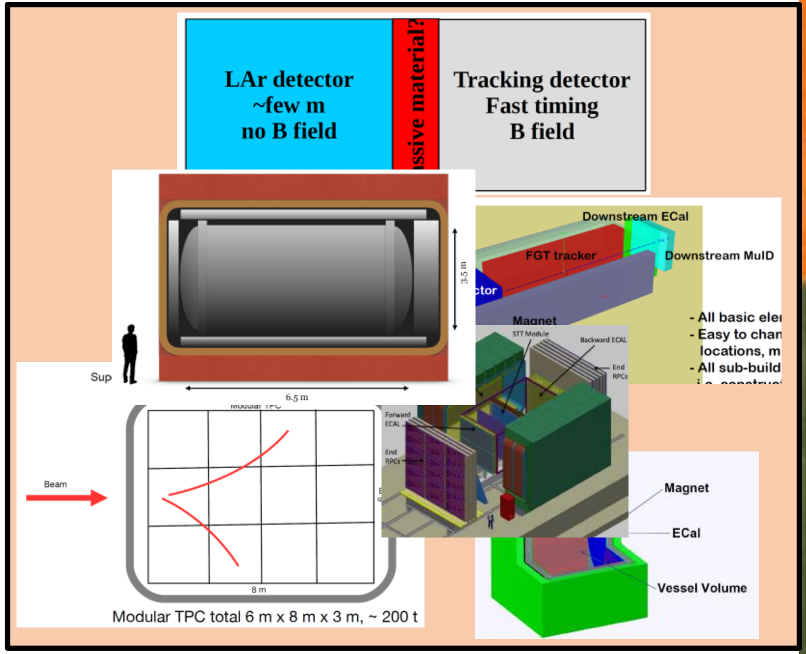
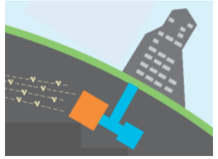
~~How to evaluate detector options~~
What now? Getting from here to there.

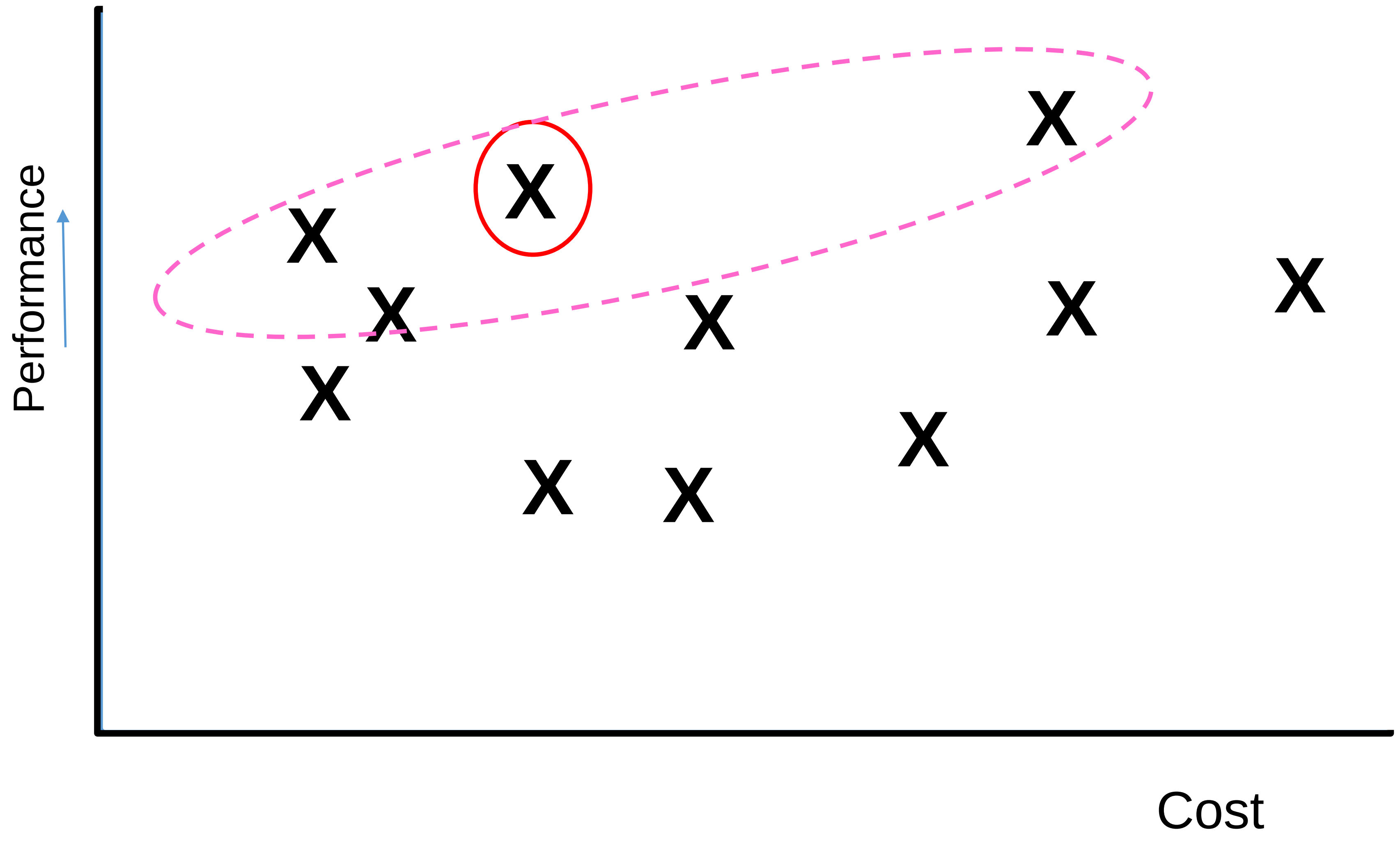
Thoughts meant to promote discussion
Can we construct a reasonable todo list
that will help us get from here to there?

DUNE Near Detector Workshop
FNAL
March 27-29, 2017
S. Manly
+ special guest speaker!

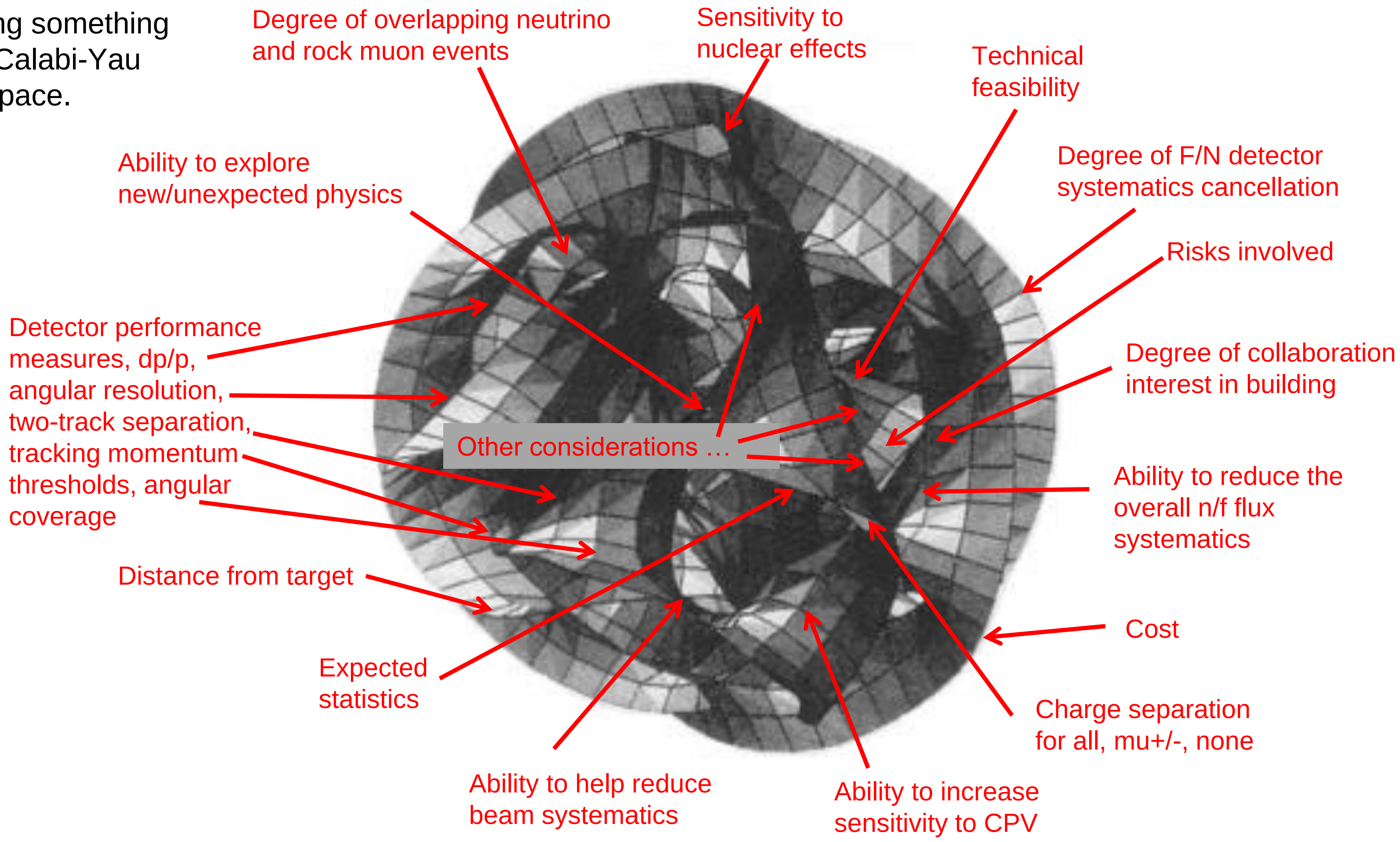


Dr. Suess

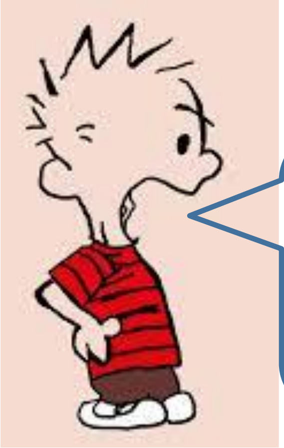



Performance
Cost

We are facing something more like a Calabi-Yau parameter space.

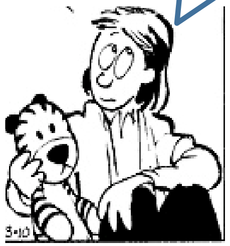


Reasonable people can make good arguments and wind up in rather different places



We should use an ND that is "identical" to the FD. This will cancel nuclear/xsec and detector systematics in the ratio.

Maybe sample-sample comparisons take care of the uncertainties mostly



We need a very powerful detector that is sensitive to new physics, contains Ar target(s), and can extract as much detailed information about the interactions as possible to feed into our models and constrain what happens at the FD.

Constraining the FD with such complex machinery is scary. How do you know when you are right? Can we really understand and model things to the level that we need to have confidence in high precision measurements?

I only want to do neutrino-electron scattering. It's the only thing we understand.

You can't build an ND that is identical to FD! Even if you do, the spectrum is different. So, you really have no choice but to deal with some things not canceling in the F/N ratio. More information from a lighter density detector is helpful. It's better for surprises and provides the ability to measure many processes to inform the fits. Smart people can do many cross-checks for confidence.

My opinion:
everybody's right

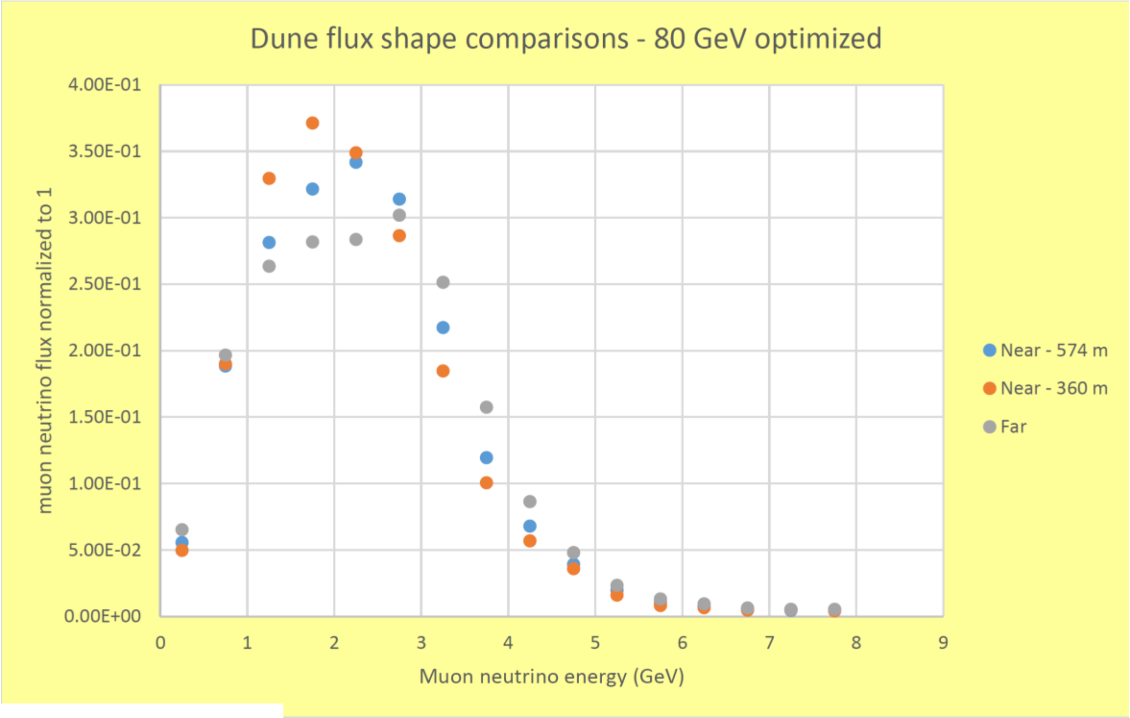
- ND ≠ FD and $\mathrm{Flux(E)}_{ND}$ ≠ $\mathrm{Flux(E)}_{FD}$ and rate dependent effects and differences in readout, etc.

- No choice but to measure/model detector and nuclear/xsec effects and use that information to inform the N/F ratio and its error budget

- Given that, would be nice to have detector that can do spectacular job on flux and xsec as function of E and neutrino type and interaction topology

- Still, also seems prudent to have a component of the ND be as similar to the FD as we can manage in order to reduce the size of the nuclear/xsec and detector-related systematics as much as possible.

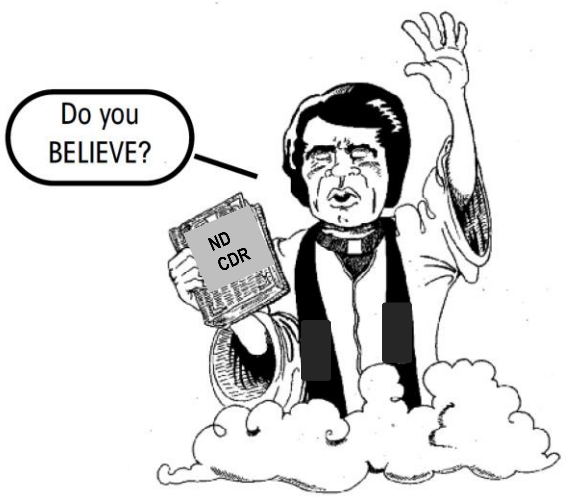
- Neutrino-electron scattering is powerful. At the very least it can give a handle on the integral flux and some spectral information. Hooray! This is very hard business. Give me handles! Can we get spectral information to the hoped for precision? Is that precision really needed?



Maybe we can have it all with a hybrid design.

Did anyone hear me?

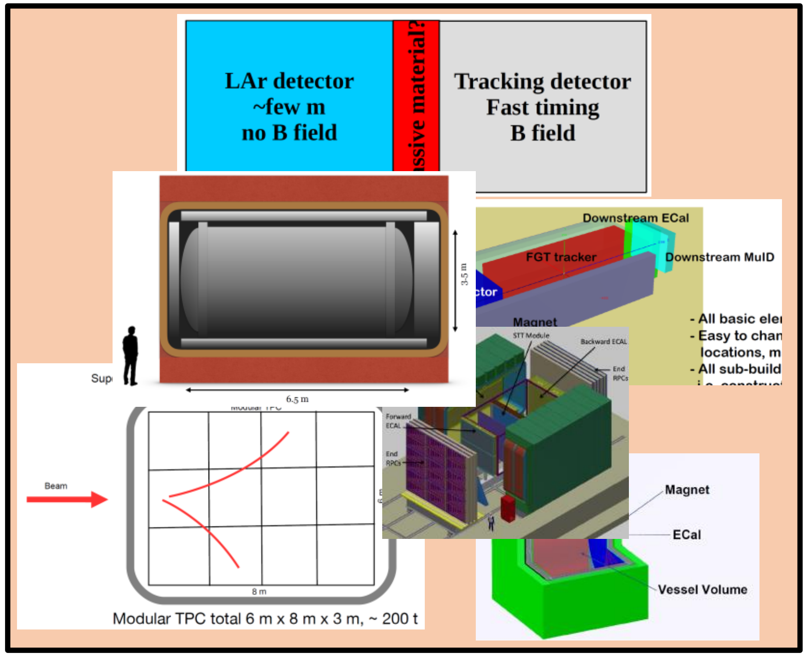
I still want to do neutrino-electron scattering. It's the bomb!



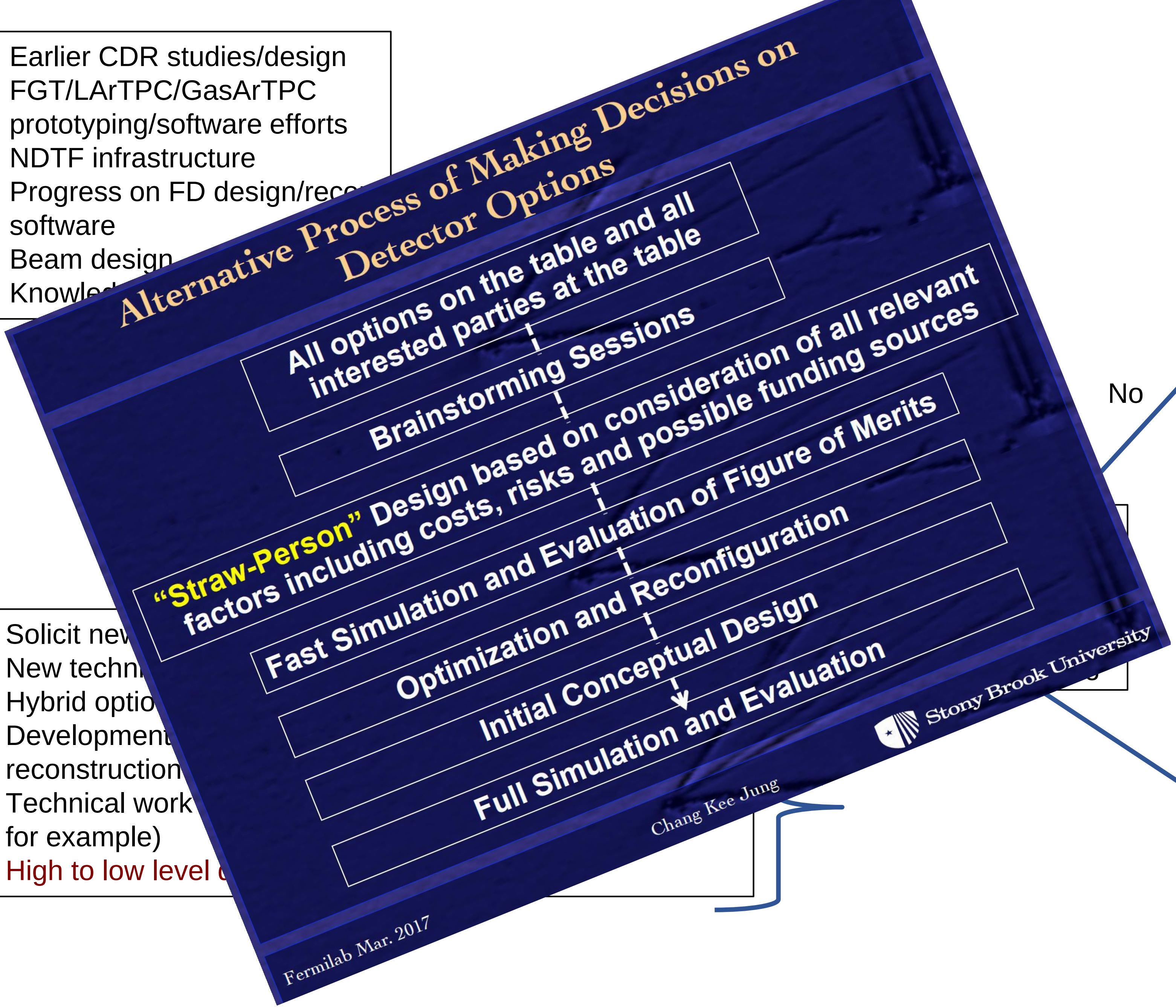
In the end, judgement and maybe even a little faith will come into play, but for now …

Regardless of the candidate technology(ies) for a proposed detector, we need to quantify as best we can (with time/resources available):

- ➢ Degree to which detector can reduce detector and nuclear/xsec systematics
- ➢ Constraint provided on the flux error at FD
- ➢ Performance on basic/exploratory physics via FOM analyses and performance proxies and Valor/CP sensitivity framework
- ➢ Technical feasibility, cost, available manpower, etc.
- ➢ Other pressing questions, see later in slides



- Earlier CDR studies/design
- FGT/LArTPC/GasArTPC prototyping/software efforts
- NDTF infrastructure
- Progress on FD design/reco software
- Beam design
- Knowled



- Solicit new
- New techni
- Hybrid optio
- Development reconstruction
- Technical work for example)
- High to low level

No

Some as of now undefined process involving collaboration, collaboration management and well thought out physics and political insights combined with financial constraints and educated guesses about the future.

Yes

Consensus ND concept, realistic to build, acceptable performance, happy collaboration

- Earlier CDR studies/design
- FGT/LArTPC/GasArTPC prototyping/software efforts
- NDTF infrastructure
- Progress on FD design/recon software
- Beam design
- Knowledge/intuition

- Solicit new interested groups
- New technical ideas
- Hybrid options
- Development/continued improvement of simulations and reconstruction (real and cheated)
- Technical work where needed (pixelated LArTPC readout, for example)
- High to low level quantitative work

Eternal discussions and meetings.
Digest the work, iterate

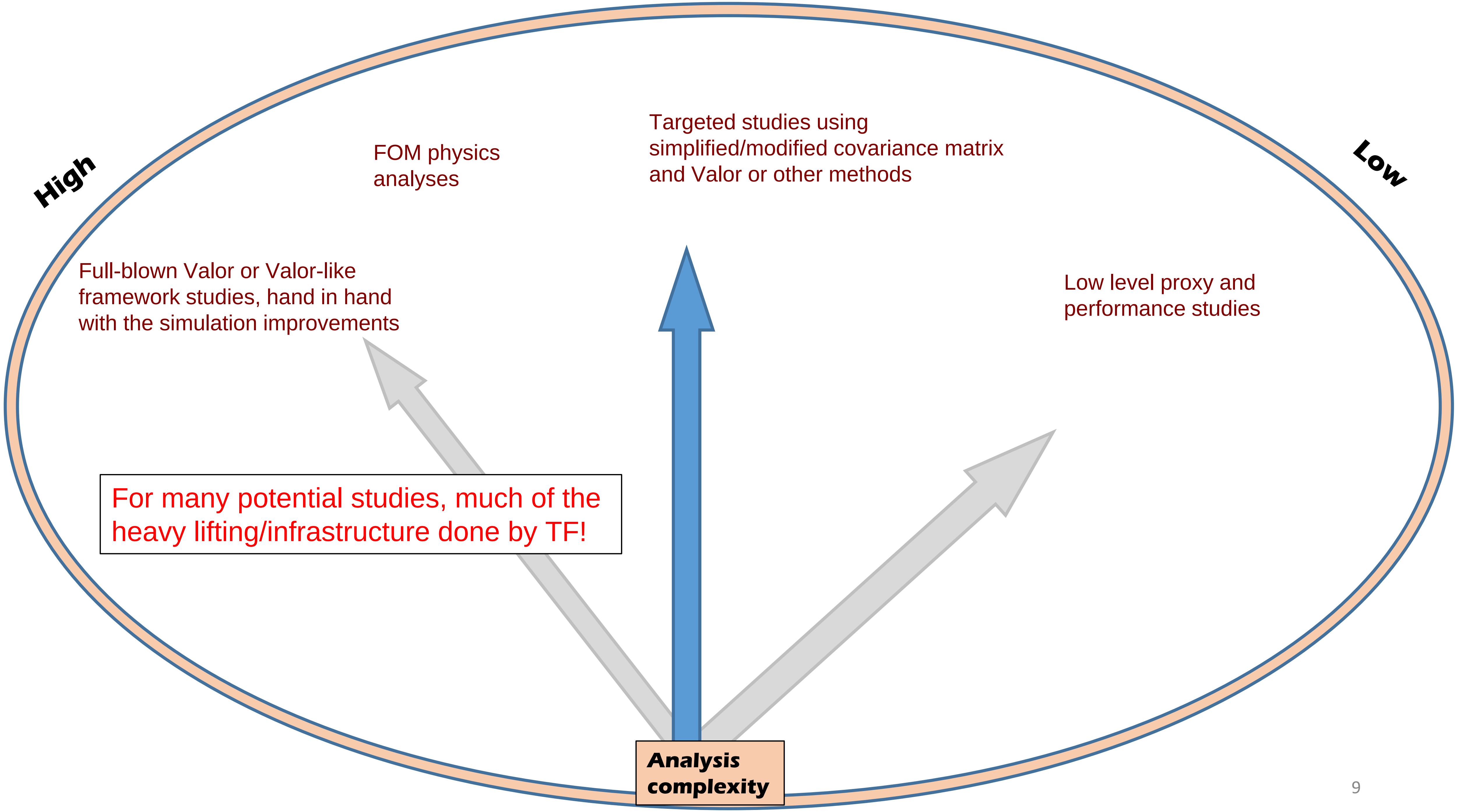
A particular choice/plan becomes broadly compelling

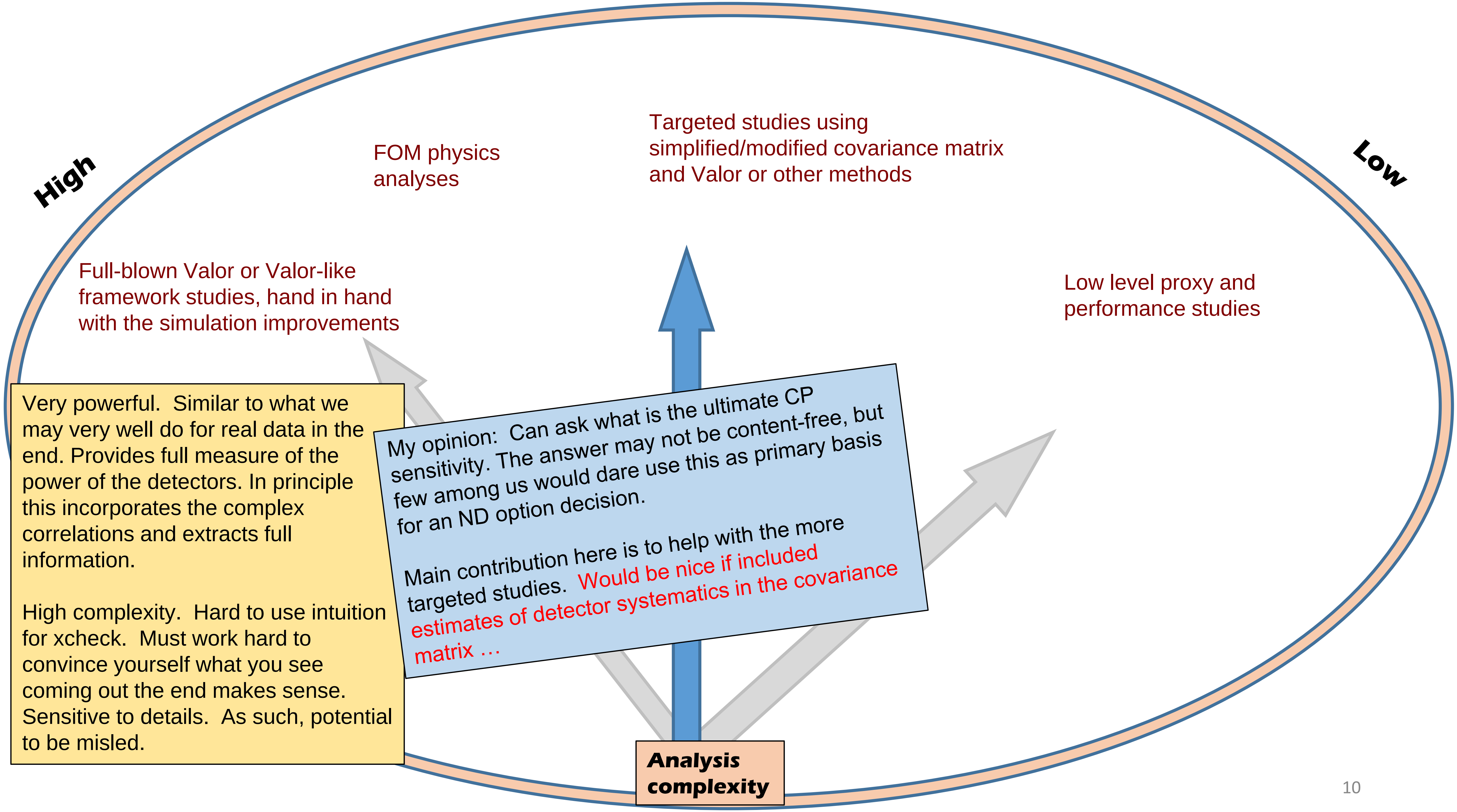
No

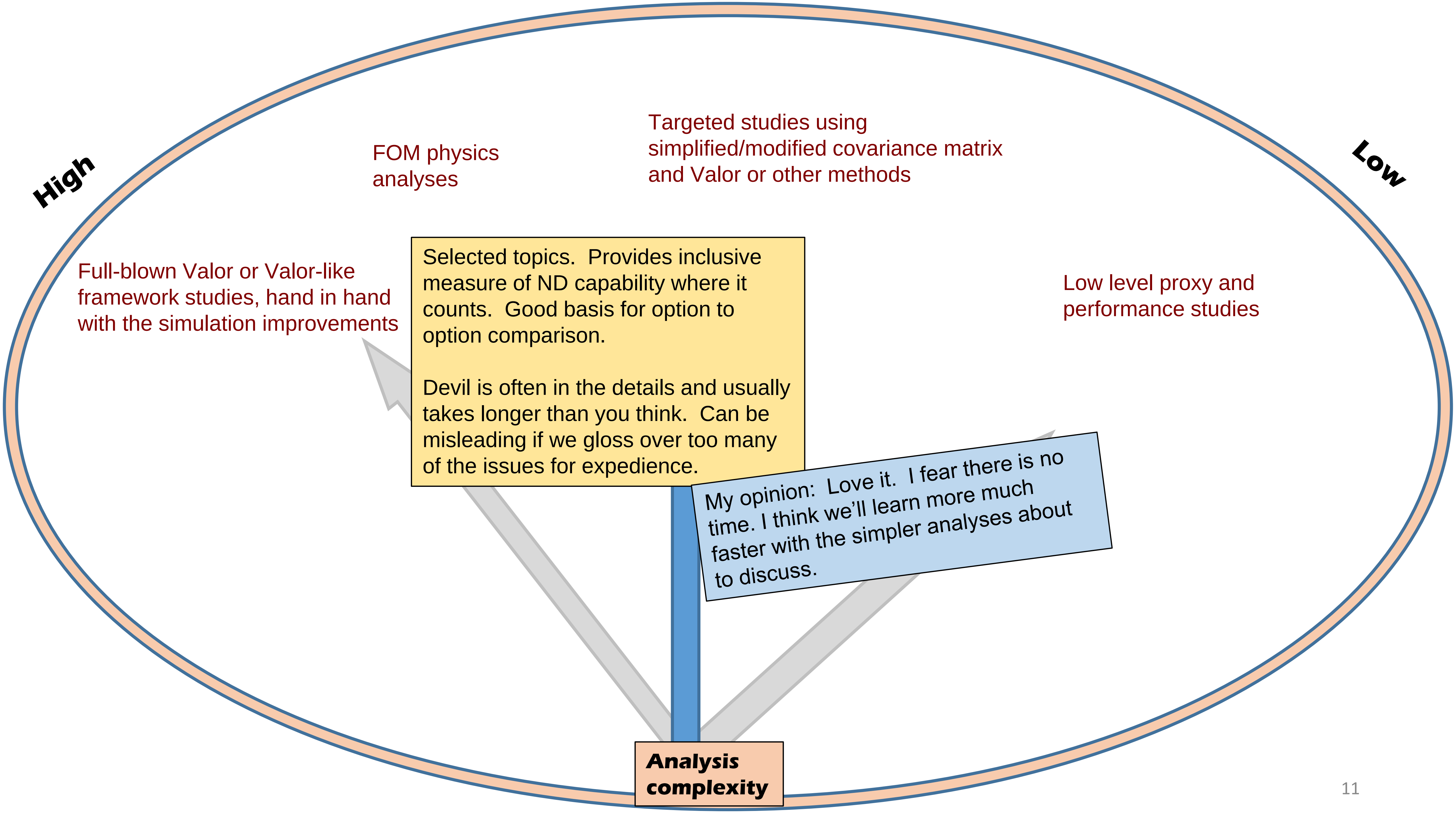
Some as of now undefined process involving collaboration, collaboration management and well thought out physics and political insights combined with financial constraints and educated guesses about the future.

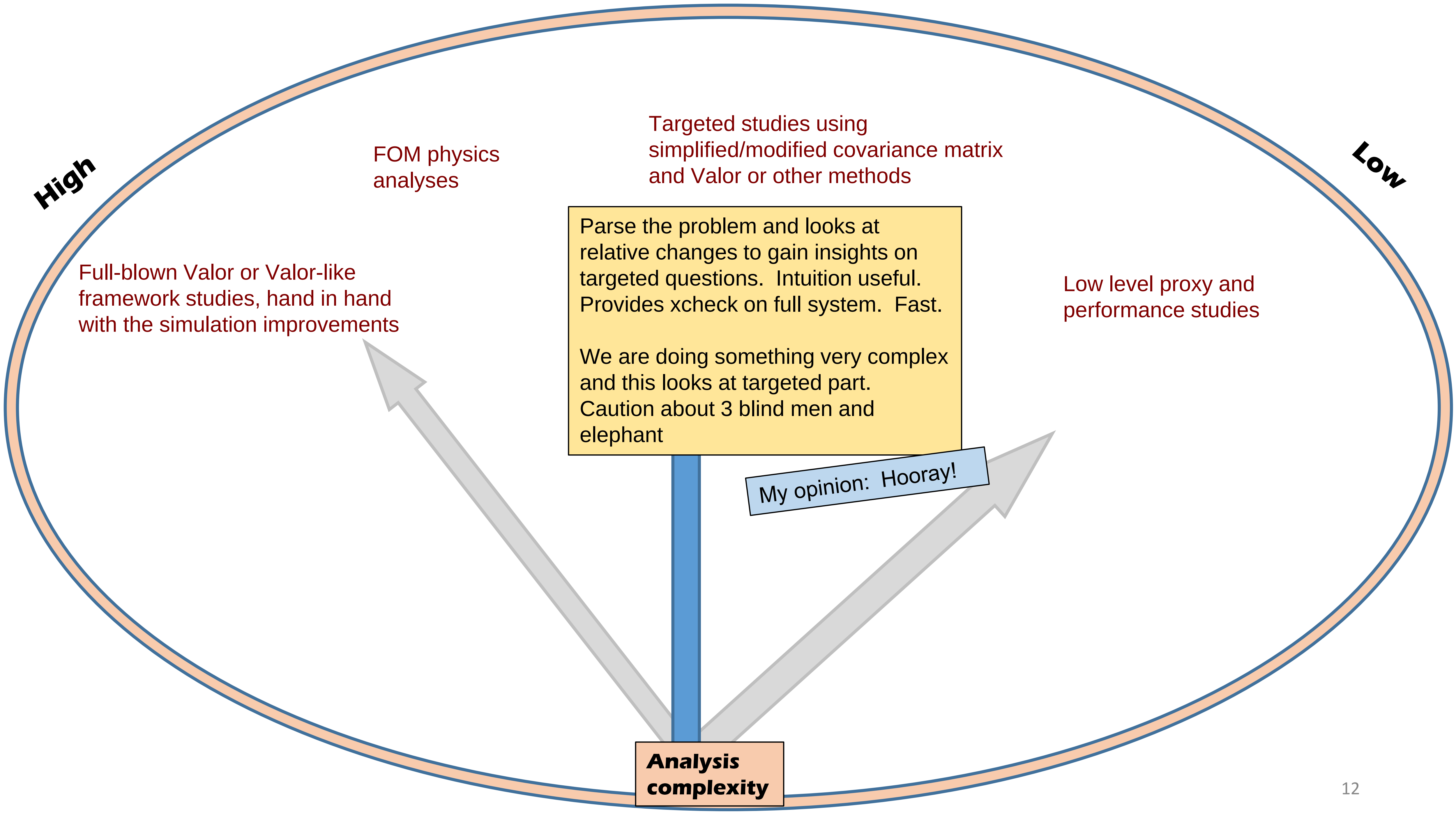
Yes

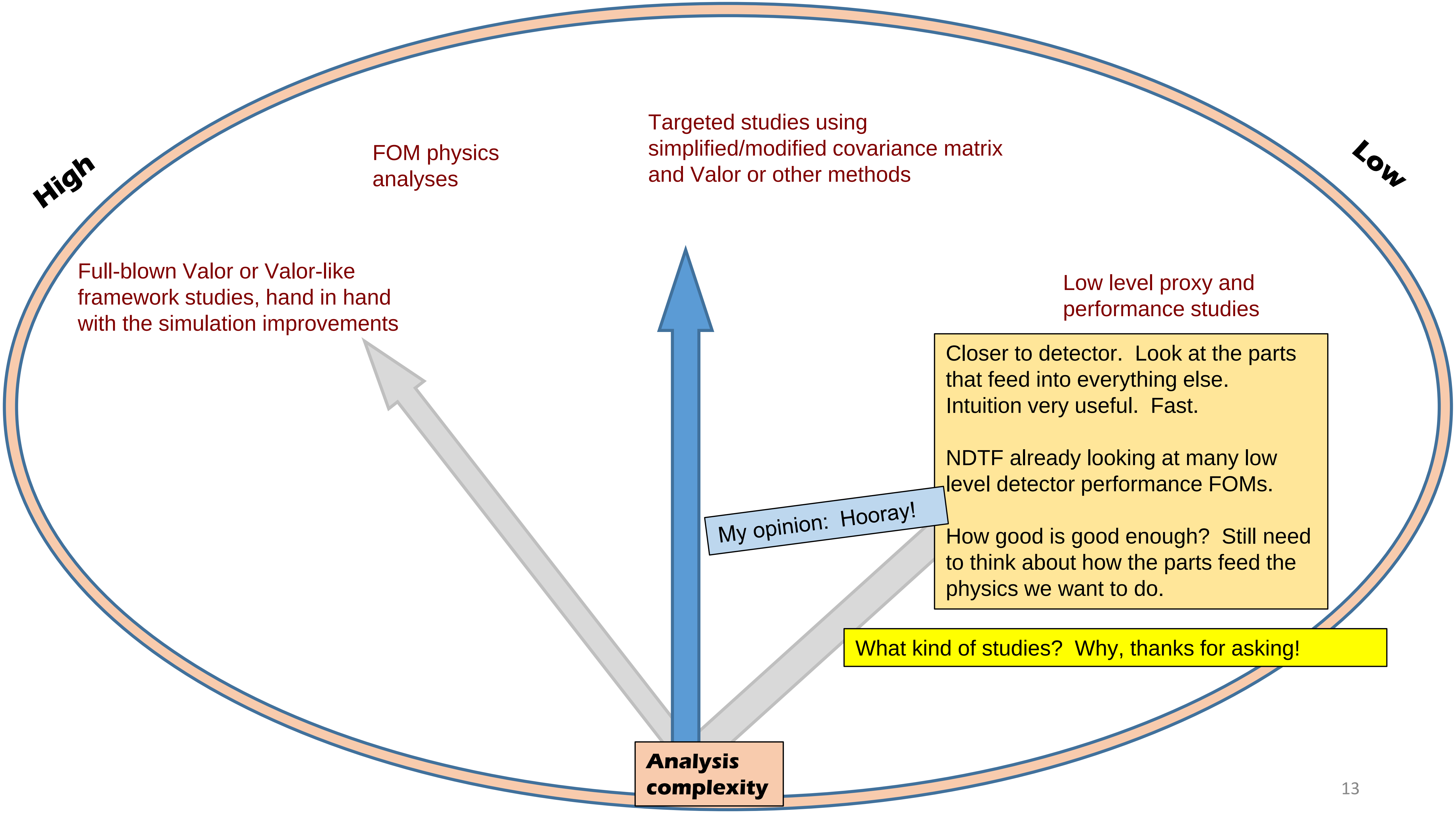
Consensus ND concept, realistic to build, acceptable performance, happy collaboration


High
FOM physics analyses
Targeted studies using simplified/modified covariance matrix and Valor or other methods
Low
Full-blown Valor or Valor-like framework studies, hand in hand with the simulation improvements
Low level proxy and performance studies
For many potential studies, much of the heavy lifting/infrastructure done by TF!
Analysis complexity


High
FOM physics analyses
Targeted studies using simplified/modified covariance matrix and Valor or other methods
Low
Full-blown Valor or Valor-like framework studies, hand in hand with the simulation improvements
Low level proxy and performance studies
Very powerful. Similar to what we may very well do for real data in the end. Provides full measure of the power of the detectors. In principle this incorporates the complex correlations and extracts full information.
High complexity. Hard to use intuition for xcheck. Must work hard to convince yourself what you see coming out the end makes sense. Sensitive to details. As such, potential to be misled.
My opinion: Can ask what is the ultimate CP sensitivity. The answer may not be content-free, but few among us would dare use this as primary basis for an ND option decision.
Main contribution here is to help with the more targeted studies. Would be nice if included estimates of detector systematics in the covariance matrix …
Analysis complexity

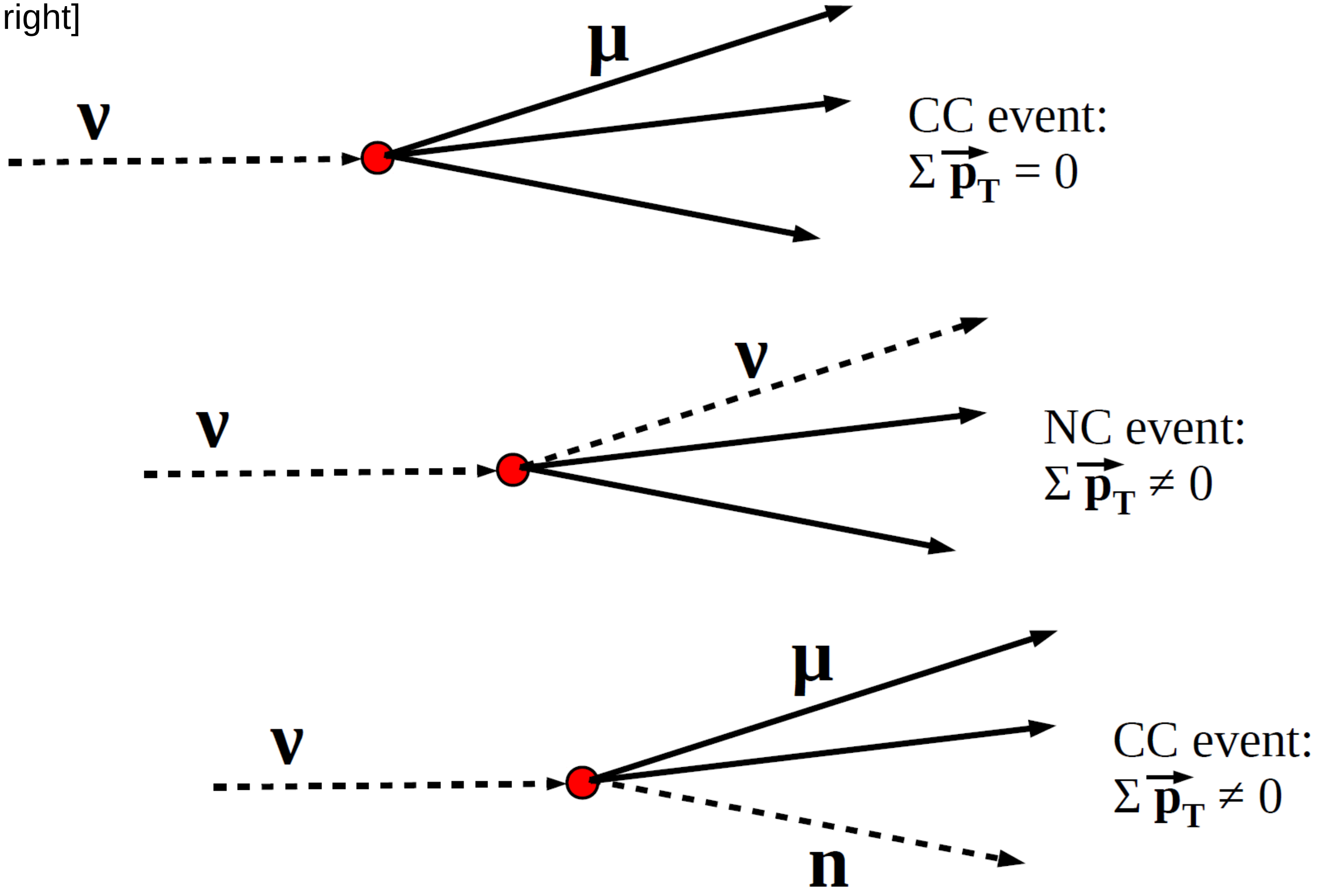

High
Low
FOM physics analyses
Targeted studies using simplified/modified covariance matrix and Valor or other methods
Full-blown Valor or Valor-like framework studies, hand in hand with the simulation improvements
Selected topics. Provides inclusive measure of ND capability where it counts. Good basis for option to option comparison.
Devil is often in the details and usually takes longer than you think. Can be misleading if we gloss over too many of the issues for expedience.
Low level proxy and performance studies
My opinion: Love it. I fear there is no time. I think we'll learn more much faster with the simpler analyses about to discuss.
Analysis complexity


High
FOM physics analyses
Targeted studies using simplified/modified covariance matrix and Valor or other methods
Low
Full-blown Valor or Valor-like framework studies, hand in hand with the simulation improvements
Parse the problem and looks at relative changes to gain insights on targeted questions. Intuition useful. Provides xcheck on full system. Fast.
We are doing something very complex and this looks at targeted part. Caution about 3 blind men and elephant
Low level proxy and performance studies
My opinion: Hooray!
Analysis complexity


High
Low
FOM physics analyses
Targeted studies using simplified/modified covariance matrix and Valor or other methods
Full-blown Valor or Valor-like framework studies, hand in hand with the simulation improvements
Low level proxy and performance studies
Closer to detector. Look at the parts that feed into everything else. Intuition very useful. Fast.
NDTF already looking at many low level detector performance FOMs.
How good is good enough? Still need to think about how the parts feed the physics we want to do.
My opinion: Hooray!
What kind of studies? Why, thanks for asking!
Analysis complexity

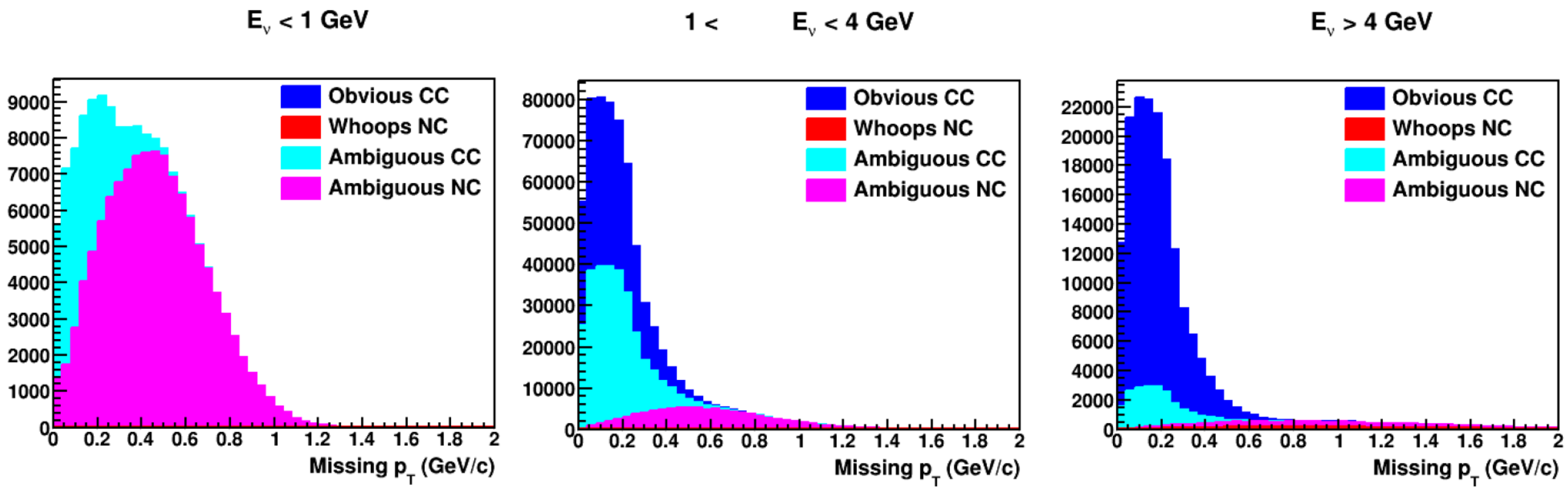
Have been discussing a high performance FGD. How powerful a detector is good enough? What do we give up as performance degraded somewhat? There are practical technical and cost limits, after all.
[Enter Chris stage right]

Missing p_T



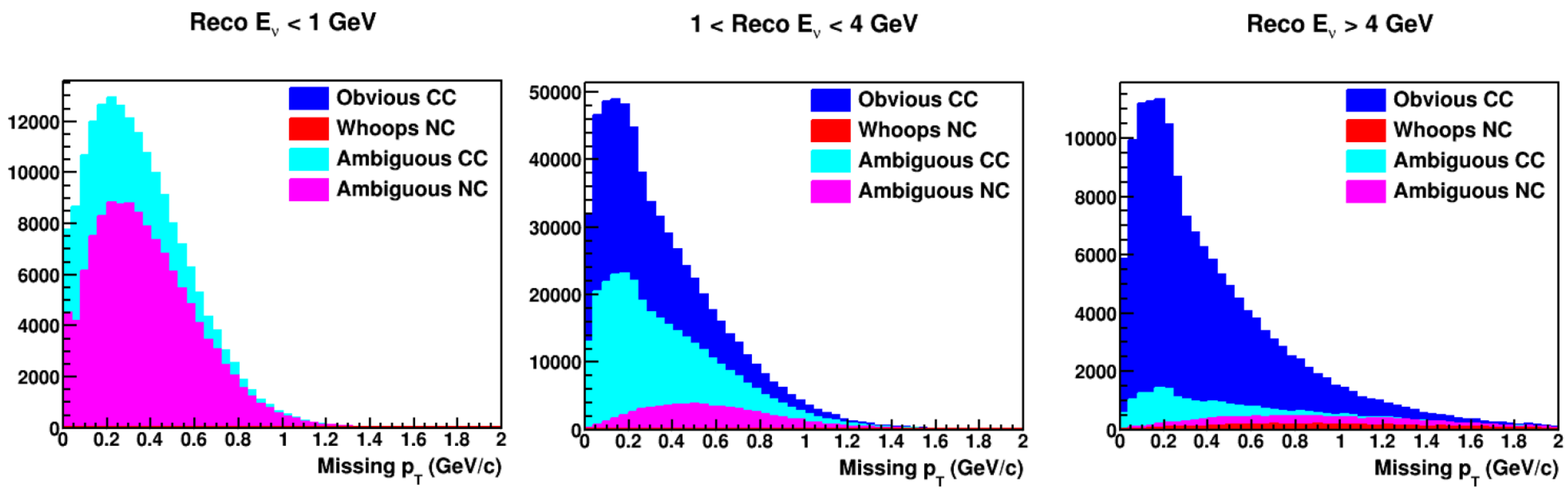
Missing p_T for CC/NC: perfect reconstruction

- Obvious CC = μ^- KE > 1.25 GeV
- Ambiguous CC = μ^- KE < 1.25 GeV
- Whoops NC = π^- KE > 1.5 GeV
- Ambiguous NC = all π^- KE < 1.5 GeV

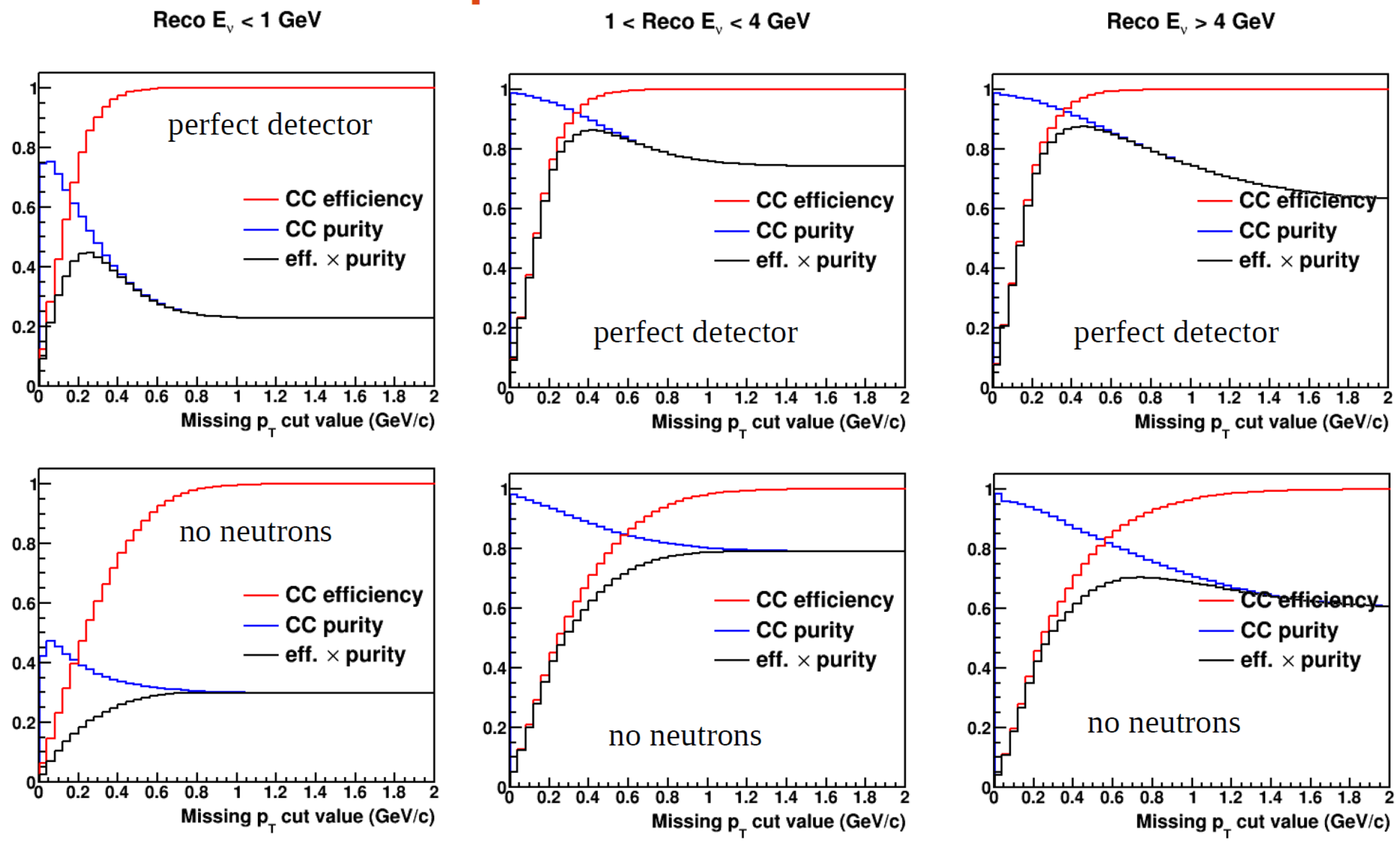


Missing p_T for CC/NC: no neutrons

- Obvious CC = μ^- KE > 1.25 GeV
- Ambiguous CC = μ^- KE < 1.25 GeV
- Whoops NC = π^- KE > 1.5 GeV
- Ambiguous NC = all π^- KE < 1.5 GeV



FHC $E_{\mu-}$ < 1.25 GeV only



Conclusions

- Simply requiring that the detector $E_{visible} > 1$ GeV gives high CC purity in PMNS region, albeit highly dependent on flux model
- Missing p_T is not useful for improving CC purity in 1-4 GeV energy region, even once you have already removed very long muon tracks
- Missing p_T could be an interesting variable for studies of nuclear effects even if it is not used to select CC events

High level physics studies

Much discussion in ND meetings. These five processes get at most of the things we need the ND to do, and if studies done right can provide us much information about relative merits of different detector options.

I. $\nu(\bar{\nu})$-e NC ELASTIC SCATTERING

II. RELATIVE $\nu_\mu(\bar{\nu}_\mu)$ FLUX VS. ENERGY

III. INCLUSIVE $\nu_e(\bar{\nu}_e)$ CC

IV. π^0 PRODUCTION IN NC & IN CC

V. NUCLEAR EFFECTS

See Roberto Petti's talk at this workshop

Targeted physics studies using VALOR covariance matrix or something similar

See Xin Qiang's talk: breaks up the problem and looks at conditional variance

$$\boxed{\Sigma_{Y|X} = \Sigma_{YY} - \Sigma_{YX} \cdot \Sigma_{XX}^{-1} \cdot \Sigma_{XY}}$$

Need for magnetic field?

SM

- Take the full FGT + VALOR framework and compare -
  - errors in fluxes at the FD with full separation of the processes involving the 4 neutrinos at ND
  - errors in fluxes at the FD with full separation of numu and numubar, but NOT enu and enubar at ND
  - errors in the fluxes at the FD with no separation of neutrinos and antineutrinos at ND; need to adjust energy estimator with lost of muon momentum measurement

Tossing information … so we can do, in principle.

If we had estimates for detector systematics in the VALOR framework, then:

To what extent will an LArTPC that can operate technically as ND reduce the detector and nuclear/xsec systematics at the FD?
(Remove topologies/events that will not be contained well enough or which are bothered by pileup.)

To what extent will a powerful low density detector with Ar (gas TPC or Ar target layers) reduce the detector and nuclear systematics?
(Compare detector systematics before and after tossing event topologies dominated by 1-track events.)

Low level performance measures

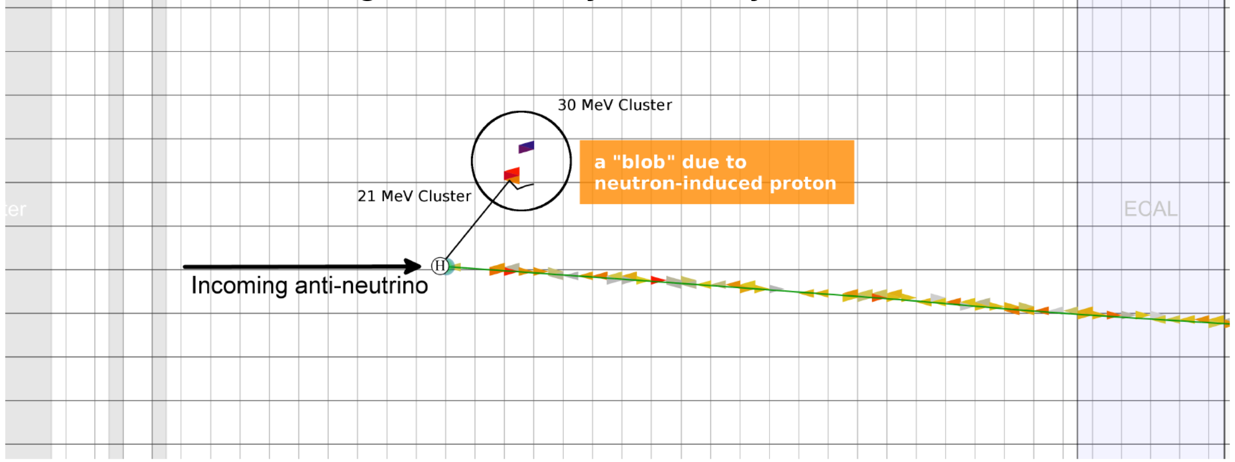
Items to study relevant for vertex activity (energy reconstruction):

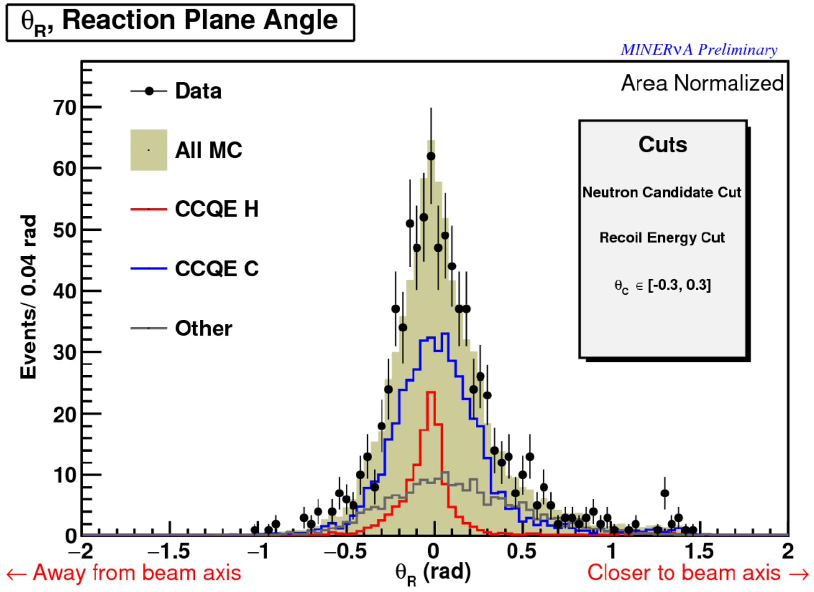
- Charged particle dp/p
- Angular resolution for charged pions, muons
- Angular resolution for electrons
- Energy resolution for different particles
- Pizero tagging/reconstruction efficiency
- NC/CC separation
- e/gamma separation
- Amount of overlap in ECAL from other events/backgrounds

Items to study relevant for vertex activity (energy reconstruction):

- Compare detection thresholds of different options (TF framework).
- Examine how overlapping activity effects ability to do something with neutrons (TF framework)
- Two-track separation
- Sensitivity to neutrons

MINERvA has preliminary results showing some success in tagging neutrons – SM forgot to show yesterday.





Tejin Cai

Beam questions (not big detailed physics analysis or VALOR dependent)

How does dispersion effect on the neutrino-electron scattering measurement change with z?

Can $\delta(N/F)$ be improved by use of simultaneous off-axis and on-axis flux measurements?
If so, how small/big θ effective?

How well are the beam systematics (focusing and hadron production errors) constrained in the N/F ratio as function of Z?

All background studies in detectors should be done for z=360 and z=574

I like big questions and I cannot lie

- To what extent do we need spectral high precision information from neutrino-electron analysis?
  If needed, is it realistic technically at the required level with beam dispersion?
- To what extent do the proposed LArTPC or FGD cancel detector systematics at the FD?
- To what extent to we need a magnetic field? Do we need for electrons AND muons?
- To what extent will the sample-sample cancellation of uncertainties help? Are we comfortable relying on significant cancellation of cross-section/interaction uncertainty among FD samples? Or do we want to get close to required constraints with ND only?
- How well can we do neutrino-electron scattering in LArTPC

Many other important/interesting questions and comments in later slides.
I hope we can go through them.

Questions about going forward - SM

Meeting structure - proposal

- ND meeting moves to more a mode of reports on studies
- Hardware progress reports and deep physics studies worked in as needed
- Some version of NDTF POC “in the weeds” meeting moves forward with broader participation, designed for support and planning of studies

Software framework used for studies

- Near-term needs versus long-term usefulness
- Support

Questions/comments/summary slides sent to SM

From E. Worcester's talk this workshop

Ideas for Future Studies

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

- See Section 3.6 (Effect of Systematic Uncertainties) in physics volume of CDR. Studies suggested there include:
  - Flux covariance matrix from MINERvA ✓
  - Impact of improved models of nuclear initial state (eg: 2p2h), resonance production, FSI, etc in GENIE
  - Comparison to other generators (eg: GiBUU)
  - More quantitative understanding of sample-sample cancellation of uncertainty
  - Data-MC comparisons with test-beam and existing LArTPC detectors
- ND requirements studies:
  - Work backwards from FD – what level of constraint is required? Some attempt at this previously with mgt studies – needs to be completed and quantified. New effort also planned.

Xin Qian

1. ND location:
   How much degradation in constraining far-detector muon neutrino flux given a detector at 360 m vs. 580 m?
   How much gain do we have for two detectors at 360 and 380 m?
   How much gain do we get if we allow the ND to be moved to an off-axis location?

2. Can we do electron-neutrino elastic scattering in LArTPC?
3. Can we select neutrino-nuclei coherent cross section with full kinematics?

4. Low-nu method:
   Can we do low-nu on nu_e at ND?
   Is there advantages to do low-nu on multiple nucleus?
   What's the impact of missing some energetic neutron?
   What's the impact of incomplete acceptance?

5. Magnetic field
   What's the impact of magnetic field on the energy response of LArTPC?

6. General question:
   Can we constrain the nu_e flux at ND to below 1%?
   How much relative detector uncertainty do we need to control for the detector related systematics?
   How much relative flux uncertainty do we need to control?

7. How much angular resolution is needed to achieve:

i) energy spectral information for neutrino-electron elastic scattering
ii) to select cleanly the coherent charged pion production.

Mark Thomson

General:

- do we *need* a magnetic field, should identify a study to answer this question.
- is the neutrino - election CC scattering measurement a strict requirement. Need a study to demonstrate the impact and the required precision.

FGT:

- is the argon target (140 atm. in Carbon Fibre tubes) realistic. What are the engineering challenges (140 atm)? Ratio of material between tubes and argon gas still means that there isn’t a measurement on argon.

LArTPC:

- there is a claim that the return yoke is not needed. I am not convinced. What are the limits on the allowable magnetic field at an experimental site at FNAL.
- not clear to me that a good reconstruction of neutrals will be possible in a high-pile environment. This needs to be demonstrated.

Elizabeth Worcester

*Does choice of analysis strategy impact ND design choices? Is one strategy more or less effective for each design? Or should we be able to do either/both with a well-designed ND?

*What is a realistic uncertainty on flux determination with nu-e scattering and low-nu method given ND detector effects?

*Are we comfortable relying on significant cancellation of cross-section/interaction uncertainty among FD samples? Or do we want to get close to required constraints with ND only?

*Is cancellation of detector uncertainty between ND and FD realistic? A priority?

Jon Link

This morning we saw a 586 parameter covariance matrix which was, at least as a method, intended to incorporate all of the interdependence of the individual parameter on the near/far extrapolation. This method contains within it the detail of that extrapolation, but also inherently hides them. It seems to me that there are just a few high-level things that the advocates of the different near detector concepts are optimizing for that we should be discussing in a centralized way. One example of this that I find very important is the following: high-density detector advocates note the benefits of using electron elastic scattering to determine the neutrino flux, while low-density advocates highlight the robustness against pile-up. It seems clear to me that the low-density detector will produce the best input on exclusive mode cross sections and event kinematics (at least of the argon target is the primary detector material). So my question for discussion is: how important is the elastic scattering sample for the near/far extrapolation and if it is important, can we design a low-cost high-mass detector, optimized for the elastic scatting measurement and pair it with a low density detector?

Jon Miller

The biggest one that I have is that of the use of LArTPC. Basically, many people are in favor of it (~90%?) because of the strong cancelation of systematics seen in MINOS/NOvA. However, it doesn't seem so obvious to me how strong the cancelation will be because of the differences in acceptance, size, granularity, and so on. The different detector technology for T2K caused the detector related systematics to be the strongest uncertainty and is a motivation for not solely having a FGT, but I have seen no numbers (For example for K2K) as what the cancellation might be for a mismatched ND. This seems like it should be a central question that must be addressed.

The other concern/question I have is about the idea of making a hybrid detector of all the technologies that people want to make. I understand the point, and it is very useful for people to make detectors they are excited to make and to provide motivation for detector R&D work, but it is hard for smaller groups/nations (like Chile) to get involved in such a format. We would like to get involved and will make a request, but it is a very different thing to make a request for a detector R&D versus making a physics request where we need to be able to say that we are making the optimal detector for the optimal price for the given project. I am just saying that it would be best, for a physics based grant, if it doesn't appear haphazard and if it appears as cheap as possible.

The final point I would like to make is that if there is 4pi coverage, multiple targets (p, C, Ar) and a high energy beam (which I have heard discussed for Tau appearance), then there is an amazing neutrino nuclear physics program and we really should enable it if we can do so without the cost of our prime \delta_cp measurement.

Kendall Mahn

1) I came up with a list of studies, mostly related to the cross section model, that I will start working on with Chris M. and Dan. D:
a) Neutrons varying with generator. What's the role? What size LAr is needed to check our models of neutron deposit.
b) Tracking threshold and FSI relationship
c) Continue acceptance/efficency studies of the models
d) proton threshold, checks of transversity, missing energy in calorimetry
e) Size of nue cc inclusive total statisical? Maybe left to theory?
f) Role of CC coherent. As we spoke briefly, I'd like to talk this through with you and bring in a new student to flesh this out. Is this possible?

2) I need to talk to Steve D more about this, but I meant to do some other tire kikcing of VALOR
a) Results of a CC inclusive only (no subsample fit)
b) checks of true effecive degrees of freedom in the fit. We did this a while ago on T2K, would be good to make sure we're not overconstrained.

My gut says we need both a low density tracker (for nu-e) and LAr (secondary interactions checks and I found Dan's talk to be helpful for framing this.

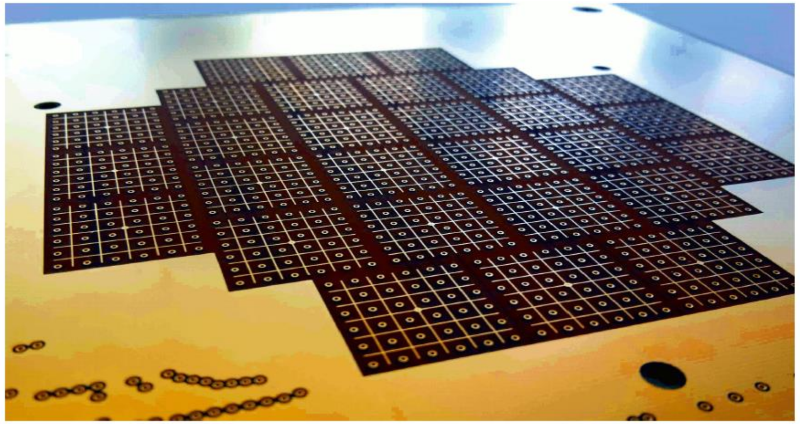
I still wish to gently convince anyone who says we can do it all only with the ND. We will need significant flux, cross section theory and about everything we can throw at this problem.

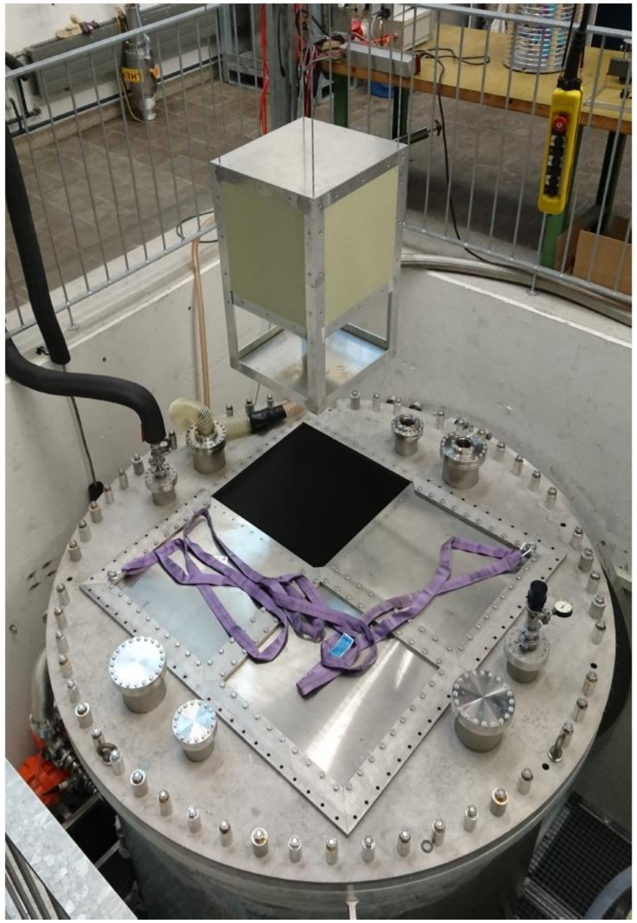
James Sinclair

u^b UNIVERSITÄT BERN AEC ALBERT EINSTEIN CENTER FOR FUNDAMENTAL PHYSICS

LAr ND: Modular, Magnetize & 3D Charge readout

The Good:
- Homogeneous calorimeter
- Precise tracking
- Good e gamma separation
- Density – high Statistics





The Less Good:
- Slow – Pileup
- Density – multiple scattering at low E & poor resolution of nuclear effects

… even the bad is the same as far the detector

Also worth noting:
Similar infrastructure to Gar, potentially run in two modes

10 tonne scale is achievable with 2 x the current prototype

Plastic scintillator tracker option

Pros

- High mass density – high statistics
- Good containment
- Can put in layers of Ar targets (and other targets)
- Fast – can take high rate
- Decent segmentation – can isolate different topologies
- Can separate e from gamma
- Tracking and angular resolution fairly good

Cons

- Not at all like FD
- Ar target layers possible, but those will not be useful for 1-track topologies
- Angular hole in acceptance at 90 degrees

Probably a cheap-ish option

No real attempt at costing.

A very rough guess based on a few T2K P0D & MINERvA numbers and number of channels is O($10M) for tracker (not including ECAL or magnet or Ar target planes)