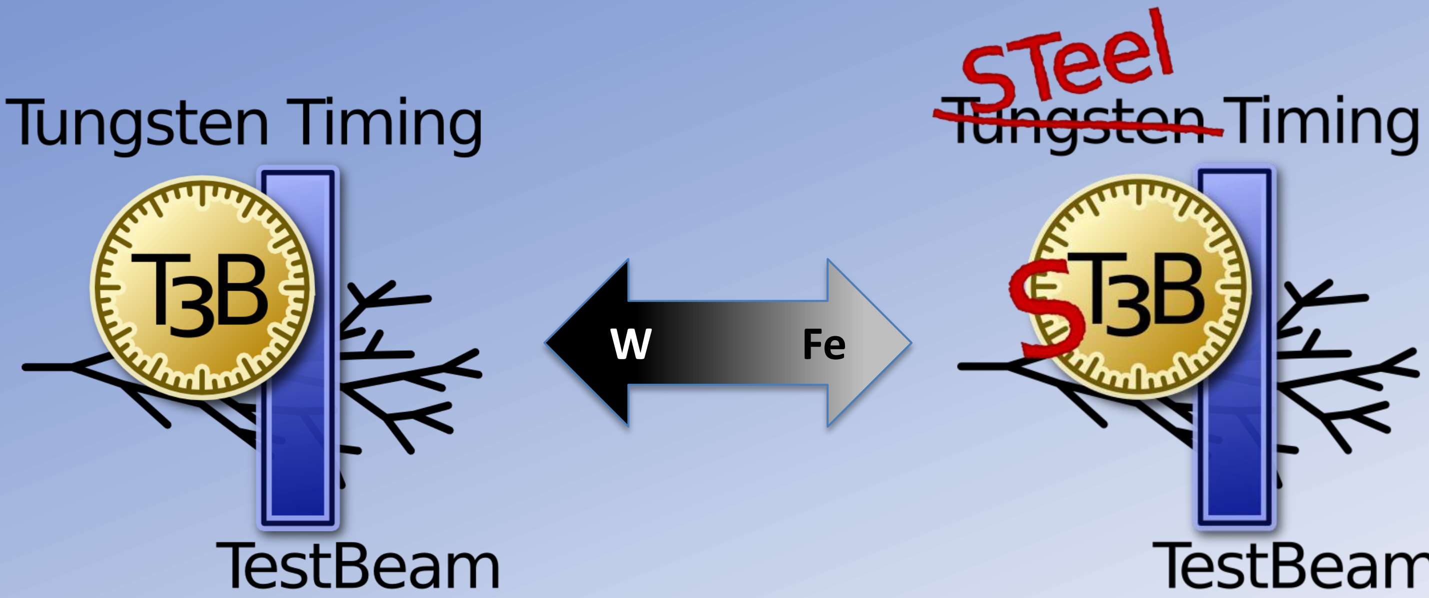
T3B Standalone Analysis

Calibration, Time Profile, Steel/Tungsten Comparison



Calice collaboration meeting– March 6th 2012 – Shinshu, Japan

Christian Soldner
Max-Planck-Institute for Physics

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

CALICE Calorimeter for ILC

TUM LMU Excellence Cluster Universe

Outline

- Introduction: CALICE and T3B
- Calibration to the MIP scale
  → Time of First Hit Analysis
- Afterpulsing Study
  → Time of Hit Analysis
- Summary and Outlook

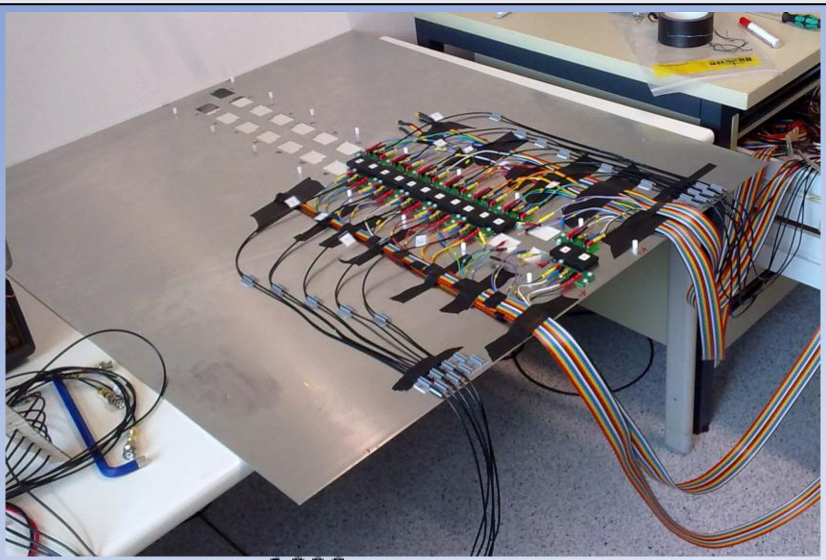
THE CALICE CALORIMETER AND THE T3B EXPERIMENT

The T3B Experiment

What is T3B?

- One row of 15 scintillator tiles
- Tile dimensions: 3 x 3 x 0.5 cm^3
- Light Readout by SiPMs: MPPC-50P
- Data Acquisition: 4 fast USB Oscilloscopes

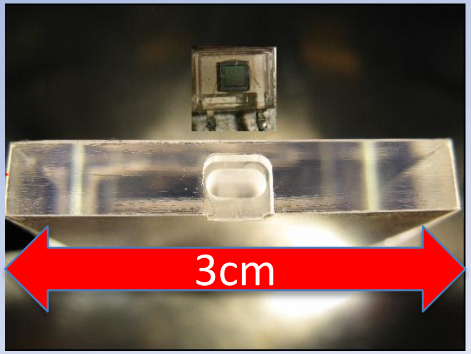
Setup optimized to observe the time development of hadron showers



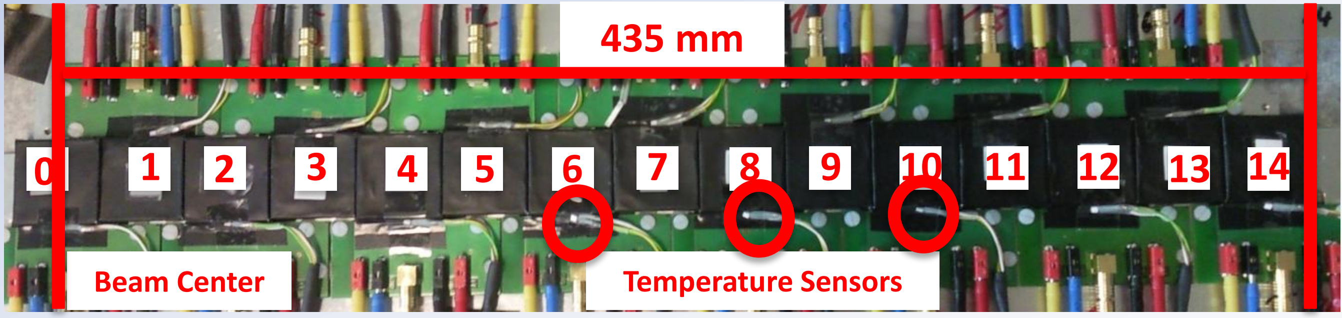
CALICE:

+ 3D reconstruction of hadronic shower shapes

- No timing information on the showers → (s)T3B

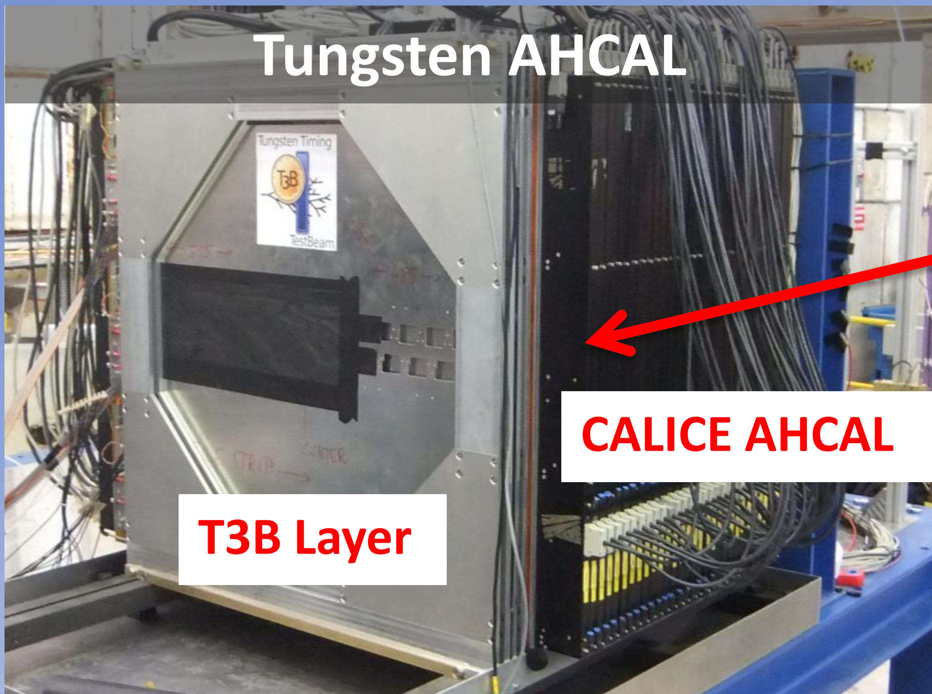


Tile geometry optimized for direct coupling

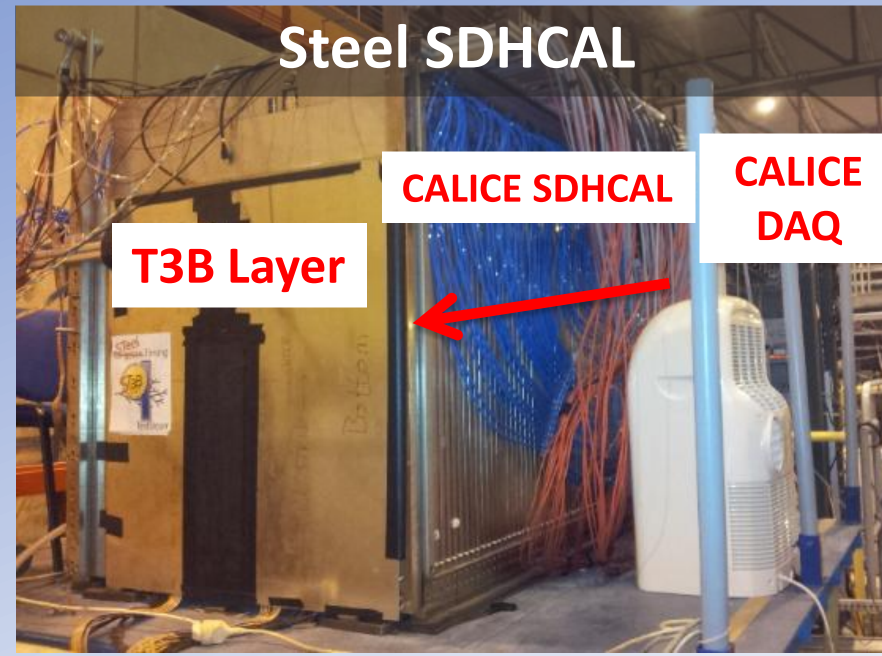


1 Temperature Sensor PT1000 for each T3B cell

The T3B Experiment within the CALICE Calorimeters

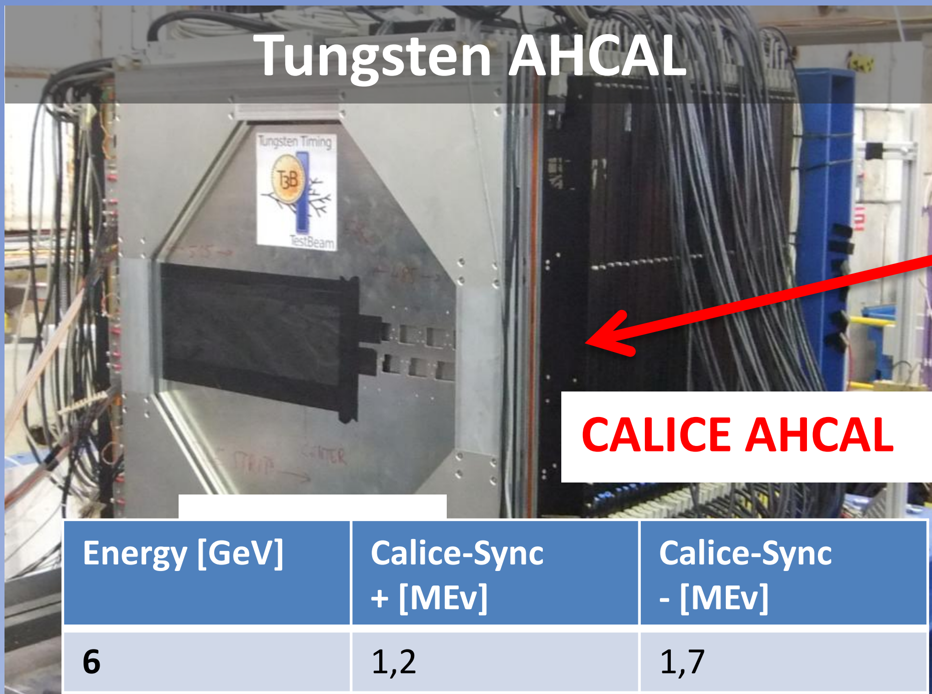


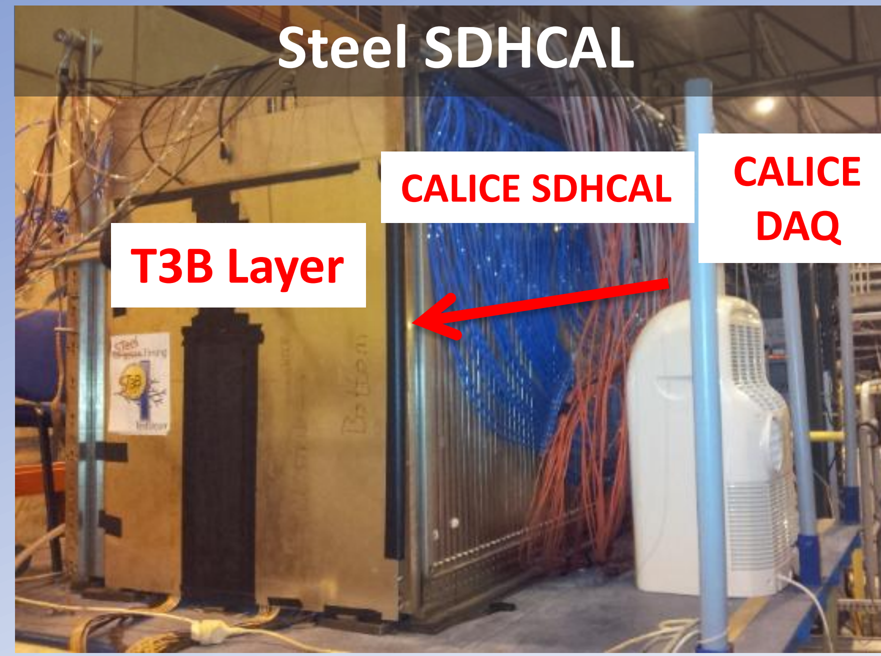
Run Periods:	PS: Nov 2010
	SPS: June/July/Sept 2011
Energy Range:	2-300GeV
Trigger:	CALICE Synchronous
Shower Depth:	~3λ_I (PS), ~5 λ_I (SPS)
Total Had. Events:	27 Million



Run Periods:	SPS: October 2011
Energy Range:	40-180GeV
Trigger:	T3B Standalone
Shower Depth:	~6 λ_I
Total Had. Events:	5 Million

The T3B Experiment within the CALICE Calorimeters





Energy [GeV]	Calice-Sync + [MEv]	Calice-Sync - [MEv]
6	1,2	1,7
8	1,5	1,5
10		4,6
40	2,0	
50		1,7
60	4,1	
80	4,5	
150		1,2
180	0.9	0.7

W ⟷ **Fe**

Energy [GeV]	T3B Standalone + [MEv]
60	1,6
80	2,0
180	1,2

CALIBRATION TO THE MIP SCALE

T3B Calibration to the MIP Scale: Sr90 Data

During the Test Beam T3B monitors the SiPM Gain continuously

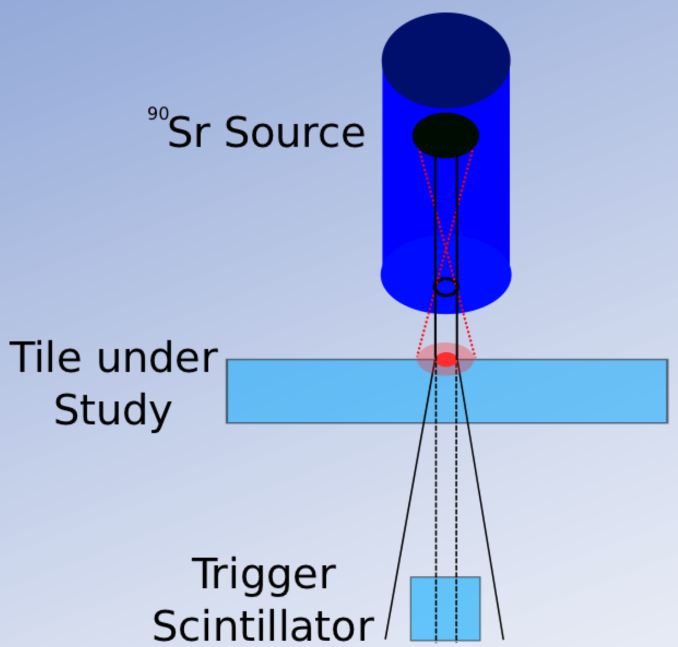
→ This data can be used to calibrate energy depositions to the MIP Scale

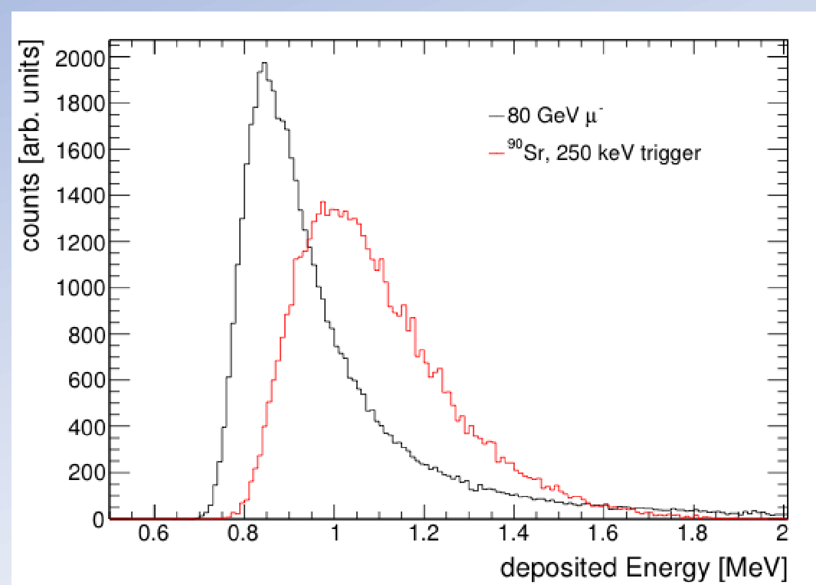
Assumption: The MIP MPV depends in first order only(!) on the Gain

Offline Calibration Setup:

- Consecutive calibration of all T3B cells individually

  → Use T3B DAQ: Acquire Sr90 and SiPM gain data at the same time

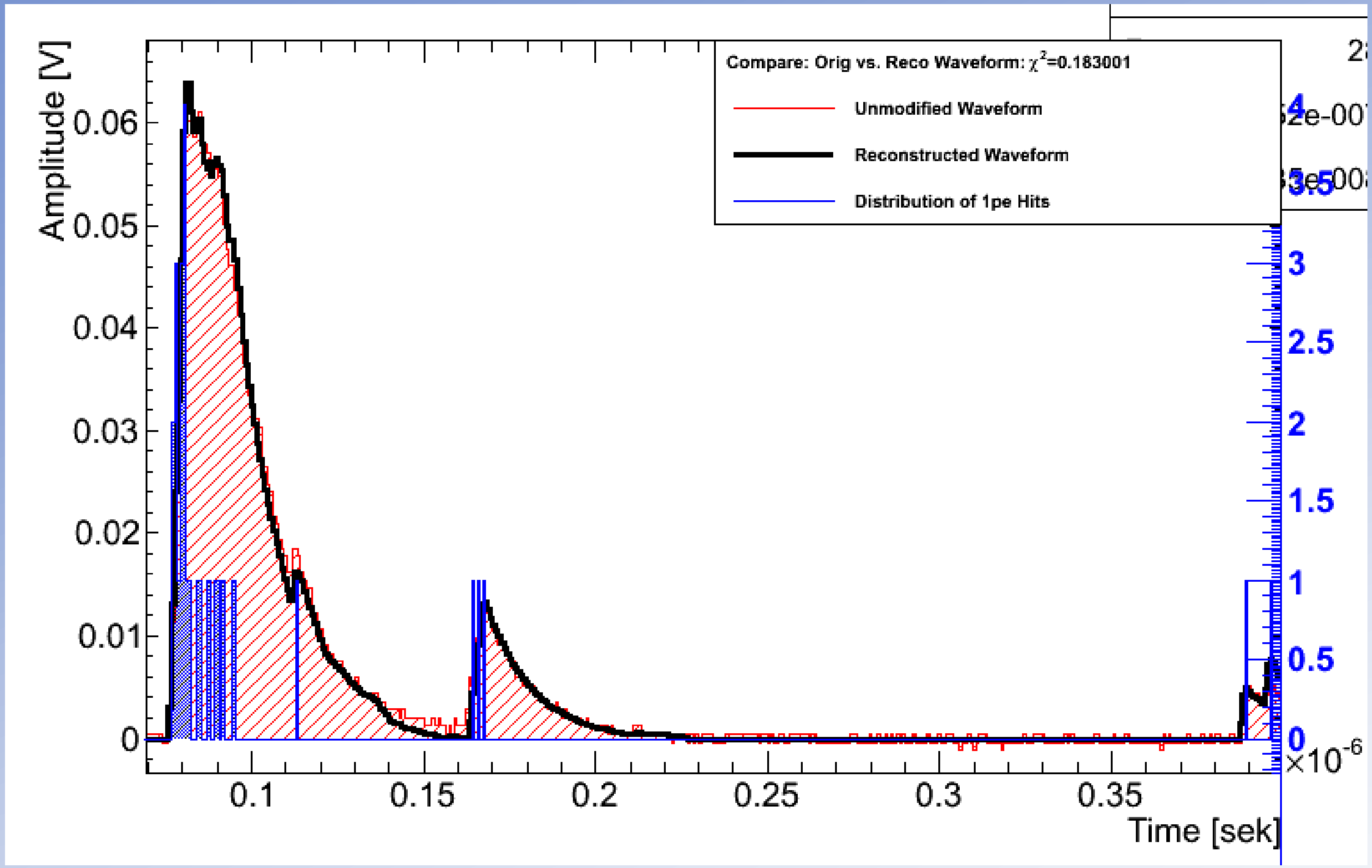




GEANT4 Simulation:
MPV (mu) = MPV(e)*0.82

Note:
Electrons are no perfect MIPs
→ need scale factor

The Time Integration Window

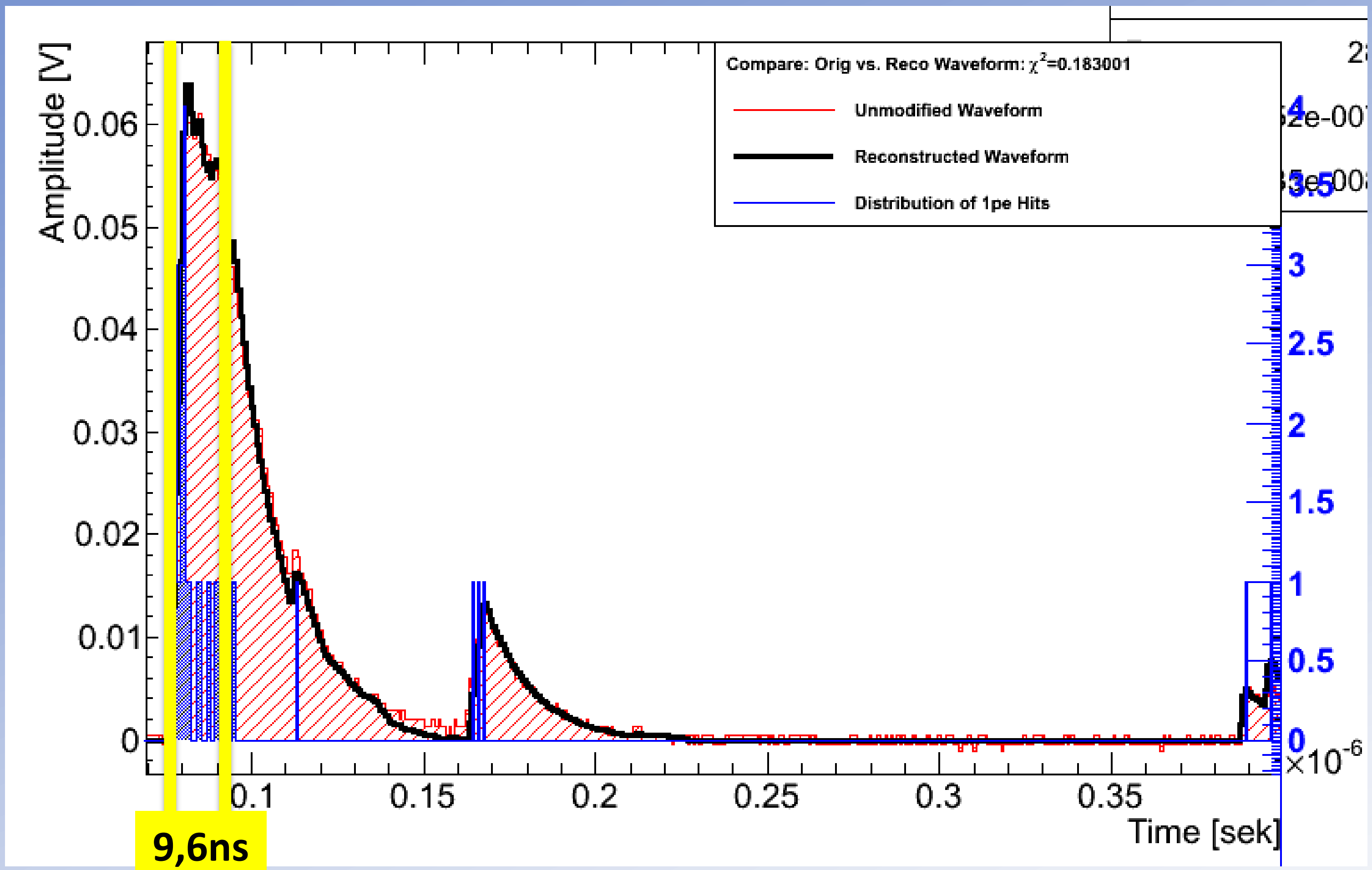


The MPV is very sensitive on the Time Integration Window

→ Dominant effect: SiPM Afterpulsing

- Separate afterpulsing from energy depositions
- Study the effect of afterpulsing

The Time Integration Window



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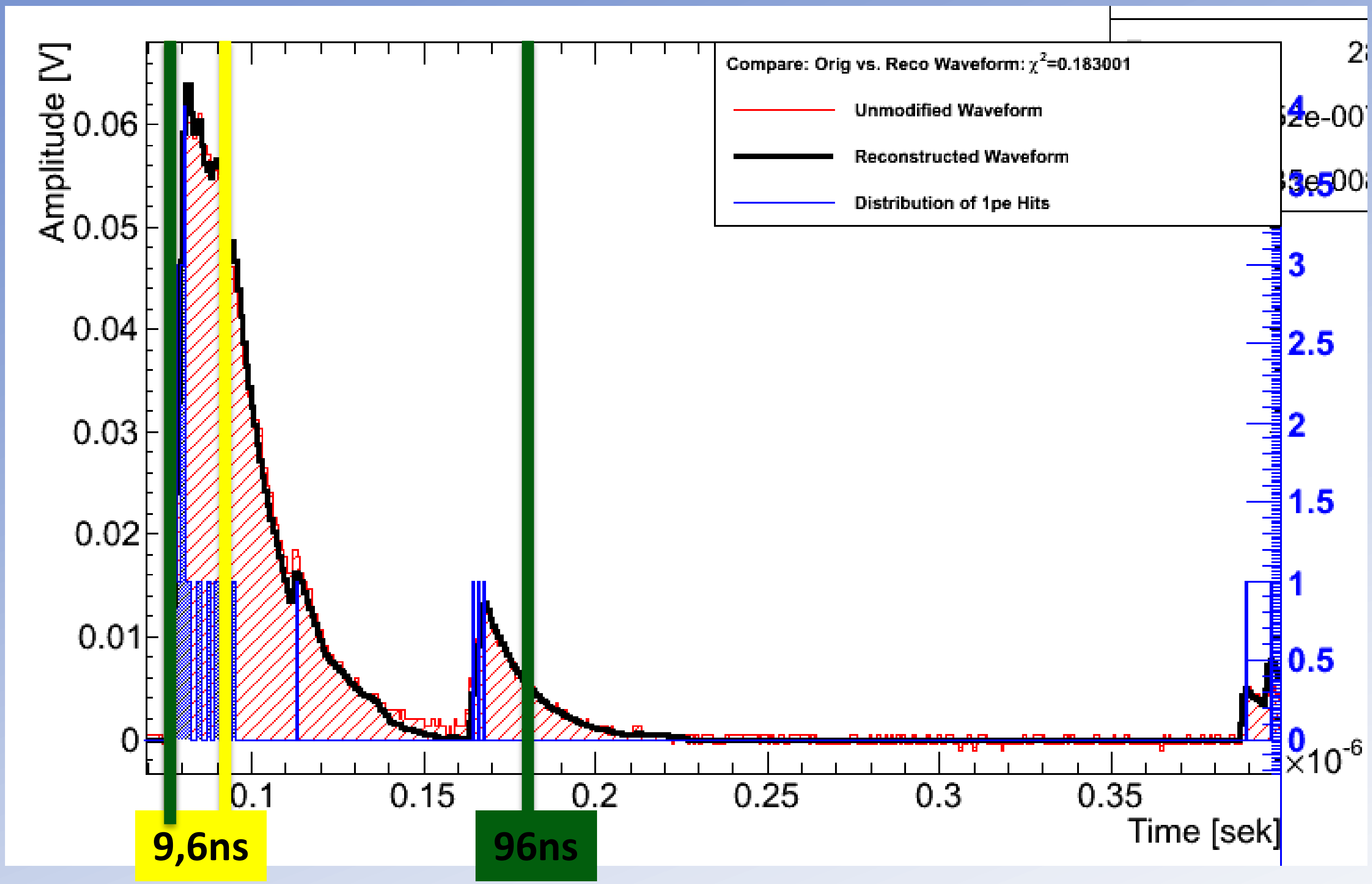

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→ Dominant effect: SiPM Afterpulsing

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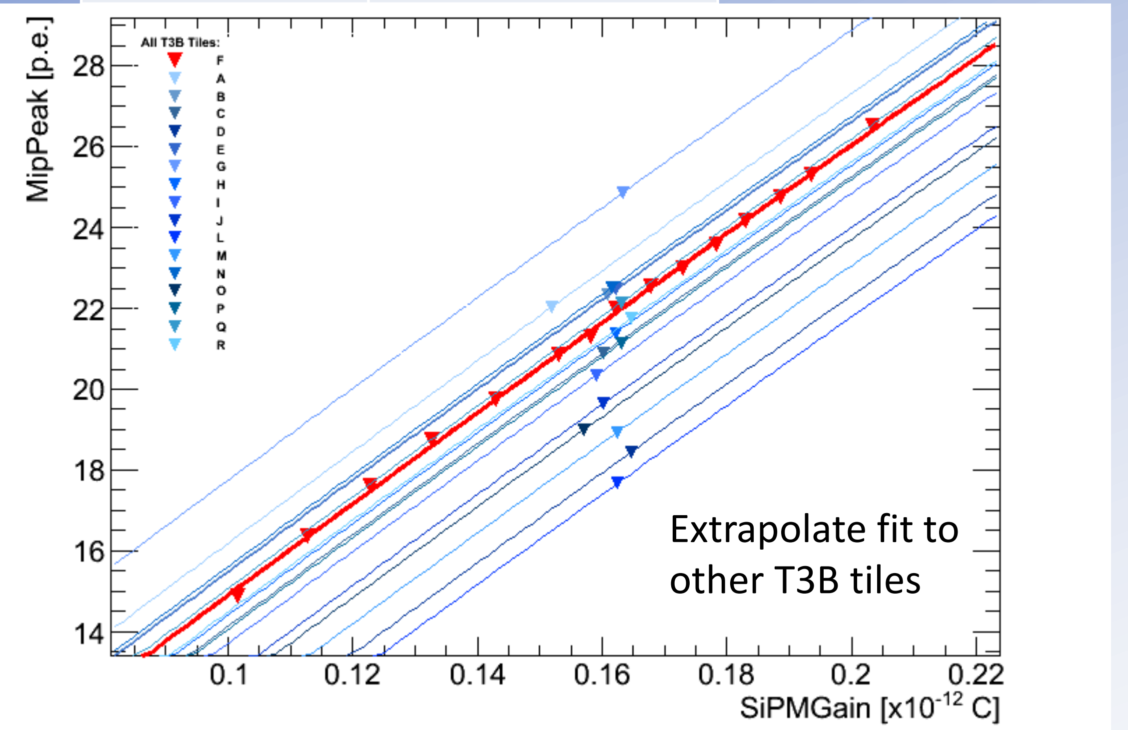
The Effect of Afterpulsing

Bias Voltage Scan for one T3B "Master Tile"
One Measurement for all other T3B tiles

Time Window	MPV-Gain dependence
Short (~10 ns)	Linear (no AP)
Long (~100 ns)	Quadratic (with AP)



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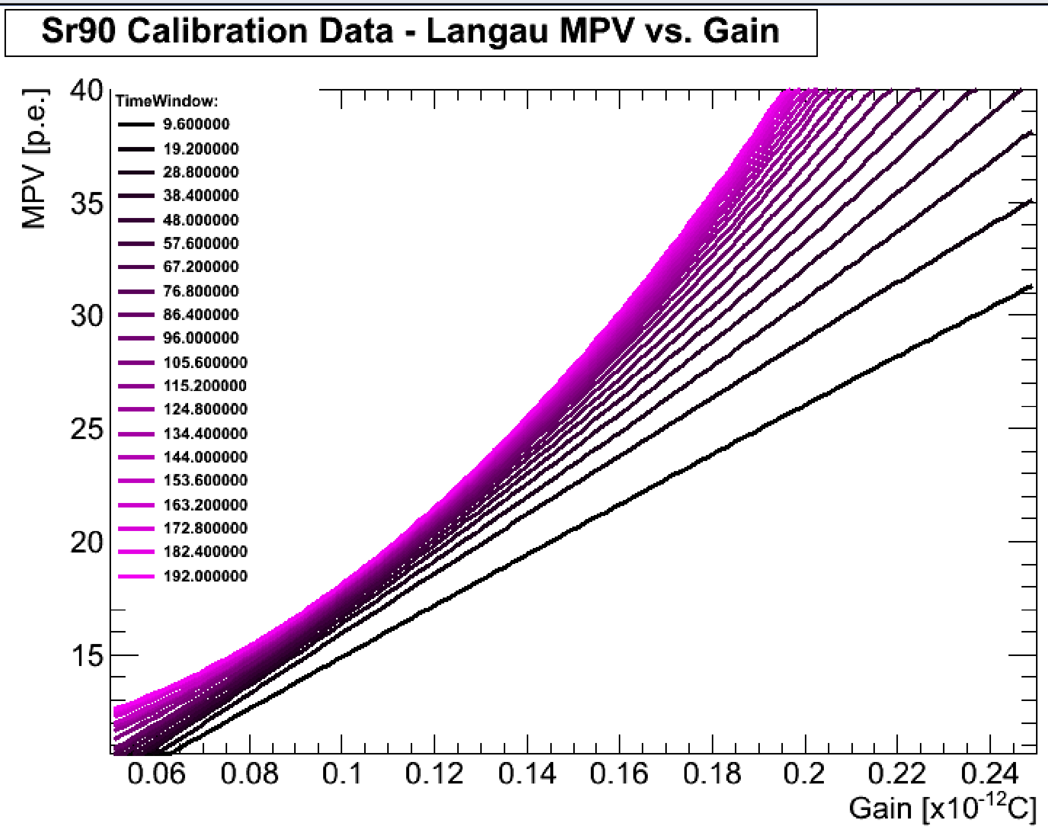
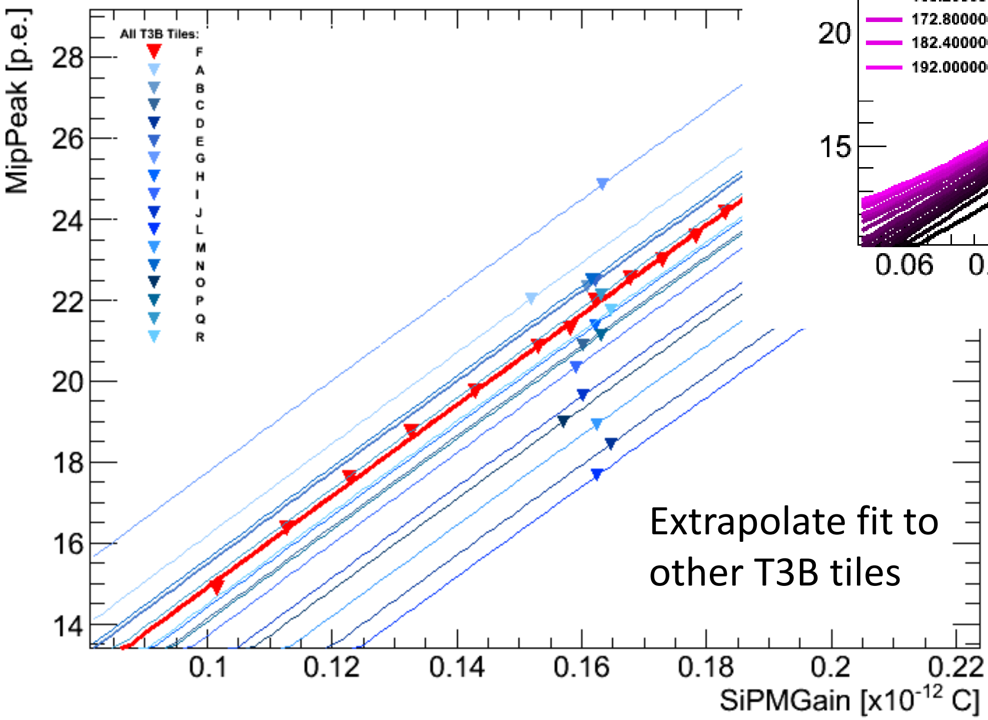
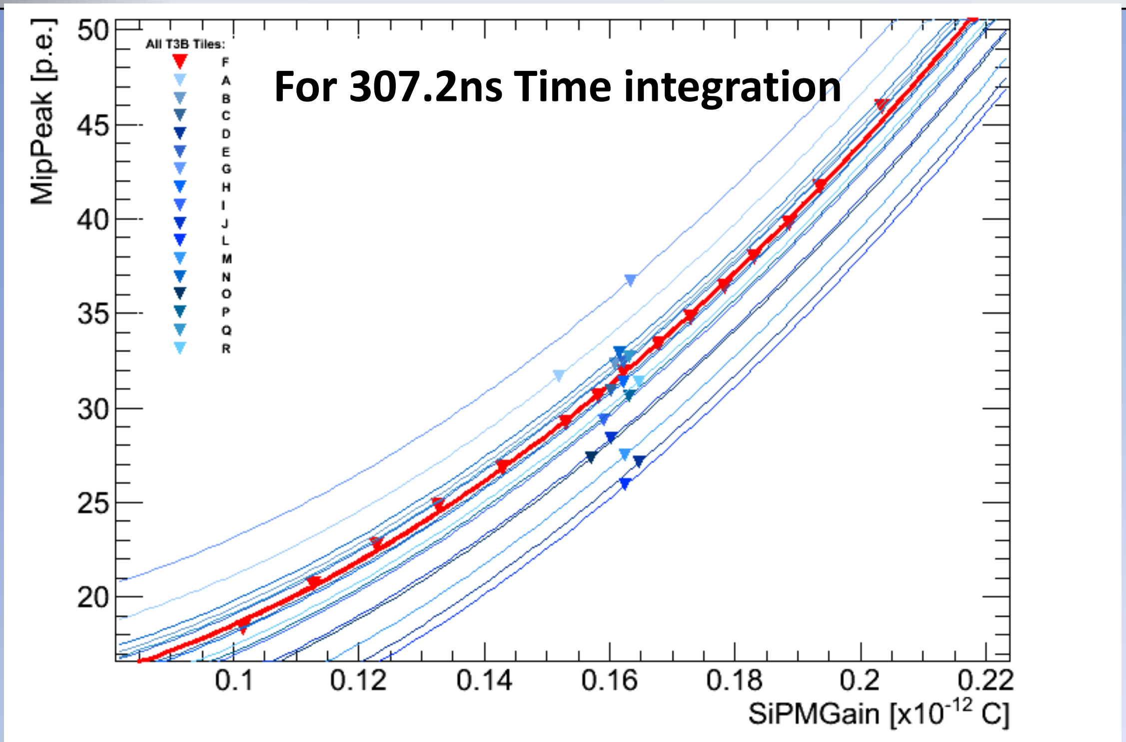




Higher Gain
- → Afterpulsing and Crosstalk probability increased
- → Increased MPV dependence for long integration times

Needs to be taken into account in Calib

T3B Calibration to the MIP Scale



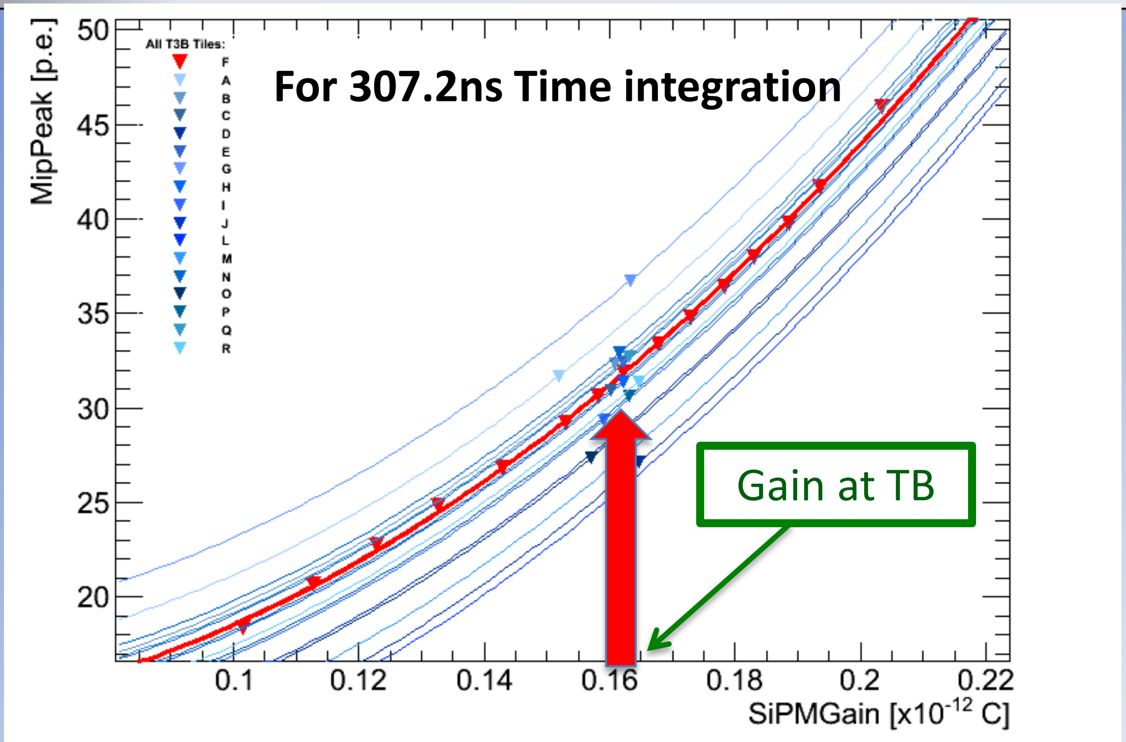
Obtain a dictionary:

Determine live SiPM Gain from testbeam data

Select MPV-Gain dependence for distinct time integration window

Obtain corresponding MPV of MIP distrib.

T3B Calibration to the MIP Scale



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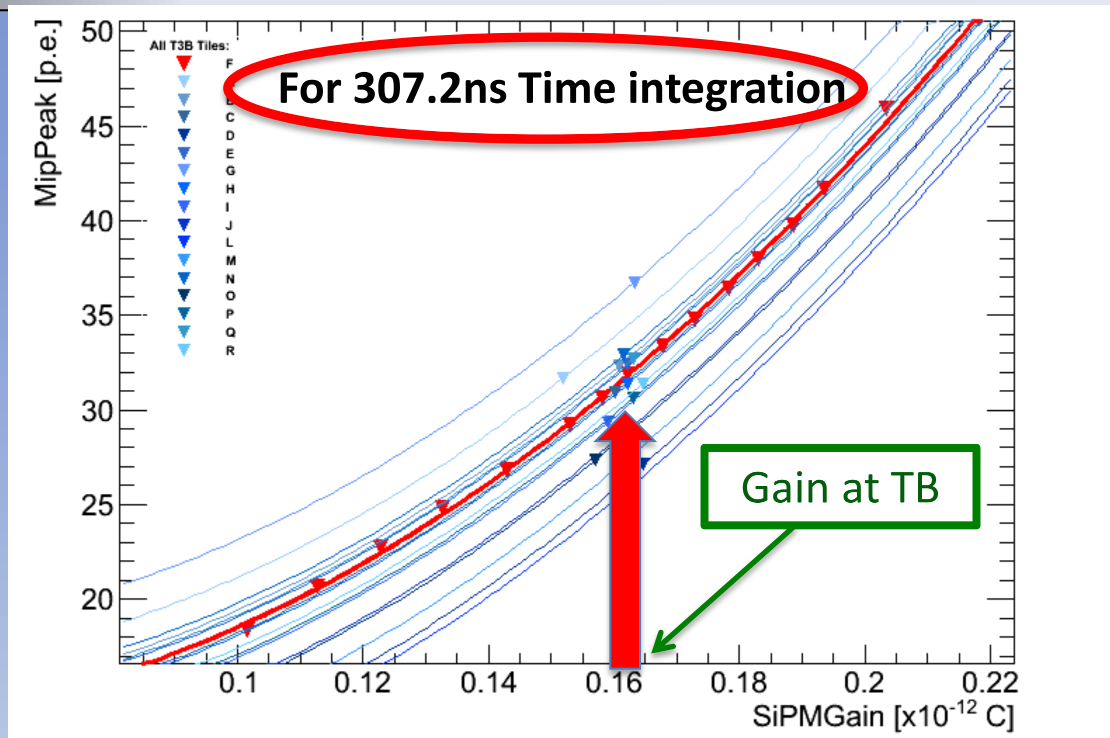

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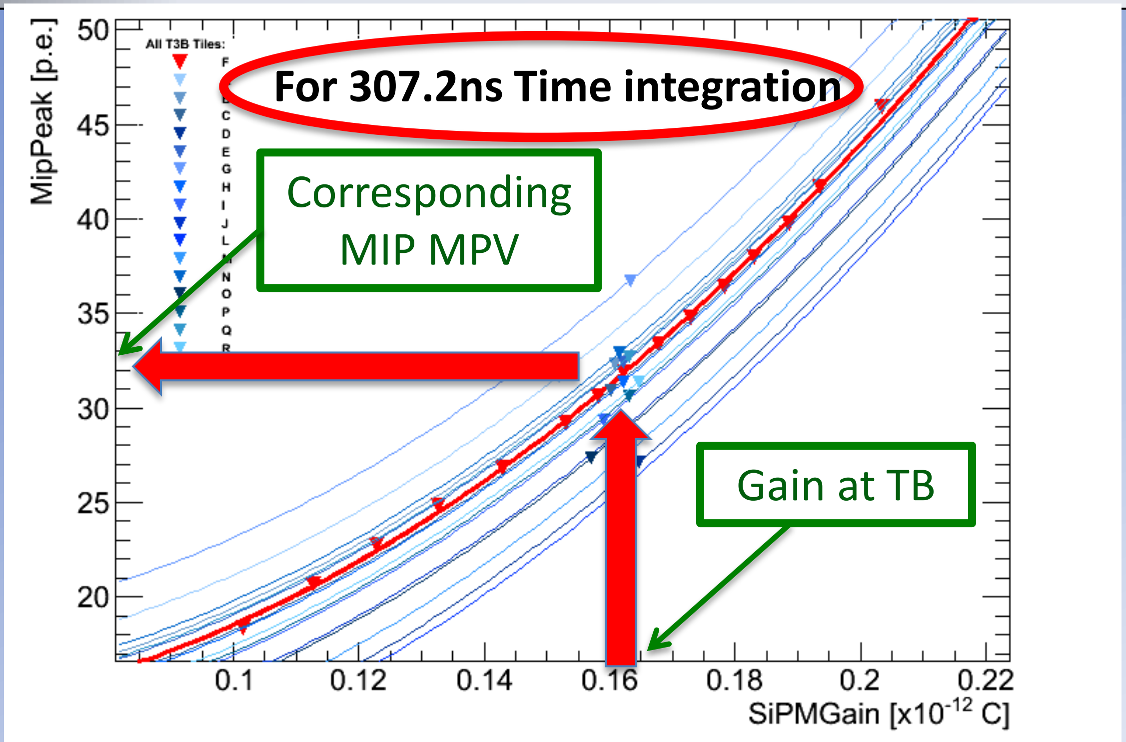

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Select MPV-Gain dependence for distinct time integration window

Obtain corresponding MPV of MIP distrib.

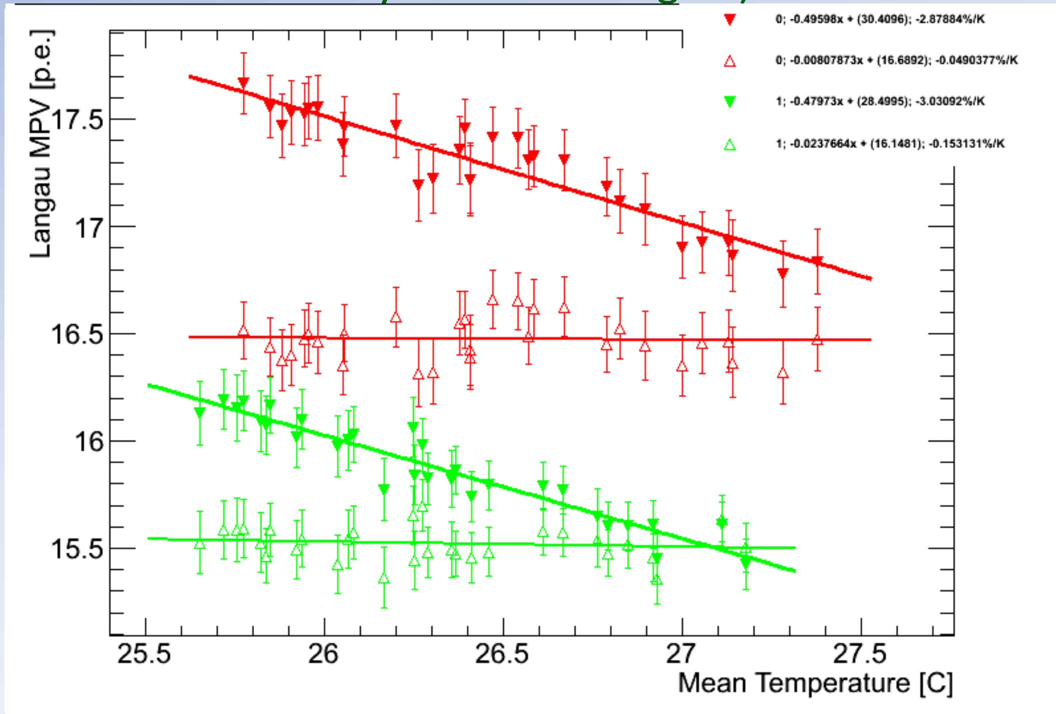
Verification of the Calibration Principle: Muon Data

<u>During the commissioning of the SDHCAL we could take an large amount of muon data:</u>

- 14 mio Muon Events
- 40 hours without interruption
- Day-night-cycle Temperature Range: ~25.5C to 27.5C

→ Enough to extract the Mip MPV-Temperature dependence

→ Then: Apply correction factor from Sr90 Data to eliminate the dependence (remember: We assume the MPV depends in first order only on the SiPM gain)



Verification of the Calibration Principle: Muon Data

Corrected MPV-Temperature dependence

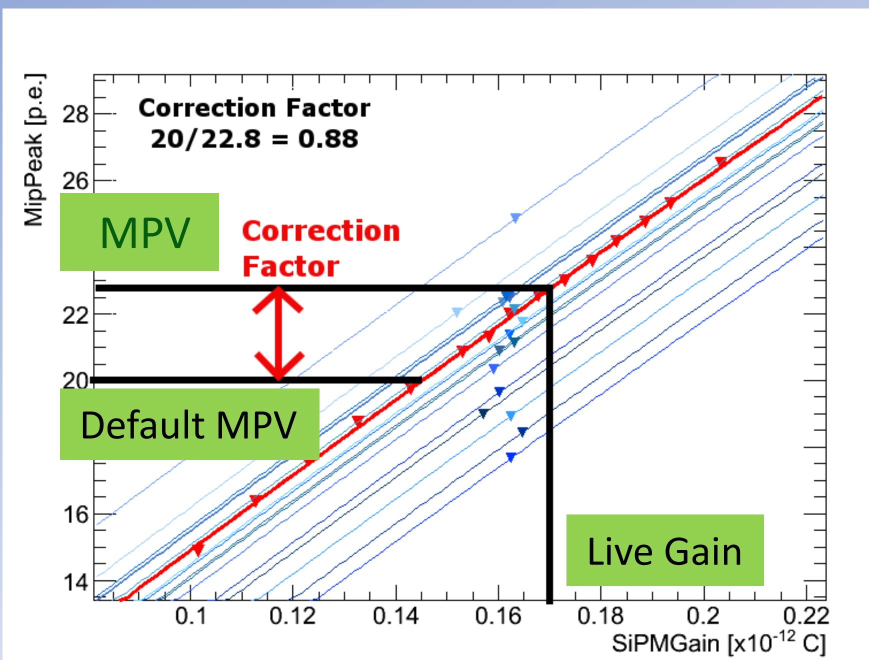
Calibration results in efficient elimination of the dependence

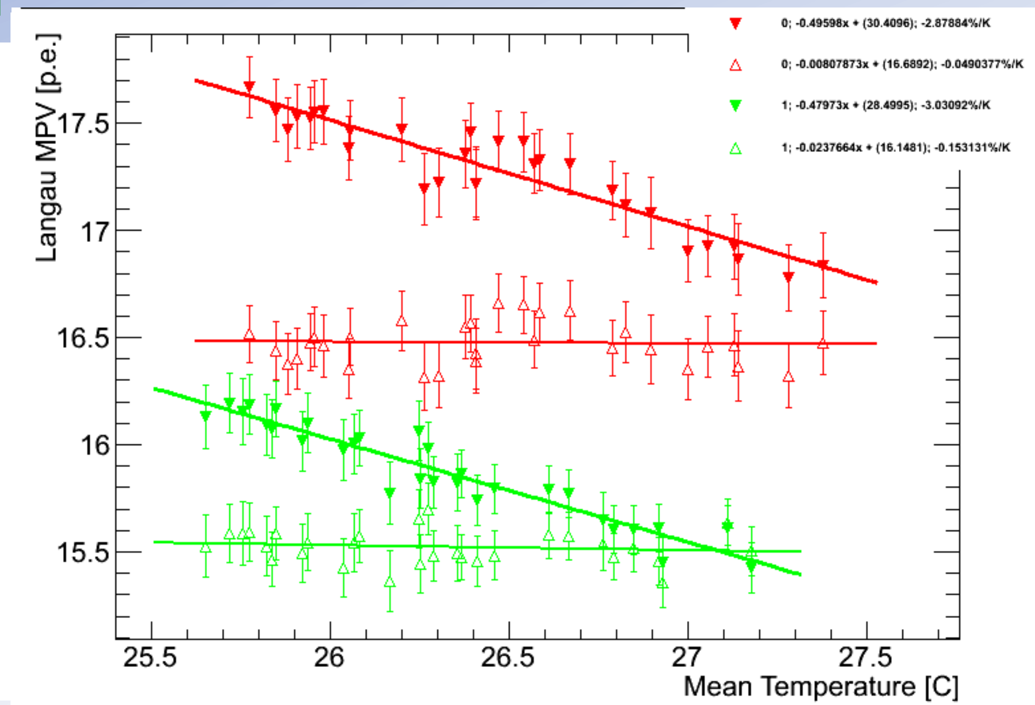
Note (TilePosition 0, analogous for other tiles): Corrected MPV values at ~16.5 p.e., not at the 20 p.e. we corrected to.

Interpretation: 0.82 is the Sr90←→Muon MPV conversion factor

Matches simulations → Experimental proof

T3B Tile	MPV Drop	Slope
Center	-2.9 %/K	-0.5 p.e./K
Center corr.	-0.05 %/K	-0.008 p.e./K





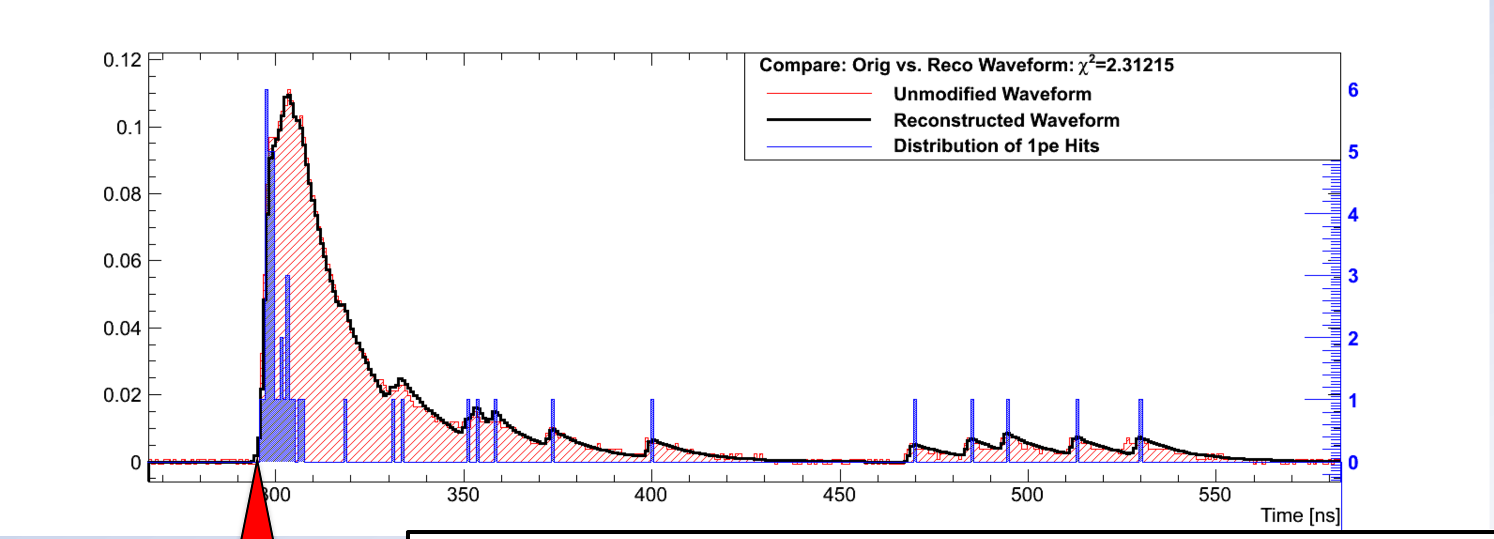
TIME OF FIRST HIT

Time of First Hit

Analysis:

– Consider a hit if > 8 p.e. are deposited within 9.6 ns (basically AP free!)
– Take the time of the second fired SiPM Pixel as the TofH

(reduced bias through thermal darkrate → on average 1 pixel per waveform of 2.4 microsec)



Analysis of the time of first energy deposition within the tiles of the T3B layer for hadronic showers

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Run selection:

- Choose runs @ 60GeV, 80GeV and 180GeV for Tungsten, Steel and Muon data
  - All runs have > 1mio Events (Tu @ 60, 80GeV ~4mio Ev, Steel @ 60, 80GeV ~2mio Ev)
  - All runs for one energy from same testbeam period (no mixing)
  - Quality of all runs checked with CALICE and T3B run log
- Note: T3B after 5 lambda for Tu, but after ~6 lambda for Steel data
- Slightly increased overall bias voltage for Tu compared to Steel data (200mV)

We present work in progress → all plots preliminary

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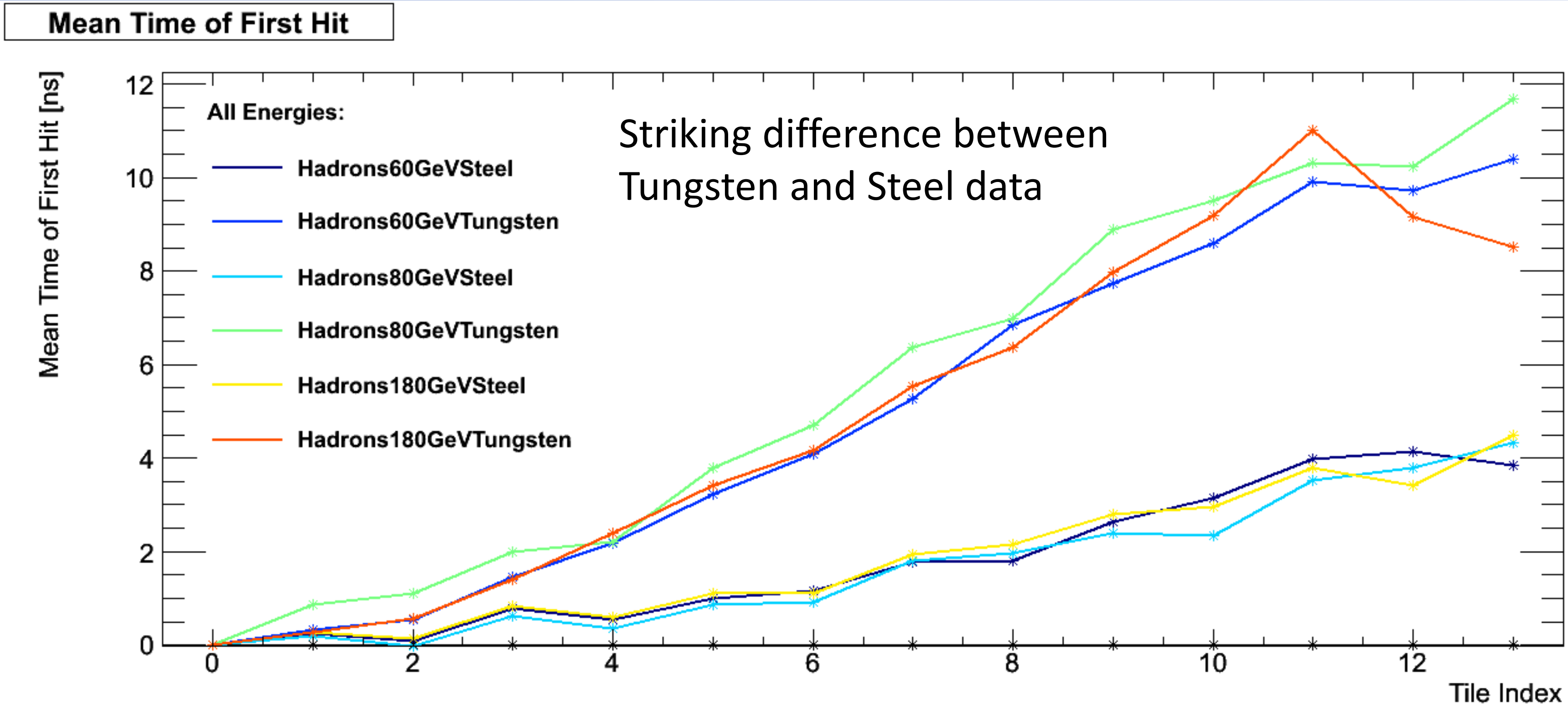

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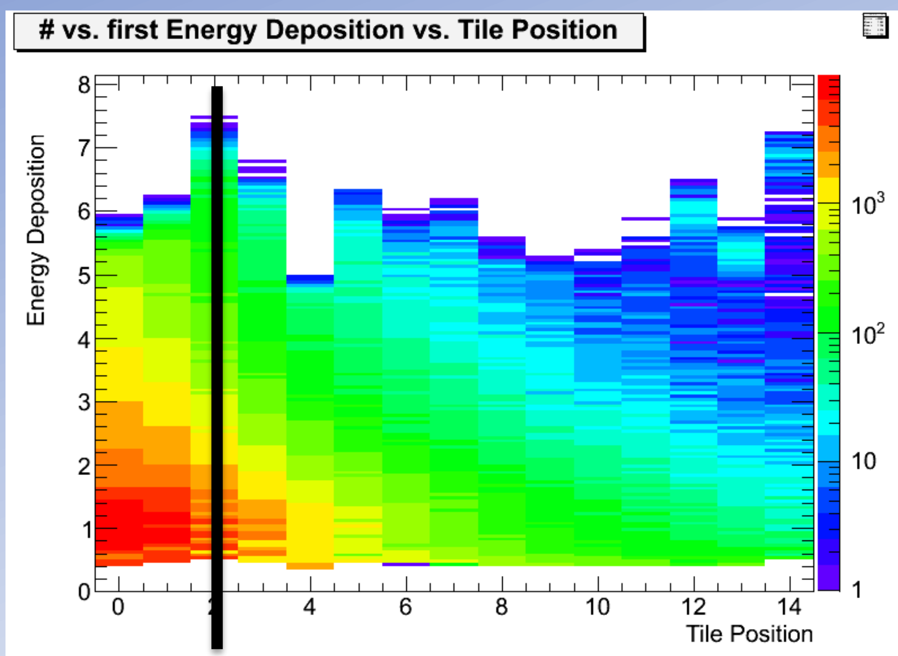
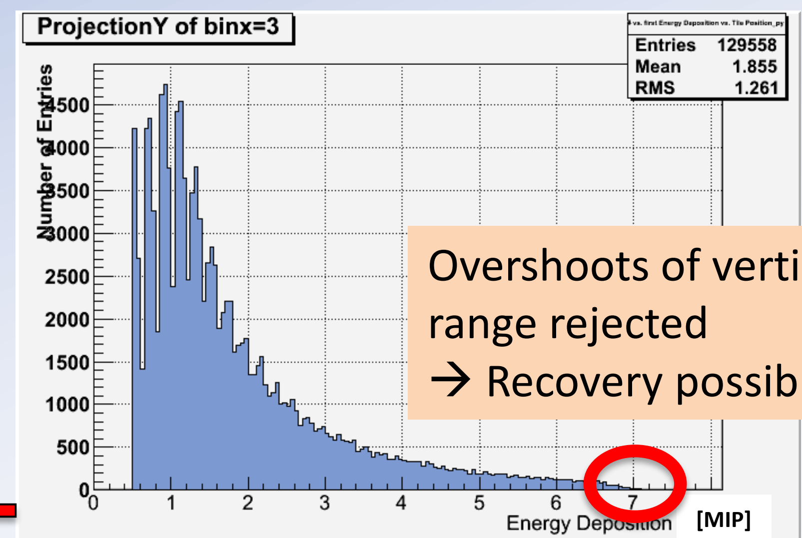
- Sum the number of pixels fired within the identified hit

    → Calibrate to the MIP scale





Overshoots of vertical range rejected
→ Recovery possible?

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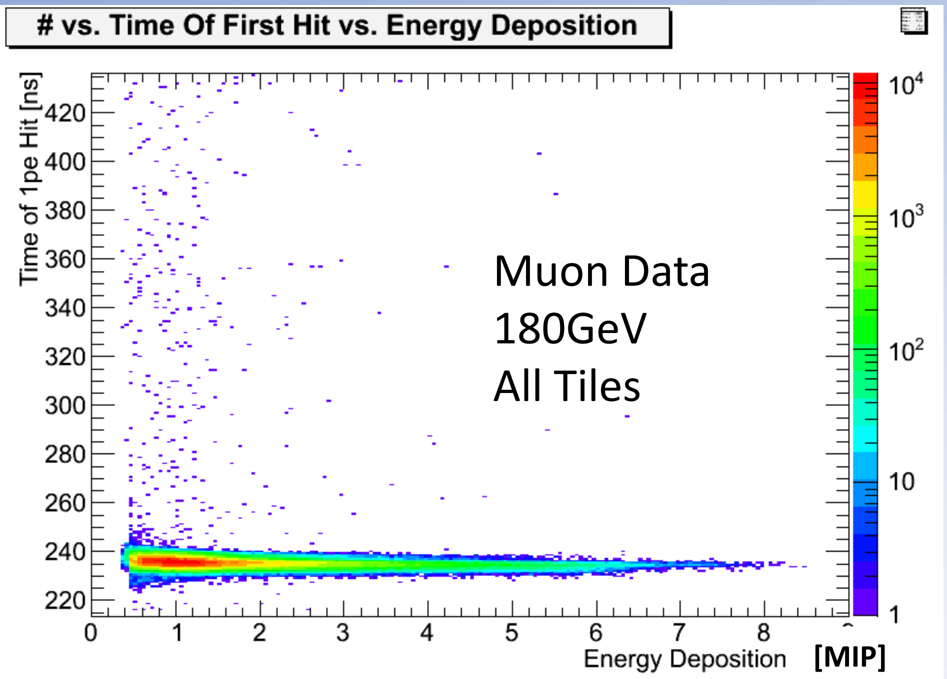


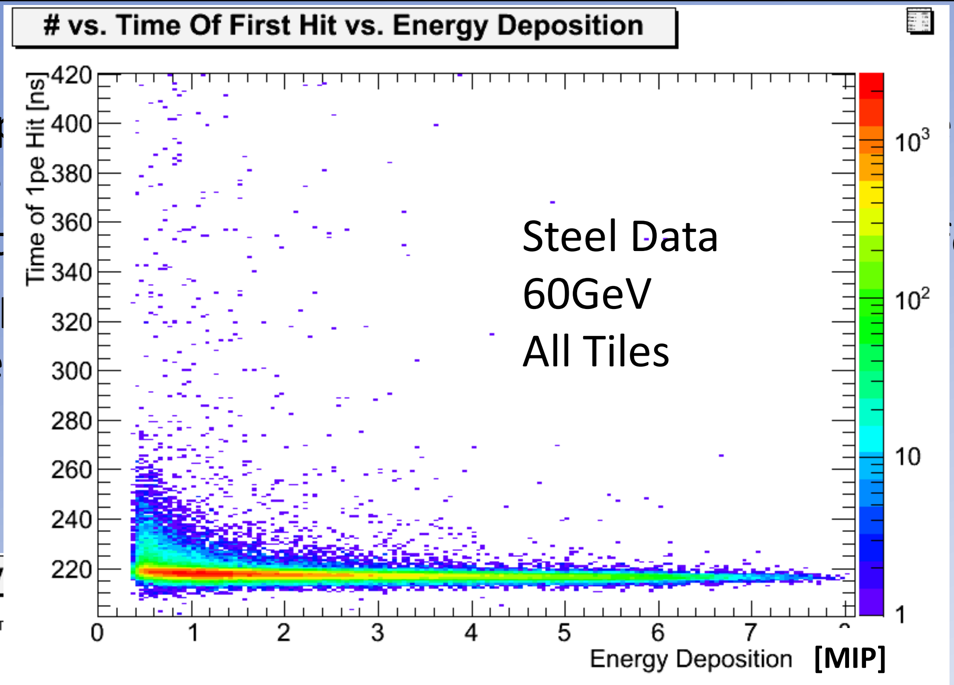
Time of First Hit

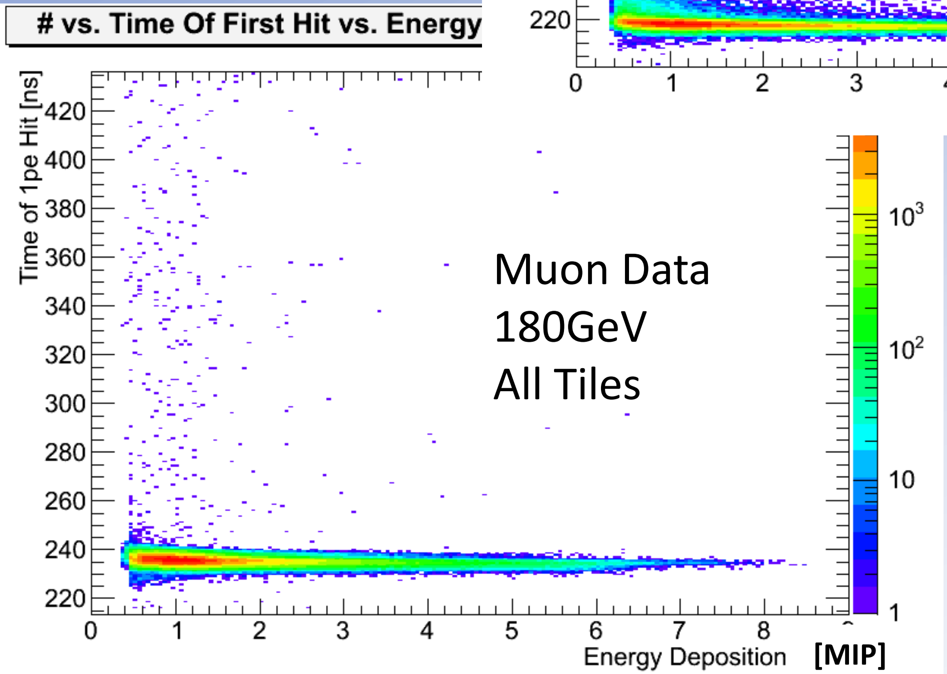
Analysis:

- Consider a hit if > 8 [...] !)
- Take the time of the [...]

(reduced bias through t[...]orm of 2.4 microsec)

- Sum the number of [...]
  → Calibrate to the [...]





Time of First Hit

Analysis:

- Consider a hit if > 8 p … !)
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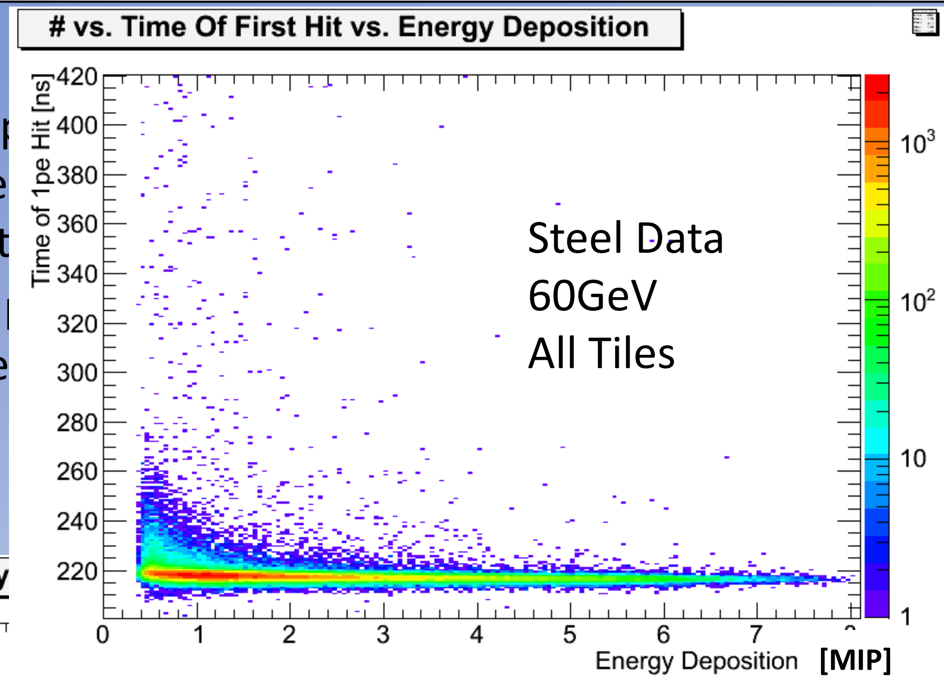
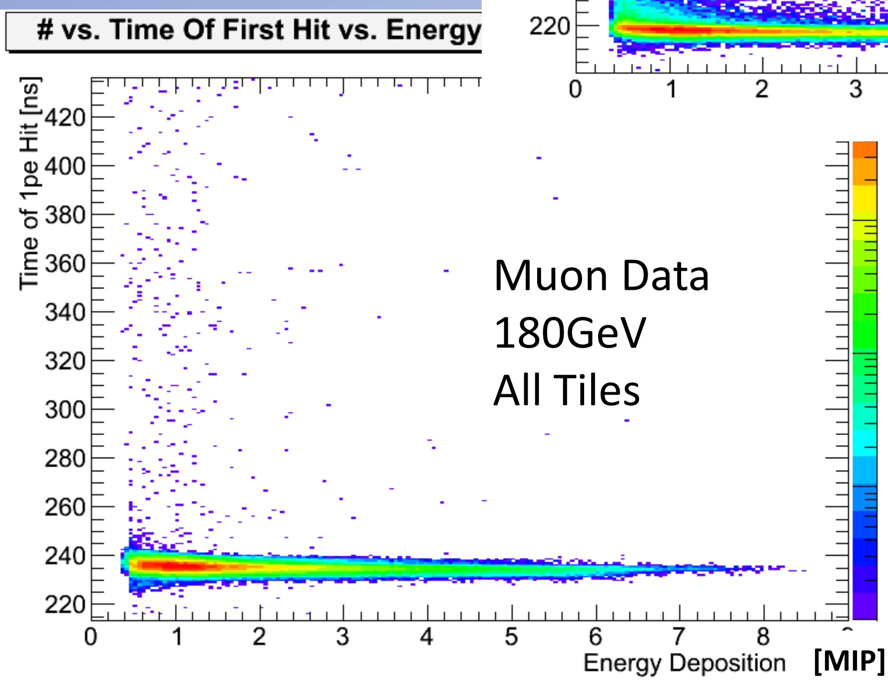
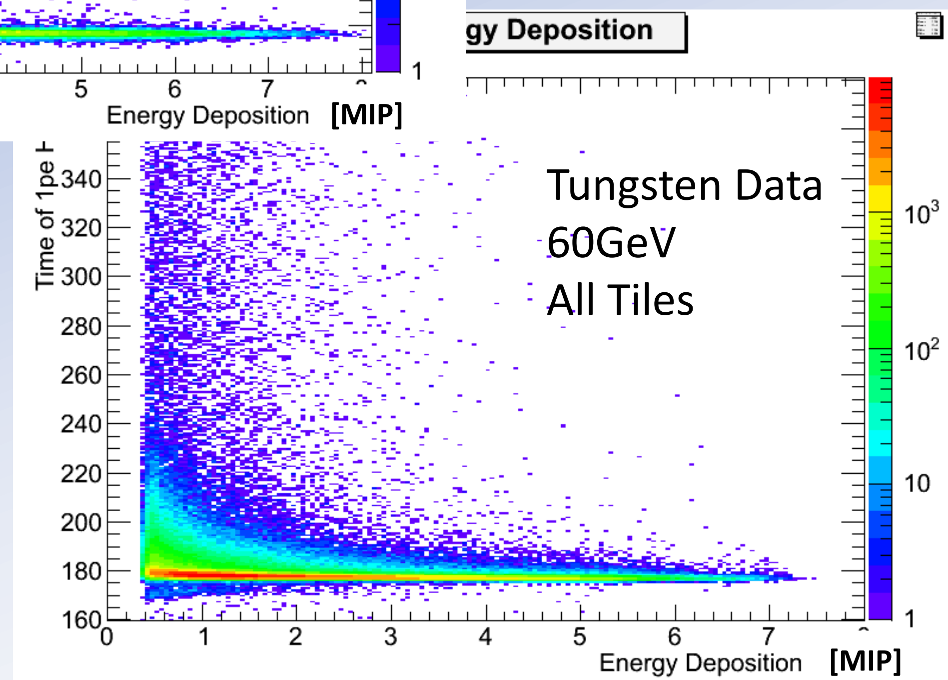
(reduced bias through t … orm of 2.4 microsec)
- Sum the number of p …
  → Calibrate to the …







Time of First Hit

Analy

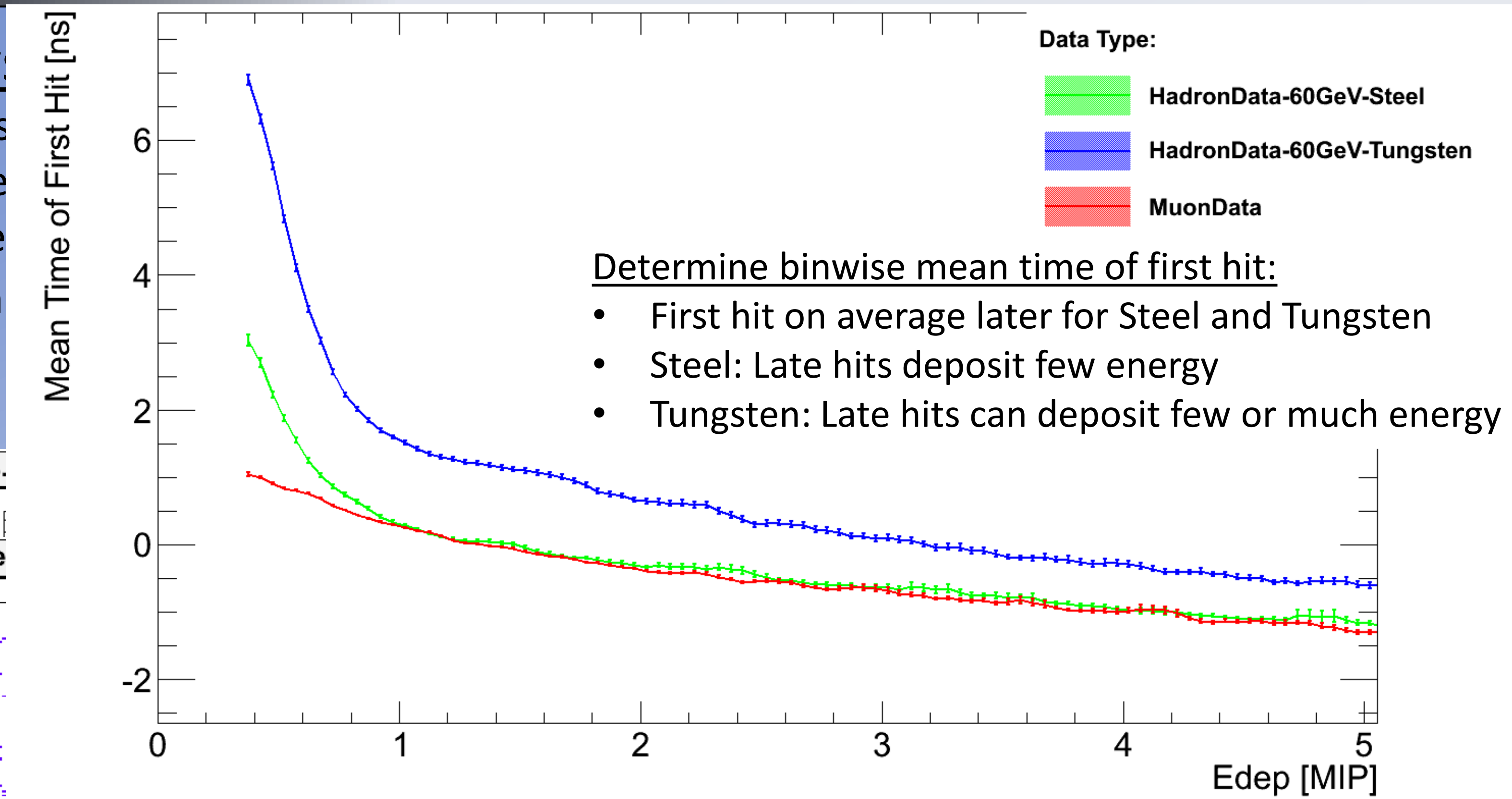
– Cons

– Take

(reduce … sec)

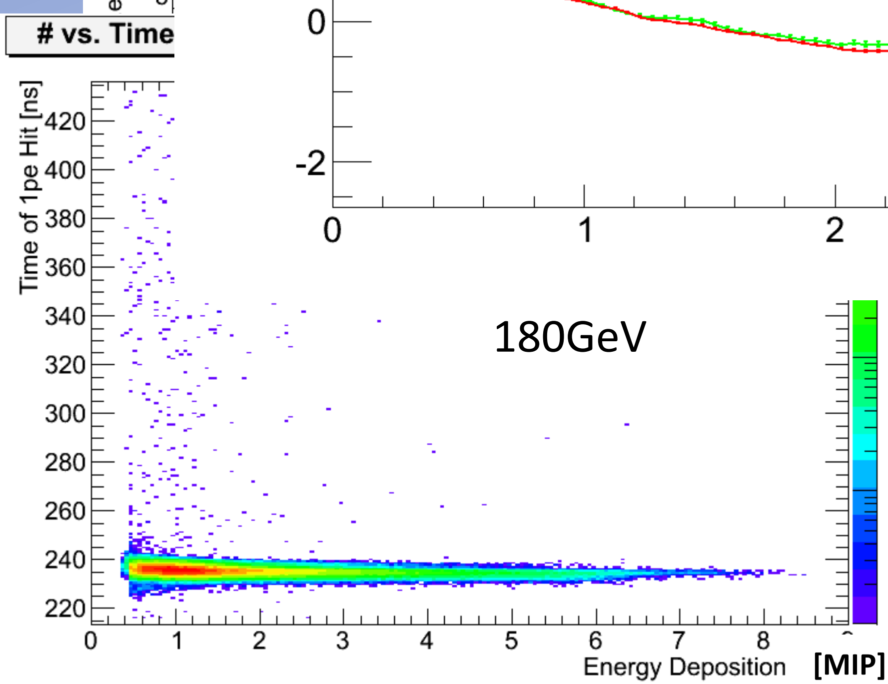
– Sum

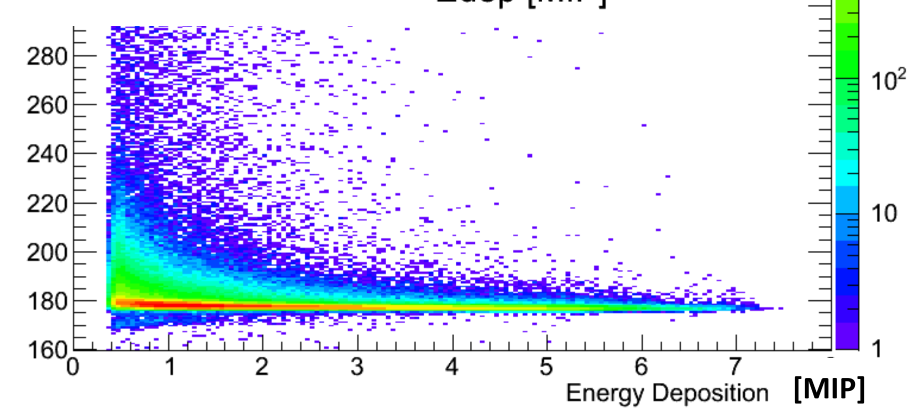
→



Determine binwise mean time of first hit:

- First hit on average later for Steel and Tungsten
- Steel: Late hits deposit few energy
- Tungsten: Late hits can deposit few or much energy





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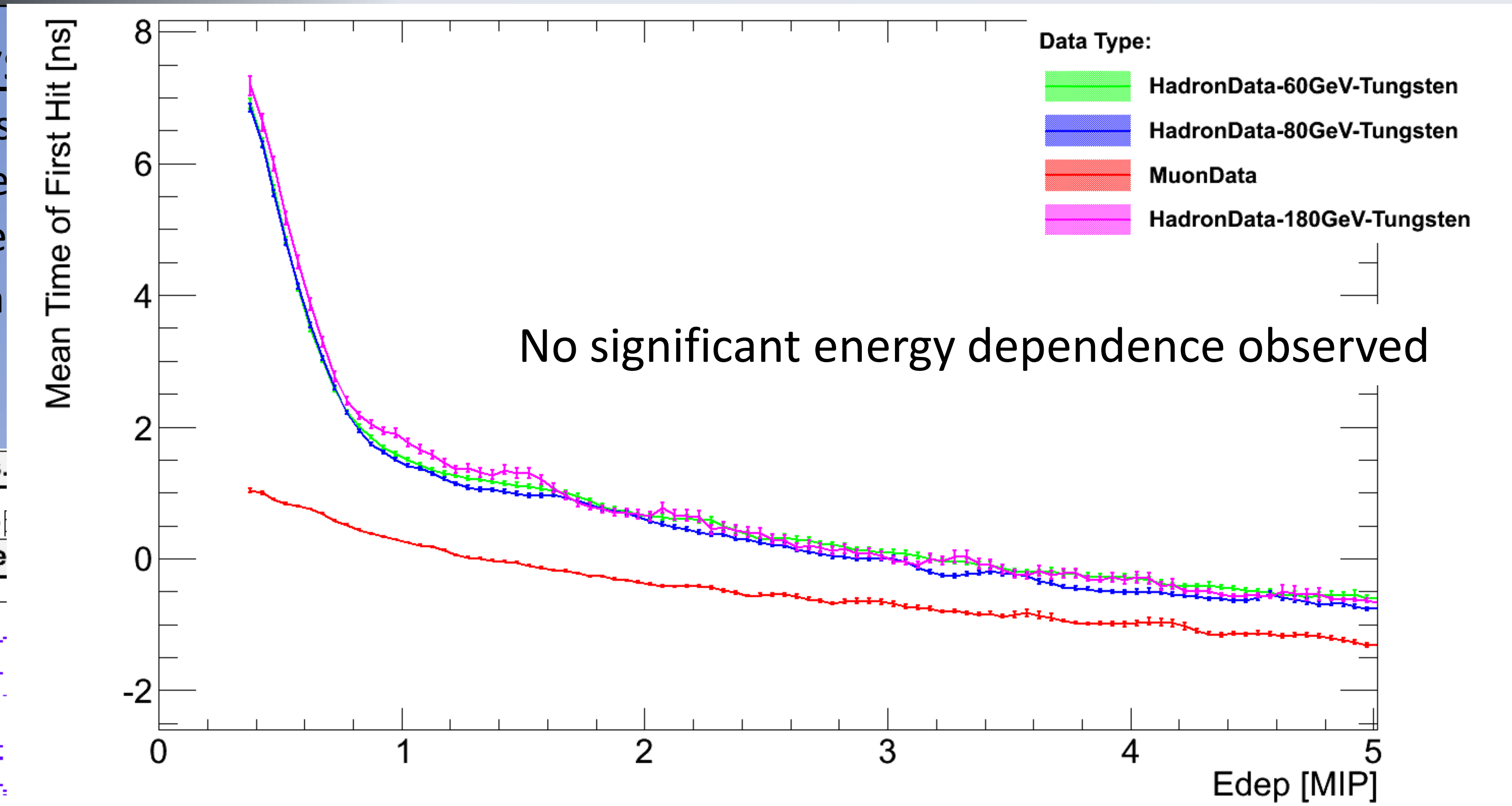

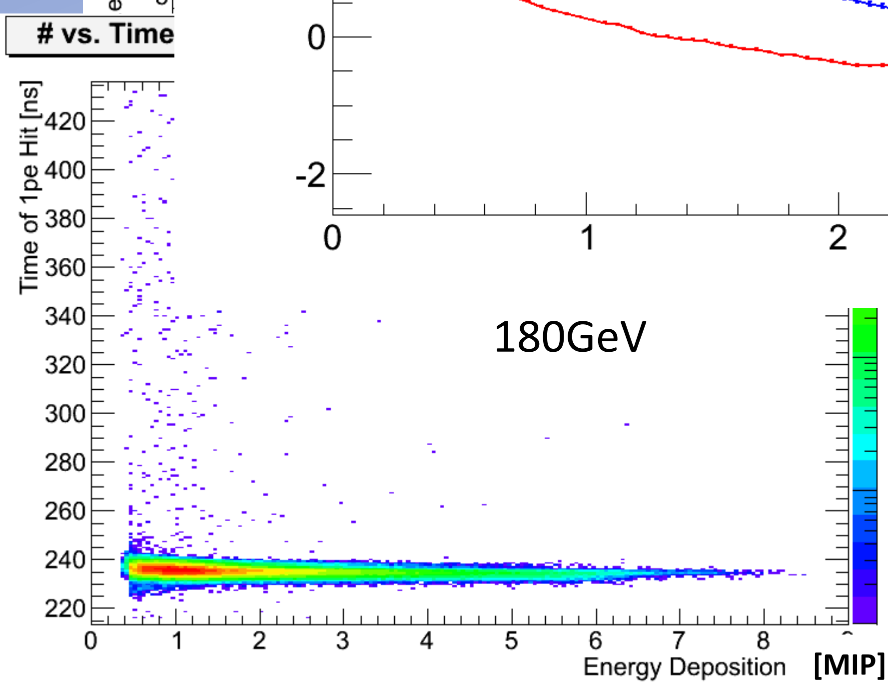

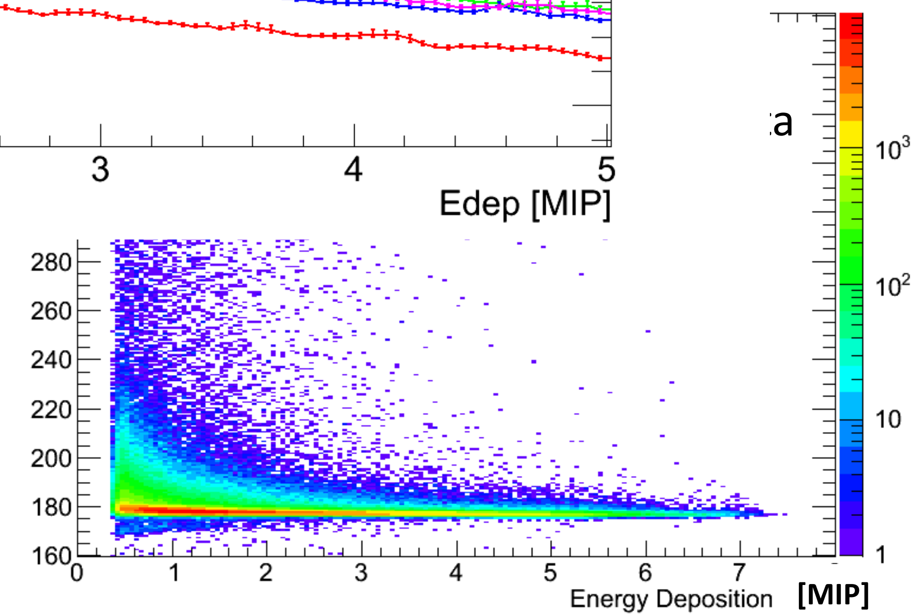

AFTERPULSING ANALYSIS

Afterpulsing Analysis

Dedicated Afterpulsing Runs:

- Taken in May 2011 with all 15 T3B tiles → No SPS beam available at that time
- Record only SiPM Darkrate → higher pixel counts due to crosstalk (higher counts less likely)
- Threshold scan: 5 runs with 400k Events @ 0.5, 1.5, 2.5, 3.5 and 4.5 p.e. threshold
  + 1 random trigger run (for pedestal substraction)

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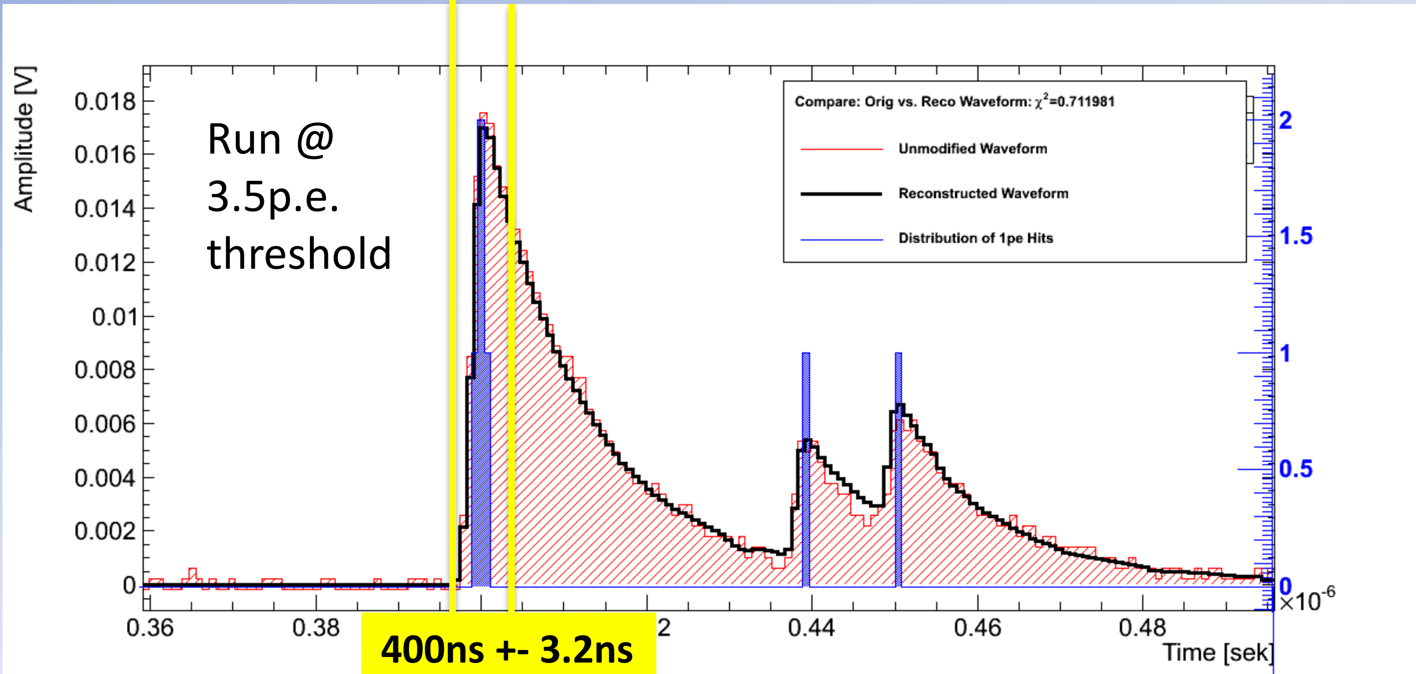
- Threshold scan: 5 runs with 400k Events @ 0.5, 1.5, 2.5, 3.5 and 4.5 p.e. threshold
  + 1 random trigger run (for pedestal substraction)

- Criterion to accept waveform for analysis:

  Demand exactly N p.e. within the acceptance range of +-3.2ns around the trigger time for the N p.e. threshold run.

  e.g.: Run with threshold at 3.5 p.e. → demand exactly 4 p.e. within 400ns +- 3.2ns

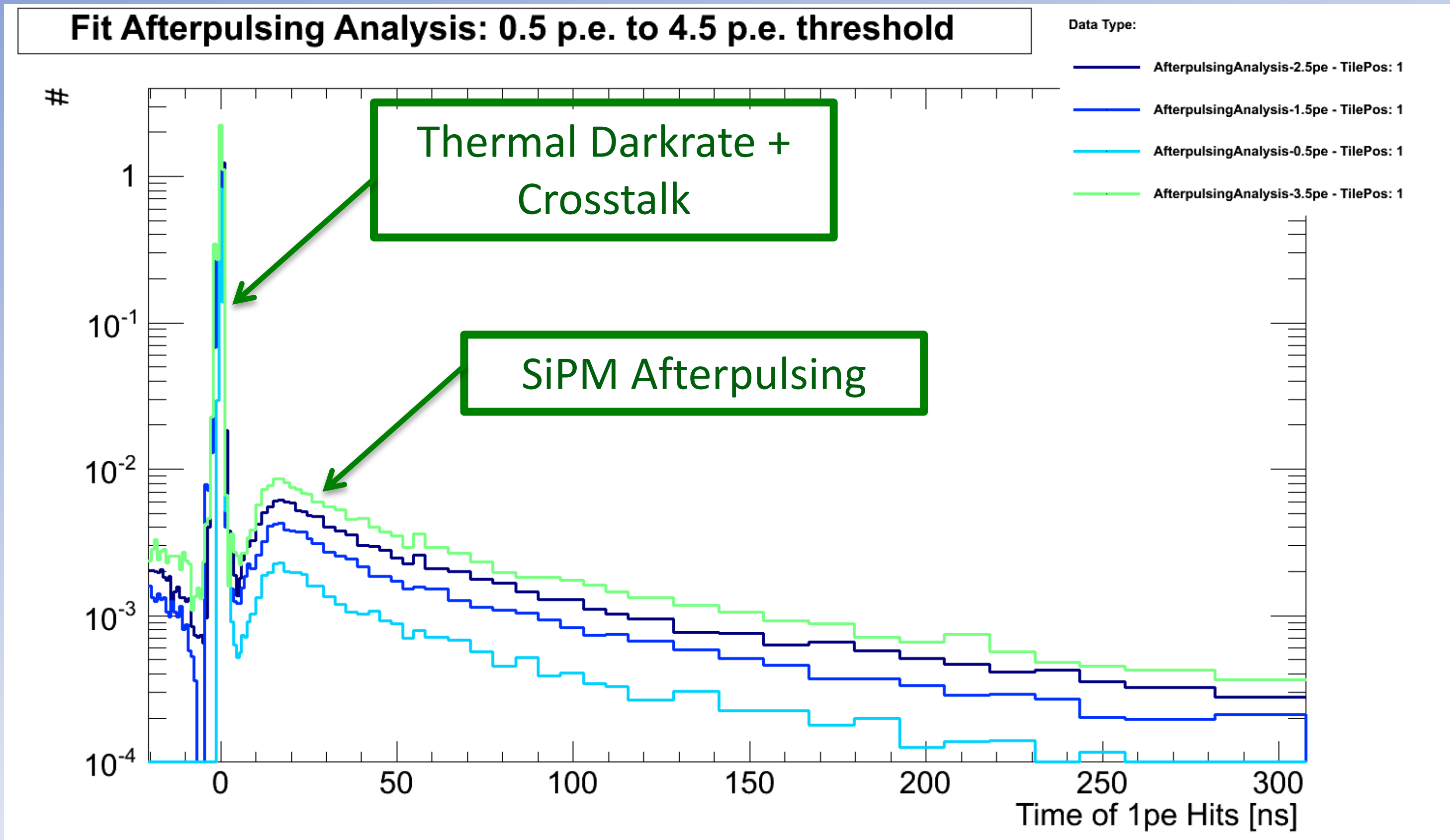


Afterpulsing Analysis

Procedure to extract the average SiPM afterpulsing per fired pixel:

Fill the time of each firing pixel into one histogram for all selected waveforms

→ Normalize to the number of selected waveforms



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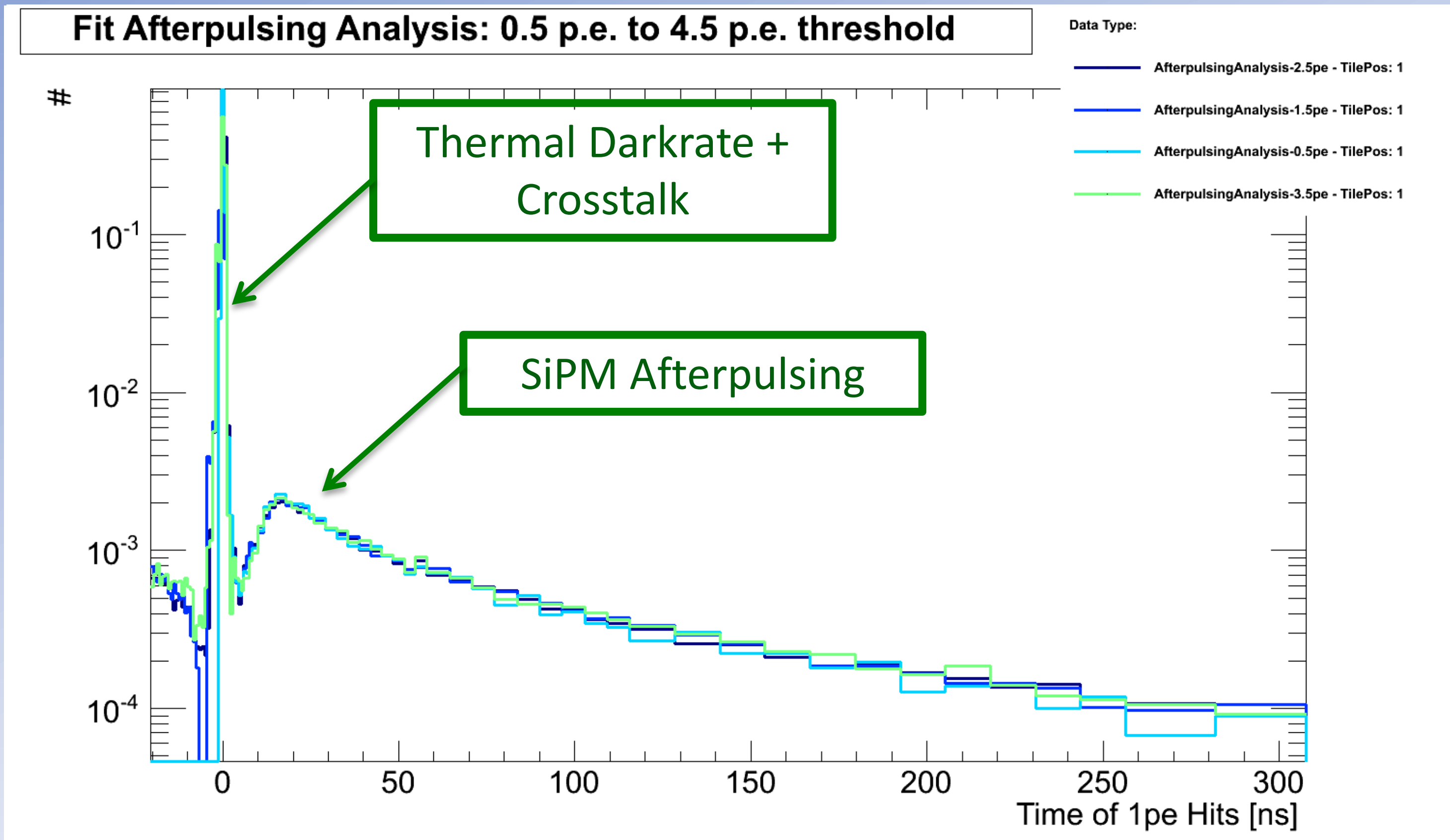
→ AP distribution independent of the number of fired pixels → scale



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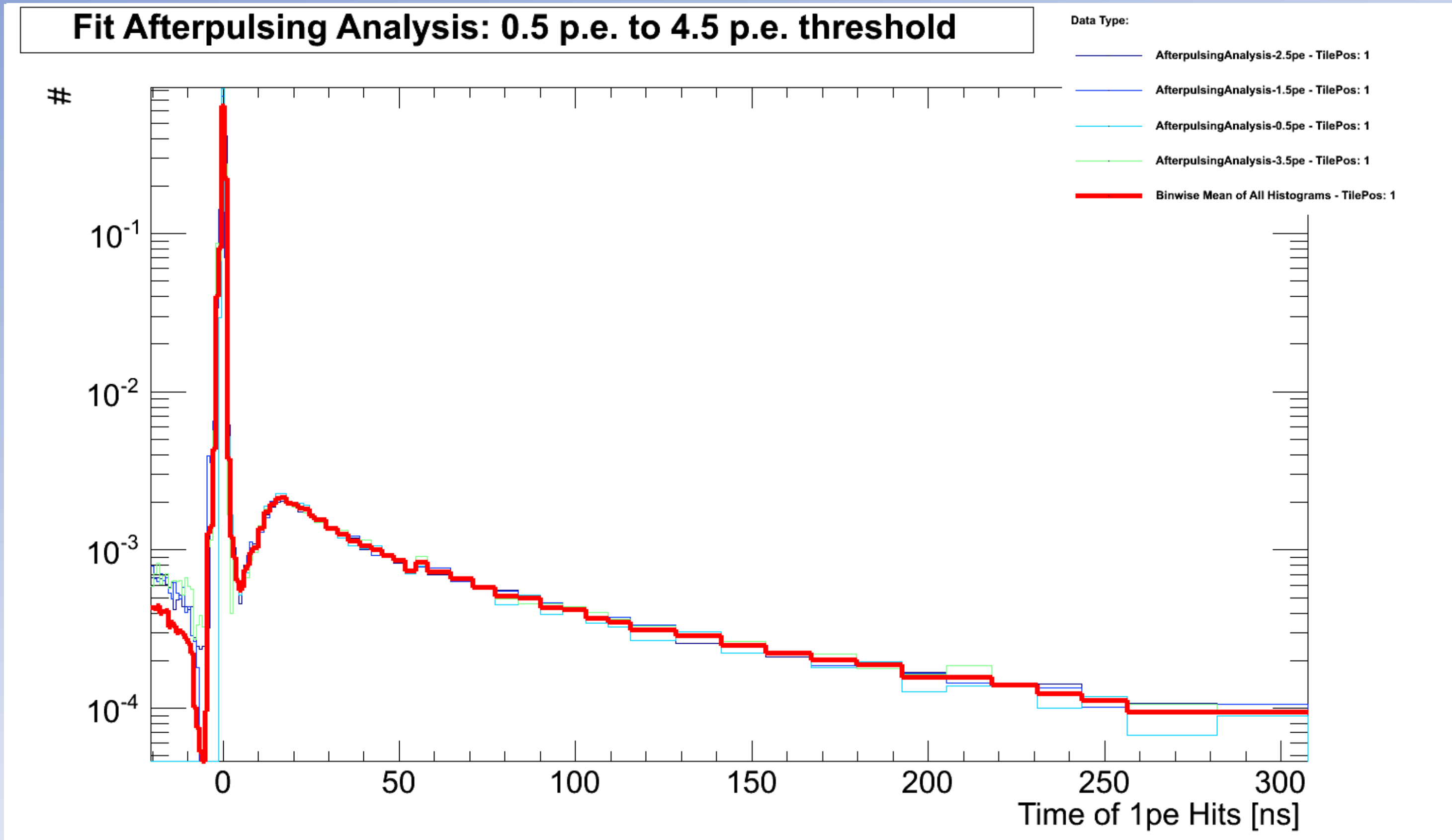
→ Increase the statistics by averaging binwise

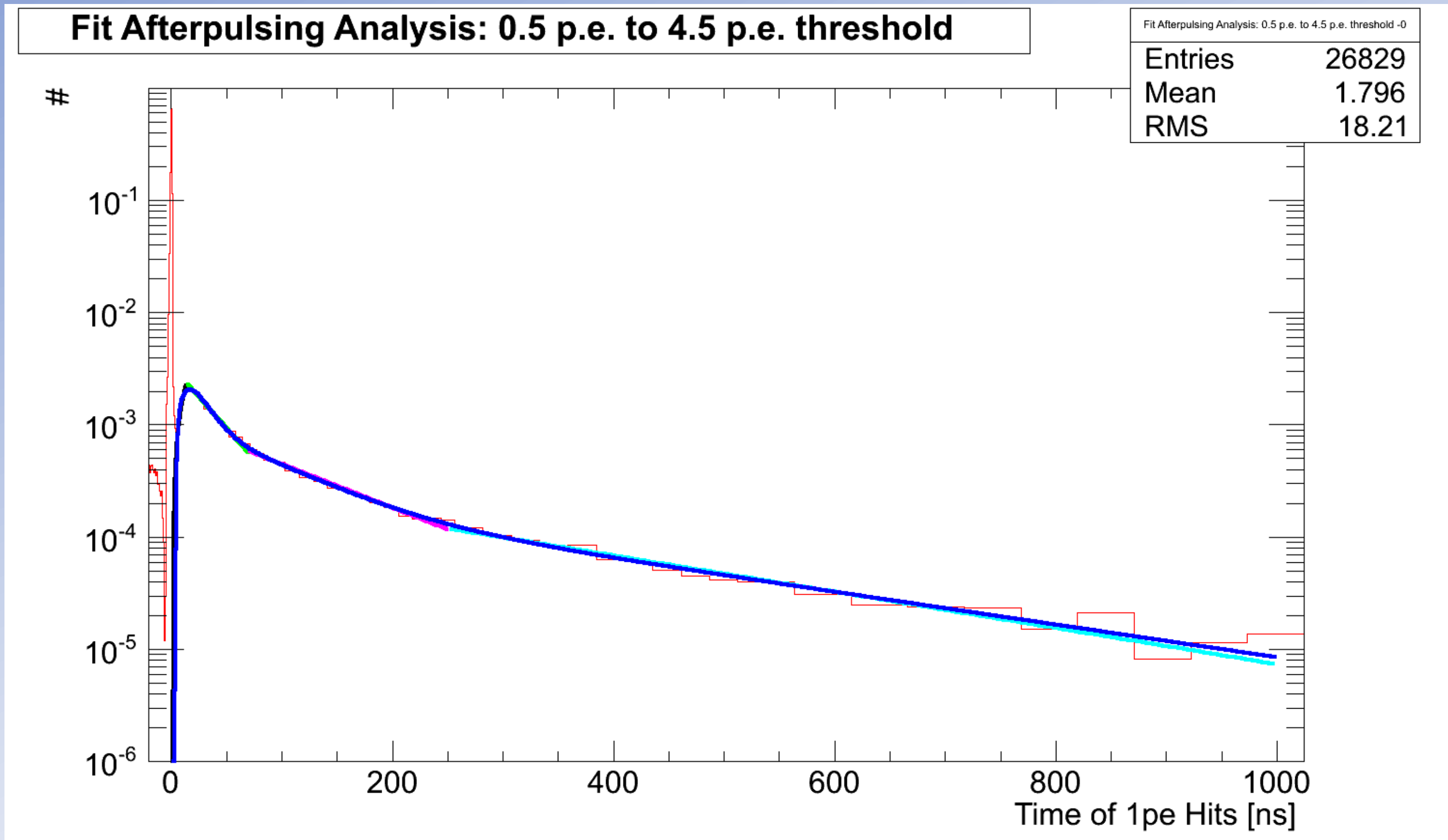


Afterpulsing Analysis

Procedure to extract the average SiPM afterpulsing per fired pixel:

AP distribution is best fit by function:

$$f(t)_{AP} = \left(1 - e^{-\frac{(t-t_0)}{\tau_{rec}}}\right) \bullet \left(a \cdot e^{-\frac{t}{\tau_1}} + b \cdot e^{-\frac{t}{\tau_2}} + c \cdot e^{-\frac{t}{\tau_3}}\right)$$



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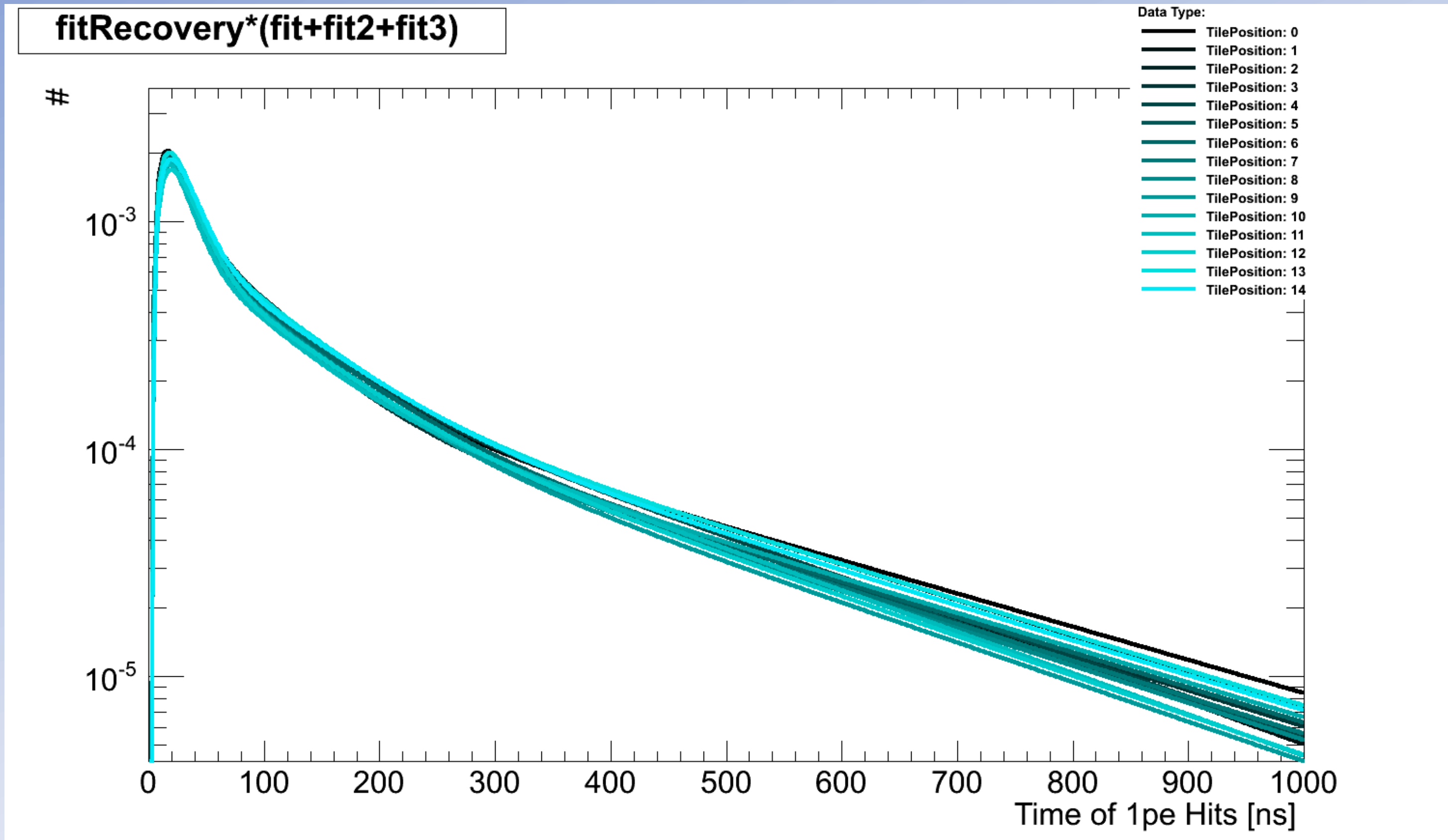
→ Obtain a stable fit to the AP distribution for all T3B tiles → use as template to correct for AP



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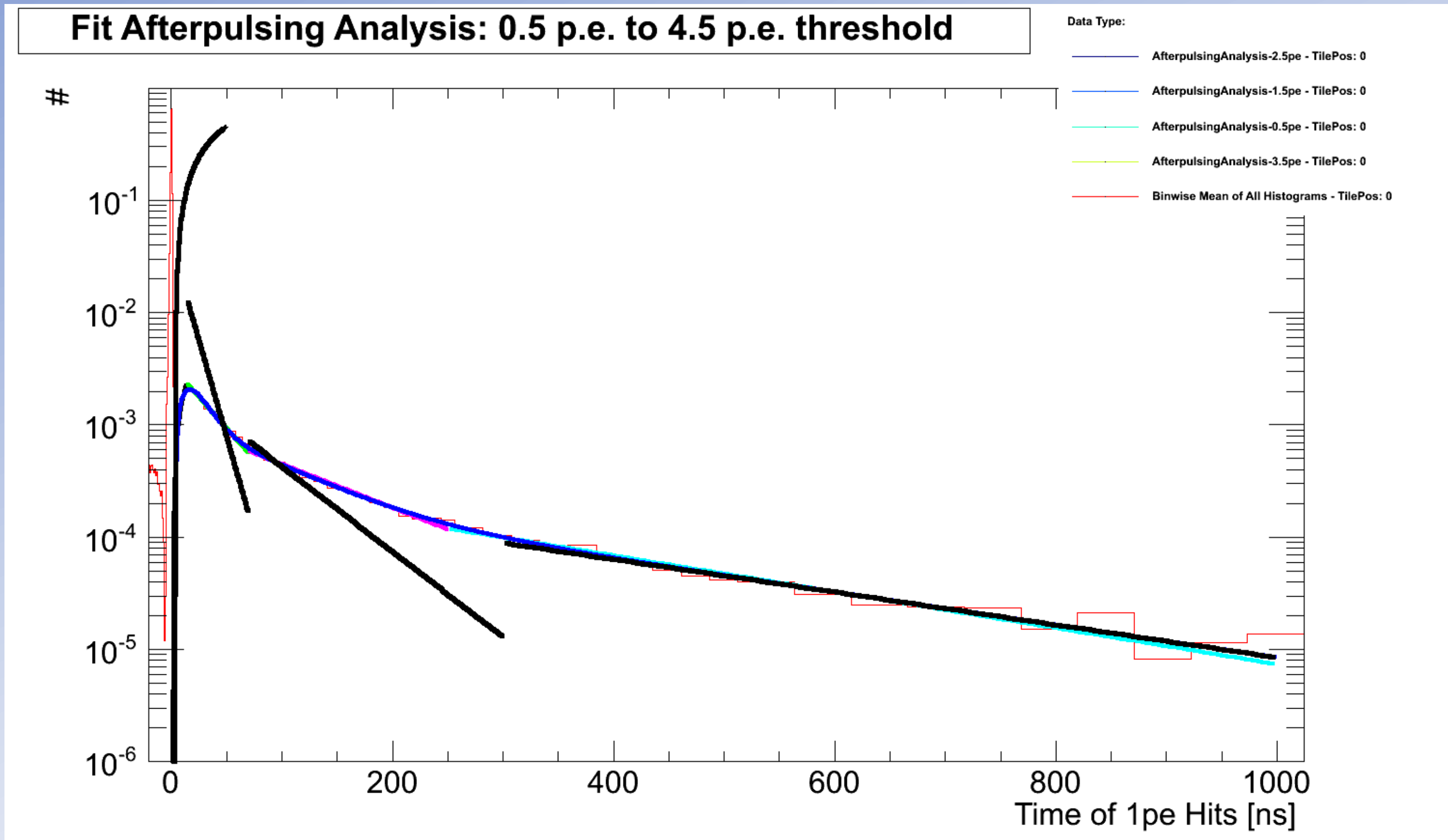
→ Obtain a stable fit to the AP distribution for all T3B tiles → use as template to correct for AP



Afterpulsing Analysis

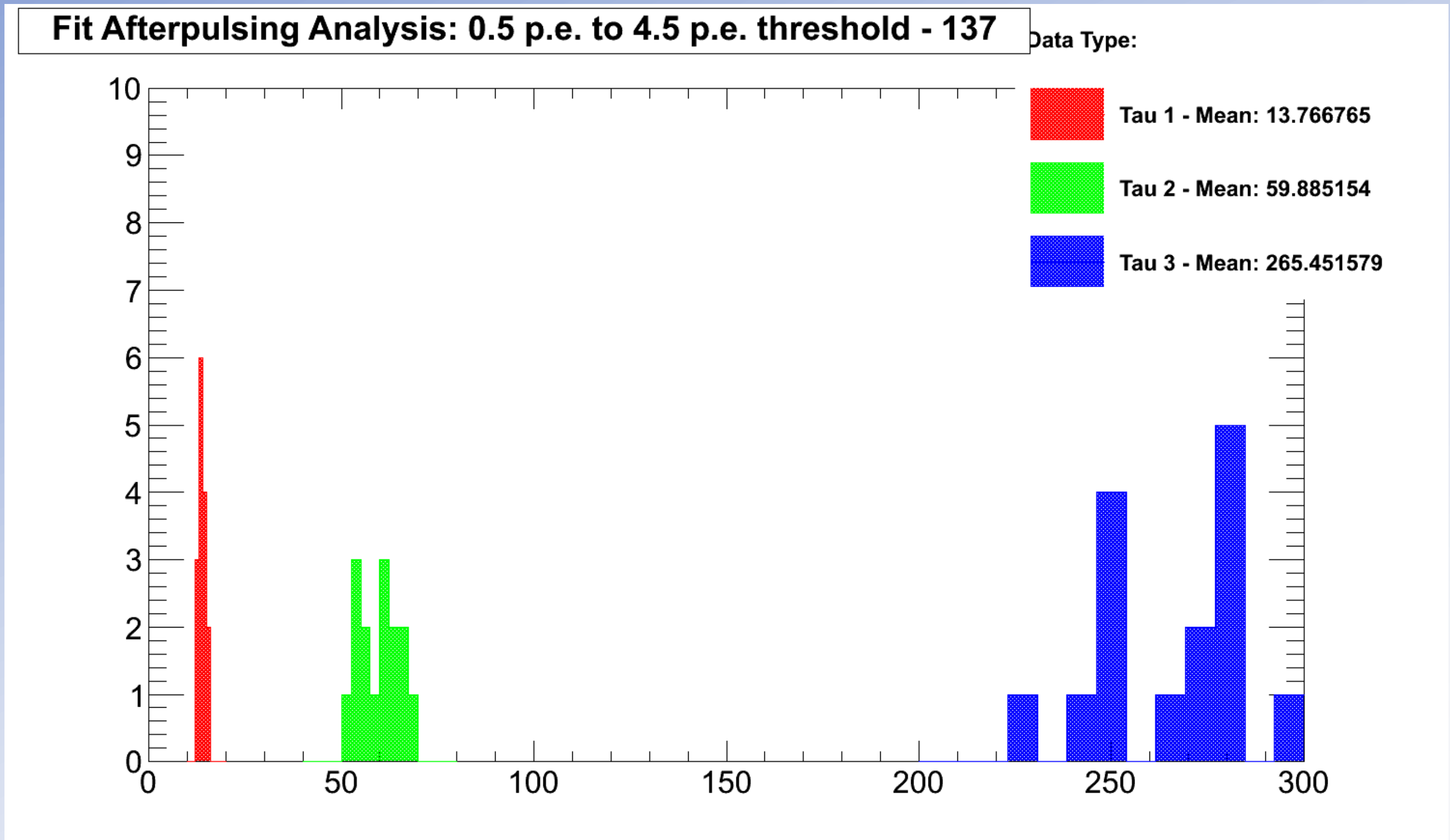
Procedure to extract the average SiPM afterpulsing per fired pixel:

AP distribution is best fit by function:

$$f(t)_{AP} = (1 - e^{-\frac{(t-t_0)}{\tau_{rec}}}) \bullet (a \cdot e^{-\frac{t}{\tau_1}} + b \cdot e^{-\frac{t}{\tau_2}} + c \cdot e^{-\frac{t}{\tau_3}})$$

→ Obtain a stable fit to the AP distribution for all T3B tiles → use as template to correct for AP

→ Attempt to extract the time constants of the AP distribution



TIME OF HIT ANALYSIS

Time of Hit Analysis

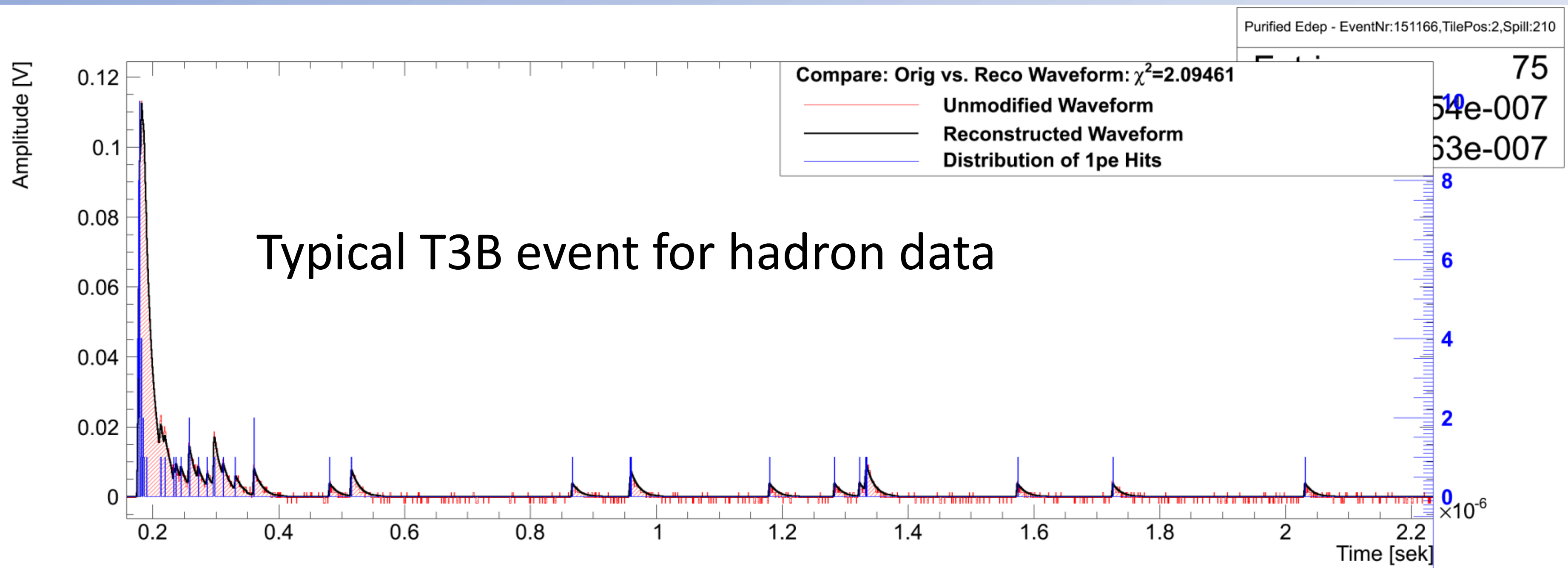
Analysis Criteria:

- Events Rejected for analysis:
  - Overshoots of vertical range of T3B Oscilloscopes (400mV)
  - Events without or with multiple particles (scintillator coincidence signal)
  - Events with < 15 p.e. in the whole acquisition window of 2.4 microseconds

Time of Hit Analysis

Analysis Steps (All plots for Hadron Data, 60GeV, Tungsten, 4mio Events):

- Fill the time of every single fired pixel into one timing histogram (per E and tile)



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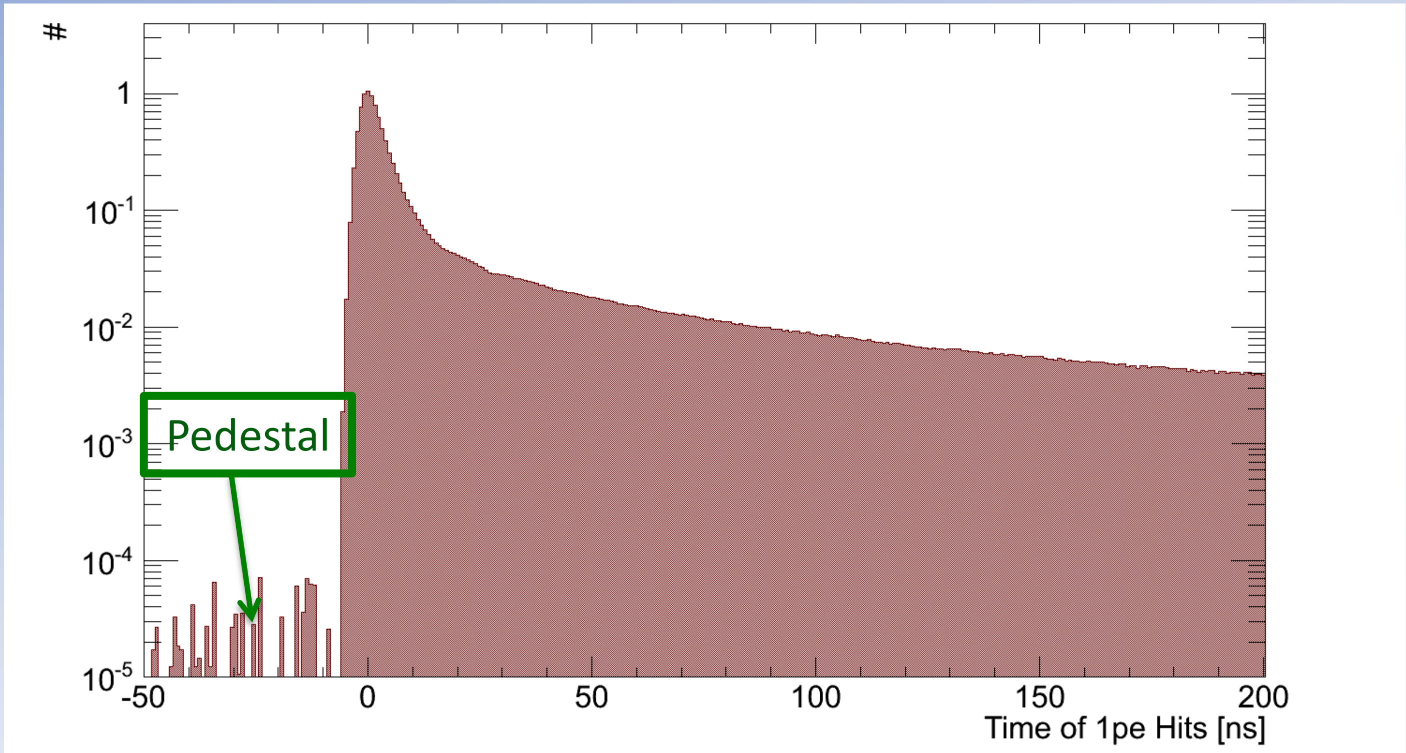

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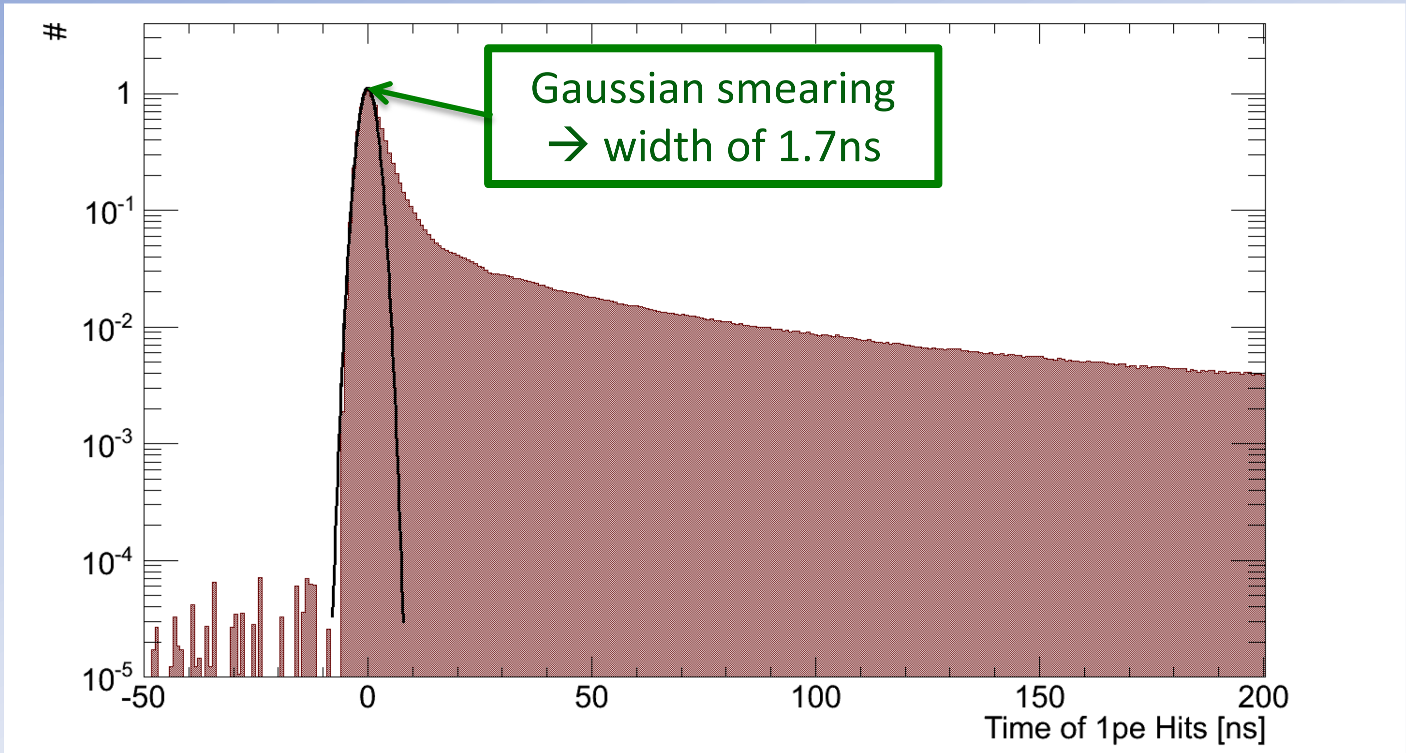

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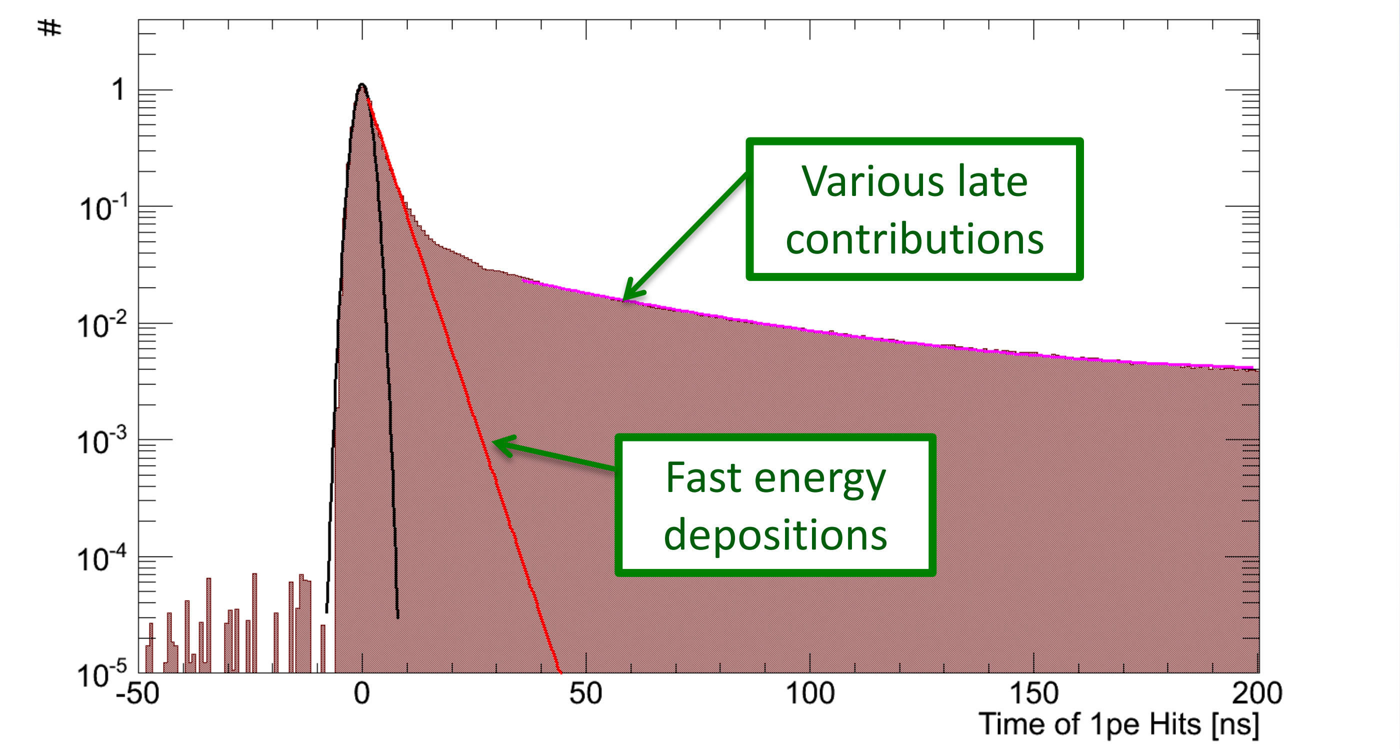

Time of Hit Analysis

Analysis Steps (All plots for Hadron Data, 60GeV, Tungsten, 4mio Events):

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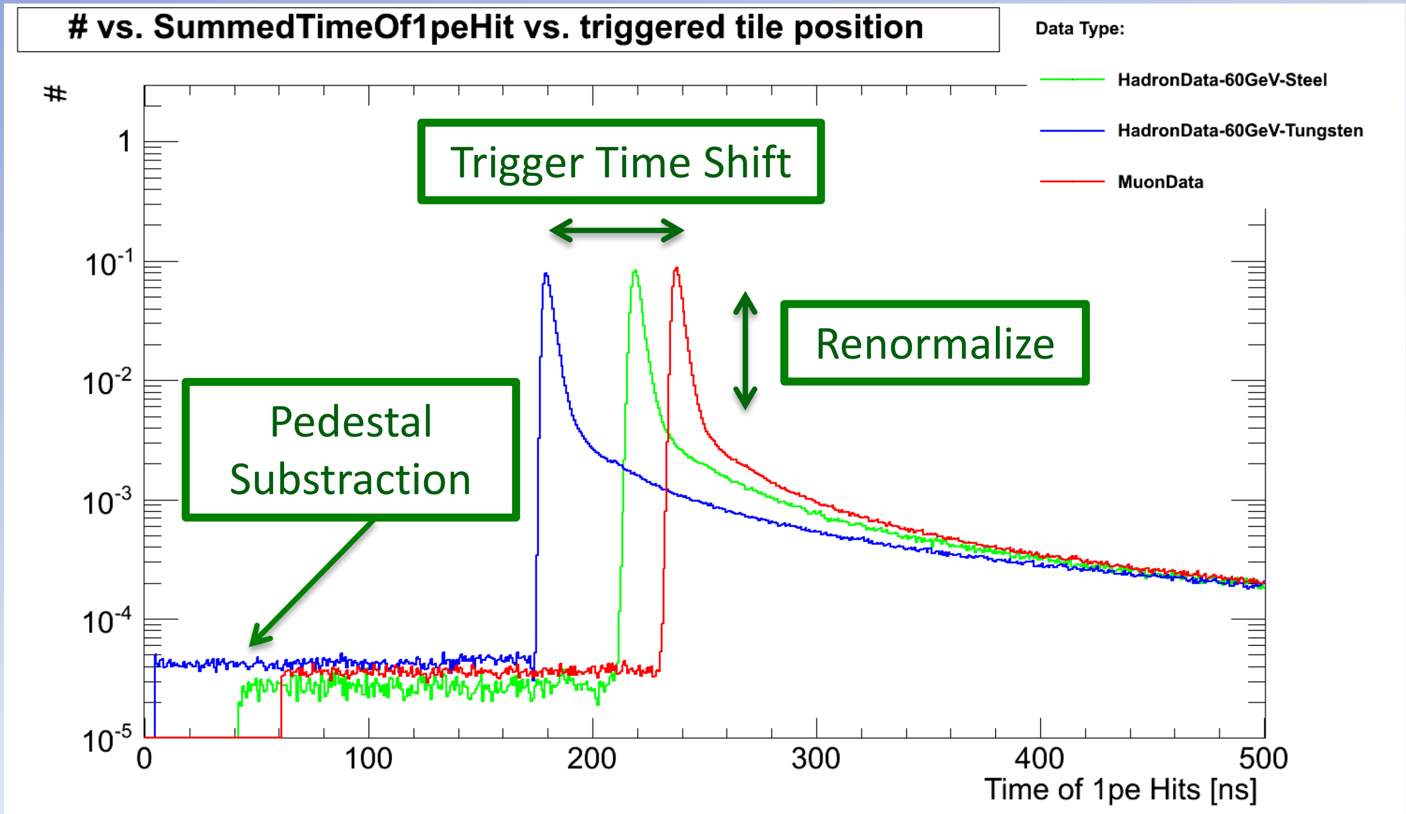

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- Fill the time of every single fired pixel into one timing histogram (per E and tile)
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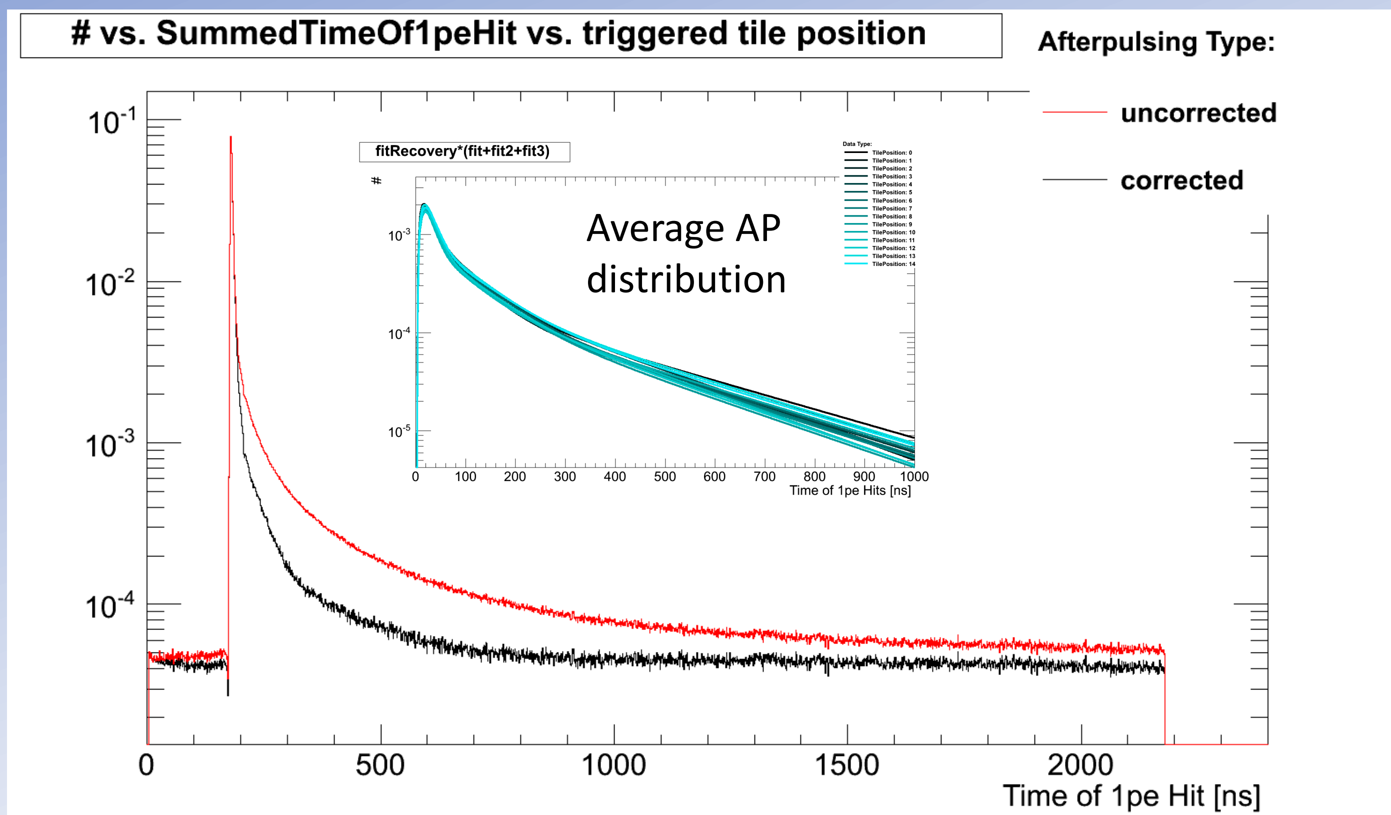
- Correct Afterpulsing → substract tile corresp. AP distribution for every fired pixel



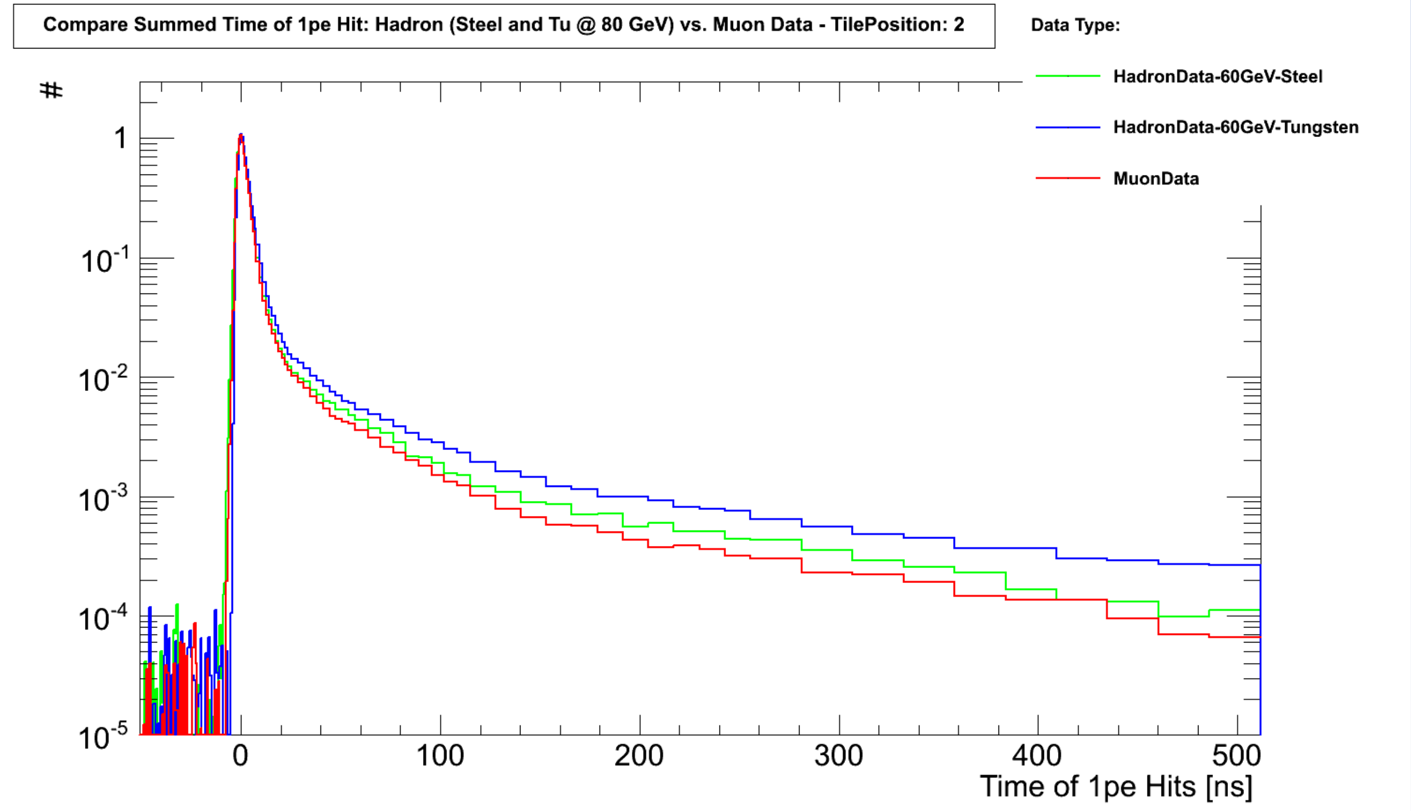
Time of Hit Analysis

Analysis Steps (All plots for Hadron Data, 60GeV, Tungsten, 4mio Events):

Muon Data does not drop to zero after AP correction:
- Additional long time components: Mirror Foil, long time constant of scintillator?
- AP behavour must be adjusted to current SiPM gain (T, V(bias))

→ Contributions should be in Hadron AND Muon data identially

→ Comparison possible



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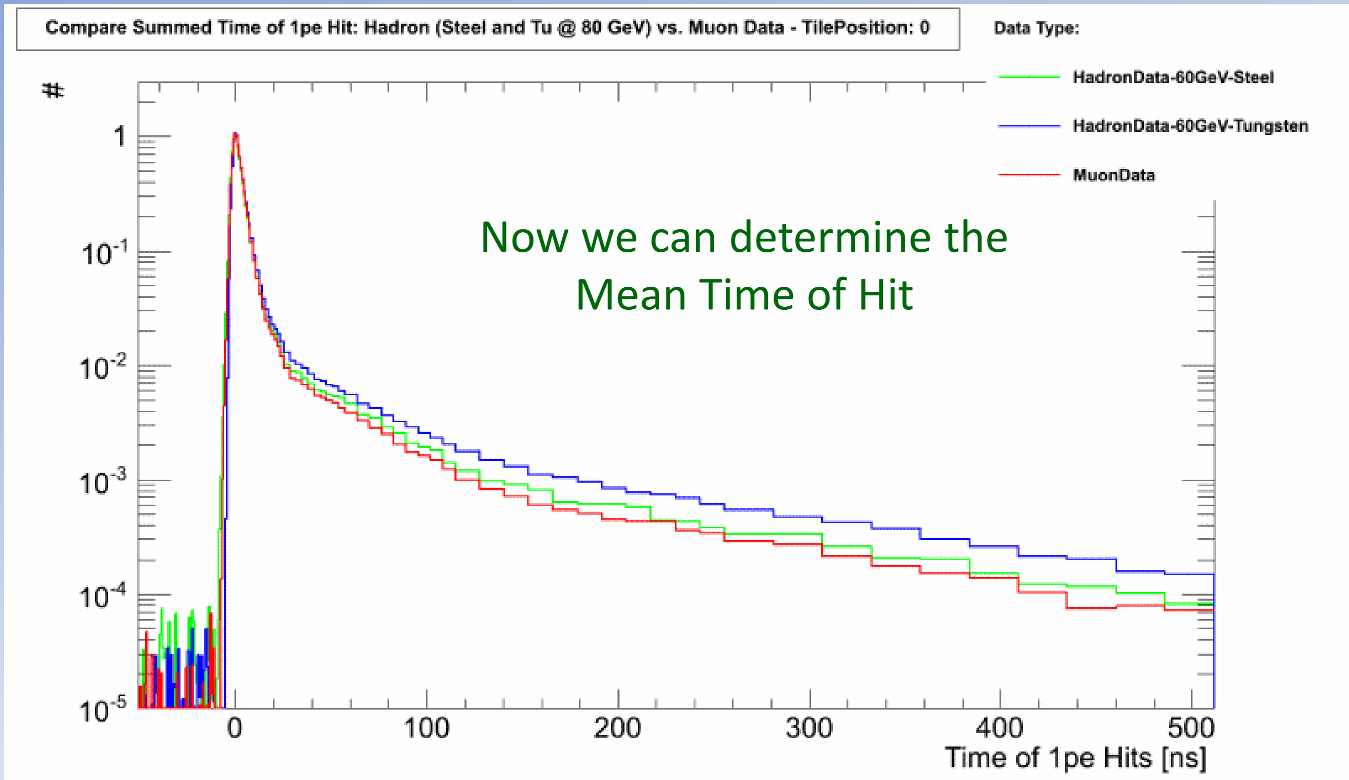

http://www.mpp.mpg.de/~soldner/Shinshu2012/SummedTimeOf1pe.gif

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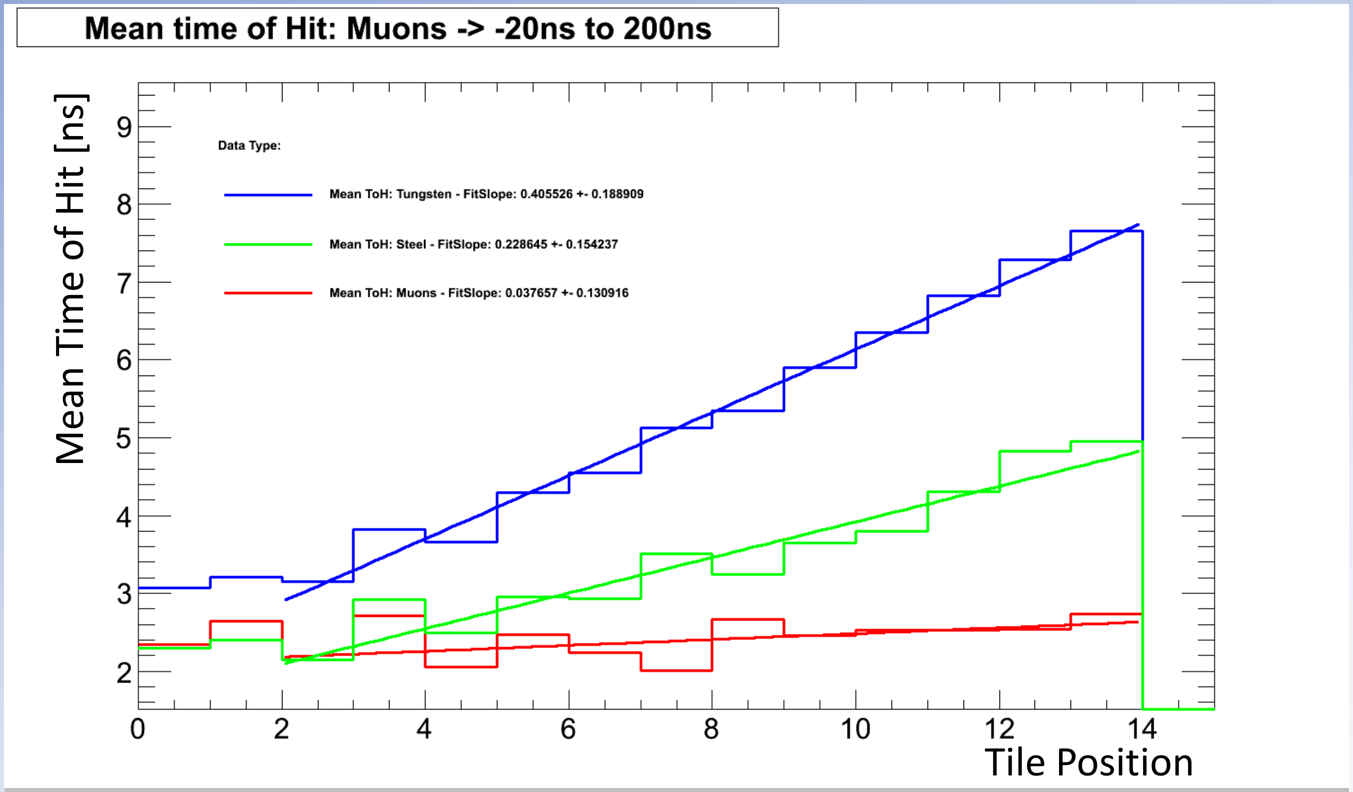

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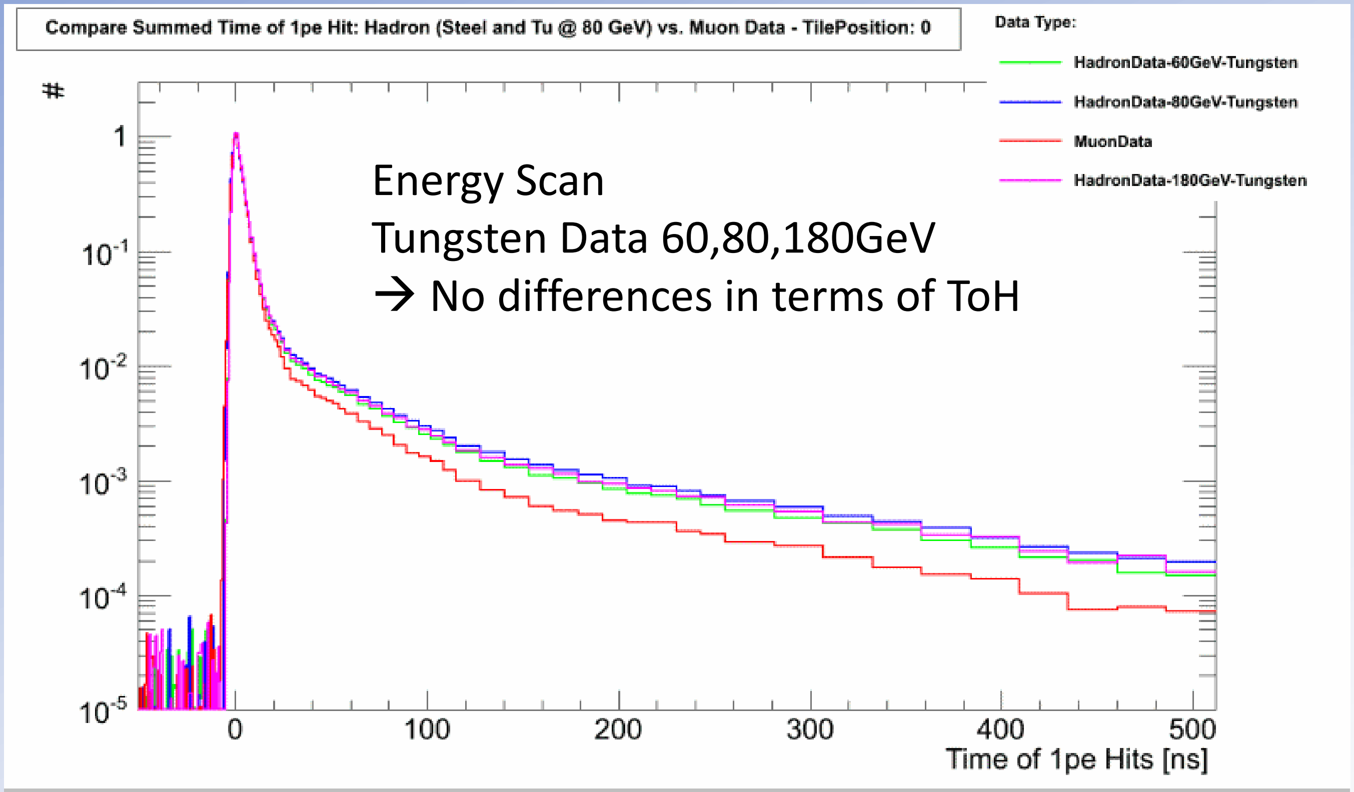
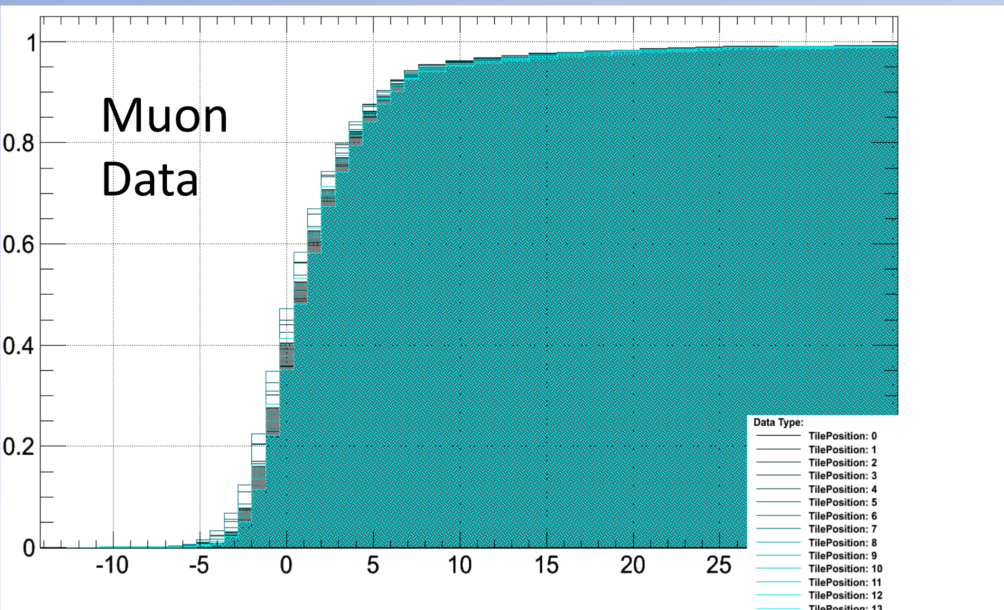


http://www.mpp.mpg.de/~soldner/Shinshu2012/SummedTimeOf1pe-EnergyScan.gif

Time of Hit Analysis

Analysis Steps (All plots for Hadron Data, 60GeV, Tungsten, 4mio Events):

- Which fraction of the total Energy is deposited at which time?
  - Tilewise
  - T3B Overall



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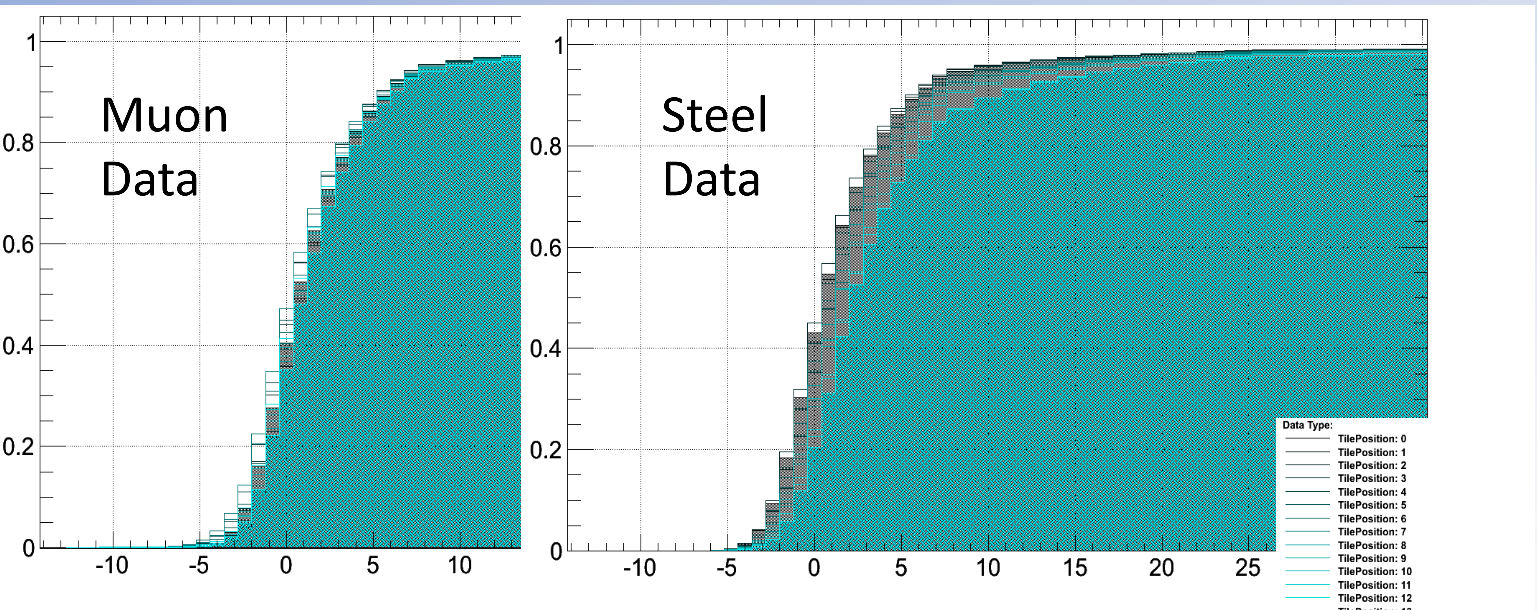

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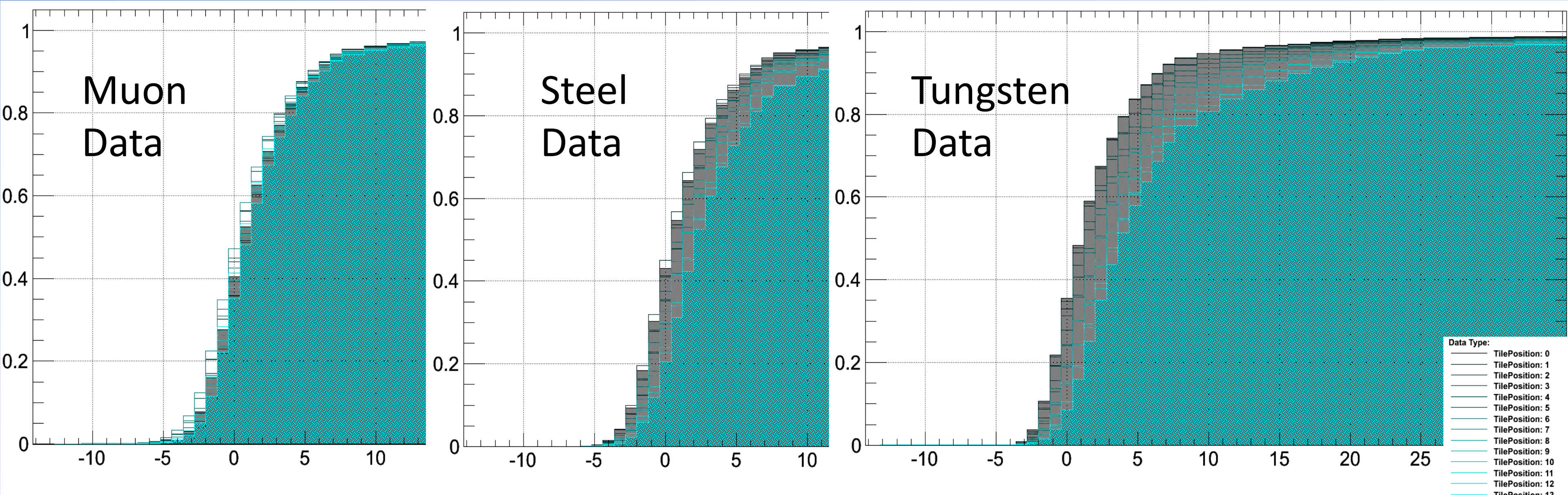

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- Which fraction of the total Energy is deposited at which time?
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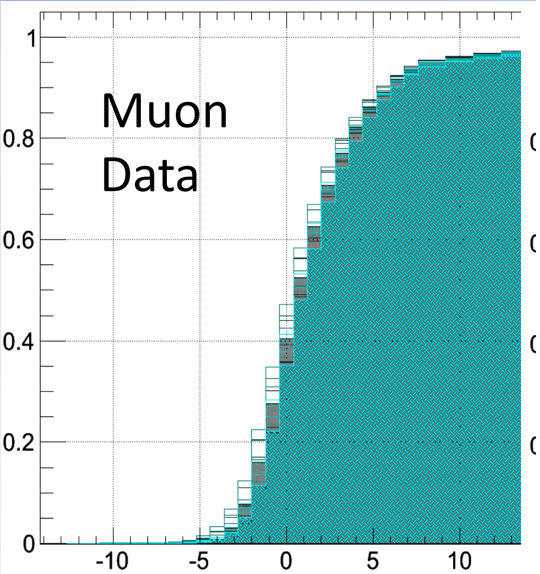
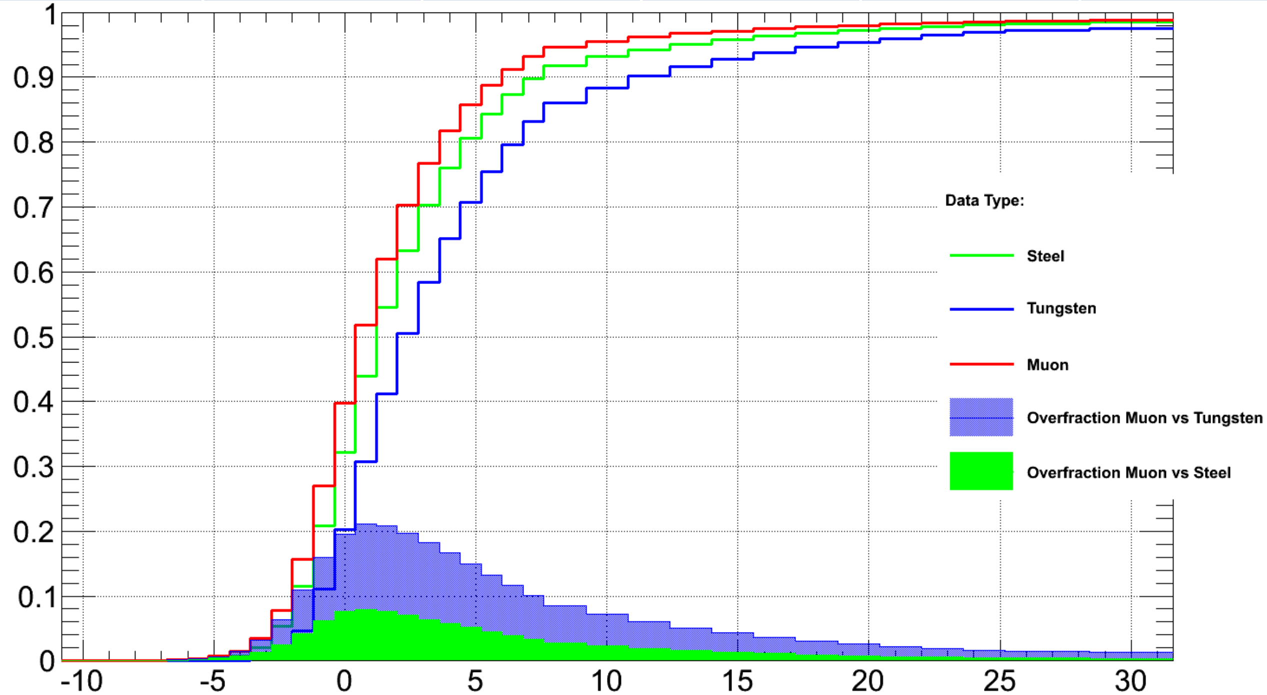
Time [ns]	Fraction Mu [T3B]	Fraction Steel [T3B]	Fraction Steel [CDR]	Fraction W [T3B]	Fraction W [CDR]
6	89%	84%	90%	76%	n.A.
10	96%	93%	n.A.	88%	n.A.
25	99%	98%	n.A.	97%	82%





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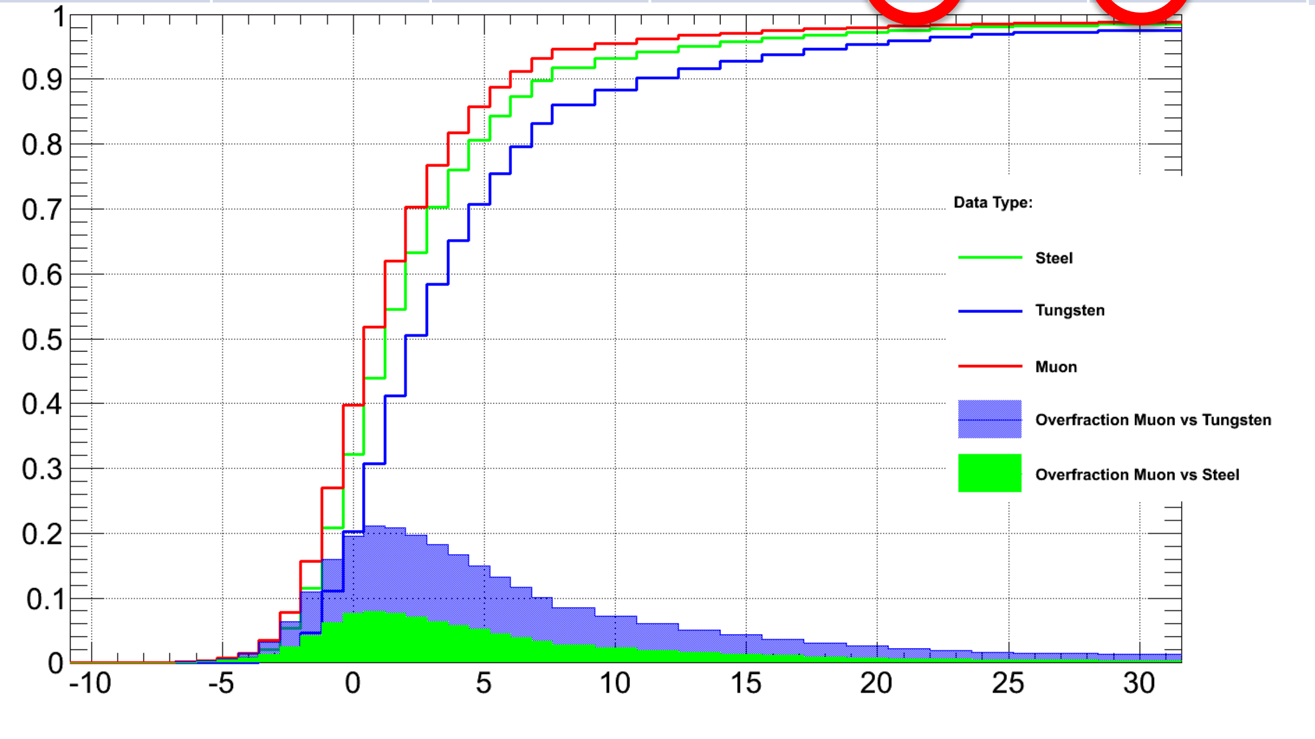
Discrepancies due to:

- Integrating over only a small strip instead of whole shower?
- Position behind the HCAL? → Answer through Calice-T3B sync. Information
- Missing correction factors (e.g. Overshoot, Saturation correction…)



SUMMARY AND OUTLOOK

Summary and Outlook

Summary:

We presented results on the time development of hadronic showers

Mean time of first hit:

- We see significant differences in the lateral shower timing between Tu and Steel, but no differences for different energies
- Calibration to the MIP scale allows us to quantify late energy depositions
- Late (first) energy depositions are small for Steel but can be high for Tungsten

Mean time of Hit:

- Device specific templates could be used to correct for SiPM afterpulsing
- We see significant differences in the lateral shower timing between Tu and Steel, but no differences for different energies
- The timing of the fraction of total energy deposited within the T3B strip shows differences wrt. the values in the CLIC CDR

Summary and Outlook

Outlook:

Geant4: Need extensive simulation study to compare to data results and identify discrepancies

Calibration:

- Implement Afterpulsing correction depending on SiPM gain (Overvoltage, Temperature)
- Use synchronization information to clean data from punch throughs and muon contamination
- …

Now pass to Lars with his successful T3B-Calice synchronization studies

BACKUP

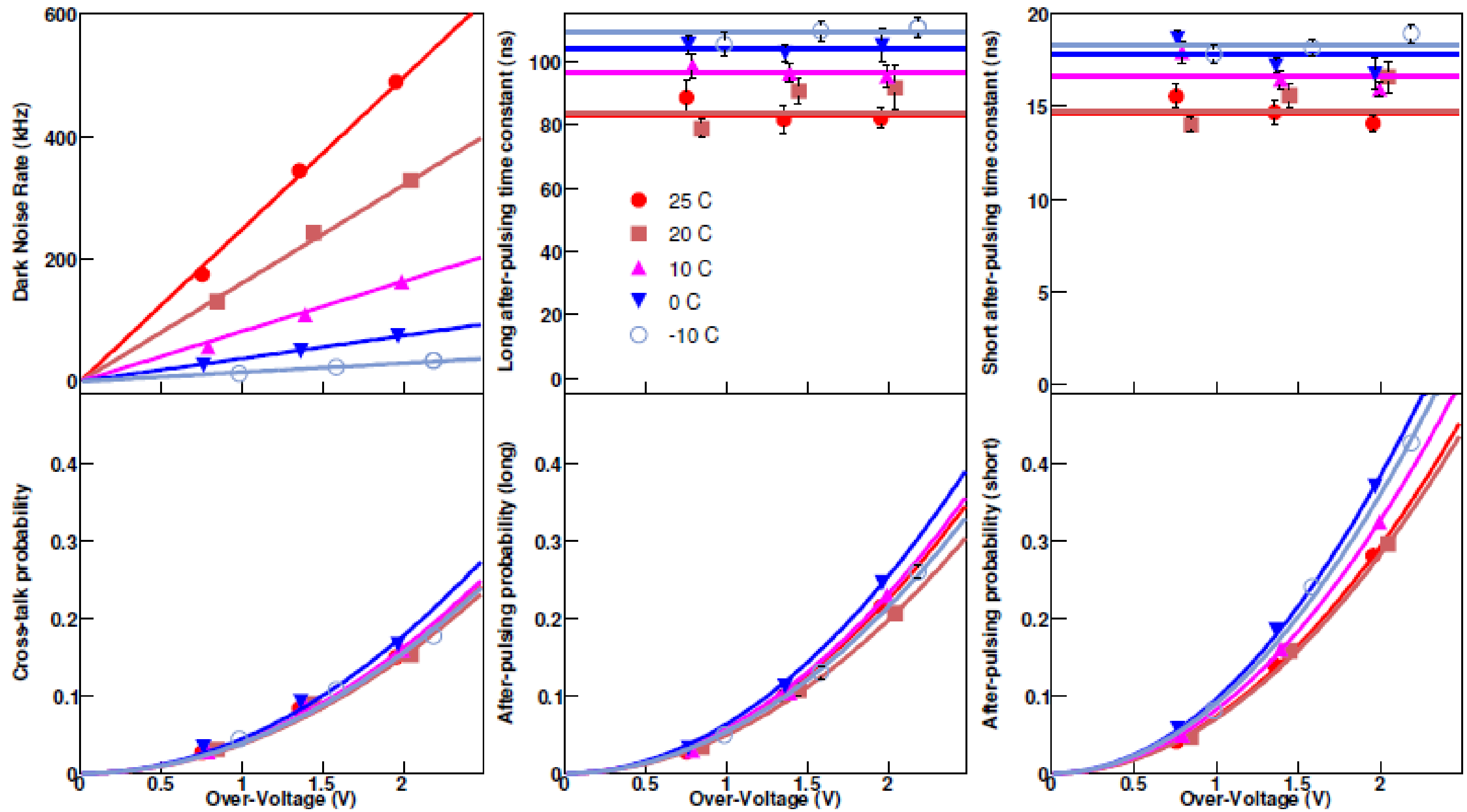


Fig. 1. Dependence of the dark noise rate, cross-talk probabilities and after-pulsing parameters on over-voltage and temperature, measured by triggering on thermally generated pulses

*trshare.triumf.ca/~fretiere/**T2K**/Talk/NDIP/FRetiere.ps*

T3B Calibration to the MIP Scale: Sr90 Data

During the Test Beam T3B monitors the SiPM Gain continuously

→ This data can be used to calibrate energy depositions to the MIP Scale

Assumption: The MIP MPV depends in first order only(!) on the Gain

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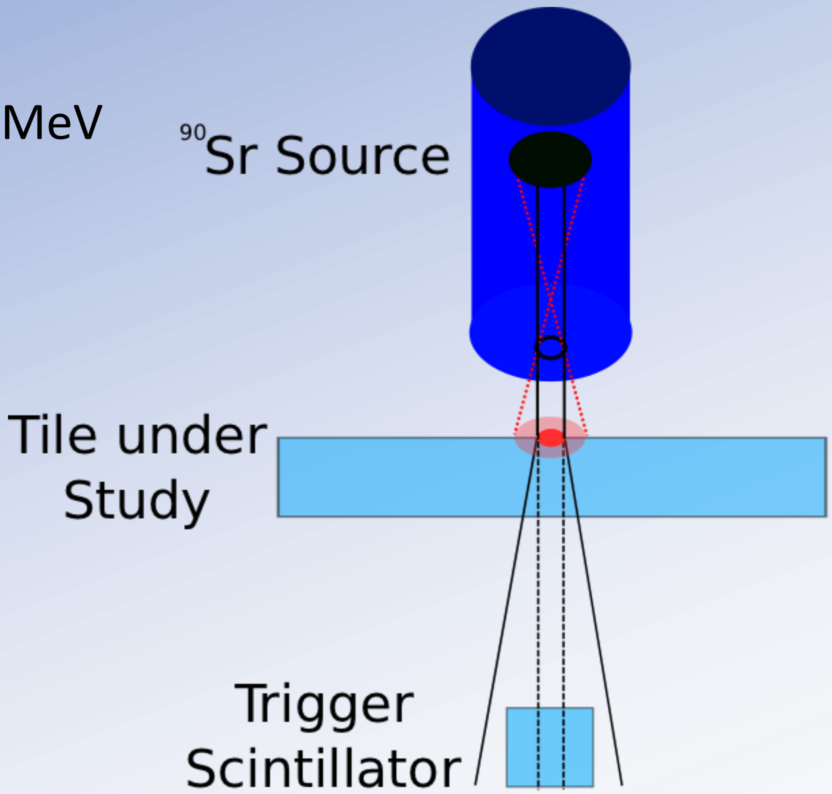
Offline Calibration Setup:

- Sr90 Source with end point energy of 2.27MeV
- Coincidence trigger to ensure penetration of tile under study
- Consecutive calibration of all T3B cells individually
- Use T3B DAQ: Acquire Sr90 and SiPM gain data at the same time
- Use climate chamber to ensure temperature stability



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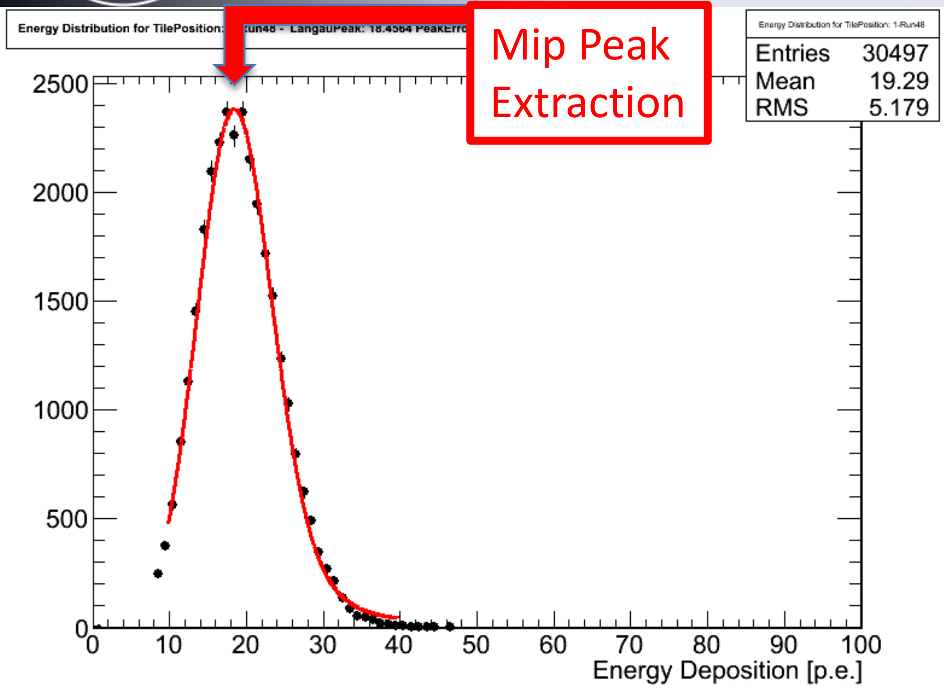
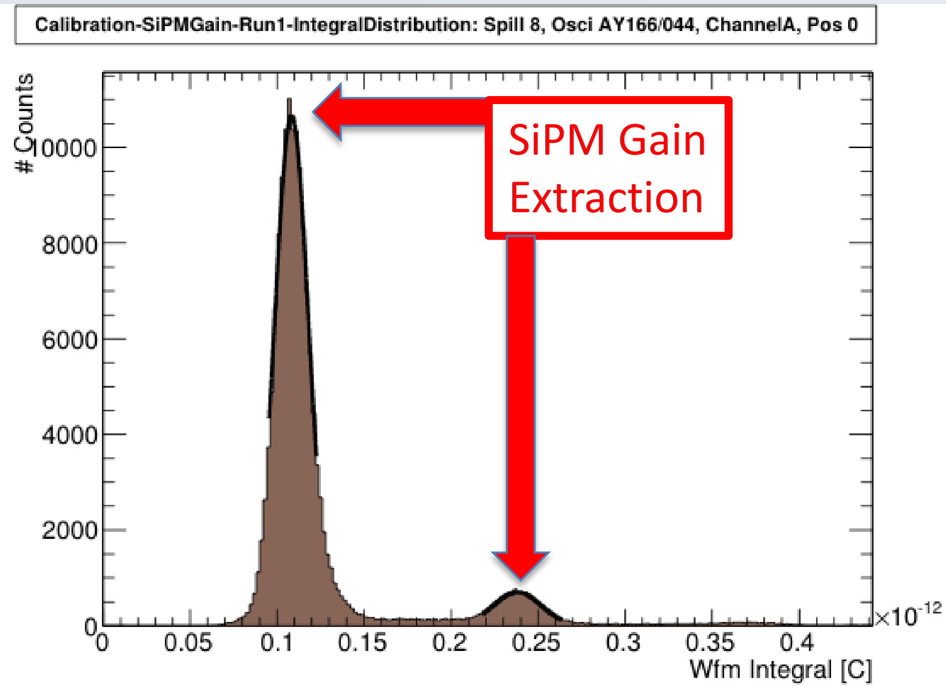
GEANT4 Simulation:
MPV (mu) = MPV(e)*0.825

$$MPV_{mu} = MPV_{e} \cdot 0.825$$

Note: Electrons are no perfect MIPs → need scale factor

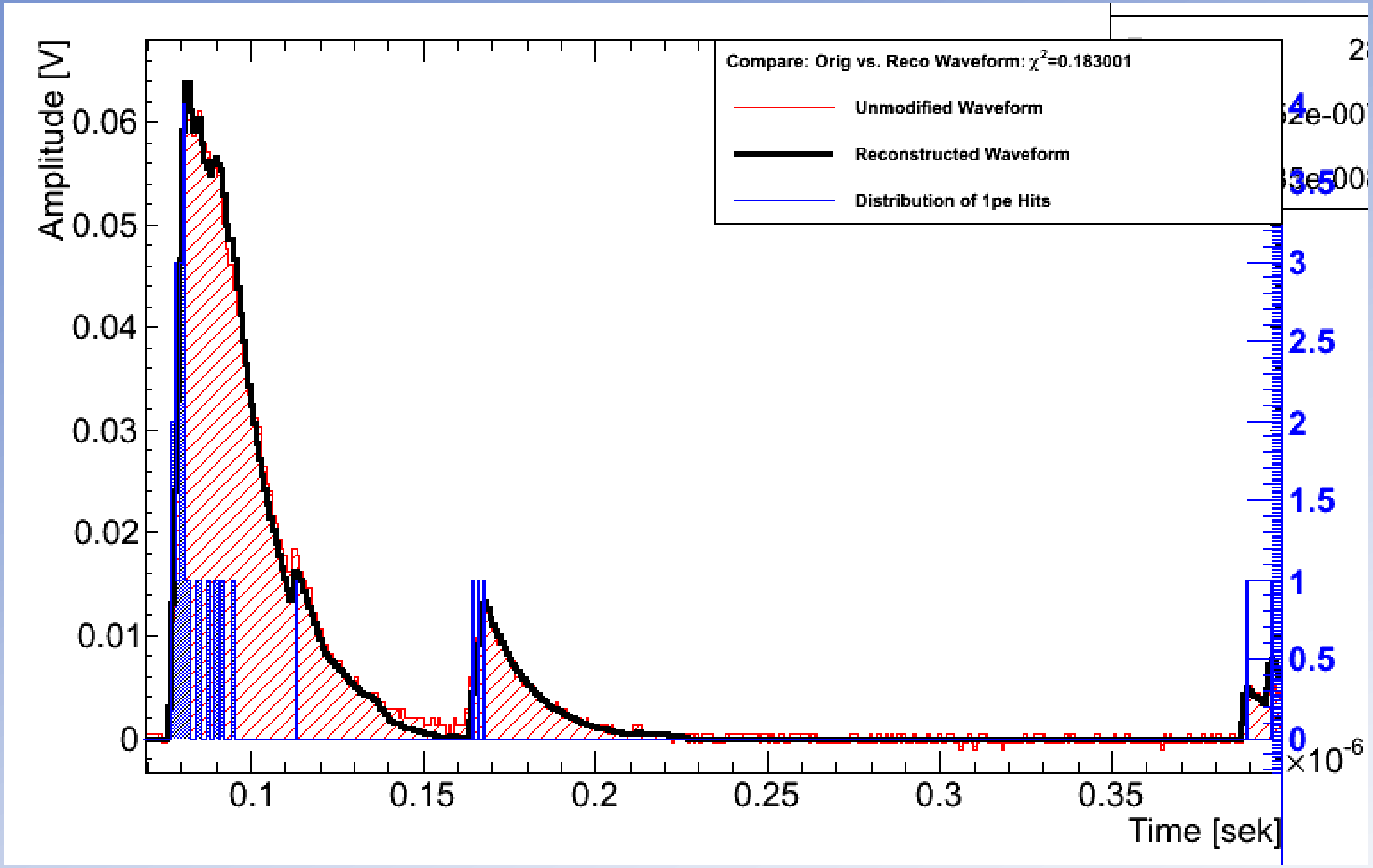
T3B Calibration to the MIP Scale: Sr90 Data





Simultaneous extraction of
SiPM Gain and most probable value
of energy deposition of Sr90 electrons

The Time Integration Window

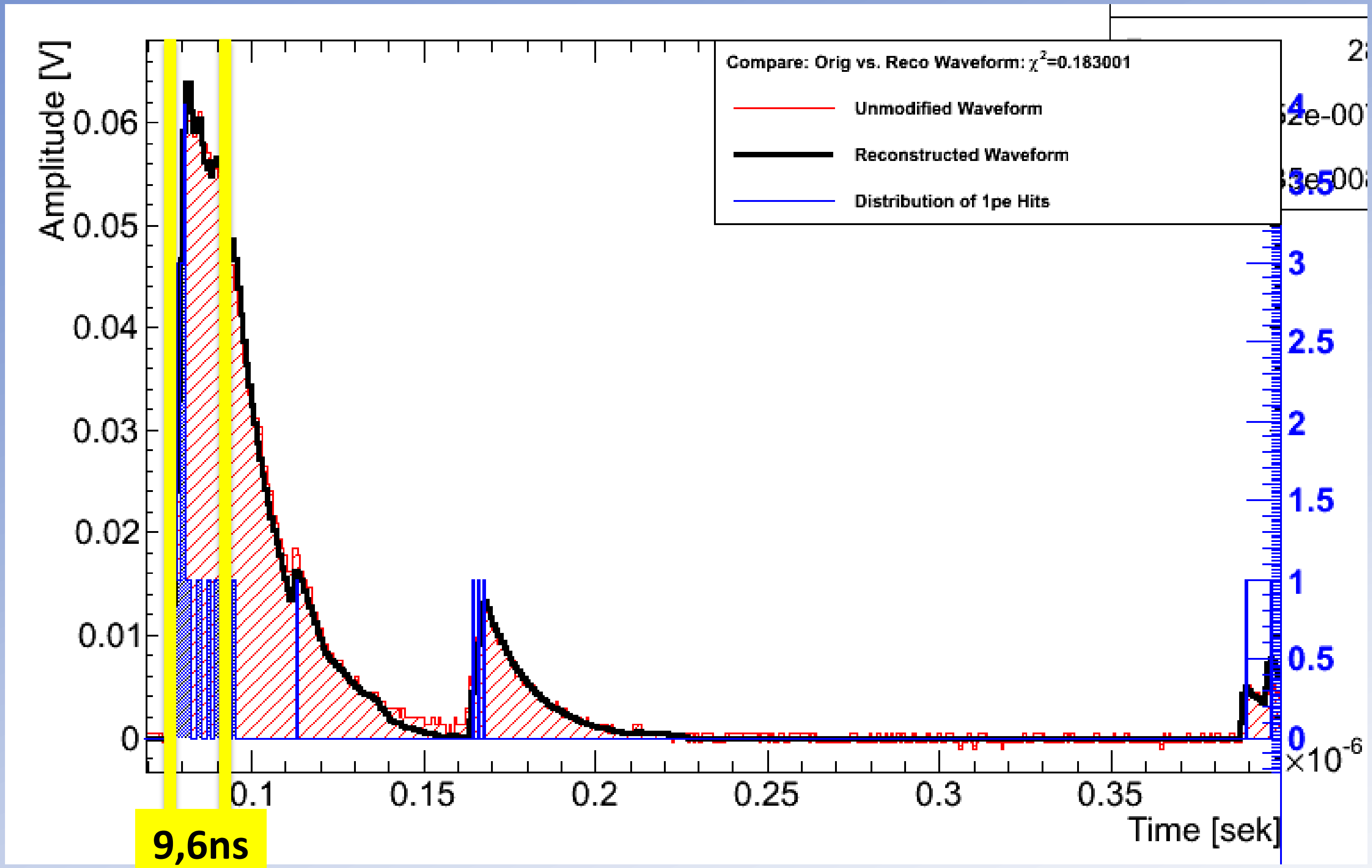


The MPV is very sensitive on the Time Integration Window

→ Dominant effect: SiPM Afterpulsing

- Separate afterpulsing from energy depositions
- Study the effect of afterpulsing

The Time Integration Window



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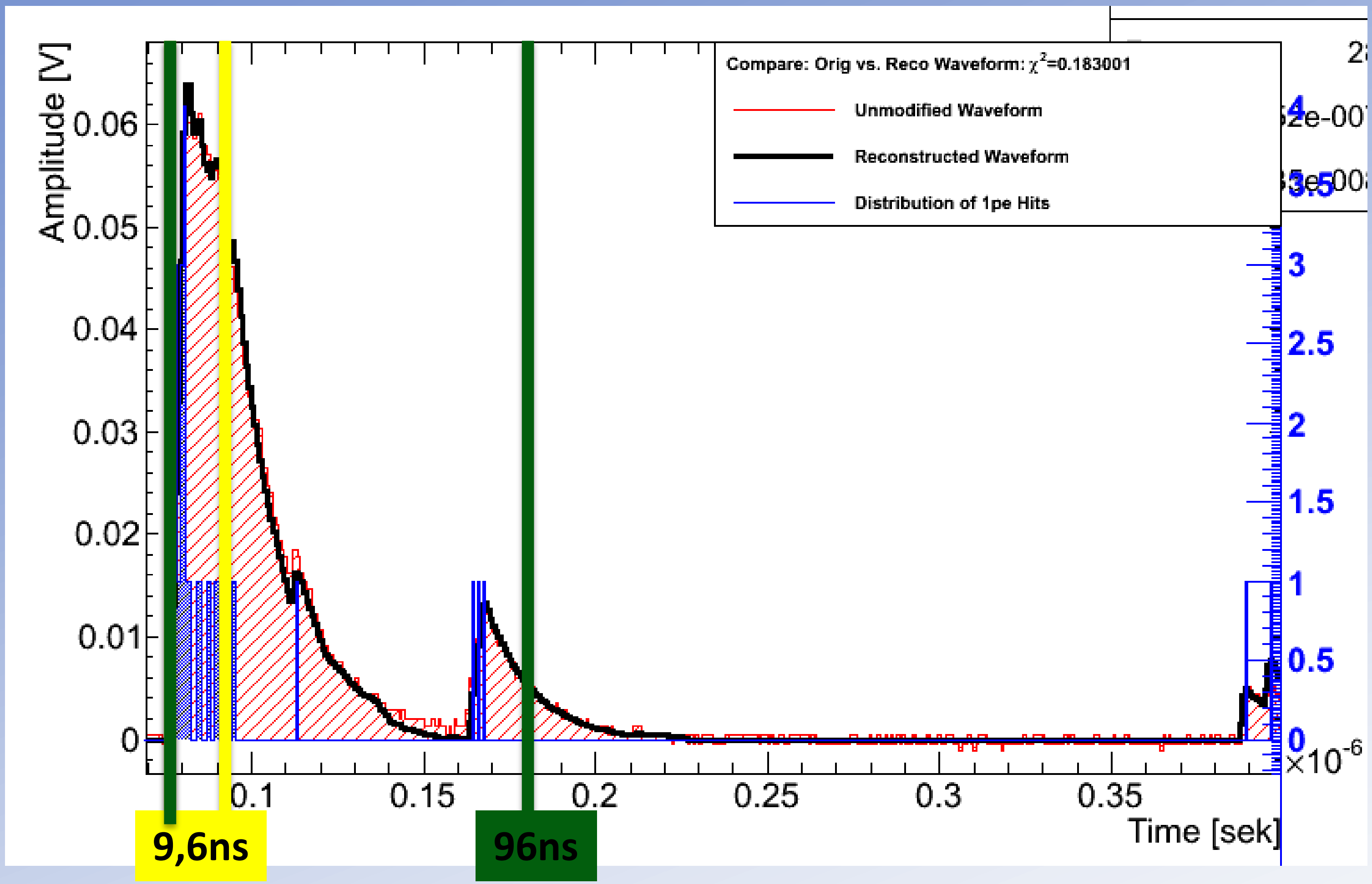

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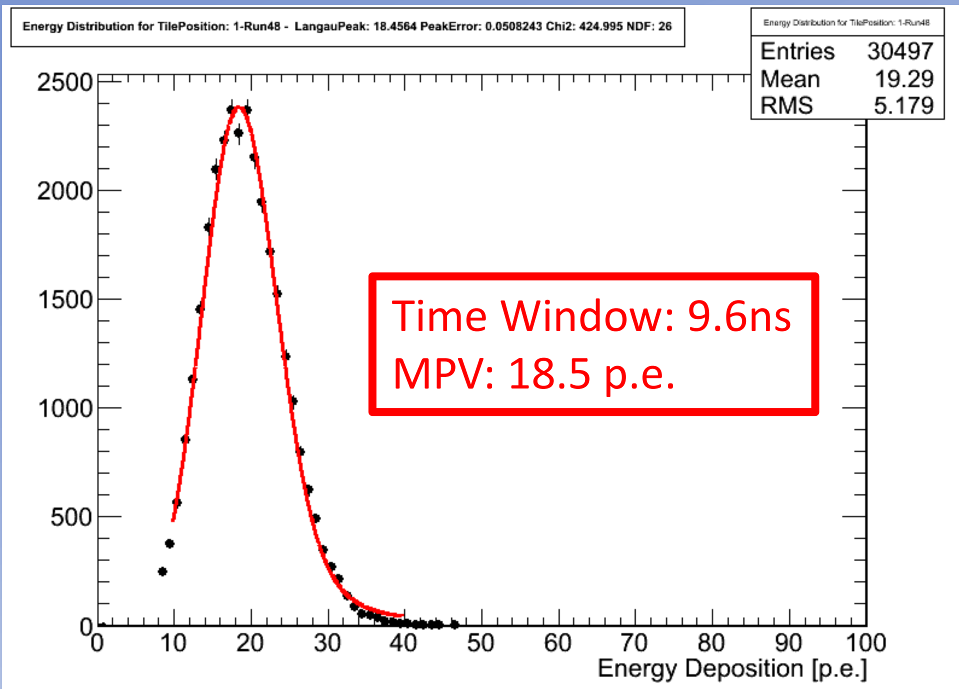

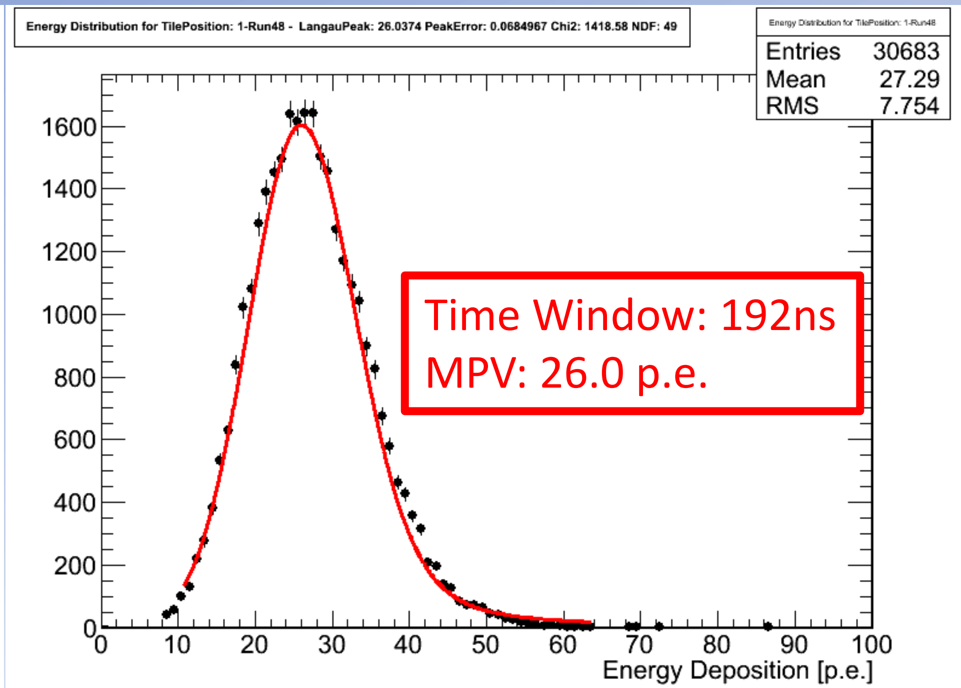

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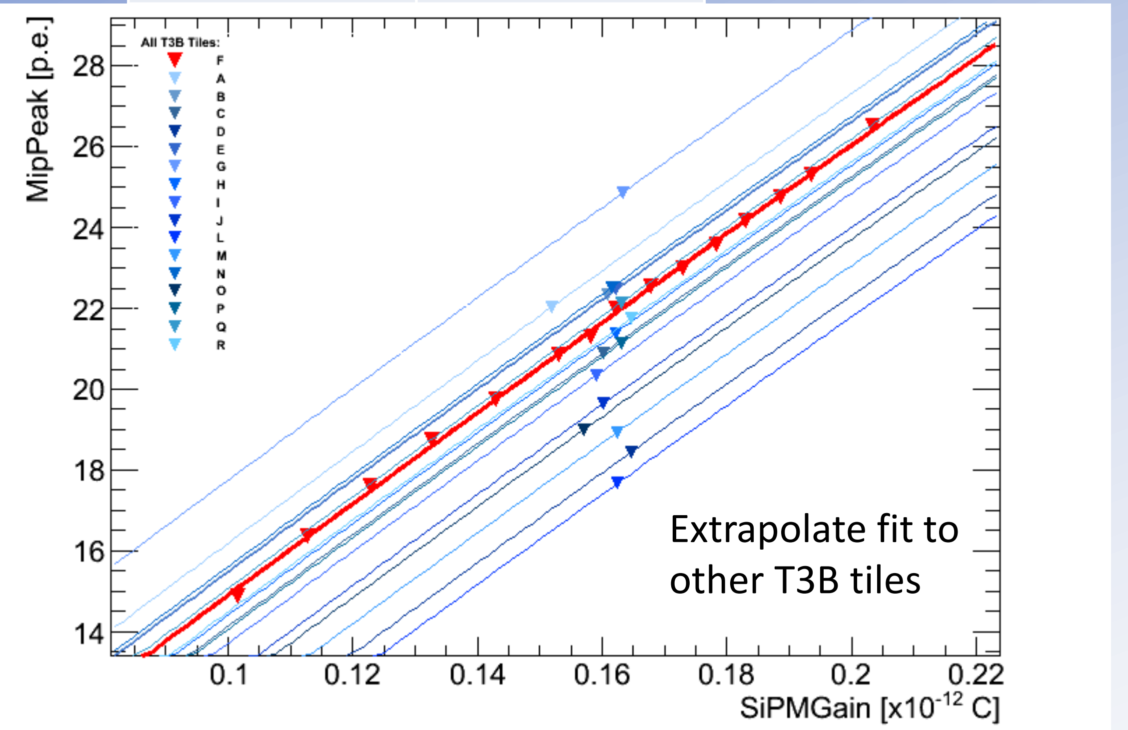
The Effect of Afterpulsing

Bias Voltage Scan for one T3B "Master Tile"
One Measurement for all other T3B tiles

Time Window	MPV-Gain dependence
9.6 ns	linear
307.2 ns	quadratic



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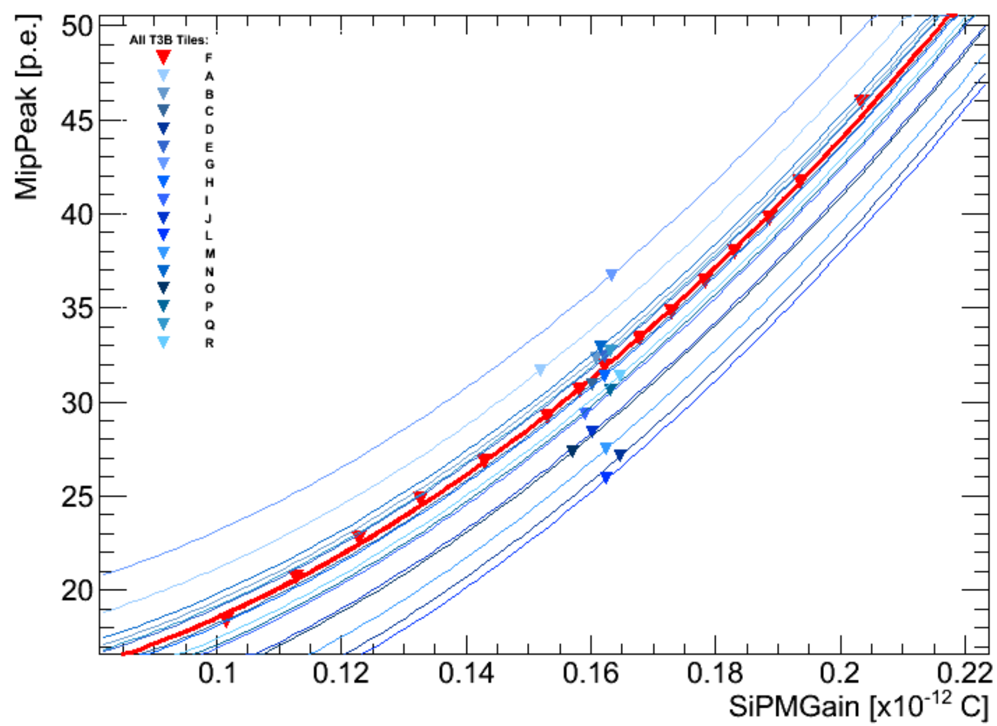

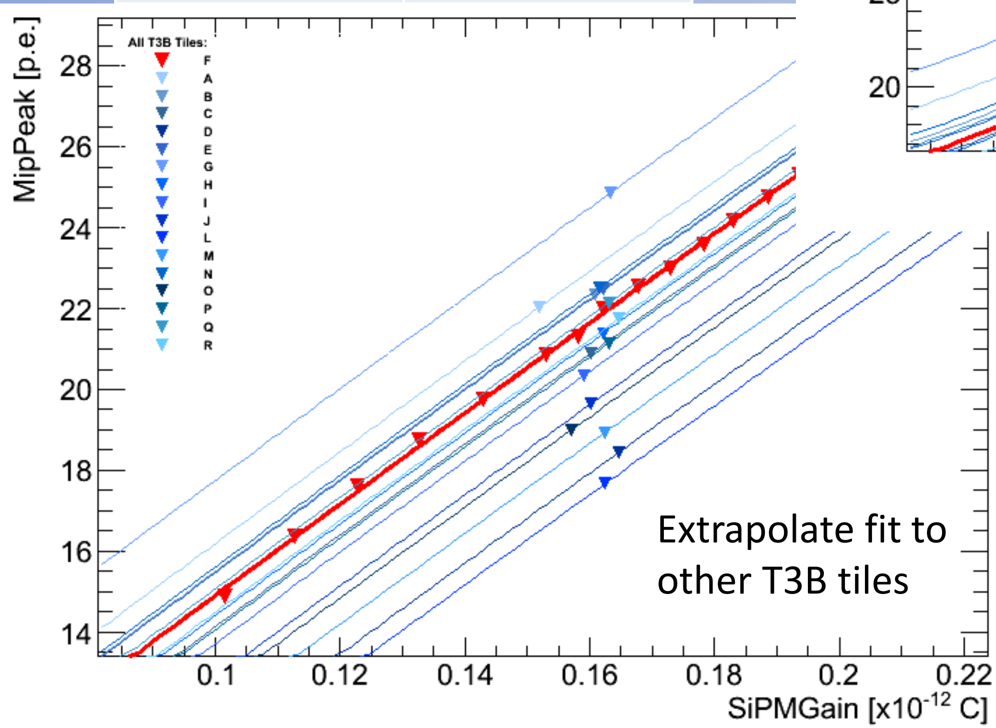

Extrapolate fit to other T3B tiles

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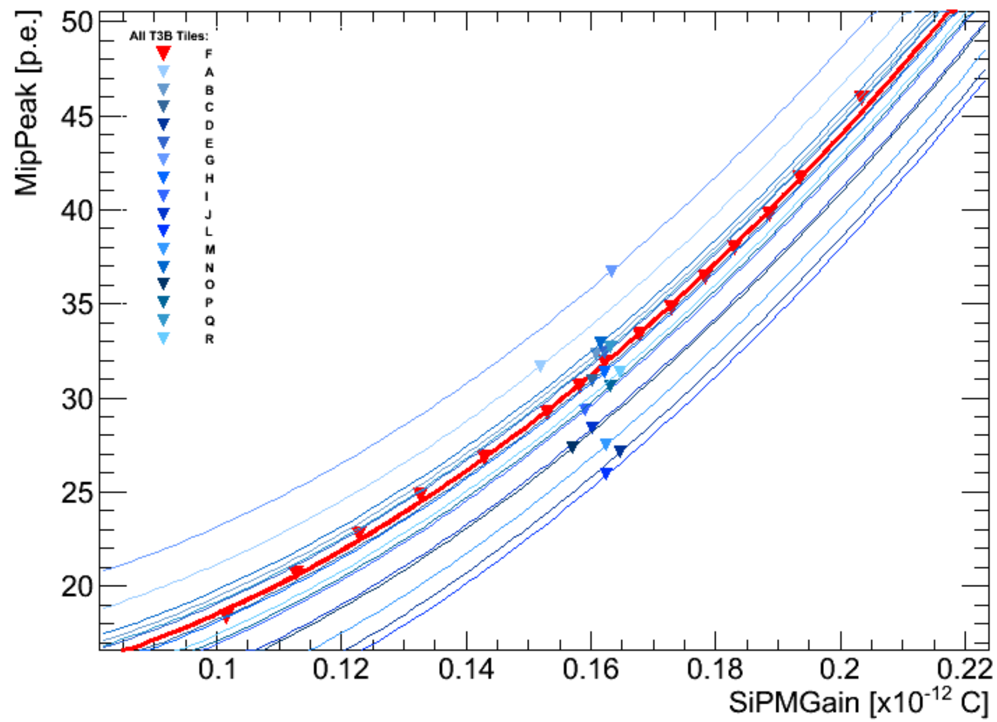
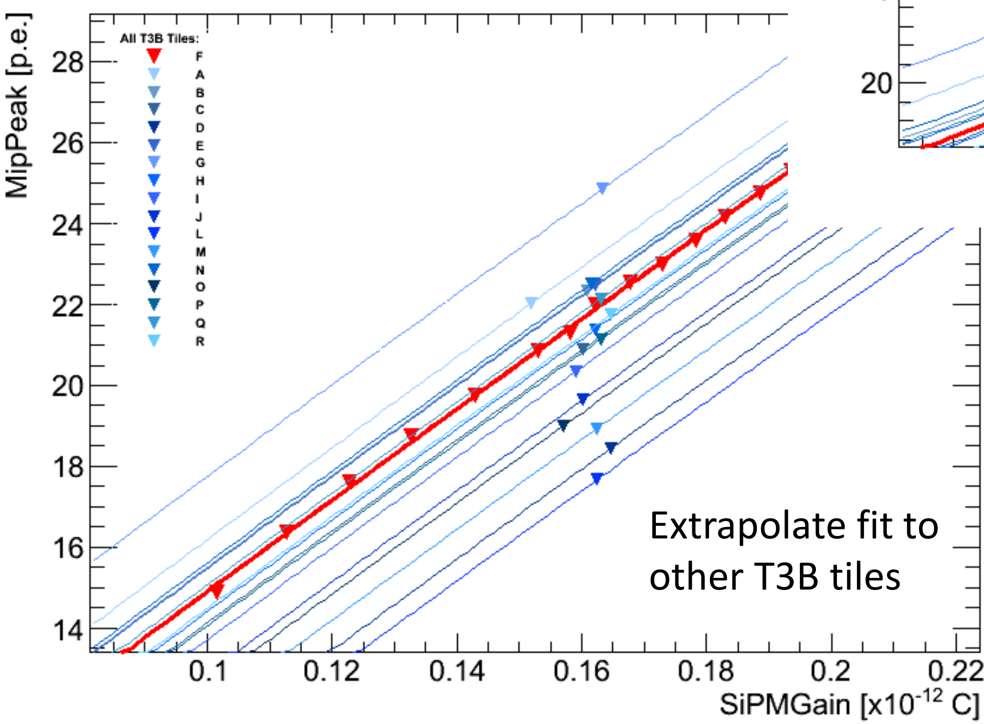




Extrapolate fit to other T3B tiles

Interpretation:

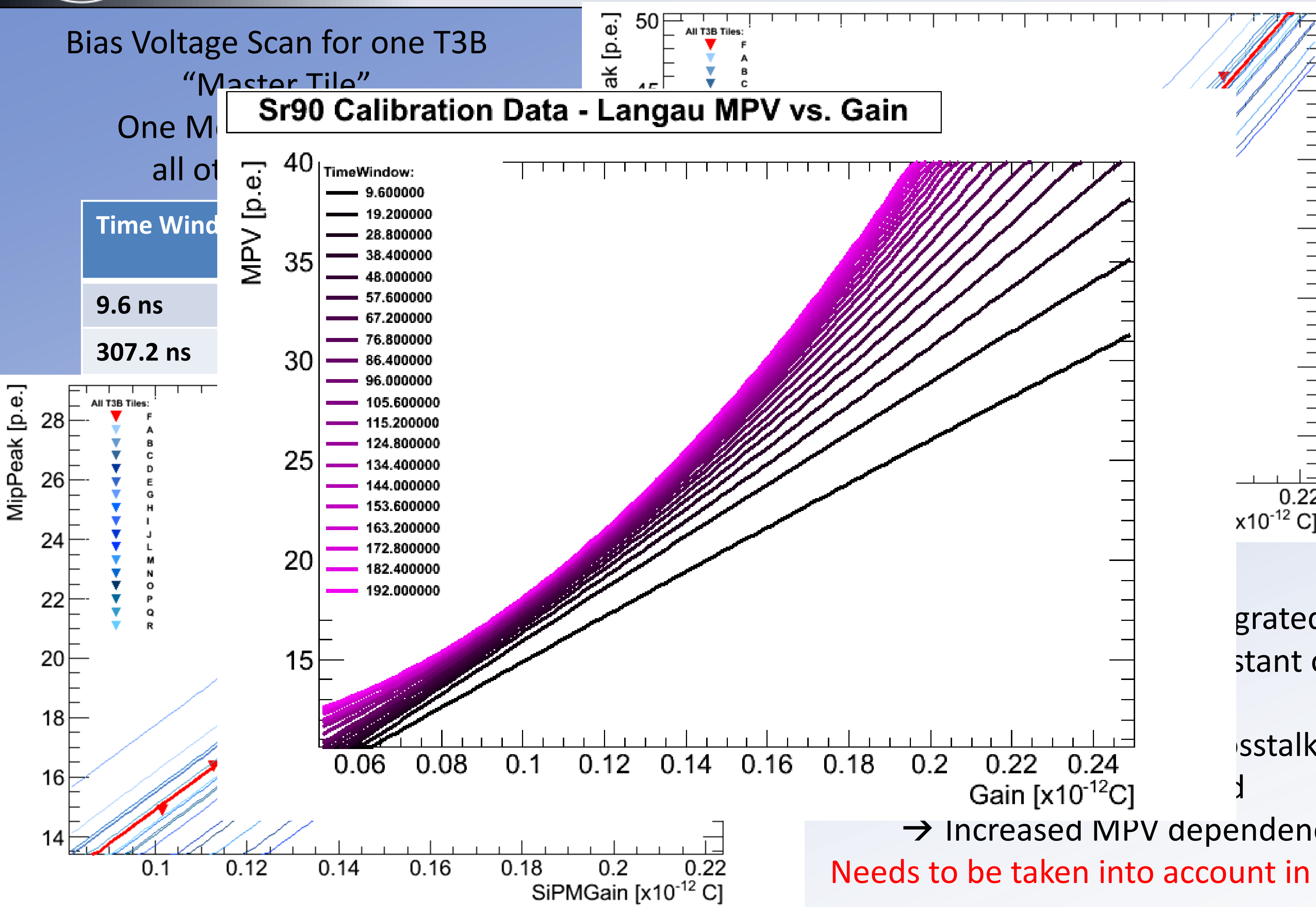
1. More afterpulsing is integrated
   → would just result in a constant offset
2. Higher Gain
   → Afterpulsing and Crosstalk probability increased
   → Increased MPV dependence

Needs to be taken into account in Calib

The Effect of Afterpulsing

Bias Voltage Scan for one T3B
“Master Tile”
One M
all ot

Time Wind
9.6 ns
307.2 ns



grated
stant offset

sstalk
d

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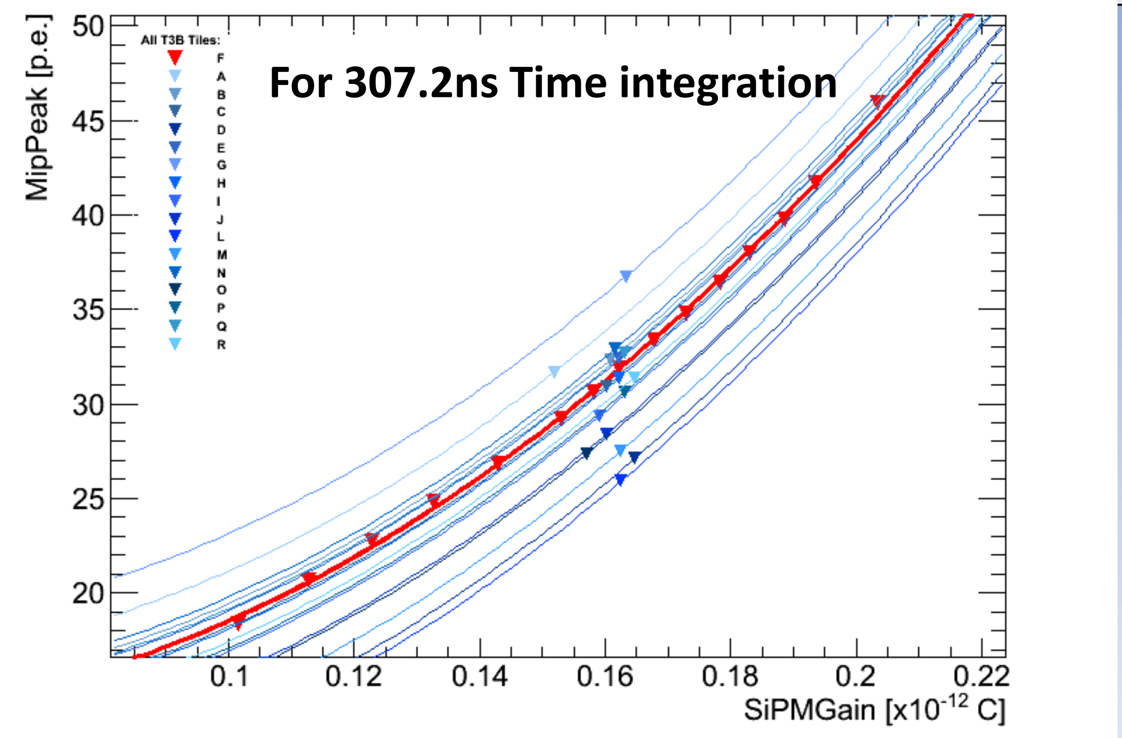
T3B Calibration to the MIP Scale



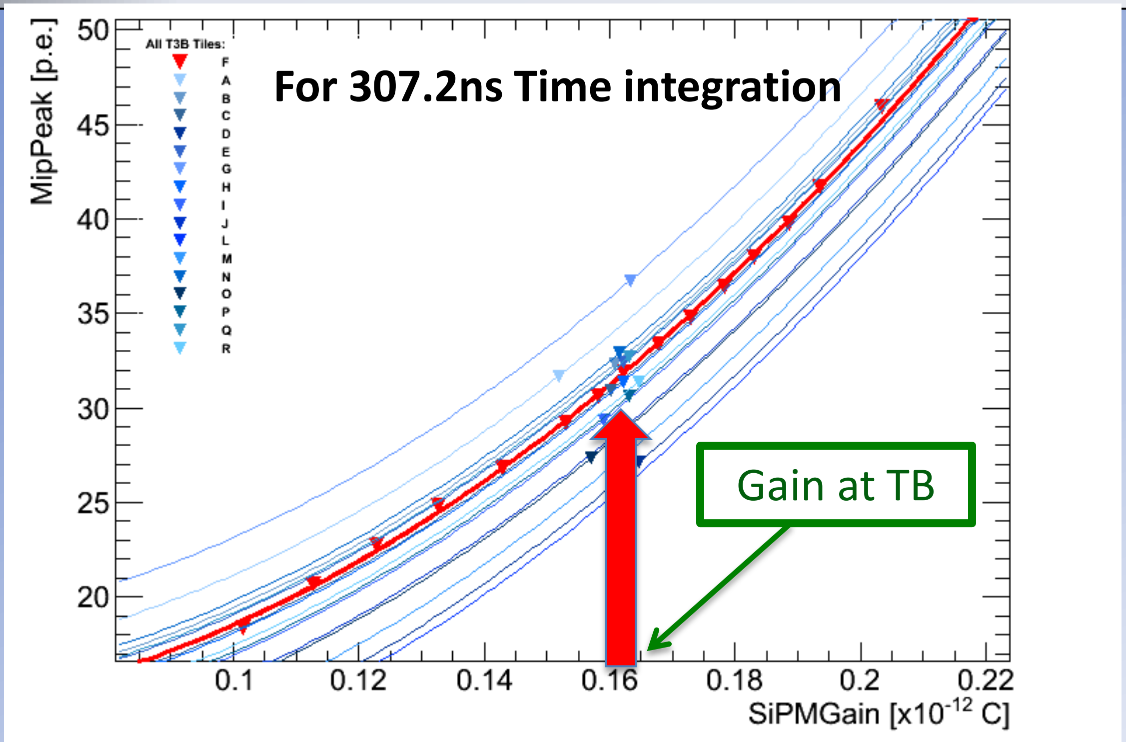
Obtain a dictionary:

Determine live SiPM Gain from testbeam data

Select MPV-Gain dependence for distinct time integration window

Obtain corresponding MPV of MIP distrib.

T3B Calibration to the MIP Scale



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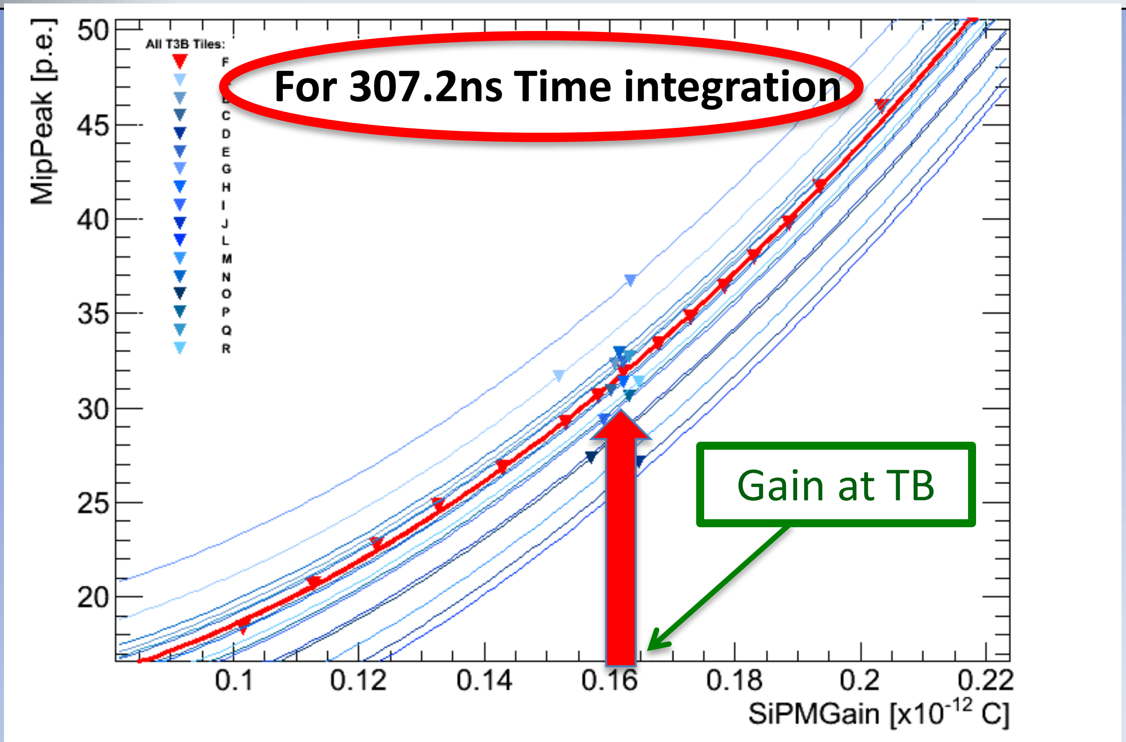

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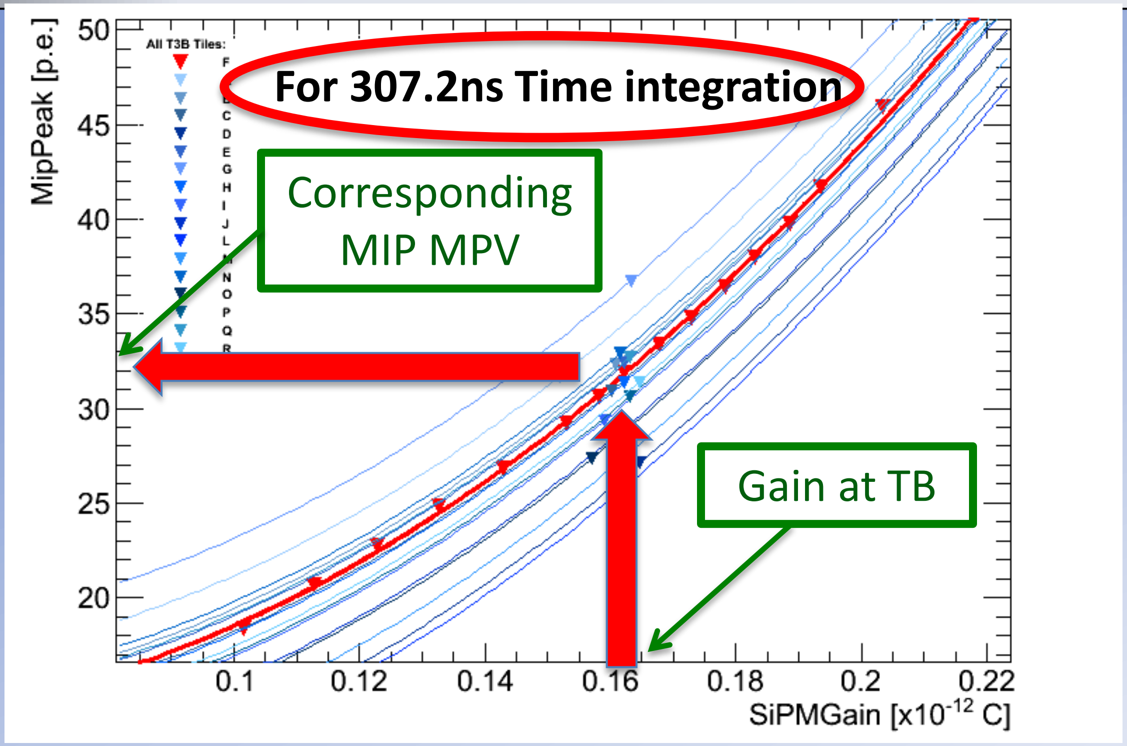

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VERIFY CALIBRATION PRINCIPLE: TESTBEAM MUON DATA

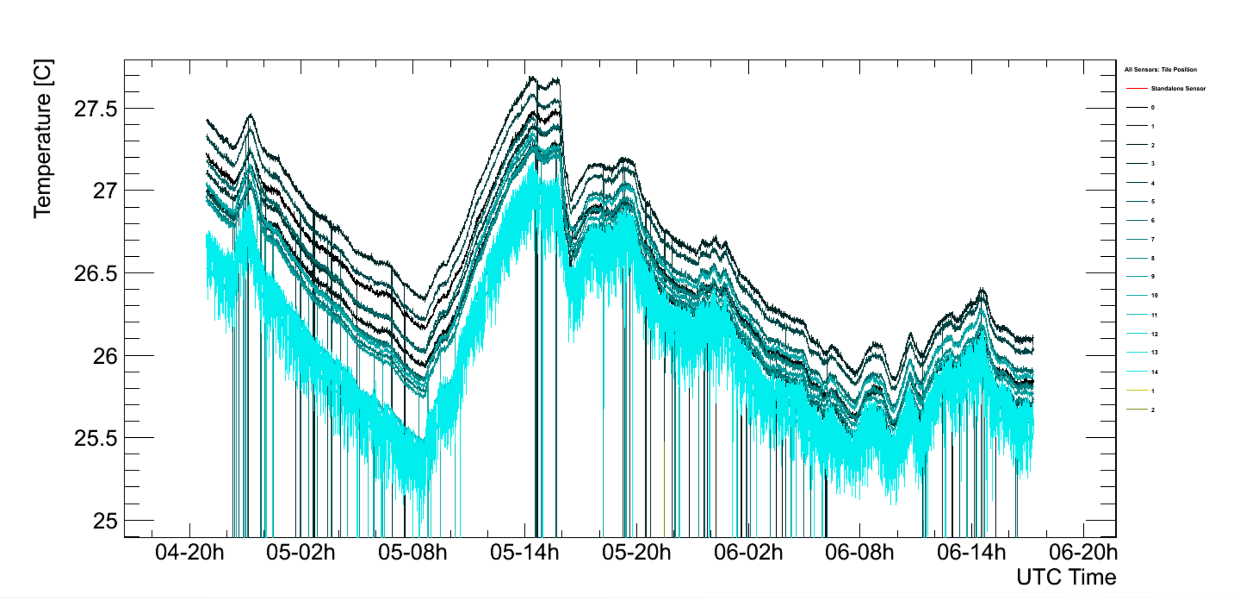
Verification of the Calibration Principle: Muon Data

During the commissioning of the SDHCAL we could take an excessive amount of muon data:

– 14 mio Muon Events
– 40 hours without interruption
– Day-night-cycle Temperature Range: ~25.5C to 27.5C

→ Enough to extract the Mip MPV-Temperature dependence

→ Then: Apply correction factor from Sr90 Data to eliminate the dependence (remember: We assume the MPV depends in first order only on the SiPM gain)



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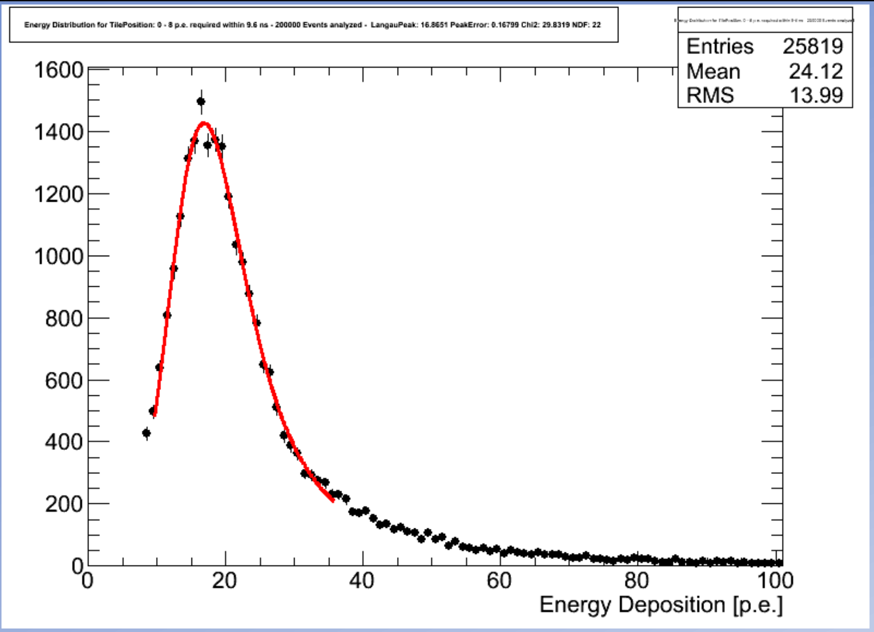
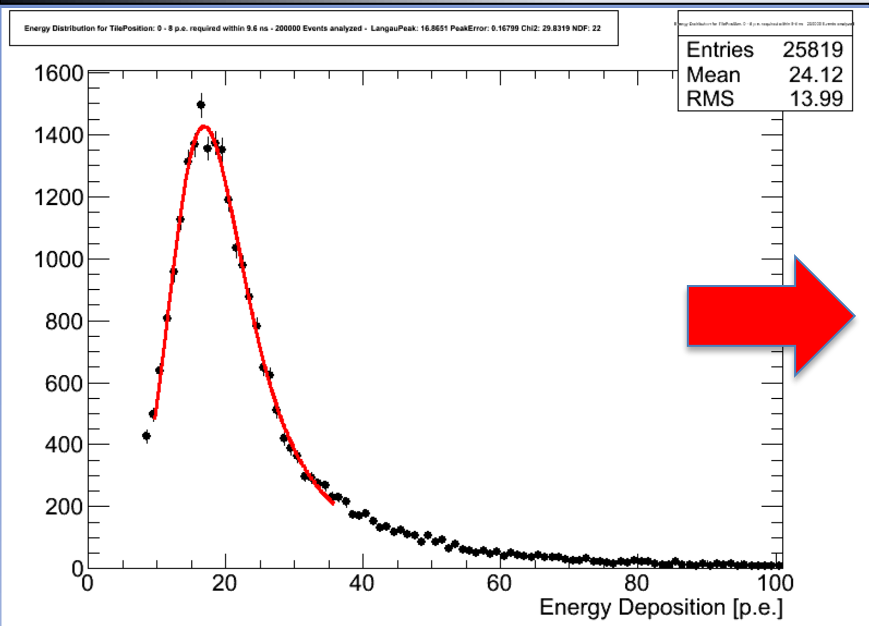
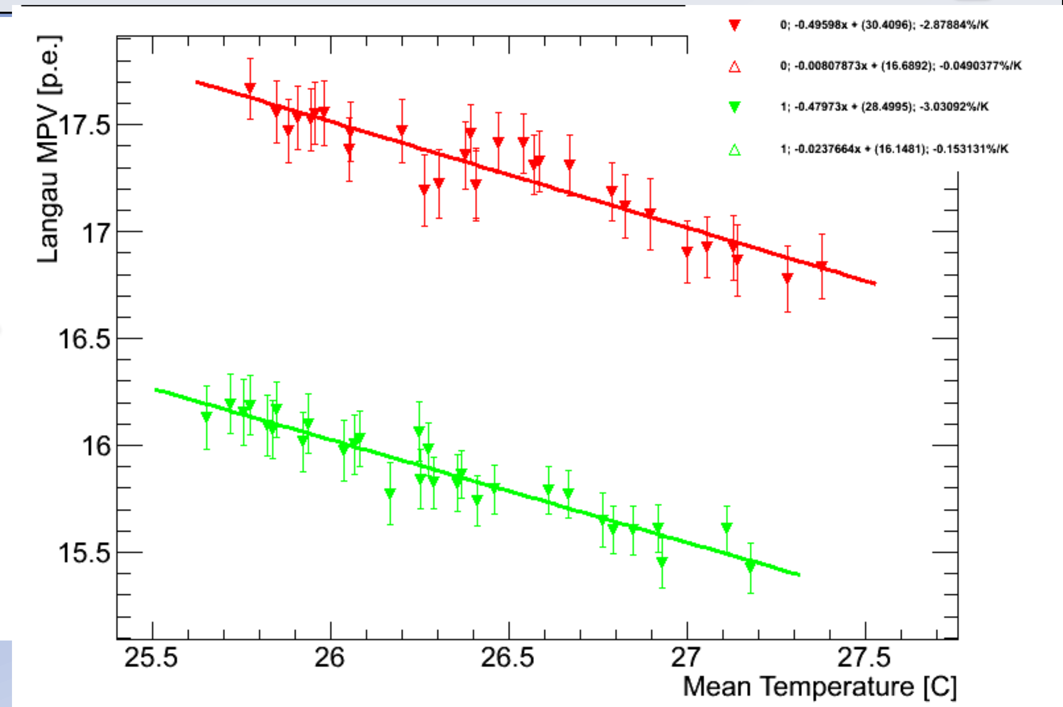


- T3B tiles hit in a small fraction of triggers
  → Determine MIP MPV every 200k events
- Time window of 9.6ns selected

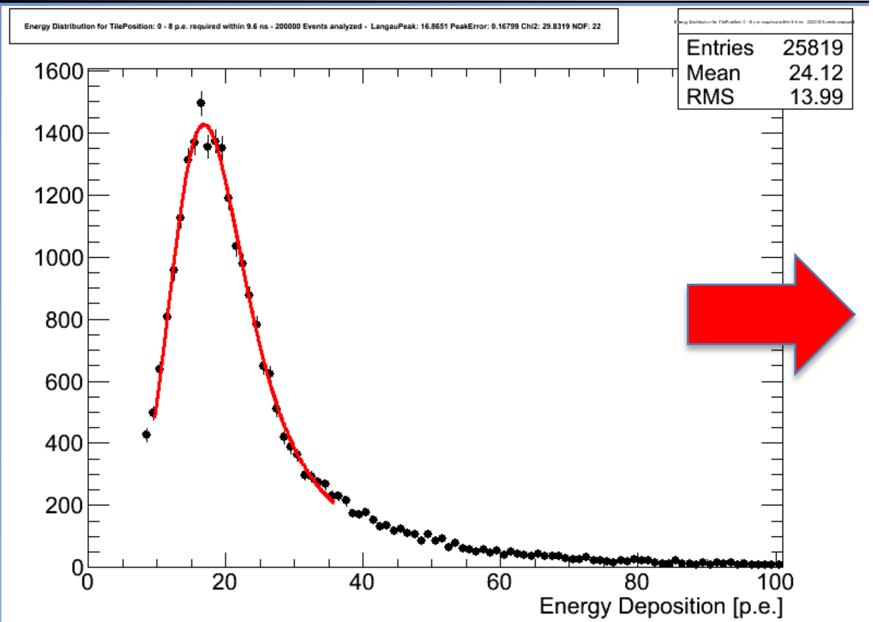
Verification of the Calibration Principle: Muon Data

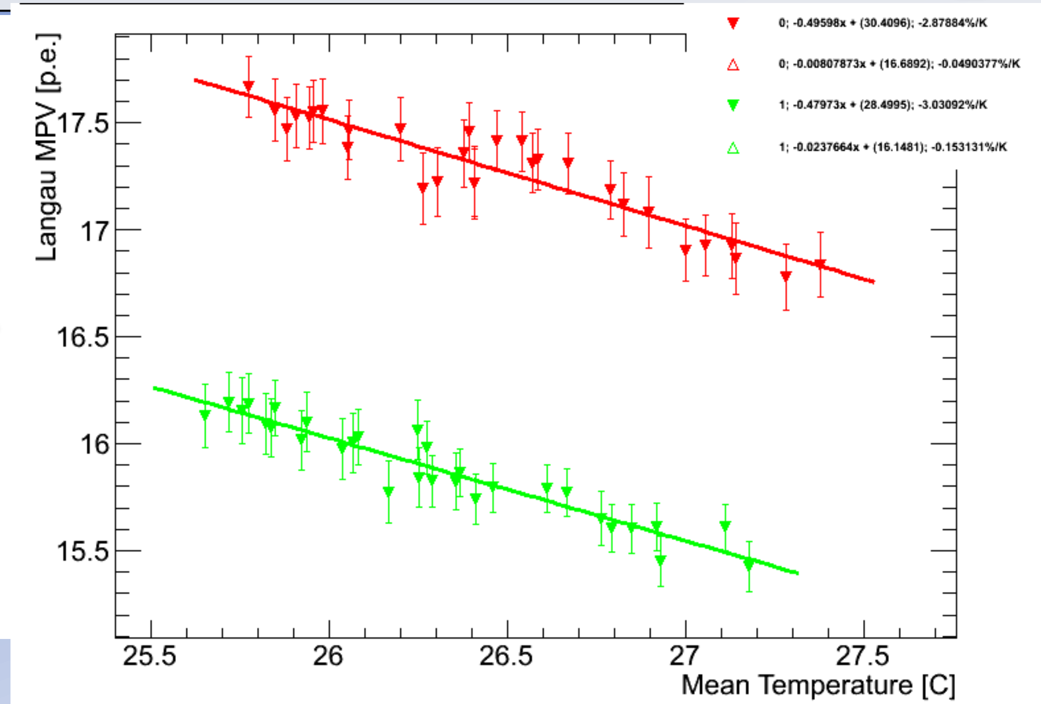




- Time window of 9.6ns

Verification of the Calibration Principle: Muon Data





- Time window of 9.6ns

T3B Tile	MPV Drop	Slope
Center	-2.9 %/K	-0.5 p.e./K
Center + 1	-3.0 %/K	-0.48 p.e./K

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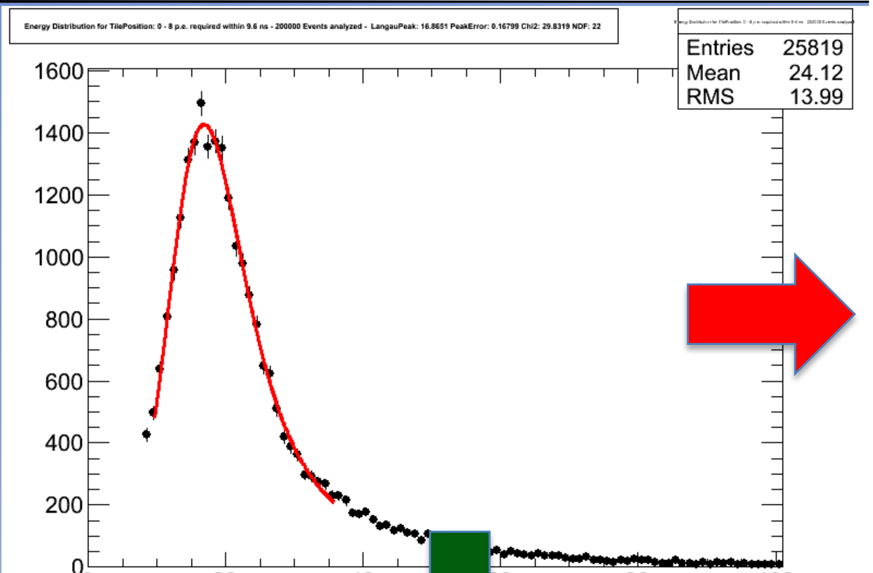

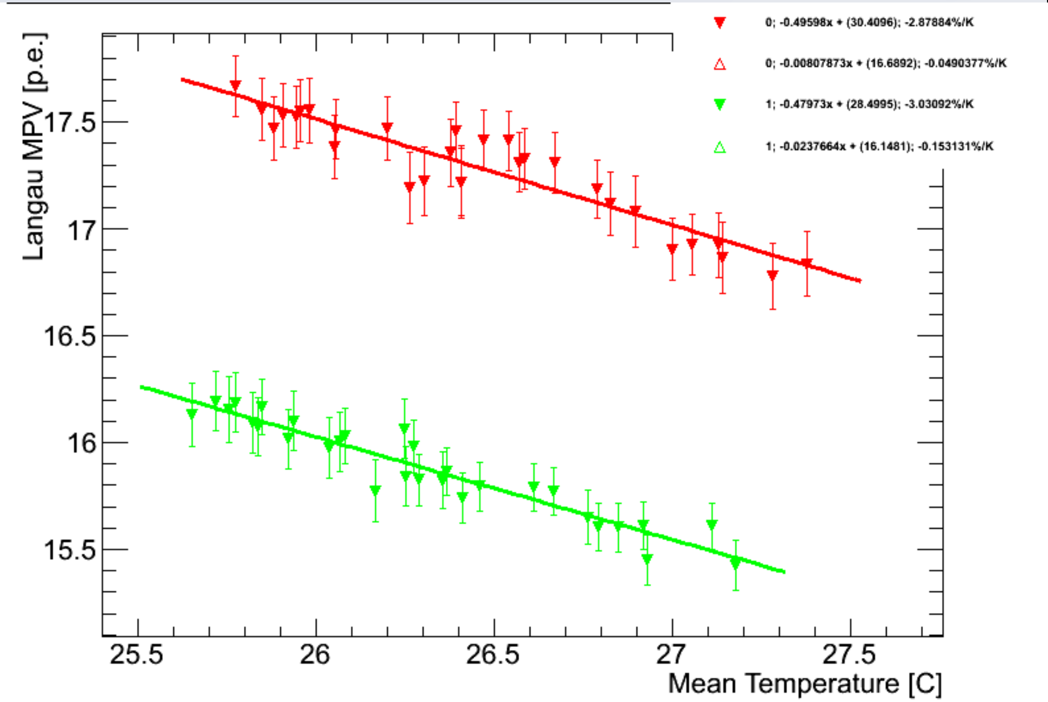

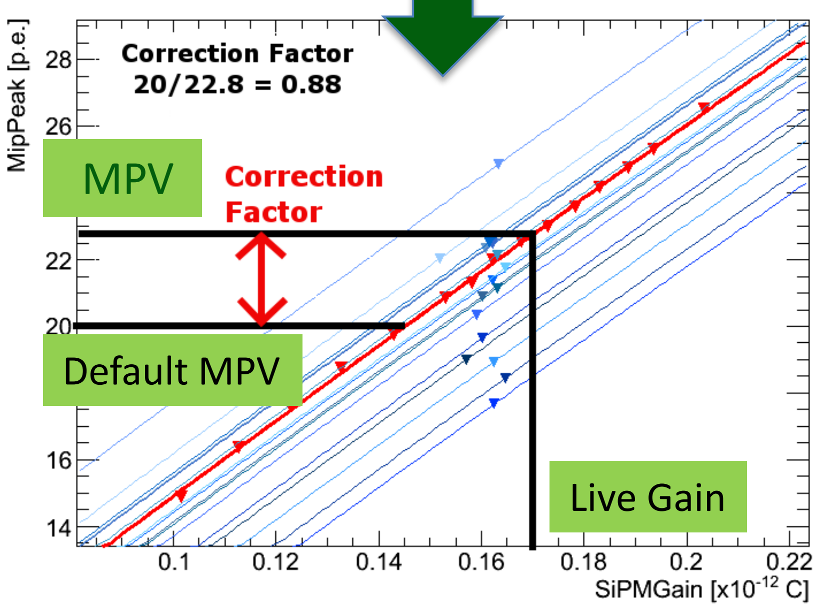

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- Get live gain from Intermediate RM
- Determine corresponding Sr90 MPV
- Choose default MPV of 20 p.e.→later 1MIP
- Obtain Correction factor

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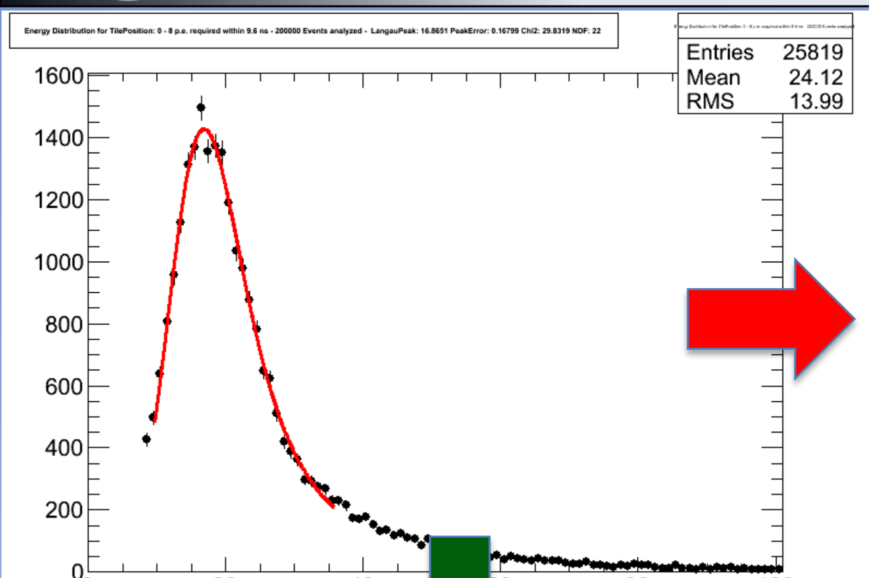

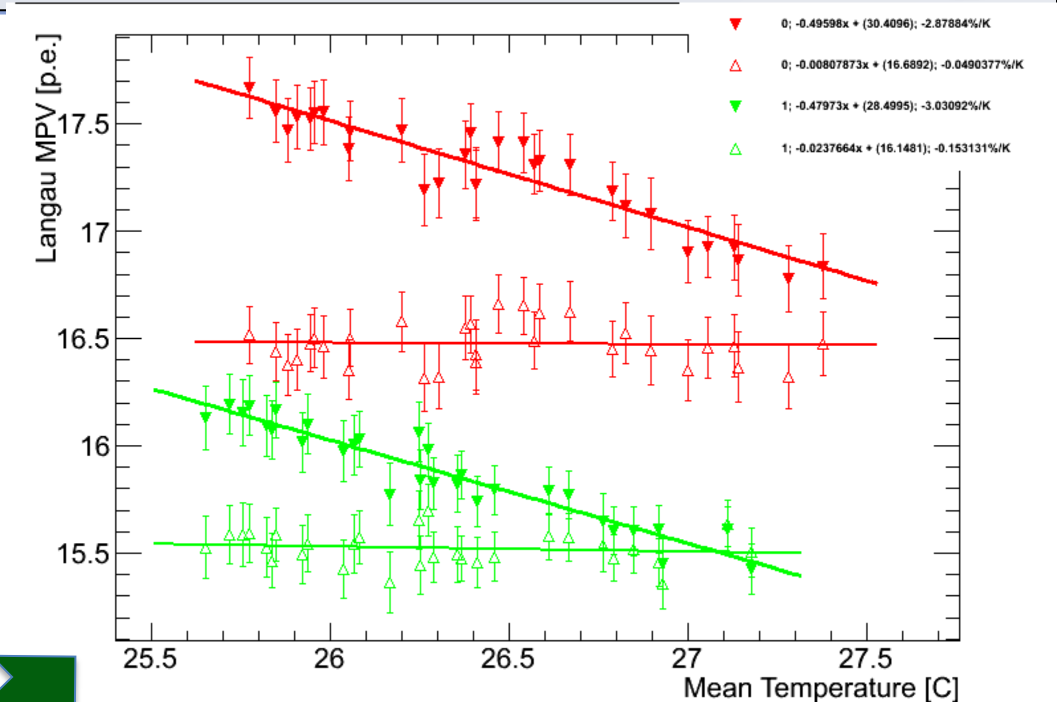

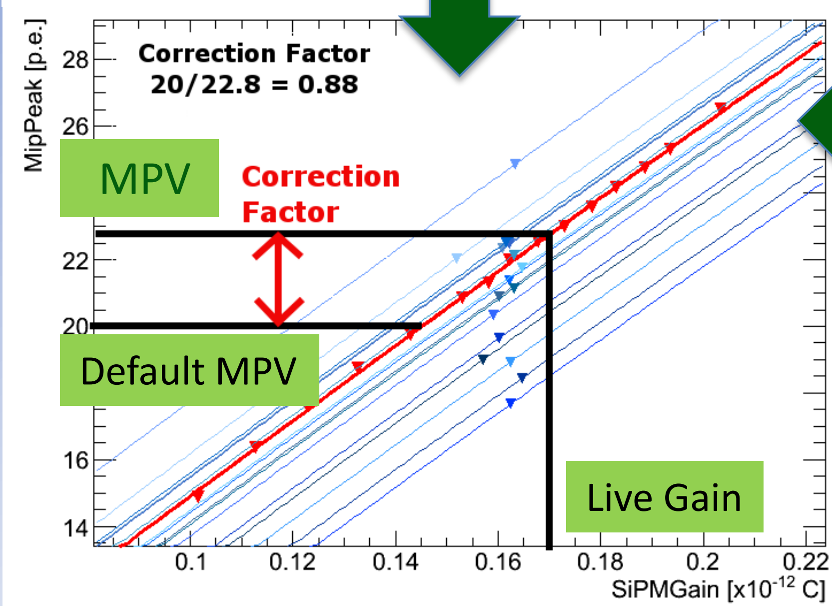

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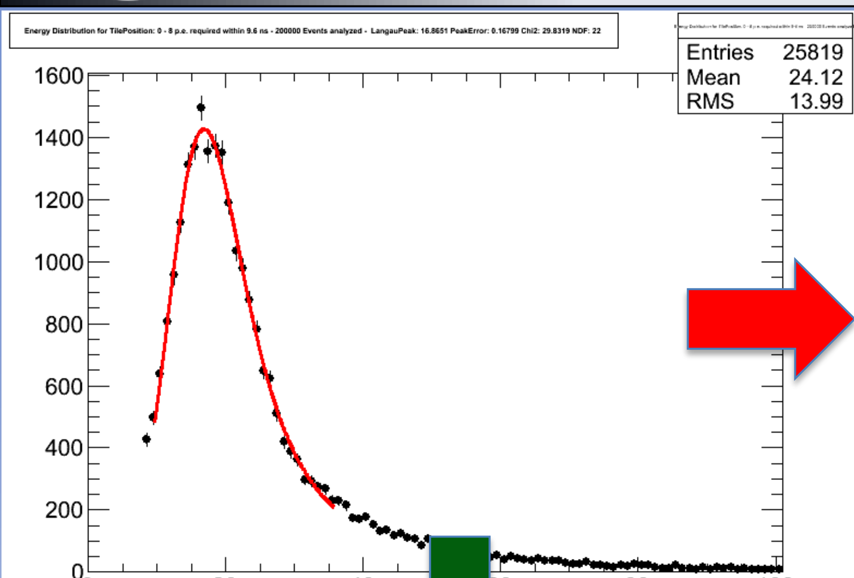
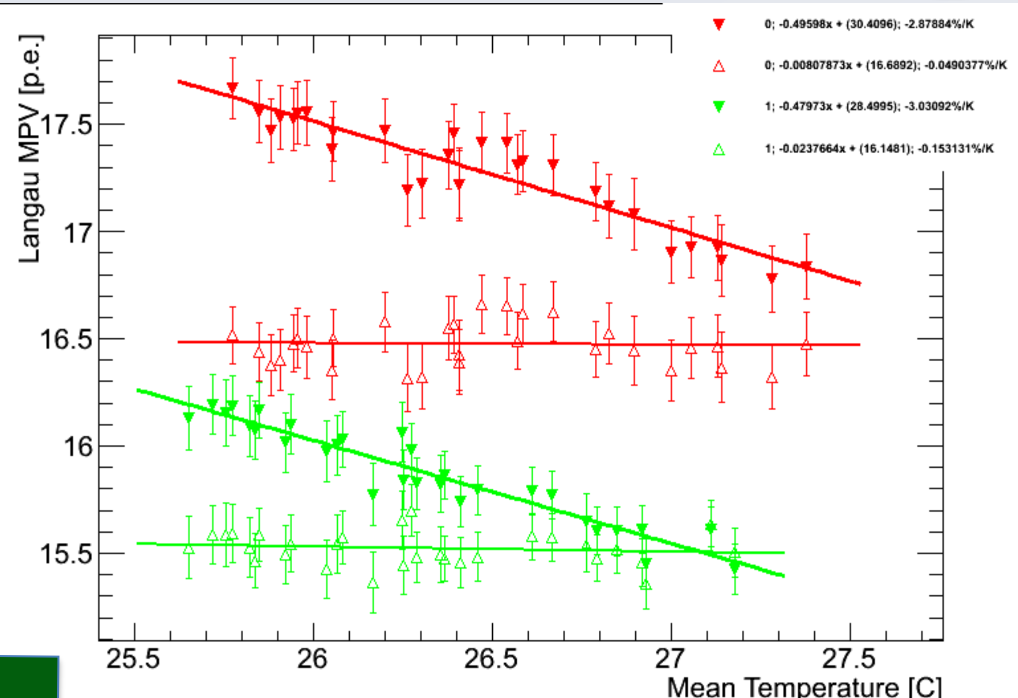
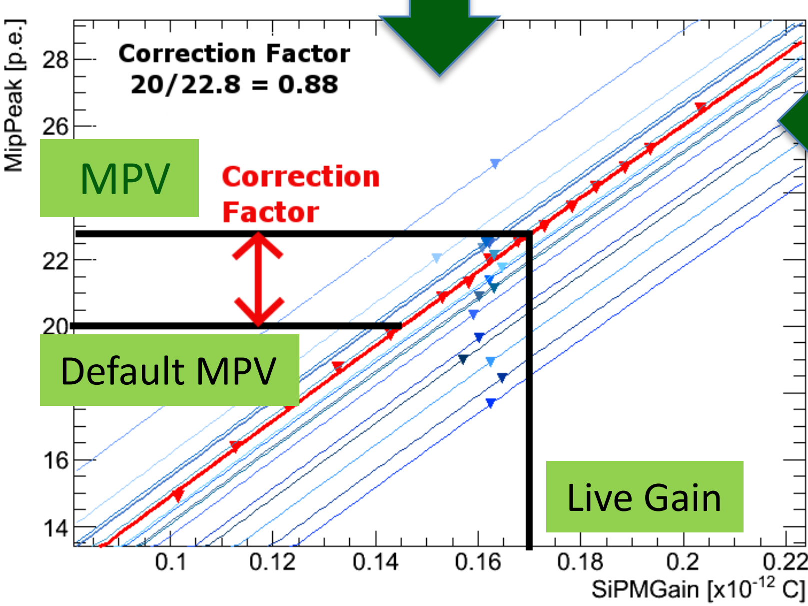




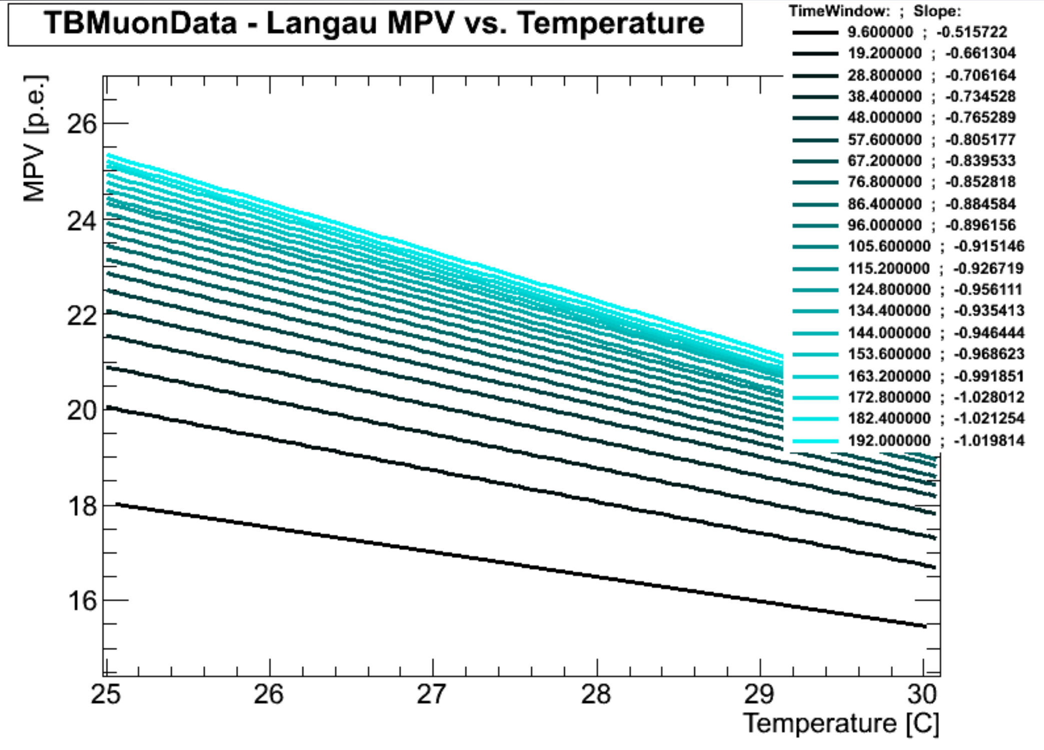


- Time window of 9.6ns

T3B Tile	MPV Drop	Slope
Center	-2.9 %/K	-0.5 p.e./K
Center + 1	-3.0 %/K	-0.48 p.e./K
Center corrected	-0.05 %/K	-0.008 p.e./K
Center + 1 corrected	-0.15 %/K	-0.024 p.e./K

- Obtain Correction factor

Verification of the Calibration Principle: Muon Data



<u>Extracted MPV-Temperature dependence</u>

Time integration window: 9.6 ns – 192 ns

→ Lower Temperature equivalent to higher gain

→ As before: Results in higher Afterpulsing and Crosstalk Probability

Linearity due to low T-Range (2C)!?

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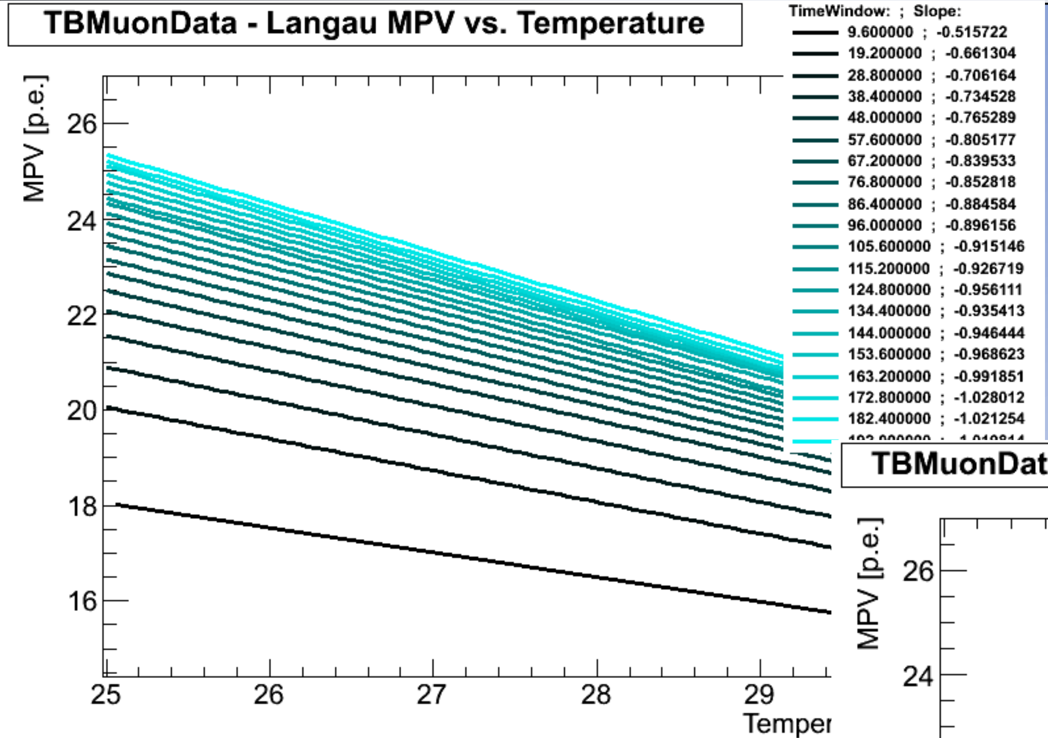

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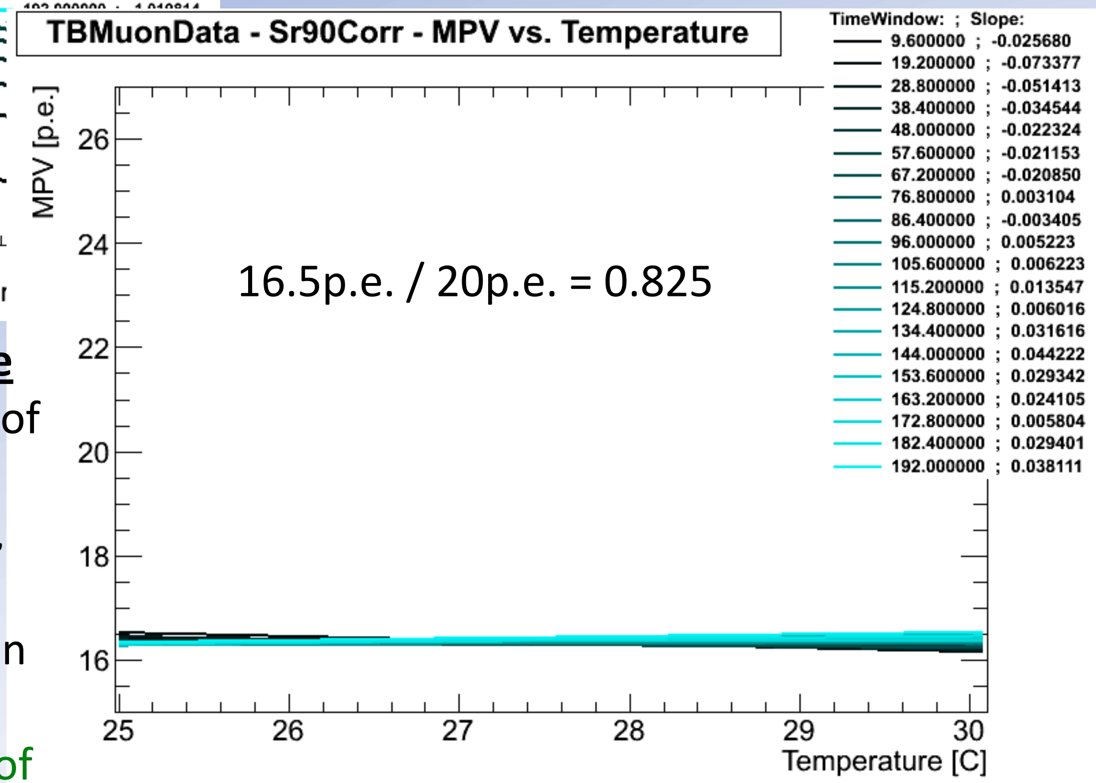


Corrected MPV-Temperature dependence

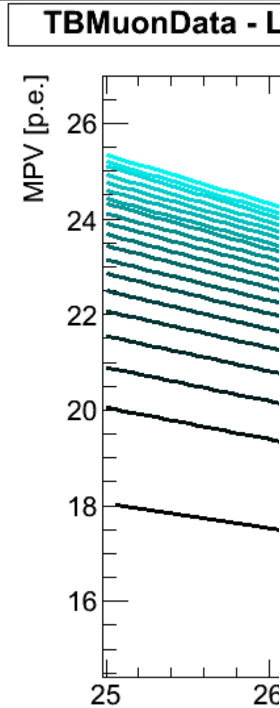
Calibration results in efficient elimination of the dependence

Note: Corrected MPV values at ~16.5 p.e., not at the 20 p.e. we corrected to.

Interpretation: 0.825 is the Sr90←→Muon MPV conversion factor

Matches simulations → Experimental proof

Verification of the Calibration Principle: Muon Data



Extracted MPV-Temperature dependence

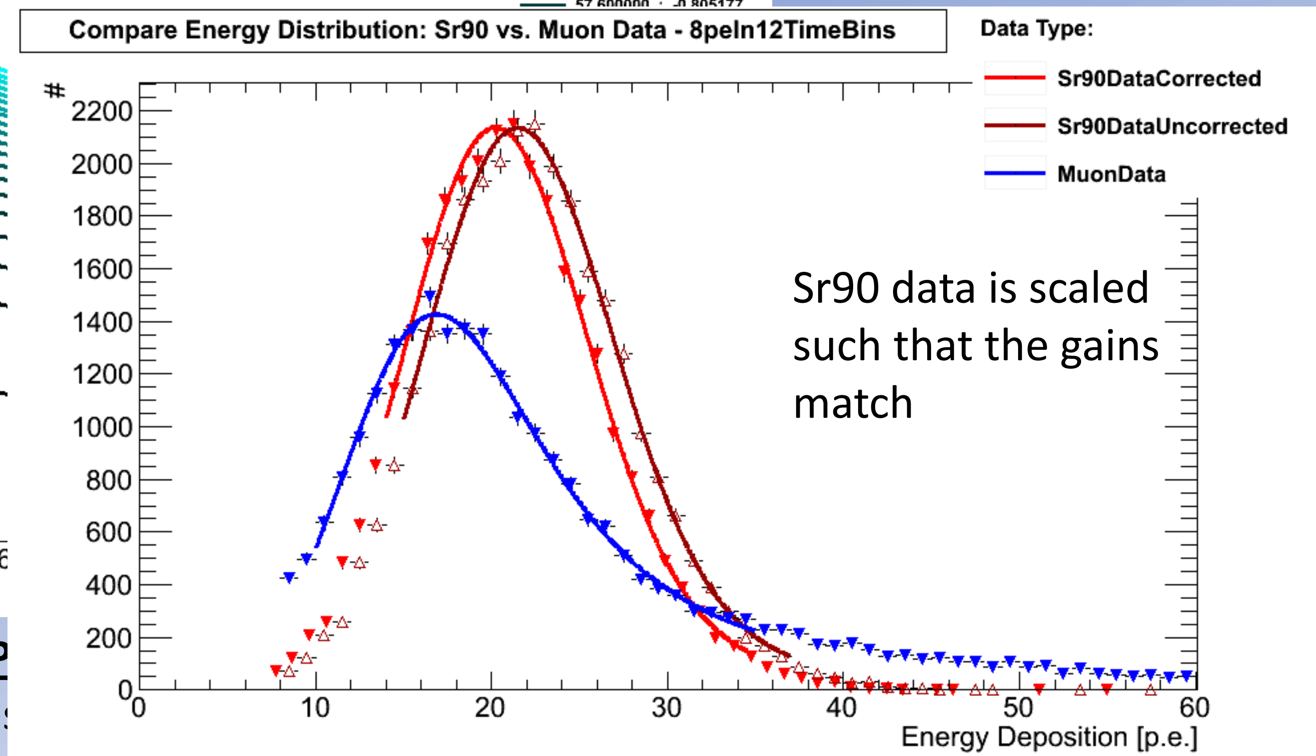
Time integration window: 9.6 ns – 192 ns

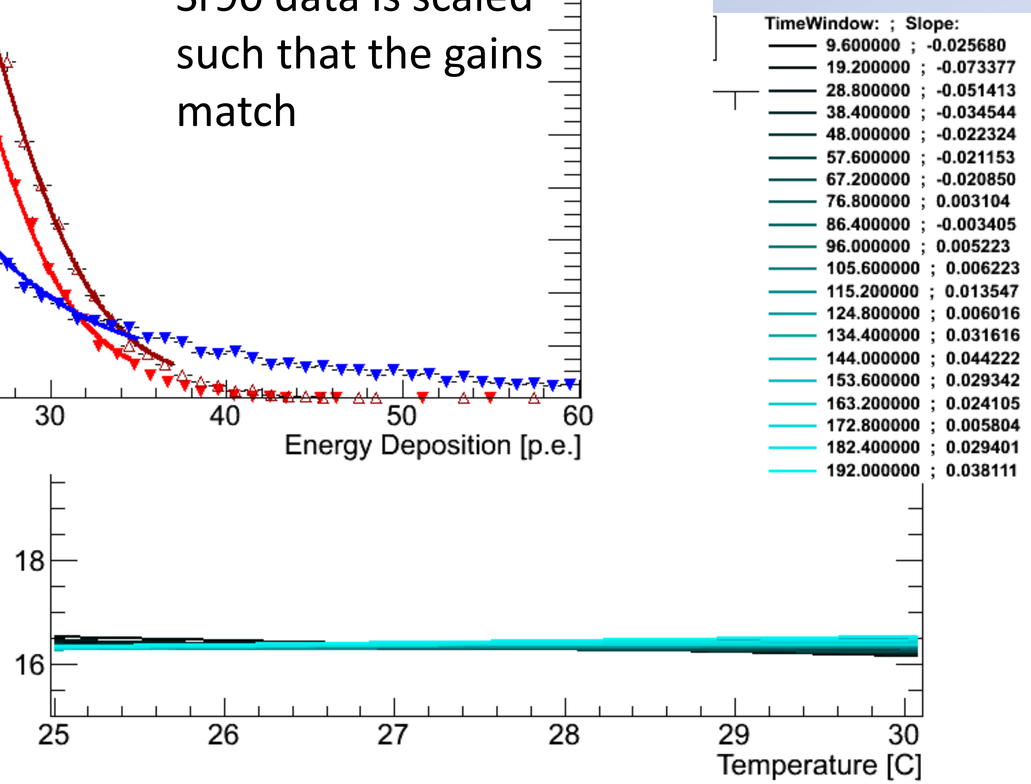
…ivalent to

…her

…lk Probability

…e (2C)!?





Corrected MP…

Calibration re…

the dependence

Note: Corrected MPV values at ~16.5 p.e., not at the 20 p.e. we corrected to.

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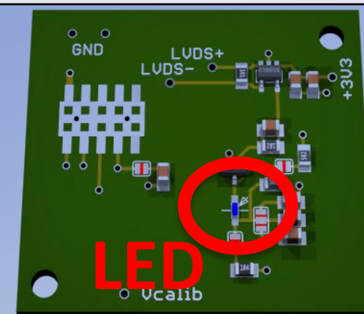
ROADMAP

Roadmap: Missing Calibration Steps



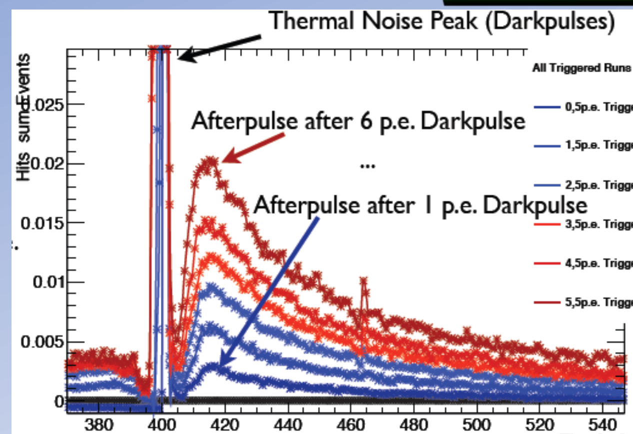
- **SiPM Saturation correction:**

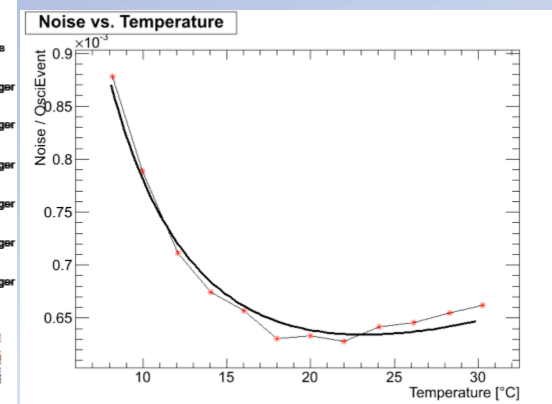
Very promising results from Marco with Wuppertal LED board and T3B tiles

- **Correction for Afterpulsing:**

  → Need a dictionary: Which pulse height causes on average which afterpulsing contribution at a certain time after the initial pulse?

  → Promising results by Simon (also correction for darkrate)



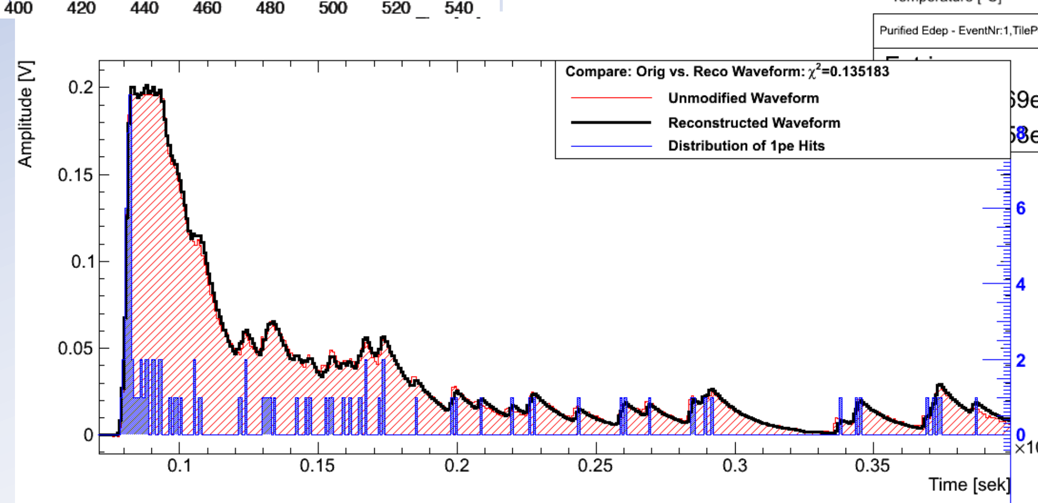


- **Clipping Correction:**

  Waveform decomposition can only work up to +-200mV range with an 8bit ADC

  →Higher energy depositions clipped

  → Original waveform probably recoverable from the signal shape



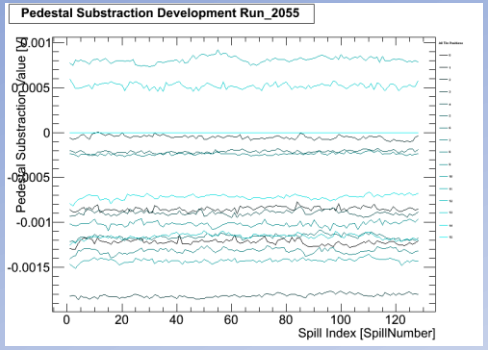
Roadmap: Run Quality Checks

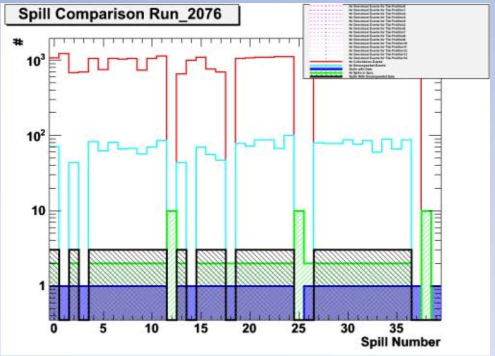
T3B is a very high statistics experiment → need to concatenate all Runs at one energy

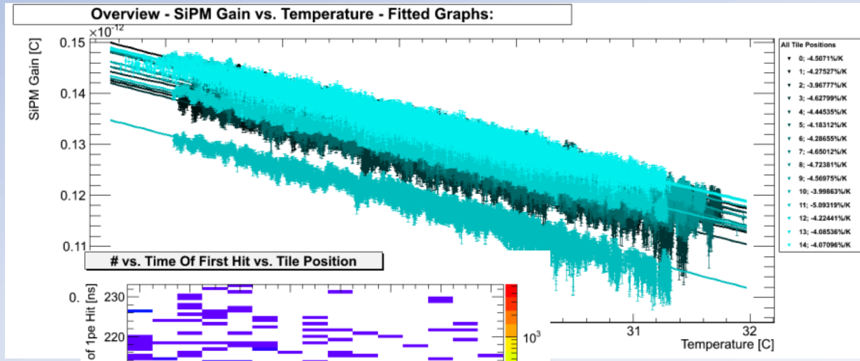
Processing power is no issue: Analyze ~ 15min/million events on a standard CPU

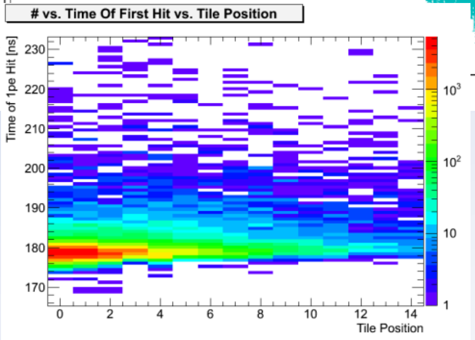
Developing procedure to identify suboptimal run conditions:

- CALICE Runlog → by eye ☹
- Use Particle ID (from Cerenkovs), Beam profile
  → needs T3B-Calice synchronization for most of the data → Lars ongoing…
- T3B Hardware (e.g. pedestal jumps…) → automated "Calibration Quality Check" exists









Final step → obtain timing results that are bullet proof

- Energy deposition vs. time
- Shower timing vs. particle energy
- Longitudinal timing of hadron showers
- …

There is still big potential in the T3B data → we look forward to a successful year 2012