Some Preliminary Thinking about the beam test for the CEPC Tracker

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Motivation

- A successful particle detector, including its sensor, readout electronics, device assembly, and module design needs to do the irradiation testing studies by the suitable beam line facilities, in particular for their properties and performances in harsh radiation environment.

- The first objectives of test beam: detector development and its evaluation in radiation up to the level of appropriate range, to try a possibility for new detector implementation in High Luminosity;

  The second is to study the performance of device or modules, and measure their hit efficiency, energy and position resolutions, … and so on.

I'd like to briefly introduce some of the beam experiments which I've been involved in before.

- **During the 1992-1994, I participated in the SSC project at the University of Arizona, USA, and our research group was mainly engaged in gem detector R&D. Every summer, our team was going to the Brookhaven National Laboratory in long island, New York for beam test experiments.**

- **From 1996 to 2006, I joined with the detector construction of the LHC-ATLAS project at CERN. Nanjing University, as a main member of the ATLAS-China Cluster, mainly involved in R & D of Liquid Argon Calorimeter. Our group is mainly engaged in Hadronic End Cap detector's design, development, assembly and beam test experiments. So that, I took part in the relevant modules' beam tests many times during the past 10 years.**

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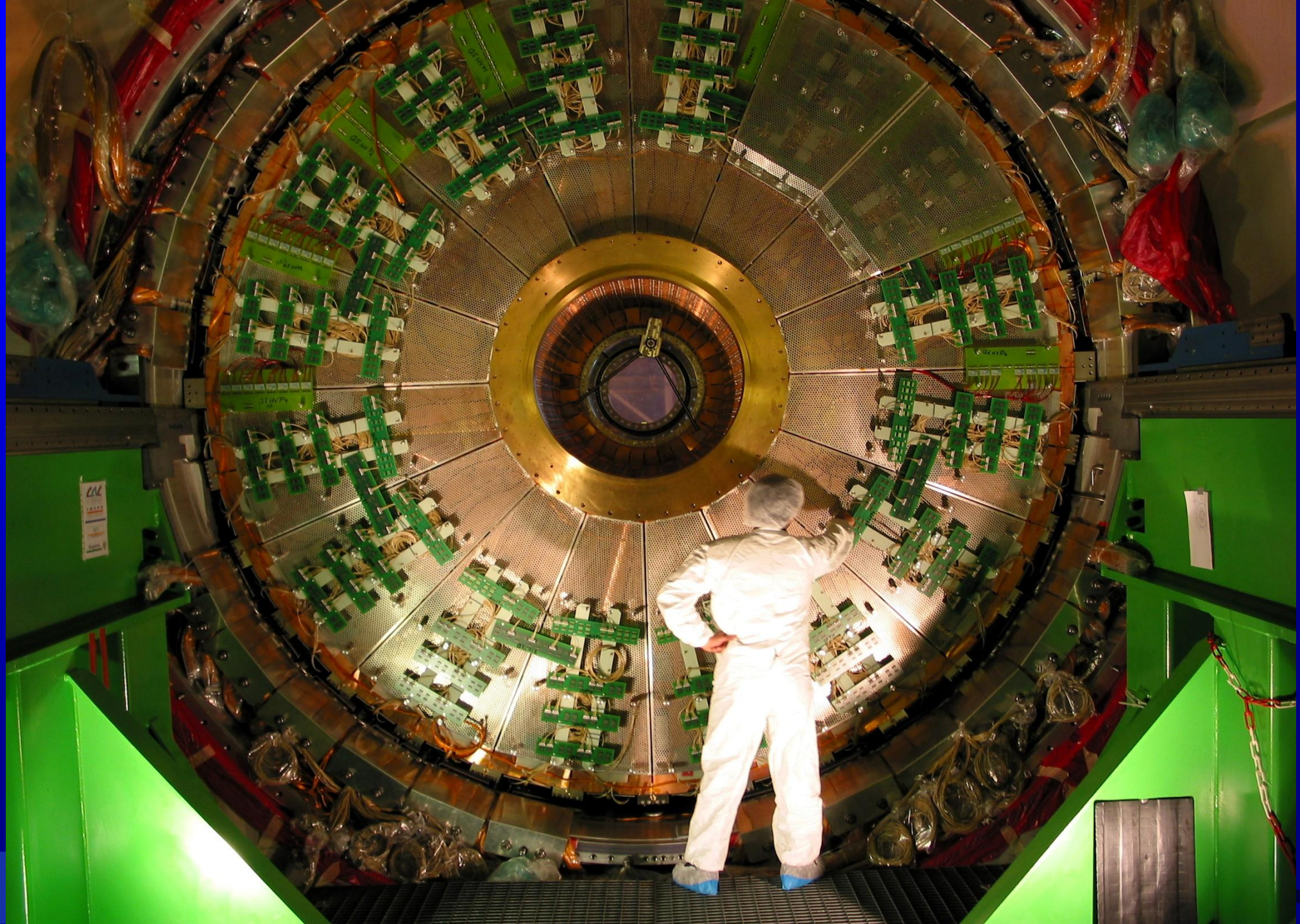

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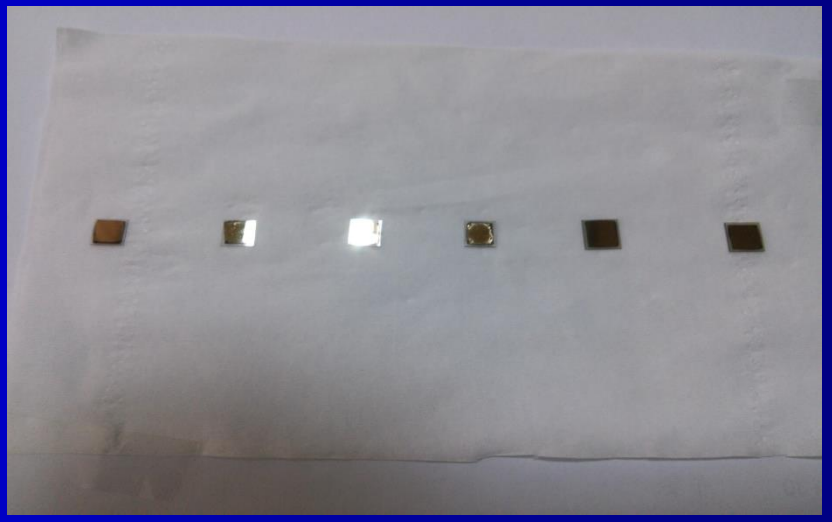
Neutron irradiation for the Diamond sensors at Dubna

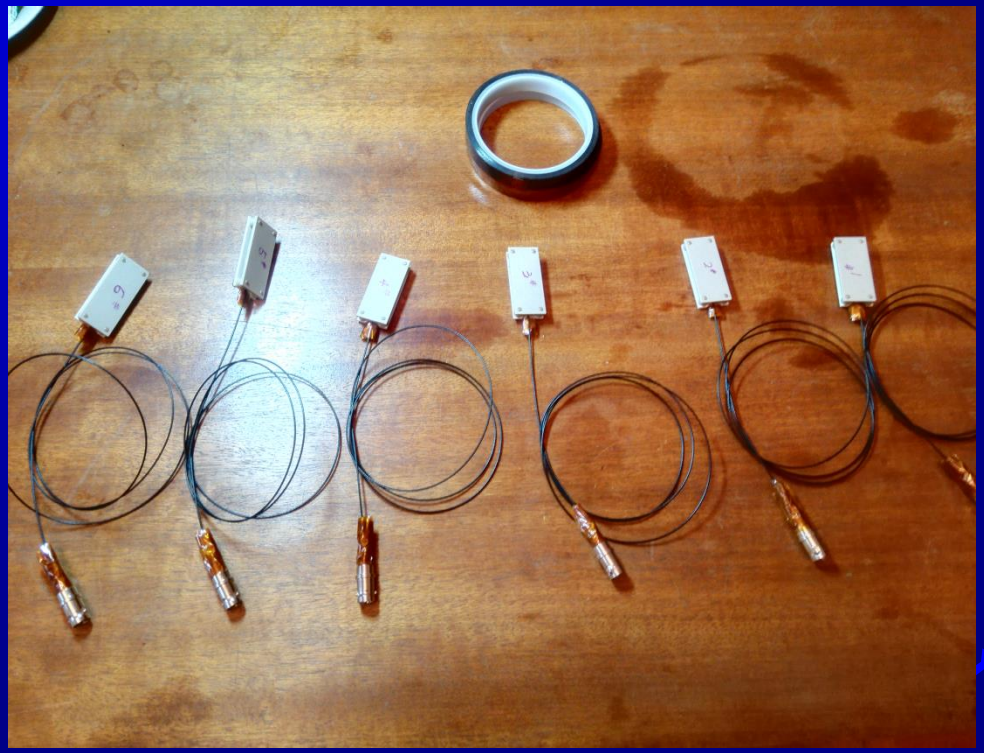
- With the great helps from ATLAS JINR Team, we have fulfilled the first beam test of Neutron irradiation in Dubna, from Oct. 12 – Nov. 01, 2015;
- In Oct. 2010, the ATLAS-Canadians have done proton beam 500MeV- 2.25 x 10^{17}p/cm^2 irradiation test at TRIUMF, Vancouver;
- A lot of preparation works have been done for this testing.

- the main purpose of these beam tests are to determine the radiation hardness of diamond detector, with 500MeV proton, to a fluence of $2.25x10^{17}p/cm^2$; or 1-2MeV neutron, to a fluence of $2.5x10^{17}n/cm^2$ irradiation.
- this is equivalent to the effect of device can run for 10 years in the HL-LHC, i.e. integrated luminosity up to $5x10^{34}$, (or $1x10^{35}$ and more high), the final response values reduced not below to 5% of the initial value.

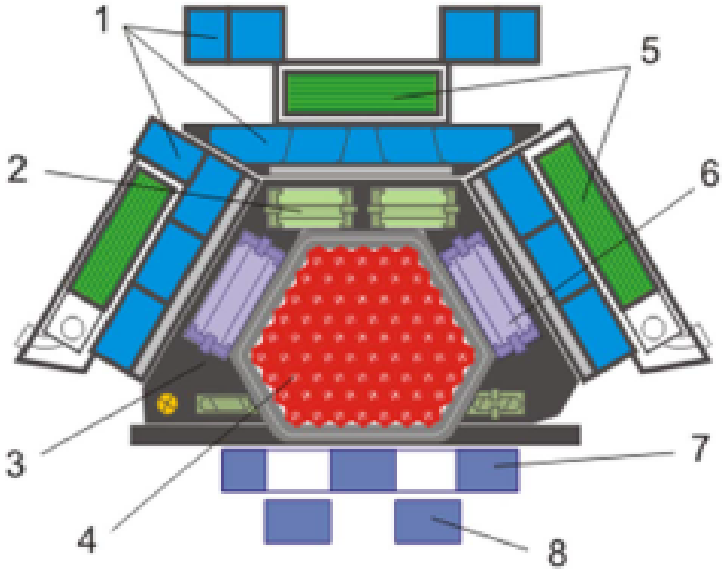
A total of 6 pieces of DD modules were installed in the arm's box, 4 sensors are scCVD, 2 are pCVD;

(thickness 280-330 μm, size 0.6 x 0.6 cm^2)

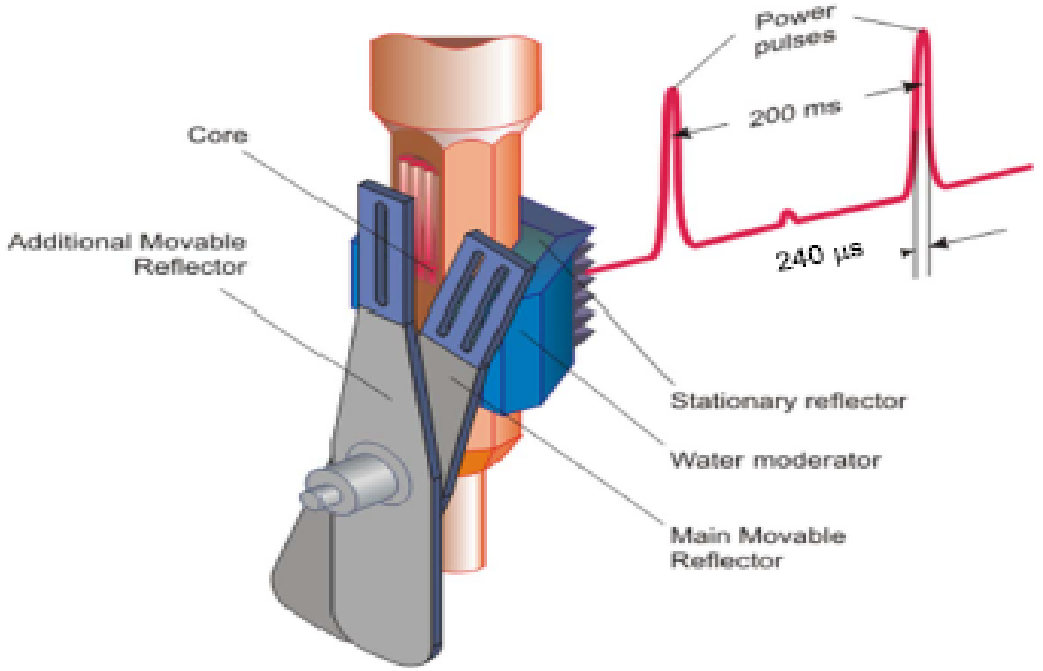




IBR-2 reactor at JINR, Dubna



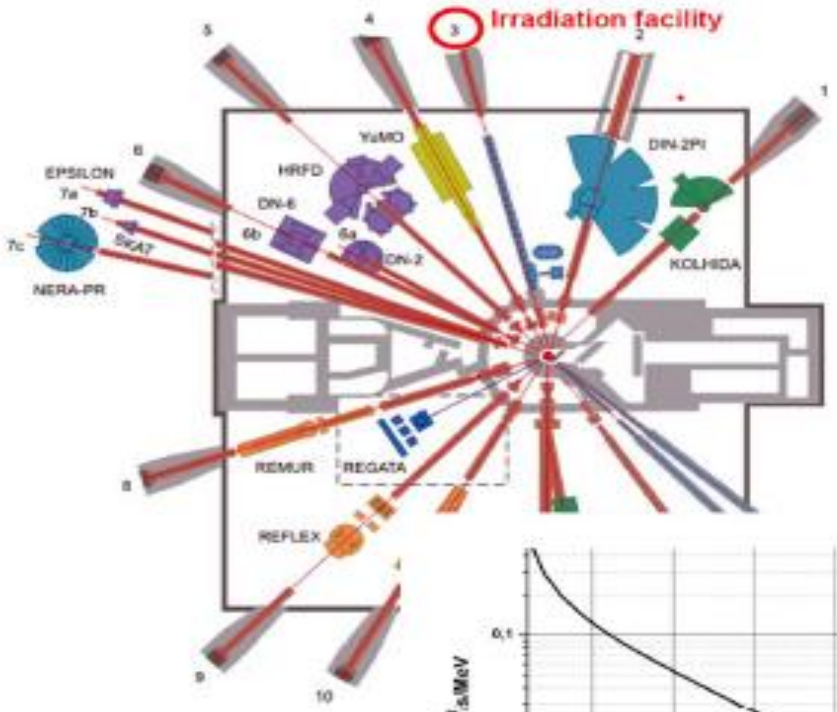
1 - Water moderators
2 - Emergency system
3 - Stationary reflector
4 - Fuel assemblies
5 - Cold moderators
6 - Control rods
7 - Main movable reflector
8 - Auxiliary movable reflector

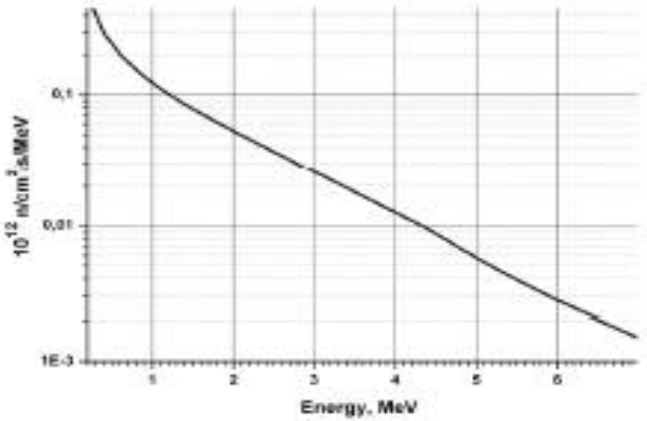


Average power, MW	2
Fuel	PuO_2
Pulse repetition rate Hz	5
Pulse half-width. μs	240
Rotation rate, rev/min	
main reflector	600
auxiliary reflector	300
Thermal neutron flux density at moderator's surface	
- time averaged	10^{13} n/cm^2/s
- burst maximum	10^{16} n/cm^2/s

Beam line and neutron spectrum

The facility details were shown by V. Kukhtin at Como-2013: *http://villaolmo.mib.infn.it/home*



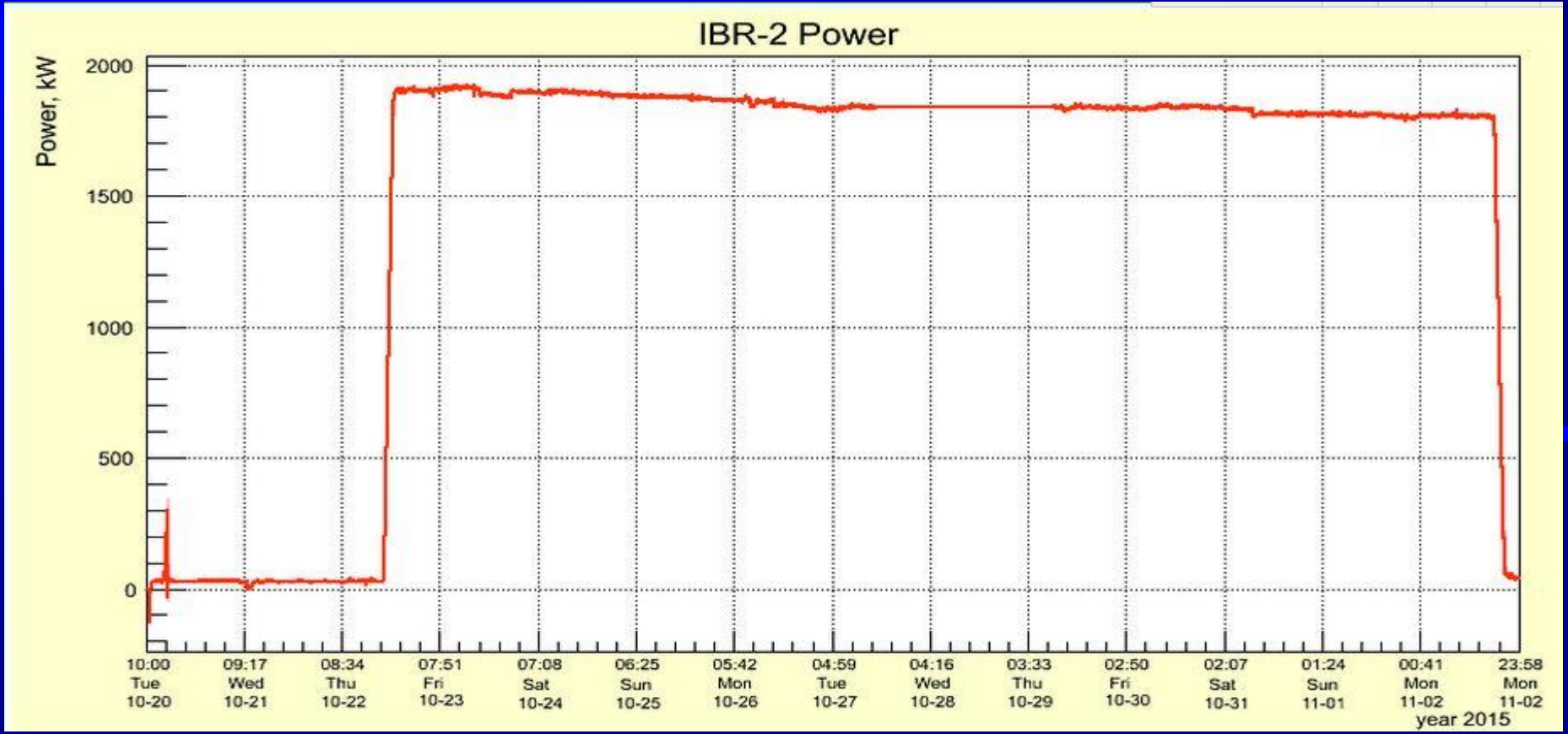


neutron energy spectrum has tail above 6 MeV

Al arm with samples moves towards reactor core

Flux is defined by the distance and total dose is controlled by a set of foils

IBR-2 reactor power kept almost stable during the whole irradiation, only has a slightly decline than nominal in the second half of testing period.



Expected ionization signal

No activation reactions below 6 MeV

$C^{12} + n \rightarrow Be^{9} + \alpha$ starts at 6.2 MeV (~0.1B)

Both α and Be produce ionization

Predicted average ionization current for IBR conditions ~ 1-2 μA → quite measurable

Dark current < 1 nA

(n,α) cross section vs. neutron energy

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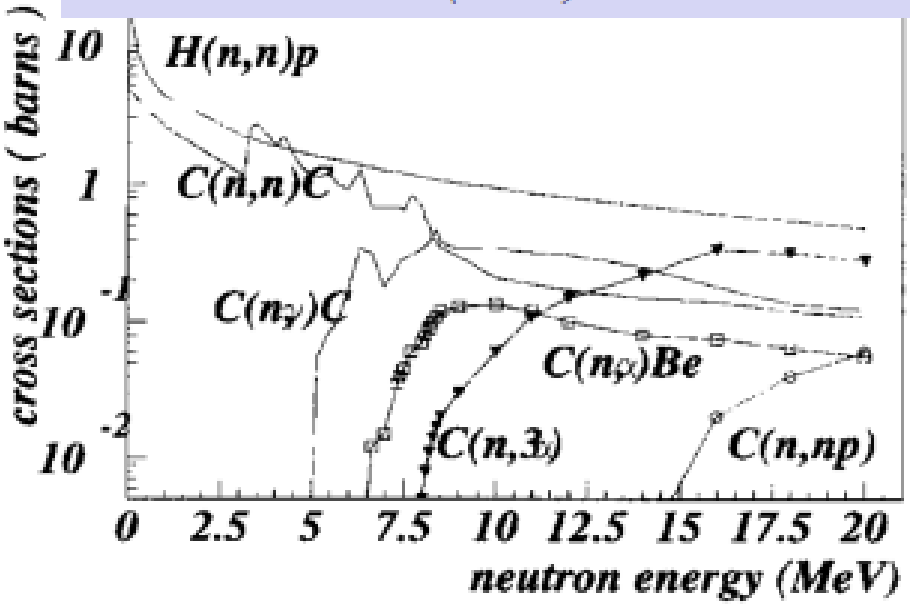


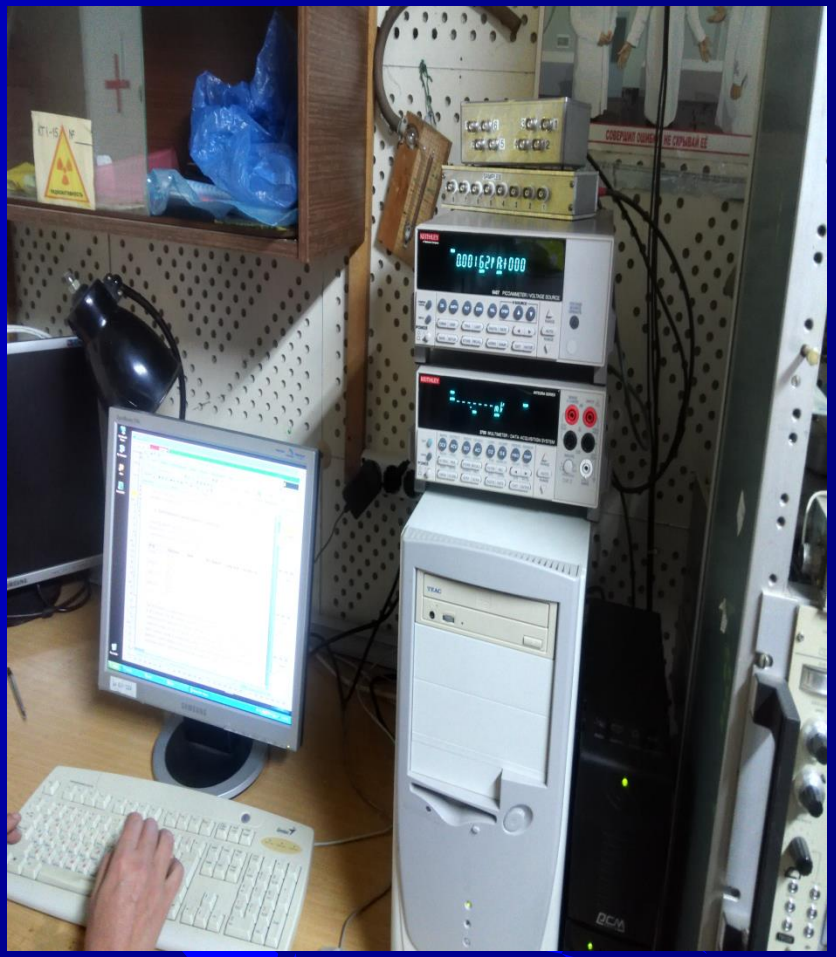
Measurements concept:

Integrate (average) IBR modulated ionization pulses (rate 5 pulses/s)

Measure DC current by a DMM with HV bias on

Test setup

- Multi-channels DMM (Keithley 2700 with GPIB control/readout)
- Box with passive RC integration
- Stand-alone HV unit (Keithley 6487) provides ±260V bias, 20V/ per step
- Continuously running DAQ program reads DMM channels for every measurement cycle / 30 minutes



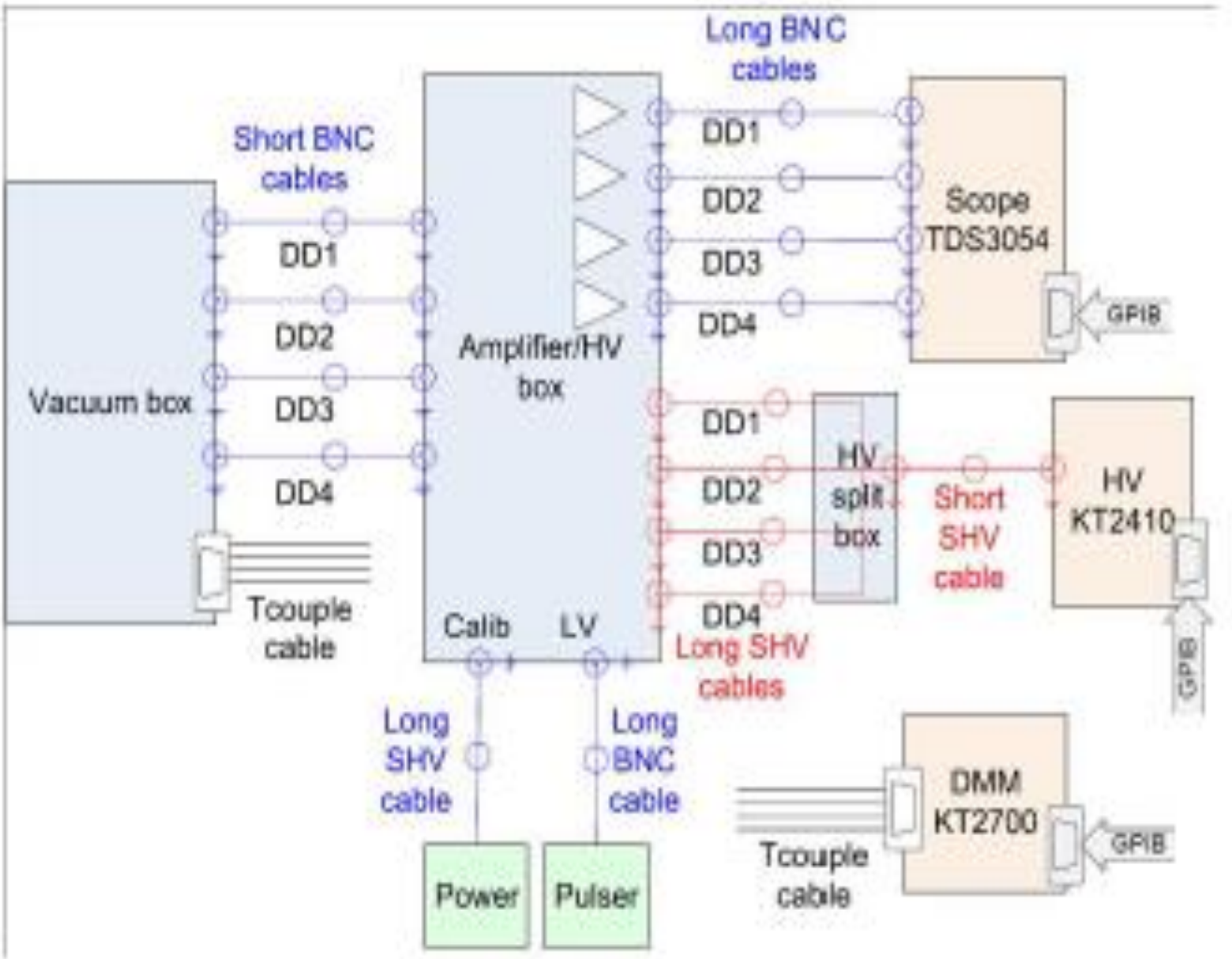


Figure 4. Schematic of the components in the beam line tunnel and the data acquisition system.

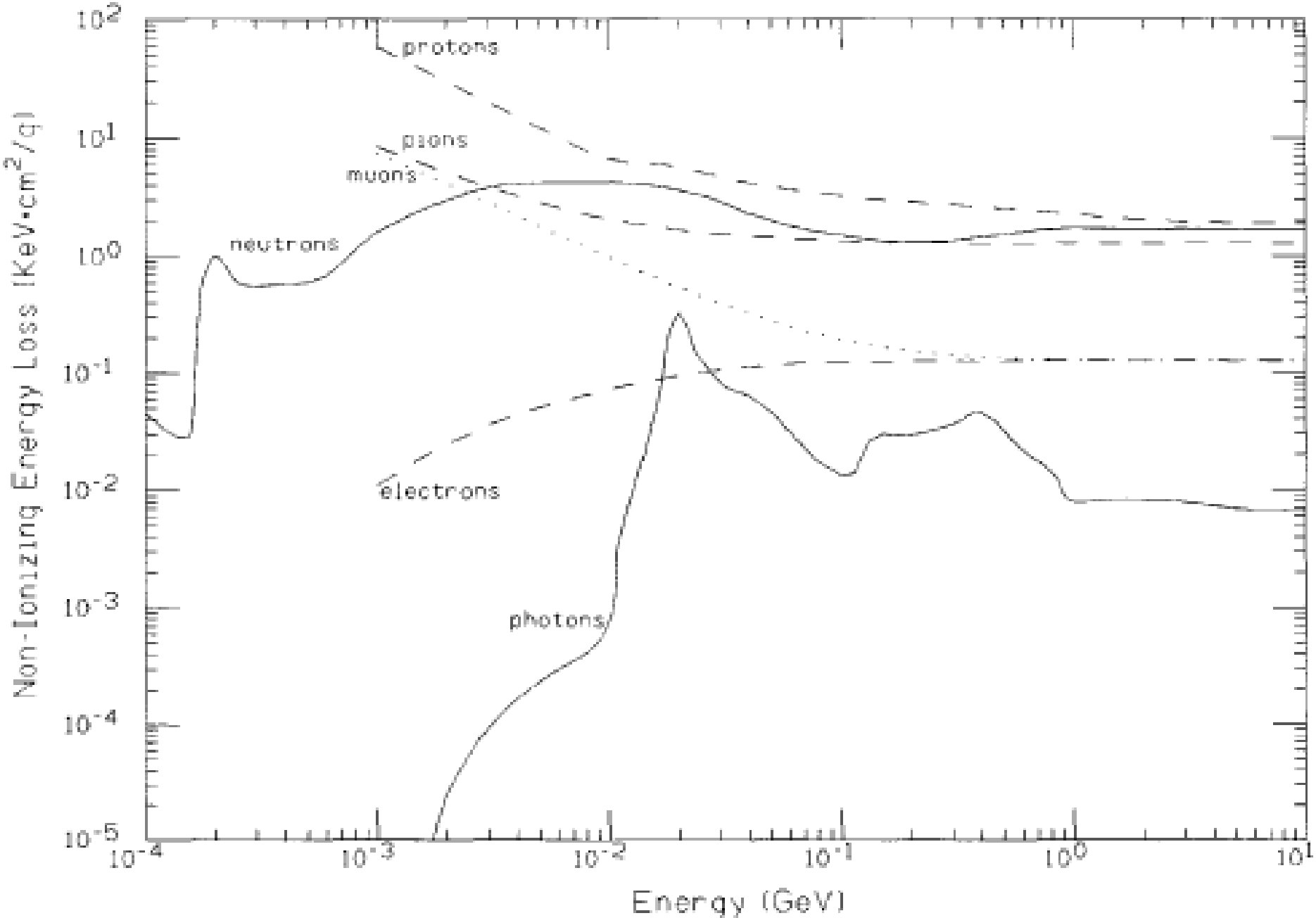
Understanding of the radiation damage mechanism to the silicon-based devices/detectors

The radiation hardness of silicon based sensors/ devices was investigated so many years. the signal loss is mainly proportional to the Non-Ionizing Energy Loss (NIEL), sometimes it depends on the effect of a single particle. At incident proton and neutron energies well above 0.1 GeV the radiation damage is dominated by the inelastic cross section, while at non-relativistic energies the elastic cross section prevails.

- At low beam energies E, the NIEL cross section is dominated by the long-range Rutherford scattering, which falls like $1/E^2$ and creates many small scale lattice displacements.
- At intermediate energies (above a few MeV) the anomalous elastic Rutherford scattering from the nuclear interactions between the incoming beam and the nuclei in the sensor starts to play a role.
- while at energies above a few hundred MeV the inelastic cross section, which is almost energy independent, dominates. The inelastic collisions fragment the nuclei and the slow moving nuclear fragments lead to strong lattice defects by the Rutherford scattering again. Impurities like oxygen, can reduce the signal losses by forming stable non-trapping defects with the vacancies, thus leading to a deviation from the NIEL scaling hypothesis.

图 2.1-1 质子在铅中的阻止截面。曲线的形状在不同的能区用不同的理论描述

Fig. 1. Non-Ionizing Energy Loss versus Incident Energy



With the dose integration increased gradually, the density of the crystal defects will also rise up, and result in generation of the lattice distortion, which could enhance obviously the multiple elastic scattering for the incident ions. So that, the "dechanneling" effect will happen and influence seriously the detector response. The signal degradation will exponentially increase with the accumulation of irradiation dose.

The very preliminary Plan for the beam Test during this five year period

- To test and develop 3 - 4 batches of the Si-based sensor/trackers (prototype) for metallization and characterization, including irradiation damage test (protons and neutrons; electrons? pions? more?).

- Some samples of diamond sensor and others will also be studied at the same time for the further comparison.

Open issues:

- What are the different purposes and requirements of beam tests from your diverse sensors and devices?
- Where and which type of the beam line facilities we should be to select?

  such as: PS/SPS in CERN; PSI in Switzerland; IUC in IU, and MGH in Boston, MA, USA; IBR-II in Dubna, Moskva; Proton Cyclotron Facility in TRIUMF, Vancouver, and CIAE(401) in Beijing, CSNS in Dongguan, Guangdon?
- Which kind of the equipment and instruments, and related components of the testing set up we need to collection and preparing from now?

Many thanks to those who are listening !