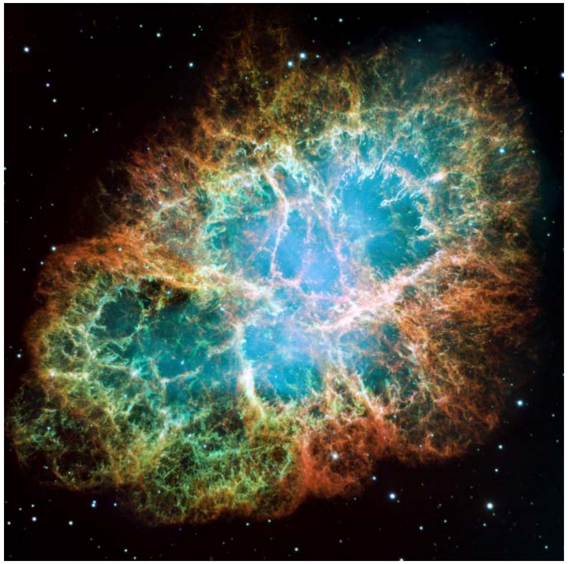
Artemis with deer. Roman bronze, 1 B.C.



Search for extra spatial dimensions using the Weak Gauge Bosons

Yury Shcheglov, PNPI- D0

Gatchina, February, 2, 2010

Outline

- Introduction
- Extra Dimension model experimental signatures and Tevatron ED search results
- Modeling ED with gauge weak bosons and cross sections
- Initial criteria for the MC and Data sample events
- Signal Monte-Carlo. Main distributions
- Background and Monte-Carlo signal properties

  Main parameters using for the background suppression
- Multivariate Data Analysis and efficiency of the background suppression
- Conclusion

Introduction

- ***Our usual world has 3 space dimensions. Nobody knows why.***
- ***One of the hypothesis is anthropic principle:***

  In physics and cosmology, the **anthropic principle** is the collective name for several ways of asserting that the observations of our physical universe must be compatible with the life observed in it

- ***My example : in the world with dimension < 3, it is a difficult to collaborate for physicists*** -

  in the one-dimensional world one person can contact only with two nearest persons. There is the same problem in the two-dimensional world, because all possible collaborators exist on the circle's line which is surface of the two-dimensional Earth. And only in the case of the 3-dimensions physicists have a world very comfortable to collaborate with each other..

Introduction. Collaboration

- DØ is an international collaboration of 670 physicists from 19 nations who have designed, built and operate a collider detector at the Tevatron

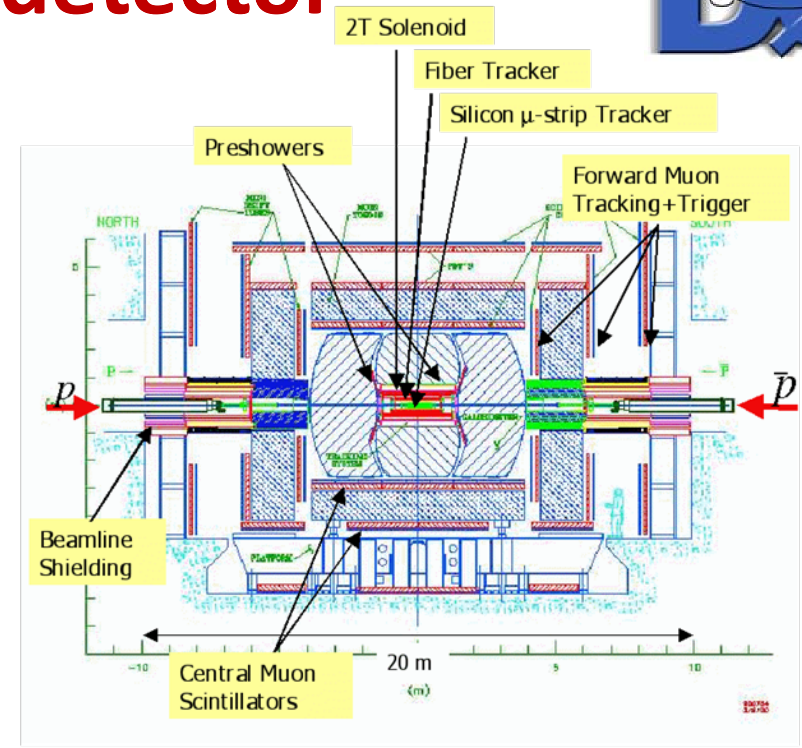
Institutions: 84 total, 35 US, 49 non-US

Collaborators:

- 50% from non-US institutions (note strong European involvement)

- Petersburg Nuclear Physics Institute, Gatchina, Russia involved to DØ-project through design and programming of electronic readout for 50 thousands channels of mini drift tubes; support of operation of the Muon Forward System; QCD physics, B physics, Electroweak physics, New Phenomena studies

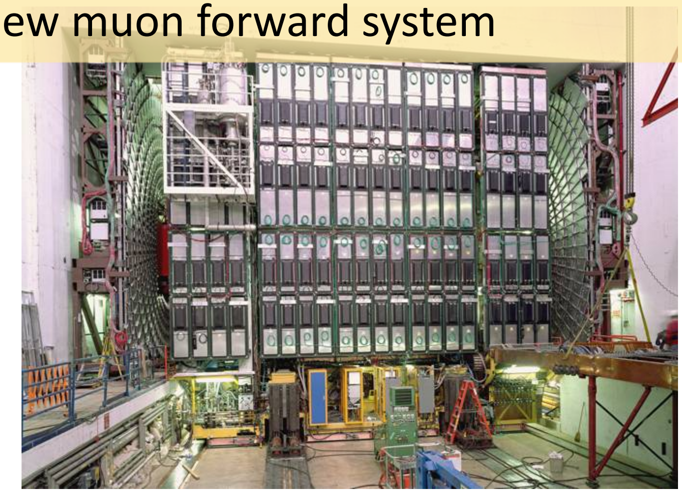
Introduction. DØ - detector



- Main parts of the detector – central tracker, preshower detectors, calorimeter, muon system and toroid (1.8 T)
- Run II upgrade – central tracker and forward muon system was completely replaced:

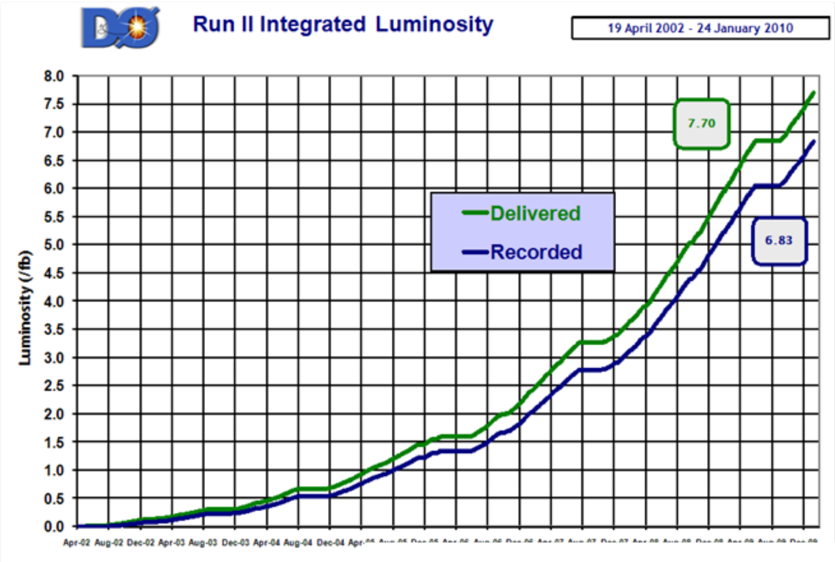
-Silicon microstrip tracker and scintillating fiber tracker were installed and located within 2T solenoidal magnet

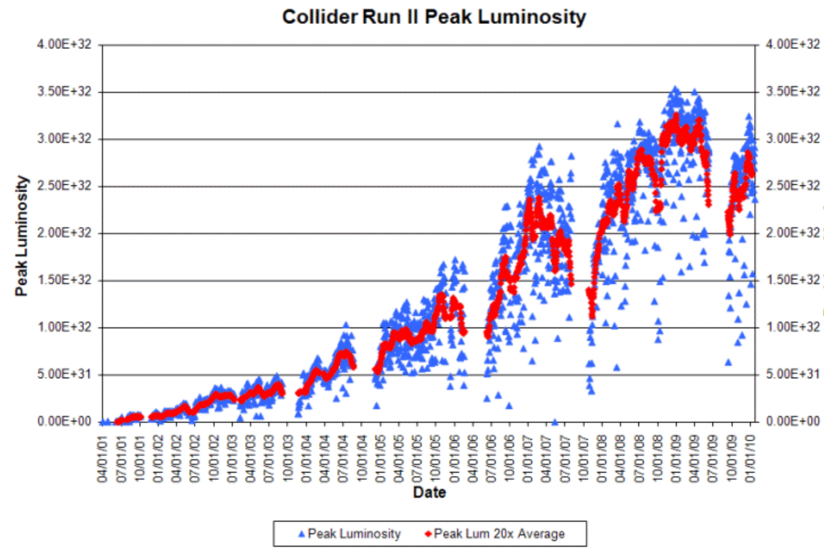
- 50000 mini drift tubes were used for the new muon forward system

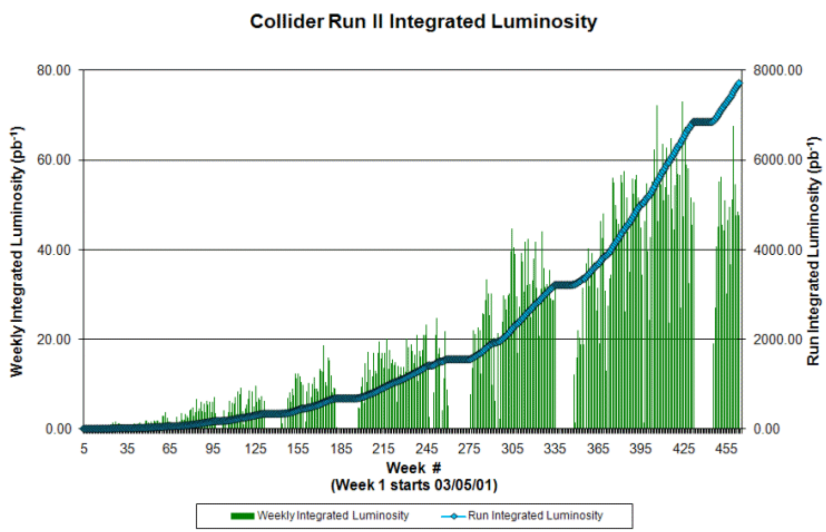


- During Run II Tevatron is operated with 36 bunches of protons and antiprotons with a bunch spacing of 396 ns and at an increased center-of-mass energy of 1.96 TeV (Run I, 1.8 TeV)
- Luminosity was increased by more than a factor of ten to greater than $1 \cdot 10^{32}$ cm^{-2} s^{-1}

Introduction. D0 Run II Integrated Luminosity in the beginning of 2010 year





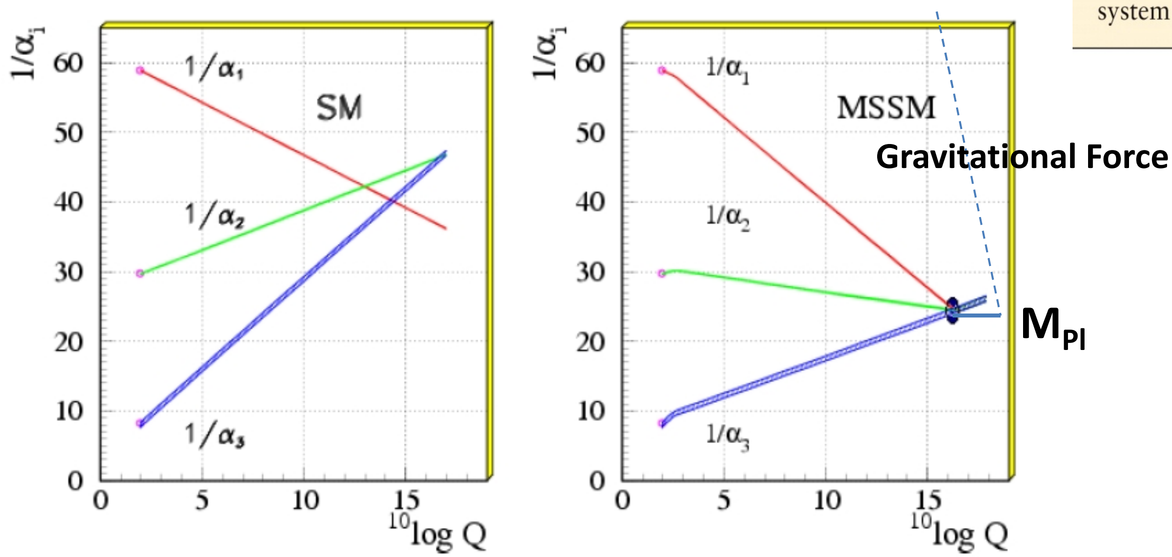


Introduction. Four Basic Forces

➢Four basic forces—gravity, electromagnetism, the strong force, and the weak force—explain all the interactions observed in the universe

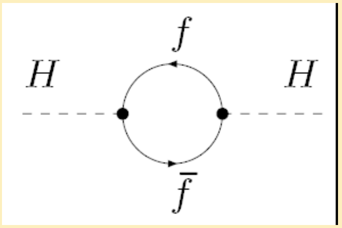
table 29-1 The Four Forces

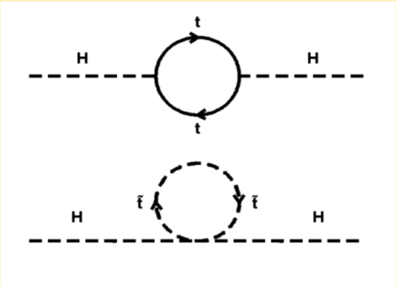
Force	Relative strength	Particles exchanged	Particles on which the force can act	Range	Example
Strong	1	gluons	quarks	10^{-15} m	holding protons, neutrons, and nuclei together
Electromagnetic	$1/137$	photons	charged particles	infinite	holding atoms together
Weak	10^{-4}	intermediate vector bosons	quarks, electrons, neutrinos	10^{-16} m	radioactive decay
Gravitational	6×10^{-39}	gravitons	everything	infinite	holding the solar system together



Introduction. Hierarchy problem of the Standard Model

- **Higgs mass receives corrections from fermion loops:**





- **The size of corrections is proportional to the UV cutoff (Λ) squared:**

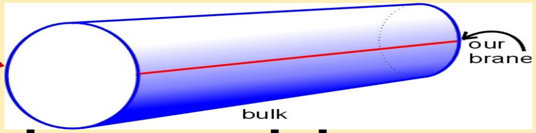
$$\Delta m_H{}^2 = \frac{\lambda_B}{16\pi^2}(\Lambda_{UV}{}^2 + \dots)$$

- **In order for the Higgs mass to be finite, a fine tuning (cancellation) of various loops is required to a precision ~$(M_H/\Lambda)^2$ ~ 10^{-34} for Λ ~ M_{Pl}**
- **Supersymmetric Solution** ***- for every fermion exists a superpartner - boson and vice-versa***
- **Solution via Extra Dimensions (ADD, Randall-Sundrum and Universal Extra Dimensions)**
- **Nevertheless.. If no Higgs , no Hierarhy problem**

Extra Dimensions Models

- The setup of these brane-world models is motivated by String Theory
- **ADD model** *(Arkani-Hamed, Dimopoulos, Dvali)*

The **ADD**-model proposed by **A**rkani-Hamed, **D**imopoulos and **D**vali in '98 adds ***d*** extra spacelike dimensions without curvature, in general each of them compactified to the same radius. All SM particles are confined to our brane, while gravitons are allowed to propagate freely in the bulk



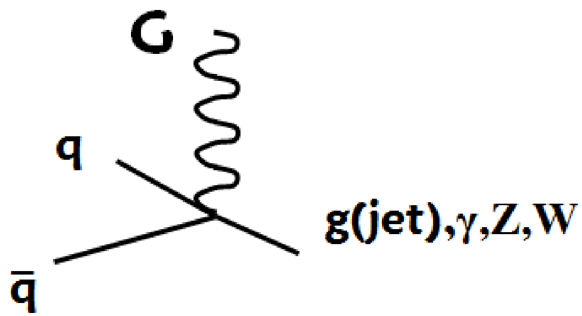
- **Randall- Sandrum model**

is a 5-dimensional spacetime with so called 'warped' geometry, all your scales depend on the distance to our brane. In the type I model the extra dimension is compactified, in the type II model it is infinite. The resulting metric is an AdS-Space $ds^2 = e^{-2kr|\phi|}\eta_{\mu\nu}dx^\mu dx^\nu - r^2 d\phi^2$

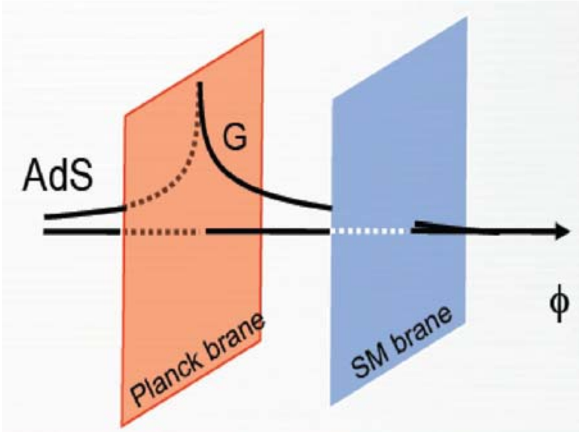
- **Universal Extra Dimensions** Within the model of universal extra dimensions all particles (or in some extensions, only gauge fields) can propagate in the whole higher dimensional spacetime. These extra dimensions are compactified and typically have radii of ~ 10^{-18} m to reproduce SM gauge degrees of freedom. These models come closest to the original idea of Kaluza and Klein.

Extra Dimensions Models

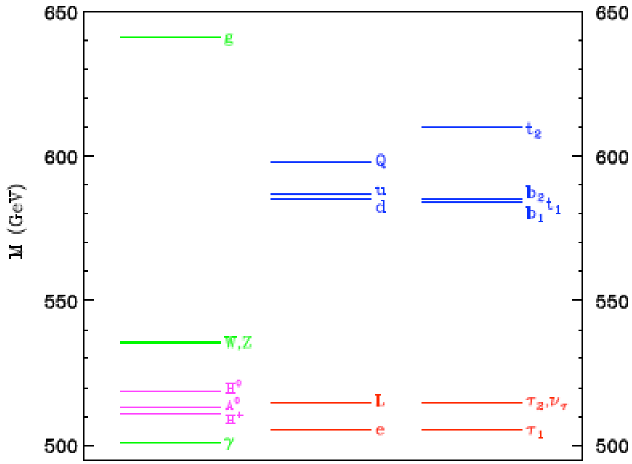
ADD model

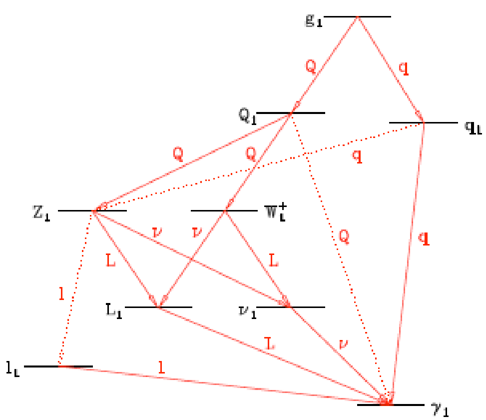


Randall-Sandrum model



Universal Extra Dimensions

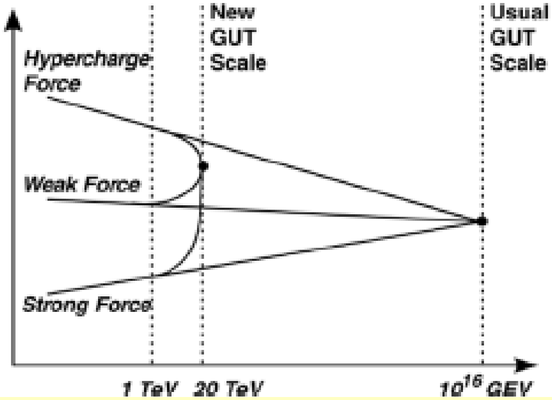




Extra Dimensions. ADD model

Large Extra Dimensions (LED) or
ADD (*Arkani-Hamed, Dimopoulos, Dvali* ***)*** , Phys Lett B429 (98)

They postulated that the standard model (SM) particles and gauge interactions are confined to a three-dimensional ''brane'' embedded in a ''multiverse,'' which consists of the three standard plus ***n additional compact spatial dimensions***



Extra Dimensions model where SM particles live on a D3 - brane:

- Hierarchy problem explained: gravity appears weak (**M_{EW} << M_{Pl}**) because it propagates in LEDs.
- LEDs are compactified, R = compactification radius
- M_S is the fundamental scale, not M_{PL} :**$M^2_{PL} \sim M_S^{n+2} R^n$ => M_S** can be lowered to TeV scale
- gravitons propagate in the bulk => Kaluza-Klein tower $G^{(k)}$

⇒ expect: virtual exchange of graviton KK modes, real graviton emission

Gravity effects interfere with SM => prod. Cross section:

$$\sigma = \sigma_{SM} + \eta_G \sigma_{int} + \eta_G^2 \sigma_{KK}$$

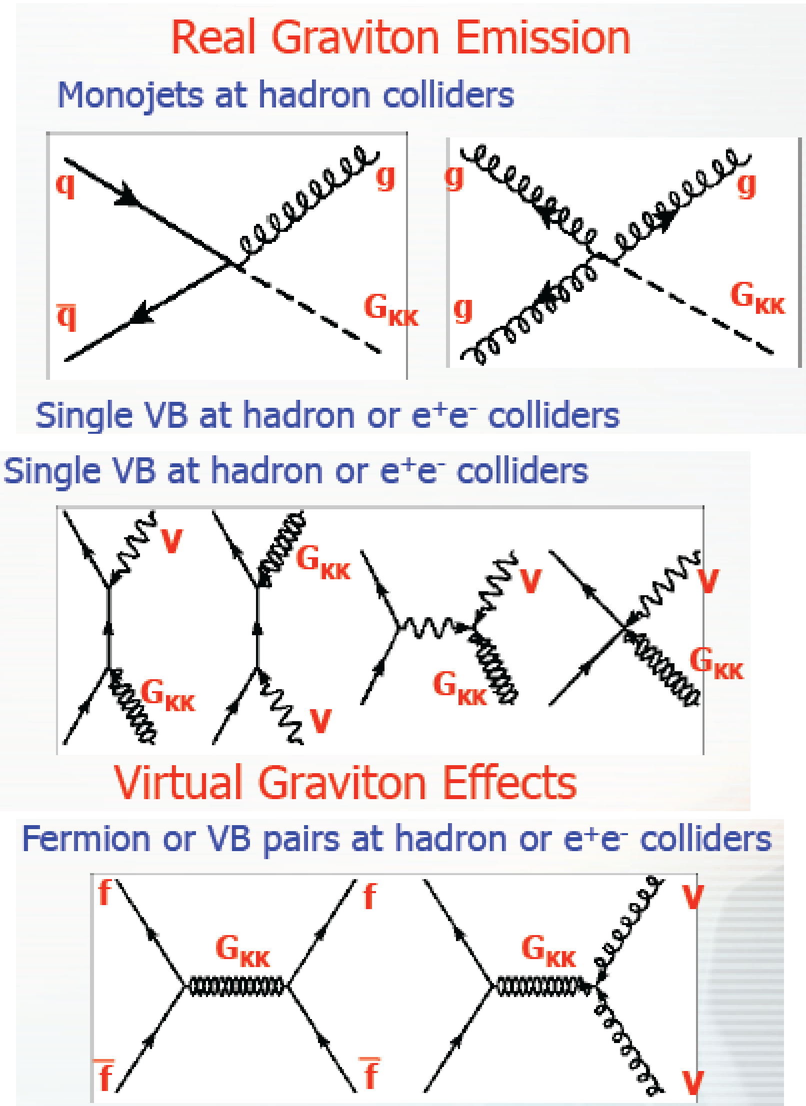
- Effect of ED parameterized by a single variable:

$$\eta_G = F/ M_S^4$$

- 3 conventions on writing the effective Lagrangian:
  - Hewett: (Hewett, Phys Rev Lett 82, 4765 (99) $F = 2\lambda/\pi$ with $\lambda = \pm 1$
  - GRW: (Giudice, Rattazzi, Wells, hep-ph/9811291 F = 1
  - HLZ: (Han, Lykken, Zhang, hep-ph/9811350) $F = \log(M_S^2/s)$ for n = 2,

  $F = 2/(n-2)$ for $n > 2$

Diagrams with Kaluza-Klein graviton



$$\mathbf{g}(\mathbf{r}) = -Gm\frac{\mathbf{e_r}}{r^2}$$

$$G = \frac{1}{M_{Pl}^2}$$

$$\mathbf{g}(\mathbf{r}) = -m\frac{\mathbf{e_r}}{M_{Pl+3+1+\delta}^{2+\delta} r^{2+\delta}}$$

$$\mathbf{g}(\mathbf{r}) = -m\frac{\mathbf{e_r}}{M_{Pl+3+1+\delta}^{2+\delta} r^{2} n^{\delta}}$$

$$-m\frac{\mathbf{e_r}}{M_{Pl}^2 r^2} = -m\frac{\mathbf{e_r}}{M_{Pl+3+1+\delta}^{2+\delta} r^{2} n^{\delta}}$$

$$\frac{1}{M_{Pl}^2 r^2} = \frac{1}{M_{Pl+3+1+\delta}^{2+\delta} r^{2} n^{\delta}} \Rightarrow M_{Pl}^2 = M_{Pl+3+1+\delta}^{2+\delta} n^{\delta}.$$

LEP RESULTS

Direct Graviton Emission

Experiment	$e^+e^- \to \gamma G$ n=2	n=3	n=4	n=5	n=6	$e^+e^- \to ZG$ n=2	n=3	n=4	n=5	n=6	Color coding
ALEPH	1.28	0.97	0.78	0.66	0.57	0.35	0.22	0.17	0.14	0.12	≤184 GeV
DELPHI	1.38	**1.02**	0.84	**0.68**	0.58						≤189 GeV
L3	1.02	0.81	0.67	0.58	0.51	0.60	0.38	0.29	**0.24**	**0.21**	>200 GeV
OPAL	1.09	0.86	0.71	0.61	0.53						λ=-1 λ=+1 GL

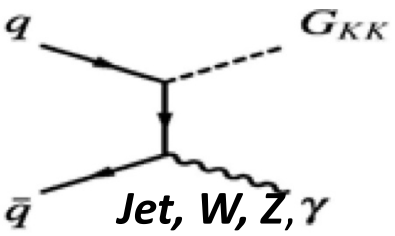
All limits are in TeV

Virtual Graviton Exchange

Experiment	e^+e^-	$\mu^+\mu^-$	$\tau^+\tau^-$	qq	ff	$\gamma\gamma$	WW	ZZ	Combined
ALEPH	1.04 0.81	0.65 0.67	0.60 0.62	0.53/0.57 0.46/0.46 (bb)	1.05 0.84	0.81 0.82			0.75/1.00 (<189)
DELPHI		0.59 0.73	0.56 0.65		0.60 0.76	0.83 0.91			0.60/0.76 (ff) (<202)
L3	0.98 1.06	0.56 0.69	0.58 0.54	0.49 0.49	0.84 1.00	0.99 0.84	0.68 0.79		1.0/1.1 (<202)
OPAL	1.15 1.00	0.62 0.66			0.62 0.66	0.89 0.83		0.63 0.74	1.17/1.03 (<209)

LEP Combined: 1.2/1.1 TeV

Extra Dimensions. ADD model. Tevatron results.



- The experimental signatures for the Kaluza-Klein graviton emission in ADD model are:

  jet(s) + MET, γ + MET, W(Z) +MET

- Some of them were studied on Tevatron with next results:

γ**+ MET** - for n = 2 M_s > 0.778 GeV,.,,, for n=8 M_s > 0.884 GeV - D0,
γ**+ MET** - for n=2 M_s > 1.31 GeV,.,,for n=6 M_s>0.9 GeV - CDF
Jets+**MET** - for n=2 M_s > 1.31 GeV, .,,, for n=6 0.9 M_s>0.88 GeV -CDF

Virtual Graviton exchange, Gkk→2e – M_s > 1.12 TeV, n=2 , 200 pb^{-1} ,D0

We are going to study W(Z) + G_{kk}. The theoretical paper:
Collider Test of Compact Space Dimesions Using Weak Gauge Bosons , C. BalaZs,H-J.He, W.W.Repko, C.-P. Yuan,D.A. Dicus, hep-ph/990422v2

Extra Dimensions. ADD model

Collider Tests of Compact Space Dimensions Using Weak Gauge Bosons

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(February 1, 2008 and hep-ph/9904220)

We present collider tests of the recent proposal for weak-scale quantum gravity due to new large compact space dimensions in which only the graviton ($\mathcal{G}$) propagates. We show that the existing high precision LEP-I Z-pole data can impose non-trivial constraints on the scale of the new dimensions, via the decay mode $Z \to f\bar{f} + \mathcal{G}$ ($f = q, \ell$). These bounds are comparable to those obtained at high energy colliders and provide the first sensitive probe of the scalar graviton. We also study $W(Z)+\mathcal{G}$ production and the anomalous $WW(ZZ)$ signal from virtual $\mathcal{G}$-states at the Fermilab Tevatron, and compare them with the LEP-I bound and those from LEP-II and future linear colliders.

PACS number(s): 04.50.+h, 11.25.Mj, 14.70.-e [MSUHEP-90105]

The smallness of the Newton constant, $G_N \simeq 1/(1.2 \times 10^{19}\,\mathrm{GeV})^2$, suggests that the characteristic scale for the gravitational interaction is the Planck scale $M_P = 1/\sqrt{G_N}$. This traditional wisdom holds, however, only if gravitons ($\mathcal{G}$) effectively propagate in the usual 4- ... so that it is testable for $M_* = O(\mathrm{TeV})$ [1]-[7] [1].

In this paper, we first analyze a direct probe of both spin-0 and spin-2 KK excitations via the decay $Z \to f\bar{f} + \mathcal{G}$ ($f = q, \ell$) and derive non-trivial bounds on the scale M_* (and R) from the existing high precision Z-pole

Authors estimates with $\int L = 2fb^{-1}$ →

The 95%C.L. bounds on M_* (in TeV) for $n = (2, 4, 6)$ are found to be

$$\mathrm{TEV}(1.8):\quad M_* \geq .89(.76),\ .78(.72),\ .67(.71), \qquad (17)$$

$$\mathrm{TEV}(2.0):\quad M_* \geq 1.2(1.1),\ .98(.98),\ .90(.92). \qquad (18)$$

W(Z) +G_{kk} Tevatron cross-sections

- TEV (2.0) , W(Z) + G_{kk} (for n= 2,4,6) in fb:

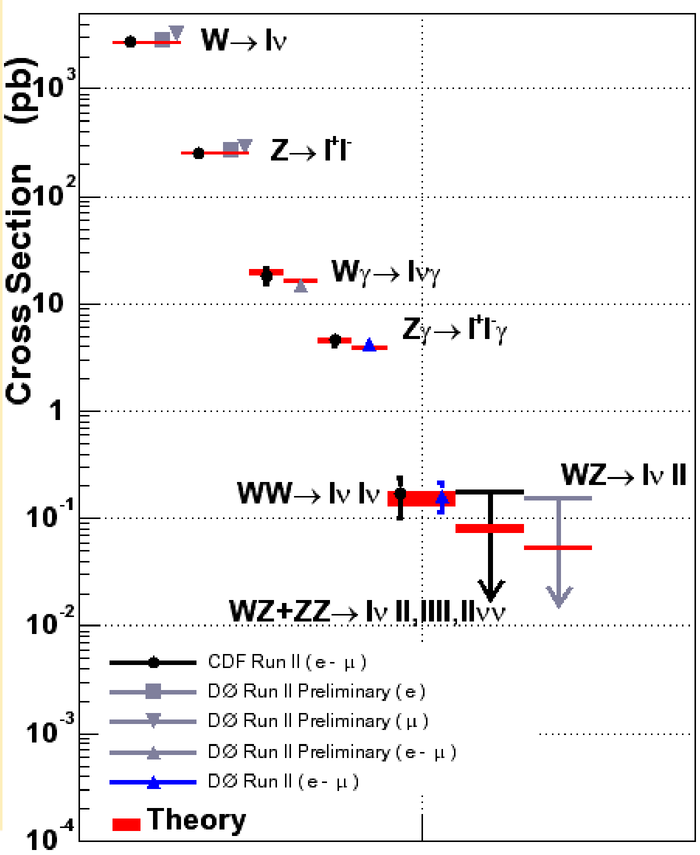
  $241(212)/M_S^4$, n=2,

  $108(112)/M_S^4$, n=4,

  $54(65)/M_S^4$, n=6;

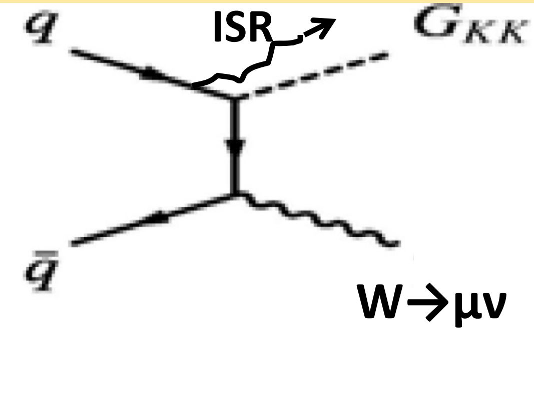
- Cross-sections are comparable with diboson cross-cross sections
- The main backgrounds are:

W(Z) + jets; Drell-Yan ; WW, WZ, ZZ;



Experimental signature

- The best thing is – the single muon and the low activity in calorimeter
- The high muon transverse momentum or

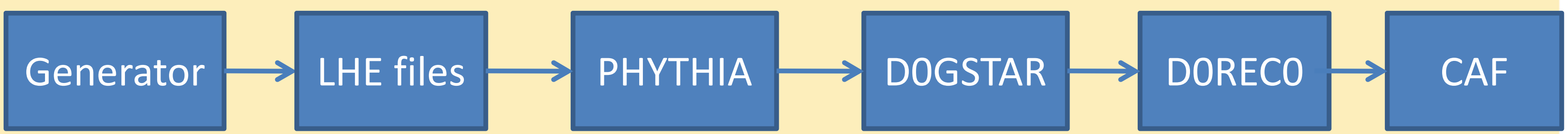


ISR–Initial State Radiation

large fully corrected missing ET and the low ratio between fully corrected missing ET muon pT momentum

Signal modeling

- **$W+G_{kk}$** processes was included as external processes to provide a hadronization (ISR,FSR) and particles decays The event generator designed in Michigan State University was used;
- Les Houches Event Files format files generated to provide an interface for the event generator with PYTHIA
- 30000 events $W(\mu\nu) + G_{kk}$ were generated for the $M_s = 1.3$ TeV
- Next $W(\mu\nu) + G_{kk}$ event data sample was processed using the D0 Monte-Carlo tools - **D0GSTAR** and **D0RECO** programs.
- The analysis chain:



The D0GSTAR Program

- Based on GEANT 3.21 (Fortran) with C++ wrapper
  - Linux and IRIX Platforms
- Input is ISAJET, PYTHIA
- Output are Hits and Digi information
- Typical event size : 1.0 - 1.5 MB
- Typical detector simulation time : 1 - 2 minutes
  - Shown for SGI R12000 processor at 2000-3000 MHz

Example of LHE file

- <LesHouchesEvents version="1.0">
- <!--
- File written by Large Extra Dimensions Generator
- -->
- <init>
- 2212 -2212 9.800000e+02 9.800000e+02 0 0 0 0 3 1
- 0.420104E-01 0.474281E-03 0.100000E+01 7777
- </init>

- <event>
- 4 7777 0.100000E+01 0.181162E+03 0.108420E+00 0.776400E-02
- -2 -1 0 0 0 101 0.0000000000E+00 0.0000000000E+00 0.2095597492E+03 0.2095597492E+03 0.0000000000E+00 0. 0.5
- 3 -1 0 0 101 0 0.0000000000E+00 0.0000000000E+00 -.1902714138E+03 0.1902714138E+03 0.0000000000E+00 0. 0.5
- -24 2 1 2 0 0 0.1079686848E+02 0.1716722259E+03 0.6360867453E+02 0.2002444191E+03 0.8039800262E+02 0. 1.
- 39 2 1 2 0 0 -.1079686848E+02 -.1716722259E+03 -.4432033908E+02 0.1995867439E+03 0.9100906755E+02 0. 9.
- #pdf -2 3 0.213836E+00 0.194155E+00 0.181162E+03 0.450761E+00 0.406429E-01 0.210797E+01 0.209333E+00
- </event>
- <event>
- 4 7777 0.100000E+01 0.232378E+03 0.104819E+00 0.776400E-02
- -2 -1 0 0 0 101 0.0000000000E+00 0.0000000000E+00 0.9363502189E+02 0.9363502189E+02 0.0000000000E+00 0. 0.5
- 3 -1 0 0 101 0 0.0000000000E+00 0.0000000000E+00 -.9336867014E+03 0.9336867014E+03 0.0000000000E+00 0. 0.5
- -24 2 1 2 0 0 0.9113893317E+02 0.2060614880E+03 -.2685854913E+03 0.3596799223E+03 0.8039800262E+02 0. 1.
- 39 2 1 2 0 0 -.9113893317E+02 -.2060614880E+03 -.5714661882E+03 0.6676418010E+03 0.2615422111E+03 0. 9.
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- <event>
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- 3 -1 0 0 101 0 0.0000000000E+00 0.0000000000E+00 -.4977124728E+03 0.4977124728E+03 0.0000000000E+00 0. 0.5
- -24 2 1 2 0 0 0.2348792645E+03 0.1218233541E+03 0.1011672574E+03 0.2944619685E+03 0.8039800262E+02 0. 1.
- 39 2 1 2 0 0 -.2348792645E+03 -.1218233541E+03 0.1662743854E+03 0.9684046199E+03 0.9165975879E+03 0. 9.
- #pdf -2 3 0.780770E+00 0.507870E+00 0.270631E+03 0.499213E-02 0.184281E-03 0.639386E-02 0.362851E-03
- </event>

Initial criteria for the MC and data sample events

- **Triggers:**

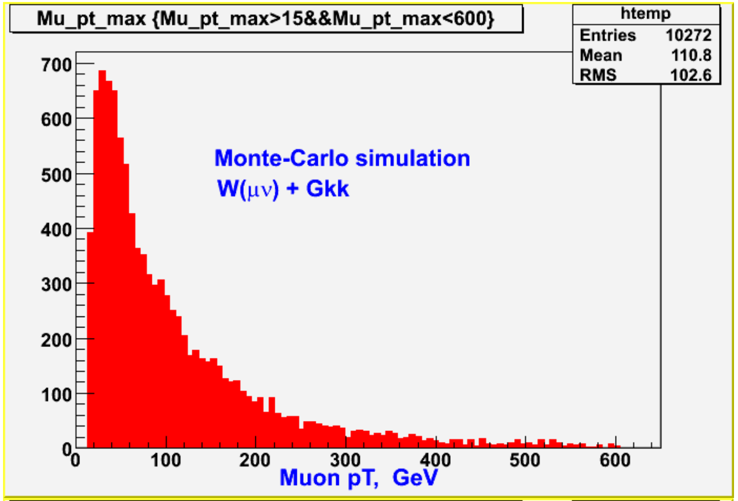
- OR for all single muon triggers

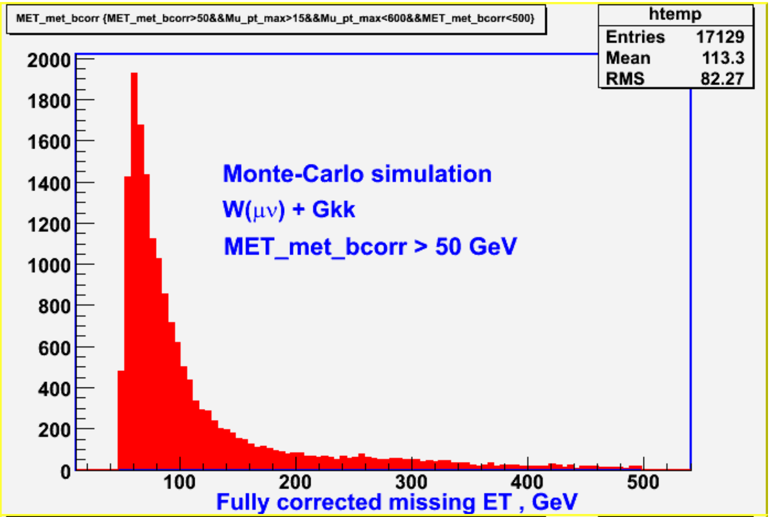
- **Muons:**

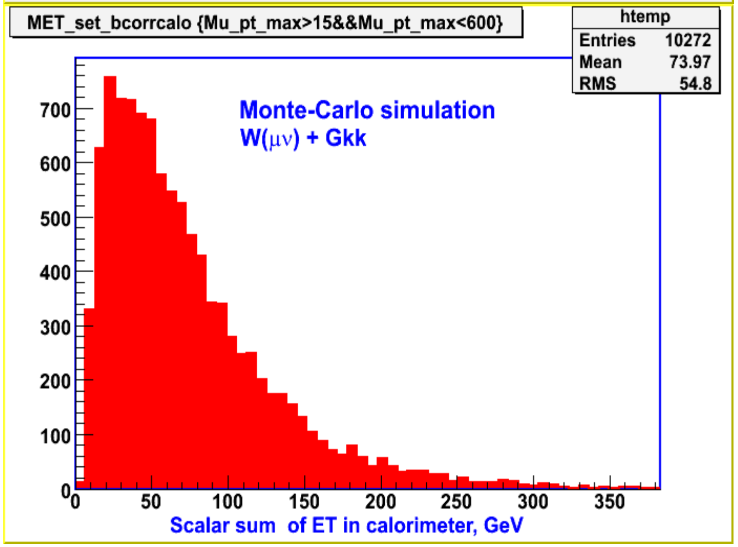
- pT > 15 GeV
- muon.MuonQualityName: loose
- muon.TrkQualityName: trackmedium
- muon.IsoQualityName: NPTight

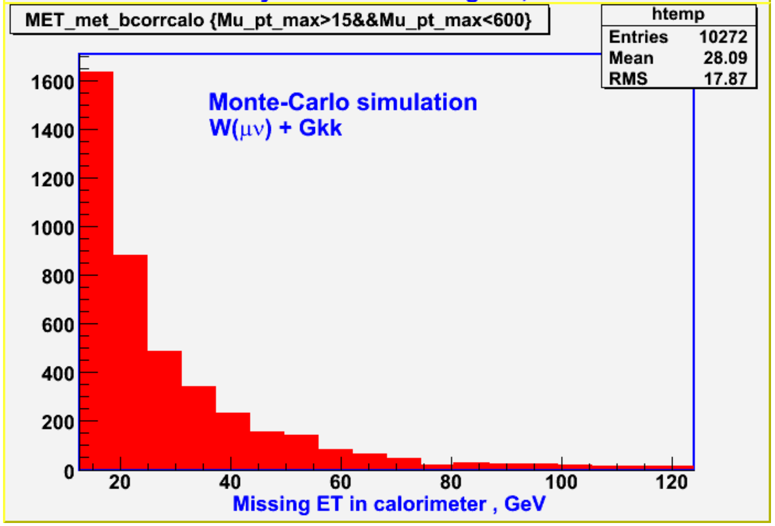
- No special requirements for jets
- RunIIb-1 single muon data sample was skimmed with the MET in event > 50 GEV

MC Signal. Main distributions

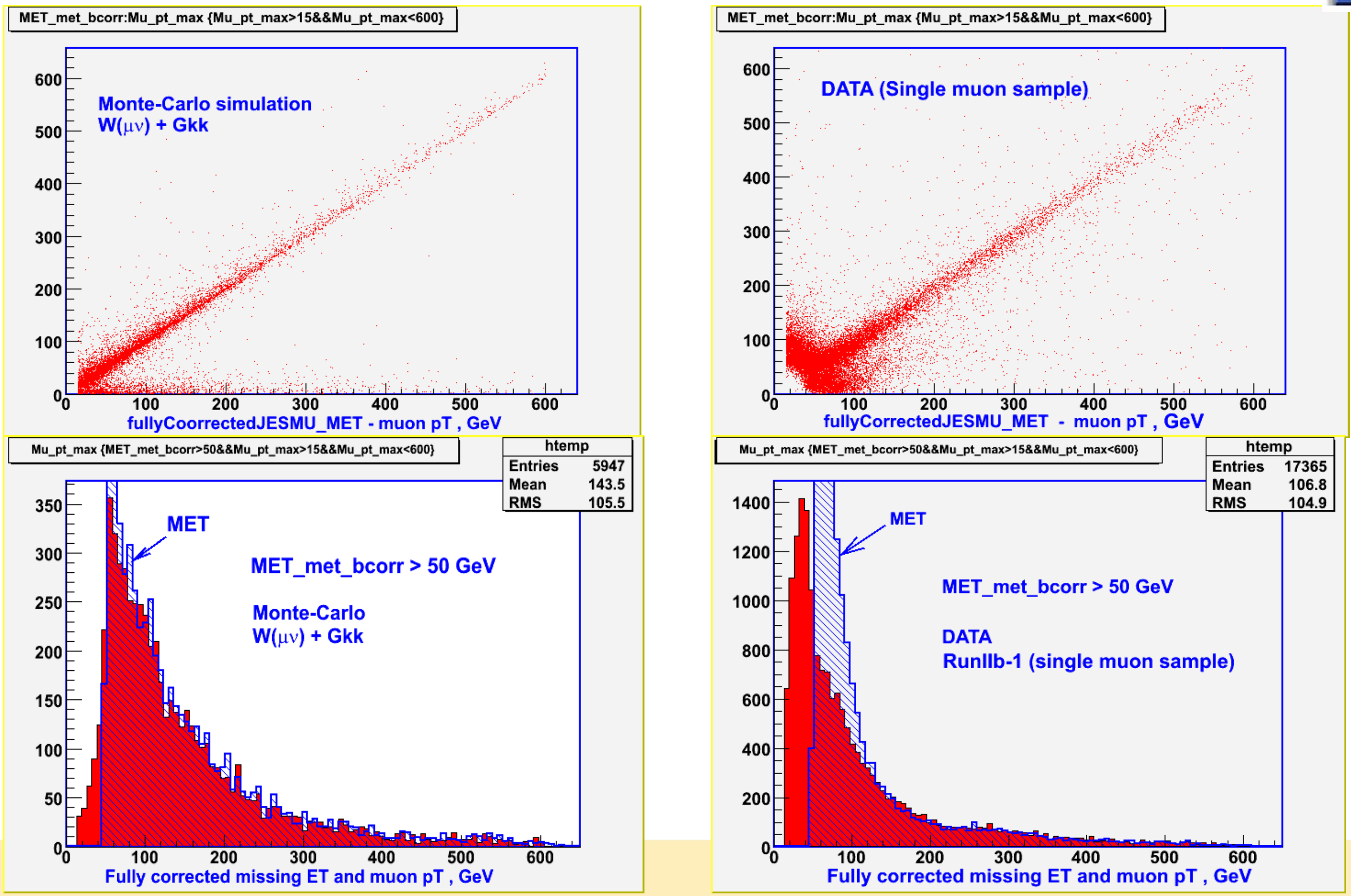






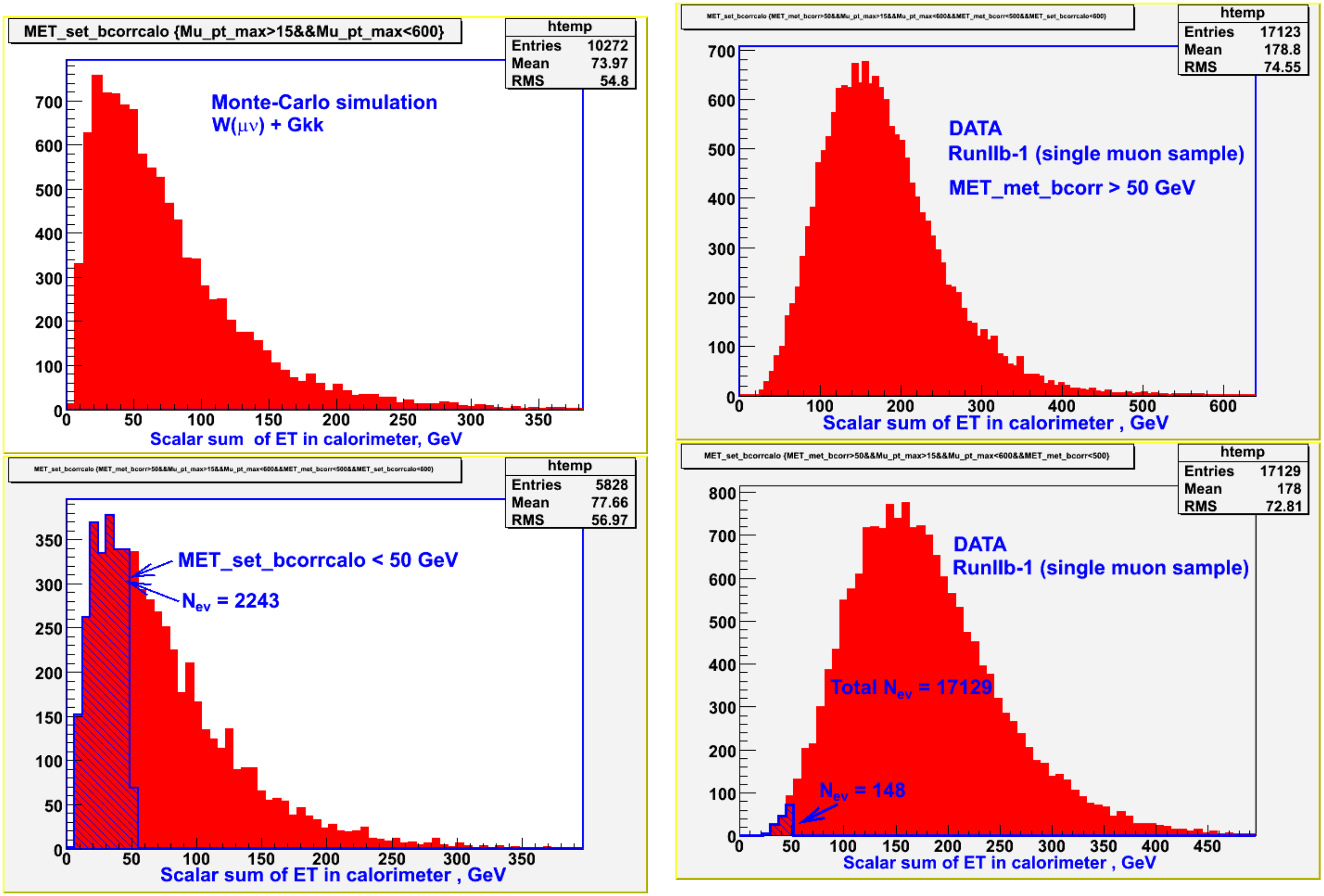


Background and Monte-Carlo signal properties



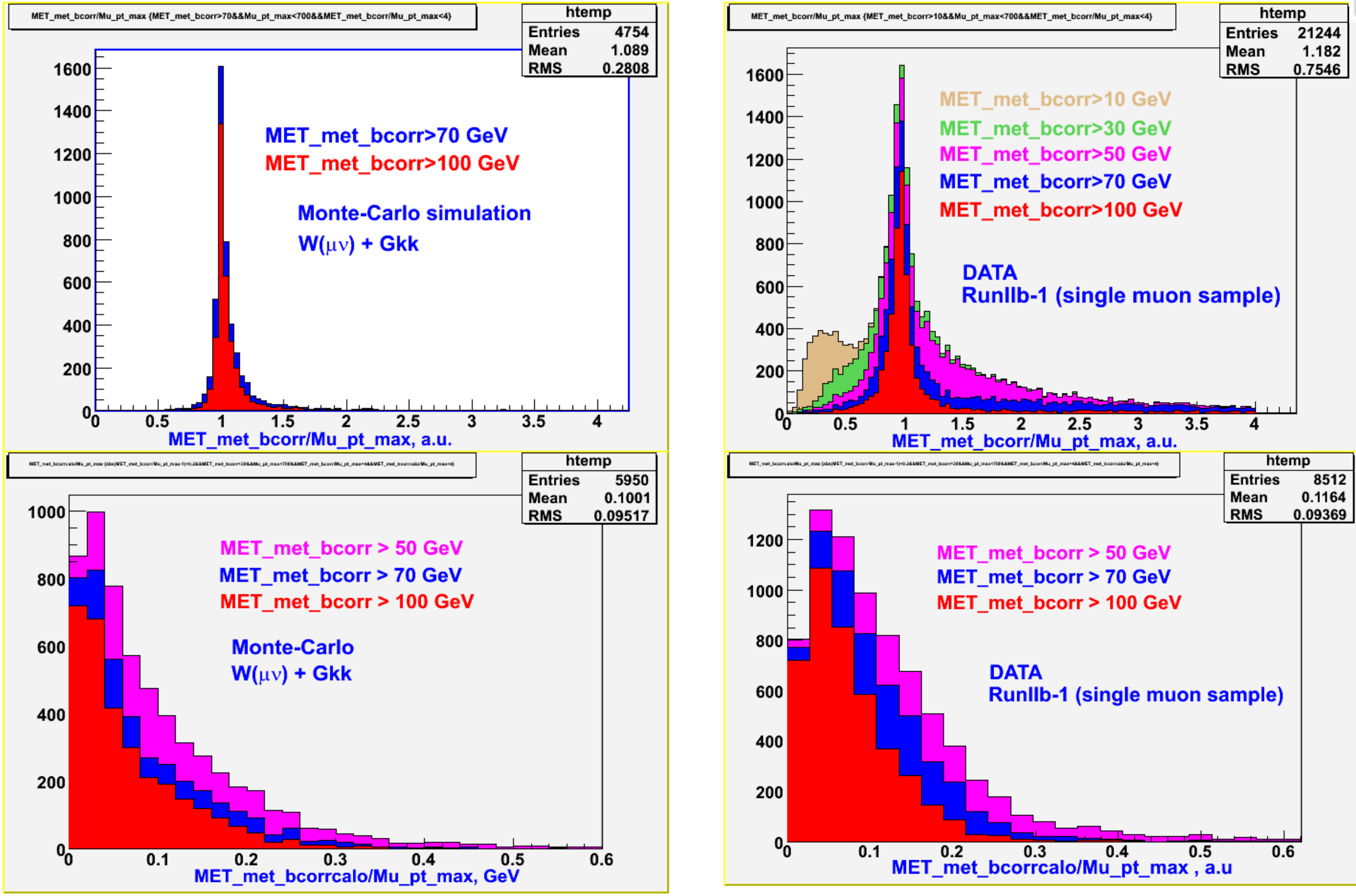
- The real data was used to model the background
- As clearly seen, we need a strong cut to the fully corrected missing ET (> 100 GeV) to avoid the large enough contribution from background

Background and Monte-Carlo signal properties



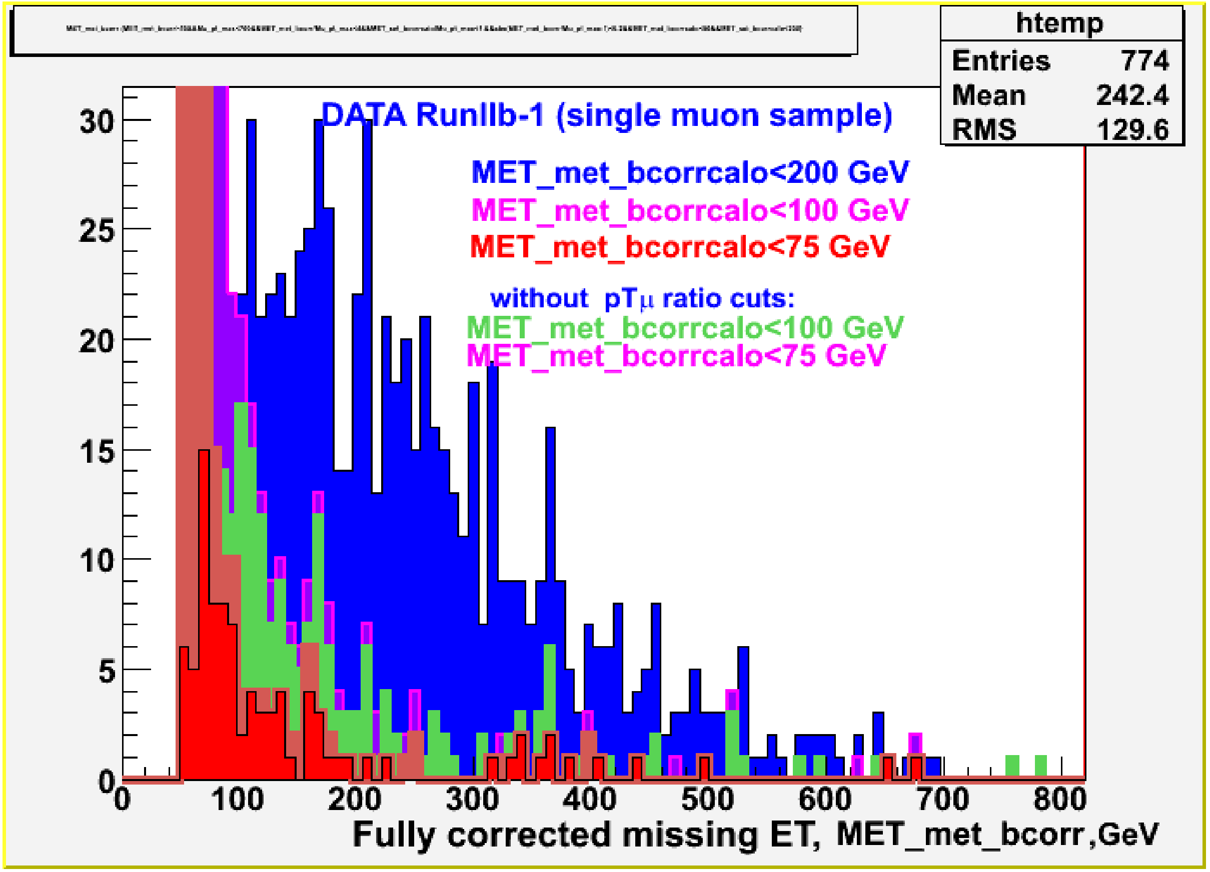
•As we can see the scalar sum of ET in the calorimeter can provide a good discriminating power. At SET < 50 GeV background can be suppressed > 100 times

Background and Monte-Carlo signal properties



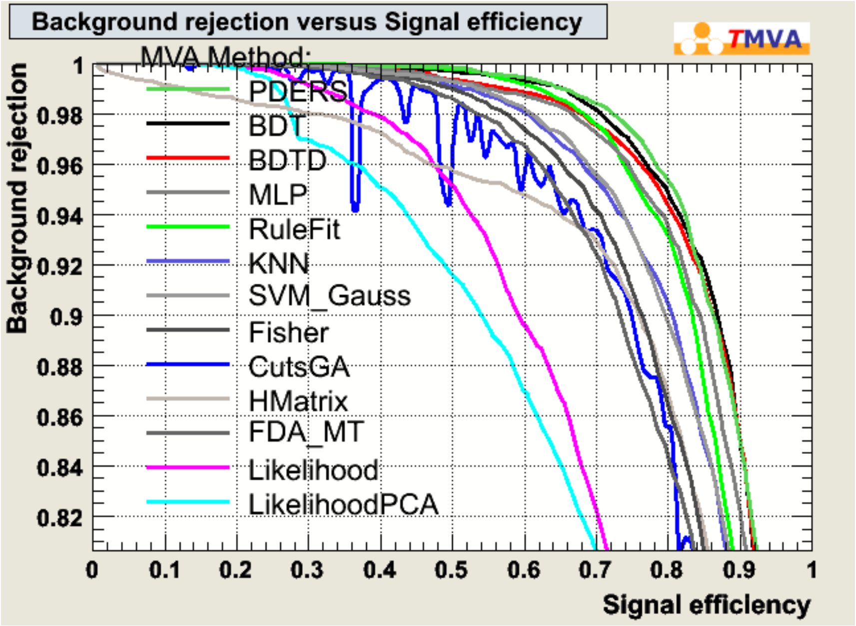
Also the ratios between fully corrected missing ET or scalar sum of the ET in the calorimeter and muon pT can be useful to discriminate the signal (W(μν)+Gkk) from the background

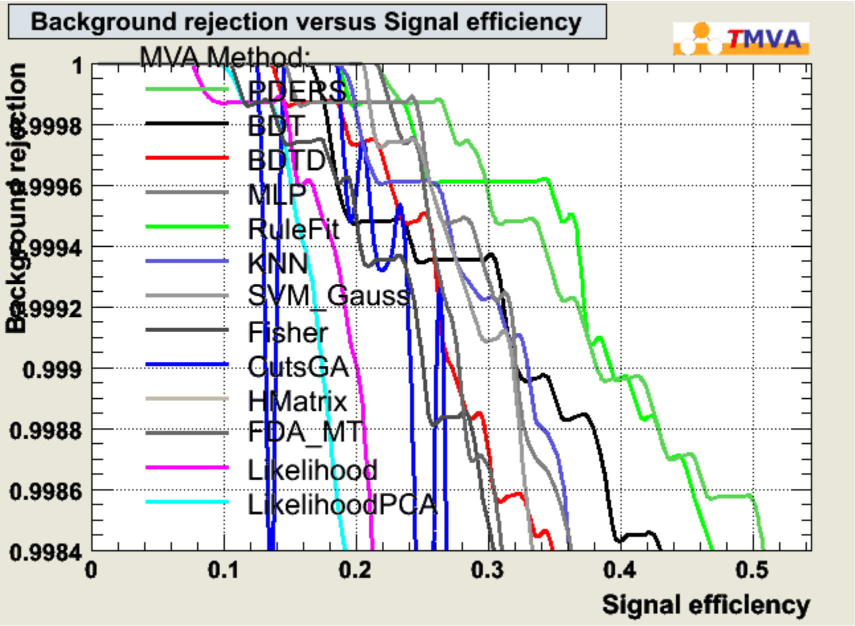
Background and Monte-Carlo signal properties



- The fully corrected missing ET preliminary spectrum after different cuts
- Finally the background was suppressed by factor 200 by comparison with already skimmed data with the fully corrected missing ET > 50 GeV with the total signal efficiency 16%.

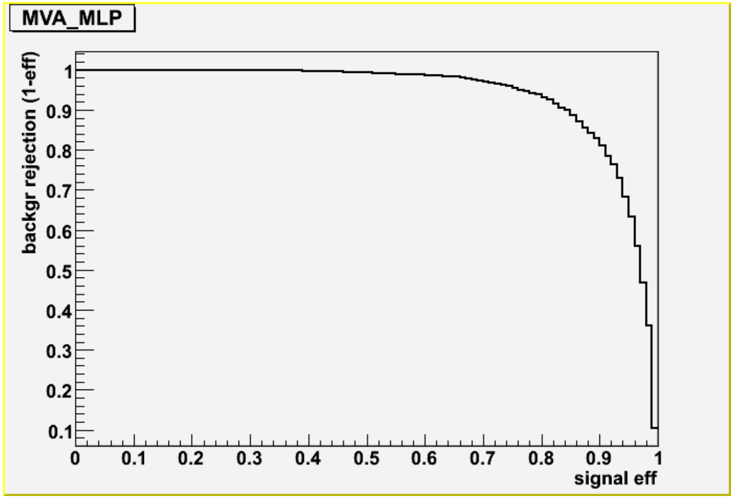
Multivariate Data Analysis

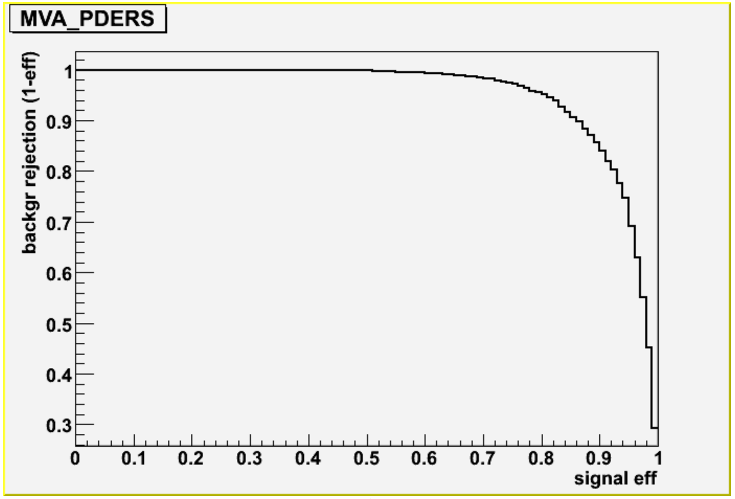


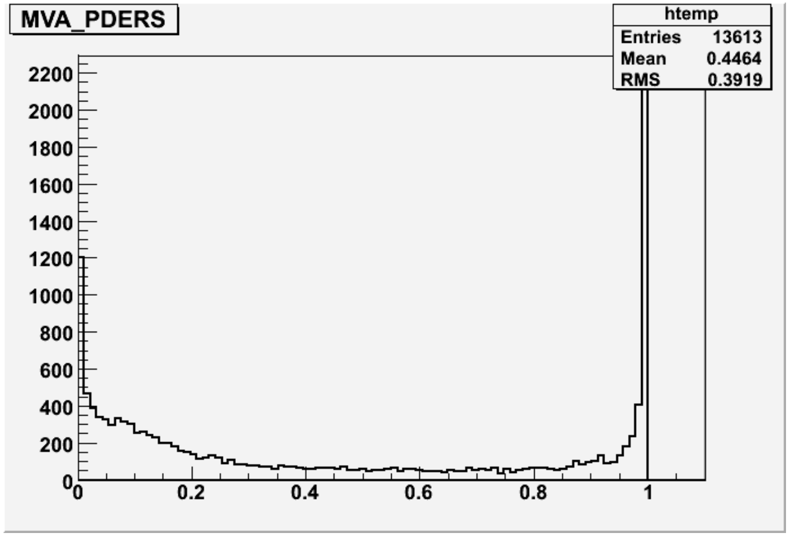


- Multivariate data analysis program package was used to estimate the discriminating power for the chosen criteria
- Six variables were used for the training of the MVA : fully corrected missing Et, scalar sum of ET, Missing Et in the calorimeter and their ratios with the maximal muon pT in the event
- As we can see, for the some methods we have the reasonable signal efficiency at good enough background suppression

Multivariate Data Analysis

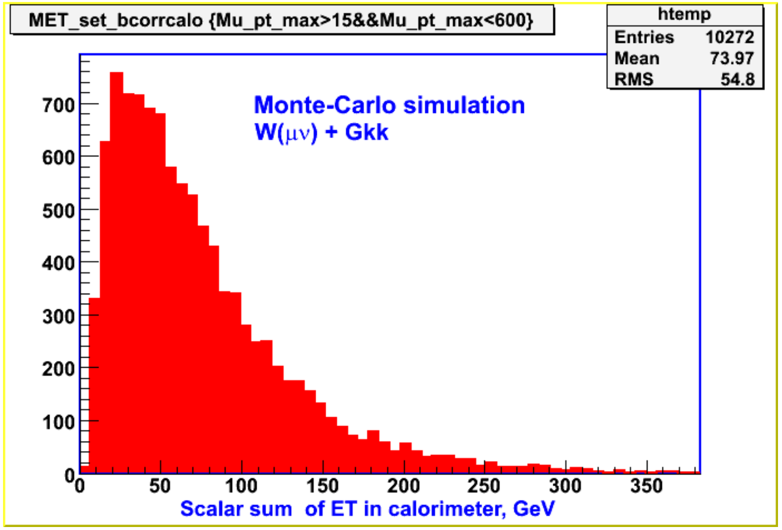


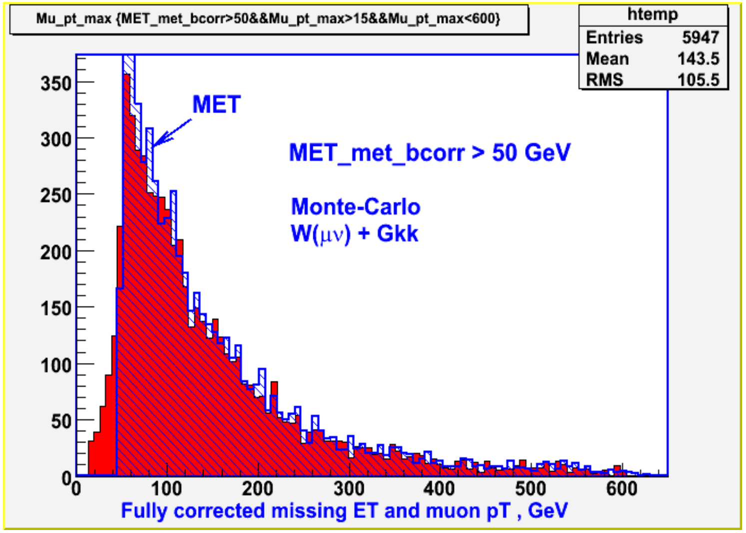




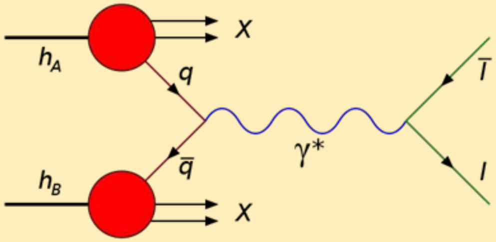
•The best methods are the MLP (neural network) and PDE-RS – probability density estimator
• The final winner PDERS method can provide a good discriminating power

MAIN PROBLEMS





- We need to be sure about the quality of the MC MET distributions - the scalar sum of ET in calorimeter and the fully corrected missing ET
- We need to study Drell-Yan process at the high (> 100) dimuon invariant masses:



- Estimated efforts for these studies is 2 years full time job

Conclusion

- The preliminary result is we have good criteria for the signal and background to start next studies
- The problem is we need to adjust the MC to the real data for the calorimeter variables
- Cuts to reject any jets should be implemented to improve the selection
- Next channel Z(2μ) + G_{kk} should be considered
- Thanks

ПАК ФА, Т-50

Технические характеристики

Экипаж: 1 человек

Длина: 22 м

Размах крыла: 14,2 м

Высота: 6,05 м

Площадь крыла: 78,8 м²

Масса пустого: 18 500 кг

Нормальная взлётная масса: 26 000 кг

Максимальная взлетная масса: 37 000 кг

Масса полезной нагрузки: 7 500 кг

Объём топлива: 10 300 л

Двигатели: 2 × ТРДДФ

Тяга максимальная: 2 × 8 800 кгс

Тяга на форсаже: 2 × 14 500 кгс

Масса двигателя: 1 520 к

Углы отклонения вектора тяги: ±16° в любом направлении, ±20° в плоскости

Скорость отклонения вектора тяги: 60 °/с

Лётные характеристики

Предельная скорость на высоте: 2 600 км/ч (М. 2,45)

Крейсерская скорость: 1 300—1800 км/ч

Перегоночная дальность: 4 000—5 500 км

Продолжительность полёта: 3,3 ч

Практический потолок: 20 000 м

Скороподъёмность: 350 м/с

Длина разбега/пробега: 350 м

Yury Shcheglov, PNPI- D0

Gatchina, February, 2, 2010

Definitions

- **Technicolor theories** are models of physics Beyond the Standard Model that address electroweak symmetry breaking, the mechanism through which elementary particles acquire masses. Early technicolor theories were modelled on quantum chromodynamics (QCD), the "color" theory, which inspired their name. Instead of introducing elementary Higgs bosons, technicolor models break electroweak symmetry and generate masses for the W and Z bosons through the dynamics of new gauge interactions. Although asymptotically free at very high energies, these interactions must become strong and confining (and hence unobservable) at lower energies that have been experimentally probed. This dynamical approach is natural and avoids the hierarchy problem of the Standard Model.
- In physics, **Kaluza–Klein theory (KK theory)** is a model that seeks to unify the two fundamental forces of gravitation andelectromagnetism. The theory was first published in 1921 and was proposed by the mathematician Theodor Kaluza who extendedgeneral relativity to a five-dimensional spacetime. The resulting equations can be separated out into further sets of equations, one of which is equivalent to Einstein field equations, another set equivalent to Maxwell's equations for the electromagnetic field and the final part an extra scalar field now termed the "radion".

Definitions

- In theoretical physics, **M-theory** is an extension of string theory in which 11 dimensions are identified. Because the dimensionality exceeds the dimensionality of five superstring theories in 10 dimensions, it is believed that the 11-dimensional theory unifies all string theories (and supersedes them). Though a full description of the theory is not yet known, the low-entropy dynamics are known to be supergravity interacting with 2- and 5-dimensional membranes
- **String theory** is a developing branch of quantum mechanics and general relativity with the aim of merging and reconciling the two areas of physics into a quantum theory of gravity. The strings of string theory are one-dimensional oscillating lines, but they are no longer considered fundamental to the theory, which can be formulated in terms of points or surfaces too
- In particle physics, models with **universal extra dimensions** propose that there are one or more additional dimensions beyond the three spatial dimensions and one temporal dimension that are observed. These models differ from the ADD model by assuming that all fields propagate universally in the extra dimensions; in contrast, the ADD model requires that the fields of the Standard Model are confined to a four-dimensional membrane, while only gravity propagates in the extra dimensions. The universal extra dimensions are typically assumed to be compactified with radii much larger than the traditional Planck length, although smaller than in the ADD model, ~10^{-18} m

Motivation to continue. Look from the outside of Standard Model

- **Explanation of supersymmetry can be found in string theory uniting gravity with the other three forces in nature and providing a basis for Universe theory. One of variants of string theory uses 6D- spaces which help to describe particles properties. These spaces generalized as Kaluza-Klein compactification spaces are known as Calabi-Yau spaces. 6 of the 10D wrapped into compact space, and the quantized components of momenta become part of the internal particles machinery that determines their quantum numbers**
- **Calabi-Yau spaces are thousands of 6D spaces, each with a different topology, including holes, tunnels and handles are described by hundreds of parameters called moduli that determine the dimensions shape and size. The moduli can simply be thought of as fields in space that determine the local conditions. A simplest modulus is the compactification radius, R, which smallest is the string scale. Moduli not determines exactly the theory parameters (masses, couplings) but give rise mathematically consistent theories**
- **The field potential is zero for every value of the moduli, and it is a reason of super-symmetry of string theory. For every fermion exists a superpartner - boson and vice-versa. Otherwise the vacuum have a huge zero-point energy density with a radius of the space-time curvature order of Planck scale. Besides, supersymmetry save the vacuum from hypothetical instabilities, that allows to make exact mathematical** conclusions

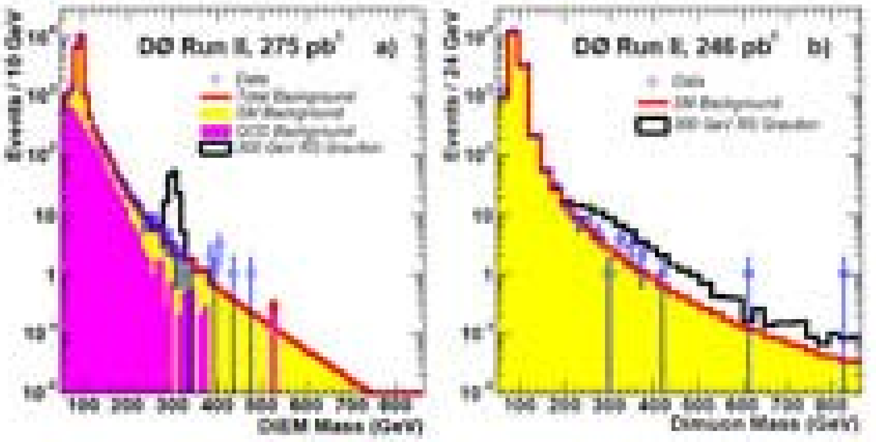
Extra Dimensions. Models

- In their 1998 paper, Arkani-Hamed, Dimopoulos, and Dvali (ADD) suggested that the seemingly unreachable Planck energy scale (conventionally thought to be M_{Pl} ~ 10^{19} *GeV) may be, in fact, much lower, i.e., within the* reach of current and planned future colliders
- They postulated that the standard model (SM) particles and gauge interactions are confined to a three-dimensional ''brane'' embedded in a ''multiverse,'' which consists of the three standard plus ***n additional compact spatial dimensions***
- Gravitons in this framework can propagate in the entire multiverse. The gravitons propagating in compact extra dimensions appear as a tower of Kaluza-Klein (KK) excited modes from the point of view of the SM brane
- The radius of compactification (*R)* of extra dimensions in the ADD model is much larger than

  either the Planck or electroweak length, and may be as large as 1 mm. Since gravitons are free to propagate in these large extra dimensions, the gravitational interaction would appear suppressed on the SM brane, due to the extra volume gravity permeates
- Consequently, while the apparent Planck scale is 10^{19} GeV, with respect to the 3 n-dimensional space, the fundamental Planck scale (MS) can be as low as 1 TeV, thus eliminating the hierarchy problem of the SM
- For a review of the possible effects of large extra dimensions, ranging from modification of Newtonian gravity to black hole production at future colliders

D0 results for Randall-Sandrum Extra Dimensions model

RS model
Poincaré hypothesis
Duality to technicolor



Goddess of Hunting Sculpture

Artemis with deer. Roman bronze, 1 B.C.