Low scale gravity black holes at LHC

Enikő Regős
(CERN)

Search for Extra Dimensions

- LHC : Quantum Gravity & Extra Dimensions
- Stringy Quantum Black Holes
- Low-scale Gravity Black Holes at CMS

Quantum gravity and accelerator physics

- Obtain limits from collider experiments
- Graviton interference effects at Large Hadron Collider, CERN
- Decay modes of particles with mass in TeV range
- Hadron/lepton scatterings and decays in extra-dimensional models
- Black holes at LHC, CMS

- Limits from cosmology and astrophysics: cosmic rays and supernovae
- Particle astrophysics
  - Dark matter
  - mass of particles,
    Ex: Axions

Evidence from observations for extra D

- Quantum black holes: energy spectrum, depend on parameters of space times, strings

Collider Physics : QG & ED

- QG & ED, the hierarchy problem
- Experimental signatures at colliders : Kaluza – Klein graviton production
- Gravitational decay of heavy particles in extra dimensions
- Virtual KK graviton exchange at Z pole
- Bounds from astrophysics, cosmology

Hierarchy problem & ED

- Fundamental scales in nature :

  Planck mass : E19 GeV

  Electroweak scale : 240 GeV

Supersymmetry : fundamental theory at M_Pl ,

EW derived (small #) from dynamics

Broken (particle mass) : gravity mediated

gravitino mass determines partner masses

EW breaking induced by radiative corrections

Extra dimensions

- EW scale fundamental, M_Pl derived
- Compact ED (radius R)
- Matter confined in 4D
- Gravity : propagates in all D ,

  weak : compact space dimensions large compared to electroweak scale

  $G = G_D / (2 \pi R)^{(D-4)}$

TeV scale M_Pl

- Planck mass of order 1 TeV :
- 1 ED : R ~ E8 km
- 2 : 0.4 mm
- 4 : E-5 µm
- 6 : 30 fm
- Newton law modified at small scale (exponent)

LHC and extra-dimensional models

Planck scale at TeV

Strong gravity at TeV: black hole formation

- New particles
- Gravity is weak as diluted in extra-D's , matter confined in 4D
- Polarization asymmetries, forward-backward
- Shift of Z peak

LHC and Kaluza-Klein gravitons

- Graviton production
- Gravitational decay of heavy particles
- Top decay , Higgs, Z
- pp -> jet + missing transverse energy
- g-2 of muon
- Rare decays : K, qq_ , Y, Z, J/ψ, μ
- Higher-dimensional seesaw mechanism to give mass to light neutrinos

Rare decays

- μ -> v_μ e v__e + G , K -> π + G ,
  J / ψ -> γ + G , Υ -> γ + G ,
  Z -> f f_ + G , t -> b W + G ,
  H -> f f_ + G , H -> W + W_ + G

Rare decays to KK

- Quarkonium   q q_ -> γ + G
- Υ decay prefered to J / ψ

    experimental BR < E-5   ->

      M_D > 50 (9) GeV (2, 6 ED)

Discussion

- Strong gravity at TeV scale : Black Hole production
- If new TeV particles - KK excitations of SM fields at LHC : quantum gravity significantly affects their decay modes
- Emission of KK gravitons : main decay modes of heavy particles , SM ones too
- Z -> ff_ + E_miss : experimental resolution on BR constrains M_D

- Higgs decay : for lower bound on M_D :

  M_H = 120 GeV E-7

  500 GeV E-5

  resolution on gravitational BR

- Virtual KK graviton exchange not affects Z- resonance observables for current experimental sensitivity

Stringy Black Holes : D branes

- D branes
- D = 5 type – IIB black hole :
- Q1 D1 and Q5 D5 branes intersections
- in ds^2 :
- $f = \prod [\, 1 + (r0 \, sh\, \delta / r)^2 \,]$ (1, 5, p)
- 1, 5 – brane charges : electric, magnetic, KK charge
- $T = 1 / 2 \Pi \, r0 \prod ch\, \delta$
- $S \sim \prod ch\, \delta$
- $S = 2 \Pi \prod (\sqrt{N} + \sqrt{N_{-}})$
- $Q = N - N_{-}$ (1, 5, R - L)
- (anti) 1, 5 – branes, right/left moving momentum #

D = 4 string : Entropy and quasi-normal modes known

- $ds^2 = -g / \sqrt{f}\, dt^2 + \sqrt{f}\, (dr^2 /g + r^2\, d\Omega)$
- δ-s : higher dimensions' compactification
- $f = \prod (1 + r0\, sh^2\, \delta / r)$ (2, 5, 6, p)
- Entropy S similar to previous, 4 factors :
- $S_{stat} = S_{BH} = A / 4$
- String QNM – s known :
- Theory's parameters can be determined from resonant oscillations' normal modes (observable)

Further examples:

- D = 5 Type – IIB with electric charges
  - BPS black hole : Reissner – Nordstrom spacetime
- D = 5 : Rotating, spin
  - equal charges : D = 5 Kerr - Newman
- D = 4 rotating :
- D1, D5 branes' intersection
- Type –II : heterotic string on T^6 torus
- Levels' correspondance, BPS state, rotating
- In all cases :
- $S = 2 \Pi \sqrt{(\Pi \text{ charges} - J^2)}$
- S_stat = S_BH = A / 4

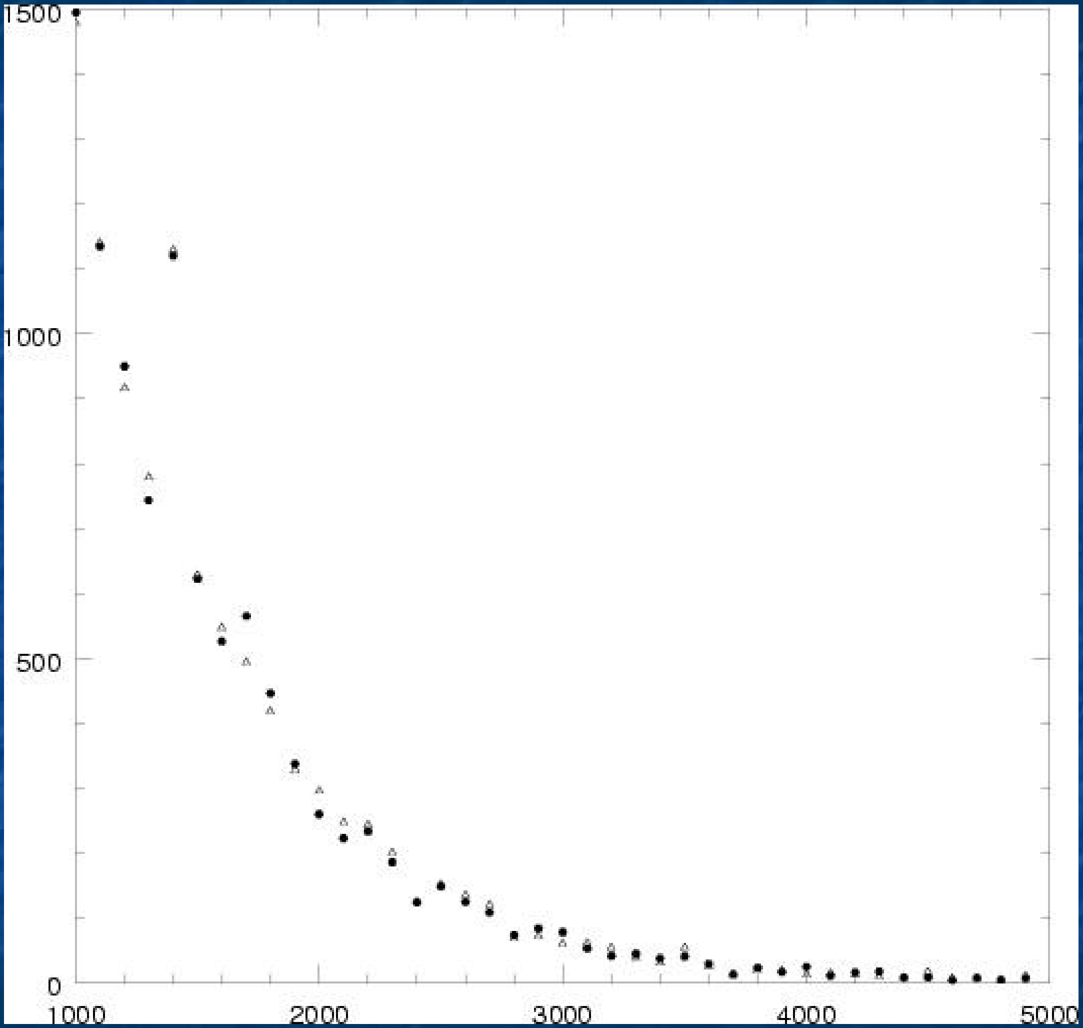
Low-scale Gravity Black Holes at CMS

with
Z. Trócsányi
A. de Roeck

Black holes at LHC

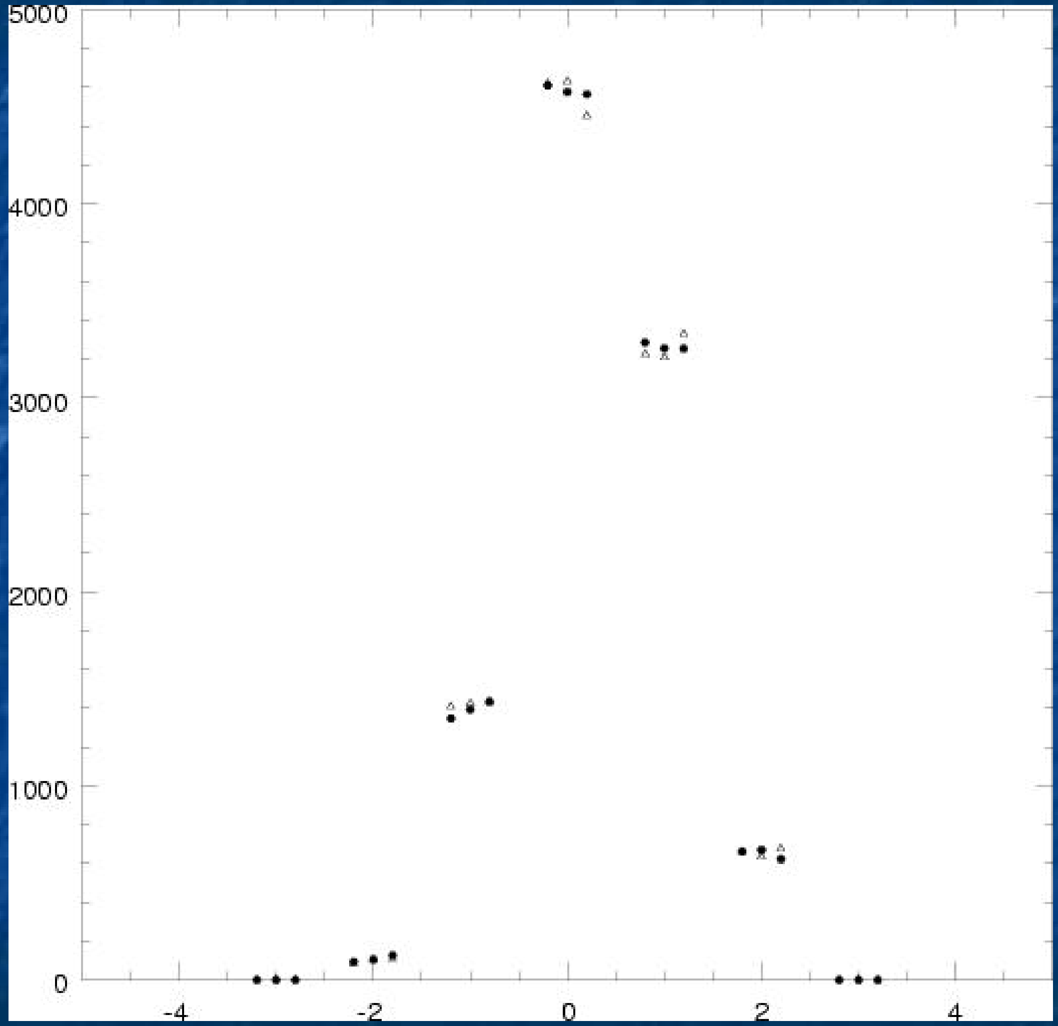
- Event generator for ED BHs : BlackMax I-II
- Rotation, fermion splitting, brane tension
- Experimental signatures, particle decay
- CMSSW analysis
- Further models of Dvali suggest Black Hole detection even more likely

Distribution of black hole mass



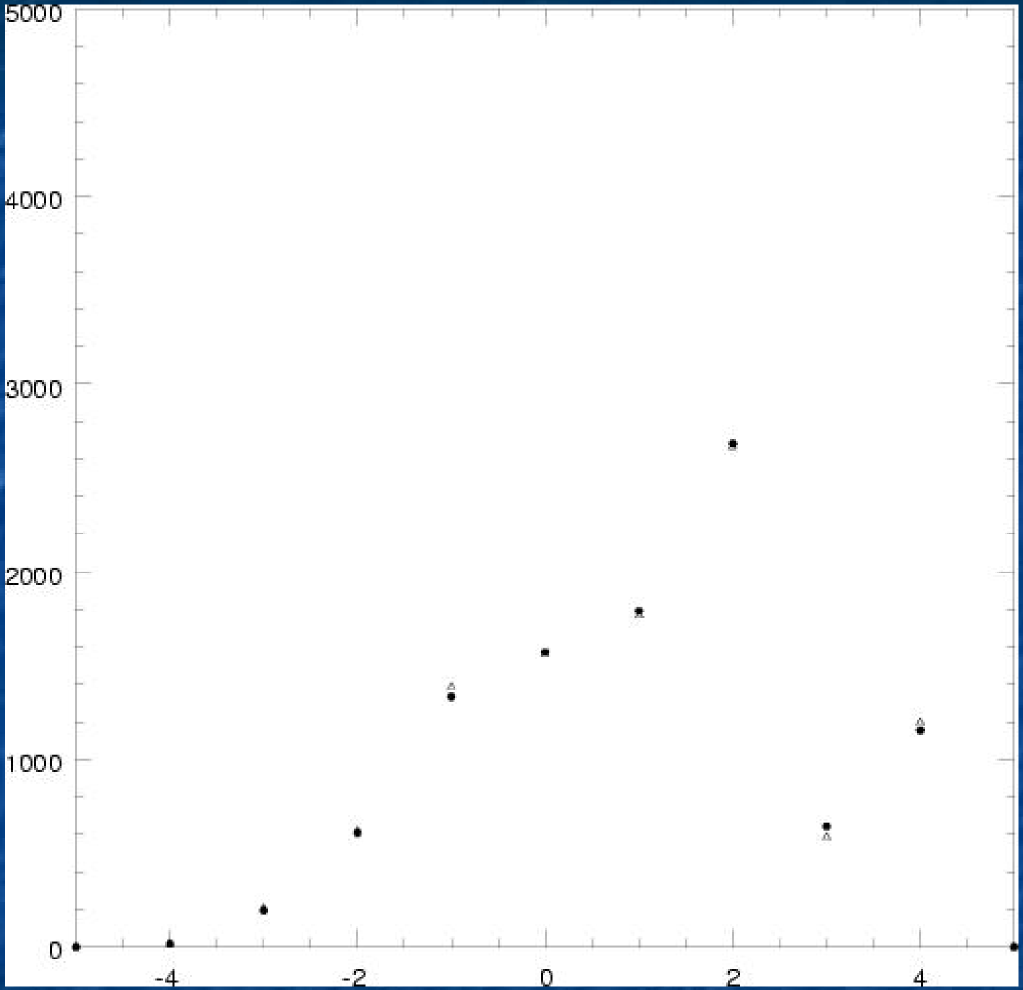
Rotating and non-rotating , 2 ED , 1-5 TeV

Distribution of BH color (red – blue - green)



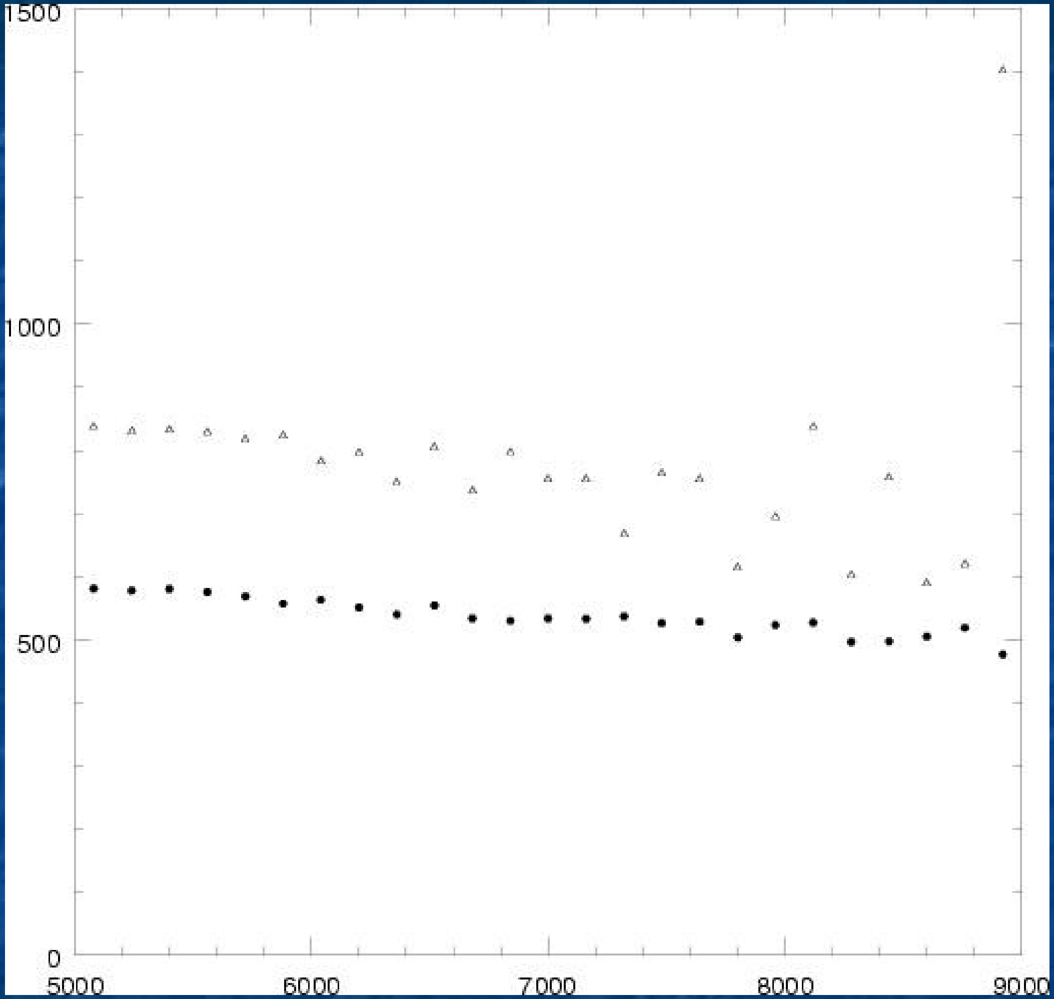
Rotating and non-rotating , 2 ED , 1-5 TeV

Distribution of BH charge / 3q /



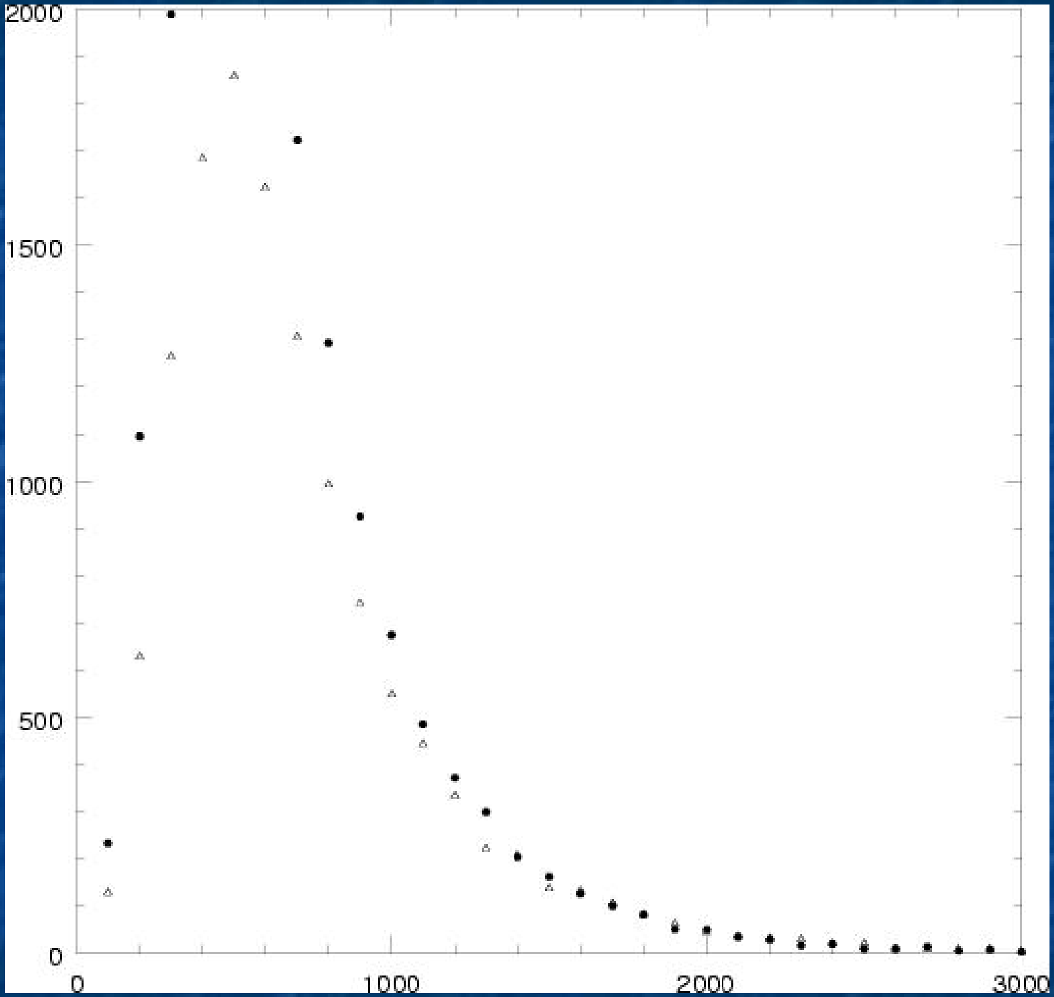
Rotating and non-rotating, 2 ED, 1-5 TeV

< Energy > of emitted particles vs. BH mass



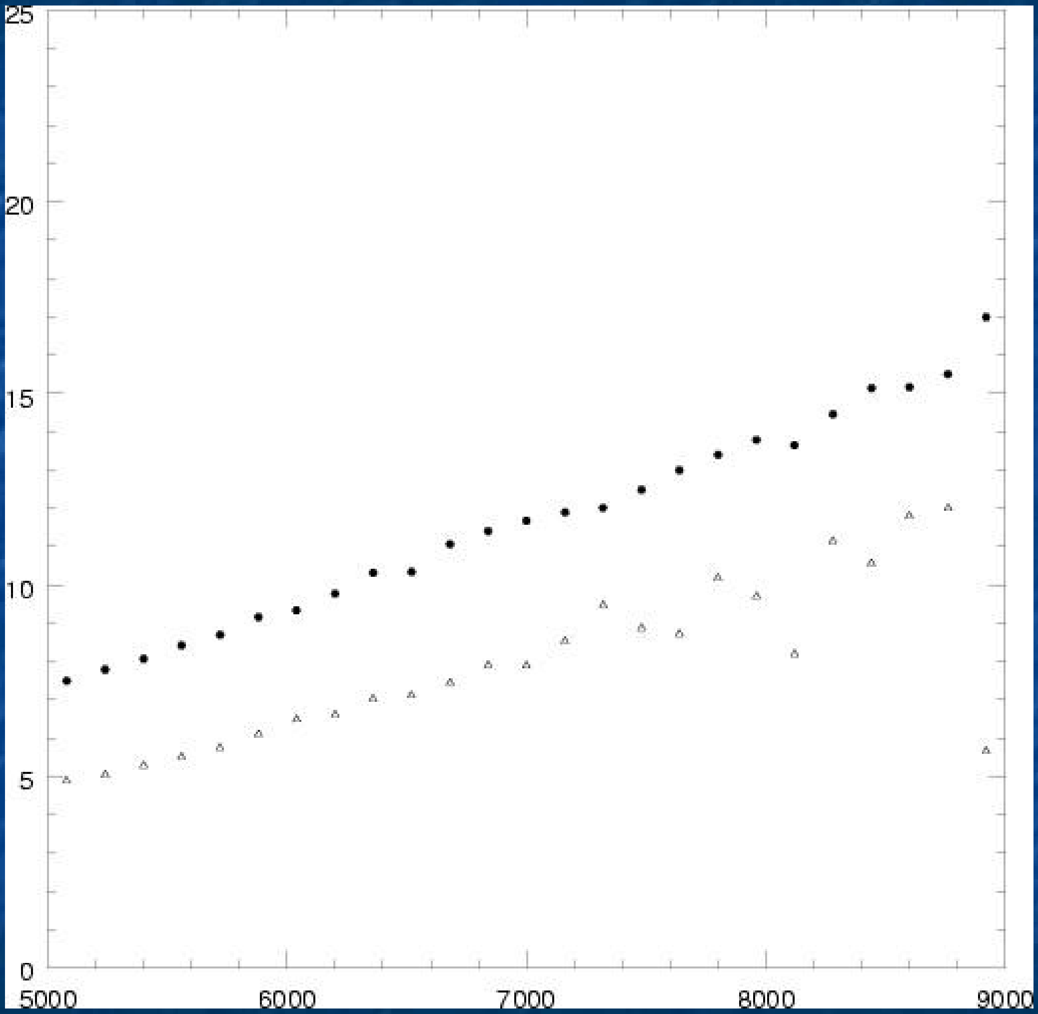
Rotating and non-rotating, 2 ED, 5-14 TeV

Energy spectrum of emitted particles



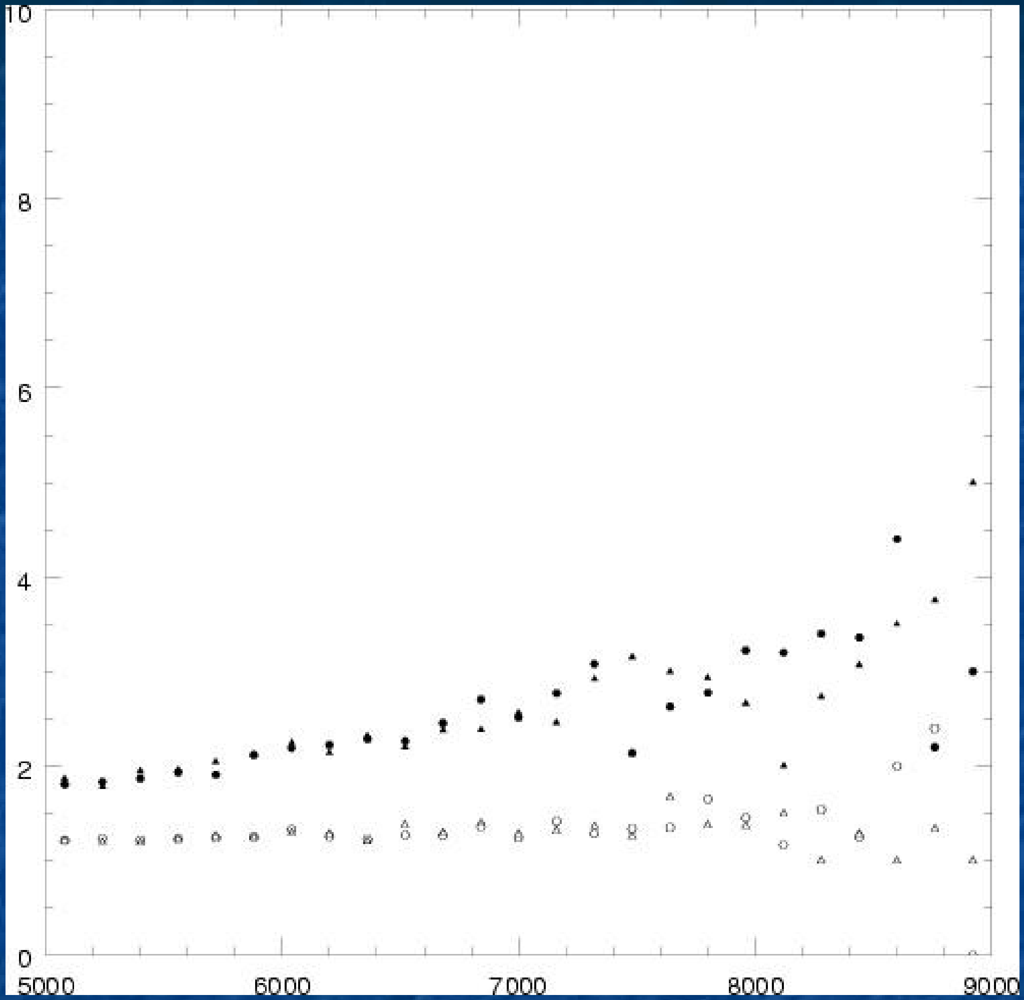
Rotating and non-rotating , 2 ED, 1-5 TeV

Number of emitted particles vs. BH mass during Hawking phase



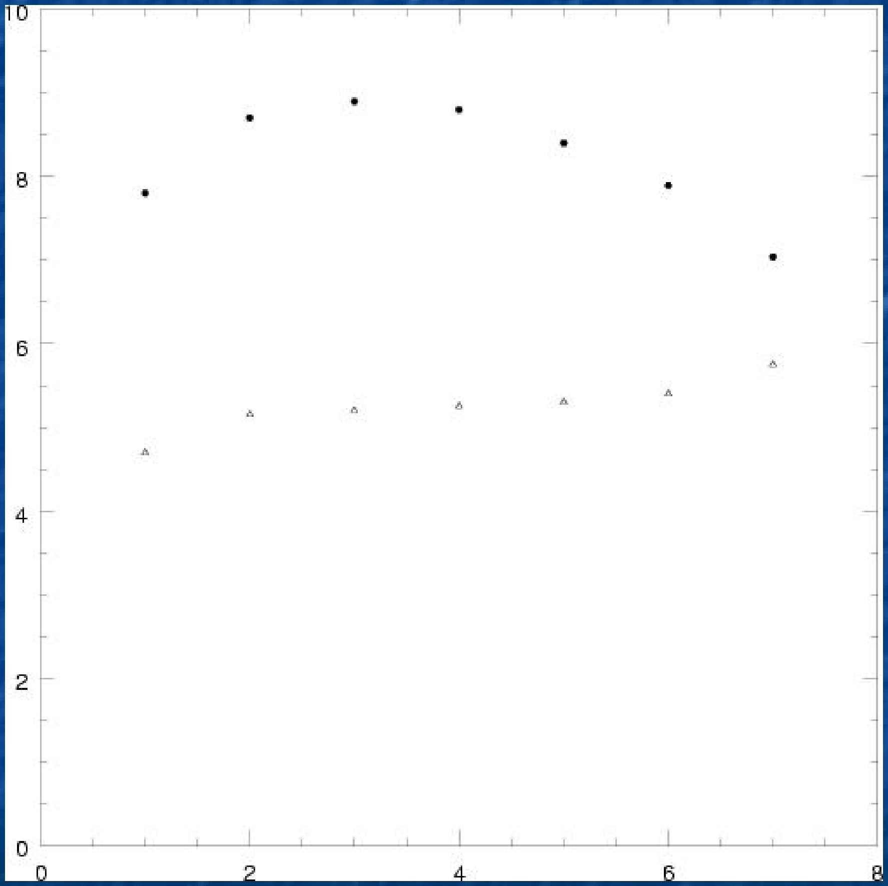
Rotating and non-rotating, 2 ED, 5-14 TeV

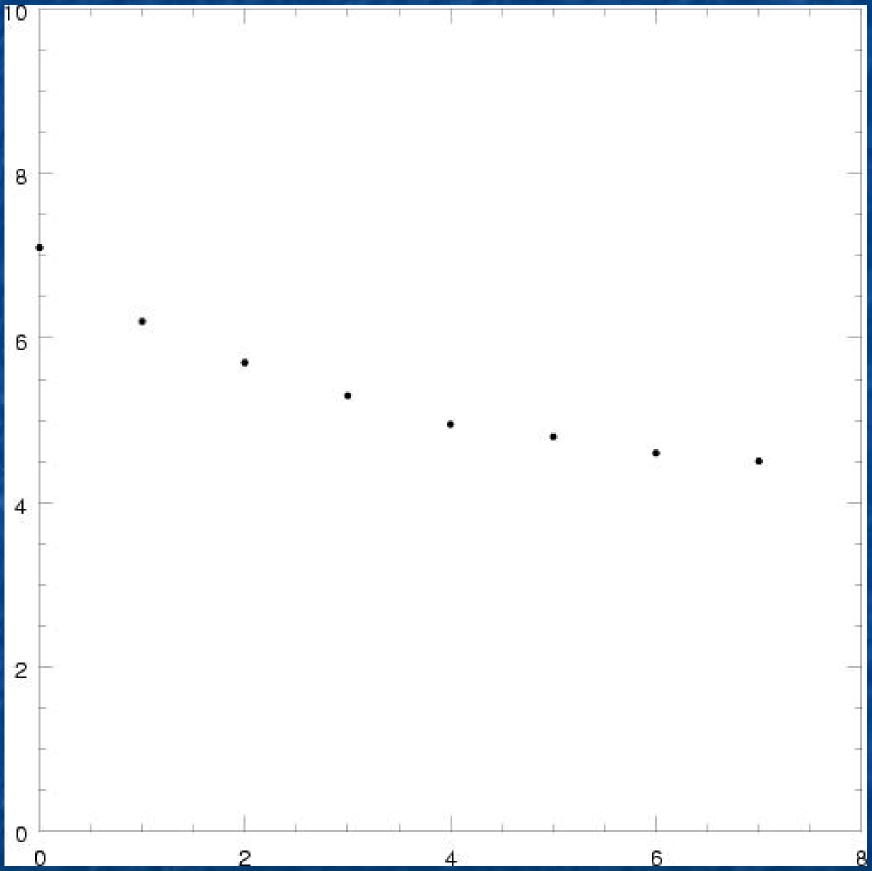
Multiplicity of various species (Hawking)



Rotating and non-rotating, 2 ED, 5-14 TeV , quarks, anti-quarks, leptons, anti-leptons

Number of emitted particles vs. # extra dimensions and # fermion splitting dimensions

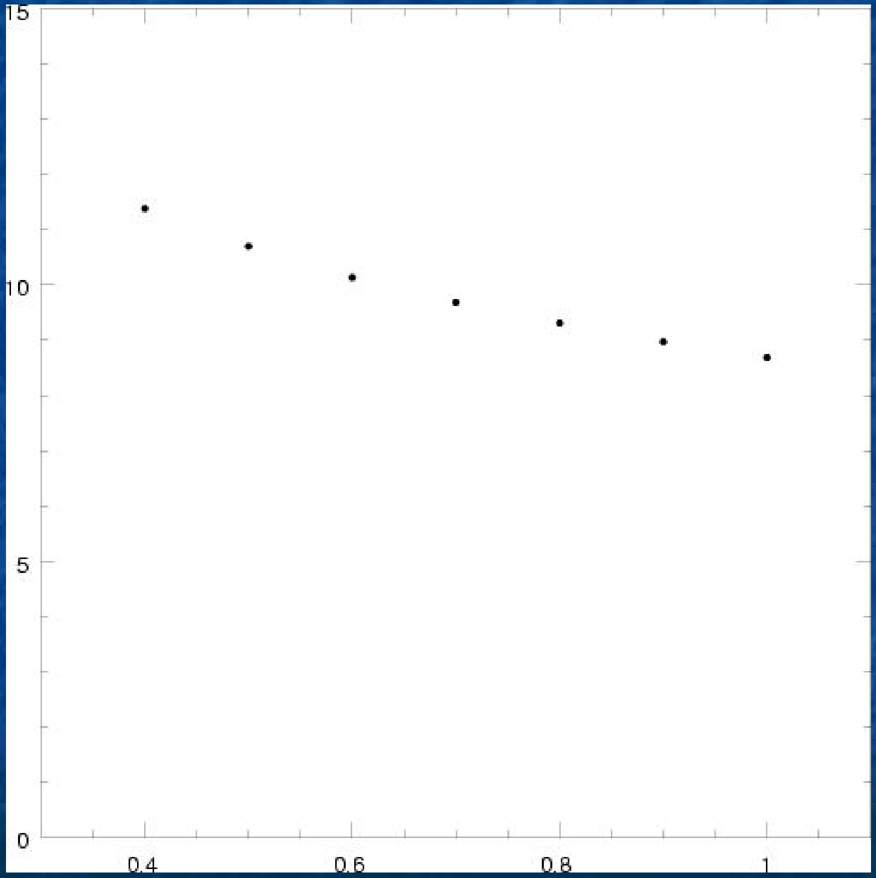




rotating and non-rotating

ED = 7

Number of emitted particles / BH vs. brane tension B



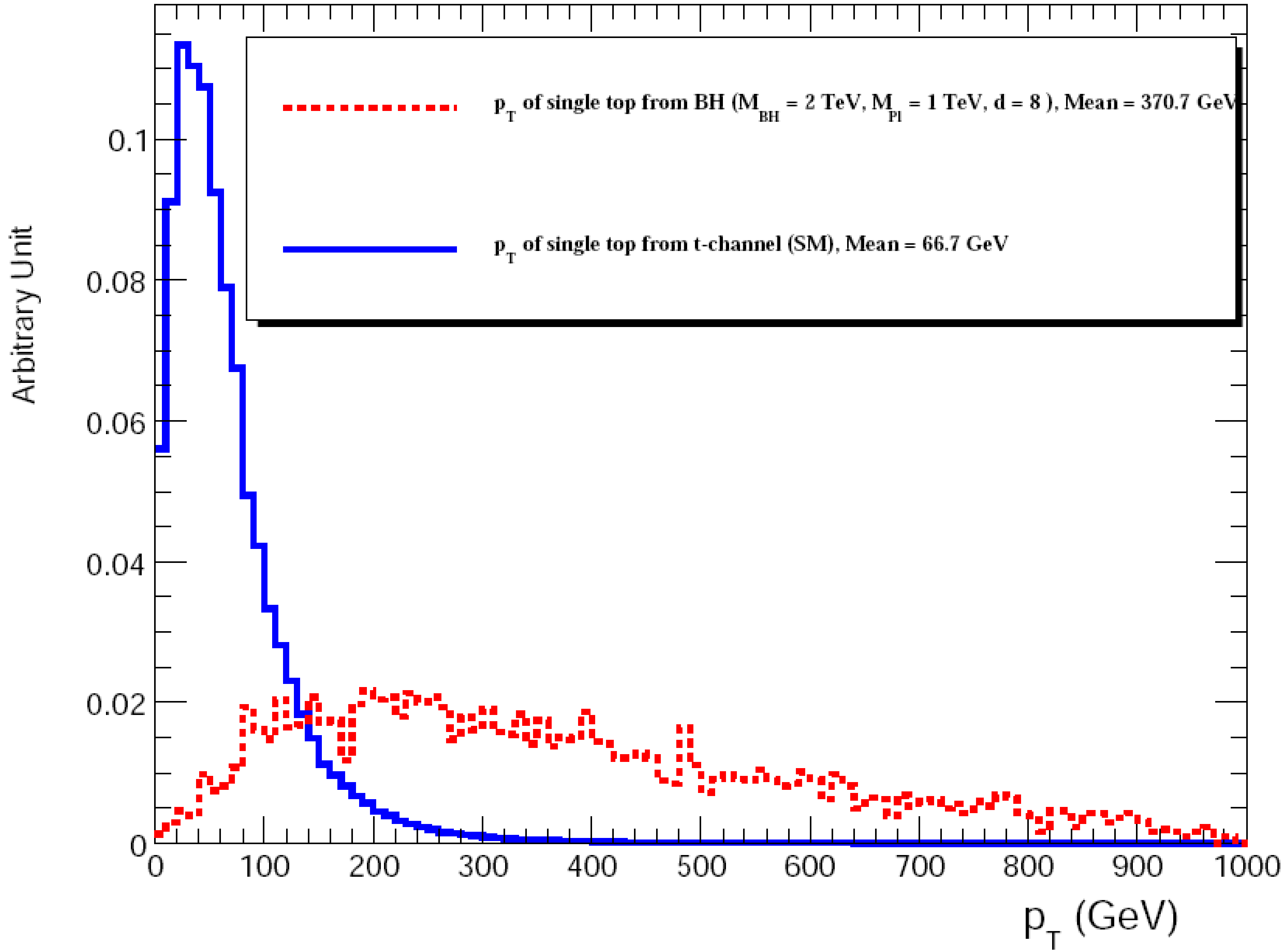
non-rotating

ED = 2

5-14 TeV

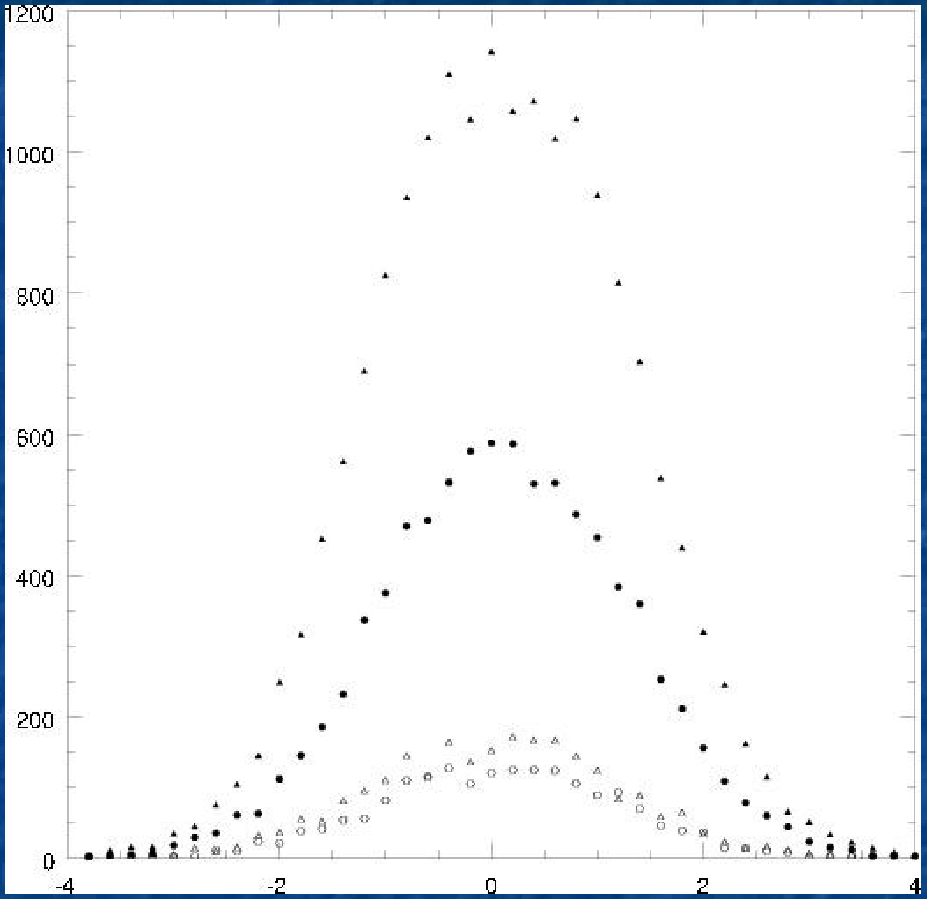
Hawking phase

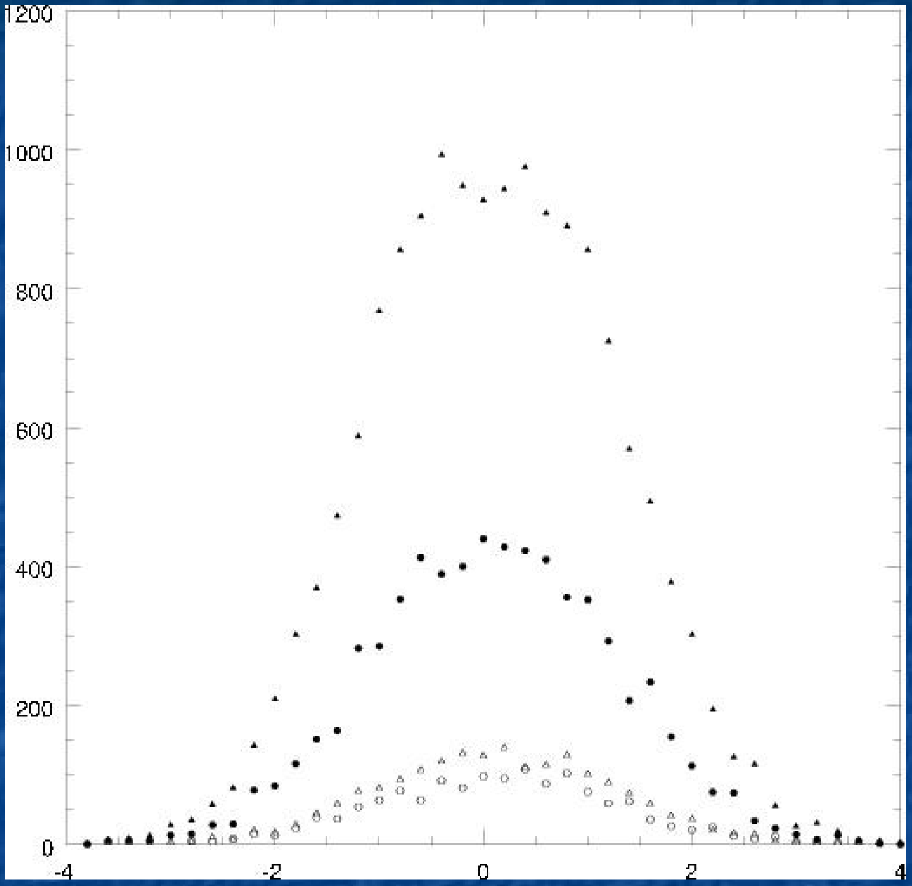
M_Pl = 1 TeV



p_T of single top from BH (M_BH = 2 TeV, M_Pl = 1 TeV, d = 8), Mean = 370.7 GeV
p_T of single top from t-channel (SM), Mean = 66.7 GeV
Arbitrary Unit
0
0.02
0.04
0.06
0.08
0.1
0
100
200
300
400
500
600
700
800
900
1000
p_T (GeV)

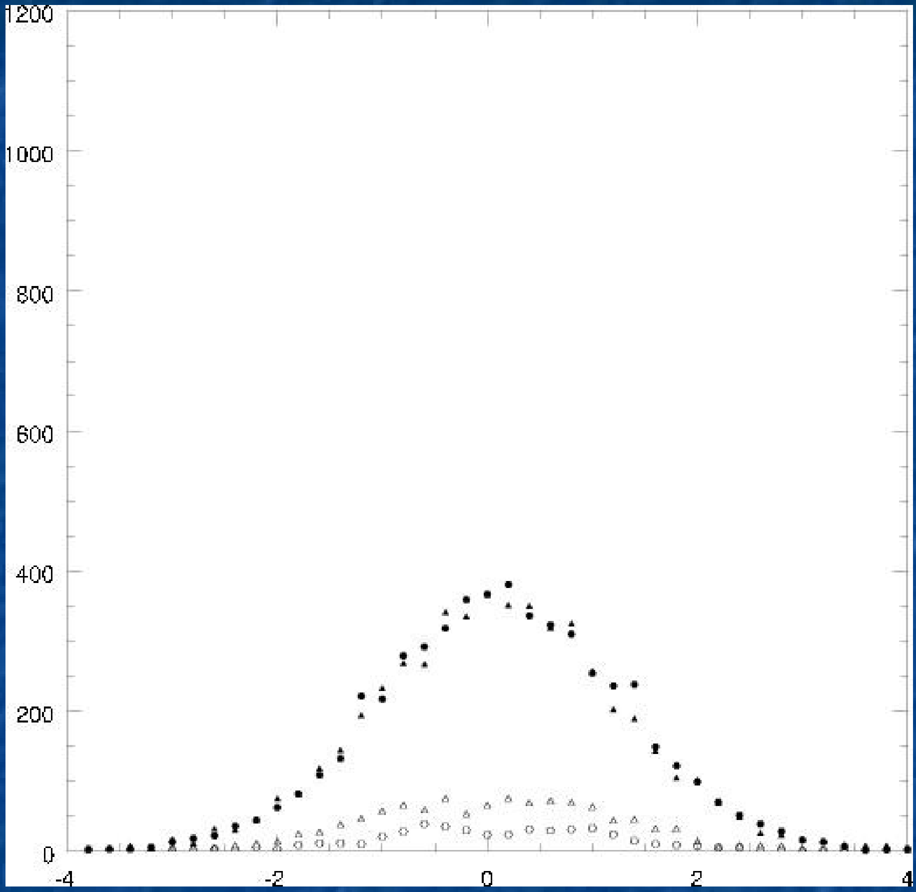
Pseudorapidity with final burst

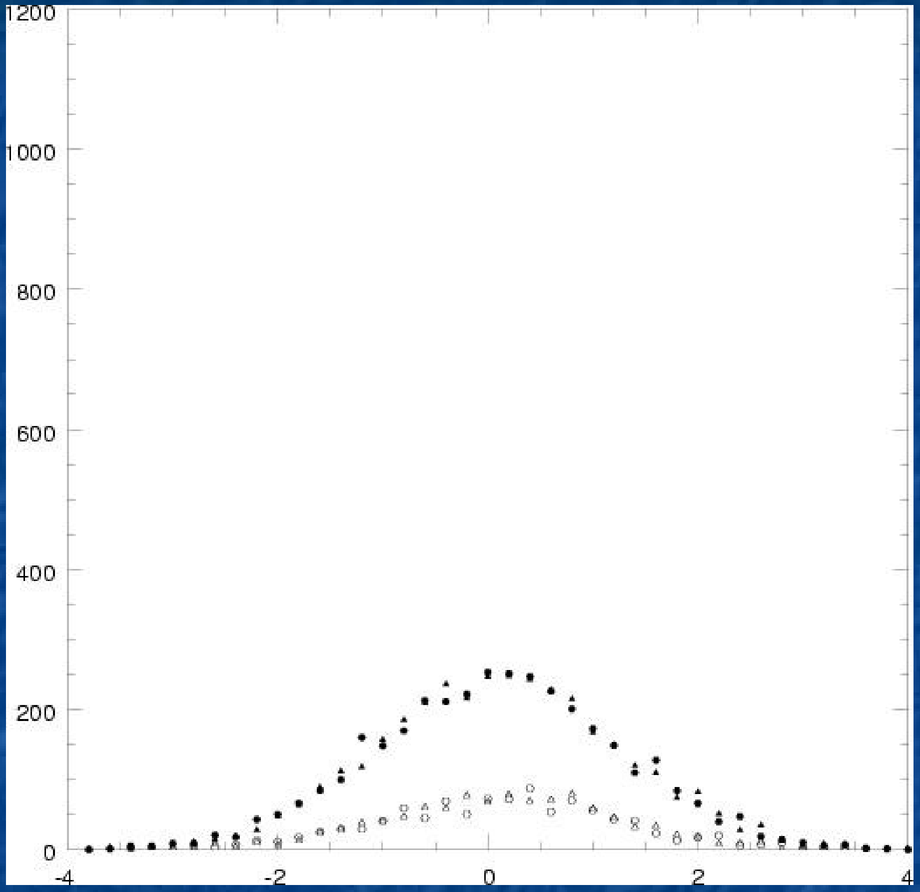




Non-rotating and rotating , 2 ED , 1-5 TeV , quarks, anti-quarks, leptons, anti-leptons

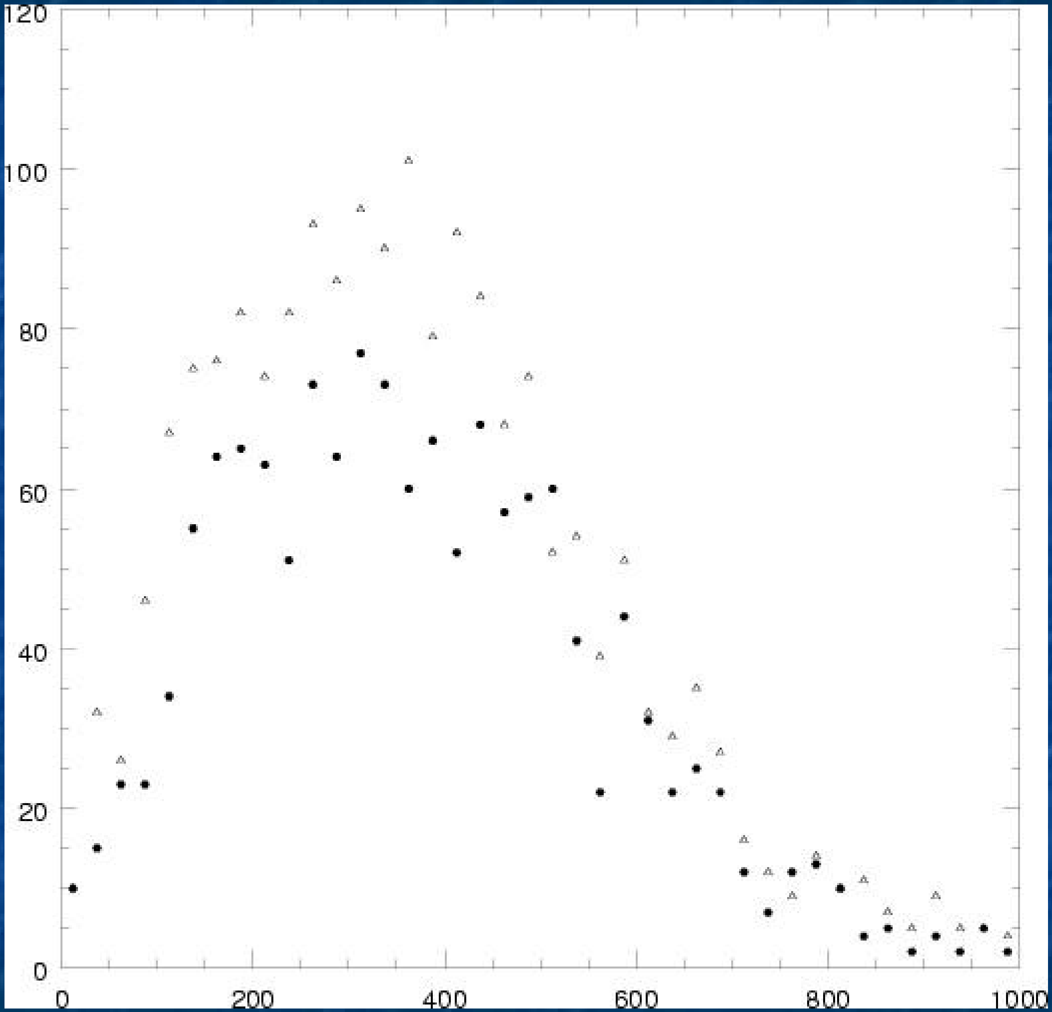
Pseudorapidity without final burst





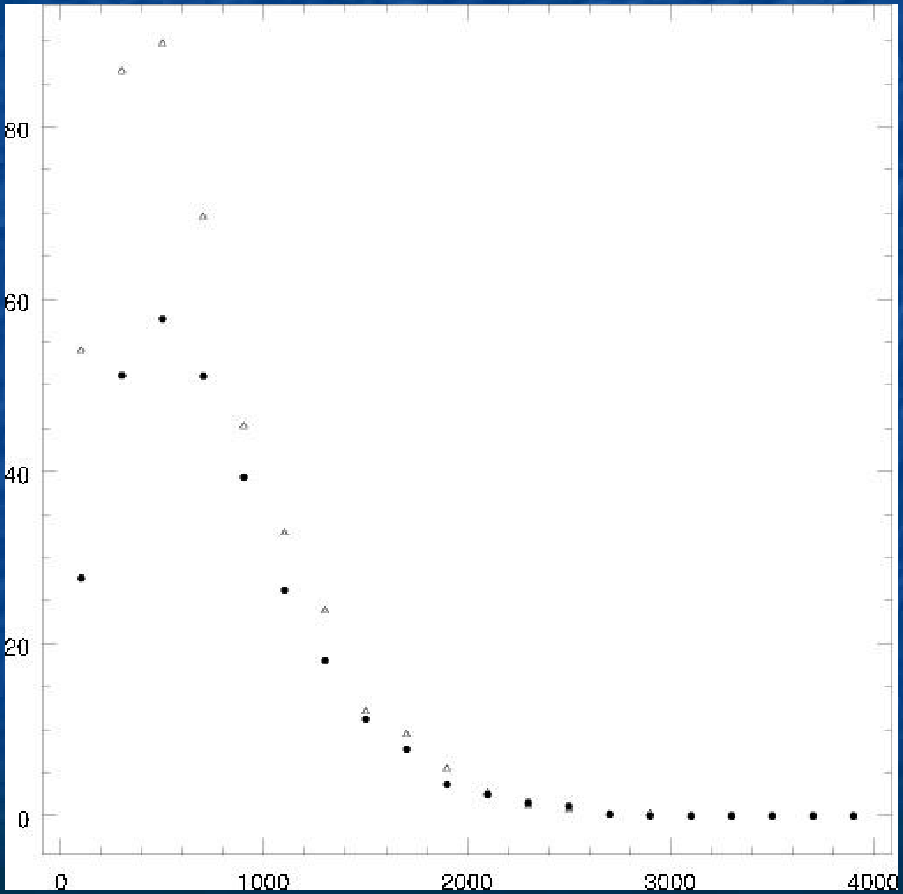
Non-rotating and rotating , 2 ED , 1-5 TeV , quarks, anti-quarks, leptons-, anti-leptons+

Distribution of lepton transverse momentum



Leptons & anti-leptons, rotating, 2 ED, 1-5 TeV

Lepton transverse momentum : models



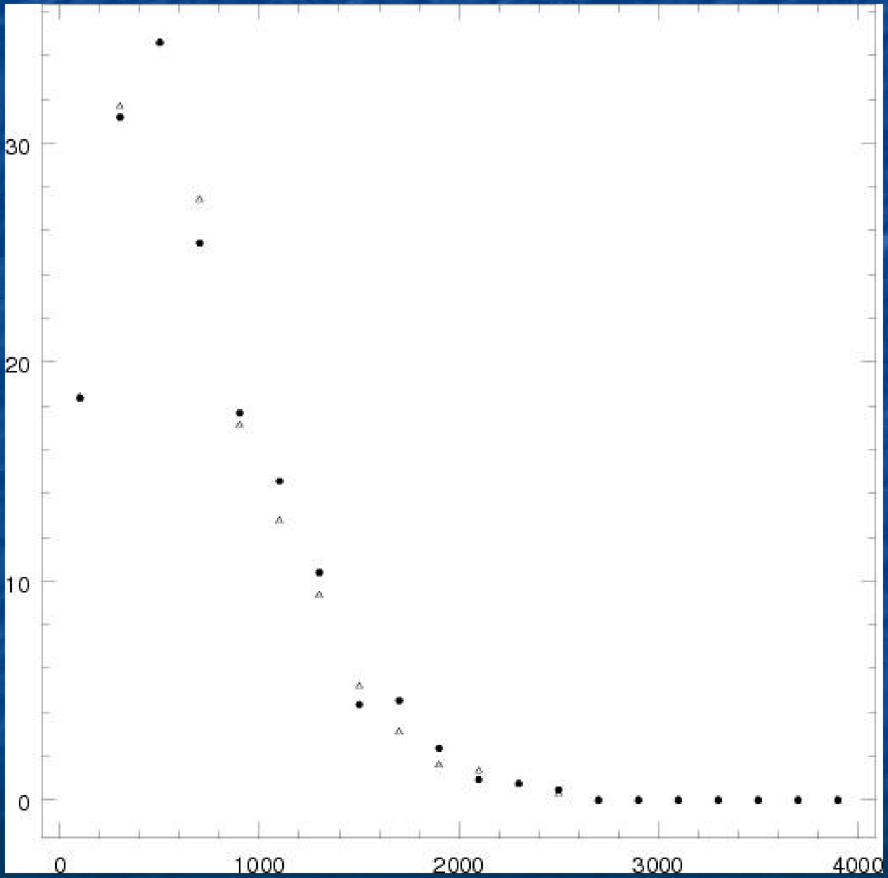
- Planck mass : 2 TeV
- ED = 3
- 5 – 14 TeV

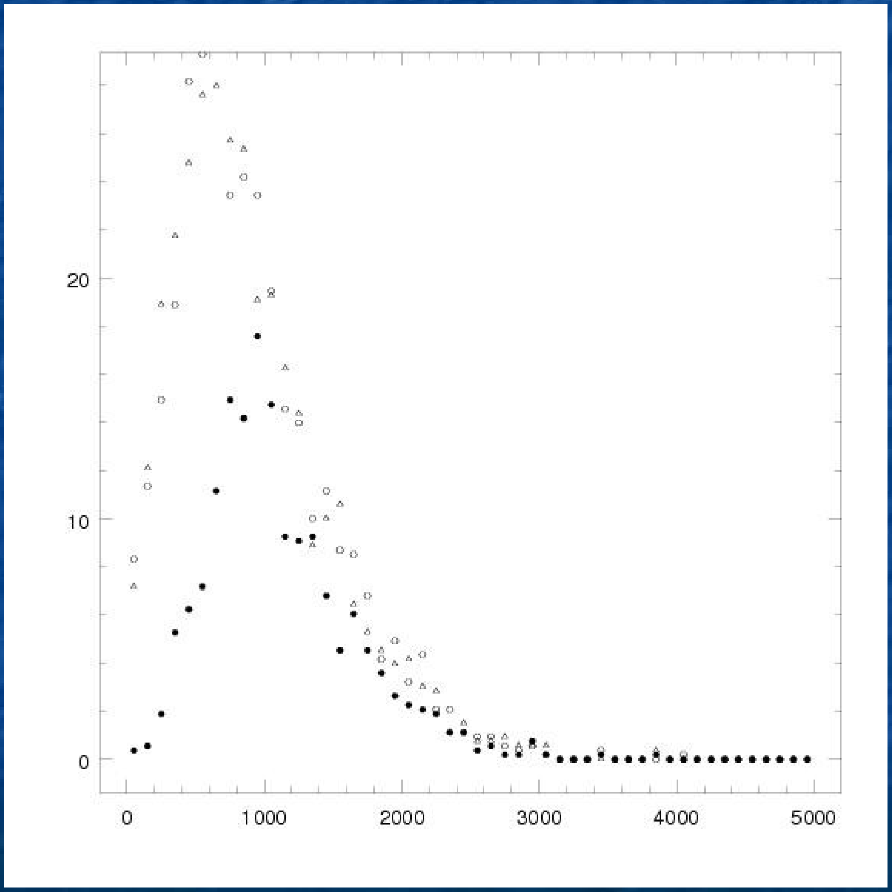
  Minimum black hole mass (non-rot)

Multiplicity decreases w Planck mass

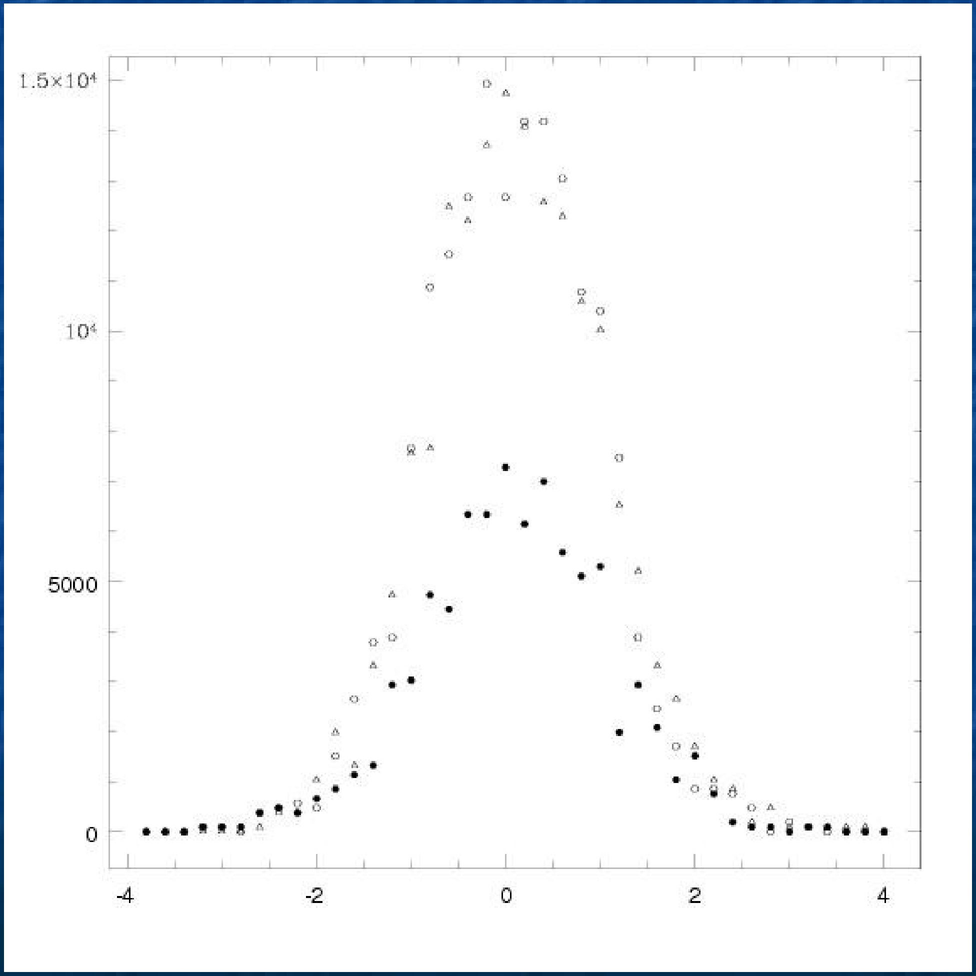
Energy & momentum increase

Electrons/positrons, (anti)muons, photons : Transverse momentum & energy spectrum





Pseudorapidity : e - μ - γ

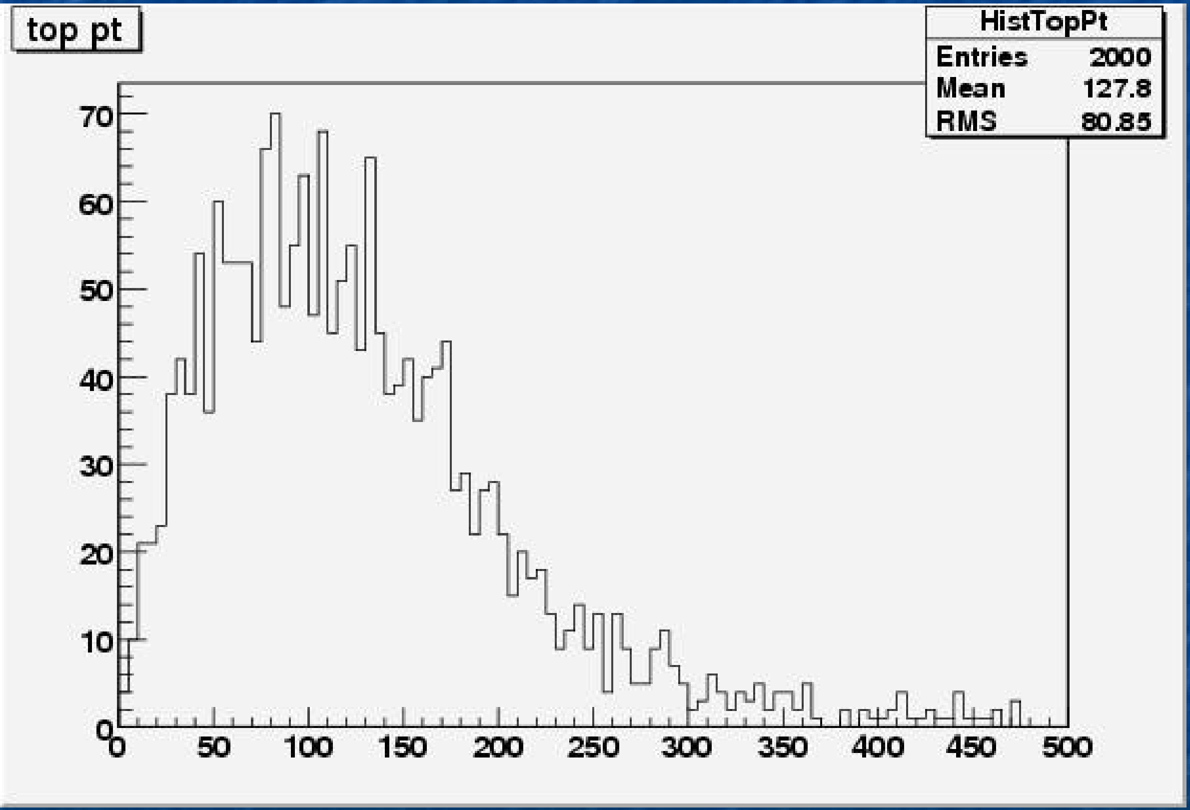


- Ratio of $0 < \dot{\eta} < 0.5$ & $0.5 < \dot{\eta} < 1$

distinguishes among beyond standard models

All models and species have values very different from QCD

Model comparisons



Further models :

Planck mass :

2, 5 TeV

ED = 5, 3

Minimum mass :

4, 7 TeV

Vs.

Standard Model

top quark transv.

momentum /GeV

Analysis at CMS

- Rate : ợ * L_t * event : (same for rot & non-rot)
- Total ET, missing ET
- Missing: G + v : model dependent
- Peak (most likely) or mean for lepton & jet distributions : ratio different from Standard Model
- Jet finder for CMS
- Hardest lepton transverse momentum : lepton easy to identify, cuts off for SM

  Combined cuts : ή , p_T distribution

Model settings for detector which have different signature

Angular acceptance cut for detector acceptance

- ή_lepton < 2.5   Jets, q, W, Z < 5
- t, b
- Implementation of generators in CMSSW
- Interface BlackMax II
- CMSSW : signal and SM background
- Fast simulation, Triggering
- Comparison w Charybdis : BlackMax has higher multiplicities and lower momenta
- missing ET : gravitons only in BlackMax

Further models to test at LHC :

- BHs in Dvali model for SM copies :

  BH -> SM particle rates different,

  difference in particle decay

  distribution of p_T, MET

  Even more likely for BHs w ADD & finding them

Thank you for your attention !