QUA AT

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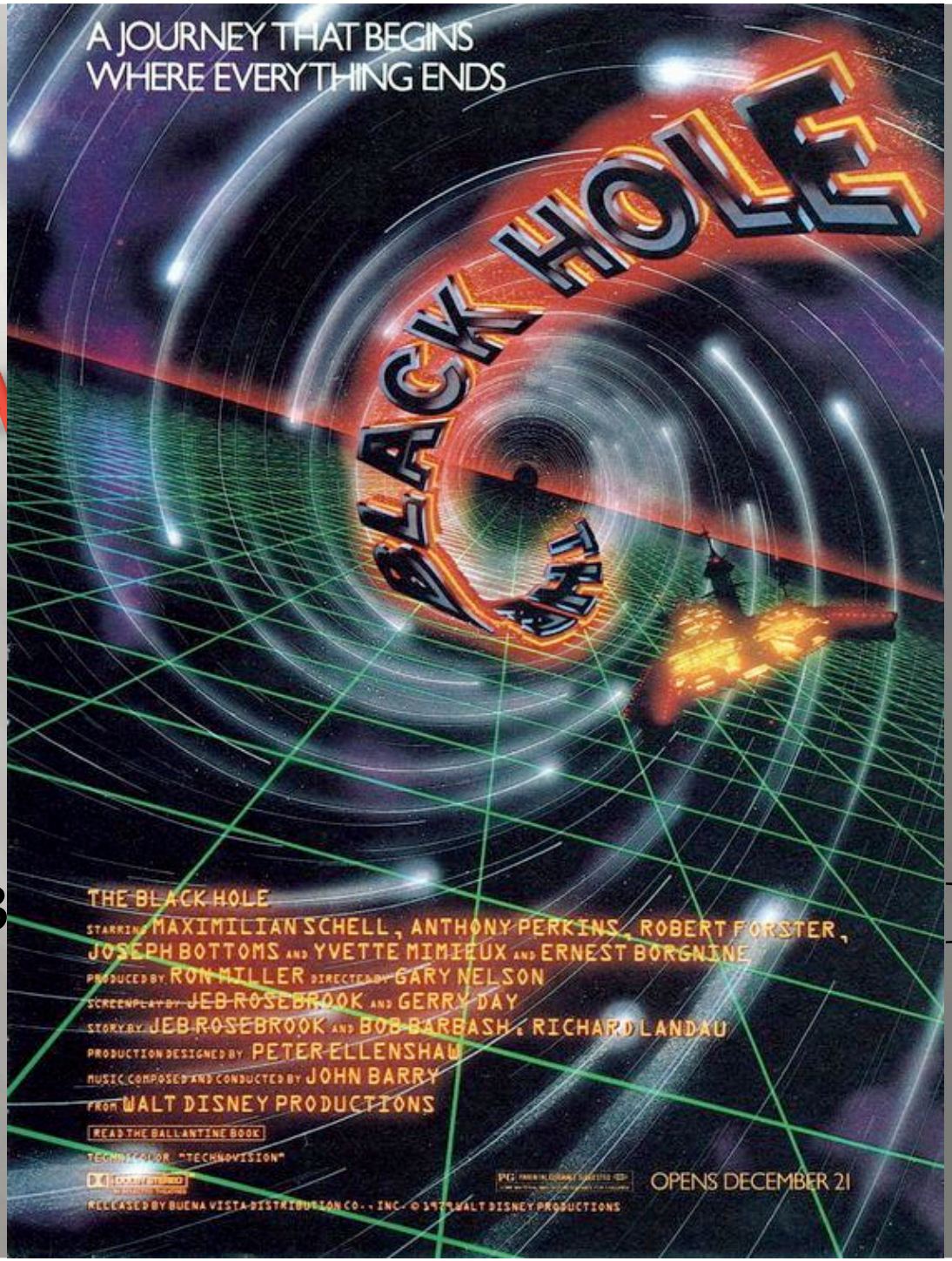
A JOURNEY THAT BEGINS
WHERE EVERYTHING ENDS
THE BLACK HOLE
STARRING MAXIMILIAN SCHELL, ANTHONY PERKINS, ROBERT FORSTER,
JOSEPH BOTTOMS AND YVETTE MIMIEUX AND ERNEST BORGNINE
PRODUCED BY RON MILLER DIRECTED BY GARY NELSON
SCREENPLAY BY JEB ROSEBROOK AND GERRY DAY
STORY BY JEB ROSEBROOK AND BOB BARBASH & RICHARD LANDAU
PRODUCTION DESIGNED BY PETER ELLENSHAW
MUSIC COMPOSED AND CONDUCTED BY JOHN BARRY
FROM WALT DISNEY PRODUCTIONS
READ THE BALLANTINE BOOK
TECHNICOLOR "TECHNOVISION"
PG
OPENS DECEMBER 21
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Where does this all come from?

- Low Scale Quantum Gravity as a solution of the hierarchy problem a la ADD or RS
- Many experimental signatures eg KK modes
- Most interesting signature is obvious
  - BLACK HOLES!!!!! (circa 2001)
    - (Dimopoulos, Landsberg, Giddings, Thomas)

Many ramifications both scientific and unscientific

Hot Topic (at least in the "press")

"World's Largest Supercollider Could Destroy the Universe"

"Local man-made black holes could end the world"

http://www.lhcdefense.org/

LARGE HADRON COLLIDER –
THE LEGAL DEFENSE FUND SITE
The Legal Intervention Donation Site

Dear Elected Official,

As a concerned citizen of planet Earth and a registered voter in your district, I am deeply concerned about the potential risks involved in collider research that is being proposed for the Large Hadron Collider (LHC) located at the CERN research facility along the France / Switzerland border.

Please explain to me why the United States is supporting with tax dollars supplied by tax payers such as myself, research that could have such potentially horrendous consequences. I would like to know your opinion and those of your constituents on this subject. You may read more about this, if you have not already, at www.LHCdefense.org

Respectfully yours,

A Concerned Citizen

From the CERN website

"Microscopic black holes will not eat you..."

http://public.web.cern.ch/public/Content/Chapters/AboutCERN/CERNFuture/LHCSafe/LHCSafe-en.html

This is a direct quote!

Also reassuring:

"... nor will stranglets"

Speculative hypotheses amongst physicists as well…

arXiv.org > hep-ph > arXiv:0710.2696
Search or Article-id
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Citations
SLAC-SPIRES HEP (refers to, cited by, arXiv reformatted)
previous | next
High Energy Physics - Phenomenology
Title: Time Machine at the LHC
Authors: I.Ya. Aref'eva, I.V. Volovich
(Submitted on 15 Oct 2007)
Abstract: Recently, black hole and brane production at CERN's Large Hadron Collider (LHC) has been widely discussed. We argue that if the scale of quantum gravity is of the order of few TeVs, proton-proton collisions at the LHC could lead to the formation of time machines (spacetime regions with closed timelike curves). One model for the time machine is a traversable wormhole. We argue that the traversable wormhole production cross section at the LHC is of the same order as the cross section for the black hole production. Traversable wormholes assume violation of the null energy condition (NEC) and an exotic matter similar to the dark energy is required. Decay of the wormholes/time machines and signatures of time machine events at the LHC are discussed. Comments: 10 pages, LATEX Subjects: High Energy Physics - Phenomenology (hep-ph); General Relativity and Quantum Cosmology (gr-qc); High Energy Physics - Theory (hep-th)
Cite as: arXiv:0710.2696v1 [hep-ph]
Submission history
From: Aref'eva Irina [view email]
[v1] Mon, 15 Oct 2007 16:38:54 GMT (11kb)

Which authors of this paper are endorsers?
Link back to: arXiv, form interface, contact.

Scientific Conventional Wisdom

Gigantic rate (1 per second)

Spectacular Signature

- Hawking radiation(explosion of particles)

Black Holes at ATLAS

Outline of talk

- Review where the conventional scientific wisdom came from
- Discuss why more realistic estimates throw cold water on the original hopes
- Propose alternate way quantum gravity / "Black Holes" should be searched for in experiments

- We will suspend EFT disbelief about the normal concerns in ADD and literal RS1 for the time being

Higher Dimensional Black Holes

$$\frac{1}{16\pi G_D}\int d^{D+1}x\sqrt{g}R$$

Myers Perry Solution

D+1 dimensional flat space Schwarzschild
n=number of extra dimensions

$$r_s = \left(\frac{M_{BH}\Gamma\left(\frac{n+3}{2}\right)}{L_N(n+2)2\pi^{\frac{n+3}{2}}}\right)^{\frac{1}{n+1}}$$

Higher Dimensional Black Holes

For our purposes we focus on ADD n=6 and literal RS1

$$r_s \sim \frac{1}{M}\left(\frac{M_{BH}}{M}\right)^{\frac{1}{7}} \qquad r_s \sim \frac{1}{M}\left(\frac{M_{BH}}{M}\right)^{\frac{1}{2}}$$

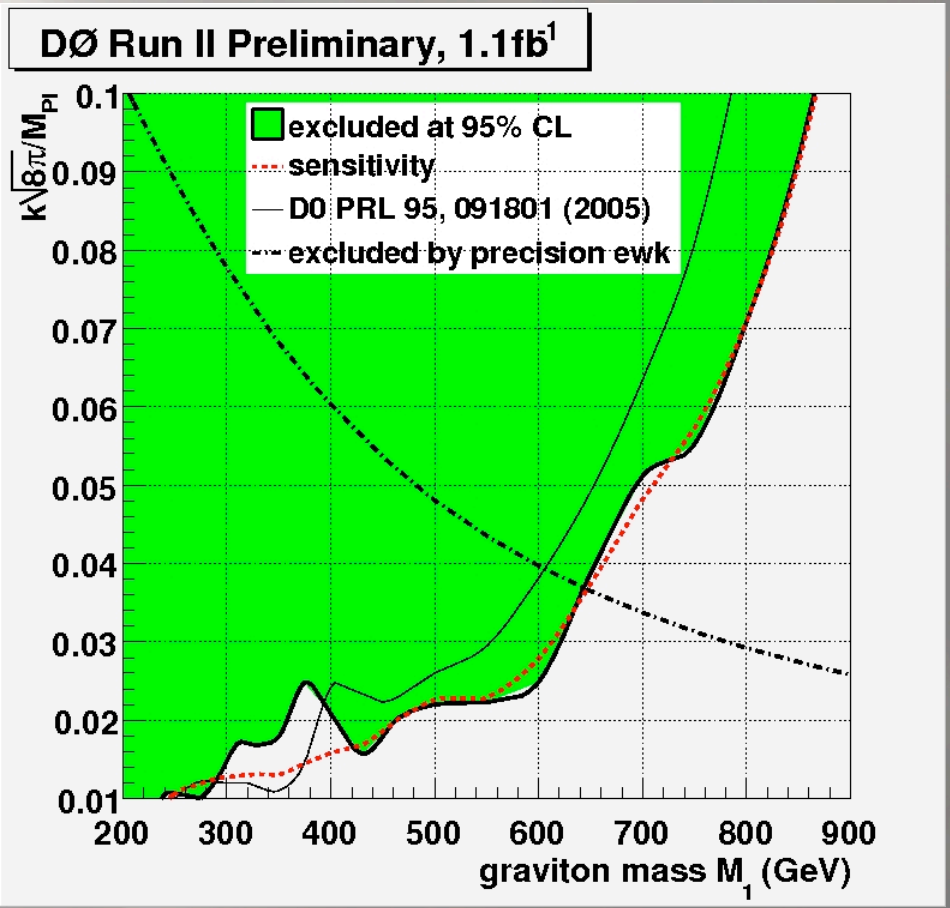
For RS black holes there is an added subtlety

$$\frac{1}{M} \lesssim r_s \lesssim \frac{1}{k}$$

$$M \lesssim E \lesssim \left(\frac{M}{k}\right)^2 M$$

Bounds Used

- ADD n=6 M_D ~900 GeV



- M~500 GeV

Black Hole Production

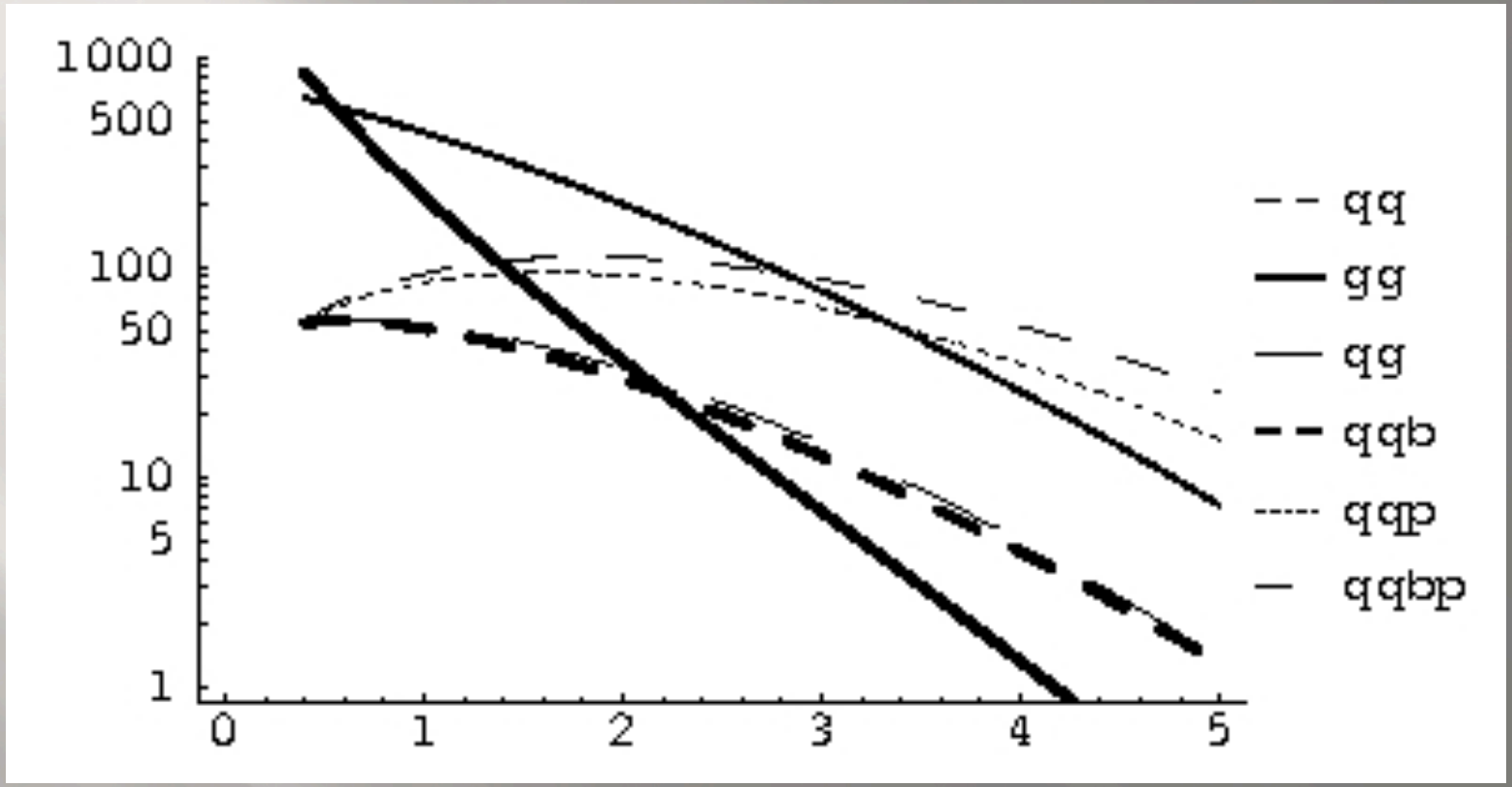
$$\sigma(E) \sim \pi r_s(E)^2 \sim \frac{1}{M^2}\left(\frac{E}{M}\right)^{\alpha}$$

$$\alpha \leq 1$$

M ~1 TeV σ ~100 pb

BH production is gigantic because of no small numbers!!

Gigantic Cross Section Right?



Scale at which production occurs is *crucially* important to rate

When is a black hole a black hole?

$$r_s = \left(\frac{M_{BH}}{M^3 3\pi^2}\right)^{\frac{1}{2}}$$

M is the appropriately warped 5d Planck scale

E>M but what M??

$$r_s = \left(\frac{8M_{BH}}{M_P^3 3\pi}\right)^{\frac{1}{2}}$$

$$r_s = \left(\frac{2M_{BH}}{M_D^3 3\pi}\right)^{\frac{1}{2}}$$

What is the physical production scale that sets black hole production?

Criteria for Black Hole

Define a quantity $x_{min} \equiv \frac{E}{M}$

One criteria could be $\lambda_c \sim \frac{4\pi}{E} < r_s$

$x_{min} > 4.1$ $x_{min} > 16$

ADD n=6 RS

Already done??

Criteria for Black Hole

$$r_s = \frac{1+n}{4\pi T} \qquad S = \frac{1+n}{2+n}\frac{M_{BH}}{T}$$

$$\langle N \rangle = \rho \left(\frac{4\pi k(n)}{2+n} \right) \left(\frac{M_{BH}}{M_D} \right)^{\frac{n+2}{n+1}}$$

Is it thermal?

Criteria for Black Hole

$$\langle N \rangle \gg 1$$

$$\left|\frac{\partial T}{\partial M}\right| \ll 1$$

$$\frac{\partial T}{\partial M} \sim \frac{1}{(n+2)S} \sim \chi_{min}^{\frac{n+2}{n+1}}$$

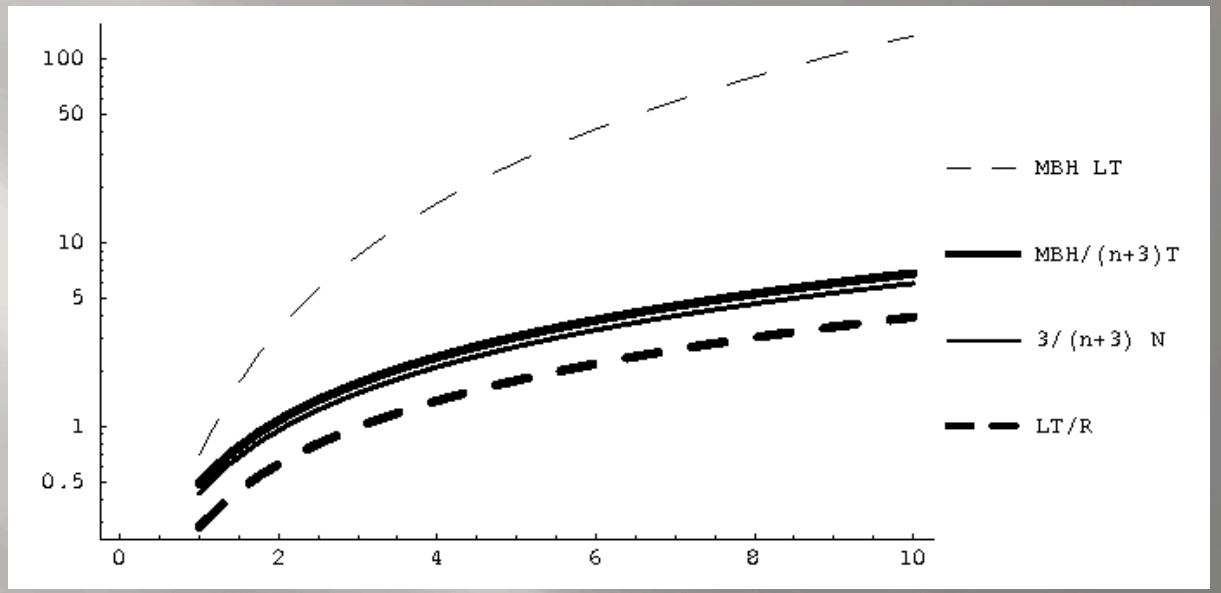
$$(n+3)T \ll M$$

$$\frac{\partial M}{\partial N} \ll M$$

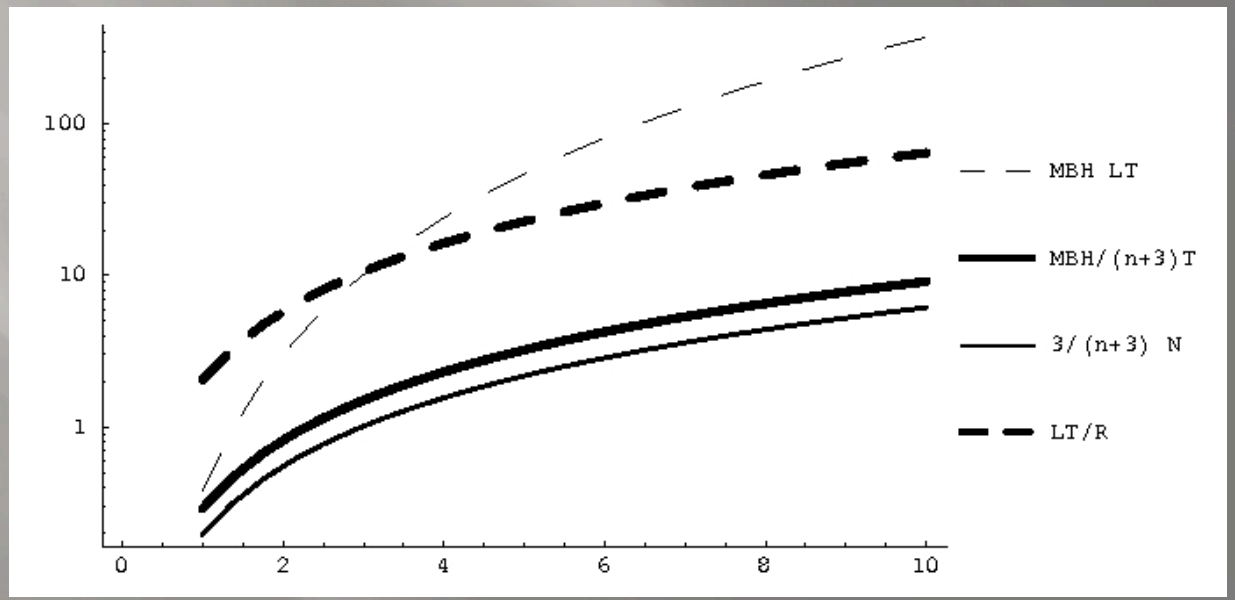
$$\tau M \gg 1$$

$$\frac{\tau}{r_s} \gg 1$$

RS

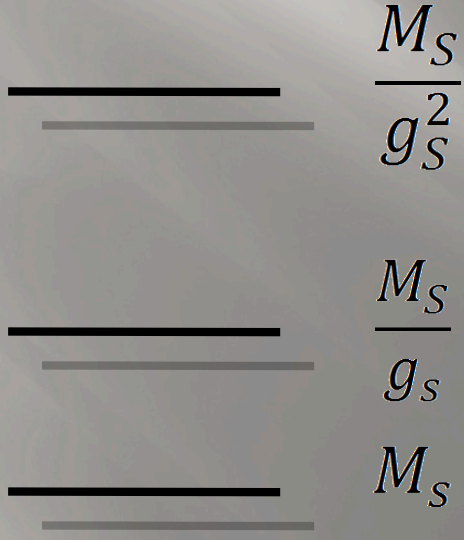

100
50
10
5
1
0.5
0
2
4
6
8
10
MBH LT
MBH/(n+3)T
3/(n+3) N
LT/R

ADD n=6


100
10
1
0
2
4
6
8
10
MBH LT
MBH/(n+3)T
3/(n+3) N
LT/R

Does string theory give any insight into the correct scale?

- So far we have assumed there is only one scale
  - In string theory we have an additional scale M_S and coupling g_s
- Multiple regimes stringy, "string ball", BH/String crossover point

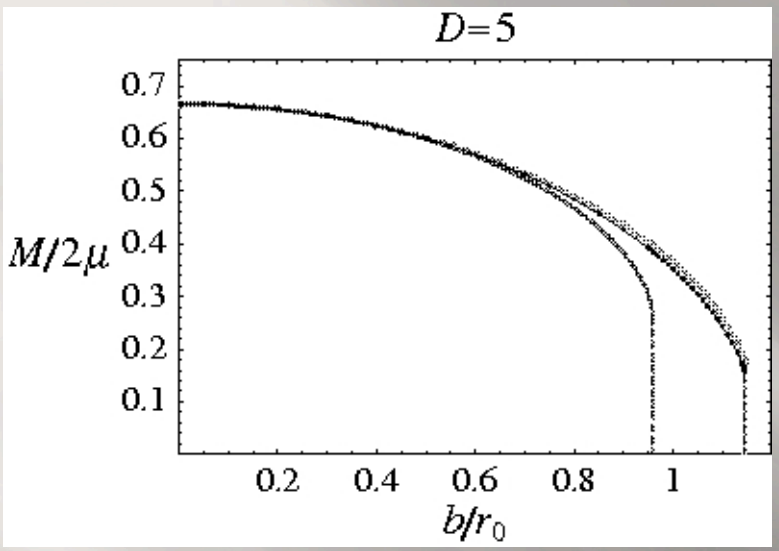


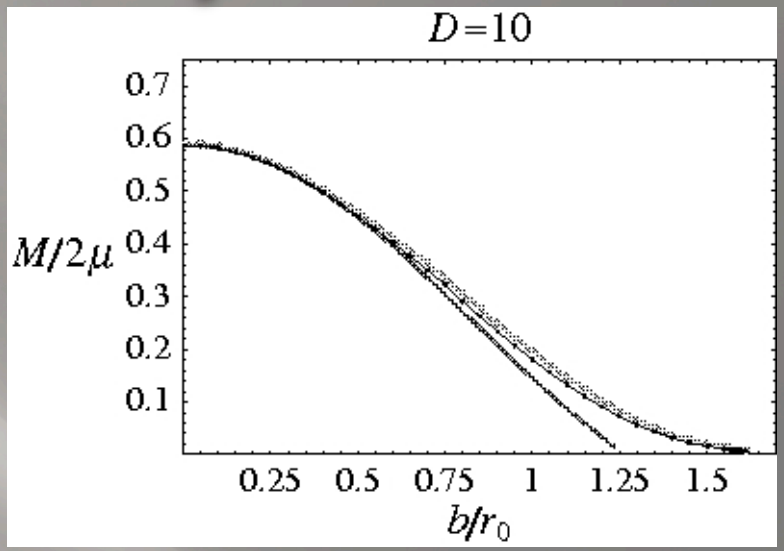
Dimopoulos and Emparan

- Nothing to say when g_s ~1

D'eath, Payne,Giddings, Eardley, Yoshino, Nambu, Rychkov

Inelasticity





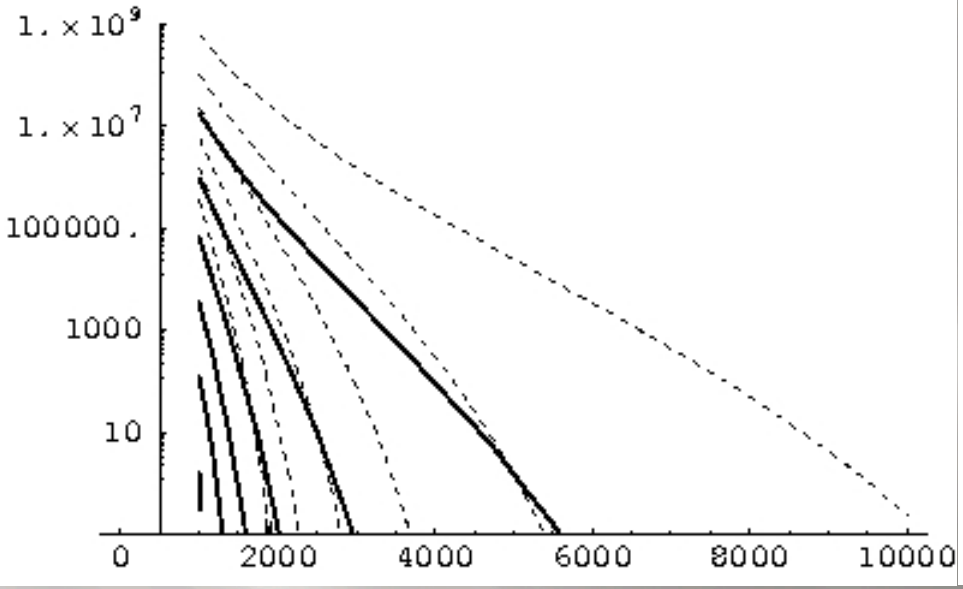
Collide two Aichelburg-Sexl shock waves look for trapped surface

Not all the energy initially available goes into your final BH

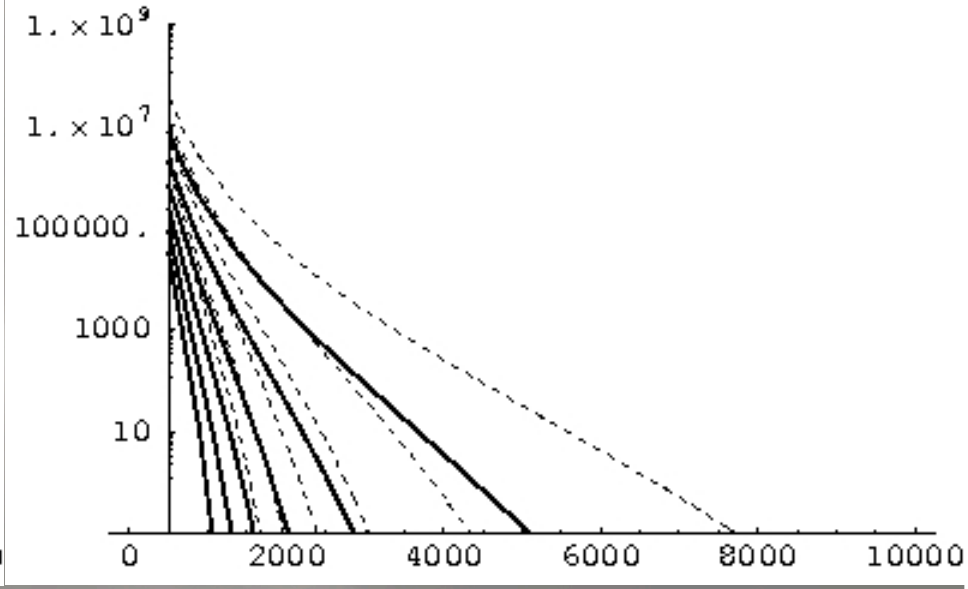
$$\sigma(pp \to X) = \sum_{i,j} \int dx_1 dx_2 f_i(x_1) f_j(x_2) \hat{\sigma}_{ij \to X}$$

Change to an impact parameter weighted average to include inelasticity

Total Black Hole Cross Section in fb



ADD n=6



RS1

That's certainly different than 1 per second…

Black Hole Decays

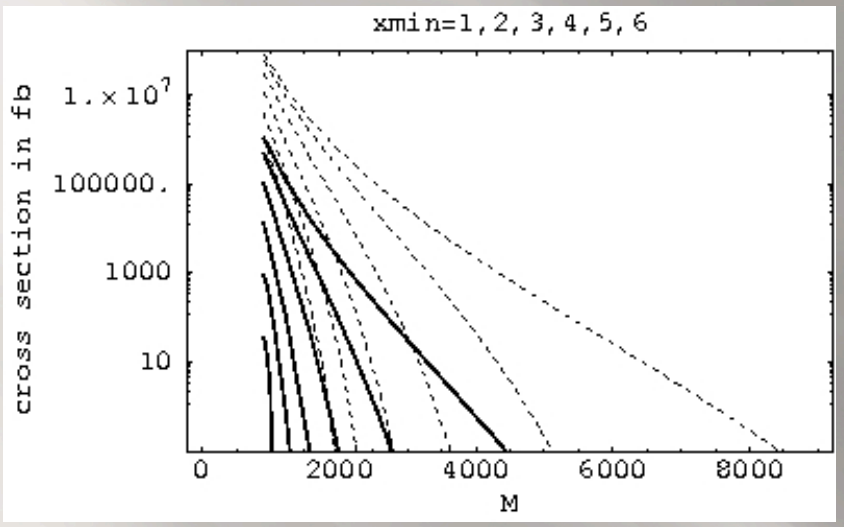
Bekenstein

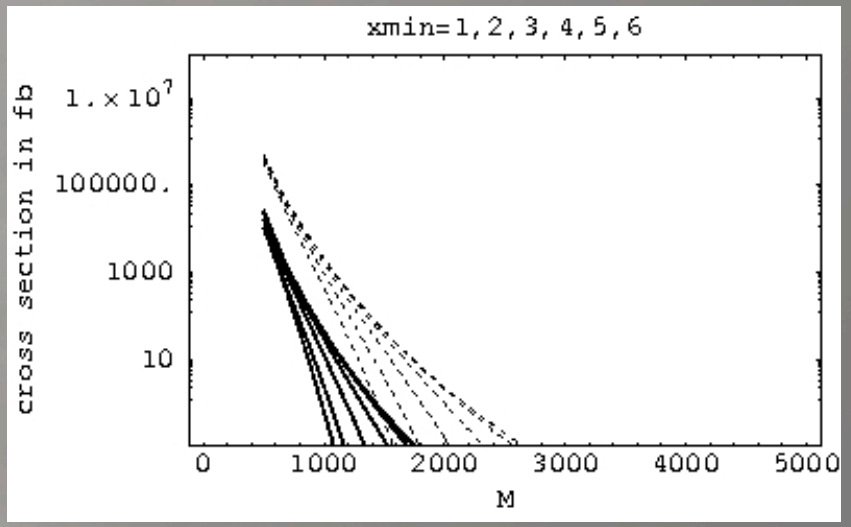
Parameterize decays by a Poisson distrbution

$$P_i = e^{-\langle N \rangle} \frac{\langle N \rangle^i}{i!}$$

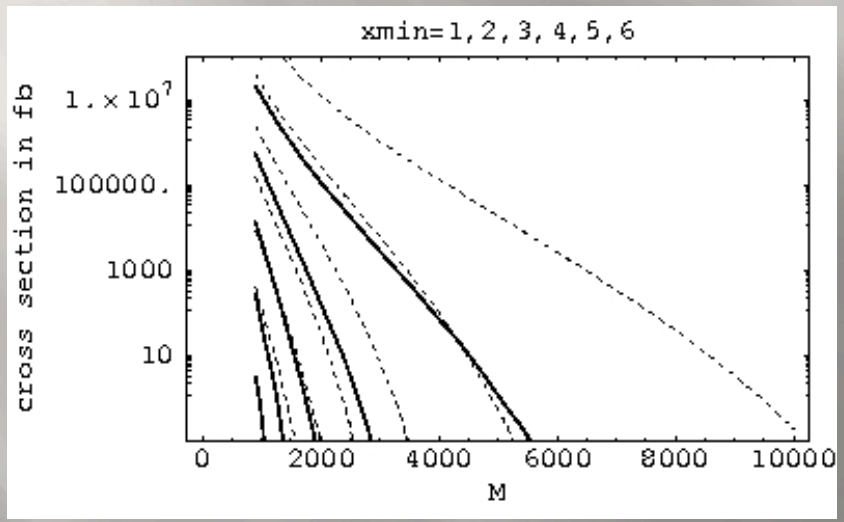
$$\langle N \rangle = \rho \left(\frac{4\pi k(n)}{2+n} \right) \left(\frac{M_{BH}}{M_D} \right)^{\frac{n+2}{n+1}}$$

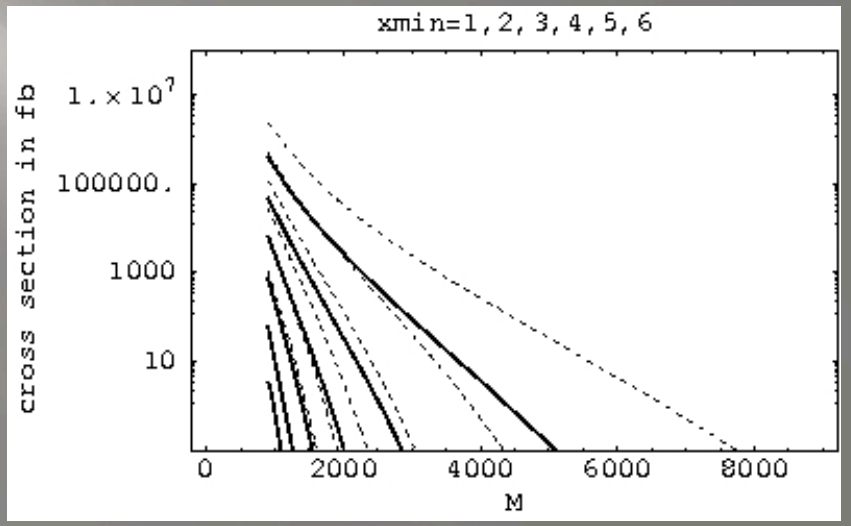
6 particles





2 particles

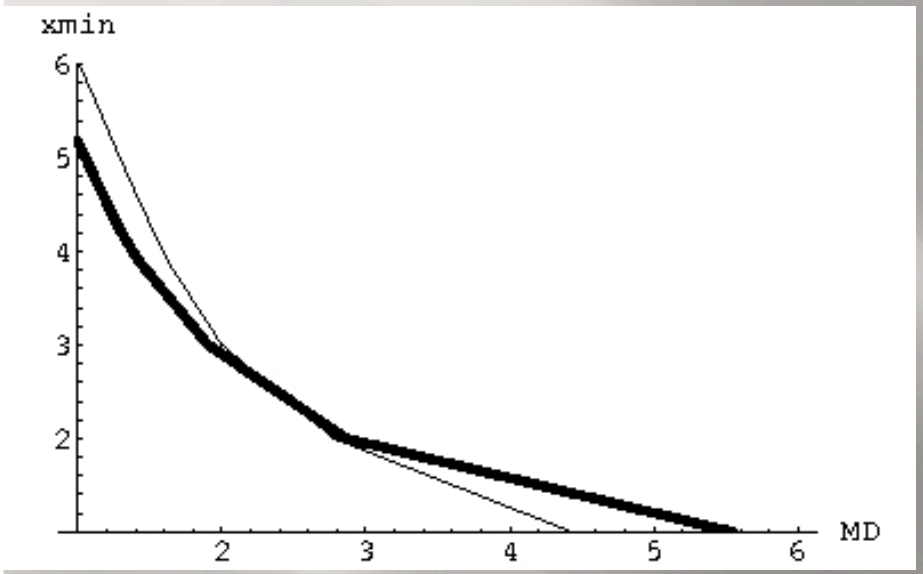




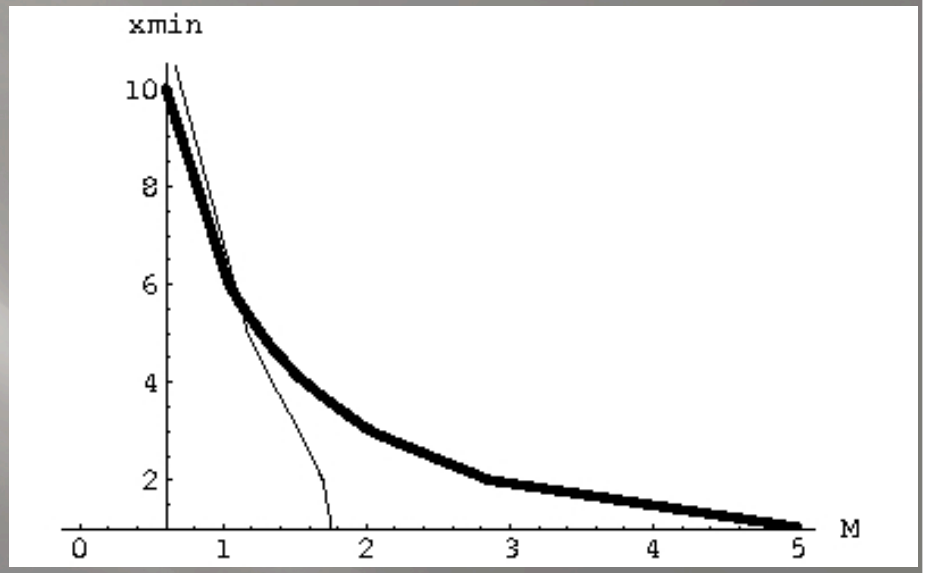
ADD n=6

RS1

Multiparticle vs 2 particle reach



ADD n=6



RS1

Kind of the obvious conclusion!

Isn't this opposite the conventional wisdom??

- Didn't Banks and Fischler tell us that the signature of black holes was a turn off of dijets at high energies???
  - Several papers looking at this as a consequence
- Of course this is correct… when the "black hole" is thermal and really a black hole
- At lower energies(that we can actually probe) it is natural to expect an *increase* in the two body final state cross section (higher dim ops, strings)
- Can actually learn something *interesting*

After all… What would you do with a transplanckian collider?

Two Body Final States

- We haven't solved quantum gravity thus we have to model around our ignorance
  - Parameterize by higher dimensional operators
  - Take the two body extrapolation of real black holes at face value
  - Toy stringy Models
- How do experimentalists already search for two body final states
  - dijets for instance

Dijets at the Tevatron and LHC

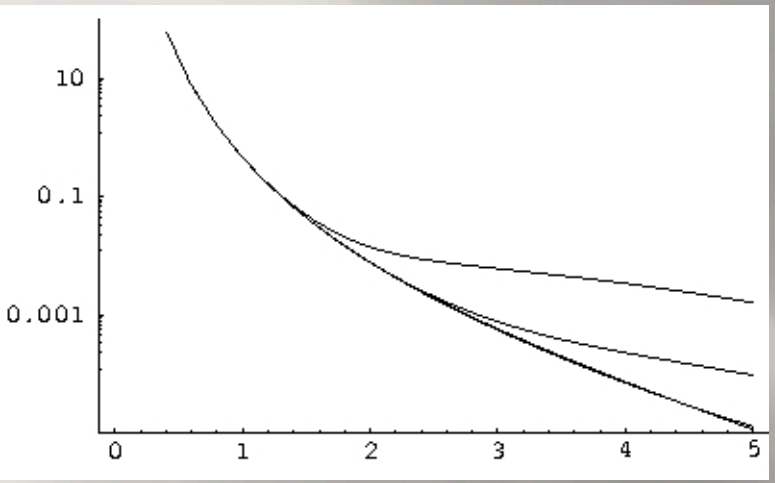
- Don't use differential cross section wrt dijet mass because systematics can kill you (similarly with angular distribution)
- What do you want to do to find a reliable signal when you are not necessarily bump hunting?
- Define ratios where systematics cancel!

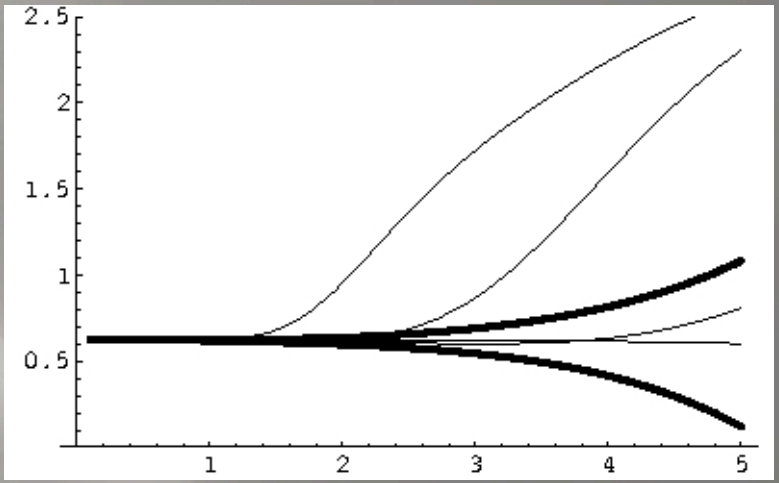
$$R_\eta \equiv \frac{N(0 < |\eta| < .5)}{N(0.5 < |\eta| < 1)}$$

D0, now CMS

Four Fermion Operators/ Compositeness Searches

pb/GeV





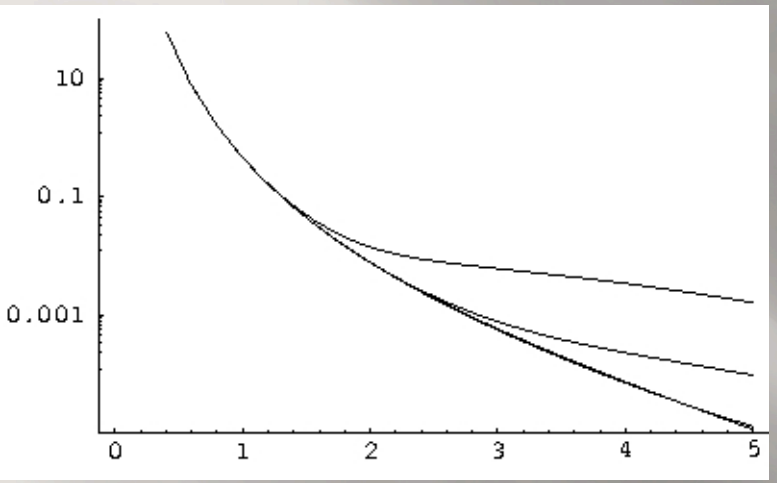
$$\sum \frac{c}{\Lambda^2}(\bar{f}\gamma^{\mu}f)^2$$

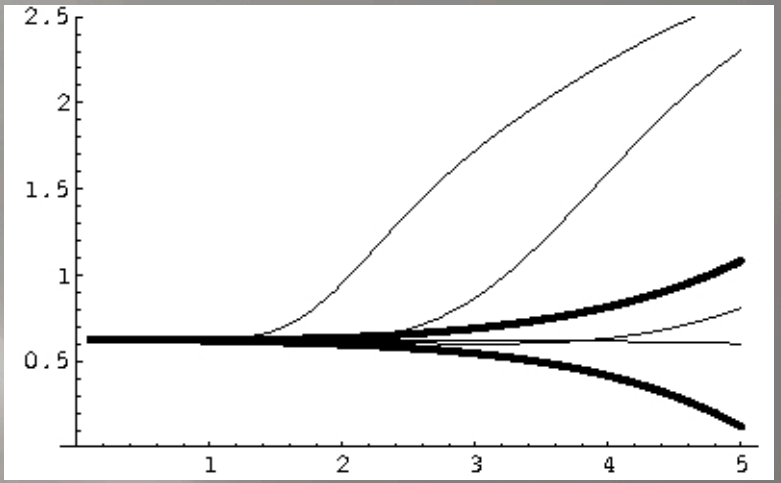
Normally c chosen to be 4π

Bounds now are Λ~2.7 TeV,
projected CMS bounds 15 TeV, discovery 12 TeV with 10 inv fb

Four Fermion Operators/ Compositeness Searches

pb/GeV





$$\sum \frac{c}{\Lambda^2}(\bar{f}\gamma^{\mu}f)^2$$

Could repeat this just for black holes with c=1, what do you match onto?

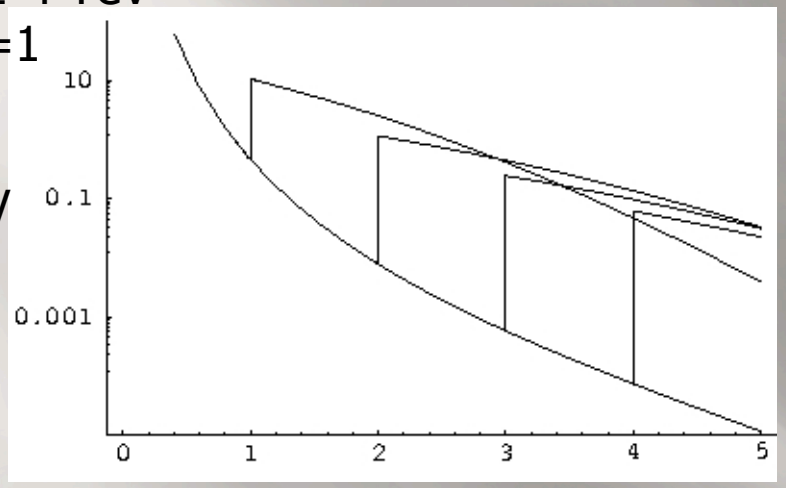
Can control everything in a nice gauge invariant manner,
account for other spin structures etc

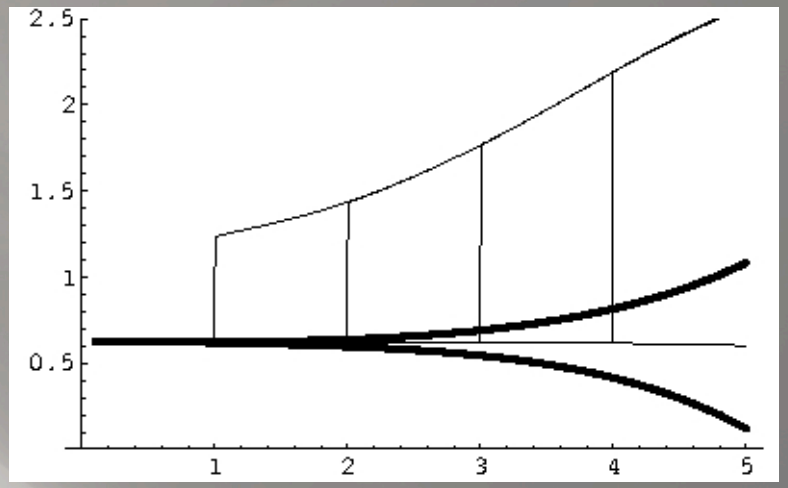
Funky four fermions finally not frustrated(large anomalous dimensions or otherwise)

"Black Hole" Dijets

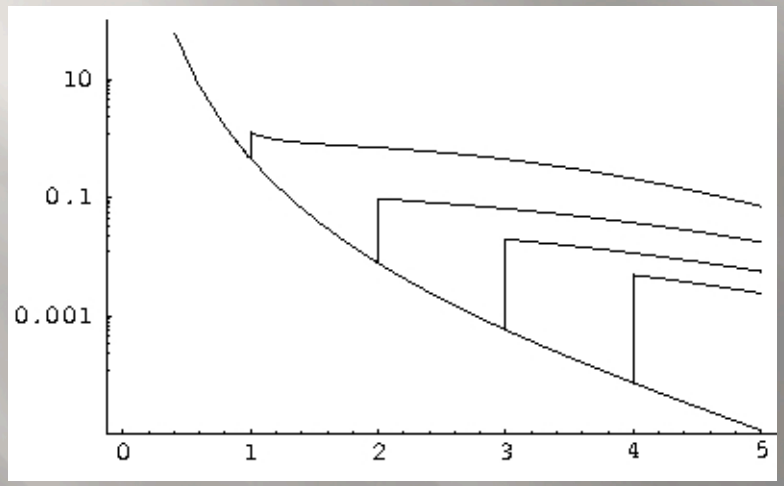
ADD
n=6
M_D=1-4 TeV
x_min=1

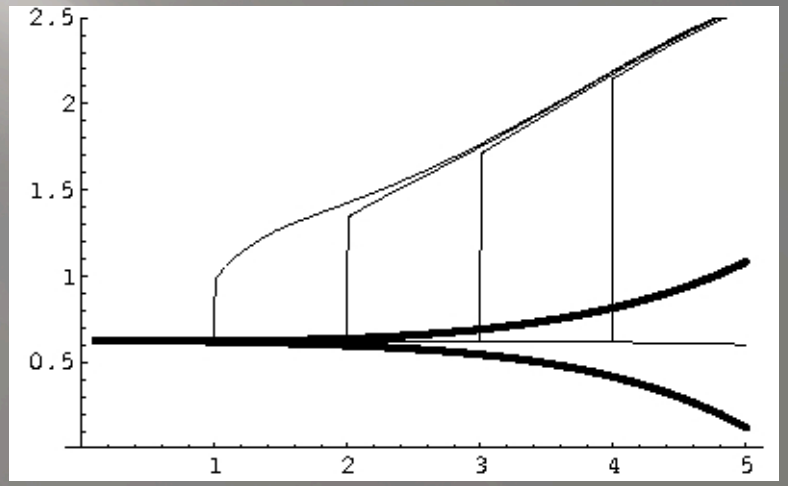
pb/GeV





RS

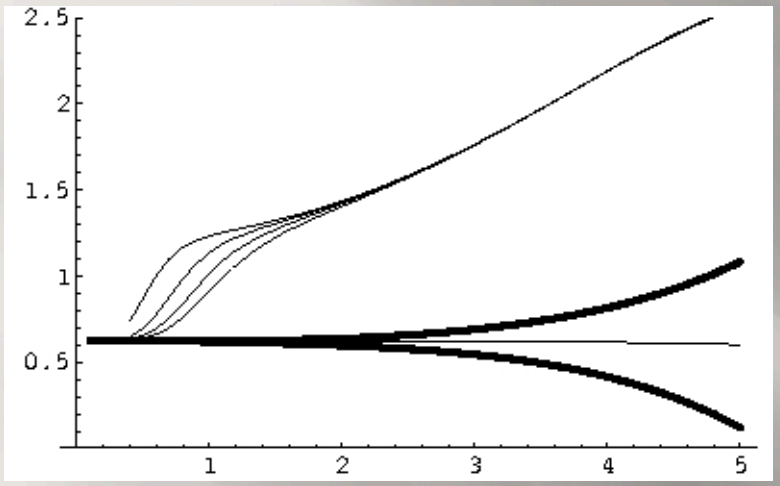


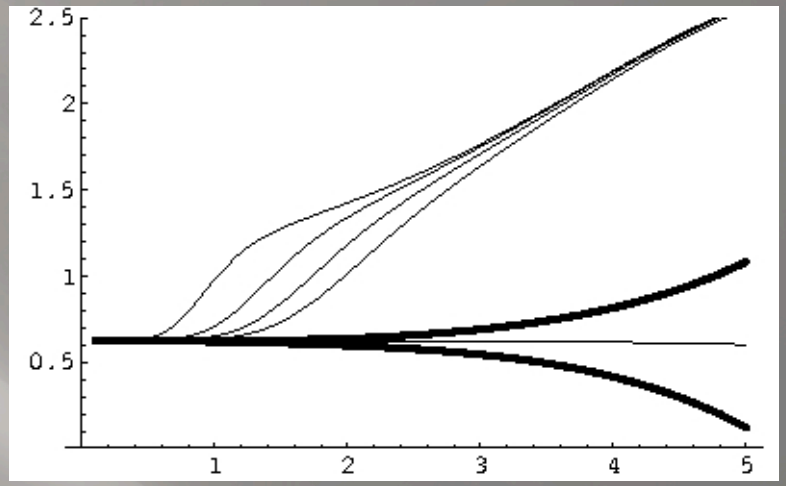


1 inverse fb 1 sigma *gaussian* error bars

No interference with SM just add

“Black Hole” dijets no threshold





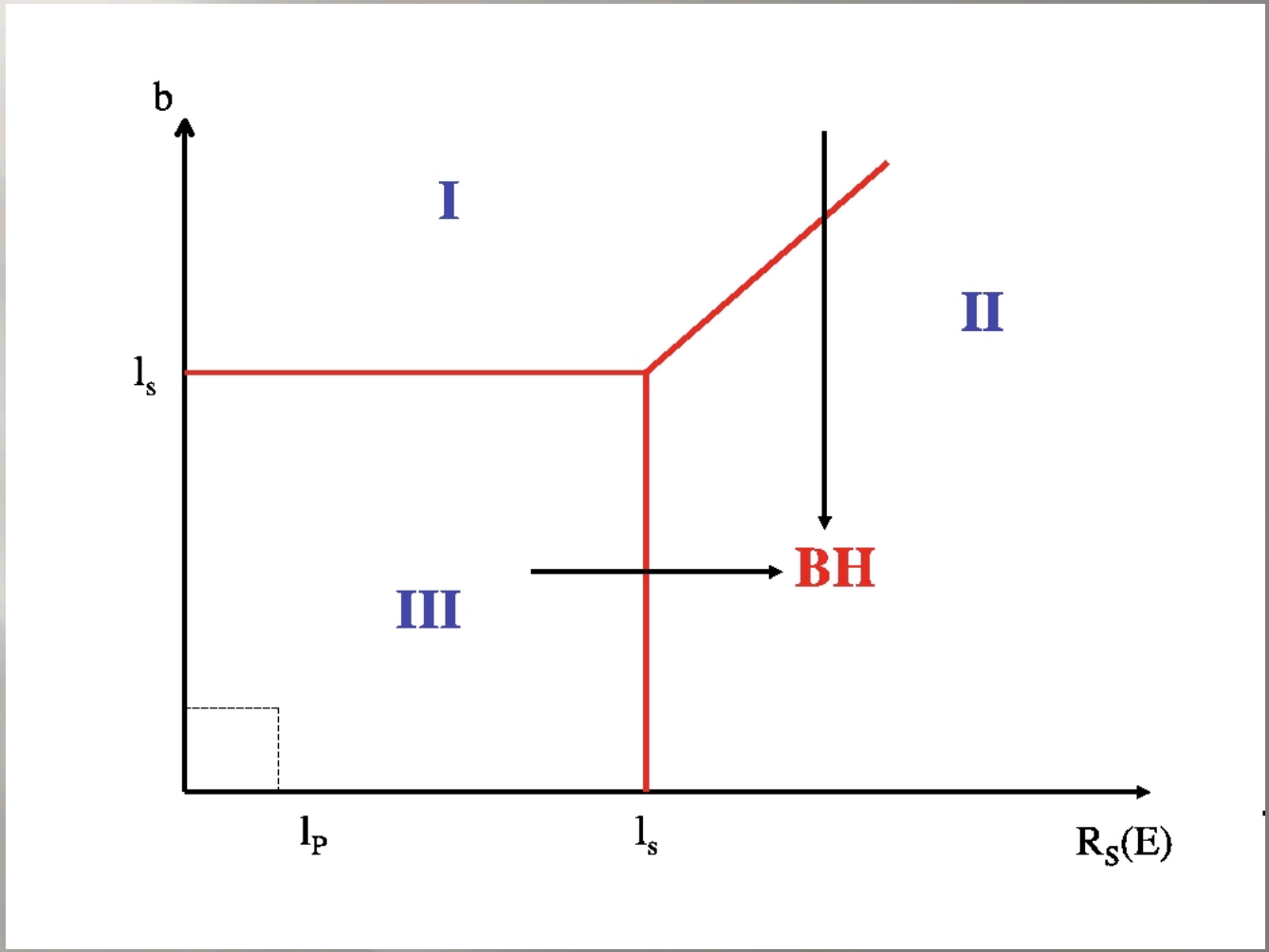
Once you beat out SM just probing PDF all asymptote together

Possible to distinguish models at low energy?

String Theory and Quantum Gravity…

- Shouldn't String Theory have something to say about this regime?
  - As per earlier this is true in principle but there are additional scales involved in the game and not necessarily reliable for all regimes
- Additionally even if you fix the scales the calculation isn't just performable in all regimes
  - String scattering: Gross, Mende, Ooguri and Veneziano et al (flat space)
    - Strassler, Polchinski: what about in nontrivial backgrounds?

String Theory "Phase" Diagram



Veneziano

Even in flat space at weak coupling this calculation isn't in control in all regimes

Toy String Theory

$$A_{pp\to ij} \equiv A_{SM} A_{ST}$$

$$A_{ST} \equiv \frac{\Gamma\left(1 - \frac{s}{M_S^2}(1 + i\gamma)\right)\Gamma\left(1 - \frac{t}{M_S^2}(1 + i\gamma)\right)}{\Gamma\left(1 - \frac{s}{M_S^2}(1 + i\gamma) - \frac{t}{M_S^2}(1 + i\gamma)\right)}$$

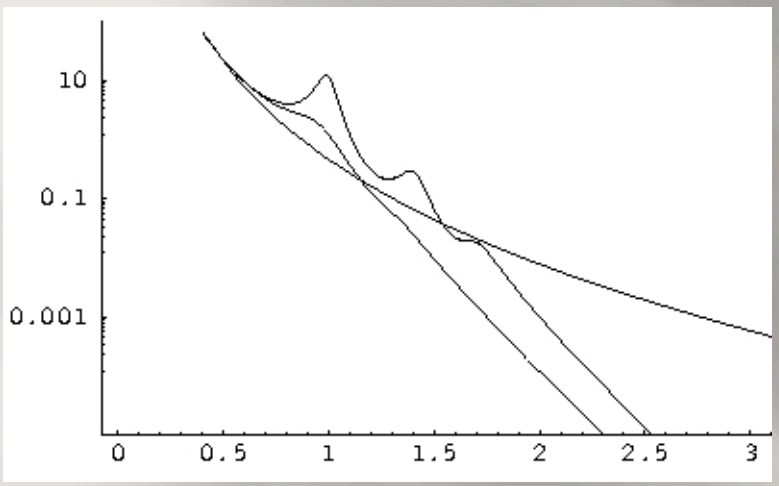
Just modifying by a Veneziano amplitude motivated form factor

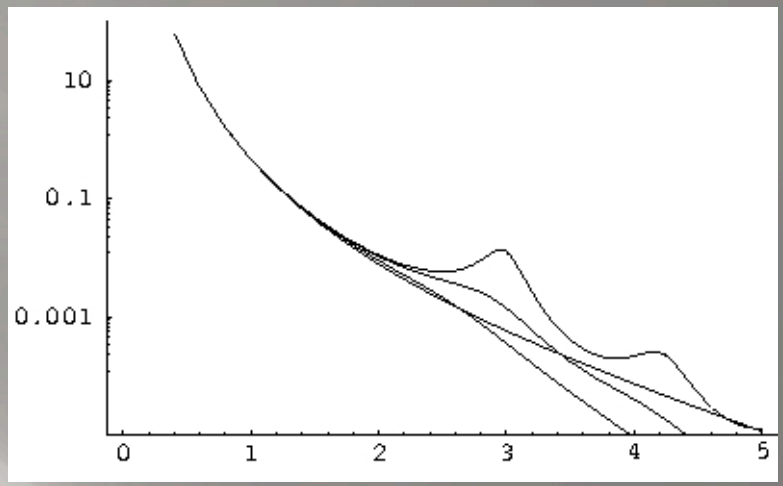
Similar to Bars,Hinchliffe for SSC

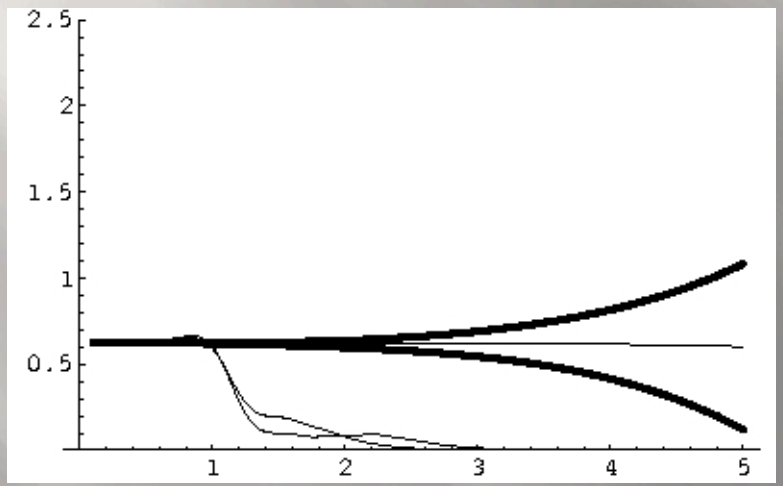
This has the characteristic forward suppression as in Gross and Mende

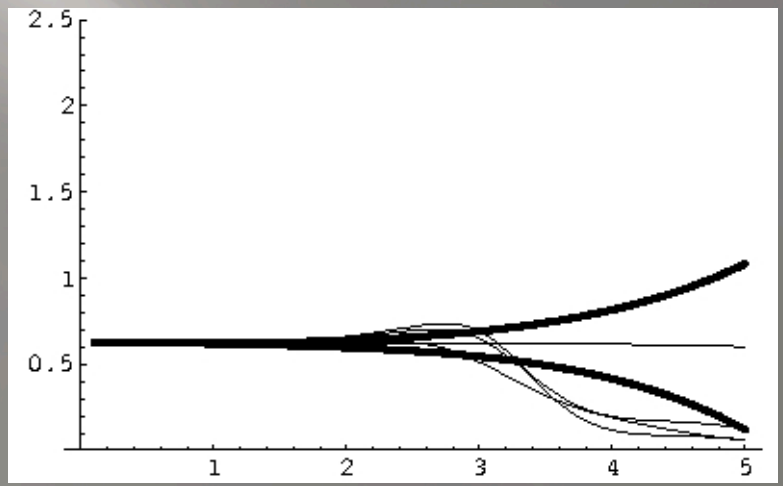
"Stringy" Results

Pb/GeV



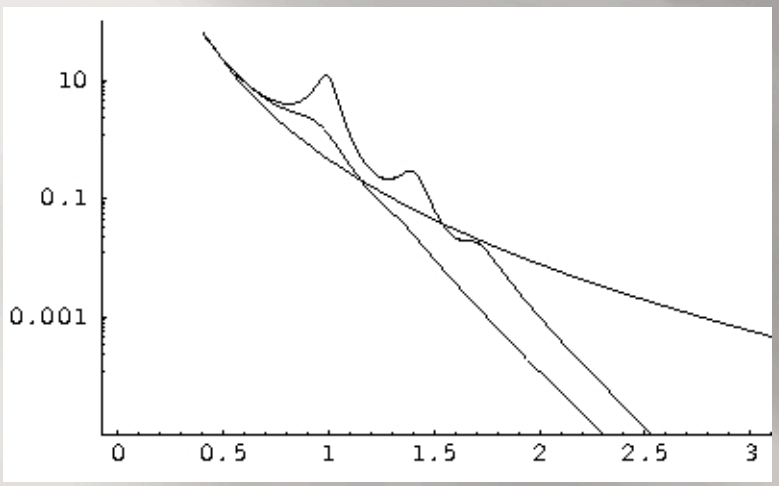


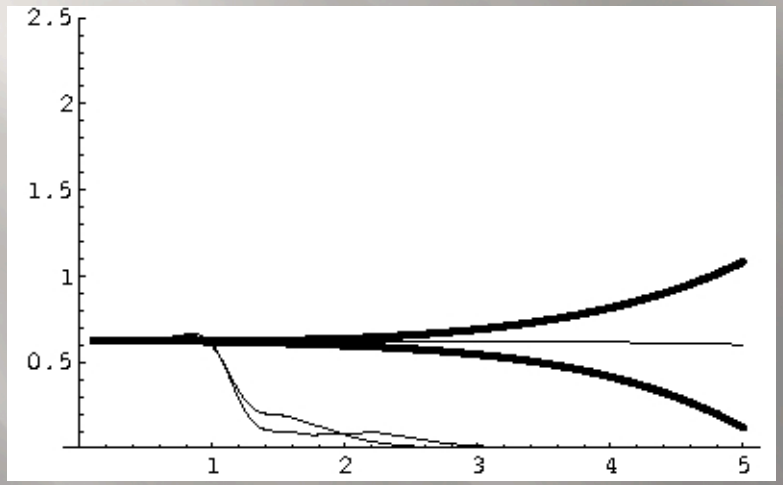


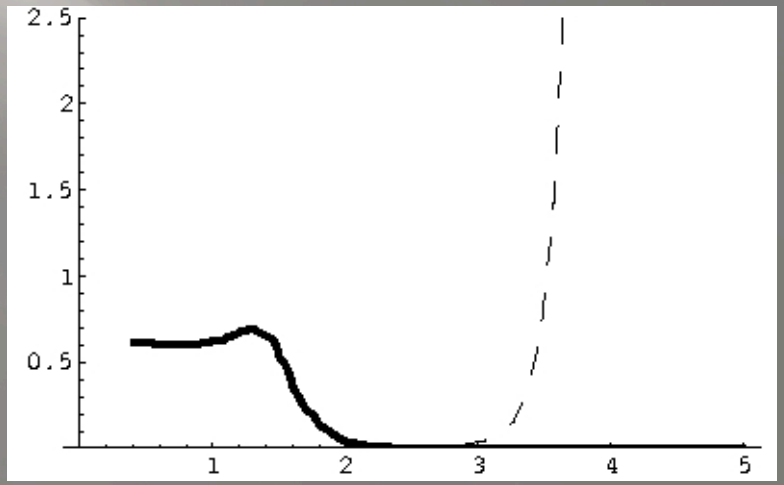


"Stringy" Results

Pb/GeV



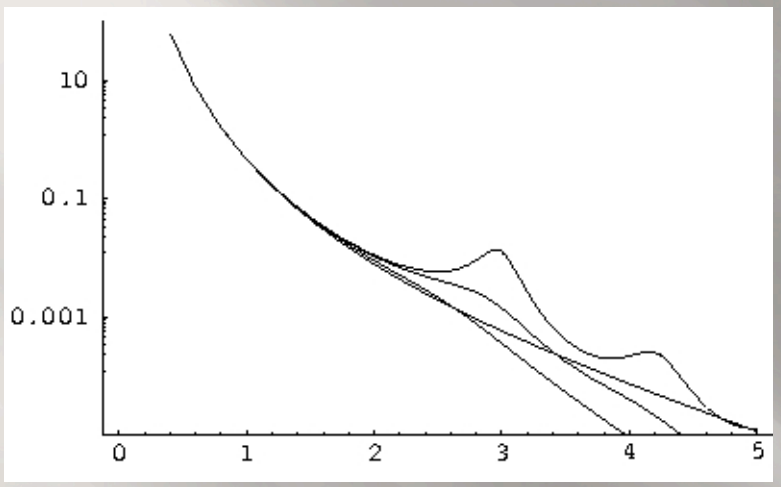


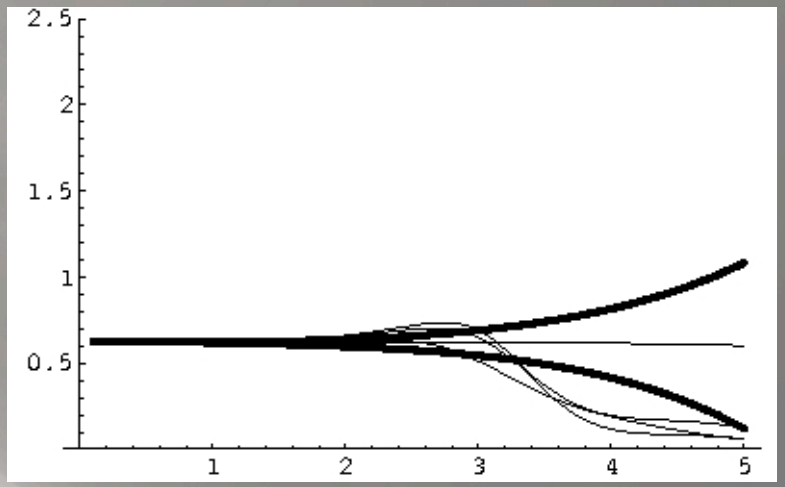


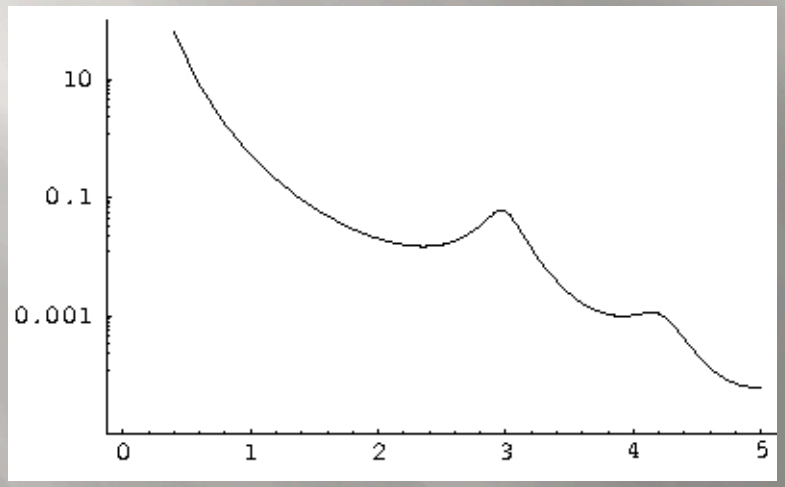
Error bars small enough that this should be distinguishable from QCD dijets

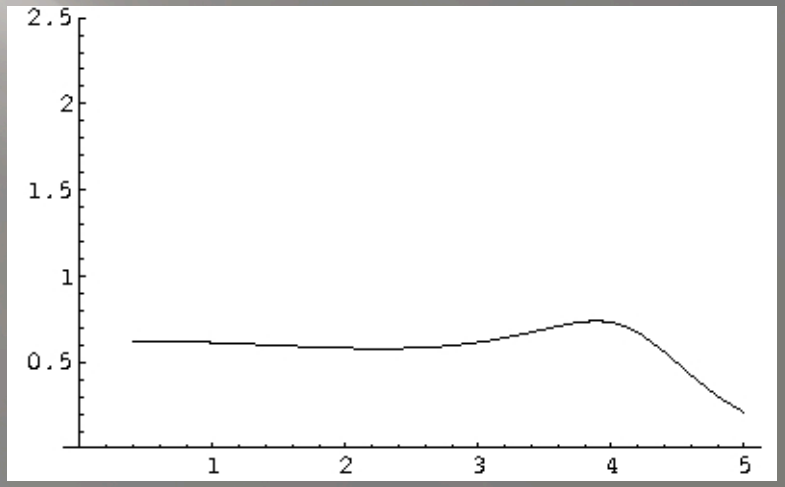
Different Veneziano FF

Peskin, Perelstein, Cullen



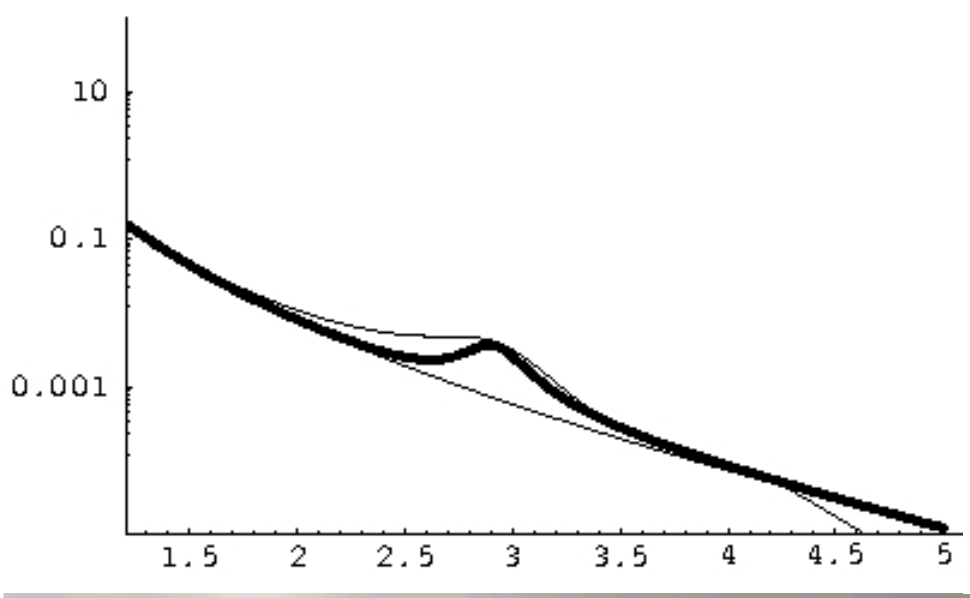


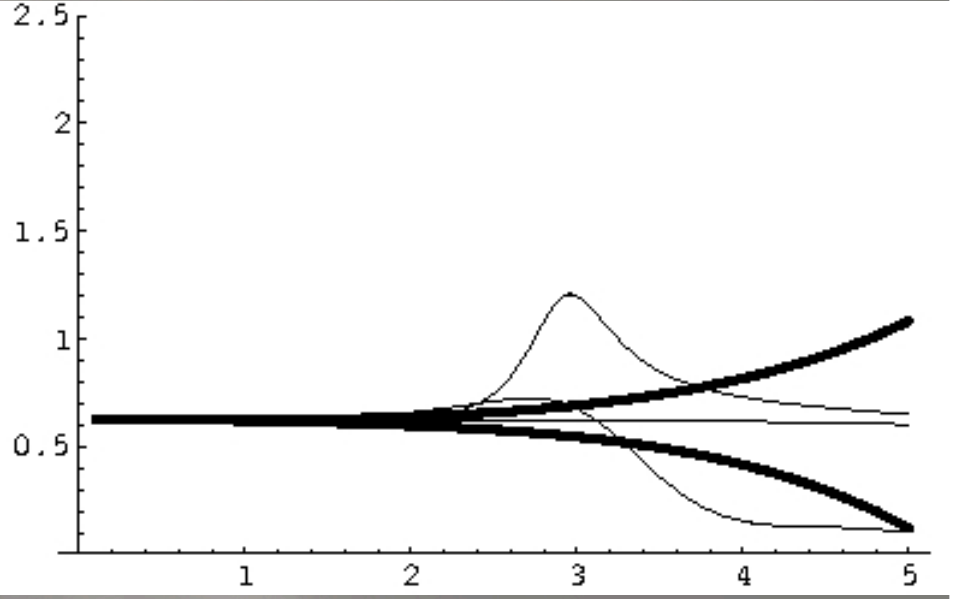




Important when thinking about higher dimensional operators and bounds
dim 6 absent in Peskin et al case

“String” Resonance vs Z’ ish thing



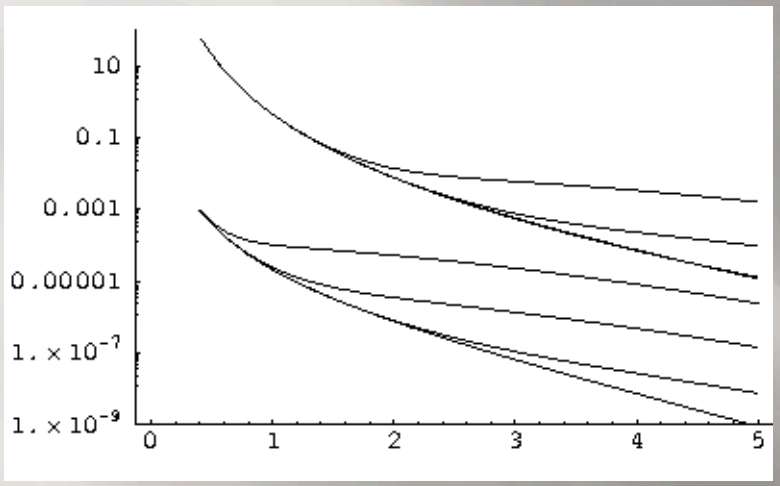


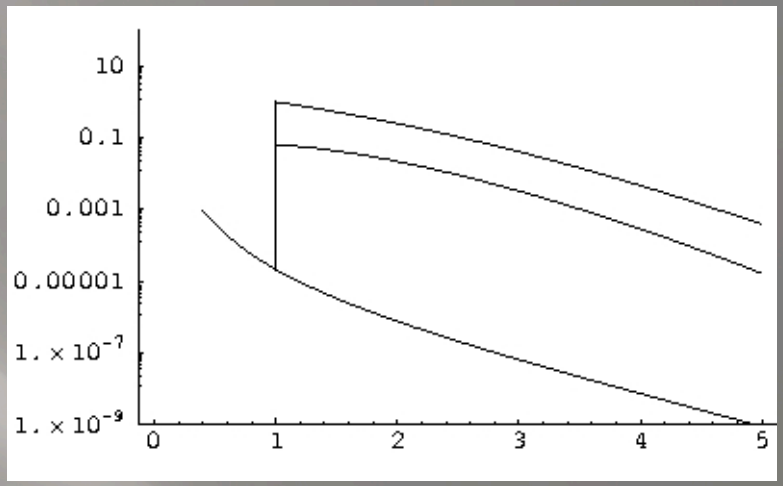
Differential cross section looks very similar

Can potentially distinguish with R_η

Conclusions/Speculations/Future Working Directions

- Black Holes probably not occuring at an appreciable rate at the LHC
  - Many uncertainties all pushing in the wrong direction
  - When to trust semiclassical calculations
- "Black Holes" could occur quite often and you could in principle learn quite a bit more
- How to distinguish this from strongly coupled physics?
- Experimentally how to distinguish amongst toy models
- Theoretical progess in understanding string theory threshold behavior?
- What is the physical theshold for black hole production?


10
0.1
0.001
0.00001
1. × 10^-7
1. × 10^-9
0
1
2
3
4
5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