A Dual Measurement System for Radioactive Tracer Pebble Tracking in Pebble Bed Reactors (PBRs)

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Agenda

- **Introduction**
- **Methods and experiments reviews**
- **Dual measurement system**
- **Experimental results**
- **Conclusions and discussions**
- **Future work**

PBR

- Cylindrical ceramic core

 3 m (diameter) X 9.4 m (height)

- 360,000 spherical fuel elements

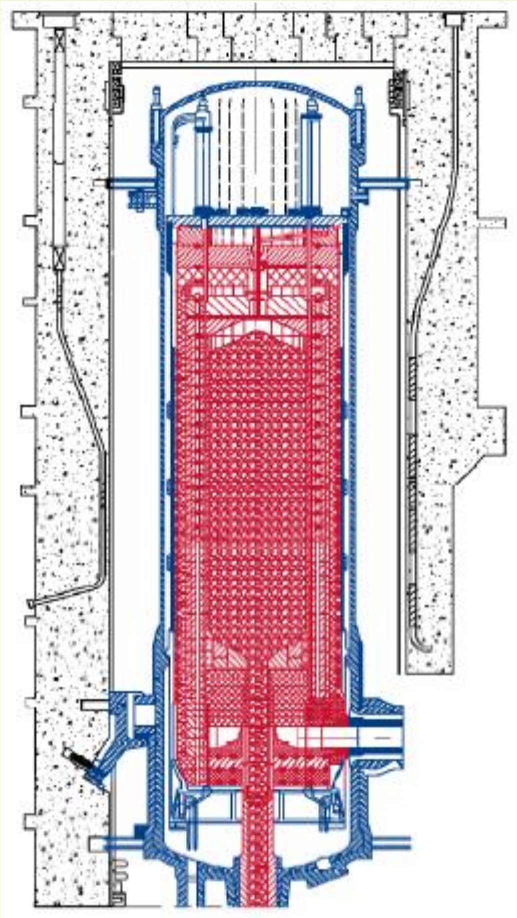
6 cm (diameter); 11,000 TRISO particles(UO2)

- Slow flow rate system

5000 / day recirculated;360 /day replaced

- High temperature

250-530-700 degree



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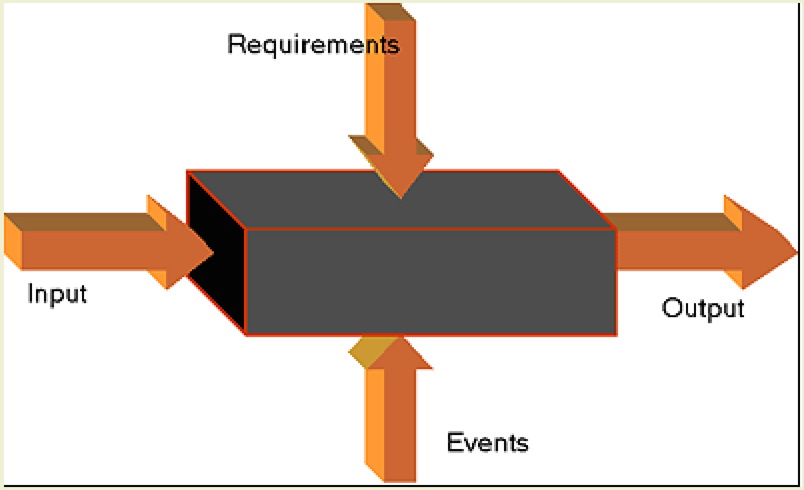
PBR

- The data of the pebble motion in PBR is limited. Do not have confident methods for tracking purpose with convenience.
- Especially, in high temperature, data for pebble motion is almost non-existent (Future work).

The study and research on PBR –
a Black Box process



The Motivations and Targets

- **The pebble motion or flow is an important issue for PBR which affects the neutron behavior in the core as well as the safety analysis. Well understanding this issue make these possible:**

1. Core power density and temperature distribution analysis.
2. Possible fuel failures and accident situations analysis.

- **But the pebble motion can not be tracked in the real PBR that we carry the researches in the modeling one. The reasons are:**

1. The scale and the safety shielding of the PBR make the radioactive particles are not measurable or not allowed to.
2. The homogeneous pebbles can't be indentified by the outside detectors.
3. The scaled down modular PBR pebble behavior can represent that in the real PBR.

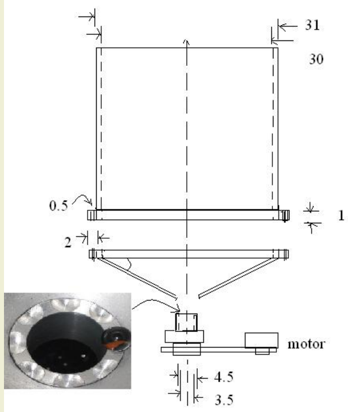
- **A dual measurement system is developed for single and multiple pebbles motions tracking in the modeling PBR.**

1. New tracking methods.
2. Data for pebble flow modeling.

Approaches-Dual measurement system

Our method for pebble motion study:

- Scaled modeling PBR
- Collimated detectors system
- Un-collimated detectors system



How we developed our system?

Gatt's Experiments

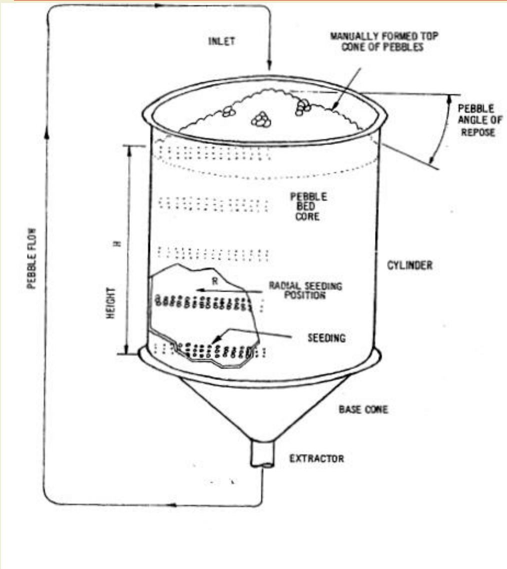
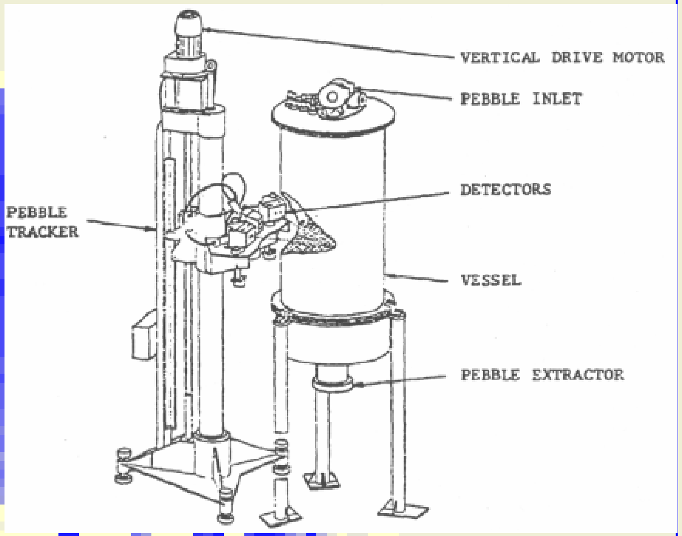


FIGURE 1. SKETCH OF PEBBLE BED NUCLEAR REACTOR SHOWING FULLY SEEDED PEBBLE BED



From the late 1960's to early 70's Gatt, F.C, Australia

Pebble: 1 inch (0.75inch)

Vessel:30/D;60/H(30,000 pebbles)

1. The optimum pebble bed height would approximately 27.5 in with the above pebbles.

2. The optimum base angle would be 45 ° or greater. Then with 25°.

3 . The flow pattern 1-50,000 per minute not significant affect (Seeding particles)

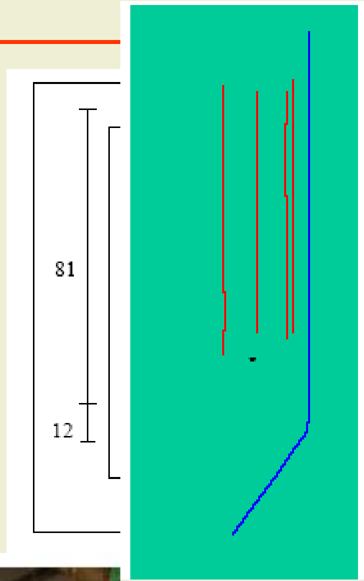
4. The single particle motion tracking without automation control not real time. (Radiation Tracer with Collimated Detectors)

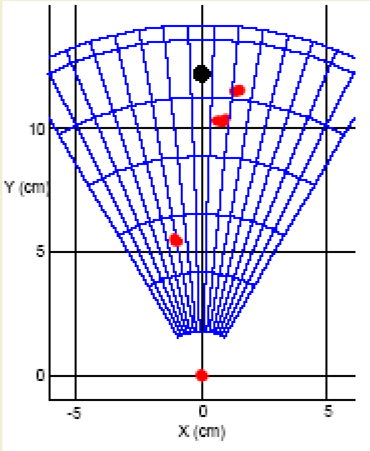
Experiments in MIT

Andrew C. Kadak and Martin Z. Bazant 2004 MIT

One-tenth of the actual size.(30cm/D;6mm/d)

- Half Model (Visible tracking)
- 3-D Model (Collimated Detectors)
  1. Streamlines in the straight section are not significantly affected by changes in cone angle, refueling pattern, or drainage hole diameter.
  2. Material properties, include friction, do not appear strong influence the flow pattern

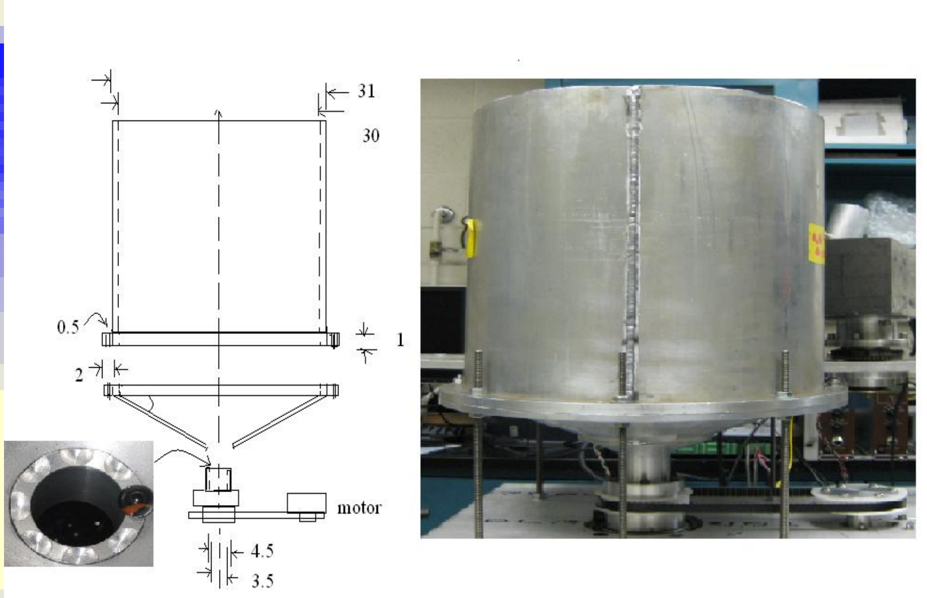




Modeling PBR

Table of Nature of the problem:

Vessel Diameter (D)	30 cm
Height of the cylindrical portion of pebble bed (H)	30 cm
Base cone Angle measure from the horizontal (θ)	25 °
Pebble diameter (d)	1.20 ± .15 cm
Bed inventory, defined as the total number of pebbles in the bed (N)	21000
Density of the pebbles	2.3 ±0.1g/cm^3
Outlet orifice diameter	3.5cm



- A design according to Gatt's experiments' conclusions

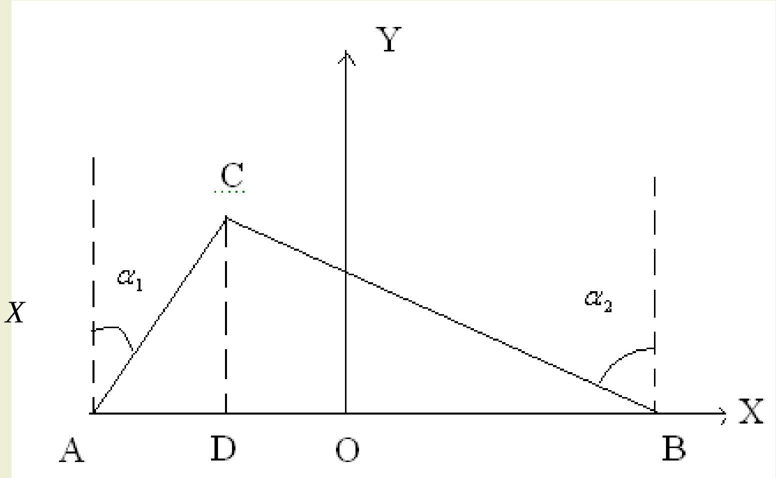
Collimated detectors system

- Three collimated 2”X2” NaI detectors
- Scanning technique to locate the tracer particle.
- Labview automatic control

L=AD+ BD= $CD\tan\alpha_1 + CD\tan\alpha_2 = CD(\tan\alpha_1 + \tan\alpha_2)$

$$CD = \frac{L}{\tan\alpha_1 + \tan\alpha_2} = Y$$

$$OD = BD - OB = CD\tan\alpha_1 - \frac{1}{2}L = \frac{L}{\tan\alpha_1 + \tan\alpha_2}\tan\alpha_1 - \frac{1}{2}L = X$$



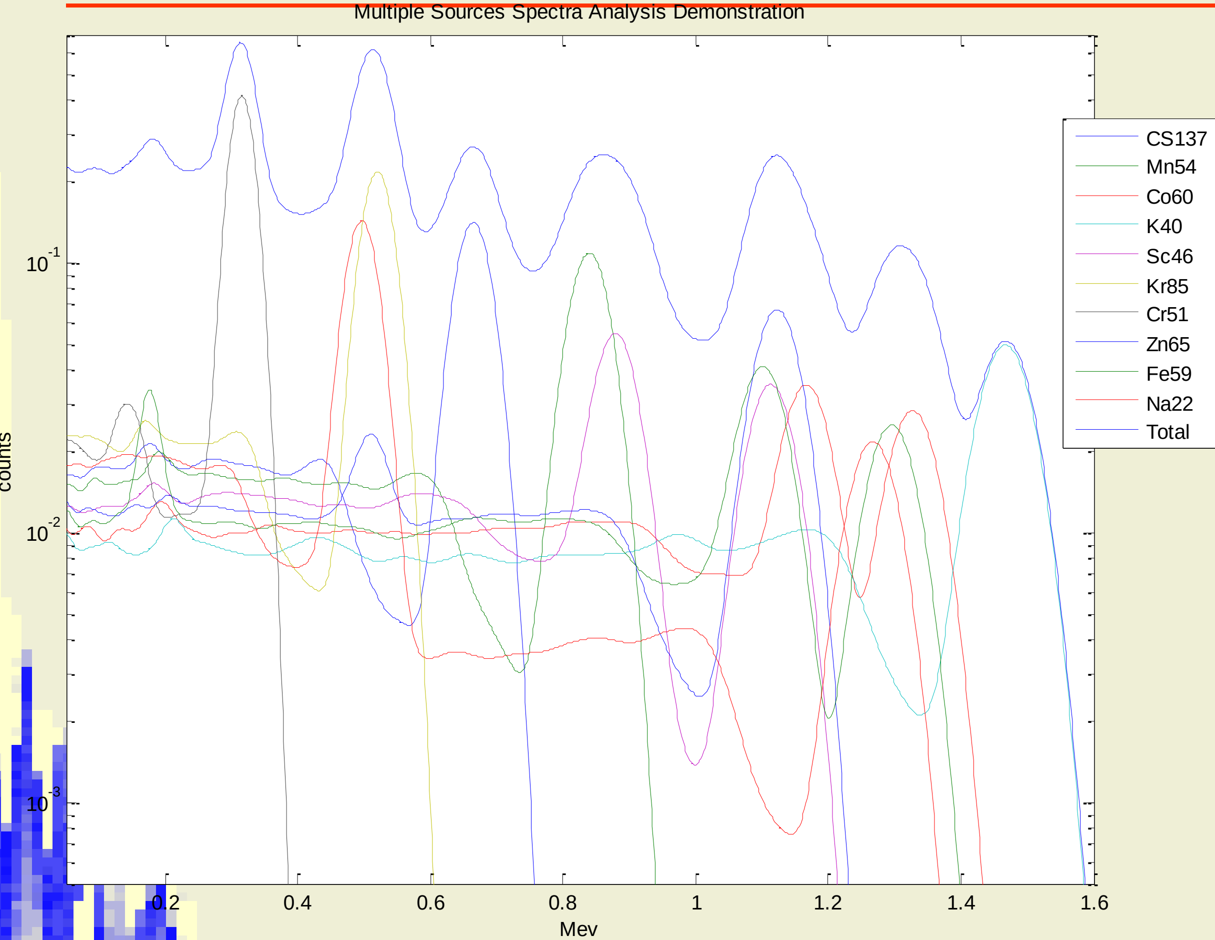
Configurations

1. Six un-collimated detectors uniformly distributed. (2"X2" NaI detectors, size and type)

2. Simultaneously measurements (Labview)

3. MCLLS method

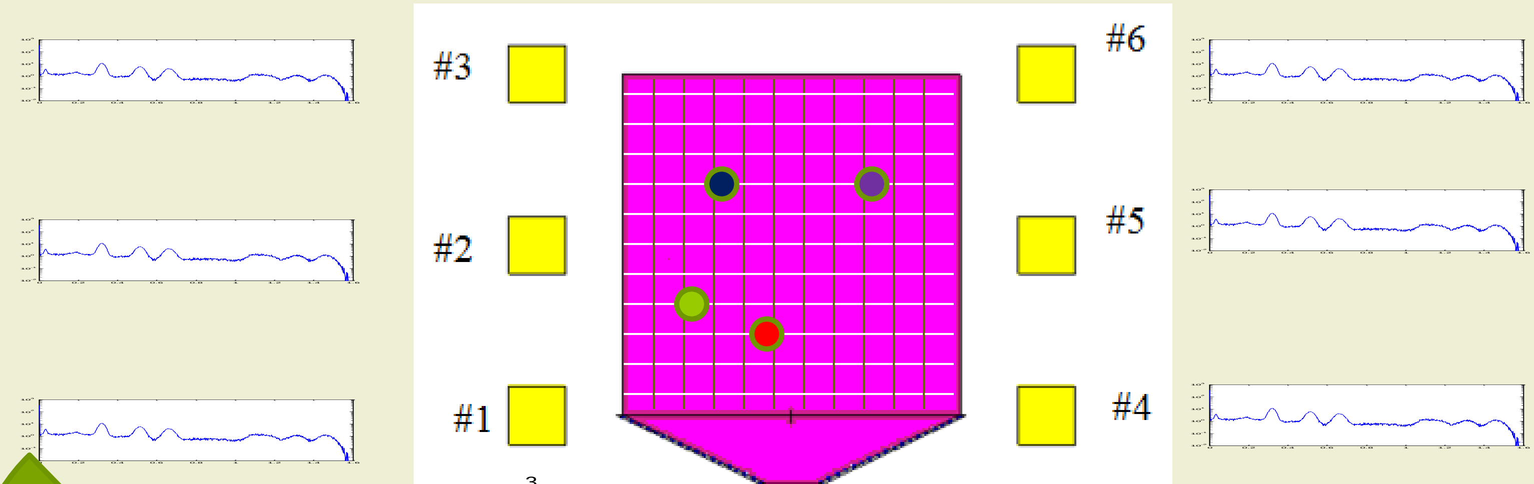
MCLLS method for Ten Sources



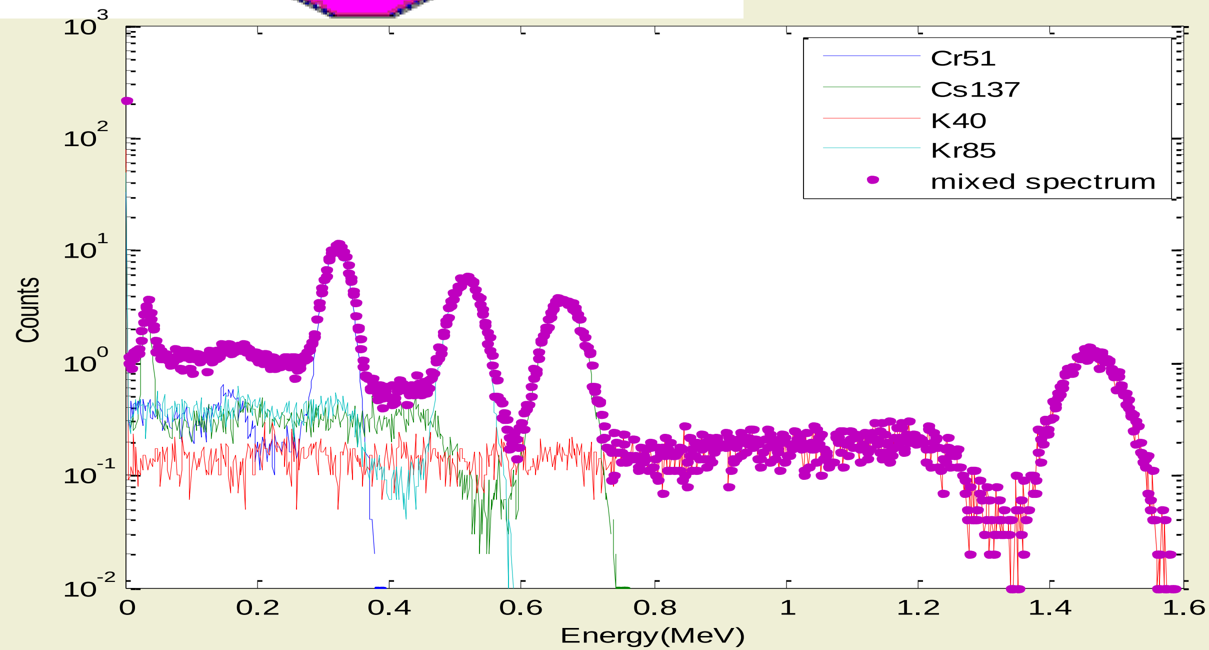
$$y_i = \sum_{j=1}^{m} x_j a_{ij} + e_i$$

Sources(T1/2)	Energies (Mev) and Relative intensity
CS137(30y)	0.032 0.037 0.662 0.054 0.013 1.0
Mn54(312d)	0.835 1.0
Co60(5.27y)	1.173 1.332 1.0 1.0
K40(1.248E+9y)	1.460 1.0
Sc46(83d)	0.889 1.121 1.0 1.0
Kr85(10.73y)	0.514 1.0
Cr51(27.7d)	0.320 1.0
Zn65(243.66d)	0.511 1.116 0.056 1.0
Fe59(44.50d)	0.192 1.099 1.292 0.055 1.0 0.765
Na22(2.6y)	0.511 1.275 1.0 0.556

MCLLS for multiple particles



K40
Kr85
Cr51
Cs137



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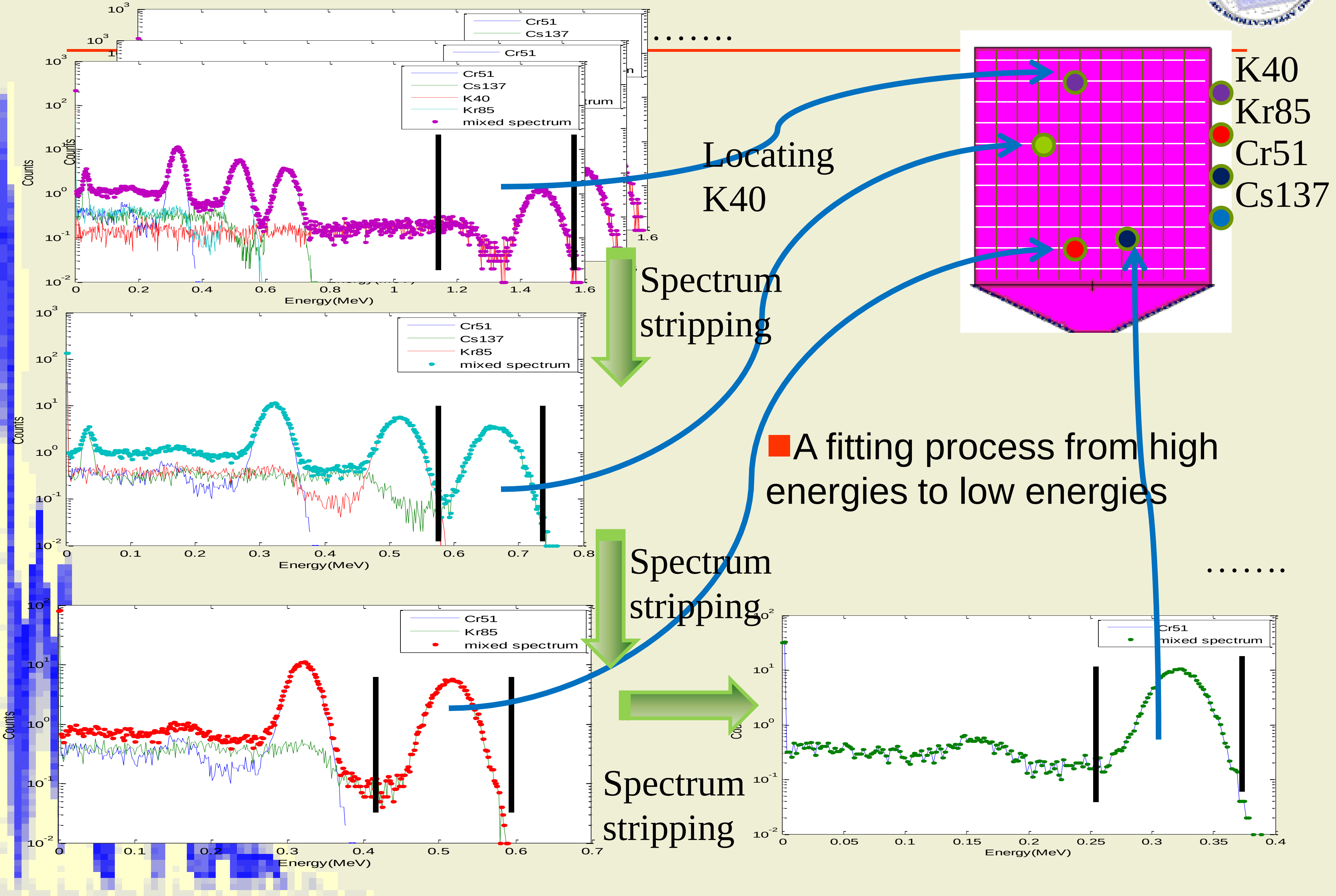
MCLLS



The major processes of MCLLS

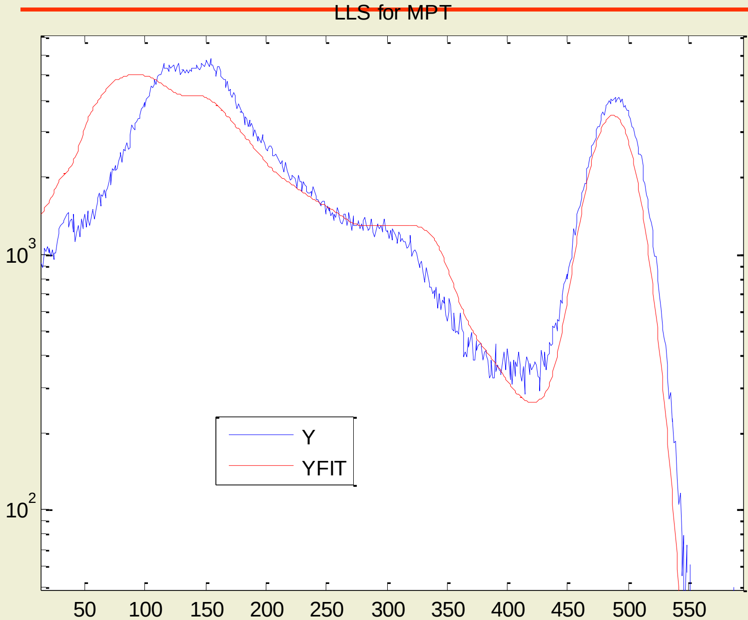
1. Measurements of the spectra with unknown positions of the sources.

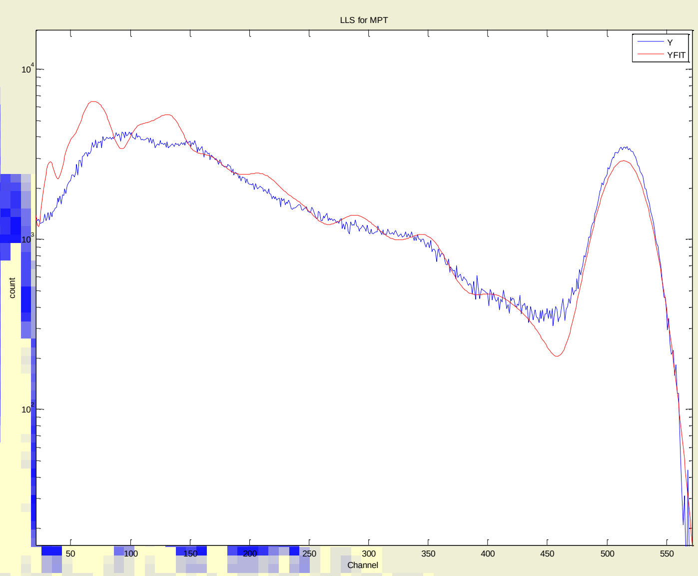
2. Pre-calculations for Library with Detector Response Function's (DRF's) Generator with known positions of the sources.

3. Library Least Square fitting for positions in step 1 with the results in step 2.

The DRF's is critical in this method as a tools (Why?)

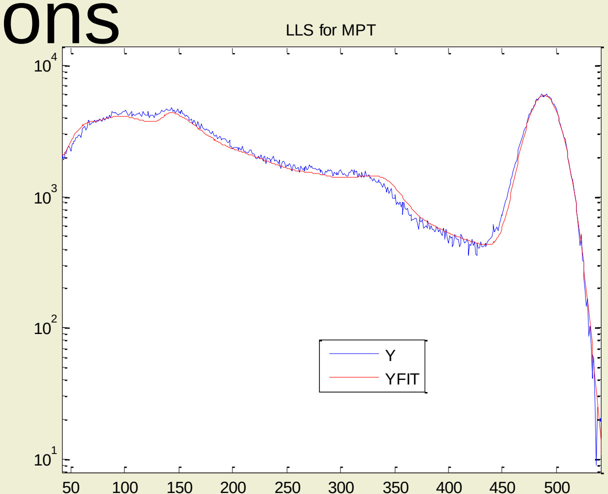
How DRF's matter?





- Inaccurate or high statistical errors in generating Lib's can fail in tracking with MCLLS correctly.

1. Accurate DRF's
2. High efficiency in generating Lib's with Monte Carlo simulations



DRF's development in MCNP5

Accuracy

Flat continua and Nonlinearity

Estimated position (X,Z) = (5.0,21.5)by collimated detectors system

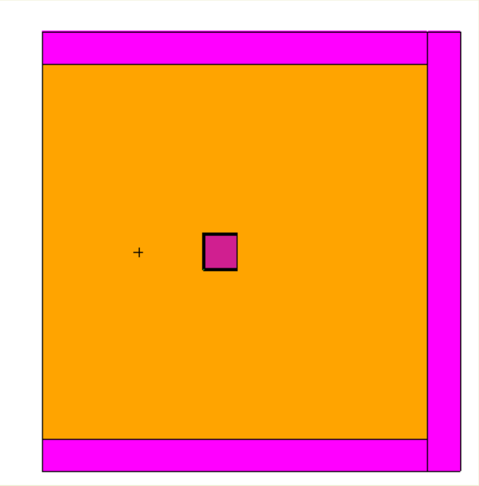
Codes	(X,Z) (cm)	χ^2	Sum area
Original MCNP5	3.4,18.06	25.7	86.0%
Modified MCNP5	4.7,21.52	0.766	98.8%

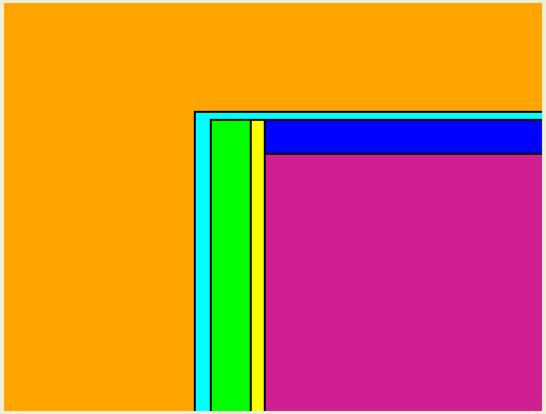
Speed-up features

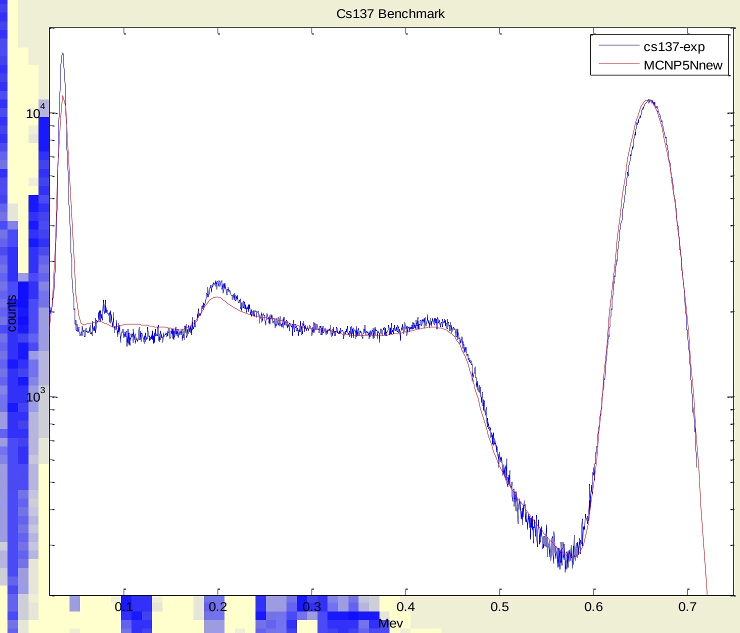
In code and variance reduction techniques and computer Cluster in CEAR

PC need 220 minutes; cluster need 5 minutes; with speed up can reach 1.5 minutes (case for 20m history)

NaI 2X2 DRF's Benchmark







A) Aluminum house 0.025”

B) Rubber pad 0.060”

C) White teflon sheet reflector 0.02”

D) White reflective powder 0.096”

E) NaI crystal

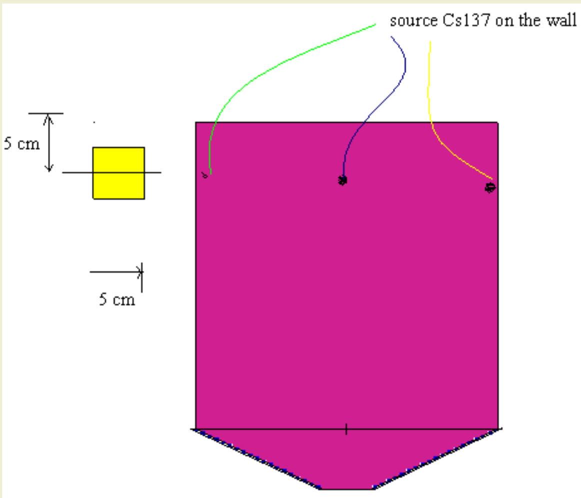
Model for different sizes of NaI detectors:

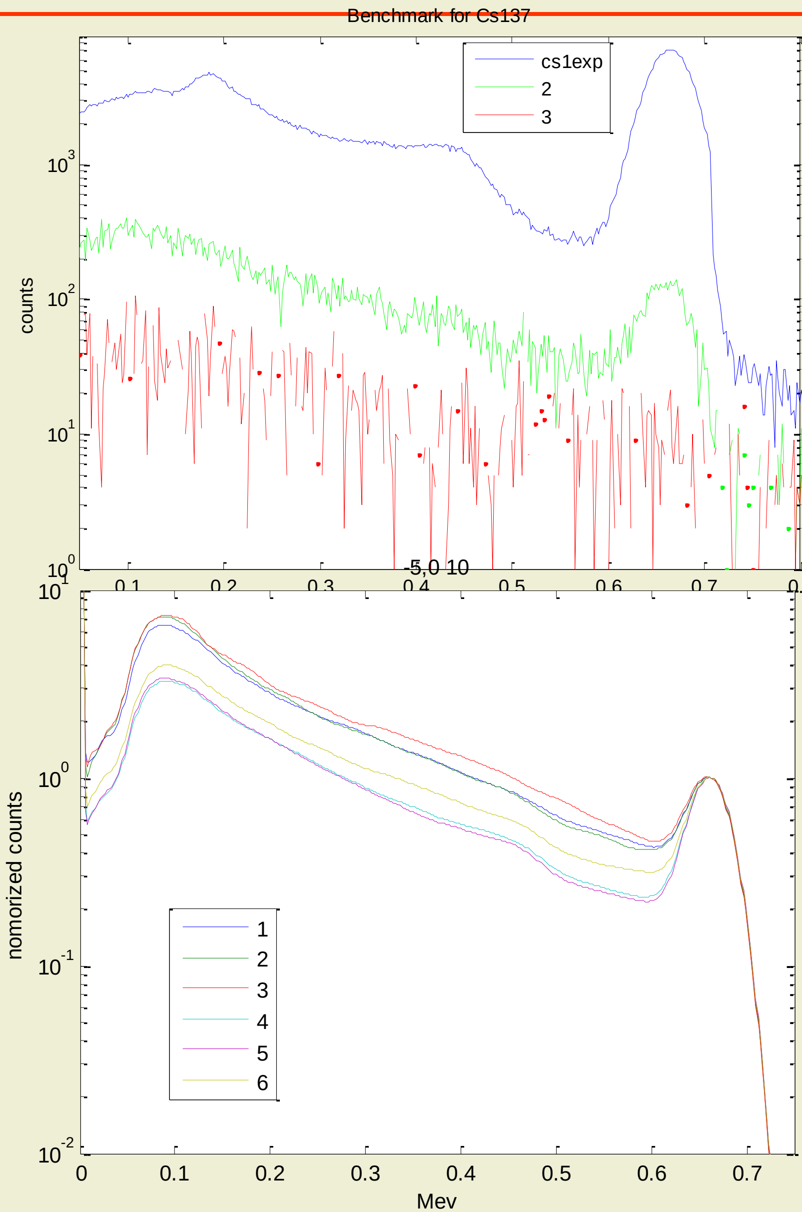
$$F_D = F_3 * (3/D)$$

DRF's for particles tracking

- Different positions of the sources have different responses in the detectors.
- The sources passing through different path with different transport processes results in different responses in the detectors
- If this difference is sensitive enough, it can be used to inverse analyze for the positions of the sources

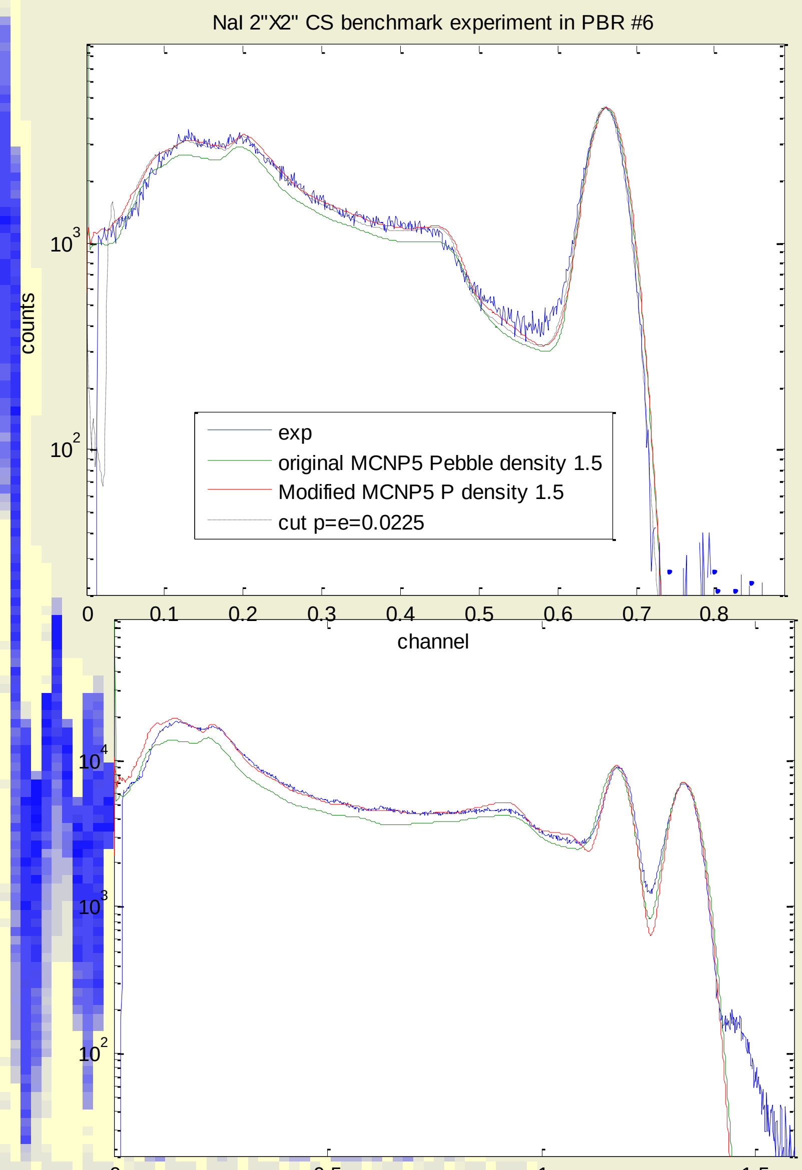
The position sensitivity in PBR





- Potentially good for Inverse analysis (verified both in experiment and simulation results)

Benchmark for tracking system



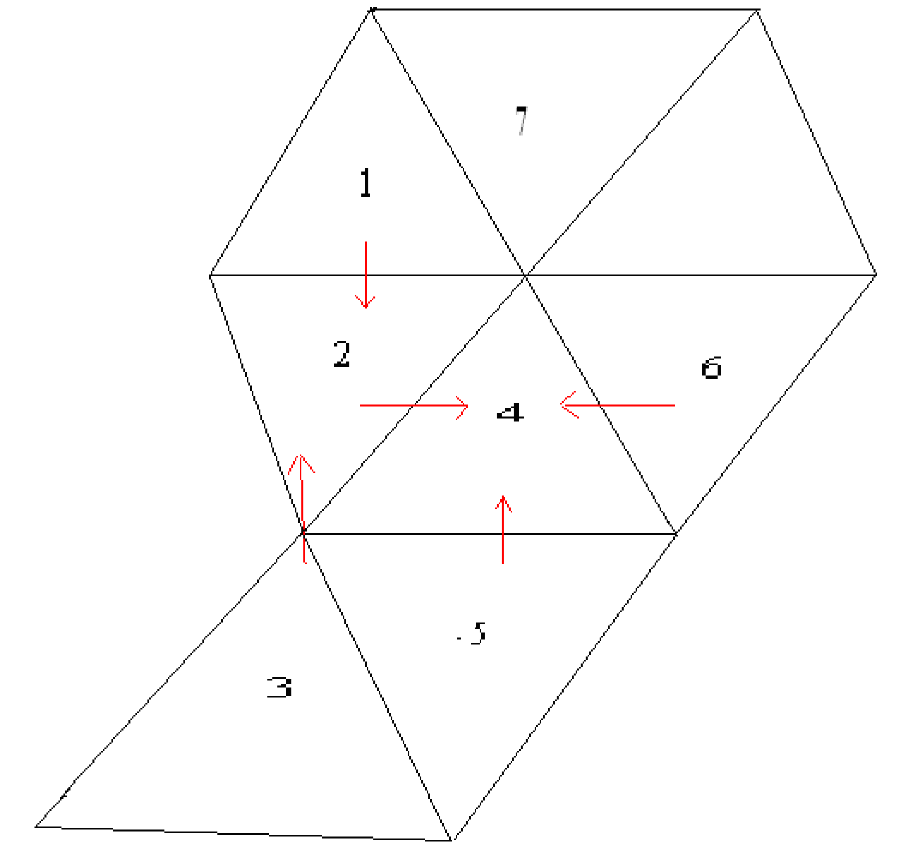
- Multiple energies benchmark experiments for Gaussian Broadening factors

$$\delta = aE^{b}$$

A=2.165404e-002;b=0.7533

The search for the minimum χ^2

- Force the search to go downward first and then to the axis direction
- The search program based on the library matrix

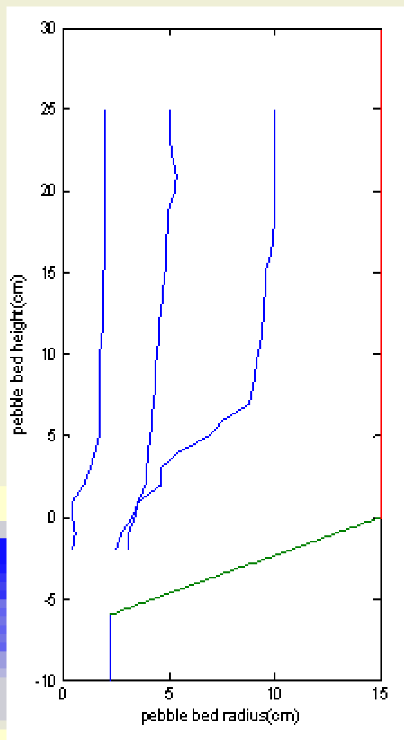


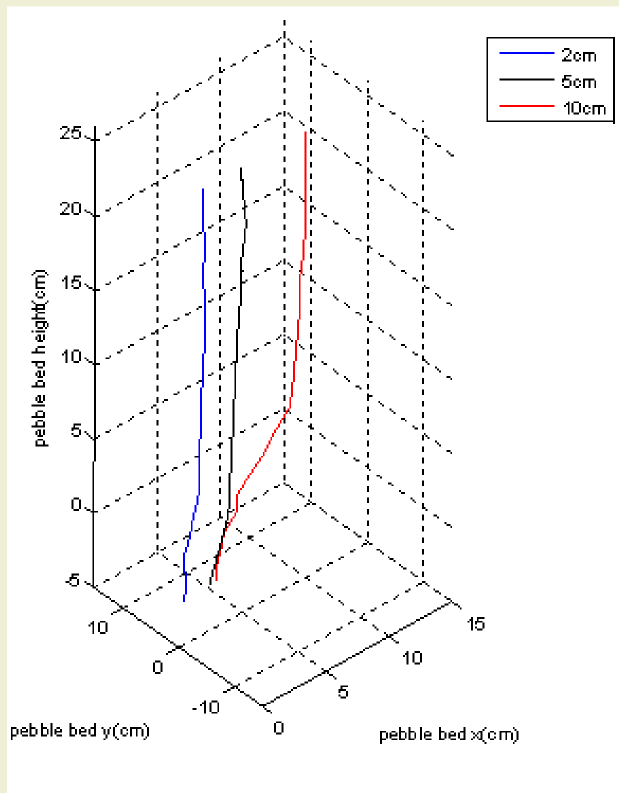
For example step in element #1:

```
if (snchisqr < ochisqr)then
i00=1
kkk=int(i1/16)+1
kk=mod(kkk,2)
if (kas==2) then
nl1o(1)=nl1(1)
nl1o(2)=nl1(2)
nl1o(3)=nl1(3)
i1=nl1(2)
nl1(1)=i1
nl1(2)=i1+1
nl1(3)=i1+16+kk
kas=1
```

The collimated detectors system

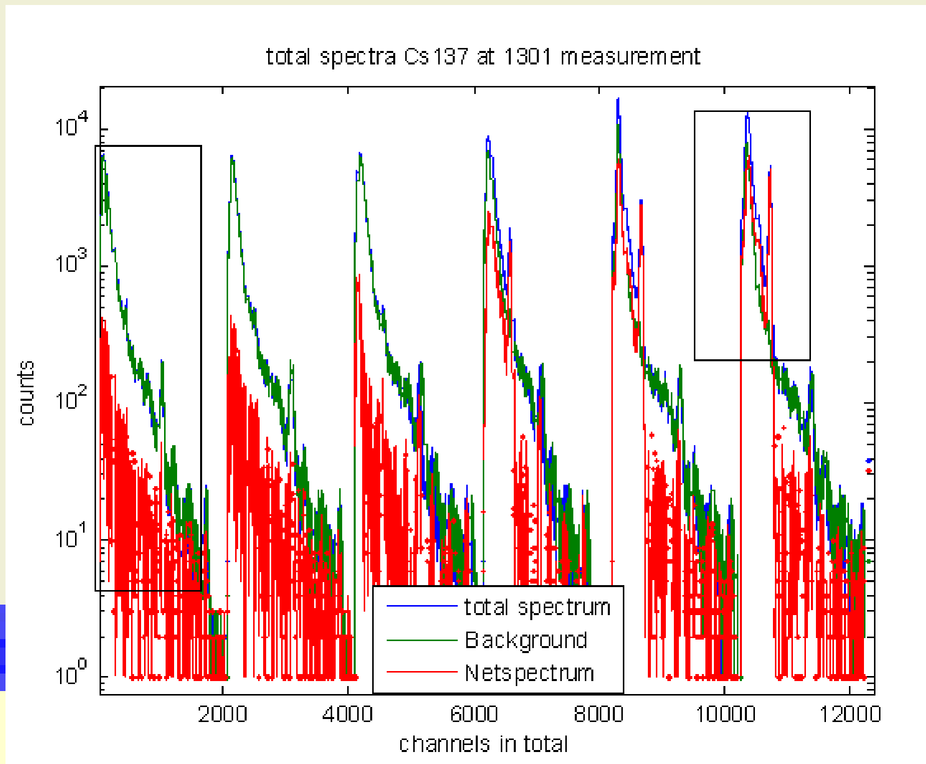
- The streamlined area is likely in Z>10cm.
- The motion focuses on a plane (x-z)

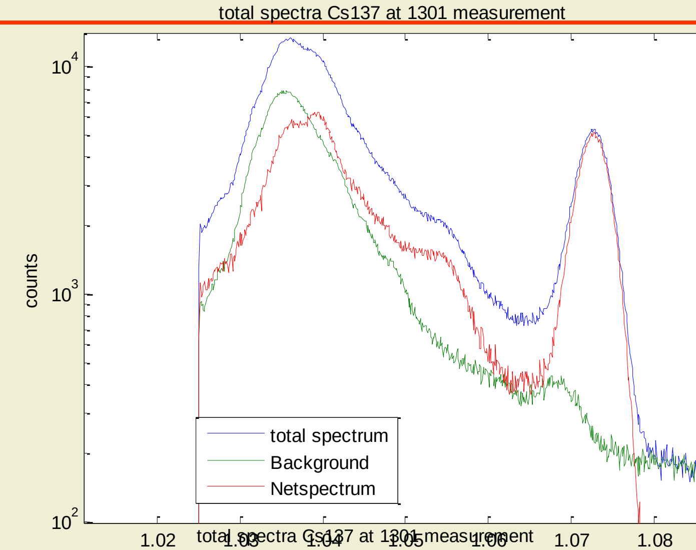


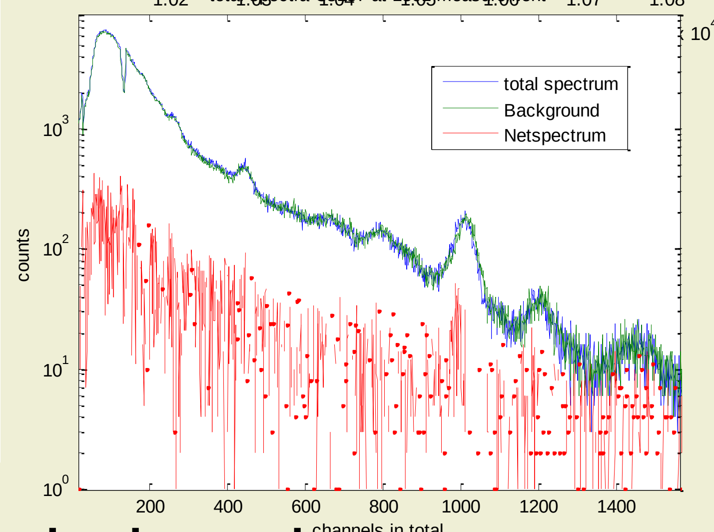


The un-collimated detectors system

Measurements

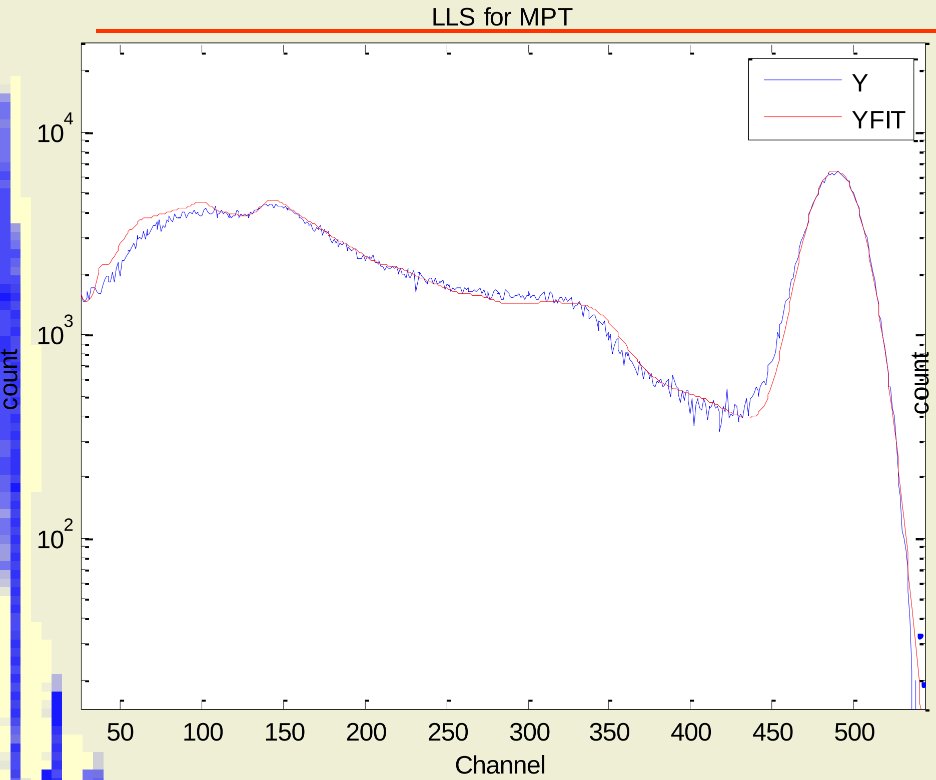


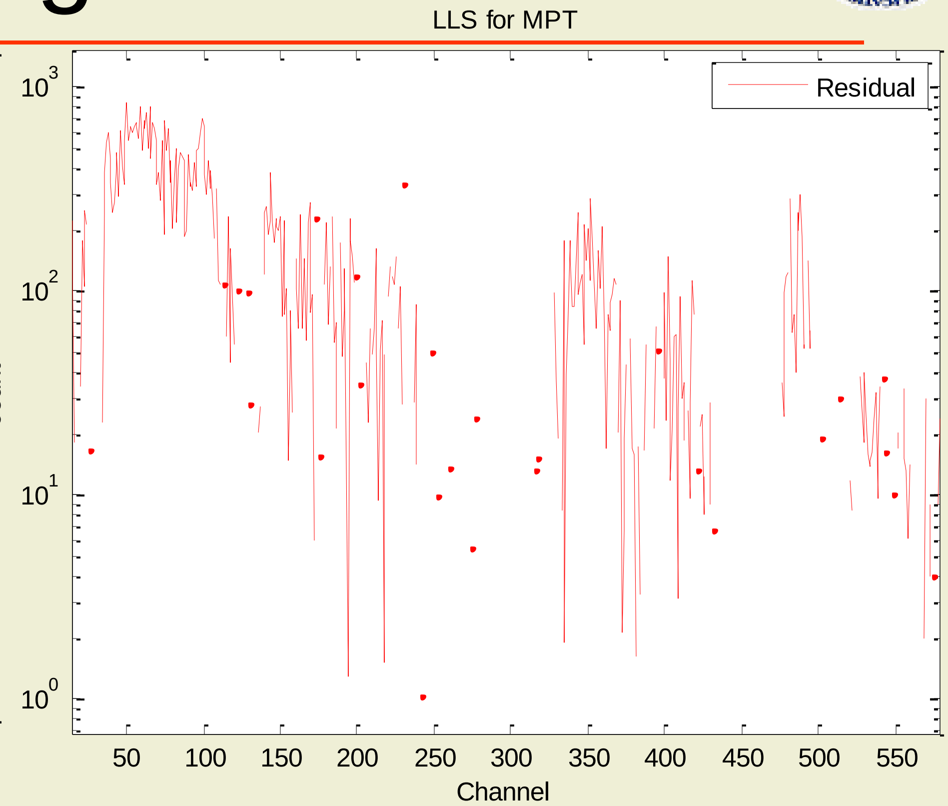




- A weighting out technique is necessary for different detectors

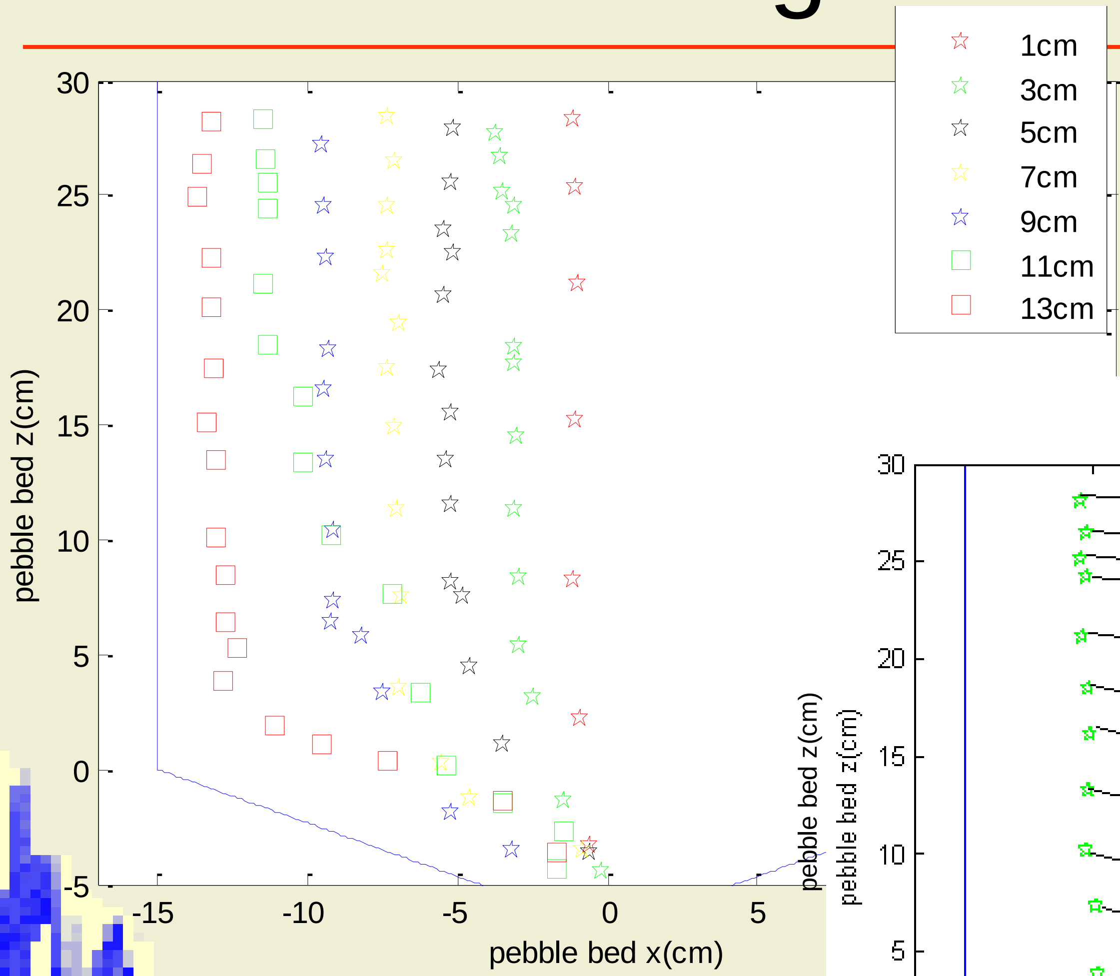
The fitting results





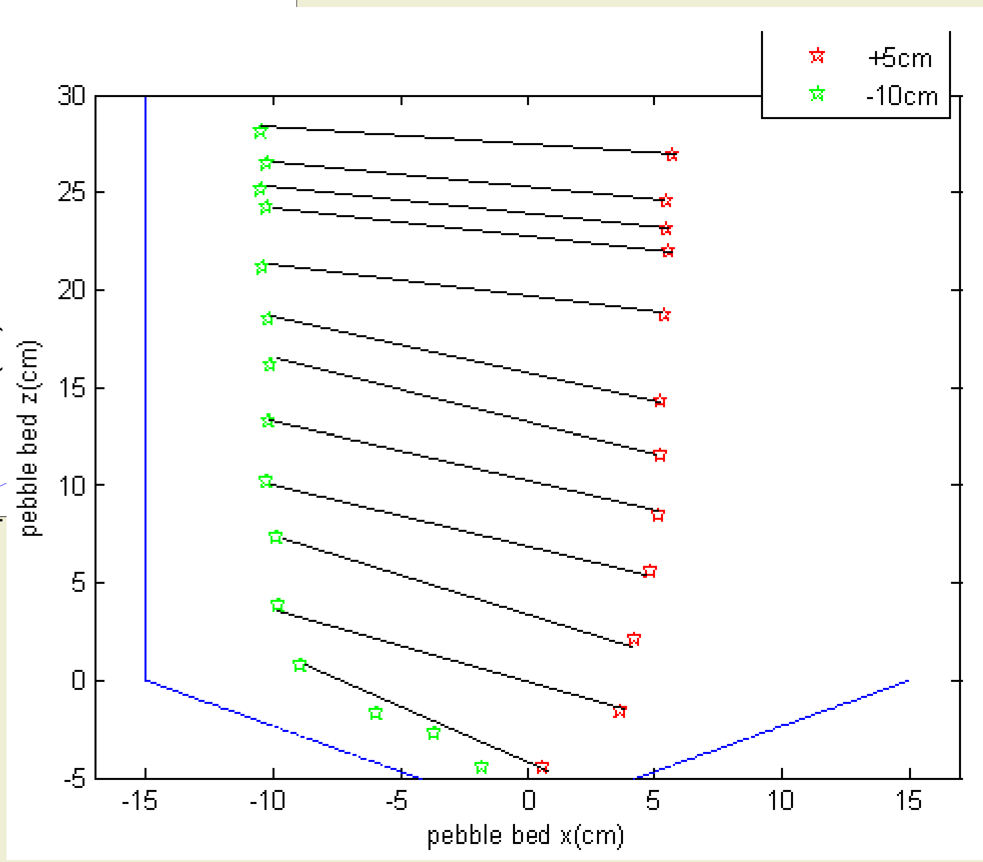
- Pretty good fitting result for overall spectrum
- Little high residual in scatter peak can be weighted out (1-150 channel)

The tracking results in PBR



Single particle tracking (left)

Multiple particle tracking (right)



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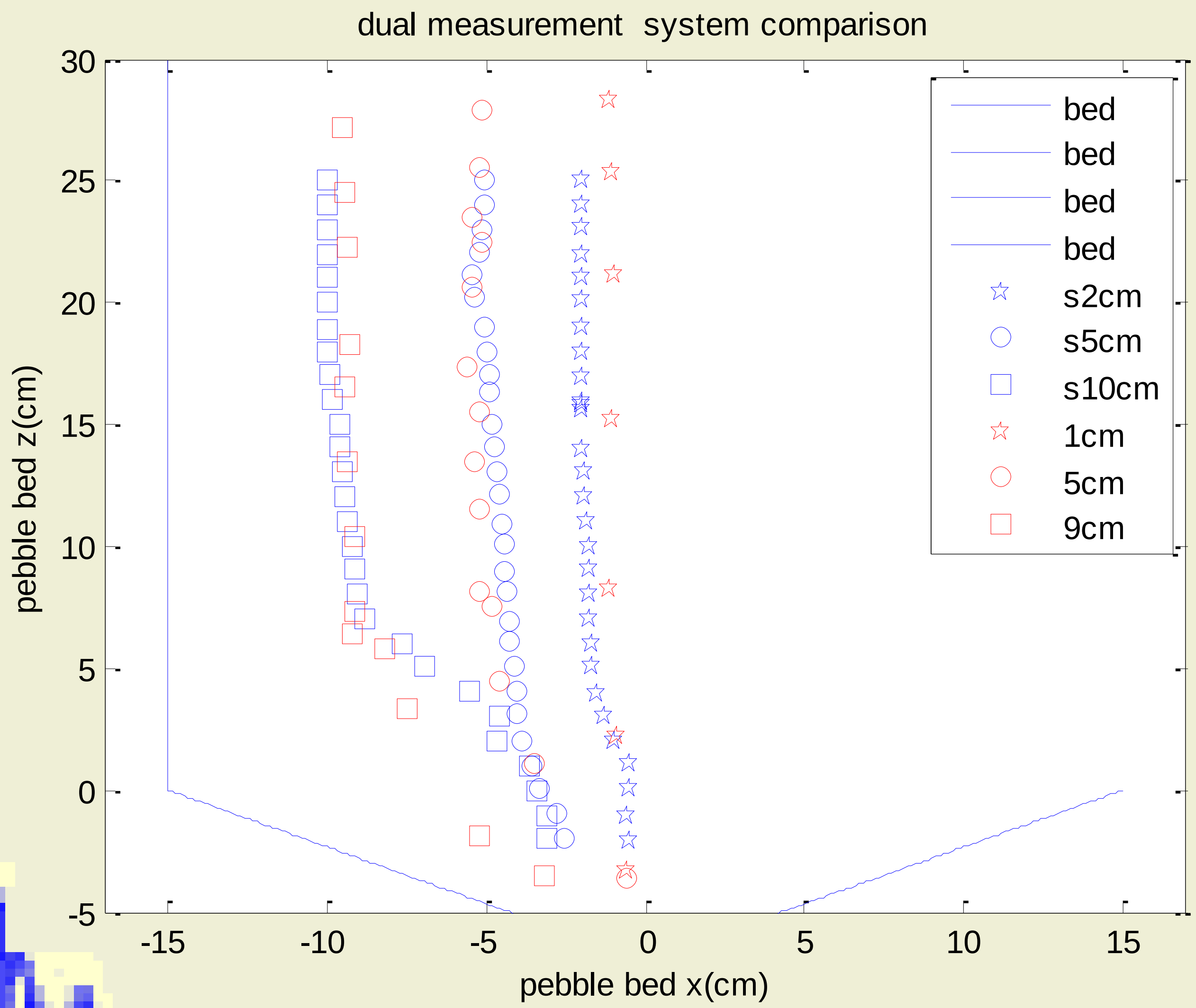
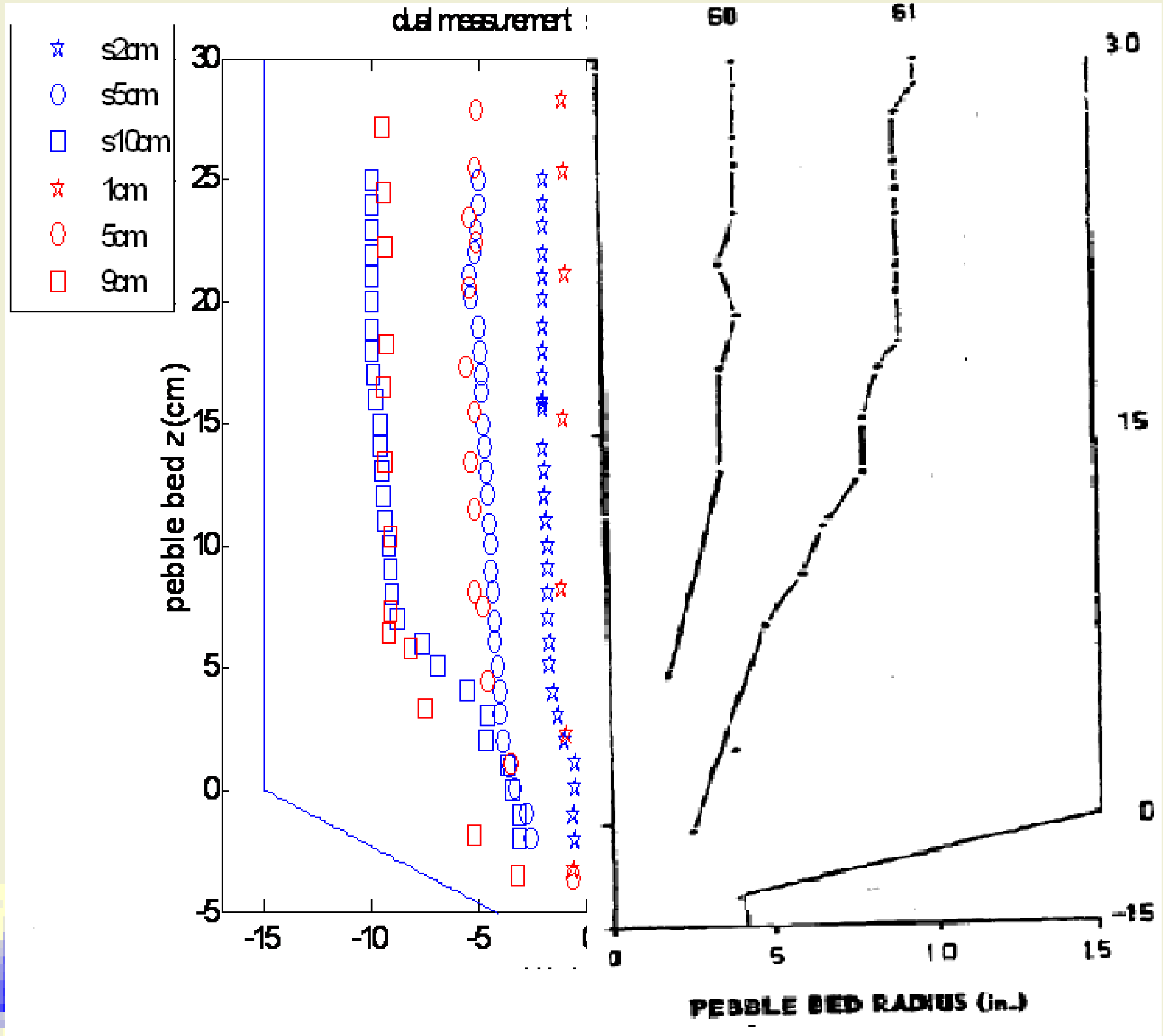
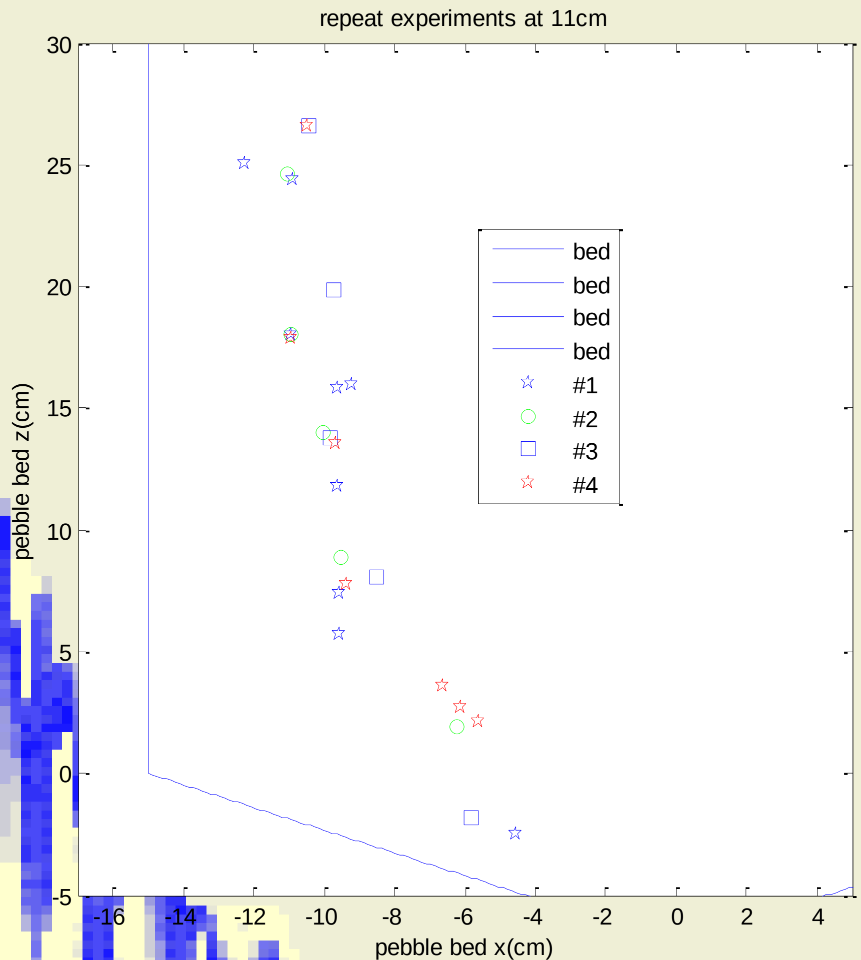
Dual measurements comparison



Comparison with Gatt's



Fluctuation in motion



- All start from around -11cm (x coordinate)
- The fluctuation is quite big in the area close to the 5cm and under

Conclusions and Discussions

- Modeling PBR is designed and used to mimic the PBR.
- The un-collimated detectors system tested in with modeling PBR for multiple pebbles tracking.
- It can do off line fast analysis and multiple particles tracking, which is important for pebbles interactions study, but the system arrangement is complicate and a lot of measurement and analysis techniques are required.
- The benchmark experiments in un-collimated detectors system is very important, and must work with the collimated detectors system

Future work

- The flow fluctuation study and pebbles interaction study.
- Proposal program to NEUP for graphite pebble and high temperature tracking situation.
- More detectors may necessary for big scale modeling PBR.


Спасибо
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Gracias
SPANISH
ありがとうございました。
JAPANESE
CÁM ƠN
VIETNAMESE
Thank You!
ENGLISH
Merci
FRENCH
Ευχαριστώ
GREEK
شكراً
ARABIC
고맙습니다
KOREAN
谢谢
CHINESE