1. Search for Electric Dipole Moment of Atom at RCNP

2. Nuclear Physics with Neutrino Beam at J-PARC

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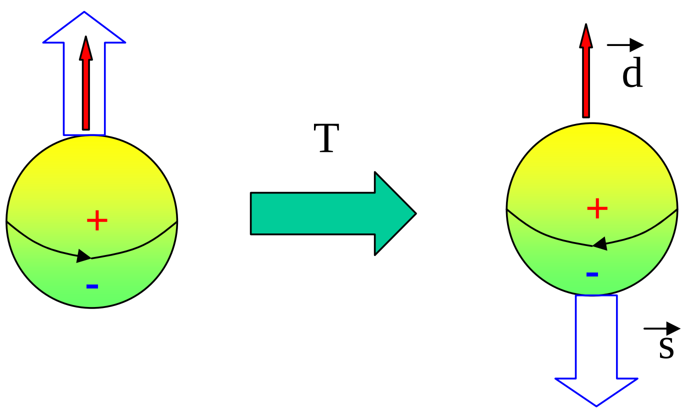
RCNP

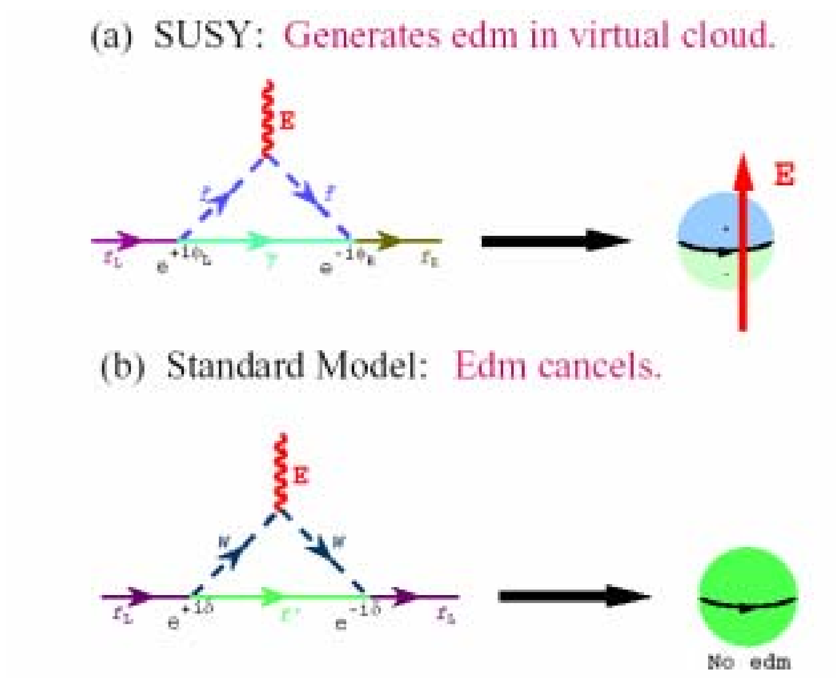
Search for permanent EDM

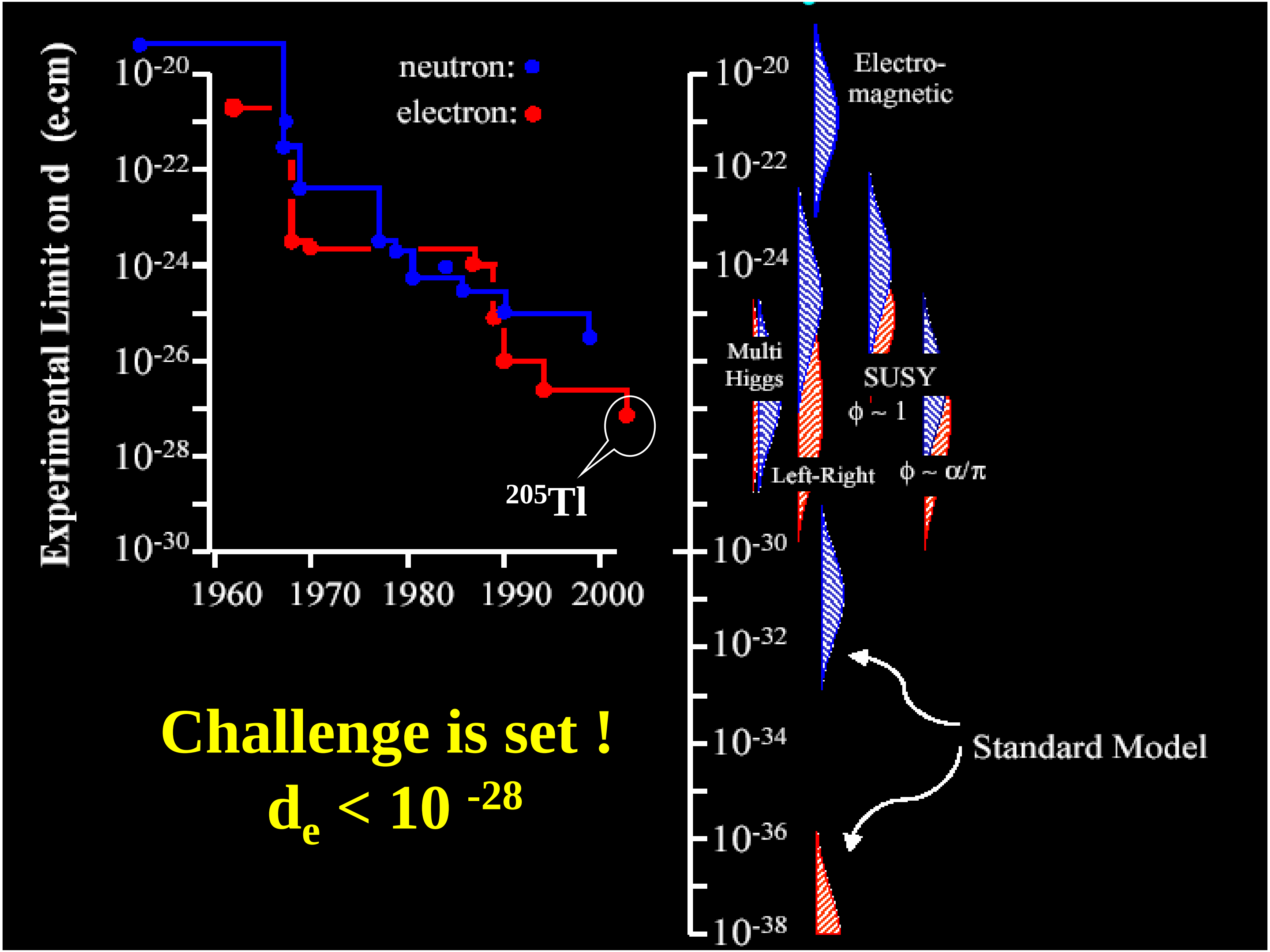
Time Reversal Symmetry ~ Violation ? ~ Test !

CPT ~ invariant in quantum field theory : No evidence of violation
✓T: Time Reversal ~ No evidence of violation
✓CP: violation was found ~ K^0, B decay
✓CPT theorem + CP violation → T violation ?

Window to look at Beyond the Standard Model

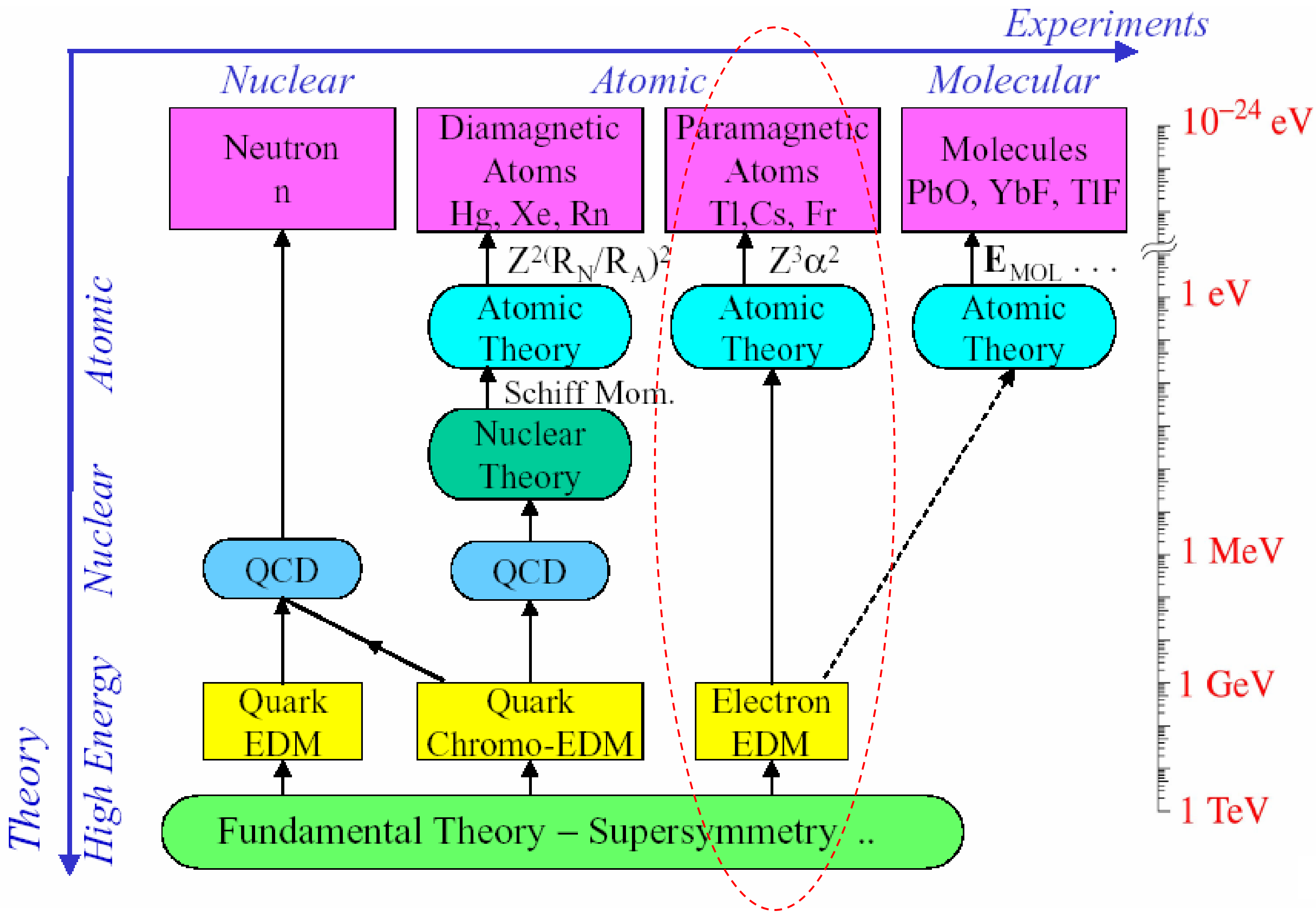






Experimental Limit on d (e.cm)
neutron:
electron:
10-20
10-22
10-24
10-26
10-28
10-30
1960
1970
1980
1990
2000
205Tl
Electro-
magnetic
Multi
Higgs
Left-Right
SUSY
φ ~ 1
φ ~ α/π
10-32
10-34
10-36
10-38
Standard Model
Challenge is set !
d_e < 10 -28

Electron EDM



Enhancement effect for Atomic EDM

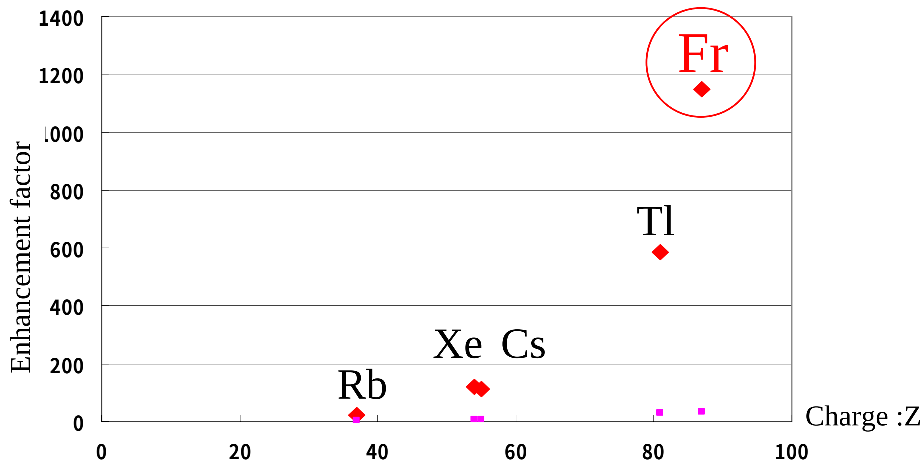
$$\frac{d_{atom}}{d_e} \sim Z^3 \alpha^2$$

$$H' = -d_e \sum_i \beta_i \sigma_i E_i$$

$$= \frac{d_e}{e}\left[H_0, \sum_i \sigma_i \cdot \nabla_i\right] + \frac{d_e}{e}\left[\sum_i \sigma_i \cdot \nabla_i, \sum_{j \neq k} \frac{1}{2} B_{jk}\right]$$

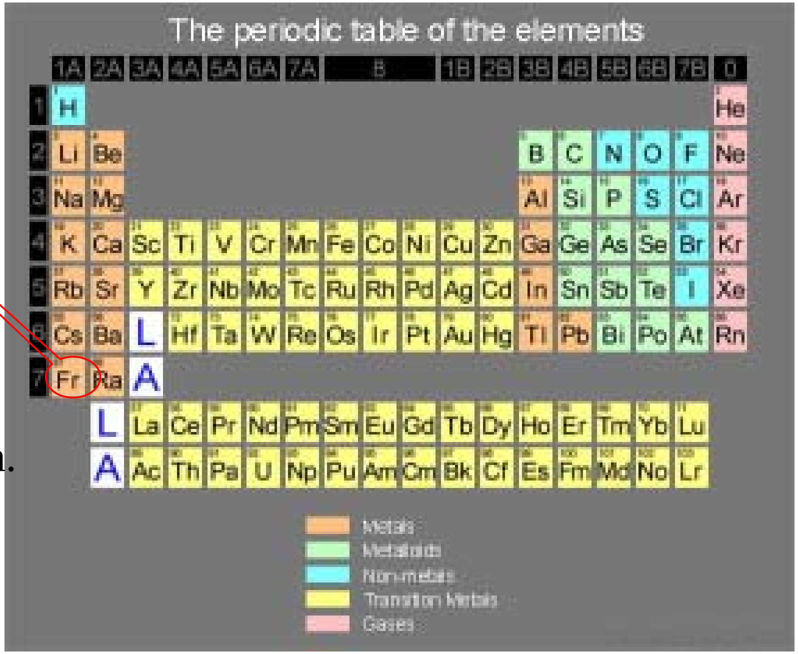
$$+ d_e \sum_i (1-\beta_i)\sigma_i \cdot E_i$$

Relativistic effect

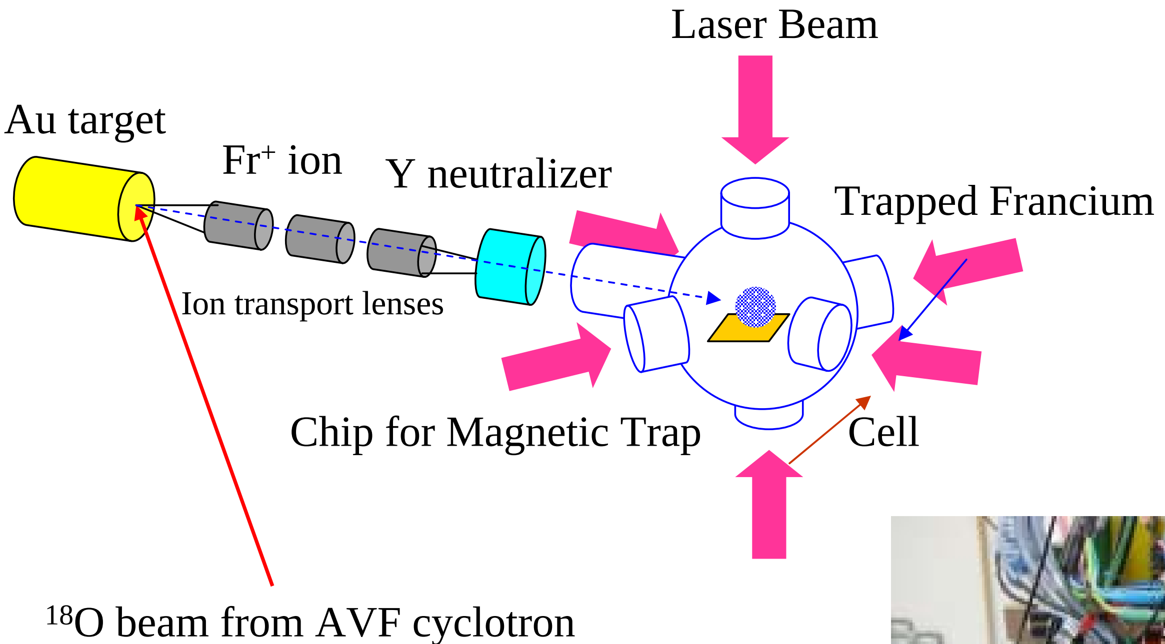


Heaviest Alkali Atom : Francium ^{210}Fr ~ K=1150

- ✓1939 found
- ✓Atomic number 87
- ✓Average atomic weight 215
- ✓Ionization Potential 4.08 eV
- ✓Radioactive lifetime of Fr^{210} =3.2 min
- ✓No stable isotopes ~ longest lifetime ^{223}Fr: 22min.

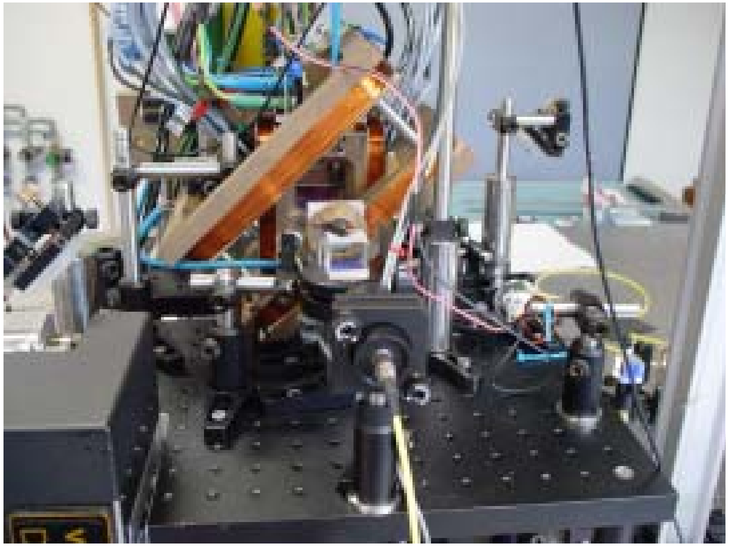


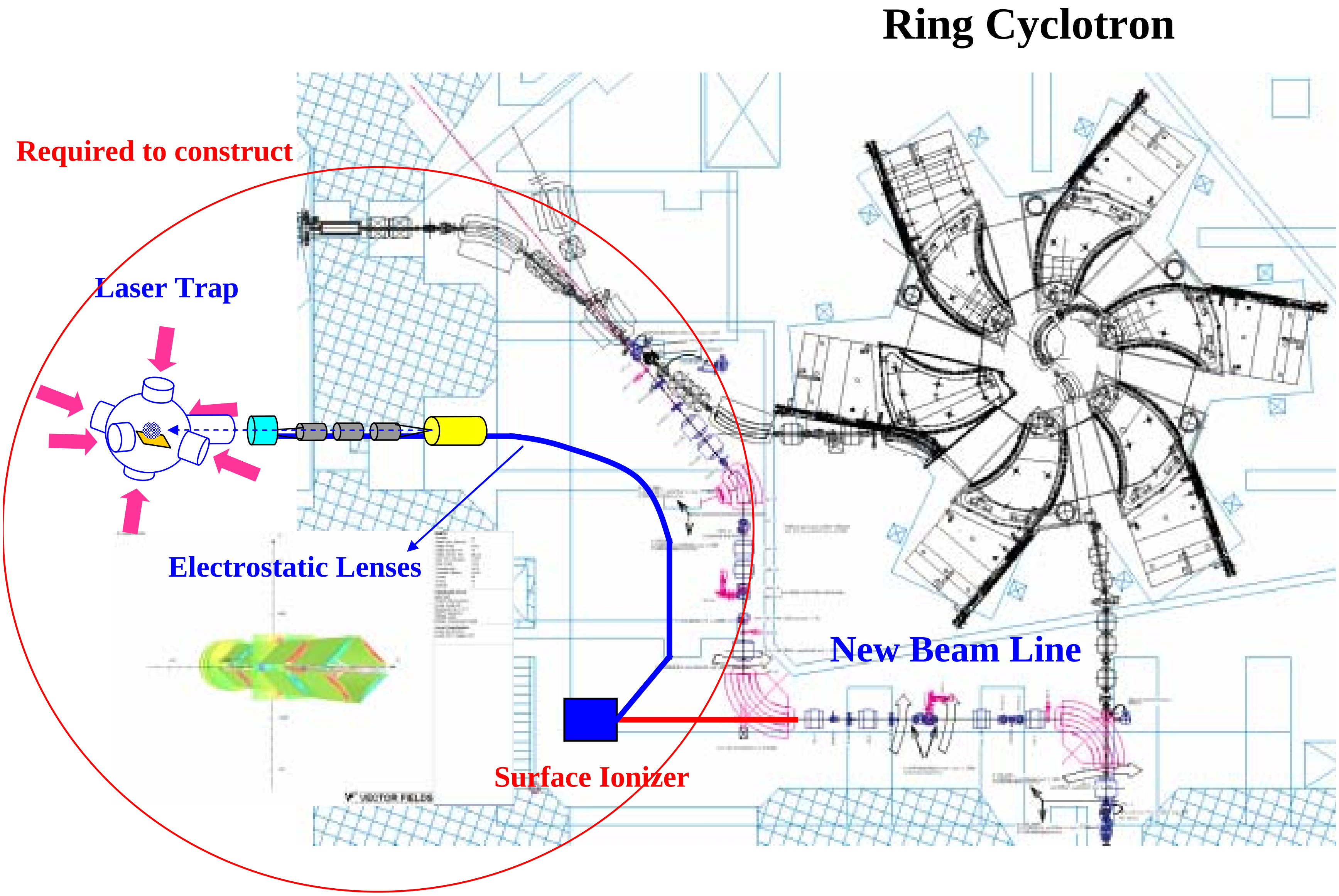
Experimental Overview



Francium Production with
Heavy Ion Fusion Reaction :

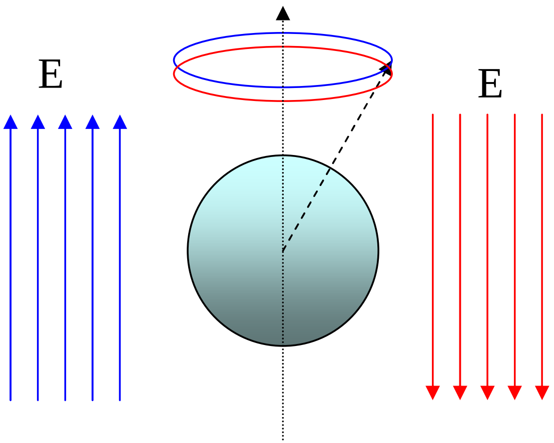
$^{197}Au(^{18}O,xn)^{209\text{-}211}Fr$





Ring Cyclotron
Required to construct
Laser Trap
Electrostatic Lenses
New Beam Line
Surface Ionizer
VECTOR FIELDS

EDM Measurement and Sensitivity



$$h\nu_{\uparrow\uparrow} = 2\mu \cdot B + 2d \cdot E$$

$$h\nu_{\uparrow\downarrow} = 2\mu \cdot B - 2d \cdot E$$

$$\Rightarrow h\Delta\nu = 4d \cdot E$$

Electric dipole moment : d

Sensitivity : $$\delta d = \frac{h}{2e} \cdot \frac{1}{K} \cdot \frac{1}{E} \cdot \frac{1}{\sqrt{N \cdot \tau \cdot T}}$$

K: Enhancement factor	~ Atom EDM	= Largest ~ Francium
E : Electric Field	~ Strong, 100 kV/cm	= Laser trap in high vacuum
N : Number of Particles	~ Many particles !	= Ion Source + Ion guide
τ : Coherence Time (Stored time)	~ Long !	= Laser trap
T : Lifetime of Experimentalist	~ Long !	

EDM measurement

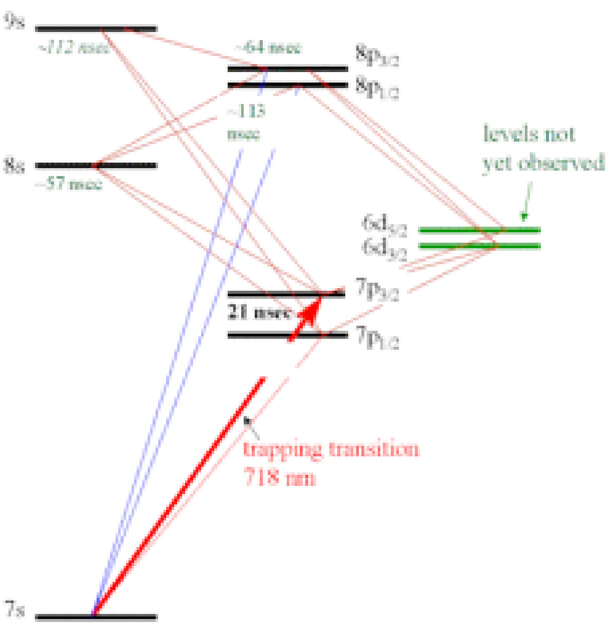
$$\delta d = \frac{h}{2e}\cdot\frac{1}{K}\cdot\frac{1}{E}\cdot\frac{1}{\sqrt{N\cdot\tau\cdot T}} \sim 10^{-28}$$

- ✓ Enhancement factor : K=1150 for Fr
- ✓ E~100kV/cm
- ✓ Coherence time : τ ~ 1 s
- ✓ N~6000 atoms @ 1 uA ^{18}O beam

Measurement time : T ~ 60 days needed

- ➢ If we have 10 days beam time / year → 6years
- ➢ If we have 10 μA ……

Francium Atomic Level Scheme



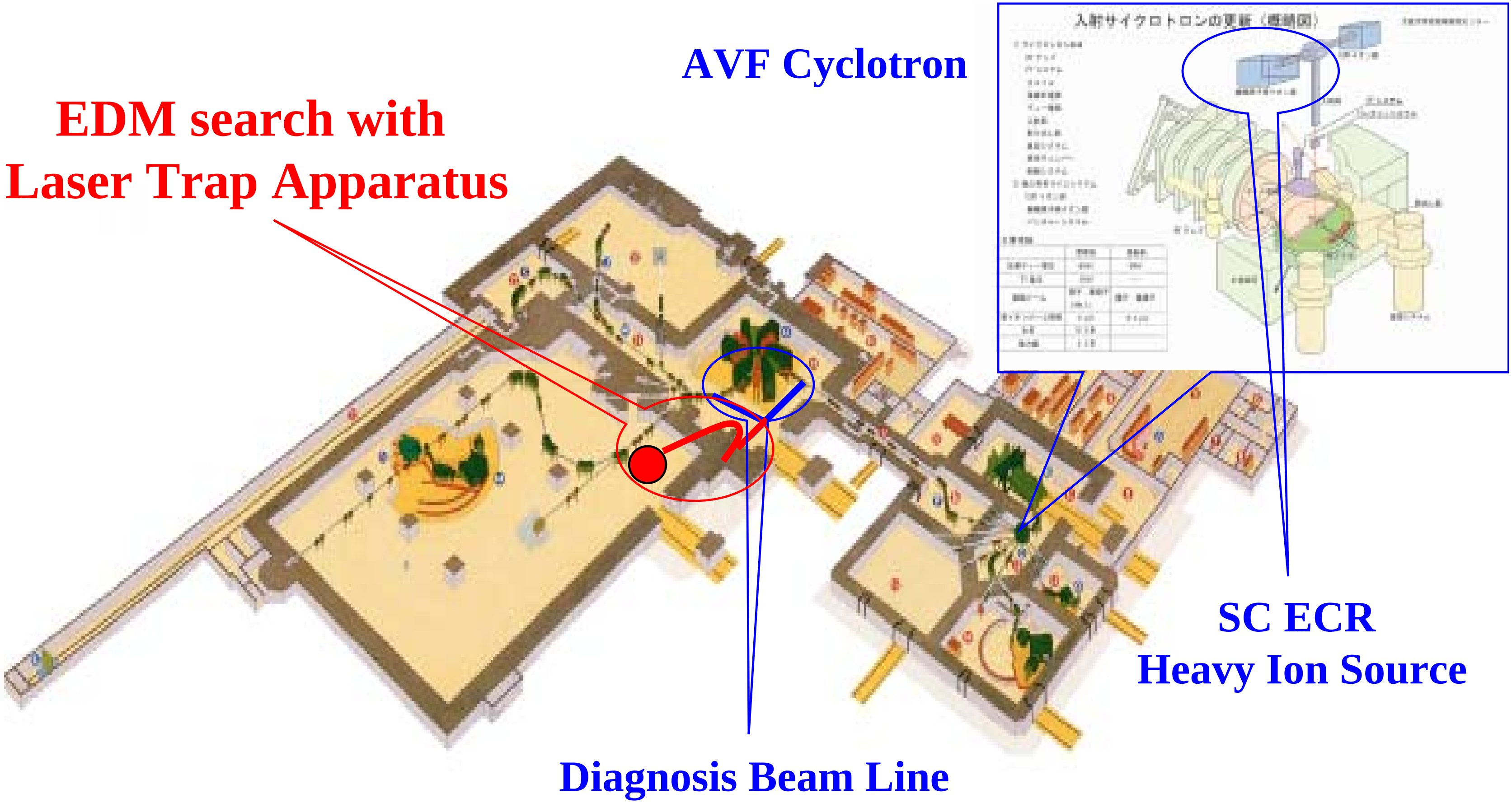
- ☐ Collection efficiency : trapping/cooling technique
- ☐ ECR ion source ~ High intensity
- ☐ Radiation protection
- ○ Low cost ~ AVF cyclotron only , RING cyclotron NOT used..
- ○ Not so much effect to beam time
  ~ no effect to main physics program at RCNP (high resolution, spin-isospin, cluster…)

Present status

Institute	Project	Elements	Trap	Status	Goal
SUNY		^{210}Fr	MOT	Atomic structure	
KVI	TRIuP	Ra (p)	MOT/Penning	First beam	
TRIUMF	TISOL		MOT		
California / LBL		^{205}Tl (e)	Atomic beam	Best limit	
Kyoto		^{171}Yb (p)	MOT		
T.I.T.		Xe (p)			
RCNP		$^{207\text{-}211}$Fr	MOT+Laser Trap	No plan…	

EDM	Elements						
Electron	Rb	Cs	Fe^{3+}	^{129}Xe $^{3}P_{2}$	^{205}Tl	**Fr**	Others
Nucleus	^{129}Xe $^{1}S_{0}$	Rn	^{199}Hg	Ra	Yb	Dy,Sm,Ba	Others

AVF Cyclotron Upgrade Project at RCNP



New Technique = Radioactive Atom Production with Accelerator + Laser Trap
using
New machines constructed in AVF Upgraded Project in 2004/2005

Cost, Manpower, Timeline

Cost:

(Beam Line, Vacuum System, Surface Ionizer, Ion Guide, Laser Trap, Detector)

~ Total : 1 ~1.5 億円程度

Plan:

●**Francium Production :**

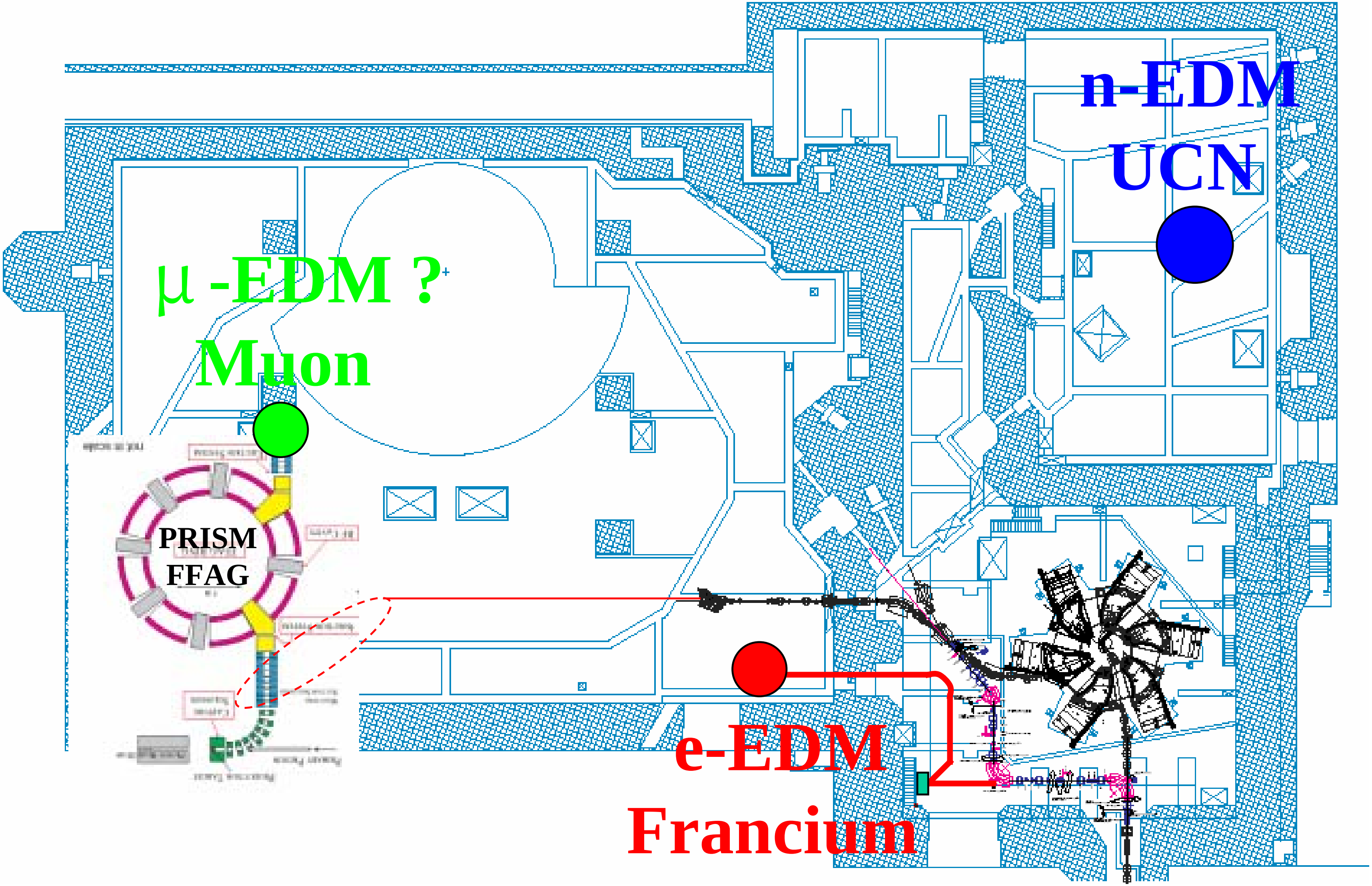
~ Feasibility Test Experiment : proposed at next B-PAC (Feb-21)

●**Laser Trap : Design work in progress**

~ Collaboration with Quantum Optics Group at Kyoto Univ.

When feasibility check is completed ,

Propose to Experimental Project at B/P-PAC



Muon Yield at RCNP @ 400 MeV proton 1 uA

- **QQD-Solenoid-QQDQQ** $\mu^+ \sim 10^4$/s $\mu^- \sim 5*10^3$/s
- **Solenoid capture + Muon cooling** $\mu^+ \sim 10^9$/s $\mu^- \sim 5*10^8$/s

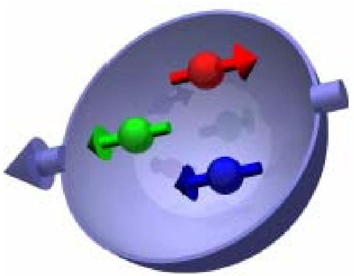
Nuclear Physics with Neutrino Beam

New Beam ~ Neutrino at J-PARC : E_ν~1 GeV

- **Spin structure of nucleon : Hadron physics**
  ~ Strange quark spin content ΔS

- **Spin response function : Nuclear physics**
  ~ π, Δ propagation in the interior of the nucleus

Spin structure of the nucleon



Naive Parton Model :

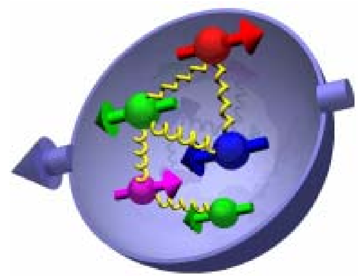
$$\Delta u_V + \Delta d_V = 1$$

But

1988 EMC measured :

$\Delta\Sigma = 0.123 \pm 0.013 \pm 0.019$

$\Rightarrow$ Spin Puzzle



From Inclusive Data :

✓Valence quark ~ well known

✓Sea quarks ?

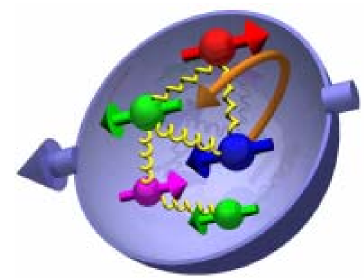
From Unpolarized Data :

✓Light sea quark flavor asymmetry

✓Gluons are important

$\Rightarrow \Delta q_s$

$\Rightarrow \Delta G$



Full description of Jq & Jg

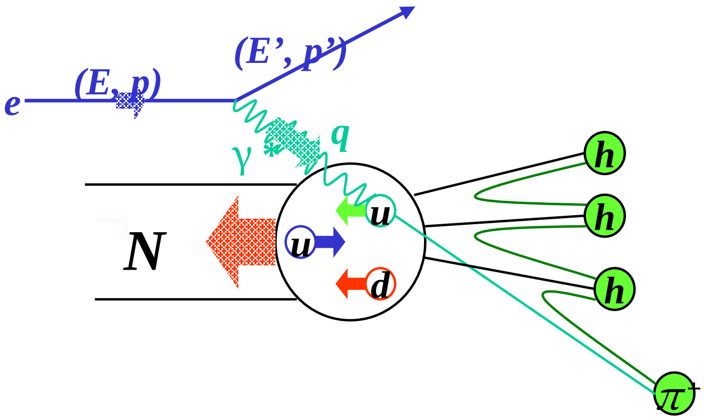
Orbital angular momentum

$$\frac{1}{2} = \frac{1}{2}\left(\Delta u_V + \Delta d_V + \Delta q_S\right) + \Delta G + L_q + L_g$$

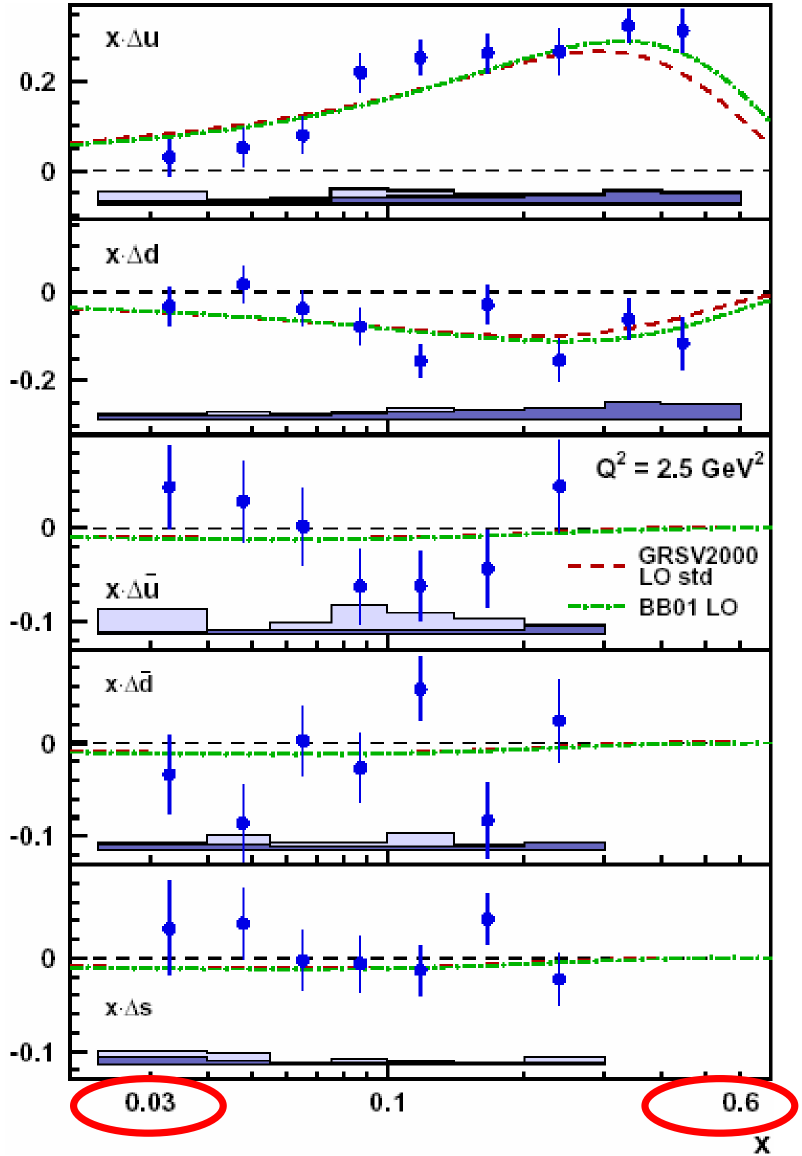
$$\Delta q_s = \Delta u_s + \Delta\bar{u} + \Delta d_s + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$

Spin Content of Strange Quark

Quark Polarization from semi-inclusive measurement at HERMES



$$A_1^{\,h}(x,z) = \Sigma_f \frac{e_f^2 \cdot q_f(x) \cdot D_f^h(z)}{\Sigma_{f'} e_{f'}^2 \cdot q_{f'}(x) \cdot D_{f'}^h(z)} \frac{\Delta q_f(x)}{q_f(x)}$$

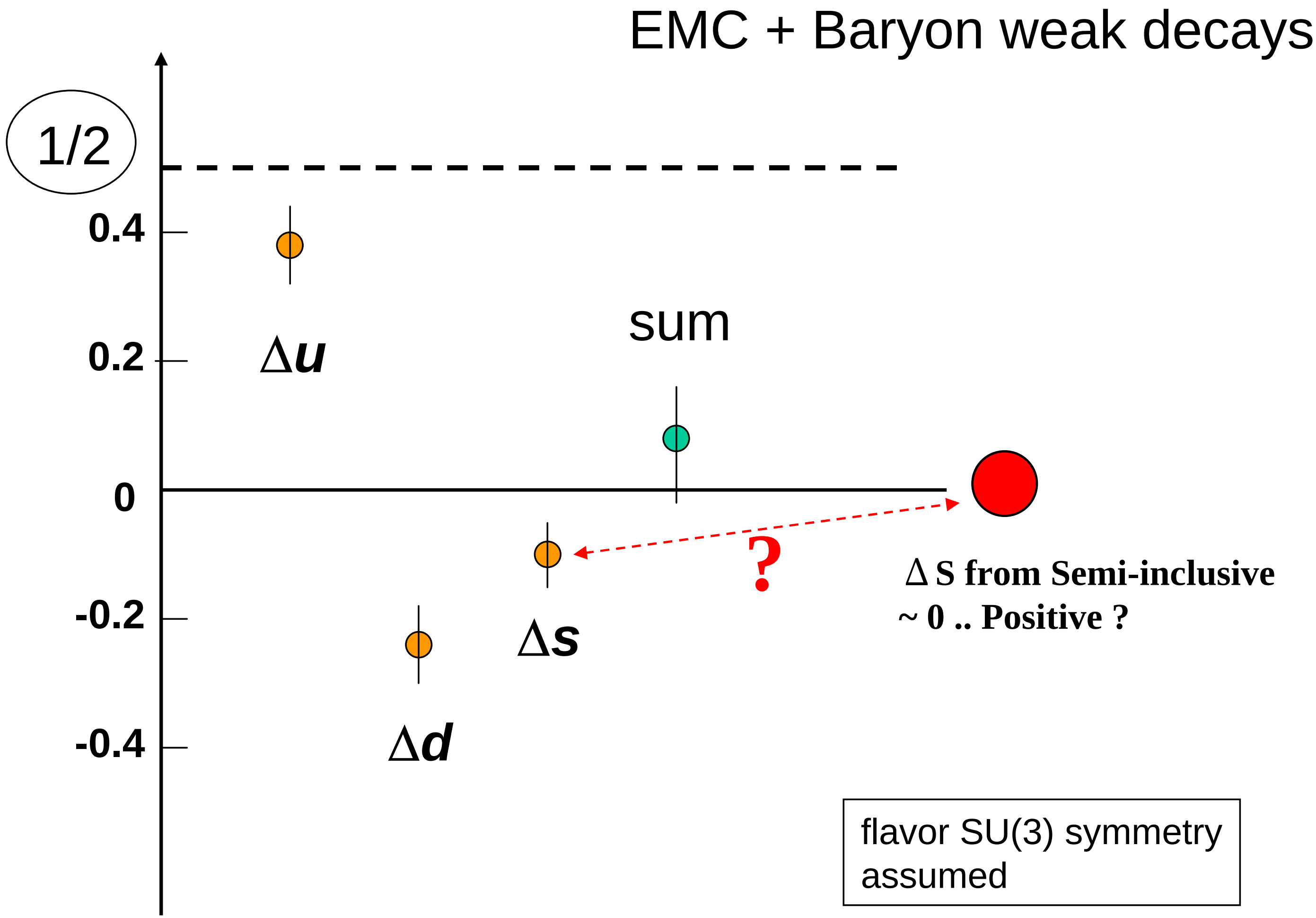


✓No indication for Δs(x)<0

✓ΔS : first moment of ΔS(x)
~ +0.03±0.03(stat.)±0.01(syst.)
→ consistent with 0,
although negative from inclusive data

$$\Delta S = \int_0^1 \Delta S(x)\, dx$$

Difficult to reach in DIS experiment



How to measure: Δs from Neutrino-Proton elastic scattering

$$\frac{d\sigma}{dQ^2} = \frac{G_F^2}{2\pi}\frac{E_\nu^2}{Q^2}\left[A \pm BW + CW^2 \right], \qquad +\text{ for } \nu, \quad -\text{ for } \bar{\nu}$$

$$W = 4(E_\nu / M_p - \tau), \quad \tau = Q^2 / 4M_p^2$$

$$A = \frac{1}{4}\left[G_1^2(1+\tau) - \left(F_1^2 - \tau F_2^2\right)(1-\tau) + 4\tau F_1 F_2\right],$$

$$B = -\frac{1}{4}\left[G_1\left(F_1 + \tau F_2\right)\right], \qquad G_1(Q^2) = \frac{-0.631}{(1+Q^2/M_A^2)^2} + \frac{G_1^s(Q^2)}{2}$$

$$C = \frac{1}{16}\frac{M_p^2}{Q^2}\left[G_1^2 + F_1^2 + \tau F_2^2\right],$$

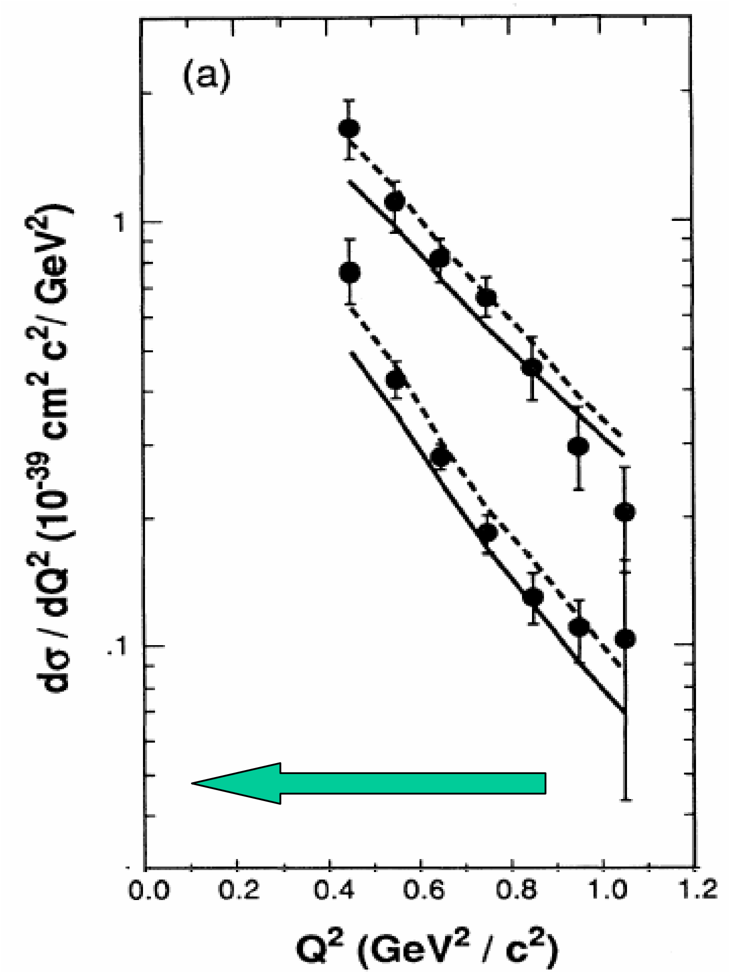
$$G_1^s(Q^2 = 0) = \Delta s$$

Axial form factor

Sensitivity for Δ*s* and Other Physics Impact

Conditions:

- Similar Detection Efficiency to E734:
  - 7.6% for neutrino-N elastic
  - 5.4% for anti-neutrino-N elastic
- with lower Q^2 cut-off : 0.1 GeV^2
  - Achievable with more uniform detector
- 25 times more statistics but pure proton only 1/6
  - Factor 2 reduction in statistical error
- Systematic control improvements to ~5%
  - E734, 7.6% dominated by Beam Flux and Nuclear Effects
  - Possible to remove Nuclear Effects which could be larger in lower Q^2 region

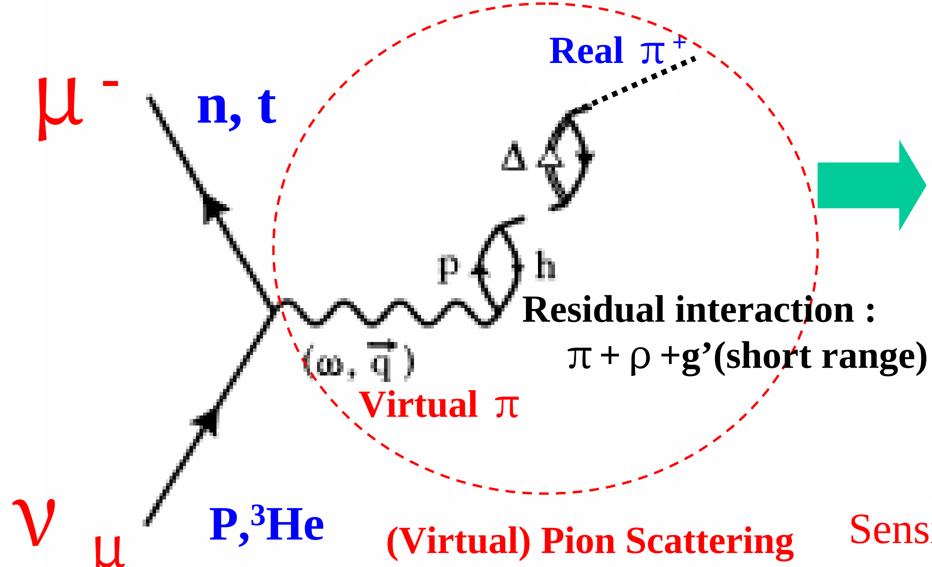


Neutron EDM ~ predicted using q-EDM and D*q*

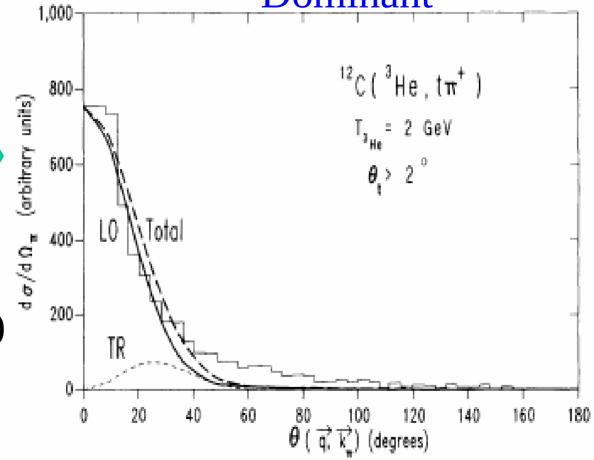
$$d_n = \eta^E (\Delta u\, d_u^E + \Delta d\, d_d^E + \Delta s\, d_s^E)$$
$$\propto m_u \Delta u + m_d \Delta d + m_s \Delta s$$

Coherent Pion Production

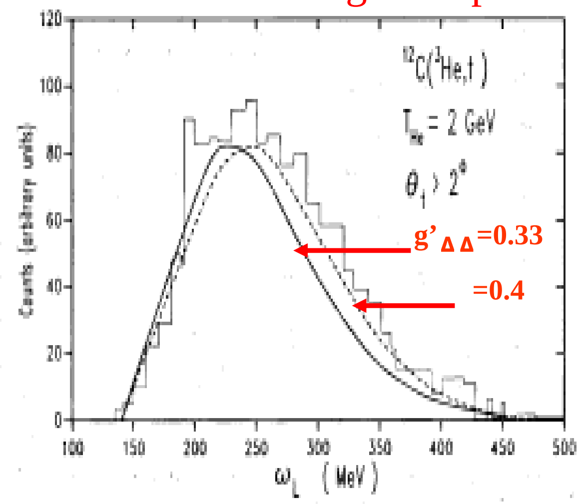
A(ν , μ⁻ π⁺)A



Spin longitudinal response function ~ Dominant



Sensitive to NN short range component g'$_{\Delta\Delta}$



●**Neutrino ~ Weak interaction**

→ **No distortion, absorption**

⇒ **test the Δ , π in the interior of nucleus**

Adler's theorem : M~T(π (q)+N→X)

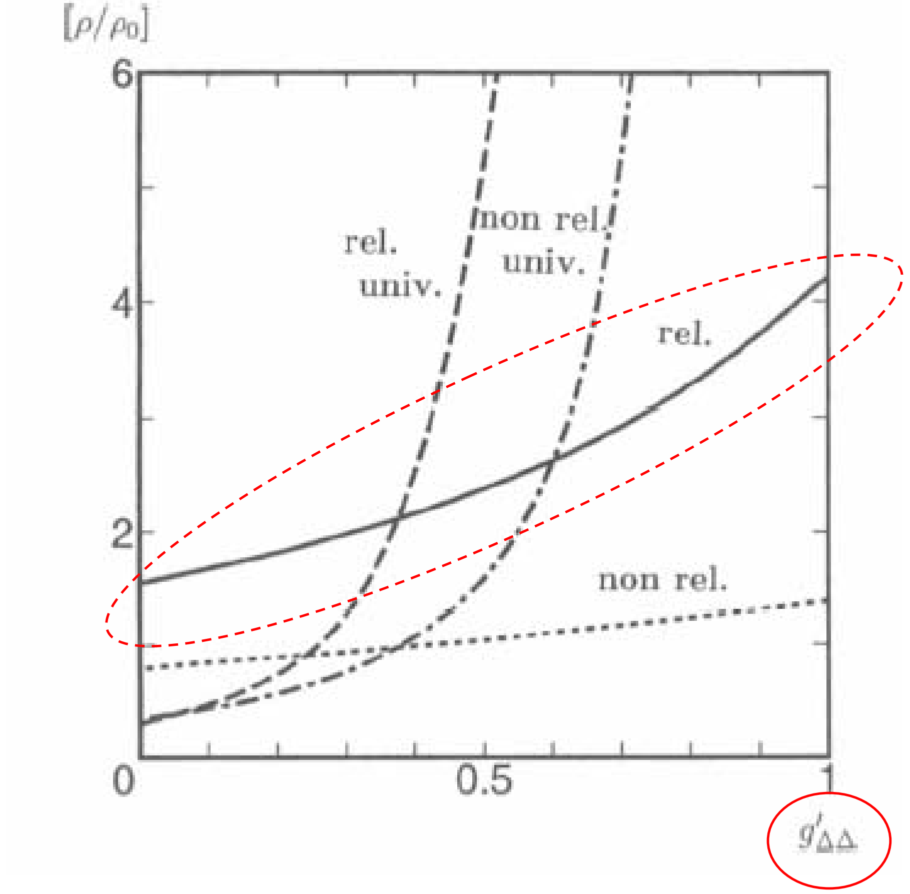
●**Hadron ~ Strong interaction**

→ **Distortion, absorption**

⇒ **peripheral reaction ~ nuclear surface**

Effect to nuclear matter property

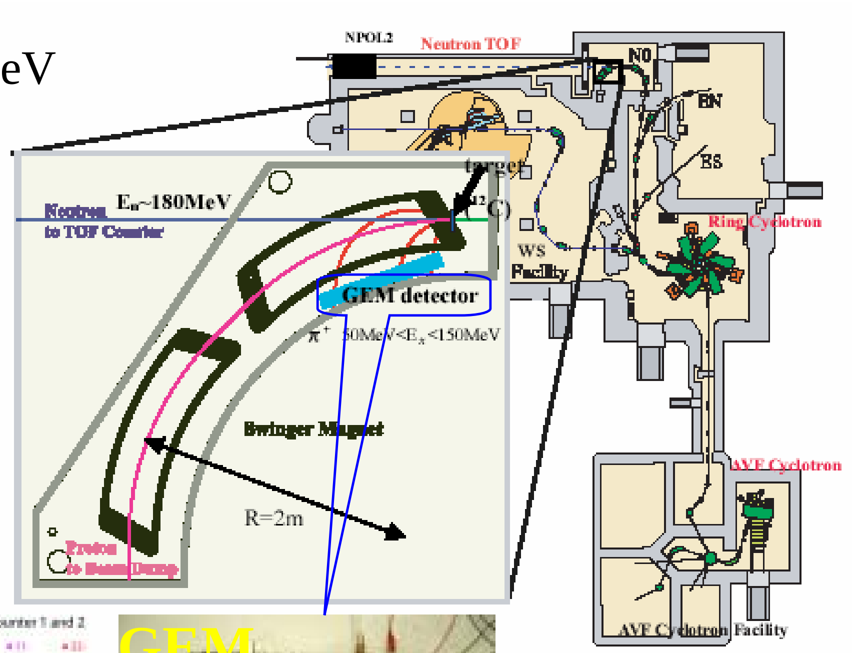
Short range correlation : $g'_{\Delta\Delta}$
~ sensitive to critical density ρ of pion condensation phase
~ determine the limit of ρ from the CPP measurement

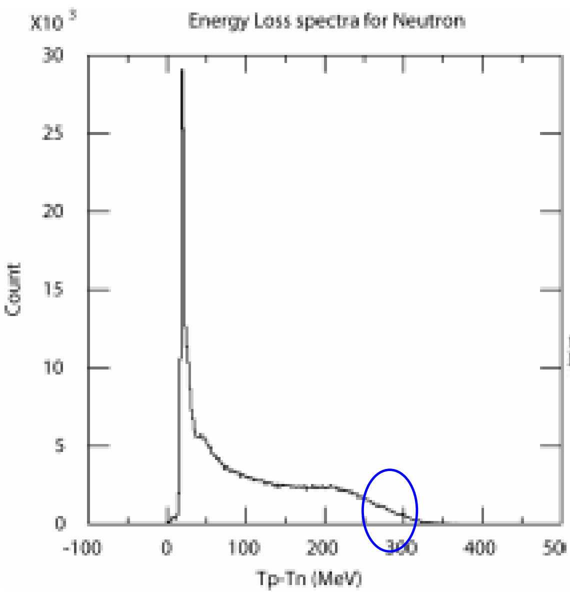


CPP experiment at RCNP

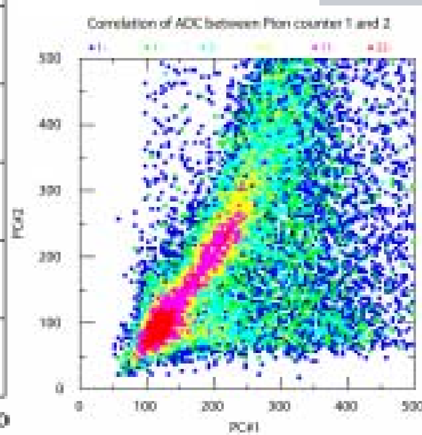
Proton Beam : $^{12}C(p,n\pi^{+})^{12}C$ at E_p=400 MeV

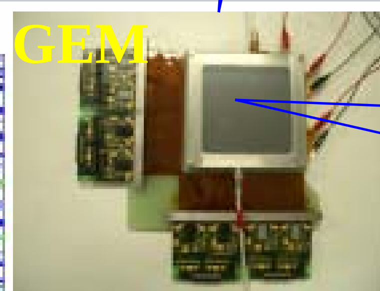
- Experiment ~ feasibility test in progress
- Detector development for π detection
  - ~ Gas Electron Multiplier (GEM)
- Hadron probe
  - ✓peripheral reaction
  - ✓Δ, π propagation in surface

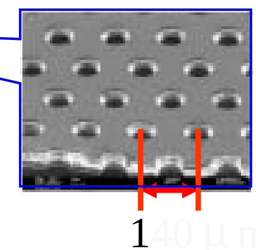




Excitation energy



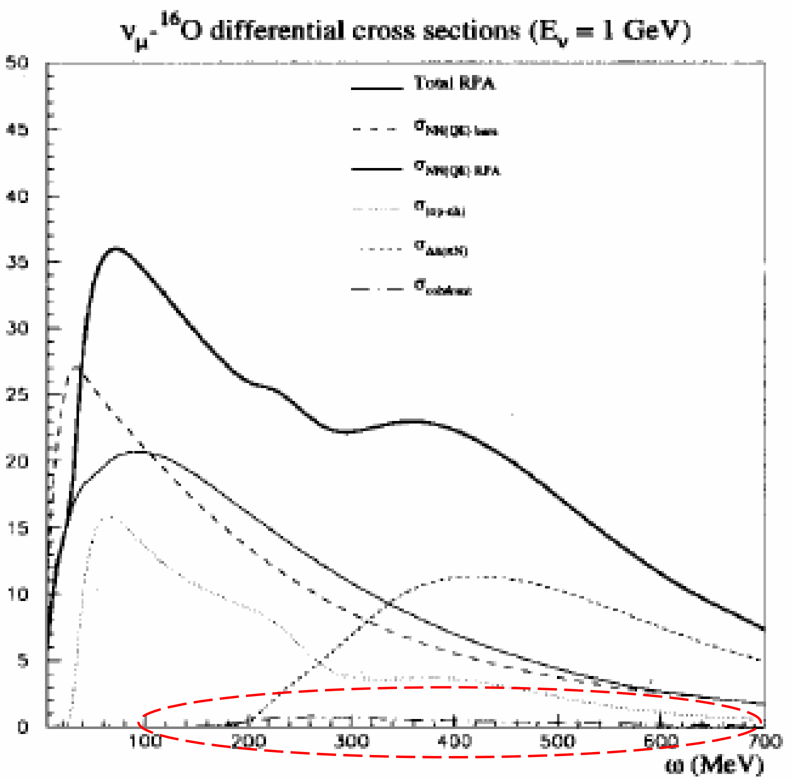




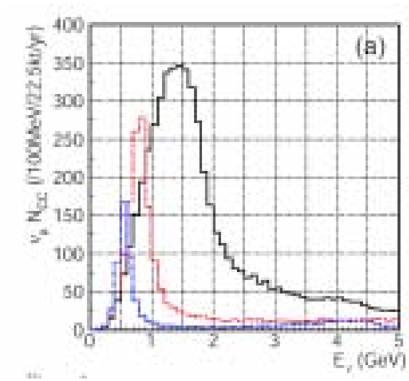
Neutrino induced CPP

ν interaction type	ν_μ 10^{20} POT 1 ton	$\overline{\nu_\mu}$ 10^{20} POT 1 ton	$\nu_e + \overline{\nu_e}$ 10^{20} POT 1 ton
CC QE, $\nu_\mu n \to \mu^- p$	11,395	184	56
NC EL, $\nu_\mu N \to \nu_\mu N$	4,903	86	22
CC π^+, $\nu_\mu p \to \mu^- p \pi^+$	3,293	24	24
CC π^0, $\nu_\mu n \to \mu^- p \pi^0$	726	11	6
CC π^+, $\nu_\mu n \to \mu^- n \pi^+$	646	10	6
NC π^0, $\nu_\mu p \to \nu_\mu p \pi^0$	606	10	5
NC π^+, $\nu_\mu p \to \nu_\mu n \pi^+$	370	6	3
NC π^0, $\nu_\mu n \to \nu_\mu n \pi^0$	454	8	3
NC π^-, $\nu_\mu n \to \nu_\mu p \pi^-$	290	5	2
CC DIS, $\nu_\mu N \to \mu^- X$	176	0	1
NC DIS, $\nu_\mu N \to \nu_\mu X$	64	0	0
CC coh π^+, $\nu_\mu A \to \mu^- A \pi^+$	539	22	3
NC coh π^0, $\nu_\mu A \to \nu_\mu A \pi^0$	349	14	2
other	464	14	1
total	24,364	394	134

Table 3.1: *Number of events expected at 50 m with a 25 m decay length for 1×10^{20} POT per ton detector. These predictions do not include final state effects and assume 100% detection/reconstruction efficiency.*



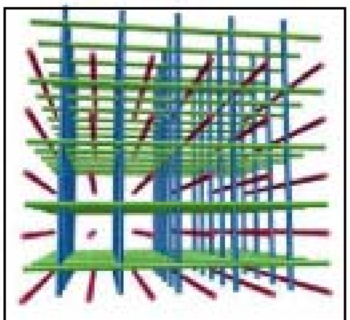
Neutrino Beam Line

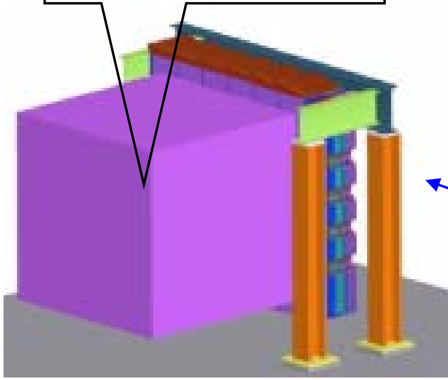


Detector
~ BNL case

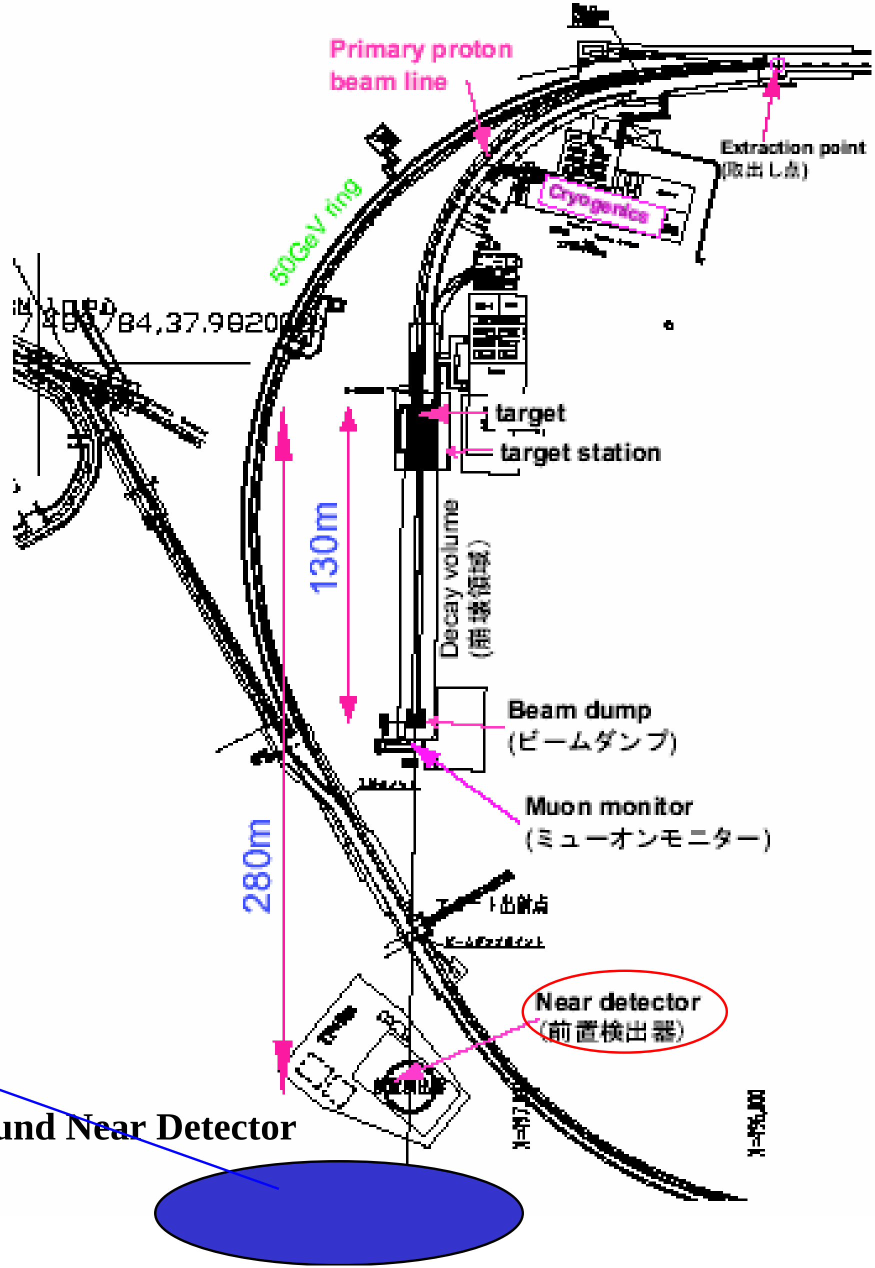
Liquid Sci.
With W.L.S

Target
- **Proton**
- **Carbon**





Around Near Detector



Cost and Timeline

- Impossible to locate the detector in the near detector hall
- New detector hall underground or ….
- Simulation study in progress to optimize the detector..

Cost ~ depend on the detector location
~ 穴掘り工事：10億円～30億円？

✓NeuFact04
✓NP04
✓Workshop at RCNP ~ Feb.-24/2005
Start to prepare Letter of Intent
Try to get budget…..

Working group : Kyoto, Tokyo Tech., KEK, RCNP,.....

Summary

EDM search of Electron

- Time reversal symmetry violation, Beyond the standard model
- Open new research area with high precision measurement at RCNP
- Based on upgraded ECR ion source, AVF cyclotron, Beam line
- Accelerator Complex

Nuclear physics with Neutrino Beam

- New probe ~ Neutrino at J-PARC
  - ✓Strange quark ~ Spin structure of nucleon
  - ✓Interior of nucleus ~ Spin response function
- Natural extension of Spin-Isospin Physics at RCNP
- Nuclear physics facility (base) with Lepton-Photon beam
  - ✓LEPS@SPring-8 + Neutrino + High energy electron beam from LC