BlackMax a Black-Hole Event Generator

for p - p, p - antip and e^- - e^+ collisions

http://projects.hepforge.org/blackmax/

Phys.Rev.D77:076007,2008

DC. Dai, **C. Issever**, E. Rizvi,
G. Starkman, D. Stojkovic, J. Tseng

IOP HEPP Particle Physics
08 April 2009

Outline

- Introduction
  - Classical Production of Black-Holes
  - Extra Dimension and Strong Gravity
  - Black-Holes at the LHC
  - Black-Hole evolution
- Black-Hole Event Generators
  - BlackMax

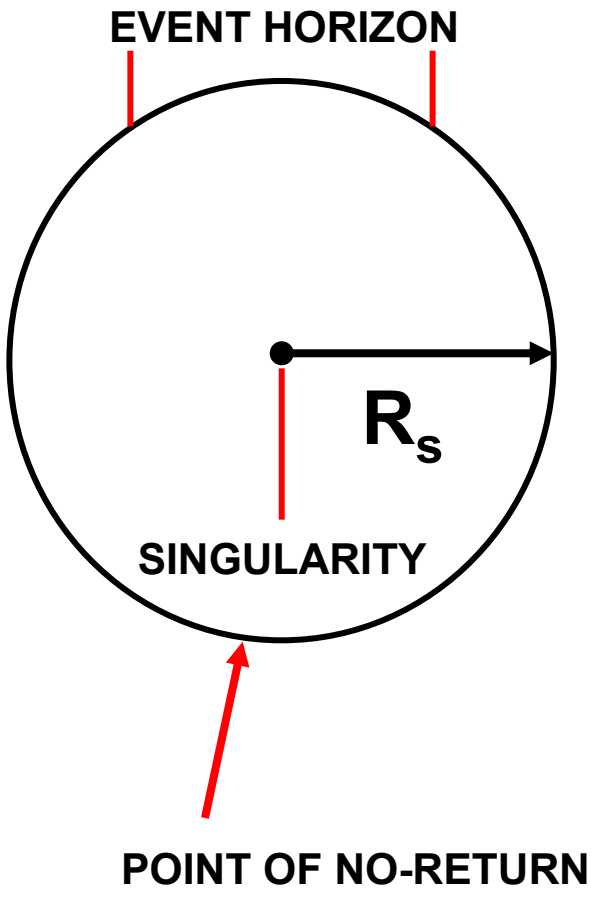
Production of Black Holes

Bring mass closer than its
Schwarzschild Radius, R_S,

$$R_S = \frac{2GM}{c^2}$$

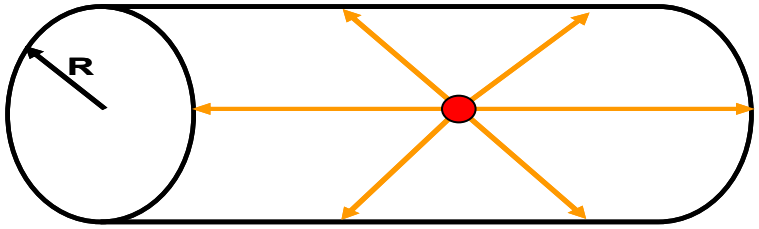
and a black hole will form!

$R_S^{Earth} = 8.8$ mm



Strength of Gravity in Extra Dimension Models

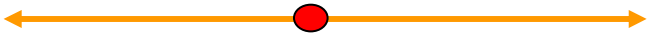
n = 1: one extra compactified spatial dimension



$$F(r < R) \sim G_D \frac{1}{r^{n+2}}$$

$$L = 2\pi R$$

How we perceive it in our daily life

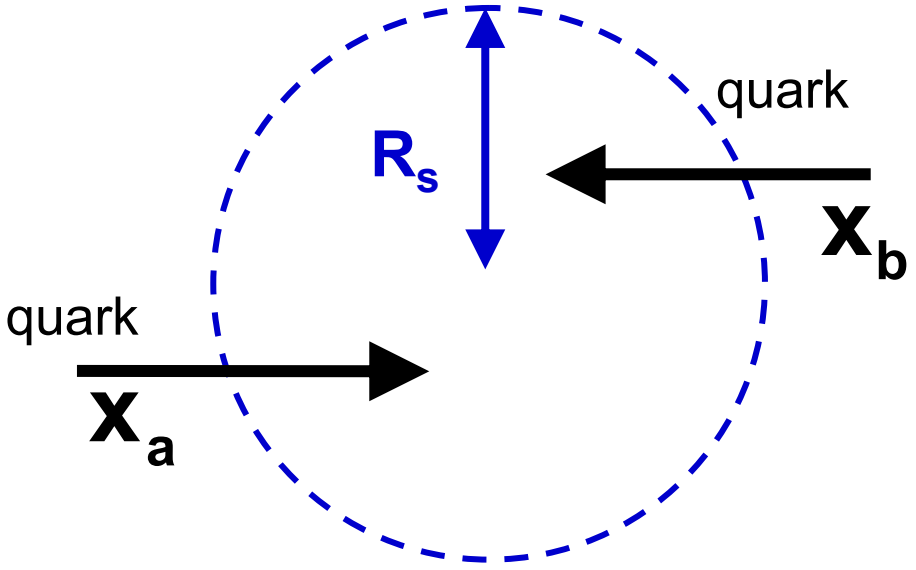


$$F(r > R) \sim G_D \frac{1}{L^n} \frac{1}{r^2} = G \frac{1}{r^2}$$

$$G_D = GL^n \qquad G_D \text{ STRONG}$$

Production of Black Holes at the LHC

$$R_S = \frac{2\,G^* L^n\,M}{c^2}$$

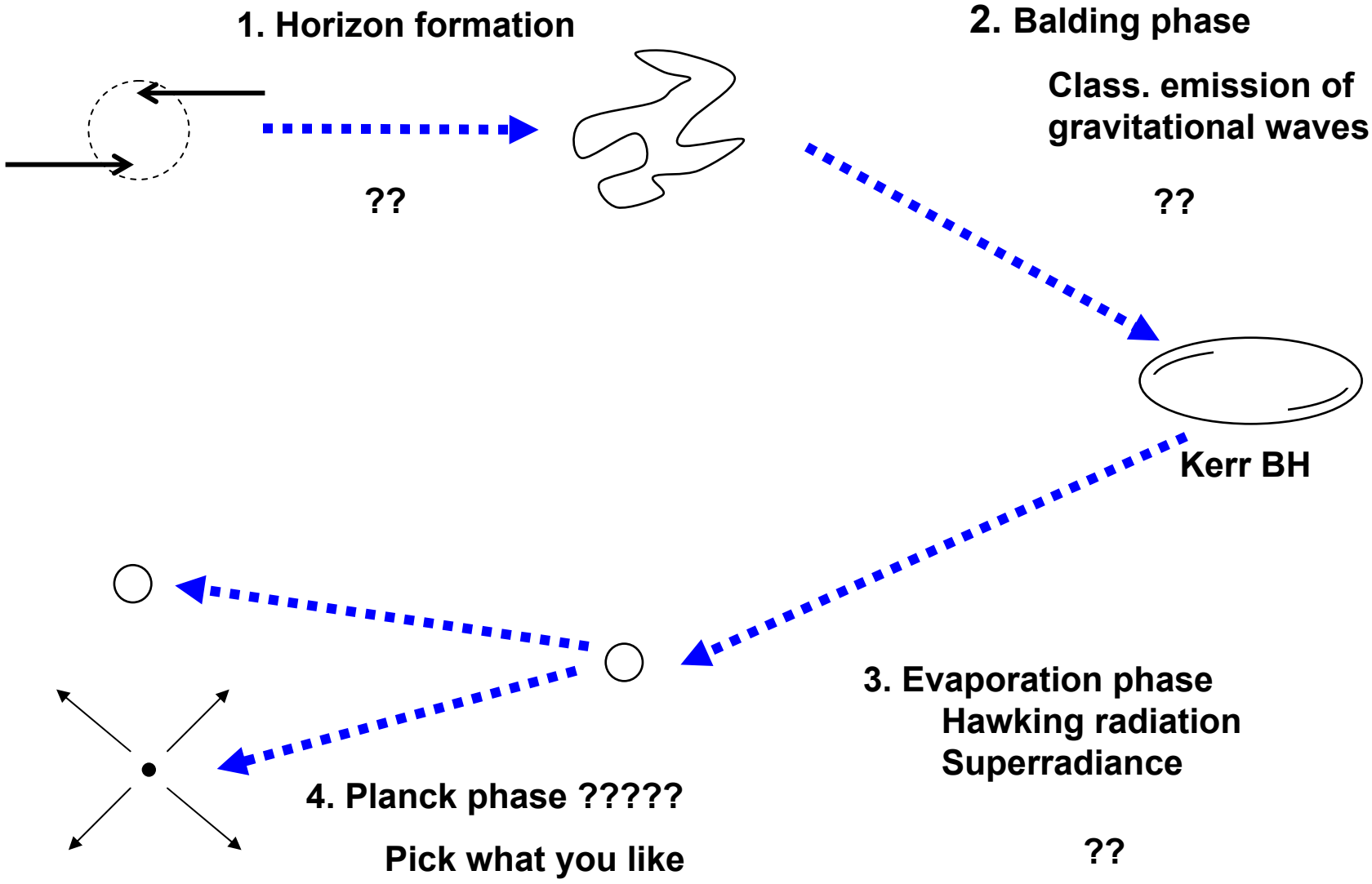


$$M = \sqrt{s x_a x_b} = \sqrt{\hat{s}}$$

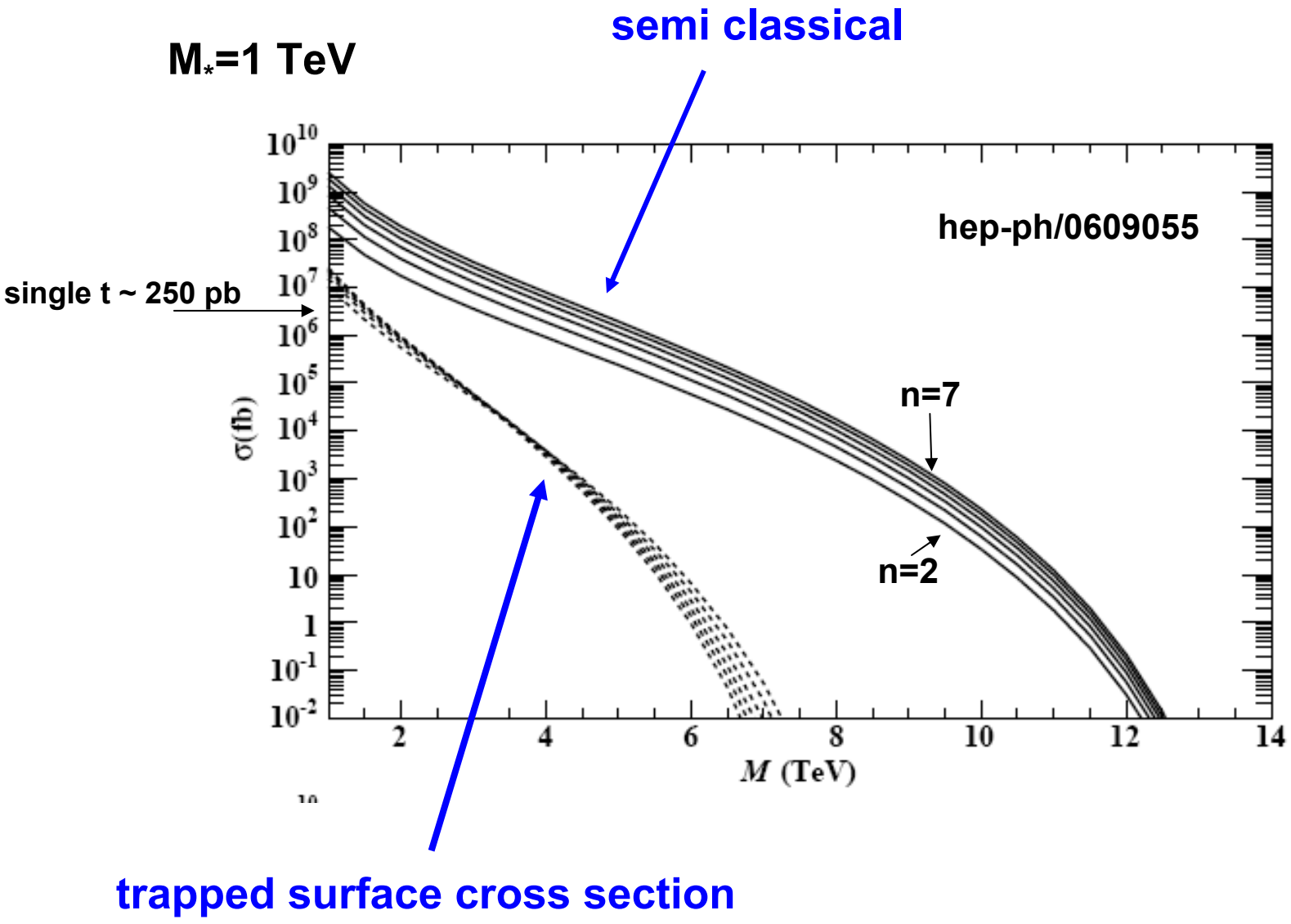
$$R_S^{2quarks} \leq 10^{-18}\,m$$

BH production @ LHC

Time Evolution of Black Holes



Effect of energy loss in formation and balding phase



Black Hole Generators

- **TRUENOIR** (Dimopoulos & Landsberg, hep-ph/0106295)
  - J=0 only; no energy loss; fixed T; no g.b.f.
- **CHARYBDIS** (Harris, Richardson & BW, hep-ph/0307305)
  - J=0 only; no energy loss; variable T; g.b.f. included
- **CATFISH** (Cavaglia et al., hep-ph/0609001)
  - J=0 only; energy loss option; variable T; g.b.f. included

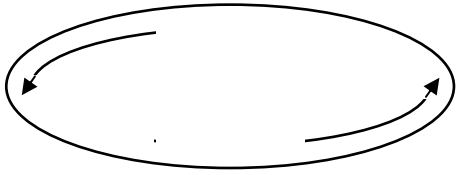
State of the art BH generators:

- **BlackMax** (Dai et al., arXiv:0711.3012)
  - J≠0; energy loss option; variable T; split & tension branes; g.b.f.
- **CHARYBDIS2** (Casals et al., **in preparation**)
  - J≠0; energy loss model; variable T; remnant options; g.b.f.

Slide from B. Webber

Goals of BlackMax

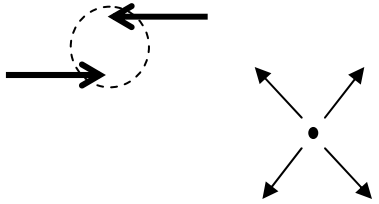
- Up-to-date theoretical calculations
  - All grey-body factors known to date
  - **Rotating** black-holes
  - Graviton emission



More in J. Frost's talk

Goals of BlackMax

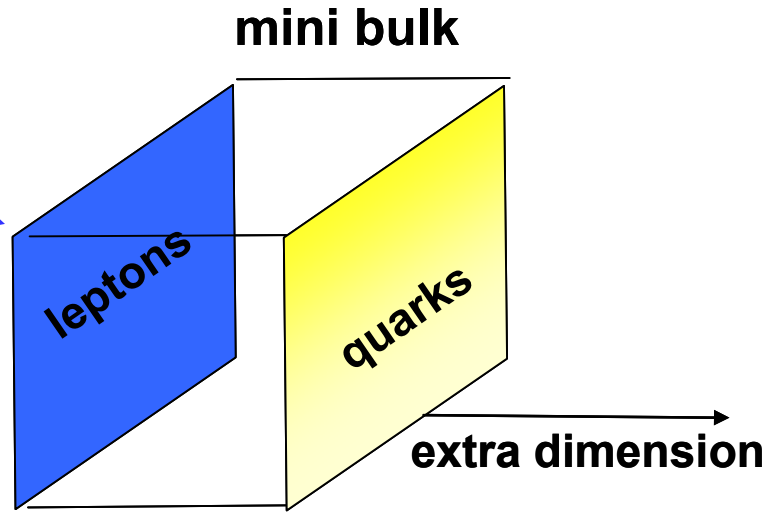
- Evaluate systematics associated with models
  - **key parameters can be changed:**
    - **BH formation**
    - **BH evaporation**
    - **BH final burst**



  - Three extra dimension scenarios
    - Flat branes (ADD)
    - Branes with tension
    - Split fermion branes
  - Quantum black-holes
    - P. Meade & L. Randall
    - arXiv:0708.3017 [hep-ph]

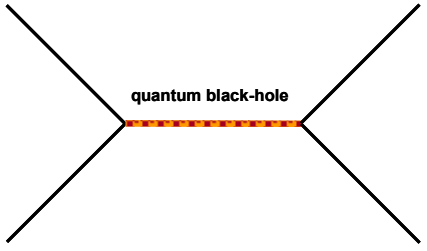
Goals of BlackMax

- Evaluate systematics associated with models
  - key parameters can be changed:
    - BH formation
    - BH evaporation
    - BH final burst
  - **Three extra dimension scenarios**
    - **Flat branes (ADD)**
    - **Branes with tension**
    - **Split fermion branes**
  - Quantum black-holes
    - P. Meade & L. Randall
    - arXiv:0708.3017 [hep-ph]



Goals of BlackMax

- Evaluate systematics associated with models
  - key parameters can be changed:
    - BH formation
    - BH evaporation
    - BH final burst
  - Three extra dimension scenarios
    - Flat branes (ADD)
    - Branes with tension
    - Split fermion branes
  - **Quantum black-holes**
    - **P. Meade & L. Randall**
    - **arXiv:0708.3017 [hep-ph]**



How to steer BlackMax

- parameter.txt defines settings for BlackMax

```
Number_of_simulations
1000
incoming_particle(1:pp_2:ppbar_3:ee+)
1
Center_of_mass_energy_of_incoming_particle
14000
M_ph(GeV)
1000.
definition_of_M_pl:(1:M_D_2:M_p_3:M_DL_4:put_in_by_hand)
1
Choose_a_case:(1:tensionless_nonrotating_2:tension_nonrotating_3:rotating_nonspl
it_4:Lisa_two_particles_final_states)
2
number_of_extra_dimensions
2
choose_a_pdf_file(200_to_240_cteq6)Or_>10000_for_LHAPDF
200
Minimum_mass(GeV)
5000.
Maxmum_mass(GeV)
14000.
```

Number of events

Type collision: pp

Planck mass: 1000 GeV

ED model: branes w tension

How to steer BlackMax

```
do_yo_shino(1:do_0:no)
0
Mass_loss_factor(0~1.0)
0.00
momentum_loss_factor(0~1.0)
0.0
Angular_momentum_loss_factor(0~1.0)
0.0
```

Parameters to steer formation/balding phase

```
turn_on_graviton(0:off_1:on)
1
L_suppression(1:none_2:delta_area_3:anular_momentum_4:delta_angular_momentum)
1
angular_momentum_suppression_factor
1
charge_suppression(1:none_2:do)
1
charge_suppression_factor
1
color_suppression_factor
20
```

Evaporation phase

```
number_of_conservation
1
d,s,b,u,c,t,e,mu,tau,nu_e,nu_mu,nu_tau
1,1,1,1,1,1,0,0,0,0,0,0
```

Conservation of baryon,lepton and Flavor numbers

Output of BlackMax

- LHEF standard conform: arXiv:hep-ph/0609017v1

BlackMaxLHArecord.lhe

```
<LesHouchesEvents version="1.0">
<header>
<BMPara>
#*********************************
#***   Welcome to:       BLACKMAX
#***   Release tag : $Name:  $
#***   Release ID  :   $Id: BlackMax.c,v 1.66 2009/03/08 09:31:44 rizvi Exp $
#***   Release date: $Date: 2009/03/08 09:31:44 $
#***   Writing input parameter set...
#***
      .
      Dump of Steering file parameter.txt
      .
#***   Finished writing input parameter set
#*********************************
#Total Cross Section =   1.8459325e+02 +/-   1.7048149e+00 pb
#*********************************
</BMPara>
</header>
<init>
  2212    2212    7.0000000e+03    7.0000000e+03       0       0   10100   10100       3       1
  1.8459325e+02    1.7048149e+00    0.0000000e+00       1
</init>
<event>
     19       1    1.0000000e+00    1.3993892e+04   -1.0000000e+00   -1.0000000e+00
      2      -1       0       0     506       0   0.0000000e+00   0.0000000e+00   4.9938965e+03   4.9938965e+03   3.1998410e-03   0.0000000e+00   0.0000000e+00
     21      -1       0       0     508     507   0.0000000e+00   0.0000000e+00  -1.6883953e+03   1.6883953e+03   8.4361105e-06   0.0000000e+00   0.0000000e+00
     -3       1       1       2       0     501   7.0352399e+01   7.8249107e+01   1.9950361e+02   2.2555283e+02   7.0000000e-02   0.0000000e+00   0.0000000e+00
    -24       1       1       2       0       0  -2.9931197e+02  -2.9644830e+02  -2.1185789e+02   4.7835259e+02   8.0425000e+01   0.0000000e+00   0.0000000e+00
     13       1       1       2       0       0  -4.6673588e+00   1.2874871e+02   1.1372752e+02   1.7184870e+02   1.0500000e-01   0.0000000e+00   0.0000000e+00
     -4       1       1       2       0     502   3.9572208e+02   5.5060457e+02   4.6740652e+02   8.2354821e+02   1.2000000e+00   0.0000000e+00   0.0000000e+00
     39       1       1       2       0       0   3.5316227e+02   1.2254914e+02   1.1265040e+03   1.1869091e+03   2.2120311e-05   0.0000000e+00   0.0000000e+00
     -2       1       1       2       0     503  -9.4872688e+01  -2.8493613e+02  -1.5440637e+01   3.0071222e+02   3.2000037e-03   0.0000000e+00   0.0000000e+00
     -6       1       1       2       0     504   4.5190005e+02   4.4094978e+02   4.1659057e+02   7.7712141e+02   1.7810000e+02   0.0000000e+00   0.0000000e+00
      2       1       1       2     505       0  -1.5666801e+02  -1.0096251e+02   4.7162677e+02   5.0711942e+02   3.2000144e-03   0.0000000e+00   0.0000000e+00
     -4       1       1       2       0     509  -1.9573550e+02  -3.0631969e+02   1.8405683e+01   3.6398399e+02   1.2000000e+00   0.0000000e+00   0.0000000e+00
     21       1       1       2     501     505  -2.0292170e+01  -1.0157417e+02   8.3393283e+01   1.3297941e+02   0.0000000e+00   0.0000000e+00   0.0000000e+00
     21       1       1       2     502     507  -2.5986842e+02  -1.8152664e+02   3.7626396e+02   4.9199399e+02   5.0898318e-06   0.0000000e+00   0.0000000e+00
    -15       1       1       2       0       0  -1.2563120e+01   8.4268364e+01   7.7901351e+01   1.1545893e+02   1.7760000e+00   0.0000000e+00   0.0000000e+00
    -13       1       1       2       0       0   4.7167503e+01  -1.1972342e+02  -4.7344300e+01   1.3711296e+02   1.0500000e-01   0.0000000e+00   0.0000000e+00
      6       1       1       2     503       0  -1.1573716e+02  -2.6248005e+01   1.1477163e+02   2.4285013e+02   1.7810000e+02   0.0000000e+00   0.0000000e+00
      4       1       1       2     504       0  -2.9734740e+01  -6.8791226e+00  -1.3147456e+00   3.0571975e+01   1.2000000e+00   0.0000000e+00   0.0000000e+00
      4       1       1       2     506       0  -1.1885981e+02   8.0898128e+00   9.3872891e+01   1.5167946e+02   1.2000000e+00   0.0000000e+00   0.0000000e+00
     -5       1       1       2       0     510  -9.9933559e+00   1.1158507e+01   2.1491011e+01   2.6530793e+01   4.2000000e+00   0.0000000e+00   0.0000000e+00
</event>
```

Detailed User Manual available

Manual of BlackMax

A black-hole event generator with rotation, recoil, split branes, and brane tension

Version 2.00

De-Chang Dai[1], Cigdem Issever[2], Eram Rizvi[3], Glenn Starkman[4], Dejan Stojkovic[1], Jeff Tseng[2]

[1] *Department of Physics, SUNY at Buffalo, Buffalo NY 14260-1500,USA*
[2] *University of Oxford, Oxford, UK*
[3] *Queen Mary, University of London, London, UK*
[4] *CERCA and ISO, Department of Physics, Case Western Reserve University, Cleveland OH 44106-7079, USA*

arXiv:0902.3577

Summary

- Introduction into black-holes at the LHC
- Versatile Generator: **BlackMax**
  - Evaluation of systematics
  - Rotating black holes
  - Different ED scenarios
  - Quantum Black Holes
  - And many more features

- Sign up for our email list at http://www.hepforge.org/lists/listinfo/blackmax


Backup Slides

Comparison with Charybids 1.003

- Charybdis:
  - Non-rotating BHs
  - Branes have no width
- BlackMax:
  - Rotating BHs
  - Brane have finite width of M^{-1}_{pl}

Comparison with Charybdis 1.003

$$\sigma_{CH} = \pi r_s^2 \qquad \sigma_{BM} = b_d^2 \pi r_s^2 \qquad b_d = \frac{2}{\left(1+\left(\frac{d-1}{2}\right)^2\right)^{\frac{1}{d-2}}}$$

d number of space dimensions

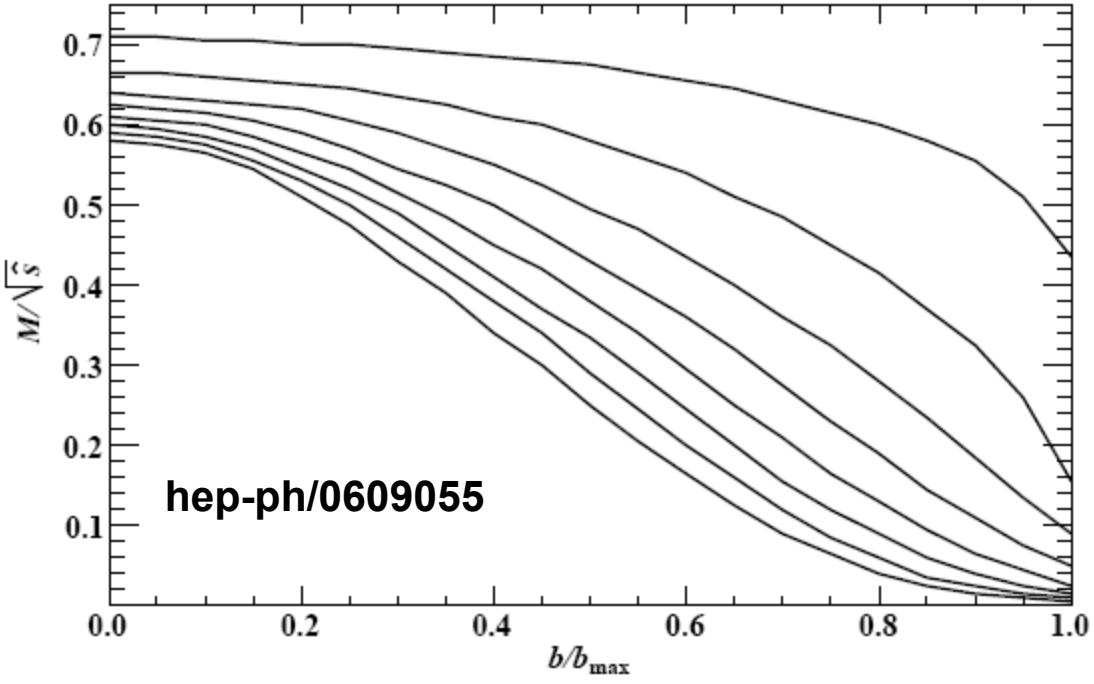
Table 1: M_D=1000 GeV, $M_{bh} > 5000$ GeV, and D is the total number of dimensions (space + time).

D	σ_{ch} [pb]	σ_{bm} [pb]	σ_{bm} with $L_{extra} = 0$ [pb]	σ_{bm}/σ_{ch}	σ_{bm}/σ_{ch} with $L_{extra} = 0$	b_d^2
6	75.20 ± 0.6968	90.69 ± 0.8407	99.70± 0.9128	1.21	1.32	1.36
7	122.0± 1.126	161.9± 1.502	177.0±1.638	1.32	1.45	1.48
8	172.6 ±1.590	247.6 ± 2.304	266.2± 2.449	1.43	1.54	1.59
9	225.7± 2.076	352.7 ± 3.149	369.0±3.285	1.56	1.63	1.69
10	280.7± 2.579	455.2± 4.182	484.8± 4.419	1.62	1.72	1.78

3 % difference

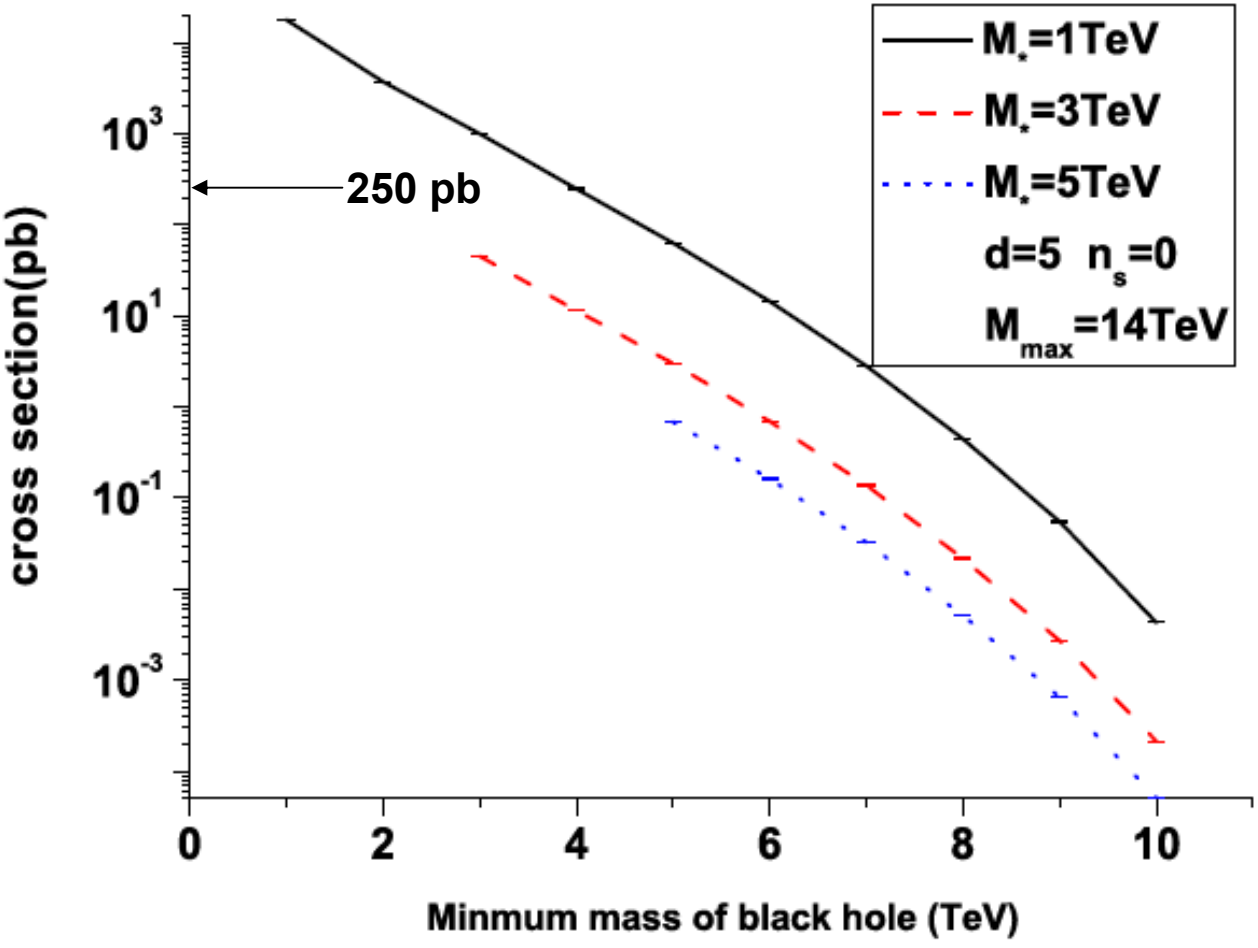
Trapped Energy Discussion

- Formation of BH is very non-linear and complicated
- $M_{BH} < \hat{s}$
- Fractions of E, p and J are lost before settling to a BH!
- Yoshino & Rychkov calculated energy loss



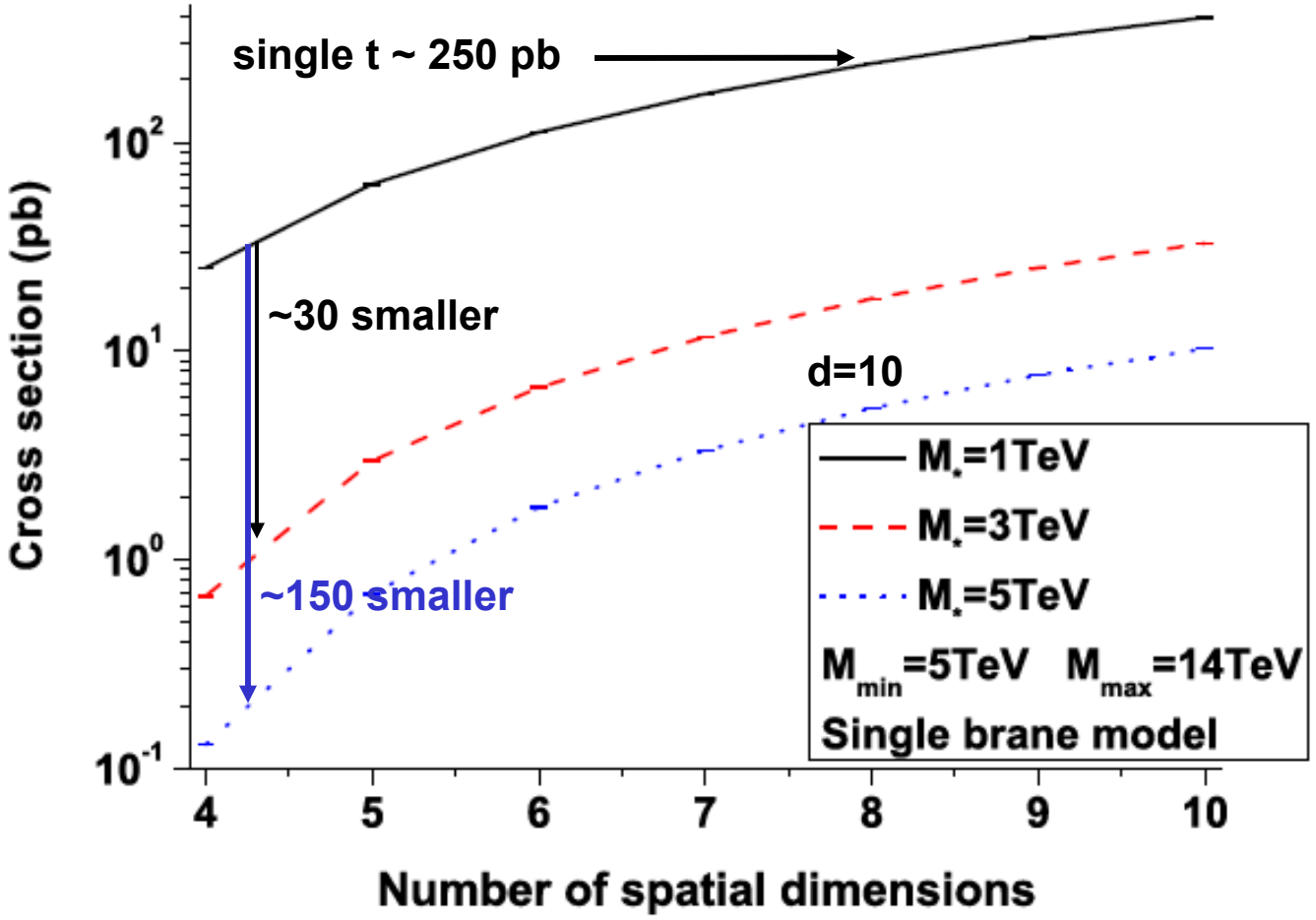
Production Cross Section for flat tensionless Brane

0711.3012 [hep-ph]



Production Cross Sections for flat, tensionless Brane

0711.3012 [hep-ph]



Split Fermion Brane Extra Dimensions

hep-ph/0605085, 0505112, 0606321, 0612018;gr-qc/0604072

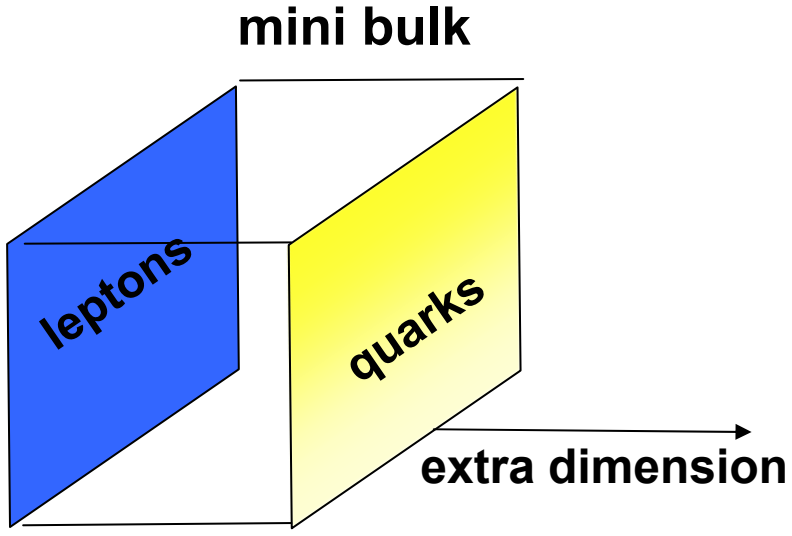
BH don't conserve B or L or flavour

- induced proton decay!
- n – nbar oscillations!
- Flavour changing neutron currents or large neutrino mixing

Introduce new symmetries

OR

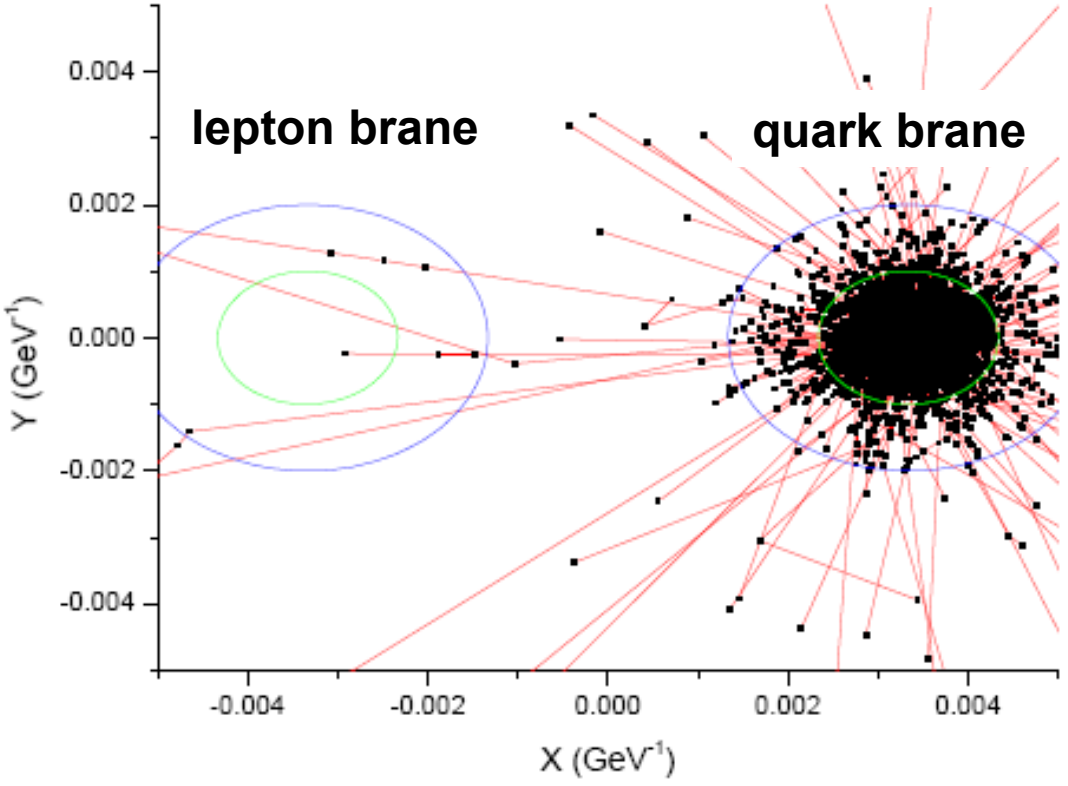
SPLIT



Split Fermion Brane Extra Dimensions

0711.3012 [hep-ph]

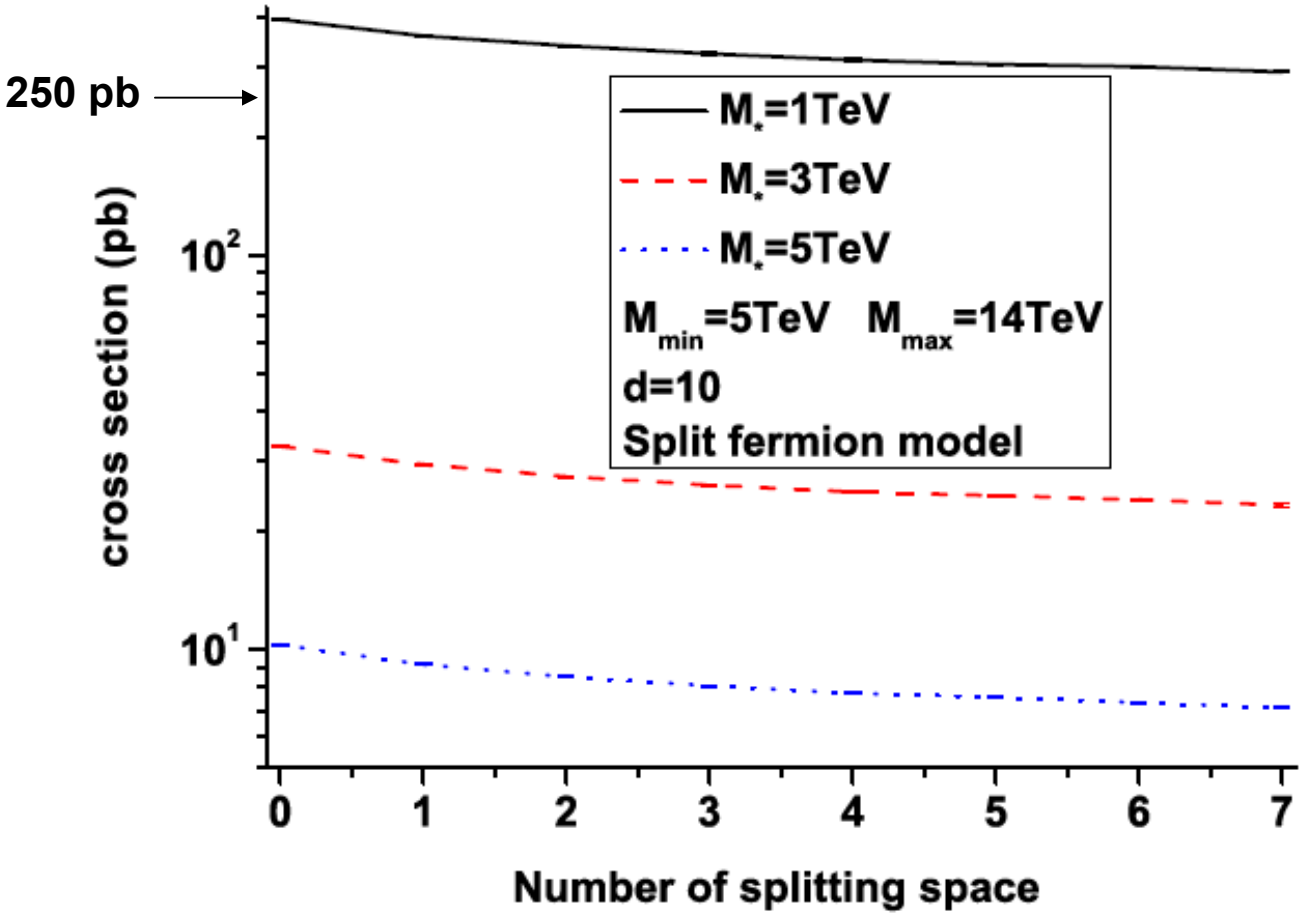
$0.002\ fm$



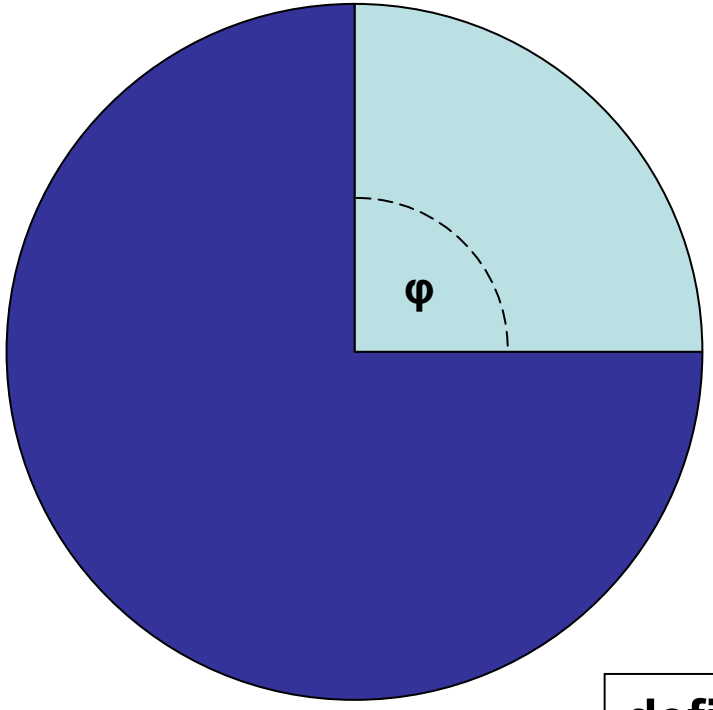
BH at the LHC will decay mainly into quarks and gluons!

Production Cross Section for Split Fermion EDs

0711.3012 [hep-ph]



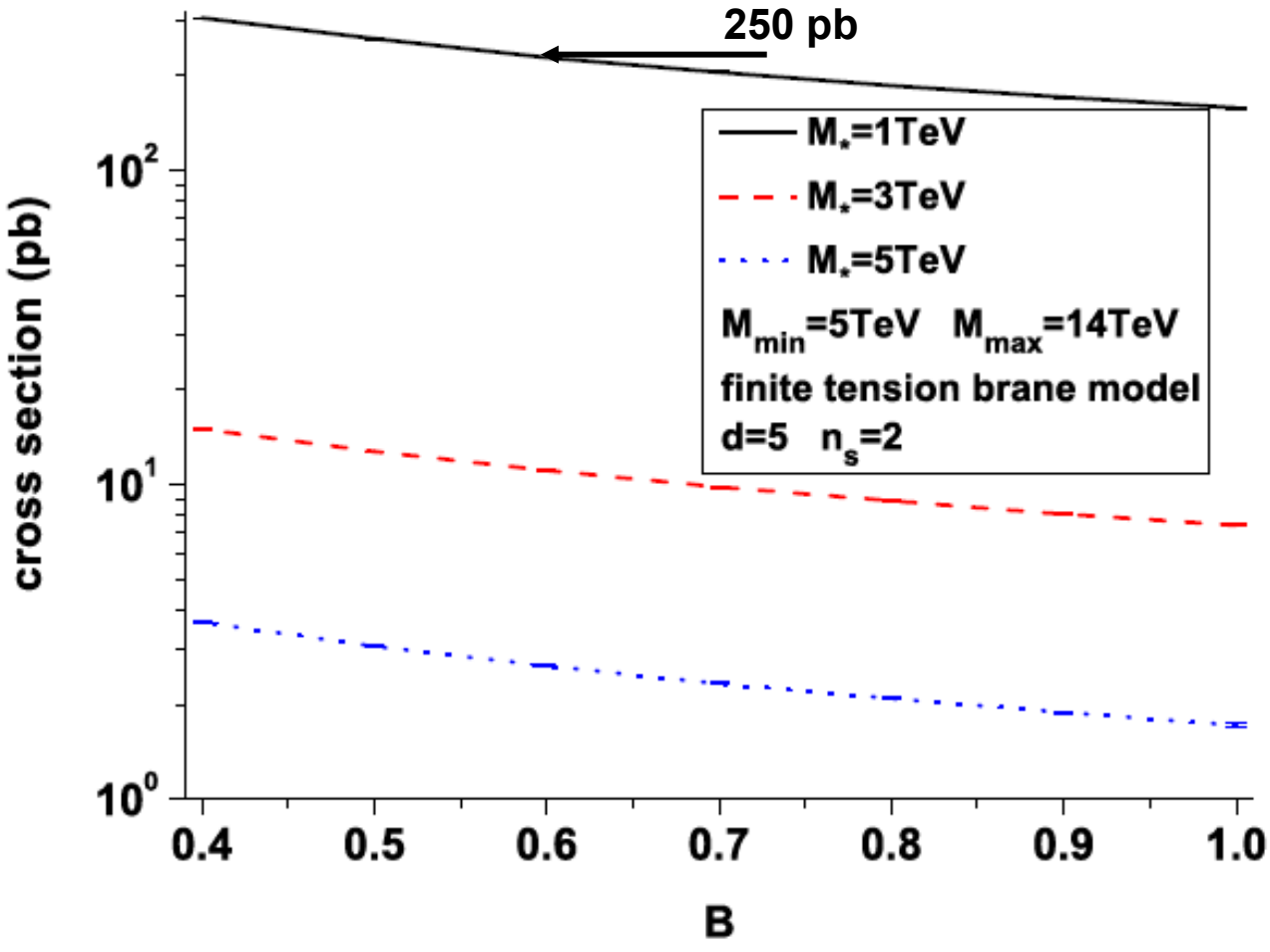
Branes with positive Tension



$$B \approx \frac{1}{\varphi}$$

deficit-angle parameter

Production Cross Section on Brane with Tension



0711.3012 [hep-ph]

scenario	q + g	leptons	W, Z	v	G	H	photons
d=4, J=0	79%	9.5%	5.7%	3.9%	0.2%	0.9%	0.8%
d=10, J=0	74%	7.7%	6.8%	3.2%	6.5%	0.7%	1.5%
d=10, J=0, n_s=7	84%	1.8%	5.4%	0.5%	6.7%	0.3%	1.6%
d=5, J=0, n_s=2, B=0.4	96%	1.6%	1.7%	0.15%	0.4%	0.2%	0.3%
d=10, J>0	78%	6.5%	9.6%	2.5%	No grey body factors	0.7%	2.6%