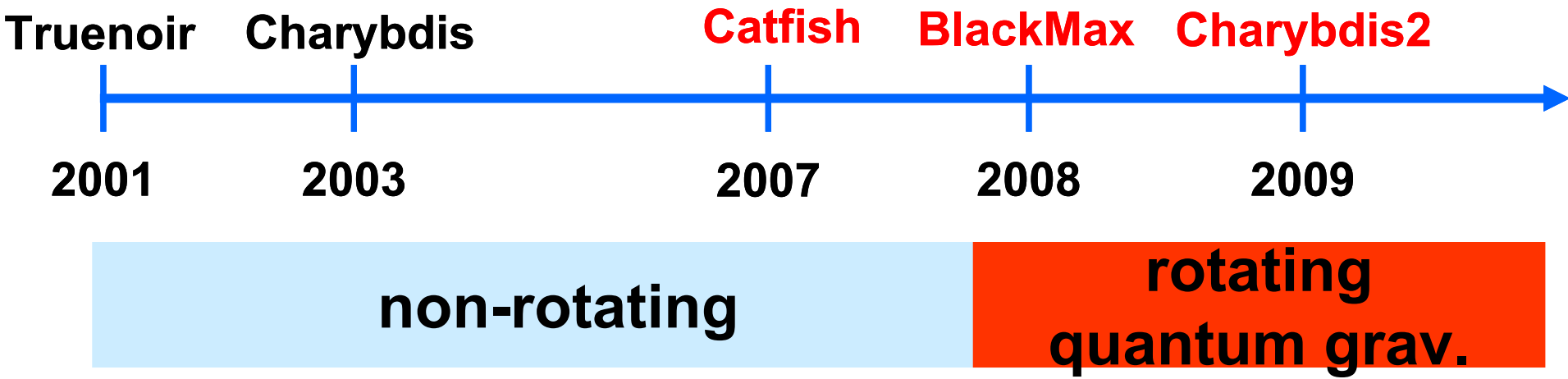


Monte Carlo Generators for Mini Black Holes

Çiğdem İşsever
University of Oxford

Hengstenberger Symposium "ED and MBH"
Heidelberg, 25.07.2009

Time Line of BH Generators



Dimopoulos & Landsberg, hep-ph/0106295

Harris, Richardson & BW, hep-ph/0307305

Black Hole Lifecycle

Formation/Balding Phase

- BH loses multipole moments – mainly graviton emission

Spin-down Phase

- Hawking radiation
- losing angular momentum before much mass

Schwarzschild Phase

- Hawking Radiation
- Loss of mass and T increase

Planck Phase

- BH temperature and/or mass reaches M_{PL}
- Quantum gravitational regime
- May decay or stay as remnant

CATFISH



M. Cavaglia, R. Godang, L. Cremaldi, D. Summers, hep-ph/0609001

<http://www.phy.olemiss.edu/GR/catfish/>

- proton-proton @ 14 TeV
- $3 \leq n \leq 7$
- CTEQ5 PDF
- $Q^2 = M_{\text{BH}}$ or inverse of r_s

CATFISH (Formation)

- Planck scale convention
 - Dimopoulos & Landsberg
- Cross sections
 - BlackDisk
 - Yoshino-Nambu TS model
 - Yoshino-Rychokov improved TS model
 - Energy which is not trapped or lost in gravitational radiation forms beam remnant
- User can set $M_{\text{BH}}^{\text{min}}$ or $M_{\text{BH}}^{\text{min}} \geq \max(M^*, M_{\text{ml}}(I_m))$

CATFISH (Evaporation)

- No balding or spin down effects
- Non-rotating spherical-symmetric BHs
- Democratic decay into SM and Higgs
- Hawking phase until mass Q_{\min}
- Momenta of particles smeared randomly by 10% to take into account quantum uncertainties

CATFISH (Final Decay)

Two choices

- Final explosion

 - 2 – 18 particles share Q_{\min} energy

- Remnant

 - Neutral

 - Charged

- Colour charge always conserved

- EM charge can be conserved or not

- Hadronization via Pythia

CATFISH (Future Plans)

- Rotating and charge BHs
- Back-reaction effects during Hawking phase
- Thermodynamic fluctuations
- SUSY effects
- Photosphere and chromosphere effects.

Generators with rotating black holes

BlackMax

D. Dai, G. Starkman, D. Stojkovic, C. Issever, E. Rizvi, J. Tseng, Phys.Rev.D77:076007,2008
<http://projects.hepforge.org/blackmax/>

■ Collider types

- proton-proton,
- proton-antiproton,
- e-e+

■ Variable beam energies

■ CTEQ6L or LHAPDF

■ $Q^2 = M_{\text{BH}}$



BlackMax

Semi classical regime

- **Rotating BHs**
- Non-rotating BHs

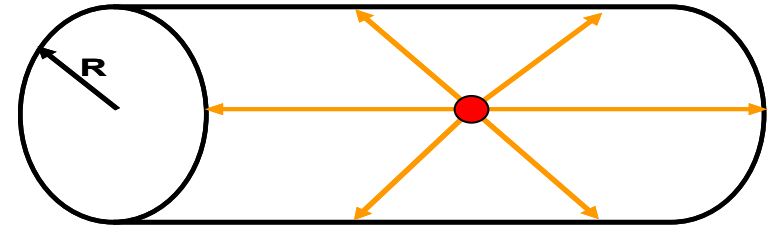
Quantum gravitational regime

- Two body final states (**Quantum BHs**)
- **String Balls**

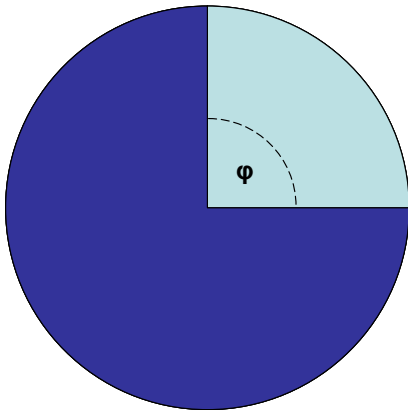
BlackMax (ED scenarios)

- 3 different ED scenarios
 - branes have finite width
- $1 \leq n \leq 7$

1) ADD

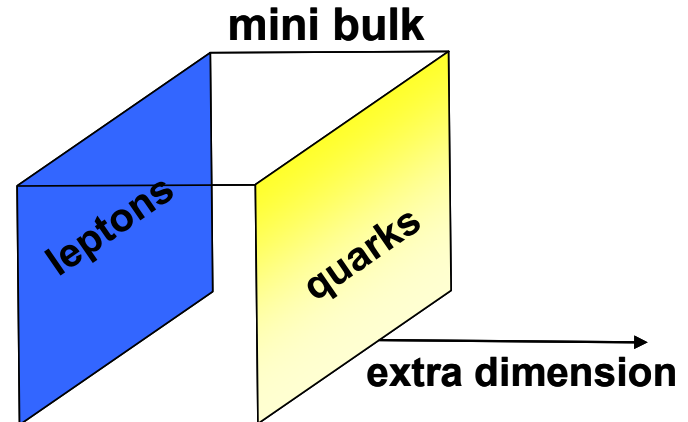


2) Tension Branes, $n=2$



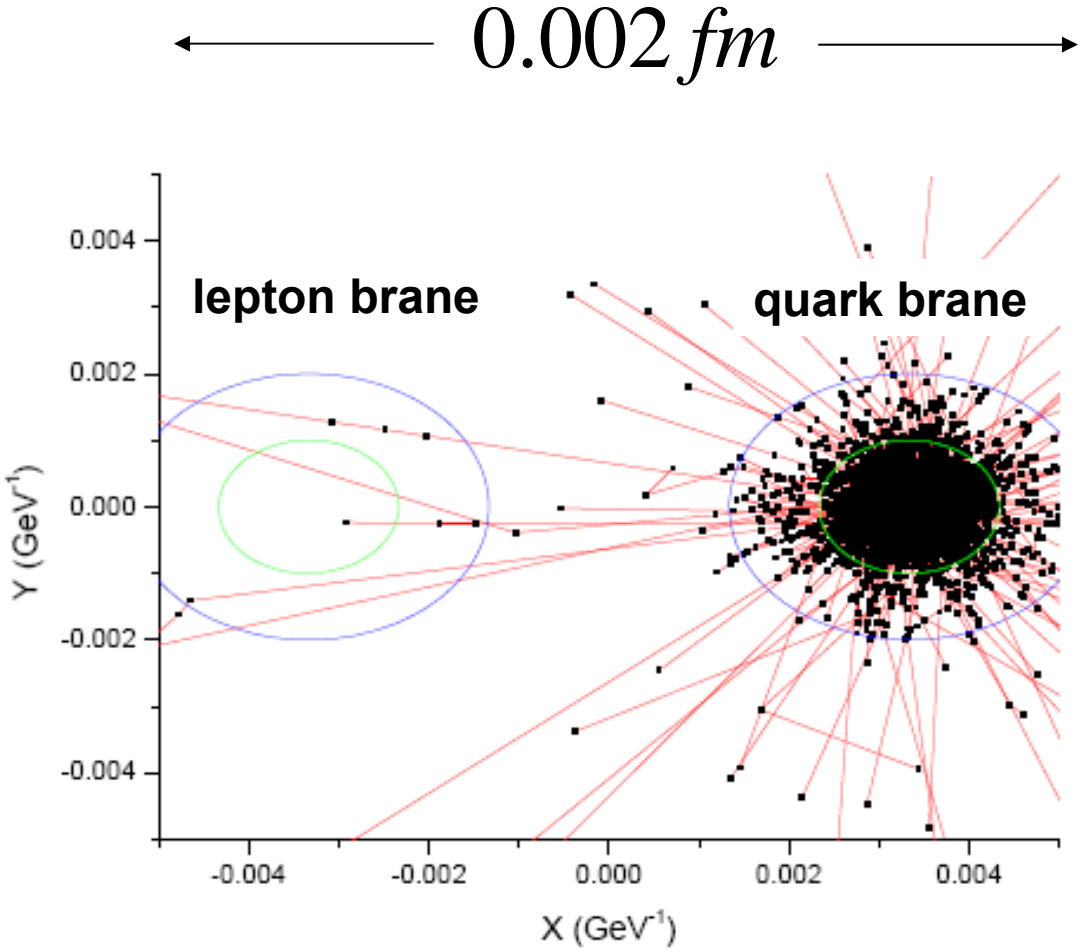
$$B \approx \frac{1}{\phi}$$

3) Split Fermion



Split Fermion Brane Extra Dimensions

0711.3012 [hep-ph]



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

scenario	q + g	leptons	W, Z	ν	G	H	photons
d=4, J=0	79%	9.5%	5.7%	3.9%	0.2%	0.9%	0.8%

scenario	q + g	leptons	W, Z	ν	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%

scenario	q + g	leptons	W, Z	ν	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%

scenario	q + g	leptons	W, Z	ν	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%

scenario	q + g	leptons	W, Z	ν	G	H	photons
d=4, J=0	79%	9.5%	5.7%	3.9%	0.2%	0.9%	0.8%
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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%	?	0.7%	2.6%

BlackMax (Formation)

■ Planck scale convention:

- **Default:** Particle Data Group, hep-ph/9811291
- Dimopoulos & Landsberg, hep-ph/0106295
- Thomas & Giddings, hep-ph/0002041
- User defined

■ Cross sections

- **Default:** $4\pi r_h^2$ (r_h = Kerr solution)
- Yoshino-Rychkov improved TS model
- πr_h^2 or $4\pi r_h^2$ (r_h = Schwarzschild solution)
- untrapped energy shed away as two gravitons

BlackMax (Formation and Balding Phase)

1. Option: User sets fractions of

- Energy loss
- Linear momentum loss
- Angular momentum loss

$$E = E_{\text{in}} f_E$$

$$P_z = P_z^{\text{in}} f_P$$

$$L = L_{\text{in}} f_L$$

2. Option: Use Yoshino-Rychkov calculations

Energy/momentum shed away via **gravitons**

BlackMax (Evaporation)

- Hawking evaporation until $M_{\text{BH}} < M_{\text{PL}}$
 - up-to-date gray-body (GB) factors
 - no graviton GB on the market
 - T variable
 - Rotation axis is varied

Optional

- suppress accumulation of large charges
- suppress accumulation of large L
- B, L and F (non)conservation

BlackMax (Final Burst)

■ BH evaporates into lowest number SM particles

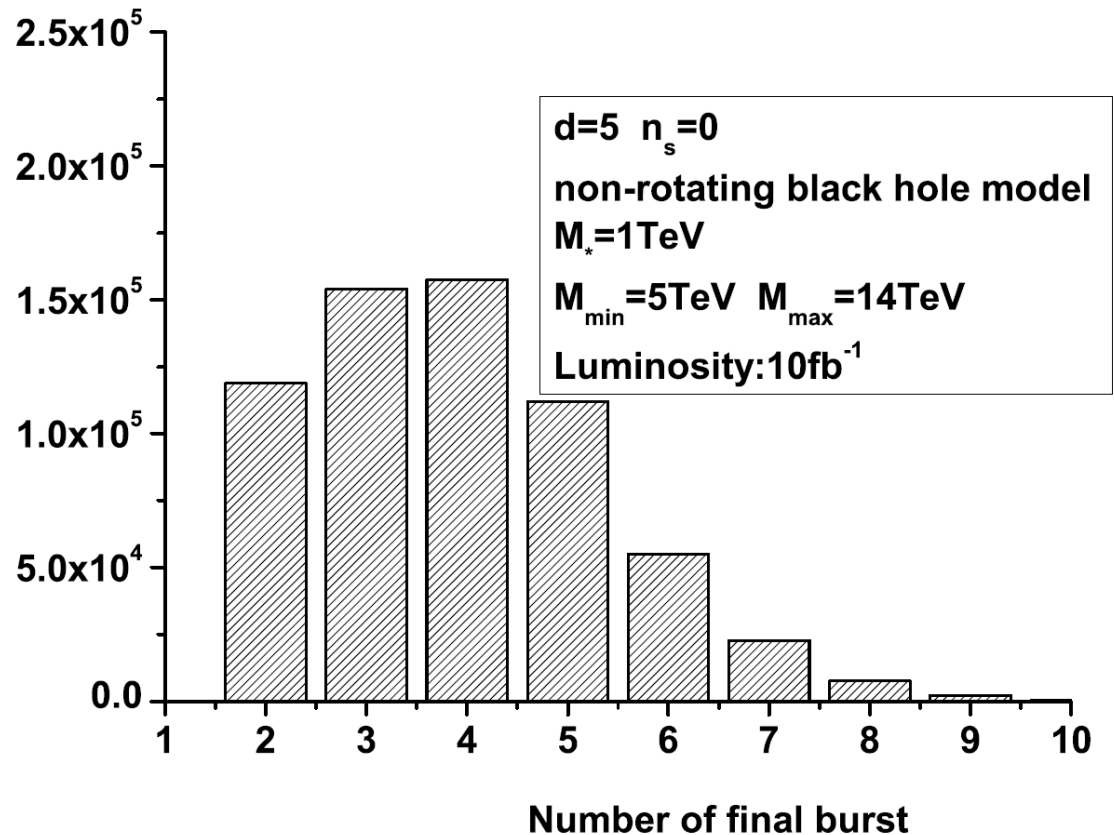
■ Conserving

■ energy,

■ momentum

■ B,L,F,

■ charges



Charybdis2

J. Frost, J. Gaunt, M. Sampaio, M. Casals, S. Dolan, M. Parker, B. Webber,
arXiv:0904.0979 [hep-ph]

<http://projects.hepforge.org/charybdis2/>

- Collider types
 - proton-proton,
 - proton-antiproton
- Variable beam energies
- PDFLIB or LHAPDF
- $Q^2 = M_{\text{BH}}$ or inverse r_h



Charybdis2

- $2 \leq n \leq 6$
- 1 ED scenarios (branes have 0 width)
 - ADD flat
- General relativistic black holes
 - **Rotating**
 - Non-rotating
- Quantum Gravitational Regime
 - Two body final states (**Quantum BHs**)
 - More body states
 - **String balls**

Charybdis2 (Formation)

■ Planck Scale convention:

- **Default:** Particle Data Group, hep-ph/9811291
- Dimopoulos & Landsberg, hep-ph/0106295
- Thomas & Giddings, hep-ph/0002041

■ Cross Sections

- Yoshino-Rychkov TS model with a probability distribution favoring smaller mass losses
- πr_h^2 (r_h = Schwarzschild solution)
- trapped energy shed away as a “net-graviton”

Charybdis2 (Evaporation)

- Hawking evaporation ends if
 - $\langle N \rangle \leq \text{NBODY}-1$
 - or emission of kinematically not allowed particle
 - or $M_{\text{BH}} < M_{\text{PL}}$
- Uses all up-to-date gray-body factors for
- T and rotation axis varies (default)
- T and rotation axis constant (optional)
- B, L and F are conserved

Charybdis2 (Final Stage)

■ Fixed Multiplicity Model

- Fix number of particles (NBODY = 2 – 5)
- Isotropic decay
- NBODY>2: isotropic phase phase or use hawking spectrum

■ Variable-multiplicity Model

- Poisson distribution

$$P_{\delta t}(n) = e^{-\langle N \rangle} \frac{\langle N \rangle^n}{n!}$$

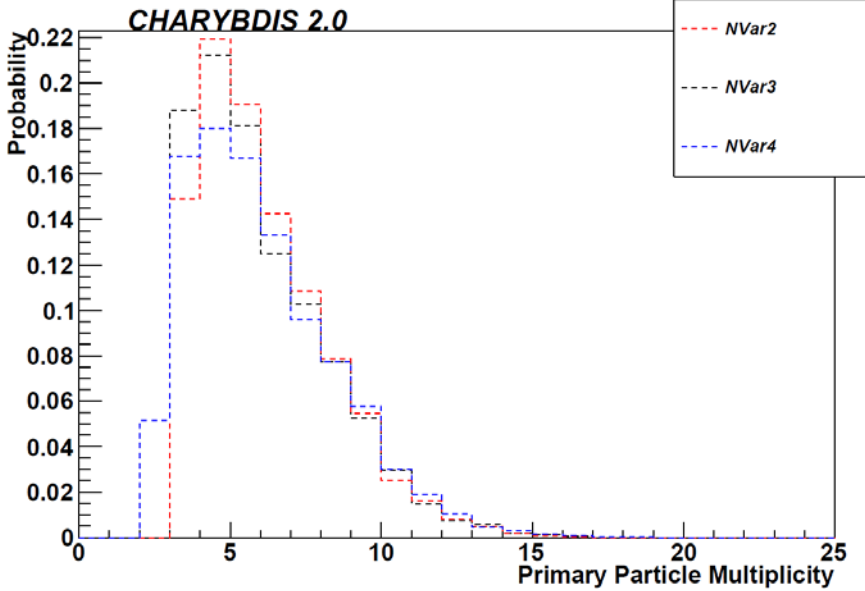
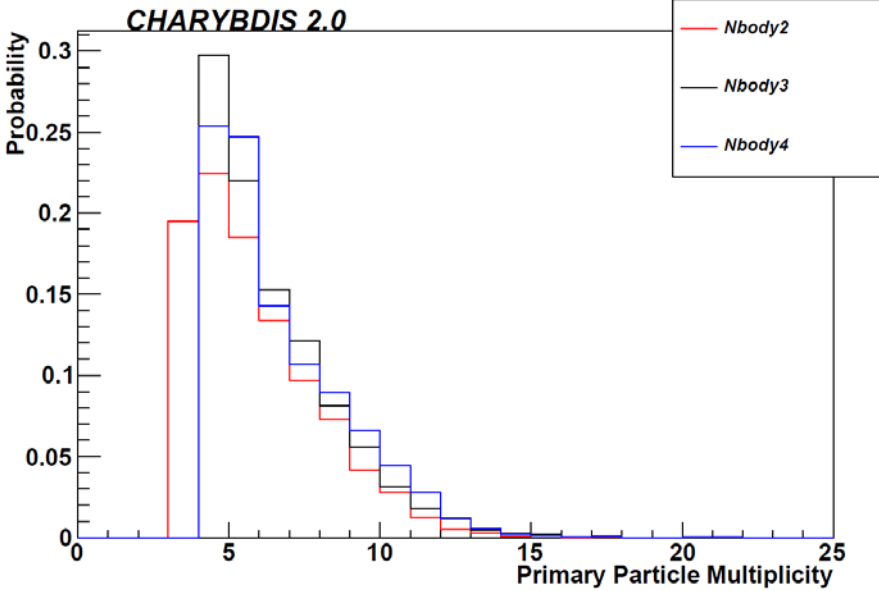
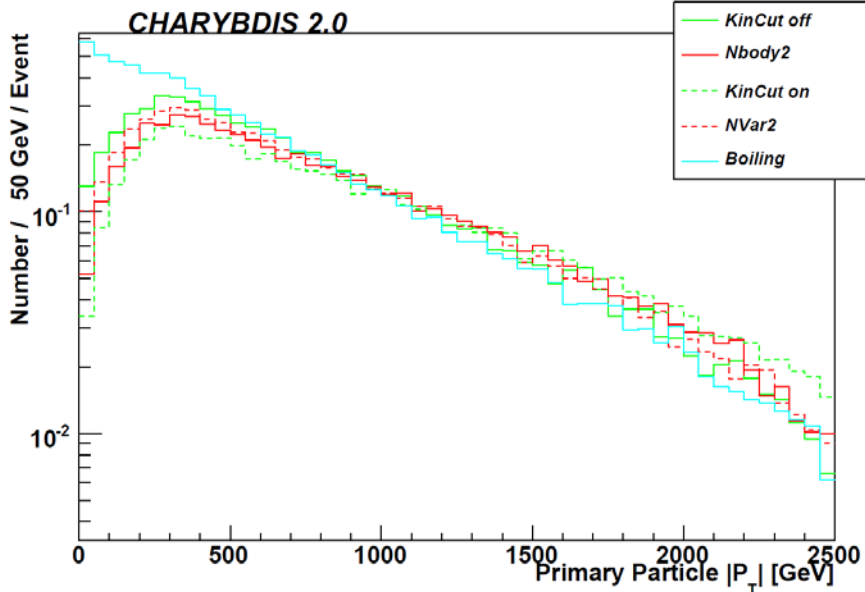
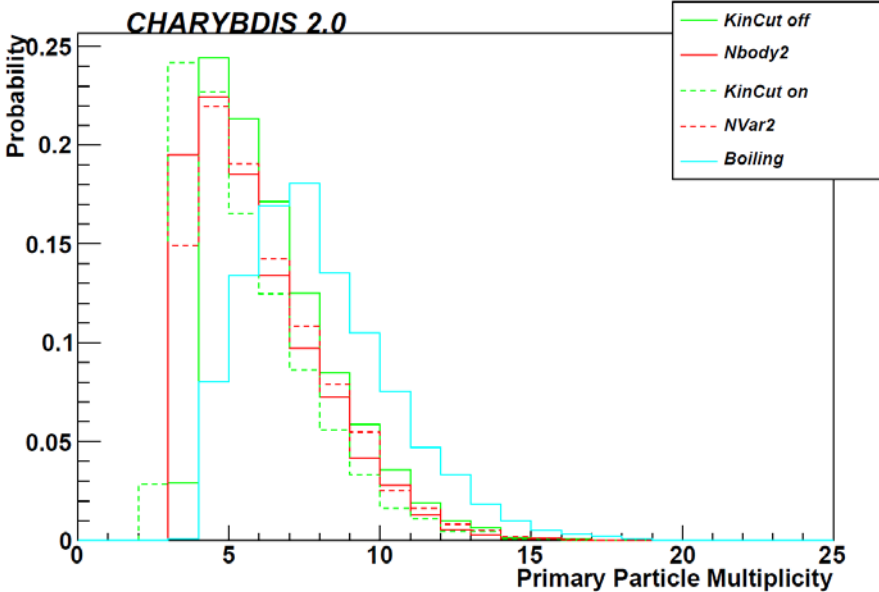
■ Boiling Model (String motivated)

- Evaporation continues a la hawking until $T > T_{\text{MAX}}$
- Evaporation continues with $T=T_{\text{MAX}}$ until mass $< R_{\text{MIN}}$
- Decay into fix number of particles

■ Stable Remnant

- Colourless, $Q = 0, -1$ or $+1$
- Baryon number, $B = 0$
- Behaviour: heavy particle with conventional interactions
- This option is slow

Charybdis2 (Final Burst)



Feature	Catfish	BlackMax	Charybdis2
Rotation	no	yes	yes
PDFs	CTEQ5	CTEQ6/LHAPDF	PDFLIB/LHAPDF
Beam particles	p	p,anti-p, e-, e+	p and anti-p
Beam energy	7 TeV	Variable	variable
Extra dim.	3 to 7	1 to 7	2 to 6
Planck scale	DL	PDG, DL, TG, user	PDG, DL, TG
Inelastic effects	yes	yes	yes
Temperature	variable	variable	variable
Final Burst	2 choices	1 choice	4 choices
Remnant	yes	no	yes
ED models	1	3	1
Quantum Gravity	no	QBH + Stringballs	QBH + Stringballs
Output	Pythia	LHE	LHE
# parameters	15	>29	29

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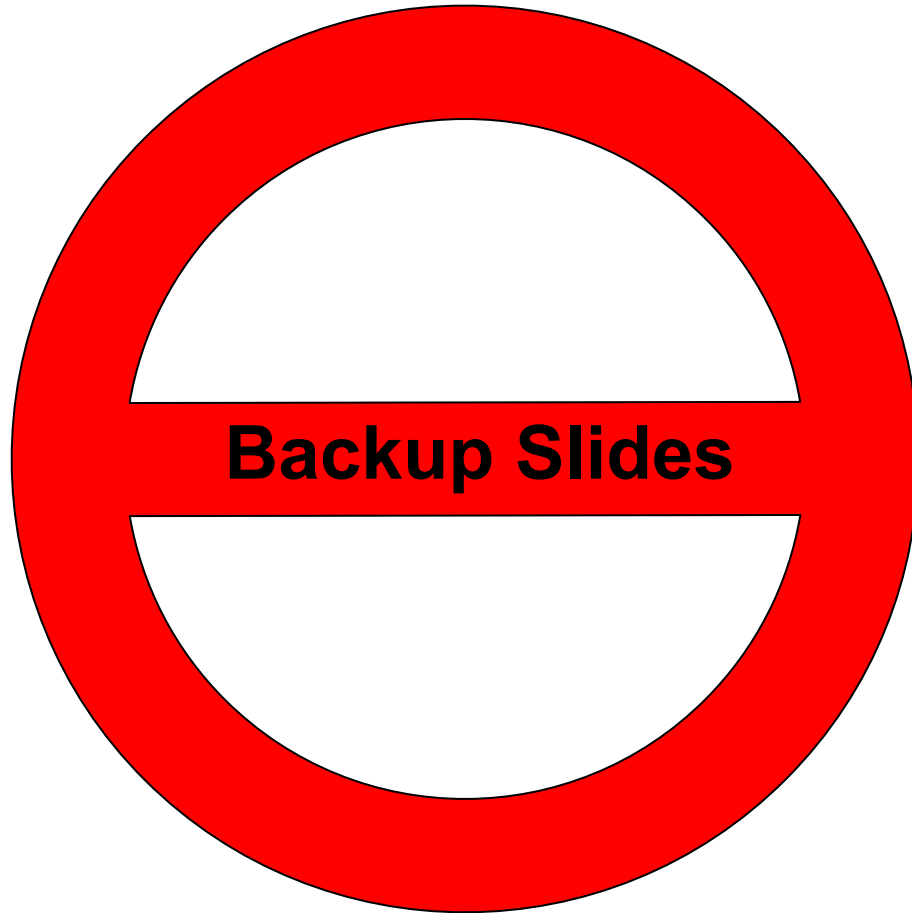
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Inelastic effects	yes	yes	yes
Temperature	variable	variable	variable
Final Burst	2 choices	1 choice	4 choices
Remnant	yes	no	yes
ED models	1	3	1
Quantum Gravity	no	QBH + Stringballs	QBH + Stringballs
Output	Pythia	LHE	LHE
# parameters	15	>29	29

Conclusions

- Black hole generator evolved very much
 - Include rotation
 - Various extra dimension models
 - Different final bursts options
 - Quantum gravitational regime
- Study model dependencies
 - Signatures
 - Acceptances
- Missing: graviton graybody factors rotating BHs
- We need to define bench mark points!
 - Discussion started @ this workshop

Thank you very much for this very nice workshop!!



Backup Slides

Planck Scale Definitions

$$M_D^{n+2} = (2\pi)^n / 8\pi G_D$$

PDG definition

$$M_{DL}^{D-2} = 1 / G_D$$

Dimopoulos & Landsberg

$$M_{GT}^{n+2} = (2\pi)^n / 4\pi G_D$$

Giddings & Thomas

$$G_D = G * (2\pi R)^n$$

D-dimensional Newton Gravity constant

$$D = n + 4$$

Total number of dimensions

hep-ph/0106219,0110127,0007016,0110067