Phenomenology of the Supersymmetric Large Extra Dimensions scenario

by

Pierre-Hugues Beauchemin

G. Azuelos, C. Burgess

from

McGill University
Université de Montréal

Université de Montréal, 2 décembre 2004

INTRODUCTION

- **GOAL OF THIS TALK**

The goal of the talk is to demonstrate that the Supersymmetric Large Extra Dimensions scenario (SLED) could provide a deep and fundamental understanding of the structure of the Universe, that it is theoretically and experimentally viable, and that must therefore be considered very seriously.

- **PLAN OF THE TALK**

In order to achieve this goal, the talk will be organized as follow:

1· Motivation of the SLED scenario:

- set the problem
- see how it requires fundamental changes in the paradigm of Particle Physics
- see how SLED is a good candidate for such fundamental new physics

2· Present the framework required to meet SLED theoretical objectives

3· Present some very general low-energy physics predictions that can be made from this scenario:

- coupling of a generic bulk scalar with quarks and gluons
- coupling of a generic bulk scalar with Higgs bosons

4· Study how these specific predictions could be experimentally tested with the ATLAS detector at the LHC.

MOTIVATION

The Standard Model is the most precise and successful theory that has been tested so far.

However, it misses many fundamental ingredients to provide a complete explanation of the structure of Nature:

1- finding the Higgs boson
2- the stability of scalar mass to radiative corrections
3- solution to the hierarchy problem
4- grand unification
5- consistent quantum description of gravity
6- solution to the cosmological constant problem

Other important problems or questions remain unsolved:
CP violation, quark/lepton compositness, number of families, QCD nonperturbative low-energy behaviour

Solving the first set of problems would require a fundamental theory beyond the SM while the second set of problems could be predictions of this new theory.

Two fundamental changes in Particle Physics paradigm can help address these problems:

- SUSY: there is a symmetry between bosons and fermions $\Rightarrow$ points 2+3+4
- Extra Dimensions: the universe has few not-too-small compactified extra-D $\Rightarrow$ point 5

WHAT ABOUT point 6???

The Cosmological constant problem is the most cumbersome of these problems

$$\Leftrightarrow$$

It reveals a profond misunderstanding of the low-energy physics:

Ex.: the electron contributes already to a too big vacuum energy density compared to the measured amount of Dark Energy measurements ($\sim$ 23 order of magnitude too big!)

CLAIM:

SUSY $\oplus$ EXTRA-D. = SLED

$$\Downarrow$$

May solve the Cosmological Problem!

The Supersymmetric Large Extra Dimension (SLED) scenario can therefore provide a fundamental understanding of Nature because:

- it includes gravity at relatively low energies

- it eliminates any hierarchy between fundamental high energy scales

- it has the suitable ingredients to solve the Cosmological Constant Problem!

- it is a new way in which SUSY can be realized at low energies

$$\Downarrow$$

This new physics candidate is at the frontier of High Energy theory, experimental particle physics and cosmology.

SLED framework must be considered seriously because:

- it can be used to solved one of the most refractory problems of physics

- its concepts are motivated by a more fundamental theory: Sting Theory

- it predicts a rich phenomenology $\Rightarrow$ can be tested

$$\Downarrow$$

It deserves as much research effort as SUSY!

The rest of the talk is to support the claim that SLED is theoretically and experimentally viable, ie that

it predicts a cosmological constant of the size of the measured Dark Energy and, it can be tested at the LHC.

SLED FRAMEWORK

- **THE COSMOLOGICAL PROBLEM**

The cosmological constant is a term added by Einstein in its equation to prevent the expansion of the Universe:

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R - \Lambda g_{\mu\nu} = -8\pi G T_{\mu\nu}$$

Assumptions

(a) The Universe R-W is a galactic fluid of density $\rho = T_0^0$ and pressure $P = -T_i^i$

(b) Hubble: the Universe is expanding at a scaling rate a(t)

$$\Downarrow$$

We can describe the dynamics of the Universe with the Friedman equations:

1. $H^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2} + \frac{\Lambda}{3}$
2. $\frac{d^2 a}{dt^2} = -\frac{4\pi G}{3}(\rho + 3P)a + \frac{\Lambda a}{3}$

Anisotropy in c.m.b. (WMAP) has recently shown that the Universe is flat ($k = 0$).

$$\Downarrow$$

$$\Omega \equiv \Omega_{\text{matter}} + \Omega_\Lambda = 1$$

From the second equation we have that if Λ is large enough, the Universe will be inflating.

The experimental evaluation of Dark Energy revealed a small but non-zero cosmological constant:

$$\Omega \sim 0.7 \quad \Rightarrow \quad \rho_\Lambda \sim 1\ (\text{meV})^4$$

When we evaluate vacuum energy density from QFT we got $\rho_\Lambda \sim M^4$

$$\Downarrow$$

SM predicts a vacuum energy density 60 orders of magnitude too big!

- **HOW IT CAN BE SOLVED?**

† Burgess *et al.*: hep-th/0304256
hep-th/0308064
hep-th/0402200
hep-th/0404135

From string theory:

(a) Universe can have few compactified extra dimensions
(b) Some fields can be trapped in a topological object called a p-brane

If the SM fields are stuck on a 3-brane

$\Rightarrow$ the vacuum energy density generated by their quantum fluctuations will be:

a localized energy density
(at the position of the brane)

$\Downarrow$

a source of gravitational fields propagating in the extra-D

NOT A COSMOL. CONST.!
(vacuum energy spreads everywhere)

Modes below the scale $M_c \sim \frac{1}{r}$ cannot be described as higher dimensional and will contribute to a cosmological constant.

If $M_c \sim v \sim 1$ meV it will be consistent with the measured Dark Energy

From string theory, e.m. and gravity couplings are related by

$$G_{eff} = \alpha_{eff}^2 \left(\frac{\ell_s}{a}\right)^n \ell_s^2$$

$$\Downarrow$$

The above condition: $M_c \sim v \sim M_W$

$$\Rightarrow$$

$$n = 2 \text{ and } \ell_s \sim \ell_W$$

$$\Downarrow$$

NO HIERARCHY AND NO FINE TUNING AT HIGH ENERGY!

No brane prevents bulk modes from contributing to a too big cosmo. const.

SUSY can preclude such contribution for scales higher than m_{sb}.

$$m_{sb} \sim GM^2 \sim \frac{M_W^2}{M_{pl}} \sim \upsilon$$

The brane tension must not curve the extra-D at classical level

$$\Downarrow$$

brane tension and curvature cancelled in N=2 SUGRA, independently of the tension

$$\Leftrightarrow$$

Self-tuned solution to the cosmological constant

- **OUTLINE**

  In order to solve the Cosmological Constant Problem SLED requires:

  - exactly 2 extra dimensions of $\mathcal{O}(10\mu\text{m})$
  - SM particle stuck to a 3-brane
  - N=2 supergravity in the bulk
  - SUSY strongly broken on the brane
  - bulk SUSY breaking scale of $\mathcal{O}(10^{-3}\text{eV})$

  $$\Downarrow$$

  We can use this to write a low-energy effective 4D field theory that couples SM particles to bulk modes

PHYSICS PREDICTIONS

- **PHENOMENOLOGY**

From a 4D point of view, bulk space will be described by an extended $N = 4$ SUSY

$$\Downarrow$$

The bulk space will be populated by particles of all spins from 0 to 2

Small SUSY breaking scale in the bulk

$\Rightarrow$ gravity spectrum will be approximately degenerate and massless (zero modes)

Extra dimensions are compactified on a torus of external and internal radius of $r \sim 10\mu$m.

$$\Downarrow$$

Kaluza-Klein modes can be seen as a continuous spectrum in 4D

Massless bulk particles couple gravitationally to SM particles.

Classical symmetries can preclude the coupling of some bulk states with brane states.

BUT

Low-energy effective coupling will be guaranteed by higher order terms (loop).

The huge phase space provides observable cross sections even if the couplings are suppressed by powers of the Planck scale

The brane breaks the conservation of momentum in the bulk (invariance under translation is broken)

$\Downarrow$

The brane tension absorbs the balance of momentum

These points determine the effective 4D low-energy theory that will be written to make SLED physics predictions.

- **PLAN OF THE ANALYSIS**

Choose a particular SLED bulk field and write the effective 4D low-energy Lagrangian describing its couplings to SM fields.

$\Downarrow$

We choose to study the coupling of a bulk scalar ϕ with SM fields

Concentrate on the lowest mass dimension interaction terms to:

-quarks and gluons
-Higgs bosons

Assume a fairly generic set of couplings to include any particular SLED models

$\Downarrow$

Model independent analysis

Evaluate the possibility to observe a bulk scalar with the ATLAS detector

jet+$\not\!\!E_T$: Beauchemin *et al.* (hep-ph/0401125)
H+$\not\!\!E_T$: Beauchemin *et al.* (hep-ph/0407196)

$\Downarrow$

Give the range of parameter for discovery

$\Leftrightarrow$

sensitivity of ATLAS to such physics

- **LAGRANGIAN**

$f\bar{f}\phi$ and $gg\phi$ interactions

at lowest order are given by:

$$\mathcal{L}_{\mathrm{EFF}} = \partial_M \phi(x,y)\partial^M \phi(x,y) - \delta^n(y)[\sum_Q \frac{1}{\bar{M}_D^{n/2}} \bar{\Psi}(x)(g + i g_5 \gamma_5)\Psi(x)\phi(x) - \frac{1}{\bar{M}_D^{(n+2)/2}} G^a_{\mu\nu}(x)(c G_a^{\mu\nu}(x) + \tilde{c}\tilde{G}_a^{\mu\nu}(x))\phi(x)]$$

Note:

– We explicitly replaced a SM Higgs factor by its *vev* and rotated to a fermion eigen-basis.
$\Rightarrow$ g could be suppressed by $v/\bar{M}_D$

– $\frac{b}{M_D}\bar{\Psi}\gamma^\mu\Psi\partial_\mu\phi = \frac{b}{M_D}\frac{m_f}{M_D}\bar{\Psi}\Psi\phi$

– Even if in SLED $n=2$, we will keep n general.

$\Downarrow$

SLED will phenomenologically be the favored scenario.

Higgs-ϕ

At lowest order, this trilinear coupling is dimensionless in SLED!

$$\Downarrow$$

This is a SLED prediction alone and it will dominate at colliders!

The effective Lagrangian of such an interaction is:

$$\boxed{\mathcal{L}_{int} = -\delta^2(y)[aH^\dagger(x)H(x)\phi(x)]}$$

In unitary gauge, we have $H = \begin{pmatrix} 0 \\ v+h(x) \end{pmatrix}$

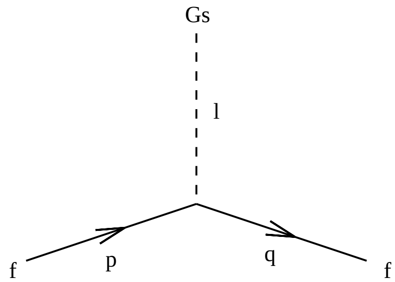
$$\Downarrow$$

$$\mathcal{L}_{int} = -\delta^2(y)[a(v+h)^2\,\phi(x)\,,]$$

We will focus on $hh\phi$

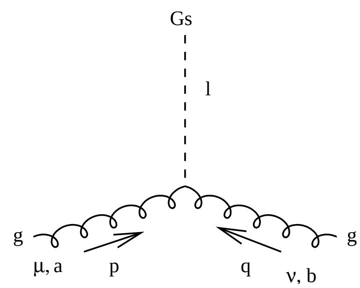
- **FEYNMAN RULES**

$\bar{q}q\phi$:



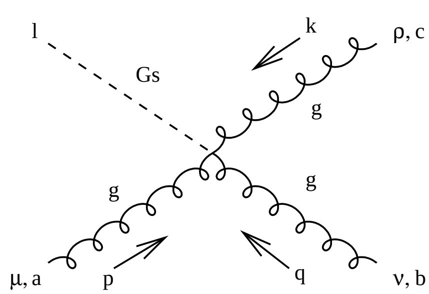
$$= -i(g + ig_5\gamma_5)$$

$gg\phi$:



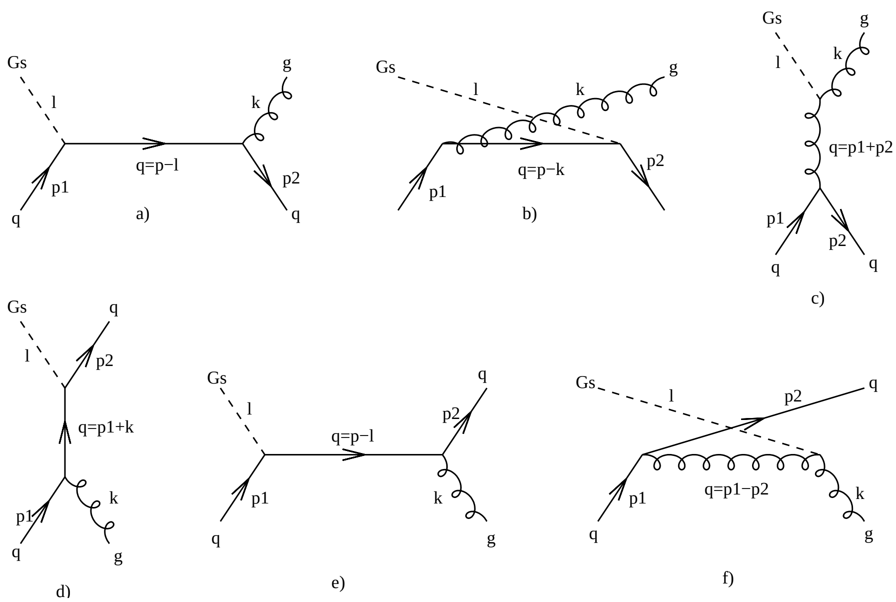
$$= 4i[c(p.q)g_{\mu\nu} - cp_\nu q_\mu + \tilde{c}\epsilon_{\mu\nu\alpha\beta}p^\alpha q^\beta]\delta_{ab}$$

$ggg\phi$:



$$= 4g_3 f^{abc}[cg_{\mu\nu}(p_\rho - q_\rho) + cg_{\mu\rho}(k_\nu - p_\nu) + cg_{\nu\rho}(q_\mu - k_\mu) + \tilde{c}\epsilon_{\alpha\mu\nu\rho}(p^\alpha + q^\alpha + k^\alpha]$$

- **PARTON-ϕ CROSS-SECTIONS**

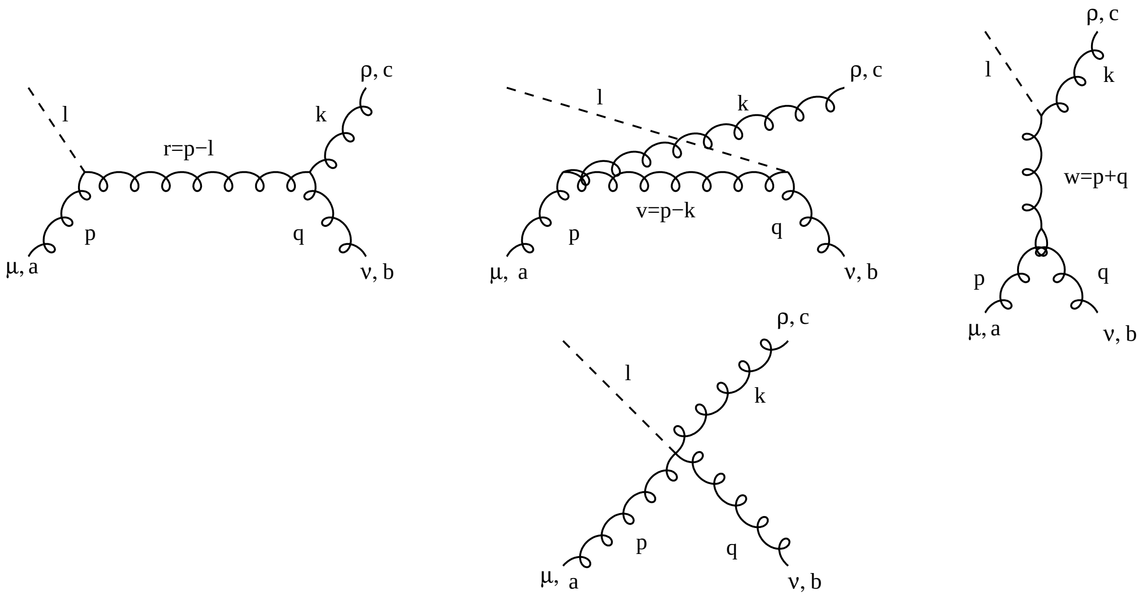


$$\frac{d\sigma(q\bar{q}\to g\phi)}{d\hat{t}d\hat{u}dM^2} = \frac{\alpha_s(2\pi)^{n/2}(M^2)^{\frac{n-2}{2}}}{18\Gamma(n/2)\hat{s}^2}\times$$

$$\left[\frac{(g^2+g_5^2)}{M_D^n(2\pi)^{\frac{2n}{2+n}}}\frac{2M^2\hat{s}+(\hat{u}+\hat{t})^2}{\hat{u}\hat{t}} + 4\frac{(c^2+\tilde{c}^2)}{M_D^{n+2}}\frac{\hat{t}^2+\hat{u}^2}{\hat{s}}\right]$$

$$\frac{d\sigma(qg\to q\phi)}{d\hat{t}d\hat{u}dM^2} = -\frac{\alpha_s(2\pi)^{n/2}(M^2)^{\frac{n-2}{2}}}{48\Gamma(n/2)\hat{s}^2}\times$$

$$\left[\frac{(g^2+g_5^2)}{M_D^n(2\pi)^{\frac{2n}{2+n}}}\frac{\hat{u}+M^4}{\hat{s}\hat{t}} + 4\frac{(c^2+\tilde{c}^2)}{M_D^{n+2}}\frac{\hat{t}^2+\hat{s}^2}{\hat{u}}\right]$$



$$\frac{d\sigma(gg\to g\phi)}{d\hat{t}d\hat{u}dM^2} = \frac{3\alpha_s(2\pi)^{n/2}(M^2)^{\frac{n-2}{2}}}{16\Gamma(n/2)\hat{s}^3\hat{t}\hat{u}}\frac{(c^2+\tilde{c}^2)}{M_D^{n+2}}[(\hat{u}+\hat{t})^4+(\hat{u}+\hat{s})^4+(\hat{t}+\hat{s})^4+12\hat{s}\hat{t}\hat{u}M^2]$$

Note: Each cross-section is multiplied by $\delta(\hat{s}+\hat{t}+\hat{u}-M^2)$

Bulk phase space:

$$\int_{\Omega_n}\frac{d^nL}{(2\pi)^n} = \frac{(M^2)^{(n-2)/2}\,dM^2}{2\,\Gamma(\frac{n}{2})\,(2\pi)^{n/2}}$$

The physical picture of a bulk scalar event is the same as for a graviton: a stable particle radiated by the brane in the extra-D

$$\Downarrow$$

We are looking for pp→jet+$\not{E}_T$ events.

- **PHASE SPACE INTEGRATION**

We want to compute the following integral:

$$\sigma = \int f(x_1, Q^2) f(x_2, Q^2) \frac{d\sigma}{d\hat{t} dM^2} dx_1 dx_2 dM^2 d\hat{t}$$

The integration limits are:

(a) for $\hat{t}$: $P_T^2 = \frac{\hat{t}\hat{u}}{\hat{s}}$ and $P_T^2 \geq P_{cut}^2$

$$\Downarrow$$

$$t_0 \equiv \frac{(M^2-\hat{s})-\sqrt{(M^2-\hat{s})^2-4P_{cut}^2\hat{s}}}{2}$$

$$\leq \hat{t} \leq$$

$$\frac{(M^2-\hat{s})+\sqrt{(M^2-\hat{s})^2-4P_{cut}^2\hat{s}}}{2} \equiv t_1$$

(b) for M^2: $\sqrt{\hat{s}} = E_g + \sqrt{|\vec{P}_G|^2 + M^2}$

$$\Downarrow$$

$$0 \leq M^2 \leq \hat{s} - 2\sqrt{\hat{s}} P_{cut} \equiv M_{max}^2$$

(c) for x: $\hat{s} = x_1 x_2 s$ and $x_{min} = \frac{2}{\sqrt{s}} P_{cut}$

$$\Downarrow$$

$$x_{min} \leq x_{1,2} \leq 1$$

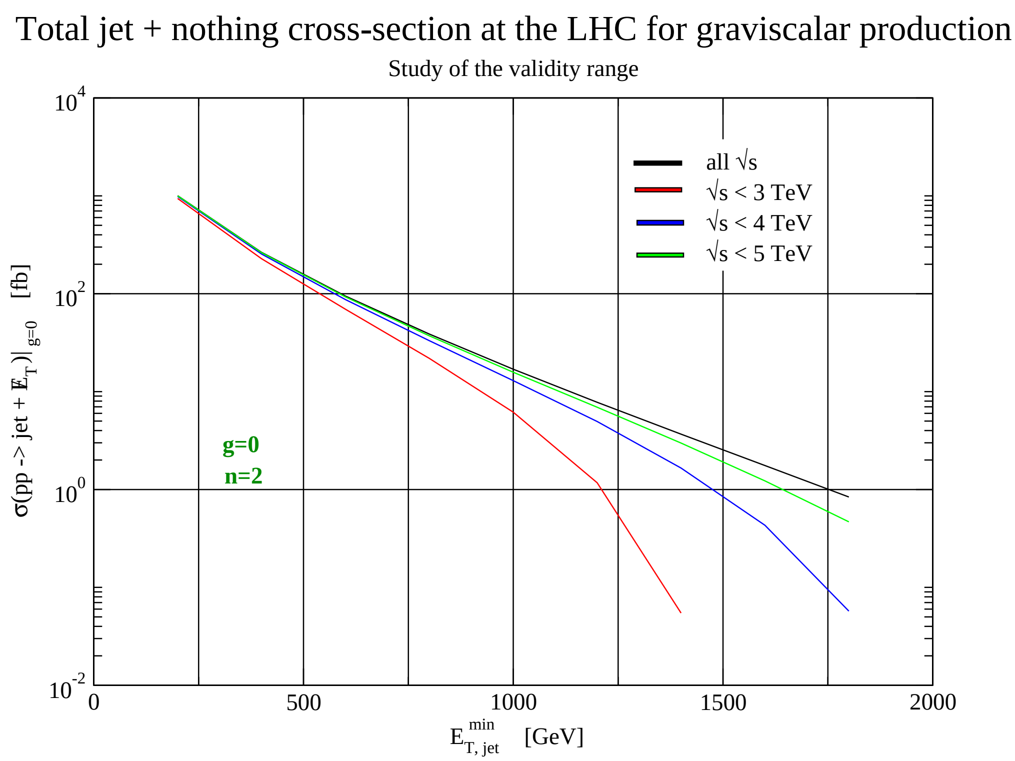
The processes have been implemented in PYTHIA.

- **RELIABILITY**

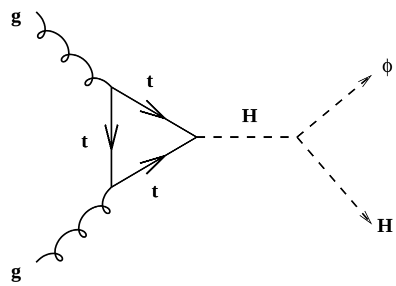
The physical predictions will not be reliable for high energies.

Quantify the UV sensibility by comparing σ vs $E_{T,jet}^{min}$ in two cases:

a: $\frac{d\sigma}{d\hat{t}}$ is fixed to 0 for $\sqrt{\hat{s}} > M_S$
b: compute σ for all $\sqrt{\hat{s}}$



- **H-ϕ CROSS-SECTIONS**



$$\frac{d\sigma}{d\hat{t}\, dM_\phi^2}(gg \to h\phi) = \left(\frac{a^2\alpha_s^2}{144v^2}\right) \frac{|\mathcal{F}(\frac{m_t^2}{Q^2})|^2}{(\hat{s}-m_h^2)^2}.$$

We follow the conventions of hep-ph/9912459:

$$\mathcal{F}(r) = 3[2r + r(4r-1)f(r)]$$

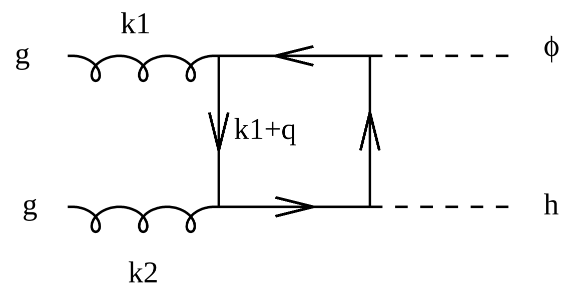
where $f(r) =$

$$\begin{cases} -2\left[\arcsin\left(\frac{1}{2\sqrt{r}}\right)\right]^2 & \text{if} \quad r > \frac{1}{4}; \\ \frac{1}{2}\left[\ln\left(\frac{\eta_+}{\eta_-}\right)\right]^2 - \frac{\pi^2}{2} + i\pi \ln\left(\frac{\eta_+}{\eta_-}\right) & \text{if} \quad r < \frac{1}{4}; \end{cases}$$

with $\eta_\pm = \frac{1}{2} \pm \sqrt{\frac{1}{4} - r}$.

Note: contribution of the top-quark loop suffices.

Other Feynman graph contributions are suppressed by powers of $\frac{E}{M_D}$



we study the more rare, but cleaner, $h \to \gamma\gamma$ channel.

$$\Downarrow$$

The desired signal is two photons plus $\not{E}_T$

Higgs mass (GeV)	100	110	120	130	140	150
Cross sect. (pb)	22.5	18.8	15.9	13.6	11.8	10.3
Branch. ratio (%)	0.15	0.19	0.22	0.22	0.19	0.14
$\sigma \times B$ (fb)	35.6	34.9	30.2	22.7	14.2	5.9
SM $pp \to h$ (pb)	31.8	26.7	23.0	20.0	17.4	15.8
Mass resol. (GeV)	1.31	1.37	1.43	1.55	1.66	1.74

$$a = 0.5$$

EXPERIMENTAL ANALYSIS

- **PARTON-ϕ ANALYSIS**
  (Using ATLFAST)

The standard background is (following Vacavant & Hinchliffe):

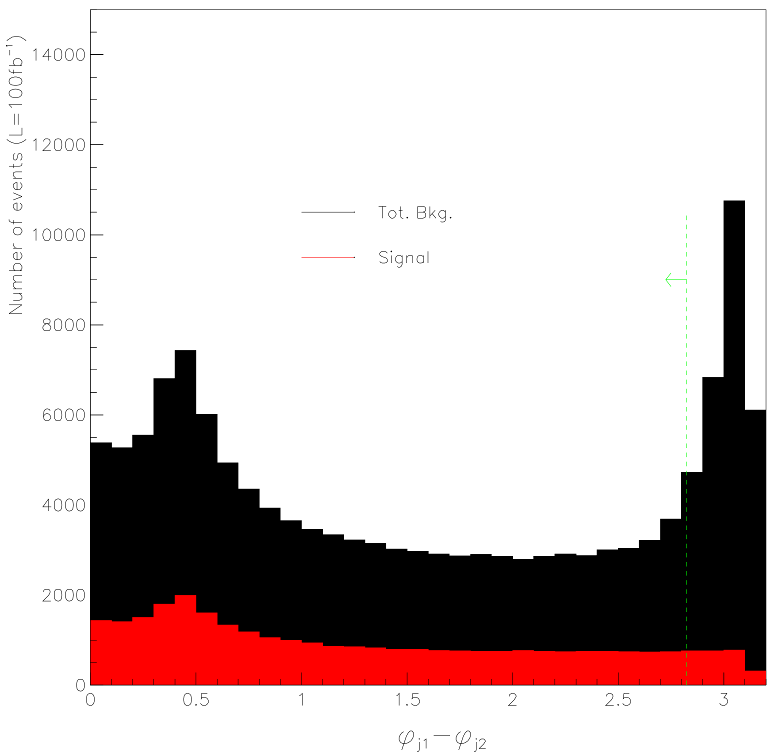
- $pp \to jet + Z(\to \nu\nu)$ (277.6 fb)
- $pp \to jet + W(\to e\nu_e)$ (364.2 fb)
- $pp \to jet + W(\to \mu\nu_\mu)$ (363.7 fb)
- $pp \to jet + W(\to \tau\nu_\tau)$ (363.3 fb)

CUT 1: number of leptons = 0

In the c.m.s. the bulk scalar and the jet are back-to-back

$$\Downarrow$$

CUT 2: accept $|\varphi_{j_1} - \varphi_{j_2}| < 2.83$



Processes	Total	Cut 1	Cut 2
jet+$Z(\rightarrow \nu\nu)$	27760	27100	24940
jet+$W(\rightarrow e\nu_e)$	36420	5224	1430
jet+$W(\rightarrow \mu\nu_\mu)$	36370	957	866
jet+$W(\rightarrow \tau\nu_\tau)$	36330	24600	9459
jet+bulk scalar	30960	30090	27720

For a 5σ discovery, we need $\frac{S}{\sqrt{S+B}} > 5$

With $100 fb^{-1}$

$$B = 36700 \text{ events } (P_T > 500 GeV)$$
$$\Downarrow$$
$$S > 970 \text{ events} \Rightarrow \sigma > 10.9 fb$$
$$\Downarrow$$
$$\bar{c} = 5.1 \times 10^{-3} TeV^{-2}$$
$$\bar{g} = 7.1 \times 10^{-2} TeV^{-1}$$

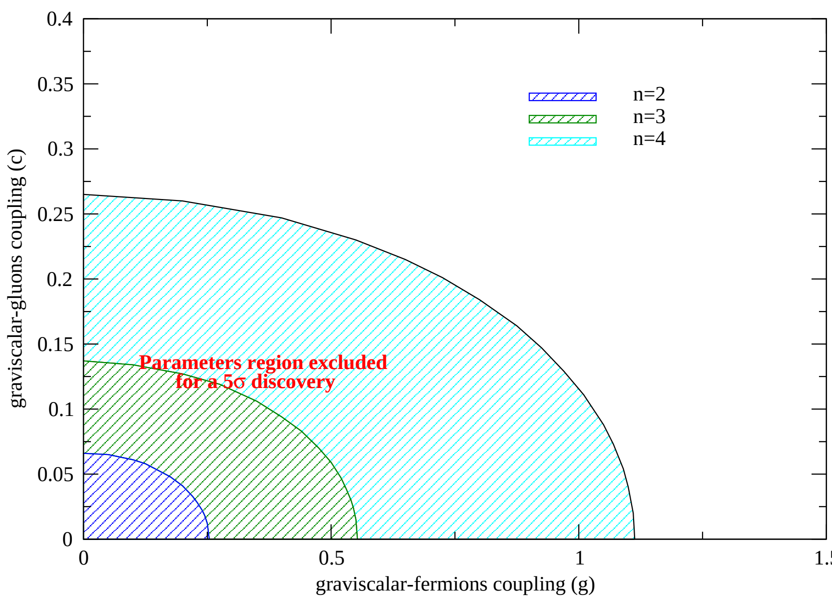
where $g = \bar{g} M_D^{\frac{n}{2}}$ and $c = \bar{c} M_D^{\frac{n+2}{2}}$

This analysis applies for any number of extra-D.

- **RESULTS**

To be valid and testable at the LHC, any model of graviscalar must satisfy:

$1 \gtrsim g > \bar{g}_0^{(n)} (M_D^{min})^{\frac{n}{2}}$ $1 \gtrsim c > \bar{c}_0^{(n)} (M_D^{min})^{\frac{n+2}{2}}$



The sensitivity range of ATLAS to M_D is:

ndim	Graviton	bulk scalar	
	M_D^{max}	M_D^{min}	M_D^{max}
2	7.5 TeV	3.60 TeV	14.00 TeV
3	5.9 TeV	4.30 TeV	6.45 TeV
4	5.3 TeV	4.85 TeV	1.45 TeV

- **GRAVITON**

Graviton production rate is have same $\not{p}_T$ behaviour as for the bulk scalar.

$$\Downarrow$$

We cannot use $P_{T,jet}$ or $\not{E}_T$ to discriminate.

But the only handle we have is $P_T(jet)$:
- no angular distribution in cm of parton system;
- no FB asymmetry
- possible discriminating variable: η vs P_T.

$$\Downarrow$$

Even if spins are distinct, the discrimination will be very difficult (possible ???)

- **WHAT CAN WE LEARN?**

a) We find a discriminating distribution, graviton will then be another background

$$\Downarrow$$

increase c and g for discovery.

b) We can't distinguish between these particles

$$\Downarrow$$

Theoretical uncertainty on graviton signal and on M_D, r and n measurement.

c) Other physics give a measurement of M_D, n and r to fix graviton production rate.

$$\Downarrow$$

bulk scalar would appear as an excess of graviton events;

This last case is exactly what SLED offers using the measurement of Dark Energy

$$\Downarrow$$

SLED is more predictive and offers stronger experimental tests than other large extra-D scenario!

- **H-ϕ ANALYSIS**

(Using ATLFAST)

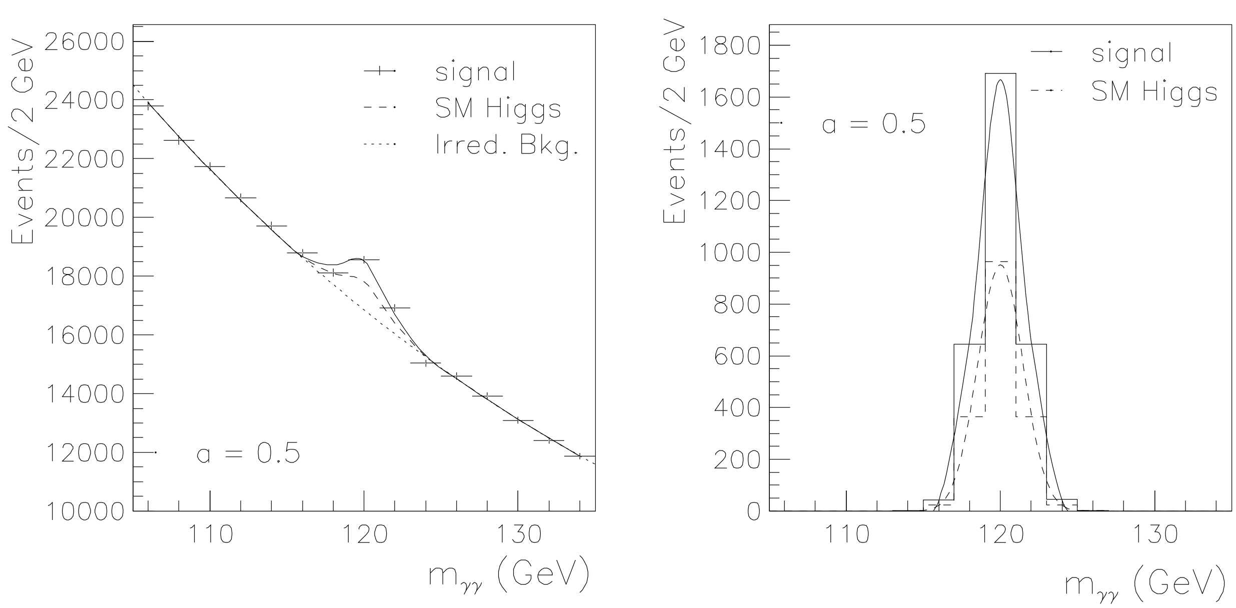
The standard backgrounds are (following TDR):

- $q\bar{q} \to \gamma\gamma$ (56.2 pb)
- $gg \to \gamma\gamma$ (49.0 pb)
- QCD jet-jet (4.9×10^8 pb)
- QCD γ-jet (1.2×10^5 pb)
- $q\bar{q} \to hZ \to \gamma\gamma\ \nu\nu$ (1.22×10^{-3} pb)
- $q\bar{q} \to t\bar{t}h\ h \to \gamma\gamma$ (1.28×10^{-3} pb)

1. add a correction to the total irred. bkg. for quark brems. by a 50% scaling factor
2. requiring two γs in the final state $\Rightarrow$ rejection factor for red. bakg: 2×10^7 and 8×10^3 respectively.
3. expected photons reconstruction efficiency $\Rightarrow$ further reduction factor of 80%/γ
4. isolated photon if:
   - $P_T^\gamma > 5.0$ GeV
   - < 10 GeV of energy deposited by all other particles within a cone of radius $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.4$.

The cuts are imposed to optimize the significance of the $h \to \gamma\gamma$ signal for the standard Higgs search at ATLAS (TDR).

- CUT 1: $P_T > 40$ GeV for photon 1 and $P_T > 25$ GeV for photon 2
- CUT 2: γ candidates must lie in the pseudorapidity interval $|\eta| < 2.4$
- CUT 3: pseudorapidity separation of $\Delta\eta > 0.15$
- CUT 4: final state invariant mass close to Higgs mass: $M_H - 1.4\sigma_H < M_{\gamma\gamma} < M_H + 1.4\sigma_H$



38% of the initial number of signal events survive these cuts

With $100 fb^{-1}$ we expect:

- 44 700 background events
- 1,500 standard $h \to \gamma\gamma$ events
- 16 $hZ \to \gamma\gamma\ \nu\nu$ events
- 9 $t\bar{t}h\ h \to \gamma\gamma$ events

For a 5σ discovery, we need $\frac{S}{\sqrt{B}} > 5$

$$\Downarrow$$

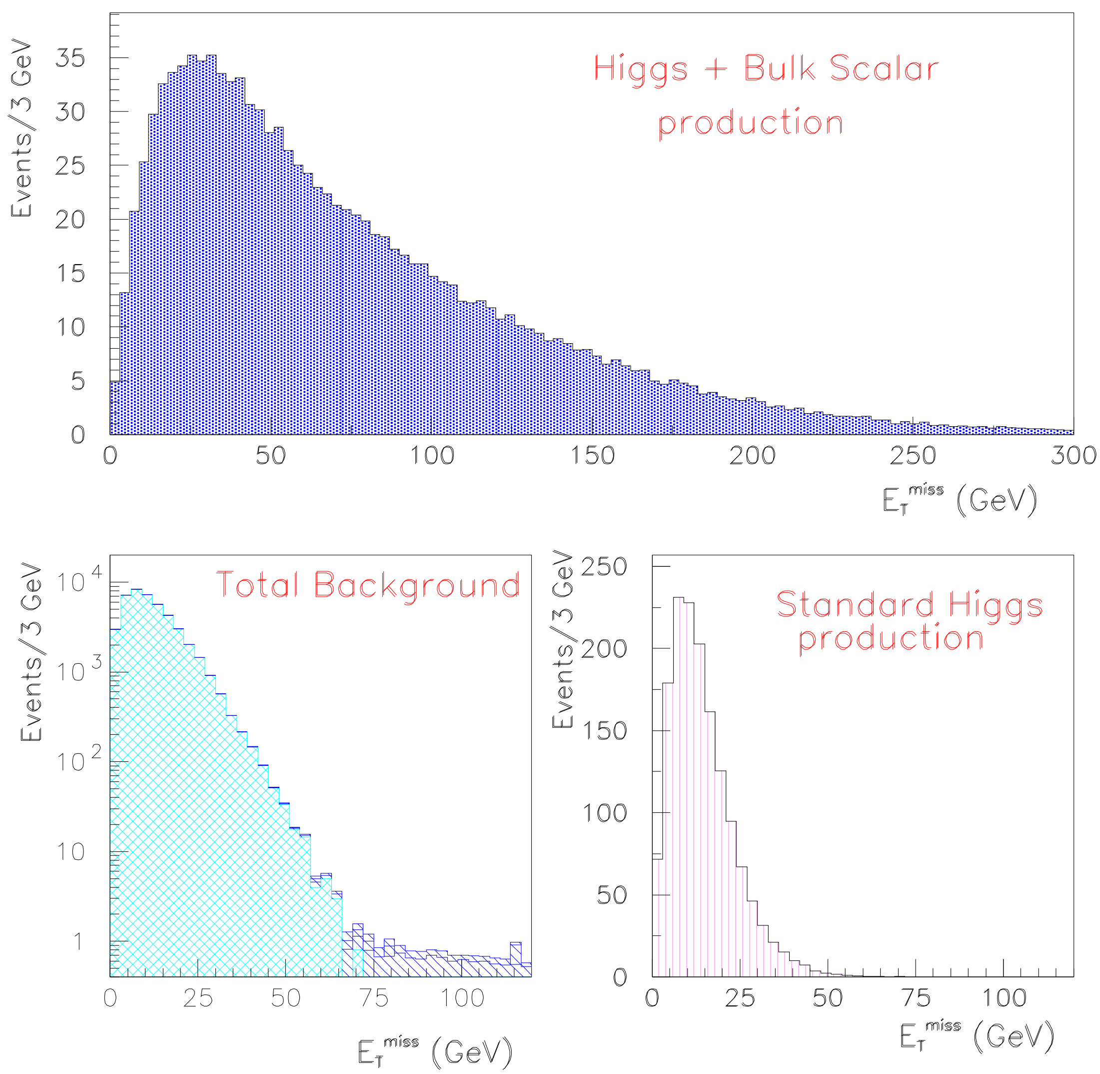
$a = 0.5$ produces roughly the same number of $pp \to h\phi$ events as from the Standard Model $pp \to h$ process ($m_h = 120$ GeV)

$$\Downarrow$$

For couplings this large roughly half of the Higgs particles are produced in association with ϕ emission into the extra dimensions.

- $\not\!\!E_T$ **CUT**

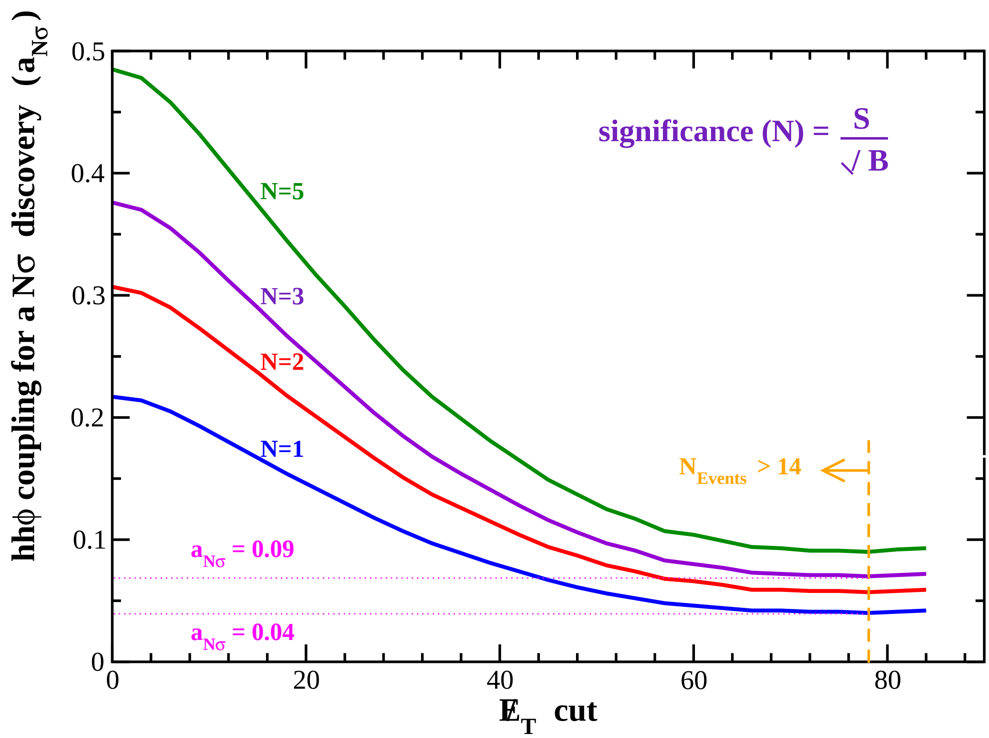
  Because of the escaping bulk scalar, we expect much more $\not\!\!E_T$ in the signal than in the bkg.



RESULTS

PARAMETER RANGE

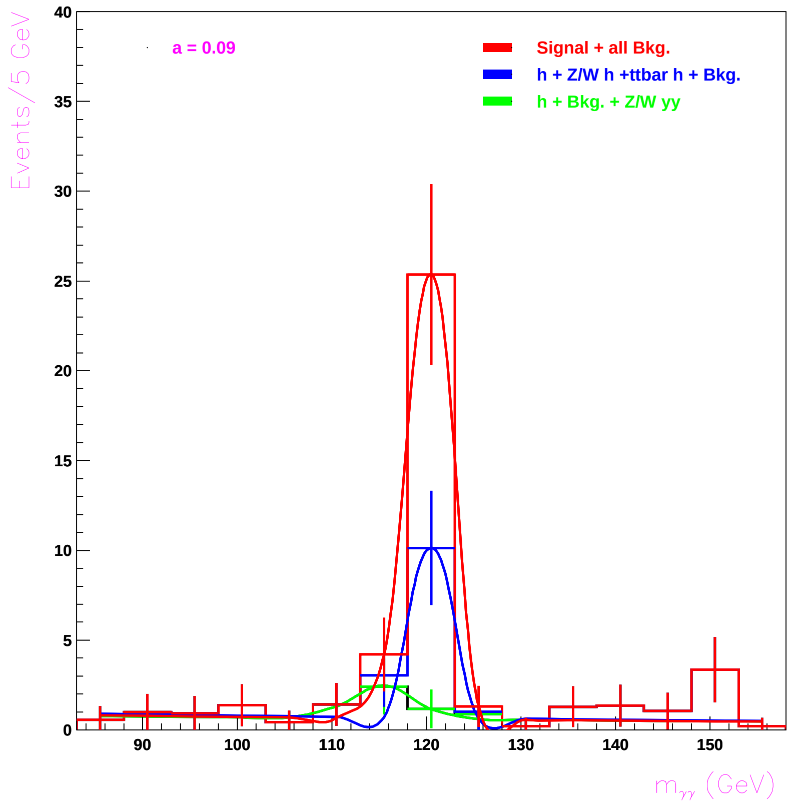
A cut on $\not{E}_T$ allows to increase the parameter range for a discovery from 0.5 to 0.09



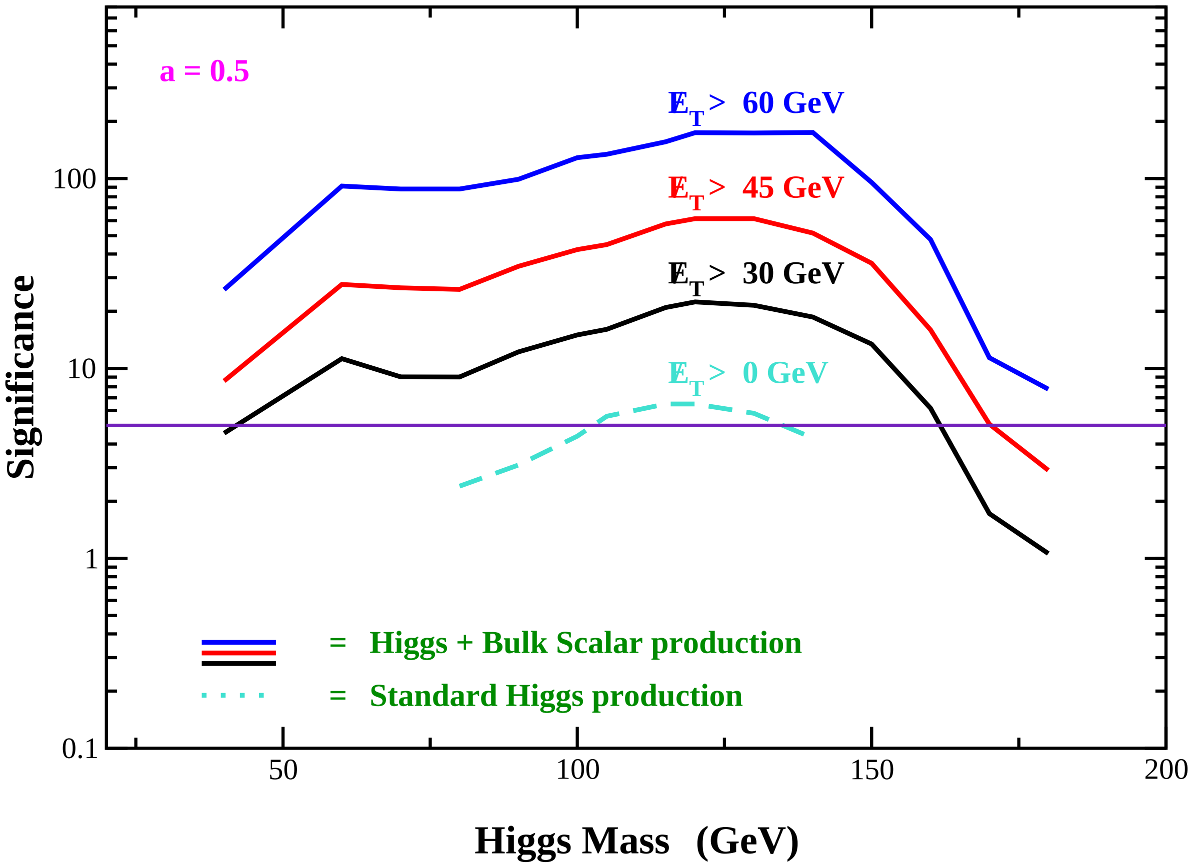
- CUT 5: missing transverse energy of the entire event must satisfy: $\not{E}_T > 78$ GeV.

HIGGS DISCOVERY

The new cut allow for a clear peak for the discovery of the Higgs with the $h\phi \to \gamma\gamma\ \not{E}_T$ channel



It increases significantly the sensitivity of ATLAS to a Higgs and extends the mass range for a potential discovery.



By itself the process $h + Zh + t\bar{t}h \;\; h \to \gamma\gamma$ has a significance of 8.3 σ when we impose a cut of 66 GeV.

ATLAS note COM-PHYS-2004-056

CONCLUSION

- SLED scenario can provide a fundamentally new understanding of high energy physics and thus deserves to be carefully studied

- SLED has a rich phenomenology. In particular, it predicts coupling of bulk scalars to SM particles.

- We compute physical predictions for a fairly generic bulk scalar-parton and bulk scalar-Higgs interaction

- Using cut on $\not{E}_T$ we evaluated ATLAS sensitivity to:
  -$q\bar{q}\phi$: $0.26 \lesssim g \lesssim 1$
  -$gg\phi$: $0.06 \lesssim c \lesssim 1$
  -$hh\phi$: $0.09 \lesssim a \lesssim 1$

- SLED offers the widest discovery possibility for the ϕ-parton couplings

- The $h\phi$ signal can significantly improve the Higgs discovery