

# Physics 373 Nucleon Lab

Prof. Justin Frantz

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3/29/11

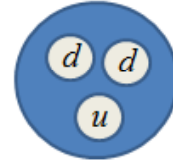
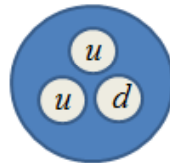
**First: a) SIGN UP SHEET**

**b) Go over syllabus...**

**c) Leo Text**

# What is a Nucleon?

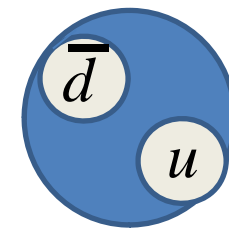
- $N = p, n$



- Inside: Collection of *quarks and gluons*
- Outside: can be combined to make Nuclei
  - Hydrogen (p, d, t) He ( $\alpha$ )
  - deuterium tritium
- This lab is not focused on detection of nucleons, but rather the particles which result from nucleon interactions
  - For example: the photon  $\gamma$

# Energies

- $1 \text{ eV} = 10^{-19} \text{ J}$        $E = mc^2$
- Atomic interactions ( $e_{\text{cloud}}$ -nucleus)
  - 1 eV to 1 keV ( $\gamma = \text{“Photon” or “X-ray”}$ )
- Nuclear Structure interactions (e.g. n,p shell transitions)
  - 1 keV  $\sim$  10 MeV ( $\gamma = \text{“Gamma Ray”}$ )
- **Nucleon** Structure Interactions
  - $m_{\text{nucleon}} = 938 \text{ MeV}$
  - $m_{\text{pion}} = 135 \text{ MeV}$
- Rare particle masses/decays  $3 \text{ GeV} \rightarrow 150 \text{ GeV}$ 
  - LHC: p+p interactions at 14 TeV



# Physics 373...

- ...is usually a low energy “nuclear” physics lab
- I am a high energy physicist so I am going to focus on teaching the *physics* I know best
- Focus: particle detection techniques
  - Generalized from low energy to higher
  - Labs focus on the techniques particle detection aspects, not *as much* on the physics
- Result: More Breadth less Depth

# Some of the Topics to Cover

- -Radiation Safety
- -Radioactivity (Maybe Reactor Physics—Japan)
- -Electronic Components (Universal low to high E)
- **-Statistical Treatment of Data (Curve Fitting)**
- -Introduction to Particle Physics
- -Introduction to Nuclear Physics
- -Very small amount of (Relativistic) Kinematics
- -Computing (C++ programming Root)
- -DAQ (including computing aspects)
  - Data Acquisition

# Intro: Particle/Nucl Physics

- **Particle physics:** seeks to understand the most basic building blocks of nature
  - the fundamental fields (like the EM fields)
  - particles
  - and importantly more recently the nature of the vacuum and space itself (> 3-Dimensions?)
- **Nuclear Physics:** concentrates on phenomena of QCD from Nuclei to Quarks
  - The strong force that governs their movements

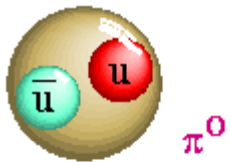
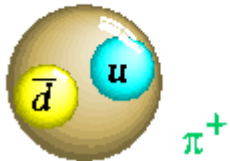
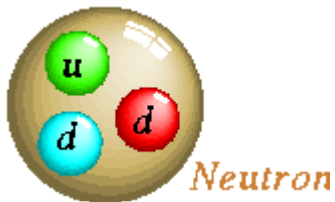
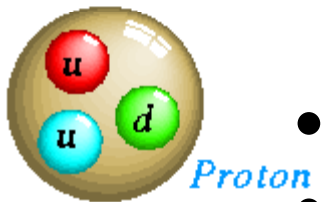
# Elementary Particles

## Elementary Particles

Quarks	$u$ up	$c$ charm	$t$ top	Force Carriers
	$d$ down	$s$ strange	$b$ bottom	
	$\nu_e$ electron neutrino	$\nu_\mu$ muon neutrino	$\nu_\tau$ tau neutrino	
Leptons	$e$ electron	$\mu$ muon	$\tau$ tau	$Z^0$ Z boson
				$W$ W boson
	I	II	III	
Three Families of Matter				

# QCD: Quarks, Gluons $\rightarrow$ Hadron, Nuclei

## Quick Reminder!:

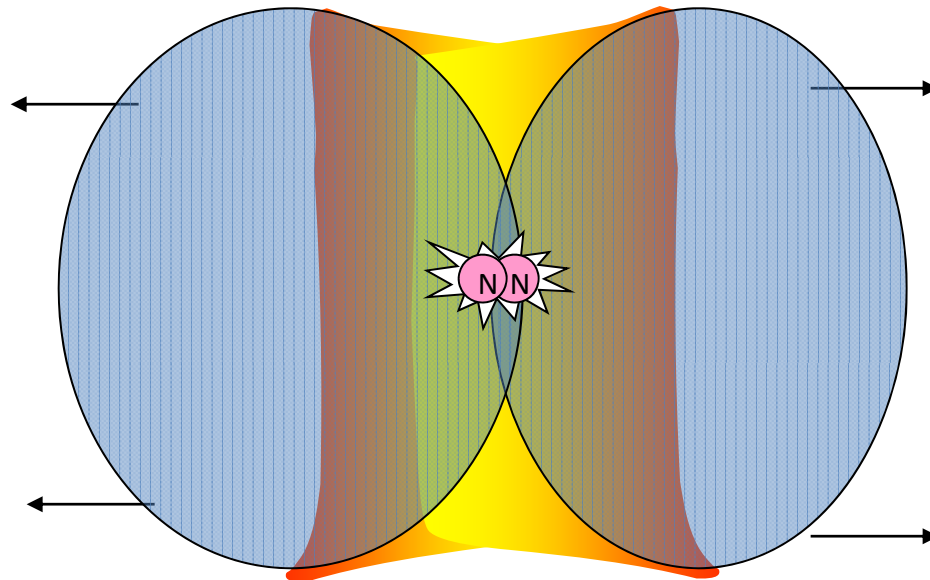


- QCD: Quantum Chromo-Dynamics theory of the Strong Force!
- Color charged quarks interacting through gluons
- Quarks/Gluons observed two ways:
  - Hadrons (particles made of q/g) : mass hierarchy based on quarks
  - Collisions of hadrons reveals “parton” quark/gluon interactions
- Gluons are colored charged too! Short range effects
- Confinement ! Raw color charge always neutralized by vacuum fluctuations
- Everything from hadron collisions to q/g dynamics to fundamental QCD properties intrinsically related!

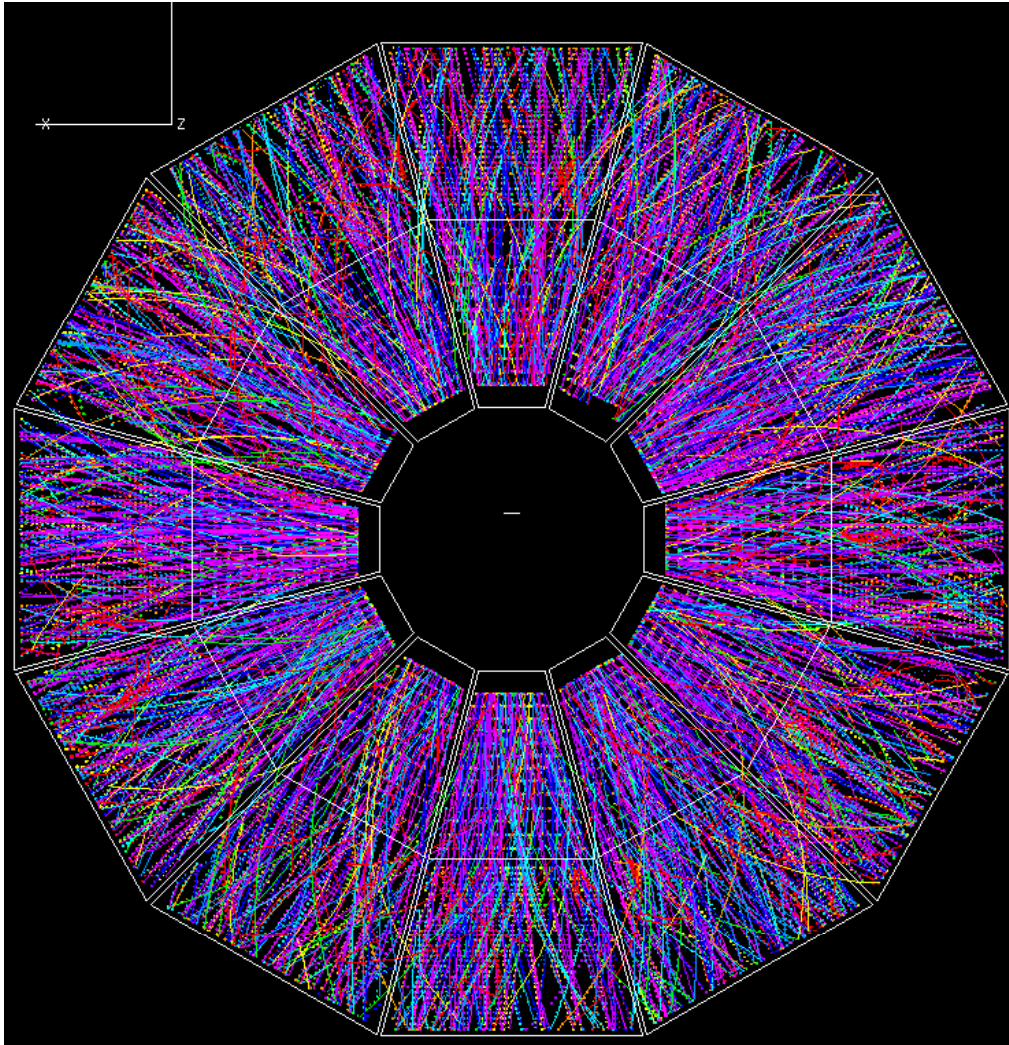


# What I do: Relativistic Heavy Ion Physics

- Combination of Particle and Nuclear
- Nucleus + Nucleus Collisions at 200 GeV: RHIC

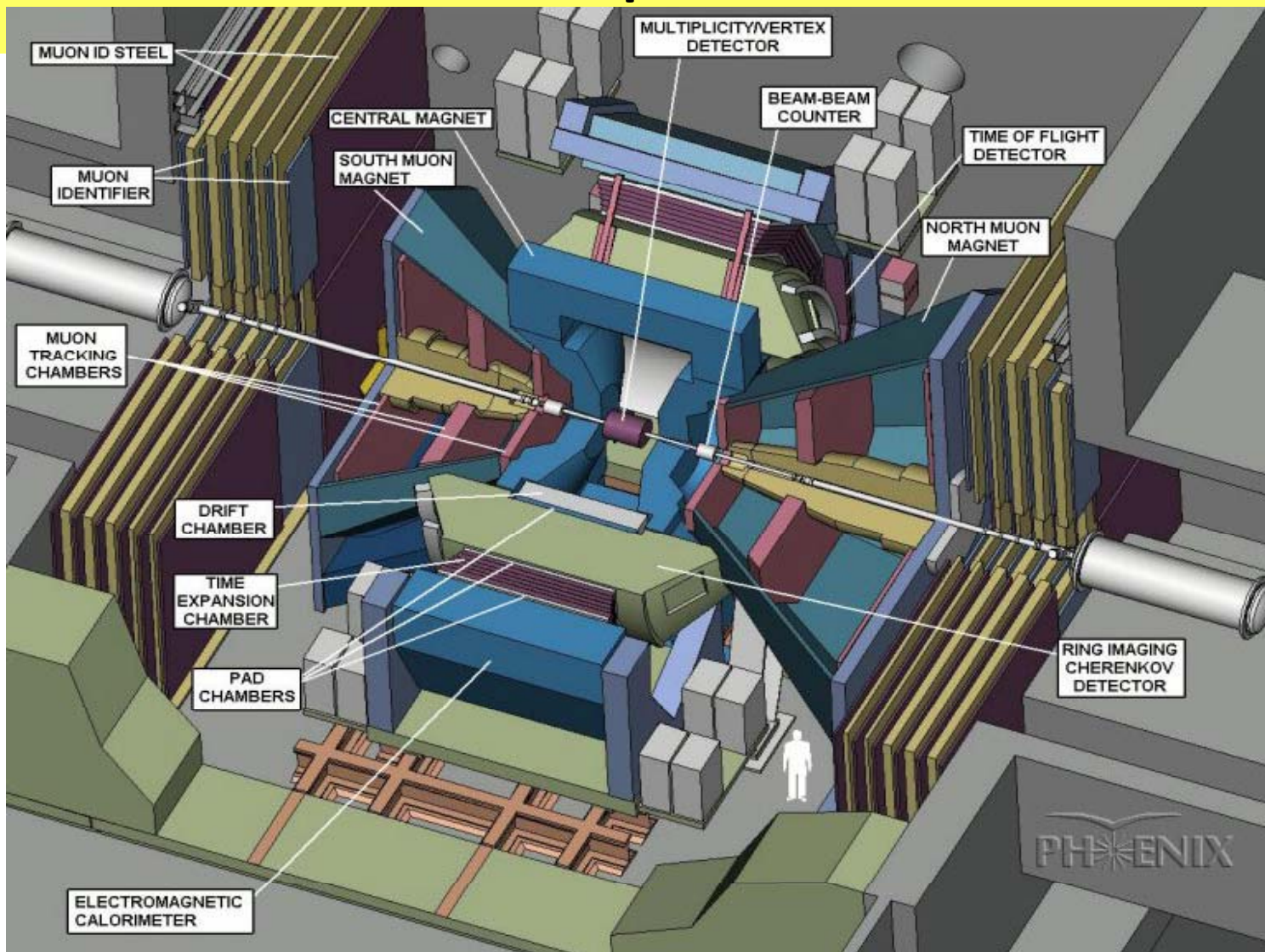


# Thousands of Particles Produced



How do  
we  
detect  
these?

# It Depends

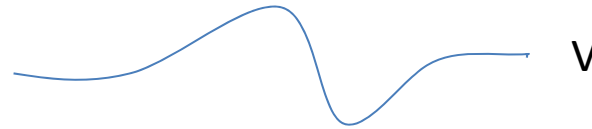


The PHENIX Detector

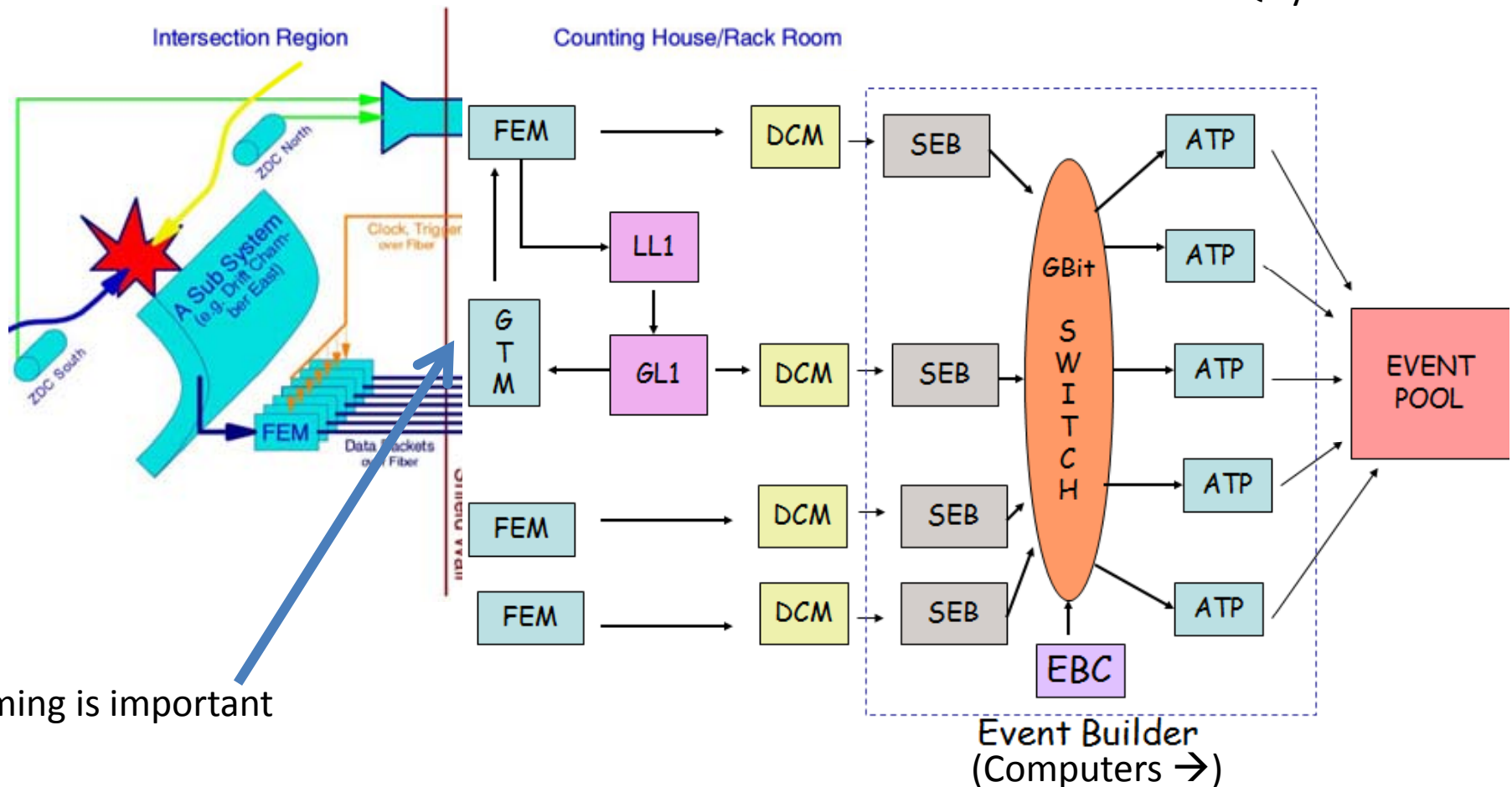


# Particles → Electronics → Charge/V

- **The Pulse**



→ "Data"  
DAQ System



# The Point

- My point is ***context***: I'd like you to keep this in mind as what most modern experimental nucl and particle set-ups look like:
  - Accelerator Facility provides “beam”
  - Multiple detectors, taking data simultaneously
  - Complicated DAQ's
- In the lab for this course, we will be focusing on the building blocks of each of these

# Intro to Radioactivity & Radiation Safety

- For all energies (high and low) there is a risk of exposure to radioactivity
  - **Activation:** Process which induces Radioactivity
  - Example PHENIX
- Radioactive sources used (e.g. in this lab) for calibration in particle detectors

# Radiation and Ionization

- Non-ionizing radiation: insufficient energy to ionize (eject an electron) an atom
  - Examples: ultraviolet light, microwaves, visible light
  - Why does UV cause cancer?
- Ionizing radiation: sufficient energy to ionize an atom
  - These are usually termed radioactive radiation
  - **Ionization can damage biological tissue. The different types of radiation have different effects in tissue; it is important to understand the properties to understand your risk.**

# Types of Radioactivity/“Radiation”

- Radioactive decay proceeds by emission of particles from the nucleus
- $\alpha$  :  ${}^4\text{He}$  nucleus — Reduces the parent by 2 protons and neutrons
- $\beta$  :  $e^+$  or  $e^-$  Changes a proton into a neutron (or vice versa)
- $\gamma$  -ray photons — Transfer between energy levels of the parent nucleus
- $n$  = Neutron (or proton) emission, fission
- $\delta$ -ray ?
  - also  $e^+$  or  $e^-$  --- from “knock-on” collisions (alpha)



# Quantities/Units

- **Dose** : Radiation energy absorbed by a material
- Radiation Absorbed Dose **Rad** = 0.01 J/kg = 0.01 Gray
- **Dose equivalent**: The unit of biological hazard is the “**rem**”, which takes into account both the dose, and the relative biological effect (quality factor or QF)
  - “Rad Equivalent Man” **rem** = **Rad** \* **QF**
  - **1 rem = 0.01 Sieverts = 10 mSv**
- **Activity**: The quantity of radioactive material present at a given time, as described by the number of decays per unit time
  - *Curie* Ci =  $3.7 \times 10^{10}$  disintegration per second (dps)
  - *Becquerel* Bq = 1dps
- **Obsolete: Exposure**: Ionization (charged) produced
  - *R Roentgen* =  $1.6 \times 10^{15}$  ion pairs/kg of air
  - Actually for some reason rem actually stands for “Roentgen Equiv Man”

# ALARA, Shielding, etc...

- Biological Effects also depend on penetrating power...
- Use Shielding

TYPE	ALPHA	BETA	GAMMA	NEUTRON
PENETRATING POWER	very small	small	very great	very great
HAZARD	internal	internal/external	external	external
SHIELDING	paper	plastic, aluminum	lead, steel, concrete	water, concrete, steel
QUALITY FACTOR	20	1	1	2-10

- As Low As Reasonably Achievable
- The worst thing that can happen is ingesting radioactive material -- **WASH YOUR HANDS!**

# Rad Safety

- Go to web pages:
- [Jlab Training Page](#) see web link on web page.  
take training Module 1.
- [OU Radiation Safety Training overview](#)
- Alan Watts training page

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Reading/Small Homework Assignments over  
the weekend (posted tomorrow).

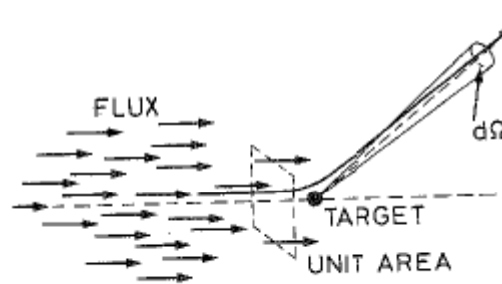
# Passage of Particles Through Matter

- Applies from low energy (Radioactive Radiation) to High energy

# Basics

- Remember from QM Scattering theory:

$$\frac{d\sigma}{d\Omega}(E, \Omega) = \frac{1}{F} \frac{dN_s}{d\Omega},$$



$$N_s(\Omega) = FA \boxed{N \delta x} \frac{d\sigma}{d\Omega}.$$

$$N_{\text{tot}} = FAN \delta x \sigma.$$

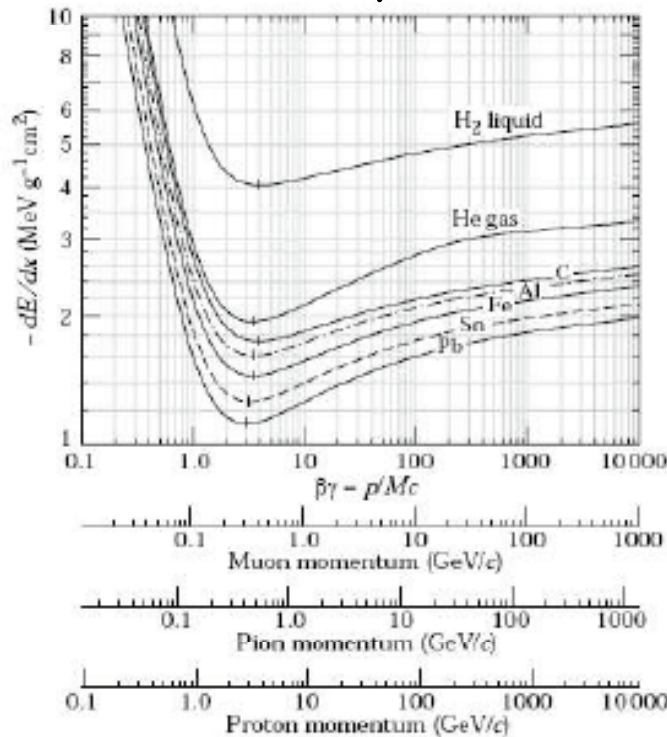
- $N^{\text{rad}} = N_0 e^{-Kx}$   
 –  $1/K = \text{mean free path } \lambda$

-From: Leo

- From special relativity  $\beta = v/c$   $\gamma = (1-\beta^2)^{-0.5}$   
 –  $\beta = p/E$   $\gamma = E/m$

# Heavy Charged Particles (e.g. $\alpha$ )

- Heavy :  $m_e \gg eV$   
 – 511 keV  $\mu \rightarrow 105$  MeV



$dE/dx$

- Heavy charged particles (pions, protons, alpha particles, other nuclei) lose energy by ionization as they pass through matter
- The energy loss per unit length depends upon the material, the ratio of the momentum to the mass, and the charge
- The energy loss occurs as lots of “low energy” ionization events

- Bethe-Bloch Formula:

$$-\frac{dE}{dx} = 2\pi N_A r_e^2 m_e c^2 \rho \frac{Z}{A} \frac{z^2}{\beta^2} \left[ \ln \left( \frac{2m_e \gamma^2 v^2 W_{\max}}{I^2} \right) - 2\beta^2 \right]$$

Relativistic Rise

-From: Leo

# Energy Loss by Electrons ( $\beta$ , $e$ )

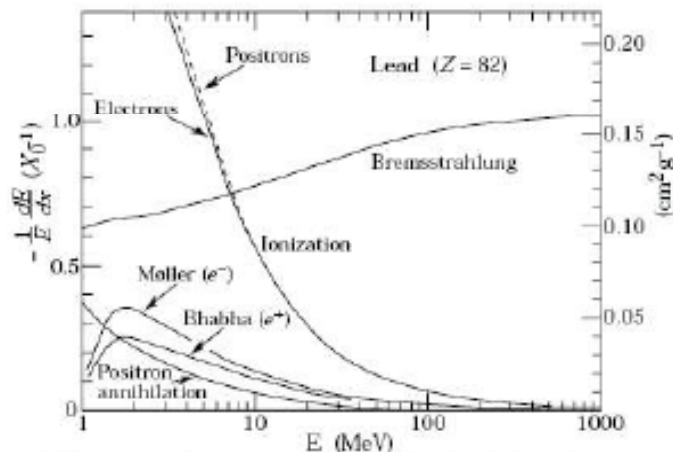


Figure 27.10: Fractional energy loss per radiation length in lead as a function of electron or positron energy.

W.M. Yao *et al.*, *J. Phys. G* 33, 1 (2006) and 2007 partial update for the 2008 edition available on the PDG WWW pages (URL: <http://pdg.lbl.gov/>)

- Energy loss by electrons and positrons below  $\sim 10$  MeV is dominated by ionization
- At higher energy, bremsstrahlung (emission of a high energy photon in the electric field of a nucleus) begins to dominate
- Radiation length: the distance over which a high energy electron loses all but  $1/e$  of its energy by bremsstrahlung; it is material dependent

- Rad Length  $L_{\text{rad}} \rightarrow E_e = E_0 e^{-x/L_{\text{rad}}}$



# Interactions of Photons

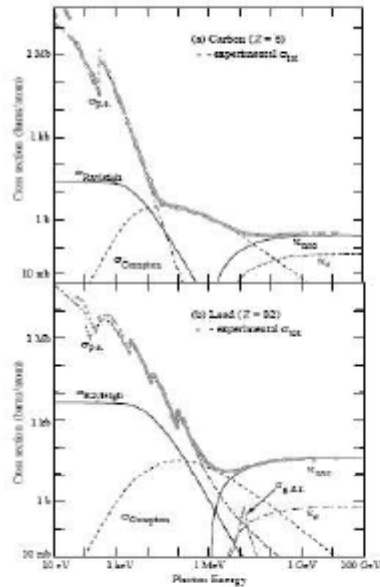


Figure 27.14: Photon total cross sections as a function of energy in carbon and lead, showing the contributions of different processes:

- $\sigma_{pe}$  = Atomic photoelectric effect (electron ejection, photon absorption)
- $\sigma_{Rayleigh}$  = Rayleigh (coherent) scattering—atom neither ionized nor excited
- $\sigma_{Compton}$  = Incoherent scattering (Compton scattering off an electron)
- $\sigma_{nuc}$  = Pair production, nuclear field
- $\sigma_e$  = Pair production, electron field
- $\sigma_{g.d.r.}$  = Photonuclear interactions, most notably the Giant Dipole Resonance [46]. In these interactions, the target nucleus is broken up.

W.M. Yao *et al.*, *J. Phys. G* 33, 1 (2006) and 2007 partial update for the 2008 edition available on the PDG WWW pages (URL: <http://pdg.lbl.gov/>)

- Probability not Energy Loss
- Pair Production  $\gamma \rightarrow e^+ e^-$

- Low energy: photoelectric effect

The emitted electron carries all the energy

- Medium energy: Compton scattering

The electron and the scattered photon

share the energy  $E'_\gamma = \frac{E_\gamma}{1 + (E_\gamma/m_e c^2)(1 - \cos\theta)}$

- High energy: pair production what Energy for  $\gamma$  ?

A high energy photon can (in the electric field of a nucleus) change into a electron-positron pair, each carrying 1/2 the energy

$$N_\gamma(E_{\text{high}}) = N_0 e^{-x/X_0}$$

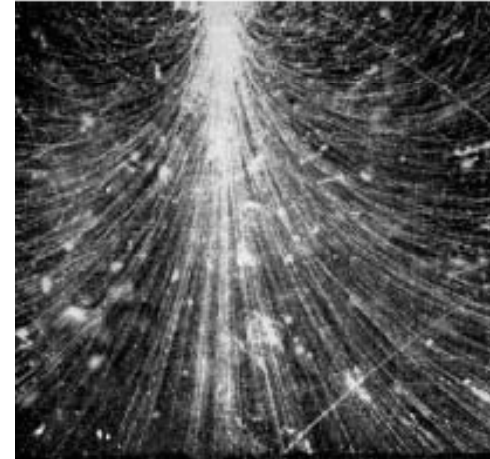
$$X_0 = 9/7 L_{\text{rad}}$$

# Break Rad Safety II

- Go to web pages:
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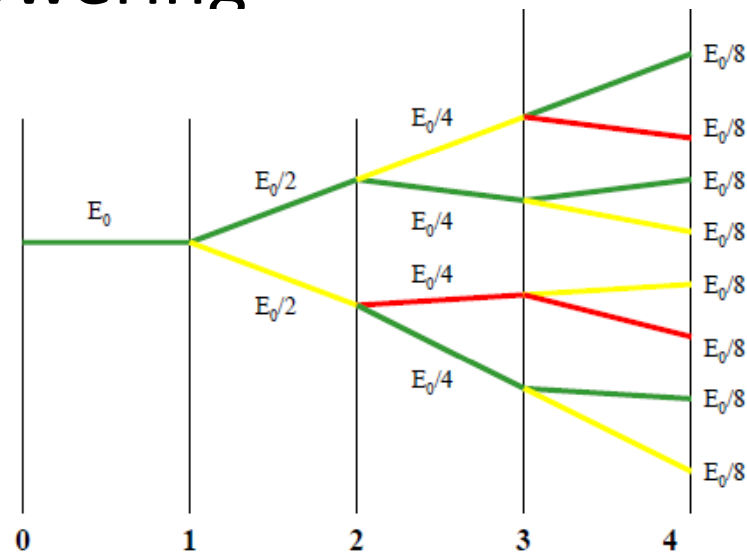
# High E $e, \gamma$ : EM Showering

- Alternating:
  - Pair Production  $\gamma \rightarrow e^+e^-$
  - Bremsstrahlung  $e \rightarrow e \gamma$
- In the lab we will be using detectors that work mainly for the Low Energy
  - But we will see  $\gamma > 1\text{MeV}$
  - But even for high energy  $e$ , photon detection, measure E by collecting all resulting low E  $e$ , photons, ( $\sim 10000$ 's) through the lower E processes



# Neutrons

- We'll come back to this...
- Low energy: come back to...
- High energy Neutrons can strike Nuclei, which then emit other high energy hadrons
- Hadronic Showering



# Intro to Error Analysis

- I don't want to have to repeat myself too many times on this...

# Data Analysis with ROOT

- C++: Object Oriented Language
  - Don't call functions as in fortran
  - rather: create object variables, tell them to run functions
  - variable type called "class", formally defined
- ROOT is a Free C++ Analysis Tool / Framework
  - A set of "C++ class libraries" Do virtually anything!
  - A command line analyzer (C++ interpreter)
- Most physics (all types) analysis is done with a similar tools: IDL (astro) MatLab (condensed matter other science too) Root (Older version PAW/Fortran)
- Links on webpage

# Things about C++/root to remember

- int, float char, arrays (int a[3]); char \* pointers
- constructors; text strings char \*
- tab for “autocomplete” (class/type name)
- TH1F h1 TF1 cout << “hi”  
– .Fill() .Draw() “guass”, “expo”, “pol”
- TRandom r .Rndm() ->Eval, “[0] + [1]\*x”
- Reference root.cern.ch (“Reference”)
- .root\_hist
- macros
-

# Propagation of Error/Uncertainty ( $\sigma$ )

- If  $X$  is some  $f(A,B,C\dots)$  e.g.  $v = d/t$  what is  $\sigma_f$  given  $\sigma_A, \sigma_B, \text{etc}\dots$
- From Wikipedia (“Propagation of Uncertainty”)

Function	Variance
$f = aA$	$\sigma_f^2 = a^2 \sigma_A^2$
$f = aA \pm bB$	$\sigma_f^2 = a^2 \sigma_A^2 + b^2 \sigma_B^2 \pm 2ab \text{COV}_{AB}$
$f = AB$	$\left(\frac{\sigma_f}{f}\right)^2 = \left(\frac{\sigma_A}{A}\right)^2 + \left(\frac{\sigma_B}{B}\right)^2 + 2\frac{\sigma_A \sigma_B}{AB} \rho_{AB}$
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$f = \pm aA^b$	$\frac{\sigma_f}{f} = b \frac{\sigma_A}{A}$
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Where do we get  $\sigma_A$ 's from?

Partial derivatives

[\[edit\]](#)

Given  $X = f(A, B, C, \dots)$

Absolute Error	Variance
$\Delta X^2 = \left \frac{\partial f}{\partial A}\right ^2 \cdot \Delta A^2 + \left \frac{\partial f}{\partial B}\right ^2 \cdot \Delta B^2 + \left \frac{\partial f}{\partial C}\right ^2 \cdot \Delta C^2 + \dots$	$\sigma_X^2 = \left(\frac{\partial f}{\partial A} \sigma_A\right)^2 + \left(\frac{\partial f}{\partial B} \sigma_B\right)^2 + \left(\frac{\partial f}{\partial C} \sigma_C\right)^2 + \dots$

[\[3\]](#)



# Example from Lab

$$R \equiv \frac{N_B \tau_A}{N_A \tau_B} = \frac{\tau_A}{\tau_A - \tau_B} [1 - \exp(-t/\tau_B + t/\tau_A)]. \quad (9)$$

The ratio  $R$  as a function of the age  $t$  is shown in Fig 1. Note also that the ratio  $R$  is also equal to the measured ratio of  $^{210}\text{Po}$  decay  $\alpha$ s to  $^{226}\text{Ra}$  decay  $\alpha$ s. Equation (9) can then be inverted to find the age  $t$ :

$$t = -\frac{\tau_A \tau_B}{\tau_A - \tau_B} \ln \left( 1 - R \frac{\tau_A - \tau_B}{\tau_A} \right). \quad (10)$$

# Propagation of Error/Uncertainty ( $\sigma$ )

- If  $X$  is some  $f(A,B,C\dots)$  e.g.  $v = d/t$  what is  $\sigma_f$  given  $\sigma_A, \sigma_B$ , etc...
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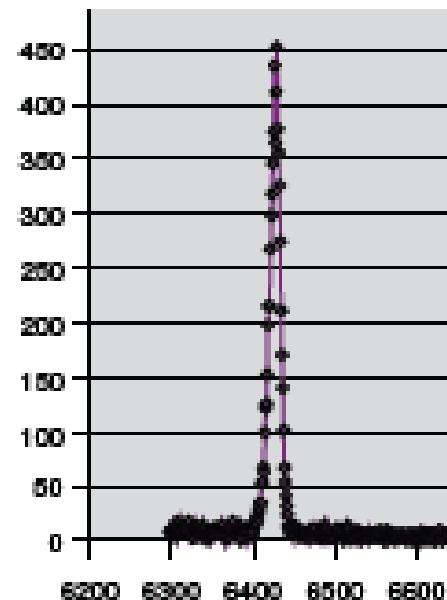
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- macros
- SetLineColor

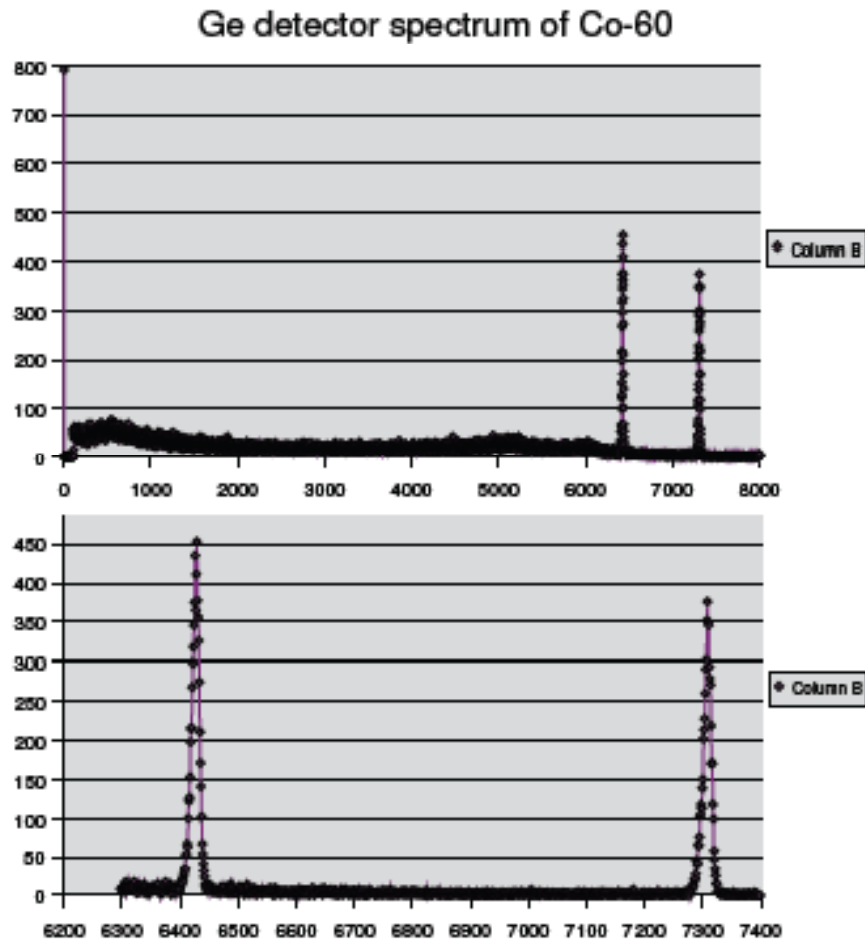
# Histogramming

- We always counting particles in Nuclear and Particle Physics.
- Typically we plot the frequency of “hits” versus some parameter like as a function of energy
- e.g. Finite Bins of Energy
  - $dN/dE$
- Typically we wish to characterize **peaks** ie, their location, total integrated count, etc...
- ROOT: TH1 class

hist->Fill() → Increment counter



# Peak “Error” Analysis



How do we describe the width of an peak?

Full Width at Half Max

$$\text{FWHM} = 2.35 \sigma_x$$

Root Mean Square (or std. deviation)

$$\text{RMS} = \sigma_x$$

$$s_x^2 = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2$$

$$\lim_{n \rightarrow \infty} s_x^2 = \sigma_x^2 = \langle x^2 \rangle - \langle x \rangle^2$$

How do we describe the error on the mean?

Std. error of the mean

$$\sigma(\bar{x}) = \frac{\sigma_x}{\sqrt{n}}$$

That describes the HORIZONTAL ERROR

# Poisson Distribution

- Poisson distribution  $\rightarrow$  limit of Binomial Distribution when  $p$  ( $q$ ) is small  $p \rightarrow R \Delta t$

In counting random events, the number of events occurring within a time interval is described by a Poisson distribution, dependent on the rate

(number expected:  $\lambda = R \Delta t$ ).

The variance of a Poisson distribution is equal to the mean

For a given measurement of  $N$  events in a given time interval, the standard deviation is  $\sqrt{N}$

$$P(n) = \frac{\lambda^n e^{-\lambda}}{n!}$$

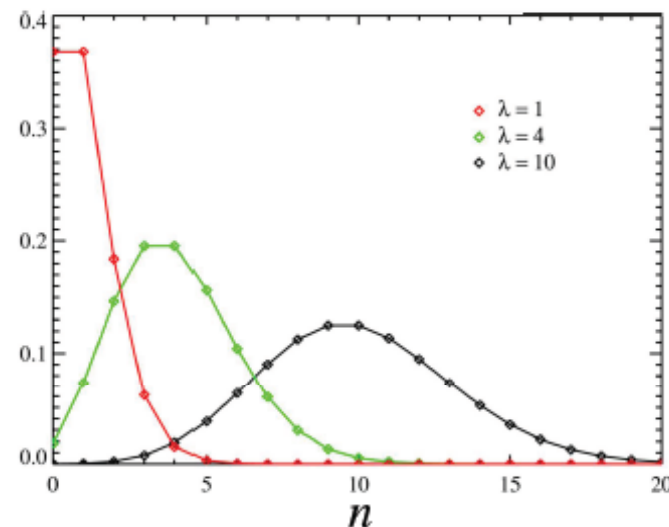
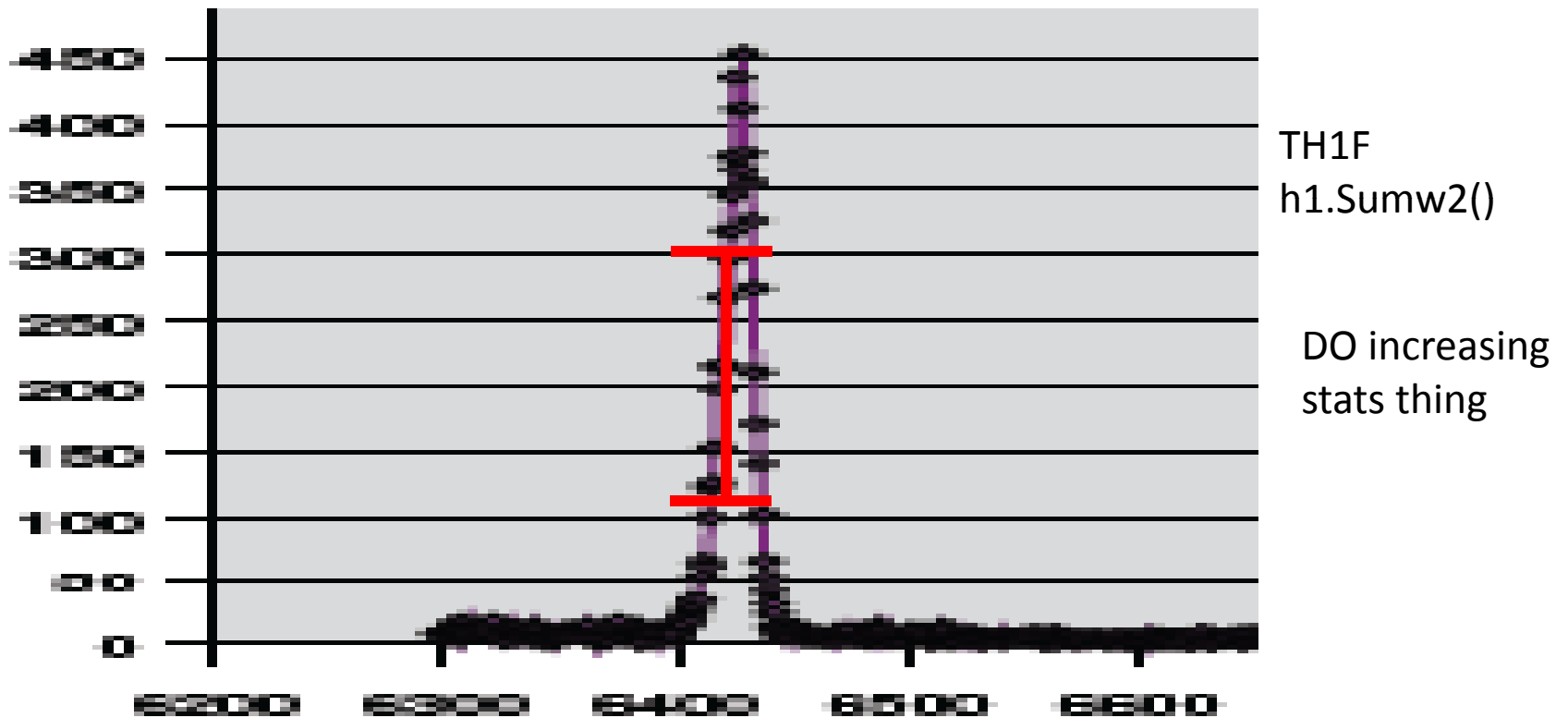


Figure from "Poisson distribution" Wikipedia entry

# Main Statistical Error

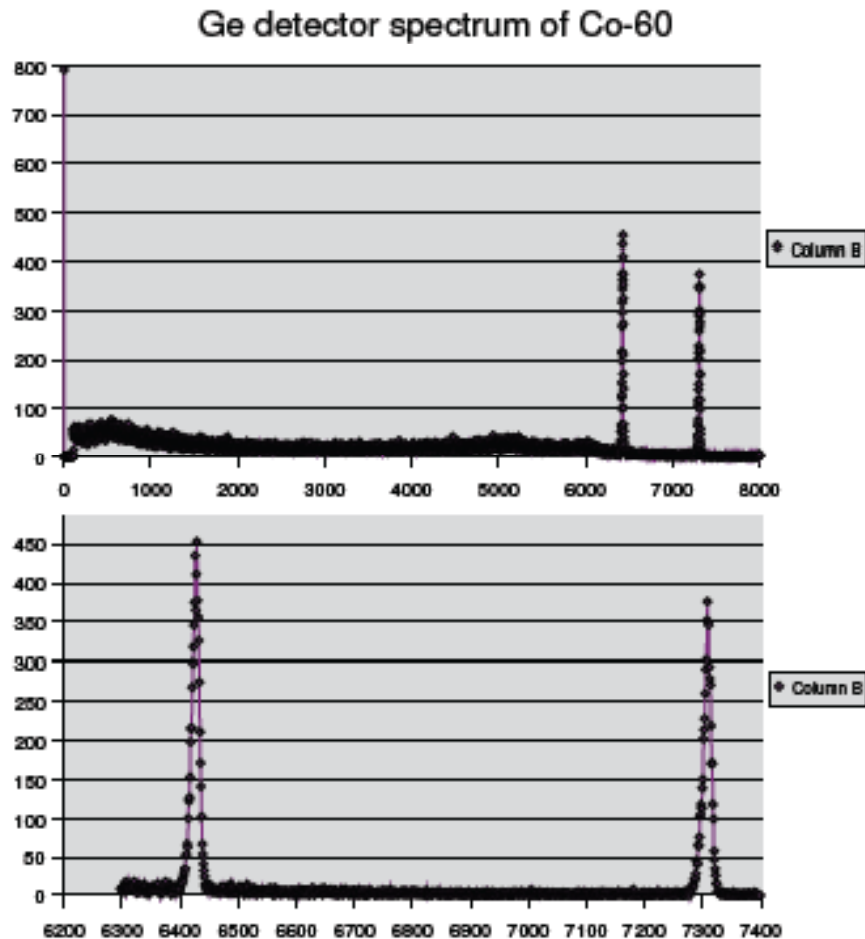
- Thus each bin gets vertical error of  $\sqrt{N}$



- Thus total counts in peak  $N$  has what uncertainty?
- Better estimate of Horizontal error (on peak mean)



# Peak “Error” Analysis



How do we describe the width of an peak?

Full Width at Half Max

$$\text{FWHM} = 2.35 \sigma_x$$

Root Mean Square (or std. deviation)

$$\text{RMS} = \sigma_x$$

$$s_x^2 = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2$$

$$\lim_{n \rightarrow \infty} s_x^2 = \sigma_x^2 = \langle x^2 \rangle - \langle x \rangle^2$$

How do we describe the error on the mean?

Std. error of the mean  $\sigma(\bar{x}) = \frac{\sigma_x}{\sqrt{n}}$

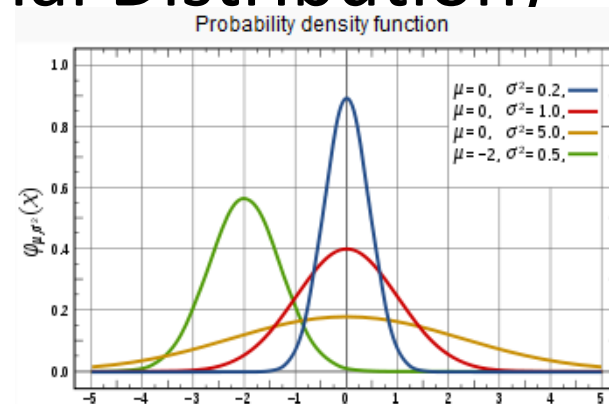
That describes the HORIZONTAL ERROR

# Fitting Peaks w/ Distributions

- Gaussian Function (Normal Distribution)

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

(root)



- Goodness of Fit...  $\chi^2$

$\chi^2$  minimization: A numerical comparison between the observed distribution of measurements  $x_i$  with precisions  $\Delta x_i$  and a function  $y$  can be defined via  $\chi^2$ :

$$\chi^2 = \sum \frac{(x_i - y)^2}{\Delta x_i^2} \quad \text{From 371 Lab Manual} \quad (3)$$

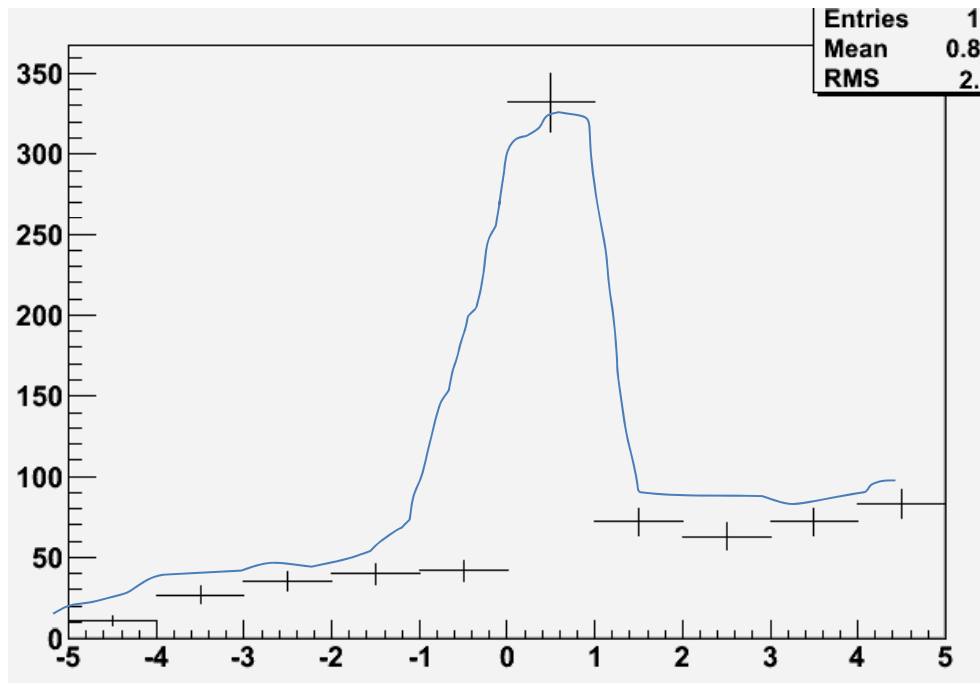
← **Error**

$y = f(x)$  where  $f = f(x, A, B, \dots)$   $A, B, \dots$  called fit parameters →

Fit: let params “float”, computer tries out many different trials for  $A, B, \dots$  determines lowest  $\chi^2$  combination. → Fit Params + error see root

# Example Fit Peaks + Bkg

- TFile f(“”, “RECREATE”);
- SetOptFit



# Interactions II and Detectors

Only some of these we will see in the  
lab

# Detecting Particles

## Scintillators + photomultiplier tubes

Incident radiation excites electrons in the material; deexcitation results in several lowenergy (nearvisible) photons  
Photons incident on PMT cathode result in p.e. emission; number of electrons is amplified by multiple stage acceleration through a series of dynodes

## Semiconductor Devices

Solidstate detectors

Incident radiation excites electronhole pairs in the material; biasing the material allows collection of the charge

## Electromagnetic shower detectors

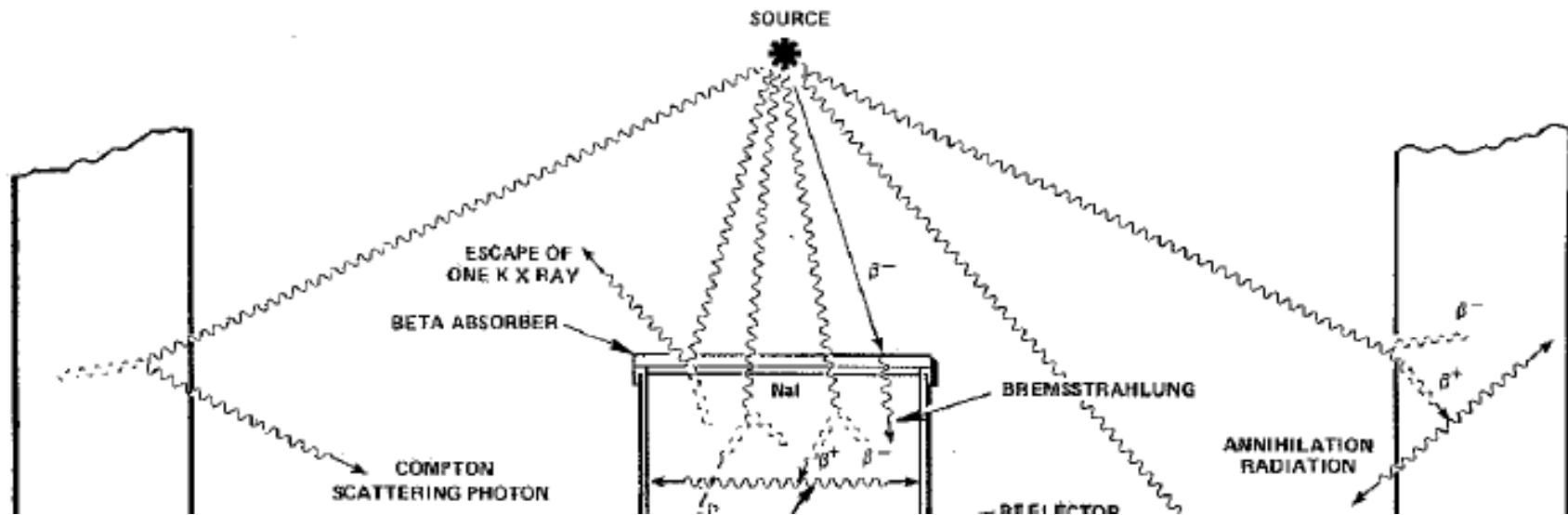
For photon (or electron) detection at energies above a few 10's of MeV

More generally: Ionization Detectors: Gas, Liquid, etc...

Classic Example: Geiger counter

# Photons vs Charged Particles

- Actually nearly all photon detectors actually detect the electrons resulting after an interaction



Detector (Scintillator)

# Experiments

- Lab1 GammaRay Ge Detector
  - Most precise E resolution, Gamma
- Lab2 BetaGamma NaI Detectors
  - Here we are detecting only Gammas also, shielding away any Beta's
- Lab3 Alpha Si Detector
  - Here we are directly detecting  $\alpha$ 's
- Final Lab Rutherford:
  - Very similar to Lab 3, but with high energy  $\alpha$  beam

# Rad Cards

- Fill Out



# 373 Nucleon Lab

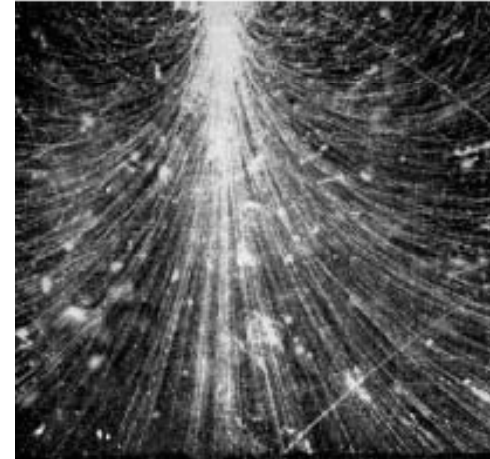
4/7/11

# Plan for Today

- Finalize groups, experiments
- Lecture
- **Lab:**
- Fun w/ Scope!
- Intro to DAQ/DAQ Tools
- Back upstairs-- Breakout session: strategize/look through binders in groups, develop initial plan for performing calibration, including steps involved
- More developed plan due Tues.

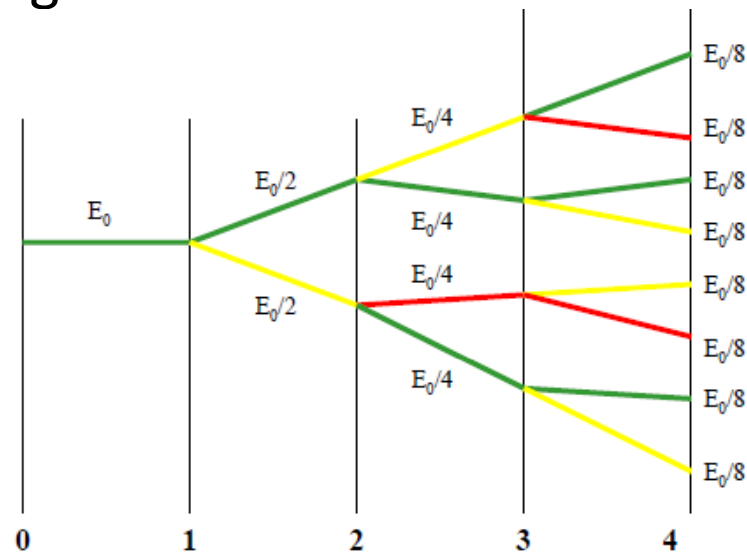
# High E $e, \gamma$ : EM Showering

- Alternating:
  - Pair Production  $\gamma \rightarrow e^+e^-$
  - Bremsstrahlung  $e \rightarrow e \gamma$
- In the lab we will be using detectors that work mainly for the Low Energy
  - But we will see  $\gamma > 1\text{MeV}$
  - But even for high energy  $e$ , photon detection, measure E by collecting all resulting low E  $e$ , photons, ( $\sim 10000$ 's) through the lower E processes

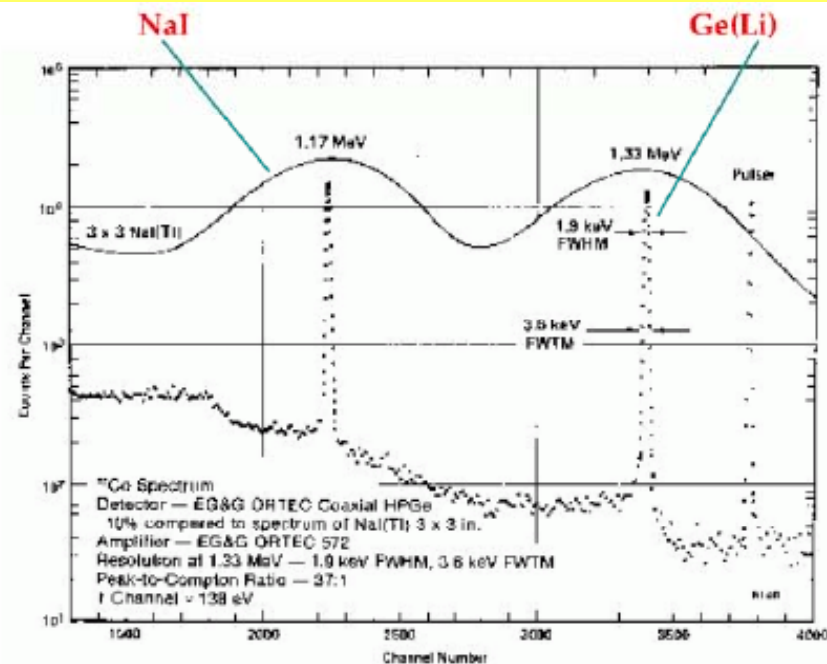


# Neutrons

- The one Radioactive radiation we didn't talk about
- Interact only with Nuclei
- $N_n = N_0 e^{-x/\lambda} \rightarrow \lambda = \text{"Nucl Interaction Length"}$
- Low energy: come back to  $\rightarrow$  knock out (e.g. H rich atoms) protons,  $h^+$  detect charge
- High energy Neutrons can strike  $n_0$ , which then emit other high energy hadrons
- Hadronic Showering



# Energy Resolution Comparison



The energy resolution in the solid state detector (Ge) is much better than in the scintillation detector (NaI)

Why use scintillators?

A: 1) Timing 2) For showering, single  $\gamma$  resolution less of an issue  
standard deviation of the mean  $\sim 1/\sqrt{N_{\text{measurements}}}$

# Semiconductor s

- Valence electrons in the semi-conductor cannot move, but can easily absorb energy and be excited to the conduction layer, leaving an “hole” (typical energies are 1-3 eV); both the electron and hole can move across the lattice
  - N-type materials have impurities with an “extra” valence electron
  - P-type materials have impurities with a “missing” valence electron, or an extra hole
- A p-n junction allows the free electrons to move from the n-type material to the p-type, leaving a net electric field due to the stationary ions in the lattice (this is the depletion region)
- If electron-hole pairs are created in the depletion region, the electric field will pull them apart, which will lead to a current
- Applying voltage across the junction adds a further field and can cause the depletion region to be larger (usually we use reverse-biased junctions)

# Semiconductor Detectors

- By putting electrical contacts on the two sides of a p-n junction, we can measure the current produced when ionizing radiation interacts in the material
  - Since the energy to create an electron-hole pair is small, we get a large number of pairs, leading to narrow energy resolution
- We apply a potential across the detector; if the electric field strength becomes too great, electric breakdown of the material can occur → a sudden increase in the current
- If the band gap is “too small”, thermal energy in the lattice can cause electron-hole pairs to be created, leading to extra current
  - To reduce this thermal current, we need to cool certain types of detectors
  - This extra current can cause damage to the detector as well

# Surface Barrier Detectors

- Silicon with a metal film applied to it develops a similar depletion region
  - Energy gap is  $\sim 1$  eV
  - Sensitive to surface damage: metal film is very thin
  - The depletion region extends from the metalized surface into the bulk of the material upon application of an external potential (up to 5mm possible)
- Typically used as charged particle detectors
  - Thin entrance window reduces the “missing energy”
  - Can be used as either a total energy measure, or if very thin, can be used to measure  $\Delta E$
- Raise the potential slowly, and watch for breakdown of the material



# Germanium Detectors

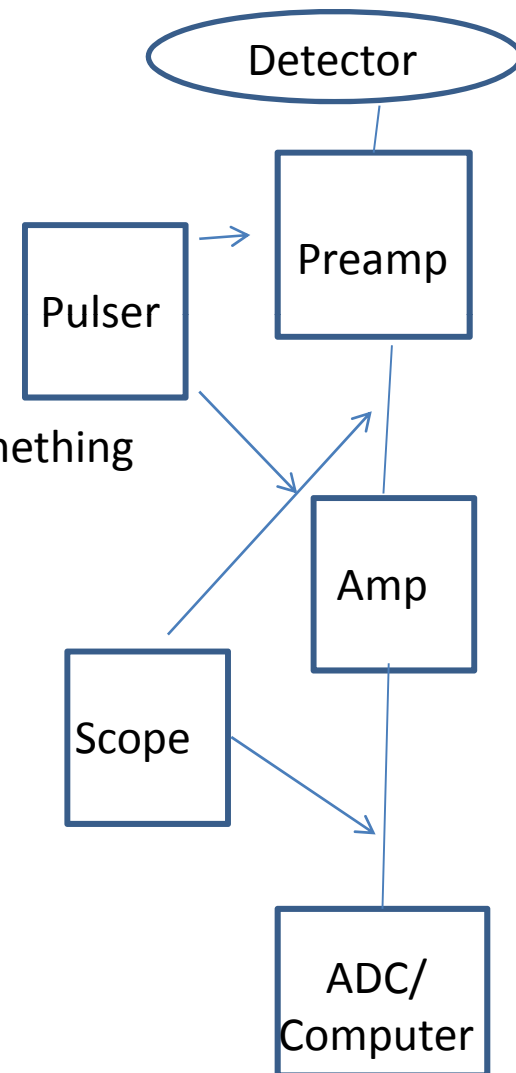
- Typically used for gamma detectors: due to the higher atomic number, Ge has a greater photoabsorption probability than Si
- It has a smaller band gap compared to Si → must be cooled during operation
  - Ge(Li): Lithium drifted Germanium detectors
    - Ge crystal with Li ions diffused from the surface, balancing other impurities in the material
    - Must be kept cold, or the Li can diffuse out of the crystal
  - HPGe: High purity Germanium
    - Very high purity Ge crystal, may be p-type or n-type
    - Only needs to be kept cold when in use



# Electronics / Components

Optimized for counting pulses, etc..

- Scope! (Triggering!)
- Preamplifier
  - Need separate power source often (lab turn on)
- NIM Modules (Nuclear Instrument Module)
- Amplifiers
  - Gain
- “Gate” Voltage pulse which tells when to start/stop something
- ADC (Analog to Digital Converter)
  - Energy to Channel “Number” conversion (“Gain”)
  - Takes time... example
- Pulsers
  - simulates physics pulses
- TAC (Time to Analog) → TDC
  - used for coincident testing
- Discriminator
  - checks a pulse to see if it’s big enough



# Pulses

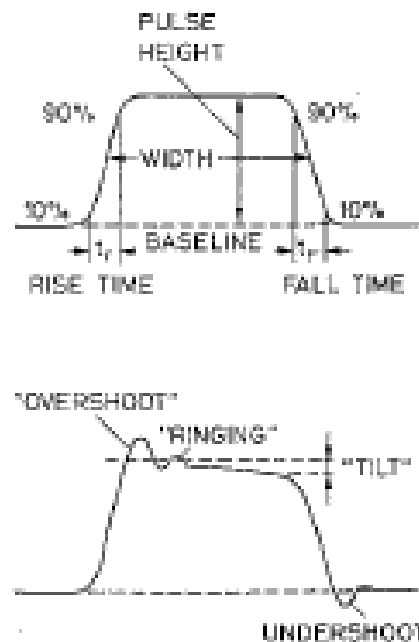


Fig. 11.1. Pulse signal terminology

- 1) *Baseline*. The baseline of the signal is the voltage or current level to which the pulse decays. While this is usually zero, it is possible for the baseline to be at some other level due to the superimposition of a constant dc voltage or current, or to fluctuations in the pulse shape, count rate etc.
- 2) *Pulse Height or Amplitude*. The amplitude is the height of the pulse as measured from its maximum value to the instantaneous baseline below this peak.
- 3) *Signal Width*. This is the full width of the signal usually taken at the half-maximum of the signal (FWHM).
- 4) *Leading Edge*. The leading edge is that flank of the signal which comes first in time.
- 5) *Falling Edge*. The falling edge or tail is that flank which is last in time.
- 6) *Rise Time*. This is the time it takes for the pulse to rise from 10 to 90% of its full amplitude. The rise time essentially determines the rapidity of the signal and is extremely important for timing applications.
- 7) *Fall Time*. In analogy with rise time, the fall time is the time it takes for the signal to fall from 90 to 10% of its full amplitude.
- 8) *Unipolar and Bipolar*. Signal pulses may also be unipolar or bipolar. A unipolar pulse is one which has one major lobe entirely (excepting a small possible undershoot) on one side of the baseline. In contrast, bipolar pulses cross the baseline and form a second major lobe of opposite polarity. Figure 11.2 illustrates these two types. Both are used in nuclear electronics.

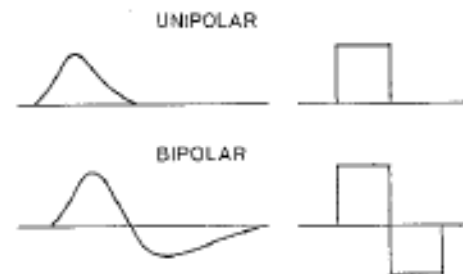


Fig. 11.2. Unipolar and bipolar pulses

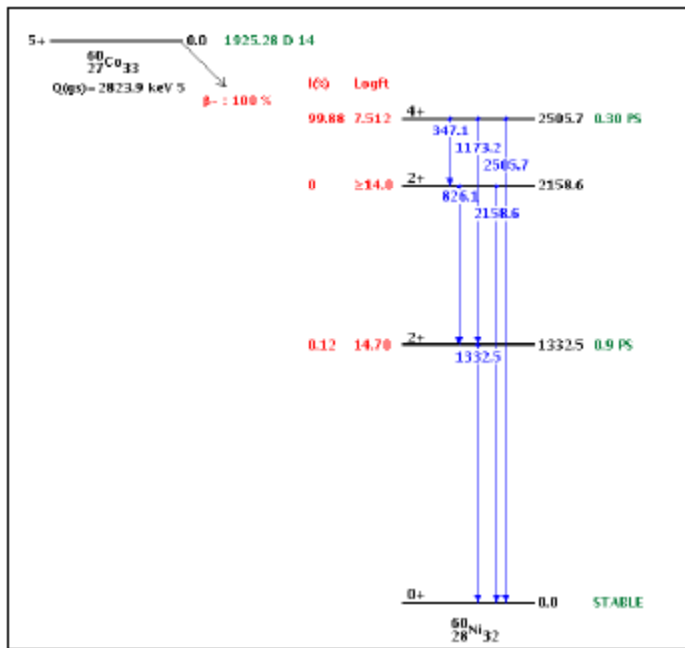
# Scope Exercises

- Find all pulse characterizations (list from Leo) for the following, using the scope:
- For all three setups:
  - Noise
  - NaI Phototube: background pulses
  - Si/Ge : Pulse from pulser
    - directly
    - through the pre-amp/amp chain
    - bipolar and unipolar
    - 6 well spaced settings of the amp (3 shapes, 3 amps)
    - 3 settings of the pulser...
  - Any other time varying signal you can think of

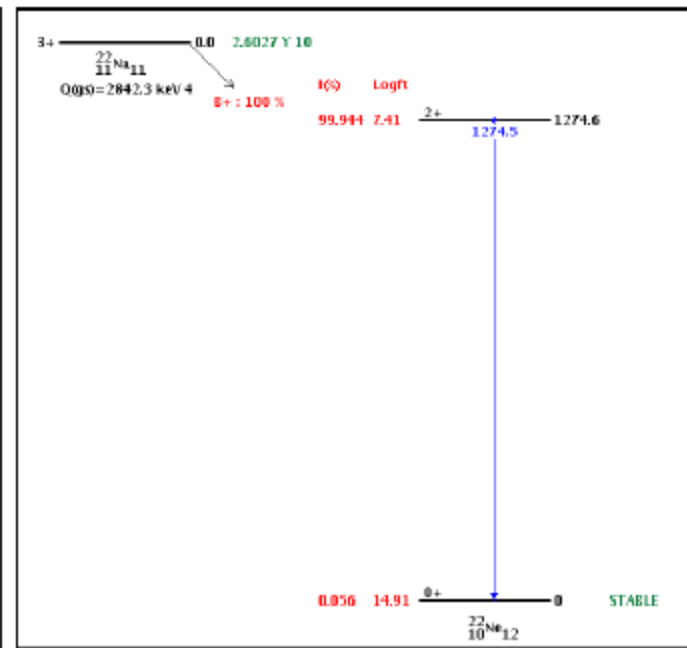
# 373 Nucleon Lab

4/14/11

# Radioactive Decay Schemes



Nuclear Data Sheets 100, 347 (2003)



Nuclear Data Sheets 106, 1 (2005)

From National Nuclear Data Center online database: <http://www.nndc.bnl.gov/nudat2/>

# Instructions for Today

- Everybody is taking calibration/bkg spectra
- Emission Rates
- Lab 1 Calibration multiple sources
  - If time, take U spectra again....
- Lab 2 - Calibration Spectra 2 detectors
  - W/ w/o Absorbers
- Lab 3 Si Detector: Additional Todo's:
  - Single source today
  - Take data at multiple angles
  - Explore electronics noise with pulser

# Schedule

- Schedule: in one week 0<sup>th</sup> Draft of Lab Report Due
- Work on labs next week (maybe not data taking?)
- Reports → See website



# 373 Nucleon Lab

4/21/11

# Lab Reports

- 1) Abstract
  - 2) Introduction
  - 3) Theoretical Bkg
  - **4) Experimental Design/Procedure**
  - **5) Analysis**
  - 6) Conclusions
  - 7) \*Questions ( I may ask some specific individual extra questions related to broader applications, involving material covered on the slides from the first couple weeks' Intro)
  - 8) Bibliography
  - All sections other than 4 & 5 should be done individually, and combined with copies of 4 & 5, resulting in one lab report document per student
    - Authors: First author : student, then other members of the group
    - Title: You may choose your own individual title if you like
  - refer to the web document for subsections that should be in each of these (other than 7)
- These 2 can/should be done in common with the other members of your group

# Remaining Schedule (Tentative)

Phys 373 2011 May Schedule						
day	MON	Tues	Wed	Th	Fri	
Week of 3-May		First Draft Lab 1 Due Start Lab 2		Lab 2 Plan Due		
	2	3	4	5	6	
Week of 10-May		Final Draft Lab 1 Due Lab 2 0th Draft in class		Finish Lab 2		
	9	10	11	12	13	
Week of 17-May		Finish Lab 2/ Rutherford Lab Introduction Lab 2 First Draft Due		Rutherford Lab Data Taking Lab 3 Data Taking Concurrently w/		
	16	17	18	19	20	
Week of 24-May	Rutherford Lab Data Taking Lab 3 Data Taking Concurrently w/	Lab 2 Final Draft Due		Rutherford 0th Draft/Lab 3 Data Due		
	23	24	25	26	27	
Week of 31-May	Rutherford Lab Data Taking Lab 3 Data Taking Concurrently w/		Rutherford 1st Draft/Lab 3 Data Due	Probably no need to have class		
	30	31	1	2	3	
5-Jun		Tuesday of Finals week: Rutherford Final Draft Due				