# Experimental search for the nuclear analog of the Prandtl-Glauert singularity effect at SIS100

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A good reason to look back to a possibility of shock wave generation in 2-30 GeV p+Nucleus reactions

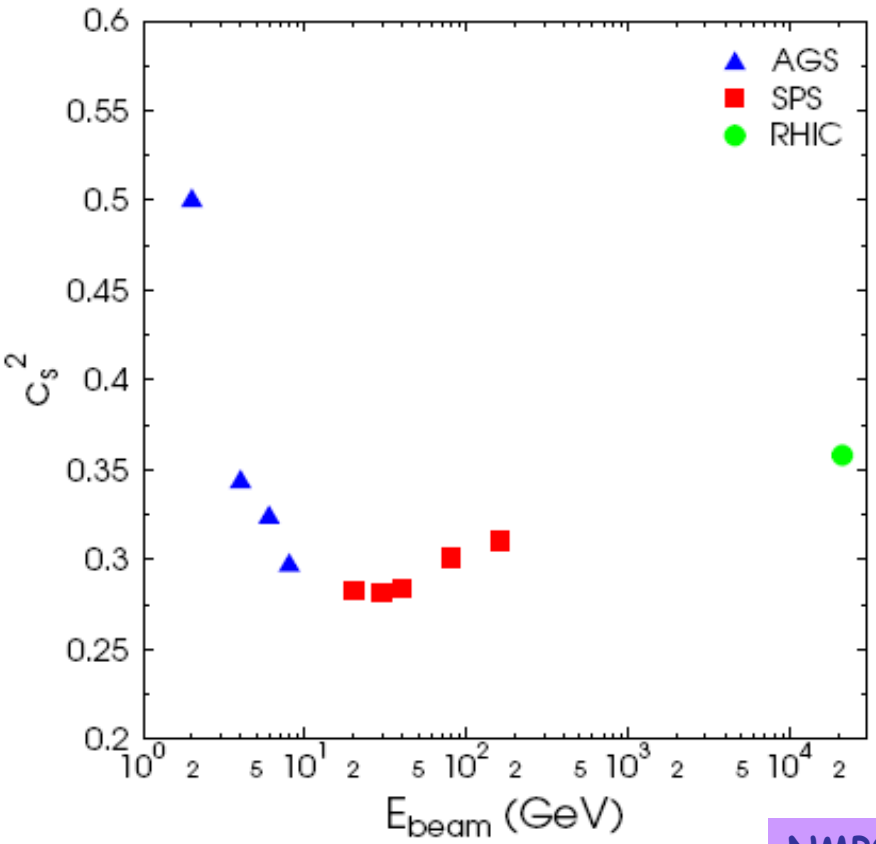
To prove sound vaves in nuclear matter exist

To clarify the nature of collective flow
Collectivity via multiple collisions or interaction with the mean field?

# Fireball and Spectator Nucleus sound different

[H. Petersen and M. Bleicher, PoS CPOD2006:025,2006]

- **extract the sound velocity $c_s^2$ from the width of the $\pi$ rapidity spectra**
- Landau's hydrodynamical model vs classical estimation : $c_s^2 = \frac{1}{3} = 0{,}577$




$$\frac{dN}{dy} \propto \frac{s_{NN}^{1/4}}{\sqrt{2\pi\sigma_y^2}} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)$$

with

$$\sigma_y^2 = \frac{8}{3}\frac{c_s^2}{1-c_s^4} \ln\left(\frac{\sqrt{s_{NN}}}{2m_p}\right)$$

→ softest point of EOS (minimum of sound velocity) at 30*A* GeV with minimum **Cs=0.52 ?!!!!**

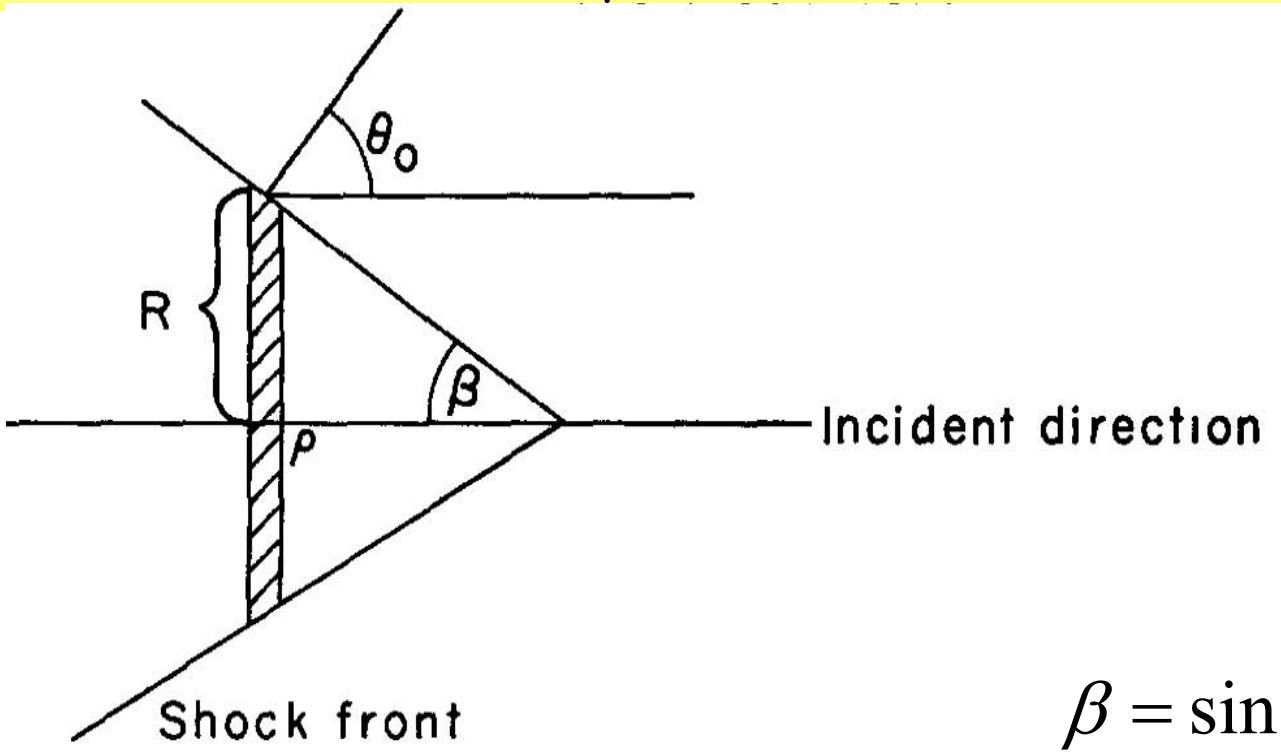
**Glassgold et al :**

$$c_s = \frac{1}{9}\frac{K}{m_n}$$

K=187 – 302 MeV→ **Cs=0.14 – 0.19 ?!!!!**

# Shock wave generation in high energy pA-collisions:

A.E.Glassgold, Warren Heckrotte, and Kenneth M.Watson.
Collective Excitations of Nuclear Matter.
Annals of Physics, 6, 1- 36 (1959)




$$\beta = \sin^{-1}(\frac{c_s}{V});$$

$$\theta_0 = \frac{\pi}{2} - \beta$$

# Shock wave generation in high energy pA-collisions:

A.E.Glassgold, Warren Heckrotte, and Kenneth M.Watson.
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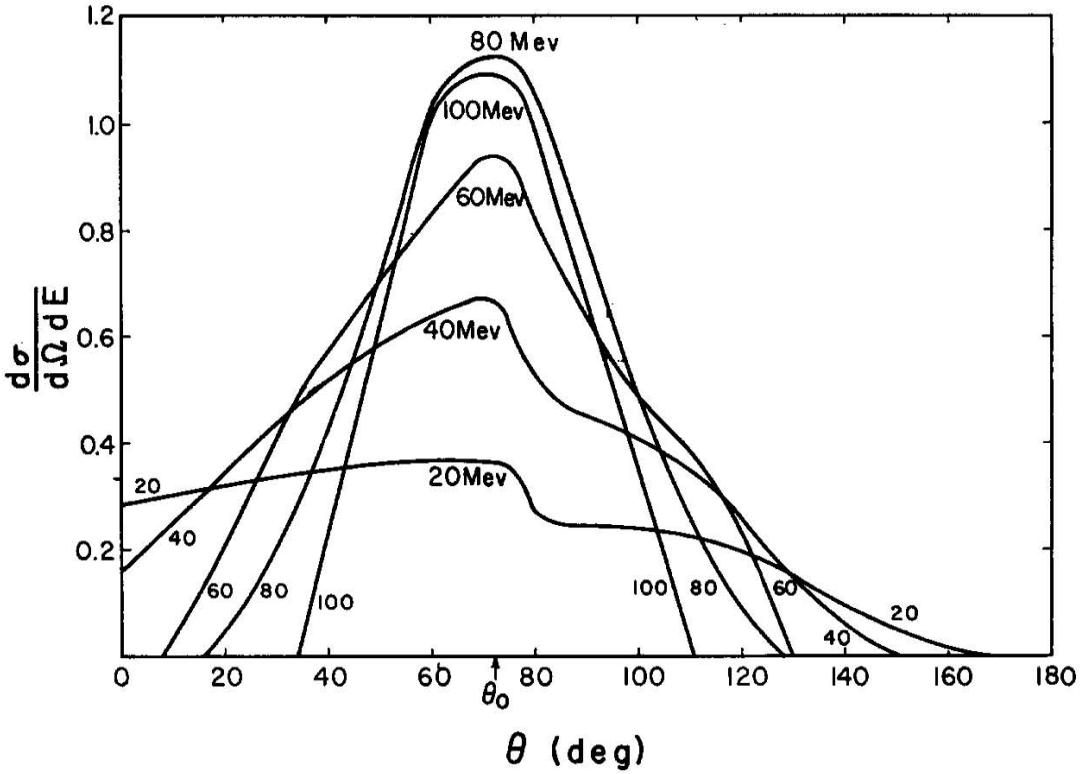



FIG. 2. The angular and energy distributions of nucleons emitted though the excitation of shock waves in nuclei by a very-high-energy incident particle. For the values of the parameters given in the text, the maximum energy for the emitted particles is about 115 Mev. The units of the ordinate are relative.

# Negative results on experimental search for shock wave in high energy pA-collisions: comments on Why?

A 100 MeV proton is inappropriate observable deep in the background of re-scattered cascade and pre-equilibrium emitted protons

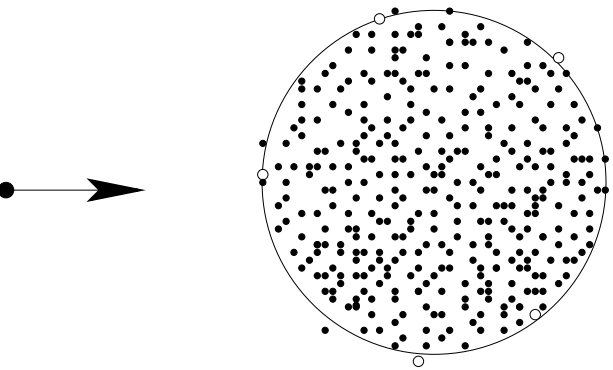
- Experiment focus was on the intermediate side-peaking mass fragments which are in fact not to appear as result of compression of nuclear matter

- Importance of strict centrality tagging for small system was ignored

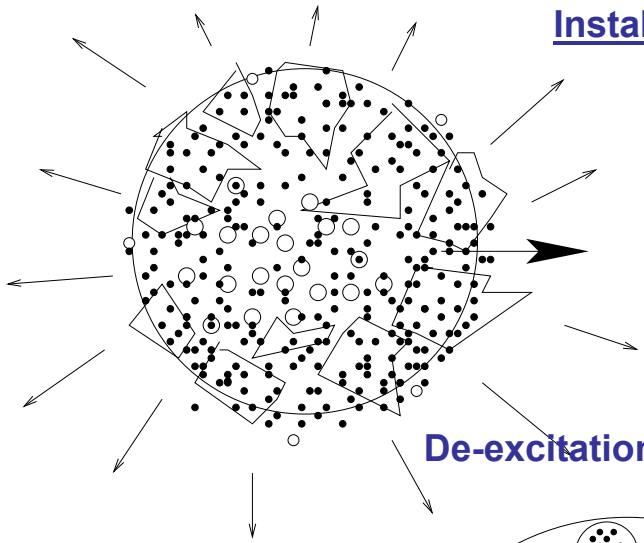
# Solution: Focus on Rarefaction Wave!

**In real life a shock wave is accompanied by a *rarefaction* wave leading to effect known in aerodynamics as Prandtl-Glauert singularity. Primordial alphas might be a sensitive probe of the *nuclear Prandtl-Glauert Singularity effect and thus point to the shock wave.***

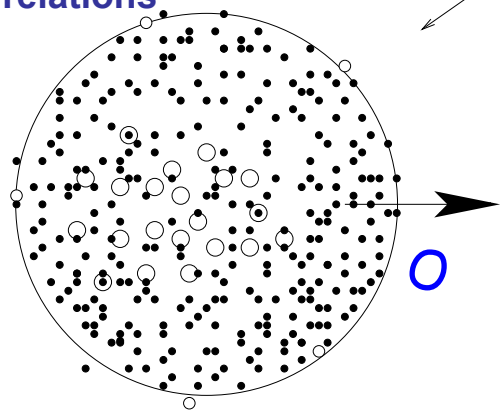
# Primordial alpha cluster induction via mechanism of Prandtl-Glauert singularity as a trigger for the instability



A gas of nucleons/ no correlations

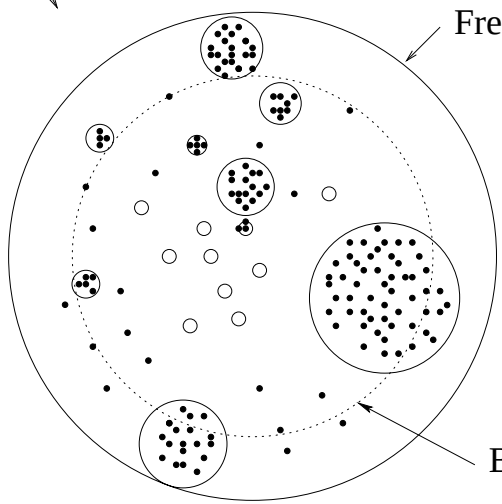


Instabilty via Mach shock



O

De-excitation/Nuclear camouflage



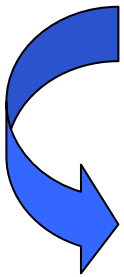

Induction of primordial alpha clusters via Prandtl-Glauert Singularity mechanism

„Hammer“ is the Prandtl-Glauert Singularity

„Cracks“ („warts“) are the primordial alpha clusters

# Approach towards the organization the study at SIS100

Reaction in need to study ….



p + Au ---> protons+primordial alphas + x

Primordial alphas are easy to identify when they move fast

$Au+H_2$ ---> protons + primordial alphas…+ x

# Mach angle in iversed kinematics: estimates for 100 MeV protons

| T0, GeV/nucleon | Fireball $C_s$ | Fireball Mach angle (exp) | Taget K=187 MeV, $C_s$=0.14 | Target K=302 MeV, $C_s$=0.19 |
|---|---|---|---|---|
| 2 | 0.71 | $14^0$ | $26^0$ | $25^0$ |
| 5 | 0.61 | $7^0$ | $14^0$ | $13^0$ |
| 10 | 0.54 | $4^0$ | $8^0$ | $7^0$ |
| 20 | 0.52 | $2^0$ | $5^0$ | $4^0$ |
| 30 | 0.52 | $1^0$ | $3^0$ | $2^0$ |

# Experimental layout at SIS100

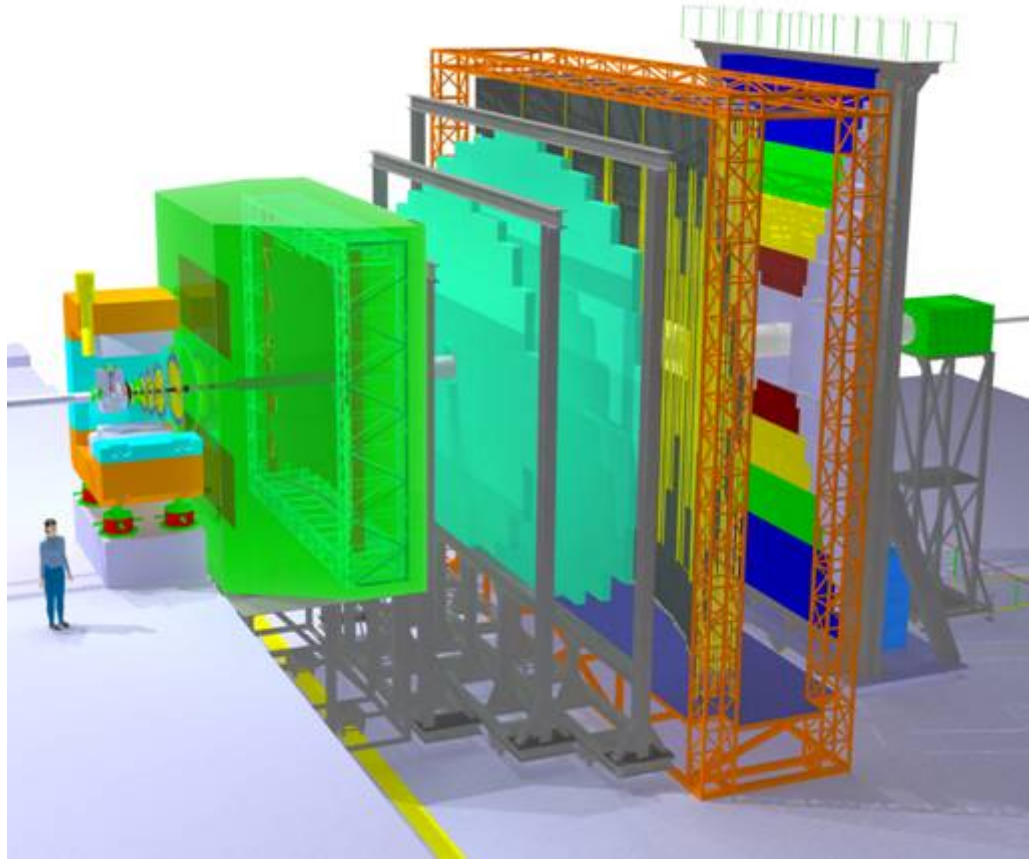
## Basic Features:

Inversed kinematics Au +$H_2$

## Usage of The CBM basic subsystems

## Building:

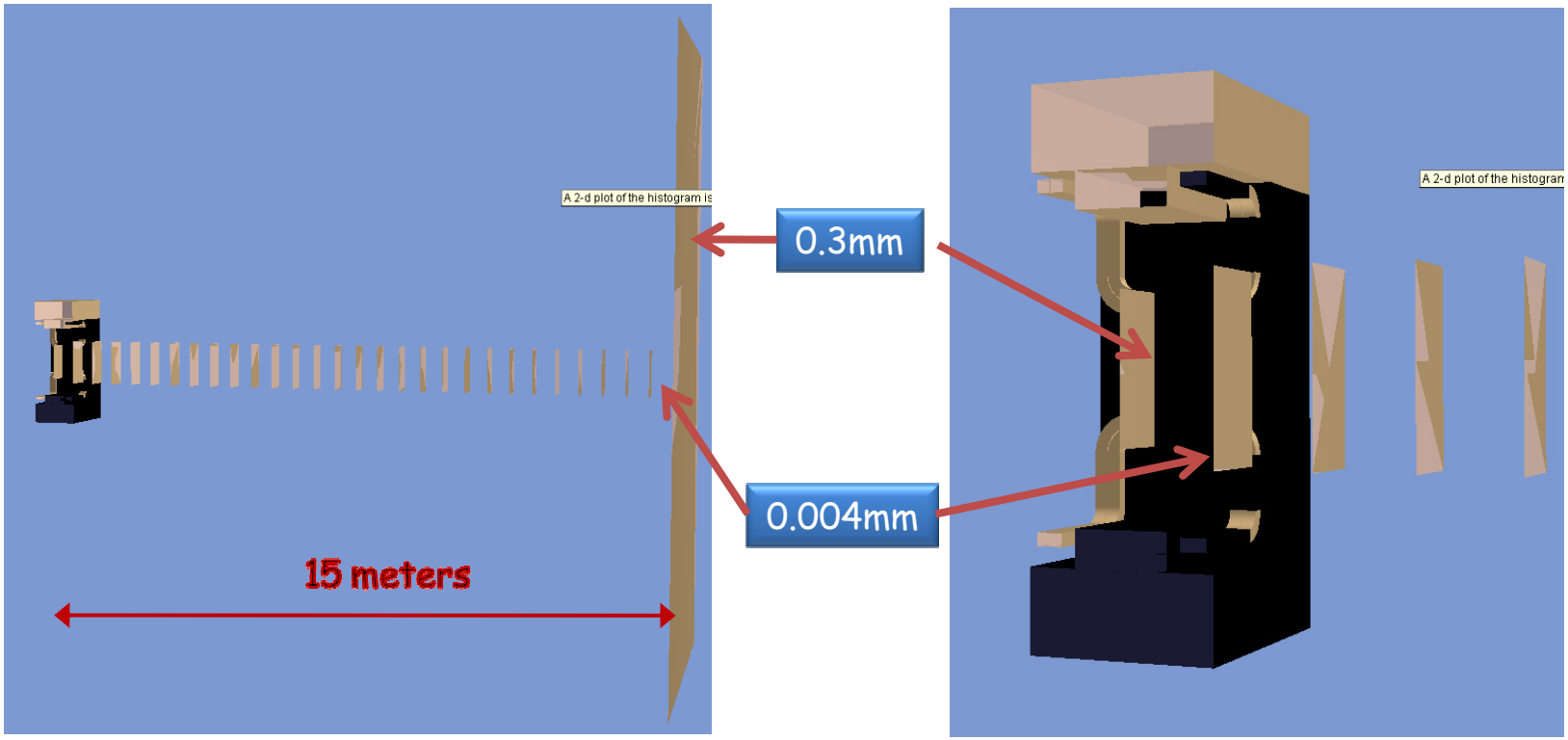
Silicon Zero Angle Detector
For primordial alphas tagging



# Separation of alphas from the beam with the CBM magnet:

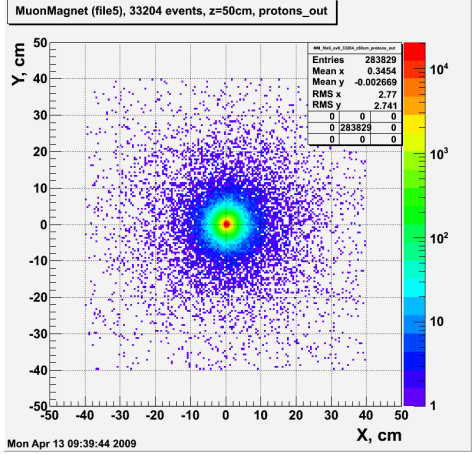
Condition of simulation:

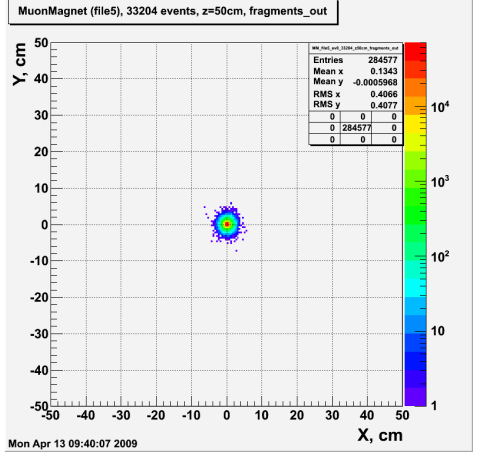
Geometry: Muon Magnet + 30 silicon planes:

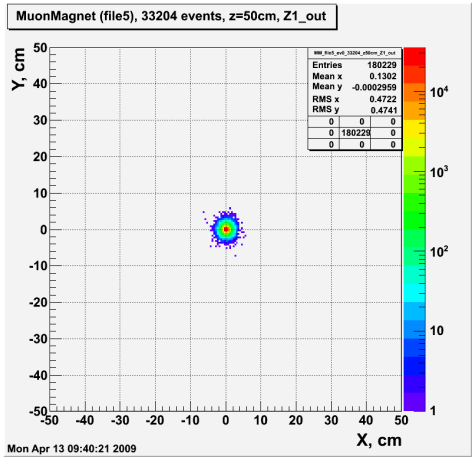


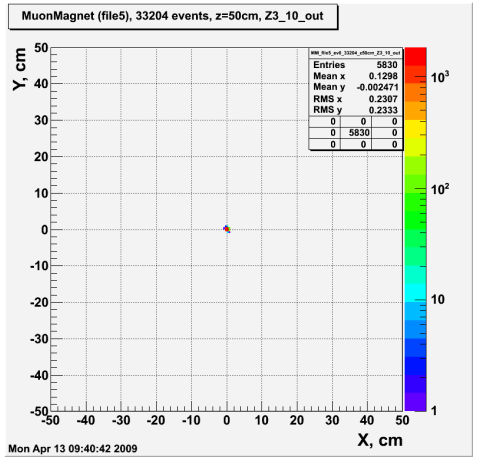

Event generator: LAQGSM
Collision: Au-p Sqrt(S)=5 GeV/u
Transport: Geant4

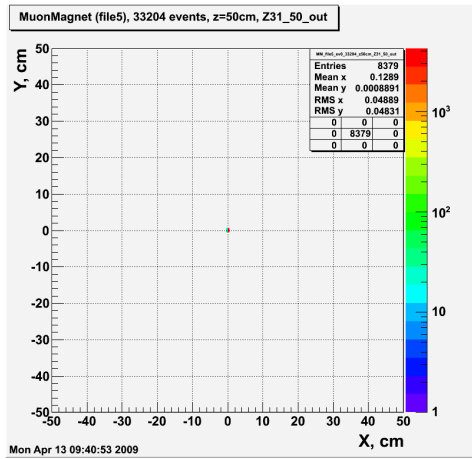
**Simulations by E.Litvinenko, based on LAQGSM event generator of K.K.Gudima et al.**

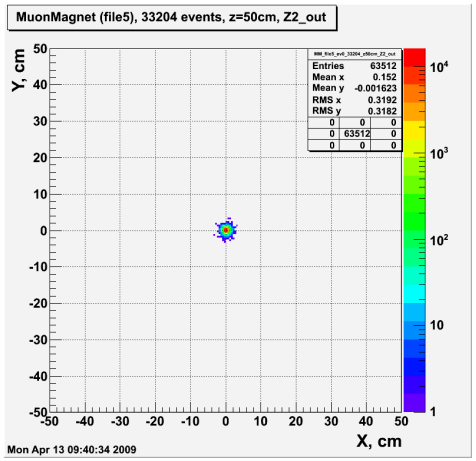

MuonMagnet (file5), 33204 events, z=50cm, protons_out
Entries 283829
Mean x 0.3454
Mean y -0.002669
RMS x 2.77
RMS y 2.741
Y, cm
X, cm
Mon Apr 13 09:39:44 2009


MuonMagnet (file5), 33204 events, z=50cm, fragments_out
Entries 284577
Mean x 0.1343
Mean y -0.0005968
RMS x 0.4066
RMS y 0.4077
Y, cm
X, cm
Mon Apr 13 09:40:07 2009


MuonMagnet (file5), 33204 events, z=50cm, Z1_out
Entries 180229
Mean x 0.1302
Mean y -0.0002959
RMS x 0.4722
RMS y 0.4741
Y, cm
X, cm
Mon Apr 13 09:40:21 2009


MuonMagnet (file5), 33204 events, z=50cm, Z3_10_out
Entries 5830
Mean x 0.1298
Mean y -0.002471
RMS x 0.2307
RMS y 0.2333
Y, cm
X, cm
Mon Apr 13 09:40:42 2009


MuonMagnet (file5), 33204 events, z=50cm, Z31_50_out
Entries 8379
Mean x 0.1289
Mean y 0.0008891
RMS x 0.04889
RMS y 0.04831
Y, cm
X, cm
Mon Apr 13 09:40:53 2009


MuonMagnet (file5), 33204 events, z=50cm, Z2_out
Entries 63512
Mean x 0.152
Mean y -0.001623
RMS x 0.3192
RMS y 0.3182
Y, cm
X, cm
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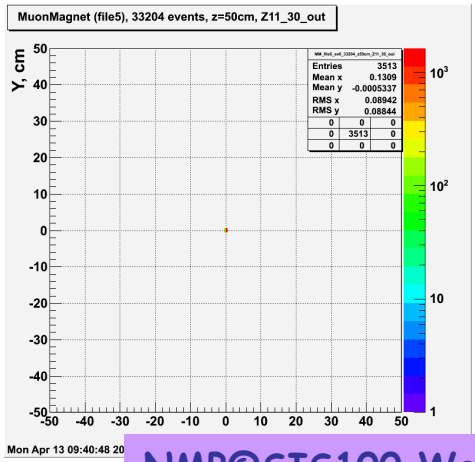
MuonMagnet (file5), 33204 events, z=50cm, Z11_30_out
Entries 3513
Mean x 0.1309
Mean y -0.0005337
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RMS y 0.08844
Y, cm
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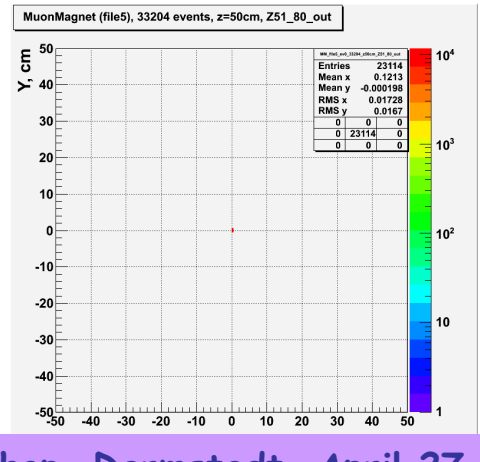
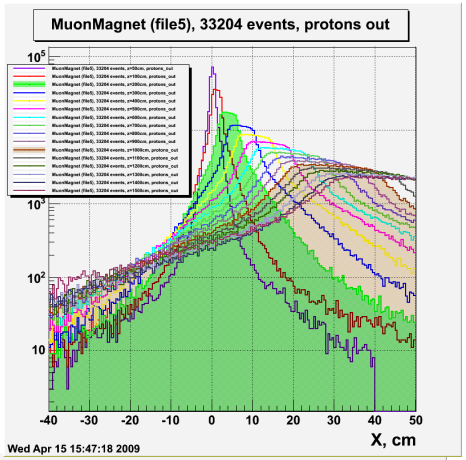
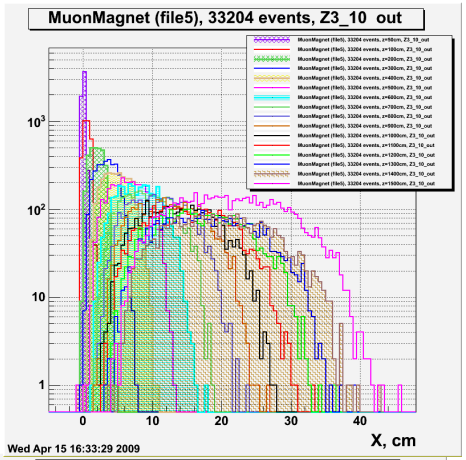

MuonMagnet (file5), 33204 events, z=50cm, Z51_80_out
Entries 23114
Mean x 0.1213
Mean y -0.000198
RMS x 0.01728
RMS y 0.0167
Y, cm


MuonMagnet (file5), 33204 events, protons out
X, cm
Wed Apr 15 15:47:18 2009


MuonMagnet (file5), 33204 events, Z3_10 out
X, cm
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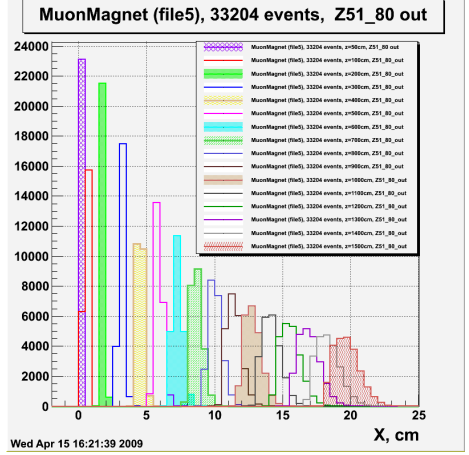
MuonMagnet (file5), 33204 events, Z51_80 out
X, cm
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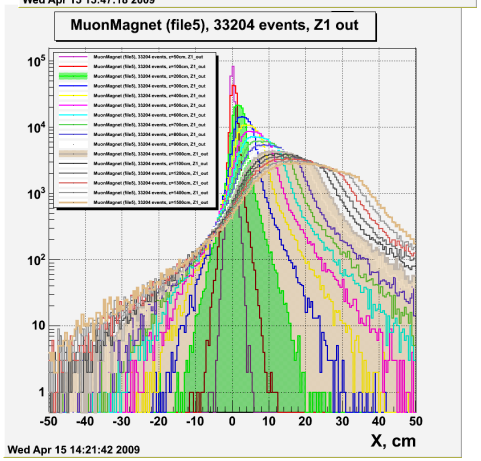
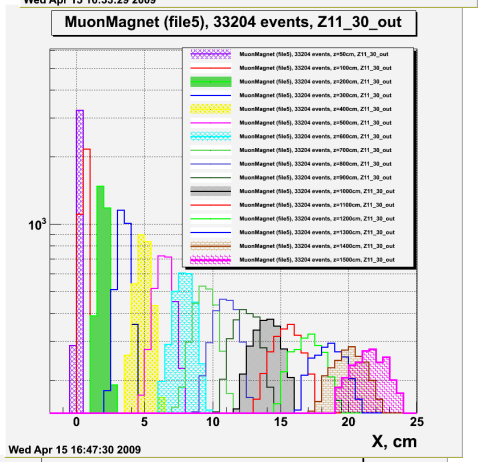

MuonMagnet (file5), 33204 events, Z1 out
X, cm
Wed Apr 15 14:21:42 2009


MuonMagnet (file5), 33204 events, Z11_30_out
X, cm
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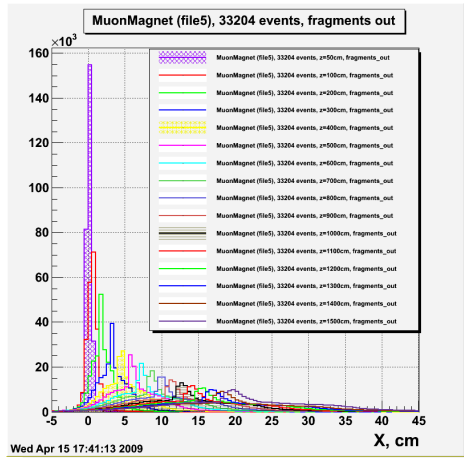
MuonMagnet (file5), 33204 events, fragments out
X, cm
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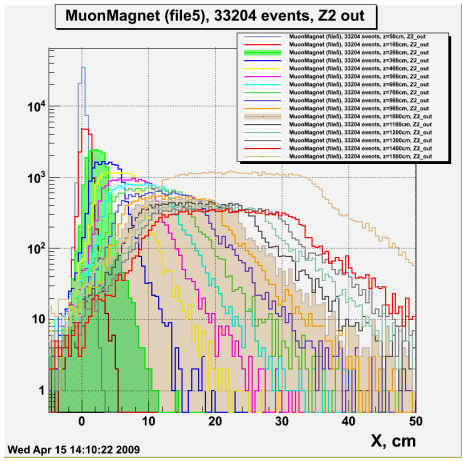
MuonMagnet (file5), 33204 events, Z2 out
X, cm
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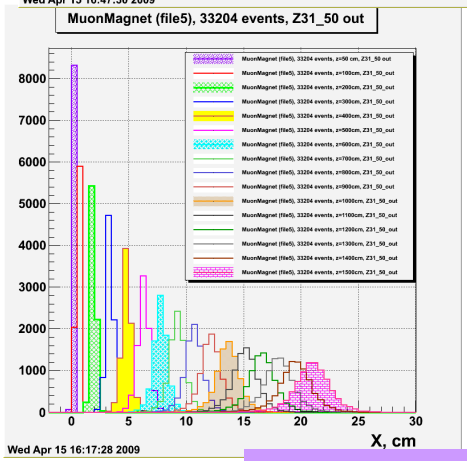
MuonMagnet (file5), 33204 events, Z31_50 out
X, cm
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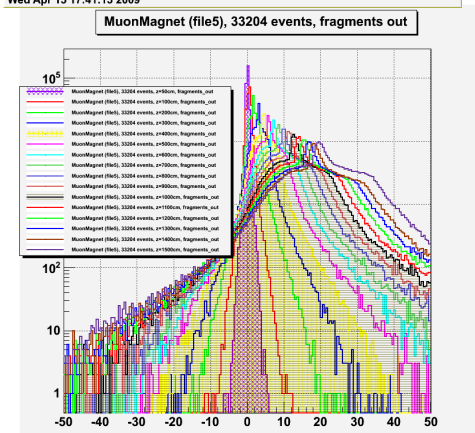
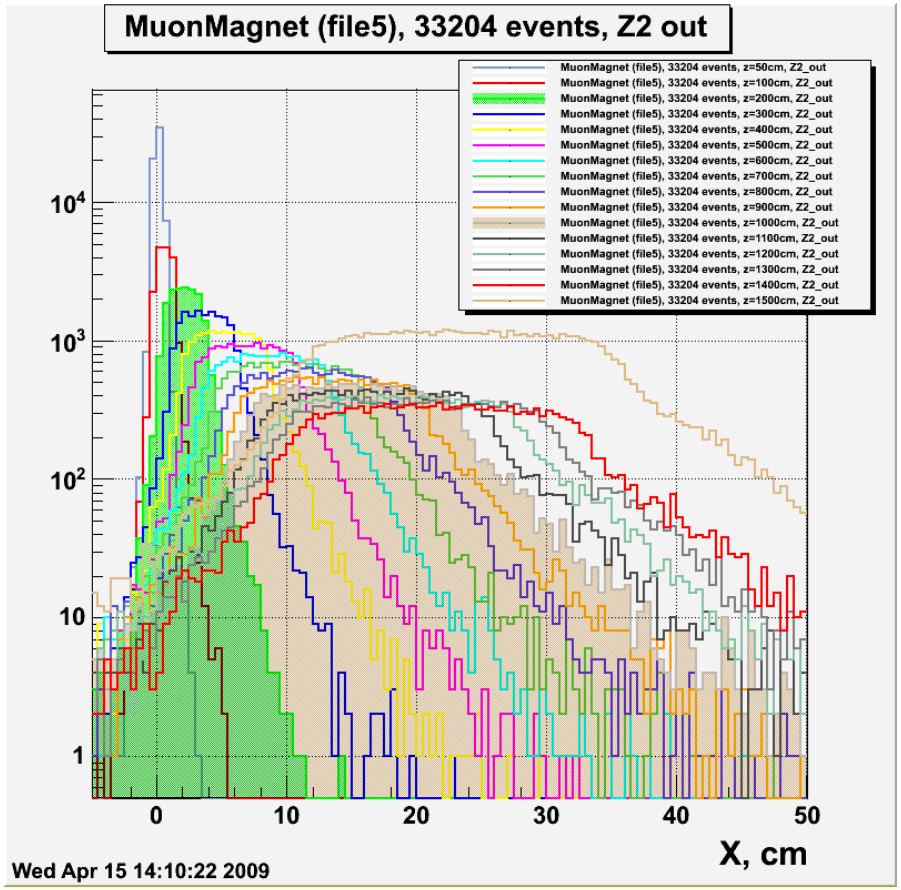
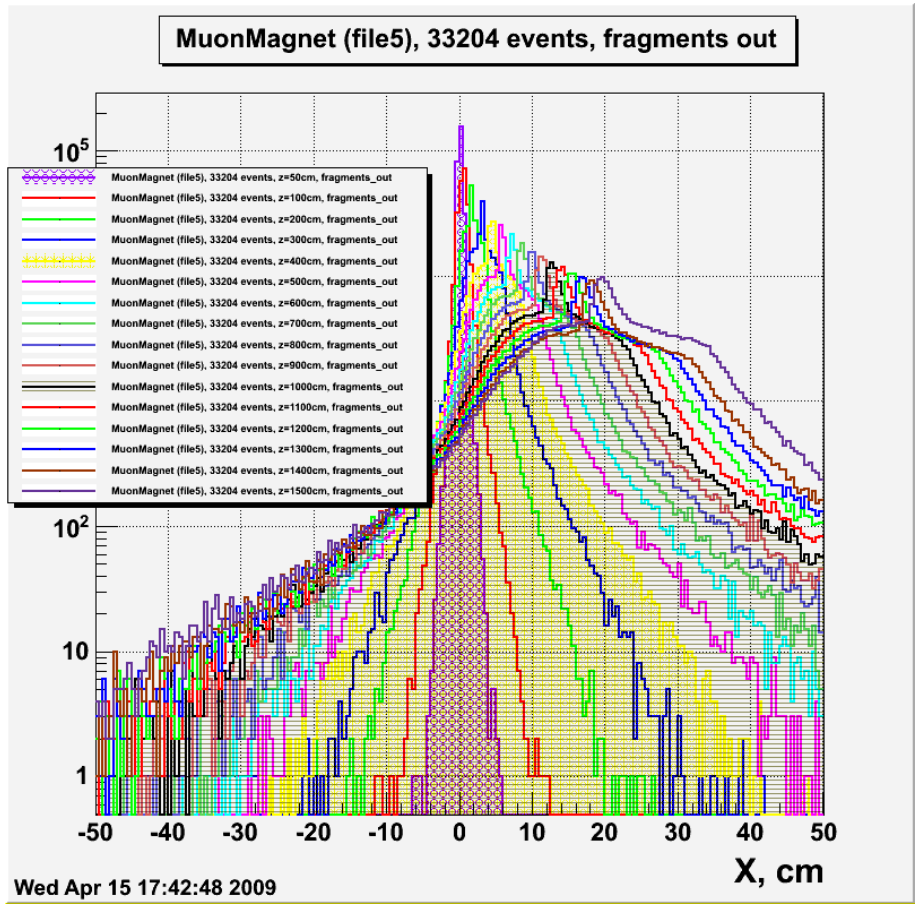

MuonMagnet (file5), 33204 events, fragments out

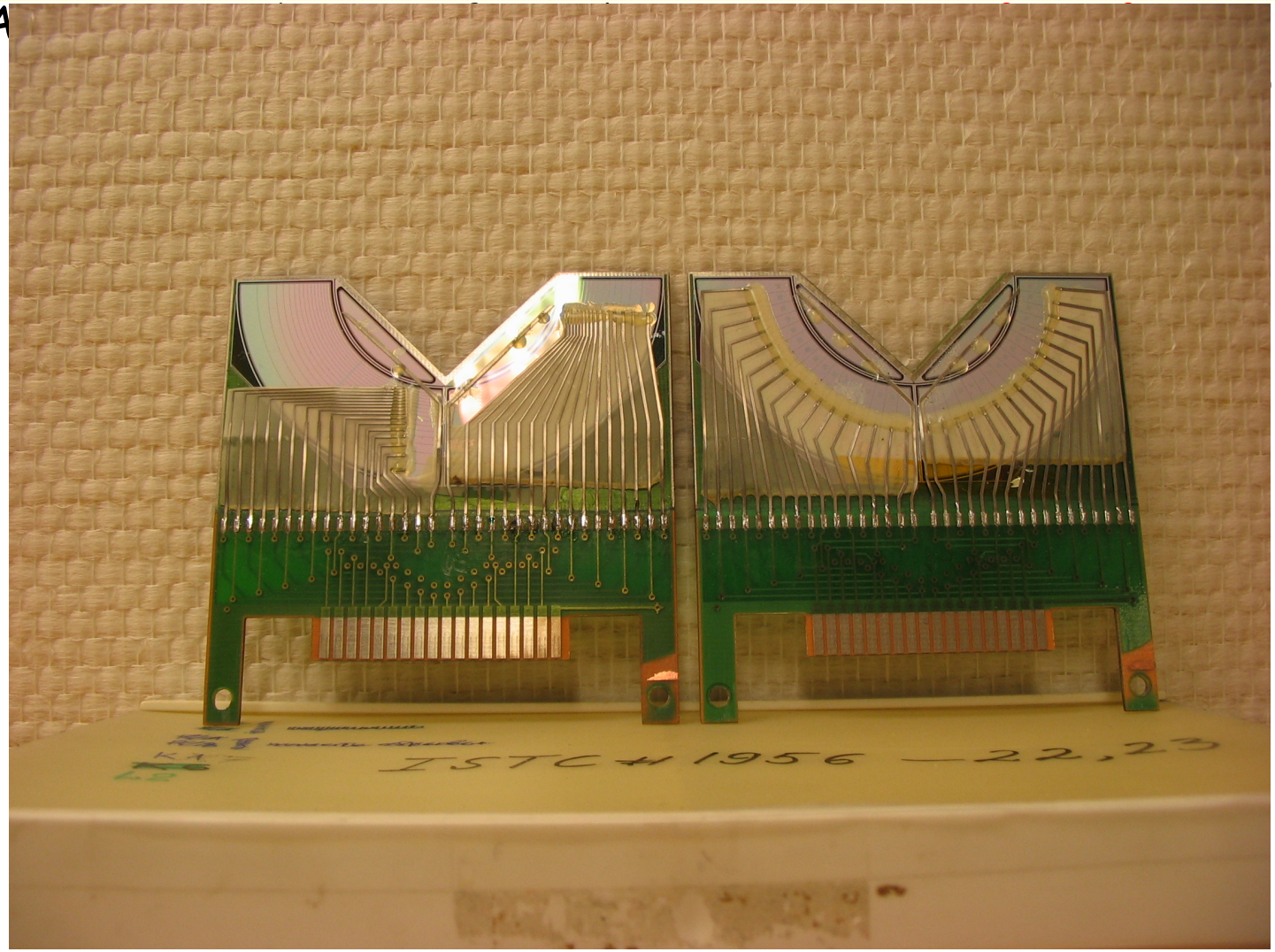
# Separation of alphas from the beam with the CBM magnet:



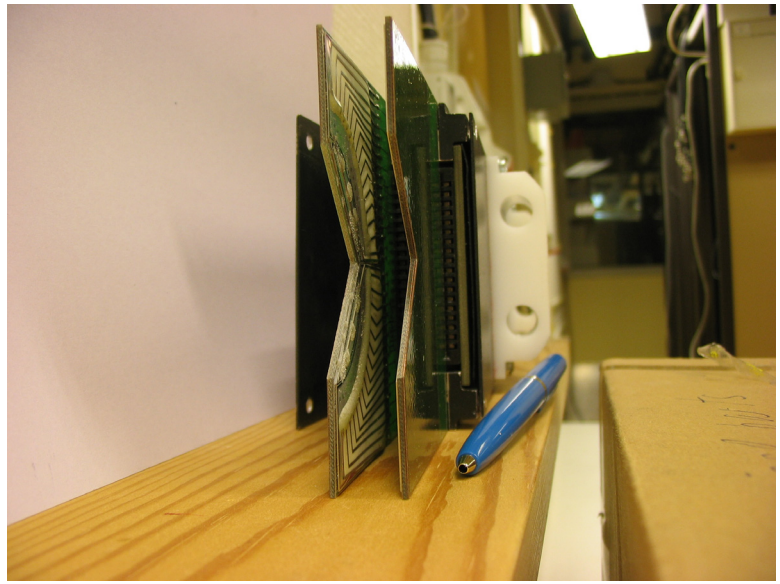



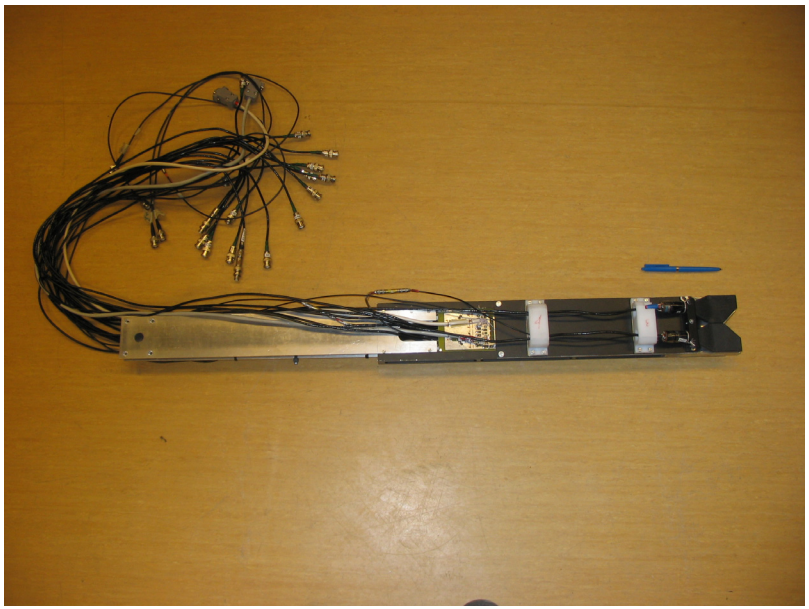

**Tagging Efficiency around 50%**

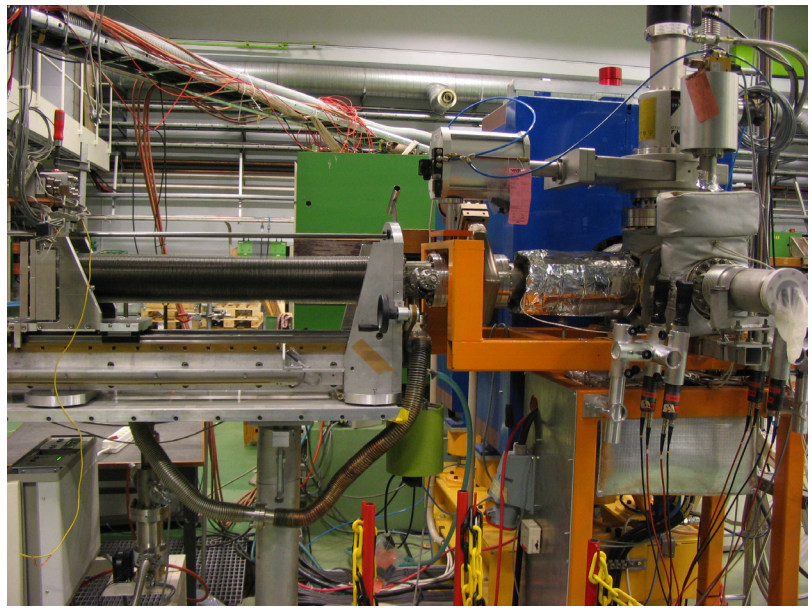
# Small Angle Detector CELSIUS Storage Ring



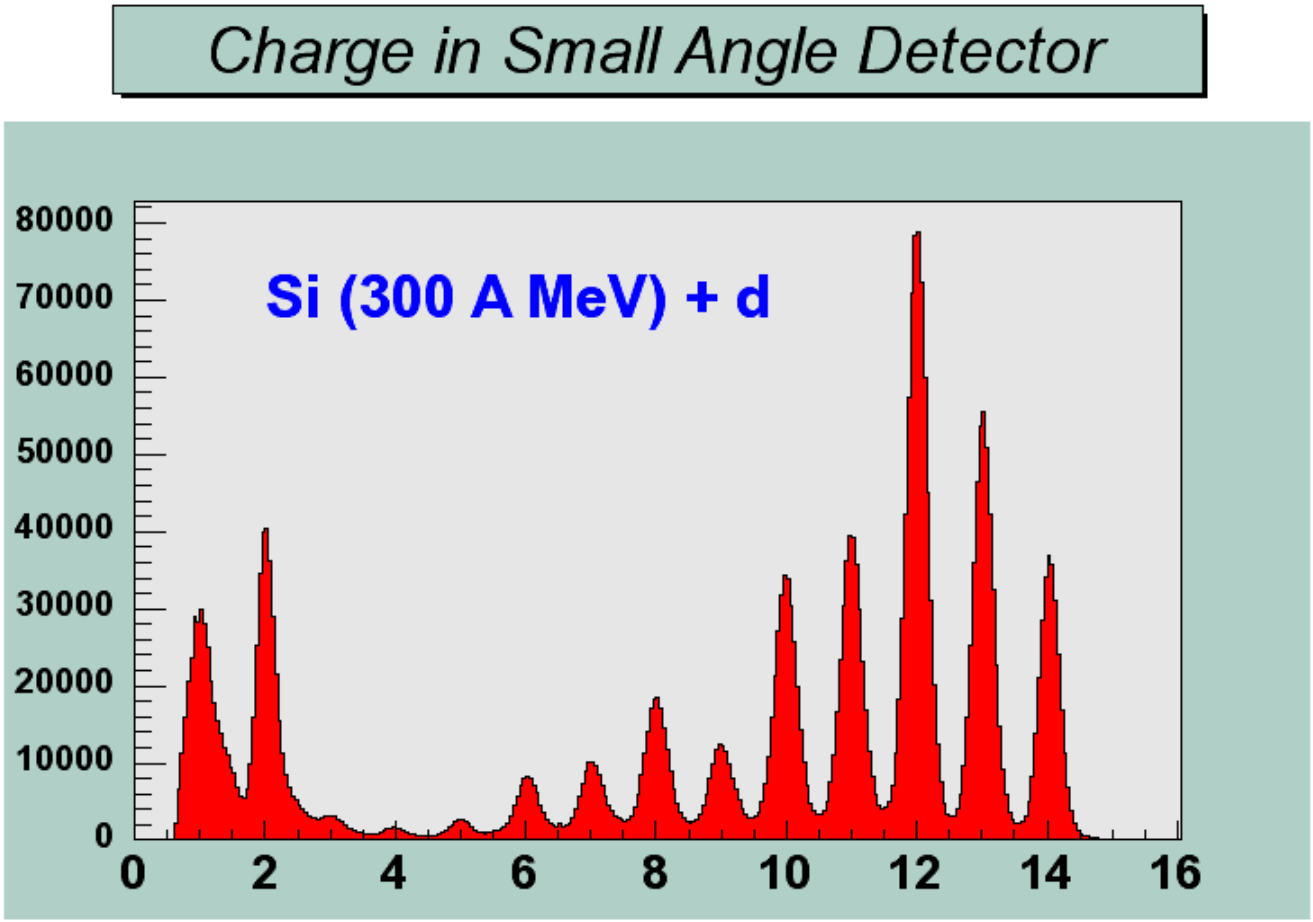
# SAD ASSEMBLY PROCEDURES :



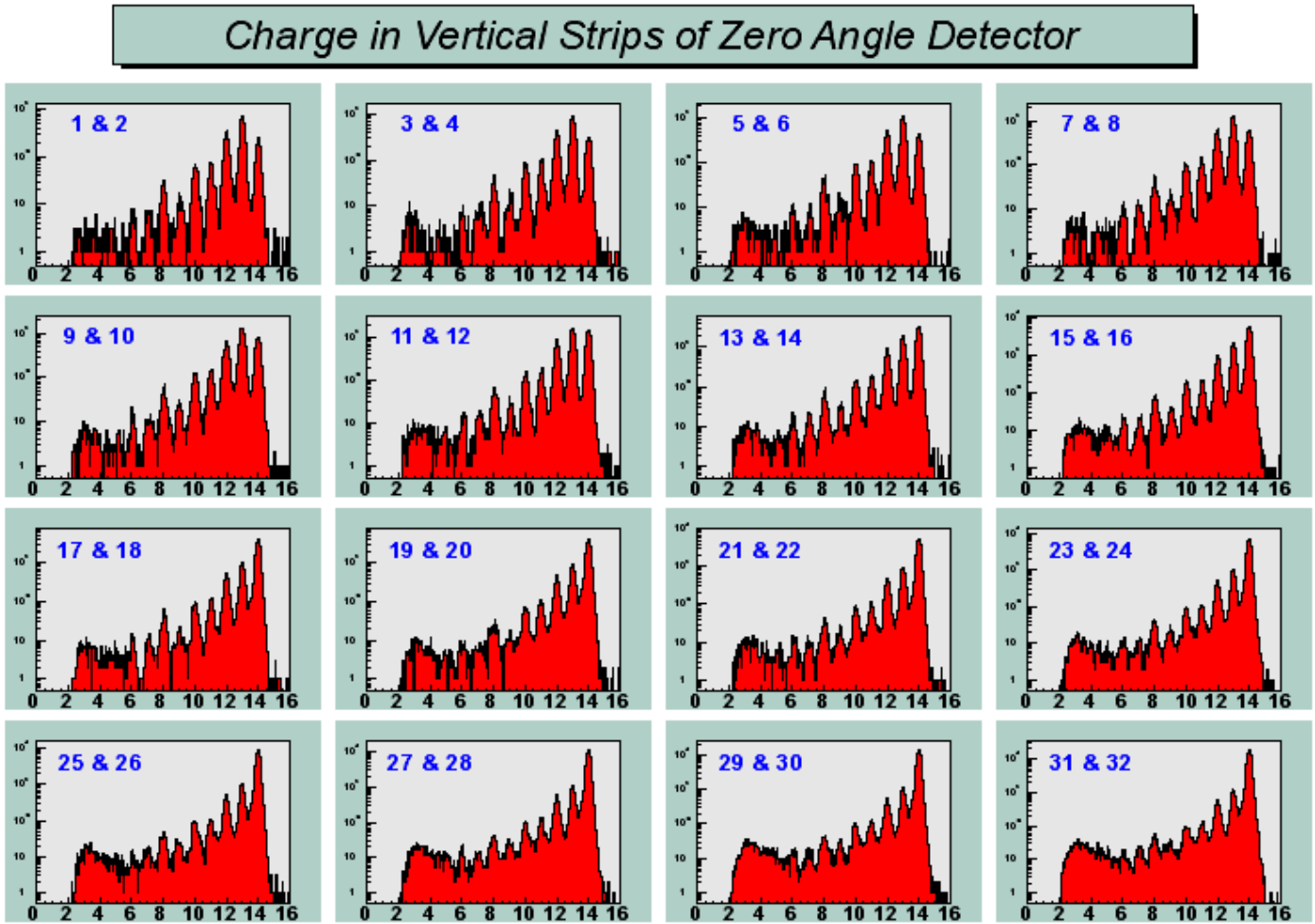




# Charge resolution of SAD



# ZAD performance (after amplitude corrections)



# Summary and conclusions:

- *Arguments are put forward for revival of interest to experimental search for Mach shocks in the heavy target induced by proton from SIS100*

- Proposal is put forward to study deep sub-barrier alpha particle production in multifragmentation of heavy nuclei induced by high energy proton with regard to the idea of the *nuclear Prandtl-Glauert singularity effect* as a genetic tagger for the Mach shock

- CBM (*even if not yet fully commissioned*) could be the very setup for the experiment provided equipped with small angle alpha particle silicon tagger

**Thank You For Your Attention!.**