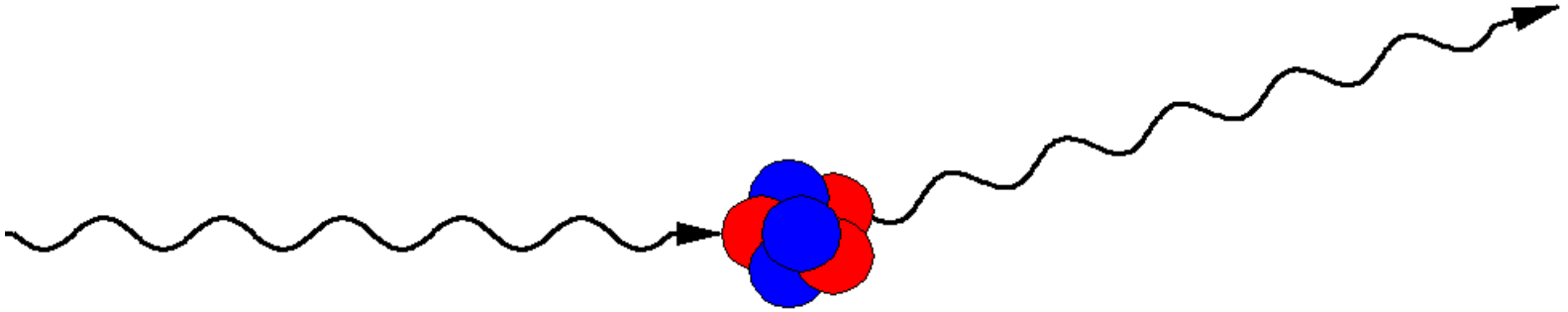
Compton Scattering from Light Nuclei at MAX-lab



Luke Myers
COMPTON@MAX-lab Collaboration

INT Workshop
Electroweak Properties of Light Nuclei
November 5, 2012

Priorities of the Experimental Program

Initially:

Extract isoscalar polarizabilities from d(γ,γ)d

Priorities of the Experimental Program

Initially:

Extract isoscalar polarizabilities from d(γ,γ)d

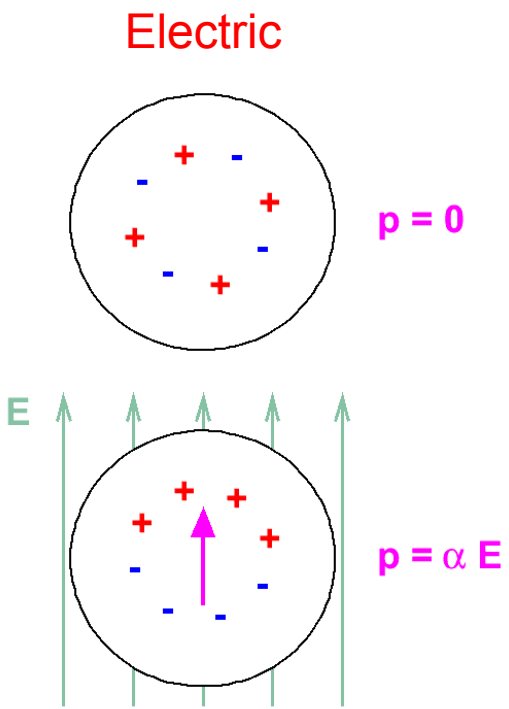
Since:

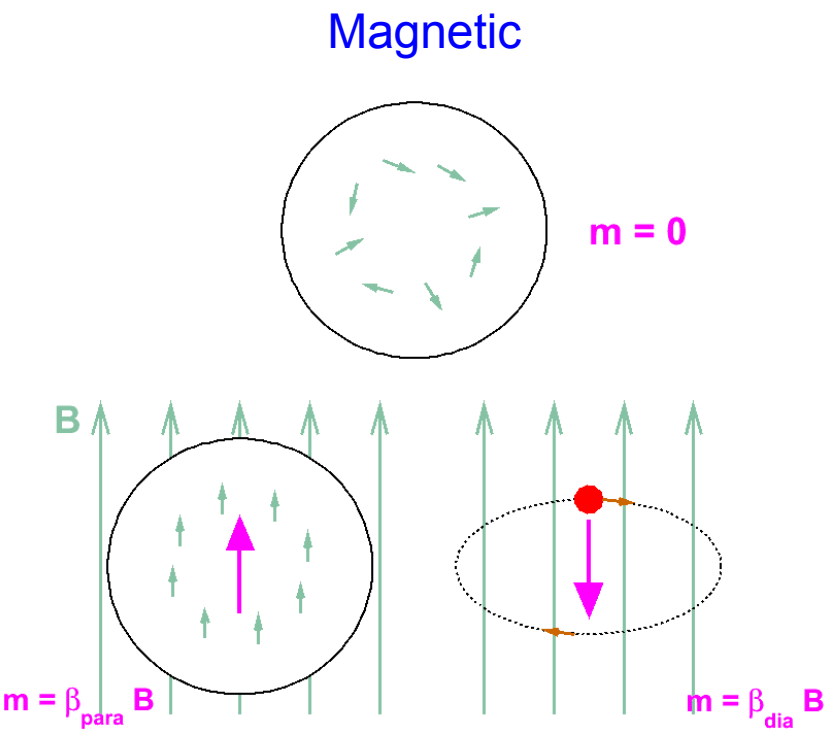
Characterization of systematics at MAX-lab [^{6}Li, ^{12}C, ^{16}O]

As a side effect, resolution of long-standing experimental discrepancies [^{12}C, ^{16}O]

Compton Scattering and Nucleon Polarizabilities

- Polarizability: relates induced dipole moment to external field





Compton Scattering and Nucleon Polarizabilities

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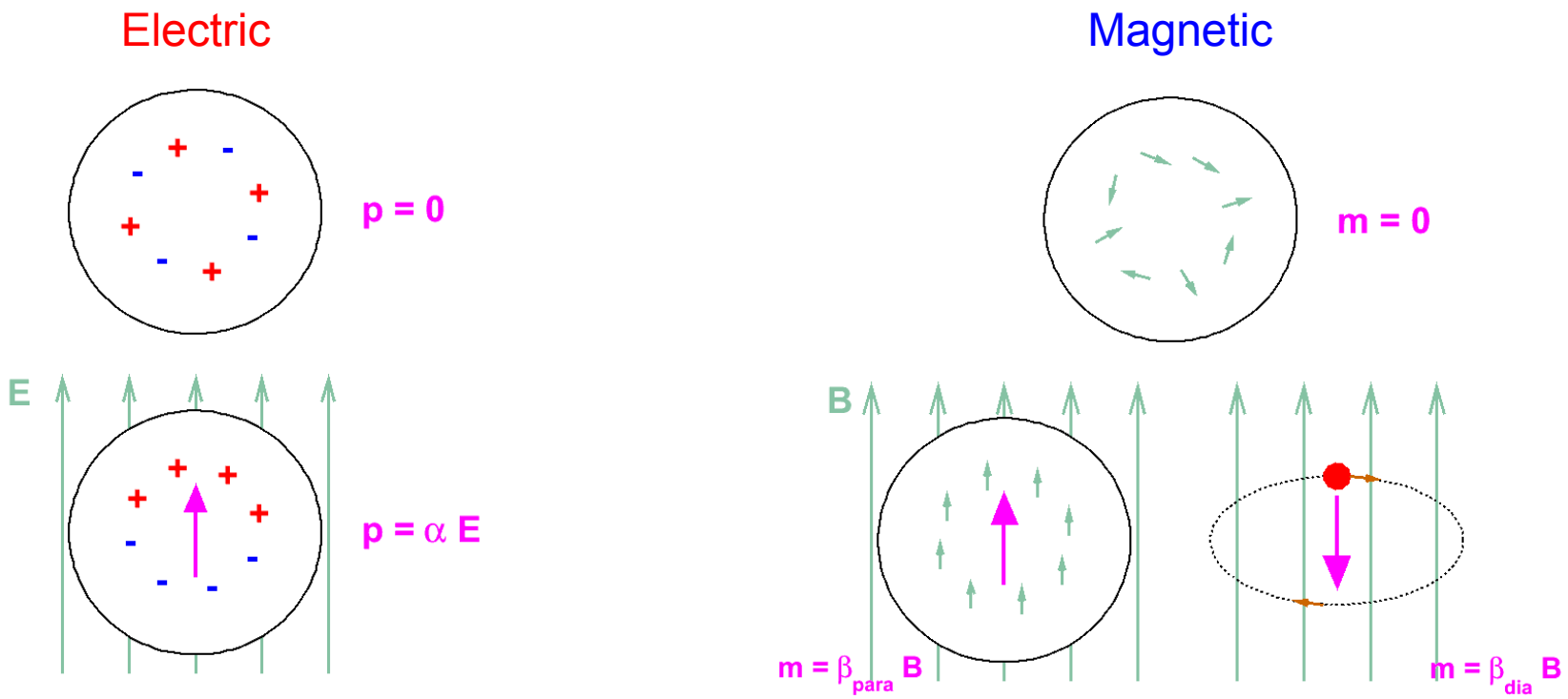

- α, β are
  - fundamental structure constants
  - leading order response of *internal* structure of nucleon
  - well-known for proton, but neutron needs more data

Compton Scattering and Nucleon Polarizabilities

- Most common method of studying α, β
- Experimentally, usually measured below π threshold (LEX)

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Powell} - \frac{e^2}{4\pi M_N}\left(\frac{\omega'}{\omega}\right)^2 \omega\omega' \left\{\frac{\alpha+\beta}{2}(1+\cos\theta)^2 + \frac{\alpha-\beta}{2}(1-\cos\theta)^2\right\} + O(\omega^4)$$

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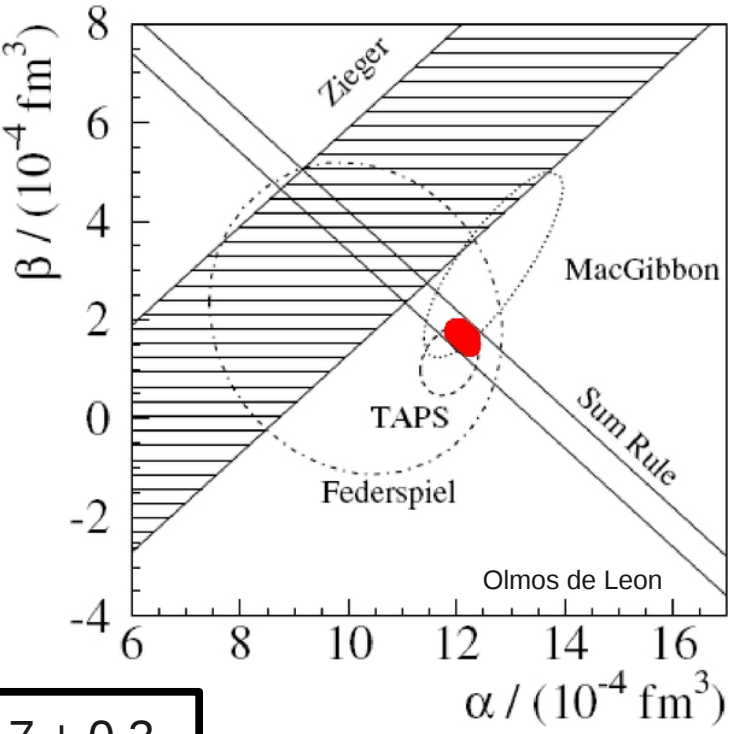
Proton



$\alpha_p = 10.7 \pm 0.3$

$\beta_p = 3.1 \pm 0.3$

Griesshammer, et al., http://arxiv.org/pdf/1203.6834

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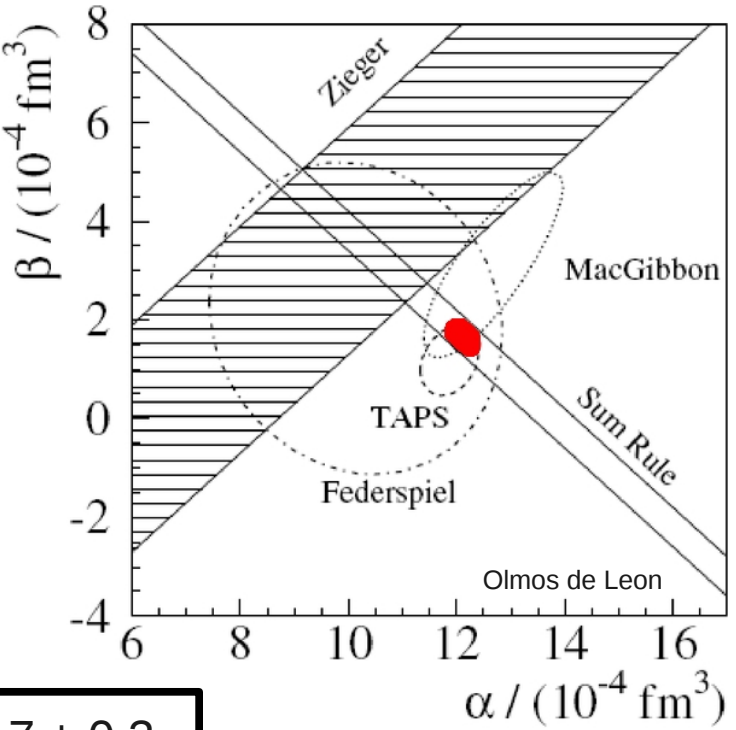

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Neutron

- No free target
- Bound neutrons (quasi-free scattering)?

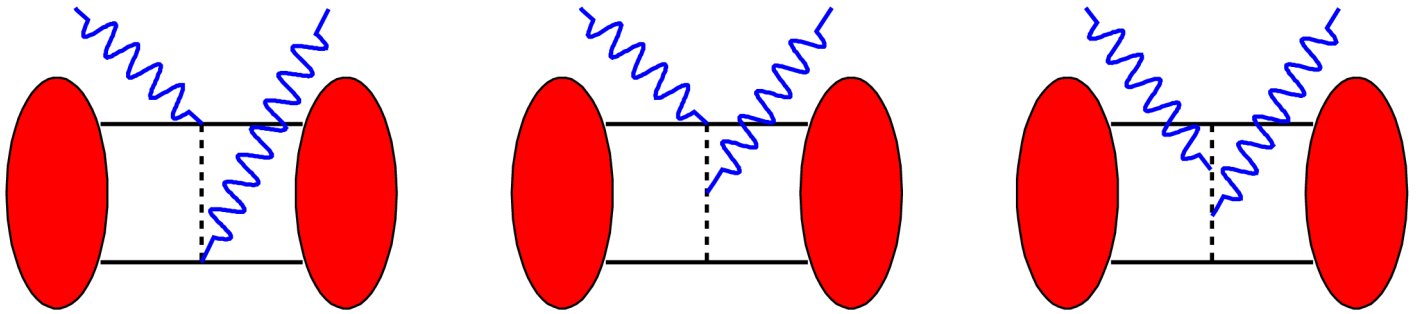
  Uncharged ⇨ $\frac{d\sigma}{d\Omega} \approx O(\omega^4)$

Solution: Compton Scattering on the Deuteron

Compton Scattering and Nucleon Polarizabilities

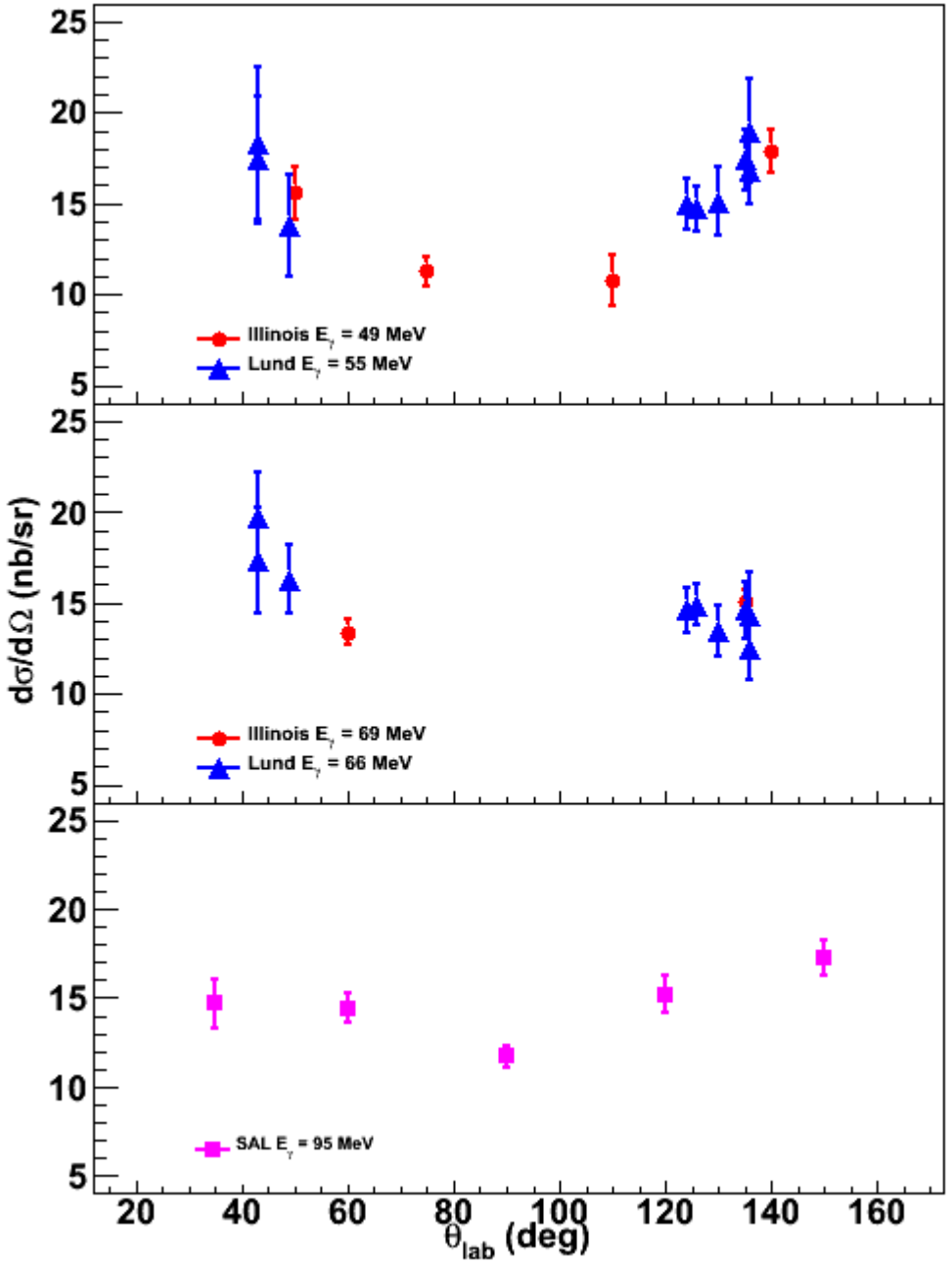
Compton Scattering on the Deuteron

Advantage	**Disadvantage**
Deuteron has net charge	Must know proton polarizabilities
Sensitive to isoscaler polarizabilities at $O(\omega^2)$	Must understand meson-exchange current scattering
	Must separate $d(\gamma,\gamma)d$ from $d(\gamma,\gamma)np$



Subset of possible scattering diagrams involving meson exchange currents

Compton Scattering and Nucleon Polarizabilities



d(γ,γ)d data sets

	E [MeV]	ΔE [MeV]	Statistical	Systematic
Illinois	49, 69	6.5, 7.7	4.2–12.6%	3.6–4.0%
Lund	55, 66	10, 10	7.5–24.4%	6.5–14.3%
SAL	95	20	5.2–9.8%	4.8–6.4%

$\alpha_n = 11.1 \pm 1.8$
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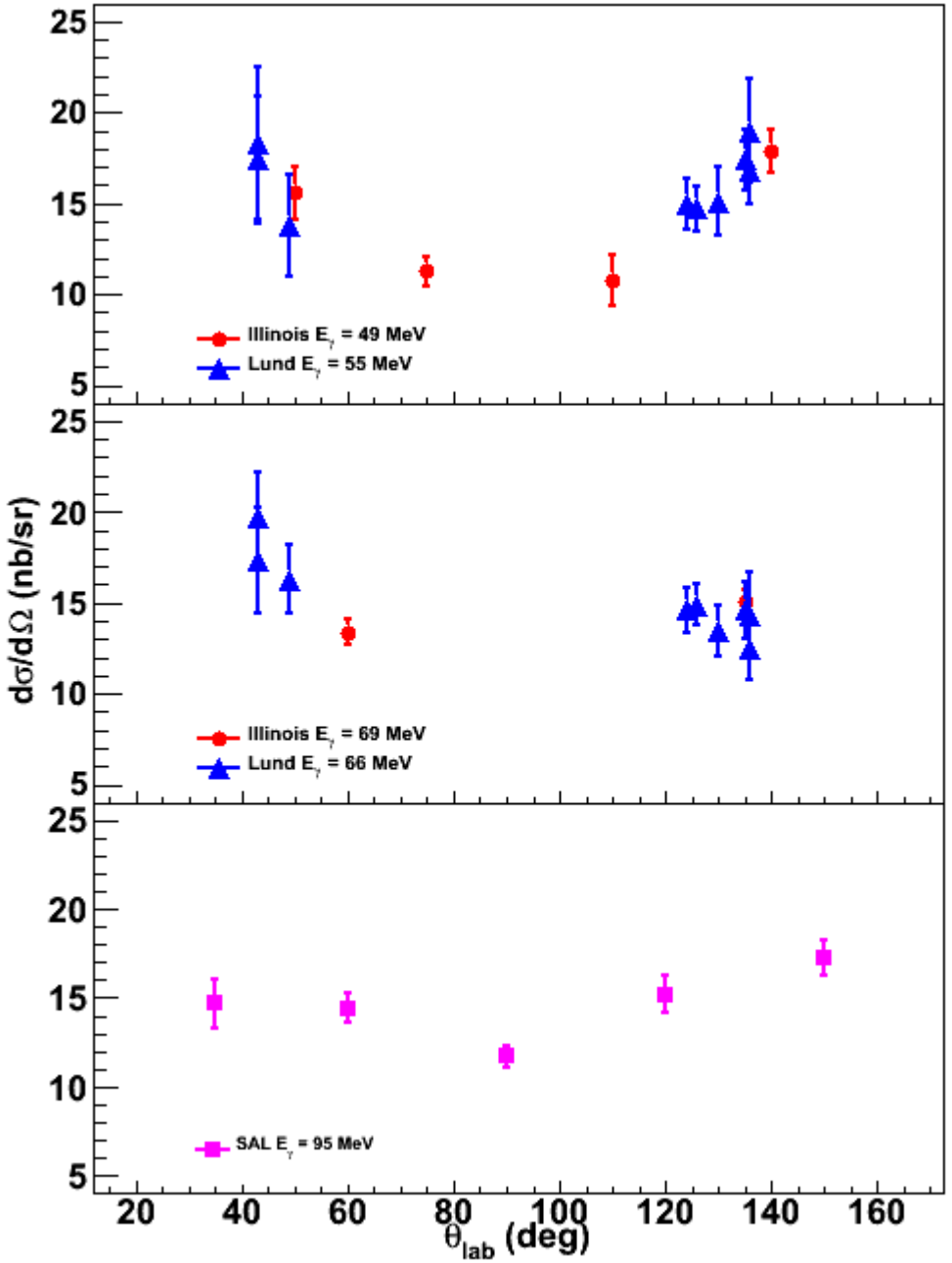

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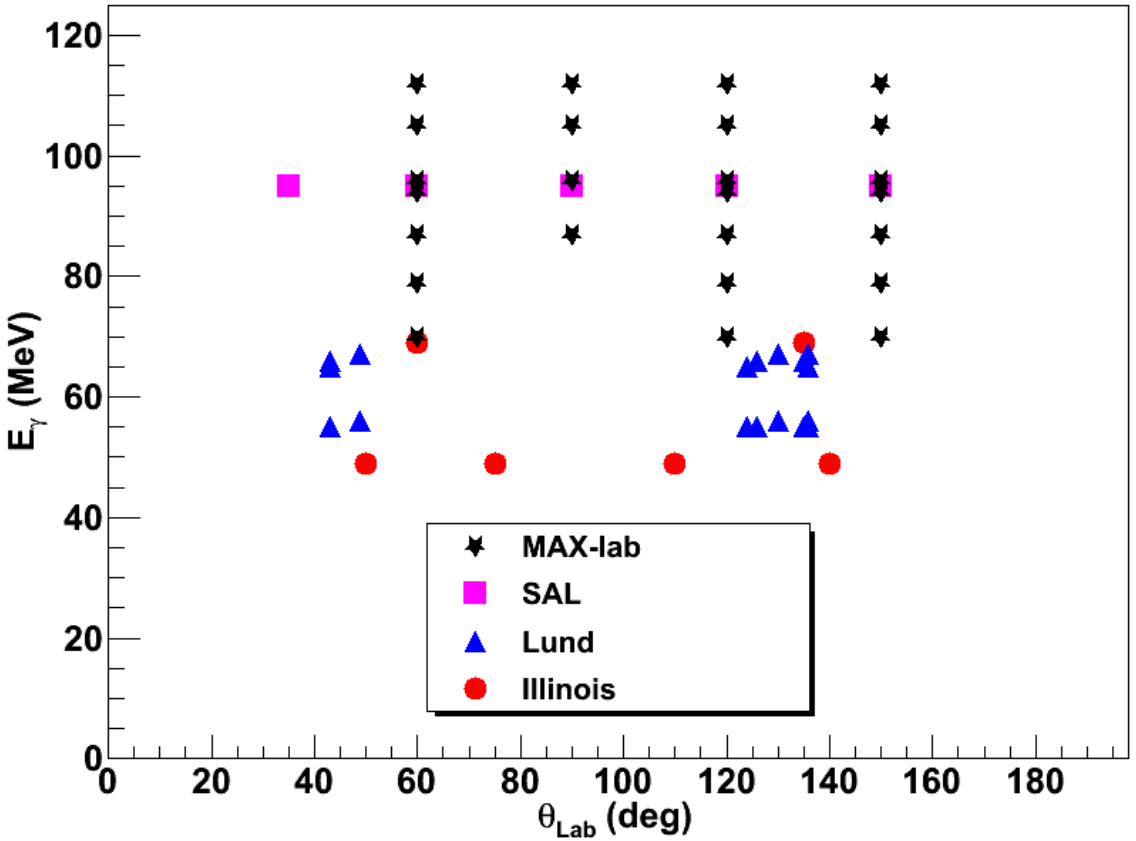
- Improvements Needed
  - Better statistics at lower energies
  - Narrower energy bins at high energies
  - Greater coverage of kinematic space
  - Push to even higher photon energies

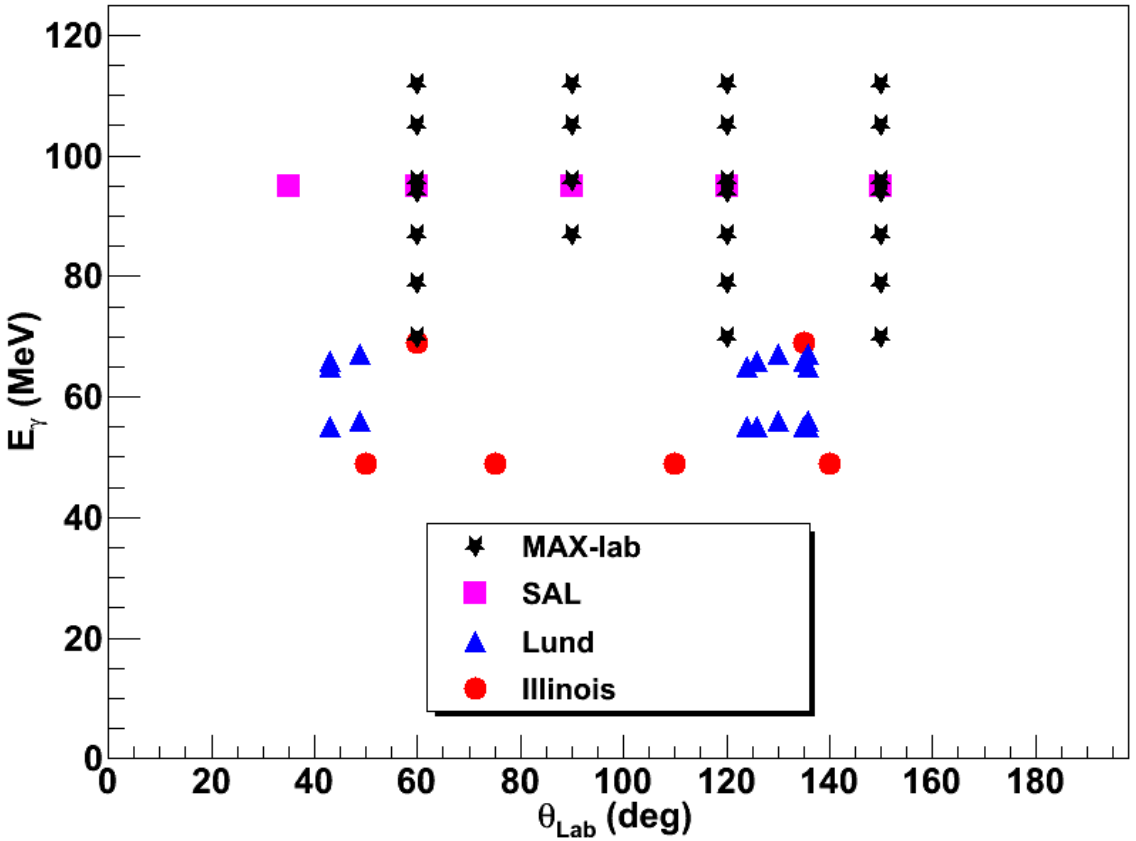
Compton Scattering and Nucleon Polarizabilities



MAX-lab program goals

- Double the number of d(γ,γ)d data points
- Keep statistical and systematics < 5 – 10%
- Investigate beam energies up to 115 MeV

Compton Scattering and Nucleon Polarizabilities



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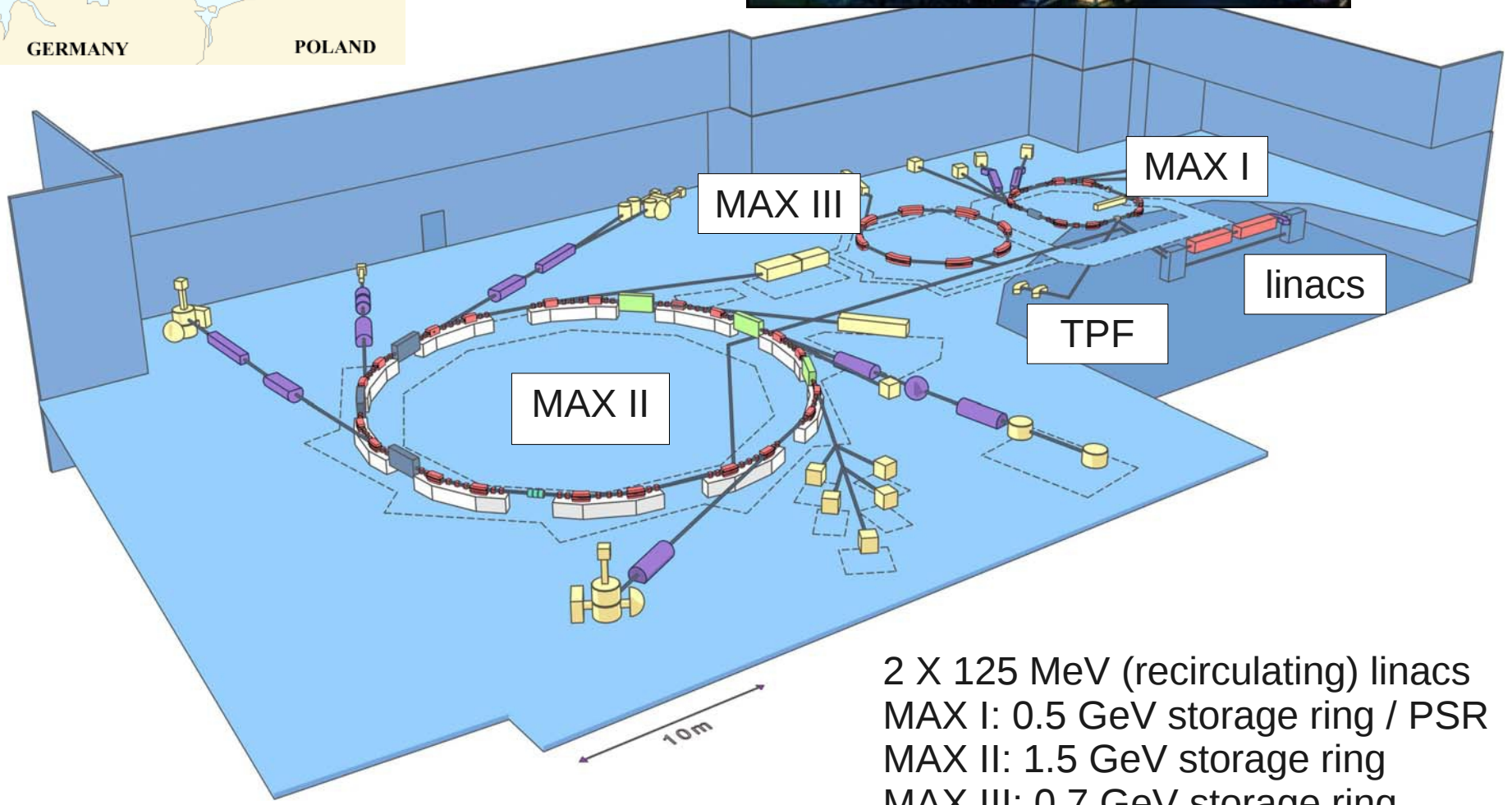
Implications of these data

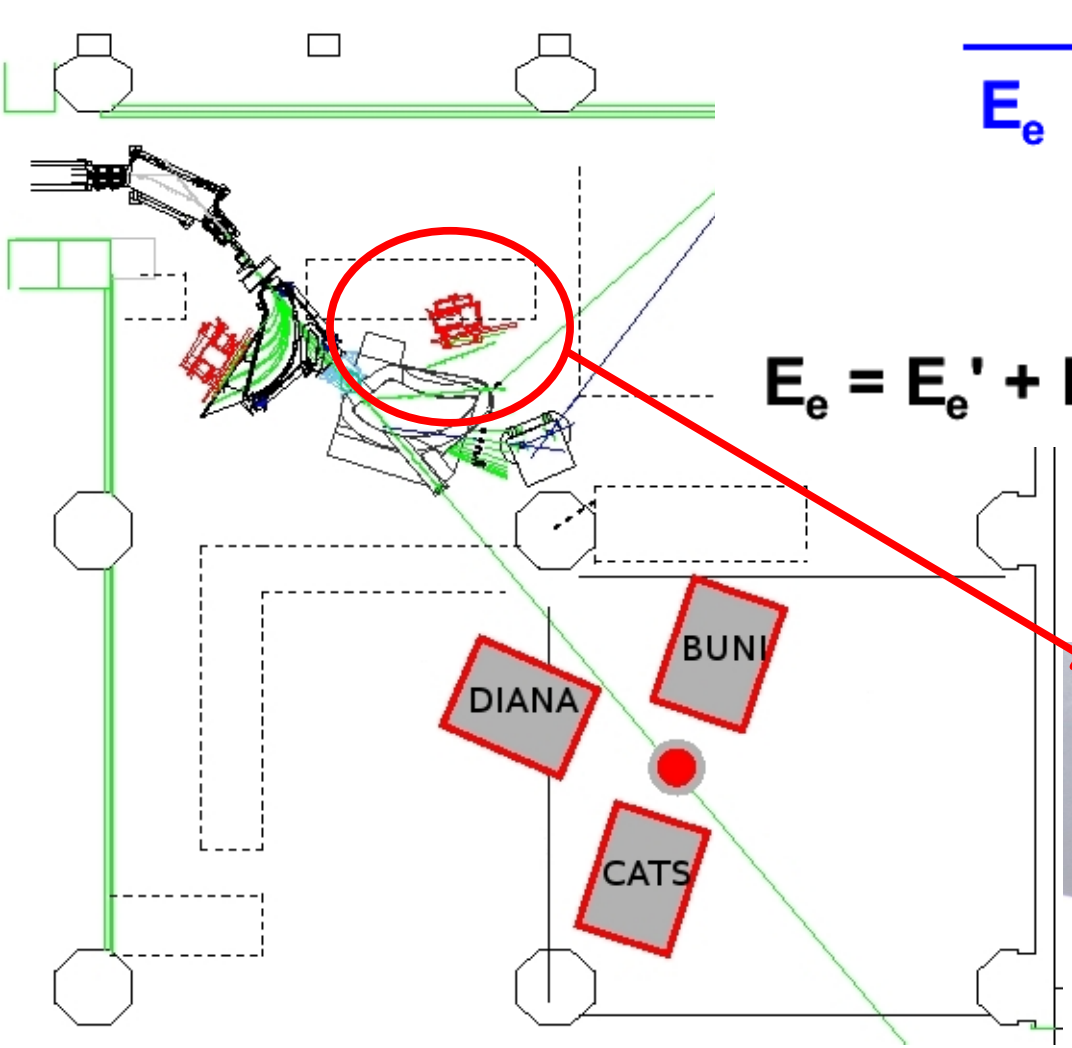
- Test theory of two-photon response of the nucleon
- Understanding meson-exchange currents
- Reduce uncertainty in the evaluation of $M_n - M_p$

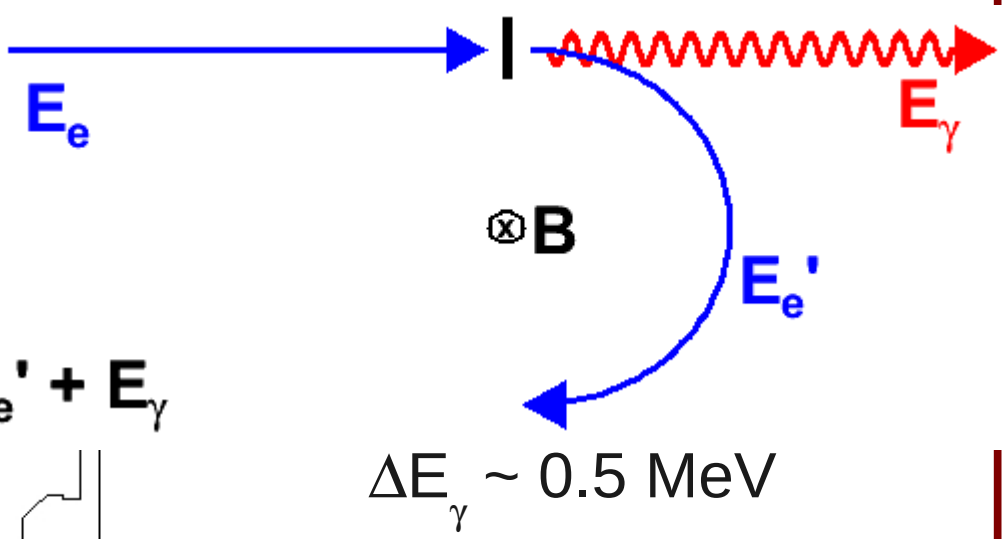
The MAX-lab Facility



2 X 125 MeV (recirculating) linacs
MAX I: 0.5 GeV storage ring / PSR
MAX II: 1.5 GeV storage ring
MAX III: 0.7 GeV storage ring

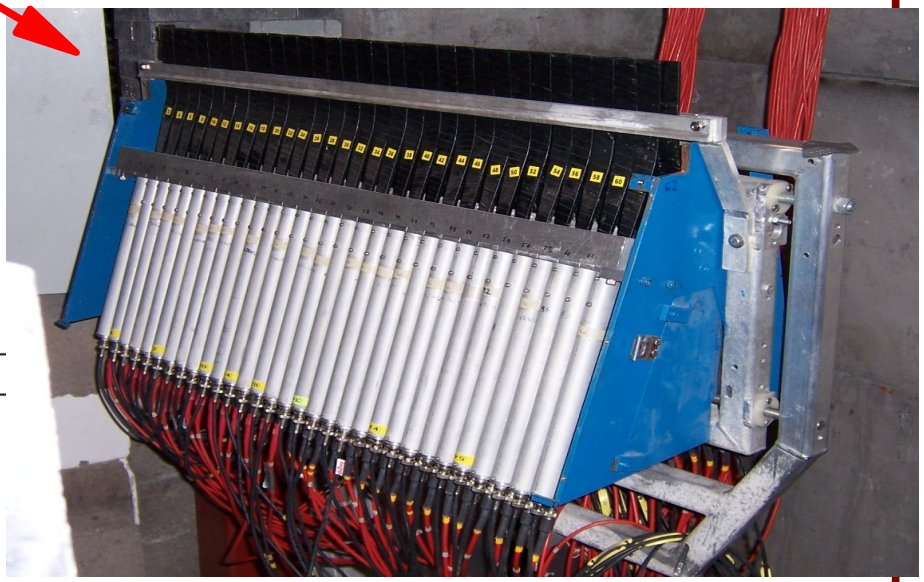
The MAX-lab Facility





$E_e = E_e' + E_\gamma$

$\Delta E_\gamma \sim 0.5$ MeV



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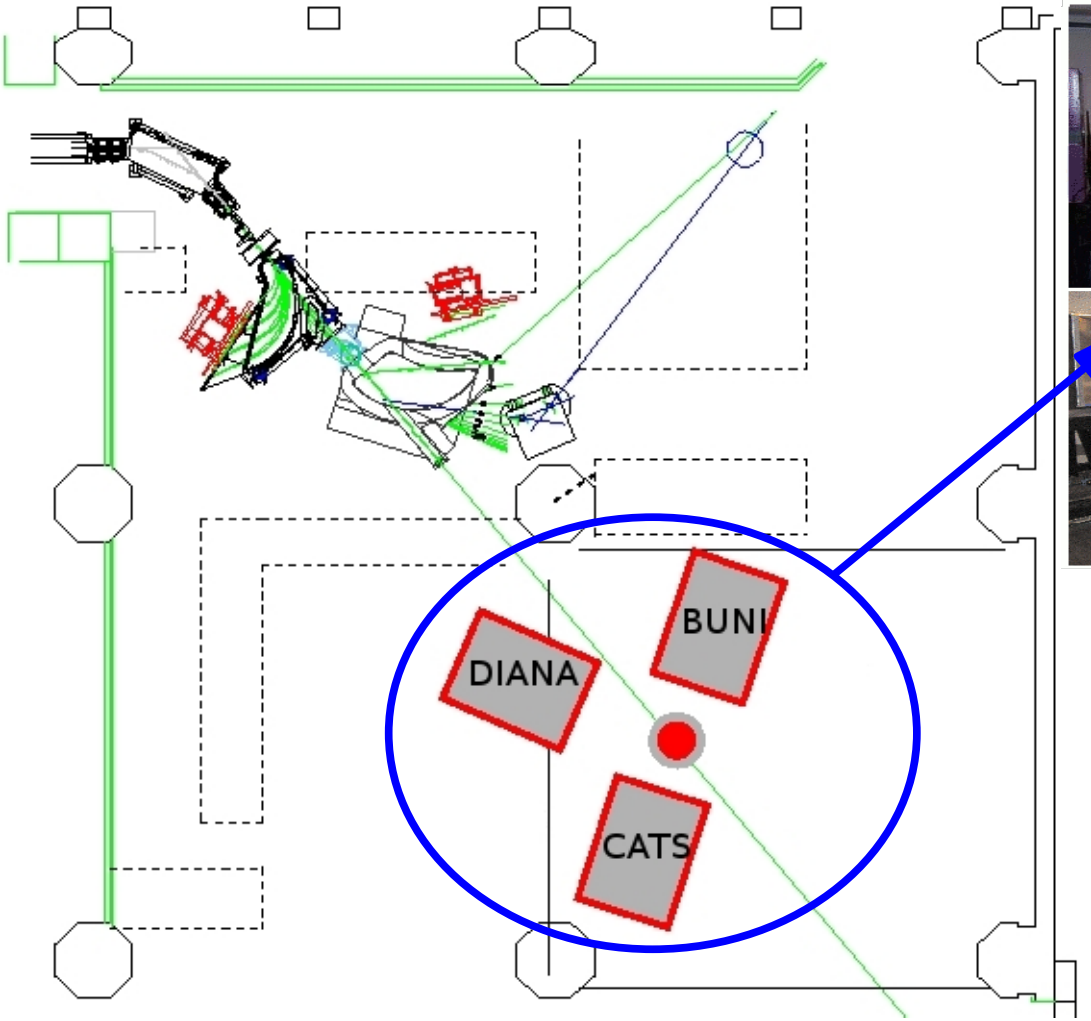

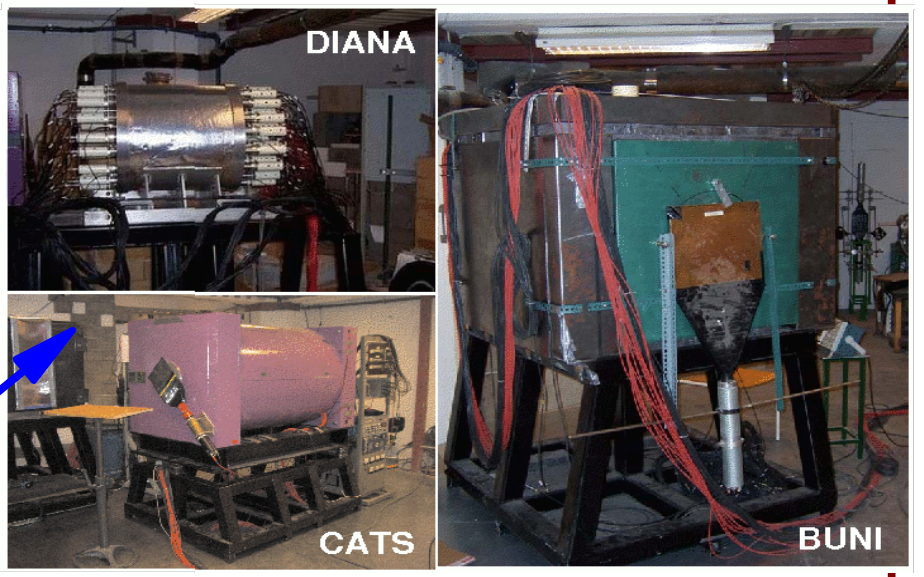

- 3 20” x 20” segmented NaI detectors
- $\Delta E/E \sim 2\%$ @ 100 MeV
- Separate elastics from break-up

The COMPTON@MAX-lab Program

Run Period	Target	Angles	E_γ [MeV]	R_{ave} [MHz]
Nov 2007	D_2, ^{12}C	60, 120, 150	66 – 98	~1.0
Nov 2008	D_2, ^{12}C	60, 120, 150	81 – 116	~1.0
Sept 2008	^{16}O	45, 90, 135, 150	65 – 96	~0.9
Nov 2009	D_2, ^{12}C	60, 90, 150	81 – 116	~0.6
Sept 2010	D_2, ^{12}C	60, 120, 150	81 – 116	~0.7
June 2011	D_2, ^{12}C	60, 120, 150	145 – 166	~0.2
Apr 2012	^{6}Li, ^{12}C	60, 120, 150	61 – 100	~0.4

(Upgrade 2002–2004, beam commissioning 2005, experimental commissioning 2006)

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(Upgrade 2002–2004, beam commissioning 2005, experimental commissioning 2006)

- Earlier data sets have larger rate corrections
  - Higher beam rate

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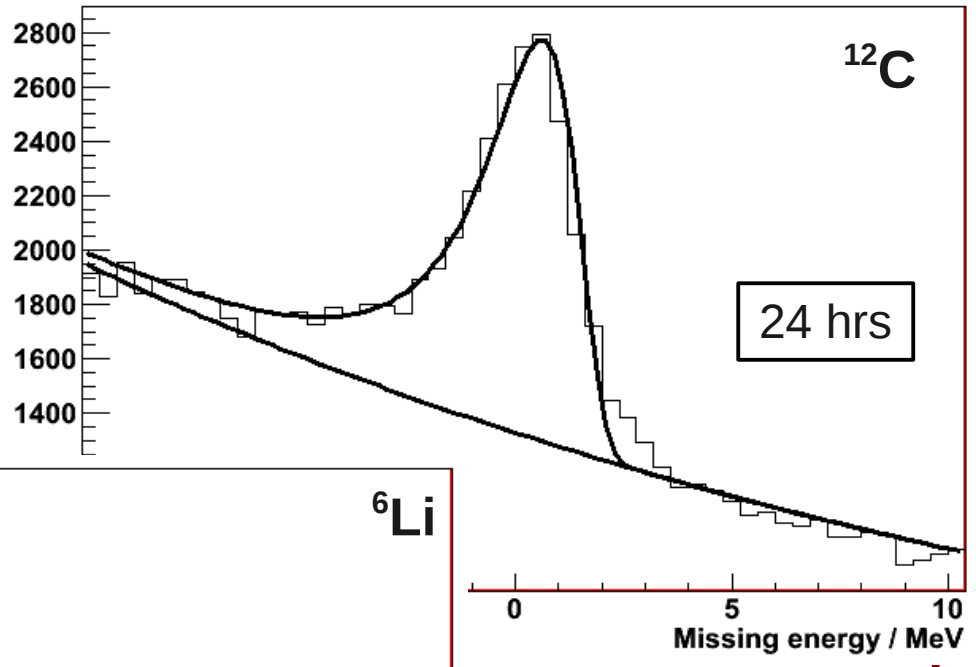
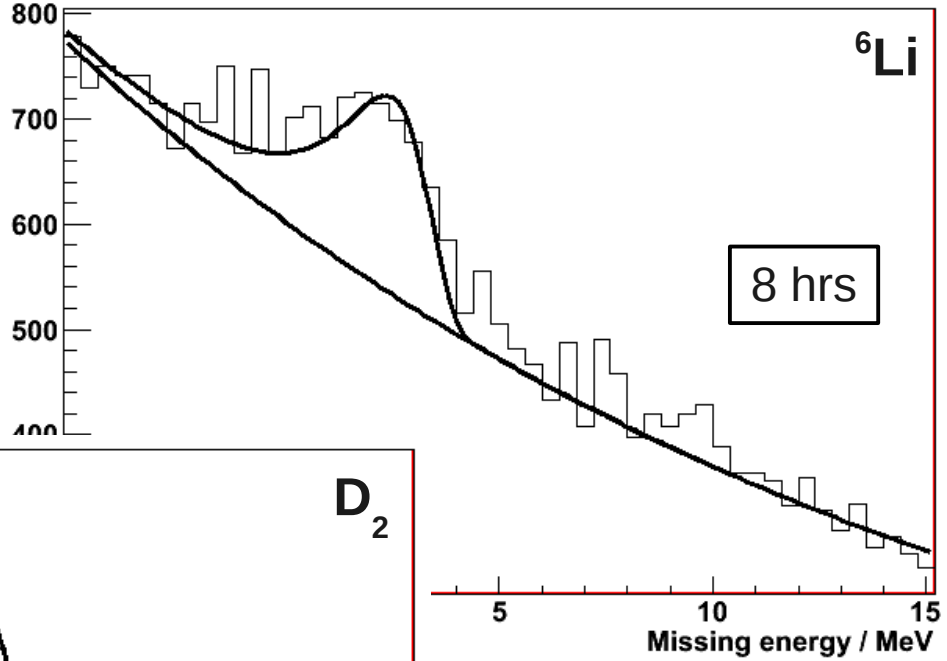
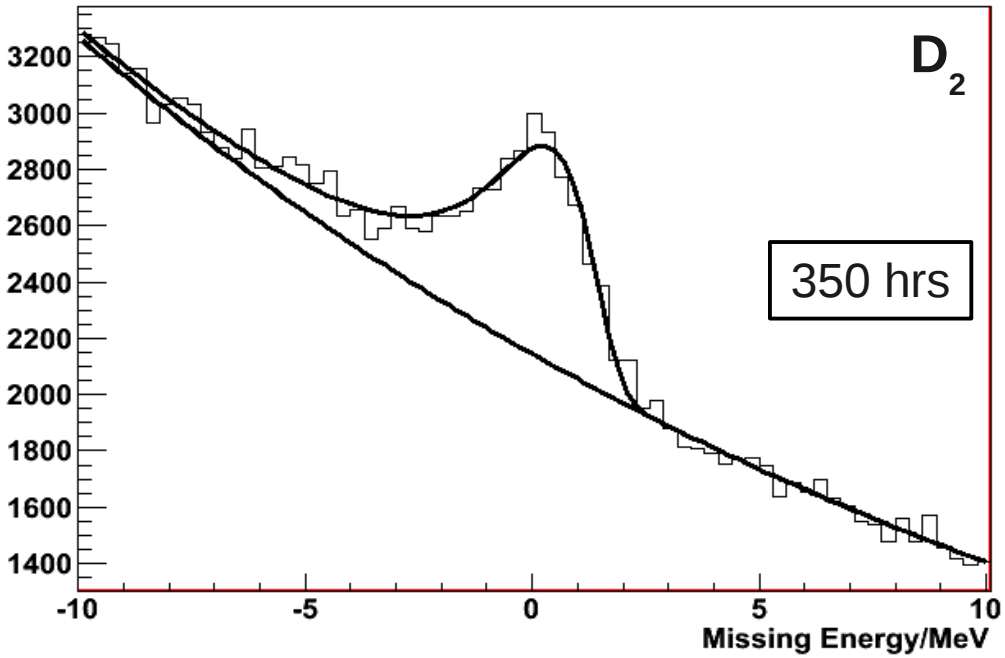
- 1^{st} d(γ,γ)d measurement near π threshold

Elastic Scattering Peaks





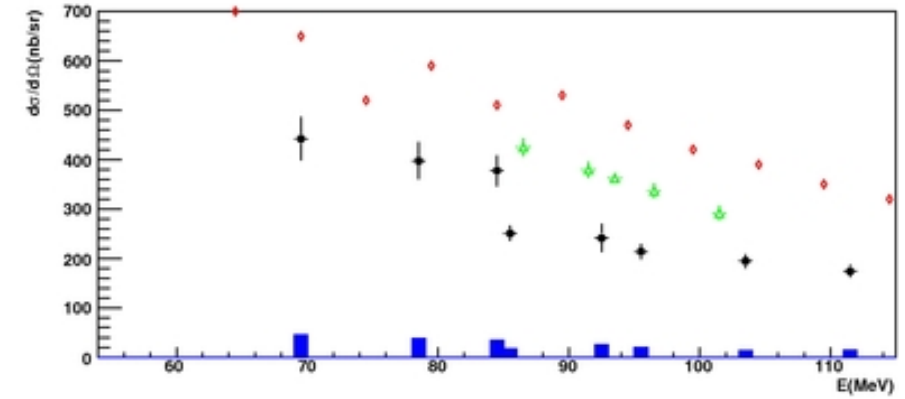


Target	S:N Ratio	E [MeV]
Carbon	~1:1	81 – 116
Lithium	~1:2	61 – 100
Deuterium	~1:3	81 – 116

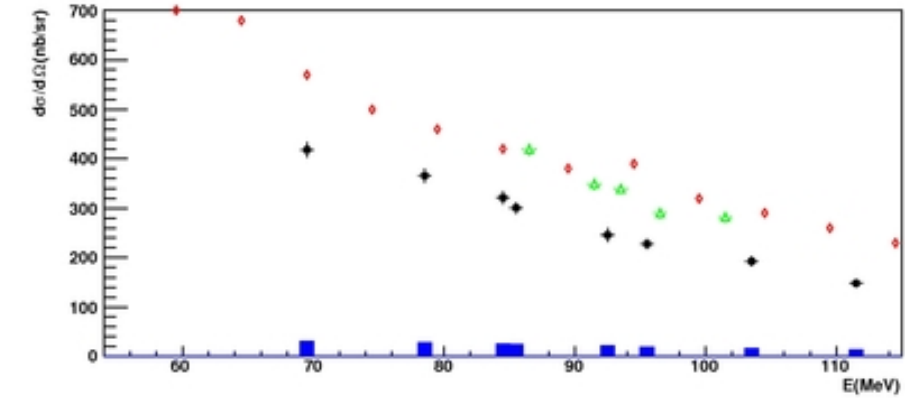
First Analysis Pass

Carbon

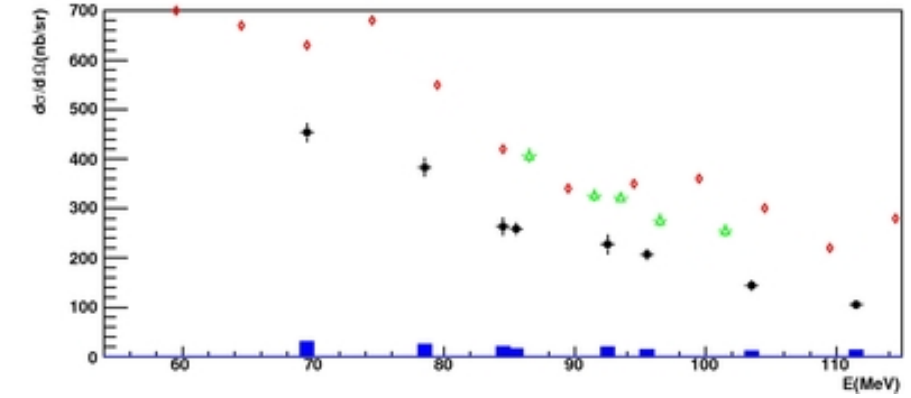
θ = 60



θ = 120

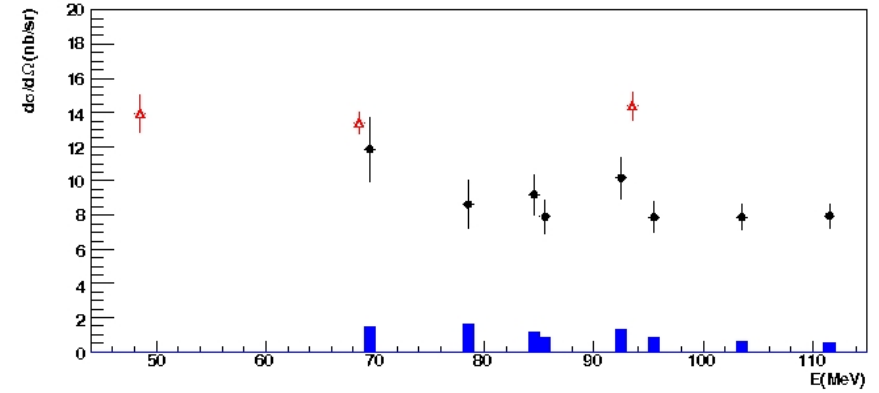


θ = 150



Deuterium

θ = 60



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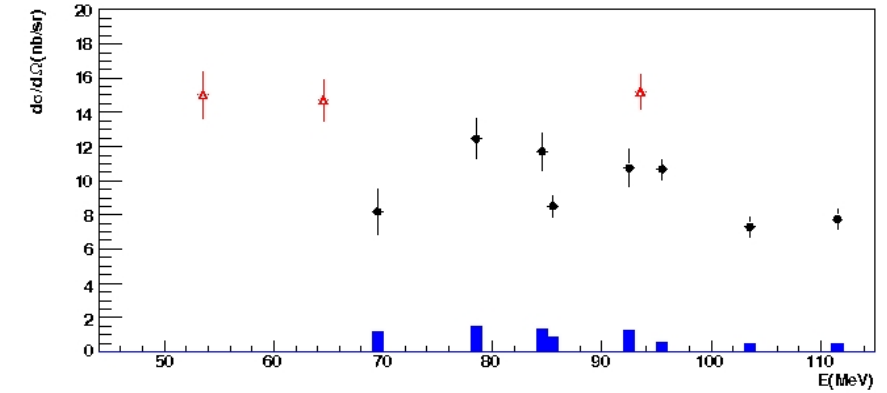
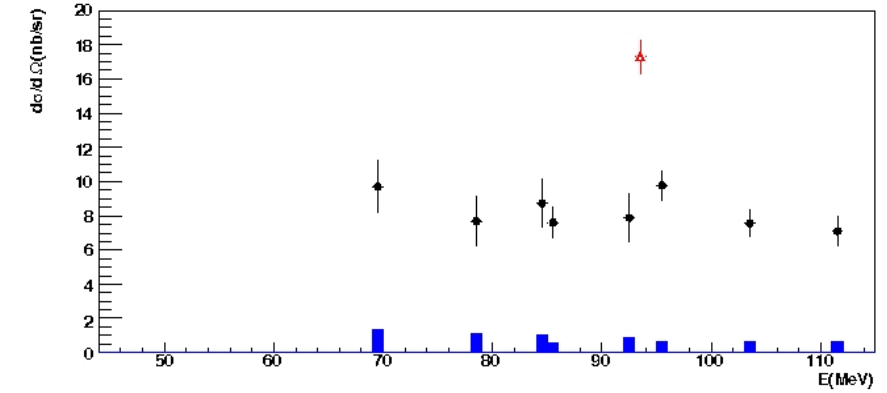


θ = 150



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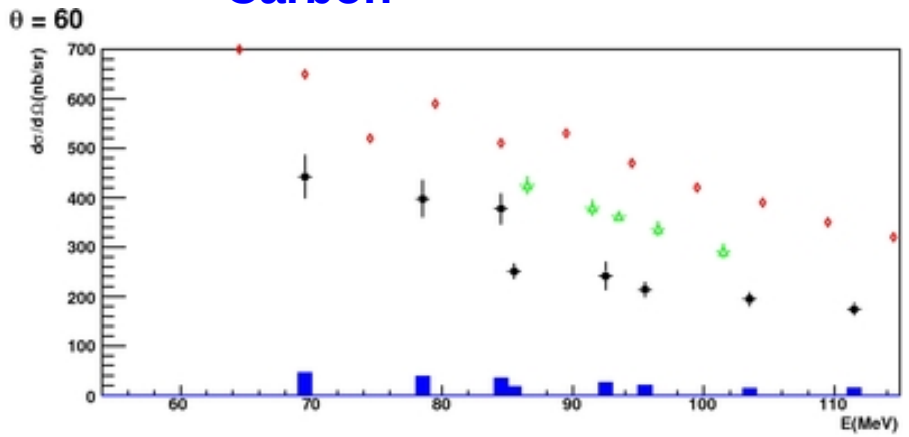
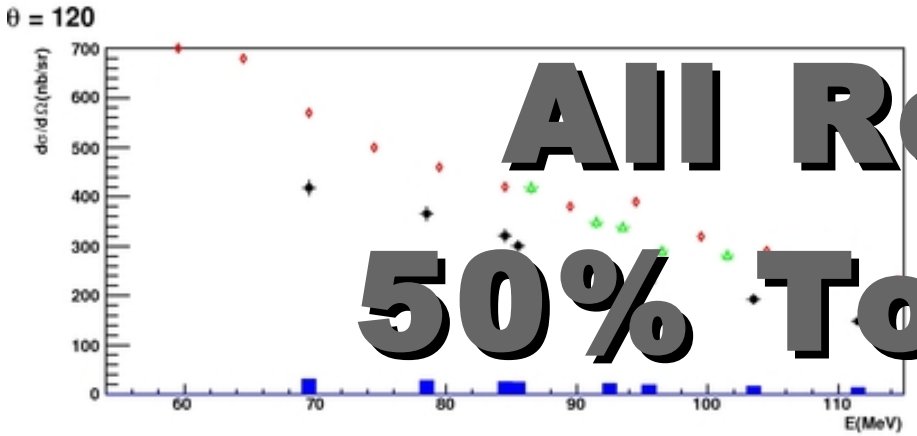
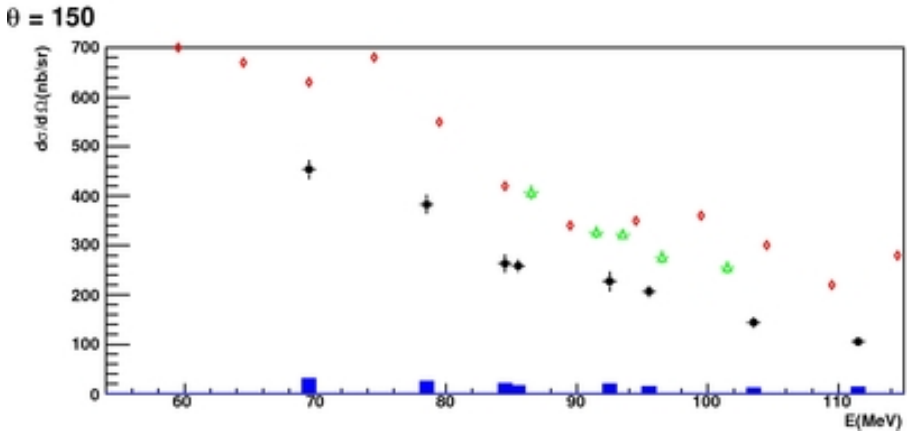
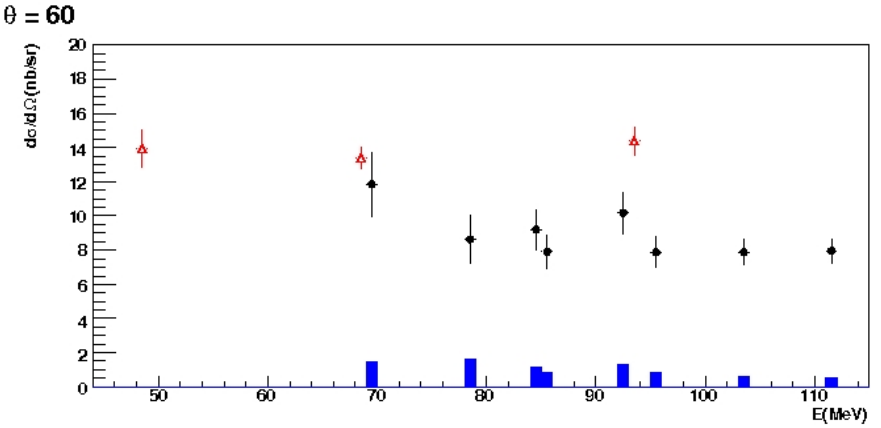
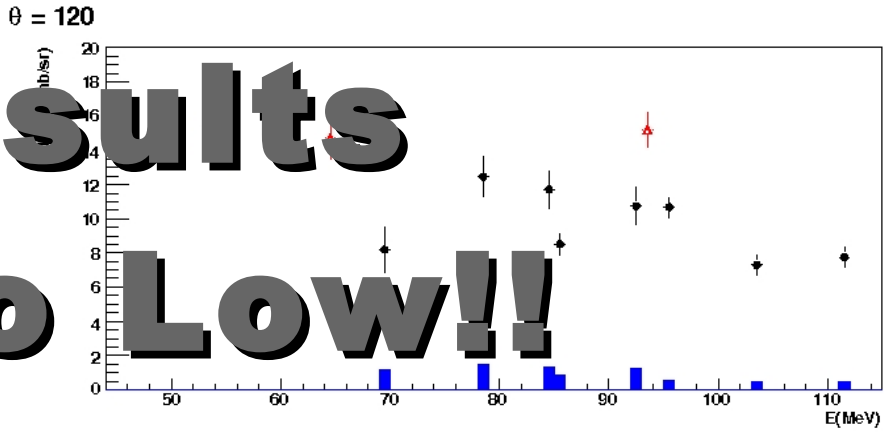


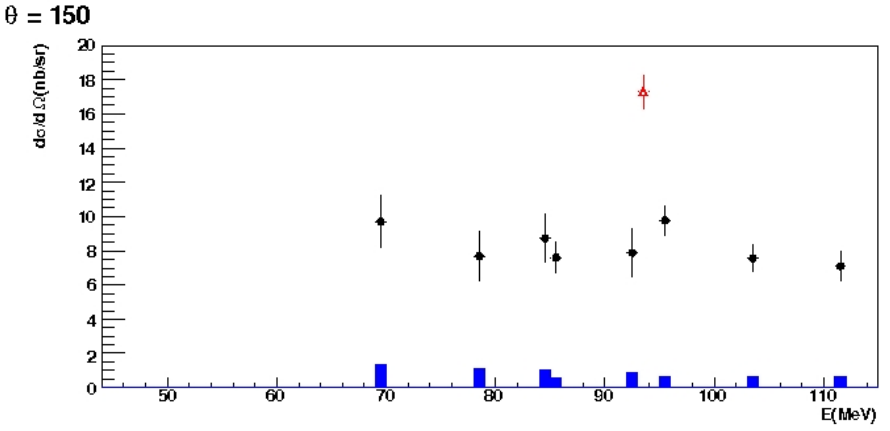




Deuterium





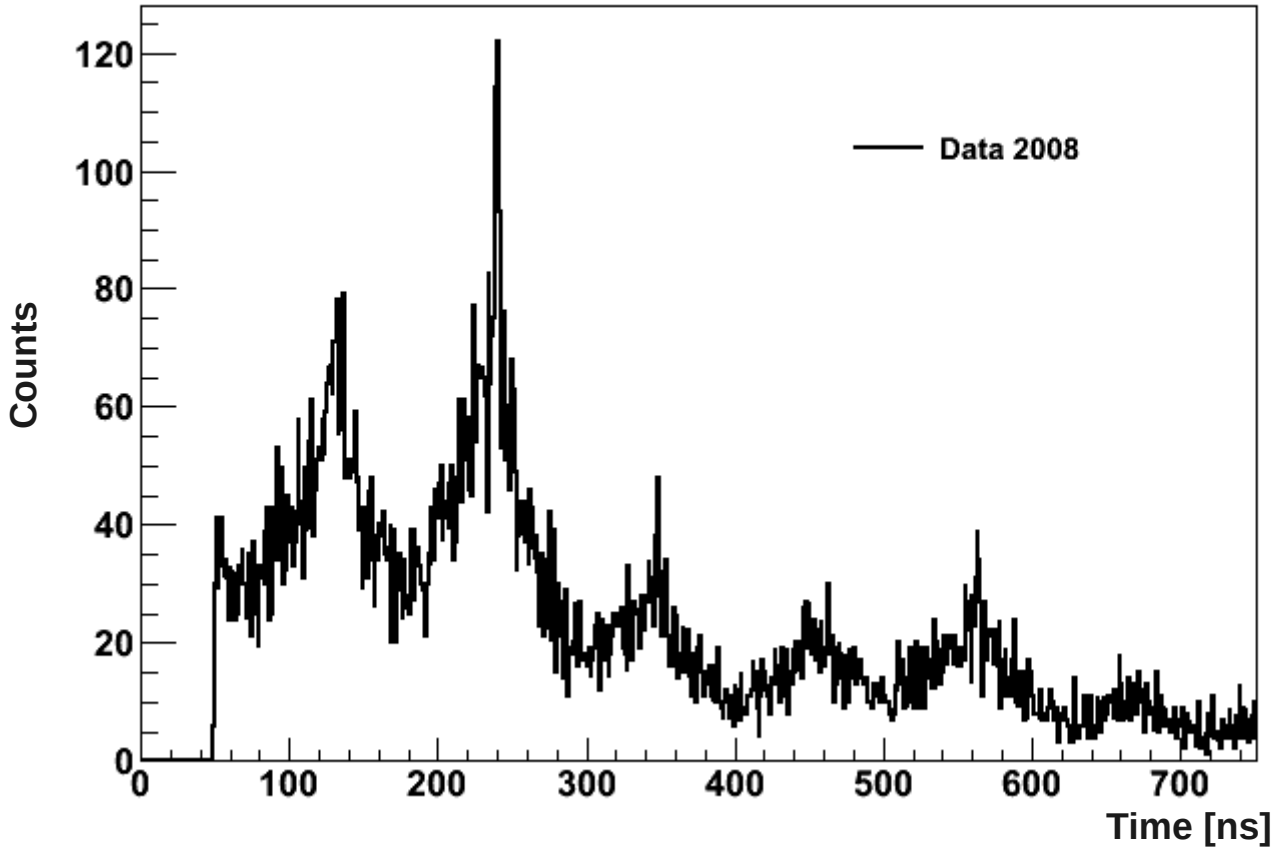


All Results 50% Too Low!!

Preliminary New Analysis

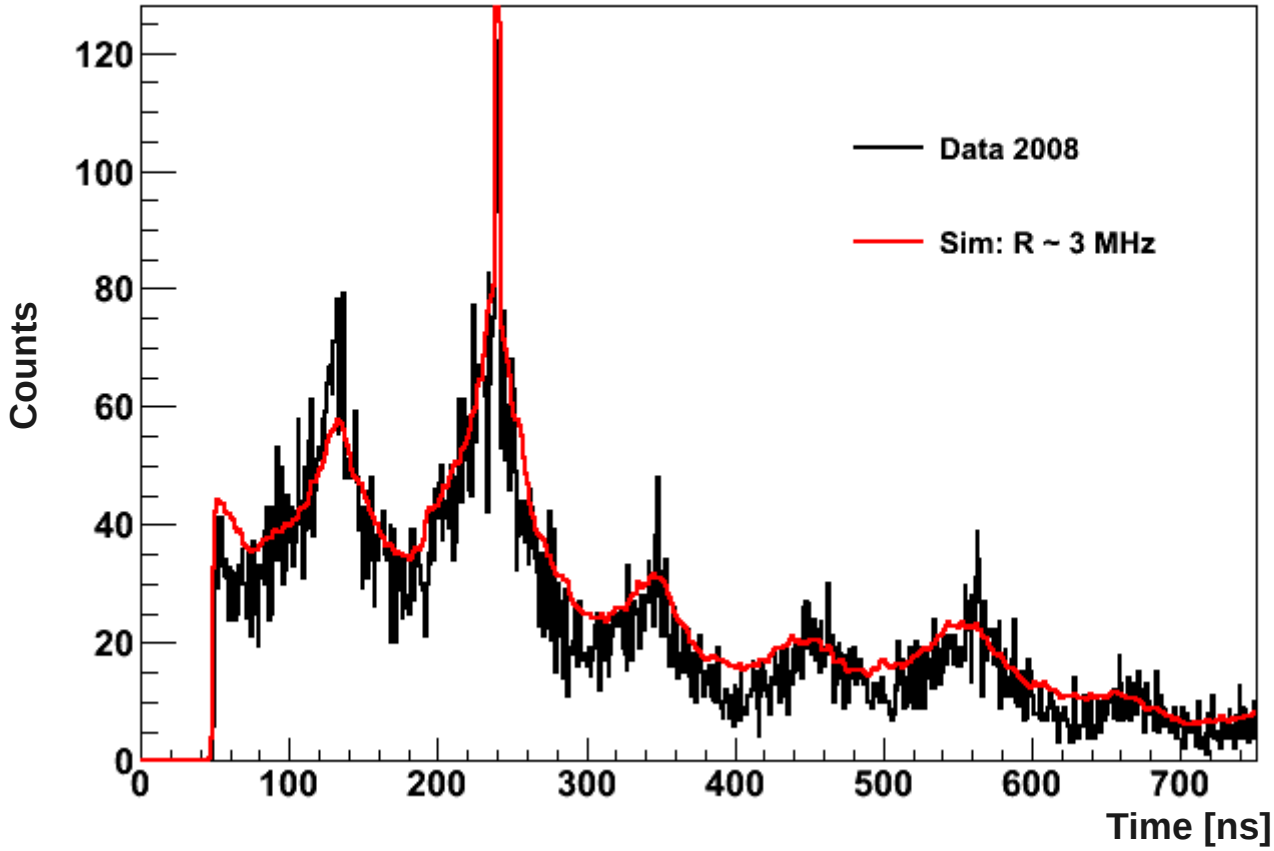
Large rate–dependent corrections

- High average rates, low duty factor
- Complicated time profile in the beam
- Can not determine all the correction analytically

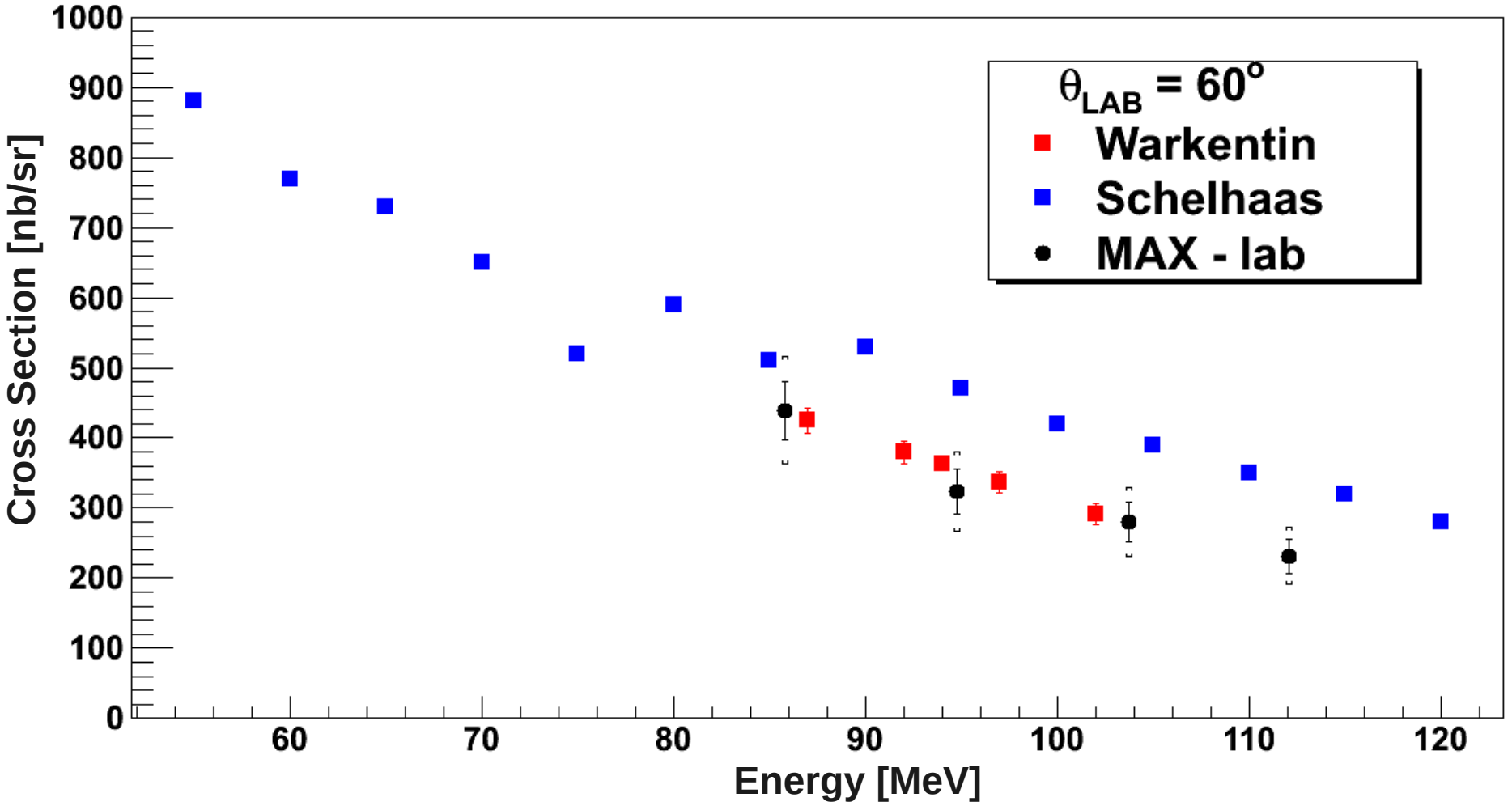


Preliminary New Analysis

- Develop a simulation to model the electronics behavior
- Include beam profile and rates
- Determine rate–dependence via simulation



Updated Preliminary Results



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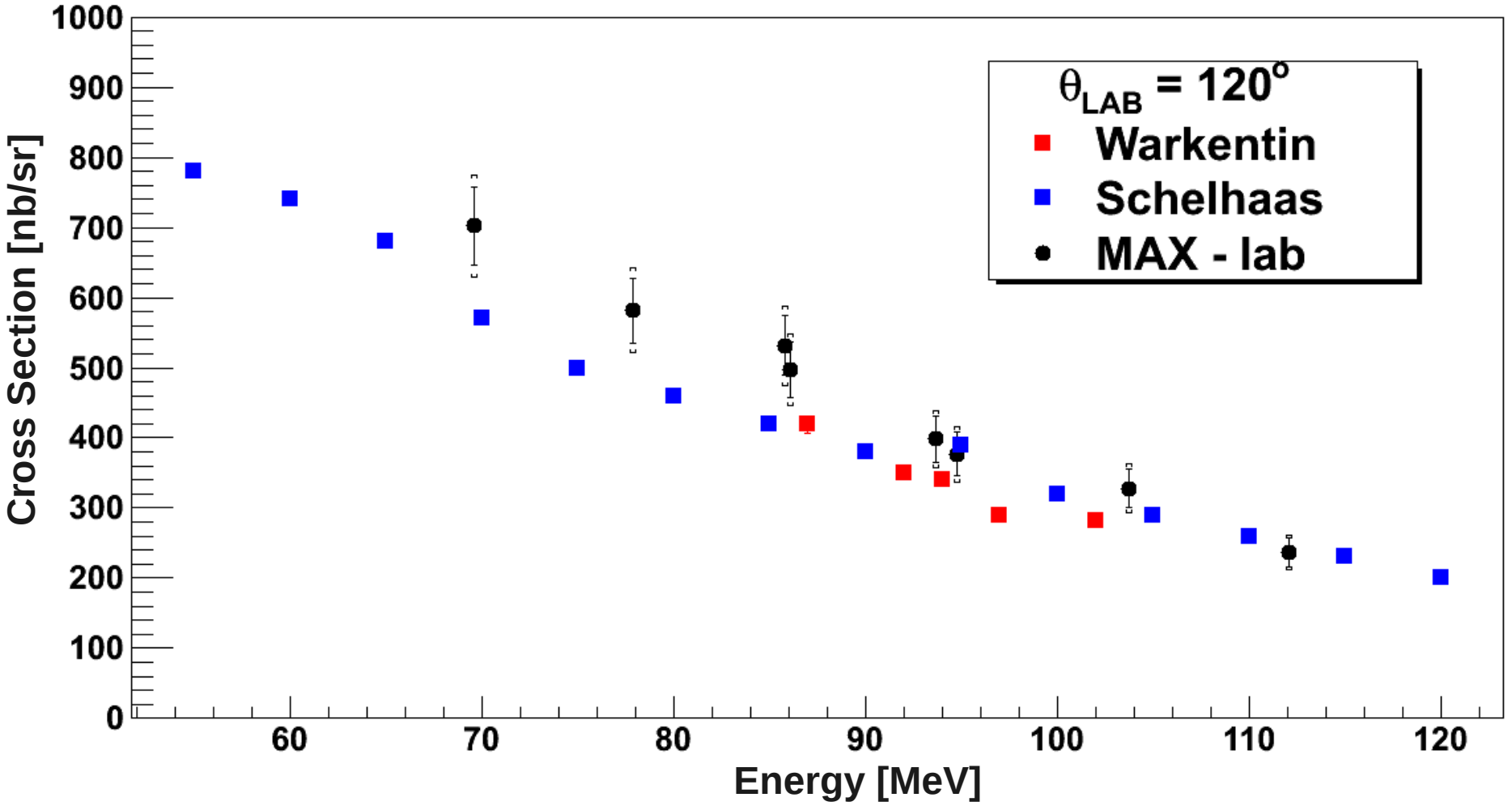

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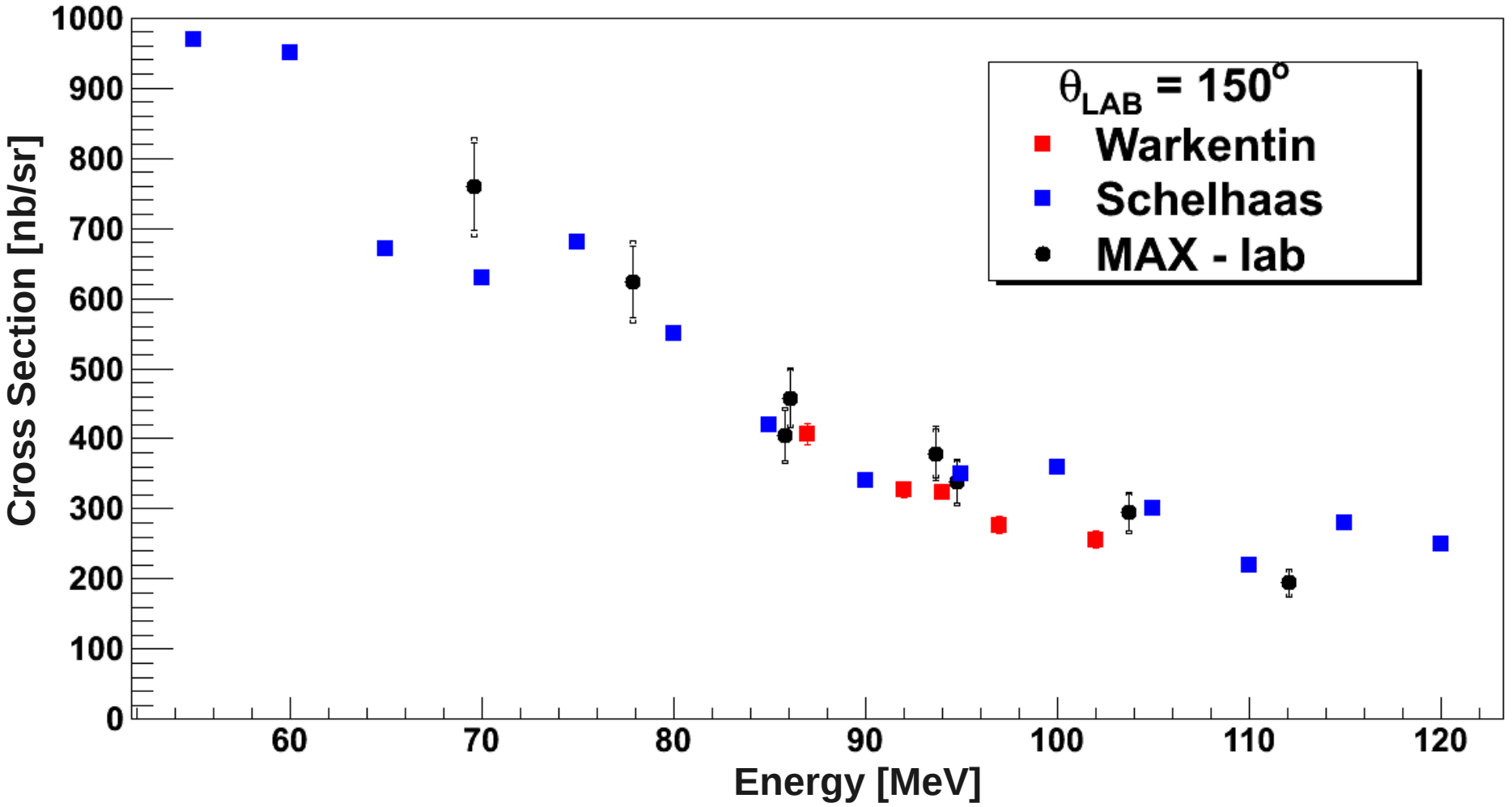


The Small Picture Outlook

Carbon data:

- More simulations to investigate systematics
- Finalize carbon results and errors

Deuterium data:

- Complete re-analysis of 2007/08 data

Publish:

- Deuterium cross sections
- Simulation and Carbon results to establish systematics

Pion Threshold – A New Regime

2008

MAX-lab NP PAC approves new measurement of π^- photoproduction with deuteron target

$$\gamma + n \rightarrow p + \pi^-$$

$$\hookrightarrow \pi^- + d \rightarrow 2n + \gamma \quad (25\%)$$

~ 130 MeV

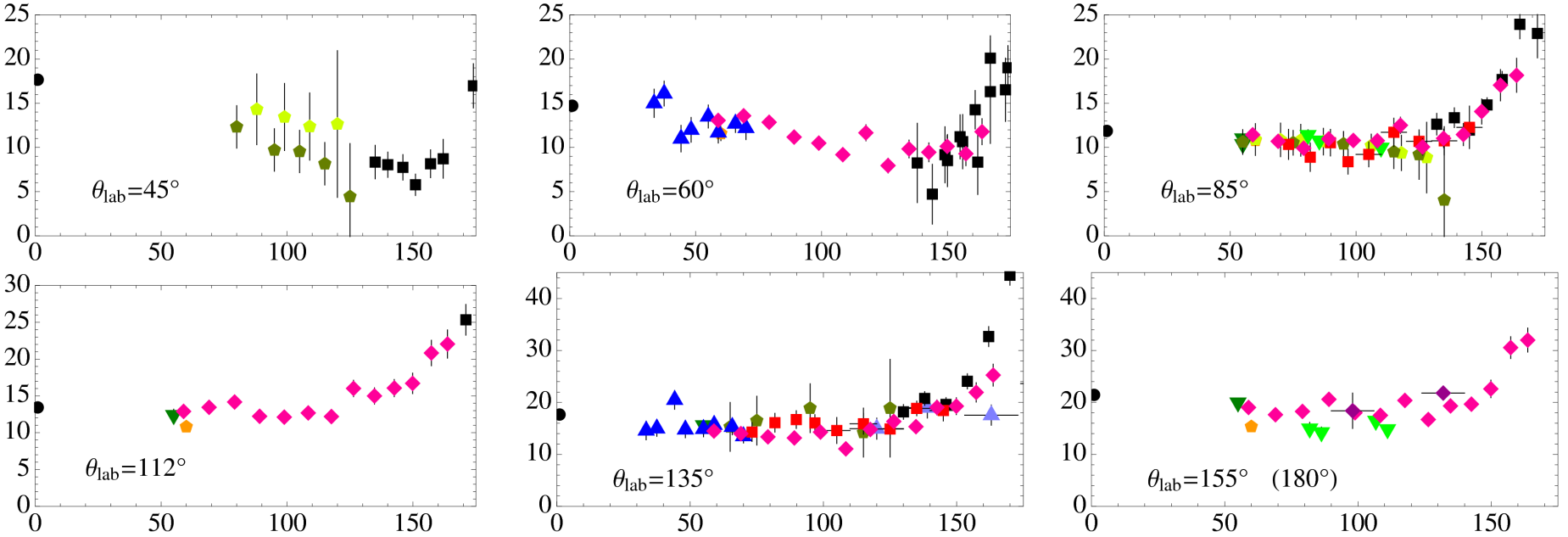
2009

Idea of extracting d(γ,γ)d cross section as well

2010

PAC approves near-threshold d(γ,γ)d measurement

Pion Threshold – A New Regime



Griesshammer, et al., http://arxiv.org/pdf/1203.6834

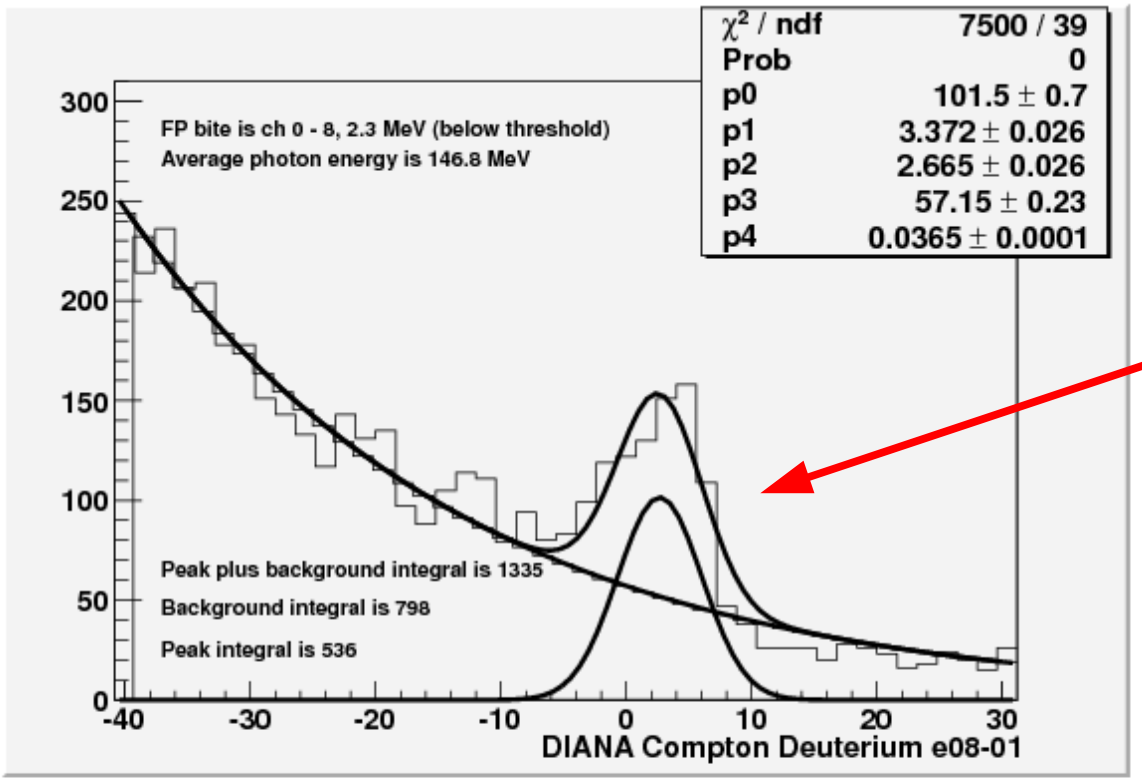
Plenty of proton data near threshold

No deuteron/neutron data

Opportunity to produce new data, balance proton data

Preliminary Analysis

- d(γ,γ)d above 140 MeV



- ~300 hrs of beam time
- ⅛ of the FP
- ~500 counts

Needs more data!

Summary and Big Picture Outlook

Normalized absolute ^{12}C cross sections

Compton Collaboration

- Finalize re-analysis
- Publish 2007/08 data
- Analyze 2009 & 2010 and publish

Other Users

- ^{4}He photoabsorption, $\pi^{+,-}$ photoproduction
- Simulation to normalize results

Experimental

- More data for “high-energy” d(γ,γ)d

Thank You

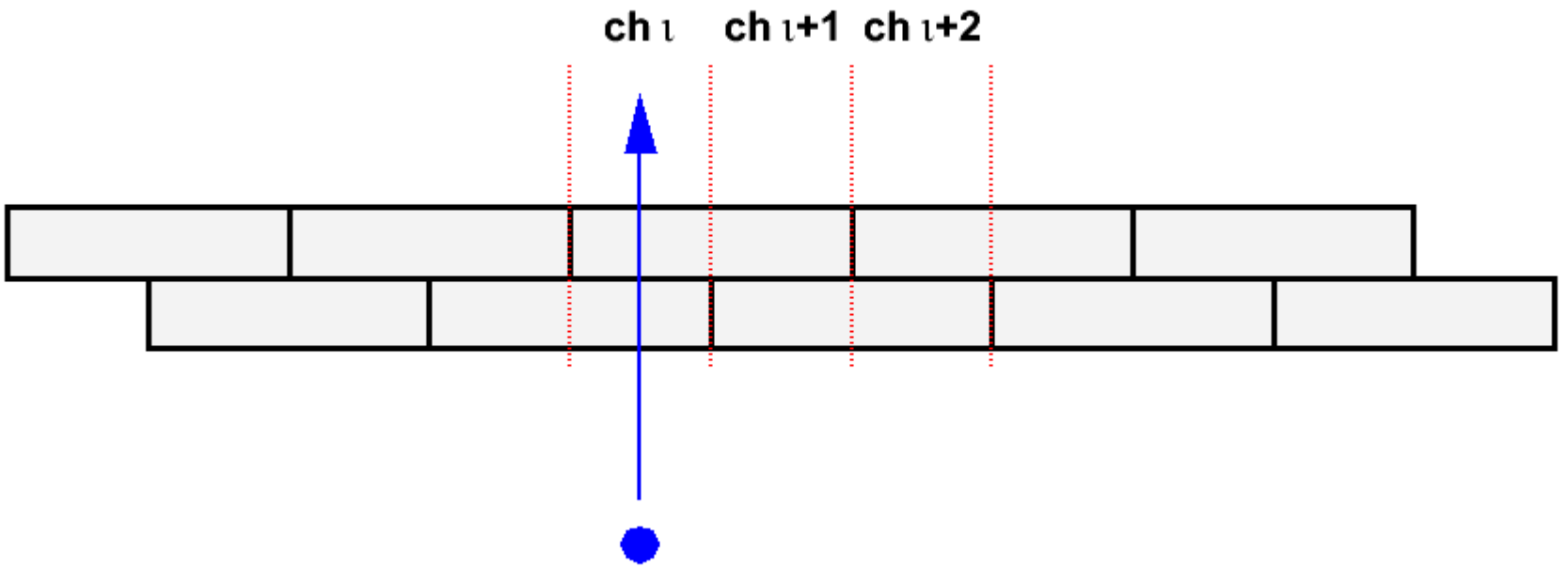
To the organizers from the

COMPTON@MAX-lab collaborators

Photon Tagging – Low Rate

Low electron rate (~10 – 10^4 Hz)

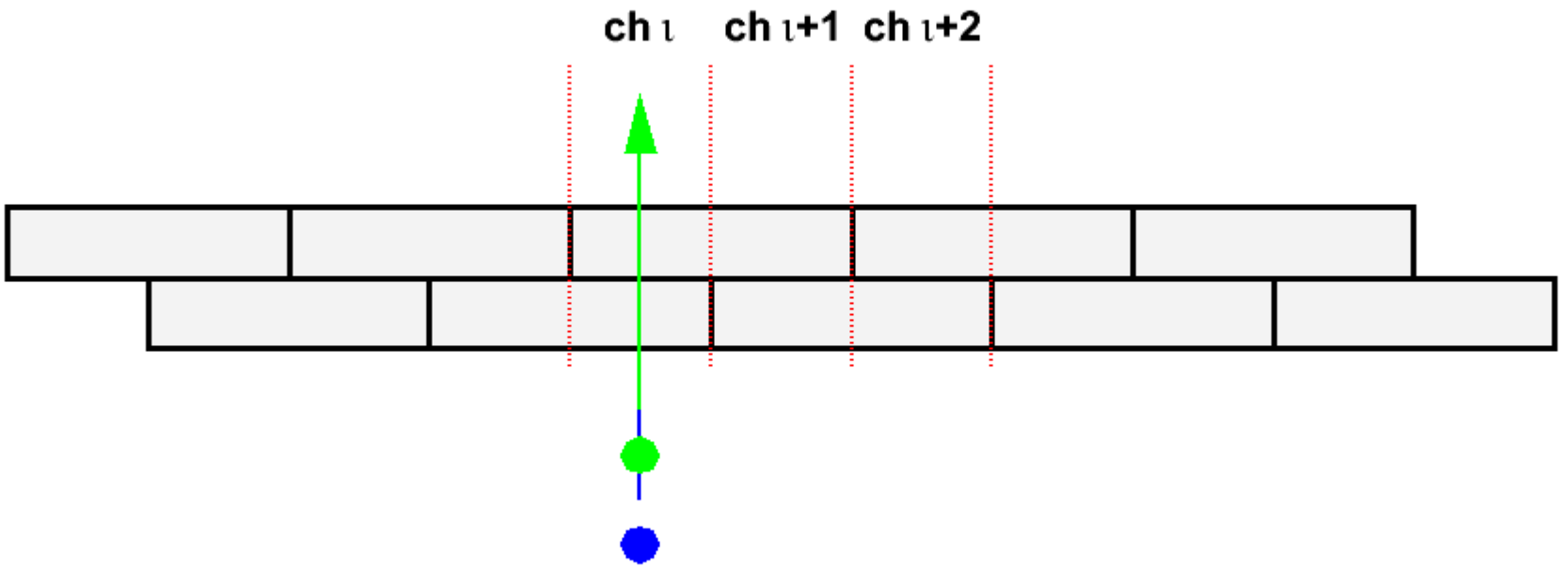
- Only one e^- per resolving time (~50 ns)
- Easy to identify electron w/ coincident photon



Photon Tagging – High Rate (I)

High electron rate (~10^6 Hz)

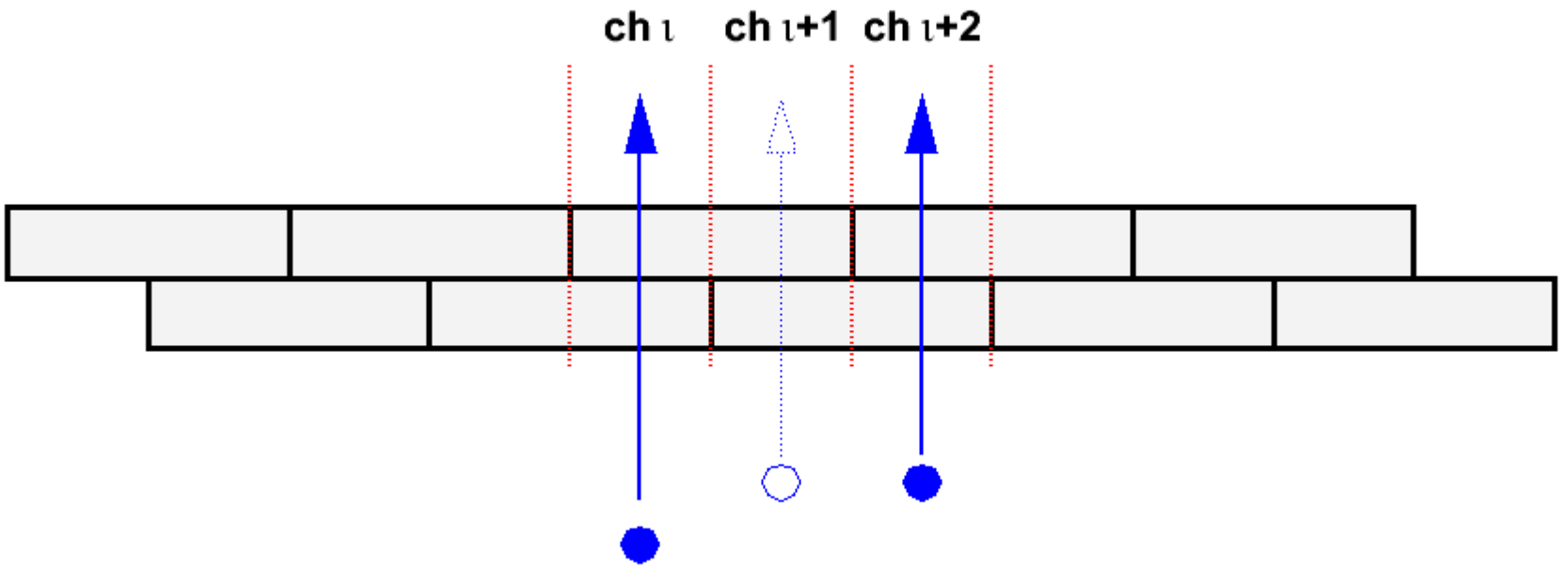
- Accidental e^- stops timing readout before coincident e^-



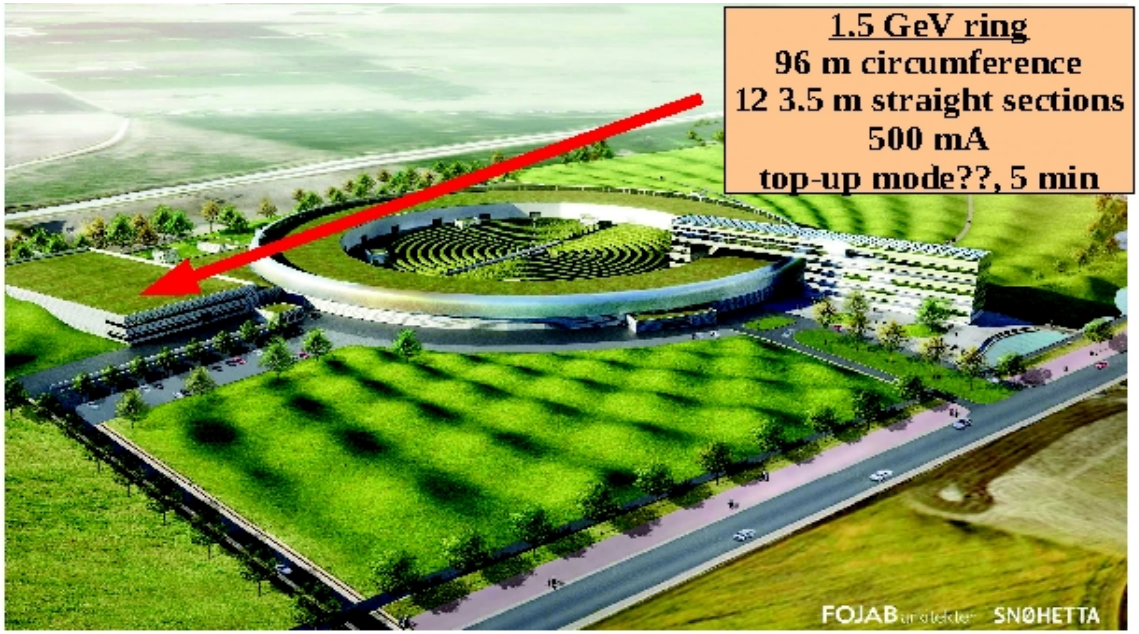
Photon Tagging – High Rate (II)

High electron rate (~10^6 Hz)

- e^- in ch ι+2 arrives within resolving time
- Looks like real e^- in ch ι+1

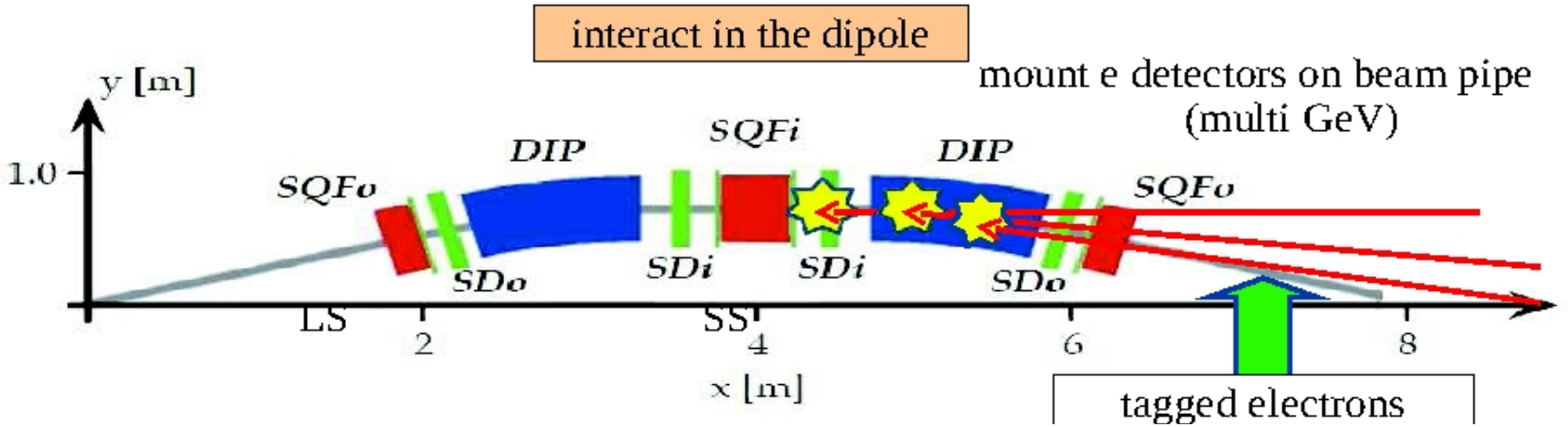


The Future at MAX–IV



Facility/Project: LBSF@M4
Institution: MAX-IV Lab
Country: Sweden
Energy (MeV): 100 – 170
Accelerator: Storage Ring, 1.5 GeV
Laser: 229 nm (5.42 ev); 244 nm (5.80 eV)
Total flux: 4×10^6 g/s (10% of ebeam lifetime)
Status: White paper/CDR in preparation

Use synchrotron light port for laser



Preliminary Analysis