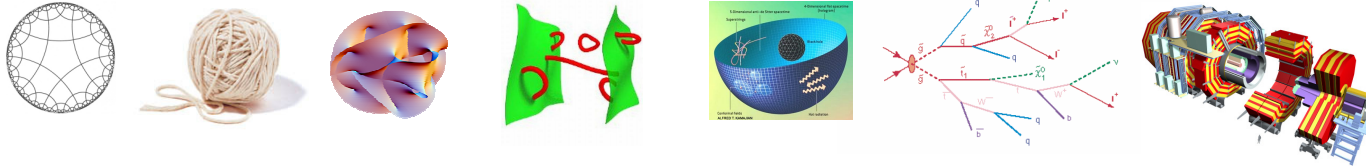


Super-Space: The Final Frontier

Scott Thomas



- High Energy Physics at Rutgers



- Story of Super-Space



- Some of What We are Doing at Rutgers to Explore Super-Space

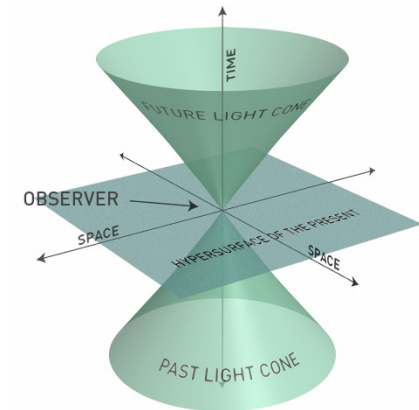


(Starting from the Physics that Any Good Undergraduate Knows)

Space and Time

Space and Time Appear to be Unrelated

But there is an Underlying Geometry that Generalizes and Unifies them into Space-Time



Rotation

$$R_{ij} \quad [R_{ij}, R_{jk}] = R_{ik}$$

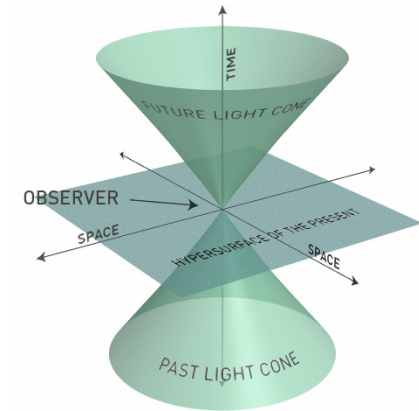
Translations

$$T_i \quad [T_i, T_j] = [T_i, R_{jk}] = 0$$

Space and Time

Space and Time Appear to be Unrelated

But there is an Underlying Geometry that Generalizes and Unifies them into Space-Time



Rotation

R_{ij}

$$[R_{ij}, R_{jk}] = R_{ik}$$

Translations

T_i

$$[T_i, T_j] = [T_i, R_{jk}] = 0$$

Space-Time Rotations

L_{ij}

$$[L_{ij}, L_{jk}] = - R_{ik}$$

Our Understanding of Space-Time Geometry -

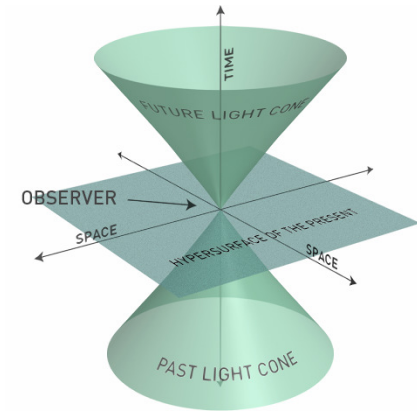
Foundation of Modern Fundamental Physics ...

Consequences: $v \leq c$ Universal Speed Limit

Space and Time

Space and Time Appear to be Unrelated

But there is an Underlying Geometry that Generalizes and Unifies them into Space-Time



Rotation

R_{ij}

$$[R_{ij}, R_{jk}] = R_{ik}$$

Translations

T_i

$$[T_i, T_j] = [T_i, R_{jk}] = 0$$

Space-Time Rotations

L_{ij}

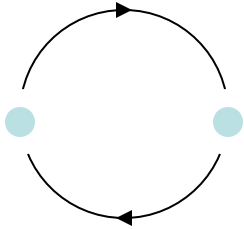
$$[L_{ij}, L_{jk}] = - R_{ik}$$

Our Understanding of Space-Time Geometry -

Foundation of Modern Fundamental Physics ...

Theorists Love to Generalize and Find Unifying Principles

Space-Time Properties of Particles



P: $x_1, x_2 \leftrightarrow x_2, x_1$

Exchange of Two Identical Particles

Probability(x_1, x_2) = Probability(x_2, x_1)

In Quantum Theory ...

$$|\psi(x_1, x_2)| = |\psi(x_2, x_1)|$$

$$P^2 \psi(x_1, x_2) = \psi(x_1, x_2)$$

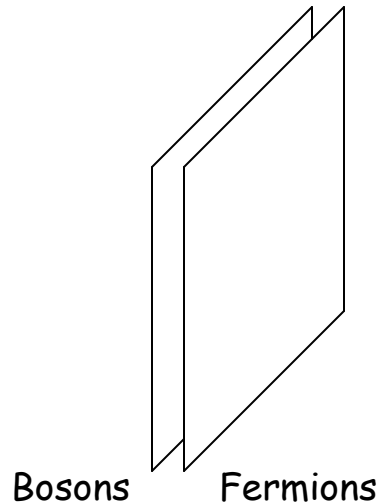
$$\psi(x_1, x_2) = (+, -) \psi(x_2, x_1)$$

(Demonstrate Properties
of Bosons and Fermions
under Full Rotation)

+ Bosons

- Fermions

Super-Space



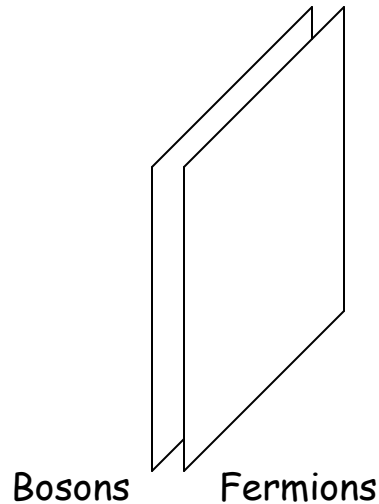
Introduce a Discrete
SuperDimension of Super-Space

Bosons Inhabit One Side of Super-Space and Fermions the Other

Rotation	R_{ij}	$[R_{ij}, R_{jk}] = R_{ik}$
Translations	T_i	$[T_i, T_j] = [T_i, R_{jk}] = 0$
Space-Time Rotations	L_{ij}	$[L_{ij}, L_{jk}] = - R_{ik}$
SuperTranslation	Q_α	$[Q_\alpha, Q_\beta] = T_i$

Generalizes the Notion of Space-Time \rightarrow Super-Space-Time and
Unifies Description of Bosons and Fermions (And it is Beautiful)

Super-Space



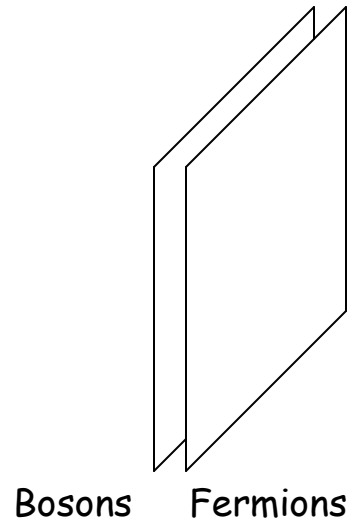
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Rotation	R_{ij}	$[R_{ij}, R_{jk}] = R_{ik}$
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Space-Time Rotations	L_{ij}	$[L_{ij}, L_{jk}] = - R_{ik}$
SuperTranslation	Q_α	$[Q_\alpha, Q_\beta] = T_i$

Generalizes the Notion of Space-Time \rightarrow Super-Space-Time and
Unifies Description of Bosons and Fermions (And it is Beautiful)

Super-Space

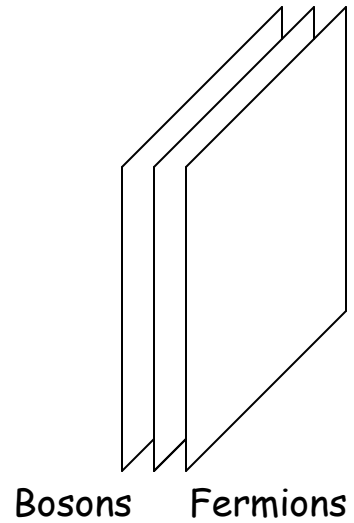


$N = 1$

Generalize Superspace to Multiple
Discrete SuperDimensions

Relates One Boson \leftrightarrow One Fermion

Super-Space

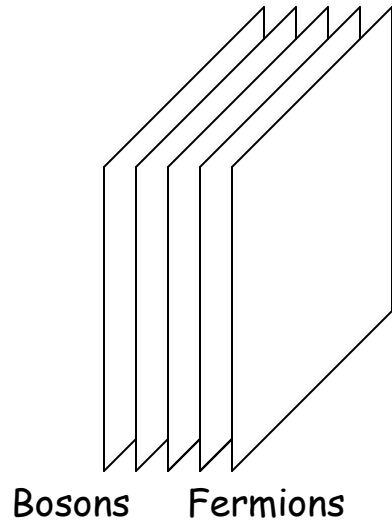


$$N = 2$$

Generalize Superspace to Multiple
Discrete SuperDimensions

Relates Two Bosons \leftrightarrow Two Fermions

Super-Space

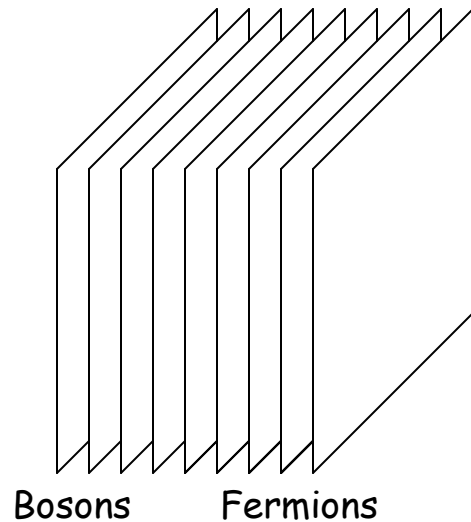


$$N = 4$$

Generalize Superspace to Multiple
Discrete SuperDimensions

Relates Four Bosons \leftrightarrow Four Fermions

Super-Gravity



$$N = 8$$

Generalize Superspace to Multiple Discrete SuperDimensions

Relates Eight Bosons \leftrightarrow Eight Fermions

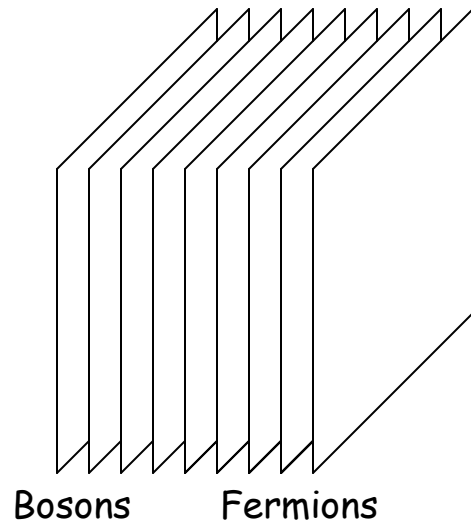
Maximal Super-Space:

All Particles are Related to the Graviton

Generalizes the Notion of Space-Time \rightarrow Super-Space-Time and Unifies Description of Bosons and Fermions and Unifies Gravity with the Everything

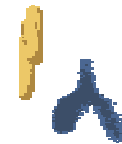
(And it is Gorgeous)

Perturbative Quantum Super-Gravity



$N = 8$

Introduce Strings as Fundamental
Stability of Strings \rightarrow Super-Space



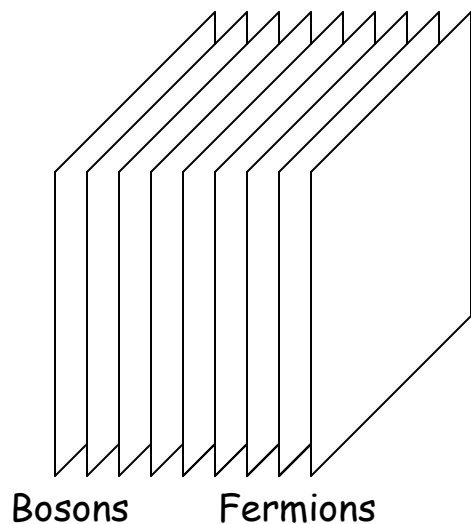
Super-String Theories:

All Particles are Modes of a Single Type
of String in Super-Space-Time

Generalizes the Notion of Space-Time \rightarrow Super-Space-Time and
Unifies Description of Bosons and Fermions and Unifies Gravity
with the Everything and is a Consistent Perturbative
Quantum Theory

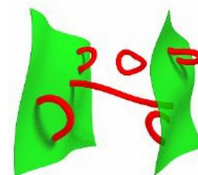
(Love at First Site)

Non-Perturbative Quantum Super-Gravity



$N = 8$

Unify All String Theories into Maximal Super-Gravity in $D = 11$



M Theory:

Fundamental Objects are Branes

Generalizes the Notion of Space-Time \rightarrow Super-Space-Time and Unifies Description of Bosons and Fermions and Unifies Gravity with the Everything and has Consistent Non-Perturbative Quantum Definition [Super-Space May Not be an Option with Gravity]

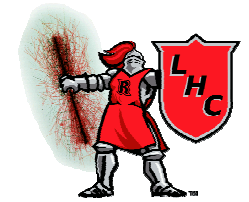
(Pledge Undying Love for All Eternity)

Super-Space at Rutgers

Many Many Theoretical Developments
in our Understanding of Super-Space
have Originated from Rutgers ...

Many Experimentalists and Theorists at
Rutgers are Now Engaged in the Search
for Super-Space ...

Rutgers Exploration of the Super-Space Frontier



Faculty + Physicists:

Yuri Gershtein, Eva Halkiadakis, Amit Lath, Steve Schnetzer, Sunil Somalwar, Tom Banks, David Shih, Greg Moore, Sasha Zamalodchikov, Emanuel Diaconescu, Daniel Friedan, Sergei Lukyanov, Matt Strassler, Scott Thomas, Bob Stone, John Doroshenko, Pieter Jacques

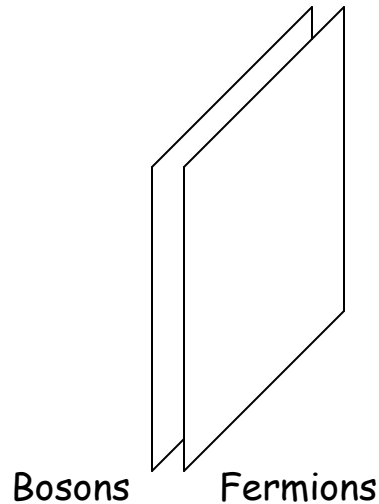
Postdocs:

Richard Gray, Dan Dugan, Dean Hidas, Can Kilic, Adam Falkowski, Olexei Atramentov, Daniel Jafferis, Alexey Litvinov, Samuel Monnier, Daniel Roggenkamp, Wu-Yen Chuang, Dieter van den Bleeken

Students:

Keith Rose, Dmitry Hits, Anthony Barker, Shruti Panwalkar, Rishi Patel, Claudia Seitz, Daryl Hare, Tim Lou, Lindsay Winter, Gautam Jain, David DeMair, Ed Ronan, Richard Bavier, Jorge Chavez, Ian LaFlotte, AJ Richards, Yue Zhao, Michael Park, Evgeny Andriyash, Jose Jukenvich, Guang Pan, Robert Schabinger, Patrick Zywicki, Emmanuel Contreras, Christian Contreras, Sean Yeager, Eric Williams, Alex Sood

Super-Space



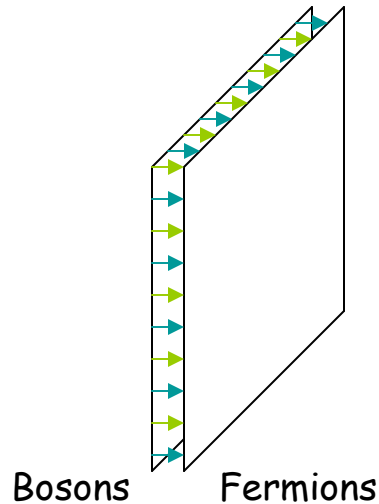
Introduce a Discrete
SuperDimension of Super-Space

Bosons Inhabit One Side of Super-Space and Fermions the Other

Consequences: Bosons \leftrightarrow Fermions by Translating/Jumping
Across the Discrete SuperDimension - SuperPartners

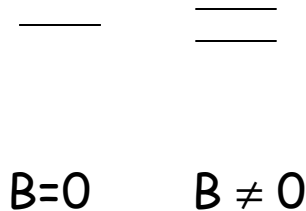
Particle - SuperParticle Transitions
Have Not Been Observed !

Magnetized Super-Space



Spontaneous Magnetization in the Discrete SuperDimension Splits the Boson-Fermion Energies

(c.f. Spin $\frac{1}{2}$ Particle in Magnetic Field)



Particle - SuperParticle Transitions
Have Not Been Observed Yet!

All We Need is Enough Energy to Push Particles from One Side of SuperSpace to the Other



where can I find superspace



where can I find superspace

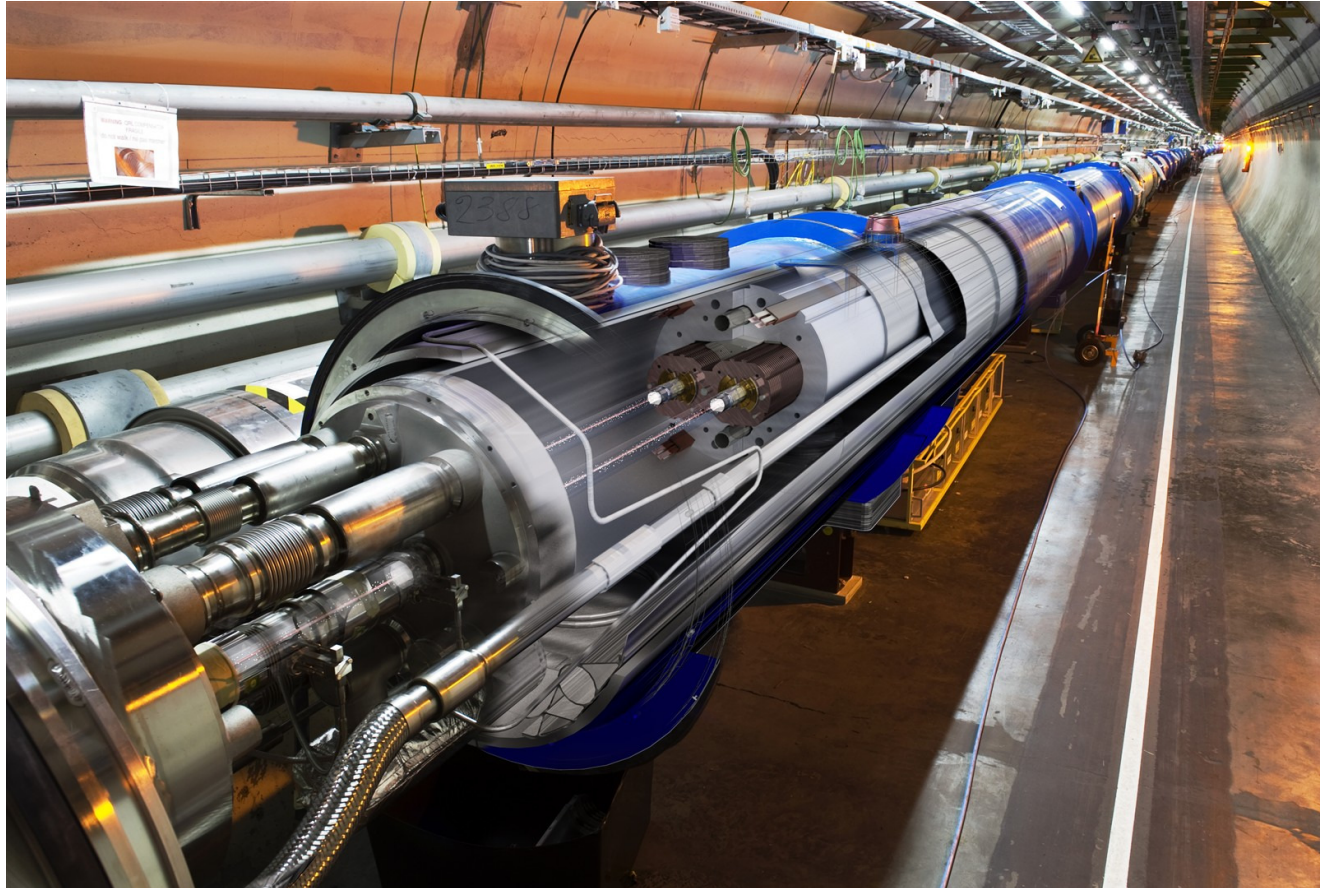




where can I find superspace



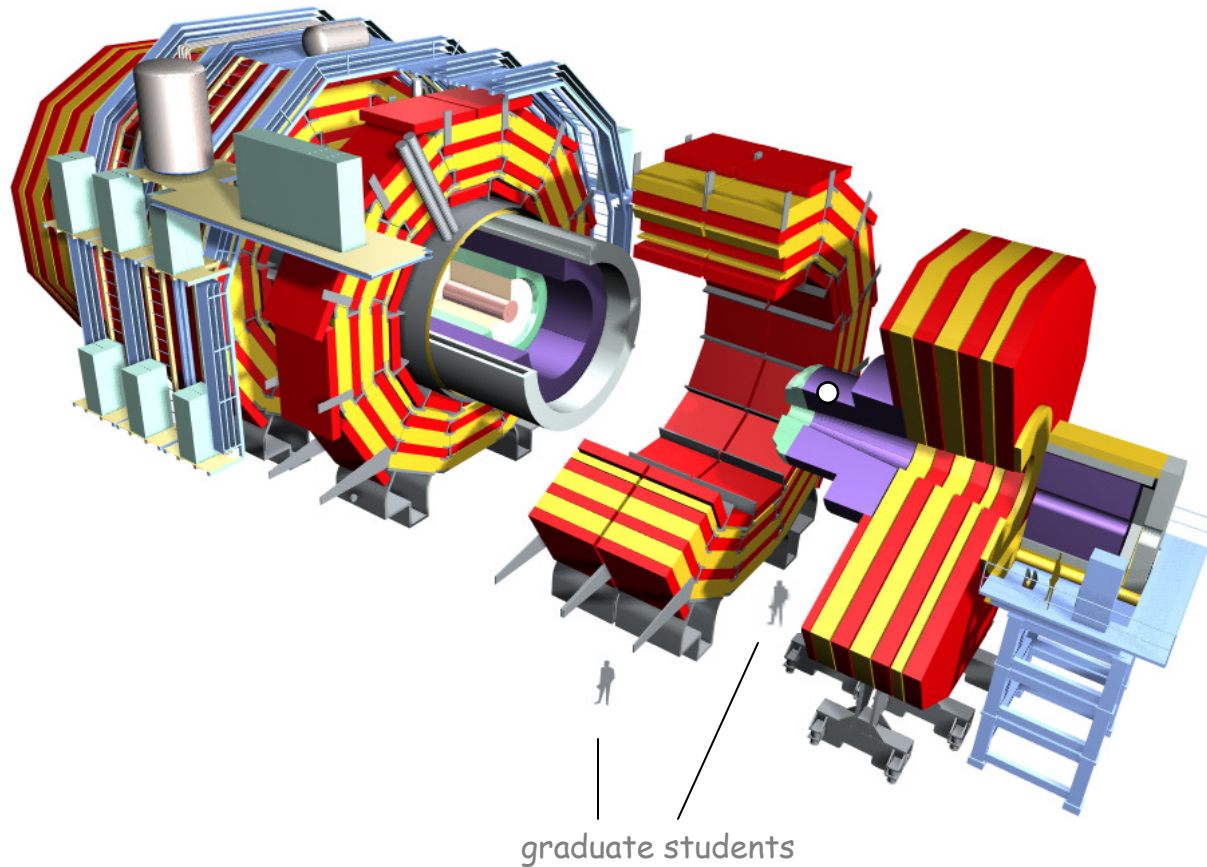
Large Hadron Collider



Souped up Microwave Ovens
1232 Super Conducting Dipole Magnets

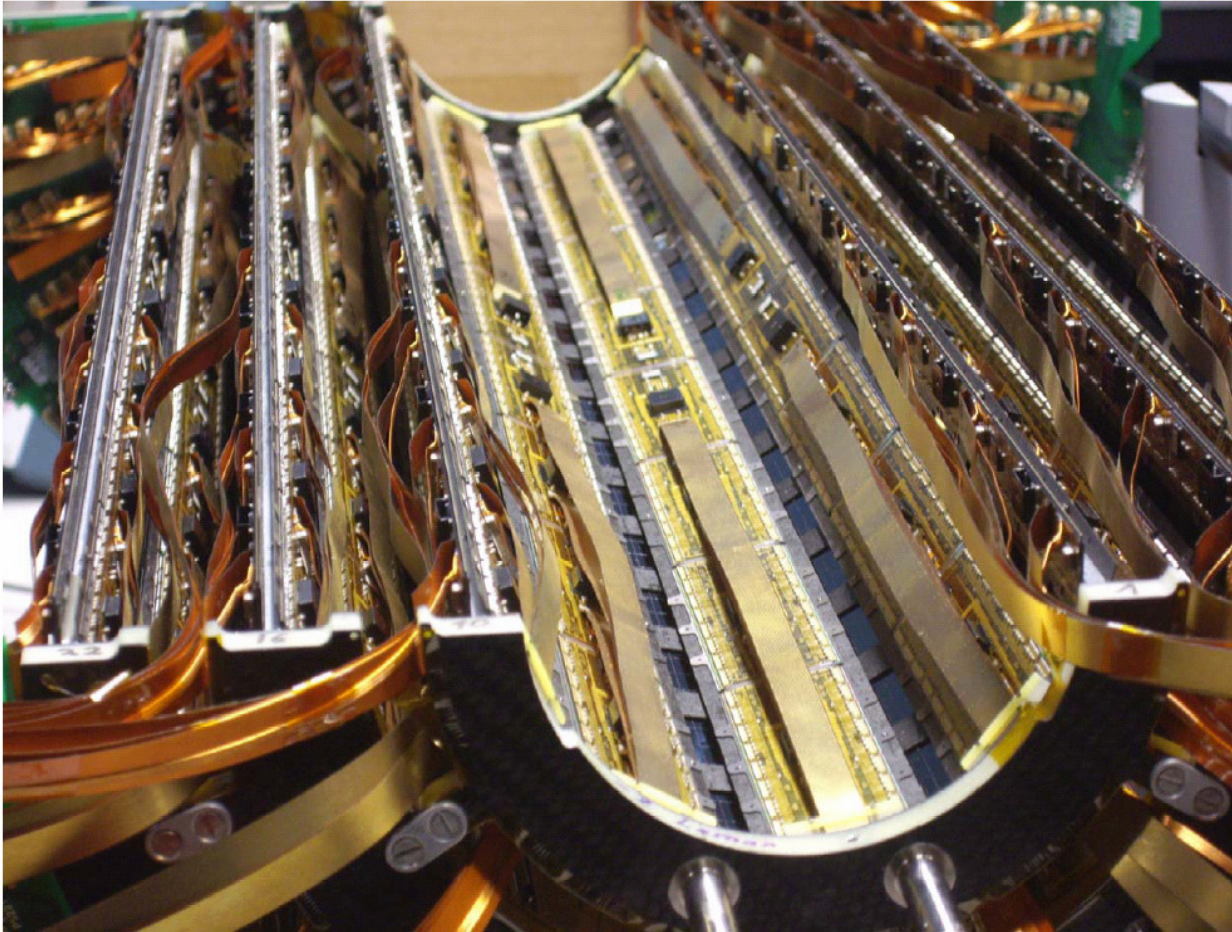
$\frac{1}{2}$ nanogram in Beam -
Kinetic Energy of High Speed TGV
between Geneva-Paris

CMS Detector



World's Largest Most Precise 3 Dimensional Digital Camera:
Records Particles that Originate from Proton-Proton Collisions

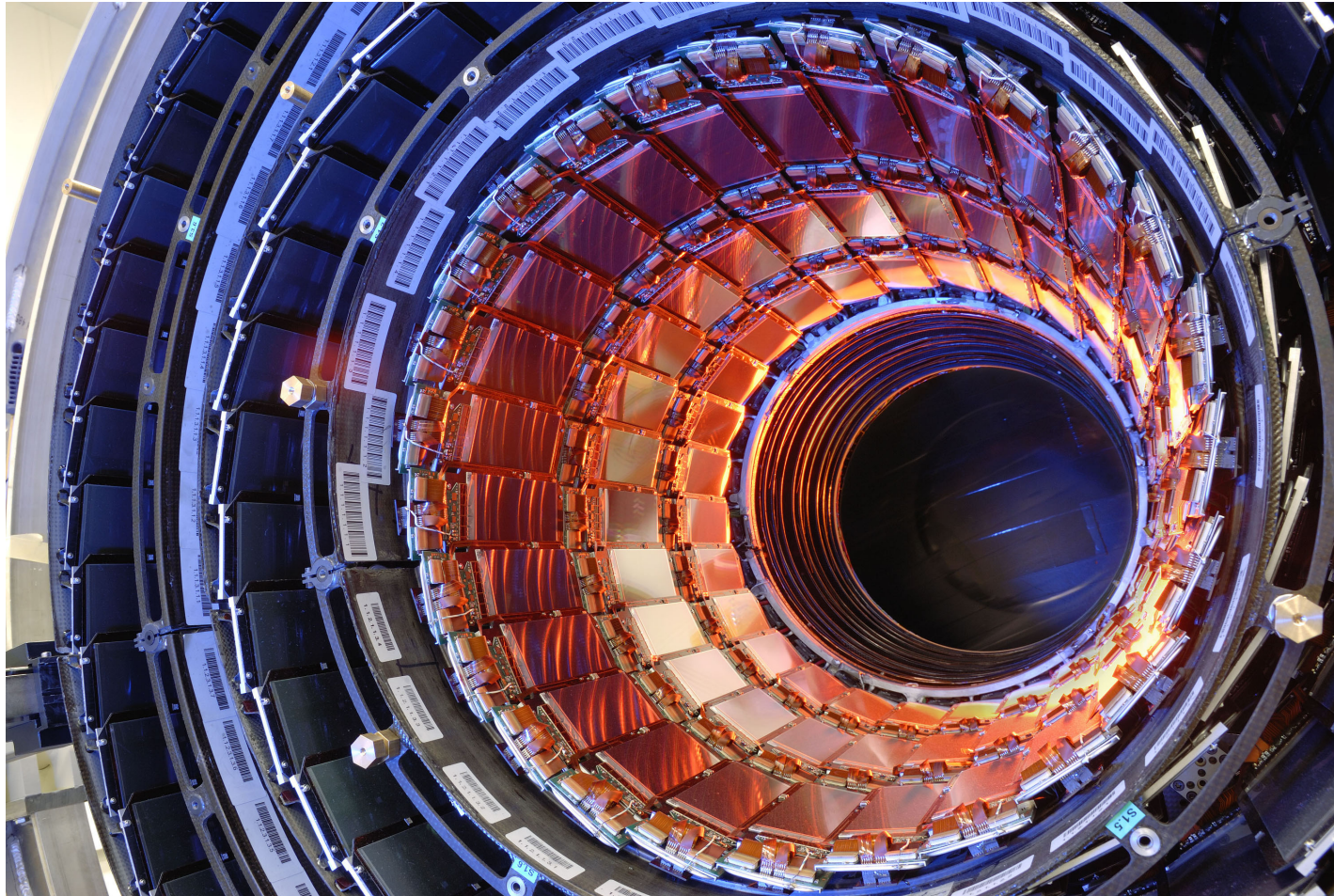
CMS Barrel Pixel Detector



Inner Radius 4 cm

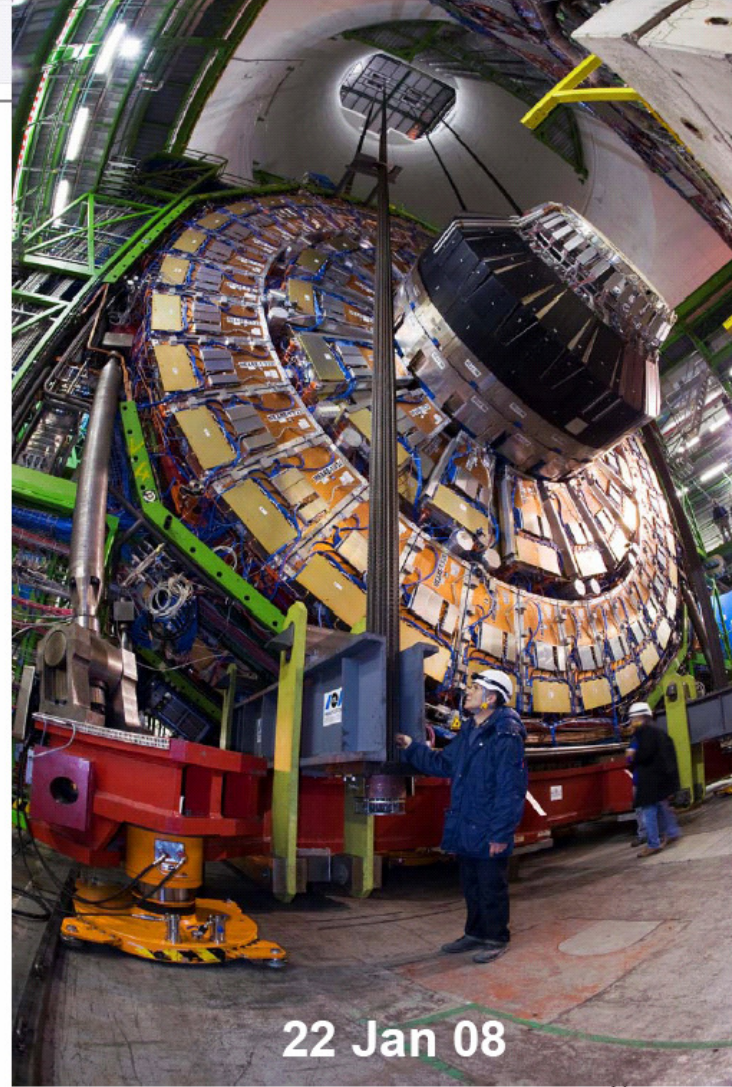
40,000,000 Channels

CMS Inner Tracker

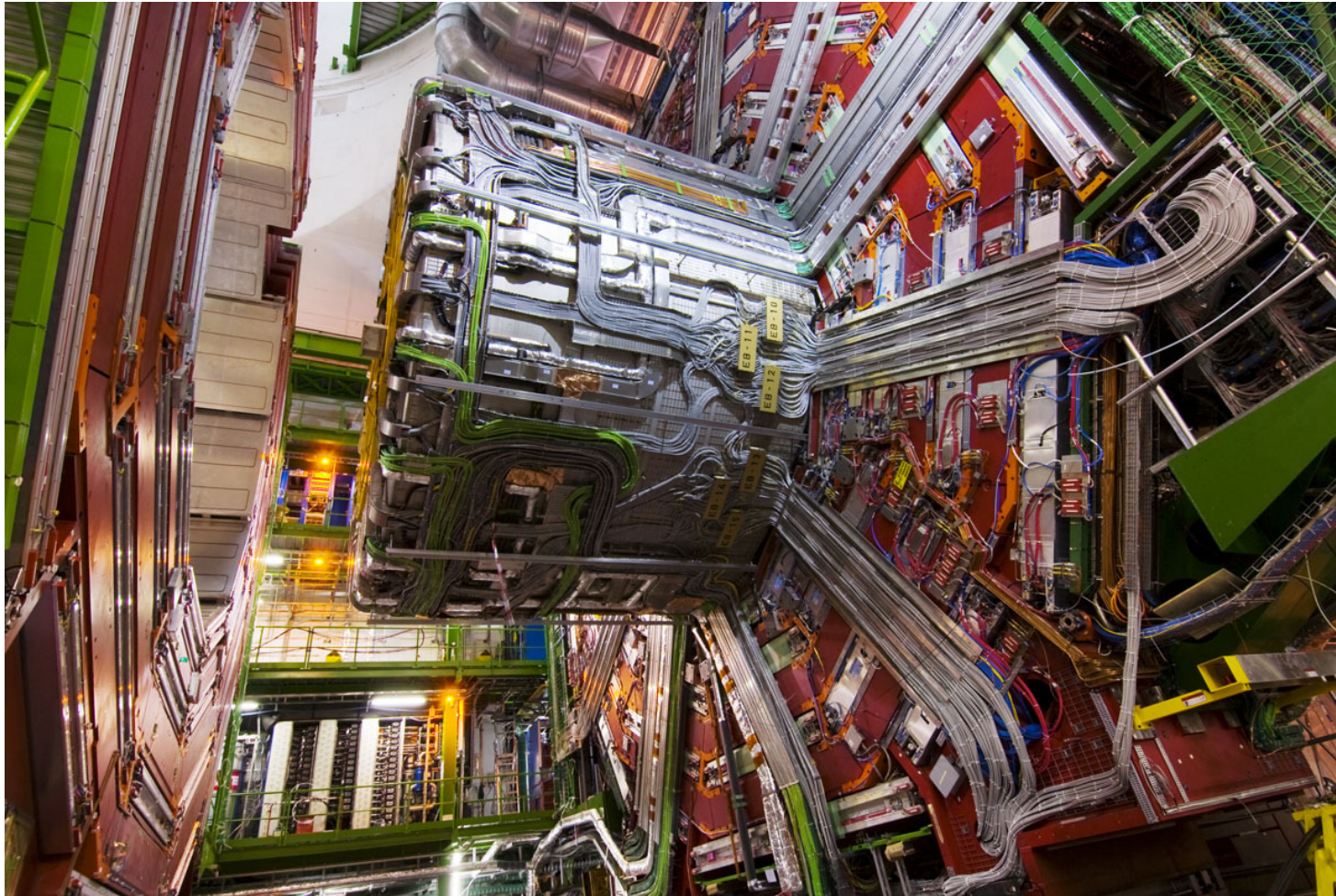


Si Area = 220 m²

CMS End Cap Calorimeter

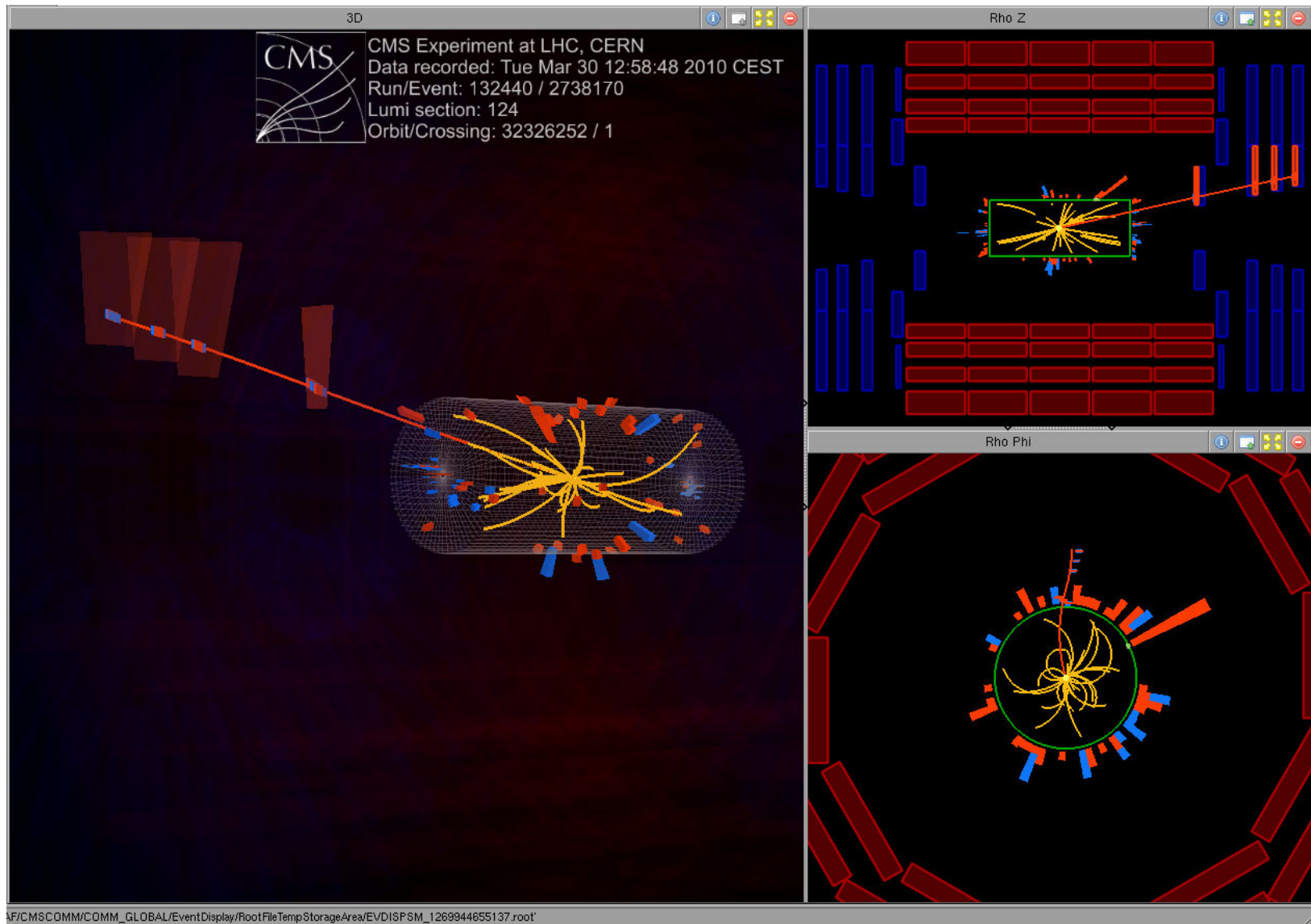


CMS Hadronic Calorimeter End Cap

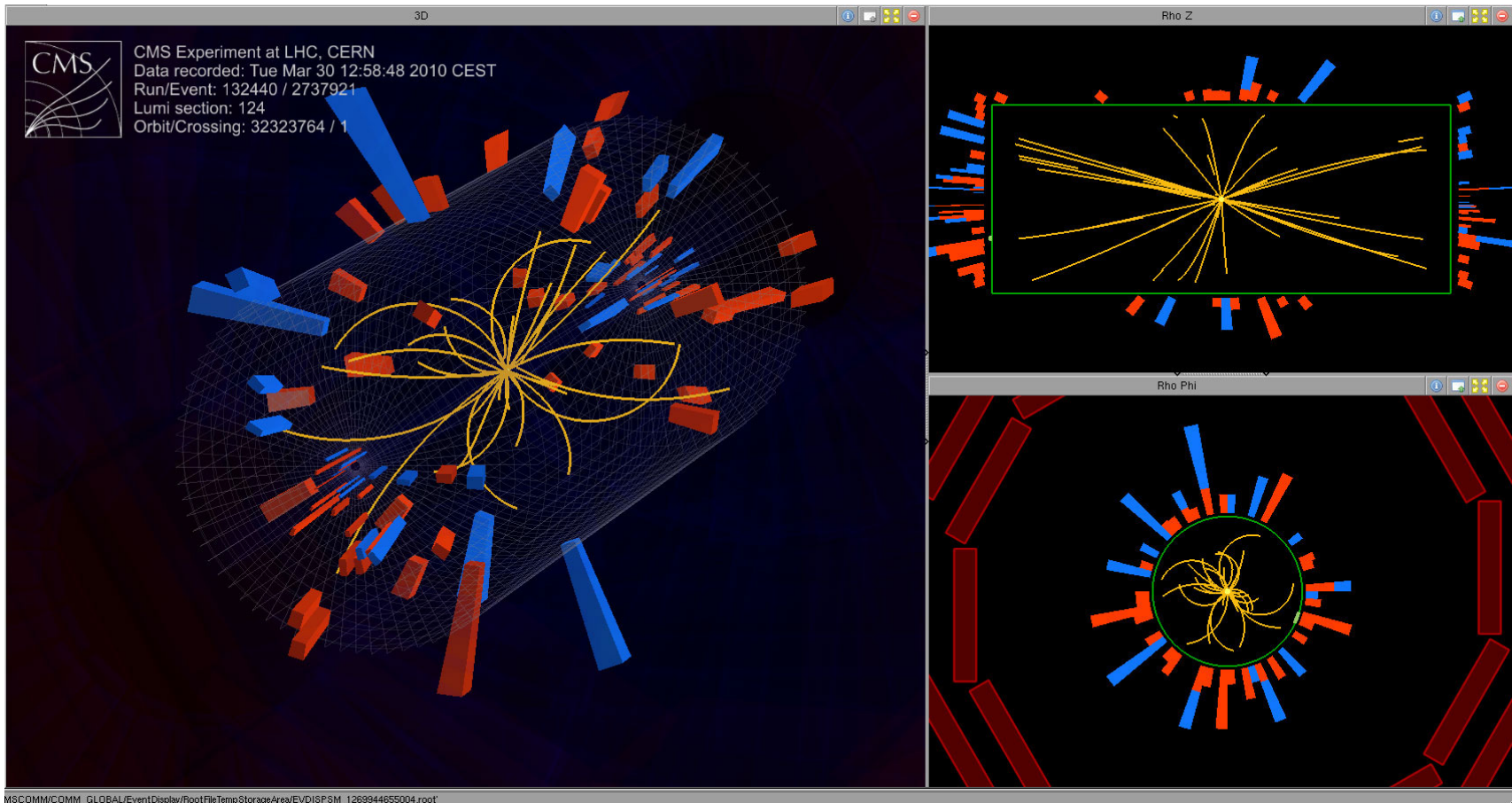


Order 1 % Mis-Cabled

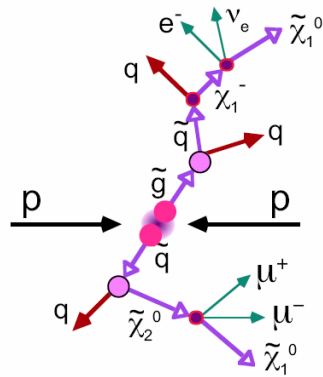
CMS Muon Event



CMS Jet Event



Rutgers Searches for SuperSpace



Reconstruct Reaction from Particle Debris from Collision

Infer Particle-SuperParticle Transitions Through the Discrete SuperDimension

Many, Many Possibilities - We'll be Searching with a Wide Net

Tiny Impurity of "Interesting" Collisions (as low as 10^{-9})

Dark Matter

Gravitational Effects of Dark Matter are Apparent
from Sub-Galactic Scales ... Entire Universe

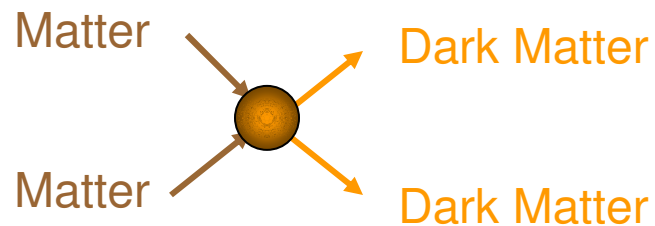
Dark Matter -

Non-Luminous, Non-dissipative Particles

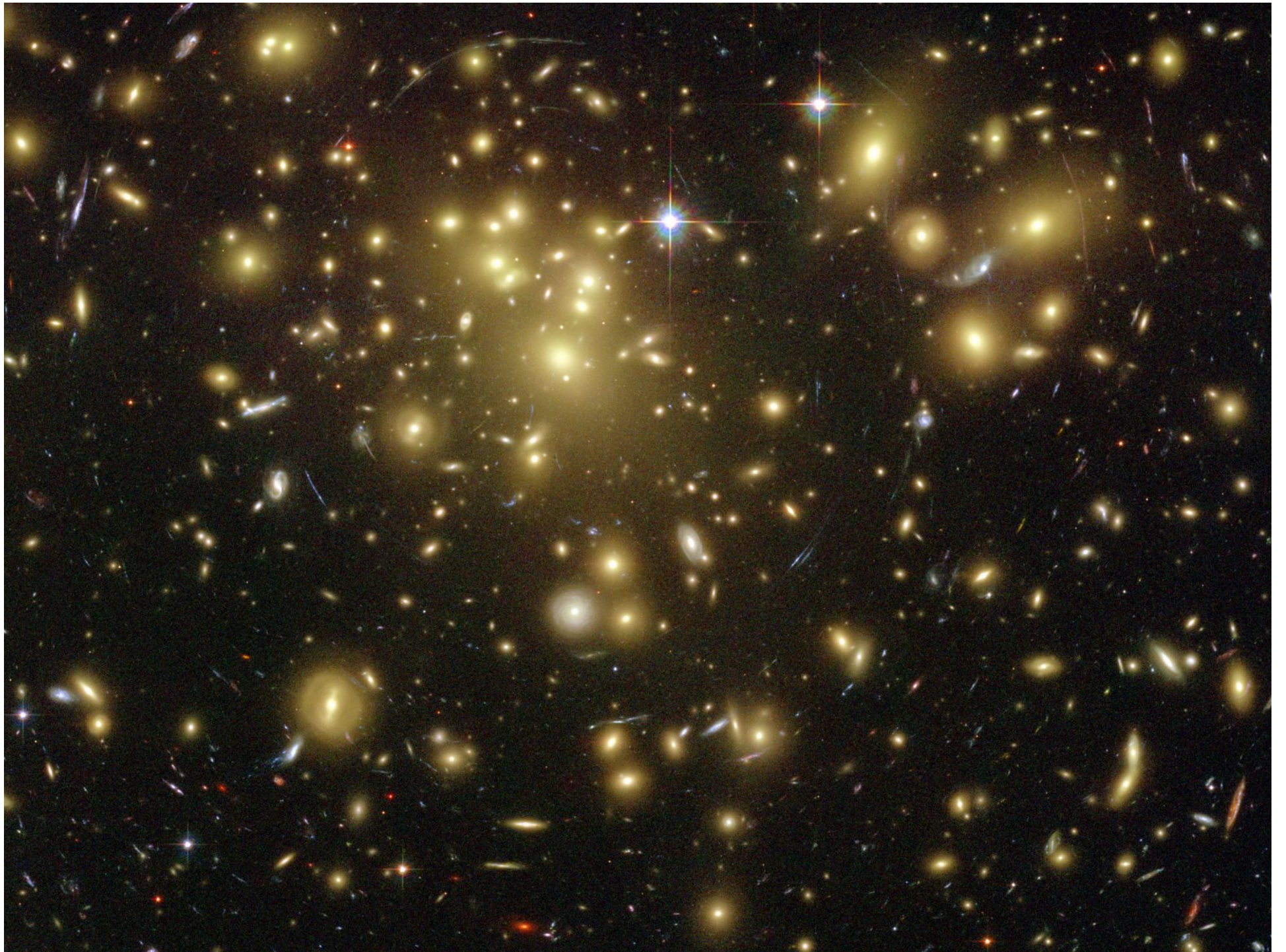
Left Over from the Big Bang



Abell 1689



Density Dark Matter / Density Normal Matter ~ 6



The Dark Side of Rutgers



Faculty +
Physicists: Chuck Keeton, Jerry Sellwood, Ted Williams, Tad Pryor, Jack Hughes,
Eric Gawiser, Andrew Baker, and Saurabh Jha, Slawomir Piatek,
Felipe Menanteau, Ben Dilday, Nick Bond

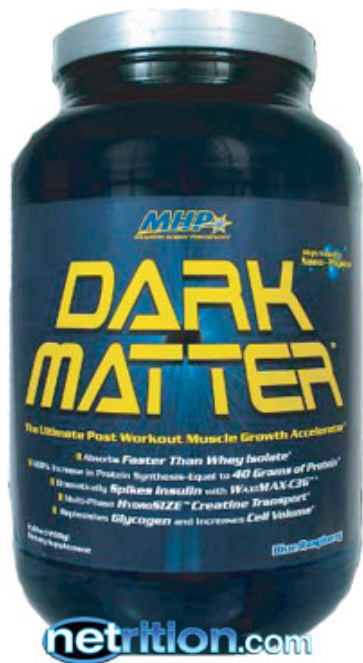
Students: Ross Fadely, Eve LoCastro, Michael Solway, Jean Walker, Chelsea
Sharon, Curtis McCully, Brett Salmon



how do I make dark matter



how do I make dark matter



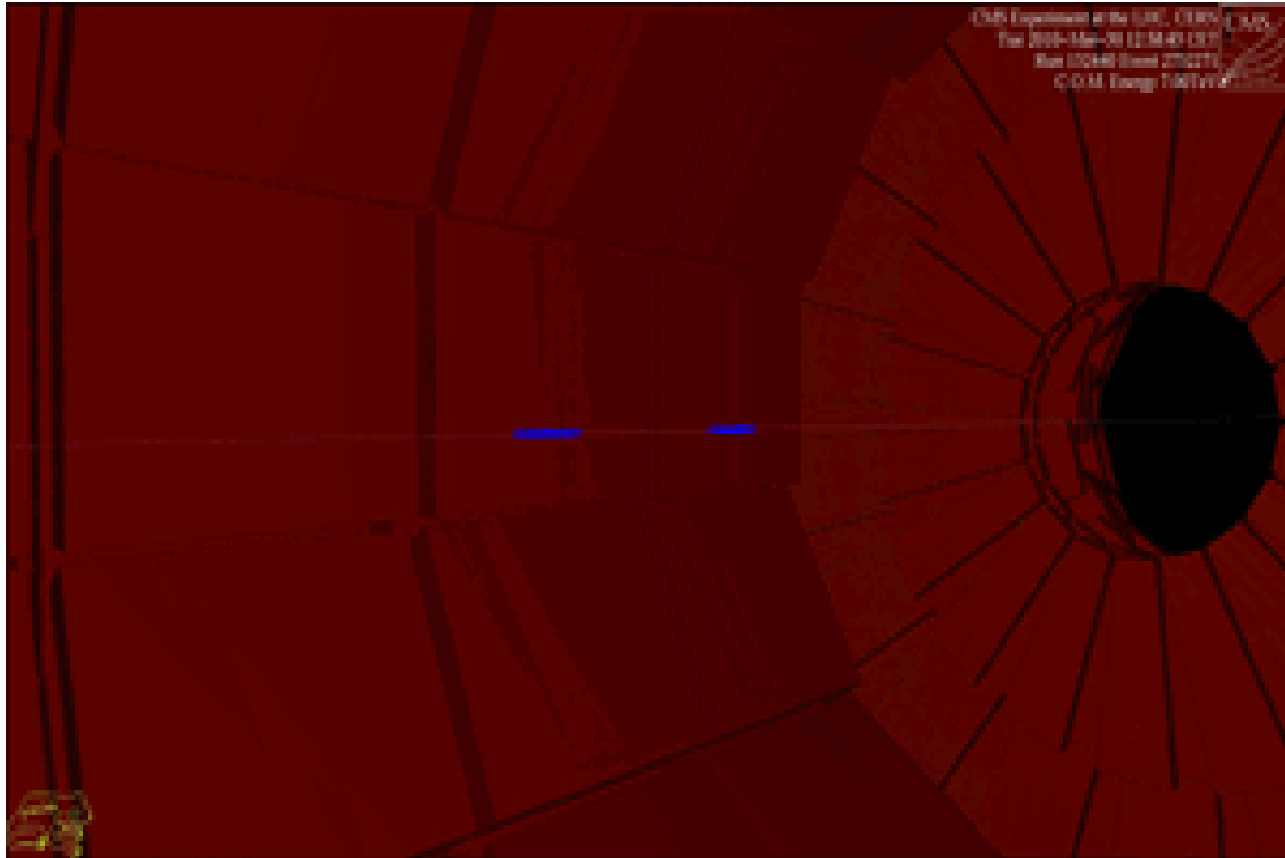
MHP DARK MATTER 2.64 LB

- **\$30.95**
- (Save 46%)

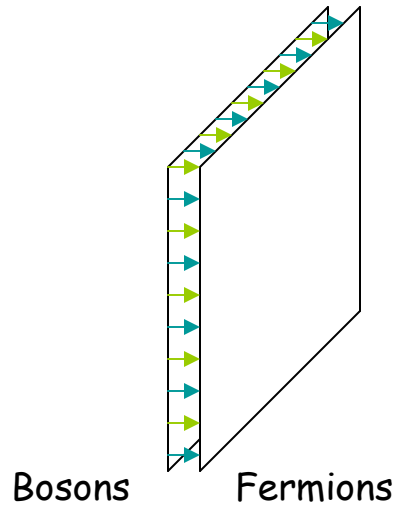
MHP DARK MATTER takes a quantum leap forward into a new dimension of post-workout muscle growth called the ANABOLIC AXIS. The Anabolic Axis is the time and point at which insulin levels simultaneously peak with amino acids, creatine and glycogen transport into muscle tissue during the critical 1 hour period immediately after your workout. MHP Dark Matter is the first and only supplement to employ a new technology called Precision Nutrient Infusion, which allows for this synergistic anabolic reaction to occur at the Anabolic Axis. In order to achieve this major breakthrough, MHP scientists bio-engineered new compounds and a revolutionary High Velocity Nano-Physics Technology. These new developments have rendered all post-workout creatines, whey protein/high carbohydrate combos and all other post-workout formulas inferior and outdated. MHP DARK MATTER blasts open the critical "Anabolic Window" faster, wider and longer allowing you to enter the ANABOLIC AXIS for the most powerful anabolic reaction ever experienced!



how do I make dark matter

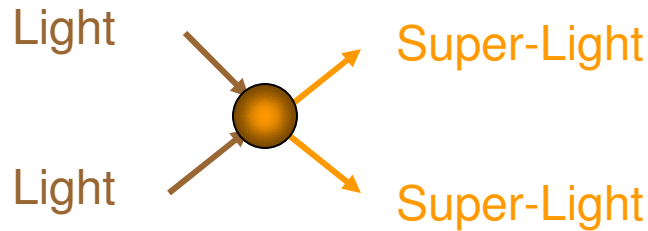


Dark Matter in the SuperDimension



Reflection Symmetry - Particles
Traverse the SuperDimension Only
in Pairs

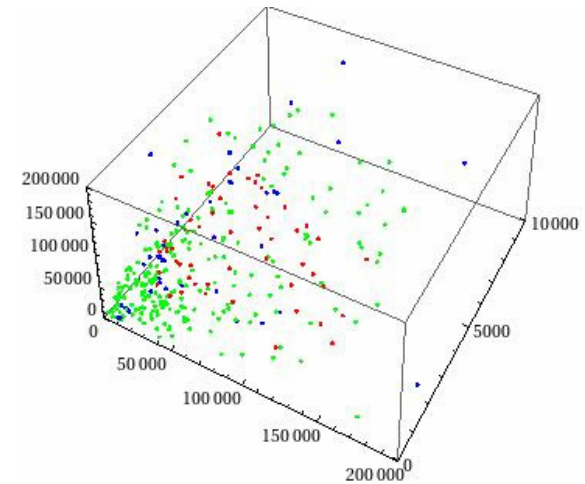
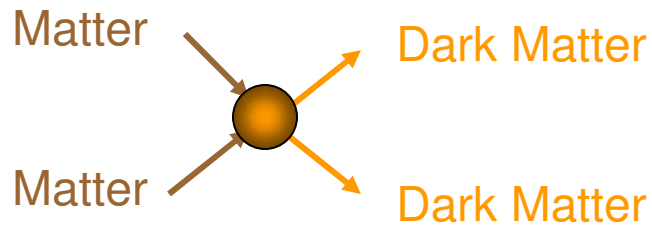
Stabilizes the Lightest
Superpartner



10^{-12} s After Big Bang

Dark Matter = Super-Light

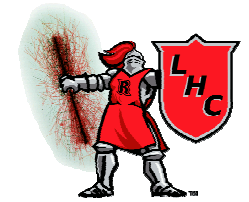
Rutgers Search for Dark Matter at the LHC



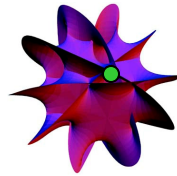
Reproduce Reactions 10^{-12} After
Big Bang → Dark Matter

Extract Mass, Spin, and Couplings
of Dark Matter Directly from Data

Rutgers Search for Quantum Gravity at the LHC

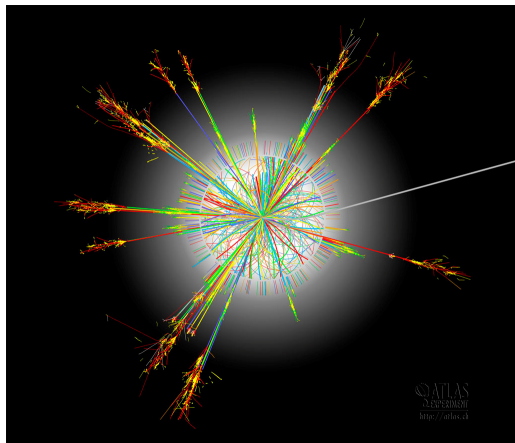


LHC Collisions Could Produce Microscopic Black Holes



Originated from People Now at Rutgers

The New York Times
Physicists Strive to Build A Black Hole



Simulated Black Hole Event



(Don't Worry)

- The Understanding of Super-Space Came During a Exciting Era of Discovery in Theoretical Physics
- We've Now Just Entered an Exciting Era of Discovery in Experimental Fundamental Physics
- If the Existence of Super-Space is Confirmed at the LHC it will be seen as a Triumph of Human Intellect
- No Matter What is there in the LHC We're Going to Have Fun Getting it Out

- Predictions - What will the LHC see a few years from now?



how was superspace discovered



how was superspace discovered

Many Predictions ...

???

Only One Prediction I'm Confident of -
If there is a Super-Space ...



where was superspace discovered

Google™

where was superspace discovered



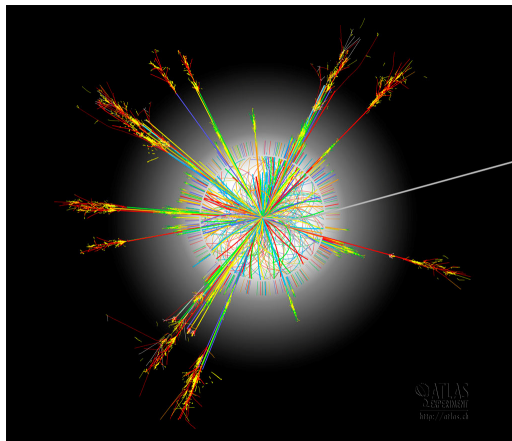
- Black Holes at the Large Hadron Collider

High Energy Collisions
Could Produce Microscopic
Black Holes

Originated from People Now
at Rutgers

The New York Times

Physicists Strive to Build A Black Hole

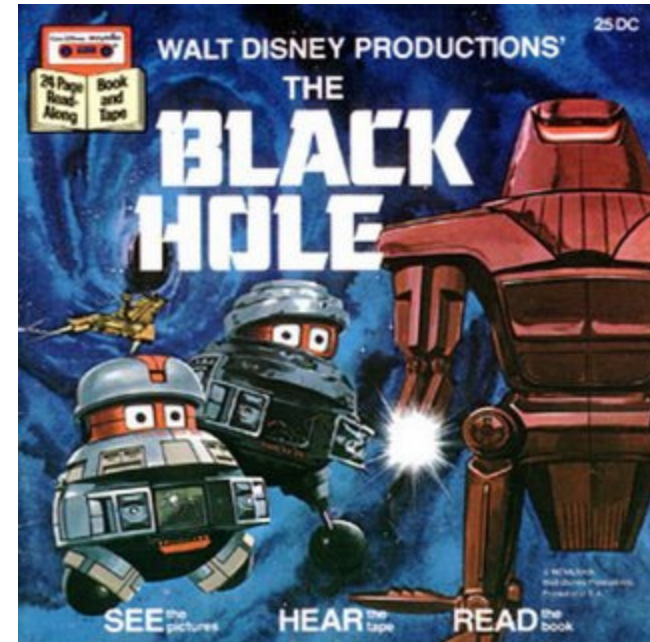
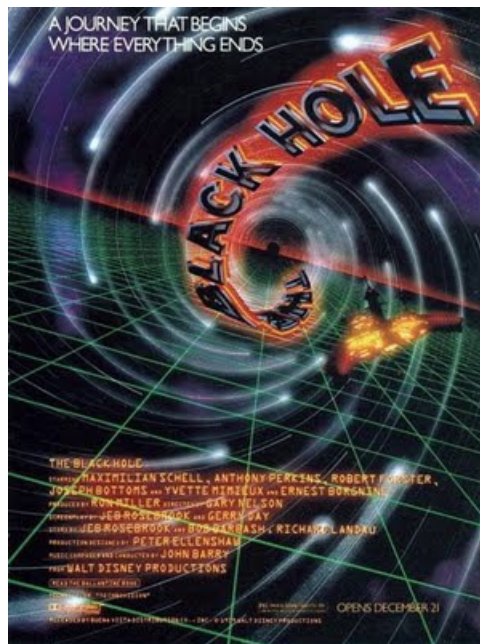


Simulated Black Hole Event



(Don't Worry)

Counting the States Inside a Black Hole



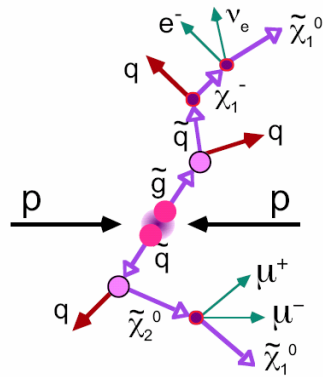
SUPERSYMMETRY



where can I find superspace

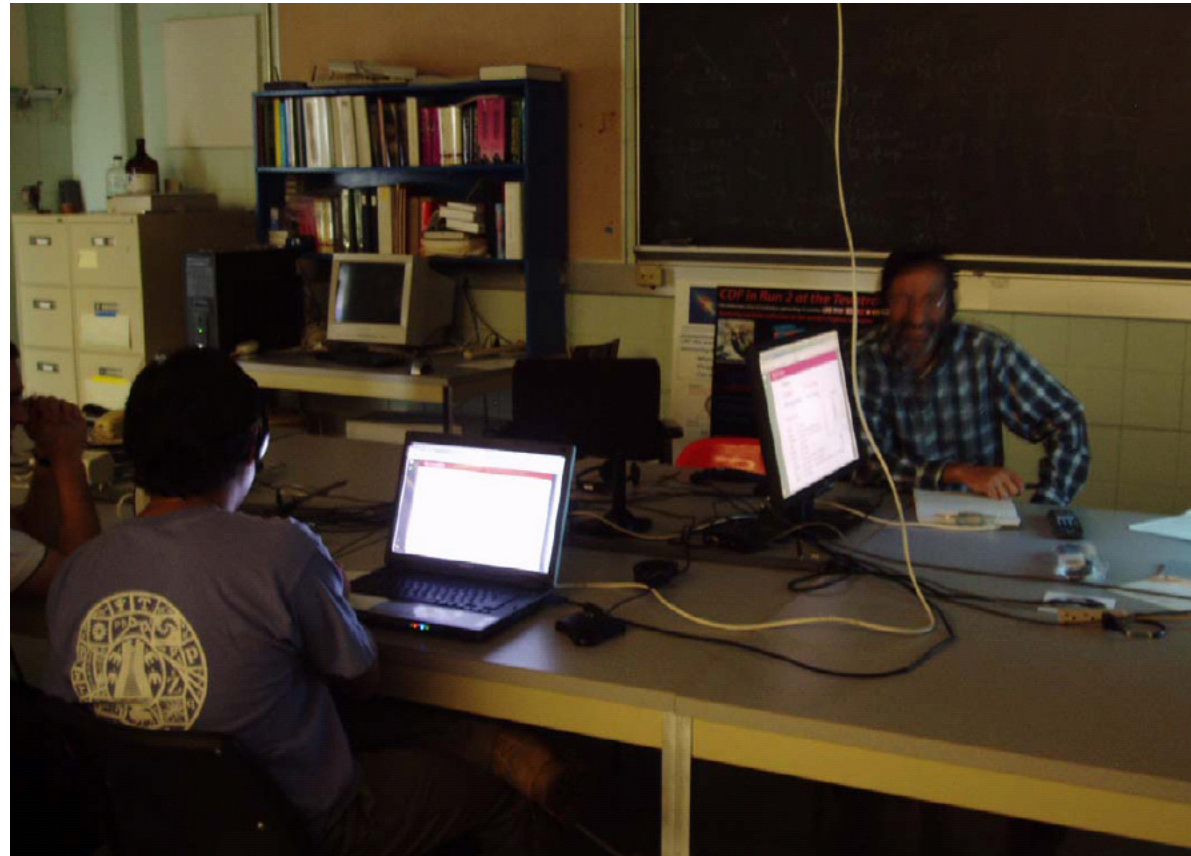


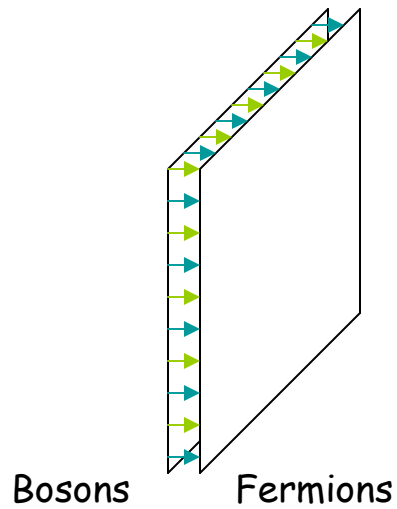
Rutgers Has Already Boldly Gone Where No One Has Gone Before



Unblinding of Rutgers' Tevatron Search for Supersymmetry

Sunil Somalwar and Sourabh Dube





Reflection Symmetry - Particles Traverse the SuperDimension Only in Pairs

Stabilizes the Lightest Superpartner

Dark Matter

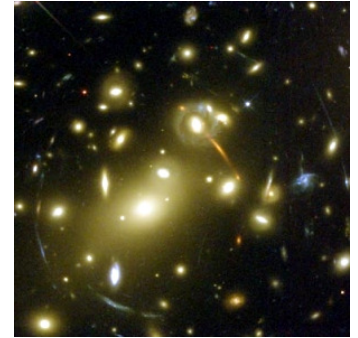
Gravitational Effects of Dark Matter are Apparent
from Sub-Galactic Scales ... Entire Universe

Dark Matter -

Non-Luminous, Non-dissipative Particles

Left Over from the Big Bang

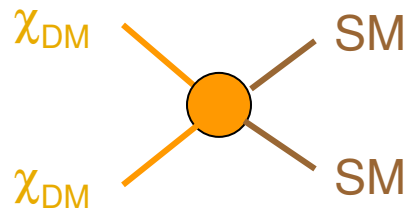
Density Dark Matter / Density Normal Matter ~ 6



Abell 1689



Weakly Interacting Dark Matter



Big Bang Thermal Freeze Out

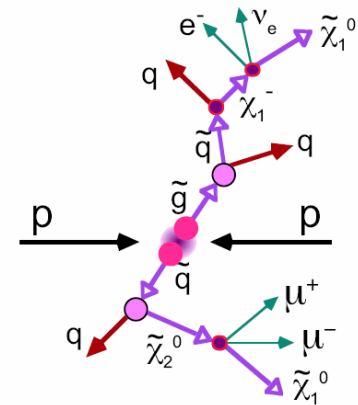
~ 1 ps After Big Bang

Weak Scale Mass + Weak Scale Interactions \sim
Correct Relic Density from Big Bang

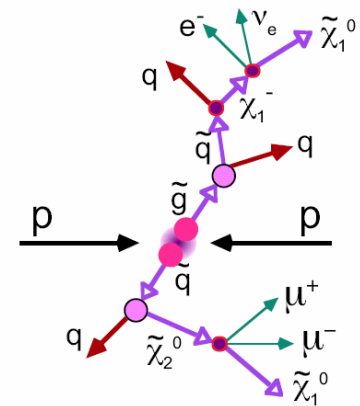
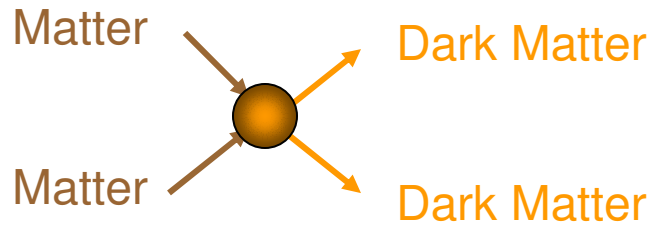
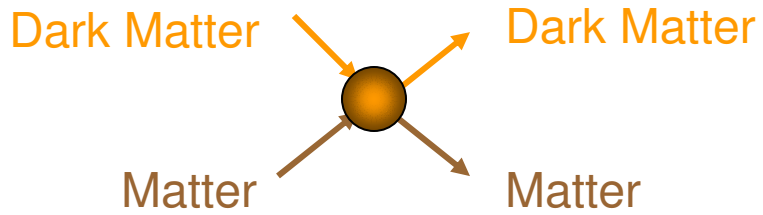
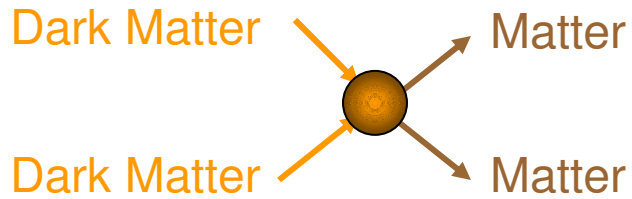
Supersymmetry:

Superpartner of Photon \sim Correct Properties

Light \leftrightarrow Dark



Weakly Interacting Dark Matter

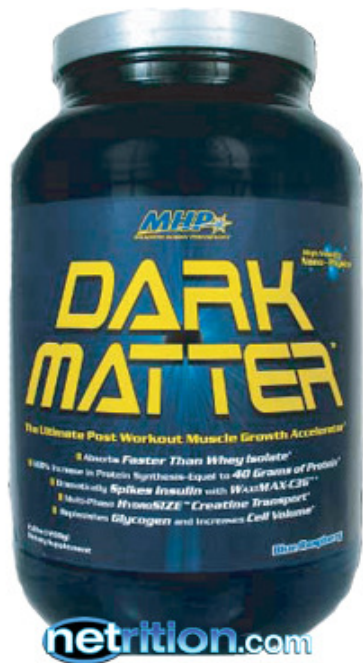




how do I make dark matter



how do I make dark matter



MHP DARK MATTER 2.64 LB

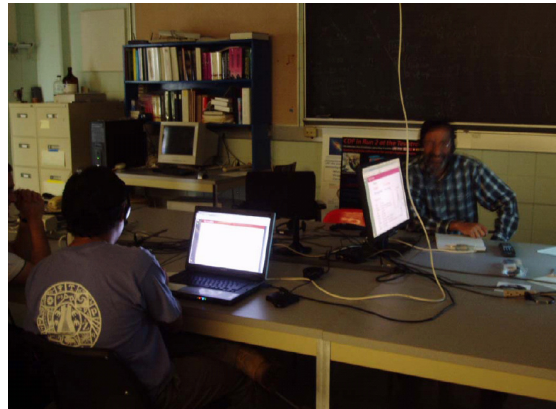
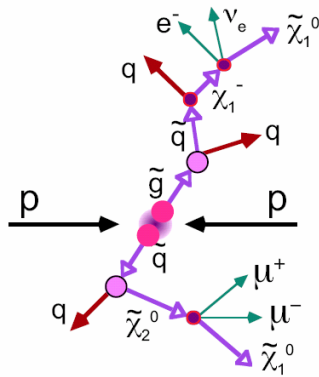
- **\$30.95**
- (Save 46%)

MHP DARK MATTER takes a quantum leap forward into a new dimension of post-workout muscle growth called the ANABOLIC AXIS. The Anabolic Axis is the time and point at which insulin levels simultaneously peak with amino acids, creatine and glycogen transport into muscle tissue during the critical 1 hour period immediately after your workout. MHP Dark Matter is the first and only supplement to employ a new technology called Precision Nutrient Infusion, which allows for this synergistic anabolic reaction to occur at the Anabolic Axis. In order to achieve this major breakthrough, MHP scientists bio-engineered new compounds and a revolutionary High Velocity Nano-Physics Technology. These new developments have rendered all post-workout creatines, whey protein/high carbohydrate combos and all other post-workout formulas inferior and outdated. MHP DARK MATTER blasts open the critical "Anabolic Window" faster, wider and longer allowing you to enter the ANABOLIC AXIS for the most powerful anabolic reaction ever experienced!

- Probe Quantum Dimensions of Space - Time



Particles Scattered Into Quantum Dimensions

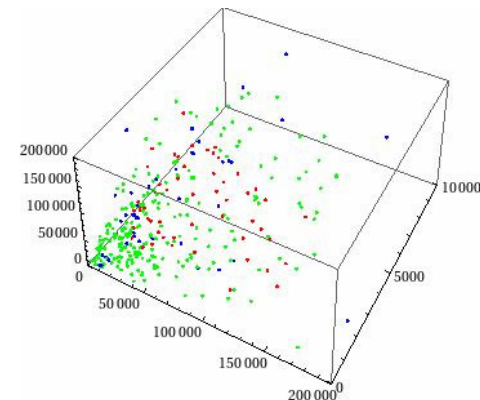


The Unveiling of
Rutger's Search for
Supersymmetry
(Somalwar)

- Produce and Measure Properties of Dark Matter

Reproduce Reactions
0.0000000000001 Second After
Big Bang → Dark Matter

Dark Matter = Super Light in
Quantum Dimension



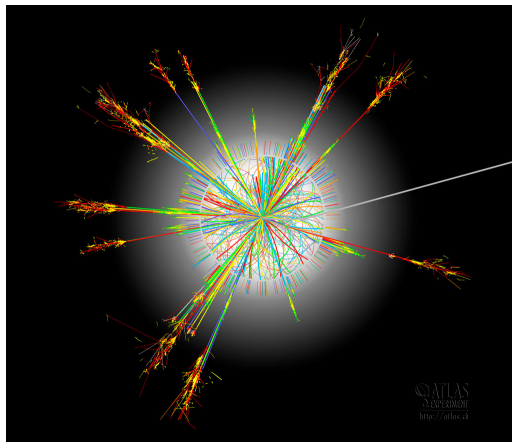
- Black Holes at the Large Hadron Collider

High Energy Collisions
Could Produce Microscopic
Black Holes

Originated from People Now
at Rutgers (Banks, Thomas)

The New York Times

Physicists Strive to Build A Black Hole



Simulated Black Hole Event



(Don't Worry)

