Accelerator beam physics and beam parameters measurements at LHC and SPS

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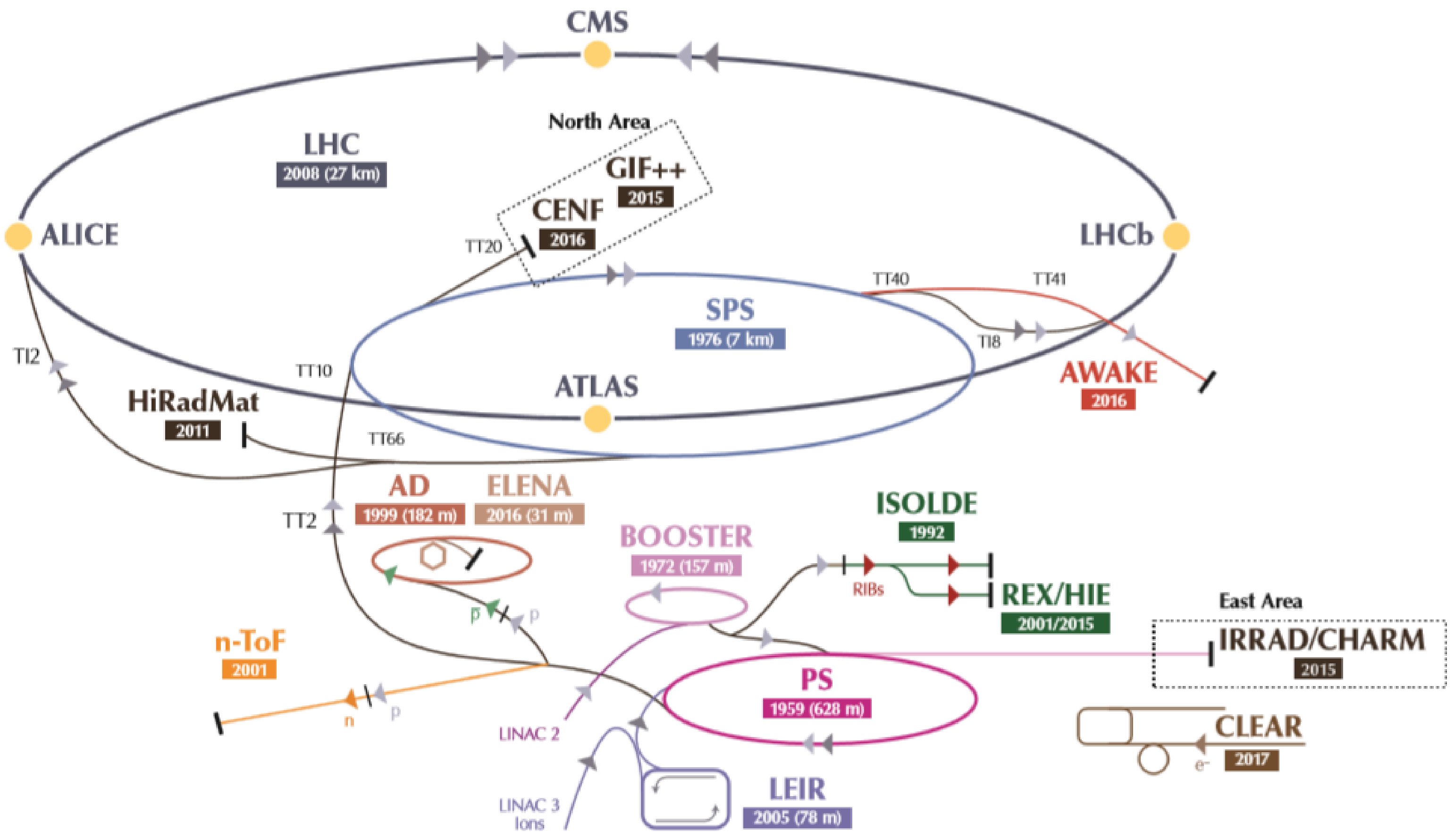
Outline

- Per bunch Intensity measurement
  - Integrating algorithm
- Signal leakage deconvolution
  - Problem of 25ns spacing
  - Results of correcting algorithm
- Single shot bunch by bunch Intensity measurements for Transfer lines
  - Analysis of the precision for different ADC
- Wrong bucket injection
- Conclusion

The CERN accelerator complex
Complexe des accélérateurs du CERN

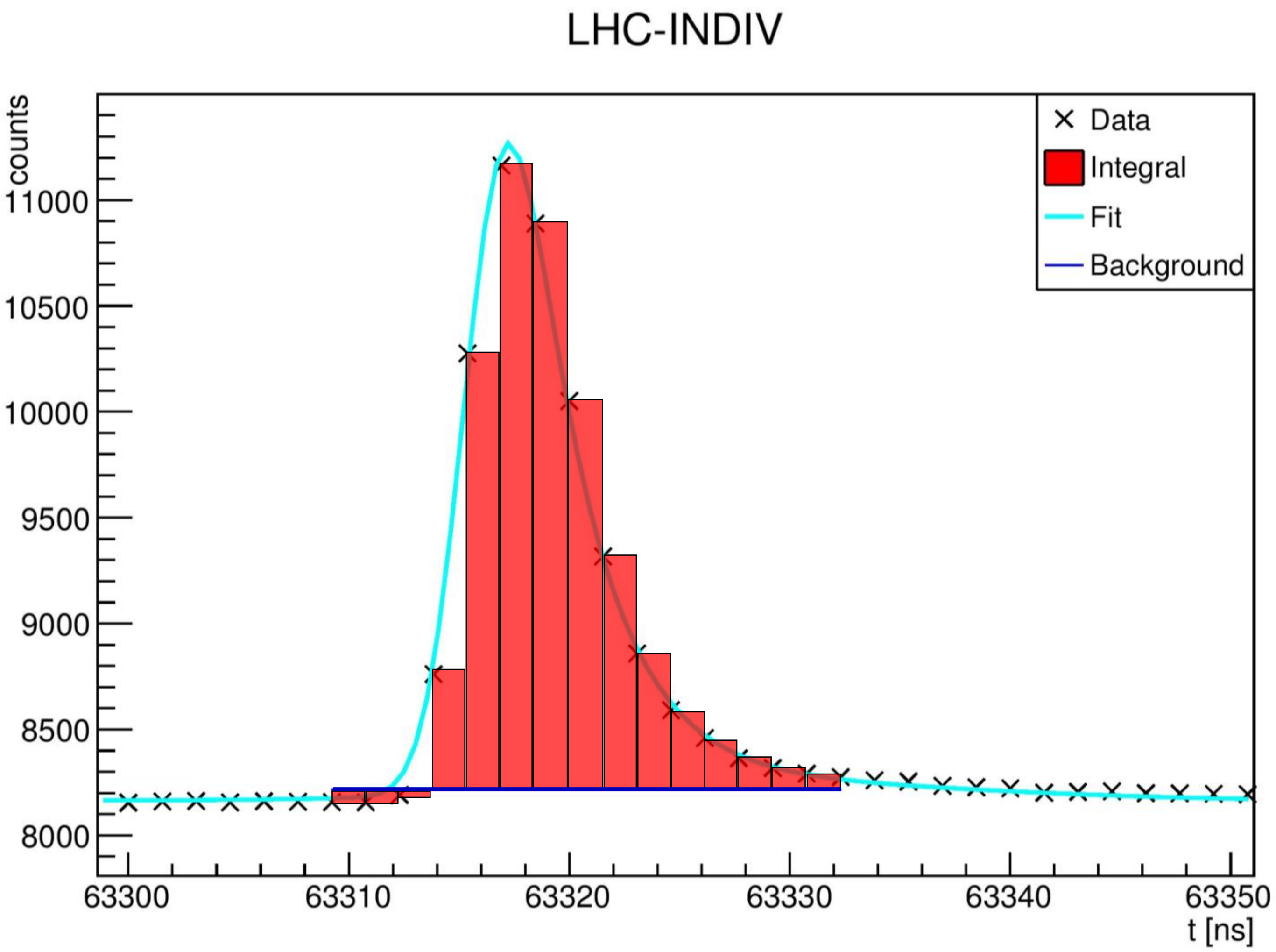


p (protons) ions RIBs (Radioactive Ion Beams) n (neutrons) $\bar{p}$ (antiprotons) e^- (electrons)

LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKefield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE - Radioactive EXperiment/High Intensity and Energy ISOLDE // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n-ToF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials // CHARM - Cern High energy AcceleRator Mixed field facility // IRRAD - proton IRRADiation facility // GIF++ - Gamma Irradiation Facility // CENF - CErn Neutrino platForm

Bunch by bunch intensity measurement

- Measures induced signal to give information about charge content of each bunch
  - Sampling is 650MHz ≈ 1.54ns
  - Raw signal shaped
  - FMC -1000 – Free running phase
    - Integrating over many sampling phases



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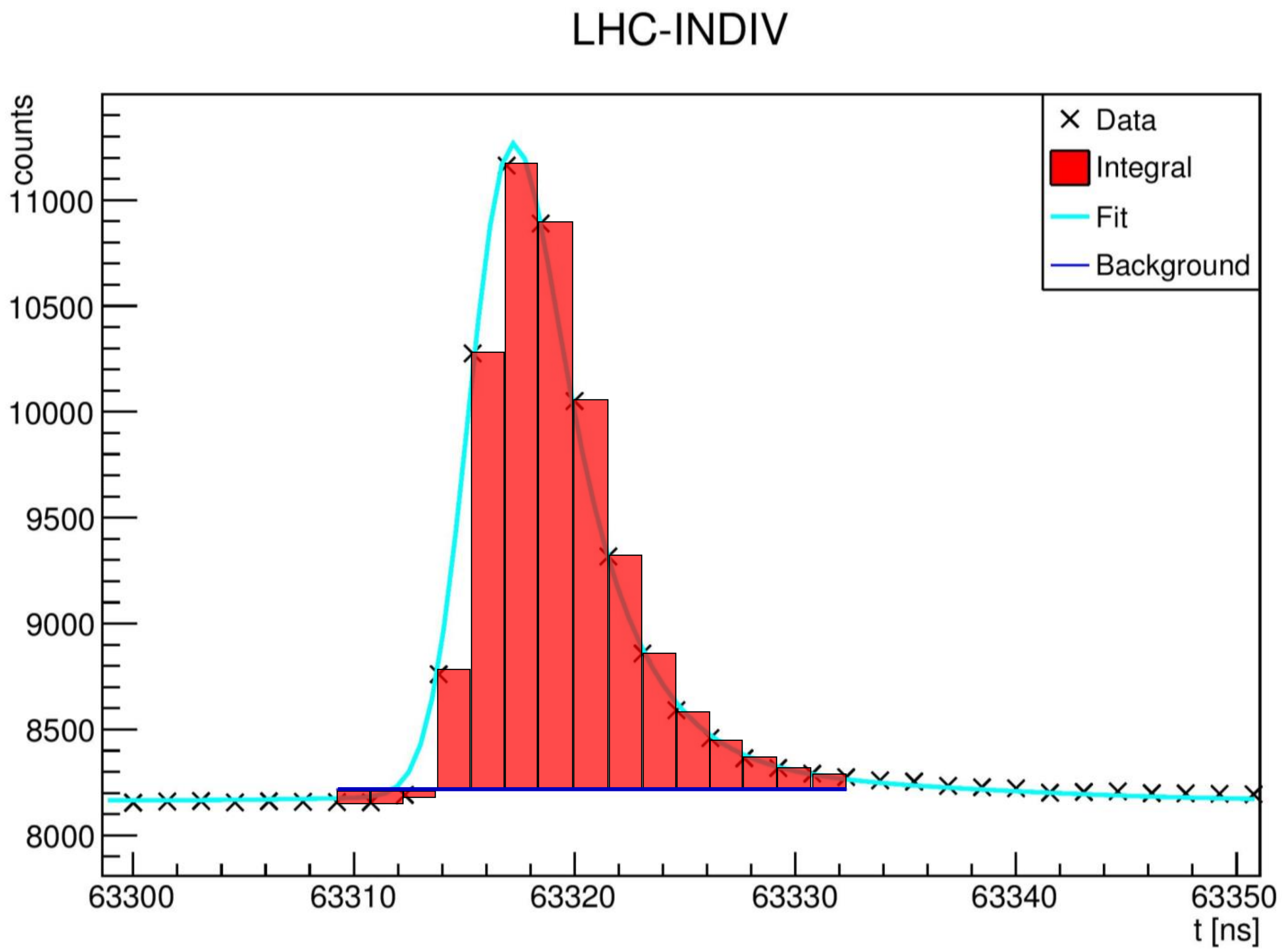
- Integrating Algorithm
  - Samples used:
    - 5 before maximum – configurable
    - 10 after maximum – configurable
    - 16 samples in total
  - Background – linearly approximated
  - Integral of peak $= \sum_{i=max-5}^{max+10}(c_i - bcg)$
    - c_i – counts in sample i
    - $bcg = (c_{max+10} + c_{max-5})/2$



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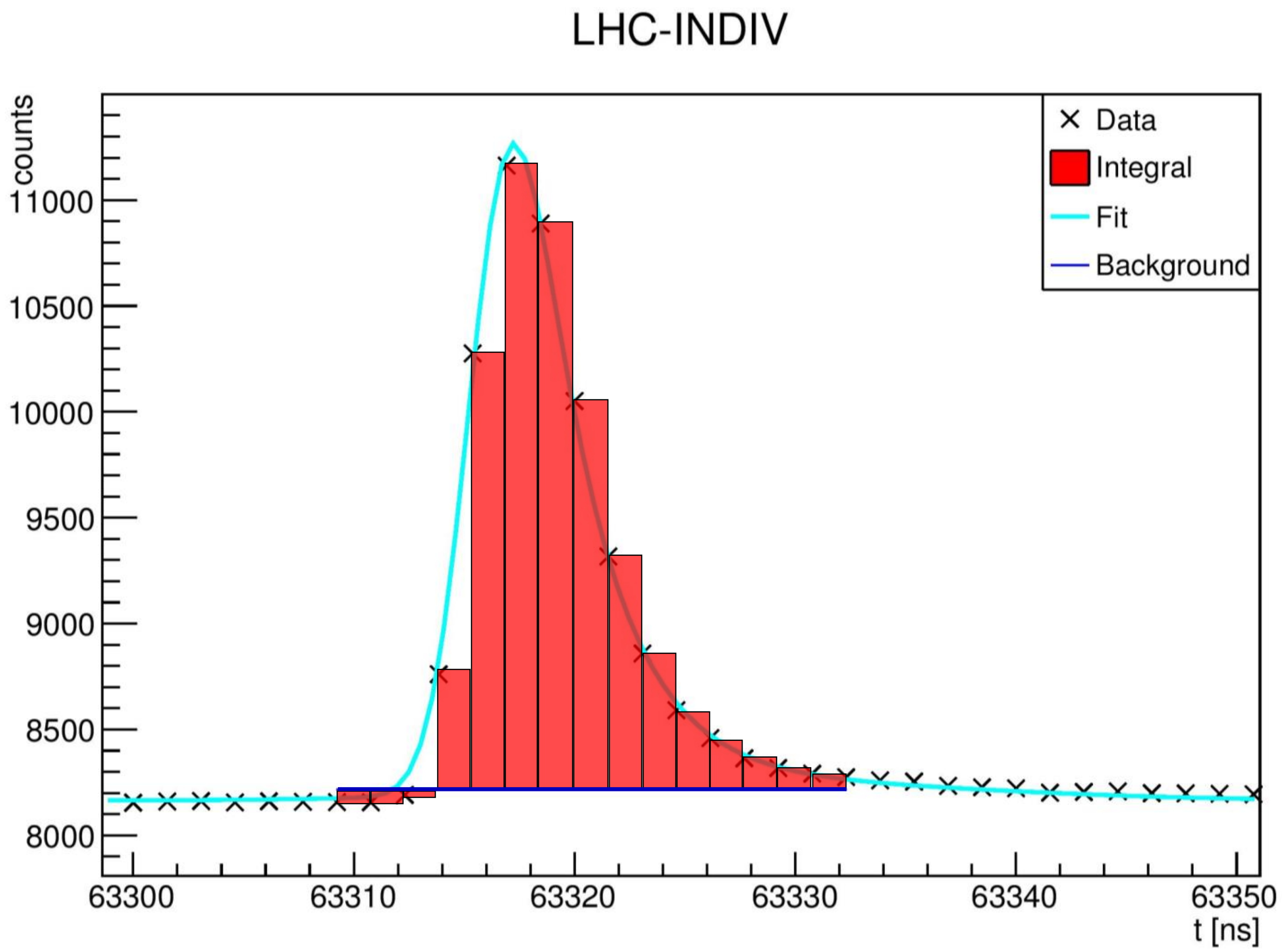
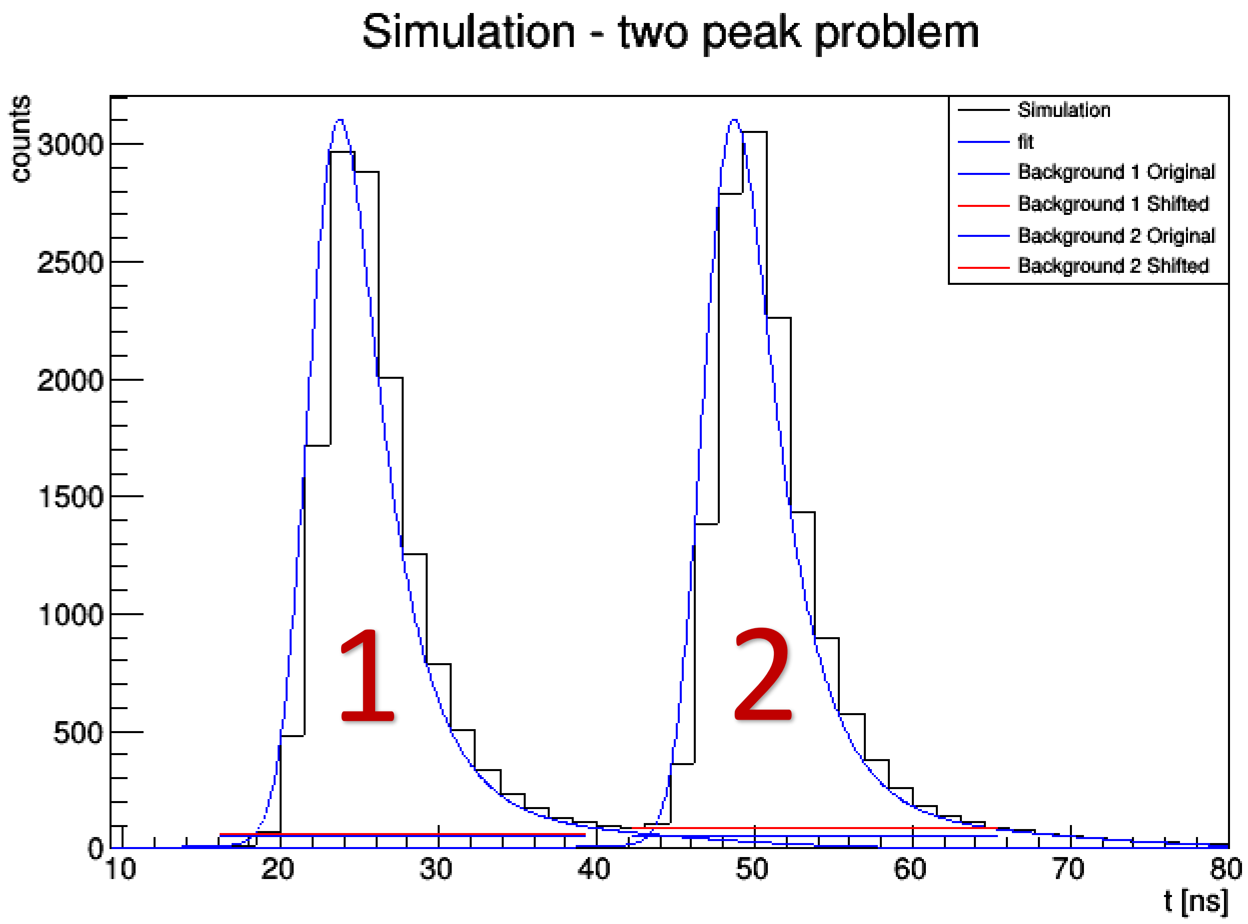
- Fit form:
  - Exponentially modified Gaussian + small Gaussian at front



Signal leakage of 25ns spacing

- Simulation
  - Fits refined with current SPS raw data
- Problem ➡ signal overlap



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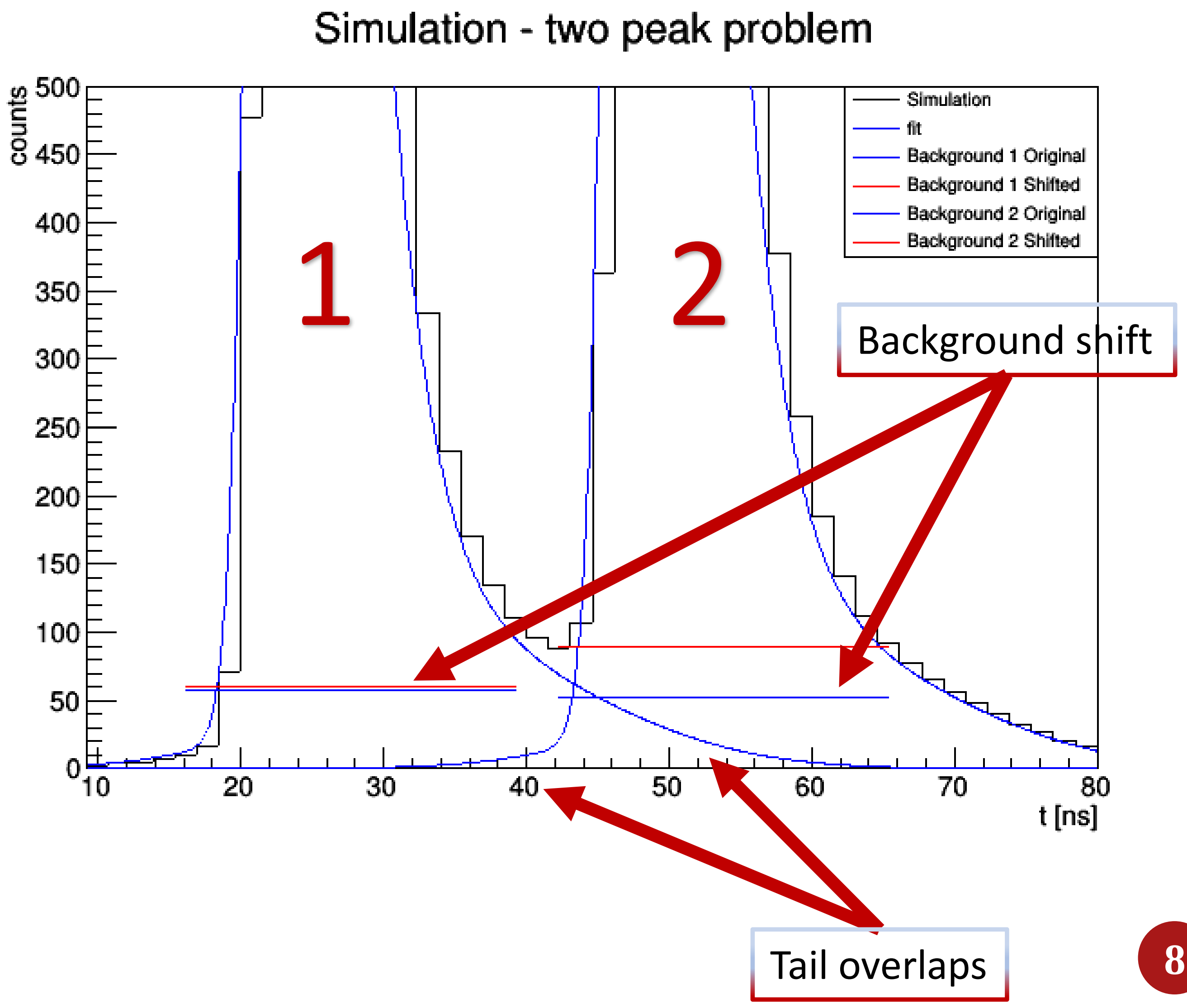
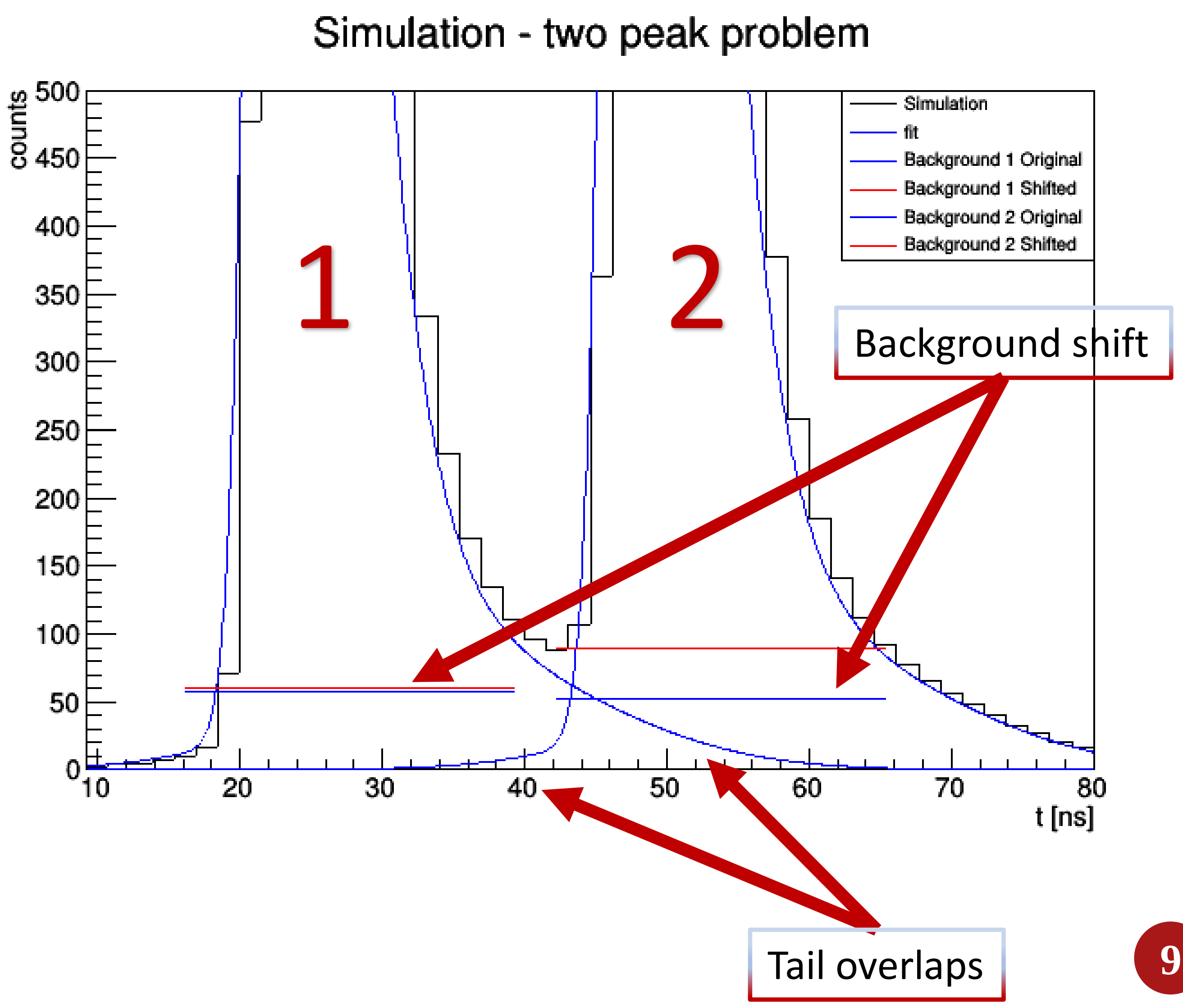
- Two parts of contribution
  - Tail overlap integral
    - Positive (rises the integral)
  - Shift of background line
    - Negative

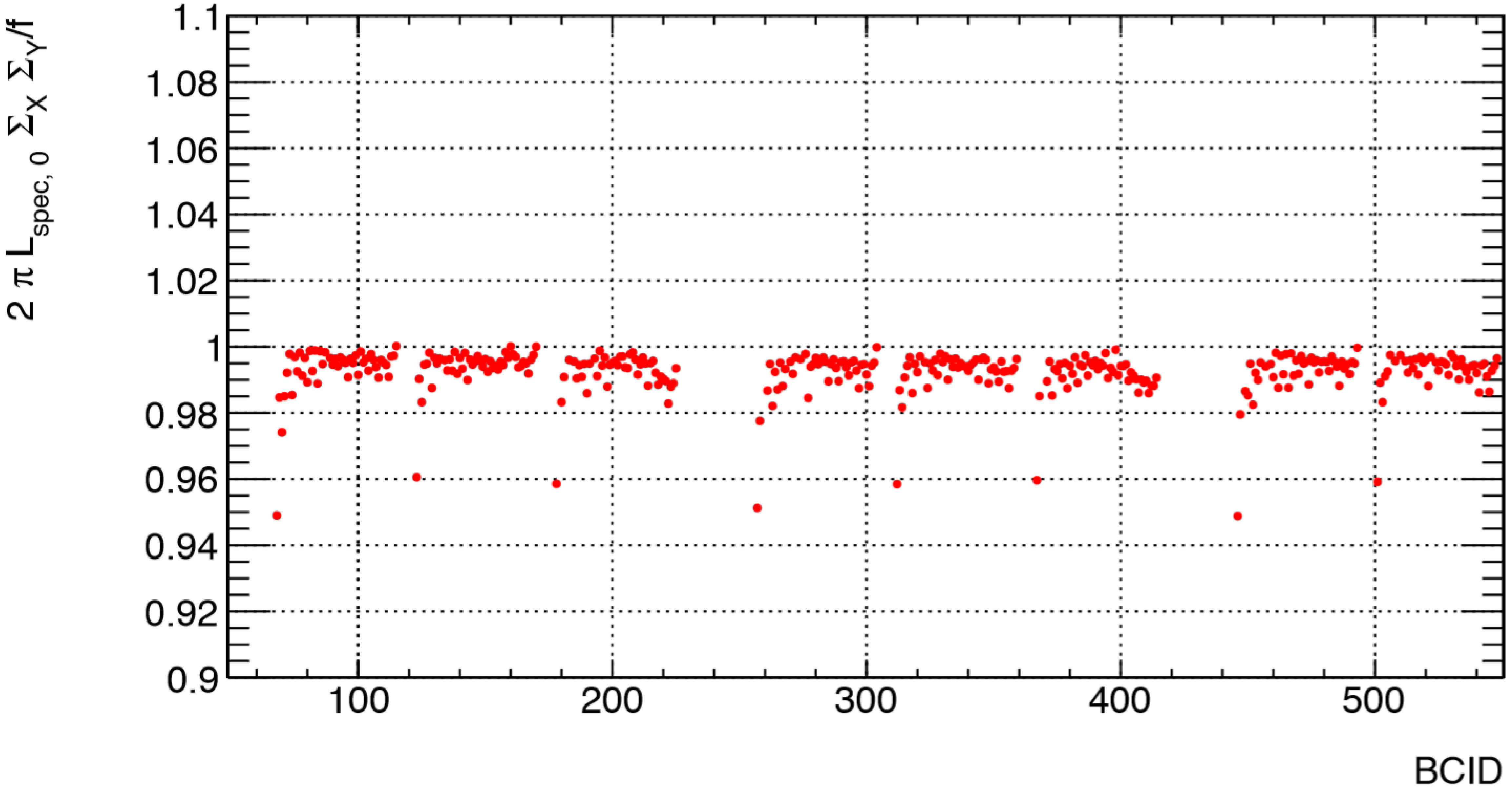


Signal leakage of 25ns spacing

- Simulation
  - Fits refined with current SPS raw data
- Problem → signal overlap
- Two parts of contribution
  - Tail overlap integral
    - Positive (rises the integral)
  - Shift of background line
    - Negative
- Simulation: using Root 6
  - Shift of background > Tail overlap integral
    - Overall negative contribution
  - Peak 1 effects peak 2 more
    - $\approx 2.5\%$
  - Peak 2 effects peak 1 less
    - $\approx 0.5\%$



Luminosity measurements: Observed/Predicted



Correcting Algorithm

- $I_b[i]$ – Integral of a broken signal num. i
- $I_{pc}[i]$ – Integral of a partially corrected signal
- $I_c[i]$ – Integral of a corrected signal

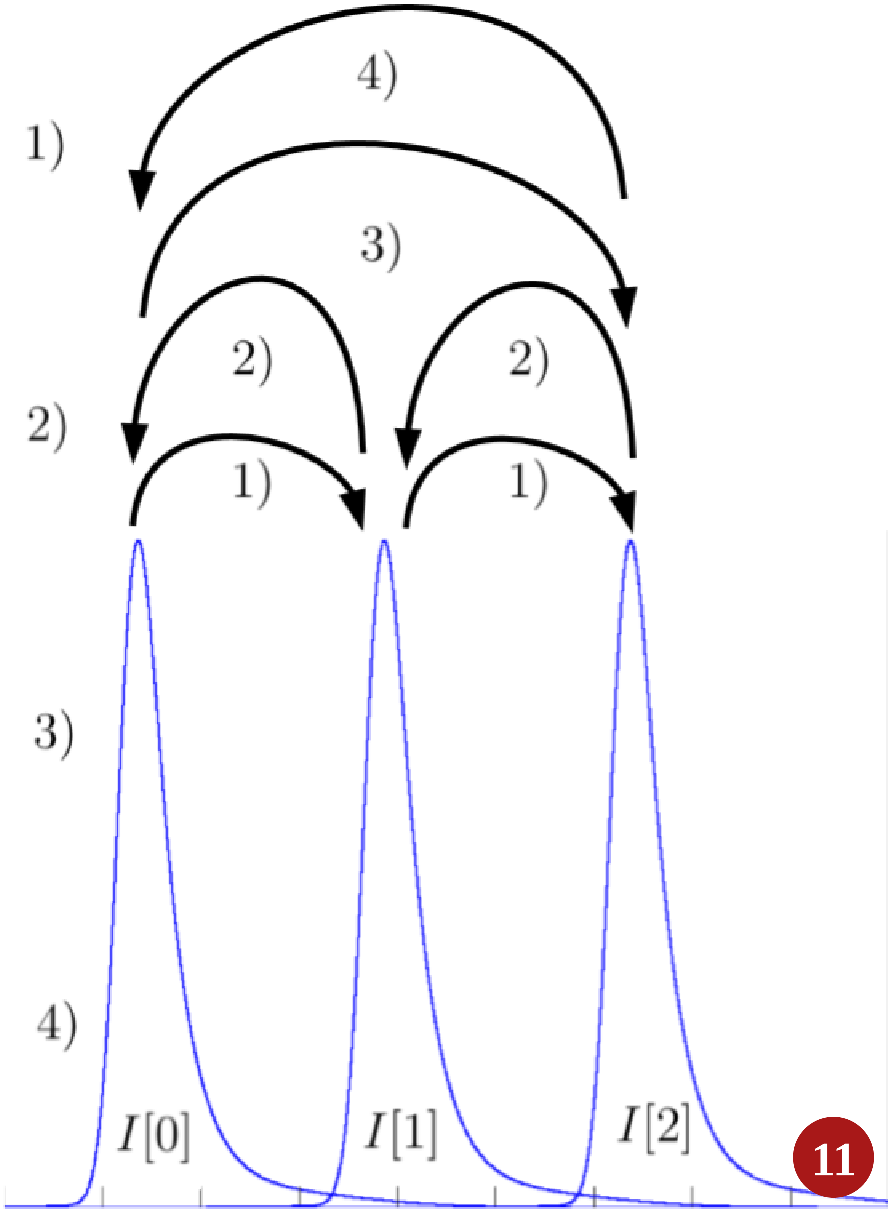
- Parameters found by numerical minimalization (Minuit)
  - Only A_1 and A_2 found nonzero

$$\left.\begin{aligned} I_{pc}^1[0] &= I_b[0] + A_1 \cdot 0, \\ I_{pc}^1[1] &= I_b[1] + A_1 \cdot I_{pc}^1[0] \,/ I_b[0] \\ I_{pc}^1[2] &= I_b[2] + A_1 \cdot I_{pc}^1[1] \,/ I_b[1] \end{aligned}\right\} \text{1)}$$

$$\left.\begin{aligned} I_{pc}^2[0] &= I_{pc}^1[0] + A_2 \cdot I_{pc}^2[1] \,/ I_b[1] \\ I_{pc}^2[1] &= I_{pc}^1[1] + A_2 \cdot I_{pc}^2[2] \,/ I_b[2] \\ I_{pc}^2[2] &= I_{pc}^1[2] + A_2 \cdot 0, \end{aligned}\right\} \text{2)}$$

$$\left.\begin{aligned} I_{pc}^3[0] &= I_{pc}^2[0] + A_3 \cdot 0, \\ I_{pc}^3[1] &= I_{pc}^2[1] + A_3 \cdot 0, \\ I_{pc}^3[2] &= I_{pc}^2[2] + A_3 \cdot I_{pc}^3[0] \,/ I_b[0] \end{aligned}\right\} \text{3)}$$

$$\left.\begin{aligned} I_{pc}^4[0] &= I_{pc}^3[0] + A_4 \cdot I_{pc}^4[2] / I_b[2] \\ I_{pc}^4[1] &= I_{pc}^3[1] + A_4 \cdot 0, \\ I_{pc}^4[2] &= I_{pc}^3[2] + A_4 \cdot 0, \end{aligned}\right\} \text{4)}$$

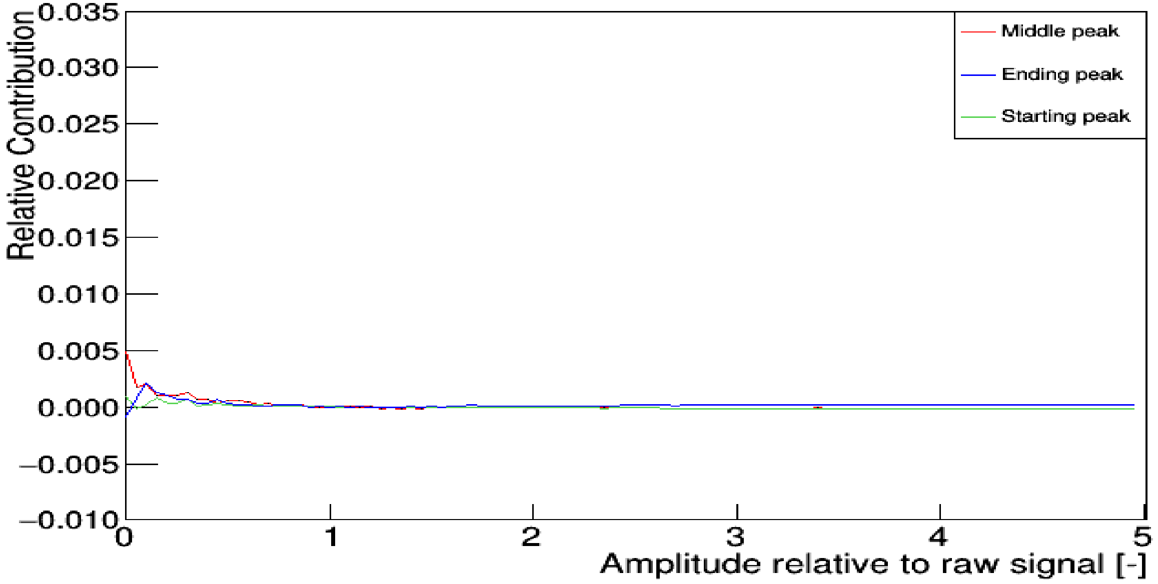


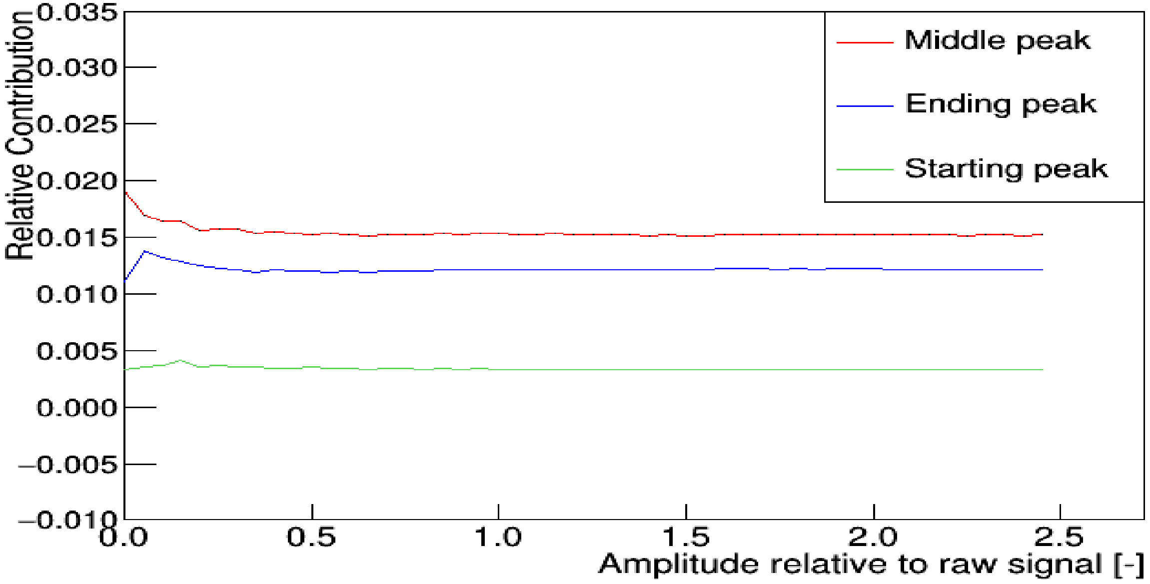
Simulation with correcting algorithm

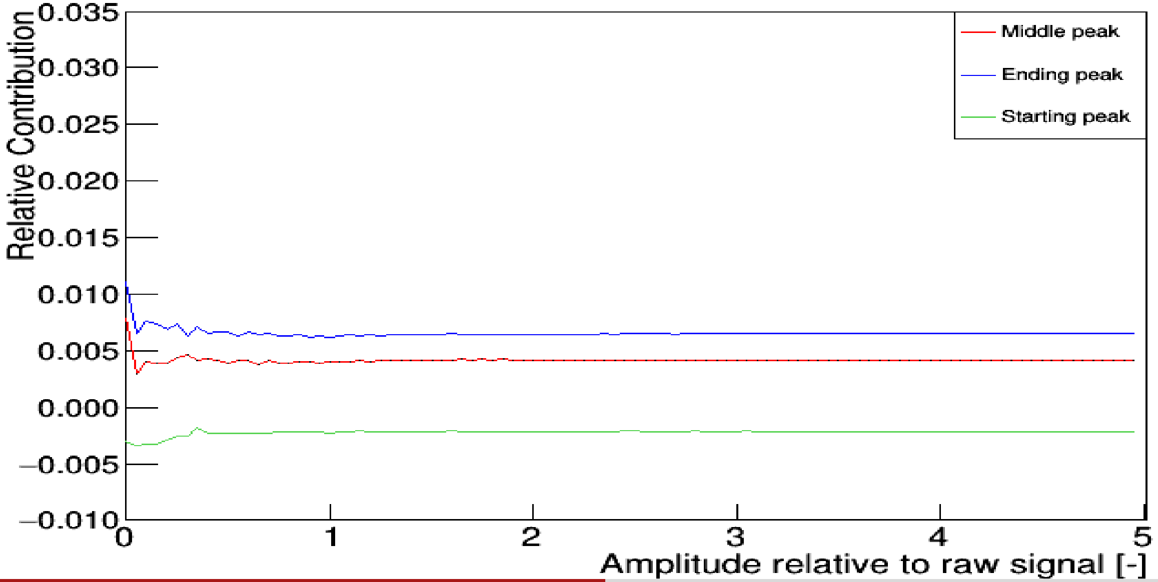
- Correcting algorithm:
  - $Int_{PartC}[i] = A \cdot Int_{PartC}[i-1] + Int_{Broken}[i]$
  - $Int_{Corr}[i] = B \cdot Int_{PartC}[i+1] + Int_{PartC}[i]$
  - First and last peak are corrected only for contribution from next or previous peak
- Fits of multiple peaks used in analysis
- Specification error of measurement for LHC and SPS is 1% and 5%, respectively.
- Relative contribution $= 1 - \frac{I_{broken}}{I_{ideal}}$
  - With use of the correcting algorithm σ = 0.19%

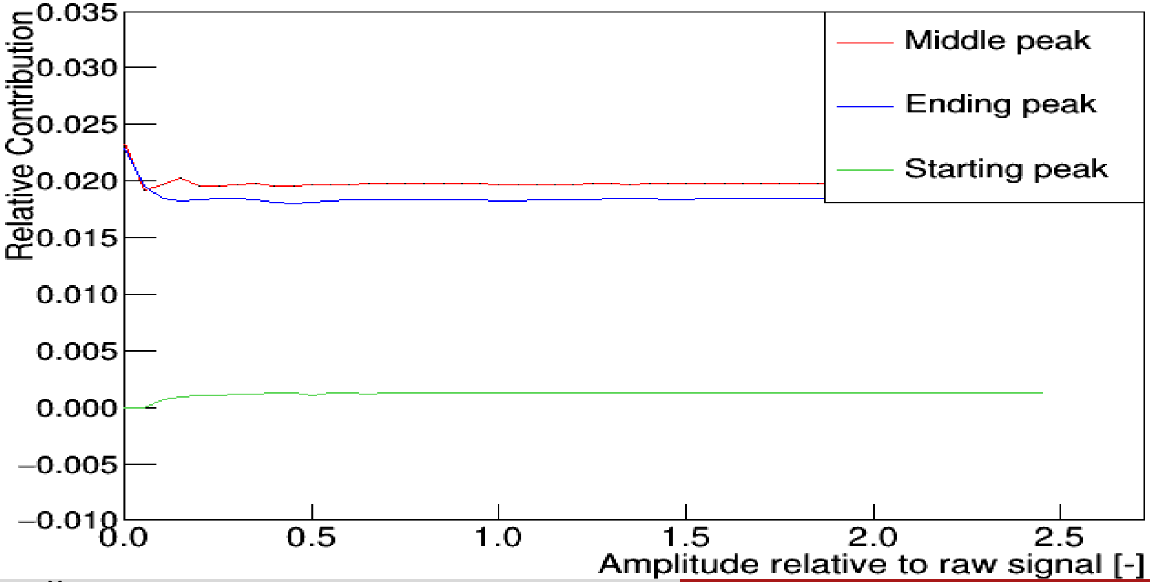
- Results from measurements will be available after Technical stop 2
  - Evaluation algorithm performance – using integrating intensity measurements

Relative contribution with (left) and without (right) use of correcting algorithm



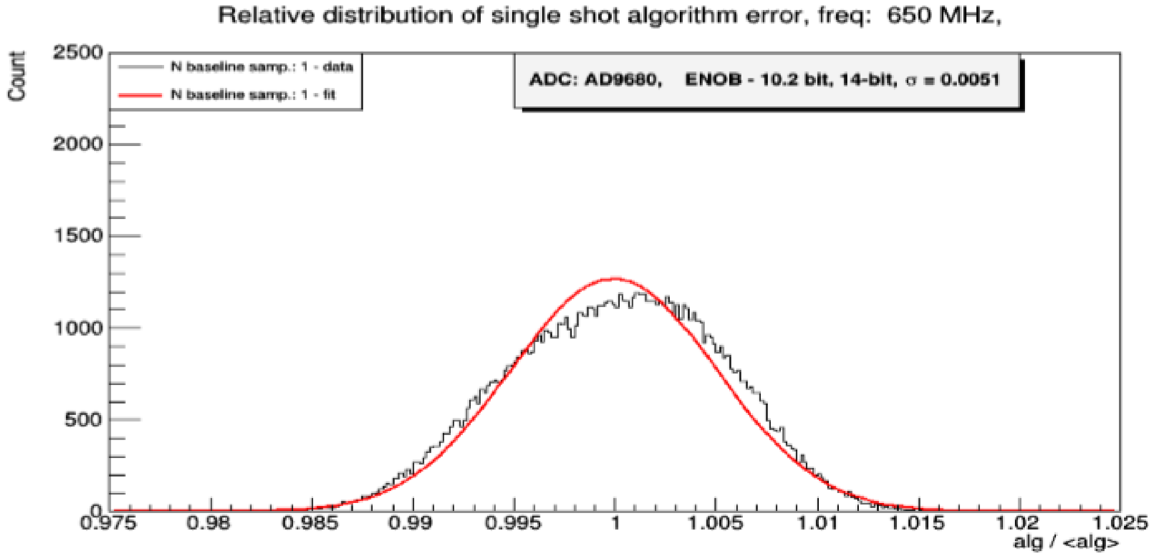


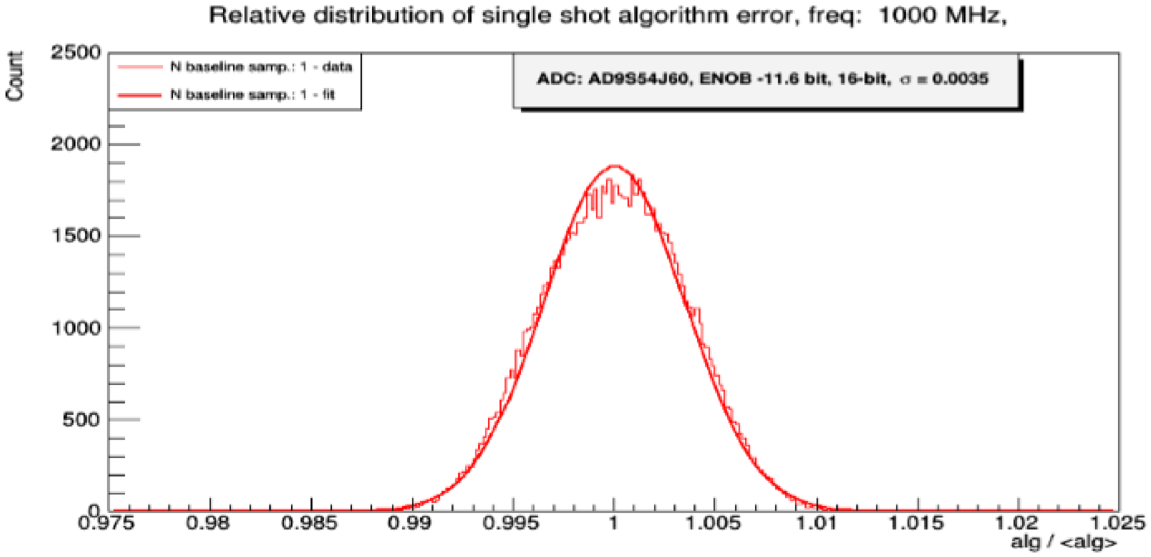


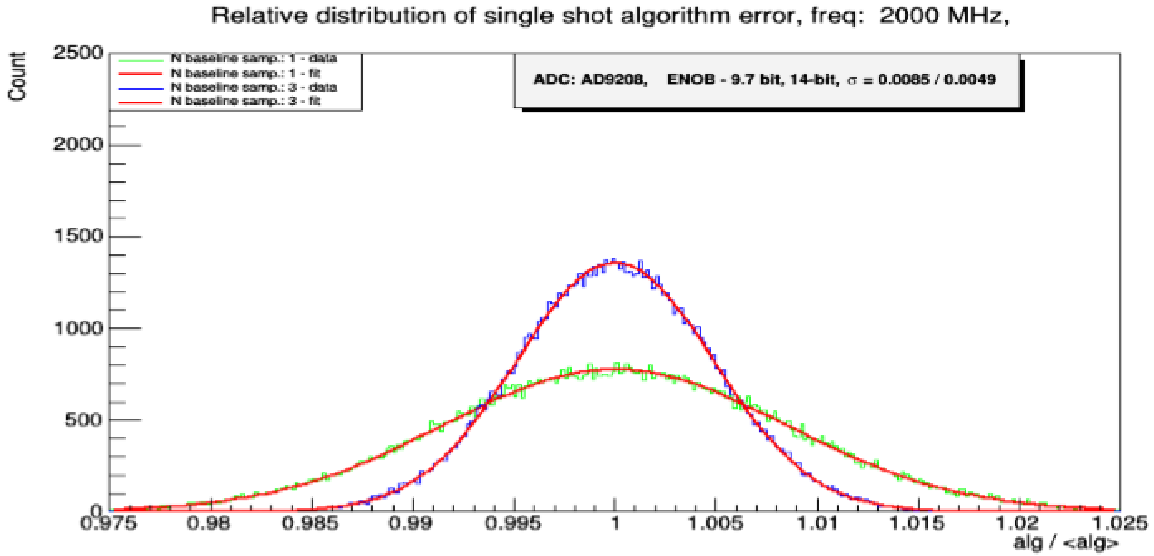


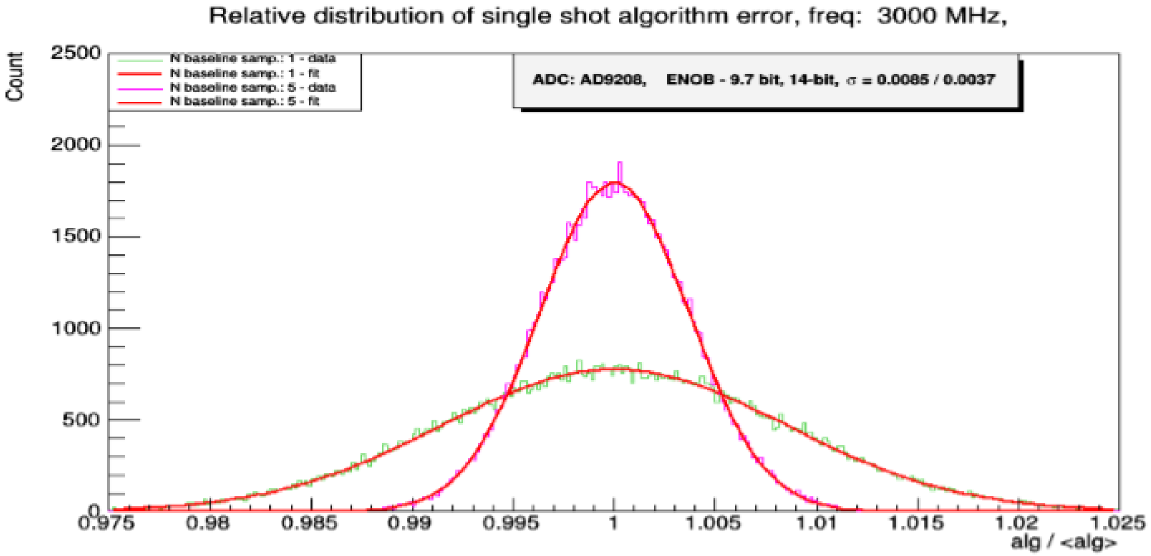
Single shot bunch by bunch Intensity measurements for Transfer lines

- Single shot measurements – no averaging over sampling phases
  - Single shot error – error steaming from different sampling phase
- Different Analog to Digital Convertors (ADCs) considered
  - Different sampling frequency (600 – 3000 MSPS)
  - Different ADC noise – Effective Number of Bits (ENOB)
  - Different precision (14-bit or 16-bit) ADC









Each distribution is constructed including gaussian noise from distribution corresponding to given ADC ENOB.

Wrong bucket injection

- The injection scheme of the LHC beam – 1 in every 10 buckets filled with bunch
- Wrong injection = Different buckets filled
  - Many measurements produce erroneous results
- Happened twice in the past -> cost 6 hours of operational time at minimum
- The alerting algorithm developed and implemented
  - Analyzes distribution of distance between asynchronous (of beam) equidistant markers and bunch peaks
  - An update to the per bunch intensity measurement system
  - Alerts the operators to minimize the cost of wrong injection

Conclusion

Signal leakage:

- For better measurement precision the deconvolution algorithm based on the analysis and simulation was developed and implemented
- Errors should be well under the specification which is 1% and 5% for LHC and SPS, respectively
- Results from measurements will be available after Technical stop 2

- Single shot bunch by bunch Intensity measurements for Transfer lines
  - The analysis of the precision of such measurements for different ADCs was carried out, to study feasibility and sustainable precision.
- Wrong bucket injection
  - Algorithm to notify operators of such wrong injection was developed and implemented
  - An update to the per bunch intensity measurements
- Cooperation with the Intensity & Tune section of Beam Instrumentation group of Beams Department of The European Organization for Nuclear Research

Thank you for your attention

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