The energy reconstruction algorithm for high injection background

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CALOR 2024

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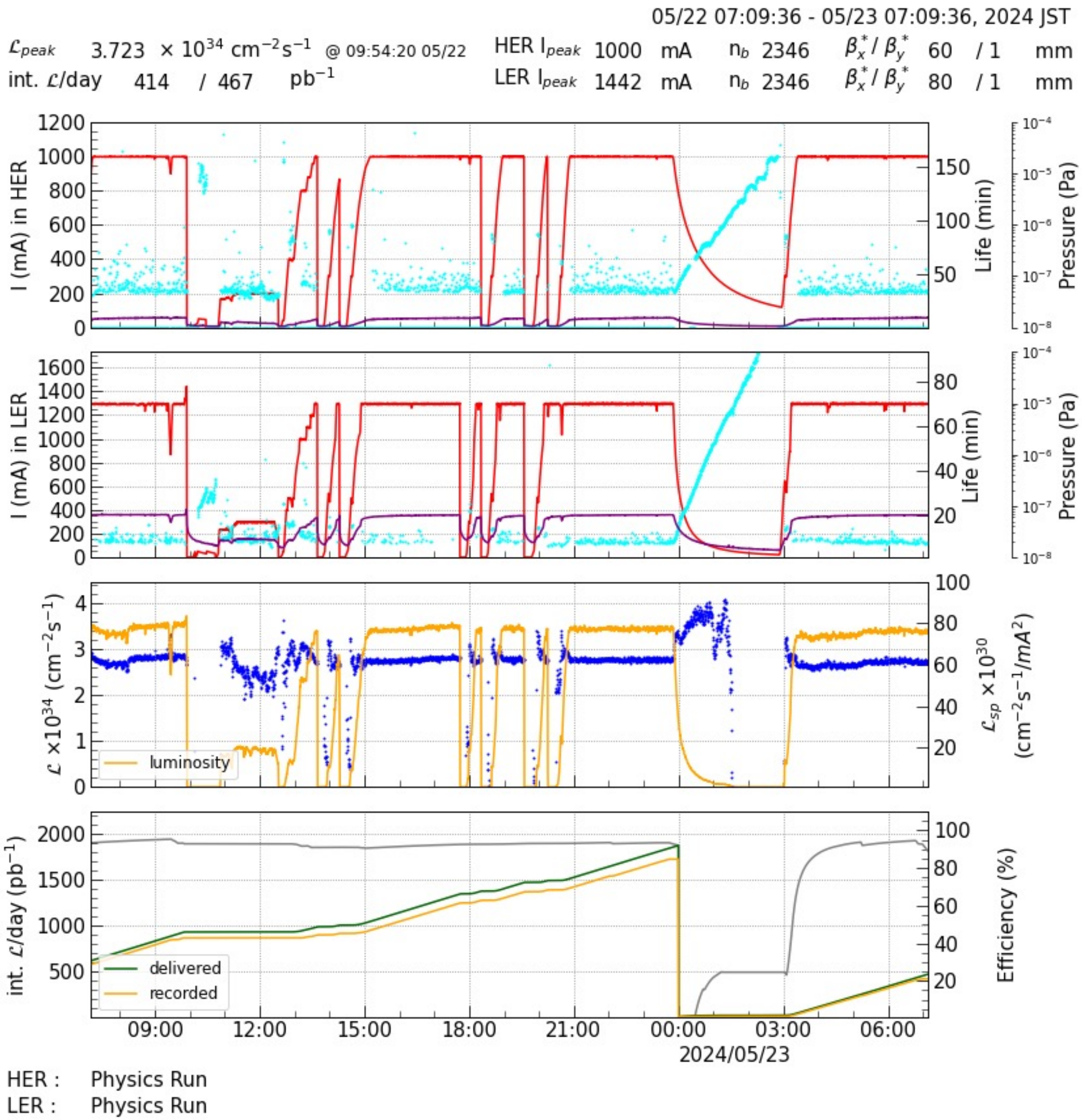
- Continuous injection at SuperKEKB
- Belle II calorimeter
- Problem with injection
- Simulation
- New algorithm
- Test with data
- Summary

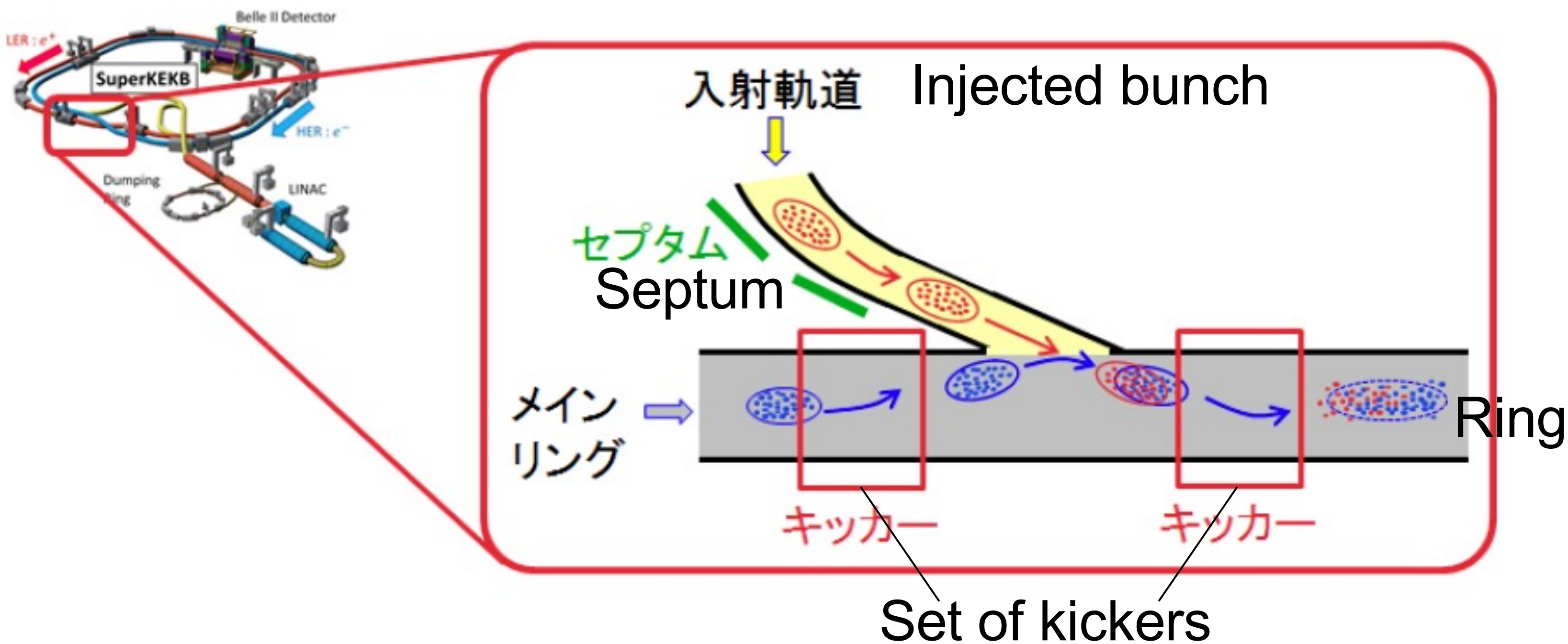
Continuous injection at SuperKEKB



Injector provides 7 GeV and 4 GeV e^- and e^+ beams to HER and LER, respectively.

Important feature to increase integrated luminosity, making machine adjustment easier because of constant beam currents.

Injection Background

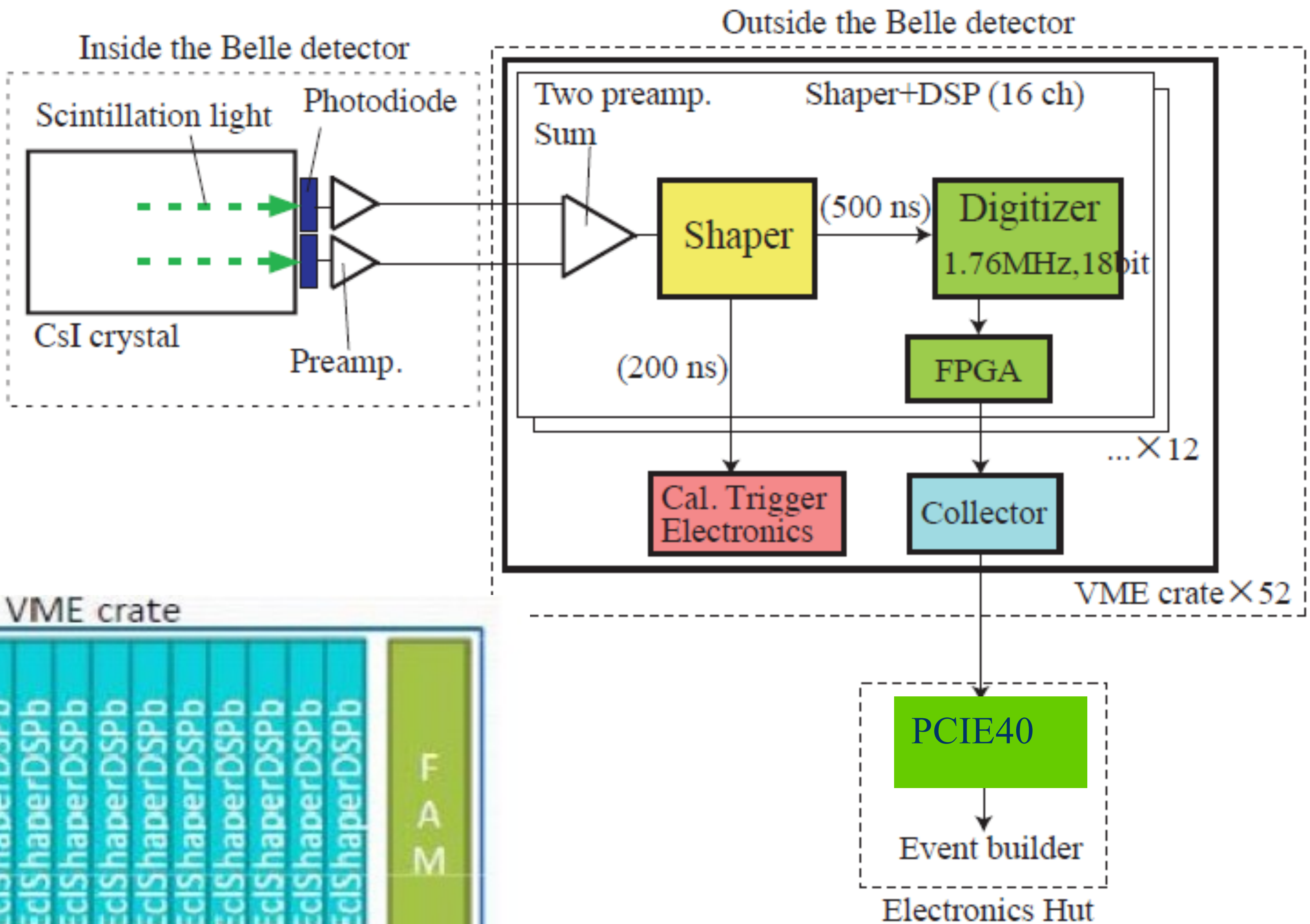


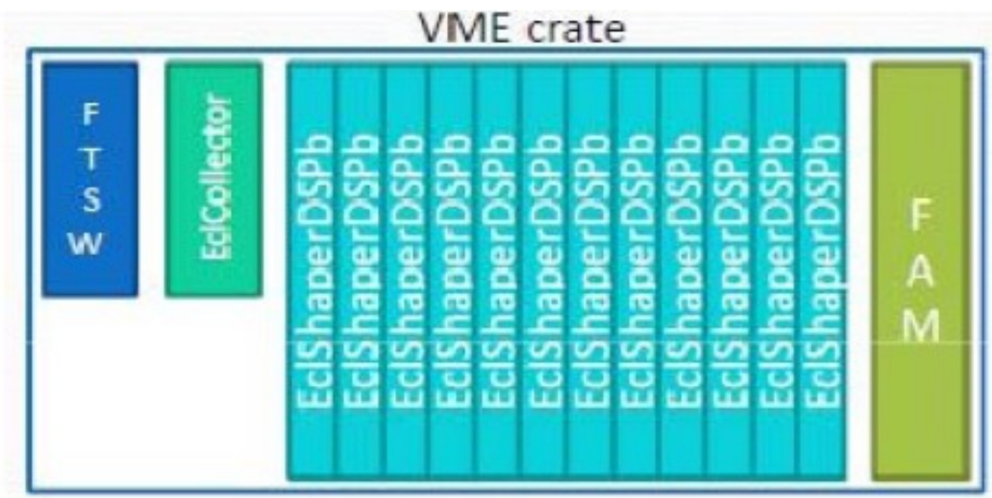
It takes a few × thousand turns to let injected bunch stabilized down to the nominal emittance in the HER/LER.

Since 3 km circumference, a still disturbing bunch goes across Belle II detector IP every 10 μs.

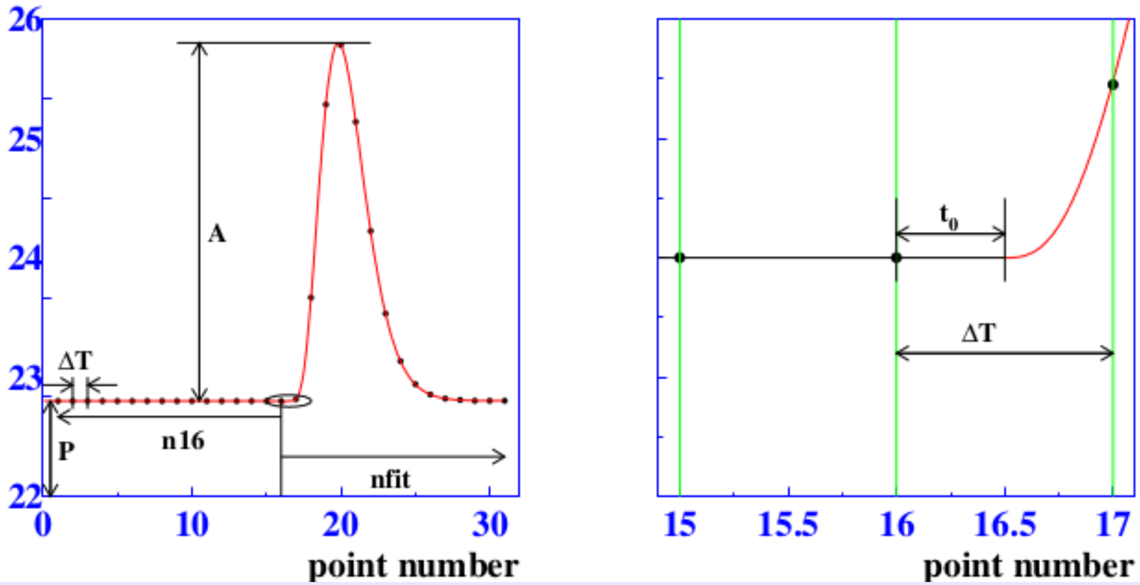
We have to apply a proper VETO at Trigger to kick out dirty events.

Calorimeter electronics





Reconstruction algorithm



-Digitization with sampling rate of 1.76MHz

-Use 31 points for reconstruction in FPGA

-16 points before signal are summed

-Fit $\chi^2 = (y_i - AF(t_i - t_0) - P)S^{-1}_{i\,j}(y_j - AF(t_j - t_0) - P) -> min,$

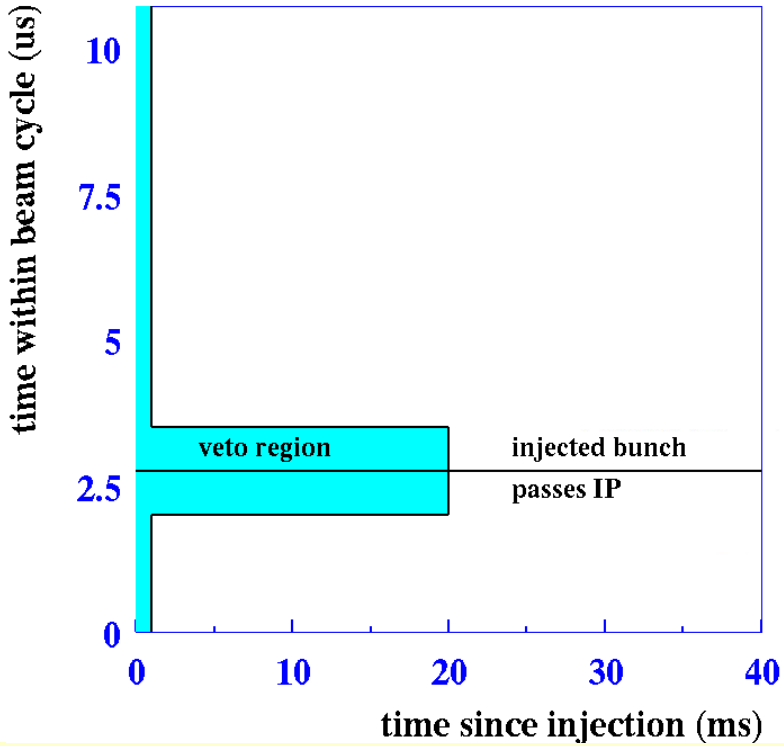
-Reconstract amplitude(A), time(τ) and pedestal:

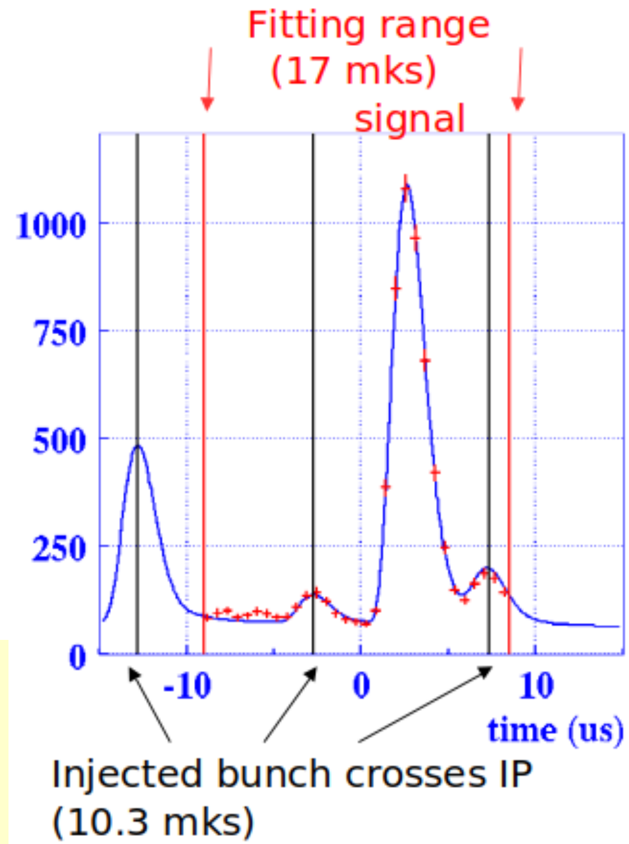
-Record A,τ and quality if A>Ath(1 MeV),

For small fraction(~10^{-3}) save raw data.

$$A = \sum_k \alpha_k^m y_k,\ B = \sum_k \beta_k^m y_k,\ p = \sum_k \gamma_k^m y_k,\quad \tau = \tau_0 - B/A$$

Injection veto





To reduce dead time:

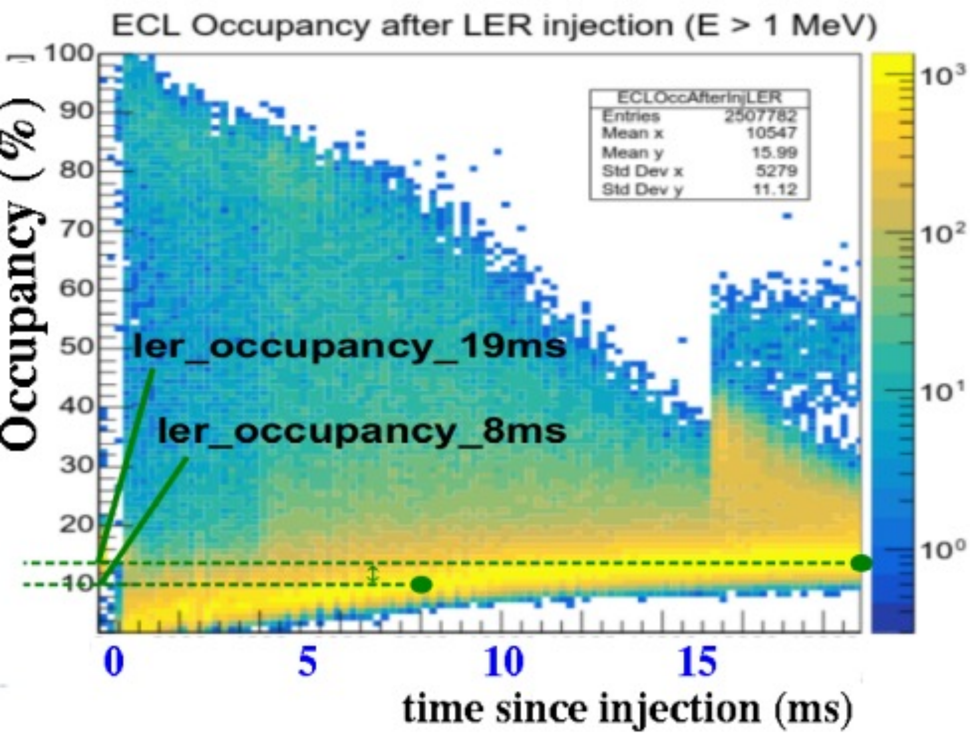
-Full veto for ~1 ms after injection

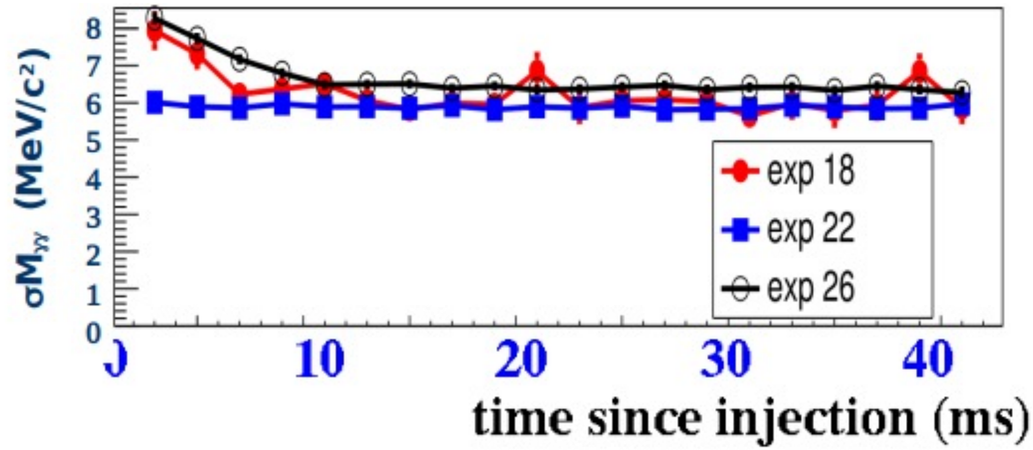
-Veto for 1-2 mks during injection bunch passing IP

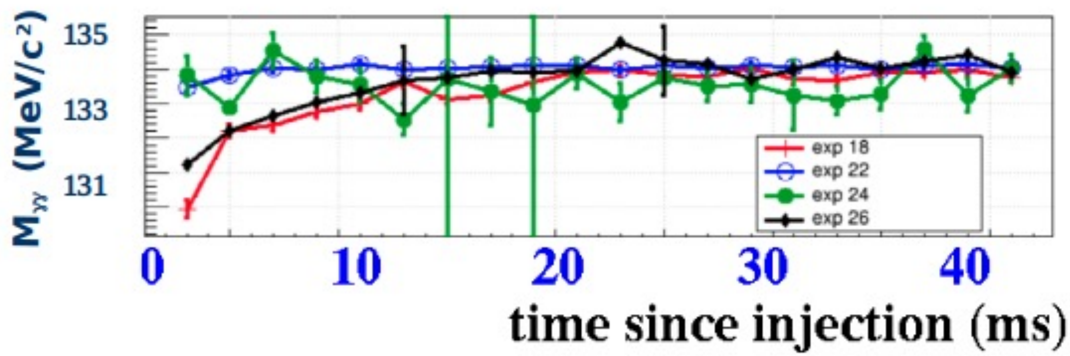
-Calorimeter signal is ~5 mks and is affected by background hits from veto region

-The noisy injection signal both before and after pulse can result in pedestal increasing and signal amplitude reduction.

Influence of injection







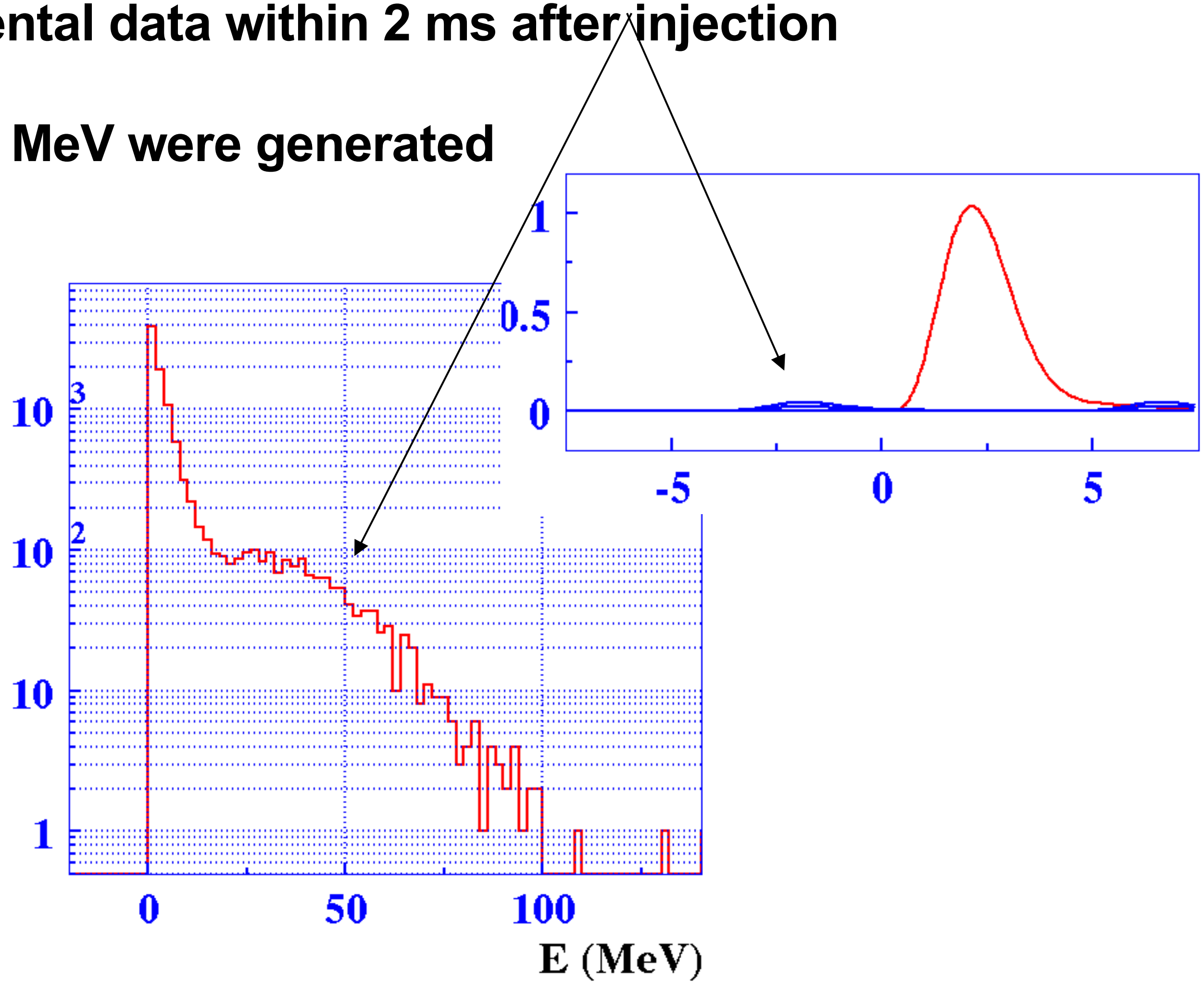
- **Pedestal=baseline is biased upward, i.e. reconstructed energy deposition gets lower.**
- **Injection background causes loss of data for low-energy hits.**
- **spreading of π^0 width as well as shift of mass position**

Simulation

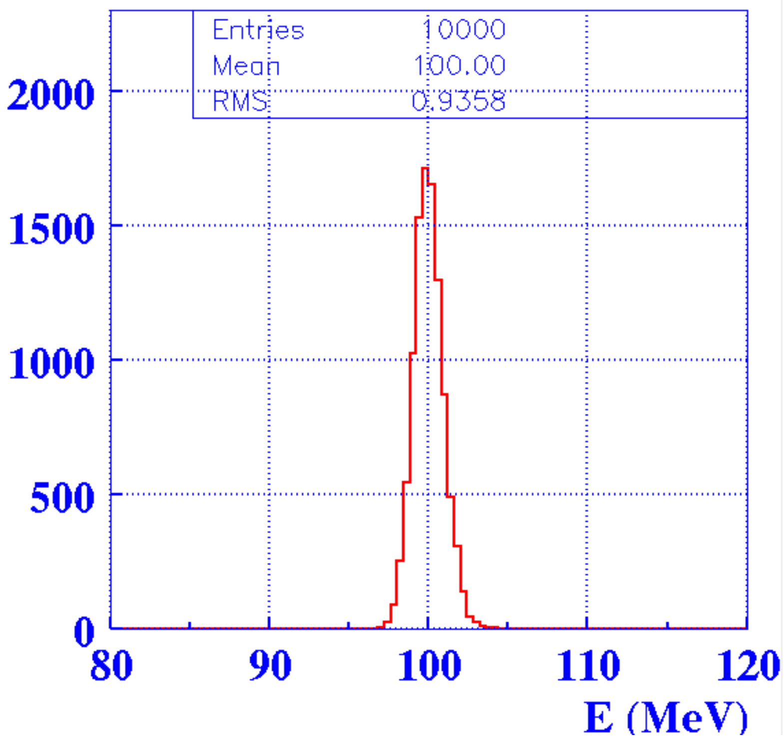
-The signals with electronic and pile-up noise of ~1 MeV were generated

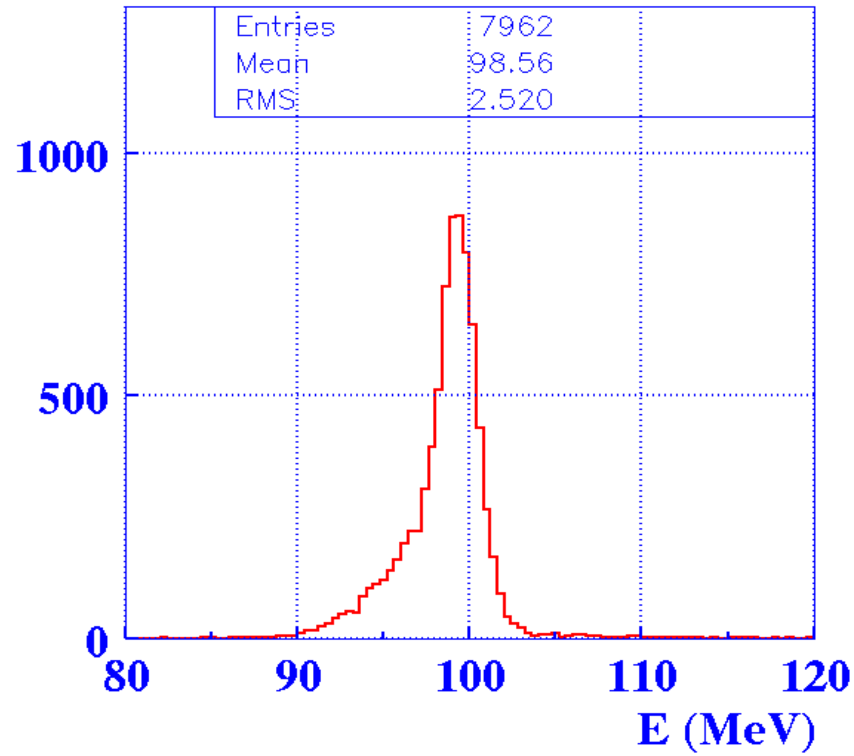
-Injection background was generated according to the spectrum obtained from experimental data within 2 ms after injection

-Signals 0-100 MeV were generated



Resolution of 100 MeV





Without injection **with injection noise**

$|t_{signal}-t_{inj}|>0.9$ mks

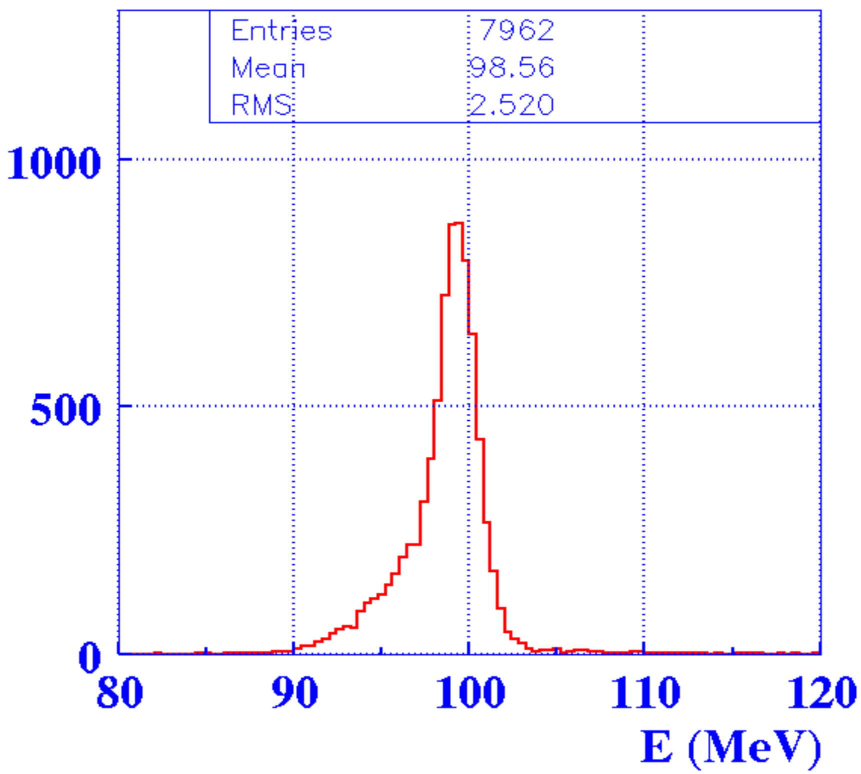
We observe increasing of signal width and shift of the amplitude

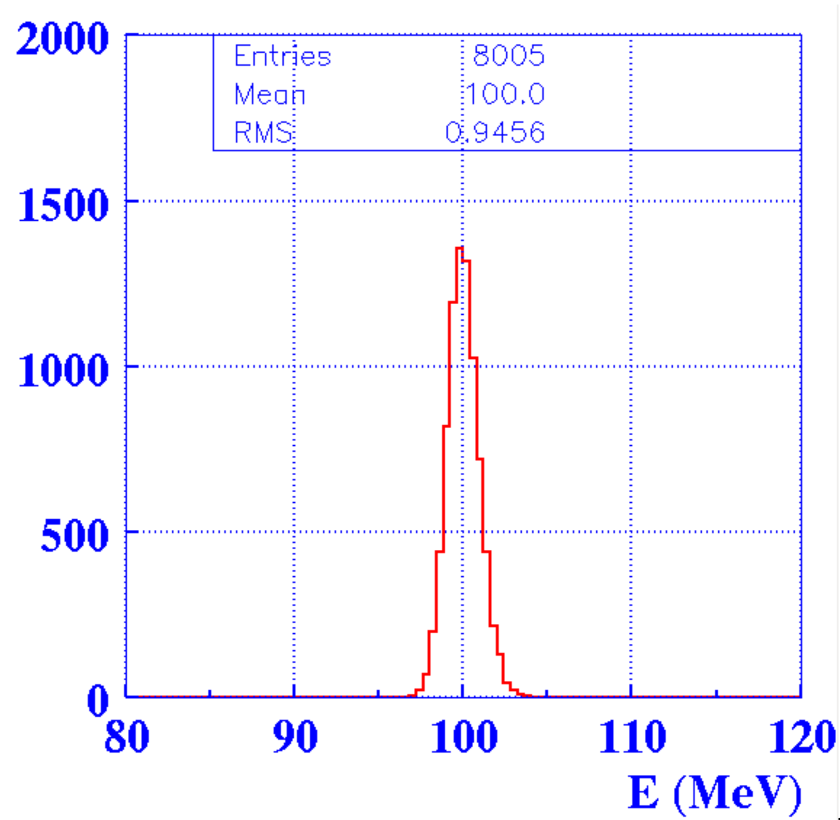
Resolution of 100 MeV

Offline fit of data with taking into account injection signal

$$f(t) = A\,F(t - t_{sig}) + P + a_1 F(t - t_{inj}) + a_2 F(t - t_{inj} - \Delta) + a_3 F(t - t_{inj} + \Delta)$$

6 free parameters: A, t_{sig}, P, a_1, a_2, a_3





With time cut +-1 mks the resolution and peak position are the same as without injection

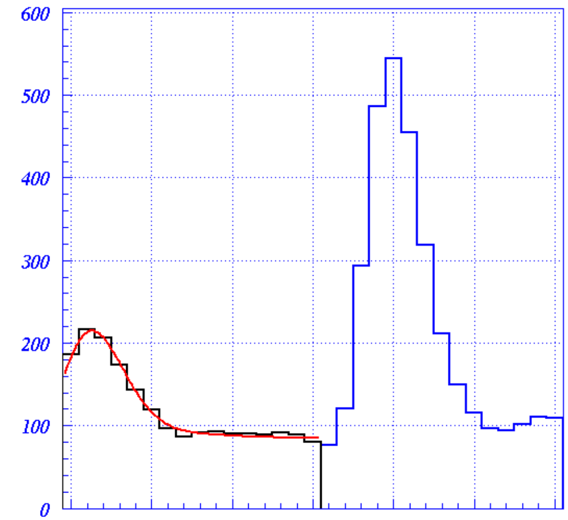
Pedestal determination in FPGA

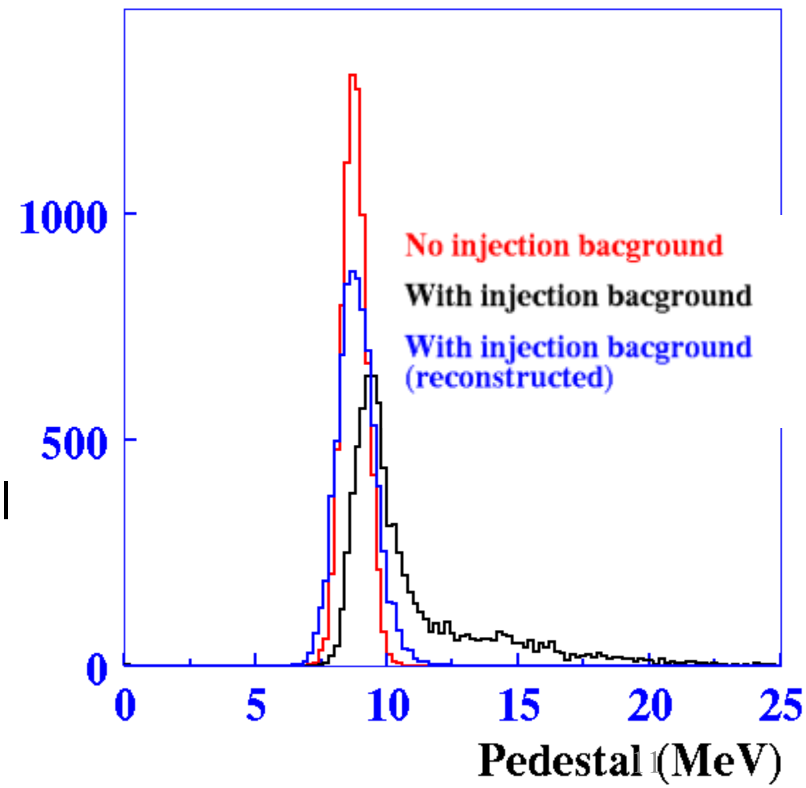
Pedestal can be estimated more correctly:
16 points before the trigger signal
Can be fitted by pedestal + 2 possible injection
Signals:

$$\chi^2 = \sum_{i=1}^{16}\left(y_i - a_1 F(t-t_{inj}) + a_2 F(t-t_{inj}-\Delta)\right)^2$$

$$P_{cor} = \Sigma \alpha_{ik} y_i$$

α_{ik} - precalculated coefficients
k -is reconstructed using the injection signal provided by the time distribution system



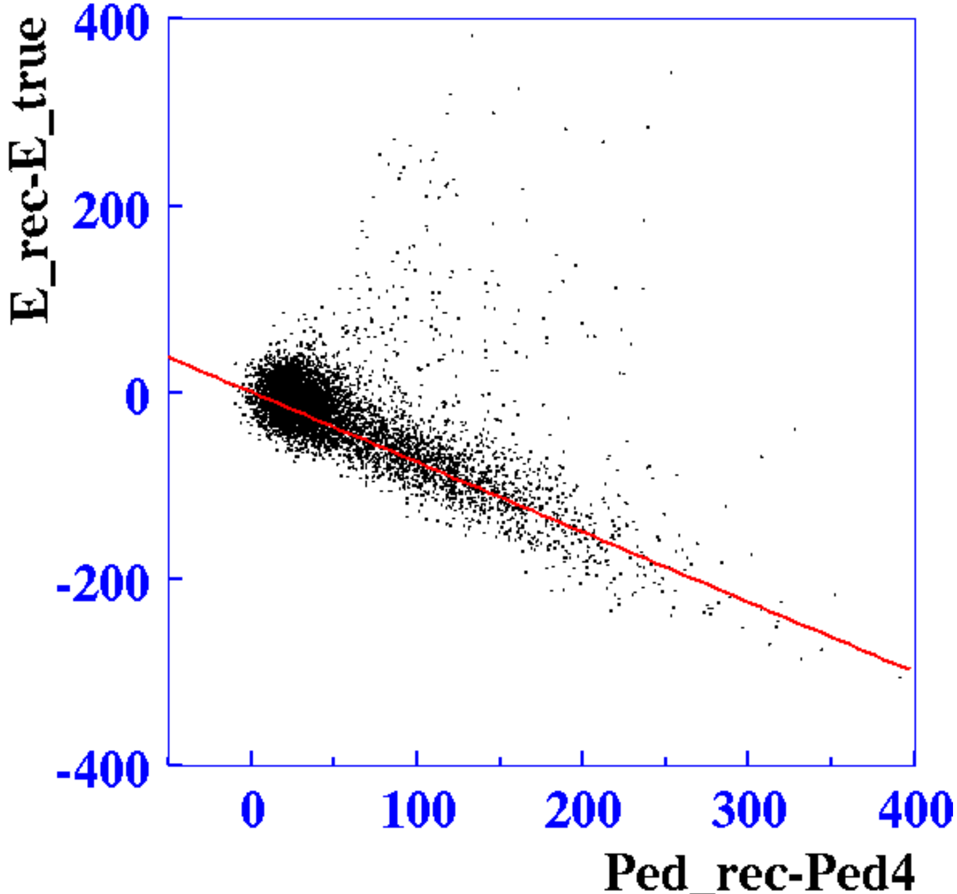


To get energy deposition more correctly

-The deviation of reconstructed amplitude is correlated with $P\text{-}P_{cor}$

$$E_{cor}=E+k(P-P_{cor})$$

-The corrected energy has resolution within close to resolution without injection If |t-t_inj|<1.7 mks



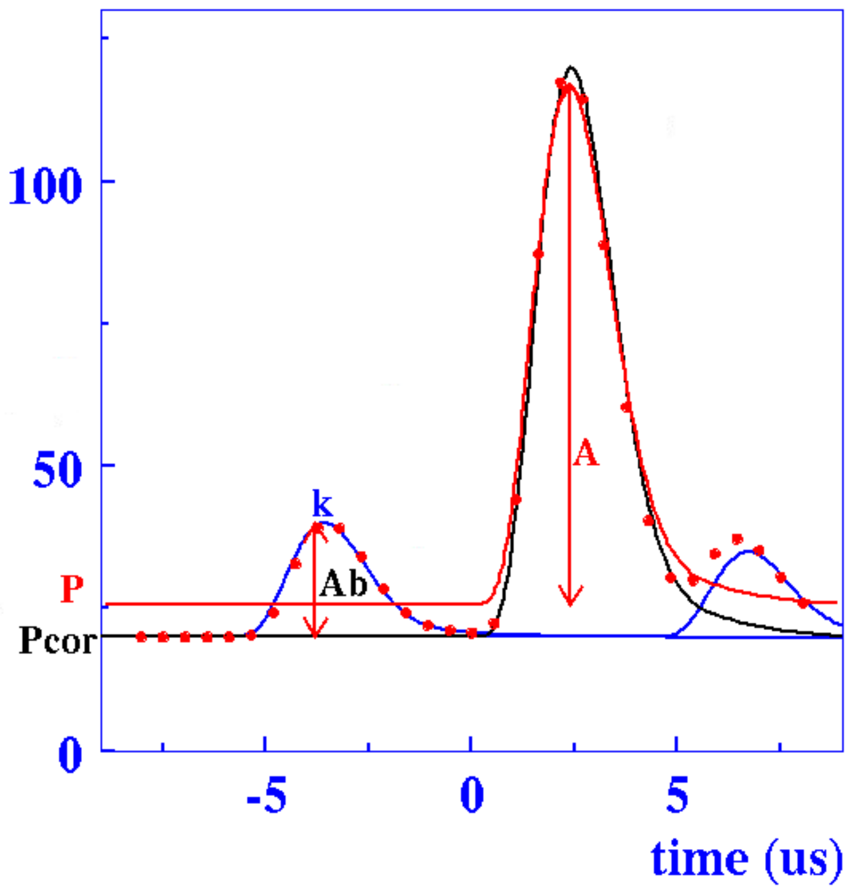
Planned modification of readout firmware

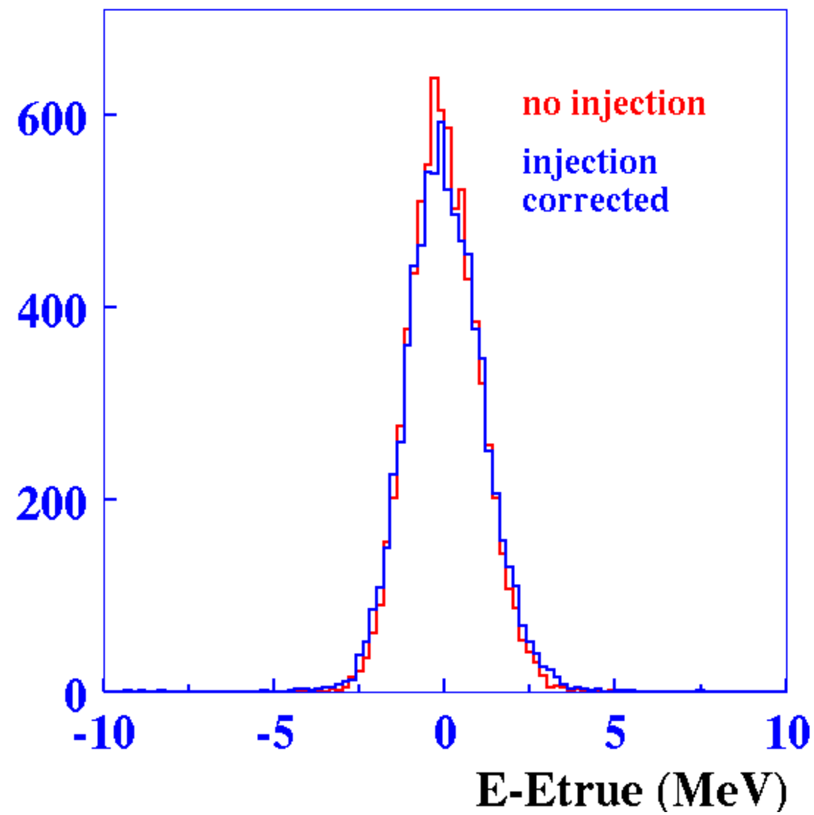
-The second injection pulse is overlaping with signal

-To take into account influence of the second pulse we apply two corrections:

$$E_{cor}=E+a_k(P-P_{cor})+b_kA_b$$

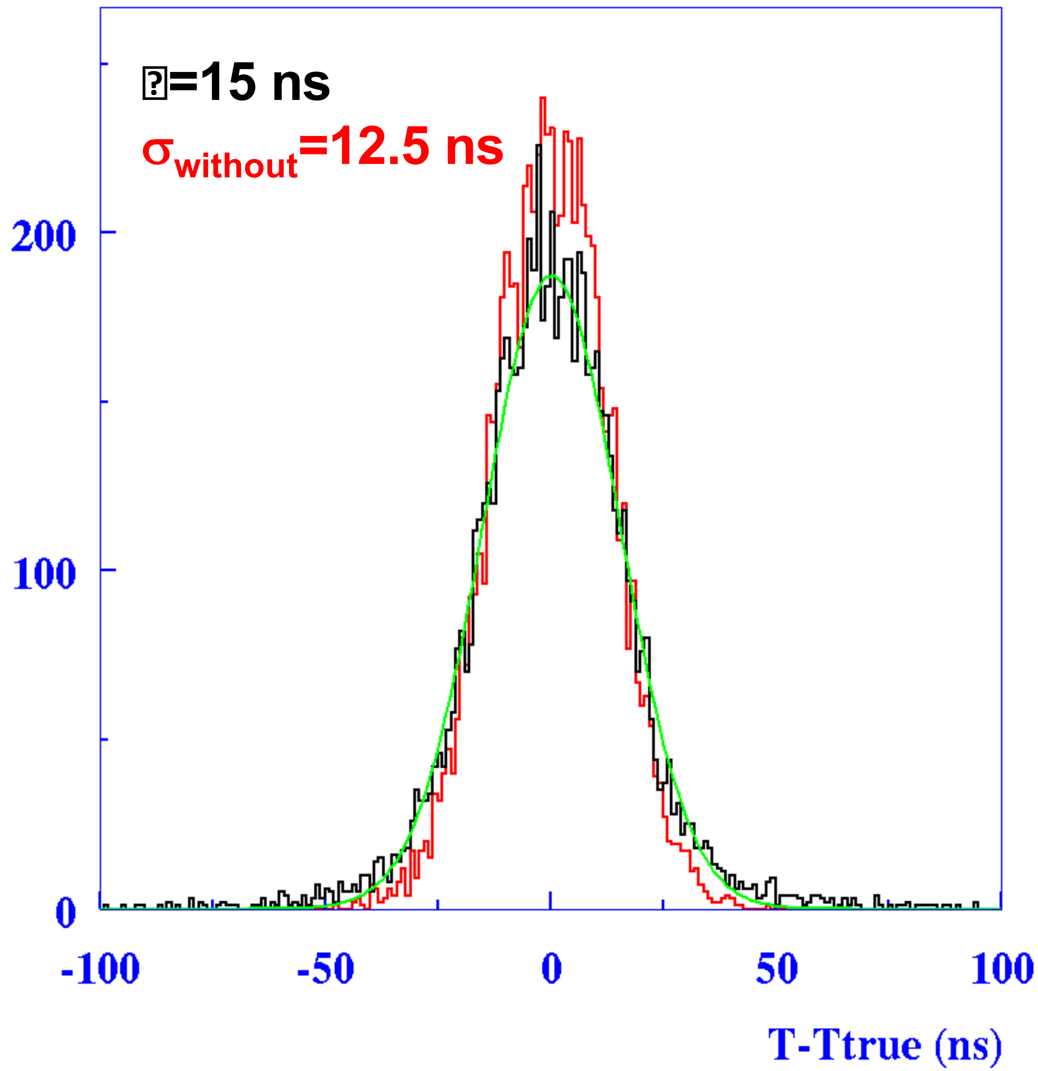
-The corrected energy has resolution close to resolution without injection If $|t-t_{inj}|<1.7$ mks





Time resolution

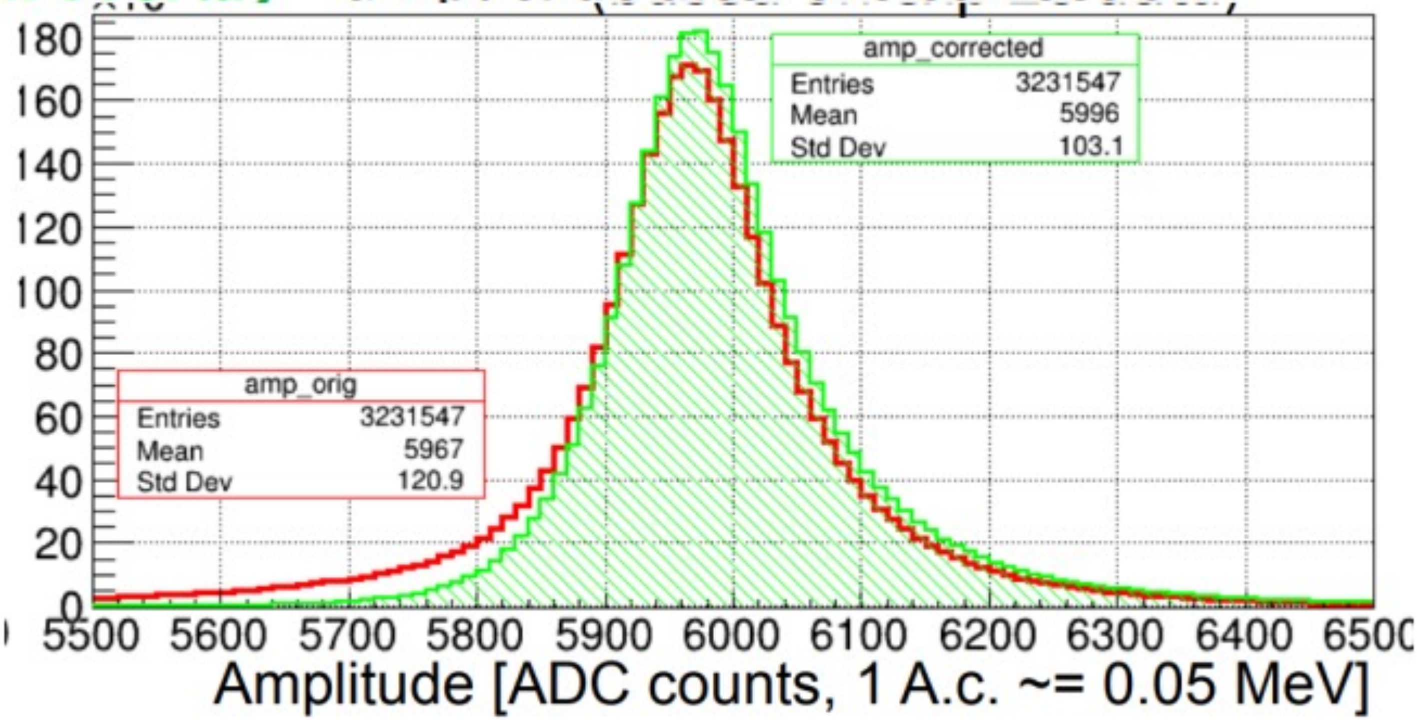
Time resolution for stored events with injection background about 15% worser for 50 MeV.



Test with recorded data (offline)

-To test algorithm we need raw data which are about 2 x 10^{-3} of all data
- **-we don't have enough statistics to study π^0 invariant mass**
- **-take the data of background overlay trigger with injection**
- **-add the simulated signal of 300 MeV**
- **-compare the resolution and position of the peak**

Red – amplitude before the correction with new algorithm
Green overlay – amplitude after the correction



Summary

Continuous injection is the important feature of SuperKEKB operation.

It takes a few thousand turns to let injected bunch stabilized completely.

Note one turn takes 10 μs.

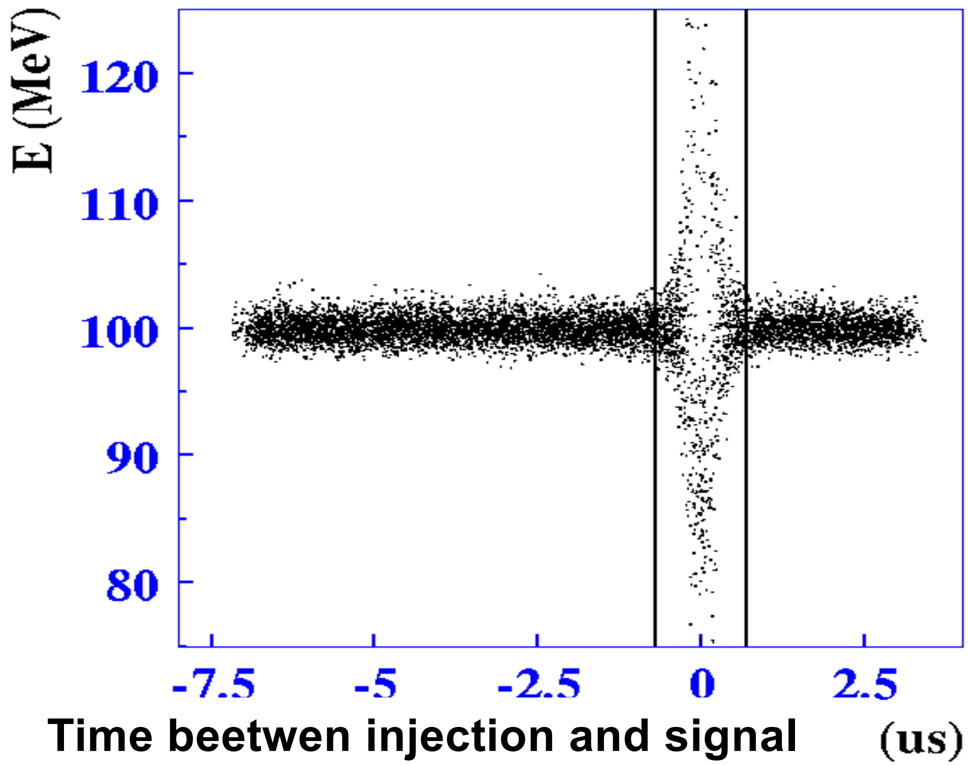
The injection background can deteriorate Belle II calorimeter energy resolution.

Simple algorithm to correct measured energy was developed.

It was tested with recorded experimental data.

The firmware development is going on.

Backup slides



The time cut can be reduced to ± 0.6 mks without resolution degradation

It is difficult to implement the fitting to FPGA

Fit can be done offline

For modification of the FPGA logic simple corrections were developed

Modification of readout firmware

-In FPGA we perform usual fit P, A, t_0.

-Calculate difference $d_i=y_i-AF(t_i-t_0)-P$

-Determine maximum deviation dmdx and injection time from FTSW

-From kicker signal we calculate time within rotation t_{inj}

-if -0.56 mks < $t-t_{inj}$ < 1.25 mks - save wf

-If -1.79mks < $t-t_{inj}$ < 2.11 mks & dmax > 5 MeV - save wf

For -0.4 < $t-t_{inj}$ < 0.4 even if we save wf we cannot separate contribution of injection

Total number of events to save ~7% (600 hits/event) for bad injection.