



# Nuovi bosoni di gauge ed Extra Dimensioni ad LHC

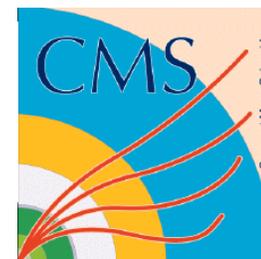
Alessandro Palma

INFN Roma1 & Università di Roma "La Sapienza"

IFAE Napoli - 11 Apr 2007



# Sommario

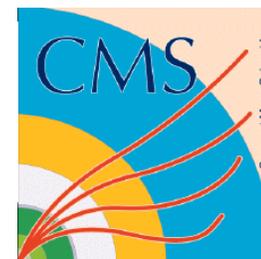


- Bosoni di gauge addizionali:  $Z'$ ,  $W'$
  - Fenomenologia delle Extra Dimensioni:
    - Buchi neri (BH)
    - Gravitoni
- Particolare attenzione a segnali "immediati" ( $\leq 1 \text{ fb}^{-1}$ )
- NO Susy, NO Higgs



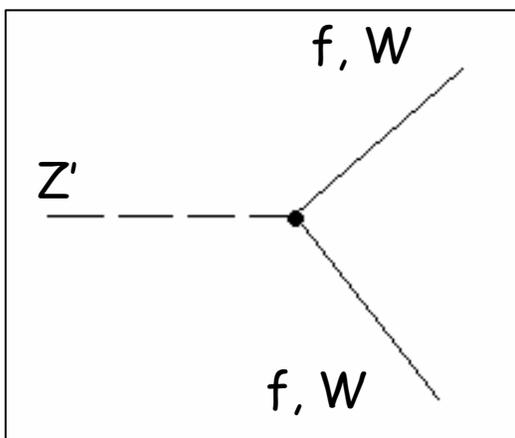
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# $Z'$ - generalità



- Bosone di gauge neutro da: GUTs, ExtraDimensioni con stati di Kaluza-Klein, modelli simmetrici LR, Little Higgs...
- **Sequential Standard Model (SSM):**  $Z'_{SSM}$  ("benchmark model")
- **GUT basate sul gruppo di gauge E6:**  $Z'_{\eta}, Z'_{\psi}, Z'_{I}, Z'_{\chi}$
- **Left-Right symmetric models:**  $Z'_{LRM}, Z'_{ALRM}$

Decadimento dello  $Z'$



$Z' \rightarrow ee$  ( $\mu\mu$ )

segnatura molto evidente

• 2 leptoni isolati di alto  $p_T = O(1 \text{ TeV})$

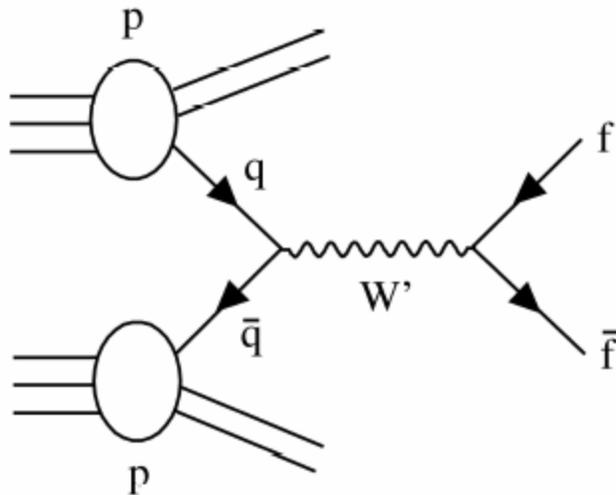
fondo molto piccolo



# $W'$ - generalità



- Bosone di gauge carico: si accoppia ai campi right-handed del Modello Standard
- Compare da gruppo di gauge  $SU(2)_R$  nei modelli simmetrici Left-Right, nelle GUT  $SO(10)$  o dalle teorie "Little Higgs" dove l' Higgs è uno pseudo-bosone di Goldstone



$W' \rightarrow e\nu (\mu\nu)$

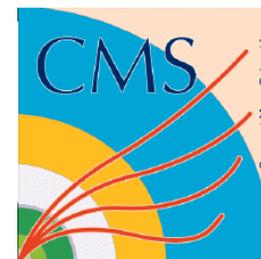
1 leptone isolato di alto  $p_T = O(1 \text{ TeV})$

$E_T = O(1 \text{ TeV})$



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# Z' - limiti attuali e fondi



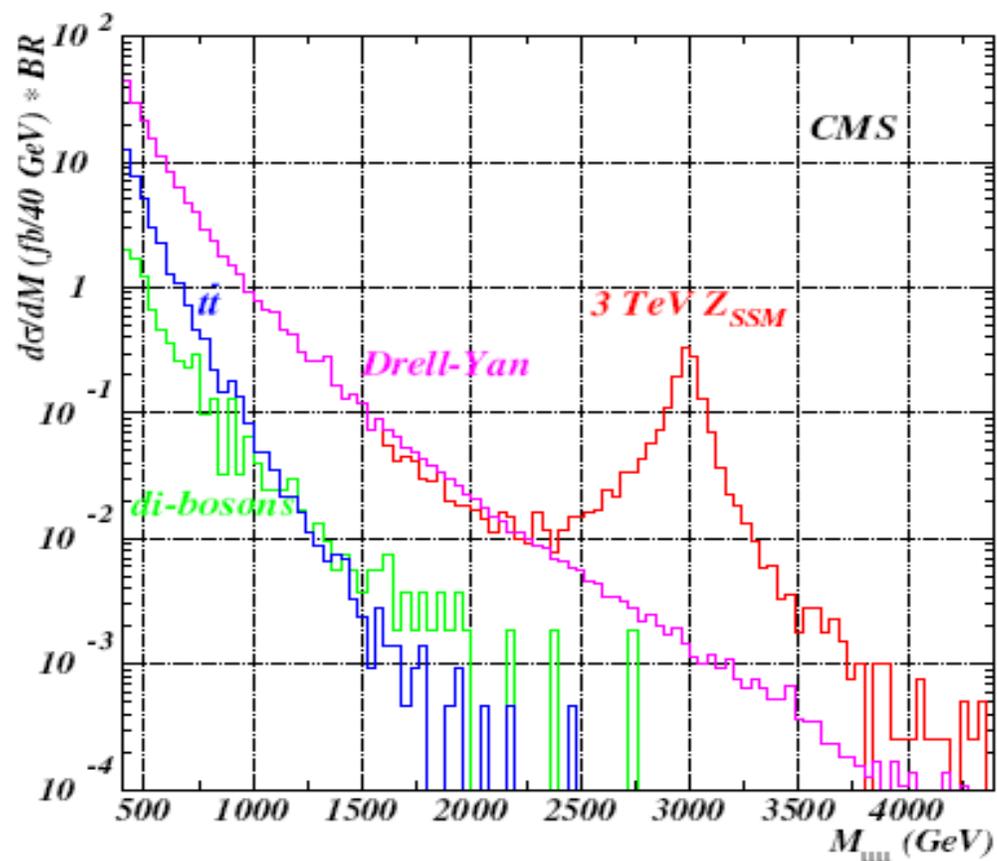
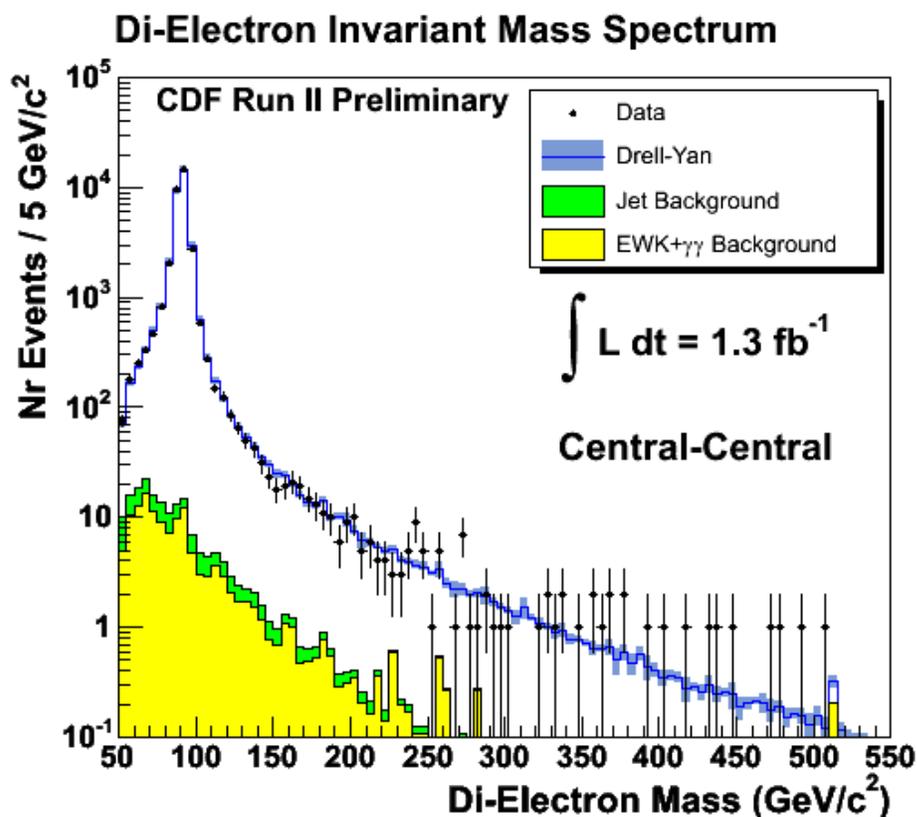
Ricerca diretta al Tevatron ( $ee, \mu\mu$ ):

[www-cdf.fnal.gov/physics/exotic/exotic.html](http://www-cdf.fnal.gov/physics/exotic/exotic.html)

$M_{Z'} > 730 \div 920 \text{ GeV}$  (dip. dal modello)

Fondo principale: DY in  $e/\mu$

Altri fondi: WW, WZ, ZZ,  $t\bar{t}$

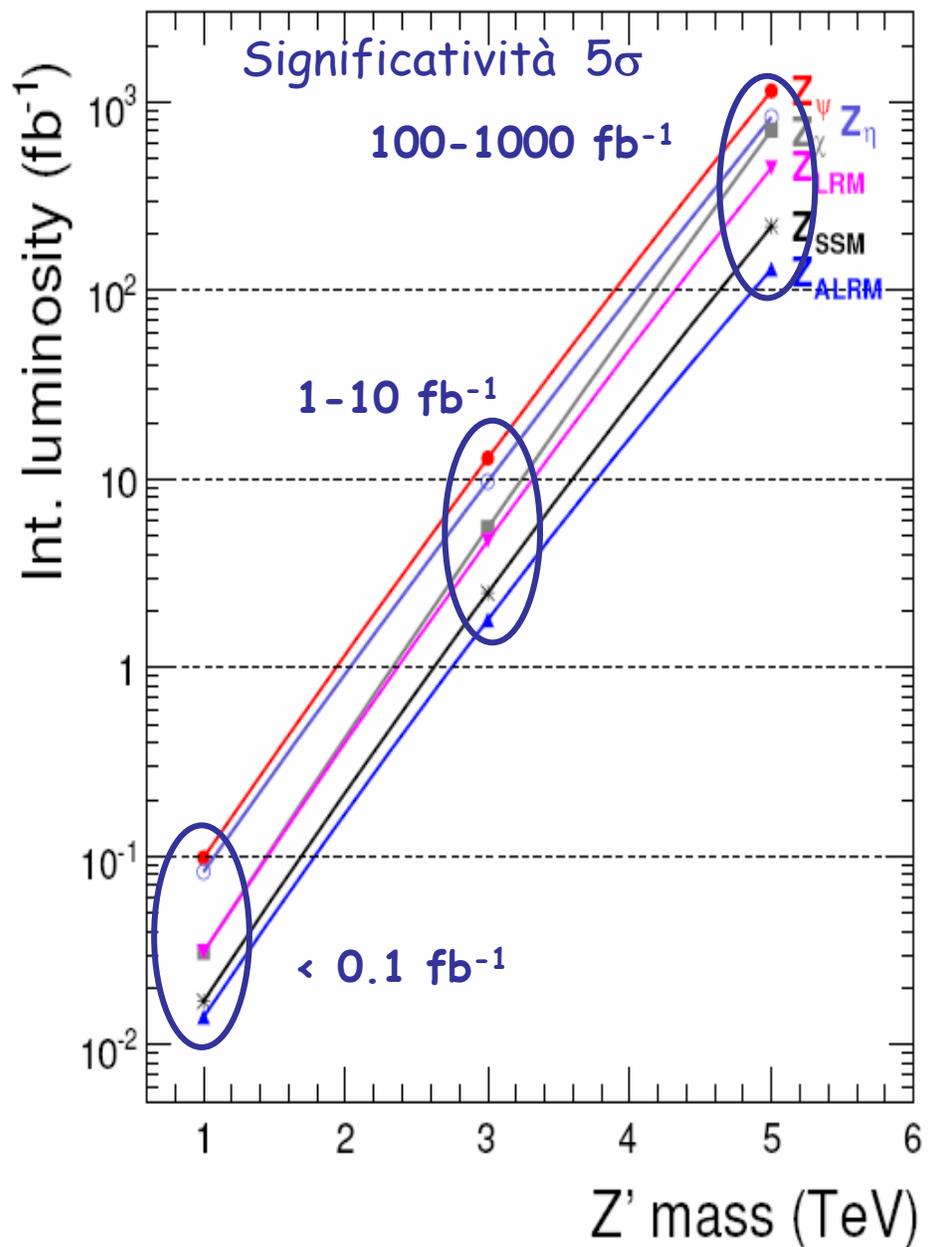
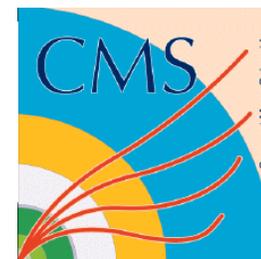




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# $Z' \rightarrow \mu\mu$ @ CMS

[CMS PTDR2]



**CMS:**

risultati analoghi  
per  $Z' \rightarrow ee$

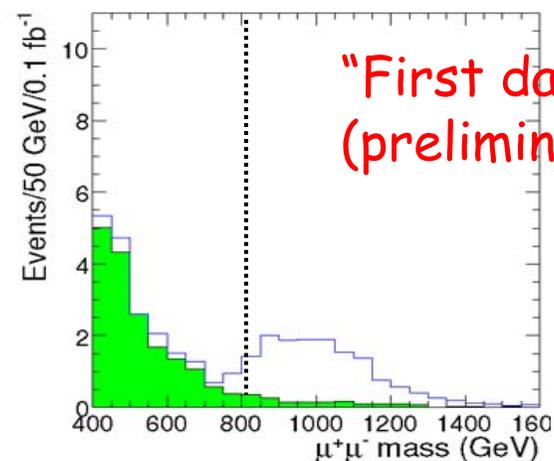
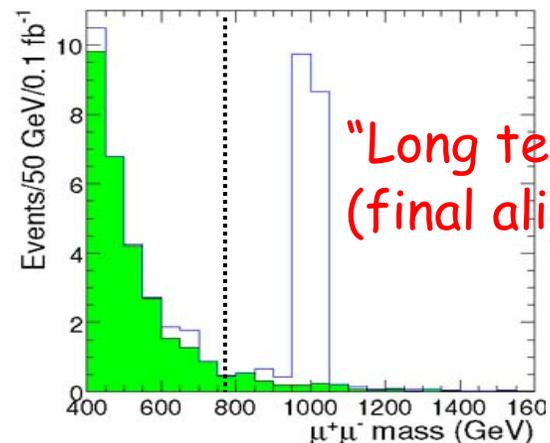
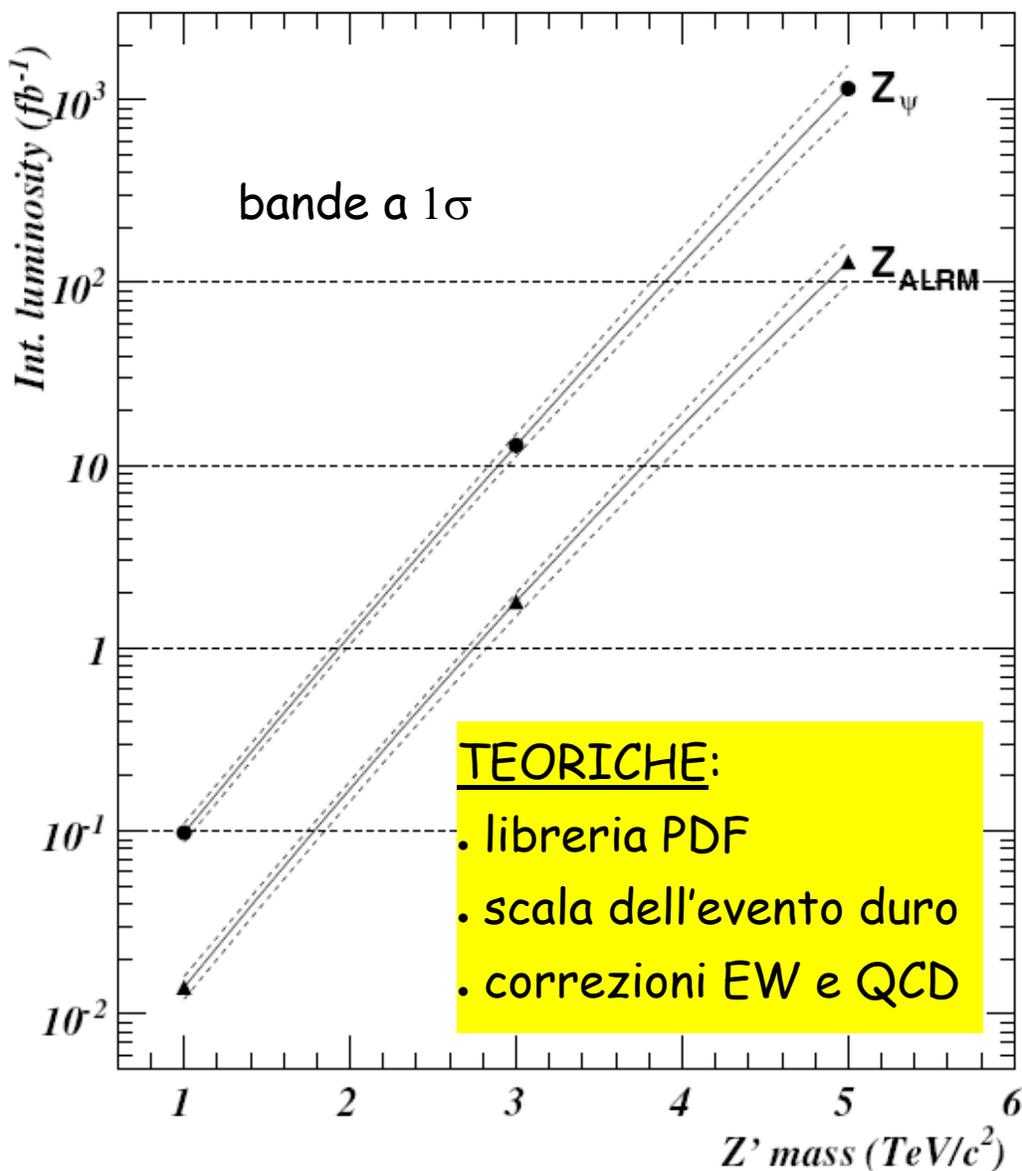
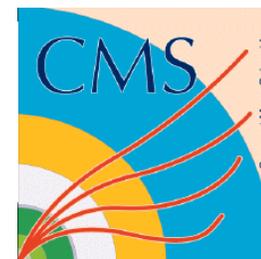
**ATLAS:**

con  $Z' \rightarrow ee$  SSM,  
bastano  $0.1 \text{ fb}^{-1}$   
se  $M_{Z'} < 1.3 \text{ TeV}$



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# $Z' \rightarrow \mu\mu$ @ CMS: sistematiche



## SPERIMENTALI:

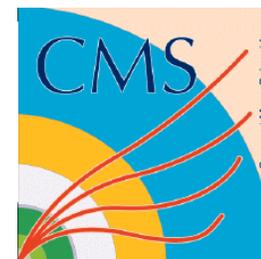
- disallineamenti TK, Muon, TK-Muon
- calibrazione Drift Tubes
- ... non influenzano lum. di scoperta



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# $W' \rightarrow \mu\nu$ @ CMS

[Hof, CMS-CR2006/054]



**Segnatura:**  $\cancel{E}_T$ ,  $\mu$  isolato

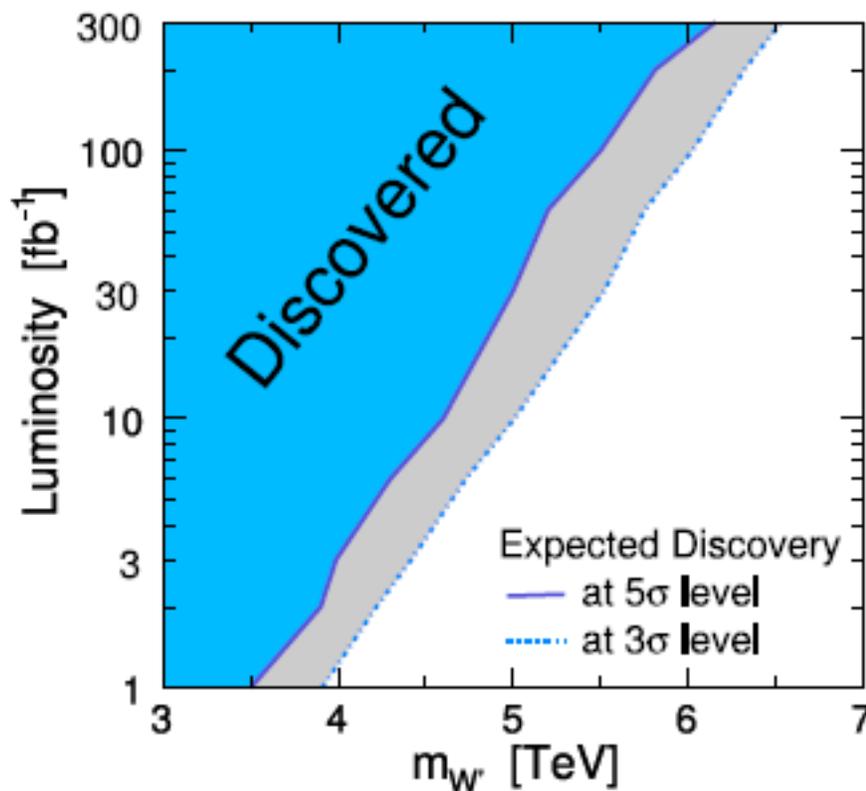
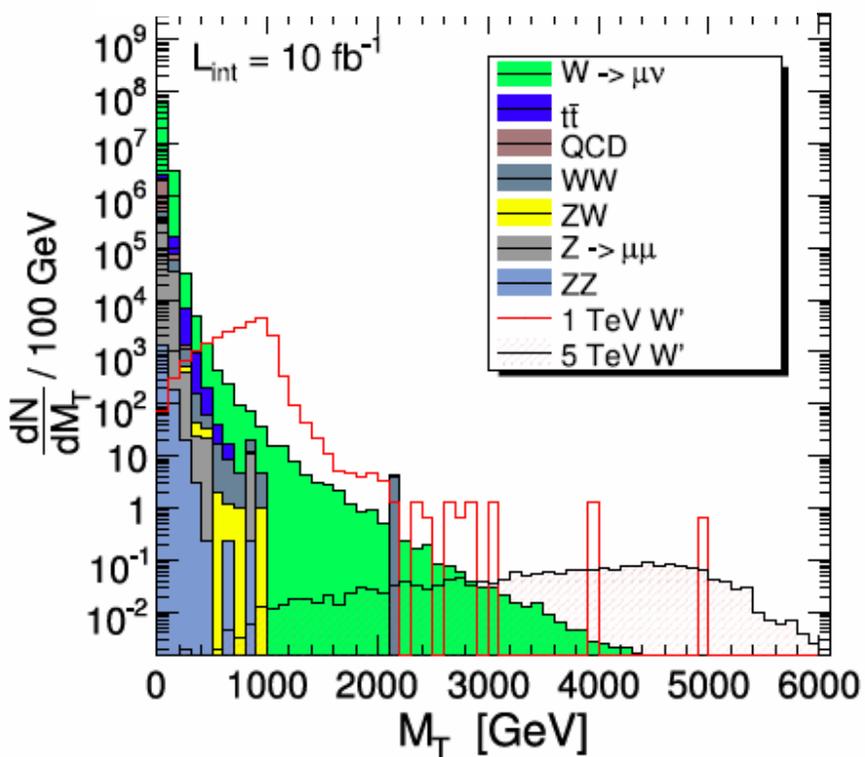
**Fondi:**  $W \rightarrow \mu\nu$ ,  $Z \rightarrow \mu\mu$ ,  $t\bar{t}$ ,  $WW$

Significanza sulla massa trasversa  $M_T$

Limite di CDF Run II:

$M > 790$  GeV @95%CL [Gris, March '06]

$$M_T = \sqrt{2p_{T\mu} E_{\cancel{T}} (1 - \cos \Delta\phi_{\mu, \cancel{E}_T})}$$



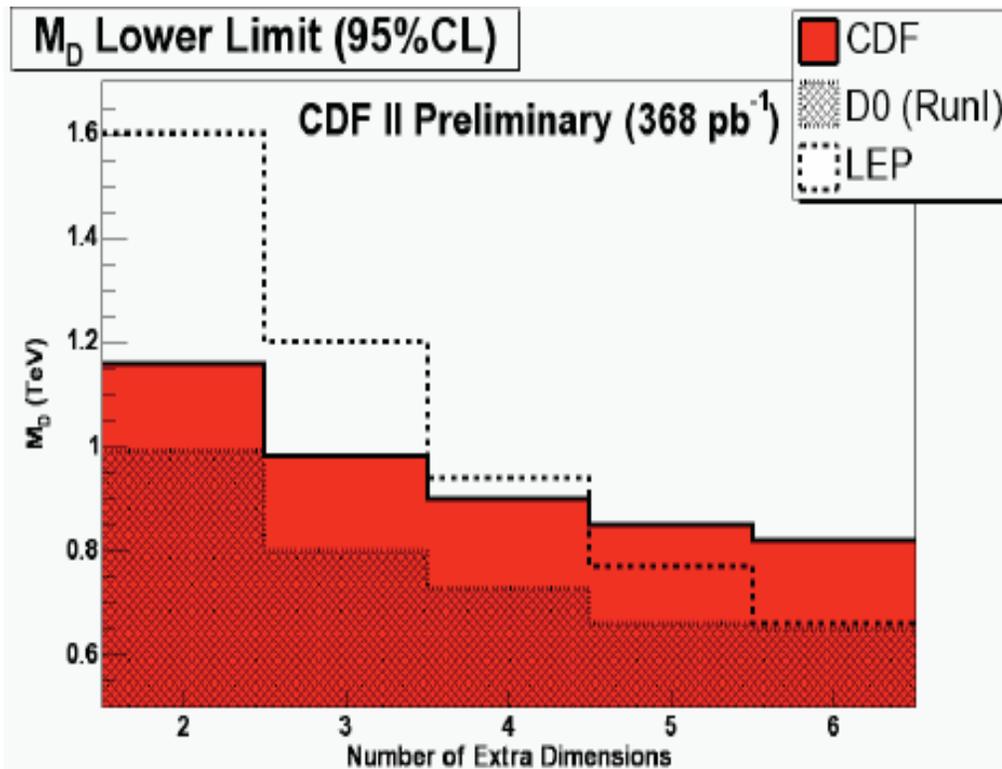


# Extra Dimensioni (modello ADD)



[N. Arkani-Hamed, S. Dimopoulos, and G.R. Dvali, *Phys. Lett.* B429(1998)]

- Problema gerarchico:  $M_{\text{Planck}} (10^{19} \text{ GeV}) \gg M_{\text{EW}} (100 \text{ GeV})$
- $n$  extra-dimensioni spaziali compattificate su scala  $R$
- la gravità si propaga nel "bulk" a  $3+n$  dimensioni, dove ha scala  $M_D \ll M_{\text{Planck}}$



## Constraints:

- $M_D < 10 \text{ TeV}$  (probl. gerarchico)
- $n > 1$  ( $n=1$  escluso dalla legge di Newton testata fino a  $200 \mu\text{m}$ )

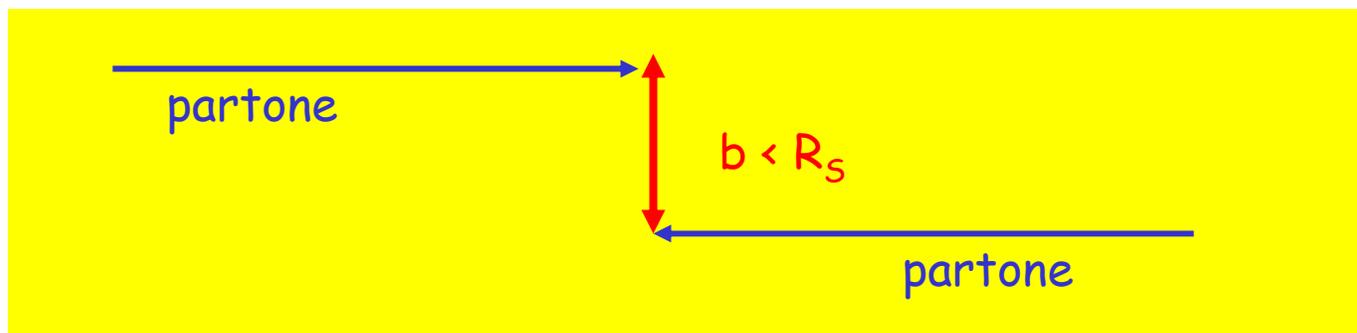


# Buchi neri (BH) ad LHC

[Gamsizkan et al., CMS AN-2006/088 ]



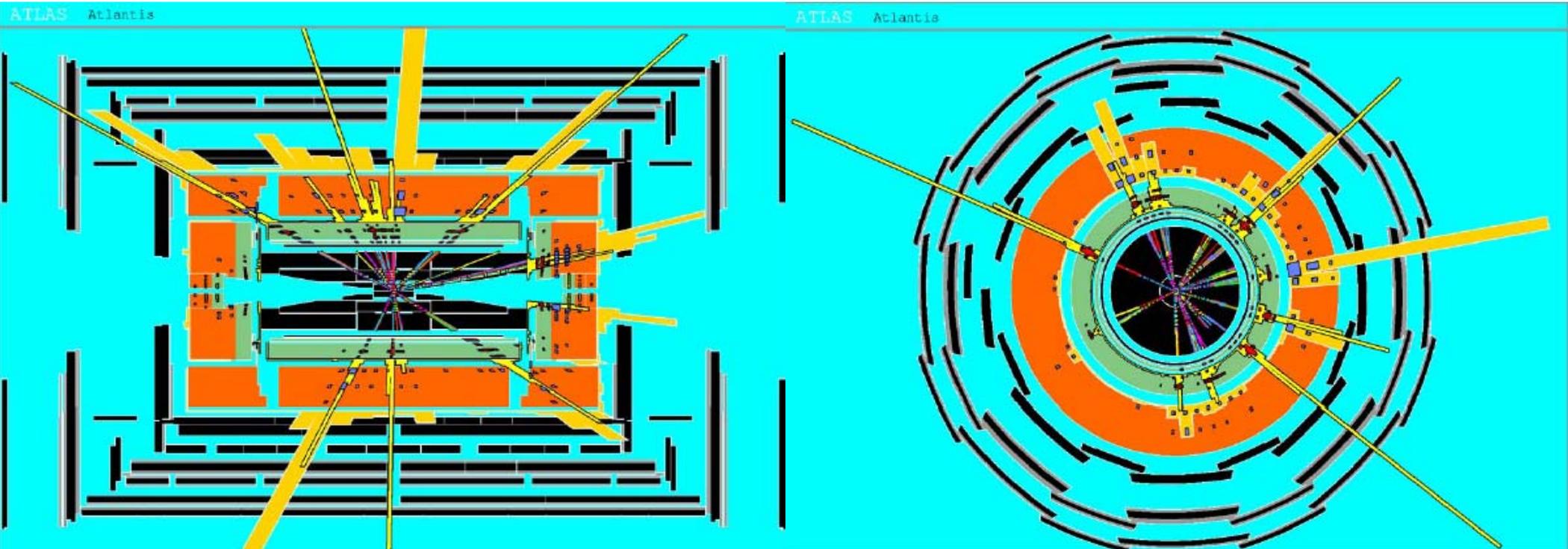
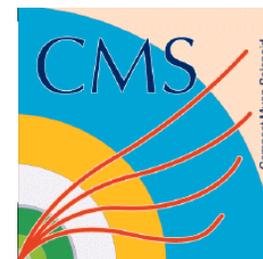
- $T = 10^{15}$  K, decadimento rapidissimo ( $10^{-27}$  s) via radiazione di Hawking
- Per creare buchi neri ad LHC è richiesto:
  - $\sqrt{s} > M_D = O(1 \text{ TeV})$
  - Parametro d'impatto  $b$  piccolo (condizione di Schwarzschild):  $b < R_S$



- Sezione d'urto ad LHC per  $M_{BH} > M_D$ :  
 $1 \text{ pb} < \sigma < 15 \text{ pb}$ , per  $1 \text{ TeV} < M_D < 5 \text{ TeV}$
- Per  $L = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ , rate di produzione  $\sim 0.1 \text{ Hz}$



# Un evento BH in ATLAS

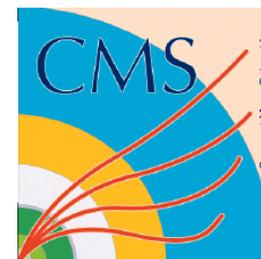


- Media di 6 particelle nello stato finale, emesse sfericamente
- Decadimento "democratico": equiprobabili  $\sim 120$  canali particella-antiparticella  $\rightarrow$  probabilità di neutrini ( $\cancel{E}_T$ ) bassa

**Fondi:**  $q\bar{q}$ ,  $t\bar{t}$ ,  $VV$  ( $V=Z,W$ ),  $gV$ ,  $gg$



# Potenziale di scoperta BH @ ATLAS



[Robindra Pabhu, Univ. of Oslo, Atlas Exotics WG meeting Nov '04]

## Selezione degli eventi:

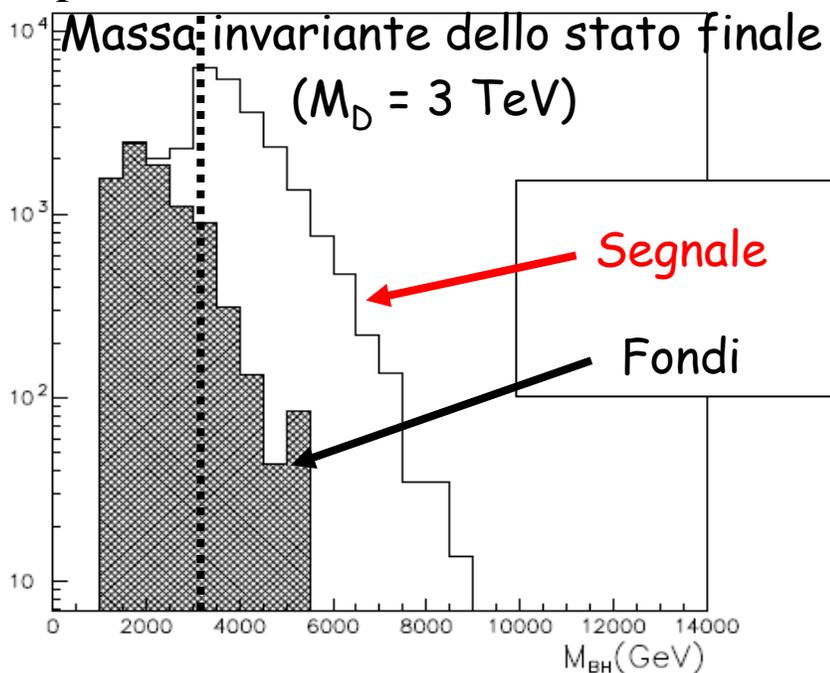
0) considero solo  $\mu, e$  con  $p_T > 30 \text{ GeV}$ ,  
 $\gamma/\text{jet}$  con  $p_T > 50 \text{ GeV}$

1) Taglio sulla sfericit  dell'evento

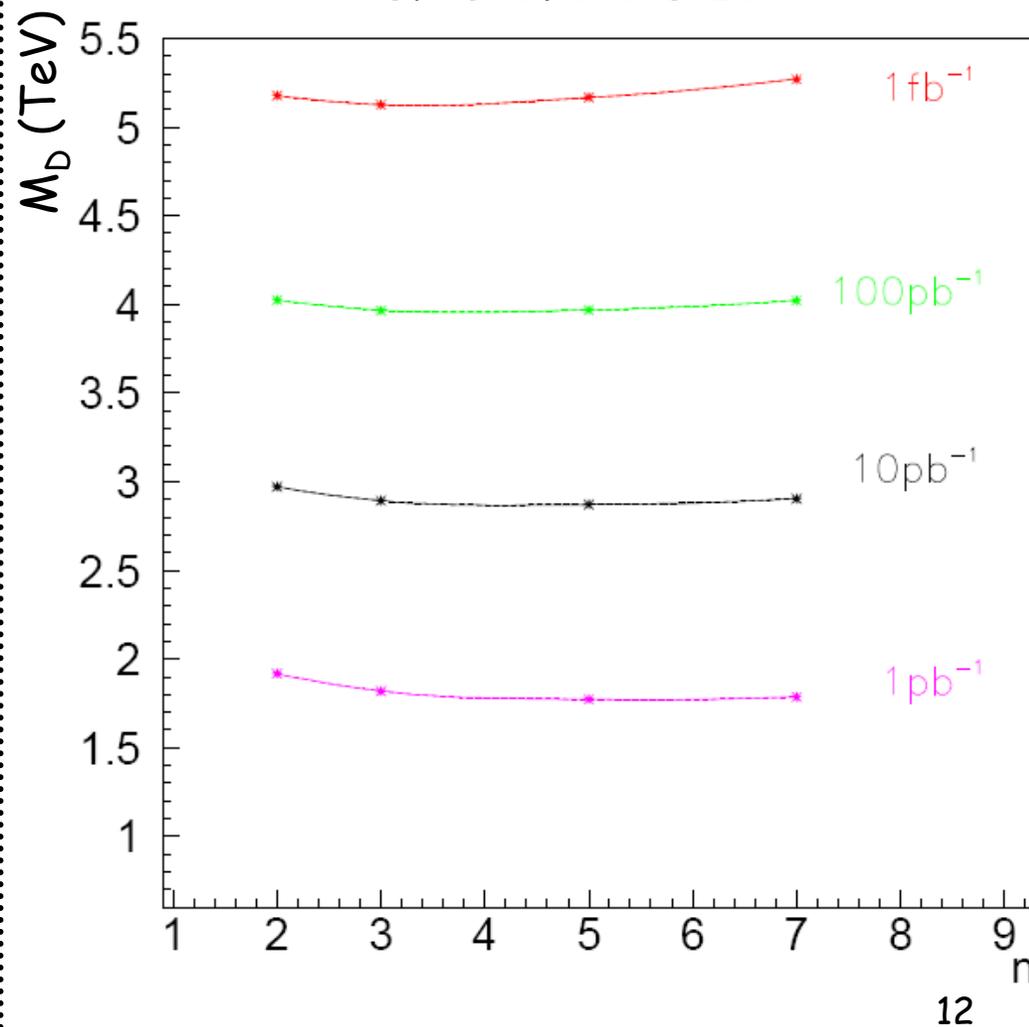
2)  $\geq 3$  particelle con  $E > 300 \text{ GeV}$ ,

$\geq 1 e^\pm$  o  $\gamma$

3)  $E_T < 100 \text{ GeV}$

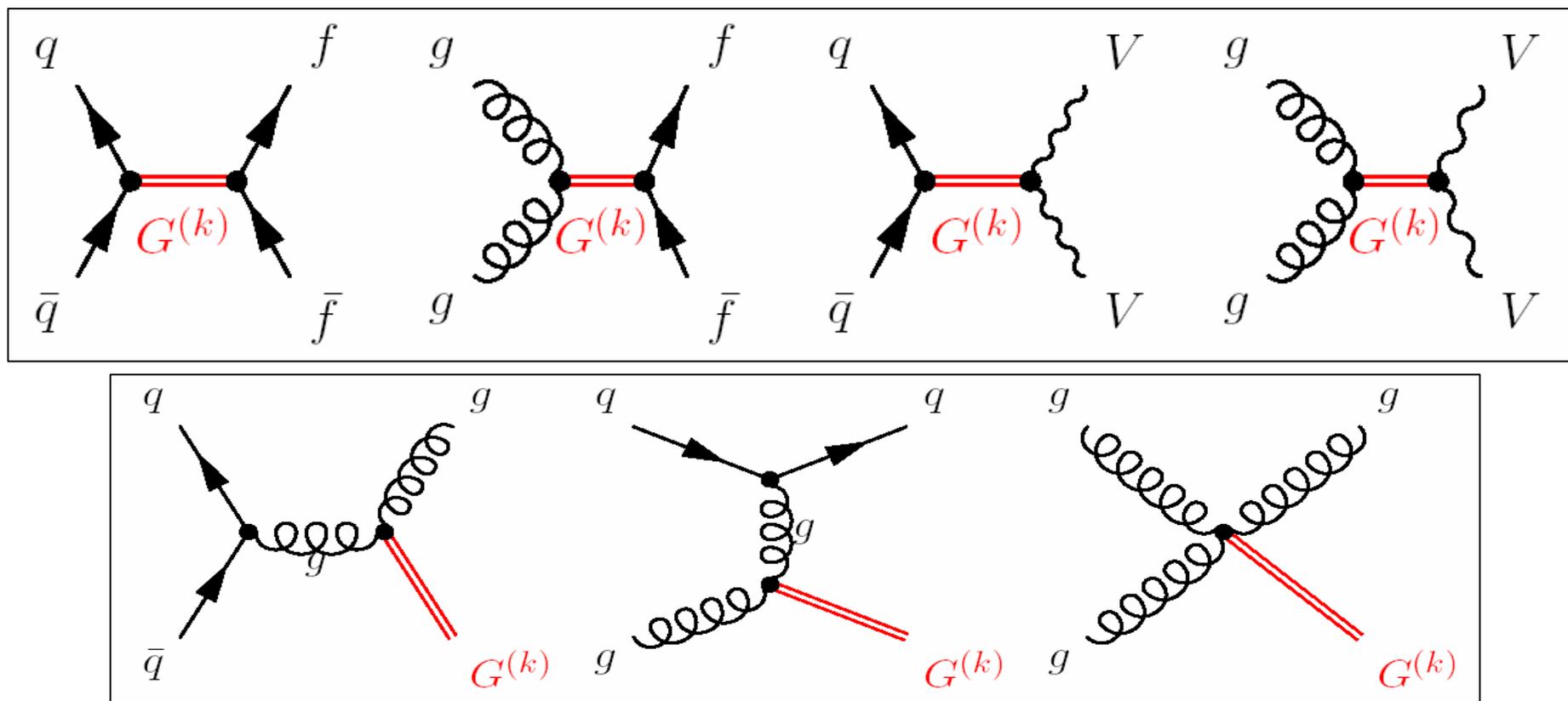


Lum. scoperta a  $5\sigma$ :  
 $S/\sqrt{B} > 5$ . and  $S > 10$



# Gravitone - generalità

- Bosone di gauge dell'interazione gravitazionale, spin 2, massa nulla
- Virtuale: decade in una coppia di fermioni o bosoni vettori
- Reale: non decade e non viene rivelato

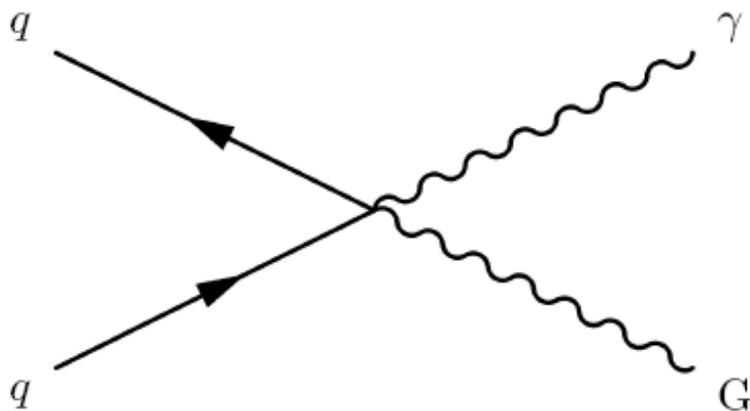




# Gravitone ADD: $pp \rightarrow G\gamma$ @ CMS

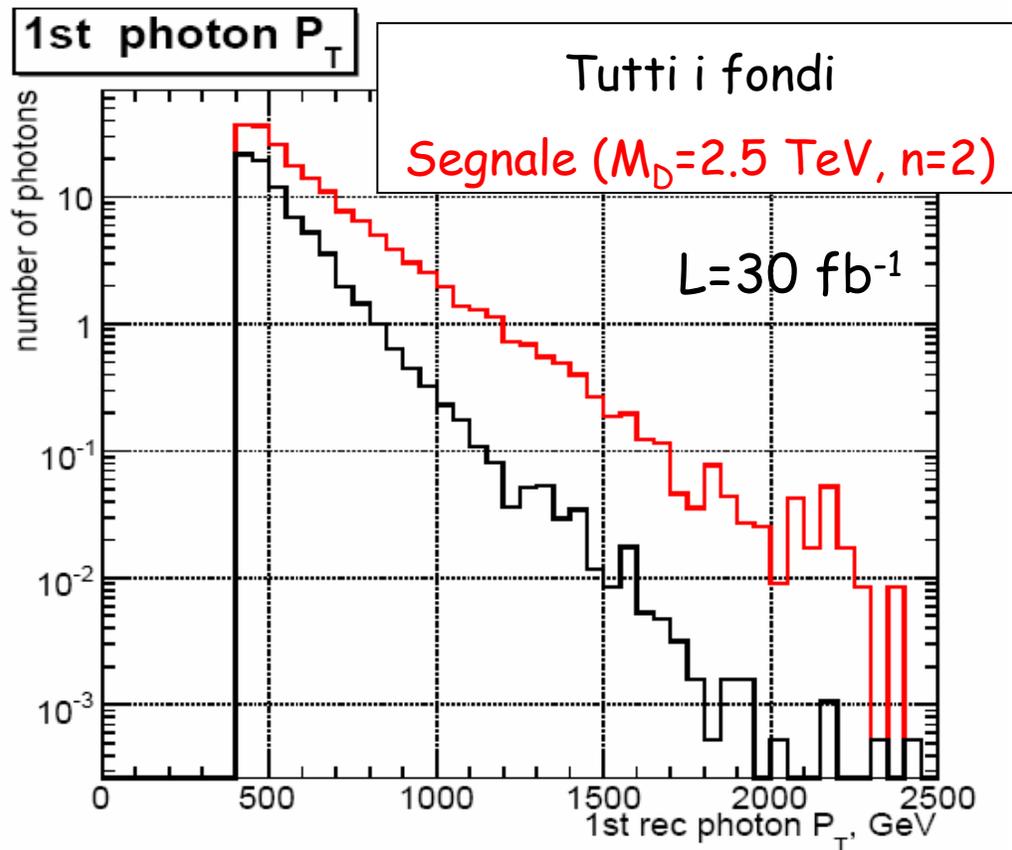
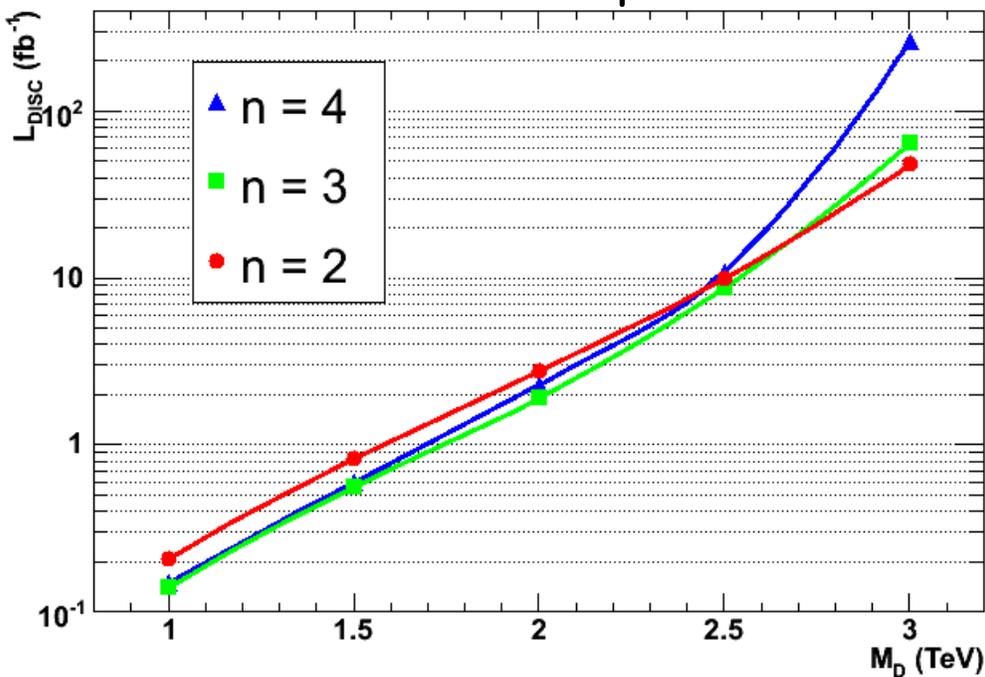


[Weng et al., CMS NOTE 2006/129]



**Segnatura:**  $\cancel{E}_T$ ,  $\gamma$  energetico  
**Fondi:**  $\gamma + Z \rightarrow \nu\nu$ ,  $\gamma + W \rightarrow l\nu$   
**Tagli analisi:**  $\cancel{E}_T$ ,  $E_T(\gamma) > 400 \text{ GeV}$

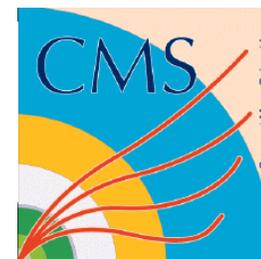
Luminosità di scoperta a  $5\sigma$ :





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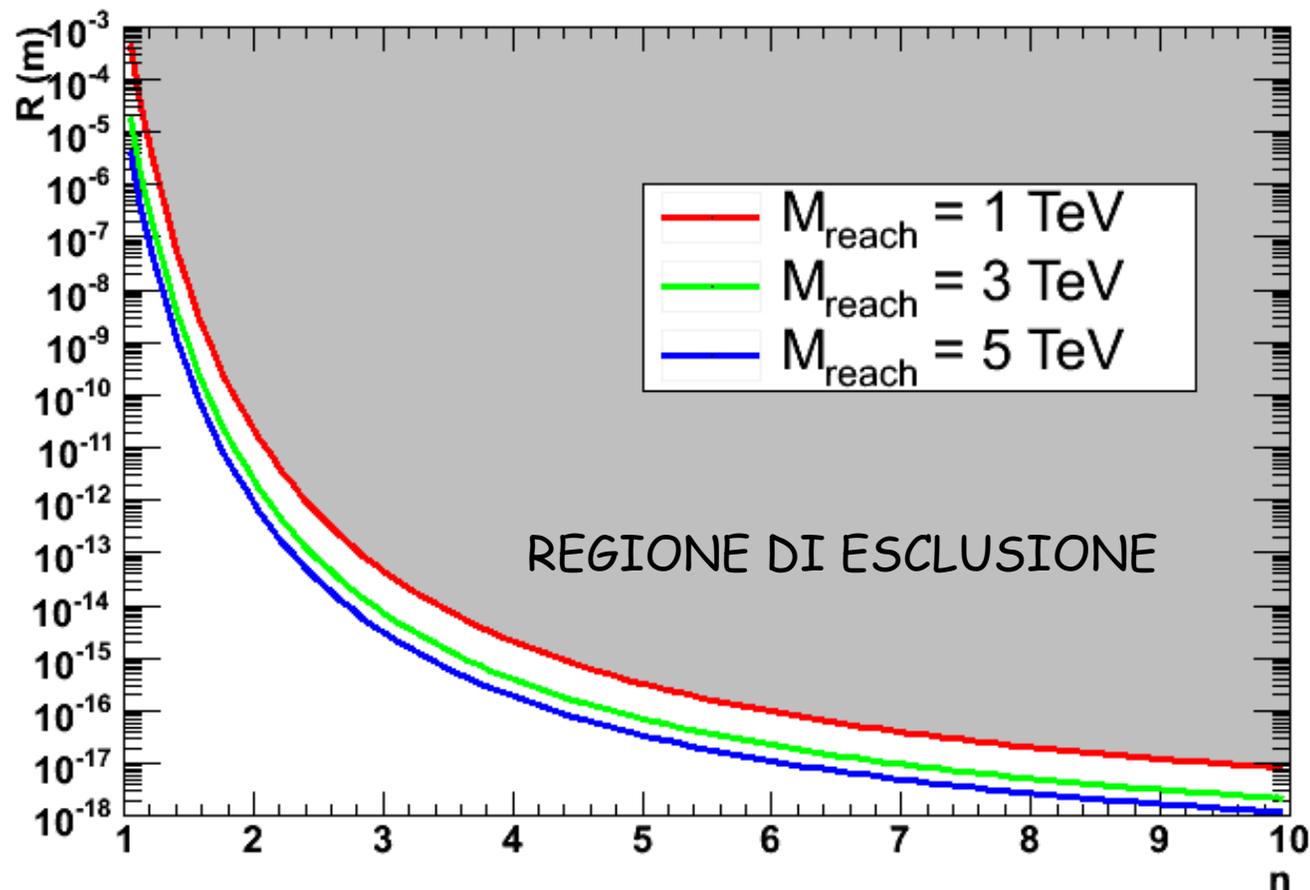
# Limiti sui parametri ADD



Se LHC mette un limite inferiore  $M_{\text{reach}}$  sulla scala della gravità:  $M_D > M_{\text{reach}} \dots$

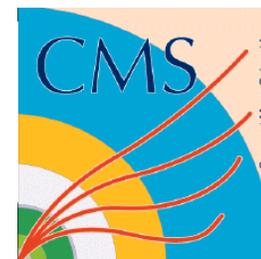
$M_{\text{reach}} = 1 \text{ TeV}$ :  $10^{-5} \text{ fb}^{-1}$  con il canale Buchi Neri (ATLAS, CMS)

$M_{\text{reach}} = 5 \text{ TeV}$ :  $1 \text{ fb}^{-1}$  con il canale Buchi Neri (ATLAS)

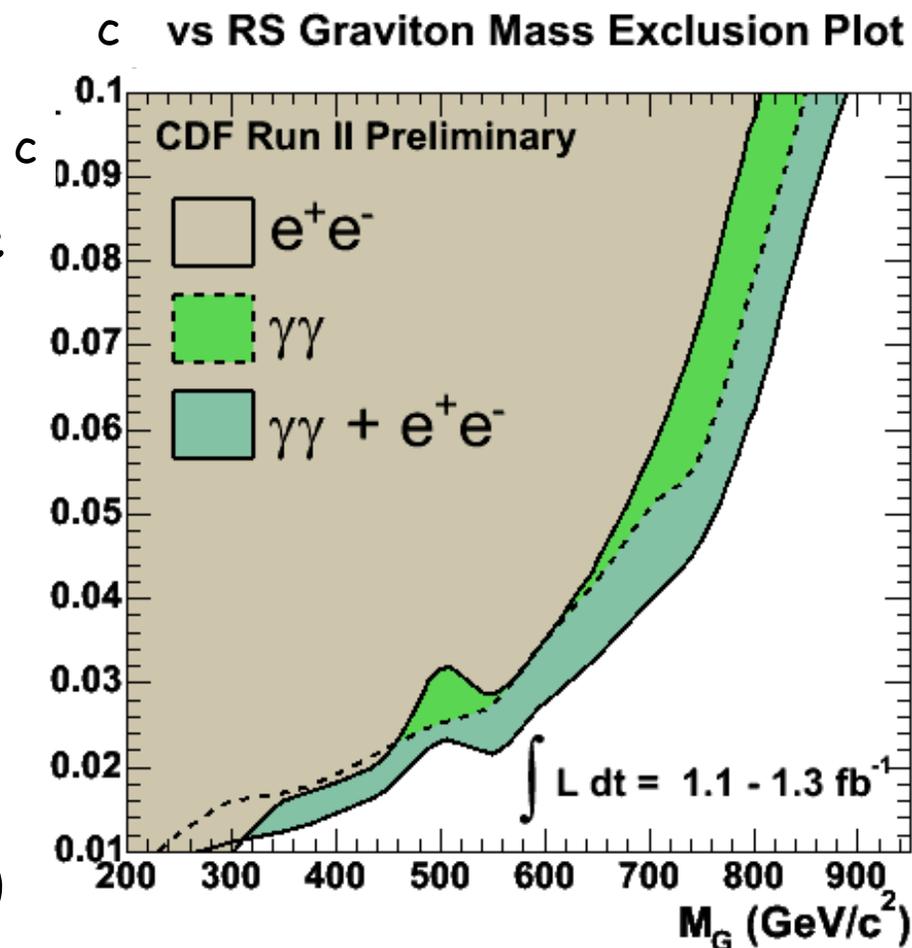




# Gravitone Randall-Sundrum



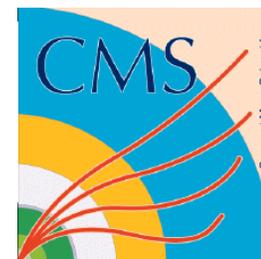
- Modello RS: 1 sola extra-dimensione
- Nel bulk la gravità ha scala  $\Lambda_\pi$
- Il gravitone si propaga nel bulk:  
in 3D appaiono sue repliche massive  
("torri di stati" di Kaluza-Klein)
- 2 parametri:
  - $\Lambda_\pi$
  - $c$  = cost. di accoppiamento
- Constraints:
  - $c < 0.1$  (curvatura 5D)
  - $\Lambda_\pi < 10 \text{ TeV}$  (probl. gerarchico)



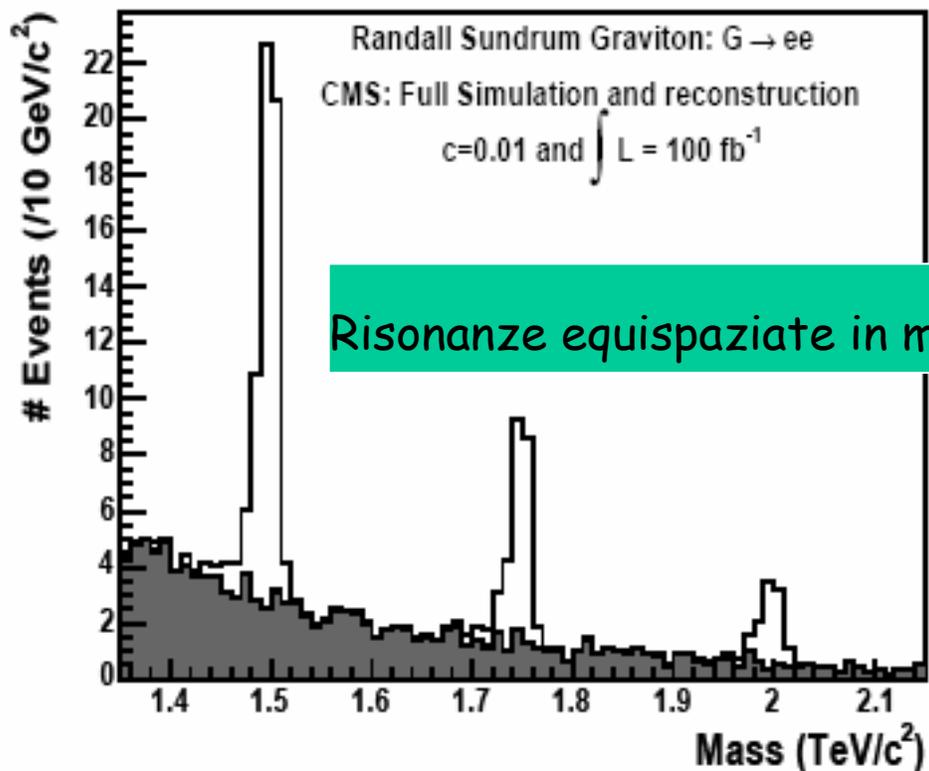
Le repliche generano risonanze...



# Randall-Sundrum: $G \rightarrow ee$ @ CMS



[Collard et al., CMS NOTE 2004/024]

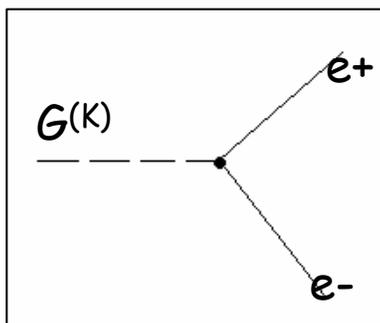
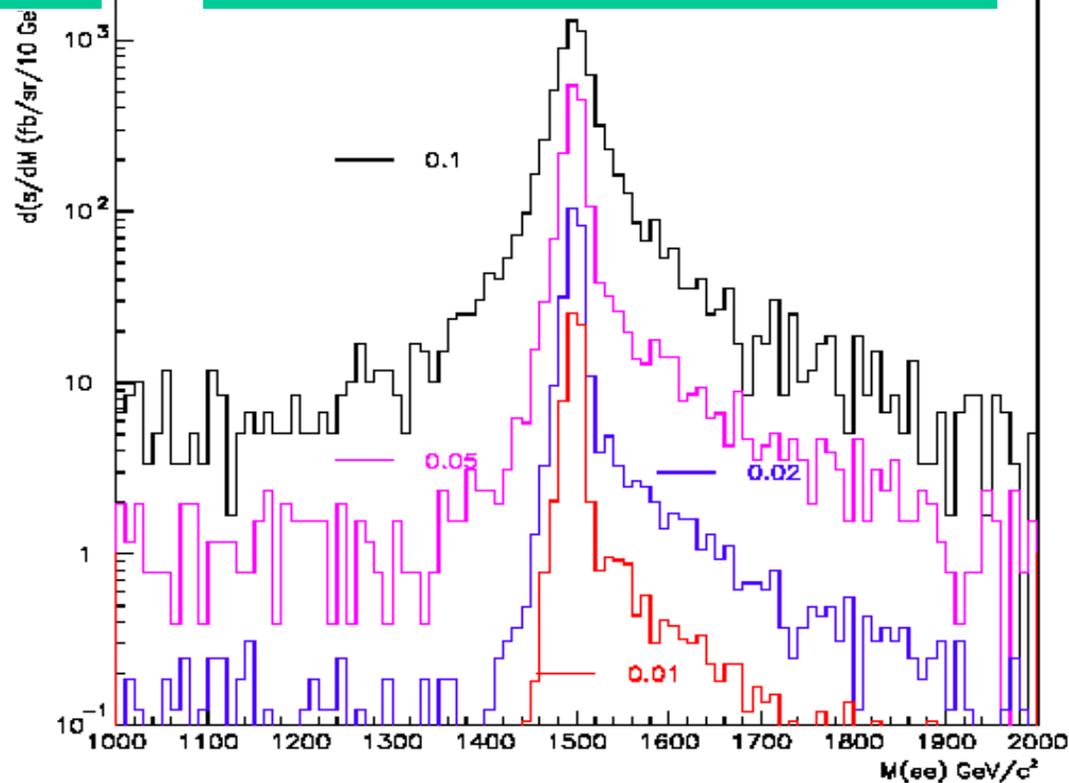


Risonanze equispaziate in massa

Fondi:  $\gamma, Z \rightarrow ee$  (DY)

Tagli analisi: 2 el. con  $E > 100 \text{ GeV}$

Risonanza  $M=1.5 \text{ TeV}$  al variare di  $c$





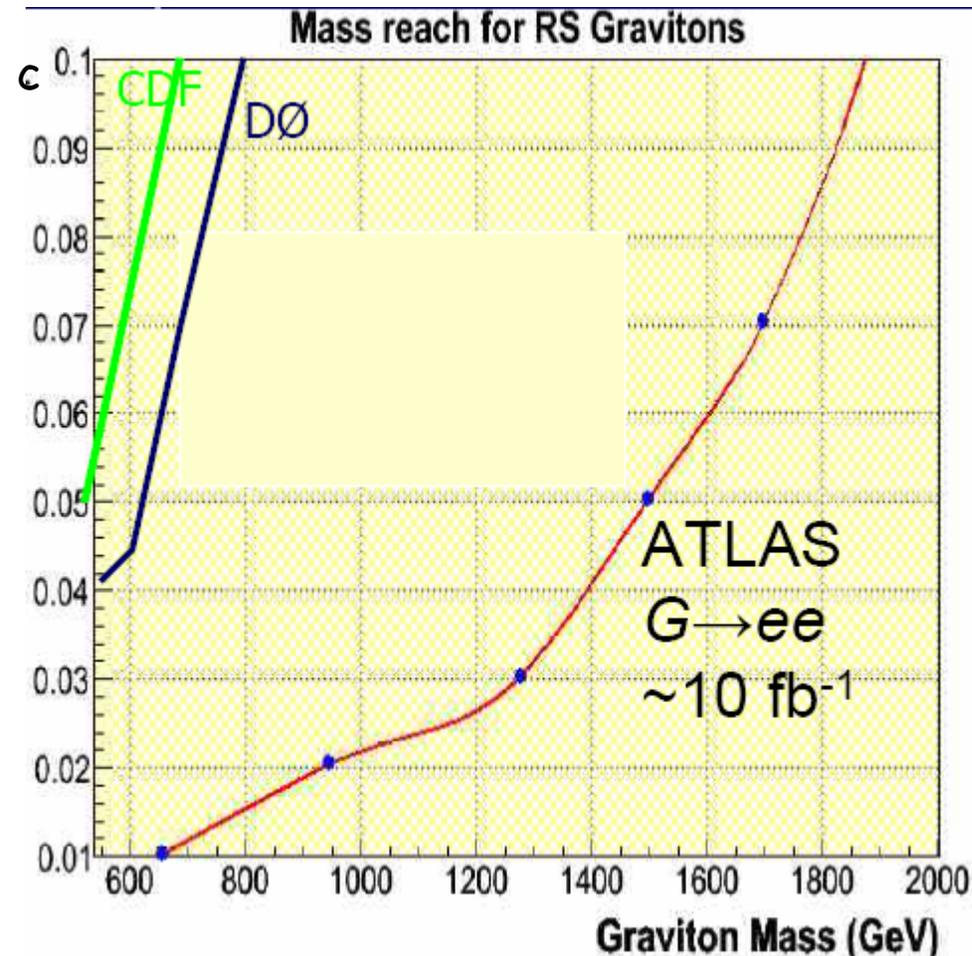
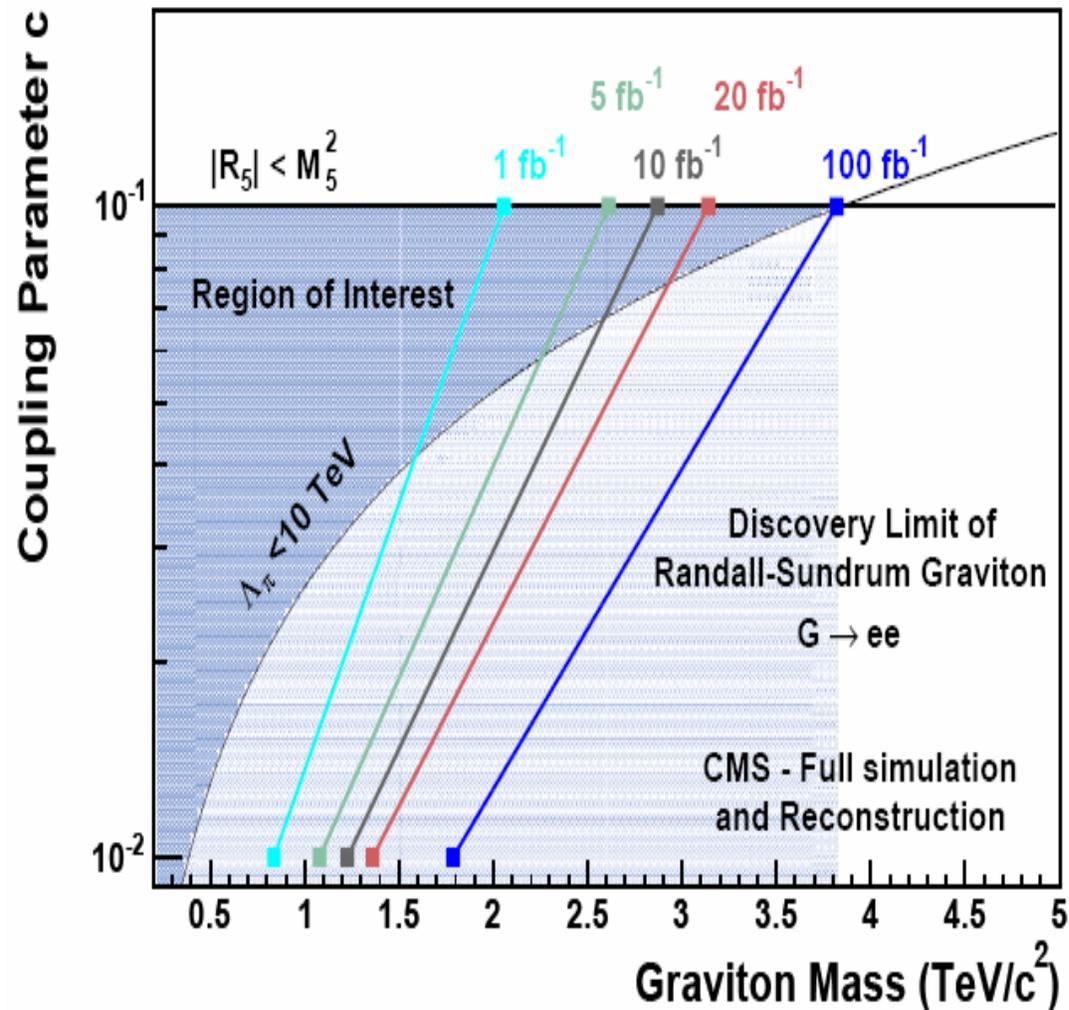
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# RS: $G \rightarrow ee$ @ CMS, ATLAS



CMS [Collard et al.]

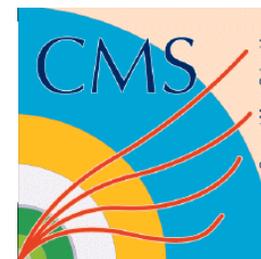
ATLAS [Baker et al.]



Risultati simili con i muoni....



# Conclusioni - cosa si scopre subito?



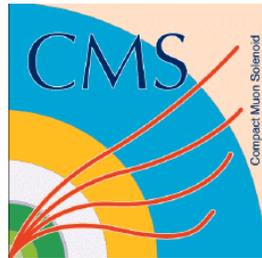
- Con 0.2 fb<sup>-1</sup> ad LHC si possono scoprire:
  - Z' fino ad 1 TeV
  - BH fino a 4 TeV
  - gravitone ADD se  $M_D < 1$  TeV
- Con 1 fb<sup>-1</sup> ad LHC si possono scoprire:
  - Z' fino a 2.5 TeV
  - W' fino a 3.5 TeV
  - BH fino a 5 TeV
  - gravitone ADD se  $M_D < 1.7$  TeV
  - gravitone RS fino a 2 TeV



# Conclusioni-cosa si esclude col tempo?



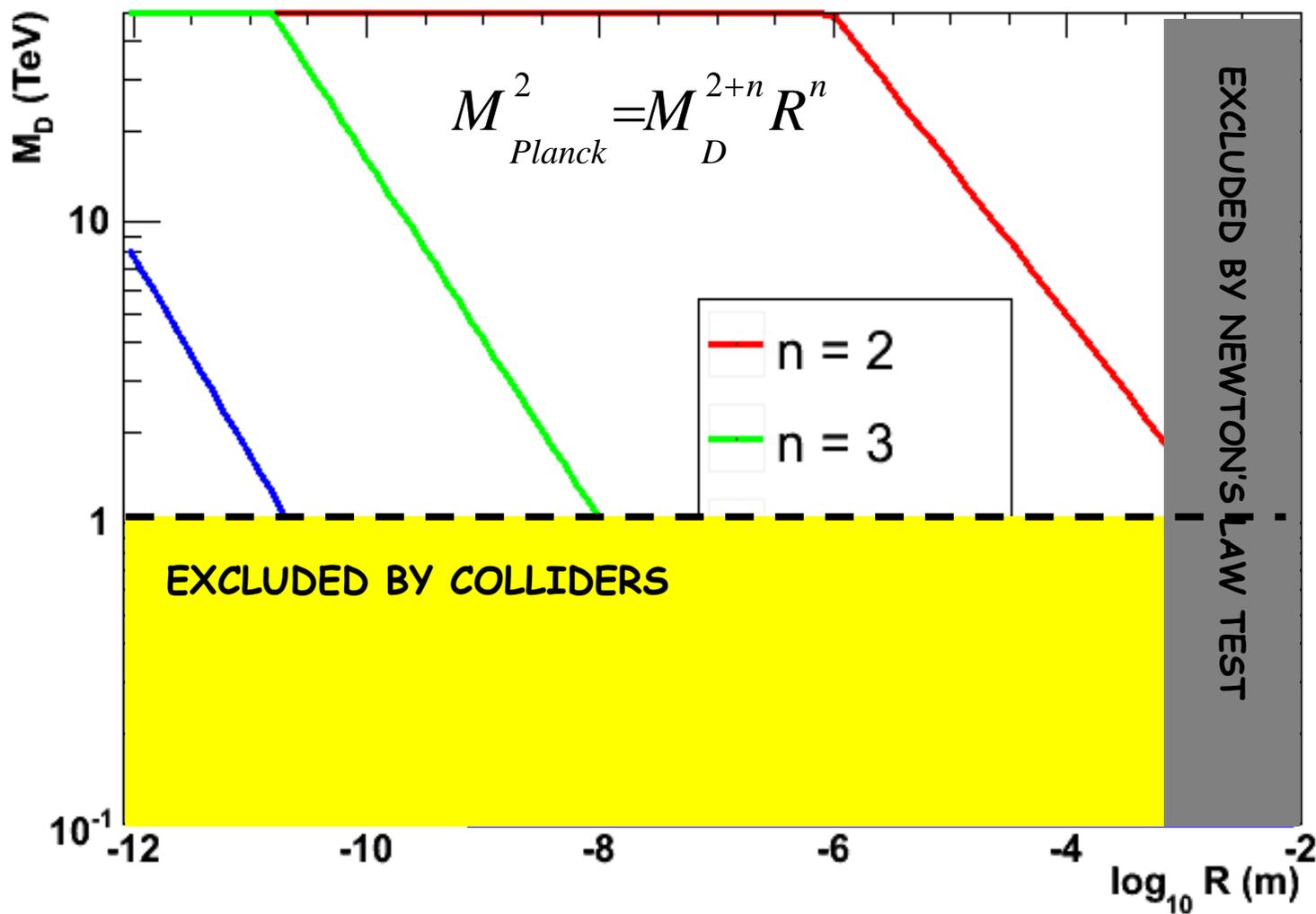
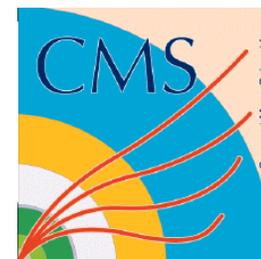
- Con 100 fb<sup>-1</sup> ad LHC si può escludere:
  - tutta la regione di interesse del modello Randall-Sundrum
  - ~ tutto il modello Little Higgs
- Con 300 fb<sup>-1</sup> ad LHC si può escludere:
  - W' nella regione accessibile (< 6 TeV)
  - Z' nella regione accessibile (< 6 TeV)



Backup

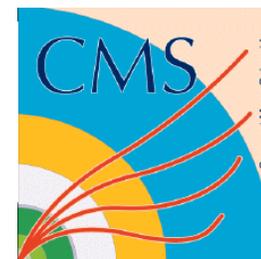


# Scala della gravità nel modello ADD

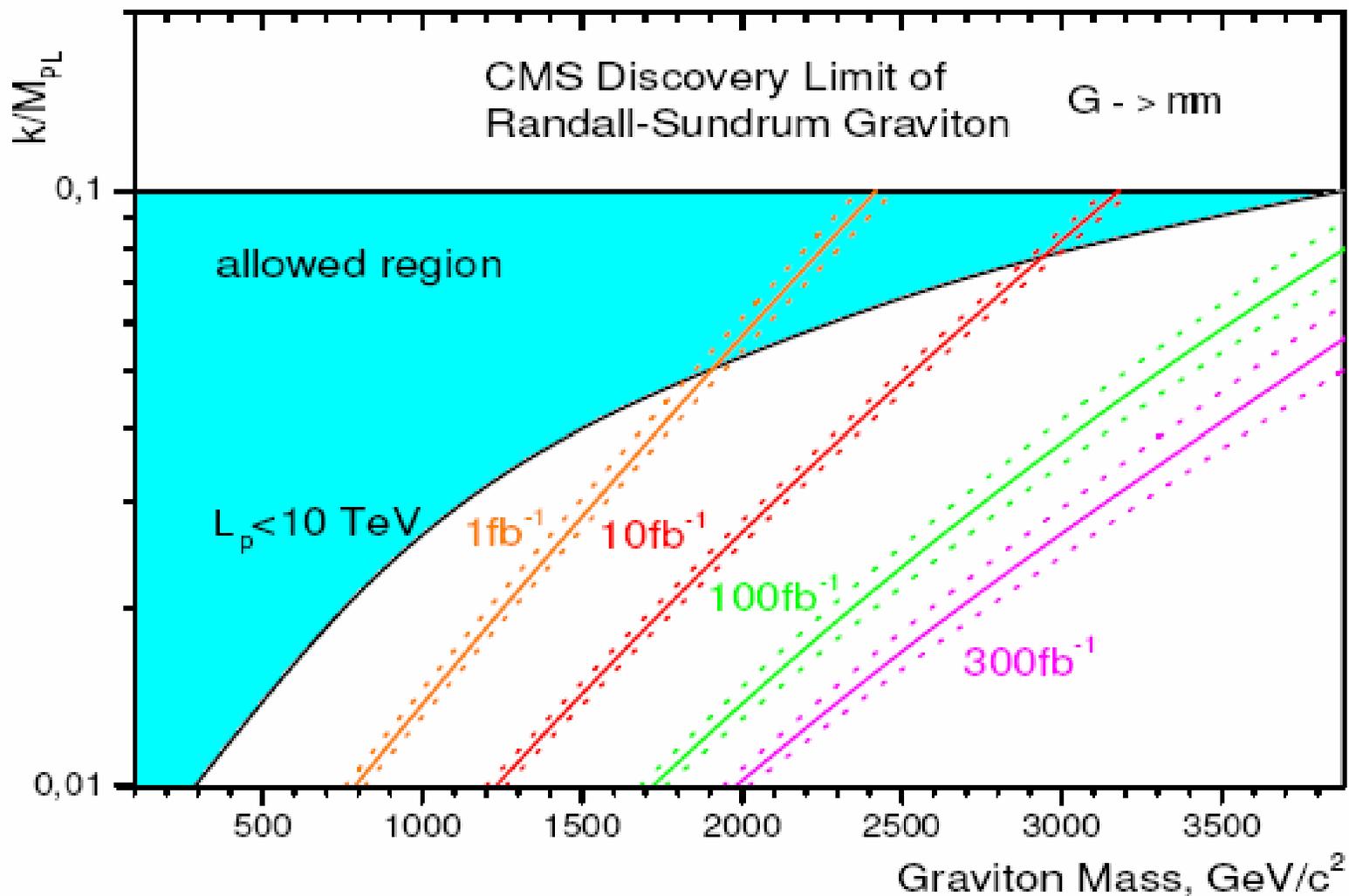




# Randall-Sundrum: $G \rightarrow \mu\mu$ @ CMS

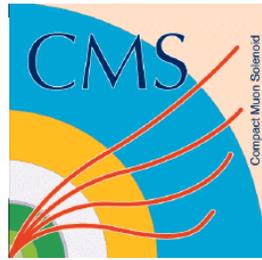


[P. Traczyk, CMS CR 2006/056]





# R-S: massa delle risonanze



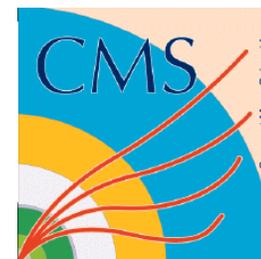
Masse dei gravitoni RS in 4D :

$$M_n = x_n k \exp(-k\pi r_c) \text{ dove } J_1(x_n)=0 \text{ [f. di Bessel]}$$
$$= x_n (k/M_{\text{Planck}}) \Lambda_\pi$$

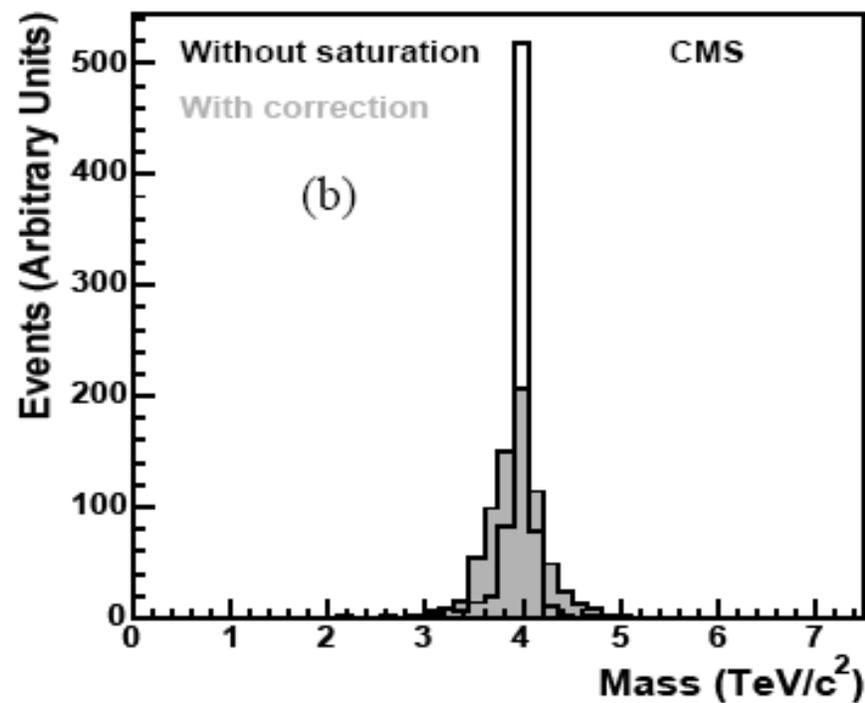
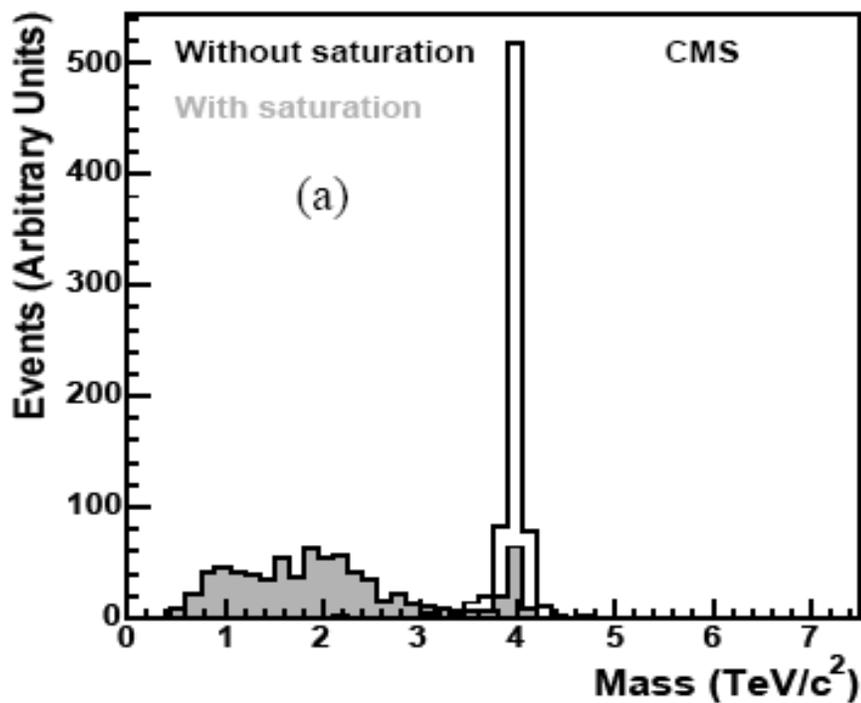


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# CMS: saturazione ECAL



$$pp \rightarrow G \rightarrow e^+e^-$$



Saturazione in ECAL  
se  $E > 1.7 \text{ TeV}$  su 1 Xtal