Dalitz-Plot Analyses

RTG Lecture 1: Decay rates and phase-space

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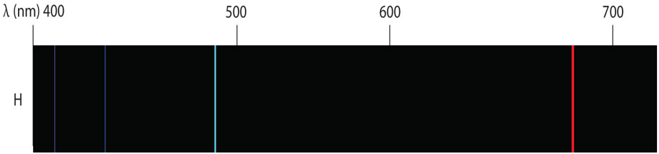
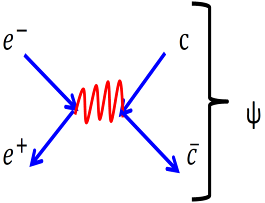
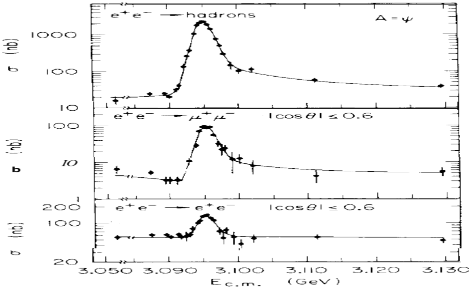
Spectroscopy



- **Atomic spectroscopy:**
  Spectral lines were observed before their origin was understood
  $\Rightarrow$ Key role in development of Quantum Mechanics (QM)
- **Hadron spectroscopy** $\Rightarrow$ Understanding of strong interaction
  (Reminder: Hadron = Bound state of quarks: $(q\bar{q}), (qqq)$, ...)

November Revolution 1974



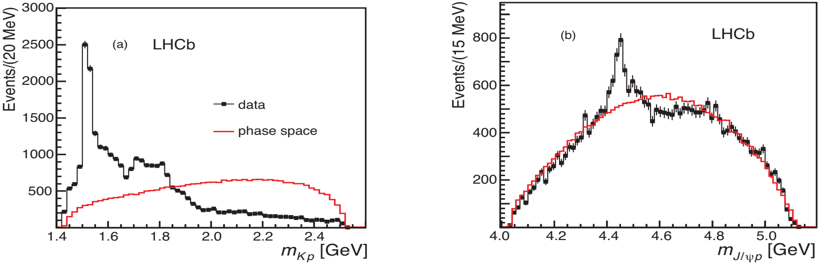


- Quark Model at that time: several hundred hadronic states explained as bound states of 3 different quarks: u, d, s
- SLAC-Mark-I experiment found new long-lived particle: $J/\psi = |c\bar{c}\rangle$ (Simultaneously confirmed by independent group: BNL)
- Soon followed by excited states: $\psi(2S), \psi(3770), \ldots$

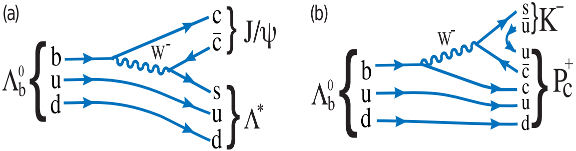
$\Rightarrow$ Key role in development of SM

See Dominiks lecture for details

Pentaquark in $\Lambda_b \to J/\psi K p$ decays ?



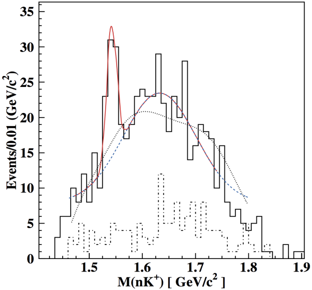
[Phys. Rev. Lett. 115, 072001]



See Marians lecture for details

Lesson from the past:

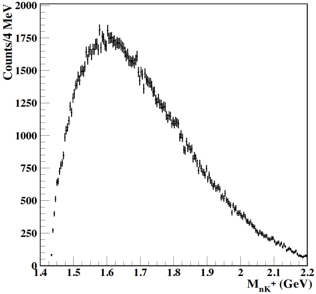
Reaction: $\gamma d \to pK^-(K^+ n)$



[PRL 91 252001]

$\Longrightarrow$

$30 \cdot$ stat.

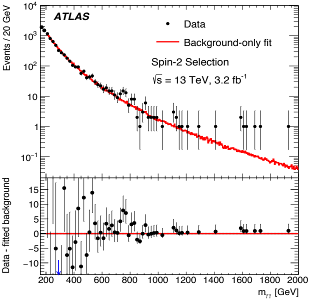


[PRL 96 212001]

Peaks can come and go ...

See Marians lecture for details

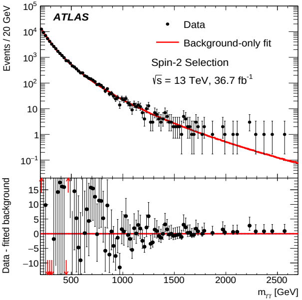
Lesson from the past:



[JHEP 09 (2016) 001]

$\Longrightarrow$

$12 \cdot \text{stat.}$



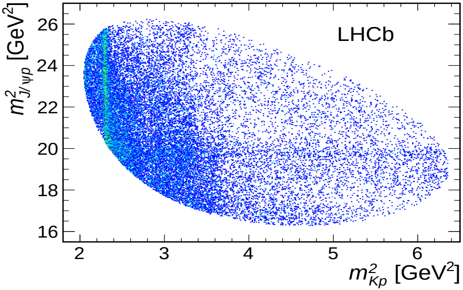
[Phys. Lett. B 775 (2017) 105-125]

Peaks can come and go ...

See physics teams presentation for details

Dalitz Plots

$$\Lambda_b \to J/\psi K p$$

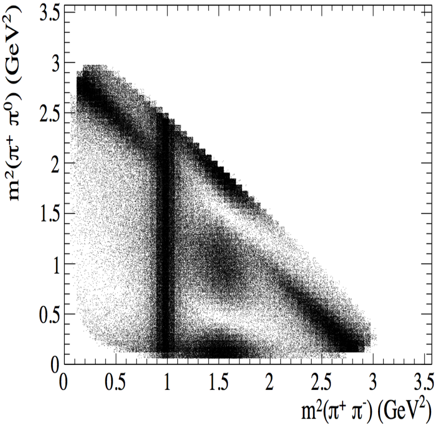


[Phys. Rev. Lett. 115, 072001]

Make use of full decay information:

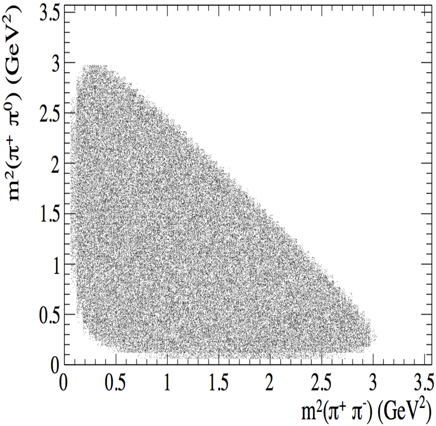
- Angular distributions $\Rightarrow$ Spin-Parity
- Interference patterns provide sensitivity to phases
  ($\Rightarrow$ Also interesting for CPV studies)

Lecture 1+2:
Dalitz Plot Technique



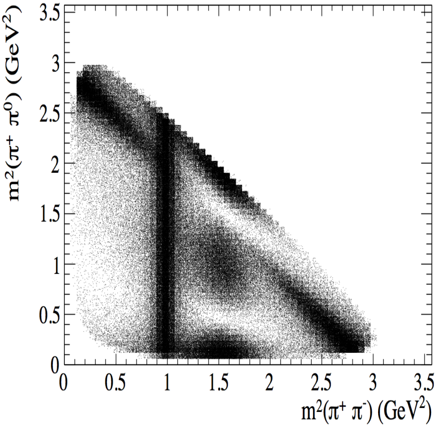
($D^0 \to \pi^+\pi^-\pi^0$ Toy Simulation)

Lecture 1:
Decay rates and Phasespace



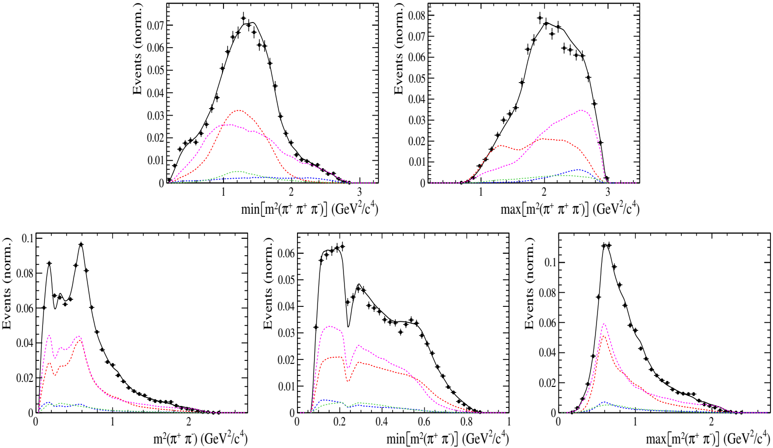
($D^0 \to \pi^+\pi^-\pi^0$ Toy Simulation)

Lecture 2:
Resonances and angular distributions



($D^0 \to \pi^+\pi^-\pi^0$ Toy Simulation)

Lecture 3:
Amplitude analysis of $D^0 \to \pi^+\pi^-\pi^+\pi^-$



[JHEP 05 (2017) 143]

Two-body Decays: Examples

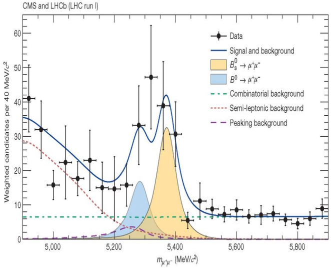
$$\Gamma(M \to 12) \propto \frac{\left[(M^2-(m_1+m_2)^2)(M^2-(m_1-m_2)^2)\right]^{1/2}}{M^3}$$

$$\frac{\Gamma(D\to K^+K^-)\,\Gamma(D\to\pi^+\pi^-)}{\Gamma(D\to K^+\pi^-)\,\Gamma(D\to K^-\pi^+)}$$

- Naive expectation (Phasespace): 0.98
- Experiment: 1.04 ± 0.06

$$\frac{\Gamma(B_0\to\mu\mu)}{\Gamma(B_s\to\mu\mu)}$$

- Phasespace: $104\% \cdot \frac{|V_{td}|^2}{|V_{ts}|^2} = 5\%$
- Experiment: $14 \pm 8\%$
  $\Rightarrow$ CKM hierarchy

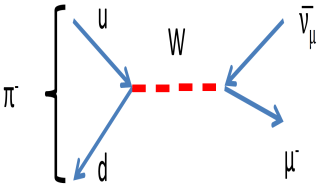


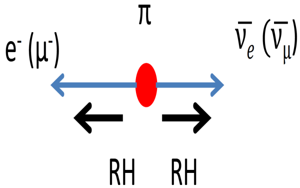
[Nature 522, 68-72]

Two-body Decays: Historic puzzles

Pion decay

- Naive expectation (Phasespace): $\frac{\Gamma(\pi \to e\nu)}{\Gamma(\pi \to \mu\nu)} = \frac{m_\pi^2 - m_e^2}{m_\pi^2 - m_\mu^2} = 3.3$
- Experiment: $\frac{\Gamma(\pi \to e\nu)}{\Gamma(\pi \to \mu\nu)} = (1.230 \pm 0.004) \cdot 10^{-4}$
- Weak interaction violates parity: $A \propto q_\mu(\bar{u}_e \gamma^\mu \frac{1}{2}(1-\gamma^5) u_\nu)$
  $\Rightarrow \frac{\Gamma(\pi \to e\nu)}{\Gamma(\pi \to \mu\nu)} = \left(\frac{m_e^2}{m_\mu^2}\right) \cdot \frac{m_\pi^2 - m_e^2}{m_\pi^2 - m_\mu^2} = 1.275 \cdot 10^{-4}$

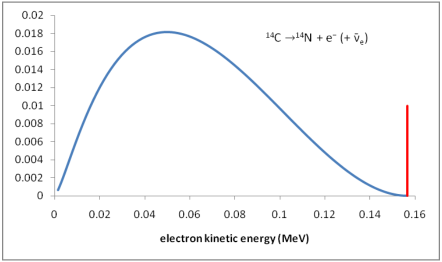




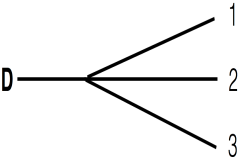
Two-body Decays: Historic puzzles

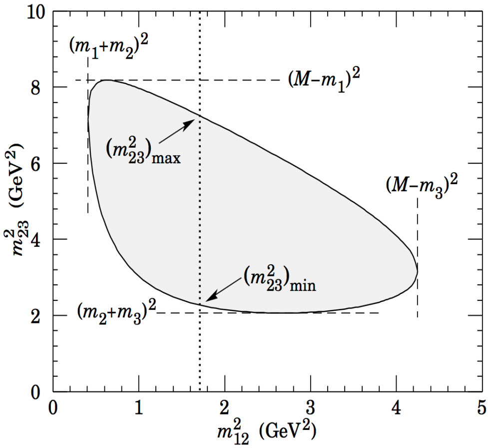
β-Decay: $n \to pe^-(\nu)$

- Expect discrete energy in 2-body decay
- Observe continuous energy spectrum of emitted e^-
  $\Rightarrow$ Prediction of neutrino



Dalitz Plots





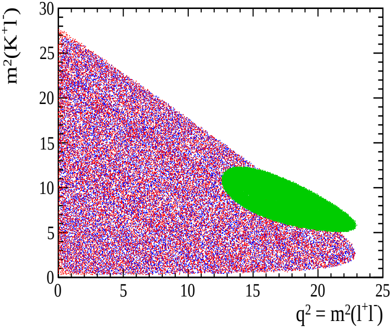
$$(m_i^2 + m_j)^2 \leq m_{ij}^2 \leq (M - m_k)^2$$

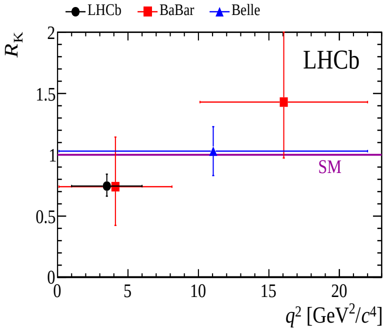
Three-body Decays: Example

$$\Gamma(M \to 123) \approx \frac{1}{M} \int dm^2_{12} dm^2_{23} \propto V_{phsp}$$

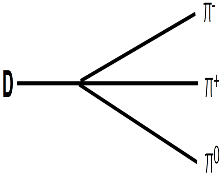
Search for lepton flavor violation

$\frac{\Gamma(B^+ \to K^+ \mu\mu)}{\Gamma(B^+ \to K^+ ee)} \approx 0.99$ $\frac{\Gamma(B^+ \to K^+ \mu\mu)}{\Gamma(B^+ \to K^+ \tau\tau)} \approx 9$





[Phys. Rev. Lett. 113, 151601]



$$A_{D \to 3\pi} = const.$$