# Systematic issues in MuCap

*P. Kammel*

- **The expected**
  - **Physics**
  - **Detectors**
- **The unexpected**
  - **Consistency checks in space and time and brain**

**emphasis on completeness, more than solutions**

**please add to the list**

| | correction(error) to $\lambda$(ppm) | | | | | |
|---|---|---|---|---|---|---|
| | global PU free data | | | local PU free data | | |
| | $\mu^-$ | $\mu^+$ | comment | $\mu^-$ | $\mu^+$ | comment |
| statistics | (10) | (10) | $10^{10}$events | (7) | (7) | 2x$10^{10}$events |
| wall stops | (2) | - | | (2) | - | |
| impurities | 2(3) | - | $c_Z=10^{-8}$assumed | 2(3) | - | $c_Z=10^{-8}$assumed |
| flat accidentals | (2) | (2) | level $10^{-4}$ | (3) | (3) | level 5x$10^{-4}$ |
| $\mu$SR | - | (2) | | - | (2) | |
| diffusion | 1(1) | - | no vertex cut | 100(5) | - | 5 cm radial cut |
| $\mu$ effect on electronics | - | - | | - | - | |
| two event correlation | - | - | | (2) | (2) | accidental structure |
| **total systematic error** | **4.2** | **2.8** | | **7.1** | **4.1** | |
| $\delta\lambda$ **total error** | **10.9** | **10.4** | | **10.** | **8.1** | |

Table 11: Summary of statistical and systematical errors for 2 complementary analysis methods

**TP 2001**

# Physics: Interpretation

*P. Kammel*

| | | $\delta\lambda$ |
|---|---|---|
| **Experimental issues** | | |
| ▪ $\lambda_{op}$ | | ± 10 ppm ? |
| | neutron detectors | |
| ▪ $\lambda_{pp}$ | | ± 10 ppm ? |
| | capture distribution | |
| ▪ $\lambda_{hfs}$ | | 0 |
| | start time scan | |

- **Other issues**
  - consistency $\Lambda_S$ calcs — ± 10 ppm ?
  - new neutron lifetime measurement — ??

# Physics: Wall stop and accidentals

*P. Kammel*

**Defer to detector section**

# Physics: Z>1 impurities

*P. Kammel*

$$x \approx \frac{c\phi\lambda_{tr}}{\lambda_0} \qquad y = \frac{\Lambda_Z}{\Lambda_Z + \lambda_0}$$

**x,y,**
**capture yields Y,**
**change of decay rate δr,**
**concentrations c(molecular)**
**in ppm.**

| element | $\lambda_{tr}$ ($10^5$/us) | x | $\Lambda_Z$(1/us) | y | Y @ c=0.1 | δr | δr/Y | δr @ Y=10 |
|---|---|---|---|---|---|---|---|---|
| C | 0.95 | 2087.91 | 0.0376 | 0.076 | 15.937 | 28.56 | 1.792 | 17.923 |
| N | 0.34 | 747.25 | 0.0693 | 0.132 | 9.877 | 16.43 | 1.663 | 16.634 |
| O | 0.85 | 1868.13 | 0.102 | 0.183 | 17.105 | 26.68 | 1.560 | 15.596 |
| Ne | 0.08 | 175.82 | 0.235 | 0.341 | 5.988 | 7.80 | 1.302 | 13.024 |
| Pb | | | | 1 | | | 1 | |

We observe $Y_{obs}=\varepsilon_Z Y$

$\delta\lambda \sim 3$ ppm

$\delta r = f(y_Z)\, Y = f(y_Z)\, Y_{obs}/\varepsilon_Z$

Approx: $\delta r = xy(2+y)/(1+y)^2 \approx 2\,xy = 2\,Y$

$\varepsilon_Z$ calibrated for $N_2$ only, assume 50% uncertainty for other Z, $\delta\lambda \sim \sqrt{3^2+8^2} = 8.5$ ppm

**small effect, still we should understand the source of impurities**

# Physics: Diffusion

*P. Kammel*

transfer: $p\mu + d \rightarrow d\mu + p$ (134 eV)

$\Lambda_d = \phi\, c_d\, \lambda_d$ = 150/s *$c_D$(ppm)

proposed $\delta\lambda$=10/s

**Special discussion later**

Understanding

- mass spec results
- $\lambda$ vs. impact parameter R from data

| | |
|---|---|
| $\mu$+, $\mu$- with different $c_D$ | St&To&Fd |
| diffusion MC with geometry | Br |
| diffuse real tracks | St&Br |
| Geant simulation and reconstructions | Be |

$\delta\lambda$~? ppm

Best extrapolation method for $c_D$ determination     Br&Pe

- $\lambda_{R1(cD)} - \lambda_{R2(cD)} \propto c_D$

  single exponential fit justified?
  better method?
  use n(R1<r<R2) instead

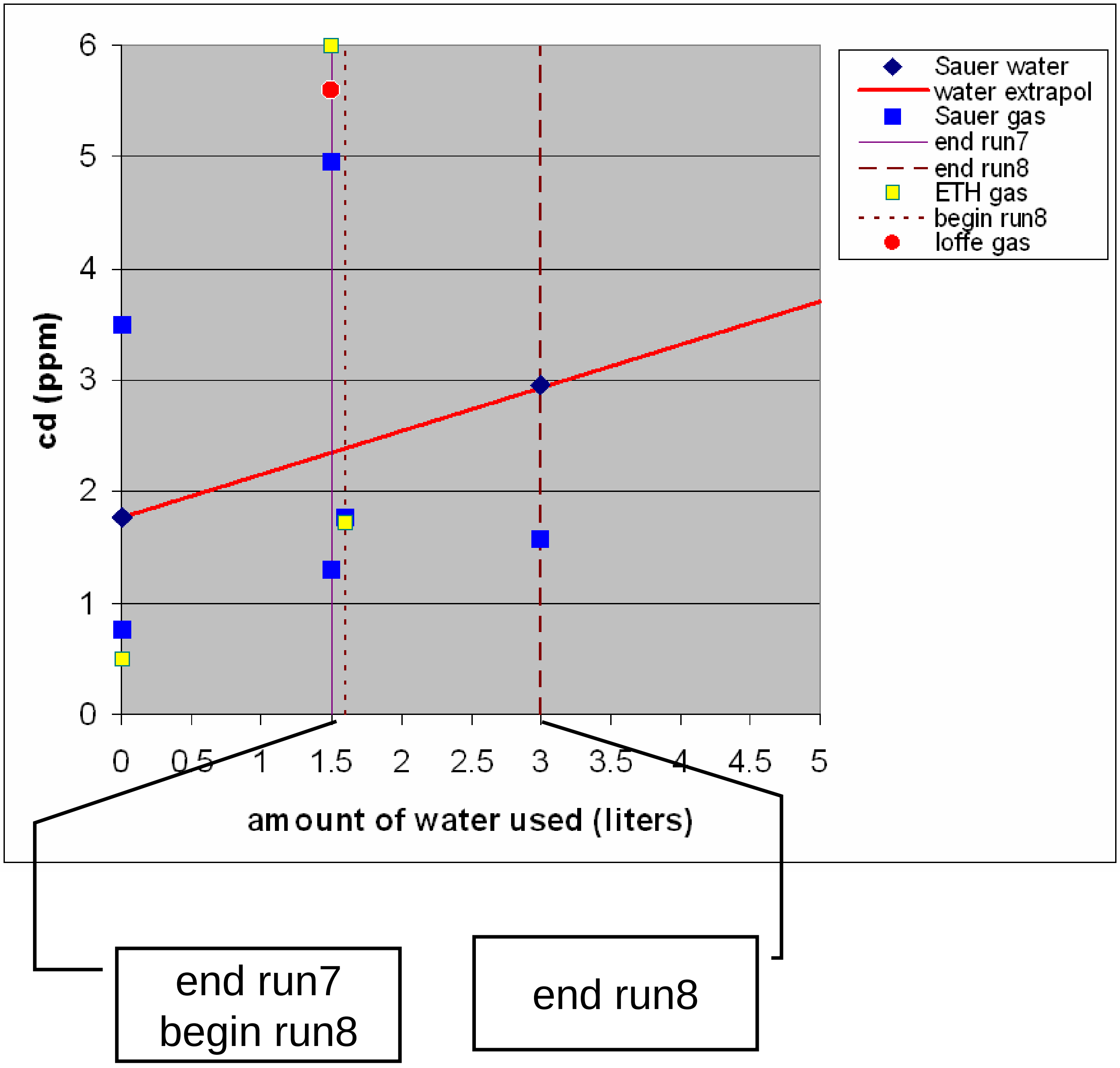
**MuCap note (**Br&Pe**)?**

Future

- cleaner protium, Tim
- other detection methods
- PNPI isotopic separation

# Diffusion: mass spec results

*P. Kammel*




**Explanations:**

- a linear line is drawn through Sauer's 2 water measurements, to indicate the cd increase in the remaining water. If it is true it would be very interesting. The slope is k~0.4/l. Thus if we electrolyze the first liter it should have k*4=1.6 ppm less deuterium than the original to keep the change in the total amount of deuterium zero( 4 liter*k= 1 liter 4k)!?

-the gas points at x=1.5 and x=3 correspond to the accumulated cd in the TPC gas, while the gas points at x=0 and 1.6 correspond to an differential sample taken at these conditions. The x=1.5 gas measurements corresponding to the end of run7 include the increase of D during the run (probably Pd filter) and thus should not be directly compared to the other measurements.

**-Discussion:**

i) There is a large scatter at x=0

ii) At x=1.5, the newest Sauer gas point does not agree with all other measurements.

iii) The Sauer gas points at x-1.6 and x=3 do not follow the expected increase in cd expected from the deteriorating cd conc in water. This figure will become more informative once we include - the results from the impact para cut c_D determination,

**Future**

-get the ETH analysis of the final run8 gas,

-- get a better understanding of the expected electrolysis separation from the PNPI experts.

# Physics: μ⁺SR

P. Kammel

TABLE I. Pressure-dependent $\mu^+$ and Mu amplitudes in different gases.

| Target Gas | Pressure (atm) | $A_\mu$ (obs)[a] | $A_\mu$ (walls)[b] | $A_{Mu}$[a] | $A_{tot}$[c] | $A_{abs}$(%)[d] |
|---|---|---|---|---|---|---|
| He | 1.2 | 0.154±0.004 | 0.085 | 0.0 | 0.07 | 31 |
| | 2.7 | 0.210±0.003 | 0.070 | 0.0 | 0.13 | 48 |
| | 3.1 | 0.222±0.002 | 0.035 | 0.0 | 0.19 | 59 |
| Ne | 0.80 | 0.100±0.002 | 0.03 | ~0.02 | 0.11 | 28 |
| | 1.2 | 0.170±0.002[e] | 0.005 | 0.005±0.005[e] | 0.18 | 41 |
| | 1.6 | 0.255±0.003 | 0.015 | 0.015±0.005 | 0.27 | 62 |
| | 2.0 | 0.300±0.002 | 0.009 | 0.027±0.002 | 0.34 | 82 |
| Ar | 1.0 | 0.071±0.004 | 0.009 | 0.100±0.003 | 0.26 | 72 |
| | 2.0 | 0.092±0.003 | 0.005 | 0.111±0.004 | 0.31 | 85 |
| | 2.4 | 0.100±0.003 | <0.005 | 0.130±0.004 | 0.36 | 90 |
| | 2.8 | 0.095±0.002 | <0.005 | 0.143±0.003 | 0.38 | 96 |
| Kr | 0.40 | 0.065±0.004 | 0.065 | 0.040±0.004 | 0.08 | 32 |
| | 0.65 | 0.020±0.003 | 0.020 | 0.086±0.004 | 0.17 | 50 |
| | 0.95 | 0.020±0.003 | 0.020 | 0.120±0.006 | 0.24 | 68 |
| Xe | 0.40 | 0.046±0.003 | 0.046 | 0.050±0.003 | 0.10 | 36 |
| | 0.60 | ~0.04 | ~0.04 | 0.070±0.010 | 0.14 | 48 |
| | 0.65 | 0.040±0.010 | 0.040 | 0.089±0.006 | 0.18 | 58 |
| $H_2$ | 3.1 | 0.126±0.008 | ~0.02 | 0.086±0.008 | 0.28 | 82 |
| $N_2$ | 1.0 | 0.045±0.003 | 0.005 | 0.125±0.007 | 0.29 | 92 |
| | 2.4 | 0.076±0.002 | <0.005 | 0.171±0.004 | 0.41 | 100 |
| $CH_4$ | 1.2 | 0.037±0.002 | 0.005 | 0.110±0.004 | 0.25 | 63 |
| | 3.0 | 0.058±0.002 | <0.005 | 0.180±0.005 | 0.41 | 100 |
| $NH_3$ | 2.8 | 0.040±0.004 | <0.005 | 0.182±0.003 | 0.40 | 100 |

[a]Experimentally observed $\mu^+$ and Mu amplitudes.
[b]Contribution to $A_\mu$ (obs) from walls at stated pressure.
[c]$A_{tot} = A_\mu + 2A_{Mu}$, where $A_\mu = A_\mu$ (obs) − $A_\mu$ (walls).
[d]$A_{abs} = A_{tot}/A_{Al}$ for same experimental conditions.
[e]Obtained with research grade (99.99% Ne).

# Detector: general understanding

*P. Kammel*

- **TPC,**
  - **drift times (1, 2)**
  - **??**
- **ePC**
  - **signal shapes, deadtimes, afterpulses**
  - **??**
- **eSC**
  - **autocorrelations, reflections**
- **mPC**
- **??**

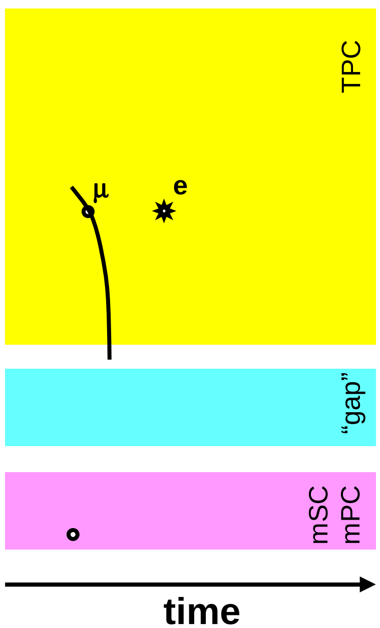
# Detector: μ stop definition

P. Kammel

- **wall stops**
- **acc distortion due to unseen pile-up**

**double kill less important?**

**acc. μ**
**t correlated**

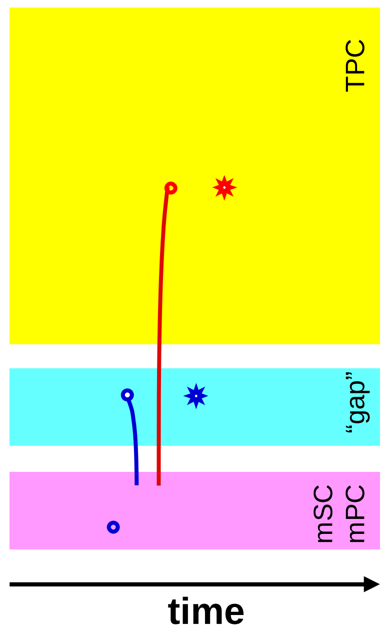



**simple wall stop**

**quantify δλ:**

- **different fiducial cuts**
  **dubious event method**
- **fit start time analysis**

**δλ~? ppm**

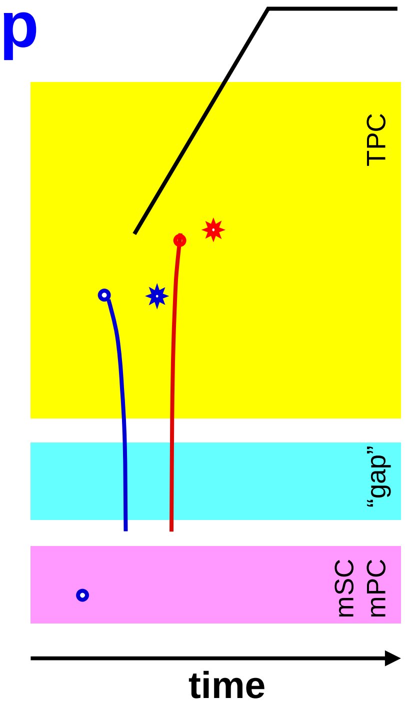



**wall stop by misreconstruction**

**quantify δλ:**

**data**

- **λ vs. impact para**
- **λ vs. μPU rejection eff.**
- **μ–μ stop correl in TPC**




**acc. deformation due time dependent μPU rejection efficiency and sweep out time**

**MC**

- **Geant with Z capture lifetime**

**MuCap note (Berkeley)?**

# Detector: electron definition incl tracking

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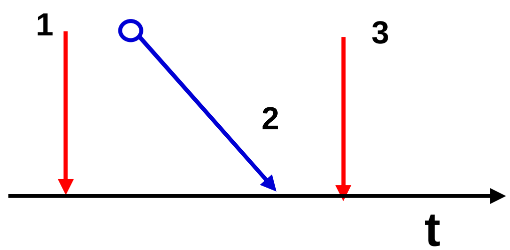
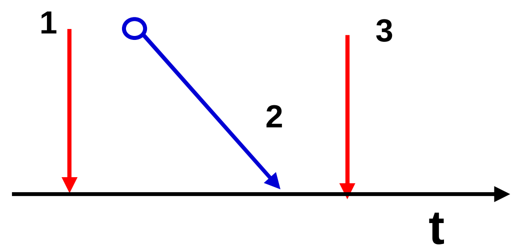
## deadtime effects and distortions




**histo all e**

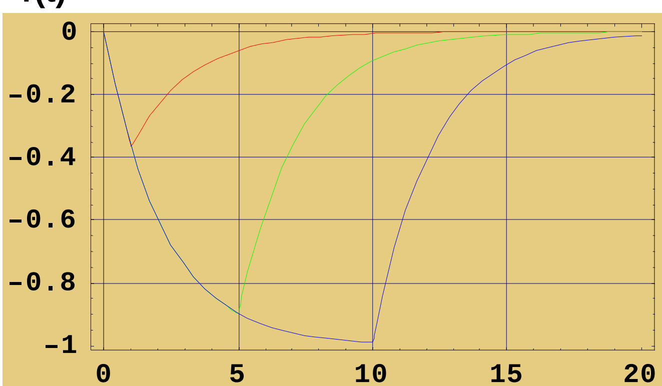
**P(1) > P(3)**
**P(2) ∝ $e^{-\lambda t}$**

**histo events with one e +- 24 us**

**P(1) < P(3)**
**P(2) ∝ $e^{-\lambda t}$**

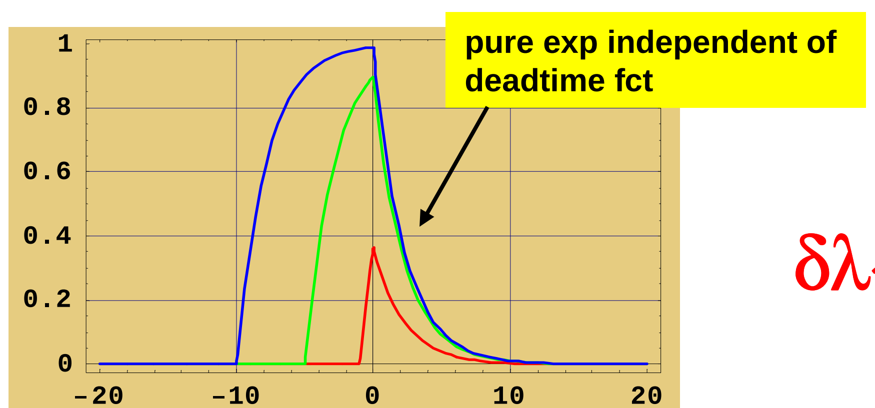
r(t)

acc(t)= a0 (1+ f r(t))




t (us)

eff reduced to f<1 for t<T




t (us)

eff reduced to f<1 for t<T

- **Fast MC (Peter)**

**MuCap note (Peter, Steve)?**

- **λ vs. different deadtime (det) definitions (Steve)**
- **λ vs. impact. par. μ+ (Fred)**
- **Geant MC with enhanced deadtime**

δλ~? ppm

# Clock and binning

*P. Kammel*

- **clock stability**
- **TDC binning effects, diff linearity**
- **beat with RF**

- **how to test that?**

**Fred short note?**

$\delta\lambda$~? ppm

# Unexpected: general strategy

*P. Kammel*

**consistency checks**

**space**

**different**

- **det regions**
- **det combinations**
- **det deadtimes**
- **impact parameters (μ+)**

**time**

**different**

- **run groups**
- **fit start-end times**

**different brains and programs**

**problems in λ up to now**

- **impact par cut**
- **gondola's**
- **comparison impact par cut vs $c_D$**
- **μ+**

$\delta\lambda \sim ?$ ppm

# Error budget spreadsheet

*P. Kammel*

| Effect | $\delta\lambda$(ppm) | tasks | | |
|---|---|---|---|---|
| lop | ~10 | | | |
| lpp | ~10 | | | |
| Z>1 impurities | 8 ? | | | |
| deuterium | ? | | | |
| MSR | ? | | | |
| m stop | ? | | | |
| e definition | ? | | | |
| clock etc | ? | | | |
| | | | | |
| consistency | | | | |
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# μSR

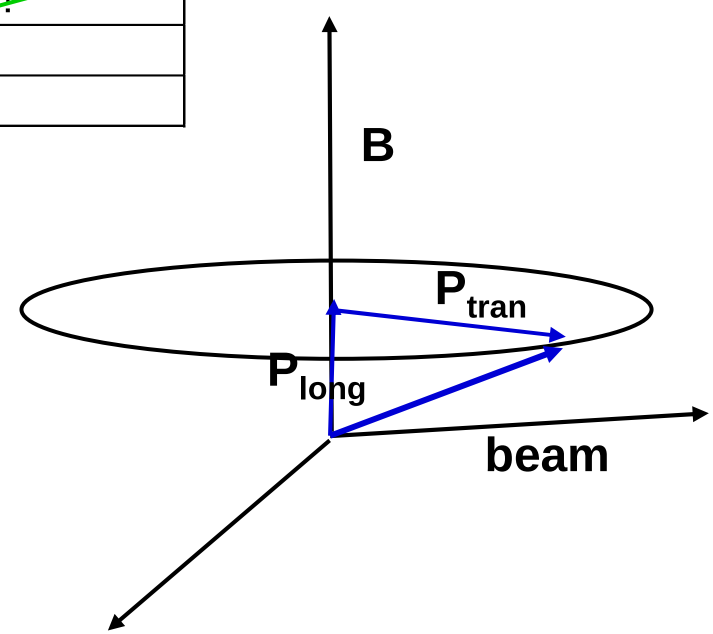
P. Kammel

| basics | | comment |
|---|---|---|
| Detector asymmetry | 0.05 | assumed for estimate, use mu- for homogeneity calibration |
| Asymmetry in H2 | 0.1 | 2/3 muonium + 1/3 mu+ |
| total (ppm) | 5000 | not good enough, MSR fitting, relaxation function |
| tranverse rotation | | |
| study best method | | relaxation function |
| MuCap Note | | |
| | | |
| Long polarization, T1 | | |
| fraction from sep | ~0.05 | B horizontal ! |
| fraction from COBRA | ~0.06 | |
| total (ppm) | 0-250 | |

| | |
|---|---|
| μ+ | 13.55 kHz/Gauss |
| Mu | 1.394 MHz/Gauss |

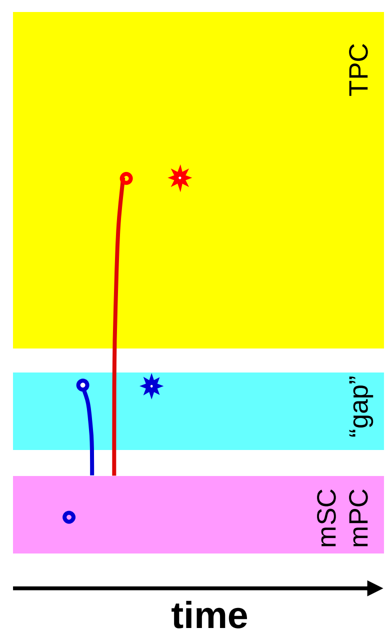
$R(t)=1+a\,\mathbf{P}(t)\bullet\mathbf{u}$

**λ+: fit N(ϕ)+N(ϕ+π),**
**λ-: fit N(ϕ)-N(ϕ+π),**
**correct λ+**




**MuCap note and discussion:**

- importance of Bz?
- which fraction of data with reversed field
- analysis & correction procedure
- determine B field direction?


TPC
"gap"
mSC
mPC
time