Dimuon production in Ultra-Peripheral In-In Collisions in NA60

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Run, Burst and Event Selection

- Run and Burst Selection
  - 2003 Indium-Indium data
  - Only the runs with 4000 A in the ACM toroidal magnet
  - NA60 standard run & burst selection for dimuon physics analyses

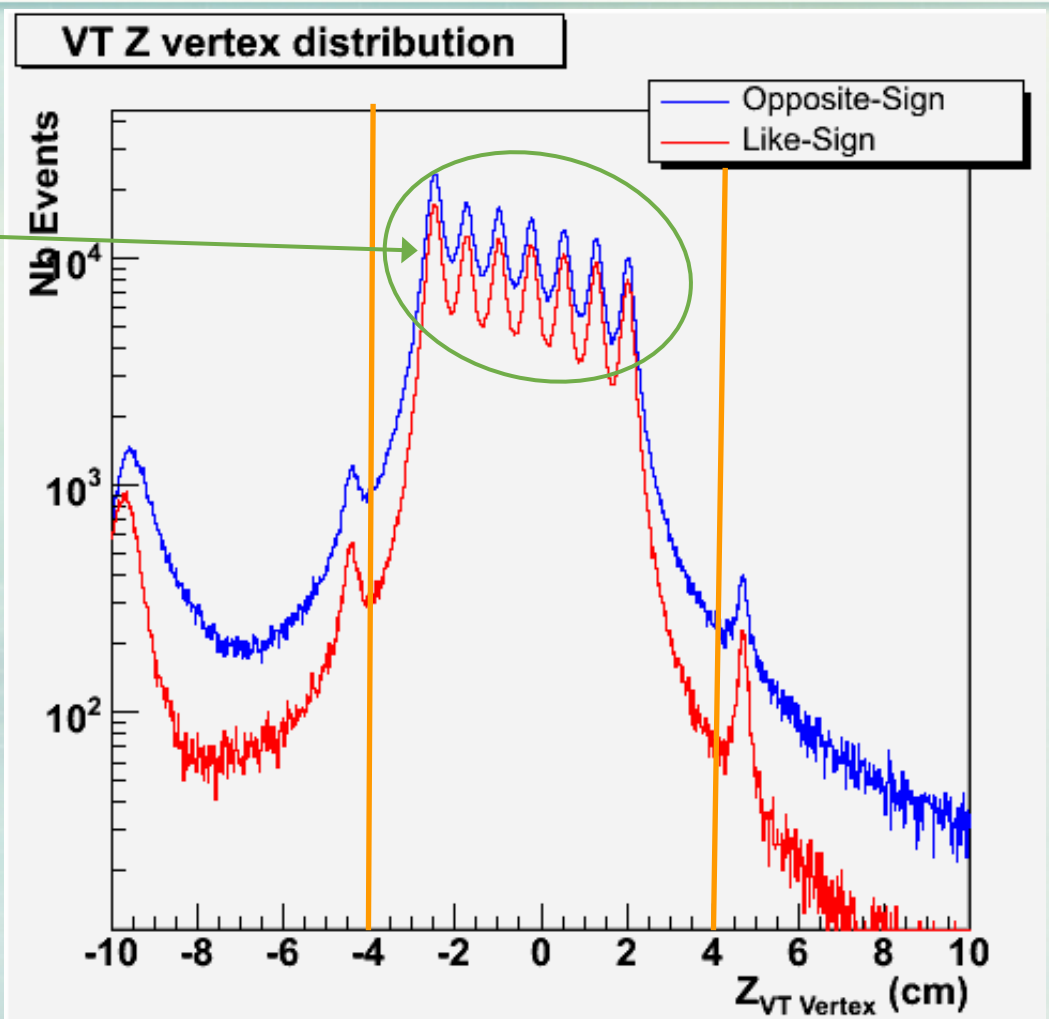
- Event Selection
  - Both muons must be matched
    (from the Muon Spectrometer to the Vertex Tracker)
  - Both matched muons must belong to the same VT-Tracks vertex
  - The VT-Tracks vertex must be in target region
    ([-4 : +4] cm, to exclude vacuum windows)
  - Only Dimuon T0J triggers
    (dimuon triggers stabilized in time by the Beam Tracker signals)

Detectors used in Event Selection

- ZDC (Zero Degree Calorimeter)
  - Measures the energy of the “beam spectator” nucleons
  - Is sensitive to Beam Pileup (and Interaction Pileup)
  - Readout gate of ~19 ns
- Quartz Blade
  - Measures the (sum of squared) number of charges of the “beam spectators”
  - Is sensitive to Beam Pileup (and Interaction Pileup)
  - Readout gate of ~30 ns
- Beam Tracker (or “beamscope”, BS)
  - Counts the beam ions and measures their time in relation to the trigger; it is also used to time-stabilize the dimuon trigger
- Interaction Counter
  - Counts the interactions and measures their time in relation to the trigger
  - Is sensitive to Interaction Pileup
- Vertex Tracker
  - Tracks charged particles and counts the number of interactions (Vertices)
  - Is sensitive to Interaction Pileup
  - Readout gate of ~200 ns

Event Selection
VT-Dimuon Z-Vertex Distribution

- The 7 Indium targets are easily recognized
- Two peaks on the edges: windows of the vacuum box
- Selection: –4.0 to +4.0 cm; keeps only dimuons produced in In-In collisions
- Opposite-sign: $\mu^+\mu^-$
  Like-sign: $\mu^+\mu^+$ and $\mu^-\mu^-$



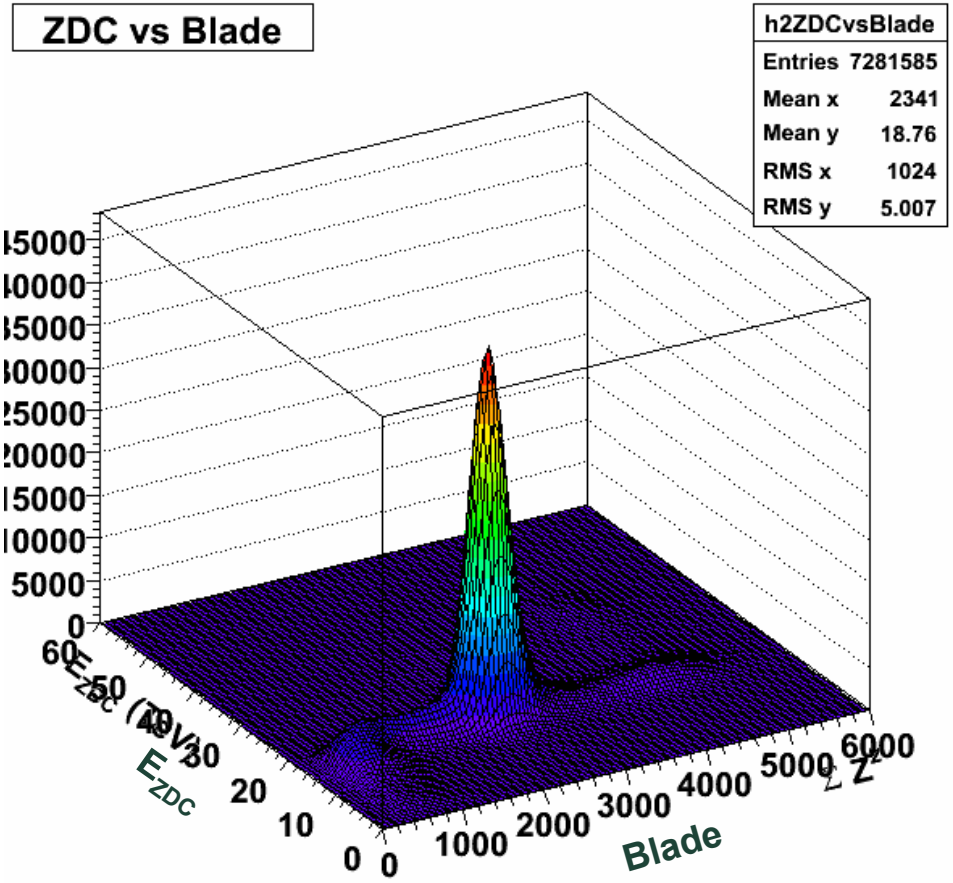
Event Selection
ZDC / Quartz Blade 2σ cut

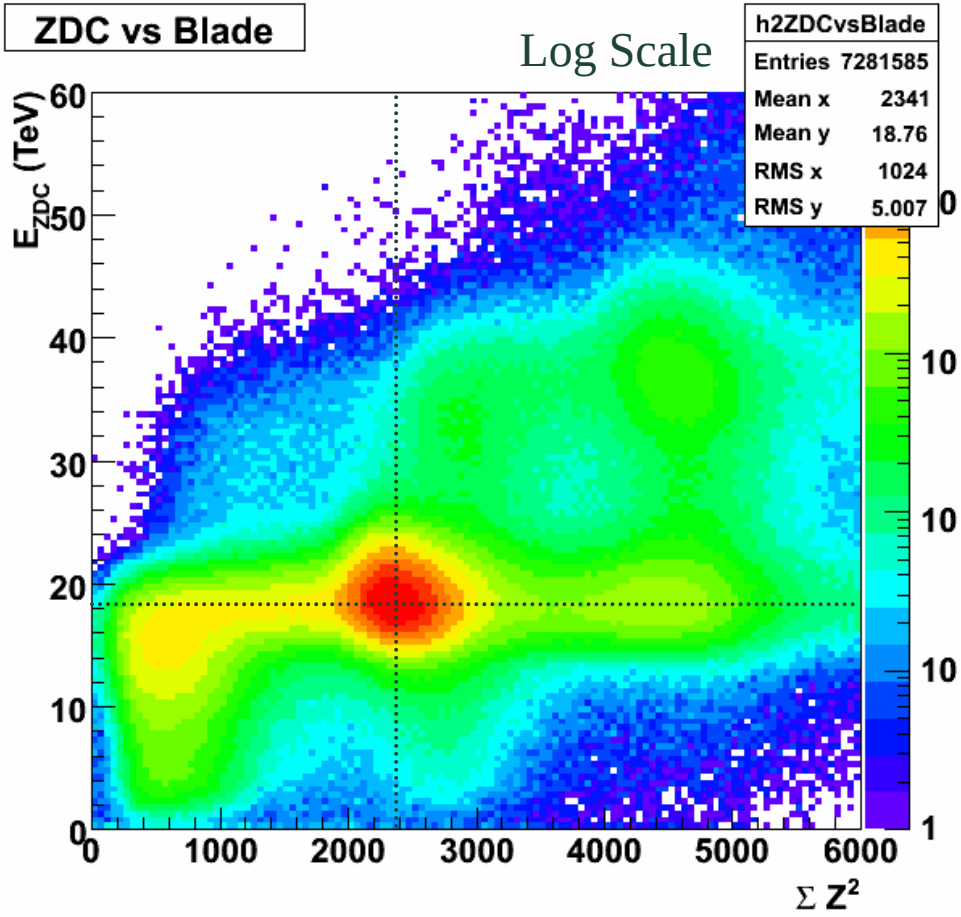
- In order to select ultra-peripheral events we use the **ZDC** and the **Quartz Blade** information and look for events with the following caracteristics:
  - The ZDC **energy of a full ion:** 115 nucleons x 158 GeV per nucleon = **18.17 TeV**
  - The number of c**harges of a full ion:** 49 protons;
    if there is no beam fragmentation, the Quartz Blade measures 49^2 = **2401**
- We can use a 2D Gaussian to select events in a 2σ range around {18.17, 2401}, where σ is the resolution; this selection will reject 14% of good events
- Given the resolutions of the ZDC and Quartz Blade detectors, the QB is better than the ZDC to distinguish “very peripheral collisions” from “no collisions at all”
- The next slides show how the resolutions of the ZDC and QB were determined and how they are used in the *Event Selection* of this analysis

Detector Resolution

ZDC vs. Blade (beam triggers)

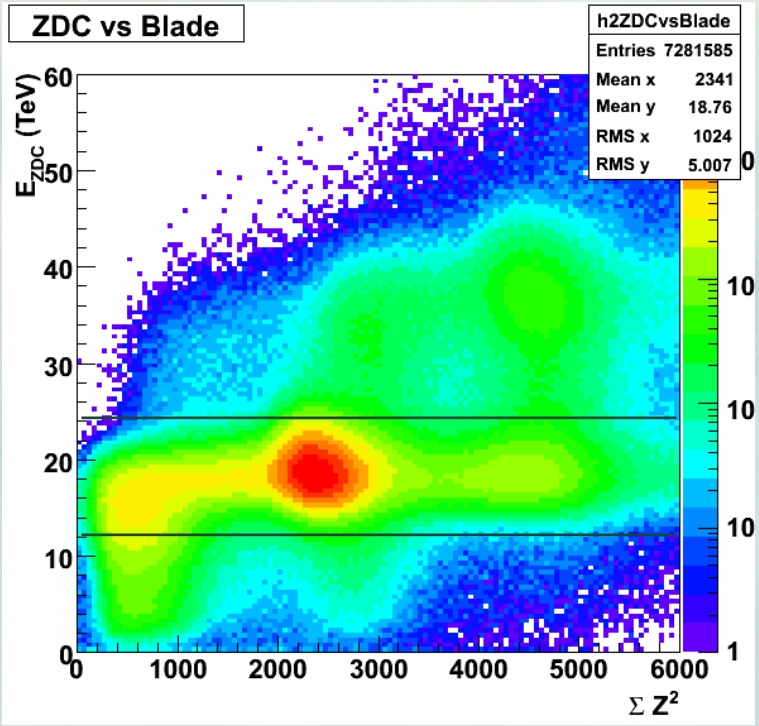
Indium beam peak: E_{ZDC} = 115x158 = **18.17 TeV** ; Blade = 49x49 = **2401**

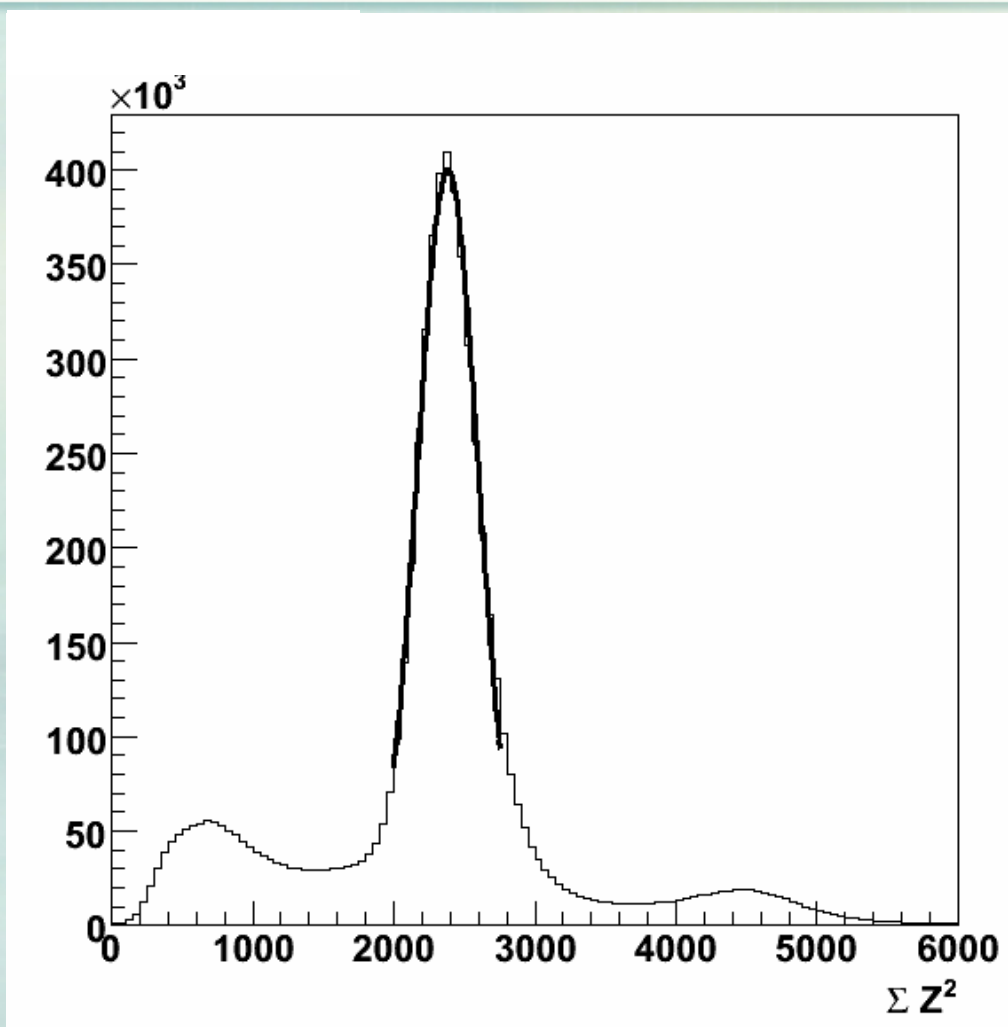




Detector Resolution
Projection on the Blade axis

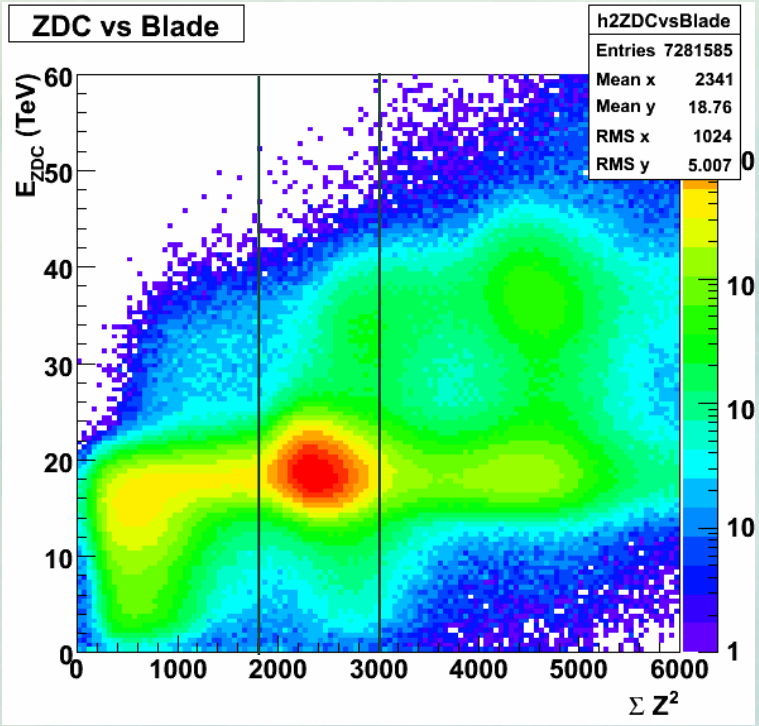
- Projection on the Blade axis using E_{ZDC} in the interval [12 : 24] TeV
- Peak at 2382 (49x49=2401)
- Sigma = 216 (**9%**)

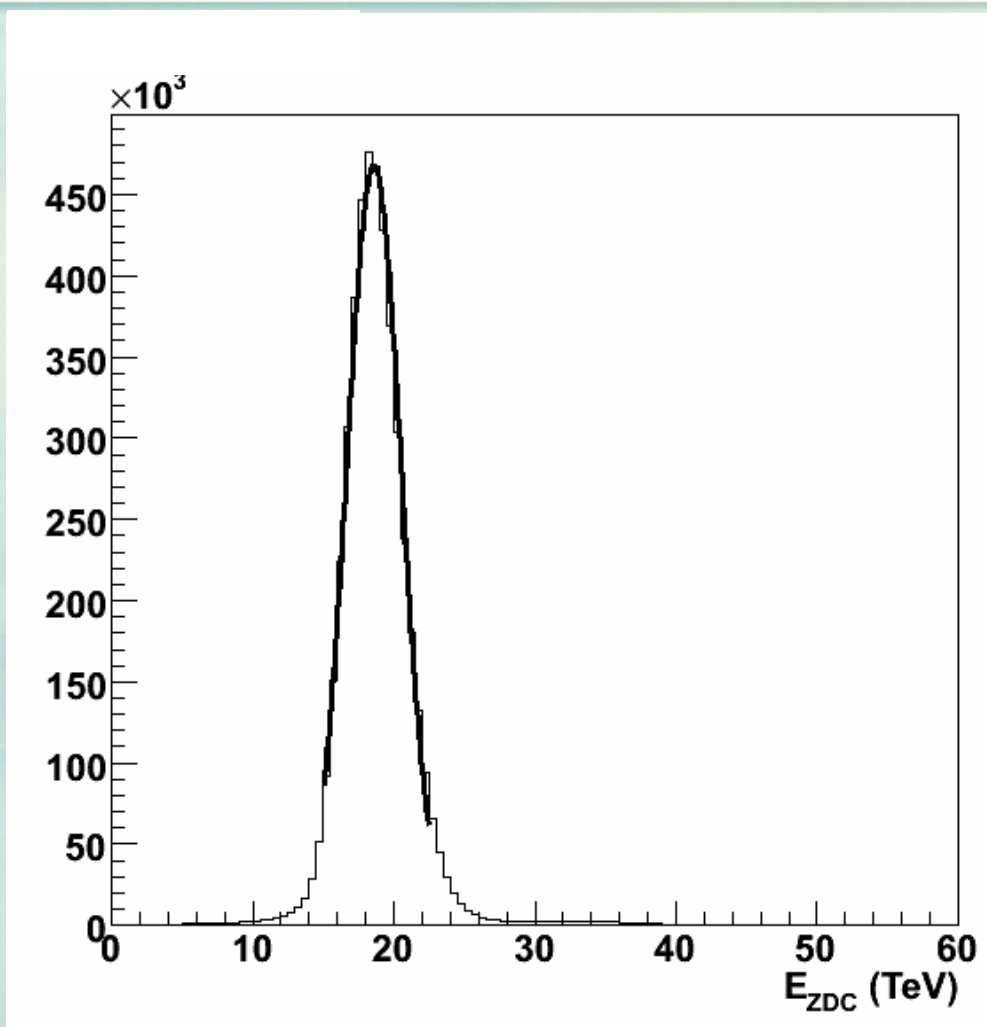




Detector Resolution
Projection on the E_{ZDC} axis

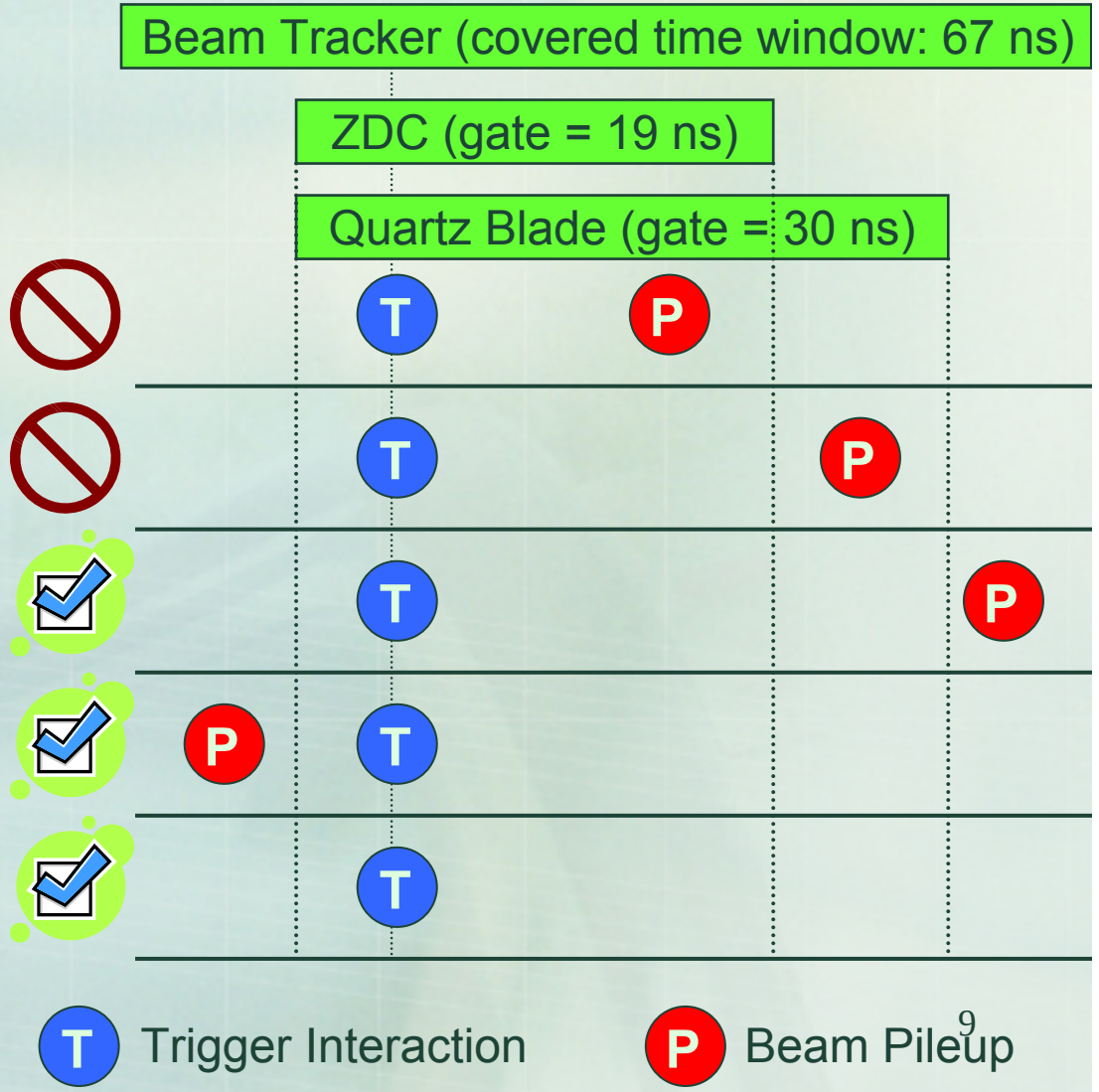
- Projection on the E_{ZDC} axis using Blade in the interval [1800 : 3000]
- Peak at 18.59 TeV (18.17)
- Sigma = 1.93 TeV (**10%**)





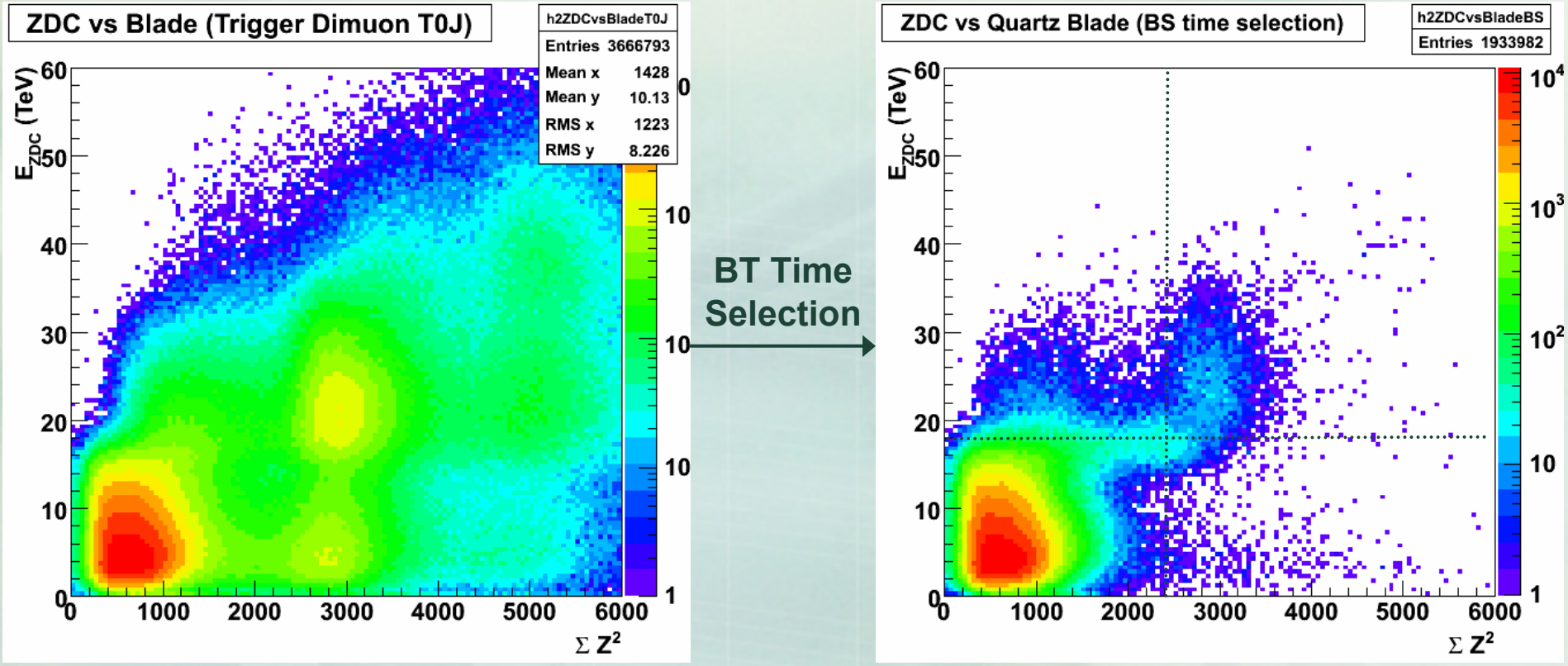
Eliminating beam pile-up in the Blade and ZDC with the BeamTracker

- We can use the Beam Tracker timing information to *validate* the values measured in the ZDC and Quartz Blade
- This procedure rejects events that have one or more pileup beam ions within the readout gates of the ZDC or Blade
- Ensures “clean” ZDC and Blade measurements
- But this does not eliminate pileup in the full 200 ns (!) time window of the Vertex Tracker



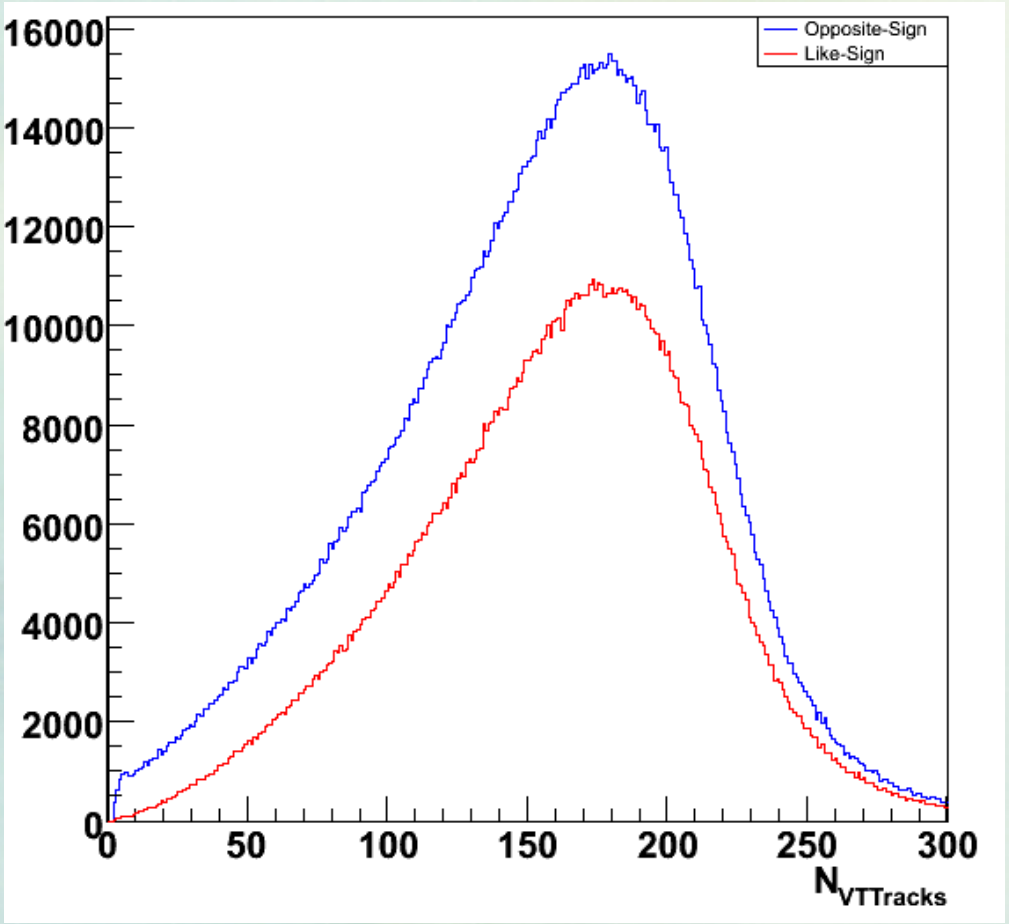
Event Selection
Beam Tracker Ion Timing

- These figures show the ZDC vs. QB distributions for Dimuon triggers, before and after *Beam Tracker Time Selection*
- This selection provides reliable measurements in the ZDC and Quartz Blade (with only very little remaining beam pileup)



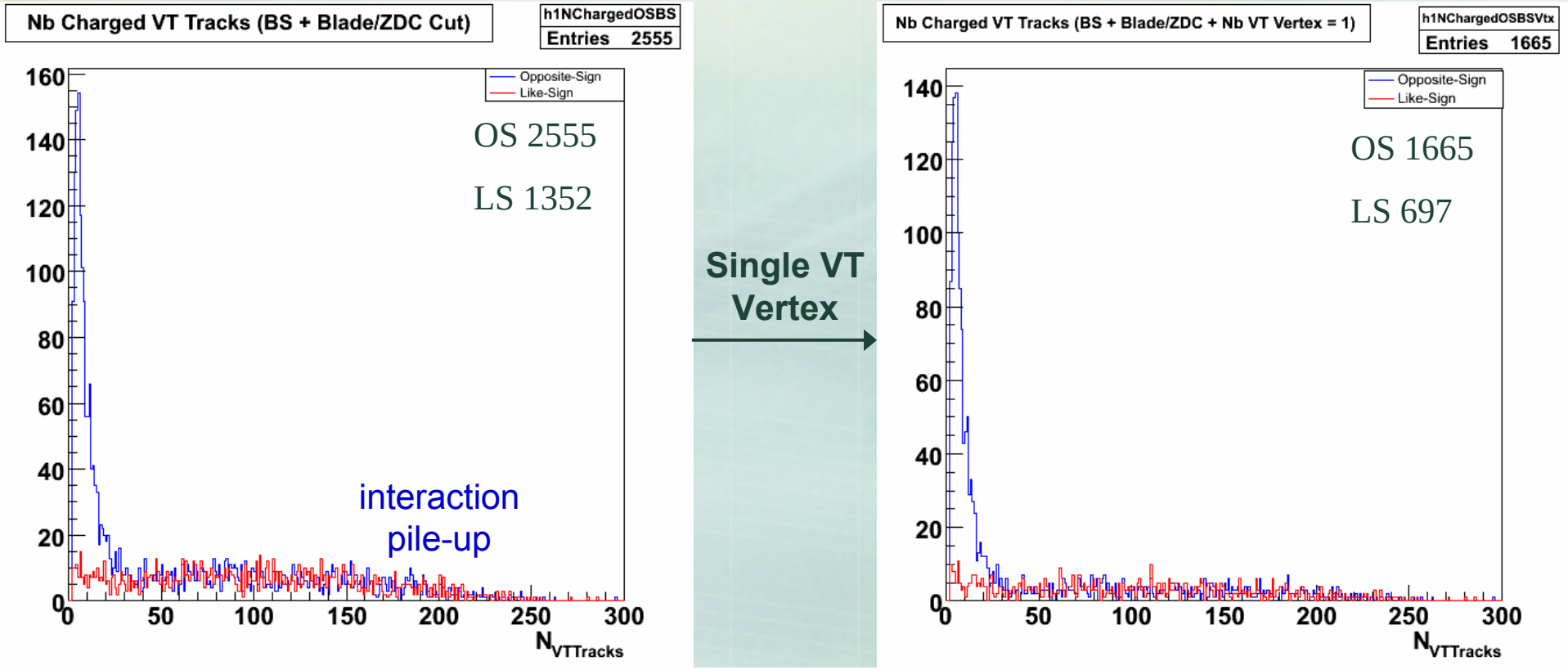
Event Selection
Charged-track multiplicity distribution

- Distribution of the number of reconstructed charged tracks when integrating over all events, from the most peripheral to the most central In-In collisions
- We only select events with a single vertex
- We only count the tracks that come from that vertex



Event Selection
Single VT Vertex

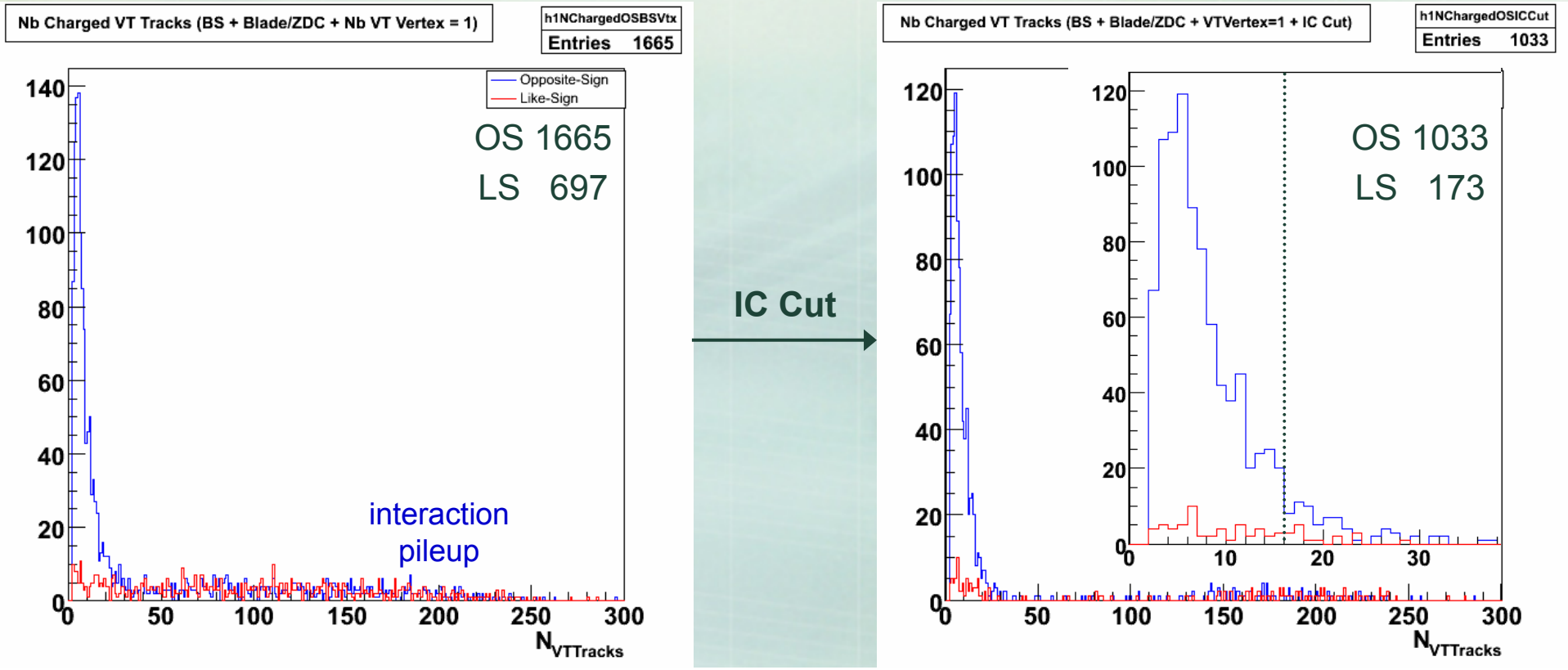
- After applying the ZDC and QB 2σ cut, the NVTTracks distribution shows two kinds of events: the expected “very peripheral collisions” and a background tail of events clearly coming from “normal collisions” (including very central ones)
- The background tail decreases when we reject events that have more than one VT Vertex reconstructed by the Vertex Tracker



Event Selection
Interaction Counter Cut

- In order to have an *even cleaner* event sample, we only select events where the IC identified only one interaction within a broad time window, and this interaction is *in time* with the trigger
- The interaction pileup tail becomes negligible

most of the remaining events
have less than 15 charged tracks



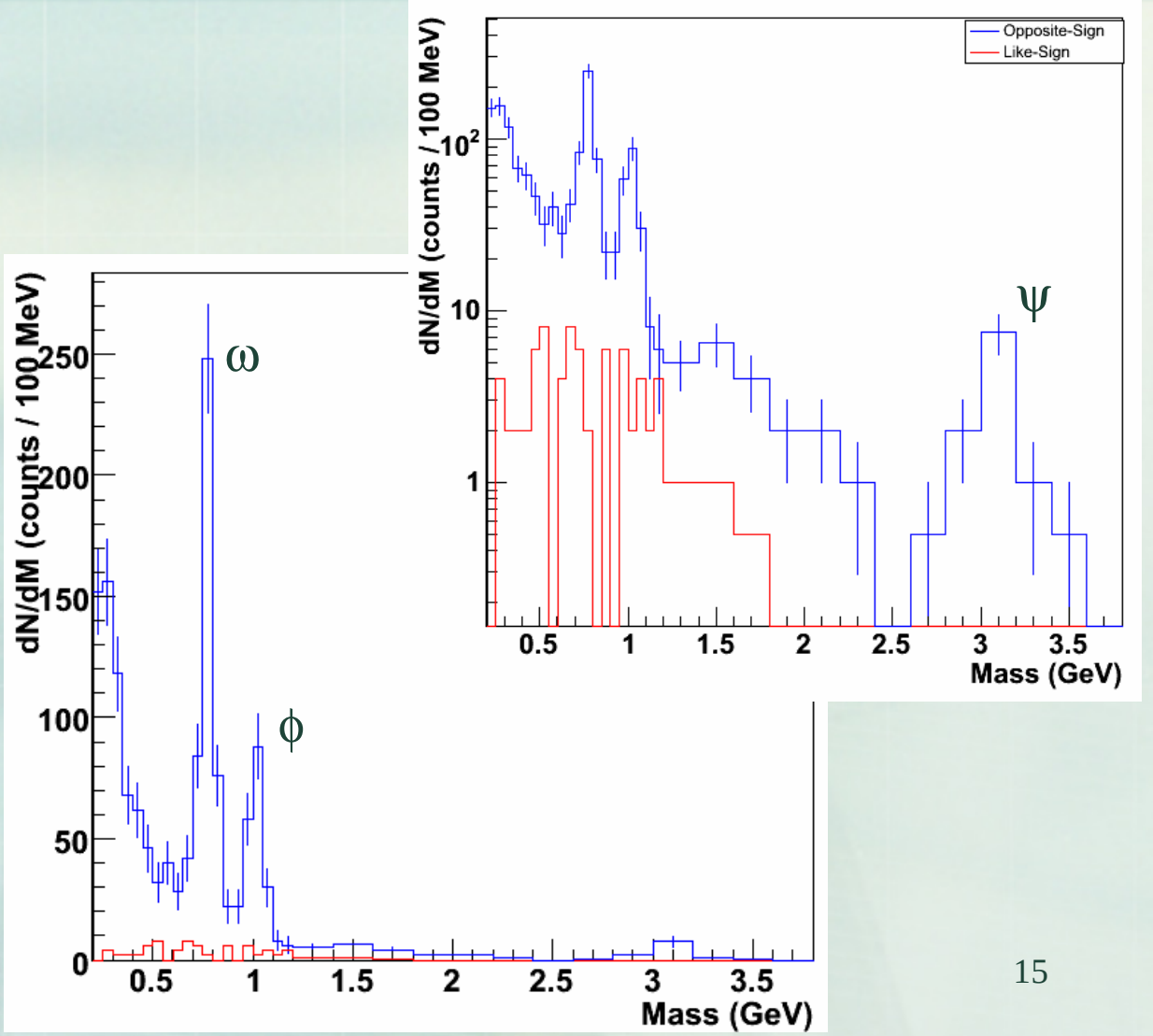
Event Selection
Summary of Selection Cuts

- Beam Tracker Timing Selection
  - Rejects events with Beam Pileup during the r/o gates of the ZDC and Blade
  - Makes the ZDC and Blade information more reliable
  - But... rejects up to 30% of the UPCs
- Blade/ZDC 2σ Eliptical Cut
  - Only selects events that look indistinguishable from “no collisions at all”
  - But... rejects 14% of the UPCs
- Nb VT Vertices = 1
  - Only selects events with one interaction during the “readout gate” of the pixels
  - But... rejects up to 28% of the UPCs
  - Note: two interactions very close to each other (in space) will be seen as one
- Interaction Counter
  - Rejects events with two interactions (if not happening “simultaneously” in time)
  - Makes the VT information more reliable
  - But... rejects 21% of the UPCs
- Some of these cuts might be released to recover statistics...

Dimuon Mass Distribution

- Standard event selection
- Beam Tracker timing
- Blade/ZDC 2σ eliptical cut
- Only one VT vertex
- Interation Counter timing
- Nb VT Tracks ≤ 15

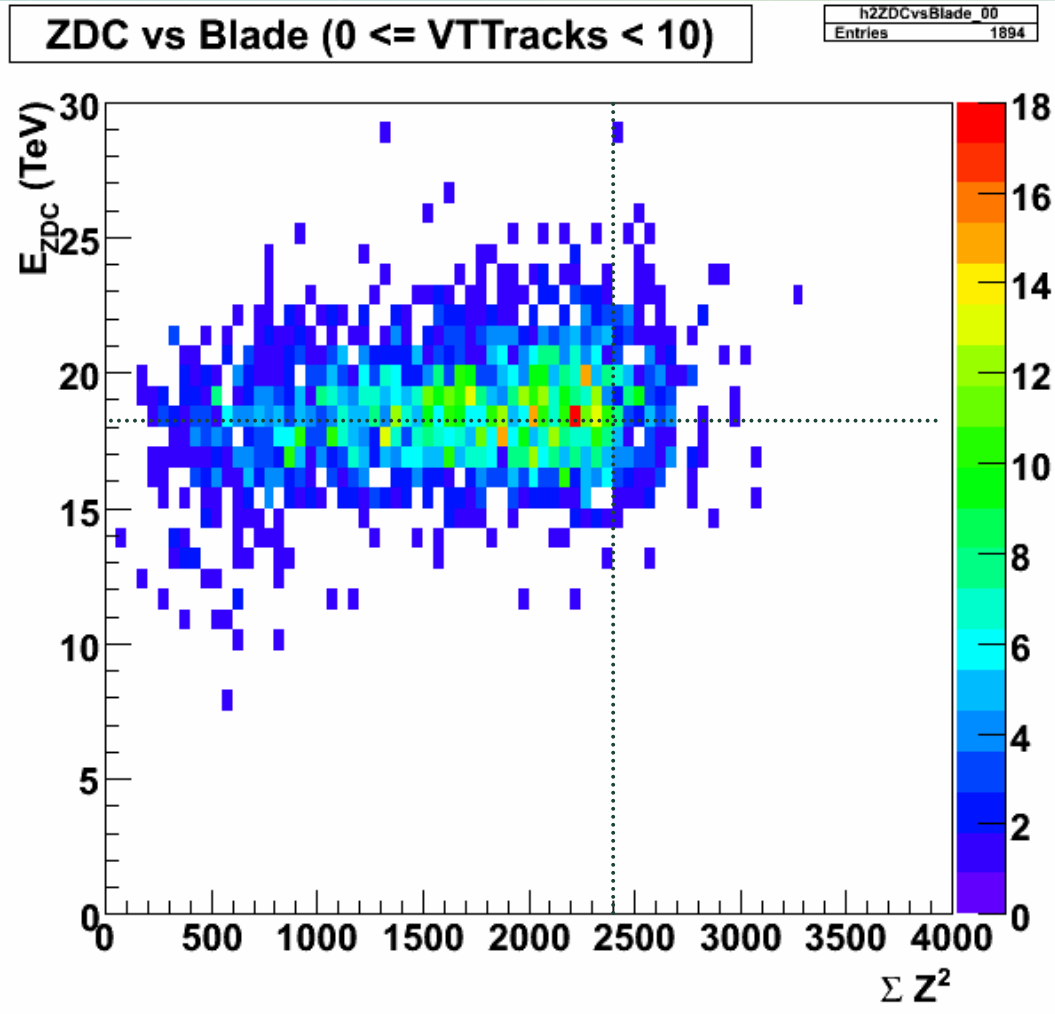
- The number of LS events is very small
- Clear ω, ϕ and ψ peaks
- But... how many of these events are *not* UPCs?



ZDC vs. QB in bins of Nb VT Tracks

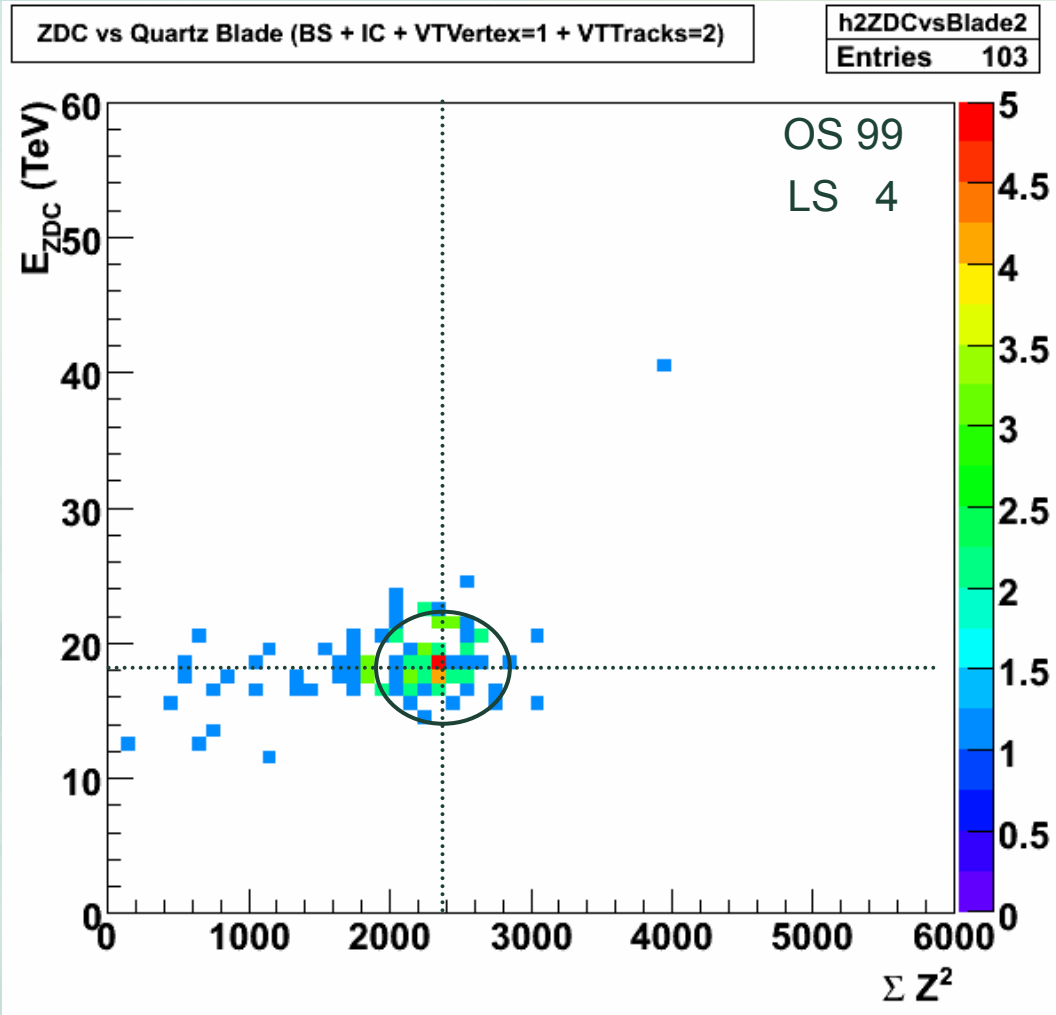
ultra peripheral

- The pollution of non-UPC events can be appreciated by seeing how the event distribution in the ZDC vs. QB plane changes when we select different bins in the number of charged tracks of the event
- There are some events with tracks that were not attached to the reconstructed vertex; we now reject such events, so that the NVTTracks variable becomes also the *total* number of tracks in the event



ZDC vs Blade for Nb VT Tracks=2

- Event selection:
  - Beam Tracker timing
  - Interaction Counter timing
  - only 1 VT Vertex (with the matched Dimuon)
  - only 2 VT Tracks in total (the two matched muons...)
- We see most events clustering in the “non-interaction” zone, plus a few in the “beam fragmentation” zone
- The pollution from hadronic collisions should be negligible
- But the remaining statistics is quite low... after all the “cleaning”



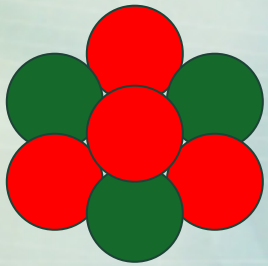
Summary

- This was only the beginning...
- We now have a reasonable understanding of the event selection procedure but we need to make another iteration to recover more statistics while keeping a clean event sample
- Next steps:
  - Monte Carlo simulations to calculate acceptances, evaluate cut efficiencies, etc.
  - Prepare acceptance corrected kinematical distributions (p_T, y, etc);
    first input files (generation) already kindly provided by Joakim Nystrand
  - Calculate absolute production cross-sections for the vector mesons

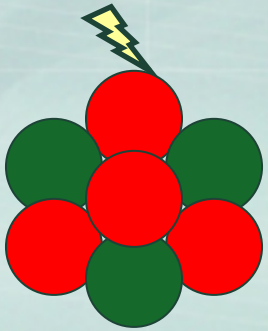
Backup

Possible Contributions
Beam ion remains intact

- Beam ion remains intact
  - ZDC measures 115x158 = 18.17 TeV
  - Blade measures 49x49 = 2401
  - Only Opposite-Sign muon pairs are created



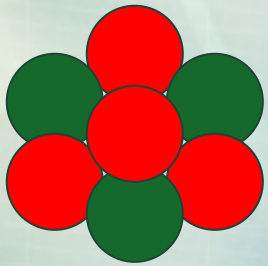
Beam



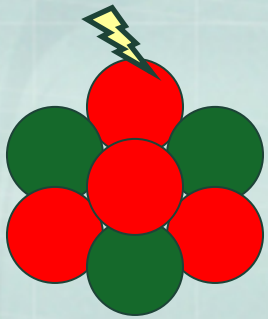
Target

Possible Contributions
Beam ion fragments

- Beam ion fragments
  - ZDC measures 115x158 = 18.17 TeV
  - Blade measures less than 49x49 = 2401
  - Only Opposite-Sign muon pairs are created



Beam



Target

Possible Contributions
Hadronic collision

- Hadronic collision
  - ZDC measures less than 115x158 = 18.17 TeV
  - Blade measures less than 49x49 = 2401
  - Opposite-Sign and Like-Sign muon pairs are created

Beam

Quartz Blade: a few numbers...

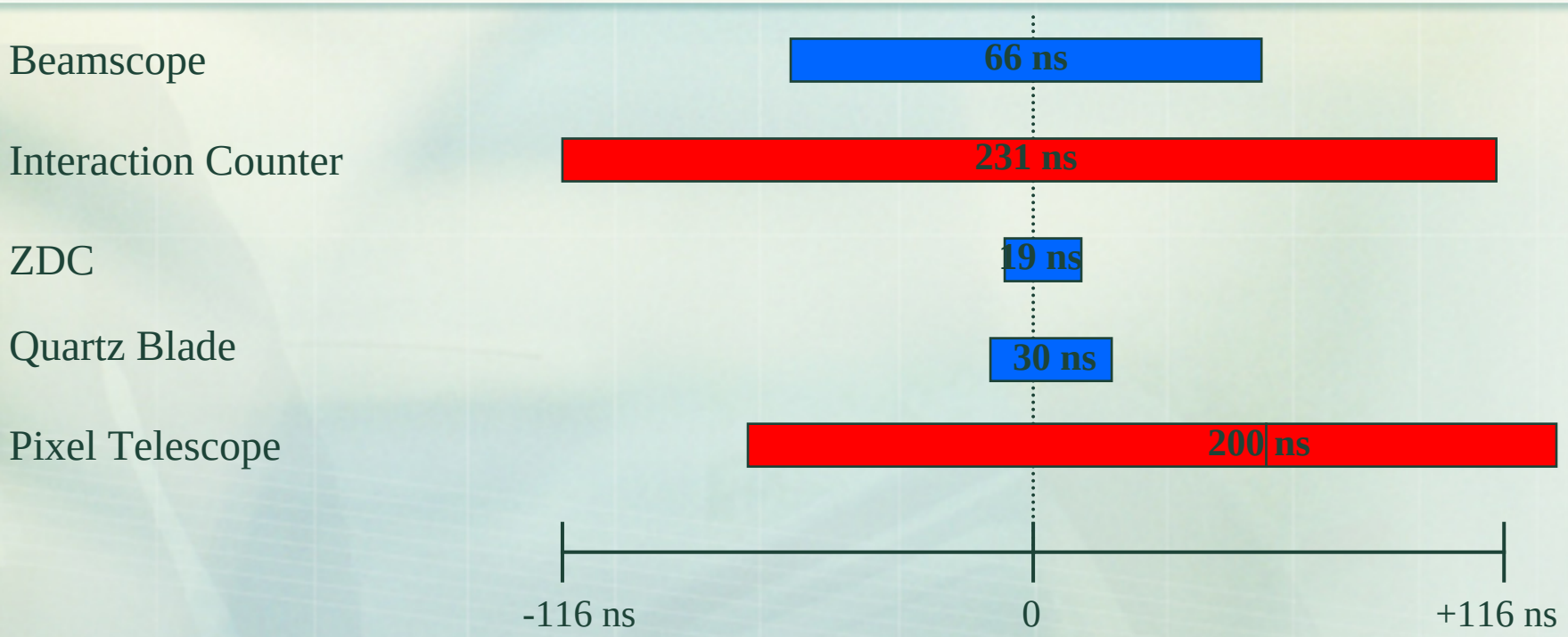
- The Quartz Blade has a σ of 216, so
  - 1σ of the peak is at 2401 – 216 = **2185**
  - 2σ of the peak is at 2401 – 2*216 = 1969
- Here are a few examples of what the Quartz Blade measures if:
  - A fragment with 1 charge is created: $\Sigma Z^2 = 48^2 + 1^2 = 2305$
  - A fragment with 2 charges is created: $\Sigma Z^2 = 47^2 + 2^2 = 2213$
  - A fragment with 3 charges is created: $\Sigma Z^2 = 46^2 + 3^2 =$ **2125** (outside 1σ)
  - A fragment with 4 charges is created: $\Sigma Z^2 = 45^2 + 4^2 = 2041$
  - A fragment with 5 charges is created: $\Sigma Z^2 = 44^2 + 5^2 = 1961$ (outside 2σ)

ZDC: a few numbers...

- The ZDC has a σ of 1930, so
  - 1σ of the peak is at 18170 – 1*1930 = **16240** GeV
  - 2σ of the peak is at 18170 – 2*1930 = 14310 GeV
- An Indium ion has 49 protons and 115 nucleons: A/Z = 115/49 = 2.35
- Here are a few examples of what the ZDC measures if:
  - 1 charge interacts with the target: E_{ZDC} = 158*(115 – 1*2.35) = 17799 GeV
  - 2 charges interact with the target: E_{ZDC} = 158*(115 – 2*2.35) = 17428 GeV
  - 3 charges interact with the target: E_{ZDC} = 158*(115 – 3*2.35) = 17058 GeV
  - 4 charges interact with the target: E_{ZDC} = 158*(115 – 4*2.35) = 16687 GeV
  - 5 charges interact with the target: E_{ZDC} = 158*(115 – 5*2.35) = 16316 GeV
  - 6 charges interact with the target: E_{ZDC} = 158*(115 – 6*2.35) = **15945** GeV (outside 1σ)

- Conclusion: the Blade is more sensitive than the ZDC to a (small) loss of charges in the beam Indium ion

Readout Timing Diagram



Detector only sees **interacting ions**

Detector is sensible to both **interacting** and **non-interacting** ions