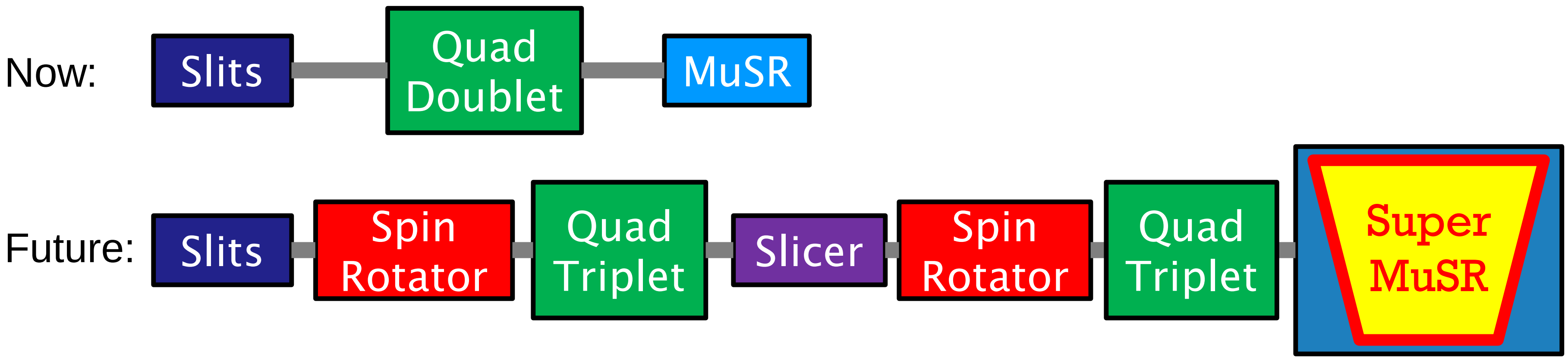
Super MuSR

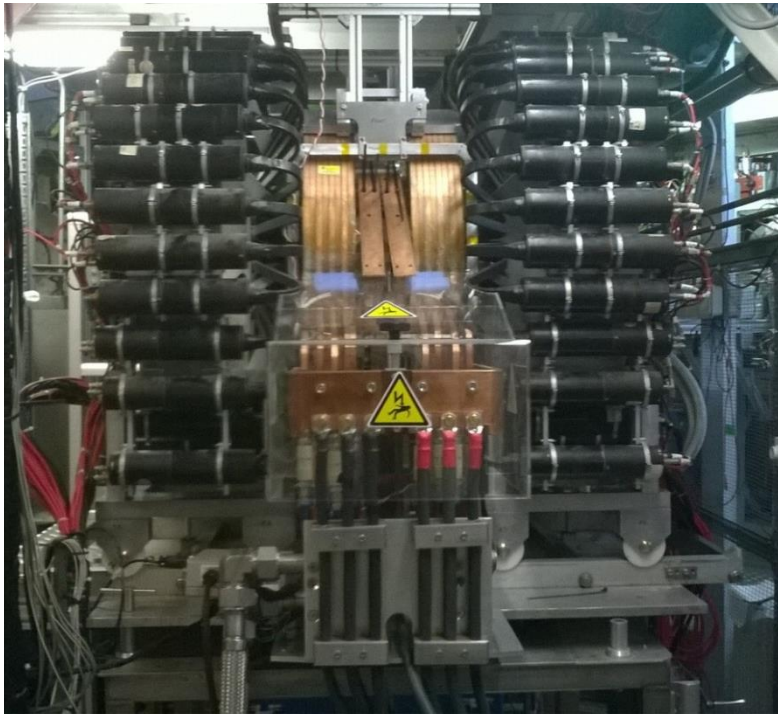
High resolution: 10x resolution at 1.5-2x current rate

High rate: 15-20x rate at current resolution



Plan of the talk

- Current instrument status
- Scientific directions
- Instrument improvements
  - Detectors
  - Flypast and ancillary equipment
- Beamline improvements
  - Pulse slicing
  - Spin rotation
- Conclusions



CURRENT INSTRUMENT STATUS

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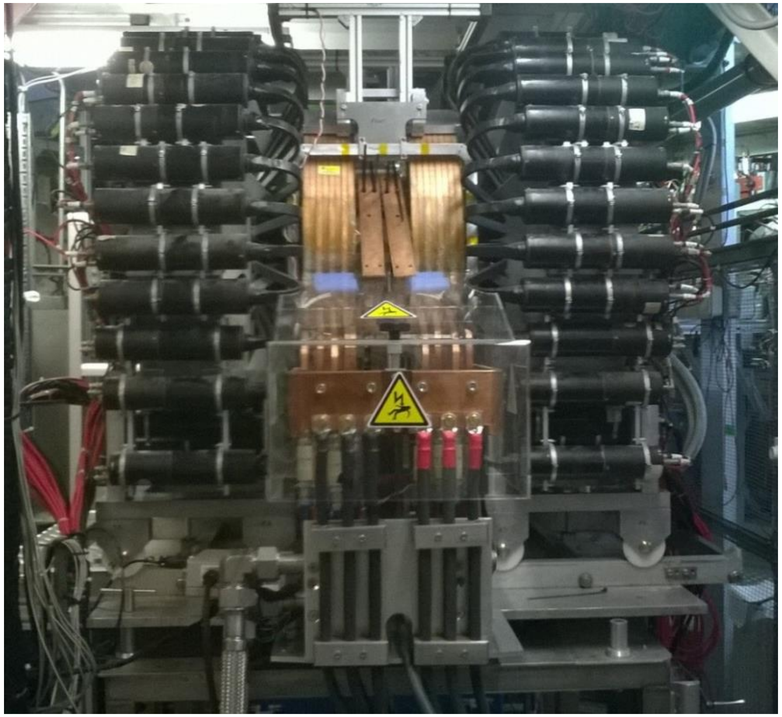
MuSR Today

- 64 detectors count ~60MEv/h
  - Limit us to using 8% of available muon flux
- 0.65T main magnet and PSU
  - Limited to 0.3T by PMT shielding
- Enables ZF/LF and TF modes by physical 90° rotation
- Counts ~20% of positrons emitted from sample
  - Solid angle ~40% of sphere
  - Positron degraders thicker than optimum to reduce count rate
- Over 60% of experiments use *T*<1K equipment



Recent MuSR publications

PRL **117**, 097201 (2016) PHYSICAL REVIEW LETTERS week ending 26 AUGUST 2016

Muon Spin Relaxation Evidence for the U(1) Quantum Spin-Liquid Ground State in the Triangular Antiferromagnet $YbMgGaO_4$

Yuesheng Li,[1,2,*] Devashibhai Adroja,[3,4] Pabitra K. Biswas,[3] Peter J. Baker,[3] Qian Zhang,[1] Juanjuan Liu,[1] Alexander A. Tsirlin,[2] Philipp Gegenwart,[2] and Qingming Zhang[1,5,†]

PRL **118**, 267202 (2017) PHYSICAL REVIEW LETTERS week ending 30 JUNE 2017

Quantum Griffiths Phase Inside the Ferromagnetic Phase of $Ni_{1-x}V_x$

Ruizhe Wang,[1] Adane Gebretsadik,[1] Sara Ubaid-Kassis,[1,*] Almut Schroeder,[1] Thomas Vojta,[2] Peter J. Baker,[3] Francis L. Pratt,[3] Stephen J. Blundell,[4] Tom Lancaster,[4,†] Isabel Franke,[4] Johannes S. Möller,[4,‡] and Katharine Page[5]

Journal of the Physical Society of Japan **86**, 044710 (2017)
https://doi.org/10.7566/JPSJ.86.044710

Nodal Superconducting Gap Structure in the Quasi-One-Dimensional $Cs_2Cr_3As_3$ Investigated Using μSR Measurements

Devashibhai Adroja[1,2*], Amitava Bhattacharyya[1,2,3], Michael Smidman[4], Adrian Hillier[1], Yu Feng[5], Bingying Pan[5], Jun Zhao[5], Martin R. Lees[6], Andre Strydom[2], and Pabitra K. Biswas[1]

RAPID COMMUNICATIONS

PHYSICAL REVIEW B **94**, 020407(R) (2016)

Unconventional magnetism on a honeycomb lattice in α-$RuCl_3$ studied by muon spin rotation

F. Lang,[1,*] P. J. Baker,[2] A. A. Haghighirad,[1] Y. Li,[3] D. Prabhakaran,[1] R. Valentí,[3] and S. J. Blundell[1,†]

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Cite this: *Chem. Commun.*, 2016, 52, 12653

Received 26th July 2016, Accepted 27th September 2016

DOI: 10.1039/c6cc05873f

www.rsc.org/chemcomm

Bimetallic MOFs $(H_3O)_x[Cu(MF_6)(pyrazine)_2]\cdot(4-x)H_2O$ (M = V^{4+}, x = 0; M = Ga^{3+}, x = 1): co-existence of ordered and disordered quantum spins in the V^{4+} system†

Jamie L. Manson,*[a] John A. Schlueter,[b] Kerry E. Garrett,[a] Paul A. Goddard,[c] Tom Lancaster,[d] Johannes S. Möller,‡[e] Stephen J. Blundell,[e] Andrew J. Steele,[e] Isabel Franke,[e] Francis L. Pratt,[f] John Singleton,[g] Jesper Bendix,[h] Saul H. Lapidus,[i] Marc Uhlarz,[j] Oscar Ayala-Valenzuela,[g] Ross D. McDonald,[g] Mary Gurak[g] and Christopher Baines[k]

nature physics ARTICLES

PUBLISHED ONLINE: 31 JULY 2017 | DOI: 10.1038/NPHYS4212

A high-temperature quantum spin liquid with polaron spins

Martin Klanjšek[1], Andrej Zorko[1], Rok Žitko[1], Jernej Mravlje[1], Zvonko Jagličić[2,3], Pabitra Kumar Biswas[4], Peter Prelovšek[1,5], Dragan Mihailovic[1,5] and Denis Arčon[1,5]*

PHYSICAL REVIEW B **95**, 134419 (2017)

Coexistence of magnetism and superconductivity in separate layers of the iron-based superconductor $Li_{1-x}Fe_x(OH)Fe_{1-y}Se$

RAPID COMMUNICATIONS

PHYSICAL REVIEW B **95**, 140505(R) (2017)

Signature of multigap nodeless superconductivity in $CaKFe_4As_4$

P. K. Biswas,[1,*] A. Iyo,[2] Y. Yoshida,[2] H. Eisaki,[2] K. Kawashima,[3] and A. D. Hillier[1]

Muon Studies of Unconventional Superconductors

MENS AGITAT MOLEM
UNIVERSITAS WARWICENSIS

Joel Alexander Thomas Barker
Department of Physics
University of Warwick

Science & Technology Facilities Council
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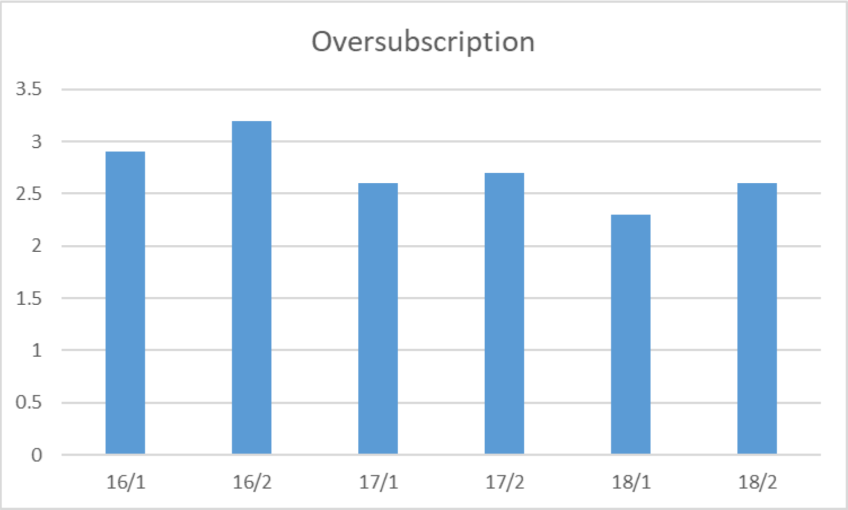
Oversubscription of MuSR

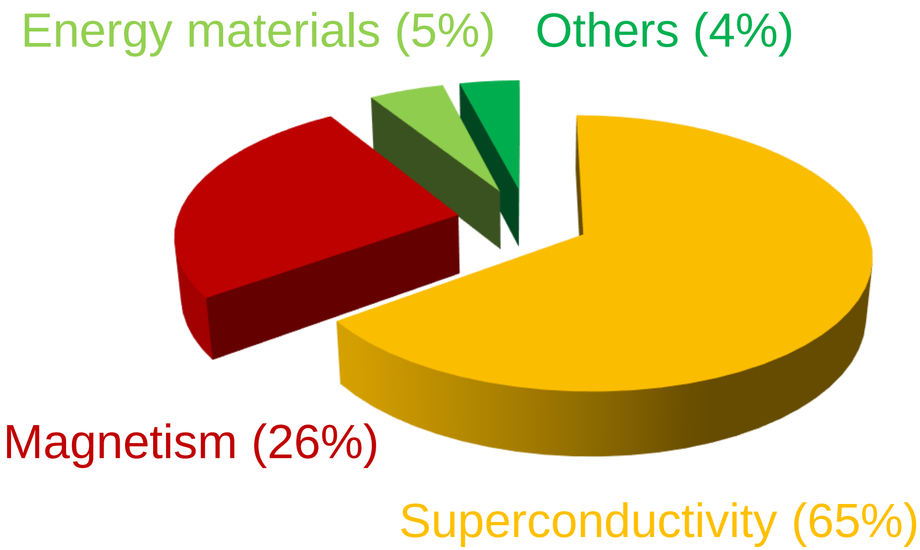
- MuSR consistently highly oversubscribed
- Normally among the most requested ISIS instruments each round
- *T*<1K experiments most acutely oversubscribed

- There is a need for more capacity

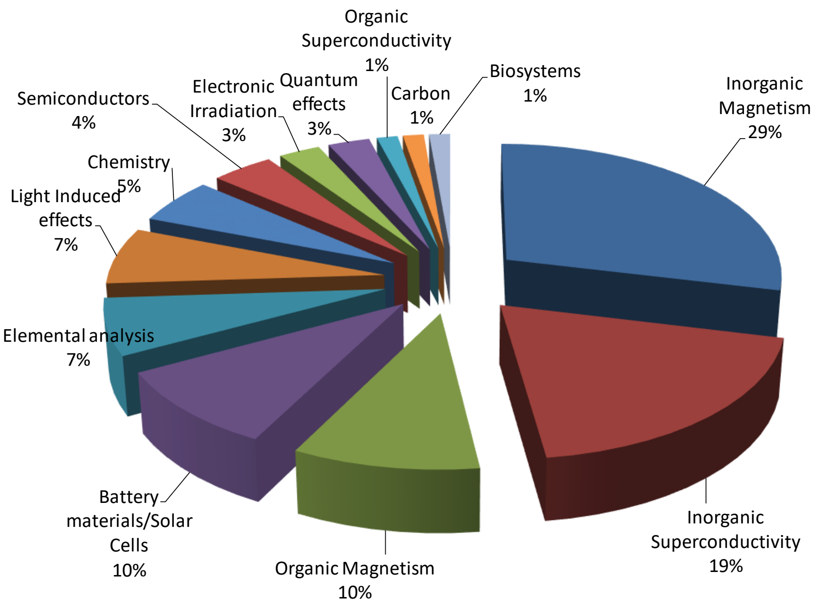


Scientific usage of MuSR

MuSR



ISIS Muons



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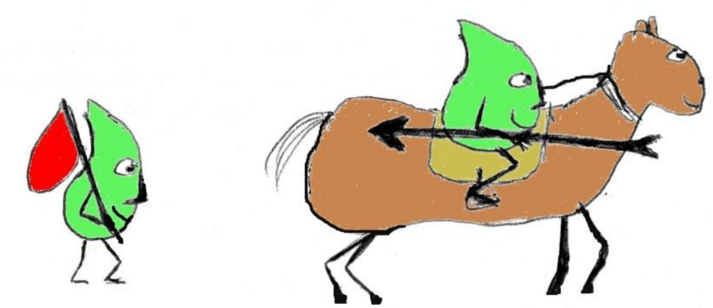
SCIENTIFIC DIRECTIONS

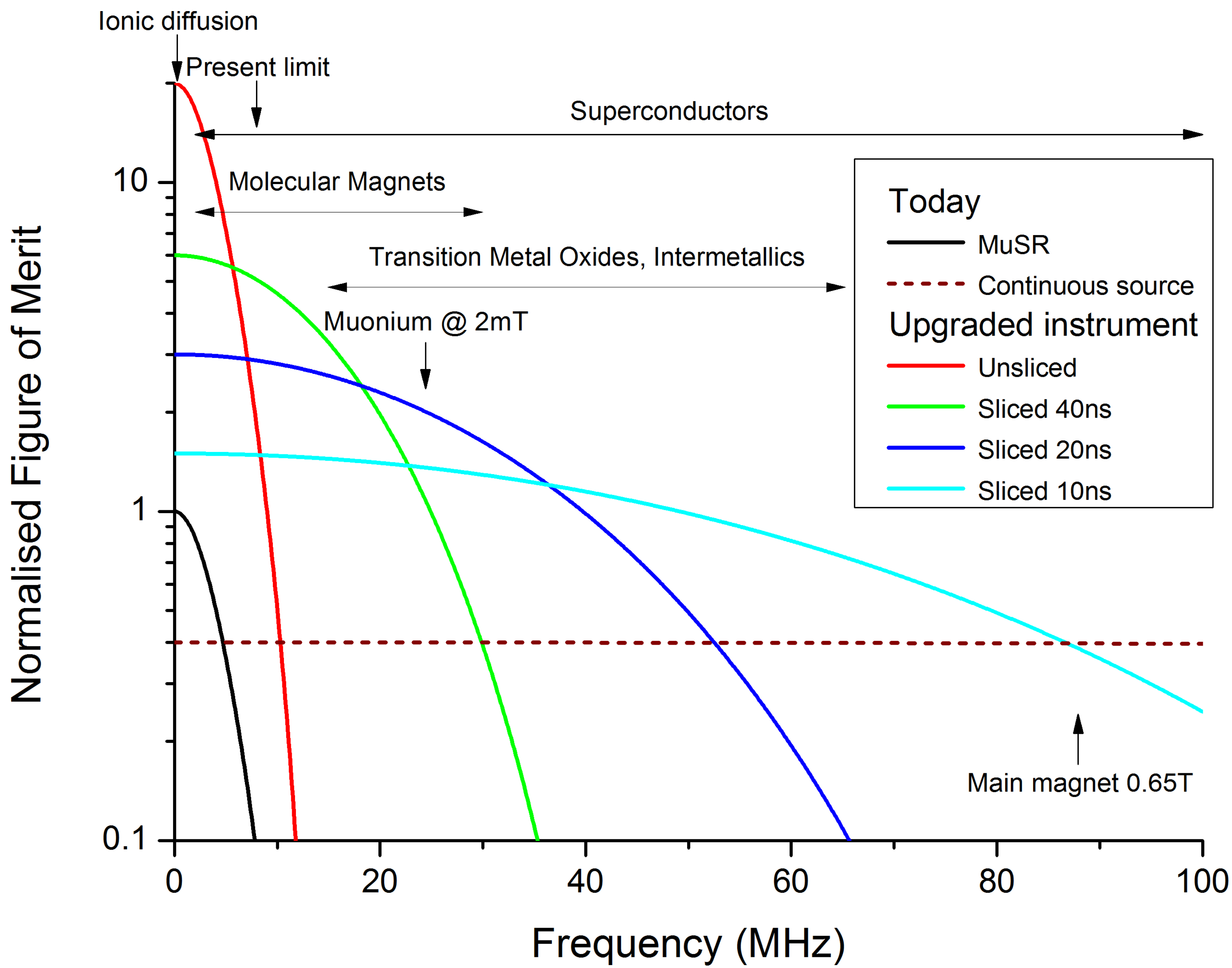


What does the science need?

Area	Improvement Required
Ionic diffusion (e.g. Li batteries)	Rate (enable in-operando work)
Magnetism – frustrated/organic/weak	**Rate**
Magnetism – oxides and intermetallics	**Resolution**
Muon chemistry – RF experiments	Rate, higher field, spin rotation
Semiconductors	Resolution, spin rotation
Skyrmions	Resolution, spin rotation
Superconductors – TRS-breaking	**Rate**
Superconductors – Topological	Rate, spin rotation
Superconductors – vortex lattices	**Resolution, spin rotation**

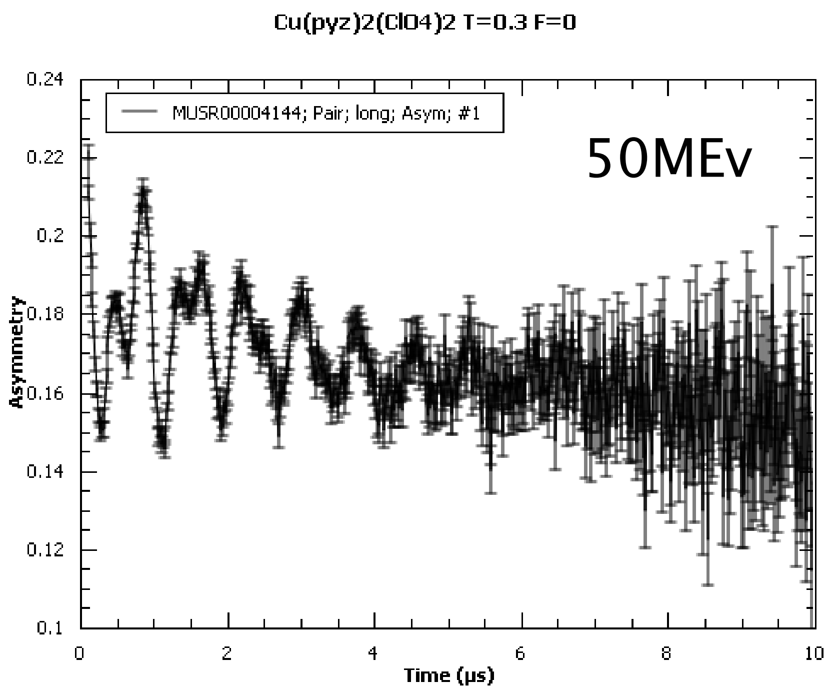
Major science areas in current programme in **bold**

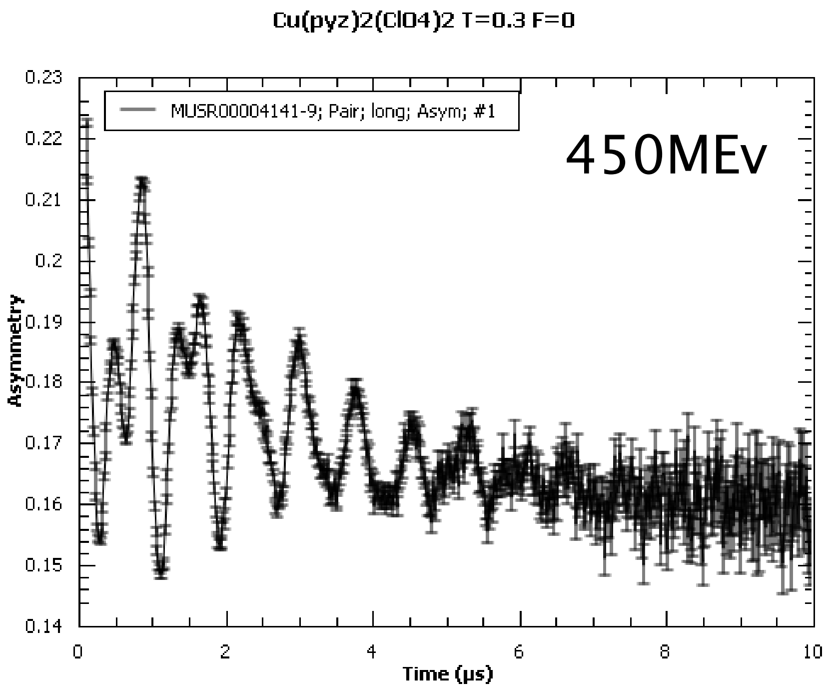
Extending the measurement envelope



Better counting rate

What used to take 10 hours can be done in 30 mins





The measurements done already can benefit from better quality data, improving parameter scans and constraint of the models used for analysis

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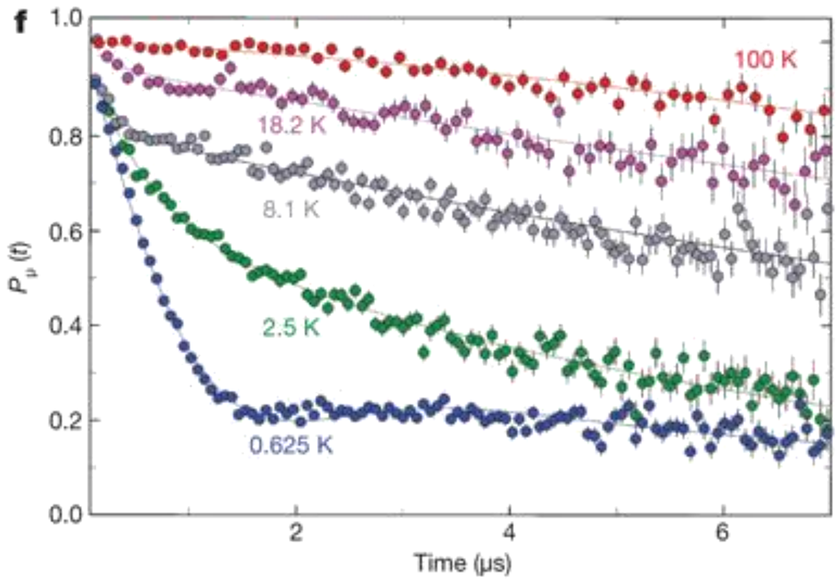
Better counting rate – Cs_3C_{60}

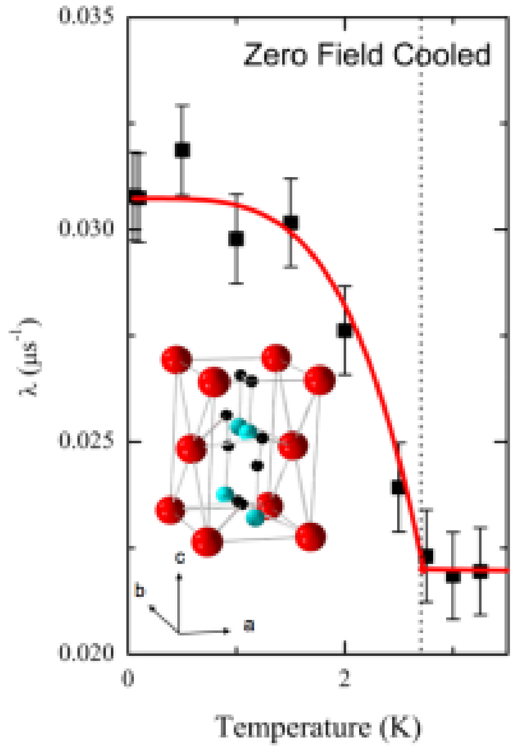
- Internal field ~ 1.5mT
- Many muon sites make distinguishing order and disorder very hard
- High statistics data vital in separating these options
- Trade-off statistics against temperature resolution
- Possibility of weak pseudogap magnetism so far unexplored



Nature **466**, 221 (2010);
also Science **323**, 1585 (2009)

Better counting rate – TRSB

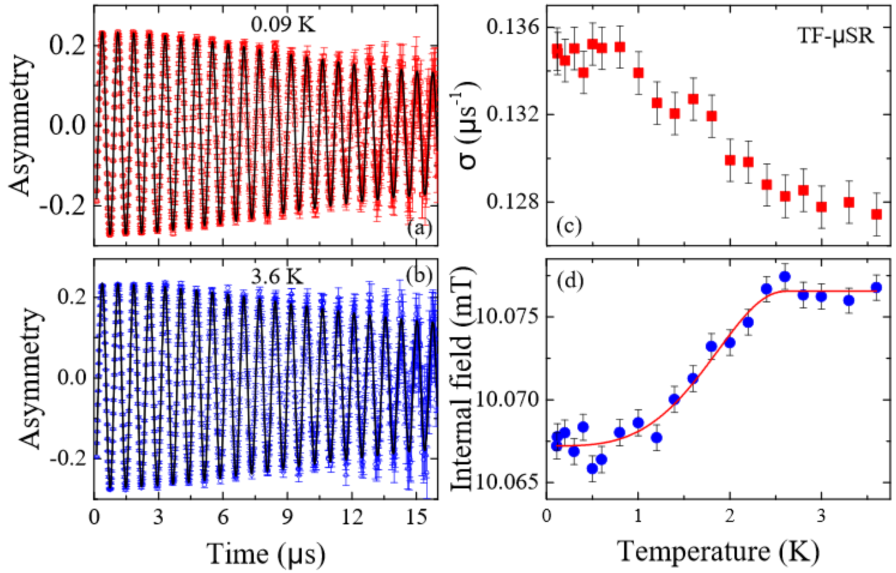
- Tiny internal fields from time-reversal symmetry breaking superconductivity
- Signals inevitably slow relaxations
- Form of signal varies between materials
- Reason not understood
- Understanding this needs better data and better models



e.g. PRL **102**, 117007 (2009)

Better counting rate and spin rotation – Topological superconductors

- Study of $Sr_xBi_2Se_3$
- Change in σ and internal field due to vortex lattice are very small
- λ(0) = 1622(134)nm
- Other topological superconductors studied are similarly challenging
- For crystals spin rotation is needed to access λ_{ab} and get bigger signal



arXiv:1804.08998

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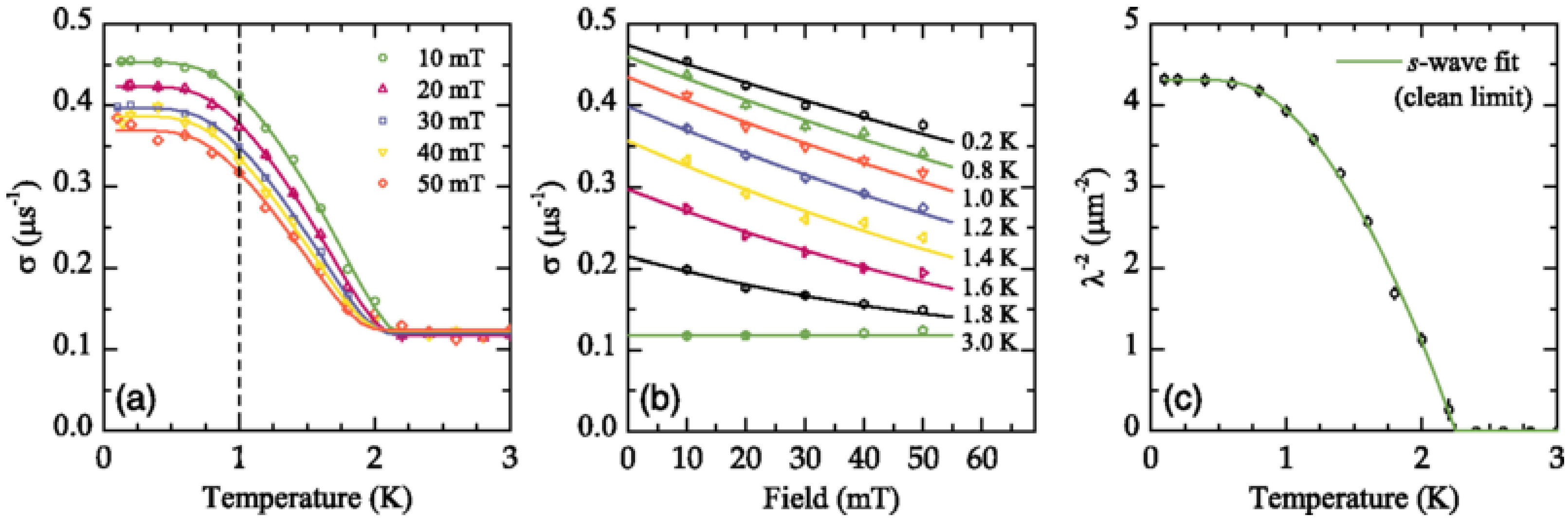
Better counting rate and spin rotation – Low-H_{c2} superconductors



- How best to determine superfluid density when H_{c2} is just above measurement fields?
- Use temperature scans in multiple fields
- Higher rates will allow us to do this far better

e.g. La_7Ir_3, PRL **115**, 267001

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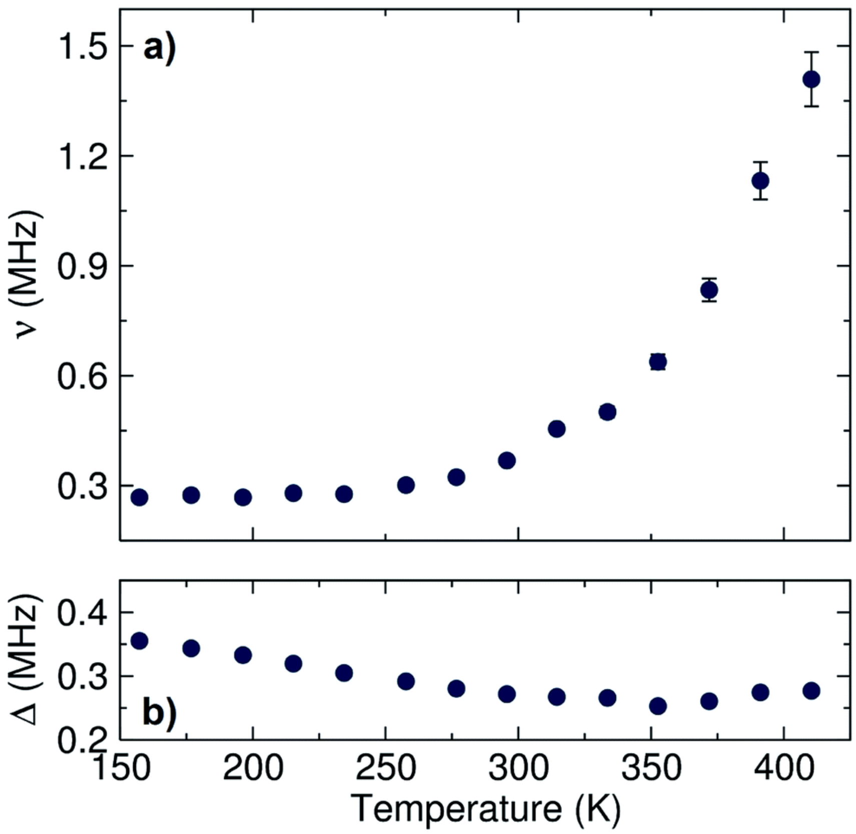
Better counting rate – Ionic diffusion

- Most experiments currently done on EMU
- Routinely measure 1 sample per day
- What if you want to measure multiple charge/discharge states?
- Needs much higher counting rates
- In-situ/in-operando studies for greater impact



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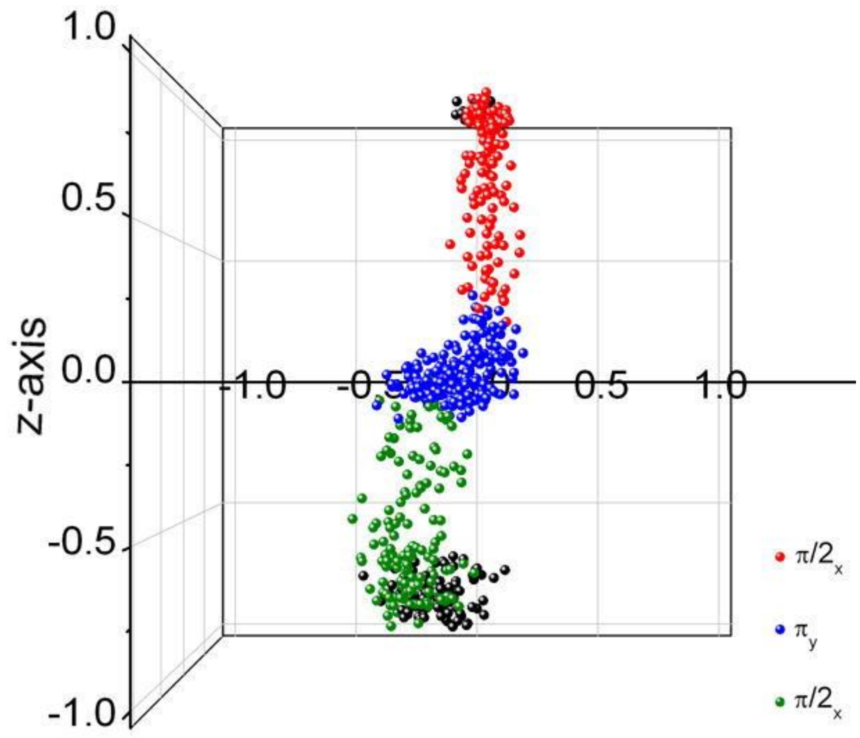
Better counting rate – RF-μSR

- High instantaneous flux is fundamentally beneficial for pulsed RF-μSR
- Complex pulse sequences take more time after muon implantation but give better results
- Rate increase like an extra 6μs to manipulate spins



J. Mag. Res. **214**, 144 (2011)

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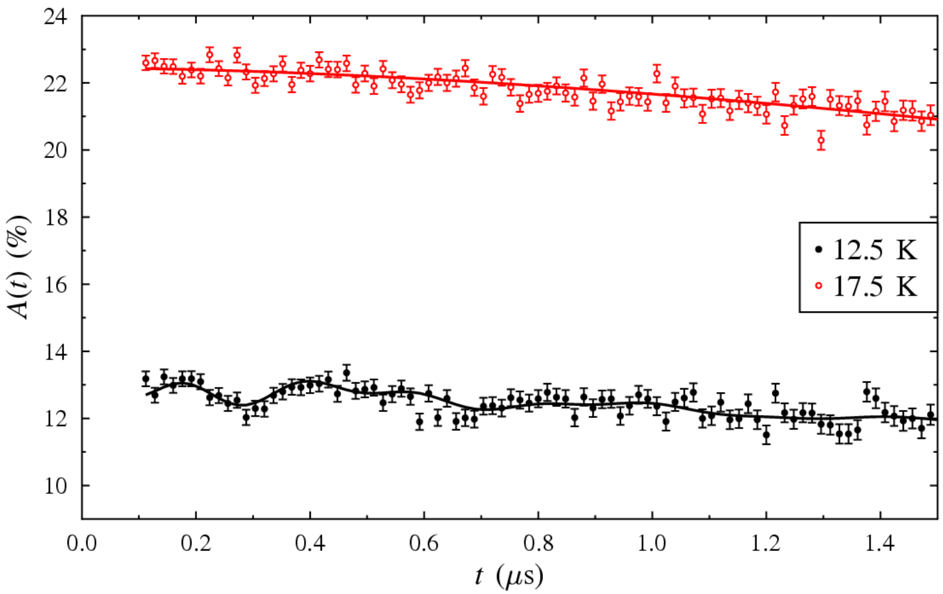
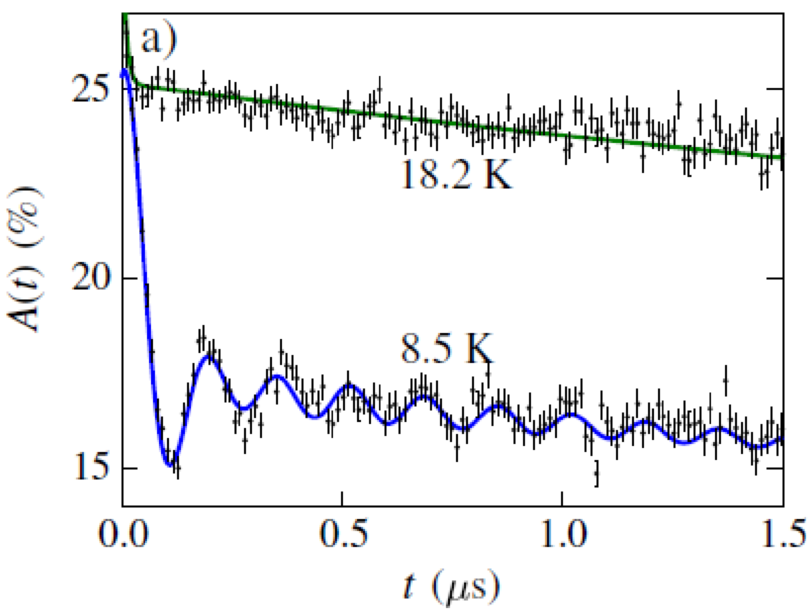
Better resolution – Na_2IrO_3

ISIS data

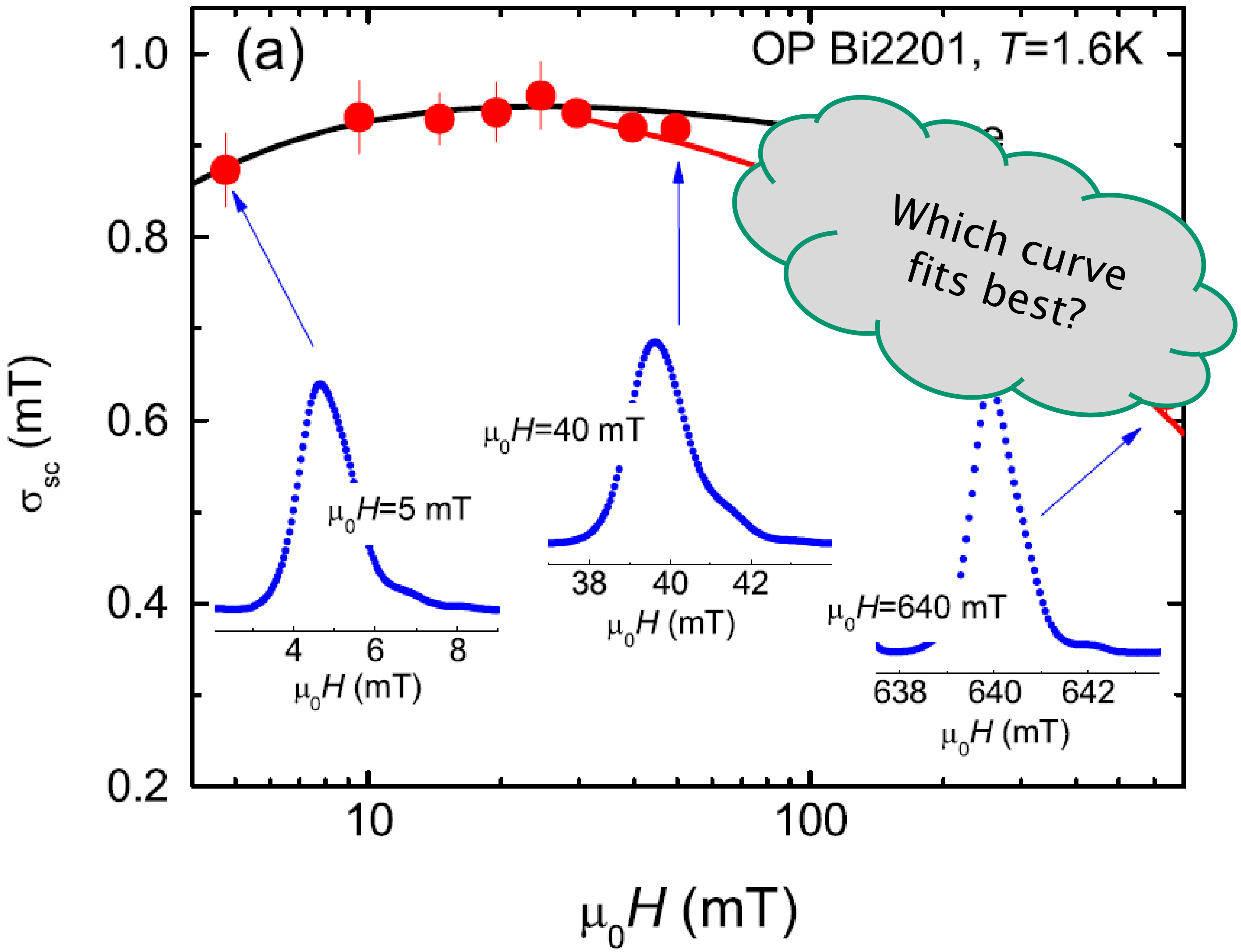


PSI data



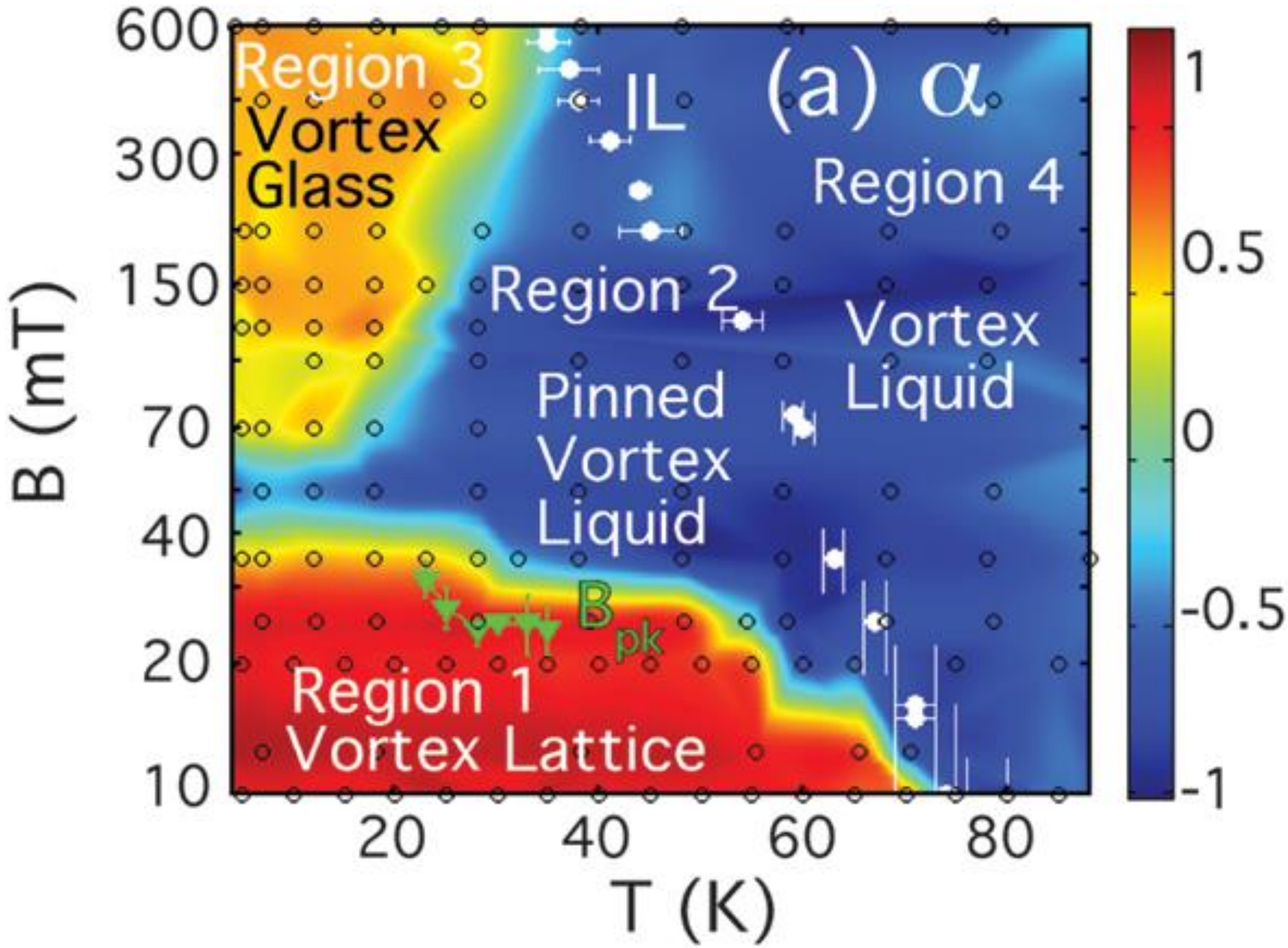
- EMU data demonstrated magnetic ordering
- Enabled MARI experiment that found magnetic structure
- PSI muons needed for publication quality data
- Pulse slicer would allow this to be done at ISIS
- PRL 2012, >250 citations

Resolution and spin rotation – Bi2201



Khasanov et al, PRL **101**, 227002
– data from PSI muons

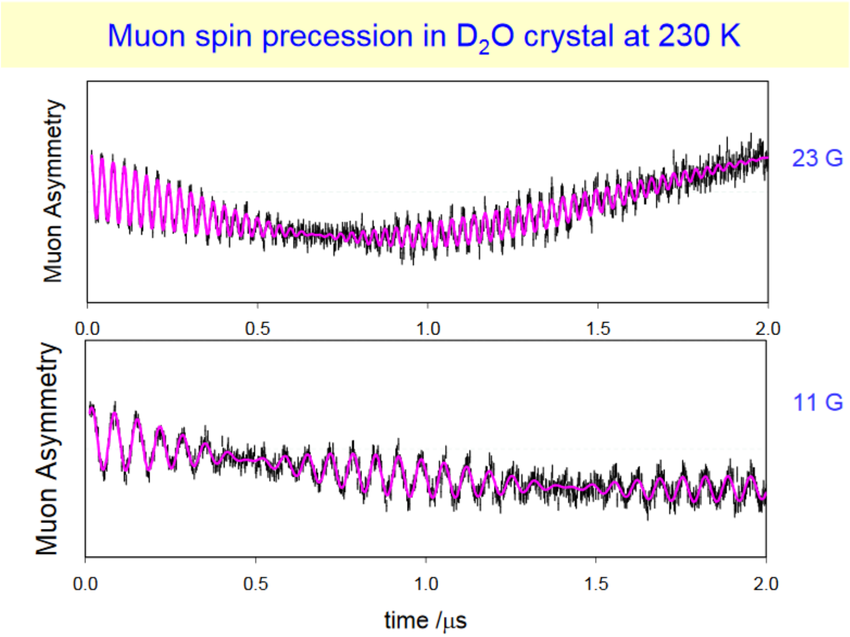
Resolution and spin rotation – La214



Heron et al, PRL **110**, 107004 (2013)
– data from PSI muons

Resolution (and spin rotation) – Muonium chemistry

- TF 2G is our present limit for muonium studies
- Even 2G shows loss of asymmetry
- Higher fields help to isolate from environment
- Resolution improvement accesses 10-20G region



Paul Percival, TRIUMF Summer School

- Also needs fixed, higher homogeneity TF coils

Directions for improvement

Use the available muons better

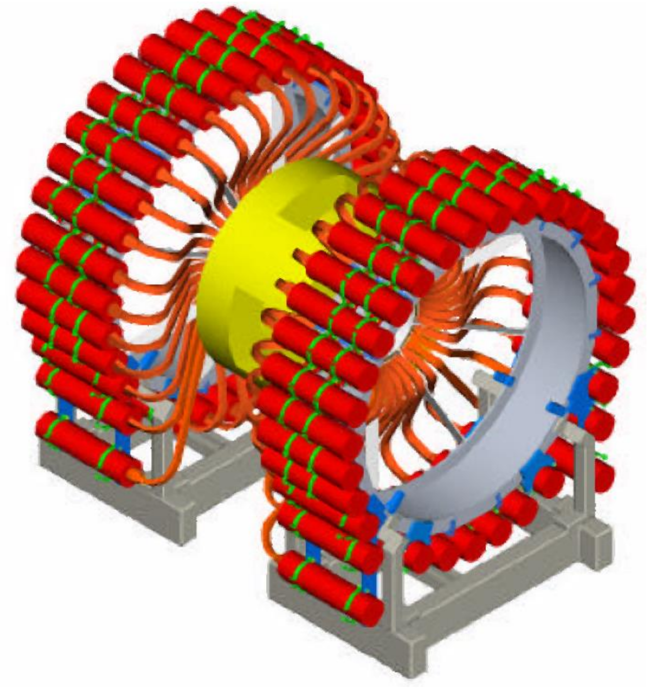
- Maximise solid angle of detectors
- Optimise positron energies counted
- Enough detectors to count the full flux on sample

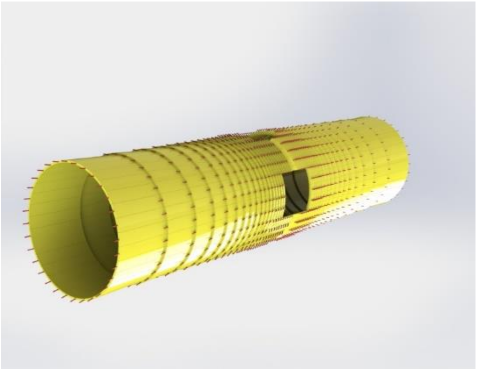
Improve the beam reaching the instrument

- Slice the pulse to 10-20ns width to improve resolution
- Use spin rotators for higher transverse field experiments

Better instrument infrastructure

- Improved weak Transverse Field coils – similar to EMU
- Fits under platform being extended this summer to give more space to prepare sample environment



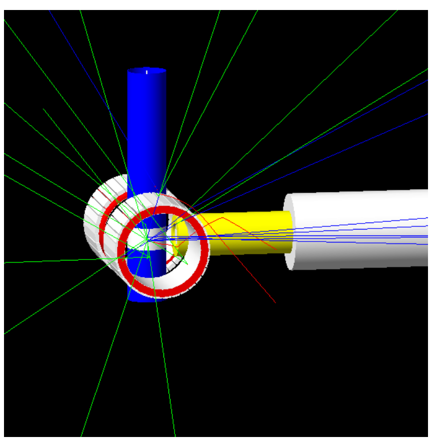


INSTRUMENT IMPROVEMENTS

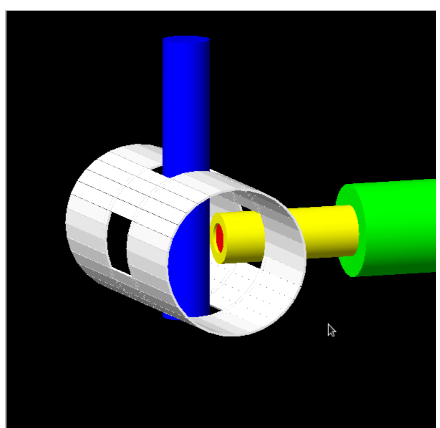
Scoping detector arrays

Detector design	Solid Angle Coverage (%)	Signal collected per muon (ZF, LF)	Signal collected per muon (TF)
2014 instrument (Old beam pipe, Current Degrader Ring)	42	1.00	1.00
2017 instrument (New beam pipe, Current Degrader Ring)	42	1.13	1.07
Cylindrical	75	2.65	3.42
Stepped	63	1.66	2.73
Spherical	78	1.22	3.02

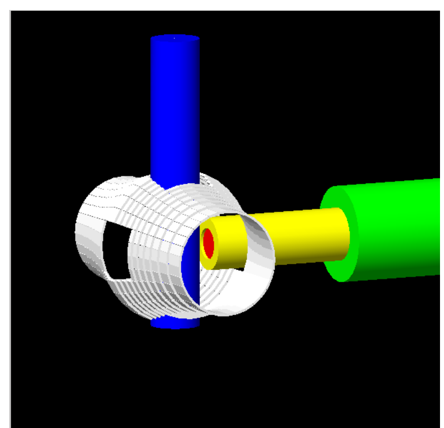
Current



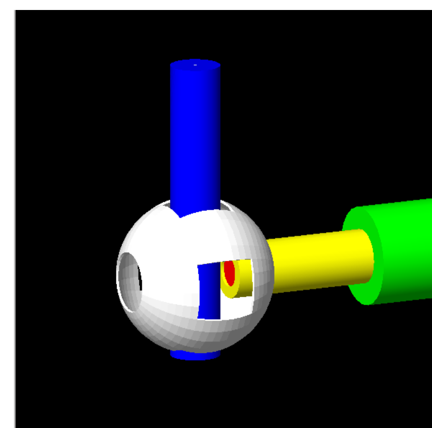
Cylindrical



Stepped



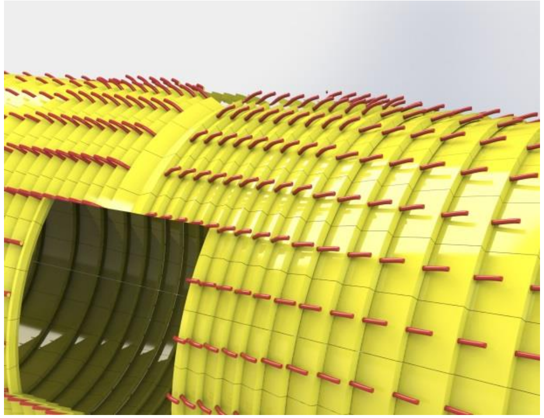
Spherical

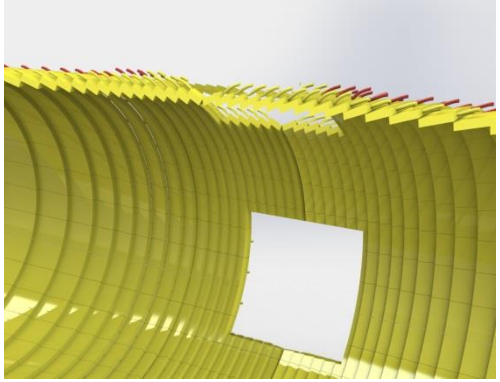


Details in RAL TR-2015-001

Preliminary detector design

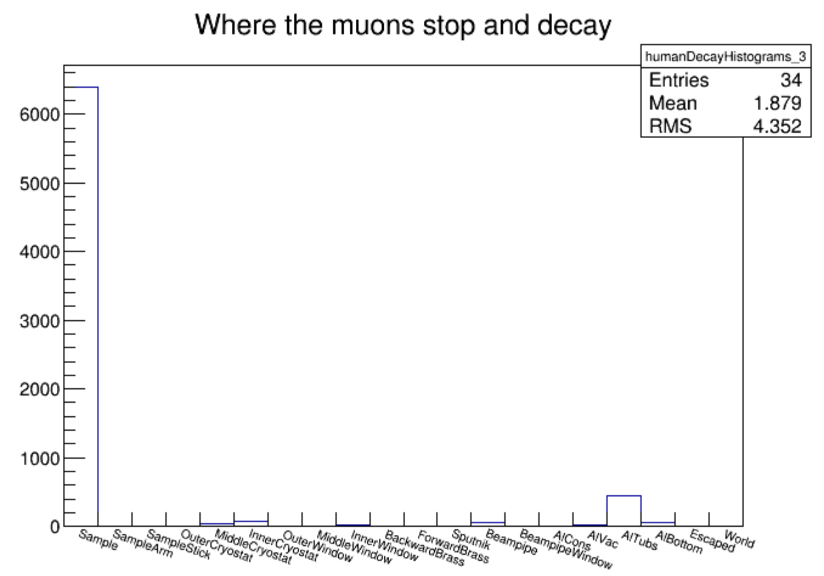
- 1216 elements
- Adds elements between magnet poles
- Maintains vertical and horizontal access
- Fits on existing trolley
- Optical fibre coupled
- Currently analysing design variations
- Further detail on readout technologies in talk later





Flypast mode

- Other 4 ISIS instruments offer flypast for small samples
- MuSR spot smallest and flux highest
- Trade-off between quick changes and low backgrounds
- Using flypast for TF on MuSR seems worthwhile



10mm Ag sample, setup like EMU

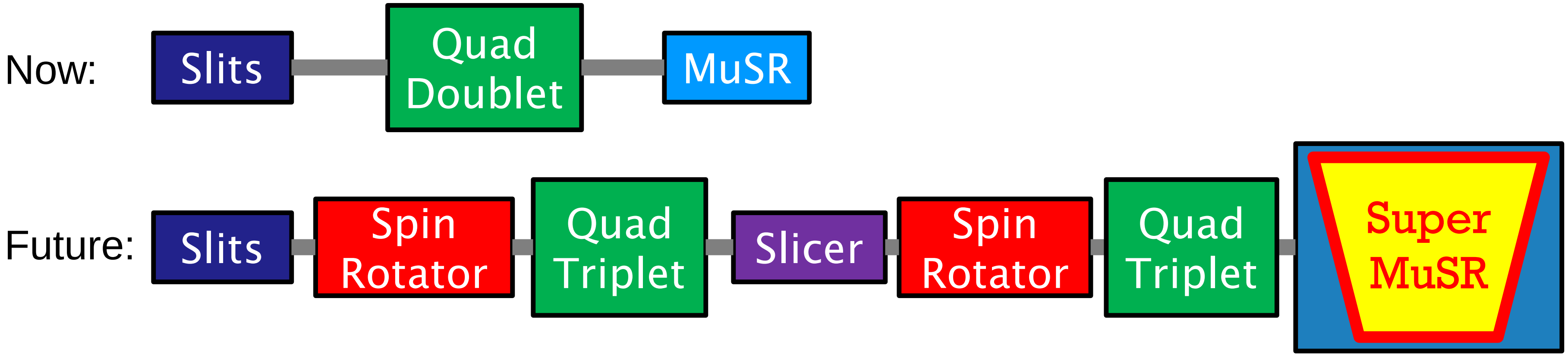
Other details

What changes

- TF coils need replacing!
- Fixed 15-20mT coils
- One axis or two?
- Do we need horizontal access for a CCR/flow cryostat on a slide?
- Improved zero field stability by being further from EMU & HiFi

What stays the same

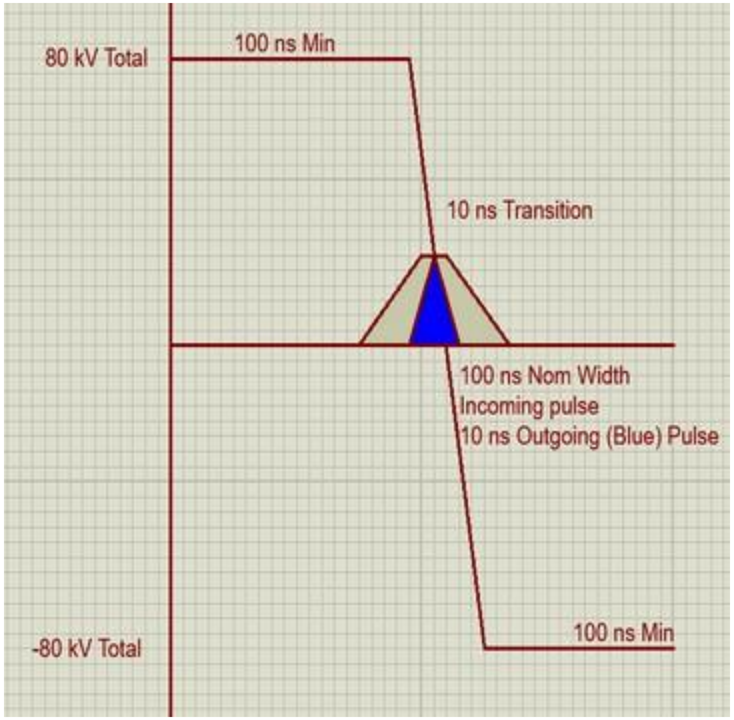
- Cryostats and fridges all retained (0.04-1000K)
- EMU and HiFi areas
- Area occupied by muon infrastructure



BEAMLINE IMPROVEMENTS

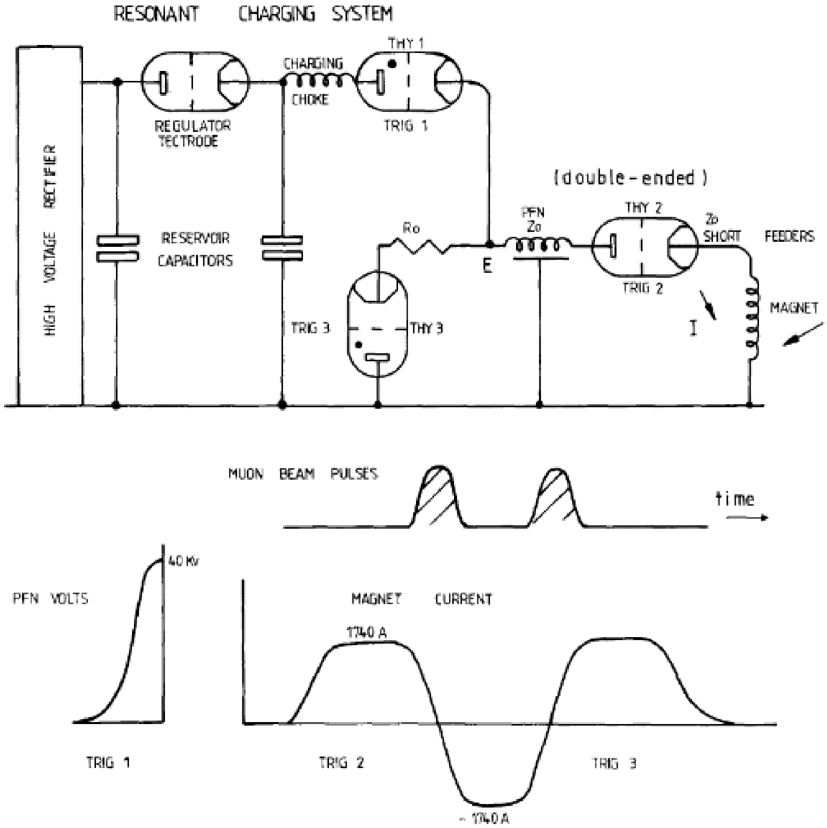
Technicalities of pulse slicing

- Allow muons to enter instrument briefly in middle of pulse
- Could be electrostatic or electromagnetic
- Voltage dip/spike or +/- transition
- Needs collimation after slicer



A Brief History of Pulse Slicing

- 1983 – 20ns pulses to two instruments viewed as optimal plan for ISIS muon facility
- Electromagnetic kickers (one shown on right) to both separate and slice
- Electrostatic kicker subsequently built for the EC muon upgrade



A Brief History of Pulse Slicing

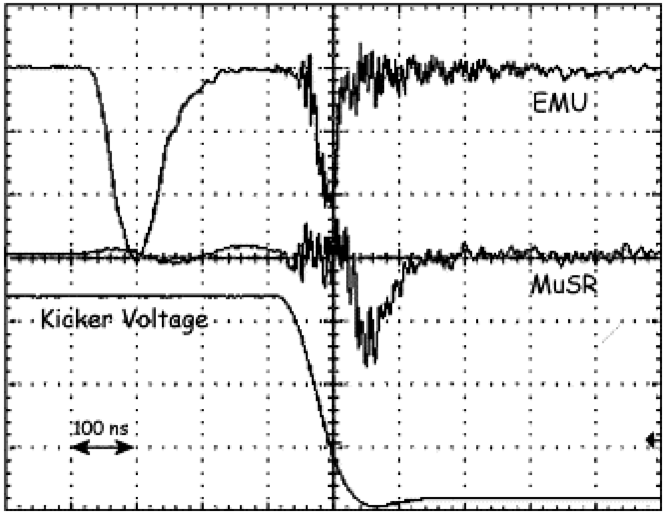
1983 – 20ns pulses to two instruments viewed as optimal plan for ISIS muon facility

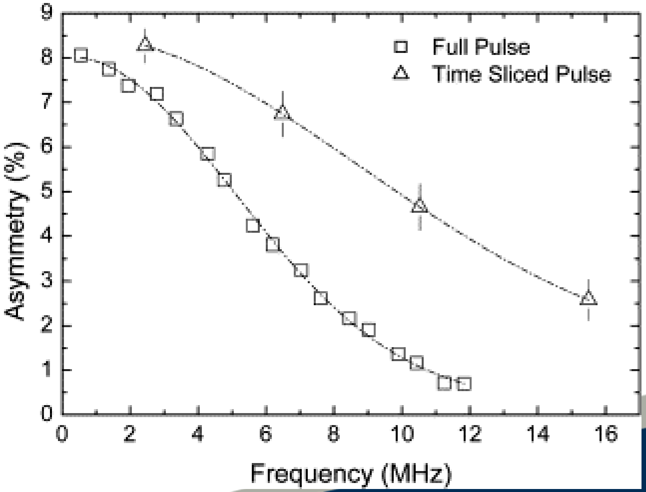
1999 – Pulse slicing demonstrated at ISIS

One edge sliced for ~45ns pulse width

Other 1½ pulses went to EMU and DEVA

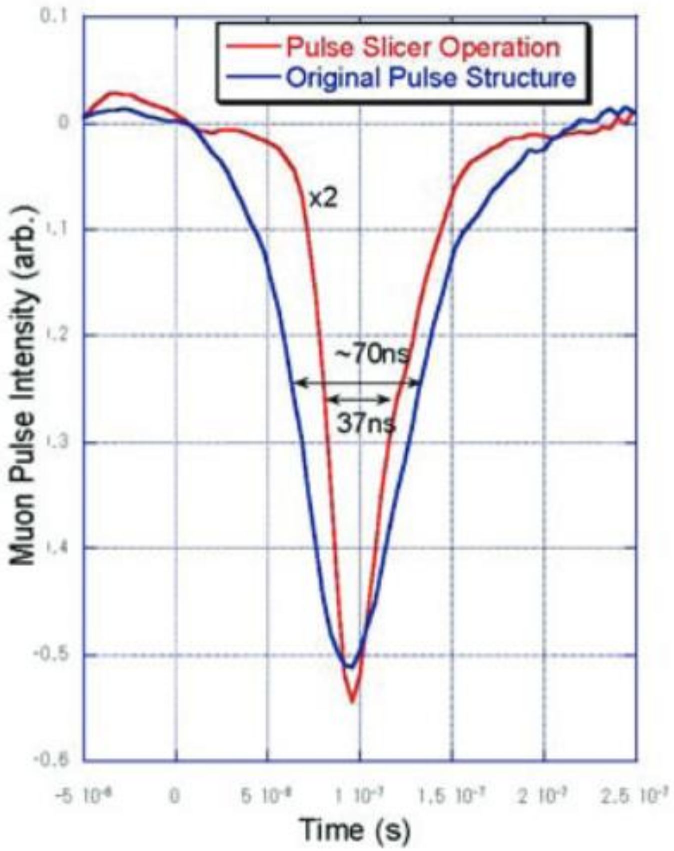
Results imply <20ns HV transition





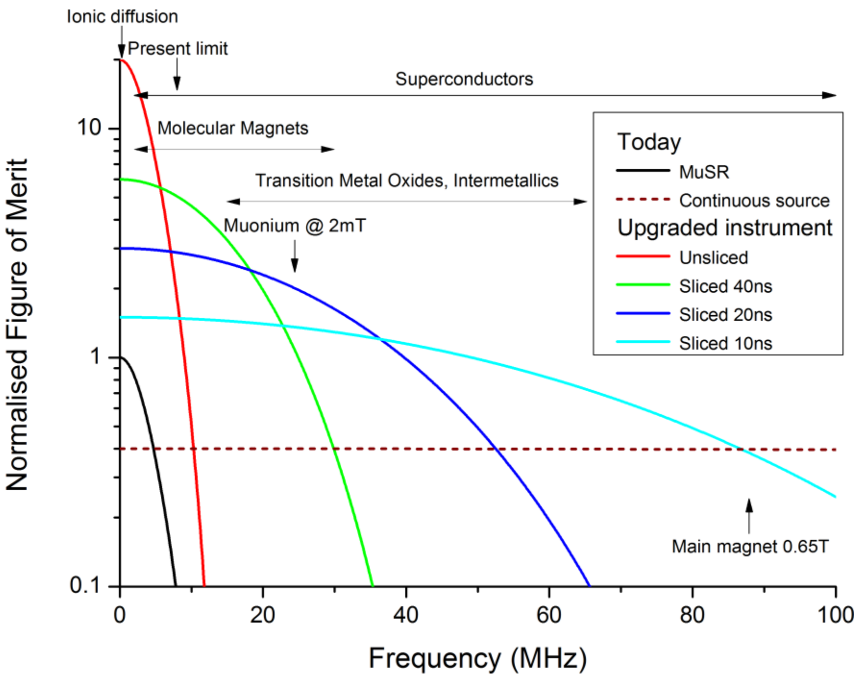
A Brief History of Pulse Slicing

- 1983 – 20ns pulses to two instruments viewed as optimal plan for ISIS muon facility
- 1999 – Pulse slicing demonstrated at ISIS
- 2012 – Pulse slicing demonstrated at J-PARC
- Similar performance to ISIS but different technical approach
- Report ~20ns HV transition



Pulse slicing when needed

- Have recommended HV drivers for a pulse slicer to work down to ~10ns
- Now to optimise reliability, consistency, and flexibility
- Likely to use HV switch and delay lines to give shortest HV pulse
- Possible modes
  - Period mode (Slicer on/off)
  - Choice of pulse length



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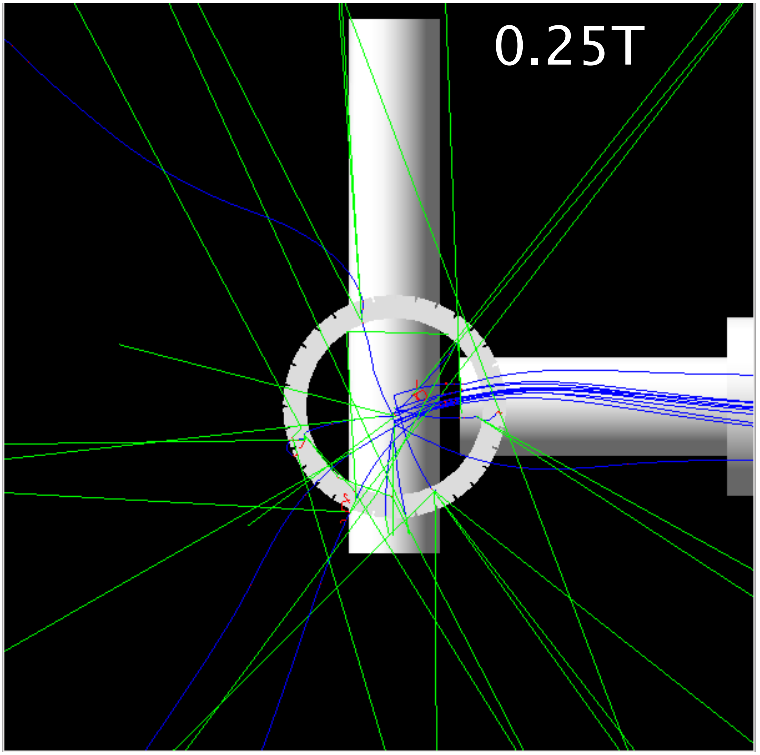
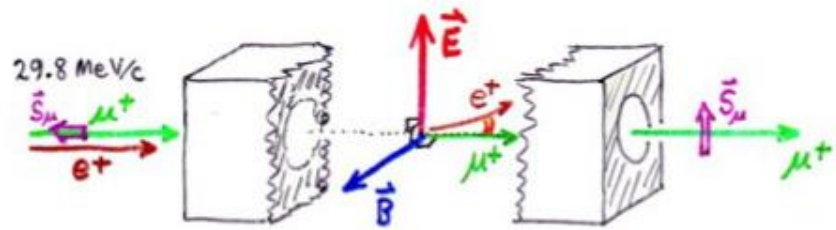
Spin rotation – the problem

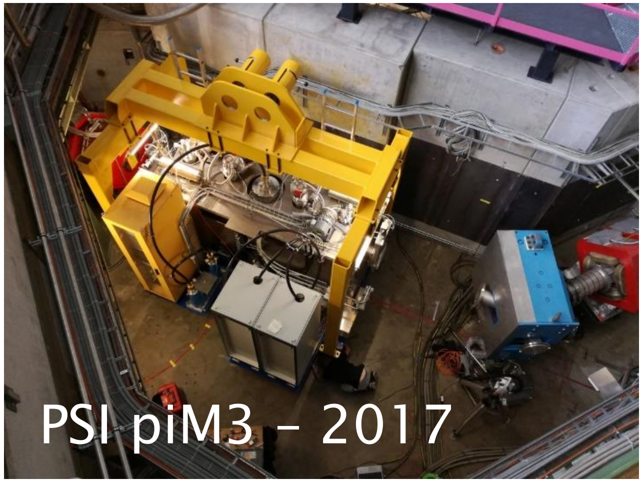
- Transverse Field currently means for spin AND momentum
- Okay with current pulse width (<0.1T)
- By 0.25T beam can't get into cryostat and hit sample
- Also limits crystal orientations that can be measured



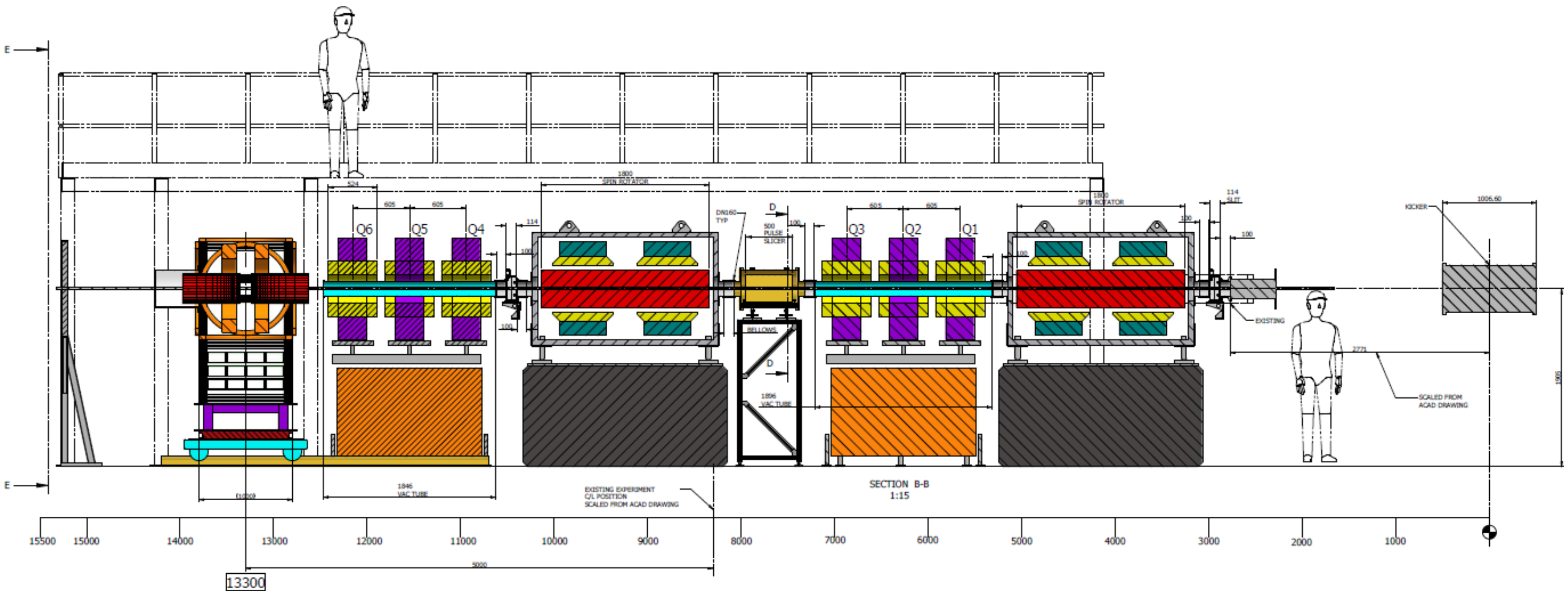
Spin rotation – the solution

- Rotate muon spins in flight
- Experimental field along beam axis
- Method already well-established at TRIUMF and PSI
- Aiming for >60° rotation with two spin rotators
- Biggest challenge probably space constraint




PSI piM3 – 2017

Beamline layout



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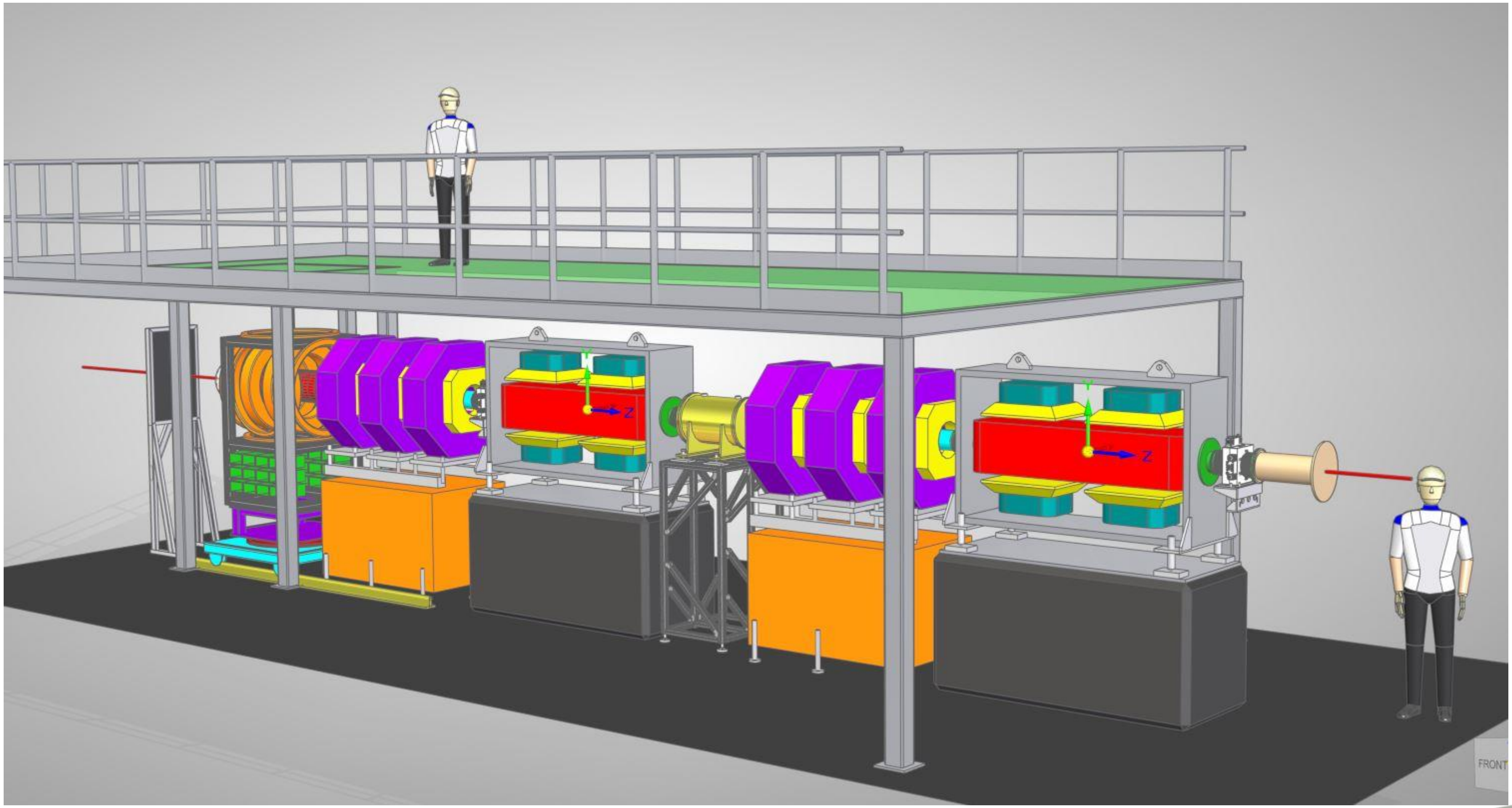
Beamline layout



CONCLUSIONS

Super-MuSR 'Tomorrow'

- Maximises benefits of available muon flux
- Maintains low backgrounds and high stability
- Intermediate resolution between ISIS today and continuous muon sources
- Greater complementarity between Super-MuSR and continuous muon sources
- Greater complementarity between Super-MuSR and elastic neutron scattering

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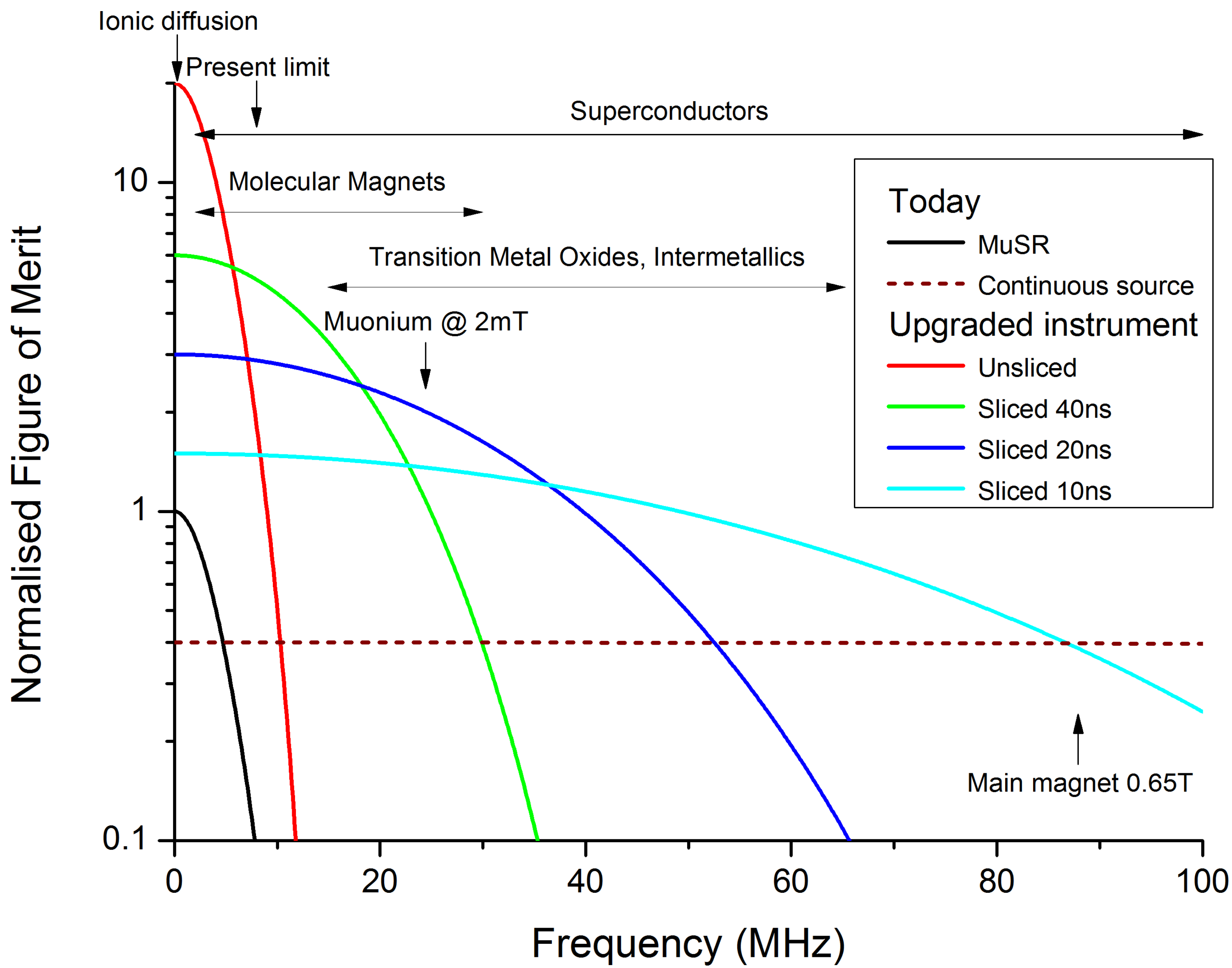
ISIS

Super-MuSR Capabilities



Before and after upgrade

	Today	Proposed	Benefit
Detectors	64	~1216	20x data rate
Muons admitted	8%	100%	Best use of larger samples
Solid angle coverage	40%	75%	Best use of muons on sample
Zero field data quality (a_0^2 * rate)	4.7	95 (full pulse) 6.3 (10ns)	Higher quality data
Maximum frequency (field)	8 MHz 0.06T	~80 MHz ~0.6T	Enables experiments not previously done at ISIS
Spin rotation	None	60°	Higher field TF measurements
Maximum field	0.32T	0.65T	Broader range of experiments