Black Hole Physics at CMS

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On behalf of

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Motivation

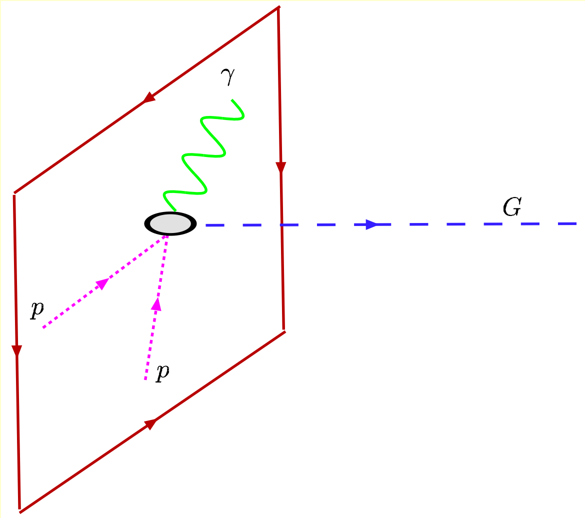
- The observable astronomical BH (in the galaxy NGC 6251) encourages us to explore miniature BH production in laboratories

- BH production in laboratories could be the most promising signal of TeV-scale quantum gravity

- Much effort has been made to predict BH production in fundamental Planck scale of $M_\star \sim$1 TeV

Extra Dimensions

- In large extra dimensions at the TeV energy scale, Gravitons can propagate in $n = D - 4$ extra dimensions

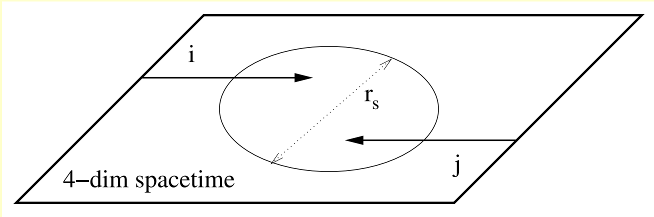


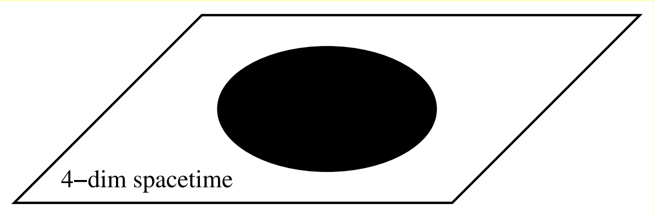
- The BH is characterized by the Schwarzschild radius

$$r_s = \frac{1}{\sqrt{\pi} M_\star} \left[\frac{8\Gamma\left(\frac{n+3}{2}\right)}{(2+n)} \right]^{\frac{1}{n+1}} \left(\frac{M_{BH}}{M_\star} \right)^{\frac{1}{n+1}}$$

  - $M_\star \sim TeV$ is fundamental Planck scale

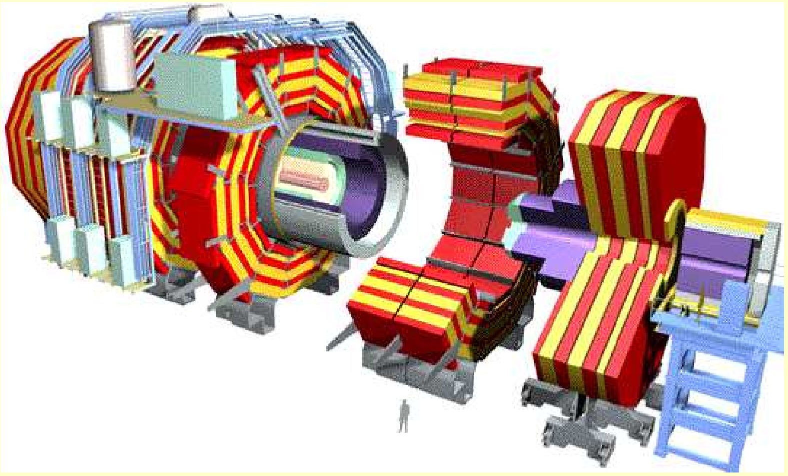
- If the impact parameter $b < r_s$, $\rightarrow$ an Event Horizon is formed





Extra Dimensions

- We look for BH production at CMS



- At TeV-energy scale, CMS could observe BH production:

1. $E_{observable} \ll M_\star$: Gravitons escapes into extra dimensions

   - $pp \rightarrow$ Jet + Gravitons $\rightarrow$ Jet + E_T^{miss} (JetMet)

2. $E_{observable} \gg M_\star$: Mini BH production

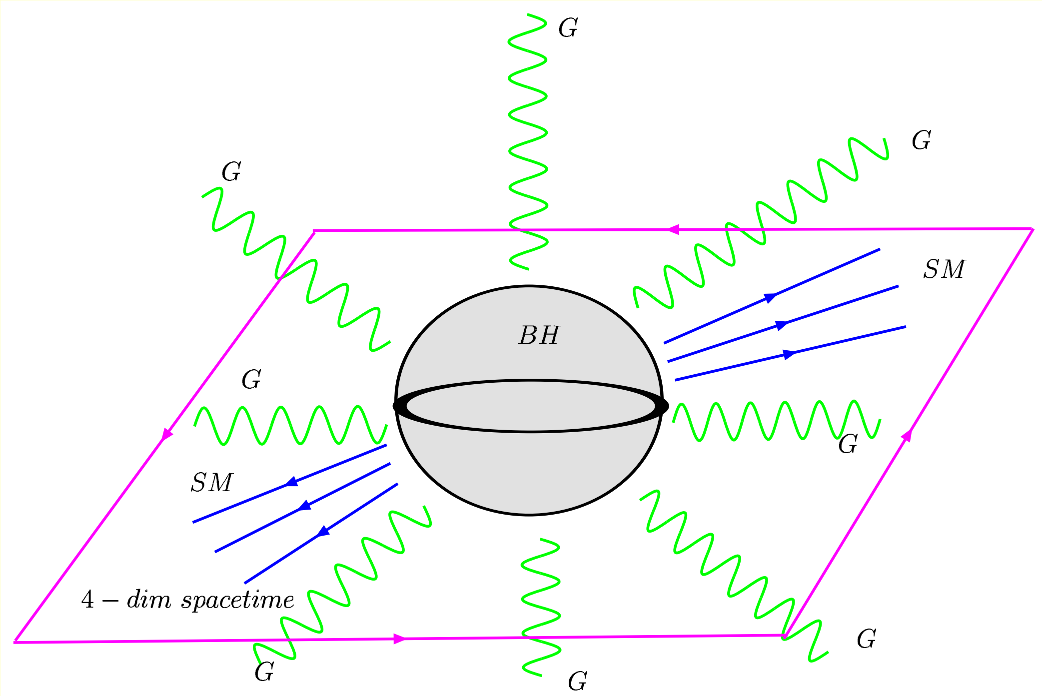
   - $pp \rightarrow$ BH $\rightarrow$ spectacular decays (High P_T leptons, Jets) (JetMet)

Hawking's Evaporation

- After Black Hole formed it decays via Hawking radiation
- The Black Holes emits into two modes :

1. Along the brane (brane mode (4D)): Standard Model fields
2. Into the extra dimensions (bulk mode (n)): Gravitons (invisible)

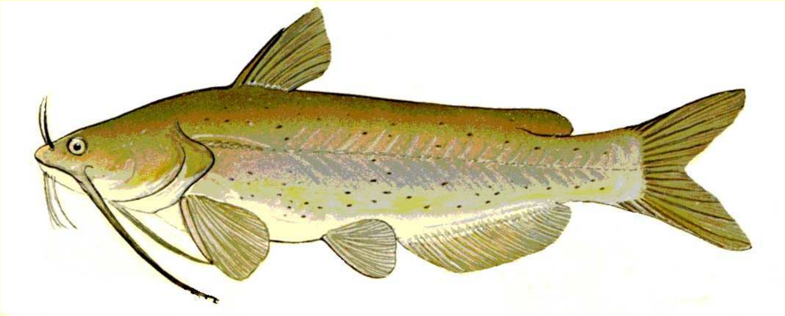
- Hawking radiation



CATFISH: New Black Hole Generator

- We wrote a new MC generator called "CATFISH"

  CATFISH (Collider grAviTational FIeld Simulator for black Holes)



CATFISH authors: M. Cavaglià, R. Godang, L. Cremaldi, D. Summers

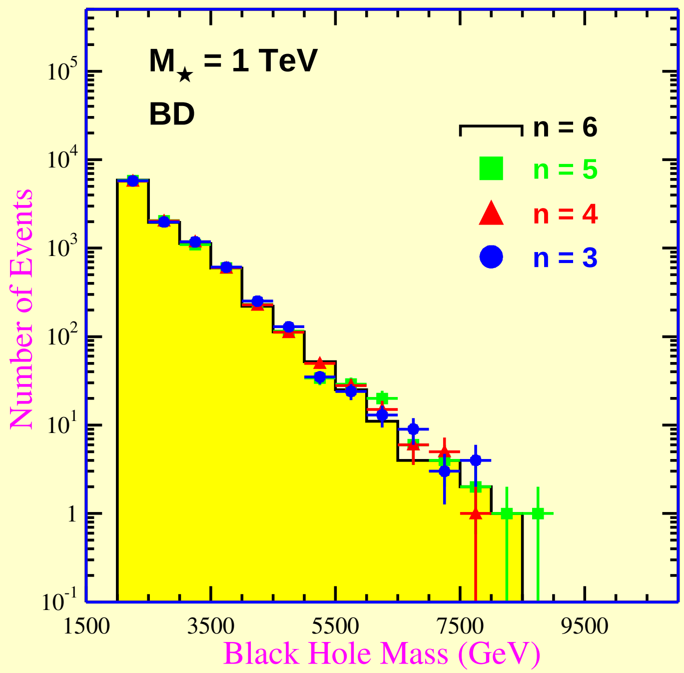
- Published in Journal of High Energy Physics, JHEP06, 055, 2007

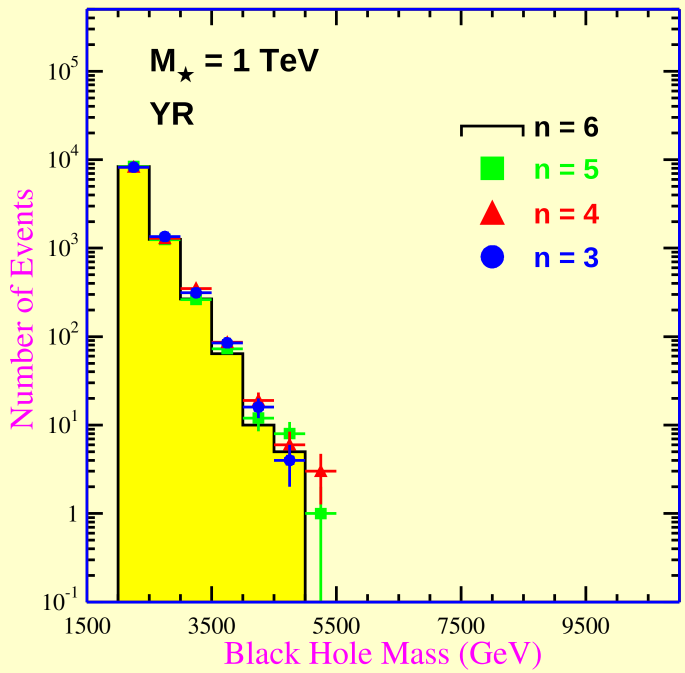
- Published in Computer Physics Communications 177, 506, 2007

M. Jenkins and R. Godang are implementing CATFISH into CMSSW

BH Mass

- BH Mass distribution for fundamental Planck scale $M_\star = 1$ TeV, $n_p = 2$





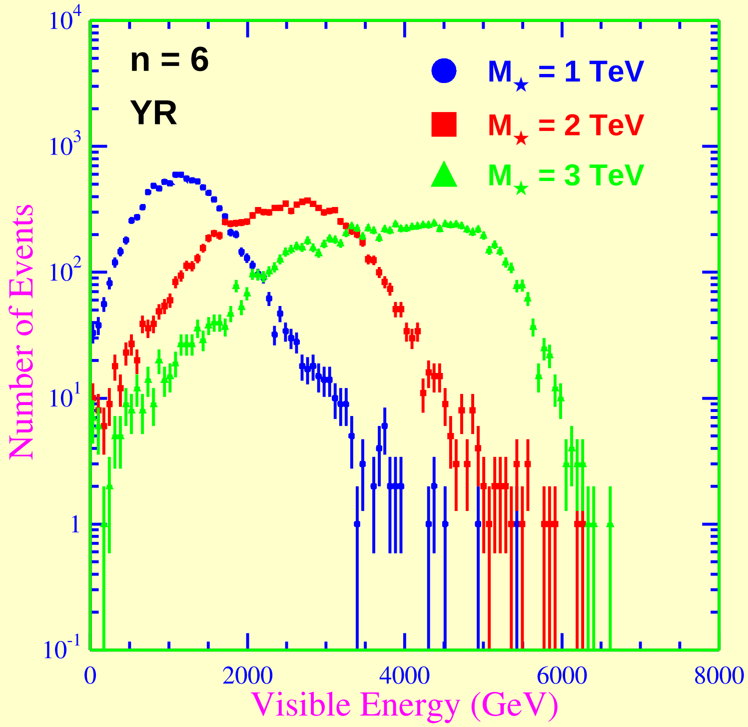
- $n = D - 4$ extra dimensions (3,4,5,6)

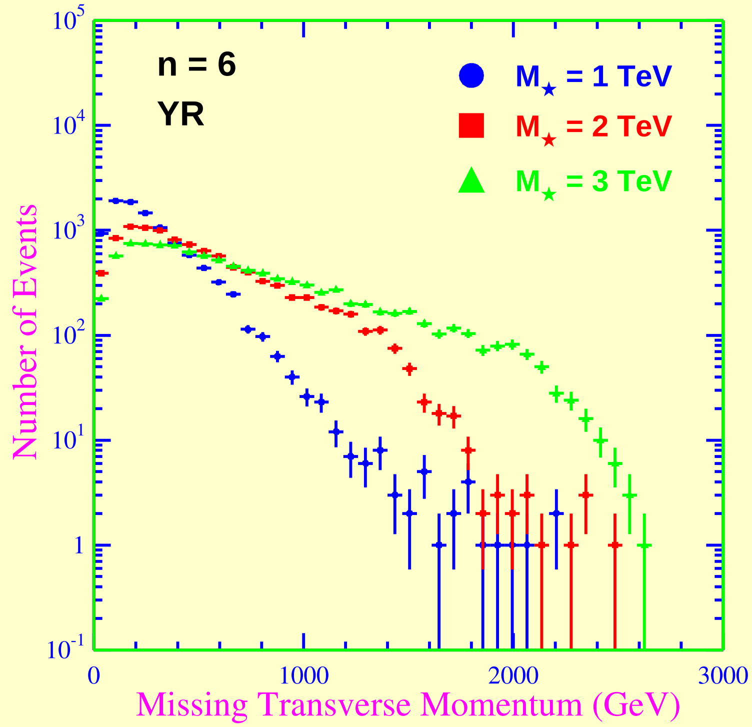
- (left) Black Disk model (BD) $\Longrightarrow$ no Gravitons loss

- (right) Yoshino-Rychkov TS model (YR) $\Longrightarrow$ with Gravitons loss

Effects of Fundamental Scale

- Visible energy and missing transverse momentum for n = 6, $n_p = 4$, YR

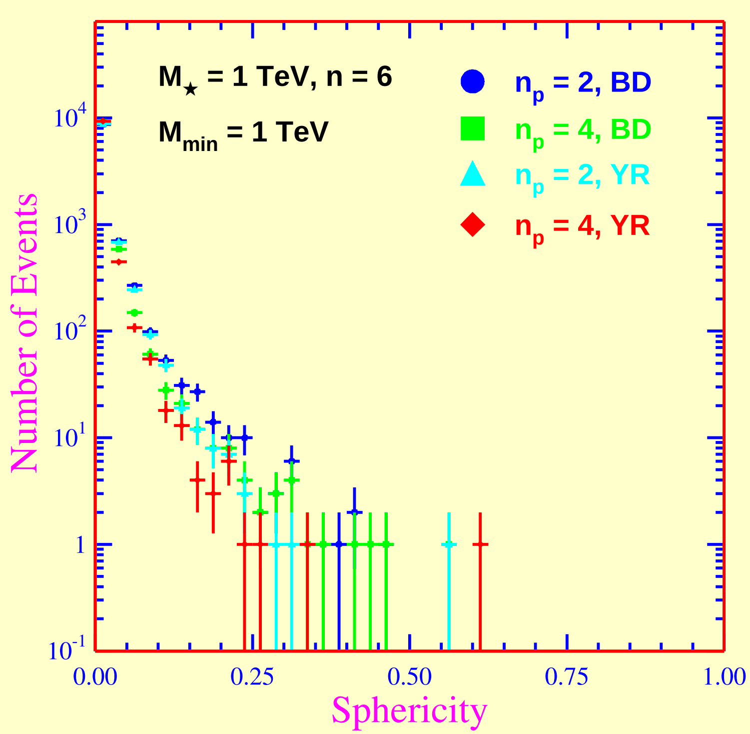


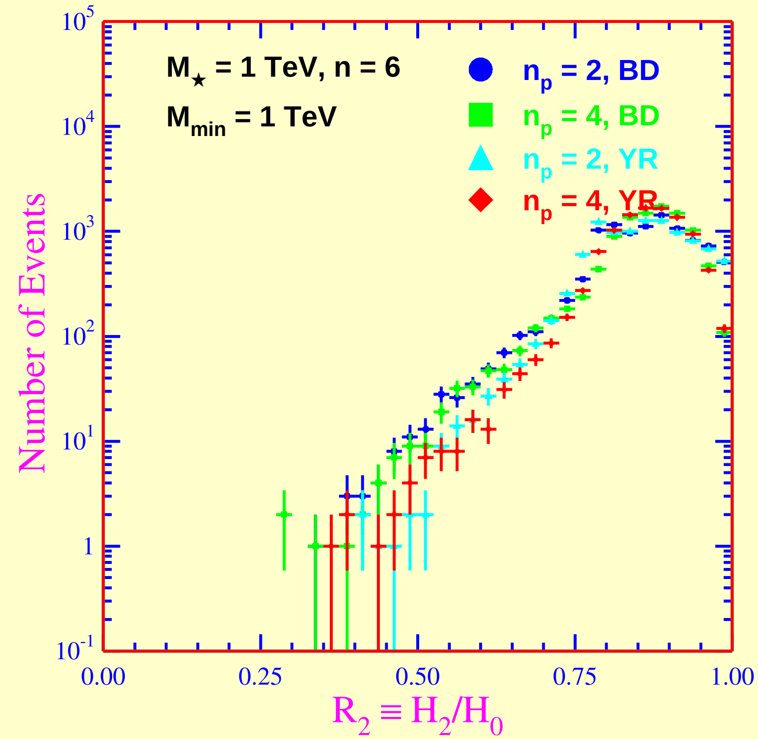


- Increasing $M_\star$ leads to higher M_{min} ($M_{min} = 2M_\star$) :
  - Larger visible energy in Hawking phase
  - Larger missing transverse momentum
- $M_\star$ could be measured to a certain degree of precision at CMS

BH Events Shape

- BH events are expected to be highly spherical due to the spherical nature of Hawking radiation





- Experimentally one needs to distinguish between BH events shape with $q\bar{q}$ events as BH-background (back-to-back events shape)
  - (left) Sphericity BH events shape $\longrightarrow S > 0.30$ (depends on M_{min})
  - (right) Fox-Wolfram moment $\longrightarrow R_2 < 0.50$

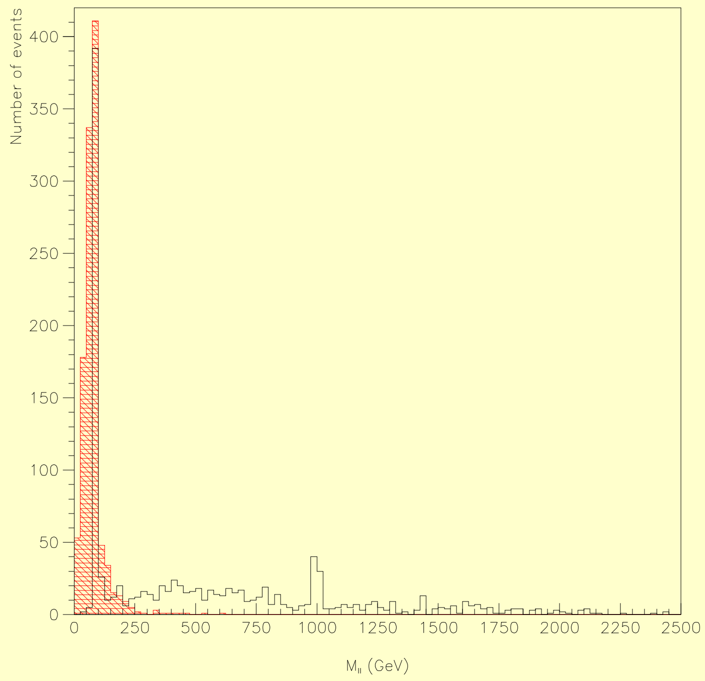
BH Vs SUSY

- High P_T dilepton distribution can be used to disentangle between SUSY and BH events

- SUSY variables: $m_0 = 100$, $m_{1/2} = 300$, $A_0 = 300$
- The ratio of BH-to-SUSY of P_T dilepton is 1:5
- $P_T(dilepton) > 700$ GeV reduces the SUSY background substantially

OSSF Dileptons

- **Opposite-Sign, Same-Flavor (OSSF) dileptons provide good discriminator between SUSY and BH events**



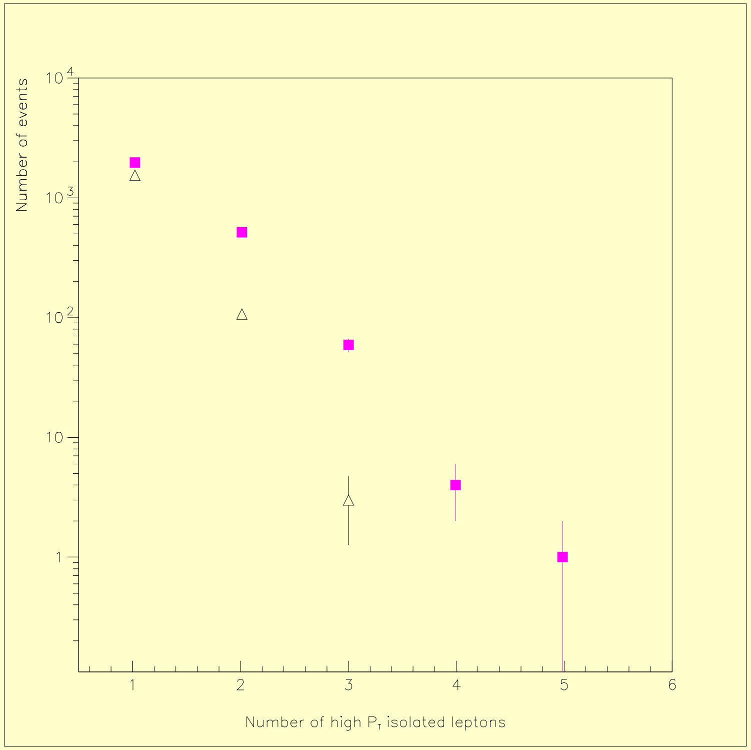
- **The final BH decay in 2-quanta: SUSY (shaded) & BH (solid)**

- $M_{\ell\ell} > $ **400 GeV reduces the SUSY background**

- **The long tail is uncorrelated lepton pairs emitted directly by BH or in top quark decays**

Number of high-P_T Leptons

- The number of high-P_T Leptons also can be used to disentangle between SUSY and BH events



- High-P_T dileptons: SUSY (filled square) & BH (open triangle)
- SUSY events are capable of producing up to 5 isolated leptons
- BH events with 3 or more leptons are very suppressed

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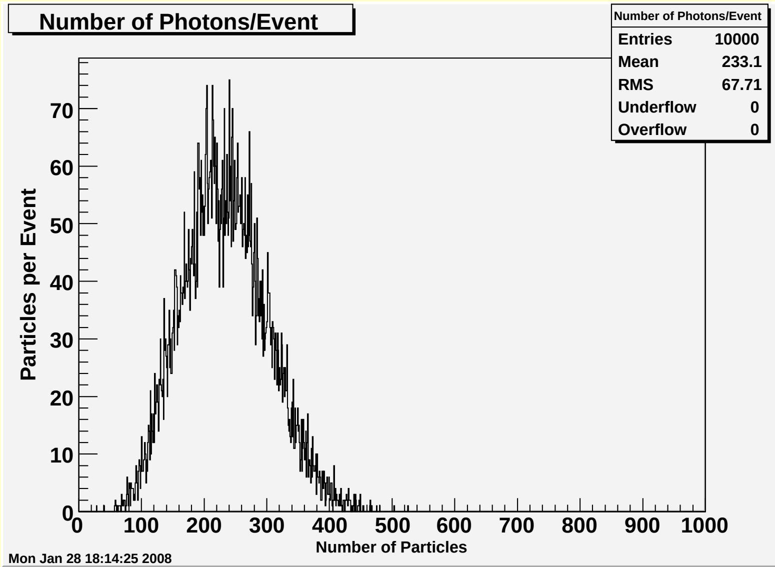
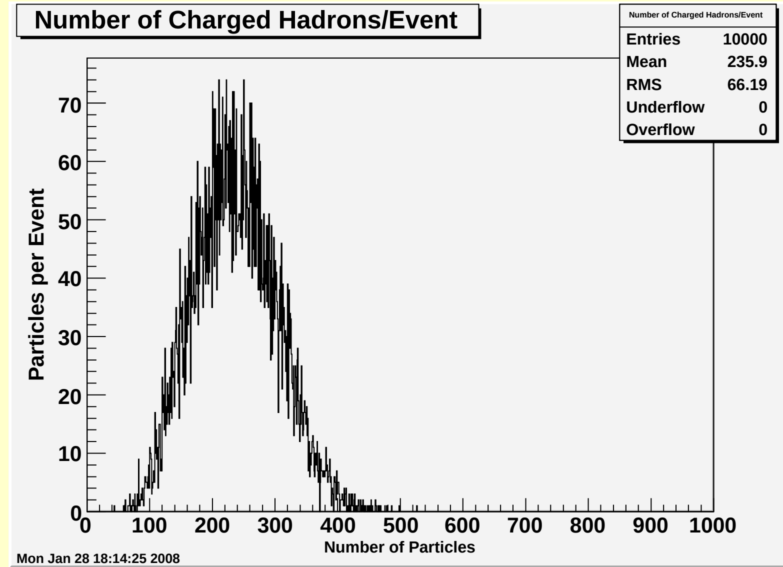
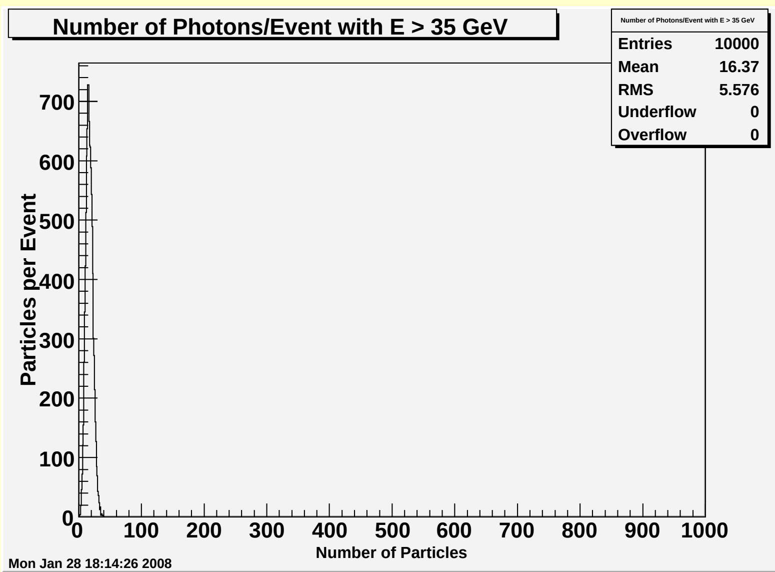
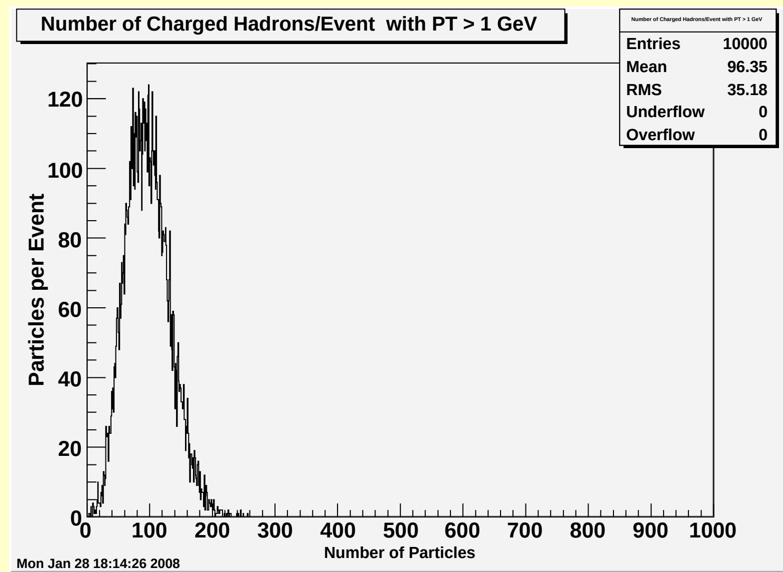
Photon and Charged Hadron Rate

Photon and charged hadron rate per event



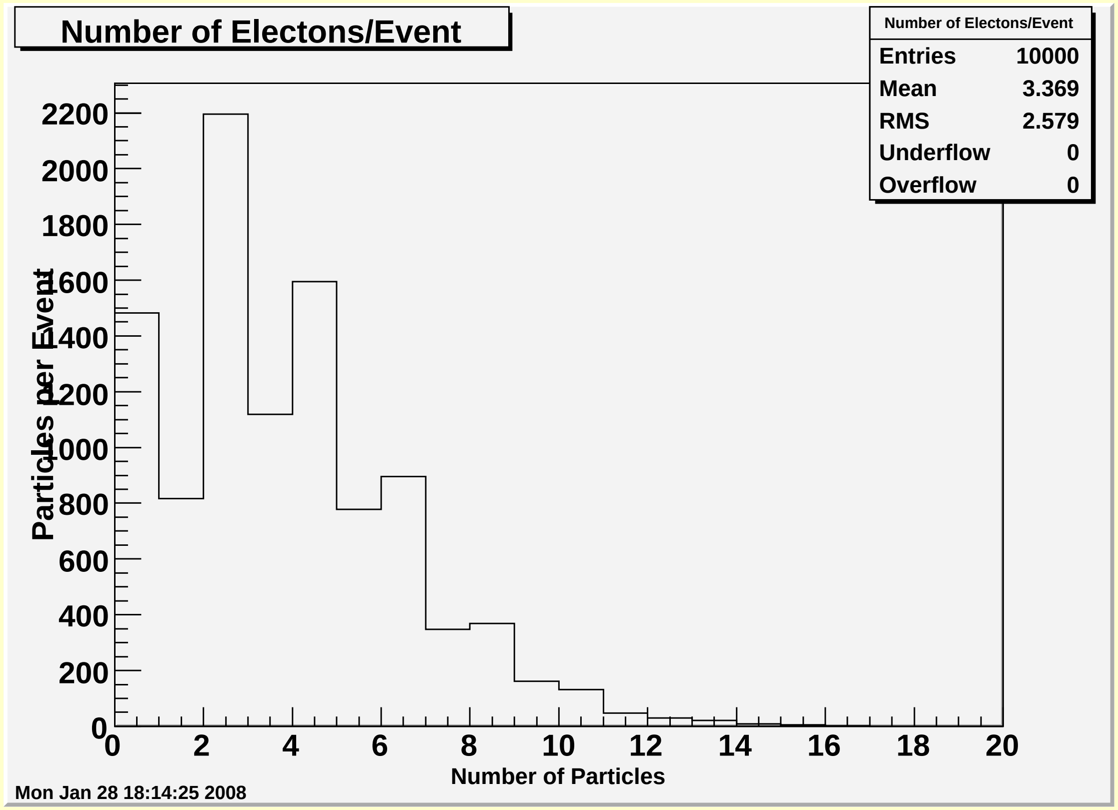






Leptons Distribution

- Number of electrons/event



- Typical number of electrons/events is 3

Summary

- **CATFISH produces consistent results compared to the other generators**

  but it has some new features such as BH remnant

- **It includes different final BH decay modes with**

  possibility of remnant formation

- **CATFISH includes Graviton field emissivities**

- **The missing energy is not only due to the neutrinos**

  but also Gravitons and BH remnant during BH formation

- **CATFISH is available with PYTHIA interface**