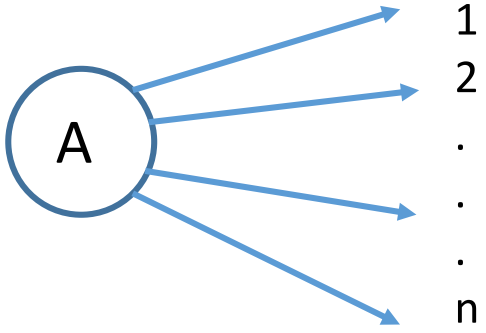
Decay Width



Differential decay with (rate):

$$d\Gamma_f(A \to 1 + 2 + \dots + n) = \frac{|M_{fi}|^2}{2E_A}(2\pi)^4\delta^4(p_A - p_1 - p_2 - \dots - p_n)$$

$$\frac{d^3p_1}{2E_1(2\pi)^3}\,\frac{d^3p_2}{2E_2(2\pi^3}\cdot\dots\cdot\frac{d^3p_n}{2E_n(2\pi)^3}$$

$$\tau = \frac{1}{\Gamma} \qquad \Gamma = \sum_f \Gamma_f$$

Two-body decay:

$$A \to 1 + 2$$

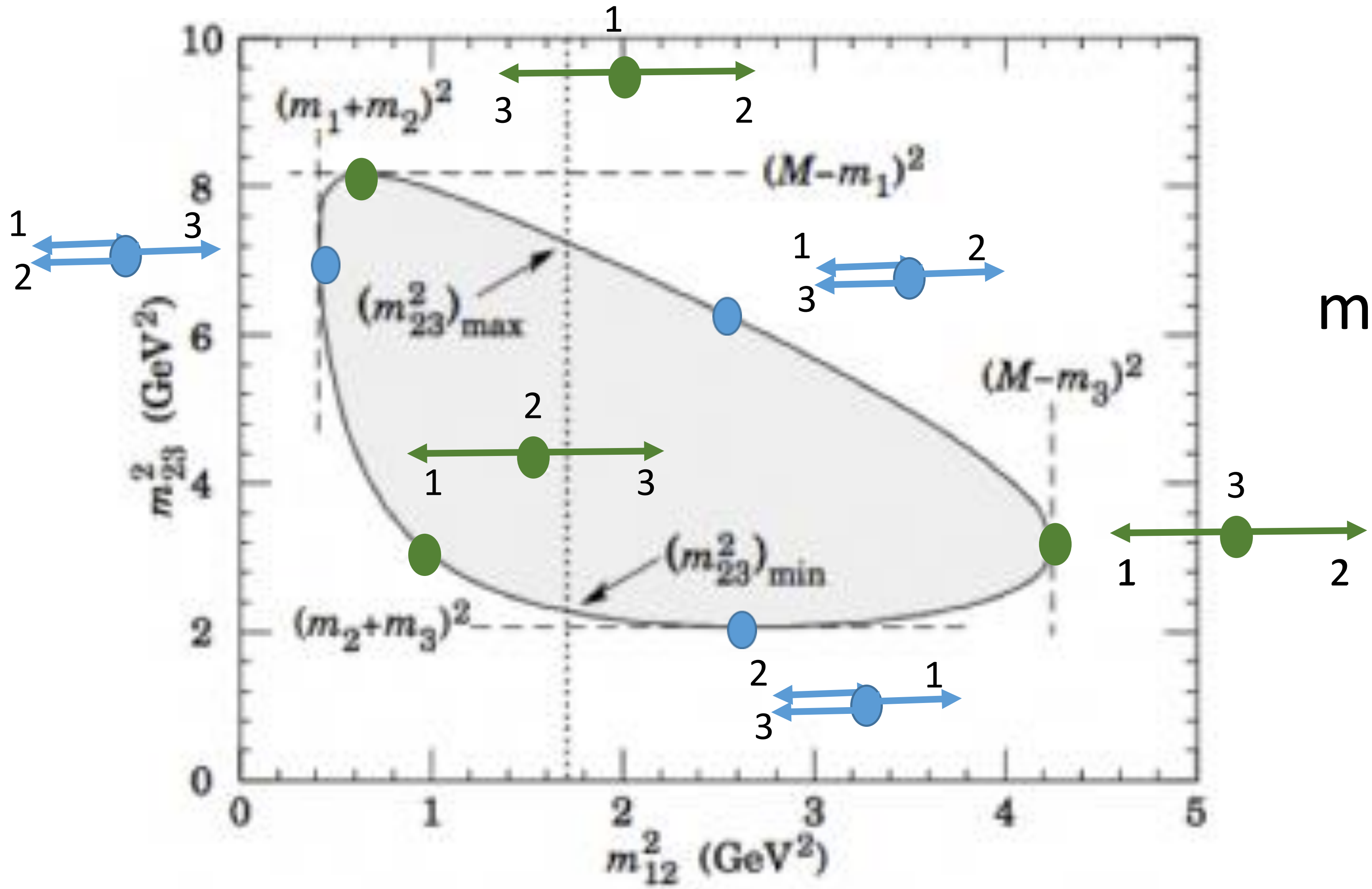
$$d\Gamma_f(A \to 1 + 2) = \frac{|M_{fi}|^2}{2E_A}dLIPS_2 = \frac{|M_{fi}|^2|}{2E_A}\frac{1}{16\pi^2}\frac{|\vec{p_f}|}{\sqrt{s}}d\Omega_f$$

$$\text{CMS: } dLIPS_2 = \frac{1}{16\pi^2}\frac{|\vec{p}_f|}{\sqrt{s}}d\Omega_f$$

$$\sqrt{s} = E_A = m_A$$

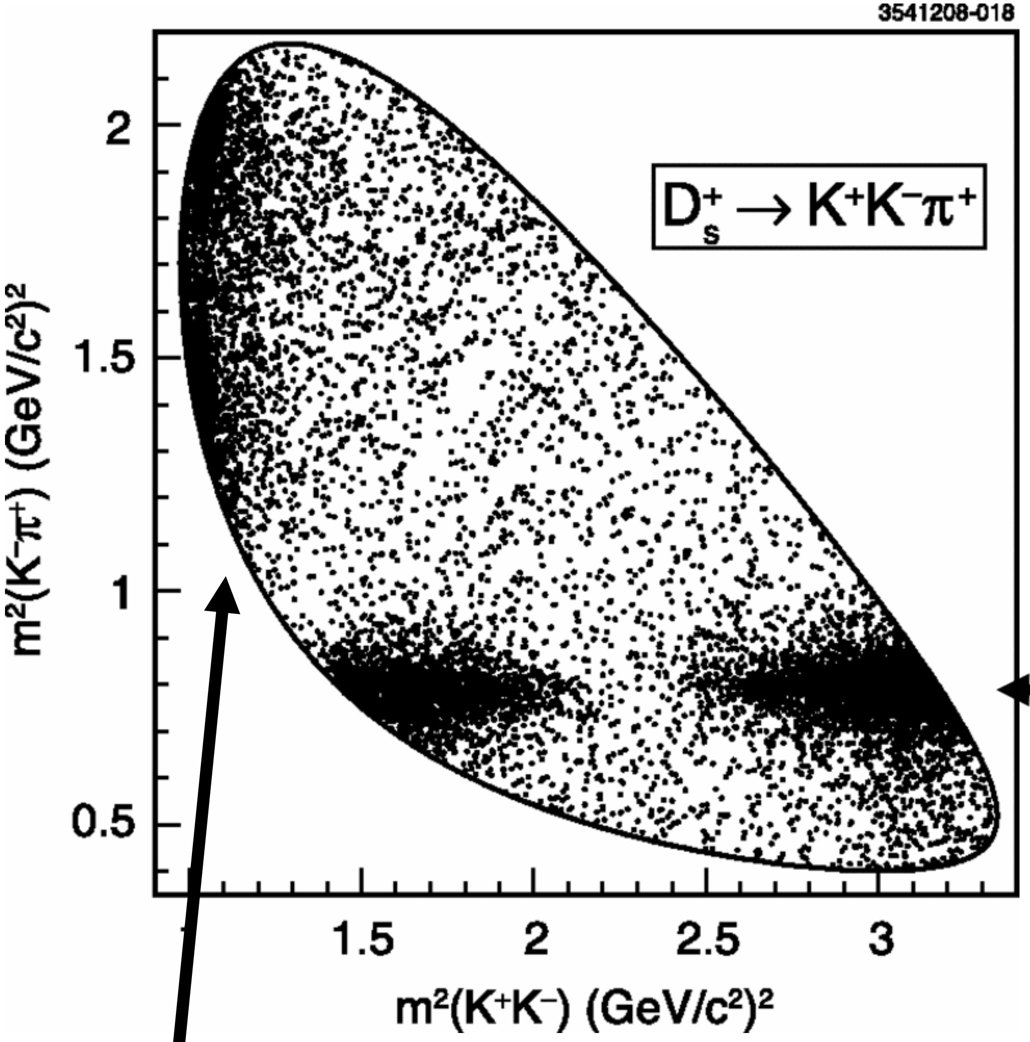
$$\Gamma_f(A \to 1 + 2) = \frac{|\vec{p}_f|}{32\pi^2 m_A^2}|M_{fi}|^2 d\Omega_f$$

Dalitz Plot: A → 1 + 2 + 3



m(A) = M

$$d\Gamma(m_{12}^2, m_{23}^2) = \frac{1}{256\pi^3}\frac{1}{M^3}|M_{fi}|^2 dm_{12}^2 dm_{23}^2$$



$$\phi \to K^+K^-$$

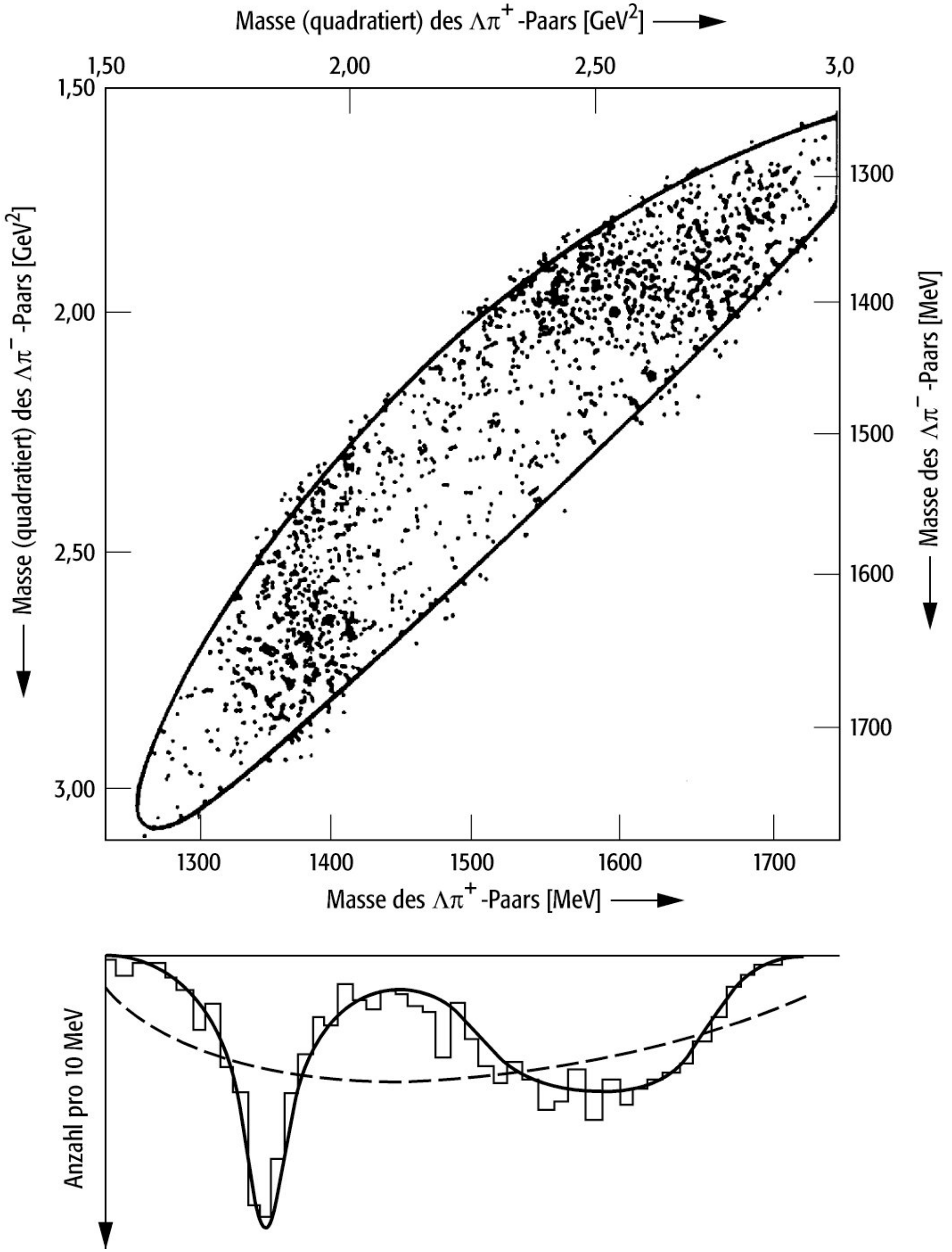
Intermediate resonances
→ non flat Dalitz plot distribution
→ non uniform $|M_{fi}|^2$

$$K^* \to K^-\pi^+$$

$S(K^*) = 1$

$S(D_s^-) = S(K^-) = S(K^+) = S(\pi^+) = 0$

→ relative angular momentum between $K^-\pi^+$
→ pefered relative orientation



Warning:

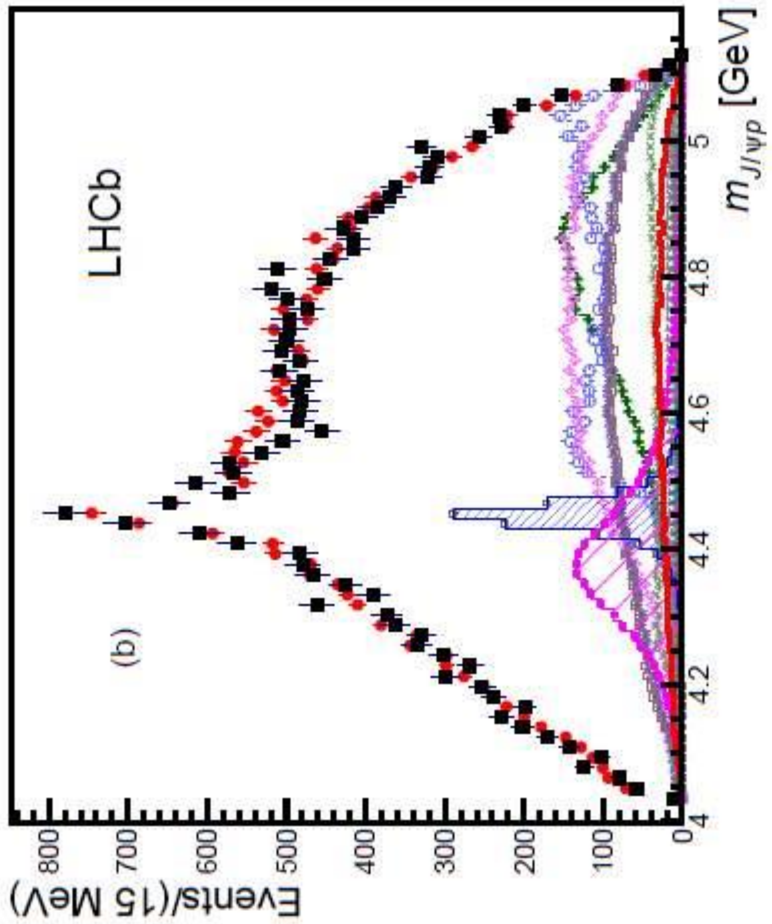
1D projection can easily give you Fake signals
Full Daltiz analysis (amplitude analysis) needed to claim discoveries.

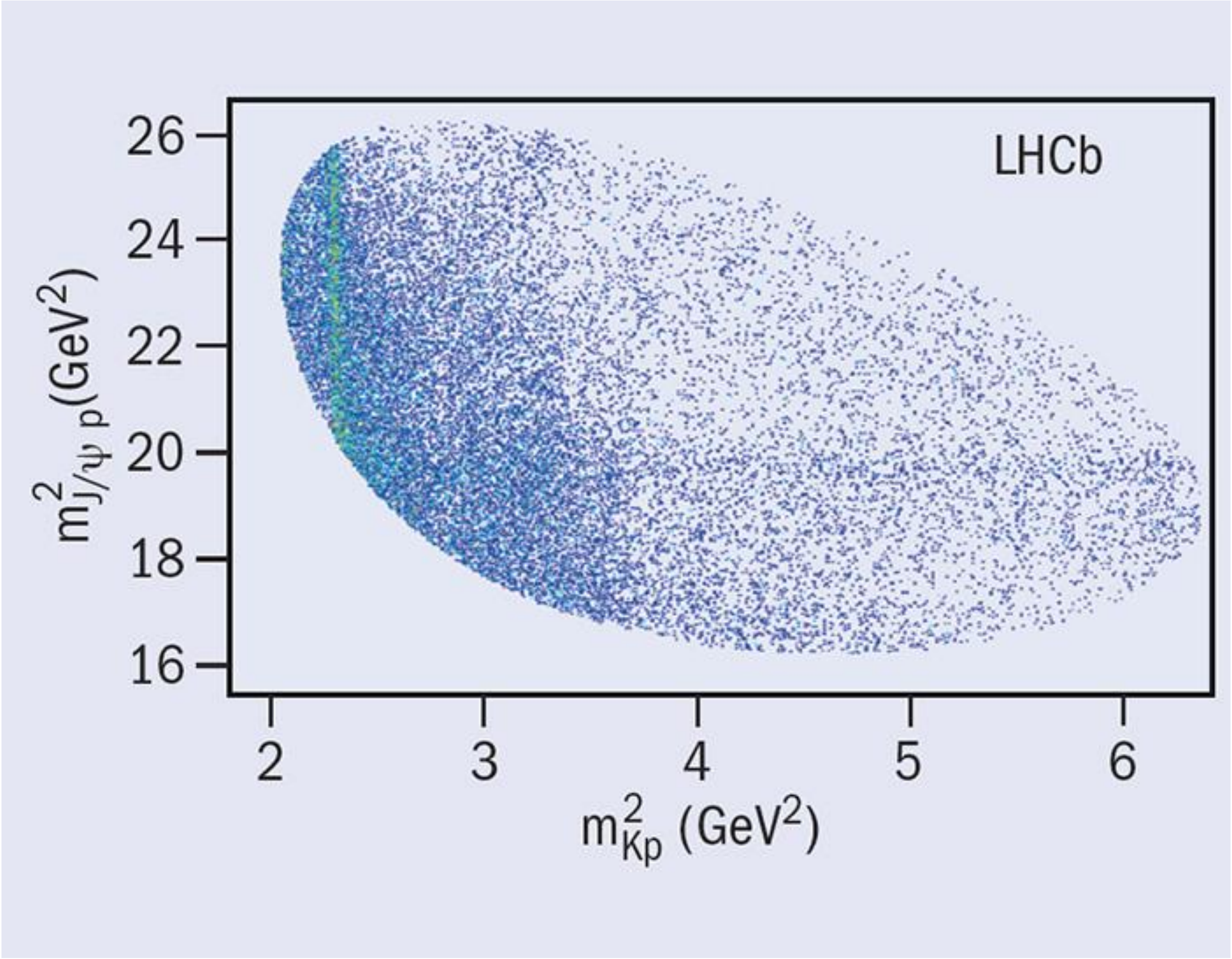
Pentaquark Discovery at LHCb (2015)

$$\Lambda_b \to \underbrace{J/\Psi p}_{\text{pentaquark}} \underbrace{K}$$

pentaquark

λ resonances





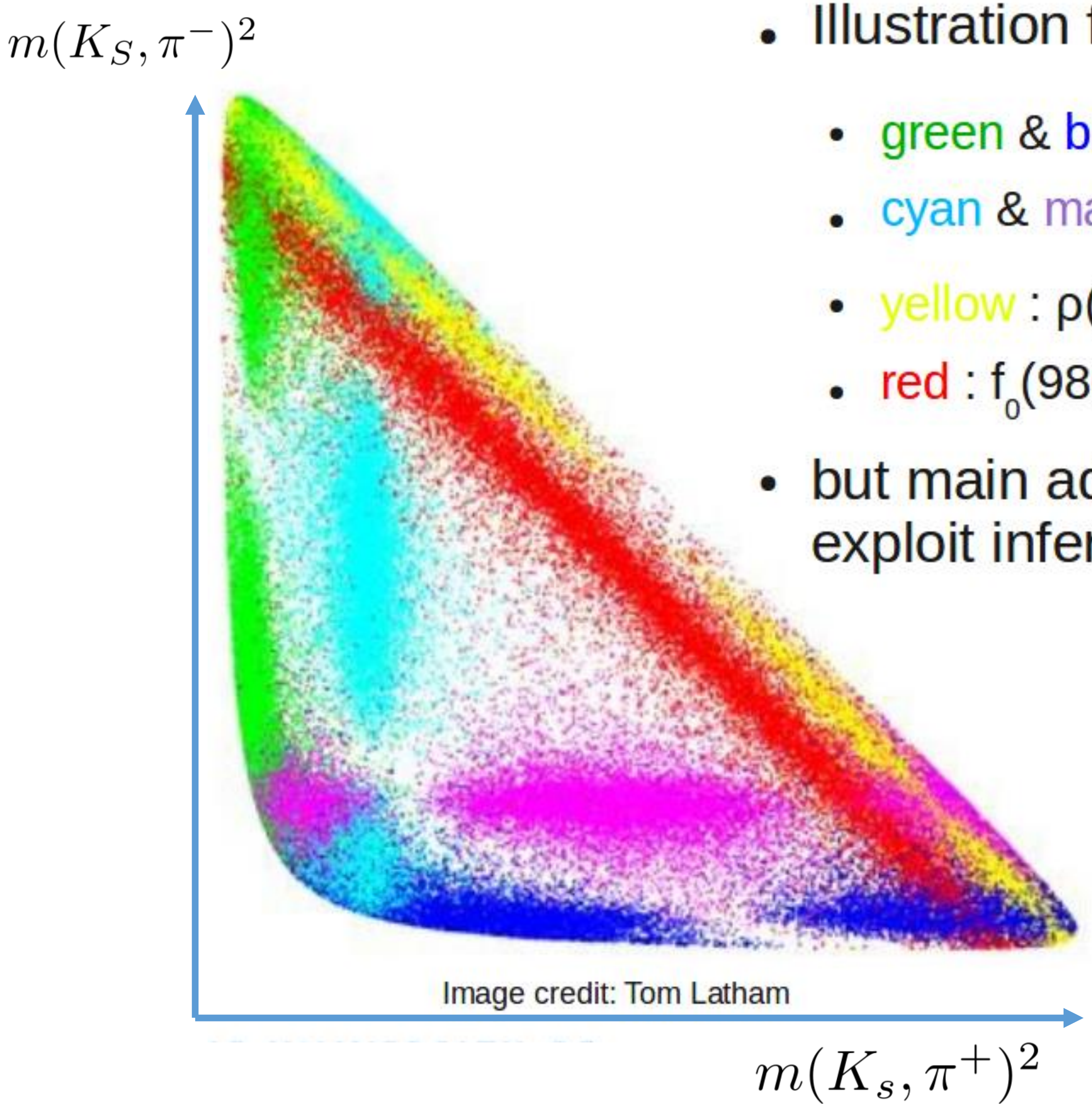
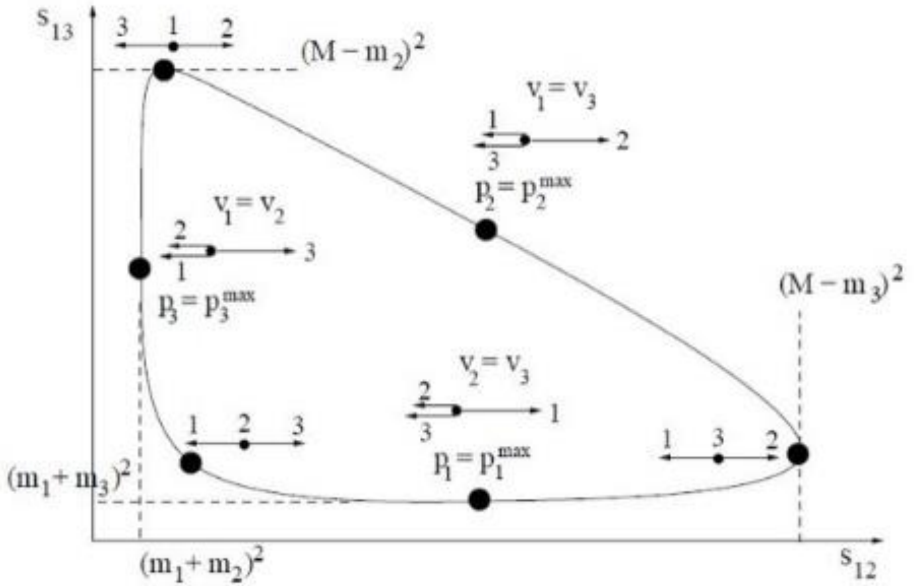


Image credit: Tom Latham

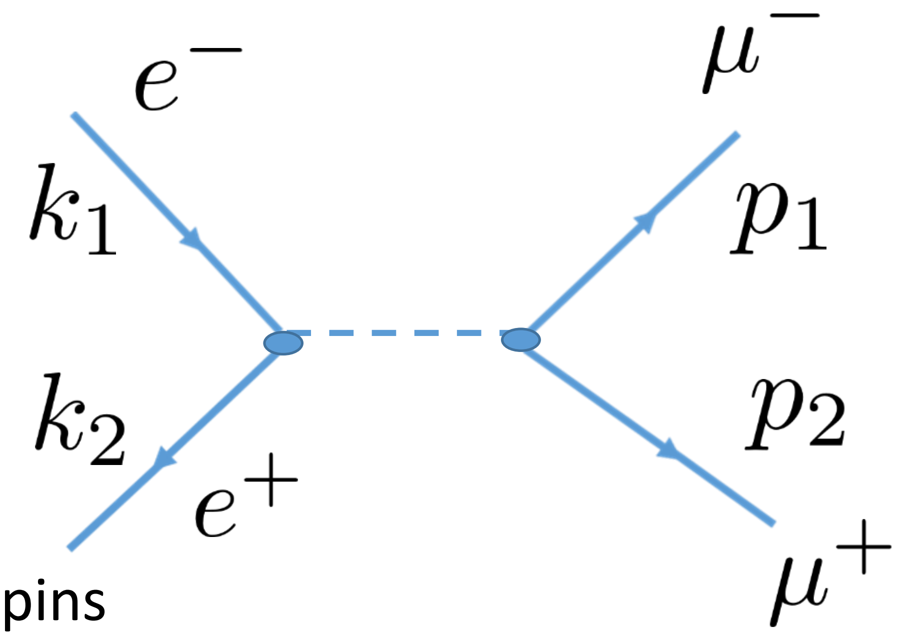
- Illustration for $D \to K_S \pi^+ \pi^-$
  - green & blue: K*(892) (vector)
  - cyan & magenta : K_2*(1430) (tensor)
  - yellow : ρ(770) (vector)
  - red : f_0(980) (scalar)
- but main advantage of Dalitz plots is ability to exploit inference between different resonance



Reminder of QED results for transition amplitudes

$$-iM_{fi} = \underbrace{[\overline{v_2}(ieQ_e\gamma^\mu)u_1]\frac{-g_{\mu\nu}}{q^2}[\overline{u_3}(ieQ_\mu\gamma^\nu)v_4]}$$

Spinors describe a specific spin state of the fermions



Spin averaged matrix element :

Unpolarize initial state and non-observation of final state spins
→ Average of possible initial state spins, sum over all final states:

$$|\overline{M_{fi}}|^2 = \frac{1}{4}\sum_{spin_i}\sum_{spin_f}|M_{fi}|^2$$

$$= 2e^4Q_e^2Q_\mu^2\frac{t^2+u^2}{s^2}$$

Mandelstamm variables

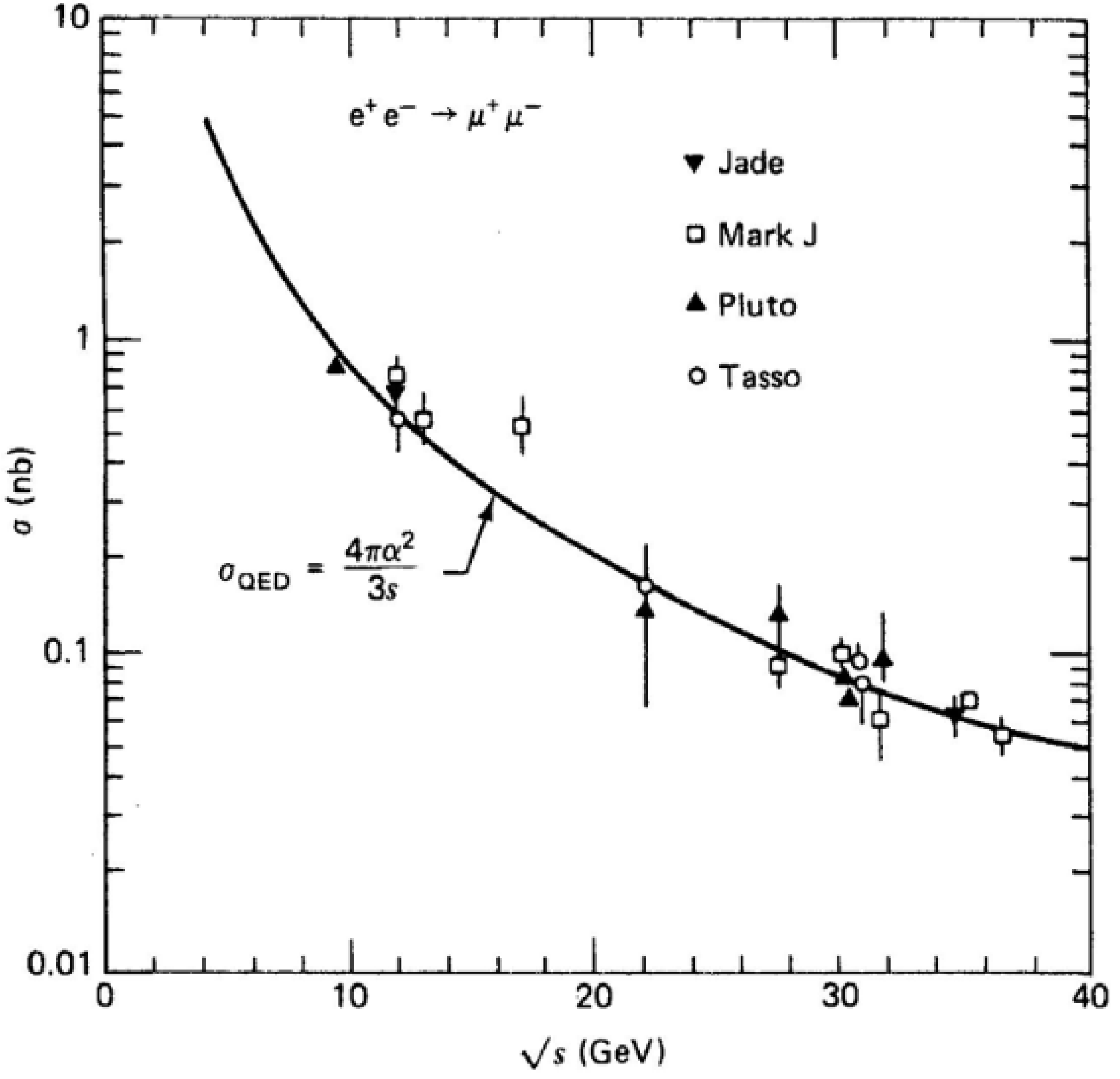
$$s = (k_1+k_2)^2$$
$$t = (k_1-p_1)^2$$
$$u = (k_1-p_2)^2 s$$

$$e^+e^- \to \mu^+\mu^-$$

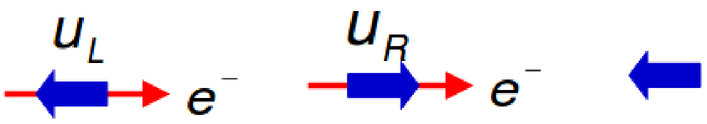
$$\frac{d\sigma}{d\Omega}_{CMS} = \frac{\alpha^2}{4s}(1+\cos^2\theta)$$

$$\sigma_{tot} = \frac{4\pi\alpha^2}{3s} \sim \frac{87nb\,GeV^2}{s}$$

Impressive agreement (1% level)
for lowest order QED computation

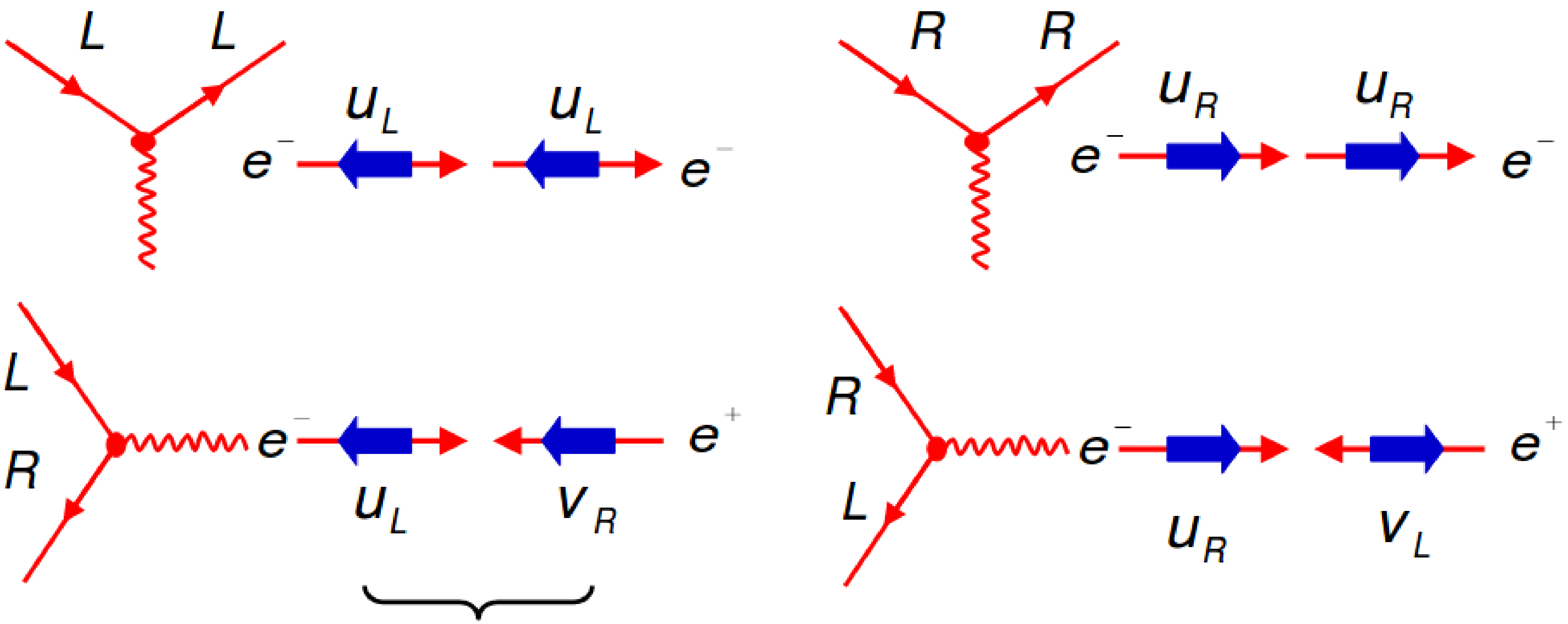


For illustration:



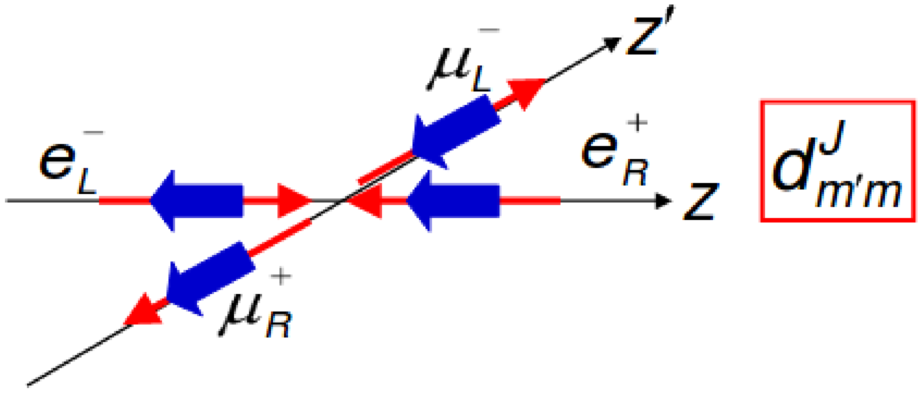
= Spin. Symbolically, correct only for massless fermions

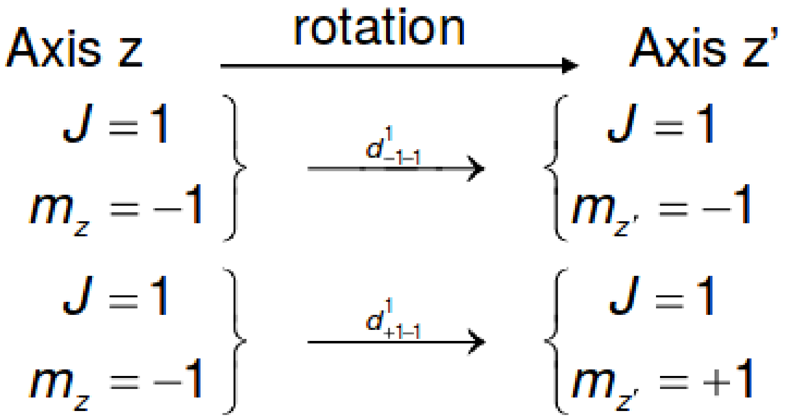
Vector current: $ie\overline{u}\gamma^\mu u$



Photon spin = 1

Angular distribution: $e^+e^- \to \mu^+\mu^-$





Scattering can be treated as a change of the quantization axis.

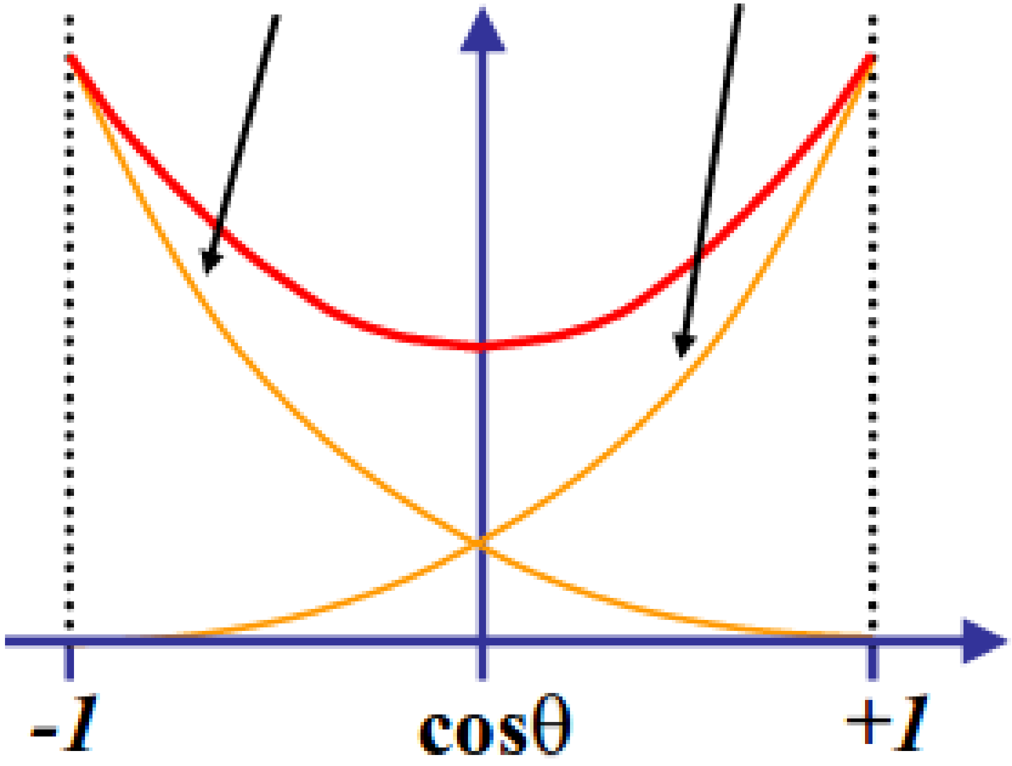
$$d^1_{1,1} = d^1_{-1,-1} = \tfrac{1}{2}(1+\cos(\theta))\ [\mathrm{LR} \to \mathrm{LR},\ \mathrm{RL} \to \mathrm{RL}]$$
$$d^1_{1,-1} = d^1_{-1,1} = \tfrac{1}{2}(1-\cos(\theta))\ [\mathrm{LR} \to \mathrm{RL},\ \mathrm{RL} \to \mathrm{LR}]$$

$$\frac{d\sigma}{d\Omega} = \frac{1}{4}(1+\cos\theta)^2 + \frac{1}{4}(1-\cos\theta)^2 \sim 1+\cos^2\theta$$

Angular distribution is an effect of vector coupling $ie\gamma^\mu$

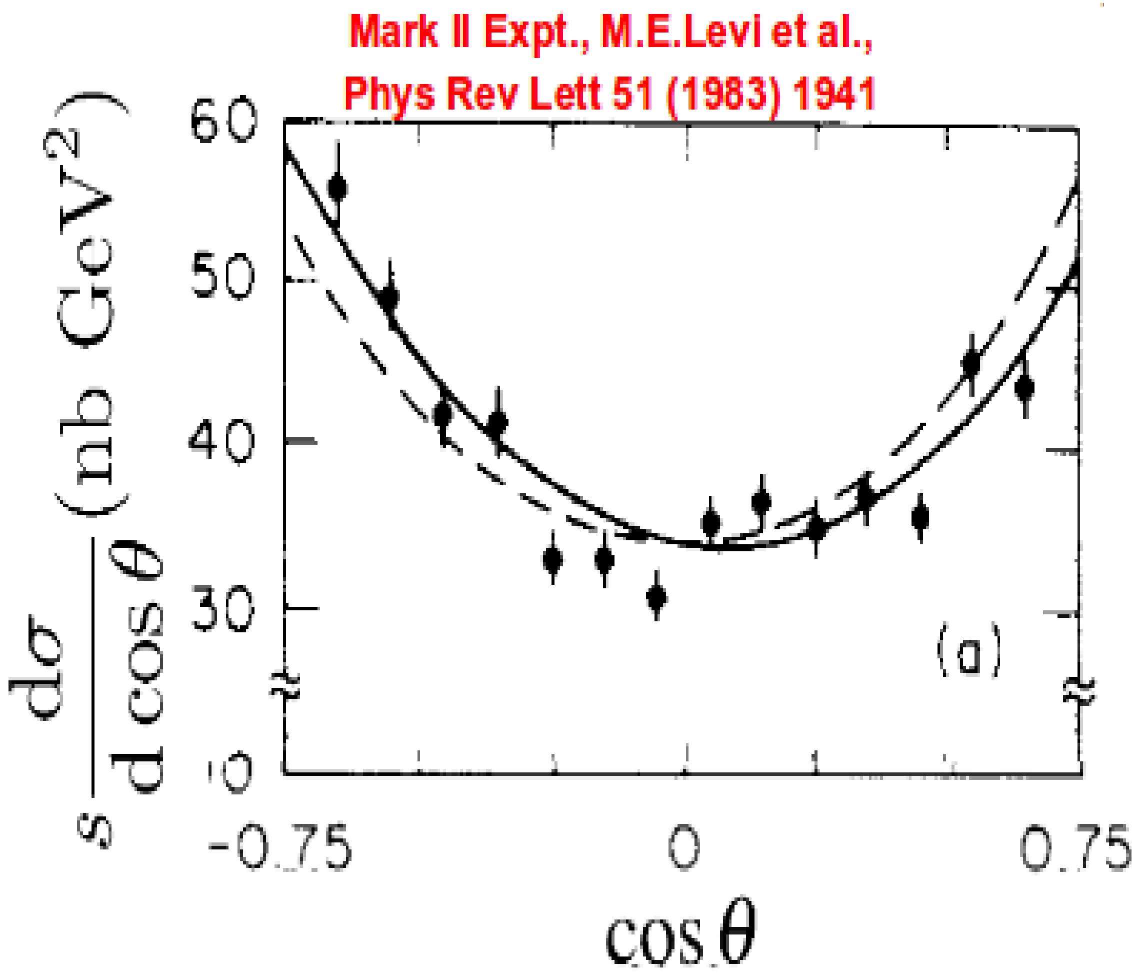
$$e^+e^- \to \mu^+\mu^-$$

LR→RL, RL→LR LR→LR, RL→RL



- - - - - pure QED

________ QED + Z corrections



angular distribution becomes slightly asymmetric
In higher order QED or when Z contribution is included