Neutrino hazard and FLUKA simulations

D. Lucchesi, Alfredo Ferrari, Anna Ferrari, P. Sala

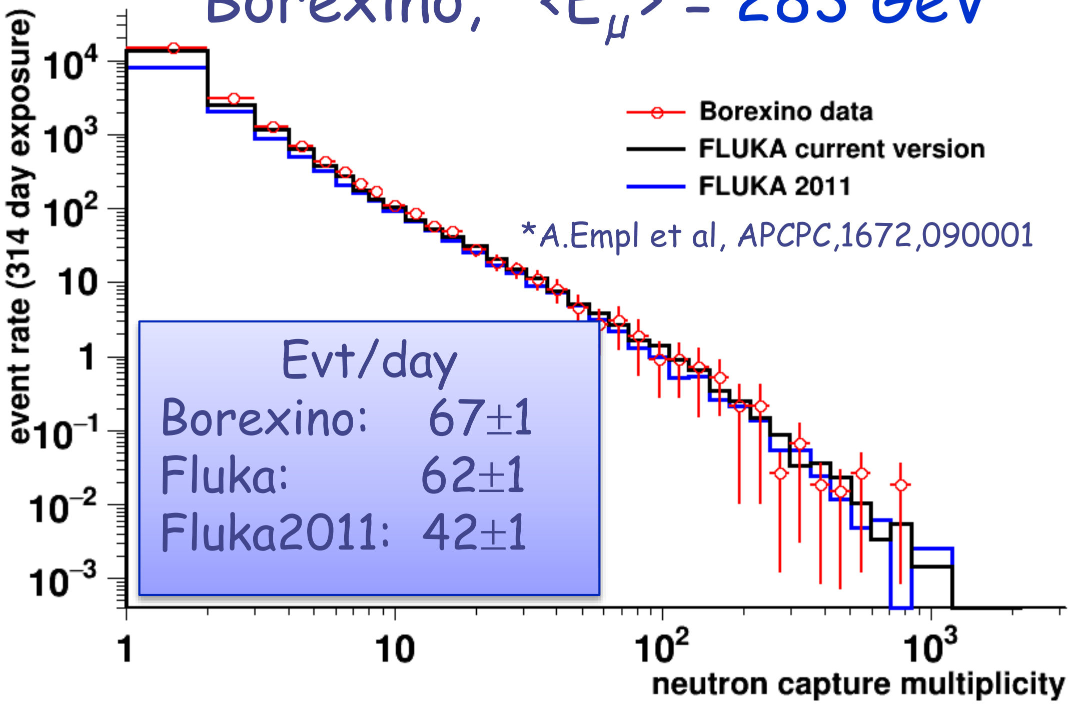
Workplan

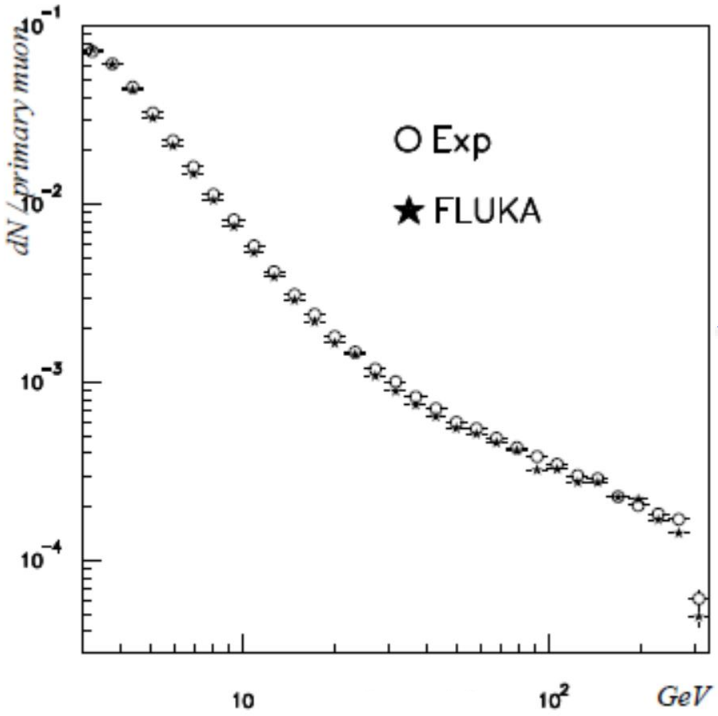
- Build tools and possibly improve simulation models for a coherent FLUKA description of
- Detectors background
- Radiation hazards from neutrinos (this talk)
- Compare with existing literature in test cases
- Implement "real "machine description
- Optimize

Muons in FLUKA

- Ionization energy losses
- Bremsstrahlung
- Pair Production
- Photonuclear interactions
- Decay, accounting for polarization

μ Induced neutron multiplicity @ Borexino, $\langle E_\mu \rangle$ = 283 GeV





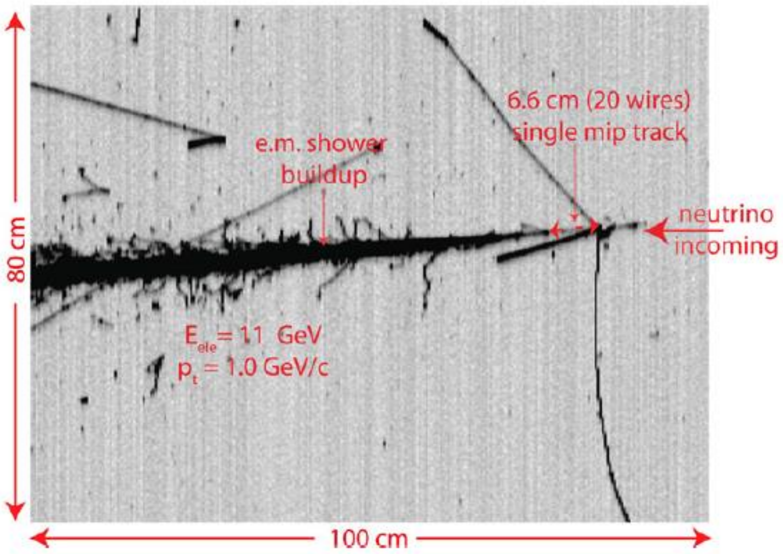
Energy loss spectrum, from 300 GeV muons, in the ATLAS Tile calorimeter prototype (Fe+Sci), for Eloss >3GeV

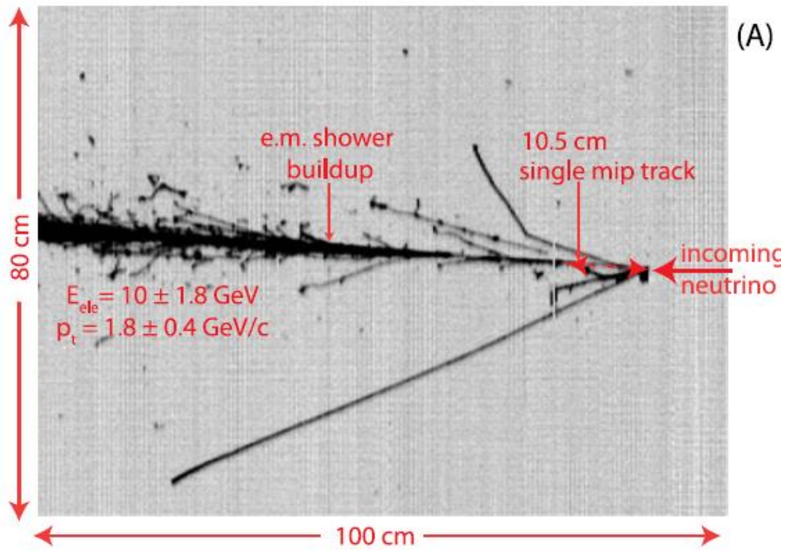
Neutrinos in FLUKA

- Generators of neutrino-nucleon interactions (NUNDIS):
  - QuasiElastic
  - Resonance
  - DIS
- Embedded in FLUKA nuclear models for Initial and Final state effects
- Products of the neutrino interactions can be directly transported in the detector (or other) materials
- Used for all ICARUS simulations/publications

Acta Phys.Polon. B40 (2009) 2491-2505
CERN-Proceedings-2010-001 pp.387-394.

MC ν_e CC



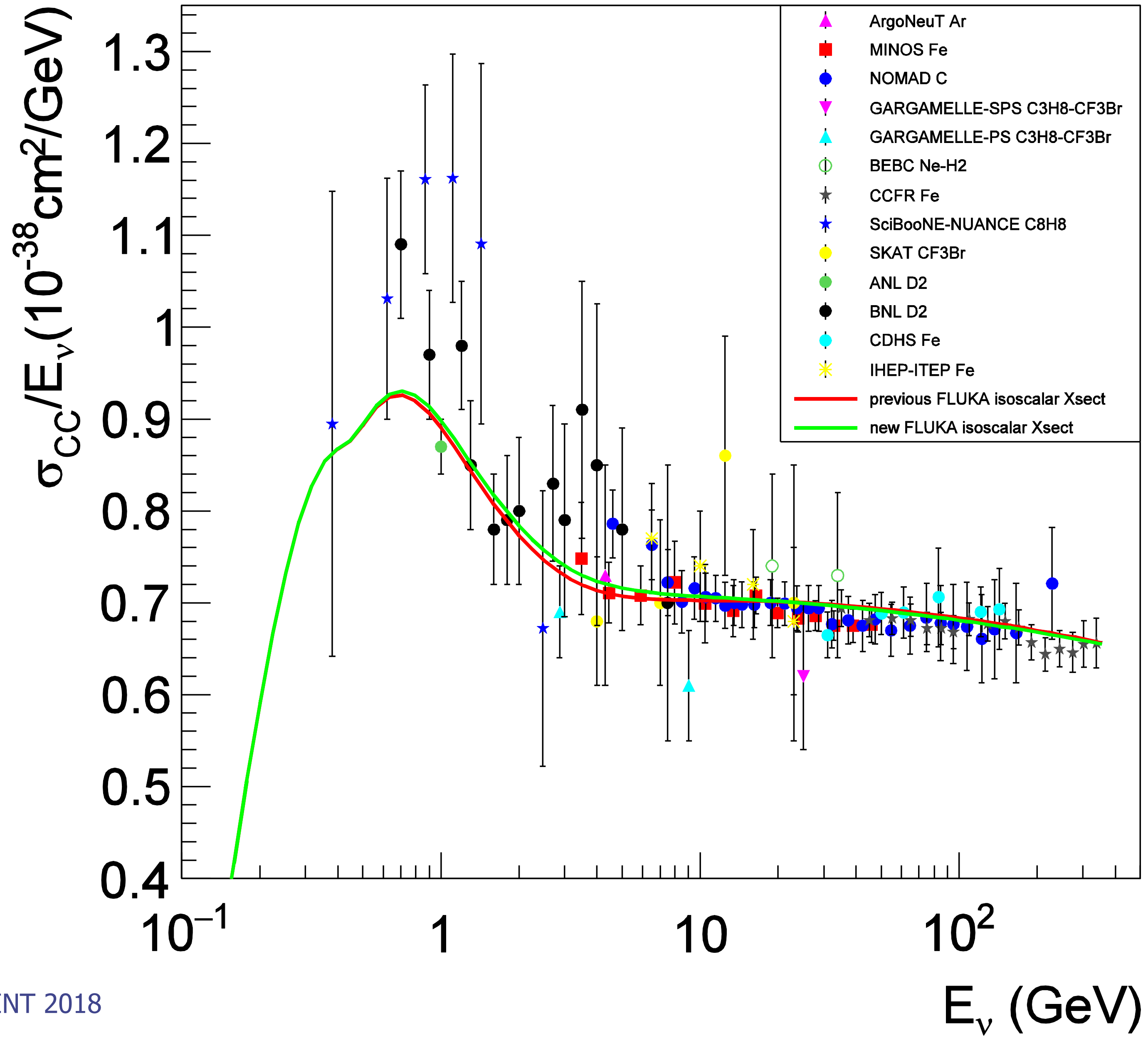


Real ν_e CC

Eur. Phys. J. C (2013) 73:2345

Comparison with data on total cross section

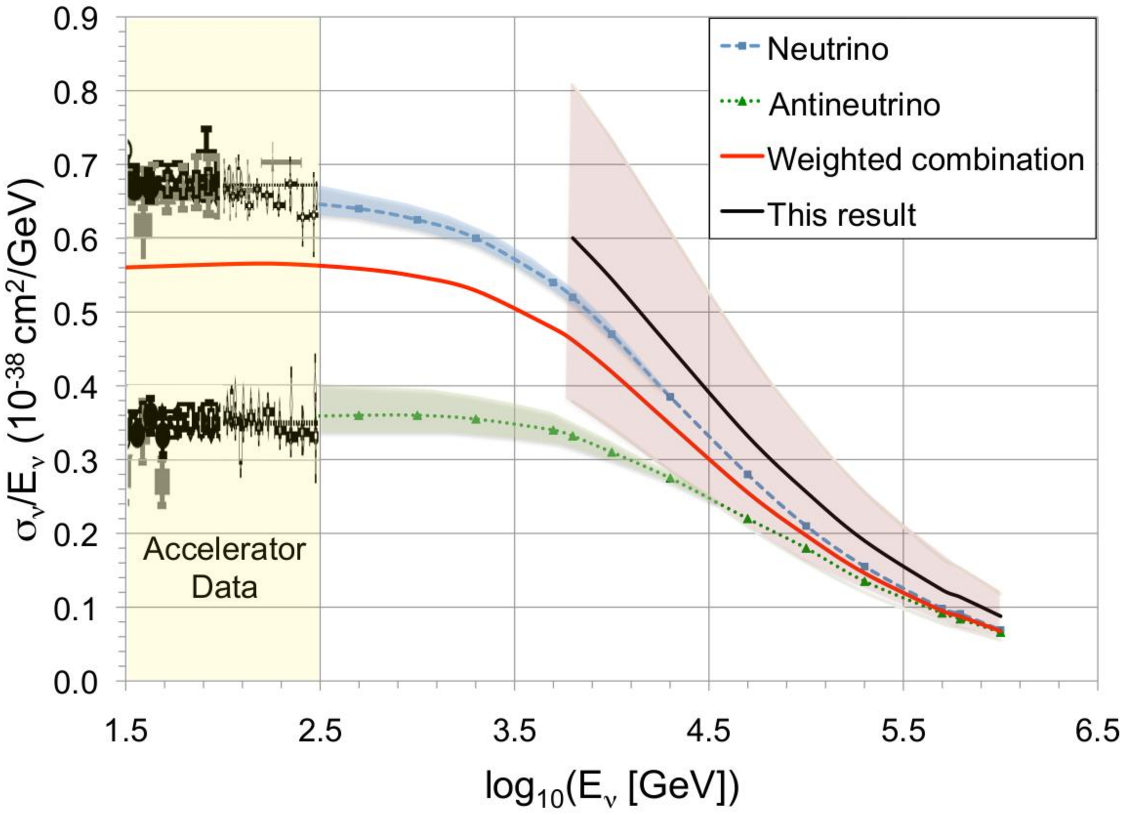
Isoscalar
ν_μ - Nucleon total
CC cross section
Fluka (lines) with
two pdf options
Vs
Experimental data

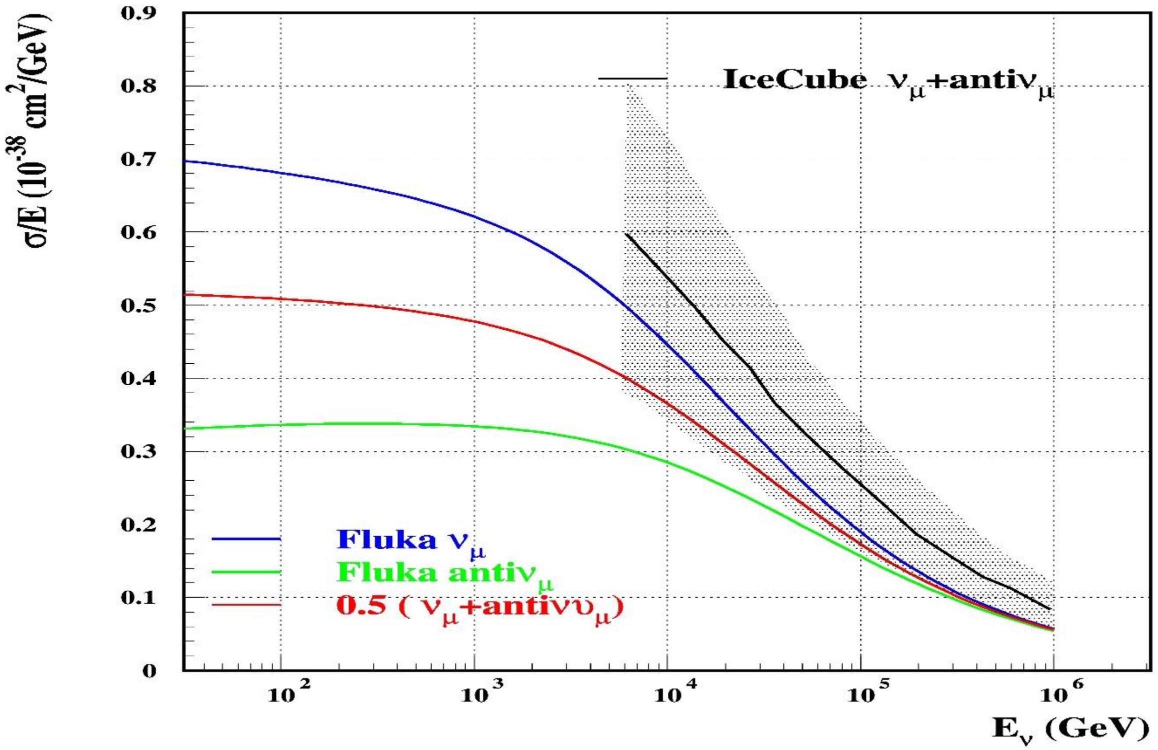


At higher energies

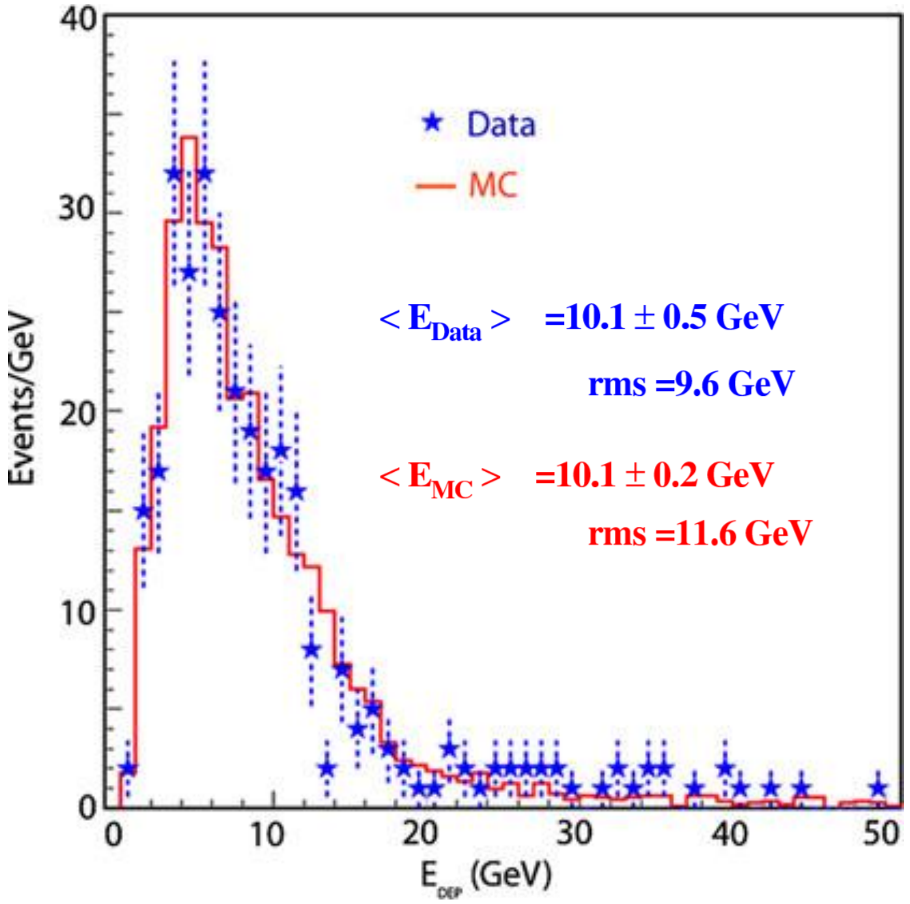
IceCube cross section data, Muon neutrino and antineutrino ,
"weighted combination" ?
arXiv:1711.08119 , *Nature* **51**,596 (2017)
Blue and green: "standard model predictions"

FLUKA results





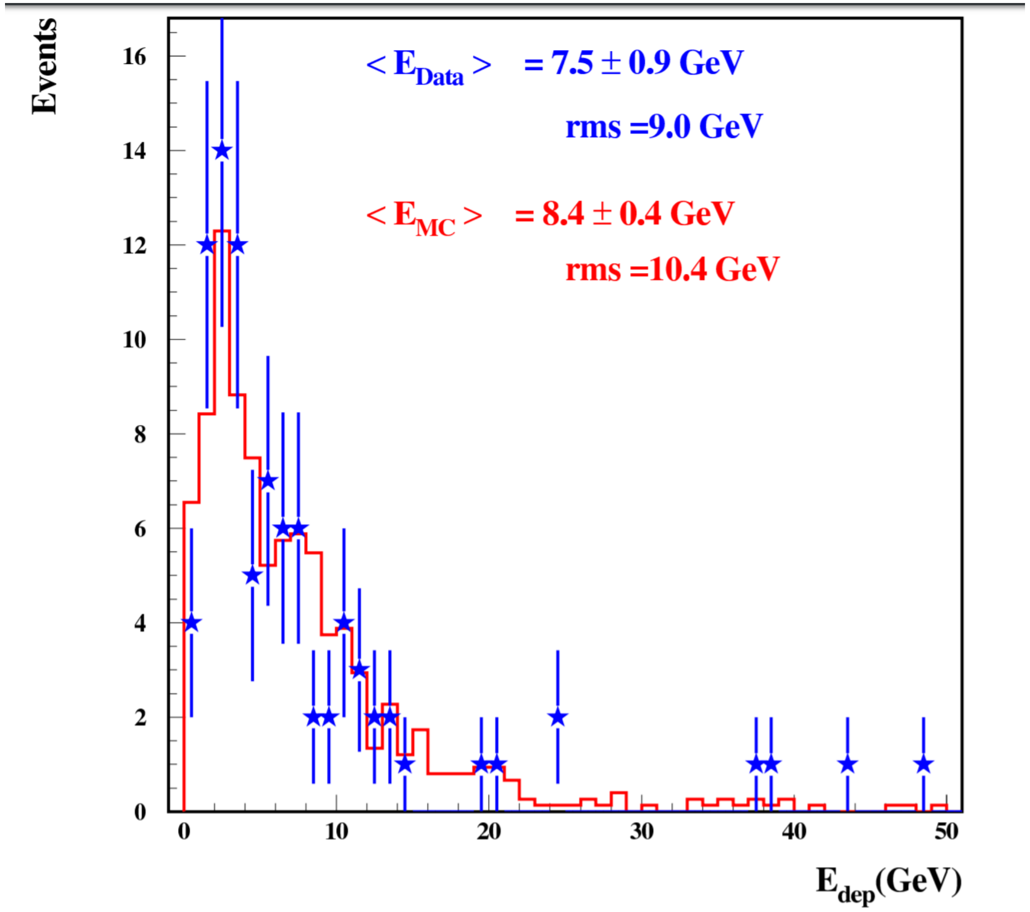
Reaction products: CNGS data (≈20 GeV Eν)



Distribution of total deposited energy in the T600 detector

Left:
ν_μ CC events

Right:
ν NC events



Same reconstruction in MC and Data
Neutrino fluxes from FLUKA cngs simulations
Absolute agreement on neutrino rate within 6%

Eur. Phys. J. C (2013) 73:2345
Phys. Lett. B (2014)

Neutrino Hazard

- Importance of radiation hazard due to highly collimated intense neutrino beams known since many years
- Already studied in analytical way and with MARS simulations: see for instance
  - Nikolai Mokhov & Andreas Van Ginneken *Neutrino Radiation at Muon Colliders and Storage Rings*, J. of Nuclear Science and Technology, 37:sup1, (2000) 172
  - R. B. Palmer *Muon Colliders* RAST 7 (2014) 137
  - B. J. King *Neutrino Radiation Challenges and Proposed Solutions for Many-TeV Muon Colliders* arXiv:hep-ex/0005006 (2000)

Rules of Thumb etc

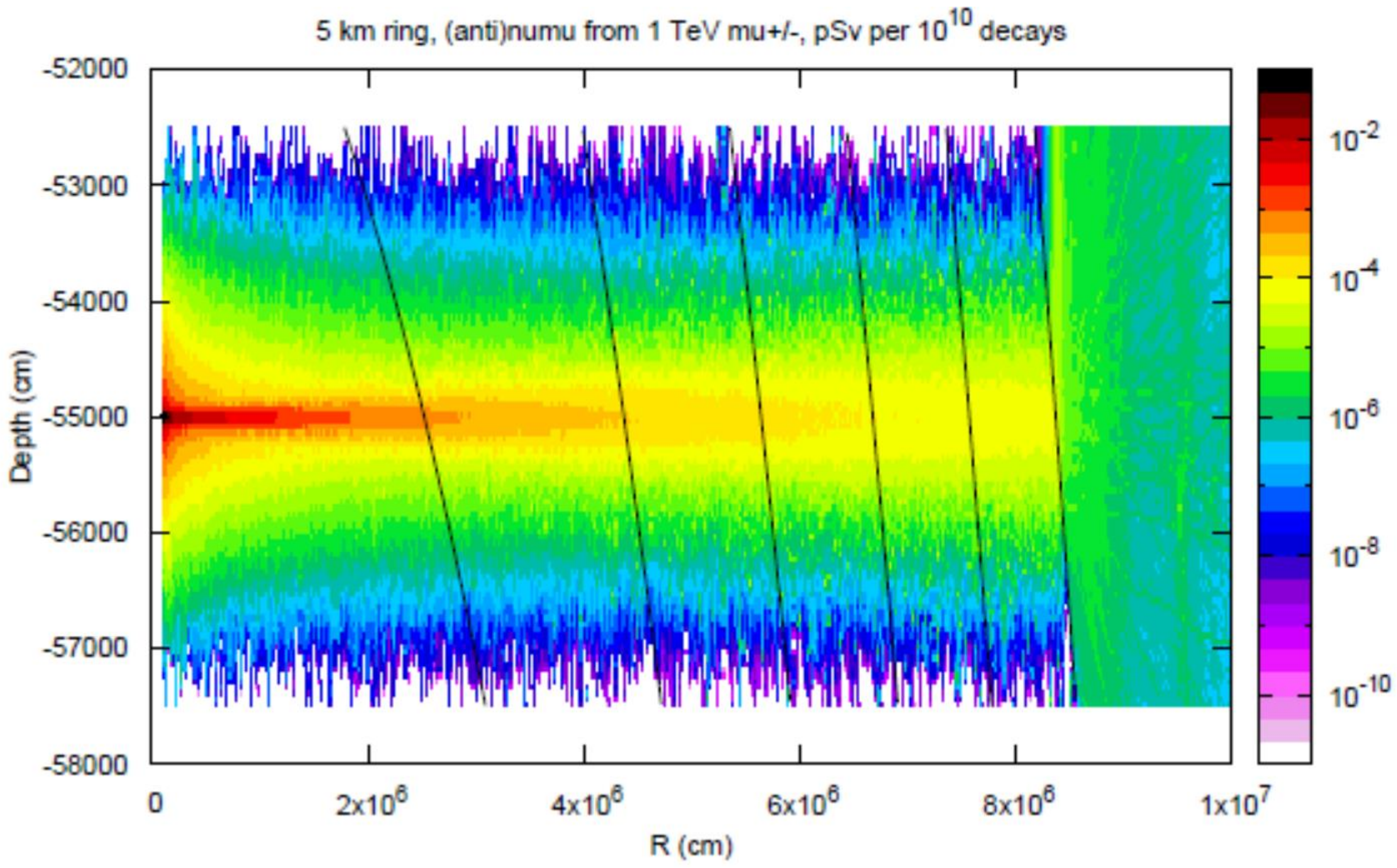
- Concerns come from dose at the point where the neutrino beam reaches earth surface, far away from production point. Limit is given by limit to population → below 0.1mSv/y
- Neutrino beam size roughly given by muon $1/\gamma$. At 1 TeV, $1/\gamma \approx 10^{-4}$, means 100m at 100 km distance
- Dose scales with $1/R^2$, thus $\approx 1/D$ (R=distance, D=depth of the collider)
- Given a total muon intensity $N\mu$ in a ring of circumference C, dose from decays in any straight section of length L is proportional to $N\mu$ * L/C
- Products from ring Neutrinos will reach Earth's surface all along a ..2π ring,
- "Ring" dose scales $\sim E^3$ (from released energy, cross section scaling, $1/\gamma$)
- Products from straight sections neutrinos emerge on a spot-like area
- Straight sections dose scales $\sim E^4$ (released energy, cross section ,$(1/\gamma)^2$)

Implemented

- Idealized ring: continuous bend, no beam divergence
- Wobbling within ring
- Idealized straight section, again no beam divergence
- Idealized earth: flat, no mountains
- Simulation at one fixed depth, use depth-exit point relation to recover smaller ring depths
- Calculated: ambient dose equivalent (H*(10)) due to neutrinos.
- H*(10) from convolution of particle fluence and conversion coefficients (online in Fluka)

- Results here for 1+1 TeV, 1.5+1.5 TeV, 62.5+62.5 GeV

Ring Example at 1TeV + 1 TeV, (anti)muon neutrinos:



Ambient dose equivalent from $\nu_\mu + \bar{\nu}_\mu$ at 1+1 TeV,

pSv/10^{10} μ decays

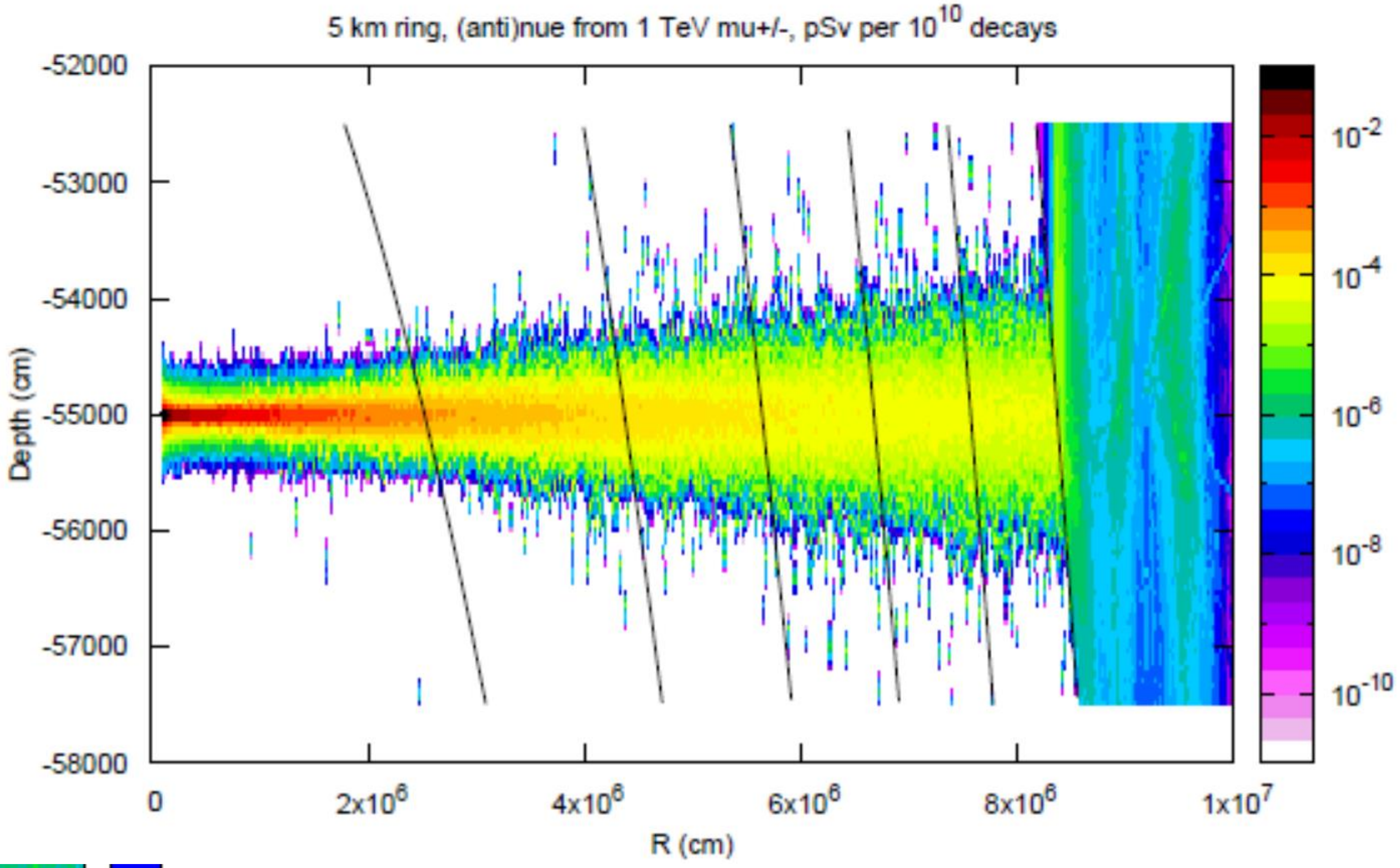
Horizontal axis: radial distance from ring, up to 100km

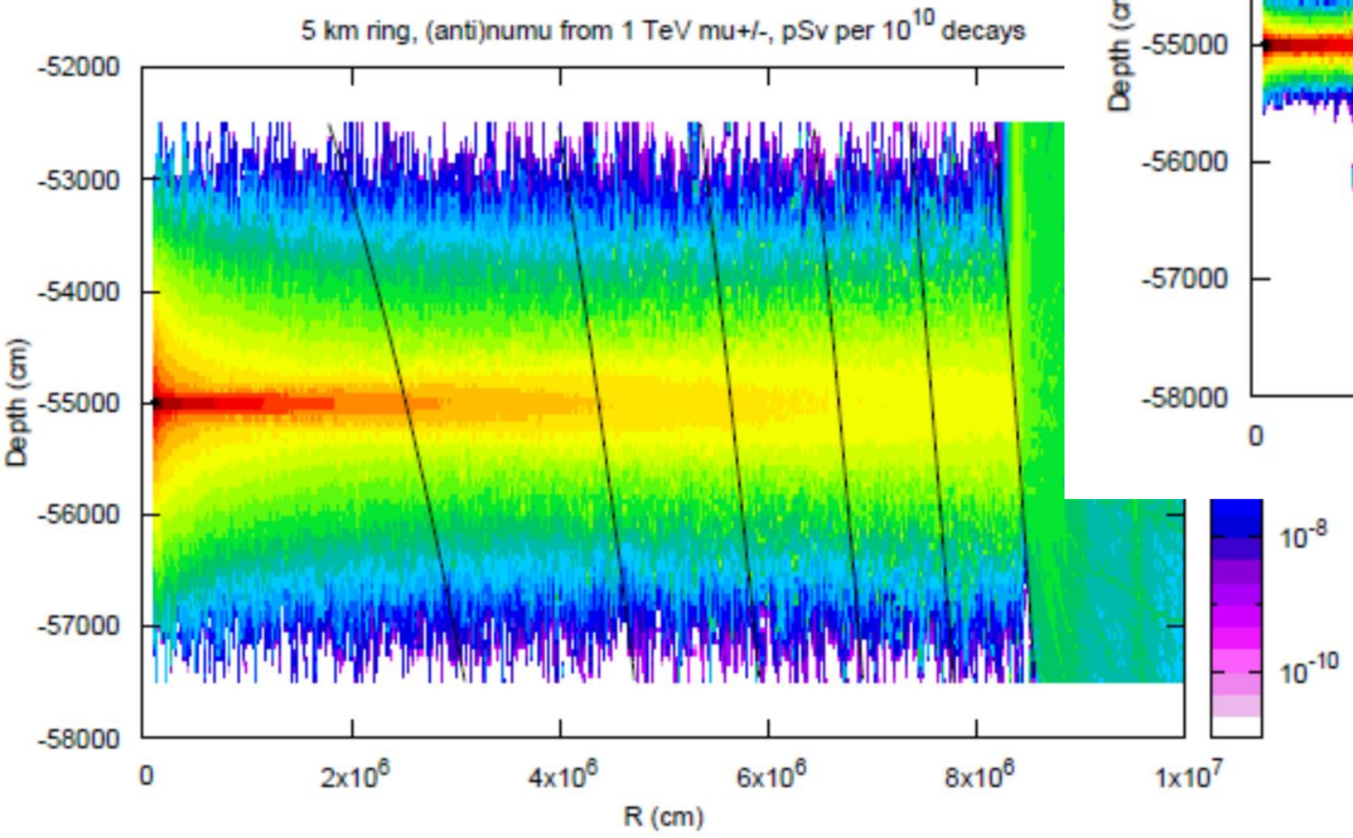
Lines correspond to earth surface for different depth (100 m step)

Note tiny vertical axis spread, +-30m

Same, (anti) electron neutrinos

Left: (anti) electron neutrinos
Bottom: (anti) muon ν
Same color scale
Same as previous slide

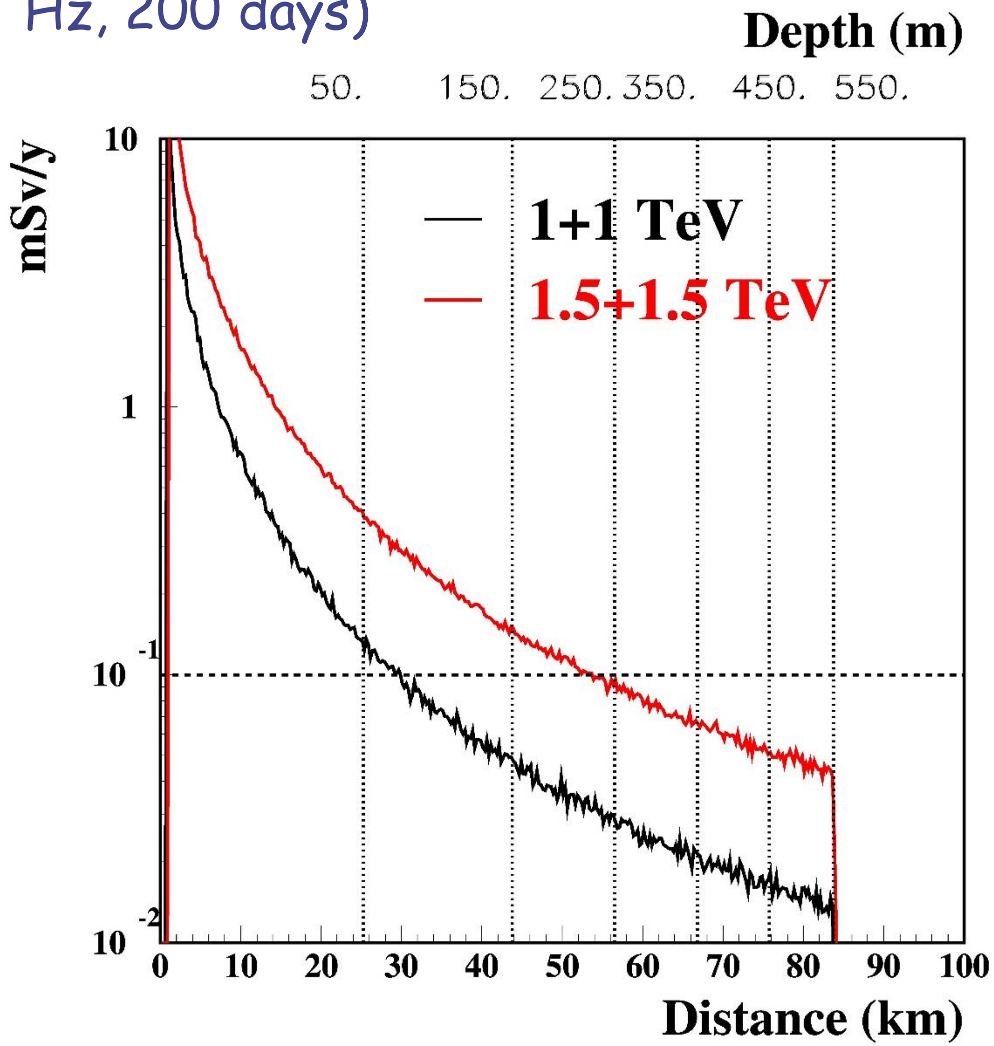




Note different lateral spread,
From different electron/muon
ranges

Ring: results and comparisons

Left: FLUKA results for H*(10) as a function of distance from ring, or equivalently, depth of the ring. Averaged over 1m in the vertical plane. Assuming **1.2 10 ^{21}** decays/y (2.10^{12} μ/bunch, 15 Hz, 200 days)



Within a factor 2 from previous results

Can be further mitigated with, for instance, wobbling

Contribution of straight sections to be considered (see later)

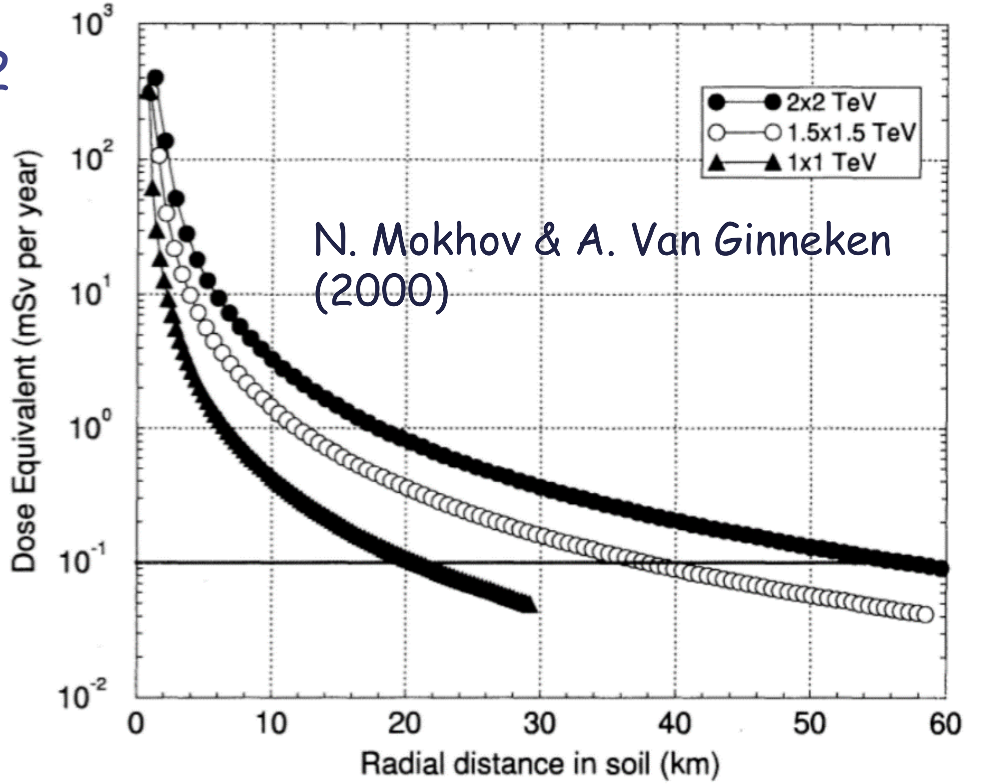
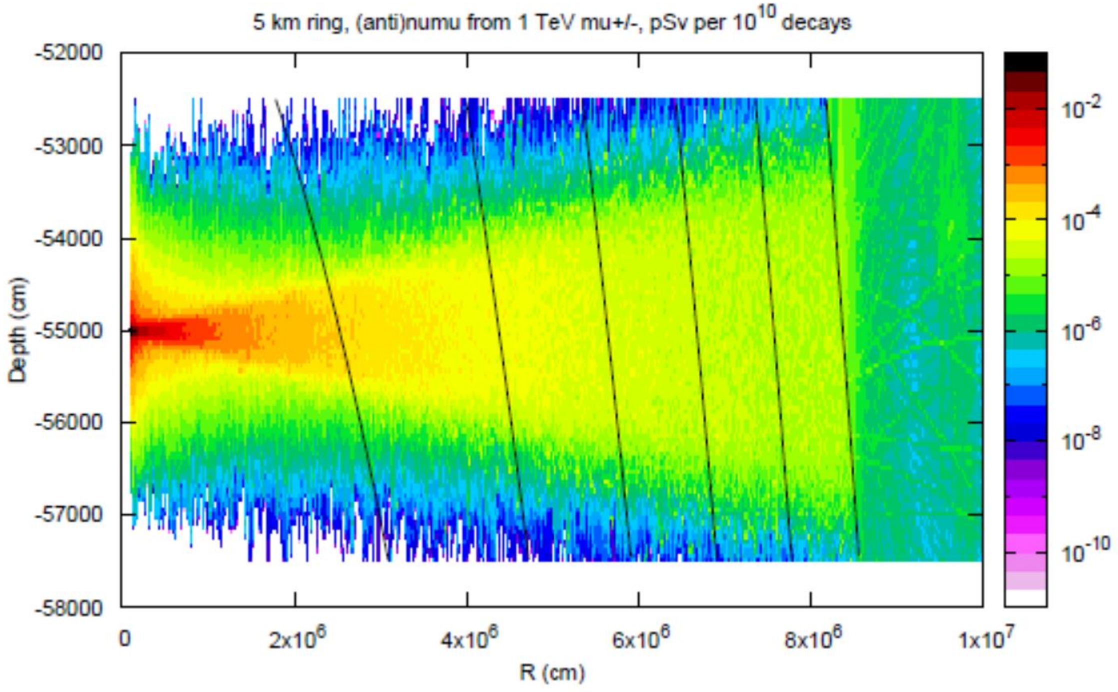
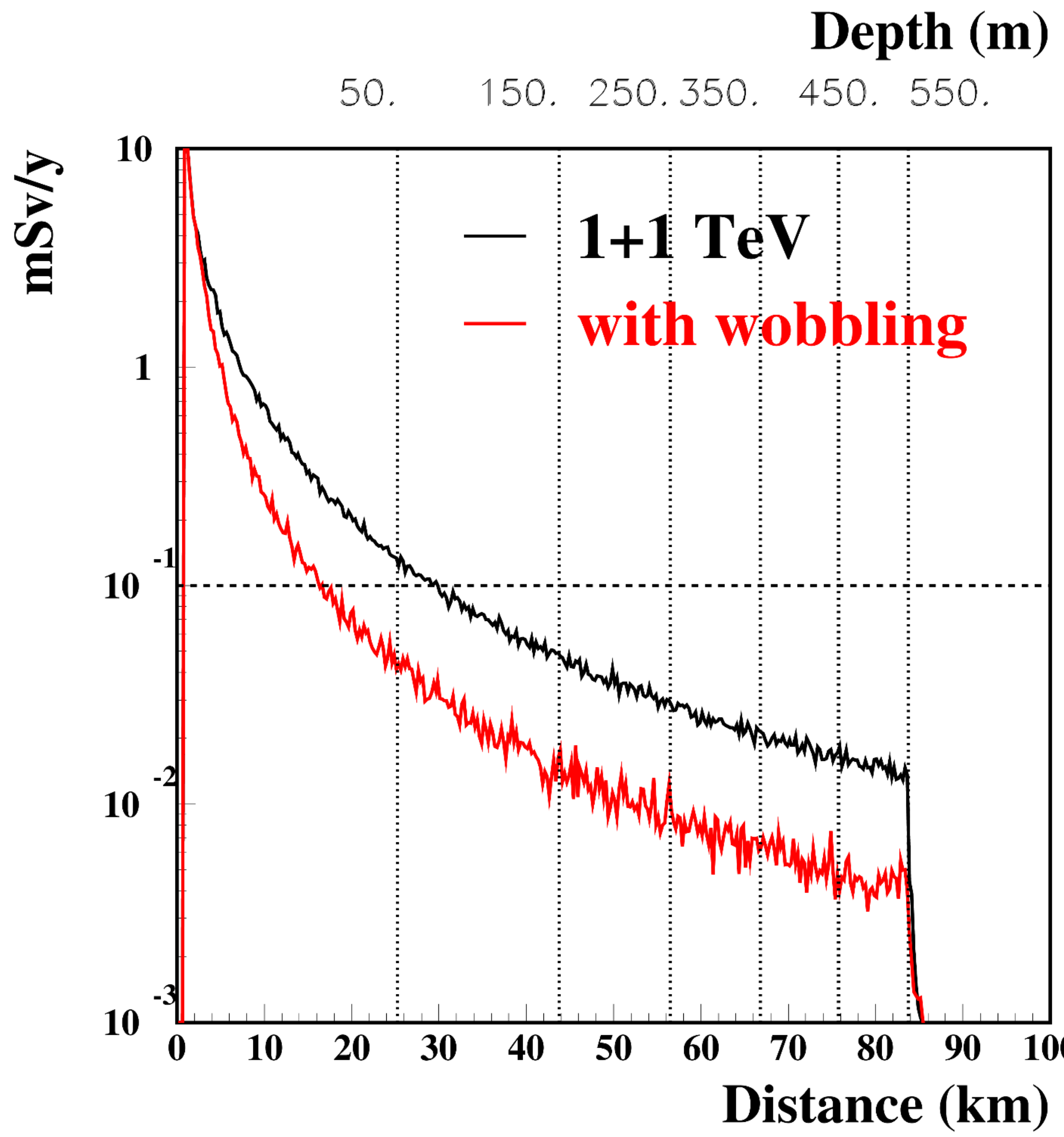


Fig. 8 Maximum dose equivalent in TEP embedded in soil in high-energy muon collider orbit plane with 1.2×10^{21} decays per year *vs* distance from ring center.

Wobbling

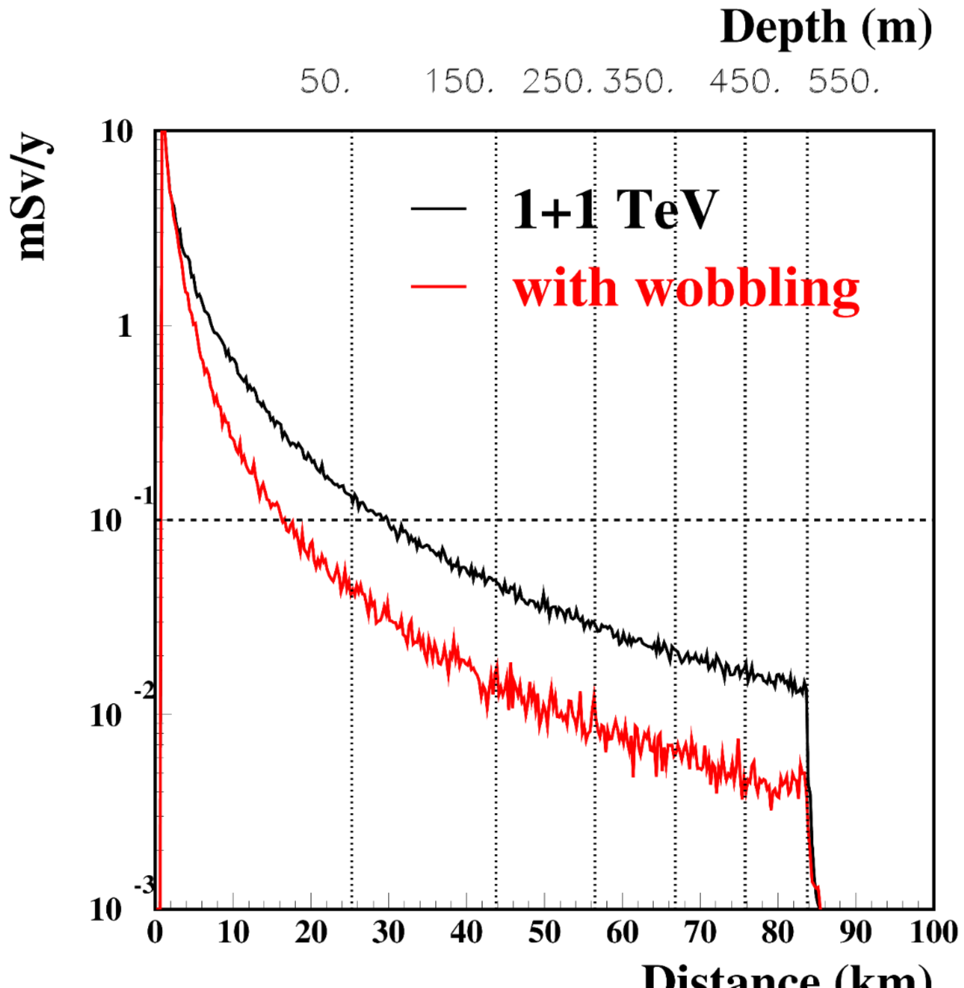
Vertical periodic deflection of muon beams in the ring (achievable with small tilt of the magnets). Here example with a 200μrad kick , 1+1TeV beam.



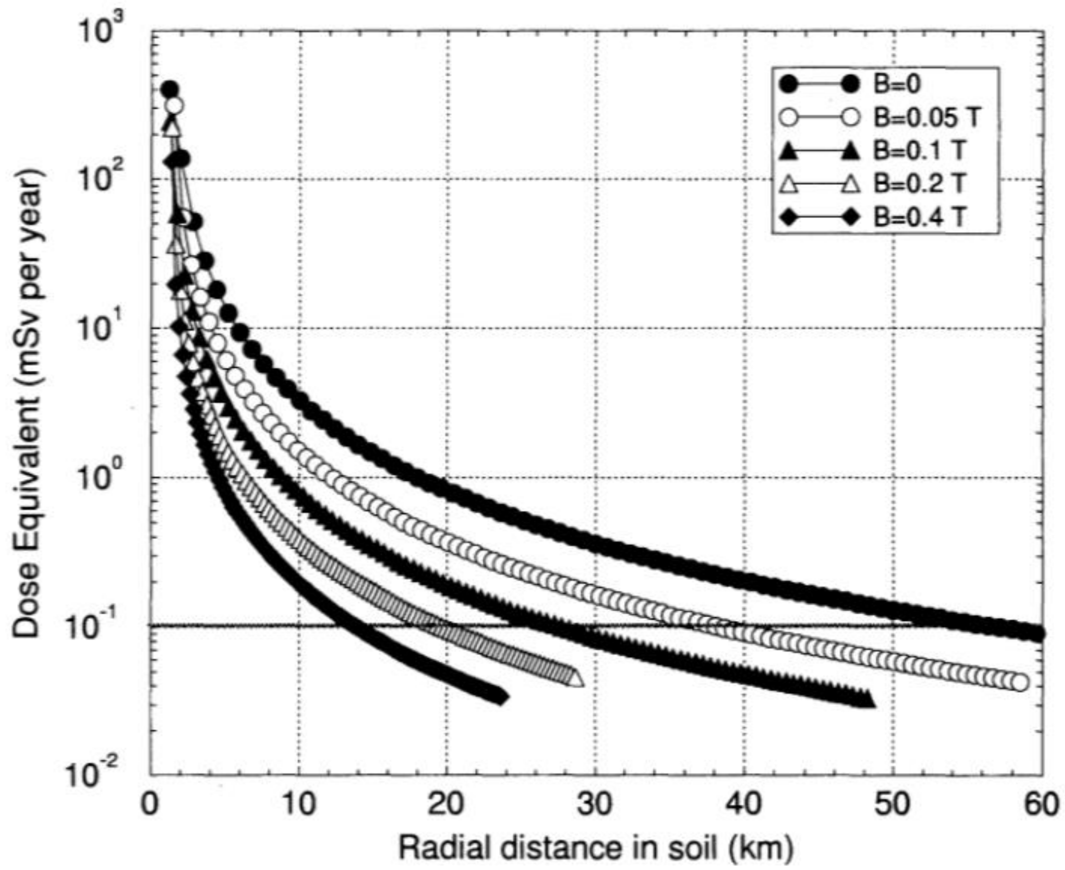


Wobbling-II

The effect at 1 TeV should be rougly comparable with the effect of the B=0.1 T case at 2 TeV (the ratio, not the absolute value): OK

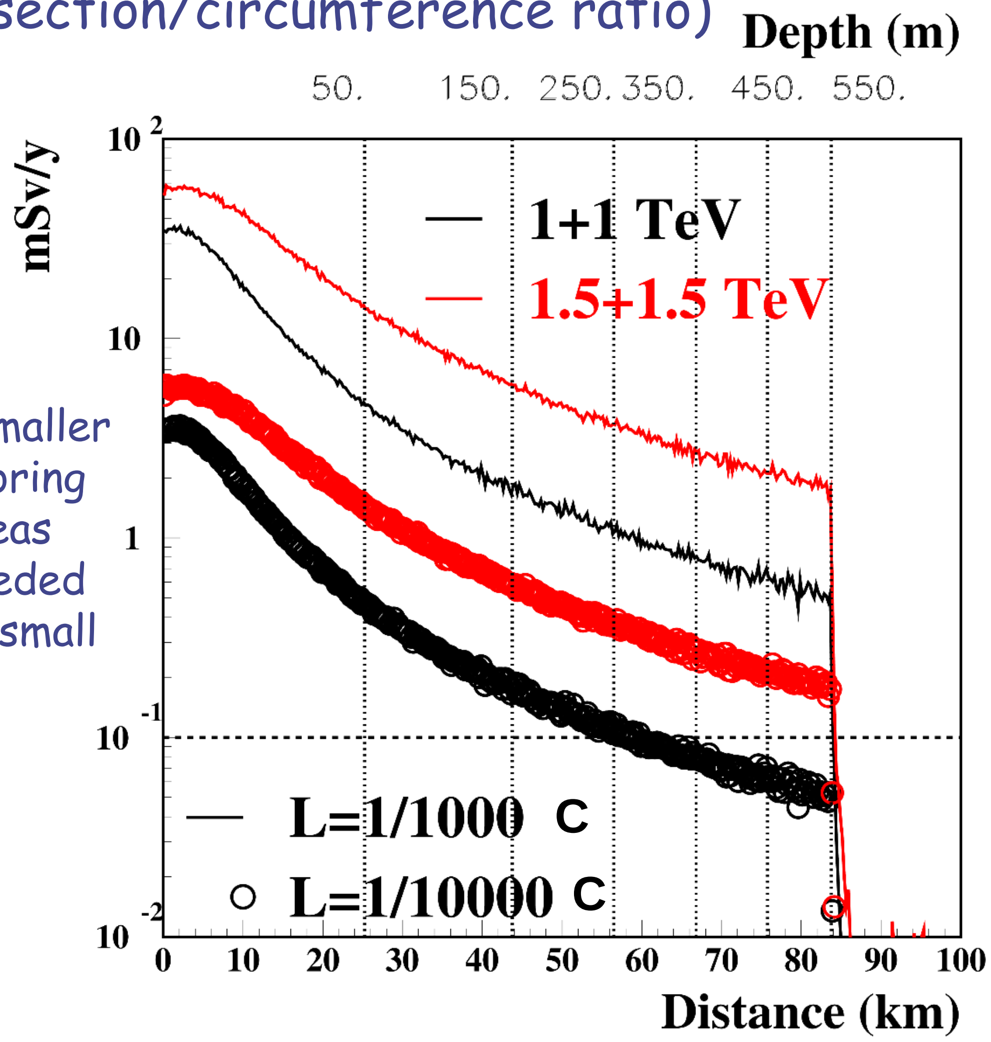


2+2 TeV from N. Mokhov & A. Van Ginneken (2000)



Straight sections

FLUKA results for H*(10) as a function of distance fromstraight section, or equivalently, depth of the ring. Averaged over 1m in the vertical plane. Assuming **1.2 10 ^{21}** decays/y (2.10^{12} μ/bunch, 15 Hz, 200 days). For different lengths (L) of the straight section (L/C is the section/circumference ratio)

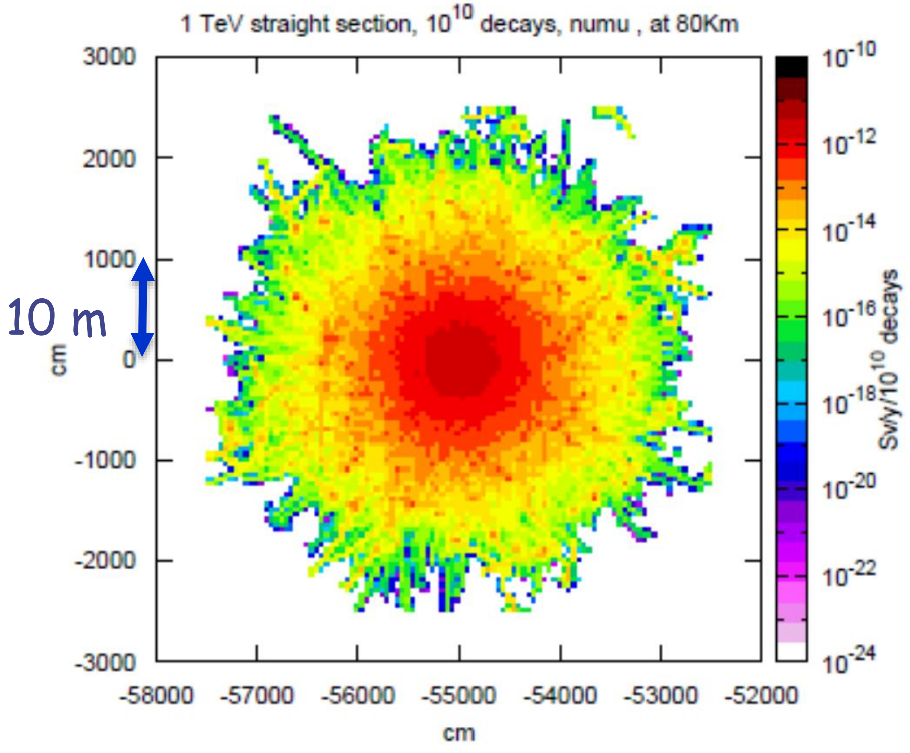


(Smaller scoring areas needed at small D)

Straight sections largely dominate over arcs.

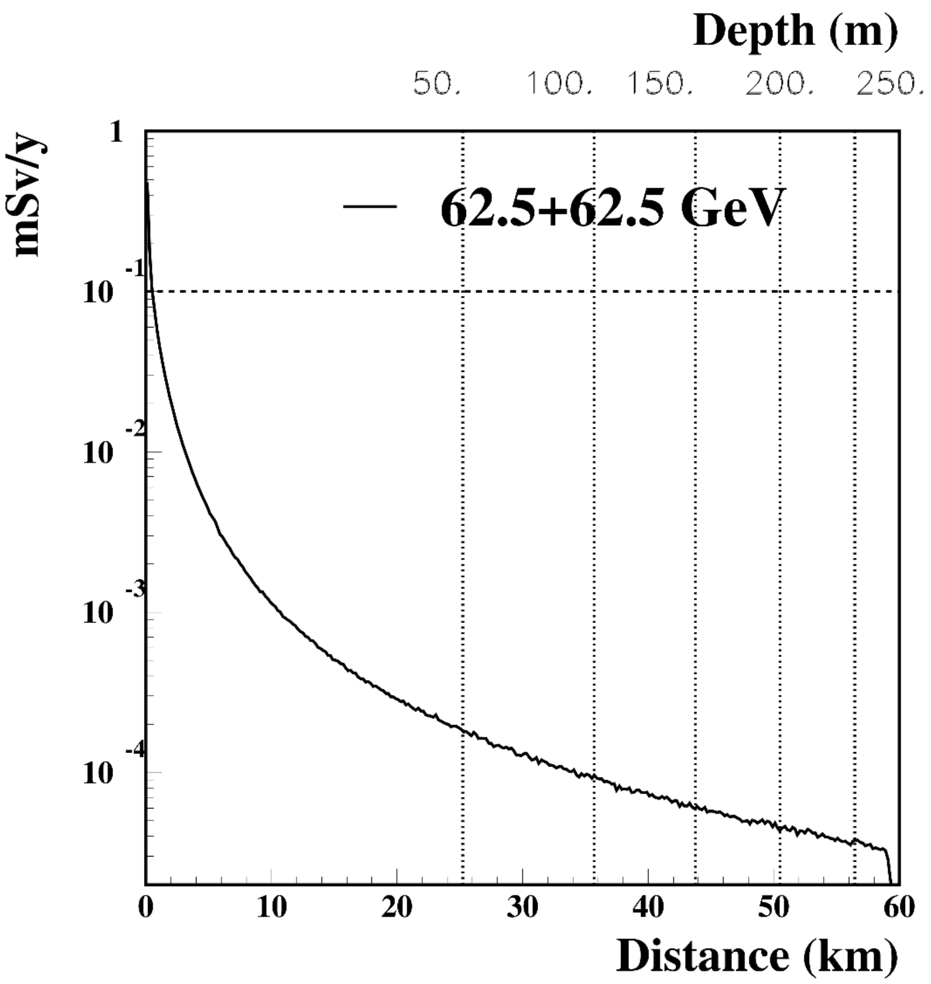
Still not included: muon beam divergence

Spot shape at surface assuming 550 m deep ring. Contained in 20m radius



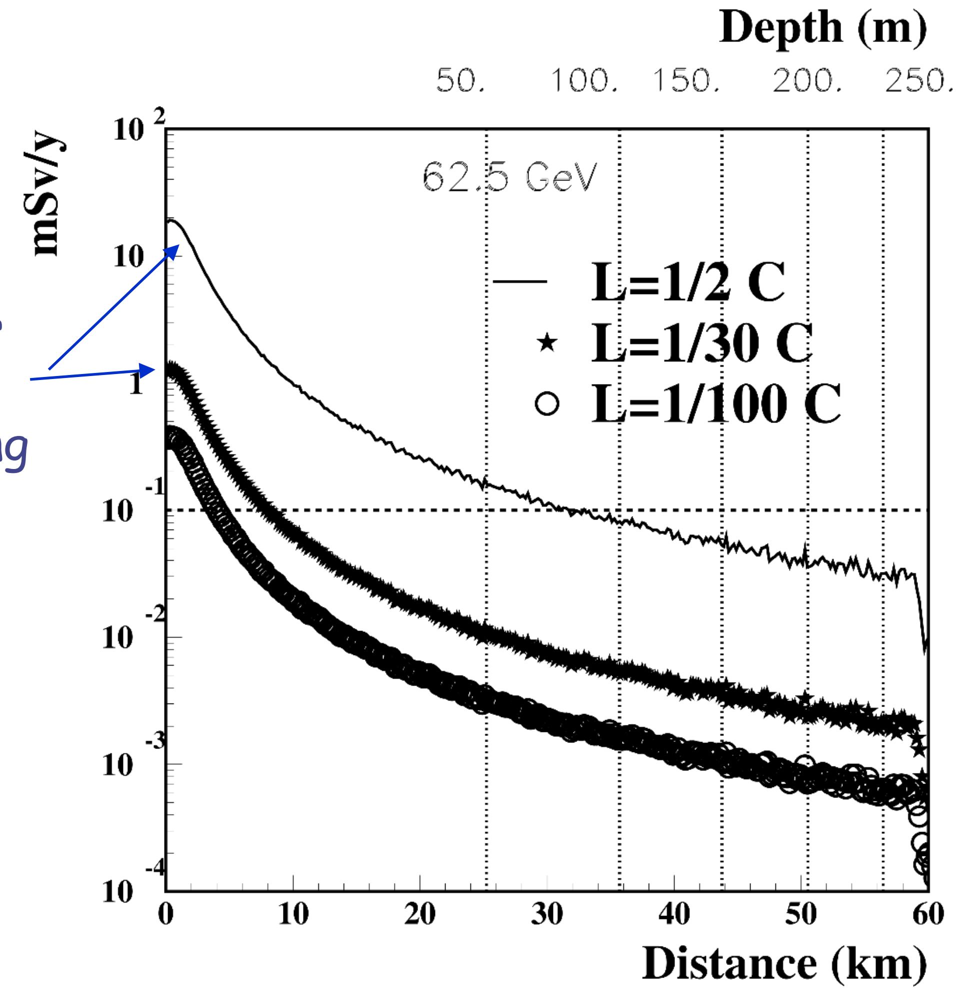
Higgs energy

H*(10) from ring at 62.5+62.5 GeV. Averaged over 4m in the vertical plane. Assuming **4.8 10 ^{21} decays/y** (4.10^{12} μ/bunch, 30 Hz, 200 days)



H*(10) from straight section at 62.5 GeV. Averaged over 4m in horizontal and vertical plane. Circumference C will be of the order of 300 m

Will need smaller averaging area when investigating zones near to production



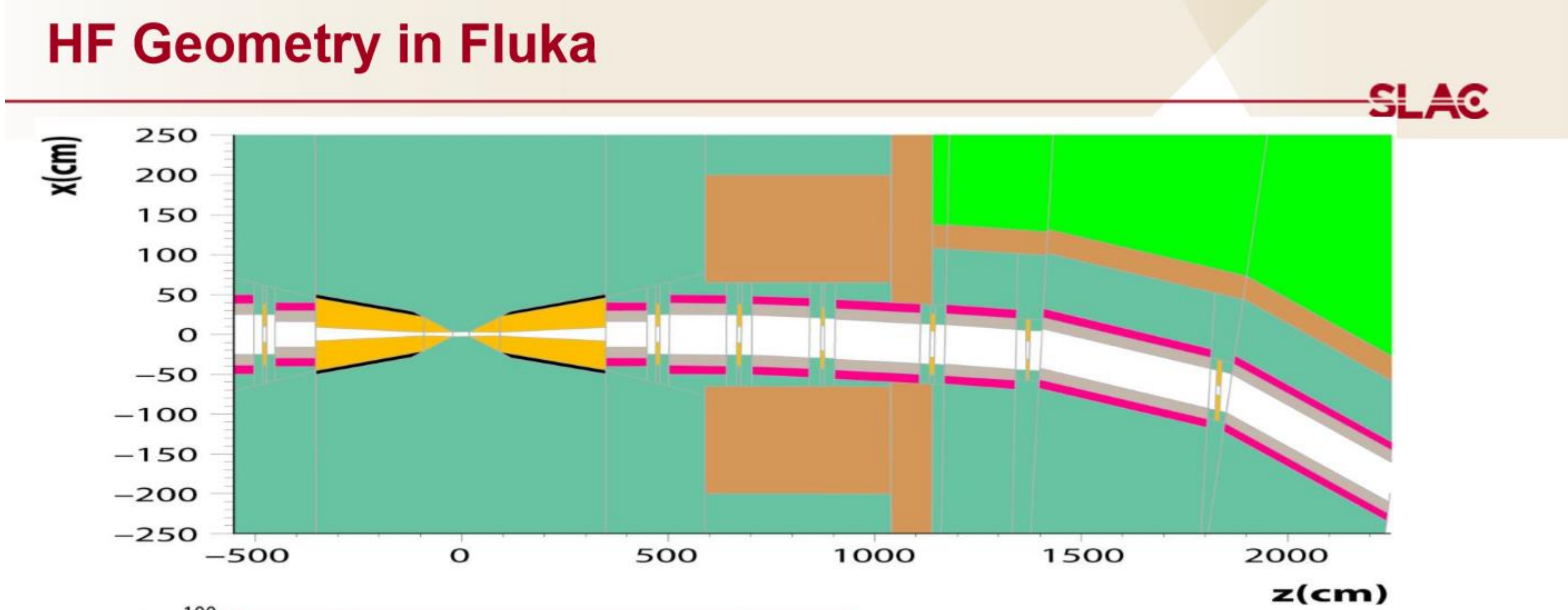
Conclusions

- Implementation of neutrino dose simulation in FLUKA started
- Results compatible with literature
- Can easily simulate at other energies

- Most of the risk comes from straight sections
- Wobbling in the ring factor >~10 reduction in “ring”dose.

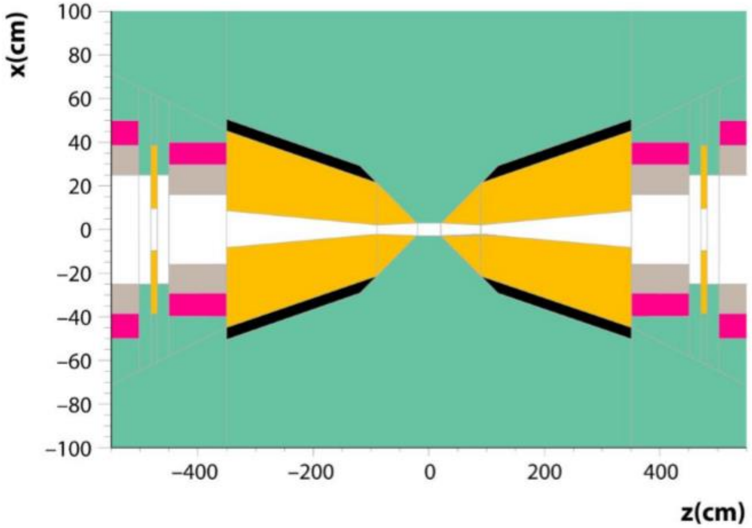
- Need to implement plausible beam optics, to account for non-parallelism of the beams➔ will reduce the peak dose

- Background to detectors comes next:



Colleagues at SLAC kindly provided their FLUKA geometry of the interaction point, for a Higgs factory configuration

Good staring point!



MDI Simulations at SLAC

Takashi Maruyama, Lew Keller, Thomas Markiewicz, Uli Wienands, SLAC

MAP Collaboration Meeting, FNAL

June 21, 2013