Physics 214 UCSD
Physics 225a UCSB
Experimental Particle Physics

Lecture 17

A few words about the final

Attempt at a summary of the quarter.

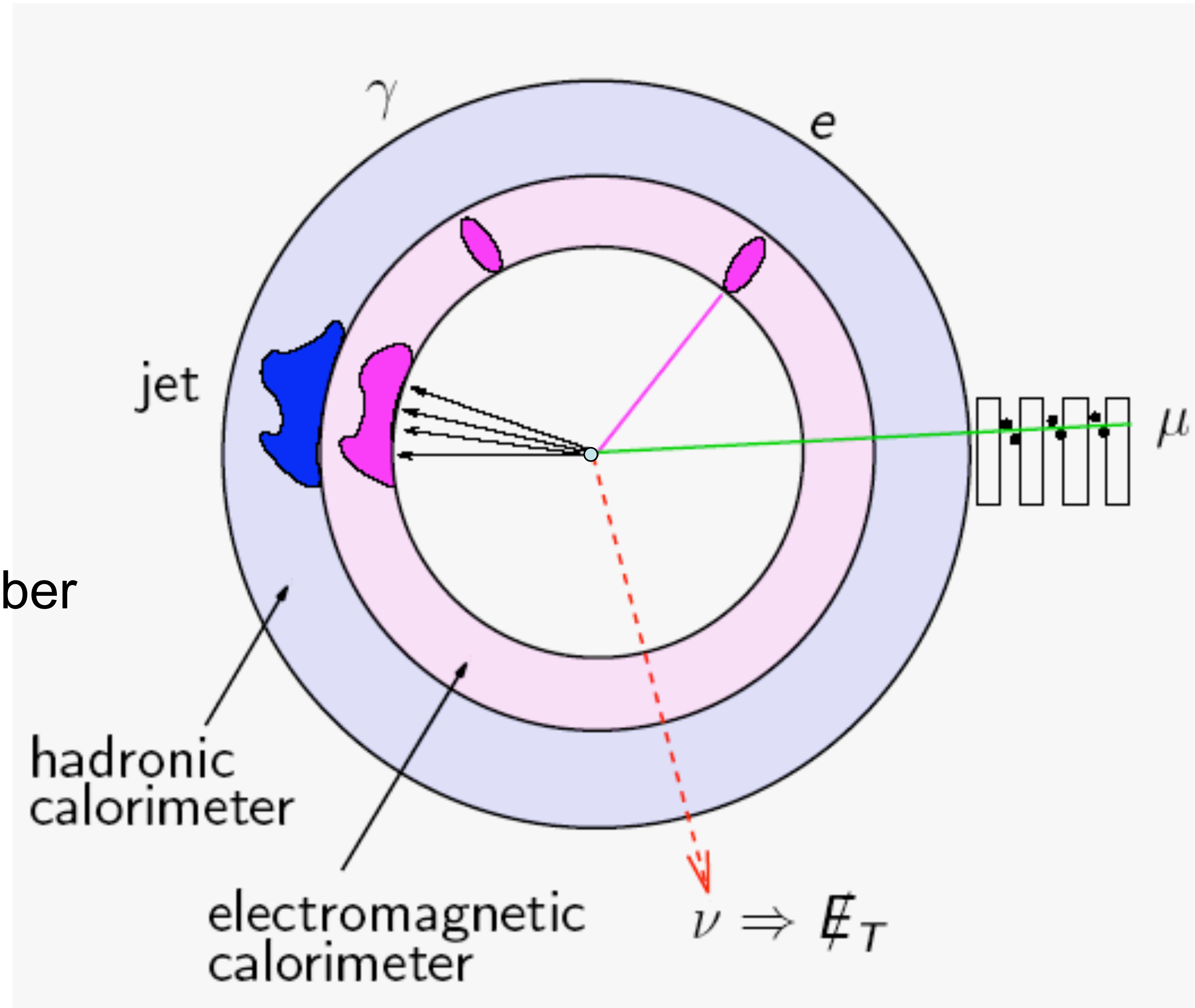
What do we need to detect?

- Momenta of all stable particles:
  - Charged: Pion, kaon, proton, electron, muon
  - Neutral: photon, K^0_s , neutron, K^0_L , neutrino
- Particle identification for all of the above.
- "Unstable" particles:
  - Pizero
  - b-quark, c-quark, tau
  - Gluon and light quarks
  - W,Z,Higgs
  - … anything new we might discover …

All modern collider detectors look alike

Increasing radius

- beampipe
- tracker
- ECAL
- solenoid
- HCAL
- Muon chamber



What you need to know:

- Exprimentalists:
  - Everything we talked about !
- Theorists:
  - The basic model how all collider detectors are built.

Symmetries

- Theorists:
  - Need to know everything, and more.
- Experimentalists:
  - Basic ideas
  - How to apply them to:
    - Know what transitions are allowed
    - Calculate ratios of amplitudes
    - Calculate angular distributions

Summary on Lie groups

- Let L be the N dimensional Lie group of Rank k for the Hamiltonian H.
- Then we have the following set of operators that mutually commute:

$$H, C_1,\ldots,C_k,L_1,\ldots,L_k$$

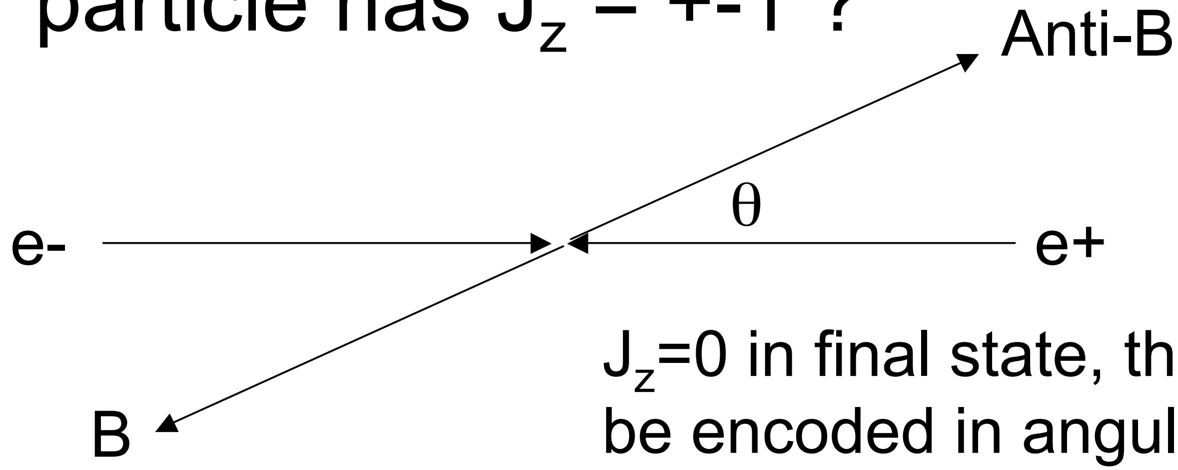
- Any state is thus characterized by 2k quantum numbers.
- The energy E is given as some function of the $C_1,\ldots,C_k$.

Example:
Group of Rotations in 3-space

- Generators: J_x, J_y,J_z
- Lie algebra: $[J_k, J_l] = i\, \varepsilon_{klm}\, J_m$
- Rank = 1
- Casimir Operator: J^2
- Multiplets are classified by their total angular momentum J
- States are classified by J and J_z, the latter being one of the three generators.

Final Exam Question 3

- What's the angular distribution for the decay products in the decay $J^{PC} = 1^{--}$ to two pseudoscalars if the decaying particle has J_z = +-1 ?



J_z=0 in final state, therefore L must be encoded in angular distribution of B anti-B axis !!!

$$\sigma \propto \left(\left| d^1_{10} \right|^2 + \left| d^1_{-10} \right|^2 \right) \propto \sin^2\theta$$

Final Exam Question 8

- Most of you got some fraction of this right.
- Almost everybody missed the fact that there are two reduced matrix elements in play, and that you need to do an isospin decomposition after adding the isospin of the B meson and the isospin of the transition operator $H_{effective}$!!!

Neutrino Physics

- The basic Phenomenology
  - There are 3 families of neutrinos
  - They are produced and observed in their weak eigenstates but propagate in their mass eigenstates => mixing
  - What we know from experiment
  - The *research frontier*
    - Measuring sin(theta13)
    - Understand hierarchy
    - Majorana vs Dirac

Discussion of QFT and scattering of point particles

- From Feynman Diagrams to Matrix elements.
  - You need to come up with the diagram for a process (e.g. Q6 of final)
  - You need to write down the ME
- Relationship between ME, cross section, and physical observable.
- Understand basic characteristics to know when you’ve screwed up royally.
- Theorists need to actually master the algebra.

“Rules” for dealing with antiparticles

- Antiparticles get arrow that is backwards in time.
- “Incoming” and “outgoing” is defined by how the arrows point to the vertex.
- Antiparticles get negative energy assigned.

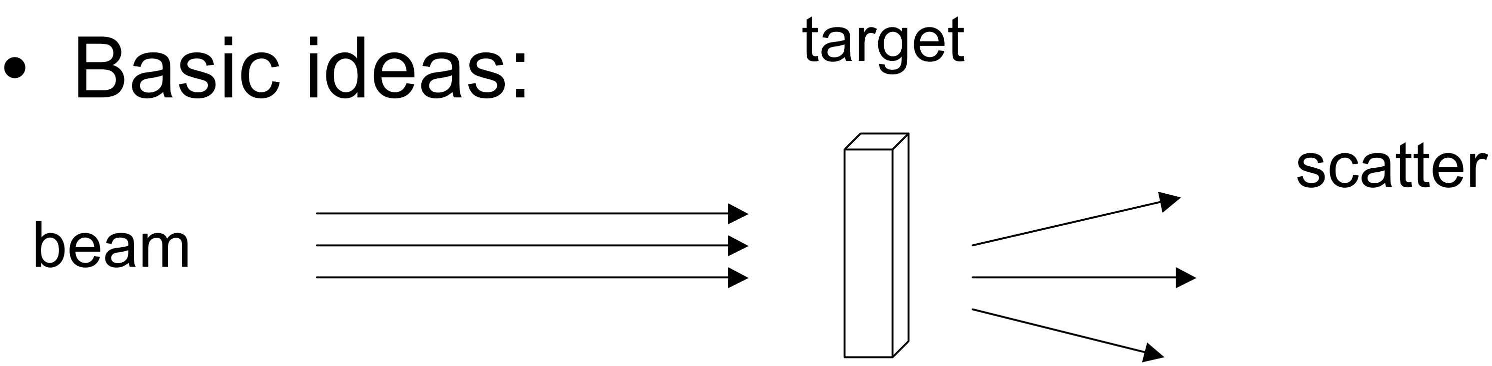
Two-by-two process

- Understand how to relate number of scatters in AB -> CD scattering to “beam & target independent” cross section in terms of W_{fi} .
- Relate W_{fi} to matrix element.

=> Understand relationship between cross section and Matrix Element”, and be able to relate it to physical observable.

Cross Section for AB -> CD

- Basic ideas:



# of scatters = (flux of beam) x (# of particles in target) x σ

$$\text{Cross section} = \sigma = \frac{W_{fi}}{(\text{initial flux})} (\text{number of final states})$$

W_{fi} = rate per unit time and volume

"Cross section" is independent of characteristics of beam and target !!!

Experimental perspective

- We measure event yield within some ragged kinematic corner of phase space.
- We divide by our detector acceptance

=> *We get produced yield for well defined corner of phase space.*

- We measure integrated luminosity of the colliding beams for our data taking period.

=> σ = *produced yield / integrated luminosity*

Theoretical perspective

$$\text{Cross section} = \sigma = \frac{W_{fi}}{\text{(initial flux)}} \text{(number of final states)}$$

$$\sigma = \frac{W_{fi}}{v_A\,(2E_A/V)\,(2E_B/V)} \frac{V dp_C^3}{(2\pi)^3 2E_C} \frac{V dp_D^3}{(2\pi)^3 2E_D}$$

$$W_{fi} = (2\pi)^4 \frac{\delta^{(4)}(p_D + p_C - p_A - p_B)}{V^4} |M|^2$$

M is obtained from Feynman rules, and the rest is algebra.

It is customery to re-express

$$d\sigma = \frac{|M|^2}{F} dQ$$

F = flux factor: $F = 4\sqrt{\left(p_A^{\mu} p_{\mu}^{B}\right)^2 - m_A^2 m_B^2}$

dQ = Lorentz invariant phase space:

$$dQ = \frac{1}{16\pi^2} \delta^{(4)}(p_D + p_C - p_A - p_B) \frac{dp_c^3 dp_D^3}{E_c E_D}$$

e+e- -> f+ f-

- Question 1 on final is probably the most important example process to understand.
- I promise to revisit this next quarter, and discuss it in some detail then.

$p_f \sim p_i$ **=>** $$\left.\frac{d\sigma}{d\Omega}\right|_{cm} \approx \frac{|M|^2}{64\pi^2 s}$$

$t = -2\,k^2\,(1 - \cos\theta)$

$u = -2\,k^2\,(1 + \cos\theta)$ **=>** $$\overline{|M|^2} = 2e^4\,\frac{8k^4\left(1+\cos^2\theta\right)}{16k^4}$$

$s \sim 4k^2$

$\alpha = e^2/4\pi$

$$\left.\frac{d\sigma}{d\Omega}\right|_{cm} \approx \frac{\alpha^2}{4s}\left(1+\cos^2\theta\right)$$

$$\sigma(e^+e^- \rightarrow \mu^+\mu^-) \approx \frac{4\pi\alpha^2}{3s}$$

Relativistic limit

- $e_L^- \, e_R^+$ -> $mu_L^- \, mu_R^+$ J_z +1 -> +1
- $e_L^- \, e_R^+$ -> $mu_R^- \, mu_L^+$ J_z +1 -> -1
- $e_R^- \, e_L^+$ -> $mu_L^- \, mu_R^+$ J_z -1 -> +1
- $e_R^- \, e_L^+$ -> $mu_R^- \, mu_L^+$ J_z -1 -> -1
- *Next look at the rotation matrices:*

$$d^1_{11}(\theta) = \frac{1}{2}\left(1 + \cos\theta\right) \approx \frac{-u}{s}$$

$$d^1_{-1-1}(\theta) = \frac{1}{2}\left(1 + \cos\theta\right) \approx \frac{-u}{s}$$

$$d^1_{-11}(\theta) = \frac{1}{2}\left(1 - \cos\theta\right) \approx \frac{-t}{s}$$

$$d^1_{1-1}(\theta) = \frac{1}{2}\left(1 - \cos\theta\right) \approx \frac{-t}{s}$$

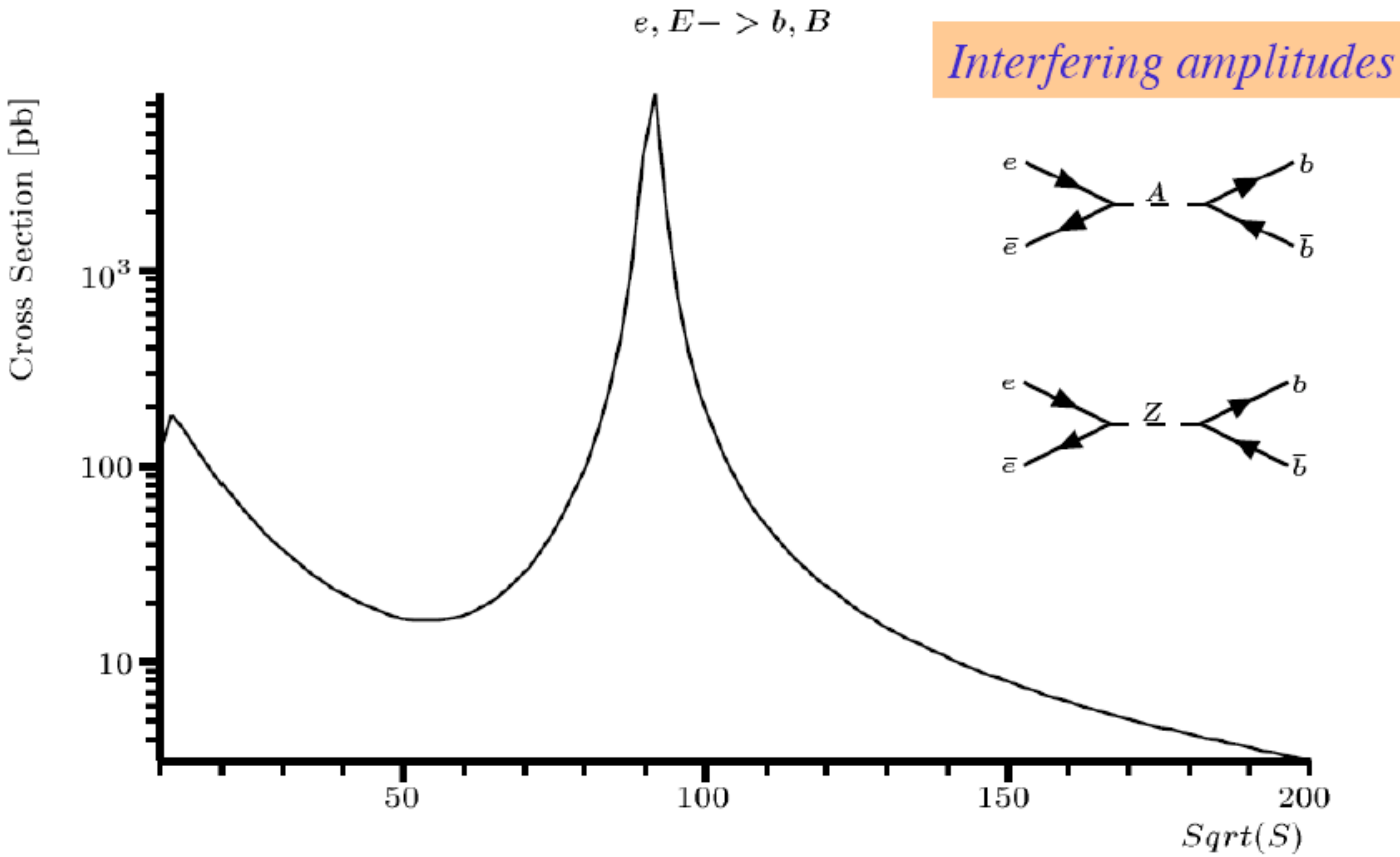
Cross products cancel in Spin average:

$$\overline{|M|^2} \propto \left(1 + \cos^2\theta\right)$$

d^J_{1-1}

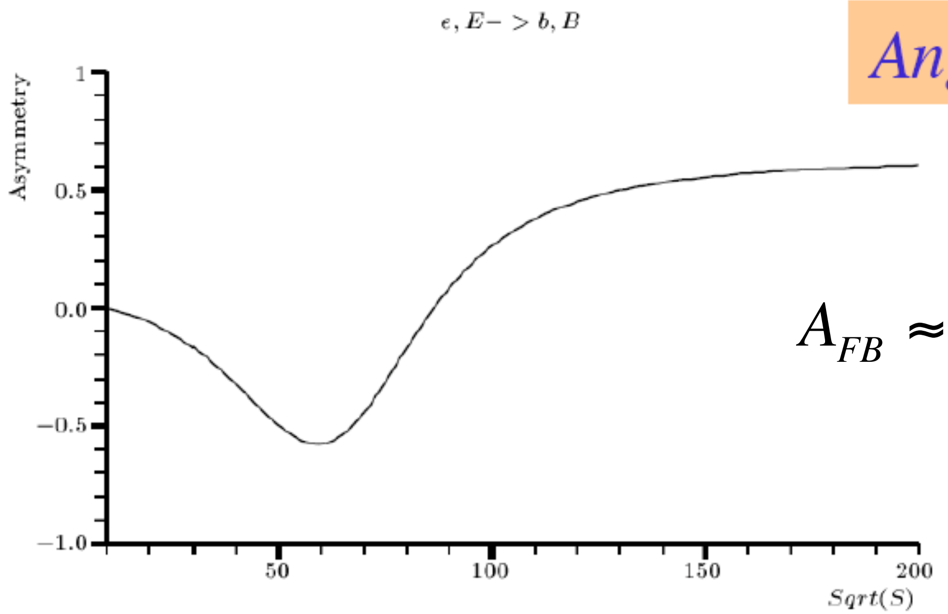
initial final J_z

QED piece goes like $1/E^2$ => -2logE on log scale.
Weak piece must have a Z-pole.



Forward-backward asymmetry

Must start at 0 because of 1+cos^2 dependence.
For dependence look at Eq. 13.66 and 13.61 in H&M.



Angular asymmetry vs. CM energy

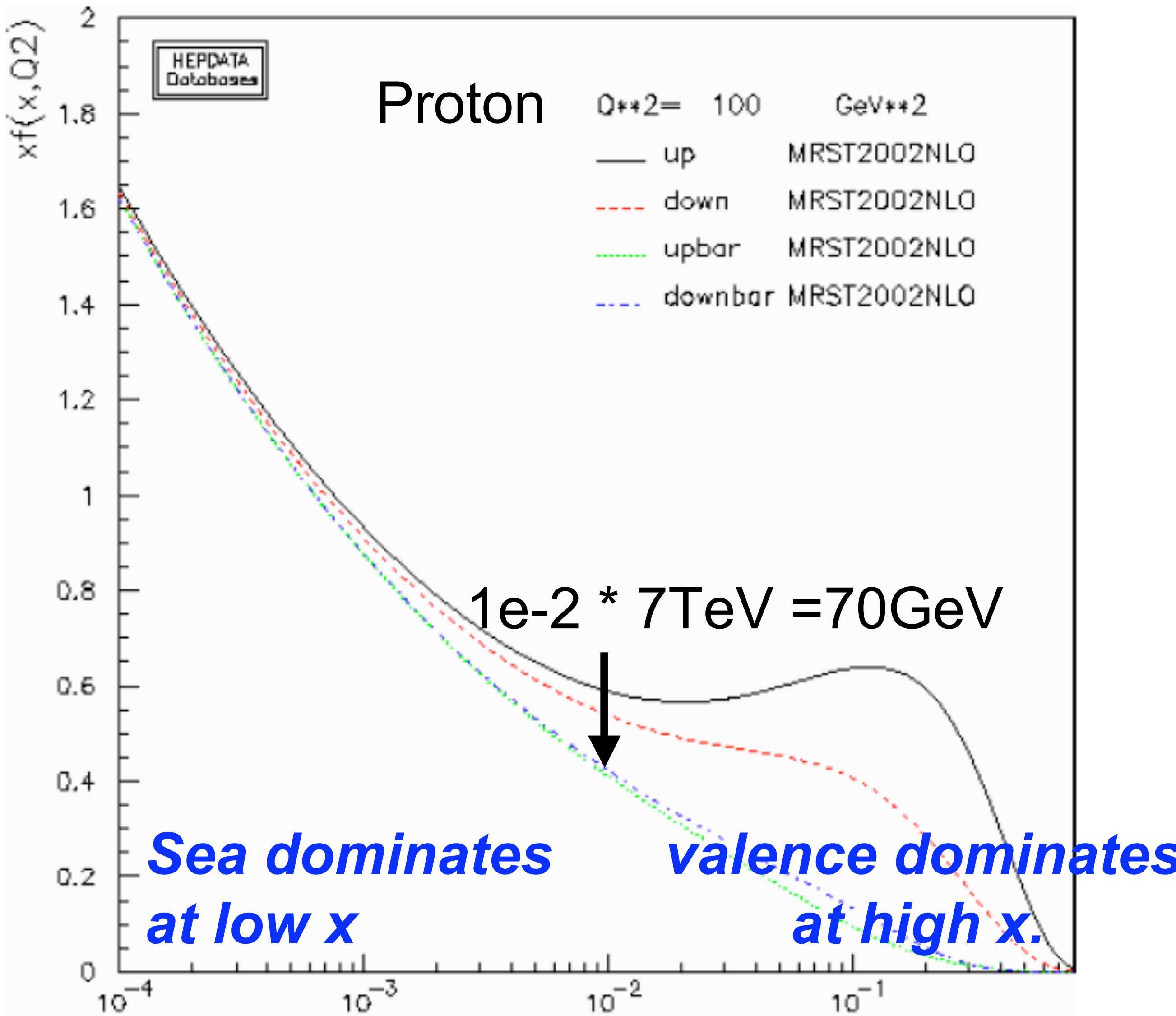
$$A_{FB} \approx \frac{3}{2}\Re\left[\frac{\sqrt{2}GM_Z^2}{s - M_Z^2 + iM_Z\Gamma_Z}\left(\frac{s}{e^2}\right)\right]c_A^2$$

It goes negative like -s as s increases from 0.
It reaches a minimum t a place that's not immediatey obvious.
It goes asymptotically towards a positive value.

Deep Inelastic Scattering

- Bjorken Scaling is a sign of point particles inside the proton.
- The parton picture, and pdf’s that describe the structure of the proton
  - At what x do valence quarks dominate
  - At what x do sea quarks dominate
  - At what x do gluons dominate
  - How do I use this information to gain some intuition about proton proton and proton antiproton collisions as a function of sqrt(s).

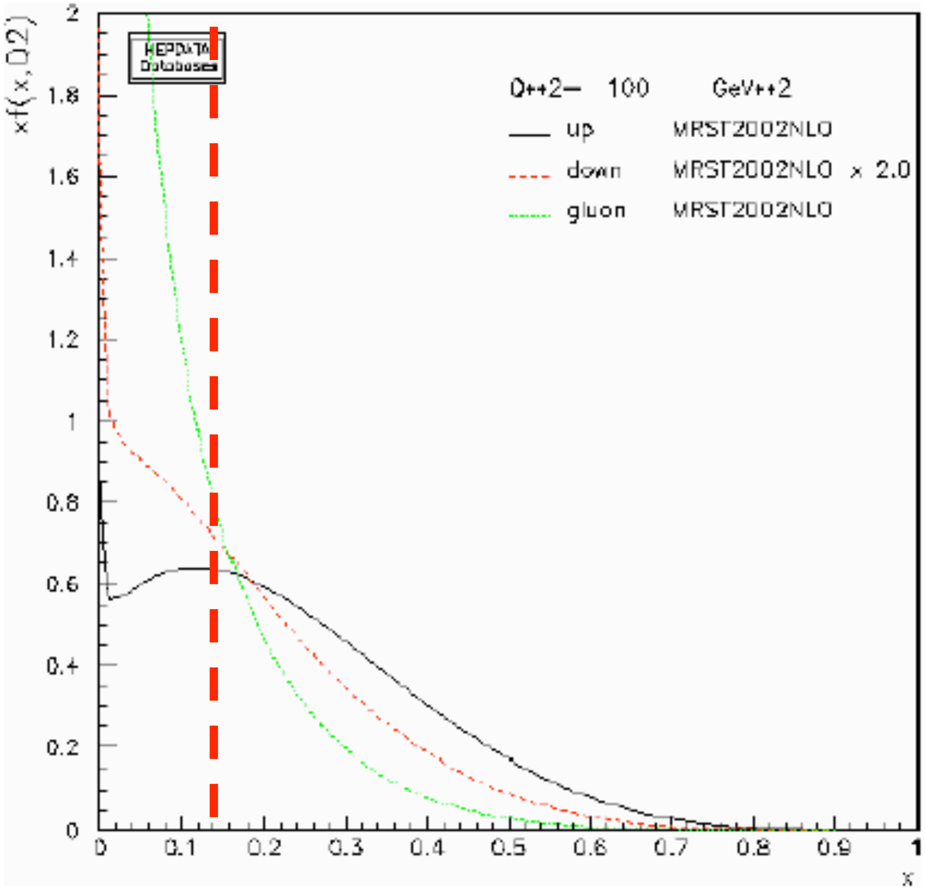
PDFs from http://durpdg.dur.ac.uk/hepdata/pdf3.html

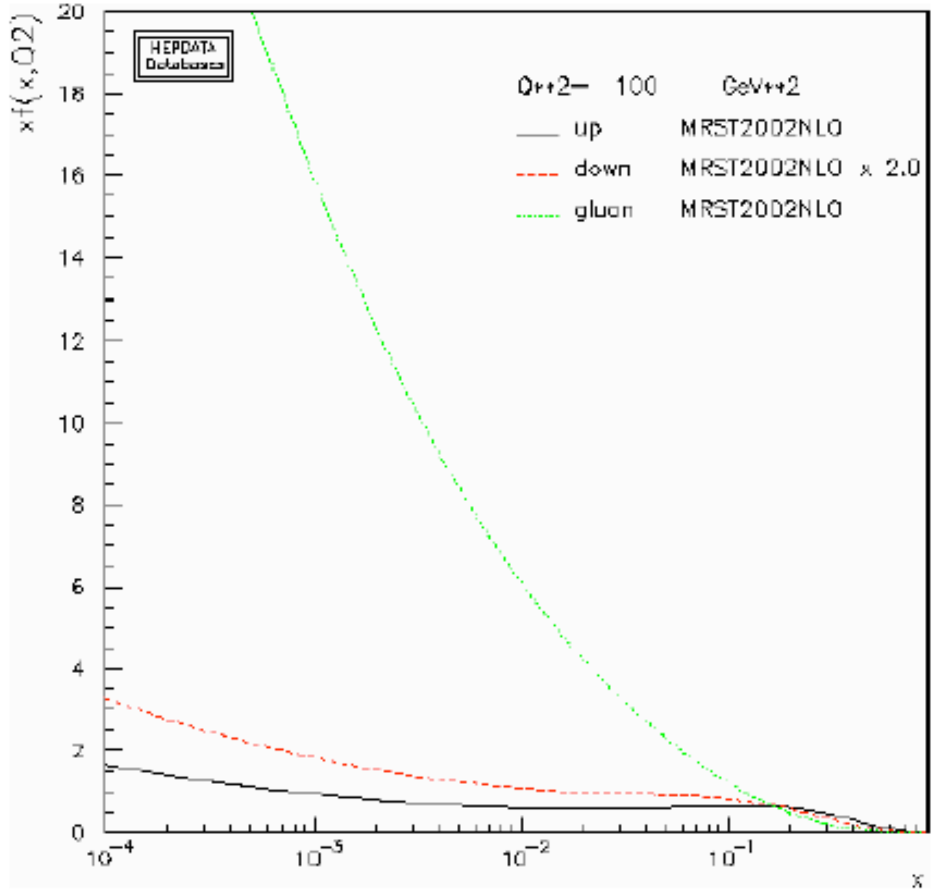


Note:

$$\hat{s} = x_i x_j s$$

A 14TeV collider can be pp instead of ppbar because all Standard model processes involve low x at that s !!!



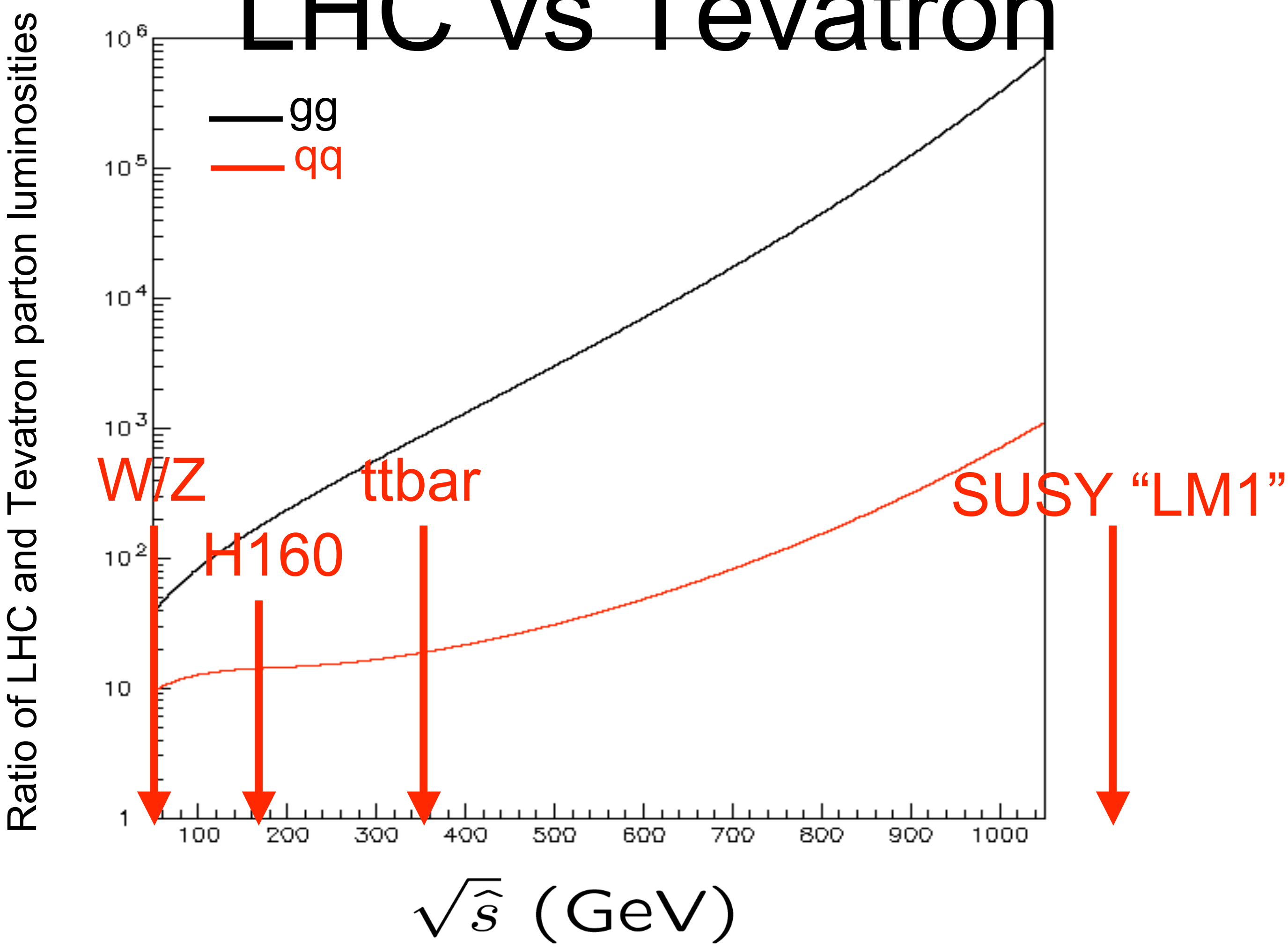


Gluons dominate at low x .

To set the scale, x = 0.14 at LHC is 0.14 * 7TeV = 1TeV

=> The LHC is a gluon collider !!!

LHC vs Tevatron



simplistic rule of thumb:

- For 1 TeV gg processes, 1 fb^{-1} at FNAL is like 1 nb^{-1} at LHC
- For 1 TeV qq processes, 1 fb^{-1} at FNAL is like 1 pb^{-1} at LHC

Cross sections at 1.96TeV versus 14TeV Tevatron vs LHC

	Cross section		Ratio
$Z \rightarrow \mu\mu$	260pb	1750pb	6.7
WW	10pb	100pb	10
H_{160GeV}	0.2pb	25pb	125
$mSugra_{LM1}$	0.0006pb	50pb	80,000

At $10^{32}cm^{-2}s^{-1}$ CMS might accumulate $10pb^{-1}$ in one day!

… and SUSY might not exist in nature.

In case you want to prepare for next quarter during the break.

Make yourself comfortable with question 1 on final.

Play around a bit with comphep, madgraph, etc.

Have a great holiday!

And see you all back in the new year
in the continuation of this lecture.