L'effet de désordre sur les propriétés des supraconducteurs à base de fer

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Collaborateurs:

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Samples

- $Ba(FeAs_{1-x}P_x)_2$: Shibaru Kasahara, Kyoto University, Japan
- LiFeAs: Kee Hoon Kim, Seoul National University, Seoul, Korea
- $BaK(FeAs)_2$: Hai-Hu Wen, Nanjing University, Nanjing, P. R. China
- $Sr(FeAs_{1-x}P_x)_2$, $Ba(Fe_{1-x},Ru_xAs)_2$: Paul C. Canfield, The Ames Laboratory, USA
- FeSeTe: Zhiqiang Mao, Tulane University, New Orleans, USA

Hall arrays: Vincent Mosser, ITRON, Issy-les-Moulineaux, France

Irradiations:

electrons: SIRIUS platform Ecole Polytechnique
swift heavy ions: GANIL (Caen)

Disorder in superconductors Outline

Flux pinning: As grown samples: Superposition of strong pinning from nanometer scale defects and of weak collective pinning from charged defects.

Irradiated materials: Columnar defects, Bose glass type of pinning.

Pairbraking: No effect from large (columnar defects) Strong depression of T_c, increase of resistivity and modification of superconducting gap structure by point defects.

Implication for pairing mechanism.

Two types of irradiation induced disorder

Swift heavy ions: typically 5.8 GeV Pb

Columnar amorphous tracks few nanometers diameter

Strong pinning for H// tracks

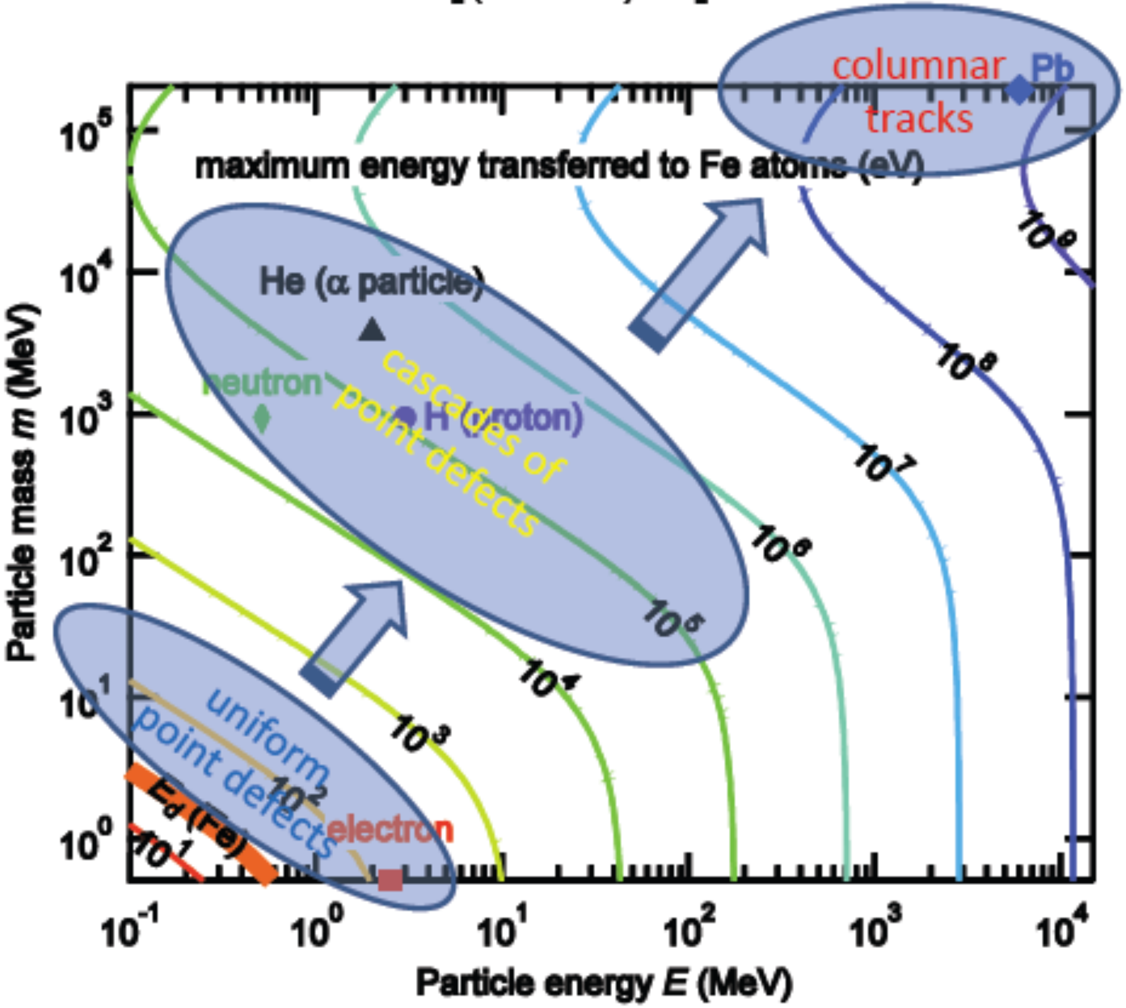
Electron irradiation 2.5 MeV of samples cooled to 20K.

Creation of stable Frenkel pairs on all sub-lattices

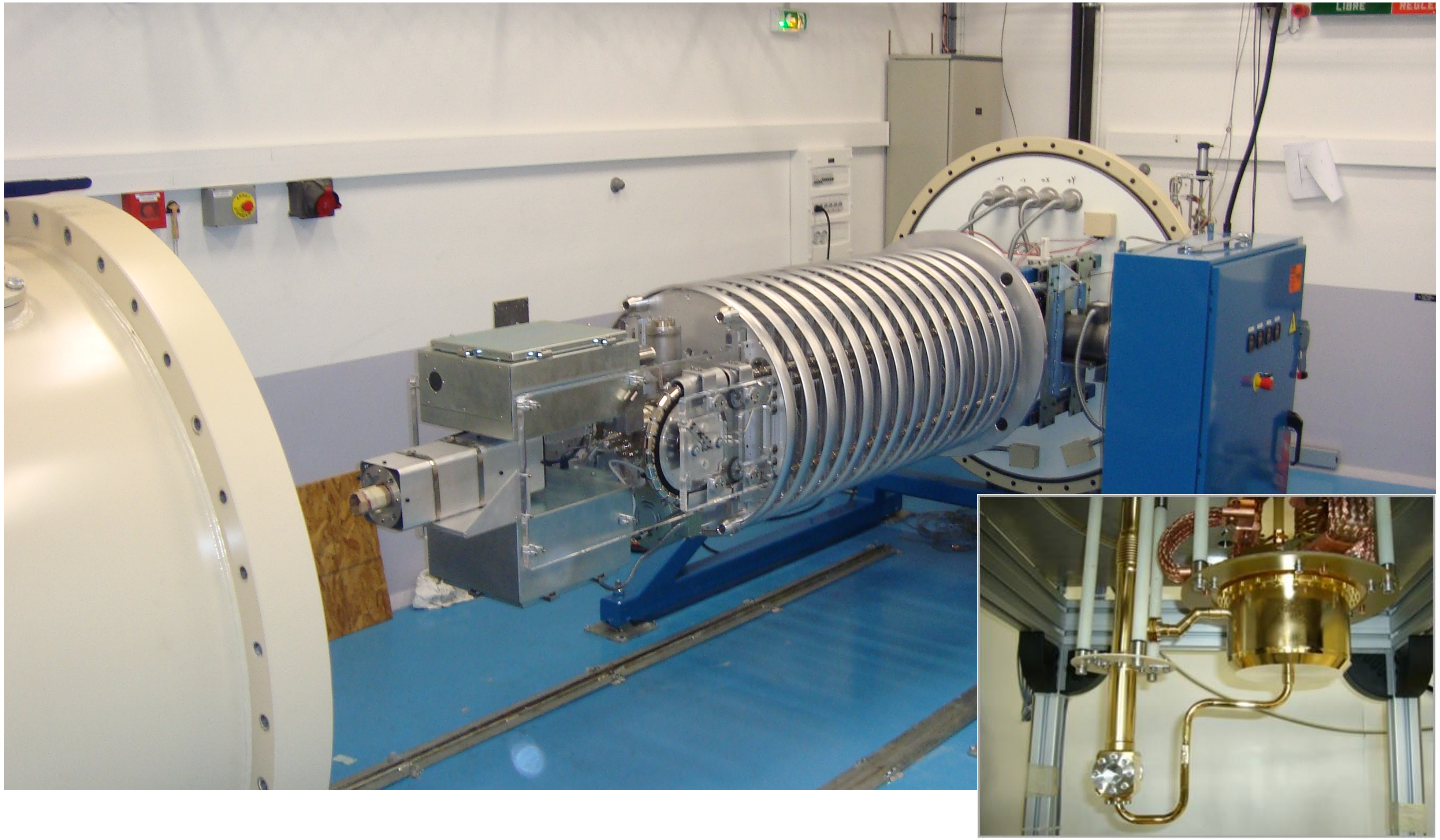
Partial recombination of defects on warming but final state: uniform spread of point defects

Defauts crées par irradiation

$$E_{p\,max} = \frac{2E(E + 2mc^2)Mc^2}{[(m+M)c^2]^2+2EMc^2}$$

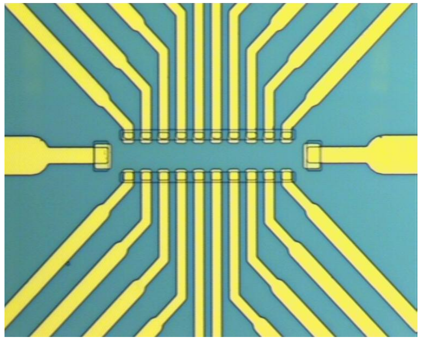


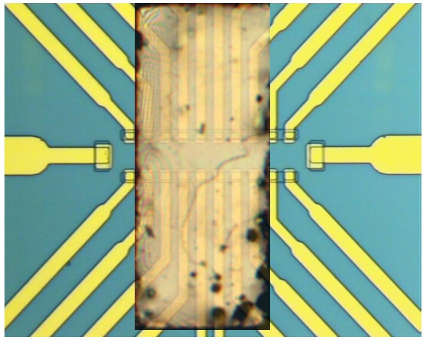
SIRIUS platform NEC Pelltron accelerator



Target at low temperature (20K liquid hydrogen) to prevent defect migration
electron beam energy from 0.3 to 2.5 MeV
In-situ measurements: resistivity (operating, AC Hall in progress)

Magnetometry using 2D Electron Gas
Hall sensor gradiometer

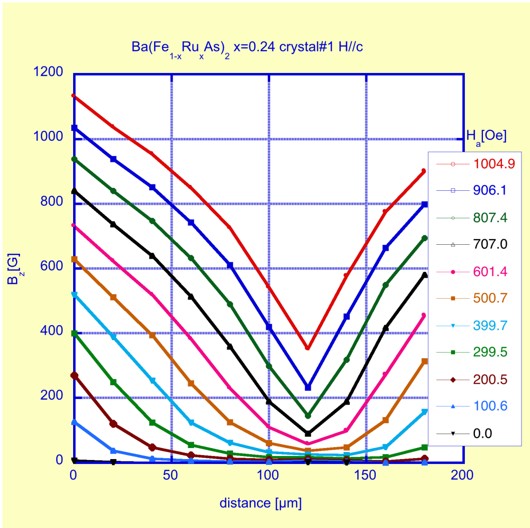


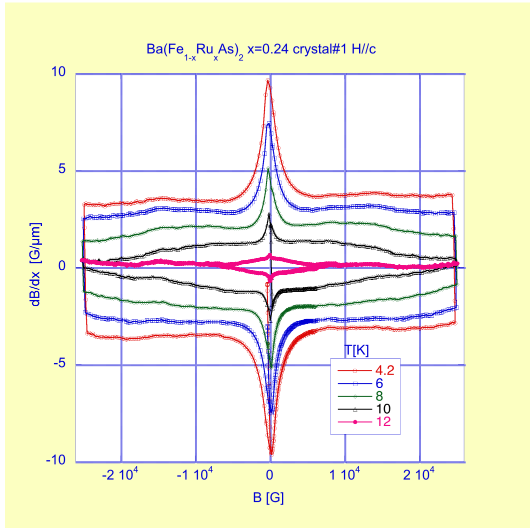


Local gradient dB/dx vs. local induction B isothermal loops

$$j = \frac{2}{\mu_0}\frac{dB}{dx}$$

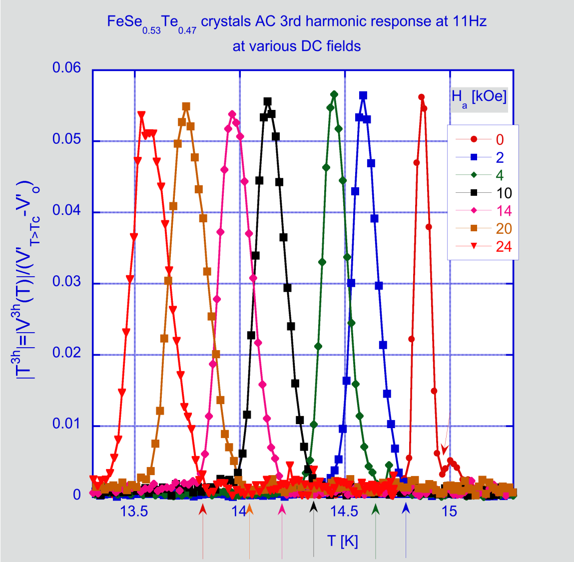
- Pseudomorphic AlGaAs/InGaAs/GaAs heterostructure
- Passivated, ion implantation delimited line of 10 sensors
- Sensor size 3x3µm^2 each, spaced by 10µm or 20µm
- Constant sensitivity 80mΩ/Gauss (from milliK to RT).
- Spatially resolved measurement of the local flux density B
- e.g single crystal $Ba(Fe_{0.76}Ru_{0.24}As_{0.64})_2$ cut to rectangle

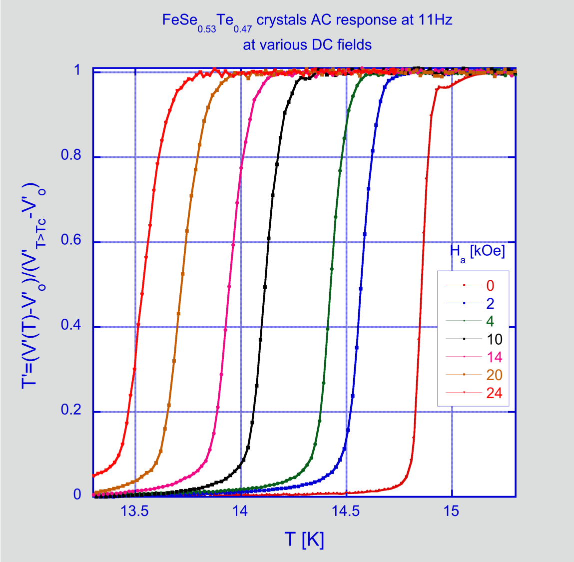


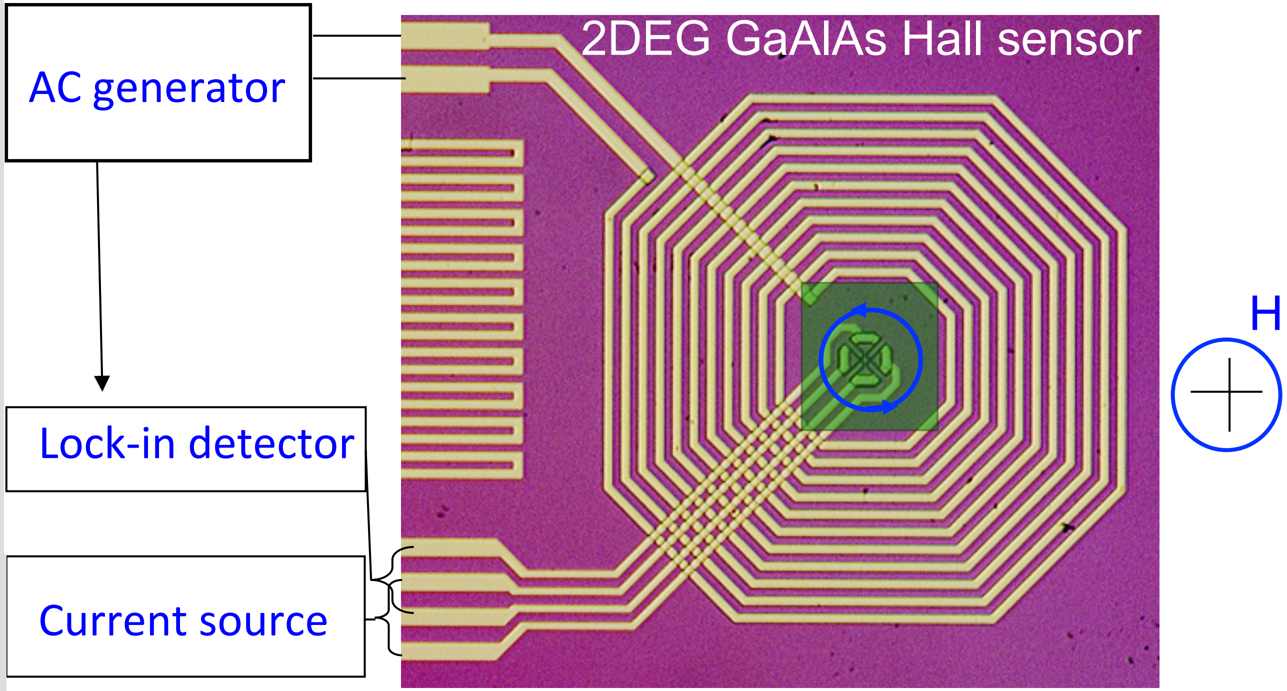


1G/µm=16000 A/cm^2

Magnetometry using 2D Electron Gas Hall sensor in AC mode







$T' = B'_{AC}/H_{AC}$ can be converted to screening current

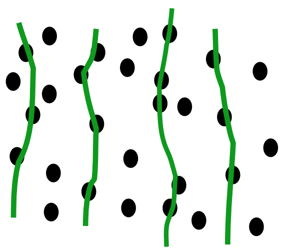
$J_c = 1/\pi \arccos(2T'-1)$

Onset of T'_{3H} marks nonlinear I-V used to determine IRL

Gilchrist & Konczykowski Physica C 212, 43 (1993)

Disorder in pristine material: two origins of pinning

Low field, central peak
“Strong pinning”, nm scale
fluctuation of T_c



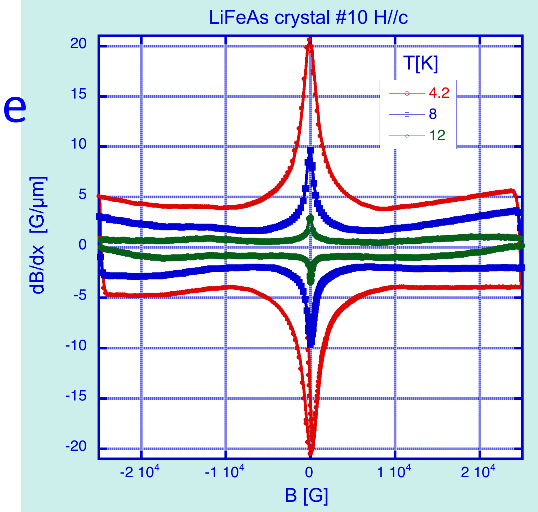
$n_i \xi^3 << 1$

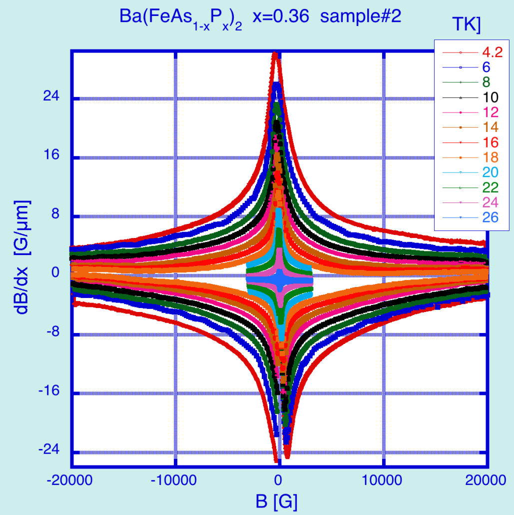
$j_c = n_i u_0^2 f_p / \Phi_0$

direct sum of the f_p

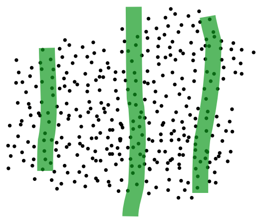
Yu. Ovchinnikov and B. Ivlev,
Phys. Rev. B **43**, 8024 (1991)

C.J. van der Beek et al.,
PRL **105**, 267002 (2010)
PRB **81**, 174517 (2010).





High field “weak collective
pining” by charged defects



$n_p \xi^3 >> 1$

$j_c = F_p / B$

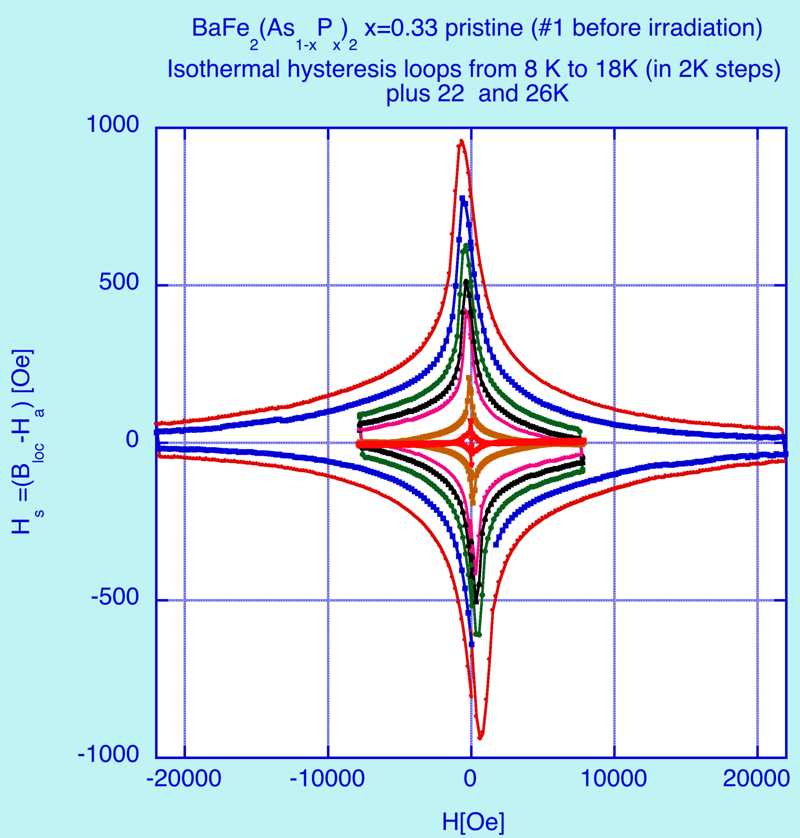
determined by $\langle f_p^2 \rangle$

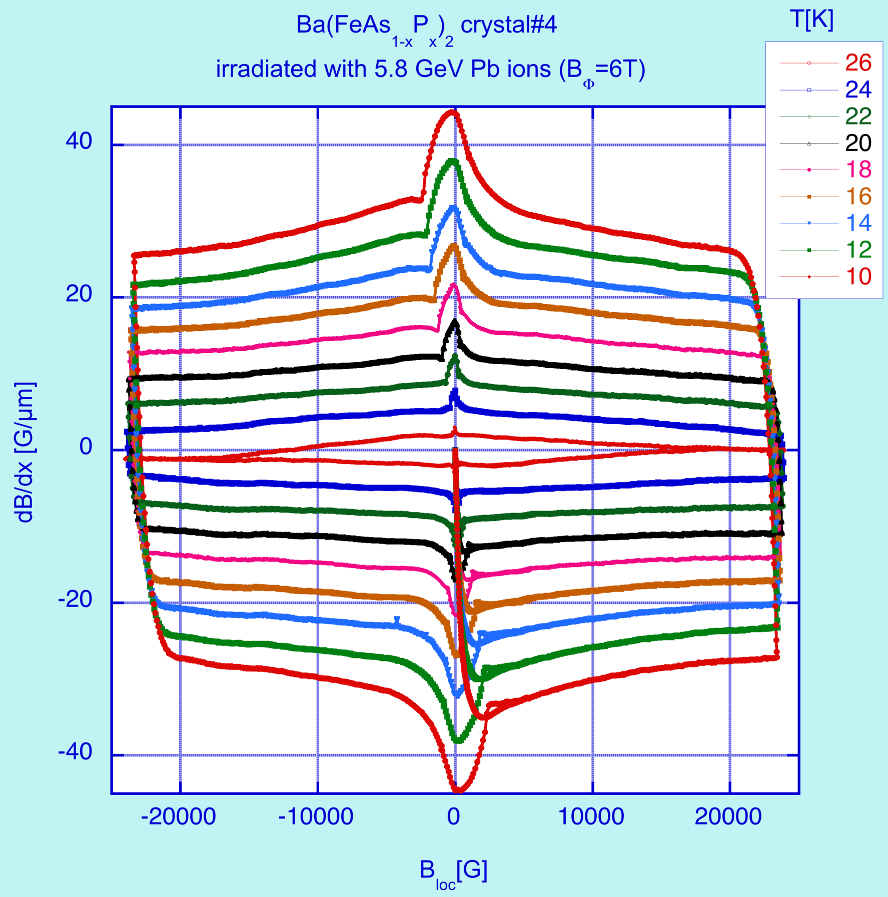
A.I. Larkin and Yu. Ovchinnikov,
JETP **31**, 784 (1970); J. Low.
Temp. Phys. **34**, 409 (1979)

Exception: isovalently substituted
$Ba(FeAs_{1-x}P_x)_2$
No signature of “weak collective
pinning” regime

Controlled disorder: columnar defects

Heavy ion irradiation: columnar defects, strong enhancement of pinning
attenuate or erase central peak => field independent J_c





Controlled disorder

Heavy ion irradiation: columnar defects, strong enhancement of pinning
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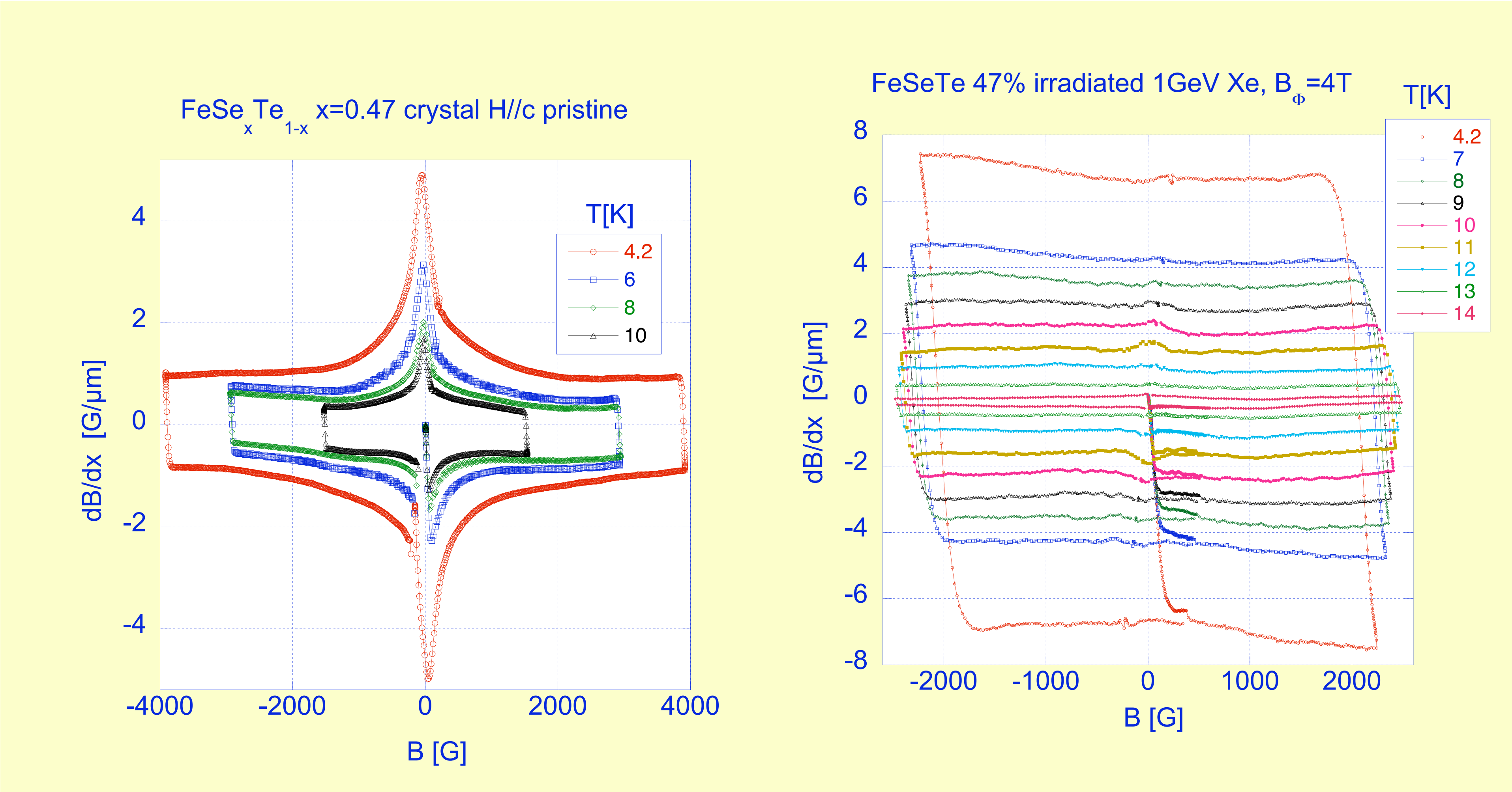
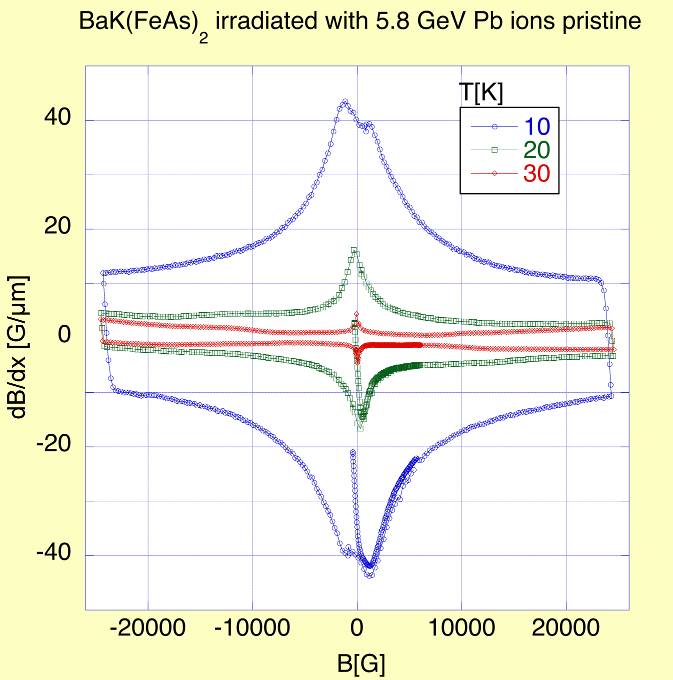
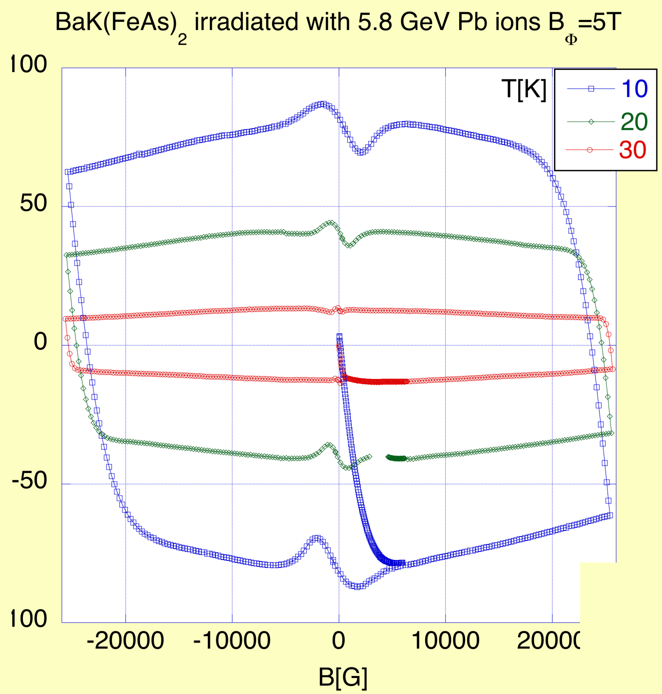
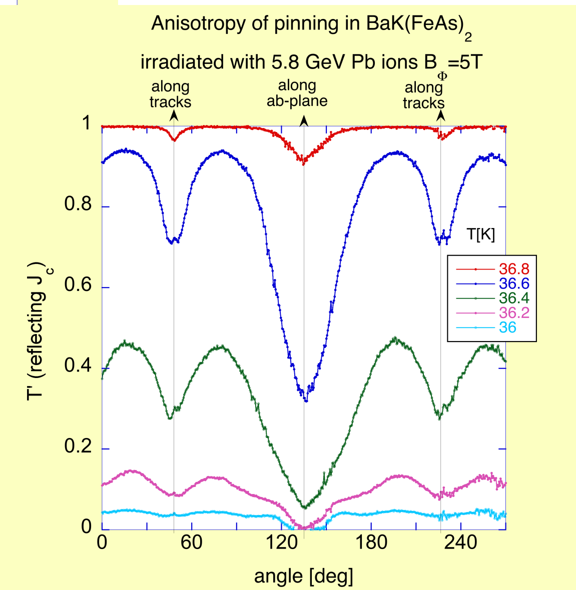


Controlled disorder: columnar defects



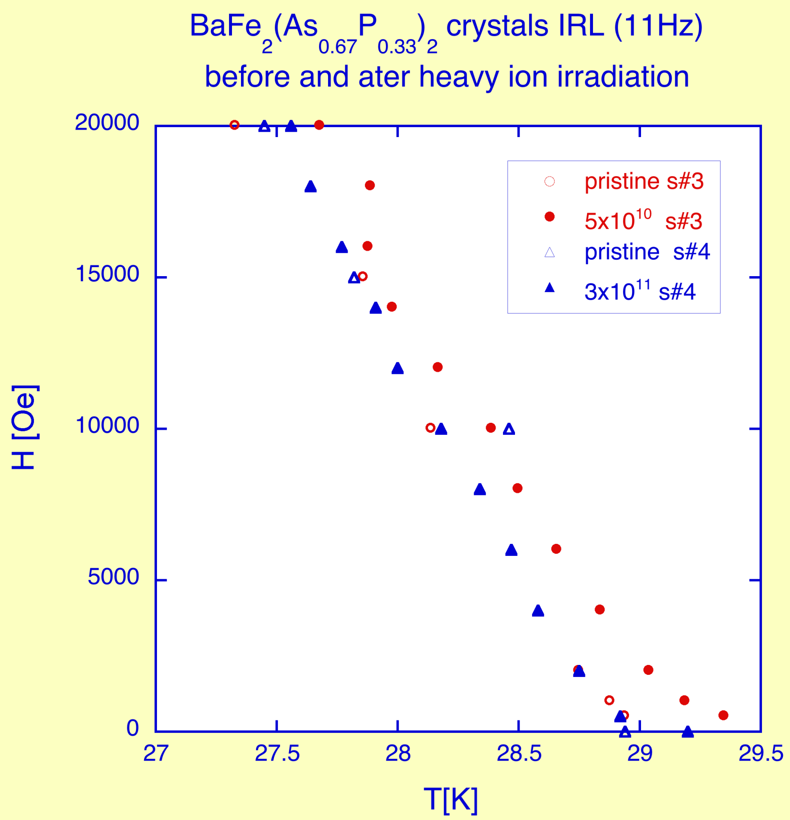


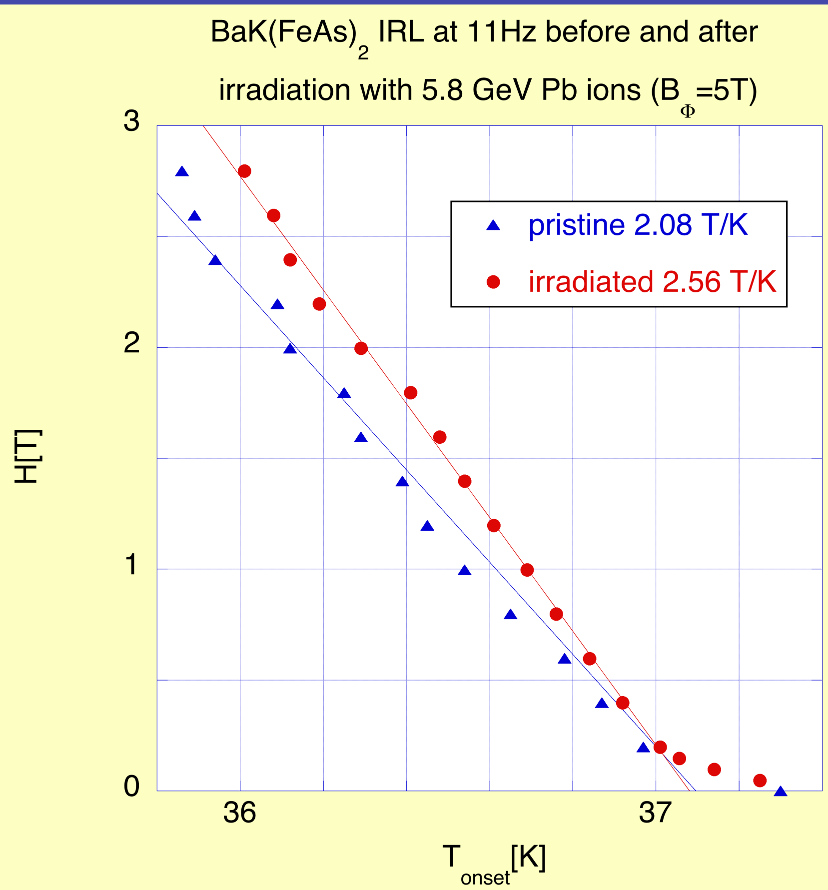
Columnar defects:
Proof from anisotropy of pining
But small diameter and unstable (annealing at room temperature)



Pronounced flux creep: ≈ 5% time decade with $U(J) \approx (J_c/J)^{\mu}$.
Persist after irradiation with change of regime
fromμ =0.5-1 in pristine samples (vortex loop nucleation)
μ=0.3 in ion irradiated irradiated samples (variable range hopping)

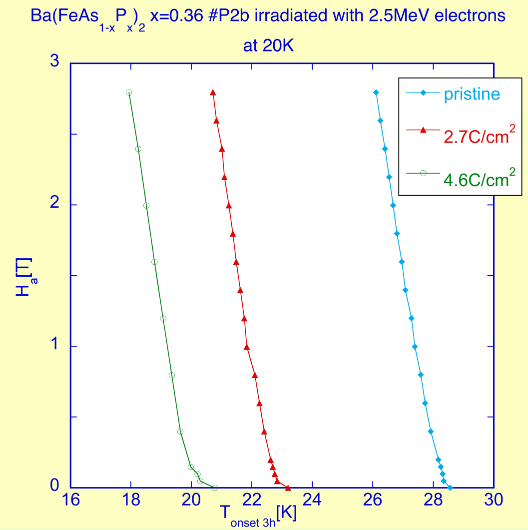
Columnar defects: IRL & T_c

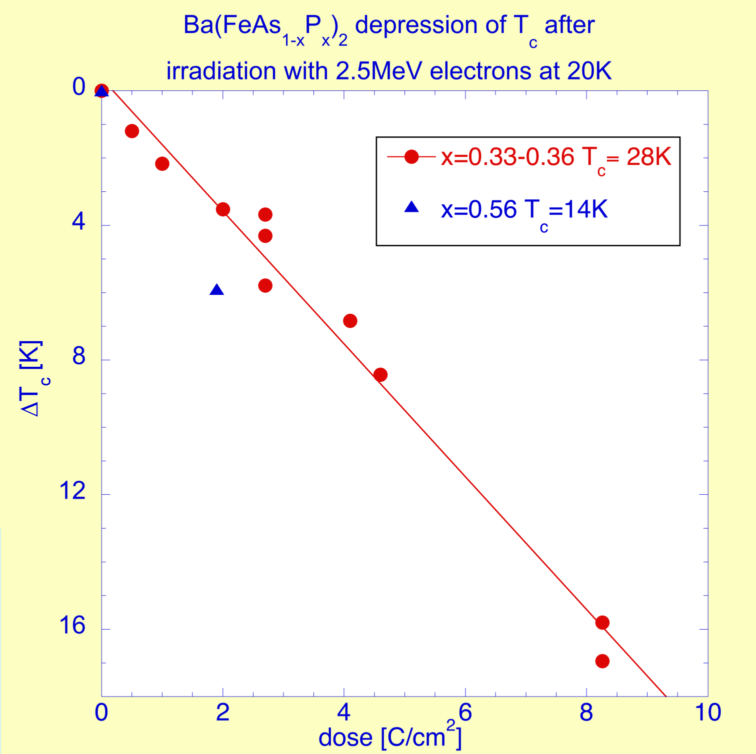


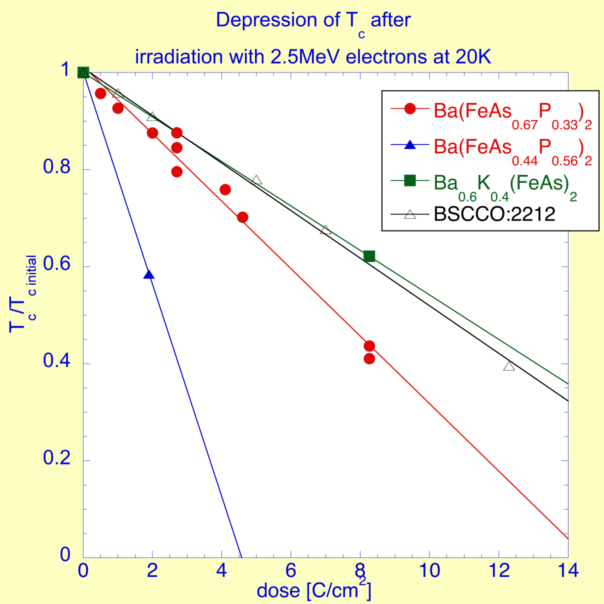


Heavy ion irradiation: enhancement of pinning without depression of T_c
Isovalently substituted $Ba(FeAs_{1-x}P_x)_2$: no measurable change of IRL, other compounds slight upward shift of IRL

$Ba(FeAs_{1-x}P_x)_2$ & $Ba(Fe_{1-x}Ru_xAs)_2$ point disorder

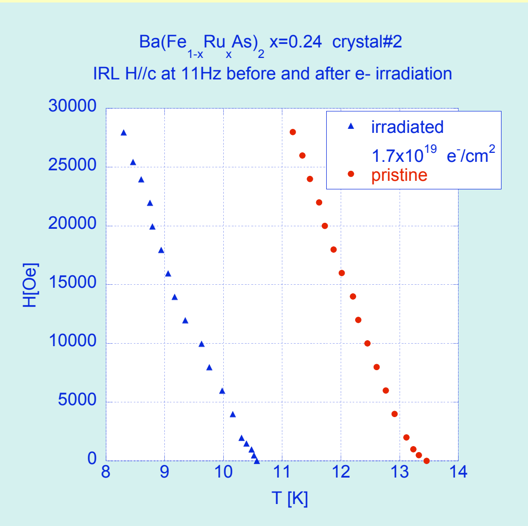


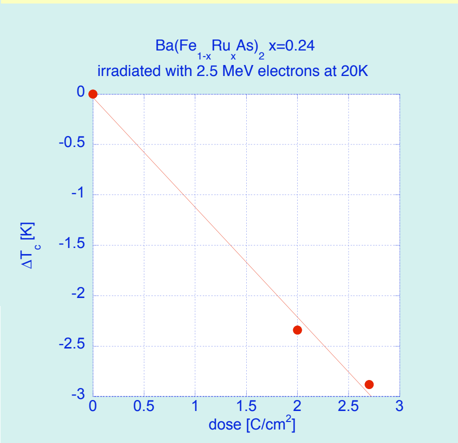




Strong depression of T_c
By point like disorder
Linear with irradiation dose
Down to <50% of initial T_c

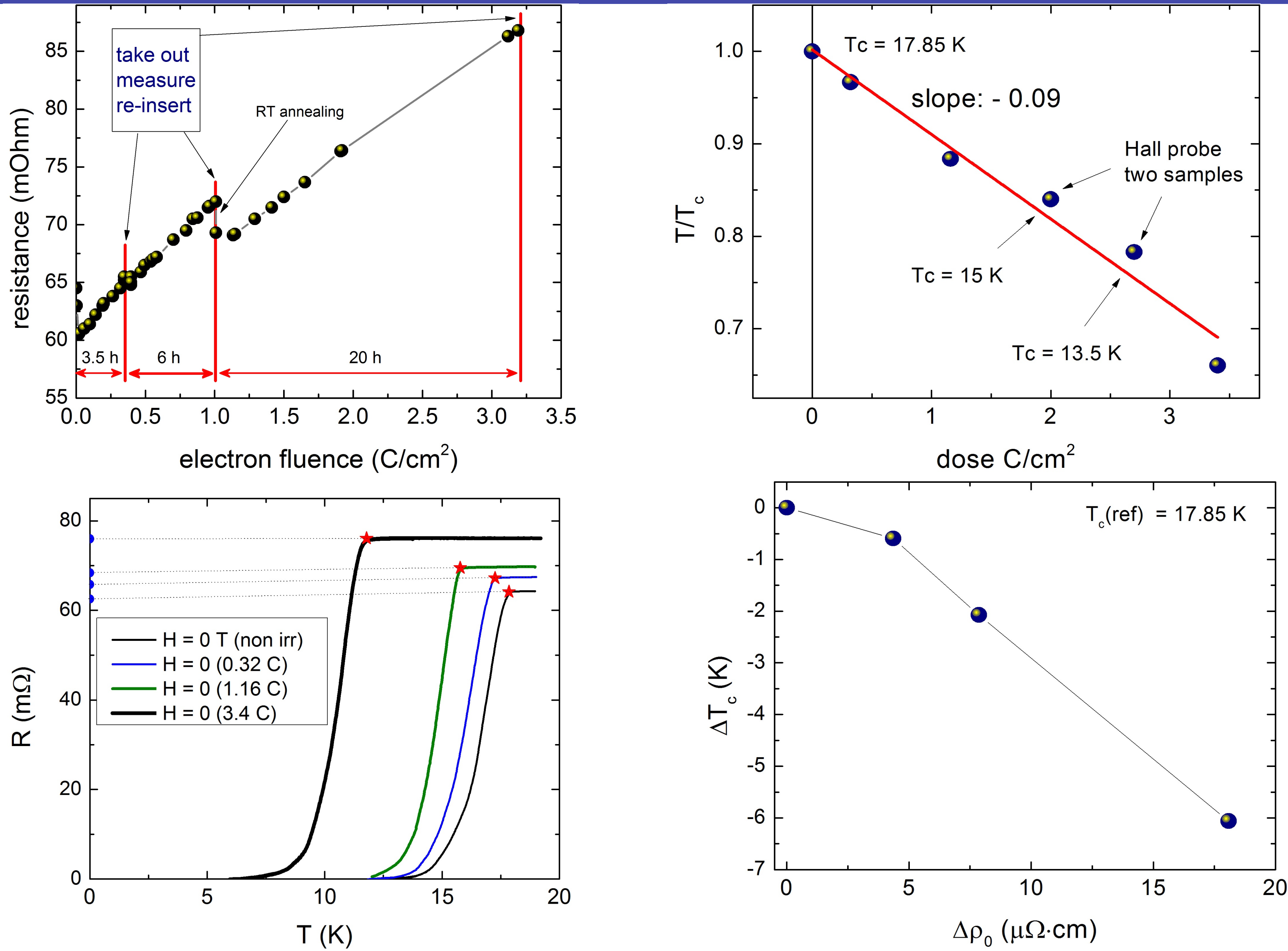
Faster than in HTC cuprates



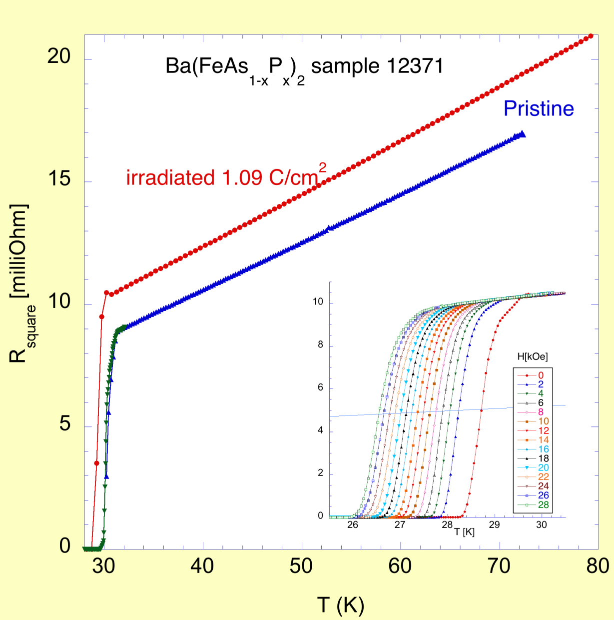


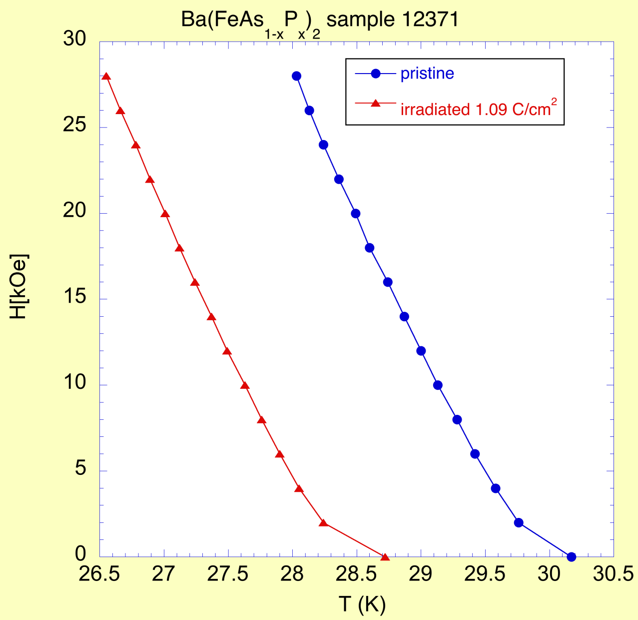
Strong depression in all compounds except FeSeTe

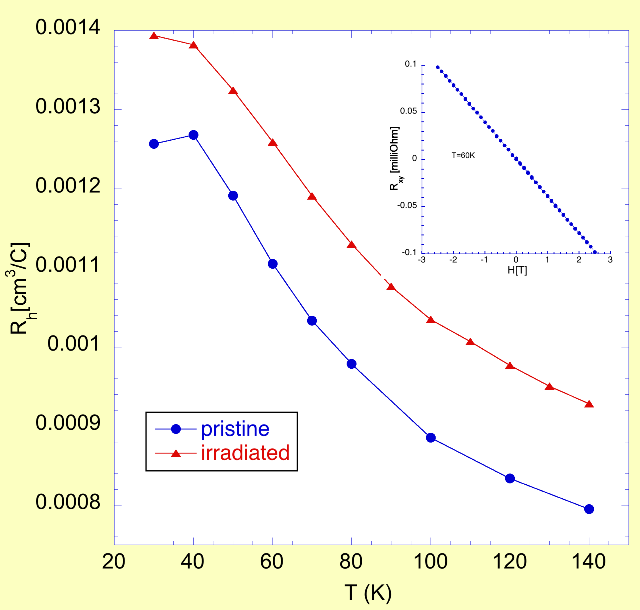
$Ba(Fe_{1-x}Ru_xAs)_2$ resistivity point disorder



$Ba(FeAs_{1-x}P_x)_2$ point disorder







Determination of scattering rate from resistivity:
problem: semi metallic two band conductivity
Hall coefficient does not reflect carrier concentration.
Need high magnetic field to separate hole and electron contribution.

Change in $R_h(T)$ variation after irradiation indicate charge redistribution.

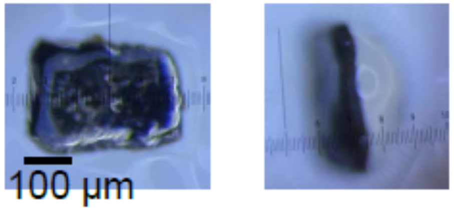
Introducing point defects

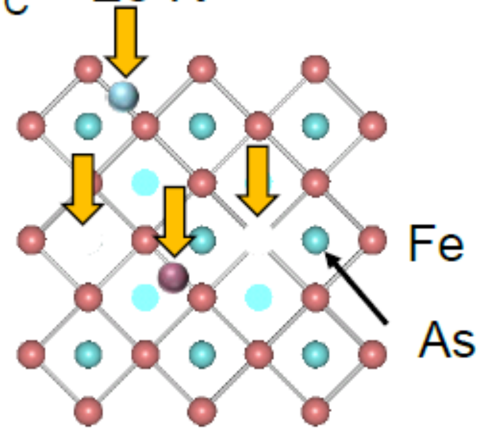
Electron irradiation

Single crystal : $BaFe_2(As_{1-x}P_x)_2$ $T_C = 28$ K

$T = 20$ K 2.5 MeV e^-

@Ecole Polytechnique, France



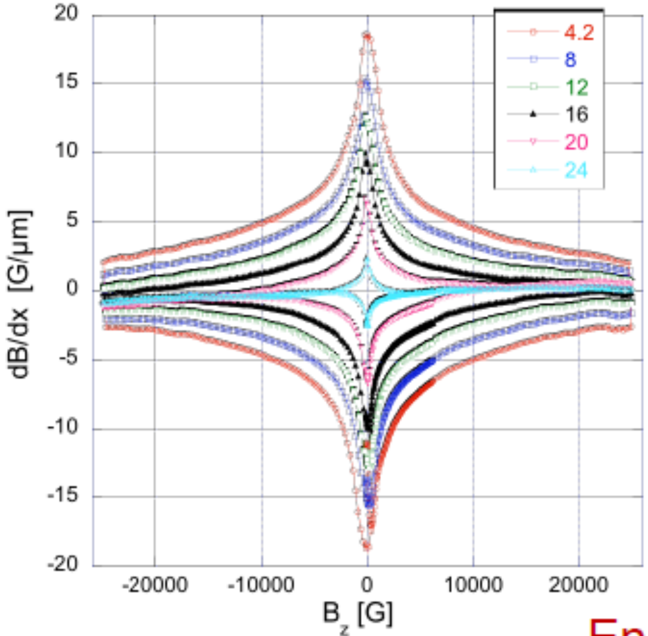


✓Point defects

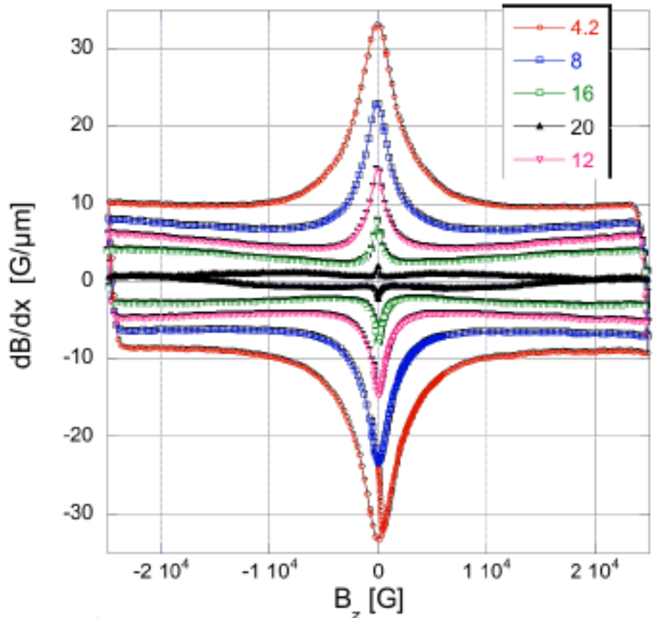
✓No carrier doping

✓Systematic change

Magnetization



Irradiation



Enhanced critical current

→ Point defects

CONCLUSIONS

Distinct effects of different types of disorder on pinning and paibraking

- Large defects (columnar) : interband scattering little effect on Tc
- Point defects: intraband scattering: strong pairbraking effect.
- Suppression of nodes in superconducting gap by disorder incompatible with symmetry induced nodes (d-wave)
- Evolution of gap structure with disorder compatible with S+/- coupling