Jefferson Lab

Beam Energy Analysis

E04 – 007, E05 – 004

Presentation

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Introduction

My Goals:

- Determine the beam energy in Hall-C (G0 experiment - measurements taken during LEDEX experiment)

  Currently working on

- Determine the beam energy in Hall-A (Threshold π^0 experiment)

  Yet to be done

Using the same analysis, procedures and algorithms In both cases

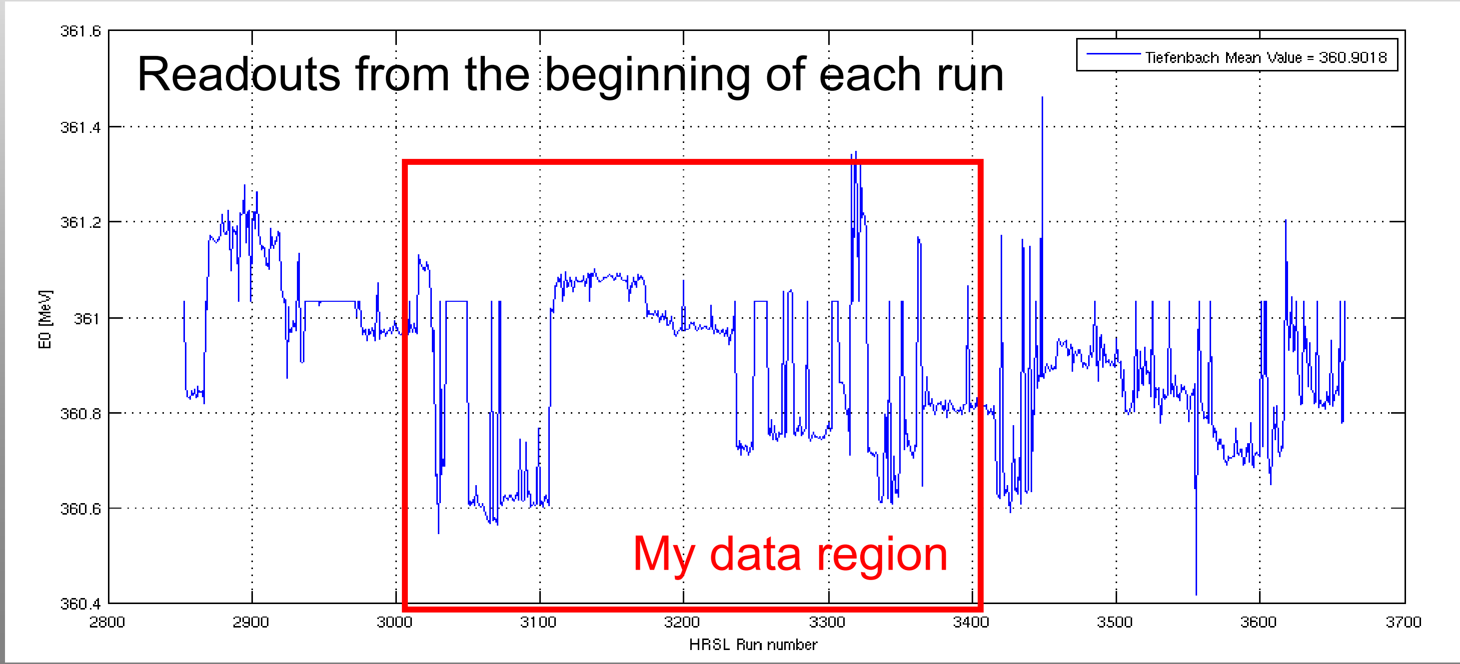
EPIS information ← Used Data → Elastic scattering data

- Tiefenbach energy,
- Hall-probe data

- Various Targets: LH_2, LD_2, ^{12}C, (Al), Ta
- Various Kinematics: E_{beam}, $\theta_{scattering}$

Tiefenbach Data

- Energy lock was **off** (in both cases)
- Fluctuating Tiefenbach readouts
- In this energy regime (~ 360 MeV) the Tiefenbach calibration not known any more.
- More Tiefenbach readouts in HRS-R runs than HRS-L

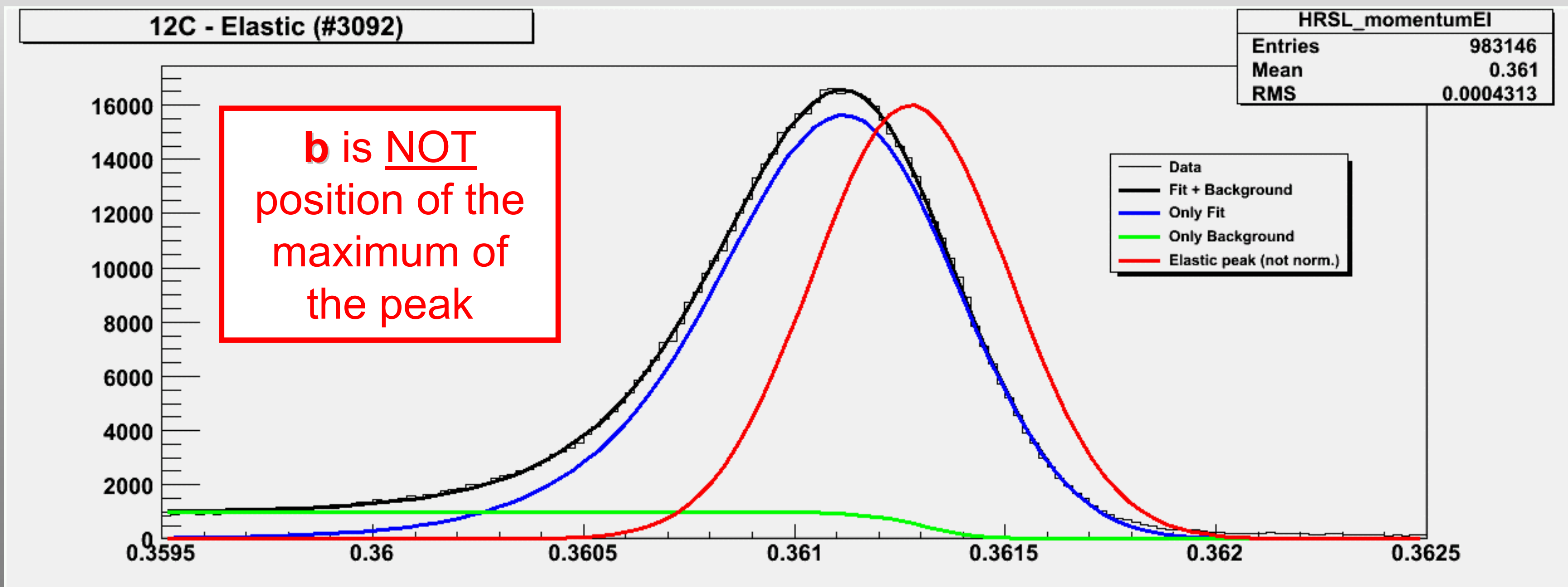


Elastic Peak Fitting #1

I used modified Nilanga's formula to fit data:

- First attempt:

$$f(E')=\underbrace{\sqrt{\frac{\pi}{2}}\frac{\sigma}{\alpha}\exp\left(\frac{1}{2\alpha}\left(\sigma^2/\alpha+2(E'-b)\right)\right)Erfc\left(\frac{|\alpha|}{\sqrt{2}\sigma\alpha}\left(\sigma^2/\alpha+(E'-b)\right)\right)}_{\text{Basic Nilanga's fit}}+\underbrace{\boxed{\frac{c_1}{1+\exp((E'-c_2)c_3)}}}_{\text{Fermi-like function for description of background}}$$



Elastic Peak Fitting #2

There is a better way to describe background !!

- Second Attempt:

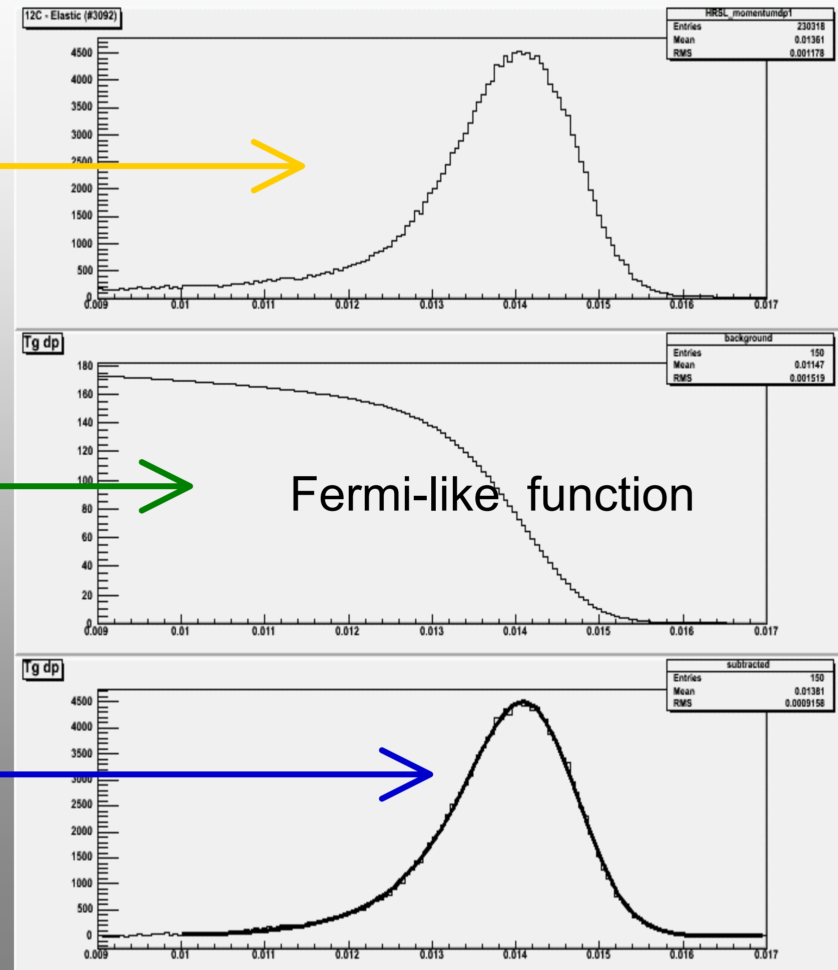
Raw data (elastic peak momentum distribution)

Calculate sum of distribution

$$\sum_{i=nbins}^{1} N_{\delta}(i) \approx \int_{\delta_{max}}^{delta} N(\delta)$$

Subtract background from the data and use Nilanga’s formula

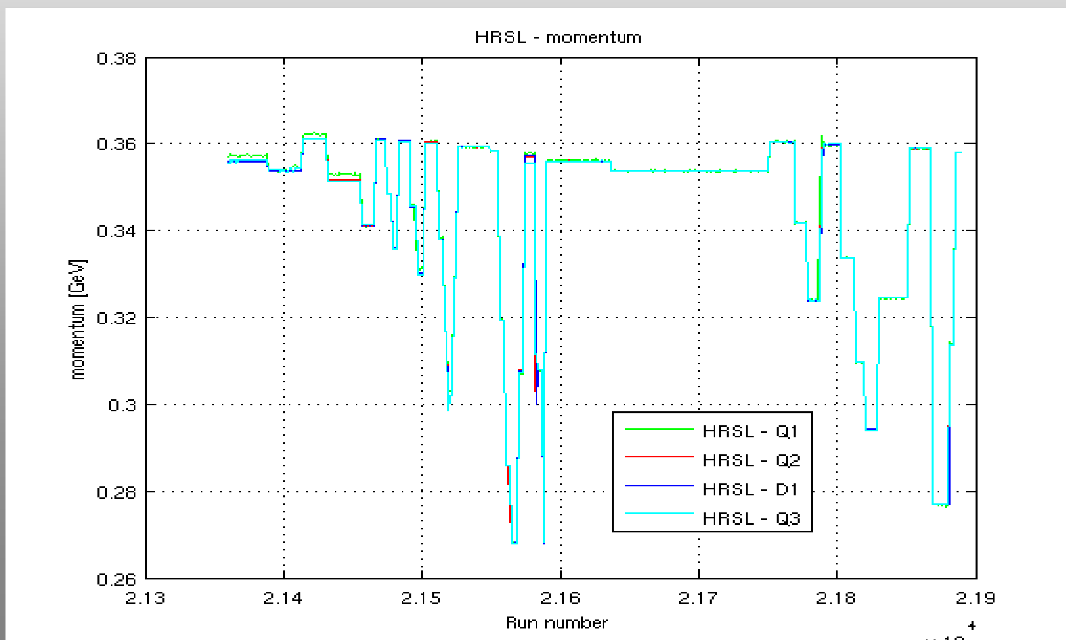
$$f(E')=\sqrt{\frac{\pi}{2}}\frac{\sigma}{\alpha}\exp\left(\frac{1}{2\alpha}(\sigma^2/\alpha+2(E'-b))\right)Erfc\left(\frac{|\alpha|}{\sqrt{2}\sigma\alpha}(\sigma^2/\alpha+(E'-b))\right)$$



Central Momentum of the HRS

- Central momenta of the HRS's are ~ 350 MeV
- In this regime NMR is **not** functioning !!!
- Instead we use Hall-probe data

Using **John LeRose's** formulas to calculate momentum from the Hall-probe readouts.



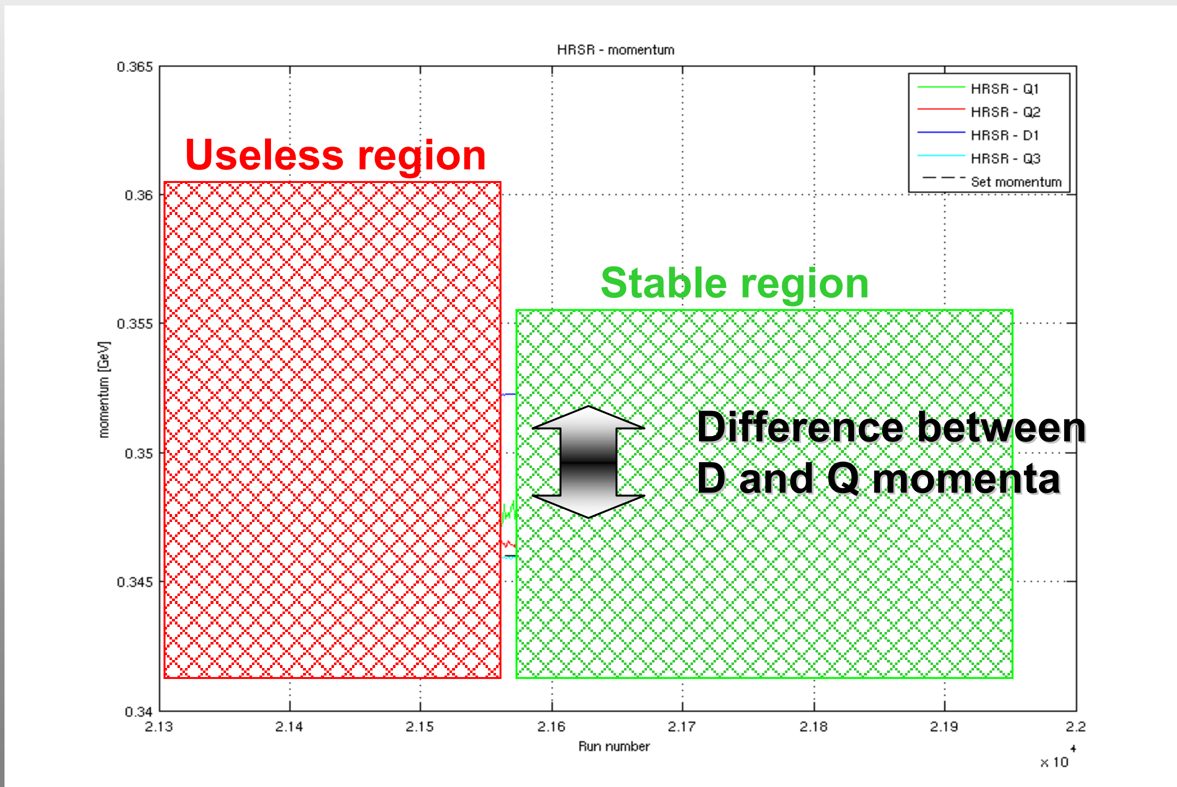
It works quite well for the **HRS-L**:

- Momenta from various magnets are approximately consistent with **each other**
- Consistent with the **set** momentum

HRS-R problem

There were many problems with the HRS-R:

- The magnetic field in Dipole was constantly drifting
- <u>Set</u> momentum does **not** agree with the <u>actual</u> <u>momentum</u> !!!



- Restricted analysis to **region** with stable magnets.

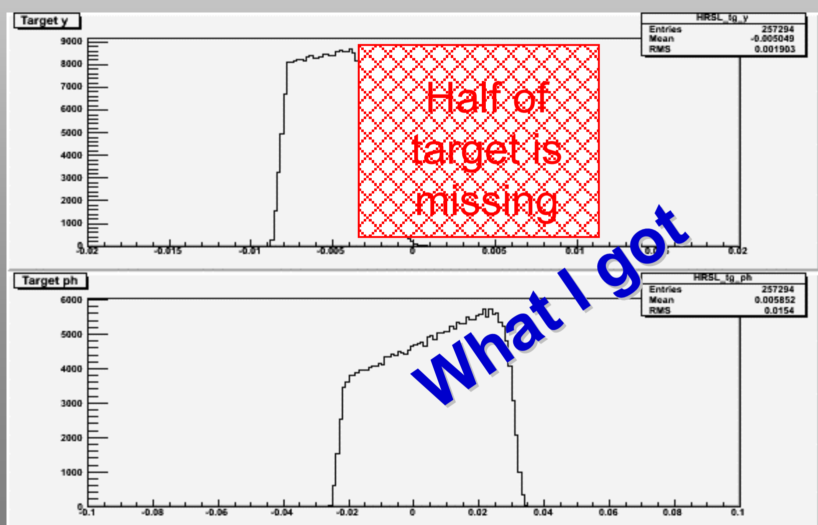
- **Only few good series (from H to Ta) of elastic runs**

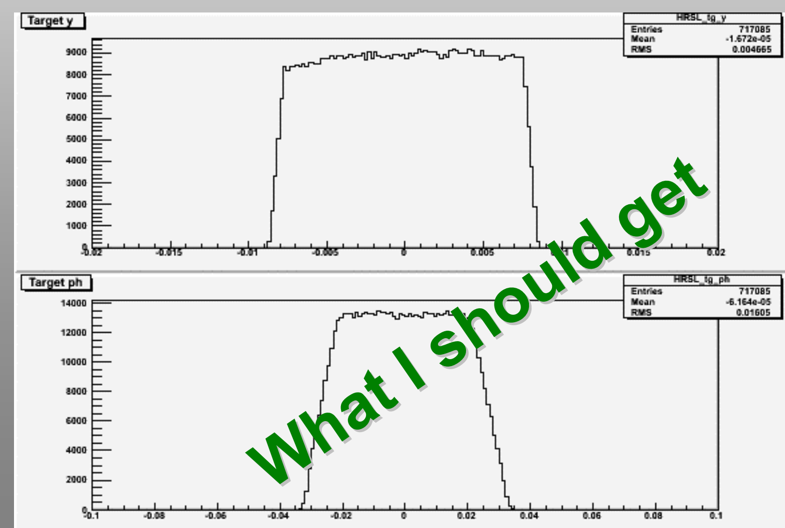
Energy Losses #1

- **Electrons lose energy** traveling through target:
    1. In the target it self
    2. In the target windows
    3. In the air between HRS and target
    4. In the kapton window of the HRS

~ 1.3 MeV for LH_2

- **Extremely good knowledge of energy losses is necessary.**
- I have used Mceep to estimate energy losses but got funny results.





Energy Losses #2

- I did not understand Mceep very well
- I made <u>my own program</u> for energy losses calc.
- I extracted important code from Mceep and tried to understand it.

Two contributions to the energy losses:

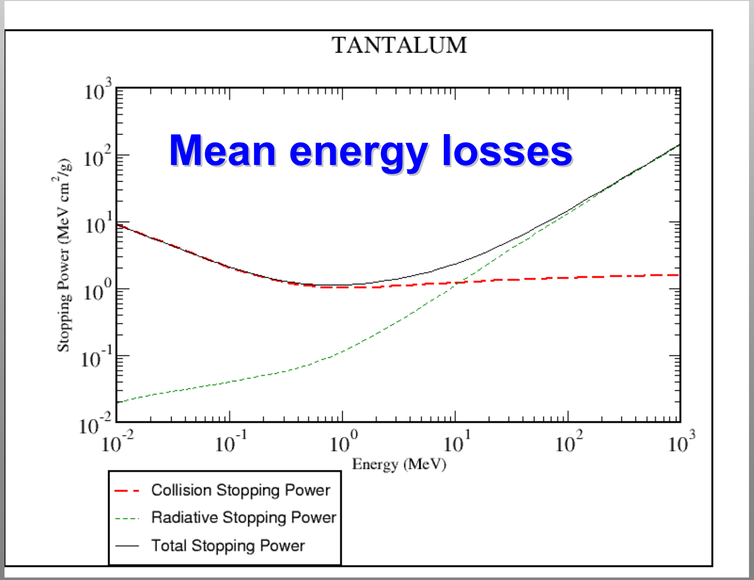
1. Collision Losses:

$$W_{max} = \frac{2 m_e c^2 \eta^2}{1 + 2s\sqrt{1+\eta^2} + s^2}$$

Bethe-Bloch Formula:

$$-\frac{dE}{dx} = 2\pi N_a r_e^2 m_e c^2 \rho \frac{Z}{A}\frac{z^2}{\beta^2}\left[\ln\left(\frac{2 m_e \gamma^2 v^2 W_{max}}{I^2}\right) - 2\beta^2 - \delta - 2\frac{C}{Z}\right]$$

This gives us <u>Mean energy losses</u> !!!



2. Radiation Losses

$$d\sigma = 4 Z^2 r_e^2 \alpha \frac{d\nu}{\nu}\left\{(1+\varepsilon^2)\left[\frac{\phi_1(\xi)}{4} - \frac{1}{3}\ln Z - f(Z)\right] - \frac{2}{3}\varepsilon\left[\frac{\phi_2(\xi)}{4} - \frac{1}{3}\ln Z - f(Z)\right]\right\},$$

Energy Losses #3

- Radiation losses **do not** shift momentum peak. They only cause long tails in the distributions.
- Collision losses **move** the momentum peak
- Energy straggling distributions are **NOT** Gaussian but Landau-like (Landau, Vavilov, Symon distributions)

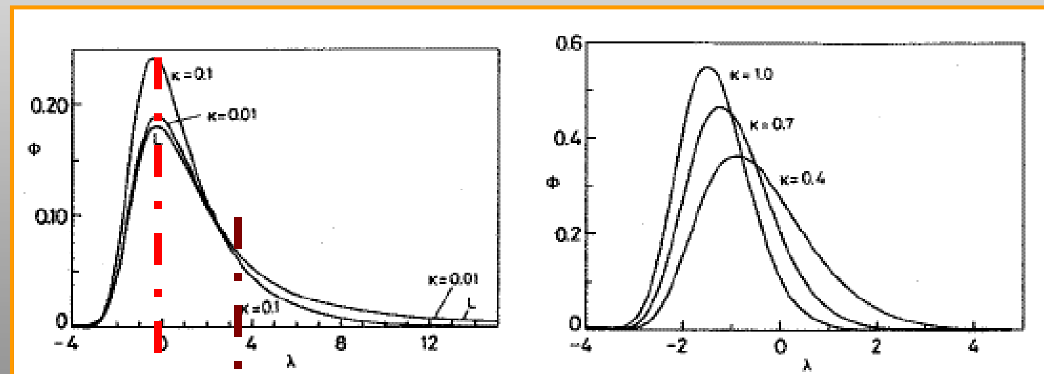
Landau distribution:

$f(x, \Delta) = \phi(\lambda)/\xi$, where

$$\phi(\lambda) = \frac{1}{\pi}\int_0^\infty \exp(-u\ln u - u\lambda)\sin \pi u \, du$$

$$\lambda = \frac{1}{\xi}[\Delta - \xi(\ln \xi - \ln \varepsilon + 1 - C)]$$

Leo: Techniques in Particle Physics



Mean Energy Loss (Bethe-Bloch)

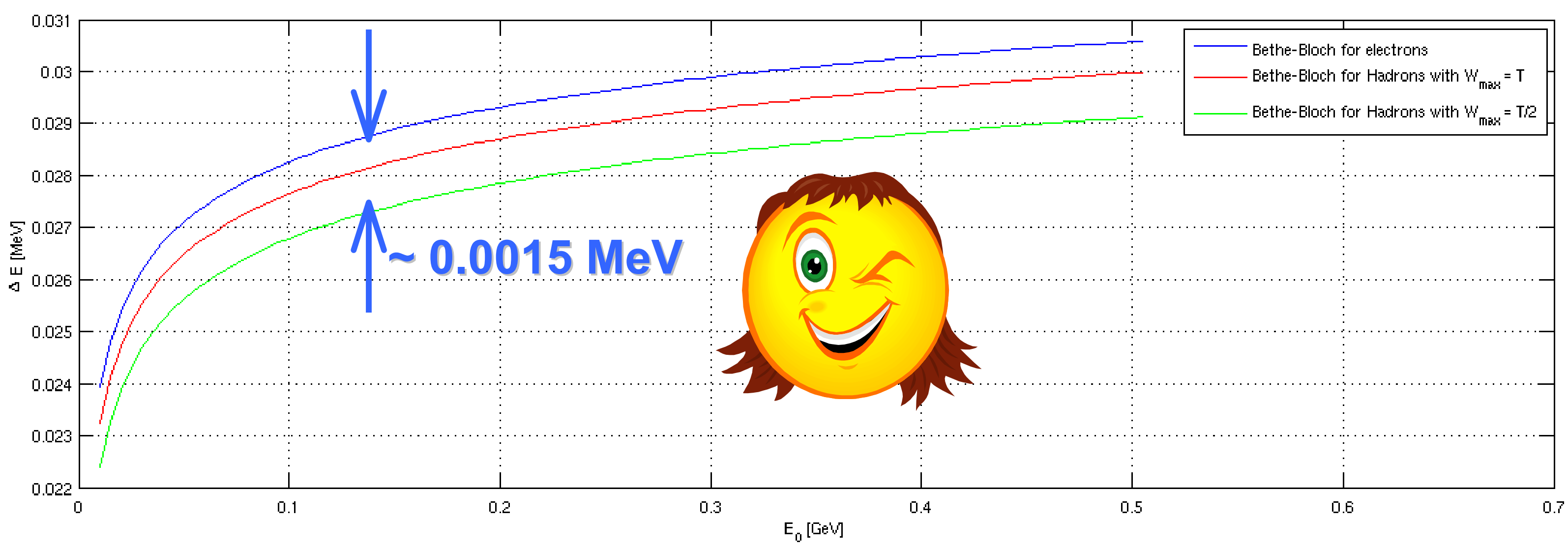
Most Probable Energy Loss

We need most probable energy losses for the correction of our meassurements

Energy Losses #4

- Mceep uses Bethe-Bloch formula for Heavy Ions to calculate energy losses of electrons.

This is WRONG in general but it works in this case.



- This corrects for the difference between the **mean** and **most probable** energy loss:

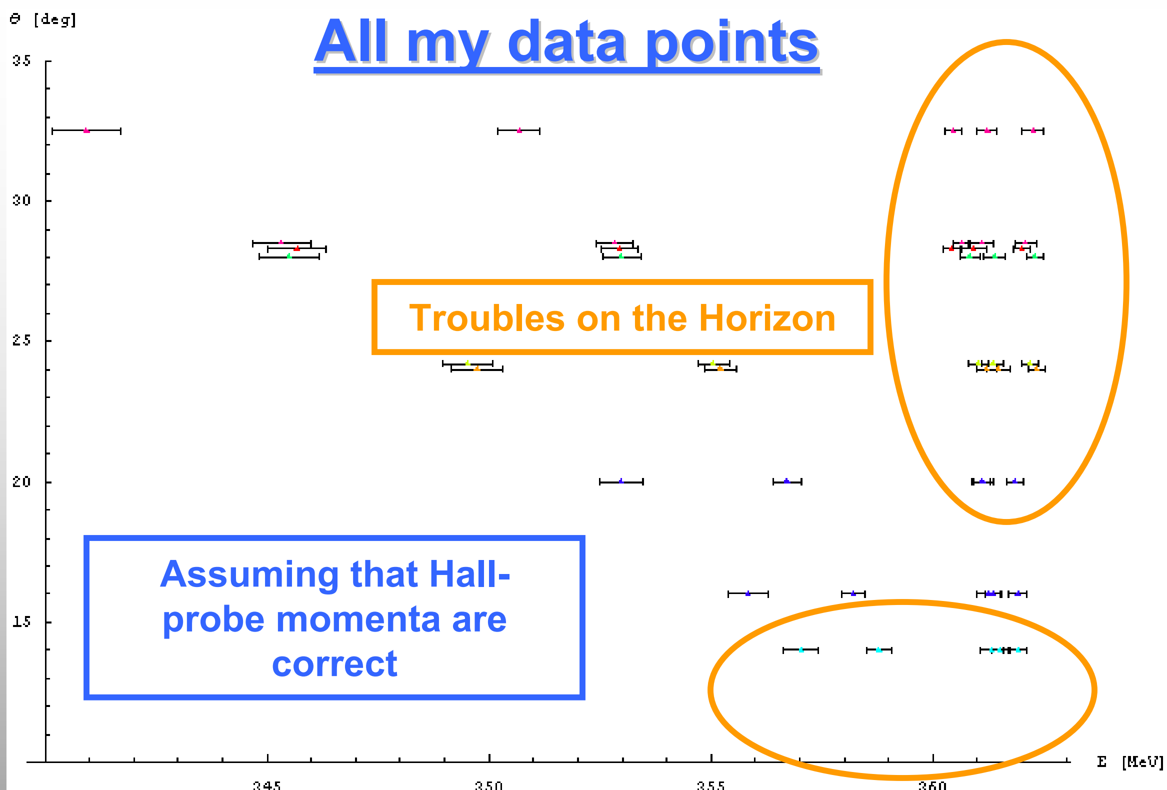
$$\Delta_p = \overline{\Delta}_{Bethe-Bloch} + \xi\left(\beta^2 + \ln\kappa - C_{Euler} + 1 + \lambda_{MP}\right)$$

$$\kappa = \frac{\xi}{W_{max}}$$

$$\xi = 2\pi N_a r_e^2 m_e c^2 \rho \frac{Z}{A}\frac{1}{\beta^2} L$$

$$\lambda_{MP} \approx -0.22$$

Basic Idea



Using these data and my fitting function need to find :

Beam Energy

Central Momentum of HRS

Scattering angle

Main fitting Formula:

$$(1+\delta)\,E_c + \Delta E_{Loss} = \frac{E_0}{1+\frac{E_0}{M}(1-\cos\theta)}$$

Determining the beam energy

- To fit each kinematics we have to find minimum of the χ^2 function.

$$\chi^2(E_{beam}, E_C, \theta) = \sum_{i=1}^{N} \frac{1}{\sigma_i^2} \left[\delta_i - \delta(M_i, E_{beam}, E_C, \theta)\right]^2$$

I have tried various approaches to fit the data and realized

- We **<u>can not</u>** fit all three fitting parameters: $\boldsymbol{\theta}$, $\mathbf{E_b}$, $\mathbf{E_C}$
- Therefore fix the scattering angle – the angular positioning system is accurate enough.
- $\mathbf{E_b}$, $\mathbf{E_C}$ can <u>not be</u> determined independently. Need additional constraints to fit data.

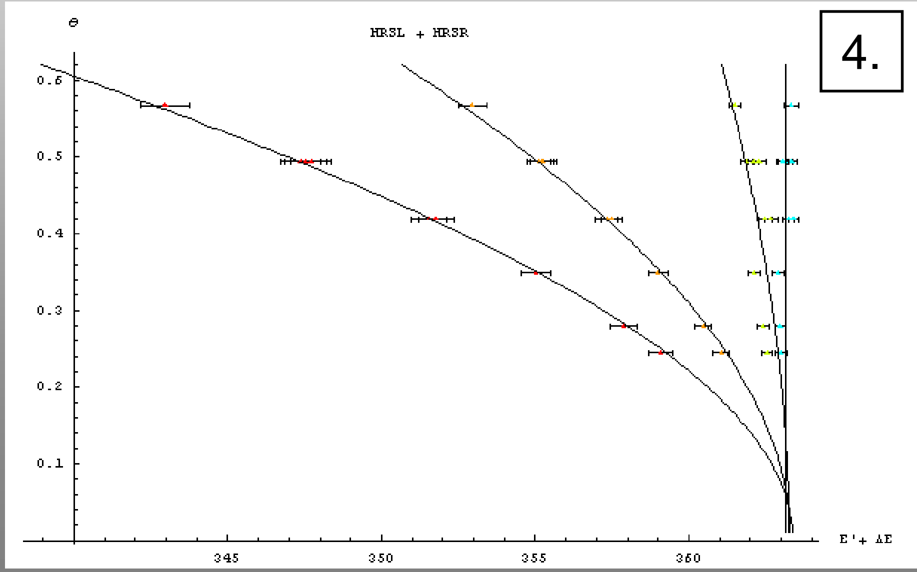
Almost Equivalent Changes

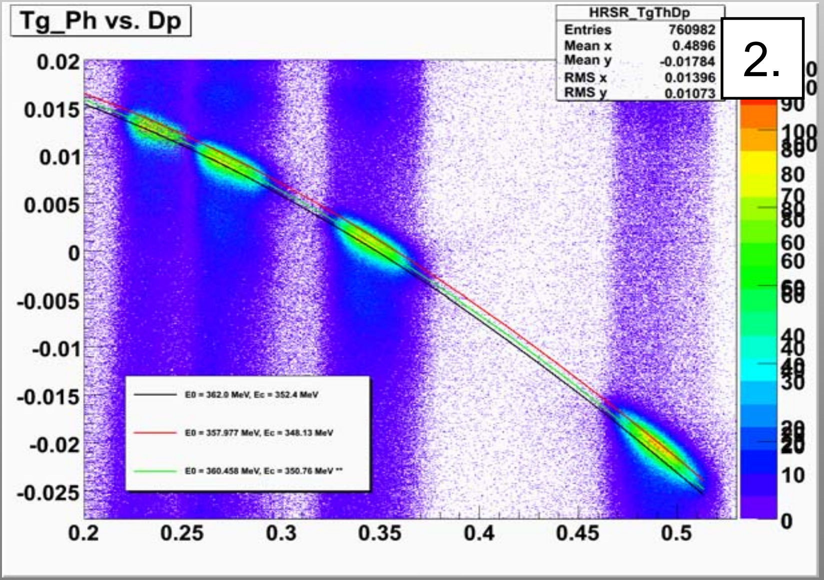
$$E'_c \approx \frac{E_c}{(1+\kappa)} \Longleftrightarrow E'_{beam} = E_{beam}(1+\kappa)$$

κ is small

Various fitting methods

1. Fitting each kinematics separately: **NOT GOOD**
2. Direct fits with threshold: **NOT GOOD**
3. Fitting with $(E - E0)^{2n}$ constraints in χ^2 function: **NOT GOOD**
4. "Transverse" fits (Each target separately): **NOT GOOD**
5. Fits with Tiefenbach constraints: **PROMISING**
6. Fits with Hall-probe data constraints: **NOT YET EXAMINED**





The ratio method

Our main problem: **Too many fitting parameters**

N – different kinematics: N(1+1) = **2N** parameters

Assuming that Tiefenbach energies are <u>relatively correct</u>

$$E_0 = E_T + b,$$

$$\frac{(1+\delta_1)E_c^1 + \Delta E_{Ta}}{(1+\delta_2)E_c^2 + \Delta E_{Ta}} = \frac{(E_T^1 + b)}{(E_T^2 + b)} \frac{1 + \frac{E_T^2+b}{M}(1-\cos\theta_2)}{1 + \frac{E_T^1+b}{M}(1-\cos\theta_1)}$$

$$\frac{E_c^1}{E_c^2} = \Omega\kappa \frac{1+\delta_2}{(1+\delta_1)}$$

$$1 + \frac{E_T^1 - E_T^2}{E_T^2} = \Omega$$

$$\left(1 + -\frac{1}{M}(E_T^2\cos\theta_2 - E_T^1\cos\theta 1)\right) = \kappa$$

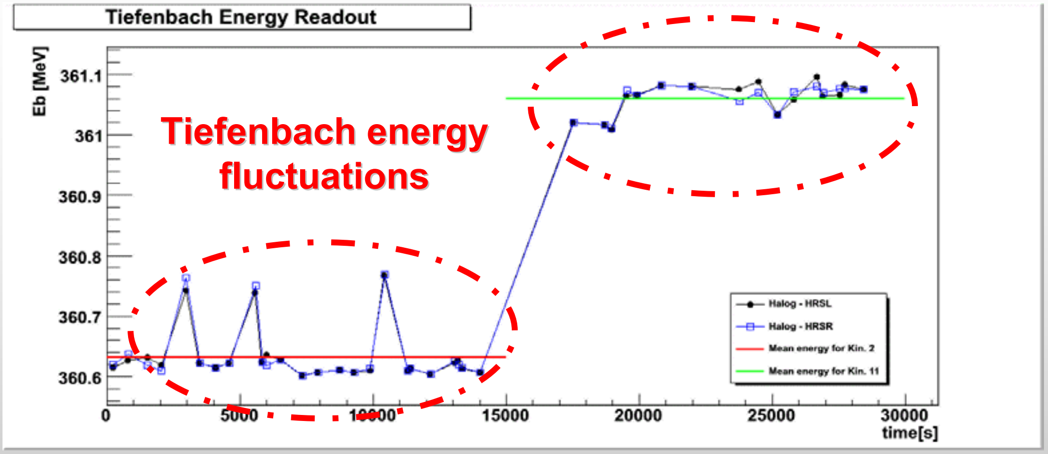
Ratio $\frac{E_c^i}{E_c^1}$	Scat.Angle	Value
HRSL-2	24.0	1.00047
HRSL-3	28.3	0.995165
HRSL-4	28.3	0.994785
HRSL-5	32.5	0.988508
HRSL-6	16.0	1.00063
HRSR-1	28.3	0.991122
HRSR-2	20.0	0.991621
HRSR-3	14.0	0.991821
HRSR-4	16.0	0.991951

<u>New number of free parameters:</u>

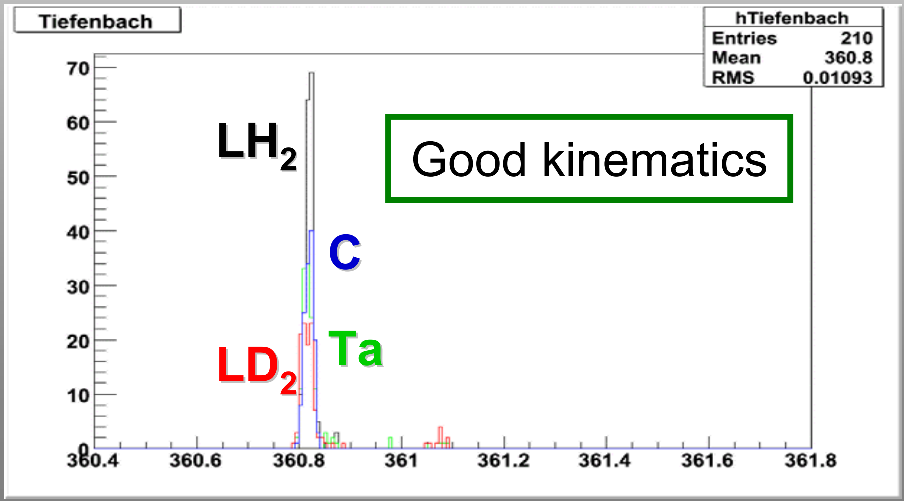
2N – (N-1) = **2N+1** **(This now works!!!)**

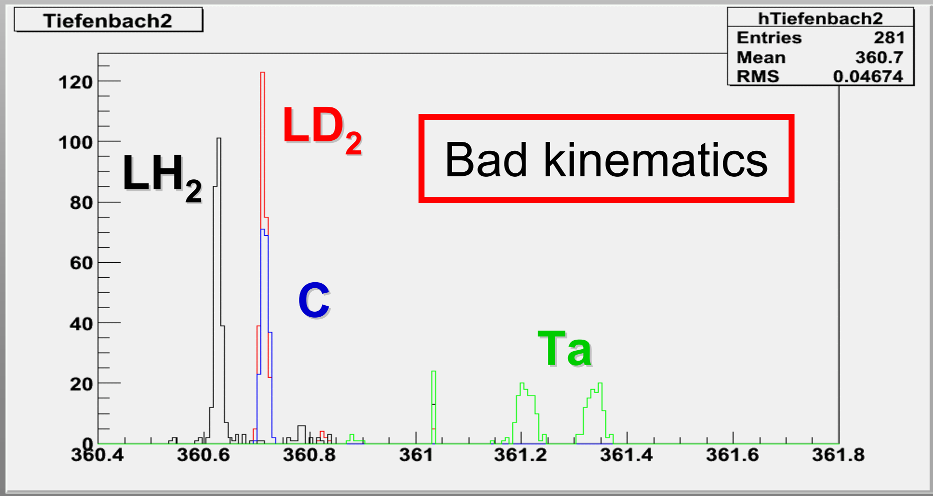
Problems with Tiefenbach

We already know that Beam energy fluctuates between runs:



How does beam energy change during **each run** and inside each **kinematics** ?



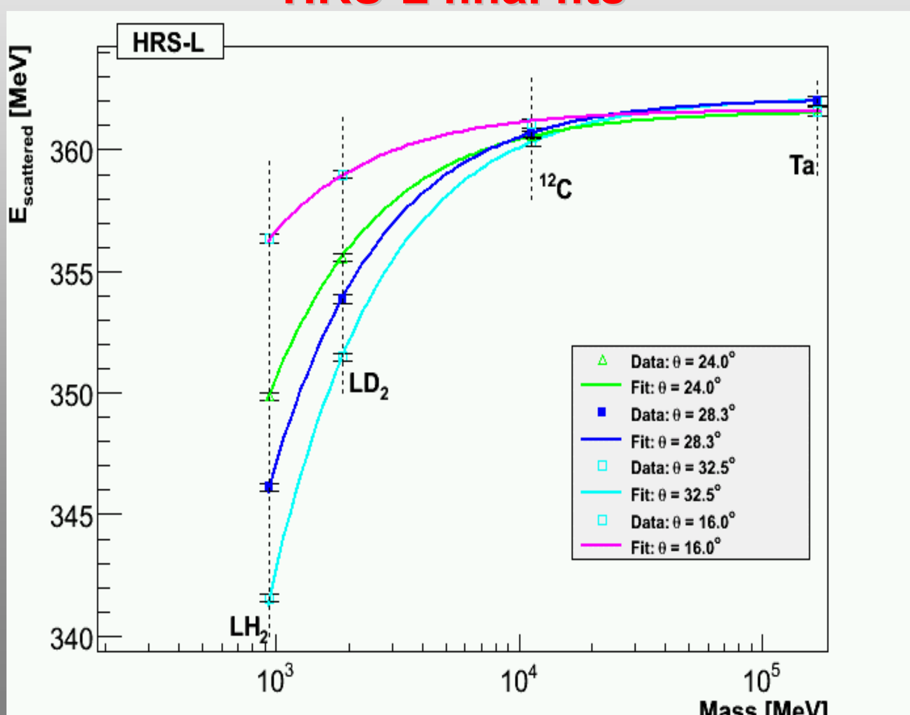


Present Results #1

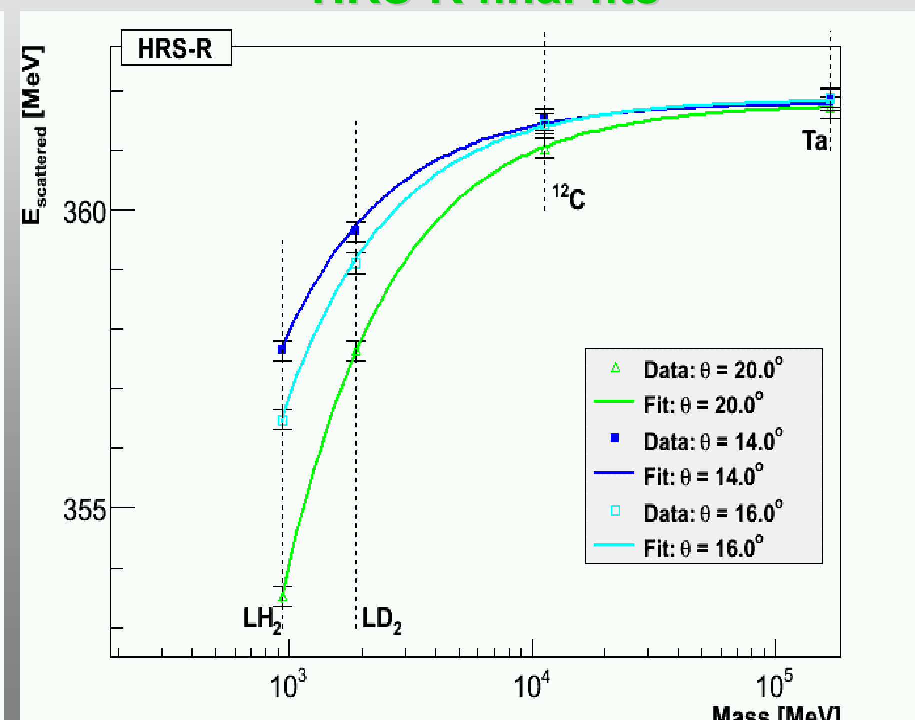
Tiefenbach energy fluctuations **reduce** the number of good kinematics:

- **4** Good kinematics for **HRS-L** (starting with 6)
- **2** Good kinematics for **HRS-R** (starting with 4)

HRS-L final fits

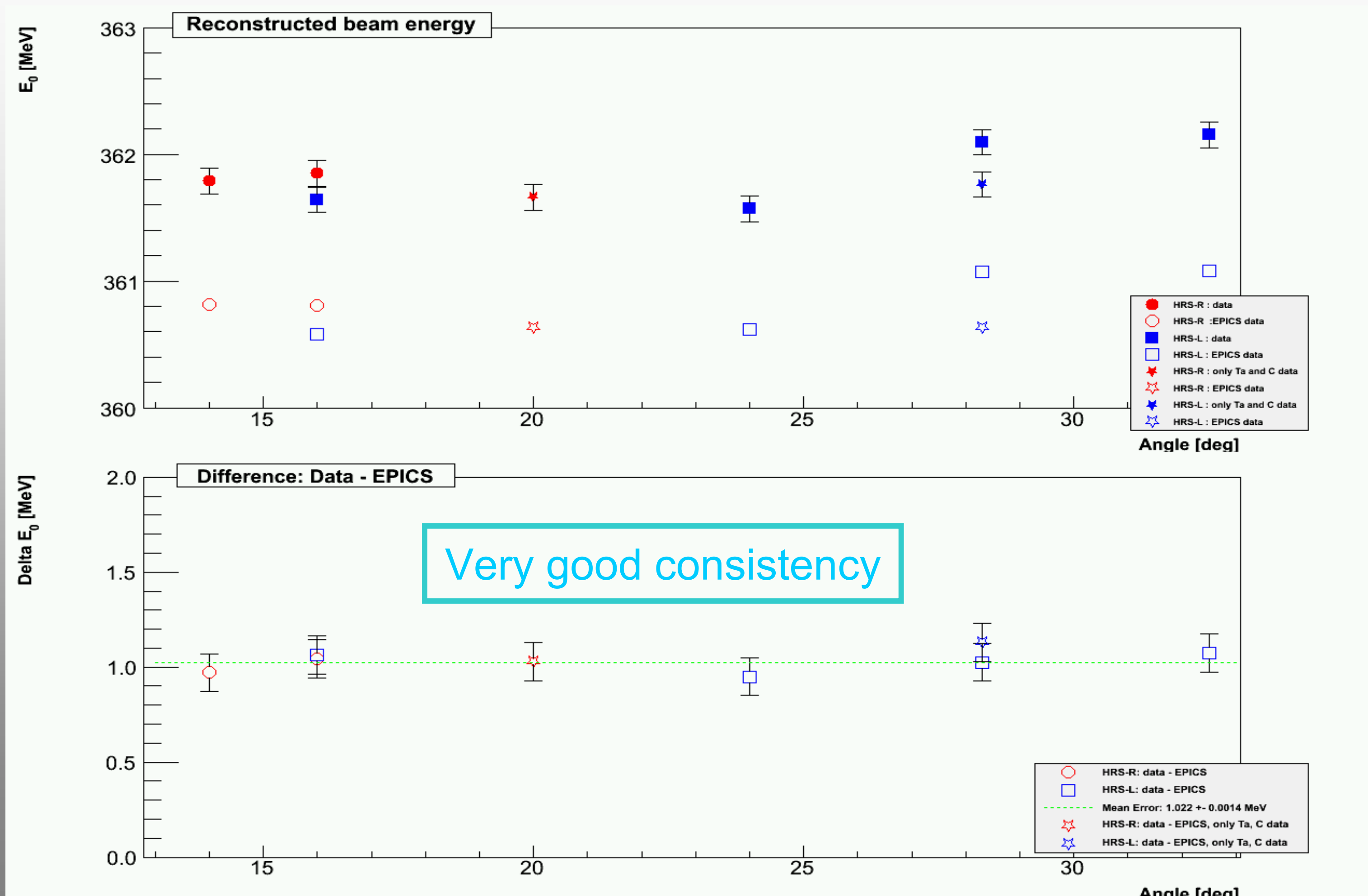


HRS-R final fits



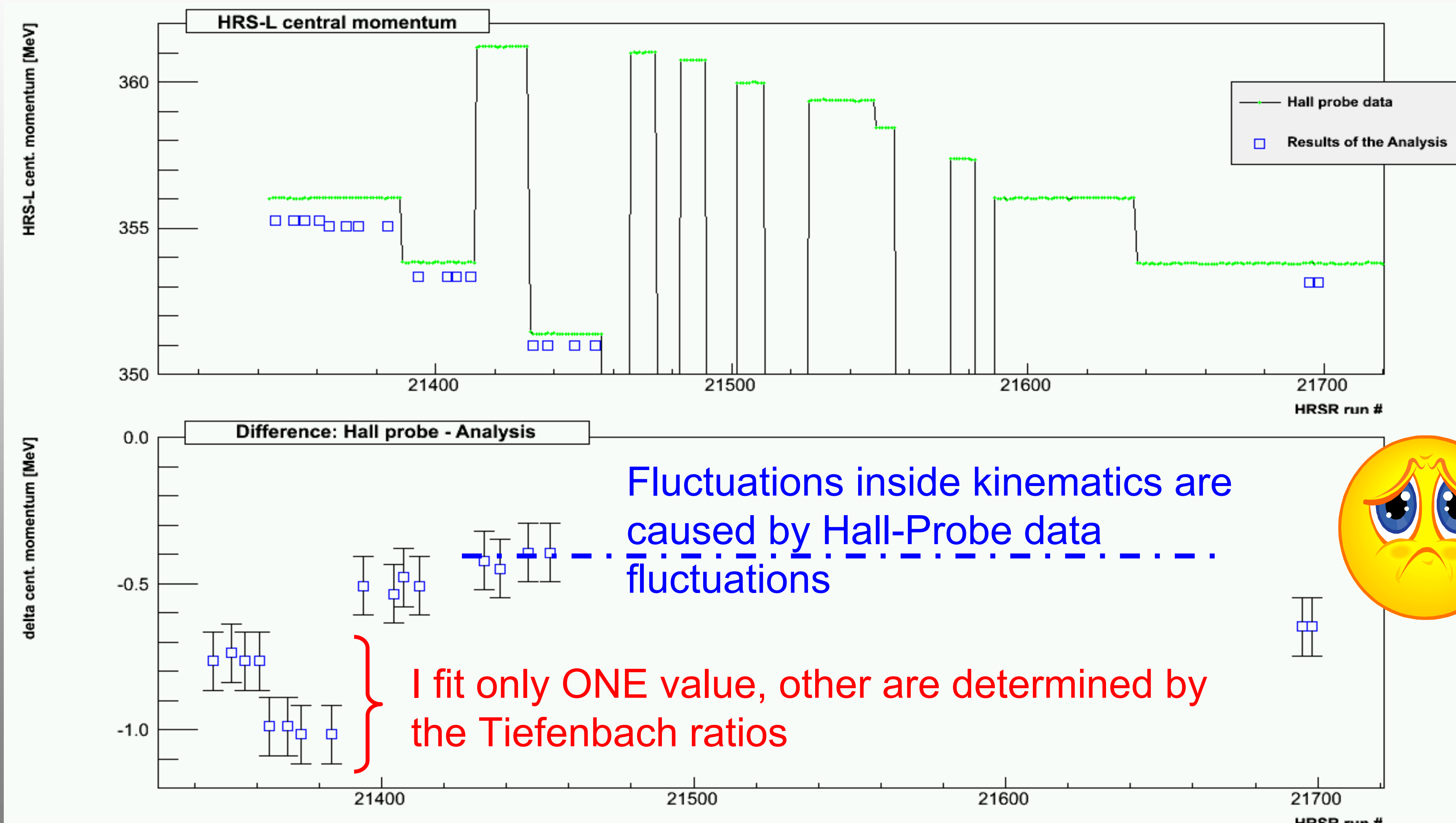
Present Results #2

Comparison of the **fitted beam energies** with **Tiefenbach values** (EPICS):



Present Results #3

Comparison of **fitted central momenta of HRS-L** with **Hall-Probe data** (EPICS):

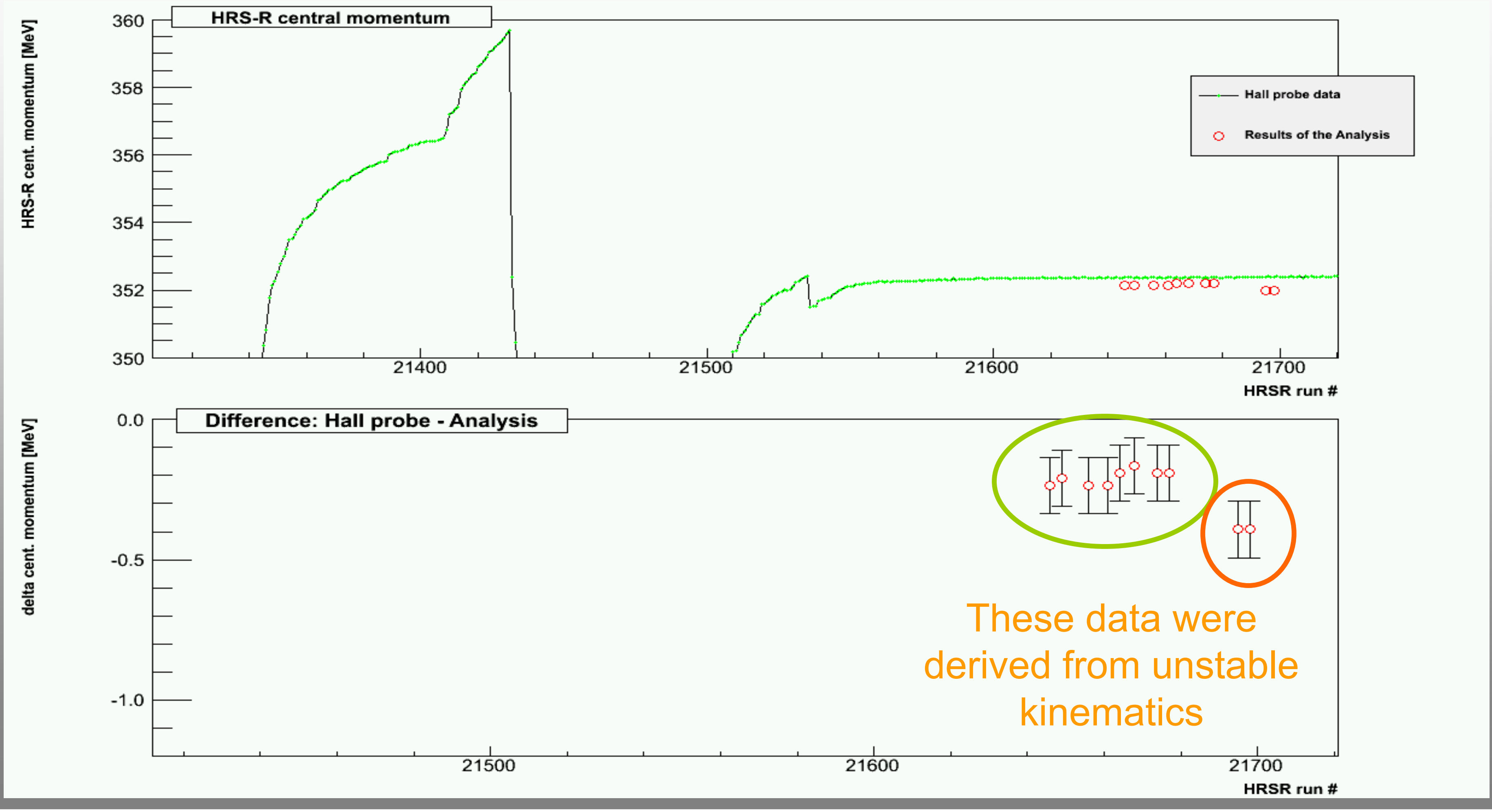


Fluctuations inside kinematics are caused by Hall-Probe data fluctuations

I fit only ONE value, other are determined by the Tiefenbach ratios

Present Results #4

Comparison of **fitted central momenta of HRS-R** with **Hall-Probe data** (EPICS):

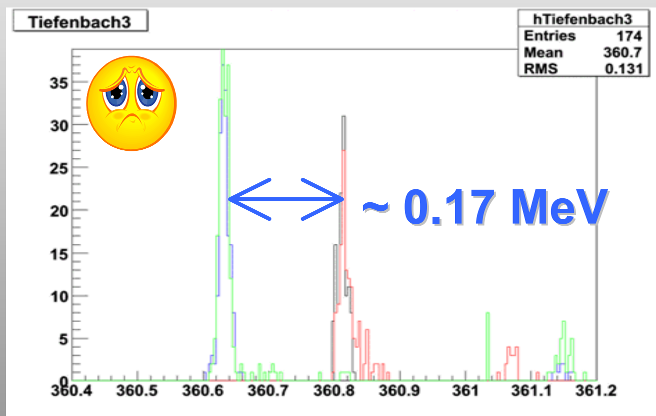


Work in Progress

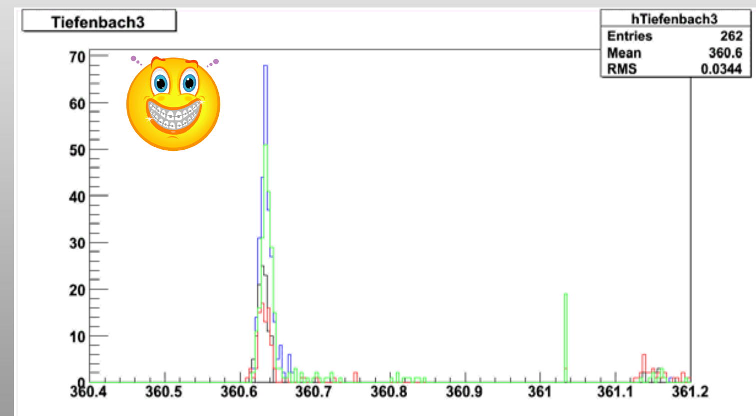
Problems:

- There are inconsistencies with the Hall-probe data
- Bad kinematics: Better results **without** offset corrections of shifted peaks

Are observed shifts in the Tiefenbach energy real?



Same kinematics ran one after another



$\underbrace{\Delta E_{Tief} = 0.17 \text{ MeV}, \quad E_c = 352.1 \text{ MeV}}$

$\boxed{\Delta\delta \sim \Delta E_{Tief} / E_c = 4.83 \times 10^{-4}}$

Directly measured $\Delta\delta$:

Ta:	1.6×10^{-5}
1. C :	2.9×10^{-5}

The End – Thank You