Fermilab

Particle (I) and Particle Astro (II) Theory

Stephen Parke (and Albert Stebbins)
Fermilab Institutional Review
June 6-9, 2011

Part I: Theoretical Physics Dept.

Stephen Parke
Fermilab Institutional Review
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Fermilab Theoretical Physics

"Fermi National Accelerator Laboratory,"
Unique national center for HEP
Creation of theory group stimulated by R. Wilson, L. Lederman
1970's leadership, Lee, Quigg, Bardeen, Bjorken ...

Vision of Fermilab Theory Group:

- Conduct world-class research
- Proximity to data leads to research synergistic with experiments
- Central national "hub" for university physicists
- Provides connection of laboratory scientific staff to mainstream particle physics
- Strong focus on RA (post-Doc) continuing education, alumni are leaders at many institutions around the world
- Large group: "above threshold" in key research areas excellent RA's in an environment that stimulates research in theory relevant to experiment

Current Fermilab Particle Theory Group Staff (FY 2011)

12+1 Scientists (I-III)

Bill Bardeen	(pheno/formal)
John Campbell	(QCD 1/10)
Marcela Carena	(pheno)
Estia Eichten	(pheno/lattice)
Keith Ellis	(QCD)
Walter Giele	(QCD)
Christopher Hill	(pheno/formal)
Andreas Kronfeld	(lattice)
Joe Lykken	(pheno/CMS)
Paul Mackenzie	(lattice)
Bogdan Dobrescu	(pheno)
Stephen Parke	(pheno)
Chris Quigg	(pheno)

Guest Scientist + Ben Lee Fellow

Boris Kayser (GS)	(pheno)
Graham Kribs (BL fellow)	(pheno)

2 Associate Scientists

Paddy Fox	(9/07)	(pheno)
Roni Harnik	(4/10)	(pheno)

9 Research Associates

Wolfgang Altmannshofer	(pheno)
Johan Alwall	(QCD)
Elvira Gamiz (4/2011)	(lattice)
Joachim Kopp	(Neutrinos)
Ethan Neil	(pheno)
Adam Martin	(pheno)
Nausheen Shah	(pheno)
Gerban Stavenga	(QCD)
Ciaran Williams	(QCD)
Felix Yu (starts 8/2011)	(pheno)

Core strengths of the Fermilab Theory Group

Perturbative QCD : Next-to-Leading Order Pert. QCD, MCFM, TESS (Ellis, Giele, Campbell)

Neutrinos : Neutrino Masses and Mixing Angles, Leptogenesis UHE Cross-sections, Anomaly mediated processes (Kayser, Parke, Fox, Harnik, Hill, Quigg)

Beyond Std Model : Higgs, SUSY, Extra Dims, Strong Dynamics,… (Dobrescu, Carena, Eichten, Fox, Harnik, Hill, Lykken, Quigg)

Lattice Hadronic Flavor Physics, Matrix Elements, Masses (Mackenzie, Kronfeld, Eichten)

Formal Physics: New Applications of Anomalies, Chiral Dynamics, Gravitational (Bardeen, Hill)

People and the Lab Mission:

Perturbative QCD : Ellis, Campbell, Giele,

Energy Frontier

Tevatron, LHC: CMS and Atlas, LHCb, ILC, MC

SM and BSM Model Bldg

Bardeen, Carena, Dobrescu,
Eichten, Fox, Hill, Lykken, Parke,

Neutrinos : Hill, Kayser, Parke, Quigg

Project-X, NOVA, LBNE, MiniBooNE, ...,

Intensity Frontier

Lattice Eichten, Kronfeld, Mackenzie

Flavor physics, Project-X LS computing

Mentorship of Research Associates

We attract bright young RA's and provide them with excellent career development opportunity through collaboration with senior theorists.

Examples of Fermilab RA's who have recently received Assistant Professorships:

Richard Hill (U. of Chicago)

Eduardo Ponton (Columbia U.),

John Campbell (Glasgow -> Fermilab),

Mu Chun Chen (U.C. Irvine),

Elvira Gamiz (-> U. Granada)

Jay Hubicz (Syracuse U.),

Olga Mena (IFIC, Valencia, Spain),

Peter Skands (CERN staff member),

Giulia Zanderighi (lecturer, Oxford),

Jose Santiago (Univ. Granada) winner 2010 IUPAP Young Scientist Prize

National and International Community Service

Cern Scientific Policy Committee R. K. Ellis

American Physical Society

- DPF: Lykken (Past Chair), Kayser (Chair), Kronfeld (ExecCom), Carena (NomCom, Outreach)
- APS: Carena (CISA, Gen'l Councilor, Exec Board, Cmtes)

Agency advisory committees

- HEPAP: Lykken
- P5: Carena, Kayser, Lykken
- USQCD: Mackenzie (ExecCom), Kronfeld (SPC Chair)
- Other subpanels: Kayser, Lykken, Carena, ...

Institutional advisory committees

- Aspen Center for Physics: Carena, Lykken
- KITP Board: Lykken
- Fermilab PAC: Parke
- DUSEL PAC: Kayser

...

Participation in Laboratory Future Planning

Project-X Golden Book (authorship & editing)

Carena, Eichten, Hill, Lykken, Parke, Kayser …

Tevatron Run-III Letter of Intent

Carena, Dobrescu, Eichten, Ellis, Hill …

Extreme Beams Lecture Series

DeGouvea (sabbatical visit and former RA) …

Muon Collider – physics, detector studies, etc. and Theory Lepton Collider Discussion Group

Eichten , Hill …

• • • • •

Recent Conferences and Workshops

(co) hosted by members of the Fermilab Theory Group

Muon Collider Workshop (2011) Eichten & Hill

Joint Fermilab-CERN Hadron Collider Physics Summer School (2006 - 2010) Fox, Kronfeld, Dobrescu, Carena

Neutrino 2008, Christchurch, New Zealand Parke

Hadron Collider Physics Conference (2008, Galena, Illinois) Ellis

Quarkonium Working Group workshop, Fermilab, 2010 Eichten, Kronfeld

Int'l Neutrino Summer School, 3rd since 2006 Kayser, Parke

Int. Organizing Committee of the Worldwide Study of Physics and Detectors for Future Linear e+e- Colliders, Kronfeld

...

Formal Visitor Programs:

The Fermilab Theory Group Regular Visitors Programs

approx. 30 Academic Visitors per year

Summer Visitors Program

typically 10 - 15 Summer Visitors (2007)

Latin Scholars Program

typically 2 per year (for 6 month each)

Ben Lee Fellows (formerly "Frontier Fellows")

28 Fellows since inception (1998)

Ben Lee Fellows :

Vernon Barger (10-12/98)

Howard Haber (9-12/98)

Stuart Raby (2-6/99)

Wu-Ki Tung (2-6/00)

Stefan Pokorski (9-12/00)

Jo Anne Hewett (9-12/00)

Steve Gottlieb (9-6/02)

Ulrich Baur (2-4/02)

Scott Willenbrock (7-12/02)

Peter Zerwas (9-11/04)

Manny Paschos (10/04 –12/04)

Sherwin Love (1/05 –04/05)

Frank Petriello (spring 2006)

Matthias Neubert (8/07 – 11/07)

Graham Kribs (2011)

Thomas Appelquist (10-12/98)

Pierre Ramond (6/99; 5/00)

Steve Ellis (3-6/00)

Moshe Moshe (3-9/00)

Mariano Quiros (9-12/00)

Alexei Yu. Smirnov (4/01)

Ken Lane (9-2/02)

Eric Braaten (10-12/02)

Aida El-Khadra (7-12/02)

Tao Han (10/04 –12/04)

Edward Boos (10/04 –12/04)

Paul Langacker (9/05 –2/06)

Mariano Quiros (9/07 – 12/07

Gustavo Burdman (2009)

Summer Visitors Program

2009	2010
Partha Konar	Anjan Giri
Silvia Pascoli	Tuhin Roy
Jason Gallicchio	Satya Nandi
Satya Nandi	Tania Robens
Ulrich Haisch	Jure Zupan
Kirill Melnikov	Roger Rosenfeld
Giulia Zanderighi	Raj Gandhi
Elvira Gamiz	Ulrich Nierste
Hiroshi Nunokawa	Gabriela Barenboim
Renata Z Funchal	Yurii Shylnov
John Campbell	Olga Mena
Werner Rodejohann	Jonathan Rosner
Enrique Fernandez-Martinez	Marta Losada
Greg Mahlon	Hsin-Chia Cheng
Nuria Rius	Jay Wacker

Fermilab Fellows [graduate students]: (1yr)

5 Shared with **Astros**

2010/11 – Chris Bouchard - UIUC
Alejandro de la Puente – Notre Dame Univ.
Gordon Krnjaic – John Hopkins Univ.
Tim Linden – UC, Santa Cruz (Astro)
Yuhsin Tsai – Cornell Univ

2011/12 – Heribertus Hartanto - Florida State
Christopher Kelso - Chicago (Astro)
Azadeh Moradinezhad Dizgah - Buffalo (Astro)
Reinard Primulando - William & Mary
Chiu-Tien Yu - Wisconsin

Latin Scholars Program

2011 – Maria Pia Zurita,
Univ. de Buenos Aires
Carlos Arguelles Delgado,
Pontificia Univ. Catolica del Peru

2010 - Pedro Accioly Nogueira Machado,
Univ. de Sao Paulo, Brazil
Alfonso Diaz Furlong,
Benemerita Univ. Autonoma de Puebla, Mexico

2009 - Roger Jose Hernandez Pinto, CINVESTAV, Mexico
Mauricio Ramirez, Pontificia Univ. Catolica del Peru

2008 - Jose Francisco Zurita, Univ. de Buenos Aires, Argentina

... since 2002

Theory Group Sponsored Seminar/Lecture Series

Joint Experimental-Theoretical Seminar
(typically 52 per year). Campbell, Giele

http://theory.fnal.gov/jetp/index.html

Theory seminar (typically 45 per year)
Fox, Harnik, Kopp

http://theory.fnal.gov/seminars/seminars.html

Special Seminars: e.g., Semi-Annual Joint Theory-CMS Seminar

Academic Lectures (for grad students, RA's, et.al.)

Organization: Kronfeld, Carena, Quigg, …
Lectures: Eichten, Quigg, Kayser, Parke, Ellis, Giele, Kronfeld;

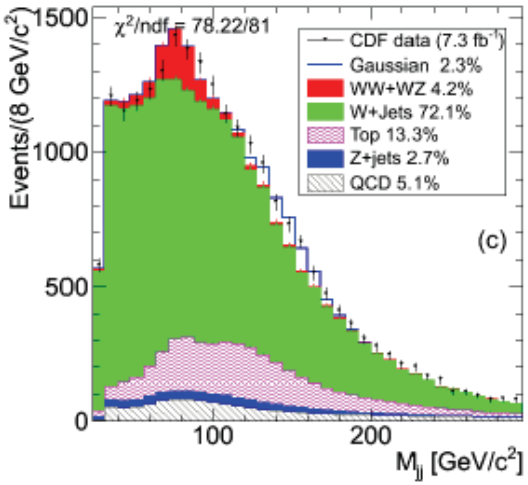
Theory Group Member High Honors

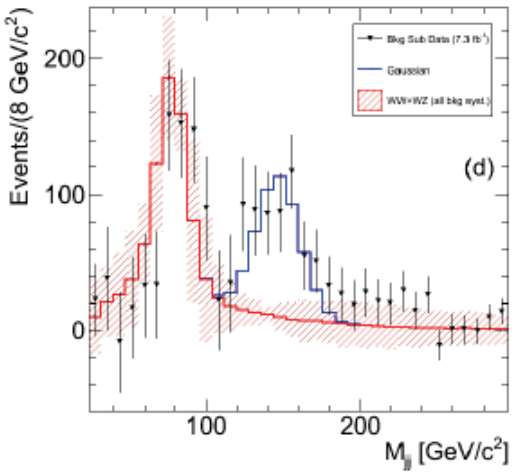
J.J. Sakurai Prize:	2010	E. Eichten, C. Quigg
	2009	R.K. Ellis
	1996	W. A.Bardeen
National Academy of Science:		W. A. Bardeen
American Academy of Arts and Sciences:		W. A. Bardeen
Fellow of the Royal Society of London:		R. K. Ellis
Alexander Von Humboldt Foundation:		
Senior Scientist Award:	2011-2015	M. Carena
	2007-2011	C. Quigg

Our Research

(just a taste)

CDF Bump:

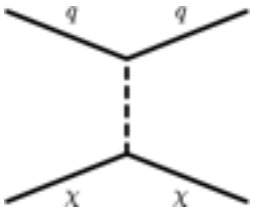




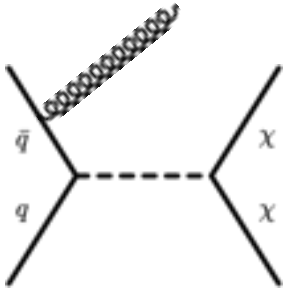
- Technicolor at the Tevatron.
  By Estia J. Eichten, Kenneth Lane, Adam Martin.
  [arXiv:1104.0976] FERMILAB-PUB-11-165-T (Apr 2011) 5p.
- Weak-triplet, color-octet scalars and the CDF dijet excess.
  By Bogdan A. Dobrescu & Gordan Z. Krnjaic.
  [arXiv:1104.2893] FERMILAB-PUB-11-141-T (Apr 2011) 14p.
- Light Z' Bosons at the Tevatron.
  By Matthew R. Buckley, Dan Hooper, Joachim Kopp, Ethan Neil.
  [arXiv:1103.6035] FERMILAB-PUB-11-154-A-T (Mar 2011) 12p.
- W plus two jets from a quasi-inert Higgs doublet.
  By Qing-Hong Cao, Marcela Carena, Stefania Gori, Arjun Menon, Pedro Schwaller, Carlos E.M. Wagner, Lian-Tao Wang.
  [arXiv:1104.4776] EFI-11-11 (Apr 2011) 15p.
- .....

Dark Matter at the Tevatron

Yang Bai, Patrick Fox, Roni Harnik



$$\sigma_{\rm DD} \sim g_\chi^2 g_q^2 \frac{\mu^2}{M^4}$$

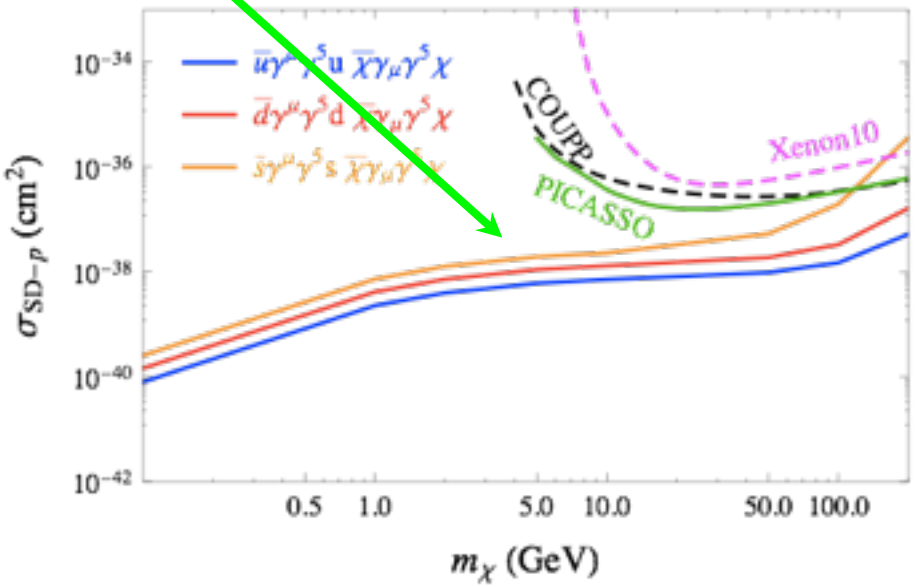


Mono-jet + $\not{E}_T$

New idea: use CDF's monojet search ($1fb^{-1}$) to constrain pair-production of light WIMPS

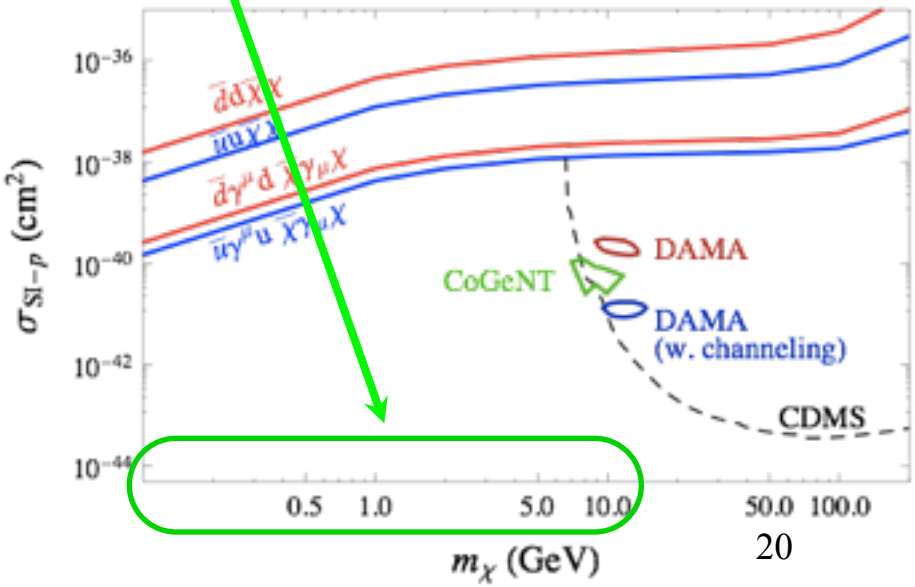
World's best limits !!
up to ~200 GeV

Spin-dependent



World's absolute best limits
at low mass !!

Spin-independent



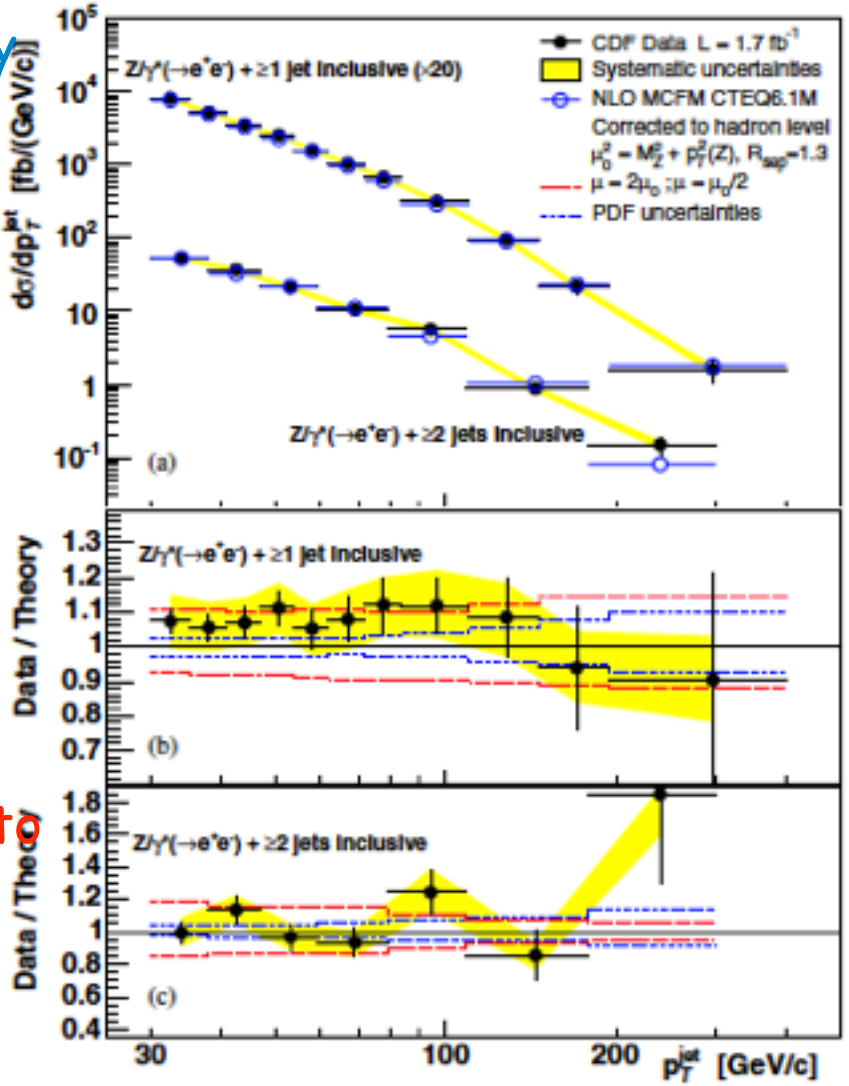
Perturbative QCD: MCFM

Campbell
Ellis

Parton level Monte Carlo, includes many SM processes at NLO.

- used extensively at the Tevatron.

Example: Successful description of Tevatron Z + 1 and 2 jet production



Instrumental in studies of:

All important backgrounds to a Higgs signal

- diboson production
- W+jets
- W/Z+heavy flavor
- single top production

Recent developments in MCFM

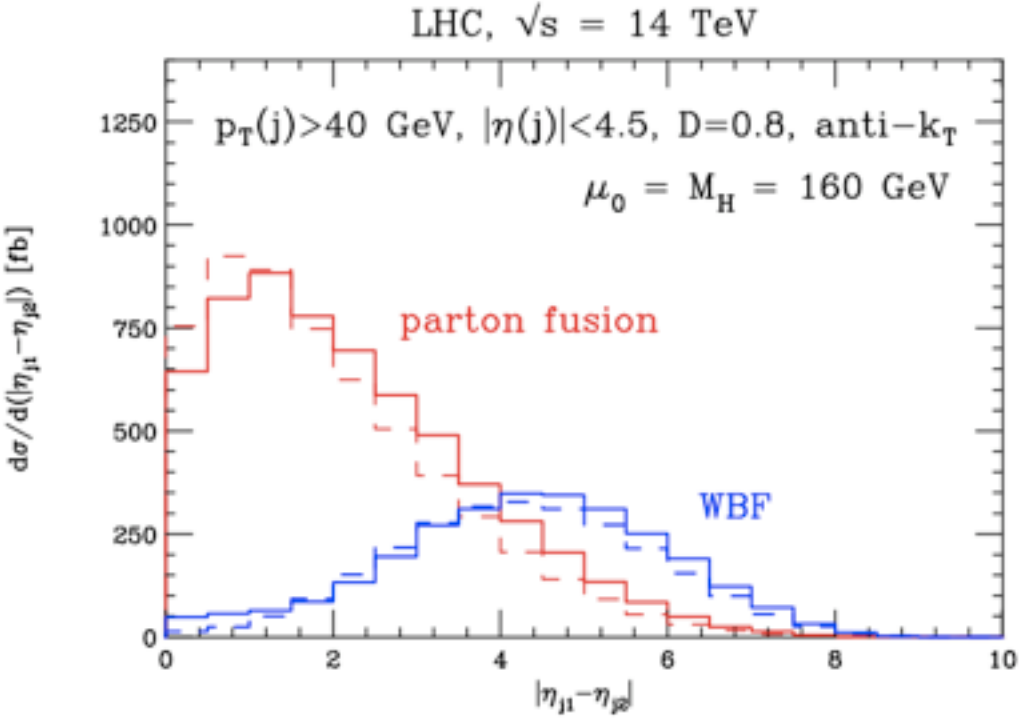
New processes included at NLO:

- Higgs + 2 jet production
- top-antitop production with decay
- t-channel single top production

Example: predictions for Higgs + 2 jets via parton fusion, necessary for:

1. setting best Tevatron high mass Higgs boson limits.

2. extracting Higgs couplings at the LHC.

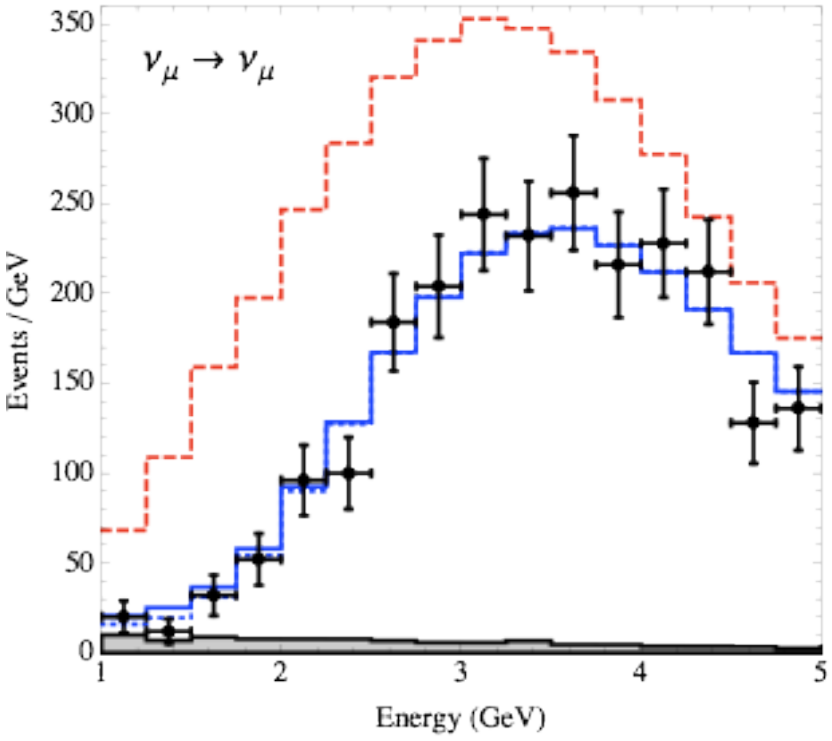


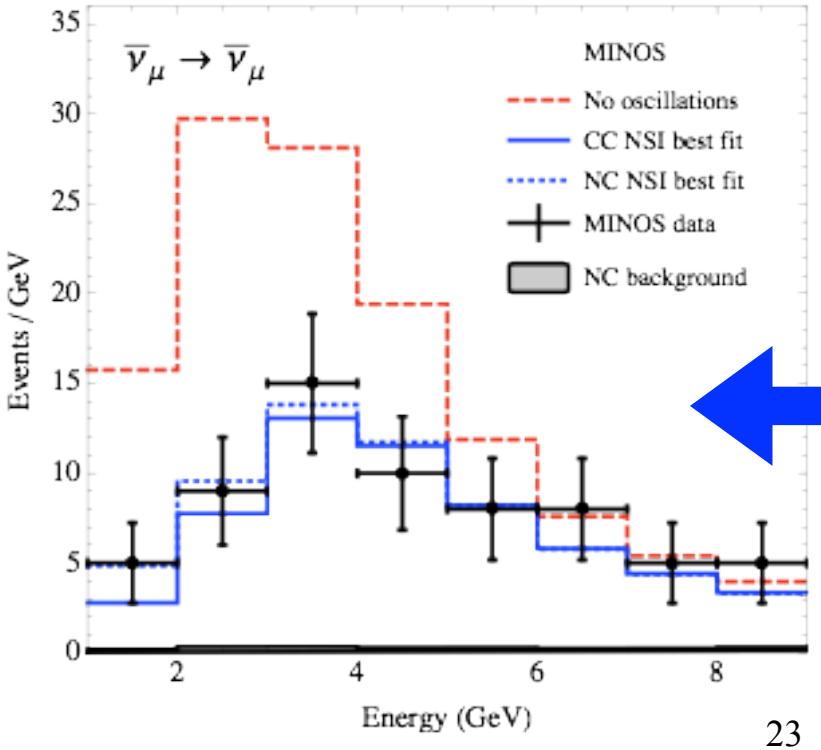
jet-jet rapidity separation in different Higgs production processes

Theoretical Neutrino Physics

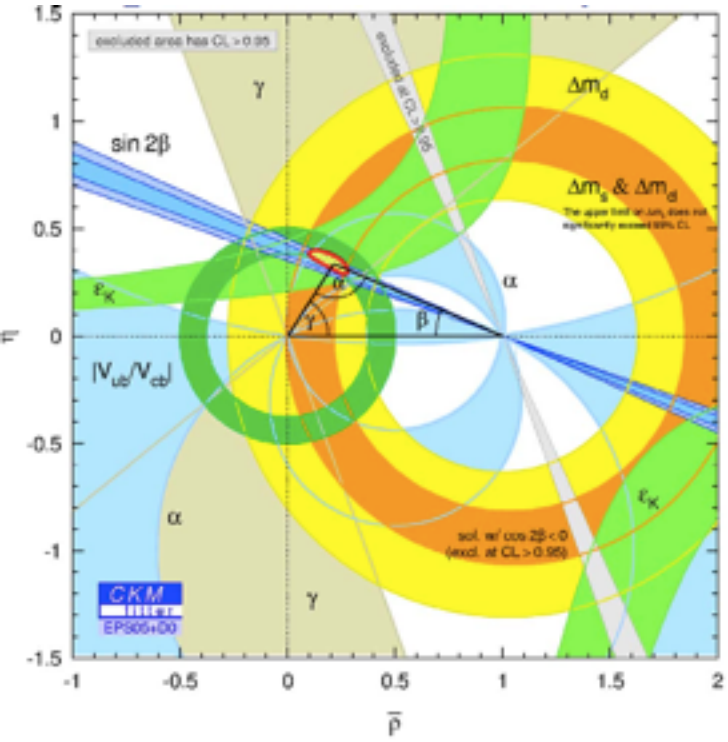
Fermilab theorists provide theoretical support for both current and future Fermilab Neutrino Program.

Is Minos Seeing New Physics? (Parke, Kopp, Machada)





Lattice QCD Recent Achievements



About half of the best constraints on the CKM matrix (such as those for ρ and η) require lattice QCD calculations.

CDF's first publication of B_s-$B_s$bar mixing employed results from a review by Fermilab postdoc Masataka Okamoto to determine $|V_{ts}|$.

- Fermilab's lattice group has undertaken a broad program to determine almost all of the CKM matrix elements through the decay constants of the D, D_s, B, and B_s mesons, the semileptonic decays $B \to \pi l \nu$, $B \to D l \nu$, $B \to D^* l \nu$, $D \to K l \nu$, $D \to \pi l \nu$, $K \to \pi l \nu$, and the mixings of the B and B_s mesons.
- Recent results:
  - $B \to D^* l \nu \Rightarrow |V_{cb}| = (38.7 \pm 0.9_{exp} \pm 1.0_{theo}) \times 10^{-3}$. Most accurate exclusive determination. Phys. Rev. D79:054507, 2009.
  - $B \to \pi l \nu \Rightarrow |V_{ub}| \times 10^3 = 3.38 \pm 0.36$. Most accurate exclusive determination. Phys. Rev. D79:014506, 2009.
- Paper on heavy-light decay constants now being completed.

Lattice QCD - USQCD and the National Program

USQCD was formed in 1999 to organize hardware and software infrastructure for lattice calculations. It represents almost all lattice gauge theorists.

- USQCD oversees grants for software and hardware
  - SciDAC-2: community software.
  - LQCD-ext: dedicated capacity computing clusters at Fermilab and JLab.
  - Incite: capability computing at leadership class centers at ALCF and ORNL.
- Fermilab provides leadership to USQCD.
  - Paul Mackenzie has served on the Executive Committee of USQCD from its inception in 1999, and has been Chair since 2009.
  - Andreas Kronfeld served on the Scientific Program Committee for six years, and was its Chair in 2006 and 2007.
  - James Simone heads the department in CD that designs, builds, and operates LQCD & cosmology clusters.
- The Fermilab Lattice and MILC Collaborations mount the largest US effort in lattice flavor physics.

Lattice QCD - Ongoing progress

Experimental bounds on CKM matrix elements require 0.1% precision in lattice calculations. (Currently 1-5%.) Big opportunities and challenges ahead . Requires 1,000 fold increase in power foreseen in the "Exascale Era." Exascale computing expected to be disruptively different from today's. Much work to do.

Precision goals in sample calculations

quantity	CKM element	current precision (%)	1-2 years	3-4 years
$B \to D^* l \nu$	V_{cb}	2.6	1.7	0.8
$B \to \pi l \nu$	V_{ub}	9.0	5.5	2.5
f_B	V_{ub}	4.0	2.0	1.0
f_{Bs}	(BSM)	3.1	1.7	0.9
$f_{Bs}/f_B\ (B_{Bs}/B_B)^{1/2}$	V_{ts}/V_{td}	1.8	0.9	0.3

Estimates from talks of Claude Bernard and Junko Shigemitsu at "Lattice Meets Experiment 2010" at Fermilab, April 26-27, 2010, http://www.usqcd.org/lattice-experiment2010/ , and from Paul Mackenzie.

Goal: reduce uncertainties by as much as a factor of two.

Future set of calculations with dramatically improved discretization errors and charmed sea in preparation.

We have not hired a lattice Associate Scientist since 1990. Crucial to redress this soon.

Part II:

Part II: Theoretical Astrophysics Group

Albert Stebbins
Fermilab Institutional Review
June 6-9, 2011

Theoretical Astrophysics Group

- What we do
- Who we are
- Research Associates (shortage)
- Science
  - Highlights
    - Dark Matter: Hints of Detection
    - Cosmological Computing

What We Do

- **Environment:** Foster exciting, innovative, focused intellectual environment.
  - Mix of staff scientists, postdocs, and long term visitors/students.
  - Seminars, workshops, short term visitors.
  - Individual participation in external collaborations and conferences.

- **Productivity:** produce new scientific results, support lab programs/projects.
  - Scientific publications.
  - New projects (played important role in SDSS I&II, SNAP, DES, Auger)

- **Citizenship:** support of scientific infrastructure (lab/Chicagoland/U.S./world)
  - Education/Outreach:
    - training (RAs),
    - students (U.C.,Brinson, new DOE program),
    - teaching (U.C., summer schools),
    - books (textbooks, popular science)
    - public lectures.
  - Quality Control: Refereeing/Editing, Grant/Program Reviews
  - Making the Future: for Fermilab and for U.S. Cosmology.

Current Scientific Staff

4 Scientists (Associate, I,II,III)

Scott Dodelson (CMB, modified gravity, lensing, ...)

Joshua Frieman (Dark Energy, LSS, inflation, ...)

Nick Gnedin (numerical cosmology)

Dan Hooper* (DM models and predictions)

Albert Stebbins (lensing, CMB, LSS)

*Associate Scientist Hooper most probably promoted to Scientist I in FY11.

1 David N. Schramm Fellow

Matt Buckley (DM models and predictions)

3 regular Research Associates

Robert Feldmann (numerical cosmology)

Dave Johnston (weak lensing ⇒ leaving Fall 2011)

Douglas Spolyar (DM predictions)

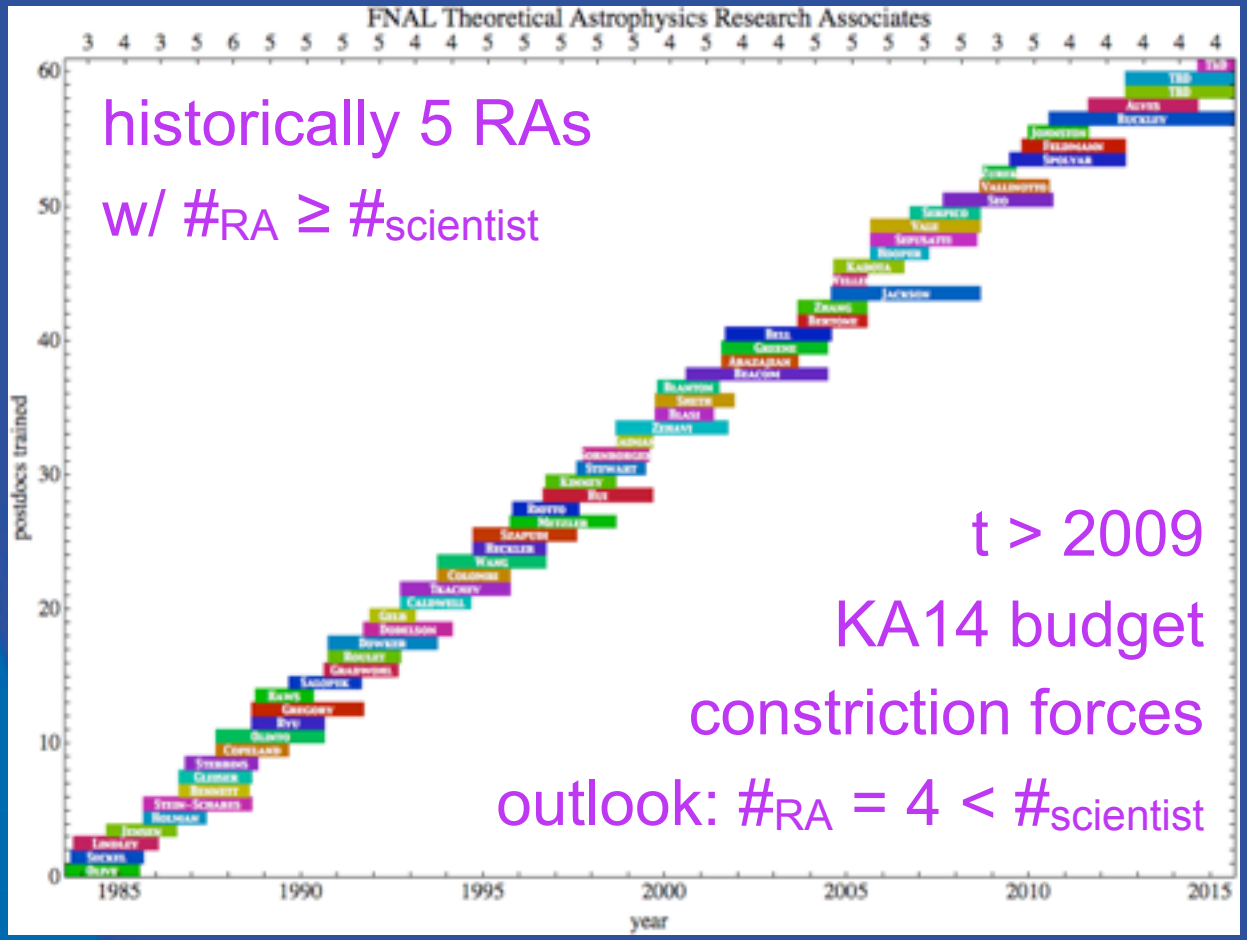
Daniele Alves (DM models predictions ⇐ arriving Fall 2011)

Visitors:

numerous short term visitors

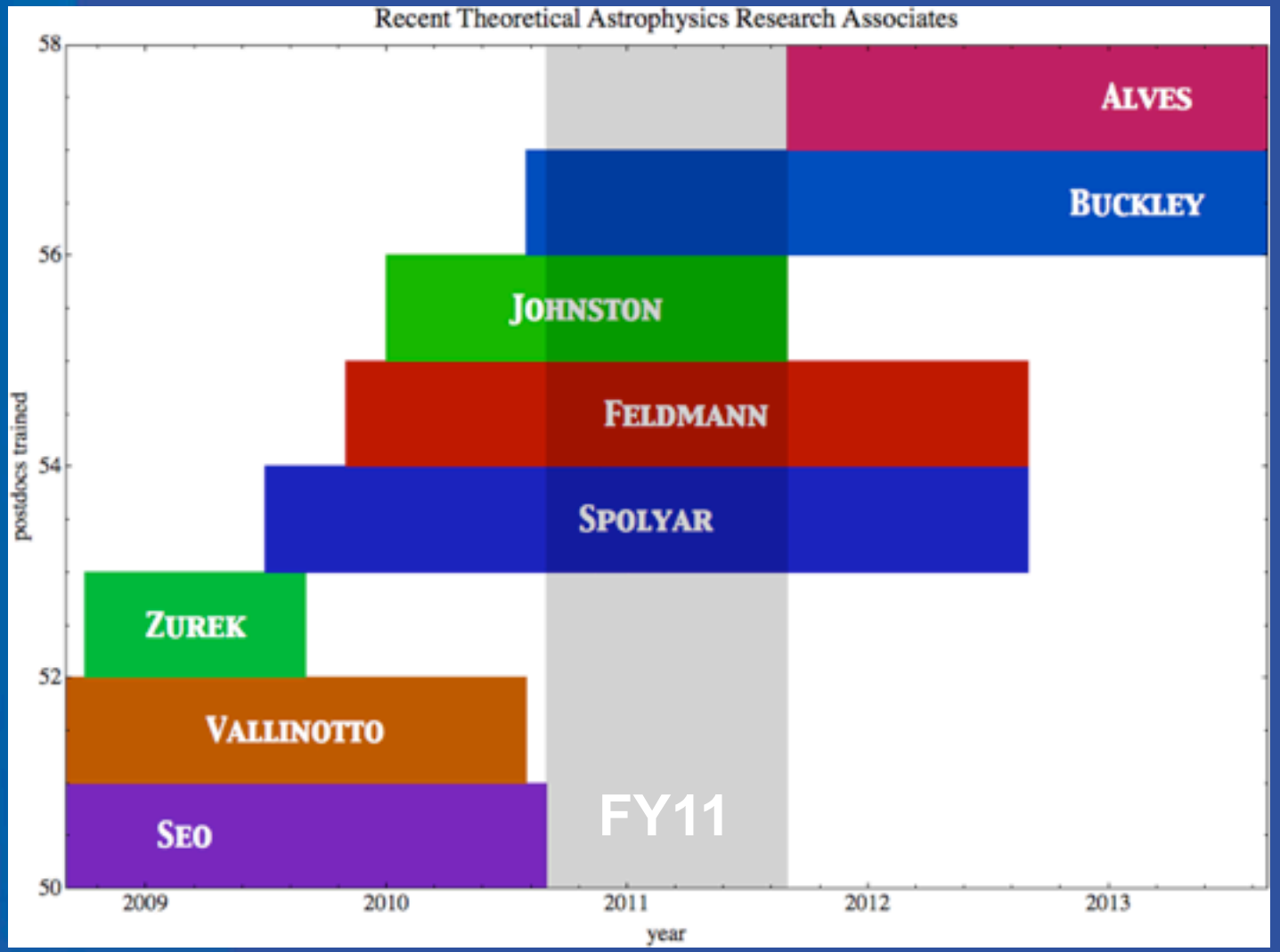
Peter Meszaros (Penn State Fall 2010)

Theoretical Astrophysics Research Associates



1st priority: would like to at least restore 5th RA.

Recent Past/Present/Future RAs



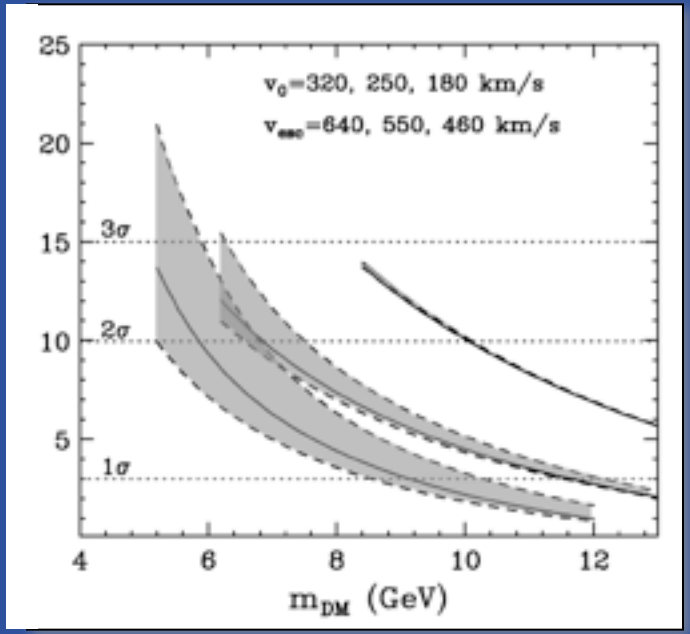
Science

- Papers
  - 50 since May 2010 (already cited 353 times)
- Major Topics
  - Dark Matter
    - Models / Observational Predictions / Hints of Detection!
  - Dark Energy
    - Supernovae Type Ia / Weak Lensing
    - Lemaitre-Tolman-Bondi models (mostly ruled out)
    - Development of 21cm large scale structure method
    - Gearing up for Dark Energy Survey
  - Cosmological Simulations
    - Reionization / Realistic Galaxies
- Collaboration
  - increased collaboration w/ Particle Theory Group
  - continued strong ties w/ rest of FNAL Cosmic Frontier
  - continued strong ties UChicago incl. Ph.D. students

HIGHLIGHTS

Dark Matter: DAMA/COGENT Direct Detection?
Key Test: COGENT Annual Modulation (Hooper)

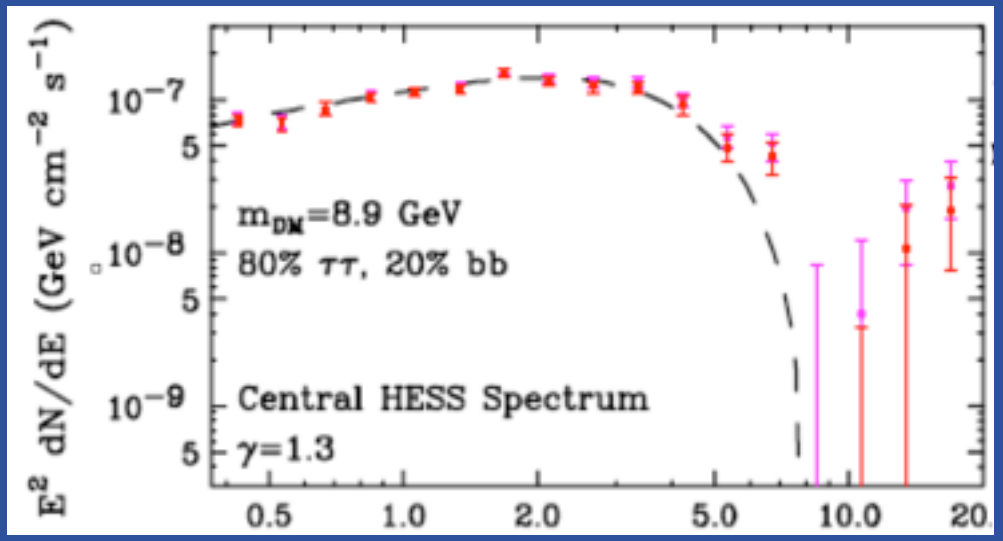
- The published CoGeNT excess consists of ~10^2 events, from winter season (56 days); insufficient to observe any annual variation in rate
- If CoGeNT and DAMA are observing elastically scattering dark mater, we predicted a ~5-15% annual modulation at CoGeNT (10-30% higher rate in summer than in winter), which should be observable at the ~2σ level with one year of data from CoGeNT
- The CoGeNT collaboration recently announced the observation of evidence for modulation; favored over the null hypothesis at 2.8σ
- Observed amplitude (16.6±3.8%), phase (347±29 days), and period (maximum at April 16±12) are consistent with our predictions for a light, elastically scattering dark matter particle



Kelso, Hooper, arXiv:1011.3076; Hooper, Collar, Hall, McKinsey, PRD, arXiv:1007.1005

Dark Matter: FERMI Galactic Center Indirect Detection? (Hooper)

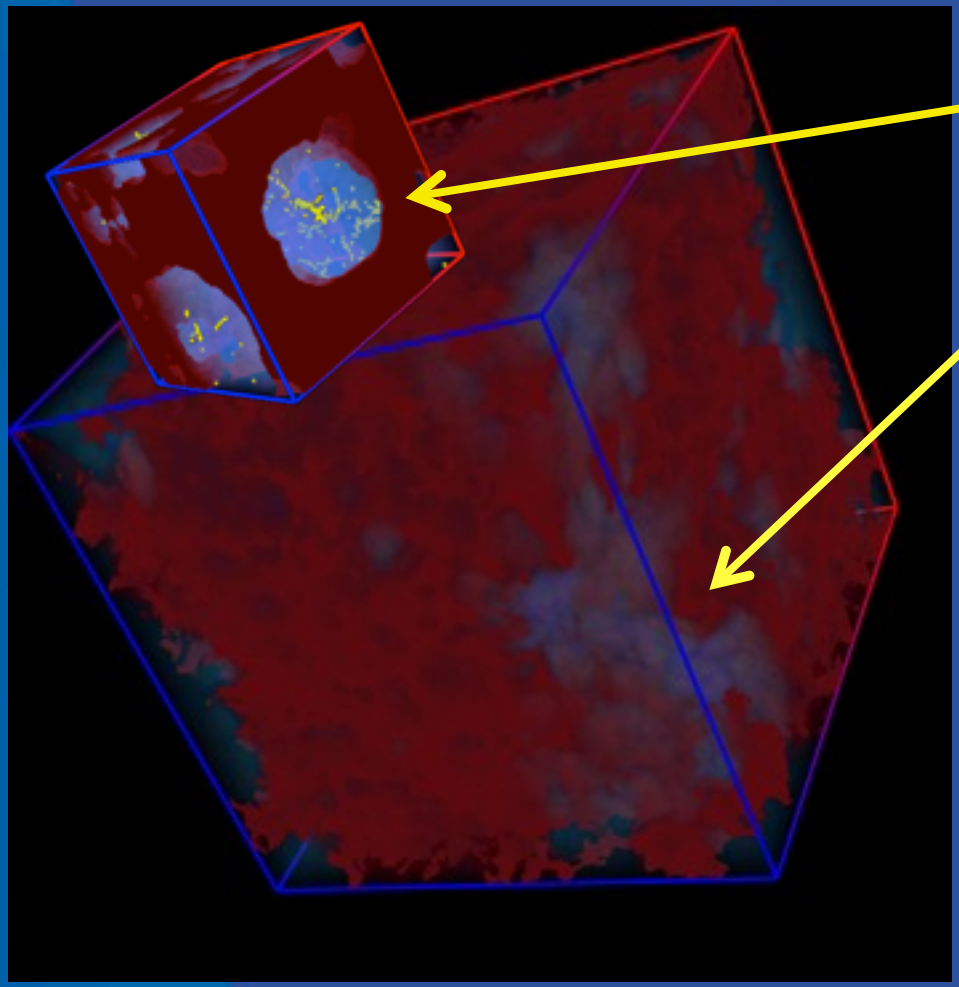
The spectral shape of the FERMI excess gamma rays can be well fit by a dark matter particle with a mass in the range of 7 to 10 GeV (*similar to that required by CoGeNT and DAMA*), annihilating primarily to $\tau^+\tau^-$ (possibly among other leptons)



The angular distribution of the signal is well fit by a flux distribution that scales with $r^{-\alpha}$, with α=2.36 to 2.66; if interpreted as dark matter, this implied an inner profile $\rho(r) \sim r^{-\gamma}$, with γ=1.18 to 1.33 (*in good agreement with the best fit to the Via Lactea simulation, for example*)

The normalization of the signal requires the dark matter to have an annihilation cross section (to $\tau^+\tau^-$ and hadronic channels) of $\sigma v = 4.6\times10^{-27}$ to 5.3×10^{-26} cm^3/s (*in agreement with the value of 3×10^{-26} cm^3/s predicted for a simple thermal relic*)

COSMIC REIONIZATION (Gnedin)

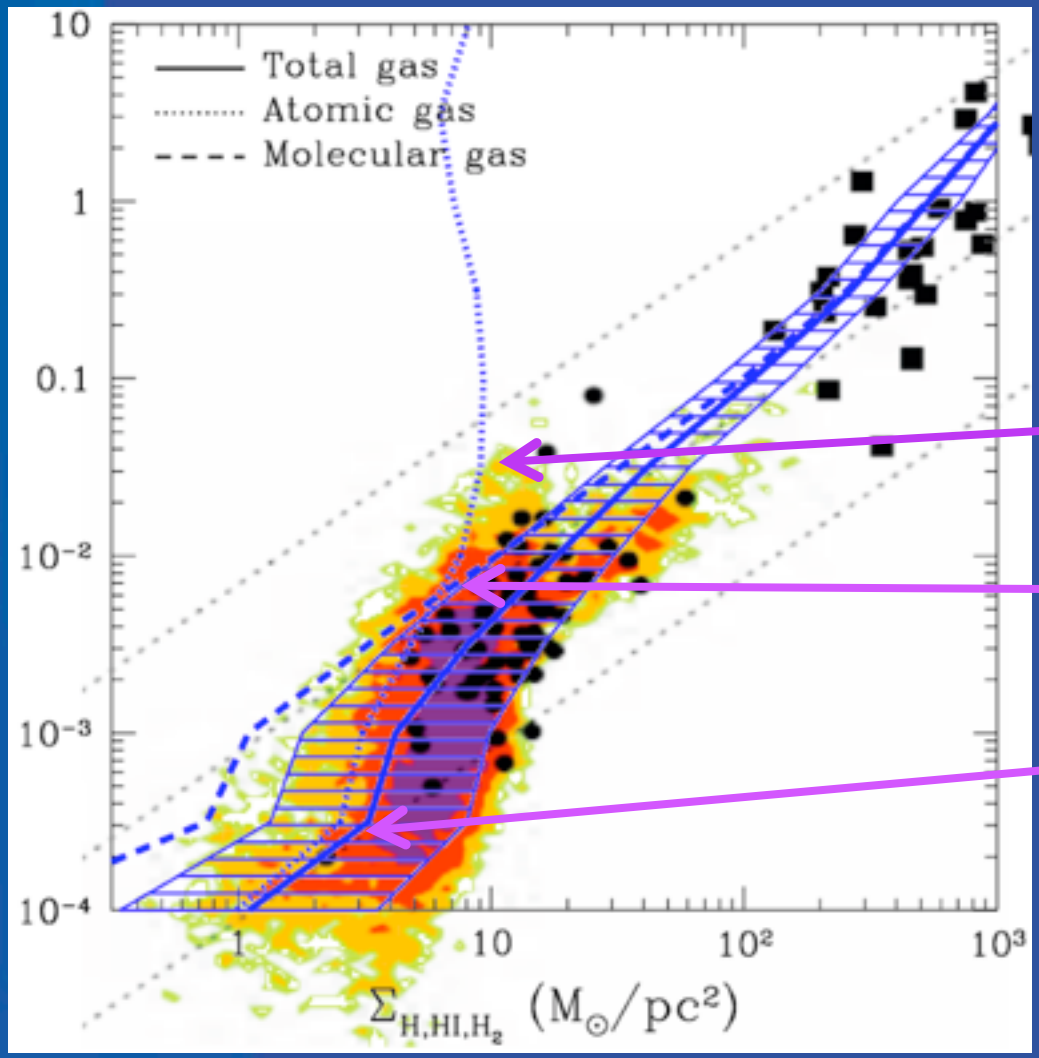


20thC codes
- 4 months @ NCSA.

21stC codes
w/ AMR:
- 2 days @ FNAL/Chicago Cosmology Cluster
- 2.5x larger box

REALISTIC GALAXIES (Gnedin)

- **Major advance in modeling galaxies properties, such as multi- component gas and star formation**



Atomic gas

Molecular gas

All neutral gas

Summary:

- Both groups are essential for the intellectual vitality of the Lab and is a national resource. Their research is well aligned with the experimental program and is of world class quality.
- Fermilab Fellows Program is a resounding success so far in both groups.
- Theoretical Particle Physics Dept. is adjusting to W. Bardeen's retirement. When can we hire an Ass. Scientist in Lattice and/or Intensity Frontier ?
- Theoretical Astrophysics Group: Priority is to return to 5 RA's from current 4.

Competitive Review is July 25-27, 2011:
Documentation is due next week !!!

Fermilab Theoretical Physics

Unique national center for HEP

Creation of the Theory group stimulated by R. Wilson, L. Lederman
1970's leadership: Lee, Quigg, Bardeen, Bjorken ....

Vision of Fermilab Theory Group

- Conduct world-class research
- Proximity to data leads to research synergistic with experiments
- Central national "hub" for University Physicists
- Provides connection of lab scientific staff to mainstream particle physics
- Strong focus on RA (post-doc) continuing education
  - alumni are leaders at many institutions around the world
- Large group: "above threshold" in key research areas
  - excellent RA's in an environment that stimulates research in theory relevant to experiment