Assured PNT and the PTA Strategy:

Status, Issues and Observations

May 2022

Brad Parkinson*

* Statements that have not been made previously as PNTAB conclusions and recommendations are my own.

Primary Advisory Board Objective:

Assured *PNT* for all Users and to encourage/exploit system improvements and new techniques to advance PNT for all applications

Primary Advisory Board Objective:

Assured *PNT* for all Users and to encourage/exploit system improvements and new techniques to advance PNT for all applications

- Our Strategy is the ***PTA Program:***
  - ***Protect*** the **radio spectrum** + identify + shut down interferers
  - ***Toughen*** GPS receivers against natural and human interference (Jamming and Spoofing)
  - ***Augment*** with additional GNSS/PNT sources and Techniques

Bottom Line Up Front

P, T, and A are complementary and are all needed

Bottom Line Up Front

P, T, and A are complementary and are all needed

- In spite of efforts to *Protect* there will always be situations where interferers break the rules. Toughen and Augment fill in during those situations

Bottom Line Up Front

P, T, and A are complementary and are all needed

- In spite of efforts to *Protect* there will always be situations where interferers break the rules. Toughen and Augment fill in during those situations
- *Toughening* makes GPS much more resistant to challenges, but there may still be situations where Toughening is not enough. Augment can address these situations.

Bottom Line Up Front

P, T, and A are complementary and are all needed

- In spite of efforts to *Protect* there will always be situations where interferers break the rules. Toughen and Augment fill in during those situations
- *Toughening* makes GPS much more resistant to challenges, but there may still be situations where Toughening is not enough. Augment can address these situations.
- In spite of Protecting and Toughening GPS, relying on a single source of PNT can be unwise. That's the role of *Augmentation*. But there is no known Augmentation, except for foreign satnav, that provides the GPS-like capability. So Augment alone cannot be the answer. Protect and Toughen reduce the burden on Augment.

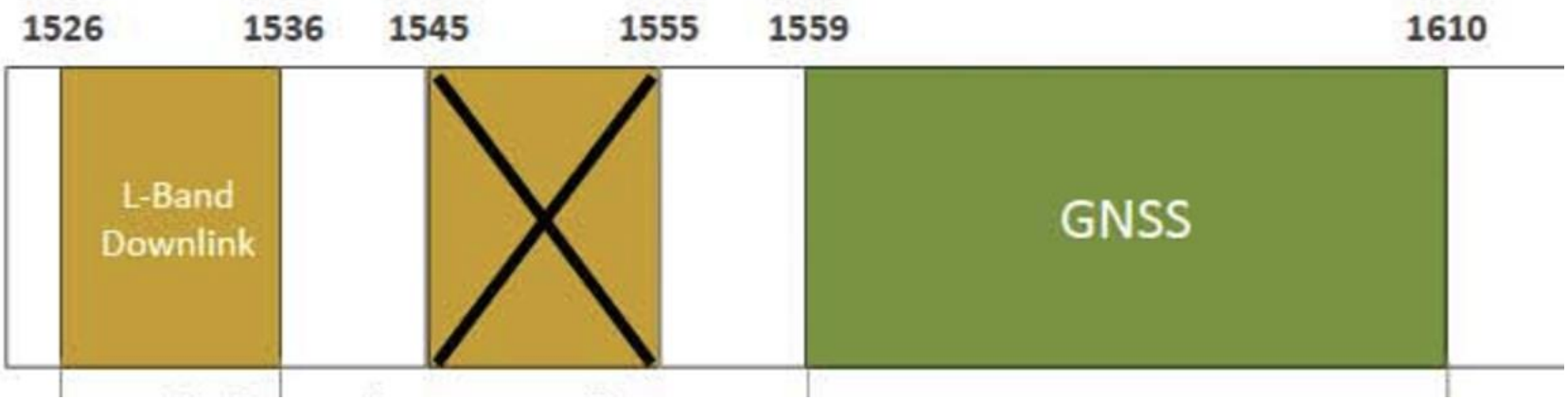
Strategy 1 : Protect the **radio-spectrum**

+ identify & prosecute interferers

Observations:

- Ligado Problem is ***not*** resolved– Particularly for the installed base of Precision Applications
- Identifying and Prosecuting Interferers does not seem to be an active priority of the FCC or USG – but effort is slowly increasing

Ligado Adjacent band interference concern



Ligado Adjacent band interference concern

"Upper" band is apparently off the table. Is this forever?

Ligado Adjacent band interference concern

"Upper" band is apparently off the table. Is this forever?

"Lower" band Power reduced to 10 Watts. FCC order specified minimum spacing of 433 meters. To meet broadband requirements it could be much less - Micro or Femtocells call for 100 to 200 meters.

Maximum allowable Ligado Power to protect *90% of Area for High Performance Receivers (HPRs)*

(i.e. Degradation limited to 10% of Transmitter Region)

% of High-Performance Receivers Degraded	400m Tower Spacing Maximum Power
None	0.004W
10%	0.031W

Based on quantitative data taken from 40 Different HPRs, tested by DOT for Adjacent Band Compatibility

It may be worse – not included in analysis…

- Multiple towers contribute additive noise
- Reflections from ground and buildings can increase normal $1/R^2$ models by factors of over 10 (Factors of 15 measured in Las Vegas tests)
- The newer GNSS signals have wider RF bandwidths for greater accuracy and A/J, but the receivers also may have greater sensitivity to the adjacent band power. In ABC tests, the Galileo E1 signal ***was more sensitive*** for HPRs.
- The new military signal deliberately pushes energy away from the center frequency, closer to Ligado power.

But it may also ***slowly*** be getting Better…

- Manufacturers fielding more resistant receivers
  - Does not quickly solve the fielded-equipment problem

The Protect Strategy – Ligado, the take away

- A reasonable compromise is to ***protect 90% of the Installed High-Performance receivers in 90% of the area***. This would require either:
  - A maximum of 31 milliwatts of Ligado power at original tower spacing of 400 meters

  Or:
  - A minimum of 7000 meters spacing between Ligado towers at the "new" power level of 10 watts.

However, Ligado seems to be planning a typical mini-tower spacing of 400 to 1000 meters. **In that case I propose a PNTAB recommendation for the EXCOM and FCC:**

Either swap the Ligado spectrum or <u>Just say no</u>.

Strategy 2:Toughen GPS receivers against natural and human interference

- Techniques for making GPS ***receivers*** virtually Jam and Spoofing immune ('Toughening") have been known and demonstrated for the last 40 years - were first tested in 1978.
  - Major Techniques: 1. New signals and signal processing. 2. Deep integration with inertial sensors, 3. use of multiple element Digital Beam steering antennas (CRPAs)
- This is a largely underemphasized strategy – although being pursued by some manufacturers
- Reasons for neglect:
  - Perceptions of excessive cost – particularly retrofit for Aircraft
  - Conformal (flat) Antennas would benefit from a 1 meter diameter
  - New L5 signal not yet operational
  - Federal regulations (ITAR) have precluded use of more than three element's in beam-steering antennas

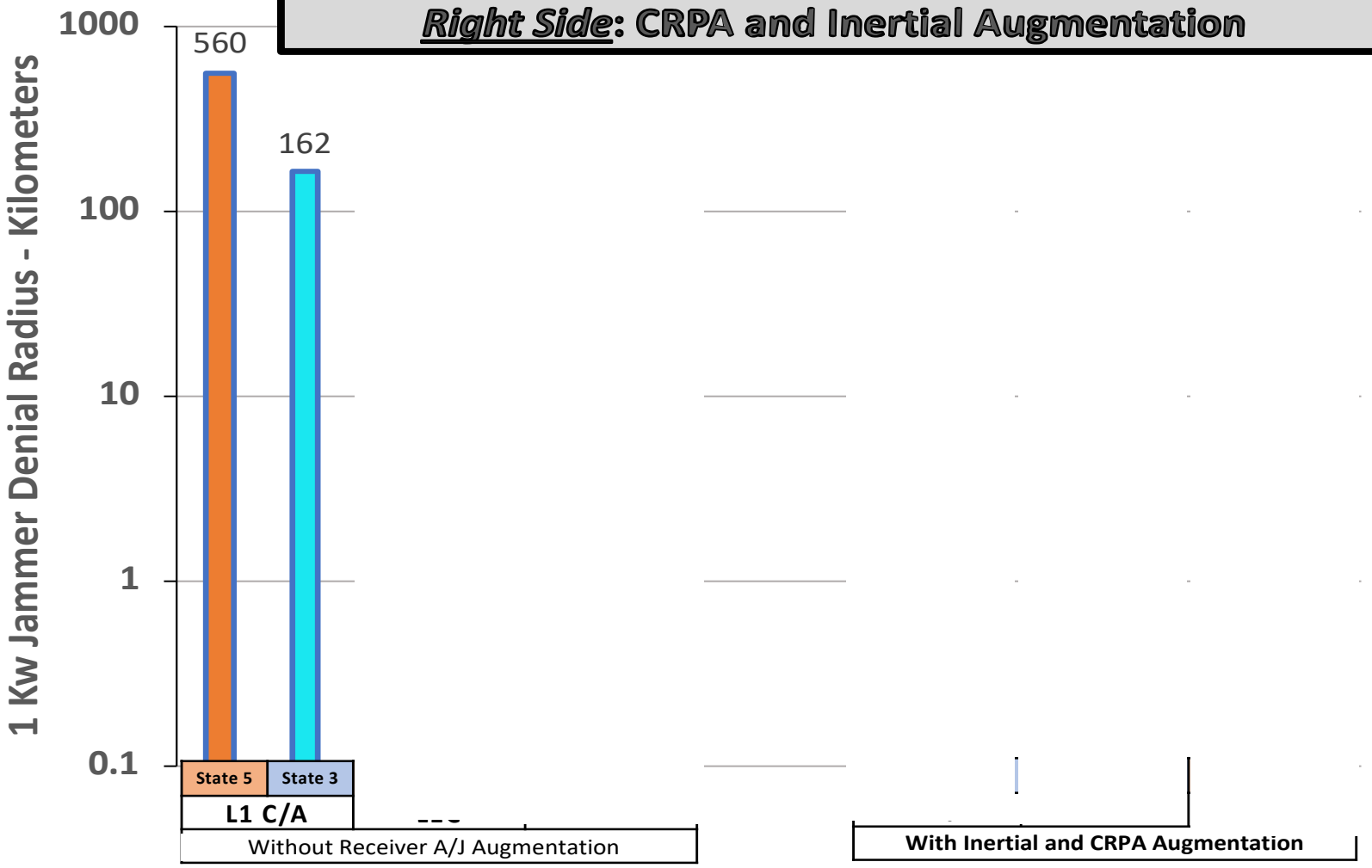
But Receiver Toughening is clearly the quickest solution to threats of J&S

Denial Radius of 1Kw Jammer (Kilometers)

Three GPS signals: L1 C/A, L1C, and L5

***Left side*: No Receiver Augmentation ,**

***Right Side*: CRPA and Inertial Augmentation**

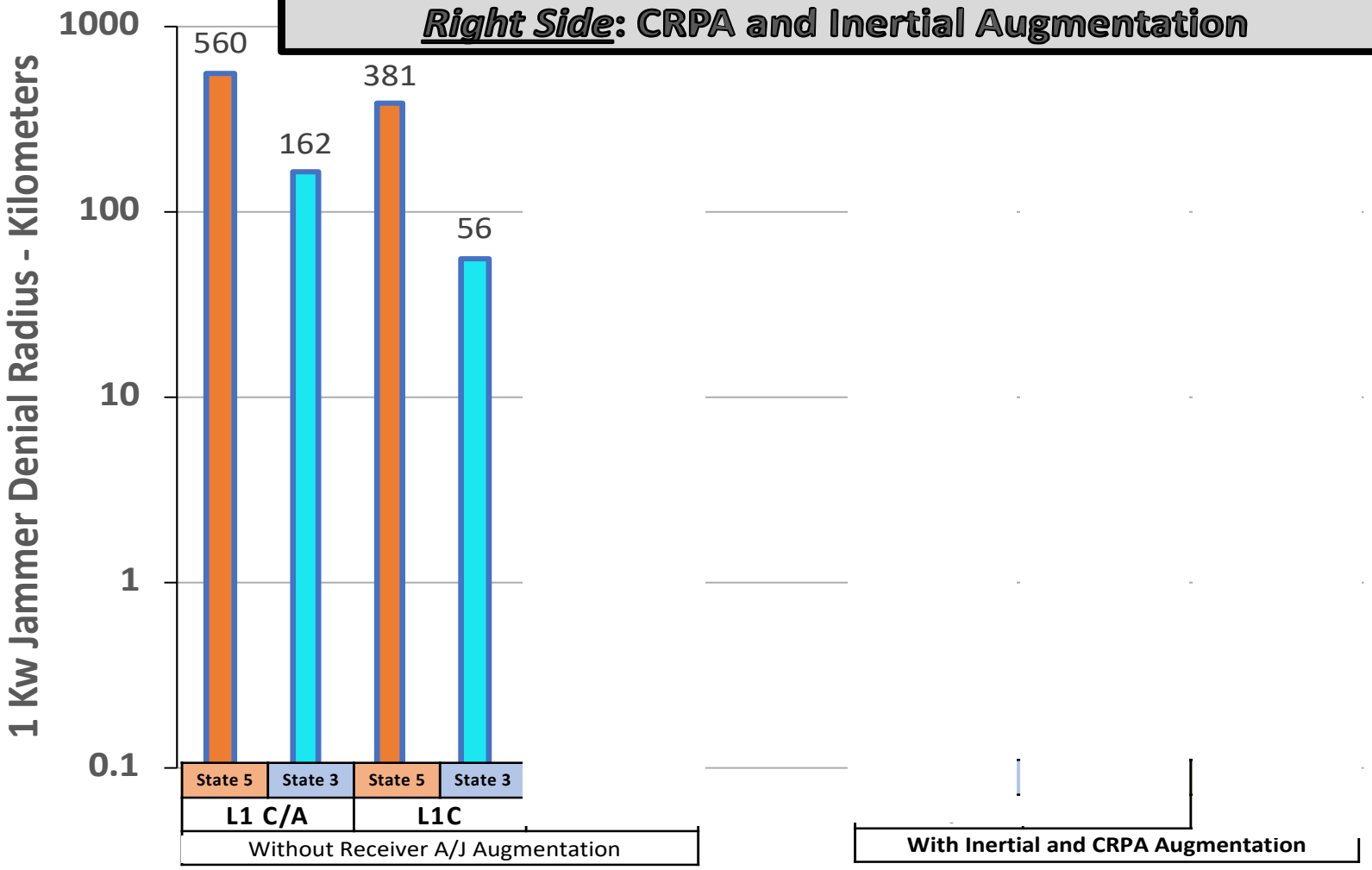


Denial Radius of 1Kw Jammer (Kilometers)

Three GPS signals: L1 C/A, L1C, and L5

***Left side*: No Receiver Augmentation ,**

***Right Side*: CRPA and Inertial Augmentation**

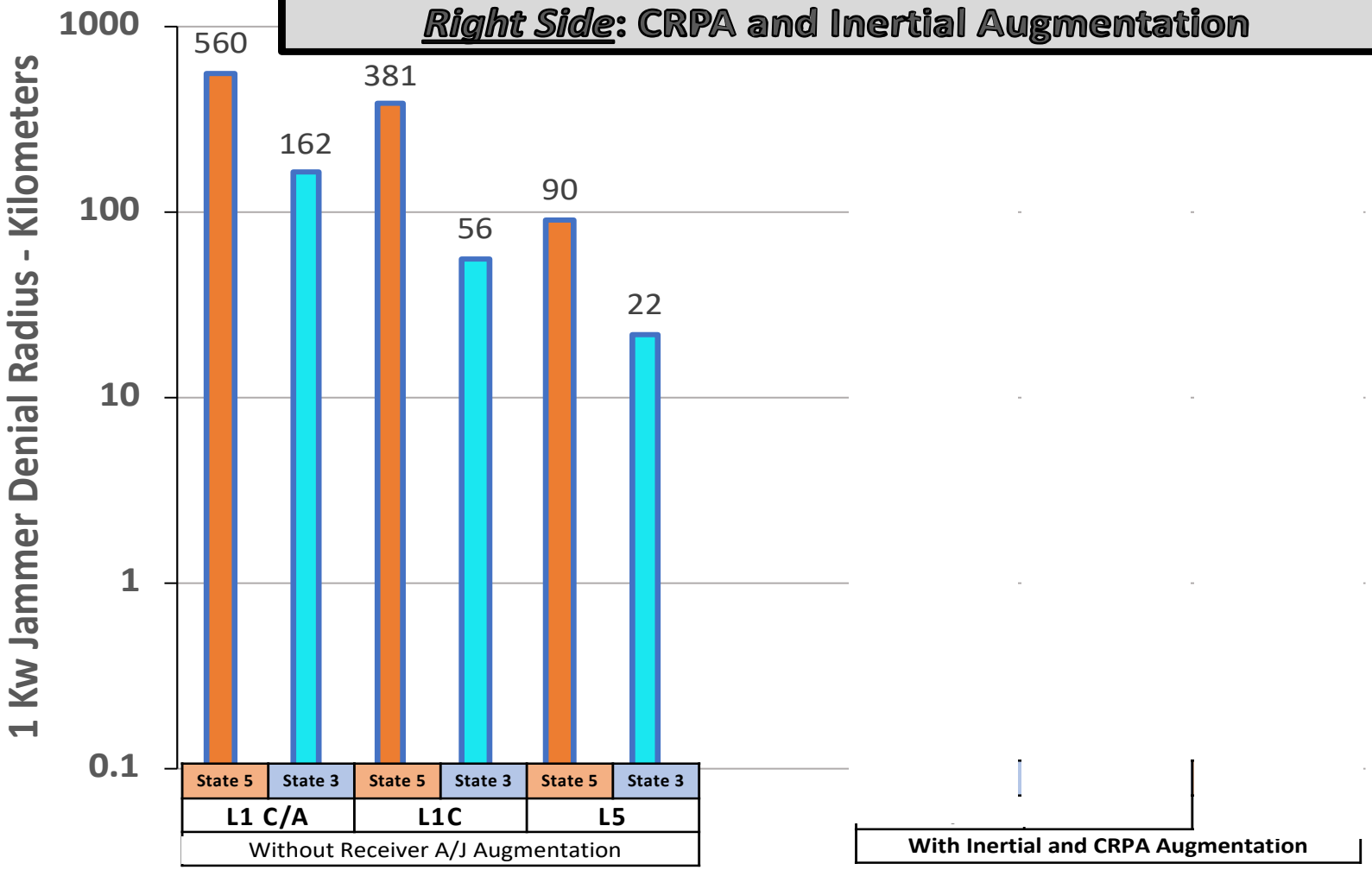


Denial Radius of 1Kw Jammer (Kilometers)

Three GPS signals: L1 C/A, L1C, and L5

***Left side*: No Receiver Augmentation ,**

***Right Side*: CRPA and Inertial Augmentation**

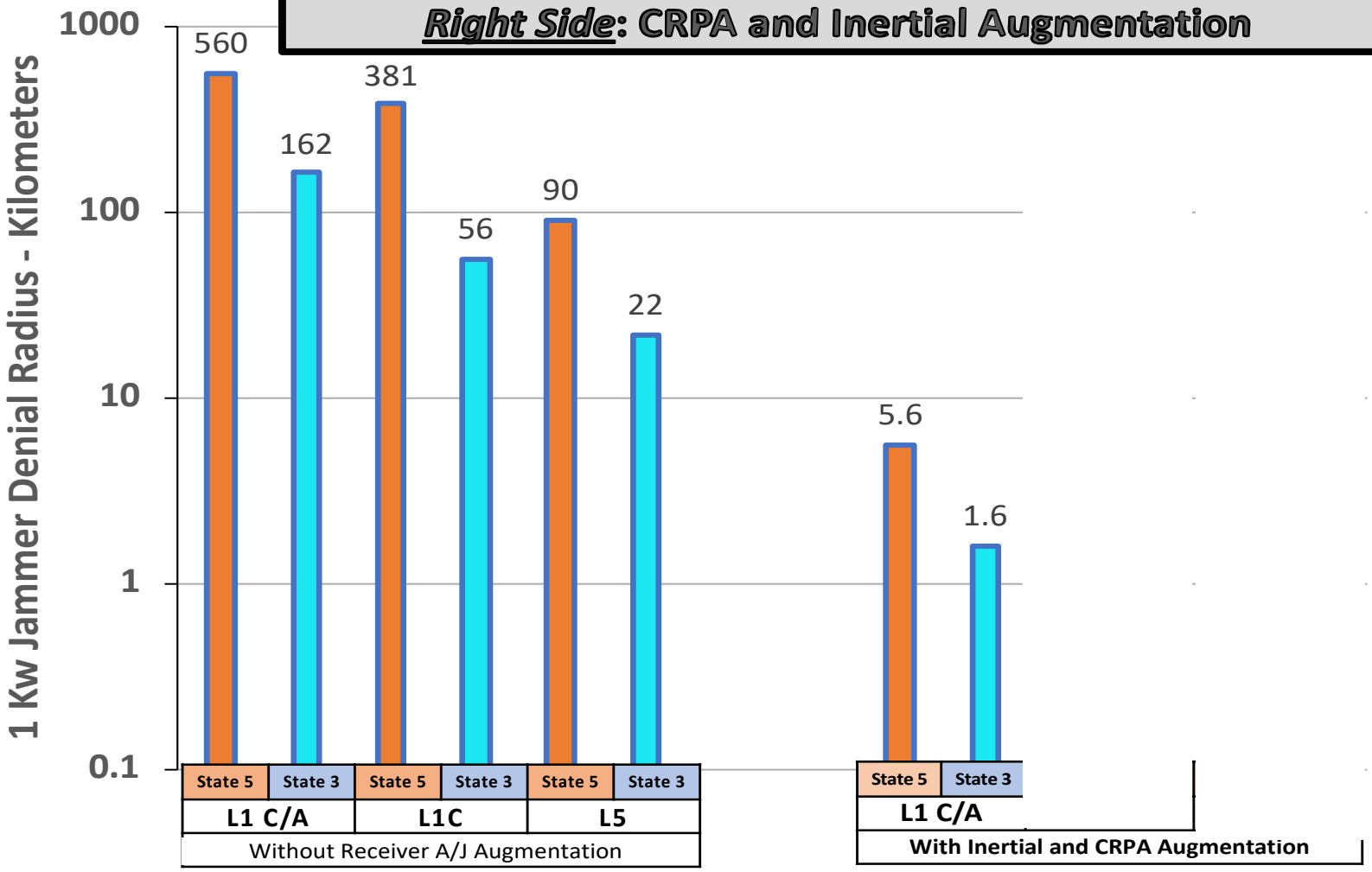


Denial Radius of 1Kw Jammer (Kilometers)

Three GPS signals: L1 C/A, L1C, and L5

***Left side*: No Receiver Augmentation ,**

***Right Side*: CRPA and Inertial Augmentation**

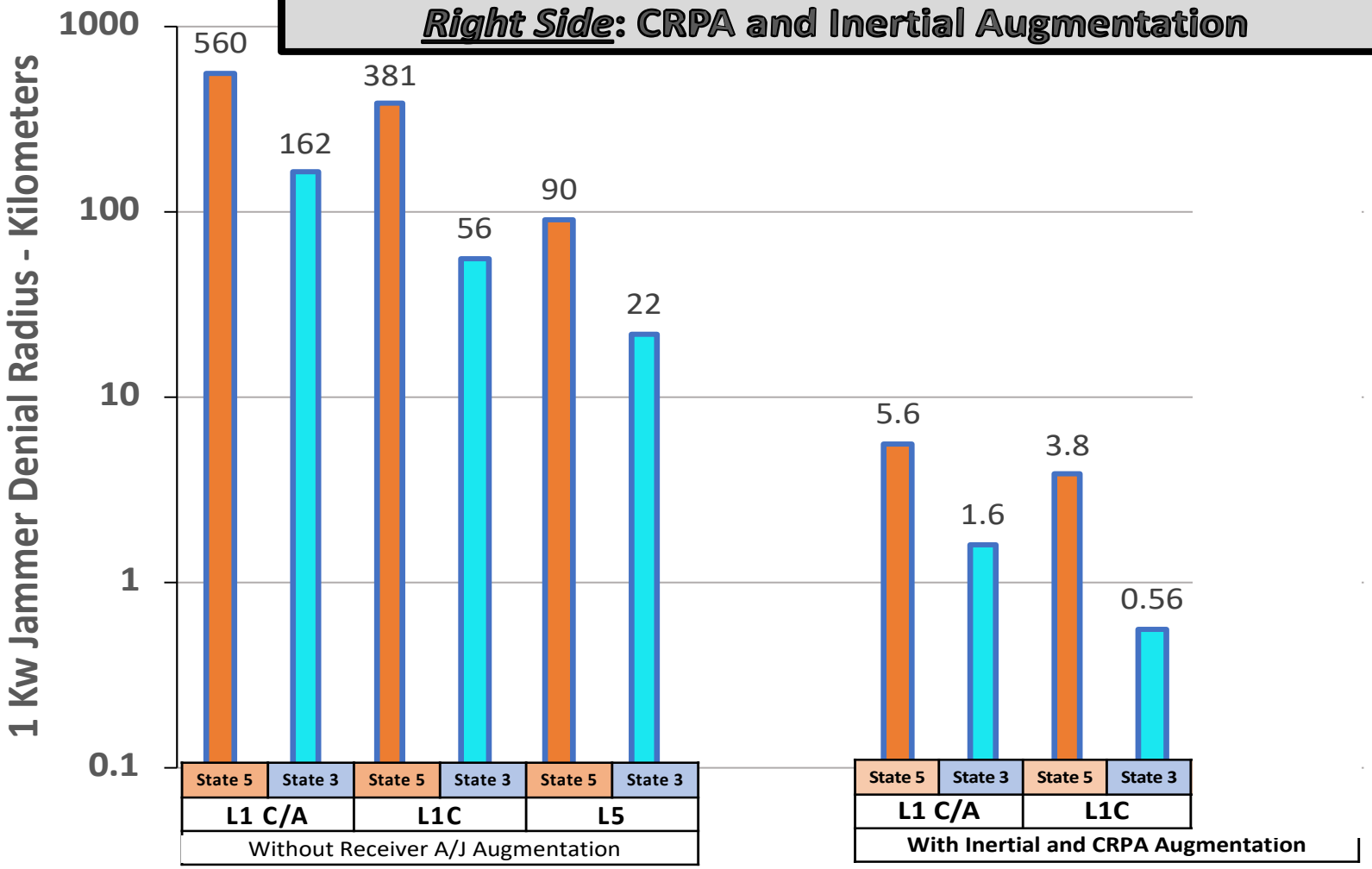


Denial Radius of 1Kw Jammer (Kilometers)

Three GPS signals: L1 C/A, L1C, and L5

***Left side*: No Receiver Augmentation ,**

***Right Side*: CRPA and Inertial Augmentation**

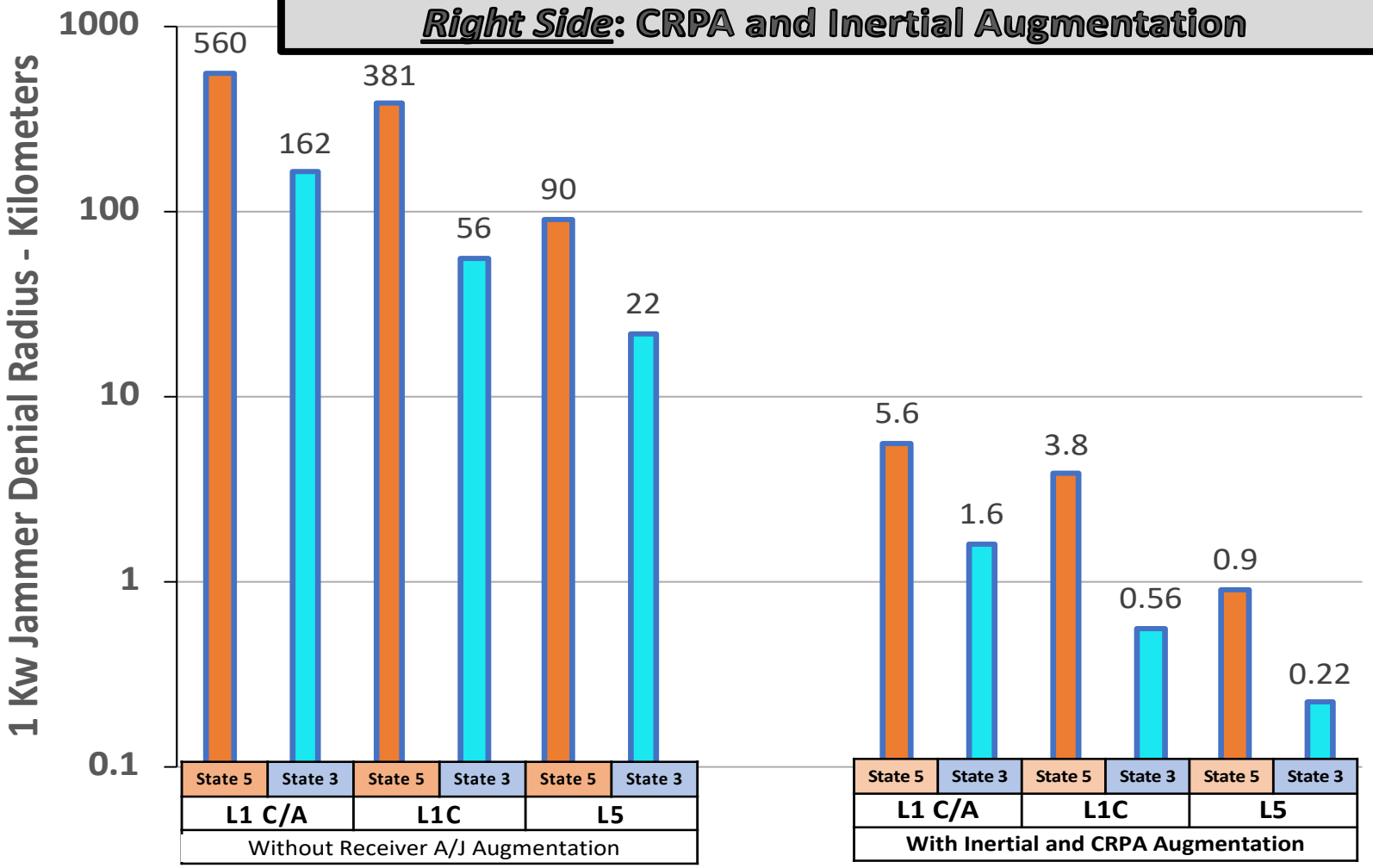


Denial Radius of 1Kw Jammer (Kilometers)

Three GPS signals: L1 C/A, L1C, and L5

***Left side*: No Receiver Augmentation ,**

***Right Side*: CRPA and Inertial Augmentation**

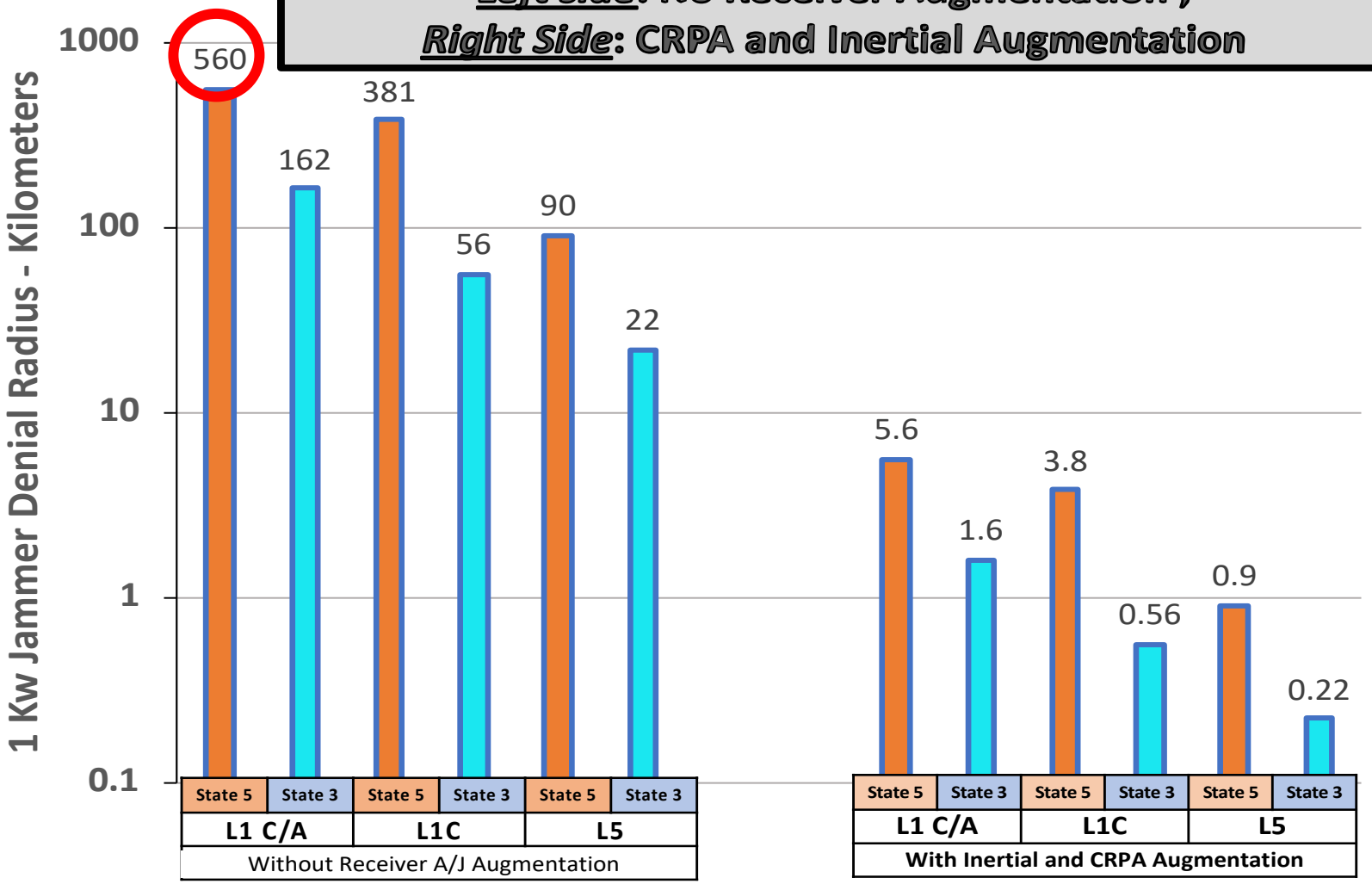


Denial Radius of 1Kw Jammer (Kilometers)

Three GPS signals: L1 C/A, L1C, and L5

***Left side*: No Receiver Augmentation ,**

***Right Side*: CRPA and Inertial Augmentation**

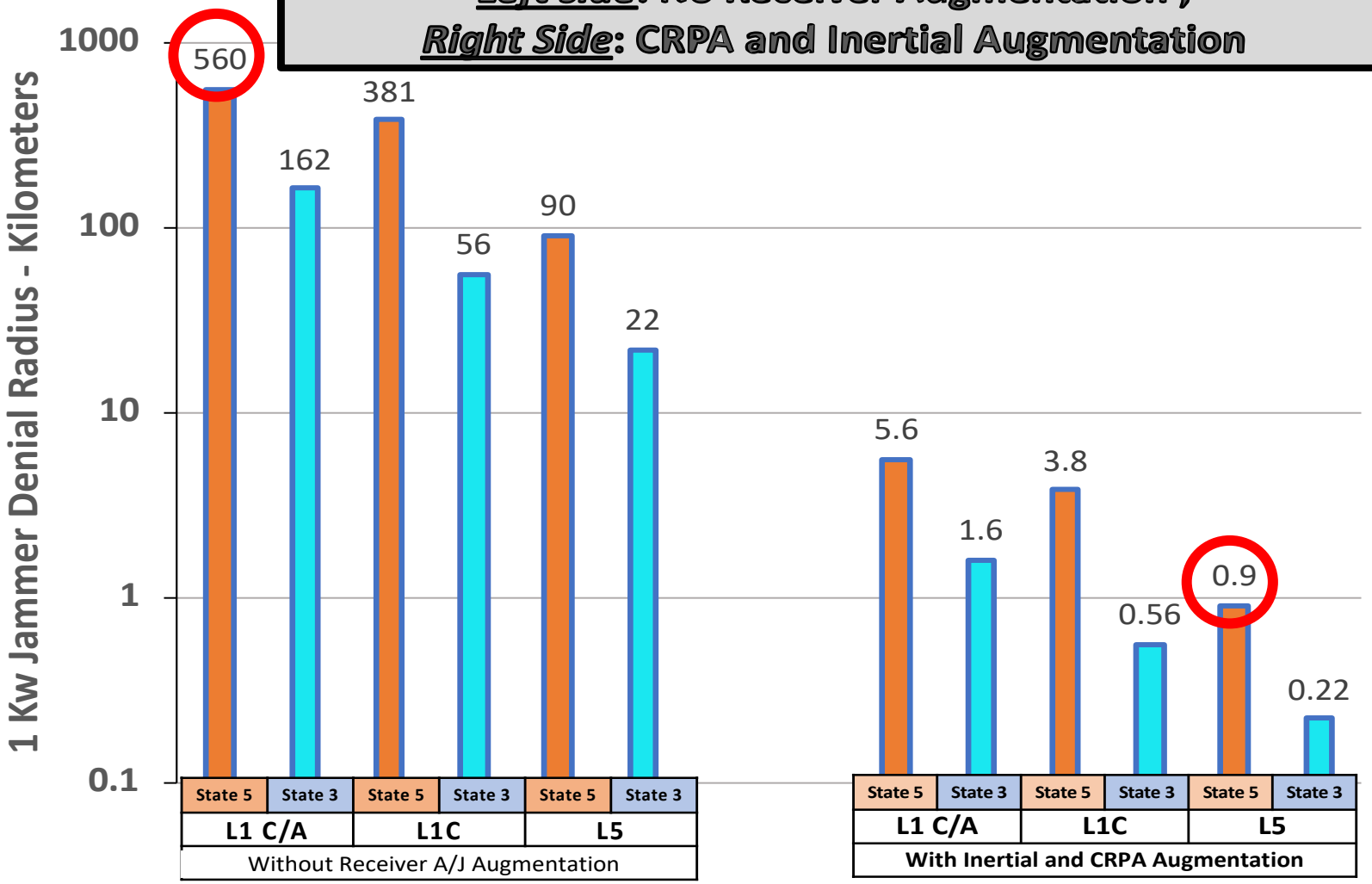


Denial Radius of 1Kw Jammer (Kilometers)

Three GPS signals: L1 C/A, L1C, and L5

***Left side*: No Receiver Augmentation ,**

***Right Side*: CRPA and Inertial Augmentation**

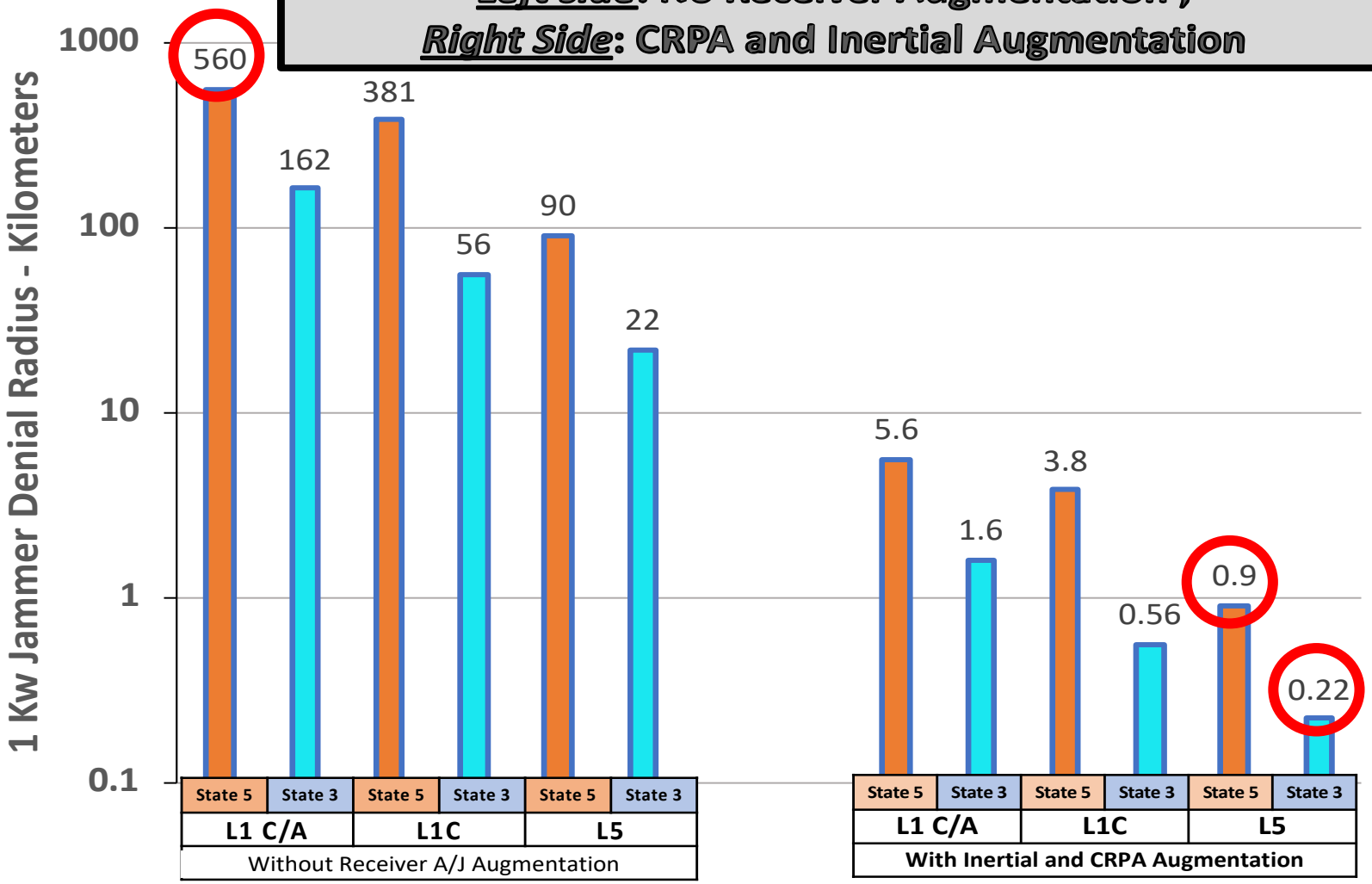


Denial Radius of 1Kw Jammer (Kilometers)

Three GPS signals: L1 C/A, L1C, and L5

***Left side*: No Receiver Augmentation ,**

***Right Side*: CRPA and Inertial Augmentation**



Toughen - Conclusions

- With known (and demonstrated) toughening techniques, the high-powered Jammer threat can be reduced by factors of over 100,000*.
- ITAR has been a major impediment through restrictions that preclude the needed, beam-forming (and interference-rejecting) digital antennas. Needs USG action.
- Small highly-capable digital devices have plummeted in cost – reducing resistance that was due to toughened receiver cost
- The L5 signal is a significant improvement over the ubiquitous L1 C/A.
- Manufacturers and Sensitive user groups should be encouraged to pursue this – particularly commercial aviation, self-driving vehicles, and maritime.

* 1kW jammer effective area reduced from about a million square km to about 2.5 square km.

Strategy 3: Augment - with additional GNSS/PNT sources and Techniques

- Augmenting/replacing is the current USG focus for resolving jamming and spoofing issues
  - Examples: LEO/Comm Satellites, eLORAN, Inertial Navigators, fiber for timing
  - Other GNSS also can augment, both with and without assured integrity (WAAS look-alikes)
- Generally supported by the PNTAB – we feel that implementing augmentation is long overdue, "***we have admired the problem long enough"***
  But let us be clear: **None Of The Known AugmentationTechniques Can "Replace GPS/GNSS" For Most High-Value/High-Precision Applications.**
- Propose (notionally) conbsidering some measures of need/requirements:
  - Accuracy
  - Integrity – Probability that PNT measurement is "out of Protection Limits"
  - **Less Susceptibility to interference**
- Of course other categories are also important, such as:
  - Availability – Geographical and temporal
  - Time and Cost to Field
  - Applications served or not served

12 Application ***Categories*** with A few (65!) Example GPS Applications: *23 High* ***Precision in Red***---

Categories	Example applications
Aviation	Area navigation, approach, landing up to Cat III, NextGen
Agriculture	AutoFarming: crop spraying, precision cultivating, yield assessment
Automotive	Turn-by-turn guidance, OnStar, driverless Cars and Trucks
Emergency and Rescue Services	911, ambulance, fire, police, IFR rescue helicopters, emergency beacons, airplane and ship locaters, OnStar
Intelligent Transportation	Train control and management, Precision UAVs, Intelligent Highways
Military	Rescue, precision weapon delivery, unit and individual location
Recreation	GeoCaching, control of models, hiking, outdoor activities
Robotics and Machine Control	Bull dozers, Earth graders, mining trucks, oil drilling
Scientific	Earth movement and shape, atmosphere, weather forecasting, climate modeling, ionosphere, space weather, tsunami warning, soil moisture, ocean roughness, wind velocity, snow, ice, and foliage coverage, ……
Survey and GIS	Mapping, tectonic motion monitoring, tagging disease outbreaks
Timing	Cell phone towers, banking, power grid
Tracking	Fleets, assets, equipment, shipments, children, Alzheimer's patients, wildlife, animals, law enforcement, criminals, parolees, ……

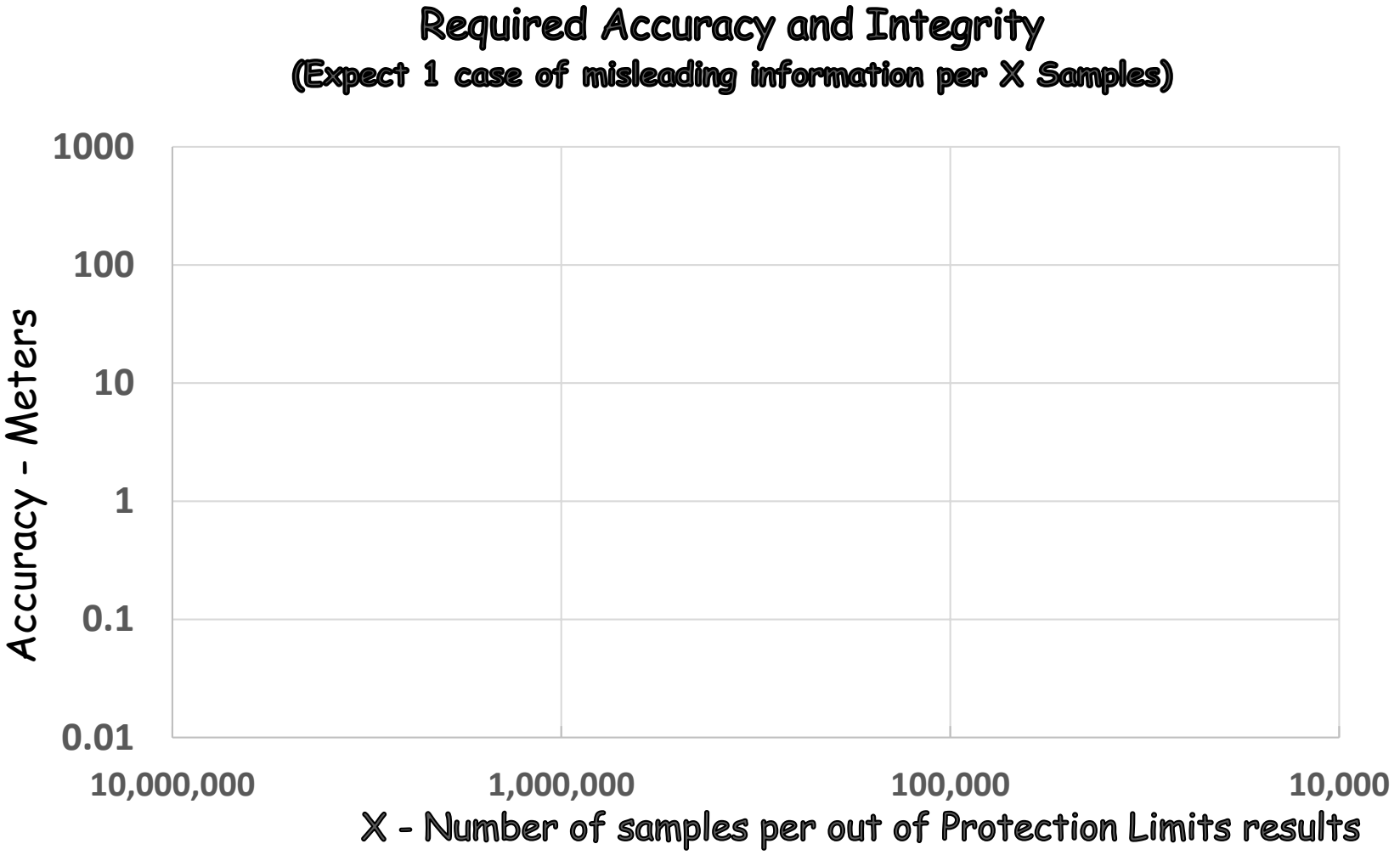
High ***Precision – need accuracies of a few meters or better***

Categories	Example applications
Aviation	Precision and non-Precision Landing To Cat III, Nextgen
Agriculture	Autofarming: Precision Cultivating, Yield Assessment
Automotive	Driverless Cars And Trucks
Emergency and Rescue Services	IFR Rescue Helicopters
Intelligent Transportation	Train Control And Management, Precision UAVs, Intelligent Highways
Military	Precision Weapon Delivery,
Recreation	
Robotics and Machine Control	Bull Dozers, Earth Graders, Mining Trucks, Oil Drilling
Scientific	Earth Movement And Shape, Atmosphere, Ionosphere, Space Weather,
Survey and GIS	Mapping, Tectonic Motion Monitoring,
Timing	Require High Availability but do not press accuracy
Tracking	

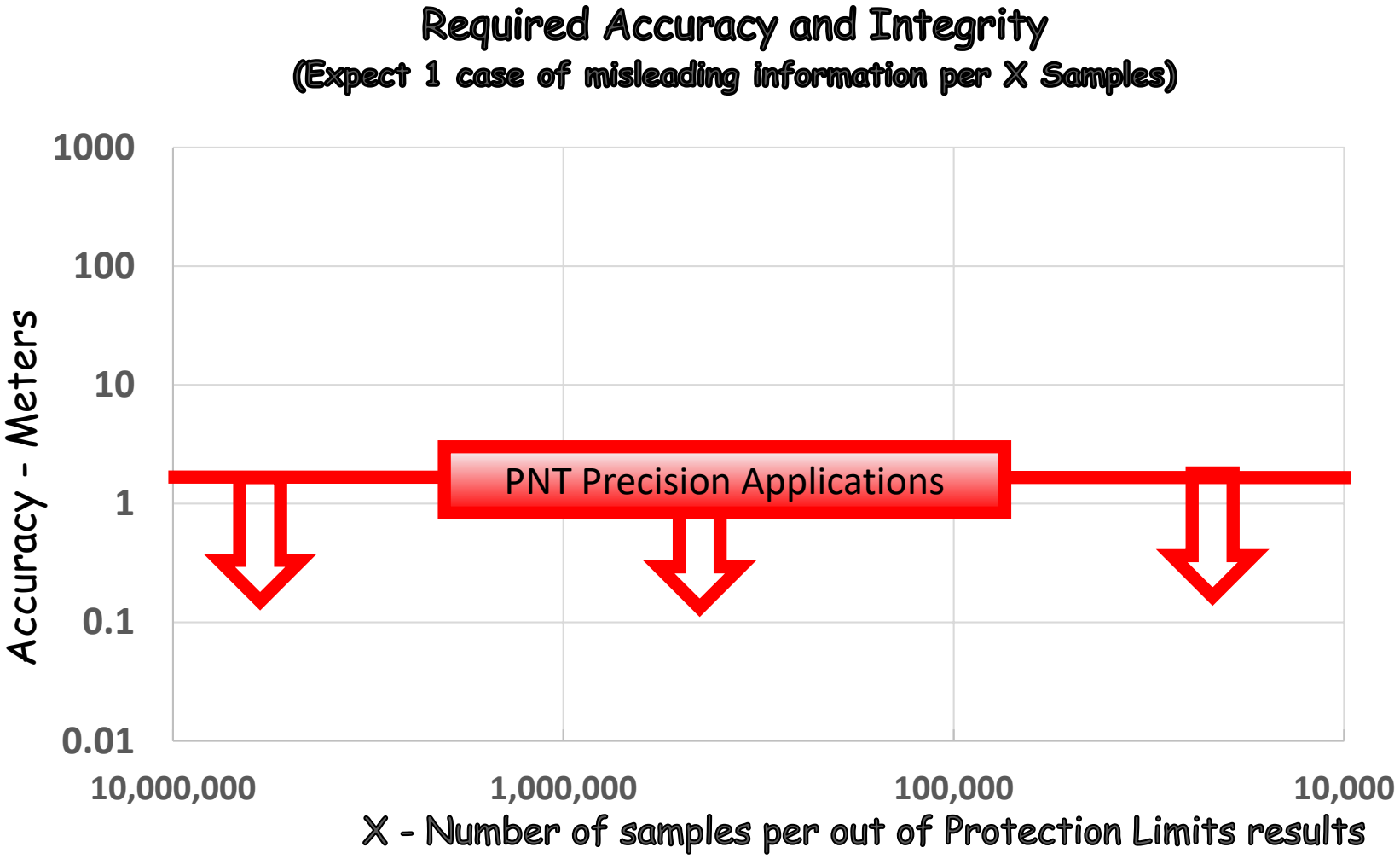
Non-Precision GPS Applications

Categories	Example applications
Aviation	Area navigation
Agriculture	crop spraying
Automotive	Turn-by-turn guidance, OnStar
Emergency and Rescue Services	911, ambulance, fire, police, emergency beacons, airplane and ship locaters, OnStar
Intelligent Transportation	
Military	Rescue, unit and individual location
Recreation	GeoCaching, control of models, hiking, outdoor activities
Robotics and Machine Control	
Scientific	weather forecasting, climate modeling, tsunami warning, soil moisture, ocean roughness, wind velocity, snow, ice, and foliage coverage, ……
Survey and GIS	tagging disease outbreaks
Timing	Cell phone towers, banking, power grid
Tracking	Fleets, assets, equipment, shipments, children, Alzheimer's patients, wildlife, animals, law enforcement, criminals, parolees, ……

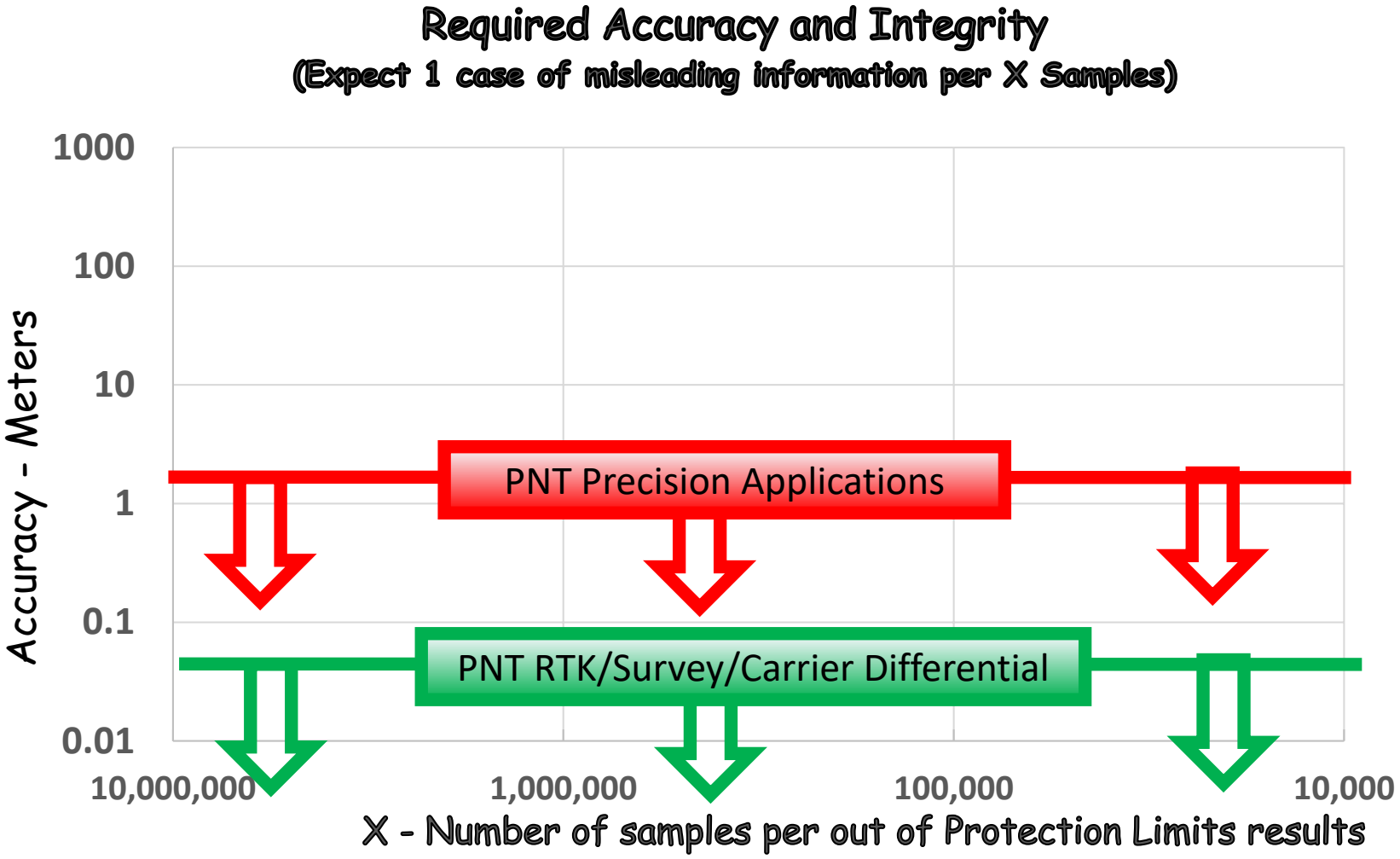
Accuracy and Integrity of Positioning (Notional) – System Needs for *Precision* or *Safety-of-Life* Applications



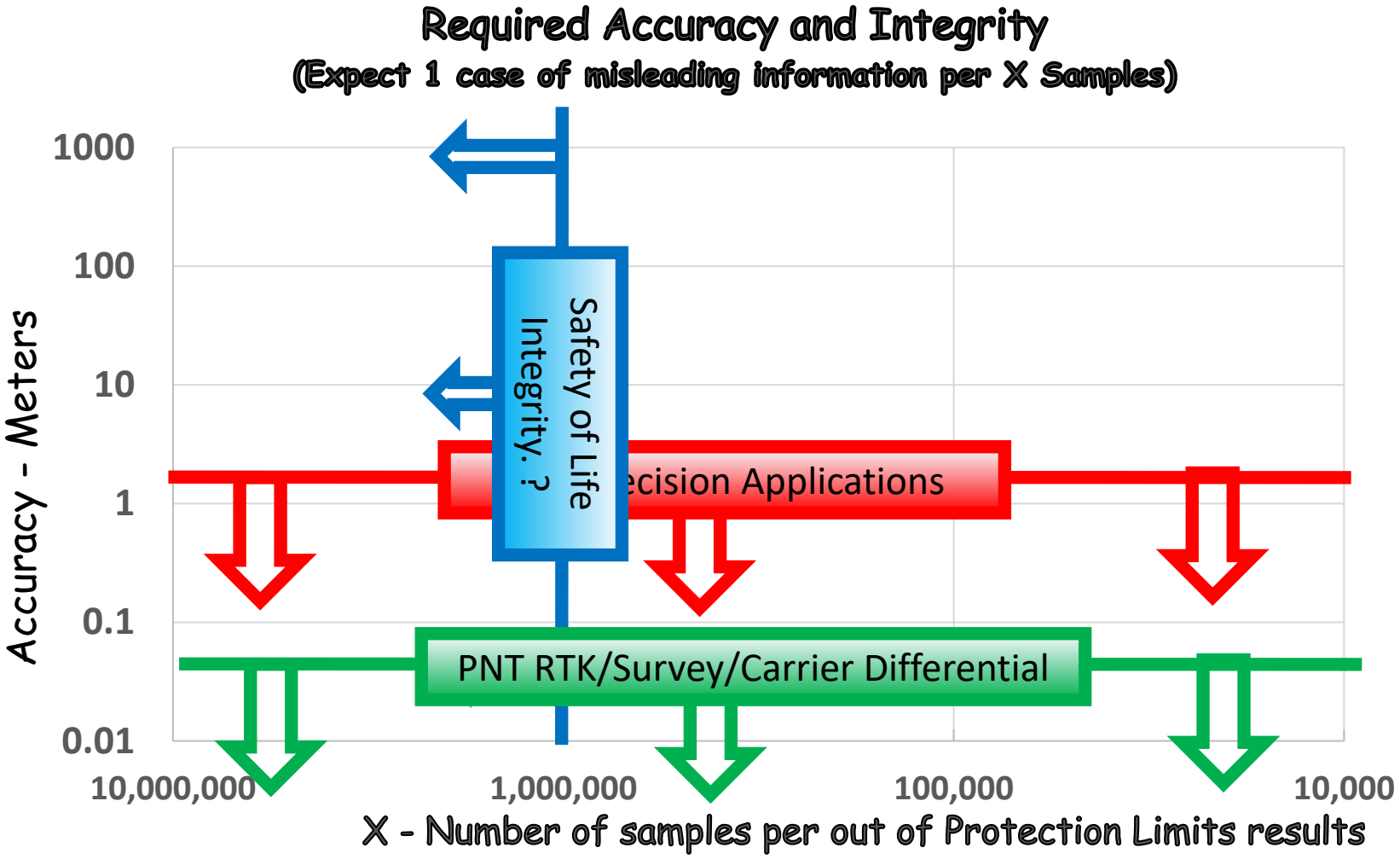
Accuracy and Integrity of Positioning (Notional) – System Needs for *Precision* or *Safety-of-Life* Applications



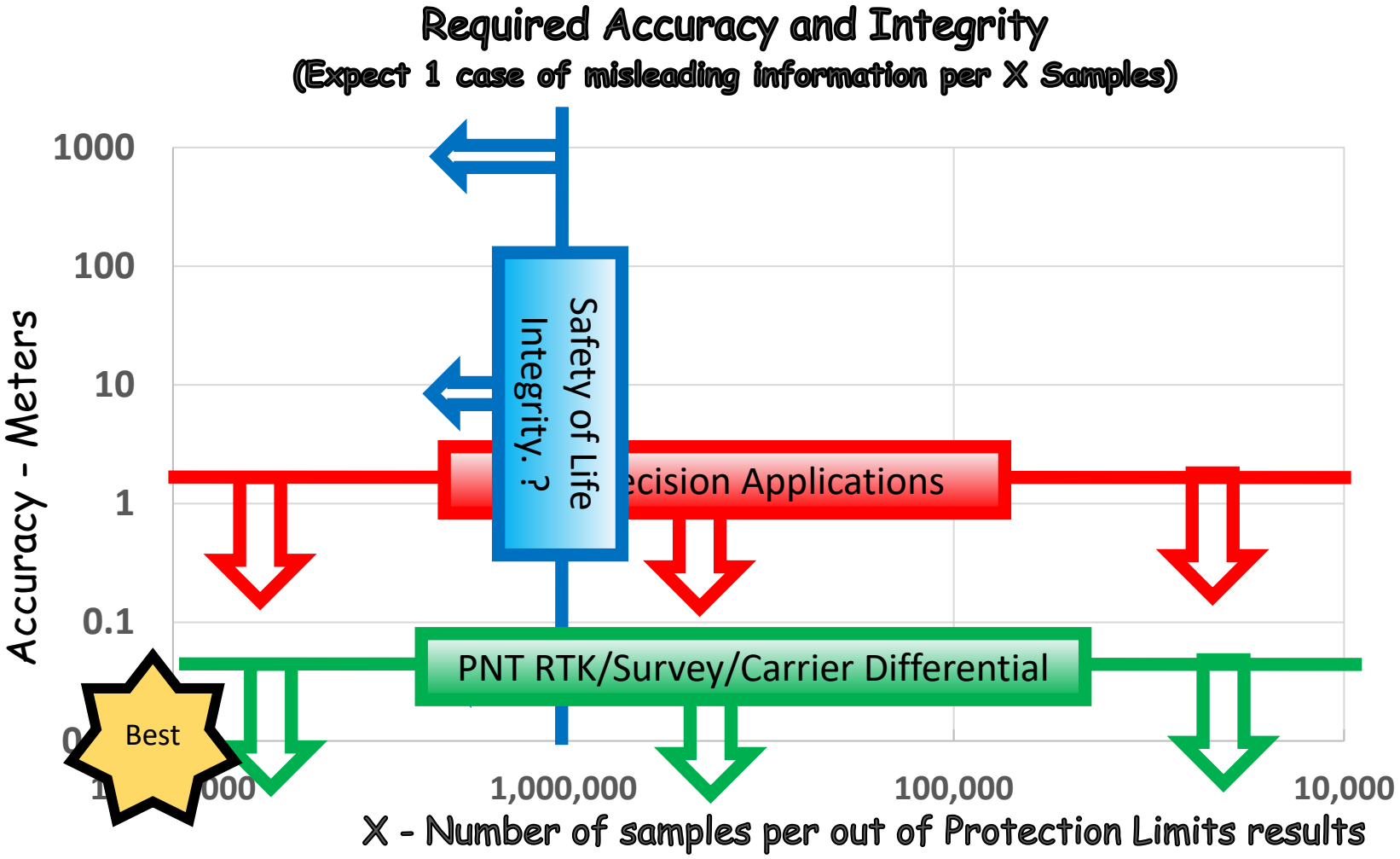
Accuracy and Integrity of Positioning (Notional) – System Needs for *Precision* or *Safety-of-Life* Applications



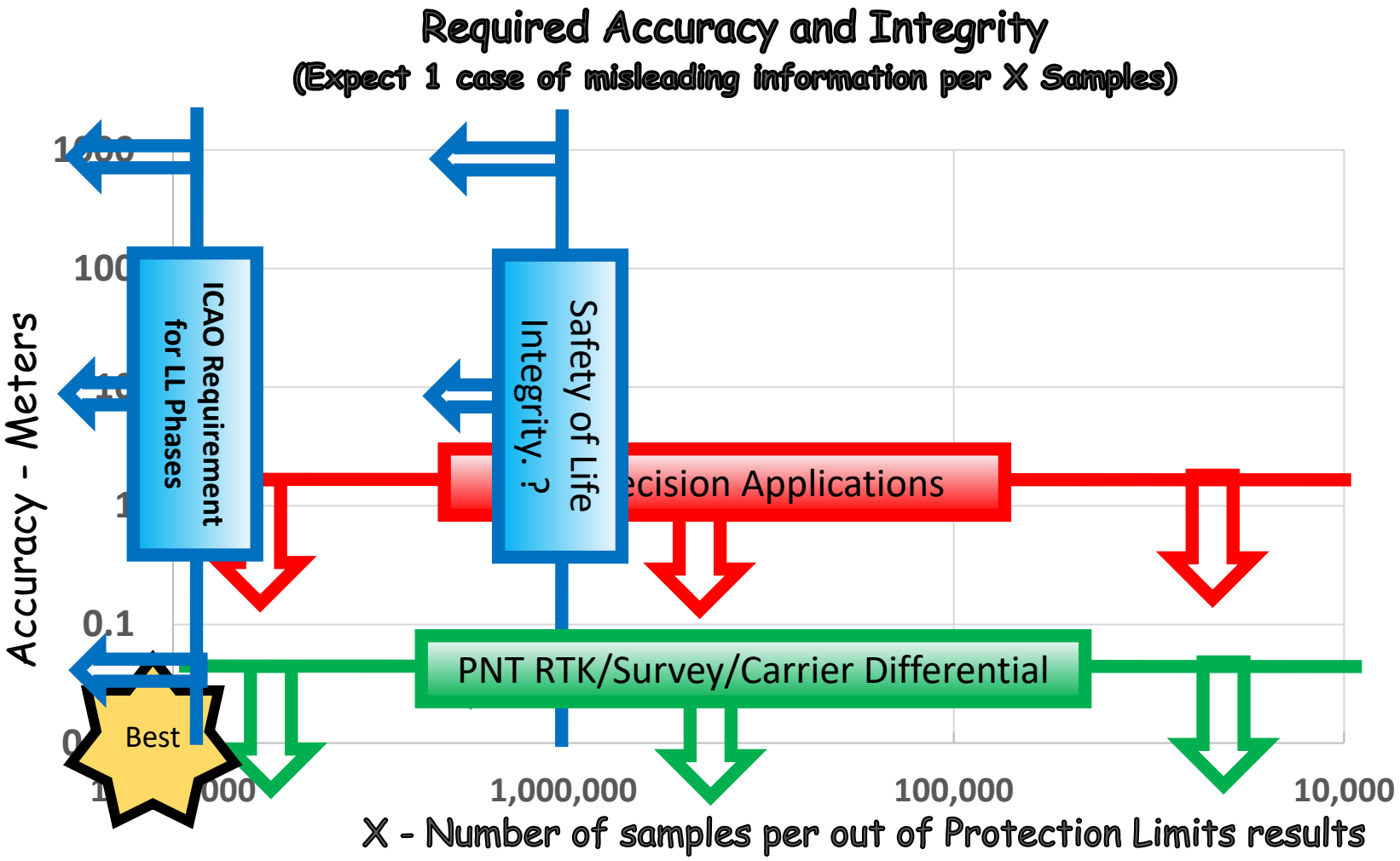
Accuracy and Integrity of Positioning (Notional) – System Needs for *Precision* or *Safety-of-Life* Applications



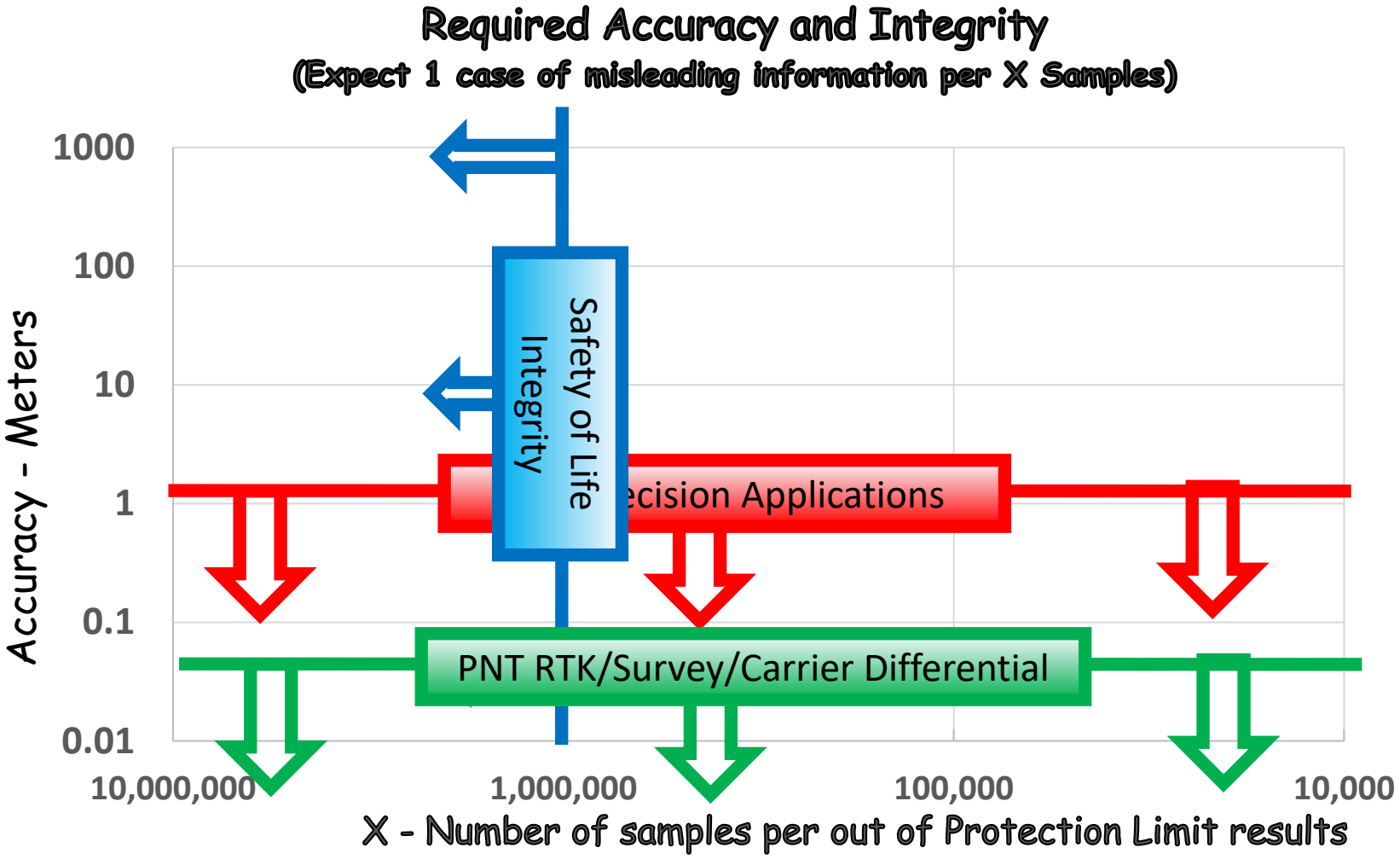
Accuracy and Integrity of Positioning (Notional) – System Needs for *Precision* or *Safety-of-Life* Applications



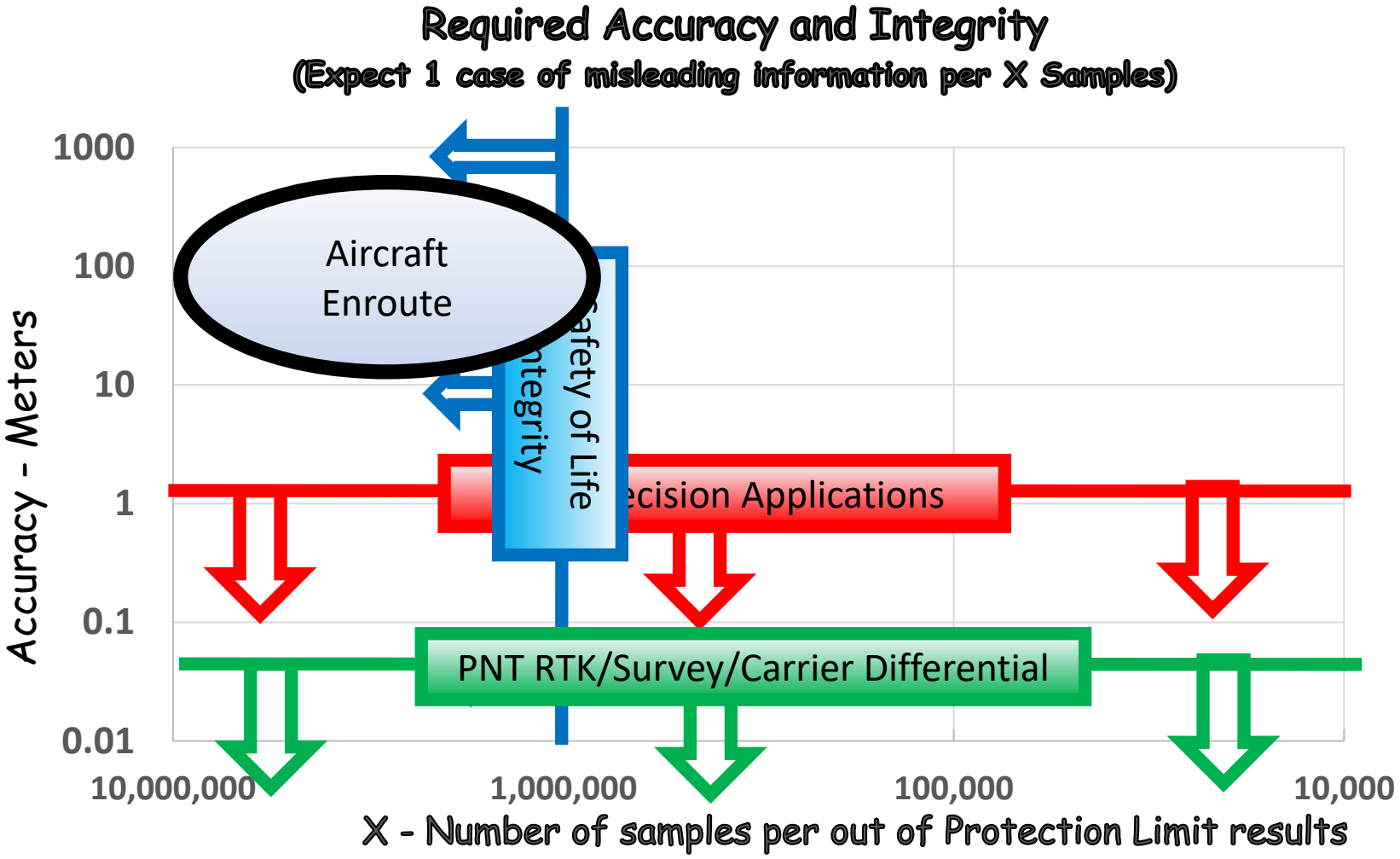
Accuracy and Integrity of Positioning (Notional) – System Needs for *Precision* or *Safety-of-Life* Applications



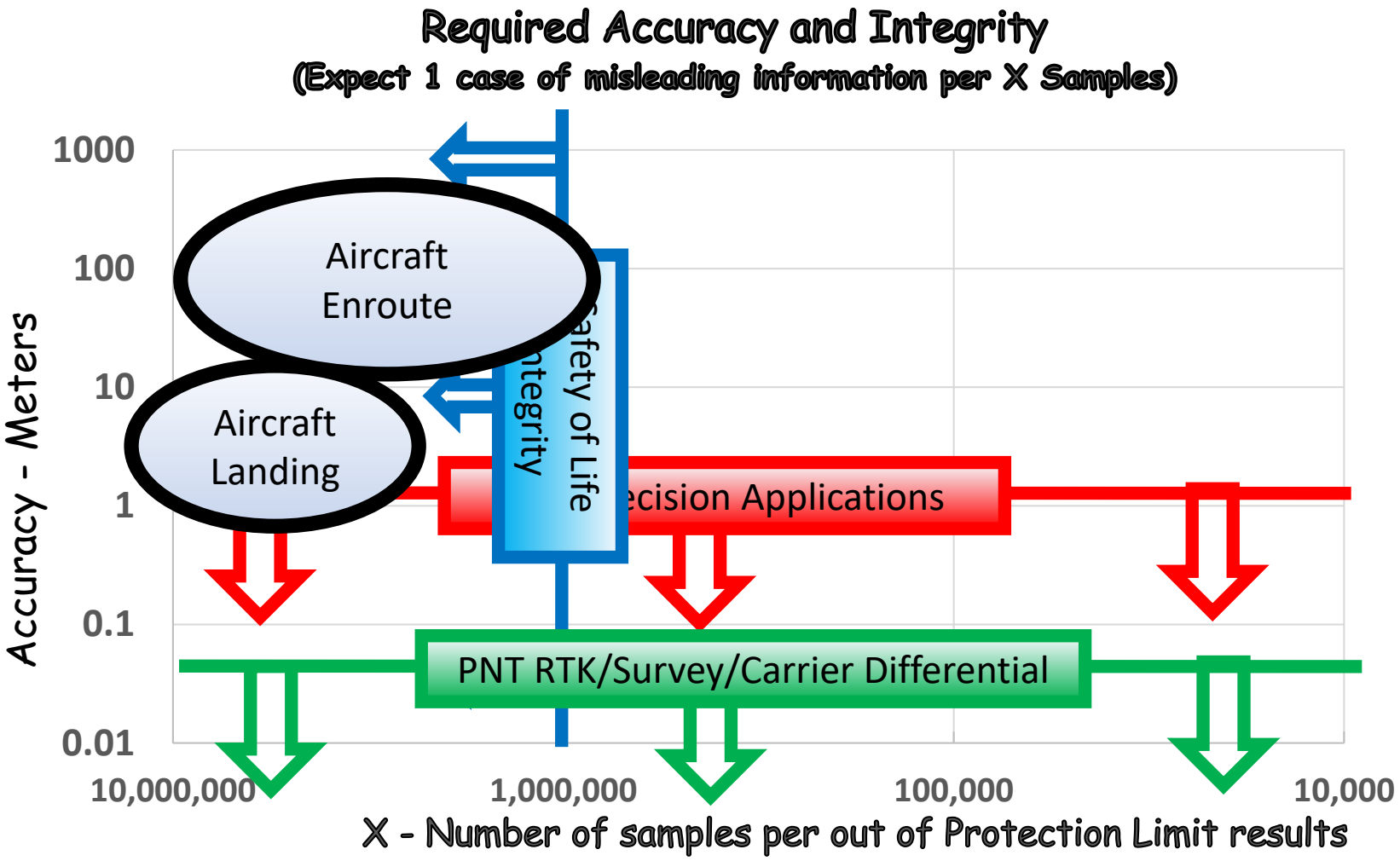
Accuracy and Integrity of Positioning – System Capability for *Precision* or *Safety-of-Life* Applications



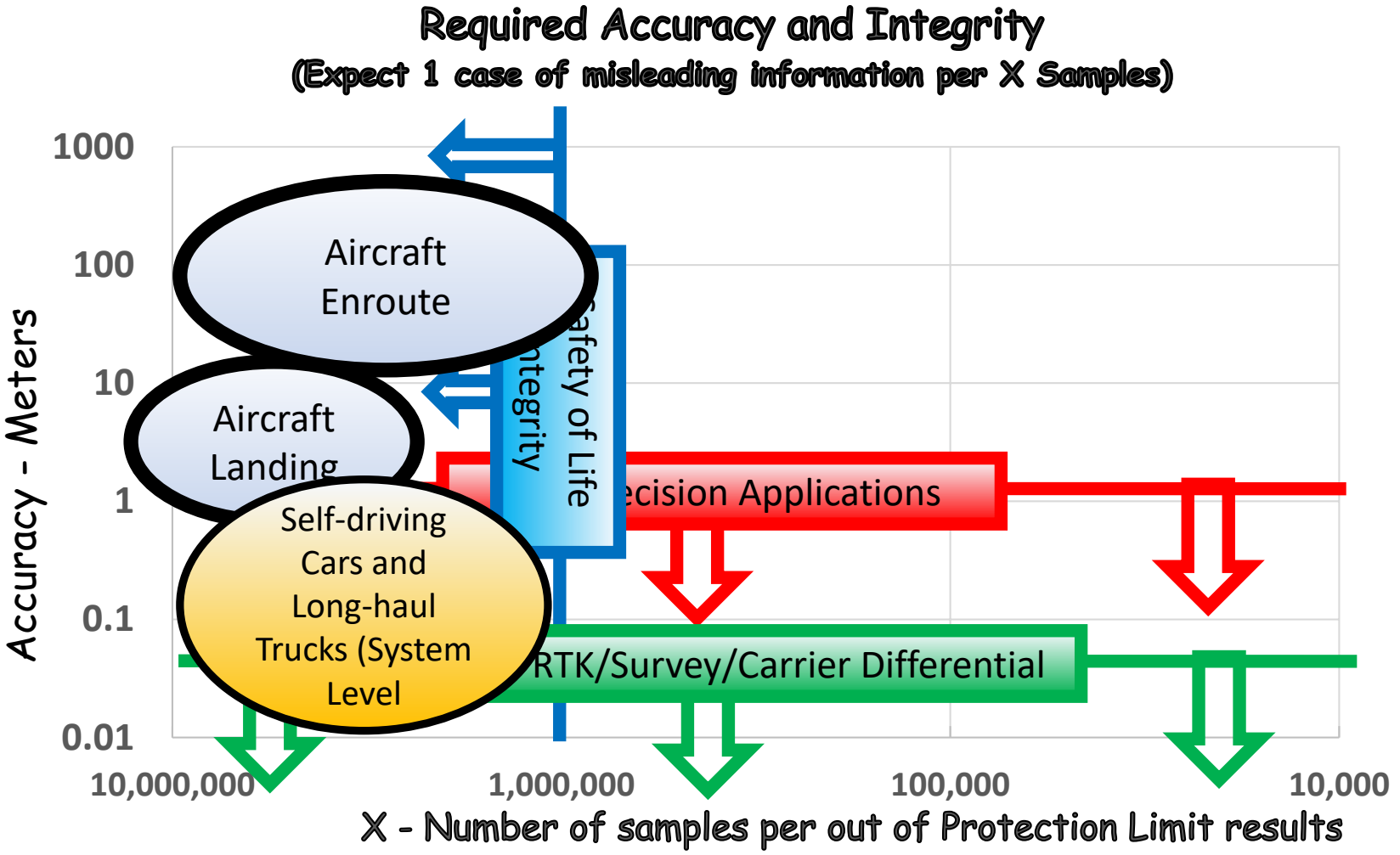
Accuracy and Integrity of Positioning – System Capability for *Precision* or *Safety-of-Life* Applications



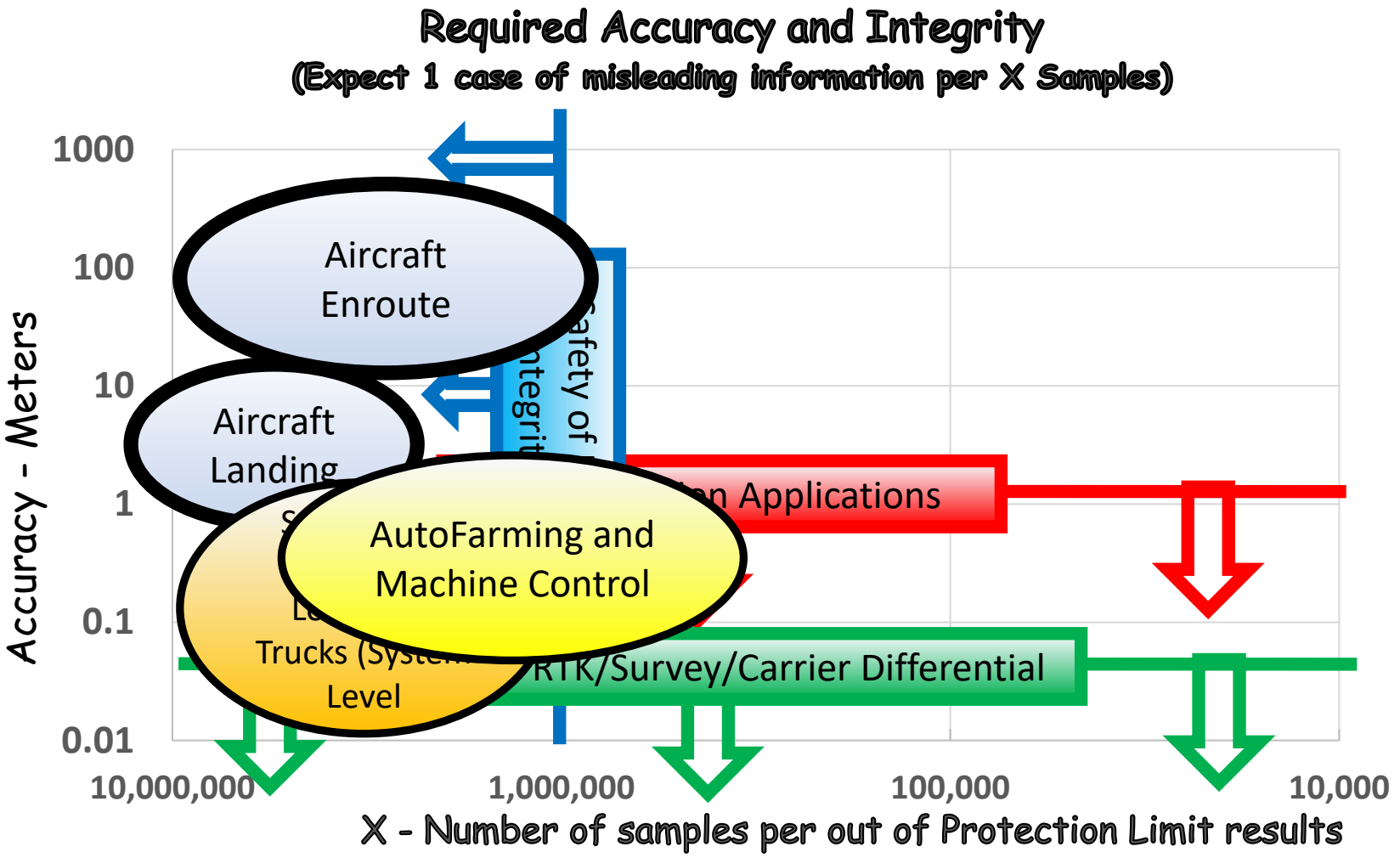
Accuracy and Integrity of Positioning – System Capability for *Precision* or *Safety-of-Life* Applications



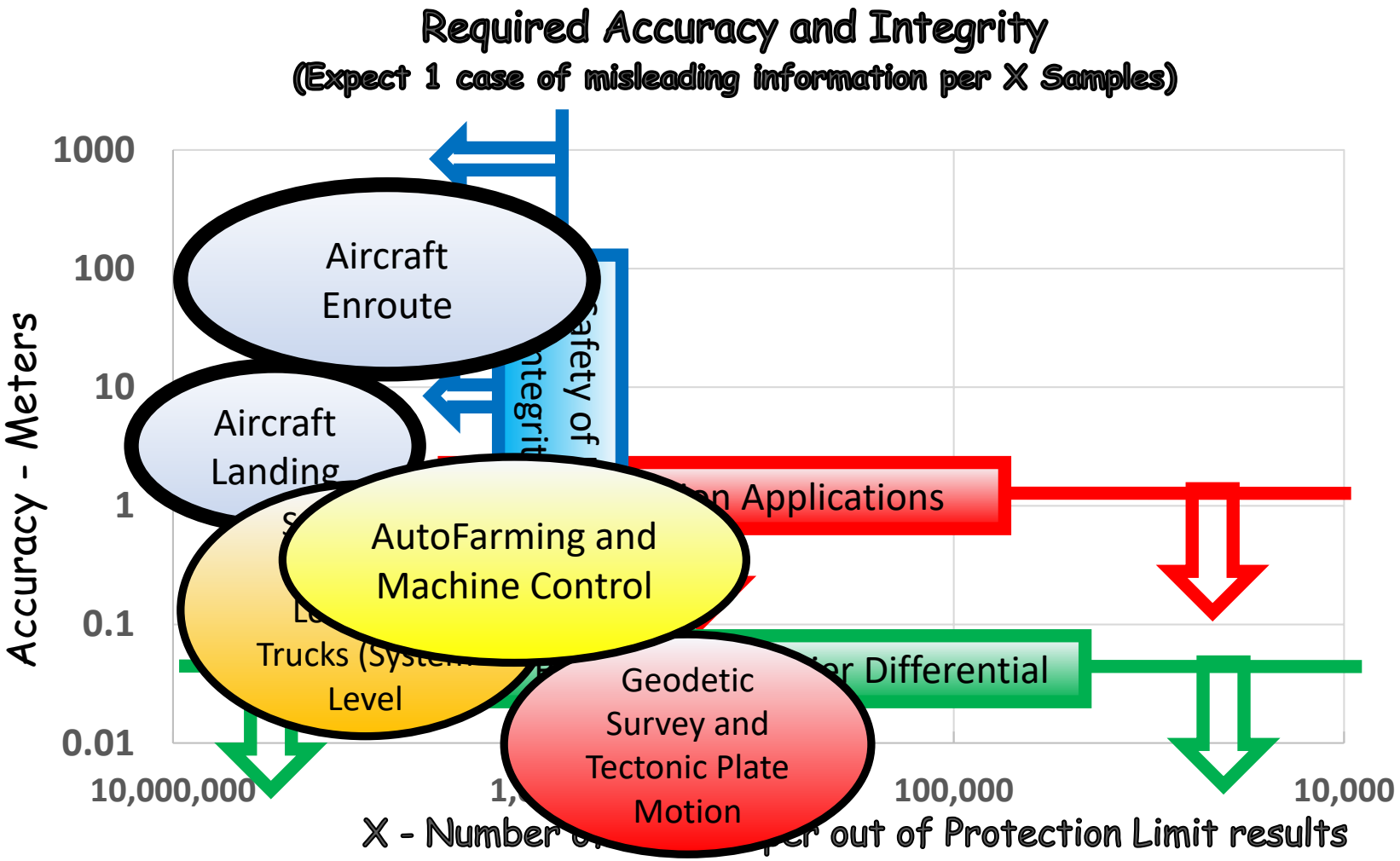
Accuracy and Integrity of Positioning – System Capability for *Precision* or *Safety-of-Life* Applications



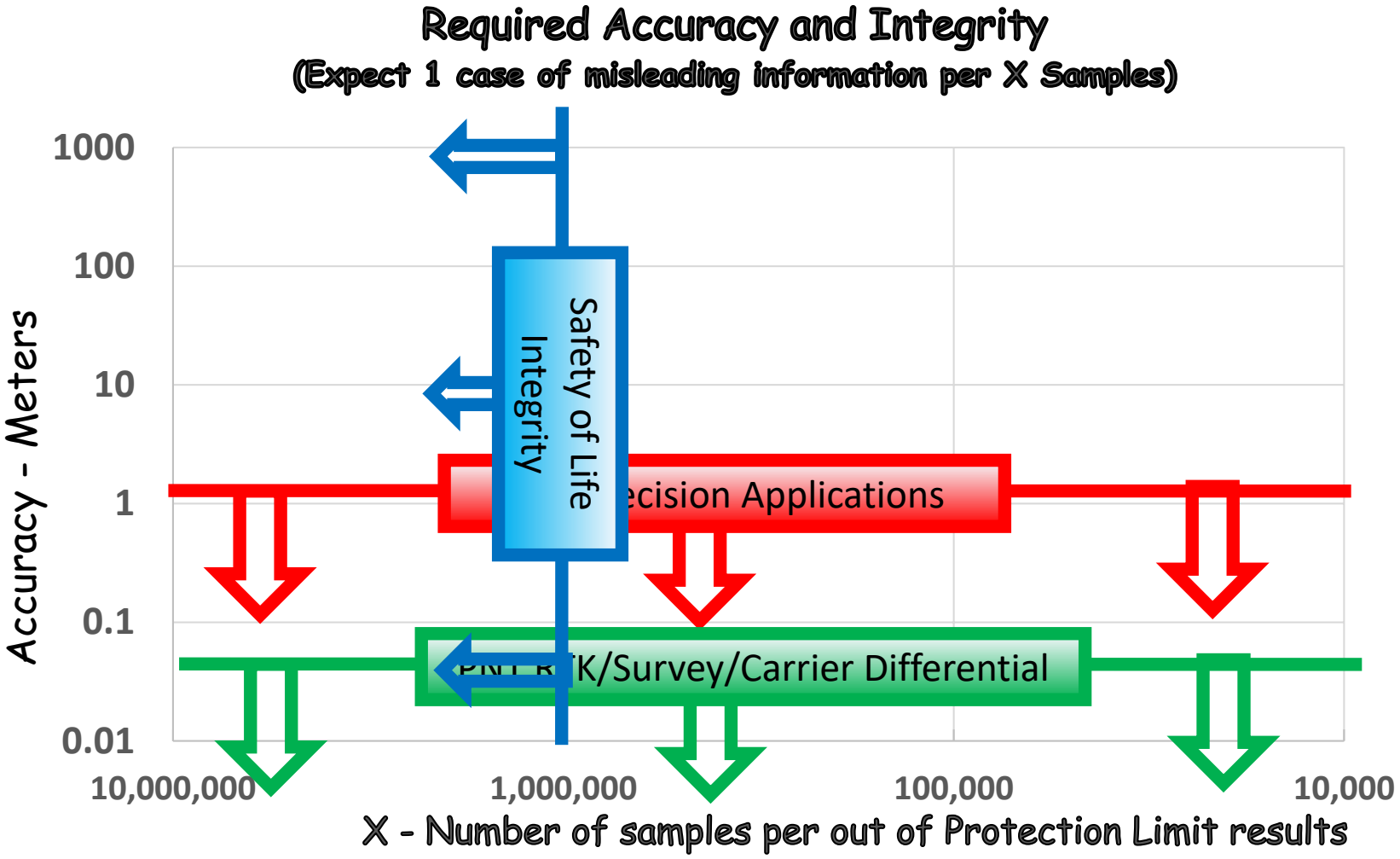
Accuracy and Integrity of Positioning – System Capability for *Precision* or *Safety-of-Life* Applications



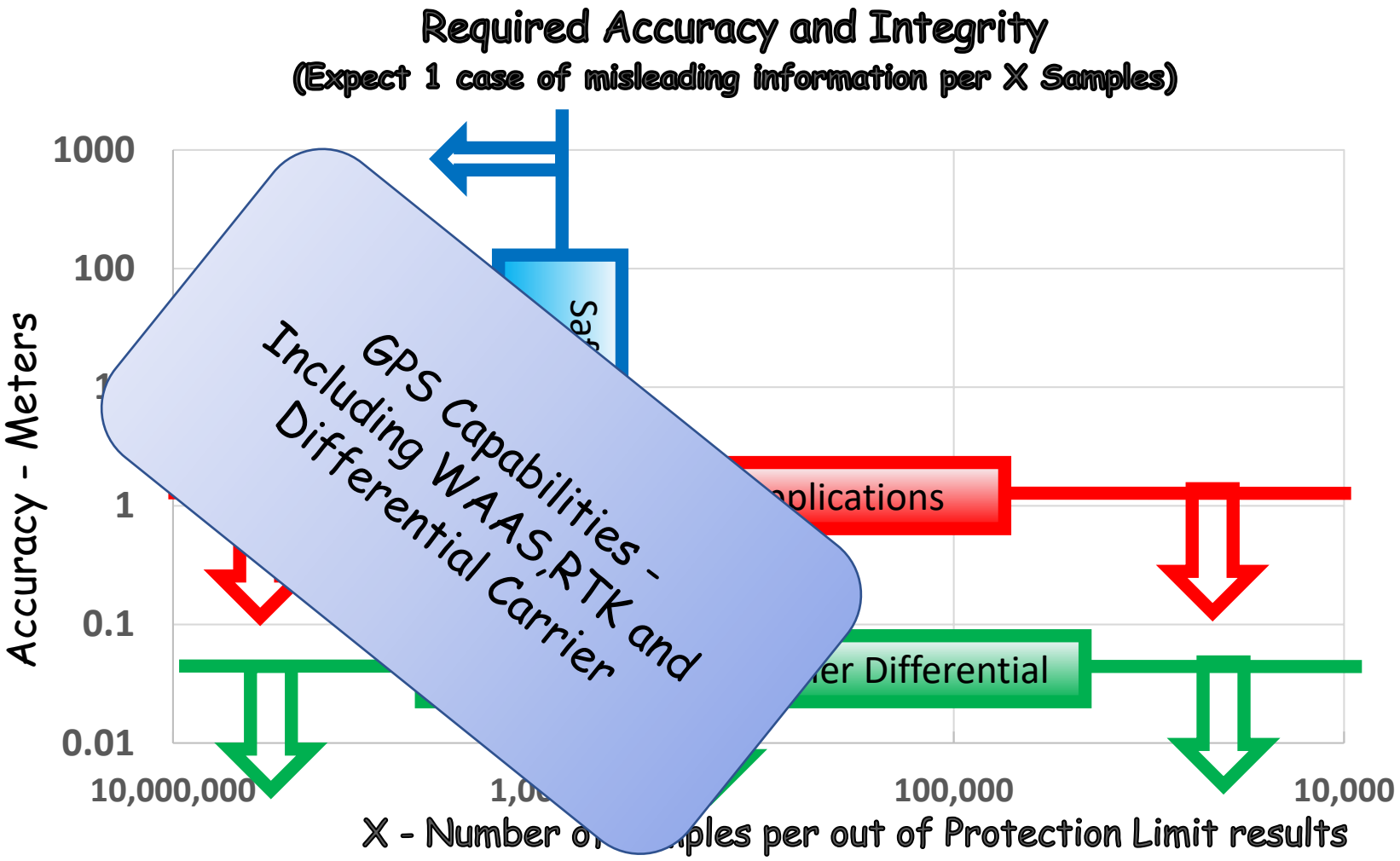
Accuracy and Integrity of Positioning – System Capability for *Precision* or *Safety-of-Life* Applications



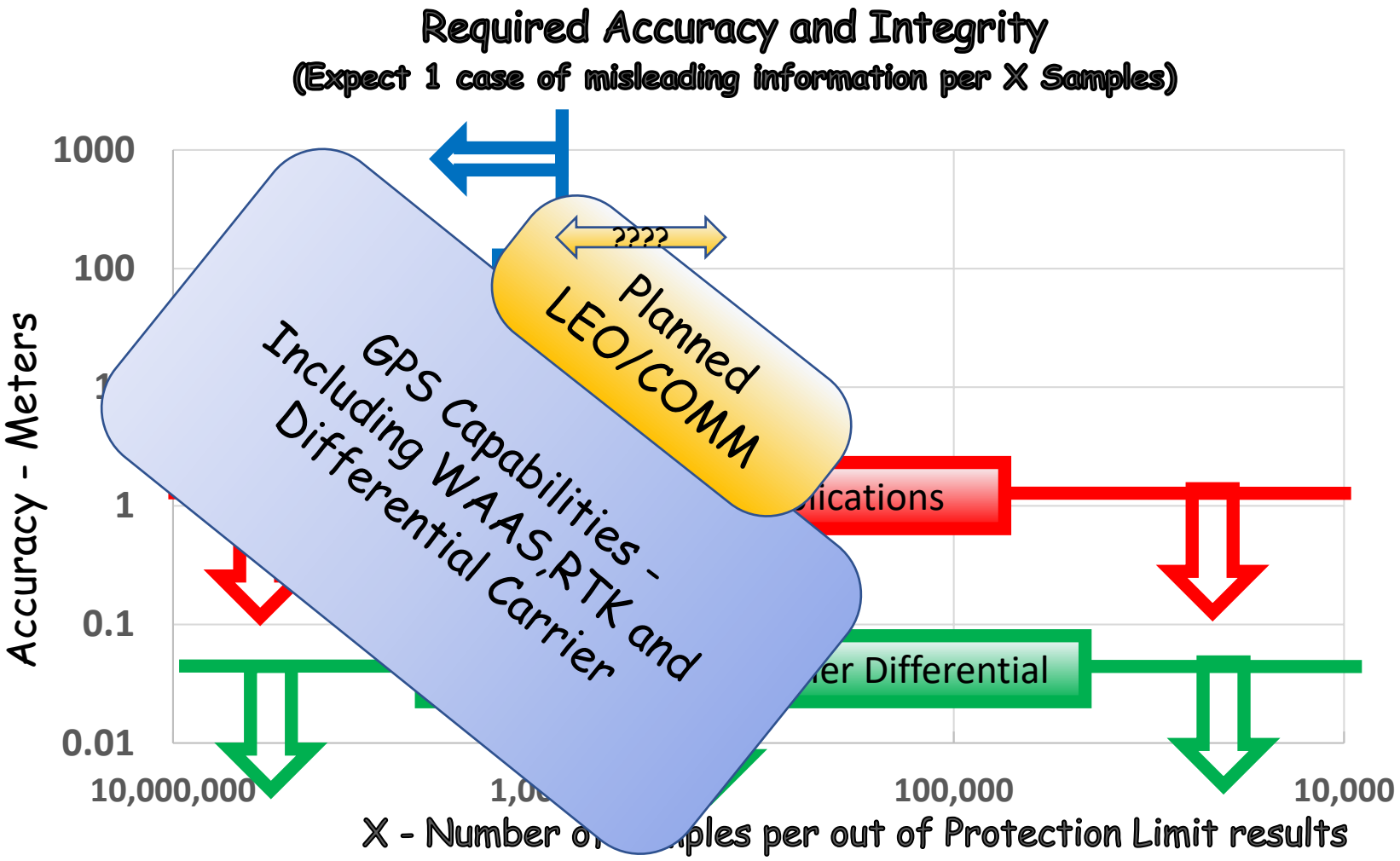
Accuracy and Integrity of Positioning – System Capability and Application Requirements



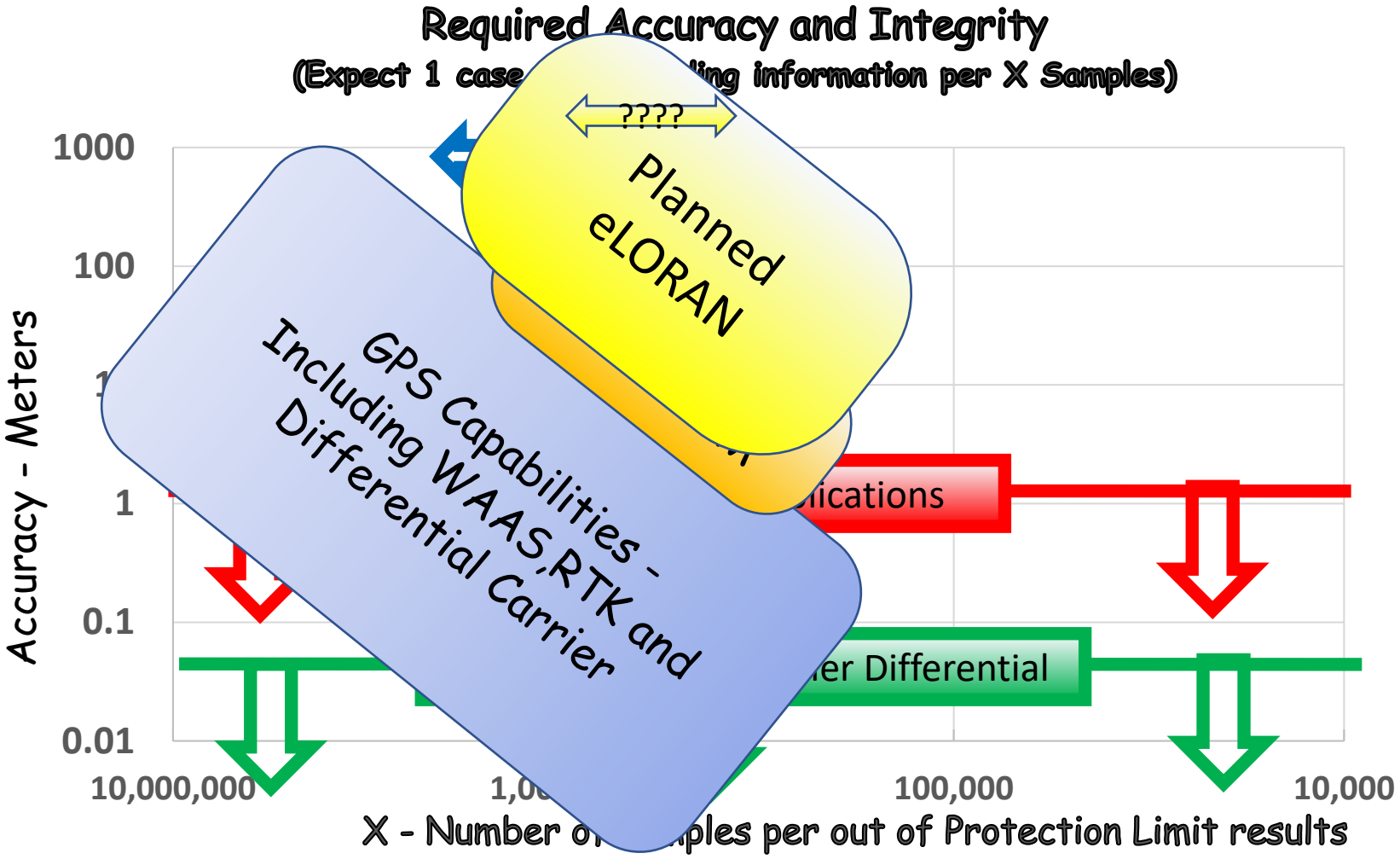
Accuracy and Integrity of Positioning – System Capability and Application Requirements



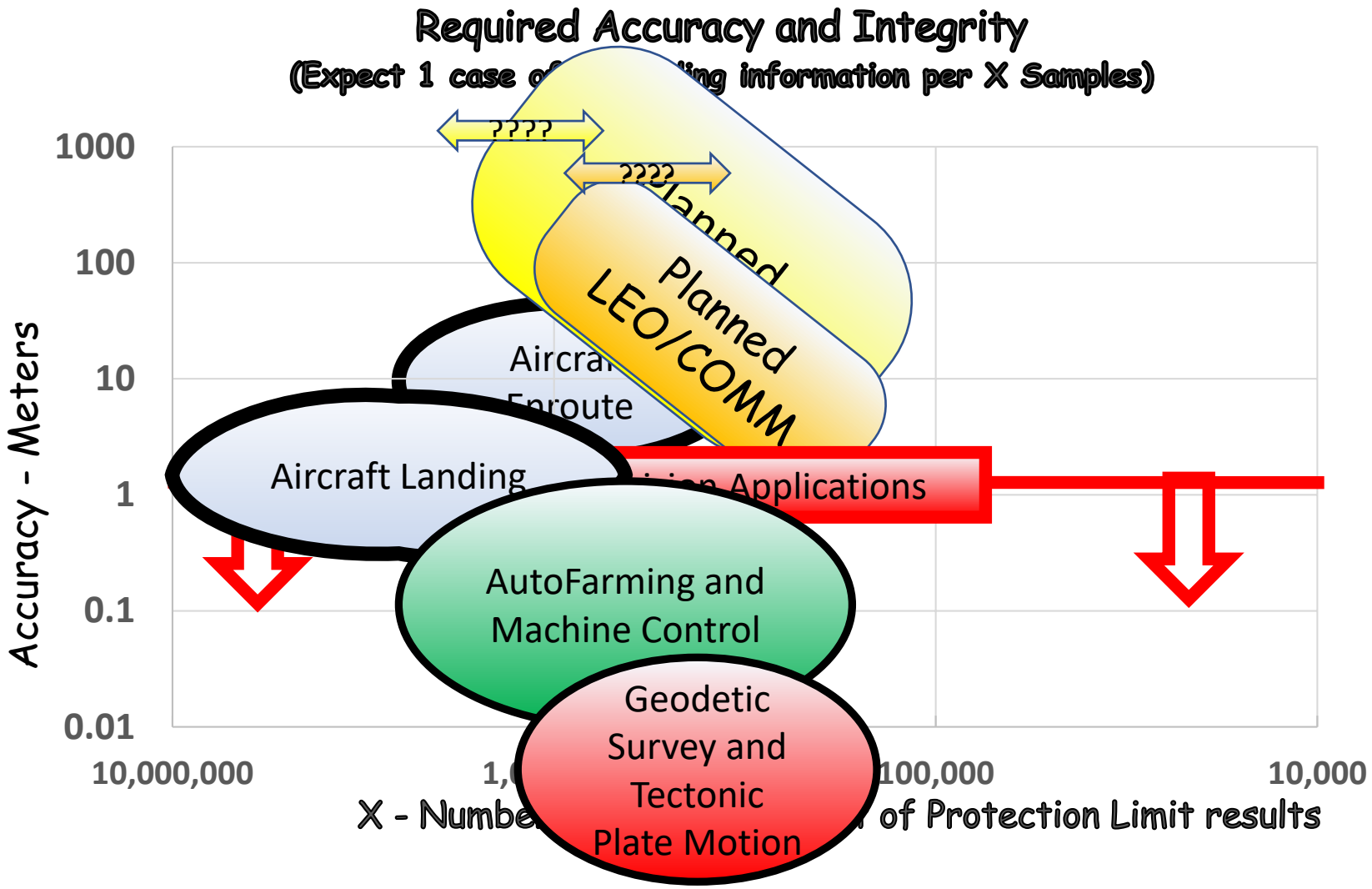
Accuracy and Integrity of Positioning – System Capability and Application Requirements



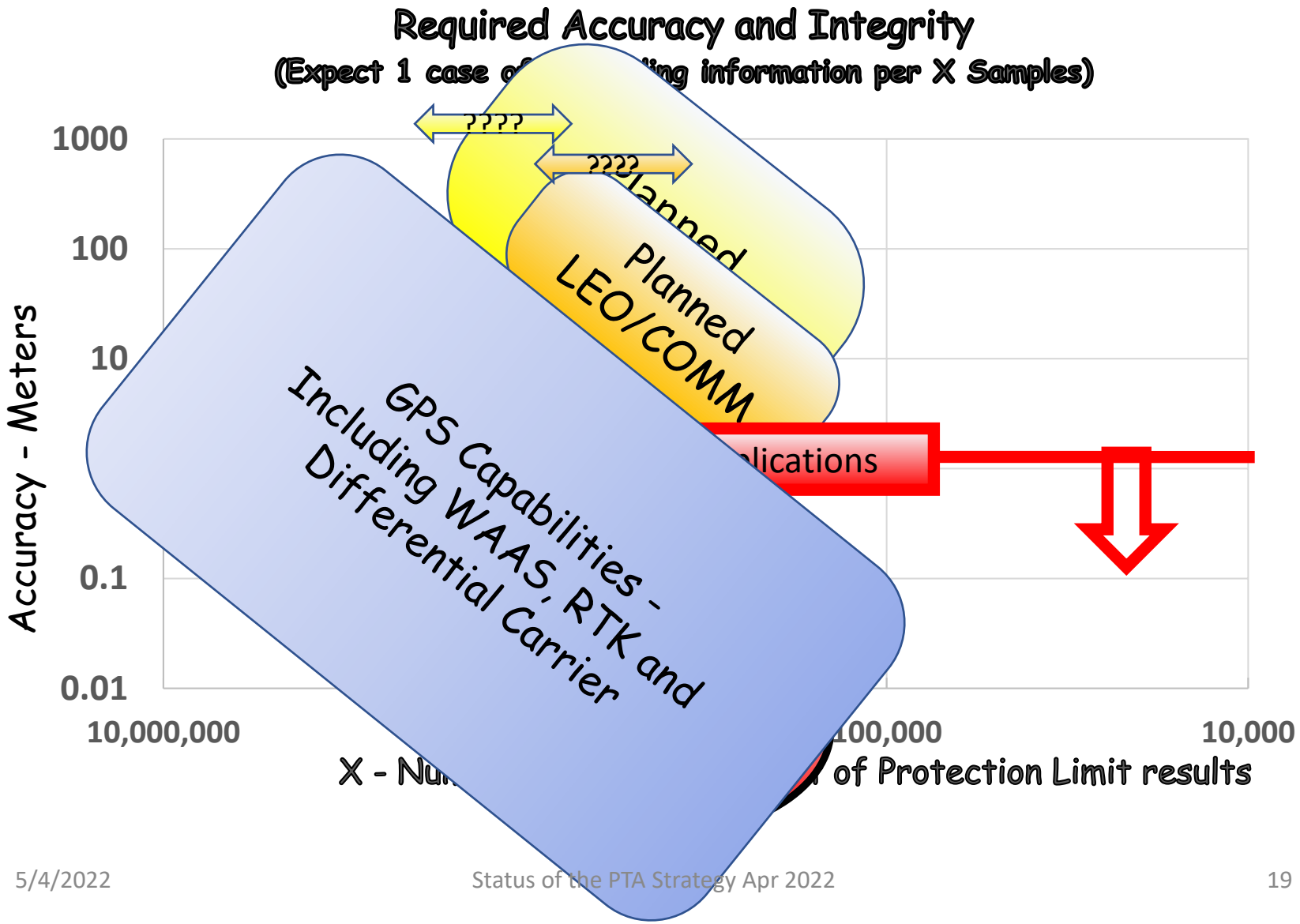
Accuracy and Integrity of Positioning – System Capability and Application Requirements

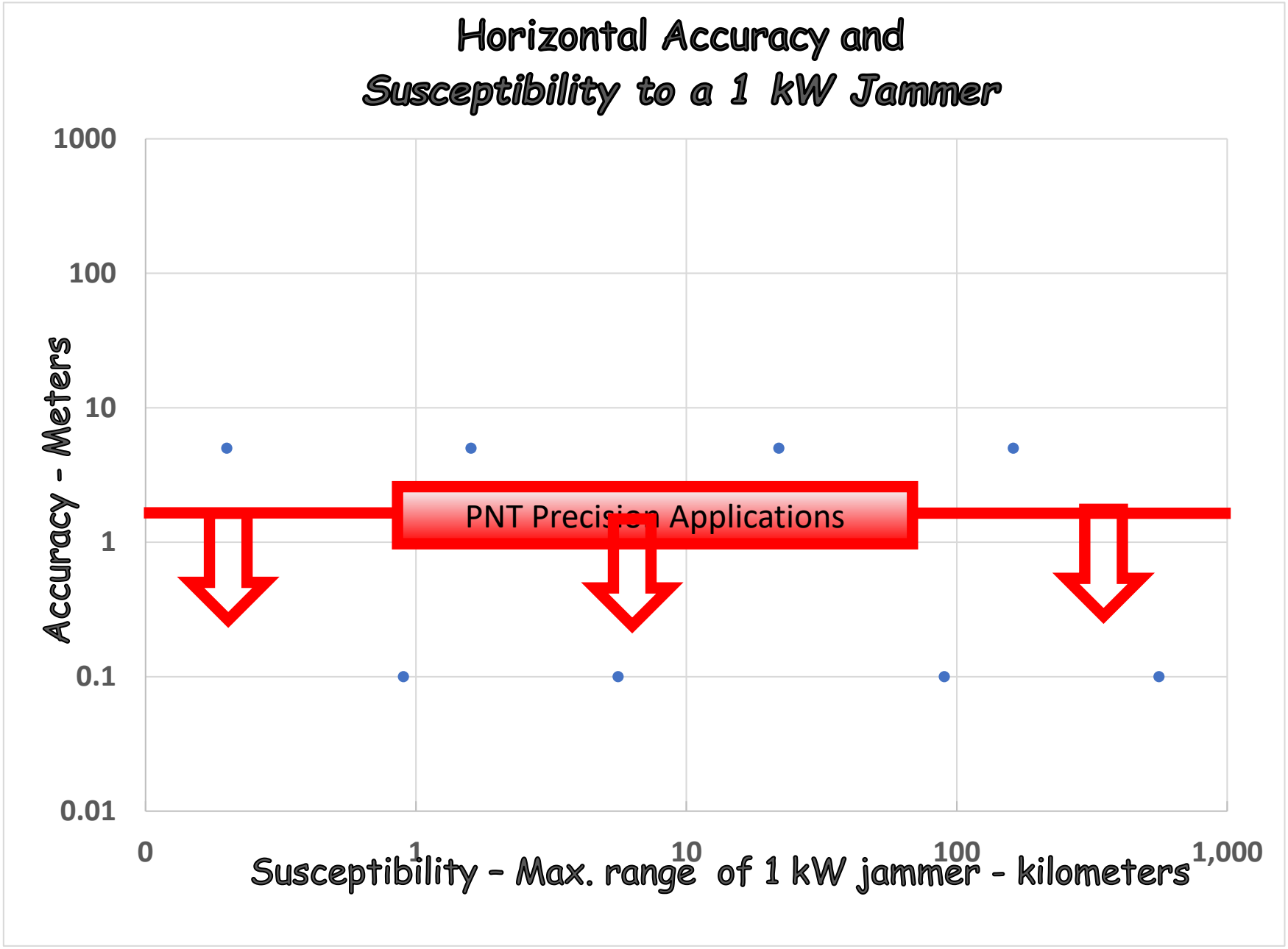


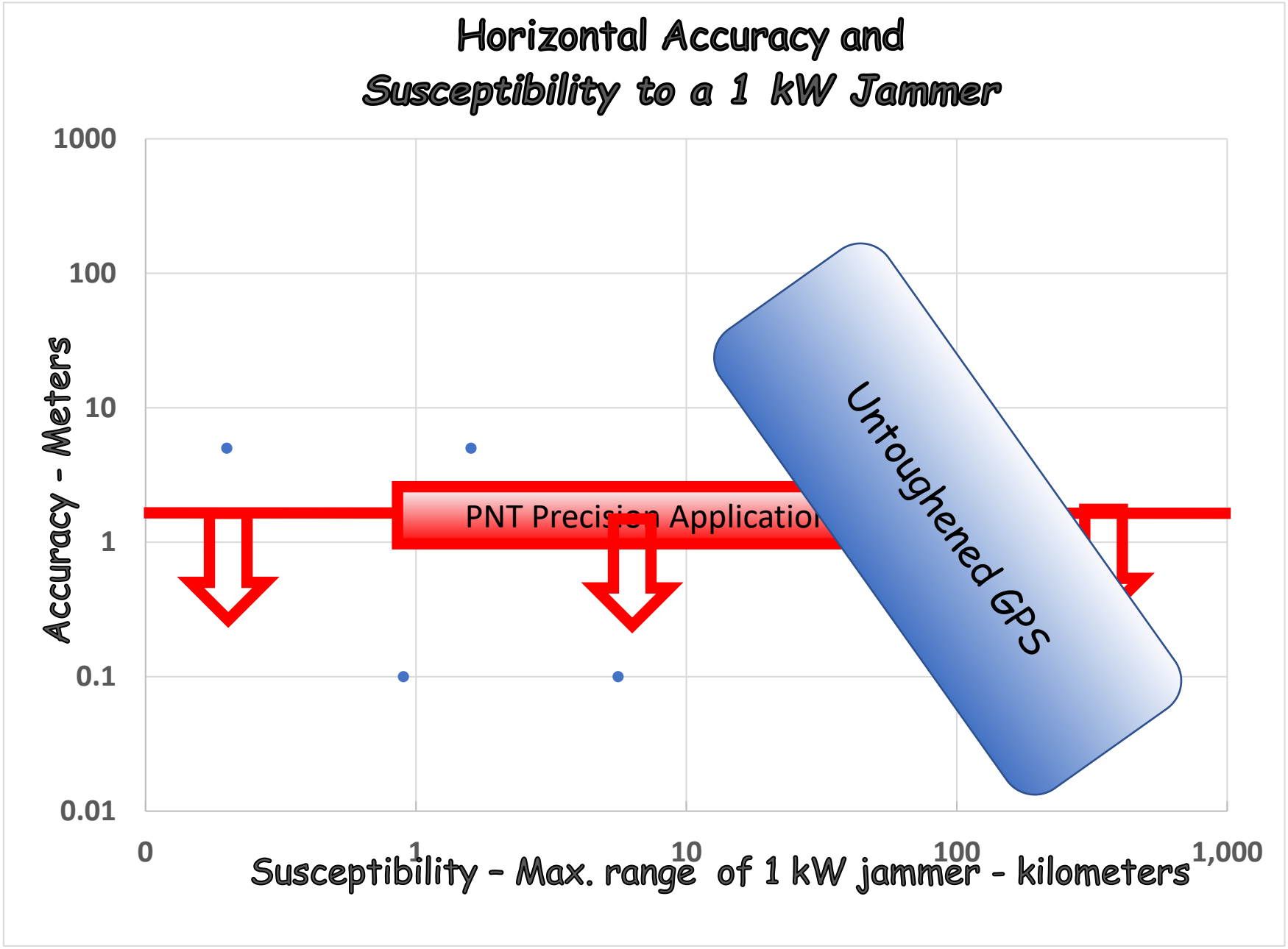
Accuracy and Integrity of Positioning – System Capability and Application Requirements

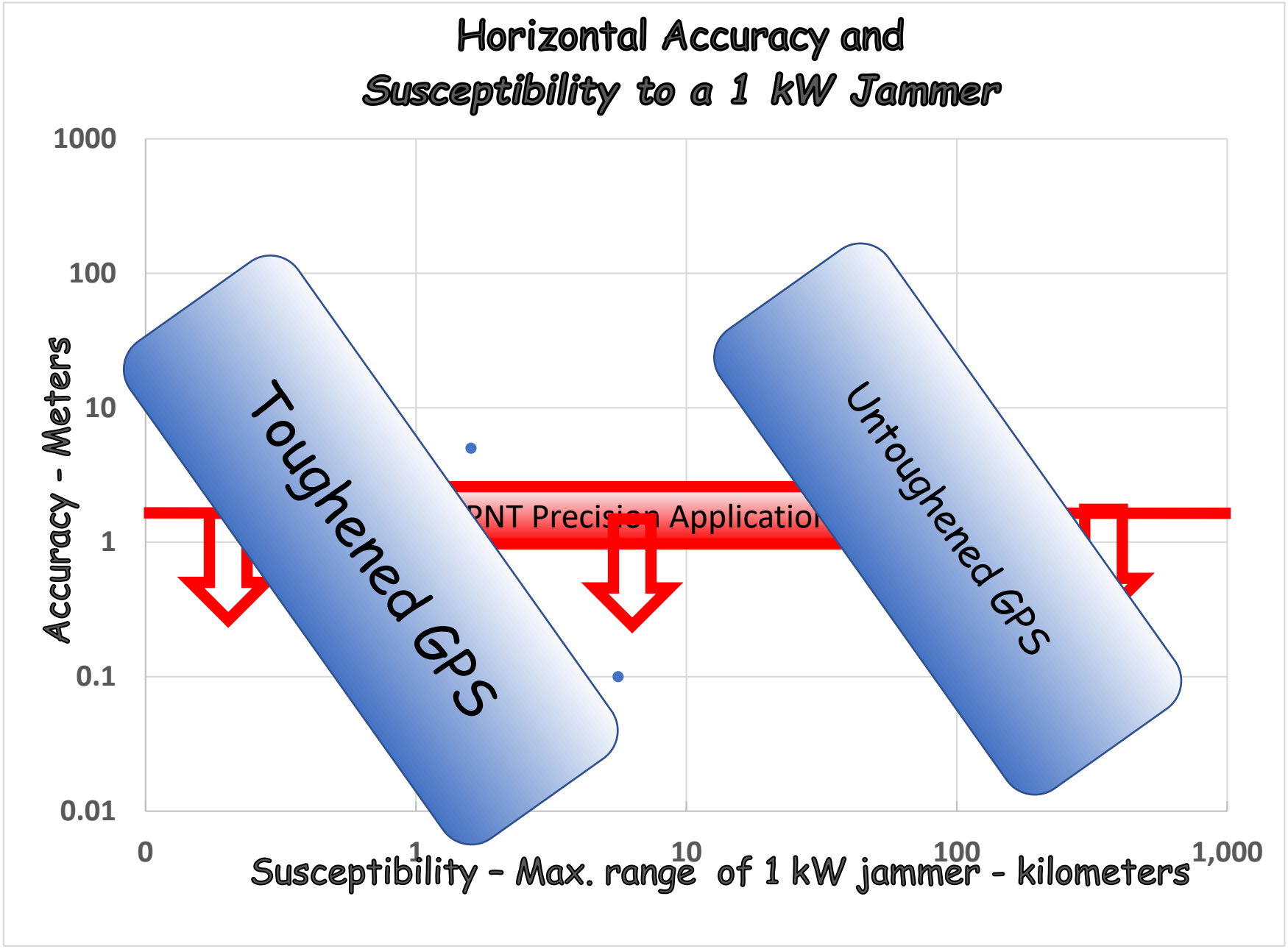


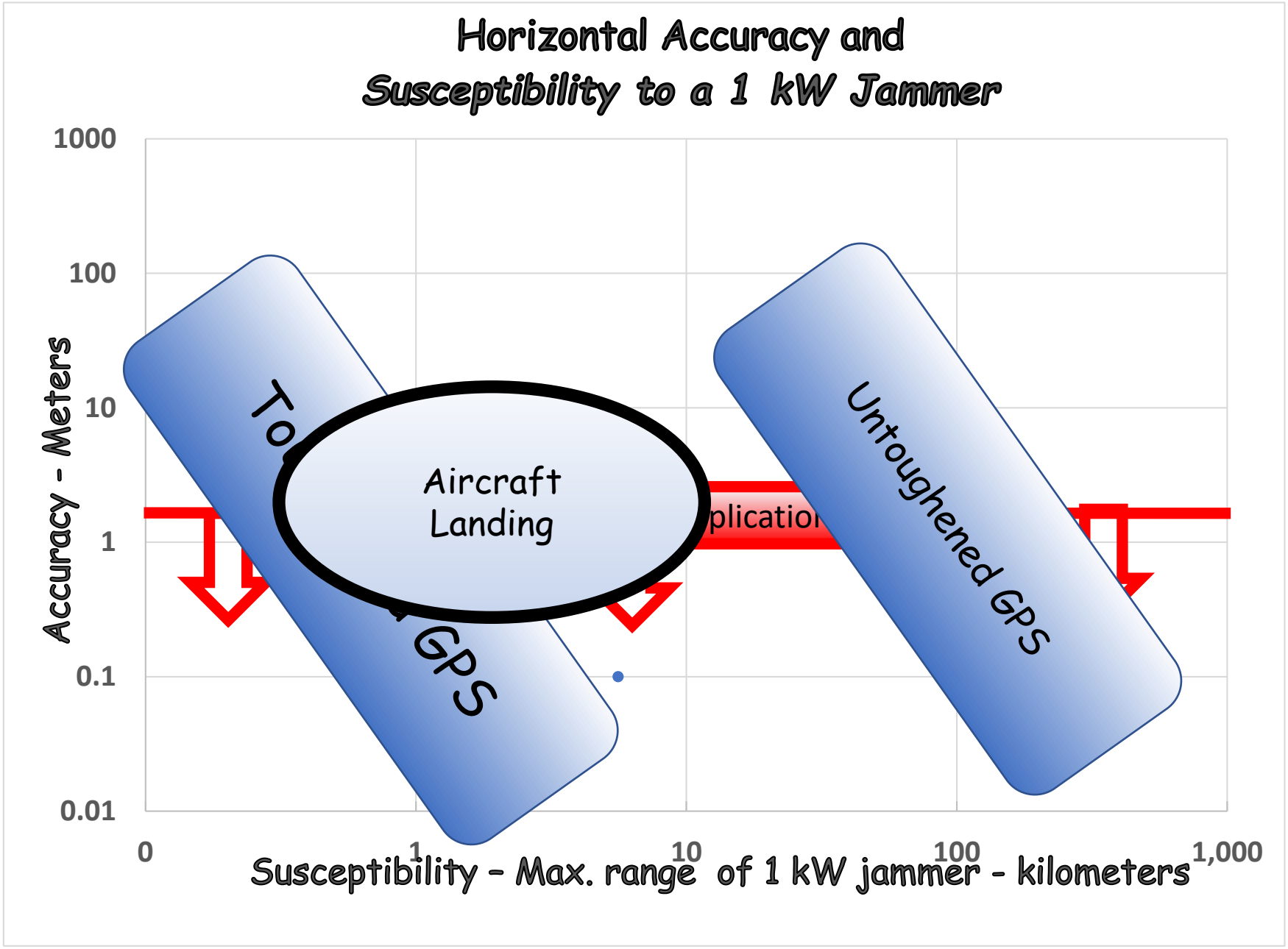
Accuracy and Integrity of Positioning – System Capability and Application Requirements

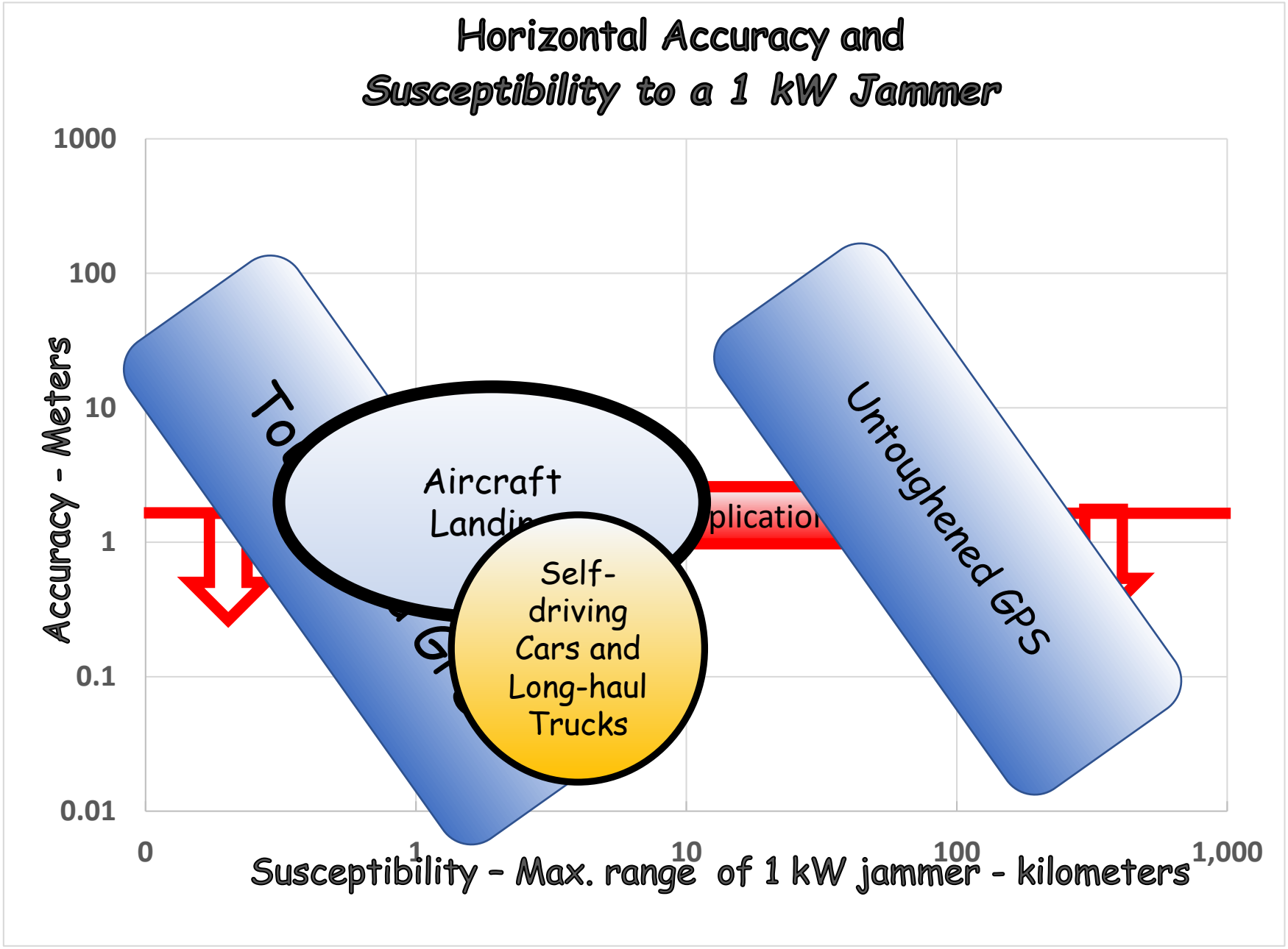


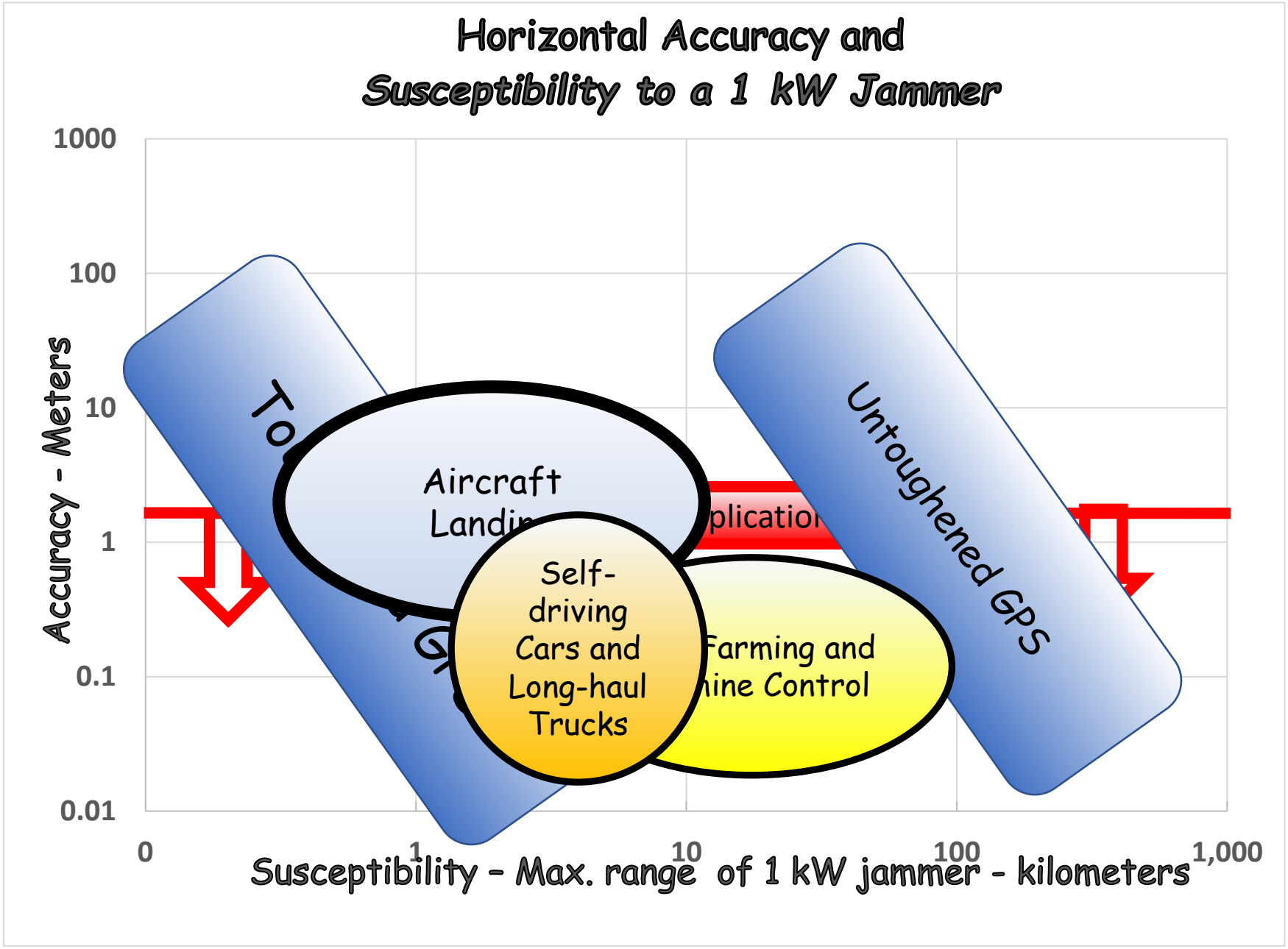

Horizontal Accuracy and
Susceptibility to a 1 kW Jammer
1000
100
10
1
0.1
0.01
Accuracy - Meters
PNT Precision Applications
0
1
10
100
1,000
Susceptibility – Max. range of 1 kW jammer - kilometers

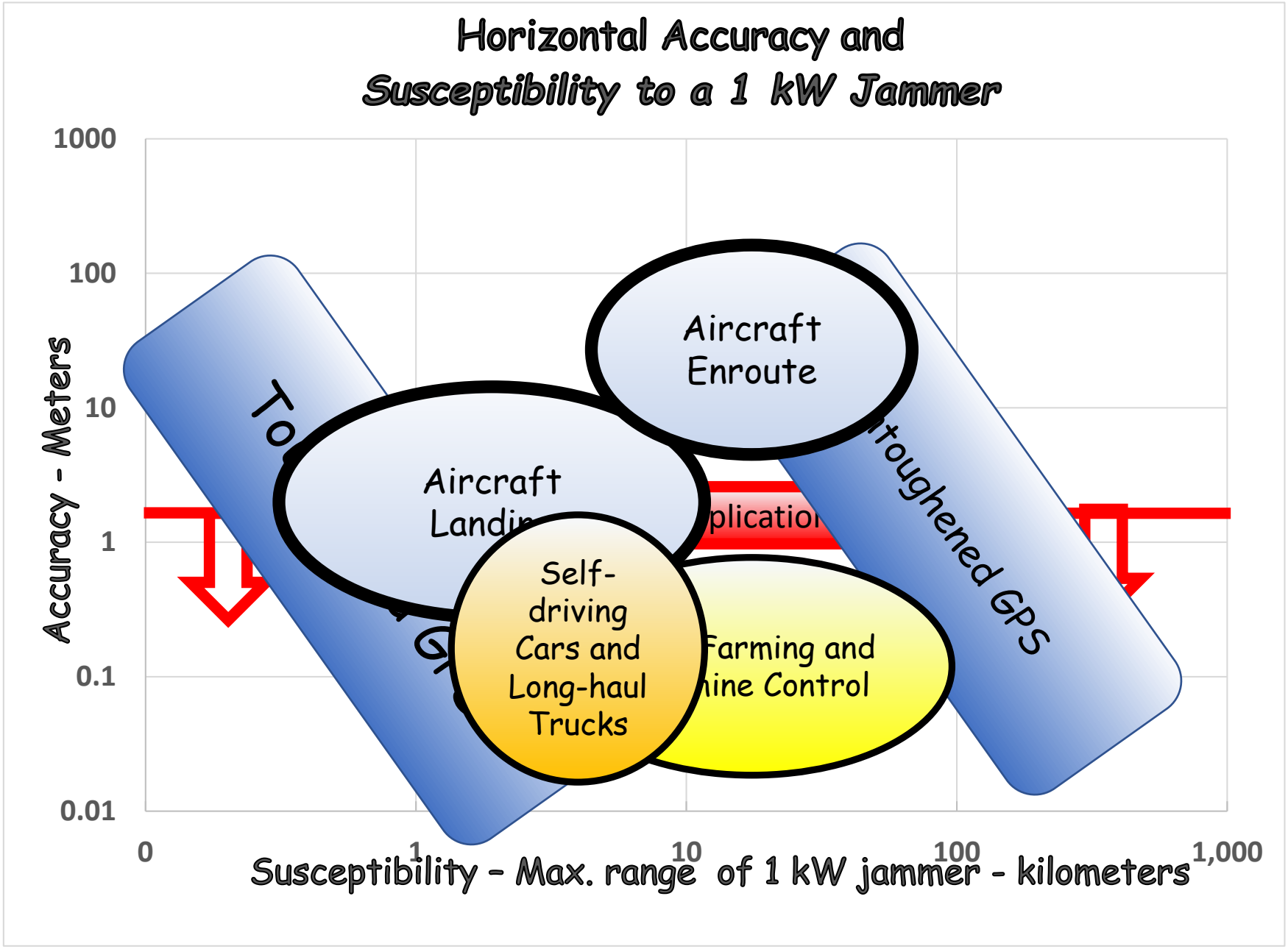

Horizontal Accuracy and
Susceptibility to a 1 kW Jammer
1000
100
10
1
0.1
0.01
Accuracy - Meters
PNT Precision Application
Untoughened GPS
0
1
10
100
1,000
Susceptibility – Max. range of 1 kW jammer - kilometers

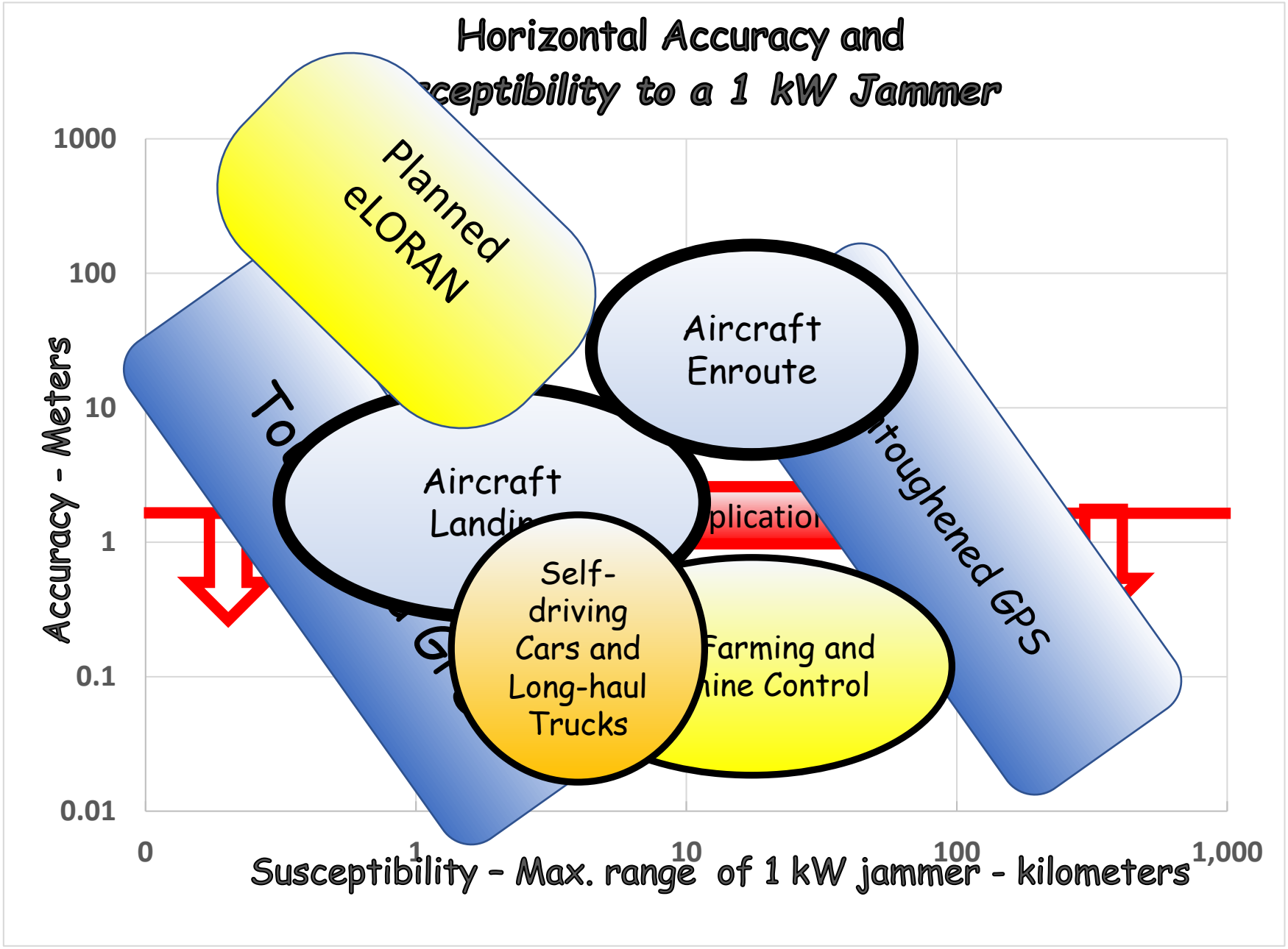

Horizontal Accuracy and
Susceptibility to a 1 kW Jammer
1000
100
10
1
0.1
0.01
Accuracy - Meters
Toughened GPS
PNT Precision Application
Untoughened GPS
0
1
10
100
1,000
Susceptibility – Max. range of 1 kW jammer - kilometers

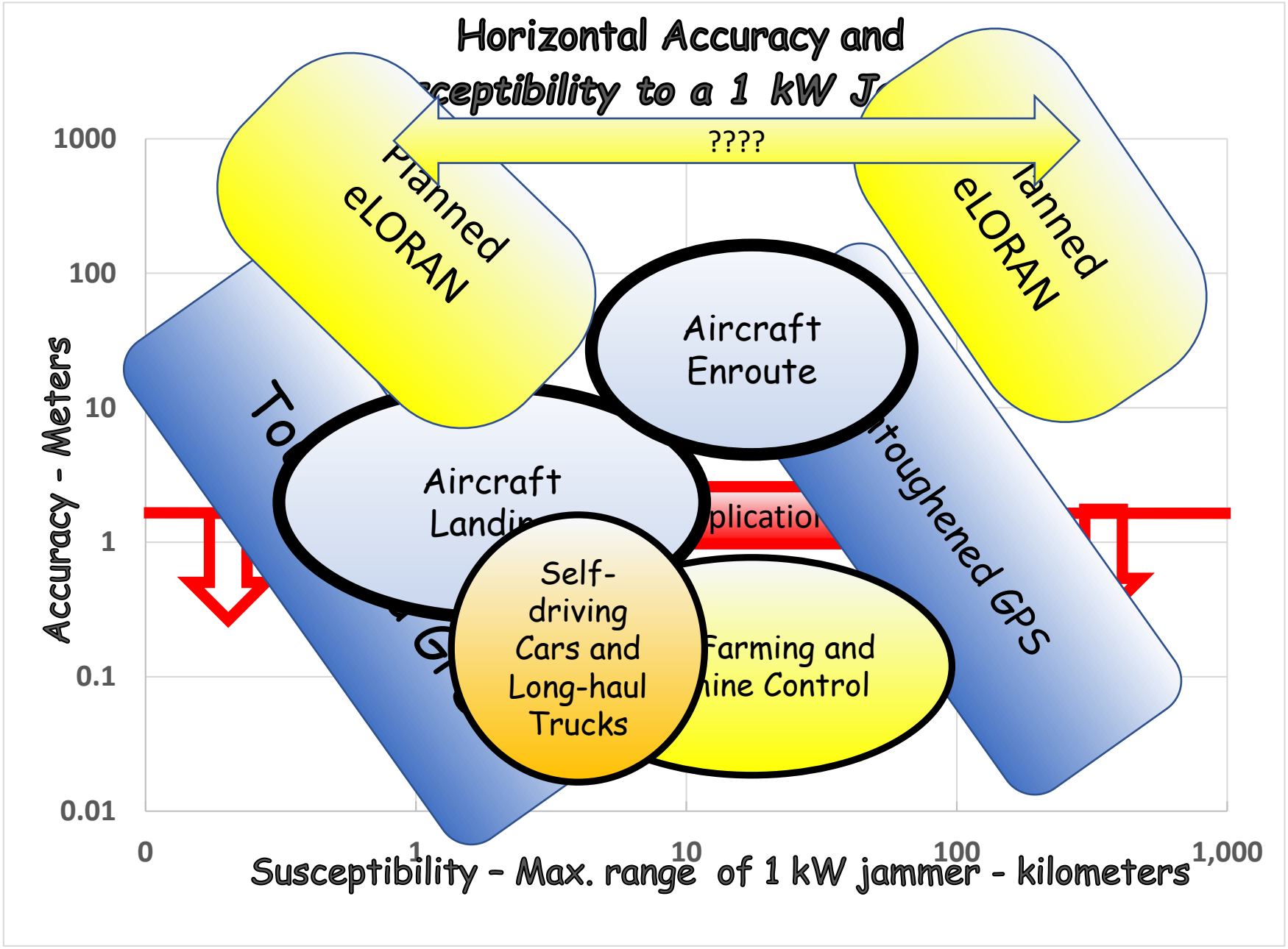

Horizontal Accuracy and
Susceptibility to a 1 kW Jammer
1000
100
10
1
0.1
0.01
Accuracy - Meters
Aircraft
Landing
Untoughened GPS
0
1
10
100
1,000
Susceptibility – Max. range of 1 kW jammer - kilometers

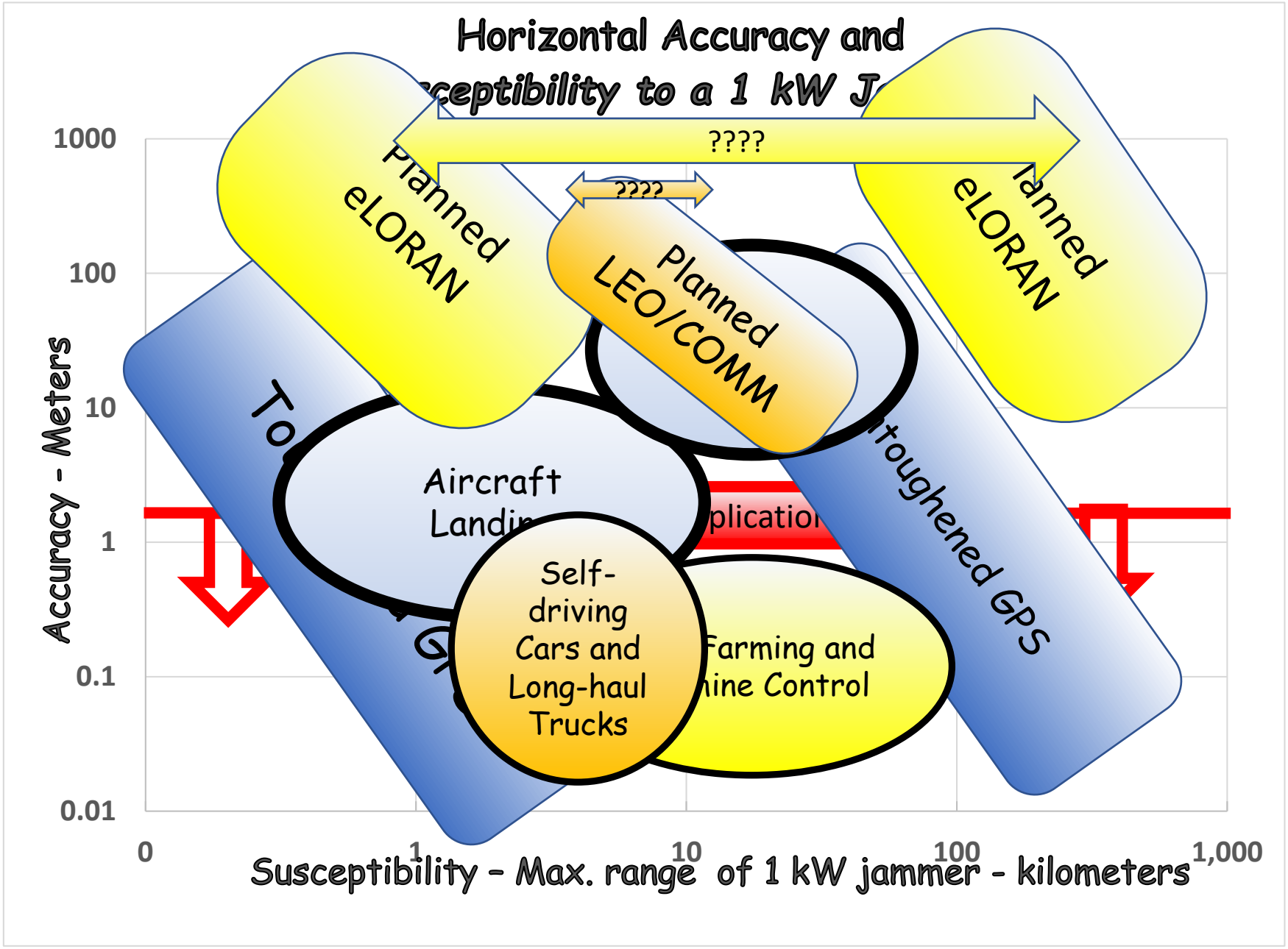

Horizontal Accuracy and
Susceptibility to a 1 kW Jammer
1000
100
10
1
0.1
0.01
Accuracy - Meters
Aircraft
Self-
driving
Cars and
Long-haul
Trucks
Untoughened GPS
0
1
10
100
1,000
Susceptibility – Max. range of 1 kW jammer - kilometers

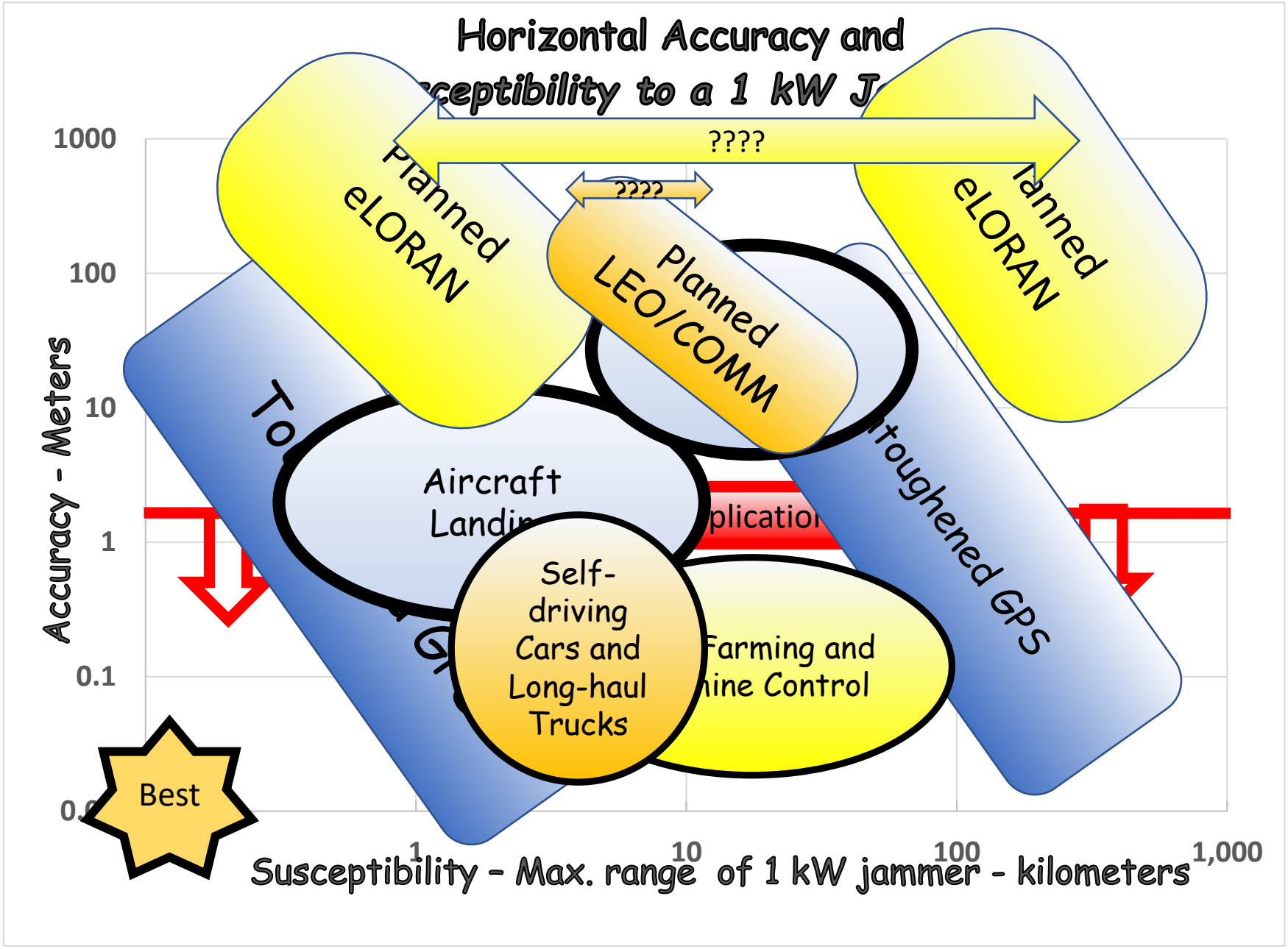

Horizontal Accuracy and
Susceptibility to a 1 kW Jammer
1000
100
10
1
0.1
0.01
Accuracy - Meters
Aircraft
Self-
driving
Cars and
Long-haul
Trucks
Untoughened GPS
0
1
10
100
1,000
Susceptibility – Max. range of 1 kW jammer - kilometers


Horizontal Accuracy and
Susceptibility to a 1 kW Jammer
1000
100
10
1
0.1
0.01
Accuracy - Meters
Aircraft Enroute
Aircraft Landi
plicatio
Self-driving Cars and Long-haul Trucks
Farming and
hine Control
toughened GPS
0
1
10
100
1,000
Susceptibility – Max. range of 1 kW jammer - kilometers


Horizontal Accuracy and
ceptibility to a 1 kW Jammer
Planned eLORAN
Aircraft Enroute
Aircraft Landi
Self-driving Cars and Long-haul Trucks
Farming and
hine Control
toughened GPS
plicatio
1000
100
10
1
0.1
0.01
Accuracy - Meters
0
1
10
100
1,000
Susceptibility – Max. range of 1 kW jammer - kilometers


Horizontal Accuracy and
????
Planned eLORAN
Planned eLORAN
Aircraft Enroute
Aircraft Landi
Toughened GPS
Self-driving Cars and Long-haul Trucks
Farming and
Control
1000
100
10
1
0.1
0.01
Accuracy - Meters
0
1
10
100
1,000
Susceptibility – Max. range of 1 kW jammer - kilometers


Horizontal Accuracy and
ceptibility to a 1 kW J
????
????
Planned eLORAN
Planned LEO/COMM
lanned eLORAN
Aircraft Landi
plicatio
toughened GPS
Self-driving Cars and Long-haul Trucks
Farming and hine Control
1000
100
10
1
0.1
0.01
Accuracy - Meters
0
1
10
100
1,000
Susceptibility – Max. range of 1 kW jammer - kilometers


Horizontal Accuracy and
ceptibility to a 1 kW J
????
????
Planned eLORAN
Planned LEO/COMM
anned eLORAN
toughened GPS
Aircraft Landi
plicatio
Self-driving Cars and Long-haul Trucks
Farming and hine Control
Best
1000
100
10
1
0.1
Accuracy - Meters
1
10
100
1,000
Susceptibility – Max. range of 1 kW jammer - kilometers

Augmentation SUMMARY

- None Of The Known Augmentation Techniques Can "Replace GPS/GNSS" For Most High-Value/High-Precision Applications.
- Augmentations have good promise for the non-precision applications such as shown earlier
- In comparisons, a pivotal issue is vulnerability to Jamming and Spoofing. *GPS toughening can, largely, prevent harmful interference.* **This deserves higher priority in terms of funding and priority.**
  - ITAR restrictions on number of beam-steering antenna elements should be completely removed, The techniques and inexpensive basic devices are widely understood and available

Summary of Recommendations

- **Protect** the spectrum and silence interference sources
- **Toughen** our GPS satellite receivers through the known techniques, unhampered by outdated government restrictions.
  - This is the only known way to meet the accuracy, availability and integrity requirements of the high precision applications which reap the greatest economic benefits.
- Select and field **augmentation** techniques, but recognize that they cannot be used for many consumer nor for most of the precision and safety-of-life PNT applications **(the GPS economic benefit study showed these applications provide 10s of billions of $ of yearly economic benefits to US)**
- **Protect, Toughen, and Augment are complementary. No one of these is adequate by itself.**

Current PNTAB Assessment:

"No *current* or *foreseeable* alternative to GNSS (Primarily GPS) can deliver equivalent accuracy (to millimeters, 3D), integrity, and world wide 24/7 availability."

Backup

- Needed - a simplified way to categorize alternatives:
  - A. Accuracy – all continuous, real-time
    1. AC1 – down to dm/cm/mm (Purple)
    2. AC2 – down to a few meters (Blue
    3. AC3 - down to 10 meters Green
    4. AC4 – 0.1 miles/hour since initialization Yellow
    5. AC5 – 1.0 Miles/hour since initialization Red
  - B. Availability – Geographical

    WW Worldwide, R – Regional , L-Local
  - C. Availability - Temporal
  - D. 24/7 Purple, Intermittent Red
  - E. Integrity – Probability that PNT measurement is “out of Protection Limits”
    1. I1 – Integrity at least 10^{-7}
    2. I2 - Integrity at least 10^{-5}
    3. I3 - Integrity at least 10^{-4}
  - F. Time, Cost and Political Probabilities to Field – years and dollars. and governmental champions. Difficult to quantify
  - G. Susceptibility to interference. Perhaps the range of a 1 kW Jammer
  - H. Applications served or not served (The real payoff, must be carefully assessed on a case-by-case basis)