A Quest for The Origin of The Universe

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Physics Department Colloquium
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Outline

- What is High Energy Physics?
- Where are we at present?
- What's in the future?
- What does HEP got to do with us?

We always wonder…

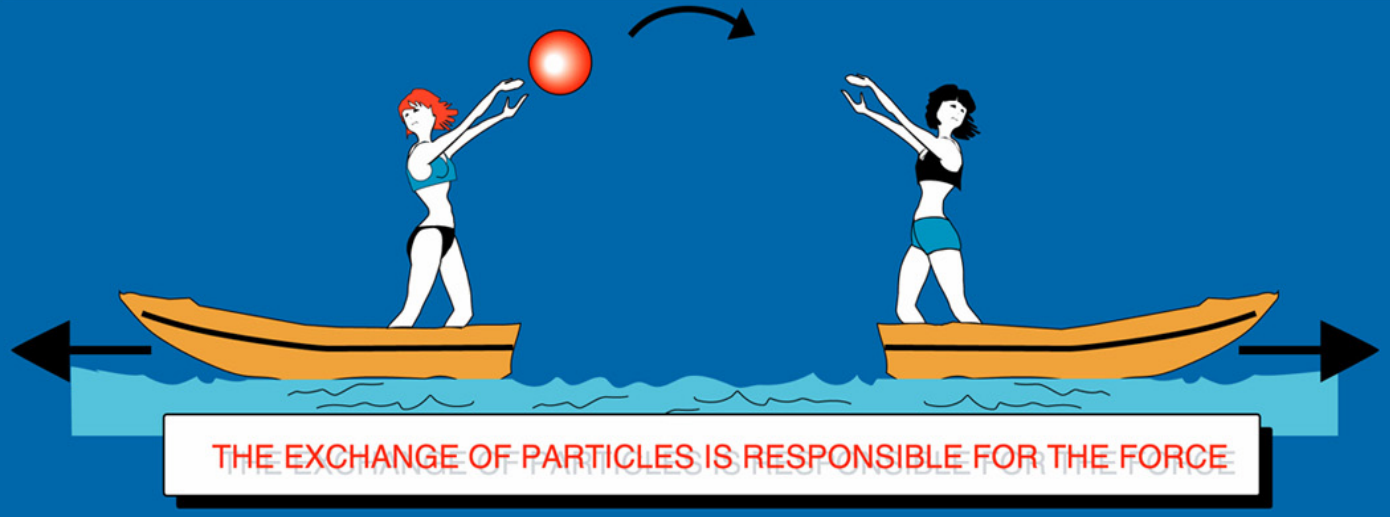
- What is the universe made of?
- How does the universe work?
- What are the things that holds the universe together?
- What are the governing principles of the universe?
- How can we live in the universe well?
- Where do we all come from?
- HEP looks into the smallest possible things to find the answers to these deep questions

High Energy Physics

- Definition: A field of physics that pursues understanding the fundamental constituents of matter and basic principles of interactions between them.
- Known interactions (forces):
  - Gravitational
  - Electro-Weak
  - Strong
- Current theory: The Standard Model of Particle Physics
  - Unified Weak and Electromagnetic: SU(2)xU(1)
  - Strong Interaction: SU(3)
  - Currently:SU(3)xSU(2)xU(1)
  - Meaning: 8+4 mediators for forces

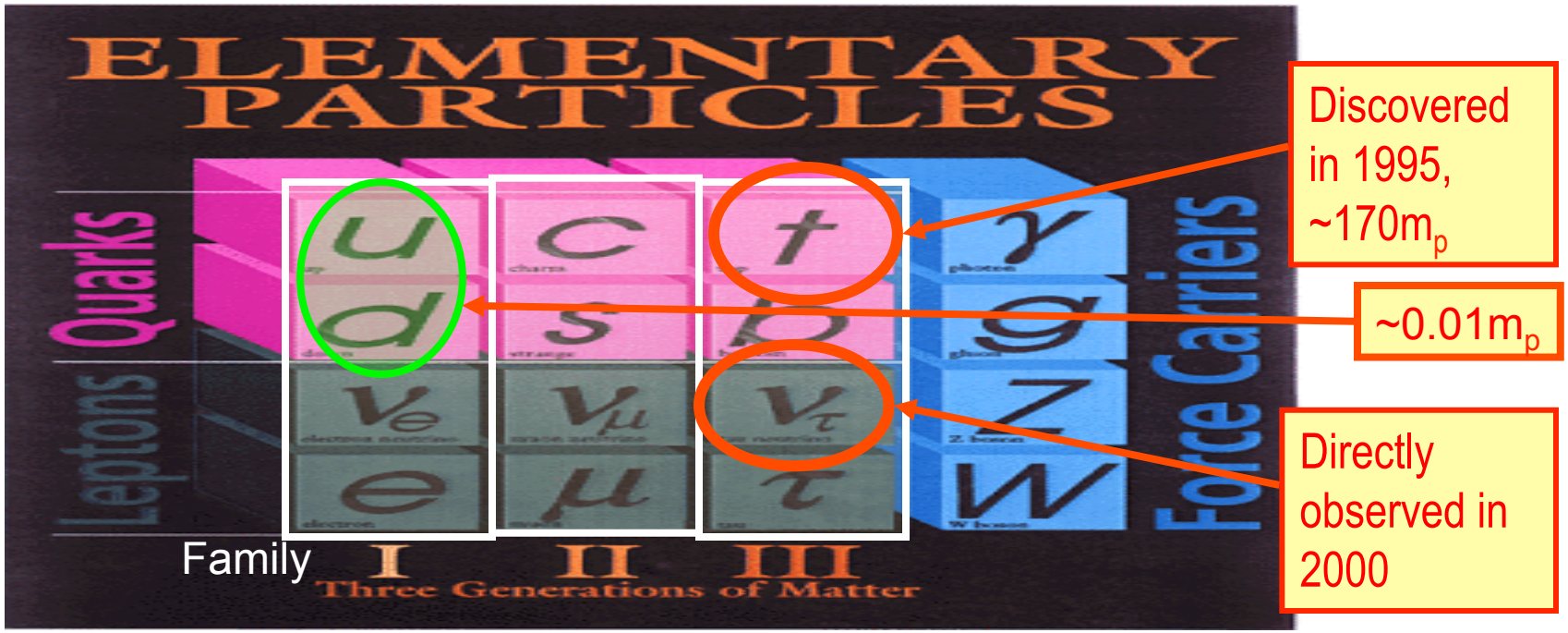
The forces in Nature

TYPE	INTENSITY OF FORCES (DECREASING ORDER)	BINDING PARTICLE (FIELD QUANTUM)	OCCURS IN :
STRONG NUCLEAR FORCE	~ 1	GLUONS (NO MASS)	ATOMIC NUCLEUS
ELECTRO -MAGNETIC FORCE	~ 10^{-3}	PHOTONS (NO MASS)	ATOMIC SHELL ELECTROTECHNIQUE
WEAK NUCLEAR FORCE	~ 10^{-5}	BOSONS Z^{o} , W^{+} , W^{-} (HEAVY)	RADIOACTIVE BETA DESINTEGRATION
GRAVITATION	~ 10^{-38}	GRAVITONS (?)	HEAVENLY BODIES



The Standard Model of Particle Physics

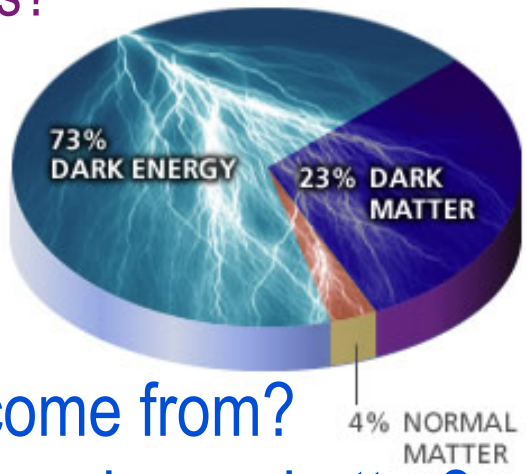
- Prescribes the following fundamental structure:



- Three families of leptons and quarks together with 12 force mediators ➔ Simple and elegant!!!
- Tested to a precision of 1 part per million!

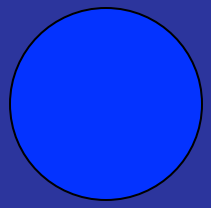
Good, but still lots we don't know…

- Why are there three families of quarks and leptons?
- Why is the mass range so large ($0.01m_p$ – $175\ m_p$)?
- How do matters acquire mass?
  - Higgs mechanism but where is the Higgs, the God particle?
- Why is the matter in the universe made only of particles?
  - What happened to anti-particles? Or anti-matters?
- Why are there only three apparent forces?
- Is the picture we present the real thing?
  - What makes up the 96% of the universe?
  - How about extra-dimensions?
- How is the universe created? Where do we come from?
- Are there any other theories that describe the universe better?
  - Does the super-symmetry exist?

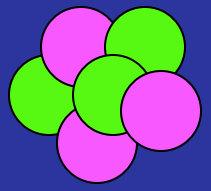


Accelerators are Powerful Microscopes.

They make high energy particle beams
that allow us to see small things.



seen by
low energy beam
(poorer resolution)



seen by
high energy beam
(better resolution)

Accelerators are also Time Machines.

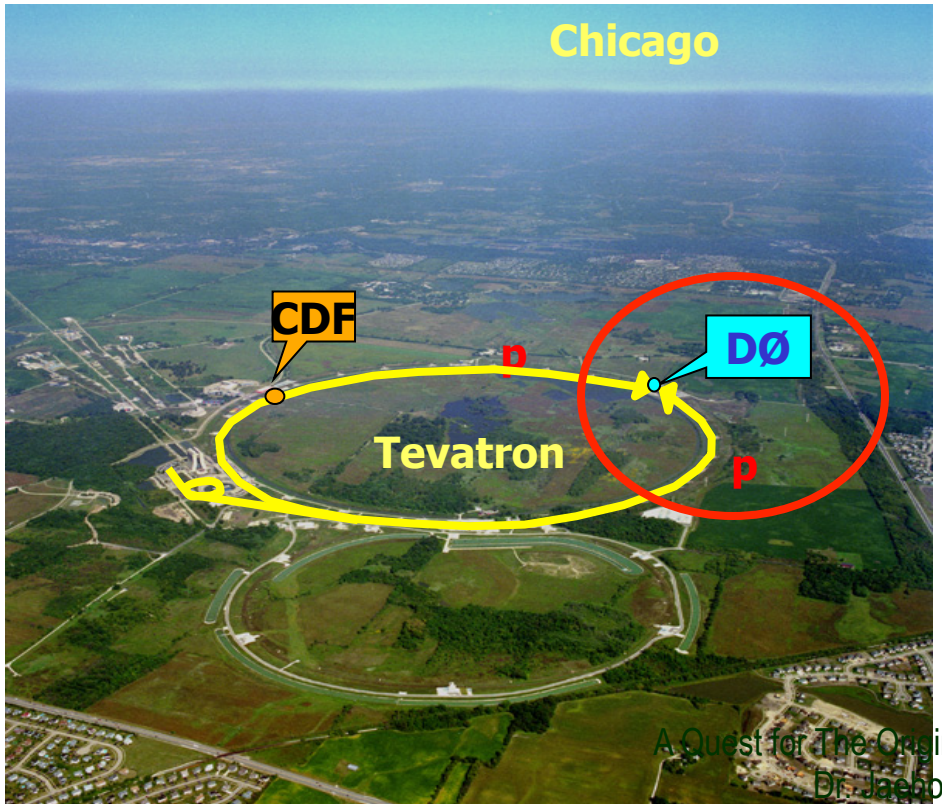
They make particles last seen
in the earliest moments of the universe.

Particle and anti-particle annihilate.

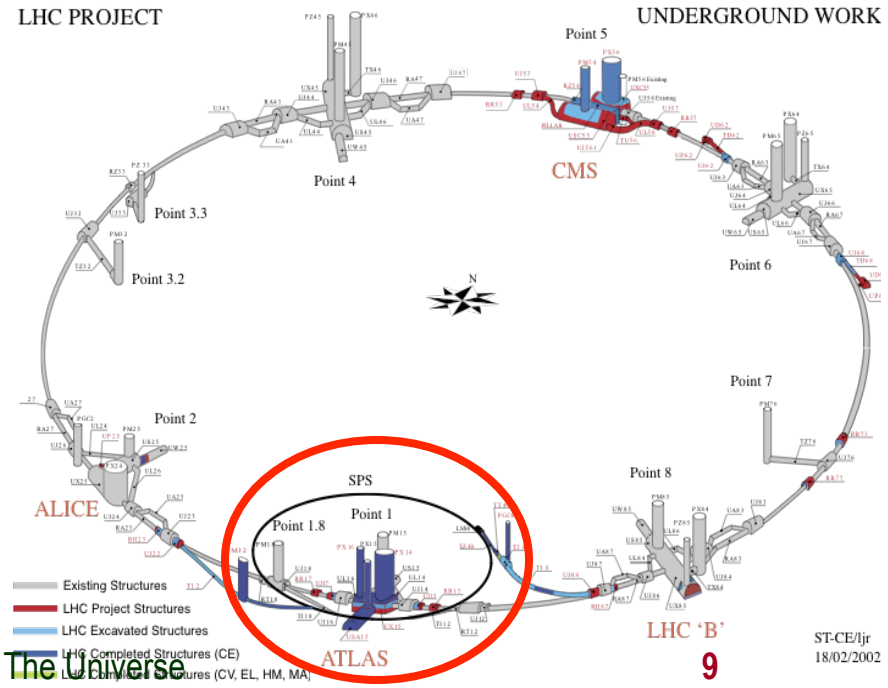
$$E = mc^2$$

Fermilab Tevatron and LHC at CERN

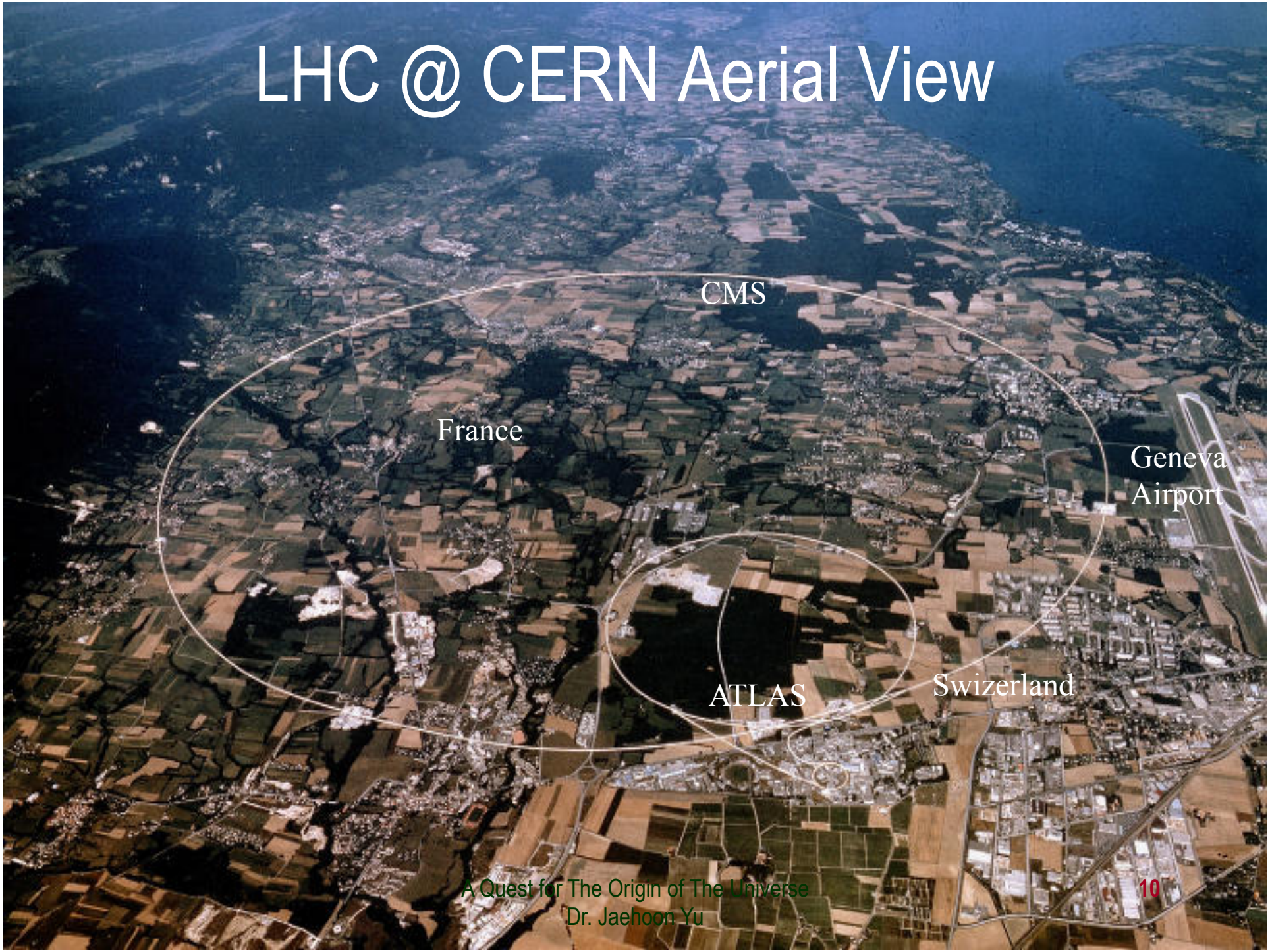
- World's Highest Energy proton-anti-proton collider
  - 6km circumference
  - E_{cm}=1.96 TeV (=6.3x10^{-7}J/p➔ 13M Joules on $10^{-4}m^2$)
  - Equivalent to the kinetic energy of a 20t truck at the speed 81mi/hr➔ 130km/hr
    - ~100,000 times the energy density at ground 0 of the atom bomb dropped on Hiroshima
  - **To be shut down Sept. 30, 2011**



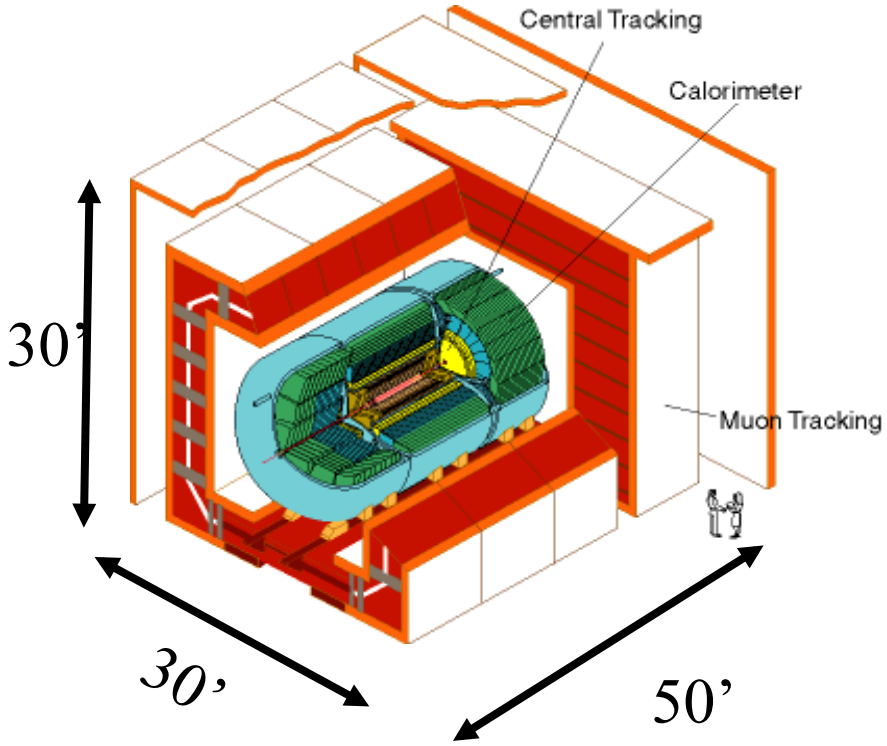
- World's Highest Energy p-p collider
  - 27km circumference, 100m underground
  - Design E_{cm}=14 TeV (=44x10^{-7}J/p➔ 362M Joules on the area less than $10^{-4}m^2$)
  - ➢ Equivalent to the kinetic energy of a B727 (80tons) at the speed 193mi/hr ➔ 312km/hr
    - ➢ ~3M times the energy density at ground 0 of atom bomb dropped on Hiroshima
- First 7TeV collisions on 3/30/10 ➔ The highest energy humans ever achieved!!
  - **First collisions in 2011 in mid March, 2011**



LHC @ CERN Aerial View

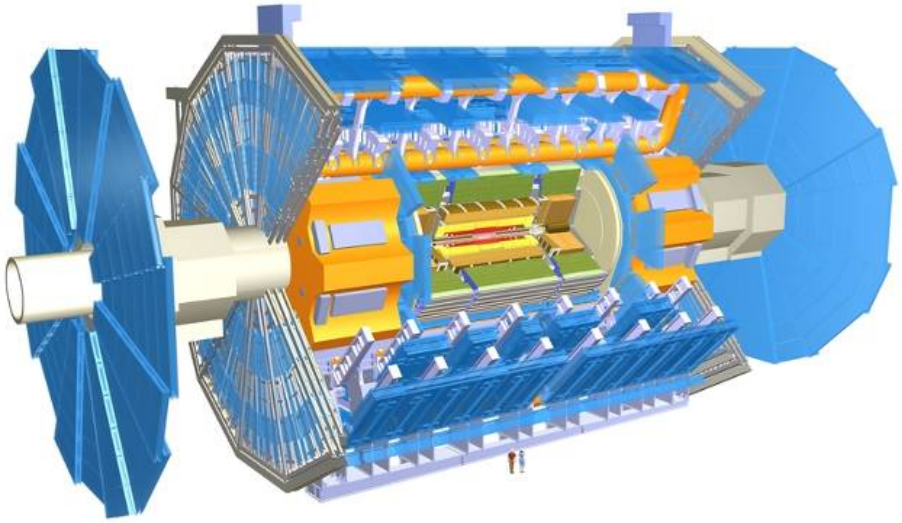


DØ Detector

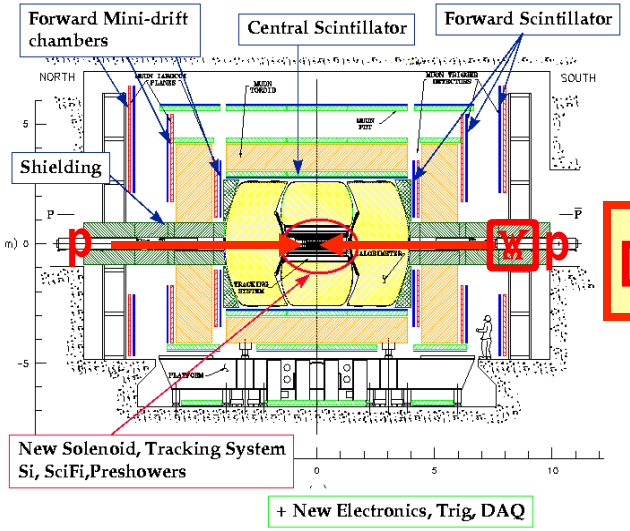


- **Weighs 5000 tons and 5 story tall**
- Can inspect **3,000,000** collisions/second
- Record **100 collisions/second**
- Records approximately **10,000,000** bytes/ second
- Records **0.5x10^{15}** (500,000,000,000,000) bytes per year (0.5 PetaBytes).

ATLAS Detector



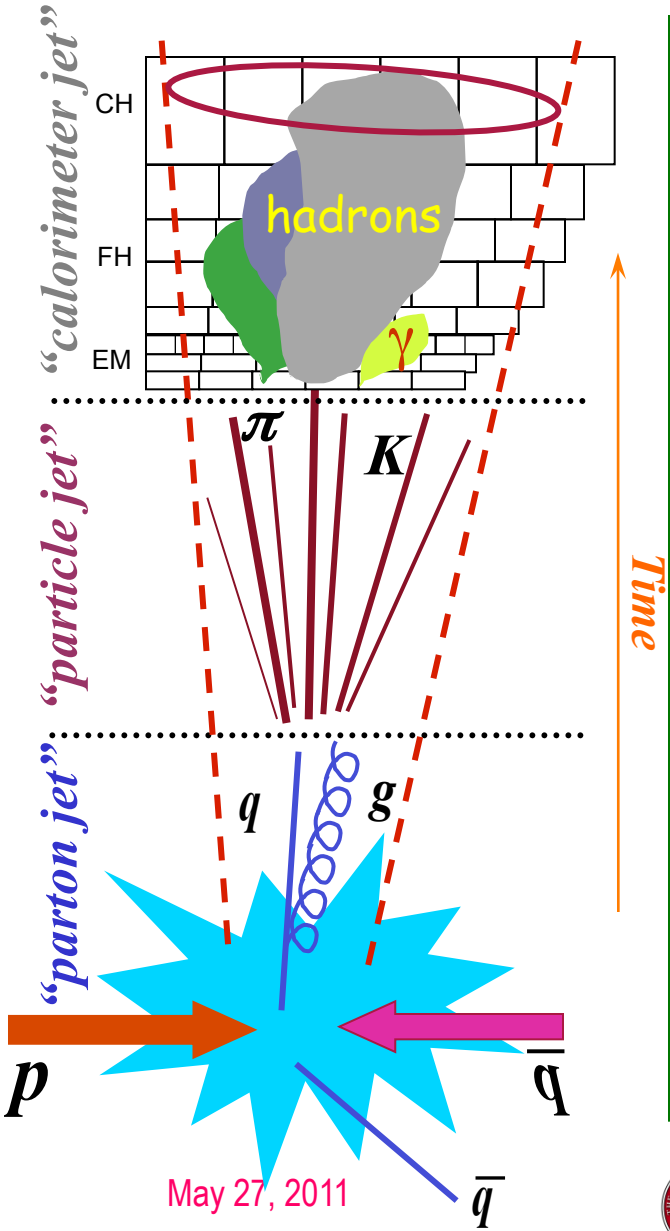
- **Weighs 7000 tons and 10 story tall**
- Can inspect **1,000,000,000** collisions/second
- Records **200 – 400 collisions/second**
- Records approximately **350,000,000** bytes/ second
- Record **2x10^{15}** (2,000,000,000,000,000) bytes each year (2 PetaByte). ➔ **200*Printed material of the US Lib. of Congress**

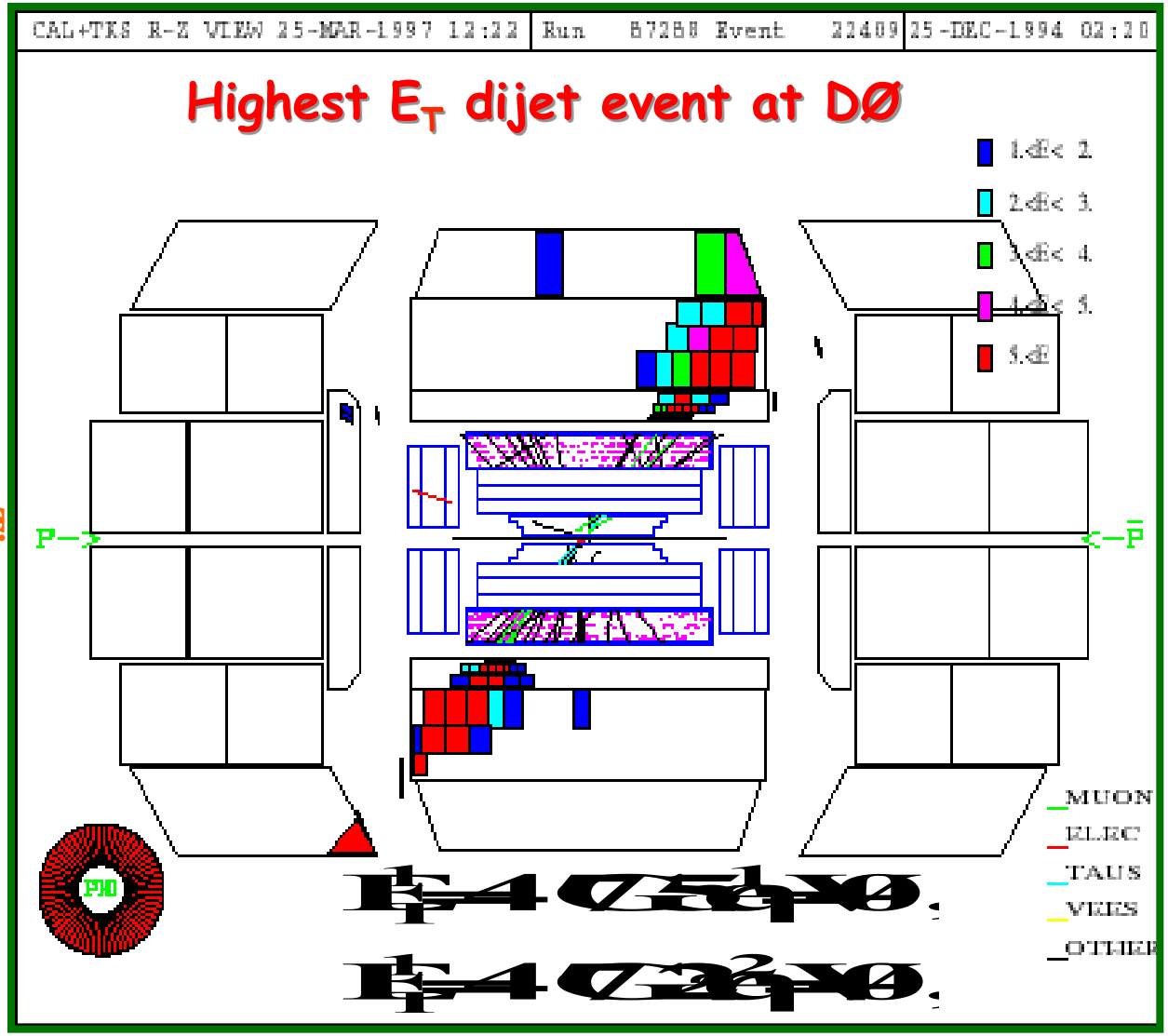


Digital data

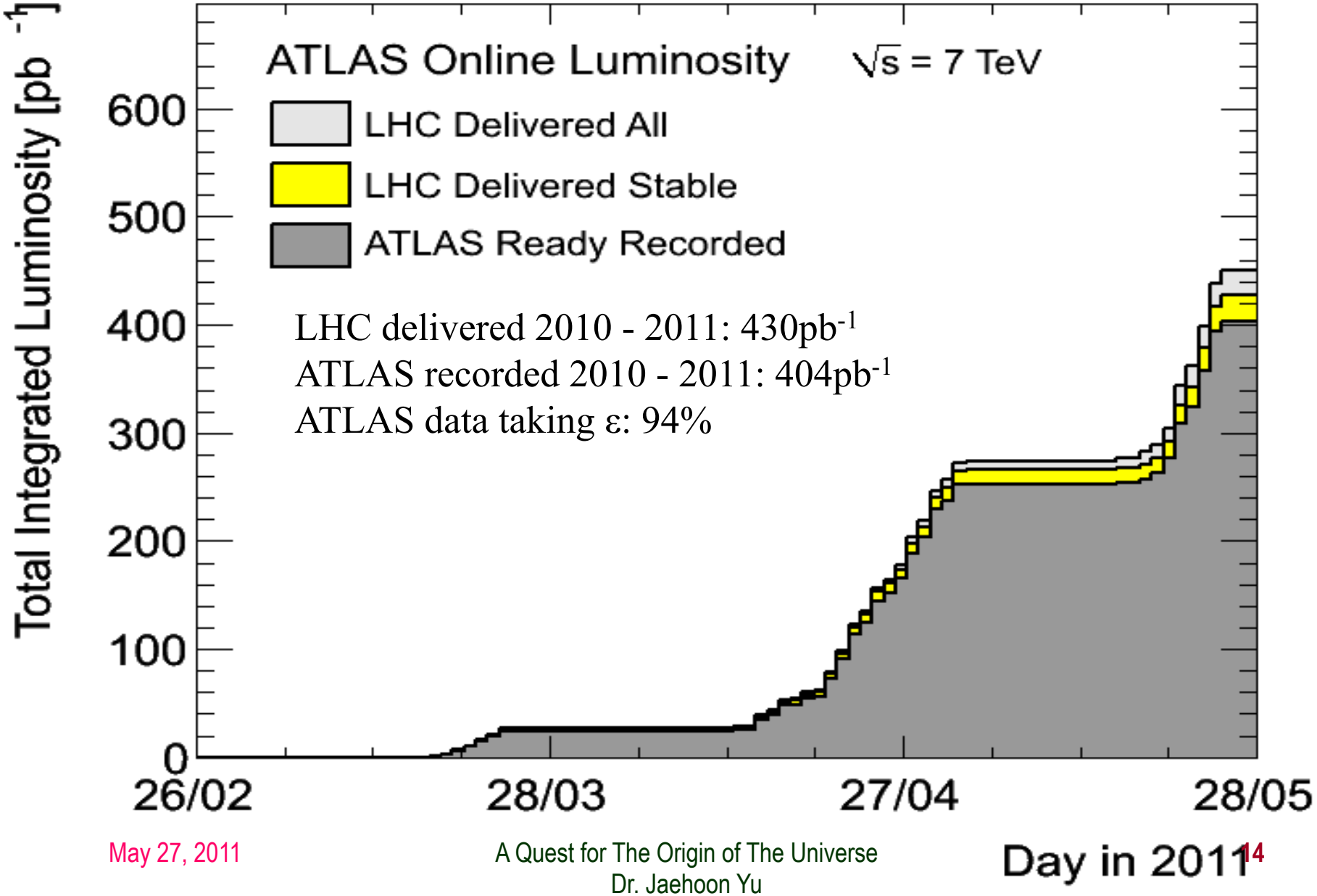
Data Reconstruction

How does an Event Look in a Collider Detector?

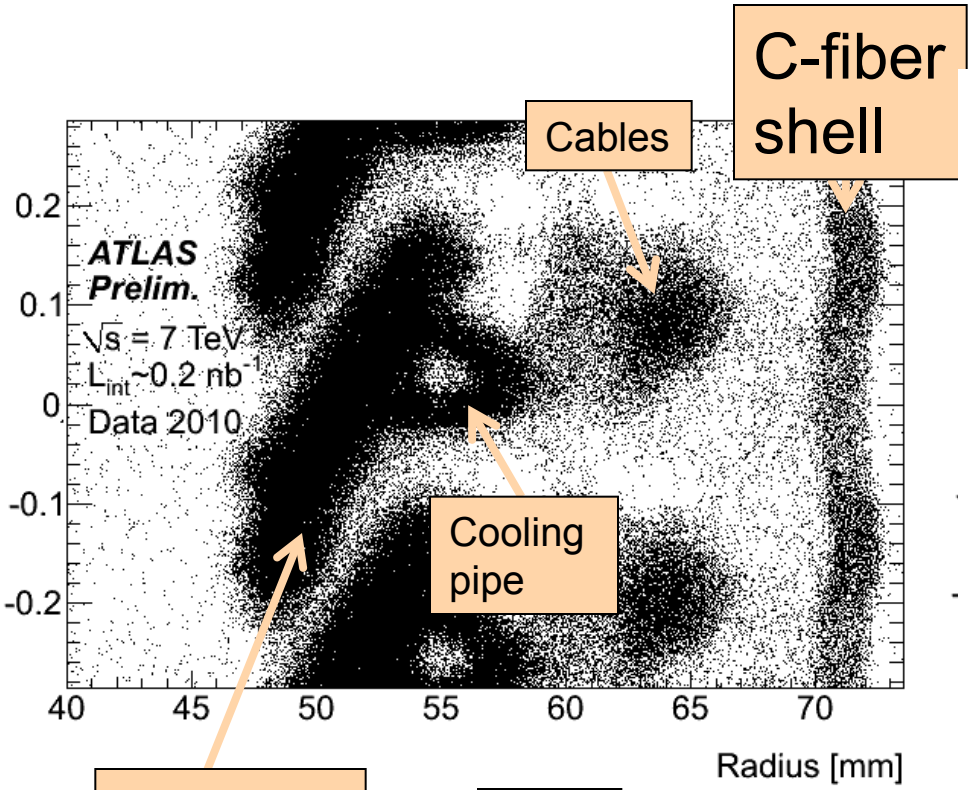




ATLAS Integrated Luminosity in 2011



Step one: Understanding the ATLAS Detector



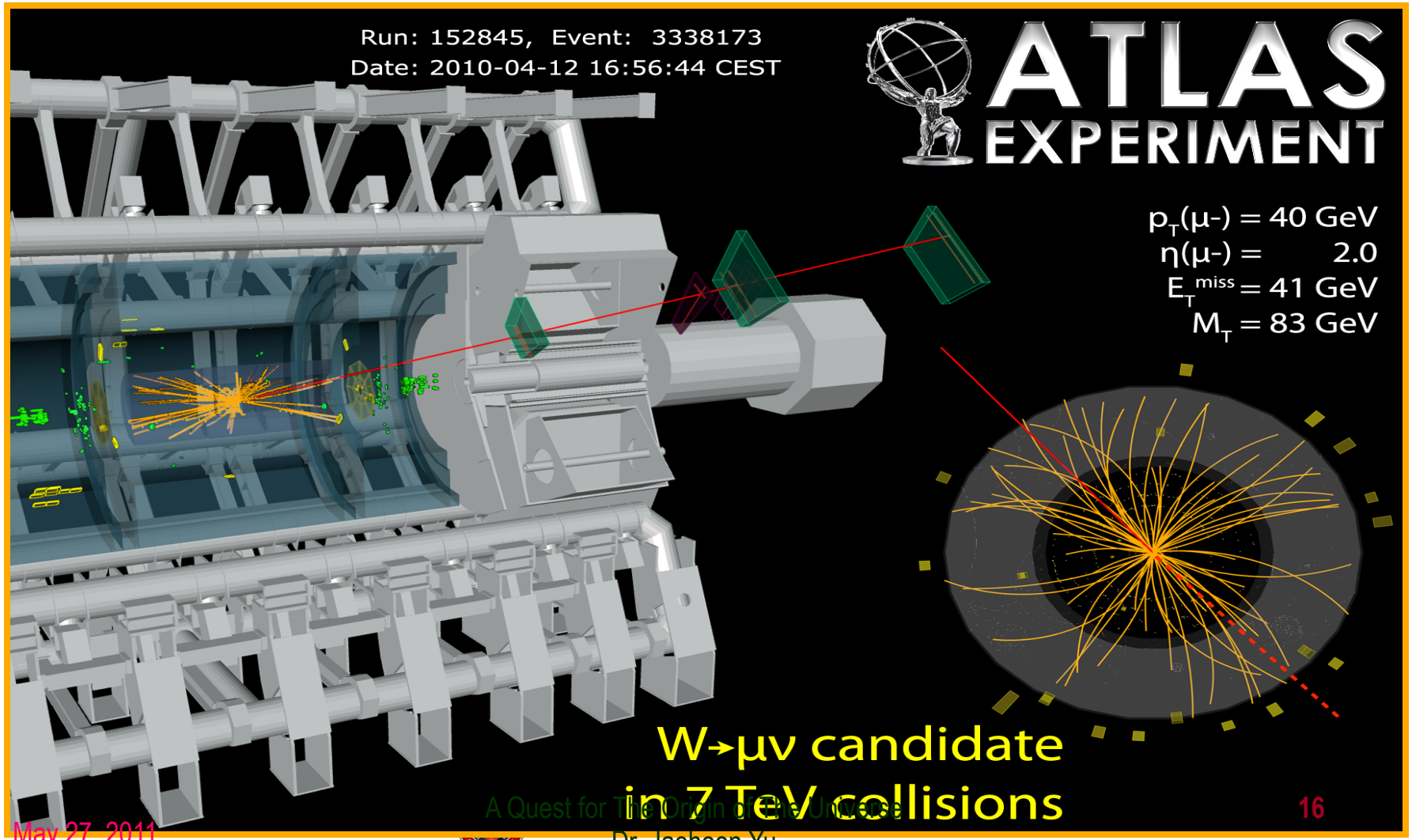
Data

Simulation

This technique is sensitive to interaction length instead of radiation length.

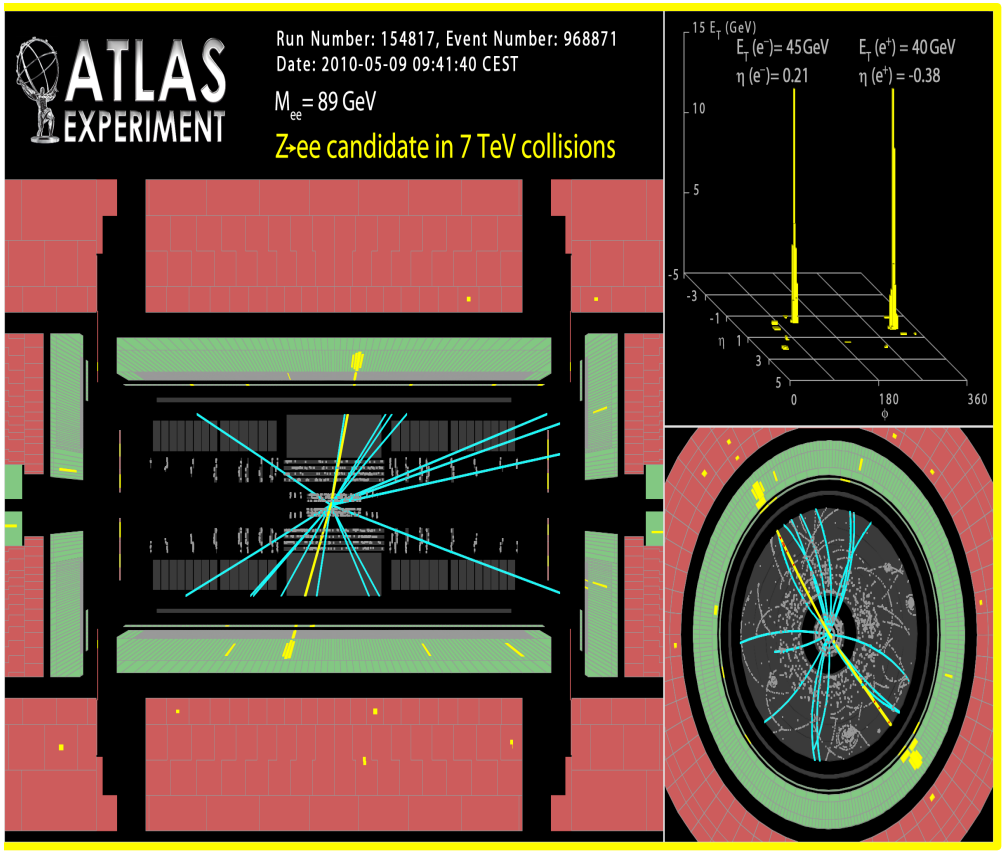
Step two: Verify SM ➔ Weak Bosons

- Important first steps are the verification of the Standard Model physics at $\sqrt{s}$ = 7 TeV
- W/Z weak vector boson are powerful tools to constrain PDF's and to understand detector

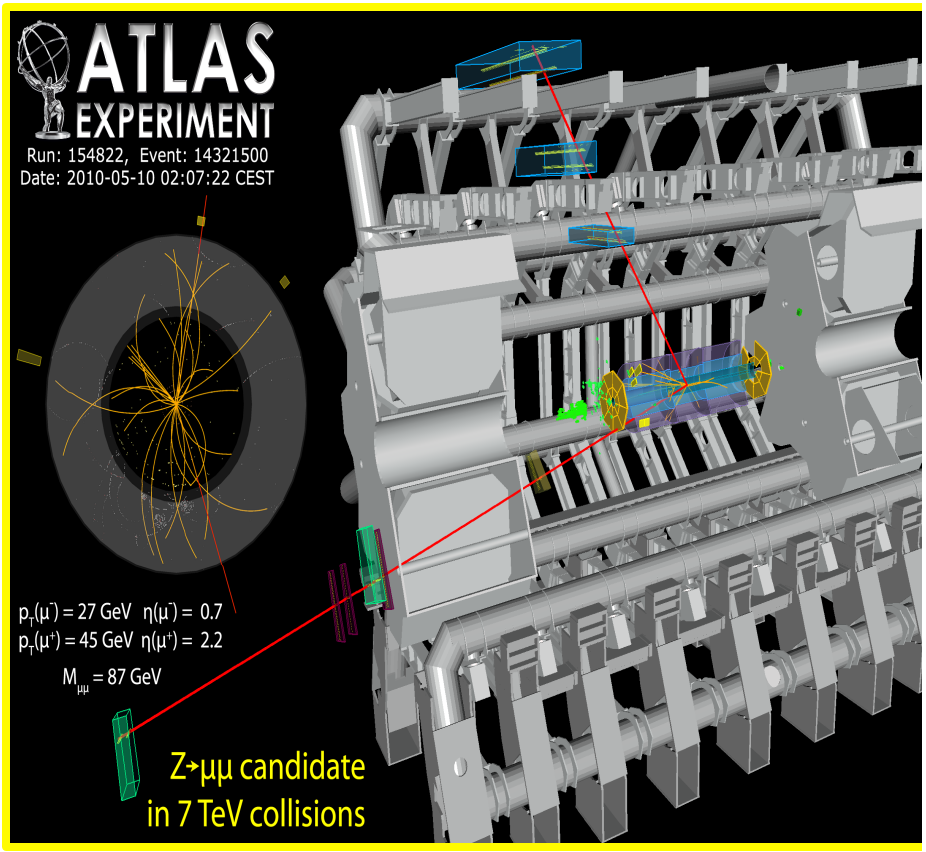


Of course, we see Z → ee and μμ!!

Z → ee candidate



Z → μμ candidate

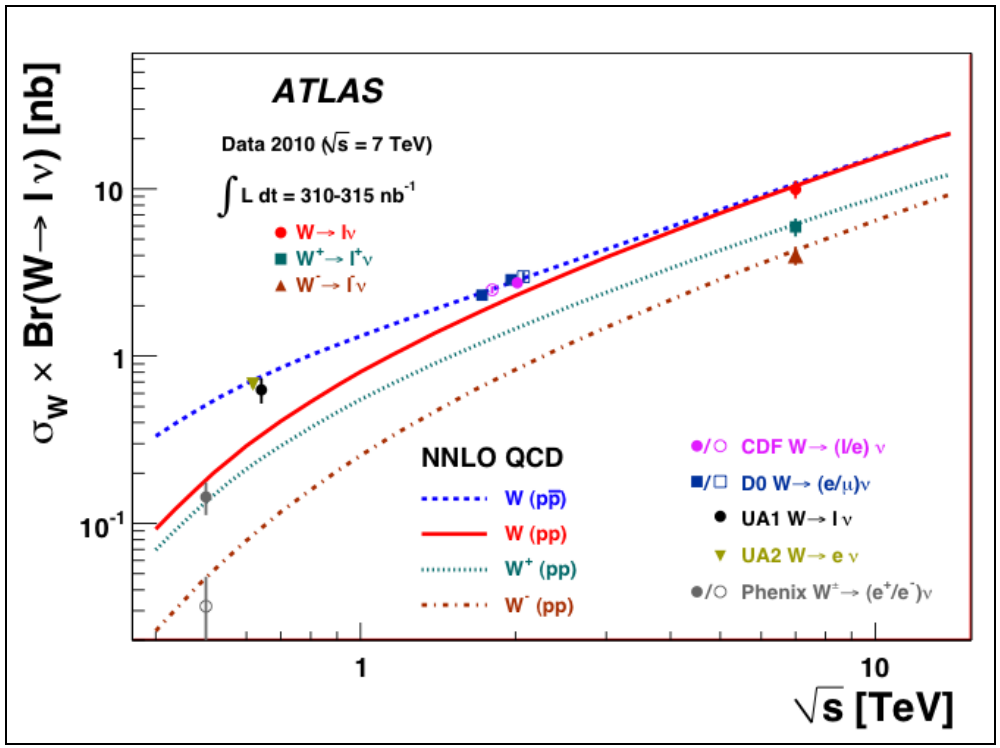


Total efficiency : ~ 30%
Main background: QCD
S/B ~ 100

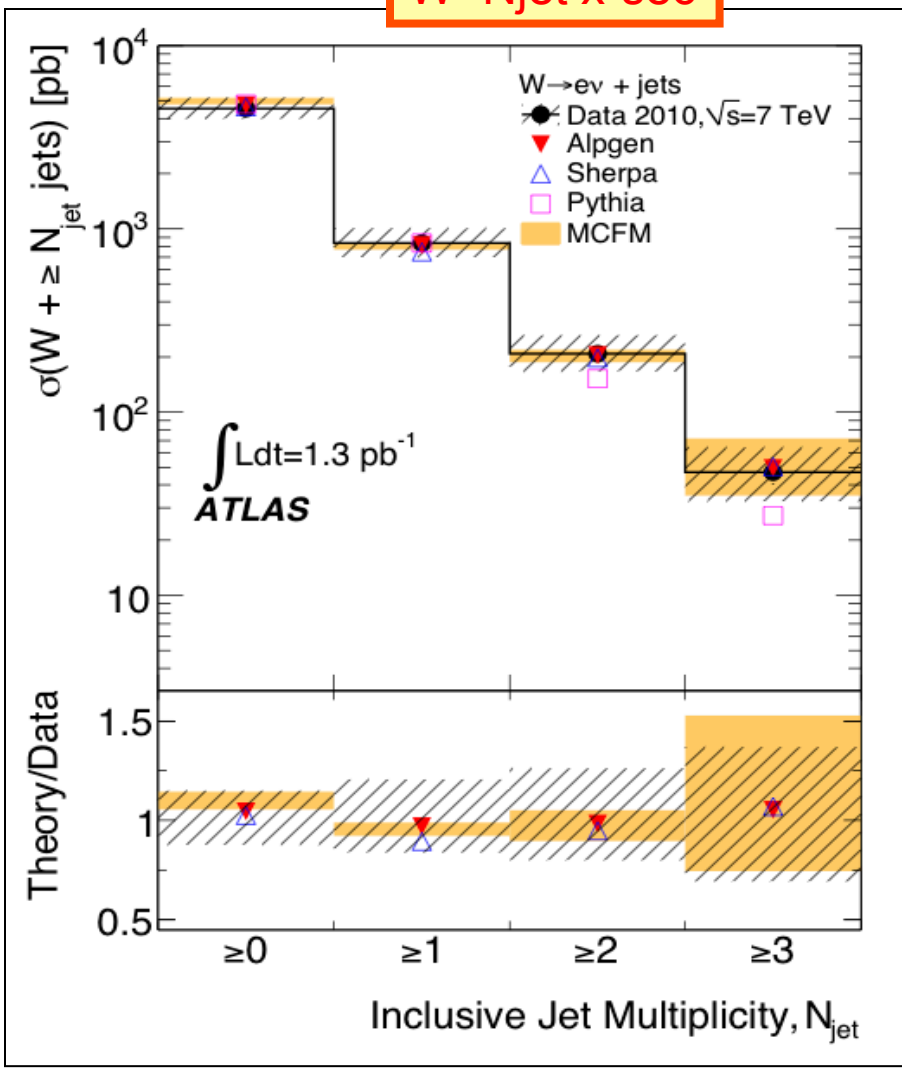
Total efficiency: ~ 40%
Main background: tt, Z→ ττ
S/B ~ 400

Step 3: Understanding SM background to Higgs!!

W x-sec vs CMS Energy



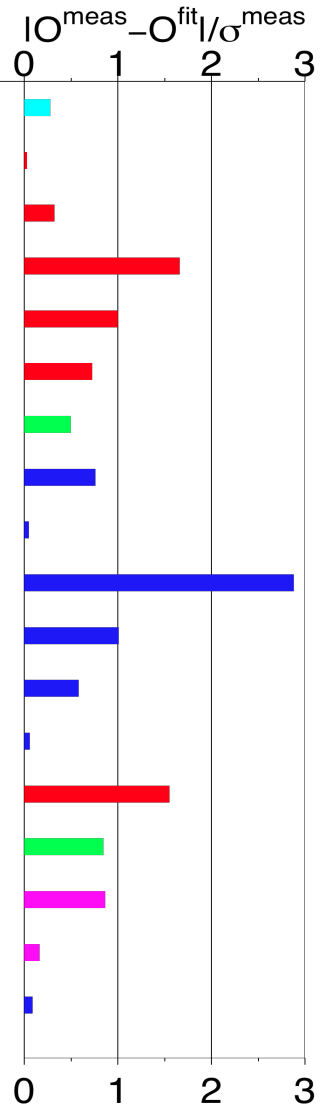
W+Njet x-sec

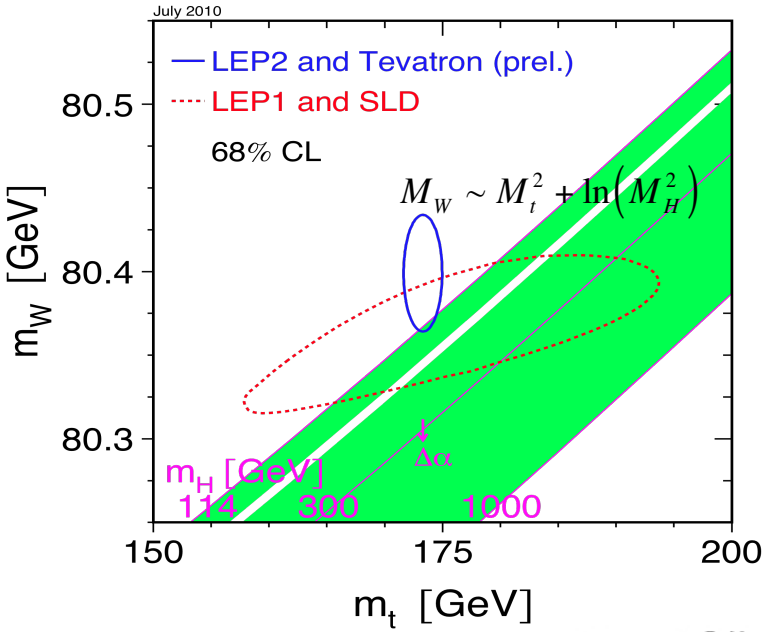


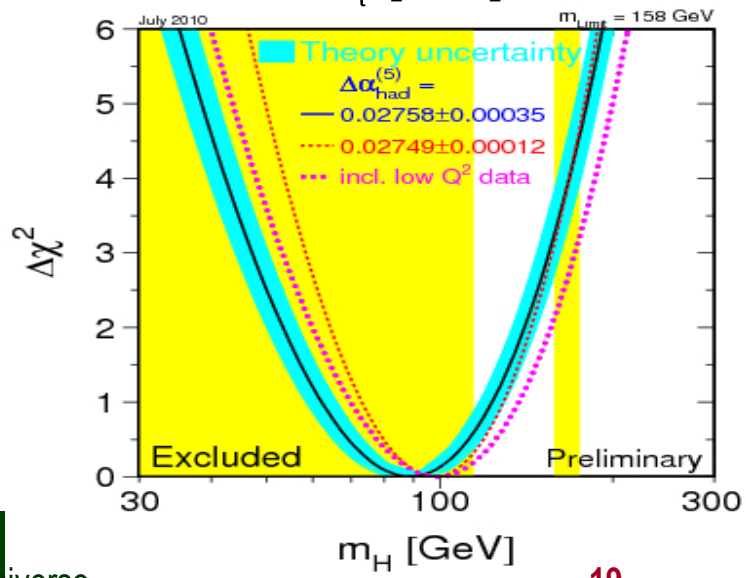
Validation of theoretical predictions!!

What do we know now on Higgs?

	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959
σ^0_{had} [nb]	41.540 ± 0.037	41.479
R_l	20.767 ± 0.025	20.742
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21579
R_c	0.1721 ± 0.0030	0.1723
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.399 ± 0.023	80.379
Γ_W [GeV]	2.085 ± 0.042	2.092
m_t [GeV]	173.3 ± 1.1	173.4



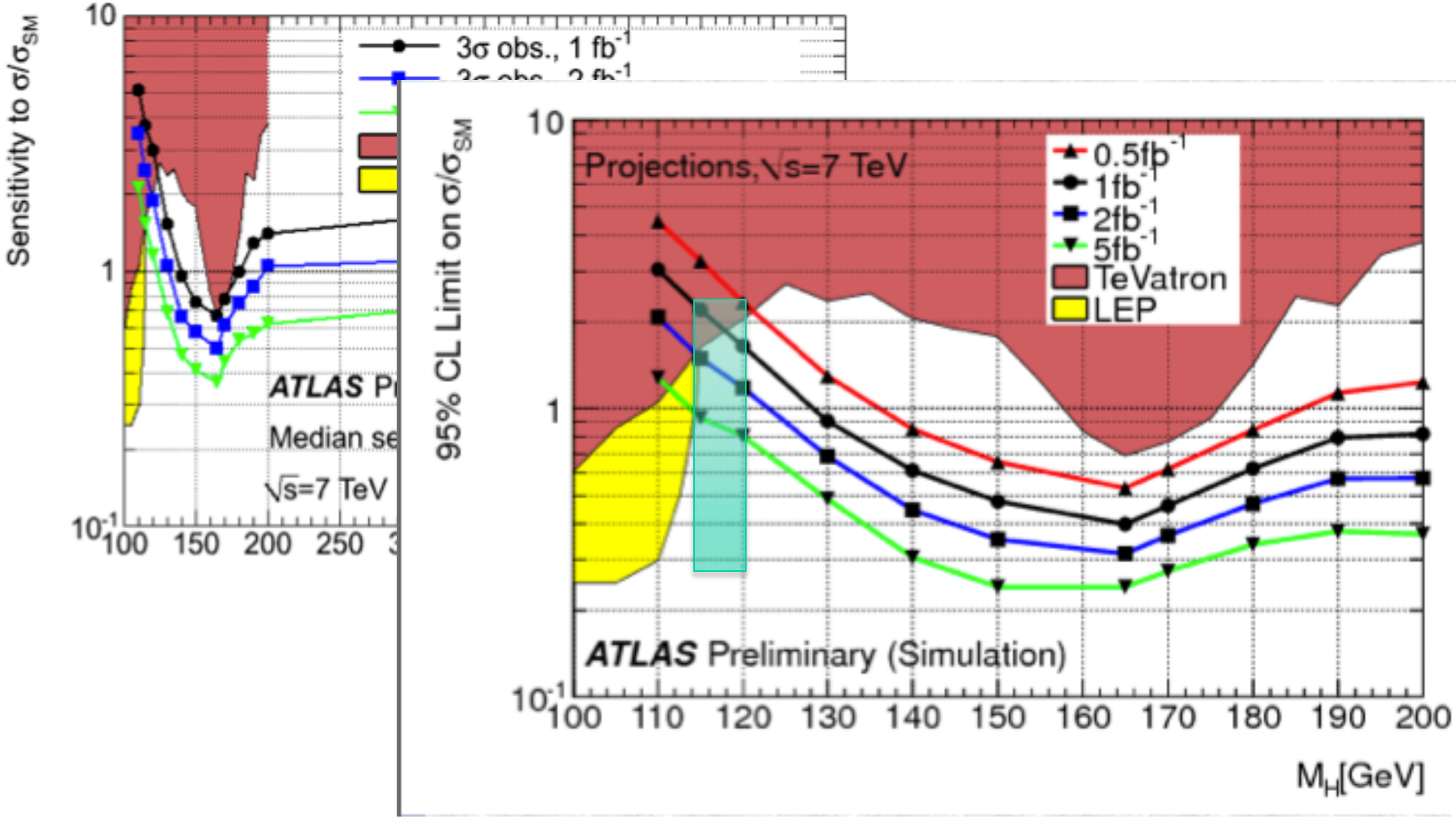




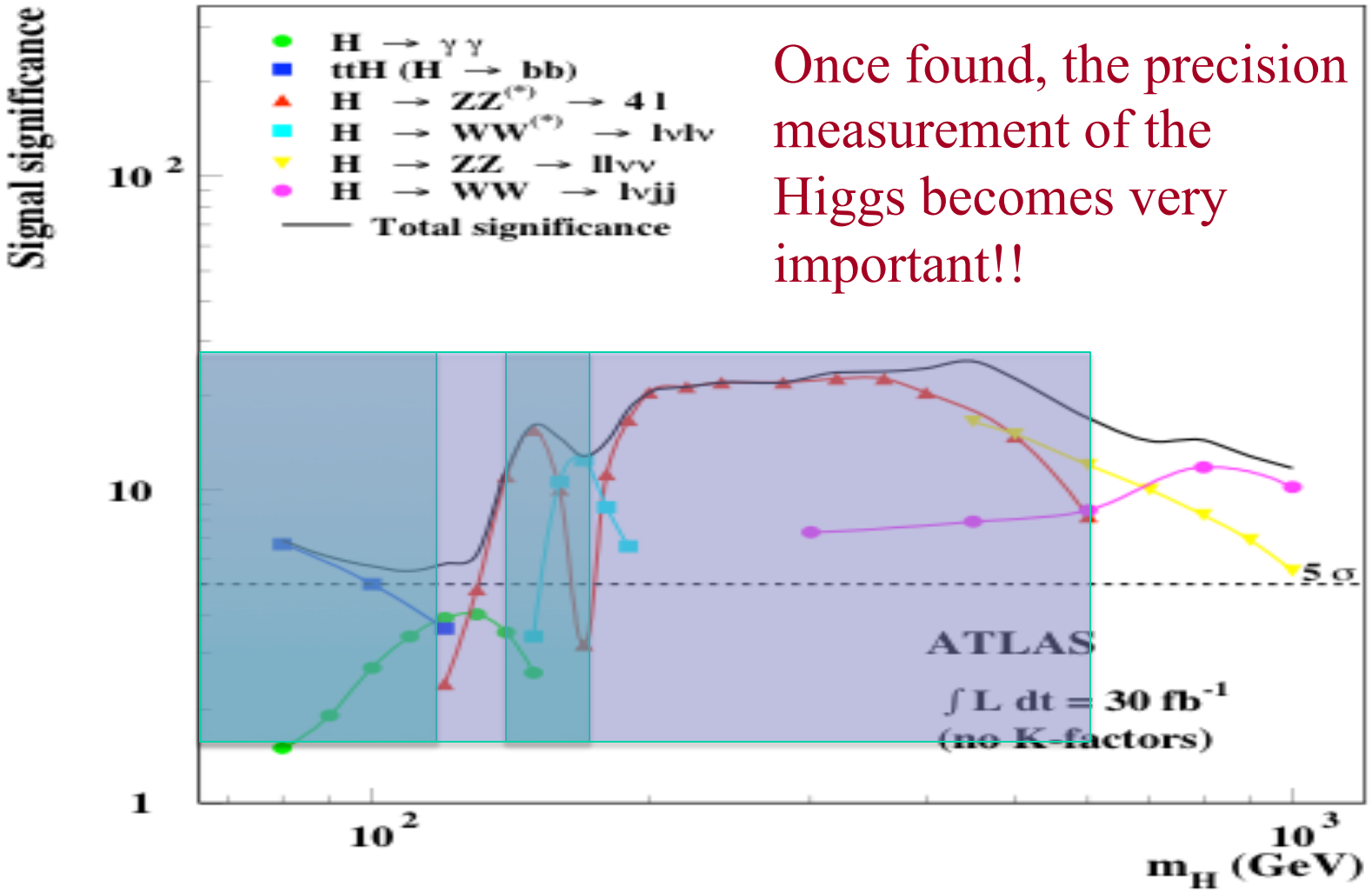
LEP EWWG: http://www.cern.ch/LEPEWWG

$114 < M_H < 300+700-186$ GeV

ATLAS 7TeV Expectation??



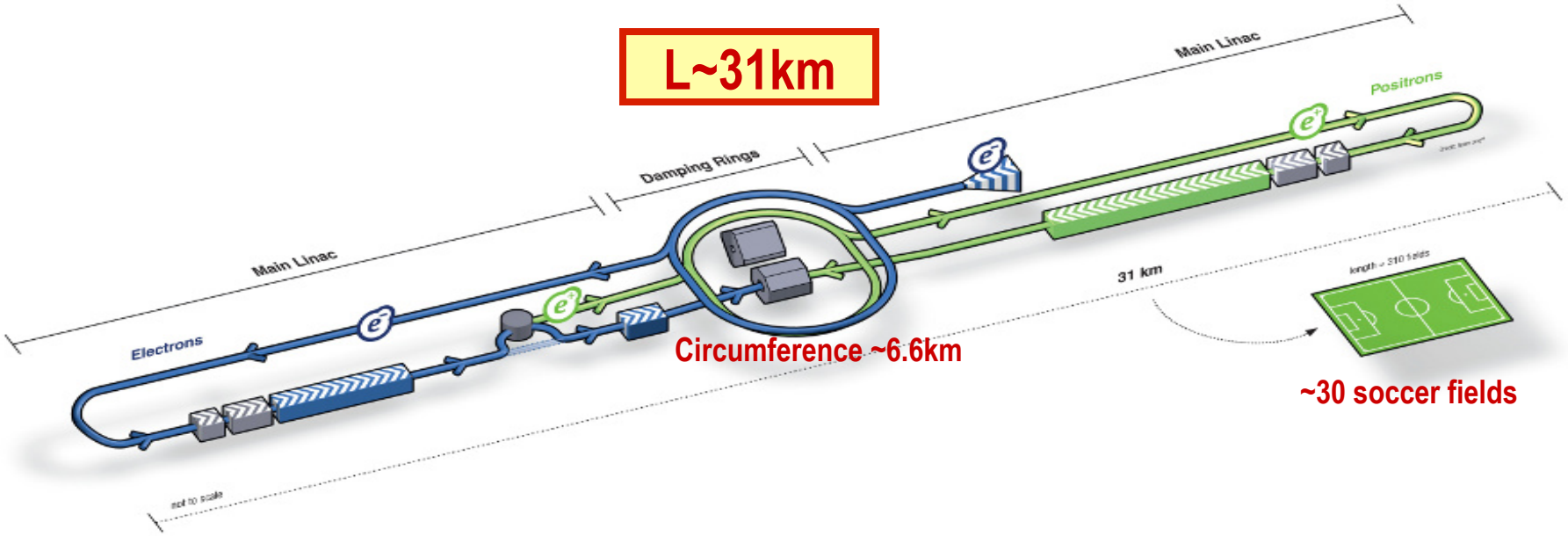
ATLAS 14TeV Expectations for Higgs



Once found, the precision measurement of the Higgs becomes very important!!

A Future Linear Collider

- An electron-positron collider on a straight line for precision measurements
- CMS Energy: 0.5 – 1 TeV
- 10~15 years from now
- Takes 10 years to build the accelerator and the detector



Particle Flow Algorithm for precision measurements

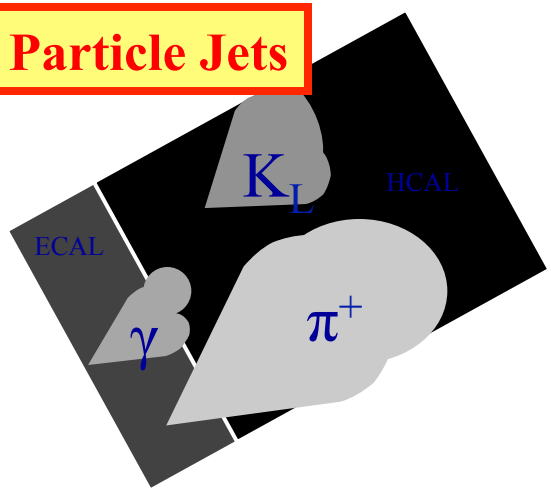
The idea…

Charged particles } measured with the { **Tracker**

Neutral particles } { **Calorimeter**

$$E_{jet} = \sum_{Charged\ Particles} P_{TRK} + \sum_{EM\ particles} E_{ECAL} + \sum_{Neutral\ Hadrons} E_{HCAL}$$

Particle Jets



Particles in jets	Fraction of energy	Measured with	Resolution [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with 15%/√E	$0.07^2\ E_{jet}$
Neutral Hadrons	10 %	ECAL + HCAL with 50%/√E	$0.16^2\ E_{jet}$
Confusion		Required for 30%/√E	**$\leq 0.24^2\ E_{jet}$**

} 18%/√E

Requirements on detector

→ Need excellent tracker and high B – field
→ Large R_I of calorimeter
→ Calorimeter inside coil
→ Calorimeter with extremely fine segmentation

Figure of merit BR_I^2

Gas Electron Multipliers (GEM)

GEM foil etching

Fig. 14 (a) Chemical etching Process of a GEM (b) A GEM foil

A new concept of gas amplification was introduced in 1996 by Sauli: the Gas Electron multiplier (GEM) [27] manufactured by using standard printed circuit wet etching techniques' schematically shown in Fig. 14(a). Comprising a thin (~50 μm) Kapton foil, double sided clad with Copper, holes are perforated through (fig. 15b). The two surfaces are maintained at a potential gradient, thus providing the necessary field for electron amplification, as shown in Fig. 15(a), and an avalanche of electrons as in Fig. 15(b).

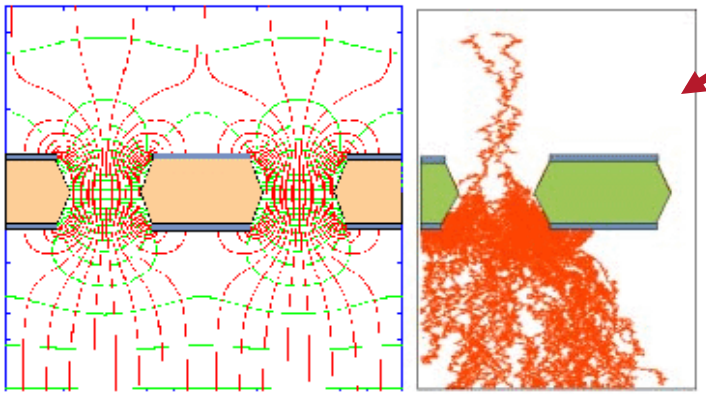
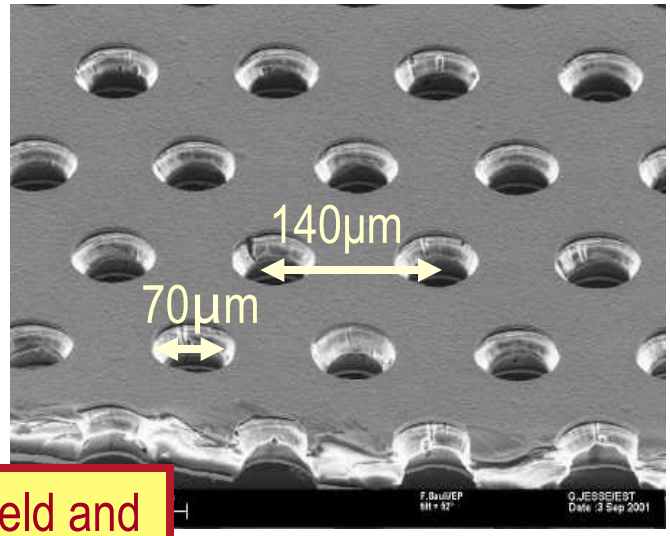
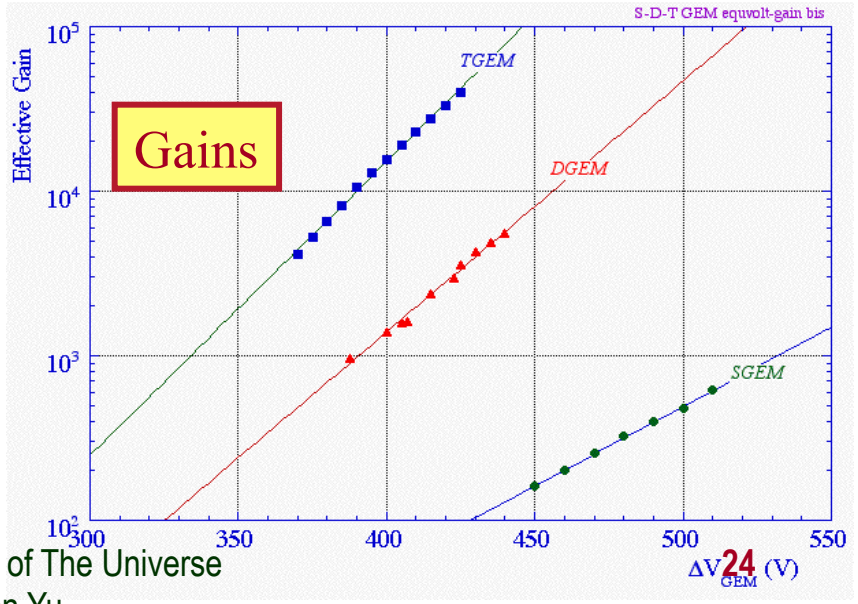


Fig. 15(a) Electric Field and (b) an avalanche across a GEM channel

Coupled with a drift electrode above and a readout electrode below, it acts as a highly performing microparttern detector. The essential and advantageous feature of this detector is that amplification and detection are decoupled, and the readout is at zero potential. Permitting charge transfer to a second amplification device, this opens up the possibility of using a GEM in tandem with an MSGC or a second GEM.



GEM field and multiplication



From CERN-open-2000-344, A. Sharma

How does a GEM chamber work?

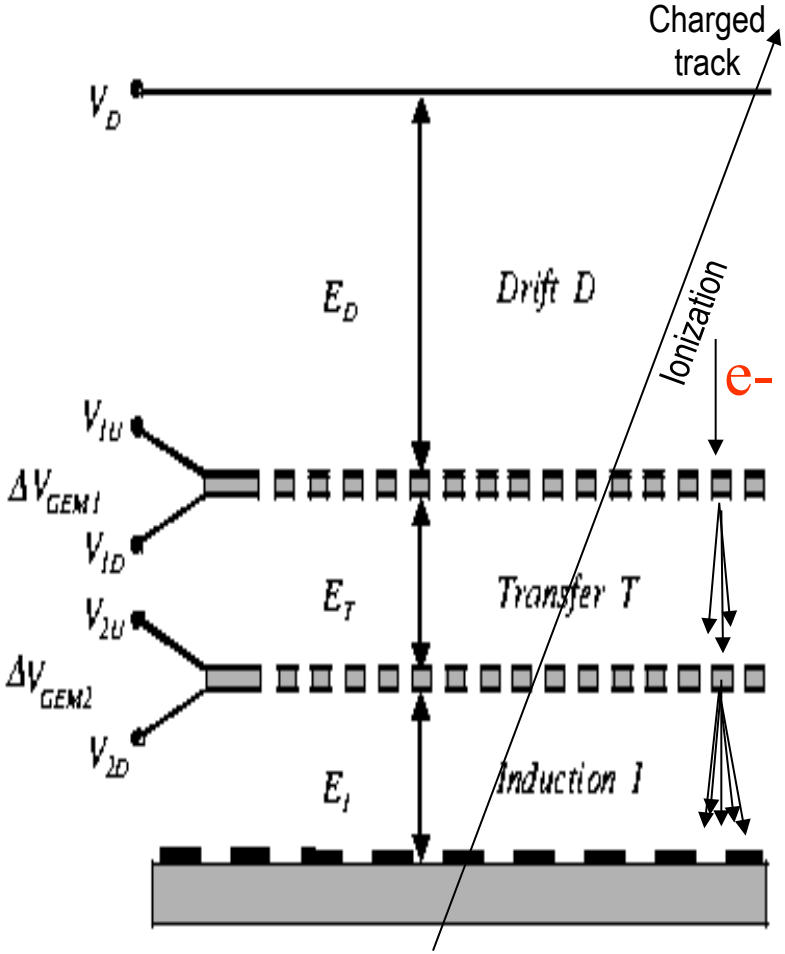


Fig. 1: Schematics of a double-GEM detector.

-2100V

ΔV ~400V

ΔV ~400V

0V

How large is the electric field across a GEM foil?

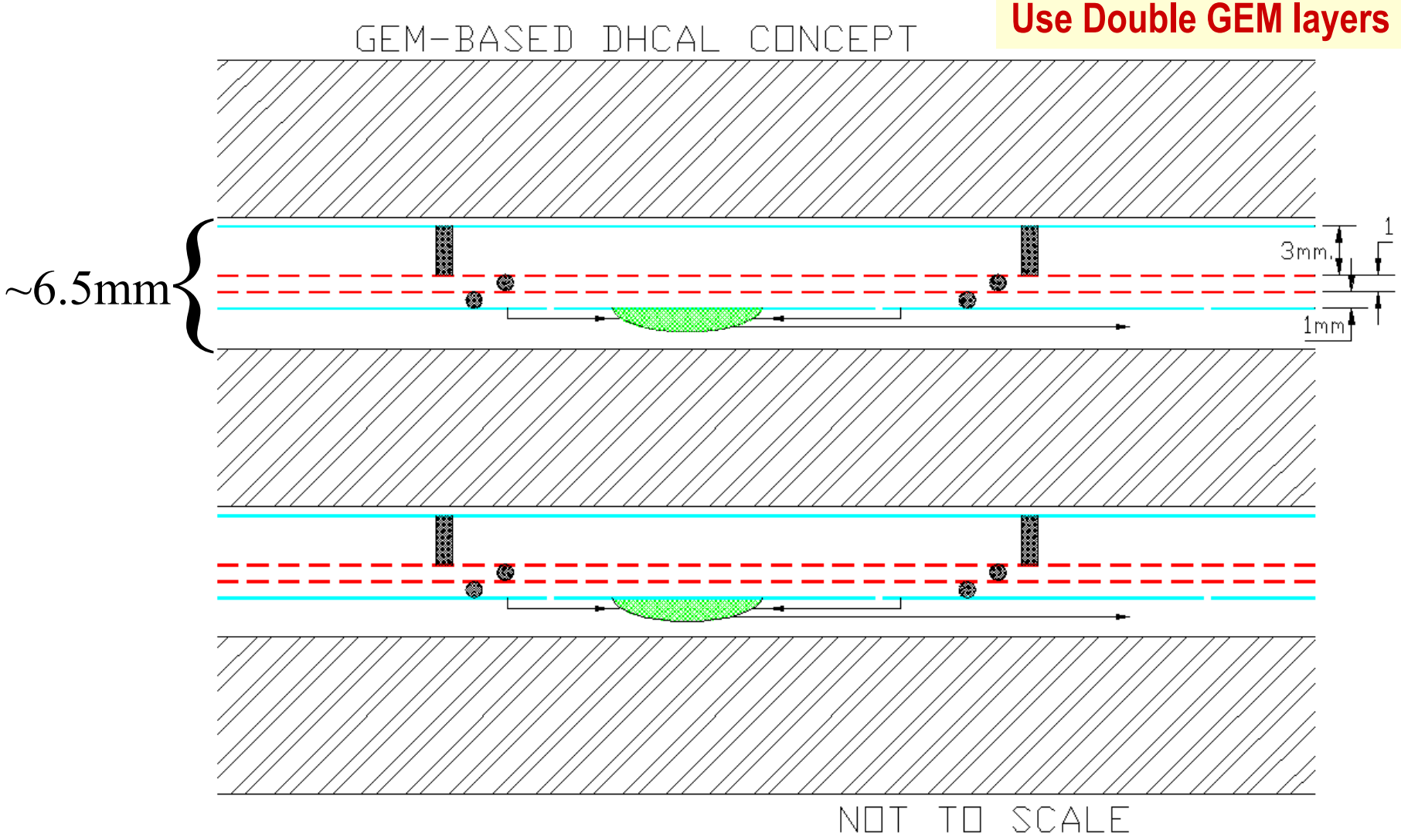
$E = V/d$

$= 400V/6x10^{-5}cm \sim 6.7x10^{5}V/cm$

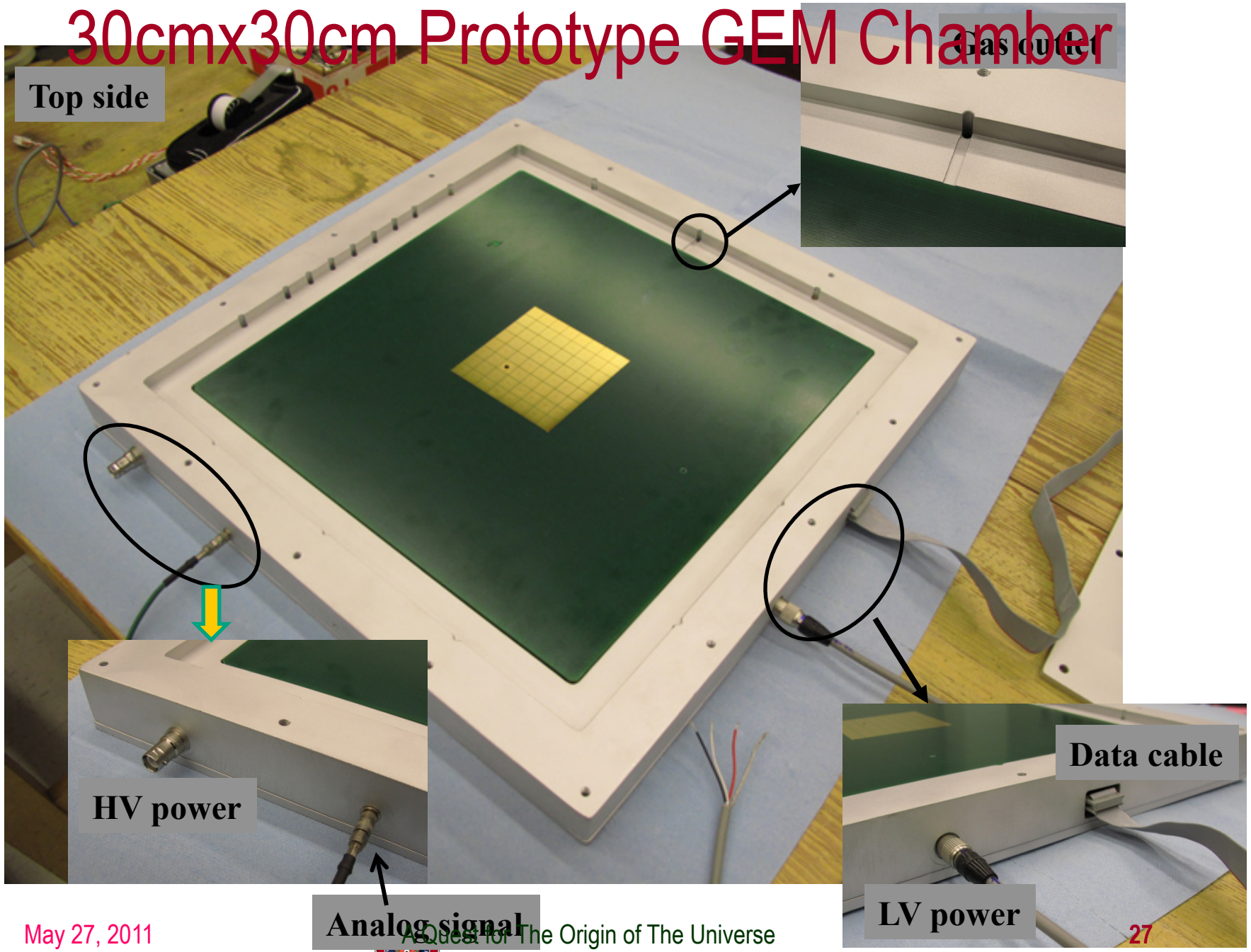
- Sensitive to a wide range of particles, from low E γ-rays and X-rays to several TeV charged particles
- Flexible with high position resolution and high efficiency ➔ Good imaging device
- Relatively low operational voltage
- Can operate with normal operational gas – $ArCO_2$ or other noble gasses (such as Xe)
- Short response time ~ 50ns
- **High gain (10^2 /layer @400V)**
- Robust to high flux radiation

GEM-based Digital Calorimeter Concept

Use Double GEM layers

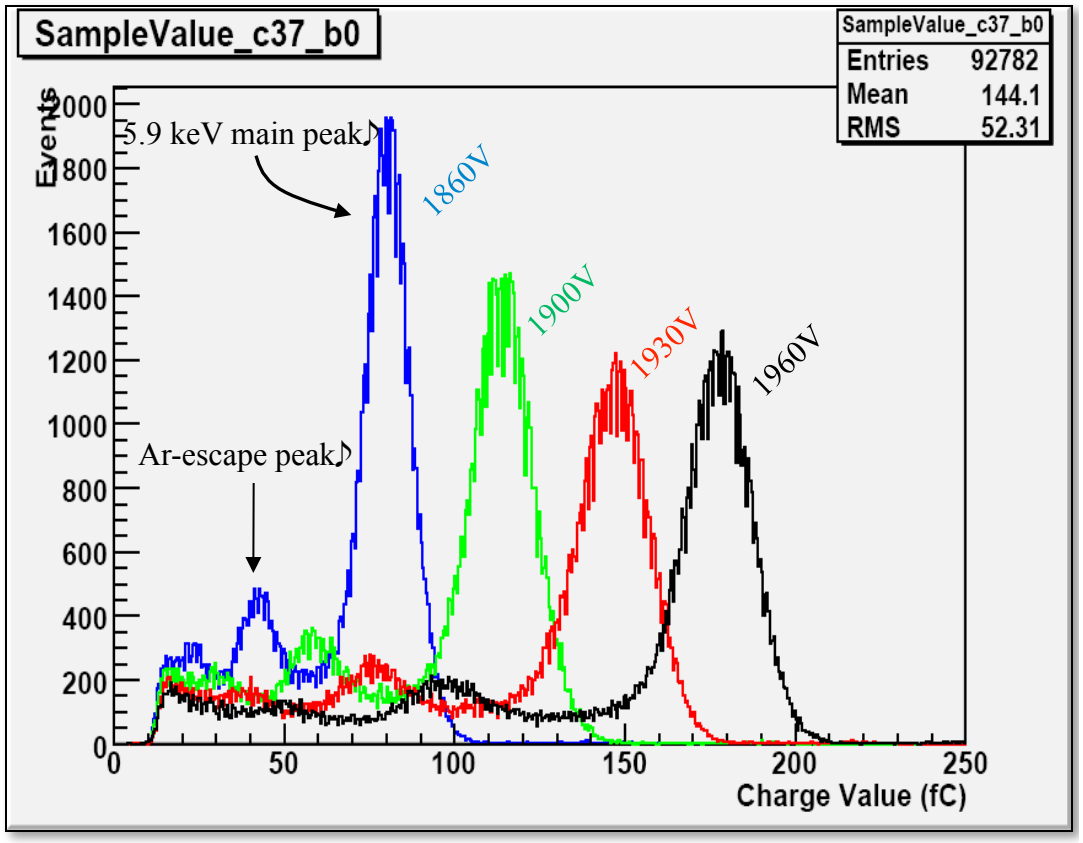


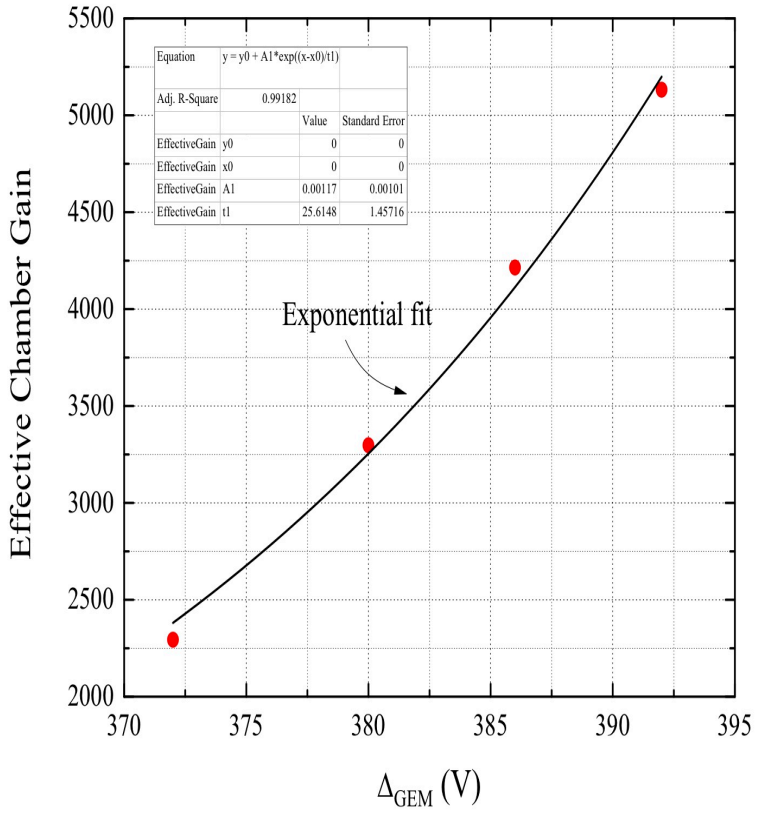
30cmx30cm Prototype GEM Chamber



^{55}Fe Spectrum vs HV and Chamber Gain

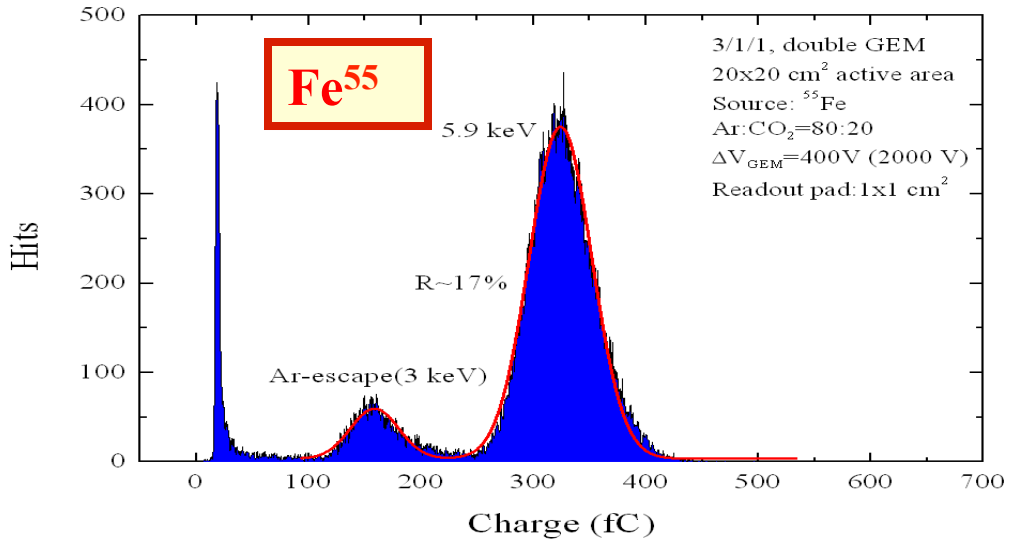
Fe55, Self Trigger Th=2.1V=8 fC

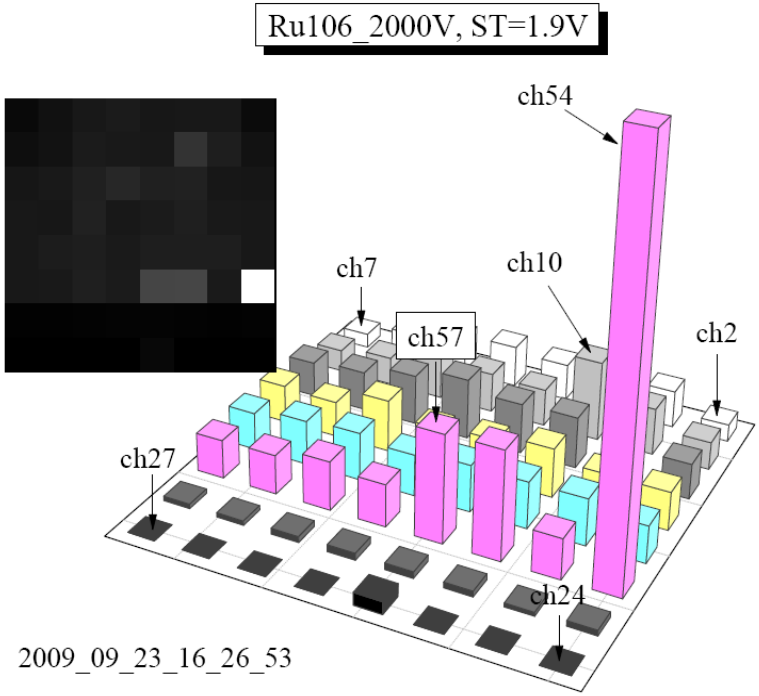


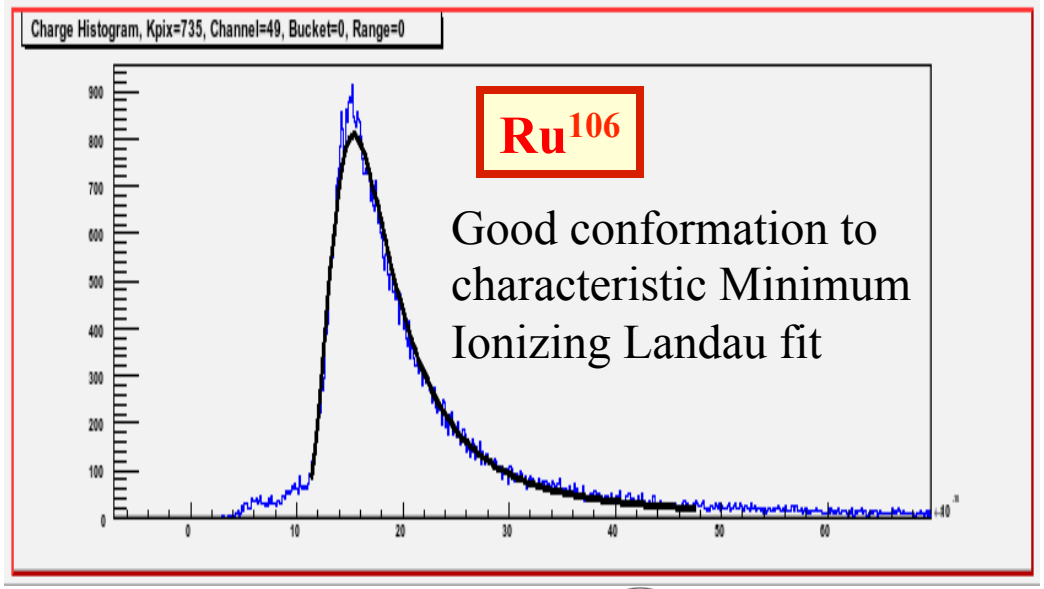


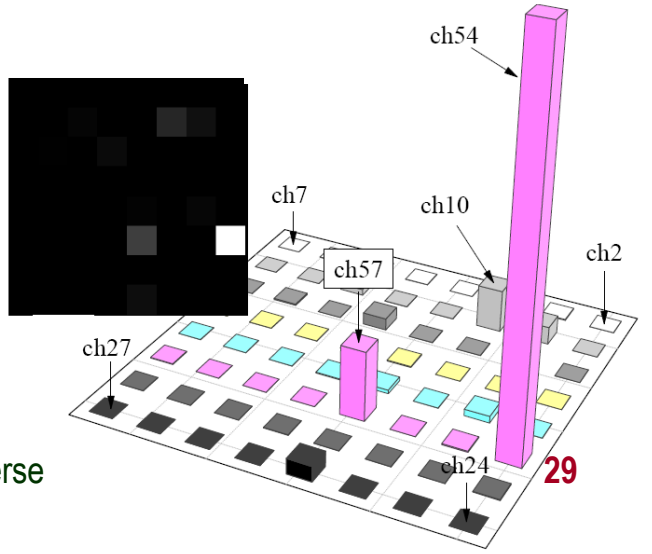
- ✓ Fe55: Observed both 5.9 keV main peak, 3 keV Ar-escape peak
- ✓ Effective gain consistent with previous results♪

GEM Fe^{55} and Ru^{106} Spectra

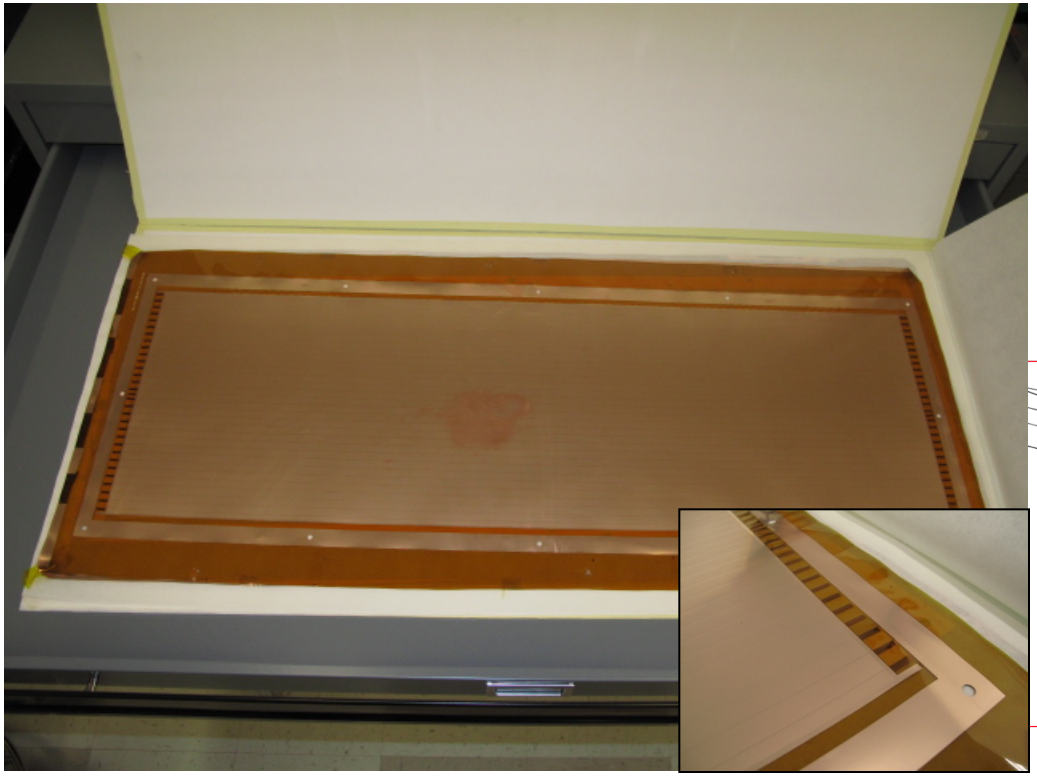




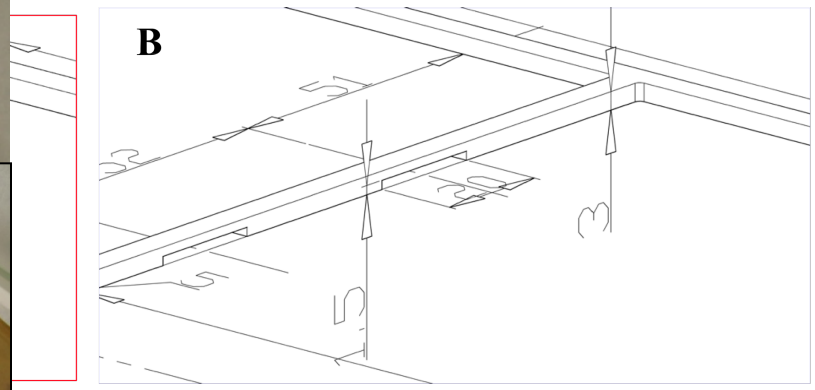




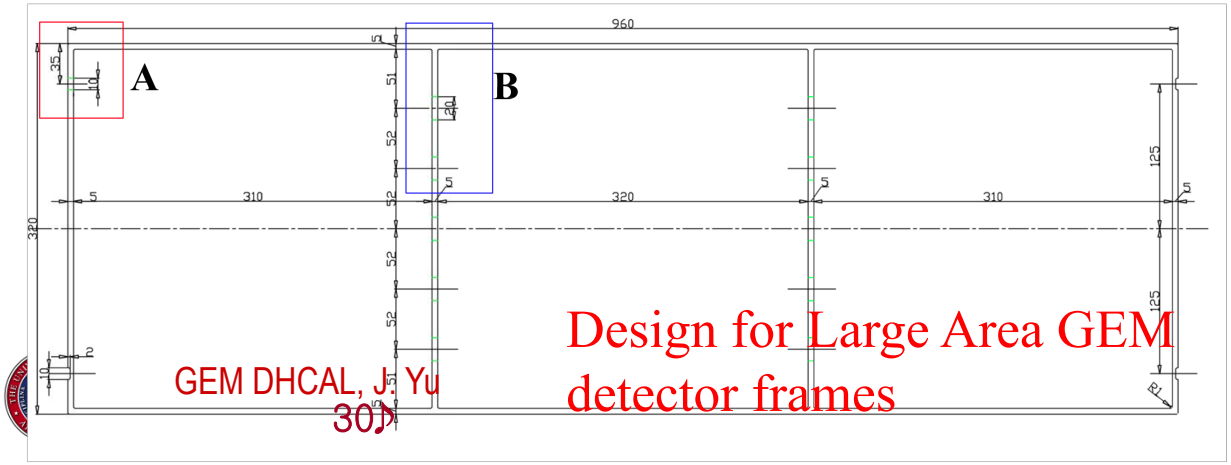
33cmx100cm Large Area GEM



First 5 of 33cmx100cm GEM foils delivered in 2010

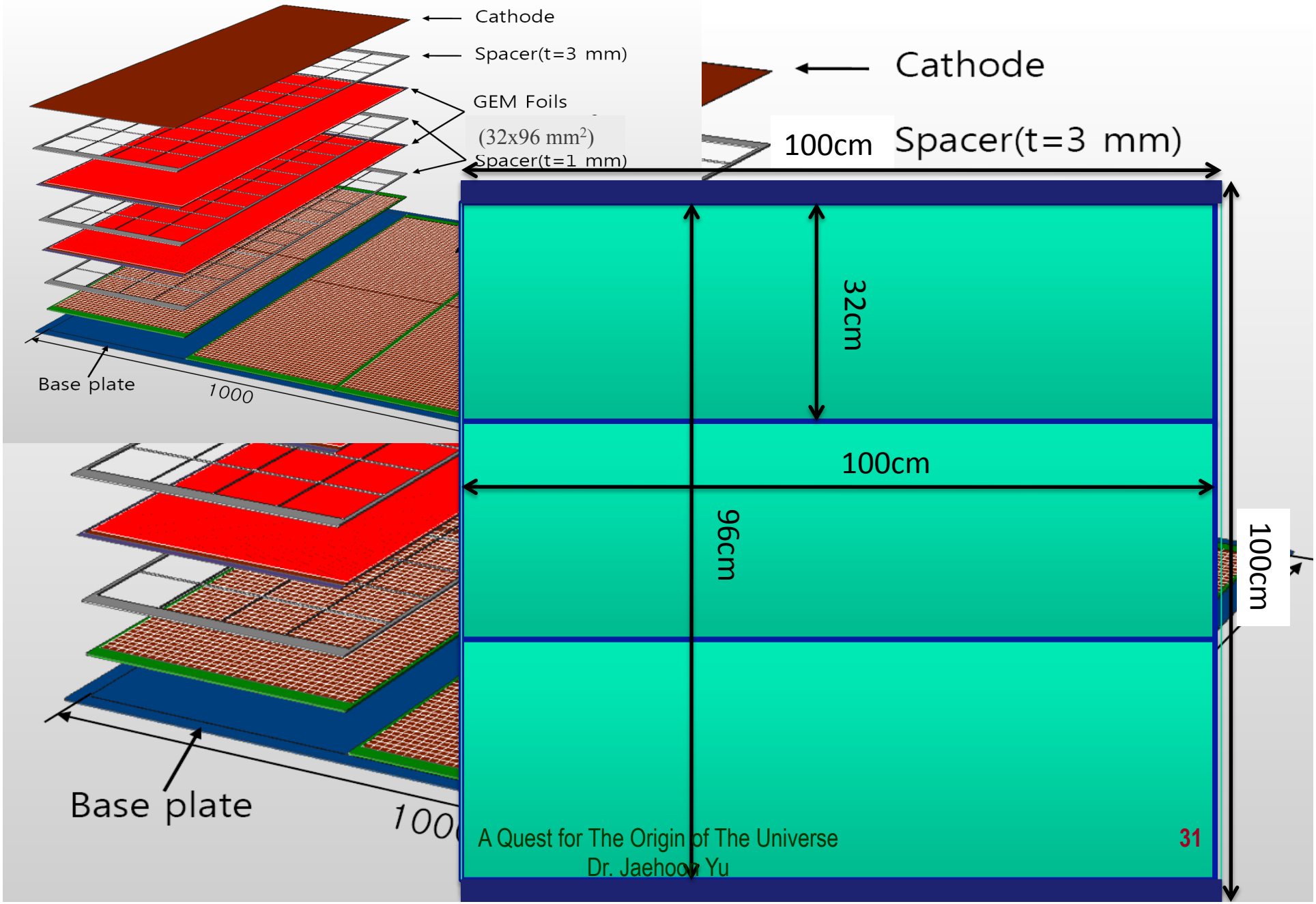


Spacer for drift gap

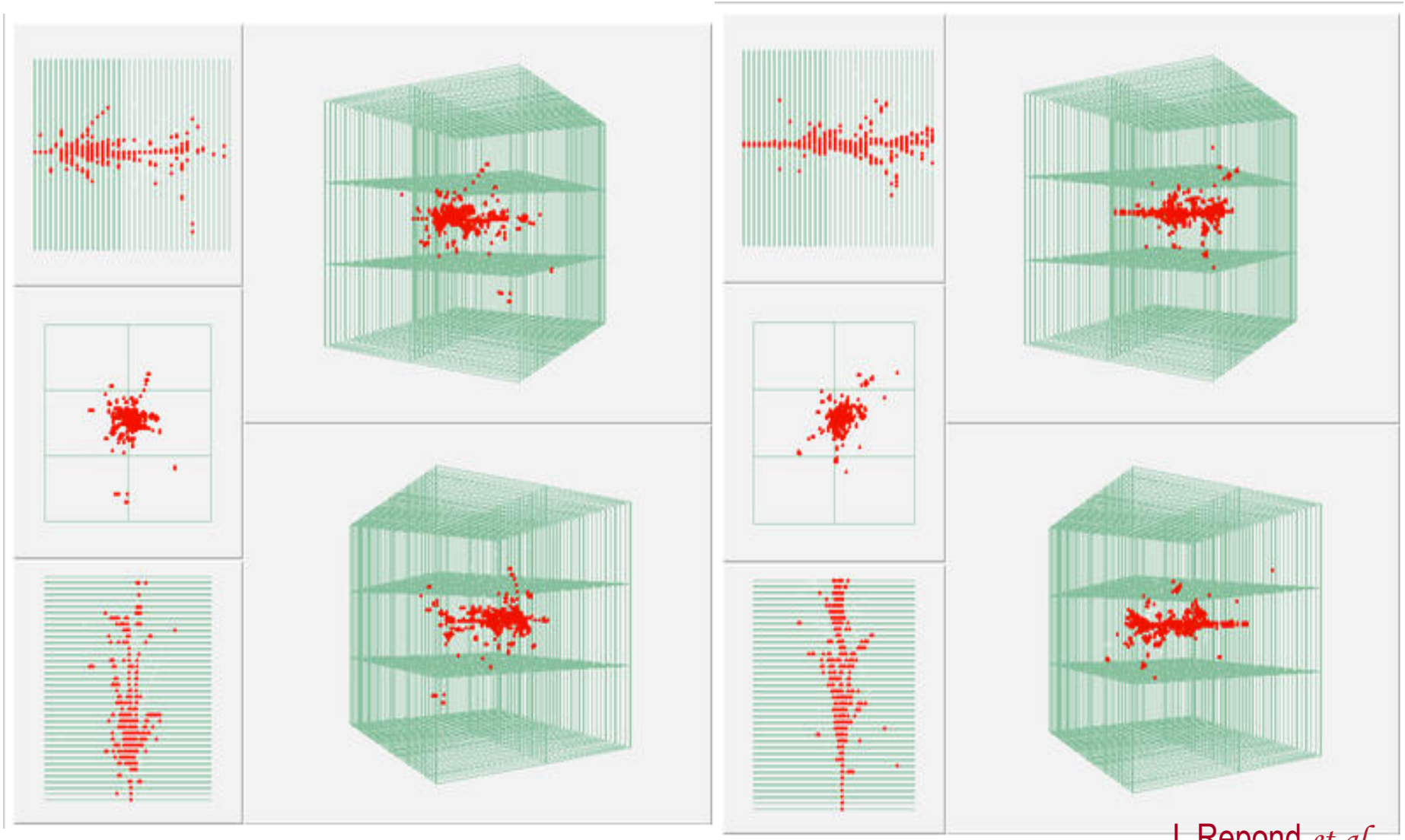


Design for Large Area GEM detector frames

UTA's 100cmx100cm Digital Hadron Calorimeter Plane



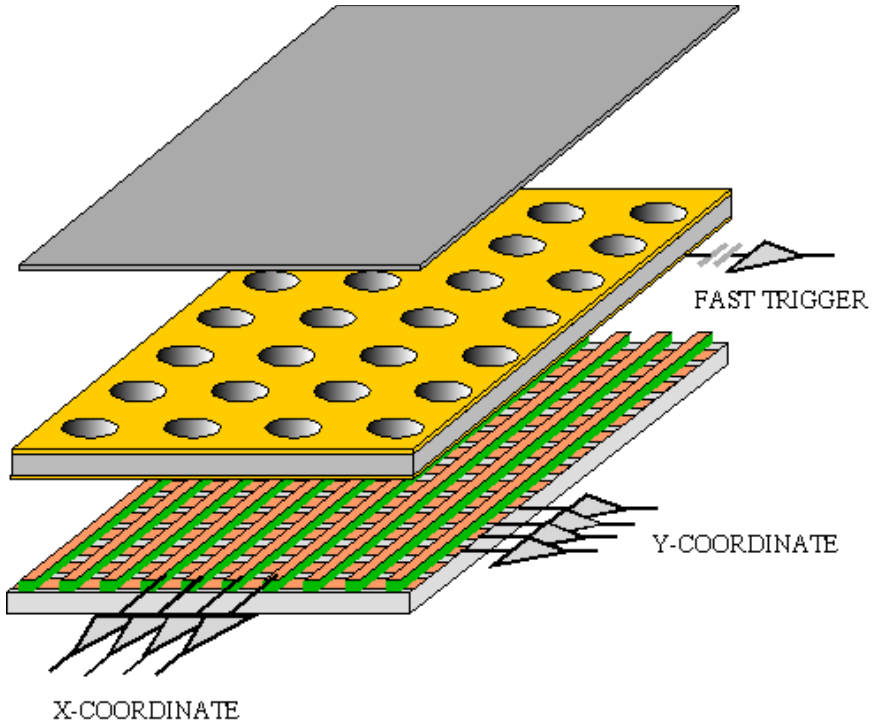
A DHCAL Beam Test Result



J. Repond *et al.*

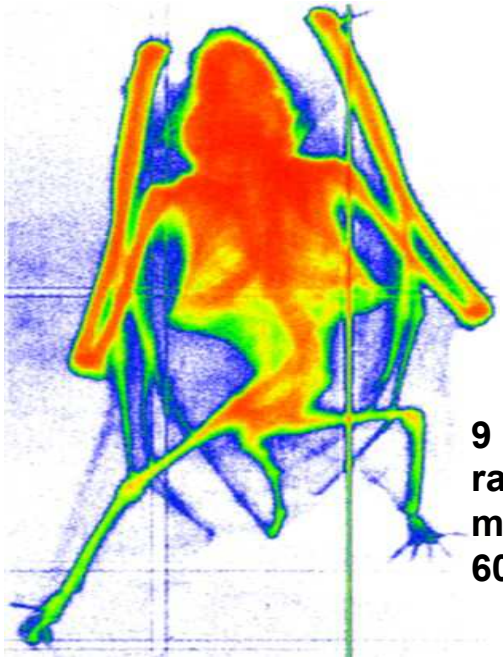
GEM Application Potential

Using the lower GEM signal, the readout can be self-triggered with energy discrimination:



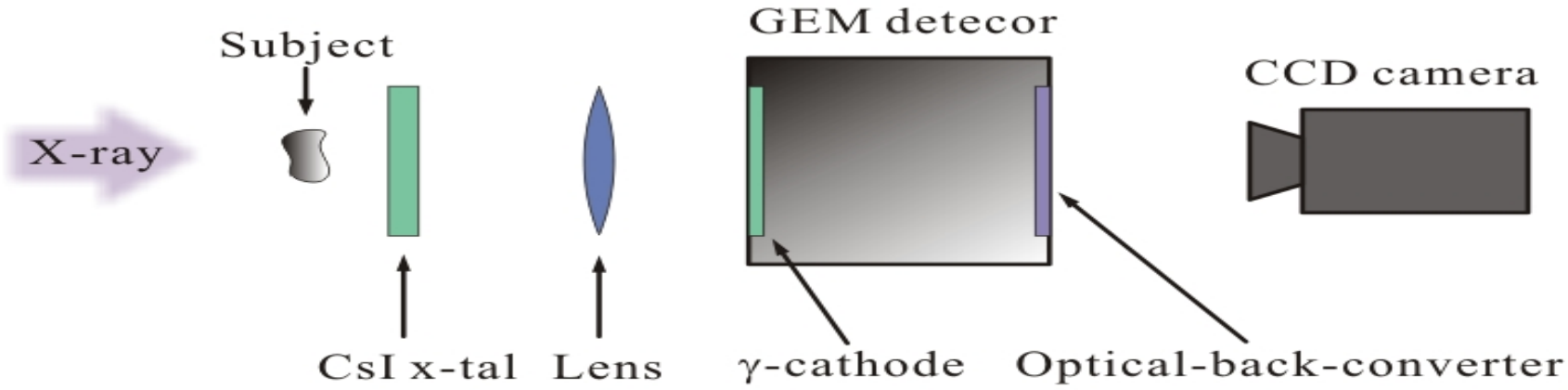
A. Bressan et al,
Nucl. Instr. and Meth. A 425(1999)254
F. Sauli, Nucl. Instr. and Meth.A 461(2001)47

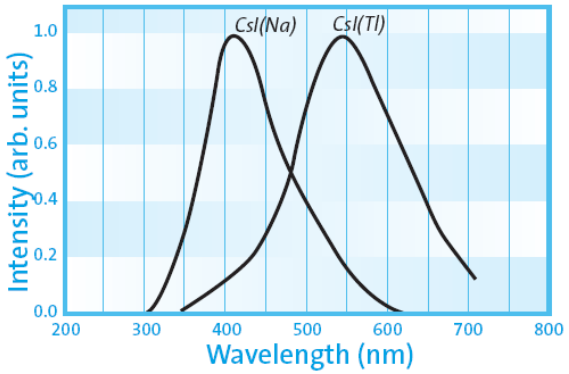
FAST X-RAY IMAGING

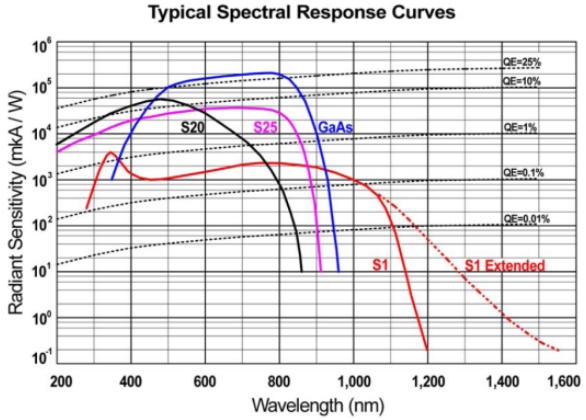


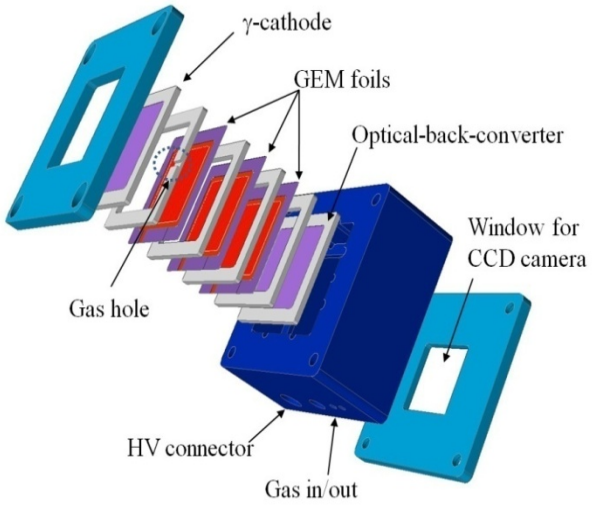
9 keV absorption radiography of a small mammal (image size ~ 60 x 30 mm^2)

GEM Image Amplifier (GIA) Design







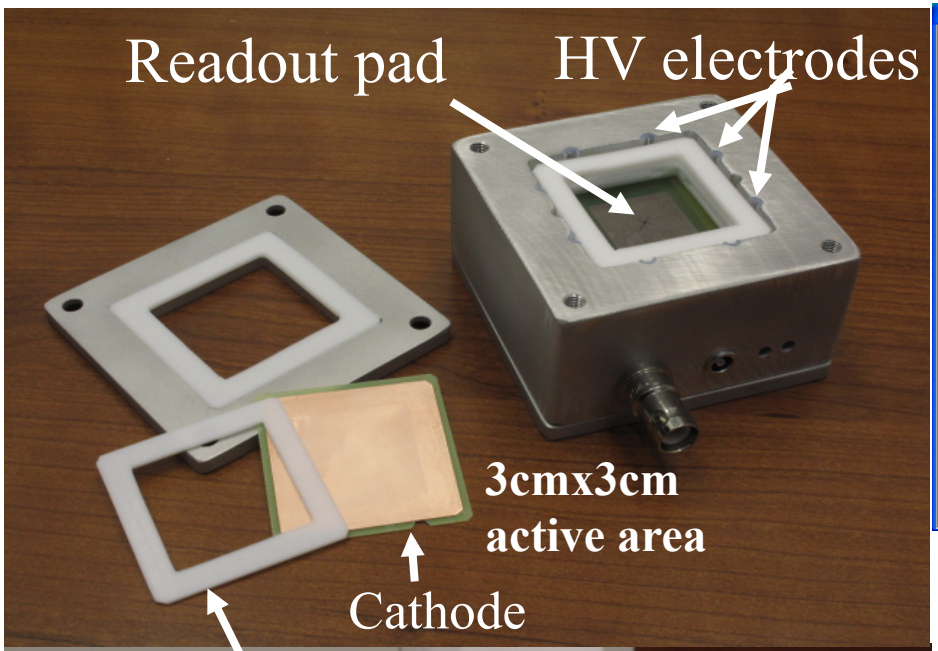


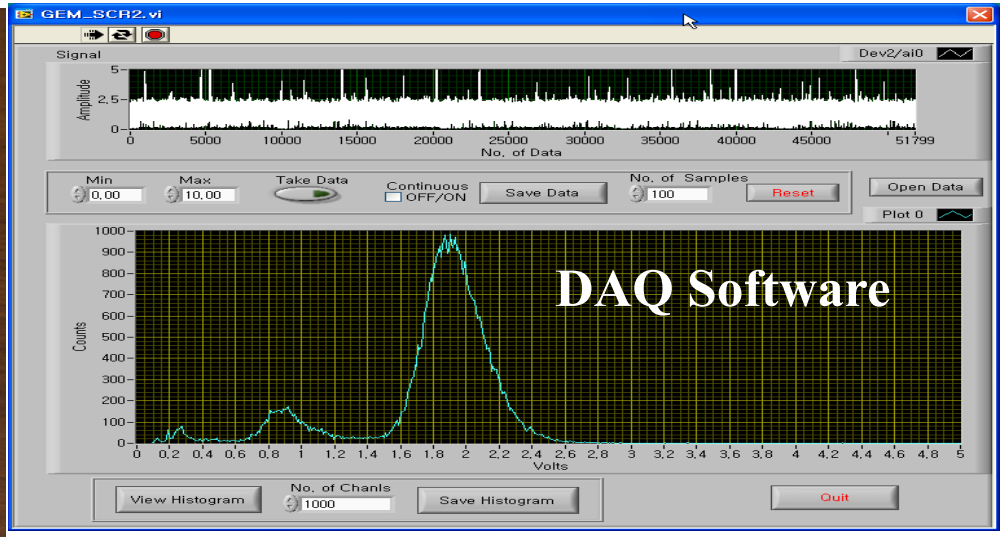
Scintillator:CsI

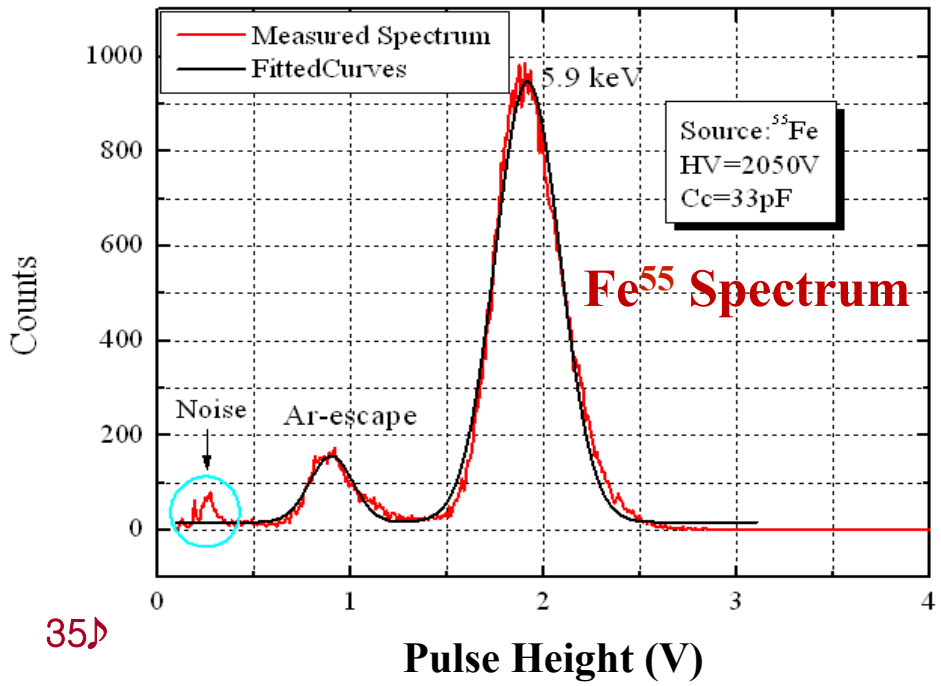
Σ-20 photo-converter

Optical-back-converter: $BaFBr:Eu^{2+}$

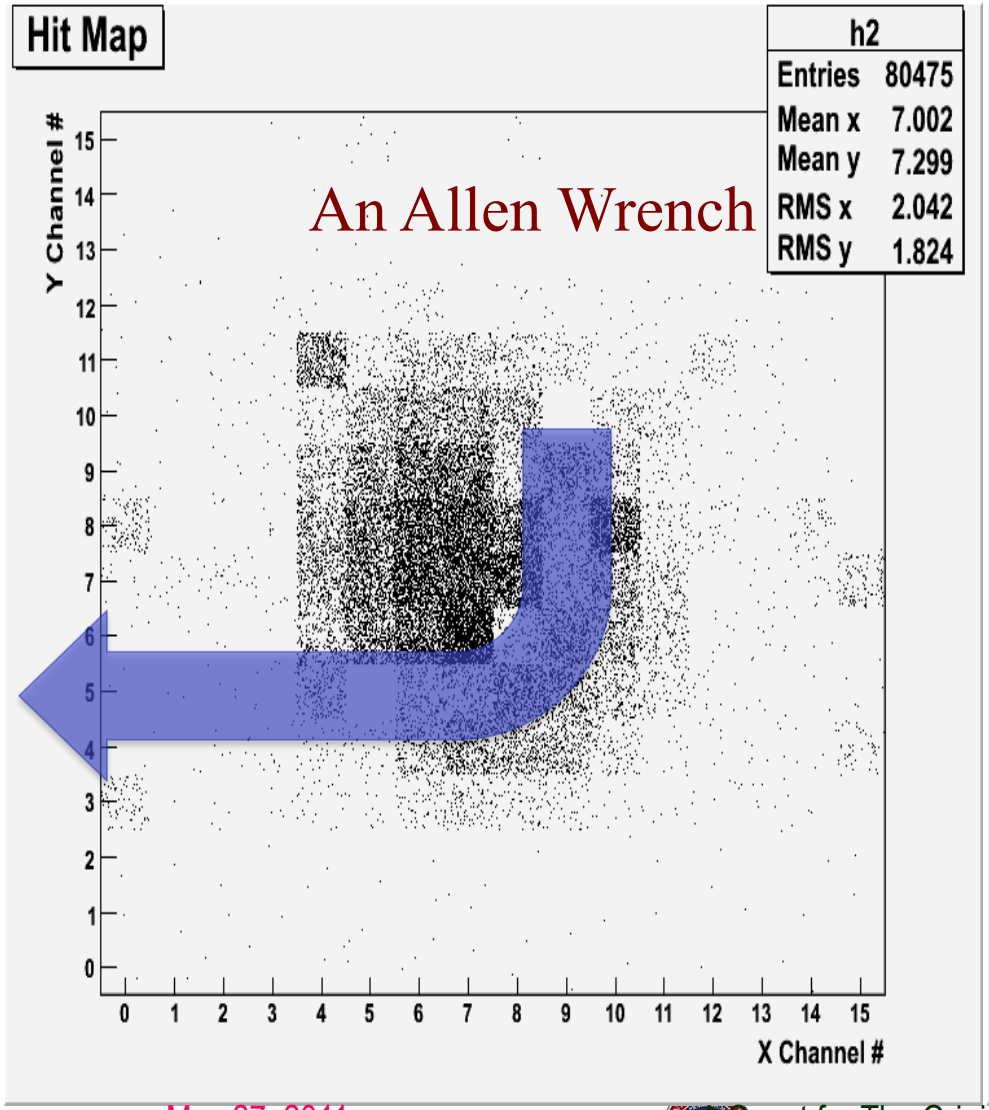
GIA Prototype Chamber

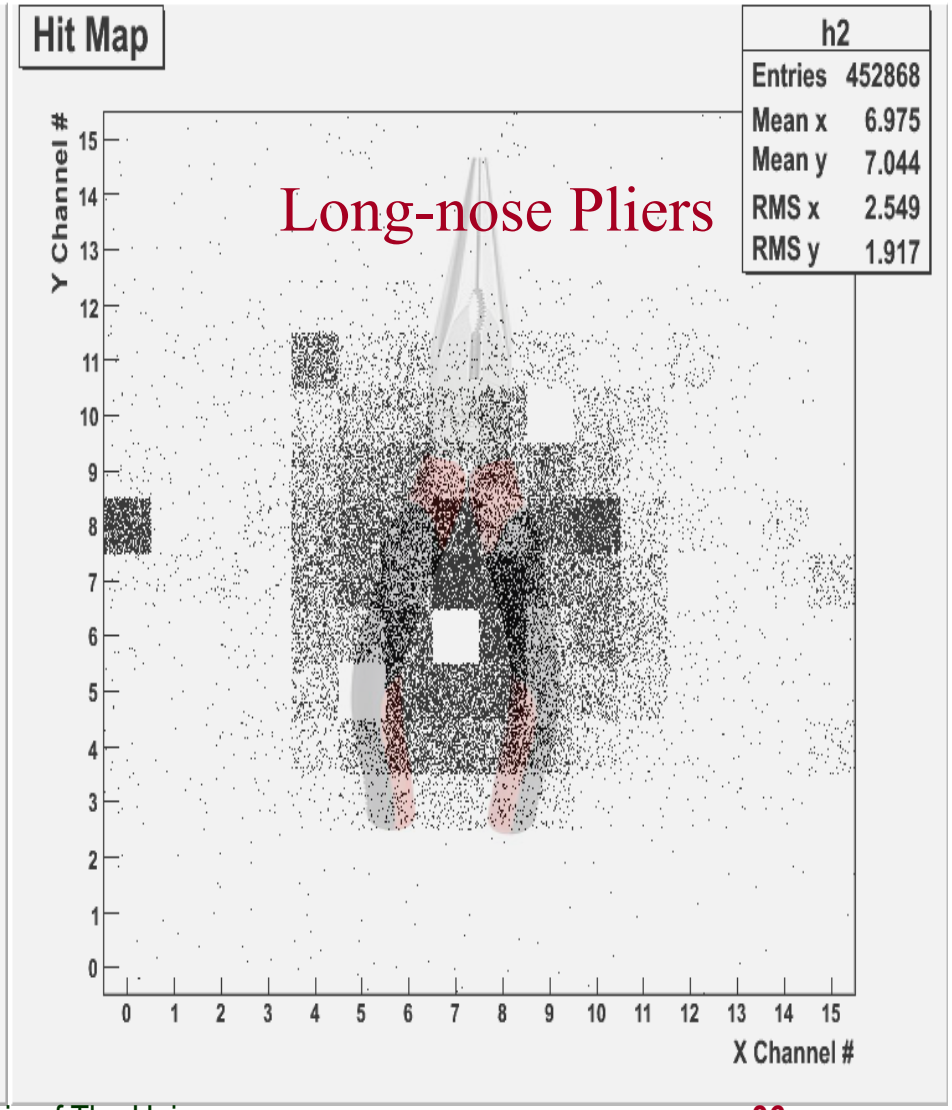




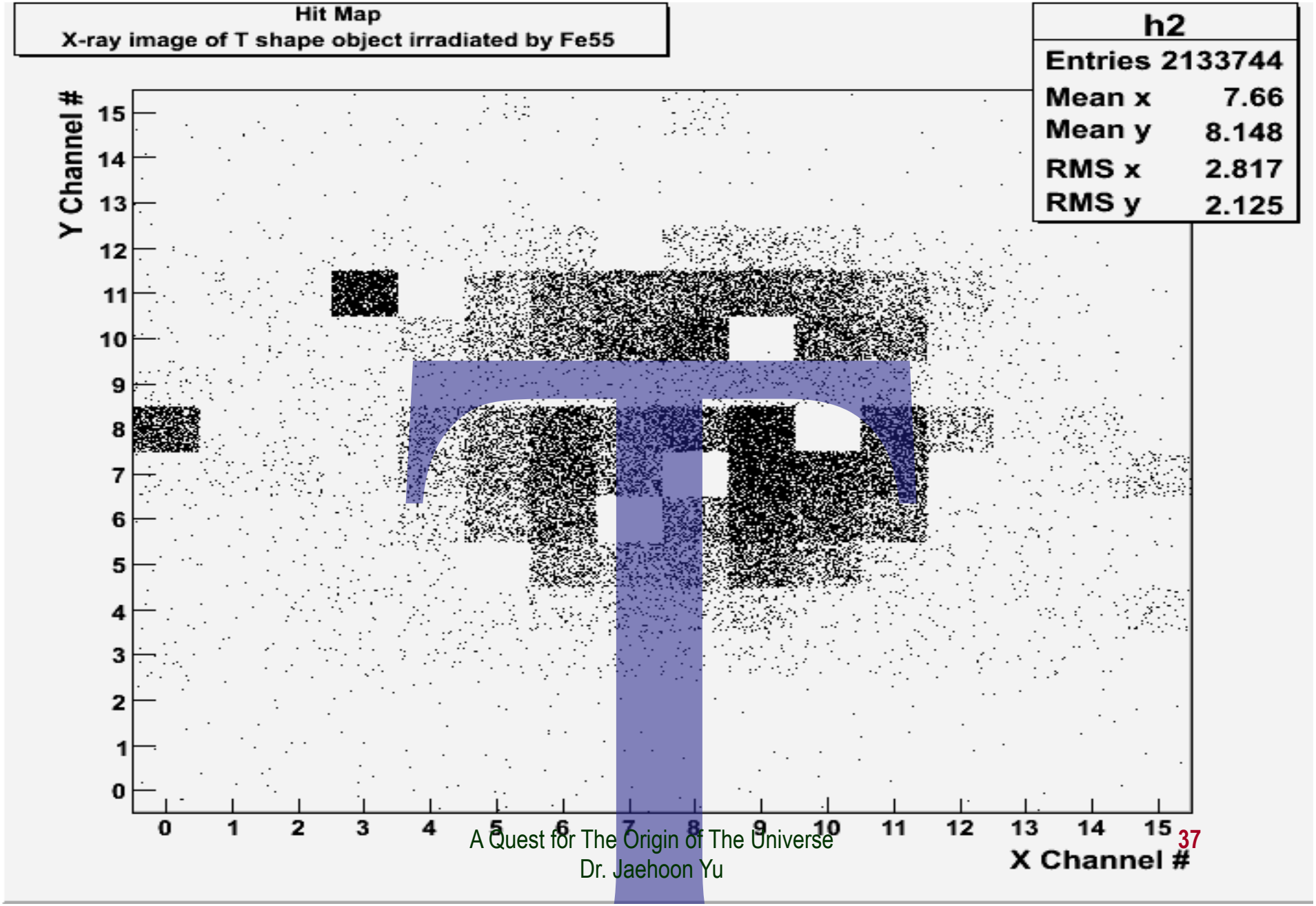


Just for fun, X-ray images using Fe^{55} Source





Of course, we must do…



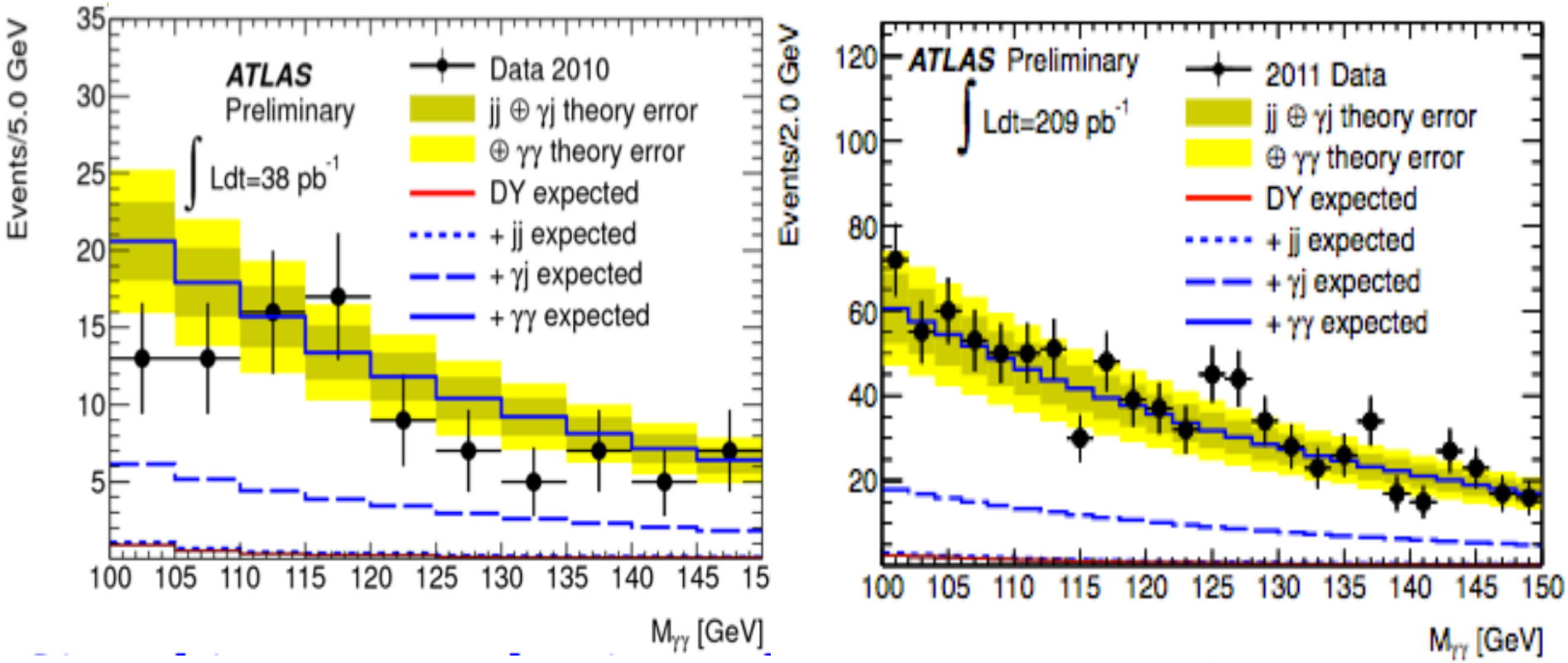

And in not too distant future, we could do ...

Conclusions

- In the quest for the origin of the universe, powerful accelerators and complex detectors are necessary
- The LHC opens up a whole new kinematic regime
  - Anything and everything we see at the LHC have never been seen before at this kinematic regime!
  - LHC was turned on at 7TeV, the highest human has ever achieved ➔ High statistics run planned in 2011 and 2012
  - In 2013 – 2014, an 18 month work on the accelerator toward the designed 14TeV
- Linear collider and advanced detectors are being developed for future precision measurements of Higgs and other new particles
- Outcome and the bi-product of HEP research impacts our daily lives
  - WWW came from HEP
  - GEM will make a large screen low dosage X-ray imaging possible
- Ultimately we want to understand the rule of the universe to make our lives better

Did ATLAS see H→γγ Signal?

- Internal scientific scrutiny process must be respected ➔ Statistical fluctuation along with specific kinematic cuts could generate "bumps"



- Intermediate amount of data early April showed an unusual bump if specific cuts were made
- Larger data set early May no longer shows this "bump"