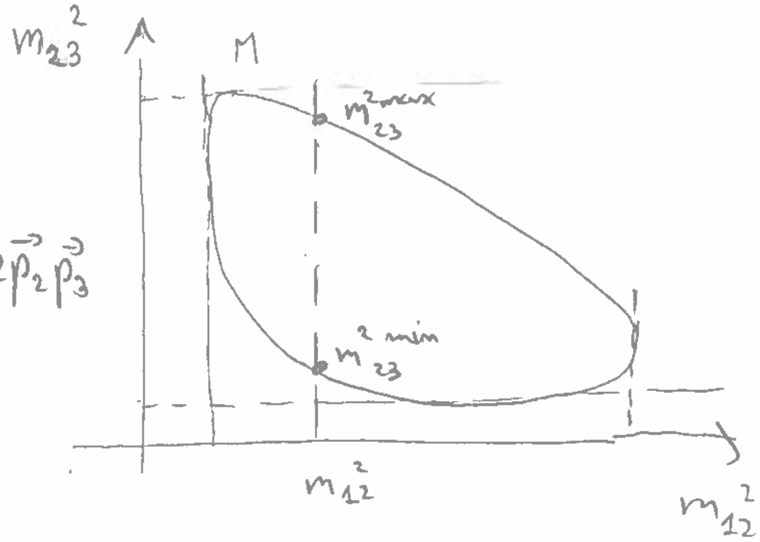
9.

$$\underset{(M)}{\rho} \to \underset{m_i}{1}\ 2\ 3$$

$$m_{23}^2 = (\mathcal{P}_2 + \mathcal{P}_3)^2 =$$

$$= m_2^2 + m_3^2 + 2E_2E_3 - 2\vec{p}_2\vec{p}_3$$



See: PDG 2016: p.324
PDG 2018: p.239
PDG 2020: p.252

To understand the kinematic boundaries e.g. along the m_{23}^2 axis, think of the system of particles 2 and 3 as if they were a single particle of mass m_{23}.

- Min value: $m_2 + m_3$

  Possible kinematically? What does it correspond to?

  Yes! The 2 particle move together (same velocity) as if they were a single object.

  It is clear that then $m_{23}^2 = (m_2 + m_3)^2$

  (think about the rest frame of m_2/m_3.)

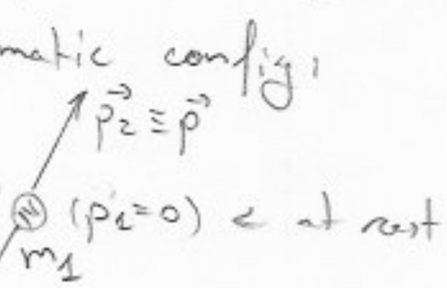
- Max value: $M - m_1$

  Same questions ...

  Yes! In the rest frame of M particle 1 and the syst 23 are produced "at rest" (all the difference $M - m_1$ becomes m_{23})

  In fact, the kinematic config:

$|\vec{p}|$ easily computable...



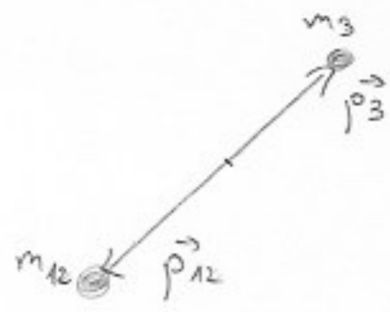
$$p_2 = (E_2, \vec{p})$$
$$p_3 = (E_3, -\vec{p})$$
$$p_{tot} = (M - m_1, 0)$$
$$(p_{tot} - p_3)^2 = \underbrace{p_2^2}_{m_2^2}$$

$$p_{tot}^2 - 2 p_{tot} \cdot p_3 + p_3^2 = p_2^2$$
$$(M - m_1)^2 + m_3^2 - m_2^2 = \\ = 2(M - m_1) E_3$$
$$E_3 = \frac{\cdots}{2(M - m_1)}$$
$$p = \sqrt{E_3^2 - m_3^2} = \cdots$$

Contour of the kinematic boundaries:

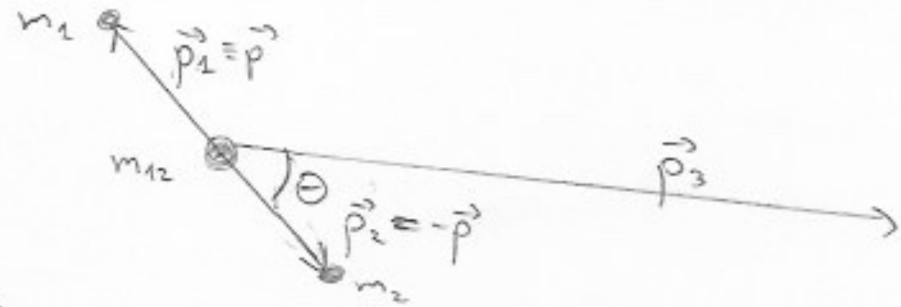
at a given m_{12}^2 : $[m_{23}^{2\,min}, m_{23}^{2\,max}]$?

M rest frame:



Only thing that can change m_{23}: angle between 2 and 3.

In the rest frame of 12:



Modules of all momenta are easily computable

$\Theta \equiv$ helicity angle

It is clear that:

$m_{23}^{min} \Leftrightarrow \Theta = 0$

$m_{23}^{max} \Leftrightarrow \Theta = \pi$

The computation itself does not have any conceptual difficulty.