle flow” $\not{E}_T$
- background uncert.

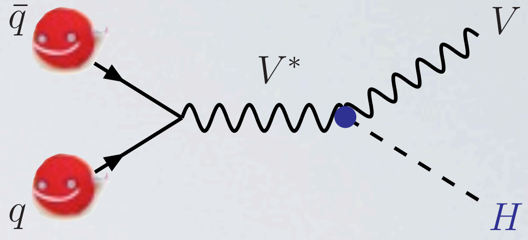
(in)visible non-standard branching ratios

[CE, Spannowsky, Wymant `12]

$$\mathcal{L}_{\rm new} \overset{???}{\not\supset} \eta|\phi_{\rm SM}|^2|\phi_{\rm hid}|^2$$ (allowed by gauge invariance & renormalizability)



(a) (b) (c) (d)

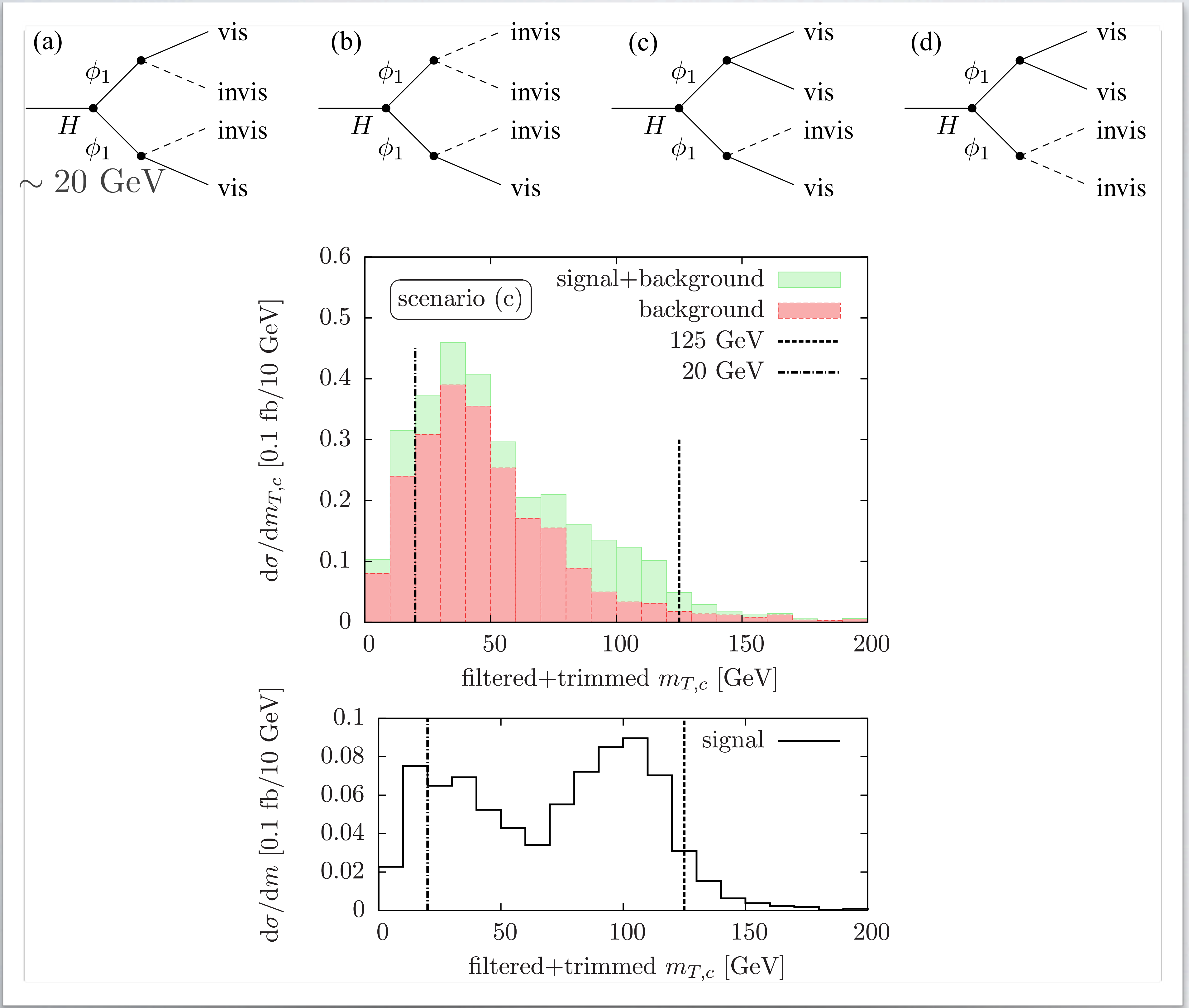


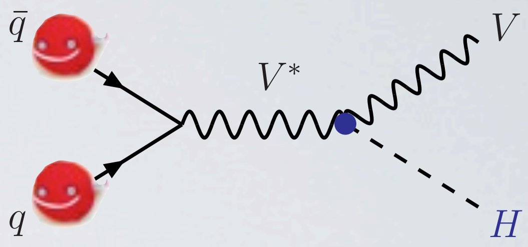
- boosted kinematics
- triggers
- subjet algorithms
  - mass drop
  - filtering
  - trimming
- b tagging
- “particle flow” $\not{E}_T$
- background uncert.

(in)visible non-standard branching ratios

[CE, Spannowsky, Wymant `12]

$$\mathcal{L}_{\rm new} \overset{???}{\not\supset} \eta|\phi_{\rm SM}|^2|\phi_{\rm hid}|^2$$ (allowed by gauge invariance & renormalizability)





- boosted kinematics
- triggers
- subjet algorithms
  - mass drop
  - filtering
  - trimming
- b tagging
- "particle flow" $\not{E}_T$
- background uncert.

Self-coupling measurements

Electroweak symmetry breaking relies on self-interactions in the Higgs potential.

$$-\mathcal{L} \supset \frac{1}{2} m_H^2 H^2 + \overset{=\,\lambda_{\mathrm{SM}}}{\sqrt{\frac{\eta}{2}}} m_H H^3 + \frac{\eta}{4} H^4$$

Self-coupling measurements

Electroweak symmetry breaking relies on self-interactions in the Higgs potential.

$$-\mathcal{L} \supset \frac{1}{2}m_H^2 H^2 + \overset{\lambda_{\mathrm{SM}}}{\overset{\shortparallel}{\sqrt{\frac{\eta}{2}}m_H}} H^3 + \frac{\eta}{4}H^4 \longrightarrow$$

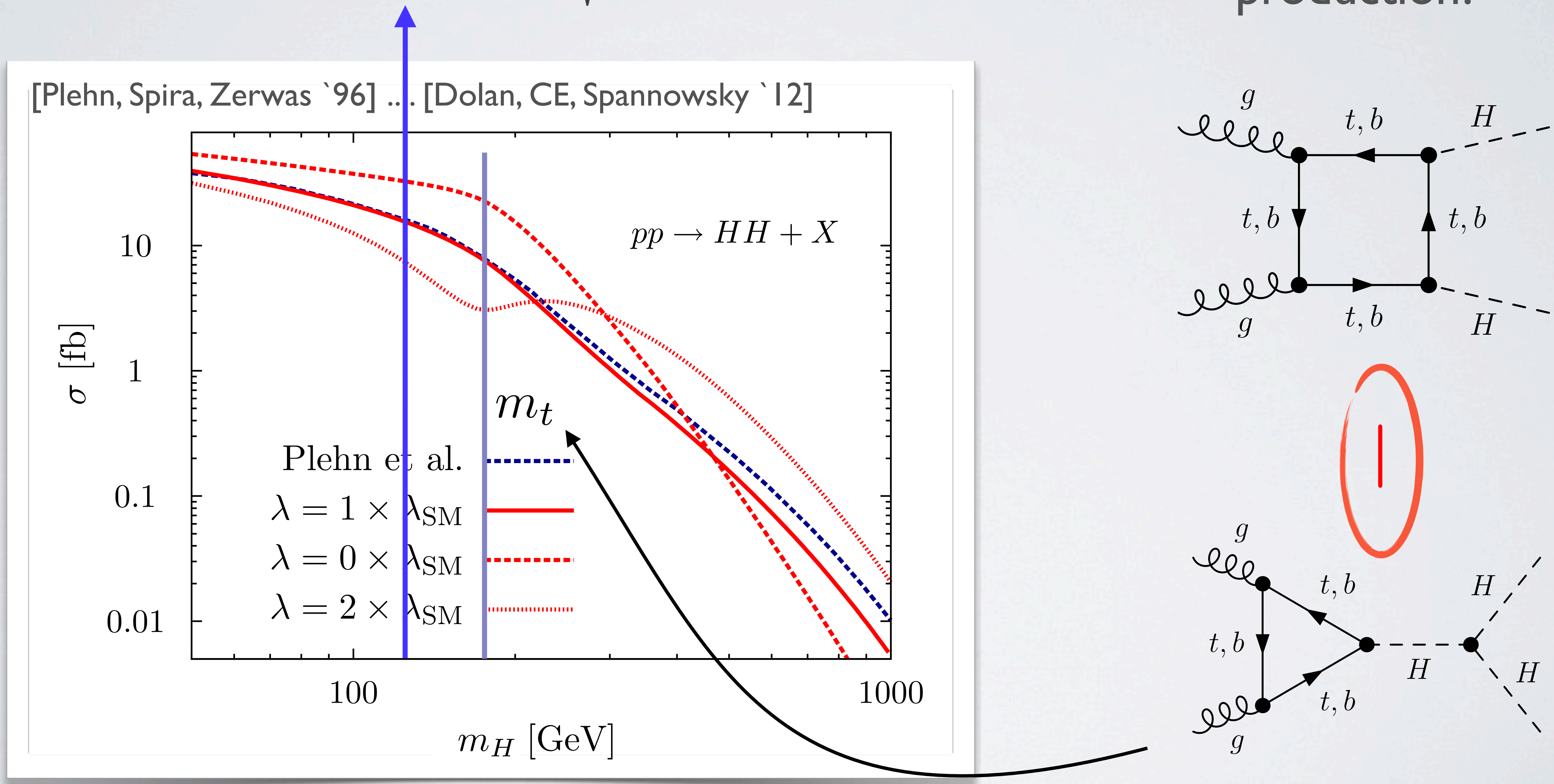
need at least di-Higgs production!

Self-coupling measurements

Electroweak symmetry breaking relies on self-interactions in the Higgs potential.

$$-\mathcal{L} \supset \frac{1}{2} m_H^2 H^2 + \sqrt{\frac{\overset{= \lambda_{\mathrm{SM}}}{\eta}}{2}}\, m_H H^3 + \frac{\eta}{4} H^4 \longrightarrow$$

need at least di-Higgs production!



[Plehn, Spira, Zerwas `96] .... [Dolan, CE, Spannowsky `12]

maximum at $m_H \sim m_t$

Self-coupling measurements at the hadron level

- inclusive searches hopeless except for rare $b\bar{b}\gamma\gamma$ [Baur, Plehn, Rainwater `03]
- jet substructure techniques on boosted final states revive $b\bar{b}\tau^+\tau^-$

$b\bar{b}\tau^+\tau^-$

apply subjet strategies inspired by BDRS

	$\xi = 0$	$\xi = 1$	$\xi = 2$	$b\bar{b}\tau\tau$	$b\bar{b}\tau\tau$ [ELW]	$b\bar{b}W^+W^-$	ratio to $\xi = 1$
cross section before cuts	59.48	28.34	13.36	67.48	8.73	873000	$3.2 \cdot 10^{-5}$
reconstructed Higgs from τs	4.05	1.94	0.91	2.51	1.10	1507.99	$1.9 \cdot 10^{-3}$
fatjet cuts	2.27	1.09	0.65	1.29	0.84	223.21	$4.8 \cdot 10^{-3}$
kinematic Higgs reconstruction ($m_{b\bar{b}}$)	0.41	0.26	0.15	0.104	0.047	9.50	$2.3 \cdot 10^{-2}$
Higgs with double b-tag	0.148	0.095	0.053	0.028	0.020	0.15	0.48

$b\bar{b}\tau^+\tau^- + j$

	$\xi = 0$	$\xi = 1$	$\xi = 2$	$b\bar{b}\tau^+\tau^- j$	$b\bar{b}\tau^+\tau^- j$ [ELW]	$t\bar{t}j$	ratio to $\xi = 1$
cross section before cuts	6.45	3.24	1.81	66.0	1.67	106.7	$1.9 \cdot 10^{-2}$
2 τs	0.44	0.22	0.12	37.0	0.94	7.44	$4.8 \cdot 10^{-3}$
Higgs rec. from taus + fatjet cuts	0.29	0.16	0.10	2.00	0.150	0.947	$5.1 \cdot 10^{-2}$
kinematic Higgs rec.	0.07	0.04	0.02	0.042	0.018	0.093	0.26
$2b$ + hh invariant mass + $p_{T,j}$ cut	0.010	0.006	0.004	<0.0001	0.0022	0.0014	1.54

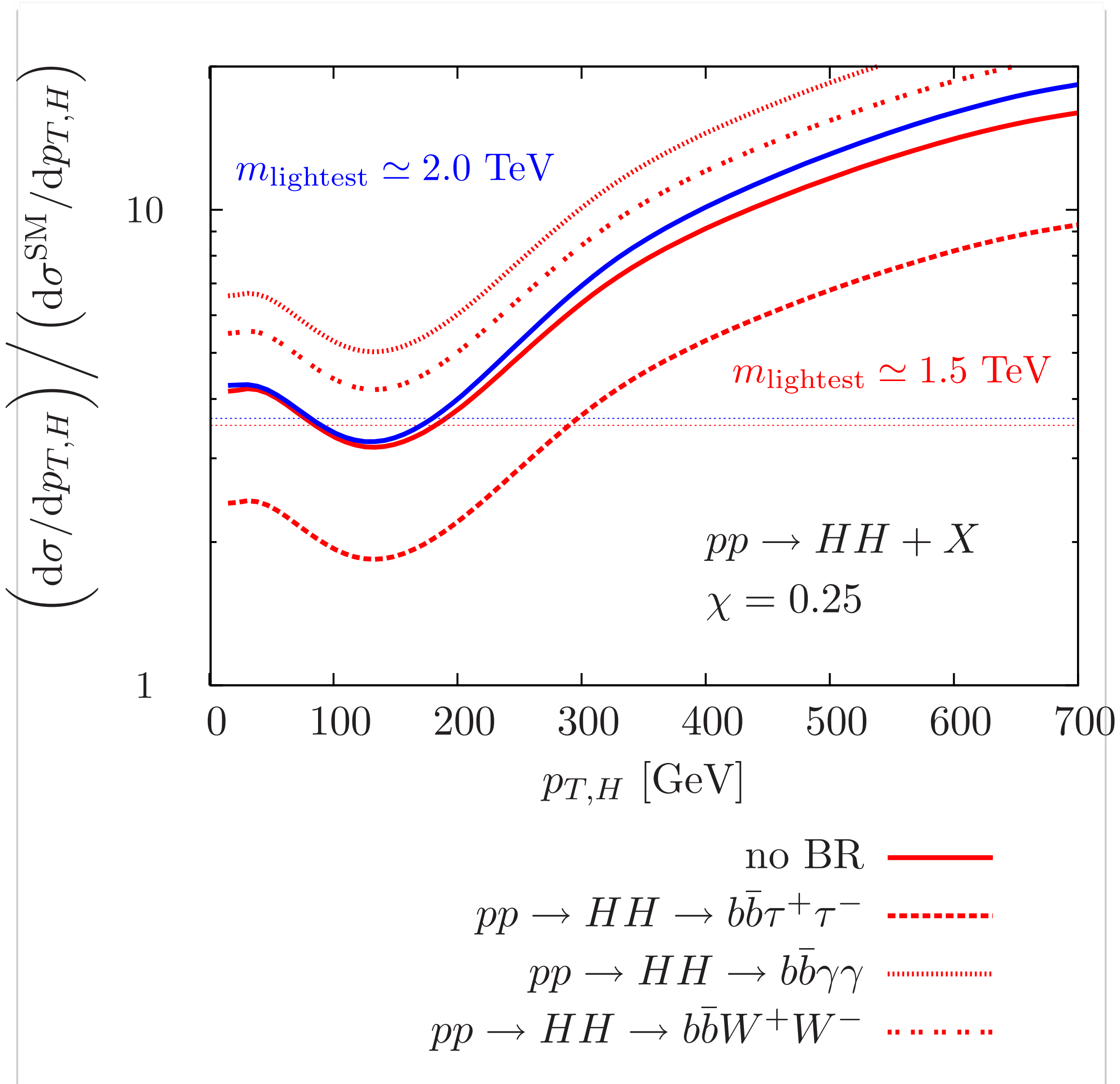
$m_H = 125$ GeV

This all has consequences on BSM searches as well !

composite Higgs

[Dolan, CE, Spannowsky `12]

- heavy top partners
- non-diagonal Higgs couplings $H\bar{t}_i t_j$
- nonstandard $HH\bar{t}_i t_j$ couplings
- modified Higgs trilinear couplings



$$\sigma(HH + j)/\sigma(\mathrm{SM}) \simeq 4.6 \text{ !!!}$$

This all has consequences on BSM searches as well !

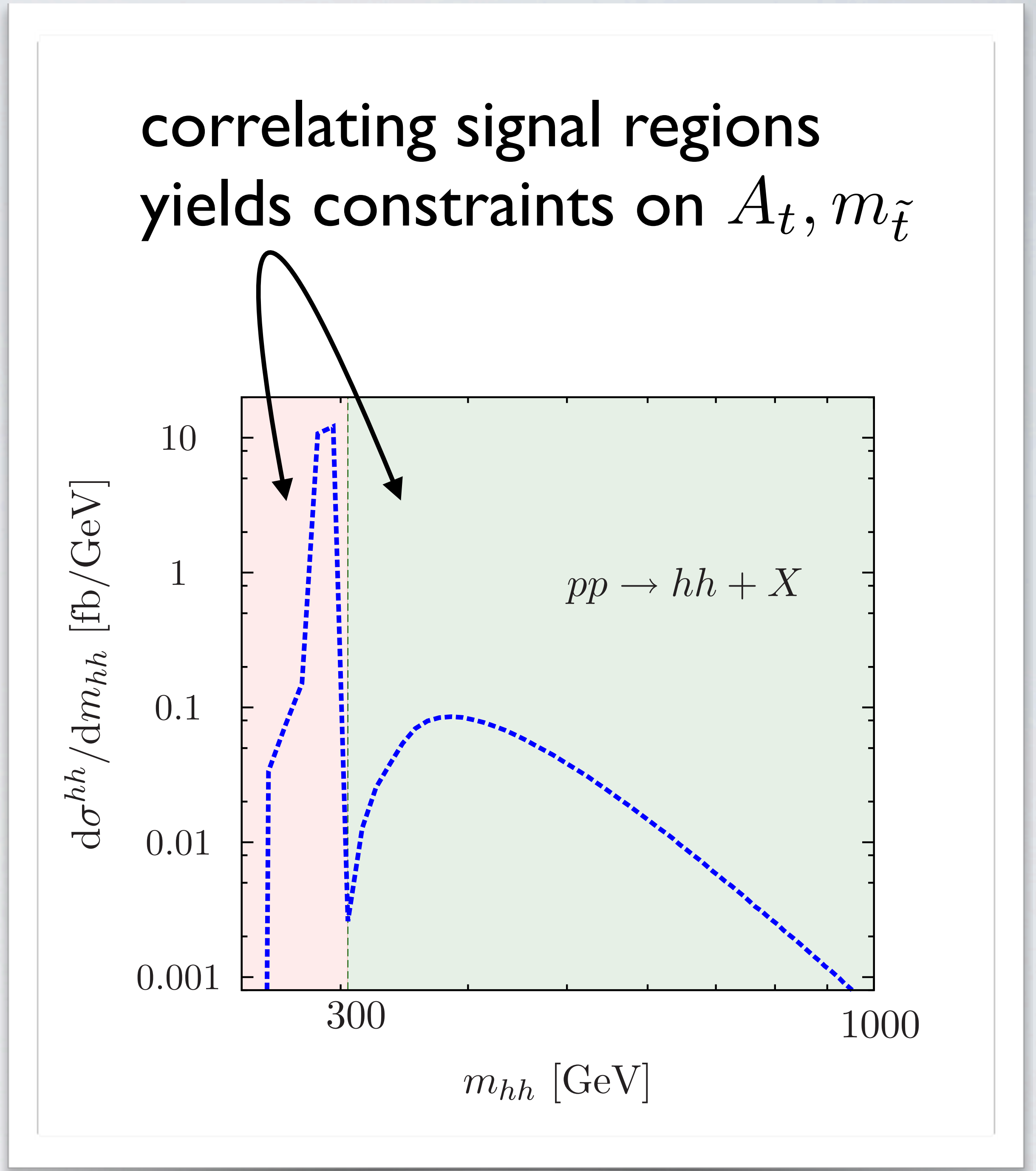
composite Higgs

- heavy top partners
- non-diagonal Higgs couplings $H\bar{t}_i t_j$
- nonstandard $HH\bar{t}_i t_j$ couplings
- modified Higgs trilinear couplings

split/natural/λ SUSY

- decoupling limit, weak scale tuned
- Hhh branching enhanced
- di-Higgs production is the only sensitive channel for such scenarios

[Dolan, CE, Spannowsky `12]


correlating signal regions yields constraints on $A_t, m_{\tilde{t}}$

This all has consequences on BSM searches as well !

[Dolan, CE, Spannowsky `12]

composite Higgs

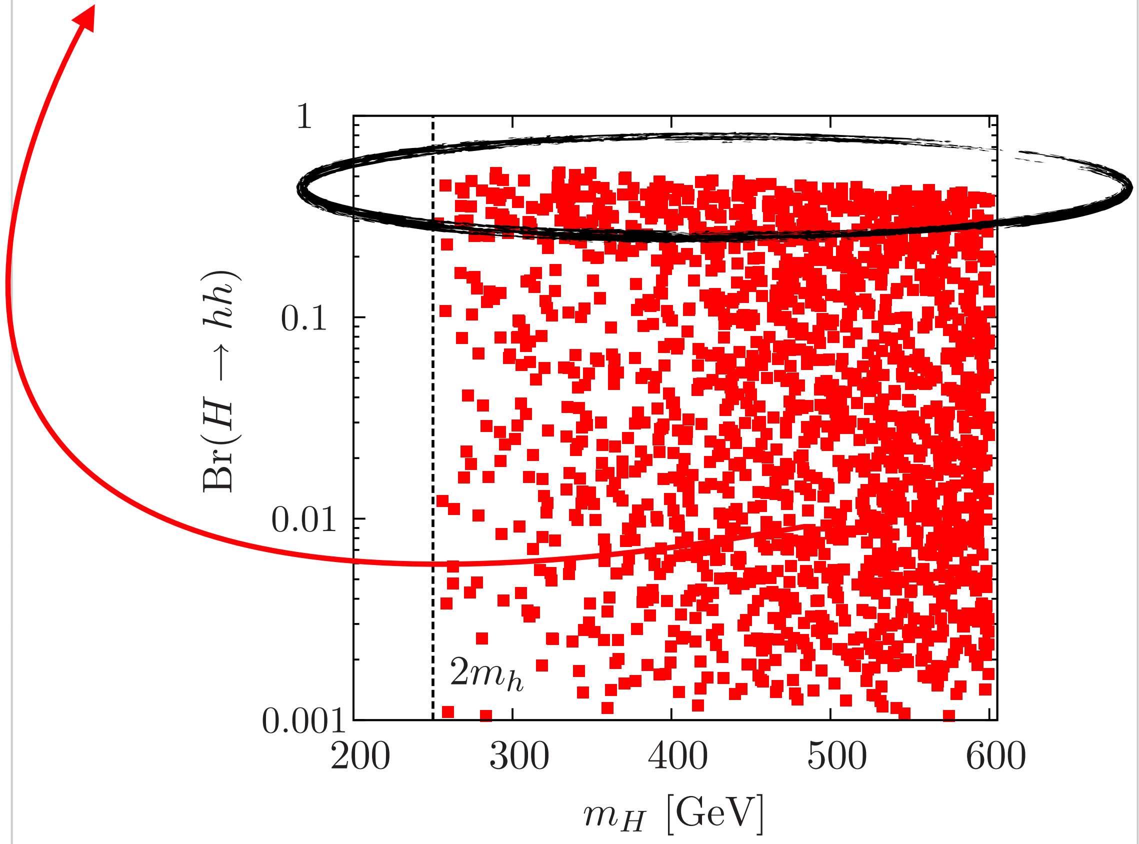
- heavy top partners
- non-diagonal Higgs couplings $H\bar{t}_i t_j$
- nonstandard $HH\bar{t}_i t_j$ couplings
- modified Higgs trilinear couplings

split/natural/λ SUSY

- decoupling limit, weak scale tuned
- Hhh branching enhanced
- di-Higgs production is the only sensitive channel for such scenarios

Higgs portal reconstruction

- large branching to SM-like Higgs allowed, currently no sensitivity


electroweak precision data

constraints from direct measurements

This all has consequences on BSM searches as well !

composite Higgs

[Dolan, CE, Spannowsky `12]

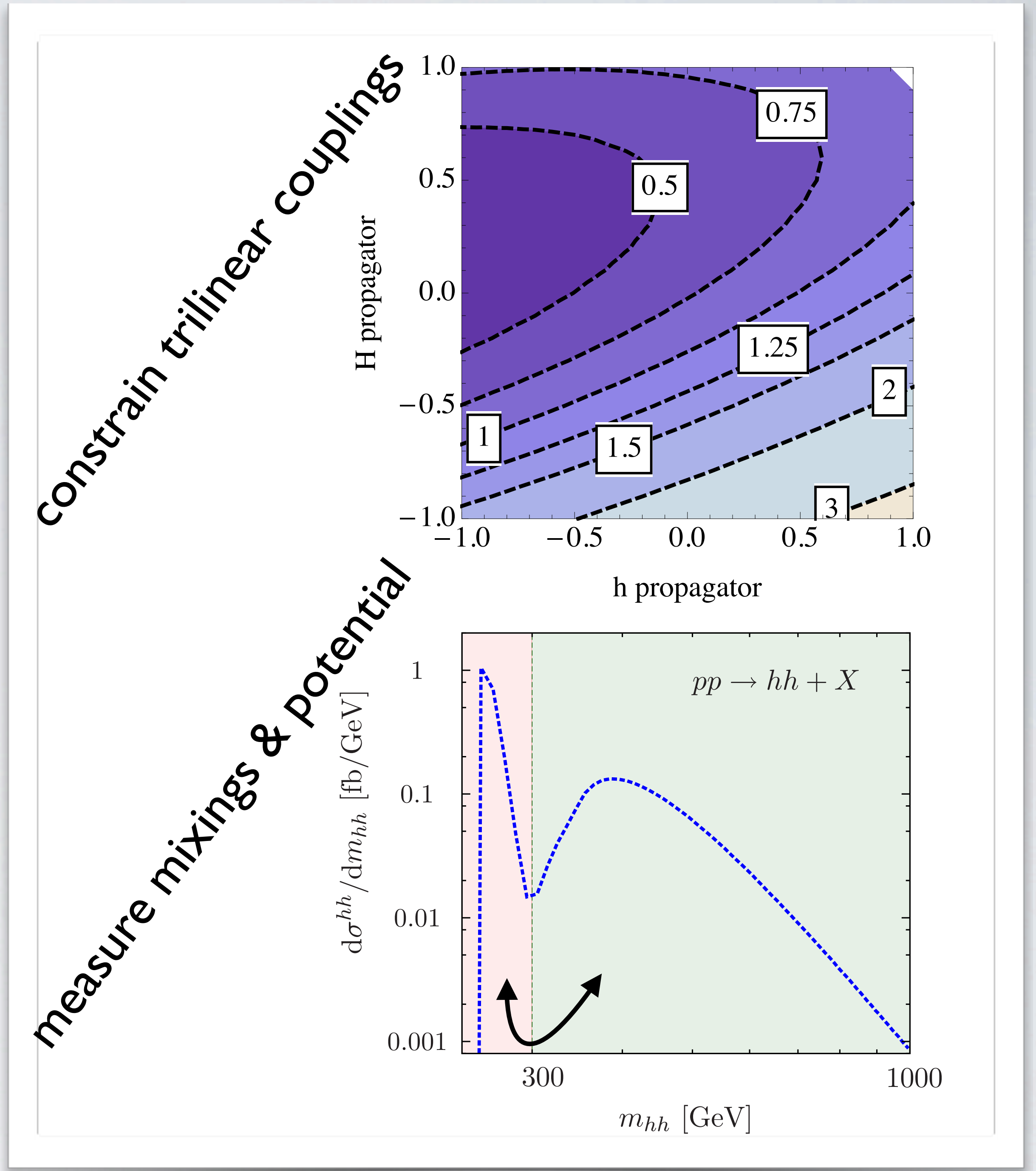
- heavy top partners
- non-diagonal Higgs couplings $H\bar{t}_i t_j$
- nonstandard $HH\bar{t}_i t_j$ couplings
- modified Higgs trilinear couplings

split/natural/λ SUSY

- decoupling limit, weak scale tuned
- Hhh branching enhanced
- di-Higgs production is the only sensitive channel for such scenarios

Higgs portal reconstruction

- large branching to SM-like Higgs allowed, currently no sensitivity



This all has consequences on BSM searches as well !

[Dolan, CE, Spannowsky `12]

composite Higgs

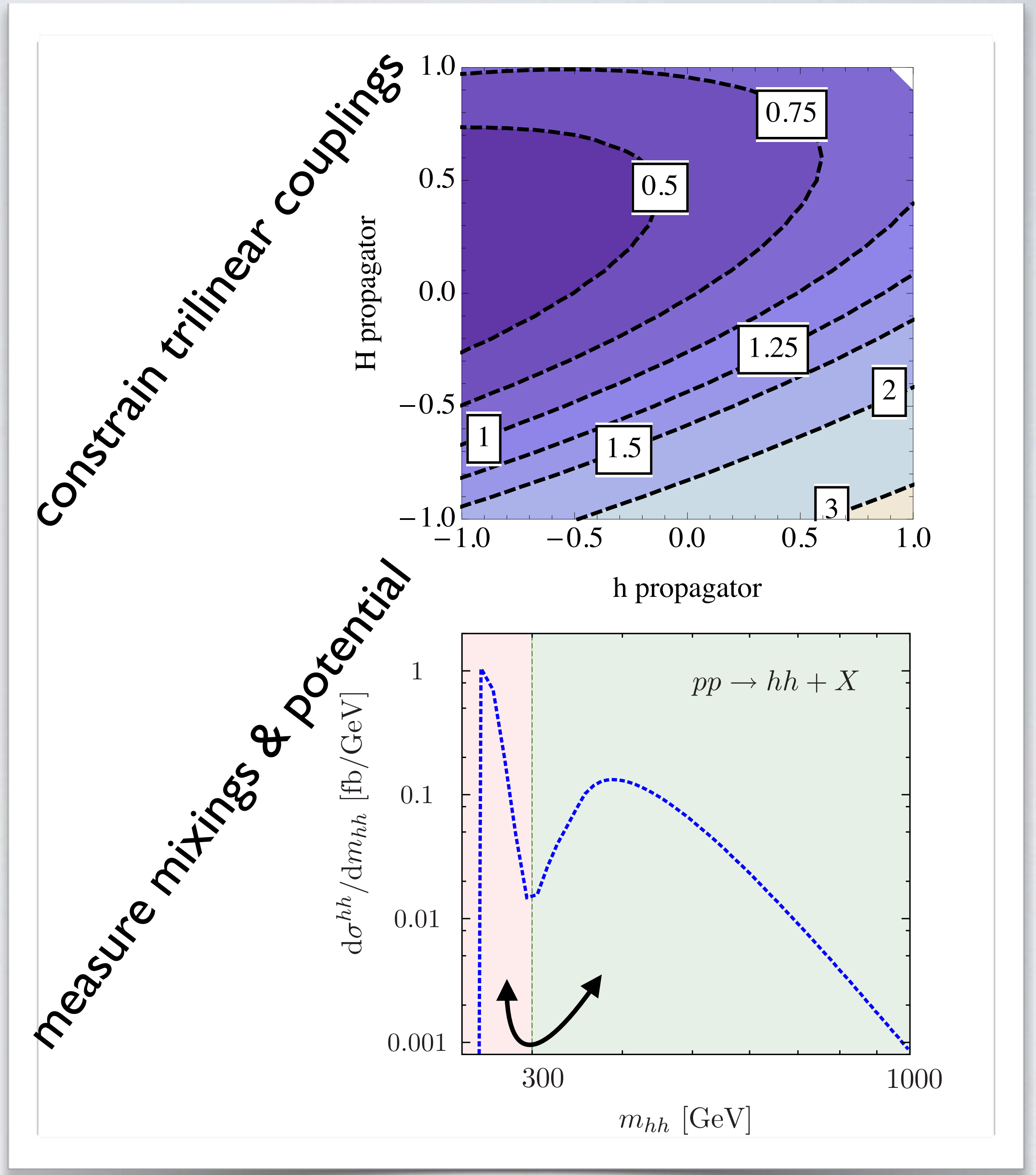
- heavy top partners
- non-diagonal Higgs couplings $H\bar{t}_i t_j$
- nonstandard $HH\bar{t}_i t_j$ couplings
- modified Higgs trilinear couplings

split/natural/λ SUSY

- decoupling limit, weak scale tuned
- Hhh branching enhanced
- di-Higgs production is the only sensitive channel for such scenarios

Higgs portal reconstruction

- large branching to SM-like Higgs allowed, currently no sensitivity


constrain trilinear couplings

measure mixings & potential

pseudo-dilaton, Higgs triplet models, ...

... challenges in Higgs theory after discovery

" The more important fundamental laws and facts of physical science have all been discovered..."

A. A. Michelson, 1894

... challenges in Higs theory after discovery

" The more important fundamental laws and facts of physical science have all been discovered..."

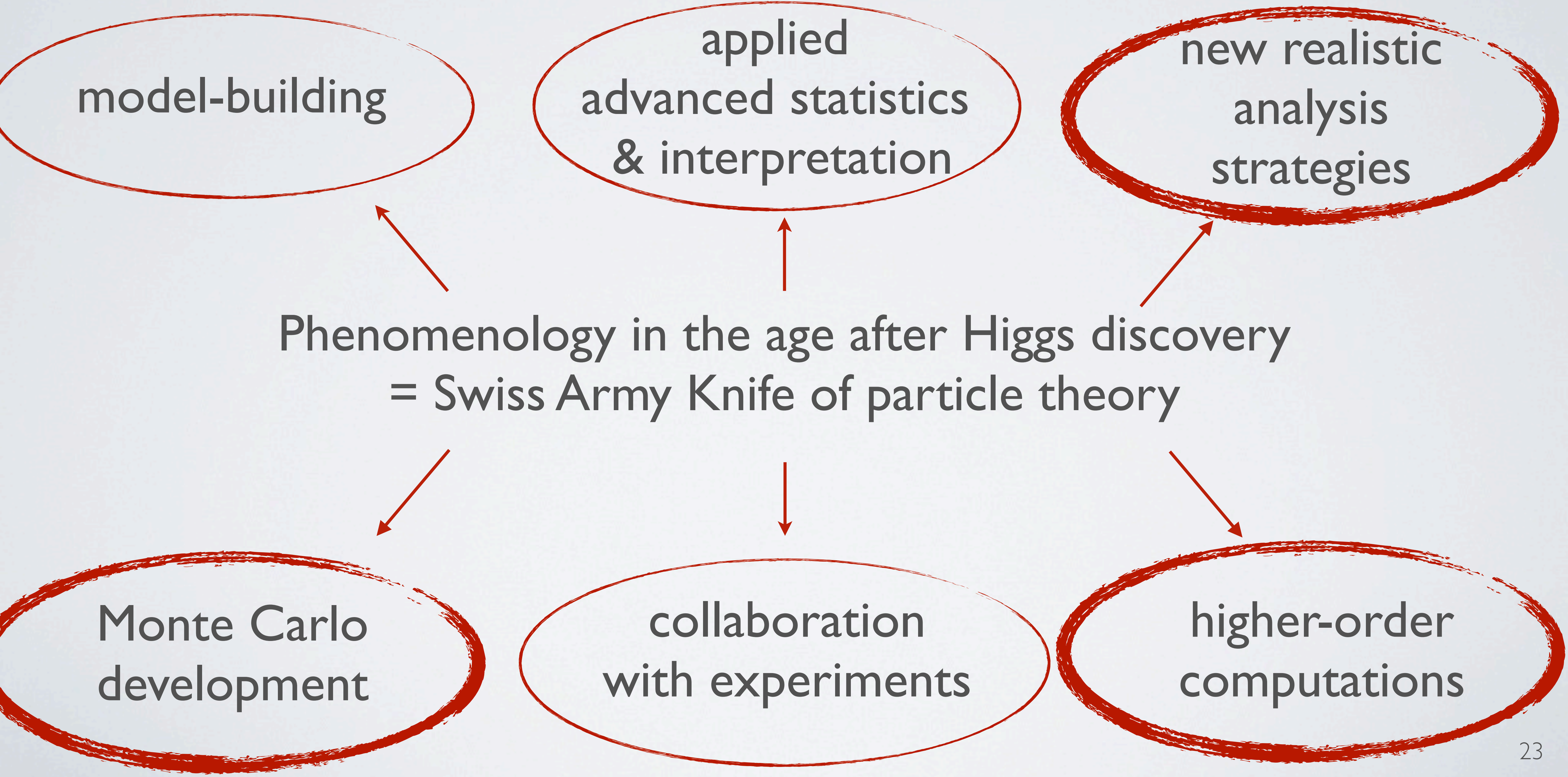
A. A. Michelson, 1894

Phenomenology in the age after Higgs discovery
= Swiss Army Knife of particle theory

... challenges in Higgs theory after discovery

" The more important fundamental laws and facts of physical science have all been discovered... "

A.A. Michelson, 1894



model-building

applied advanced statistics & interpretation

new realistic analysis strategies

Phenomenology in the age after Higgs discovery
= Swiss Army Knife of particle theory

Monte Carlo development

collaboration with experiments

higher-order computations

SUMMARY

- new states in the TeV region induce high mass scales and modifications of distributions at large transverse momenta
- boosted final states offer an efficient handle to reduce backgrounds
- jets are a theoretical necessity but also storytellers
- methods to suppress UEV, pile-up etc. exist and validated (to some degree):
  - filtering
  - trimming
  - pruning
- tools available!
  - Parton-level calculations, showers, event generators: Mcfm, Vbfnlo, Herwig(++), Sherpa, Pythia, MadEvent, ...
  - jet clustering, subjet algorithms/analyses: FastJet, SpartyJet, Rivet, ...

make use of the hands-on session!