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# Precision spectroscopy of pionic atoms: from pion mass evaluation to tests of chiral perturbation theory

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In collaboration with
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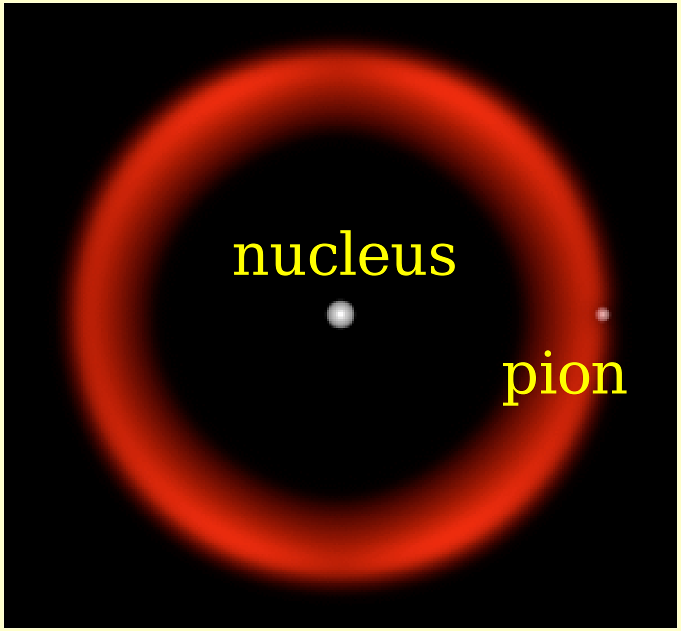
IMEP, Österreichisch Akademie der Wissenschaften, Wien, Austria

# Why pionic atoms




Pionic atoms:

•Nucleus + pion =bound system

Characteristics:

•Pion lifetime = 20 ns

•Pion mass = 273 electron mass

Interests:

•Measurement of pion mass

•Measurement of the pion-nucleus strong interaction effect (->ChPT)

$$E_n = \frac{1}{2n^2}(Z\alpha)^2 mc^2$$

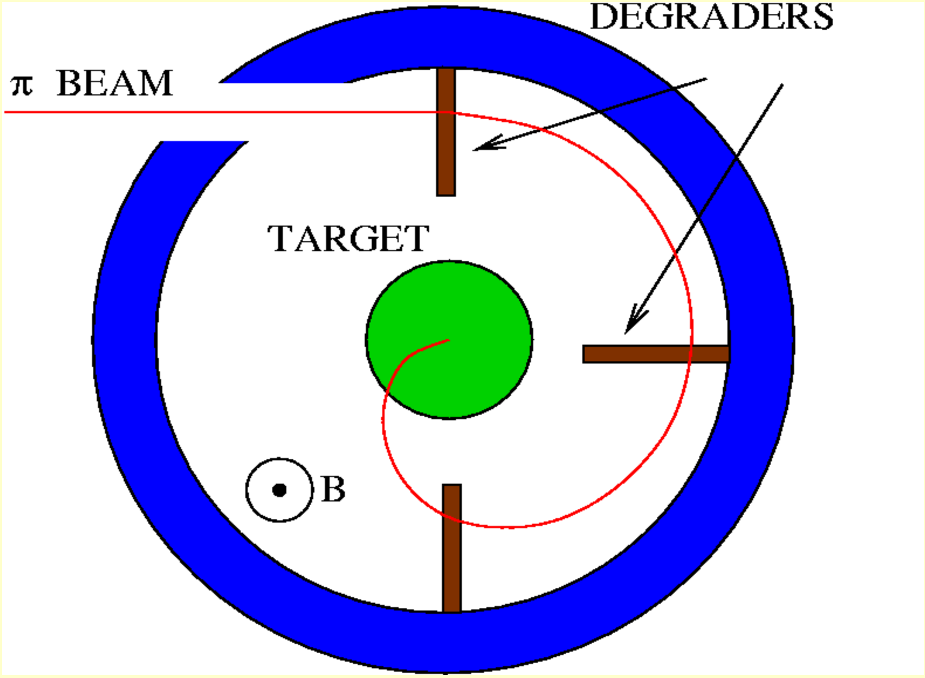
$$r_0 = \frac{\hbar}{Z\alpha mc}$$

Z = nucleus charge, m=reduced mass

# Pionic atoms production (1)

•Pions from PSI facilities

(10[8] pions/sec, $E_{kin}$=110 Mev/c)




•Cyclotronic trap:
max. magnetic field B= 3.5 Tesla

•Target cell:
gas temp=14°K to amb. temp.
Eff. Pressure=~0 to 40 bars

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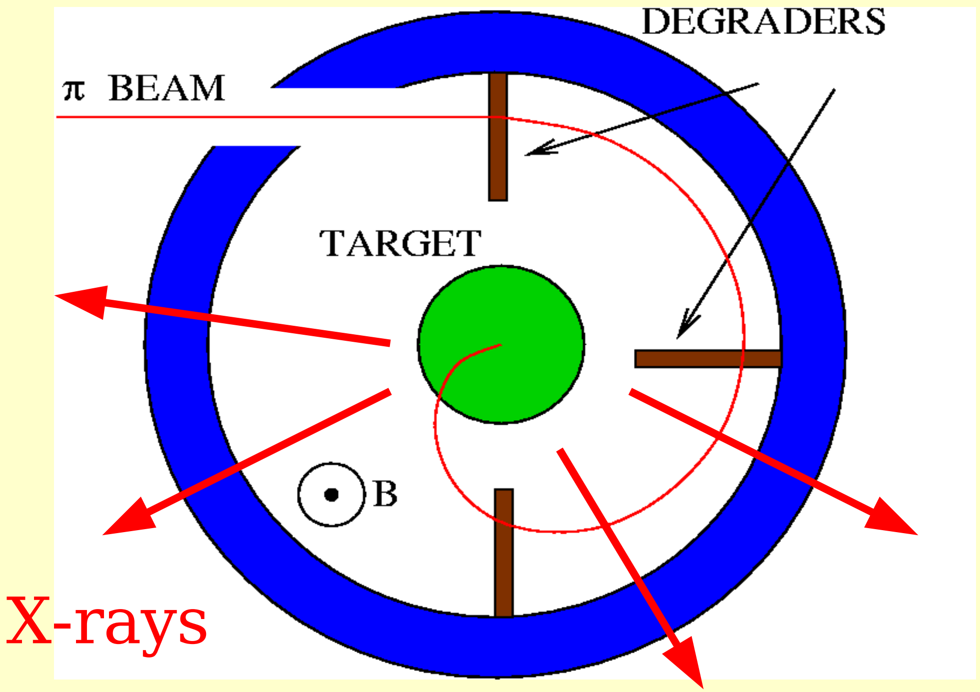
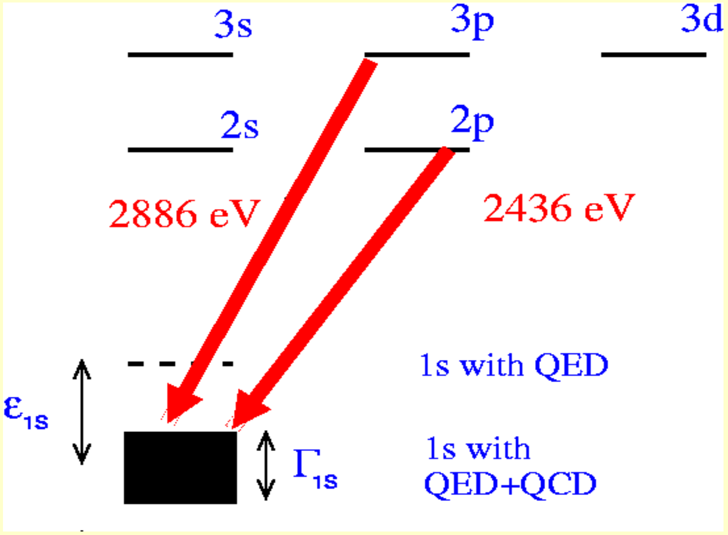
•Target cell:
gas temp=14°K to amb. temp.
Eff. Pressure=~0 to 40 bars

-> pionic atom formation in exited state

-> radiative cascade with X-ray emission



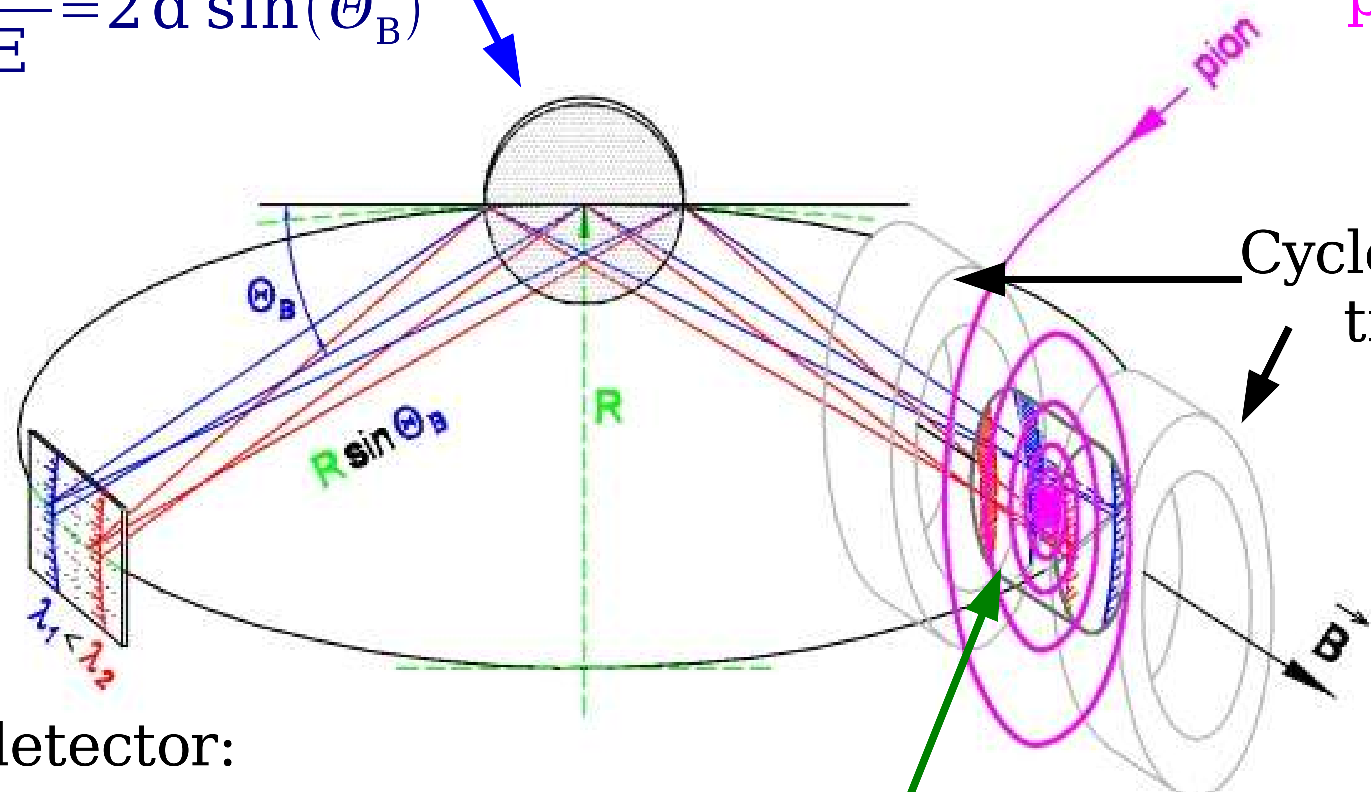

Energy transition in pionic hydrogen

# Pionic atoms production (2)

Spherically bent crystal for the Bragg reflection

$$\frac{hc}{E} = 2\,d\,\sin(\Theta_B)$$

pions beam



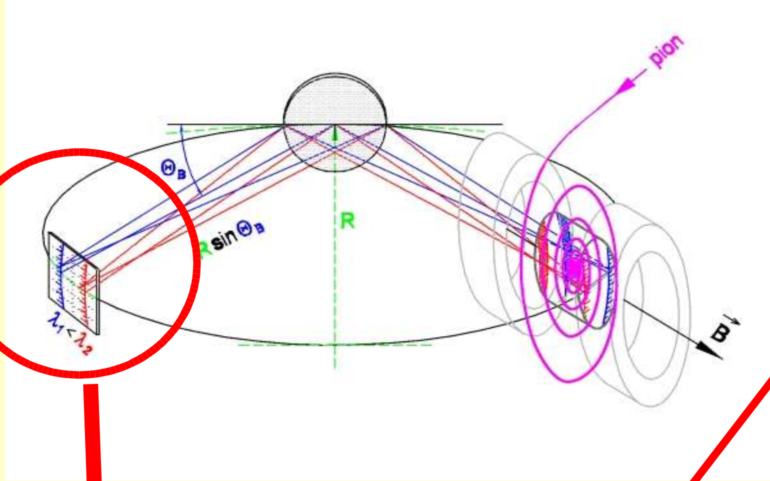

Cyclotronic trap

Position detector:
6 x CCD array
(610x604 pxl each)
Energy Res.=150 eV
@3 keV

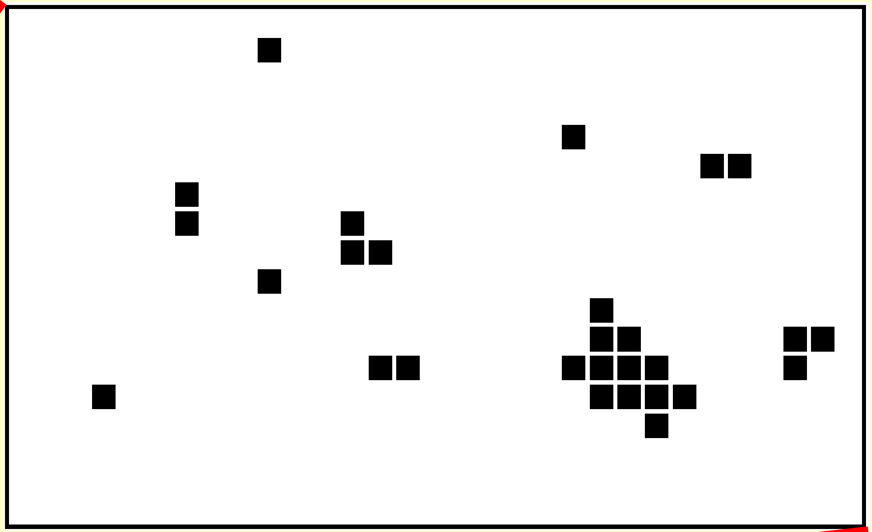
Target cell

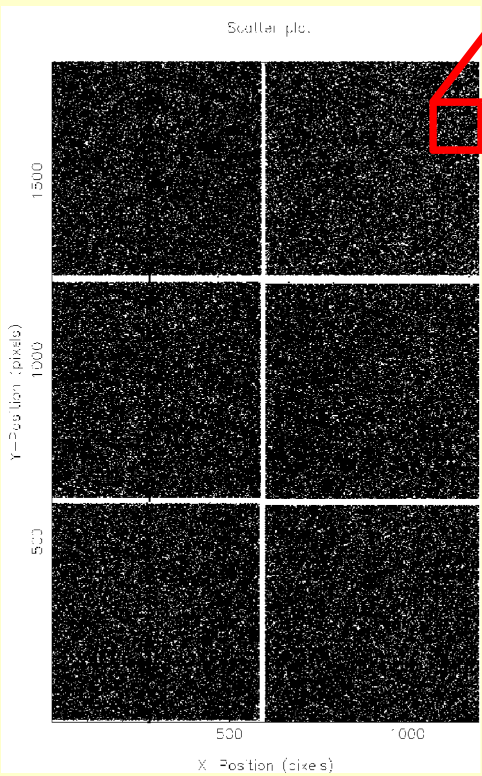
**D.Gotta et al.Nucl. Phys. A 660, 283 (1999)**

# Detection (1)



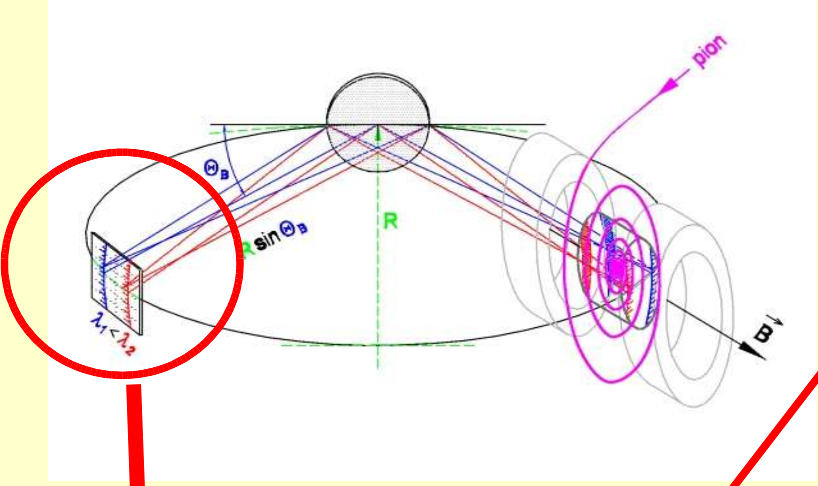
pion
$\Theta_B$
$R\sin\Theta_B$
R
B
$\lambda_1 < \lambda_2$

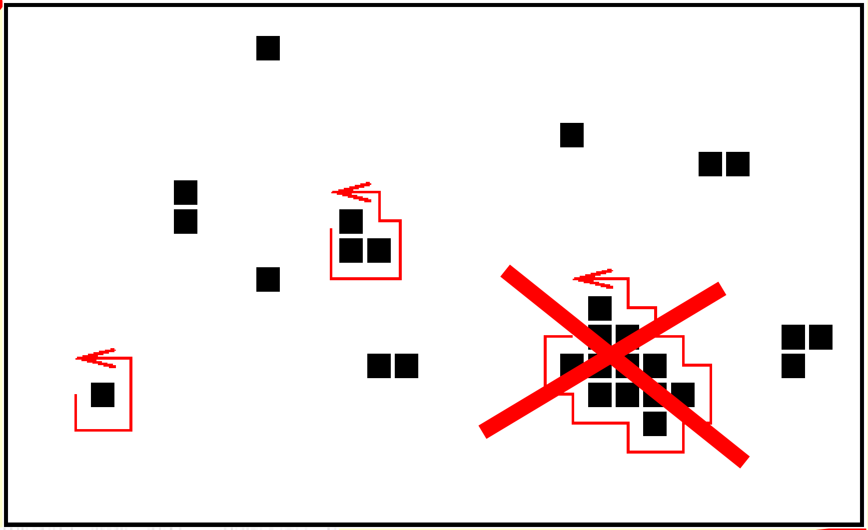



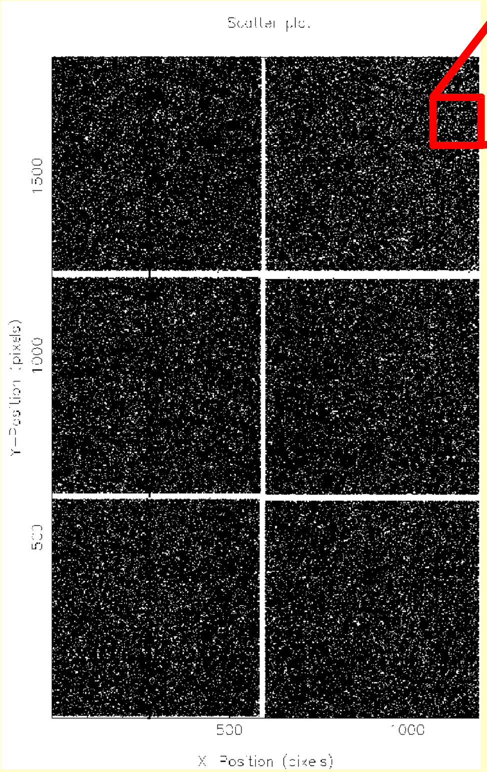


Scatter plot
1500
1000
500
Y-Position (pixels)
500
1000
X-Position (pixels)

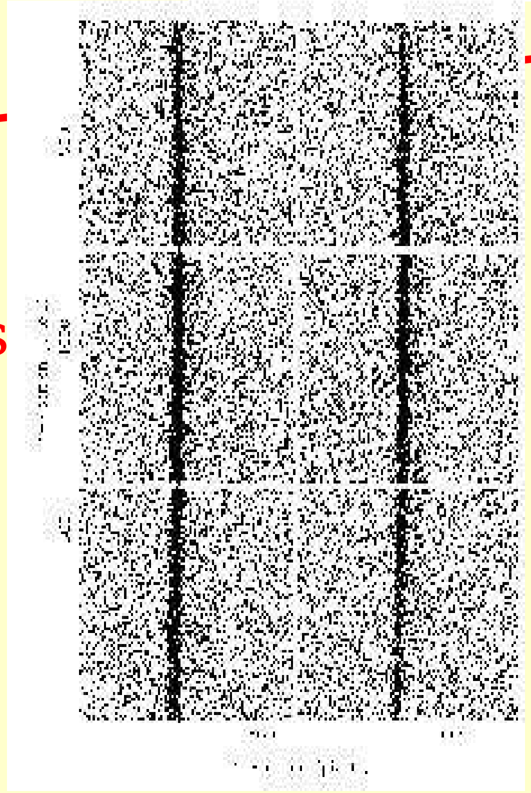
# Detection (1)






cluster analysis on



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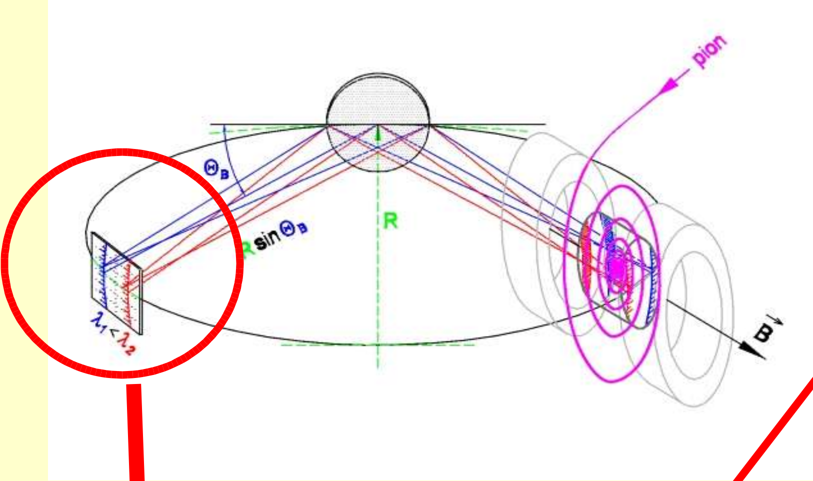
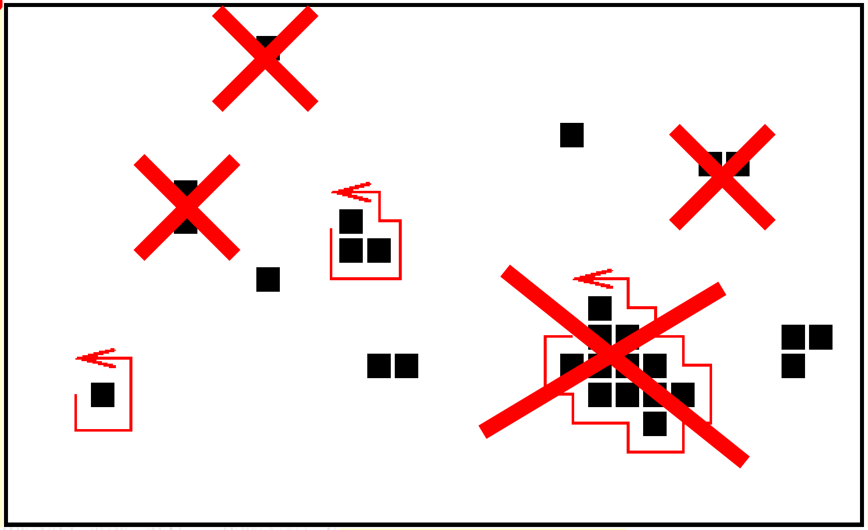
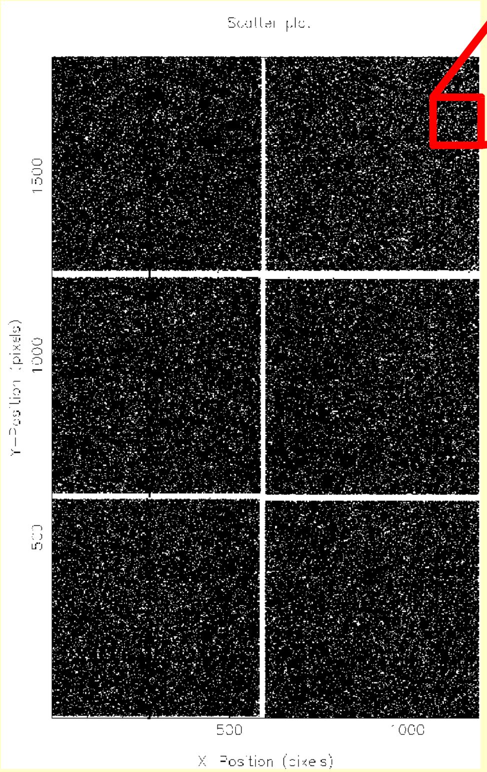
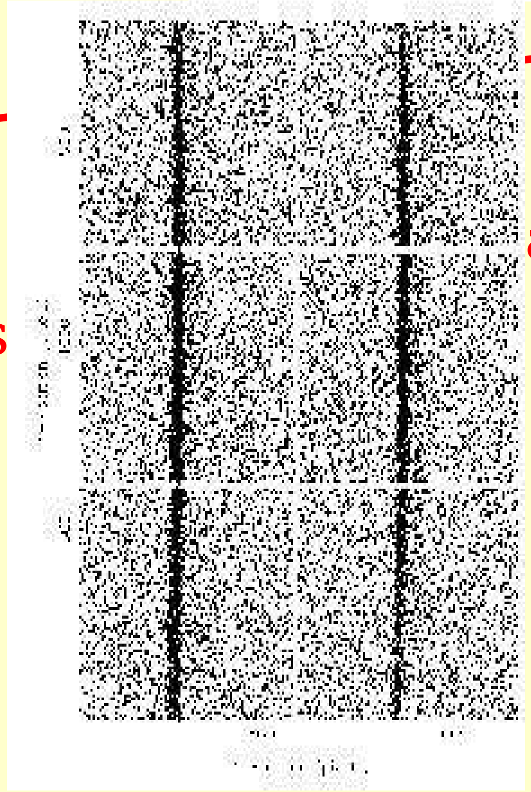


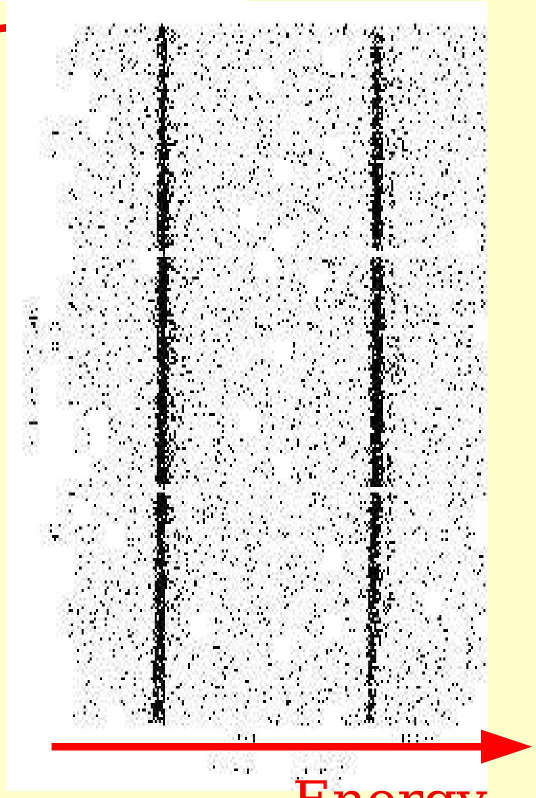






cluster analysis on

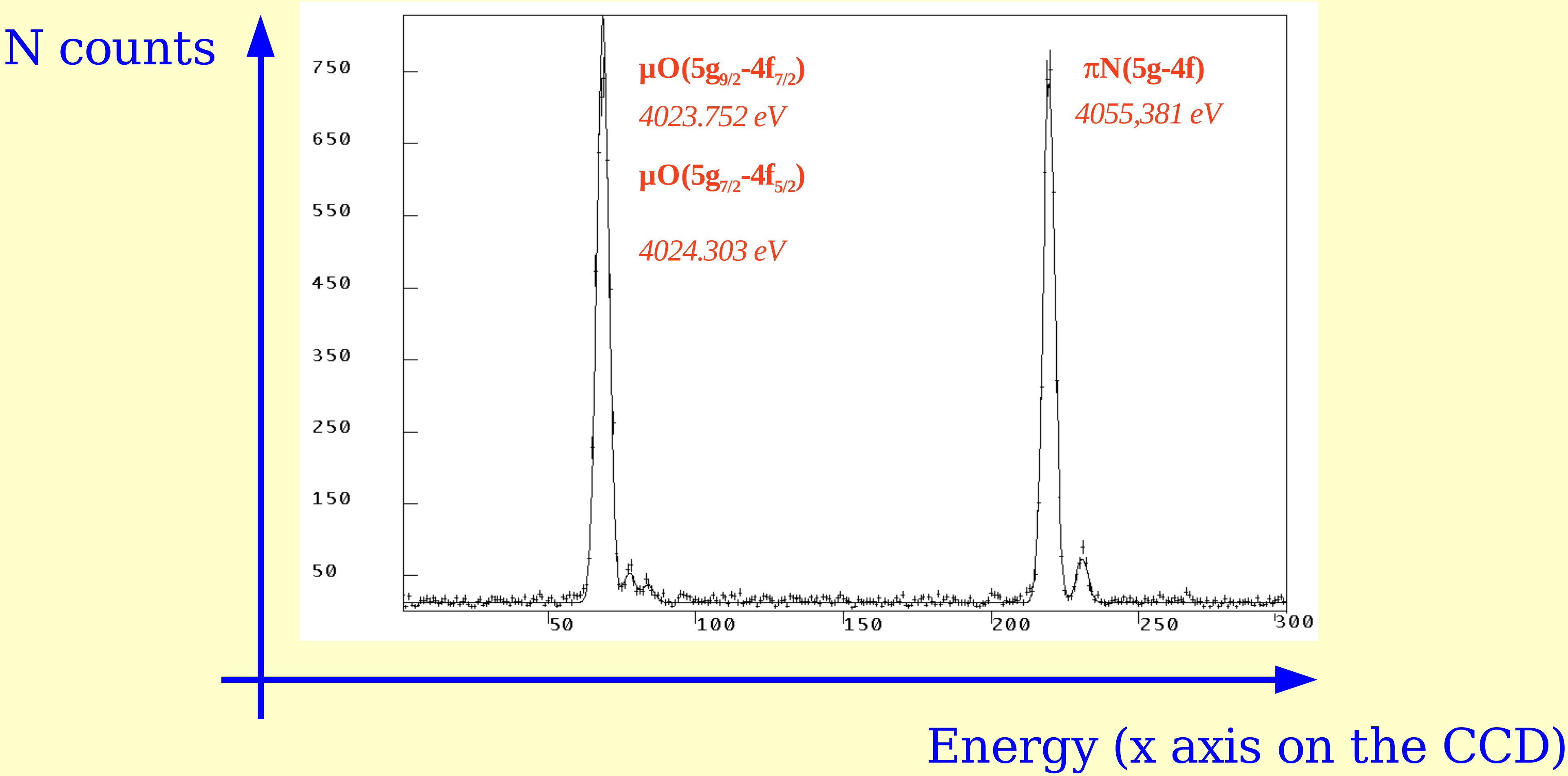


cluster analysis and energy cuts on



Energy

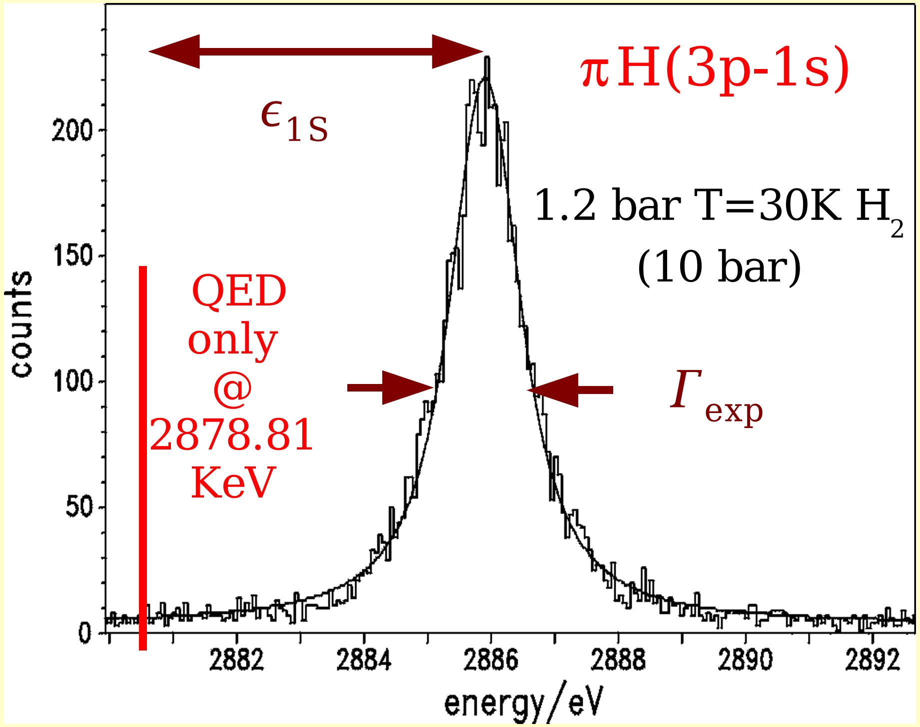
# Detection (2)




- Spectrometer resolution = 0.4 eV
- Peak determination accuracy < 0.05 eV

(depending on intensity and spectrometer configuration)

# Pionic hydrogen measurements




## Deser's formulas

Line width <-> hadronic cross sections a

$$\frac{\Gamma_{1S}}{E_{1S}} = 8\frac{Q_0}{r_B}\left(1+\frac{1}{P}\right)\left(a_{\pi^- p \rightarrow \pi^0 n}\left(1-\delta_\Gamma\right)\right)^2$$

Line shift <-> hadronic cross sections a

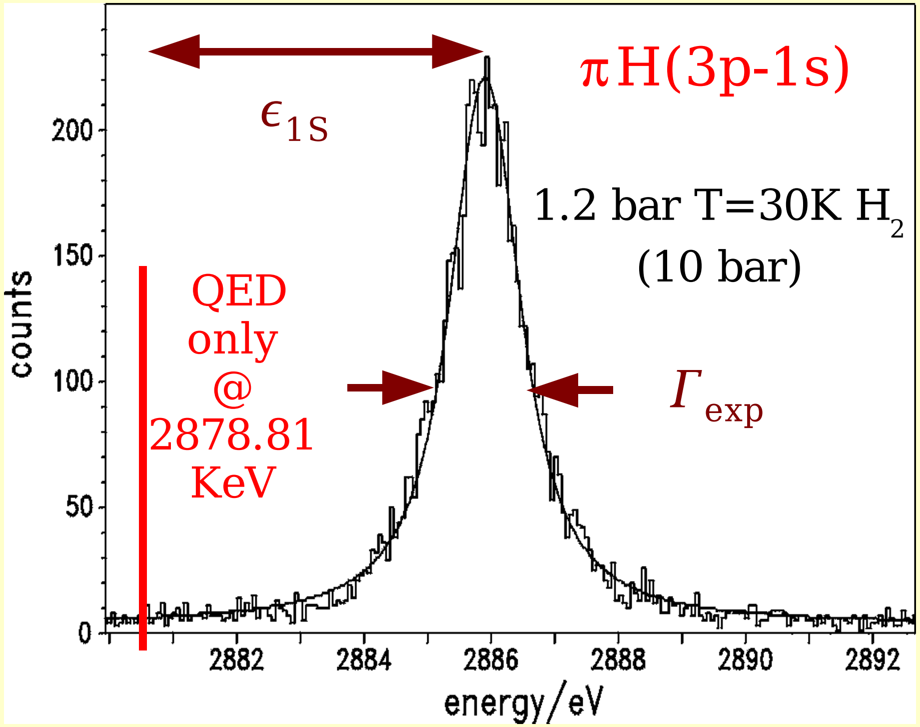
$$\frac{\epsilon_{1S}}{E_{1S}} = \frac{-4}{r_B} a_{\pi^- p \rightarrow \pi^- p}\left(1-\delta_\epsilon\right)$$

$$\Gamma_{exp} = \Gamma_{SPECTROMETER} \otimes \Gamma_{DOPPLER} \otimes \Gamma_{1S}$$

$\delta_\varepsilon$, $\delta_\Gamma$=em.corretions[1,2] P=Panofsky ratio,

$r_B$ Bohr radius, $Q_0$=kinematic factor

# Pionic hydrogen measurements

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$\delta_\varepsilon$, $\delta_\Gamma$=em.corretions[1,2] P=Panofsky ratio,

$r_B$ Bohr radius, $Q_0$=kinematic factor

## Results:

$\varepsilon_{1S}$= +7.120 ± 0.017 eV, $\Gamma_{1S}$= 800 ± 30 meV (3-4%)[3]

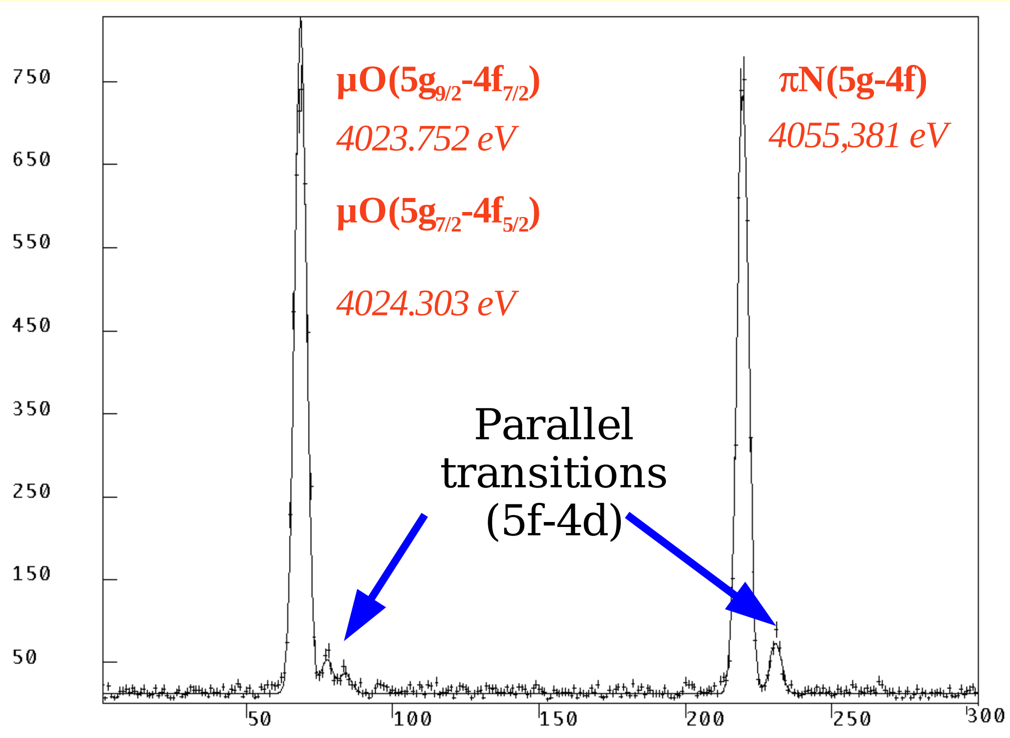

**[1] T.E.O.Ericson, B.Loiseau and S.Wycech, arXiv:hep-ph/0310134.**
**[2] J. Gasser et al., Eur. Phys. J. C 26, 13 (2003)**
**[3] D.Gotta and al. Nucl.Phys.A721, 849 (2003)**

# Pion mass measurement

Relative measurement between pionic Nitrogen and muonic Oxygen transitions

Muon mass error=0.05 ppm

-> pion mass measurement with error < 2  ppm




$$\frac{m_\pi}{m_\mu} = F\left(\alpha, m_O, m_N\right) + O\left(\frac{m_\pi}{m_O}\right)^3 + O\left(\frac{m_\mu}{m_N}\right)^3$$

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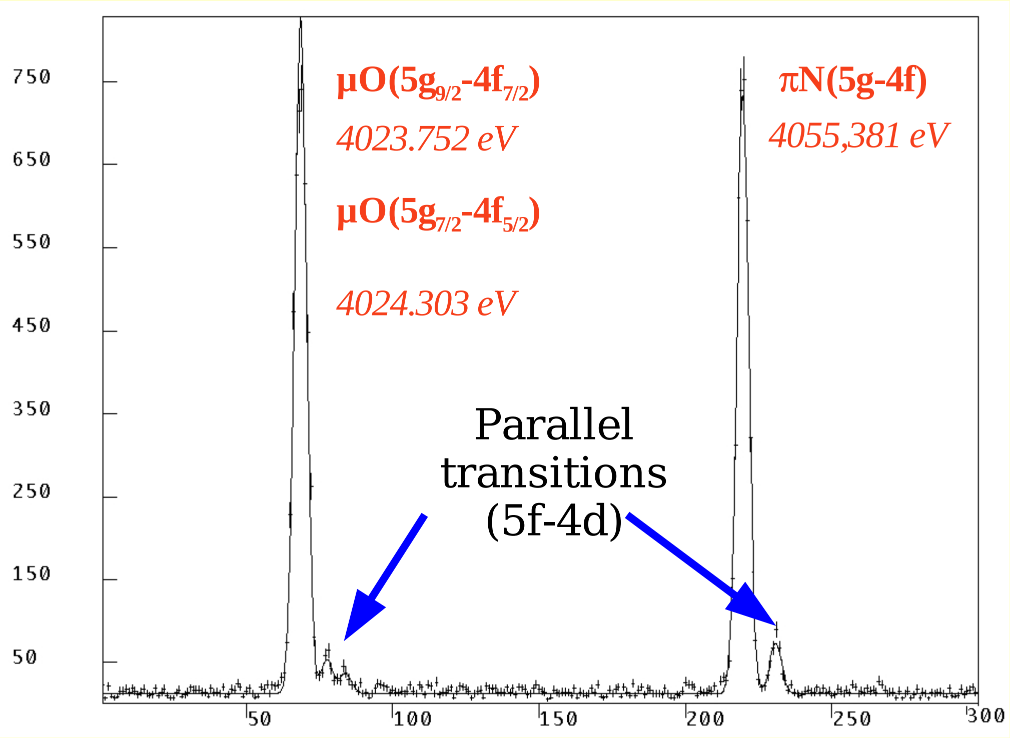
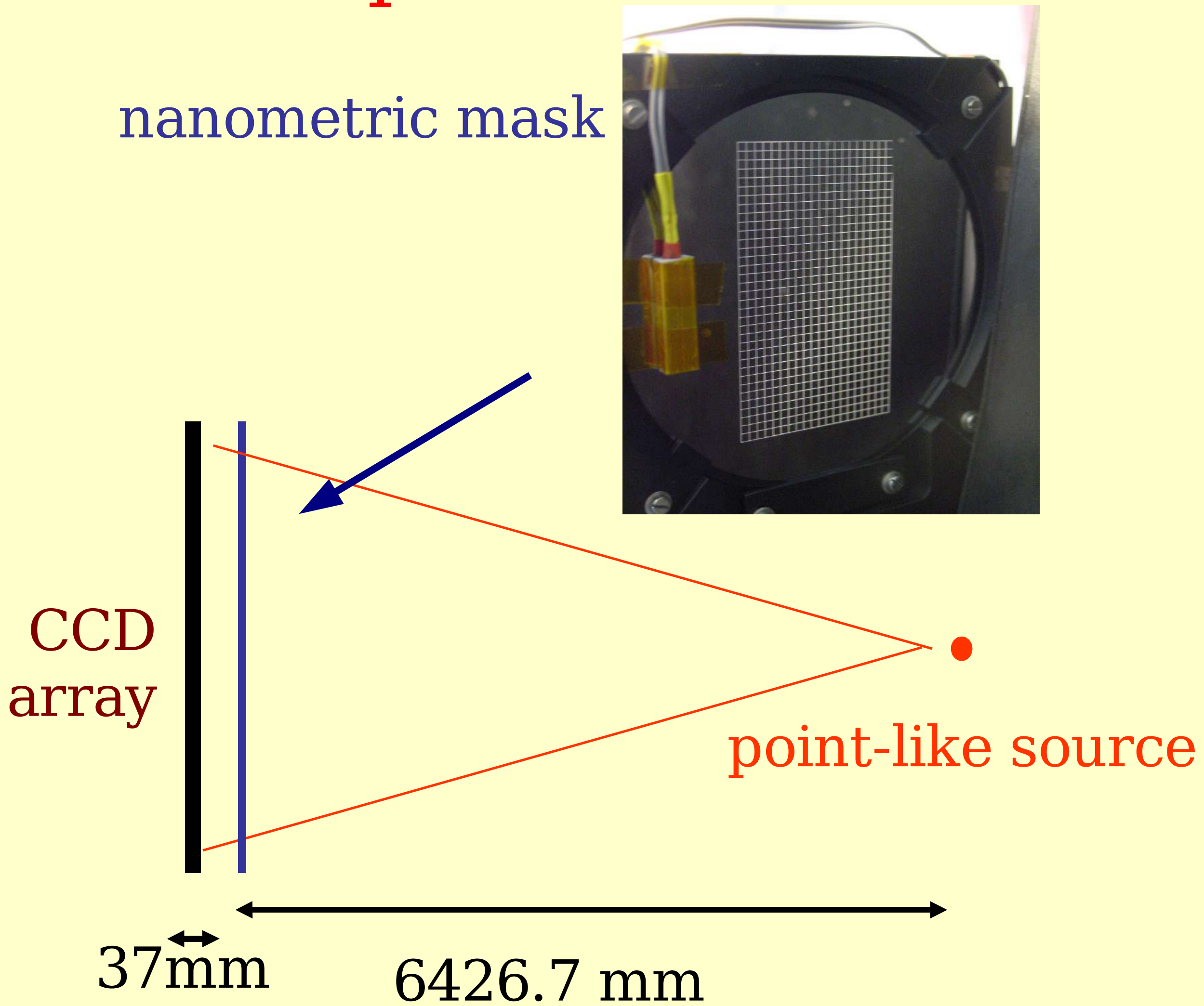



$$\frac{m_\pi}{m_\mu} = F\left(\alpha, m_O, m_N\right) + O\left(\frac{m_\pi}{m_O}\right)^3 + O\left(\frac{m_\mu}{m_N}\right)^3$$

•Result? to get the final mass, we need the exact pixel size and crystal curvature radius

N.Lenz et al. Nucl.Phys.A 626, 375c (1997)

# Pixel measurement setup



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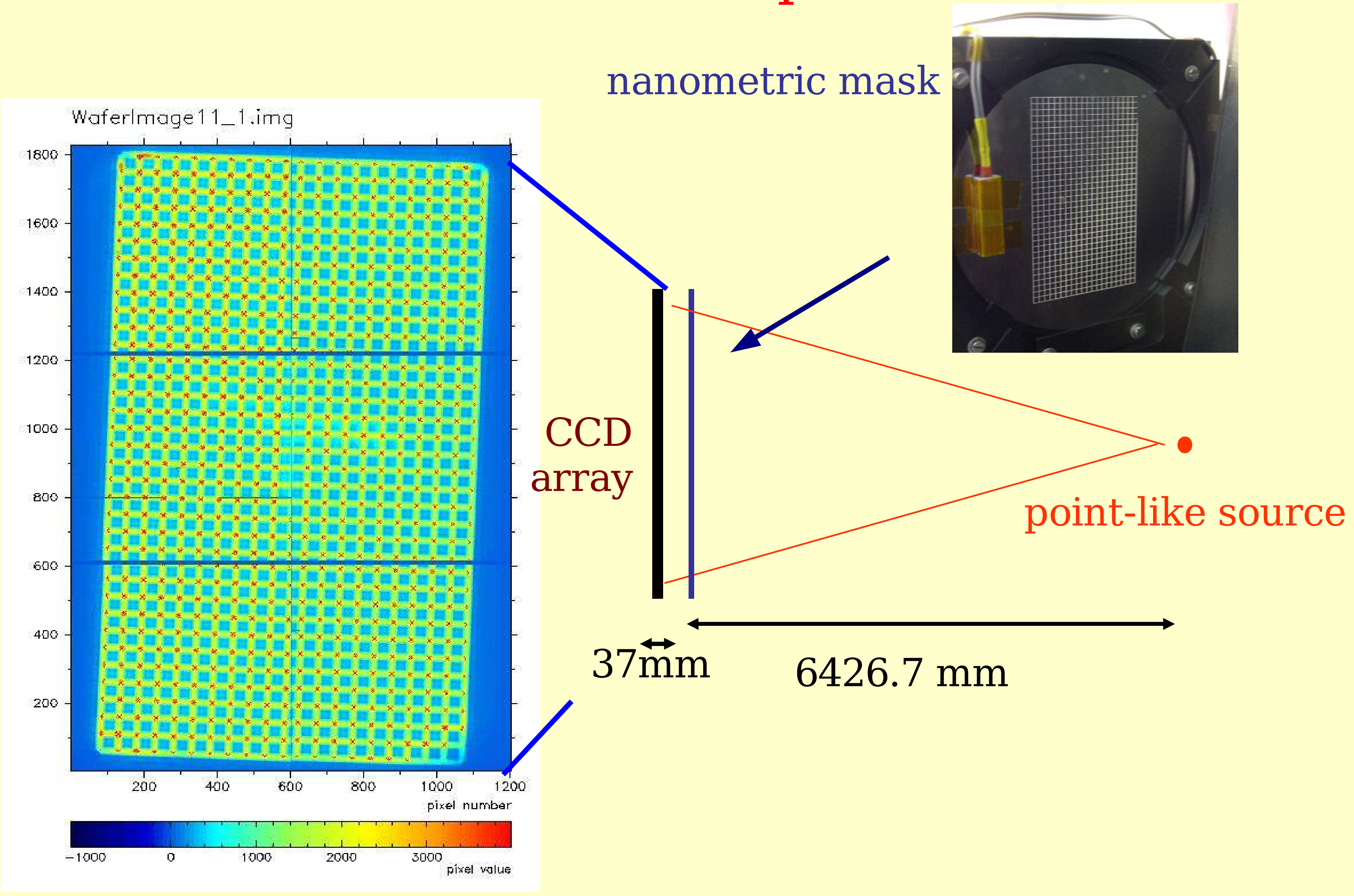

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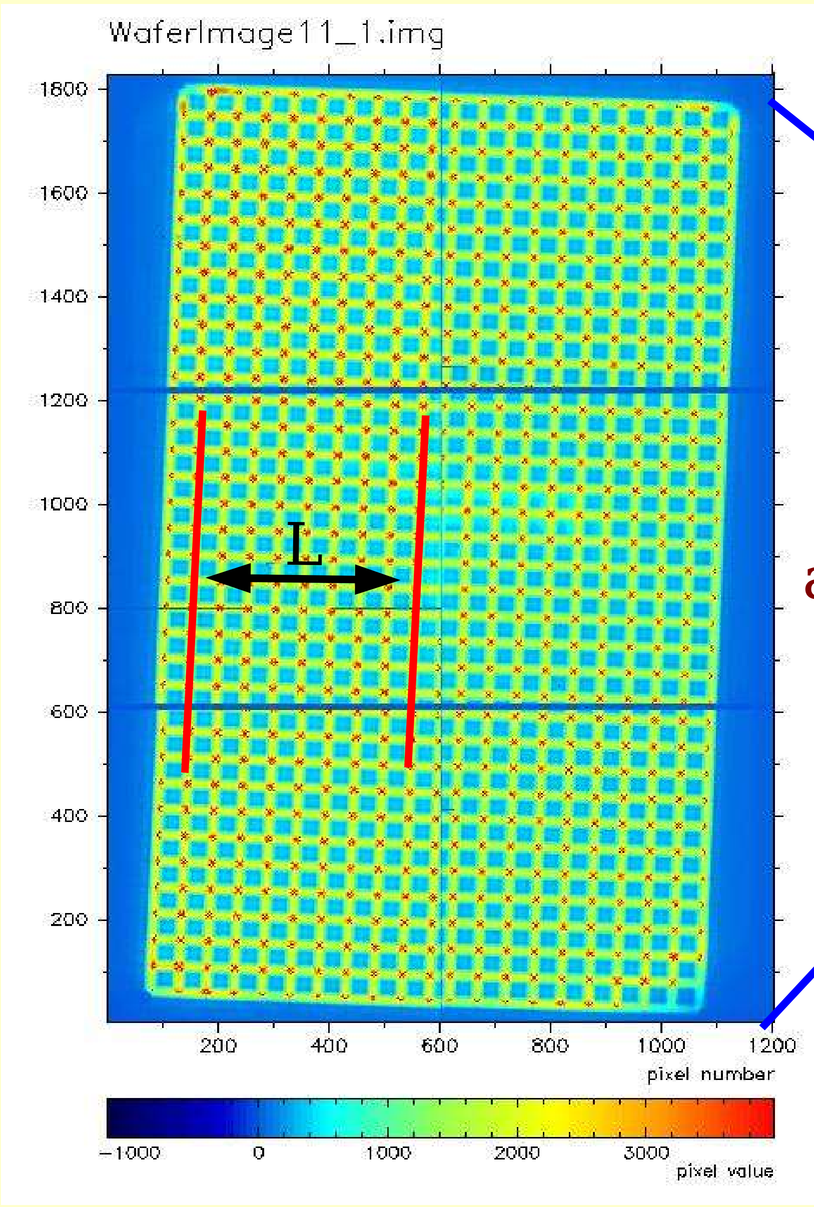


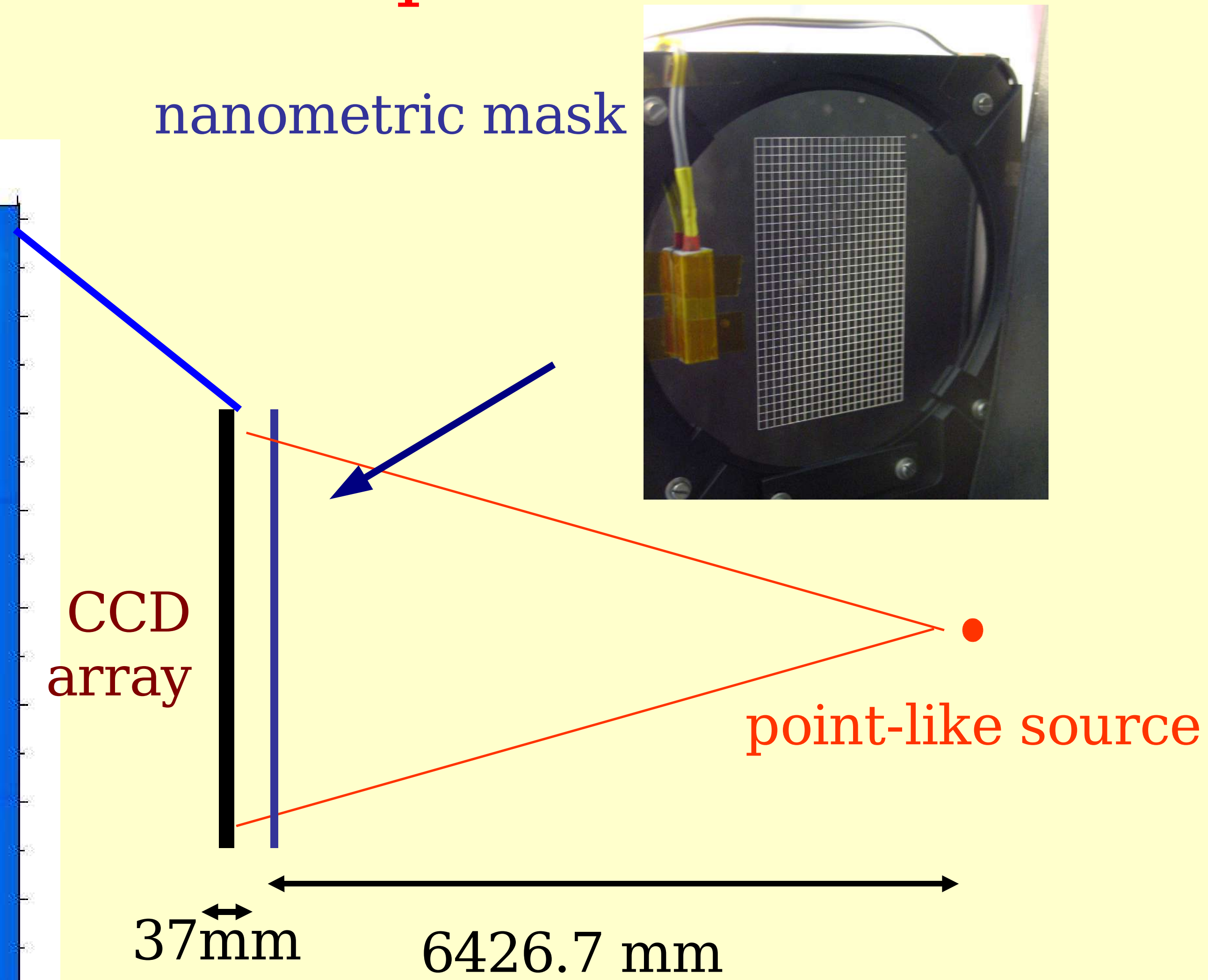


lines fitting (L) ->Pixel size measurement

39.9943 ± 0.0035 µm

# Conclusions and outlooks

## Results:

- $\varepsilon_{1S}$ on $\pi H$: meas. done: $\Delta\varepsilon_{1S}/\varepsilon_{1S}=0.2\%$ (prev. exp.= 0.5%[1])
- $\Gamma_{1S}$ on $\pi H$: meas. done: $\Delta\Gamma_{1S}/\Gamma_{1S}=4\%$ (prev. exp.= 7%[1])
- Ending of pion mass measurement: expected precision < 2 ppm
  (end 2004-beginning 2005, PDG2002= 2.5 ppm[2])

## Next steps:

- $\mu H$ measurement for radiative cascade study ($\Delta\Gamma_{1S}/\Gamma_{1S}$->1%)
- $\pi H$ high-statistic run
- $\varepsilon_{1S}$ and $\Gamma_{1S}$ on $\pi D$, $\pi T$ and $\pi^3He$

**[1] H.C.Schroder et al., Phys. Lett.B 469, 25 (1999)**
**[2] Particle Data Group, Phys. Rev. D 66, 010001 (2002)**