

Low Scale Gravity Black Holes at LHC

Enikő Regős

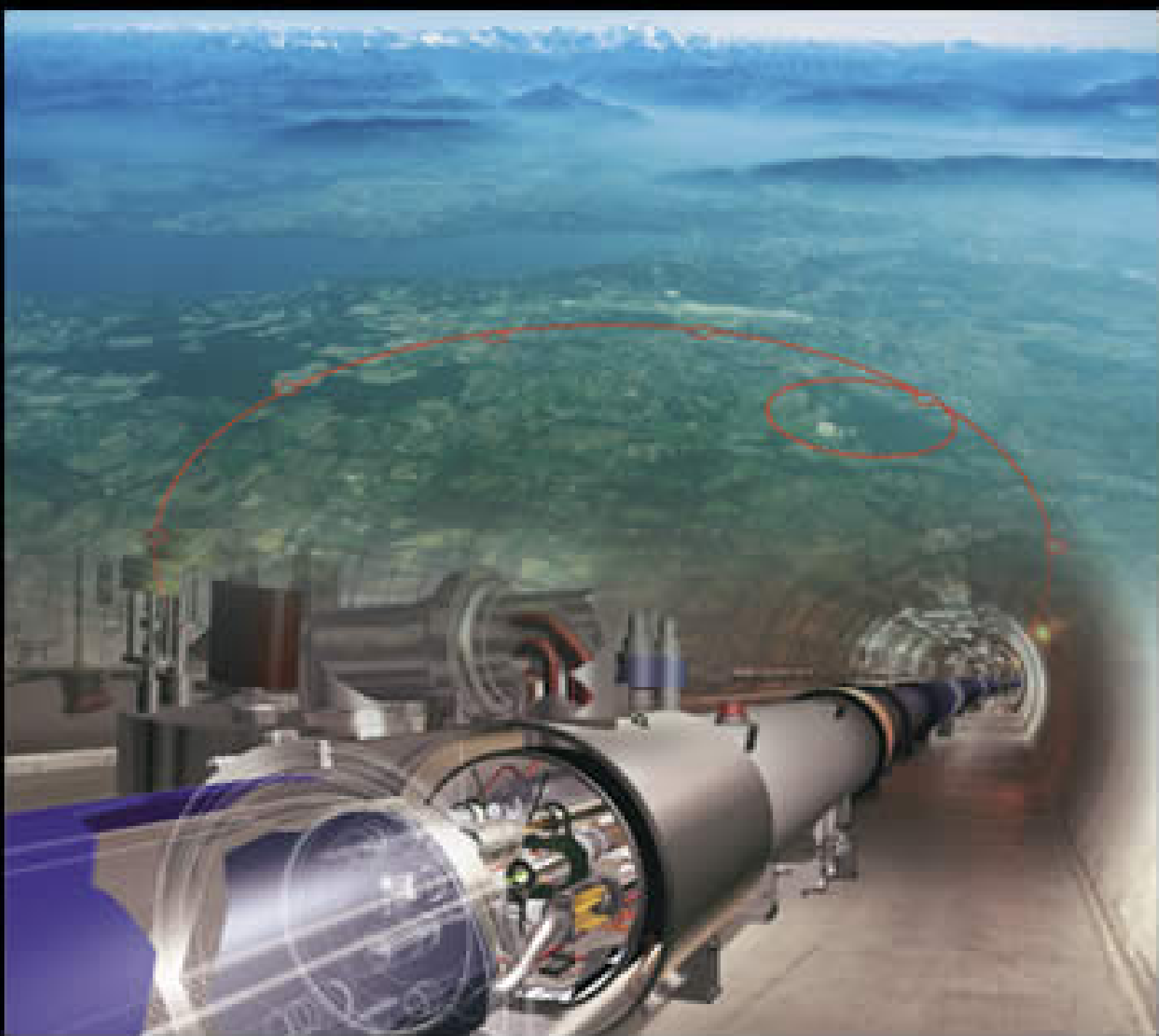
Search for Extra Dimensions

- LHC : Quantum Gravity & Extra Dims
- Stringy Quantum Black Holes
- Low-scale Gravity Black Holes at LHC
- Comparison of Black Hole Generators

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De Roeck Gamsizkan Trocsanyi





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

Hierarchy problem & ED

- Fundamental scales in nature :

Planck mass : 10^{19} 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

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

Stringy Black Holes : D branes

- D branes
- $D = 5$ type – IIB black hole :
- Q_1 D1 and Q_5 D5 branes intersections
- in ds^2 :
- $f = \prod [1 + (r_0 \text{ sh } \delta / r)^2] \quad (1, 5, p)$
- $1, 5$ – brane charges : electric, magnetic, KK charge
- $T = 1 / 2 \prod r_0 \prod \text{ch } \delta$
- $Q = N - N_- \quad (1, 5, R - L)$
- (anti) $1, 5$ – branes, right/left moving momentum #

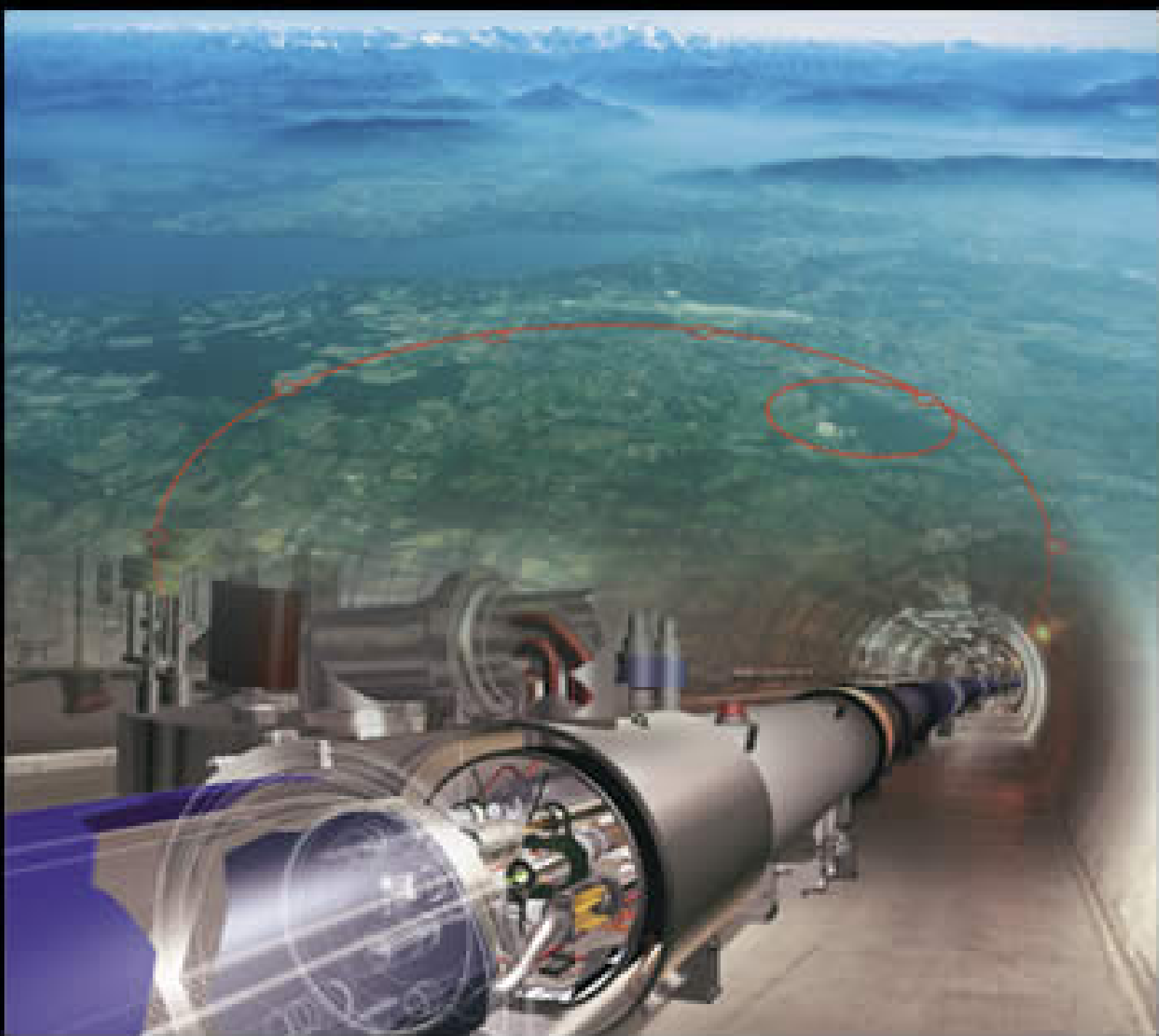
- $ds^2 = -g / \sqrt{f} dt^2 + \sqrt{f} (dr^2 / g + r^2 d\Omega)$
- δ -s : higher dimensions' compactification
- $f = \prod (1 + r_0^{sh^2} \delta / r) \quad (2, 5, 6, p)$

Further examples:

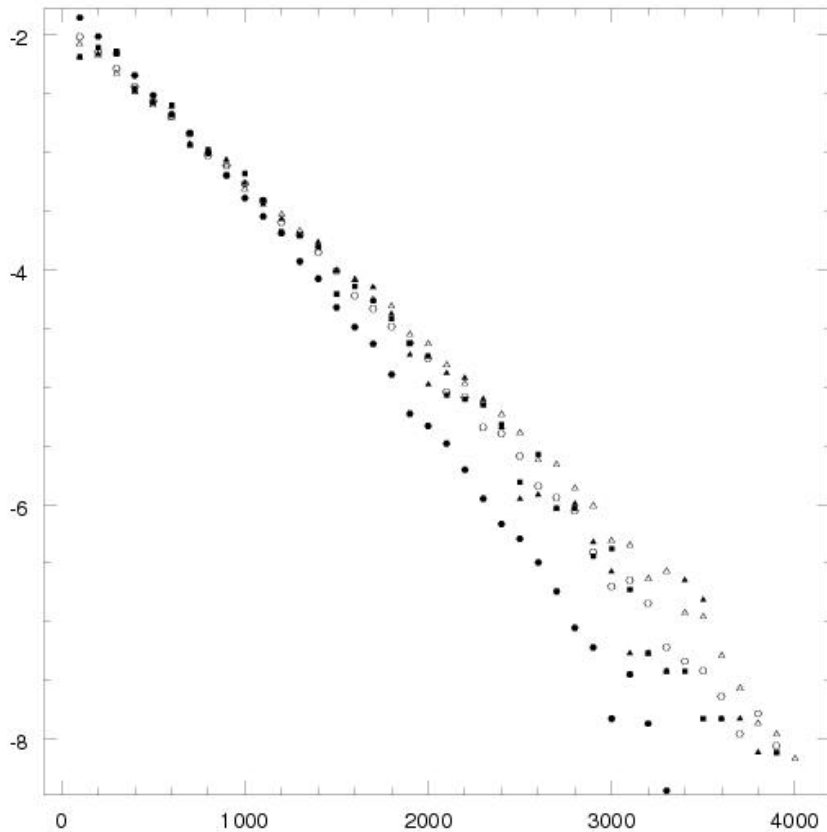
- $D = 5$ Type – IIB with electric charges
 - BPS black hole : Reissner – Nordstrom spacetime
- $D = 5$: Rotating, spin
 - equal charges : $D = 5$ Kerr - Newman
- $D = 4$ rotating :
- $D1, D5$ branes' intersection
- Type –II : heterotic string on T^6 torus
- Rotating

Black holes at LHC

- Event generator for ED BHs : BlackMax I-II
- Rotation, fermion splitting, brane tension
- Experimental signatures, particle decay
- CMSSW analysis
- Comparison with Charybdis I-II
- TRUENOIR, CATFISH : no rotation
- Energy loss



Black Hole Mass function

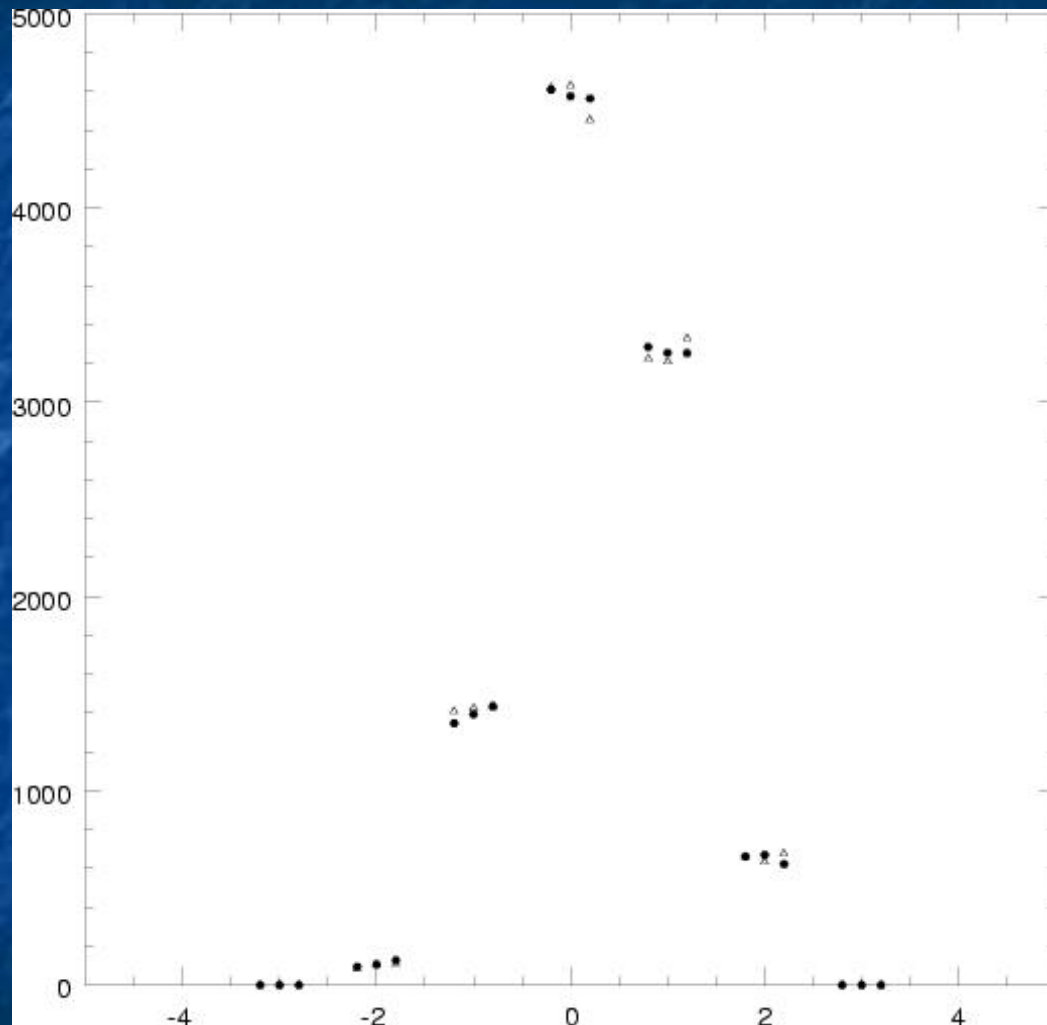


- $\text{Log } \phi \sim M - M_{\text{min}}$

for various models of
Planck mass, ED, M_{min} ,
rotation, brane tension

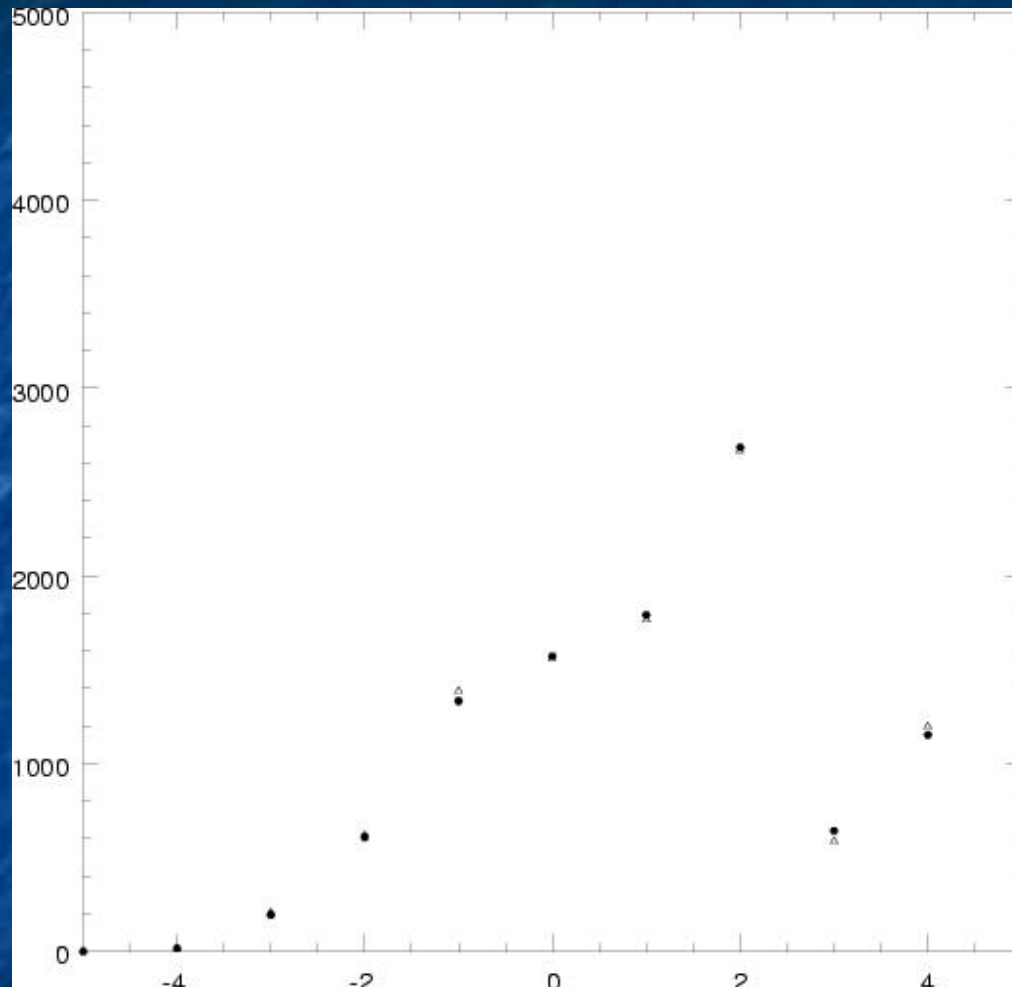
BlackMax & Charybdis agree
on initial mass distribution
as not affected by mass loss

Distribution of BH color (red – blue - green)



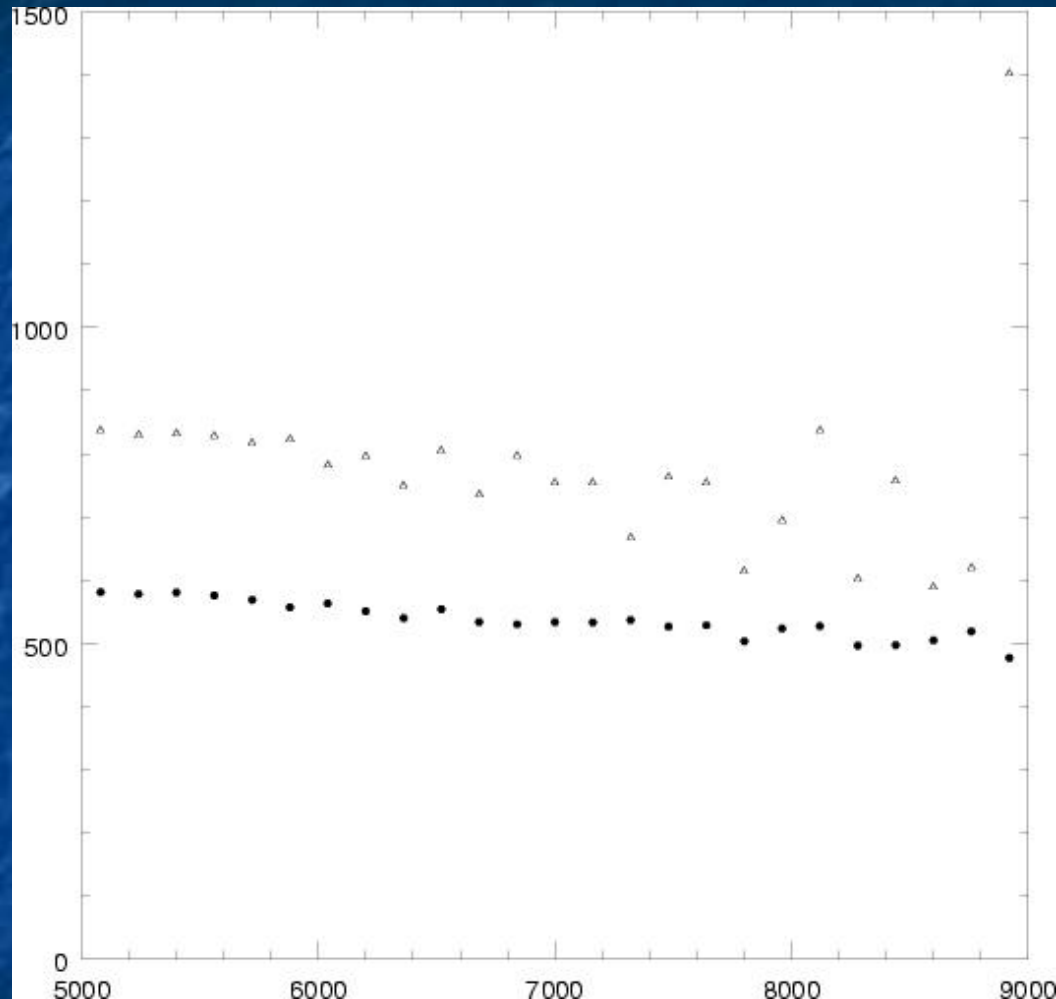
Rotating and non-rotating , 2 ED , 1-5 TeV

Distribution of BH charge / $3q$ /

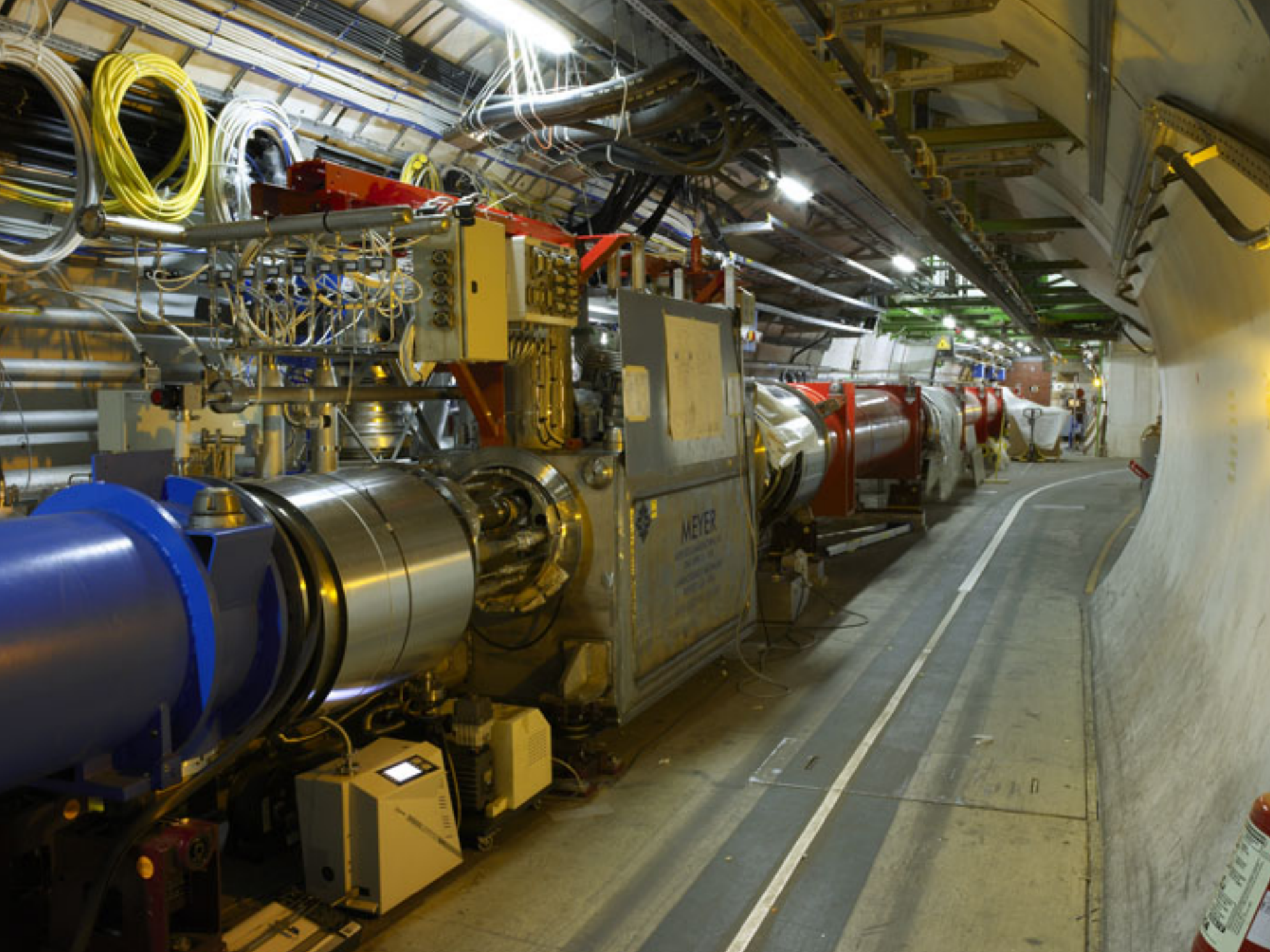


Rotating and non-rotating, 2 ED, 1-5 TeV

< Energy > of emitted particles vs. BH mass



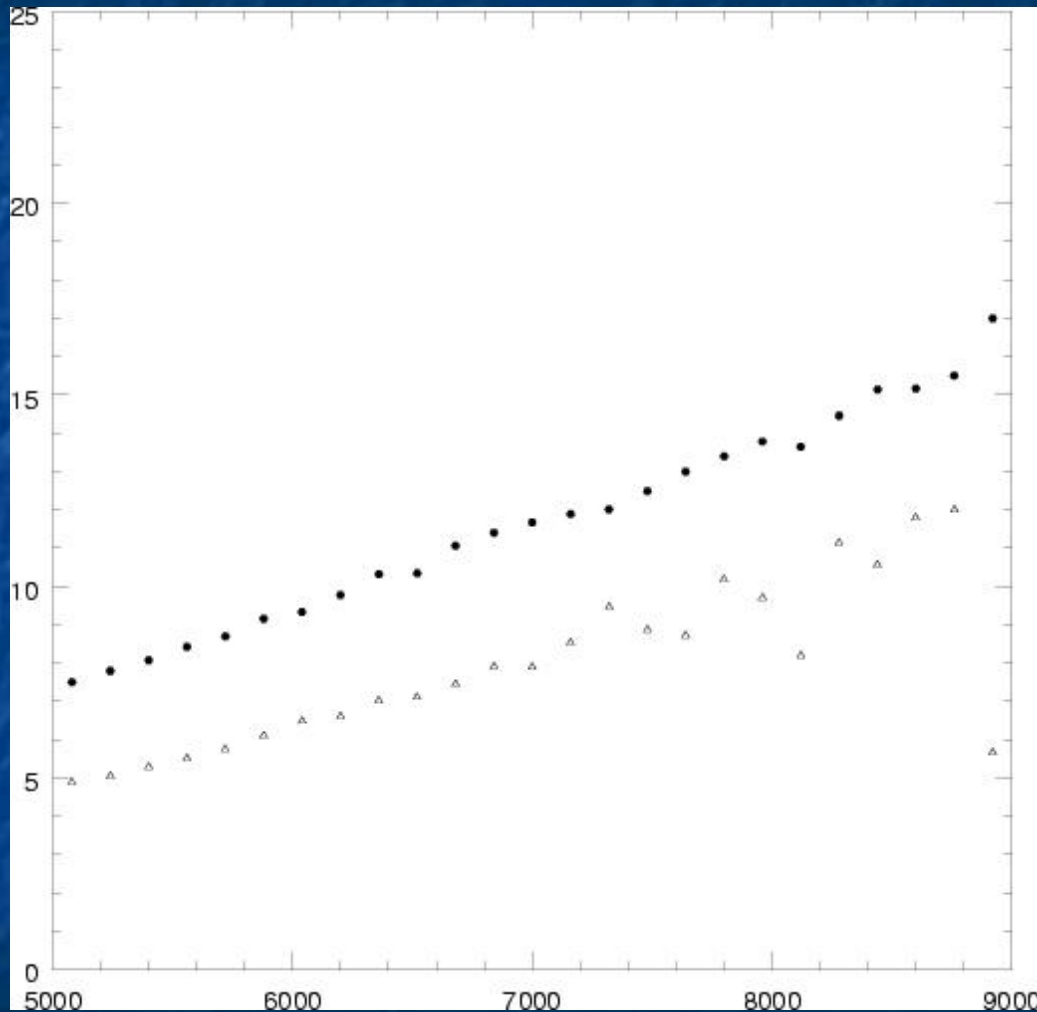
Rotating and non-rotating, 2 ED, 5-14 TeV



MEYER

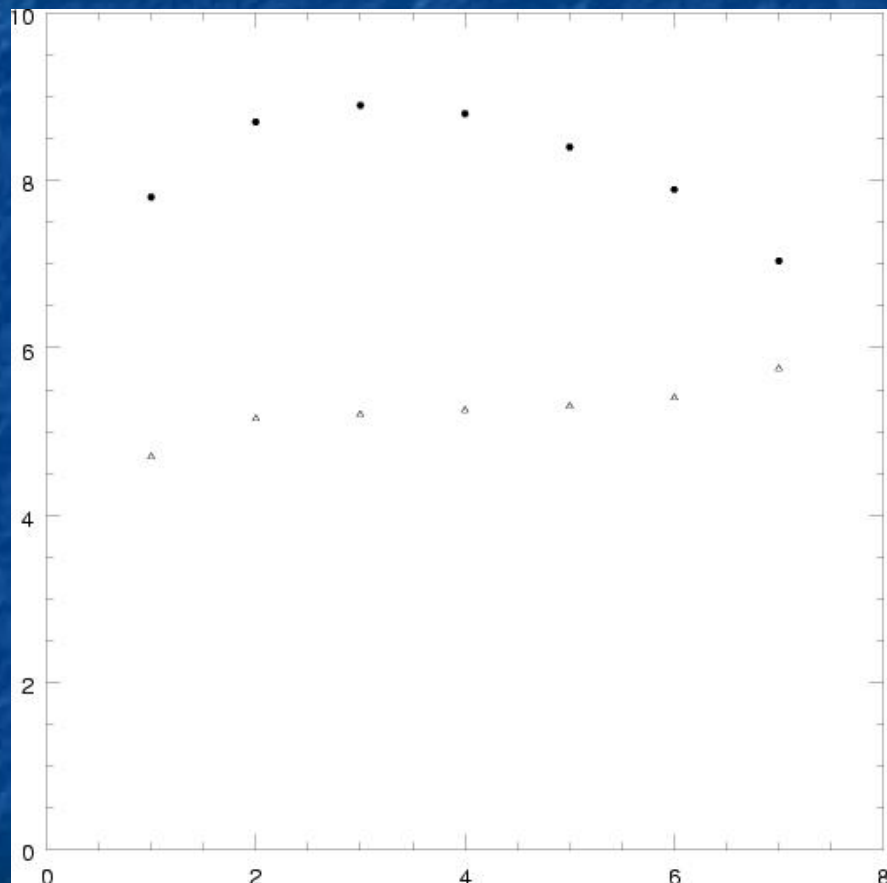


Number of emitted particles vs. BH mass during Hawking phase

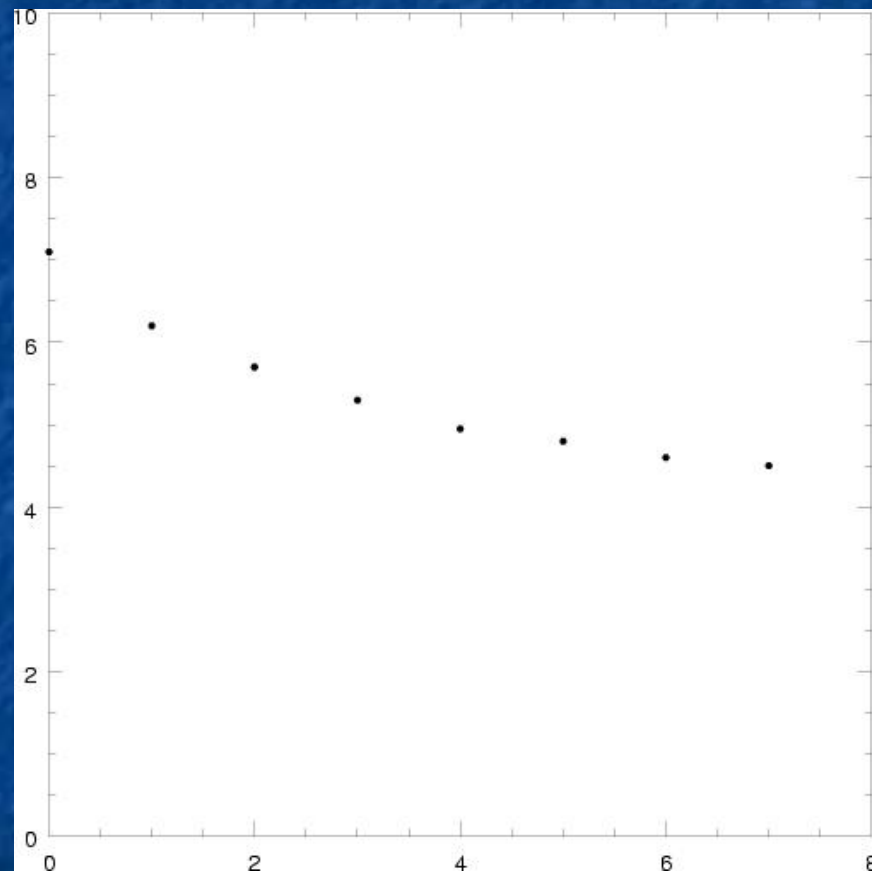


Rotating and non-rotating, 2 ED, 5-14 TeV

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

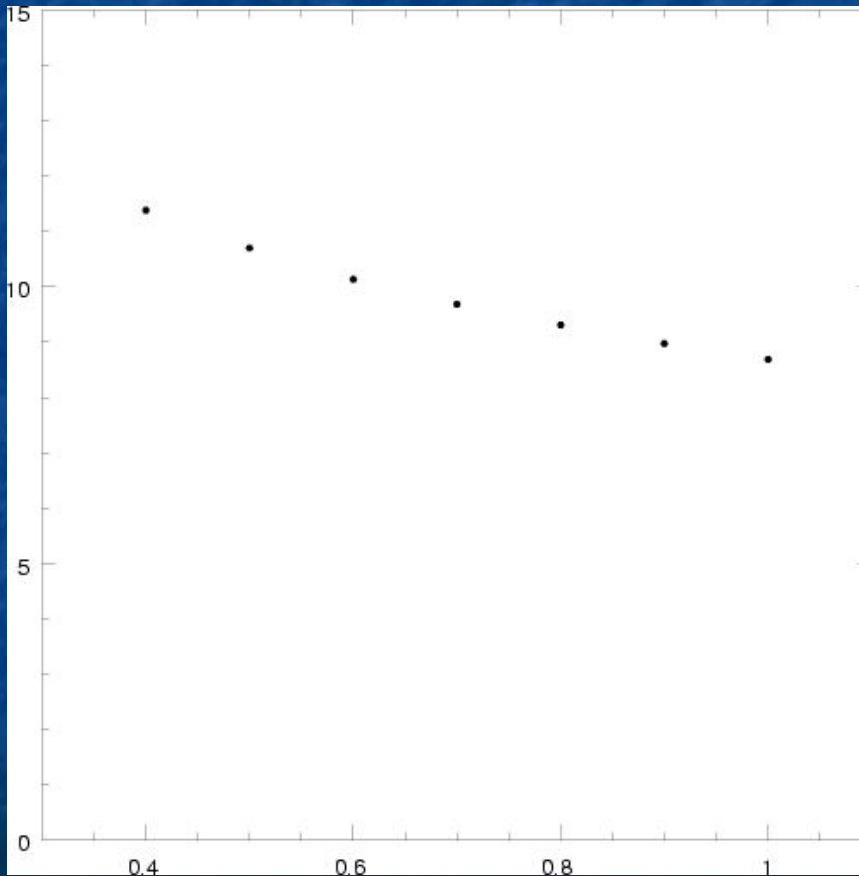


rotating and non-rotating



ED = 7

Number of emitted particles / BH vs. brane tension B



non-rotating

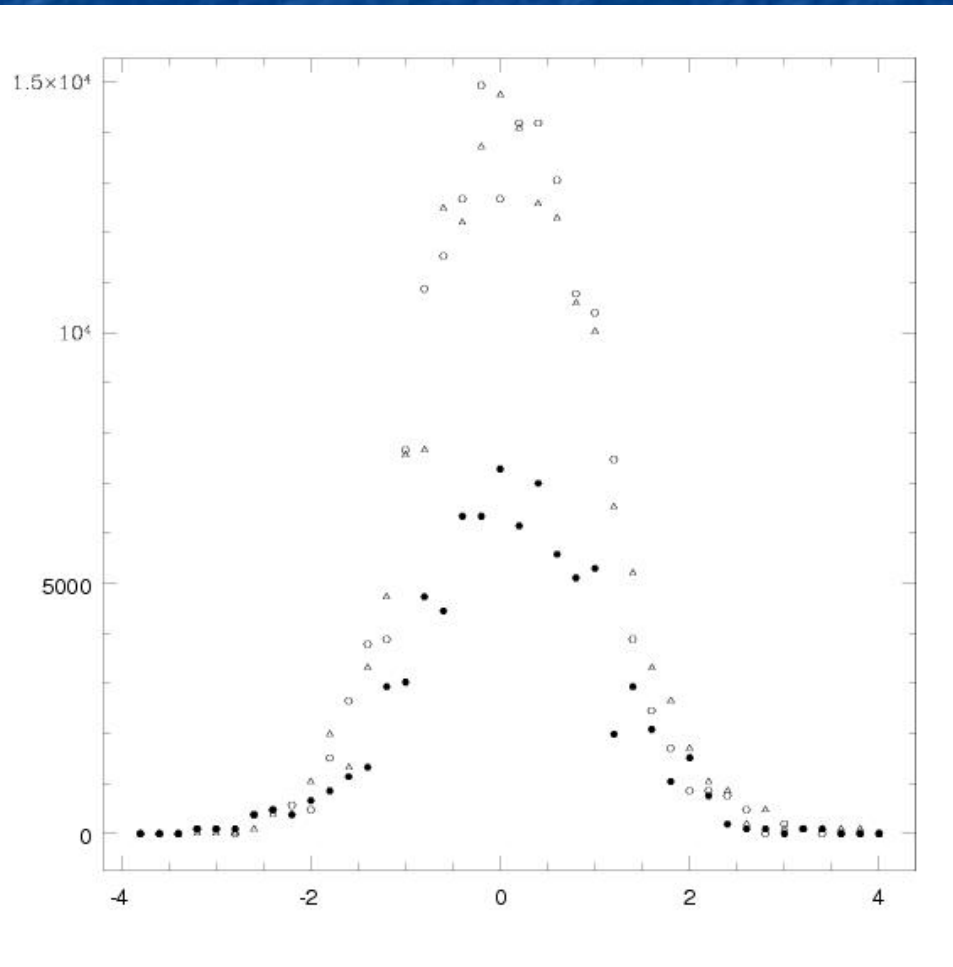
$ED = 2$

5-14 TeV

Hawking phase

$M_{Pl} = 1 \text{ TeV}$

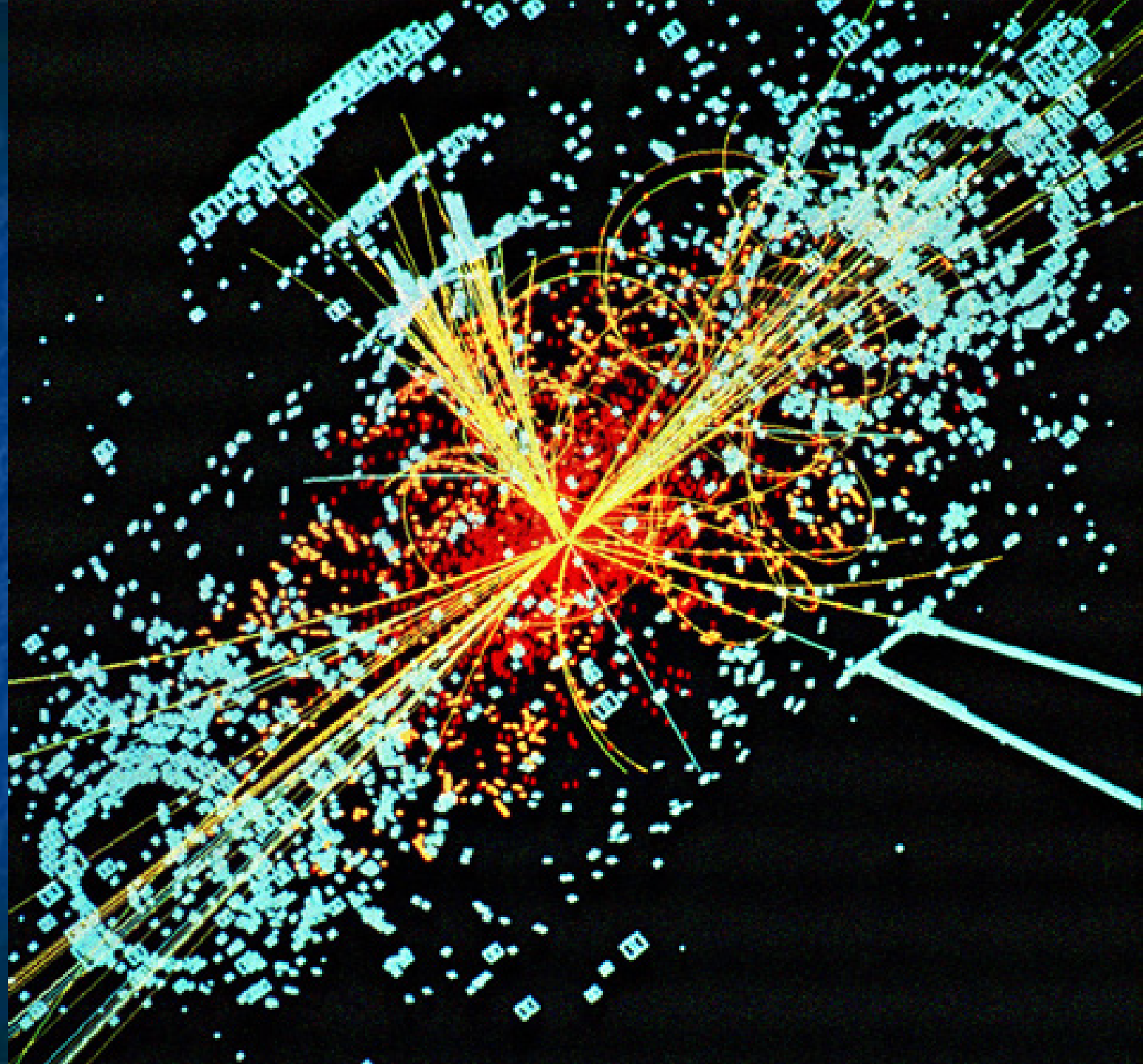
Pseudorapidity : $e - \mu - \gamma$



- Ratio of $0 < \eta < 0.5$
& $0.5 < \eta < 1$

distinguishes among
beyond standard
models

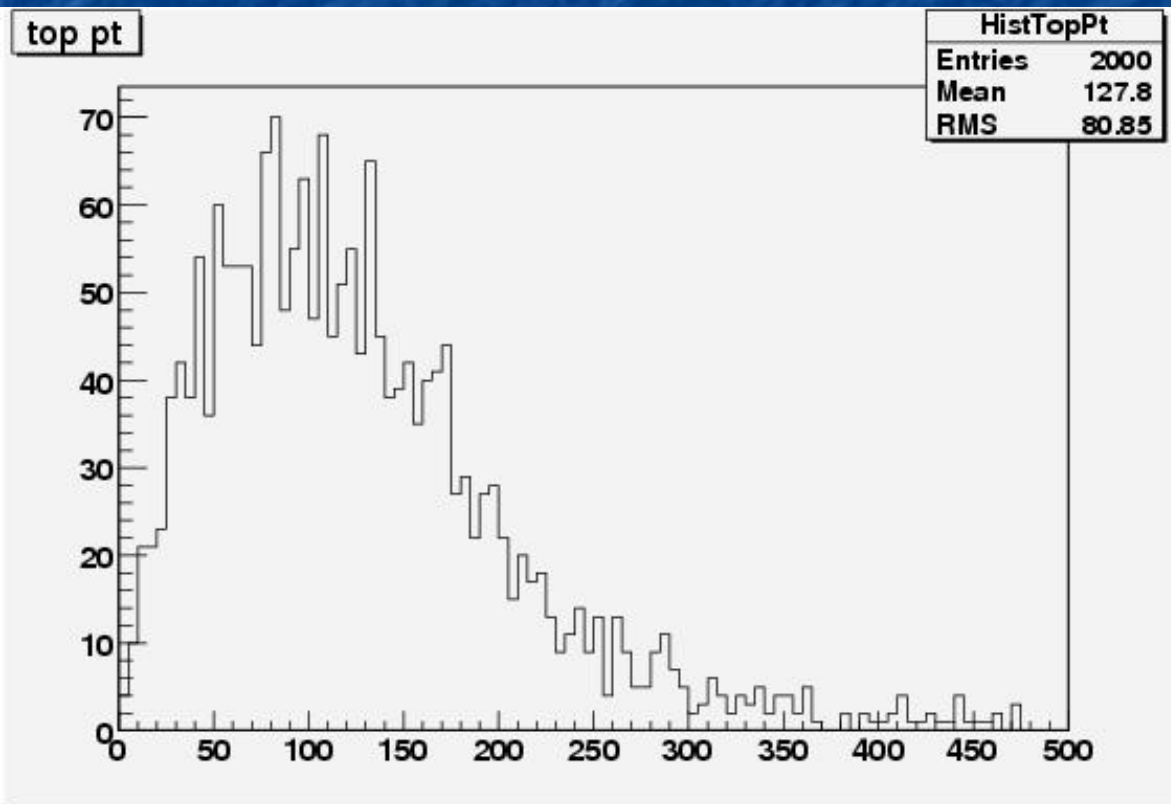
All models and species
have values very
different from QCD



Lepton transverse momentum : models

- **Planck mass** : 2, 2, 5 TeV
 - **Extra dimensions**: 5, 3, 3 (> 2)
 - **Center of mass energy**: 14 TeV
- Minimum black hole mass** : 4, 5, 7 TeV
- Multiplicity decreases with Planck mass**
(fermions dominate)
- Energy and momentum increase**
- Model comparisons**

Model comparisons



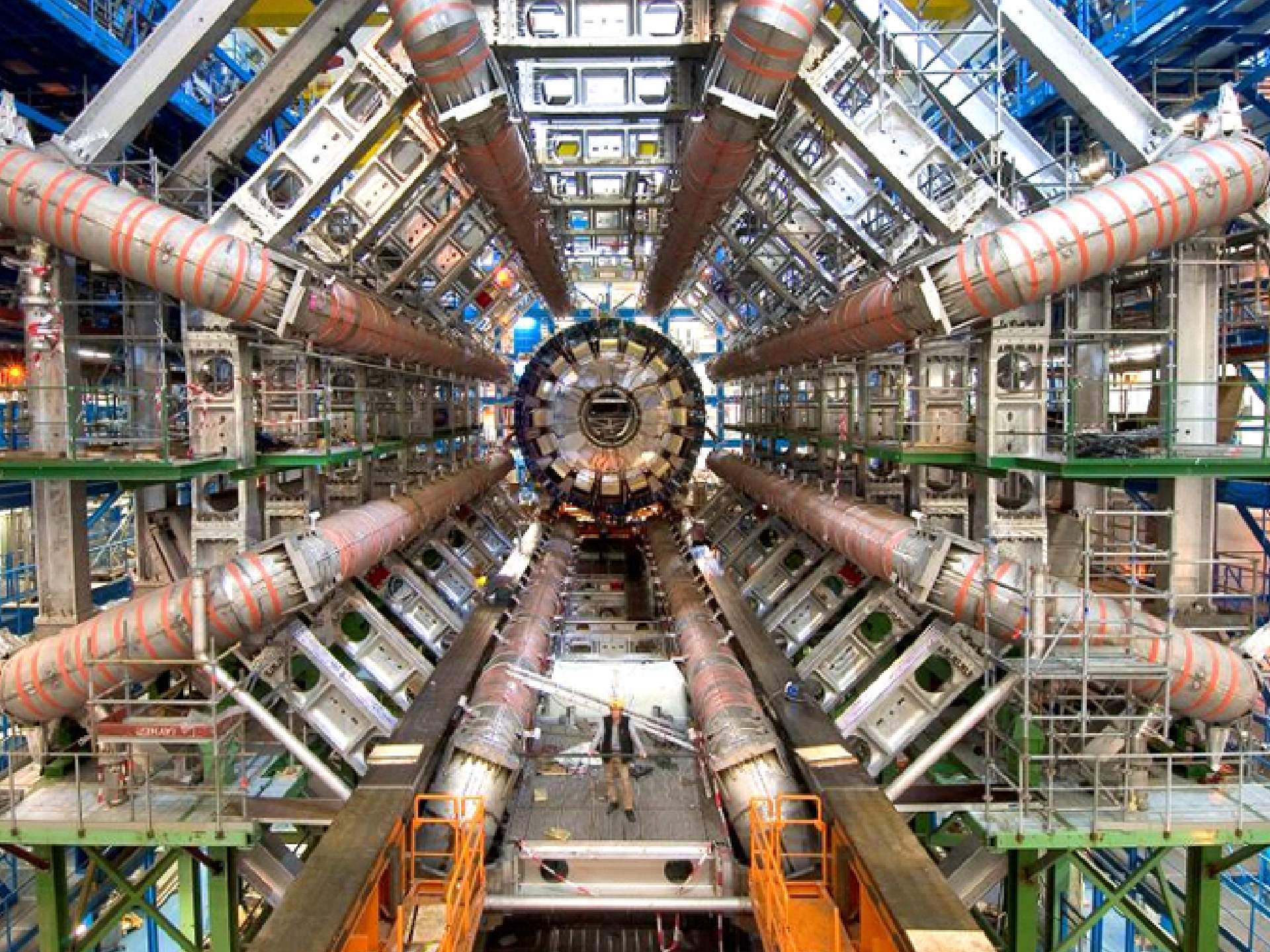
Models

Vs.

Standard Model
top quark transv.
momentum /GeV

Analysis at CMS

- Missing Transverse Energy :
graviton + neutrino : model dependent
 - Lepton transverse momentum :
easy to identify, cuts off for Standard Model
- Combined cuts : $\dot{\eta}$, p_T distribution

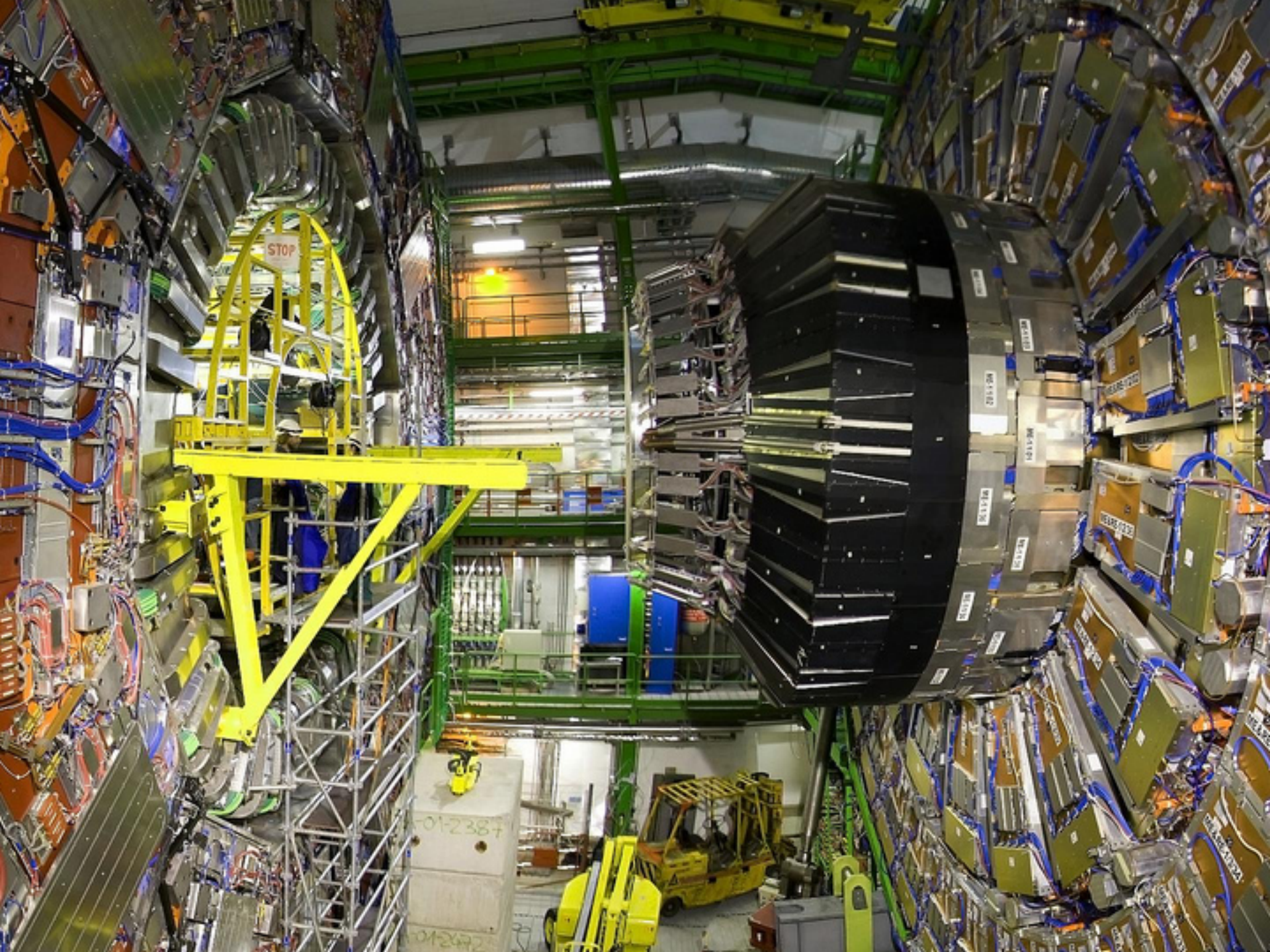


Model settings for detector which have different signature

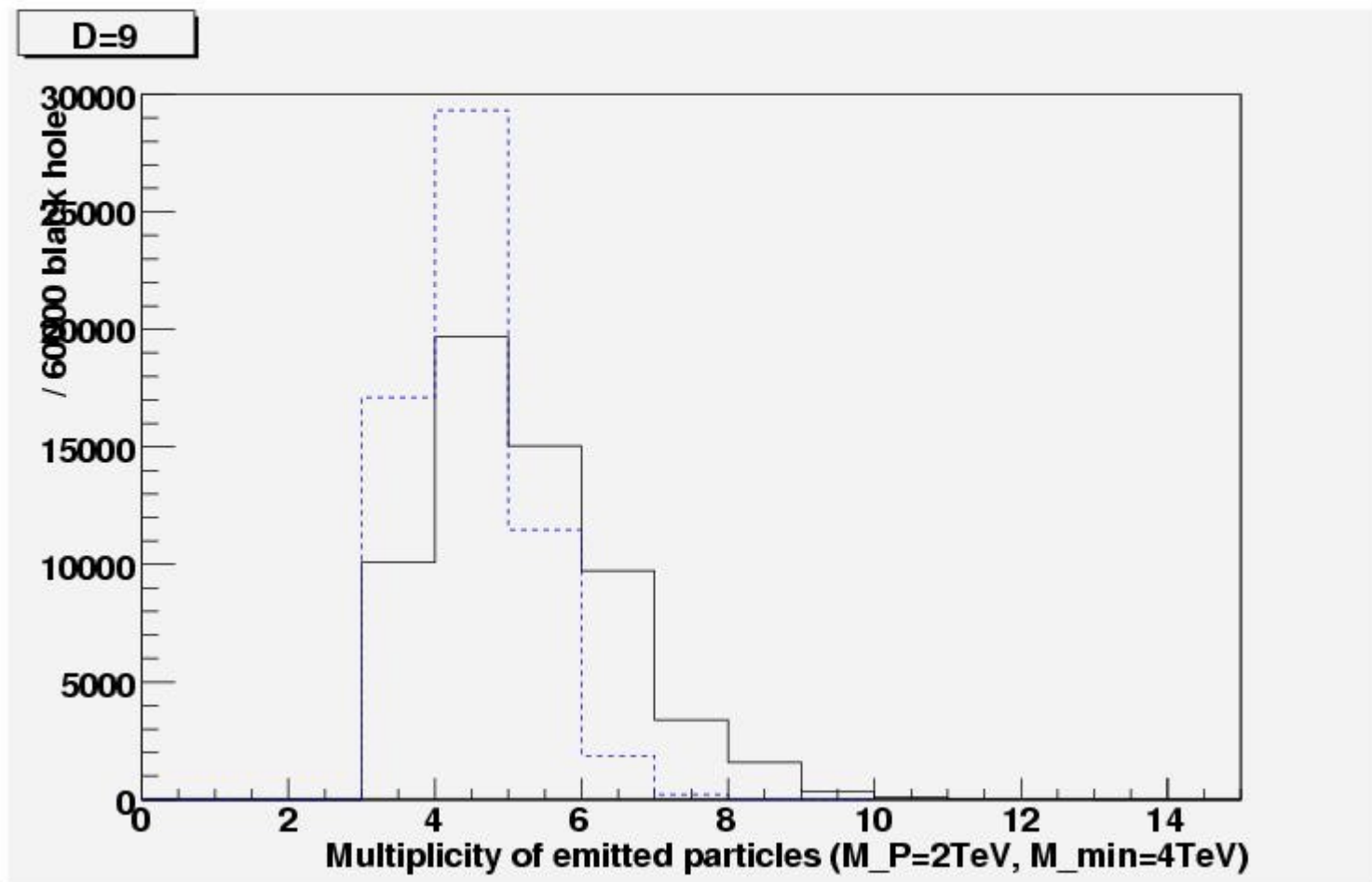
- Implementation of generators in CMSSW
- Interface BlackMax II
- CMSSW : signal and SM background
- Model with 4TeV minimum black hole mass experimentally most accessible

Comparison of BlackMax with Charybdis for non-rotating black holes

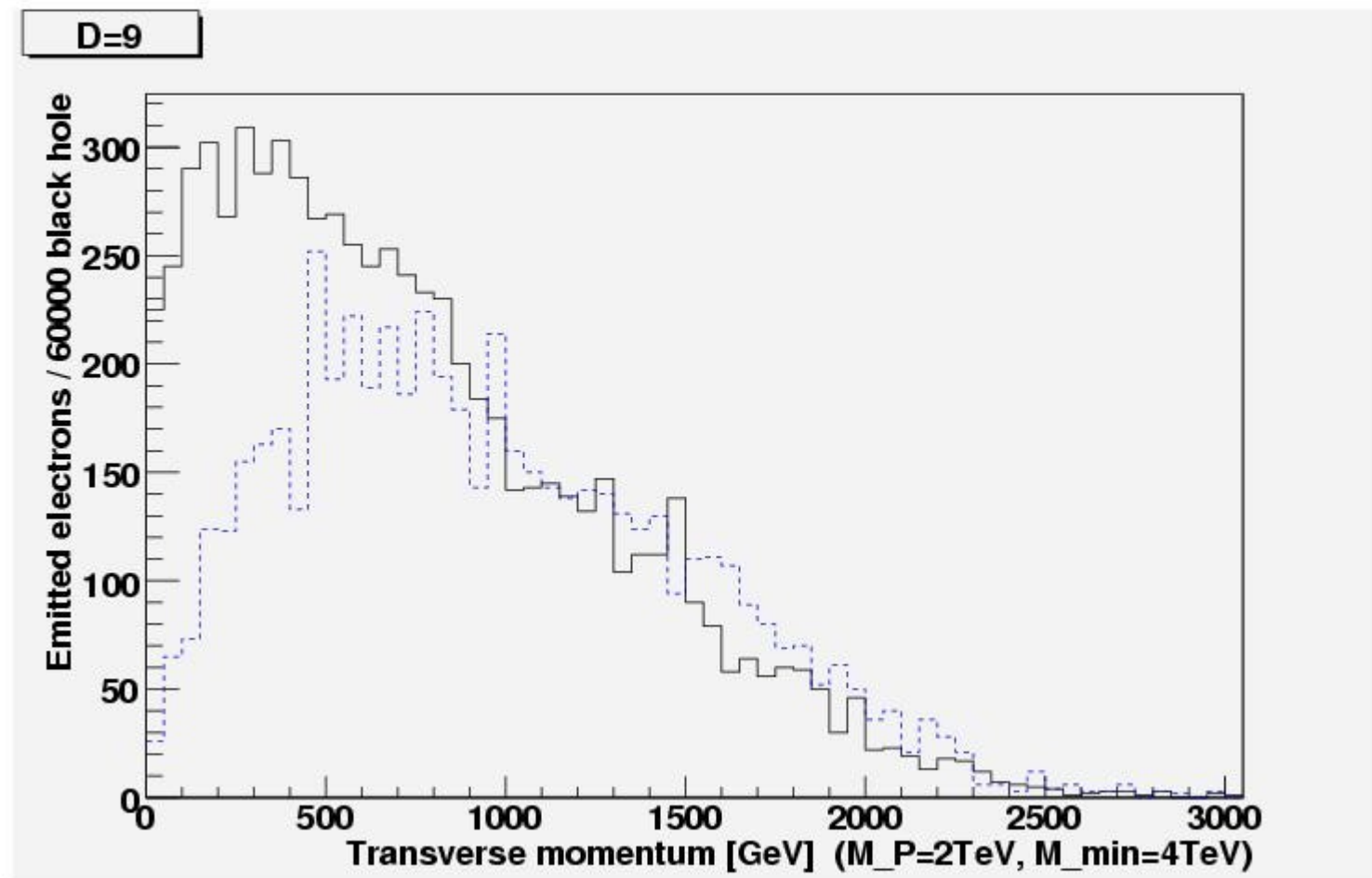
- BlackMax has higher multiplicity & lower momenta
 - Missing Transverse Energy :
gravitons only in BlackMax (black curves)
BlackMax-II : gravitons in final burst too
Higher MET
- Apart from cross sections good agreement
Yoshino – Rychkov suppression decreases σ



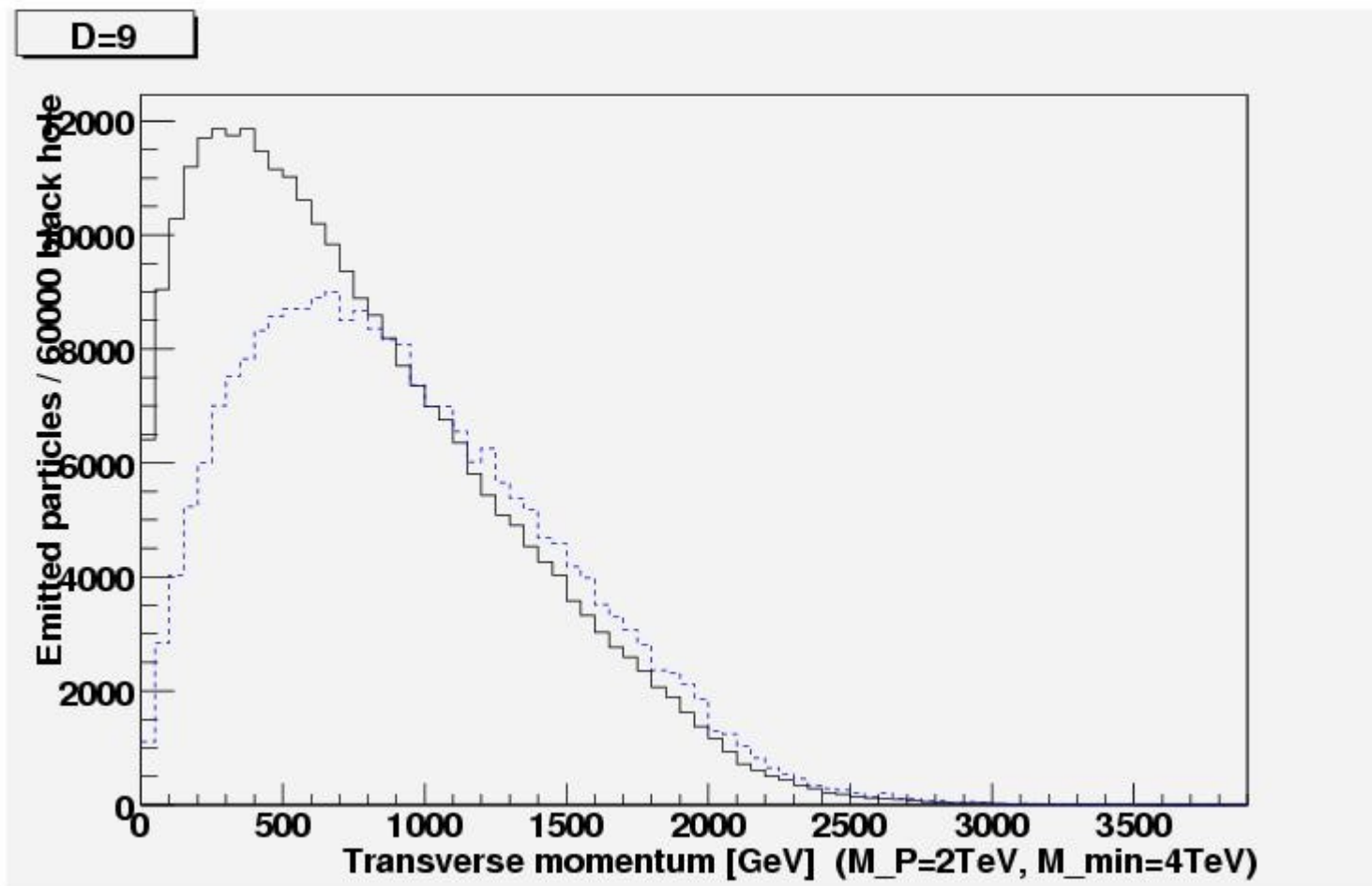
Multiplicity in BlackMax & Charybdis



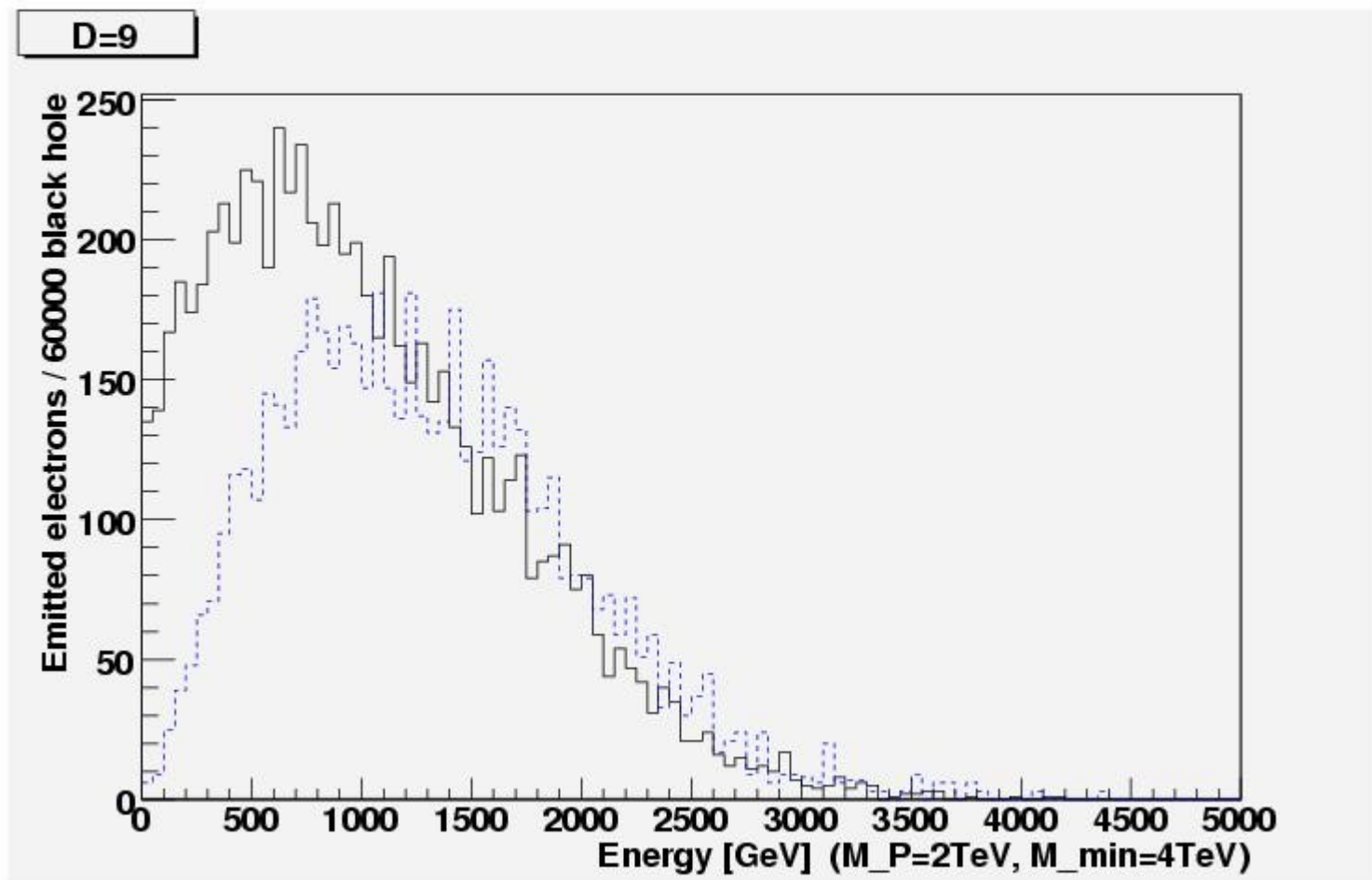
Transverse momentum of emitted electrons



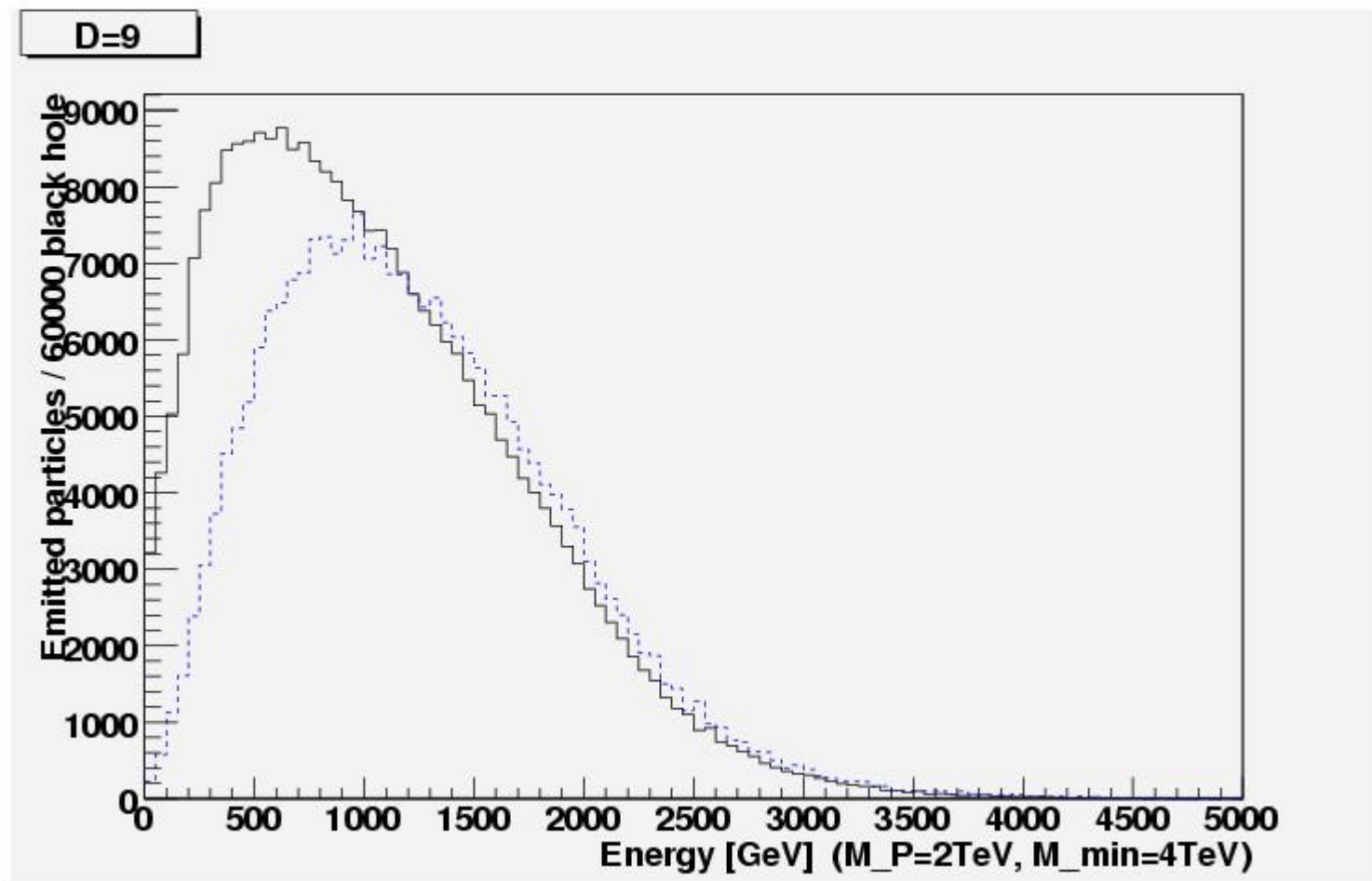
Transverse momentum of all particles



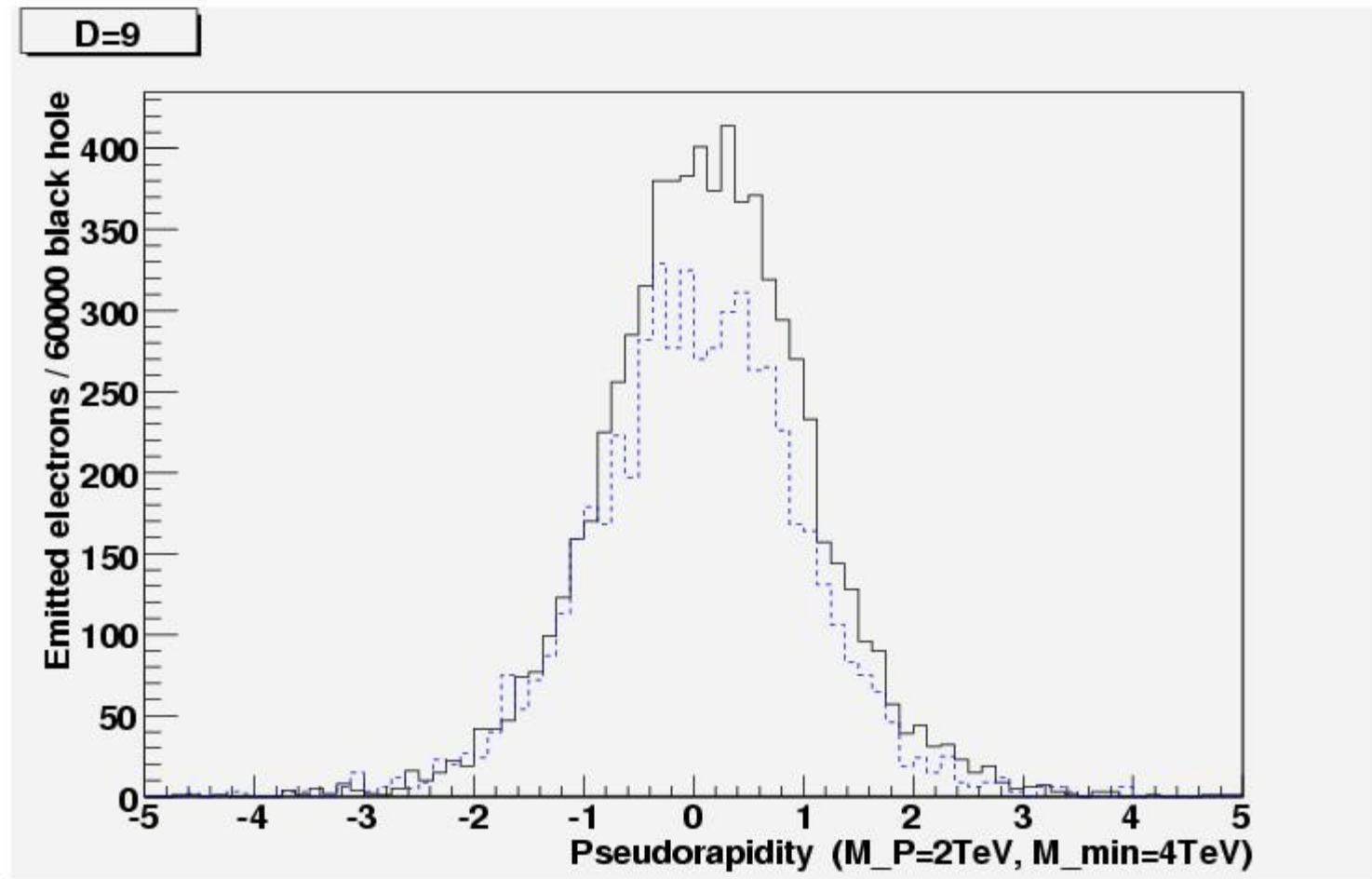
Spectrum of emitted electrons



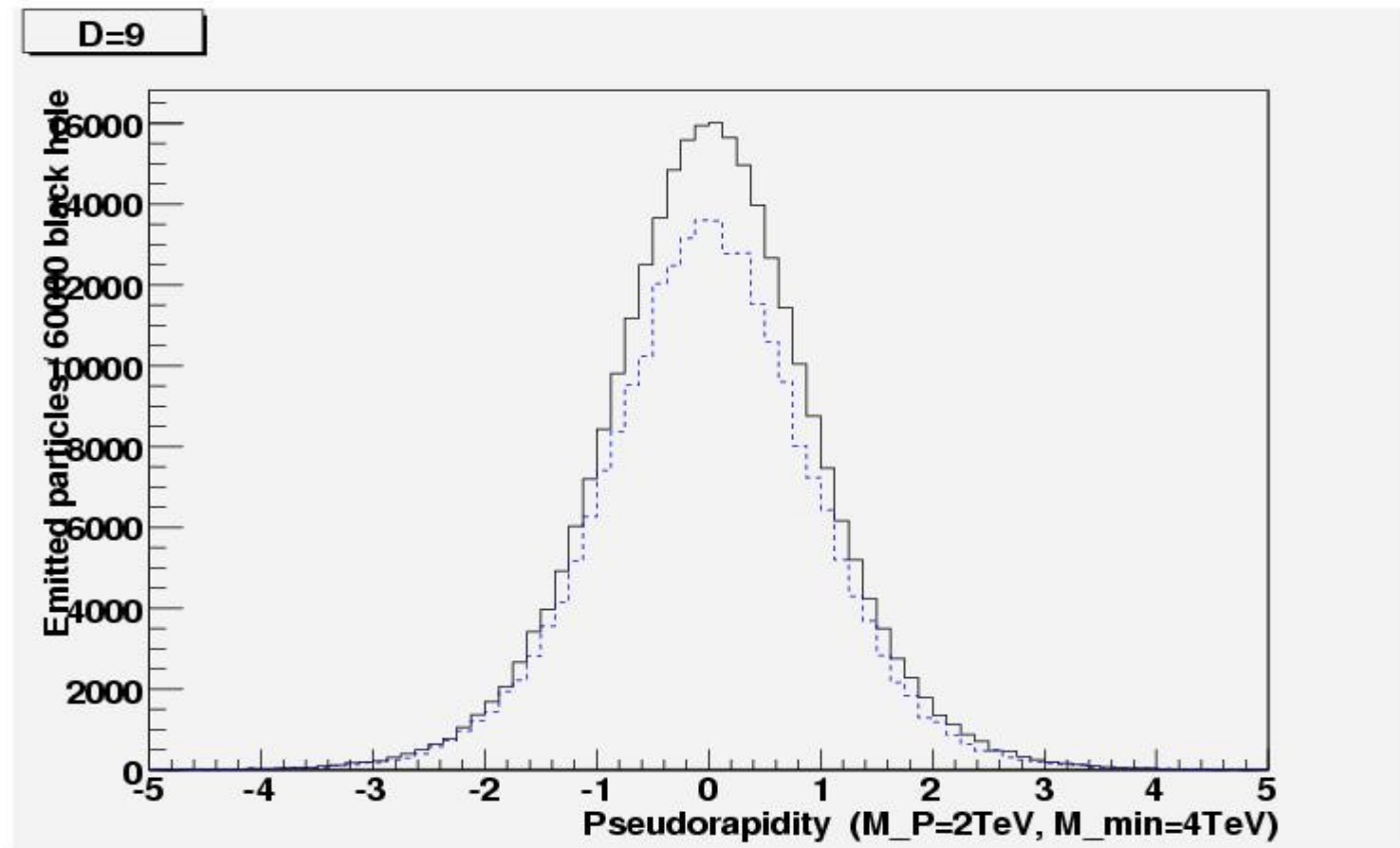
Spectrum of emitted particles



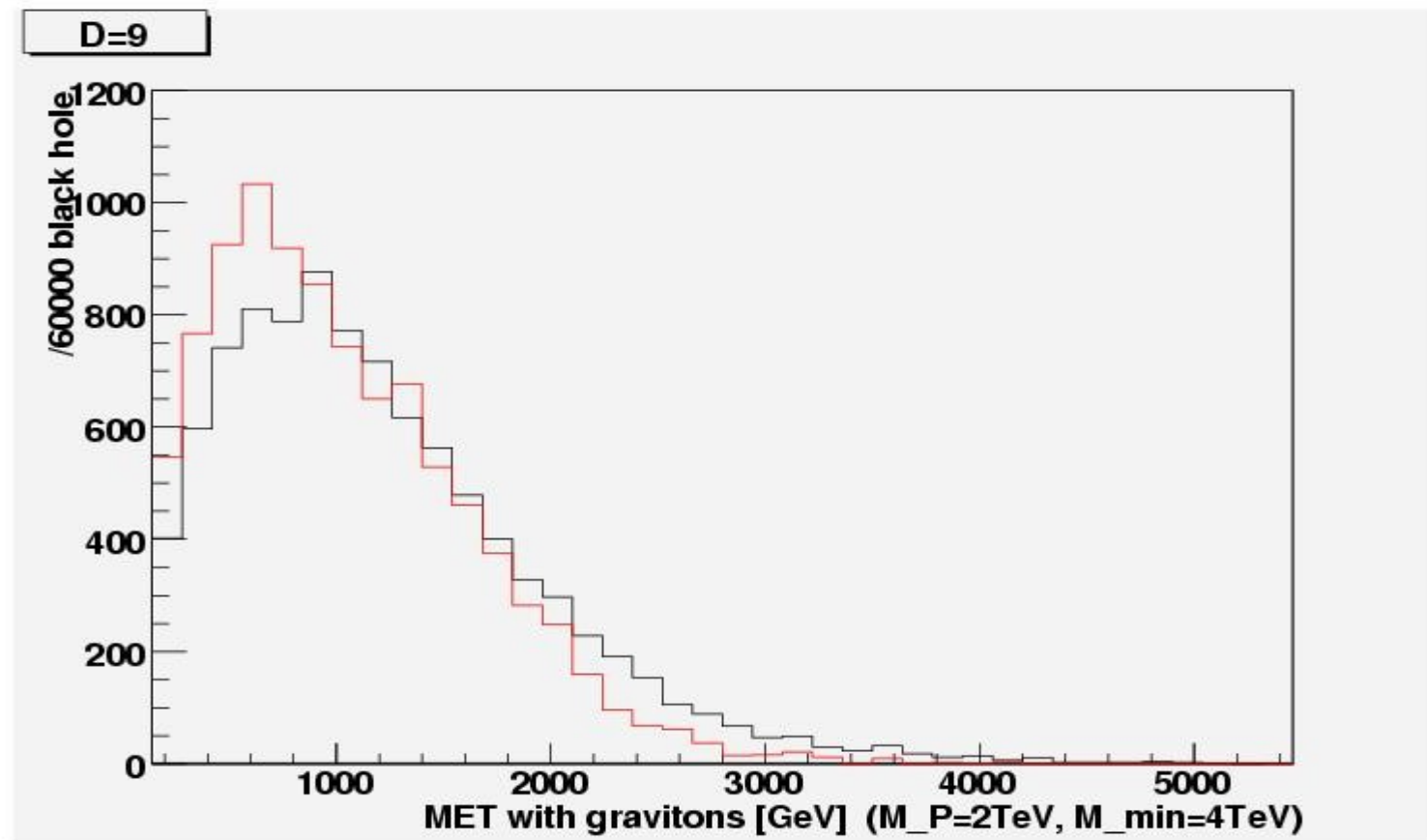
Pseudorapidity of electrons



Pseudorapidity of emitted particles



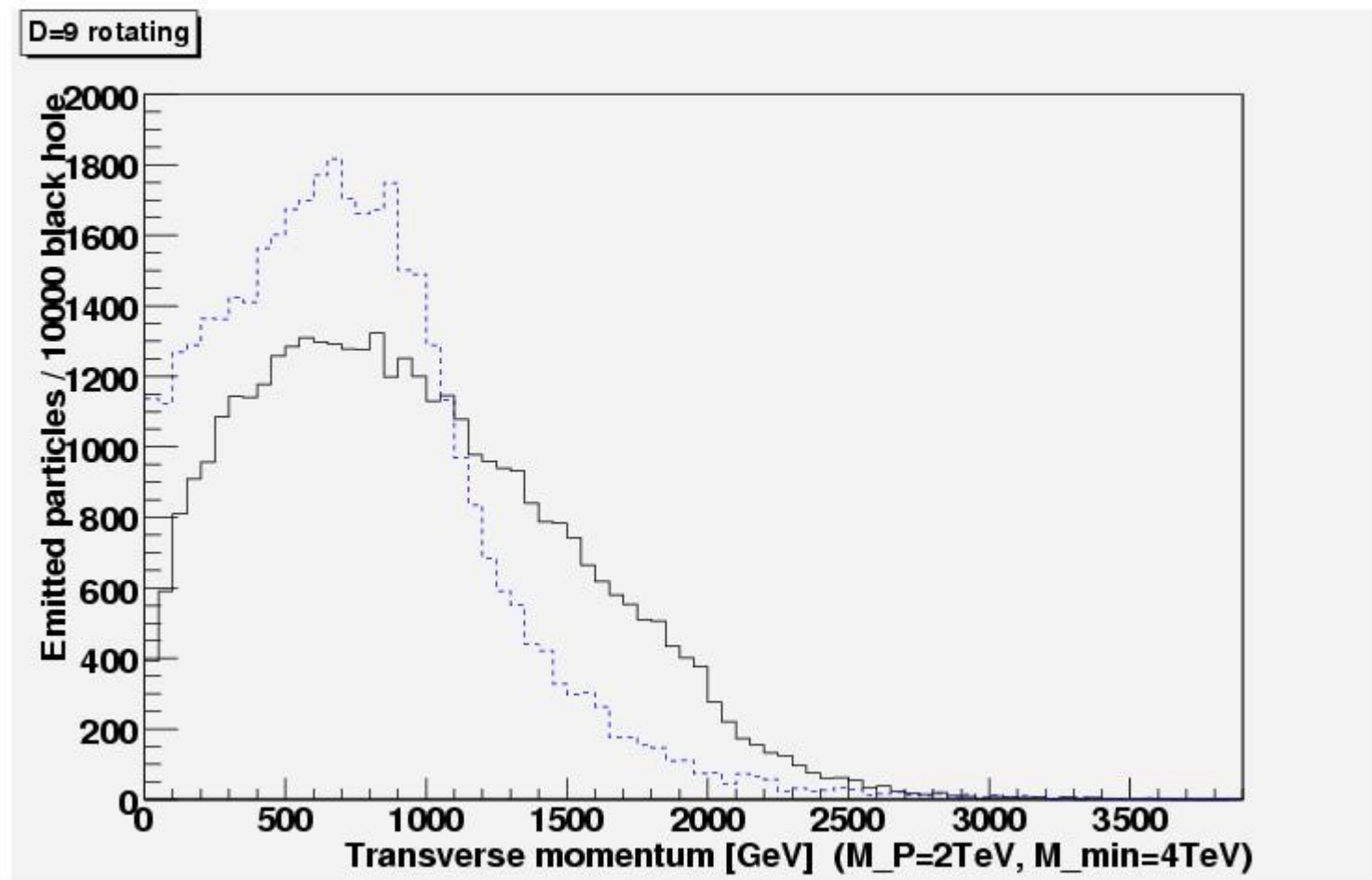
Missing Transverse Energy with Gravitons



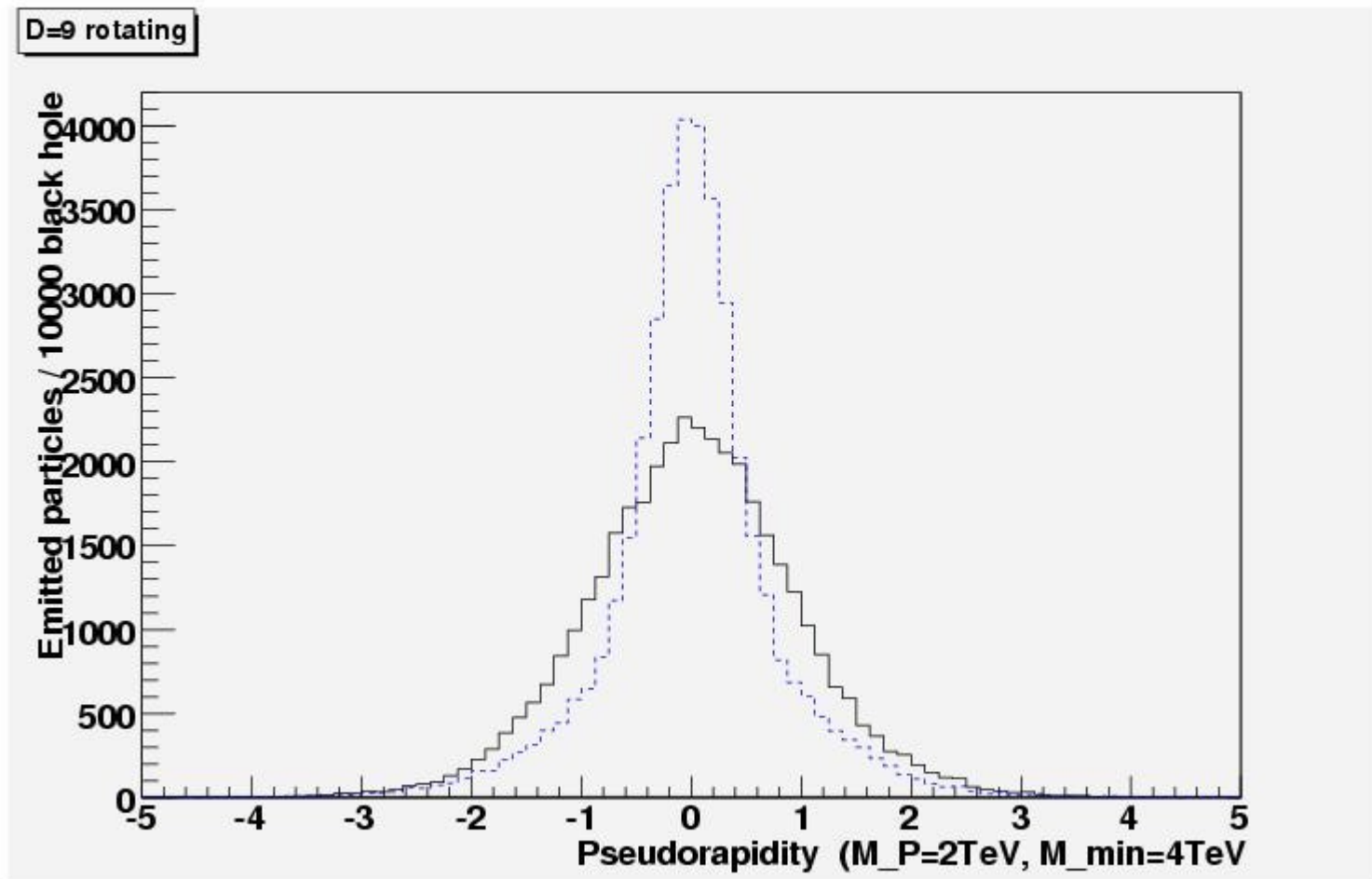
Rotating Black Holes : Compare BlackMax II with Charybdis II

- BHs carry spin from impact parameter
 - Spin : fewer, more energetic particles
 - Enhanced vector emission: more gluons, photons, W, Z
 - Particle spectra, angular distributions, multiplicities strongly affected by BH spin
- In rotating $D > 5$ graviton emission unknown

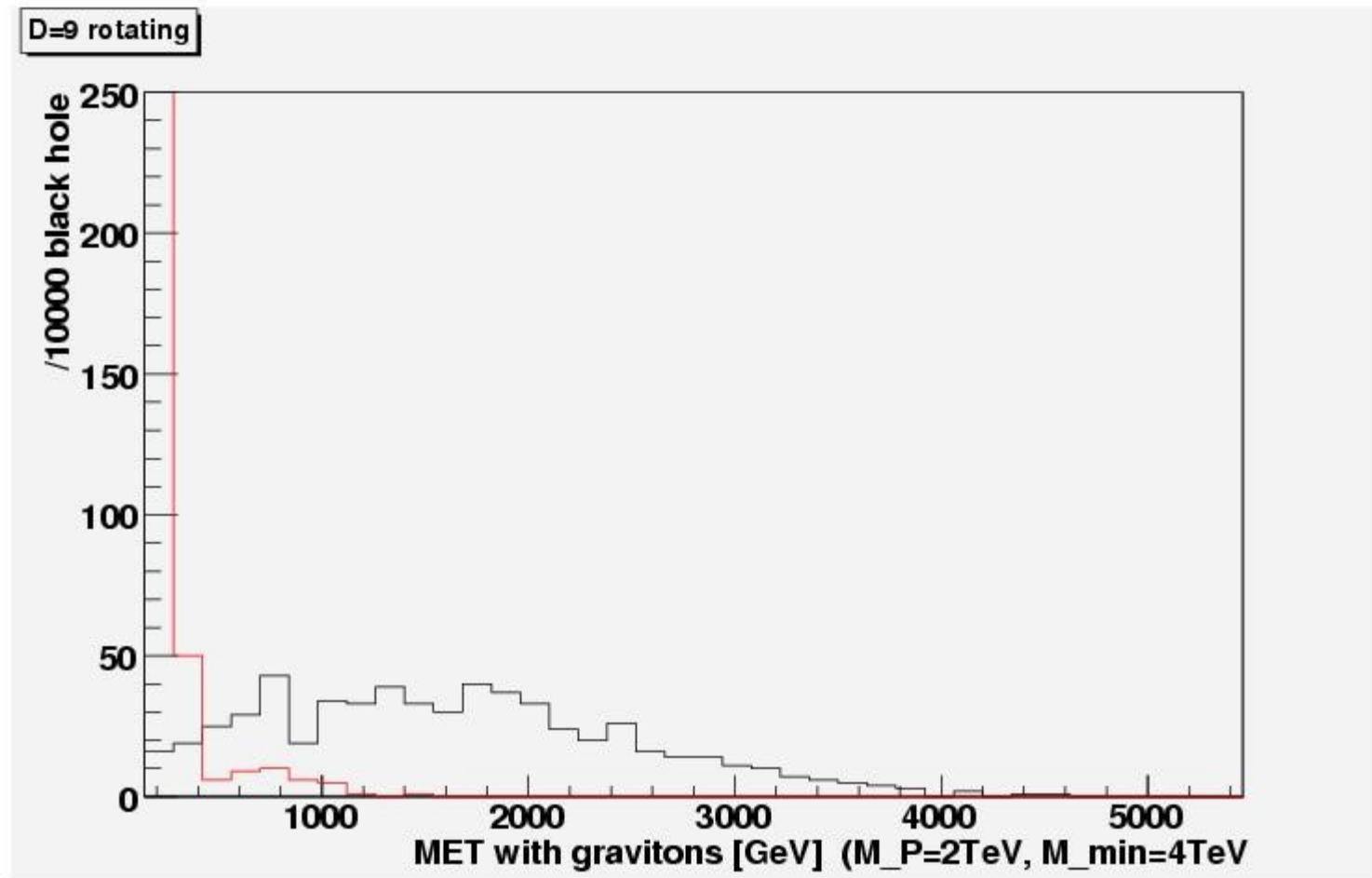
Transverse momentum of all particles for rotation



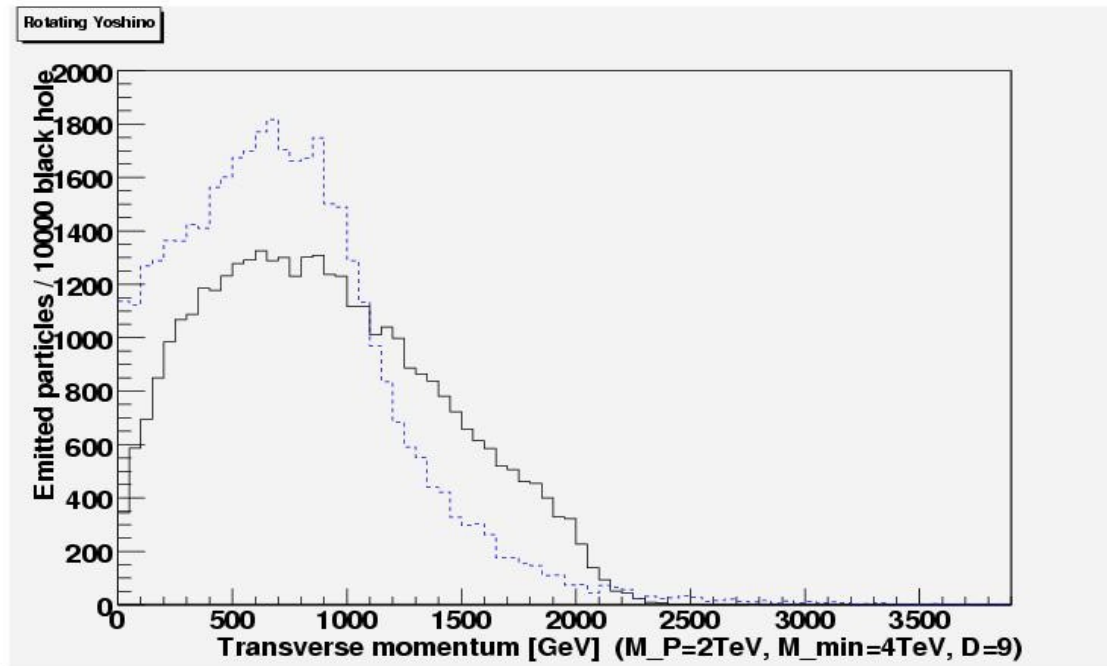
Pseudorapidity of all particles for rotation



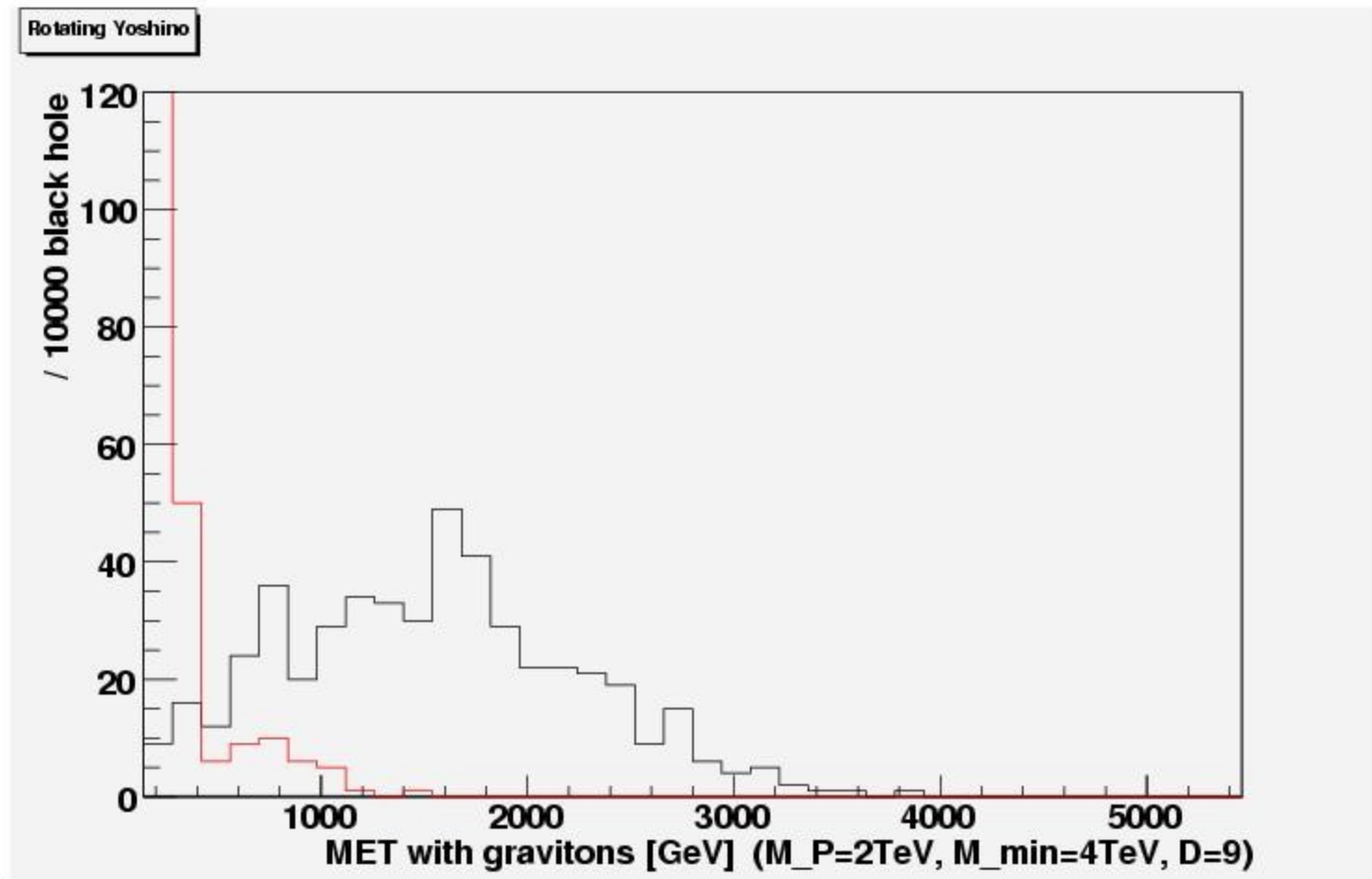
Missing Transverse Energy with rotation



Transverse momentum of all particles : rotating black hole with Yoshino - Rychkov



MET with rotation, Yoshino - Rychkov



Further models to test at LHC :

BHs in Dvali model for SM copies :

BH \rightarrow SM particle rates different,
difference in particle decay

non-integer extra dimension

MET is larger

Explanation for Dark Matter

Even more likely for BHs w ADD & finding them

Thank you for your attention !