detect_wells() — One■Page Spec

Purpose: Identify and label canonical wells (stable signal geometries) in per■primitive residual traces for NGF Stage■11 (Warp → Detect → Denoise).

API

Signature
detect_wells(traces: Dict[str, np.ndarray], *, jitter: int = 3, z_abs: float = 2.5, overlap_delta: float = 0.8) -> List[WellDescriptor]

Inputs
• **traces**: dict[primitive_id → 1■D float array] residual■energy signals (length T).
• **jitter**: number of stochastic resamples for stability checking (small input perturbations).
• **z_abs**: absolute z■score threshold to consider a peak significant.
• **overlap_delta**: minimum z■gap to suppress overlapping weaker peaks (lateral inhibition).

Outputs
• List of **WellDescriptor**: {primitive_id, well_type, center_t, width, z, stability, features, notes}.

Pre■conditioning

1) **Normalize** per channel (z■normalize or robust MAD).
2) **Smooth/band■limit** (e.g., 5–11 sample moving average). Preserve both raw and smoothed versions.
3) **Span■complement** to remove common■mode energy across channels if available.

Prototype kernels (matched filtering)

Use a compact family $K_\theta(t)$:
• **Unimodal** (half■sine / Gaussian) — axis pull.
• **Skewed unimodal** — quadrant well (off■center rise/decay).
• **Mexican hat** (two■lobe) — ring/oscillation well.
• **Broad hill** — shallow origin.
• **Narrow spike (edge■biased)** — deep edge.

For each channel, sweep θ (width, skew) and take the best correlation score and peak time.

Null calibration → z■scores

For each channel, build a **null** distribution via time permutations / phase shifts of the trace. Convert the best matched■filter score into a **z■score** relative to the null. Keep the tuple (best_kernel, z, t_peak).

Feature vector ϕ (measured at winning peak)

• **Height** (z), **width** (FWHM), **skewness**, **lobe ratio** (two■lobe vs one),
• **location** (early/mid/late window), **area** under bump, **pre/post slope symmetry**,
• **harmonic leakage** (energy outside passband). Concatenate into $\phi \in \blacksquare^m$.

Labeling rule (tiny decision tree)

If z < z_abs → **reject** (no well). Else:
• **Axis■Pull**: unimodal, low skew, mid width.
• **Quadrant**: unimodal, high skew, off■center peak.
• **Ring**: two lobes with central dip; balanced lobe ratio.
• **Shallow■Origin**: broad width, low height.
• **Deep■Edge**: very narrow, peak near boundary.

Lateral inhibition & stability

Overlap suppression: if two peaks (same channel or neighbors) overlap in time/shape and differ by ≥ overlap_delta in z, keep the stronger, suppress the weaker.
Jitter test: rerun detection on *jitter* perturbed inputs; compute stability = fraction of runs with same label ±Δt. Require stability ≥ 0.67–0.8.

Acceptance criteria

Criterion	Default
Significance (z)	z ≥ 2.5 (tune 2.3–3.0 from validation)
Exclusivity (Δz to next overlap)	≥ 0.8
Stability (jitter)	≥ 0.67 (2/3) — prefer ≥ 0.8
False discovery rate on synthetic nulls	≤ 1%

WellDescriptor schema

WellDescriptor = {
primitive_id: str,
well_type: Literal['Axis-Pull','Quadrant','Ring','Shallow-Origin','Deep-Edge'],
center_t: int, width: int, z: float, stability: float,
features: Dict[str,float],
notes: Optional[str]
}