LHC ATLAS実験における ブラックホール探索

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All our results are preliminary.

Introduction

- Large Extra Dimensions

  N.Arkani-Hamed, S.Dimopoulos, G.Dvali PLB **429** (1998) 263

  - One of theories of "Extra Dimensions."
  - ***Hierarchy problem*** – 階層問題
    - EW scale ~ 10^3GeV <- -> Planck scale ~ 10^{18}GeV
    - Need a fine tuning to solve this problem.
  - Planck scale can become a TeV scale.
    - ***Solve the hierarchy problem automatically.***
- Black hole (BH)
  - "BH mass > Planck scale(M_p)" → BHs can be produced.

If M_p is ~TeV, LHC ($\sqrt{s}$=14TeV) can produce BHs!

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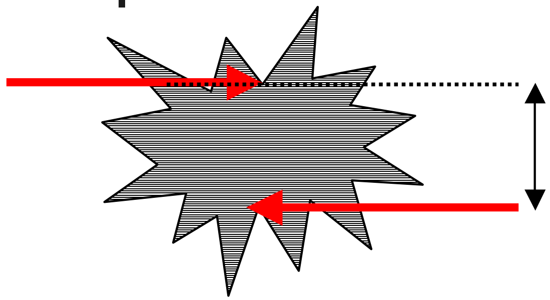
Black Hole

M_p : Planck scale
n : extra dimenstions
M_{BH} : BH mass



d < R_s

$$R_S = \frac{1}{\sqrt{\pi} M_P} [\frac{M_{BH}}{M_P} (\frac{8\Gamma(\frac{n+3}{2})}{n+2})]^{\frac{1}{1+n}}$$

R_s = ~10^{-20}(m) < R_n~10^{11}m(n=1) ñ ~10^{-17}m(n=7)

- When an impact parameter (d) is smaller than Schwarzschild radius (R_s), a BH is produced.
- A geometric cross section of BHs is

$$\sigma(M_{BH}) \sim \pi R_S^2 = \frac{1}{M_P^2} [\frac{M_{BH}}{M_P} (\frac{8\Gamma(\frac{n+3}{2})}{n+2})]^{\frac{2}{1+n}}$$

→ σ ~ *O*(100)pb → Large cross section!

Expressions, which are used here, are valid at **M_{BH} >> M_p**. (厳密に言えば)

(~10^5event/yr@L=10^{33}cm^{-2}s^{-1}.)

S.Dimopoulos, G.Landsberg
PRL **87** (2001) 161602

Simulation

- Signal samples **BH → PYTHIA → ATLFAST**
  - We have developed ***our original BH generator***.
  - Initial state parton showers, hadronisation and decay are performed using PYTHIA 6.2.
  - Q^2_{ren}=(Generated BH mass)^2
- Background samples
  - jj, Wj, Zj, tt, WZ, WW, ZZ, γj, γV, γγ
    "j" = quark, lepton, gluon by PYTHIA 6.2.

All samples are processed through the *ATLFAST*.
(Low luminosity condition)

- PDF = CTEQ5L

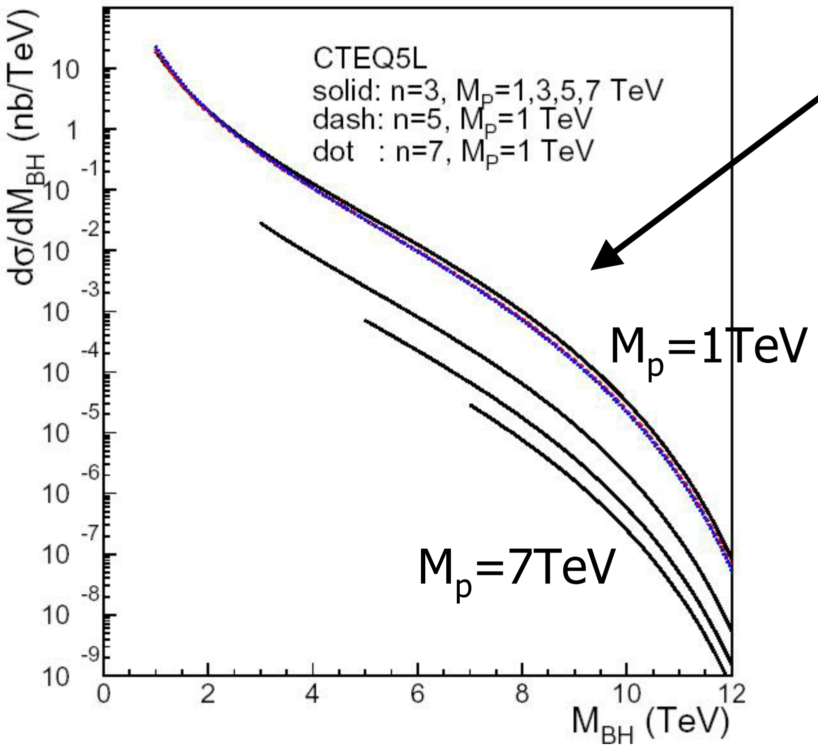
Generator – BH production

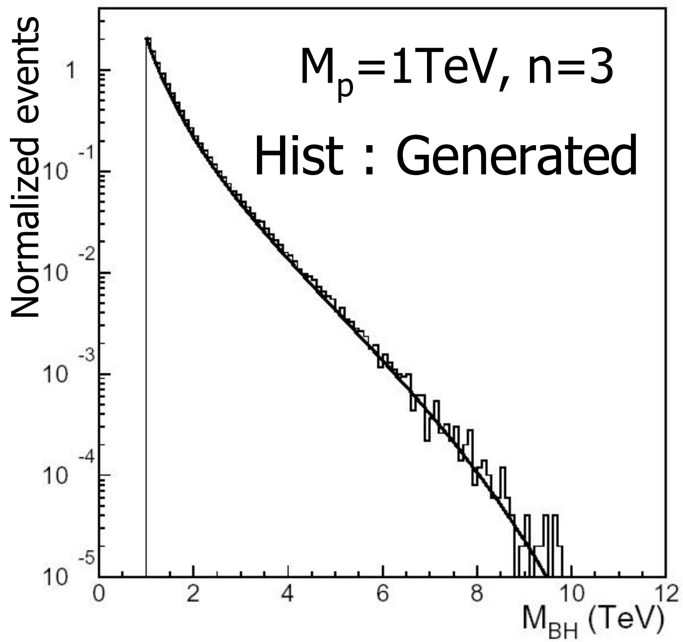
- We take into account a PDF in the differential cross section.

$$\frac{d\sigma(pp \to \mathrm{BH}+X)}{dM_{\mathrm{BH}}} = \frac{dL}{dM_{\mathrm{BH}}}\hat{\sigma}(ab \to \mathrm{BH})|_{\hat{s}=M_{\mathrm{BH}}^2}$$

$$\frac{dL}{dM_{\mathrm{BH}}} = \frac{2M_{\mathrm{BH}}}{s}\sum_{a,b}\int_{M_{\mathrm{BH}}^2/s}^{1}\frac{dx_a}{x_a}f_a(x_a)f_b\left(\frac{M_{\mathrm{BH}}^2}{sx_a}\right)$$

$$\hat{\sigma}(ab \to \mathrm{BH})|_{\hat{s}=M_{\mathrm{BH}}^2} = \pi R_S^2$$





M_{BH} is continuous. (be measured event-by-event.)
M_p and **n** are unknown parameters. (should be measured.)

Generator – BH decay 1

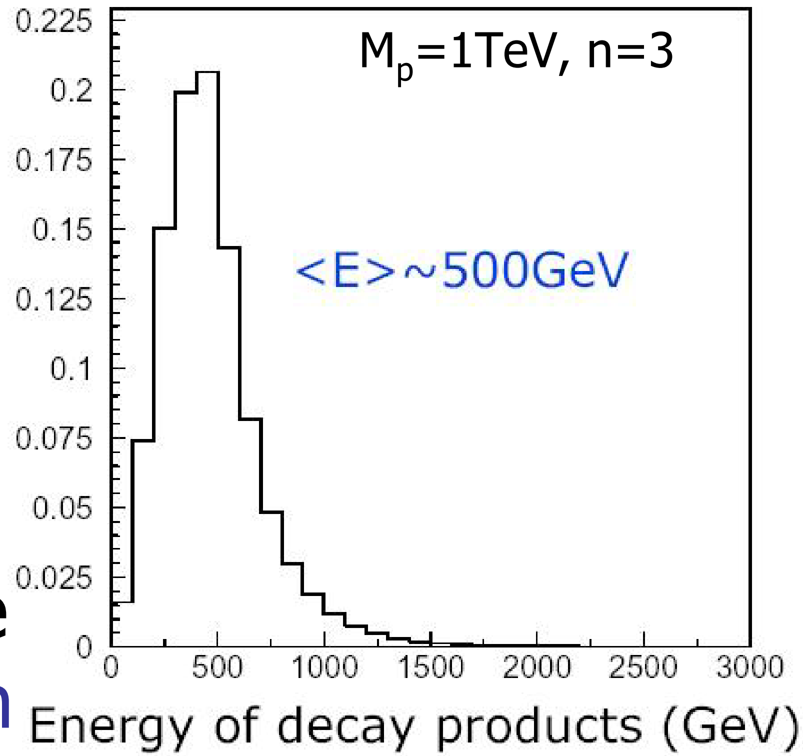
- We require the following conditions for the decay of a BH.
  - Charge conservation
  - Momentum conservation
  - Color conservation
  - The even-odd number of fermions for the spin conservation
  - A BH Lifetime is assumed to be zero.
  - Assumption of Boltzmann distribution for the energy spectrum of decay products
  - Assumption of democratic property in the decay products

Generator – BH decay 2

- BH evaporation is assumed to be "Blackbody radiation" with the Hawking Temperature T_H.

$$T_H = M_P\left(\frac{M_P}{M_{\mathrm{BH}}}\frac{n+2}{8\Gamma(\frac{n+3}{2})}\right)^{\frac{1}{n+1}}\frac{n+1}{4\sqrt{\pi}}$$

- Energy of decay products are determined by the Boltzmann distribution with T_H.



Problem: Other conservation laws distort a distribution from a shape of the Boltzmann distribution.

Generator – BH decay 3

- BH decays promptly into **ordinary SM particles**.
  - BH has no time-evolution.
- Democratic property
  - Species of decay products are determined democratically.
    - Degree of freedom: Charge, spin and color.

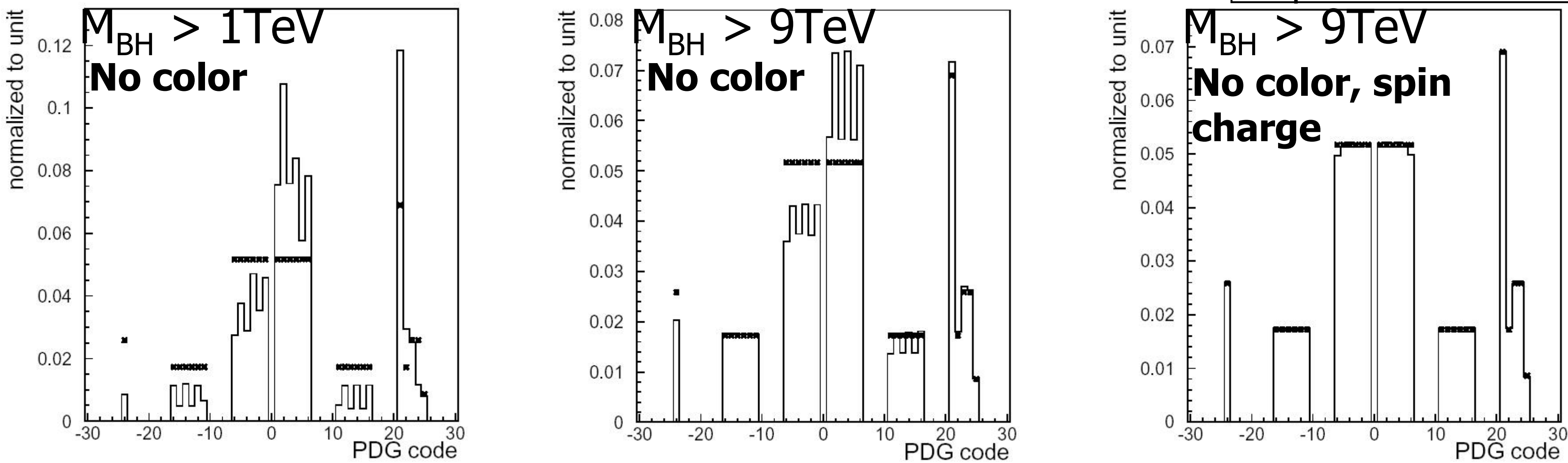
Particle	Degree of Freedom	Assigned Probability
g (gluon)	8	0.0690
W	6	0.0517
Z	3	0.0259
γ	2	0.0172
lepton (e, μ, τ)	4	0.0345
neutrino $(\nu_e, \nu_\mu, \nu_\tau)$	4	0.0345
quark (u, d, c, s, t, b)	12	0.1034
Higgs	1	0.0086

Generator – BH decay 4

However,

- Due to other conservation laws, the “democratic” property is not achieved.

M_p=1TeV,n=3



Horizontal axis : PDG particle code, ex) u → 2, e^- → 11

Point : assigned probability, Hist : generated particle

Multiplicity: <N> ~ $M_{BH}/2T_H$

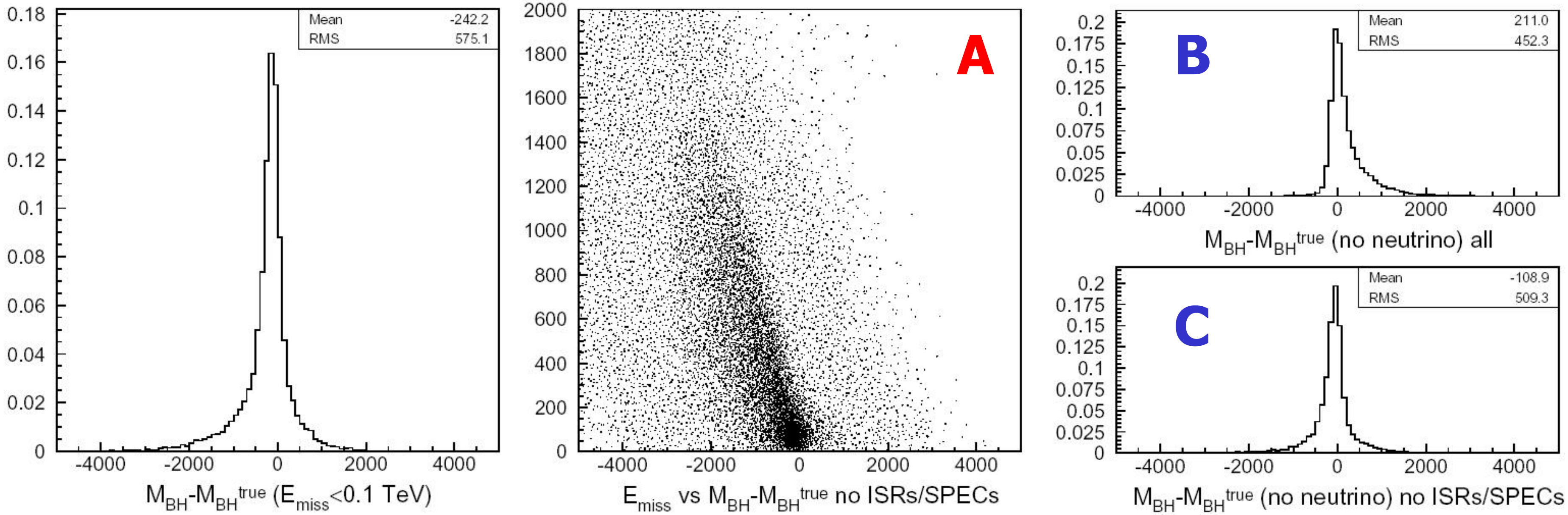
Selection Criteria

- P_t cut for the rejection of particles from ISRs and specrators.
  - P_t > 30GeV for μ, e
  - P_t > 50GeV for γ, jet
- Events must contain at least 4 particles (e,μ,γ,jet) with E > 300GeV and at least 1 particle is either e or γ.
- R_2 < 0.8
  - R_2 is an event-shape parameter.
  - R_2 → 0 : Spherical event
- Missing E_t < 100GeV for BH mass reconstruction

Mass Reconstruction

M_p=1TeV,n=3, M_{BH} > 6TeV

- Effects of missing E_t : Fig **A**.
- Effects of particle from ISRs and spectators. : Fig **B**.
  - Remove these particles using the generator information. →Fig **C**.

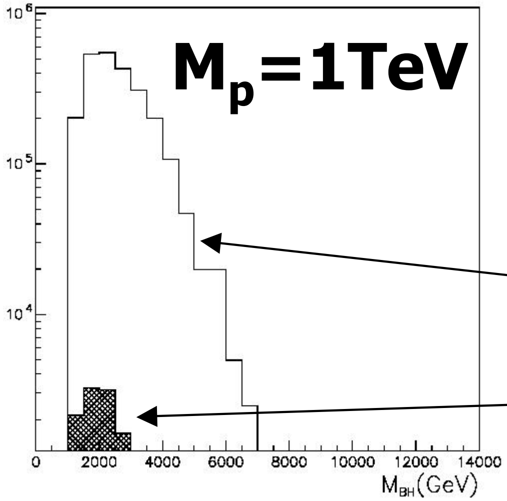


Figs : Difference between reconstructed and generated mass

Mass Distributions

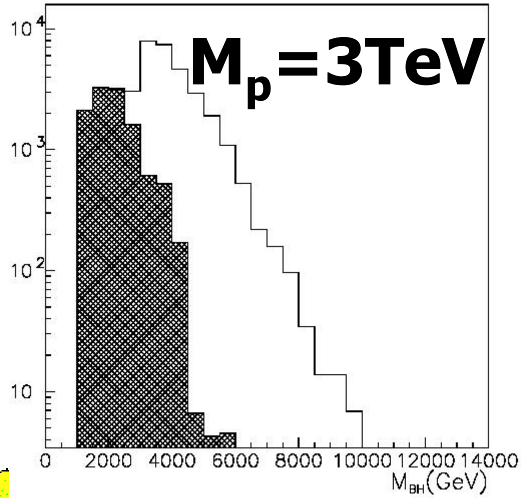
n=3, ∫ *L* = 30 fb^{-1}

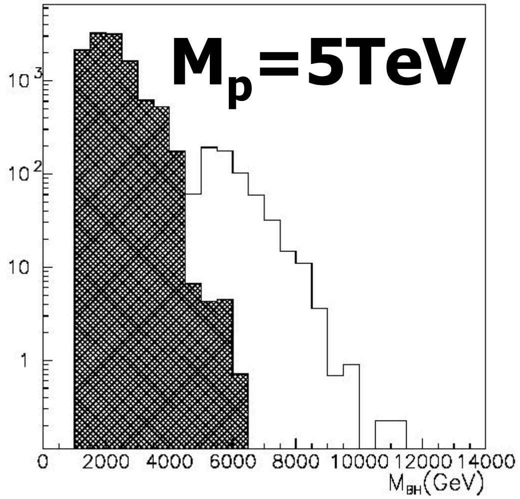
- As M_p becomes larger, the excess of events becomes smaller.

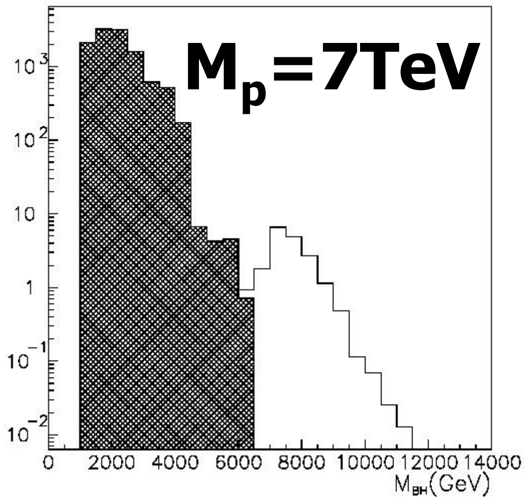


Signal+Background

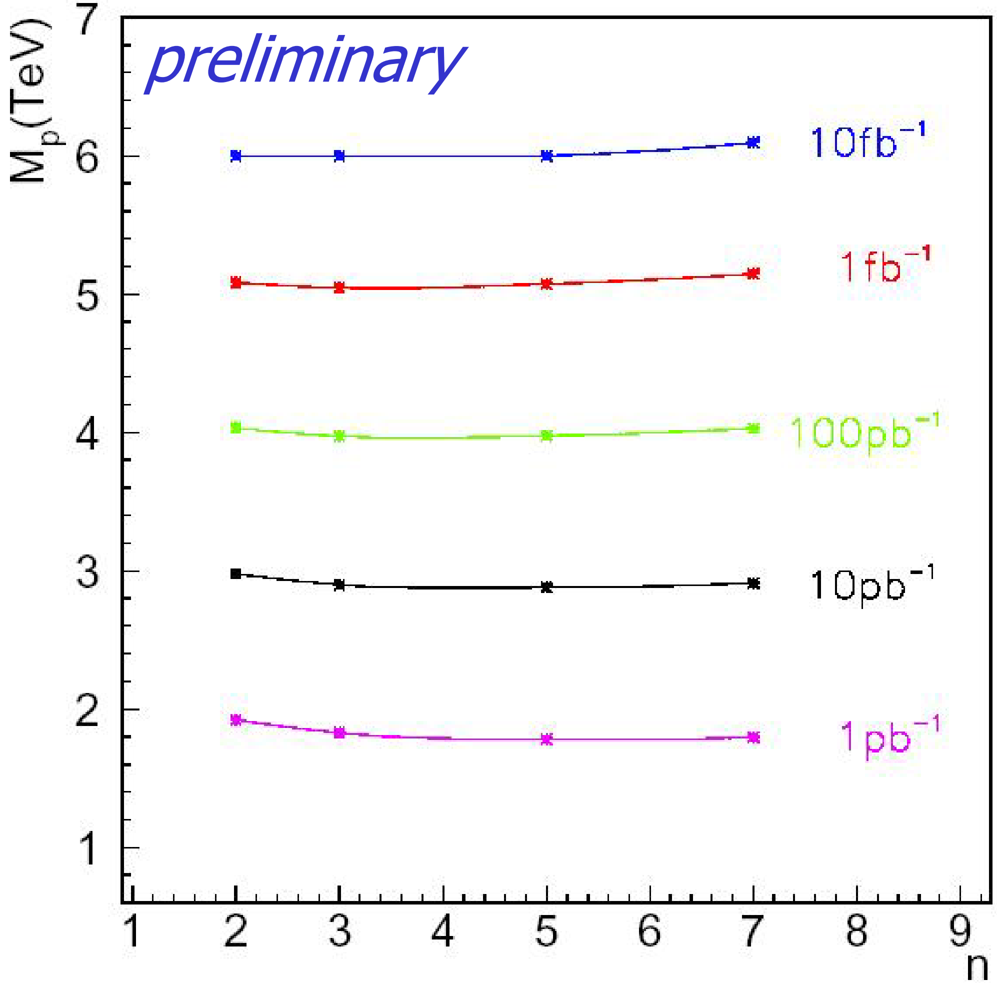
Background







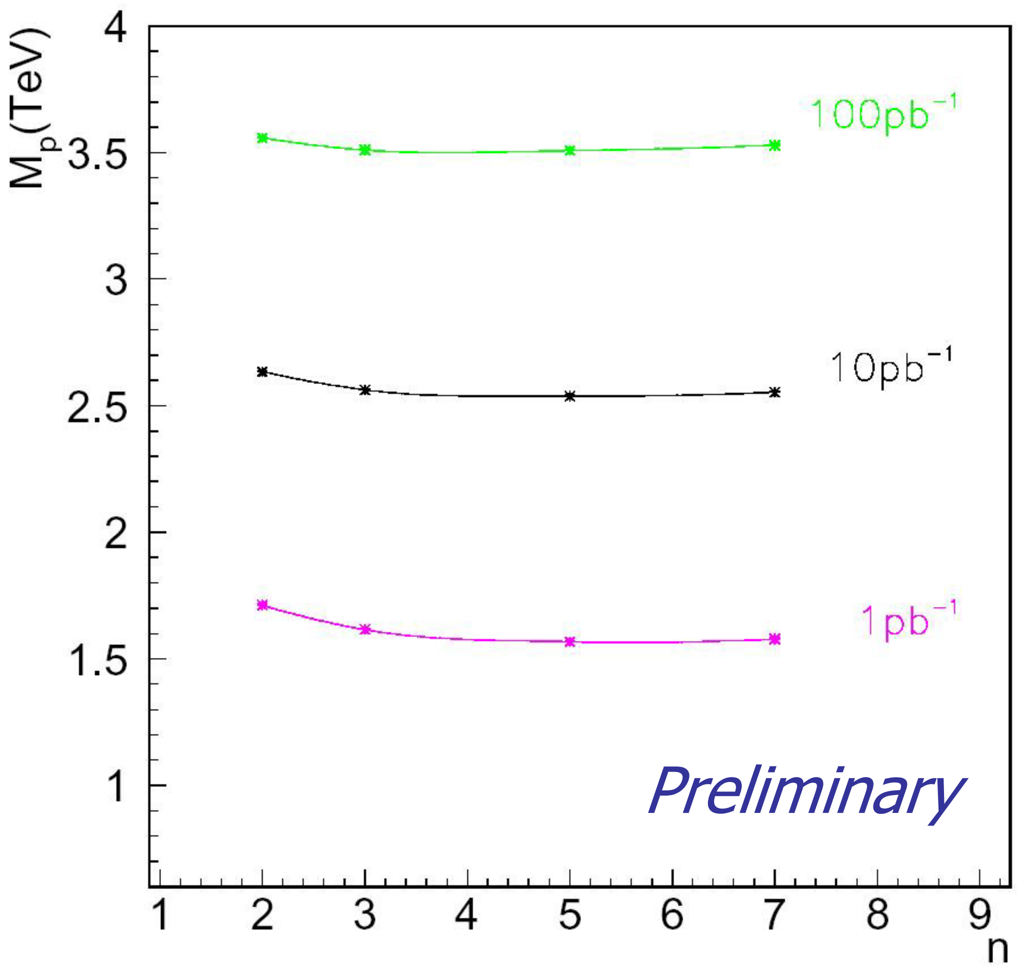
Discovery Potential



Contour of 5σ discovery in (M_p,n) plane

- Discovery potential depends almost only on M_p.
- **M_p < 4TeV**
  - BH will be discovered with **$\int L$ = 100 pb^{-1}**, which corresponds to
    ~ 1 day !

Discovery Potential

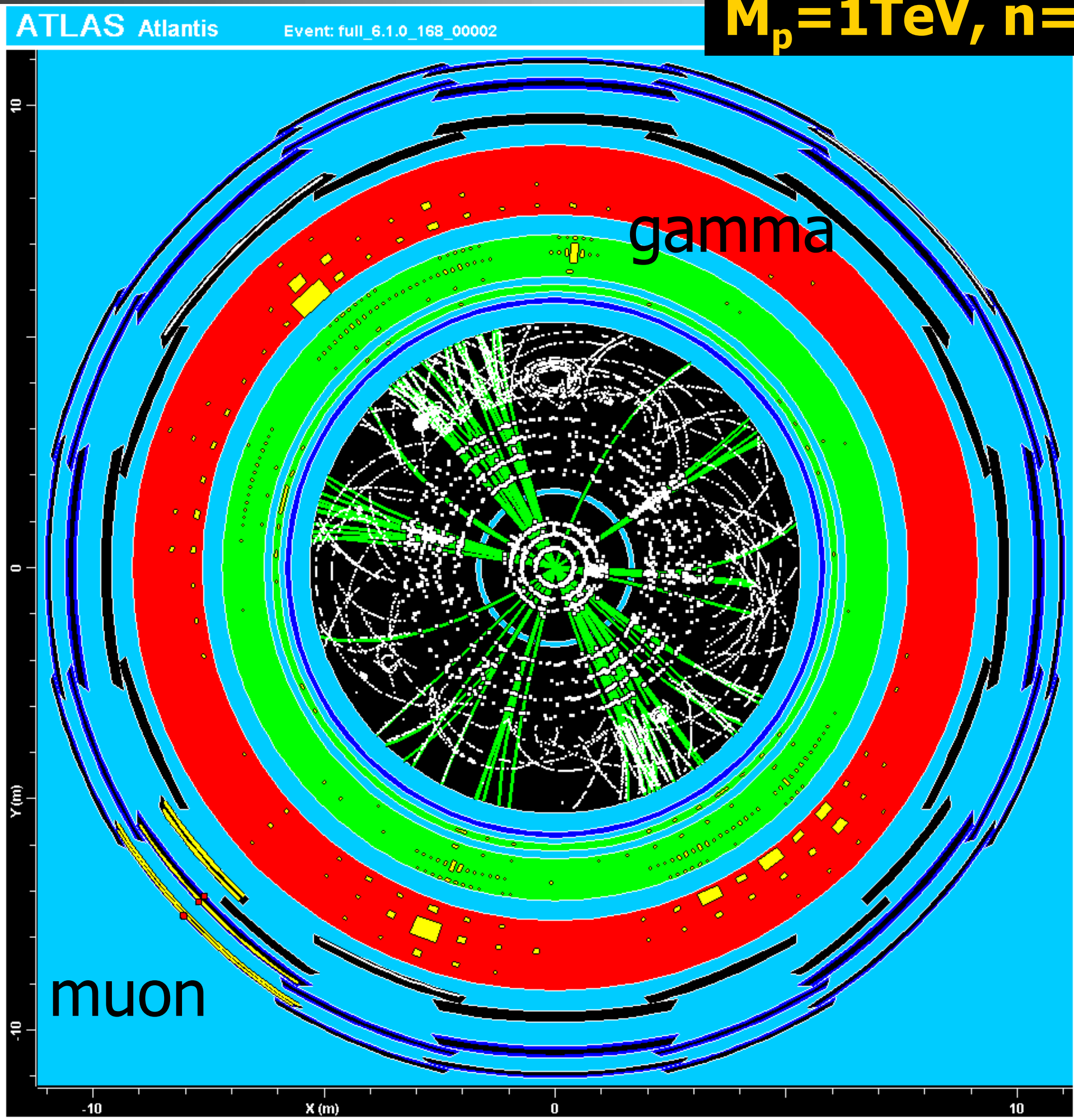


- **M_{BH}^{min}>M_p + 1TeV** の条件を入れた場合
- More *L* is required. But the excess will be observed a few days of running for M_P up to a few TeV.

Event Display

M_p=1TeV, n=2, M_{BH} = 6.1TeV

w/o pile-up

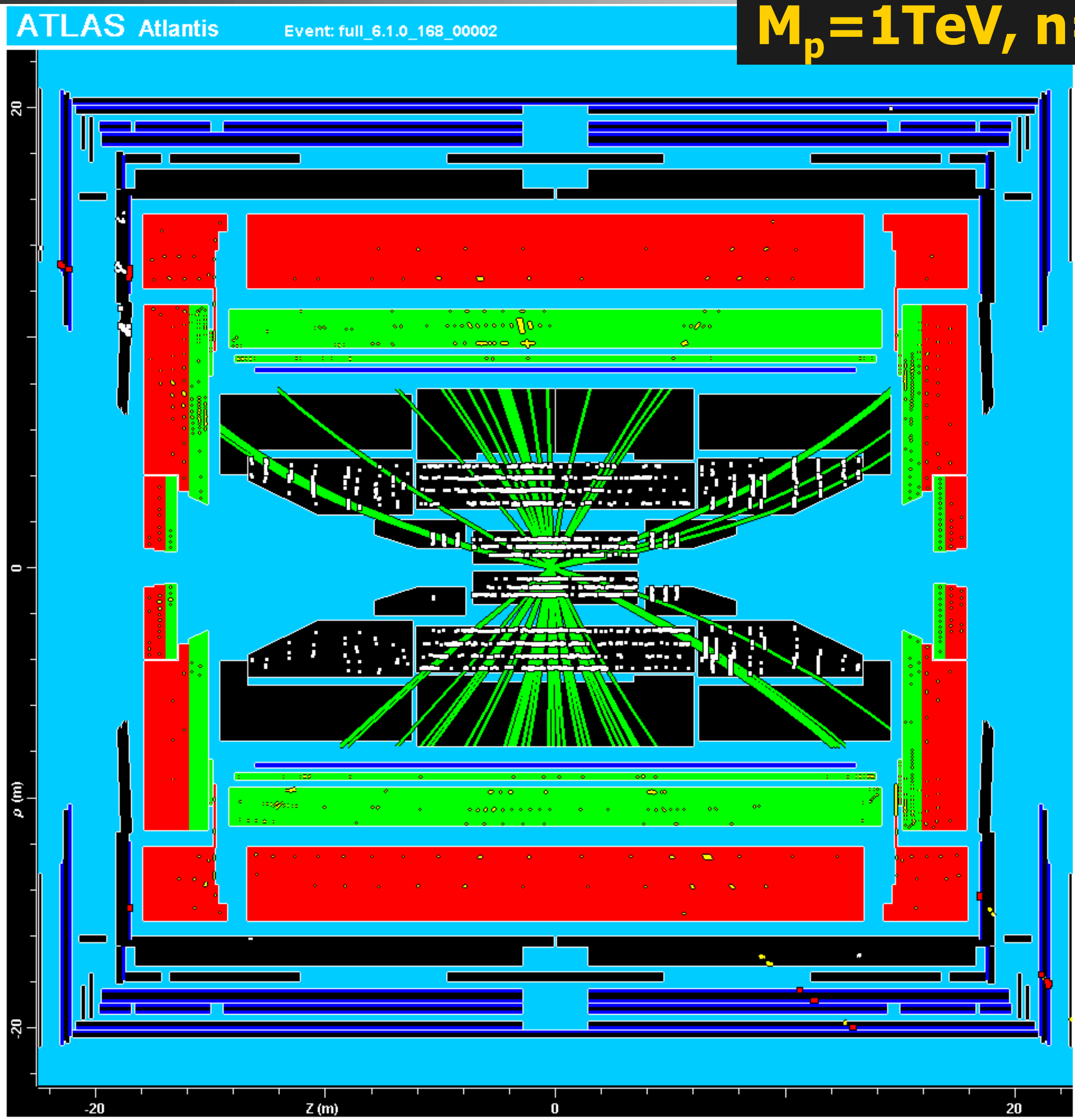


xy-view with fisheye

Event Display

M_p=1TeV, n=2, M_{BH} = 6.1TeV

w/o pile-up



ρz-view(φ=0) with fisheye

Summary 1

- Black hole generator
  - Need to add more properties:
    - "Greybody" factors →
    - Time evolution of BH →
      - M_{BH} and T_H depends on "t".
  - Expressions, which are used here, are valid at $\mathbf{M_{BH} >> M_p}$.
    - M_{BH} < ~5 M_p → **need new theories!** … **String balls** …

    String balls have a similar properties as BHs.

    (S.Dimopoulos and R.Emparan PLB **526** (2002) 393)
- Study methods to measure "large extra dimensions."

最近リリースされた
ブラックホールジェネレーター
"CHARYBDIS"（hep-ph/0307305）

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Summary 2

- We have developed our black hole generator.
  - *Use simple assumptions*
  - Known limitations
    - Some assumptions are not perfectly achieved due to other conservation laws.
    - *Classical approximations* are used at the $M_{BH} \sim M_p$.
- Discovery potential : preliminary results
  - $M_p < \sim 4$ TeV → < **~ 1 day**
  - $M_p < \sim 6$ TeV → < **~ 1 year**