Larry Leipuner

Tribute to a Mentor, and a Tale of Two Lifetimes

Colloquium at Brookhaven National Laboratory
3/27/07 Michael Schmidt, Yale University

Outline

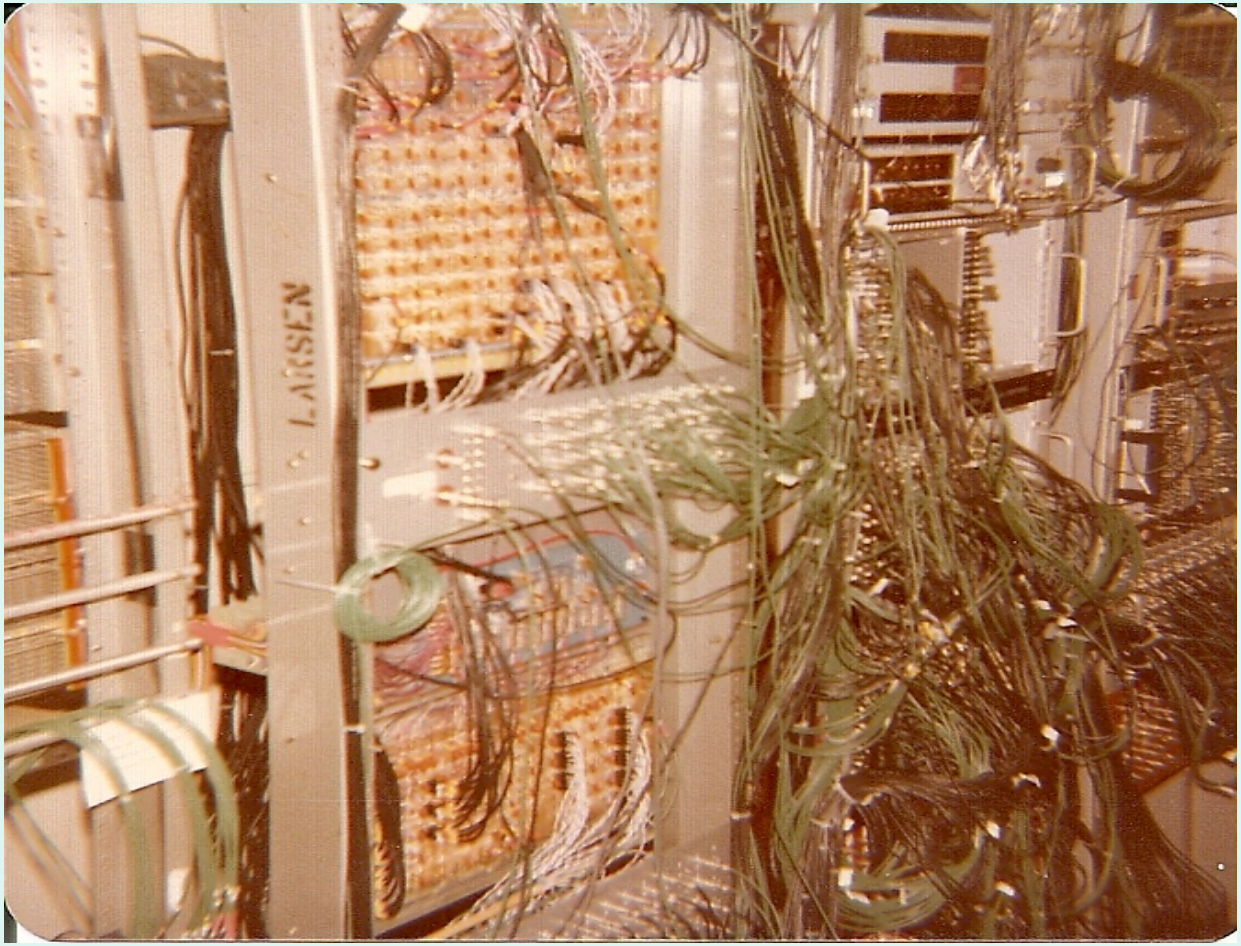
- Larry in his role as mentor
- Physics interlude: B^0_s lifetime difference
- Extracurricular activities

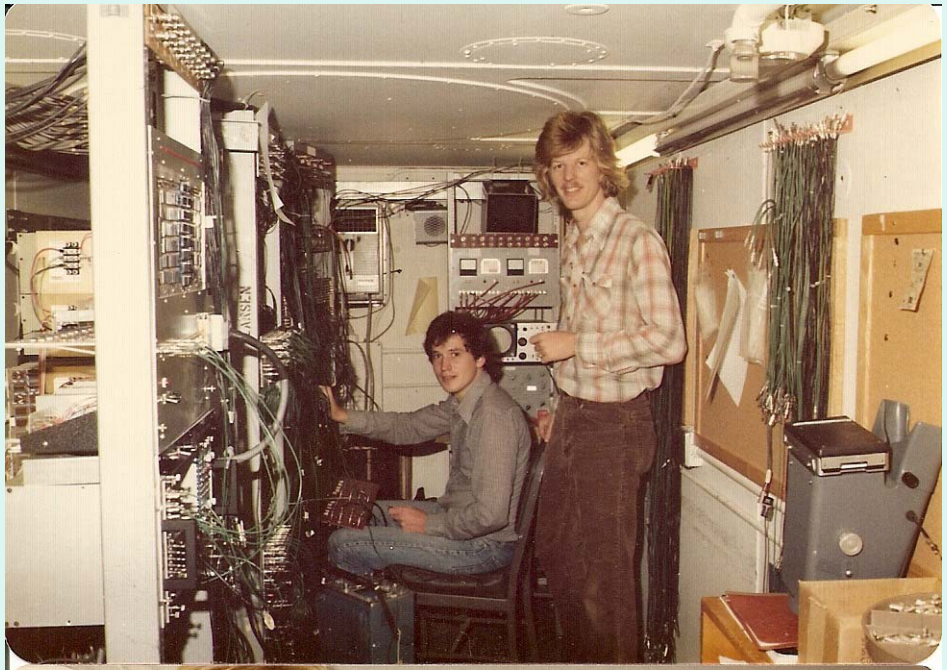
Lessons from Larry

- BNL-Yale collaboration
- DeMorgan’s Theorem, Again!
- Always the latest things
- Extensions of Moore’s Law
- To build or buy?
- To wait for consensus or to build?

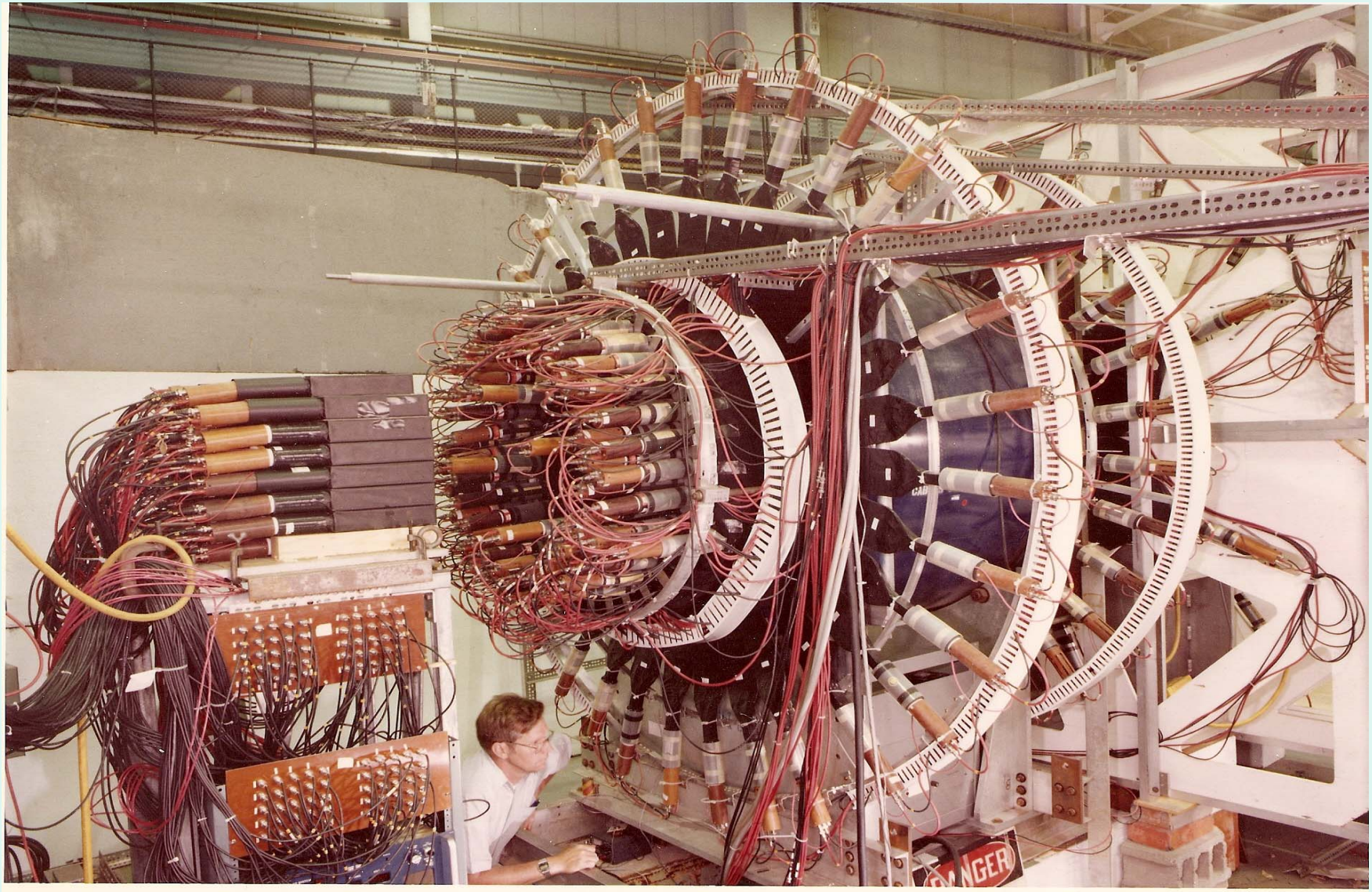
BNL-Yale Collaboration (`77)

Trigger Electronics for E696





Polarimeter and Lead Glass (E735)



Leipuner the innovator

Brookhaven water cooled version of FASTBUS

A New Standard For The 80s

If every home appliance had to have a different kind of plug, and every automobile a special fuel, life would be much more difficult and expensive than it already is. With the whirlwind development of electronic equipment, high energy physics researchers now find themselves in such a situation when constructing equipment for an experiment.

While some electronic equipment must be built explicitly for a particular experiment, most of the devices are similar to those used in other experiments. By having a standard electronic system specification, equipment can be used over and over again in different configurations to do different research. Brookhaven's high energy equipment pool, HEEP, makes this equipment available, most of which has been built to one of two earlier standards, NIM or CAMAC. These standards have served well for several decades, but the development of the integrated circuit, in particular, has made them less useful and more expensive.

Taking advantage of the cost reduction and speed made possible with intregrated circuits, a new computerized data acquisition system called FASTBUS has been built by Larry Leipuner's group in the Physics Department in collaboration with Bob Adair's group at Yale. Experimenters can now control an experiment from a centralized facility. This system will allow equipment to be used over and over again in different experiments, and will allow the easy interconnection of all kinds of electronics. Not only can experiments be done more cheaply and quickly, but FASTBUS will permit new experiments that cannot now be done with current equipment and standards.

Nowadays, in most high energy experiments, computers are used to gather and analyze data, and to monitor and control the equipment. FASTBUS takes its name from what is known as a computer bus. A computer bus is the linkage between the various parts of the computer, and FASTBUS extends this architecture to all of the high energy experimental electronic equipment. When viewed from the computer side of the bus, drift chambers or proportional wire chambers, or scintillation counters are just other devices such as card readers or printers. Now, experiments can be controlled from a central point. The more repetitive and boring tasks can be relegated to automatic facilities provided by the computer. As soon as control of the equipment becomes routine, experimenters can transfer it easily to computer management.

FASTBUS *is* fast. Normally, the speed is about 10 million, 32 bit transactions per second. Blocks of data may be transferred at about two and one half times this rate, giving almost a billion bits of transfer per second.

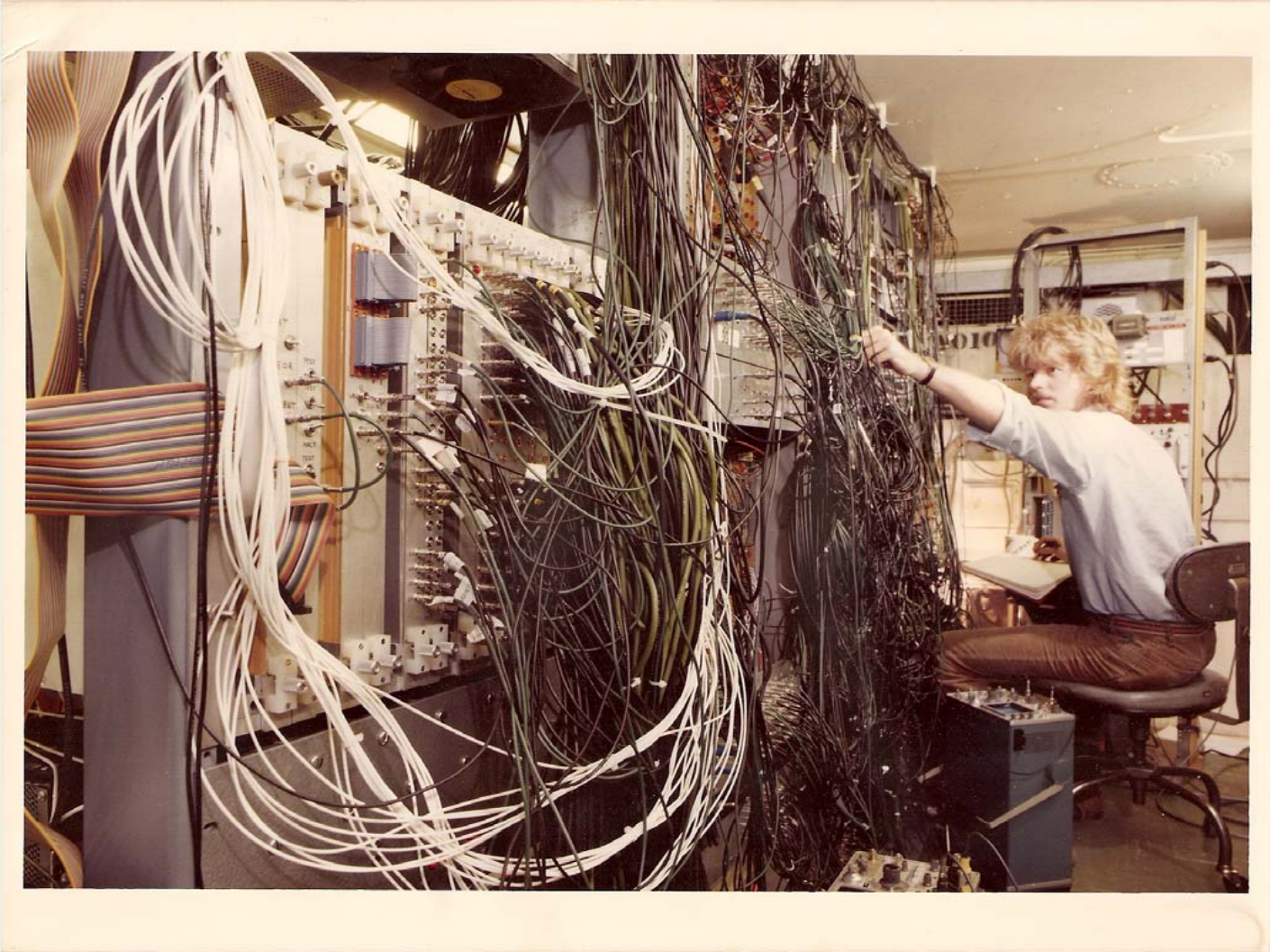
Larry Leipuner

These rates are greater than present computers can handle, but can be processed by the next generation of computers. Currently, however, the speed can be used to do low level processing while the data is still on the bus.

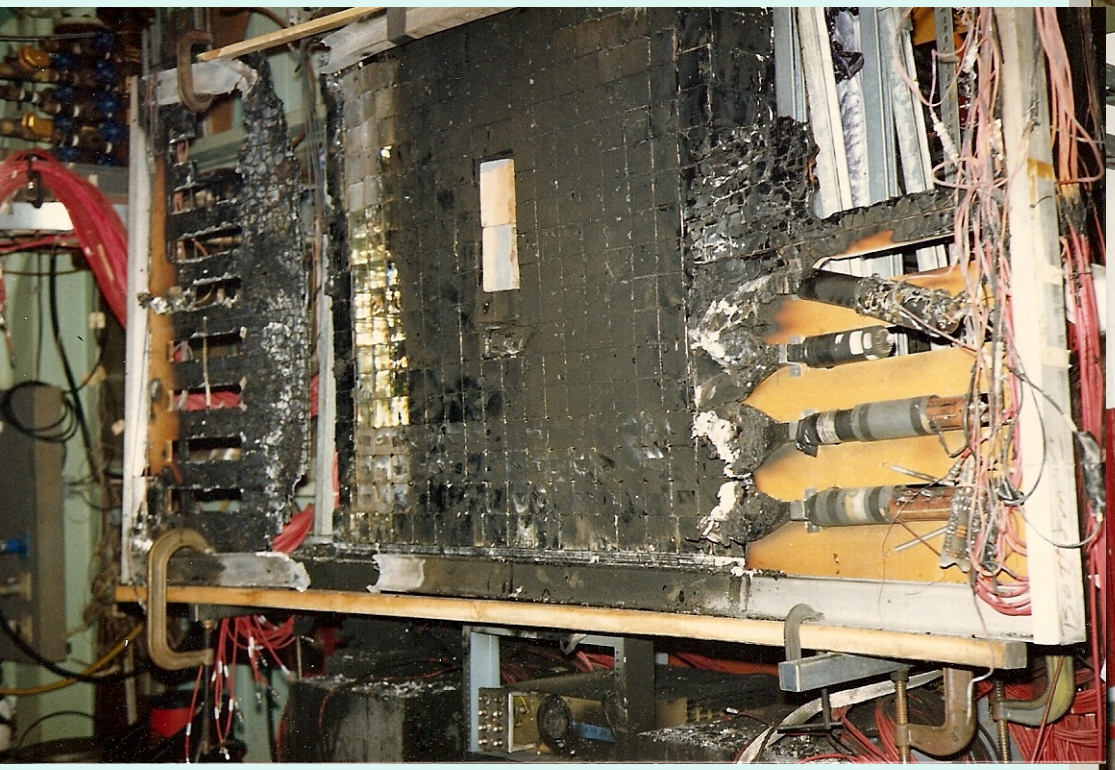
Experiment 735, now running at the AGS, has a simple data processor module designed for just this purpose. Using special registers, the processor relieves the computer of the task of finding which of over 200 scintillation counters responded to an event. The on-bus processor directs the data gathering and performs the data compaction as well.

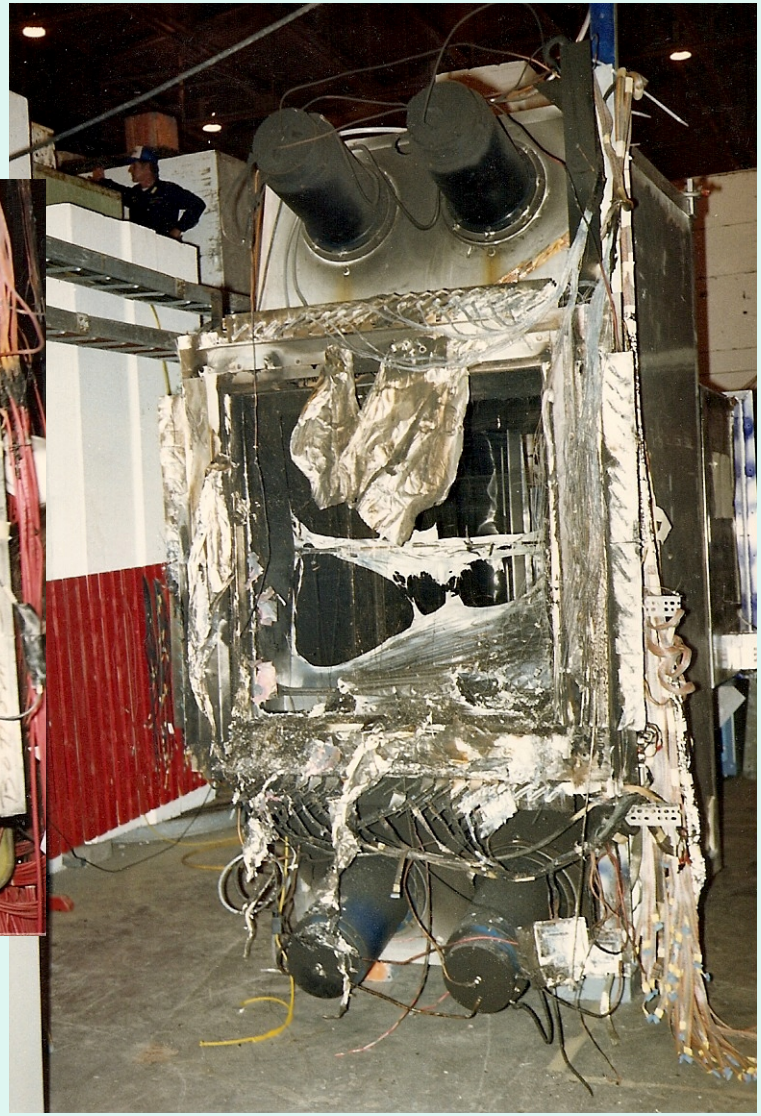
This experiment, a Yale/BNL collaboration, is the first experiment to use FASTBUS. It is Leipuner's expectation that, in the future, most high energy electronics will be built to this more powerful standard.

Brookhaven Fastbus in E735

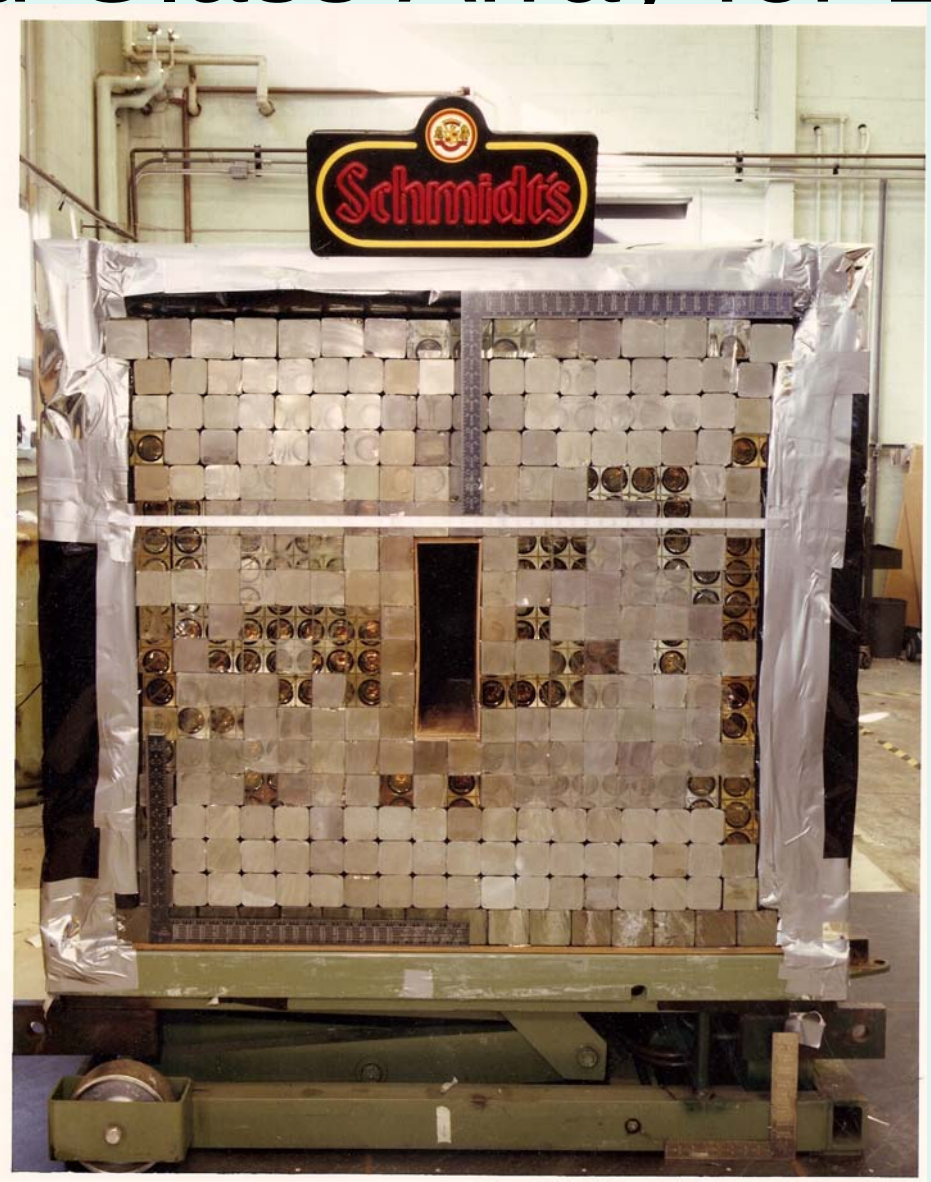


Fire! (E780)

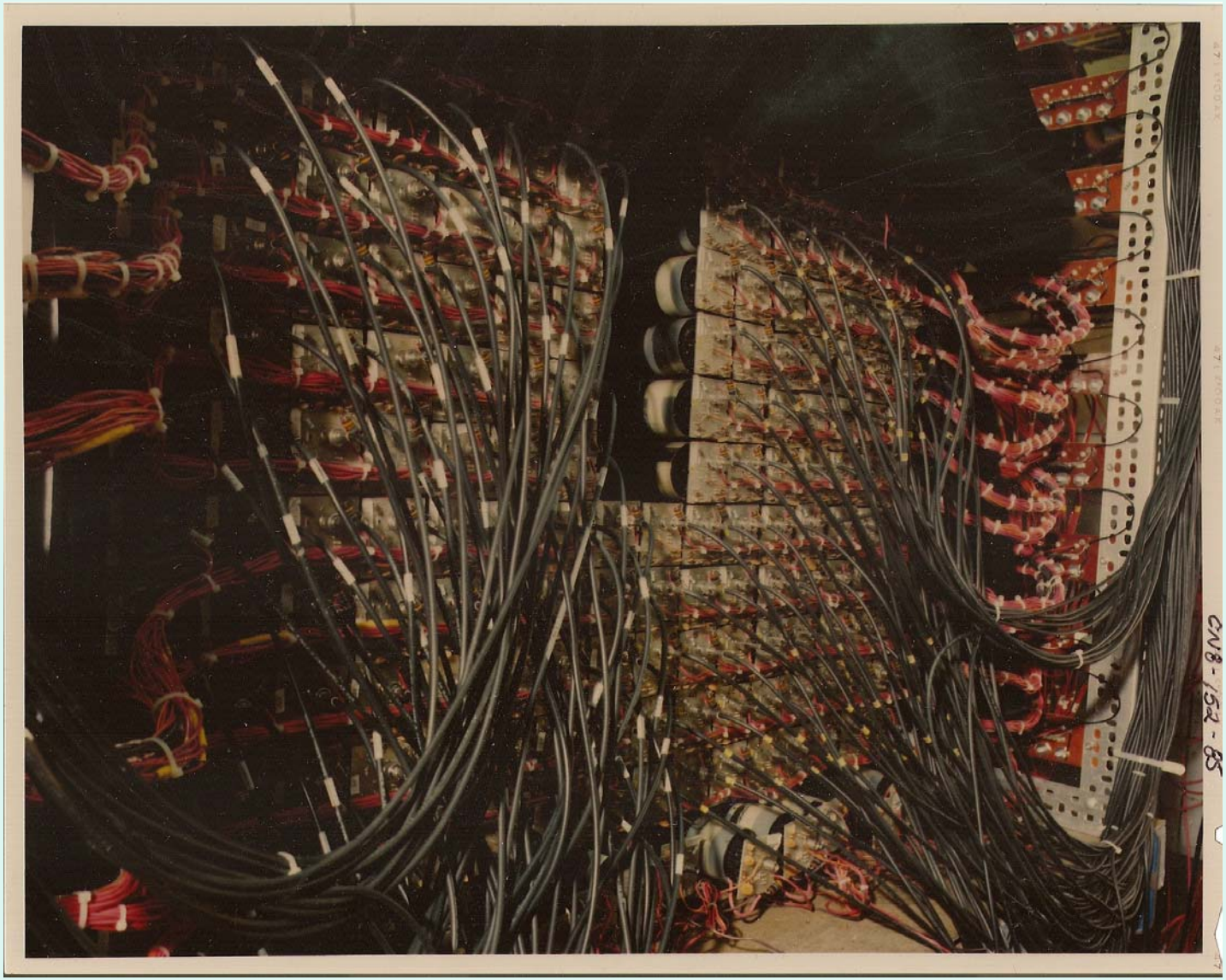




Lead Glass Array for E845



Lead Glass Array for E845



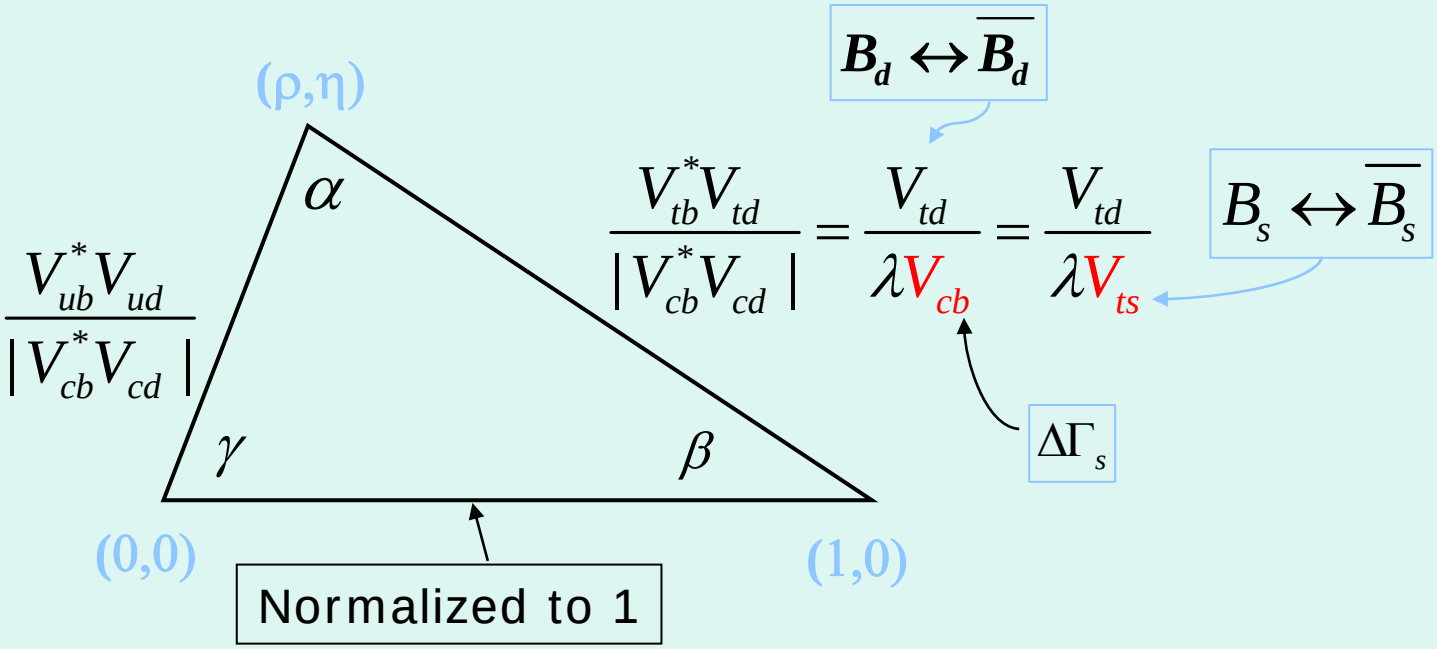
Some of the BNL-Yale Collaboration (’89)

25th Anniversary Discovery of CP Violation, Conference in Blois, 1989

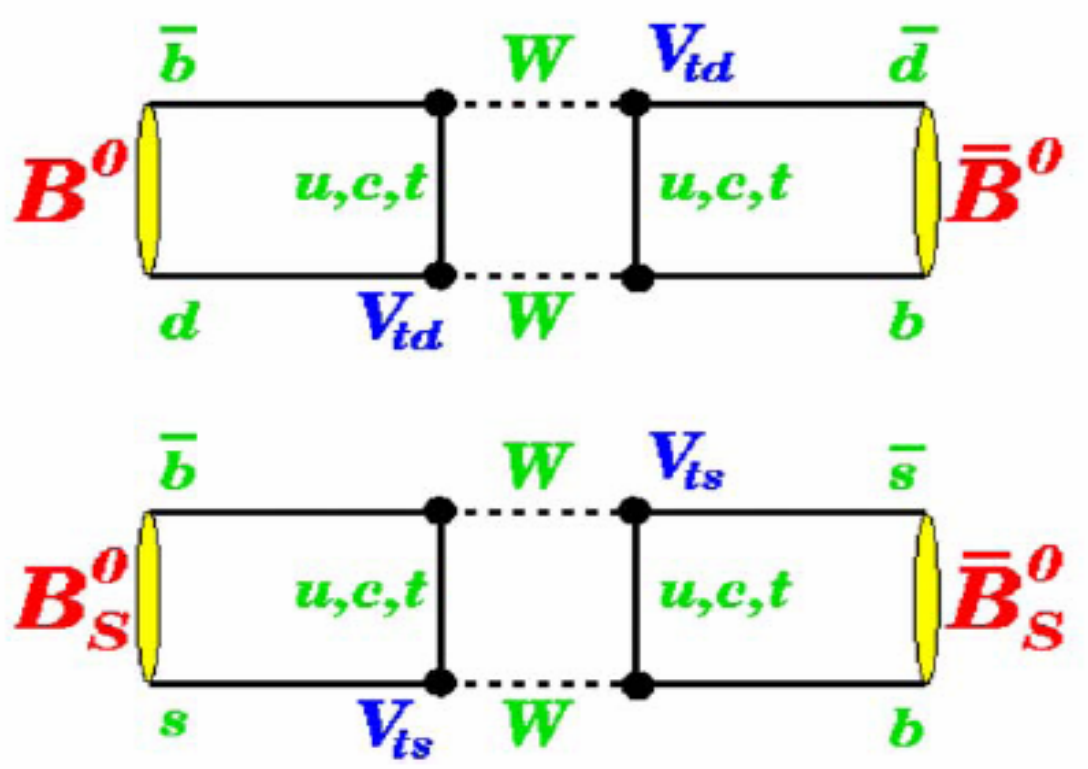
CKM Unitarity Triangle

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \cong \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \Rightarrow \frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} + 1 + \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} = 0$$



Second Order Weak Mixing



$$m \equiv \tfrac{1}{2}\left(m_H + m_L\right),\ \Gamma \equiv \tfrac{1}{2}\left(\Gamma_H + \Gamma_L\right),$$

$$\Delta m \equiv \left(m_H - m_L\right), \Delta\Gamma \equiv \left(\Gamma_L - \Gamma_H\right)$$

Eigenstates

- Our phase convention $CP|B_s\rangle = -|\bar{B}_s\rangle$
- E.g. in the B_s case, where we expect no phase from CKM

$$|B_s^H\rangle = p|B_s\rangle + q|\bar{B}_s\rangle = \frac{1}{\sqrt{2}}(|B_s\rangle + |\bar{B}_s\rangle) \quad \text{CP-Odd}$$

$$|B_s^L\rangle = p|B_s\rangle - q|\bar{B}_s\rangle = \frac{1}{\sqrt{2}}(|B_s\rangle - |\bar{B}_s\rangle) \quad \text{CP-Even}$$

- An initial particle or antiparticle is then

$$|B_s> = \frac{1}{\sqrt{2}}(|B_s^H> + |B_s^L>)$$

$$|\bar{B}_s> = \frac{1}{\sqrt{2}}(|B_s^H> - |B_s^L>)$$

Kaon Expert Guide:

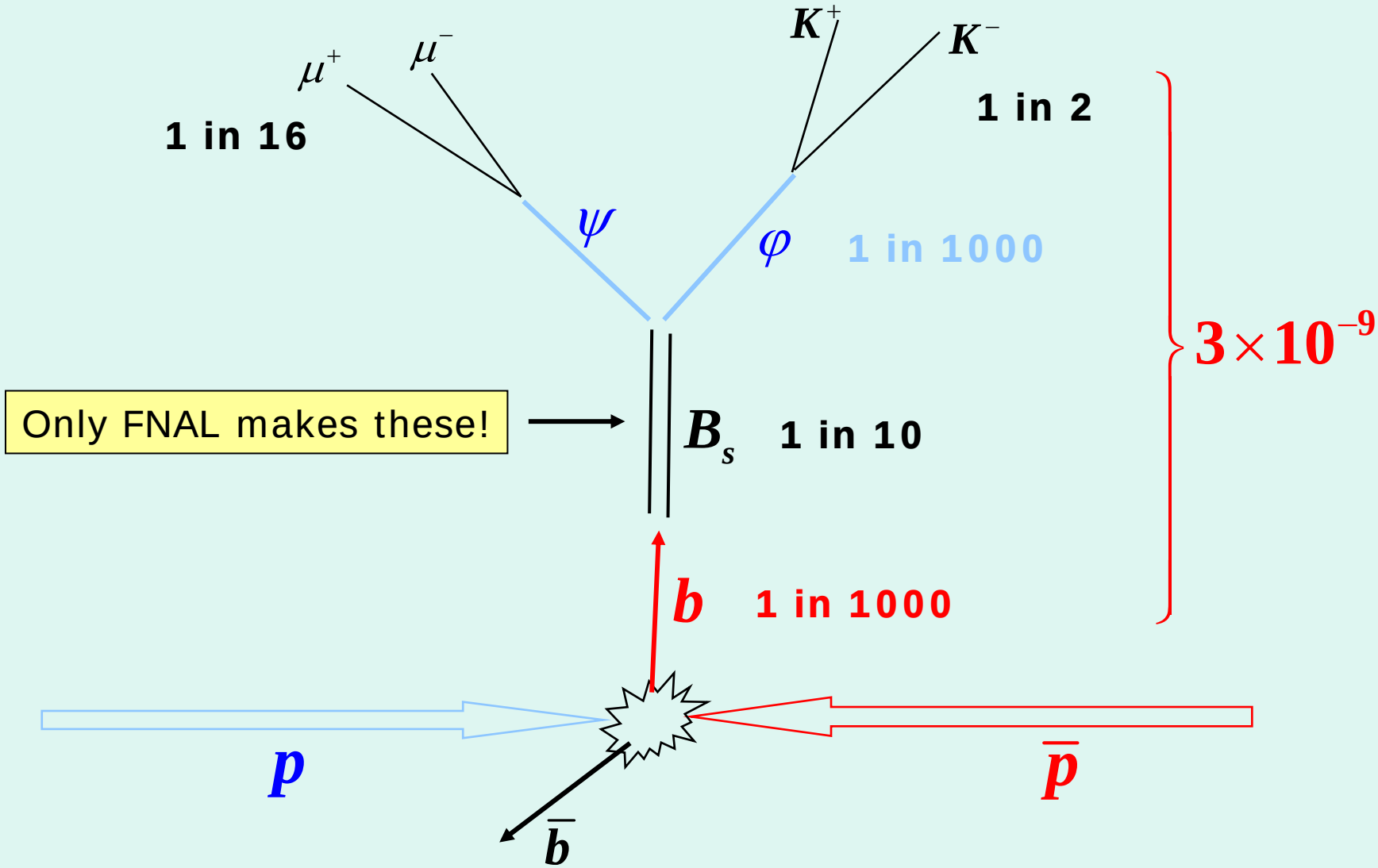
s=Strange, not Short

L=Light, not Long

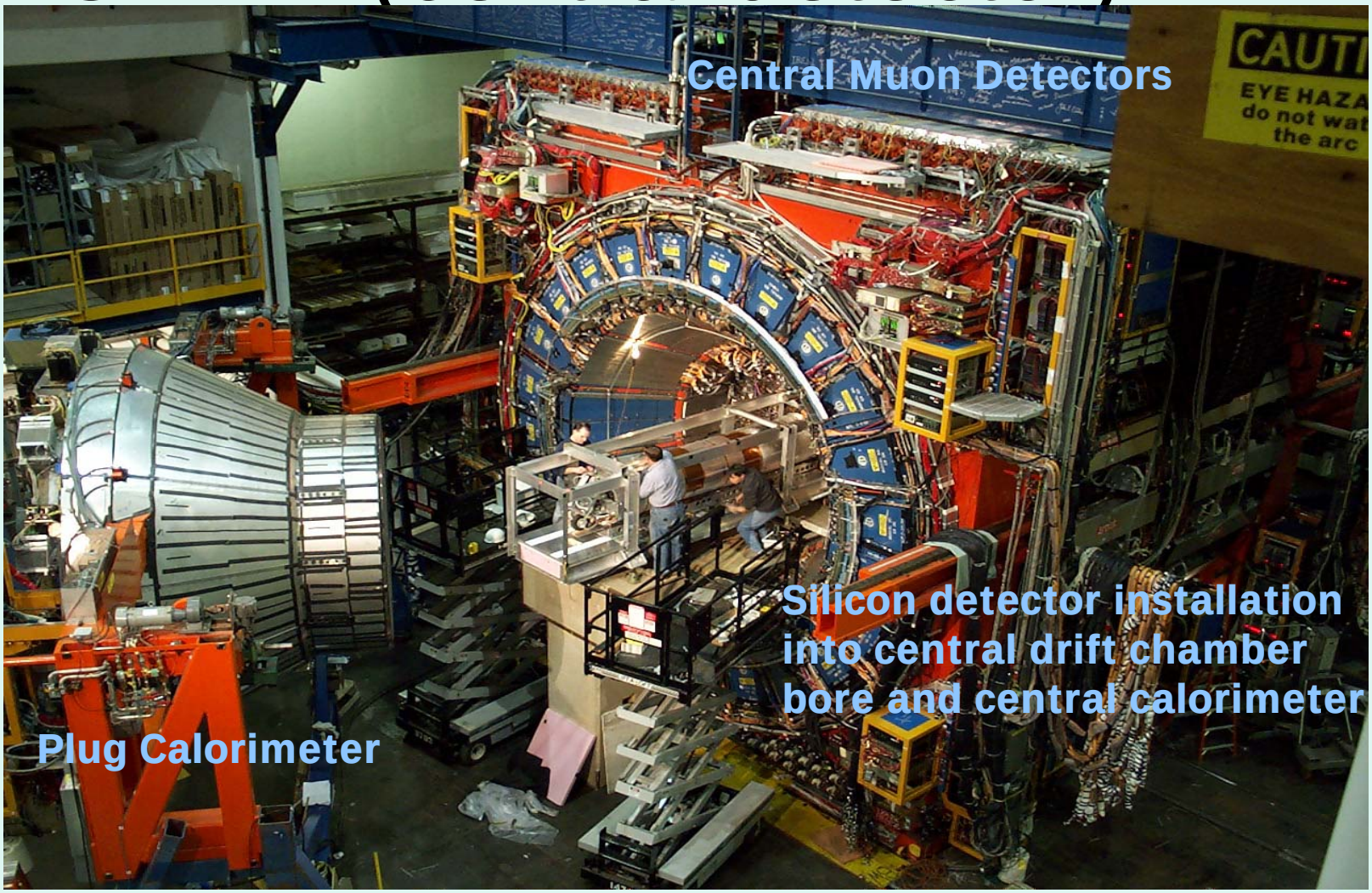
H=Heavy

$\Delta\Gamma$ due to kinematics

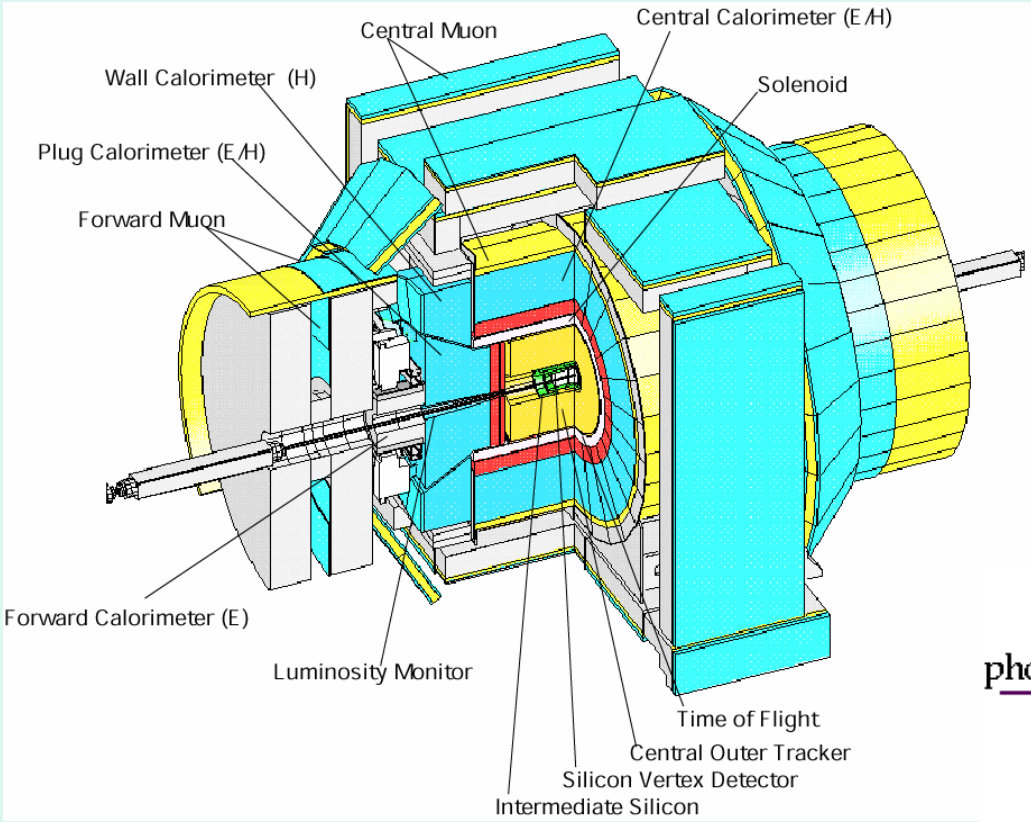
Why is studying the B_s tough?

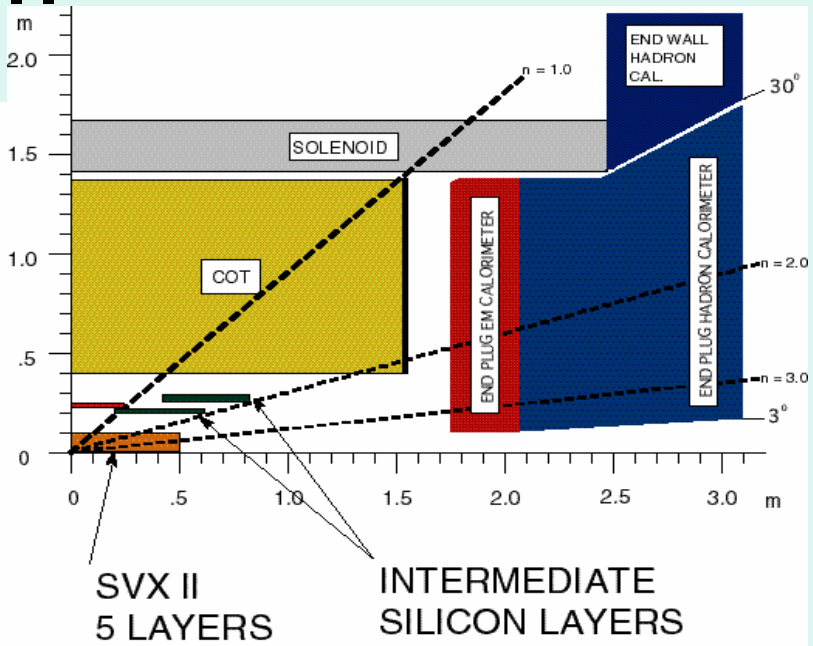


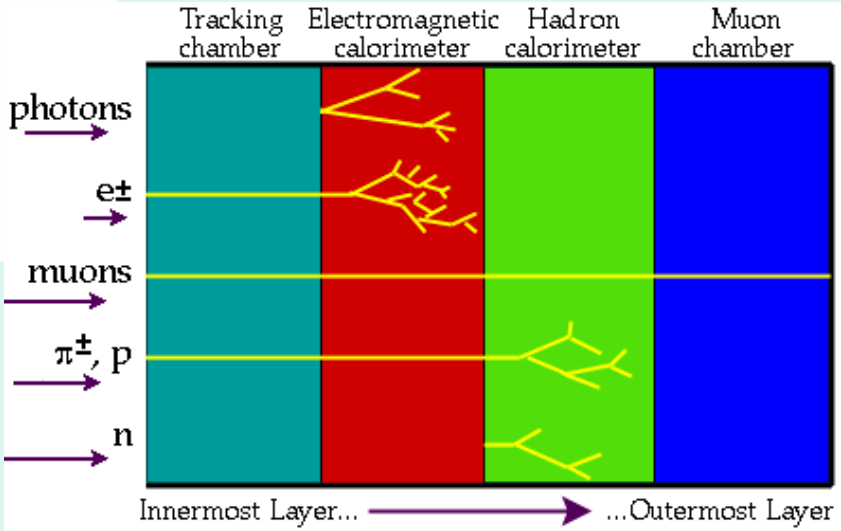
CDF II (central detector)



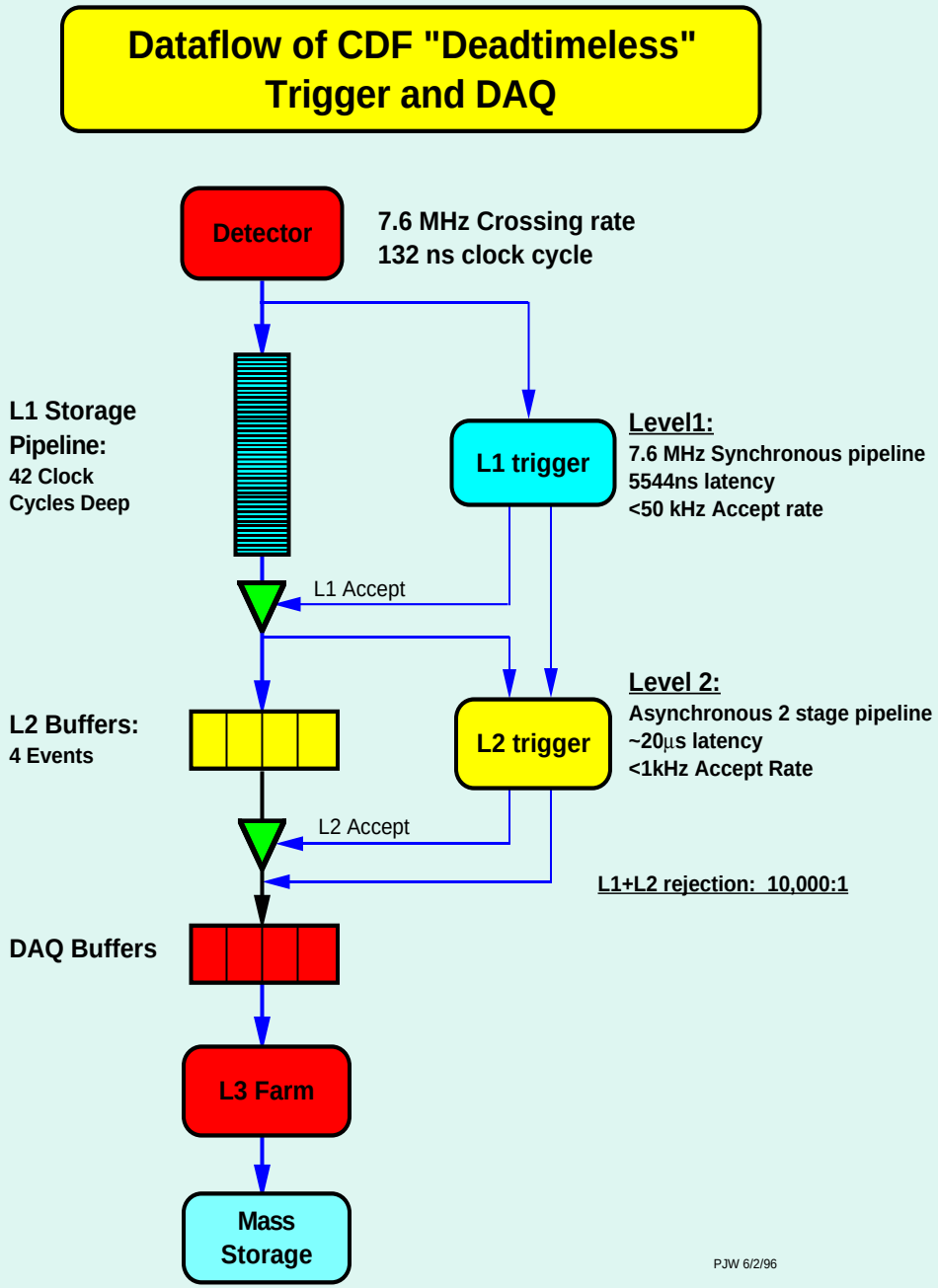
CDF II


Central Muon
Central Calorimeter (E/H)
Wall Calorimeter (H)
Solenoid
Plug Calorimeter (E/H)
Forward Muon
Forward Calorimeter (E)
Luminosity Monitor
Time of Flight
Central Outer Tracker
Silicon Vertex Detector
Intermediate Silicon

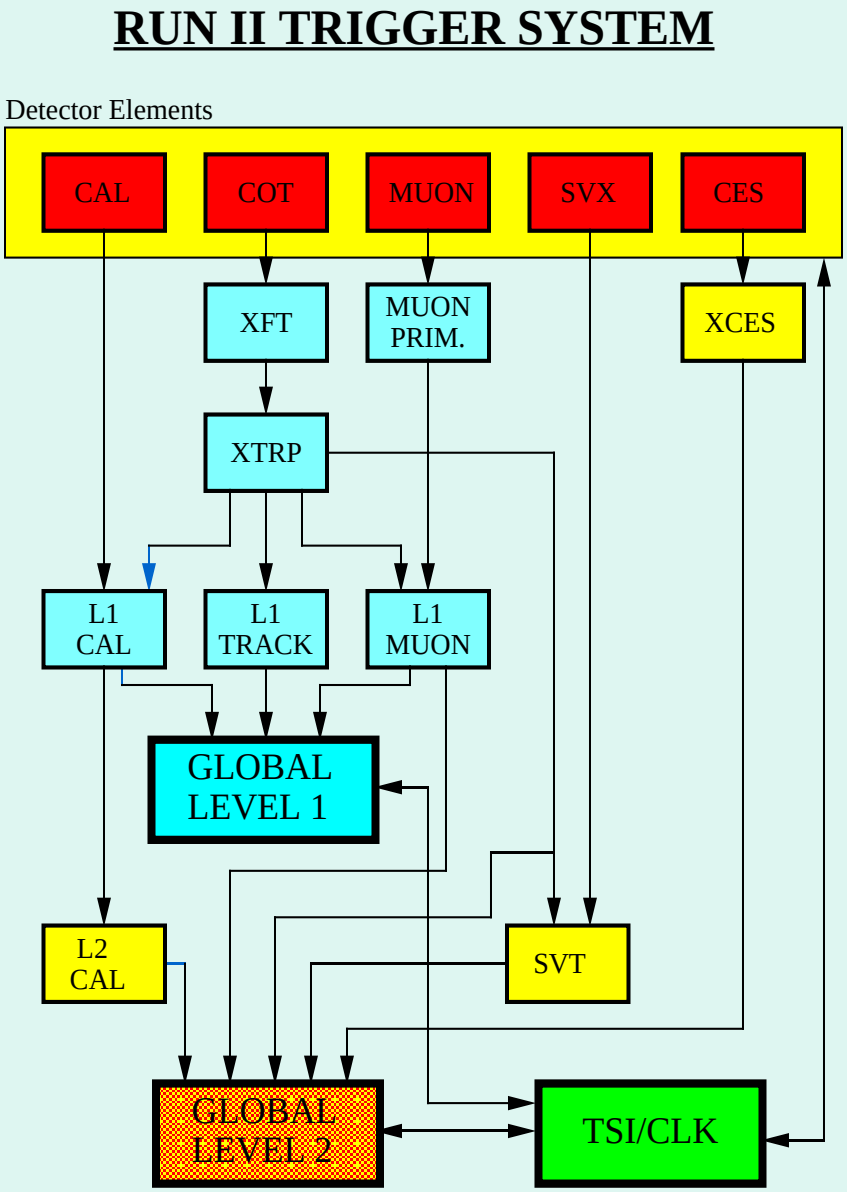

m
2.0
1.5
1.0
.5
0
0
.5
1.0
1.5
2.0
2.5
3.0
m
n = 1.0
n = 2.0
n = 3.0
30°
3°
END WALL HADRON CAL.
SOLENOID
COT
END PLUG EM CALORIMETER
END PLUG HADRON CALORIMETER
SVX II
5 LAYERS
INTERMEDIATE
SILICON LAYERS


Tracking chamber
Electromagnetic calorimeter
Hadron calorimeter
Muon chamber
photons
e±
muons
π±, p
n
Innermost Layer...
...Outermost Layer

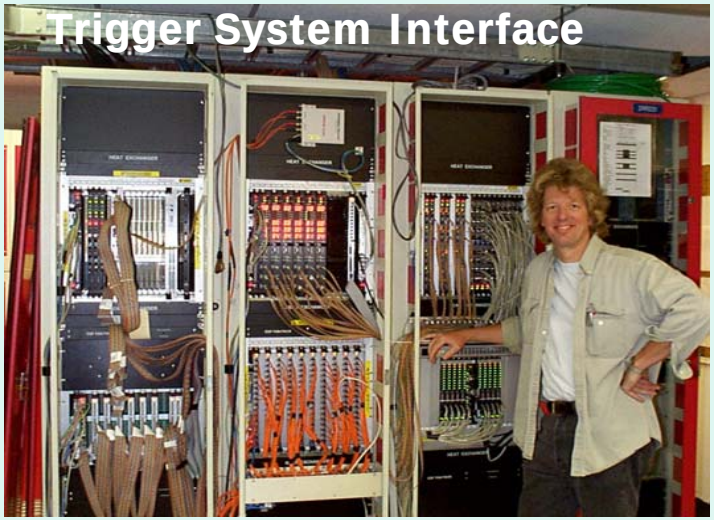
- Each detector element clocked into a synchronous pipeline every 132 nsec
- Level 1 trigger decision in < 5.5 μsec
- Events saved in 1 of 4 asynchronous buffers during Level 2 trigger decision
- Accepted events sent to Level 3 processor farm



- L1 triggers:
  - Jets, Sum or Missing transverse E (CAL)
  - Tracks (COT)
  - Muons (stubs.and.tracks)
  - Electrons (emCAL.and.tracks)
- L2 triggers
  - Tracks with non-zero impact parameter by using r - ϕ hits in silicon detector
  - Uses L1 tracks and Silicon Vertex Trigger (SVT)



Trigger System Interface & Silicon Data Acquisition System



Dedicated electronics, protocols, and parallel network for control throughout CDF of the synchronous pipeline and Level-1 trigger, and the asynchronous buffers for Level-2 decisions.

# of electronics boards: ~60

Deadtimeless readout for the L00, SVXII and ISL detectors:

558 silicon strip ladders,

5764 SVX-3 chips,

737,792 channels.

# of electronics boards: ~250

Analysis Sketch

$$B_s \to J/\psi\varphi \qquad \begin{cases} J/\psi(c\bar{c}) \to \mu^+\mu^- \\ \varphi(s\bar{s}) \to K^+K^- \\ K^{*0}(s\bar{d}) \to K^-\pi^+ \end{cases}$$

$$B_d \to J/\psi K^{*0}$$

- Angular momenta:

$$P \to VV$$

- Total J of final state = 0
- Two spin-1 => J = 0, 1, 2
- Orbital L = 0, 1, 2 (S,P,D wave)

  => Need 3 amplitudes (partial wave, helicity, or transversity)

Isolates P-odd nicely

- S,D wave = Parity Even, (CP Even for $J/\psi\varphi$)
- P wave = Parity Odd, (CP Odd for $J/\psi\varphi$)

$$B_s^H = \frac{1}{\sqrt{2}}(|B_s\rangle + |\bar{B}_s\rangle) = CP-odd$$

$$B_s^L = \frac{1}{\sqrt{2}}(|B_s\rangle - |\bar{B}_s\rangle) = CP-even$$

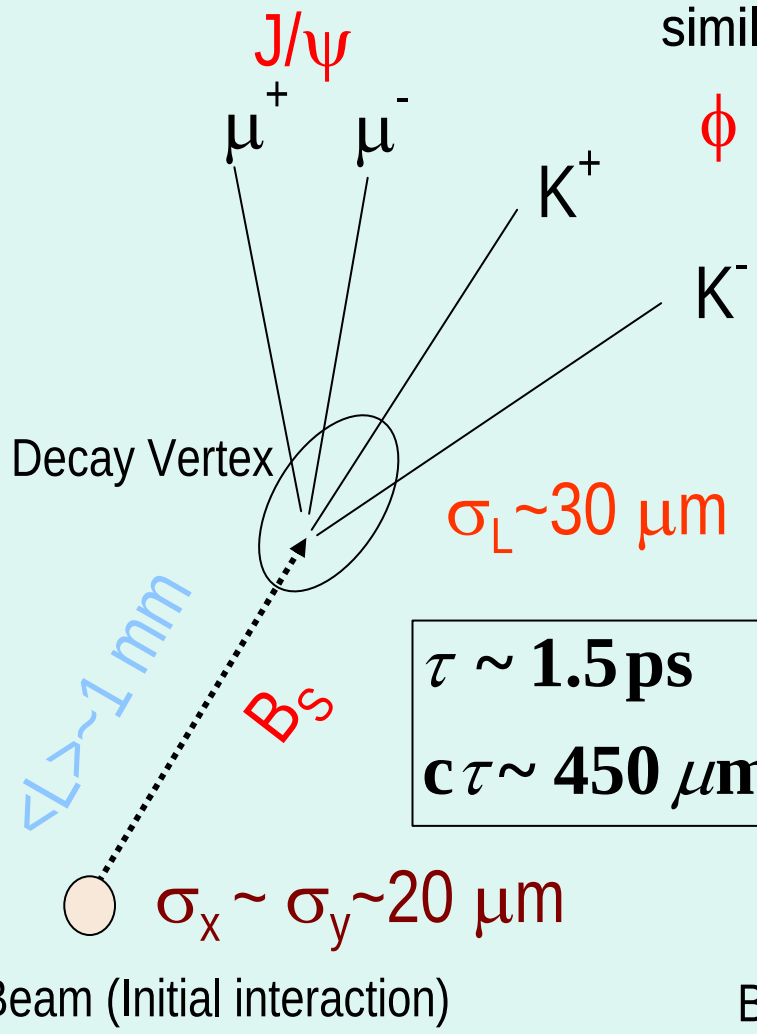
Disentangle different L-components of decay amplitudes → isolate two B states

Branching ratios ~ 10^{-3}

$B_s \rightarrow J/\psi\phi$

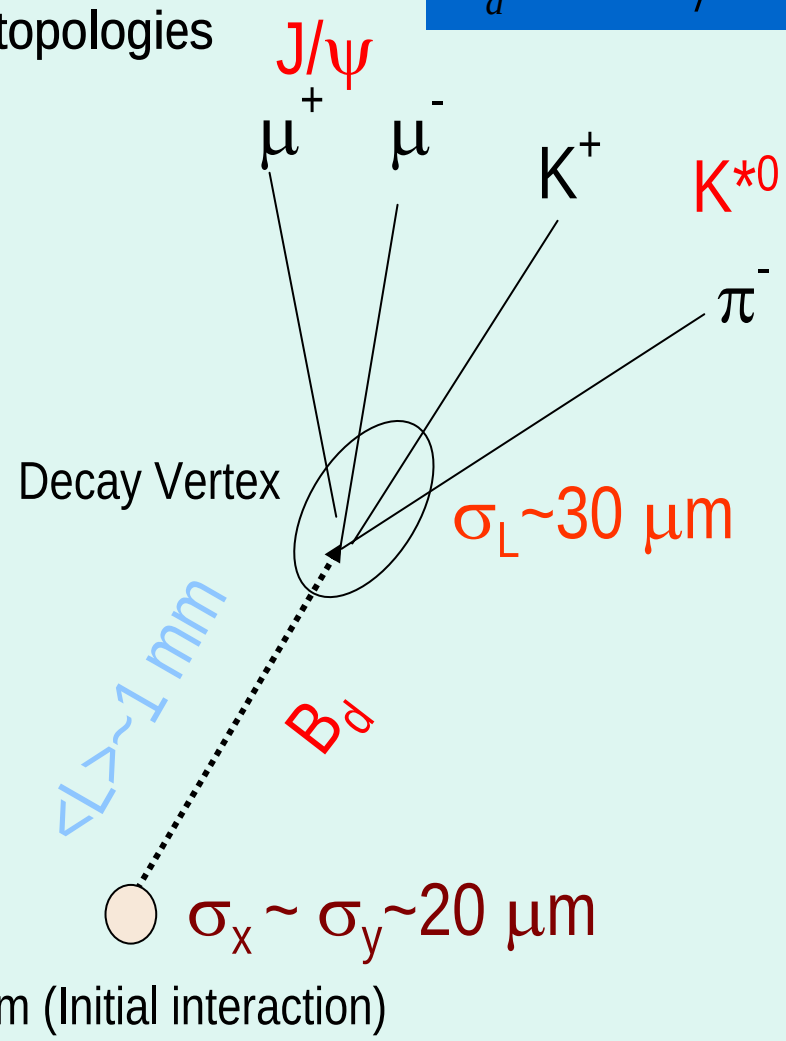
Compare the two similar topologies

$B_d \rightarrow J/\psi K^*$

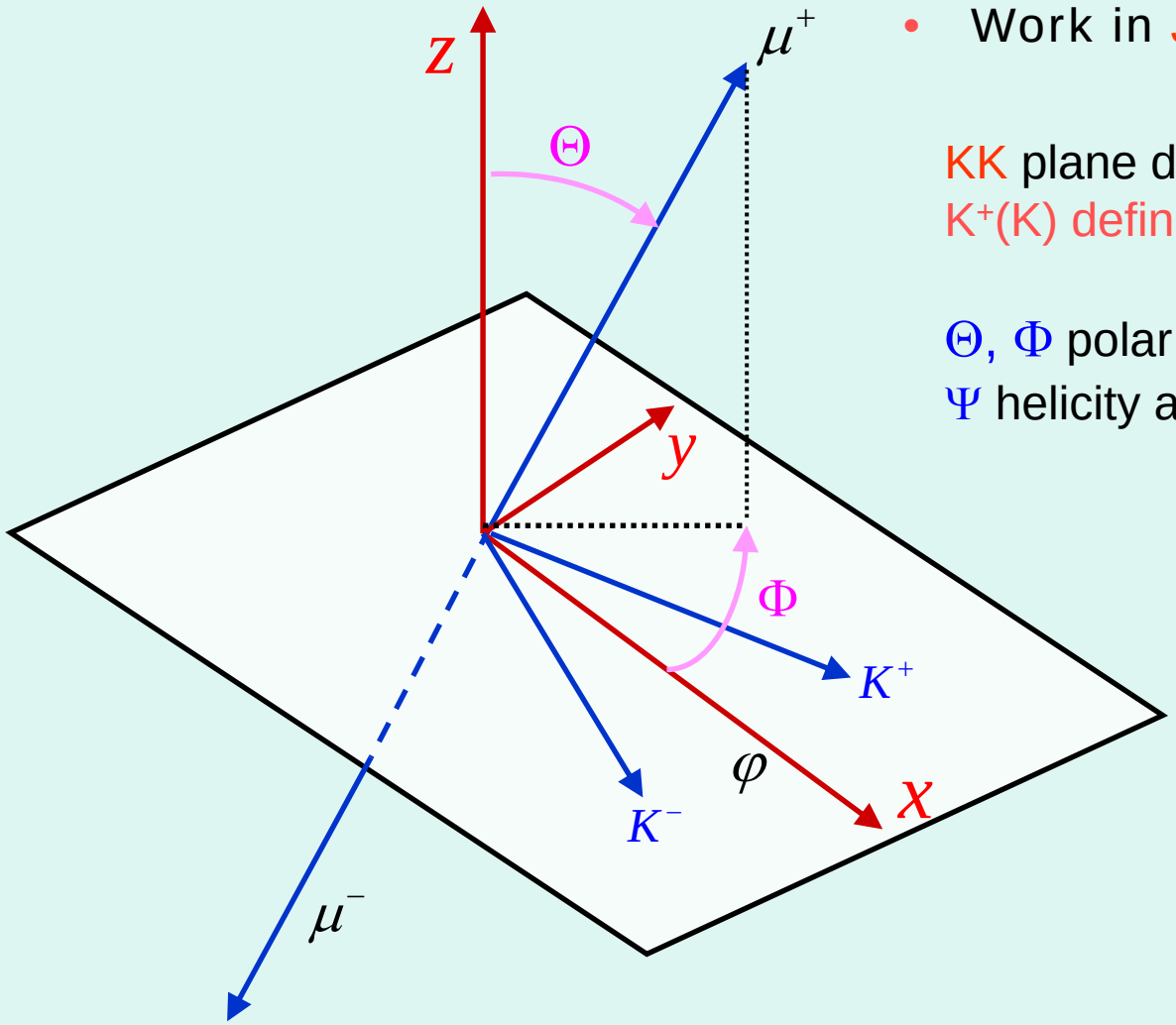


$\tau \sim 1.5\,\mathrm{ps}$

$c\tau \sim 450\ \mu\mathrm{m}$



Transversity Angles

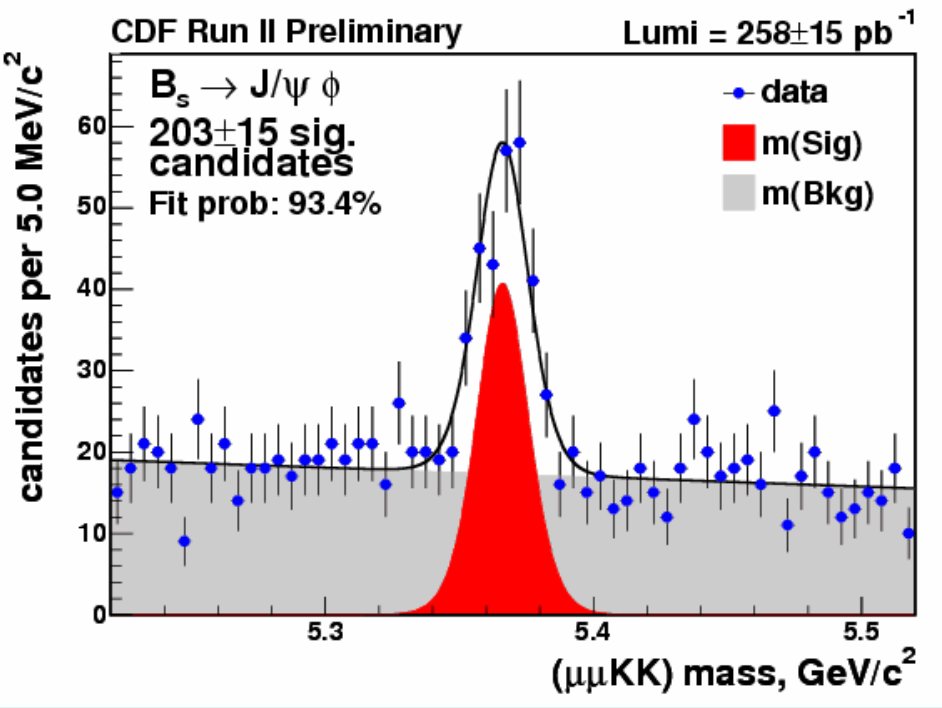


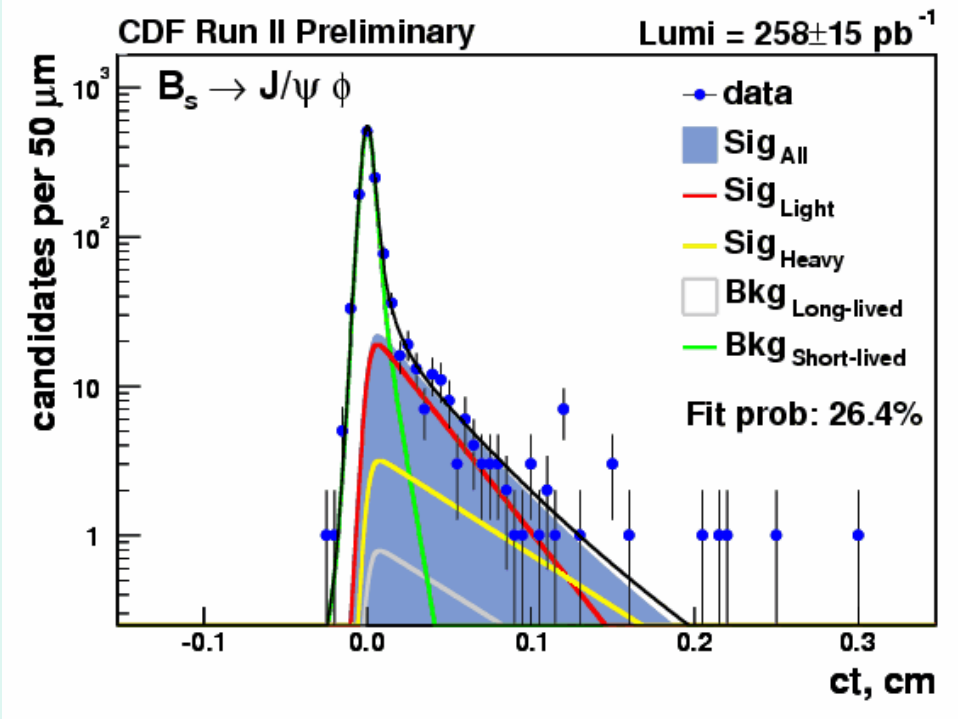
- Work in J/Ψ rest Frame

KK plane defines (x,y) plane
K^+(K) defines +y direction

Θ, Φ polar & azimuthal angles of μ+
Ψ helicity angle of φ (K*)

Mass and Lifetime Projections (Bs)





$$\tau_L = 1.05^{+0.16}_{-0.13} \pm 0.02\,\text{ps}$$

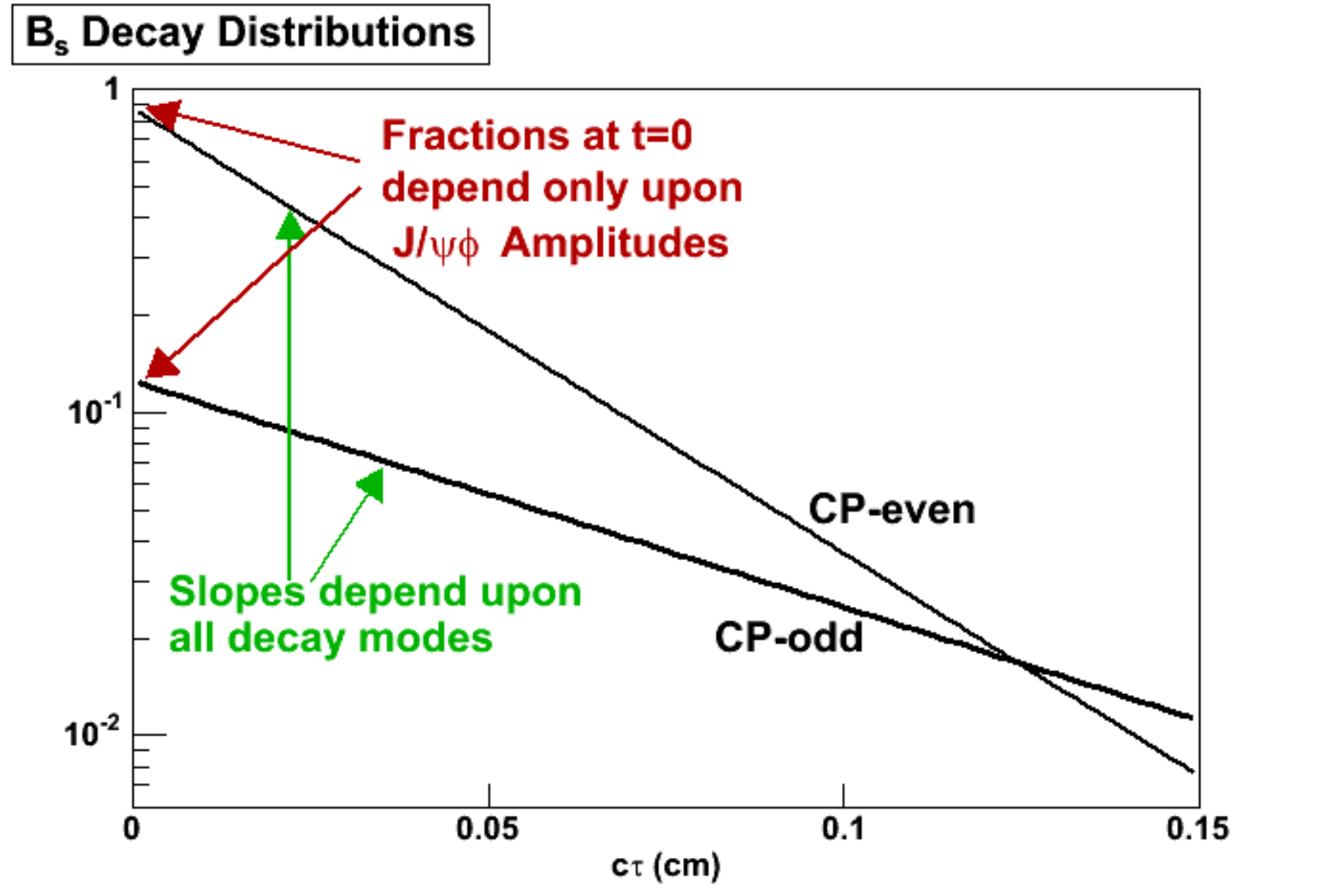
$$\tau_H = 2.07^{+0.58}_{-0.46} \pm 0.03\,\text{ps}$$

$$\Delta\Gamma_s = 0.47^{+0.19}_{-0.24} \pm 0.01\ \text{ps}^{-1}$$

$$\frac{\Delta\Gamma_s}{\Gamma_s} = 0.65^{+0.25}_{-0.33} \pm 0.01$$

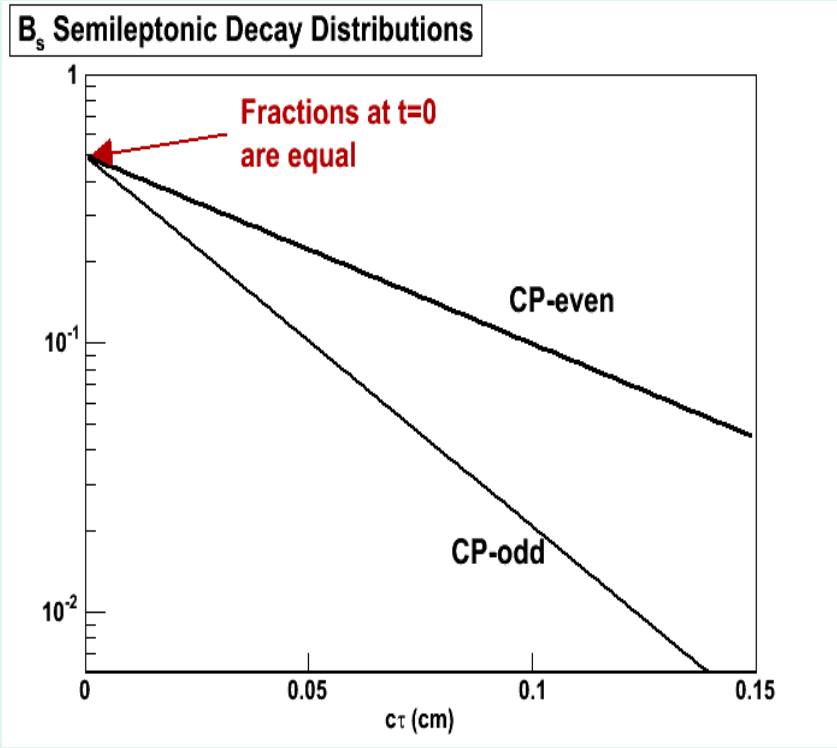
CP-odd fraction (τ_H) ~ 22%

Expectation for two lifetimes



Other Measures of B_s "lifetime"

- When a significant $\Delta\Gamma$ exists, lifetime measurements are sample composition dependent
- Measured lifetime is $\tau_{meas} = f_L \tau_L + f_H \tau_H$ where f_L = fraction of light state
- e.g. single lifetime as measured in semi-leptonic decays



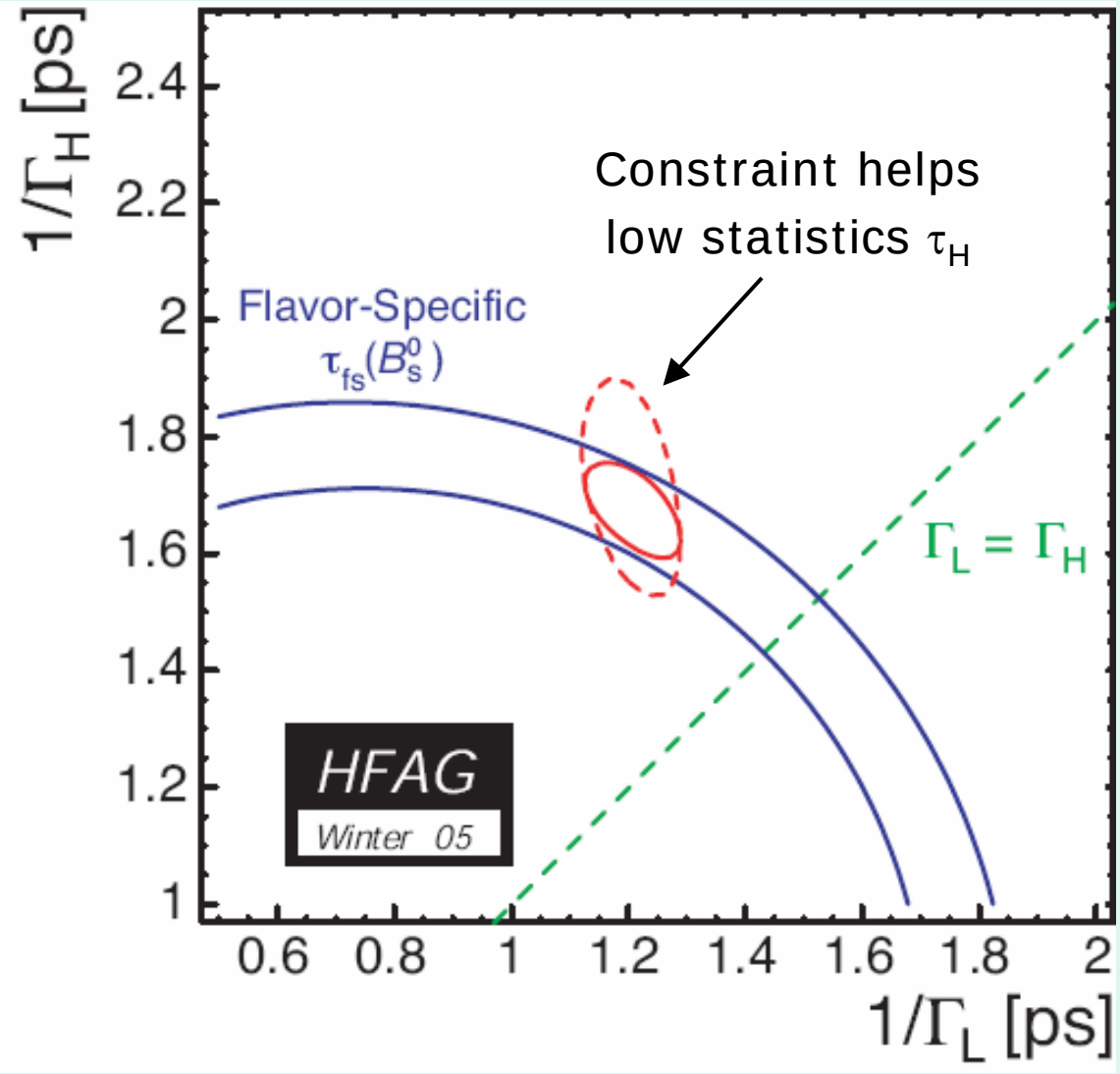
$$\tau_{SL} = f_L \tau_L + f_H \tau_H = \frac{\tau_L^2 + \tau_H^2}{\tau_L + \tau_H} = \frac{1}{\Gamma_s} \frac{1 + \left(\frac{\Delta\Gamma}{2\Gamma}\right)^2}{1 - \left(\frac{\Delta\Gamma}{2\Gamma}\right)^2}$$

- Assuming $\Gamma_s = \Gamma_d$ (theoretical guidance suggests this is good to 1%)

$$\tau_{SL} = \tau_d \frac{1 + \left(\frac{\Delta\Gamma}{2\Gamma}\right)^2}{1 - \left(\frac{\Delta\Gamma}{2\Gamma}\right)^2} > \tau_d$$

$$\boxed{\begin{aligned} \tau_{SL} &= 1.472 \pm 0.045 \\ \tau_d &= 1.53 \pm 0.009 \end{aligned}}$$

The two Lifetimes

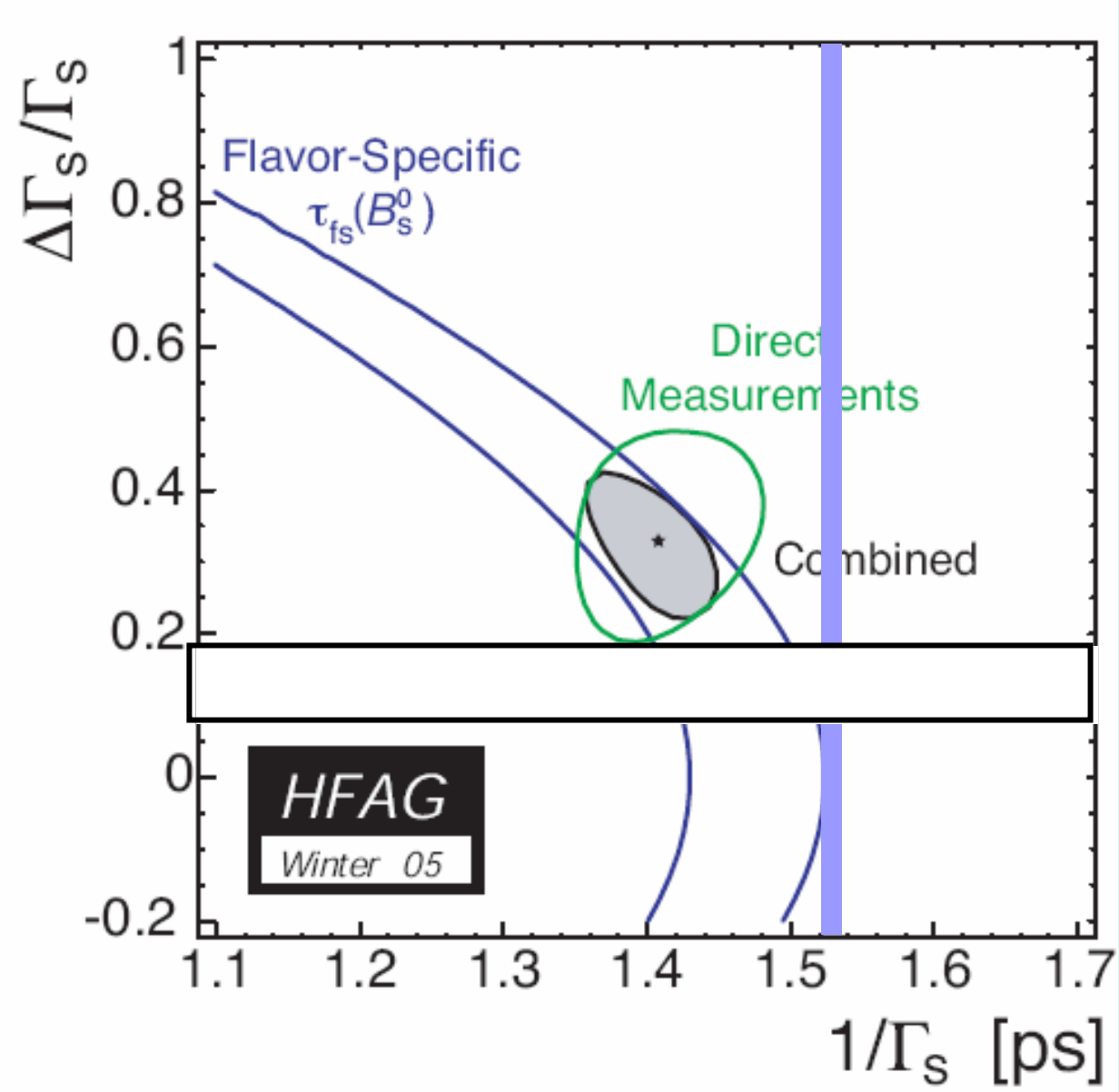


$$\tau_L = 1.21 \pm 0.08\text{ps}$$

$$\tau_H = 1.68^{+0.08}_{-0.09}\ \text{ps}$$

$$(\tau_d = 1.53 \pm 0.009)$$

Combined Fit



$$\Delta\Gamma_s = 0.23 \pm 0.08 \text{ps}^{-1}$$

$$\frac{\Delta\Gamma_s}{\Gamma_s} = 0.33^{+0.09}_{-0.11}$$

$$\frac{1}{\Gamma_s} = 1.405^{+0.043}_{-0.047} \text{ ps}$$

Extracurricular Activities

- No spectators
- Cheating death again
- Now for the dangerous part
- Flight Plan B

Acknowledgements

- Larry, Bob, Henry and Bill
- All my fellow students and postdocs in the BNL-Yale collaboration
- All the engineers, technicians, riggers, and other scientists at BNL who supported our efforts
- All my colleagues at Yale and the whole of the CDF collaboration