PIERRE AUGER OBSERVATORY

CBPF

The Angular Resolution of the Pierre Auger Observatory

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CBPF – CNRS/In2p3

Pierre Auger Collaboration

Vulcano Workshop 2006 - Frontier Objects in Astrophysics and Particle Physics

May 21 – 27, Vulcano, Italy

Objective

Extract optimal arrival direction information

Angular Resolution for Surface Detector

Angular Resolution for Surface Detector

- From experimental data

Angular Resolution for Surface Detector

- From experimental data
- Using the information from the geometrical reconstruction

Angular Resolution for Surface Detector

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Ground

Angular Resolution for Surface Detector

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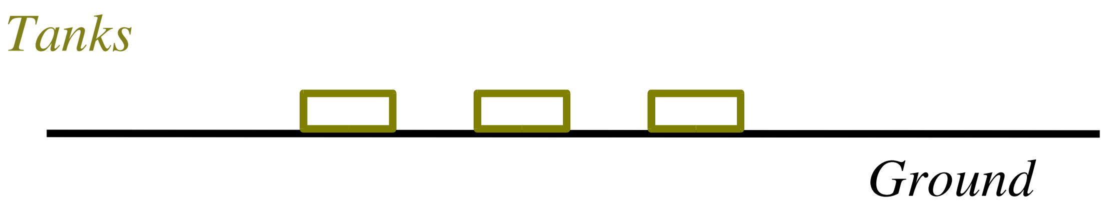

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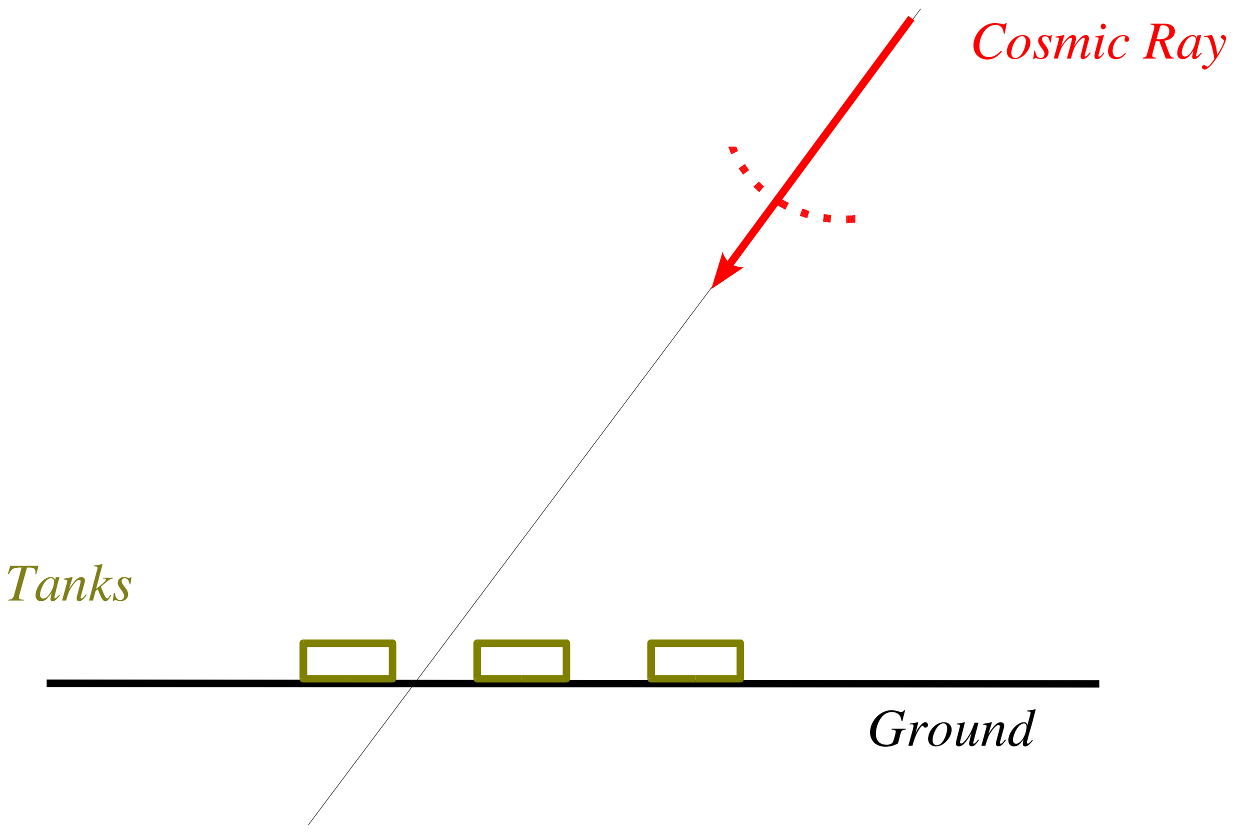

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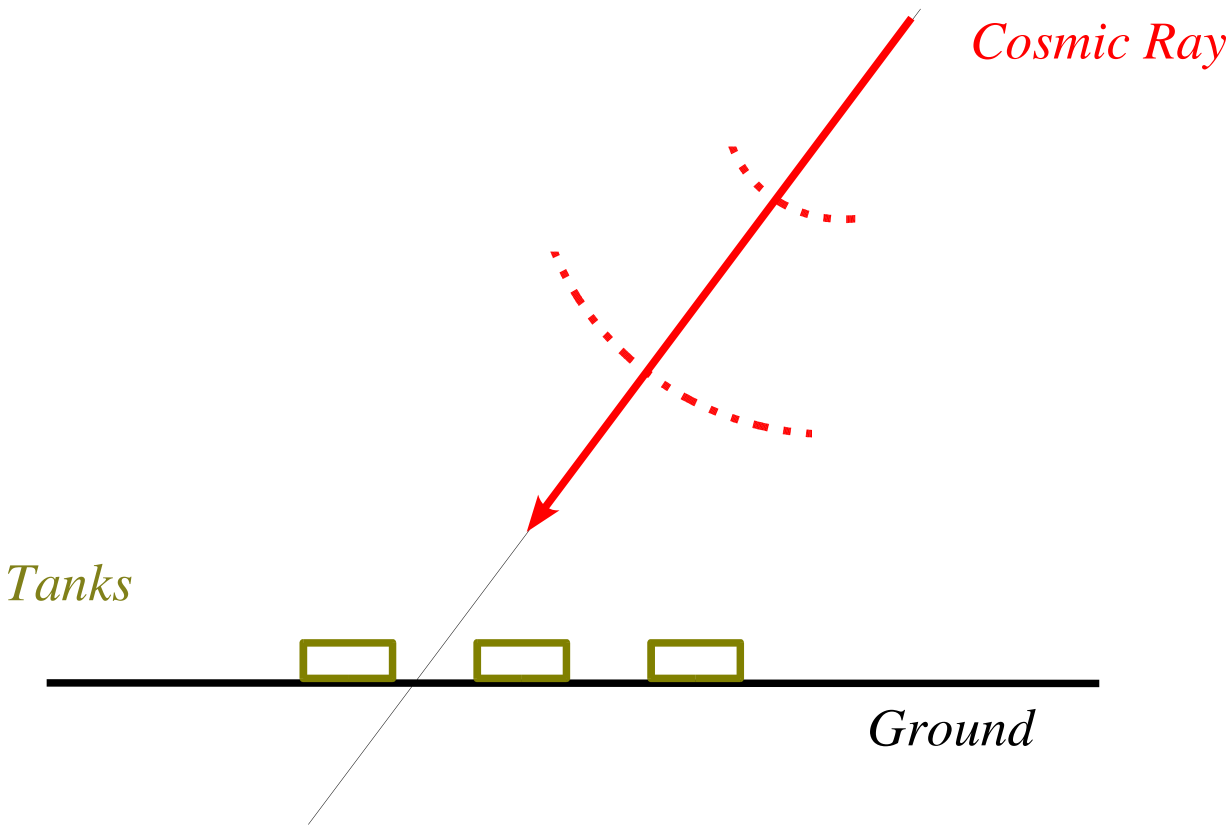

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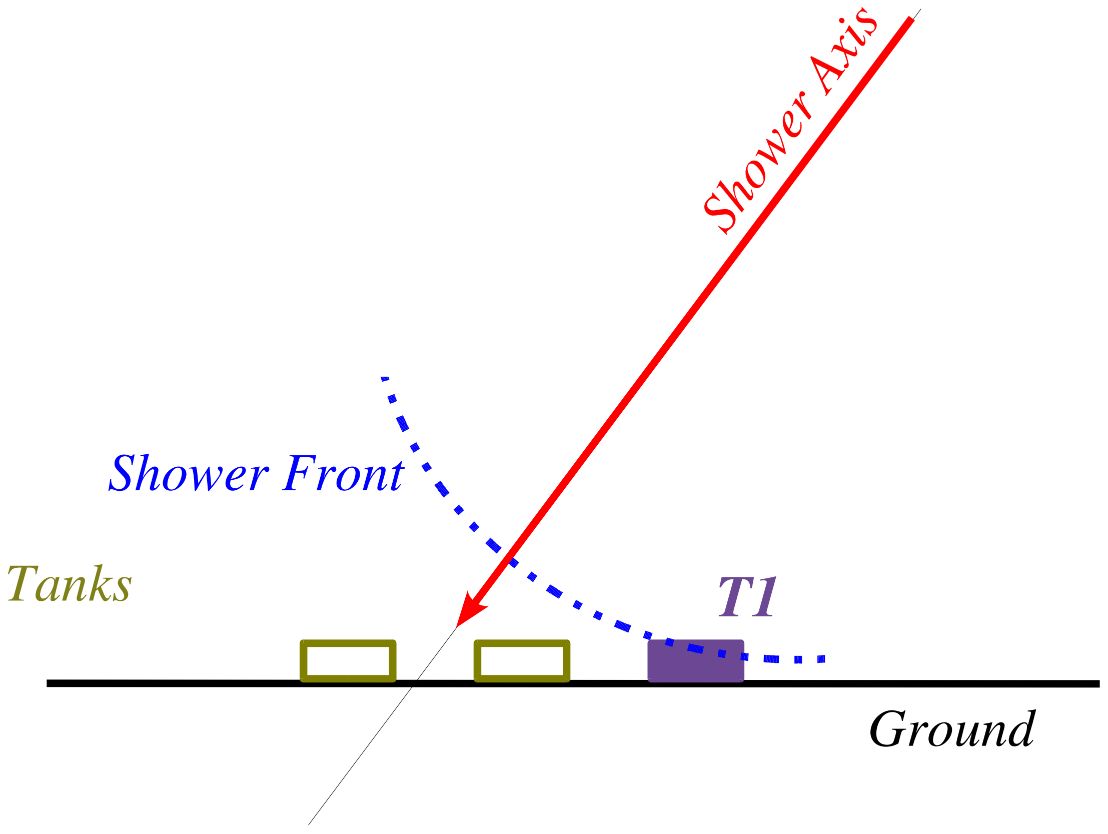

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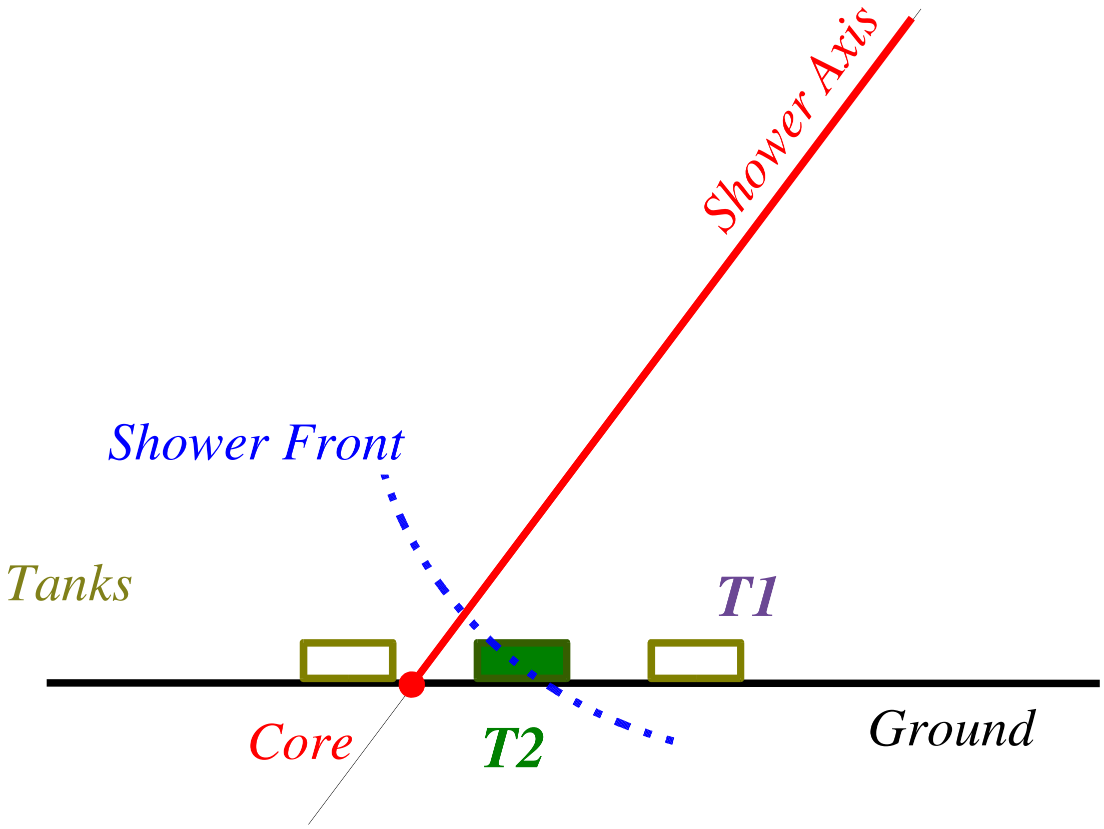

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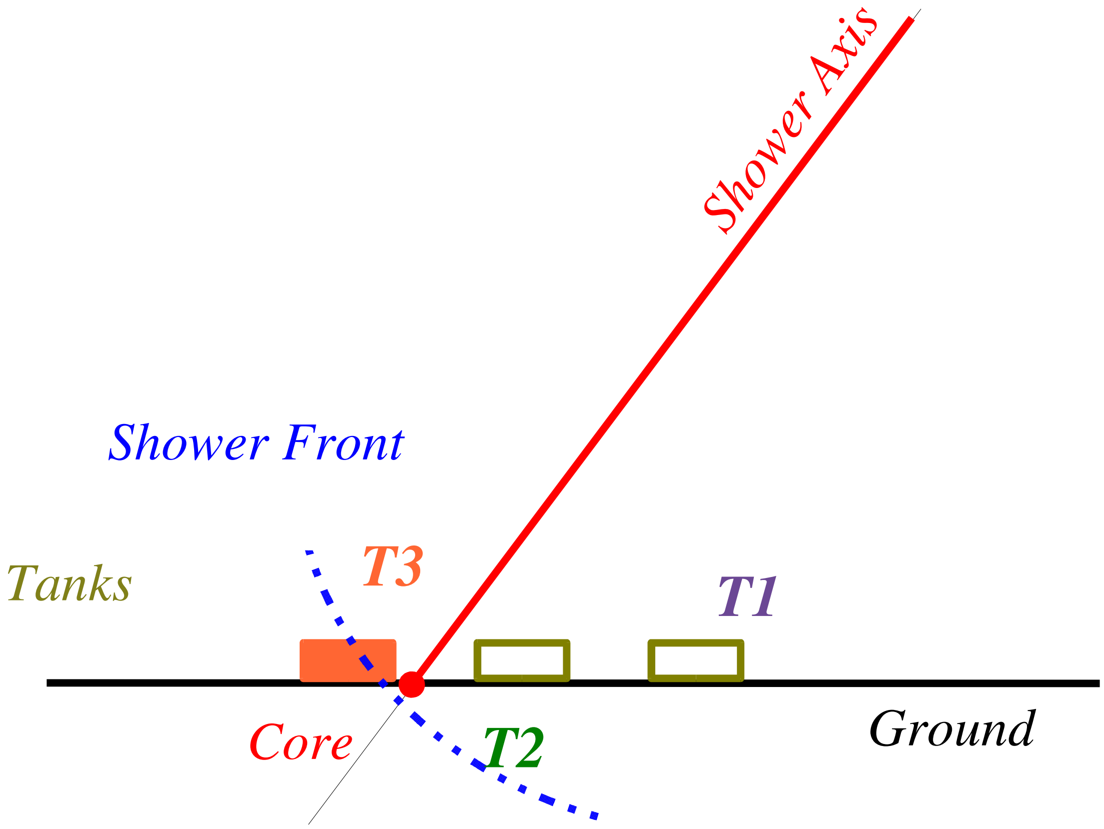

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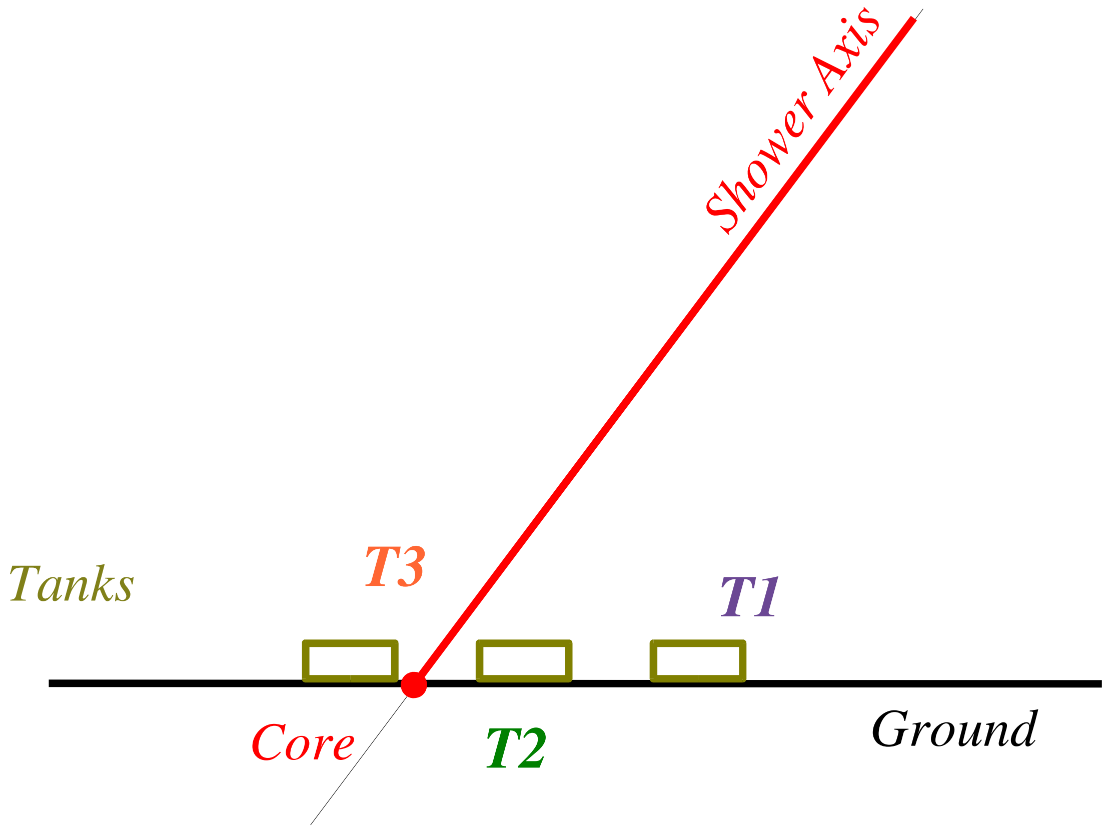

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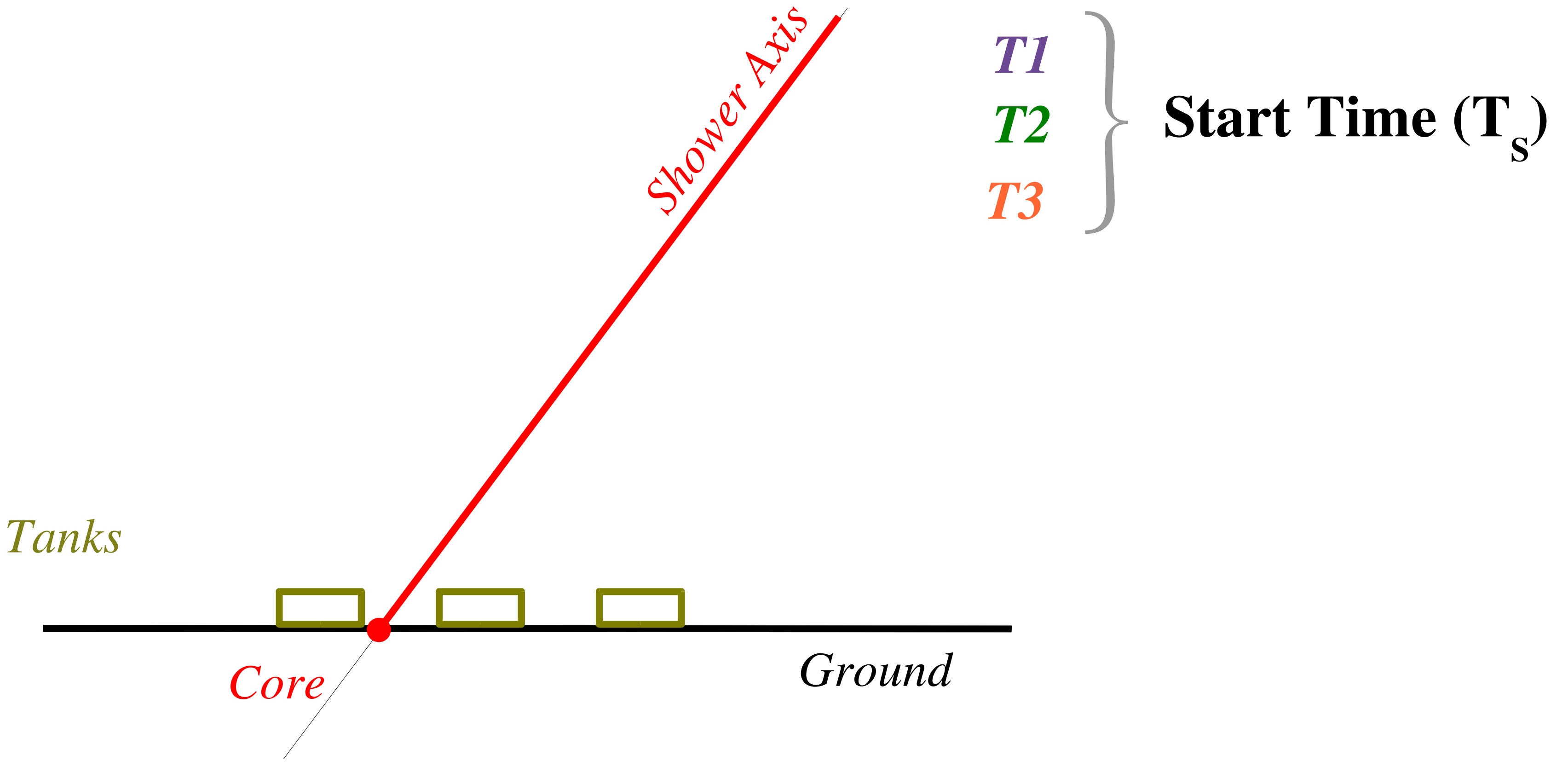

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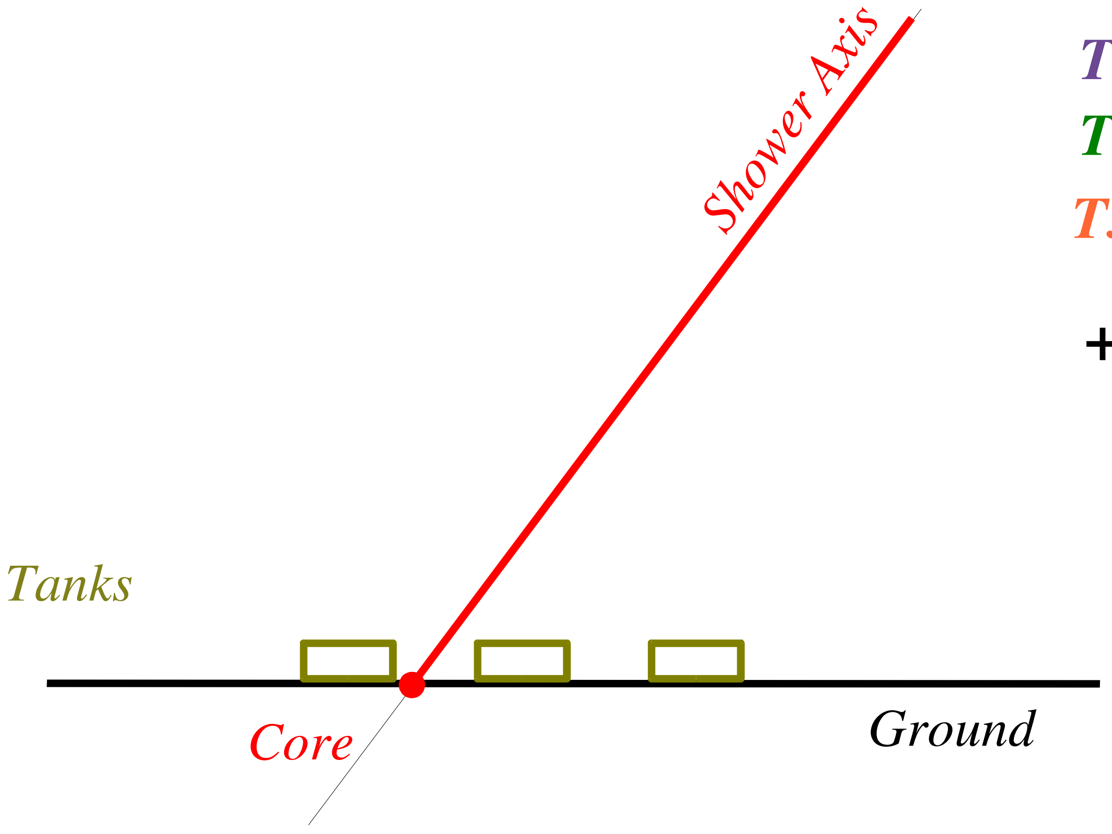

T1
T2
T3

Start Time (T_s)

+ Variance T_s

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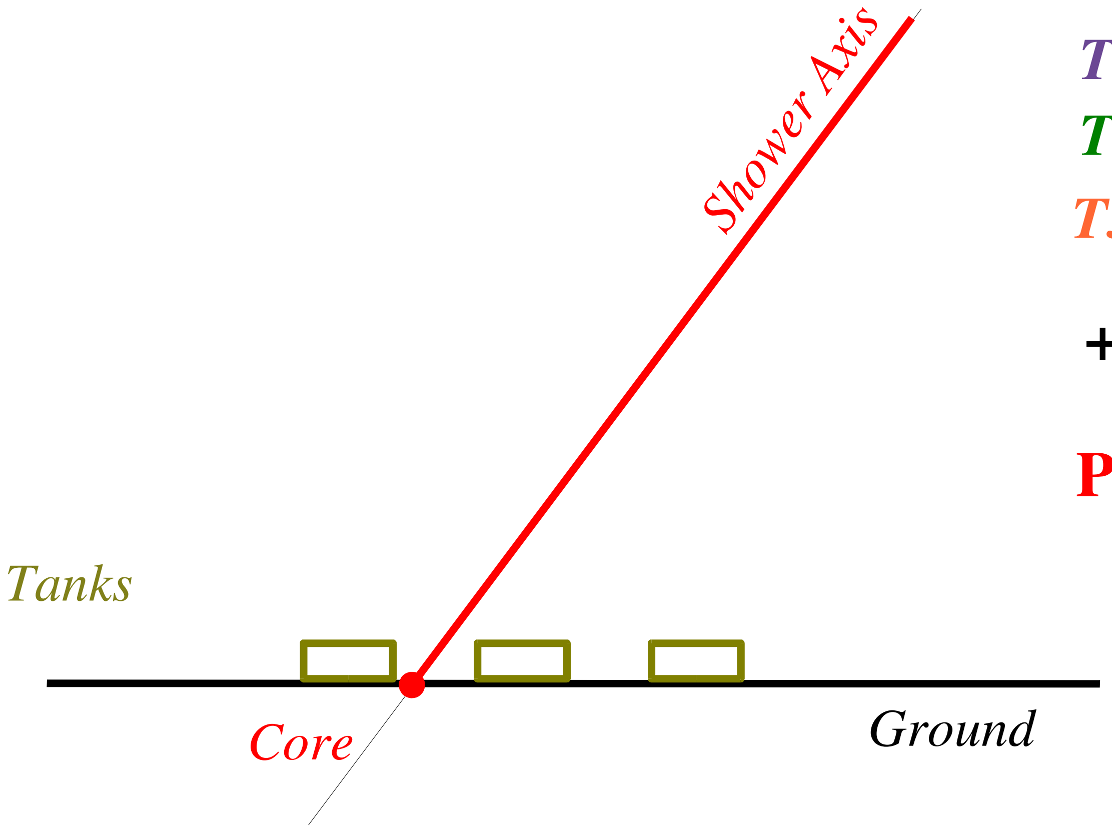

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T2
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Start Time (T_s)

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Parabolic Shower Front

Angular Resolution for Surface Detector

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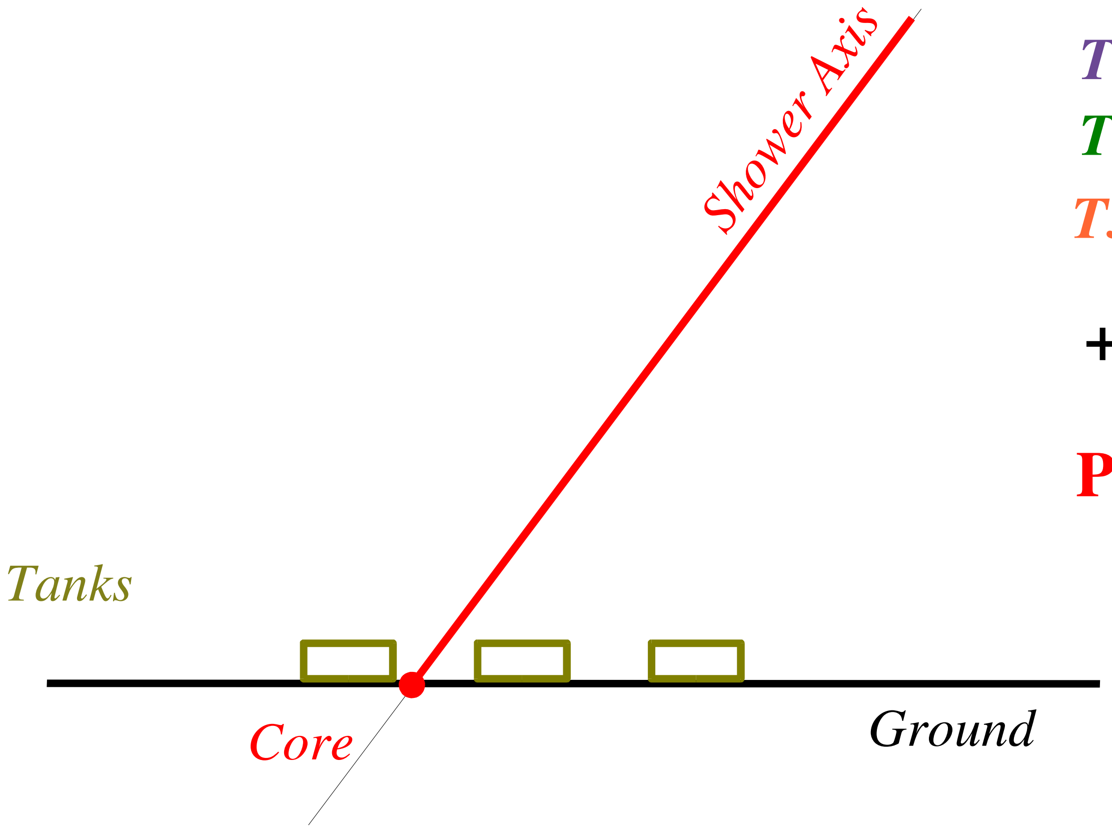

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T2
T3

Start Time (T_s)

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Parabolic Shower Front

↓

T_0, θ, φ, R (+ errors)

Angular Resolution

The Angular Resolution is defined by the angular radius contour that contains 68% of the event coming from a point source.

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$$F(\eta) = \tfrac{1}{2} \left(V[\theta] + \sin^2(\theta)\, V[\phi] \right)$$

η is the spacial angle

θ is the zenith angle

ϕ is the azimuth angle

If θ and $\phi/\sin^2(\theta)$ have Gaussian distribution with variance σ^2, then $F(\eta) = \sigma^2$, and η has distribution proportional to $\exp\{-\eta^2/2\sigma^2\}\, d(\cos(\eta))d\phi$

The relation between σ and the angular resolution is: $AR = 1.5\,\sigma$

Angular Resolution from Experimental Data

SD Resolution depends on:

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Validate model with real data: Doublets and hybrids

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Data set: January 2004 to March 2006

Time Variance Model

Shower front described as a Poisson process (n particles arriving uniformly within time T)

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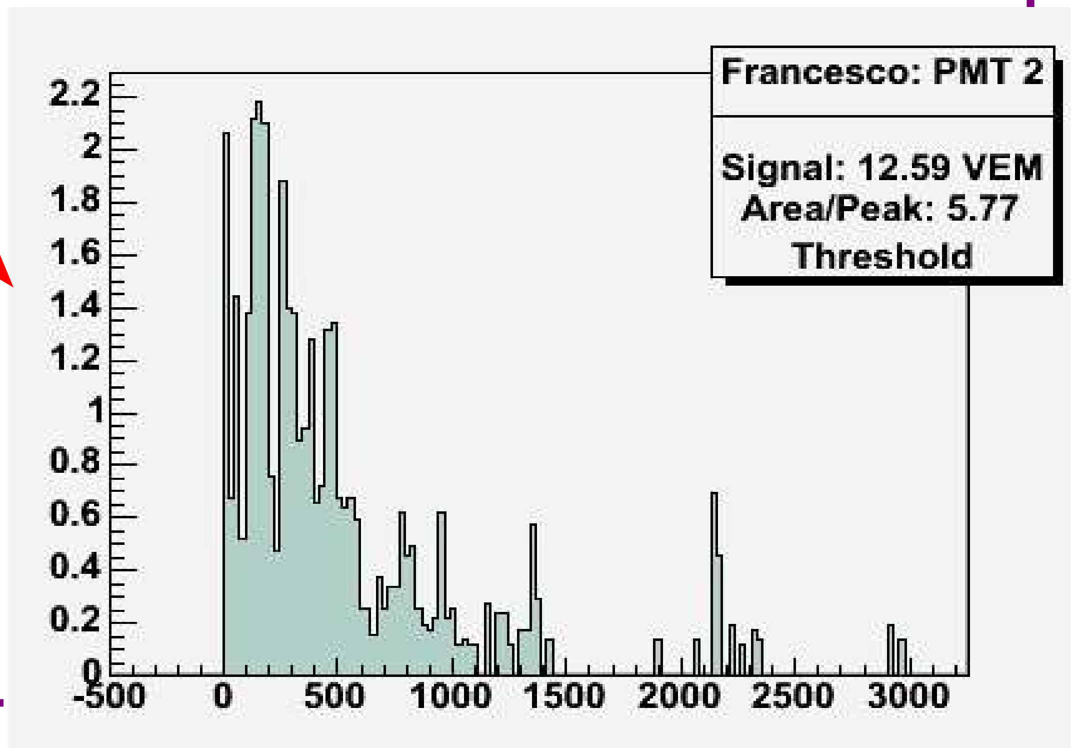

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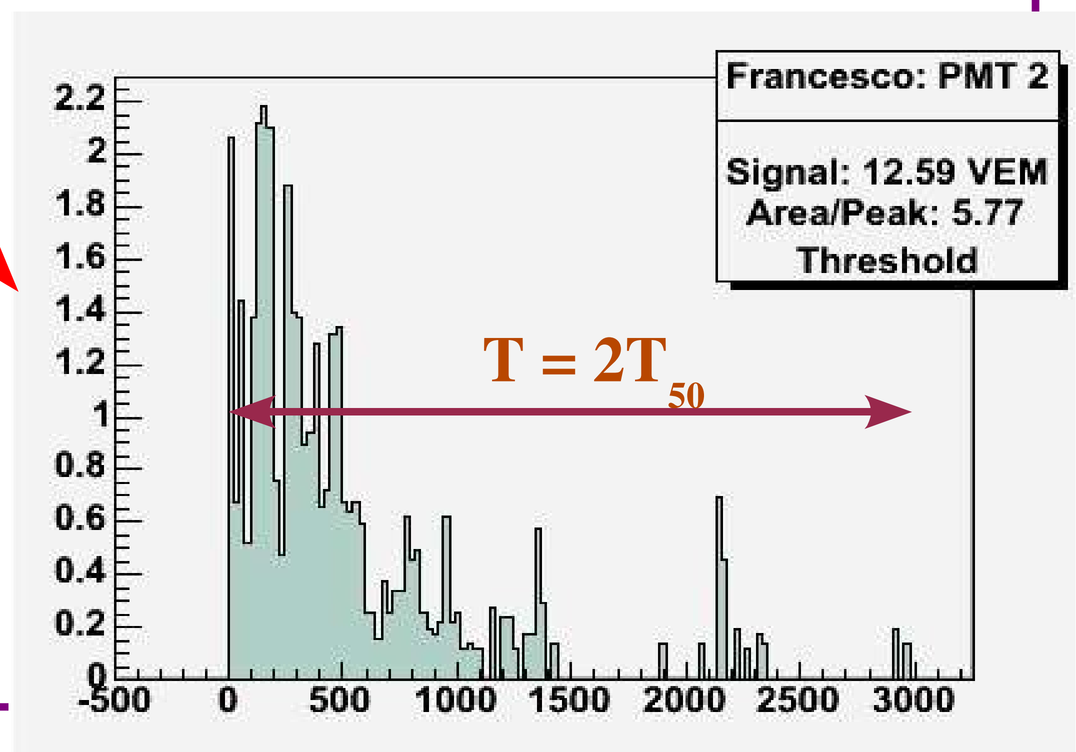

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$$\mathbf{n} = \frac{\mathbf{S}}{\mathbf{TL(\theta)}}$$

S = Integrated Signal in VEM

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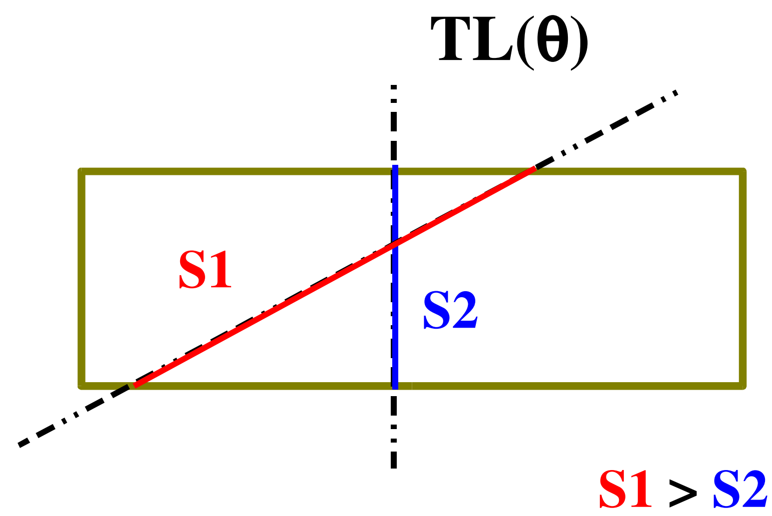

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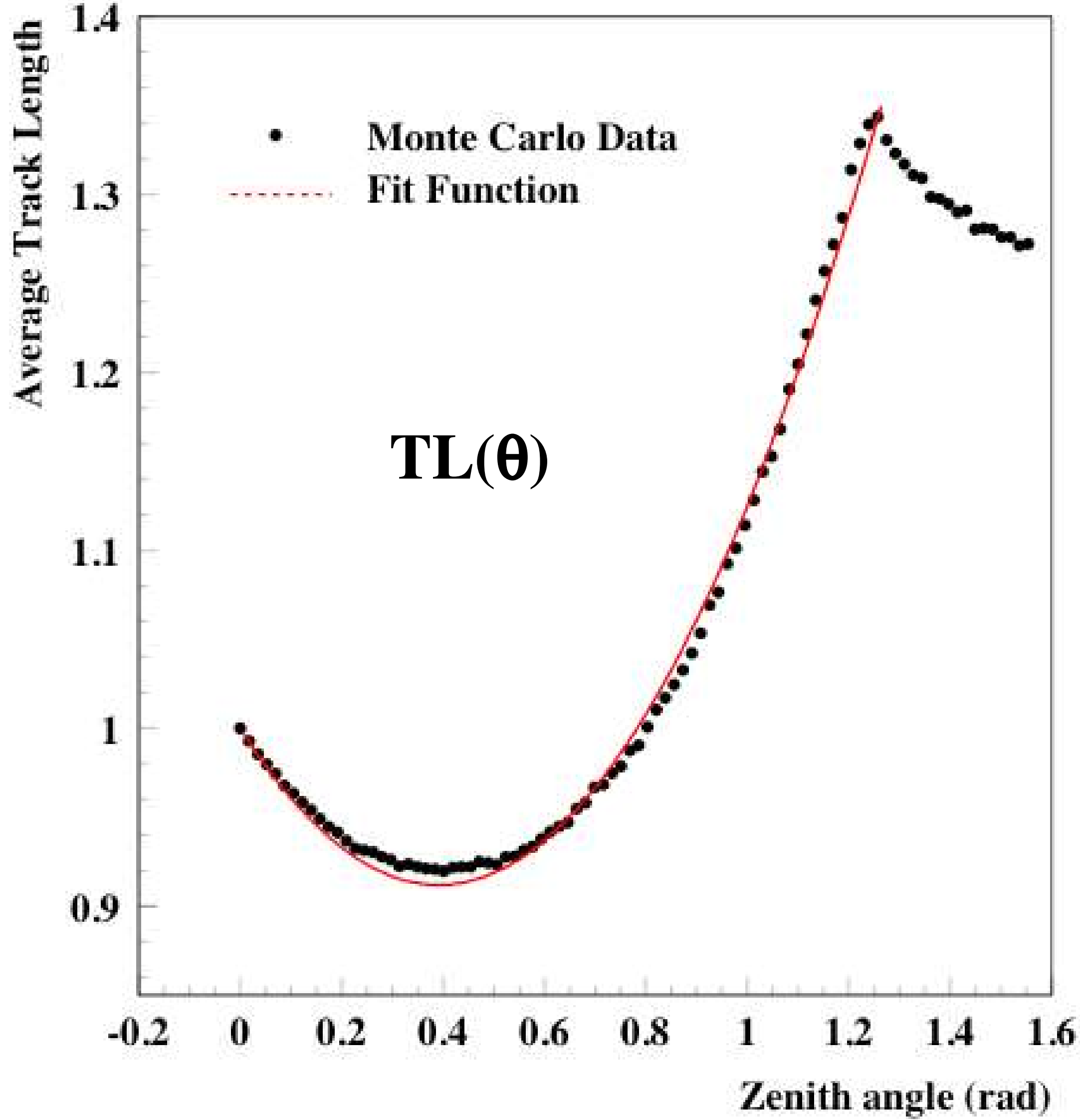

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Can be predicted

a = 1

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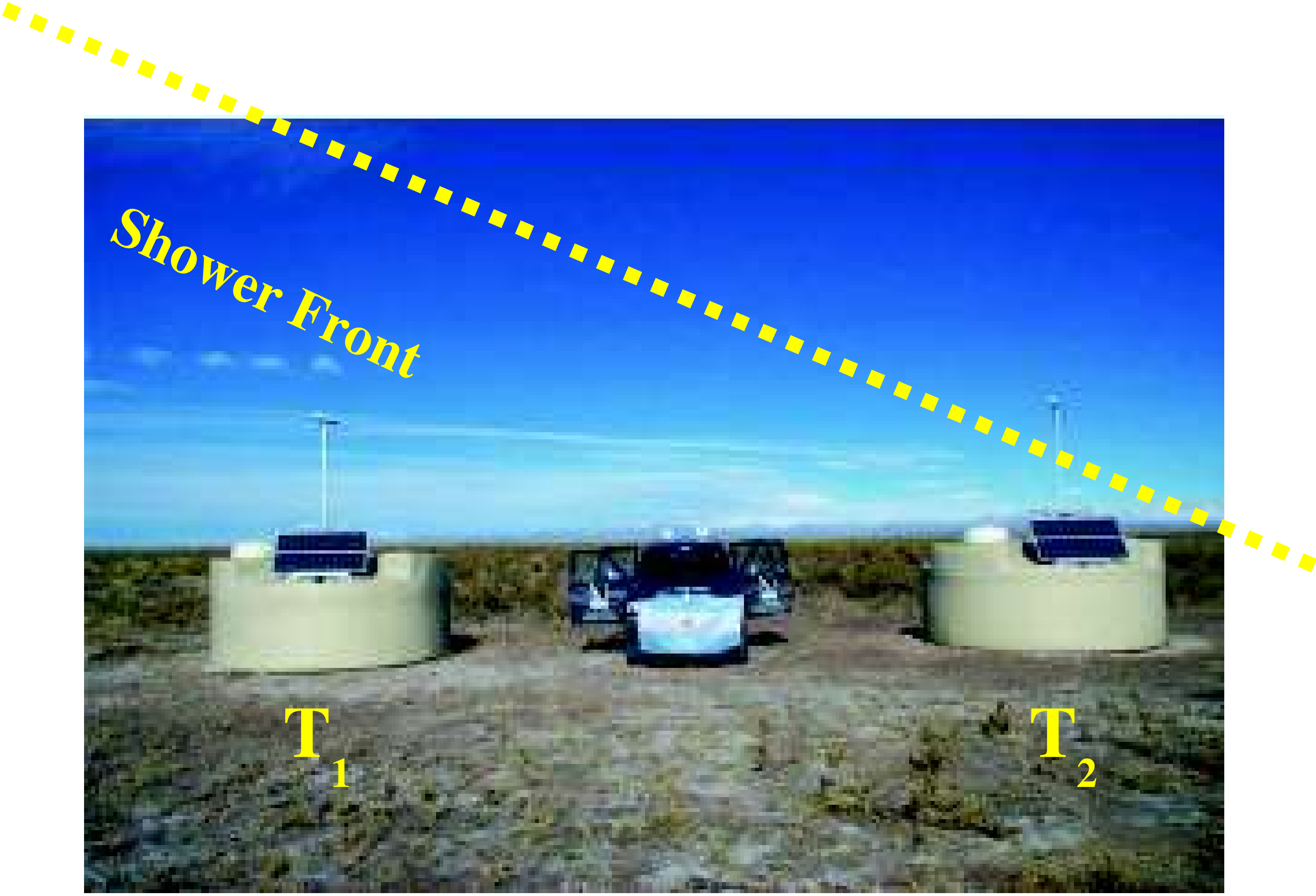
or adjusted on the doublet data...

Doublets



$$\mathfrak{L} = \prod_{k=1}^{N} \frac{1}{\sqrt{2\pi V[\Delta T_k]}} \; e^{-\frac{\Delta T_k^2}{2\, V[\Delta T_k]}}$$

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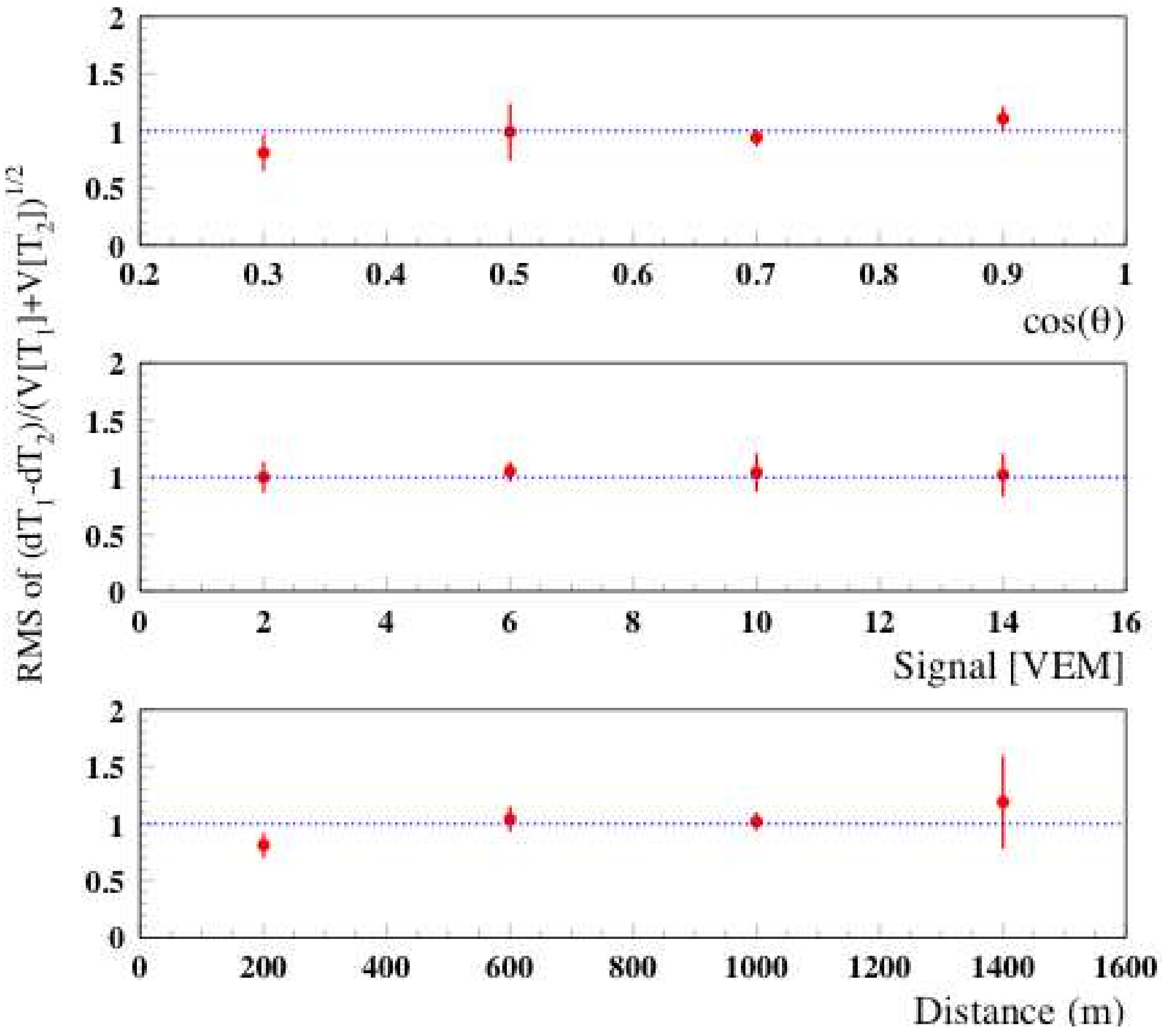
Extraordinarily consistent !

Doublets

Verifying model quality on doublet data:



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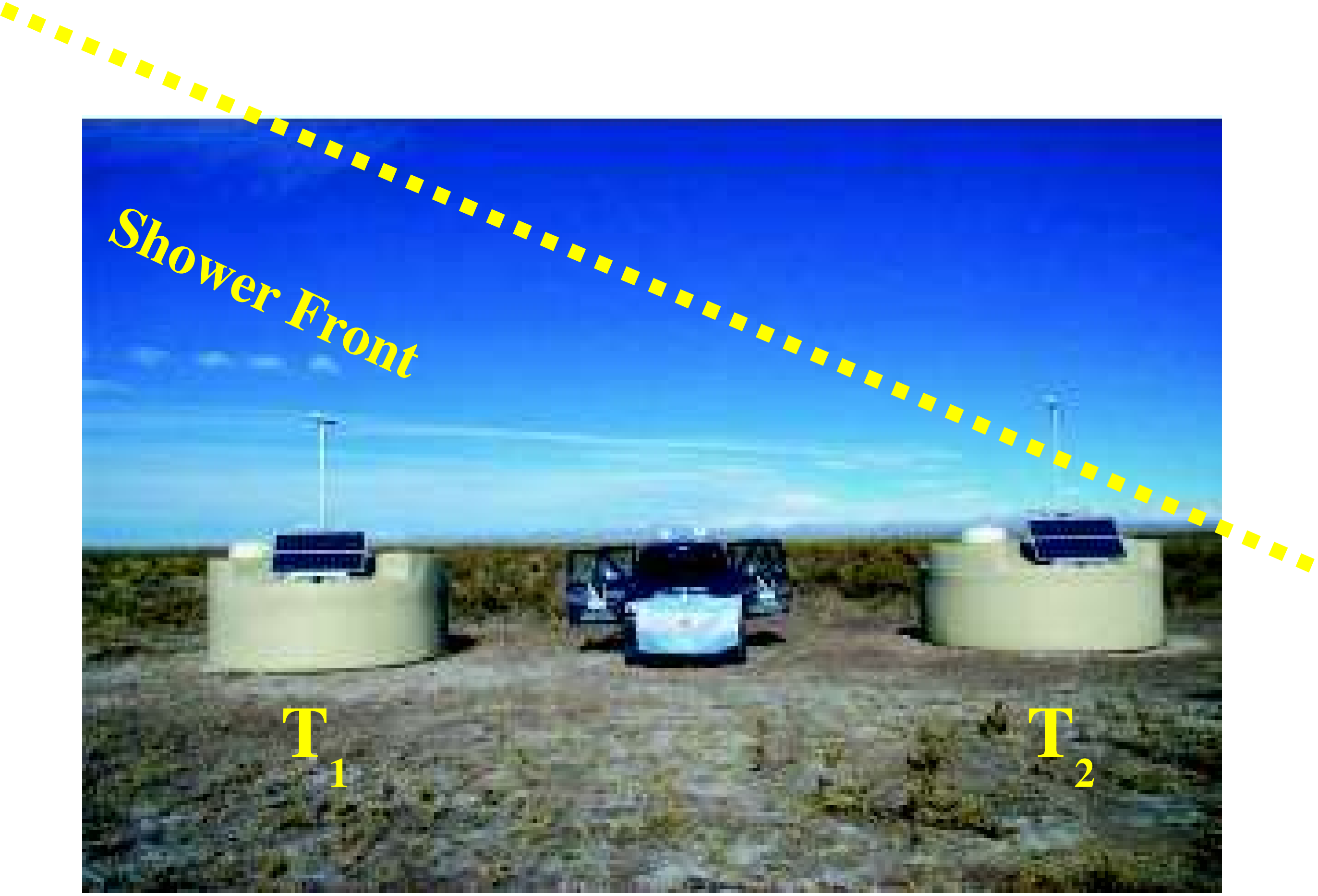

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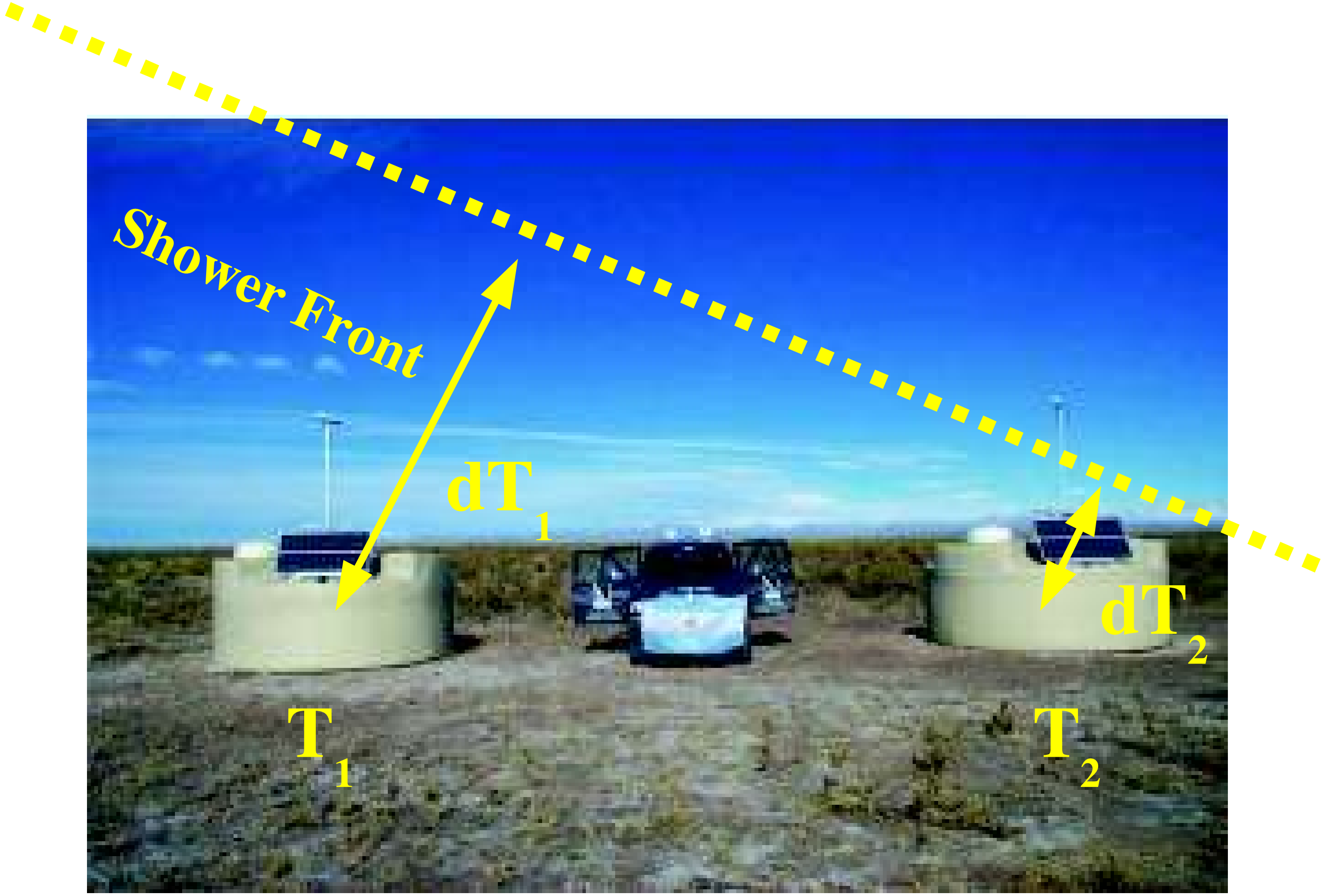

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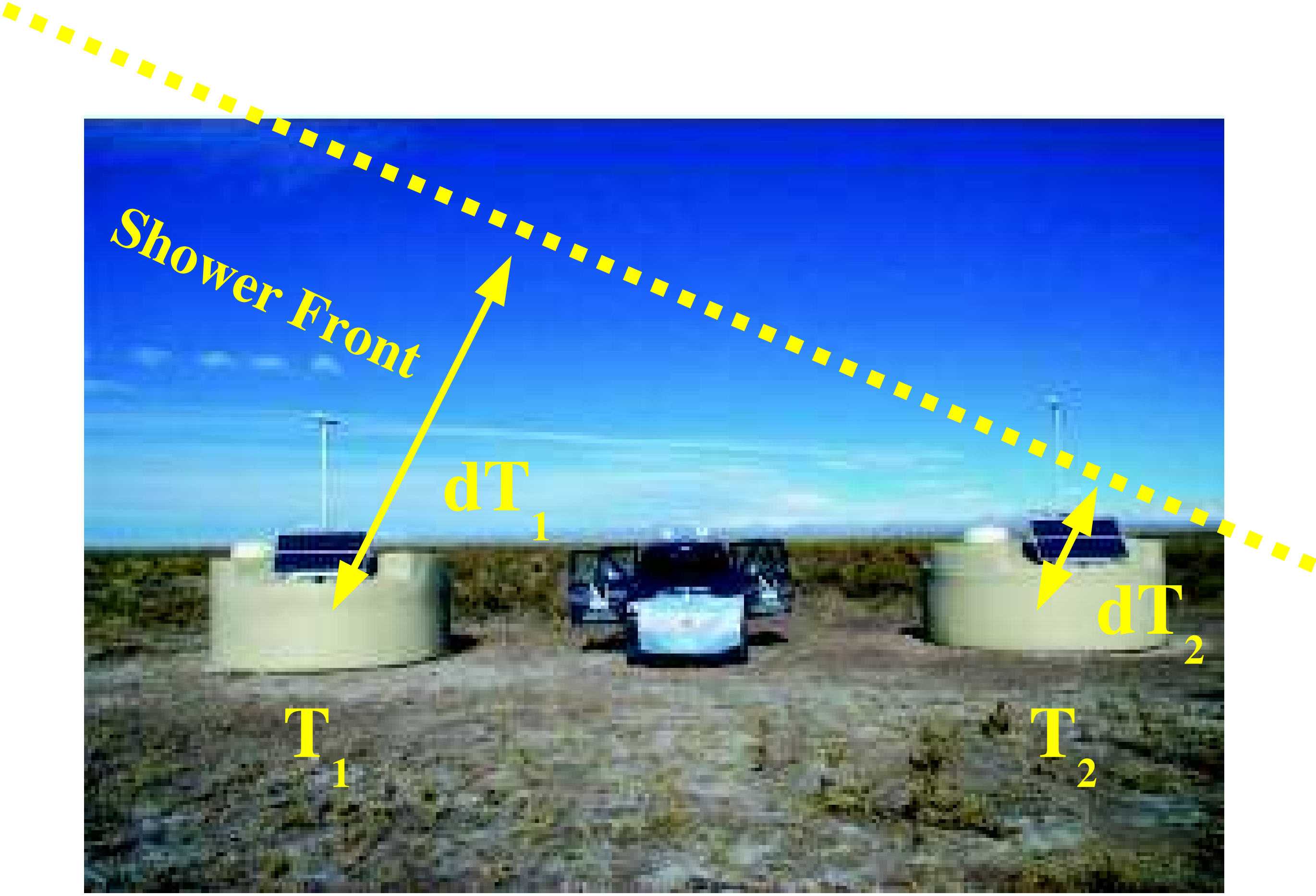

$$\frac{dT_1 - dT_2}{\sqrt{V[T_1] + V[T_2]}}$$

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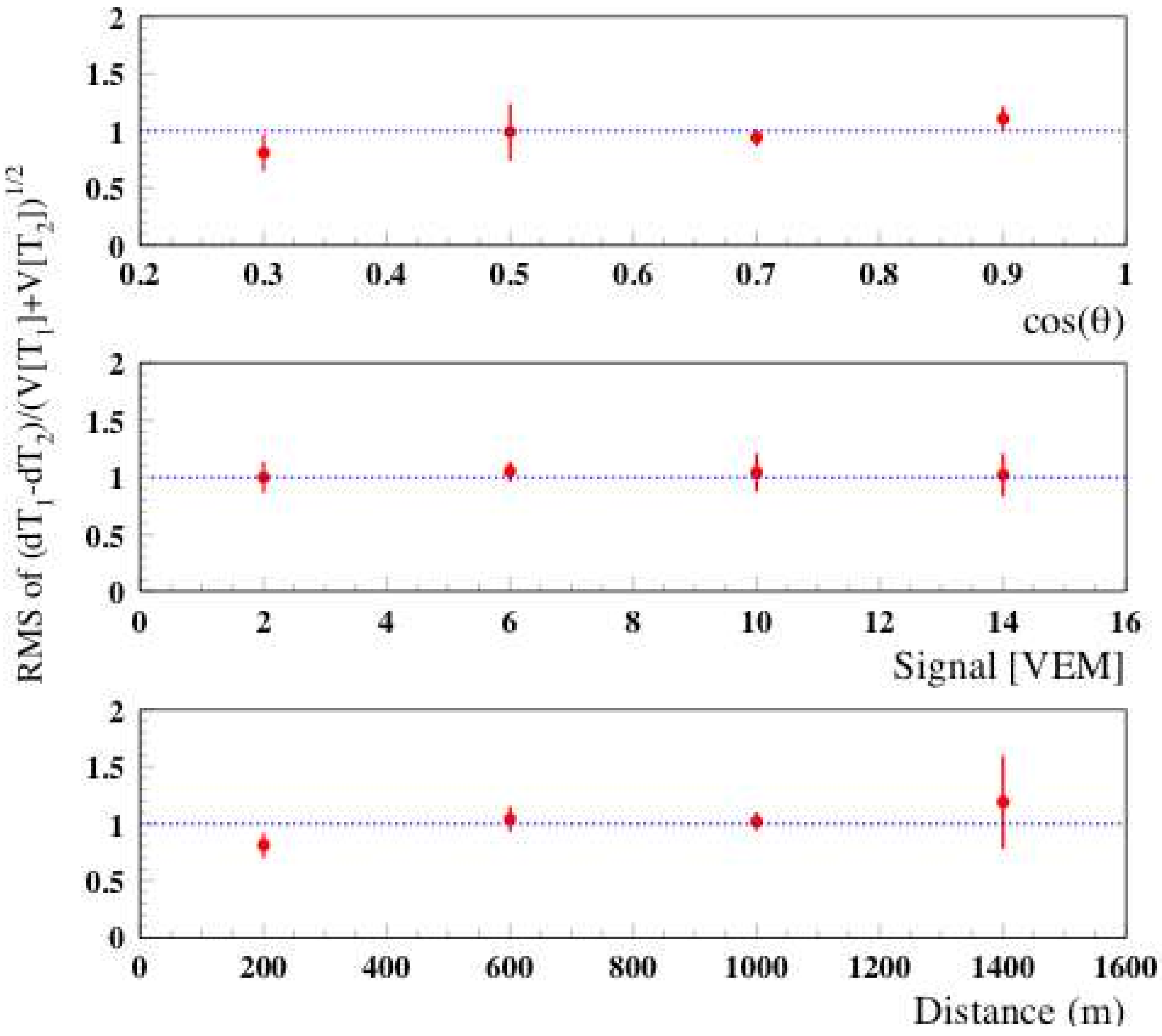
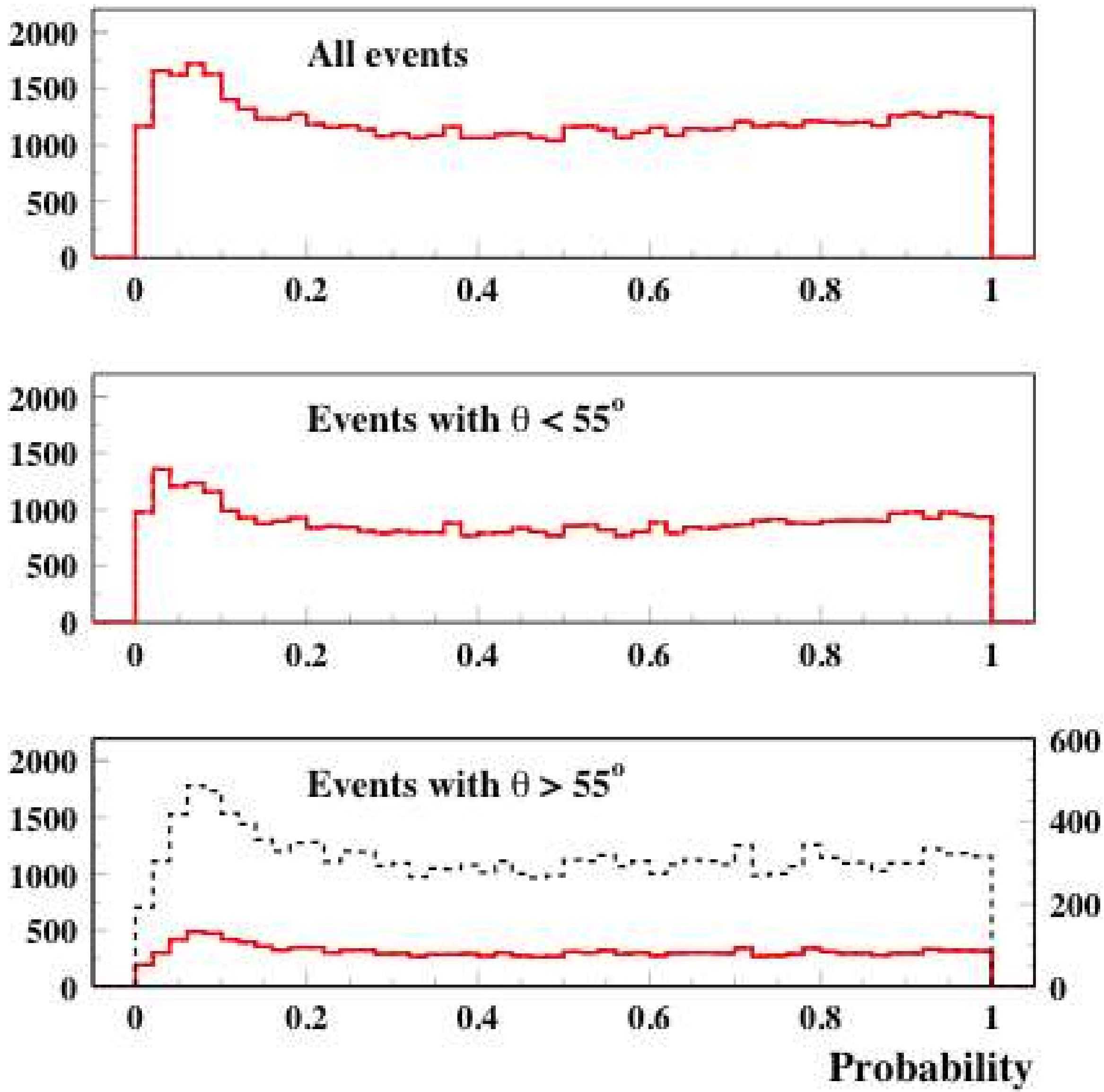


All Data

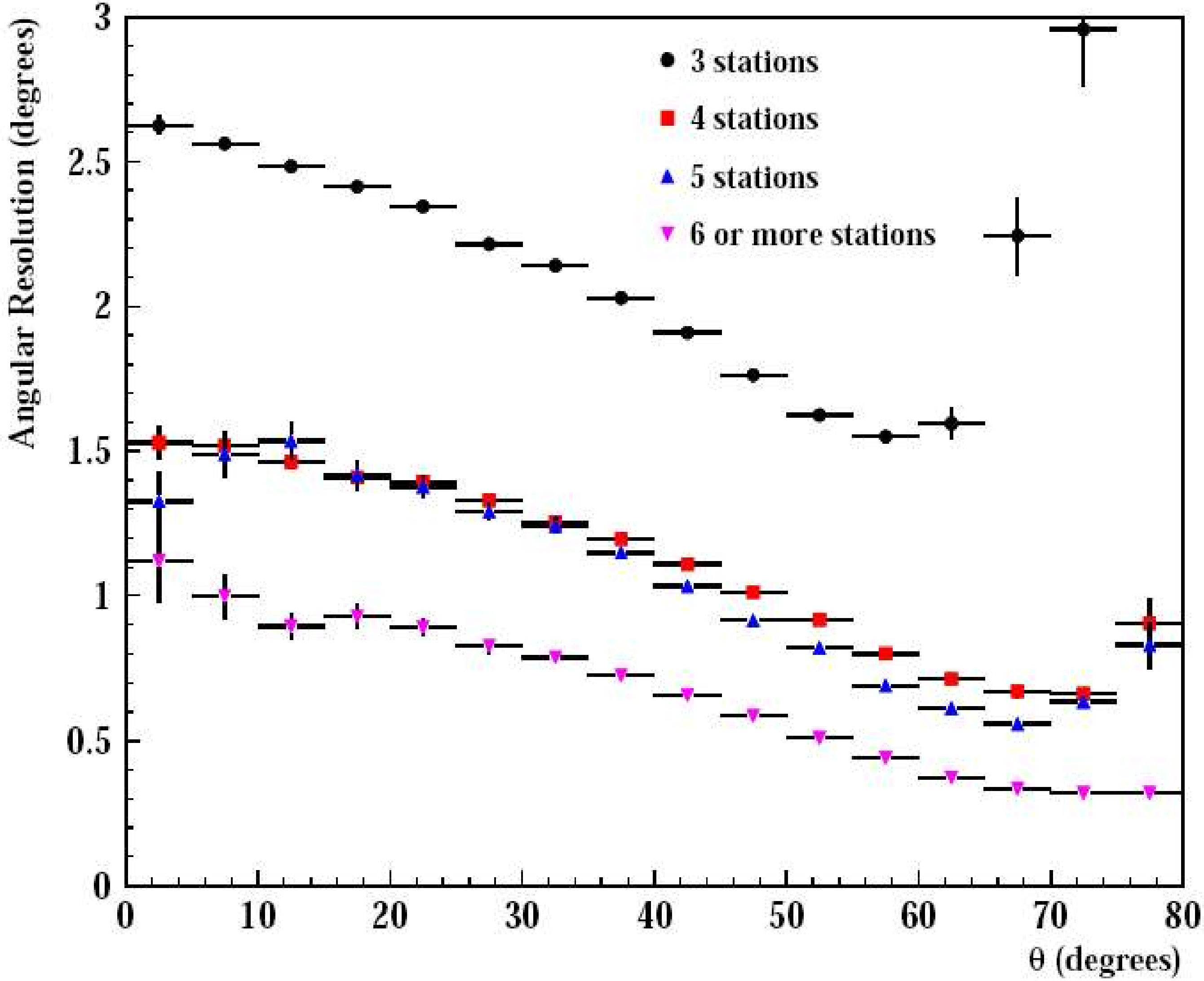
χ^2 probability distribution:



All Data

$$AR = 1.5\sqrt{(V[\theta] + V[\varphi]\sin^2(\theta))/2}$$

Resolution extracted from the **geometrical reconstruction**



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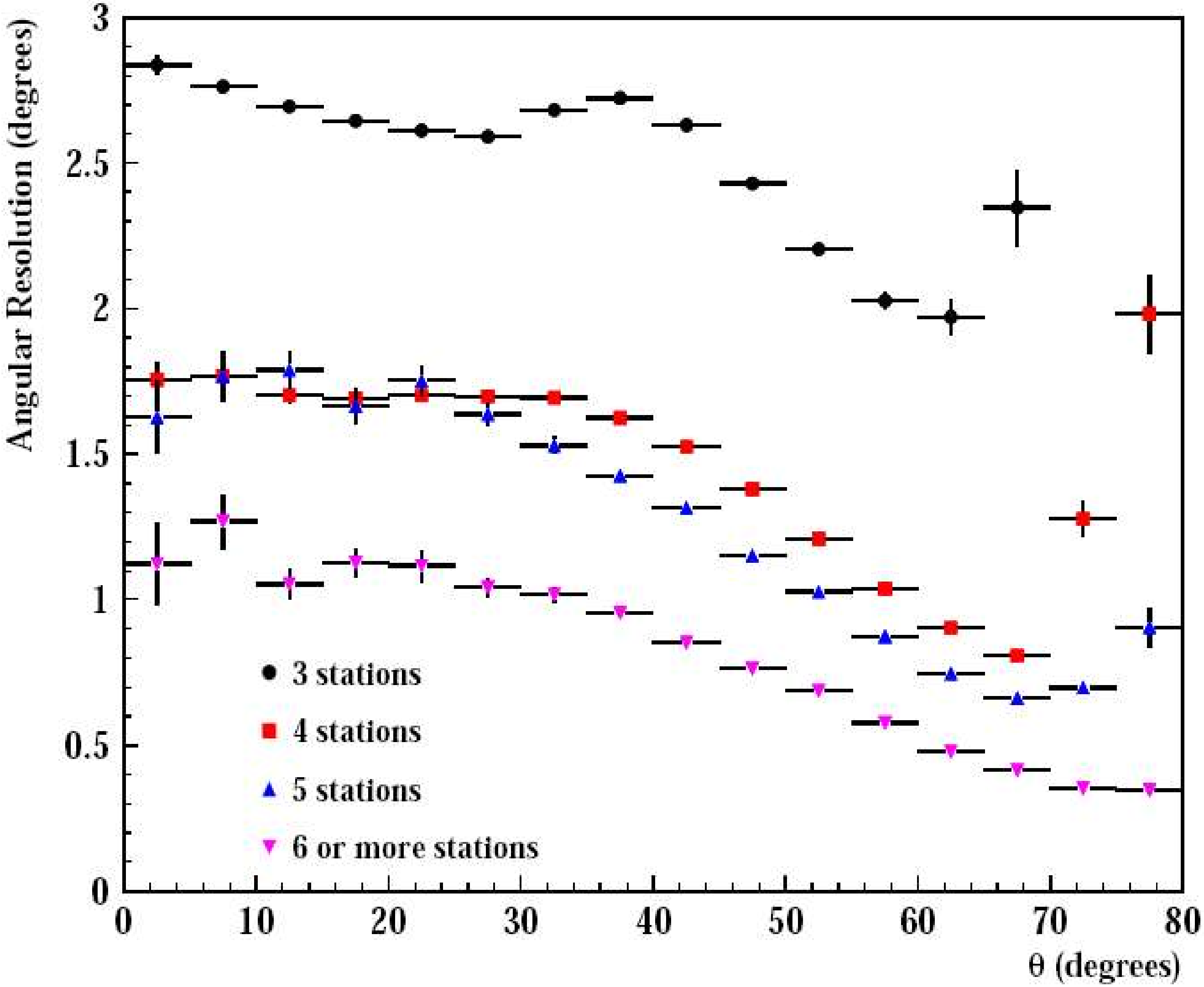
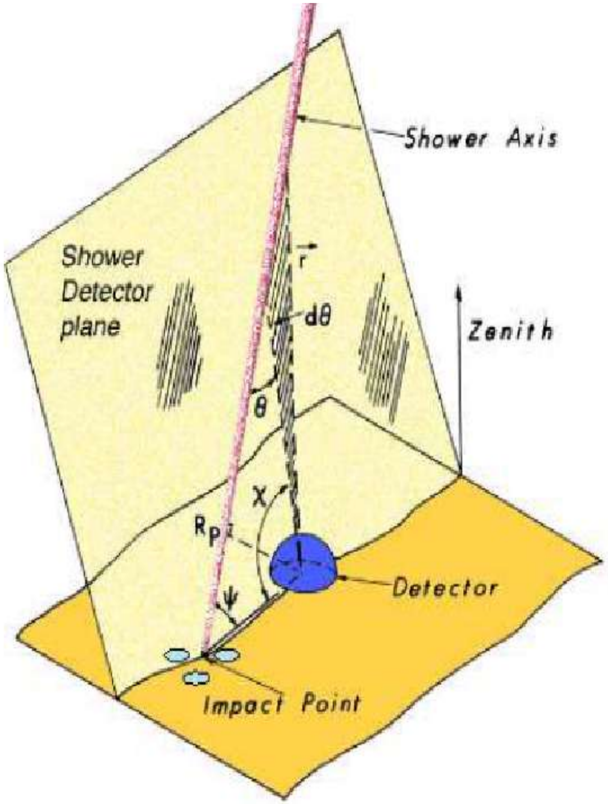
Resolution extracted from the **full reconstruction**

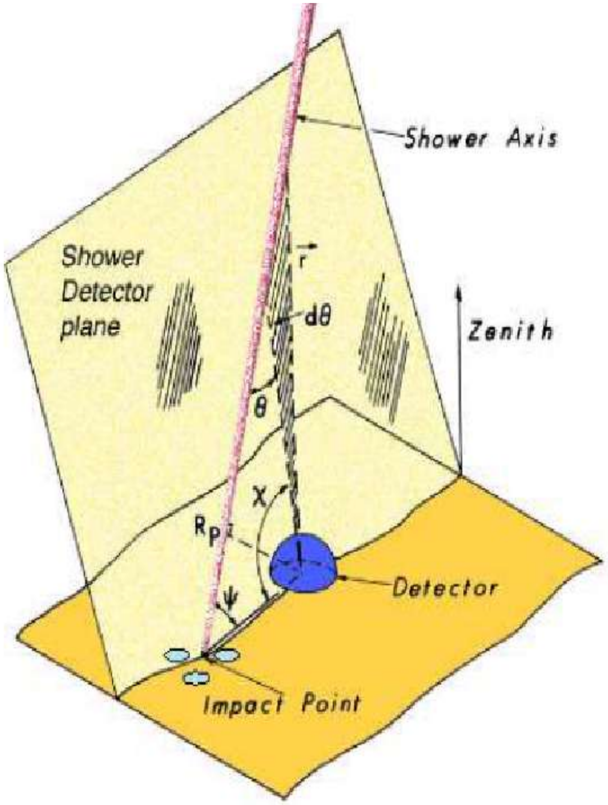


Comparison with hybrid data



Comparison with hybrid data

Miguel Mostafá (next talk)



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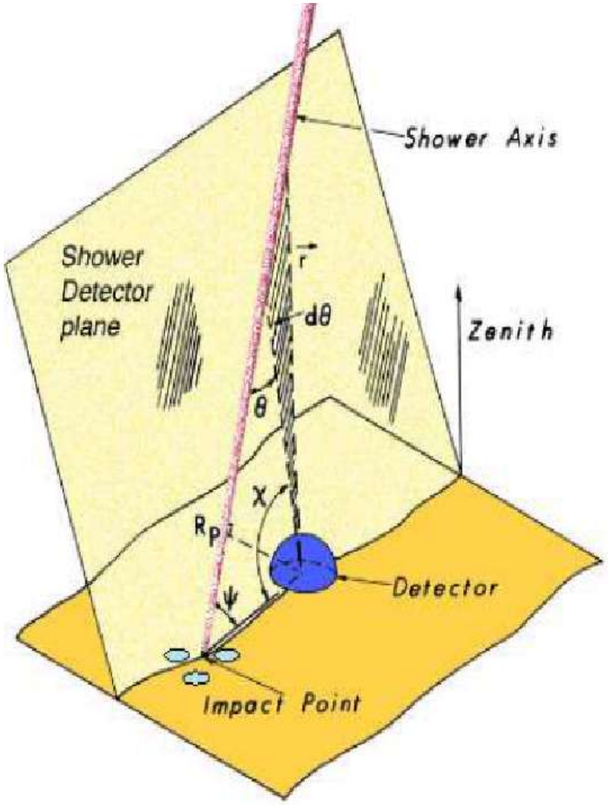
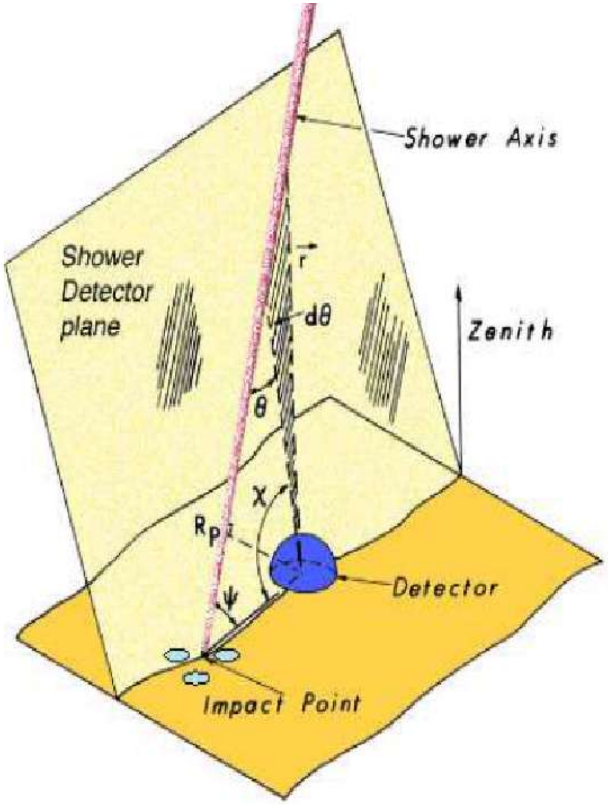


Comparison with hybrid data

- Good angular resolution in the arrival direction



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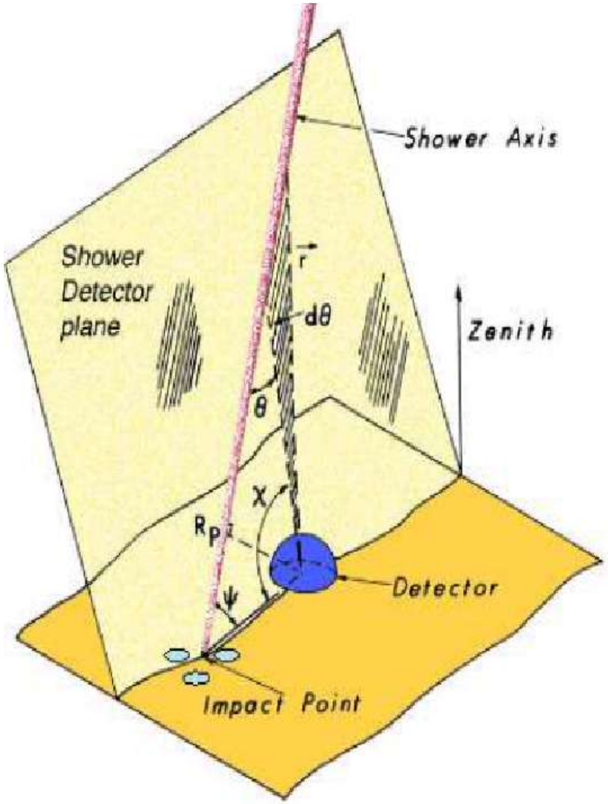

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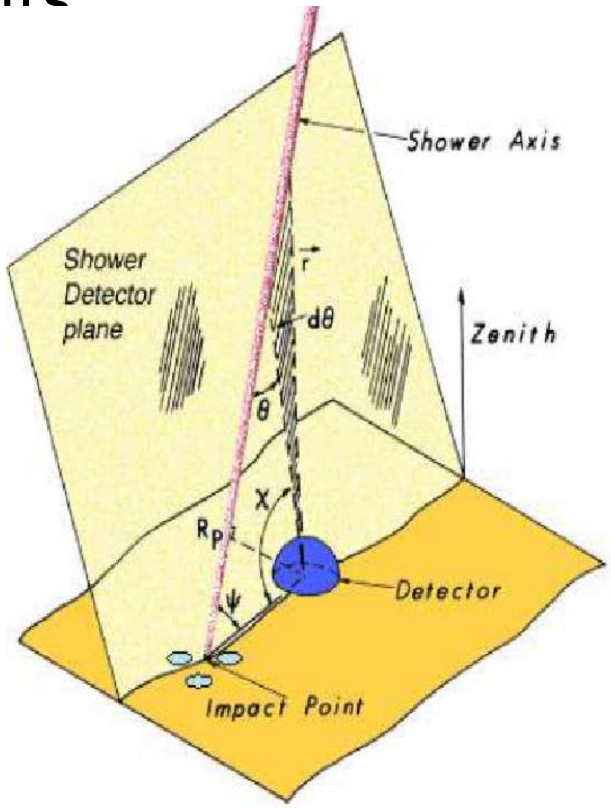
Angular resolution for hybrid events was obtained with the same formula used for SD-only events



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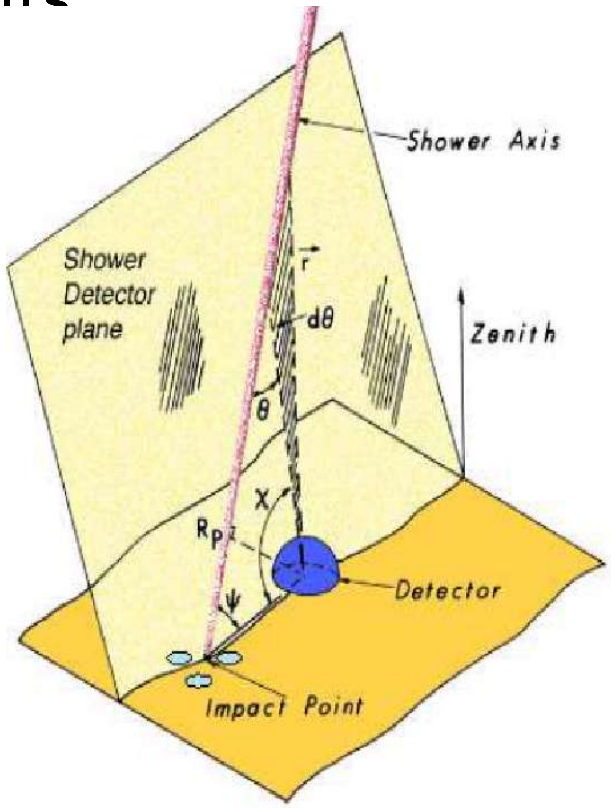

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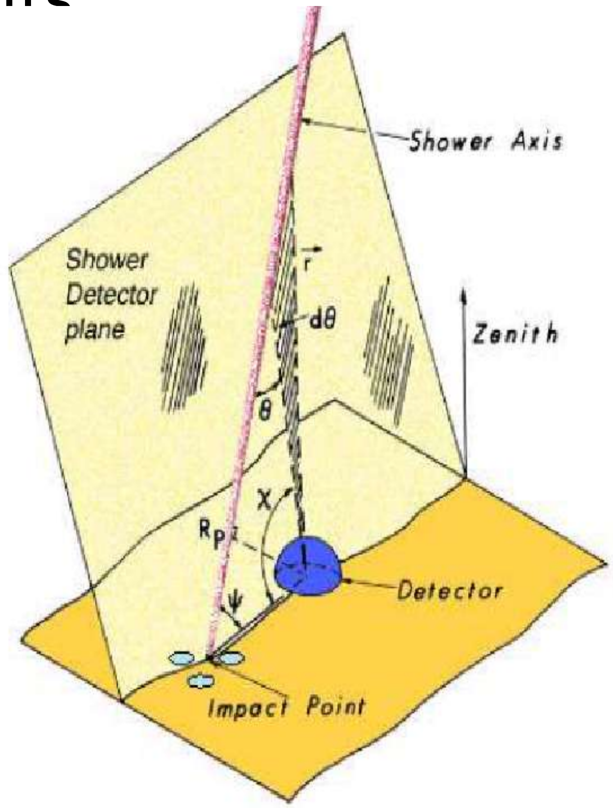
# Tank	AR
3	0.8°
4	0.7°
5	0.6°
≥ 6	0.5°



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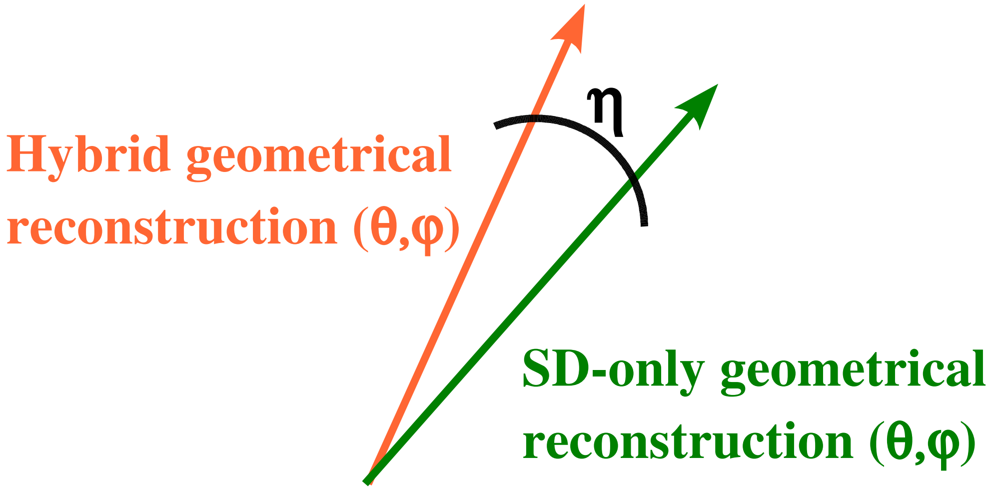

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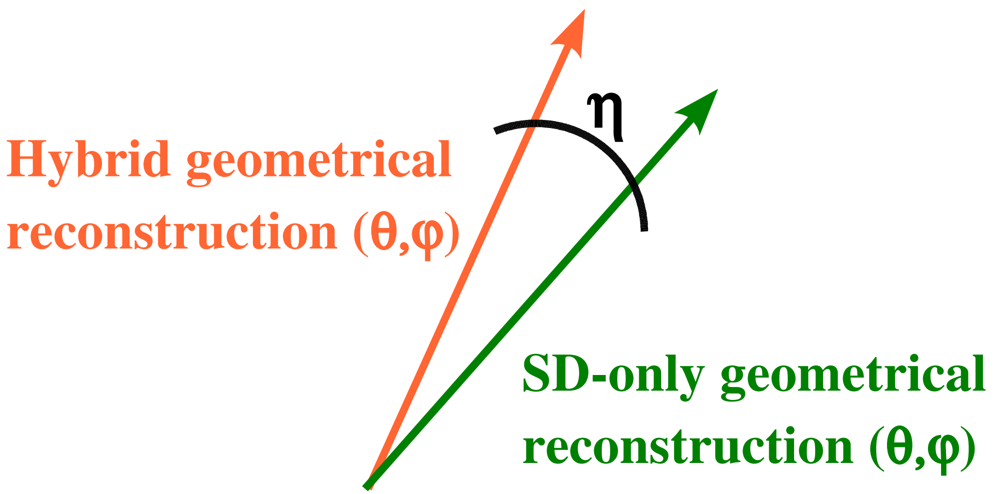

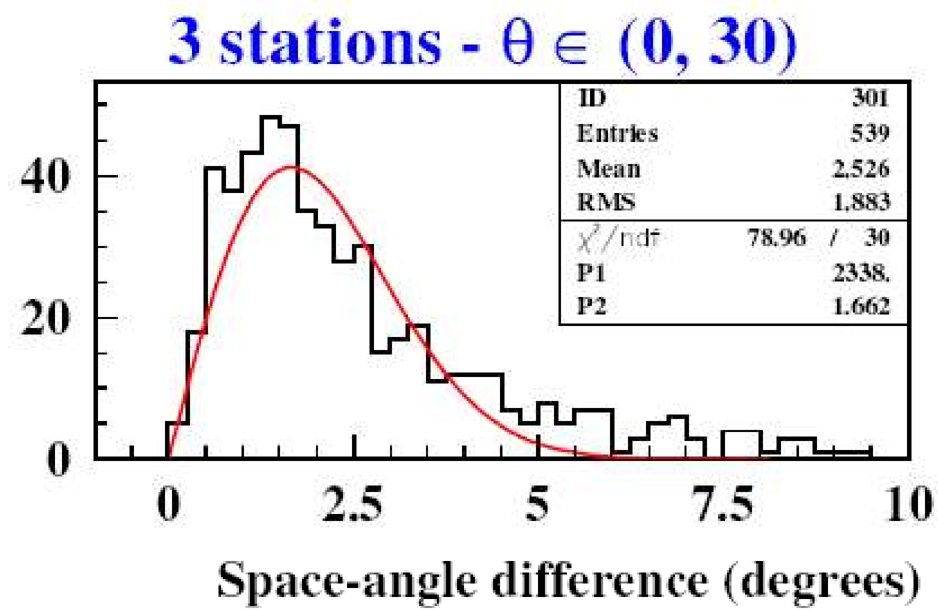

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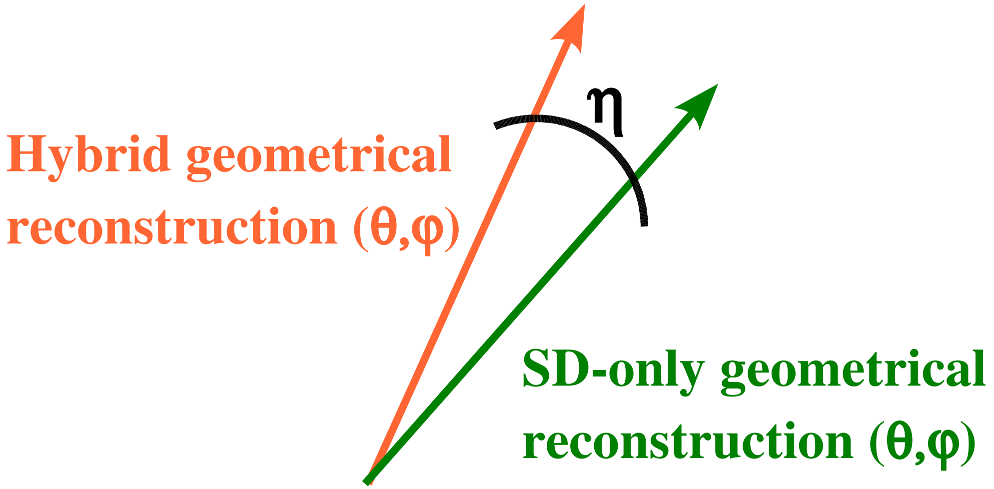
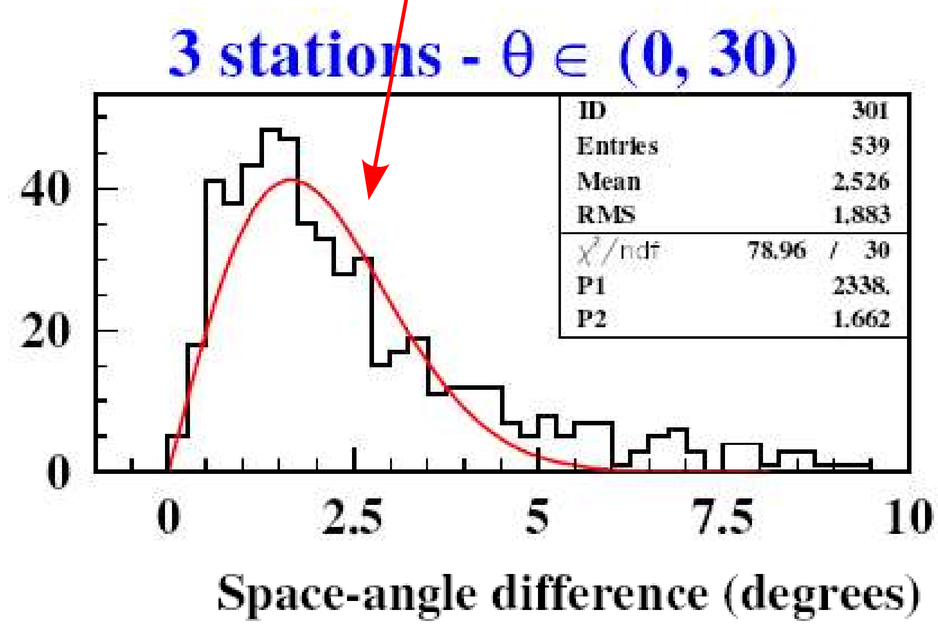


$$e^{-\eta^2/2\sigma^2}\ d(\cos(\eta))d\phi$$



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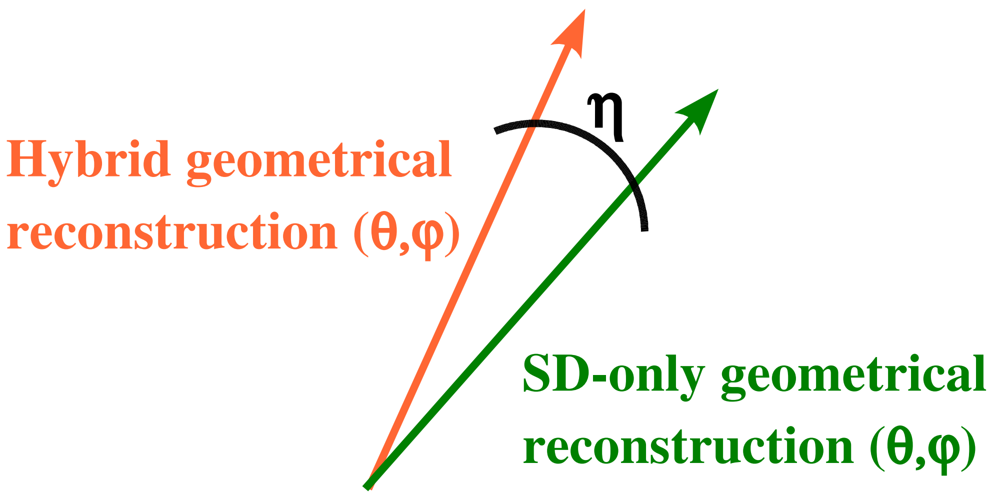
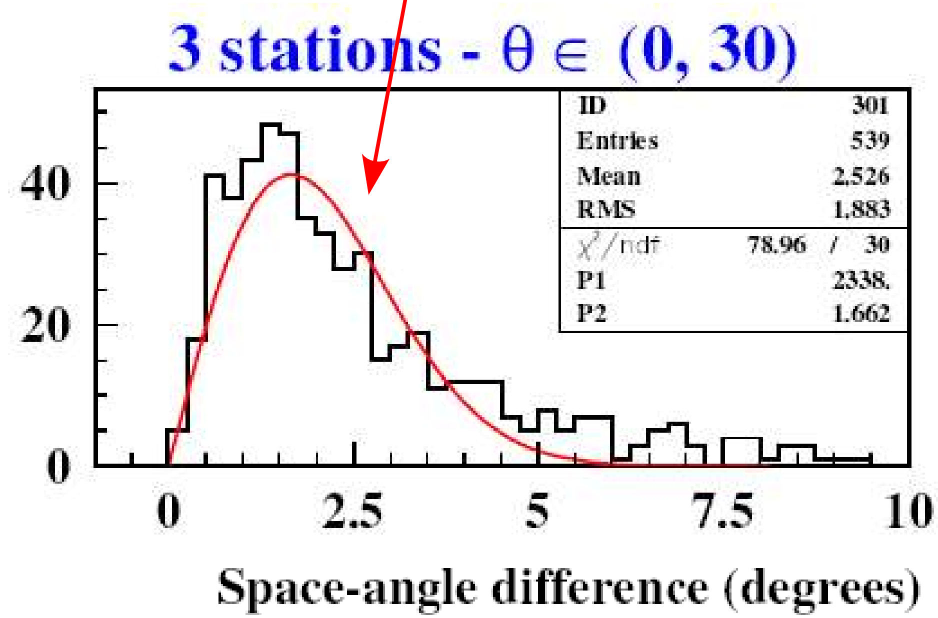
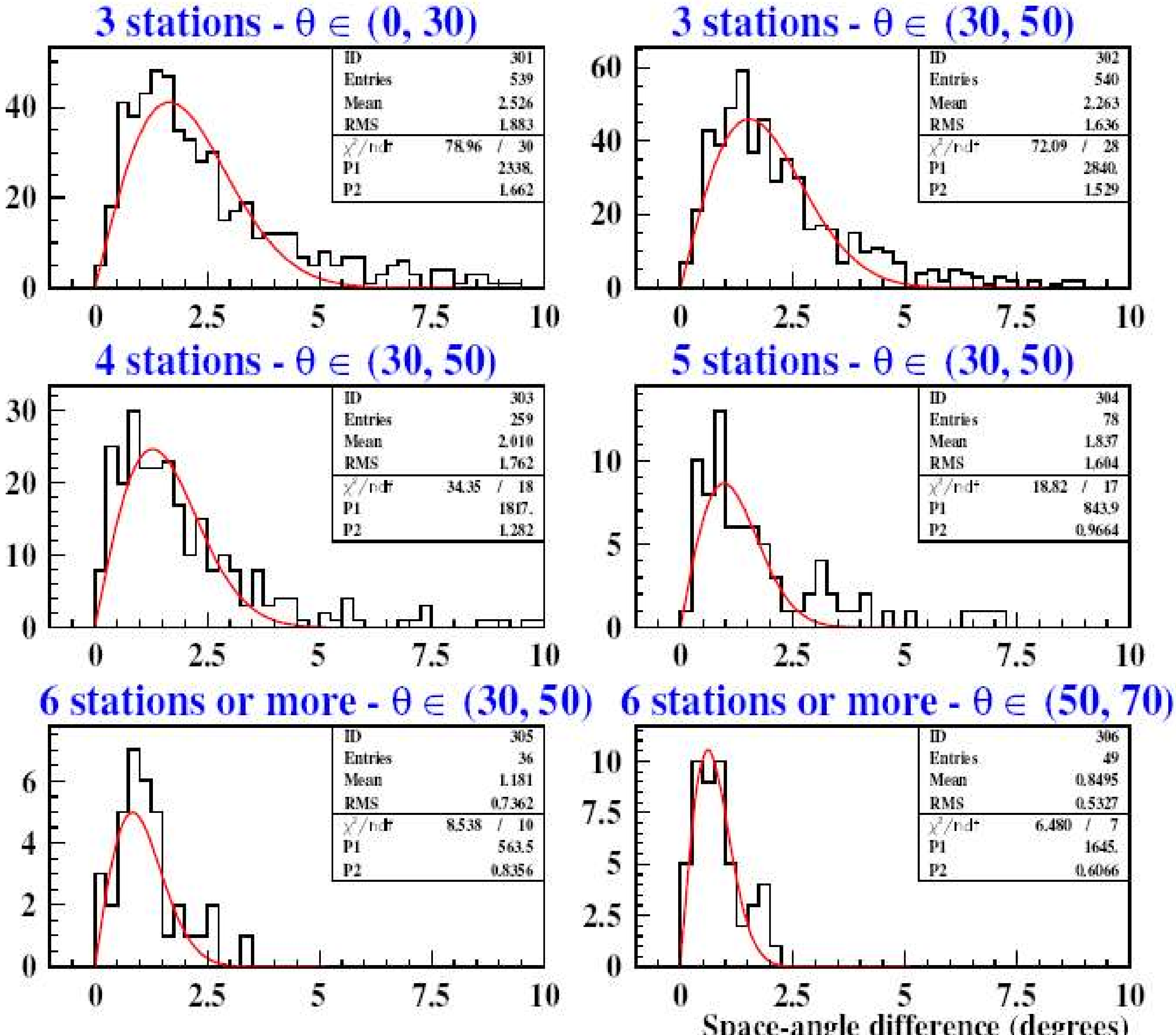


$$e^{-\eta^2/2\sigma^2}\ d(\cos(\eta))d\phi$$

$$\sigma_{SD} = \sqrt{(\sigma_\eta^2 - \sigma_{Hyb}^2)}$$




3 stations - θ ∈ (0, 30)
ID 301
Entries 539
Mean 2.526
RMS 1.883
χ²/ndf 78.96 / 30
P1 2338.
P2 1.662
3 stations - θ ∈ (30, 50)
ID 302
Entries 540
Mean 2.263
RMS 1.636
χ²/ndf 72.09 / 28
P1 2840.
P2 1.529
4 stations - θ ∈ (30, 50)
ID 303
Entries 259
Mean 2.010
RMS 1.762
χ²/ndf 34.35 / 18
P1 1817.
P2 1.282
5 stations - θ ∈ (30, 50)
ID 304
Entries 78
Mean 1.837
RMS 1.604
χ²/ndf 18.82 / 17
P1 843.9
P2 0.9664
6 stations or more - θ ∈ (30, 50)
ID 305
Entries 36
Mean 1.181
RMS 0.7362
χ²/ndf 8.538 / 10
P1 563.5
P2 0.8356
6 stations or more - θ ∈ (50, 70)
ID 306
Entries 49
Mean 0.8495
RMS 0.5327
χ²/ndf 6.480 / 7
P1 1645.
P2 0.6066
Space-angle difference (degrees)

Comparison with hybrid data

# Stations	θ range	σ_η	σ_{Hyb}	$\sigma_{SD-only}$	σ_{SD} from σ_η
3	$[0°; 30°]$	$1.7°$	$0.6°$	$1.8°$	$1.6°$
3	$[30°; 50°]$	$1.5°$	$0.6°$	$1.8°$	$1.4°$
4	$[30°; 50°]$	$1.3°$	$0.5°$	$1.1°$	$1.2°$
5	$[30°; 50°]$	$1.0°$	$0.4°$	$1.0°$	$0.9°$
6 or more	$[30°;50°]$	$0.8°$	$0.4°$	$0.6°$	$0.7°$
6 or more	$[50°;70°]$	$0.6°$	$0.3°$	$0.4°$	$0.5°$

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3	[0°; 30°]	1.7°	0.6°	1.8°	1.6°
3	[30°; 50°]	1.5°	0.6°	1.8°	1.4°
4	[30°; 50°]	1.3°	0.5°	1.1°	1.2°
5	[30°; 50°]	1.0°	0.4°	1.0°	0.9°
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Thank you !