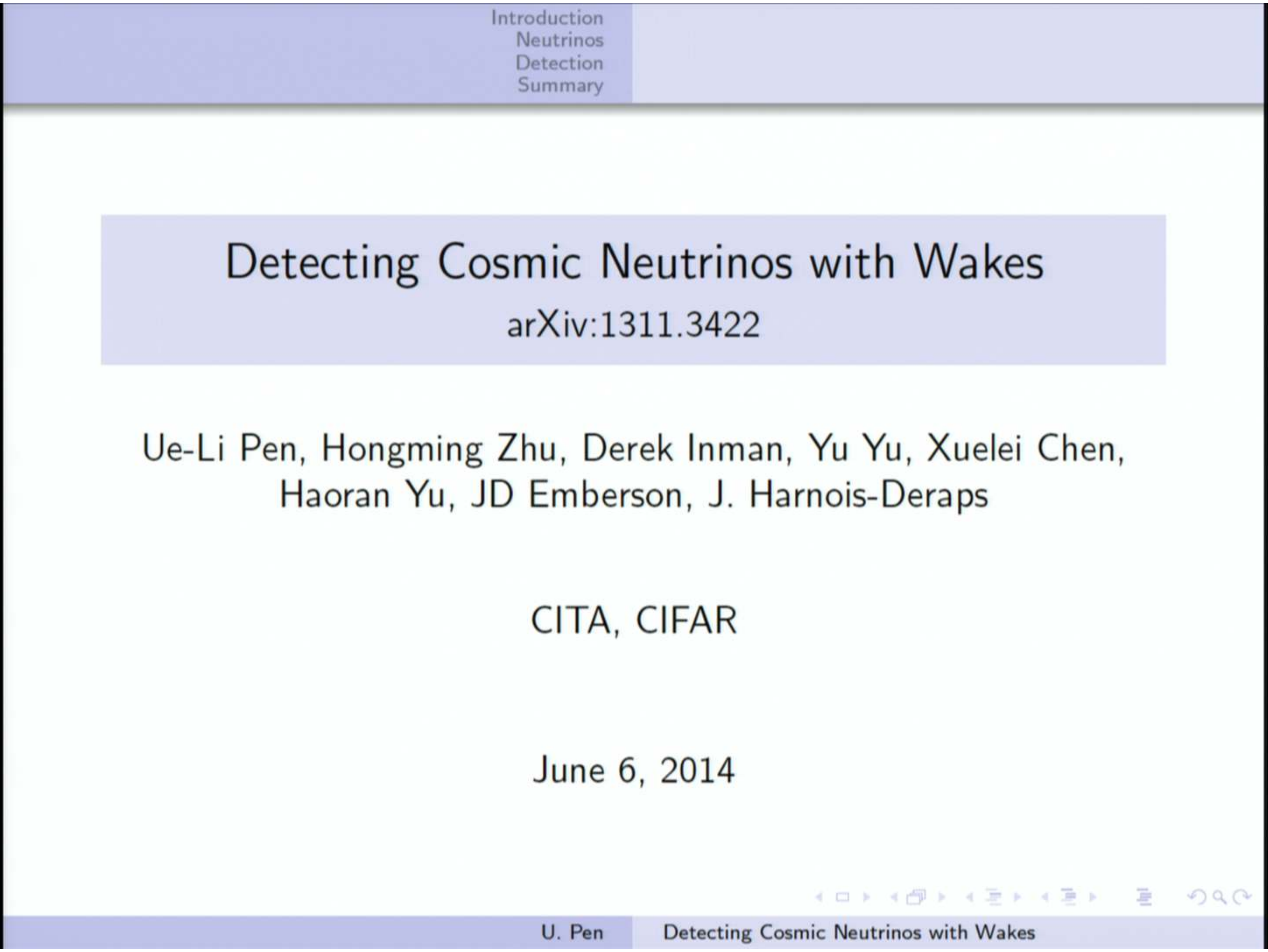
Title: Neutrino Wakes

Date: Jun 06, 2014 03:00 PM

URL: http://pirsa.org/14060041

Abstract: We identify a new non-linear neutrino wake effect, due to the streaming motions of neutrinos relative to dark matter, analogous to the Tseliakhovich-Hirata effect. We compute the effect in moving background perturbation theory, compare to direct n-body simulations, and forecast its observability in current and future surveys. Depending on neutrino mass, this effect could be observable in upcoming surveys through a cross correlation dipole in lensing and galaxies. Unlike previous cosmological neutrino effects, this depends primarily on neutrino mass, making it complementary to measurements that depend on neutrino density.



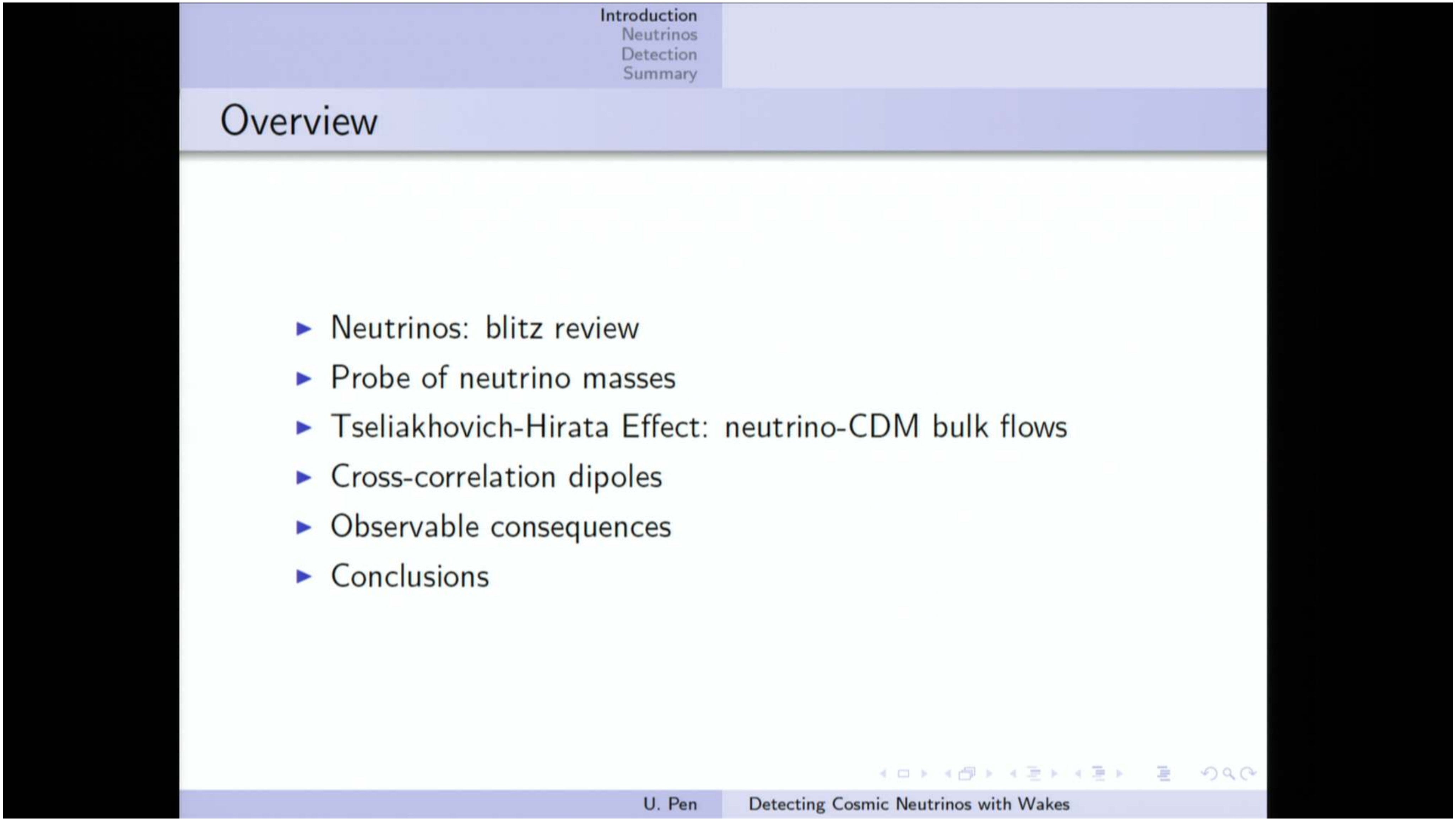
Detecting Cosmic Neutrinos with Wakes

arXiv:1311.3422

Ue-Li Pen, Hongming Zhu, Derek Inman, Yu Yu, Xuelei Chen,
Haoran Yu, JD Emberson, J. Harnois-Deraps

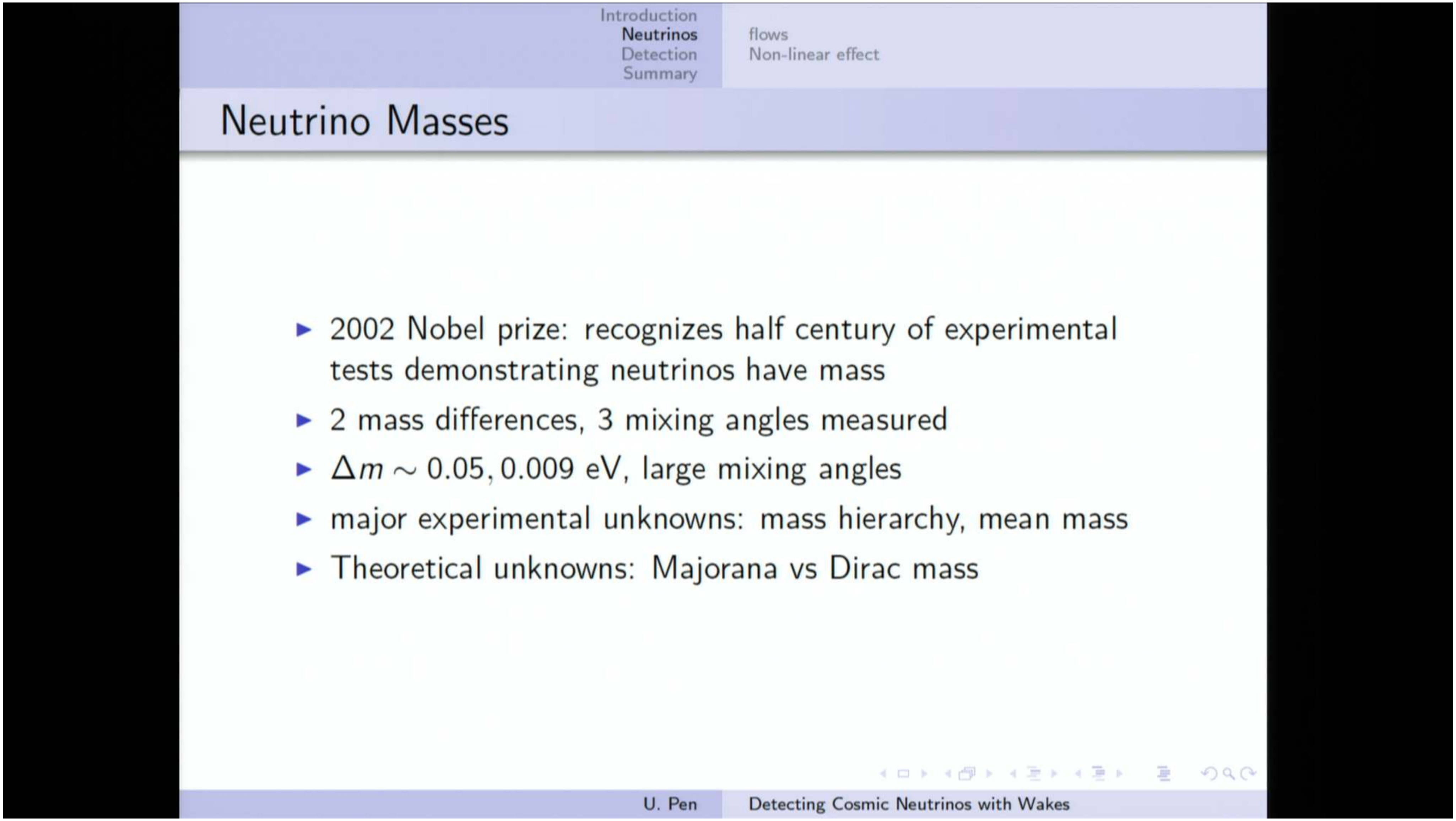
CITA, CIFAR

June 6, 2014



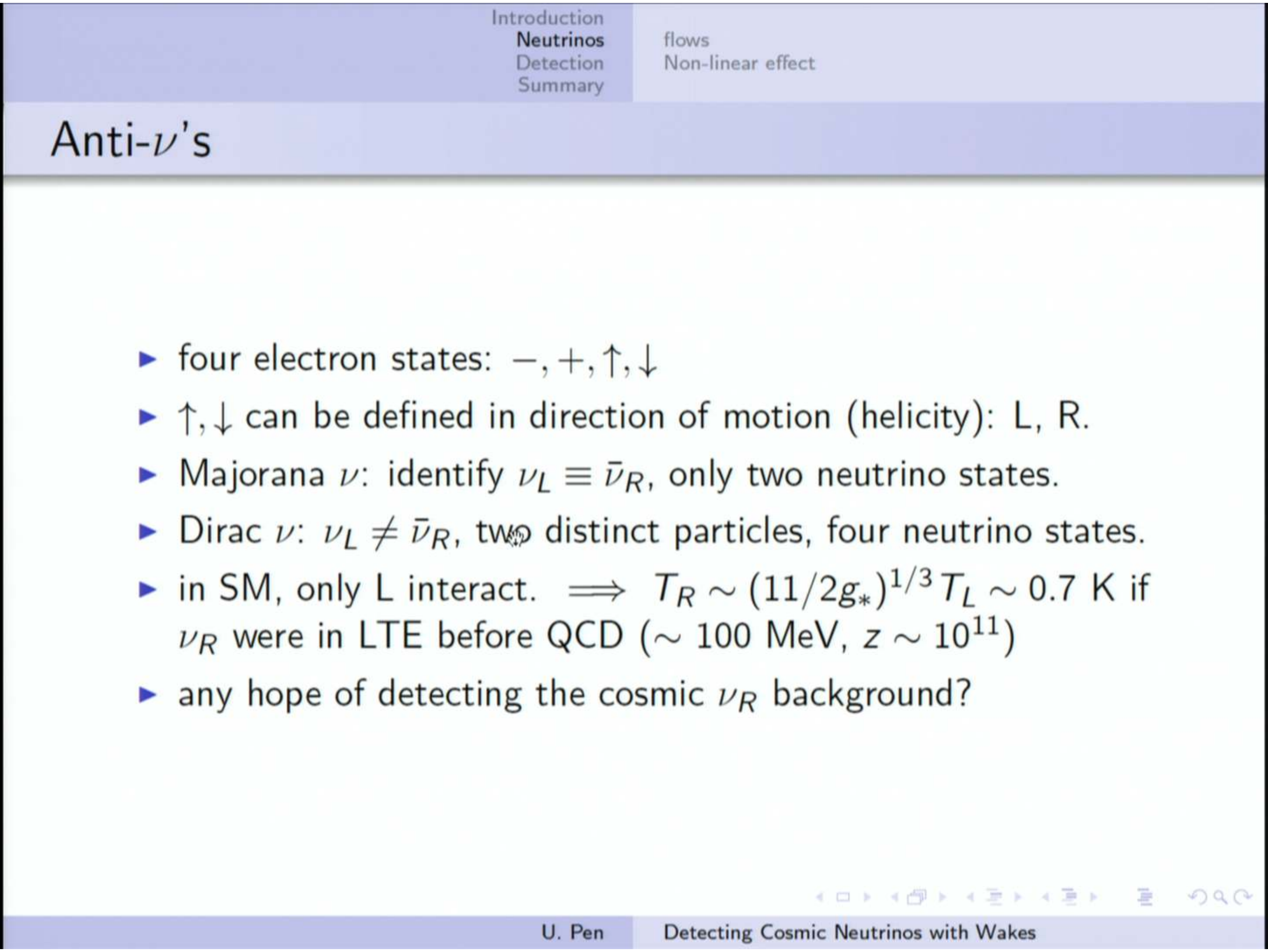
Overview

- Neutrinos: blitz review
- Probe of neutrino masses
- Tseliakhovich-Hirata Effect: neutrino-CDM bulk flows
- Cross-correlation dipoles
- Observable consequences
- Conclusions



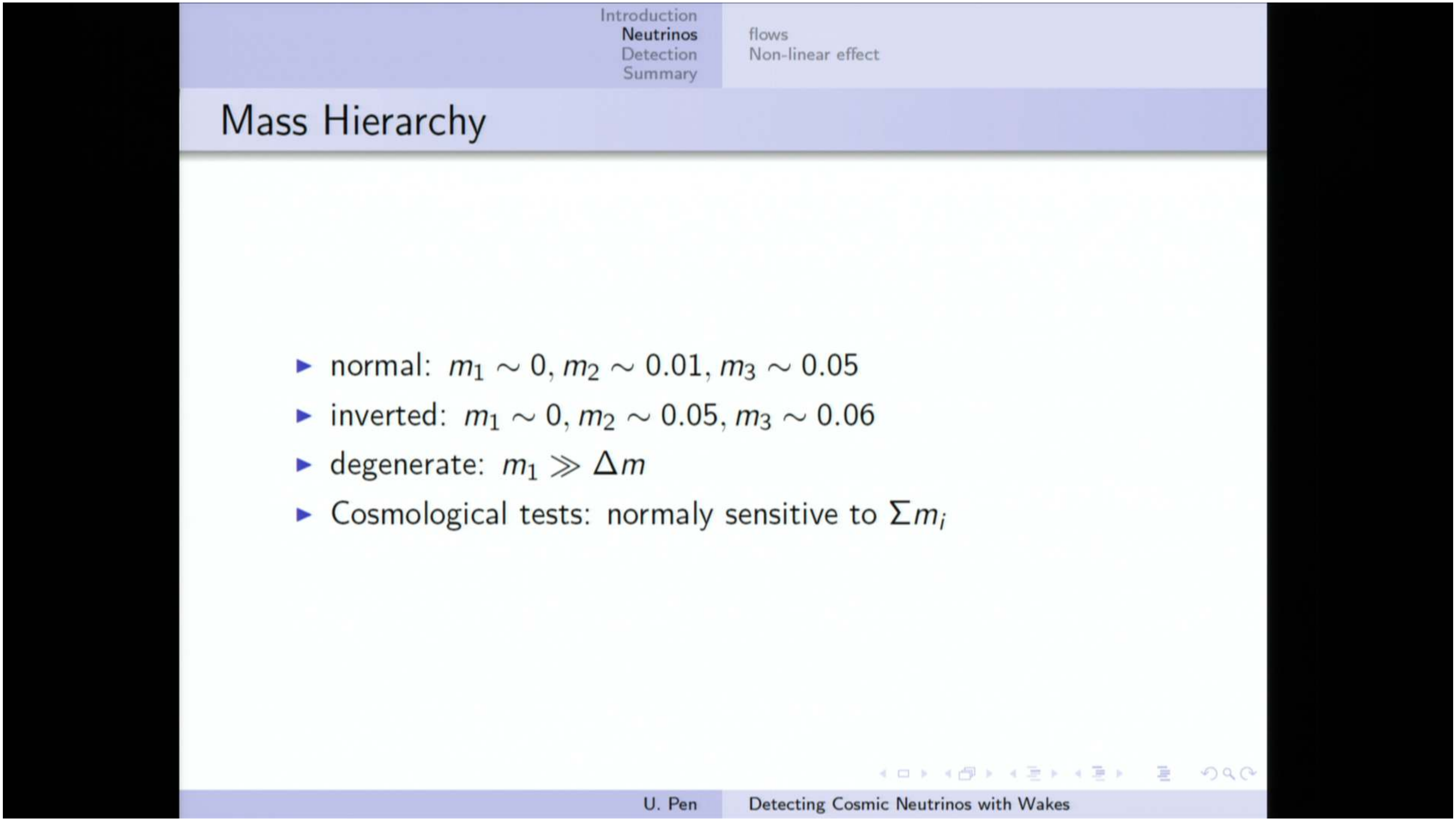
Neutrino Masses

- 2002 Nobel prize: recognizes half century of experimental tests demonstrating neutrinos have mass
- 2 mass differences, 3 mixing angles measured
- $\Delta m \sim 0.05, 0.009$ eV, large mixing angles
- major experimental unknowns: mass hierarchy, mean mass
- Theoretical unknowns: Majorana vs Dirac mass



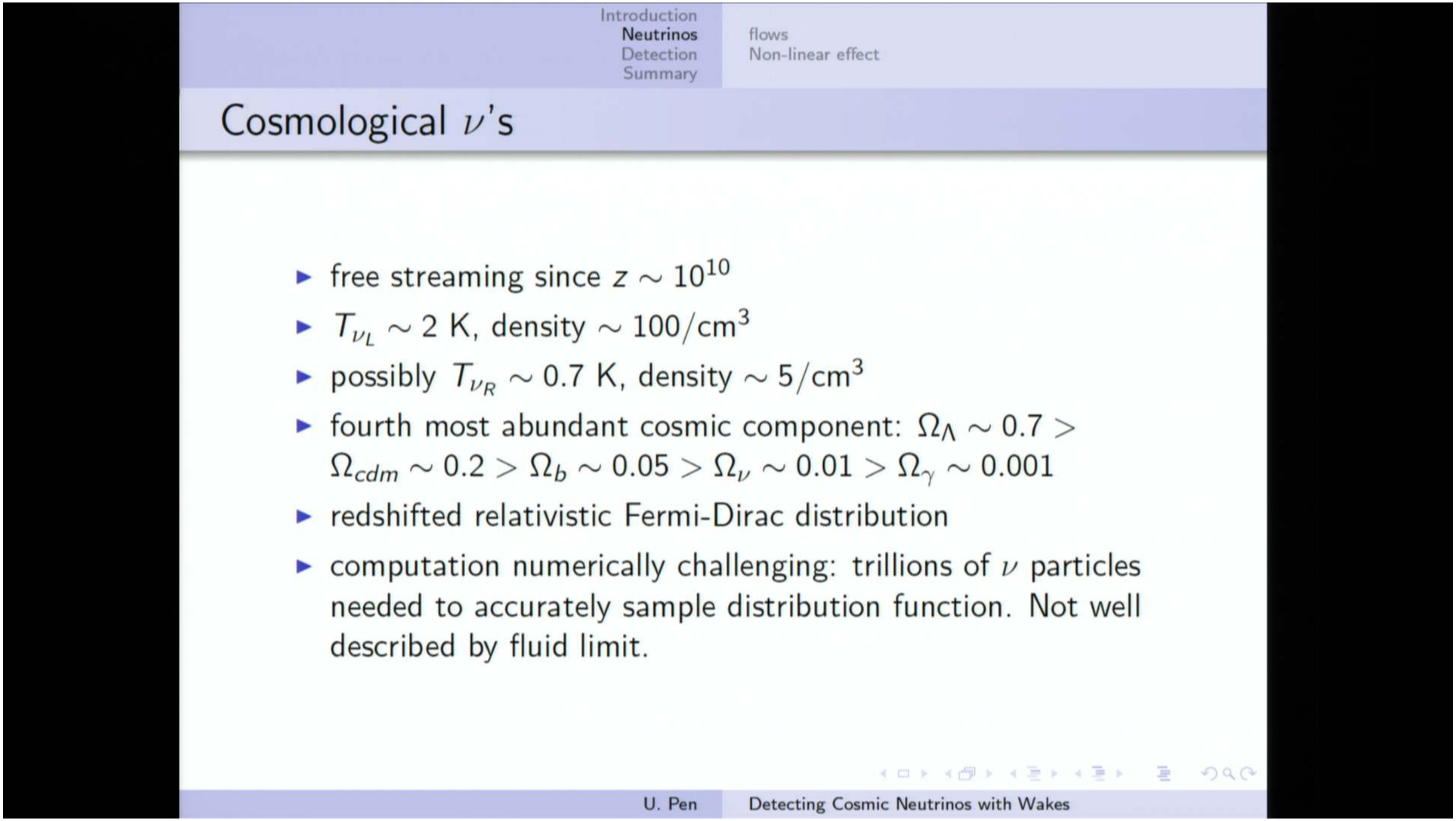
Anti-ν's

- four electron states: $-, +, \uparrow, \downarrow$
- $\uparrow, \downarrow$ can be defined in direction of motion (helicity): L, R.
- Majorana ν: identify $\nu_L \equiv \bar{\nu}_R$, only two neutrino states.
- Dirac ν: $\nu_L \neq \bar{\nu}_R$, two distinct particles, four neutrino states.
- in SM, only L interact. $\implies T_R \sim (11/2g_*)^{1/3} T_L \sim 0.7$ K if ν_R were in LTE before QCD (~ 100 MeV, $z \sim 10^{11}$)
- any hope of detecting the cosmic ν_R background?



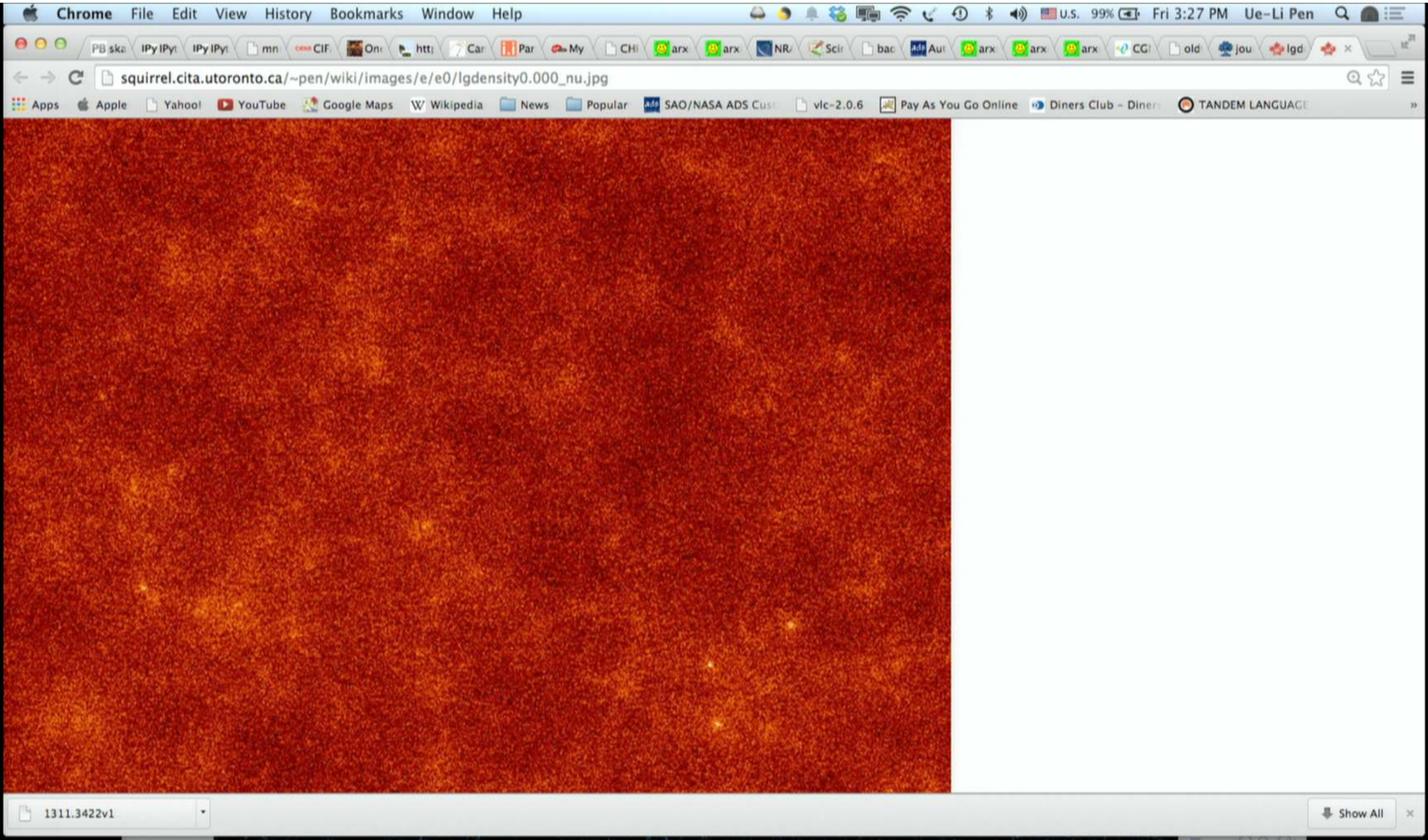
Mass Hierarchy

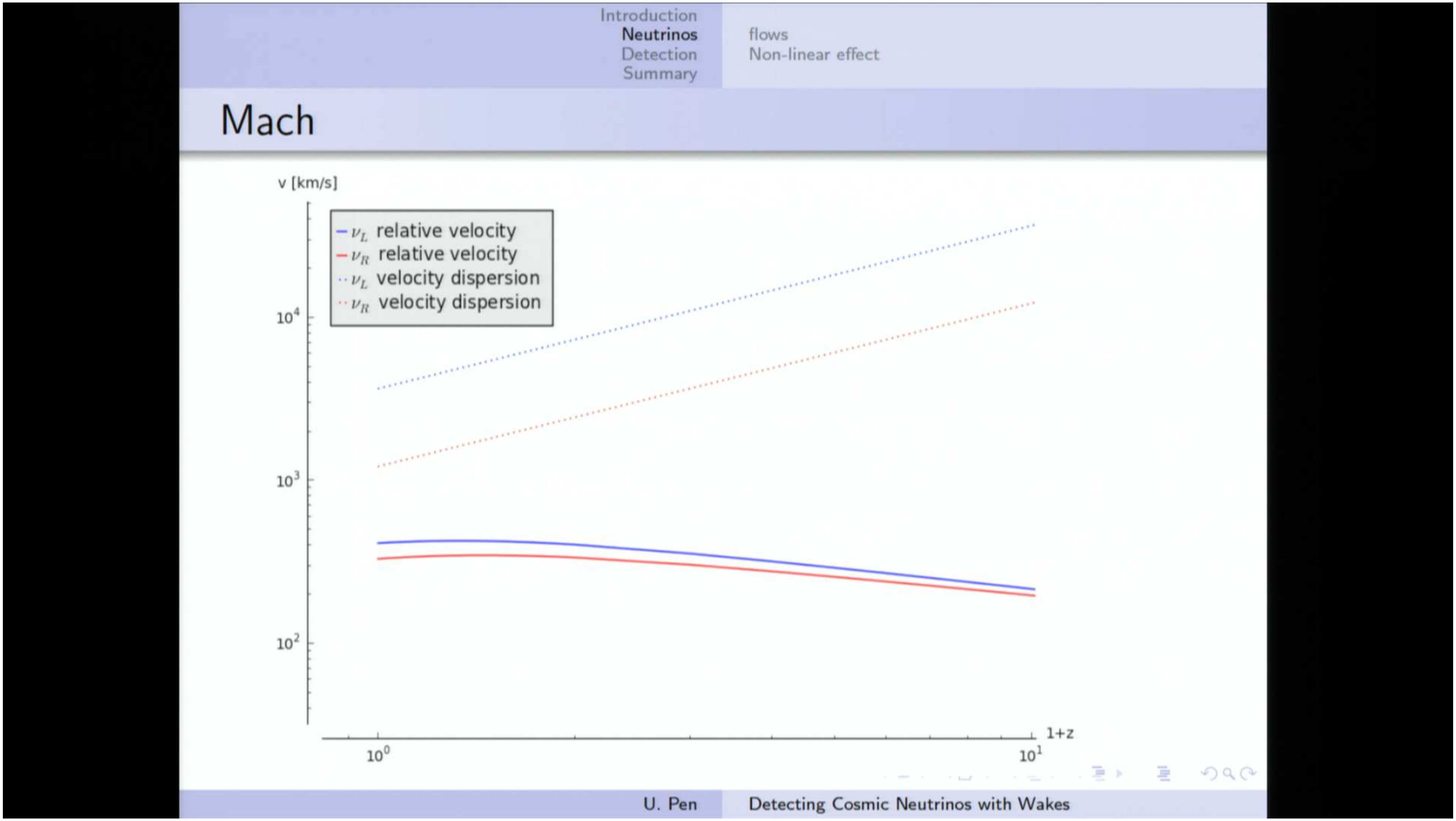
- normal: $m_1 \sim 0, m_2 \sim 0.01, m_3 \sim 0.05$
- inverted: $m_1 \sim 0, m_2 \sim 0.05, m_3 \sim 0.06$
- degenerate: $m_1 \gg \Delta m$
- Cosmological tests: normaly sensitive to Σm_i



Cosmological ν's

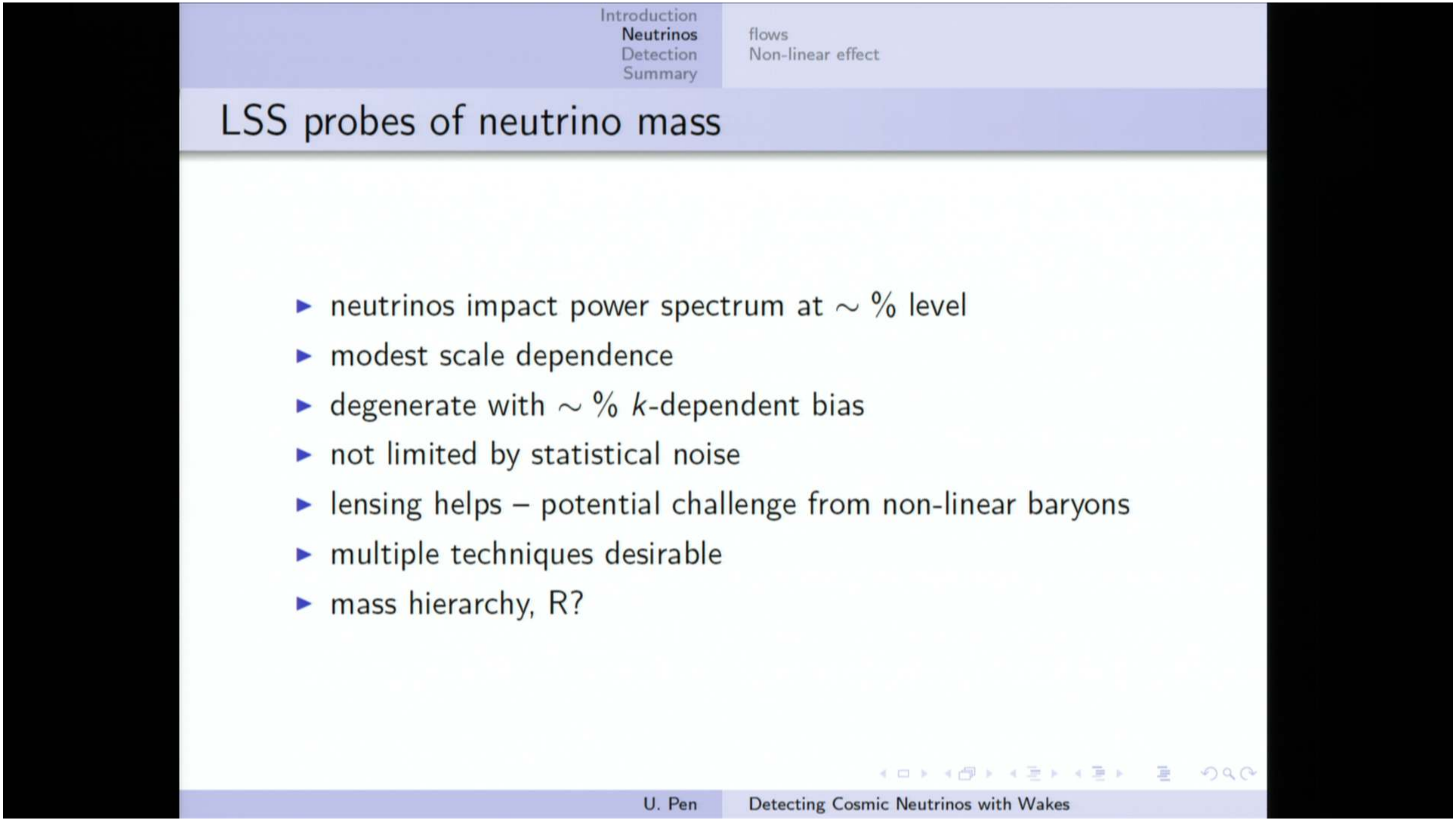
- free streaming since $z \sim 10^{10}$
- $T_{\nu_L} \sim 2$ K, density $\sim 100/\mathrm{cm}^3$
- possibly $T_{\nu_R} \sim 0.7$ K, density $\sim 5/\mathrm{cm}^3$
- fourth most abundant cosmic component: $\Omega_\Lambda \sim 0.7 > \Omega_{cdm} \sim 0.2 > \Omega_b \sim 0.05 > \Omega_\nu \sim 0.01 > \Omega_\gamma \sim 0.001$
- redshifted relativistic Fermi-Dirac distribution
- computation numerically challenging: trillions of ν particles needed to accurately sample distribution function. Not well described by fluid limit.


Chrome File Edit View History Bookmarks Window Help
Fri 3:27 PM Ue-Li Pen
squirrel.cita.utoronto.ca/~pen/wiki/images/e/e0/lgdensity0.000_nu.jpg
Apps Apple Yahoo! YouTube Google Maps Wikipedia News Popular SAO/NASA ADS Cus vlc-2.0.6 Pay As You Go Online Diners Club - Diner TANDEM LANGUAGE
1311.3422v1
Show All



Mach

v [km/s]
ν_L relative velocity
ν_R relative velocity
ν_L velocity dispersion
ν_R velocity dispersion
10^4
10^3
10^2
10^0
10^1
1+z



LSS probes of neutrino mass

- neutrinos impact power spectrum at $\sim \%$ level
- modest scale dependence
- degenerate with $\sim \%$ k-dependent bias
- not limited by statistical noise
- lensing helps – potential challenge from non-linear baryons
- multiple techniques desirable
- mass hierarchy, R?

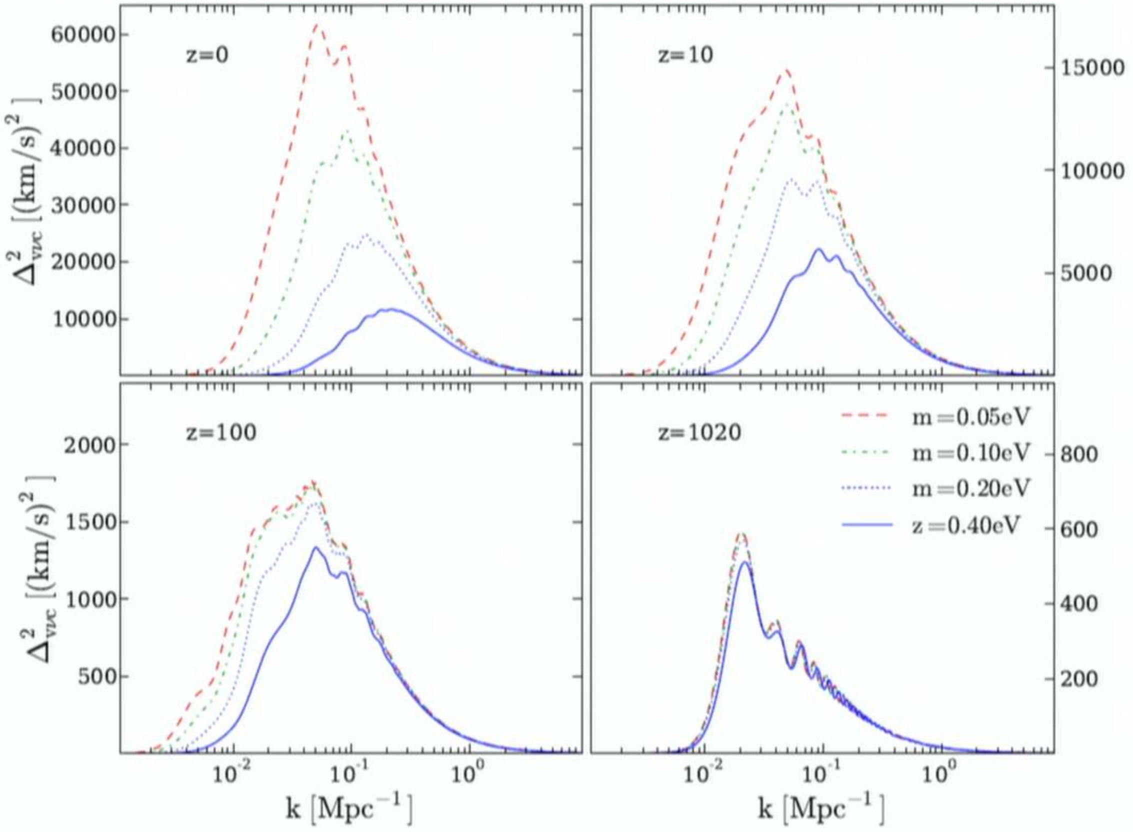
Tseliakhovich-Hirata Effect

- Tseliakhovich and Hirata (2010) realized that baryons and dark matter develop non-perturbative relative velocity flows after recombination.
- Analogous effect for neutrino-dark matter flow

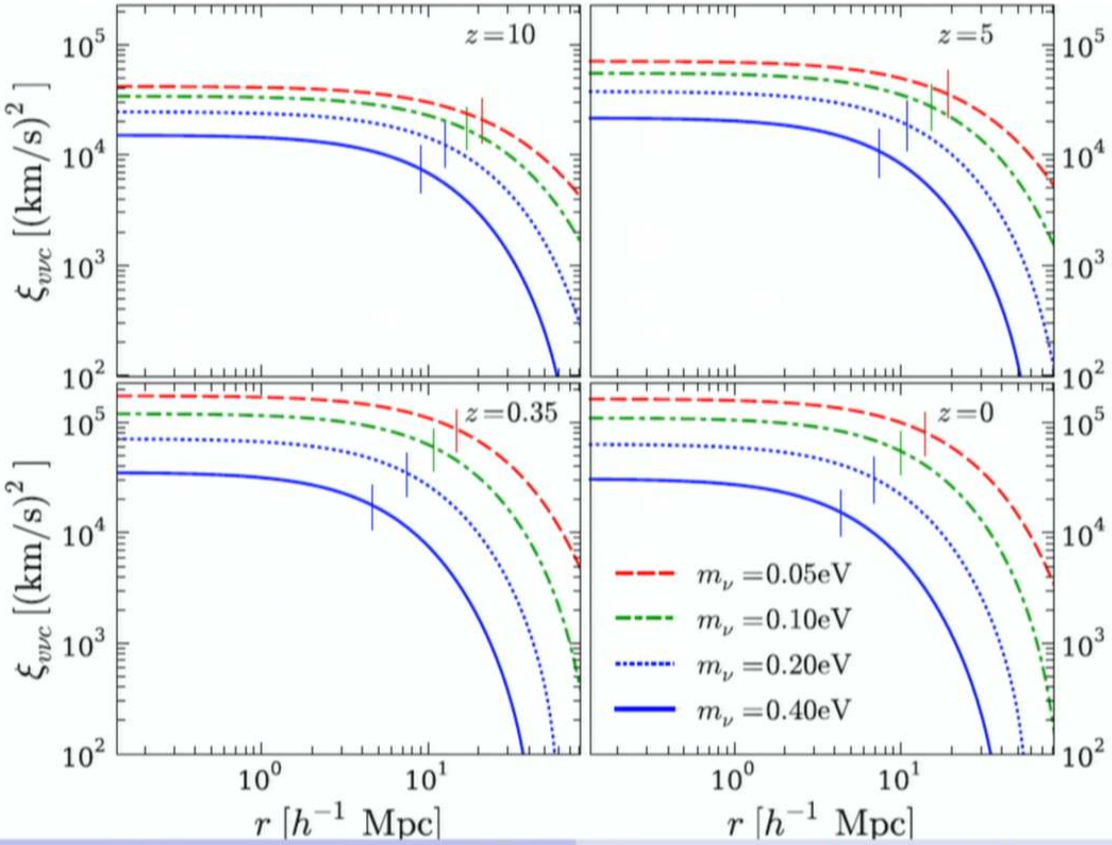
CDM-ν flows

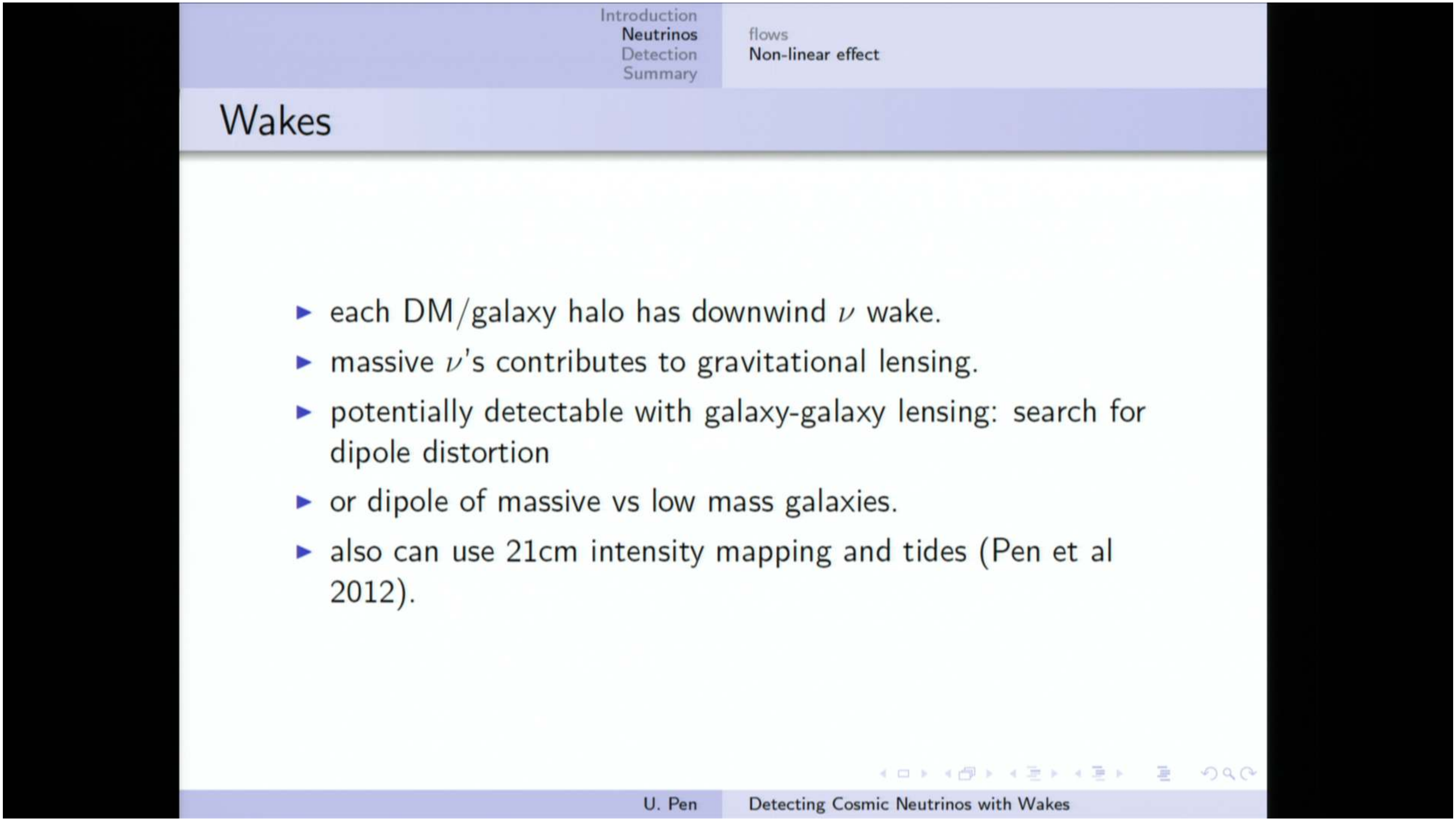
- linear theory predicts velocity of all fluids from density field
- neutrino density: $\delta_\nu = \delta_c \frac{T_\nu}{T_c}$
- velocity: $\vec{v}_\nu \sim \delta_\nu \dot{T}_\nu \frac{i\vec{k}}{k^2}$
- relative flow: $\vec{v}_{c\nu} \sim \delta_g \frac{\dot{T}_c - \dot{T}_\nu}{T_c} \frac{i\vec{k}}{k^2}$
- use galaxy survey (e.g. SDSS) to predict $\delta_c, \delta_\nu, v_{c\nu}$
- predictable today at high S/N.

Flows


z=0
z=10
z=100
z=1020
$\Delta^2_{\nu c}$ [(km/s)^2]
60000
50000
40000
30000
20000
10000
15000
10000
5000
2000
1500
1000
500
800
600
400
200
m =0.05eV
m =0.10eV
m =0.20eV
z =0.40eV
10^{-2}
10^{-1}
10^{0}
k [Mpc^{-1}]

Coherence

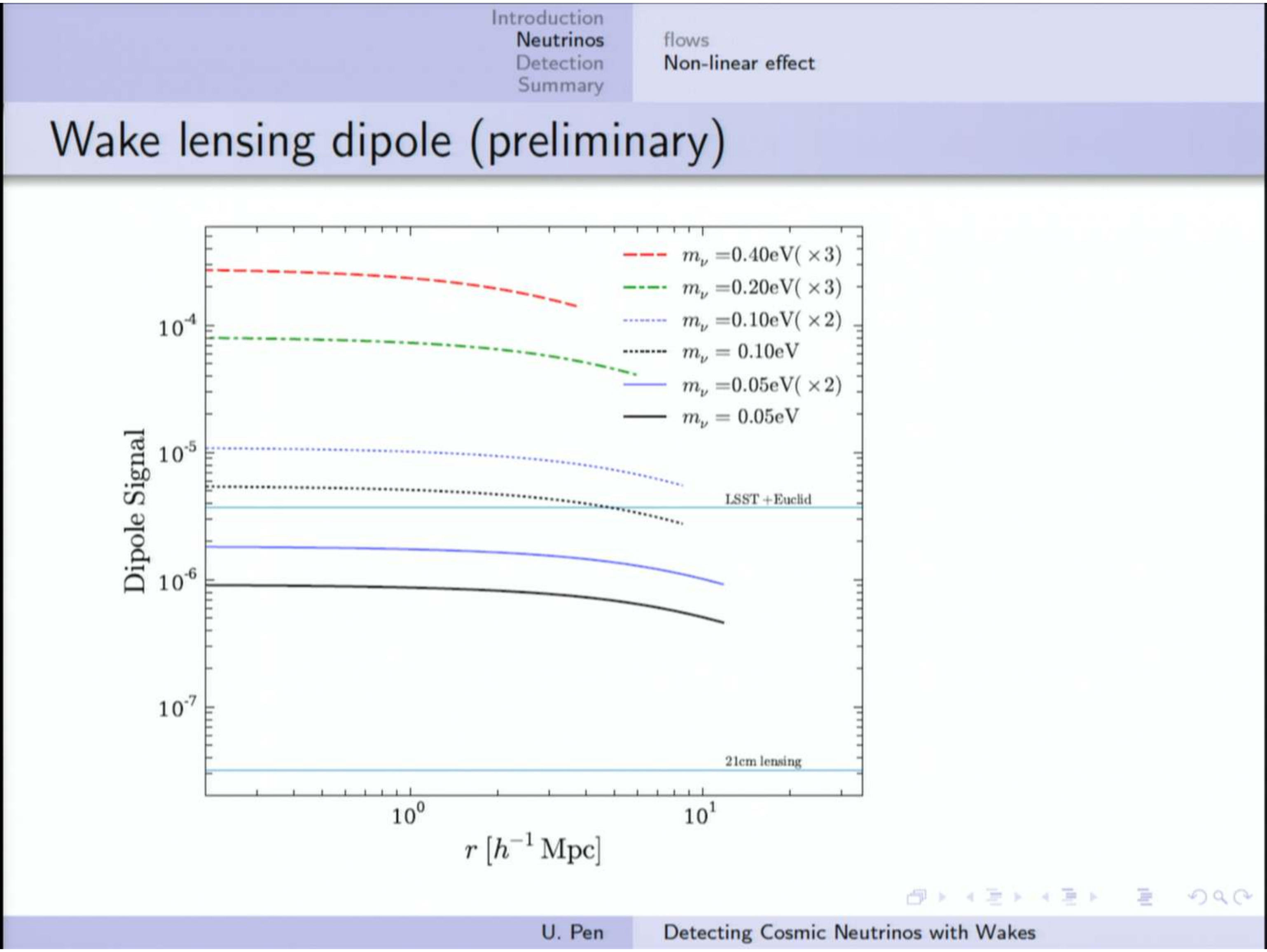

$z = 10$
$z = 5$
$z = 0.35$
$z = 0$
$\xi_{vvc}\ [(\mathrm{km/s})^2]$
10^5
10^4
10^3
10^2
10^0
10^1
$r\ [h^{-1}\ \mathrm{Mpc}]$
$m_\nu = 0.05\mathrm{eV}$
$m_\nu = 0.10\mathrm{eV}$
$m_\nu = 0.20\mathrm{eV}$
$m_\nu = 0.40\mathrm{eV}$

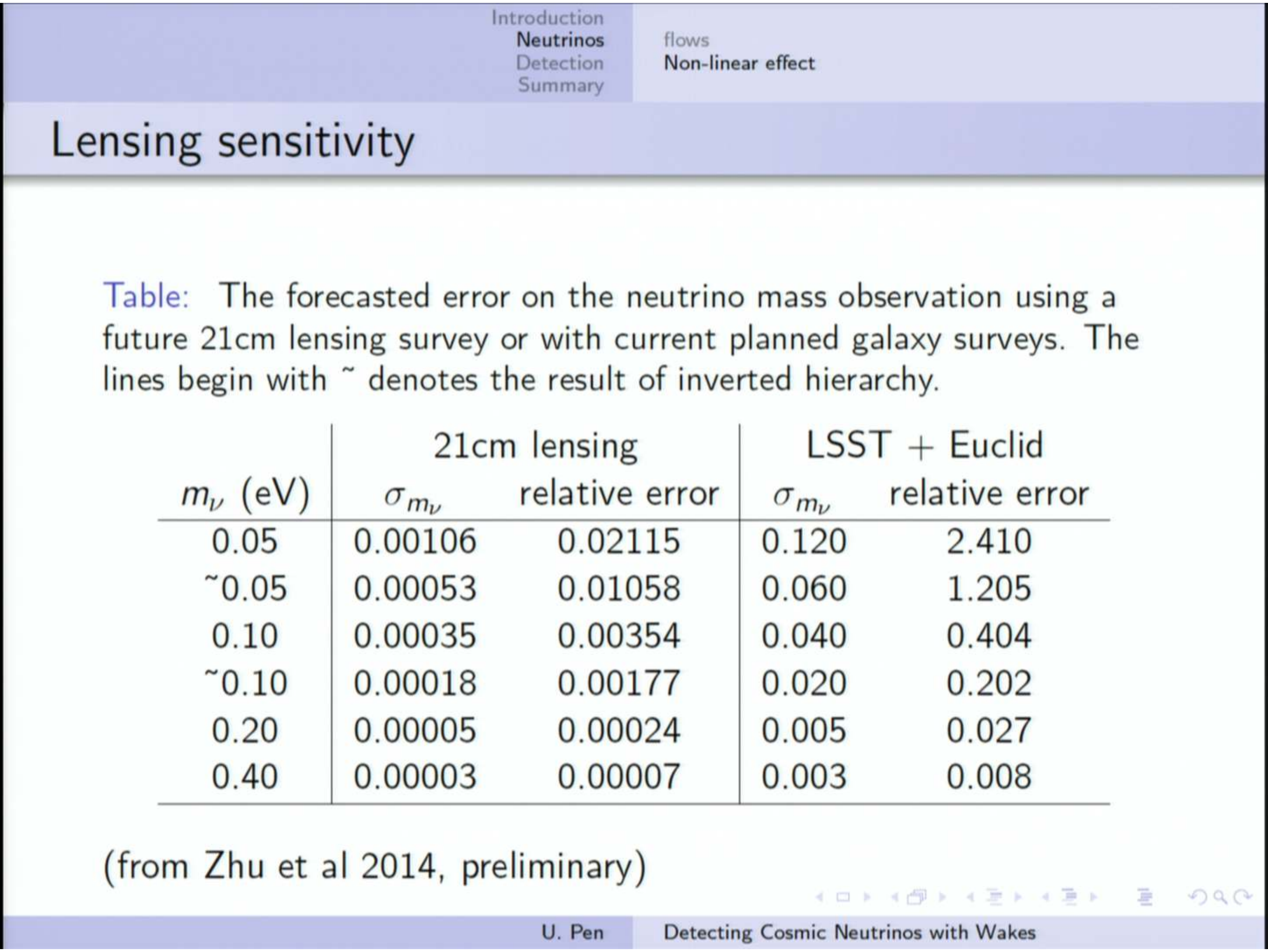


Wakes

- each DM/galaxy halo has downwind ν wake.
- massive ν's contributes to gravitational lensing.
- potentially detectable with galaxy-galaxy lensing: search for dipole distortion
- or dipole of massive vs low mass galaxies.
- also can use 21cm intensity mapping and tides (Pen et al 2012).

Wake lensing dipole (preliminary)



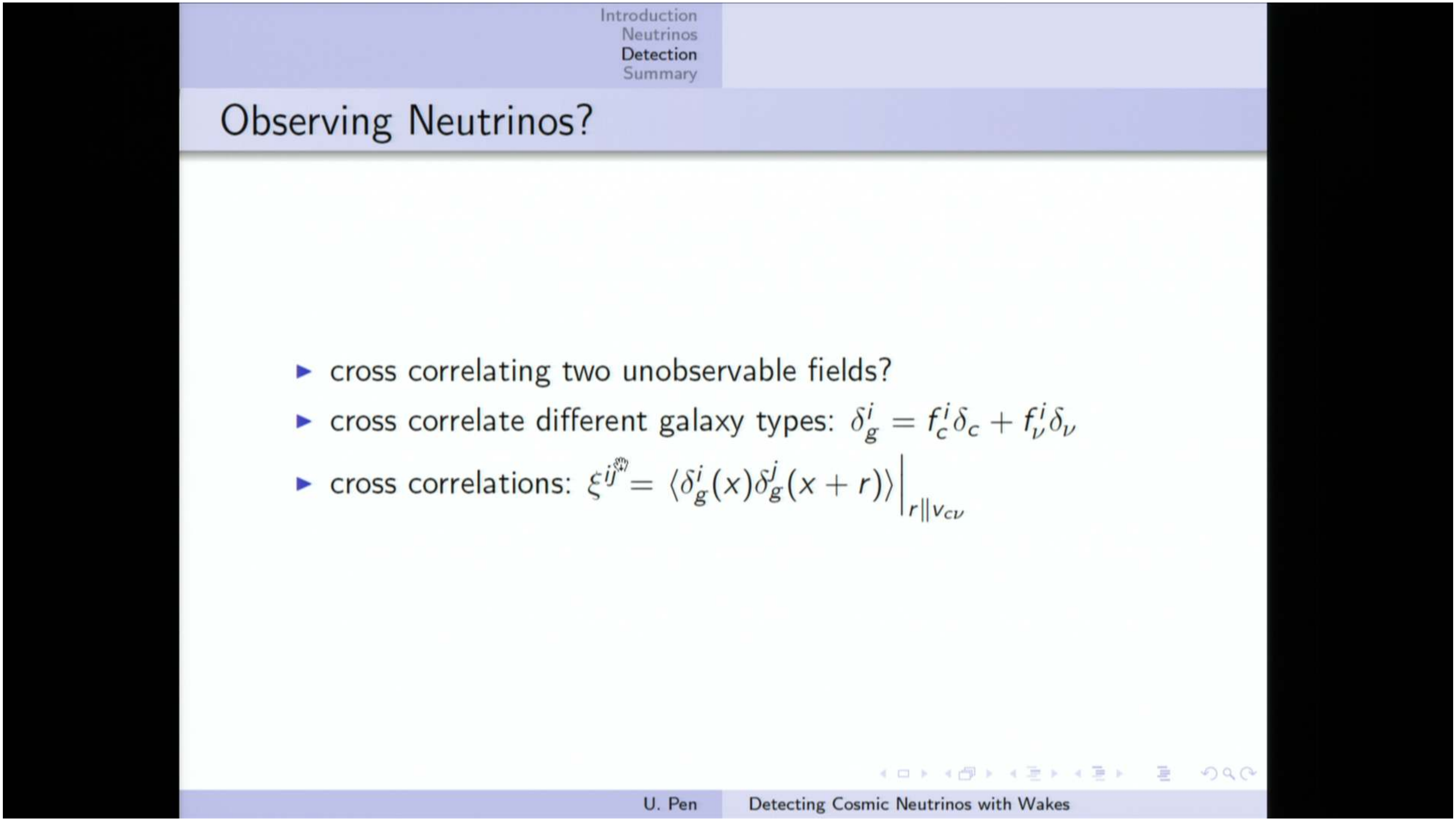


Lensing sensitivity

Table: The forecasted error on the neutrino mass observation using a future 21cm lensing survey or with current planned galaxy surveys. The lines begin with ˜ denotes the result of inverted hierarchy.

	21cm lensing		LSST + Euclid	
m_ν (eV)	σ_{m_ν}	relative error	σ_{m_ν}	relative error
0.05	0.00106	0.02115	0.120	2.410
˜0.05	0.00053	0.01058	0.060	1.205
0.10	0.00035	0.00354	0.040	0.404
˜0.10	0.00018	0.00177	0.020	0.202
0.20	0.00005	0.00024	0.005	0.027
0.40	0.00003	0.00007	0.003	0.008

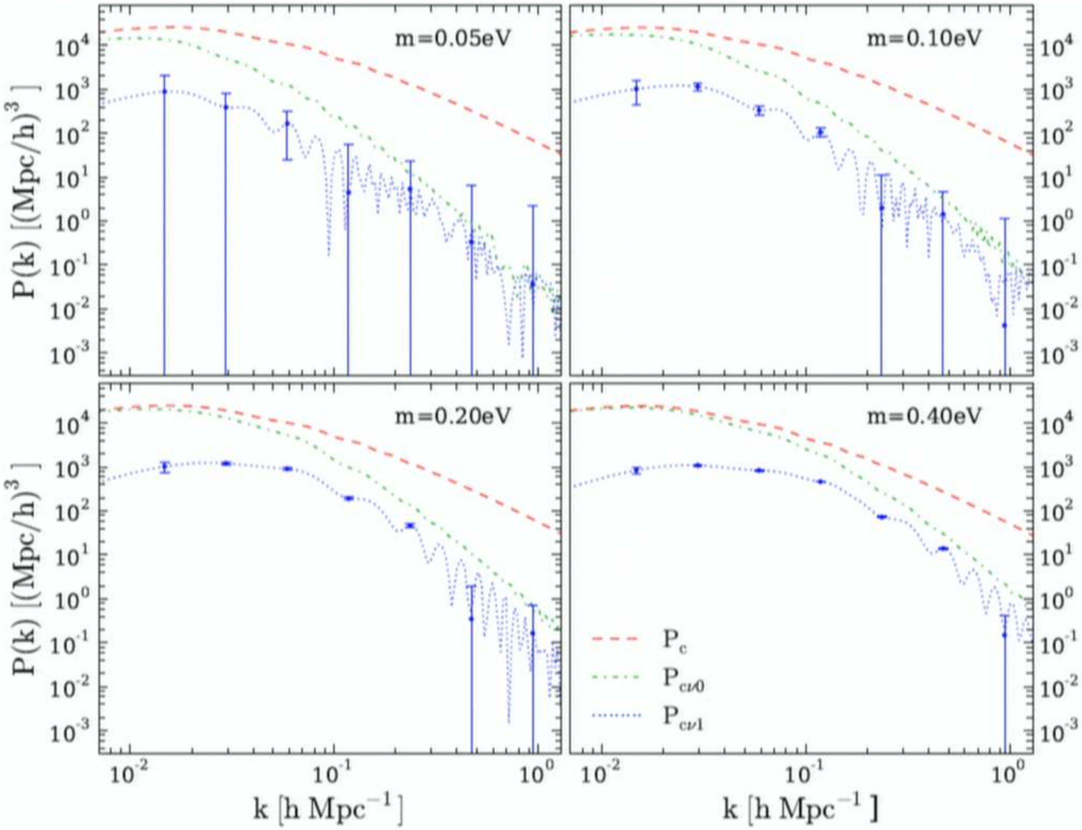
(from Zhu et al 2014, preliminary)

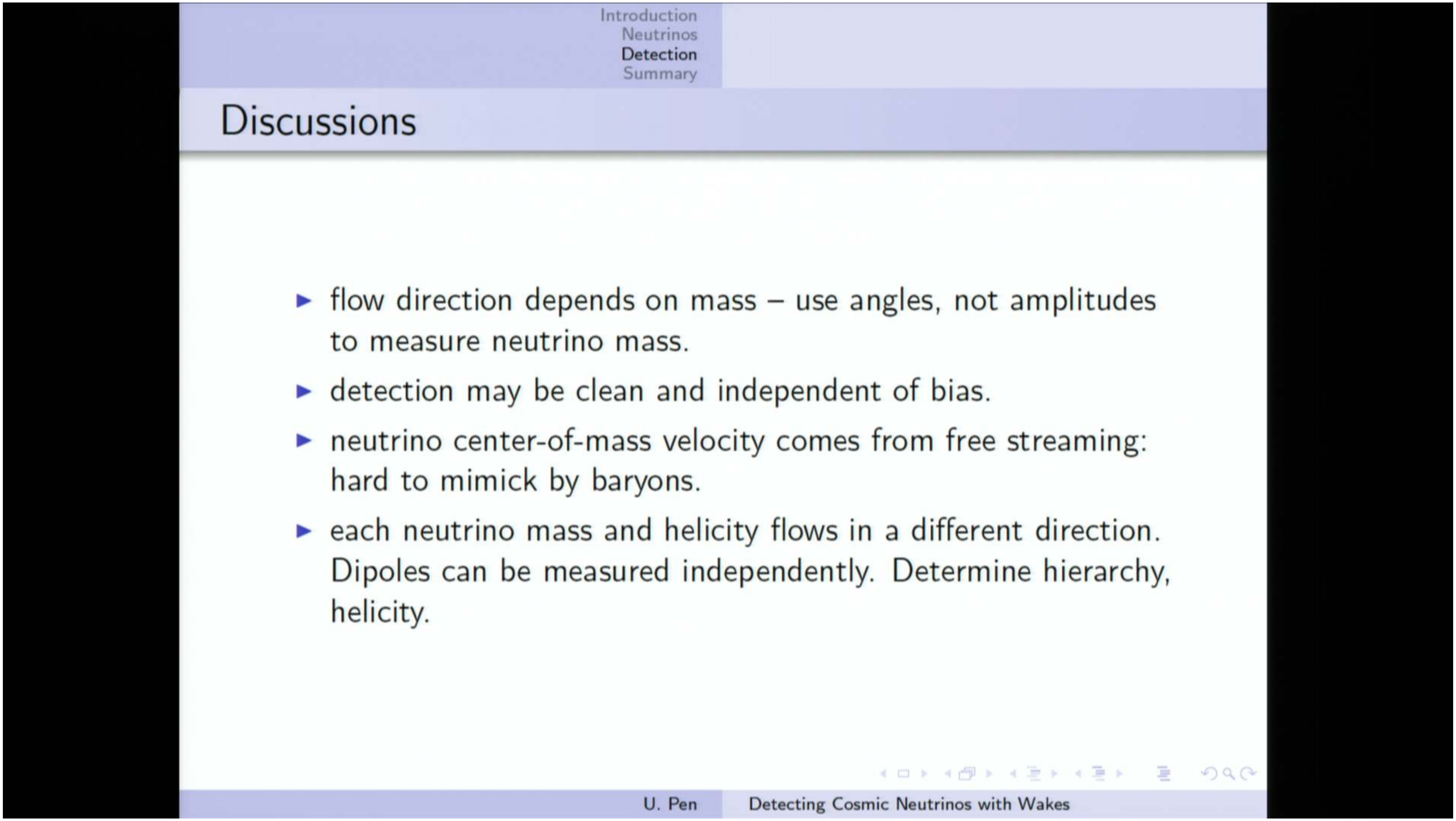


Observing Neutrinos?

- cross correlating two unobservable fields?
- cross correlate different galaxy types: $\delta_g^i = f_c^i \delta_c + f_\nu^i \delta_\nu$
- cross correlations: $\xi^{ij} = \langle \delta_g^i(x) \delta_g^j(x+r) \rangle \Big|_{r \| v_{c\nu}}$

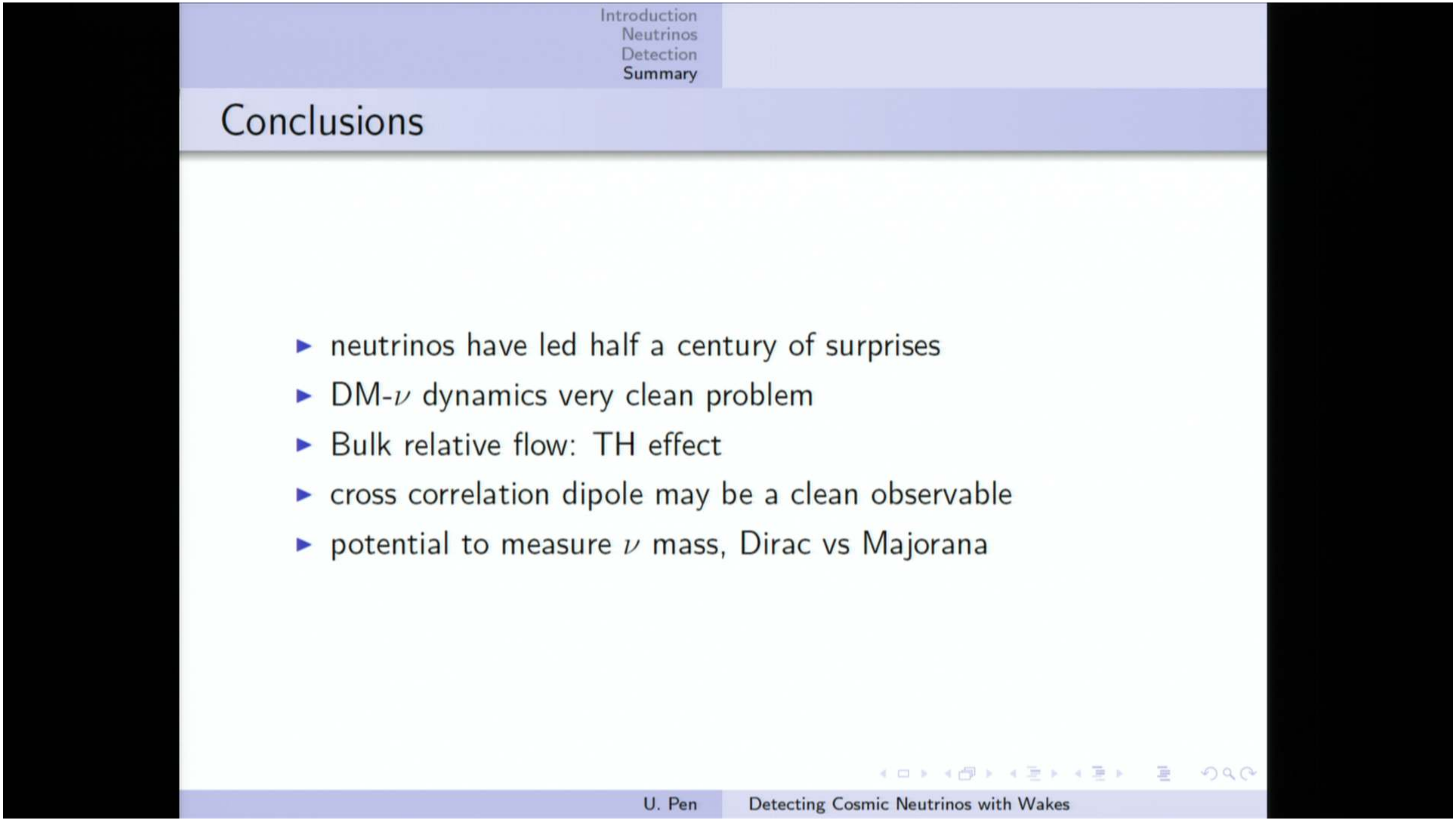
cross power


m=0.05eV
m=0.10eV
m=0.20eV
m=0.40eV
$P(k)\ [(\mathrm{Mpc}/h)^3]$
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}
10^0
$k\ [h\ \mathrm{Mpc}^{-1}]$
P_c
$P_{c\nu 0}$
$P_{c\nu 1}$



Discussions

- flow direction depends on mass – use angles, not amplitudes to measure neutrino mass.
- detection may be clean and independent of bias.
- neutrino center-of-mass velocity comes from free streaming: hard to mimick by baryons.
- each neutrino mass and helicity flows in a different direction. Dipoles can be measured independently. Determine hierarchy, helicity.



Conclusions

- neutrinos have led half a century of surprises
- DM-ν dynamics very clean problem
- Bulk relative flow: TH effect
- cross correlation dipole may be a clean observable
- potential to measure ν mass, Dirac vs Majorana