Neutron Analysis

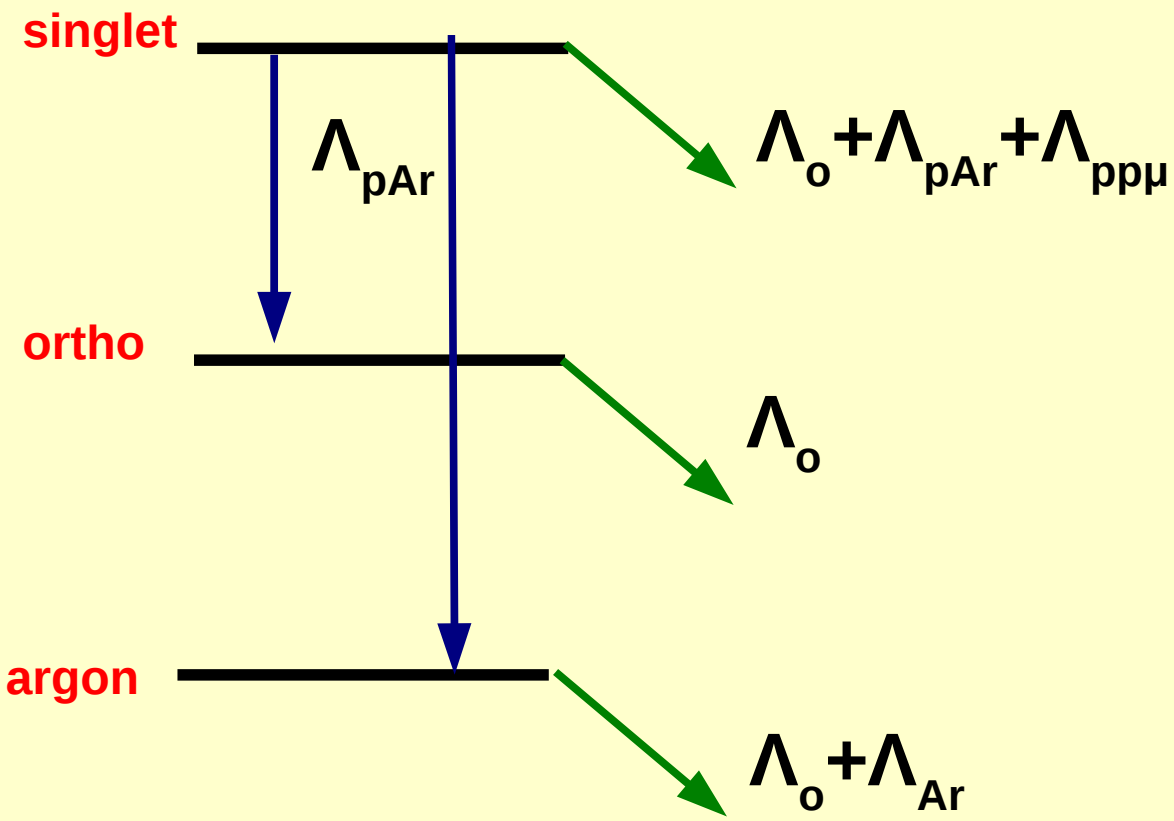
Seattle, Sept 2010

Electron time spectrum fits

2010/2009 pass comparison
of pure H, neutron time spectra

2010/2009 pass comparison
of H+Ar neutron time spectra

H_2+Ar kinetics



electron time dependence,

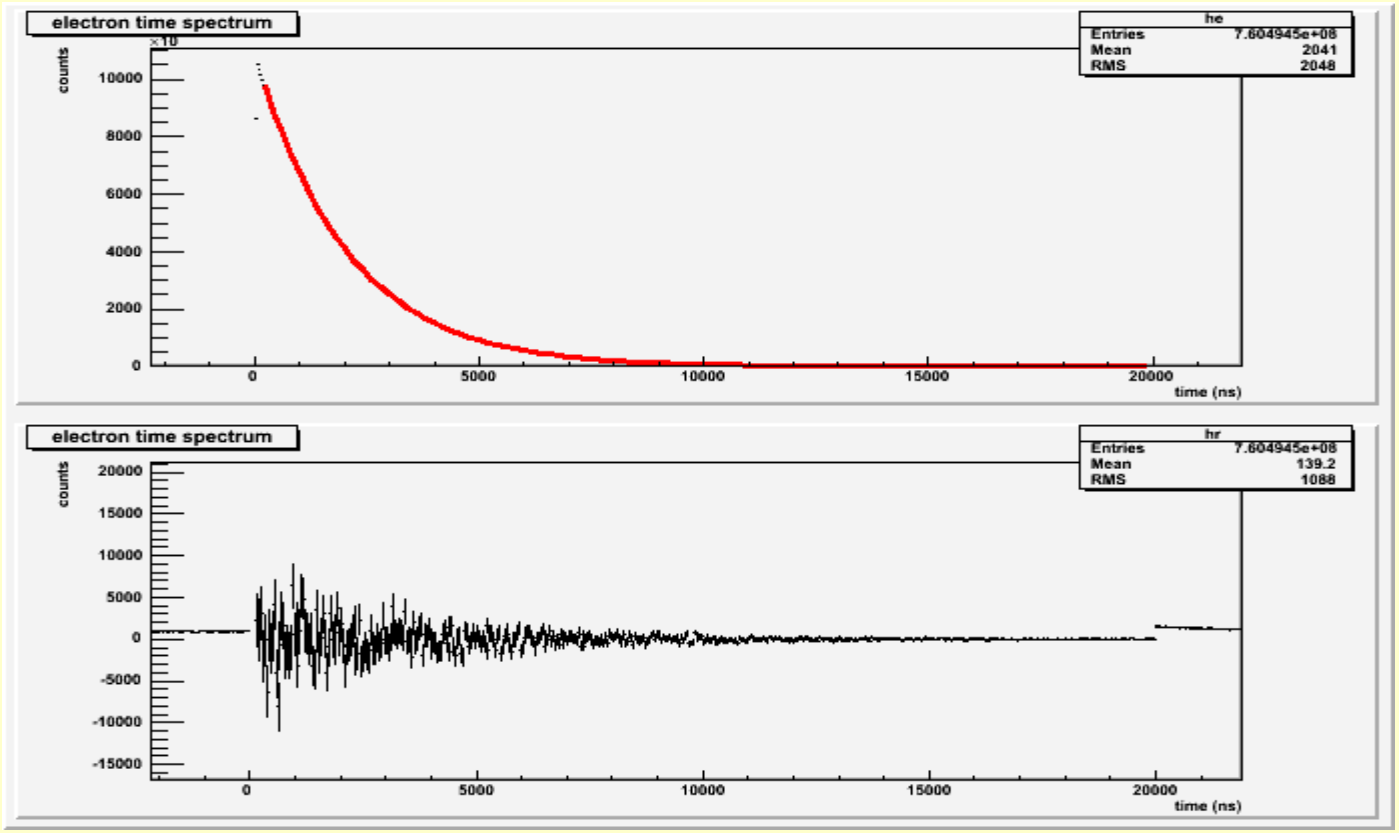
$$N_n(t) \sim A_1 \exp(-\Lambda_0 t) + A_2 \exp(-\Lambda_1 t) + A_3 \exp(-\Lambda_2 t))$$

i) fits with three fit functions

ii) fits with direct atomic capture, excited state transfer, Huff factor, and H/Ar efficiency difference.

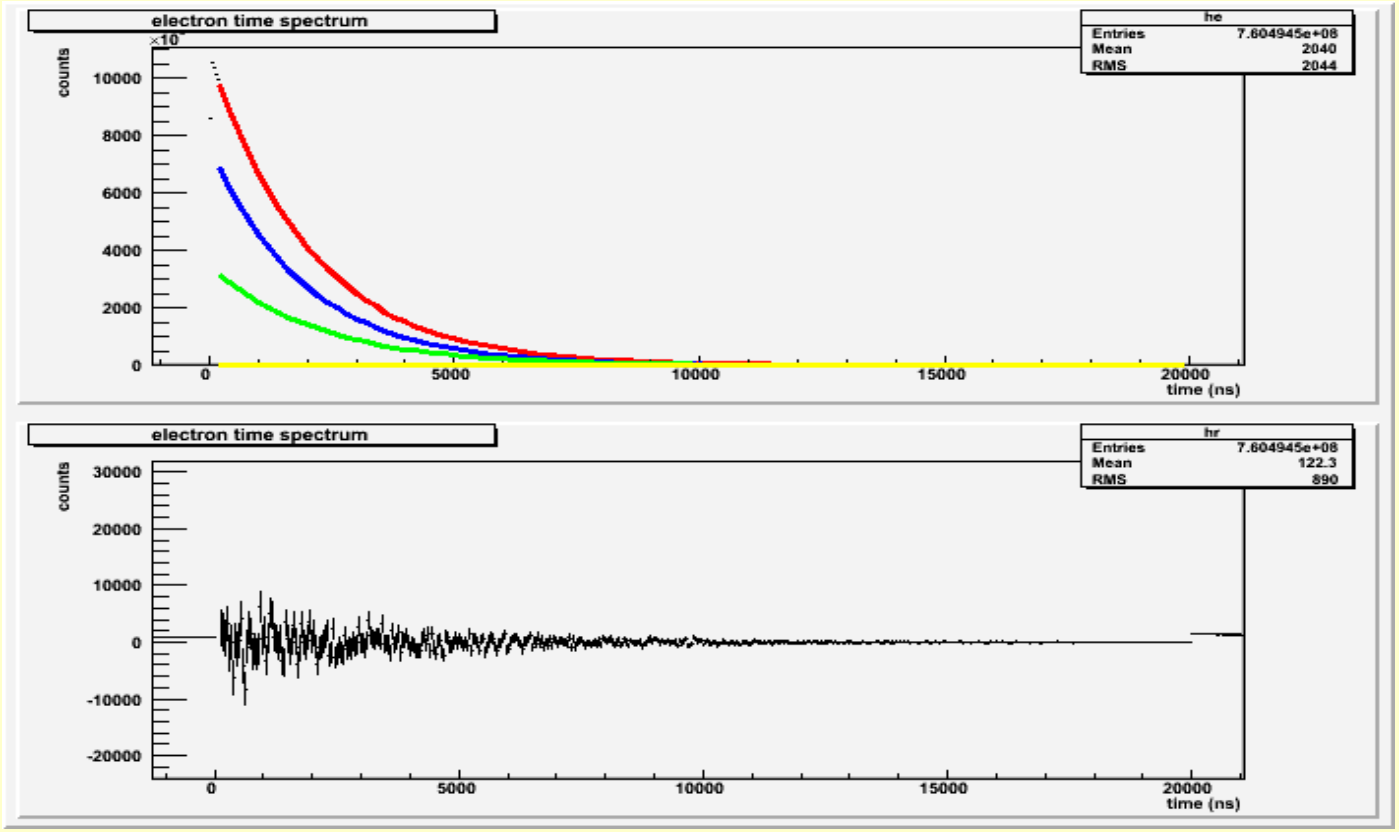
```
root [4] electron(120,20000,1,16,1.0)
```

```
FCN=504.772 FROM MINOS     STATUS=SUCCESSFUL   1012 CALLS        1316 TOTAL
                     EDM=1.2595e-09    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                          STEP         FIRST
  NO.   NAME       VALUE            ERROR                SIZE      DERIVATIVE
   1  Amp           7.68336e+06   5.96706e+04   4.05799e+02  -1.94306e-07
   2  Rate1         5.21781e-04   8.49890e-07  -5.61465e-09  -1.34872e+04
   3  Rate2         4.55162e-04     fixed
   4  Rate3         1.78740e-03   3.42504e-05   1.36660e-07  -3.96343e+01
   5  t0            7.00000e+00     fixed
   6  dAmp2         4.53631e-01   1.20507e-02  -8.22698e-05  -1.21630e-01
   7  dAmp3        -4.97269e-02   1.09106e-03   6.62425e-06  -8.13793e-01
   8  Bkd           9.03294e+02   6.58916e+00   6.58916e+00   9.09158e-06
```



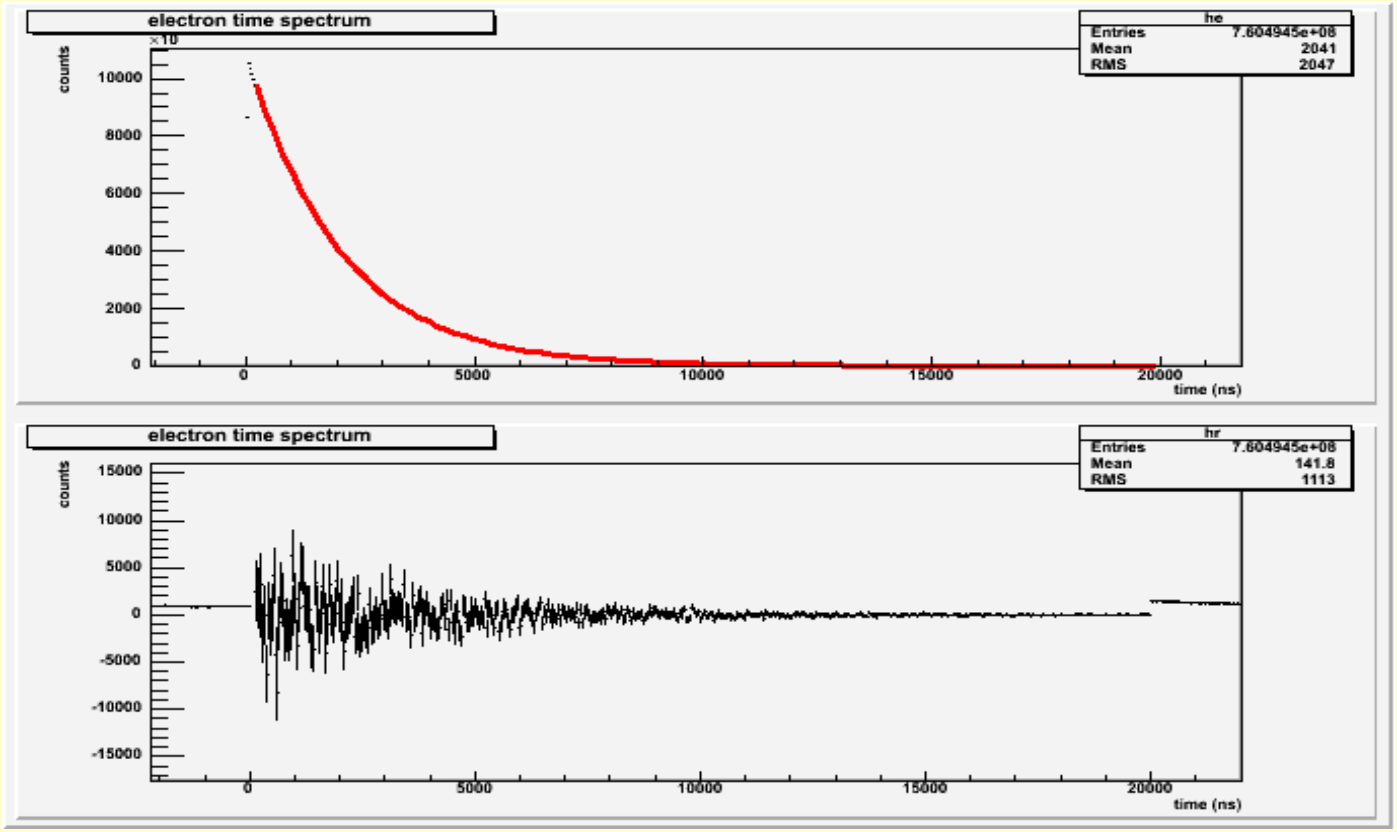
```
root [4] electron(120,20000,1,16,1.0)
```

```
FCN=504.839 FROM MINOS     STATUS=SUCCESSFUL    384 CALLS          479 TOTAL
                     EDM=3.61239e-13    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                          STEP         FIRST
  NO.   NAME      VALUE            ERROR                 SIZE      DERIVATIVE
   1  Amp          1.07860e+07   1.03642e+03  -1.39405e+01   6.66397e-07
   2  Rate1        5.21667e-04   6.99816e-07   1.86383e-08   7.03005e+03
   3  Rate2        4.55162e-04     fixed
   4  Rate3        1.79546e-03   1.35686e-05  -3.51833e-07  -9.67009e+01
   5  t0           7.00000e+00     fixed
   6  dAmp2        3.22384e-01   5.17960e-03   1.27191e-04  -1.28415e+00
   7  Bkd          9.03712e+02   6.31060e+00   6.31060e+00  -1.14481e-05
   8  releff       1.00000e+00     fixed
```



```
root [4] electron(120,20000,1,16,1.0)
```

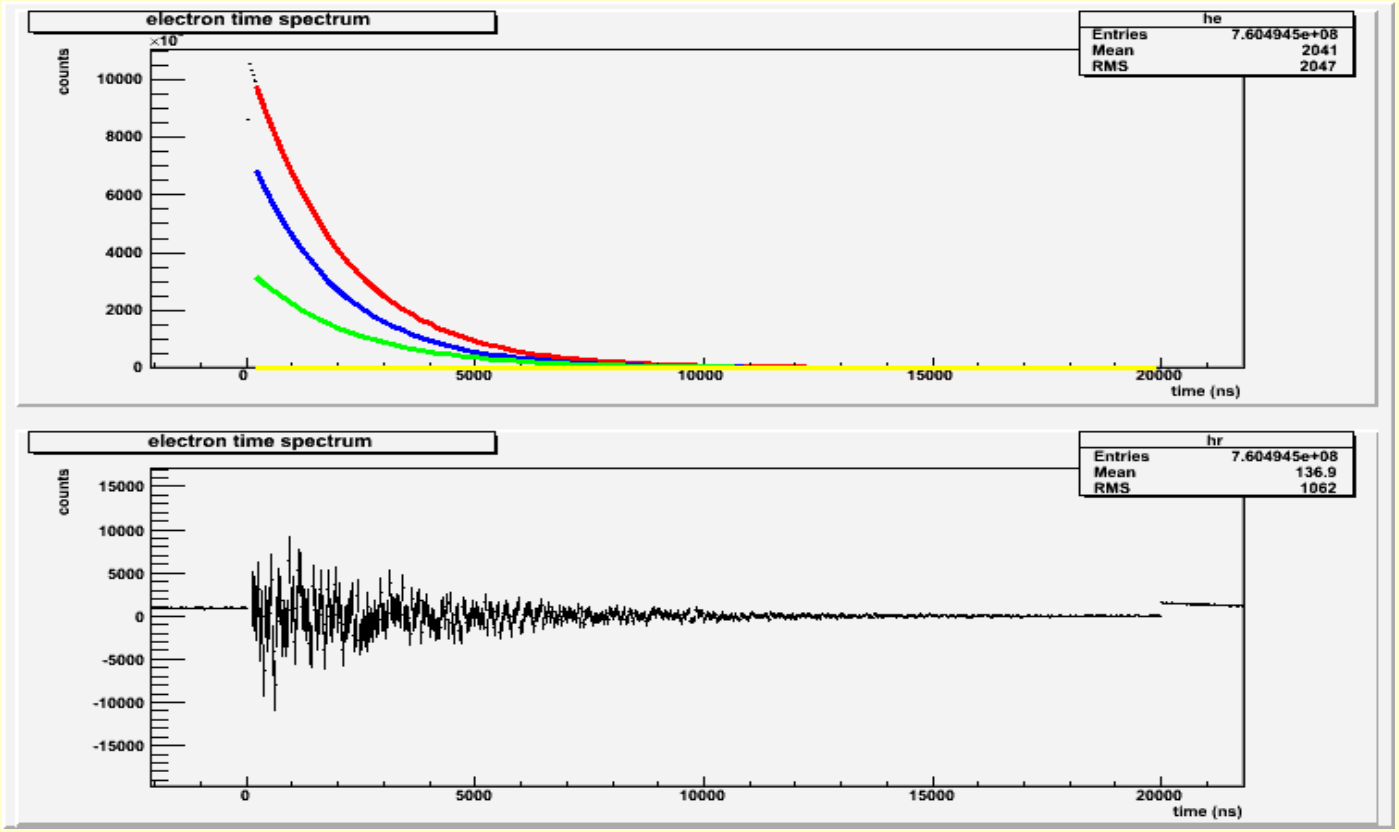
```
FCN=504.839 FROM MINOS     STATUS=SUCCESSFUL    873 CALLS         1841 TOTAL
                     EDM=1.32696e-09    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                          STEP         FIRST
  NO.   NAME      VALUE            ERROR                 SIZE      DERIVATIVE
   1  Amp          7.38202e+07   8.77290e+05  -8.57316e+01  -2.30184e-08
   2  lambda0      4.55162e-04      fixed
   3  m            4.71041e-02   1.40841e-03   1.43535e-07  -1.16089e+01
   4  x            9.90077e-02   3.32266e-04   4.64531e-08  -7.65959e+00
   5  y            2.94466e+00   3.23072e-02  -1.39890e-06   1.96311e-02
   6  t0           7.00000e+00      fixed
   7  Bkd          9.03712e+02   6.66092e+00   6.66092e+00  -4.40793e-07
   8  releff       1.00000e+00      fixed
rate1, rate2, rate3 4.551620e-04 1.795459e-03 5.216665e-04
```



```
root [4] electron(120,20000,1,16,1.0)
```

Ar direct capture + H->Ar e.s. transfer

```
FCN=504.799 FROM MINOS     STATUS=SUCCESSFUL    369 CALLS          484 TOTAL
                     EDM=1.40404e-14    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                          STEP         FIRST
  NO.   NAME      VALUE            ERROR                 SIZE      DERIVATIVE
   1  Amp          1.07836e+07   1.04064e+03  -1.38012e+01   6.38066e-07
   2  Rate1        5.21854e-04   7.04029e-07   1.83833e-08   7.73624e+03
   3  Rate2        4.55162e-04     fixed
   4  Rate3        1.78234e-03   1.34017e-05  -3.40132e-07  -7.70852e+01
   5  t0           7.00000e+00     fixed
   6  dAmp2        3.23693e-01   5.18029e-03   1.24614e-04  -1.34101e+00
   7  Bkd          9.03030e+02   6.31751e+00   6.31751e+00  -1.01250e-05
   8  releff       1.00000e+00     fixed
```



Investigation of charge transfer from excited muonic hydrogen atoms to argon

Y.-A. Thalmann, R. Jacot-Guillarmod, F. Mulhauser, L. A. Schaller, L. Schellenberg, H. Schneuwly, S. Tresch, and A. Werthmüller
Institut de Physique de l'Université de Fribourg, CH-1700 Fribourg, Switzerland
(Received 18 November 1996)

A method is proposed for investigating muon transfer from excited muonic hydrogen atoms to an element $Z>2$, and is applied to argon measurements. It makes use of a comparison between the muonic x-ray intensity patterns of the Lyman series of this element measured in mixtures with and without hydrogen. The analysis of the data taken in two gas mixtures H_2 + Ar at 15 bar with argon concentrations of 2% (0.3%), yields consistent results. In both mixtures, two thirds of the prompt argon x rays proceed from transfer from excited μp^* states. The Coulomb capture ratio determined in both mixtures yields a mean value of $A(H_2,Ar)$ = 0.21(2), and agrees with the corresponding pionic ratio. [S1050-2947(97)06207-0]

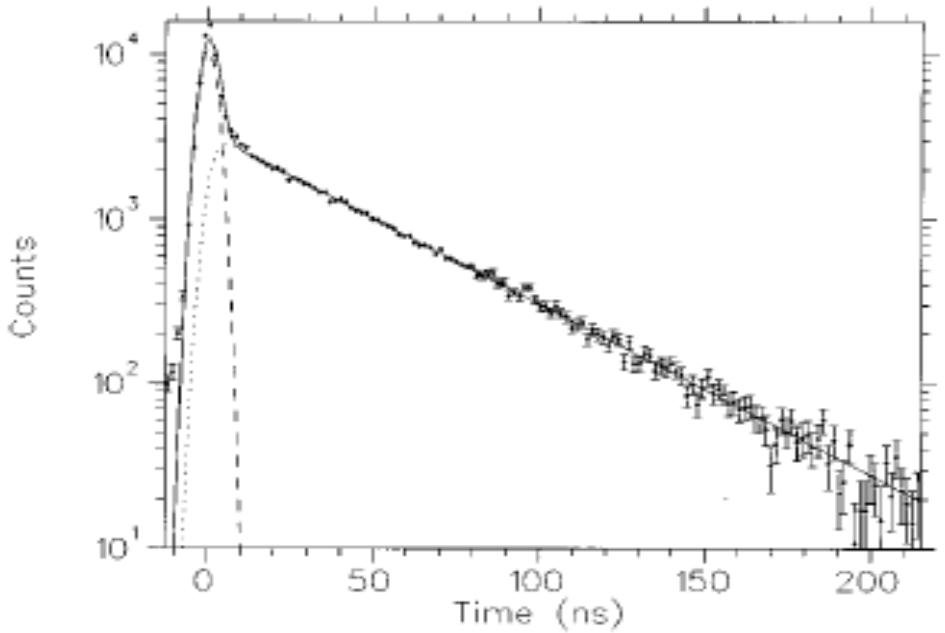


FIG. 1. Typical time spectrum after background subtraction. Here the μAr(2-1) transition measured in H_2 + 2% Ar at 15 bar. The solid line represents a fit made with the sum of a prompt Gaussian peak (dashed line) and a delayed exponential part (dotted line).

The proposed method, which requires a knowledge of the muonic x-ray time structure of the investigated element Z, makes use of a comparison of the x-ray intensity pattern due to direct capture measured in pure Z, and the transfer pattern measured in mixtures of H_2 + Z.

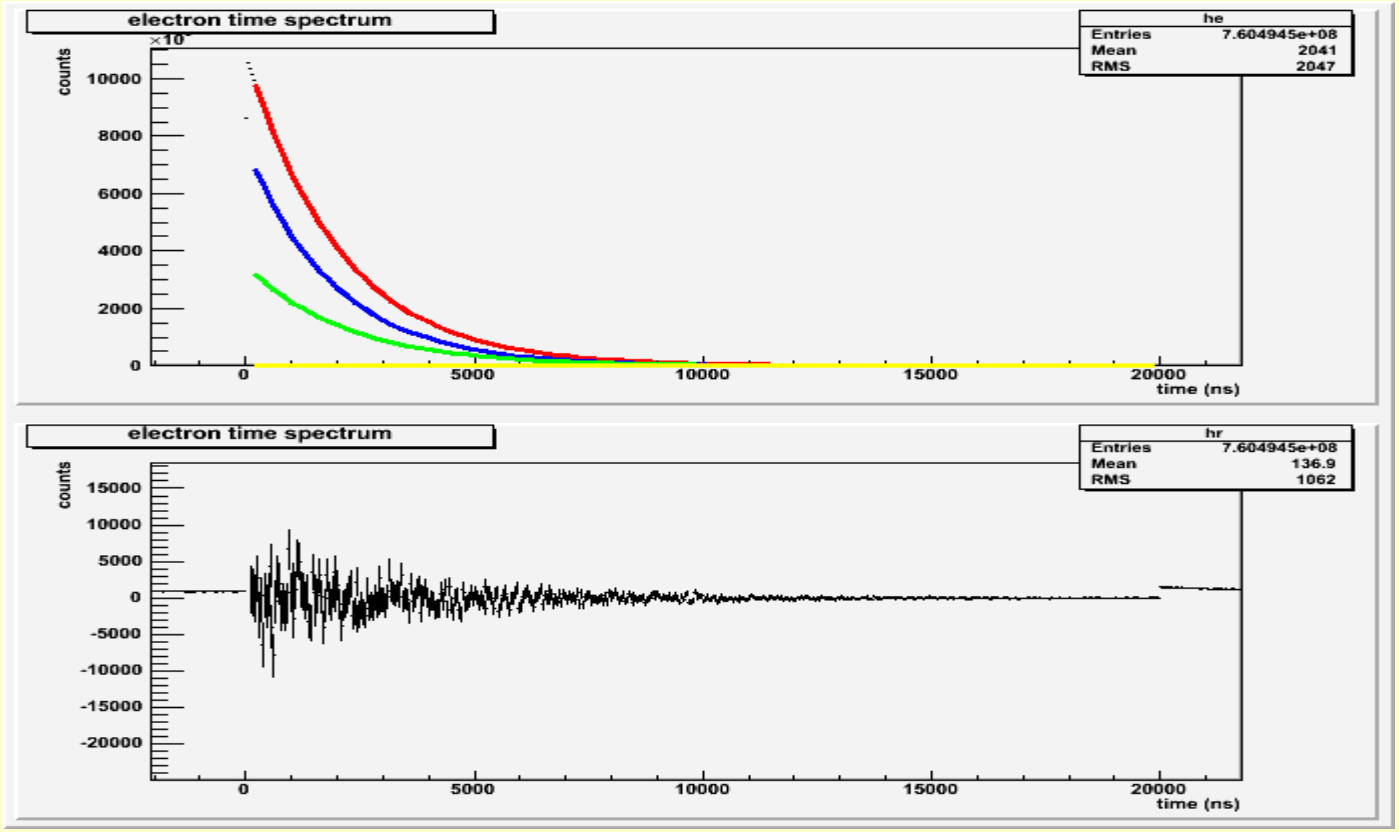
The per molecule ratios are $A(H_2,Ar)$ = 0.19(3) for the H_2 + 2% Ar mixture and 0.22(3) for H_2 + 0.3% Ar, with a mean value of 0.21(2).

We conclude that in both mixtures about two-thirds of the prompt events are due to muon transfer from excited states, even if the argon concentrations differ by one order of magnitude. The agreement between both mixtures was not unex-

```
root [6] electron(120,20000,1,16,0.988)
```

Ar direct capture + H->Ar e.s. transfer + Huff factor

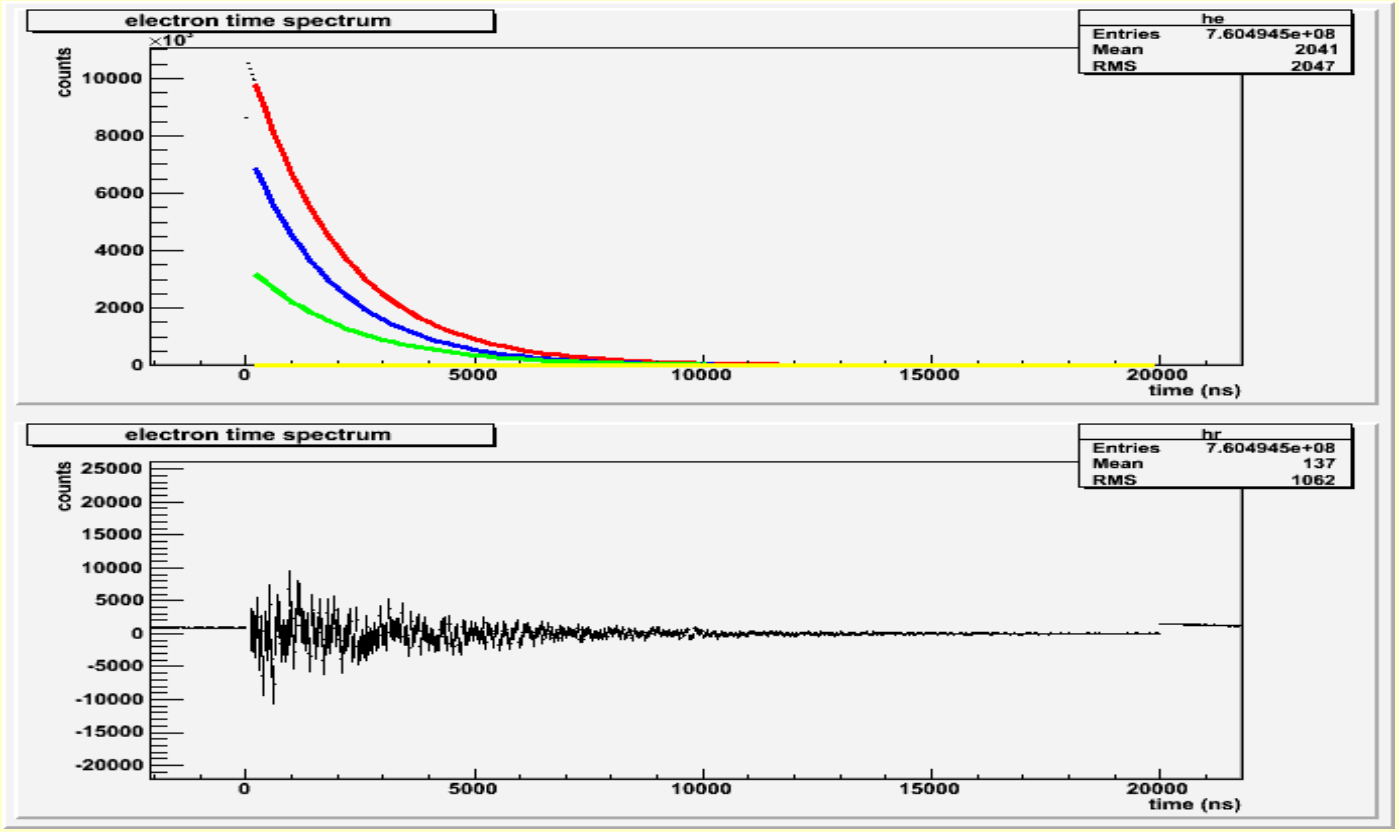
```
FCN=505.257 FROM MINOS     STATUS=SUCCESSFUL    367 CALLS          481 TOTAL
                     EDM=1.37536e-12    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                          STEP          FIRST
  NO.   NAME      VALUE            ERROR                 SIZE      DERIVATIVE
   1  Amp          1.07851e+07   1.03390e+03  -1.38710e+01   6.49488e-07
   2  Rate1        5.22093e-04   7.10340e-07   1.88742e-08   7.96529e+03
   3  Rate2        4.55162e-04     fixed
   4  Rate3        1.76589e-03   1.33776e-05  -3.46549e-07  -7.83743e+01
   5  t0           7.00000e+00     fixed
   6  dAmp2        3.25212e-01   5.18273e-03   1.26798e-04  -1.39259e+00
   7  Bkd          9.02169e+02   6.32518e+00   6.32518e+00  -1.04101e-05
   8  releff       9.88000e-01     fixed
```



```
root [7] electron(120,20000,1,16,0.988-0.01)
```

Ar direct capture + H->Ar e.s. transfer
+ Huff factor + 1% H/Ar efficiency difference

```
FCN=506.092 FROM MINOS     STATUS=SUCCESSFUL    369 CALLS          469 TOTAL
                     EDM=1.06875e-08    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                          STEP         FIRST
  NO.   NAME      VALUE            ERROR                 SIZE      DERIVATIVE
   1  Amp          1.07862e+07   1.02859e+03  -1.37200e+01   6.57474e-07
   2  Rate1        5.22295e-04   7.16265e-07   1.92051e-08   8.58886e+03
   3  Rate2        4.55162e-04      fixed
   4  Rate3        1.75210e-03   1.33700e-05  -3.49014e-07  -5.63359e+01
   5  t0           7.00000e+00      fixed
   6  dAmp2        3.26488e-01   5.18838e-03   1.28068e-04  -1.43822e+00
   7  Bkd          9.01447e+02   6.33299e+00   6.33299e+00  -1.02200e-05
   8  releff       9.78000e-01      fixed
```

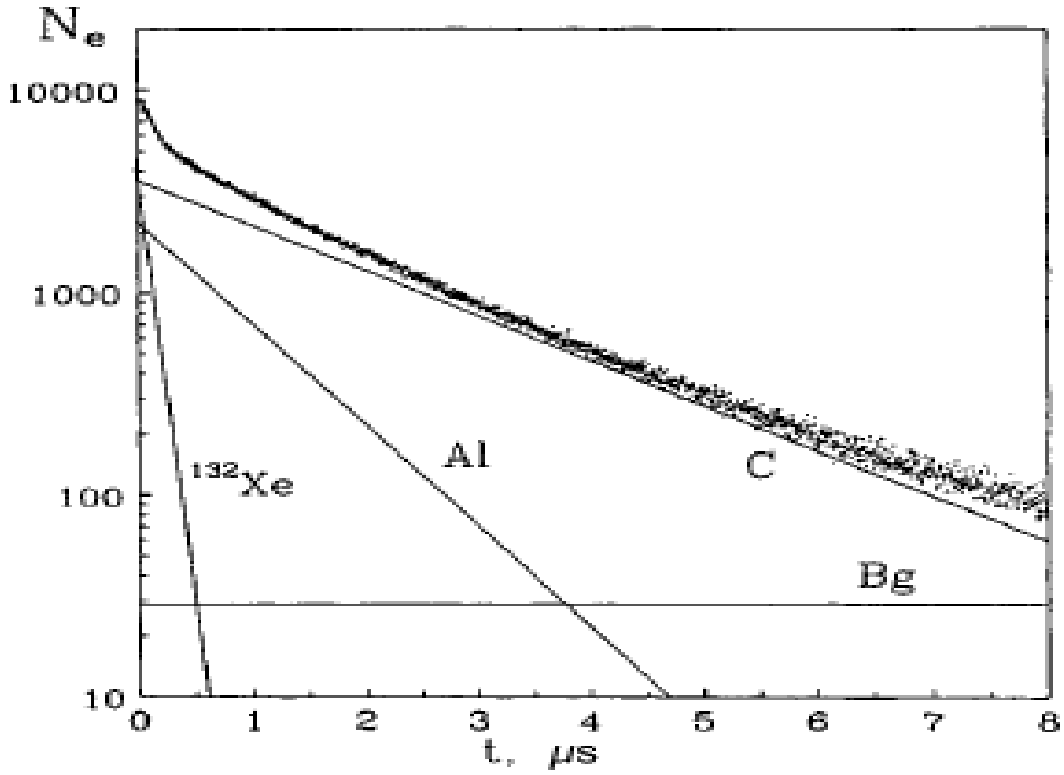


Total rates of nuclear capture of negative muons in the isotopes ^{132}Xe and ^{40}Ar

T. N. Mamedov,* V. G. Grebinnik, K. I. Gritsaĭ, V. N. Duginov, V. A. Zhukov, V. G. Ol'shevskiĭ, and A. V. Stoĭkov
Joint Institute of Nuclear Research, 141980 Dubna, Moscow Region, Russia

(Submitted 10 January 1999)
Pis'ma Zh. Éksp. Teor. Fiz. **69**, No. 3, 181–183 (10 February 1999)

The lifetimes of a negative muon in the isotopes ^{132}Xe and ^{40}Ar in the solid phase are measured. The lifetime of μ^- in the $1s$ state of the isotope ^{132}Xe is $\tau(^{132}\text{Xe}) = 101.7 \pm 1.7$ ns, which corresponds to a total nuclear capture rate $\Lambda_c(^{132}\text{Xe}) = 9.4 \pm 0.2\ \mu\text{s}^{-1}$. The lifetime of μ^- in the isotope ^{40}Ar, viz., $\tau(^{40}\text{Ar}) = 568 \pm 6$ ns, corresponding to a capture rate $\Lambda_c(^{40}\text{Ar}) = 1.31 \pm 0.01\ \mu\text{s}^{-1}$, is obtained to several times better accuracy as compared to previously published results. © *1999 American Institute of Physics.* [S0021-3640(99)00503-4]



Ar disappearance rate of 1.76±0.01 μs^{-1}

FIG. 1. Spectrum of the temporal distribution of the electrons from $\mu^- \rightarrow e^-$ decay. The target chamber is filled with solid ^{132}Xe. The straight lines show the contributions to the spectrum from the individual components.

muCap analysis: run 9, 10, 11

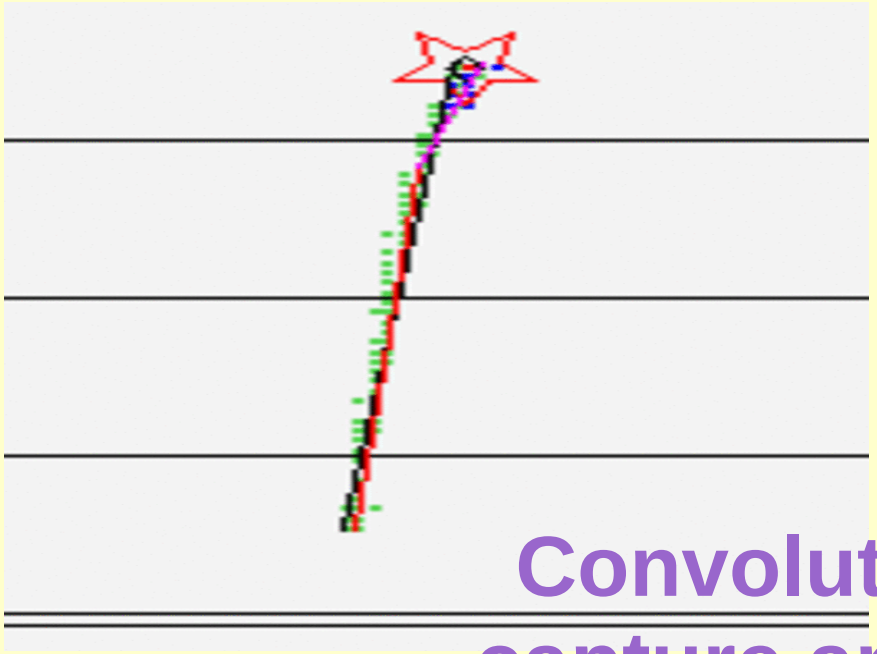
Message ID: **522** Entry time: **Tue Mar 23 14:35:02 2010**

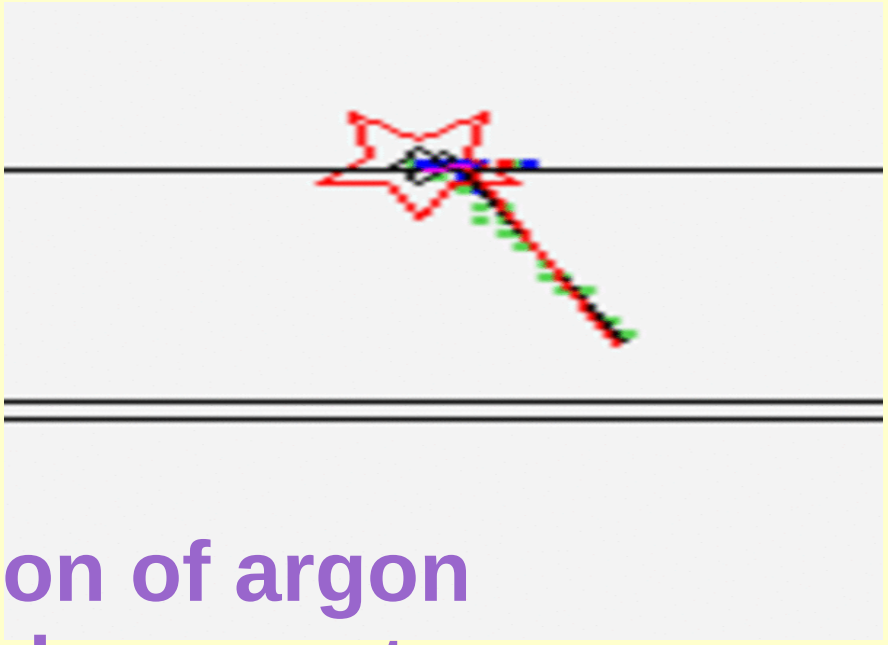
Author:	Tim Gorringe
Type:	Analysis Run 9-11
Category:	Lifetime fit results
Subject:	redo on H/Ar analysis

I have repeated the H/Ar analysis for the May09 pass on the Feb10 pass. Attached are the benchmark fits and results for the Feb10 pass (attachments 1/2) and the results for the May09 pass (attachments 3/4).

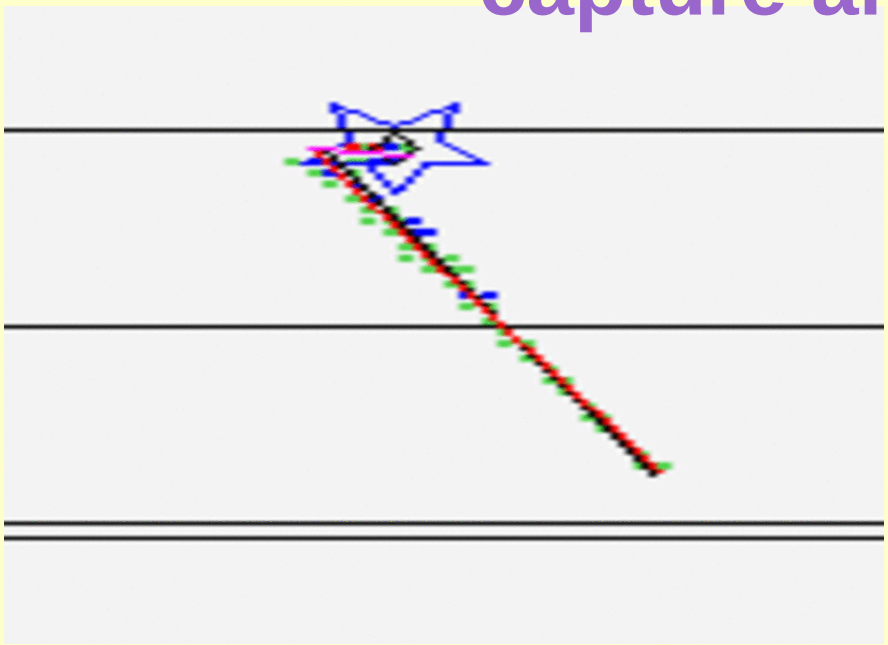
The value of Lambda_1 has changed from 0.524+/-0.002 mus^-1 to 0.526+/-0.002 mus^-1 and value of Lambda_2 has changed from 1.65+/-0.02 mus^-1 to 1.64+/-0.02 mus^-1 where the quoted errors are statistical only. Since the datasets are the same the shifts in Lambda_1/2 are systematic effects - and based on earlier studies - may result from changes in stop definitions.

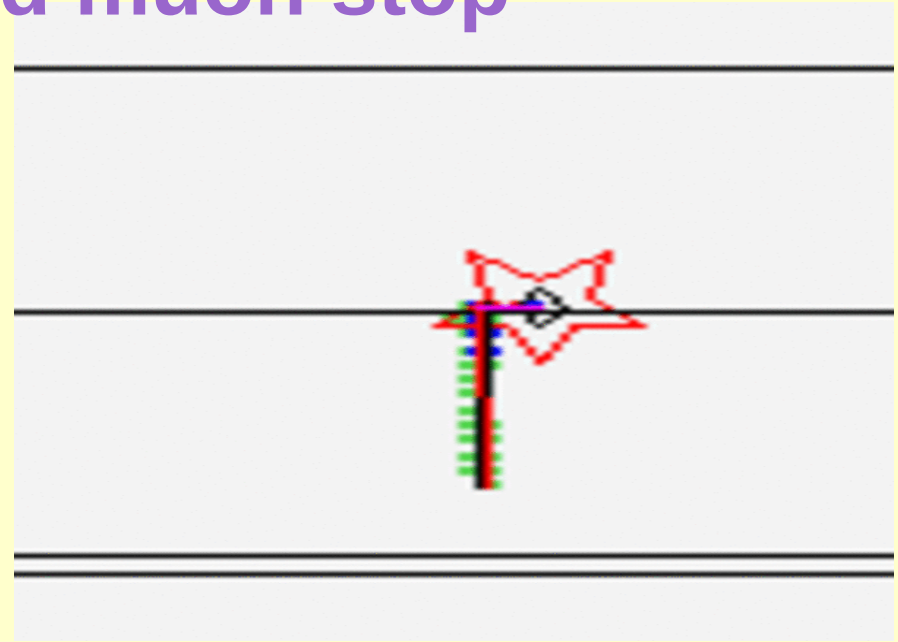
Comparison of 2009/2010 H+Ar neutron time spectra



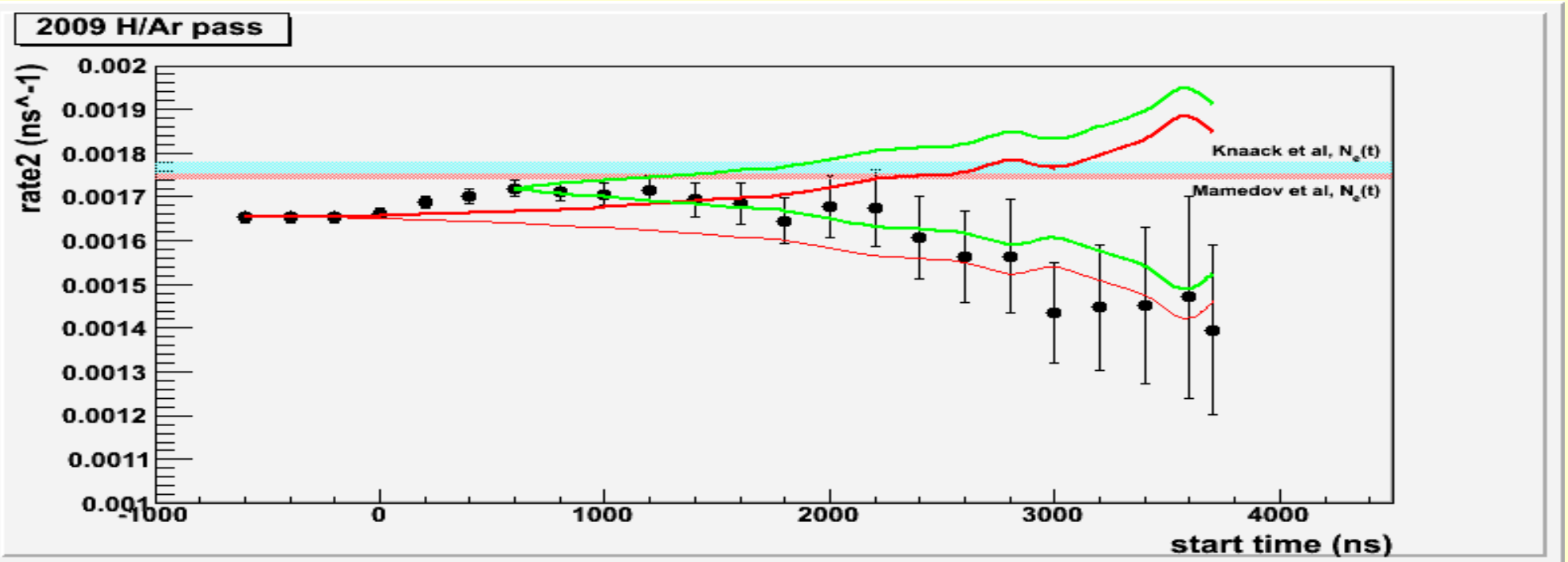


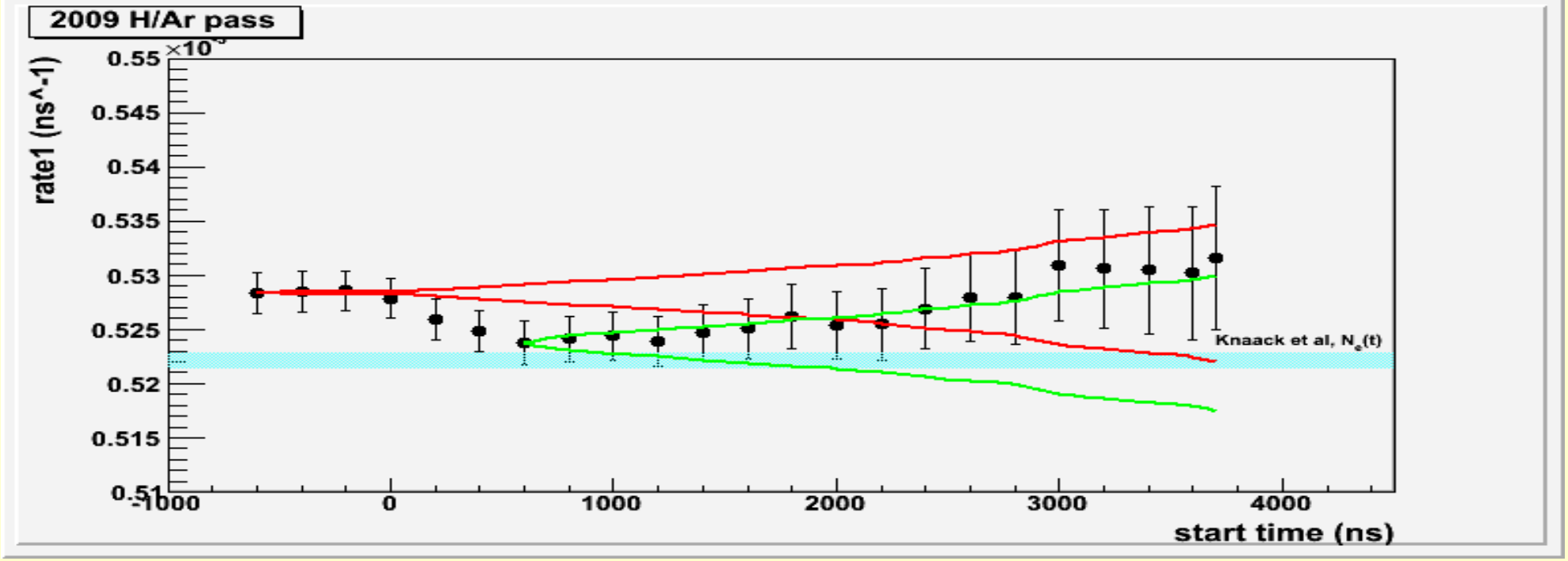
Convolution of argon capture and muon stop

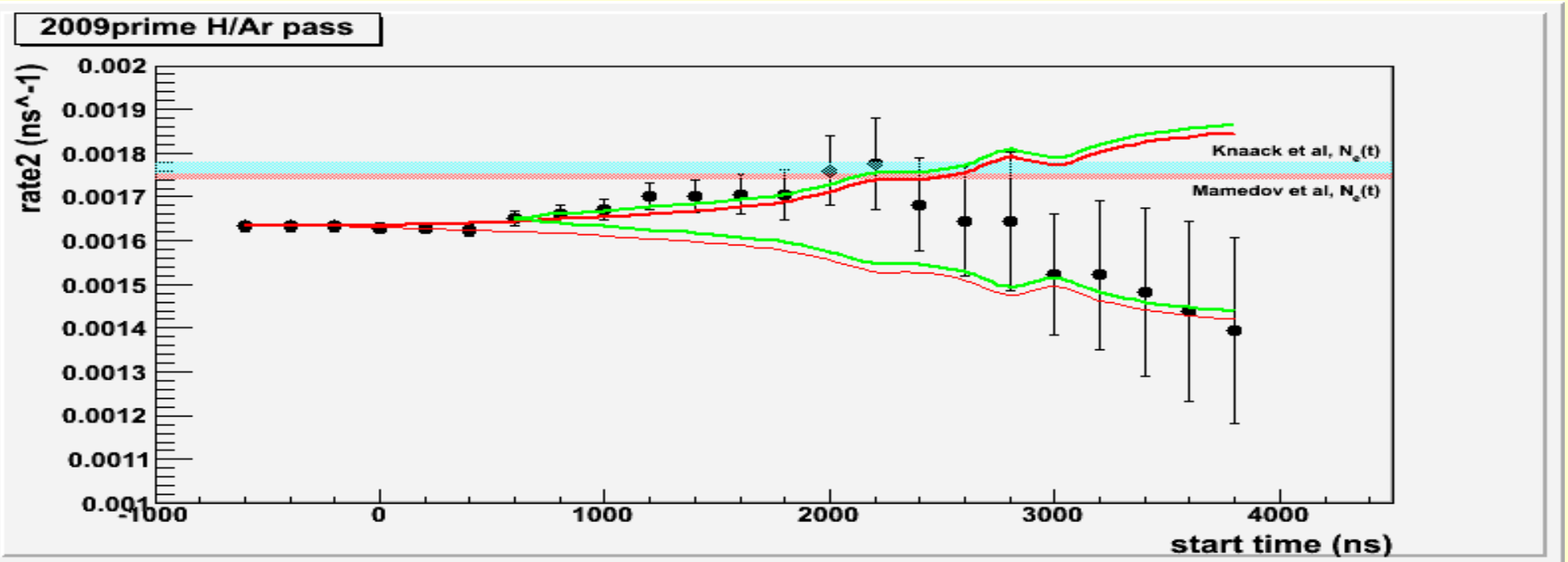


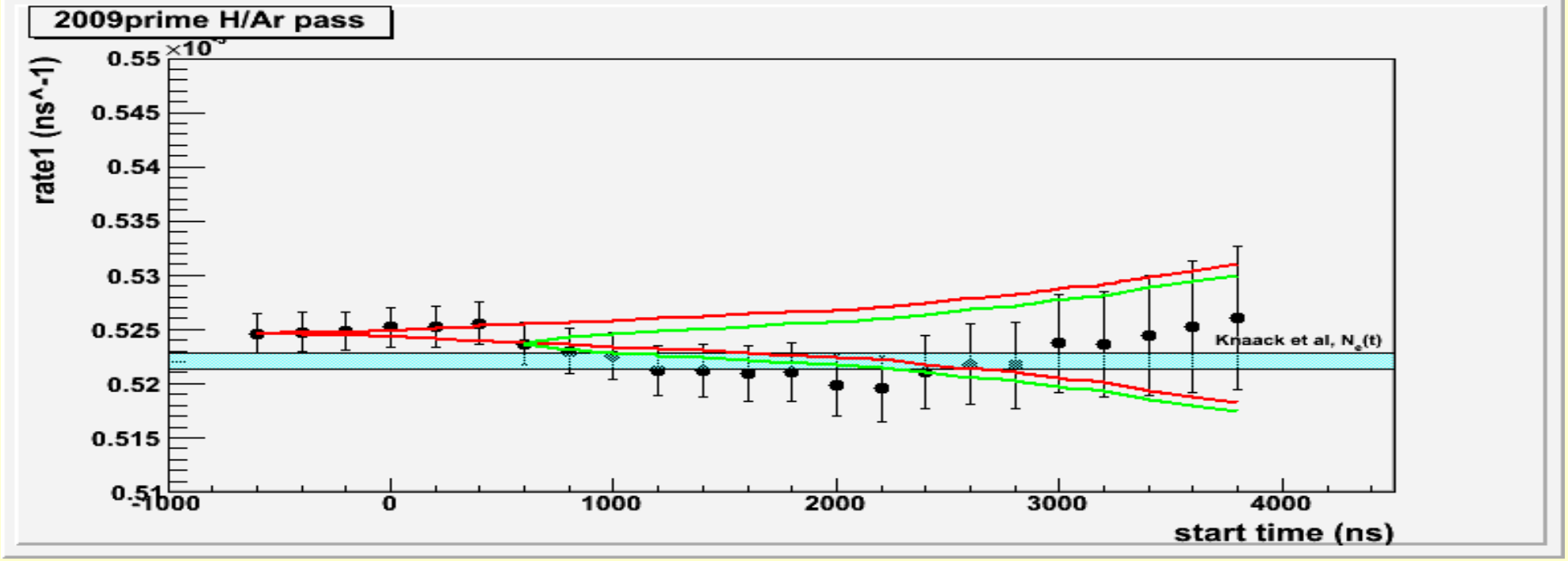


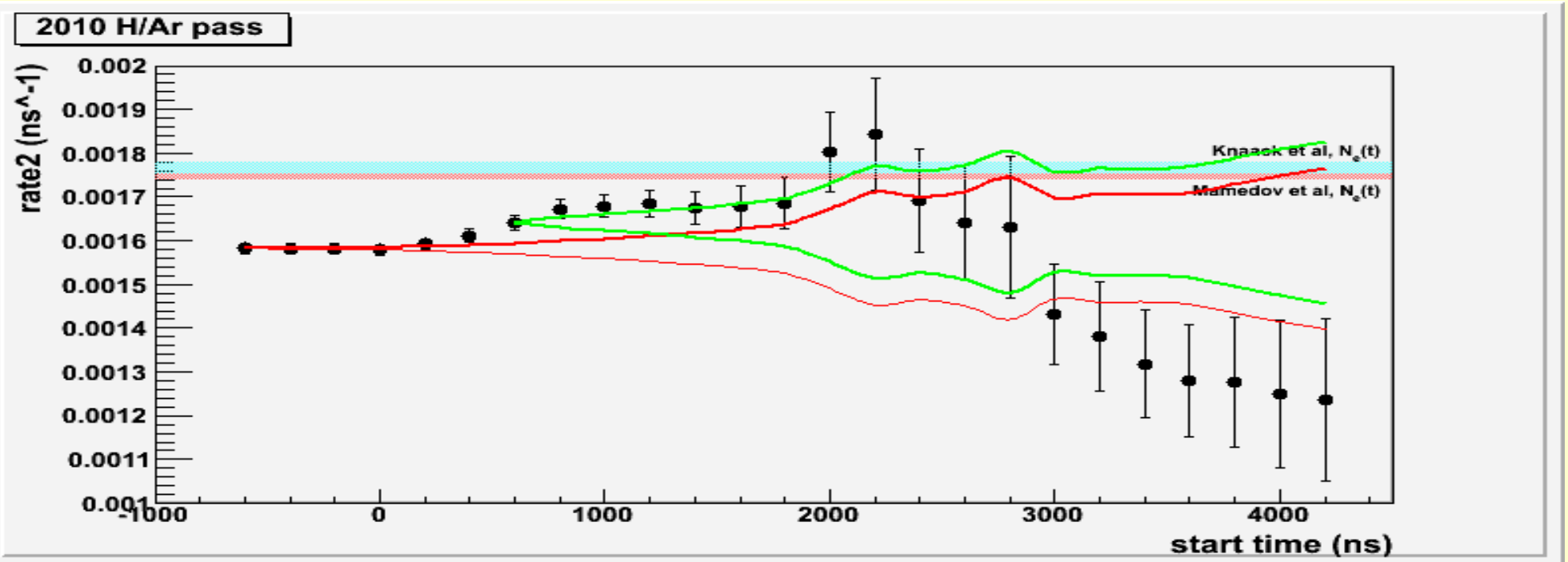
muon stops with detected neutron in range $0 < t < 0.5$ µs

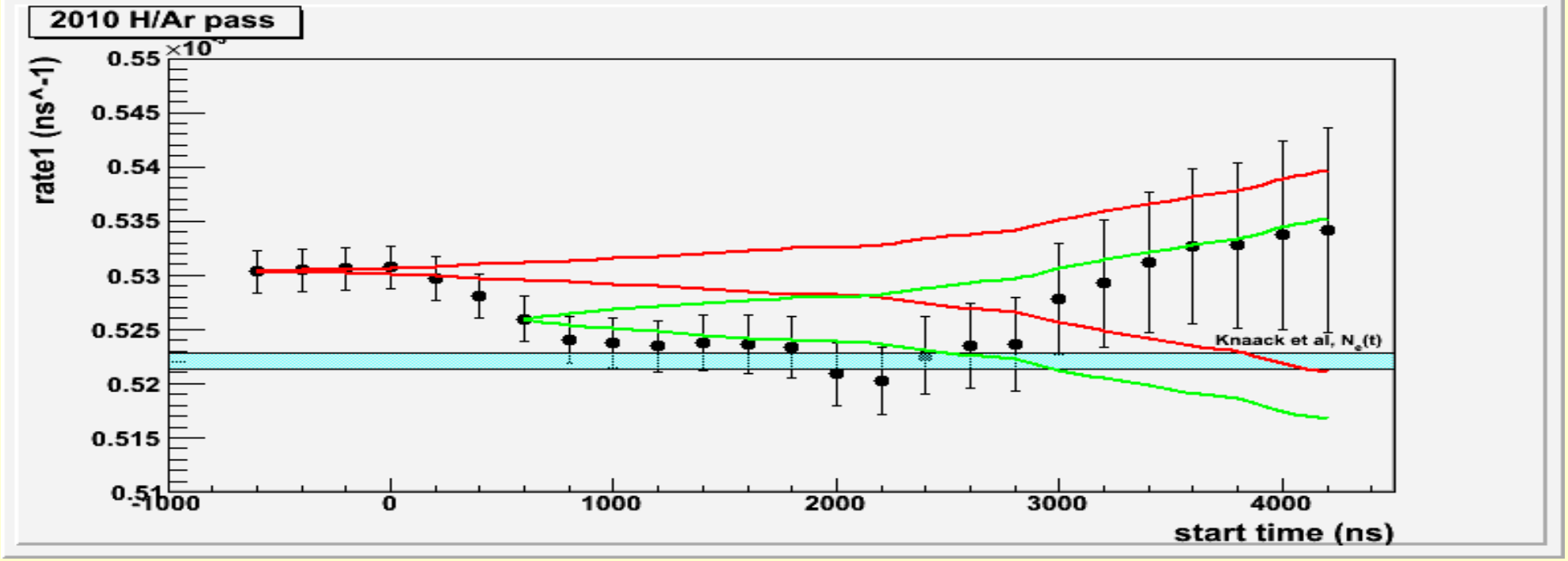

2009 H/Ar pass
rate2 (ns^-1)
0.002
0.0019
0.0018
0.0017
0.0016
0.0015
0.0014
0.0013
0.0012
0.0011
0.001
-1000
0
1000
2000
3000
4000
start time (ns)
Knaack et al, N_e(t)
Mamedov et al, N_e(t)

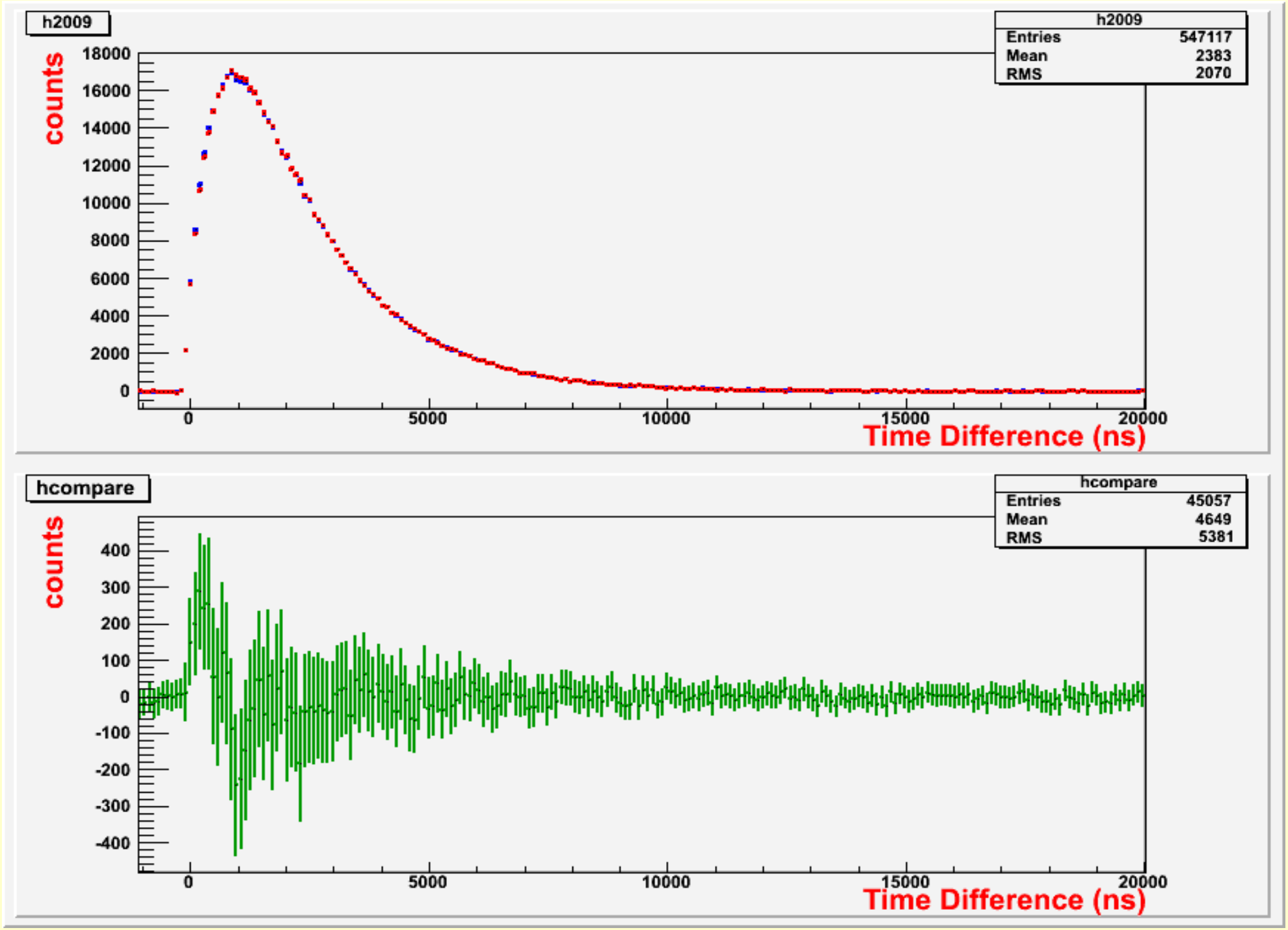

2009 H/Ar pass
rate1 (ns^-1)
×10^-3
0.55
0.545
0.54
0.535
0.53
0.525
0.52
0.515
0.51
-1000
0
1000
2000
3000
4000
start time (ns)
Knaack et al, N_e(t)

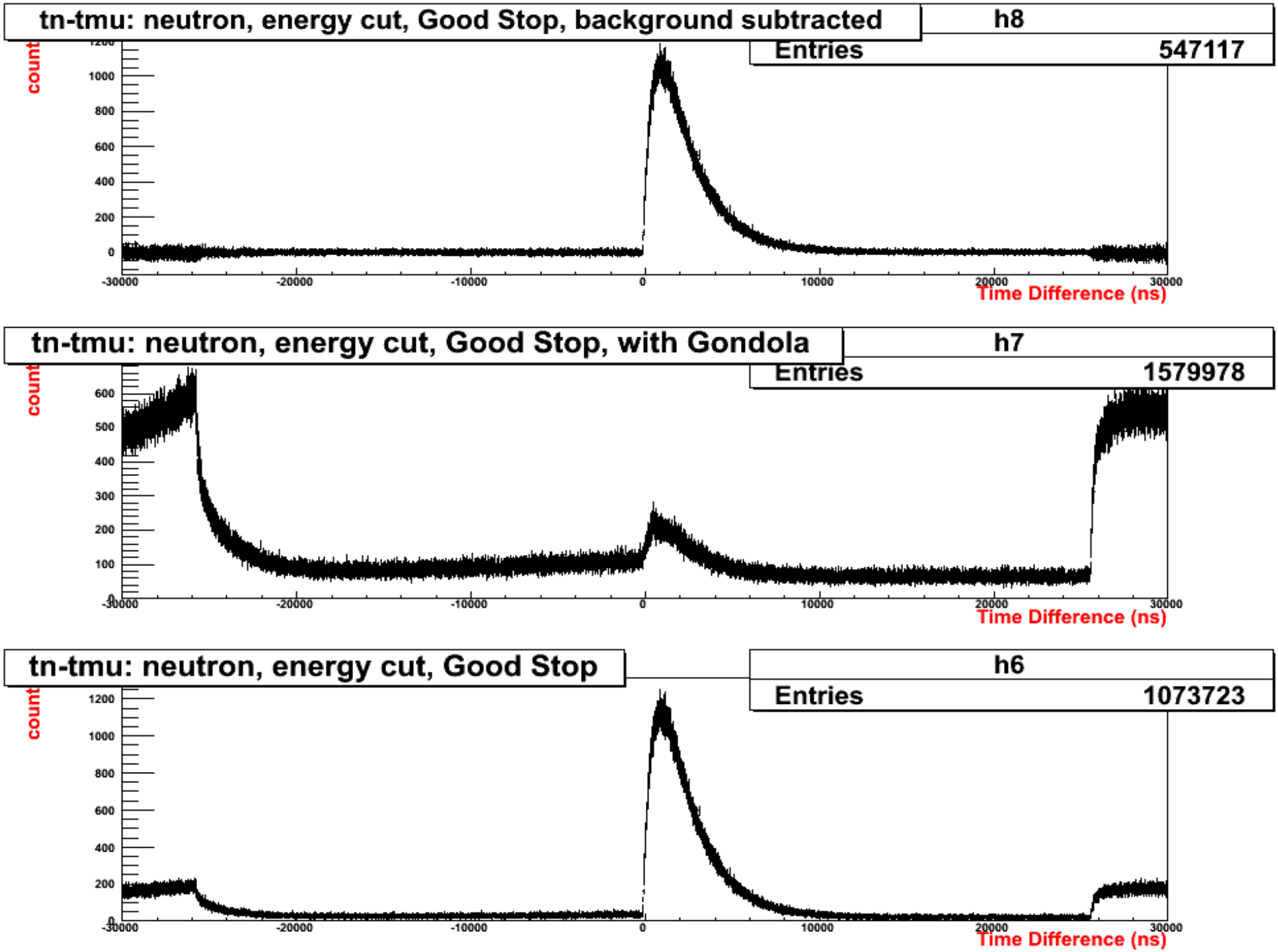

2009prime H/Ar pass
rate2 (ns^-1)
0.002
0.0019
0.0018
0.0017
0.0016
0.0015
0.0014
0.0013
0.0012
0.0011
0.001
-1000
0
1000
2000
3000
4000
start time (ns)
Knaack et al, N_e(t)
Mamedov et al, N_e(t)


2009prime H/Ar pass
rate1 (ns^-1)
×10^-3
0.55
0.545
0.54
0.535
0.53
0.525
0.52
0.515
0.51
-1000
0
1000
2000
3000
4000
start time (ns)
Knaack et al, N_e(t)


2010 H/Ar pass
rate2 (ns^-1)
0.002
0.0019
0.0018
0.0017
0.0016
0.0015
0.0014
0.0013
0.0012
0.0011
0.001
-1000
0
1000
2000
3000
4000
start time (ns)
Knaack et al, N_e(t)
Mamedov et al, N_e(t)


2010 H/Ar pass
rate1 (ns^-1)
×10^-3
0.55
0.545
0.54
0.535
0.53
0.525
0.52
0.515
0.51
-1000
0
1000
2000
3000
4000
start time (ns)
Knaack et al, N_e(t)


h2009
h2009
Entries 547117
Mean 2383
RMS 2070
counts
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
5000
10000
15000
20000
Time Difference (ns)
hcompare
hcompare
Entries 45057
Mean 4649
RMS 5381
counts
400
300
200
100
0
-100
-200
-300
-400
0
5000
10000
15000
20000
Time Difference (ns)

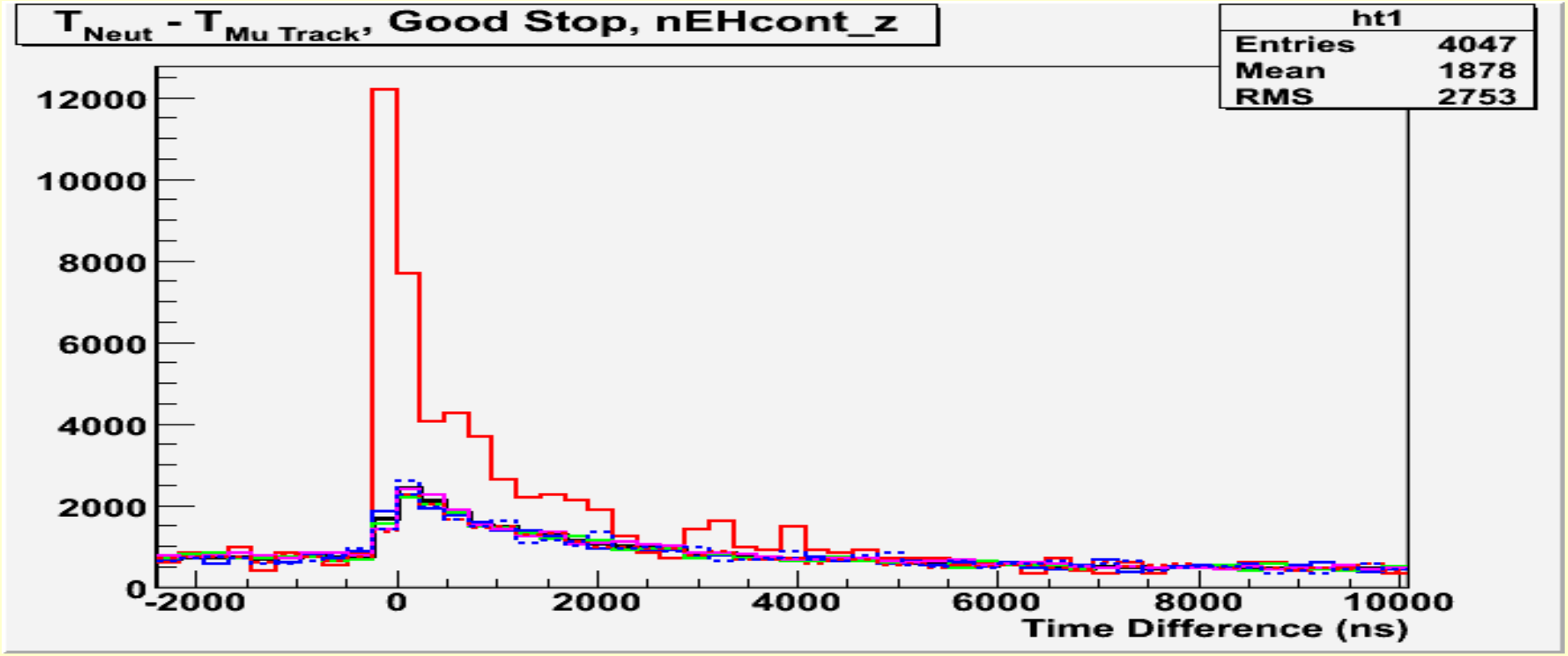

tn-tmu: neutron, energy cut, Good Stop, background subtracted
h8
Entries 547117
count
1000
800
600
400
200
0
-30000
-20000
-10000
0
10000
20000
30000
Time Difference (ns)
tn-tmu: neutron, energy cut, Good Stop, with Gondola
h7
Entries 1579978
count
600
500
400
300
200
100
0
-30000
-20000
-10000
0
10000
20000
30000
Time Difference (ns)
tn-tmu: neutron, energy cut, Good Stop
h6
Entries 1073723
count
1200
1000
800
600
400
200
0
-30000
-20000
-10000
0
10000
20000
30000
Time Difference (ns)

Comparison of 2009/2010
pure H neutron time spectra

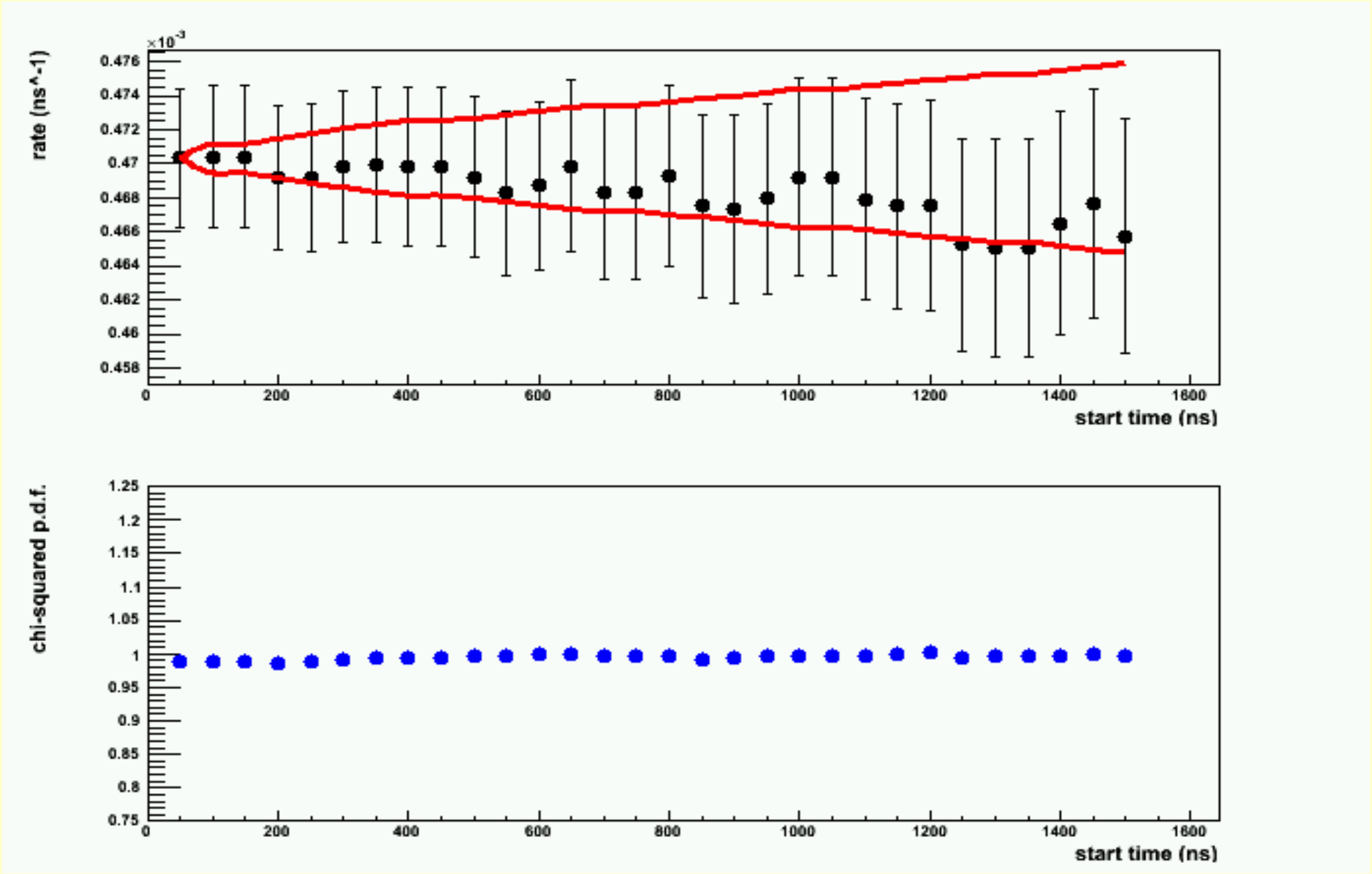
Neutron time spectrum for various continuous EH's normalized to t > 5000ns

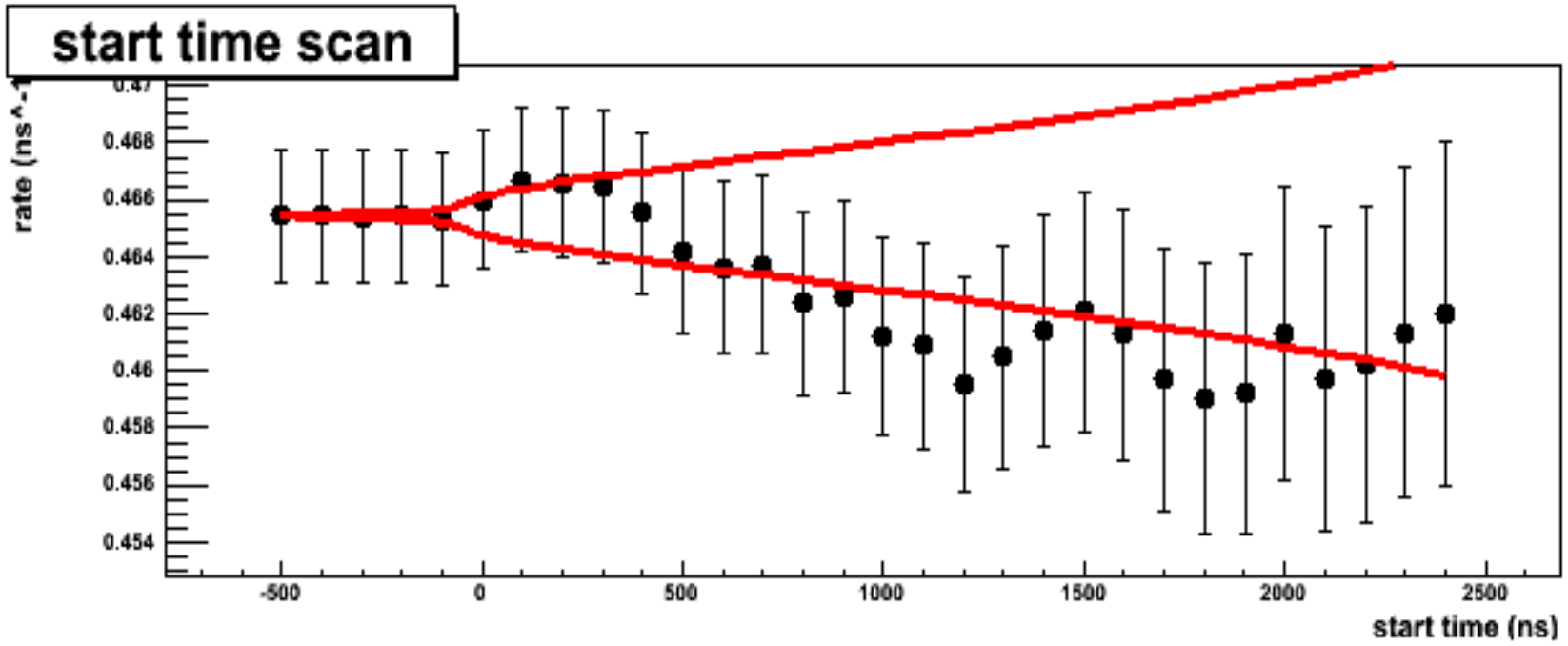
black: nContEH = 1-6, red: nContEH = 1, blue: nContEH = 2,
green: nContEH = 3, magenta: nContEH = 4,dash-red: nContEH = 5,
dash-blue: nContEH = 6

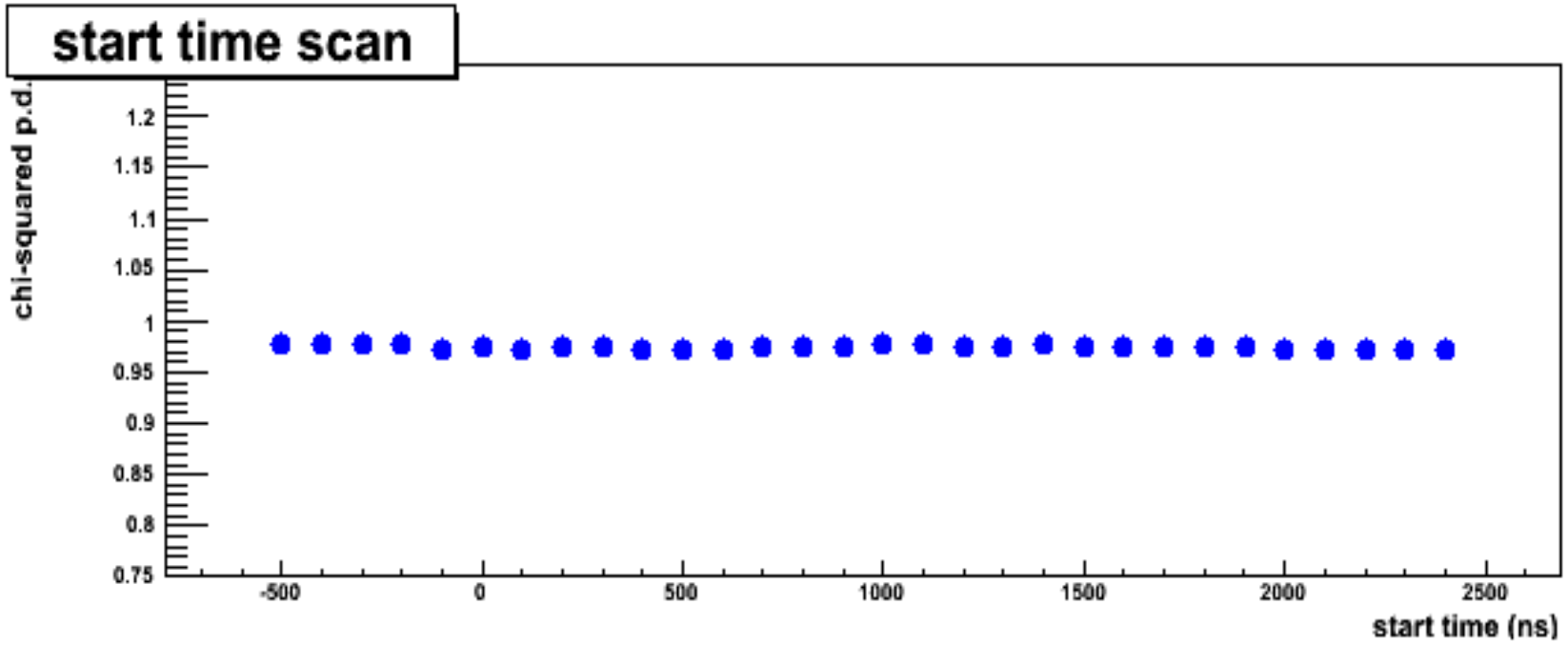
red curve (nContEH=1) shows short lifetime compoent
due to muon scatters.

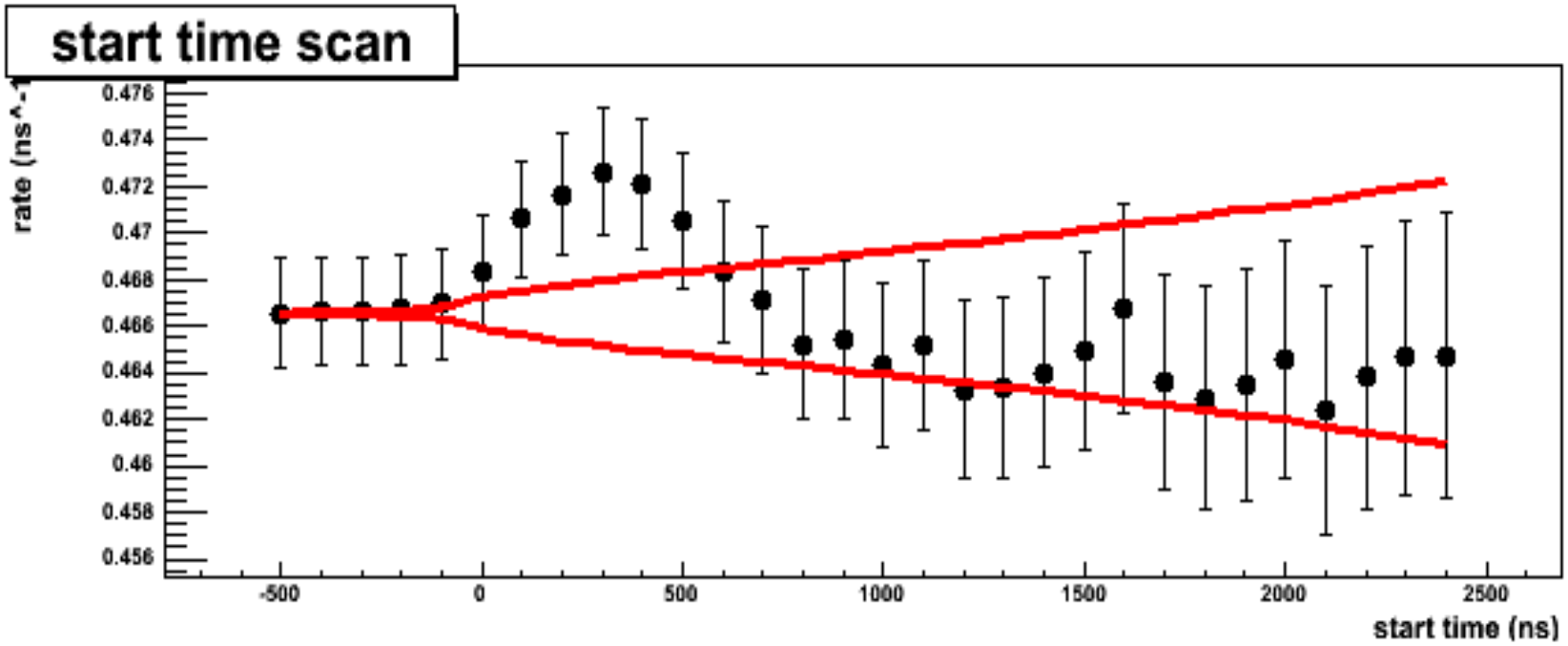


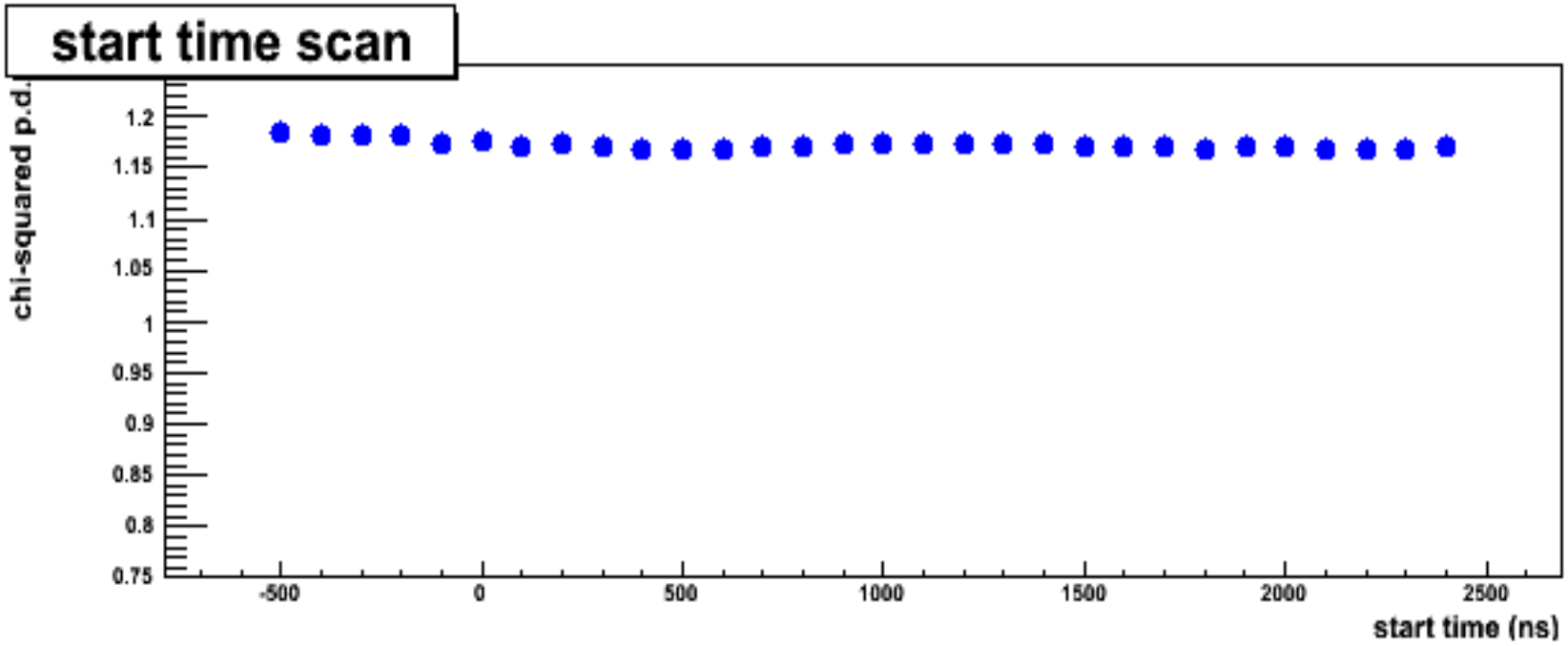
Start Time Dependence

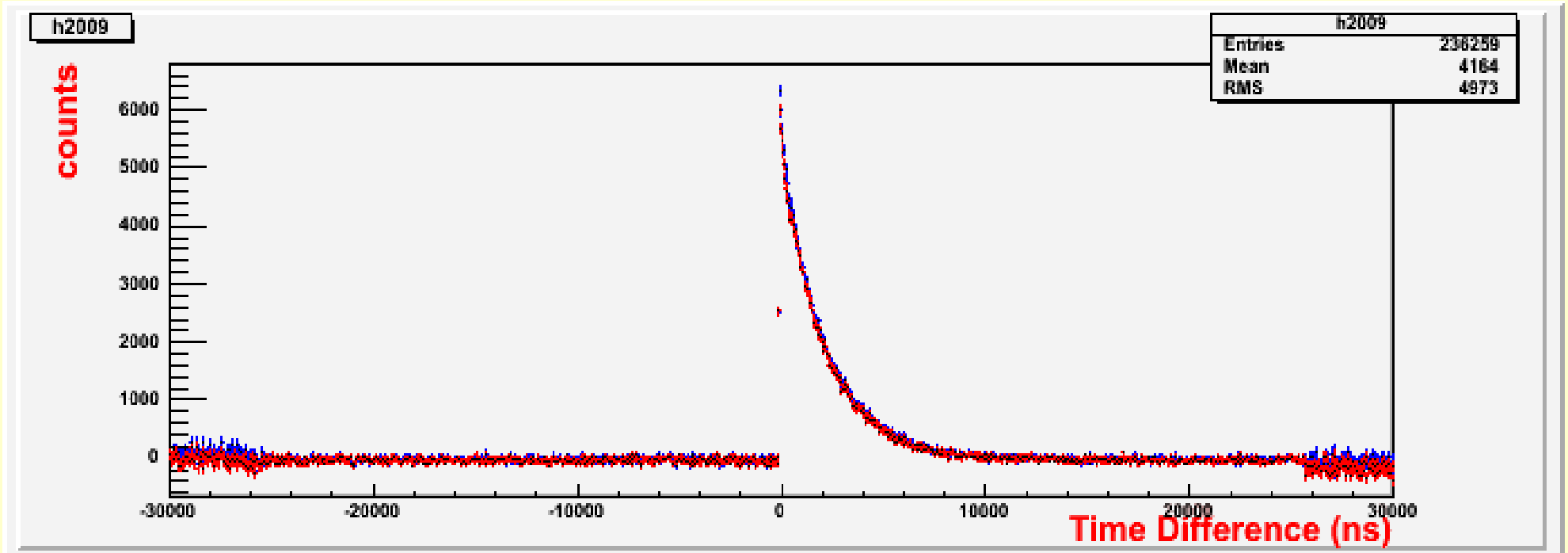


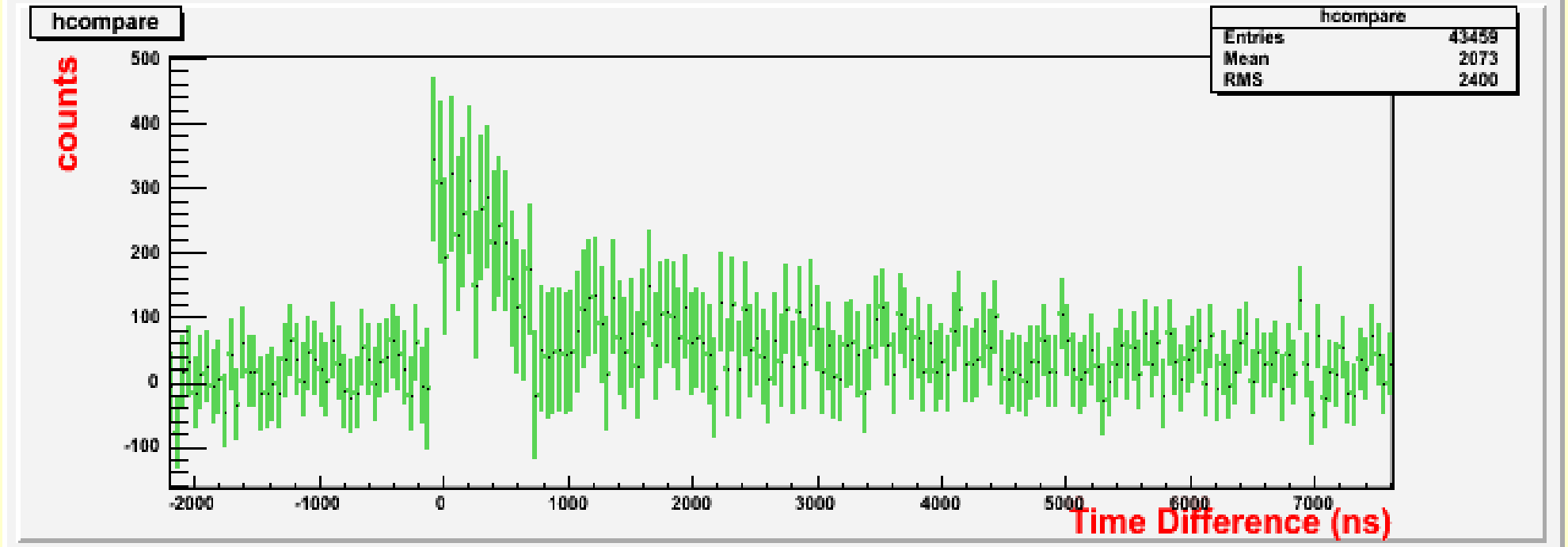

start time scan
rate (ns^-1
0.468
0.466
0.464
0.462
0.46
0.458
0.456
0.454
-500
0
500
1000
1500
2000
2500
start time (ns)

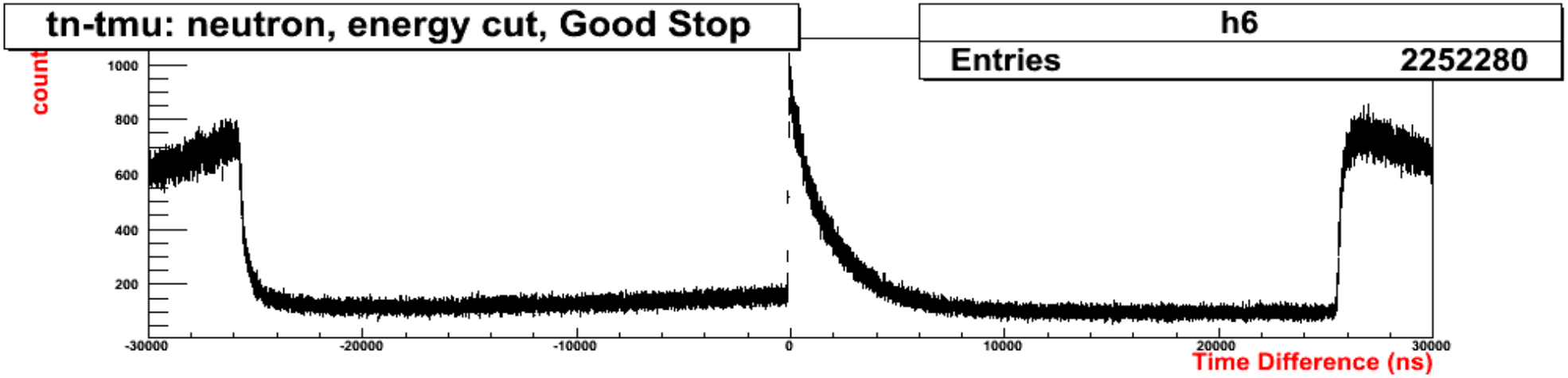

start time scan
chi-squared p.d.
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
-500
0
500
1000
1500
2000
2500
start time (ns)

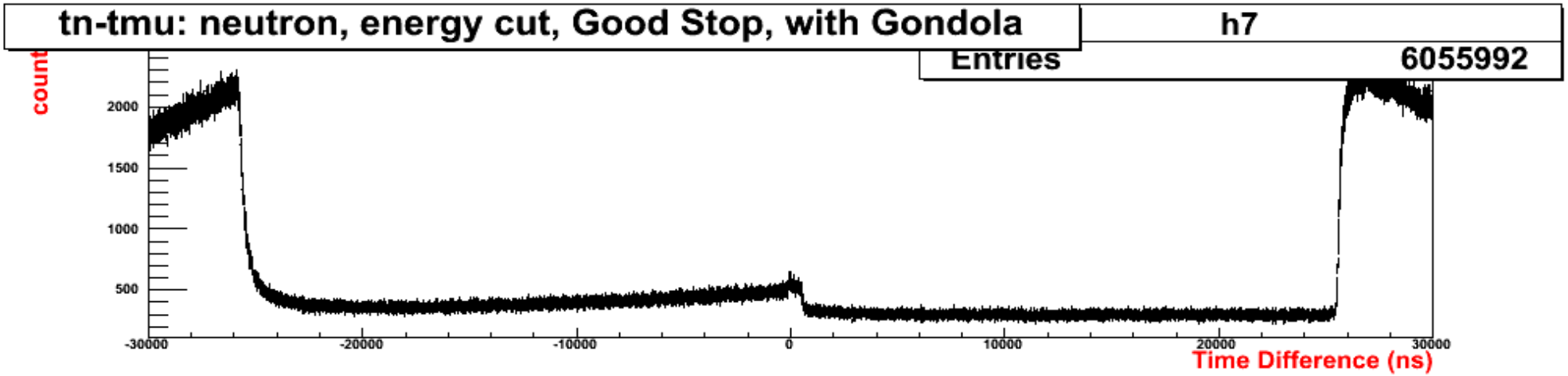

start time scan
rate (ns^-1
0.476
0.474
0.472
0.47
0.468
0.466
0.464
0.462
0.46
0.458
0.456
-500
0
500
1000
1500
2000
2500
start time (ns)

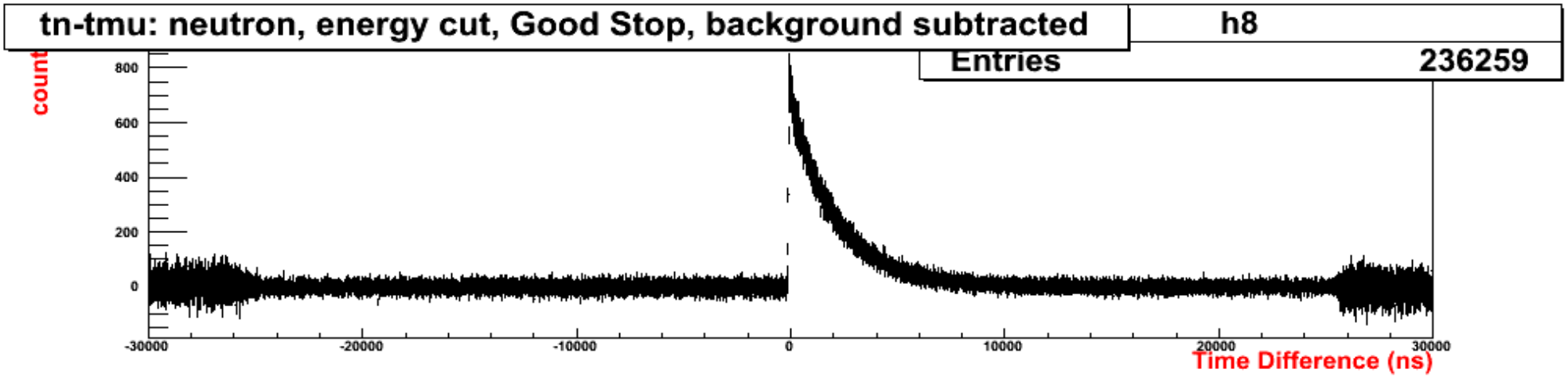

start time scan
chi-squared p.d.
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
-500
0
500
1000
1500
2000
2500
start time (ns)

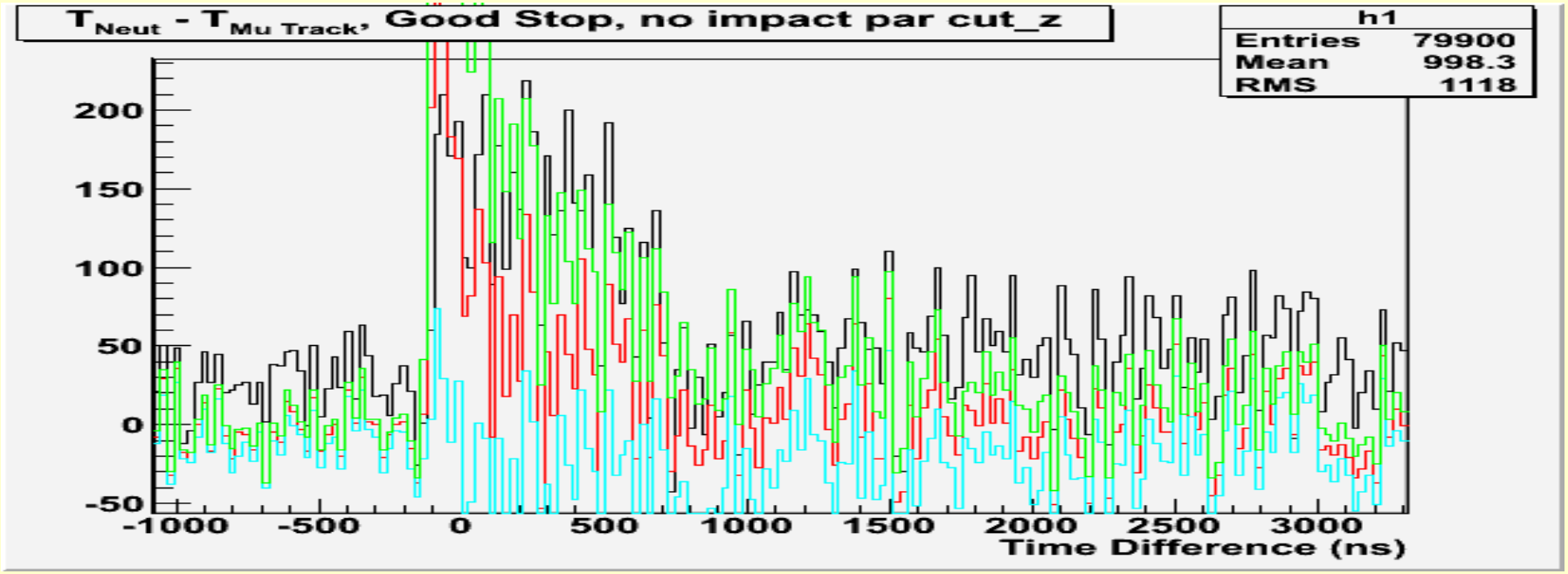

h2009
h2009
Entries 236259
Mean 4164
RMS 4973
counts
6000
5000
4000
3000
2000
1000
0
-30000
-20000
-10000
0
10000
20000
30000
Time Difference (ns)


hcompare
hcompare
Entries 43459
Mean 2073
RMS 2400
counts
500
400
300
200
100
0
-100
-2000
-1000
0
1000
2000
3000
4000
5000
6000
7000
Time Difference (ns)


tn-tmu: neutron, energy cut, Good Stop
h6
Entries 2252280
count
1000
800
600
400
200
-30000
-20000
-10000
0
10000
20000
30000
Time Difference (ns)

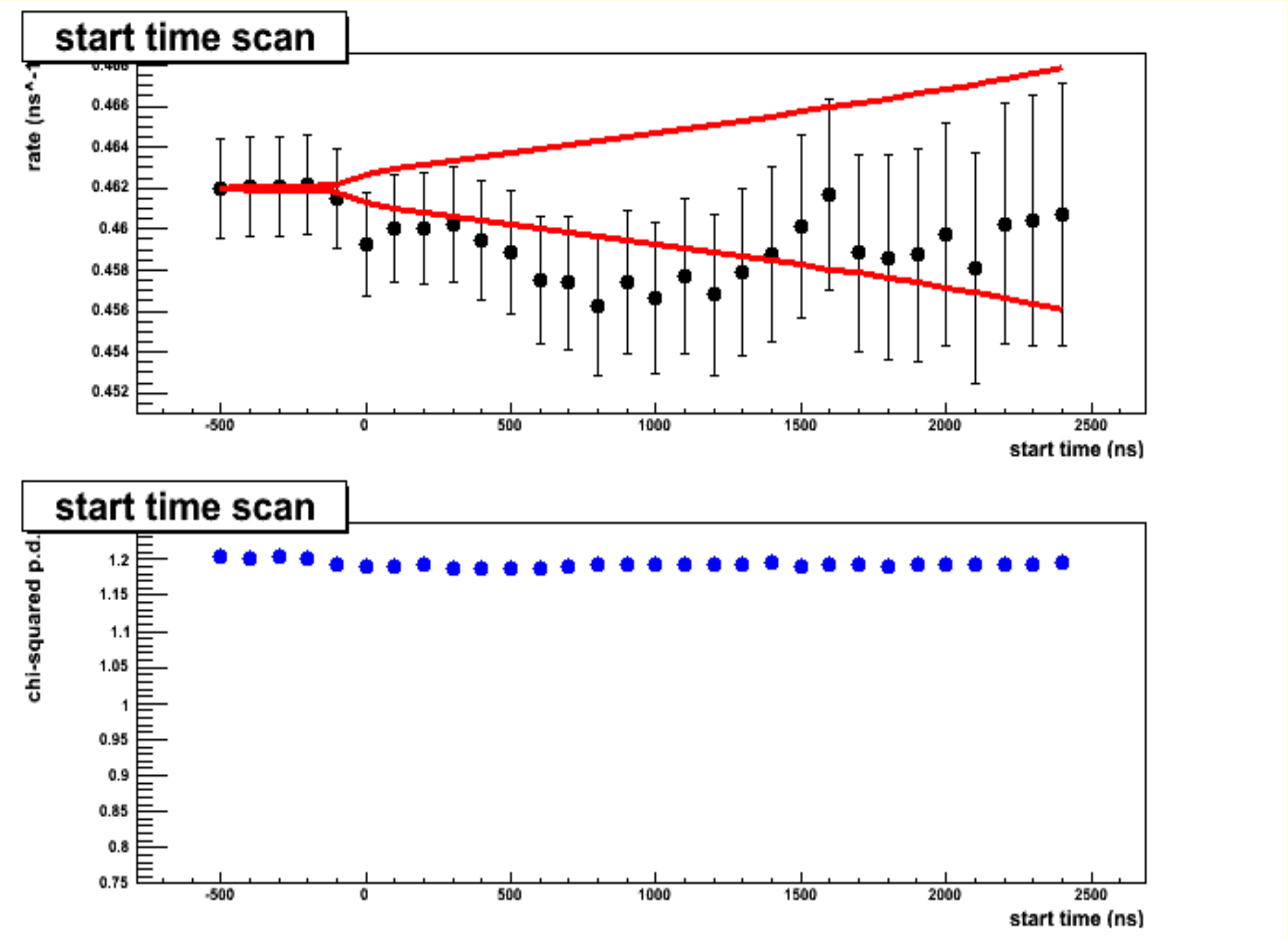

tn-tmu: neutron, energy cut, Good Stop, with Gondola
h7
Entries 6055992
count
2000
1500
1000
500
-30000
-20000
-10000
0
10000
20000
30000
Time Difference (ns)


tn-tmu: neutron, energy cut, Good Stop, background subtracted
h8
Entries 236259
count
800
600
400
200
0
-30000
-20000
-10000
0
10000
20000
30000
Time Difference (ns)

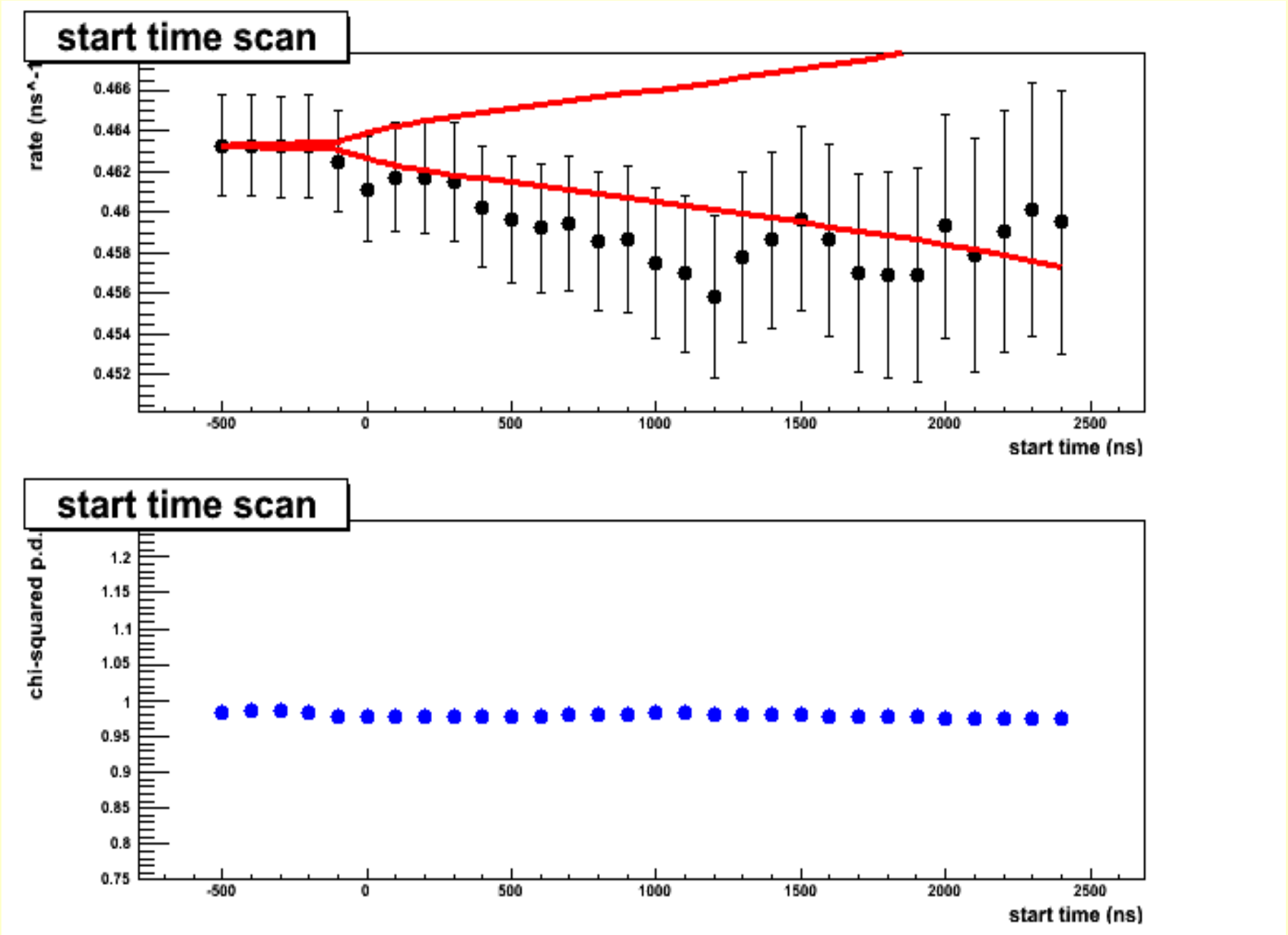


Black – nominal muon stop definition
green – ContEH>0, Head<5
red – CntEH>0, Head<3
cyan – CntEH>1, Head<5

Ratios of 2010 / 2009 neutron time spectra


start time scan
rate (ns^-1
0.466
0.464
0.462
0.46
0.458
0.456
0.454
0.452
-500
0
500
1000
1500
2000
2500
start time (ns)
start time scan
chi-squared p.d.
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
-500
0
500
1000
1500
2000
2500
start time (ns)

C0H5 2009


start time scan
rate (ns^-1
0.466
0.464
0.462
0.46
0.458
0.456
0.454
0.452
-500
0
500
1000
1500
2000
2500
start time (ns)
start time scan
chi-squared p.d.
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
-500
0
500
1000
1500
2000
2500
start time (ns)

C0H5 2010

What next
on muon stop sensitivity?