Search for microscopic black holes with CMS

Debrecen, April 1, 2008

Starter lecture

Should be understood by everybody, so will be trivial

Beware: I am not an expert, corrections are welcome

Enikő Regös, Zoltán Trócsányi

When you measure what you are speaking about and express it in numbers, you know something about it, but when you cannot express it in numbers your knowledge about is of a meagre and unsatisfactory kind.

Lord Kelvin

Folk lore

(not supported by observations)

- Fundamental interactions become the same at the Planck scale M_{Pl}, or fundamental gravity scale M_*
- M_{Pl} is uncomfortably high (10^{18} GeV), requires unnatural fine-tuning of parameters and…
  - …testing unification at M_{Pl} experimentally is impossible
- Assuming more than 4 space-time dimensions brings M_* to the TeV region, close to the electroweak scale

TeV-scale quantum gravity

- SM lives in the 4-dimensional brane, gravity can propagate in the full space (bulk)
- Gravity is weak because the ”strength of gravity is diluted in the large volume of the bulk”
- Predicts the production of microscopic black holes (MBH) at the LHC (”hoop conjecture”):
  - two particles collide with $E_{cm} > M_*$
  - If the impact parameter of the two colliding particles, $b < 2r_h$, the radius of the horizon corresponding to E_{cm} ($r_h \sim E_{cm}/M_*^2$), the probability of MBH formation is high
  - LHC can produce MBH if $M_* \cong 1\text{TeV}$

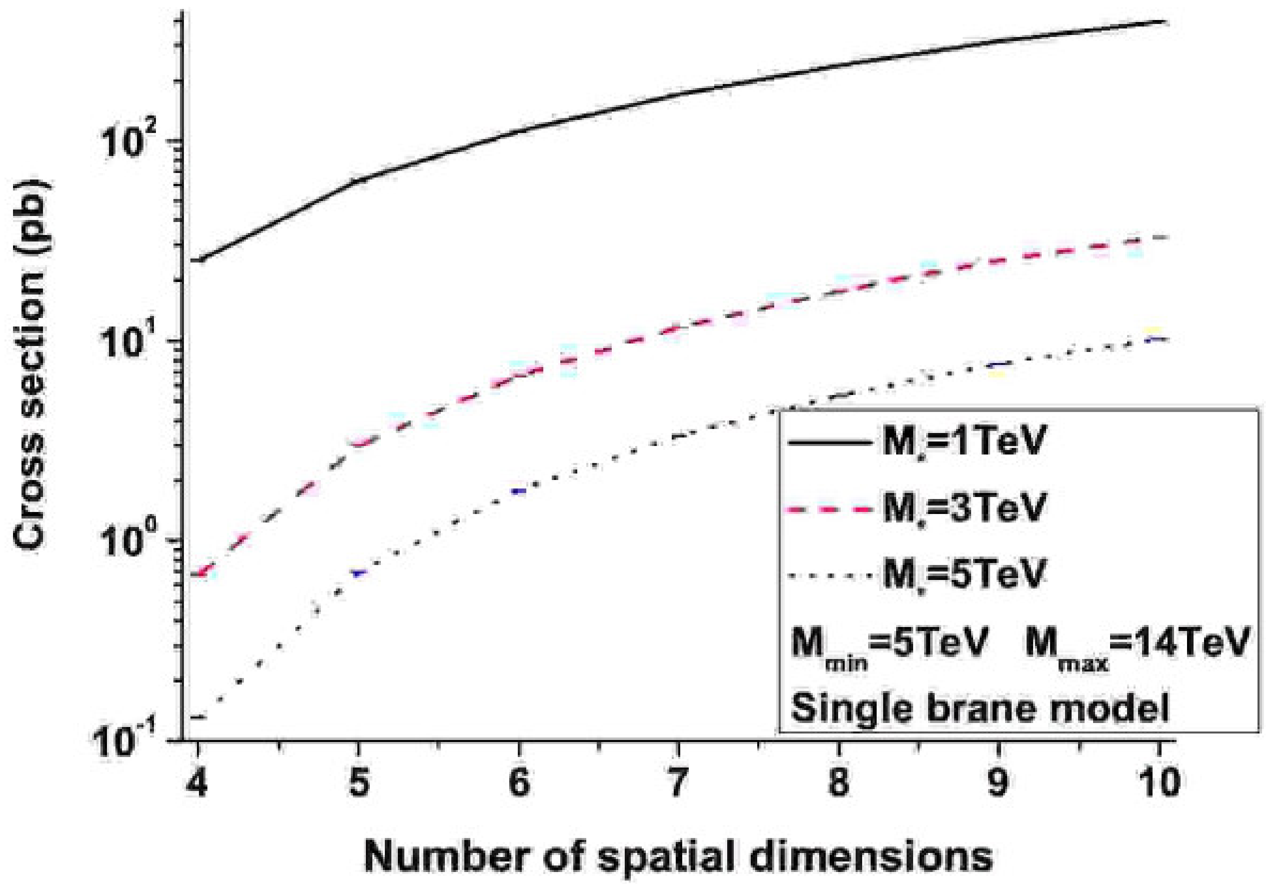
MBH production in pp collisions

- Geometric cross section for partons ≅ $(2r_h)^2 \pi$
- Total cross section:

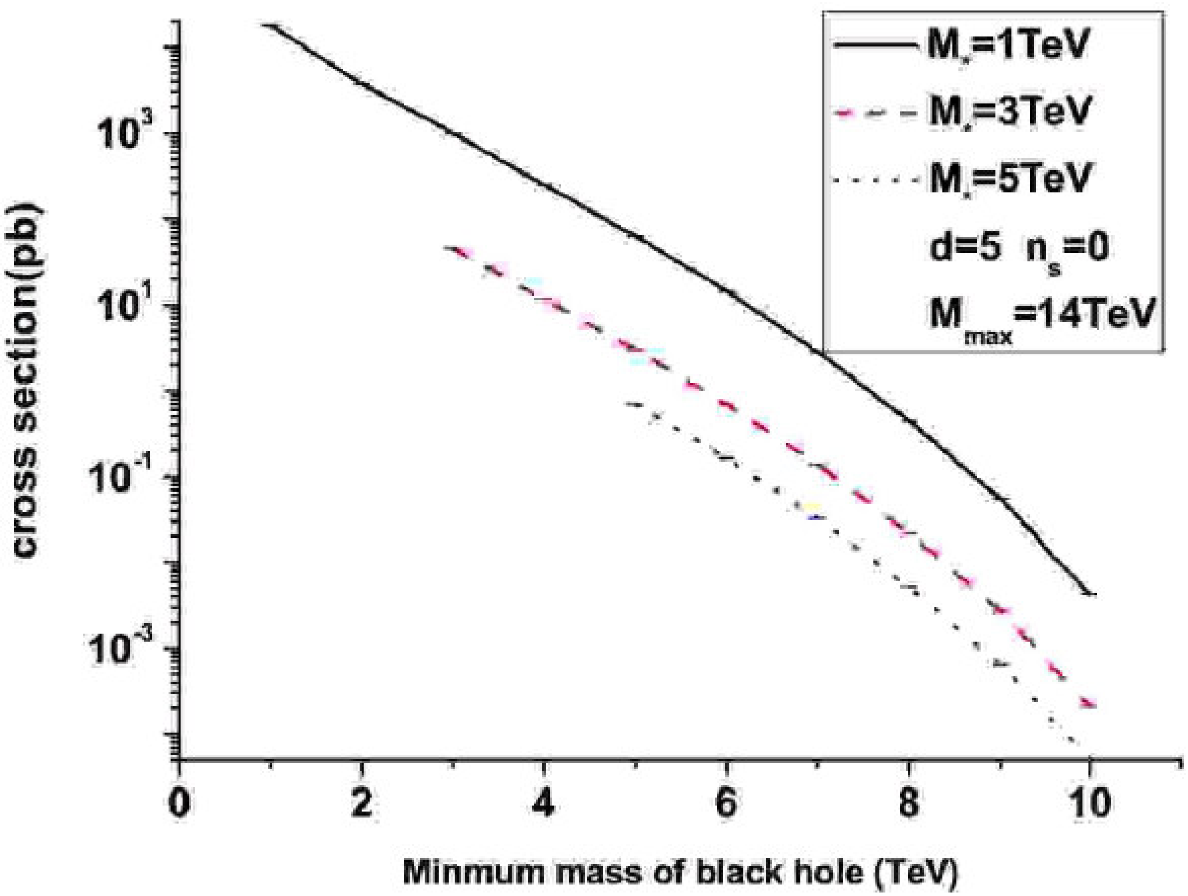
$$\sigma^{pp\to BH}(s;d,M_*) = \int_{M_*^2/s}^{1} \mathrm{d}u \int_{u}^{1} \frac{\mathrm{d}v}{v} \left[b_{\max}\left(\sqrt{us};d\right)\right]^2 \pi \times \sum_{ij} f_i\left(v,\sqrt{us}\right) f_j\left(u/v,\sqrt{us}\right)$$

- After production the BH looses energy, momentum and angular momentum via gravitational waves, until reaches a ”stationary configuration”

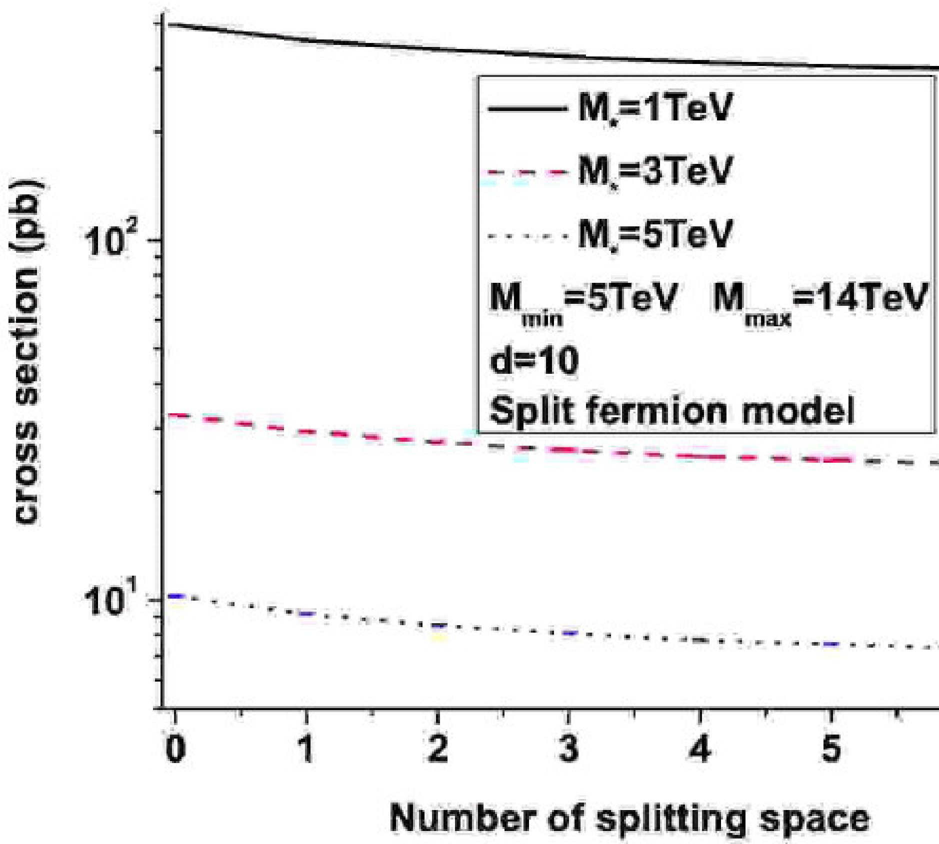
BH production cross section on a tensionless brane



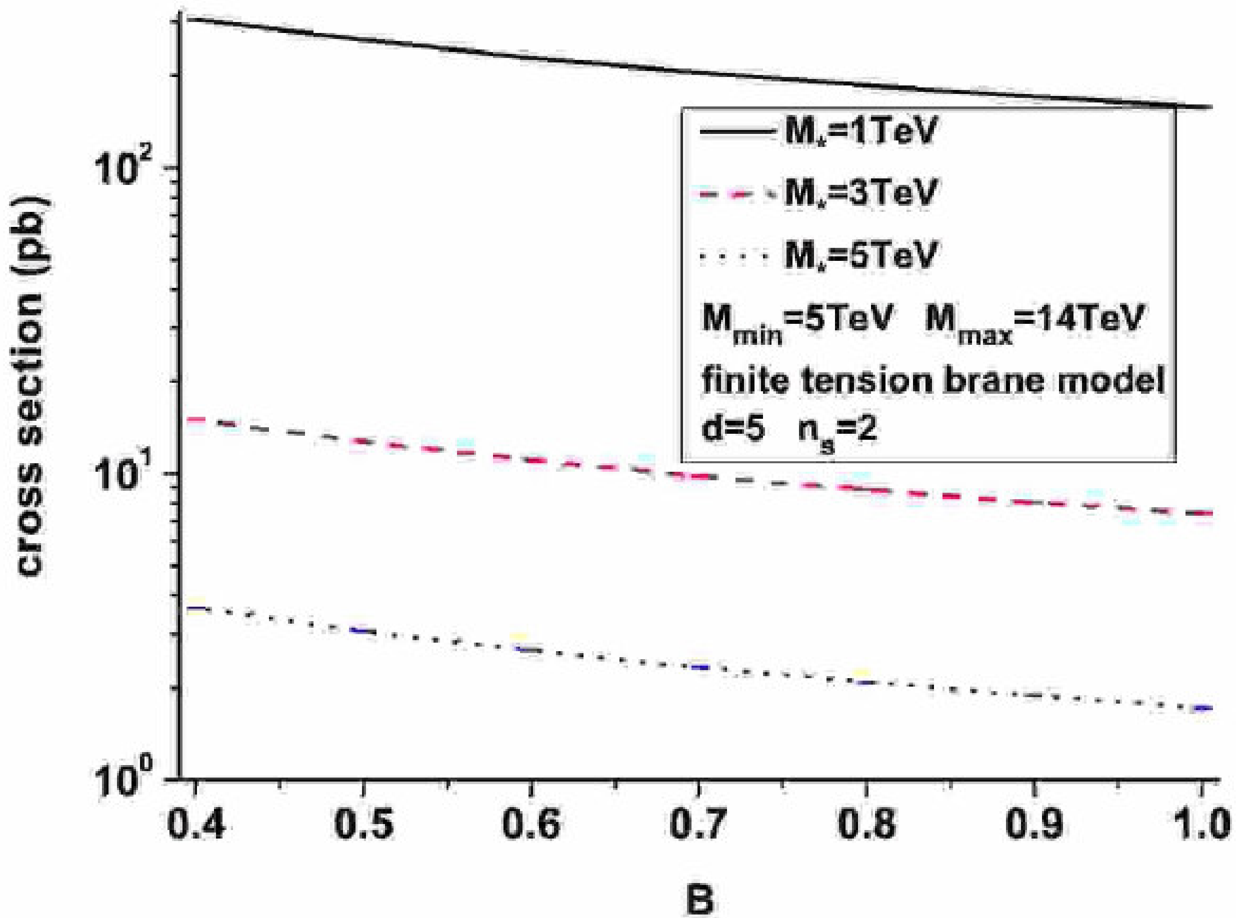
BH production cross section on a tensionless brane



BH production cross section on a tensionless brane with fermion brane splitting



BH production cross section on a brane with tension



Evaporation of MBH

- Hawking radiation of
  - SM particles into the brane and
  - gravitons into the bulk (invisible)
- Probability of emission of a particle is proportional to its gray-body factor, implemented in MBH generators:
  - TRUENIOR
  - CHARYBDIS
  - CATFISH

  } use Schwarzschild-BH, neglect MBH recoil
  - BlackMax uses rotating BH (super-radiating: emission of higher-spin particles is favoured)
- Brane tension modifies gray-body factors, considered only in BlackMax for non-rotating BH

Gray-body factors

…depend on the type of BH

Types covered in BlackMax:

- Non-rotating BH on a tensionless brane
- Rotating BH on a tensionless brane: gravitons in the bulk are not known
- Non-rotating BH on a tensionless brane with fermion brane splitting
- Non-rotating BH on a brane with tension
- Non-rotating BH on a brane with tension: not known
- Two-particle final states: the cross section for these suddenly jump to a larger value at M_*

MBH–search with CMS

- Two studies in the ”Exotica” group
  - Romulus Godang (in the author list of CATFISH) with M. Jenkins are implementing CATFISH in CMSSW
  - A. DeRoeck with a Turkish group uses CHARYBDIS and plan to use BlackMax
- …have not contacted them yet, but we should start analysis only if we can do better $\Longrightarrow$
- Try with BlackMax

Caution: two phases of discovery

1. Establishing deviation from the SM
   - Mass peaks: not for BH
   - Shape discrepancies
   - Excess in counting experiments
2. Understanding what the deviation corresponds to

…if not mass peaks

- Shape discrepancies:
  - One needs an internal validation of background estimate, evidence on new physics cannot depend on theory (cf. with high E_T jets at CDF)
  - Claiming discovery by comparing to MC is dangerous
- Counting experiments come into the game if the expected statistics is too small to allow for using distributions: not the case of BH

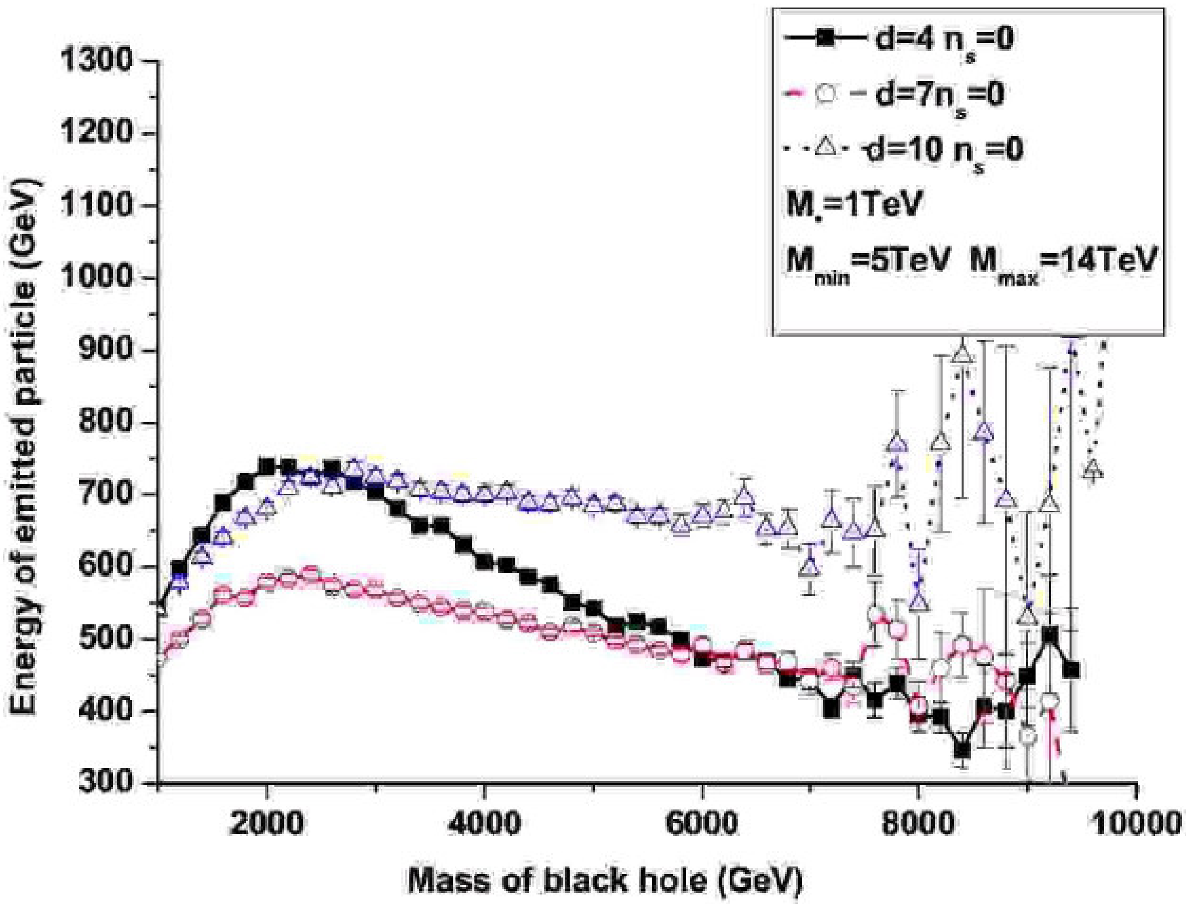
Needed asap (before LHC starts)

- Signature
- Triggers if any
- At which Tier2 the skims to be stored
- Selection cuts if any
- Any special challanges for particle ID, calibration
- Backgrounds (list, means of estimates, uncertainties)
- Systematic uncertainties
- How to demonstrate that signal is a signal (checks)

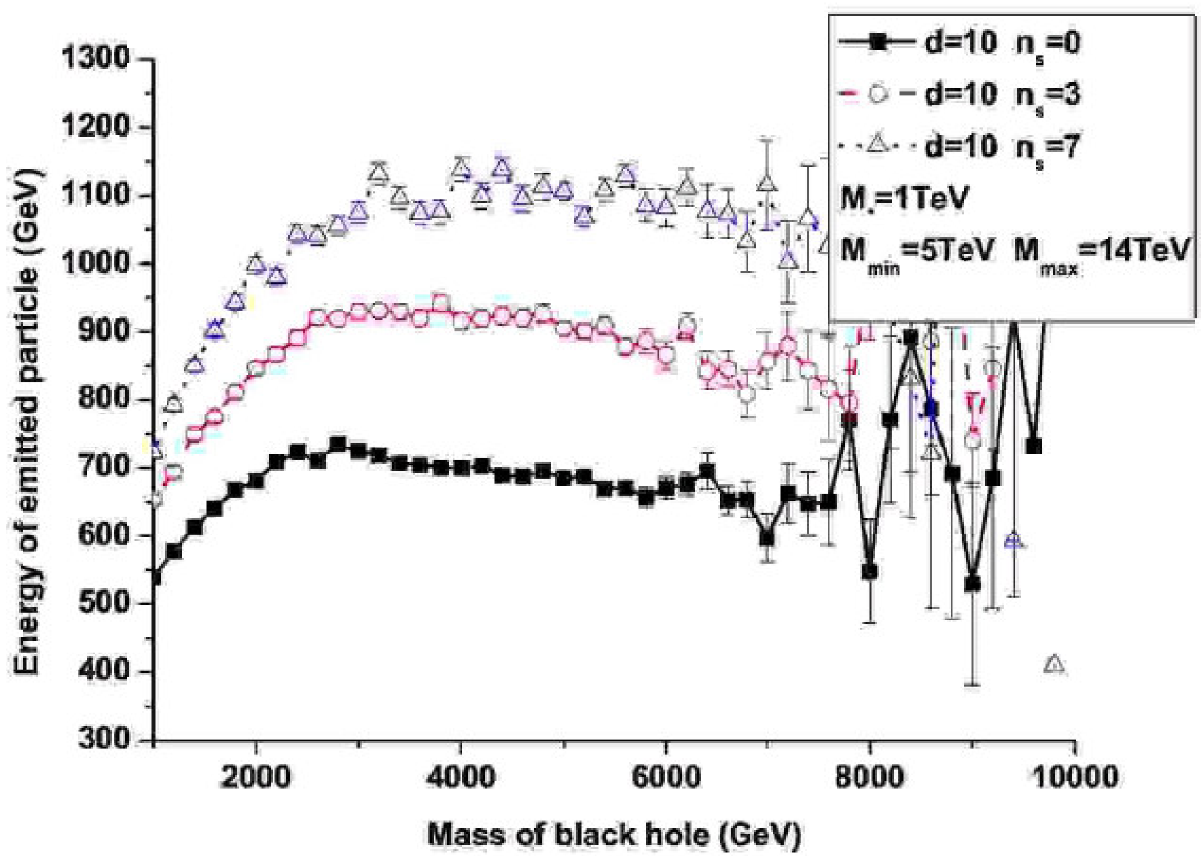
Signatures

- Try to find the promising distributions
  - p_T, rapidity, else?
- Thermal Hawking radiation: all SM particles (mostly quarks and gluons) can be emitted with high energy, jets/leptons ratio > 6

Average energy of particles from non-rotating BH on unsplit tensionless brane



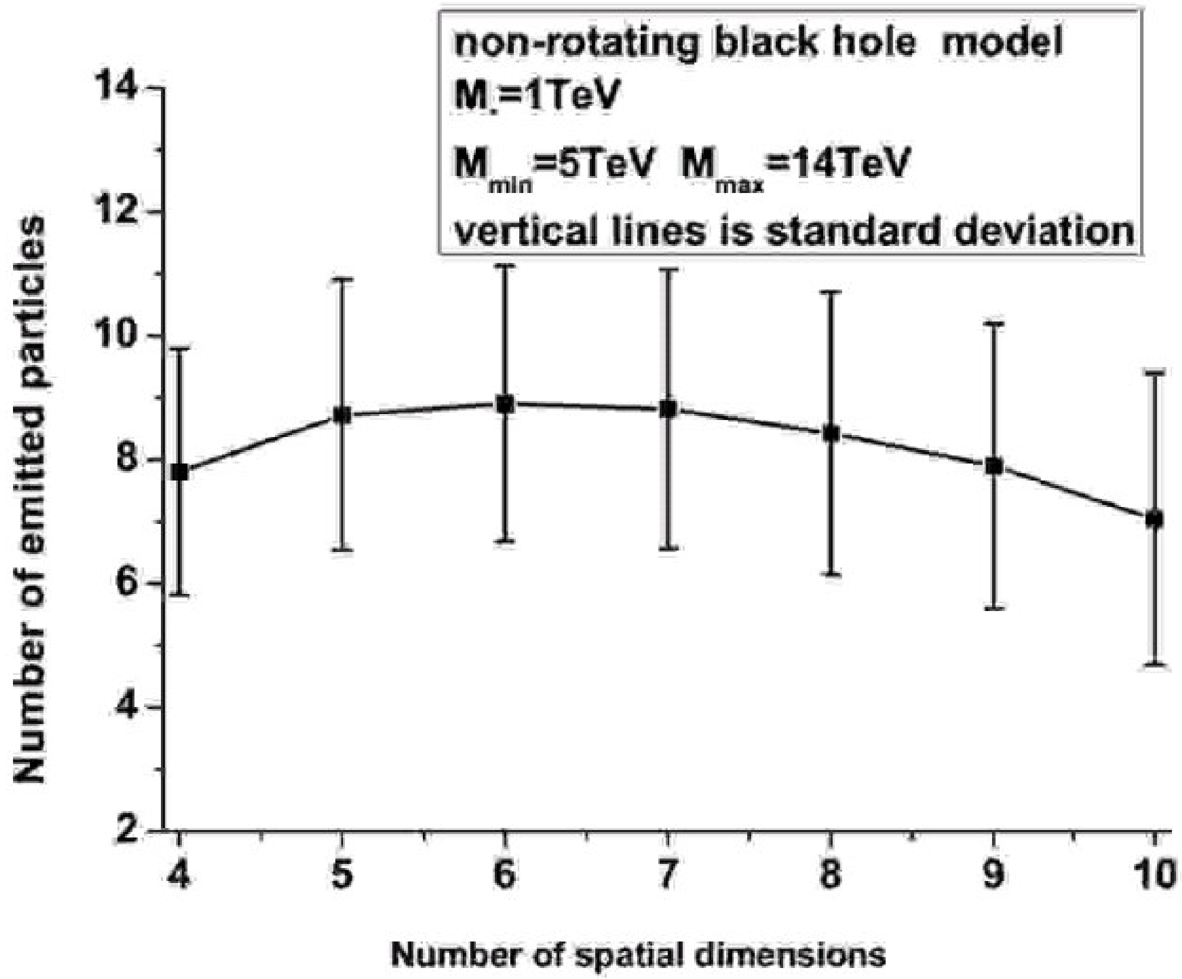
Average energy of particles from non-rotating BH on split, tensionless brane



Signatures

- Try to find the promising distributions
  - p_T, rapidity, else?
- Thermal Hawking radiation: all SM particles (mostly quarks and gluons) can be emitted with high energy, jets/leptons ratio > 6
- Multiplicity

Number of emitted particles during Hawking radiation



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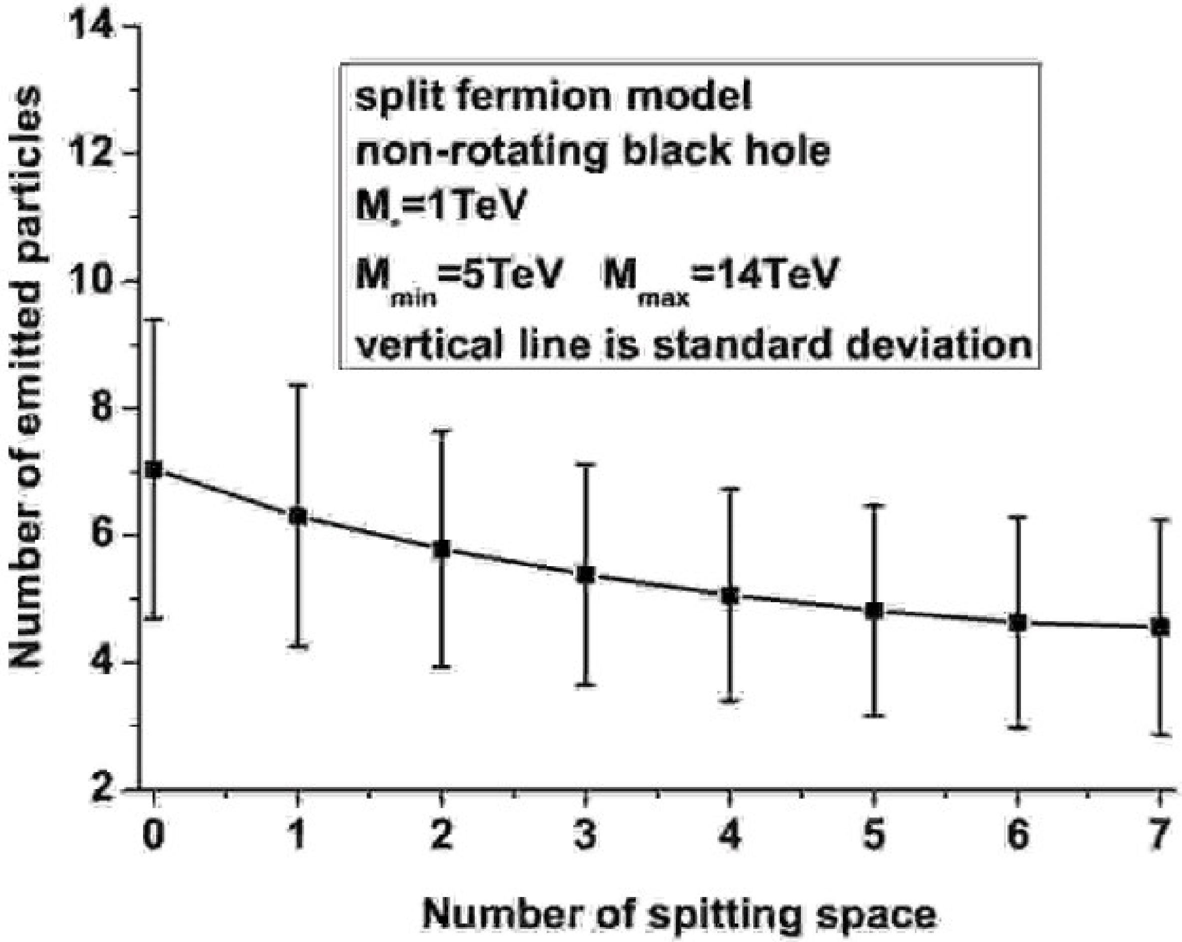

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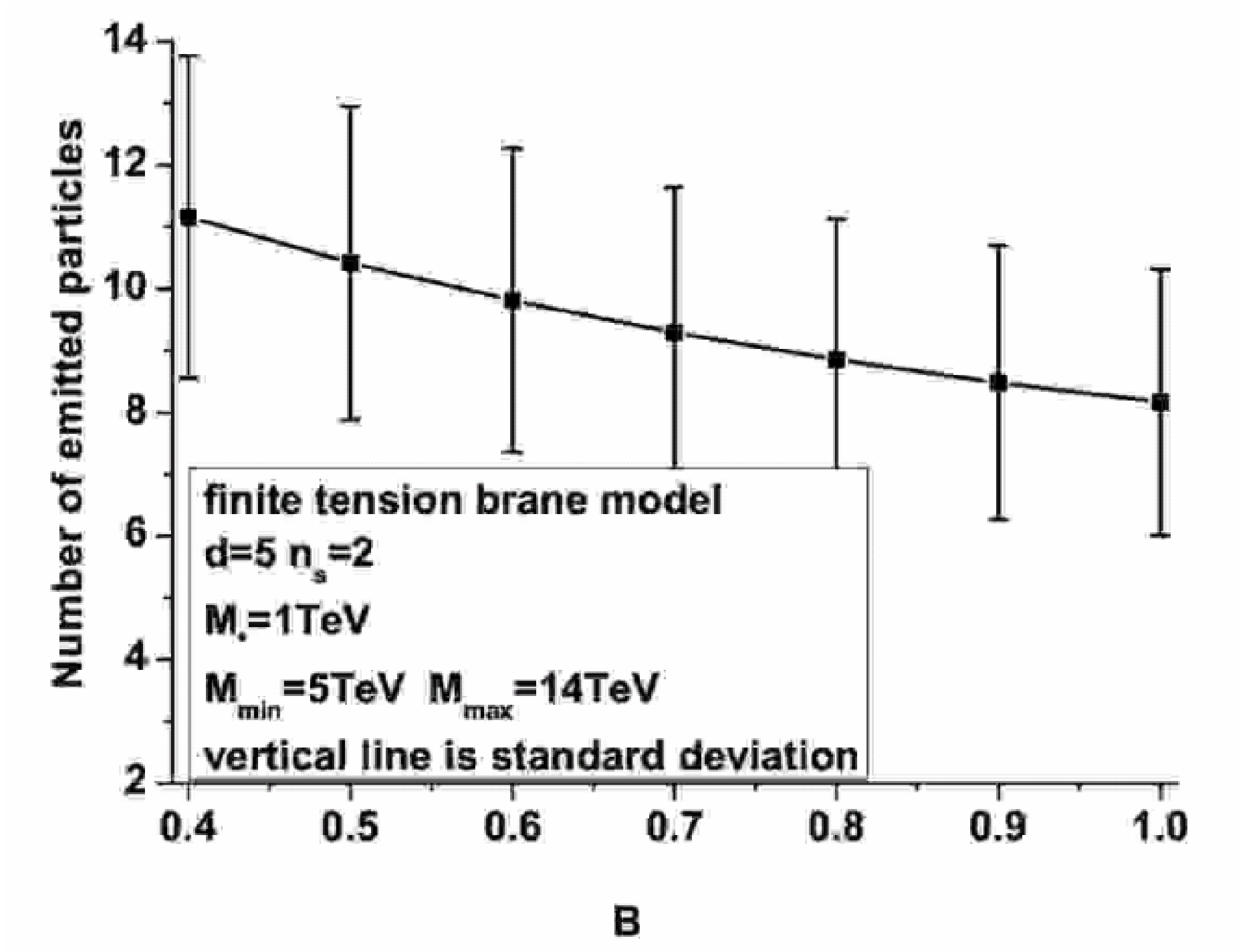

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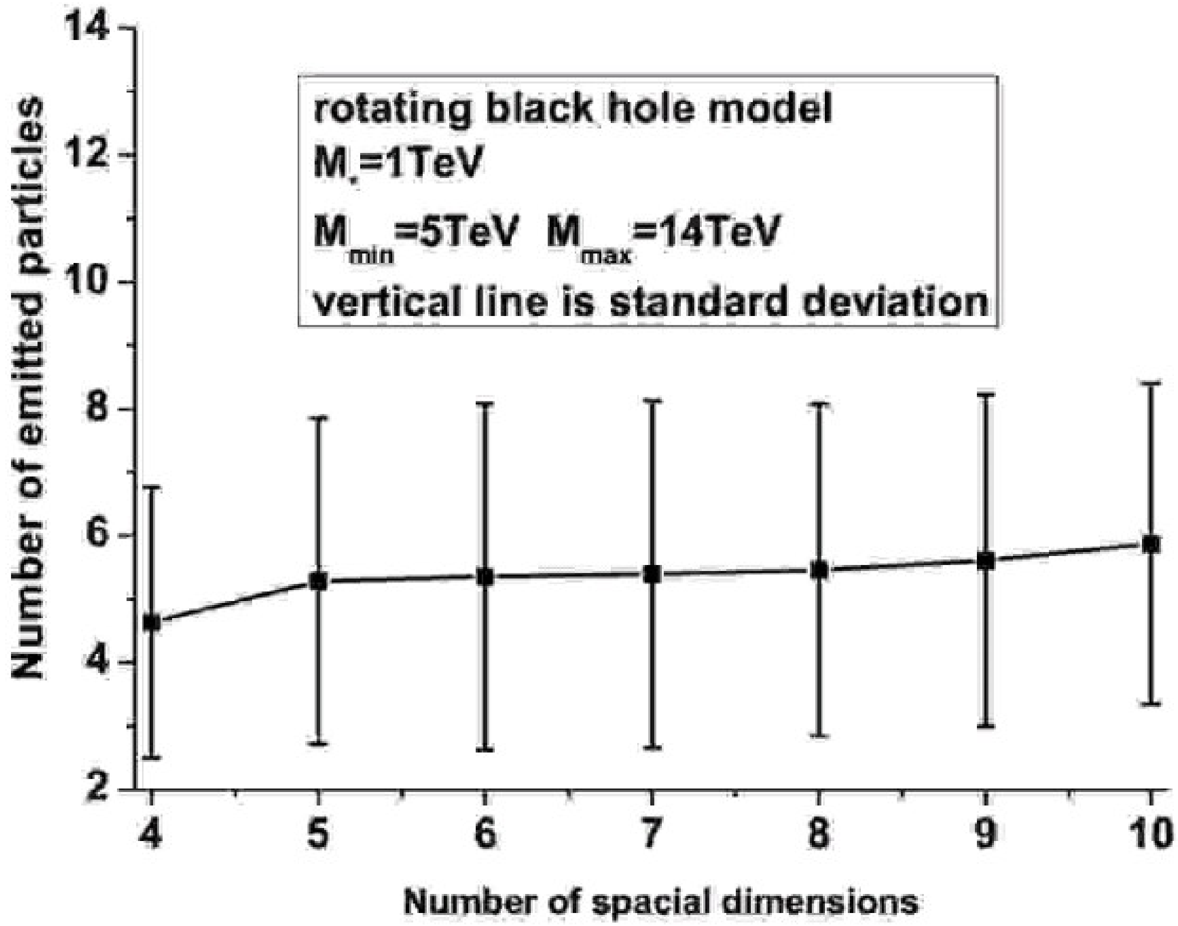
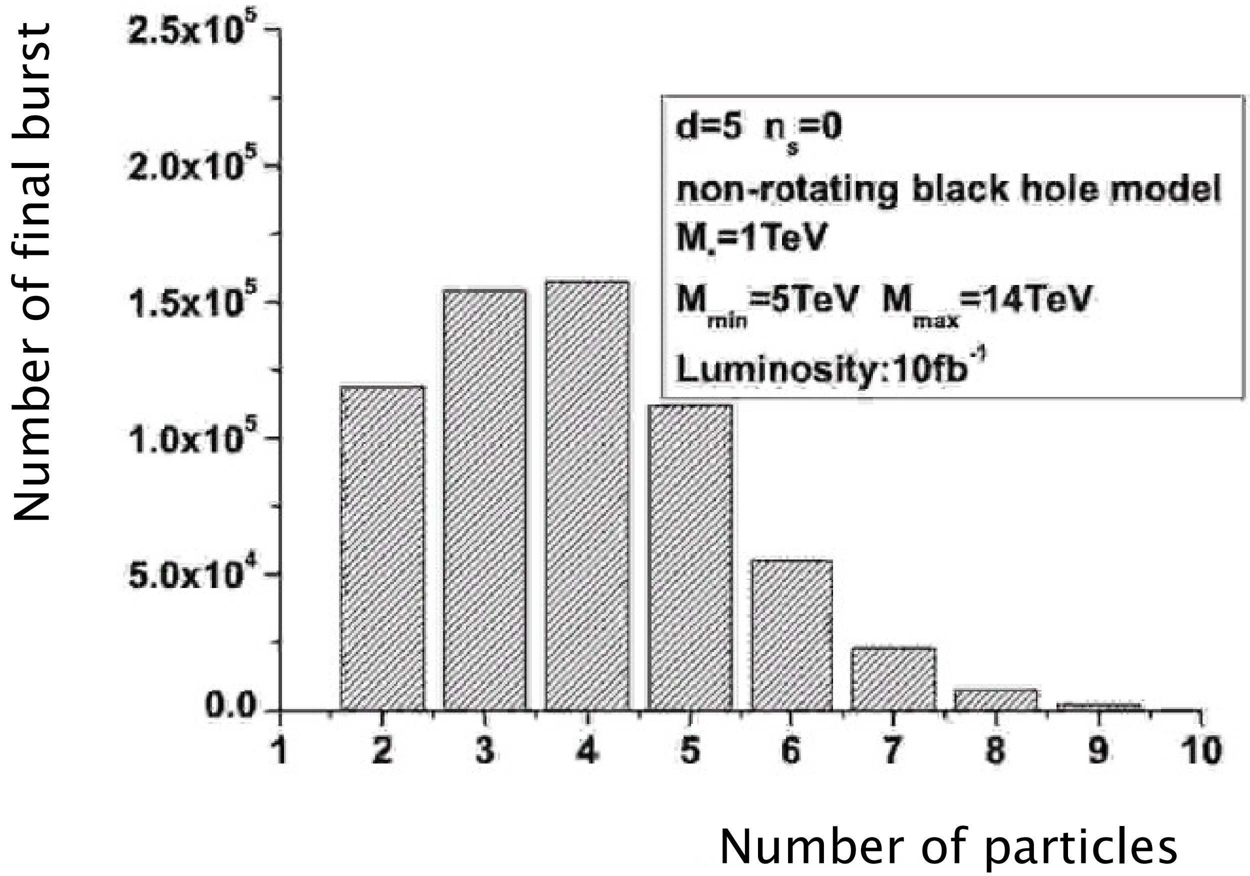


Distribution of number of emitted particles during final burst



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- Try to find the promising distributions
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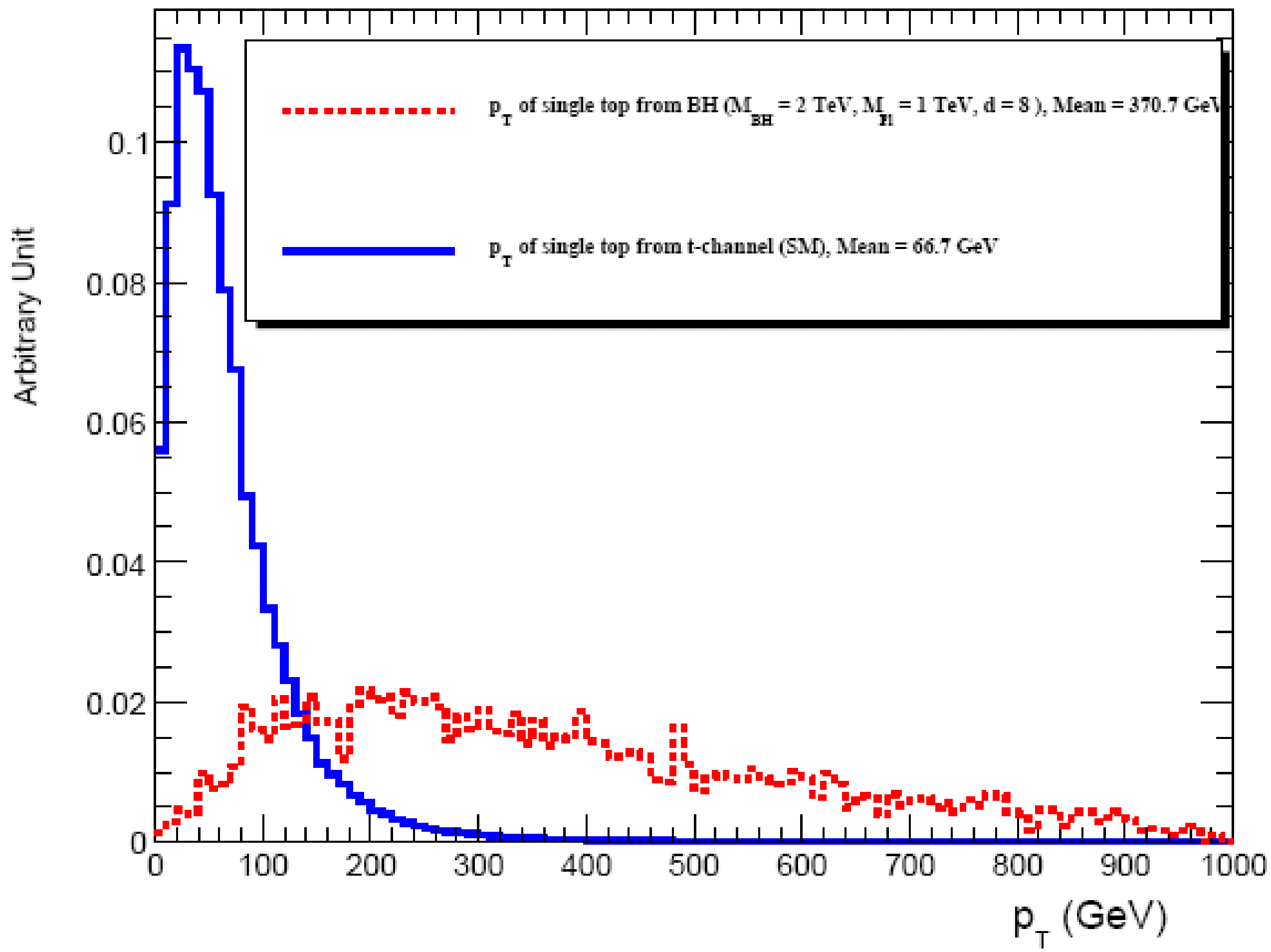
- Thermal Hawking radiation: all SM particles (mostly quarks and gluons) can be emitted with high energy, jets/leptons ratio > 6
- Multiplicity
- Typical p_T spectra are harder than in SM

p_T spectrum of single top quark production SM versus BH decay



Signatures

- Try to find the promising distributions
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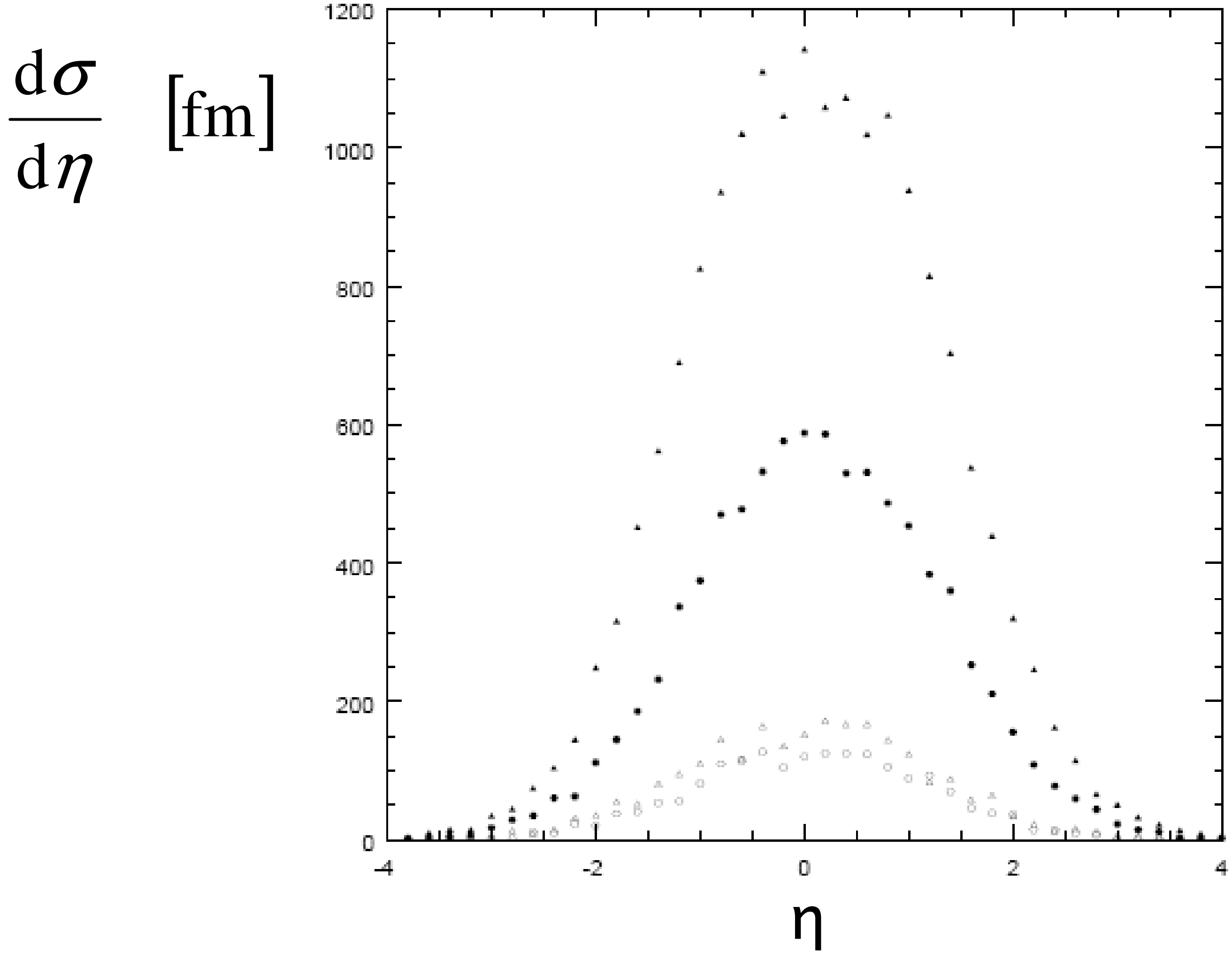
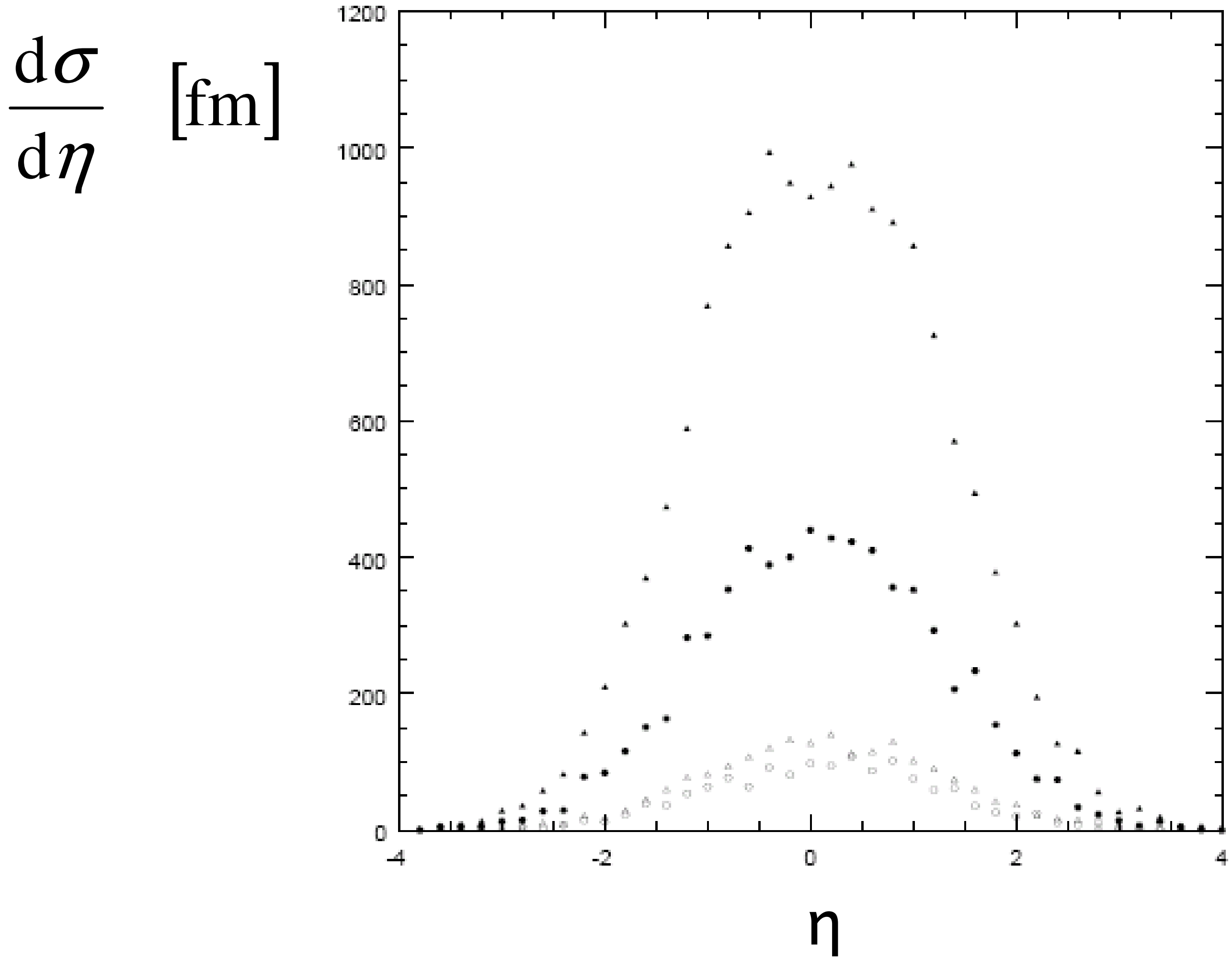
- Thermal Hawking radiation: all SM particles (mostly quarks and gluons) can be emitted with high energy, jets/leptons ratio > 6
- Multiplicity
- Typical p_T spectra are harder than in SM
- Mainly in the central rapidity region (end products have spherical distribution in the parton cm system due to thermal radiation)

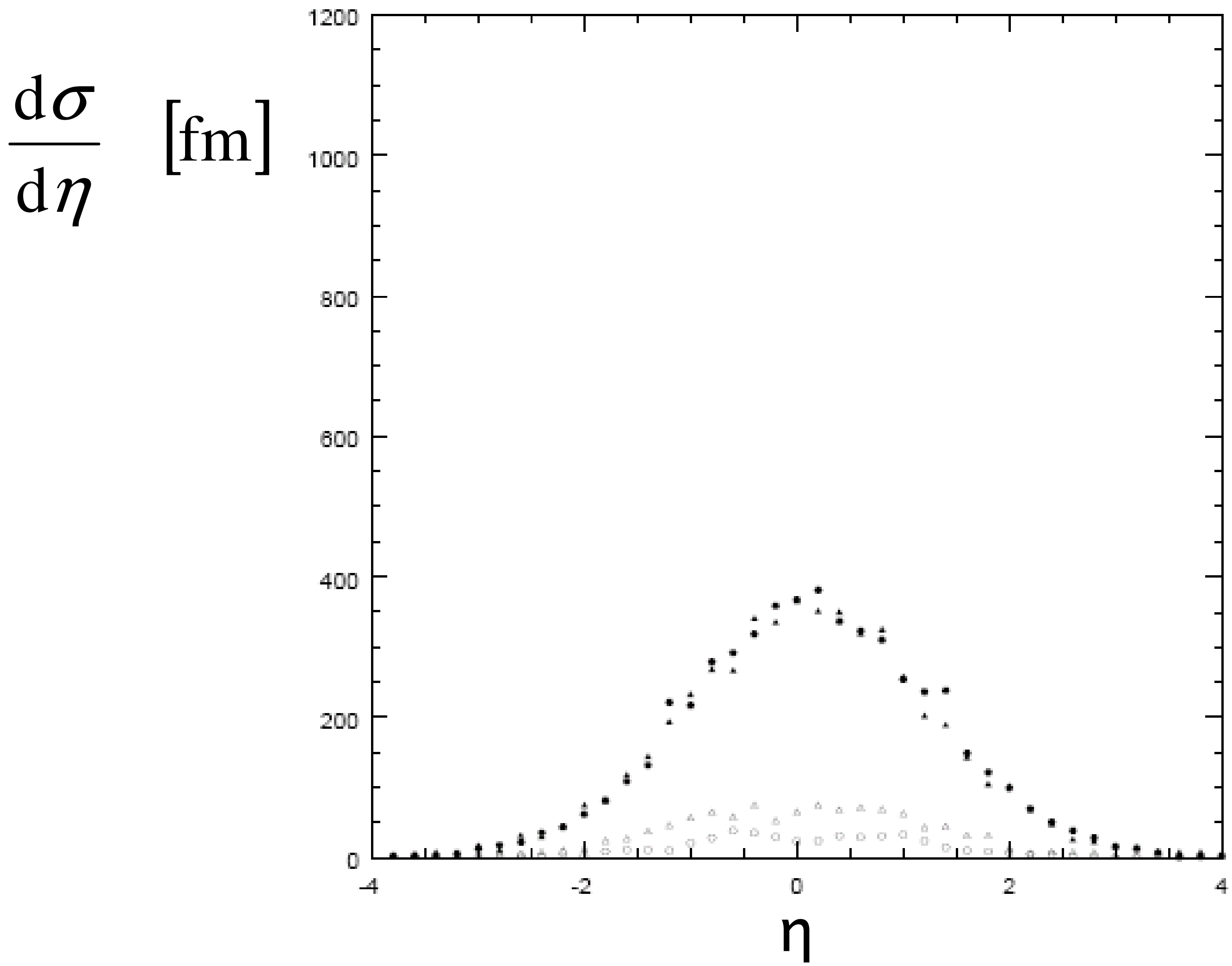
Rapidity distribution of quarks and leptons from a non-rotating BH on tensionless brane with final burst



Rapidity distribution of quarks and leptons from a rotating BH on tensionless brane with final burst

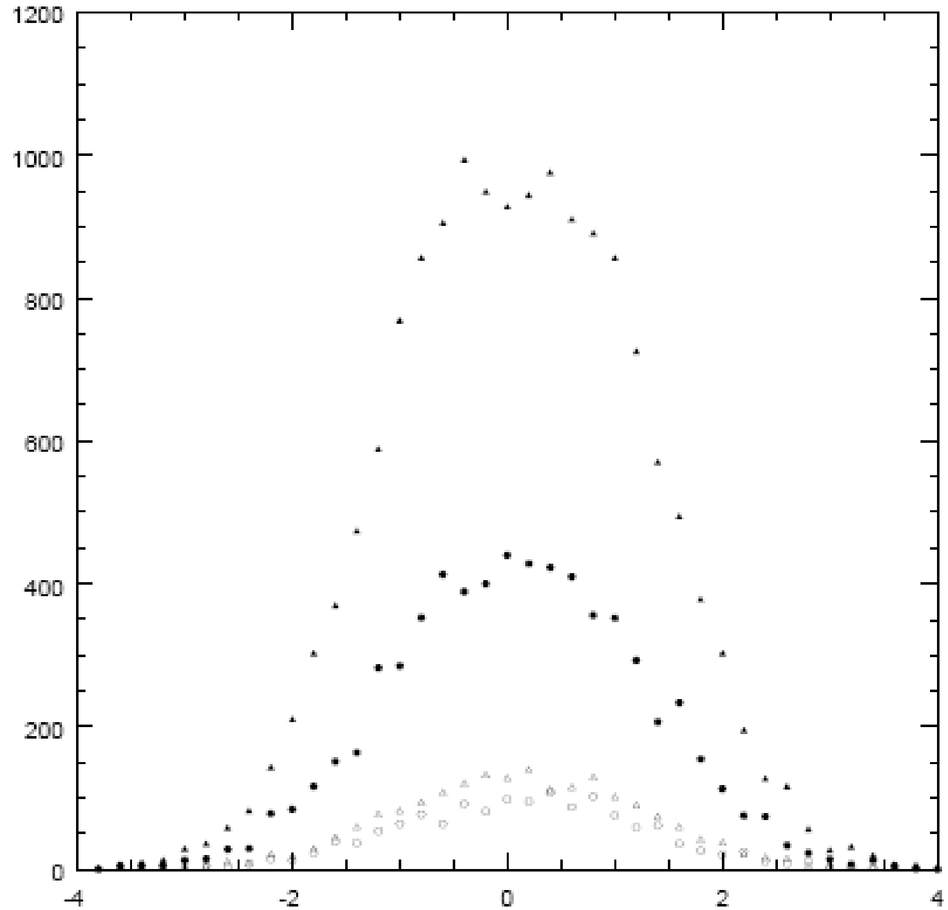


Rapidity distribution of quarks and leptons from a non-rotating BH without final burst



Rapidity distribution of quarks and leptons from a rotating BH without final burst

$$\frac{d\sigma}{d\eta} \quad [\text{fm}]$$



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