Possibilities for Collaborations on KSTAR: Magnetics, TRANSP and TSC, X-Ray Imaging Crystal Spectrometer

Presented by L. R. Grisham

For PPPL

Compiled from many contributors

KSTAR Workshop April 15-16, 2009

Motivation to Study Error Fields

Dennis Mueller

- Plasma TV showed obvious vertical displacement downward of KSTAR plasma

- Up/down coils were connected in series

- Implies a stray field either from eddy currents or some other source
  - –Since the source is unknown, the stray field may not be purely radial

- During plasma operation, an early gas puff was needed in order for reliable plasma ramp-up
  - –This implies problems with low density operation
  - –Error fields are more likely to cause locked modes at low density

- Locked modes limit plasma Beta and the low density limit;

Resolution requires: discovering the source(s) and applying corrective action(s).

Probe Drives for KSTAR E-Beam

- PPPL has two probe drives capable of 1 meter of motion
- Were used on TFTR to move e-beam and detector
- Could be loaned to KSTAR if would be useful mounts for the e-beam and detector screen it is building

•Had some discussions at PPPL of how to apply NSTX error field measurement techniques to KSTAR

PPPL PRINCETON PLASMA PHYSICS LABORATORY

Supported by

U.S. DEPARTMENT OF ENERGY | Office of Science

Error Field Correction using IPEC (Ideal Perturbed Equilibrium Code)

College W&M
Colorado Sch Mines
Columbia U
Comp-X
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Maryland
U Rochester
U Washington
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Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

US-Korea KSTAR Workshop
April. 15, 2009

Ideal Perturbed Equilibrium Code (IPEC) solves free boundary perturbed equilibria in ideal MHD

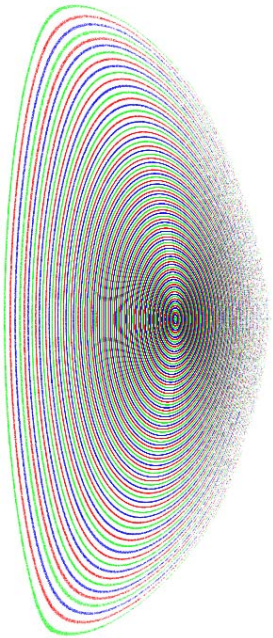
- Given an axisymmetric equilibrium (such as EFIT) and given an external (vacuum) non-axisymmetric error field, IPEC solves free boundary perturbed equilibrium with ideal constraints [*Park et al, Phys. Plasmas 14, 052110 (2007)*]

- IPEC gives far better description for tokamak plasmas with error field, before the onset of locking and islands opening, than vacuum superposition

NSTX
#129916
n=3 EFC field

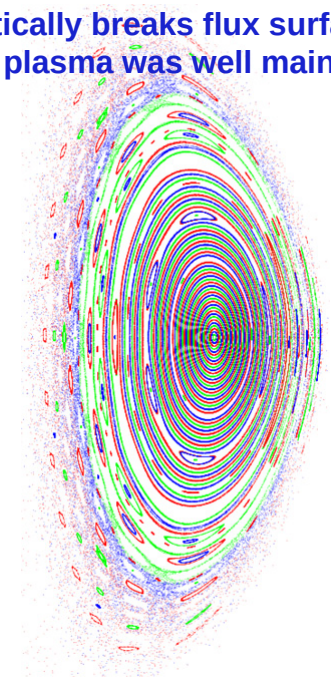
Field line tracing

EFIT



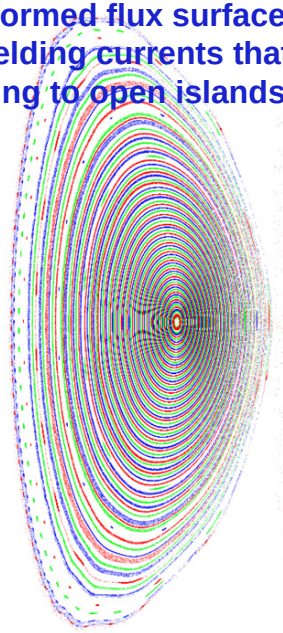
EFIT+ Vacuum field

Unrealistically breaks flux surfaces even if the plasma was well maintained



IPEC

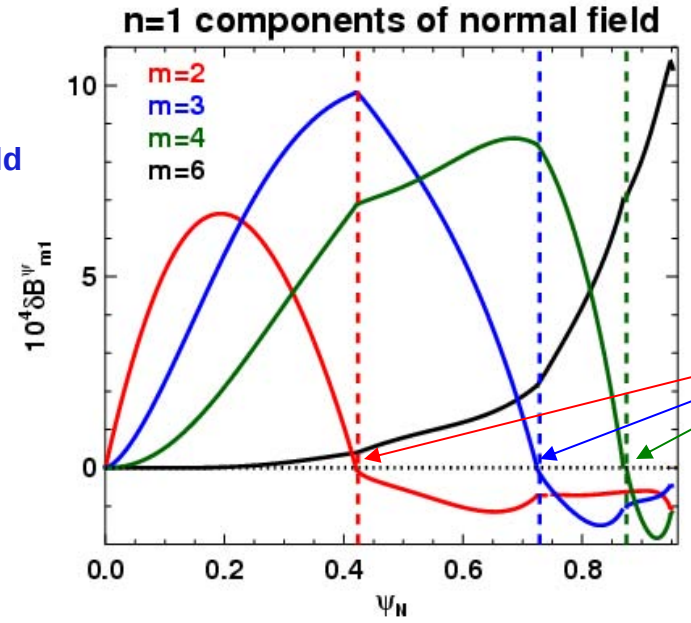
gives deformed flux surfaces with the shielding currents that are trying to open islands



Non-axisymmetric error field can cause plasma locking

- Plasma locking is an event destroying flux surfaces by opening islands at the rational surfaces in the presence of error field
  - Resonant field driving islands is the critical information
  - IPEC calculates **the total resonant field suppressed by shielding currents (jump in the derivative of normal field),** instead of **the external resonant field** that is calculated by the direct superposition of vacuum field

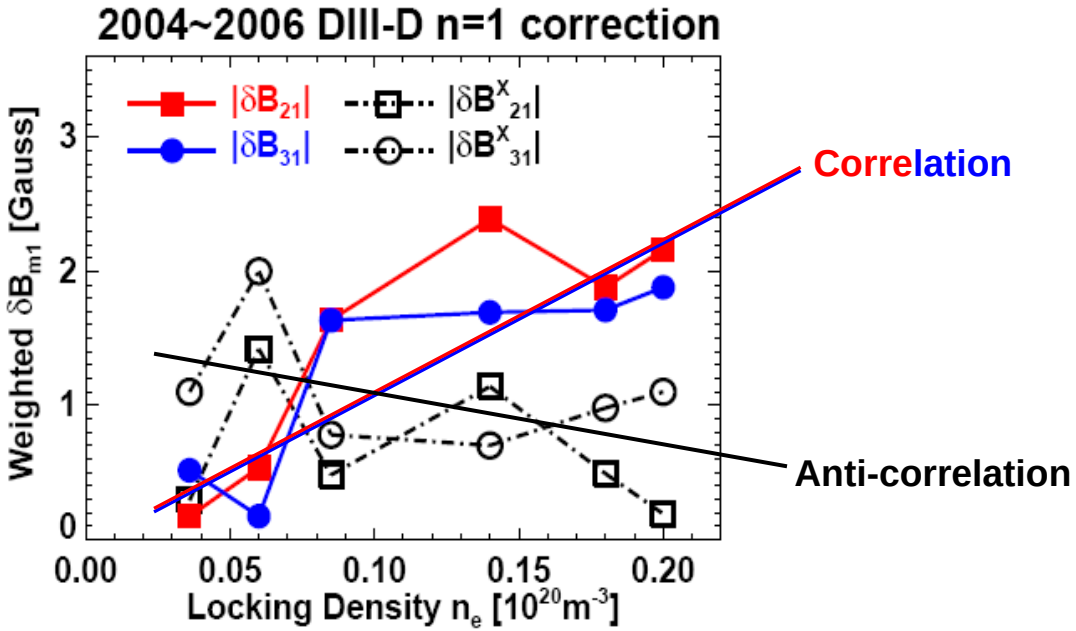
DIII-D
#127737
n=1 I-coil field



- External resonant field : δB^{x}_{mn}
  Incorrect, often paradoxical
- Total resonant field : δB_{mn}
  Correct in ideal MHD, and far better

Total resonant field explained NSTX and DIII-D error field problem

- Some paradoxical error field correction results in NSTX and DIII-D have been explained by IPEC total resonant field
  - Expected linear correlations between the resonant field and locking density were restored



[*Park et al, Phys. Rev. Lett. 99, 0195003 (2007) with corrections*]

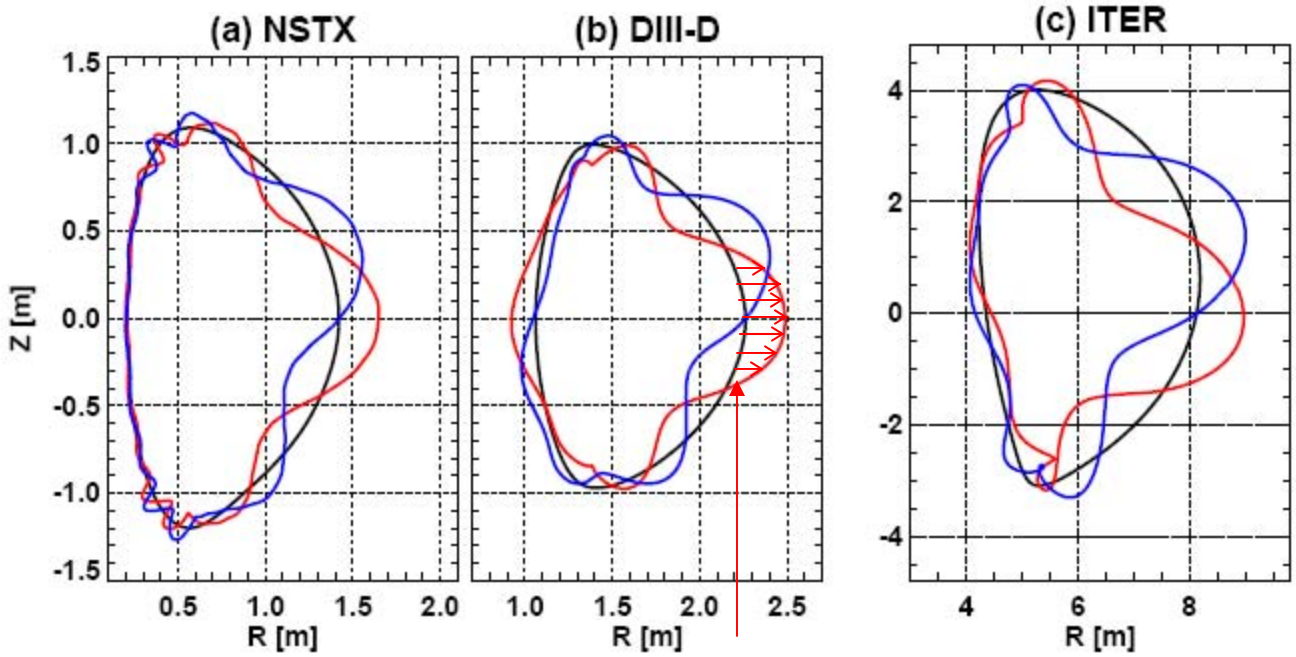
[*Park et al, to be published in Phys. Plasmas explains the corrections using the weighted (invariant) resonant field*]

IPEC can give an intuitive way for error field problem

- The shape of the normal external (vacuum) field to which plasma core is most sensitive can be resolved

Shape of the n=1 dominant external field for the core (>80%)
<Cosine part (red) and Sine part (blue)> on the plasma boundary

$$\delta\vec{B}^{x}\cdot\hat{n}_b = A(\theta)cos(n\phi) + B(\theta)sin(n\phi)$$



This is the shape of the external (vacuum field) to be minimized, and other distributions of the external field are less important roughly by an order of magnitude

Total resonant field, and overlap field with normalized dominant external field can be used for locking scaling

- Three US major tokamaks data are being collected for scaling

Total resonant field at q=2 rational surface

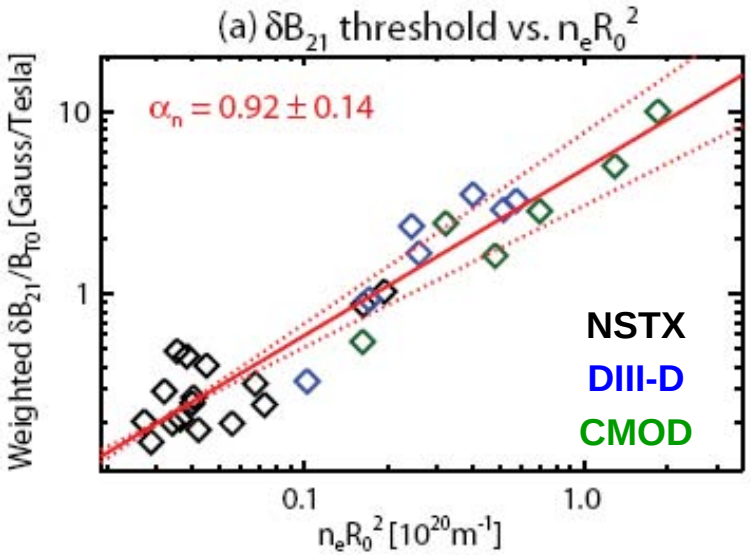
$$\frac{\delta B_{21}}{B_{T0}} \approx 16\times10^{-4}\times n_e^{0.92}[10^{20}m^{-3}]B_{T0}^{-1.3}R_0^{0.22}$$

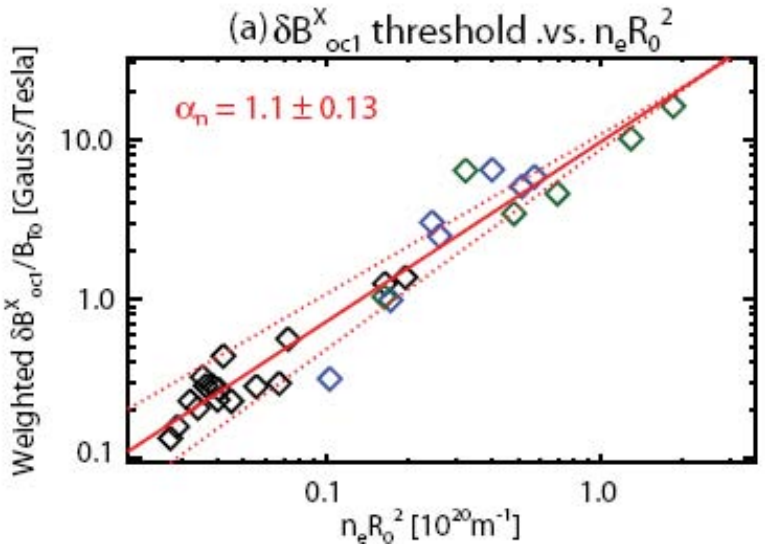
For ITER scen2, $\delta B_{21} \approx 14\,Gauss$

Overlap external field with (dominant external field normalized over the surface)

$$\frac{\delta B^x_{oc1}}{B_{T0}} \approx 11\times10^{-4}\times n_e^{1.1}[10^{20}m^{-3}]B_{T0}^{-1.8}R_0^{0.05}\beta_N^{-0.46}$$

For ITER scen2, $\delta B^x_{oc1} \approx 3\,Gauss$

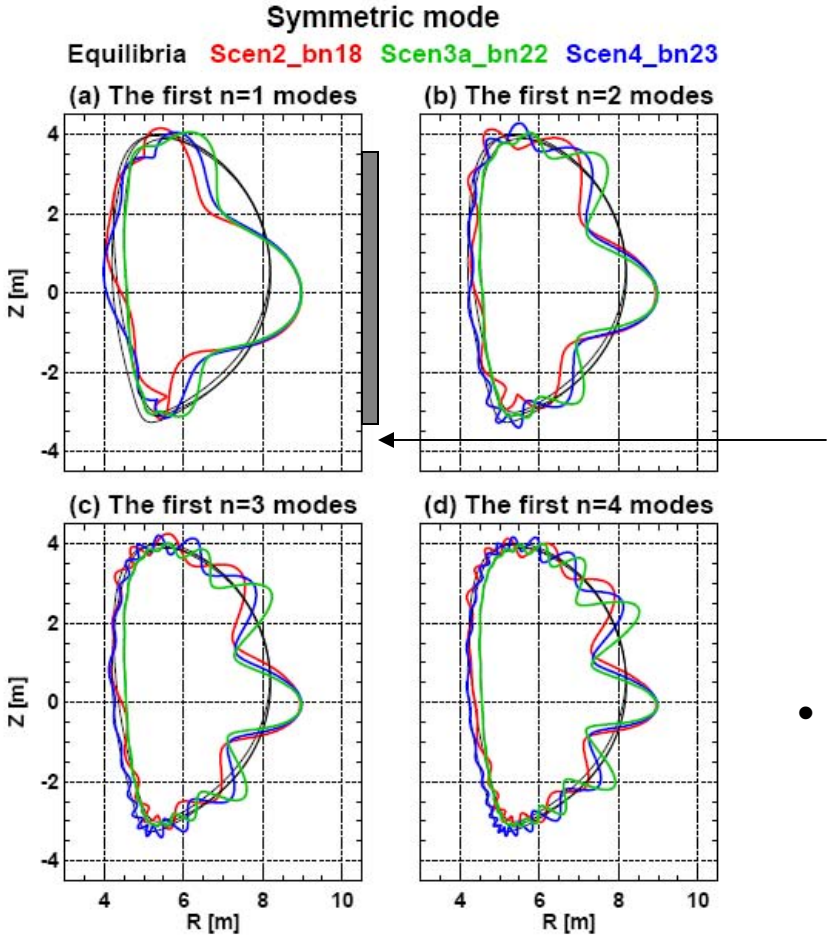




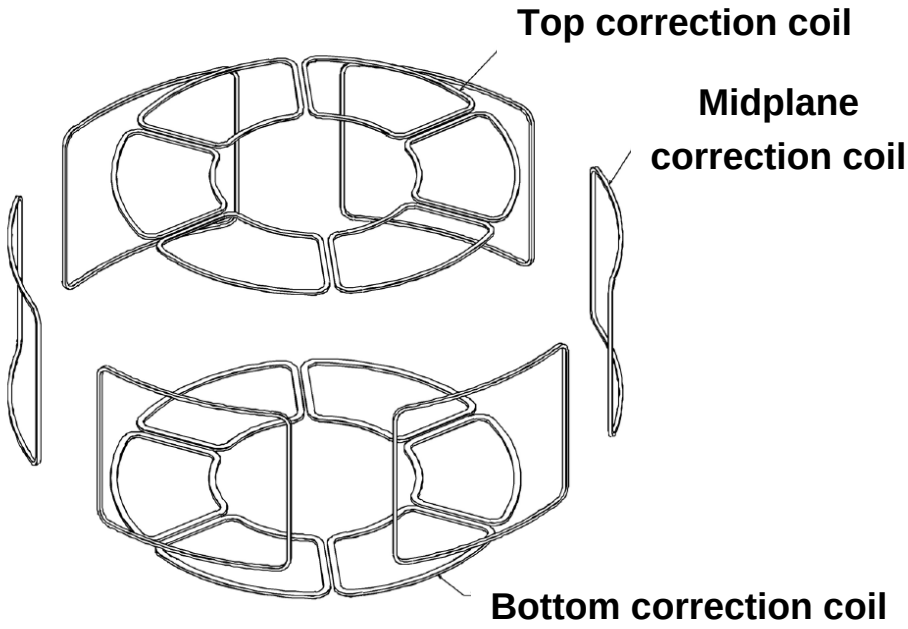
[Park, Ph. D Thesis, Princeton (2009)]

Dominant field for the core can make the assessment for error field corrections in ITER more reliable

- Dominant field for the core is very similar across different scenarios



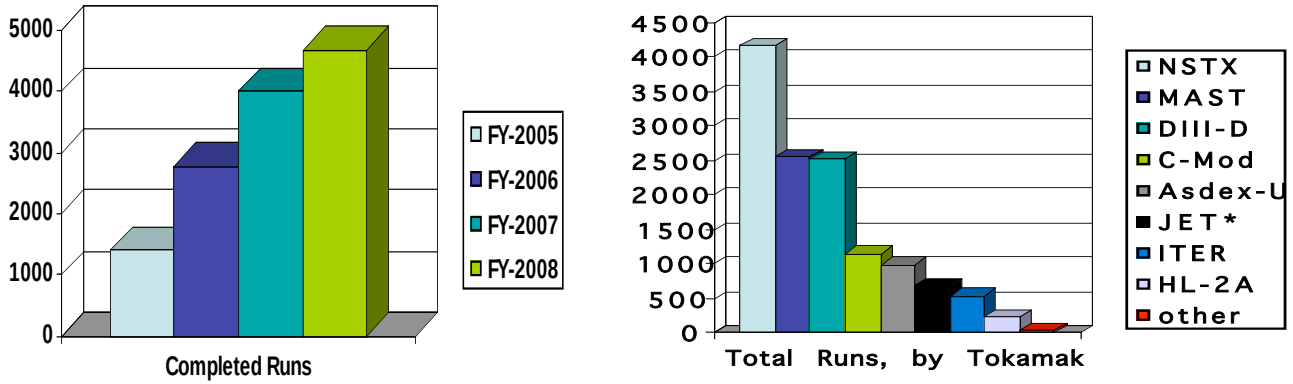
[*Park et al, Nucl. Fusion 48 045006 (2008)*]



- Three quantities will be used to assess the effectiveness of the designed coils
  1) **Invariant external resonant field**
  2) **Invariant total resonant field**
  3) **Overlap external field with the dominant field**

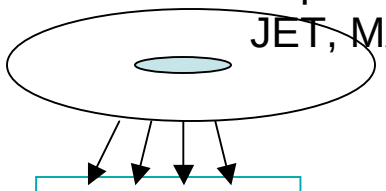
A Web-accessible International Platform for TRANSP & PTRANSP

- Fusion Grid TRANSP/PTRANSP service available now.
  - Users obtain PPPL account, arrange for SecurID or trusted host access through PPPL firewall;
  - Prepare input data, request runs, receive output data.
- PPPL TRANSP team supports experimental projects:
  - Answer questions about code use and data.
  - Troubleshoot problems in run production.



Fusion Grid TRANSP Run Statistics, Oct. 1 2004 – Sep. 30 2008

Fusion Grid TRANSP Workflow



Experiments (Asdex-U,CMod, DIII-D, JET, MAST, NSTX, KSTAR, ITER…)

Diagnostic Hardware

Preliminary data Analysis and Preparation (largely automated)

20-50 signals {f(t), f(x,t)} Plasma position, Shape, Temperatures, Densities Field, Current, RF and Beam Injected Powers.

Pre- and Post-processing at the experimental site…

TRANSP Analysis*:
Current diffusion, MHD equilibrium, fast ions, heating, current drive, power, particle and momentum balance.

Experiment simulation Output Database ~1000-2000 signals {f(t), f(x,t)}

Visualization

Load Relational Databases

Detailed time-slice physics simulations (ORBIT, M3D, GYRO…)

*Fusion Grid TRANSP & PTRANSP production codes on PPPL servers.

PPPL

D. McCune Apr 2009

Thomson Scattering

- Provided design of Thomson scattering cassette along with conceptual design of parts of Thomson system

- More work will be needed to turn into a final design for the Thomson system

- This activity has been completed as defined in original scope

PPPL/KSTAR Collaboration on X-Ray Spectroscopy

Manfred Bitter and Sang Gon Lee

- PPPL's contributions have been important in the design of KSTAR's X-Ray spectrometers (horizontal and vertical X-ray imaging crystal spectrometers)

- Data analysis will be performed by KSTAR with software developed at PPPL

- Manfred Bitter will visit KSTAR in October to check alignment of spectrometer

- If count rate is too high for the installed multi-wire proportional counters, then PPPL will loan KSTAR three Pilatus II solid state detectors for short-term use