KINEMATICS @ THRESHOLD

- extented tagging
- the mass of the τ-neutrino
- the mass of the τ-lepton

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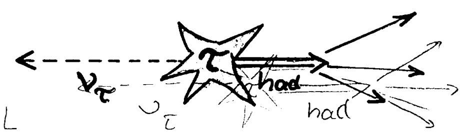
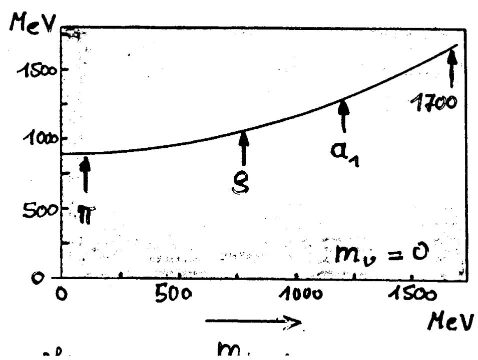
Semi-Hadronic Decays in the Restframe



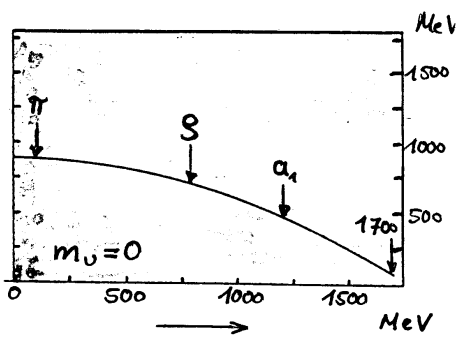
$$E^*_{had} = \frac{m_\tau^2 + m_{had}^2 - m_\nu^2}{2 m_\tau}$$

$$p^*_{had} = \frac{\sqrt{\left(m_\tau^2 - (m_{had} + m_\nu)^2\right)\left(m_\tau^2 - (m_{had} - m_\nu)^2\right)}}{2 m_\tau}$$

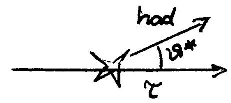
E^*_{had}



p^*_{had}



The boost

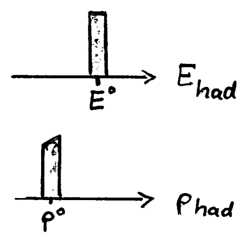


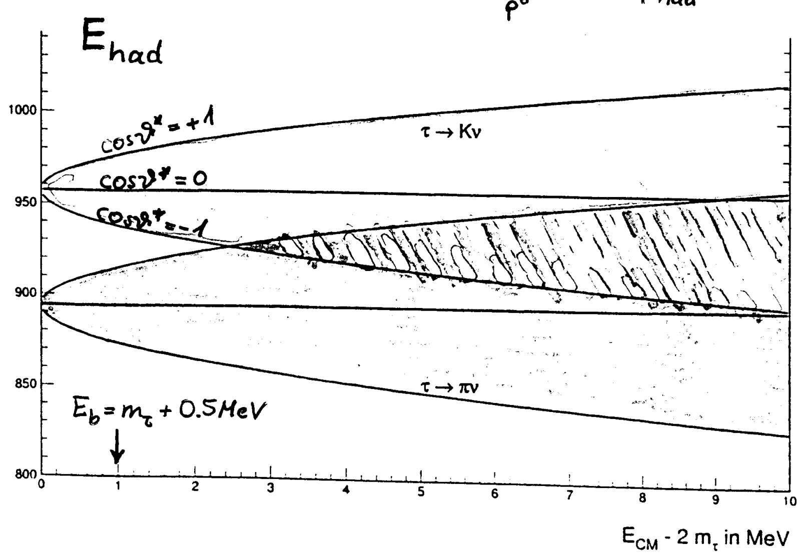
$$E_{had} = \gamma E^*_{had} + \beta\gamma\, p^*_{had} \cdot \cos\vartheta^*$$

$$p_{had} = \left[\left(\beta\gamma E^*_{had} + \gamma\, p^*_{had} \cos\vartheta^* \right)^2 + \left(p^*_{had} \sin\vartheta^* \right)^2 \right]^{1/2}$$

➡ shift

➡ width





A "quick & dirty" MC

single $\tau \to \pi \nu_\tau$ / $\tau \to 3\pi \nu_\tau$ decays

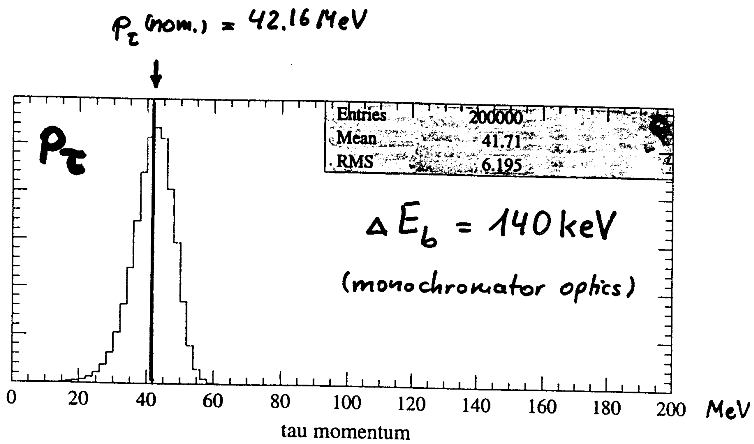
τ production: WQ: born + Coulomb-correction
gaussian smearing of E_b (140keV / 1.4Me
$(1 + \cos^2\vartheta_\tau)$ distribution
$E_b = m_\tau + 0.5$ MeV

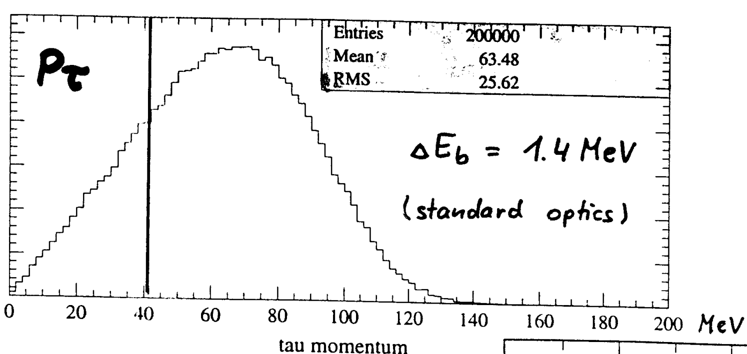
τ-decay: $\tau \to \pi \nu_\tau$, $\tau \to a_1 \nu_\tau$ } no rad. corrections
a_1: gaussian peak 1.2 GeV Γ: 400 MeV
$a_1 \to \rho\pi$ gaus. peak 770 MeV Γ: 150 MeV
$\tau \to a_1 \nu_\tau$ phasespace, but no ρ, π phasespace effects

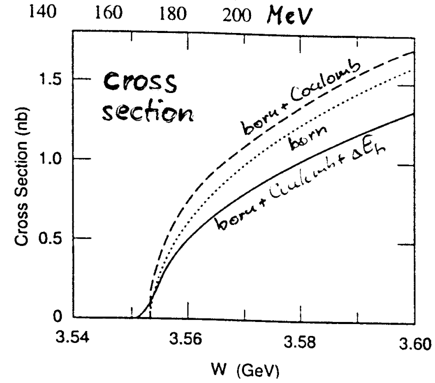
track smearing: $\sigma_{p_T}/p_T = 0.2\%\, p_T \oplus 0.2\%/\beta$
$\sigma_{\varphi,\vartheta} = 2/p\beta$ [mr]
acceptance { $|\cos\vartheta| < 0.95$, $p_T > 50$ MeV

no background / const. efficiency

Energy Spread

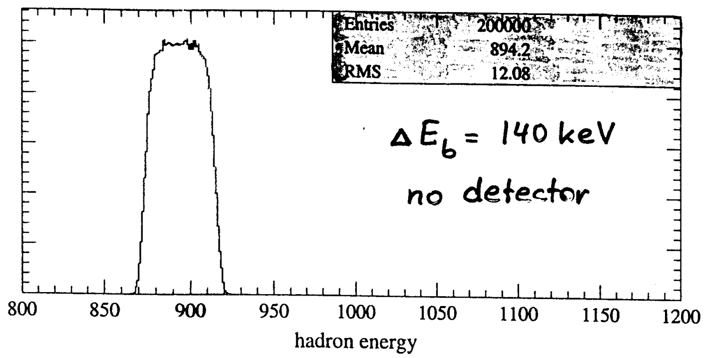


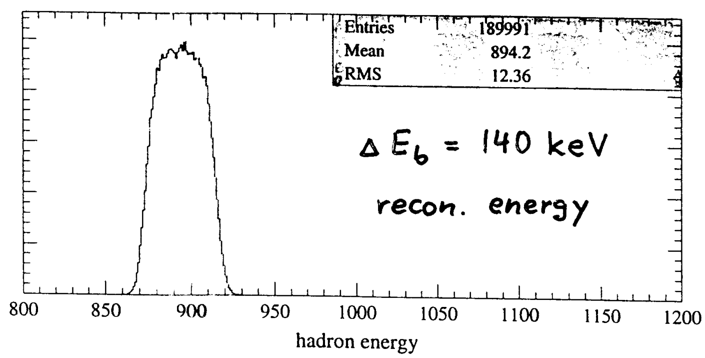


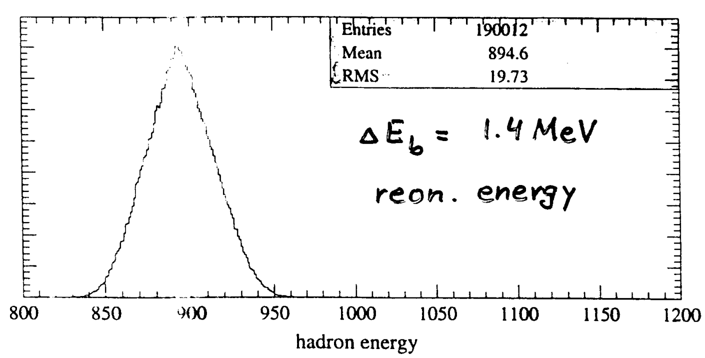


The π-Peak

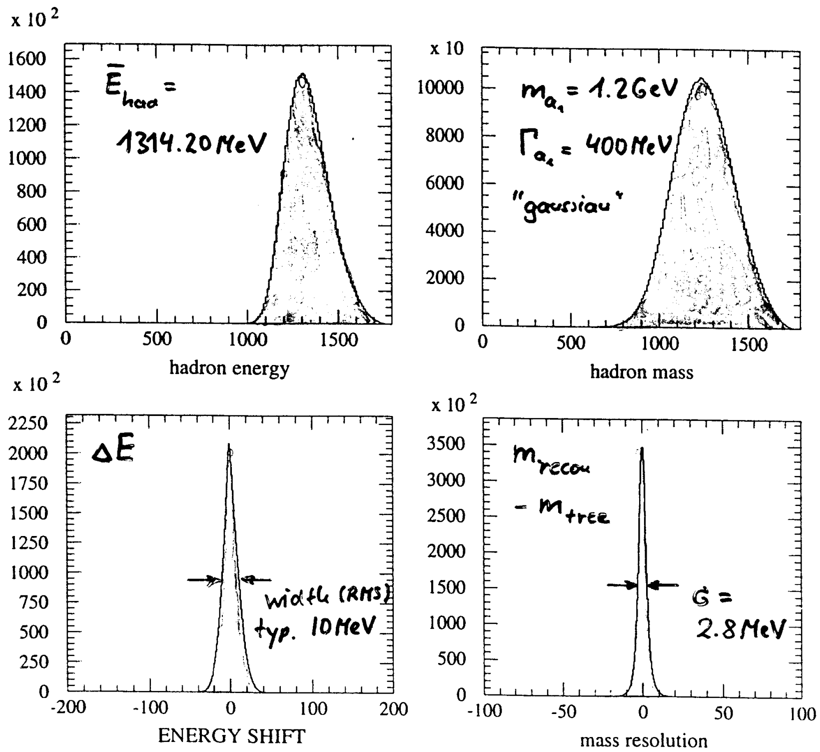
$$E^{\circ}(\tau \to \pi \nu_{\tau}) = 894.006 \text{ MeV}$$







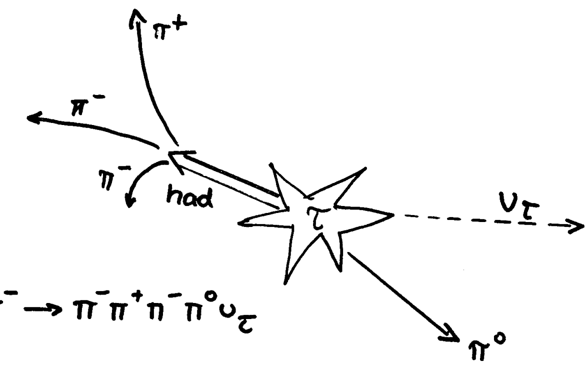
Tagging the a_1



$$\Delta E = E_{had} - E^{\circ}(m_{had})$$

$$E^{\circ} = \gamma \cdot \frac{m_\tau^2 - m_{had}^2}{2 m_\tau}$$

mis-tag



$\tau^- \to \pi^-\pi^+\pi^-\pi^0\nu_\tau$

$$\tau^- \to \underbrace{(\pi^-\pi^+\pi^-)}_{m_1}\ \underbrace{(\pi^0\nu_\tau)}_{m_2}$$

$$E^0 = \frac{m_\tau^2 + m_1^2 - m_2^2}{2m_\tau}$$

mis-tag, if $m_2 = 0$

- $\vec{p}^{\,*}_{\nu_\tau} = \vec{p}^{\,*}_{\pi^0}$
- $\vec{p}^{\,*}_{\pi^0} = 0$

π^0 lost : bad luck

π^0 recon : check 4π tag

Conclusion: TAGGING

You can tag any semi-hadronic decay
with $\Delta E = E_{had} - E^{\circ}(m_{had})$

Purity: Needs Simulation of Background

Use double-tags! No bias

τ_1 : any tag

τ_2 : signal tag

Possible tags:

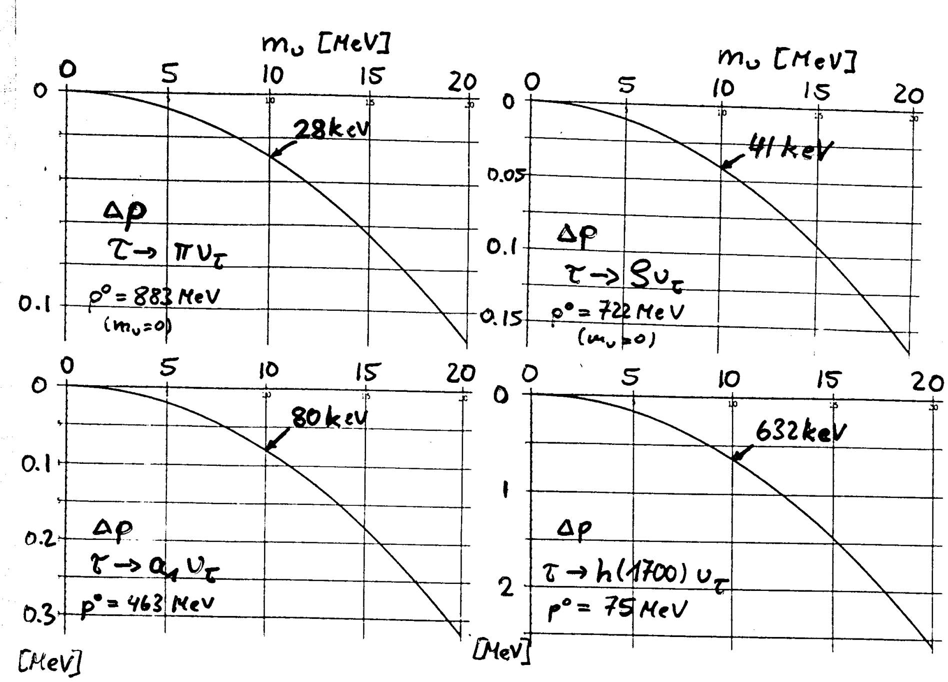
$\tau \to e\nu\nu$	17.8%	
$\tau \to \mu\nu\nu$	17.3%	
$\tau \to \pi\nu$	11.1%	
$\tau \to K\nu$	0.7%	
$\tau \to \rho\nu$	25.3%	$\approx$ 50% tagging efficiency
$\tau \to \pi^+\pi^-\pi^-\nu_\tau$	9.5%	
$\tau \to \pi^-\pi^0\pi^0\nu_\tau$	9.1%	
$\tau \to \pi^+\pi^-\pi^-\pi^0\nu_\tau$	4.3%	
	95.1%	

Neutrino Mass

$$E^{o} = \gamma E^{*} \qquad p^{o} = \sqrt{(\beta\gamma E^{*})^2 + p^{*2}}$$

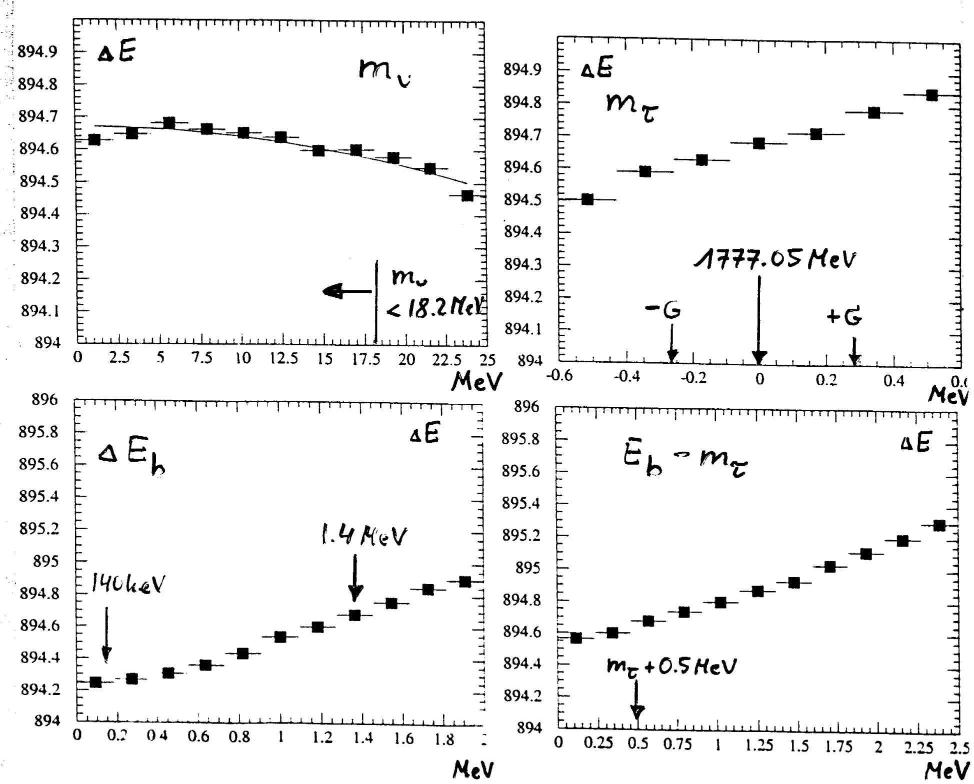
$$E^{*} = \frac{m_\tau^2 + m_{had}^2 - m_\nu^2}{2 m_\tau}$$

$$p^{*} = \frac{\sqrt{\left(m_\tau^2 - (m_{had} + m_\nu)^2\right)\left(m_\tau^2 - (m_{had} - m_\nu)^2\right)}}{2 m_\tau}$$



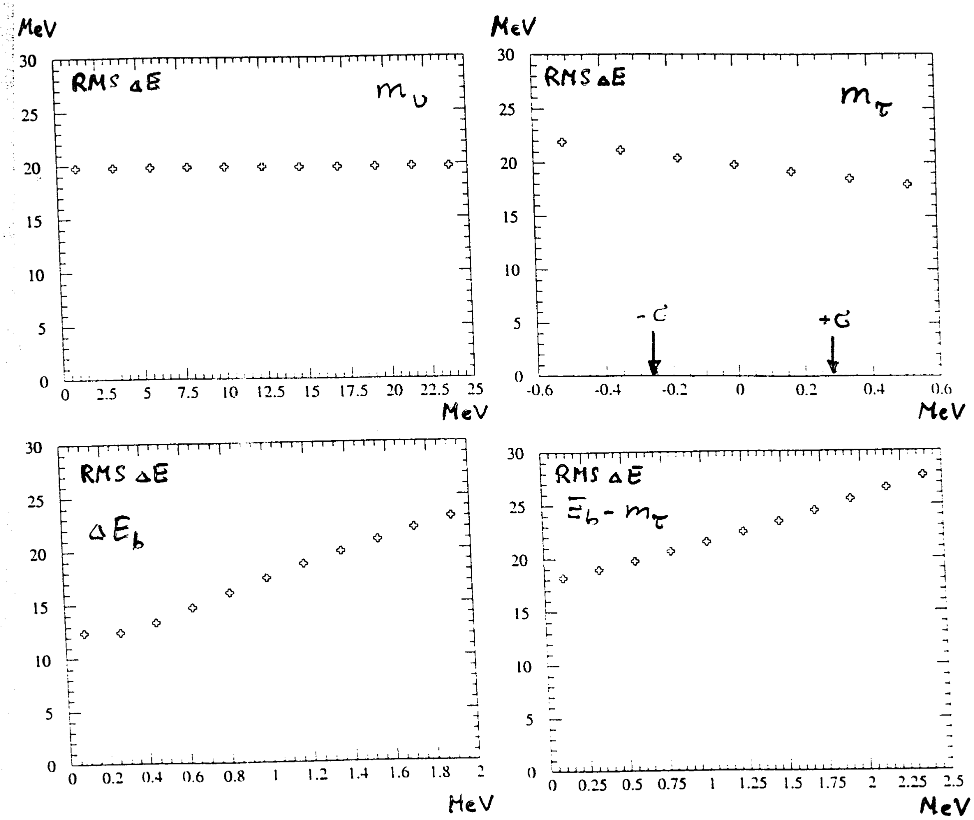
Shifts of π-Peak

- m_ν
- m_τ
- E_b
- ΔE_b
- Detector calibration
- exp. Resolution



Width of π-peak

- m_ν
- m_τ
- E_b
- ΔE_b
- Detector calibration
- exp. Resolution



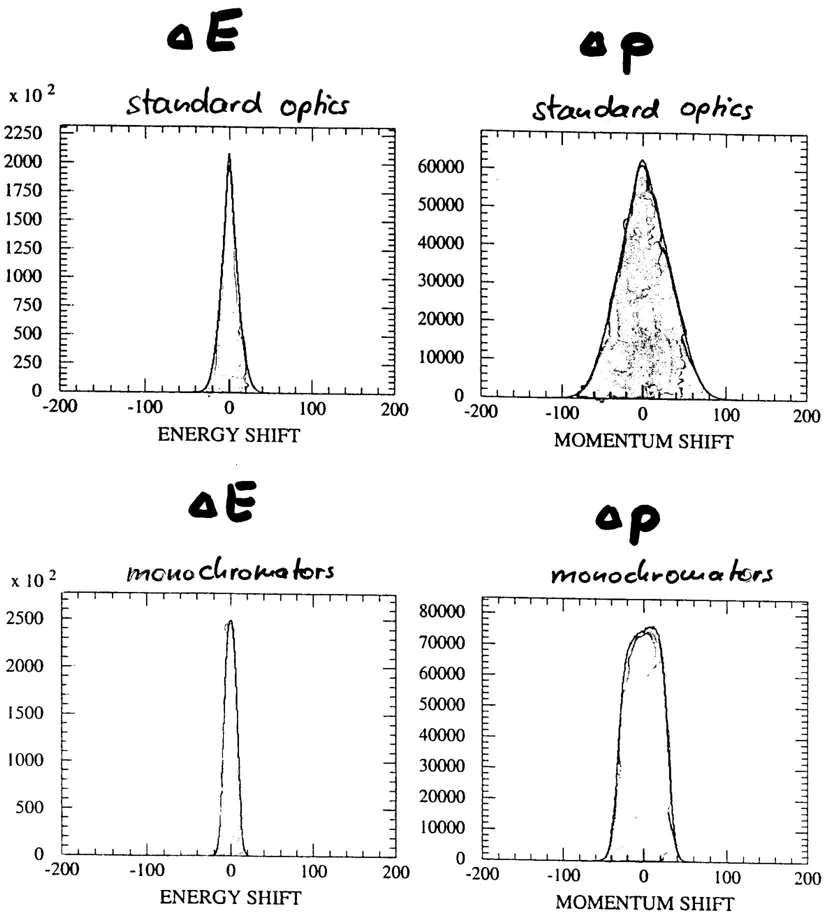
Summary: ν-peak

		peak	width
m_ν	10 MeV	28 keV	–
m_τ	± 0.1 MeV	70 keV	$E_b - m_\tau$: 800 keV (for m_τ and E_b together)
E_b	± 0.2 MeV	60 keV	
ΔE_b	± 0.1 MeV	70 keV	700 keV
calib.	10^{-4}	90 keV	–
resol.	10%	–	–

⇨ shift is too small to see m_ν

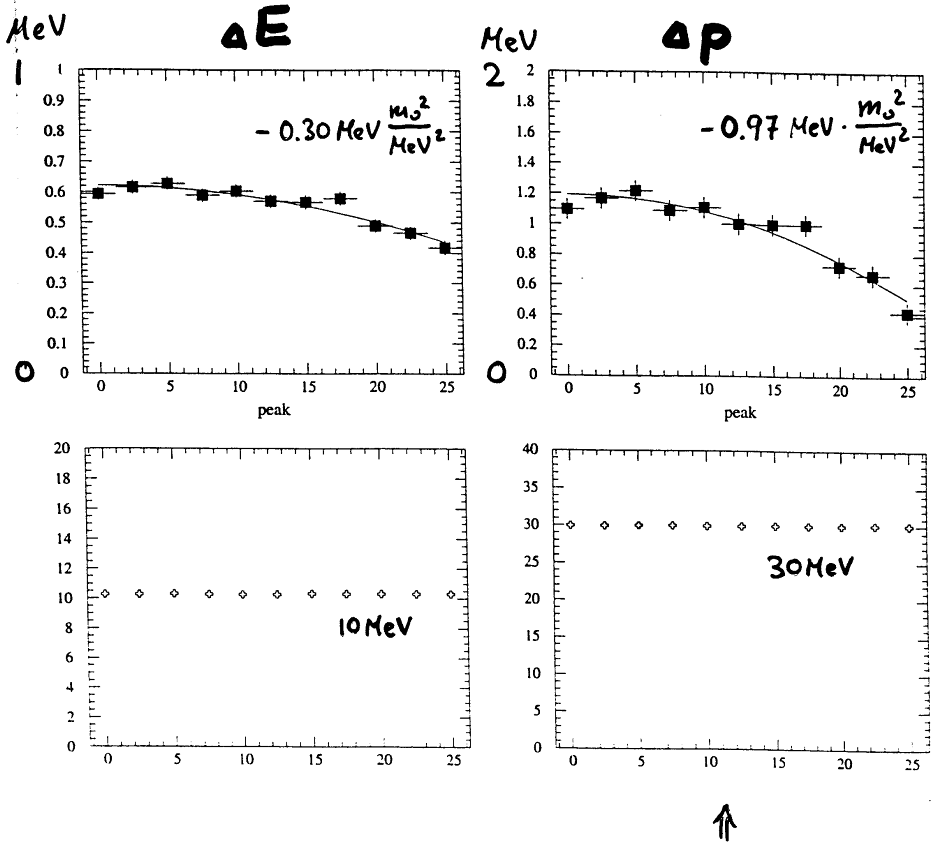
⇨ interesting cross check from position and width on m_τ, E_b, ΔE_b

a_1 - Peak



ΔE
standard optics
x 10 2
2250
2000
1750
1500
1250
1000
750
500
250
0
-200
-100
0
100
200
ENERGY SHIFT
Δp
standard optics
60000
50000
40000
30000
20000
10000
0
-200
-100
0
100
200
MOMENTUM SHIFT
ΔE
monochromators
x 10 2
2500
2000
1500
1000
500
0
-200
-100
0
100
200
ENERGY SHIFT
Δp
monochromators
80000
70000
60000
50000
40000
30000
20000
10000
0
-200
-100
0
100
200
MOMENTUM SHIFT

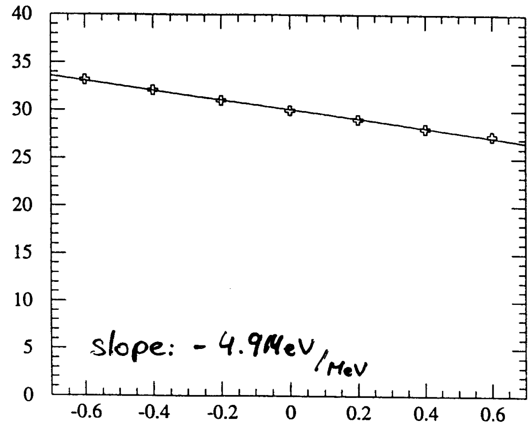
a_1 - peak



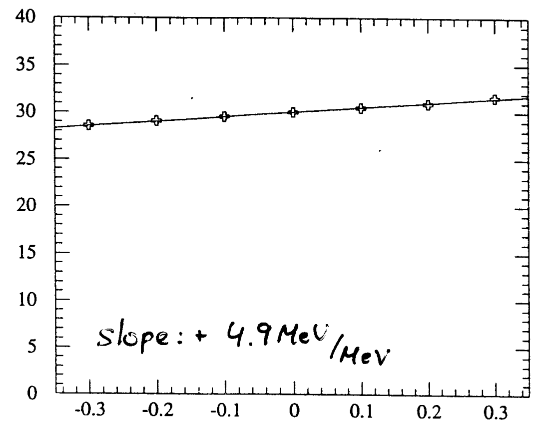
larger shifts!

Width

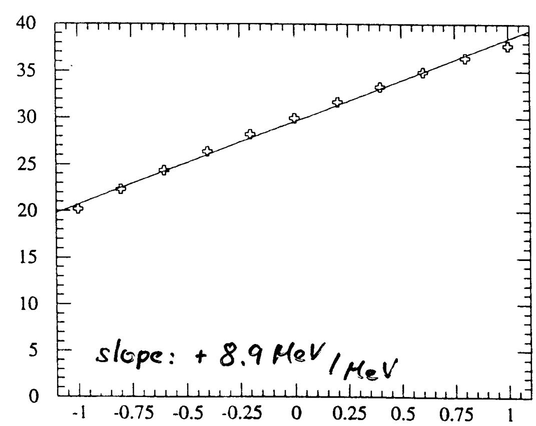
independent of m_ν !



m_τ



$E_b - m_\tau$



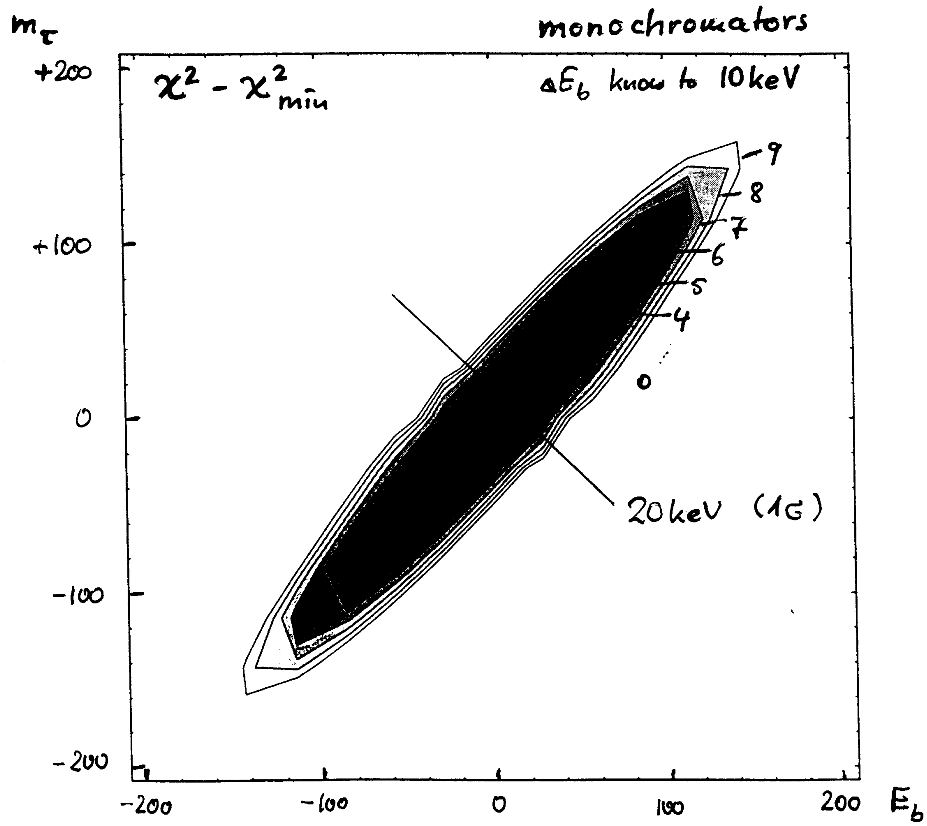
ΔE_b

Secondary Information

- ⇨ π - peak pos.
- ⇨ π - peak width
- ⇨ a_1 - peak width

} independent of m_ν

Fit: E_b , m_τ , ΔE_b



The τ-mass

- The width of the peaks measures the distance to the threshold!

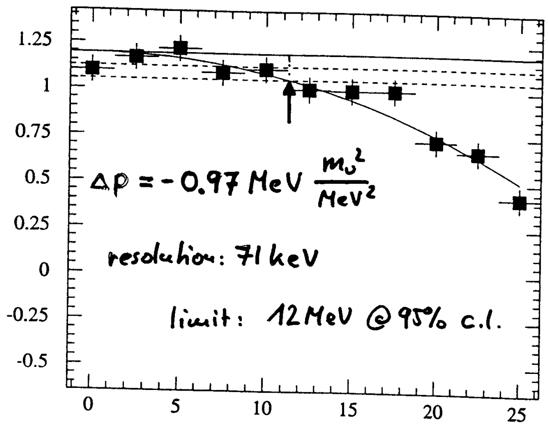
  ΔE_b known to 100keV: ΔE_b, $E_b - m_\tau$ similar

  ΔE_b known to 10keV: $E_b - m_\tau$ dominant

$$\begin{aligned} RMS(\Delta E) &= E(\cos\vartheta = +1) - E(\cos\vartheta = -1) \\ &= 2\beta\gamma p^* \\ &\vdots \\ &\approx \sqrt{E_b^2 - m_\tau^2}\left(1 - \frac{m_{had}^2}{m_\tau^2}\right) \end{aligned}$$

➡ measure m_τ without scanning

m_ν: statistical precision

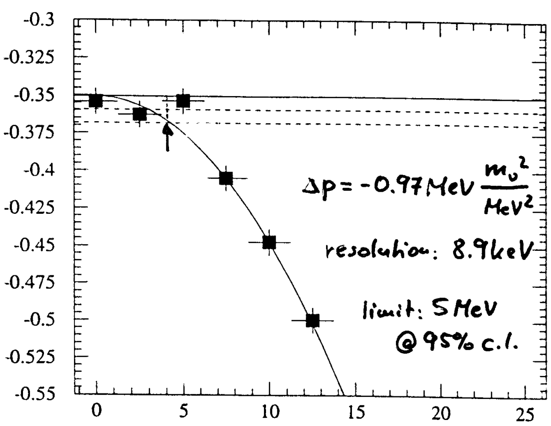


szenario A

$\mathcal{L} = 10^{33}/cm^2/s$

10^7 sec running

standard optics



szenario B

$\mathcal{L} = 10^{34}/cm^2/s \cdot 0.7$

3.5 10^7 sec running

"monochromators"

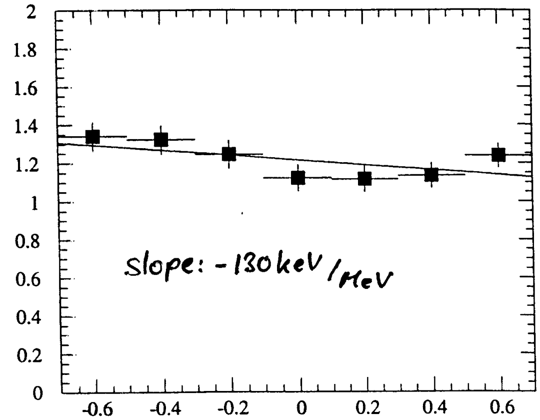
Systematics

Goal: better than

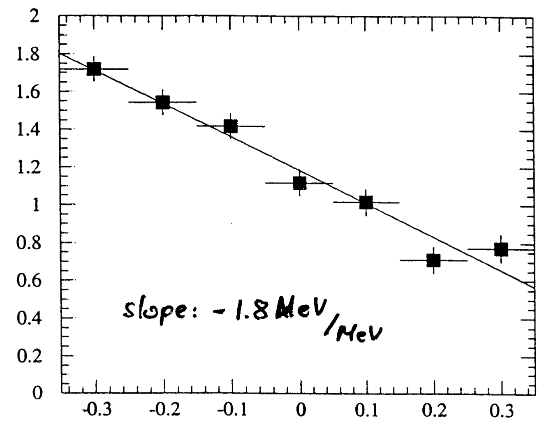
100 keV / 10 keV

(A) (B)

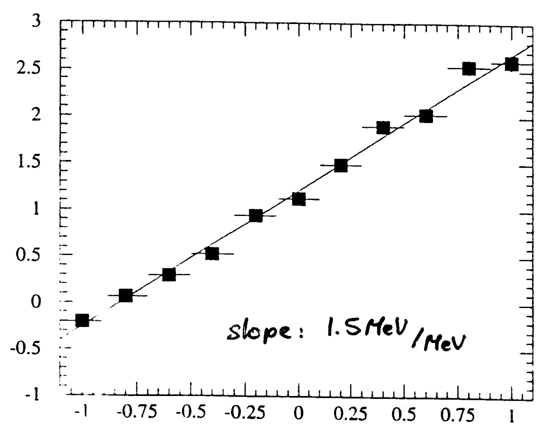
Standard optics



m_τ okay



$E_b - m_\tau$ okay



ΔE_b need 10 keV precision for (B)

Summary on m_ν

$\tau \to \pi \nu_\tau$: shift too small

$\tau \to a_1 \nu_\tau$: szenario A: 12 MeV not enough!

szenario B : 5 MeV interesting

SYSTEMATICS

		Ⓐ	Ⓑ
energy scale	+ 200 keV	0.4 keV	0.4 keV
$E_b - m_\tau$	10 keV	19 keV	19 keV
ΔE_b	100 keV 10 keV	(150 keV)	15 keV
Det. calibration	10^{-4} 10^{-5}	120 keV	(120 keV) (12 keV)
Resolution	10%	negl.	negl.
statistics:		71 keV	9 keV

How good can we calibrate the detector?

The Conclusion

- **Improved Tagging**

  50% should be possible

- **τ - mass**

  Possible without scanning

- **neutrino mass**

  ??? Maybe 5 MeV ???

  (Calibration to 10^{-5})