Searches in the dilepton final states with ATLAS

Samir Ferrag

University of Glasgow

Physics with LHC early data, LBL, May 6th-8th

Introduction

- **Searches by Final state topologies**
  - **Huge number of the Exotic (non SUSY BSM) Models.**
  - **Exotic searches in ATLAS: generic searches by final state topologies *to maximize the number of Exotic models to be tested simultaneously (but the sensitivities are done for each model).***
- ***Dileptons: Understand the Standard Model before looking for Exotic Physics***
  - **Standard Model side**: "*Drell-Yan*"
    - Uncertainties from theory PDF, μ_{fact}, μ_{ren}
    - Corrections: K Factors, EW corrections…

    . Backgrounds: WW, tt, $\tau\tau$, ECal linearity, charge mis-id, W+jet, γ-conversion

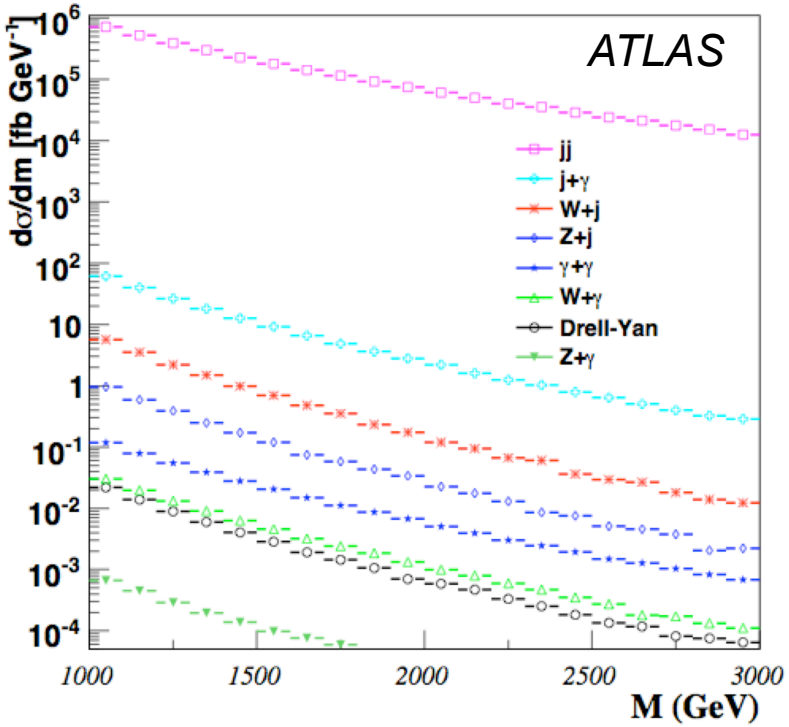
  → ***Draw the uncertainty band of SM prediction and any deviation of this band signs Exotics***
  - **Exotics side:**
    - **S-channel resonances: Z' Z_H,Z_{KK} G**
    - **Virtual exchange of gravitons**
    - Leptoquarks, Leptogluons, Heavy scalars (Graviscalar, radion, heavy higgs)

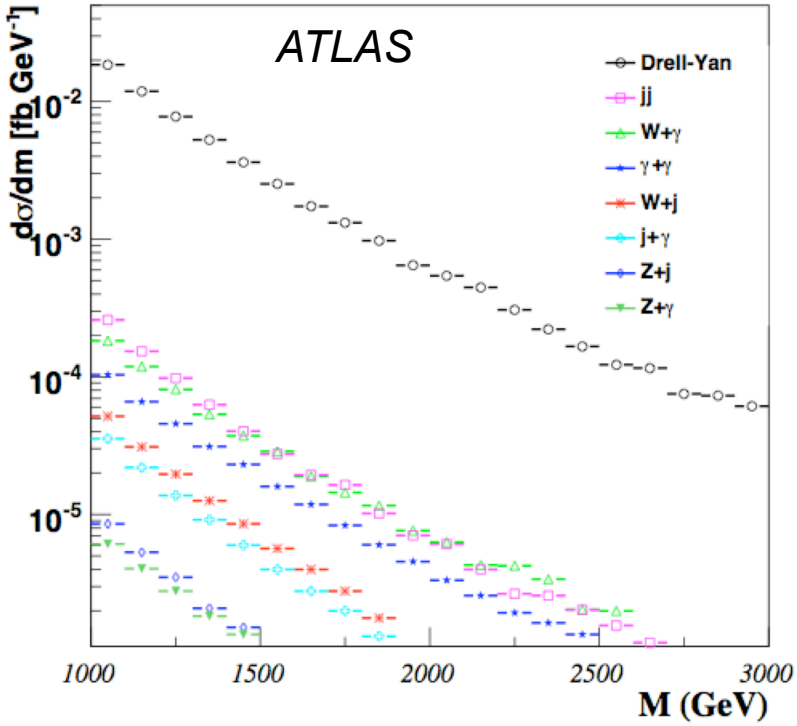
Results on dilepton resonances for √s=14 TeV are presented in this talk:

- ***For 10 TeV, the cross section is 75%-50% in the range m_{ll}=100GeV-1000GeV***
- ***Standard Model backgrounds***
- ***Systematic uncertainties***
- ***Statistical methods***
- ***Results on Exotics sensitivities: Z's, G* and Technicolor (the Exotic Models are not detailed here)***

Expectation: How to identify the underlying model in Case of discovery ?

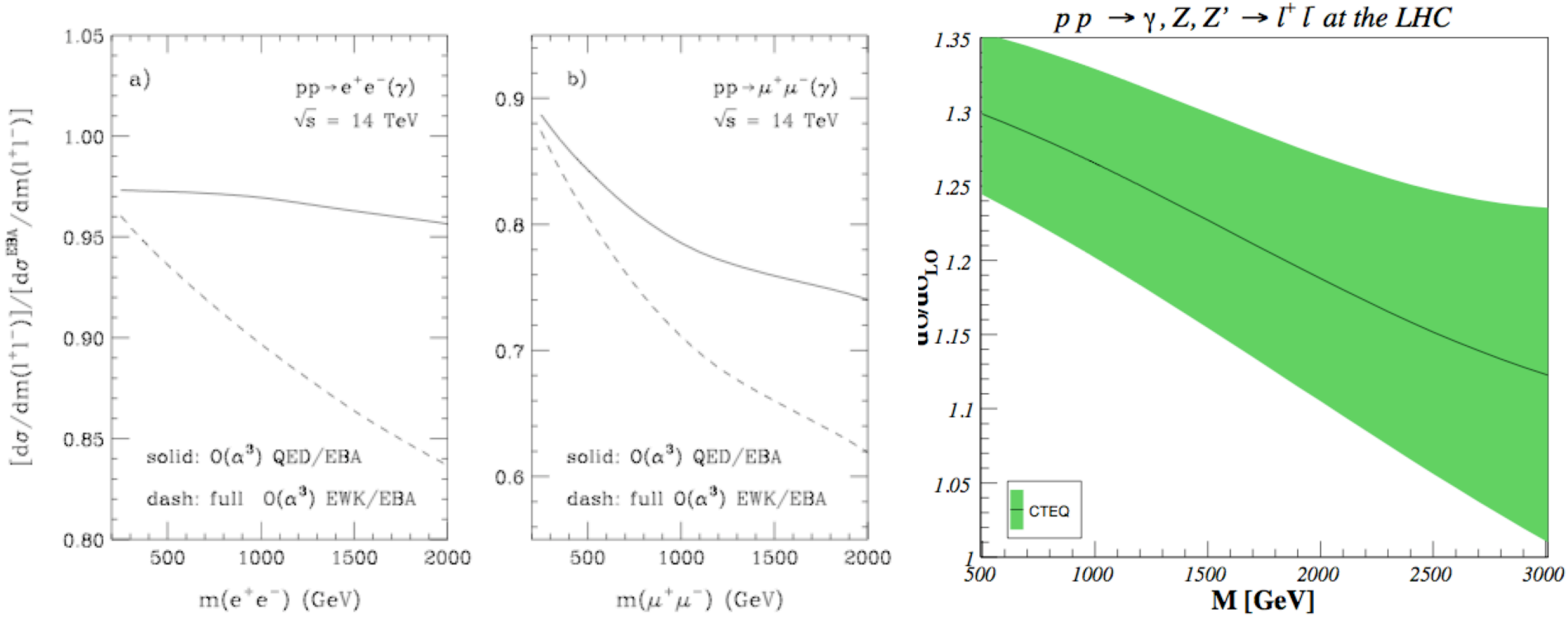
Standard Model: backgrounds





- Source of (ir) reducible background: (non ττ)
  - Drell-Yan
  - Jet→e, γ→e contamination
  - e and μ production from Z and W decay
- Cuts:
  - $R_{e\text{-}jet}=10^4$, $R_{e\text{-}gamma}=10$, Pt and pseudorapidity ($R_{e\text{-}jet}$ & $R_{e\text{-}gamma}$ varied by a factor 2)
  - The Drell-Yan is the dominant background
- Muons are cleaner & ττ studied separately (see below)

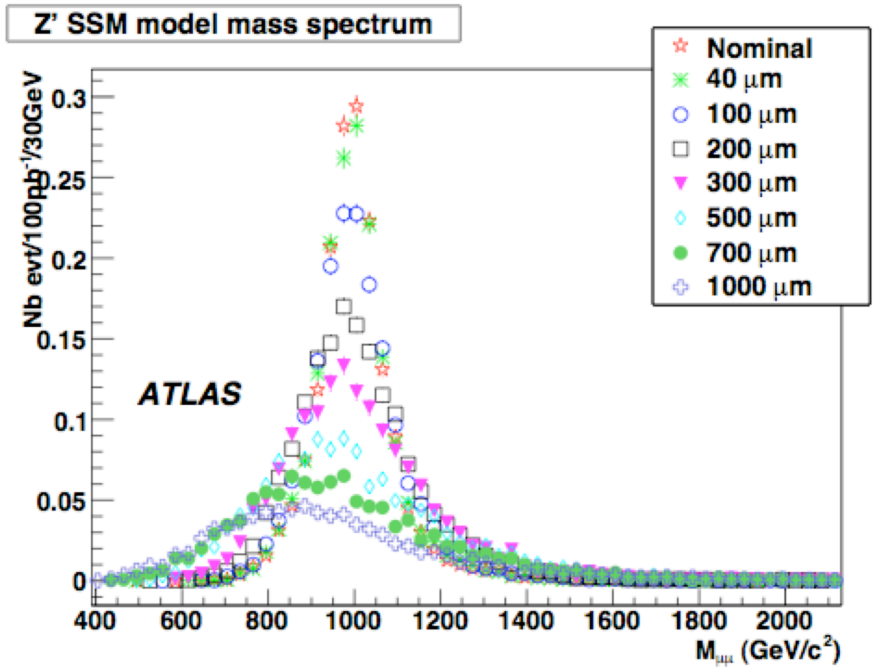
Standard Model: NLO corrections



- 2 independent studies: γ,Z,Z' and γ,Z
- ee and μμ studied separately
- EW corrections -12to-18% for ee, -4to-16% for μμ
- QCD corrections using MC@NLO
- Combination QCD/QED re-summation

Systematic uncertainties

- Alignment for Z'→μμ
  - Most important systematic.
  - Affects the reconstruction efficiencies and sensitivities
  - 8 configurations are investigated. 40,100,…,1000μ
- Systematic uncertainties:
  - Renormalization/factorization energy
  - PDFs: 5% @ 1TeV, 11% @ 3TeV
  - Efficiencies: 1%(e), 5% (μ,τ)
  - Energy scale: 1%(e), 5% (μ,τ)
  - Resolution: 20% e, 45% τ
  - Luminosity: 20% @100 pb^{-1}, 3% @ $10fb^{-1}$

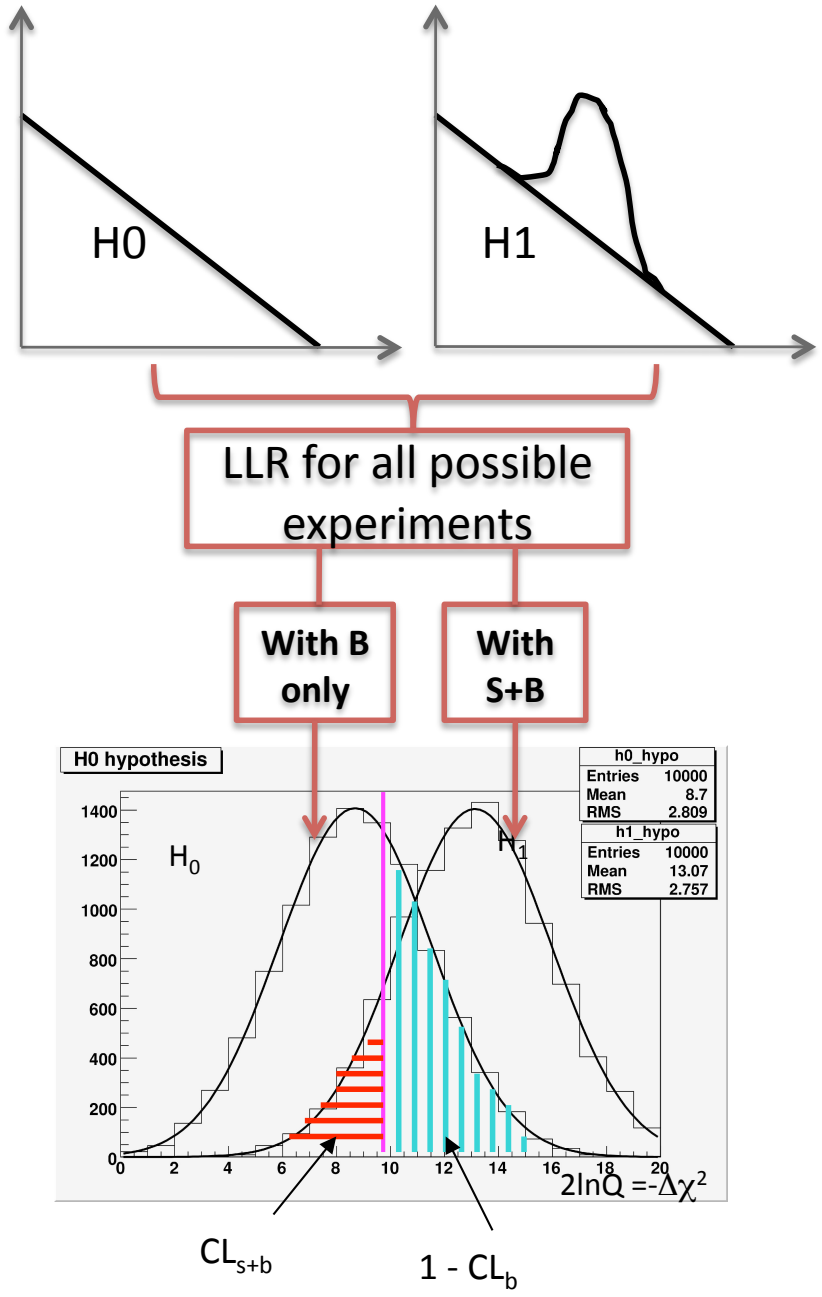


Misalignment (μm)	Nominal	40	100	200	300	500	700	1000
Relative loss	0.984	0.984	0.984	0.98	0.973	0.948	0.918	0.877

Exotic searches

- Investigated physics channels
  - Z'→ee,μμ,ττ.
  - G*→ee
  - Technicolor in μμ
- Statistical Methods:
  - Counting
  - Shape analysis (CLs method)
    - Bayesian
    - Parameterized
      - Direct Log Likelihood Ratio

        $5\sigma \Leftrightarrow 1\text{-}CL_b = 2.9\text{x}10^{-7}$ → ***high number of pseudoexperiments***
      - Fast Fourrier Transform (FFT)
    - Non parameterized
- Background treatment:
  - Counting
  - Parameterized and extrapolated when needed

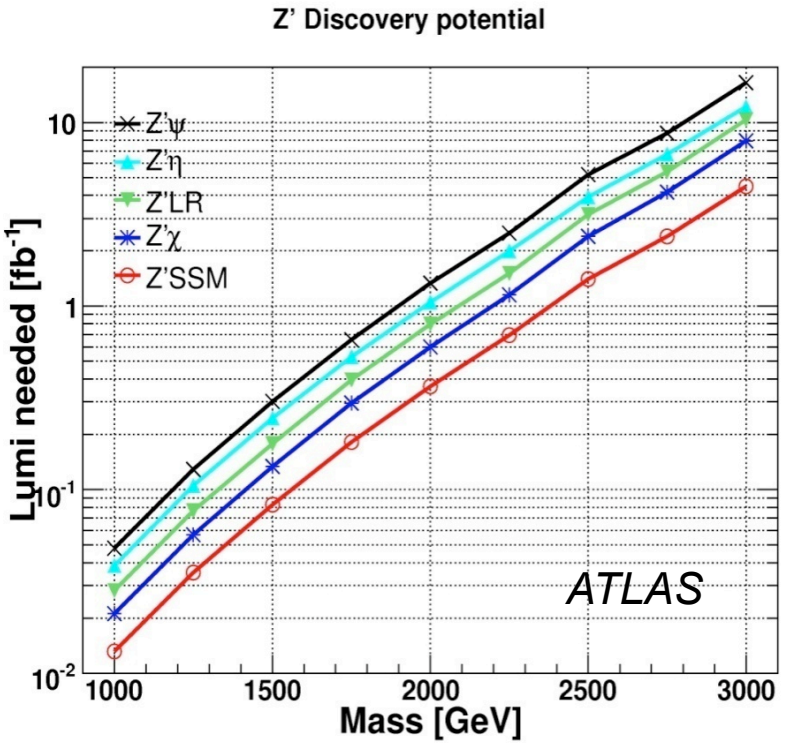


Exotics: Z'→ee

- Fully simulated Z'_{χ} with 1,2 and 3 TeV
- Mass spectrum generation for ψ,η, χ, LR and SSM models:
  - Parameterisation of both Drell-Yan and Z's
  - Width Z' resonances
- FFT methods used: DY<1%
- Uncertainties on the DY have negligible effect
- 100 pb^{-1} are sufficient to discover Z' beyond the Tevatron limits:

  1.2 TeV < $m_{Z'}$ <1.6TeV

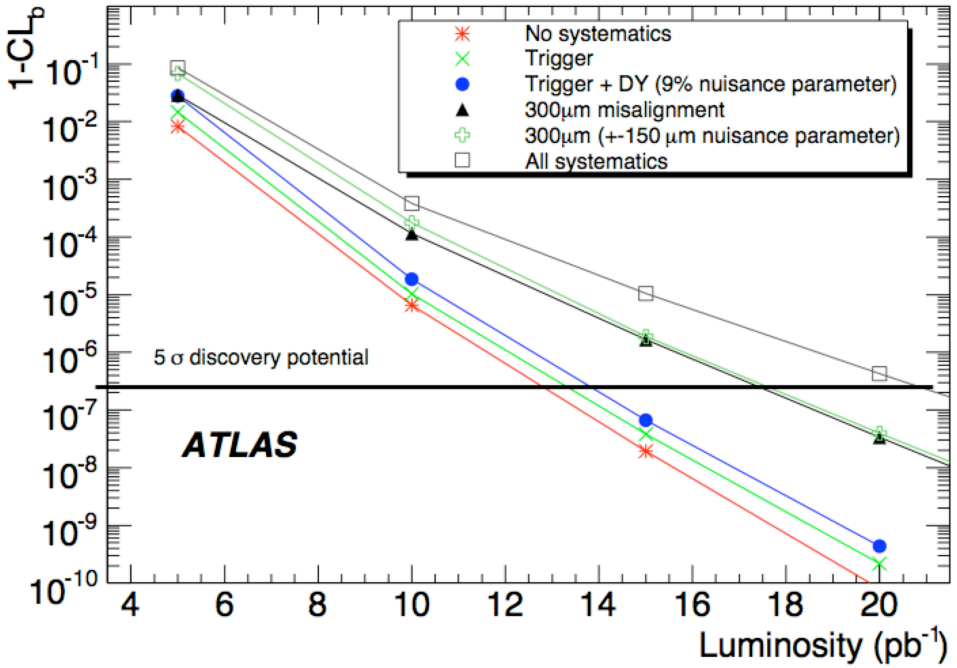
Selection	Signal at 1 TeV	DY at 1 TeV	Signal at 2 TeV	DY at 2 TeV	Signal at 3 TeV	DY at 3 TeV
	347	3.56	14.7	0.16	1.22	0.015
2 generated $e^{\pm}$, $\|\eta\| < 2.5$	299	3.07	13.7	0.15	1.16	0.013
2 clusters with a track	201	2.06	8.0	0.09	0.62	0.009
2 *loose* electrons	190	1.96	7.2	0.08	0.52	0.008
At least one $p_T > 65$ GeV	190	1.96	7.2	0.08	0.47	0.008
Event triggered	173	1.77	6.6	0.07	0.43	0.007
2 opposite charges	166	1.70	6.2	0.07	0.41	0.007



Exotics: Z'→μμ

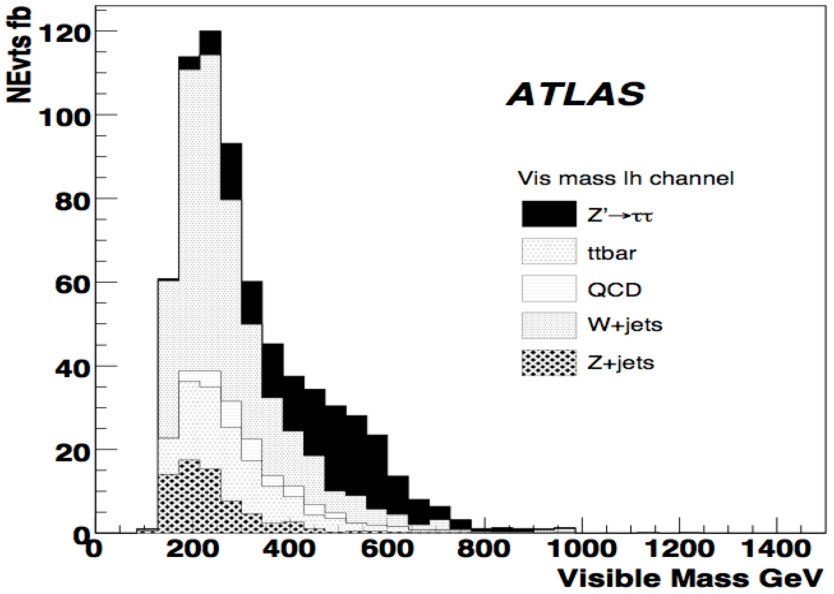
- Complement to Z'→ee, especially if the designed rejections are not reached in early data.
- SSM and χ models investigated at 1 & 2 TeV
- Sensitivity computed using FFT
- Systematics (5σ discovery):
  - Standard uncertainties have modest effect:
    - 13 → 14 pb^{-1} @ $m_{Z'}$=1 TeV
  - Alignment is the main source of degradation:
    - 14→ 20 pb^{-1} @ $m_{Z'}$=1 TeV

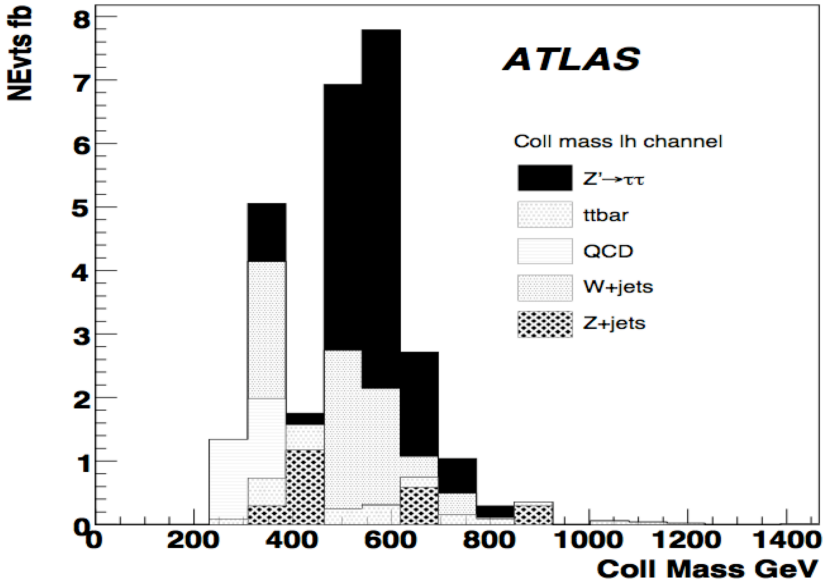
Sample	Z' (1 TeV SSM)	Z' (2 TeV SSM)	Z' (1 TeV χ)	Drell-Yan (M ≥ 800 GeV)
Generated	508.6	23.8	380.6	13.5
$\|\eta\| \leq 2.5$	366.8	18.1	271.5	10.8
$p_T \geq 30$ GeV	364.0	17.9	270.1	10.7
Muon identification	342.3	17.0	256.0	10.0
Trigger	325.2	16.2	243.2	9.5
Opposite charge	324.8	16.2	243.0	9.5



Exotics: Z'→ττ

- Study done for 1 fb^{-1} in the lepton-hadron channel only
- Collinear approximation:
  - Build the ττ invariant mass
  - breaks down at high masses
- Significance for 600 GeV:
  - 9.9 σ down to 3.4 σ with systematics
- Total systematic uncertainties 22% (luminosity, hadronic energy scale..)





	Signal	ttbar	QCD	W+jets	Z+jets
Trigger	1355.9	213578	2.3949e+07	4.19221e+06	6.69373e+06
Lepton	905.0	150921	1.25982e+07	1.08225e+06	120411
Tau selection	367.5	7818.0	145680	40080.3	4587.4
Opposite charge	314.8	2497.6	5305.5	23243.1	771.0
MET>30	269.6	2040.3	2562.1	834.7	161.9
$M_{tr} < 35$ GeV	202.5	302.4	388.0	436.4	83.8
$P_T^{tot} < 70$ GeV	155.0	106.7	331.5	221.6	28.4
$M_{vis} > 300$ GeV	132.5	26.2	105.6	33.8	15.0
MColl	13.3	2.1	5.5	2.3	2.7

Exotics: G*→e-e

- 2 loose electrons
- DY extrapolated using:

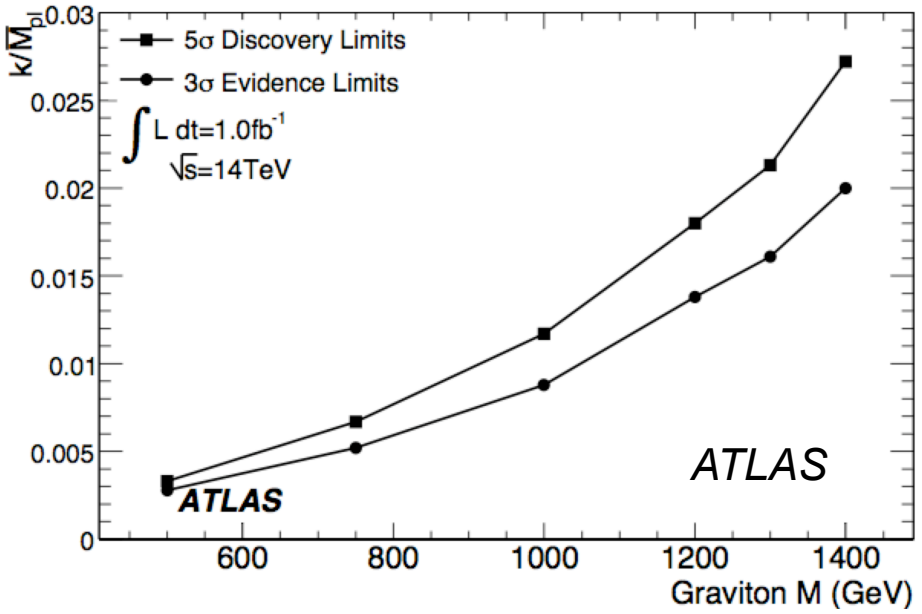
$$exp^{2.2M^{0.3}}$$

- Physics parameter in Rundall-Sundrum:

$$\frac{k}{\overline{M_{pl}}}$$

- Sensitivity for 1fb^{-1} using parameterized CLs method:
  - Up to m_{G^*}=1.5 TeV

Selection	500 GeV	750 GeV	1.0 TeV	1.2 TeV	1.3 TeV	1.4 TeV	Drell-Yan (650 ≤ M (GeV) ≤ 800)
Generated	187.4	27.7	26.0	22.4	25.3	26.8	17.7
Acceptance	172.4	25.9	24.6	21.2	24.0	25.3	16.4
hline Trigger	168.7	24.9	23.9	20.6	23.3	24.5	15.9
Electron ID	128.0	18.1	16.9	13.0	15.9	16.2	14.8
$P_T > 65$ GeV	125.7	17.7	16.3	12.8	15.6	15.9	14.6
$cos\Delta\phi_{ee} < 0$	122.5	17.0	16.0	12.5	15.1	15.3	14.0
Efficiency	65.6 ± 1.1%	64.4 ± 1.0%	61.7 ± 1.1%	56.3 ± 1.1%	56.4 ± 1.1%	53.9 ± 1.1%	60.8 ± 1.0%



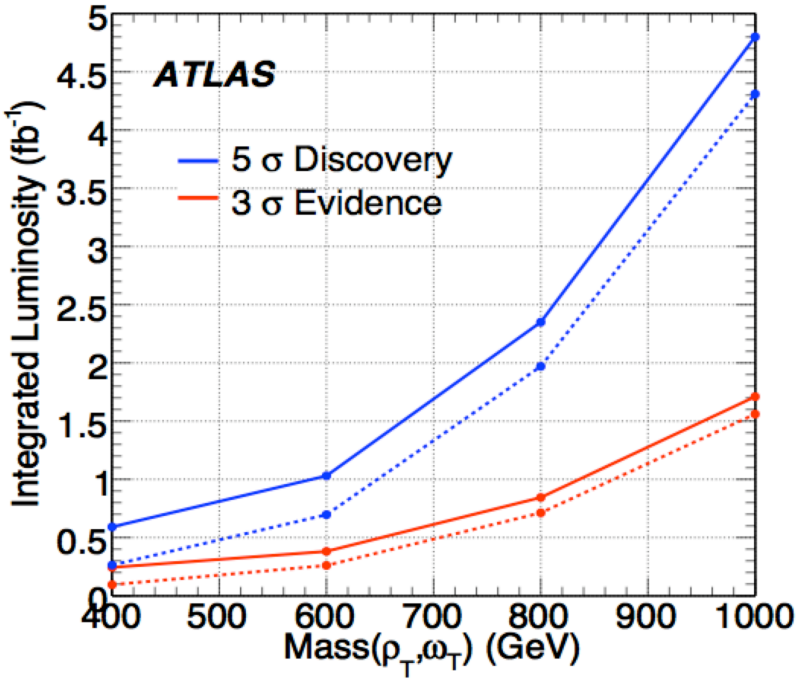
Exotics: Technicolor in μμ

- Snowmass Technicolor models: ρ_T,ω_T
- Techni-isospin symmetry:

$$m_{\rho T}=m_{\omega T}$$

- Sensitivity computed using:
  - Counting
  - D0 Bayesian method
  - Parameterized CLS method
- 1fb^{-1} are enough to discover a 600 GeV TechniMeson

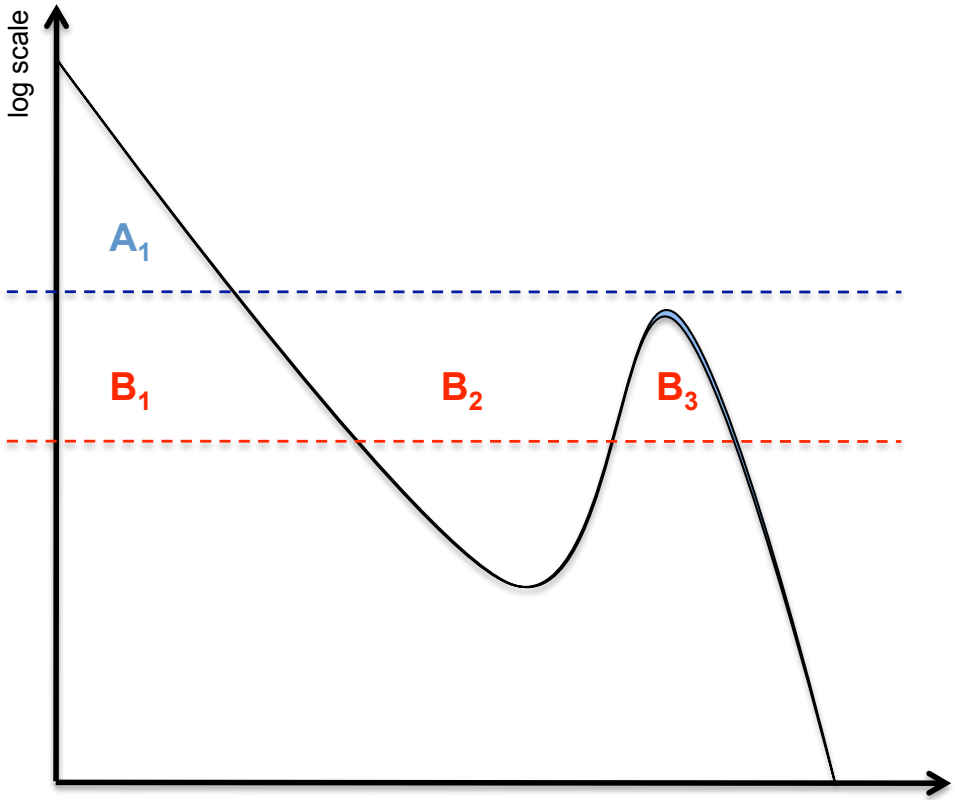
$M(\rho_T,\omega_T)$ (GeV)	400	600	800	1000
Peak Mass (GeV)	403	603	804	1004
$\sigma(M)$ (GeV)	13	22	34	46
Cut Flow				
Generated	201	60.8	23.0	10.1
$\|\eta\| < 2.5$	116	39.8	15.8	7.3
$p_T > 30$ GeV	114	39.5	15.7	7.2
L1_MU20 || L1_MU40	112	38.7	15.3	7.0
L2_Mu20i	110	38.0	15.1	6.9
EF_Mu20i	109	37.5	14.9	6.8
Match $\chi^2 < 100$	104	35.7	14.0	6.4
Opposite charge	104	35.7	14.0	6.4
Mass Window	78.2	26.3	10.3	4.7
Drell-Yan Background	46.9	14.1	6.1	2.8
Selection Efficiency (%)	38.9 ± 0.5	43.2 ± 0.5	44.8 ± 0.5	46.8 ± 0.5

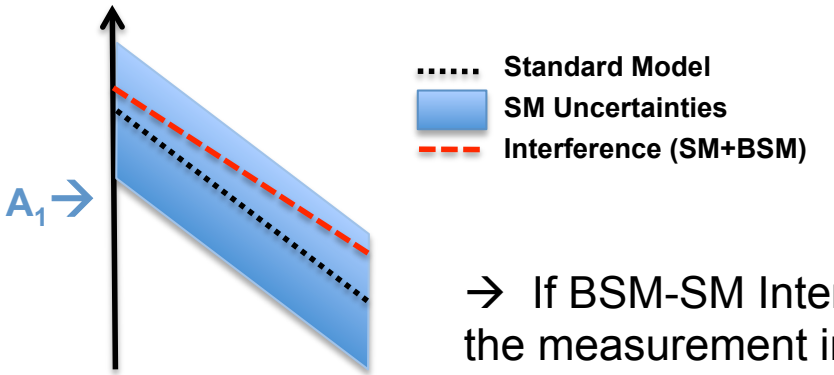


Identifying the underlying model

- Many BSM Models predicting a di-lepton final state:
  - s-channel resonances:
    - Spin 2 particles:G*
    - Spin 1 particles: Z', Z_H,Z_{KK} , Technimesons (rho, omegas…)
    - Heavy scalars:
      - Graviscalar, radion, heavy higgs..
  - Non resonant observables:
    - Compositeness
    - Virtual exchange of ADD gravitons
    - Leptoquarks in t-channel
    - Leptogluons in t-channel
- The experimental approach is generic
- In case of discovery, how to disentangle the underlying model:
  - Differentiating the resonant and non-resonant signatures is straightforward in most cases.

Resonant BSM



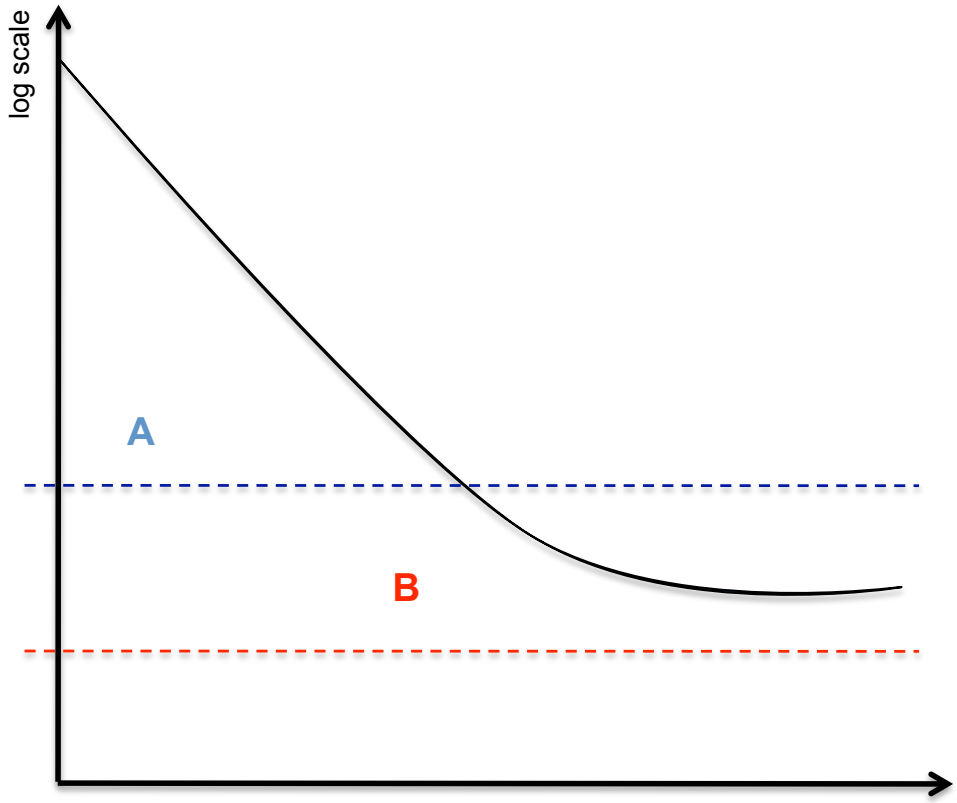


Invariant mass observable with an increasing luminosity (well understood detector)

- @ non discovery luminosities:
  - Falling Drell-Yan distribution (A_1)
  - No chance to discover BSM through interference because of the uncertainties ***(which, btw, never existed in a complete way even for the simplest processes)***
- With a discovery luminosity
  - $\sigma_{BSM} >> \sigma_{DY}$: most of the models (high couplings to fermions)
  - Discontinuous distribution: Drell-Yan (B_1)+ Gaussian (Breit-Wigner…) peak (B_3) + **empty zone** (B_2)
  - Wide resonances wash out this effect

→ If BSM-SM Interference lies inside the SM uncertainties, the measurement in the zone A_1 ***is a Standard Model measurement***

Non-resonant BSM



Invariant mass observable with an increasing luminosity

- @ non discovery luminosities:
  - Falling Drell-Yan distribution (A)
  - No chance to discover BSM through interference because of the uncertainties
- @ discovery luminosity
  - Continuous distribution (B)
  - difficulty: sensitive to detector tail effects and mis-calibration

→ For most of the BSM models, it should be easy to disentangle the Resonant and non-resonant models

Disentangling the BSM Model

BSM Model	Resonance	Other obeservables
RS Graviton	Yes	Look or diphoton, diboson channels, black holes, angular distribution, couplings
Z' (plenty of Models)	Yes	Absence of diphotons and dibosons. couplings, FB asymmetry, resonance width
Z_{KK}	Yes	next KK excitation, other particle KK excitations
Z_H	Yes	Other Little Higgs particles, W_H t_H, H_H
Technicolor mesons	Yes	?, spin ? …
Gravi-Scalar	Yes	Diphoton, diboson, black holes, angular distribution
Radion	Yes	RS graviton, angular distribution
Compositeness	No	Look at Diphotons, Dijets,
Lepto-Quarks	No	Look at Lepto-Quarks resonances (2-leptons+2-jets), rate
Lepton-Gluons	No	Look at Lepto-Gluons resonances (2-leptons+2-jets), rate
ADD gravitons	No	Blacks holes, diphotons, Jet+E_{Tmiss}

→ How to complete this table to avoid overlap between models

Conclusion

- Sensitivity to exotic dilepton resonances:
  - $Z' \rightarrow ee$, 15 to 50pb^{-1} for 5s discovery of $Z'_{\chi,\eta,\psi,LR,SSM}$
  - $Z' \rightarrow \mu\mu$, 20pb^{-1} for 5σ discovery of Z'_{χ}
  - $Z' \rightarrow \tau\tau$, 1fb^{-1} gives 3.4 σ for $m_{Z'}$=600GeV
  - $G^* \rightarrow ee$, 5σ dicovery @ 1fb^{-1}: up to m_{G^*}=1.5 TeV
  - $TC \rightarrow \mu\mu$, 5σ discovery @ 1fb^{-1}: up to m_{TC}=600GeV
- 10 to 100 pb^{-1} @ 14 TeV (20-200 pb^{-1} @ 10 TeV) are enough to go beyond the Tevatron limits for most of the dilepton resonances
- Develop tools to identify the underlying BSM dilepton model