Emulation of ILD leakage using CALICE test beam data: preliminary estimates

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Outline

1. Previous studies and goals
2. Test beam setup, event selection and energy reconstruction
3. Estimates of leakage for single particles
4. Extrapolation of single particle estimates to jets

Previous studies and goals

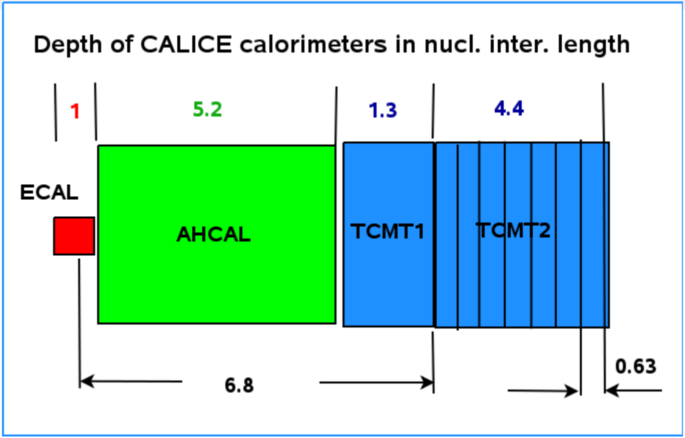
Previous studies

- **MC study** of the leakage from calorimeter in LC environment (V.Morgunov ECFA Workshop, Padova, 2000), ILD LOI (optimized calorimeter 6.86λ_I)
- **MC study** of the ILD muon system as a tail catcher (N.D'Ascenzo, V.Saveliev, ILD Workshop, LAL Orsay, 2011)
- **Test beam data** study of the leakage for 20-GeV pions and emulation of ILD coil with CALICE TCMT (JINST 7 P04015, 2011)
- HCAL leakage estimation (B.Lutz, F.Sefkow, CALICE meeting, Argonne, 2008); study of pion shower leakage with CALICE **test beam data** (8-100 GeV), imitation of non-instrumented ILD coil with TCMT and development of the leakage correction algorithm (I.Marchesini, CAN-029).

Goals

- Study of the leakage term contribution to the energy resolution for single particles using CALICE test beam data and simulations.
- Estimation of leakage for jets using parameters extracted from single particle data.
- Emulation of ILD Muon System instrumentation for single particles and jets.

CALICE test beam calorimeters



- Si-W ECAL(3 parts with SFs 1:2:3); Sci-Fe AHCAL, TCMT (2 parts with SFs 1:5)
- ECAL(last 5 layers) + AHCAL + TCMT1 $\approx 6.8\lambda_I$ = ILD CALO
- SF of TCMT1 is the same as of AHCAL (21 mm steel + 5 mm sci strips or cells).
- SF of TCMT2 corresponds to that of ILD muon system (100 mm steel + 5 mm sci).

Data, software and event selection

Test beam data

- CERN 2007 runs, $\pi^{\pm}$ @ 10-80 GeV (ECAL+HCAL+TCMT)
- Reconstruction with calice_soft v04-01

Simulations (many thanks to Lars Weuste)

- GEANT4.9.4p03, Mokka v07_07p04, QGSP_BERT physics list
- calice_soft v04-05, 816 keV/MIP, 0.1 light crosstalk for HCAL

Event selection

- HadronSelection processor (CAN-035) is used to rejects muons, empty and multiparticle events, electrons or protons are rejected using Čerenkov counter
- Events with the shower start before 25th ECAL layer are rejected
    - to minimize albedo
    - for the total depth to be consistent with that of ILD ECAL+HCAL
- The same selection procedures are applied to MC and data samples.

Reconstructed energy for different configurations

ILD-like calorimeter:

$\boldsymbol{E_{\mathrm{ILD}} = E_{\mathrm{track}} + a_e \cdot E_{\mathrm{E3}} + a_h \cdot E_{\mathrm{H}} + a_{t1} \cdot E_{\mathrm{T1}}}$

k TCMT2 layers added to ILD-like:

$\boldsymbol{E_k = E_{\mathrm{ILD}} + a_{t2} \cdot \sum_{i=1}^{k} e_{\mathrm{i}}}$

$\boldsymbol{e_{\mathrm{i}}}$ - energy deposit in i-th layer of TCMT2.

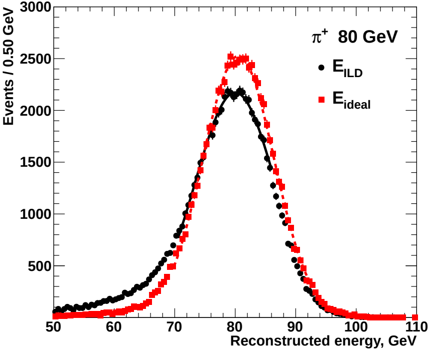
7 added layers correspond to all available depth of TCMT2:

$\boldsymbol{E_7 = E_{\mathrm{total}}}$

Minimum leakage (no late shower starts):

$\boldsymbol{E_{\mathrm{ideal}} = E_{\mathrm{total}}|_{\mathrm{start\ before\ 5-th\ HCAL\ layer}}}$

E_{E3}, E_{H}, E_{T1} and E_{T2}
are calculated in hadronic scale
(see backup slides 15-17 for details).



Energy distributions of $\boldsymbol{E_{\mathrm{ideal}}}$ and $\boldsymbol{E_{\mathrm{ILD}}}$ for 80 GeV $\boldsymbol{\pi^+}$

Fractional resolution for different TC depths

Mean and RMS of the energy distribution are calculated for different number k of added TCMT2 layers.

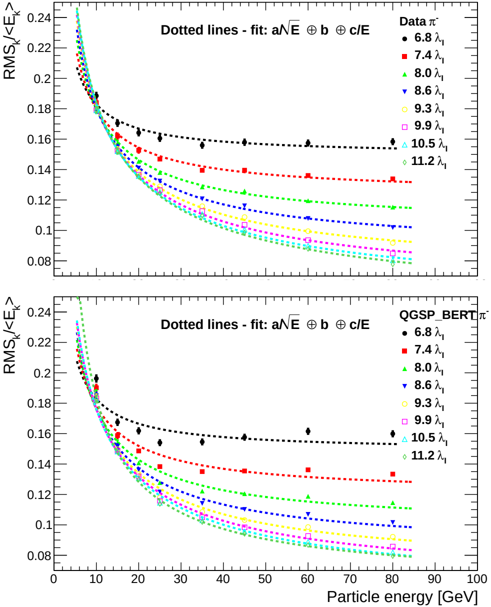
k	0	1	2	3
depth$[\lambda_I]$	6.8	7.4	8.0	8.6

k	4	5	6	7
depth$[\lambda_I]$	9.3	9.9	10.5	11.2

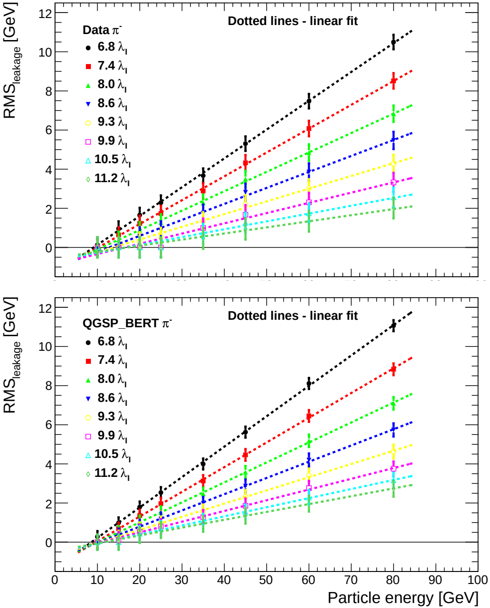
6.8λ_I corresponds to ILD Calo (at normal incidence)

For the depth of 7λ_I the constant term exceeds 10% and dominates above 30 GeV.

For the configuration with 7 added layers (11λ_I) constant term is ∼2%.



Energy dependence of $\mathrm{RMS}_{\mathrm{leakage}}$



For k added TC layers, the contribution to full RMS from leakage is

$$(\mathrm{RMS}_{\mathrm{leakage}})_k = \sqrt{\mathrm{RMS}_k^2 - \mathrm{RMS}_{\mathrm{ideal}}^2}$$

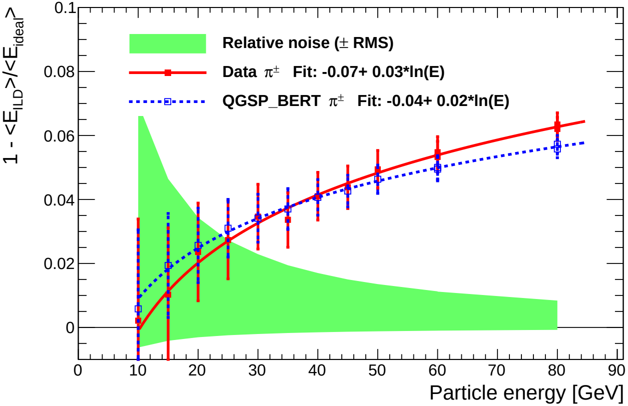
The contribution to RMS from leakage scales linear with energy.

The linear fit can be used to estimate leakage for different energies. When extrapolating to lower energies negative values are treated as zero leakage.

The dependence predicted by QGSP_BERT is more steep.

Energy dependence of fractional leakage from ILD Calo

Mean fractional leakage is determined as $f_{\text{leakage}} = 1 - < E_{\text{ILD}} > / < E_{\text{ideal}} >$.
Both π^+ and π^- samples were used for fit.



Mean fractional leakage scales logarithmically with energy.
Green band indicates relative noise in TCMT2 and its RMS.

Extrapolation of single particle estimates to jets and ILD

Simulated jets

Dijets Z→uds at 360 and 500 GeV (5000 dijets for each)

Estimation of leakage for jets

$\boldsymbol{E_{\mathrm{jetLeakage}} = \sum_{i=1}^{n} (f_{\mathrm{leakage}}(E_i) \times E_i)/2}$, $\boldsymbol{n}$ - number of particles in dijet

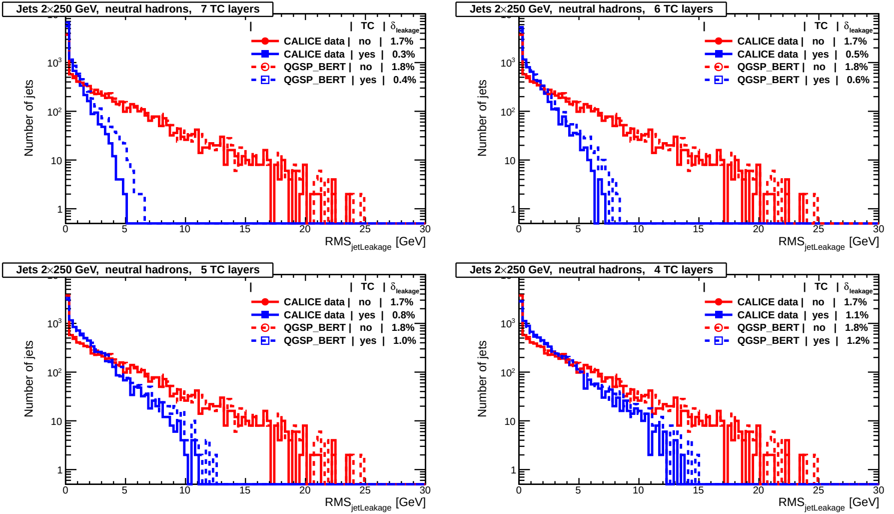
$\boldsymbol{\mathrm{RMS}^2_{\mathrm{jetLeakage}} = \sum_{i=1}^{n} \mathrm{RMS}^2_{\mathrm{leakage}}(E_i)/2}$, $\boldsymbol{E_i}$ - energy of i-th particle in dijet.

For protons (∼5% of charged hadrons) and neutrons (∼50% of neutral hadrons), pion single particle estimates are applied. For baryons, nuclear interaction length is 20% lower (overestimated leakage) while showers are ∼5% longer (underestimated leakage).

Emulation of ILD Muon System instrumentation

Active layers from TCMT2							Total
1	2	3	4	5	6	7	
+	+	+	+	+	+	+	7
+		+	+	+	+	+	6
		+	+	+	+	+	5
			+	+	+	+	4
ILD Coil			ILD Yoke				

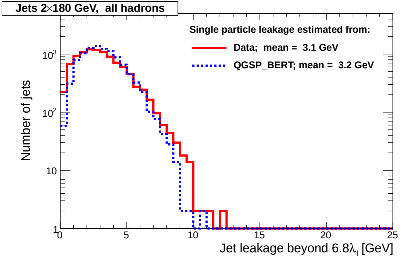
$\mathrm{RMS}_{\mathrm{jetLeakage}}$ due to neutral hadrons from 250-GeV jets

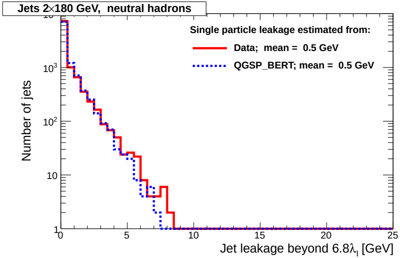


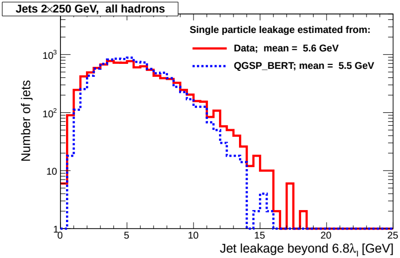
$$\delta_{\mathrm{leakage}} = \sqrt{<\mathrm{RMS}^2_{\mathrm{jetLeakage}}>}/E_{\mathrm{jet}}$$

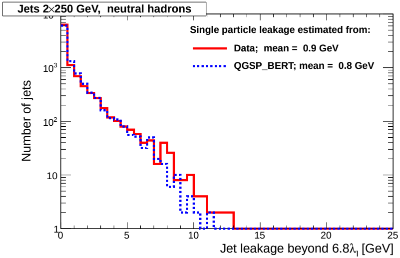
Factor 5 improvement with 7 TC layers but factor 1.5 only with 4 TC layers.

Jet energy leakage from ILD-like calorimeter without TC









Charged hadrons are reconstructed using track information (Particle Flow).

For neutral hadrons (K_{0L} and neutrons) mean leakage is $<$0.4%.

Summary

Leakage for single particles

$\pi^{\pm}$ test beam data taken at 10-80 GeV with complete CALICE setup were analysed. For ILD-like calorimeter ($6.8\lambda_{\mathrm{I}}$), the constant term contribution to fractional resolution exceeds 10%. Tail catcher helps to reduce it down to ~2%.

Leakage for jets

Leakage estimates for single pions are applied to simulated dijets (360 and 500 GeV).

- Mean absolute leakage for jets from ILD-like calorimeter due to neutral hadrons is estimated to be <0.4%.
- **The instrumentation of Muon System allows to decrease a contribution to resolution due to neutral hadron leakage by a factor of 2 (down to ~1%).**

MC and data comparison

For simulated samples, hadronic scale for TCMT was artificially adjusted (reduced by ~20% comparing to data). **To confirm the observed agreement between data and QGSP_BERT, simulation for hadrons should be redone with Birks law and time cut implemented in Mokka for TCMT.**

Backup slides

Reconstructed energy: calibration and scaling

To calculate reconstructed energy, electromagnetic calibration is used as well as additional factor e/π for hadronic scale; mip scale is applied for track in ECAL.

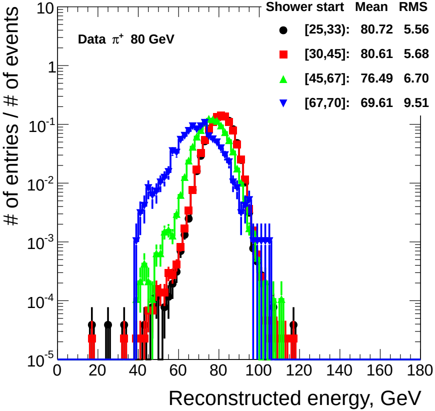
Mean and r.m.s. of the energy distributions are used for both data and MC.

	Data		QGSP_BERT	
	em scale GeV/MIP	e/π $(a_{e,h,t})$	em scale GeV/MIP	e/π $(a_{e,h,t})$
ECAL3	0.01305	1.2	0.01305	1.2
HCAL	0.02364	1.2	0.02364	1.2
TCMT1	0.02364	**1.25**	0.02364	**0.8**
TCMT2	0.11820	**1.25**	0.11820	**0.8**

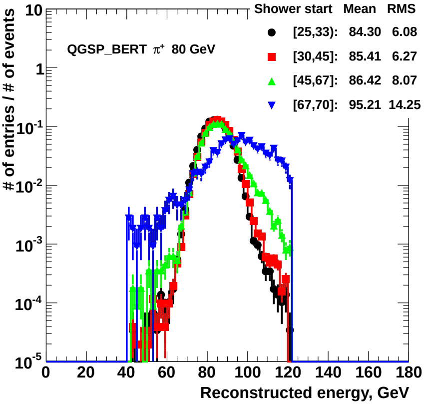
TCMT hadronic scale differs for data and MC. Explanation was proposed by Sergey Morozov: Birks law and time cut are not implemented in Mokka for TCMT.

Check of TCMT scaling: dependence on shower start

The reconstructed energy (E_{total}) is calculated identically for all samples shown using em scale for each calorimeter and additional coefficient 1.2 - only start layer ranges are different. Shower start 30 corresponds to the first HCAL layer.



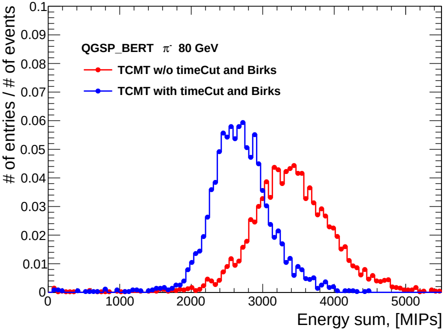
For data, reconstructed energy **decreases** with deeper shower start.
Reasonable behaviour.



For QGSP_BERT, reconstructed energy **increases** with deeper shower start.
Unreasonable behaviour. Why?

TCMT simulation and scaling

Simulations and plot by Sergey Morozov

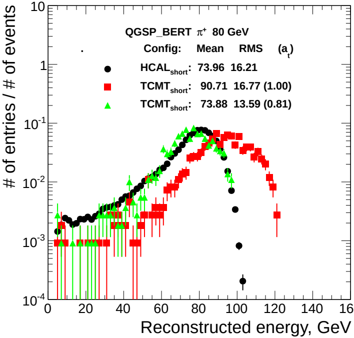


Without Birks law and time cut implemented in Mokka the TCMT response to pions is ∼25% higher.

Adjustment of TCMT scaling:

$\mathrm{HCAL}_{\mathbf{short}}$ ($\sim 5.1\boldsymbol{\lambda}_{\mathbf{I}}$): ECAL+HCAL, start from the $2^{\mathbf{nd}}$ HCAL layer

$\mathrm{TCMT}_{\mathbf{short}}$ ($\sim 5.1\boldsymbol{\lambda}_{\mathbf{I}}$): ECAL+HCAL+TCMT(15 layers), start in TCMT



For QGSP_BERT, $a_t = 1.2 \times 0.8$ is used (averaged over energies).

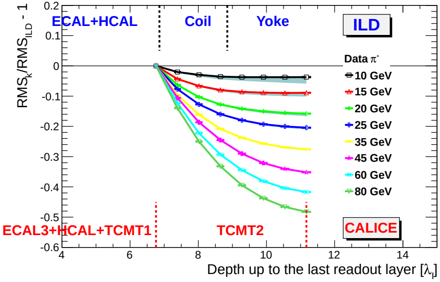
Relative improvement of RMS with added TC

The correspondence between ILD and CALICE is shown.

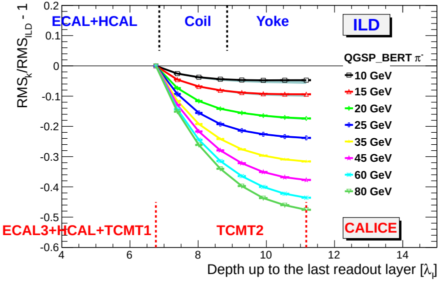
Relative improvement of RMS with k added TC layers is defined as $\mathrm{RMS}_k/\mathrm{RMS}_{\mathrm{ILD}} - 1$

Gray band shows systematics from noise.

Data



QGSP_BERT

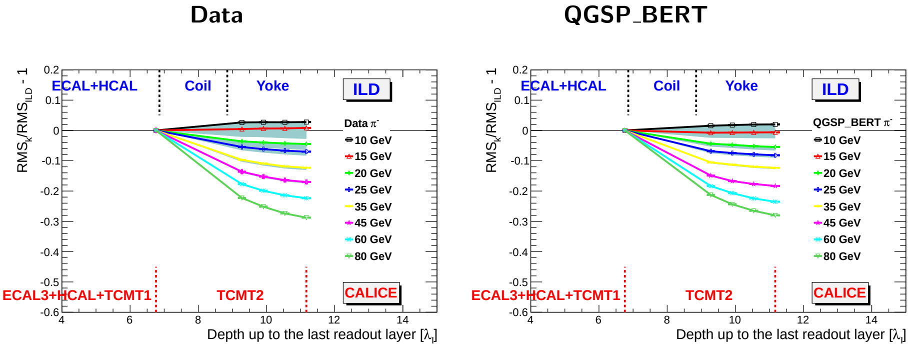


Negligible dependence on depth for 10 GeV, up to ∼50% improvement for 80 GeV at maximum available depth.

Emulation of ILD Tail Catcher w/o instrumented coil

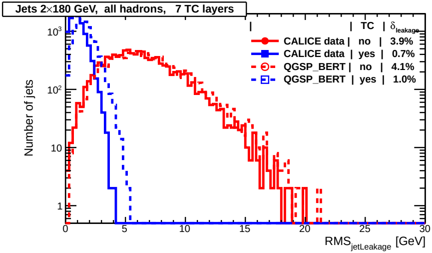
Relative improvement of RMS with active layers in ILD Yoke only (4 active layers). Gray band shows systematics from noise.

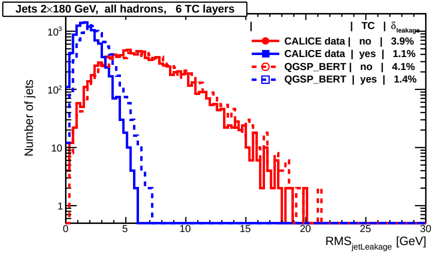
Data **QGSP_BERT**

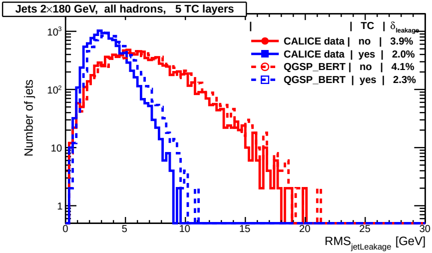


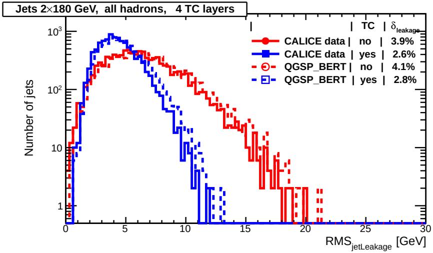
No improvement up to 20 GeV. Twice lower improvement for 80 GeV at maximum available depth comparing to that with fully instrumented TC (7 active layers).

$\mathrm{RMS}_{\mathrm{jetLeakage}}$ due to all hadrons for 180-GeV jets



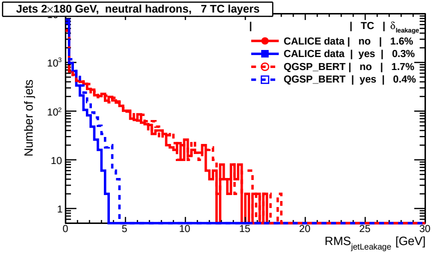


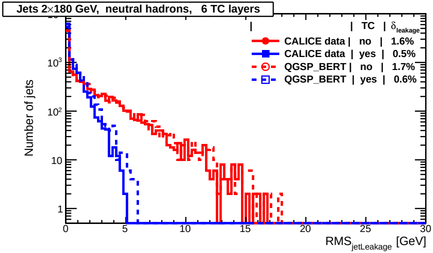


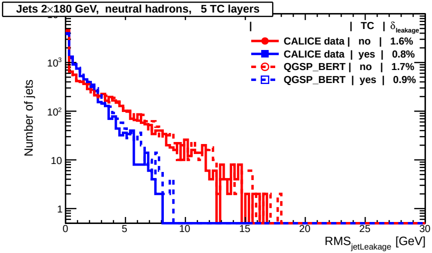


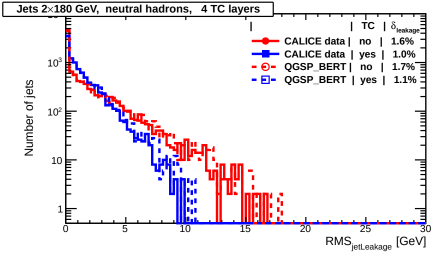
$$\delta_{\mathrm{leakage}} = \sqrt{< \mathrm{RMS}^2_{\mathrm{jetLeakage}} >}/E_{\mathrm{jet}}$$

$\text{RMS}_{\text{jetLeakage}}$ due to neutral hadrons for 180-GeV jets



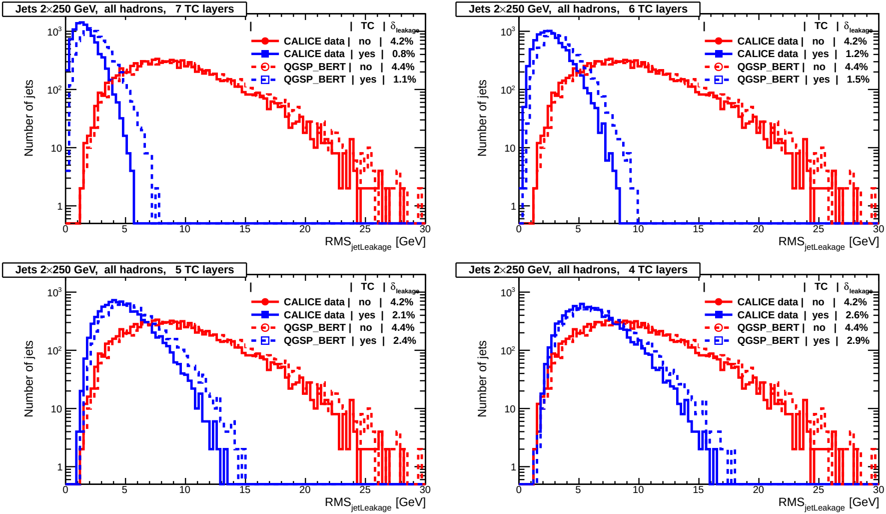






$$\delta_{\text{leakage}} = \sqrt{< \text{RMS}^2_{\text{jetLeakage}} >} / E_{\text{jet}}$$

$\mathrm{RMS}_{\mathrm{jetLeakage}}$ due to all hadrons for 250-GeV jets



$$\delta_{\mathrm{leakage}} = \sqrt{< \mathrm{RMS}^2_{\mathrm{jetLeakage}} >}/E_{\mathrm{jet}}$$