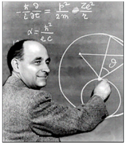
Supersymmetry in 2012 and beyond

Tilman Plehn

Heidelberg

MPI, 4/2011

Standard Model effective theory



Building a fundamental theory

– Fermi 1934: theory of weak interactions $[n \to p e^- \bar{\nu}_e]$
  $(2 \to 2)$ transition amplitude $\mathcal{A} \propto G_F E^2$
  probability/ unitarity violation
  pre-80s effective theory for $E < 600$ GeV

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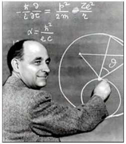

TENTATIVO DI UNA TEORIA DEI RAGGI β

Nota (1) di Enrico Fermi

Sunto. - *Si propone una teoria quantitativa dell'emissione dei raggi β in cui si ammette l'esistenza del «neutrino» e si tratta l'emissione degli elettroni e dei neutrini da un nucleo all'atto della disintegrazione β con un procedimento simile a quello seguito nella teoria dell'irradiazione per descrivere l'emissione di un quanto di luce da un atomo eccitato. Vengono dedotte delle formule per la vita media e per la forma dello spettro continuo dei raggi β, e le si confrontano coi dati sperimentali.*

Ipotesi fondamentali della teoria.

§ 1. Nel tentativo di costruire una teoria degli elettroni nucleari e dell'emissione dei raggi β, si incontrano, come è noto, due difficoltà principali. La prima dipende dal fatto che i raggi β primari vengono emessi dai nuclei con una distribuzione continua di velocità. Se non si vuole abbandonare il principio della conservazione dell'energia, si deve ammettere perciò che una frazione dell'energia che si libera nel processo di disintegrazione β sfugga alle nostre attuali possibilità di osservazione. Secondo la proposta di Pauli si può p. es. ammettere l'esistenza di una nuova particella, il così detto «neutrino», avente carica elettrica nulla e massa dell'ordine di grandezza di quella dell'elettrone o minore. Si ammette poi che in ogni processo β vengano emessi simultaneamente un elettrone, che si osserva come raggio β, e un neutrino che sfugge all'osservazione portando seco una parte dell'energia. Nella presente teoria ci baseremo sopra l'ipotesi del neutrino.

Una seconda difficoltà per la teoria degli elettroni nucleari, dipende dal fatto che le attuali teorie relativistiche delle particelle leggere (elettroni o neutrini) non danno una soddisfacente spiegazione della possibilità che tali particelle vengano legate in orbite di dimensioni nucleari.

(1) Cfr. la nota preliminare in «La Ricerca Scientifica», 2, fasc. 12, 1933.

Versuch einer Theorie der β-Strahlen. I[1]).

Von **E. Fermi** in Rom.

Mit 3 Abbildungen. (Eingegangen am 16. Januar 1934.)

Eine quantitative Theorie des β-Zerfalls wird vorgeschlagen, in welcher man die Existenz des Neutrinos annimmt, und die Emission der Elektronen und Neutrinos aus einem Kern beim β-Zerfall mit einer ähnlichen Methode behandelt, wie die Emission eines Lichtquants aus einem angeregten Atom in der Strahlungstheorie. Formeln für die Lebensdauer und für die Form des emittierten kontinuierlichen β-Strahlenspektrums werden abgeleitet und mit der Erfahrung verglichen.

1. Grundannahmen der Theorie.

Bei dem Versuch, eine Theorie der Kernelektronen sowie der β-Emission aufzubauen, begegnet man bekanntlich zwei Schwierigkeiten. Die erste ist durch das kontinuierliche β-Strahlenspektrum bedingt. Falls der Erhaltungssatz der Energie gültig bleiben soll, muß man annehmen, daß ein Bruchteil der beim β-Zerfall frei werdenden Energie unseren bisherigen Beobachtungsmöglichkeiten entgeht. Nach dem Vorschlag von W. Pauli kann man z. B. annehmen, daß beim β-Zerfall nicht nur ein Elektron, sondern auch ein neues Teilchen, das sogenannte „Neutrino" (Masse von der Größenordnung oder kleiner als die Elektronenmasse; keine elektrische Ladung) emittiert wird. In der vorliegenden Theorie werden wir die Hypothese des Neutrinos zugrunde legen.

Eine weitere Schwierigkeit für die Theorie der Kernelektronen besteht darin, daß die jetzigen relativistischen Theorien der leichten Teilchen (Elektronen oder Neutrinos) nicht imstande sind, in einwandfreier Weise zu erklären, wie solche Teilchen in Bahnen von Kerndimensionen gebunden werden können.

Es scheint deswegen zweckmäßiger, mit Heisenberg[2]) anzunehmen, daß ein Kern nur aus schweren Teilchen, Protonen und Neutronen, besteht. Um trotzdem die Möglichkeit der β-Emission zu verstehen, wollen wir versuchen, eine Theorie der Emission leichter Teilchen aus einem Kern in Analogie zur Theorie der Emission eines Lichtquants aus einem angeregten Atom beim gewöhnlichen Strahlungsprozeß aufzubauen. In der Strahlungstheorie ist die totale Anzahl der Lichtquanten keine Konstante: Lichtquanten entstehen, wenn sie von einem Atom emittiert werden, und verschwinden, wenn sie absorbiert werden. In Analogie hierzu wollen wir der β-Strahlentheorie folgende Annahmen zugrunde legen:

1) Vgl. die vorläufige Mitteilung: La Ricerca Scientifica **2**, Heft 12, 1933. — 2) W. Heisenberg, ZS. f. Phys. **77**, 1, 1932.

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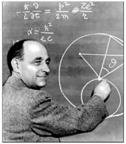

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– Yukawa 1935: massive particles
  Fermi's theory for $E \ll M$
  four fermions unitary for $E \gg M$: $\mathcal{A} \propto g^2 E^2/(E^2 - M^2)$
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  current effective theory for $E < 1.2$ TeV [LHC energy!!]

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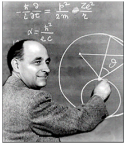

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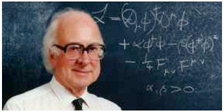

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  unitarity for massive W, Z
  unitarity for massive fermions
  fundamental scalar below TeV

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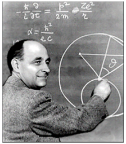

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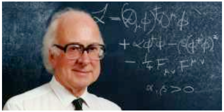

- 't Hooft & Veltman 1971: renormalizability
  forbidden $1/M$ couplings
  theory valid to high energy
  truly fundamental theory

Standard Model effective theory

Experiment: how complete?

– dark matter? [WIMP miracle?]

– quark mixing — flavor physics? [new operators above 10^4 GeV?]

– neutrino masses and mixing? [see-saw at 10^{11} GeV?]

– matter–antimatter asymmetry? [universe mostly matter?]

– gauge coupling unification?

$\Rightarrow$ large cut-off scale unavoidable

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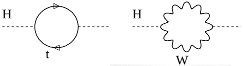
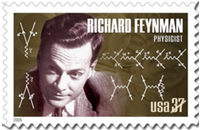
Theory: inconsistent Higgs sector

- quantum corrections to Higgs mass... [$\Delta t \, \Delta E < 1$]





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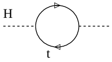

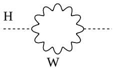

– quantum corrections to Higgs mass...

$$m_H^2 \longrightarrow m_H^2 - \frac{g^2}{(4\pi)^2} \, \frac{3}{2} \, \frac{\Lambda^2}{m_W^2} \left[m_H^2 + 2m_W^2 + m_Z^2 - 4m_t^2 \right] + \cdots$$

– hierarchy problem — Higgs without stabilization incomplete

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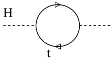

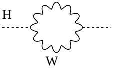

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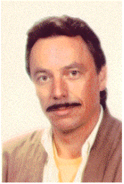
- hierarchy problem — Higgs without stabilization incomplete
- easy solution: counter term — but against idea of symmetries
- or new physics at TeV scale: supersymmetry
  extra dimensions
  little Higgs
  composite Higgs, TopColor
  YourFavoriteNewPhysics...



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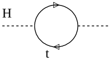
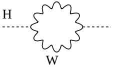
Expectations for the LHC [Uli Baur's rule: always new physics at new scales]

- see light Higgs?
- see top partner?
- see dark–matter candidate?

Supersymmetry





Setup

- partner for each Standard Model particle
- cancellation because of different spins
- obviously broken by masses, mechanism unknown
- assume dark matter, stable lightest partner

$\Rightarrow$ LHC: measure spectrum with missing energy

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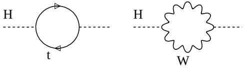

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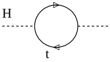
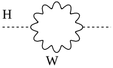
Particle spectrum

		spin	d.o.f.	
fermion	f_L, f_R	1/2	1+1	
→ sfermion	$\tilde{f}_L, \tilde{f}_R$	0	1+1	
gluon	G_μ	1	n-2	
→ gluino	$\tilde{g}$	1/2	2	Majorana
gauge bosons	γ, Z	1	2+3	
Higgs bosons	h^o, H^o, A^o	0	3	
→ neutralinos	$\tilde{\chi}_i^o$	1/2	$4 \cdot 2$	dark matter
gauge bosons	$W^\pm$	1	$2 \cdot 3$	
Higgs bosons	$H^\pm$	0	2	
→ charginos	$\tilde{\chi}_i^\pm$	1/2	$2 \cdot 4$	

Supersymmetry





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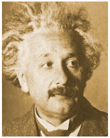
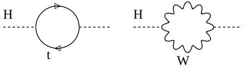


Supersymmetry at the LHC

Supersymmetry



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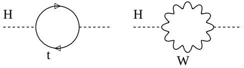
Supersymmetry at the LHC

– production of squarks and gluinos
cascade decay to DM candidate
– beyond inclusive searches
lots of strongly interacting particles
– general theme: try to survive QCD
– rate prediction not $\alpha_s/(4\pi) \sim 0.01$
(collinear) jets everywhere
better observables needed

Supersymmetry



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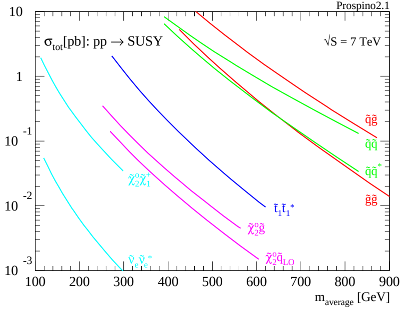

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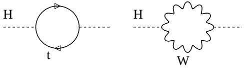

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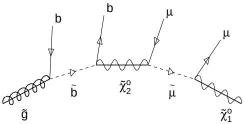
Some relativistic kinematics

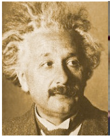


– more than 10^7 squark–gluino events at 14 TeV
– all decays to hard jets, missing energy, (leptons)
example $\tilde{g} \to \tilde{b}\bar{b} \to \tilde{\chi}_2^0 b\bar{b} \to \mu^+\mu^- b\bar{b}\tilde{\chi}_1^0$
– thresholds & edges [Cambridge, ATLAS TDR]

$$m_{ij}^2 = E_i E_j - |\vec{p}_i||\vec{p}_j| \cos\theta_{ij}$$

$$0 < m_{\mu\mu}^2 < \frac{m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\ell}}^2}{m_{\tilde{\ell}}} \, \frac{m_{\tilde{\ell}}^2 - m_{\tilde{\chi}_1^0}^2}{m_{\tilde{\ell}}}$$

⇒ masses from cascade decays — except for stops!

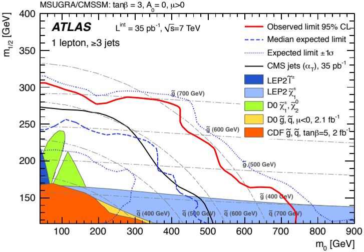



First LHC searches

First inclusive ATLAS searches [same for CMS]

1 – one lepton, jets, $\not{p}_T$ [35 pb^{-1}]

$\not{p}_T > 150$ GeV, $m_{\text{eff}} > 500$ GeV, $\not{p}_T > 0.25 m_{\text{eff}}$
inclusive search, control regions, $t\bar{t}$ main background



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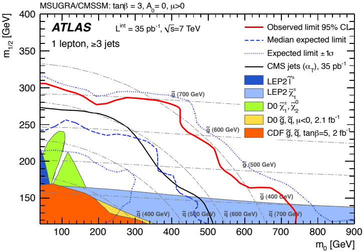


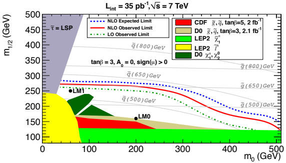
absolutely useless: MSUGRA, CMSSM

scalars — m_0 fermions — $m_{1/2}$ tri-scalar — A_0 Higgs sector — sign(μ), $\tan\beta$

not a valid SUSY breaking scenario!
heavy gluino regime not covered!

[gluino mass: line vs squark mass: ellipse]

physicists search for SUSY, not MSUGRA!



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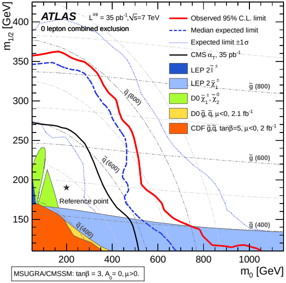
2 – jets, $\not{p}_T$ [lepton veto; 35 pb^{-1}]

e.g. $p_{T,j} > 120, 40, \ldots$ GeV, $\not{p}_T > 100$ GeV, $m_{T,2} > 300$ GeV
different regions, W+jets and QCD main backgrounds



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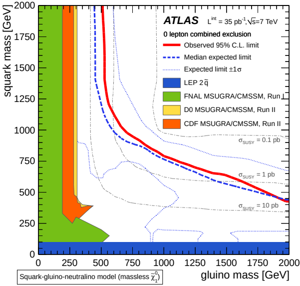

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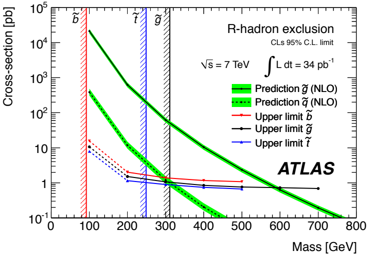
e.g. $p_{T,j} > 120, 40, \ldots$ GeV, $\not{p}_T > 100$ GeV, $m_{T,2} > 300$ GeV
different regions, W+jets and QCD main backgrounds

3 – stable squarks, gluinos [R hadrons; 34 pb^{-1}; Kilian, TP, Richardson, Schmidt]

massive muons, time of flight
trigger on $\not{p}_T > 40$ GeV, QCD with detector fake main background



First LHC searches

First inclusive ATLAS searches [same for CMS]

1 – one lepton, jets, $\not{p}_T$ [35 pb^{-1}]

$\not{p}_T > 150$ GeV, $m_{\text{eff}} > 500$ GeV, $\not{p}_T > 0.25 m_{\text{eff}}$
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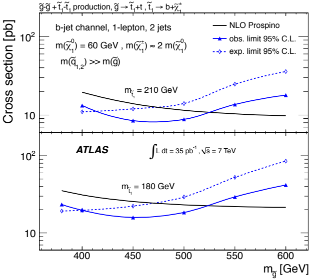
like inclusive with(out) leptons, add b tag
$t\bar{t}$ main background



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⇒ many more analyses to come, please stay inclusive!

Jets plus $\not p_T$

Jet counting [Englert, TP, Schumann, Schichtel]

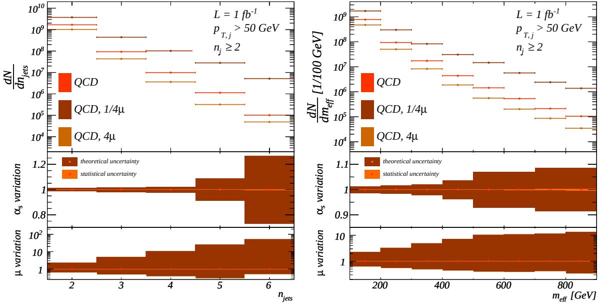
– improved background understanding needed

– DGLAP lecture: jet-inclusive
SUSY analyses: jet-exclusive
jet merging the key [Sherpa, Alpgen, MadEvent,..., including uncertainties]

– 'staircase scaling' for QCD and W+jets with constant [Ellis, Kleiss, Stirling]

$$\hat{R} \equiv \frac{\hat{\sigma}_{n+1}}{\hat{\sigma}_n} = \frac{\sigma_{n+1} \sum_{j=0}^{\infty} R^j}{\sigma_n + \sigma_{n+1} \sum_{j=0}^{\infty} R^j} = \frac{R\sigma_n}{(1-R)\sigma_n + R\sigma_n} = \frac{\sigma_{n+1}}{\sigma_n} \equiv R$$

$\Rightarrow$ magic R value helping understand m_{eff}



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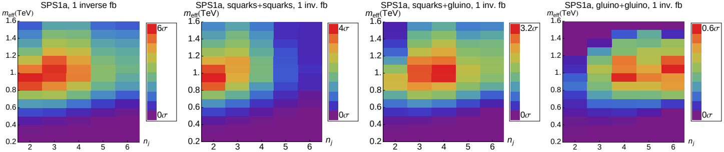
– mass of heavy states from m_{eff} [like ATLAS analyses]
color charge from n_{jest} [no gluon decay]

– exclusive two-dimensional likelihood



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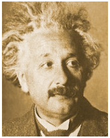
⇒ step towards studying inclusive signals

Fat jets

Fat jets from boosted particles



1– collinear decay products

2– improved mass reconstruction

3– signal combinatorics

Boosted particles at the LHC

1994 boosted $W \to$ 2 jets from heavy Higgs [Seymour]

1994 boosted $t \to$ 3 jets [Seymour]

2002 boosted $W \to$ 2 jets from strong WW [YSplitter: Butterworth, Cox, Forshaw]

2006 boosted $t \to$ 3 jets from resonances [Agashe, Belyaev, Krupovnickas, Perez, Virzi]

2008 boosted $H \to b\bar{b}$ [Butterworth, Davison, Rubin, Salam]

2008 boosted $t \to$ 3 jets from resonances [JH tagger: Kaplan, Rehermann, Schwartz, Tweedie]

2009 boosted $t \to$ 3 jets in Higgs production [TP, Salam, Spannowsky]

2010 boosted $t \to$ 3 jets from top partners [HEPTopTagger: TP, Spannowsky, Takeuchi, Zerwas]

2011 boosted $t \to j\ell\nu$ from top partners [HEPTopTagger: TP, Spannowsky, Takeuchi]

...

2010 first multi-author meta analysis review [BOOST proceedings, Ed: Karagoz, Spannowsky, Vos]

...

Jet Algorithms

Jets

- jet–parton duality ⇔ partons in the detector?
- algorithm to reconstruct parton 4-momentum

Different measures [tool: FASTJET]

- define jet–jet and jet–beam distance [and resolution y_{cut}]

$$
\begin{aligned}
&k_T \qquad && y_{ij} = \frac{\Delta R_{ij}}{D} \,\min\left(p_{T,i}, p_{T,j}\right) \qquad && y_{iB} = p_{T,i} \\
&\text{C/A} \qquad && y_{ij} = \frac{\Delta R_{ij}}{D} \qquad && y_{iB} = 1 \\
&\text{anti-}k_T \qquad && y_{ij} = \frac{\Delta R_{ij}}{D} \,\min\left(p_{T,i}^{-1}, p_{T,j}^{-1}\right) \qquad && y_{iB} = p_{T,i}^{-1} \; .
\end{aligned}
$$

- (1) find minimum $y_{\text{min}} = \min_{kl}(y_{kl}, y_{kB})$
  (2a) if $y_{\text{min}} = y_{kl} < y_{\text{cut}}$ combine k and l, go to (1)
  (2b) if $y_{\text{min}} = y_{kB} < y_{\text{cut}}$ remove k, go to (1)
  (2c) if $y_{\text{min}} > y_{\text{cut}}$, done
- fat jets: allow for heavy constituents, use clustering history

Higgs tagger

New strategy for VH, $H \to b\bar{b}$ [Butterworth, Davison, Rubin, Salam]

- desperately needed [2/3 of all light Higgses; impact Dührssen & SFitter]
  but killed by continuum $Vb\bar{b}$ background
- S: large m_{bb}, boost-dependent R_{bb}
  B: large m_{bb} only for large R_{bb}
  S/B: go for large m_{bb} and small R_{bb}, so boost Higgs
- fat jet size $R_{bb} \sim 1 \gtrsim 2m_H/p_T$ [like b tag for now]
- $q\bar{q} \to V_\ell H_b$ sizeable in boosted regime [$p_T \gtrsim 300$ GeV, few % of total rate]

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⇒ best performance: C/A algorithm

jet definition	σ_S/fb	σ_B/fb	$S/\sqrt{B_{30}}$
C/A, $R = 1.2$	0.57	0.51	4.4
$k_\perp$, $R = 1.0$	0.19	0.74	1.2
SISCone, $R = 0.8$	0.49	1.33	2.3

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$\Rightarrow$ best performance: C/A algorithm

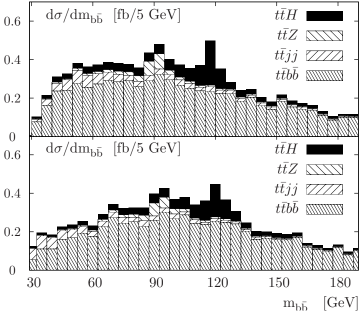
New strategy for $t\bar{t}H, H \to b\bar{b}$ [TP, Salam, Spannowsky]

– $pp \to t_\ell t_h H_b$ even harder than VH

– require tagged top and Higgs
trigger on lepton

– only continuum $t\bar{t}b\bar{b}$ left

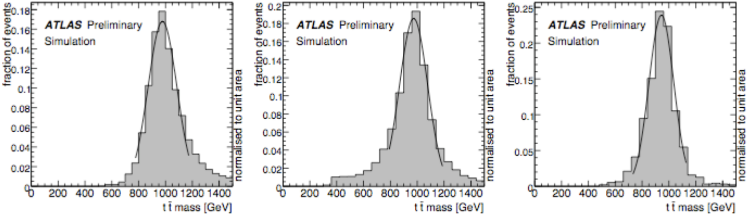
– combined C/A top and Higgs tagger



Top tagger

Highly boosted top quarks [Kaplan, Rehermann, Schwartz, Tweedie; Princeton, Seattle...]

- identify hadronic tops with $p_T \gtrsim 250...800$ GeV [isolation and b tag?]
- C/A algorithm with p_T or mass drop criterion [Hopkins tagger, HEPTopTagger]
- top mass included, no sidebins, no b tag
- ATLAS studies for semileptonic top pairs [adapted Y-splitter, full sim, ATLAS-2010-008]



(a) minimal (b) full reconstruction (c) mono-jet

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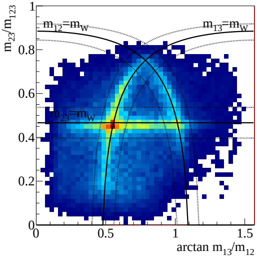
HEPTopTagger [TP, Salam, Spannowsky, Takeuchi]

- start with C/A jet [$R = 1.5$]
- uncluster one-by-one: $j \to j_1 + j_2$
  1– unbalanced $m_{j_1} > 0.8 m_j$ means QCD; discard j_2
  2– soft $m_{j_1} < 30$ GeV means QCD; keep j_1
- top decay kinematics in relevant substructures
  reconstruct $m_W = 60...95$ GeV
  reconstruct $m_t = 150...200$ GeV
  helicity angle $\cos\theta_{t,j_1}$ or second m_{ij}
- mass reconstruction w/ 2 QCD jets [filtering]



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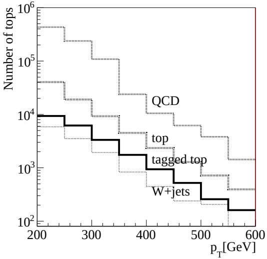

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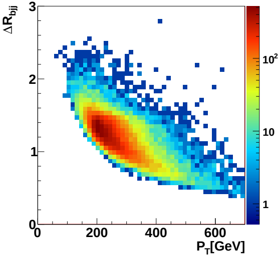

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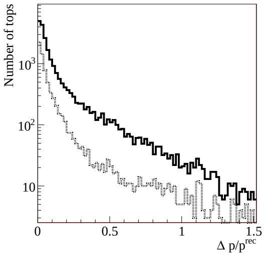

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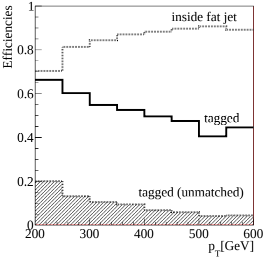

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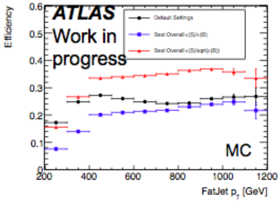

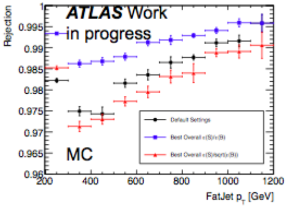

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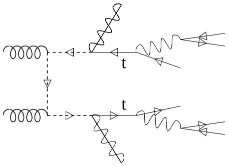
– improvable through color activity [Baryakthar, Hook, Janowiak, Wacker]
– hadronic top like tagged *b*

Stop pairs



Goal: stop pairs [TP, Spannowsky, Takeuchi, Zerwas]

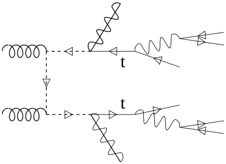
– stop crucial for hierarchy problem [review: Morrissey, TP, Tait]
  comparison to other top partners [Meade & Reece]

– dark matter means difficult semi-leptonic channel [possibly impossible]

– hadronic: $\tilde{t}\tilde{t}^* \to t\tilde{\chi}_1^0\ \bar{t}\tilde{\chi}_1^0$ [CMS: leptons as spontaneous life guards; Meade & Reece overly optimistic]

events in 1 fb^{-1}	$\tilde{t}_1\tilde{t}_1^*$						$t\bar{t}$	QCD	W+jets	Z+jets	S/B	$S/\sqrt{B}_{10\,\text{fb}^{-1}}$
$m_{\tilde{t}}$[GeV]	340	390	440	490	540	640					340	
$p_{T,j} > 200$ GeV, ℓ veto	728	447	292	187	124	46	87850	$2.4 \cdot 10^7$	$1.6 \cdot 10^5$	n/a	$3.0 \cdot 10^{-5}$	
$\not{E}_T > 150$ GeV	283	234	184	133	93	35	2245	$2.4 \cdot 10^5$	1710	2240	$1.2 \cdot 10^{-3}$	
first top tag	100	91	75	57	42	15	743	7590	90	114	$1.2 \cdot 10^{-2}$	
second top tag	15	12.4	11	8.4	6.3	2.3	32	129	5.7	1.4	$8.3 \cdot 10^{-2}$	
b tag	8.7	7.4	6.3	5.0	3.8	1.4	19	2.6	$\lesssim 0.2$	$\lesssim 0.05$	0.40	5. 9
$m_{T2} > 250$ GeV	4.3	5.0	4.9	4.2	3.2	1.2	4.2	$\lesssim 0.6$	$\lesssim 0.1$	$\lesssim 0.03$	0.88	6. 1

Stop pairs



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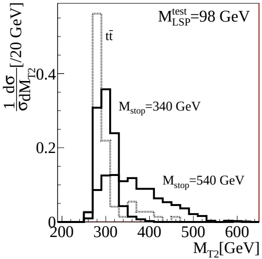
- stop mass from m_{T2} endpoint [like sleptons or sbottoms]

$$m_{T2}(\hat{m}_\chi) = \min_{\not{p}_T = q_1 + q_2} \left[\max_j \; m_{T,j}(q_j; \hat{m}_\chi) \right] \stackrel{!}{<} m_{\tilde{t}}$$

- hadronic search as easy as $b\bar{b} + \not{E}_T$



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Leptonic tag [Thaler & Wang; Rehermann & Tweedie; TP, Spannowsky, Takeuchi]

– measured: b and ℓ momenta
  unknown: 3-momentum of neutrino

– W and t mass constraints
  third parameter elsewhere
  do not use measured $\not{p}_T$ vector

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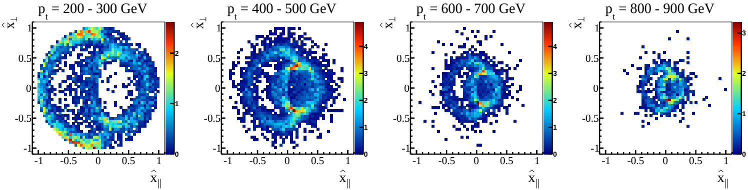
– neutrino coordinates
  leading in $b - \ell$ direction
  sub-leading in $b - \ell$ decay plane [orthogonal approx $p_\nu^{||} = 0$]
  sub-leading orthogonal to decay plane [decay plance approx $p_\nu^{\perp} = 0$]

  components $(p_\nu^{||}, p_\nu^{\perp})$



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– semileptonic top partners at LHC:

  'At the LHC, combinatorics make it unlikely that we will be able to observe stop pair production with a decay to a semileptonic top pair and missing energy.'

  [TP, Spannowsky, Takeuchi, Zerwas]

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– semileptonic top partners at LHC:

  'At the LHC, combinatorics make it unlikely that we will be able to observe stop pair production with a decay to a semileptonic top pair and missing energy.'

  [TP, Spannowsky, Takeuchi, Zerwas]

  wrong!

Stop pairs

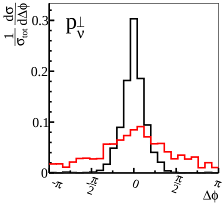
Leptonic tag [Thaler & Wang; Rehermann & Tweedie; TP, Spannowsky, Takeuchi]

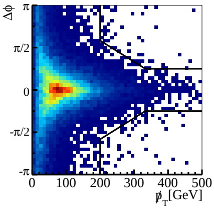
– measured: b and ℓ momenta
  unknown: 3-momentum of neutrino

– W and t mass constraints
  third parameter elsewhere
  do not use measured $\not{p}_T$ vector

– neutrino coordinates
  leading in $b - \ell$ direction
  sub-leading in $b - \ell$ decay plane [orthogonal approx $p_\nu^{||} = 0$]
  sub-leading orthogonal to decay plane [decay plance approx $p_\nu^{\perp} = 0$]

– semileptonic top partners at LHC:
  use approximate $\Delta\Phi(\not{p}_T, \hat{p}_t)$





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– semileptonic top partners at LHC:
use approximate $\Delta\Phi(\not{p}_T, \hat{p}_t)$

– top partner decays observable

	orthogonal approximation							decay plane approximation						
	$\tilde{t}_1\tilde{t}_1^*$				$t\bar{t}$	W+jets	S/B	$\tilde{t}_1\tilde{t}_1^*$				$t\bar{t}$	W+jets	S/B
$m_{\tilde{t}}$[GeV]	340	440	540	640			440	340	440	540	640			440
1.-5. base cuts	27.38	13.71	6.33	2.89	642.72	2.63	0.021							
6. approximation	14.81	7.69	3.61	1.66	285.16	1.41	0.027	27.33	13.67	6.31	2.89	642.37	2.63	0.021
7. $p_T^{est} > 200$GeV	8.61	4.53	2.41	1.24	215.62	0.60	0.021	9.13	5.16	2.87	1.61	242.21	0.54	0.021
8. $\not{p}_T$ vs. $\Delta\phi$ cut	0.97	1.52	1.23	0.76	0.72	0.02	2.06	1.22	1.82	1.53	1.02	1.31	0.06	1.33

Supersymmetry at the LHC

New physics at the TeV scale

- there is physics beyond our Standard Model
- Higgs and new physics the same question

Supersymmetry well studied

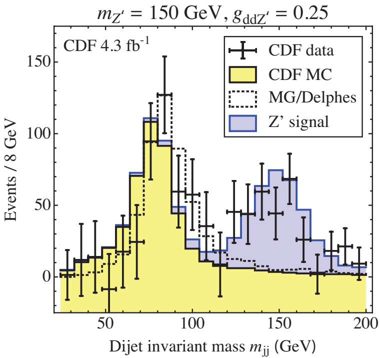
- solves the hierarchy problem
- easily explains dark matter
- exciting LHC analyses

Timely phenomenology

- inclusive searches essentially sorted
- improved analysis tools?
- new channels?

$\Rightarrow$ help LHC to find and measure whatever...

...whatever there is



New physics at the LHC

	missing energy (p.89)	cascade decays (p.91)	mono-jets/photon (p.15)	lepton resnce (p.109)	di-jet resnce (p.109)	top resnce (p.120)	WW/ZZ resnce (p.15)	W' resnce (p.93)	top partner (p.116)	charged tracks (p.123)	displ. vertex (p.123)	multi-photons (p.29)	spherical events (p.47,76)
SUSY (heavy grav.) (p.17,26)	$\checkmark\checkmark$	$\checkmark\checkmark$							$\checkmark$				
SUSY (light grav.) (p.17,27)	$\checkmark$	$\checkmark$	$\checkmark$						$\checkmark$	$\checkmark$	$\checkmark$		
large extra dim (p.39)	$\checkmark\checkmark$		$\checkmark\checkmark$										$\checkmark$
universal extra dim (p.47)	$\checkmark\checkmark$	$\checkmark\checkmark$		$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$				
technicolor (vanilla) (p.51)				$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark\checkmark$					
topcolor/top seesaw (p.53,54)					$\checkmark$	$\checkmark\checkmark$	$\checkmark$						
little Higgs (w/o T) (p.55,58)				$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$					
little Higgs (w T) (p.55,58)	$\checkmark\checkmark$	$\checkmark\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$				
warped extra dim (IR SM) (p.61,63)				$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$						
warped extra dim (bulk SM) (p.61,64)				$\checkmark$	$\checkmark$	$\checkmark\checkmark$	$\checkmark$	$\checkmark$					
Higgsless/comp. Higgs (p.69,73)				$\checkmark$	$\checkmark$	$\checkmark\checkmark$	$\checkmark\checkmark$						
hidden valleys (p.75)	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$

[arXiv:0912.3259, Morrissey, TP, Tait]