SPE-184644-MS
Quantification of Wellbore Collision Probability by Novel Analytic Methods

First presented at:
SPE/IADC Drilling Conference and Exhibition, 14-16 March 2017, The Hague, The Netherlands

Jon Bang, Gyrodata

Speaker Information

- Jon Bang
- Development Engineer
- March 17, 2017
- Gyrodata

CONTENTS

Background

Basic model; probability equation

Direct hit (DH) probability: method + results

Unintentional crossing (UC) probability: method + results

Conclusions

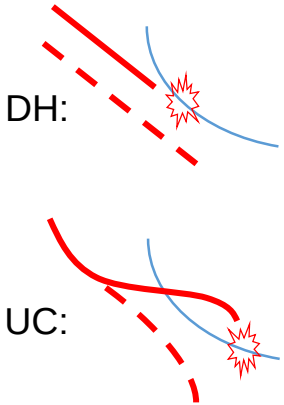
BACKGROUND

Wellbore collision: unplanned and negative event
- direct hit (DH)
- unintentional crossing (UC)

Cause (here): uncertainty in wellbore positions

What is acceptable probability?
- depends on consequences (HSE / non-HSE)

Existing analysis methods:
- approximate; suited for simple geometries only
- complex, time consuming



BASIC MODEL

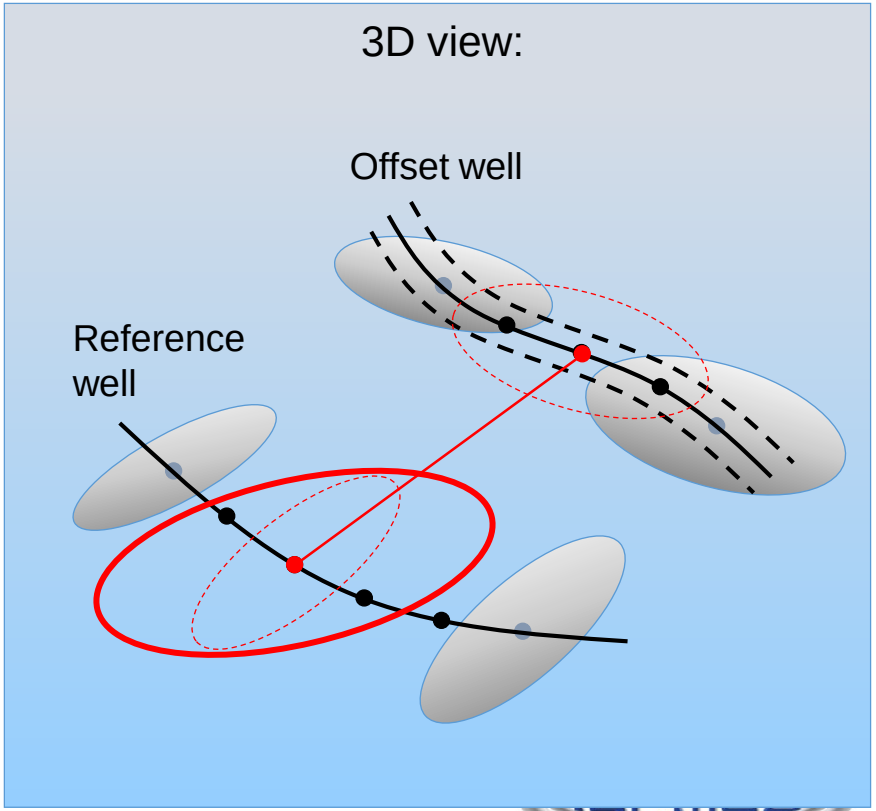
Offset well = existing
Reference well = planned, or being drilled

Standard position (N, E, V) and uncertainty (Cov) data; passed QC

Can interpolate all NEV and Cov data at any desirable MD

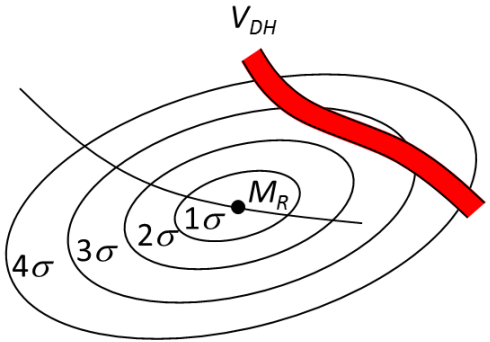
Uncertainties are combined (=> relative uncertainty) and assigned to the reference well

Wellbore dimensions are combined and assigned to the offset well

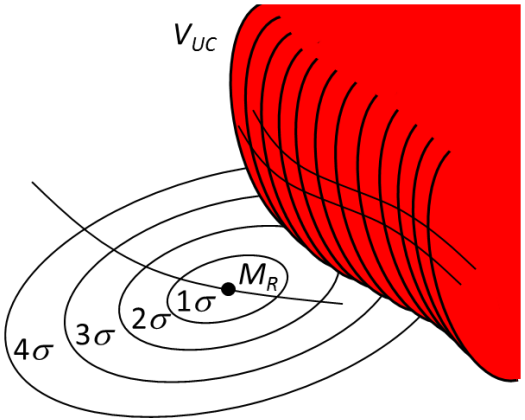


PROBABILITY

Definition: $P = \iiint_V pdf \; dV$



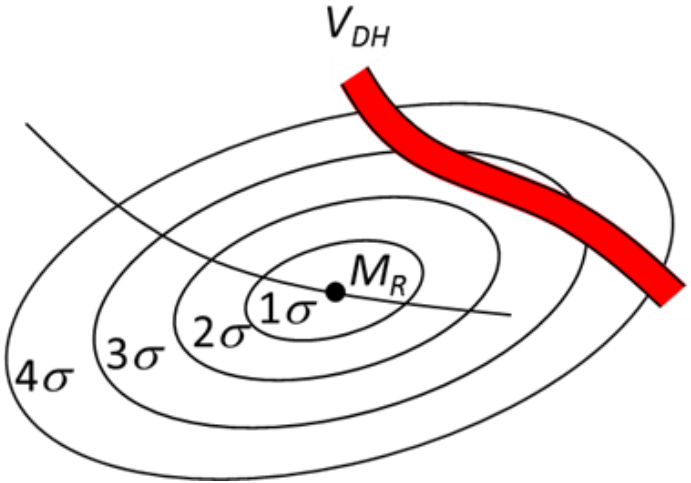
Direct hit (DH)



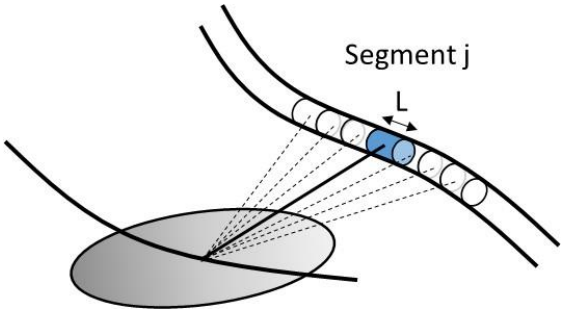
Unintentional crossing (UC)

$$P = \sum_{j=1}^{J} P_j = \sum_{j=1}^{J} \iiint_{V_j} pdf \; dV$$

DIRECT HIT PROBABILITY



DIRECT HIT PROBABILITY: METHOD



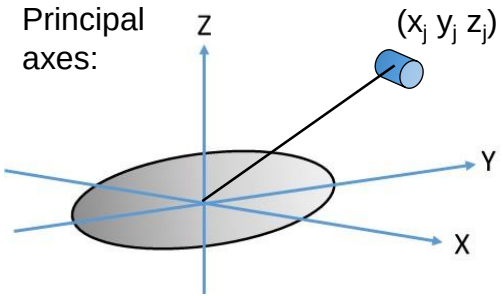
- Taylor expansion
- Symmetric segment
- Integration

P_j =	# terms	# terms contributing
P_0	1	1
+ P_1	3	0
+ P_2	9	3
+ P_3	27	0
+ ...	a lot	neglected

- Contributing terms:

$$P_j \approx f_X f_Y f_Z (\pi R_1 R_2 L)$$
$$+ [f_X'' f_Y f_Z + f_X f_Y'' f_Z + f_X f_Y f_Z''] (\pi R_1^4 L / 8)$$

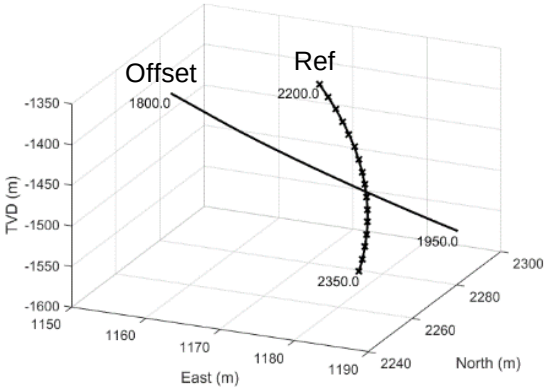
where: $R_1=R_o+R_r$, $R_2=R_o+\cos(\beta_j)R_r$, $L=\sqrt{3}(R_1+R_2)$

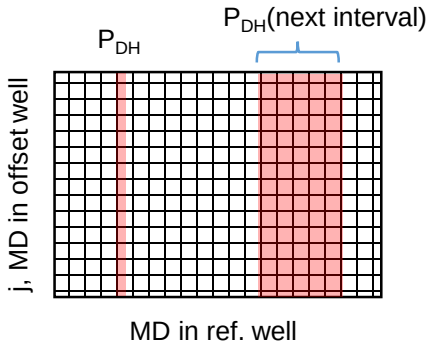


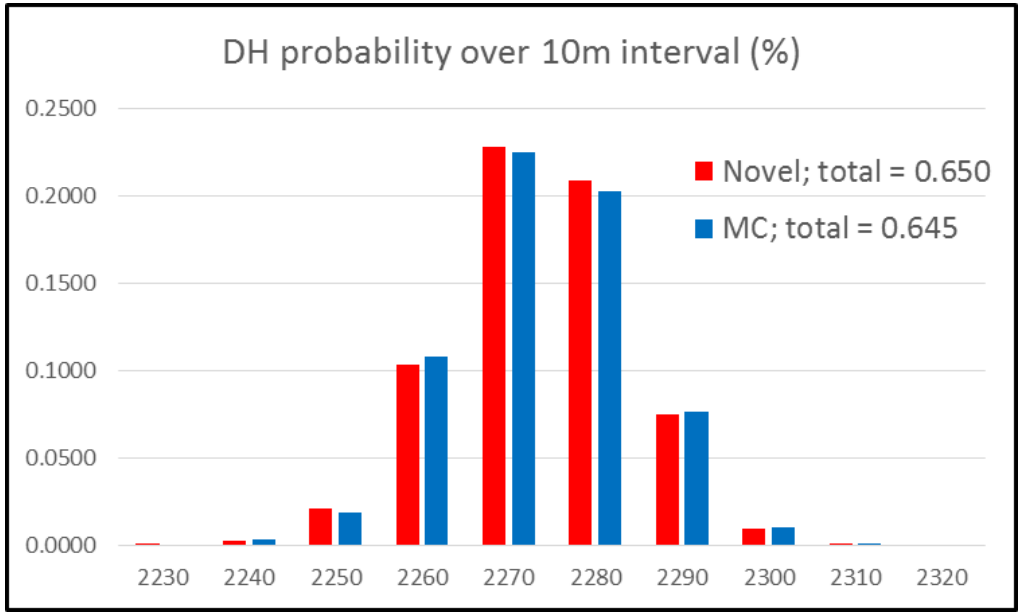
$pdf = f_X(x)\, f_Y(y)\, f_Z(z)$

1. Any reasonable pdf distribution
2. Any segment orientation

DIRECT HIT PROBABILITY: RESULTS

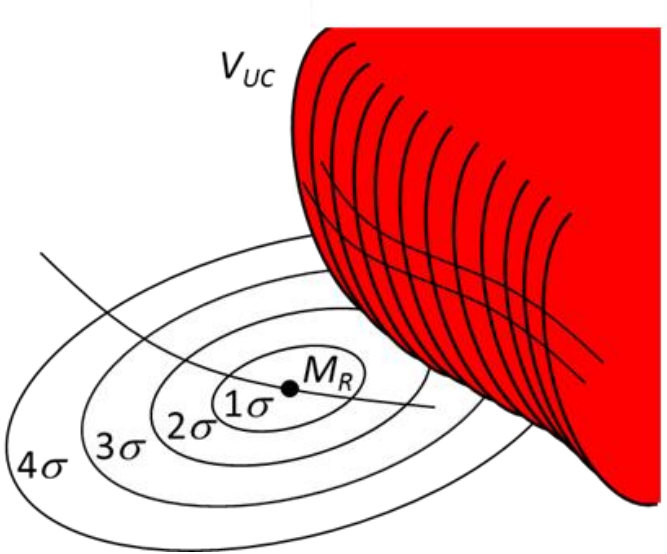






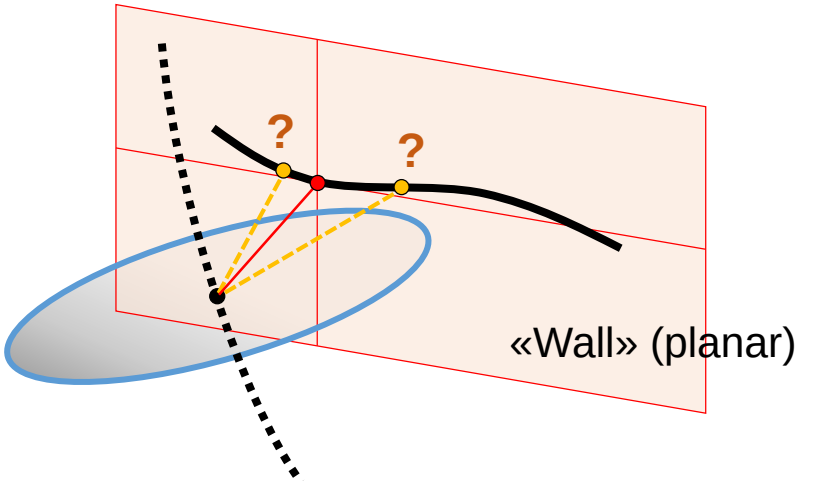
Example: 220 x 1500 points
Calculation (not optimized) and post-processing: < 4s

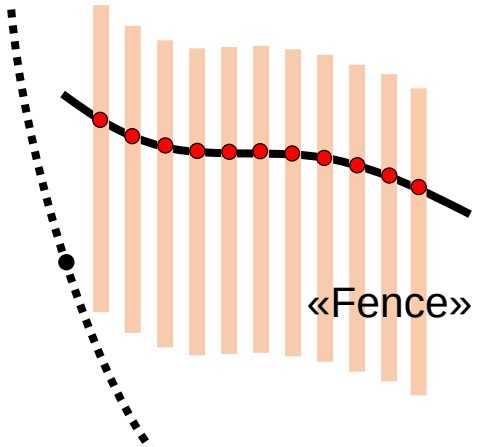
UNINTENTIONAL CROSSING PROBABILITY



WHAT BOUNDARY SHOULD BE USED?

Closest approach: minimum spatial distance

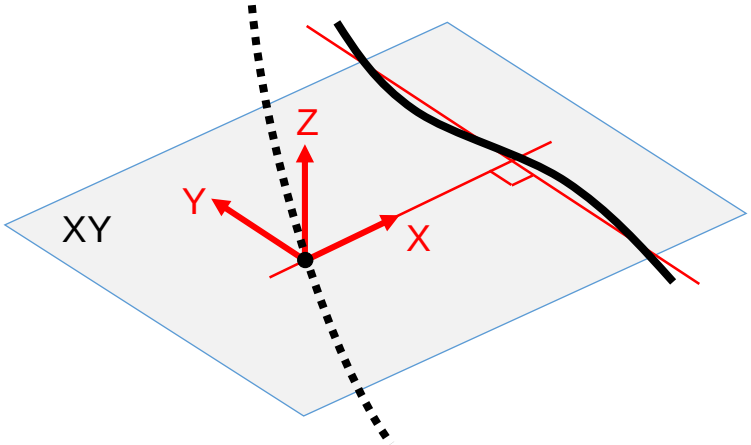




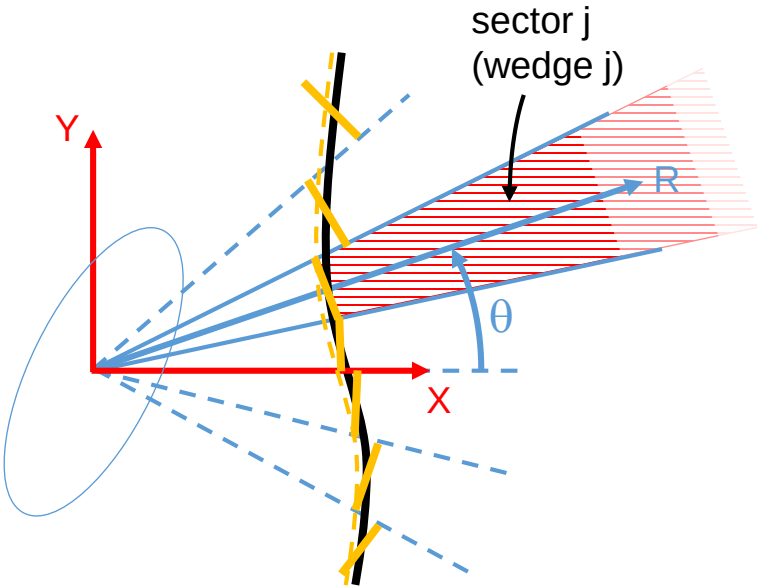
1. The closest approach method may miss high-probability points.
2. The «fence» follows the wellpath better than does the «wall».

UC PROBABILITY: GEOMETRY AND COORDINATE SYSTEM

3D:



2D:



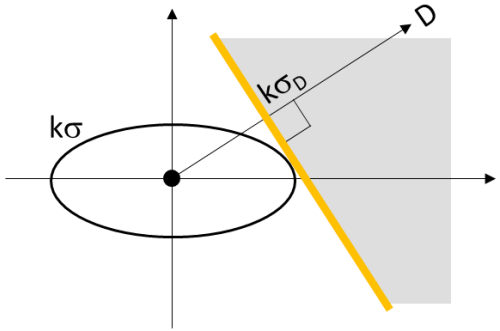
1D-by-1D:

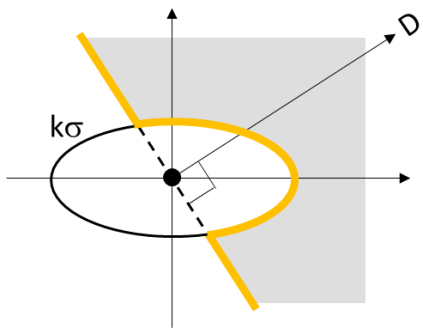
$$P_j \approx P_\Theta(inside\ sector\ j)\ P_R\left(r_j > D_{surv}\right)$$

(non-circular ellipse is sampled in polar coordinates)

UC PROBABILITY: RESULTS

(2D cases – boundaries where exact solutions exist)





k	P_{UC} (%)	Exact P_{UC} (%)
2.0	2.2750	2.2747
2.5	0.6210	0.6209
3.0	0.1350	0.1350
3.5	0.0233	0.0233
4.0	0.0032	0.0032

k	P_{UC} (%)	Exact P_{UC} (%)
2.0	6.7668	6.7668
2.5	2.1969	2.1969
3.0	0.5555	0.5555
3.5	0.1094	0.1094
4.0	0.0168	0.0168

RECOMMENDATIONS

AND

CONCLUSIONS

PRINCIPLES FOR ANTI-COLLISION PROBABILITY ANALYSIS

1. Probability = integral of pdf over specific volume

2. DH and UC scenarios involve substantially different volumes:
   - generally incompatible analysis methods
   - generally incompatible probability results

3. The closest approach method may miss points of highest probability:
   - need to analyze probability at many points / in many directions

CONCLUSIONS

Desirable features of a clearance scan method 1 - 5: «Collision Avoidance Calculations – Current Common Practice», ISCWSA (SPE-WPTS) 2013	DH methods		UC methods	
	MC	New	Existing	New
1. Based on position uncertainty	Yes	Yes	Closest approach	Yes
2. Output related to collision probability	Yes	Yes	(Some)	Yes
3. Completely valid; or conservative results	Yes	Yes	Approx.	Yes
4. All relative wellpath geometries	Yes	Yes	Straight	Yes
5. Output easily understood by user	Yes	Yes	(Some)	Yes
Probability distribution	Any	Any	Normal	Normal
P(DH) or P(UC) when drilling next interval of reference well	Yes	Yes	No	No
Analytic, compatible with existing software, fast calculation	No	Yes	Yes	Yes

Acknowledgements

John Weston, Gyrodata
Harry Wilson, Baker Hughes
Andrew Brooks, former PathFinder Schlumberger
Erik Nyrnes, Statoil
Adrián Ledroz, Gyrodata

Gyrodata Inc.

SPE-WPTS (ISCWSA); Anti-collision subgroup

Thank You

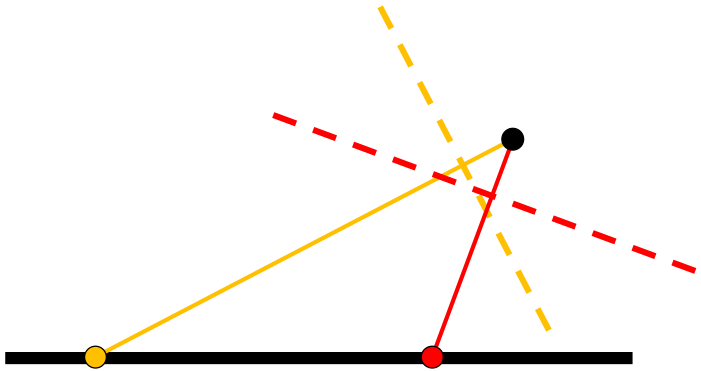
FOLLOWING SLIDES:

- ADDITIONAL DETAILS
- ANSWERS TO (SOME) QUESTIONS

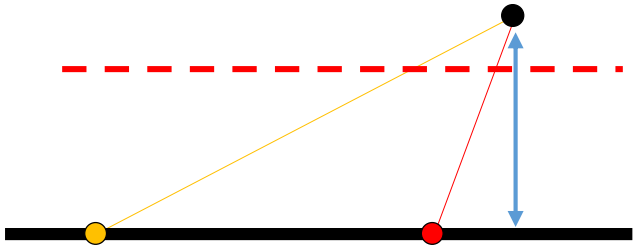
P_{UC} WHEN DRILLING AN INTERVAL

Re-orient the boundary?

– or not?



drilling direction



SEPARATION FACTOR (SF)

Criterion to determine how close two wells may come to each other:

- applies basically to UC scenarios, not DH
- compares surveyed distance to a critical distance

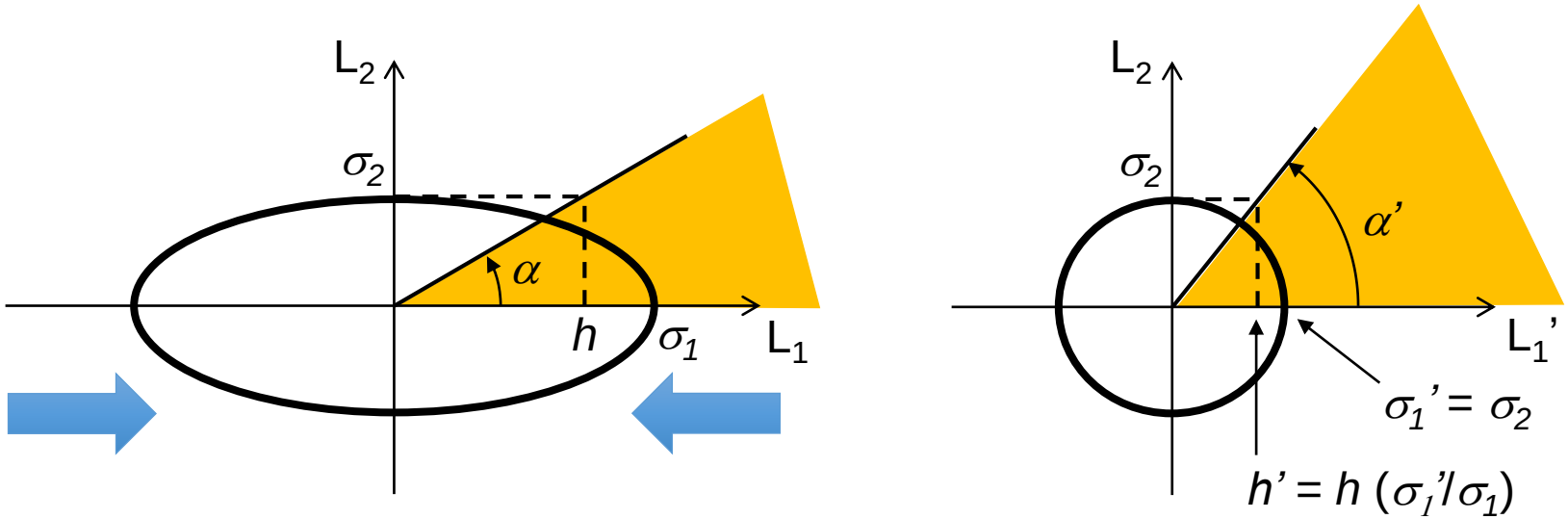
Various definitions are currently used:

- some account for uncertainty / probability, some do not
- all build on closest approach assumption (in some form)
- ok for simple geometries, less good for complex geometries

Need for a re-evaluation of SF:

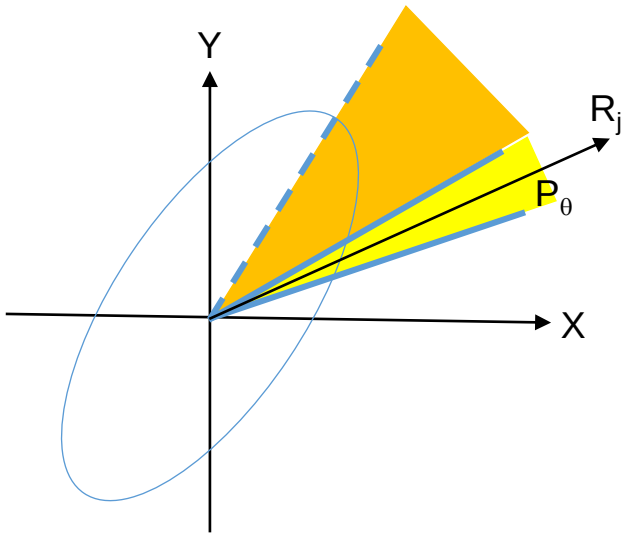
- non-ambiguous definition
- unique relation to probability
- validity for complex geometries

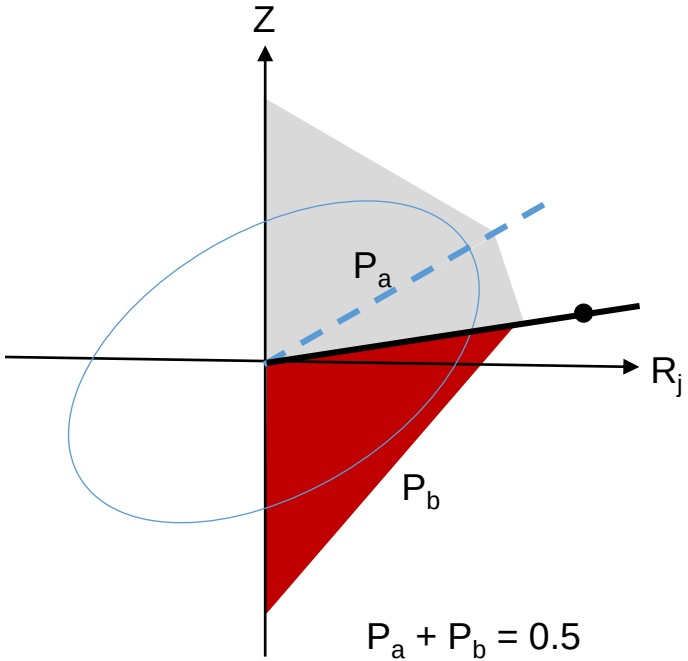
ANGULAR PROBABILITY (1D Mahalanobis transform)

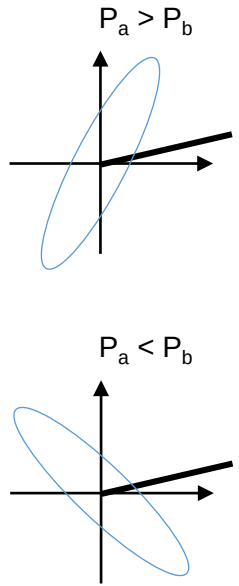


$$P(\alpha) = P(\alpha') = \alpha' / 2\pi = \arctan[\ (\sigma_1/\sigma_2)\ \tan(|\alpha|)\ ]\ /\ 2\pi \qquad (-\pi/2 < \alpha < \pi/2)$$

CROSSING «ABOVE» OR «BELOW» THE OFFSET WELL







RELATIVE UNCERTAINTY (Position differences)

Covariance matrices:

$$\Sigma_c = \Sigma_1 + \Sigma_2$$

1D equivalent:

$$\sigma_c^2 = \sigma_1^2 + \sigma_2^2 - 2\rho_{12}\sigma_1\sigma_2$$

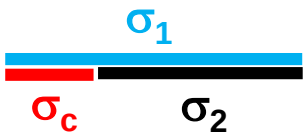
Independent (most common assumption): $\rho_{12} = 0$ $\quad \sigma_c^2 = \sigma_1^2 + \sigma_2^2$

Positive (full) correlation: $\rho_{12} = +1$ $\quad \sigma_c^2 = (\sigma_1 - \sigma_2)^2$

Negative (full) correlation: $\rho_{12} = -1$ $\quad \sigma_c^2 = (\sigma_1 + \sigma_2)^2$

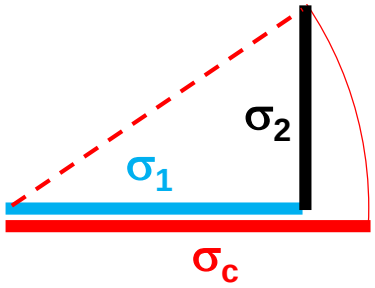
CORRELATION OR NOT?

$\rho_{12} = +1$ $\quad \sigma_c = |\sigma_1 - \sigma_2|$



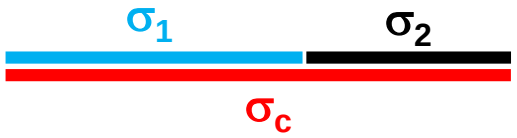
optimistic

$\rho_{12} = 0$ $\quad \sigma_c^2 = \sigma_1^2 + \sigma_2^2$



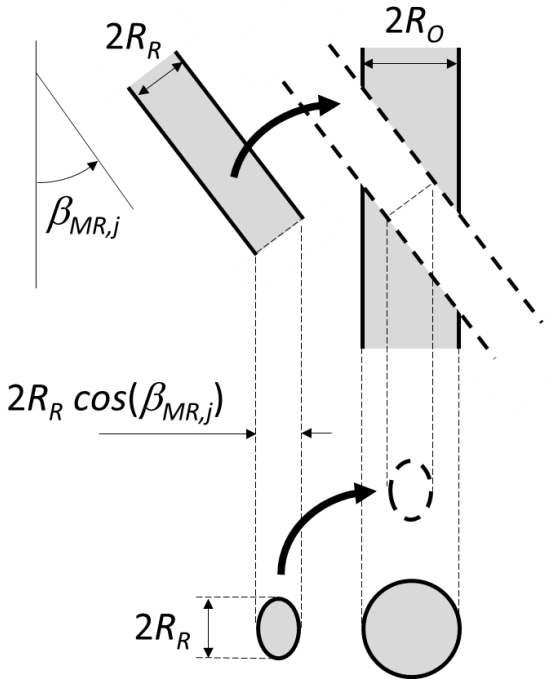
overall
best estimate

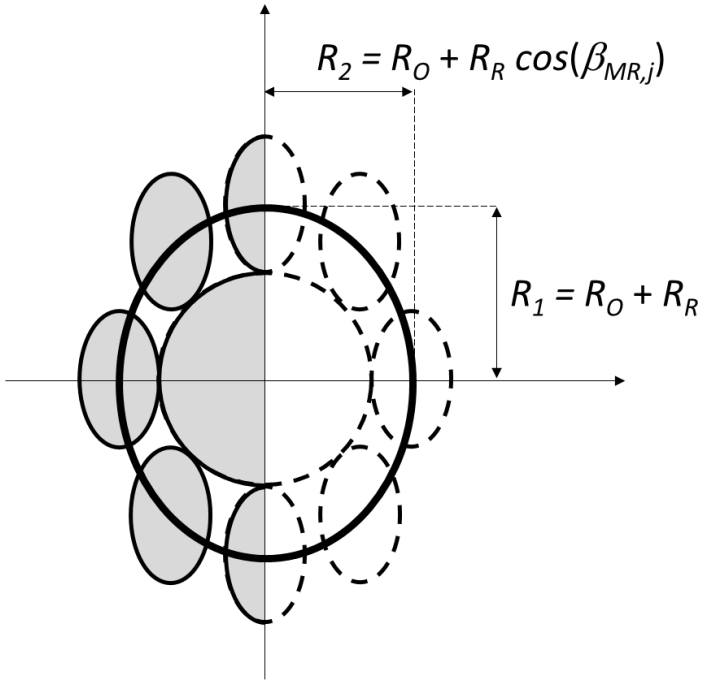
$\rho_{12} = -1$ $\quad \sigma_c = \sigma_1 + \sigma_2$



conservative

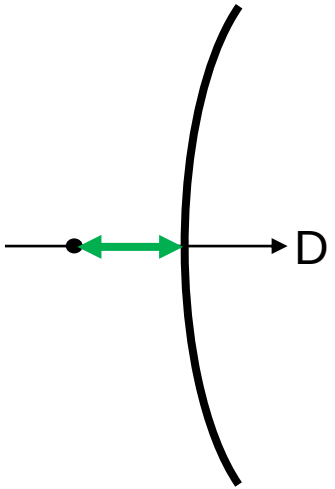
THE CROSS SECTION OF THE «COMBINED» WELL IS ELLIPTIC

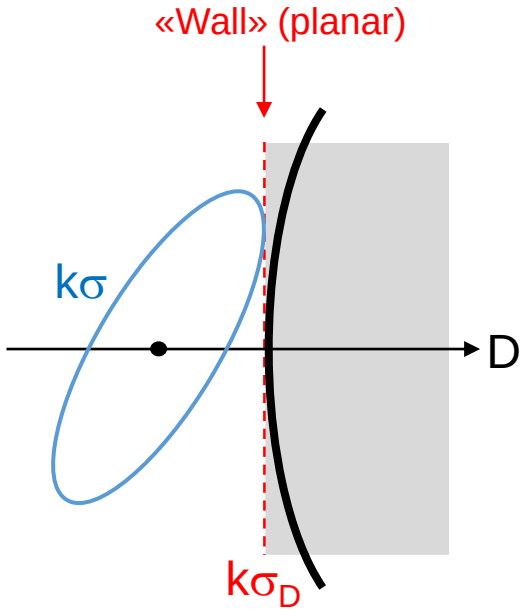


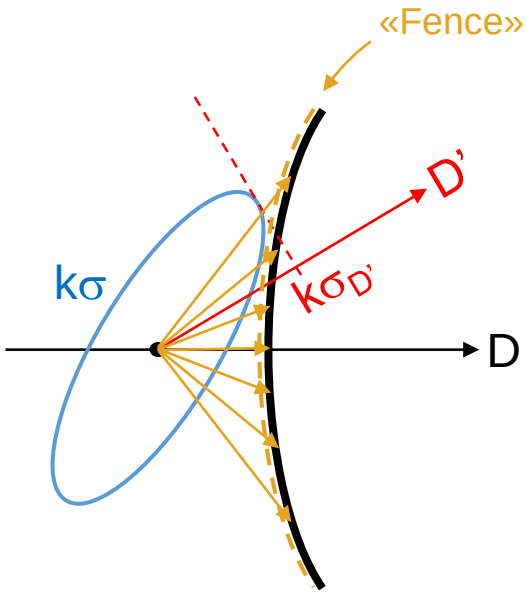


DOES A PERFECT BOUNDARY EXIST?

Closest approach =
minimum spatial distance:







1. The closest approach method may miss high-probability points.
2. The «fence» follows the wellpath better than does the «wall» => more accurate boundary.