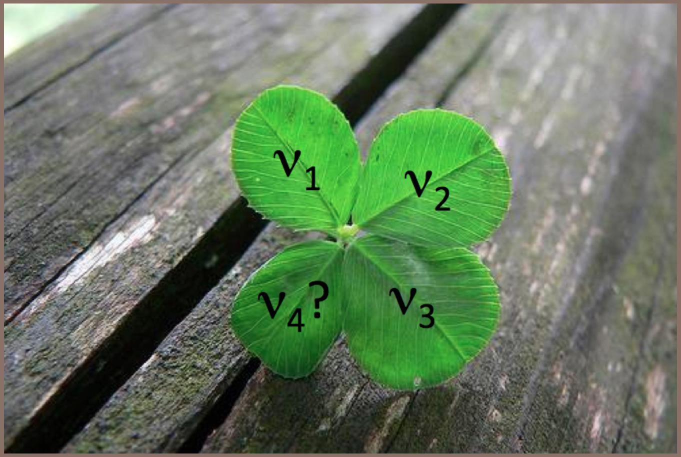
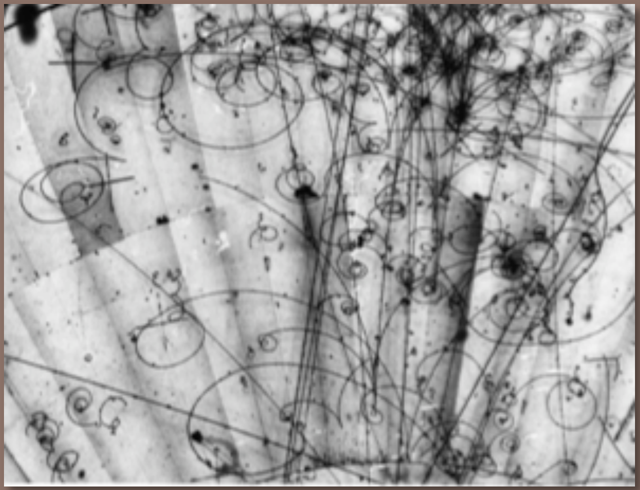
CROSS SECTION & FLUXES GROUP REPORT



Sam Zeller

SBL Workshop

March 21, 2012



- status report on behalf of our sub-group …

Cross Section and Flux Group

- Bonnie Fleming (Yale)
- Debbie Harris (FNAL)
- Patrick Huber (Virginia Tech)
- Chris Polly (FNAL)
- Sam Zeller (FNAL)*

* facilitator

- our task is to examine the neutrino cross sections and fluxes that are most relevant to a potential SBL program at Fermilab

- which σ's, Φ's are important?
- what is the status quo right now? how will this evolve in the future?
- what add'l meas might we need to ensure definitive SBL results?

Experiments Measure ν Rates

- oscillation experiments measure a neutrino interaction *rate* from which we get out information on oscillation parameters:

$$N(E_\nu) = \sigma(E_\nu) \times \Phi(E_\nu) \times \varepsilon$$

- neutrino interaction cross sections and fluxes play a crucial role in the interpretation of neutrino oscillation data

- short-baseline investigations are no exception

Which σ_ν and Φ_ν's are Important?

- depends on the neutrino source and the neutrino target
  (P. Huber, B. Fleming)

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- **π^+ decay-at-rest**
  - example: *LSND*
  - $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
  - $\lesssim$ 50 MeV
  - signal detection via inverse β decay

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  - example: *MiniBooNE*
  - $\nu_\mu \rightarrow \nu_e$, $\nu_\mu \rightarrow \nu_\mu$ and same for $\bar{\nu}_\mu$
  - 0.2-3 GeV range
  - signal detection via ν-nucleus QE scattering (mostly)

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have narrowed our initial discussions at least to these accelerator-based options but there are also radioactive sources, reactors, β beams

Experience From Existing Experiments

- to understand the role that neutrino σ and Φ knowledge plays in ν_e appearance experiments, we have started to survey experiments who have made such measurements (adding ν_μ disappearance, where applicable):

* **LSND** (G. Mills)
- π DAR example

* **MiniBooNE** (C. Polly)
- π DIF example
- lower energy ν beam, single detector system

* **MINOS** (T. Vahle)
- π DIF example
- higher energy ν beam, 2 detector set-up

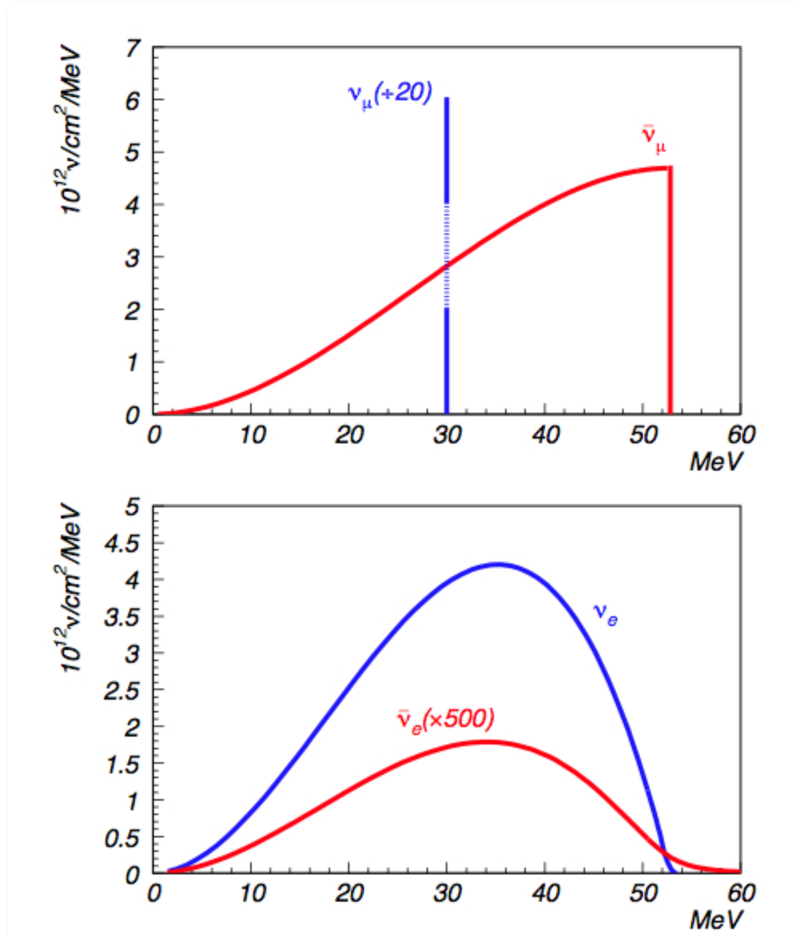
"lessons learned"
proposal vs. reality

π^+ DAR & LSND Experience

- *well-defined ν spectrum*

$$\pi^+ \rightarrow \mu^+ \nu_\mu$$
$$\hookrightarrow e^+ \nu_e \bar{\nu}_\mu$$

  - μ^+ DAR flux known to 7%
  - processes with well-known σ's to check flux normalization e.g., $\nu+e^-$, $^{12}C(\nu_e,e^-)^{12}N_{g.s.}$



(G. Mills)

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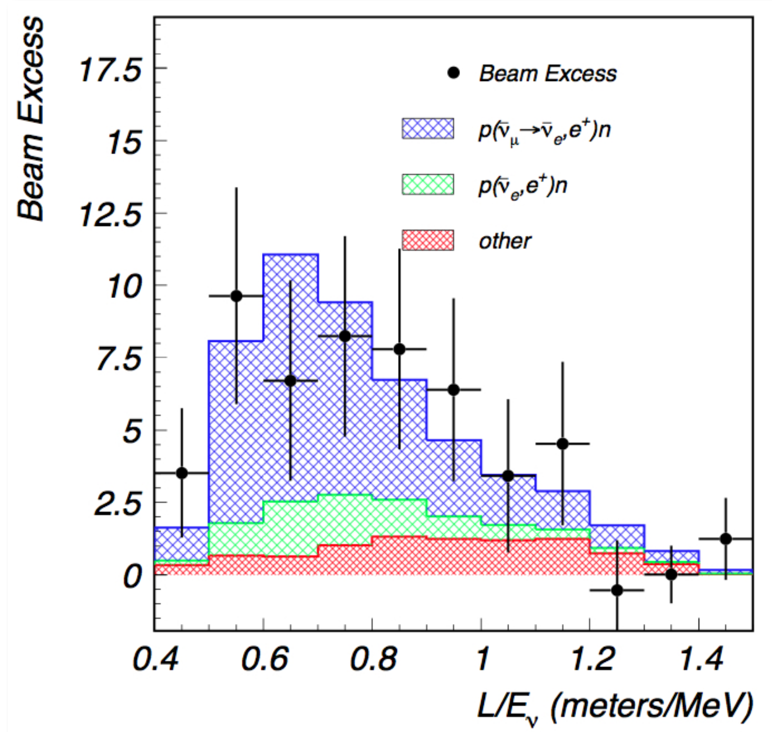
- *well-defined signal (IBD)*

$\bar{\nu}_e\, p \rightarrow e^+\, n$

  - 2 fold-signature $\Rightarrow$ low ν bkgs
  - well-known σ (few-%)



(G. Mills)

π DIF & MB/MINOS Experience

- *ν spectra known to 10's of %*
  - dependent on having good hadro-production constraints as input
  - needed to help break σ, Φ degeneracies
  - important that these be at same beam energies, on same target

  (see talks on MIPP (R. Rajendran) and N61/SHINE (D. Schmitz))

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- *ν cross sections become more complicated as move up in energy …*
  - affects both signal and background estimates
  - ν-nucleus scattering, both elastic and inelastic processes

- some (but not all) of these issues can be mitigated by having a capable near detector (T. Vahle, D. Harris)

ν Cross Sections for DIF Beams

- large uncertainties in the few-GeV energy range

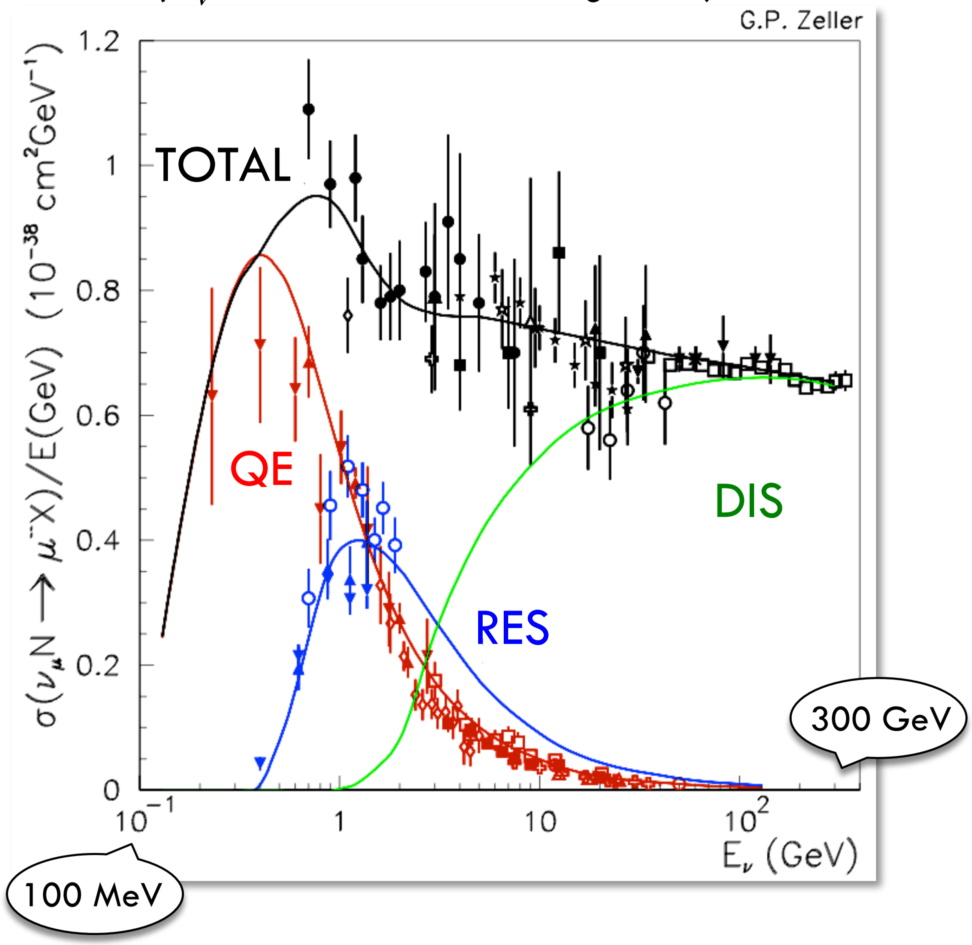
  (compared to low and high E_ν)

- lots of rich physics here

- we have been probing this region with increased precision recently …

- ex., new results on QE scattering challenging assumptions about the size and source of nuclear effects in this energy range

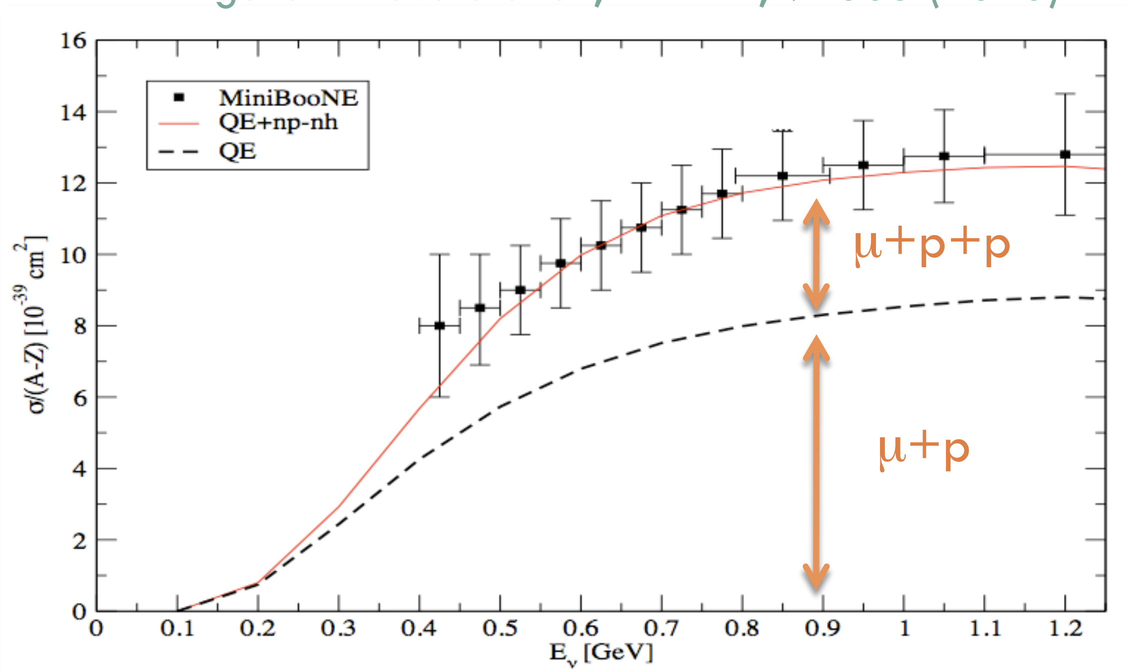
(σ_ν across 3 orders of magnitude)



Under-Appreciated Nuclear Effects

- there may be add'l nuclear dynamics present in ν-nucleus scattering
  (i.e., effects that we have not included in our standard independent particle approach)

Aguilar-Arevalo *et al.*, PRD **81**, 92005 (2010)



Martini *et al.*, PRC **80**, 065001 (2009)

- ν can scatter off of a strongly correlated nucleon state; <u>multi-nucleon correls</u> produce an enhancement in the QE cross section

  (40% increase in σ_{QE} at ~1 GeV)

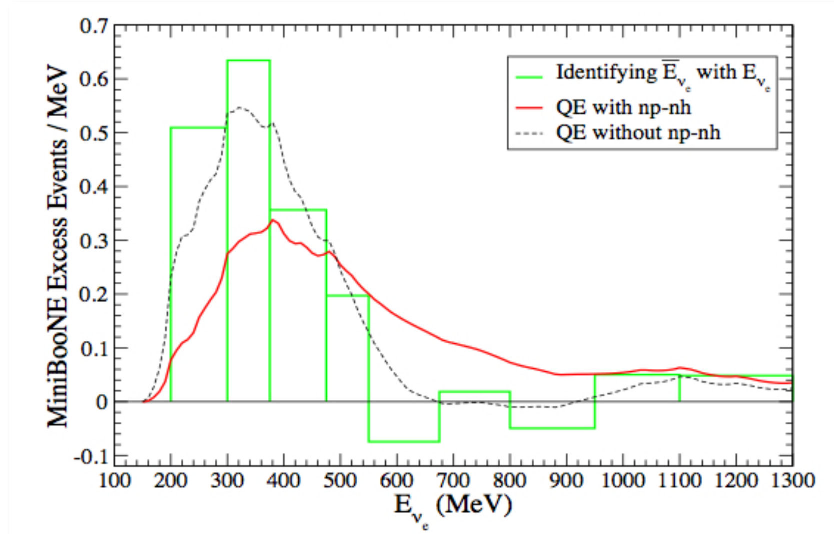
- seen e^- scattering
  J. Carlson *et al.*, PRC **65**, 024002 (2002)

- over 50 theoretical papers on this topic in past year+

Areas of Specific Concern

- how well do we reconstruct E_ν?

  (M. Martini et al., arXiv:1202.4745;
  O. Lalkulich et al., arXiv: 1203.2935)



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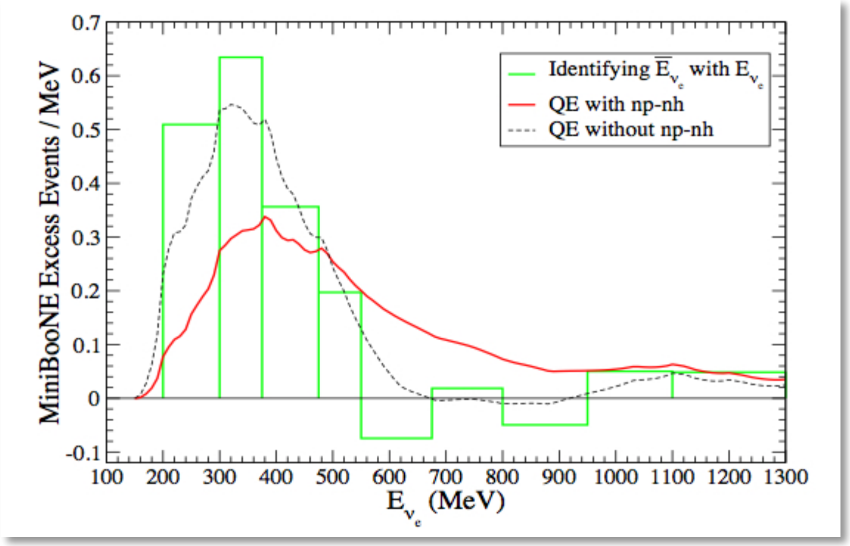
  (presentation by Natalie Jachowicz
  "there is a lot we know we don't know")



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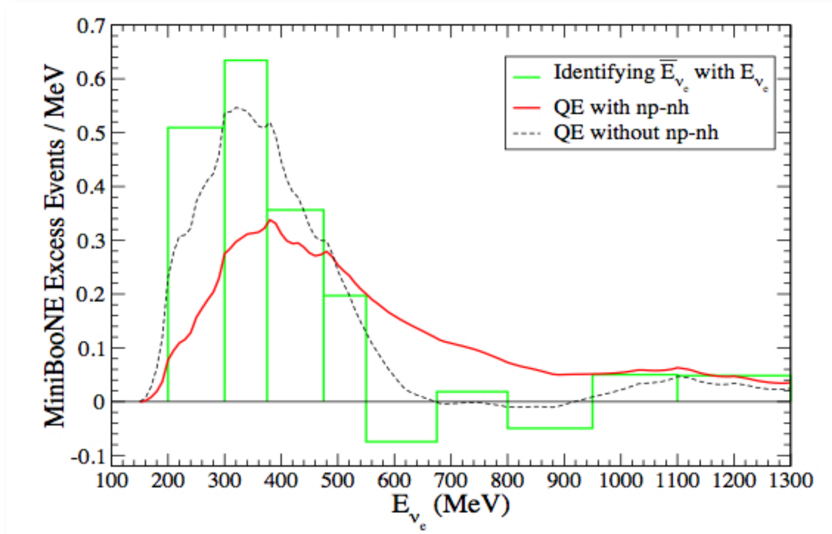

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- can there be similar nuclear effects impacting background predictions
  - NC π^0 for ν_e appearance, CC π for ν_μ disappearance?

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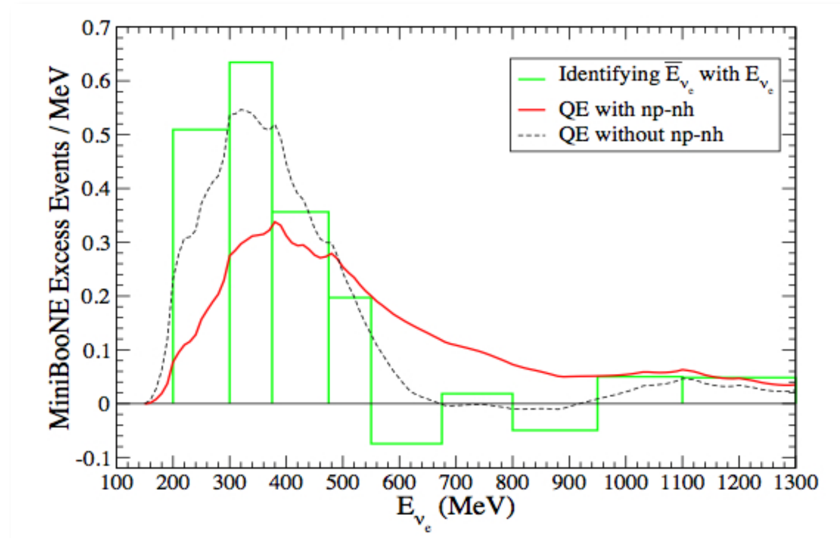

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- are there additional sources of NC γ backgrounds?
  - resonant radiative decays ($\Delta \rightarrow N\gamma$) but also "new" SM sources
  (R. Hill, PRD **84**, 017501 (2011); J. Jenkins *et al.*, PRD **80**, 053005 (2009); X. Zhang (IU))

What Might We Learn Soon?*

- additional MiniBooNE, SciBooNE, NOMAD analyses plus …

- Booster neutrino energies
  - **MicroBooNE** (argon)
  - **T2K** near detector (carbon, water)

- NuMI neutrino energies
  - **MINERνA** (multiple targets, LE and ME)
  - **NOνA** near detector (carbon, off-axis, NDOS)
  - **ICARUS** (argon)

* with help from Laura Fields (Northwestern)

Future Opportunities

σ_ν

- **MINERvA upgrades**
  - H_2, D_2 targets

- **SciNOvA**
  - fine-grained detector in NOvA off-axis beam

- **VLENF** (A. Bross)
  - measurement of neutrino σ's in a different, more well-known beam
  - first measurements of ν_e and $\overline{\nu}_e$ cross sections

Φ_ν

- **MIPP, NA61/SHINE** (R. Rajendran, D. Schmitz)
  - important for oscillations and also σ measurements

Conclusions

- neutrino cross sections are more complex and therefore problematic especially when scattering on nuclei and in few-GeV energy region (DIF harder than DAR)

- need good ν flux constraints (both in planning, data analysis, σ_ν)

- certainly want a capable near detector, but that may not be enough

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- we are in the middle of our discussions

- if you have other ideas for us to consider or want to express an opinion or give a presentation to our sub-group, please contact us!

input is welcome!