Oklahoma Center for High Energy Physics (OCHEP): Progress Report

S. Nandi, Oklahoma State University
Principal Investigator and Director of OCHEP

(Talk presented at EPSCoR Program Review, July 20-23, Hauppauge, NY)

Outline

- Introduction
- Research Activities
  - Theoretical research
  - Experimental Research: Tevatron and LHC
- Progress and status of the Grid Computing Facility
- Education and Outreach Activities
- Conclusions

Introduction

- Oklahoma Center for High Energy Physics (OCHEP): A regional center of excellence in High Energy Physics Research and Education
  - Consortium of Oklahoma State University, University of Oklahoma and Langston University
    - Established in August, 2004 with the implemental grant from the DOE EPSCoR and support from Center institutions and the State of Oklahoma
  - Currently the Center has 13 faculty members, 6 postdocs, 20 graduate and 6 undergraduate students
    - They are involved in Experimental research at the Tevatron and LHC
    - Theoretical research in HEP
    - Grid computing for HEP Research
    - Education and outreach activities

Introduction

- Two major milestones of the original implementation proposal was:
  - Initiation of an experimental High Energy Physics Program at OSU
  - Establishment of a Tier 2 Grid Computing Facility at OU for the LHC and Tevatron data analysis
- Both milestones have been achieved
  - Two tenure-track faculty (Drs. F. Rizatdinova and A. Khanov) in experimental HEP have been hired at OSU with the initial support from this grant
  - A permanent research scientist (Dr. H. Severini) has been hired at OU to maintain and run the Grid Computing Facility
  - DOE EPSCoR Implementation grant has led to the establishment of two new permanent programs

Introduction

Productivity of OCHEP in (2008-09)

- 106 research paper in refereed international journals
- 60 invited presentation in major national and international conferences
- 2 weeks Summer Workshop for High School Teachers
- 72 millions events consisting of 6.3 terabytes of simulation data for the D0 and ATLAS Collaborations at Tevatron and LHC.

Theoretical HEP Research at OCHEP

- New Models and new signals for the Higgs Bosons
- Unification of Particles and Forces
- Origin of neutrino masses
- Origin of the dark matter of the universe
- Extra dimension and its collider implication
- Signals for supersymmetry
- Study of Cassimir forces

Theoretical Research at OCHEP

- New models and new signals for the Higgs boson

(J. Lykken, Z. Murdock and S. Nandi, Phys. Rev.D79,075014(2009))

: Proposed a new model to explain fermion mass hierarchy

: Has a singlet Higgs boson in addition to the SM doublet

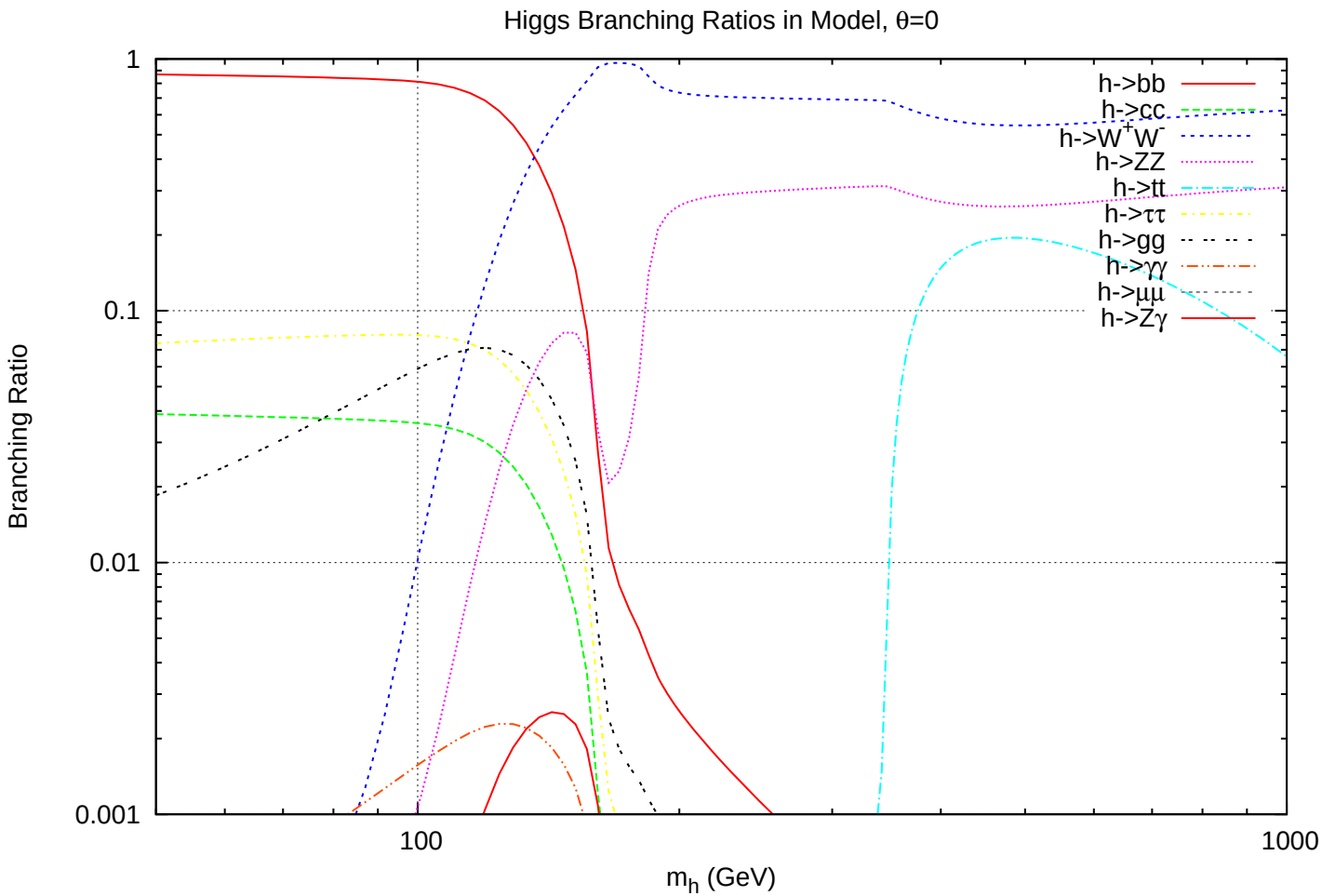
: Predict enhanced decay of the Higgs boson for the two photon mode

: Observable branching ratio for the top quark decay to charm quark and the Higgs boson

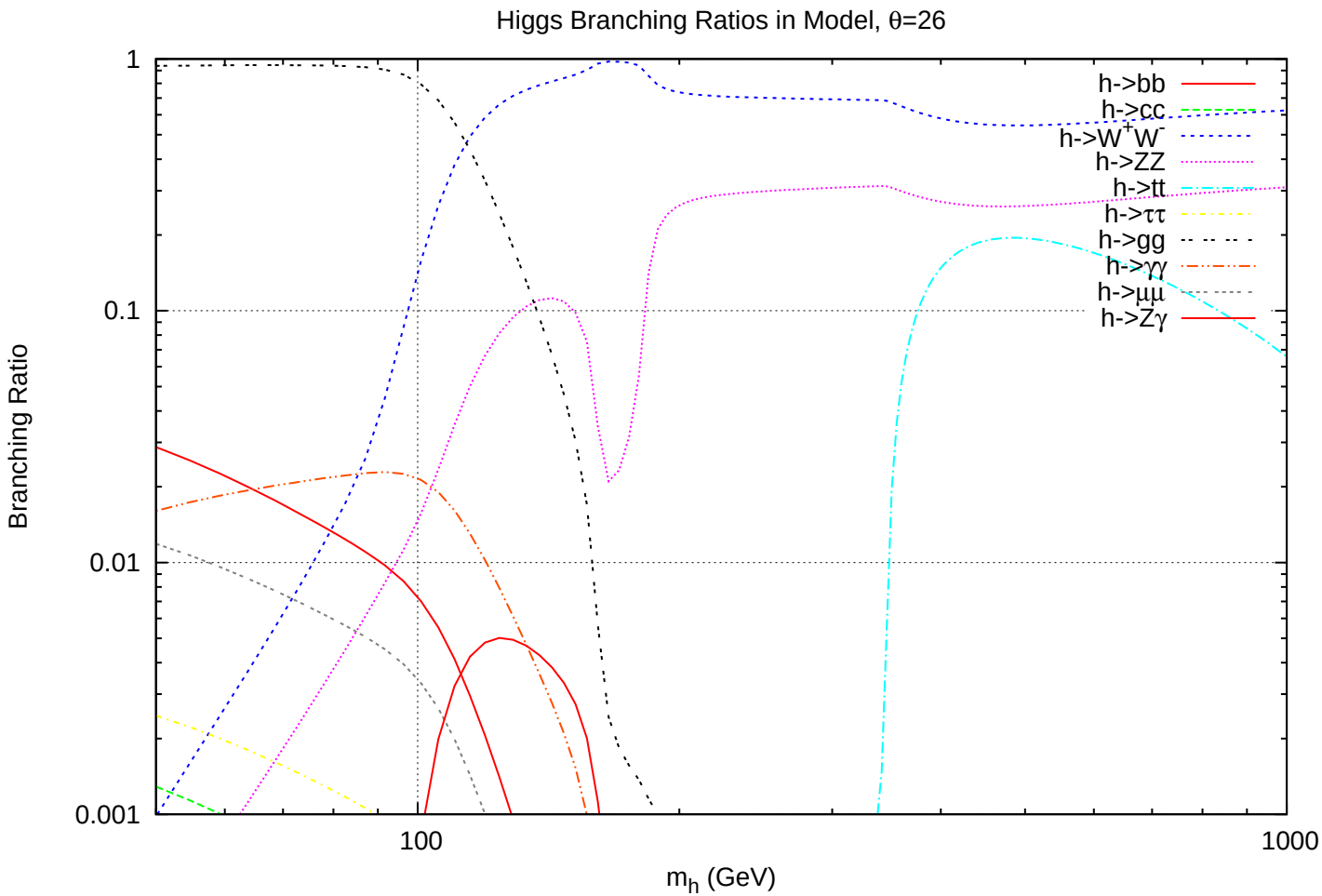
: predict the existence of an extra Z boson and several heavy vectorlike quarks.

: Predictions can be tested at the LHC, and possibly at the Tevatron

h→2x for θ=0°, (Lykken, Murdock and Nandi, 2009)



h→2x for θ=26 (Lykken, Murdock and Nandi, 2009)



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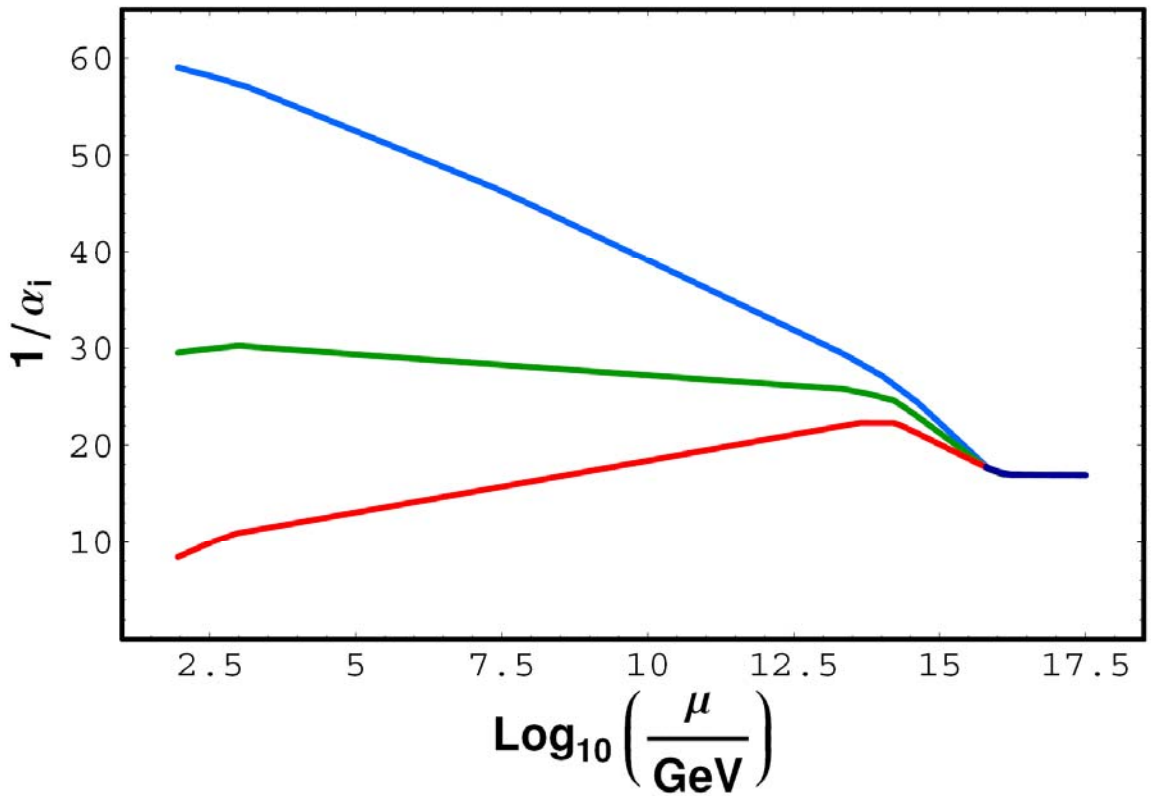
Unification of particles and forces

- OCHEP faculty proposed new ideas for the unification of particles and forces both in four and with extra dimensions.
- With extra dimensions, we can unify all the SM forces in a symmetry group, and all the particles in one representation of this symmetry group (S. Nandi and Y. Mimura, Phys. Rev. D, to appear)
- In 4 dimensions, OCHEP faculty have constructed realistic SUSY GUT model (K. S. Babu, J. C. Pati and Z. Tavartkiladze, 2009)
- Major prediction is the proton decay and its lifetime.
- This can be tested in the upcoming proton decay experiments

Grand Unification and Proton Decay

(Babu, Pati and Tavartkiladze, 2009)



Gauge coupling evolution in realistic SO(10) model

$p \rightarrow e^+ \pi^0$ lifetime in SUSY SO(10) (yr)

(Babu, Pati and Tavartkiladze, 2009)

r \ α_3	0.1156		0.1176		0.1196	
	A	B	A	B	A	B
1/50	6.7×10^{32}	3.9×10^{32}	2.5×10^{33}	1.4×10^{33}	8.1×10^{33}	4.7×10^{33}
1/100	1.7×10^{33}	1.1×10^{33}	6×10^{33}	3.5×10^{33}	$\mathbf{2 \times 10^{34}}$	$\mathbf{1.2 \times 10^{34}}$
1/200	4×10^{33}	3×10^{33}	$\mathbf{1.5 \times 10^{34}}$	$\mathbf{9 \times 10^{33}}$	$\mathbf{5 \times 10^{34}}$	$\mathbf{3 \times 10^{34}}$

A: $M_{\text{eff}} = 3 \cdot 10^{19}$ GeV B: $M_{\text{eff}} = 4.5 \cdot 10^{19}$ GeV

$r = M_\Sigma / M_X$

Theoretical Research

- New Dark Matter

  (Howard Baer, Andrew D. Box, Heaya Summy . Jun 2009. e-Print: arXiv:0906.2595 [hep-ph])

: About 20% of the matter in the universe is dark matter

: In the supersymmetric framework, the usual candidate for the dark matter is neutralino, the lightest supersymmetric particle.

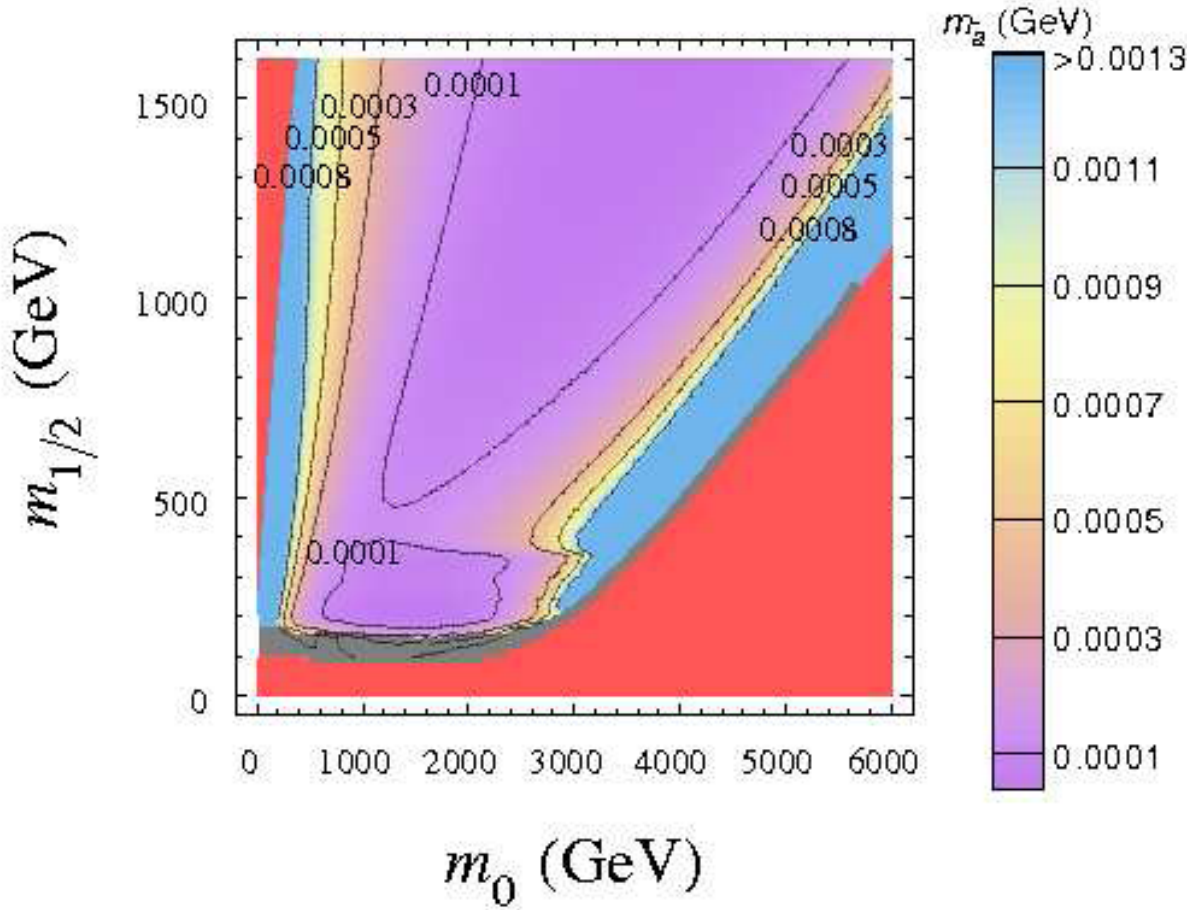
: Proposed a new kind of dark matter, a combination of axion and its supersymmetric partner, axino.

: This is favored in the parameter space where neutralino dark matter is disfavored.

: Can be tested in the LHC

Theoretical Research

(Baer, Box and Summy, 2009)

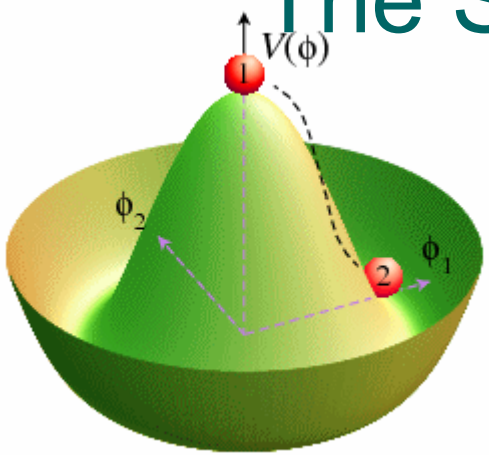


Contours of constant $m_{\tilde{a}}$ in the m0 vs. m1/2 plane for A0 = 0, tan β = 10 and μ > 0. We assume $\Omega_a h^2 = 0.11$, and $\Omega^{TP}_{\tilde{a}} h^2 = 0.006$ and $\Omega^{NTP}_{\tilde{a}} = 6 \times 10^{-6}$.

Experimental Research

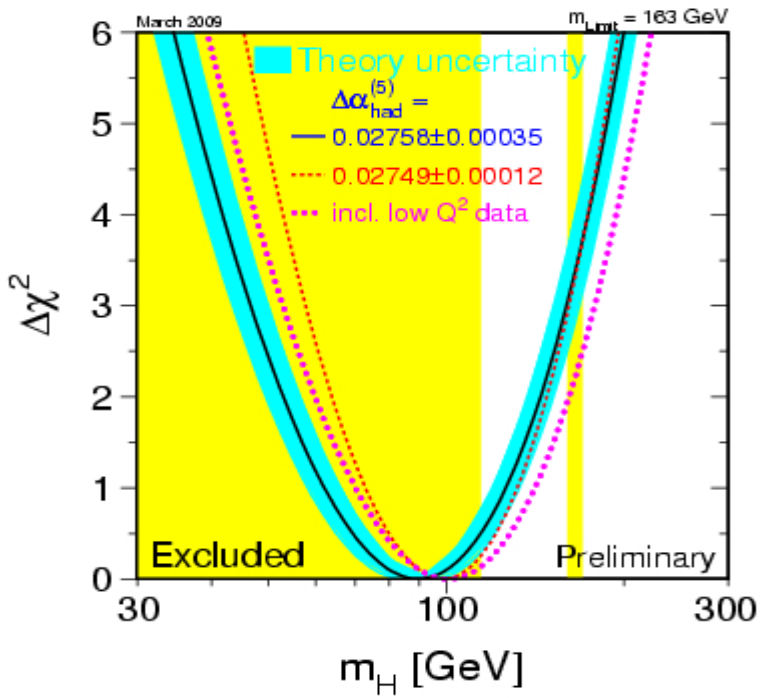
- Research at the FermilabTevatron
  - Search for the Higgs Boson (A. Khanov, F. Rizatdinova, H. Hegab)
  - Discovery of the new particle: Omega_b (B. Abbott)
- Research at the Large Hadron Collider (LHC)
  - Accurate measurement of top quark properties (F. Rizatdinova, B. Abi, P. Skubic, M. Saleem, D. Jana)
  - Search for a new symmetry of nature: supersymmetry (B. Abbott, G. Huang, P. Skubic, A. Khanov)

The Standard Model Higgs Boson



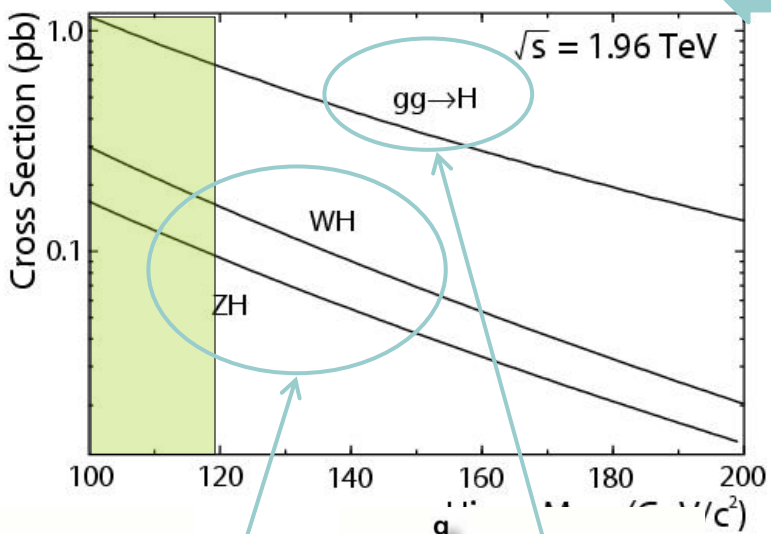
- Higgs boson: last undiscovered fundamental particle in SM, responsible for fermion/gauge boson mass generation
- Higgs mechanism: particles acquire mass through interaction with a scalar field V(φ)

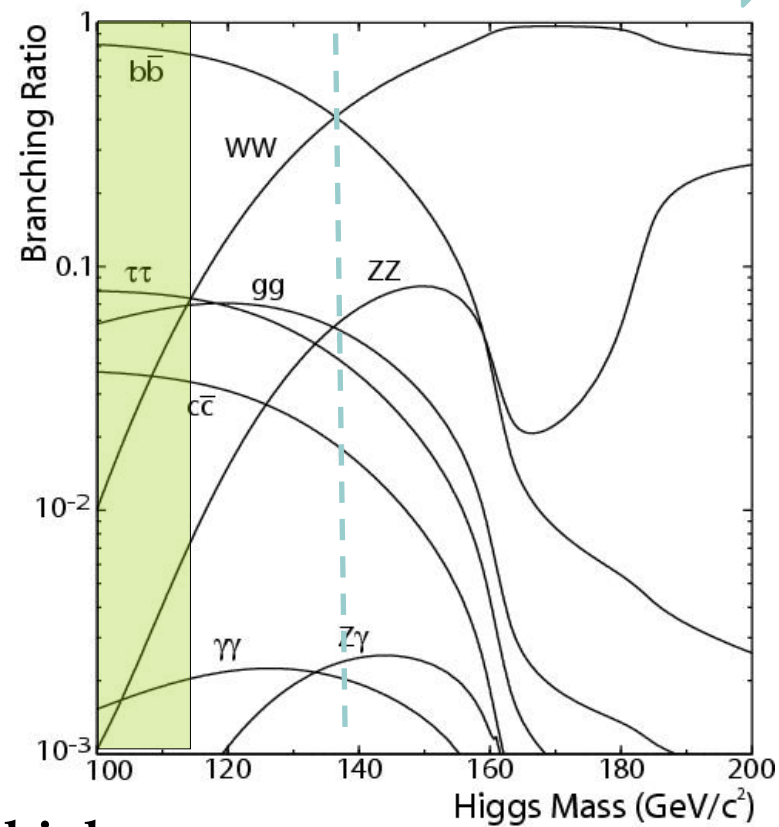
- Higgs boson mass is free parameter in the theory
- Direct searches at LEP II: M_H>114.4 GeV @ 95% CL
- EW data indirect constraint: M_H<163 GeV @ 95% CL, or < 191 GeV including LEP II limit
- Preferred value $M_H=90^{+36}_{-27}$ GeV (uncertainties at 68% CL)

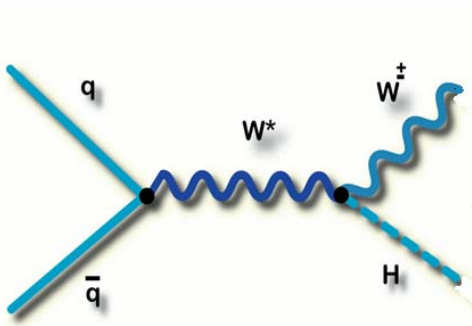


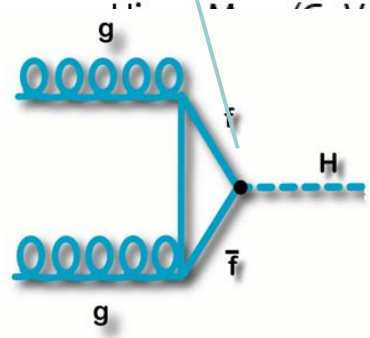
SM Higgs production and decay at the Tevatron

low mass: H→bb **high mass: H→WW**







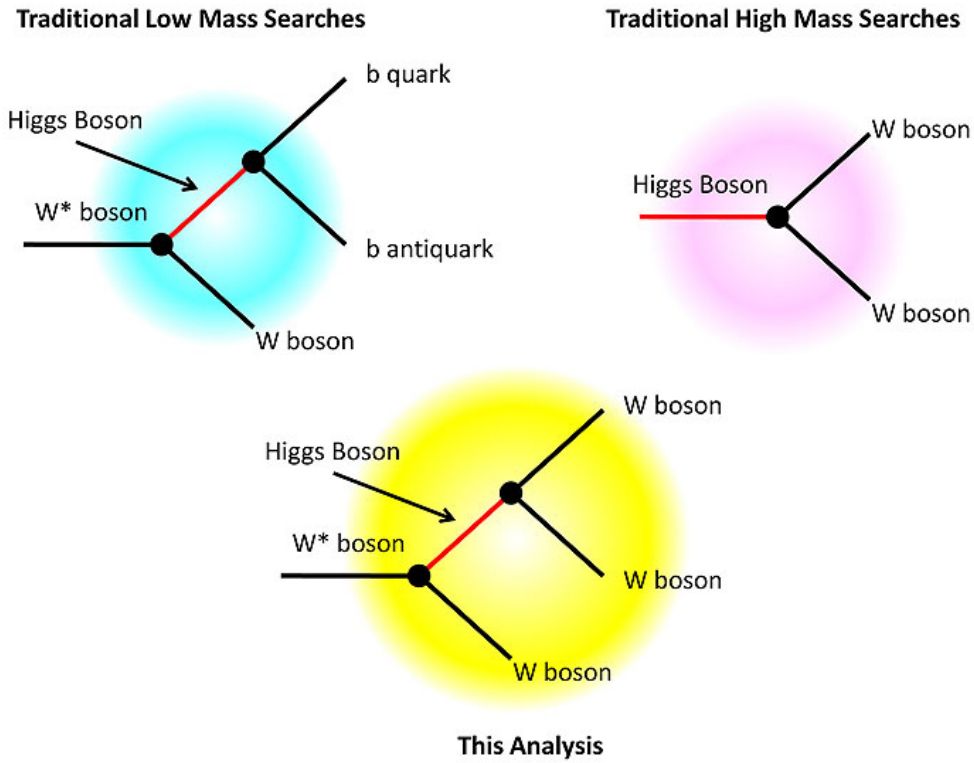


associated production: W/Z provides a handle

direct production: high yield, high background

Higgs search in the HW→WWW→$l^{\pm}l^{\pm}$ +X channel

- The channel has been proposed by OCHEP members to cover the difficult Higgs mass region near 135 GeV

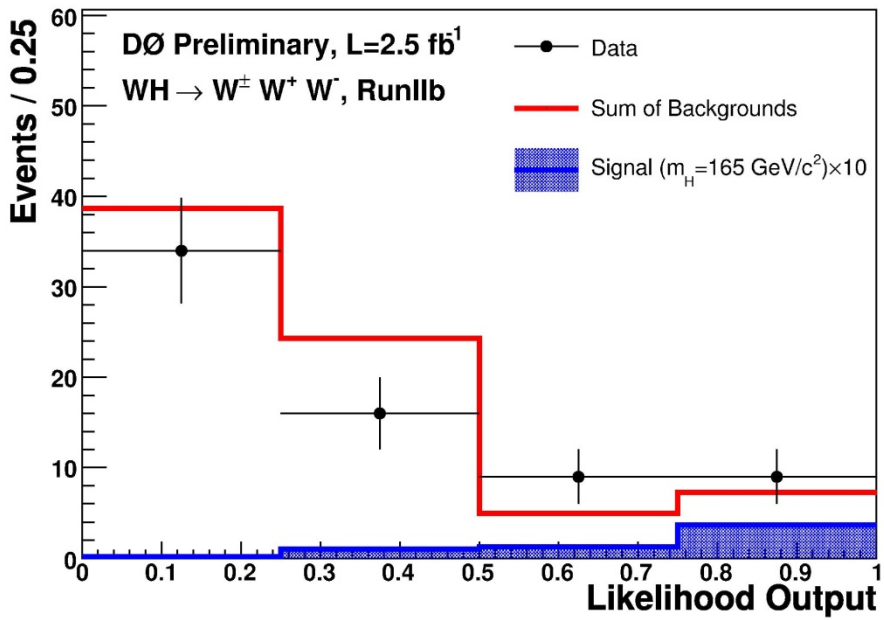


- Unique signature (two like-sign leptons), low SM background

- Difficult instrumental background:
  - electrons and muons with mis-measured charge ("charge flips")
  - non-isolated leptons from multi-jet production ("QCD")

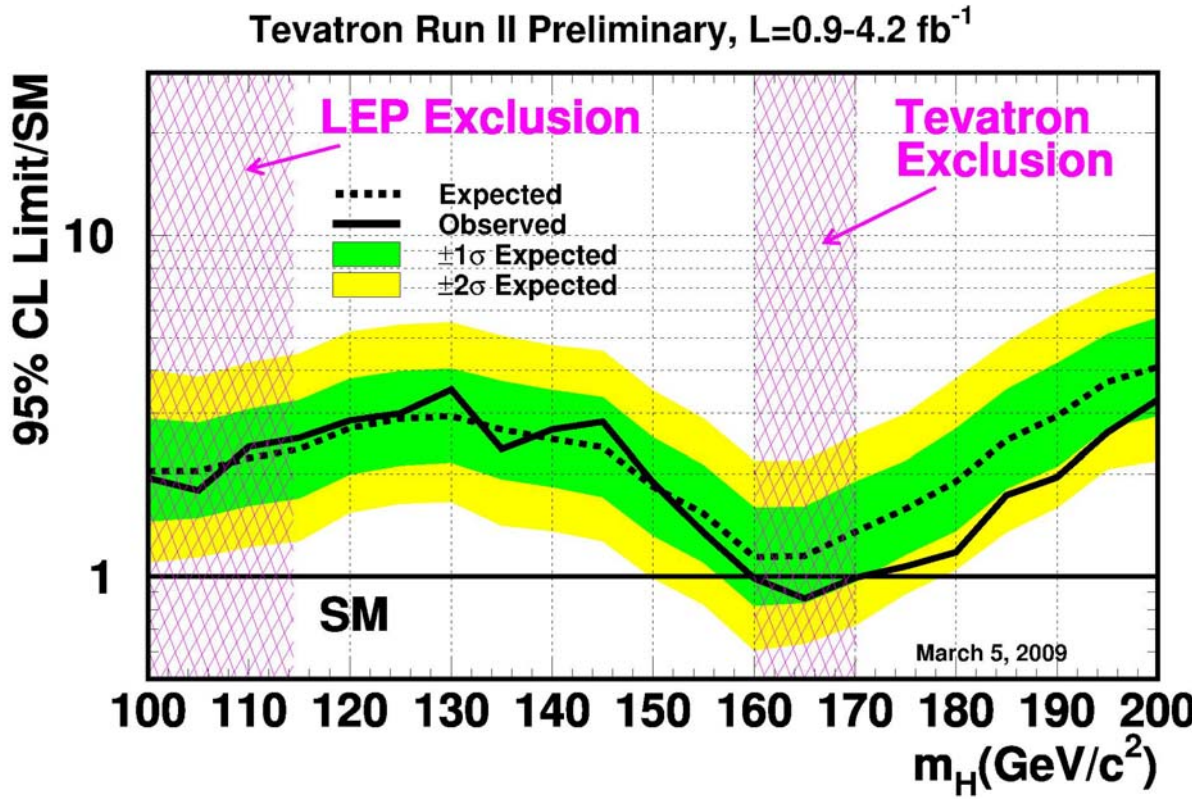
HW→WWW→$l^{\pm}l^{\pm}$ +X: latest results

- based on 2.5 fb^{-1} of integrated luminosity
- announced in Fermilab's Result of the Week
- results became part of the Tevatron SM Higgs combination



Tevatron SM Higgs combination

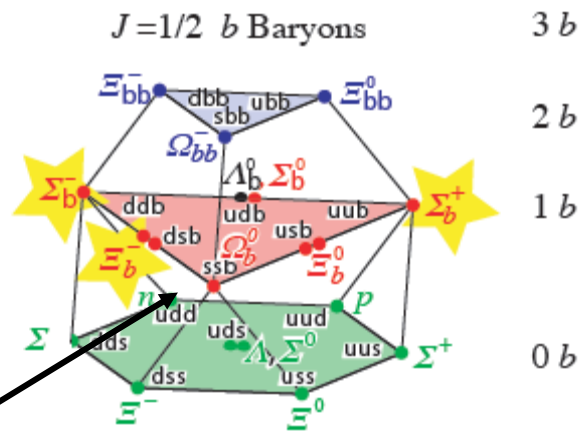
- Results obtained by OCHEP contributed to the joined DØ—CDF combination
- For the first time since LEP, exclude a region of SM Higgs masses (160—170 GeV)



arXiv:0903.4001

Discovery of the Ω_b

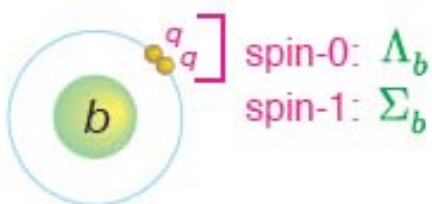
- Prior to 2006 the only directly observed b baryon was the L_b
- With Run II of the Tevatron, many new b baryons have been discovered

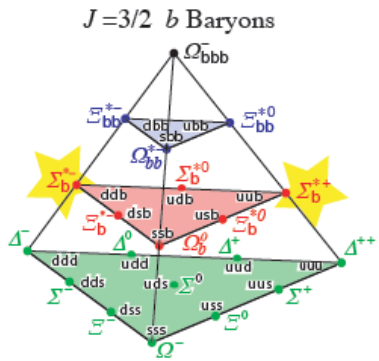


Ω^-_b(bss)

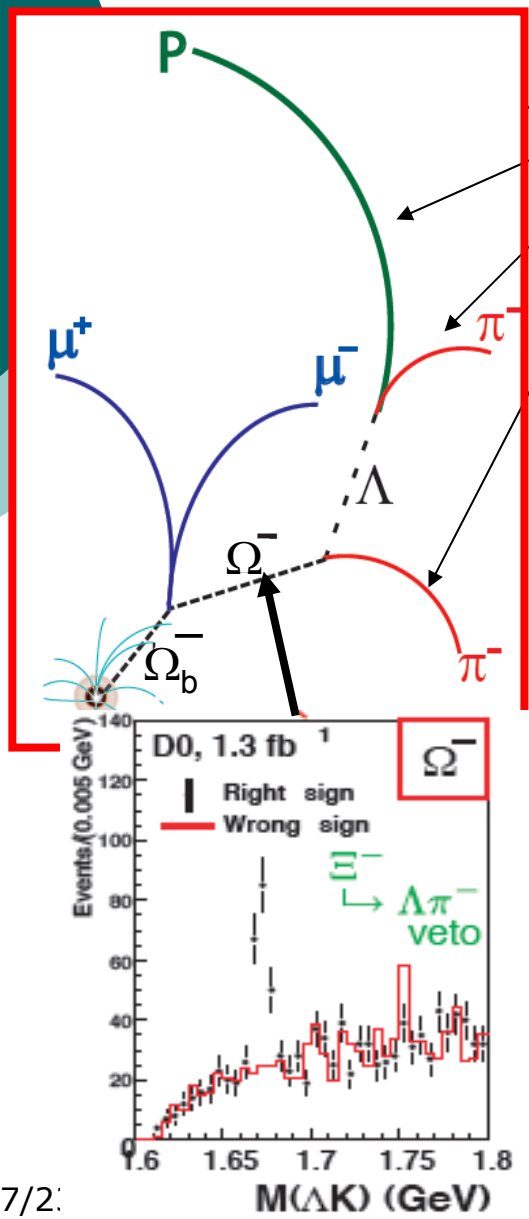
From Run II
L_b(bud) DØ,CDF
S^-_b(bqq) q=u,d CDF
X^-_b(bds) DØ,CDF

View as an L=0 atomic system with a heavy b quark and a light diquark



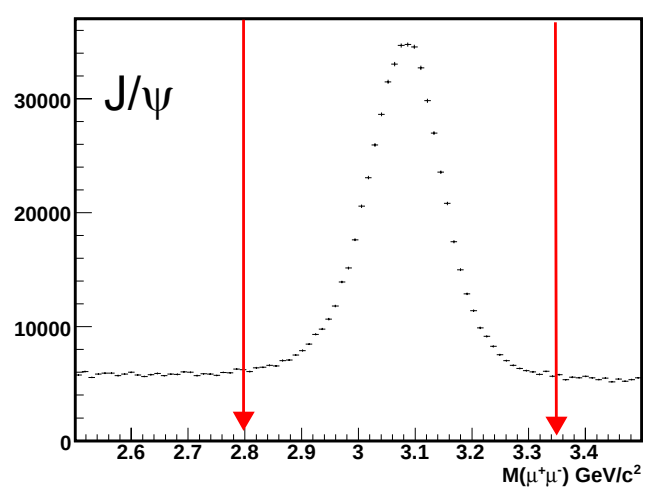


Building on experience gained by observation of the Ξ_b, DØ searched for the doubly strange Ω_b baryon through the decay $\Omega_b^- \rightarrow J/\psi\ \Omega^-$

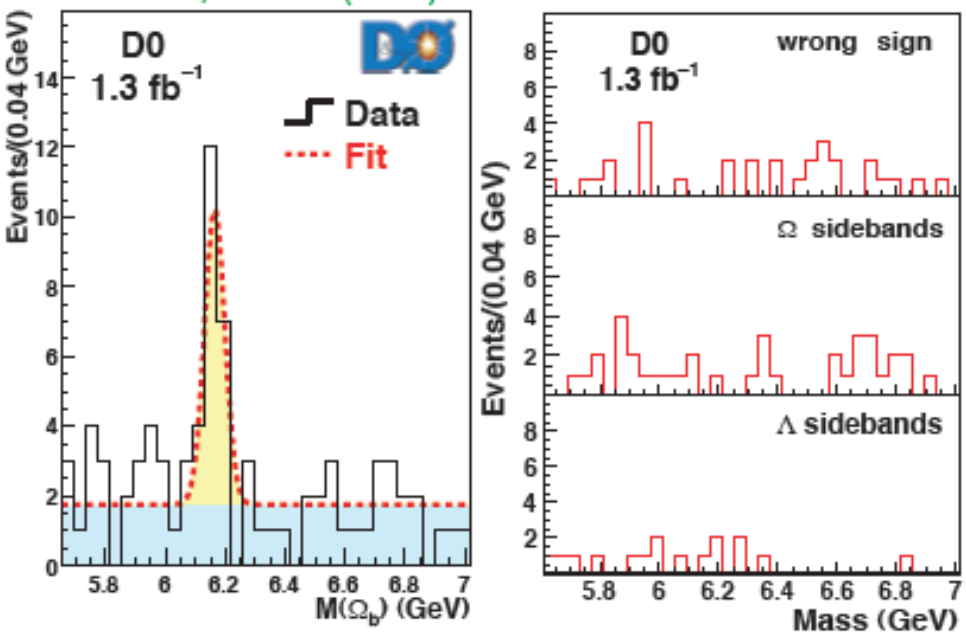


Many tracks have large impact parameters so a special reprocessing of data was performed

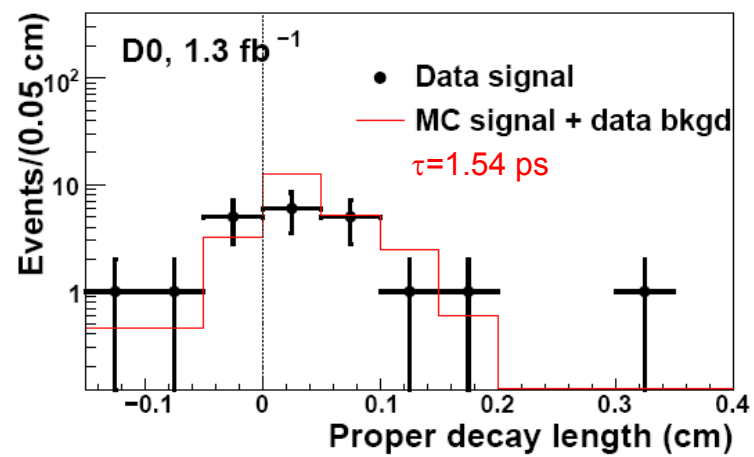
Finally Combine Ω^- with J/ψ to search for Ω_b



PRL **101**, 232002 (2008)



Significance of signal is 5.4σ
Remains > 5 σ after systematics



Number of signal events: 17.8 ± 4.9 ± 0.8

Mean of the Gaussian: 6.165 ± 0.010(stat) GeV

Width of the Gaussian fixed (MC): 0.034 GeV

Decay length consistent with weakly decaying b state

Phys. Rev. Lett. **101**, 232002 (2008)

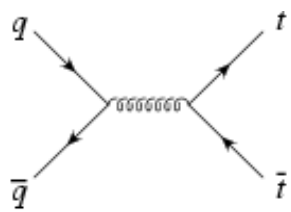
Experiment at LHC:Top quark physics with 10-100 pb^{-1} data

- ttbar is the main background to many discovery channels: stop pair production, heavy charged Higgs boson production, ttbar resonances.
  - Have to measure accurately inclusive ttbar cross section
  - Have to investigate the ttbar kinematic characteristics
- Measure differential cross sections ($d\sigma/dp_T$, $d\sigma/dM_{tt}$) which are sensitive to new physics
- Measure top quark mass
- ttbar as a tool:
  - B-tagging efficiency measurement
  - Jet Energy Scale calibration for light jets and b-quark jets
  - Calibration of missing transverse energy (from $W \rightarrow \ell\ \nu$)

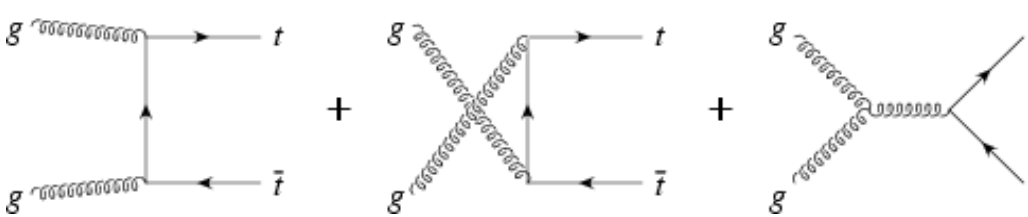
Top quark pair production at the LHC

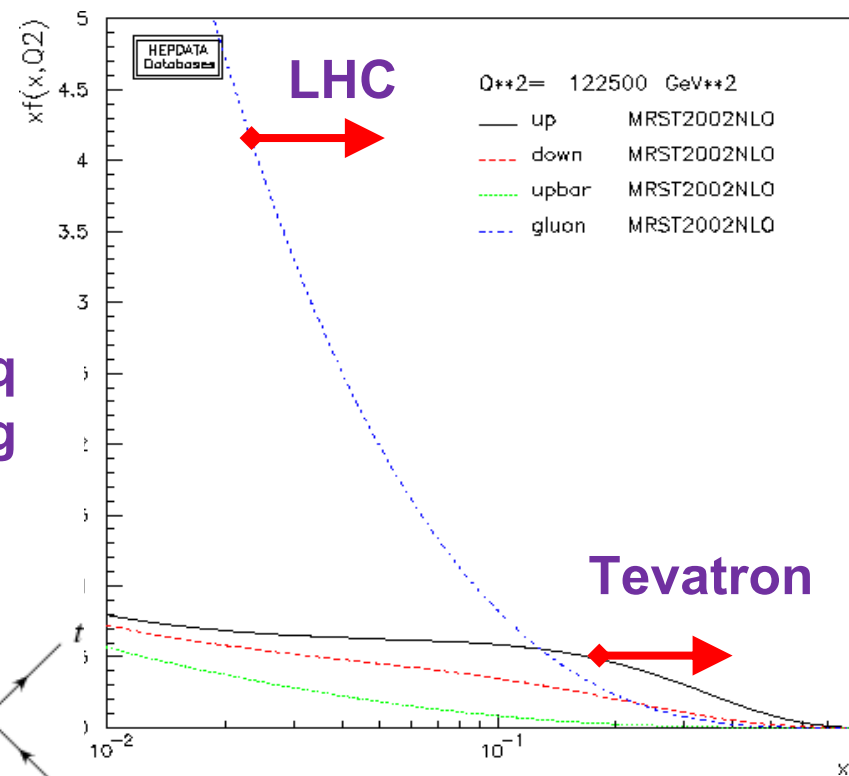
- Top quark pair production at LHC is significantly different from the one at the Tevatron

10% qq
90% gg



85% qq
15% gg





$$x \approx \frac{m_t}{\sqrt{s}/2}$$

$$\sqrt{s} = 1.96\ TeV \Rightarrow x \approx 0.18$$

$$\sqrt{s} = 14\ TeV \Rightarrow x \approx 0.025$$

LHC √s=10 TeV
575 ± 60 pb

Tevatron:
7.62 ± 0.85 pb

Event selection

- Pass e or mu trigger;
- Exactly one isolated high p_T lepton per event;
- missing E_T >20 GeV;
- At least four jets: three jets with p_T>40 GeV, and at least one jet with p_T>20 GeV

Process	N expected evts
Ttbar (signal)	3144
W($\mu\nu$)+njets	1644
Single top	242
Diboson	14
S/B	~2.0

Process	N expected evts
Ttbar (signal)	2611
W($e\nu$)+njets	1160
Single top	209
Diboson	15
S/B	~2.0

Number of expected events is calculated for 200 pb^{-1} of data

Experiment at LHC:Search for Supersymmetry

- OCHEP faculty suggested SUSY search via multimuon and same-sign dimuon states as an early LHC discovery opportunity, see H. Baer, A. Lessa, H. Summy, Phys.Lett.B 674 (2009) 49;
- The channel does not require complete knowledge of detector performance, since in the initial running the detector will not be well understood.
- The suggested search focuses only on isolated multimuon plus jets events:
  - Muon identification is more straightforward;
  - Isolated muons to reject heavy flavor background.

Standard Model MC and Event Selection

- SM background samples (full simulation): ttbar, W+njets (n=2-5), Z+njets(n=2-5), di-boson, QCD di-jets;

Event selection (no E_T^{miss} cut!)

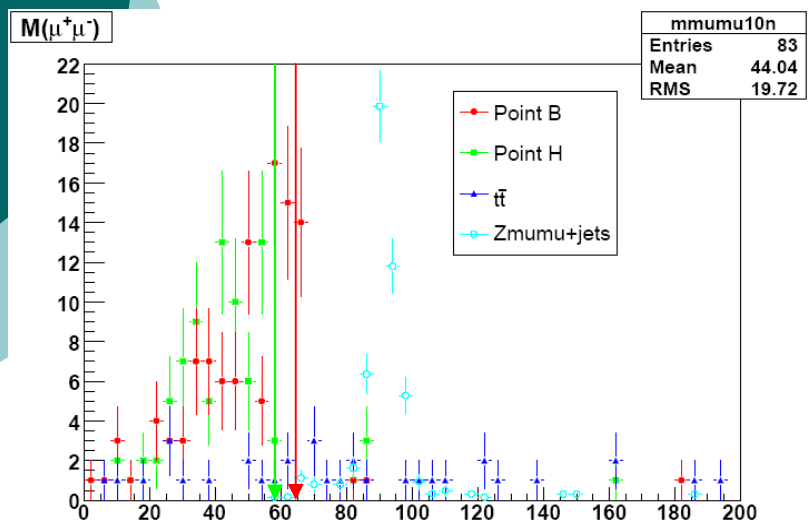
Isolated muon:

- $p_T > 10$ GeV
- $|\eta| < 2.5$,
- ETcone20 < 6 GeV and $\delta R(\mu, \text{jet}) > 0.4$;

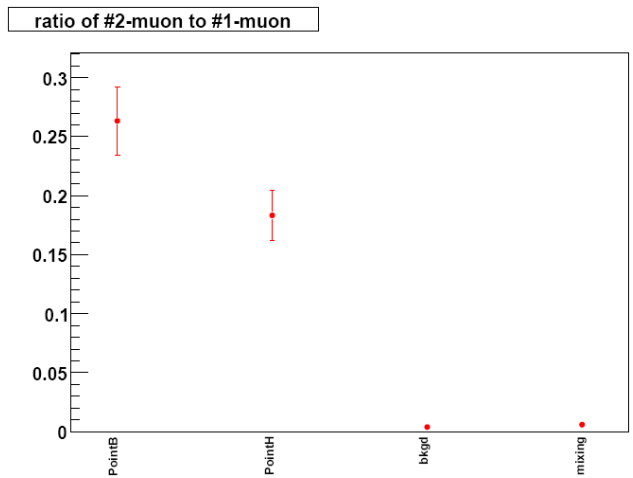
$\geq$ 4 good jets:

- $p_T > 100, 50, 50, 50$ GeV,
- $|\eta| < 2.5$;

Dimuon invariant mass distribution



The ratio of # 2μ events to # 1μ events eliminates luminosity measurement, and appears to be a very promising signature.



Kinematic edges seen at 64.6 GeV(B), 58.5 GeV(H).

This is consistent with the SUSY model: $\tilde{\chi}_2^0 \rightarrow l^{\pm} l^{\mp} \tilde{\chi}_1^0$

OCHEP Grid Computing Activities

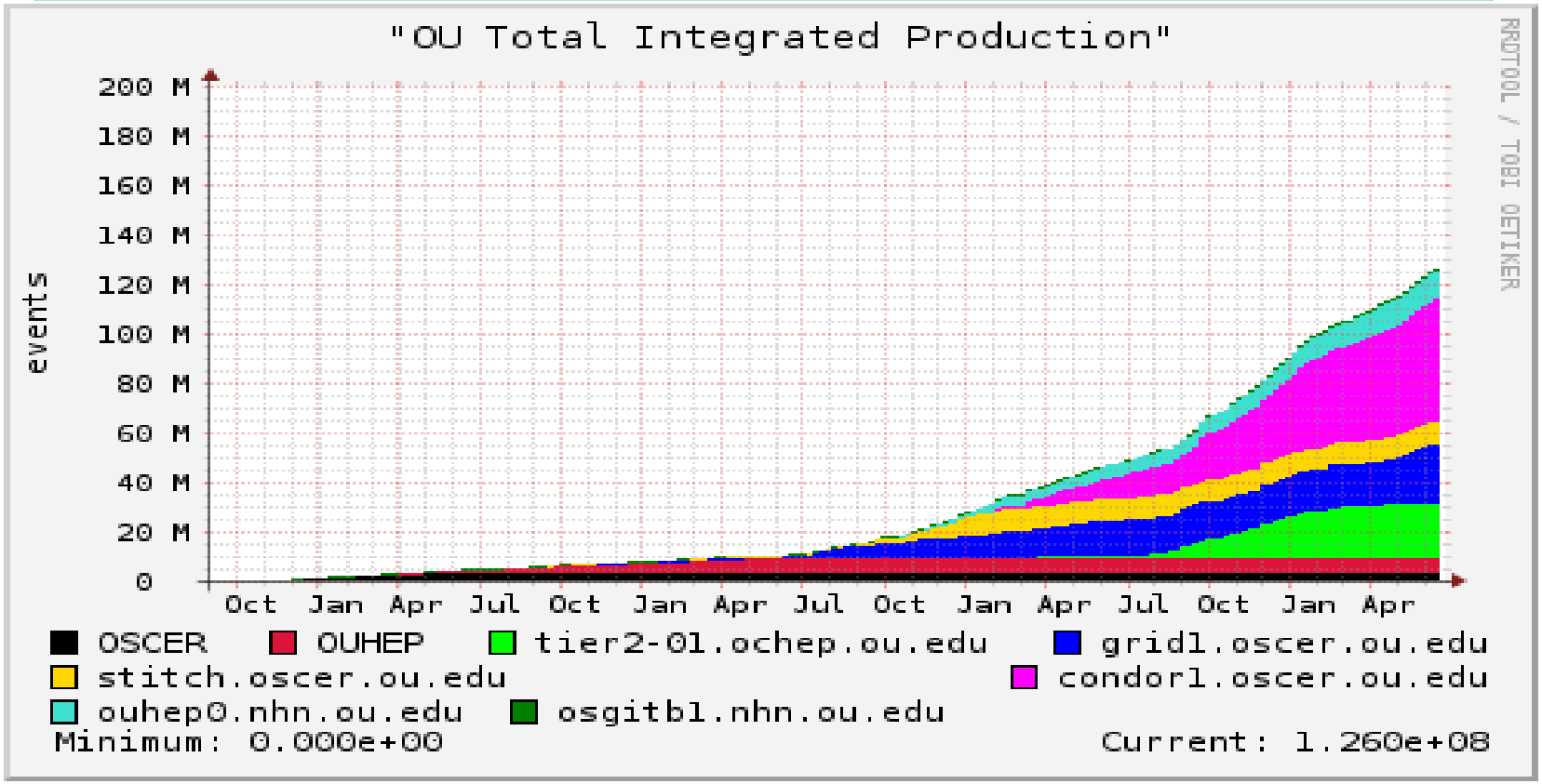
- OCHEP personnel in charge: J. Snow (LU), H. Severini (OU)
  - ATLAS Tier 2 & Tier 3 at OU
    - Component of Southwest Tier 2 – UTA/OU/LU
    - Continual simulation production
    - Support analyses
  - DZero Monte Carlo production
    - Experiment's MC production coordinator (Snow)
    - Grid sites at OU & LU
  - Open Science Grid Integration Test Bed sites at OU
  - Open Science Grid Outreach
    - Presenter at Grid schools in South Africa & Brazil (Severini)

OCHEP Grid Computing Resources

- OCHEP ATLAS Tier 2 cluster – 10 Gbps
  - 274 core, 100 TB storage, ATLAS/DØ
- OSCER Linux cluster
  - 500 max batch slots for HEP queue, DØ/ATLAS
- OU Condor Pool
  - ~350 Student lab machines (core), CoLinux inside Windows OS with grid gatekeeper - DØ
- OUHEP cluster – 51 core, DØ/LIGO
- LUHEP cluster – 27 core, DØ
- OU ITB cluster - 8 core, DØ

OCHEP Grid Computing Results

- 8.8% of total production
- 22.8% of North American production



Education and outreach activities

- Education and outreach has been an integral part of the EPSCoR grant since its inception.
- We developed a program aimed at Oklahoma high school teachers, and at undergraduate and graduate education.
- The main goals of our program are:
  - to introduce high school and undergraduate students to the modern physics and explain its important place in the everyday's life;
  - to attract under-represented minorities and women to educational opportunities;
  - to promote high energy physics throughout the state by giving lectures at various universities and service clubs.

Education and outreach: Practical implementation

- Each summer, the center, in conjunction with the Quarknet program, sponsors a workshop for high school teachers:
  - In 2008, eleven teachers from throughout the state have attended the two-weeks workshop.
  - In 2009, seven teachers attended one-week workshop; two of them are working on 8-weeks research projects at OU and at OSU.
  - The outreach program aimed at high school teachers involved series of lectures on various aspects of the particle physics, the development of ready-to-use curricula and small scale experiments
  - OCHEP members helped teachers to get and assemble a cosmic rays detectors which have been taken by teachers to their schools.

Education and outreach :Practical implementation

- OCHEP members have presented several public lectures on the Large Hadron Collider throughout the state.
- The center has also sponsored research opportunities for two undergraduate students during the school year and the summer.
- Each year, faculty members meet with students from various high schools including those that have a high percentage of native Americans, and make presentations.

Conclusions: Summary and Outlook

- OCHEP has made outstanding progress in the past 5 years.
- Two permanent program have been established
  - An experimental High Energy physics program at OSU
  - A Tier 2 Grid Computing Facility at OU
- OCHEP has consolidated the HEP research in the state of Oklahoma as a single entity under the umbrella of this Center.
- OCHEP faculty and students are making major impact in HEP research in the international scene.
  - Experimental research at the Fermilab Tevatron and LHC
  - Theoretical research in Higgs boson physics, Unification, Dark Matter, Spersymmetry, Extra Dimensions, Neutrino Physics and Cassimir Forces

Conclusions: Summary and Outlook

- Grid Computing Facility is part of Tier 2 Center and is making major contribution to HEP data analysis
- Education and outreach is making significant impact for Oklahoma High School teachers and students
- The Center is now well prepared to compete for a DOE Center, NSF Frontier Physics Center, NSF Science and Technology Center, and other opportunities as they come up