Galaxy Clustering Modelling

5° Meeting Nazionale Collaborazione Euclid
25 febbraio 2022

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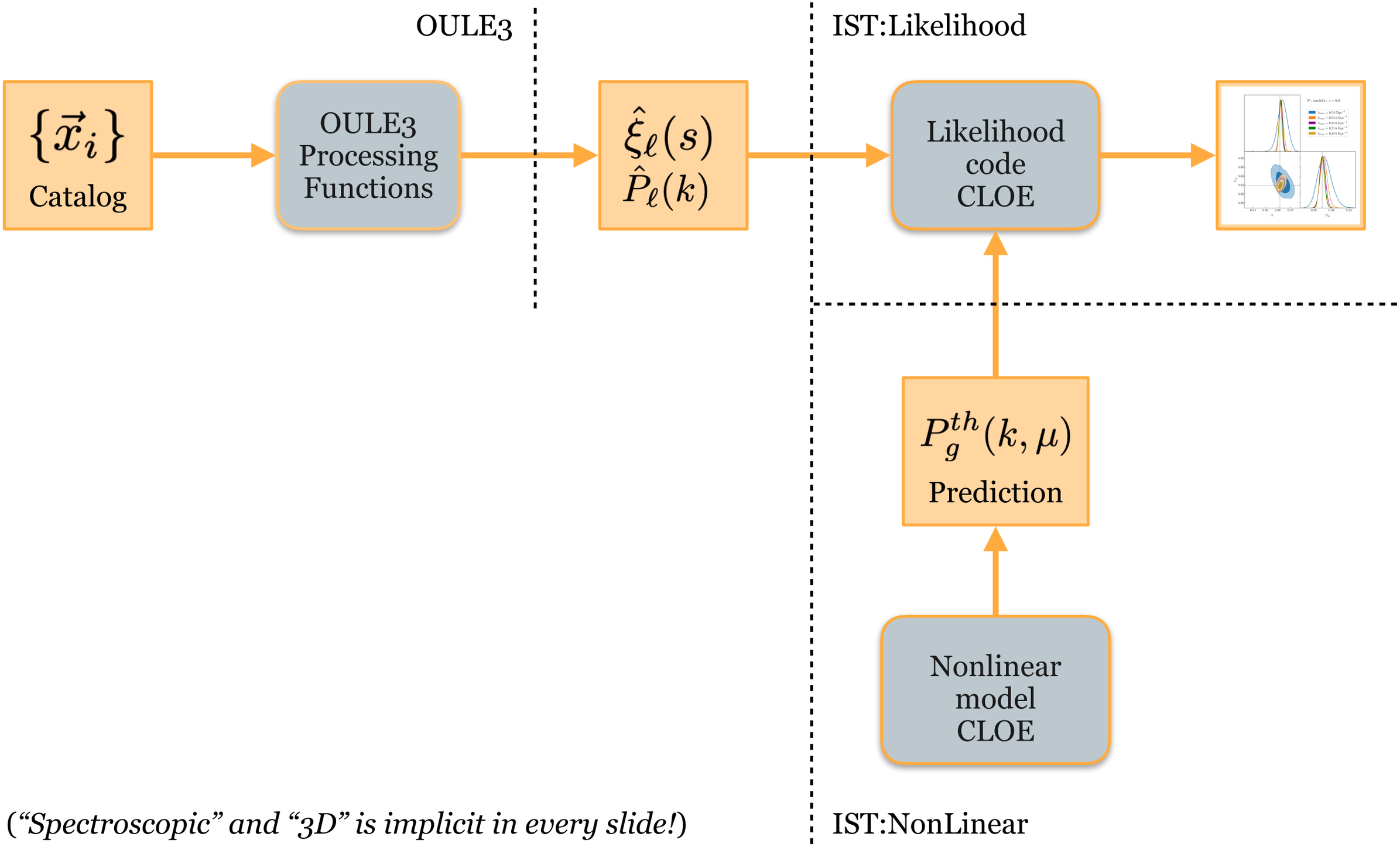
INAF, Osservatorio Astronomico di Trieste

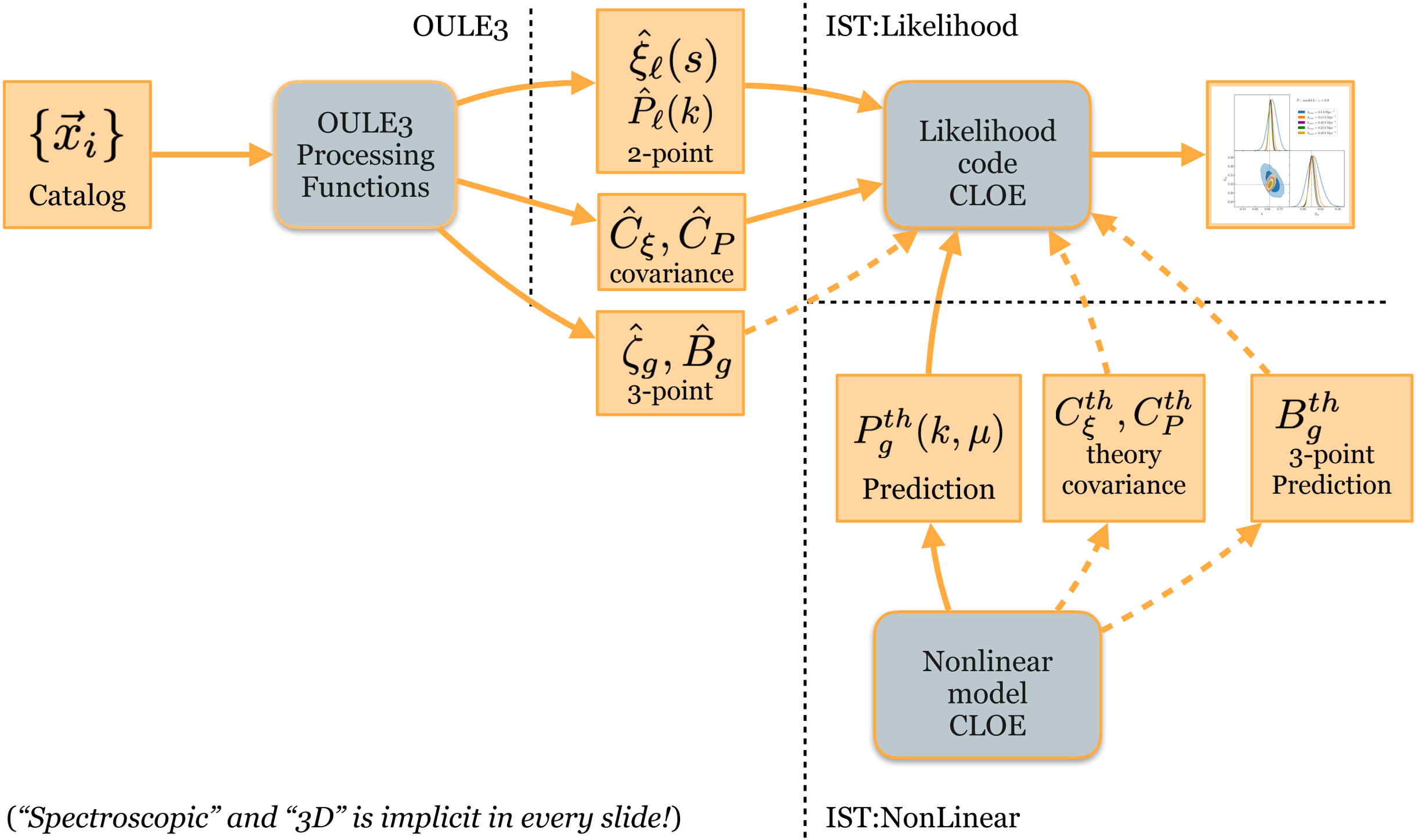
Galaxy Clustering Analysis: the basic view



(*"Spectroscopic" and "3D" is implicit in every slide!*)

IST:NonLinear

Galaxy Clustering Analysis: *beyond* the basic view



(*"Spectroscopic" and "3D" is implicit in every slide!*)

IST:NonLinear

Modelling observables in the SWG-Galaxy Clustering

Studying the problems …

… implementing solutions

Galaxy Clustering SWG

NonLinear WP
Modelling of the power spectrum and 2pcf:
full shape & BAO (reconstruction)

Higher-Order Statistics WP
Bispectrum & 3pcf modelling

Photo-z WP
Photometric sample observables

Likelihood WP
Definition of the likelihood analysis

Additional Probes
Voids, …

Theory SWG
Beyond SM

Nonlinear model CLOE

$P_g^{th}(k,\mu)$ Prediction

C_ξ^{th}, C_P^{th} theory covariance

B_g^{th} 3-point Prediction

IST:NonLinear

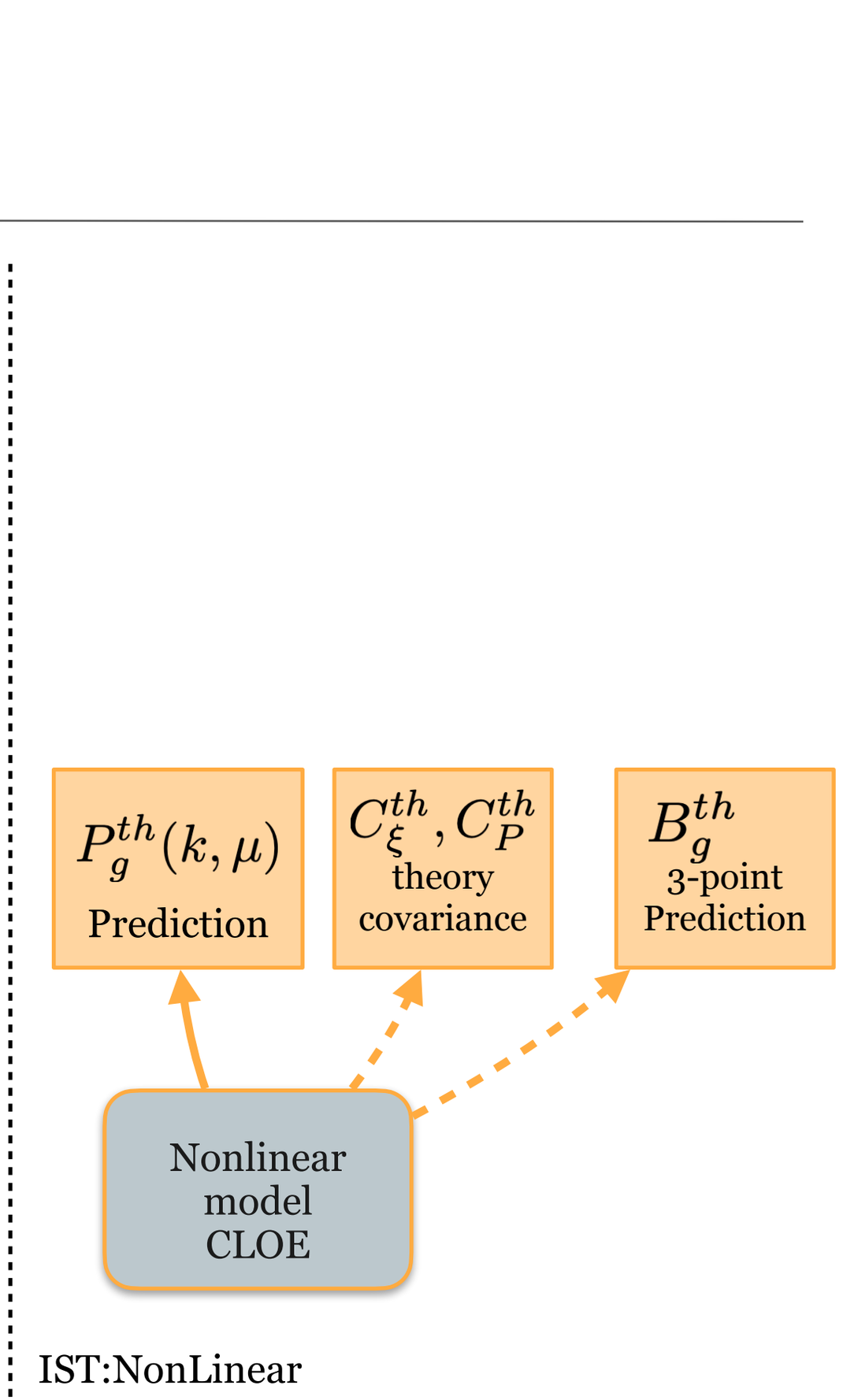
Modelling requirements

The evaluation of theoretical predictions must be:

- **Accurate**
  The accuracy of the prediction should be in line with the accuracy required to the estimators: below 1%!
  Main tools:
  Perturbation Theory & *N-body simulations*

- **Efficient**
  Likelihood sampling requires predictions for the data vector of order 1 sec. or less
  Main tools:
  FFTlog PT computations
  Emulators (linear *P*, PT, N-body)

- **Consistent** across observables
  (*e.g.* Galaxy Clustering *and* Weak Lensing)



IST:NonLinear

A reference model in Perturbation Theory

Nonlinear + Higher Order Statistics WPs

We start from the state-of-the-art model from PT:

$$P_\ell(k) = P_\ell^{\rm tree}(k) + P_\ell^{1-{\rm loop}}(k) + P_\ell^{\rm noise}(k) + P_\ell^{\rm ctr}(k)$$

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$$P_g^{\rm tree}(k,\mu) = (b_1 + f\mu^2)^2\, P_L(k)$$

linear, Kaiser

$$P_g^{1-{\rm loop}} = 2\int d^3q\, Z_2^2(\vec{q}, \vec{k}-\vec{q})\, P_L(q)\, P_L(|\vec{k}-\vec{q}|)$$

numerically challenging ...

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$$P_g^{\rm tree}(k,\mu) = (b_1 + f\mu^2)^2\, P_L(k)$$

linear, Kaiser

$$P_g^{\rm noise} = \frac{1}{\bar{n}_g}\left(c_{\epsilon,1} + c_{\epsilon,2}\frac{k^2}{k_M^2} + \dots\right)$$

$$P_g^{1-{\rm loop}} = 2\int d^3q\, Z_2^2(\vec{q}, \vec{k}-\vec{q})\, P_L(q)\, P_L(|\vec{k}-\vec{q}|)$$

$$P_g^{\rm ctr} = (b_1 + f\mu^2)\, P_L(k)\left(c_{{\rm ctr},1}\frac{k^2}{k_M^2} + \dots\right)$$

Many free parameters: bias & counterterms

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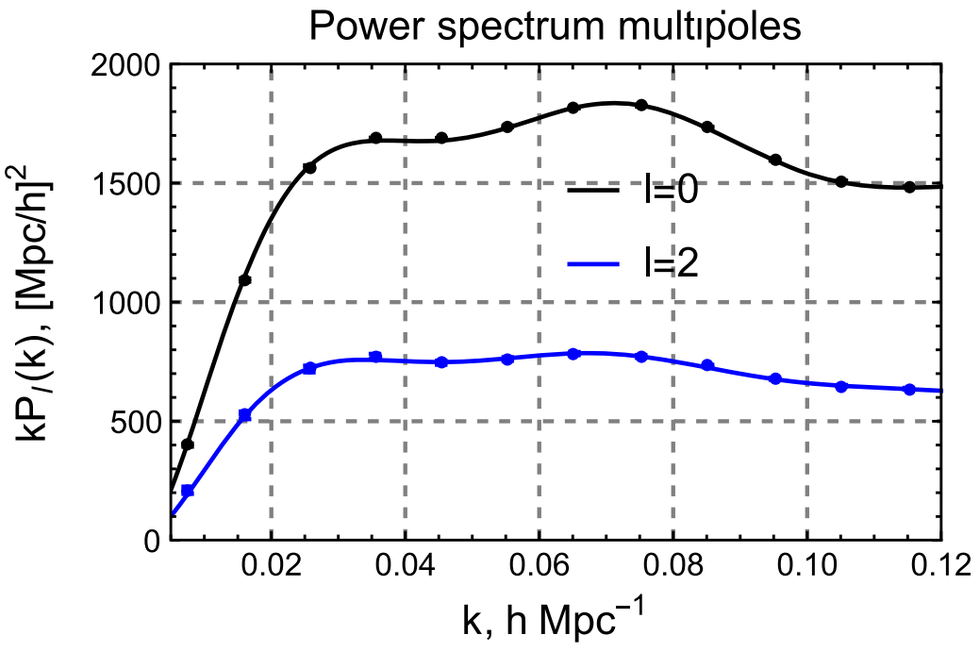
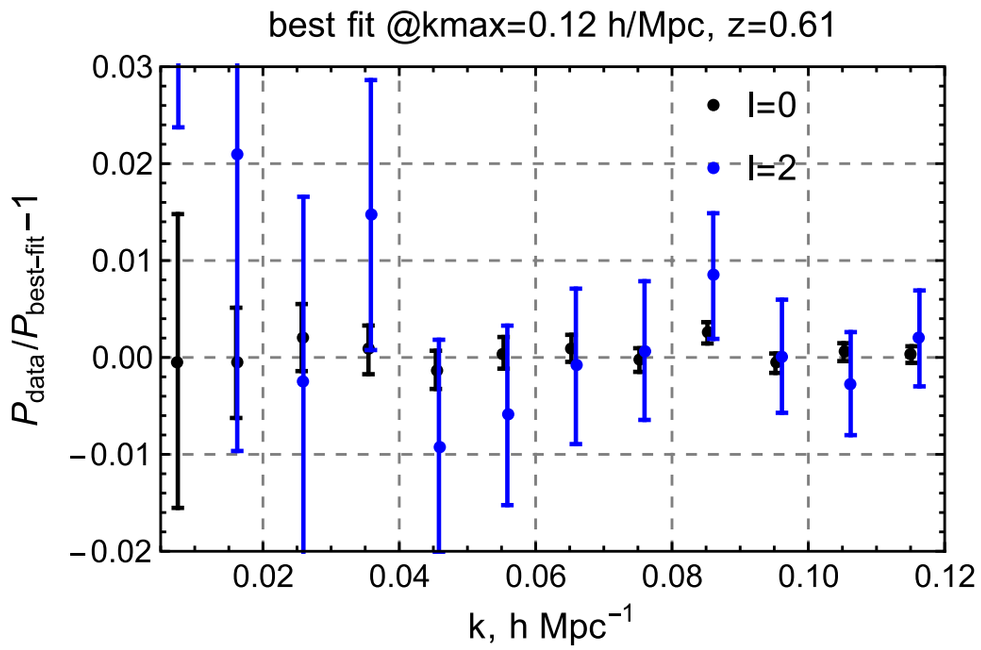
Tested on simulations, 35 times the volume of the largest redshift-bin of Euclid





Nishimichi *et al.* (2020)

+ BOSS analysis in d'Amico *et al.* (2019); Ivanov, Simonović, Zaldarriaga (2019)

PT Challenge: 2020-2021

Nonlinear + Higher Order Statistics WPs
Leads: M. Crocce, C. Porciani, E. Sefusatti

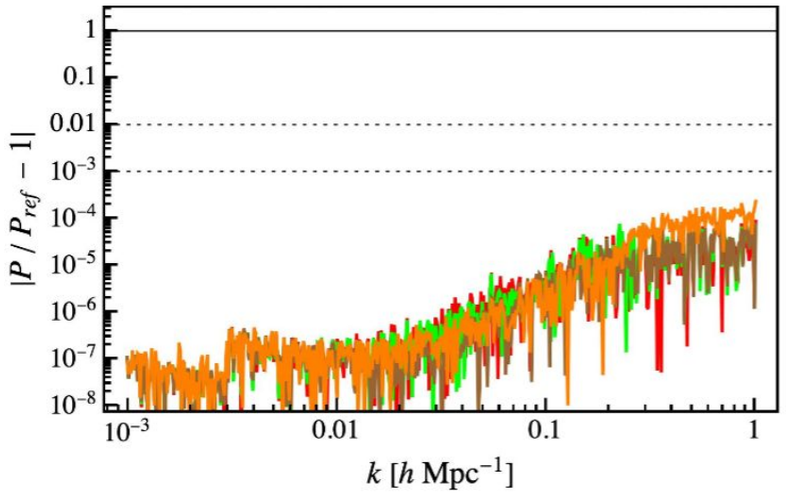
Comparison of PT codes

Several participants & independent codes:

- Veropalumbo, Guidi, Di Bella, Moresco (CosmoBolognaLib)
- D'Amico (PyBird)
- De la Torre (2pcf)
- Breton (2pcf)
- Pugno, Kuruvilla (3pcf)
- Pezzotta, Crocce, Eggemeier, Sanchez (COMPASS)
- Moretti, Rizzo, Pardede, Oddo, Sefusatti (PBJ)
- Moradinezhad (P+B with PNG)

+ Zennaro, Angulo (BaccoEmu)

Relative difference among codes on the NL power spectrum:



Outcome:

- Robust benchmark and practical suggestions for independent codes being developed across the collaboration *and* for IST:NL
- Comparison of evaluation methods (e.g. Gaussian integration, FFTlog): accuracy *vs*. speed
- Detailed description of the model and its implementation on overleaf: **Euclid GC SWG PT challenge: reference model**

→ Nonlinear model CLOE

PT Challenge 2.0: Key-Projects

Nonlinear + Higher Order Statistics WPs
Leads: M. Crocce, C. Porciani, E. Sefusatti

Likelihood analysis of the Flagship simulation

Stage 2 of the PT challenge
Two weekly telecons: configuration & Fourier space

Flagship GC measurements on gitlab:
https://gitlab.euclid-sgs.uk/pf-ist-nonlinear/gc-wp-nonlinear/

KP papers: P, $P+B$, ξ, $\xi+\zeta$

- Flagship snapshot in real space
- Flagship snapshot in redshift space
- Flagship light-cone

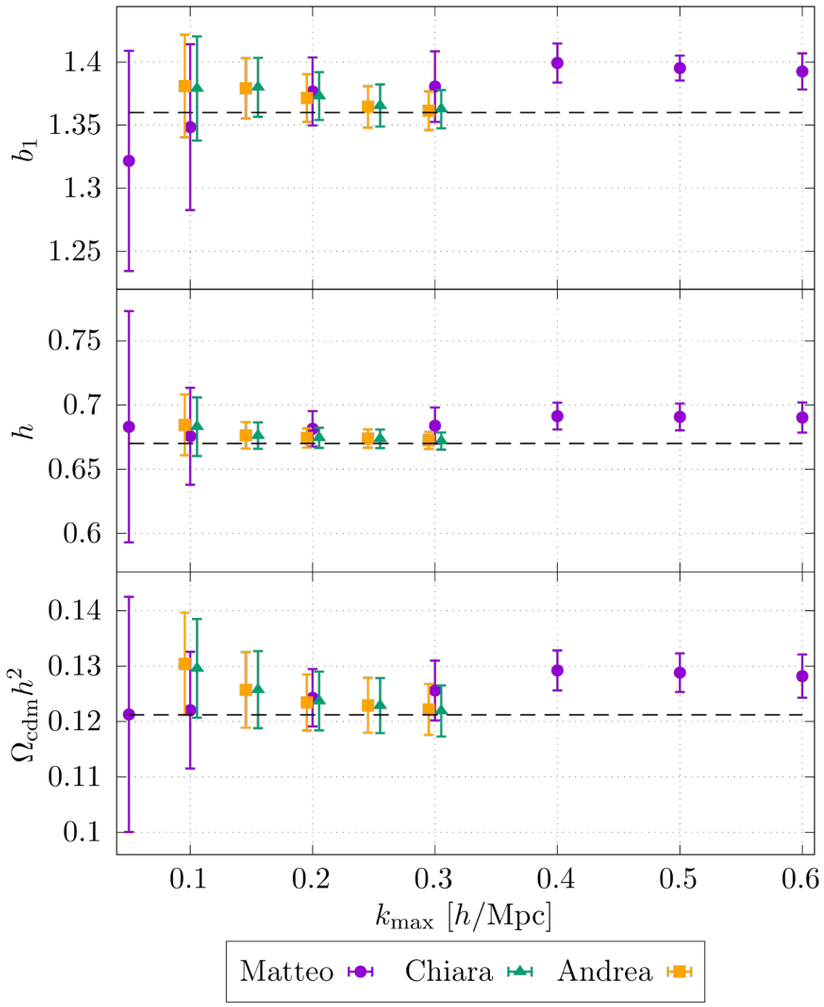
Tests:

Modelling (PT validity, bias relations, figure-of-merit, figure-of-bias)
Emulators
Covariance (theory, Gaussian vs non-Gaussian)
Samplers

Example: Paper 1 NL KP

Power Spectrum analysis
in real/redshift space

preliminary results by Andrea Pezzotta,
Chiara Moretti & Matteo Zennaro



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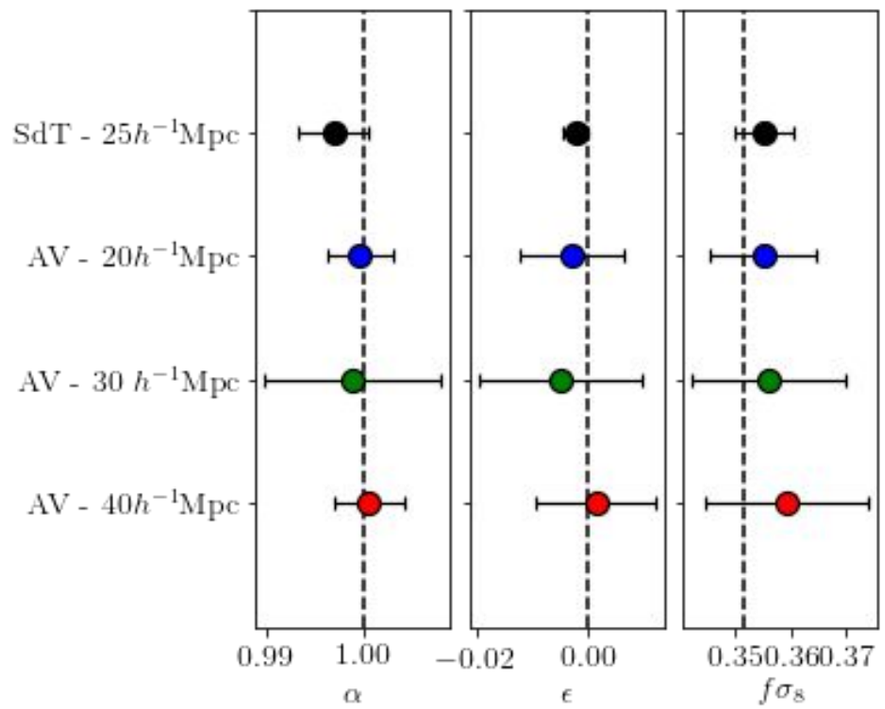
Example: Paper 2 NL KP

2PCF analysis in real/redshift space

preliminary plot by Alfonso Veropalumbo & Sylvain de la Torre



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Tests:

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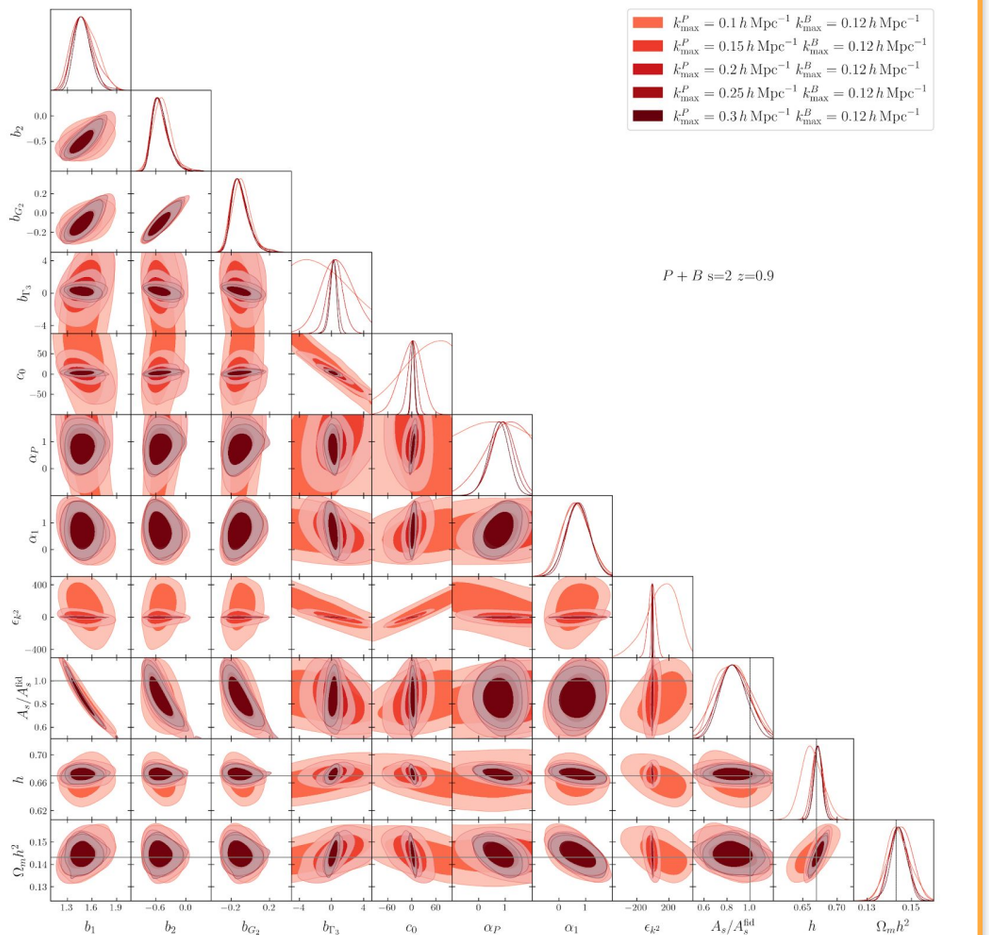
Samplers

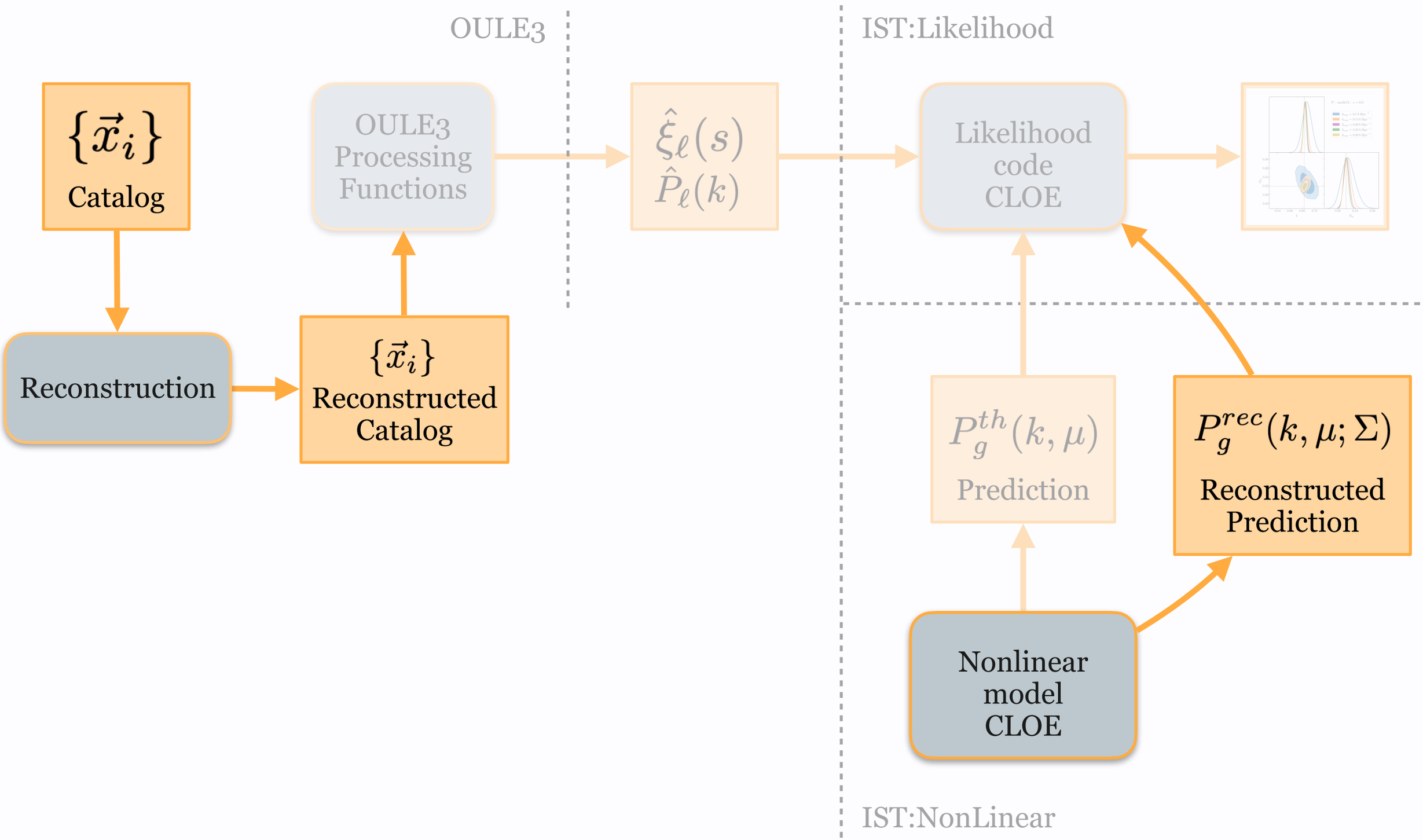
Example: Paper 1 HOS KP

Power spectrum + Bispectrum
analysis in real space

preliminary results by Davit Alkhanishvili



Nonlinear WP: Reconstruction & BAO



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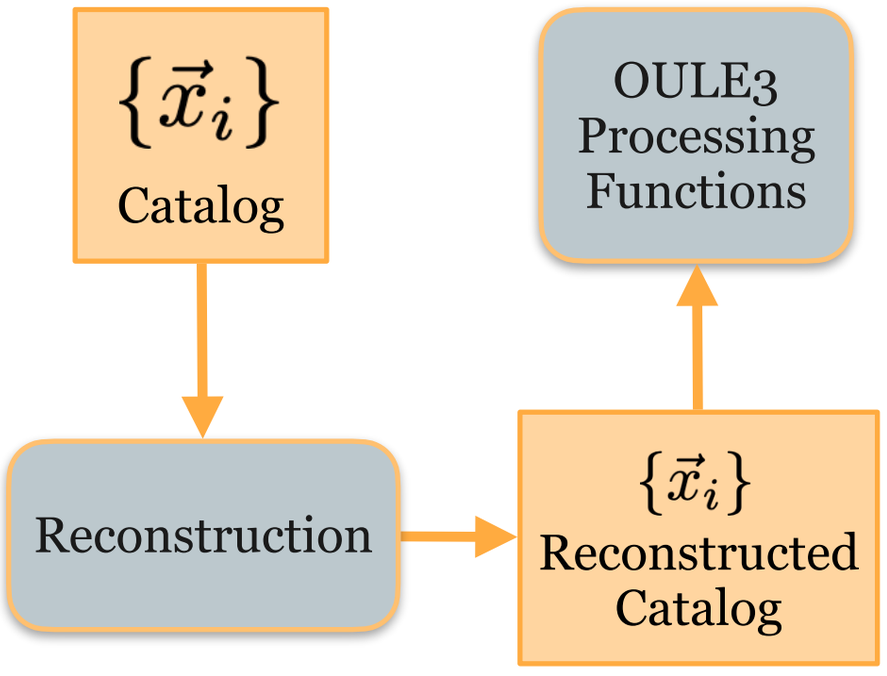
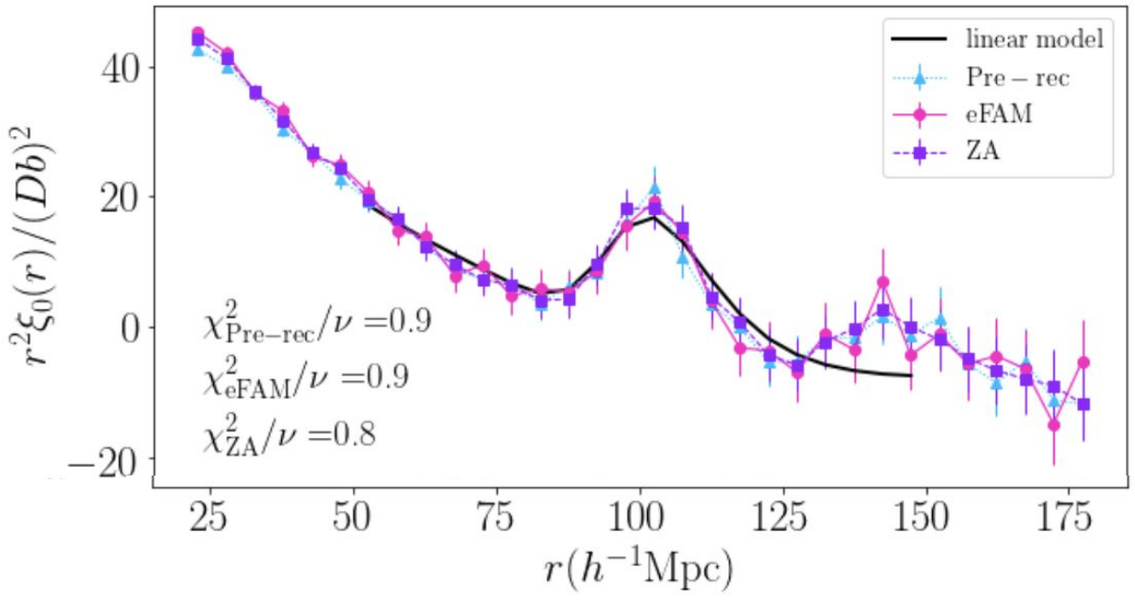


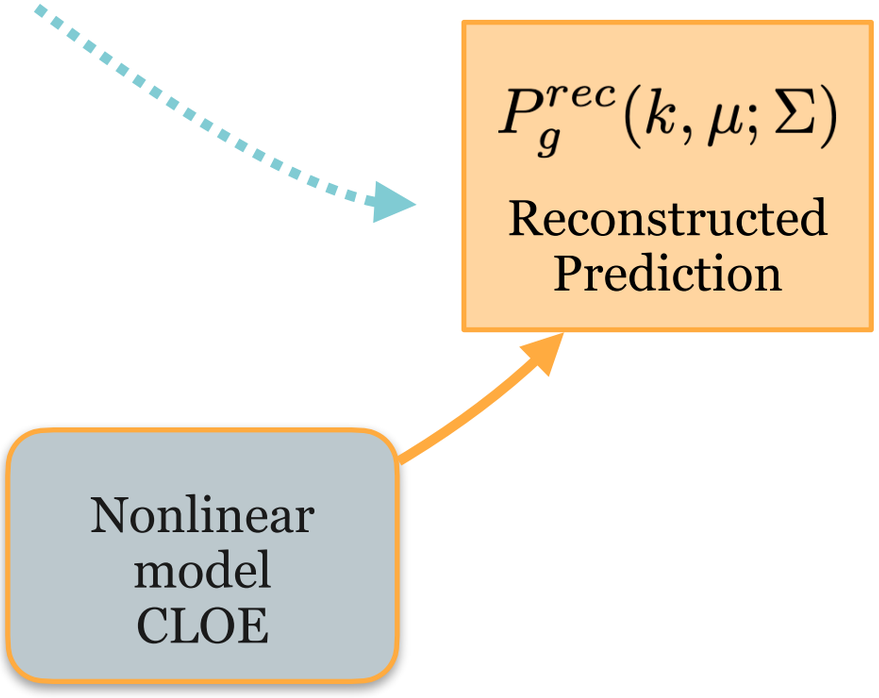
Leads: Elena Sarpa & Alfonso Veropalumbo

Reconstruction challenge

1. Comparison of recon methods:
   - Zeldovich reconstruction, ZA (pyrecon)
   - eFAM (Sarpa *et al.*, 2019, 2020)

2. Test of modelling for reconstructed correlations functions





Higher-Order Statistics WP: general interest projects

Leads: C. Porciani, E. Sefusatti

Stage I (2016-2018): forecasts

- **Fisher matrix for the redshift-space bispectrum**: Yankelevich & Porciani, 1807.07076

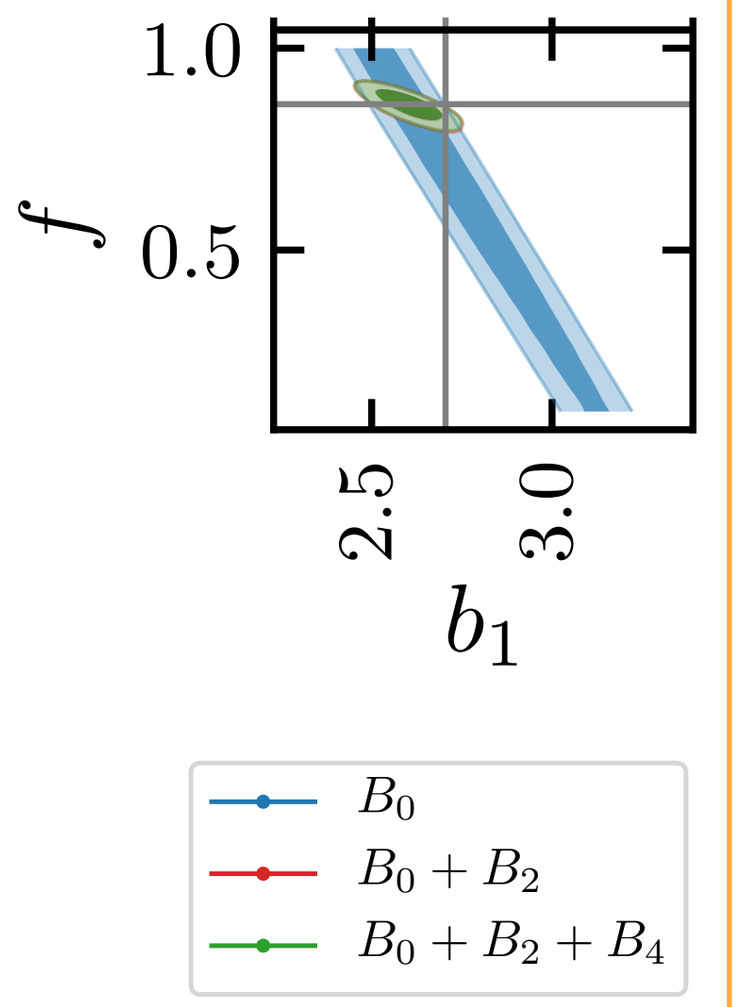
Stage II (2019-2022): codes development

- **Bispectrum likelihood set-up**: Oddo *et al.* 1908.01774
- **Matter bispectrum**: Alkhanishvili *et al.* 2107.08054
- ***P* + *B* in real space**: Oddo *et al.* 2108.03204
- ***P* + *B* with PNG in real space:** Moradinezhad *et al.* 2010.14523
- **Bispectrum multipoles in redshift space:** Rizzo *et al.* (in prep.)
- ***P* + *B* in redshift space:** Moretti *et al.* (in prep.)
- **Bispectrum window convolution:** Pardede *et al.* (in prep.)
- **Bispectrum modal estimator:** Byun *et al.* 2010.09579
- **Redshift-space 3PCF modelling:** Kuruvilla & Porciani 2005.05331
- **2PCF + 3PCF in real space:** Veropalumbo *et al.* (in prep.)
- **3PCF covariance:** Veropalumbo *et al.* (in prep.)

Stage III (2021-2023): Euclid Key Projects

Example: **bispectrum multiples**

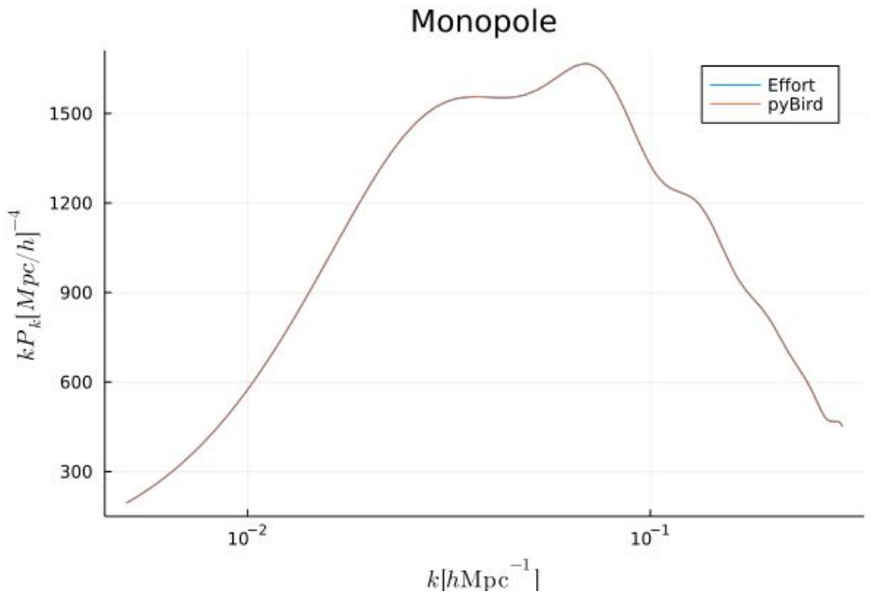
F. Rizzo, C. Moretti, K. Pardede, *et al* (in prep.)



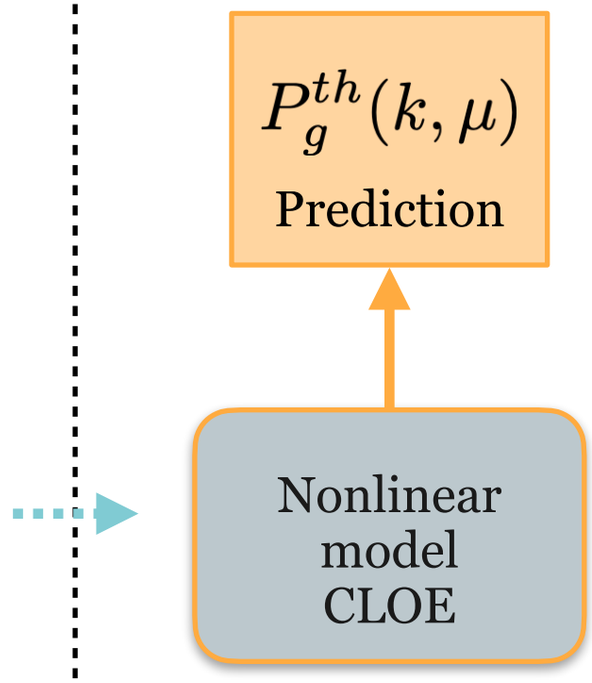
Likelihood WP: points of contacts

Leads: M. Carbone, J. Bel

KP-GC-6 Paper 3:
Emulators for PT predictions
M. Bonici, *et al*



KP-GC-6 Paper 6:
Numerical covariances for GCsp
L. Blot, A. Sanchez *et al.*

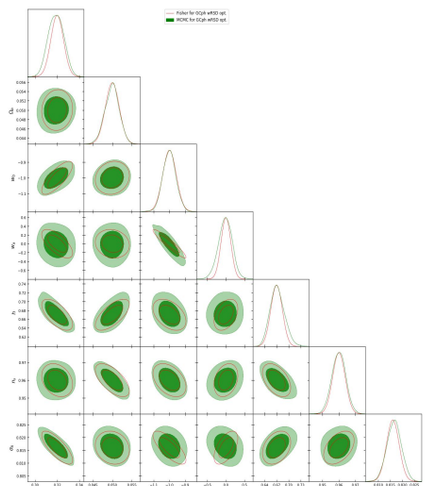


IST:NonLinear

Photo-z WP: points of contact

Leads: S. Camera, I. Tutusaus

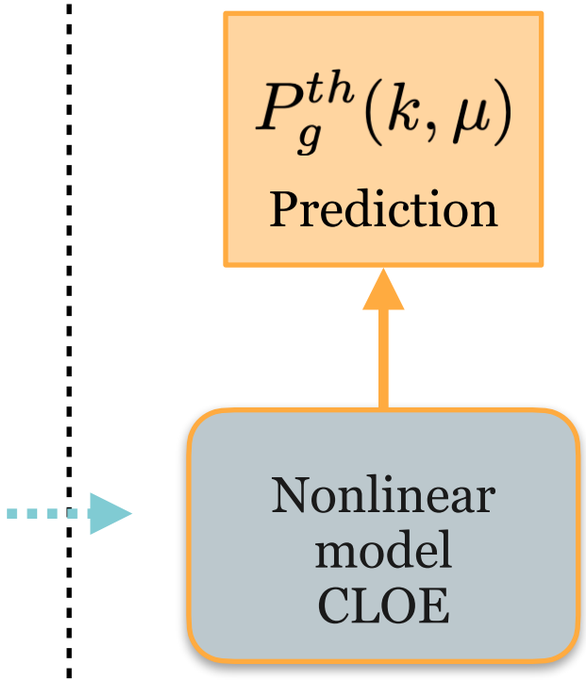
KP-GC-7 Paper 1:
RSD in Limber approximation
K. Tanidis, *et al.*



KP-GC-7 Paper 7:
E2E pipeline for GCph analysis
I. Tutusaus, *et al.*

KP-GC-7 Paper 10:
Nonlinear galaxy bias
B. Camacho, *et al.*

KP-GC-7 Paper 11:
Harmonic-space clustering, growth, and magnification measurement
S. Camera, *et al.*



IST:NonLinear

IST:NonLinear

Leads: A. Pourtsidou, M. Crocce, C. Giocoli
GC developers: C. Moretti, P. Carrilho

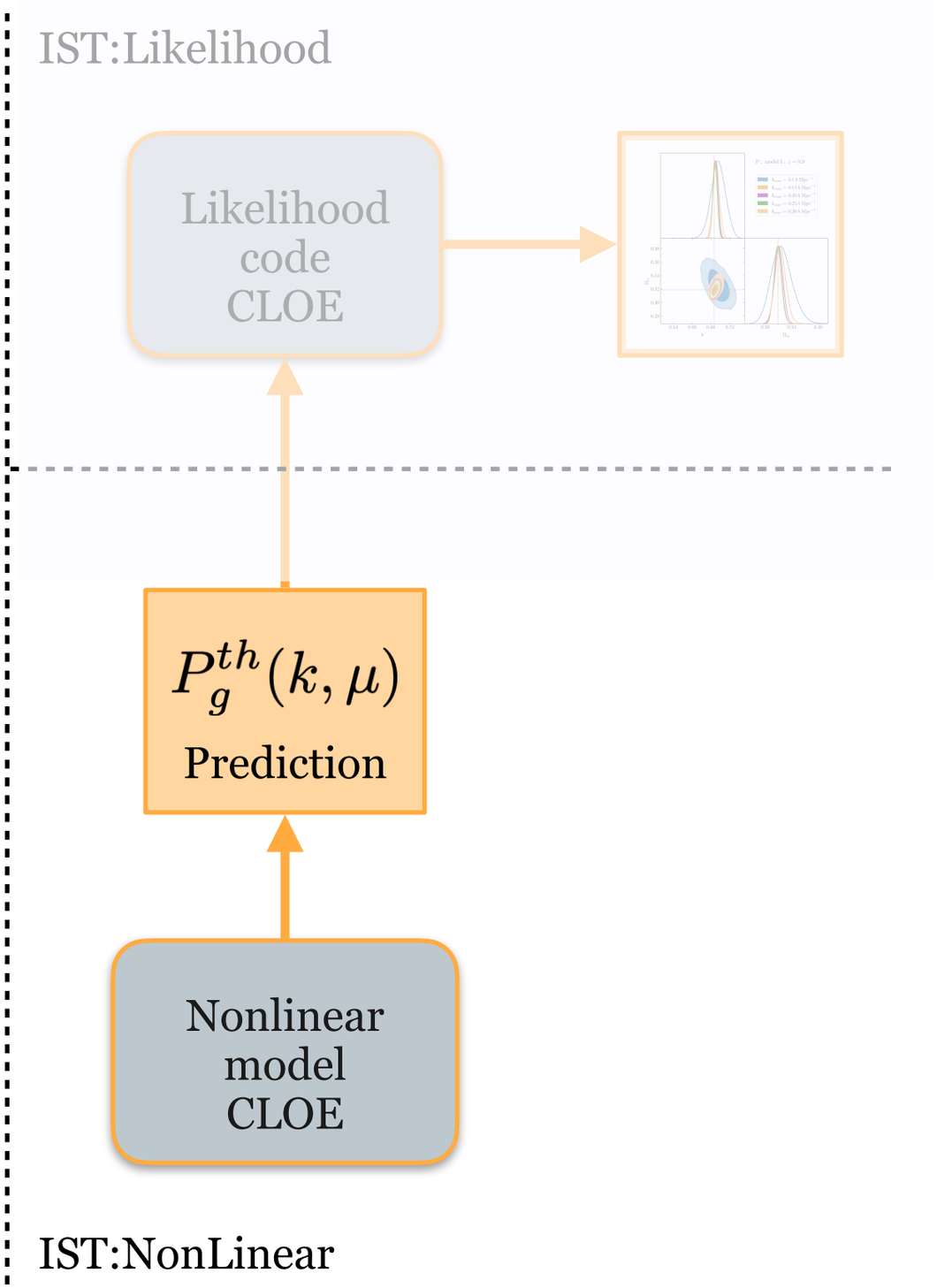
Current implementations:

- Bacco (matter)
- EuclidEmu2 (matter)
- HM-code (matter)
- HaloFit (matter)
- Nonlinear PT (from PT challenge model)

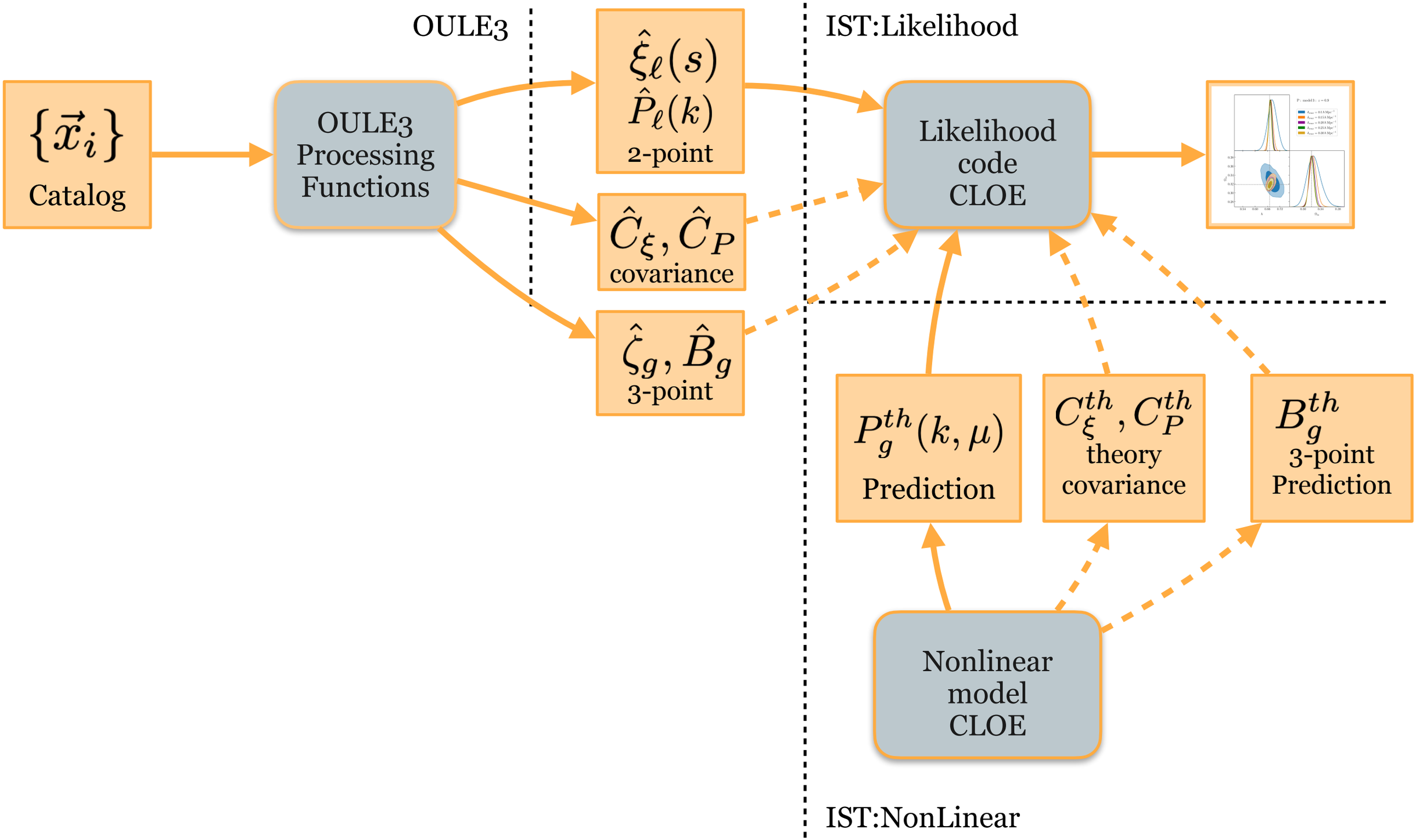
- Interface with Likelihood

Next steps:

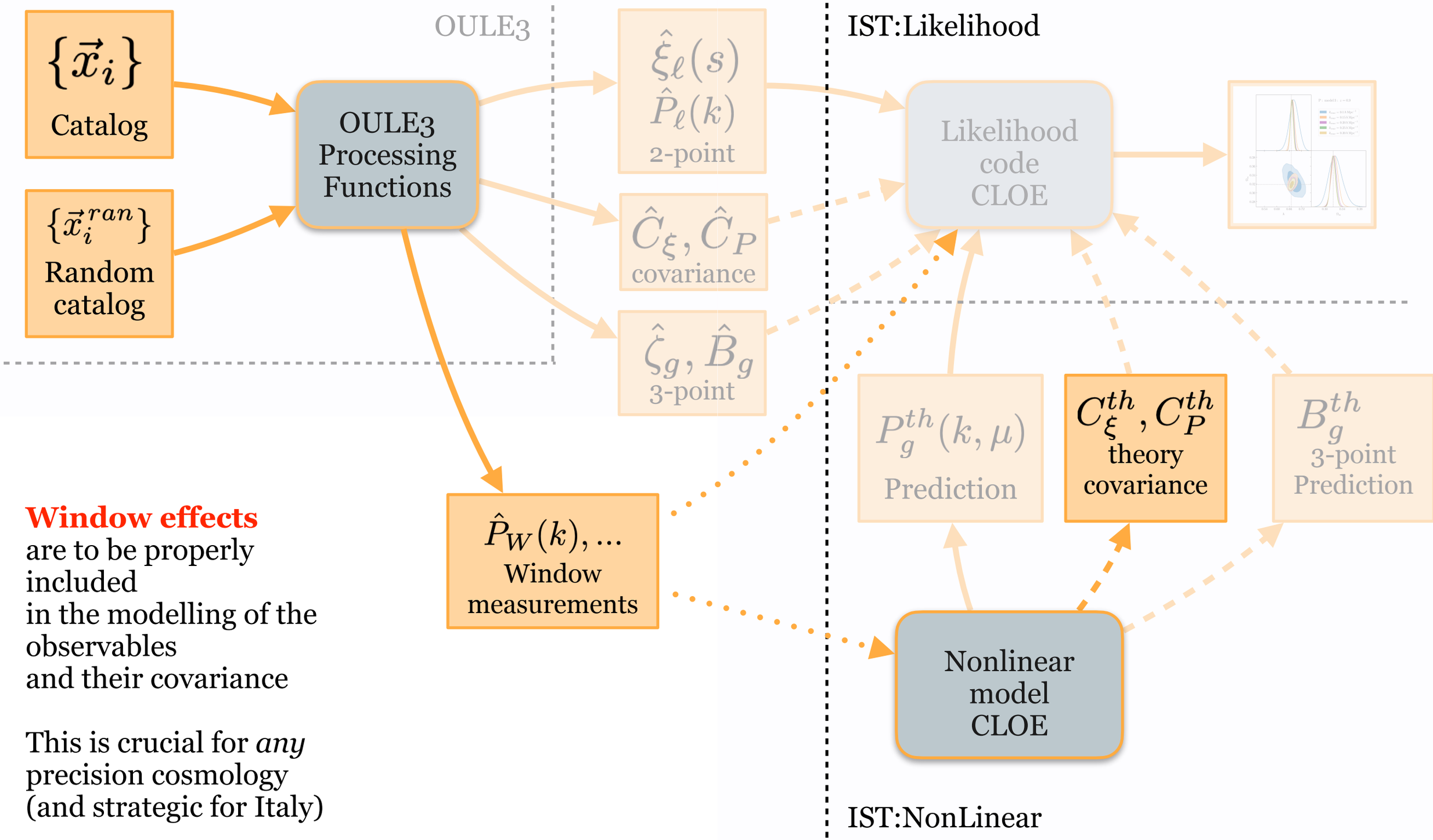
- Likelihood fits (soon)
- PT emulators
- Other NL models?
- Theory covariance
- Beyond SM (w/Theory SWG)



Galaxy Clustering Analysis: *beyond* the basic view



Galaxy Clustering Analysis: the *real thing*



Window effects
are to be properly included
in the modelling of the observables
and their covariance

This is crucial for *any* precision cosmology
(and strategic for Italy)

The near future

Tools about to be *tested* in the Euclid context (KPs)
then implement in CLOE

- **PT models**
  extensive tests on Flagship currently being run
- **PT/N-body emulators**
  lot of work being done here
- **Reconstruction methods/modelling**
- **Power Spectrum window convolution**
  Starting testing now, to be implemented in CLOE
- **Bispectrum window convolution**
  Main code developed, starting tests …
- **Theoretical covariance** for power spectrum and 2pcf (and bispectrum and 3pcf)
  Starting now … strong interaction with OULE3
- **Neutrinos & Beyond SM**
- …