Efficacy of a Radial Time Project Chamber for Tests of Lepton Universality

Keith Griffioen

College of William & Mary

griff@physics.wm.edu

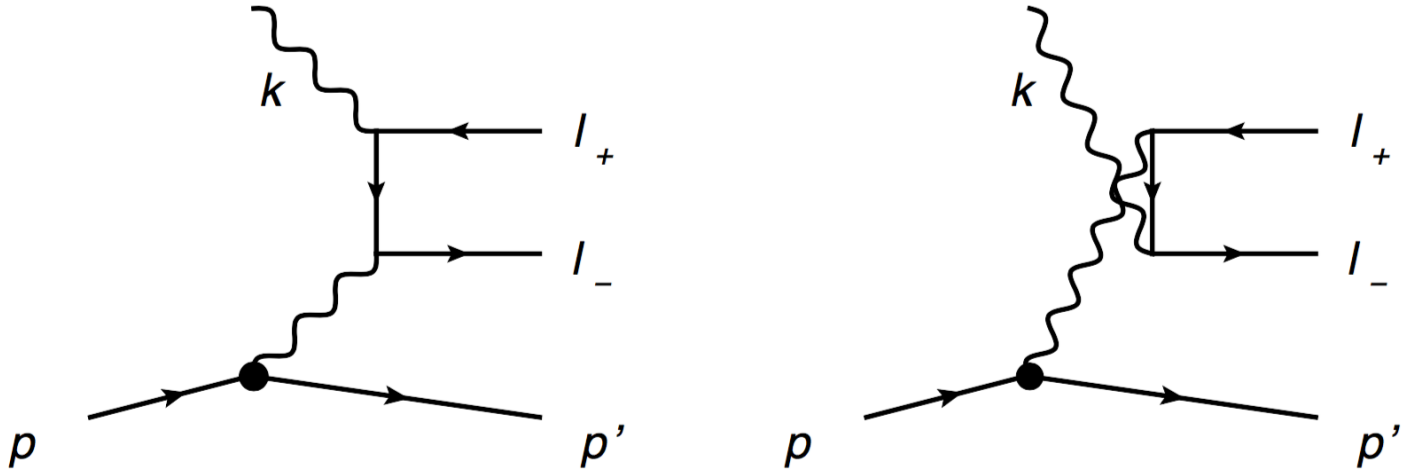
New Vistas in Low-Energy Precision Physics (LEPP)

Mainz, Germany

4-7 April 2016

Bethe-Heitler

Pauk & Vanderhaeghen arXiv:1503.01362



beam

momentum

angle

mass

$$\cos\Theta_p^{lab} = \frac{M_{ll}^2 + 2(s + M^2)\tau}{2(s - M^2)\sqrt{\tau(1+\tau)}}.$$

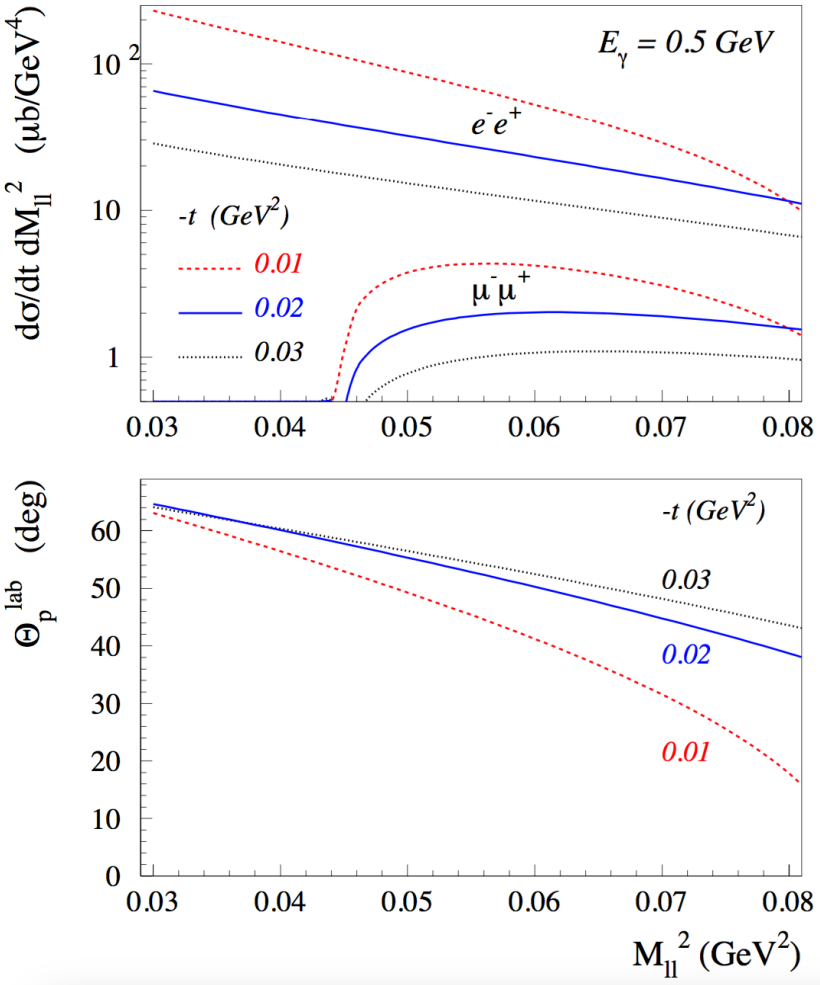
$$\tau \equiv -t/(4M^2)$$

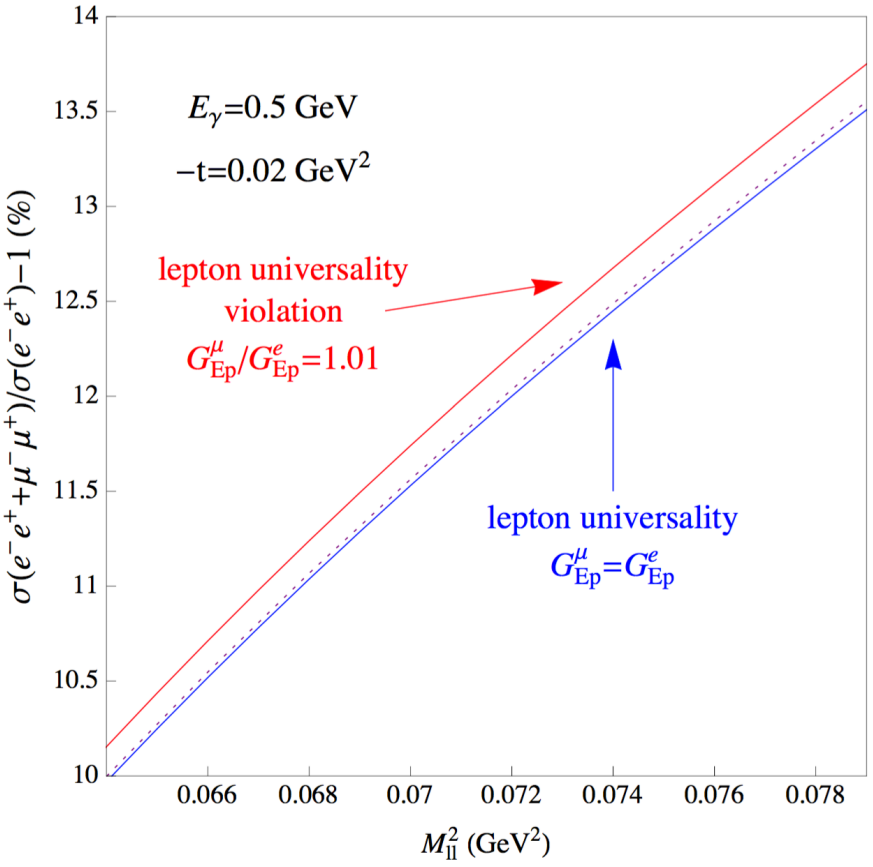
Measuring the angle of the recoil proton determines M_{ll}

Universality Test

Pauk & Vanderhaeghen 1503.01362

$$\frac{d\sigma^{BH}}{dt\,dM_{ll}^2} = \frac{\alpha^3}{(s-M^2)^2}\cdot\frac{4\beta}{t^2(M_{ll}^2-t)^4}\cdot\frac{1}{1+\tau} \times \left\{C_E\,G_{Ep}^2 + C_M\,\tau\,G_{Mp}^2\right\},$$



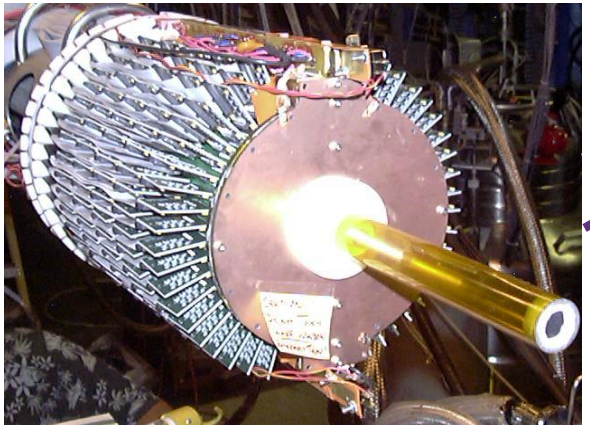


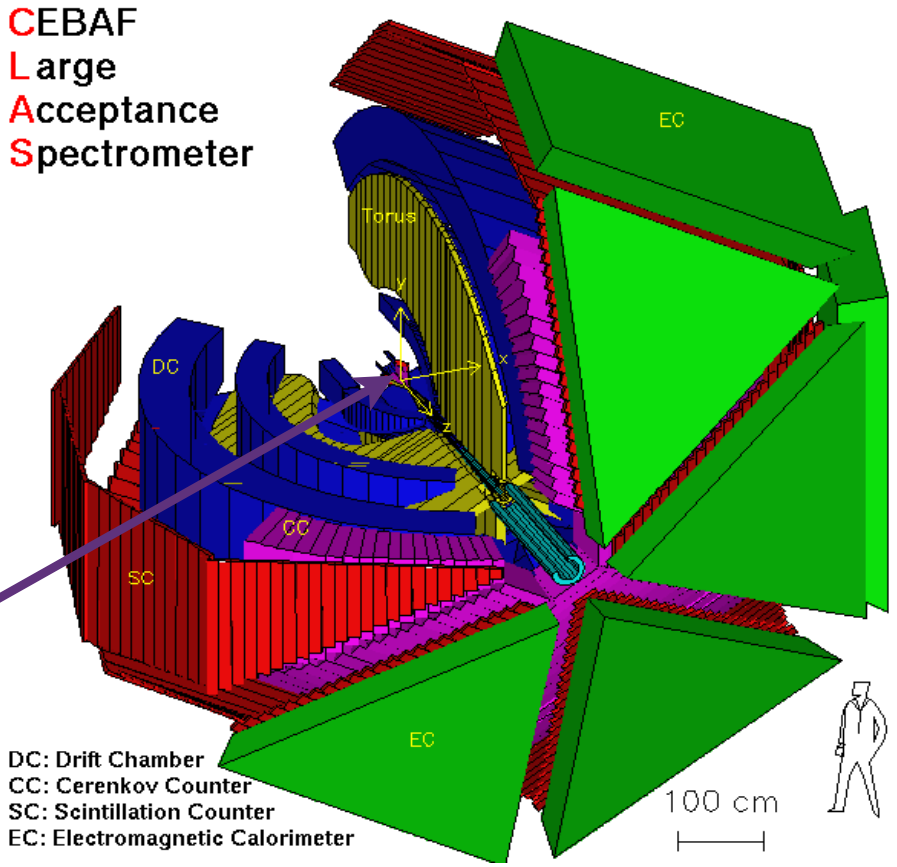
BONuS at CLAS

- Bound Nucleon Structure Experiment
- d(e,e′p_s)X [(deep) inelastic]
- Deuterium target, spectator proton
- 70 < p_s < 150 MeV/c
- JLab Hall B CLAS with an RTPC
- Measure F_2^n at high x

N.Baillie, S. Tkachenko,
W. Melnitchouk, K. Griffioen,
S. Kuhn, C. Keppel, M.E. Christy,
H. Fenker, J. Zhang, S. Bültmann

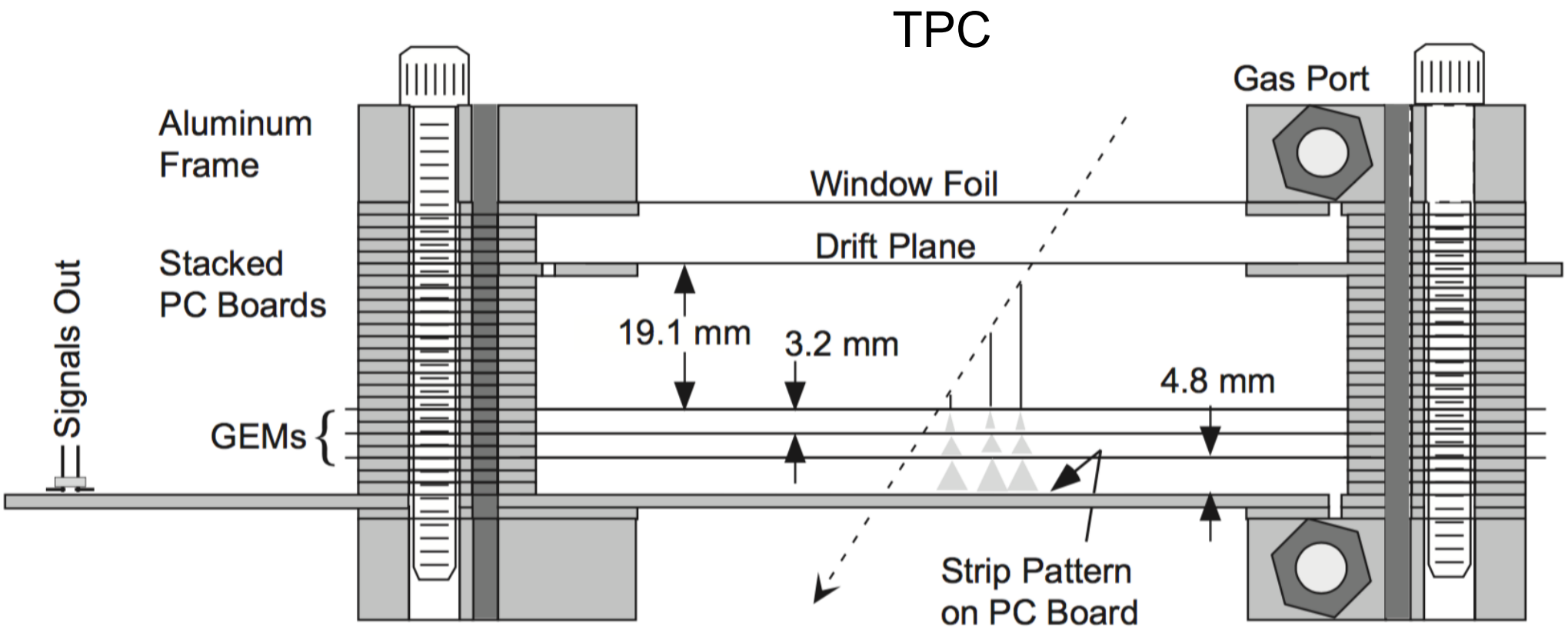
Fenker, NIM A **592** (2008) 273– 286
Baillie, PRL **108**, 142001 (2012)
Tkachenko Phys. Rev. C **89**, 045206 (2014)





Time Projection Chamber

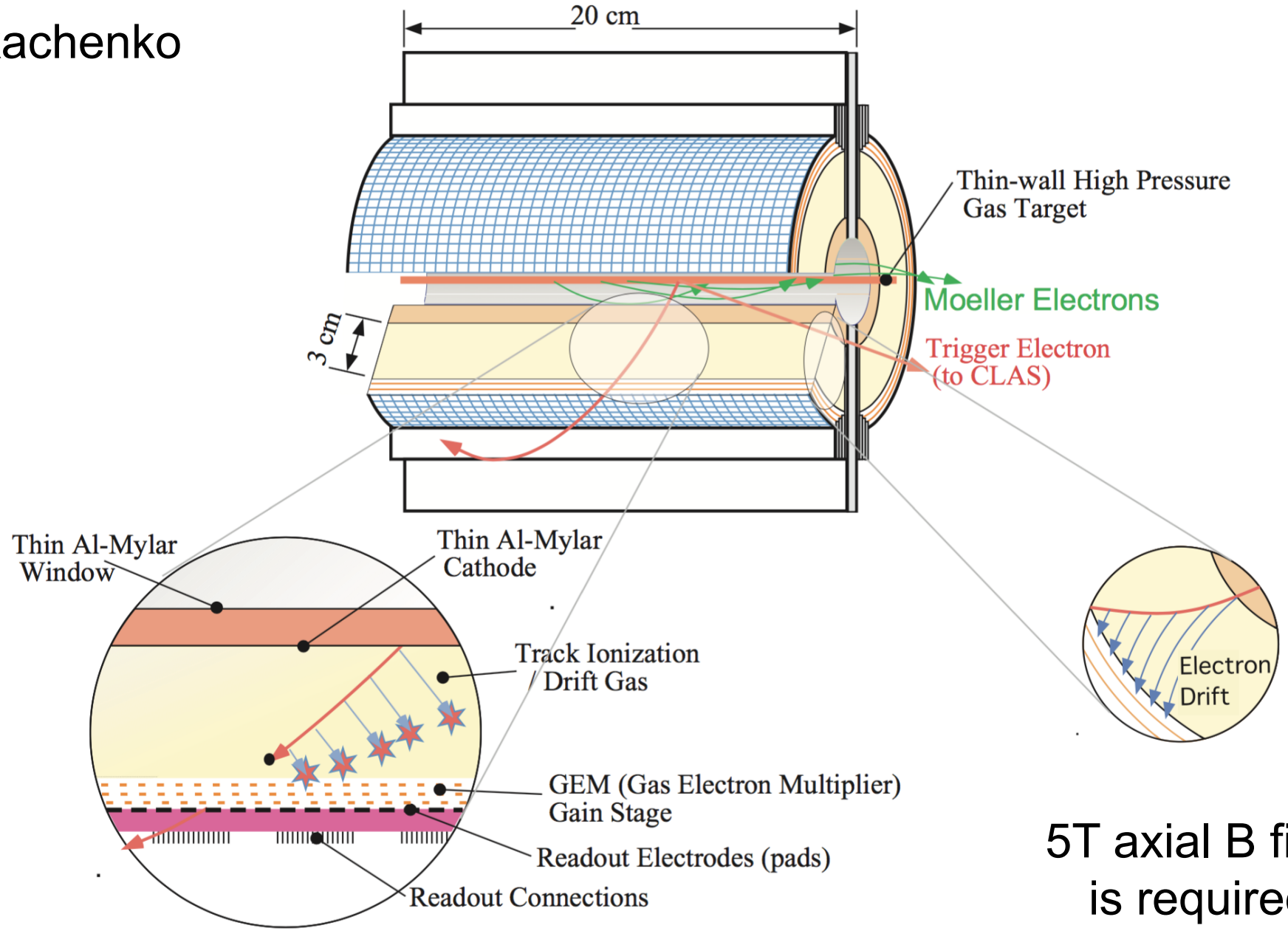
Fenker



He-DME gas mixture

Radial TPC

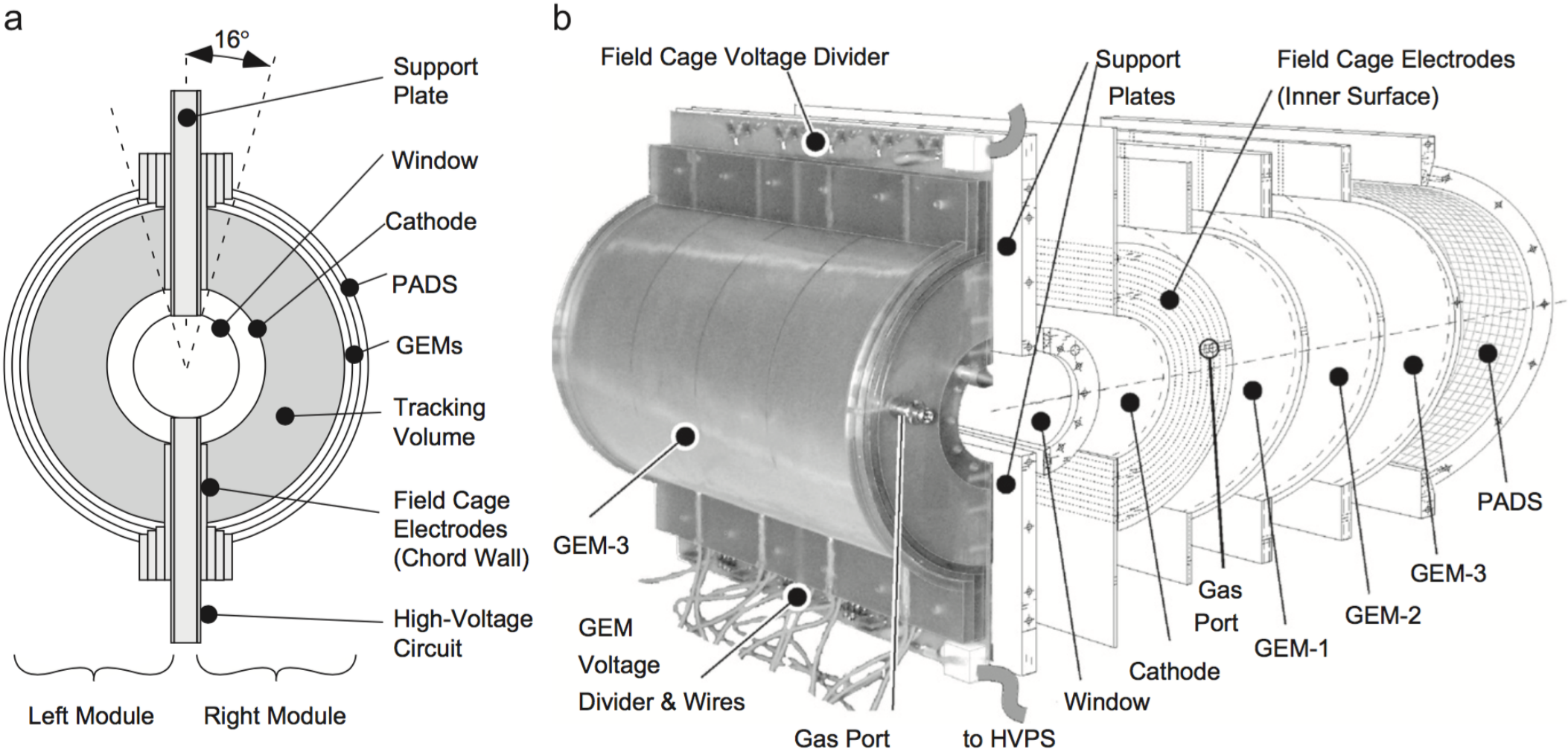
Tkachenko



5T axial B field is required

RTPC

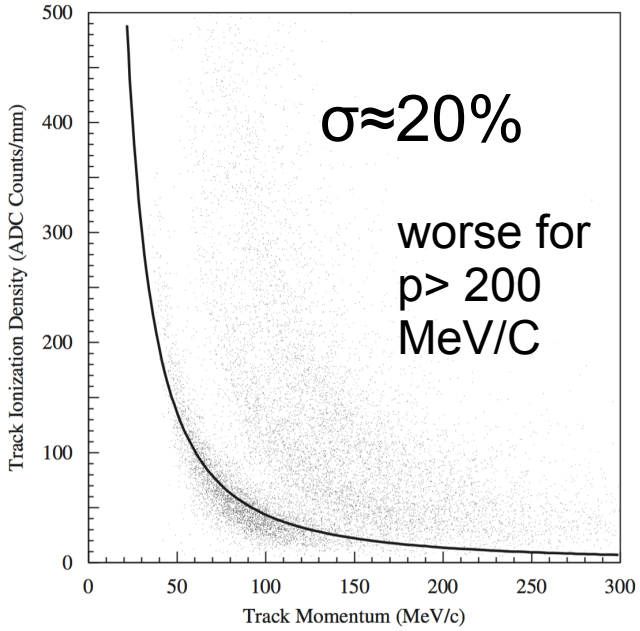
Fenker



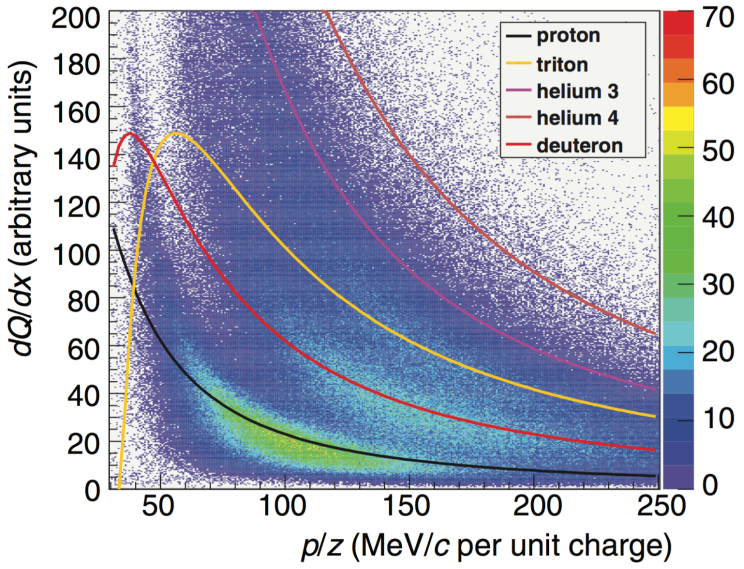
Concentric Construction

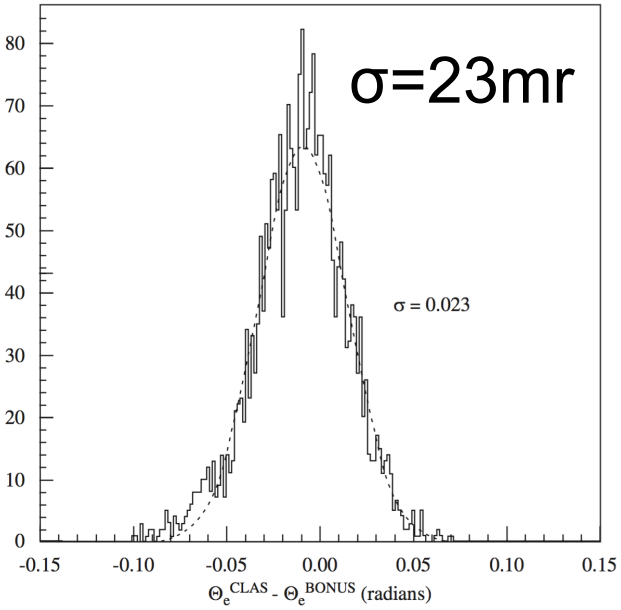
Performance

Fenker

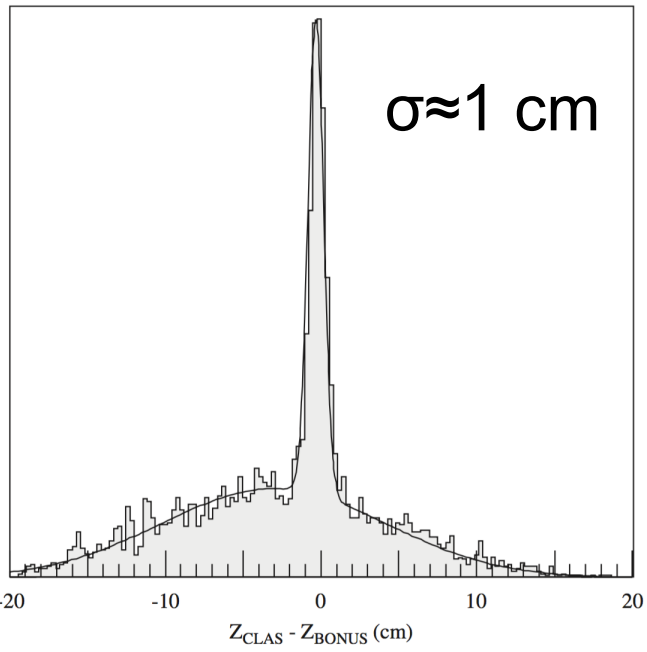


Tkachenko





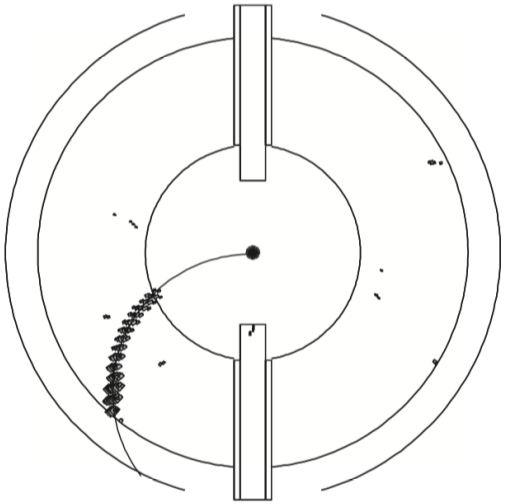
Fenker

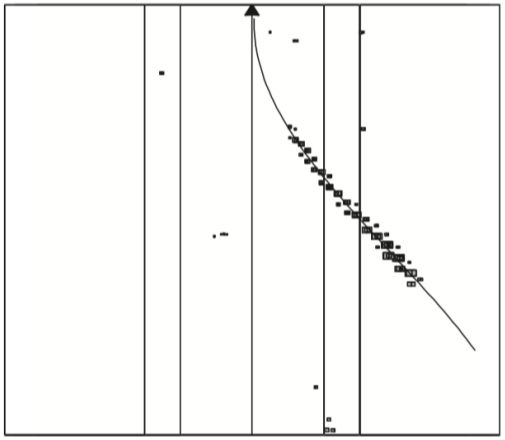


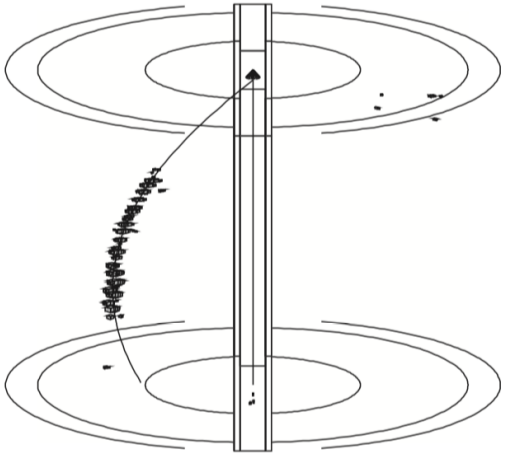
Tracking

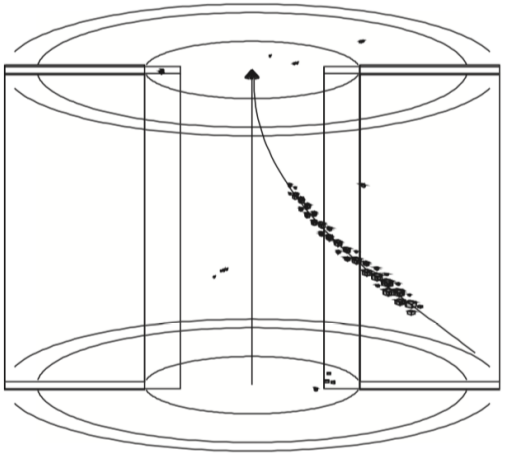
Tkachenko

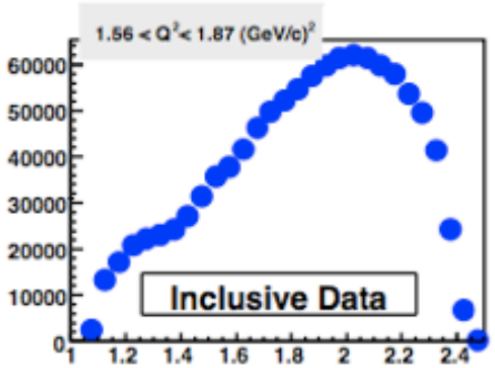
Deuteron Target

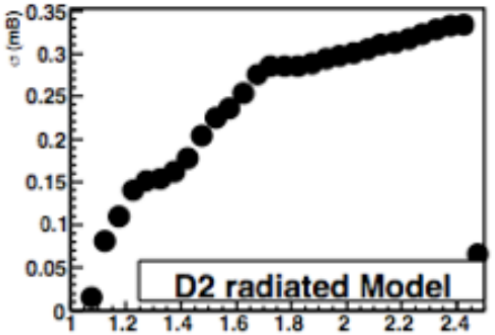


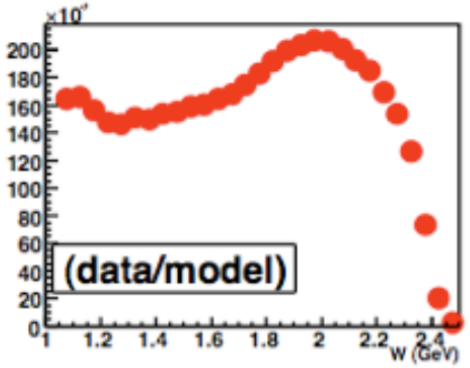








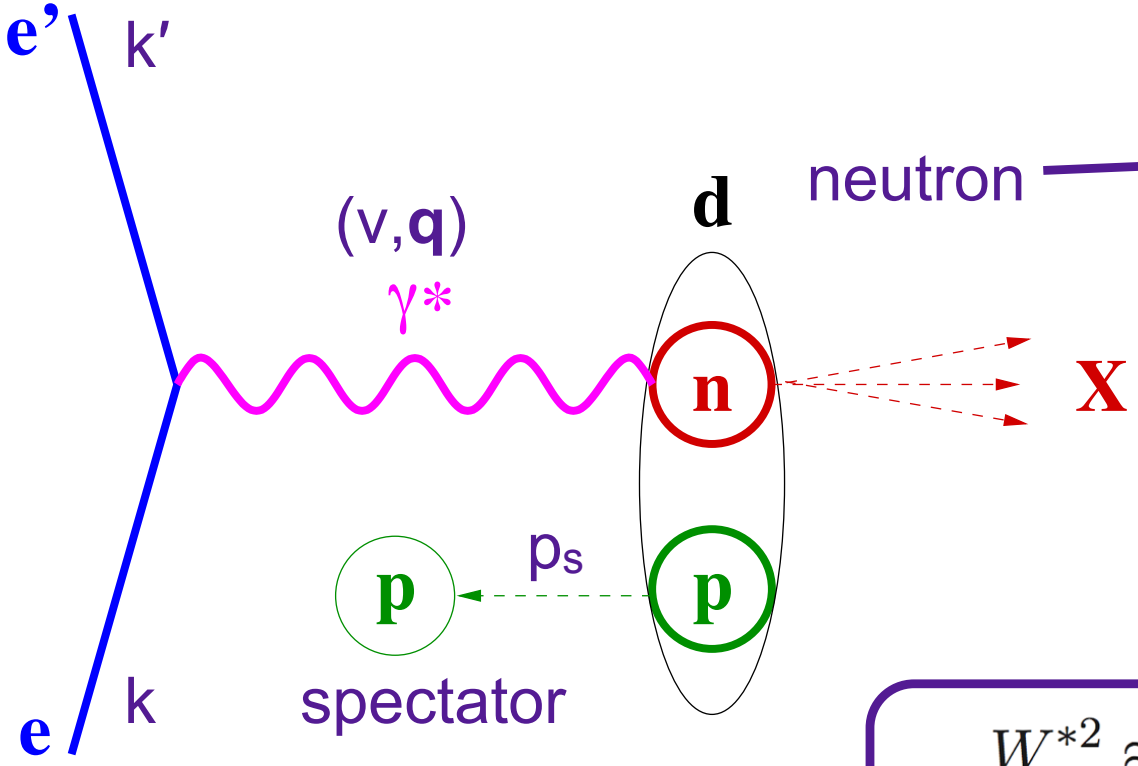




Helix-Fitting

Acceptance from inclusive eD

d(e,e'p$_s$)X



before

$$p_n = (M_d - E_s, -\vec{p}_s)$$

$$M_d = E_n + E_s$$

$$E_n = M_d - \sqrt{M_s^2 + p_s^2}$$

$$M^{*2} = (M_d - E_s)^2 - \vec{p}_s^{\,2}$$

after

$$W^{*2} \approx M^{*2} - Q^2 + 2M_s\nu(2 - \alpha_s)$$

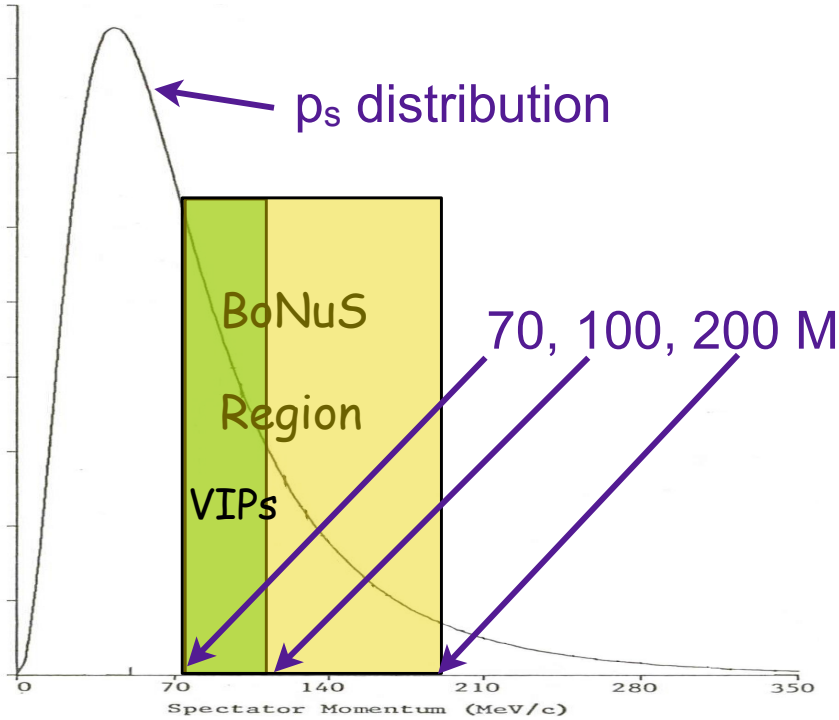
$$\alpha_s = \frac{E_s - p_{s\|}}{M_s}$$

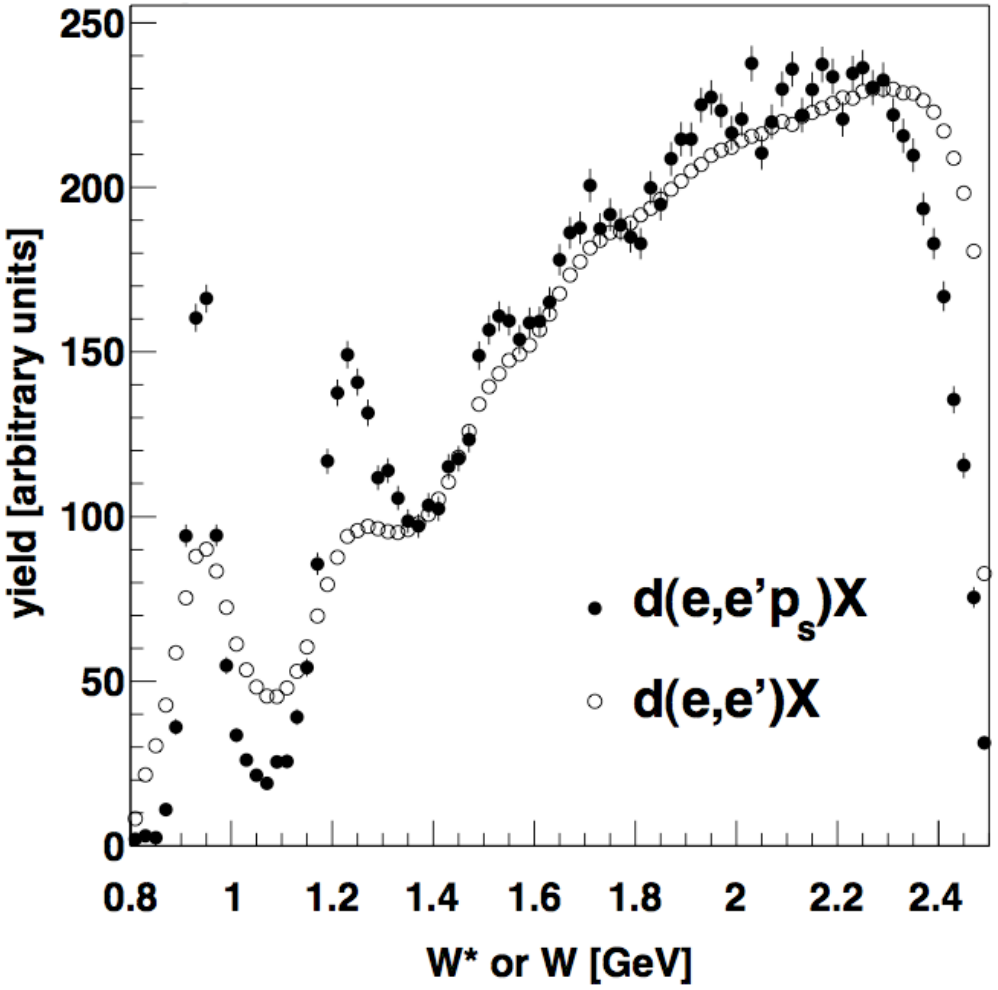
$$x^* = \frac{Q^2}{2p_n \cdot q} \approx \frac{Q^2}{2M_s\nu(2 - \alpha_s)} = \frac{x}{2 - \alpha_s}$$

- Plane-wave impulse approximation
- Backward-emitted p is a spectator
- Struck neutron is off-shell
- **p$_s$** and **p$_n$** are equal and opposite
- Lorentz invariants are corrected for initial neutron 4-momentum

BoNuS Kinematic Correction

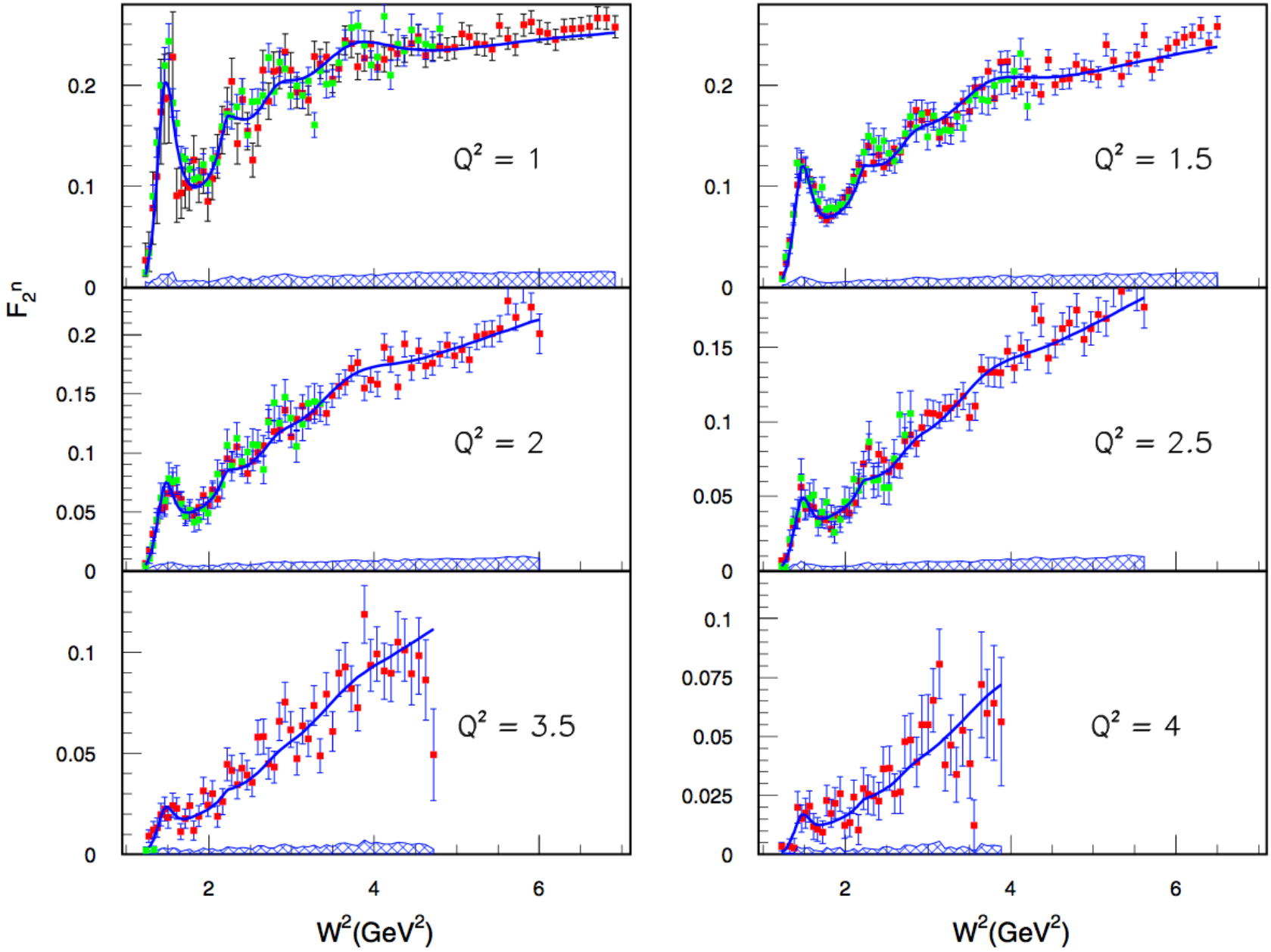
- Very Important Protons $70<p_s<100$ MeV/c
- VIPs are 17% of the p_s distribution
- Corrections make resonances stand out
- F_2^n/F_2^p can be measured at high x*



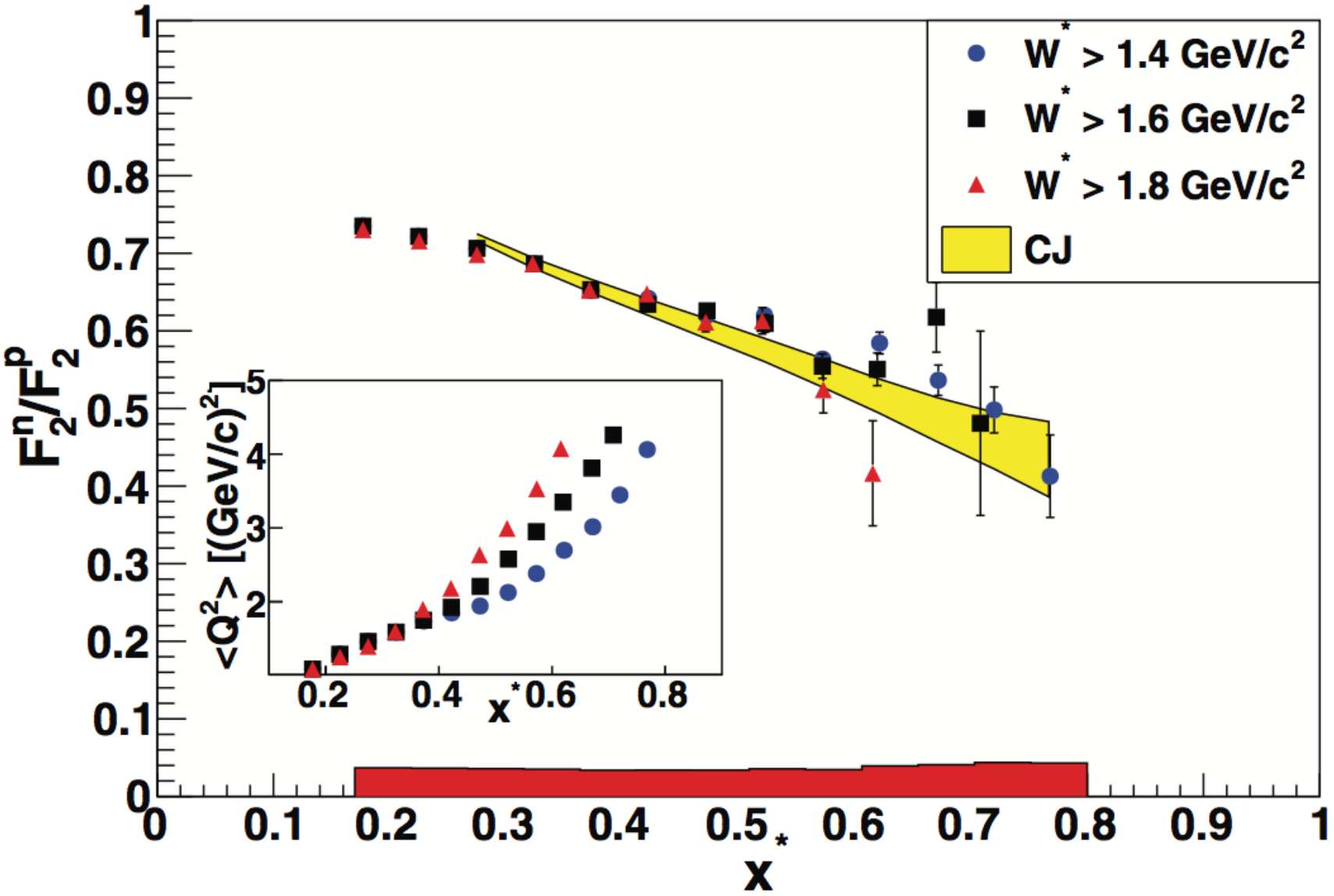


F_2^n for E = 4, 5 GeV

Curve: Kalantarians/Christy global fit before BoNuS



BoNuS F_2^n/F_2^n



Very Preliminary

Proton charge radius – simulations

March 25, 2016

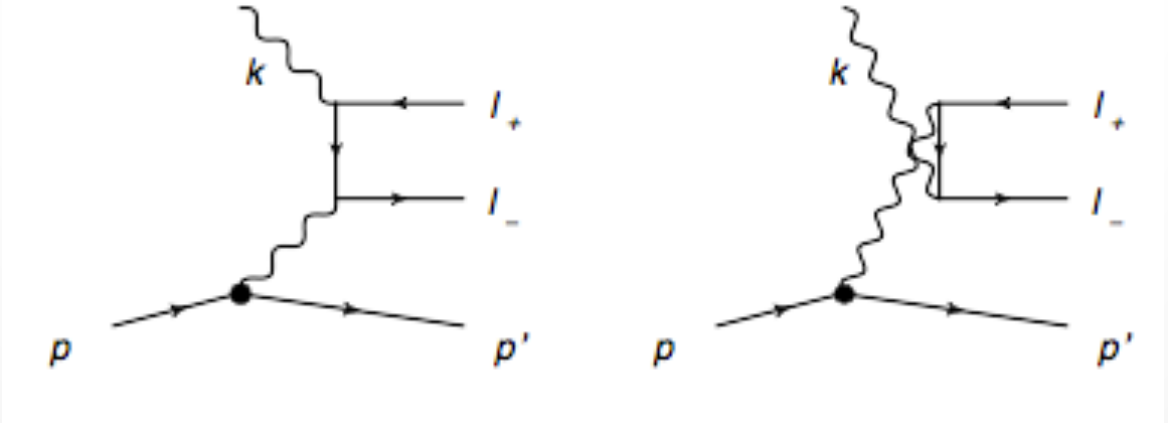
Patrik Adlarson

Study of $p\mu^+\mu^-$ differential distributions

Beam: **0.5 – 0.501 GeV In MC weighted with BH-process**
Target: **proton with produced vertex at (0, 0, 0)**

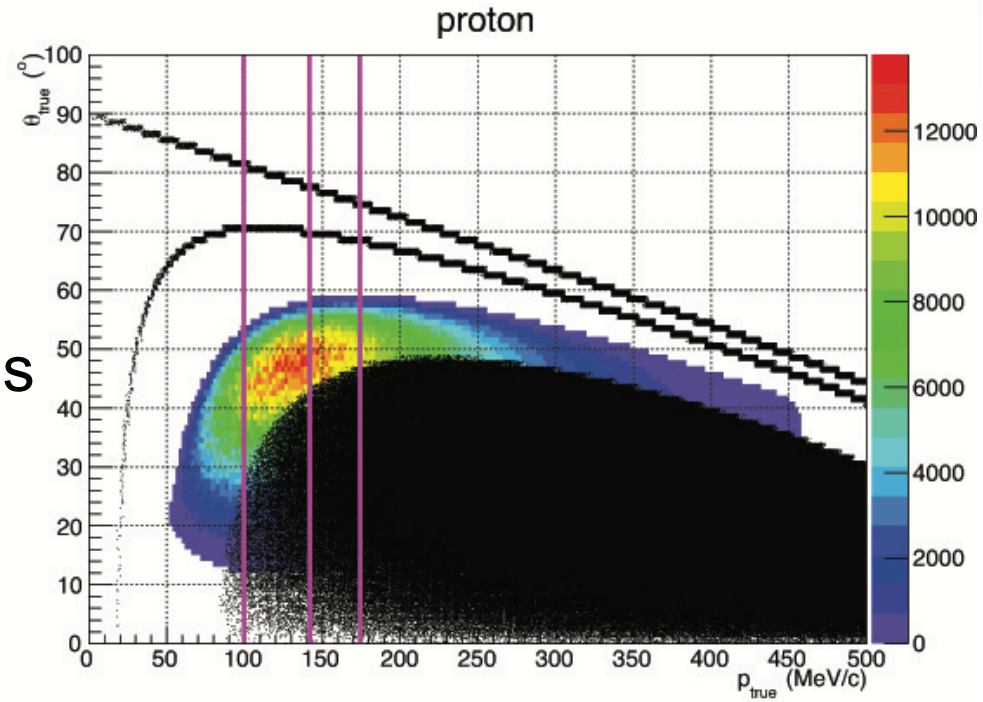
5 000 000 events produced for reaction, $p\mu^+\mu^-$

Observable:
Resolution in proton momentum and θ required to reach 3σ sensitivity to see effect of Lepton Universality Violation



True proton information with background

θ_{true} degrees



p_{true}(MeV/c)

Purple vertical lines represent –t = 0.01, 0.02 0.03, respectively

Black line top: proton associated with Compton scattering at 500 MeV
Middle line: proton associated with π^0 prod at 500 MeV
Black area: proton associated with $\pi^0\pi^0$ prod at 500 MeV

Above 50° no background contribution at all!

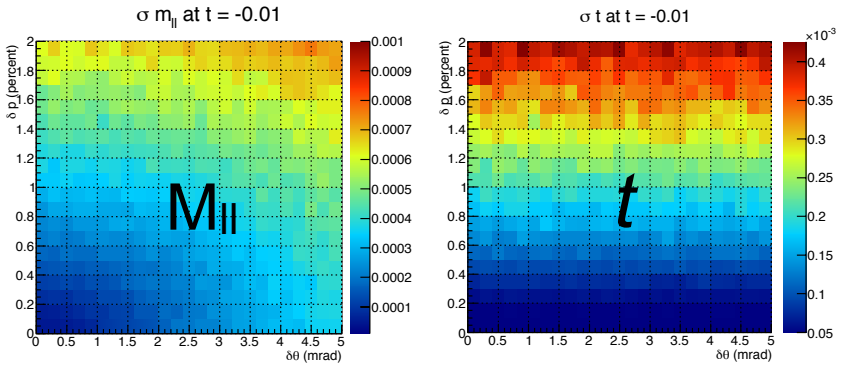
Event requirement

Only keep event if p_{true}

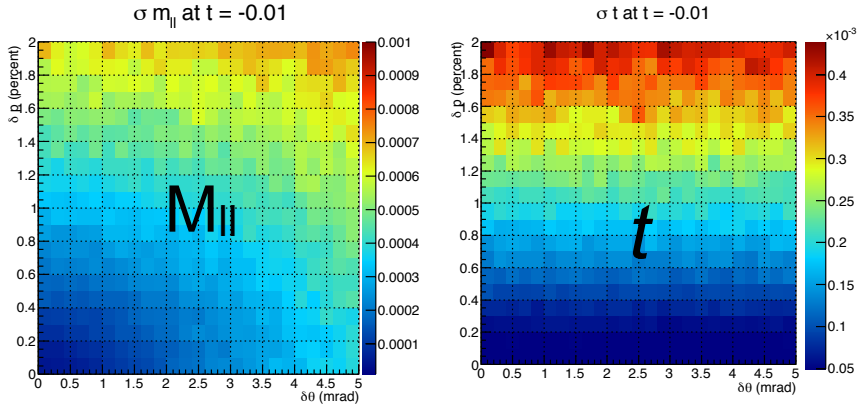
1. **95-105 MeV/c (-t = 0.01); 137-147MeV/c (-t = 0.02); 169-179 MeV/c (-t = 0.03);**
2. **And only if proton theta angle > 50^{o}**
3. **Run for three conditions on beam energy smearing: 0, 100 keV, 1 MeV**

Patrik's Talk

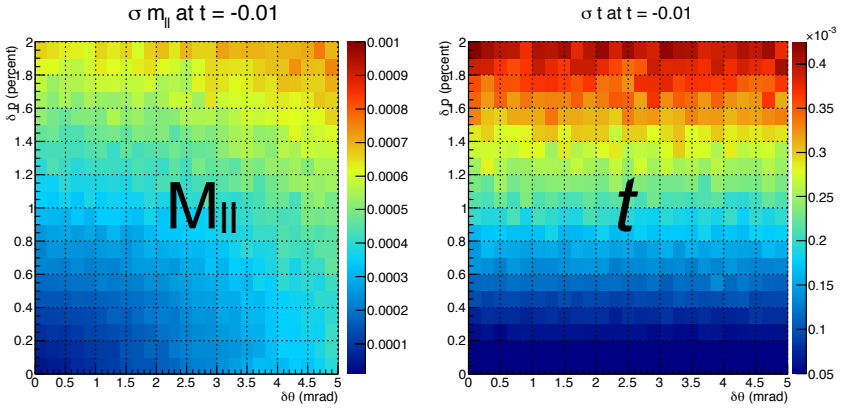
Case: -t = 0.01; Beam energy smeared: 0



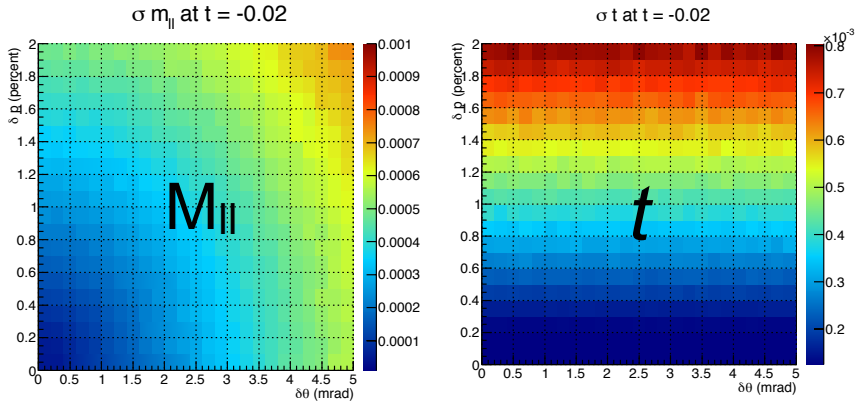
Case: -t = 0.01; Beam energy smeared: 100 keV



Case: -t = 0.01; Beam energy smeared: 1 MeV



Case: -t = 0.02; Beam energy smeared: 0

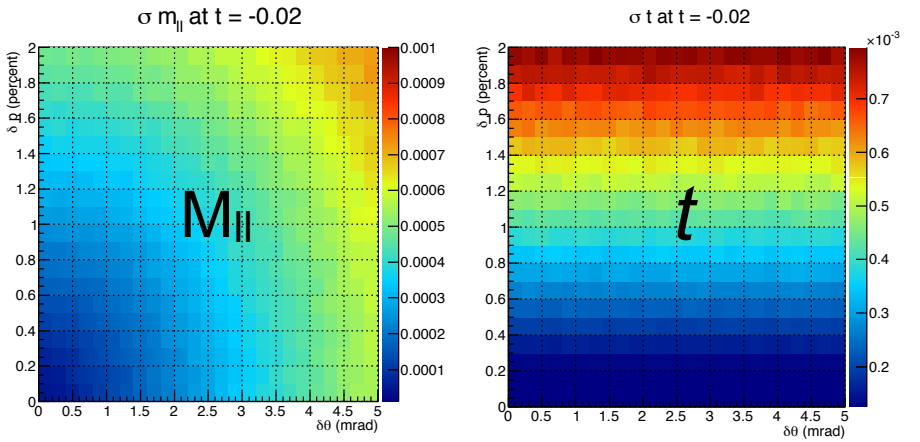


δp(%)

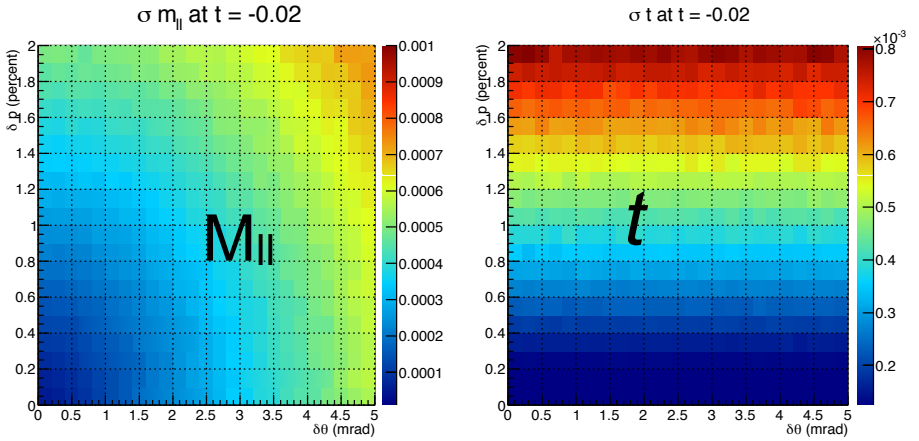
δθ (mrad)

Patrik's Talk

Case: -t = 0.02; Beam energy smeared: 100 keV

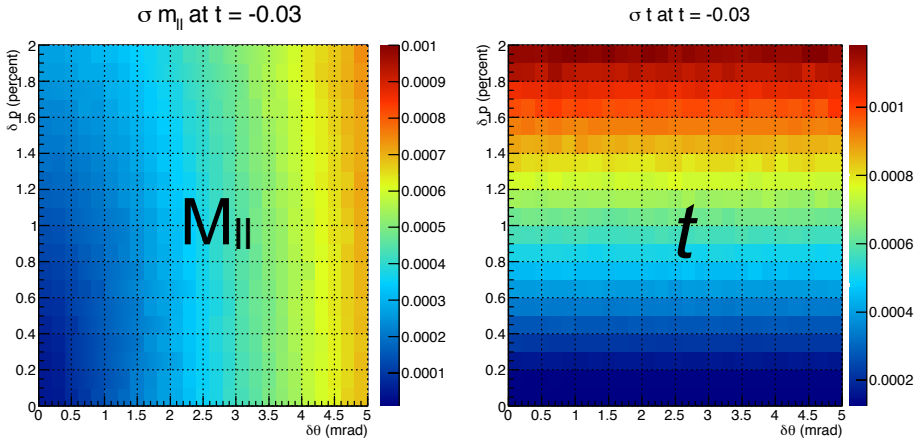


Case: -t = 0.02; Beam energy smeared: 1 MeV

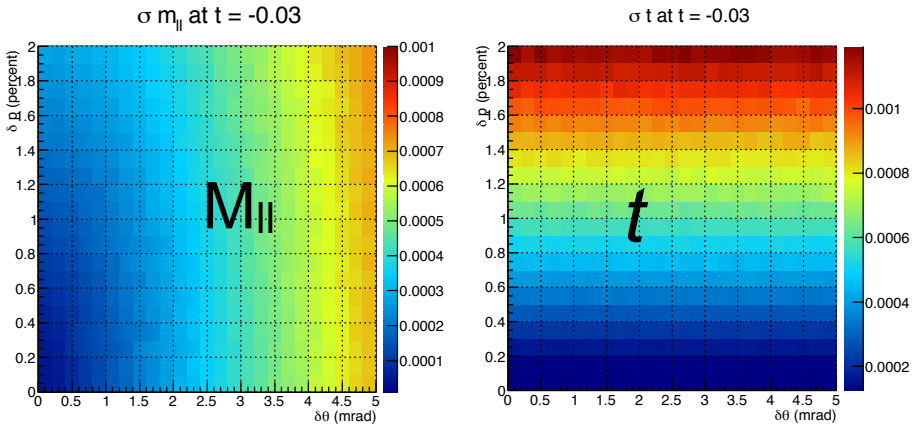


δp(%)

Case: -t = 0.03; Beam energy smeared: 0



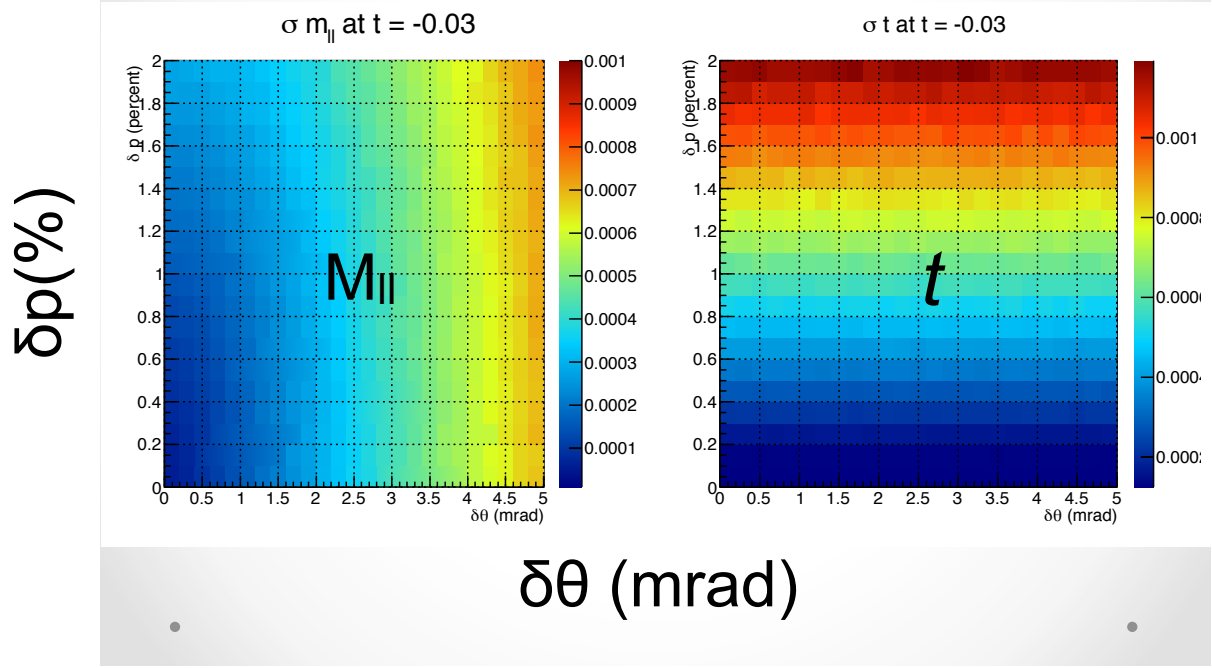
Case: -t = 0.03; Beam energy smeared: 100 keV



δθ (mrad)

Patrik's Talk

Case: -t = 0.03; Beam energy smeared: 1 MeV



Conclusions

Some regions are completely background free. In a precision experiment these regions should be used for the Lepton Universality Measurement

The error profile changes as function of –t

No great effect of beam energy smearing

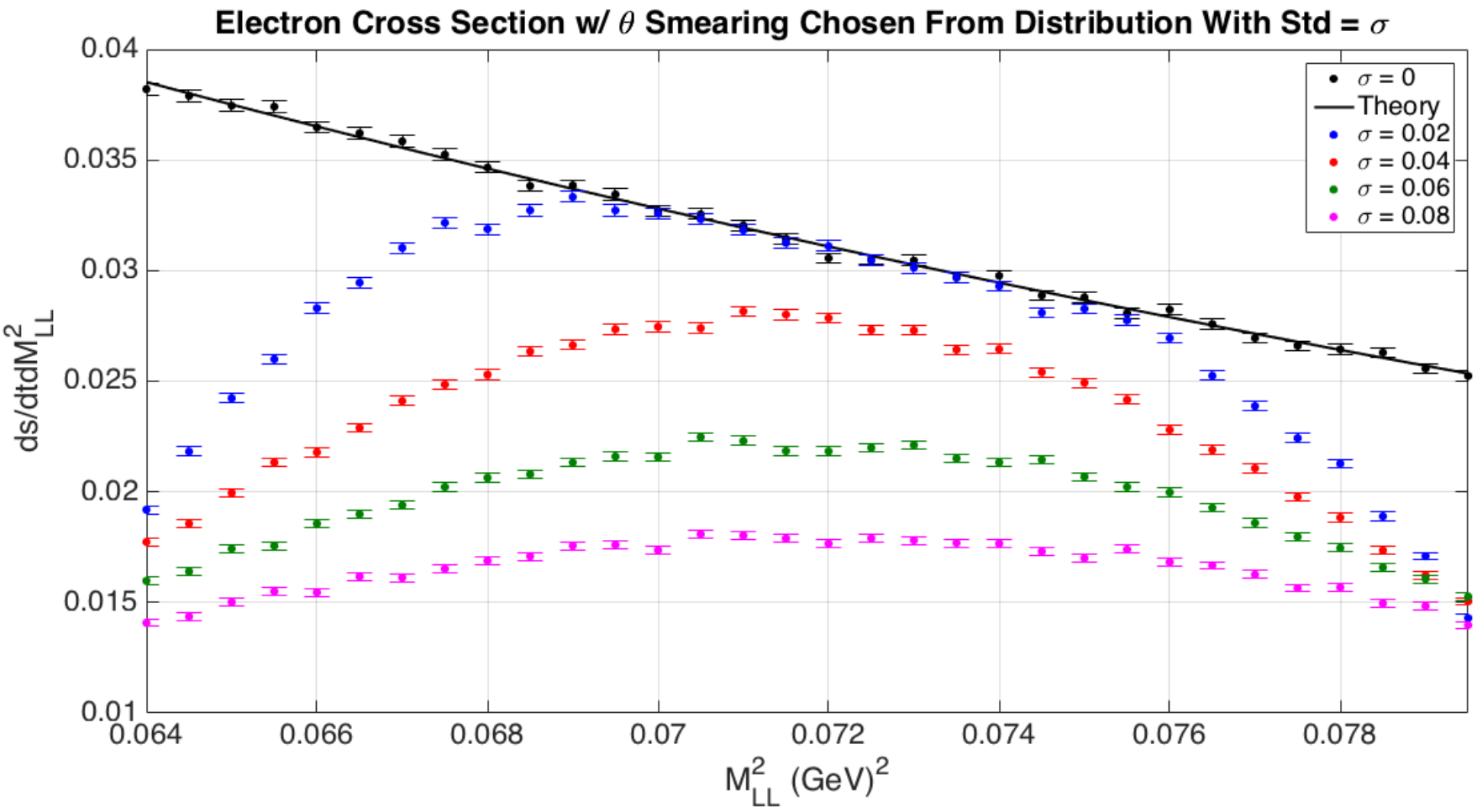
Still roughly the same conclusion though: at least 3 mrad. A few percent resolution in momentum needed. Interestingly not so sensitive at –t = 0.03. But there less curvature.

Timothy's Talk

Very Preliminary

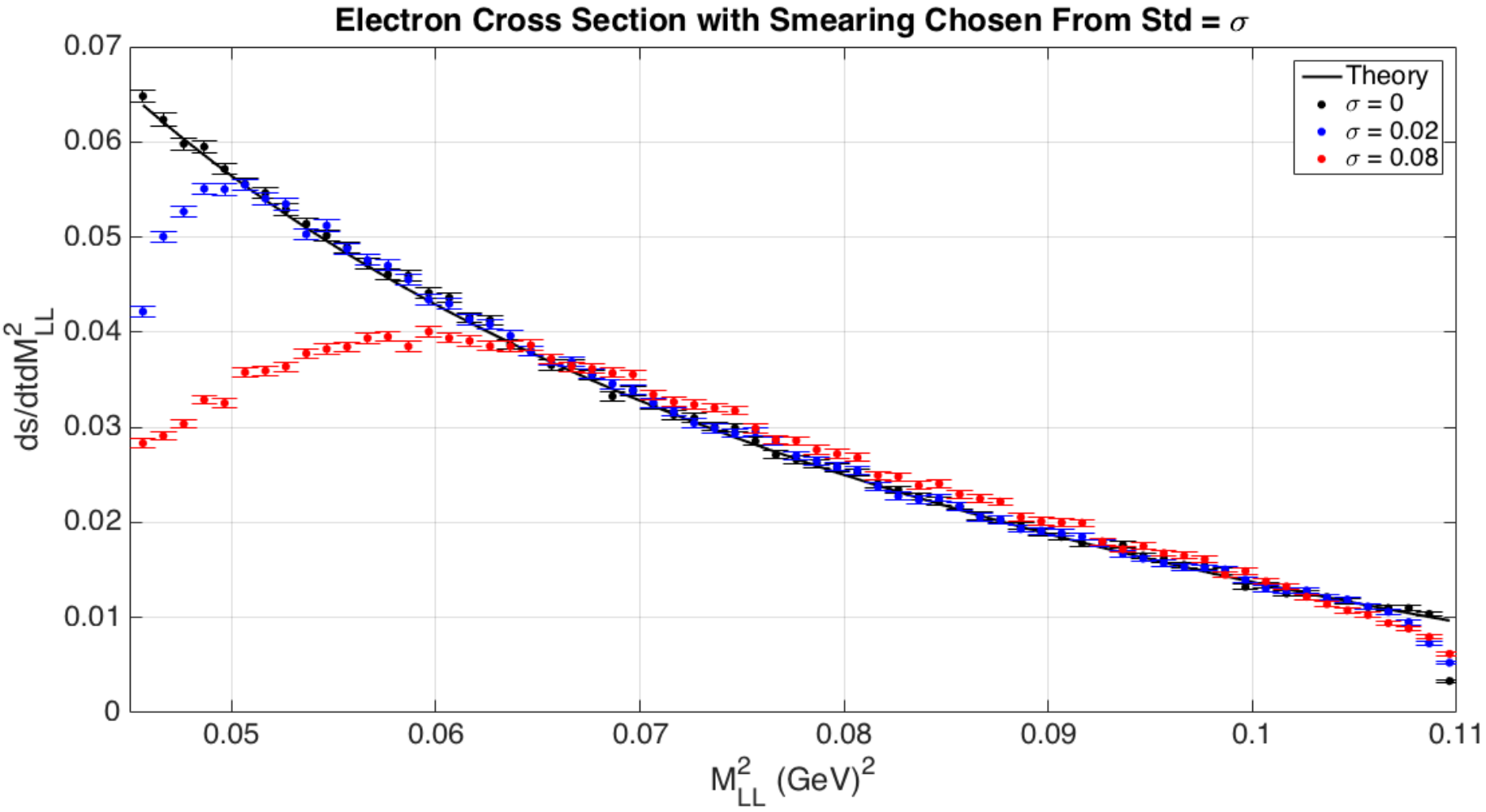
Timothy Hayward
William & Mary
Monte Carlo Simulations
of
photo production of Bethe-Heitler
Pairs

Timothy's Talk



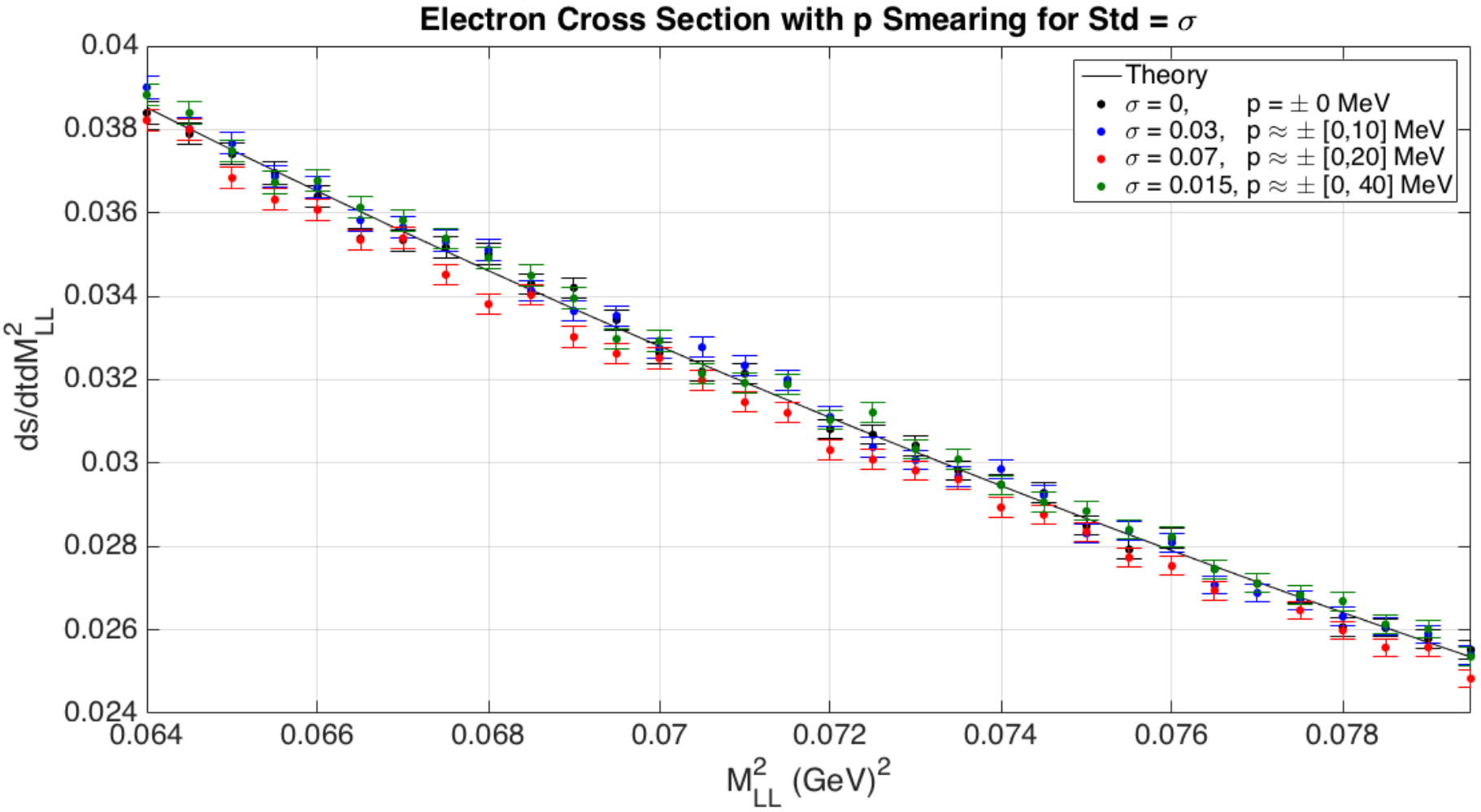
Resolution pushes M_{ll} events out of displayed region

Timothy's Talk



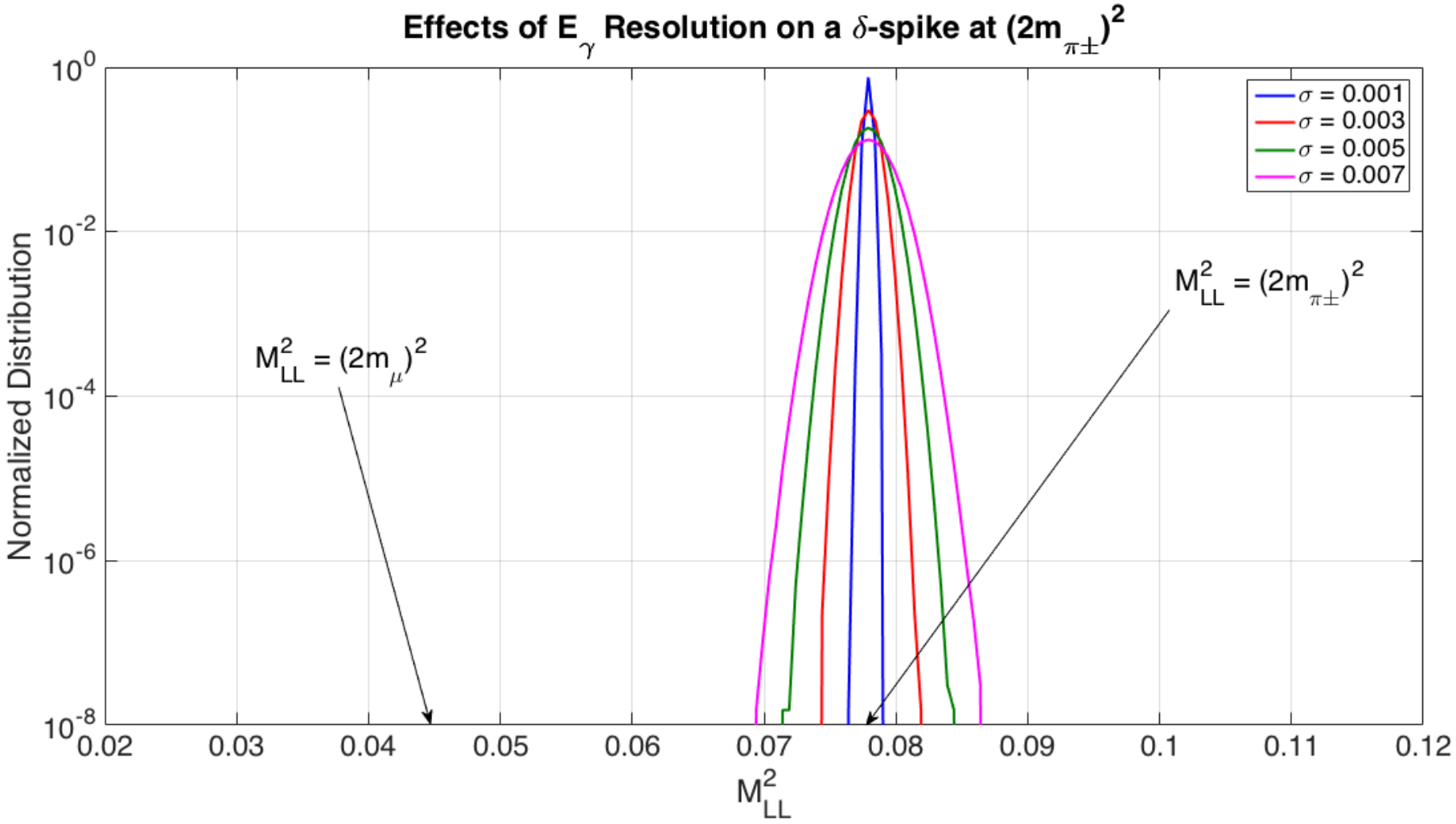
Situation improves with larger M_{ll} range

Timothy's Talk



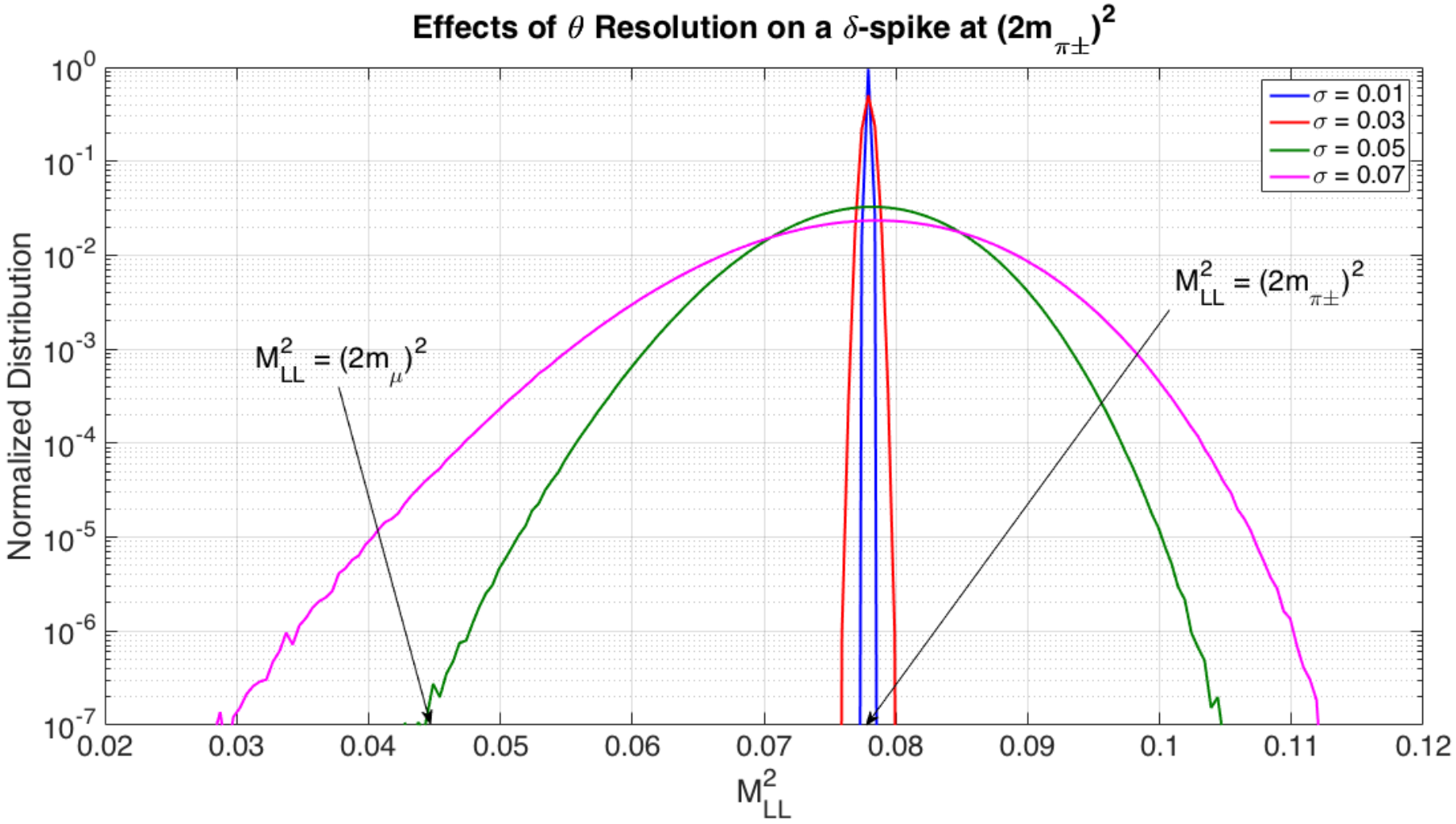
Less sensitive to momentum smearing

Timothy's Talk



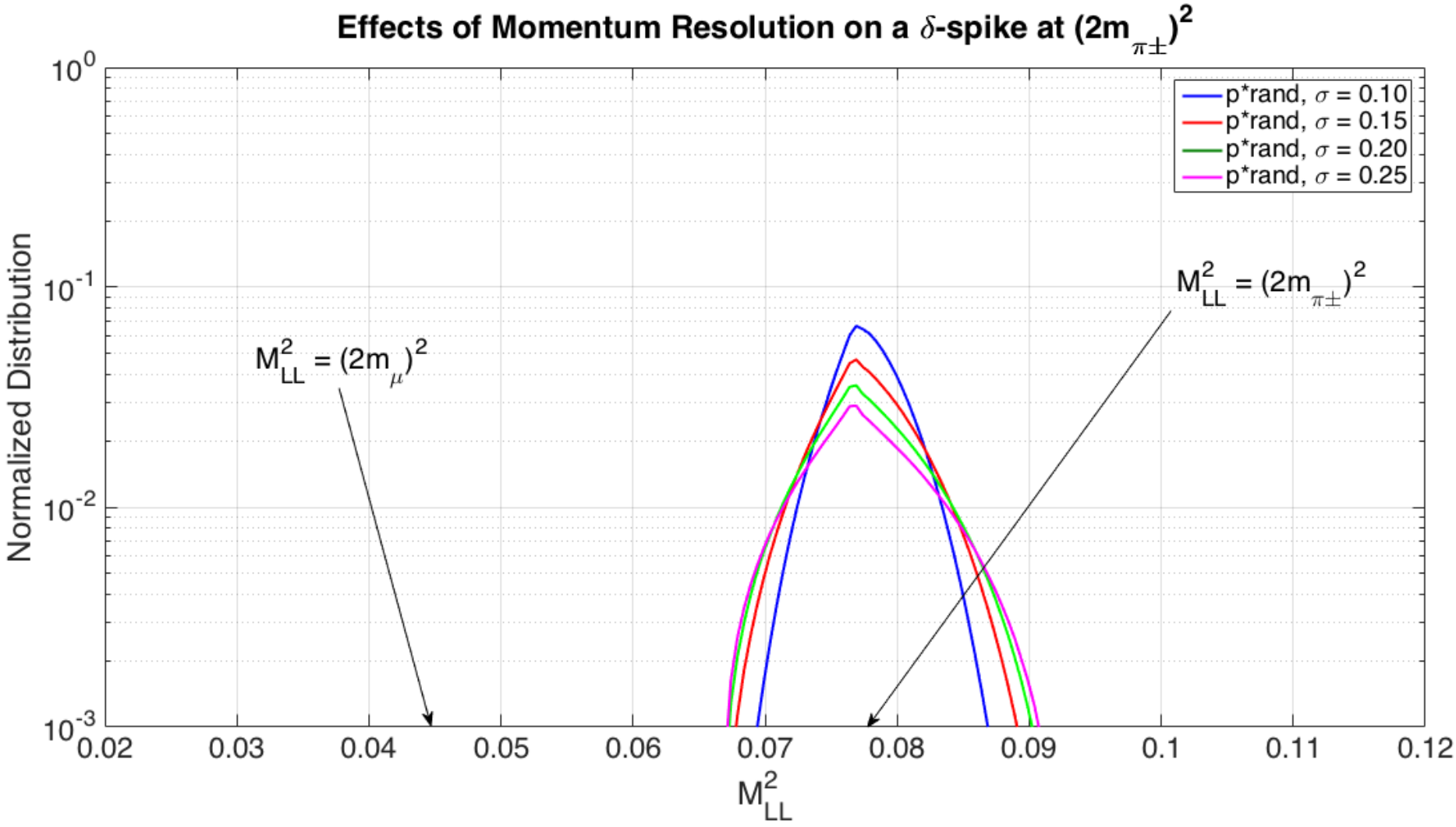
Effects of beam resolution

Timothy's Talk



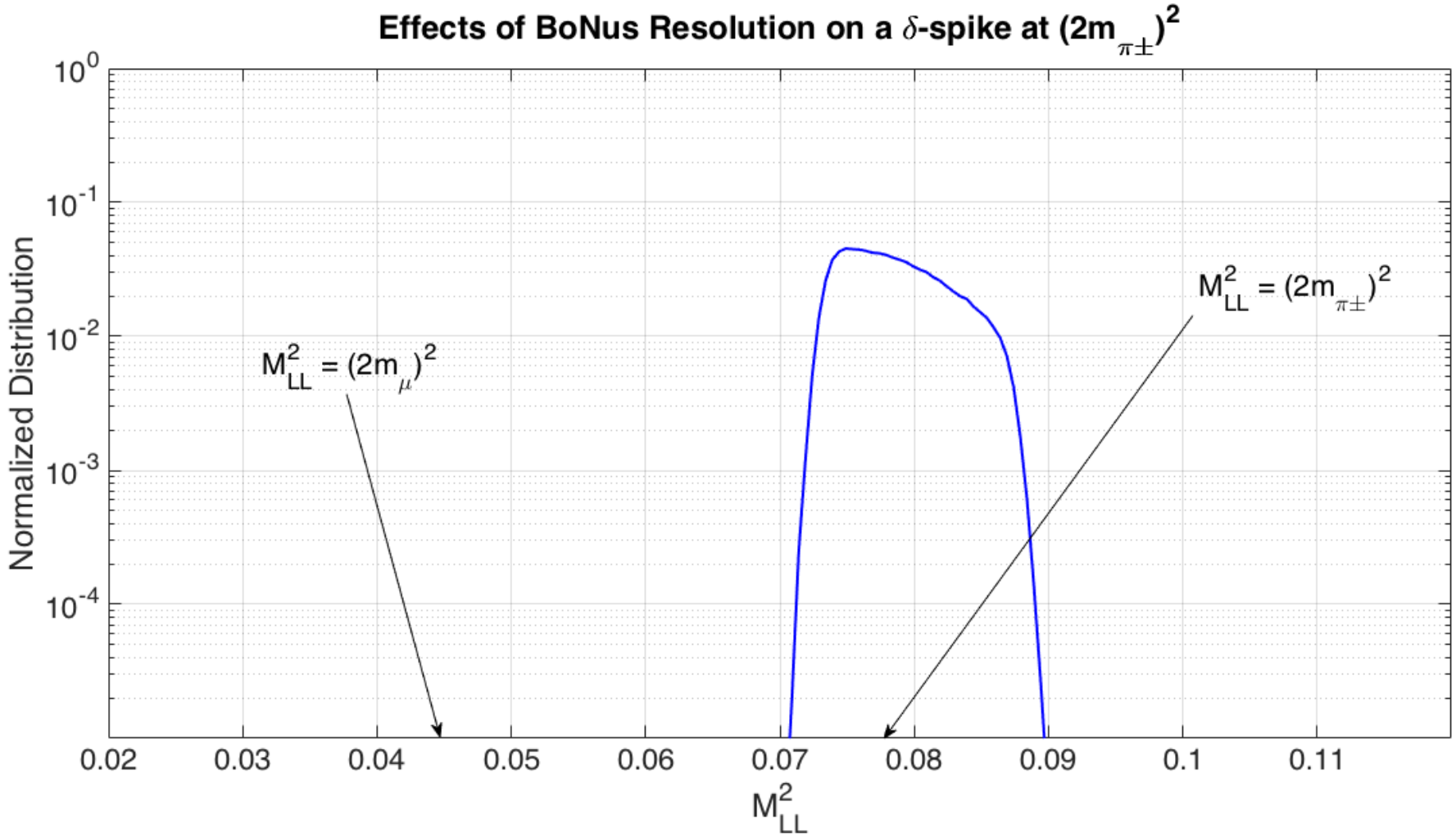
Effects of angular resolution

Timothy's Talk



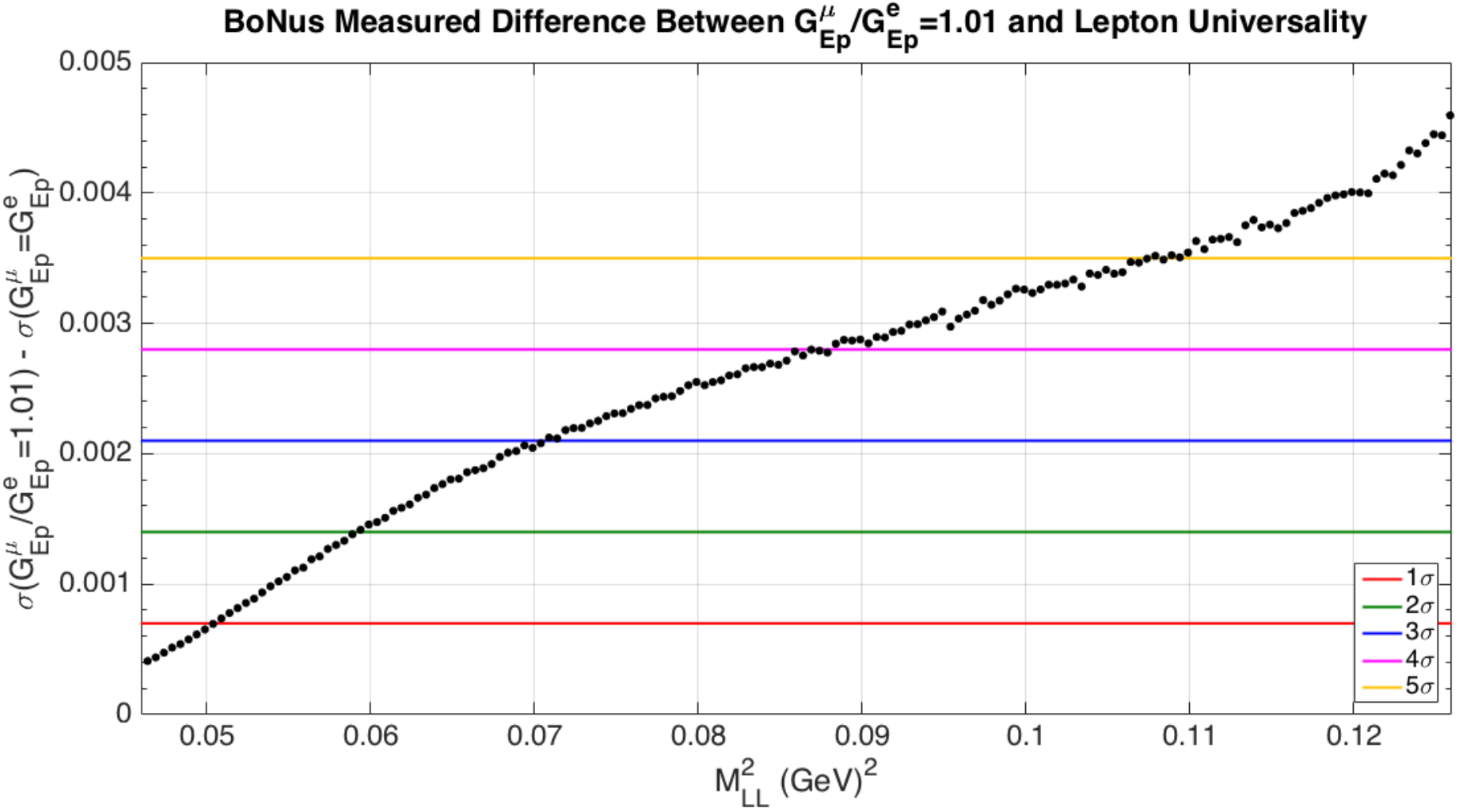
Effects of momentum resolution

Timothy's Talk



Effects of total M_{ll} resolution

Timothy's Talk



Conclusions

- Lepton Universality tests with an RTPC seem possible, but more realistic simulations must be done.
- A hydrogen gas-jet or pellet-jet target,with a silicon tracking detector is an option.
- Drift chamber design (Gabriel Charles, Paris) —-competitive with the BONuS detector—-is an option.
- Active hydrogen target TPC (Mark Dalton at JLab) is also an option.