Towards an S2 analysis in ReD

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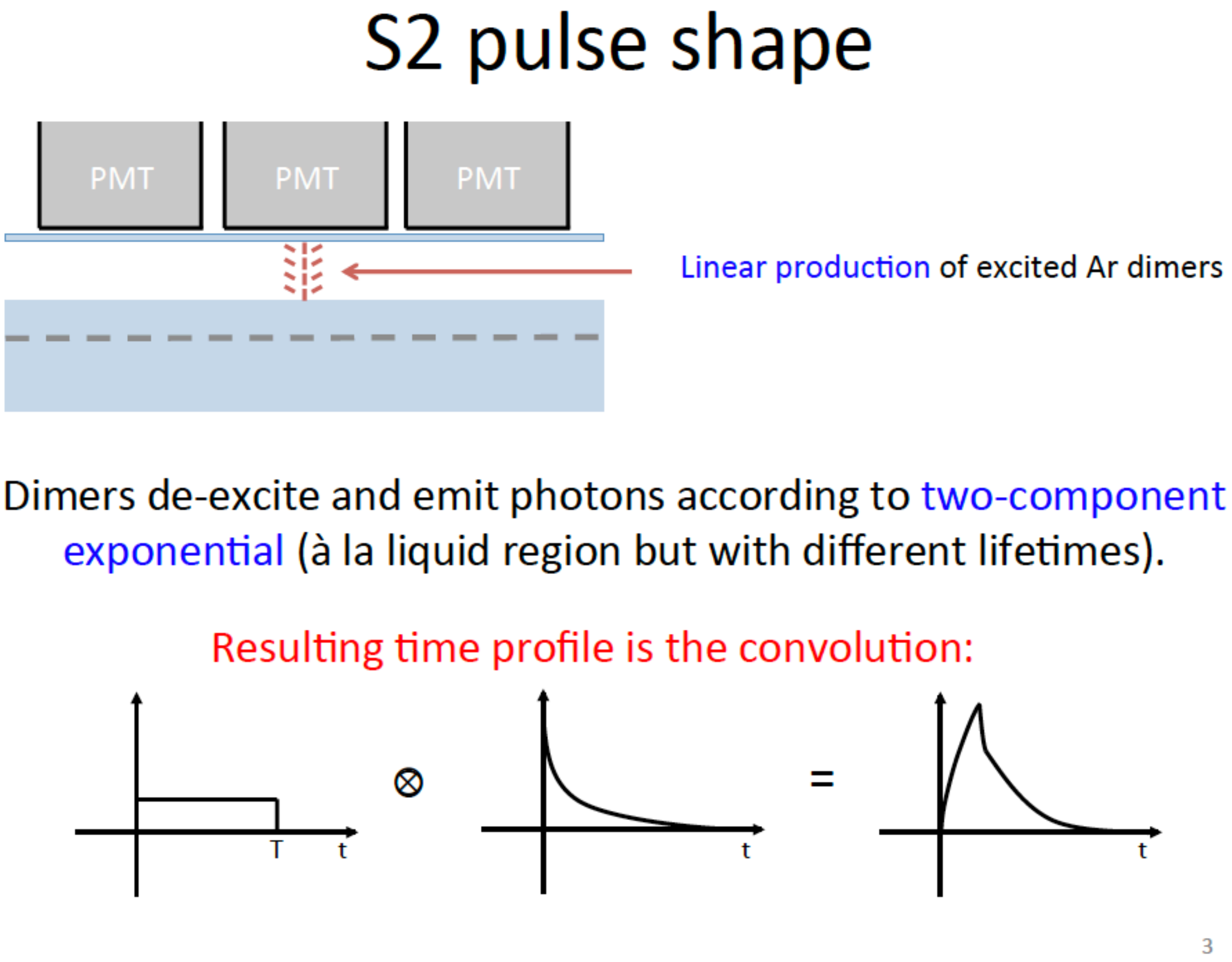
Summary

- S2 pulse shape depends from
  - The gas drift time
  - The scintillation time constants in gas
  - The fast component fraction
- The gas pocket height can be measured from the gas drift time T.
- To my understanding this parameter is “easy” to extract from the S2 pulse shape once you select a specific set of events (i.e. those which have a very short drift time in liquid). It can be fit to the average waveform and/or from Davide’s filtered signal.
- S2 pulse shape was analyzed in DS50 and we have full documentation on its analytical expression. It should be adapted to SiPM response. See the internal note from Alden (docdb#1237) and references therein.
- The gas drift time T may have a radial dependence that we can study. We do have information on xy in ReD raw data because we readout 24 single SiPM on the top. Vlad performed several uniformity studies on S2 that might be useful to this purpose. We also do have Krypton data that is uniformly distributed in the chamber.
- We also took data while forming the gas pocket that might be interesting to look at. See docdb#886 for the exercise done in DS50.
- Once T as a function of xy is known, we can extract a map of the gas pocket height (dgas) from the velocity

  v(Egas) T = dgas / v(Egas)
- In DS50 we got v(E) from Magboltz (an open source code that solves the Boltzmann transport equations with numerical integration in order to simulate the interactions of electrons in gas mixtures under the influence of electric and magnetic fields). See docdb#1172.
- In DS50 we used this analysis to level the TPC. See the results in docdb#1181. A similar effort will be needed in Proto.
- Alternative analysis methods exist. For example Chengliang in Princeton used S2/S1 analysis from Masa and compared the radial dependence to G4DS predictions in order to extract the gas pocket height map (see docdb#1161). I suppose that Paolo and Luciano should be able to do a similar MC study in G4ReD.



S2 pulse shape

Linear production of excited Ar dimers

Dimers de-excite and emit photons according to two-component exponential (à la liquid region but with different lifetimes).

Resulting time profile is the convolution:

S2 basics

From Alden Fan and Xinran Li
29 January 2015 DarkSide General Meeting
Docdb #1123

Model for S2 time profile

$$h(t) = f(t) \otimes g(t)$$

$f(t)$ is linear production of excimers

$g(t)$ describes scintillation process

$$h(t) = \frac{1}{T} \cdot \begin{cases} 0 & , t < 0 \\ 1 - pe^{-t/\tau_f} - (1-p)e^{-t/\tau_s} & , 0 \leq t < T \\ pe^{-t/\tau_f}(e^{T/\tau_f} - 1) + (1-p)e^{-t/\tau_s}(e^{T/\tau_s} - 1) & , t \geq T \end{cases}$$

τ_f = fast decay time

τ_s = slow decay time

T = drift time in gas

p = fast component fraction

From A. Fan thesis <u>docdb #2439</u>

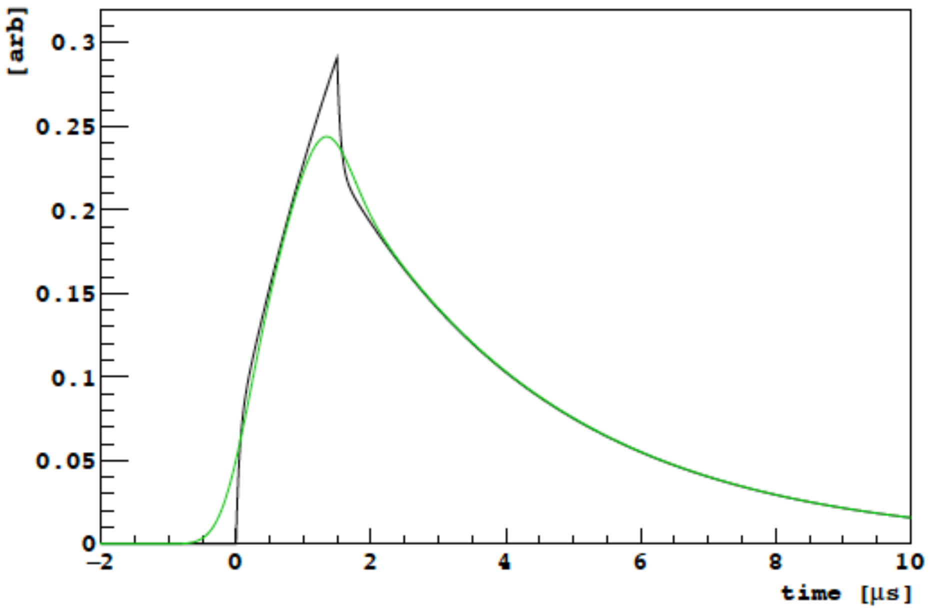


Figure 4.1: Example S2 pulse shape with τ_1 =0.05 μs, τ_2 = 3.2 μs, p = 0.1, and T = 1.5 μs. Black: idealized form (no smearing). Green: includes Gaussian smearing at σ = 0.3 μs.

S2 pulse shape with smearing

Convolution of basic S2 pulse shape with a Gaussian:

$$y(t) = k(t) * h(t)$$

$$k(t) = \frac{1}{\sqrt{2\sigma^2}} e^{-t^2/2\sigma^2}$$

$$y(t;\tau_1,\tau_2,p,T,\sigma) = y_1(t;T,\sigma) - py_2(t;\tau_1,T,\sigma) - (1-p)y_2(t;\tau_2,T,\sigma) + py_3(t;\tau_1,T,\sigma) + (1-p)y_3(t;\tau_2,T,\sigma)$$

$$y_1(t;T,\sigma) = \frac{1}{2T}\left[\mathrm{erf}\left(\frac{t}{\sqrt{2}\sigma}\right) - \mathrm{erf}\left(\frac{t-T}{\sqrt{2}\sigma}\right)\right]$$

$$y_2(t;\tau,T,\sigma) = \frac{1}{2T}\exp\left(\frac{\sigma^2 - 2t\tau}{2\tau^2}\right)\left[\mathrm{erf}\left(\frac{t\tau - \sigma^2}{\sqrt{2}\sigma\tau}\right) + \mathrm{erf}\left(\frac{\sigma^2 - \tau(t-T)}{\sqrt{2}\sigma\tau}\right)\right]$$

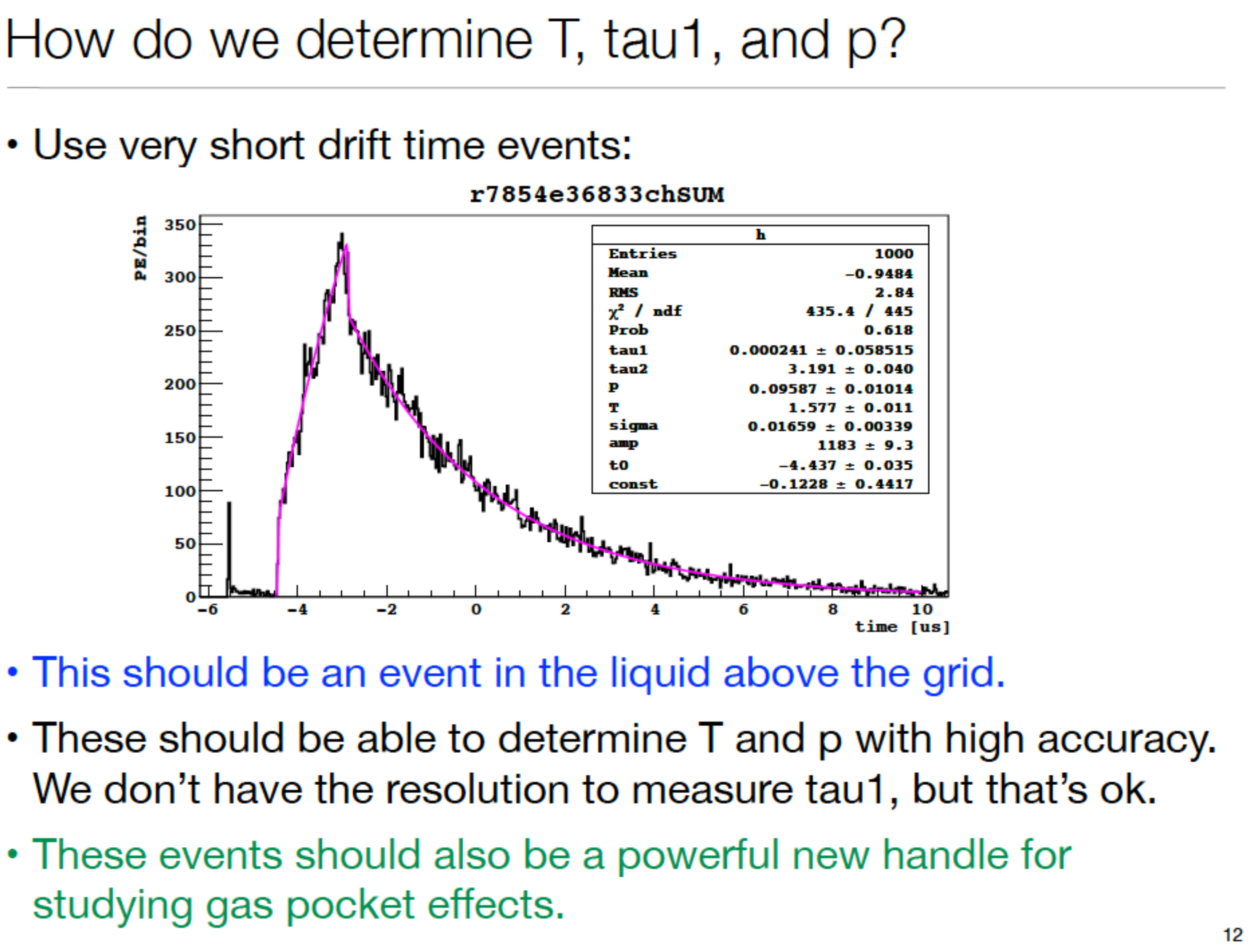
$$y_3(t;\tau,T,\sigma) = \frac{e^{T/\tau} - 1}{2T}\exp\left(\frac{\sigma^2 - 2t\tau}{2\tau^2}\right)\mathrm{erfc}\left(\frac{\sigma^2 - \tau(t-T)}{\sqrt{2}\sigma\tau}\right)$$

Fit parameters in DS50 (docdb # 886)

```
tau1  = fast component lifetime
tau2  = slow component lifetime
p     = fast component fraction
T     = electron drift time in gas
sigma = gaussian smearing
amp   = overall amplitude
t0    = horizontal (time) offset
const = vertical (amplitude) offset
```

- Fix p=0 because fit seems to work in this mode. tau1 then irrelevant and fixed at 0.01.
- Fix const to be the baseline mean, using [-5, 0] us.
- Fix amp to be the total integral over the fit range [-5,30] us, accounting for const offset.

→ 4 free parameters: tau2, T, sigma, t0



How do we determine T, tau1, and p?

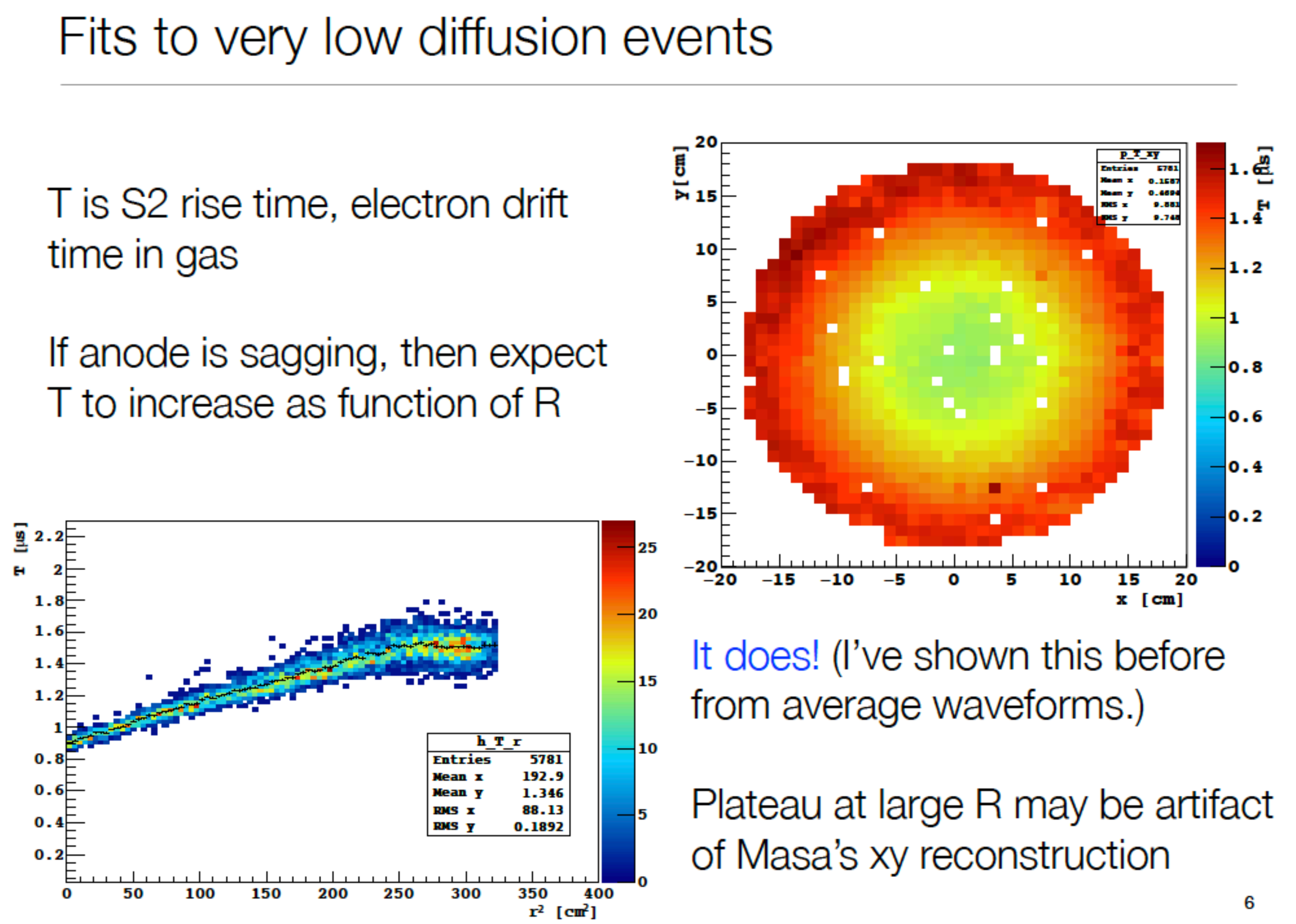
- Use very short drift time events:

h	
Entries	1000
Mean	−0.9484
RMS	2.84
χ^2 / ndf	435.4 / 445
Prob	0.618
tau1	0.000241 ± 0.058515
tau2	3.191 ± 0.040
P	0.09587 ± 0.01014
T	1.577 ± 0.011
sigma	0.01659 ± 0.00339
amp	1183 ± 9.3
t0	−4.437 ± 0.035
const	−0.1228 ± 0.4417

- This should be an event in the liquid above the grid.
- These should be able to determine T and p with high accuracy. We don't have the resolution to measure tau1, but that's ok.
- These events should also be a powerful new handle for studying gas pocket effects.

Zero diffusion events

See docdb #1143 and #1166



Fits to very low diffusion events

T is S2 rise time, electron drift time in gas

If anode is sagging, then expect T to increase as function of R

It does! (I've shown this before from average waveforms.)

Plateau at large R may be artifact of Masa's xy reconstruction

Determine T(R) from low diffusion events

see docdb @1172

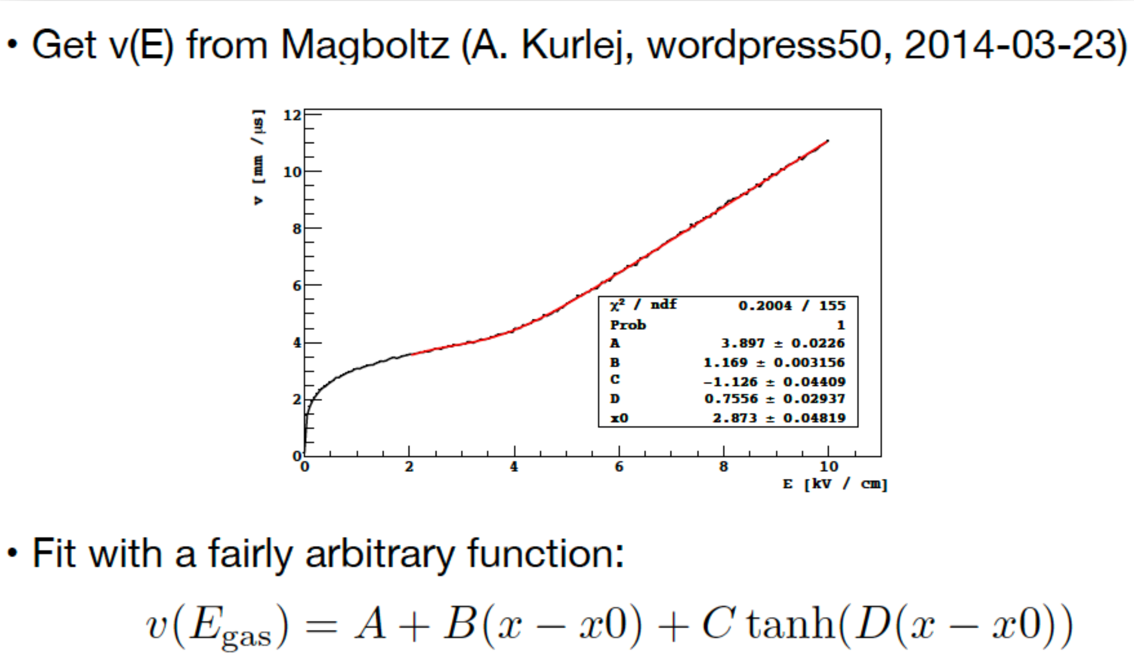
Gas pocket height

- Variations in T are due to variations in electroluminescence field and/or variations in gas pocket height.
- Assume anode is sagging and grid and liquid surface are flat.

$$T = \frac{d_{\text{gas}}}{v(E_{\text{gas}})} \qquad E_{\text{gas}} = \frac{\epsilon_{\text{liq}} V}{\epsilon_{\text{liq}} d_{\text{gas}} + \epsilon_{\text{gas}} d_{\text{liq}}}$$

- Need v(E).

- Then have T as a function of gas pocket height, d_gas.



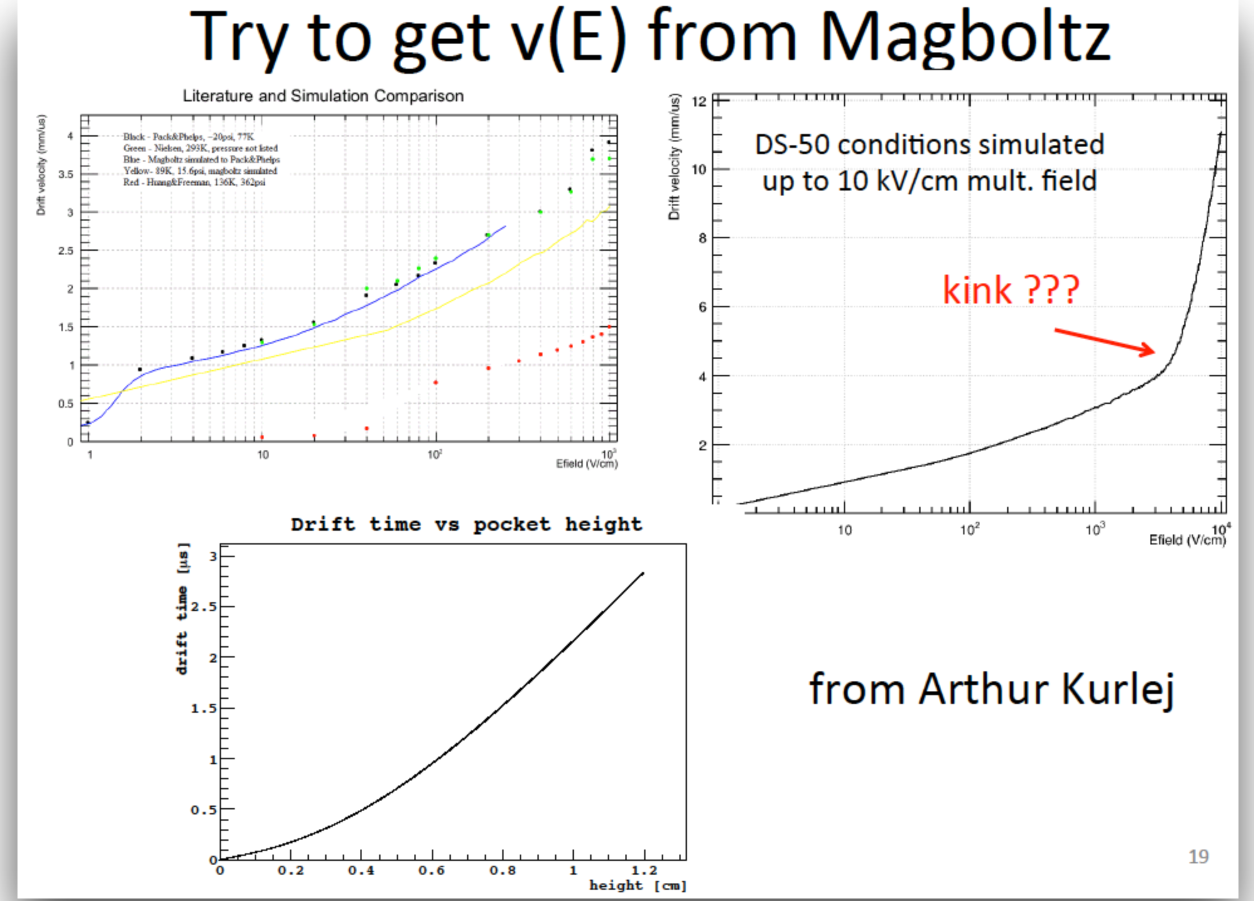
- Get v(E) from Magboltz (A. Kurlej, wordpress50, 2014-03-23)

χ^2 / ndf	0.2004 / 155
Prob	1
A	3.897 ± 0.0226
B	1.169 ± 0.003156
C	−1.126 ± 0.04409
D	0.7556 ± 0.02937
x0	2.873 ± 0.04819

- Fit with a fairly arbitrary function:

$$v(E_{\text{gas}}) = A + B(x - x0) + C\tanh(D(x - x0))$$

docdb #886



Try to get v(E) from Magboltz

Literature and Simulation Comparison

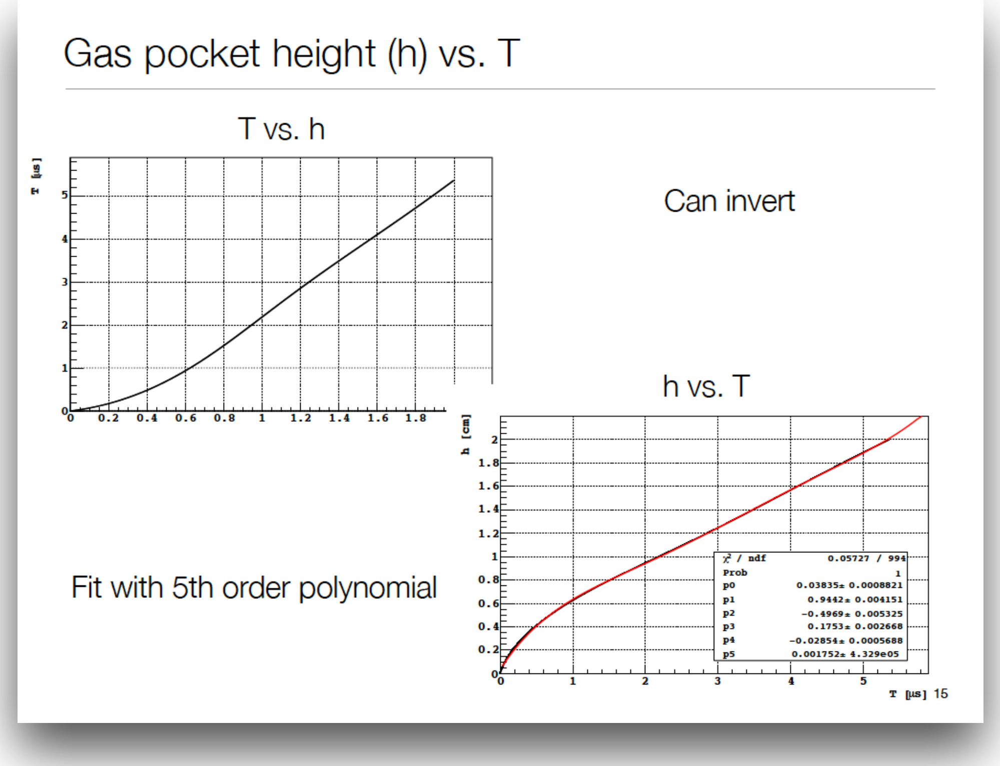
Black - Pack&Phelps, ~20psi, 77K
Green - Nielsen, 293K, pressure not listed
Blue - Magboltz simulated to Pack&Phelps
Yellow- 89K, 15.6psi, magboltz simulated
Red - Huang&Freeman, 136K, 362psi

DS-50 conditions simulated up to 10 kV/cm mult. field

kink ???

Drift time vs pocket height

from Arthur Kurlej



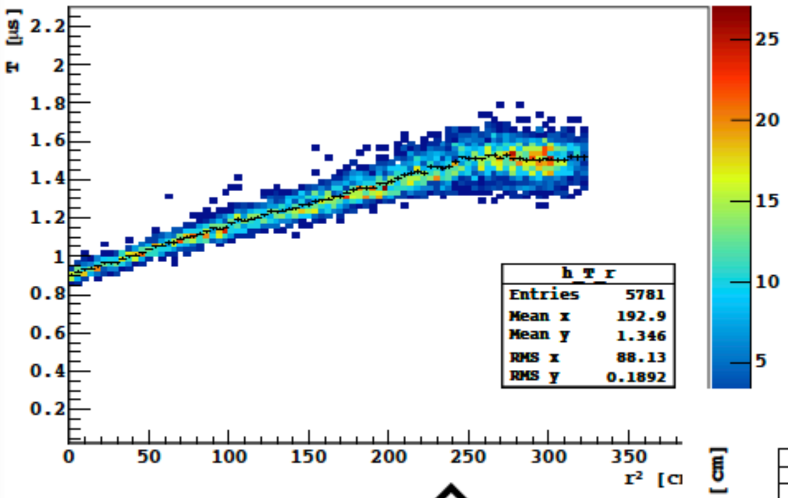
Gas pocket height (h) vs. T

T vs. h

Can invert

h vs. T

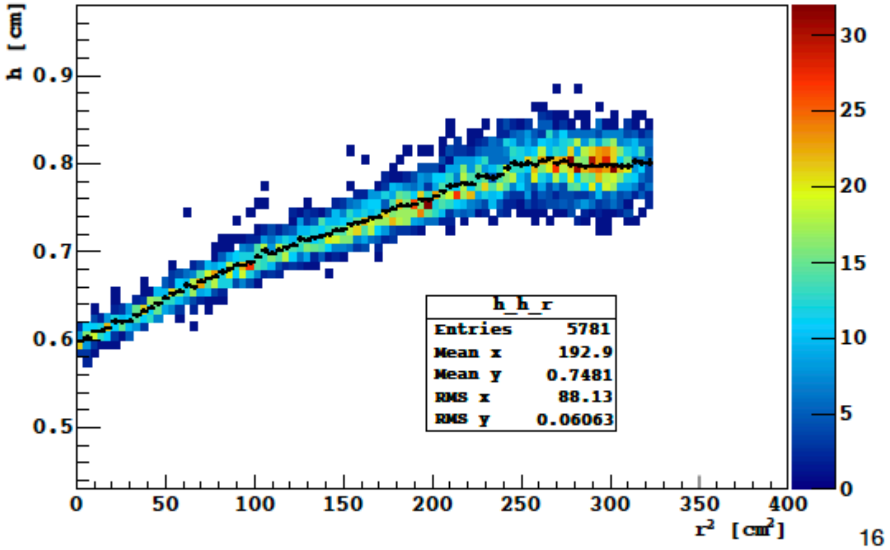
Fit with 5th order polynomial



Transform T vs. R

to

gas pocket height (h) vs. R

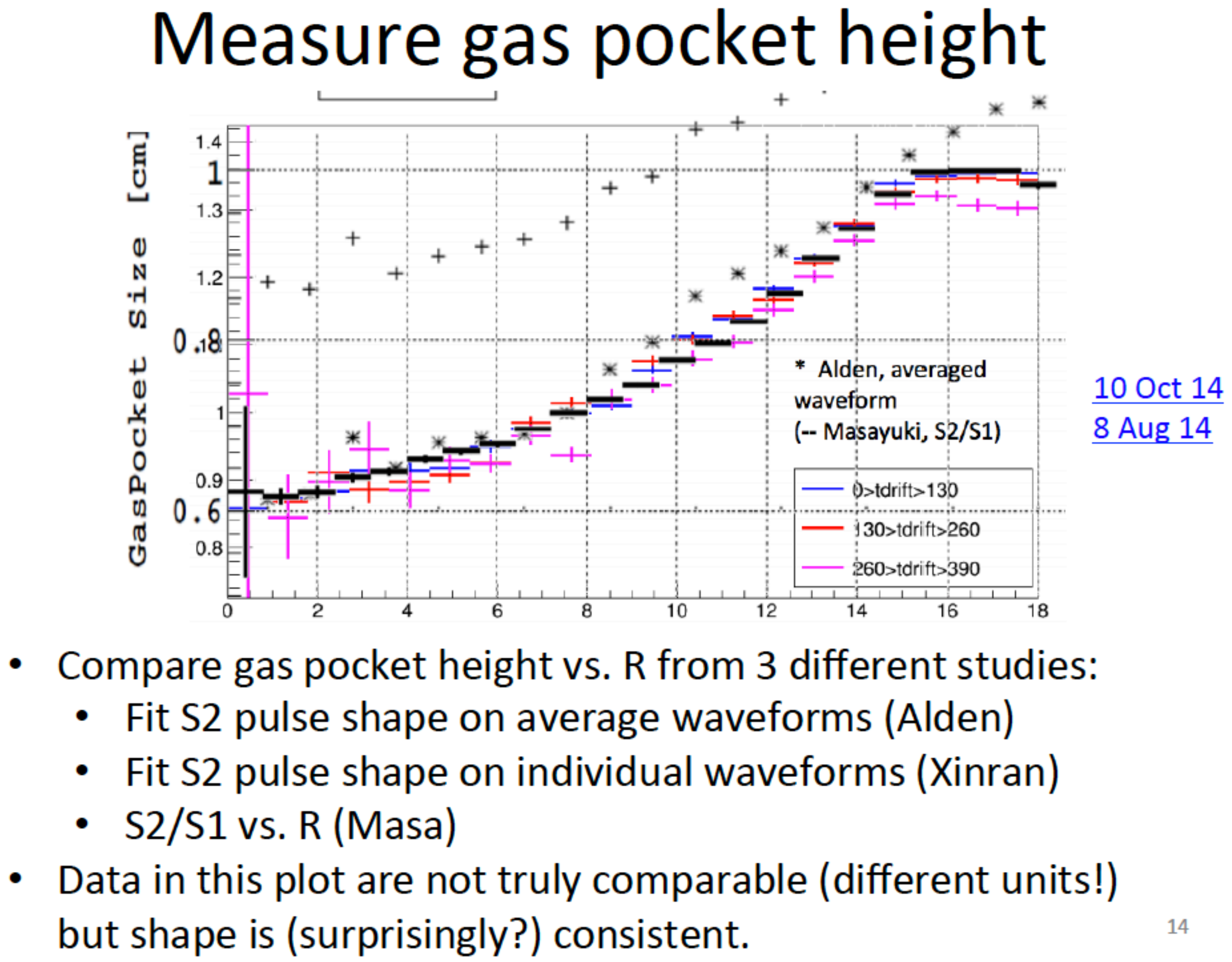


Again, plateau at large R may be artifact of reconstruction

Gas pocket height as a function of R

docdb @1172

Docdb #1123



Measure gas pocket height

- Compare gas pocket height vs. R from 3 different studies:
    - Fit S2 pulse shape on average waveforms (Alden)
    - Fit S2 pulse shape on individual waveforms (Xinran)
    - S2/S1 vs. R (Masa)
- Data in this plot are not truly comparable (different units!) but shape is (surprisingly?) consistent.

14

10 Oct 14
8 Aug 14

Gas pocket from S2/S1

see also Masa’s early study for DS50 (docdb #1334)